Rapport sur

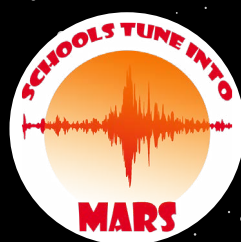# INTÉGRATION des DONNÉES de RECHERCHE des MISSIONS SPATIALES dans les ENSEIGNEMENTS STEM

SCHOOLS TUNE INTO

MARS

À propos du projet Schools Tune Into Mars

L'objectif global du projet Schools Tune Into Mars (STIM) est de fournir du matériel pédagogique avec des activités innovantes d'une grande qualité dans le domaine des sciences de la Terre, de l'univers et plus particulièrement de la planétologie. Les ressources du projet sont basées sur les dernières données de la recherche spatiale et de la pédagogie innovante et répondent aux besoins des enseignants en matière d'opportunités de développement professionnel, en utilisant des concepts scientifiques particuliers en planétologie et en sismologie planétaire.

Schools Tune Into Mars (STIM) est un projet qui réunit un réseau d'écoles et d'organisations impliqués dans les domaines de l'éducation et de l'espace, en particulier la planète Mars. Il propose des ressources pédagogiques innovantes qui sont développées dans un processus co-constructif entre chercheurs et enseignants.

Schools Tune Into Mars est un projet multipartite financé par le programme Erasmus+. Le label scolaire STEM est une initiative conjointe entre le Lycée International de Valbonne, France, European Schoolnet, Belgique; Asociación Española para la Enseñanza de las Ciencias de la Tierra, Espagne et Institut national de physique du globe, Roumanie.

Plusieurs ressources complémentaires sont développées dans le cadre du projet STIM, notamment:

- Un rapport élaboré à partir des ressources STIM (contenant des activités pratiques, des activités basées sur des données enregistrées sur Mars, des modélisations, des webinaires dédiés aux enseignants) soutenu par une étude visant à évaluer le besoin et l'opportunité des ressources STIM pour les enseignants.
- Un guide pédagogique pour accompagner l'utilisation des ressources des missions spatiales dans les salles de classe.
- Un cours en ligne Massive Open Online Course (MOOC) intitulé "Bring Mars missions into the classroom" qui fournit une formation en ligne aux enseignants afin d'utiliser du matériel pédagogique innovant lié aux missions spatiales sur Mars en classe.
- Des recommandations pour la création d'un réseau Mars-Edu afin d'assurer une dissémination efficace et qui permette de créer un réseau de collaboration novateur et à long terme sur l'éducation spatiale liée aux missions sur Mars.
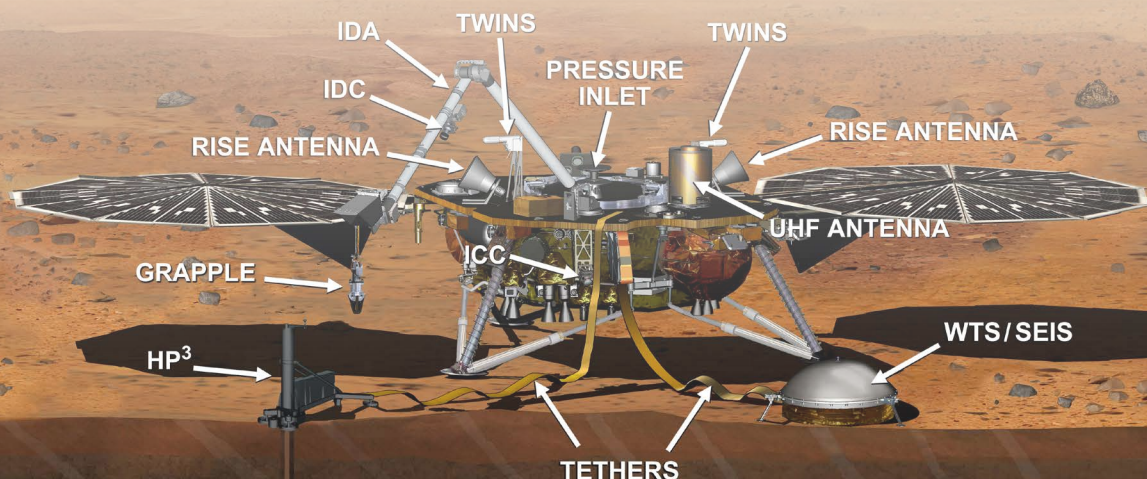
Résumé

Afin de permettre aux enseignants de faire acquérir à leurs élèves les compétences STEM, nécessaires pour leur avenir professionnel, le projet Schools Tune Into Mars (STIM) propose de développer une éducation interdisciplinaire ancrée dans les attendus de l'enseignement du secondaire. Il vise également à développer les connaissances, les compétences et l'intérêt des jeunes Européens pour l'enseignement des STEM en leur fournissant du matériel didactique interdisciplinaire réalisé dans le cadre d'un processus co-constructif entre chercheurs et enseignants dans des domaines tels que la sismologie planétaire, la géologie, la géophysique, les sciences terrestres et spatiales. L'objectif principal de STIM est également de faire participer les élèves et les enseignants à des recherches scientifiques actuelles et inédites.

Pour atteindre ces objectifs, le projet STIM s'appuie sur les résultats de mission spatiale telle qu'InSight « Découverte de la structure interne de la planète Mars pour mieux comprendre le fonctionnement de notre planète", qui fourni une occasion unique de développer un programme scientifique inédit afin qu'il puisse être pleinement intégré dans les établissements européens et développé davantage. InSight[1], abréviation de "Interior Exploration using Seismic Investigations, Geodesy and Heat Transport" est une mission du programme Discovery de la NASA pour les missions scientifiques qui posent des questions critiques en remettant en question des théories scientifiques et en les affinant.

L'utilisation des résultats des missions spatiales en classe, comme InSight, favorise la mise en œuvre d'une véritable "démarche de projet" défini comme " un modèle de pratique innovante » en classe qui s'éloigne des leçons classiques et isolées centrées sur l'enseignant et qui met plutôt l'accent sur des activités d'investigation, interdisciplinaires, axées sur les élèves et intégrées aux questions scientifiques et pratiques réelles " (Holbrook, 2007)[2].

Ce rapport présente le premier délivrable du projet STIM constitué d'un ensemble de 23 activités comprenant des activités pratiques, d'ingénierie et des expériences, mais aussi six webinaires et trois EduTeasers (qui sont de courtes vidéos éducatives enregistrées avec des chercheurs pour présenter certaines activités) dédiés aux enseignants du secondaire. Ces activités ont été développées par les partenaires du projet, sur la base des derniers résultats publiés des missions sur Mars, et en particulier d'InSight. Mais aussi des résultats recueillis via une enquête en ligne afin de déterminer les besoins et les attentes des enseignants sur des thèmes d'enseignement tels que la Terre, l'Univers et la Planétologie, mais aussi via des diagnostics réalisés avec les enseignants conviés à des formations sous forme d'ateliers en présentiel. Les résultats de l'enquête et des formations sont également présentés dans ce rapport. Ces ressources ont toutes été élaborées à la suite d'un processus co-constructif entre les partenaires du projet, les chercheurs et les enseignants.

IDA — TWINS — TWINS — IDC — PRESSURE INLET — RISE ANTENNA — RISE ANTENNA — UHF ANTENNA — GRAPPLE — ICC — HP³ — WTS / SEIS — TETHERS

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1   La mission InSight vise à découvrir comment un corps rocheux se forme et évolue pour devenir une planète en étudiant la structure et la composition interne de Mars. La mission déterminera également le taux d'activité tectonique martienne et les impacts de météorites.

2   Jack Holbrook & Miia Rannikmae (2007) The Nature of Science Education for Enhancing Scientific Literacy, International Journal of Science Education, 29:11, 1347-1362, DOI: 10.1080/09500690601007549

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Introduction

CONTEXTE DE L'ÉTUDE

Les résultats internationaux récents de l'enquête sur les tendances des études internationales des mathématiques et des sciences (TIMSS) en 2015 ont montré que les résultats des élèves dans la plupart des pays de l'Union européenne en matière de performances et de résultats dans les disciplines scientifiques étaient médiocres. Au niveau secondaire, en ce qui concerne les progrès réalisés par rapport à l'objectif de référence UE 2020, à savoir moins de 15 % de personnes peu performantes, les résultats du PISA montrent que l'UE dans son ensemble a pris du retard dans les domaines des sciences et des mathématiques et a fait un pas en arrière par rapport aux résultats du PISA 2012. En outre, de 2003 à 2013, le nombre de personnes employées dans les professions STEM (Sciences, Technologie, Ingénierie et Mathématiques) a augmenté de 12 % et, d'ici 2025, il devrait encore augmenter de 13 % (EU Skills Panorama 2014)[1]. Pourtant, la demande croissante pour ces professions n'est pas à la hauteur des difficultés de recrutement signalées dans la plupart des pays de l'UE. Comme les technologies jouent un rôle de plus en plus important dans tous les domaines du travail et de la vie, les compétences STEM et les compétences STEM de niveau supérieur deviennent la norme.

Afin d'aider les enseignants à développer les compétences STEM dont les élèves auront besoin dans un proche avenir, le projet Schools Tune Into Mars (STIM) contribue au développement professionnel des enseignants du secondaire qui permettra par voie de conséquence de consolider les connaissances, les compétences et l'intérêt des jeunes Européens pour l'éducation STEM en fournissant du matériel pédagogique de qualité, en leur proposant des leçons innovantes sur les sujets STEM et en développant la collaboration entre chercheurs et enseignants sur des sujets tels que la sismologie planétaire, la géologie, la géologie, la géophysique, les sciences de la Terre et les sciences spatiales. L'objectif principal de STIM est également de faire participer le s élèves et les enseignants à des recherches scientifiques actuelles et inédites.

Pour atteindre ces objectifs, STIM s'est appuyé sur les résultats de la mission spatiale Insight[2] " Découverte de la structure interne de Mars pour mieux comprendre la planète Terre ", qui a fourni une occasion unique de développer un programme scientifique spécifique afin qu'il puisse être pleinement intégré dans les écoles européennes et développé davantage. InSight1 abréviation de «Interior Exploration using Seismic Investigations, Geodesy and Heat Transport» est une mission du programme Discovery de la NASA pour les missions scientifiques qui interrogent le domaine des sciences du système solaire.

L'utilisation des résultats des missions spatiales tel qu'Insight en classe favorise la mise en œuvre d'une « démarche de projet « définie comme « un modèle d'activité en classe qui s'éloigne des pratiques classiques et des leçons courtes et isolées axées sur l'enseignant et qui met plutôt l'accent sur des activités d'apprentissage à long terme, interdisciplinaires, axées sur les élèves et intégrées aux questions et pratiques réelles du monde « (Holbrook, 2007)[3].

De plus, l'enseignement des missions spatiales en classe permet également aux élèves de comprendre les progrès technologiques qui ont été réalisés dans le domaine des sciences de la Terre. La compréhension de ces évolutions est essentielle au processus décisionnel de l'élève.

En effet, la géologie est l'étude de la Terre - comment elle fonctionne et son histoire de 4,5 milliards d'années. Les géologues étudient certaines questions contemporaines, comme l'énergie, l'eau et les ressources minérales, l'environnement, les changements climatiques et les risques majeurs comme les glissements de terrain, les volcans et les tremblements de terre. L'étude de la Terre et de Mars dans un esprit de «planétologie comparative» permet de mieux comprendre comment les lois physiques et chimiques universelles ont créé notre environnement.

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1 EU Skills Panorama (2014). STEM skills Analytical Highlight, prepared by ICF and Cedefop for the European Commission (https://skillspanorama.cedefop.europa.eu/sites/default/files/EUSP_AH_STEM_0.pdf)

2 La mission InSight vise à découvrir comment un corps rocheux se forme et évolue pour devenir une planète en étudiant la structure et la composition interne de Mars. La mission déterminera également le taux d'activité tectonique martienne et les impacts de météorites.

3 Jack Holbrook & Miia Rannikmae (2007) The Nature of Science Education for Enhancing Scientific Literacy, International Journal of Science Education, 29:11, 1347-1362, DOI: 10.1080/09500690601007549

OBJECTIFS DU RAPPORT

Ce rapport présente le premier délivrable du projet STIM constitué d'un ensemble de 23 activités comprenant des activités pratiques, des activités d'ingénierie et des expériences, mais aussi six webinaires et trois EduTeasers dédiés aux enseignants du secondaire. Avec ce rapport, les partenaires du projet STIM ont uni leurs forces afin de développer un ensemble de ressources STEM pour les enseignants, sous différents formats (activités pratiques, activités basées sur les données enregistrées sur Mars, expériences, webinaires dédiés aux enseignants) qui peuvent être directement utilisés en classe. Ces ressources ont été développées à la suite d'une enquête exhaustive qui a été appliquée à un grand nombre d'enseignants de 3 pays européens (Roumanie, France et Espagne) et à la suite de plusieurs ateliers dont les résultats sont également présentés dans ce rapport. L'enquête menée en ligne et en présentiel lors d'ateliers visait à évaluer les besoins et les attentes des enseignants dans des domaines complexes tels que l'enseignement des Sciences de la Terre, de l'Univers et de la Planétologie car ils font appel à la maitrise de plusieurs disciplines comme la géologie, la géophysique, la chimie… Cet enseignement est intégré dans les programmes des pays européens et nécessite donc une réelle formation des enseignants afin de leur permettre de transmettre ces notions aux élèves.

Les résultats de l'enquête sont présentés dans la première partie du rapport, y compris les informations sur les ateliers organisés avec les enseignants et visant à valider les résultats de l'étude. La deuxième partie porte sur l'ensemble des ressources qui ont été élaborées en fonction des résultats de l'enquête et à la suite d'un processus co-constructif entre chercheurs et enseignants à l'aide de nouvelles données recueillies lors d'une mission spatiale engageante (NASA Insight). Les ressources pédagogiques ont été complétées par du matériel de formation pour les enseignants - également présentés dans ce rapport - afin d'enrichir les activités éducatives liées à InSight. Par exemple, des webinaires à l'intention des enseignants et des élèves ont été organisés pour leur permettre d'acquérir une bonne compréhension de la sismologie planétaire, de la géologie, de la géophysique, des sciences de la Terre et de l'univers et pour obtenir une rétroaction directe des utilisateurs finaux, qui sont des enseignants du secondaire. Une série de courtes vidéos ont également été réalisées par des chercheurs sur des sujets liés à la mission InSight et aux actions et résultats de STIM, dans lesquelles des sujets de recherche et autres découvertes intéressantes sont brièvement expliqués aux étudiants.
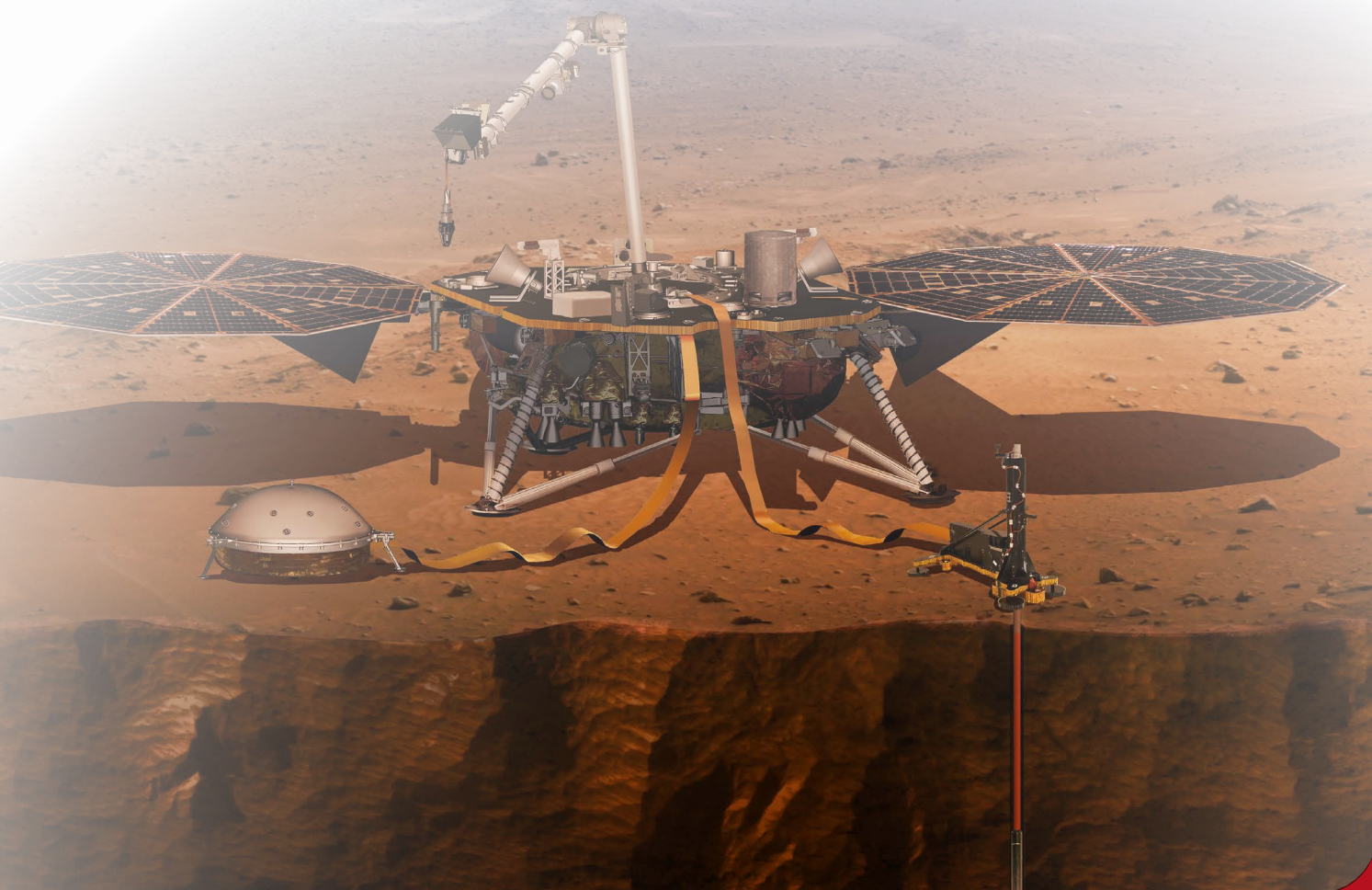
1. Évaluation des besoins et cartographie des attentes des bénéficiaires

CONTEXTE ET APPROCHE

L'objectif du projet est de développer des ressources STEM qui encourageraient l'utilisation de données de recherche, de logiciels et d'activités pratiques comme outils d'apprentissage.

Par conséquent, le but de l'enquête était de faire émerger les représentations initiales des enseignants ainsi que leurs besoins en terme de développement professionnel sur les thèmes proposés (la planétologie et de la sismologie planétaire). Il a aussi permis de déterminer la place de cet enseignement dans les programmes officiels et ainsi de mieux orienter le développement de toutes les ressources STEM. Pour ce faire, une approche en deux étapes suivantes a été mise en œuvre :

1. La diffusion d'un questionnaire en ligne
2. L'organisation d'ateliers afin de recueillir les besoins des enseignants en direct

1.1 LE QUESTIONNAIRE EN LIGNE

L'enquête a été réalisée entre octobre et février 2019 et s'adressait au principal groupe cible de la STIM (des enseignants du secondaire) avec des profils différents:

- enseignants ayant participé à d'autres projets/ initiatives STEM
- enseignants qui n'ont jamais participé en tant qu'utilisateurs à d'autres projets/initiatives STEM.

192 enseignants provenant de France, de Roumanie et d'Espagne ont complété un questionnaire en ligne conçu en collaboration avec tous les partenaires du projet et tenant compte des particularités des systèmes éducatifs nationaux (ex : noms des disciplines scientifiques, horaires scolaires des enseignants, etc). Les résultats sont présentés dans la Figure 1.

Le questionnaire a été traduit dans toutes les langues nationales des partenaires (français, roumain, espagnol) et en anglais et distribué en utilisant l'outil en ligne SurveyMonkey. L'enquête figure à l'annexe 1 de ce rapport..

Les résultats de l'enquête sont divisés en trois sections décrites ci-dessous.
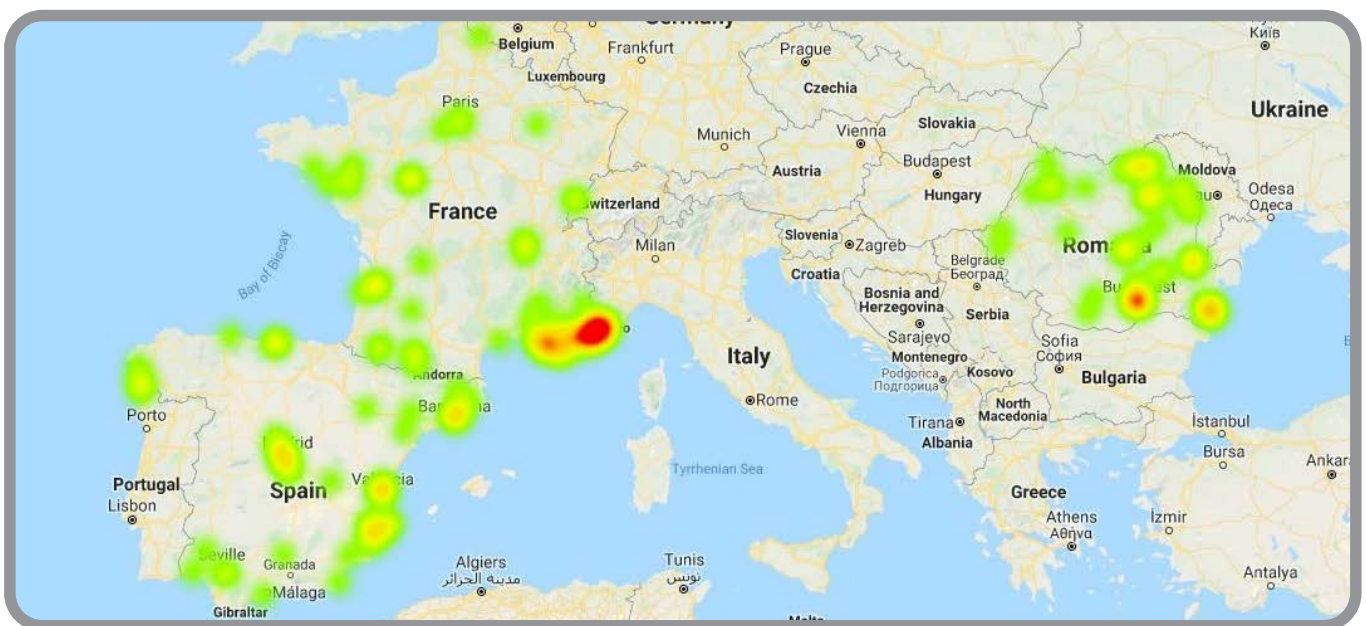
Figure 1 : Origine des participants à l'enquête

a) Echantillon de sondage

Tout d'abord, les participants ont été invités à préciser certaines informations sur la localisation de l'établissement (pays, ville, adresse de l'école, résultats sur la figure 2), le sexe (dont les résultats figurent à la figure 3) et le profil professionnel (niveau d'études et discipline enseignée, dont les résultats figurent aux figures 5 et 6). Le choix d'interroger les participants sur leur lieu de localisation

était motivé par le fait que le consortium souhaitait avoir des résultats qui reflètent des besoins à l'échelle nationale.

Les enseignants qui ont répondu ont une ancienneté dans la profession allant de 12 mois à 25 ans, avec une moyenne de 10 ans. Les principales disciplines des enseignants qui ont répondu à l'enquête étaient la physique, la biologie, les sciences, la chimie et/ou les TIC. Sur les 192 enseignants,

41 % étaient des hommes et 59 % étaient des femmes. Les résultats de l'étude n'indiquent qu'aucun des participants n'a mentionné la géologie comme matière principale enseignée. Les programmes officiels des pays partenaires proposent l'enseignement des Sciences de la Terre intégré à une autre discipline comme la biologie, la chimie ou la physique.

Les enseignants du lycée (57 %, élèves âgés de 15 à 18 ans) étaient les plus intéressés par les sujets STIM. Ceci était prévisible car le programme du Lycée est le niveau d'enseignement où les disciplines commencent à aborder de manière plus approfondie des sujets liés à la planétologie, au système solaire, à la structure interne des planètes, etc. Néanmoins, les enseignants du secondaire (30%, élèves âgés de 11 à 14 ans) considèrent également que des sujets tels que ceux abordés dans le projet STIM peuvent être utilisés à ce niveau. Les collèges intègrent les concepts des sciences de la Terre dans leurs cours généraux de sciences.

Figure 4 : Exemple de description : Niveau d'enseignement enseigné
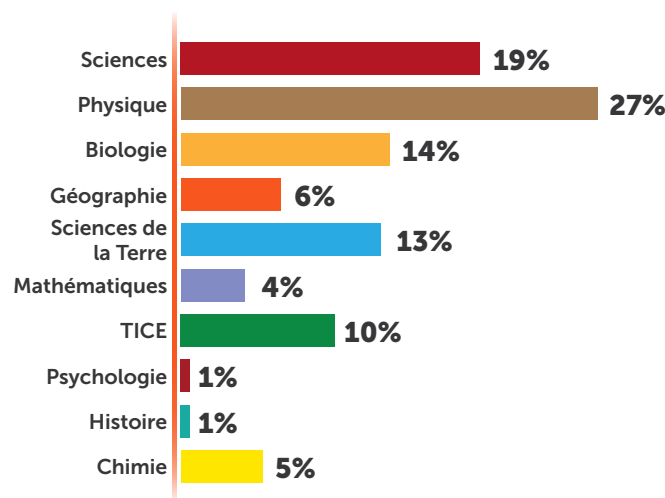
Figure 5 : Description de l'échantillon : matières enseignées par les participants au questionnaire.

b) Evaluer la pertinence des activités STIM en classe

Comme le montrent les figures ci-dessous (Figure 6, Figure 7, Figure 8, Figure 8, Figure 9, Figure 10, Figure 10, Figure 11, Figure 12), l'enquête a révélé que même si globalement les enseignants disposés des méthodes scientifiques pour enseigner les concepts en Sciences de la Terre (61 %). Près de 30 % ne se sentent pas à l'aise lorsqu'il s'agit de transmettre des notions plus spécialisées comme la planétologie et qui nécessite une approche différente. Car elle s'apparente davantage à la démarche du chercheur qui s'interroge, tâtonne, modélise et exploite des données de recherche croisant les apports de différentes disciplines qu'il doit inévitablement maitriser.

Par conséquent, les résultats nous ont conforté sur le fait que les enseignants aient besoin d'une formation scientifique plus approfondie pour consolider leurs acquis mais aussi d'activités clés en main pour les aider à dispenser cet enseignement auprès de leurs élèves.
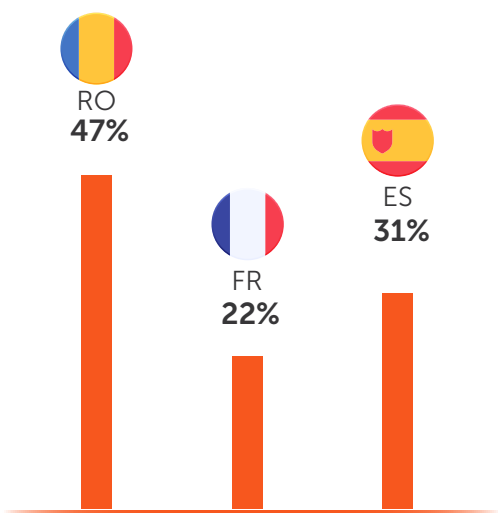

Figure 2 : Description de l'échantillon : Nombre de réponses par pays

Figure 3: Description de l'échantillon : Sexe des participants au questionnaire
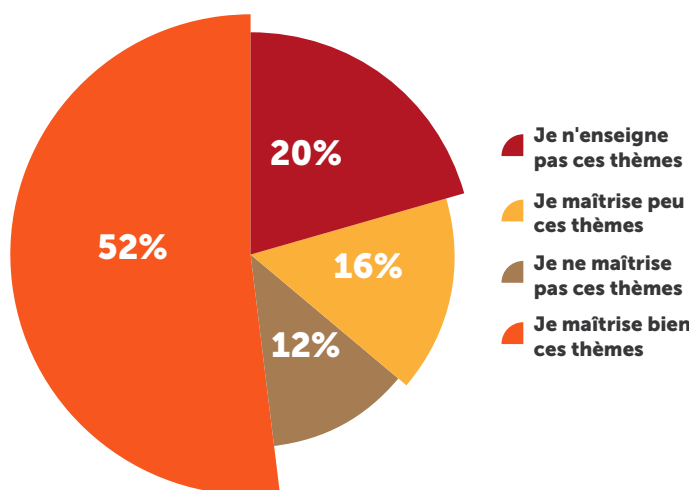
Figure 6 : Niveau de confiance des interrogés concernant l'enseignement des caractéristiques de la Terre et des processus physiques
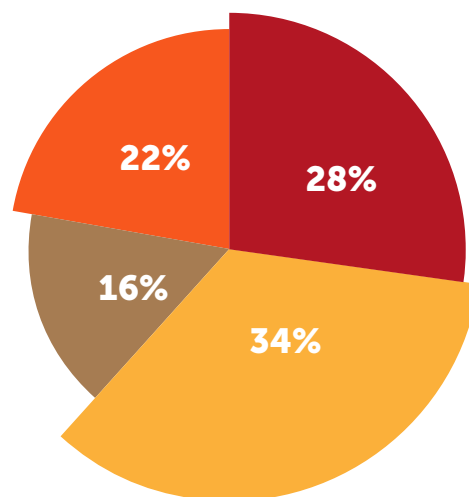
Figure 9 : Niveau de confiance des répondants à l'égard de l'enseignement de la classification et de la structure de la matière
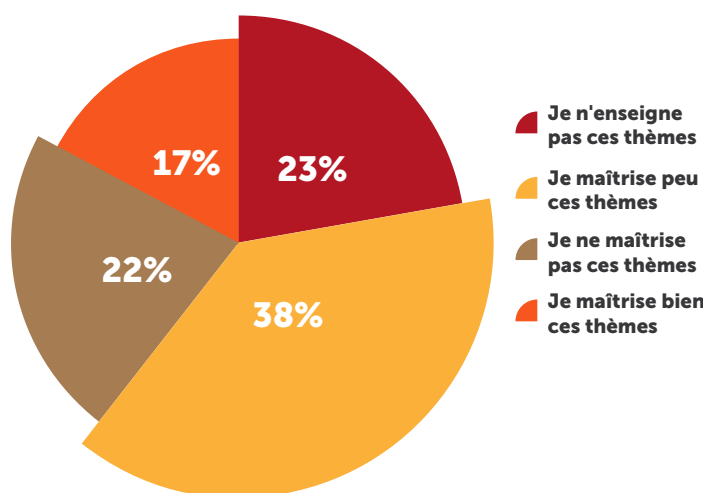
Figure 7 : Niveau de confiance des répondants à l'égard de l'enseignement du système solaire et de l'univers
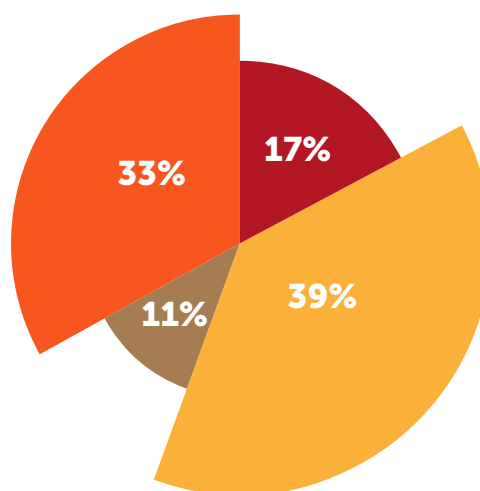
Figure 10 : Niveau de confiance des répondants à l'égard de l'enseignement de la physique, types d'énergie, sources d'énergie, conversion entre types d'énergie
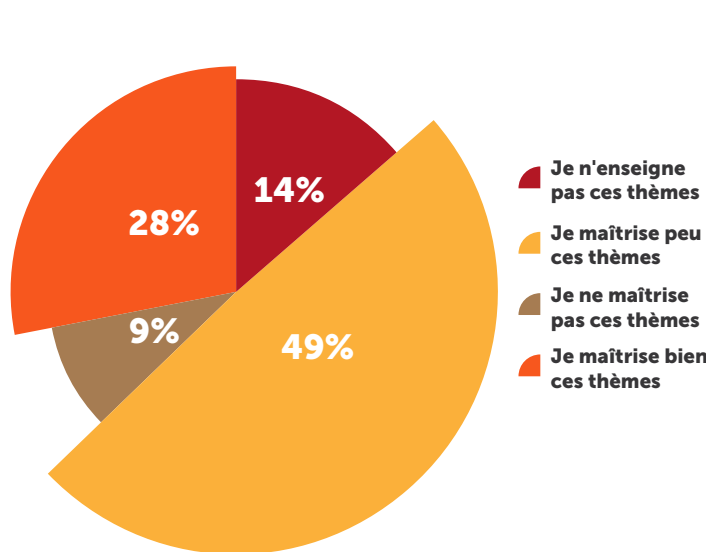
Figure 8 : Niveau de confiance des répondants à l'égard de l'enseignement du système solaire et de l'univers
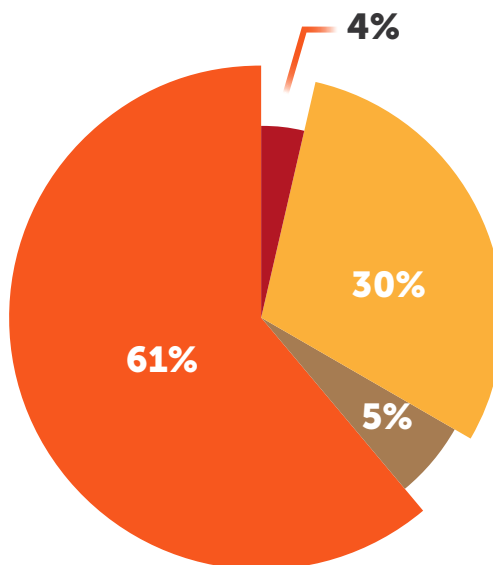
Figure 11 : Niveau de confiance des répondants à l'égard de l'enseignement du méthodes scientifique/apprentissage inquisitif
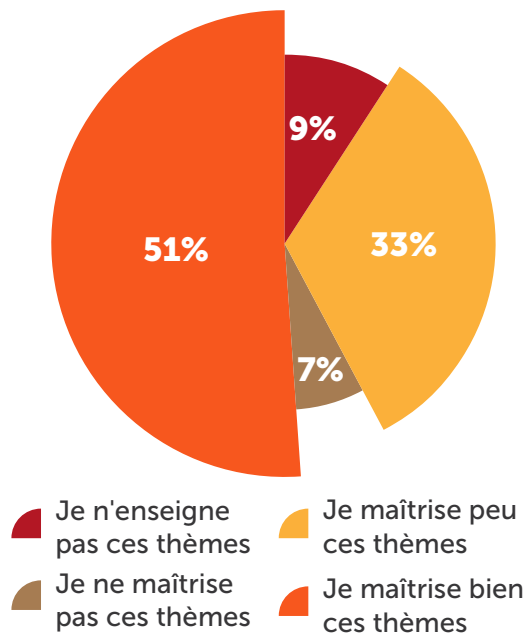
Figure 12 : Niveau de confiance des répondants à l'égard de l'enseignement des questions d'environnement et de ressources

The survey results also confirmed the teachers' need for training in subjects that require knowledge and skills to understand difficult scientific concepts (like planetology and planetary seismology) using an interdisciplinary approach (calling on physics, mathematics, geosciences, technology, etc.). The respondents validated the choices planned for the STIM project activities: workshops (53%) and online modules (e.g. MOOCs – 30%) as it can be shown in Figure 13 below:
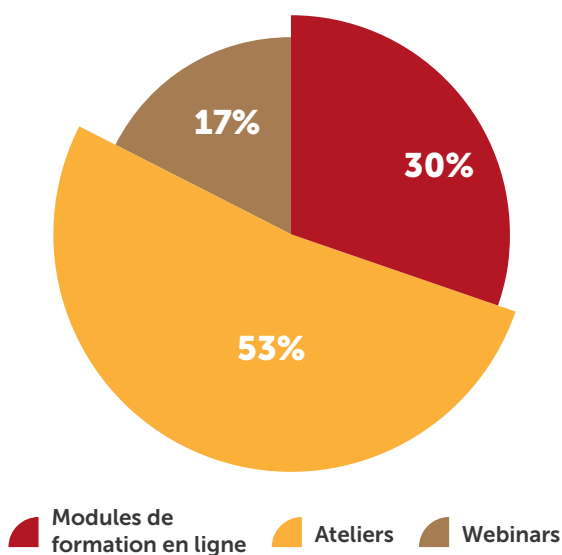
Figure 13 : Méthode préférée de perfectionnement professionnel

c) Facteurs de motivation et d'implication des enseignants et des élèves aux ressources STIM

Enfin, la dernière série de questions portait sur les facteurs susceptibles de motiver et de convaincre les enseignants à participer à des projets ou à mettre en œuvre des activités STEM en classe et en dehors de la classe (club …).

Comme le montre la Figure 14 ci-dessous, en ce qui concerne la motivation à mettre en œuvre des activités STIM, 30% des participants ont mentionné le développement de l'esprit critique et 21% ont mentionné la motivation des étudiants à apprendre. 19 % des sondés pensent que les activités de STIM pourraient être utilisées pour concevoir ou mettre en œuvre un programme d'études stimulant. Les ressources STIM répondent aux attentes des programmes officiels à la fois pour l'enseignement des Sciences de la Terre mais aussi pour l'enseignement des autres disciplines et du développement des compétences transversales. En effet le fait de pouvoir croiser le regard de différentes disciplines pour résoudre une question complexe permettra aux élèves d'être mieux formés pour comprendre le réel complexe et ainsi pouvoir être à l'aise dans le futur dans des carrières STEM
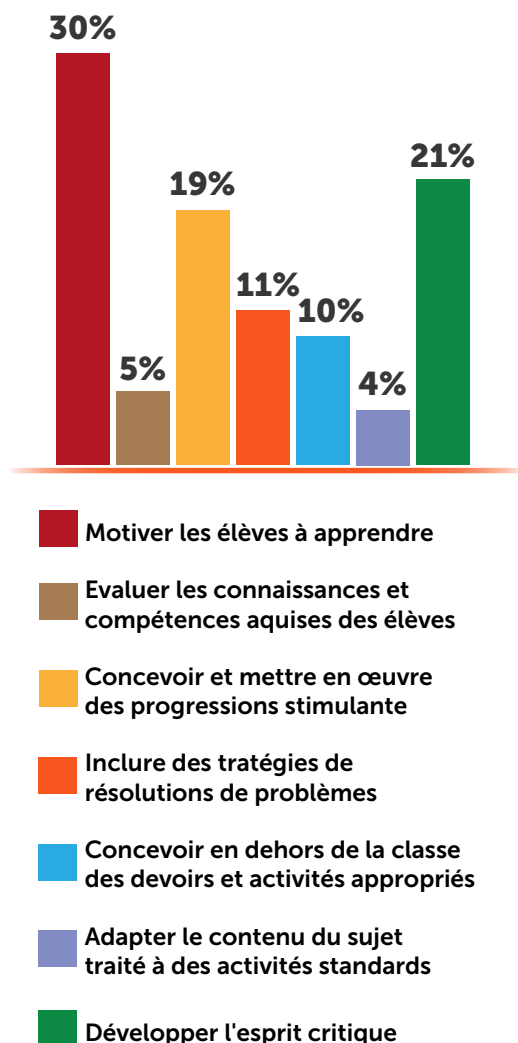
Figure 14 : Facteurs de motivation pour la mise en œuvre des activités STIM en classe selon les sondés

1.2 L'ORGANISATION D'ATELIERS AFIN DE RECUEILLIR LES BESOINS DES ENSEIGNANTS

Quatre événements ont été organisés par les partenaires et dédiés aux enseignants du secondaire, ce qui a permis de conforter les résultats du sondage en ligne. Elles visaient à recueillir les réactions directes des enseignants concernant leurs besoins en matière d'amélioration des connaissances et de meilleure compréhension de la sismologie planétaire et à orienter davantage le développement de toutes les ressources STIM en fonction des attentes.

Cette rétroaction en direct avec les enseignants stagiaires ont permis de définir les besoins des enseignants. Les formateurs ont présenté les axes du projet STIM et les objectifs des activités et des méthodes innovantes proposées. Compte tenu de l'état d'avancement des activités, le retour d'information demandé était essentiellement qualitatif et portait sur la pertinence des thèmes proposés dans le contexte des programmes officiels et sur l'adaptation au niveau d'enseignement auquel ces ressources s'adressent.

D'après les commentaires recueillis lors des quatre événements auxquels 151 enseignants au total ont participé, les conclusions peuvent être résumées comme suit :

- les thèmes abordés dans les activités de STIM ont un caractère fortement interdisciplinaire qui les rend utiles et intégrables sous de nombreuses formes tant dans le contexte de l'éducation formelle que non formelle
- les pratiques hybrides proposées sont plus proches de ce que l'on appelle la pédagogie innovante, basées sur des pratiques expérimentales, de l'interactivité et de l'investigation,

- toutes les activités sont conçues autour de thèmes engageants et pertinents pour les élèves du secondaire et qui répondent aux notions attendues des programmes officiels. En outre, la plupart des activités incitent les apprenants à réfléchir et à mobiliser les notions acquises en mettant en place une démarche d'investigation,
- la plupart des activités favorisent l'engagement de l'étudiant par l'apprentissage actif (enseignement à l'aide des technologies, échange sur les résultats, activités pratiques et activités d'apprentissage par l'expérience).

Les quatre événements qui ont été organisés sont illustrés dans les images ci-dessous :
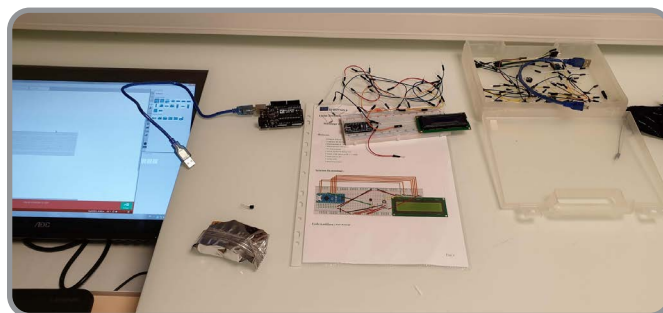
16-17 janvier 2019, Sophia Antipolis, France - ATELIER SCIENTIFIQUE INSIGHT EDUCATION - une partie des activités STIM a été présentée et testée par 65 enseignants participants de France et d'autres pays (Espagne - Portugal - Haïti - Grèce) dans le domaine des caractéristiques des planètes rocheuses.

Du 12 au 30 août 2019 Atelier des enseignants pendant l'Université d'été des sciences et de la technologie, Roumanie - Les activités de STIM ont été testées par 25 enseignants de sciences participants, les thèmes abordés concernées les caractéristiques des planètes rocheuses et la mission InSight Mars.

Les 12 et 13 juin 2019 une session de test des activités STEM a été réalisée au CNES à Toulouse – Les activités STIM traitant de l'environnement des planètes rocheuses ont été présentées et testées par les 22 enseignants stagiaires.

Les 28 et 29 septembre 2019, a eu lieu le séminaire Calisph'air au Lycée de la mer dans le Bassin d'Arcachon, organisé par le CNES - Les activités STIM ont été testées par 38 professeurs de sciences participants, les thèmes abordés concernés la géodynamique interne de Mars versus Terre.

Dans ces ateliers étaient présents des enseignants stagiaires de différentes disciplines, des scientifiques et des inspecteurs (qui font partie du comité de pilotage du projet STIM)
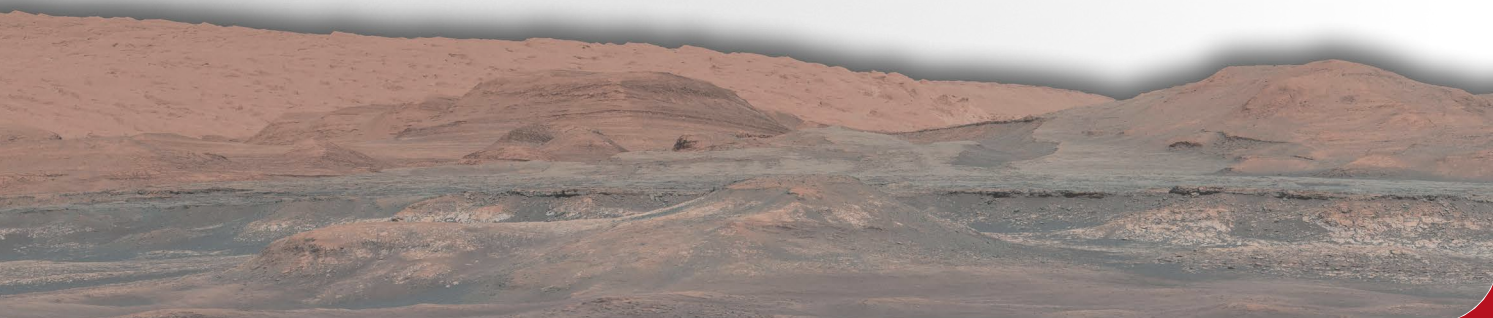
2. Ensemble des ressources STIM

Les ressources STIM peuvent être considérées comme un ensemble d'activités STEM liés à la mission Insight. Comme tout autre programme d'enseignement des STEM, ils impliquent un enseignement interdisciplinaire et visent à développer les compétences des élèves en matière de démarche d'investigation, ainsi que leur capacité à contextualiser les concepts scientifiques dans des situations réelles. Ils ne sont pas définis comme une rupture avec les matières traditionnelles, mais plutôt comme une rupture avec l'enseignement "traditionnel" [Nistor, A., Gras-Velazquez, A., Billon, N. & Mihai, G. (2018). Science, Technology, Engineering and Mathematics Education Practices in Europe. Rapport de l'Observatoire Scientix].

Un ensemble de ressources STIM a été mis au point par les partenaires pour encourager l'utilisation des données de recherche d'InSight ainsi que des logiciels spécialisés et des activités pratiques comme environnement d'apprentissage.

Les activités ont été proposées en tenant compte des thèmes abordés (système solaire, planètes, structure interne, capteurs, surveillance, paramètres atmosphériques, expéditions spatiales, etc.), des disciplines pour lesquelles elles sont pertinentes (ex : science, physique, géographie, géologie, astrophysique, technologies, etc.), de la forme de présentation (pratique, expériences, fiches de travail, etc.) et des compétences des partenaires (chercheurs et enseignants).

LA DÉMARCHE SCIENTIFIQUE INTÉGRÉE DANS TOUTES LES ACTIVITÉS STIM

Toutes les activités sont conçues en intégrant la démarche scientifique illustrée à la figure 15 afin que les élèves puissent se mettre dans la peau d'un chercheur et acquérir cette démarche indispensable à la résolution de problèmes complexes. Cette démarche pourra être remobilisée par l'élève dans d'autres contextes de la vie quotidienne.

5 Conclusion

4 Analyse des résultats

Démarche Scientifique

1 Problèmatic

2 Hypothèses

3 Observation - Expériment - Données
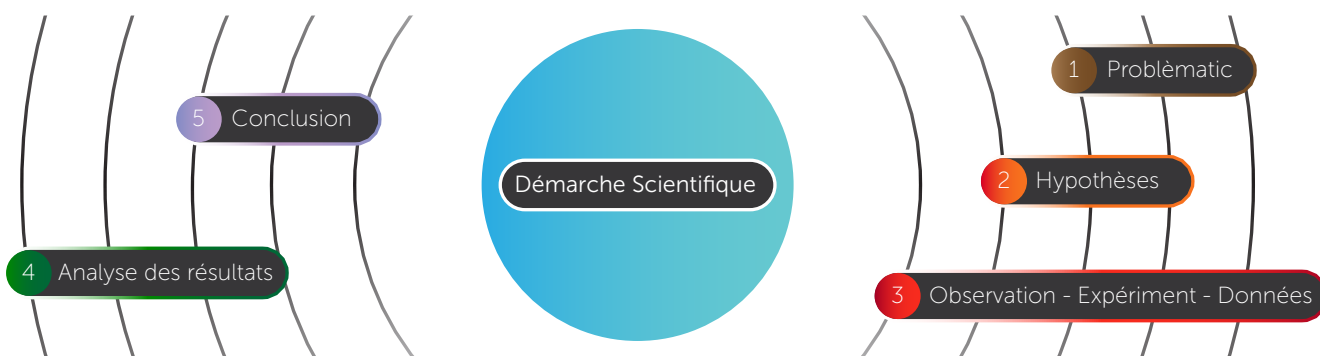
Figure 15 : Méthode scientifique utilisée pour le développement des activités STIM

Les ressources STIM et l'approche scientifique que nous proposons est une invitation aux enseignants et à leurs élèves à participer à cette formidable aventure scientifique et technologique que sont l'exploration des planètes rocheuses telles que Mars et la Terre, la quête de leurs origines et de leur fonctionnement.

Chaque ressource STIM a été réalisée avec une même structure (feuille d'activité), qui a permis de définir les principaux éléments ainsi que le matériel nécessaire à la réalisation de l'activité. Les activités ont été détaillées étape par étape, la plupart d'entre elles étant complétées par du matériel vidéo (webinaires enregistrés, tutoriels et exemples d'activités) ainsi que par des liens vers des ressources supplémentaires, permettant aux enseignants de définir le niveau de mise en œuvre, du niveau de base au niveau avancé, du niveau autonome au niveau intégré.

CATÉGORIES DES RESSOURCES

Pour étudier la planétologie, les sujets ont été divisés en cinq catégories, comme indiqué sur les pages suivantes:

Thème	Description	Activitées
Caractéristiques des planètes rocheuses **Types: Modélisation**	Cette catégorie comprend un ensemble de quatre activités qui expliquent principalement les différences entre les structures internes des planètes (rocheuses) en analysant comment elles se sont refroidies (la vitesse à laquelle la chaleur se dissipe), ainsi que l'influence de la présence ou non du champ magnétique sur leur formation et leur évolution. Les élèves utiliseront des microcontrôleurs de température pour mesurer le flux de chaleur. La cinquième activité se penche sur la localisation des planètes dans le système solaire et ce que cela implique au niveau de leurs caractéristiques.	Activité 1 – Etude du mode de refroidissement des planètes rocheuses Activité 2 – Mesure du flux de chaleur Activité 3 – Le champ magnétique Activité 4 – Mouvement de convection du Manteau Activité 5 - De quelle taille est notre système solaire ?
Environnement des planètes rocheuses **Type: Etude de données**	Ces activités permettront aux élèves de découvrir que la météorologie sur Mars, comme sur Terre est riche en perturbations telles que les tornades, vents violents qui transportent des aérosols sur plusieurs kilomètres. Jour après jour, les mouvements atmosphériques modélisent la surface de Mars et de la Terre. Les élèves comprendront, grâce à la modélisation et à l'étude des données, que le climat n'est pas figé et que ces fluctuations sont induites par les variations orbitales de la planète.	Activité 6 - Effet du bruit atmosphérique sur le sol Activité 7 - Aérosols primaires et impact climatique sur Terre Activité 8 – Aérosols primaires et impact climatique sur Mars Activité 9 – Etude des variations journalières sur Mars Activité 10 - SEIS, un sismomètre bien emballé Activité 11 – Des instruments pour mesurer la Vitesse des vents Martiens
Géologie externe de Mars versus Terre	Grâce aux données recueillies par toutes les missions martiennes, les scientifiques peuvent maintenant comparer la géodynamique externe de Mars et de la Terre. Les activités développées ici permettent de tirer des conclusions sur les facteurs responsables de leur géomorphologie. Les élèves utiliseront les données des images satellites et expérimenteront pour confirmer leurs hypothèses.	Activité 12 – L'eau salée – à l'origine des ravines sur Mars : Info ou Intox Activité 13- Des paysages façonnés par le passage des tornades sur Mars. Activité 14 – Comment peut avoir sur une planète si petite (Mars) un volcan aussi grand ?
Géologie interne de Mars versus Terre	Les géophysiciens disposent d'une méthode d'investigation efficace qui leur permet depuis plusieurs décennies d'explorer l'intérieur de la Terre et d'en comprendre la structure. Cette discipline est connue sous le nom de sismologie. Les activités de cette catégorie comprennent les spécificités de la sismologie sur Mars et sur Terre utilisées par les scientifiques et l'utilisation des données de recherche de la mission Mars Insight,	Activité 15 – Localiser l'épicentre avec une seule station sur Terre Activité 16 – Localiser l'épicentre d'un séisme Martien à l'aide d'un seul sismomètre Activité 17 – Comment modéliser l'intérieur de Mars ?

Thème	Description	Activitées
	mais aussi l'étude des paramètres atmosphériques et leur impact sur la sismologie.	Activité 18 – Planétologie comparée Activité 19 – Le sismogramme : un signal complexe Activité 20 – Impact des paramètres atmosphériques sur les enregistrements sismiques
Mission Spatiale vers Mars	Dans ces trois activités, les élèves apprendront à concevoir une mission et à utiliser des concepts d'algèbre pour déterminer la prochaine fenêtre de lancement d'une sonde spatiale pour explorer la planète rouge et imaginer un système d'absorption des chocs qui protégerait le véhicule et les astronautes lorsqu'ils atterriront.	Activité 21 - Egg drop Activité 22 – Aller sur Mars Activité 23 – Le solaire – Une source d'énergie durable

RESSOURCES STIM PRODUITES

Suite aux résultats de l'enquête, 23 activités STEM ont été produites dans le domaine de la planétologie en anglais et traduites dans les trois langues des partenaires (roumain, espagnol et français).

Mais aussi six webinaires ont été réalisés par des enseignants chercheurs en planétologie et des formateurs qui ont permis d'expliquer aux enseignants les méthodologies développées dans les activités et les notions complexes à maitriser pour pouvoir enseigner ces activités.

Les ressources ont été divisées en cinq grandes catégories mentionnées ci-dessus et sont disponibles sur le site Web Insight.oca.eu 6 sous la forme d'une carte mentale 'comme l'illustre la figure 16 ci-dessous.

Les 23 activités produites sont résumées ci-dessous:

Caractéristiques des planètes rocheuses

Activité 1 – Etude du monde de refroidissement des planètes rocheuses | Activités pratiques
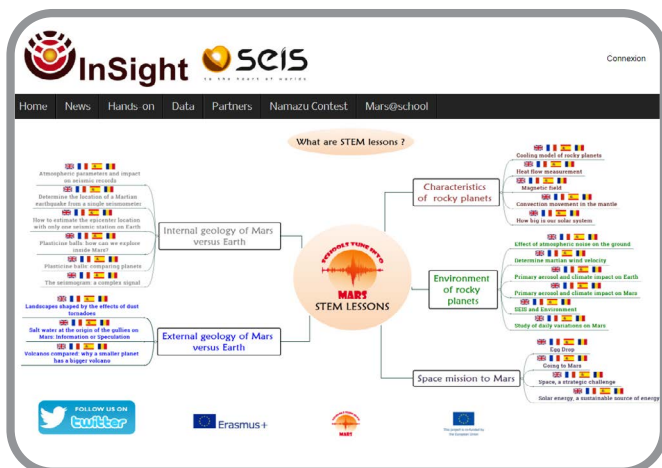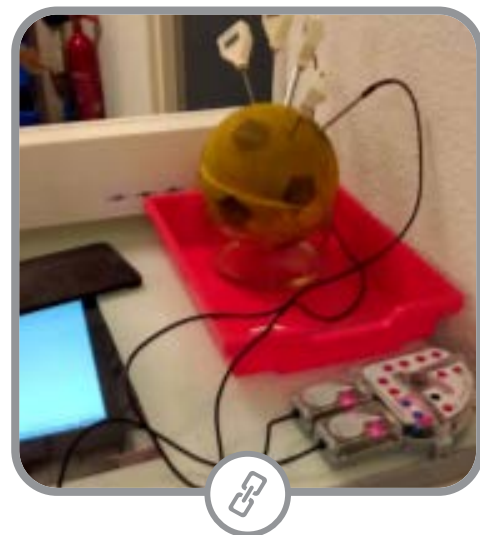
Lorsque toute l'énergie de la phase de formation a été convertie en chaleur, la planète commence à se refroidir en dissipant sa chaleur interne jusqu'à la surface et à travers celle-ci. L'un des objectifs d'InSight est de déterminer la quantité de chaleur qui continue de s'échapper de la surface de Mars (flux de chaleur). Les élèves vont exploiter les données de la mission et les comparer aux résultats de leur modélisation afin d'en apprendre davantage sur les modes de refroidissement des planètes rocheuses du système solaire. (plus d'information en Annexe 2).

Activité 2 – Mesure du flux de chaleur | Activités pratiques
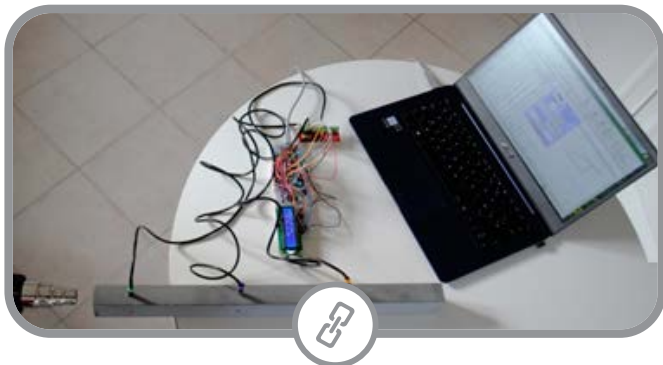
Quels sont les mécanismes à l'origine de la dissipation de la chaleur interne de Mars et de la Terre ? Sur Terre, le gradient de température est obtenu en mesurant directement la température à différentes profondeurs lors de forages ou des puits de mine. Une fois ce gradient connu et la conductivité thermique des roches sous-jacentes déterminée, les scientifiques peuvent estimer le flux thermique en un point de la surface. C'est ce que fera la mission InSight avec « Heat Flow and Physical Properties Package », un instrument appelé HP3. Dans cette activité, les élèves pourront comprendre le phénomène de conduction thermique en mesurant la conductivité thermique des roches à l'aide de trois capteurs de température, d'une source de chaleur et d'un appareil d'enregistrement de données (plus d'information en Annexe 3).

Activité 3 – Le Champ Magnétique | Activités pratiques
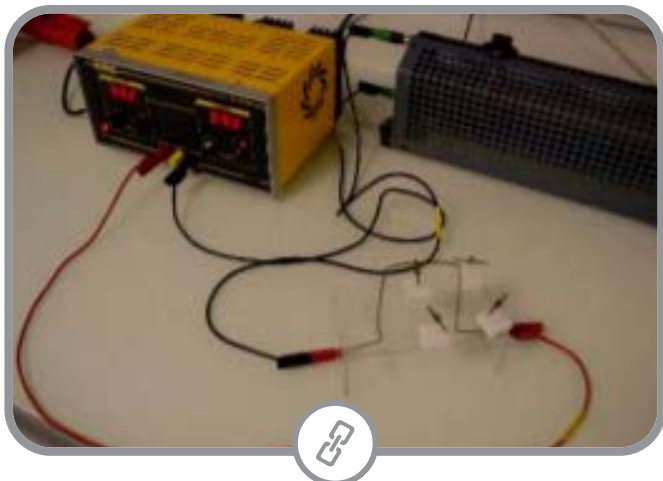
Quel est le mécanisme à l'origine de la dissipation rapide de la chaleur interne de Mars ? La mission InSight a embarqué un magnétomètre InSight Fluxgate (IFG), qui sera le premier magnétomètre à enregistrer des données magnétiques directement depuis la surface martienne. La disparition du champ magnétique de Mars pourrait expliquer la perte de chaleur beaucoup plus rapide que celle de la planète Terre. Voyons comment un champ électrique peut créer un champ magnétique et quel est le rôle du champ magnétique d'une planète rocheuse (bouclier terrestre).

Les élèves produiront et modéliseront un champ magnétique à l'aide d'un courant électrique et observeront ce qui se passe lorsque nous approchons du fil d'un tas de limaille de fer. (plus d'information en Annexe 4)

Activité 4 – Mouvement de convection du manteau | Activités pratiques

Si un corps est refroidi par en dessous et chauffé par le haut, les zones froides et denses descendent et les zones moins denses, chaudes montent. Quels sont les mécanismes qui causent la dissipation de la chaleur interne de Mars et de la Terre ? Ce processus est connu sous le nom de convection thermique et les élèves feront une expérience qui explique les différents types de convection qui causent la dissipation de la chaleur sur une planète rocheuse. (plus d'information en Annex 5).

Activité 5 - De quelle taille est notre système solaire ? Activités pratiques

Les distances entre les différentes planètes de notre système solaire sont si énormes que pour beaucoup d'élèves, il est très difficile de les comparer avec les distances quotidiennes auxquelles ils sont habitués. Cette activité vise à sensibiliser les élèves aux relations spatiales entre les différentes planètes du système solaire, en particulier Mars et la Terre. Les élèves utiliseront des objets

de la vie quotidienne pour calculer les distances relatives entre les planètes du système solaire, ce qui leur permettra d'effectuer des calculs de ratio (plus d'information en Annex 6).

Environnement des planètes rocheuses

Activité 6 – Effet du bruit sismique atmosphérique sur le sol | Modélisation
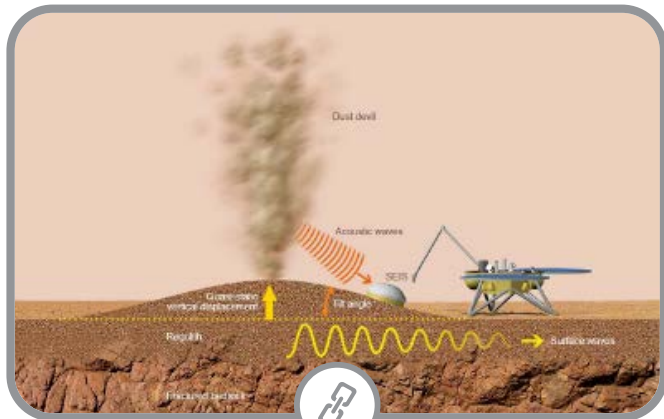
Une autre source de bruit microsismique atmosphérique est produite par des sources de bruit locales : le site d'atterrissage subit des rafales de vent ou le passage d'un tourbillon de poussière près de l'atterrisseur. Dans les deux cas, l'air martien exerce une force sur le sol : vers le haut en cas de chute de pression, vers le bas en cas de surpression. Les élèves détermineront si une simple chute de pression peut causer un effet de déformation du sol détectable par les accéléromètres, bien que ce type de déformation ne soit pas visible à l'œil nu. (Plus d'information en Annexe 7).

Activité 7 – Aérosols Primaires et impact climatique sur Terre | Modélisation

À partir d'une réalité de la vie (pluies boueuses) et de l'étude d'un échantillon d'essai, nous découvrirons ce qu'est un aérosol primaire et étudierons son impact sur le climat, qu'il soit en suspension dans l'air ou à la surface de la Terre. L'élève déterminera l'épaisseur optique des particules de l'échantillon d'essai extraites à l'aide d'un photomètre afin de déterminer leur nature et donc leur impact sur le climat. Ils peuvent alors établir si des

dispersions majeures de particules ont la capacité d'influencer de manière significative le climat de la Terre. (Plus d'information en Annexe 8).

Activité 8 – Aérosols Primaires et impact climatique sur Mars | Modélisation

Nous savons que même les aérosols naturels peuvent avoir un impact sur le climat. Sur Mars comme sur Terre, les particules minérales sont en suspension. L'impact radiatif d'un aérosol dépend de la nature de la surface sous-jacente. Peut-on déterminer si le transport des poussières minérales martiennes a une influence sur le climat ? (Plus d'information en Annexe 9).

Activité 9 – Etude des variations journalières sur Mars | Données
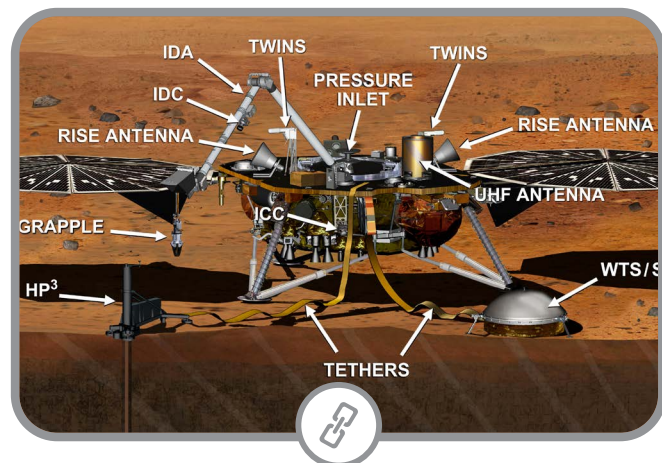
A la surface de Mars, on retrouve des tendances estivales : 20 °C, la brise des alizés… Mais à partir du début de la nuit, les températures chutent de plusieurs dizaines de degrés et les conditions de gel atteignent - 100 °C jusqu'au lendemain matin. En fait, le sol martien, sec et granuleux, ne peut stocker que très peu de chaleur. Son inertie thermique est très faible par rapport à celle de la Terre et de ses océans. L'atterrisseur InSight est équipé d'une station météorologique complète (APSS, Auxiliary Payload Sensor Suite). Comment l'analyse des données météorologiques peut-elle nous aider à améliorer nos connaissances sur les perturbations météorologiques sur Mars et sur Terre ? Les élèves utiliseront un script de traitement de données Python, afficheront les informations qu'ils peuvent

recueillir à partir des perturbations météorologiques et compareront et interpréteront les résultats obtenus pour la Terre avec ceux obtenus pour Mars. (plus d'information en Annexe 10).

Activité 10 - SEIS, un sismomètre bien emballé | Activités pratiques

La Terre et Mars sont des planètes rocheuses très semblables. Certaines personnes les appellent même des planètes " jumelles ". Mais pourquoi les scientifiques ont-ils insisté pour recouvrir le sismomètre d'une coque de protection ? Le but de cette activité est de déterminer en quoi l'atmosphère et l'environnement de Mars diffèrent de ceux de la Terre et pourquoi la construction de l'atterrisseur avait besoin d'instruments vraiment solides. Et ont nécessité de nombreux tests dans des conditions extrêmes sur Terre ? Les élèves devront rédiger un article scientifique sur les particularités des atmosphères de Mars et de la Terre, dans lequel ils intégreront les arguments avancés par les scientifiques pour expliquer le processus responsable de la perte d'une grande partie de l'atmosphère sur Mars et déduiront les arguments que les scientifiques responsables de la mission InSight Mars ont pris en considération pour développer des instruments de mesure très résistants pour faire face à l'environnement hostile de Mars. ((plus d'information en Annexe 11).
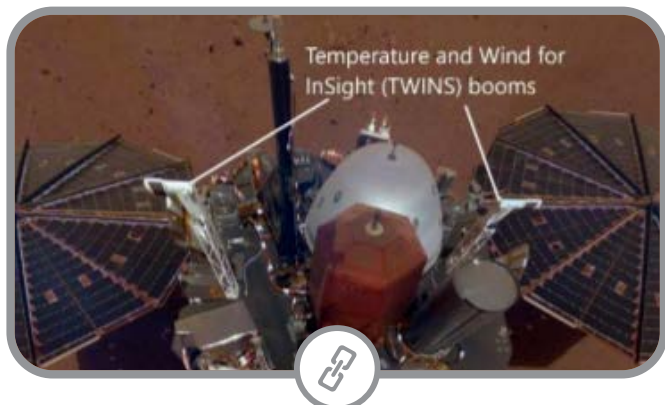
Activité 11 - Instruments pour mesurer la vitesse du vent martien | Activités pratiques

Sur Terre, les capteurs utilisés pour mesurer la force et la direction du vent sont de deux types : les capteurs mécaniques avec anémomètre et girouette et les capteurs à ultrasons. Comment déterminer la vitesse du vent martien malgré un environnement hostile ? Pour le capteur InSight, les ingénieurs ont choisi les capteurs TWINS (Temperature and Wind Sensors for InSight). Ils enregistrent la température de l'air, la vitesse et la direction du vent 2 fois par seconde. Les élèves utiliseront des capteurs semblables pour mesurer le vent et la température, détermineront la direction du vent et exploiteront ces données (plus d'information en Annexe 12).

Géologie Externe de Mars versus Terre

Activité 12 – L'eau salée à l'origine des ravines sur Mars : Info ou Intox? | Activités pratiques
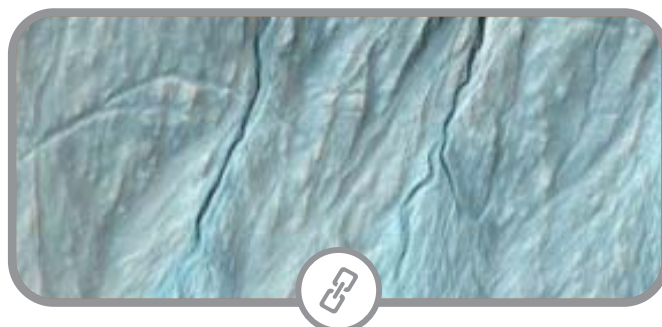
Les scientifiques croyaient que le processus de liquéfaction du sol était responsable de la présence de ravines sur Mars. C'est-à-dire un processus au cours duquel les sels absorbent les vapeurs d'eau atmosphériques lorsque la température et l'humidité sont élevées en même temps. Mais le processus permettant la formation de ravines sur Mars n'est pas dû au ruissellement de "l'eau salée", mais à un autre facteur. Comment se forment les ravines sur Terre et sur Mars ? L'érosion du sol est-elle la même ? Cette activité propose aux élèves d'analyser les documents fournis et de réaliser le protocole de modélisation du processus de formation des ravines sur Terre (Érosion - Transport - Dépôt) afin de formuler des solutions plausibles sur le processus responsable de la formation des ravines sur Mars (ex : variation saisonnière de la pression de surface globale). (Plus d'information en Annexe 13).

Activité 13 – Des paysages façonnés par le passage de tornades de poussières | Modélisation

L'atterrisseur Mars InSight a subi une tornade de vent qui a dégagé la poussière accumulée sur les panneaux solaires de l'atterrisseur depuis son arrivée. Les élèves comprendront les lois physiques qui régissent le mouvement des masses d'air, c'est-à-dire la convection atmosphérique, mais aussi le processus sous-jacent à la formation des Dust Devils pour en déduire les causes des traces laissées sur le sol si représentatif pour la planète Mars. Existe-t-il un tel phénomène sur Terre ? Les élèves effectueront une expérience pour mettre modéliser le mouvement des masses d'air. (Plus d'information en Annexe 14).

Activité 14 – Comment peut-on avoir sur une planète si petite – Mars – un volcan si grand ? | Activités pratiques
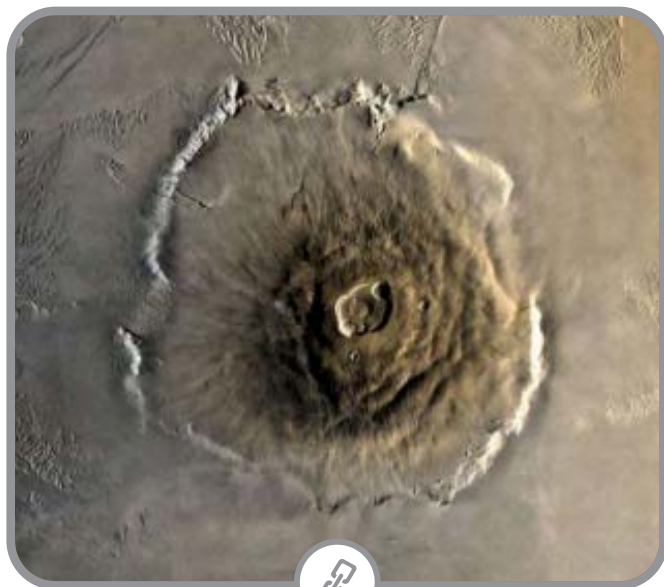
La taille et la forme d'un cône volcanique sur la Terre permettent aux volcanologues de retracer l'histoire du volcan ainsi que sur la composition et les autres propriétés physiques du magma qui en est à l'origine, comme sa viscosité. Beaucoup d'étudiants savent que le volcan sur la planète Mars, Olympus Mons, est le plus du système solaire, ou du moins, son plus haut volcan. Comment mesurer et comparer les tailles des plus hauts volcans des deux planètes, Mauna Kea sur Terre et Olympus Mons sur Mars ? Grâce à une série de calculs simples, les élèves apprendront la taille de ses sommets volcaniques. A partir de son volume, de sa composition et de sa densité, ils peuvent calculer leurs poids respectifs. Ils formuleront ensuite des théories pour expliquer les différences de taille mais aussi comparer les dynamiques interne des planètes Terre - Mars. (Plus d'information en Annexe 15).

Géologie Interne de la planète Mars versus Terre

Activité 15 – Comment déterminer l'épicentre d'un séisme avec un seul sismomètre sur Terre | Modélisation
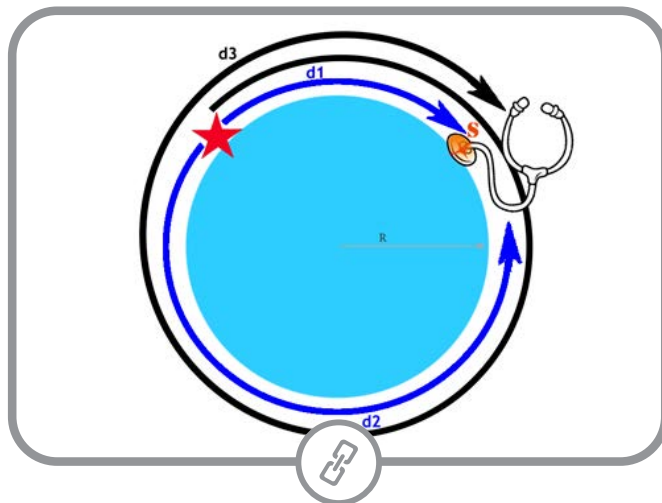
Grâce aux données de trois stations sismiques, il est possible d'estimer la localisation de l'épicentre d'un séisme. Sur Mars, il n'y a qu'un seul capteur pour détecter et estimer l'emplacement de l'épicentre d'un séisme. C'est pourquoi les élèves tenteront de localiser un tremblement de terre en utilisant également les données enregistrées à une seule station sismique. Ils apprendront à connaître les ondes de Rayleigh, estimeront l'azimut et analyseront les résultats à l'aide d'un logiciel dédié (Seisgram2K). (Plus d'information en Annexe 16).

Activité 16 – Comment déterminer la localisation d'un séisme Martien à partir d'un seul sismomètre | Données & Modélisation

La mission Insight vise à localiser les tremblements de terre à l'aide d'un seul sismomètre. Théoriquement, Mars ayant un petit périmètre, les scientifiques espèrent

enregistrer plusieurs trains d'ondes, décalés dans le temps correspondant au même séisme ou impact. Les élèves comprendront comment, à l'aide d'un seul sismomètre, il sera possible de localiser l'origine des ondes sismiques créées par un impact de météorite ou un séisme et d'expérimenter avec un modèle pour mieux comprendre la théorie. (Plus d'information en Annexe 17).

Activité 17 – Comment modéliser l'intérieur de Mars ? | Activités pratiques

Au cours des derniers siècles, de nombreux géoscientifiques ont étudié la structure interne de la Terre. En plus d'observer les roches à la surface de la Terre, de les analyser et de les tester à l'aide de différentes méthodes, un large éventail d'outils ont été mis au point pour découvrir comment la structure de la Terre se présente. Les méthodes directes comme les forages ne pouvant pas fournir d'informations sur la structure interne, les scientifiques se sont concentrés sur les méthodes dites indirectes. Dans cette activité, les élèves doivent arriver en mettant en œuvre une démarche scientifique à découvrir ce qui se cache dans deux sphères d'apparence identique mais dont les propriétés physiques sont différentes (masse et, par conséquent, leur densité). (Plus d'information en Annexe 18).

Activité 18 – Planétologie comparée | Activités pratiques

Cette activité est destinée à être réalisée après l'activité "Comment explorer l'intérieur de Mars", au cours de laquelle les élèves ont appris les différentes méthodes pour étudier la structure interne d'une planète. Deux aspects de l'étude de la structure interne d'une planète ont été développés au cours de cette activité : la distribution des masses à l'intérieur et la présence ou l'absence d'un magnétisme général. Les élèves proposeront des hypothèses et en discuteront avec les autres élèves, proposeront des méthodes pour vérifier ces hypothèses, comprendront comment ces propriétés permettent ou non de distinguer la Terre de Mars, calculeront la densité des différentes boules d'argile et les compareront pour décider quels modèles de boules sont les meilleurs pour la Terre et Mars. (Plus d'information en Annexe 19).

Activité 19 – Le sismogramme : un signal complexe | Données
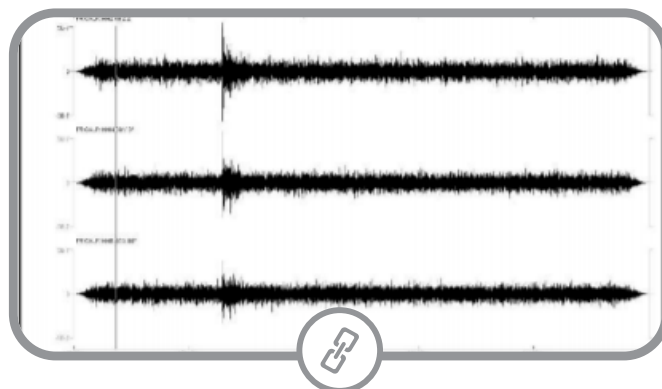
Le mouvement du sol est le résultat de l'arrivée de nombreuses ondes, qui ont leur propre fréquence. Les sismomètres enregistrent continuellement le mouvement du sol et ce signal continu, sans arrivée d'ondes sismiques, est considéré comme le bruit sismique ambiant. Lorsqu'un séisme est bien enregistré, les ondes sismiques sont clairement identifiées par rapport au bruit sismique de fond. Mais parfois, ces ondes avaient été enregistrées, mais elles ne sont pas perceptibles. Connaissant les gammes de fréquences des ondes sismiques, il est possible de trouver un séisme dissimulé dans le bruit sismique. Les étudiants utiliseront un logiciel d'analyse sismique (Seisgram), estimeront une gamme de fréquences spécifiques pour différents types d'ondes sismiques et utiliseront des filtres adaptés pour identifier le signal utile. (Plus d'information en Annexe 20).

Activité 20 – Impact des paramètres atmosphériques sur les enregistrements sismiques | Données
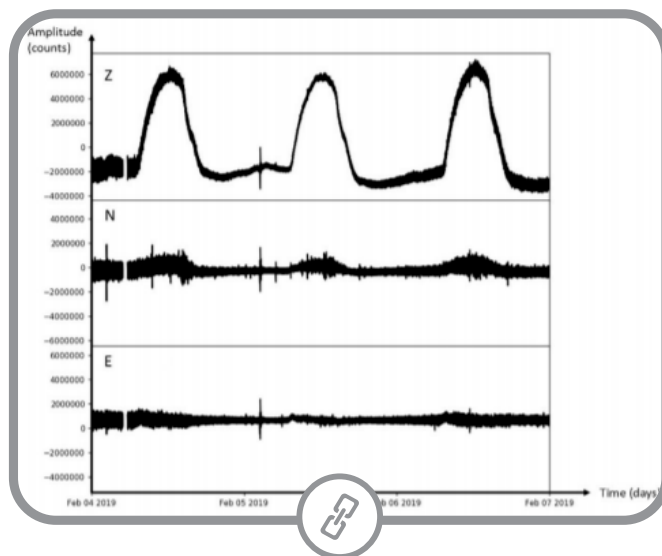
Une station sismique est conçue pour détecter les mouvements infimes du sol. Ses appareils électroniques peuvent être influencés par les mouvements du sol, ainsi que par les paramètres atmosphériques. Nous avons proposé ici des sismogrammes où le signal continu n'est pas plat : jour après jour de grandes arches quotidiennes sont

observées. Comment filtrer le bruit sismique en détectant les variations atmosphériques du signal ? Les élèves doivent analyser et décrire des signaux continus, trouver un paramètre physique qui peut induire une perturbation du signal et trouver un événement remarquable à l'exception des arcs quotidiens. (Plus d'information en Annexe 21).

Mission spatiale vers Mars

Activité 21 - Egg drop | Activités pratiques
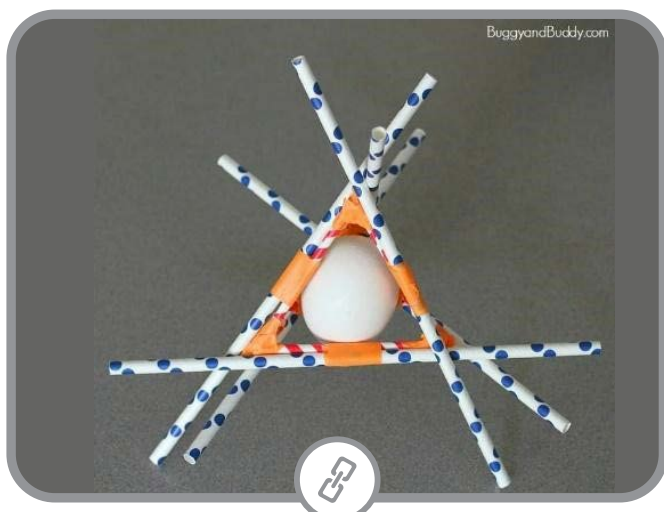
Les activités d'ingénierie donnent aux enfants l'occasion d'acquérir des aptitudes à la résolution de problèmes et à l'observation, de travailler avec des outils et du matériel intéressants et engageants, et d'apprendre à travailler en équipe. Quand on laisse tomber quelque chose, il tombe par terre. C'est parce que l'objet est attiré par la gravité de la Terre. Vous remarquerez que certains objets tombent plus vite que d'autres, c'est à cause de la résistance de l'air. Essayez de faire tomber un morceau de papier et une brique de Lego. Lequel tombera le plus vite? (Plus d'information en Annexe 22).

Activité 22 – Aller sur Mars | Activités pratiques
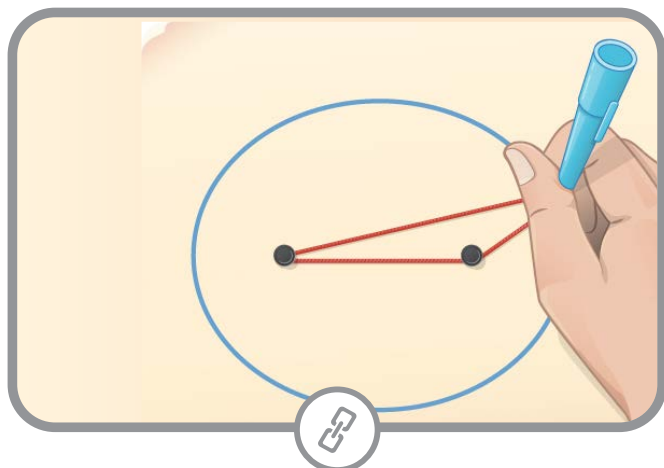
Trouver la position relative de la Terre et de Mars afin de permettre à un vaisseau spatial de suivre la trajectoire optimale en termes de consommation d'énergie.

Les données de position planétaire et les lois mathématiques qui les régissent permettent de déterminer la prochaine fenêtre de lancement vers Mars. (Plus d'information en Annexe 23).

Activité 23 – Le soleil, une source d'énergie durable
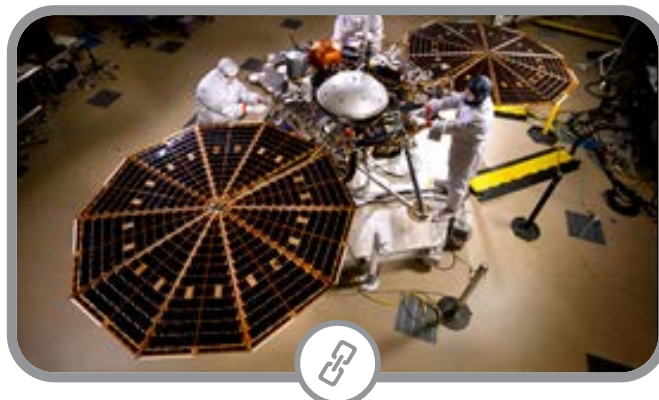
La NASA utilise plusieurs technologies différentes pour fournir l'énergie nécessaire à l'exploration spatiale. Chaque technologie répond aux exigences des différents types d'exploration et cet apprentissage basé sur la résolution de problèmes explorera l'utilisation des panneaux solaires comme source d'énergie. Au cours de ce processus, les élèves apprendront les concepts de base de la salle de classe liés à l'énergie, à la transformation de l'énergie, à l'électricité et aux circuits (Annexe 24).

WEBINAIRES POUR ENSEIGNANTS

Une série de six webinaires ont été réalisés à l'intention des enseignants dans le cadre des délovrables et ont permis aux participants d'acquérir une bonne compréhension des sujets STIM liés à la planétologie et la sismologie planétaire. Les résumés de chaque webinaire sont présentés ci-dessous et les enregistrements sont disponibles sur le site Insight.oca.eu[1] :

1   https://insight.oca.eu/fr/stim-resources

Thème	Résumé
Insight mission – passé et présent	Webinar 1 : Ce webinaire d'introduction présentera le contexte scientifique des missions spatiales vers Mars et leurs ramifications pour notre société. Les principales notions seront brièvement expliquées afin de faciliter la compréhension de ce qu'est la mission InSight et comment elle peut aider les enseignants à améliorer leurs pratiques en classe.
Sismologie et structure des planètes telluriques	Webinar 2 : La sismologie est l'étude des mouvements du sol, qui contient des informations sur la rupture brutale des roches, la propagation des ondes sismiques et les comportements du sol. Les mouvements du sol sont différents d'un séisme à l'autre, et leur étude spécifique permet d'obtenir des informations de la surface jusqu'en profondeur. Les ondes sismiques peuvent être générées par de nombreux phénomènes, comme la rupture tectonique et les impacts météorologiques. Ce sont les principales sources attendues d'ondes sismiques sur la planète Mars. Ce webinaire a montré comment l'étude de la structure interne de Mars pouvait aider les chercheurs à comprendre pourquoi Mars est une planète froide et désertique aujourd'hui ? Des sismomètres éducatifs et des expériences simples ont été proposés pour illustrer cette présentation.
La structure interne des planètes rocheuses : un regard sur la Terre	Webinar 3: L'atterrisseur InSight permet enfin d'avoir un sismomètre SEIS sur Mars. Les sismologues ont exploré la sismologie d'autres planètes pour mieux comprendre la Terre. Mais comment les scientifiques de la mission peuvent-ils déterminer l'épicentre d'un tremblement de terre ou l'impact d'une météorite avec un seul sismomètre sur Mars ? C'est le sujet de cette session.
Explorer plus loin	Webinar 4 : Grâce aux données recueillies par toutes les missions martiennes, les scientifiques peuvent maintenant comparer la géodynamique externe de Mars et de la Terre. Cette étude permet de tirer des conclusions sur les facteurs responsables de leur géomorphologie. Les élèves utiliseront les données des images satellites et expérimenteront pour confirmer leurs hypothèses.
Mars peut nous en apprendre beaucoup sur les scénarios passés et futurs de notre propre planète.	Webinar 5 : Le Lander Insight a installé un instrument HP3 qui mesure le flux de chaleur de Mars. Les données recueillies permettront aux scientifiques d'étudier la dissipation du flux thermique du noyau de Mars. Dans cette activité, les élèves expérimenteront le fonctionnement de la sonde HP3 et recueilleront les données nécessaires à son utilisation.
Créez votre propre scénario d'apprentissage	Webinar 6 : Dans ce dernier webinaire, nous planifierons et présenterons ensemble différents scénarios d'apprentissage sur la façon d'intégrer la mission spatiale vers Mars en classe.

EDUTEASERS

En plus des ressources mentionnées précédemment, trois courtes vidéos ont été enregistrées avec des chercheurs afin de présenter certaines activités et d'accroître la motivation des élèves à participer à la mission InSight.

Ces vidéos sont publiées sur le site Insight.oca.eu et sont résumées comme suit :

https://insight.oca.eu
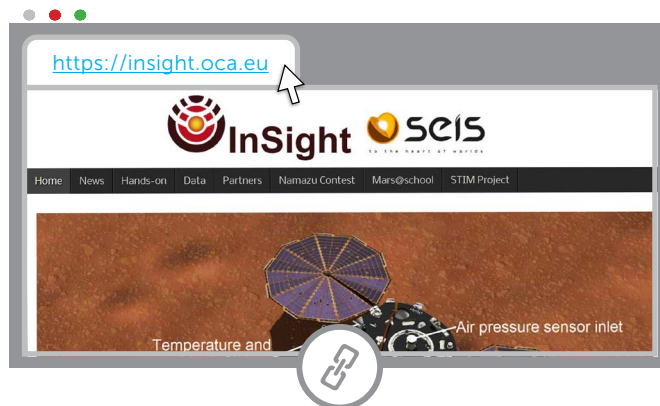
Philippe Lognonné : Professeur de Géophysique et de Sciences Planétaires, Université de Paris Diderot – Investigateur principal, instrument SEIS sur InSight (NASA), présente la mission Mars insight et ses objectifs scientifiques. Que se cache-t-il sous la surface de Mars ? Comment s'est formée la planète rouge ? Que peut nous apprendre Mars sur notre propre planète Terre ? Les premières réponses sont maintenant disponibles grâce à l'atterrisseur de Mars, l'Exploration de l'intérieur de la planète à l'aide des Investigations sismiques, de la Géodésie et du Transport thermique, également appelé InSight. Grâce à son sismomètre et à ses sondes thermiques, InSight étudie la dynamique profonde de Mars, aidant les scientifiques à découvrir ce qui se trouve dans son noyau et nous permettant d'en apprendre davantage sur la formation des corps rocheux dans tout le système solaire.

Julien Balestra : Docteur en sismologie, Ingénieur de Recherche Projet IDEX "Observatoire EduMed" Université Côte d'Azur (UCA) explique les activités dans le domaine de la géodynamique interne, en particulier liées à l'étude de la sismologie sur Terre et Mars. Les élèves découvriront comment les scientifiques exploitent les données sismiques reçues de Mars. Cet Eduteaser présente comment l'étude de la structure interne de Mars pourrait aider les chercheurs à comprendre pourquoi Mars est une planète froide et désertique.
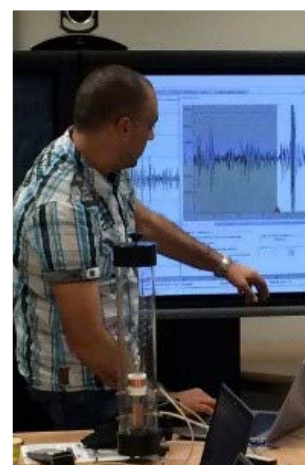
Dragos Tataru : Sismologue à l'Institut national de physique du globe, Roumanie, présente dans cet Eduteaser

Zoom sur le passé, le présent et l'avenir des missions planétaires axées sur la géophysique. Les détails de la formation et de l'évolution initiale de la Terre restent obscurs. L'étude des structures internes d'autres planètes du système solaire présente par conséquent un grand intérêt. Comment la sismologie terrestre a-t-elle vraiment contribué aux découvertes des sciences de la Terre et ce que nous savons sur la Terre ? Cette courte vidéo permet de réfléchir sur l'apport des missions planétaires dans le domaine de la sismologie, principalement la mission InSight mais aussi les autres instruments sismiques de notre système solaire.

Conclusions

Les ressources du projet STIM contribuent au développement professionnel des enseignants sur des sujets comme la Terre, l'Univers et la Planétologie mais permettent aussi de mettre en œuvre des pratiques scientifiques dans les classes.

Tous les élèves, quel que soit leur choix de carrière, devront être capable d'identifier et de comprendre les effets de la science sur les sociétés et sur l'environnement. Les sociétés modernes sont profondément transformées par la science et ses applications technologiques tels que la maîtrise des risques naturels et technologiques, la protection de l'environnement, les communications (transport, échange d'information). La compréhension de ces transformations est indispensable à la prise de décision réfléchie des élèves.

Les ressources STIM élaborées au cours de la première phase du projet, au cœur du présent rapport, proposent du matériel pédagogique innovant ancré dans cette nouvelle vision de l'enseignement des sciences, élément fondamental pour créer des méthodes d'apprentissage de qualité pour les élèves. 23 activités ont été développées au total et regroupées en cinq thèmes importants ainsi que six webinaires pour permettre aux enseignants de proposer des leçons STEM dans le domaine de la planétologie et

de la sismologie planétaire basée sur de la modélisation, de l'exploitation de données de recherche inédites et de l'utilisation de logiciels spécialisé.

L'étroite collaboration entre chercheurs – pédagogues – enseignants a permis d'élaborer une véritable pratique innovante : une approche interdisciplinaire pour transmettre un concept scientifique difficile " sismologie planétaire " et faciliter la compréhension pour chaque individu de la réalité complexe qui l'entoure.

La deuxième phase du projet sera consacrée à l'élaboration d'un guide pédagogique, qui réunira l'ensemble des outils, méthodes et supports nécessaire pour la mise en œuvre des activités STIM.

Un MOOC sera également réalisé et constitué de quatre modules de formations en ligne, chacun d'eux abordant la question sous un angle différent : science, éducation, expérimentation et échange. Ces modules seront réalisés et contribueront au développement professionnel des enseignants dans le domaine de la planétologie, en fournissant aux enseignants les connaissances et les compétences nécessaires pour enseigner des concepts scientifiques difficiles afin de les rendre accessibles à leurs élèves.
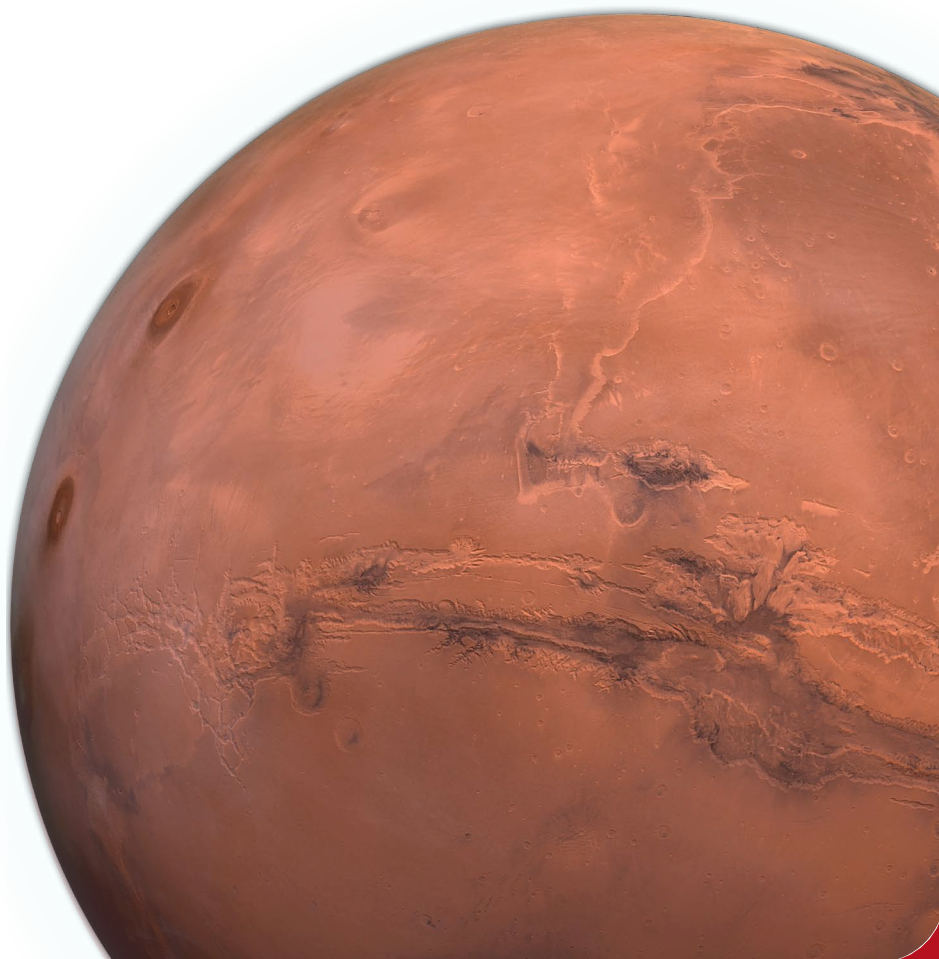
Bibliographie

National Academies of Sciences, Engineering, and Medicine 2018. Design, Selection, and Implementation of Instructional Materials for the Next Generation Science Standards: Proceedings of a Workshop. Washington, DC: The National Academies Press. https://doi.org/10.17226/25001.

National Academies of Sciences, Engineering, and Medicine 2019. Science and Engineering for Grades 6-12: Investigation and Design at the Center. Washington, DC: The National Academies Press. https://doi.org/10.17226/25216.

Annexes

Annex 1

STIM needs assessment & opportunity mapping

This survey is part of a project Erasmus+ - School Tune into Mars (STIM) that aims to
- provide pedagogical materials with high-quality inspirational lessons related to STEM subjects
- provide adequate guidance and underpin innovative activities that are developed in a co-constructive process between researchers and teachers

The objective of the survey is to get the opinion of the science teachers in order to be better able to address their needs and interest and to improve the development of the projects.
The data collected will be deleted after 36 months

The survey is addressed to different profiles:

- IF YOU TEACH & PARTICIPATE AS A USER IN PROJECTS/INITIATIVES. First, we ask for some demographic variables. Secondly, we ask you about your participation in projects/initiatives. Finally, we ask you a sets of questions about your possible motivations: those that lead you to join projects or to implement activities

- IF YOU TEACH BUT YOU ARE NOT A USER IN PROJECTS/INITIATIVES. In addition to some demographic variables, we ask you - with the option of a free text - about the factors that motivate you

The last day of receipt of surveys is 28th of February
The estimated duration is about 10 minutes.
THANK YOU FOR YOUR TIME AND COLLABORATION

Data collection and processing

The data collected through this survey will be used strictly in line with the objectives defined above. This questionnaire is supported by Schools Tune Into Mars, a project financed by the Erasmus + programme and coordinated by the Lycée International de Valbonne (LIV) in collaboration with EUN Partnership AISBL, the Asociacion Espanola para la Ensenanza de las Ciencias de la Tierra (AEPECT) and the National Institute for

Earth Physics (NIEP). All anonymous data collected via this survey will be made freely available online (open access). If they wish, participants can provide their name and email at the beginning of the survey, only if they are interested in providing follow-up information which would lead to participating to a focus group and activities related to the project. The Lycée International de Valbonne (LIV) is the controller of this personal data. This information will not be shared outside the Lycée International de Valbonne (France) and partners of the project mentioned above (for example, your name and e-mail address will not be shared with external partners), and it will be used only according to the purposes declared and will be deleted at the end of 2020. If you have any questions regarding this survey, please contact Fatima Moujdi (Fatima.Moujdi@ac-nice.fr).

Email address*:

Last Name*:
First Name:

Gender*:

School (institution)*:

Location (TOWN)*:
Location (COUNTRY):

Section I - Academic and professional backgrounds

1. Educational level you teach (multiple choice)*
   a. Secondary
   b. Highschool
   c. Other
2. You are a..........teacher (multiple choice)*
   a. Science
   b. Physics
   c. Chemistry
   d. Biology
   e. Geography
   f. Geology
   g. Earth Science
   h. Other

3. What is the highest level of formal education you have completed (single choice)?
    a. Bachelor's degree or equivalent
    b. Master's degree or PhD
    c. Other

4. By the end of this school year, how many years will you have been teaching altogether (short answer - number format validation)?

Section II - Motivation for participation

1. How well prepared do you feel you are to teach…(multiple choices one per line)*

	I do not teach these topics	Not well prepared	Some what prepared	Well prepared
earth science – earth's features and physical processes?				
earth science – the solar system and the universe?				
Planetary science (planetology)				
chemistry – classification and structure of matter?				
physics – types of energy, sources of energy, conversion between energy types?				
environmental and resource issues?				
scientific methods and inquiry skills?				
…..				

2. Preferred Method of Professional Development Training (multiple choices)*
    a. On-Line Modules
    b. Workshops
    c. Webinars

4. Which would be the main motivation to implement STIM activities in class (multiple choices)*
    a. Motivate students to learn
    b. Assess students' current skills and knowledge
    c. Design or implement a challenging curriculum

      d. Including problem solving techniques

      e. Design appropriate out-of-class assignments and activities

      f. Translate subject matter content into standards-based activities

      g. Promote critical thinking

      h. Other

3. Have you ever implement activities starting from topics presented in STIM project (for more details about STIM project and topics please access the links published at the end of the questionnaire)*

      a. Yes

      b. No

      c. Other

5. Would you be willing to implement activities / use resources developed in the STIM project in class? If yes, in what form?* (multiple choice question)

      a. No

      b. YES/in extra-curricular activities

      c. YES/in activities complementary to compulsory courses

      d. YES/in In a dedicated science class

      e. YES/in Optional school curriculum

      f. YES/in Other

....

LINKS

https://twitter.com/STIMerasmus

http://www.scientix.eu/projects/project-detail?articleId=777418

The personal data collect will be used only for:

- assessing the needs and opportunity of implementing STIM activities
- better configure the intellectual outputs of the project
- contacting to share the results and propose further involvements in the project activities

Consent By consenting to this privacy notice you are given us the permission to process your personal data specifically for the purposes identified.

Disclosure Project partner institutions will not pass on your personal data to third parties without first obtaining your consent.

Disclaimer
The European Commission is not responsible for any uploaded or submitted content. Such content expresses the views of its author(s) only

Annex 2

Cooling model for rocky planets

1. Introduction & Problem

The internal heat of a rocky planet comes first of all from the energy accumulated during the accretion phase, then from the formation of the iron core and finally from the radioactivity of the uranium, thorium and potassium present in the mantle.

When all the energy from the formation phase has been converted into heat, the planet begins to cool down.

Pb: What happens to the heat from the formation phase of a rocky planet?

2. Age of students

15 -17 years

3. Objectives

Show that the planet cools down by dissipating its internal heat up to and through the surface.
Experimental modelling and mathematical exploitation of results

4. Primary subjects

Mathematics – Physics – Earth Sciences.

5. Additional subjects

Geography – Computer Science

6. Time required

2hrs

7. Key terms

Geothermal gradient, heat flow, heat dissipation.

8. Background

Excel spreadsheet - Python

9. Materials

- - 'Pétanque' ball
- - Saucepan of boiling water
- - Foam football
- - 4 temperature sensors
- - Computer with software
- - Excel

10. Procedures

- Modelling internal heat dissipation (heat flow):
One of InSight's missions is to determine the amount of heat that continues to escape from its surface (heat flow).

- - Push 4 temperature sensors through the surface of a foam football and make sure they are at depths of
- - 1 cm, 2 cm, 3 cm and 4 cm.
    - Dip a pétanque ball in boiling water then place it inside the football.
- - Close the foam football tightly (to limit the loss of heat).
    - Note the temperature reading on the screen every minute for one hour.
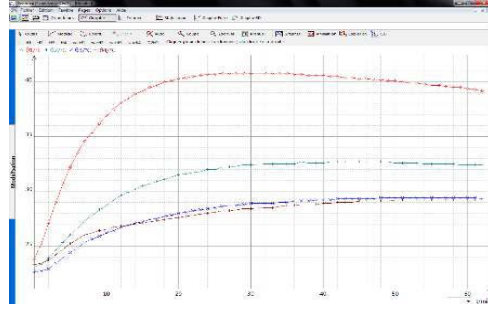
Modelling:

@ F.Bouvet -F Moujdi

Temperature change profile versus depth using a Spreadsheet Graph:

- Mathematical evaluation of measured heat flow data

We are looking for a possible relationship between time t and temperature T.
When the relationship is "affine", it means T = a + bt, so we talk about **a linear regression**.
Even if there is a relationship, the data measured do not usually match this relationship perfectly.

First study: **Using a spreadsheet to determine a relationship between time t and temperature T**

We are going to study the thermal probe database for a specific depth.
In this example, the thermal probe depth is 5 cm.

1) **Open** the file **Insight_Mars_Hp3.ods** or **Insight_Mars_Hp3.xlsx** containing the measurement data.

2) Copy the database **time *t*** and ***corresponding* temperatures *T*** to a spreadsheet.

Represent this database with a point cloud graph.

Nuage de points
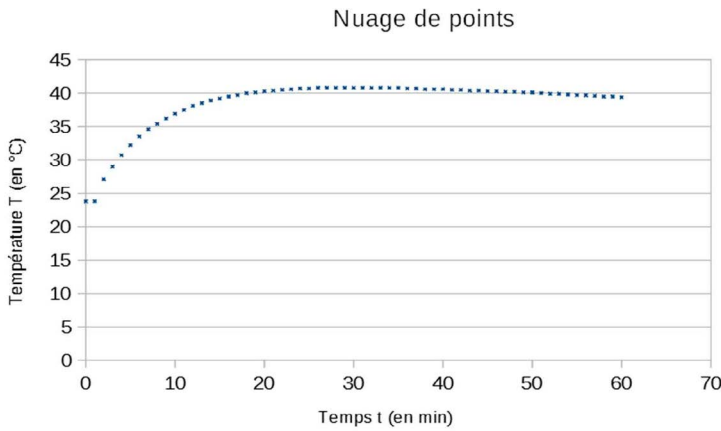
	A	B	C
1	temps	Prof 5 cm	
2	En min	en °C	
3			
4	0	23,8	
5	1	23,8	
6	2	27,1	
7	3	29	
8	4	30,7	
9	5	32,2	
10	6	33,5	
11	7	34,6	
12	8	35,4	
13	9	36,2	
14	10	36,9	
15	11	37,5	
16	12	38,1	
17	13	38,5	
18	14	38,9	
19	15	39,2	
20	16	39,5	
21	17	39,7	
22	18	40	
23	19	40,1	
24	20	40,3	
25	21	40,4	
26	22	40,5	

The second part of the curve, which reflects the cooling process (like on Earth and Mars) appears to be expressed as a straight line.
We will study how to determine this straight line and whether our data fits it.

3) In this example, measurements start at time t=35'.

Represent the database $\{(t_i, T_i), i = 35, \ldots, 60\}$ with a spreadsheet.

Nuage de points
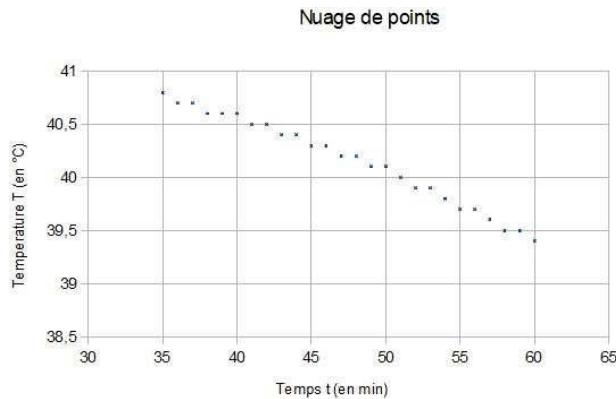
Looking for an affine relationship between two variables t and T means looking for a straight line which best fits this scatter graph.

The least squares method is used to find the line of best fit through an equation:

$y=a+bt$ *with a* and *b* which minimise the sum of squares:

$$\sum_{i=1}^{n}\left(y_i - (a + bt_i)\right)^2$$

This straight line, which is considered to be the only one like it, is called the least squares regression line.

The idea is to determine a straight line which minimises the summed measurement of a range between the points of the scatter graph and the points with the same abscissa on this line.

The smaller the measurement, the closer to all the points of the scatter graph will be the straight line and the better the fit.
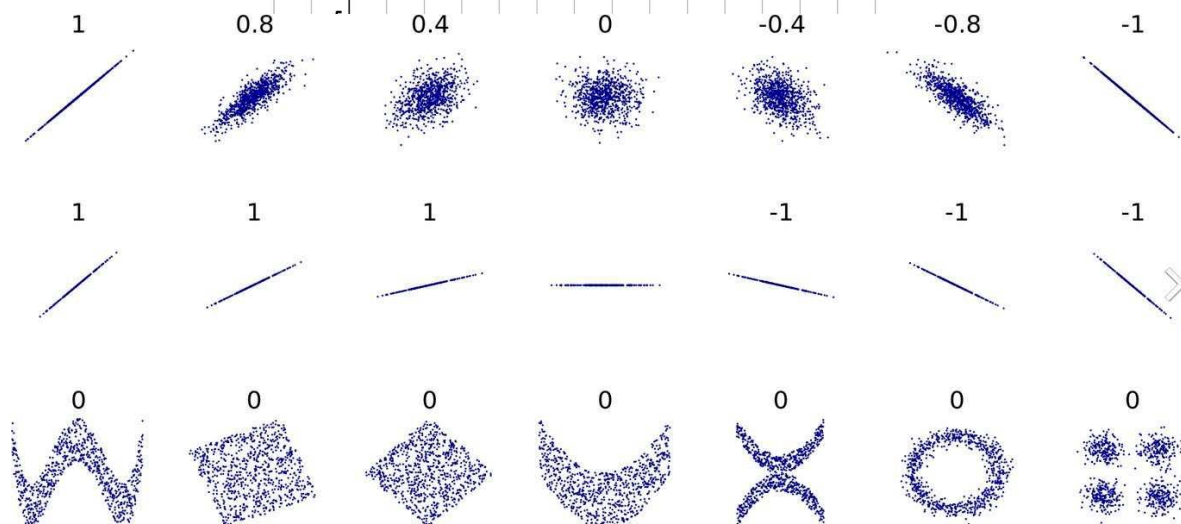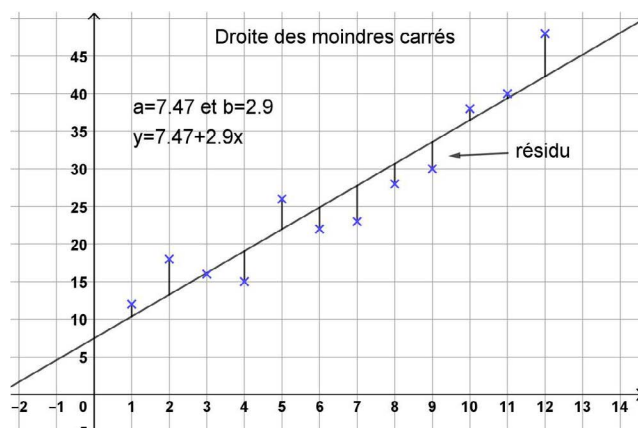
Droite des moindres carrés

a=7.47 et b=2.9
y=7.47+2.9x

résidu

We do not intend to study the minimisation of the range in this activity.

We call real number r the "linear correlation coefficient", defined by: $r = \frac{\sigma_{t,y}}{\sigma_t \sigma_y}$

With $\sigma_{t,y} = \frac{1}{n}\sum_{i=1}^{n}(t_i - \bar{t})(y_i - \bar{y})$, $\sigma_t = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(t_i - \bar{t})^2\right)}$

$\sigma_y = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2\right)}$

$\bar{t}$ and $\bar{y}$ represent the average of t_i and y_i , $\bar{x} = \frac{1}{n}\sum_{i=1}^{n}t_i$ And $\bar{y} = \frac{1}{n}\sum_{i=1}^{n}y_i$

The coefficient will reveal whether the fit is relevant or not, and give information on the scatter graph according to the value of r:

We will use the following numerical criteria using r^2:

- if $0{,}75 \leqslant r^2 \leqslant 1$ then there is a good linear correlation between Y and t

- if $0{,}25 \leqslant r^2 \leqslant 0{,}75$ then there is a weak linear correlation between Y and t

- if $0 \leqslant r^2 \leqslant 0{,}25$ then there is a poor linear correlation between Y and t

4) Calculate coefficient r with the data temperature at a depth of 5cm.

(Caution: the Y coordinates correspond to the temperature values, T)

We are going to see whether such a straight line exists during the cooling process, which in our case took between 35 min and 60 min.

Complete the spreadsheet in order to determine the value of r and r^2:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1					$t_i - \bar{t}$	$T_i - \bar{T}$	$(t_i - \bar{t})^2$	$(T_i - \bar{T})^2$	$(t_i - \bar{t})(T_i - \bar{T})$	$\sigma(t,T)$	$\sigma(t)$	$\sigma(T)$	Coefficient de corrélation r	Valeur de r²
2	temps En min	Prof 5 cm en °C												
3			Calcul de la moyenne t̄ des temps t											
4	0	23,8												
5	1	23,8												
6	2	27,1	Calcul de la moyenne T̄ des températures T											
7	3	29												

If the fit is relevant, we continue…

5) If the fit is relevant, the linear regression line $y = a + bt$ can be found by calculating numbers a and b with the formula:

$$b = \frac{\sigma_{t,y}}{\sigma_t^2}$$ and $$a = \bar{y} - b\bar{t}$$

Calculate the numbers a and b and the equation of the linear regression line fitting this scatter graph.

The existence of such a relationship between time t and temperature T at each point in time reveals the existence of thermal conductivity proper to its environment, here the foam football.

<u>Continuation:</u>

Let us pool the results found by each group in charge of the study for a particular depth.

We will highlight a relationship between time and heat exchange between two heat sensors.

<u>Second study:</u> Using Python software to determine a relationship between time t and temperature T.

We are going to study the thermal probe database for a depth of 5 cm.

We are looking for a possible relationship between time t and temperature T with the Python software and we will limit ourselves to studying linear fit.

1) Run the **Pyzo** software and **copy** files **Temps.csv** and **Temperature.csv** to the directory where the Python program is saved.

2) The following code is used to transform the csv file into a list under Python.

```python
import csv

    # Les fichiers csv doivent être stockés dans le même repertoire que les fichiers python sauvegardés

    # Code pour convertir le fichier Temps.csv en fichier utilisable par Python à fournir aux élèves

with open("Temps.csv") as f:
    Temps = list(csv.reader(f))
var_list = []
list_tot = []
for i in range(0,len(Temps)):
    var_list = Temps[i]
    var_list = list(map(int,var_list))
    list_tot = list_tot + var_list
Temps = list_tot

    # Code pour convertir le fichier Temperature.csv en fichier utilisable par Python à fournir aux élèves

with open("Temperature.csv") as f:
    Temperature = list(csv.reader(f))
var_list = []
list_tot = []
for i in range(0,len(Temperature)):
    var_list = Temperature[i]
    var_list = list(map(float, var_list))
    list_tot = list_tot + var_list
Temperature = list_tot

from math import sqrt
```

The study of Python functions Map and Open is not the subject of this activity.

The time database is stored in the list "**Temps**" **(Time)**.

The temperature database is stored in the list "**Temperature".**

We want to edit a program giving:

 - correlation coefficient r for the range of time starting at n min and ending at 60 min (n corresponds to the time the cooling regime is reached)

- coefficients a and b of the regression line being sought if the fit is relevant

To do this, we have to determine all the elements necessary for these calculations.

(The calculation formulas are recalled on the last page)

After copying the previous code into the program, proceed as follows:

```python
def equation_moindre_carre(n):
```

3) a) Complete this program to calculate the average:

- of time $\bar{t}$ noted "moyenne_t "

- of temperature $\overline{T}$ noted "moyenne_T"

b) Complete this program to obtain a list giving values $t_i - \overline{t}$ noted "ecart_t"

c) Complete this program to obtain a list giving values $T_i - \overline{T}$ noted "ecart_T"

d) Complete this program to obtain a list giving values $(t_i - \overline{t})^2$ noted "carre_ecart_t"

e) Complete this program to obtain a list giving values $(T_i - \overline{T})^2$ noted "carre_ecart_T"

f) Complete this program to calculate $\sigma_{t,T}$ noted "Sigma_t_T"

g) Complete this program to calculate σ_t noted "Sigma_t"

h) Complete this program to calculate σ_T noted "Sigma_T"

i) Complete this program to calculate the value of r when n=41.

Is the fit relevant?

4) Determination of the equation for the least squares regression line:

a) Complete this program to calculate value a.

b) Complete this program to calculate value b.

c) Complete your program so that it displays the equation for this line.

Formula:

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} t_i \quad \overline{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \quad \sigma_t = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(t_i - \overline{t})^2\right)} \quad \sigma_y = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(y_i - \overline{y})^2\right)}$$

$$\sigma_{t,y} = \frac{1}{n}\sum_{i=1}^{n}(t_i - \overline{t})(y_i - \overline{y}) \qquad r = \frac{\sigma_{t,y}}{\sigma_t \sigma_y}$$

The equation of the linear regression line is: $y = a + bt$ with: $b = \frac{\sigma_{t,y}}{\sigma_t^2}$ and $a = \overline{y} - b\overline{t}$

The following numerical criteria will be used using r^2 :

- if $0{,}75 \leqslant r^2 \leqslant 1$ then there is a good linear correlation between Y and t

- if $0{,}25 \leqslant r^2 \leqslant 0{,}75$ then there is a weak linear correlation between Y and t

- if $0 \leqslant r^2 \leqslant 0{,}25$ then there is a poor linear correlation between Y and t

11. Discussion of the results and conclusions

We have just shown that rocky planets dissipate their internal heat up to and through the surface, which leads to their cooling.

Scientists have proposed models showing how Earth's internal heat can be dissipated by convection, thermal conduction, volcanism, plate tectonics, etc. On Mars, heat dissipation is due largely to significant volcanism and probably more gradually by "convection".

We will explore these processes in the following activities (2, 3 and 4).

Annex 3

Heat flow measurement

1. **Problem :** What mechanisms cause the internal heat dissipation of Mars and Earth?

Hypothesis: It is hypothesised that for a solid and rigid planet, heat is transferred to the surface by thermal conduction.

2. **Age of students:** 14 -17 years

3. **Objective:**

To Understand the phenomenon of thermal conduction.

4. **Primary subjects:**

Mathematics – Physics – Earth Sciences.

5. **Additional subjects:**

Computer Science (Arduino)

6. **Time required :** 2hrs

7. **Key terms** :

Geothermal gradient, heat flow, heat dissipation, conductivity.

8. **Background :**

On Earth, the temperature gradient is obtained by directly measuring the temperature at different depths in boreholes or mine shafts. This is what the InSight mission to Mars will do with its Heat flow and Physical Properties Package, an instrument known as HP3.
Once this gradient is known and the thermal conductivity of the underlying rocks is determined, scientists can deduce the heat flow at a point on the surface.
To determine the thermal conductivity of rocks, they are sampled in wells and measured in the laboratory.

On Mars, the heat flow will be measured by HP3, also known as the "mole":

DLR at a glance
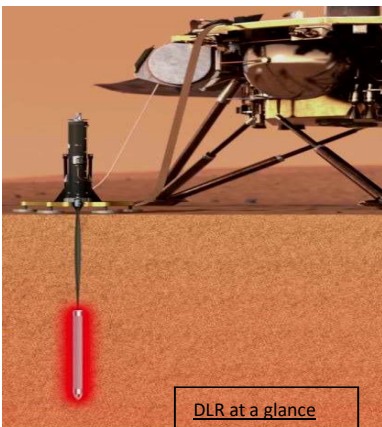
> Every 50 cm, the probe emits a hot pulse and its sensors monitor changes in this thermal pulse over time.
>
> If the crust material is a good heat conductor, such as metal, the pulse will quickly disappear.
>
> If it is a bad conductor, like glass, the pulse will cool down slowly. This tells scientists how quickly the temperature increases with depth and how heat circulates inside Mars.

The heat wave emanating from the mole's heating sheath will spread through the Martian soil, allowing scientists to determine the thermal conductivity of the regolith. Measurements should be accurate, even if the soil is not very conductive. The daily attenuation of the daytime temperature wave will provide HP3 with another way to characterise the ground's thermal conductivity.

9. Materials :

Modelling the thermal conductivity of a rock:	Modelling with temperature sensors like HP3:
- Basalt rock sample - Paraffin pellet - Flat heater	- 2 bars of rock (basalt - granite) - Heat gun. - T° Sensors - Arduino and PC

10. Procedures :

Modelling the thermal conductivity of a rock :

© F.Moujdi - F.Bouvet

- Attach a sample of rock to the support (basalt, granite...)

- Place paraffin pellets (3 to 5 depending on the length of the rock sample) on the rock, spacing them about 1.5 cm apart

- Light the candle and adjust the height so that the free end of the rock is over the flame.

- Observe.

Result:
The pellet just above the candle melts first and then the other pellets melt successively.

Modelling with temperature sensors like HP3:

© F.Moujdi - F.Bouvet

On the screen, we can follow the temperature increase for each sensor and see the heat propagate from one side of the rock to the other without moving any material.
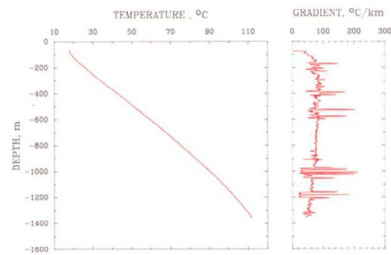
We observe heat propagation from one side to another without any displacement of material.
This heat transfer depends on the thermal conductivity of the material passed through.

Type of material	Thermal conductivity (W/m/K)
Basalt	2.5
Granite	2.7
Peridotite	4.2 to 5.8
Limestone	1.7 to 3.3
Silver	420
Water	6

Fourier's law:

$$q = -K\frac{dT}{dz}$$

We know the conductivity of rocks studied in the laboratory.
Once the thermal gradient measured on Mars is known, geophysicists will be able to deduce the heat flow, i.e. the amount of (thermal) energy that passes through a unit of surface per unit of time (unit = J/s/m^2 or W/m^2). Fourier's law explains that heat flow is the opposite of the product of the thermal conductivity of rocks by the temperature gradient.

Modelling with temperature sensors such and 2 piezoelectric cells :

Heating plate

2 Piezoelectric cells

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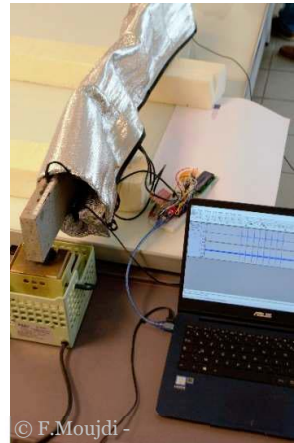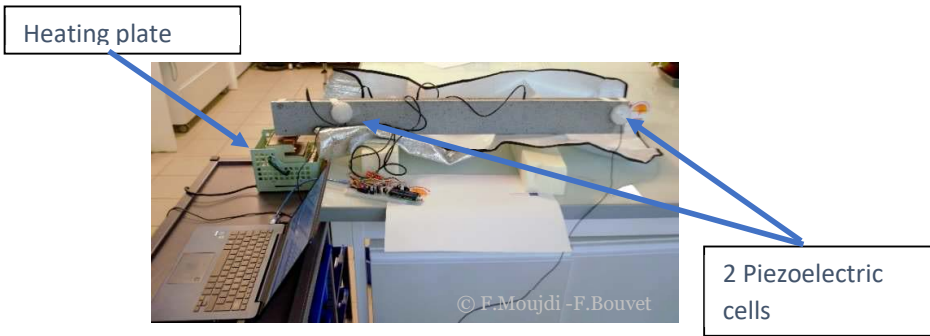
Ambient temperature in the rock : 18,5°C   T1= 63,13 °C, T2 = 22.81°C, et T3= 20,38°C
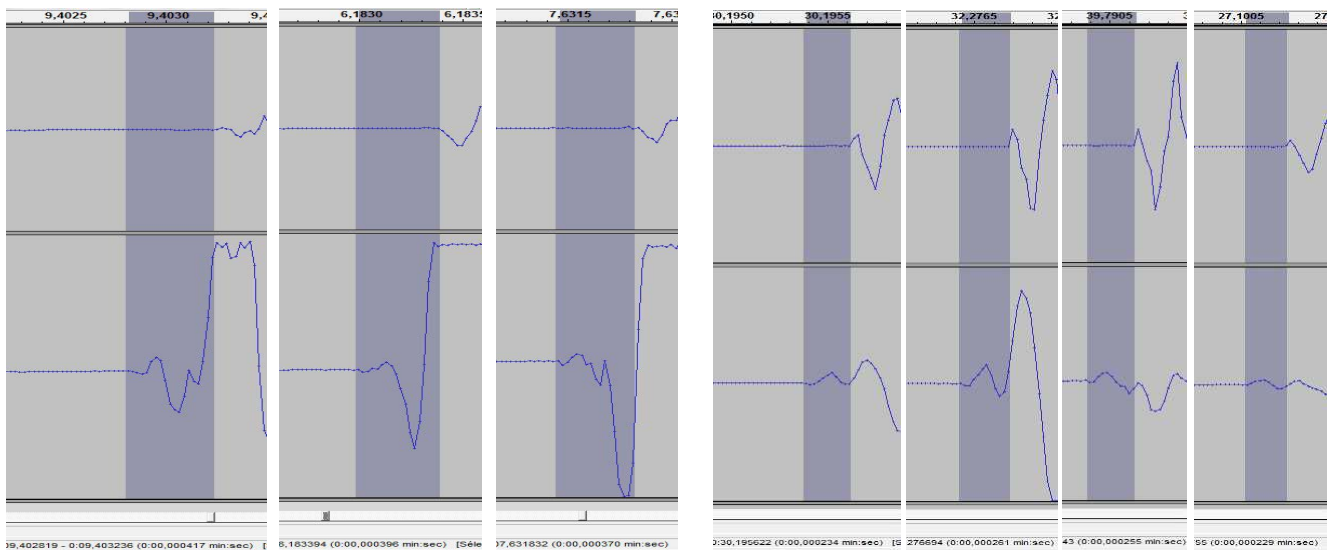
The propagation velocity of the seismic waves can be calculated in these two assemblies. The influence of temperature on wave propagation and the characteristics of the rock traversed can be determined.

11. Discussion of the results and conclusions

On Earth, internal heat is evacuated by **conduction** near the surface. But deeper down, another process known as **convection** explains heat transfer.
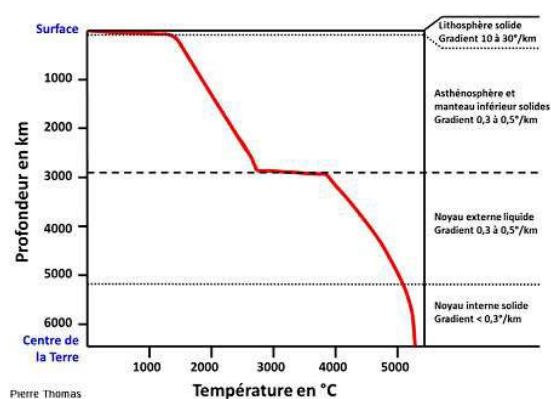
Using seismological data, combined with contributions from laboratory studies on the physical characteristics of terrestrial minerals subjected to high pressure and high temperature (diamond anvil cell studies), scientists have modelled the evolution of temperature versus depth.

<u>Evolution of the Earth's internal temperature as a function of depth:</u>

Droits réservés - © 2014 Pierre Thomas

This is what the scientists of the InSight mission are trying to do.

13. Follow-up activities

Note the temperature data from the HP3 instrument and compare it with terrestrial data to determine the type of rock that constitutes the depths of Mars.

14. Explore More (additional resources for teachers)

- https://www.seis-insight.eu/fr/?option=com_content&view=article&id=175:les-autres-instruments&catid=54:la-mission-insight&lang=fr-FR

- http://planet-terre.ens-lyon.fr/article/chaleur-Terre-geothermie.xml

- The Red Planet: "*Histoire d'un autre monde*" Belin – François Forget, François Costard, Philippe Lognonné

Annex 4

Erasmus+

This project is co-funded by the European Union

Magnetic Field

1. Problem:
What is the mechanism behind the rapid dissipation of Mars' internal heat from the Earth ?

Hypothesis: the disappearance of Mars' magnetic field could explain its much faster heat loss than that of the planet Earth.

2. Age of students: 15 -17 years

3. Objective:

Show how an electric field can create a magnetic field and power it. and Show the role of the magnetic field of a rocky planet (earth shield).

4. Primary subjects:

Mathematics – Physics – Earth Sciences.

5. Additional subjects:

Computer science: satellite image processing with the free QGis software

6. Time required: 2hrs

7. Key terms:

Magnetic field – Electric field.

8. Background:

The magnetic field of a telluric planet is created by movements in its iron core, which is both fluid and a good conductor of electricity. Scientists hypothesise that convection within the liquid core generates an electric current which, in turn, produces a magnetic field: this is known as the "dynamo" effect.

9. Materials:

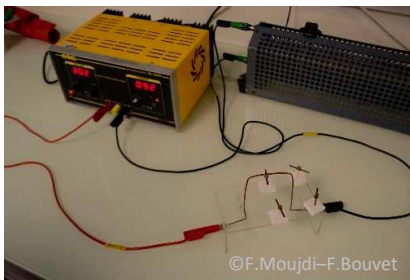| Magnetic field modelling:	Remanent magnetic field modeling:
– A power supply – Copper wire – A piece of plexiglass (about 10 cm × 10 cm) – 4 small compasses – Iron filings	– Basalt sample – Compass – 1 small compass

10. Procedures:

Magnetic field modelling:

No electric current; the compass needles are aligned with the Earth's magnetic field.
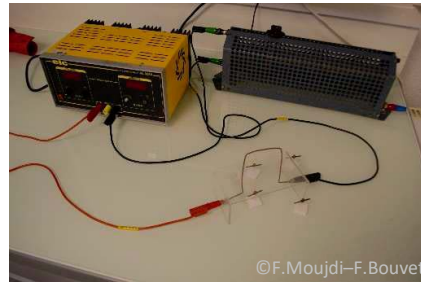
The electric current creates a magnetic field around the wire.

When the direction of the current is reversed, the magnetic field changes direction.
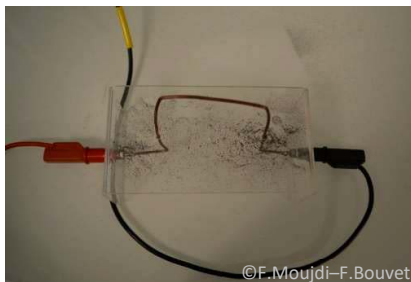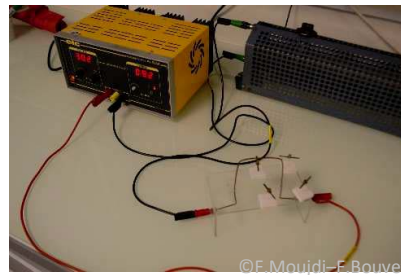
When the operation is repeated with the iron filings, they form a pattern of concentric circles around the wire.

On Mars, just after accretion (4.45 billion years ago), the planet had a liquid core hot enough for convection movements to generate a magnetic field like on Earth.
Mars Global Surveyor has detected the remains of an old magnetic field. Like the Earth, Mars has a magnetic crust producing strong magnetic anomalies.

Earth	Mars
The magnetic field's strength varies from 20 µT at the magnetic equator to 70 µT at the magnetic poles (Langlais et al.[2010]). This magnetic field has been present since 4.5 Ma. It is variable over time and is known to have undergone polarity reversals. On Earth, lava magnets in the opposite direction to the current magnetic field have been discovered, indicating that the Earth's magnetic field has already undergone several polarity inversions in the past.	The MGS spacecraft identified traces of remanent magnetization at the surface and up to 400 km above and an equatorial surface field ranging from 20 to 65 nT (Langlais et al.[2010]). It produced the first complete map of the global crustal magnetic field of Mars. FIGURE 1.11 – Composante radiale du champ magnétique crustal de Mars (Langlais et al. [2004]). These traces of magnetization indicate the presence of a magnetic field. In addition, the orientation of these magnets shows that the magnetic field has lasted long enough to have undergone an inversion of the magnetic poles. The most magnetized regions are concentrated in the former southern highlands, indicating that the magnetic field was present for about 500 million years (Stevenson[2001]).

11. Discussion of the results and conclusions

These results allow us to understand the genesis of a telluric planet's magnetic field. Scientists assume that convection movements within the liquid core (the heat from the iron core rises until it reaches the boundary with the mantle, cools on contact with it, drops back into the core and heats up, etc.) generate an electric current which in turn produces a magnetic field: this is the dynamo effect.
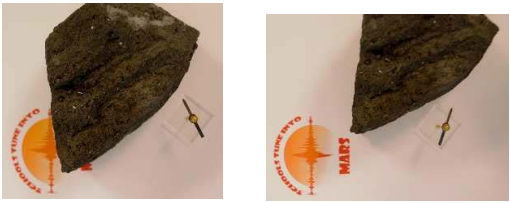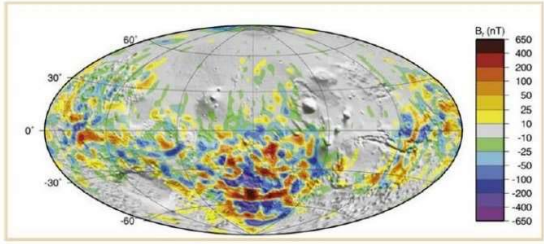
Accidentally created magnetic microfields in the environment produce the electric current which, in turn, produces a global magnetic field.

The absence of a magnetic field maintained by an internal dynamo that has not worked for a long time and the absence of a thick atmosphere have made our neighbour a cold and arid world whose surface is subjected to the harmful bombardment of cosmic rays.

13. Follow-up activities

The InSight mission has embarked an InSight Fluxgate magnetometer (IFG), which will be the first magnetometer to record magnetic data directly from the Martian surface. It is sensitive to 0.1 nano-Tesla. Once the data have been received, we may observe the remnants of a former magnetic field on Mars and compare them to the data from other missions.

14. Explore More (additional resources for teachers)

- *"Terre à cœur ouvert" Pour la Science* No. 67 April – June 2010

- Mars *"Histoire d'un autre monde"* Belin – François Forget, François Costard, Philippe Lognonné

Annex 5

Convection movement in the mantle

1. **Problem :**

    What are the mechanisms that cause the internal heat dissipation of Mars and Earth?

Hypothesis: It is assumed that the transport and evacuation of heat is carried out by convection.

2. **Age of students** 14 -17 years

3. **Objectives:**

Explain the different types of convection that cause heat dissipation in a rocky planet

4. **Primary subjects**

Mathematics – Physics – Earth Sciences.

5. **Additional subjects**

Computer science: Arduino code

6. **Time required** 2hrs

7. **Key terms:**

Convection

8. **Background:**

If a body is cooled from below and heated from above, the dense areas will be at the bottom and the less dense areas at the top. This is a stable situation that will not generate any movement. If, on the other hand, a body is heated from below and cooled from above, the dense areas will be at the top, and the less dense areas at the bottom. The cold material at the top will tend to sink and the warm, slightly less dense material at the bottom will tend to rise. This process is known as thermal convection.

9. **Materials**

Single-layer convection modelling	Two-layer convection modelling
– Beaker – Oil – Chalk – Colouring agent	– Beaker – Oil – Coloured water

10. Procedures

Single-layer convection modelling		Two-layer convection modelling	
The bottom of the heated container is hotter than the oil. The heat is transmitted to the oil, which gradually heats up. As soon as it is a little warmer and less dense than the material above, it starts to rise. As it rises, it no longer receives heat, so its temperature remains almost constant. When it reaches the top, it loses some of its heat, and sinks to the bottom without cooling down during the descent.	© F.Moujdi -F.Bouvet	If two immiscible fluids are put in a container (water at the bottom, and oil above), and heated from below, the water is subject to convection, heating the oil from below. The oil then also enters the convection process. This is referred to as "two-stage convection".	© F.Moujdi -F.Bouvet

11. Discussion of the results and conclusions

Convection can take place in three possible cases:

The dense, cold layer at the top sinks while the warmer layer rises. Between the two moving layers, the material moves little and keeps a constant
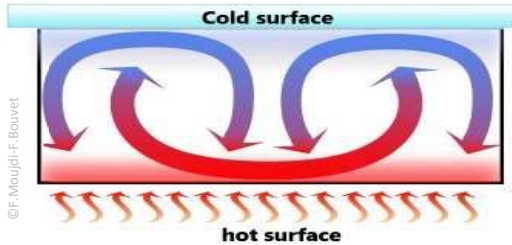
Red hot spots are produced in the material. Only the cold layer dives because it is denser.
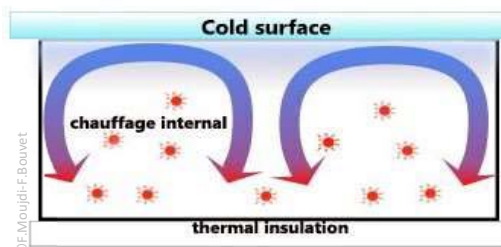
This case models the mantle where the surface is slightly heated. The core releases little heat compared to the mantle's radioactivity, which releases more heat
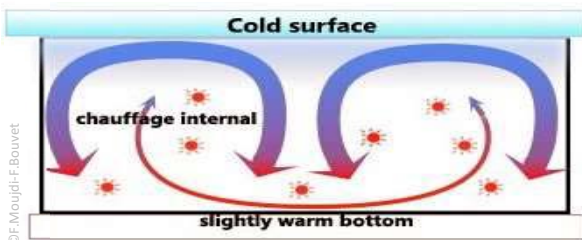
For the first 2 billion years, there was major convection in the Martian mantle, as evidenced by the planet's giant volcanoes.

Gradually, however, the most radioactive elements disappeared from the mantle, either by disintegration or because they rose into the crust with the lava.

The convection didn't stop completely, though. The crust that trapped the radioactive elements now acts as a blanket heating up the mantle. By surrounding itself with an increasingly thick shell, Mars has confined its mantle under a layer of rigid, insulating materials known as the lithosphere. Mars probably still has a very hot mantle and a liquid core. The InSight mission will provide us with more information about the structure of Mars.

On Earth, nearly 40% of heat production has been concentrated in the continental crust. Scientists are divided between two models of convection:
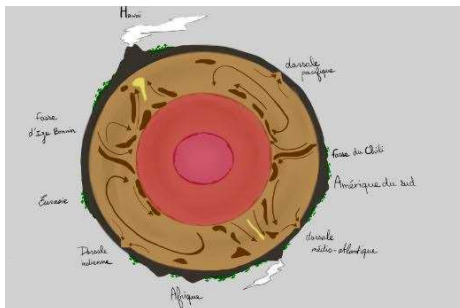
<u>1 convection layer :</u>   <u>2 convection layers :</u>
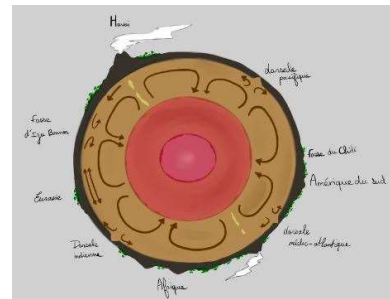
Convection in the mantle (Silver, Carlson, Nicolas) La planète Terre Ophrys

12. Explore More (additional resources for teachers)

- "*Terre à cœur ouvert*" *Pour la Science* No. 67 April – June 2010

- Mars "*Histoire d'un autre monde*" Belin – François Forget, François Costard, Philippe Lognonné

Annex 6

Erasmus+

This project is co-funded by
the European Union

How big is our Solar System

1. Introduction & Pb

The distances among the different planets of our Solar System are so enormous that for many students it's very difficult to compare them with the daily life distances they are used to. This activity is intended to improve the awareness of the students about the spatial relationships among the different planets in the Solar System, focusing especially in Mars and the Earth. Students will use daily life objects; this allows them to make ratio calculations. Before starting the activity, it could be useful if the students have already done the activity "Take a selfie with Mars". So, they can use the planets they have created themselves according to a fixed scale.

2. Age of students 12 - 16   years

3. Objectives

Students can:

- calculate de relative distances among the planets of the Solar System
- understand how big these distances are
- calculate distances in relation to the scale of the planets
- develop communication abilities
- (optional) use TIC to produce a semiautomatic method to calculate the distances between the model of the planets

4. Primary subjects

Earth Science

Mathematics

5. Additional subjects

Physics

6. Time required

"45 minutes + 15 minutes preparing the models"

7. Key terms.

Earth, Mars, Jupiter, planet distances, scale measurements

8. Materials

- Measuring tape (40 - 200m aprox.)
- Computer with the Google Earth™ software or similar that allows to measure distances

- Cardboards or (alternatively) balloons
- Scissors, ruler, pencil
- (optional): computer with a spreadsheet software

9. Background

Using models is a good strategy to improve the ability of students to be aware of absolute and relative distances among planets. Relating models made of daily materials (balloons) with the real world (the planets) is a bridging activity.

The table below shows the measurements to scale that the students may need to complete the activity:

	average orbit distance (km)	equatorial circumference (km)
Mercury	57909227	15329
Venus	108209475	38024
Earth	149598262	40030,2
Mars	227943824	21296,9
Jupiter	778340821	439263,8
Saturn	1426666422	365882,4
Uranus	2870658186	159354,1
Neptune	4498396441	154704,6
Sun		4370005,6
Data from https://solarsystem.nasa.gov/		

10. Procedures

NOTE: The distances between planets are very big, take it into account to make a model in real scale.

OPTION A : (a combination with Take a selfie with Mars)

If the students have pairs of planets in real scale which they have done with balloons. Let them to calculate the real distance between the pair of planets that they have made during the activity. If the distances and spaces in the school allow you to make previous made planets in the real distance, do it.

It is easy to work with internal planets. This is so because the distances between them are shorter than for external planets. For example: if the students take a 9cm of circumference as planet Earth and a 5cm of circumference as Mars, the real distance between them is 170m. On the other hand, if they use similar size external planets, the distance between them would have to be much higher. For example: with a 7cm of circumference as Uranus, and a 6,8 cm of circumference as Neptune, they would have to place them 700m apart one from the other.

OPTION B:

Using a school corridor of which you know its length (for example 40m) the sizes of the planets would be extremely small. In this case, you couldn't use the balloons model because of tis extremely small size, You should use cards with a design of the planet to scale, Students should calculate it by handb or using an excel table. Students could make cards with the scale planet and some information about it. After this process, cards can be fixed on the corridor walls.

Students can work in groups to make the planet cards and explain their planet characteristics to other students.

Mercury	
Planet Profile	**Facts About the Planet**
Diameter: 4,879 km Mass: 3.29×10^{23} kg (0.06 Earths) Moons: None Orbit Distance: 57,909,227 km (0.39 AU) Orbit Period: 88 days Surface Tº: -173 to 427°C First Record: 14th century BC	Mercury does not have any moons or rings. Mercury is the smallest planet. Mercury is the closest planet to the Sun. Your weight on Mercury would be 38% of your weight on Earth. A day on the surface of Mercury lasts 176 Earth days. A year on Mercury takes 88 Earth days. It's not known who discovered Mercury.
 Source: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington	Size of the planet in real scale of this solar system: Scaled diameter: X,XXmm

11. Discussion of the results and conclusions

Students understand the relative distances of the planets in the solar system. This gives them a better understanding of the solar system as a whole.

Cooperation and teamwork are also encouraged.

12. Follow up activities

If you want to try the option A of the procedures, you should do "Take a selfie with Mars" activity before. Nevertheless, these tow activities are independent from each other

13. Explore More (additional resources for teachers)

https://solarsystem.nasa.gov/planets/overview/

https://space-facts.com/planets/

Annex 7

Atmospheric seismic noise

1. Introduction & Pb

The secondary source of atmospheric micro seismic noise is produced by local noise sources: the landing site is affected by gusts of wind or the oncoming of a dust whirlwind near the lander.
In both cases, Martian air exerts a force on the soil: upwards in case of a drop-in pressure, downwards in case of overpressure.

A 10 m dust whirlwind thus causes a drop in the pression on soil of the same proportion as that of a small car blown off the surface

Static deformation of the surface of the planet will have an impact on the seismometer and particularly on the pendulums that measure horizontal and vertical movement. Although soil has a downward movement, the dominant effect is that of lateral movement, that can be detected by SEIS sensors.
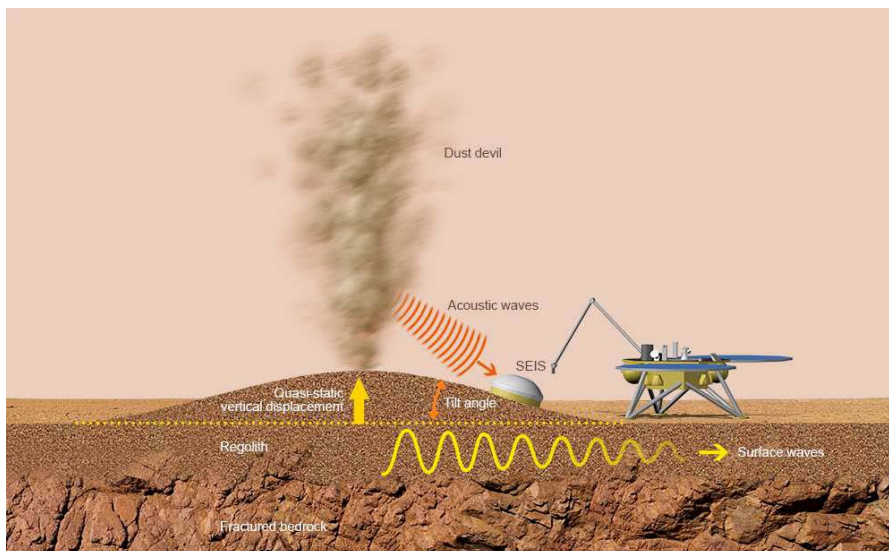
Simulation of ground deformation around the InSight lander (© IPGP/David Ducros)

2. Age of students 15 - 17 years old

3. Objectives

Let's determine if a simple drop in pressure can cause a soil deformation effect detectable by accelerometers, although this type of deformation isn't visible to the naked eye.

4. Primary subjects

Earth Science- physic

5. Additional subjects

Arduino

6. Time required 2H

7. Key terms.

Accelerometer - Seismogram - Propagation waves - Atmospheric movements.

8. Background

The Martian air, by constantly moving around the Martian globe, is able to excite the planet, and make it vibrate like a bell, at very specific frequencies.
Geophysicists call this phenomenon the "hum" of the planet, a kind of persistent hum, which only long-period sensitive seismometers like SEIS can hear.
Despite the fact that this haunting murmur can be considered as a parasitic background noise, it is of particular interest to geophysicists. Thanks to it, it will be possible to probe the surface layers of the Martian soil, at depths ranging from several tens of metres to several hundred kilometres (access to the mantle), even in the absence of earthquakes.

9. Materials

A soft elastic ball, such as a fitness ball of 250 cm in diameter

An Arduino type UNO

A MPU5060 accelerometer, a BME280 pression sensor, connected to a predefined UNO

A PC with the PLX-DAQ-v2.11 file available

A 1600W hair dryer

10. Procedures

Place the fitness ball on the polystyrene bars in order to avoid any kind of contact with the soil

Firmly attach the accelerometer and the pression sensor using adhesive tape

Hold the hair dryer's air outlet in a vertical position towards the fitness ball and blowing upwards without touching it.

Accelerometer

Pressure sensor

Accelerometer   Pressure sensor

©F.Bouvet-F.Moujdi

©F.Bouvet-F.Moujdi
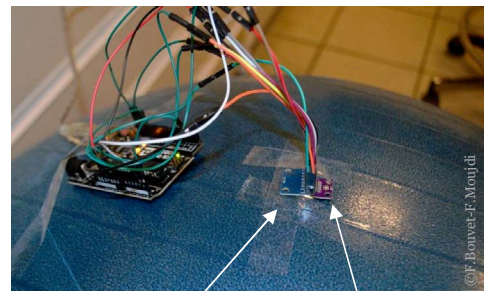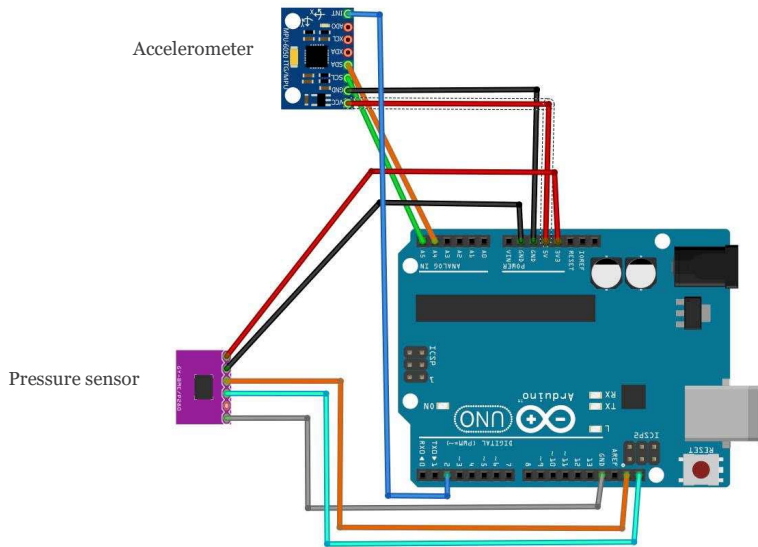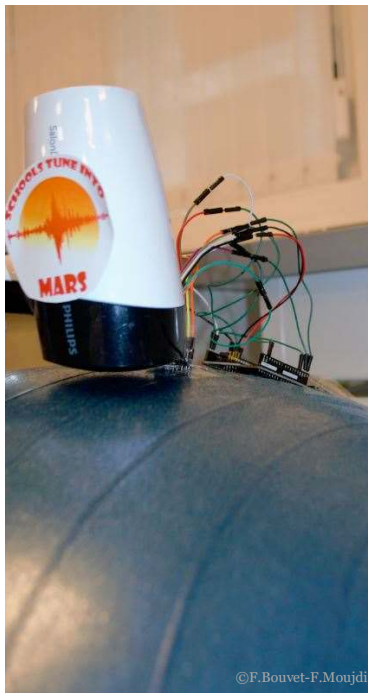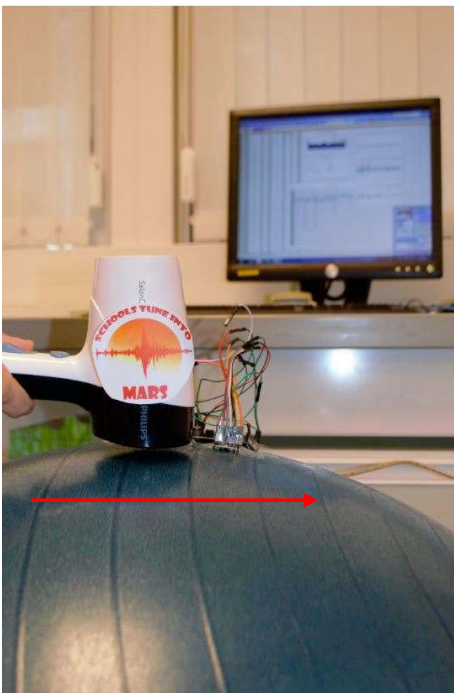
Move around the hair dryer without touching the fitness ball, but keep it close while maintaining a constant distance.

Obtained results:
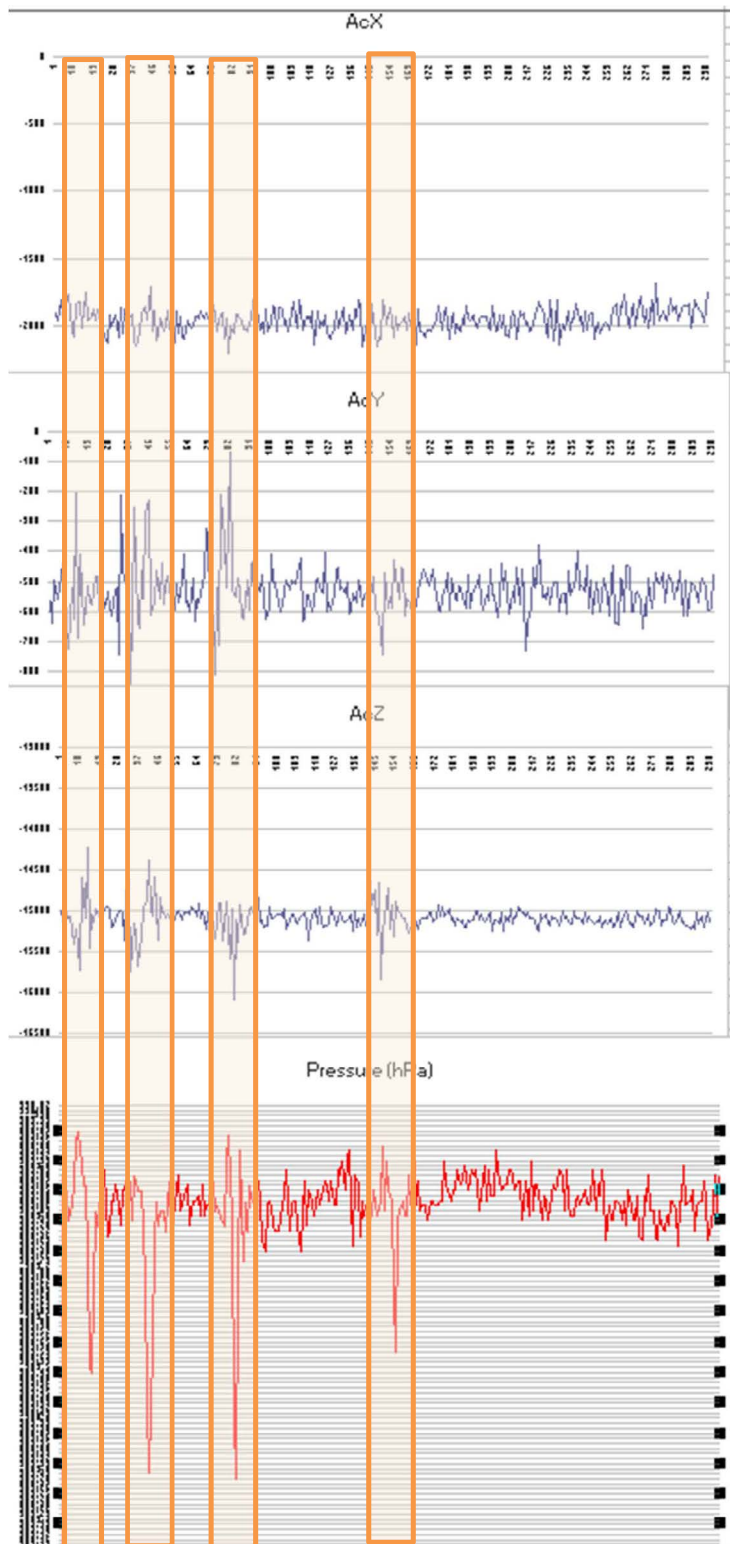
Enclosed in boxes are the recordings of the successive passages of the hair dryer above the sensors.

We can observe a movement throughout the surface at low pressure.

Erasmus+

MARS

This project is co-funded by the European Union

Primary aerosols and climatic impact on Earth

1. Introduction & Pb

In March 2018 a strange phenomenon takes place in Russia and on the whole Eastern Europe : Orange snow covers the ski slopes.

We can frequently see coloured snow layers in the French Alps during winter and so-called muddy rains to the delight of car wash workers.

In Marseille, the road, cars and buses are covered in sand.
— Maxppp
https://www.francebleu.fr/infos/climat-environnement/la-provence-touchee-par-des-pluies-de-sable-1459761392

A skier in Sotchi, Russia.
https://www.parismatch.com/Actu/Environnement/Pourquoi-il-est-tombe-de-la-neige-orange-en-Russie-1486670

Let's try to explain the phenomena.

2. Age of students 15 – 17 years

3. Objectives

Using a fact of life and the study of a test sample, we will discover what a primary aerosol is and study its impact on the climate whether it is suspended in air or back on the Earth's surface.

First, we will try to determine the optical thickness of the particles in the test sample extracted with a photometer in order to determine their nature and therefore their impact on the climate.

We can then establish if major dispersals of particles have the potential to significantly influence Earth's climate.

4. Primary subjects

Physics – Earth Science – technology

5. Additional subjects Programming Arduino

6. Time required 2hrs

7. Key terms.

Aerosols, albedo, absorbance.

8. Materials

- Step 1

- A sample of damp dustfall, for this example particles in suspension collected from the orange snow in the Southern Alps.
- A Calitoo
- Two transparent containers
- A 12 V lamp placed in a holder
- A PC with Calitoo software installed

- Step 2

- A sample of damp dustfall, for this example particles in suspension collected from the orange snow in the Southern Alps.
- A digital light meter
- Two transparent containers
- A 12 V lamp placed in a holder

9. Background

The Calitoo is a photometer that determines the level of aerosols present in the atmosphere and characterizes their size distribution (smoke, polluting gases, ice crystals, dust).
The Calitoo measures the optical thickness of the atmosphere at different wavelengths: blue (465nm), green (540nm) and red (615nm).
Scientists define an aerosol as a suspension of particles in the atmosphere. These particles are made up of solid and/or liquid substances. Mineral or organic, composed of living matter (pollens…) or not, large or fine, suspended particles constitute an extremely heterogeneous set of pollutants whose size varies from a few tenths of nanometers to a hundred micrometers.
The albedo of the Earth-atmosphere system is the fraction of solar energy that is reflected back to space. Its value is between 0 and 1, and the more reflective a surface is, the higher its albedo. The elements that contribute most to the Earth's albedo are clouds, snow and ice surfaces and aerosols. For example, the albedo of fresh snow is 0.87, which means that 87% of the energy is reflected by this type of snow.

10. Procedures

- Setting up the Calitoo arrangement:

Calitoo connected to a PC with dedicated software

transparent container with water
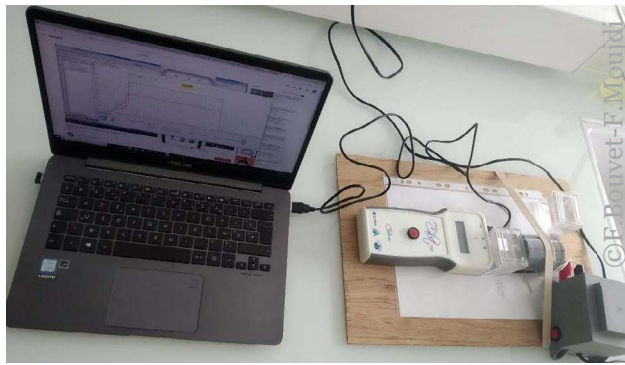
- Initialising the measurement functions

The initial step of the simulation is setting the base level. That is the equivalent of an aerosol-free atmosphere and hence we need to measure the luminous flux through a container filled with pure water.

In the monitoring module, select
◦ Low light experiment, then in order to start the measurements, click on the blue round icon in the bottom left corner.
Place the container filled with pure water and turn on the light.
Click on [Init Max] button to start the program and set the base level.
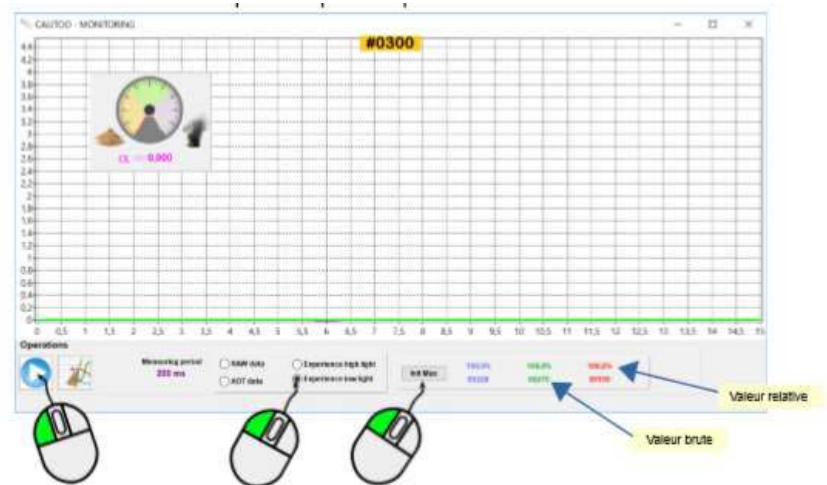
- Experiment using our sample of particles collected from orange snow.

  Replace the pure water container by a container carrying the particles in suspension.

Outcome :

The blue, green and red curves are visually close.

 - The particle gauge indicator points to the mass of sand which shows detection of large particles.

 - The Angström exponent (Alpha) is feeble, a clear sign of a preponderence of large particles.

$\alpha = 0,506$
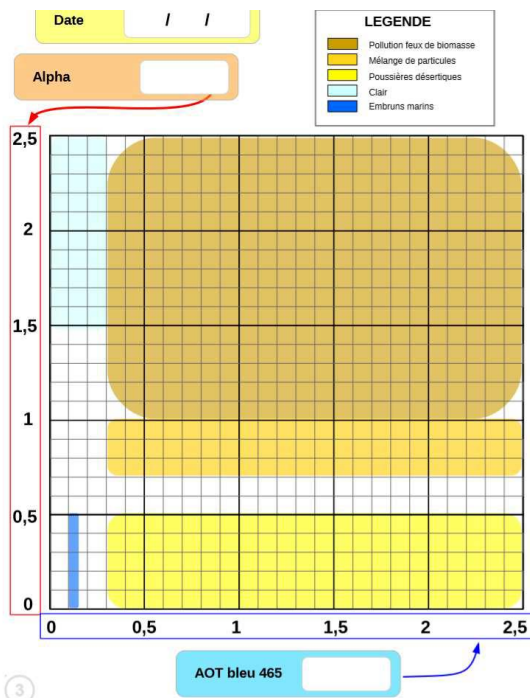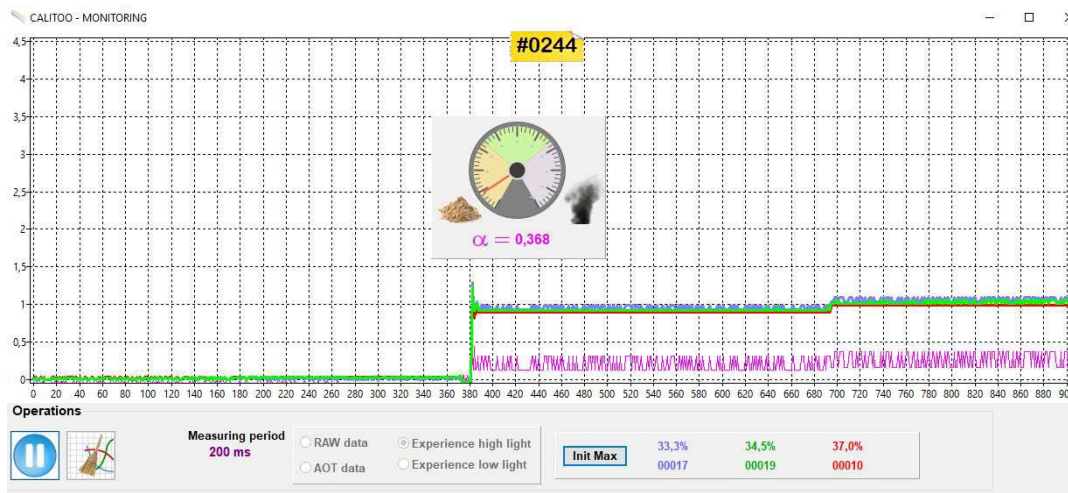
We therefore suppose that these particles are particles of sand but our hypothesis must overlap with weather data.

http://www.calitoo.fr/uploads/documents/fr/usermanual_fr.pdf

A weather map study and sattellite images from 26 and 27/08/2018 data corresponding to snowfalls in Sotchi validate the hypothesis.
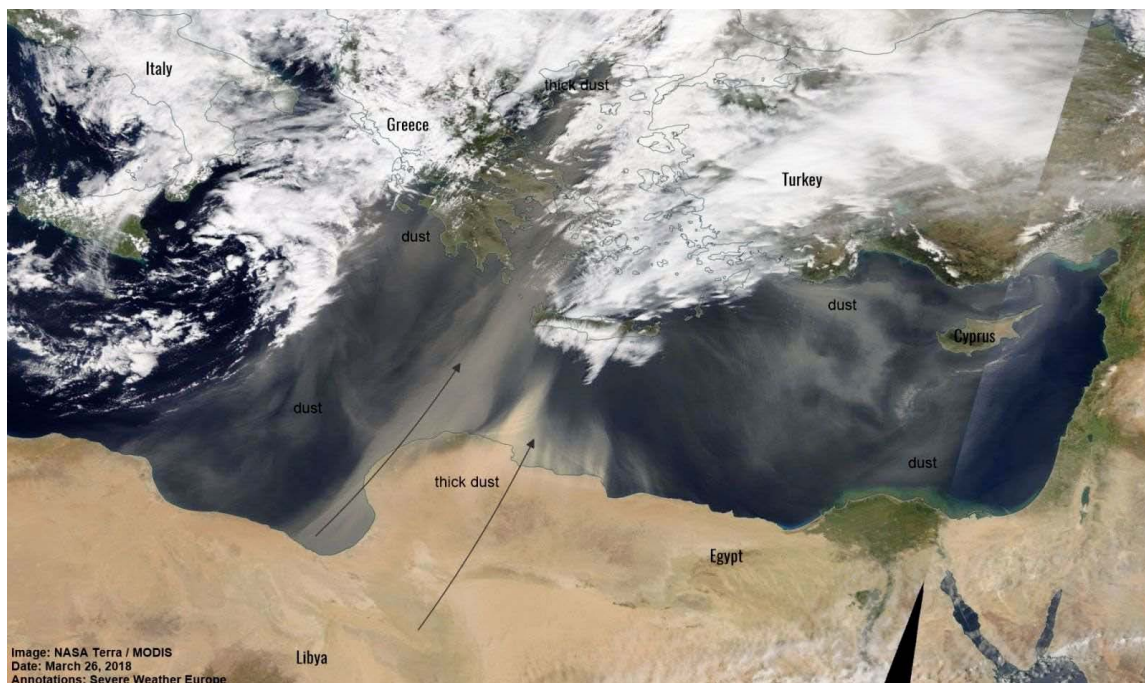
Nasa Terra / MODIS satellite image of the Mediterranean, March 26. Credit: Severe-weather.eu.

University of Athens SKIRON model forecast for March 27
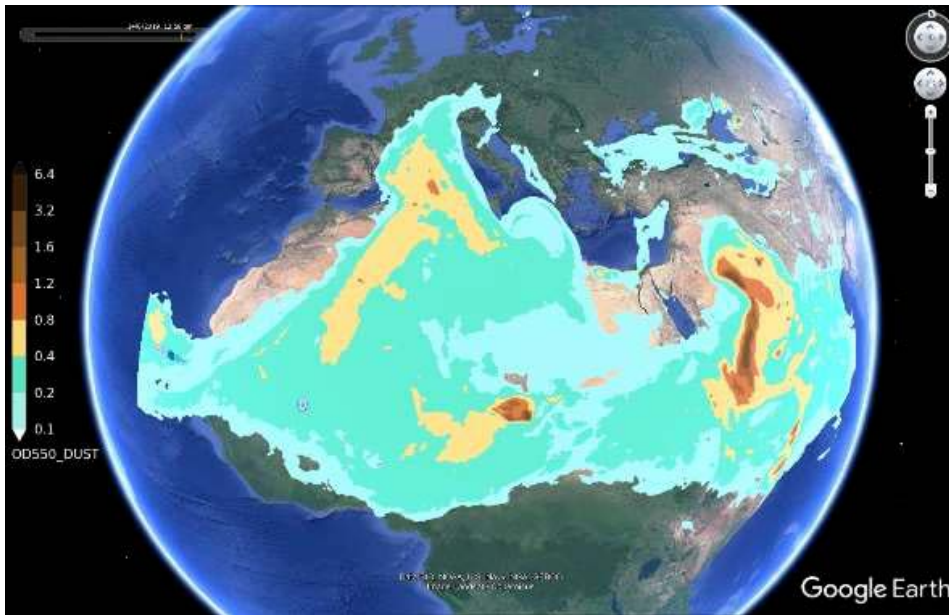
We can also observe that the South of France is frequently affected by desert dust outbreaks

https://dust.aemet.es/forecast

- What are the effects of these mineral particles on the climate ?

  <u>When the particles in the air are aerosols</u>

  The assessment of the global impact of aerosols as a whole is easier and provides more consistent values than if we think of particles individually. Scientists try however to quantify the radiative forcing of each type of aerosols. For example, we have the following estimations for the mean radiative forcing of different aerosols classes :
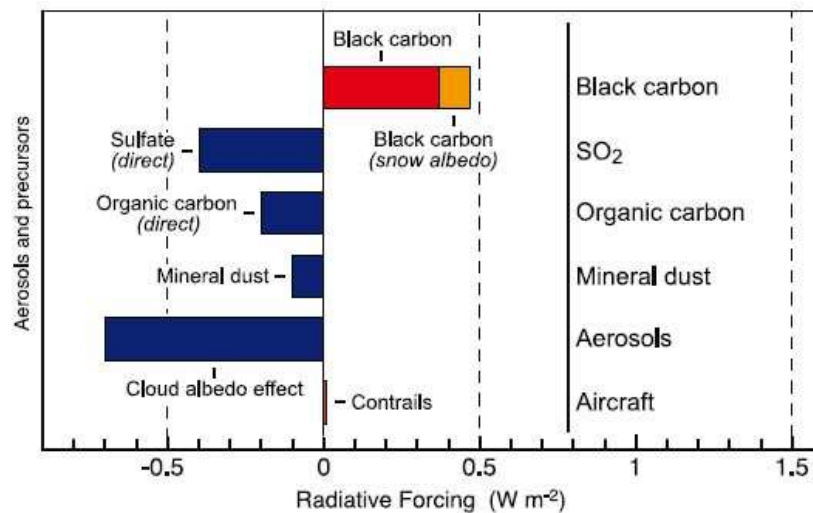
Radiative forcing by different aerosol classes (source : <u>GIEC, 4ième rapport, chp. 2, 2007</u>).

It is indeed extremely difficult to establish a radiative impact of mineral dust particles as it was shown that a great deal of factors has an influence, such as cloud formation and also the altitude of the cloud ceiling and the altitude of the dust layer, the size of dust particles and their optical depth.
Radiative forcing by mineral dust aerosols: Sensitivity to key variables H. Liao J. H. Seinfeld

Moreover, the radiative impact of an aerosol depends on the nature of the underlying surface, for example "above dark surfaces such as the ocean, the aerosols whether absorbant or not will always cause an increase in the albedo and thus a negative forcing (cooling effect). For surfaces that are more reflective, like desert surfaces ($\rho s = 0,5$), the aerosol's effect will be very significant for its absorptive capacity : a $\omega 0$ albedo lower than 0,95 will suffice for creating an warming effect on the climate."
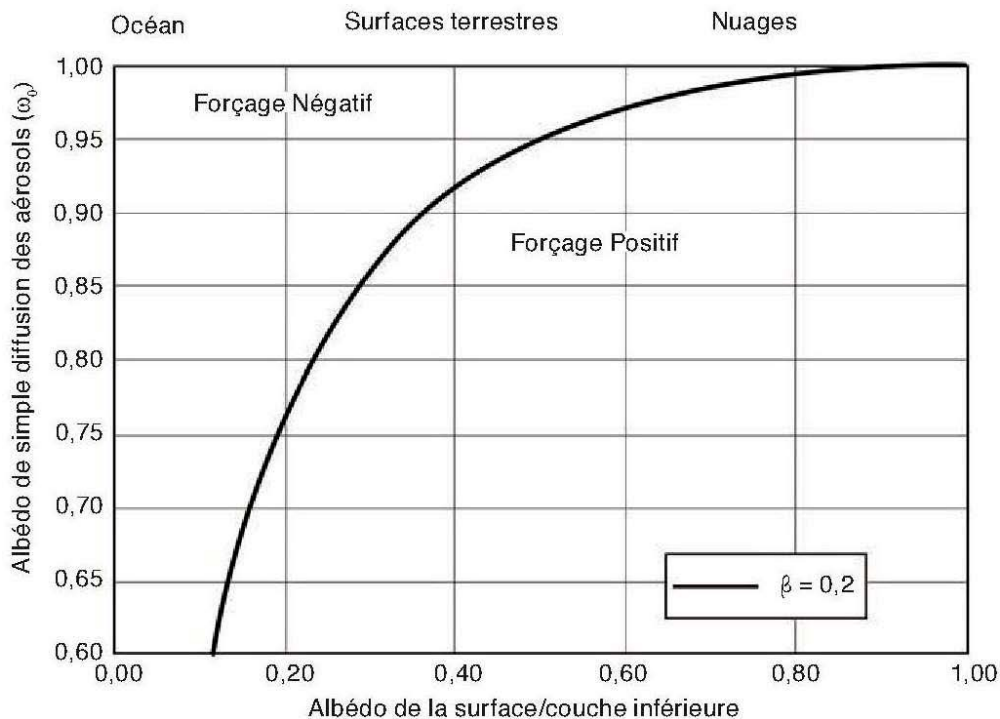
*Didier Tanré, Physicist, Research director at CNRS, LOA, Villeneuve d'Ascq.
https://books.openedition.org/editionscnrs/11354*

- Let's see of our desert dust particles extracted from orange snow can modify the surface albedo locally.

The albedo of the Earth-atmosphere system is a fraction of the solar radiation reflected back into space.

We will hence measure the luminous intensity reflected by a white surface and then the luminous intensity reflected by a white surface covered by sand particles.

©F.Moujdi-F.Bouvet
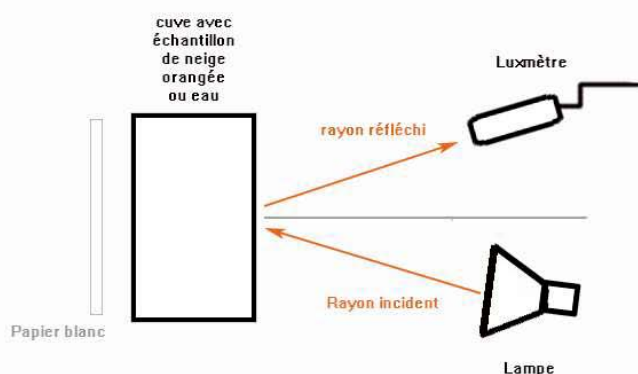
Outcome :

Be careful: As a luxmeter we used here a photoresistance mounted on an Arduino board, the measured value has no unit! This is a purely indicative value.

No sand particles: `10:51:13.092 -> Valeur luminosité = 916`

With sand particles: `10:52:41.037 -> Valeur luminosité = 897`

The amount of reflected light decreases with desert dust

The colour of the snow therefore reduces its albedo and temporarily promotes an increase in ground temperature and accelerates snowmelt.

Annex 9

Erasmus+

SCHOOLS TUNE INTO MARS

This project is co-funded by the European Union

Primary aerosol and climatic impact on Mars

1. Introduction & Pb

We know that even natural aerosols can have an impact on the climate.

On Mars as on Earth mineral particles are suspended as shown by the selfies of insight.
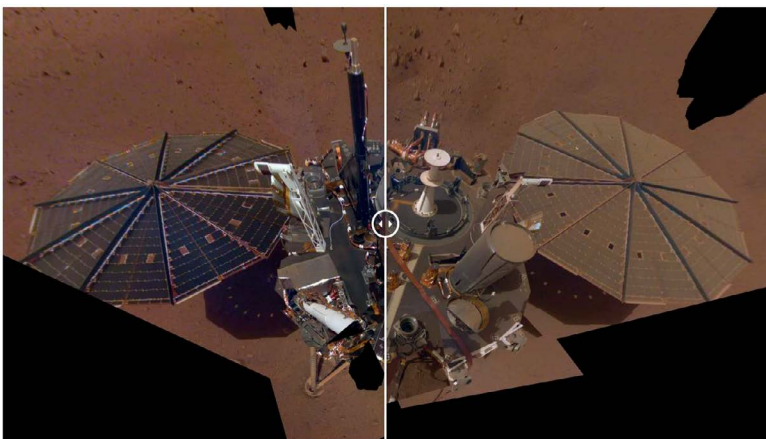
We can see on these insight selfies that mineral dust has settled on the Lander. This can also be set in motion again by atmospheric turbulences such as dust devil as evidenced by sudden variations in the efficiency of solar panels.

Selfie d'Insight fait Dec. 6, 2018
NASA/JPL-Caltech

Selfie d'Insight fait May. 6, 2019

In the same way, satellite images confirm that there are large-scale phenomena in March involving the suspension of mineral particles in the atmosphere.

Pb: How can the transport of aerosols impact the climate of a planet?

In this picture, we compare a recent dust storm on Mars with a storm that occurred earlier this year on Earth.

The top image shows a dust storm from the North Martian Pole observed on August 29, 2000. The storm moves like a front, outward from a central "jet", and marginal "eddies" can be observed. In this image, it extends about 900 km from the seasonal ice cap of the North Pole. The area on the right side of the image of Mars includes the North Pole. The bottom image shows a ground dust storm on February 26, 2000. This storm extends about 1800 km (1100 mi) off the coast of northwestern Africa, near the Earth's equator.

Both images are displayed at the same scale; 4 km (2.5 mi) per pixel.

https://www.jpl.nasa.gov/spaceimages/details.php?id=PIA02807
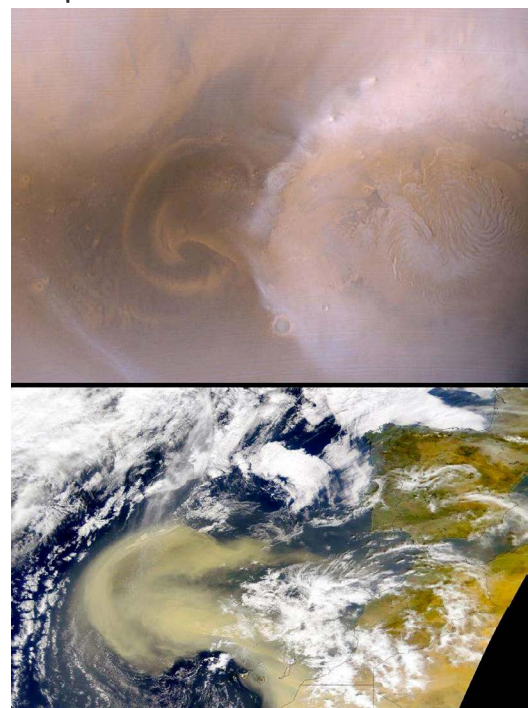
2. Age of students: 15 – 17 years

3. Objectives

Determine whether the transport of Martian mineral dust has an influence on the climate

4. Primary subjects

Physics – Earth Science

5. Additional subjects

6. Time required: 2h

7. Key terms.

Aerosols, albedo.

8. Materials

- Mesurim
- A luxmeter
- Two transparent polystyrene containers
- A 12 V lamp placed in a sleeve

9. Background

Scientists define an aerosol as a suspension of particles in the atmosphere. These particles are made up of solid and/or liquid substances. Mineral or organic, composed of living matter (pollens…) or not, large or fine, suspended particles constitute an extremely heterogeneous set of pollutants whose size varies from a few tenths of nanometers to a hundred micrometers.
The radiative impact of an aerosol will depend on the nature of the underlying surface.

10. Procedures

- We will first try to find out if the albedo differences can be explained by a difference in the composition of the Martian ground.

We will compare a map of the global albedo of March and the distribution of sand. To do this we will use mesurim and the overlay function.
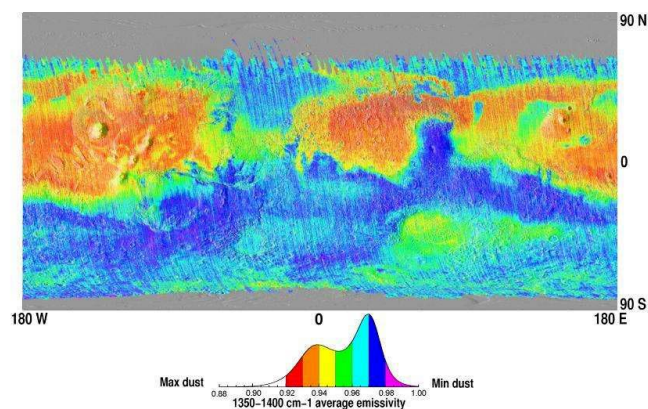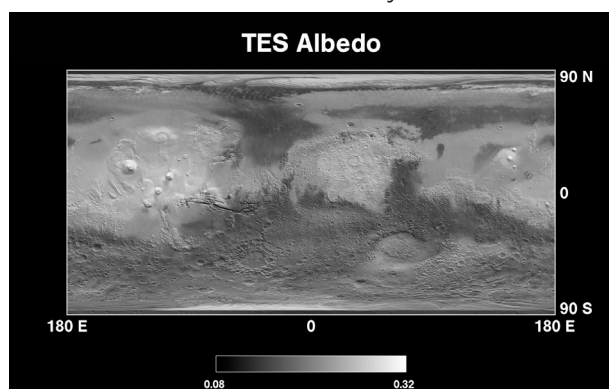
Open "albedo.jpeg" and "dust.jpeg" in mesurim.
Then in Image choose to overlay image as shown opposite
Adjust the opacity to make it easier to read.
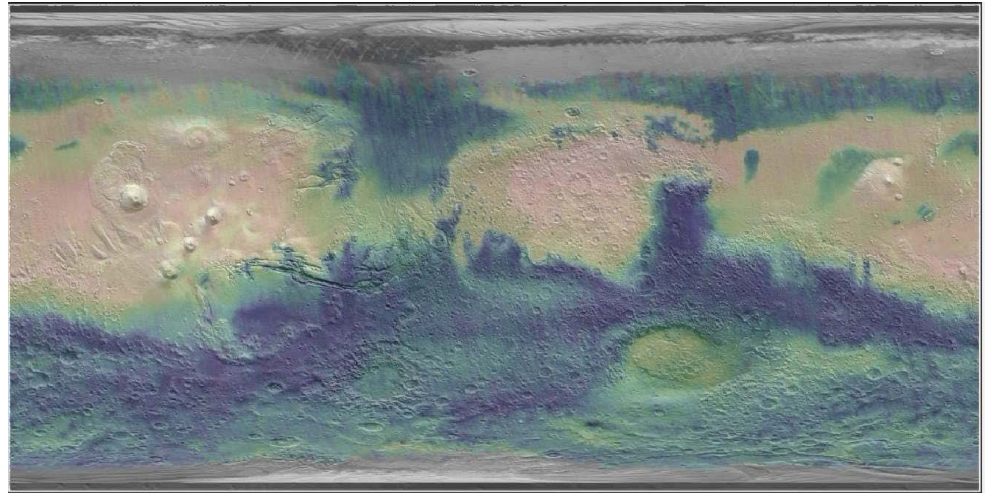
We immediately see a correlation between albedo and the presence of sand.

If we evaluate, with Mesurim, the surface of the ground covered by sand on the Martian planisphere we can see that it occupies about 50% of the total surface for which we have data.
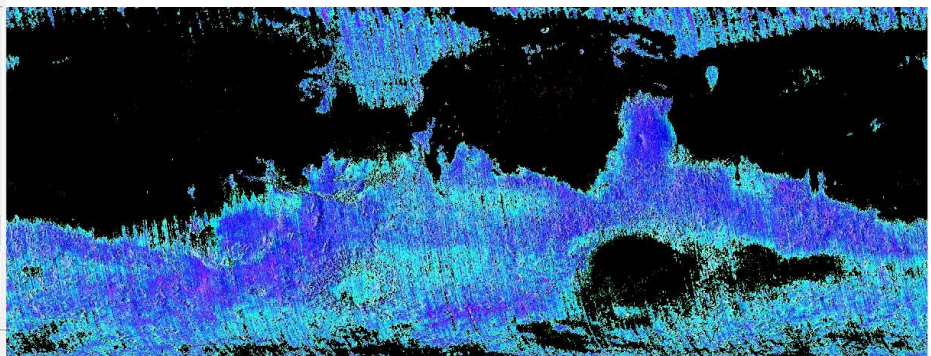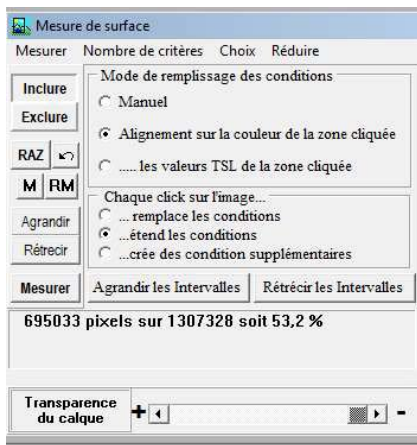
Dust transport could have an impact on the thermal inertia of areas with a lower albedo that represent a large surface area of the planet.

- Let's try to model the deposition coating of mineral particles with a high albedo from ground to lower albedo.

Compare the temperature evolution of the following three assemblies over an equivalent time period: Attention the total quantity of dust must be equivalent for each experiment
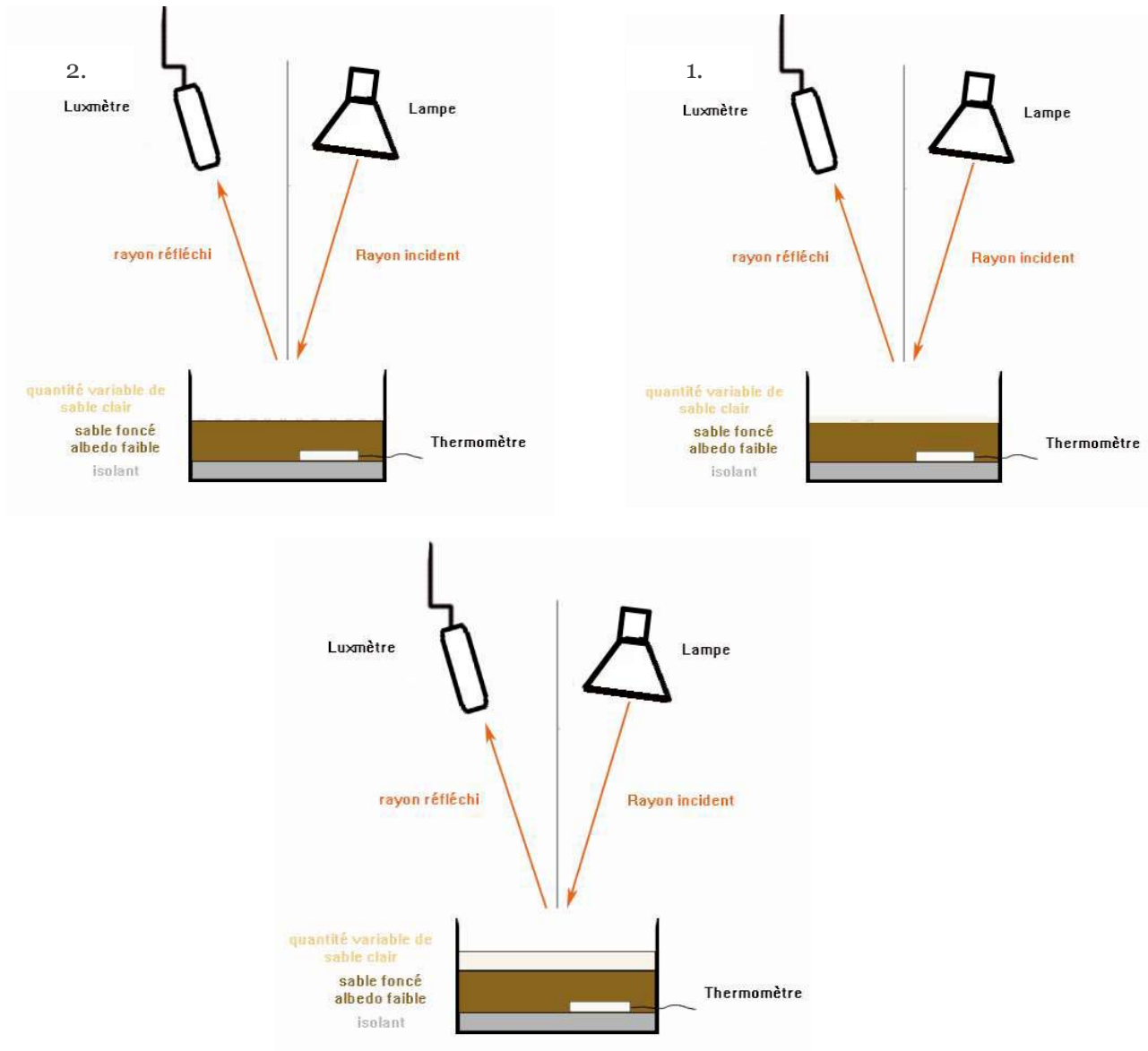
11. Discussion of the results and conclusions

There is a decrease in the heat absorbed by the ground but only if the quantity of light sand completely covers the dark ground and over a large thickness (Figure 3.) a simple under-powdering (Figure 2.) is not sufficient to have an effect on the temperature even if there is an increase in reflected light.

So only an accumulation of a large quantity of mineral matter could have an influence on albedo and therefore the inertia of the of the planet.

Source : http://www.mars.asu.edu/~ruff/DCI/2001JE001580.pdf
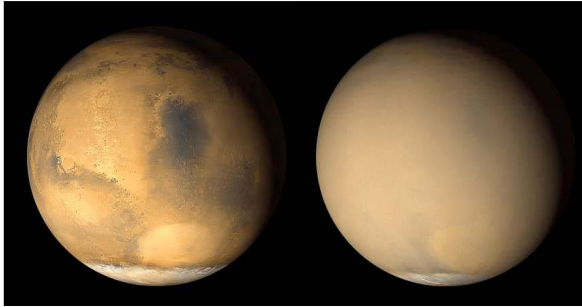
However, it has been observed that Global Sandstorms could occur on Mars, following which variations in albedo can be observed for one year following this storm.

Two images taken in 2001 by NASA's Mars Global Surveyor orbiter camera show a dramatic change in the appearance of the planet as the dust cloud raised by the storm in the south spread around the world. The images were taken about a month apart.

https://www.researchgate.net/publication/263856153_Mars_surface_albedo_and_changes
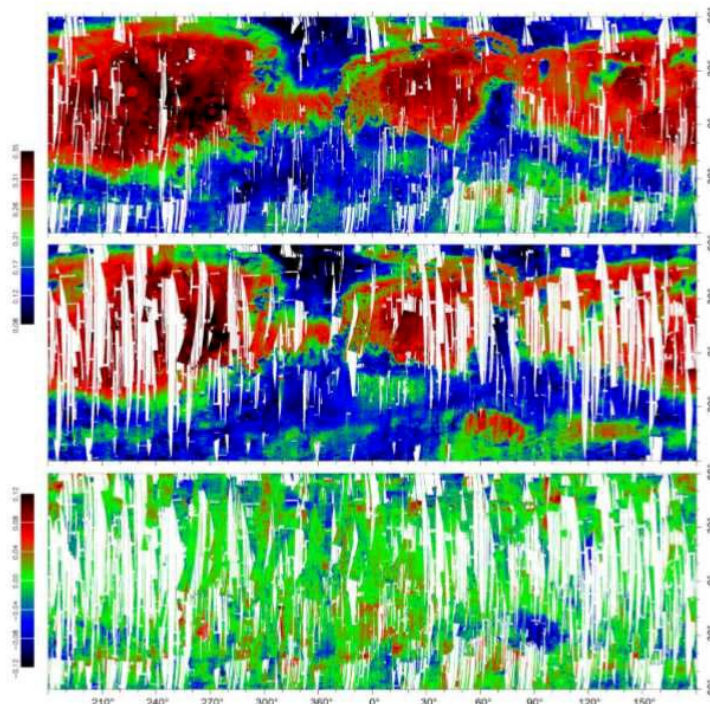
Figure 9: (top) albedo map prior to the MY28 GDS (orbits ≤ 4463: data from MY26 LS 330° to MY 28 L_s 265°: 86% coverage). (middle) albedo map after the MY GDS (orbits ≥ 4758: data from MY 28 L_s 315° to MY 30 L_s 135°: 74% coverage). (bottom) difference albedo map (middle − top: 63% coverage). Quality level # 1 (Table 1) is used. Bright areas or brightening ≥ 0.04 are in red, dark areas or darkening ≤ -0.04 are in blue. Intermediate albedo and stable areas are in green.

12. Explore More (additional resources for teachers)

- https://www.researchgate.net/publication/263856153_Mars_surface_albedo_and_changes

- Arduino

Annex 10

Daily temperature variations on Mars

1. Introduction & Pb

On Mars' surface, we can find summer trends: 20 °C, the breeze of trade winds... But starting with the onset of night, temperature values plummet by several tens of degrees and freezing conditions reaching – 100 °C will prevail until the morning after. In fact, Martian soil, dry and granular, can store only very little heat. Its thermal inertia is very small compared to that of the Earth and its oceans. The atmosphere being thin, temperature variations are more significant.

On Earth, daily temperature variations are less pregnant than those on Mars.

Chart of day-night temperatures of telluric planets:

Planet	T day (°C)	T night (°C)
Mercury	430	-170
Venus	460	450
Terra	15	5
Mars	-23	-93

Comparison between the daily variations of the atmospheric temperature on Viking 1 site and those of a terrestrial desert site (China Lake, California) :
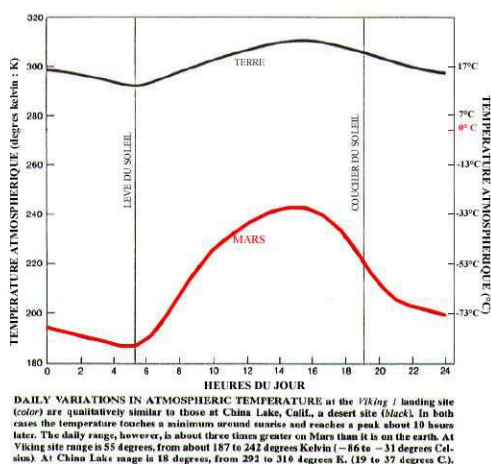
Case 2 shows a minimal temperature at sunrise.

Daily thermal fluctuations are 3 times stronger on Mars than 0n Earth.

Source: Reserved rights - © 1979 According to Ryan et Henry, JGR

The InSight lander is equiped with a comprehensive weather station (APSS, Auxiliary Payload Sensor Suite).

The various sensors on this station (temperature, weather vane, anemometer, barometer and magnetometer) play a crucial role in the interpretation of data provided by InSight's seismometer SEIS, but also in enhancing the knowledge about Martian weather and its current climate. The knowledge acquired will help us to get a better grasp of weather perturbations on our planet Earth.

The ultrasensitive air-inlet pressure sensor of the APSS weather station installed on the deck of InSight (© NASA/JPL-Caltech/IPGP/Philippe Labrot).

This pressure sensor is ultrasensitive, meaning it is capable to react to variations of pressure at an order of dozen microPascals (i.e. 10-7 mbars). It's installed on the lander's deck, underneath the Wind and Thermal Shield (WTS).
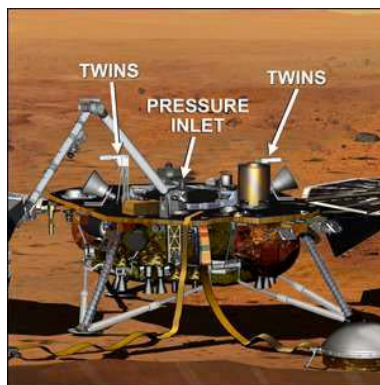
NASA/JPL-Caltech - http://photojournal.jpl.nasa.gov/figures/PIA17358_fig1.jpg

TWINS sensors (Temperature and Wind Sensors for InSight) are thermal anemometers. There are two of them on the deck. The data is recorded at a maximum rate of one per second.

At a rate of 2 times per second, they record air temperature and also wind speed and direction, all this during the entire duration of the mission, that is a Martian year, equivalent to two terrestrial years.

The data that scientists obtain on a regular basis will allow us to better understand the phenomena linked to weather on Mars.

Pb : **How can the analysis of meteorological data help us enhance our knowledge on weather perturbations on Mars, as well as on Earth ?**

2. Age of students 15 – 17 ans

3. Objectives

Using a Python data processing script, show the information we can collect from the weather perturbations such as the diurnal cycle, the passing of a Dust Devil...

4. Primary subjects

Mathematics – Physics – Python Programming

5. Additional subjects

Earth Science

6. Time required 3hrs

7. Key terms

Geothermal gradient, heat flow, heat dissipation.

8. Materials

- Computer with software
- Excel – Python

9. Background

Thermal inertia of the soil, the rotational period and the atmosphere are the main parameters that control the day-night temperature disparity of a planet.

The **moving average** is a type of statistical average value used to analyse arrays of data, most frequently temporary arrays by removing the temporary fluctuations so that we can highlight longer term trends. This average value is called *moving average* because it is continuously recalculated, using for each rendition a subset of elements in which the newest element replaces the oldest one or is added to the subset.

This type of average value is generally used as a data processing method.

10. Procedures

- On Earth :

You have at your disposal, in « csv » format, the data corresponding to 9/7/2019 (cf csv data sheet) downloaded from the meteo website « WillyWeather » on China Lake Acres site (environment similar to that of Mars).

1. **You will have to represent the Temperature, Pressure and Wind Speed plots provided to you in Python script.**

- On Mars :

You have at your disposal, in « csv » format, the meteorological data corresponding to the 15th day of the InSight mission (cf csv data sheet).

2. **You will be asked to represent the plots for the parameters provided to you in Python language.**

Expected Results :
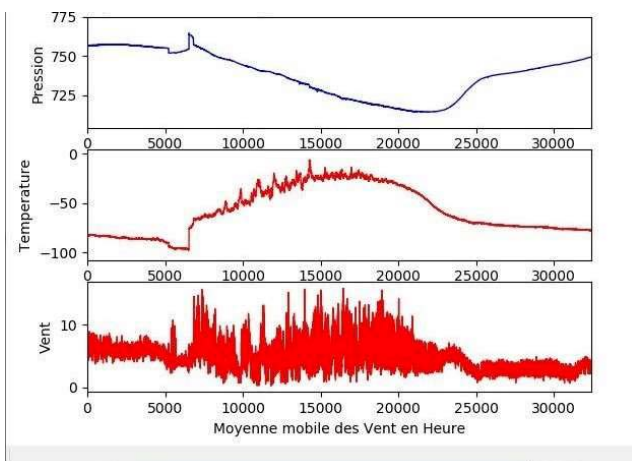
On Mars	On Earth
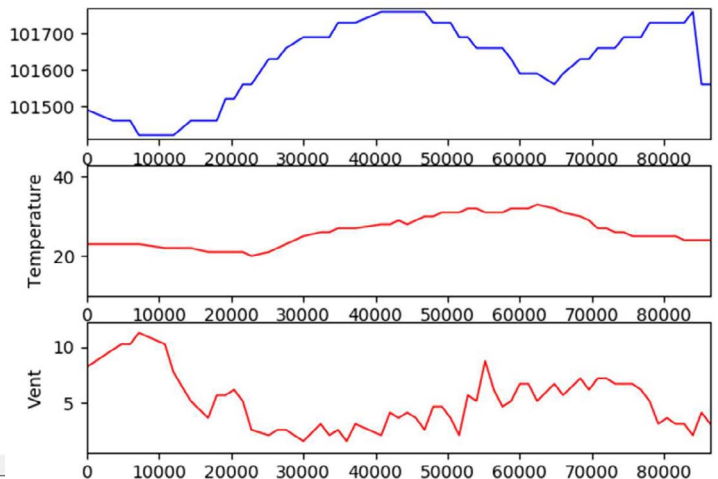
Time : second – Temperature : K – **Wind Speed :** m/s – **Pressure :** Pa

3. **Compare and interpret the results obtained for Earth with those obtained for Mars.**

We can distinguish significant temperature fluctuations on Mars, growing from – 83°C (at night) to 13°C (during day) that correspond to the diurnal cycle of Mars. In contrast, fluctuations in day-night temperatures on Earth are less significant (from 23°C to 32°C). The same goes for pressure.

In order to conduct a sharper study from the data, scientists need to take measurements less « polluted » by irregular values that re-enforce these exceptional phenomena such as dust devils and so on.

We will therefore use particular statistically obtained mean values that allow us to interpret the values with the purpose of excluding the so-called *aberrant* values (values distant from other observations made on the same phenomenon). These statistical mean values represent the «**moving average** or **rolling/running** average ».

Simple moving averages on 3 values, for a series of 9 measurements.

Mesures	2	3	5	8	8	7	8	5	2
Moyenne glissante	néant	$(2 + 3 + 5)/3$ 3,3333	$(3 + 5 + 8)/3$ 5,3333	$(5 + 8 + 8)/3$ 7	$(8 + 8 + 7)/3$ 7,6666	$(8 + 7 + 8)/3$ 7,6666	$(7 + 8 + 5)/3$ 6,6666	$(8 + 5 + 2)/3$ 5	néant

Source : https://fr.wikipedia.org/wiki/Moyenne_mobile

In our particular case, the values being related to the atmospheric domain, we will use a « moving average on 6 hours, 8 hours and 12 hours » for Temperature and Pressure values, the same as computing the average values from 0h00 to 8h00, from 1h00 to 9h00, from 2h to 10h00 and so forth...

As our data recordings cover 3 days, we will thus be able to measure the maximum and minimum value of the rolling average to get an idea on the thermic amplitude for a Martian day, etc...

The purpose of using a rolling average is to interpret the potential accidental deviations (twist devil, ...).

Operating mode for plotting the moving averages :

- Lists and operations made on the lists   - Curve plots

1) a) Write the **average** function (List_of_numbers) that allows you to obtain the mean value of a list of numbers.

Bonus) Write the **modified_average(List_of_numbers)** function that allows you to compute the mean value without the need for the **sum** function available in Python.

2) Write the **List_extract(p, n, List_of__nbrs)** that allows you to extract a list of a given **n** size starting from a given rank **p**.

3) a) Write the **Compute_Moving_Average (n, List)** function that allows you to obtain the list of moving averages
on a n range of values of a given list.

b) Provide the list of moving averages on a range of 8 values on the data recorded:
   i) time values   ii) temperature values   iii) pressure values   iv) winds

4) a) Write the **Moving_Average(n, List1, List2, List3,List4)** function that will display the temperature, pressure and wind speed mean values depending on the average time, on a range of 8 time values.
   (We take into account the following correlations List1=Time List2=Temperature List3=Pressure List4=Wind)

b) Modify the **least_square_regression(n)** function code to assess the possible correlation between the two averaged physical quantities, Temperature and Pressure.

Colour code of graphs isn't required and will be provided in the student file

Plot obtained with a moving average for 20' of Martian data values:
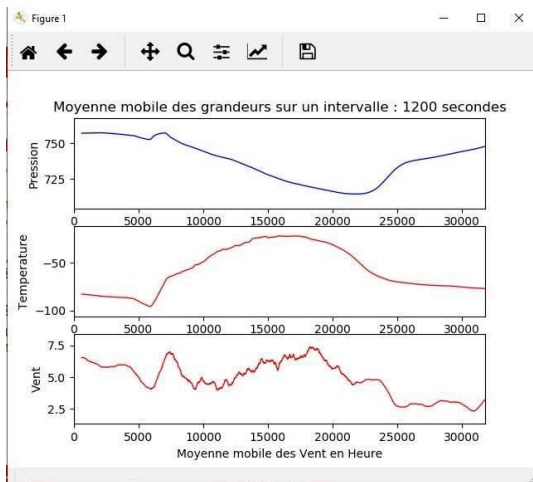
We can observe on the 'Pressure on Mars' plot large scale waves known as « thermal tides ».

Basically, thermal tides are global-scale waves generated by fluctuations in the regular day-night cycle in the Sun's heating of atmosphere (insolation). These waves are displayed on wind components and they evolve with local solar time.

We observe a significantly marked diurnal cycle and violent winds up until sunrise. They are due to the cooling T° close to the ground during the night.

We observe on the Martian data plot (below) two perturbations that could be local «dust devil » whirlwinds, but we should carry out a more precise sampling in order to make sure of their presence:
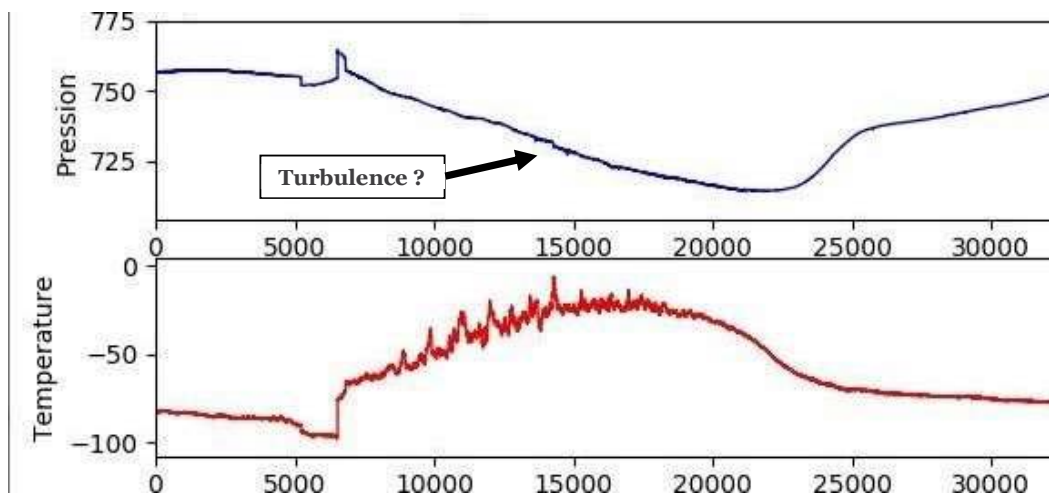
Sampling on 250 seconds of Martian data isolating the Dust-related data we observed in the previous plots:
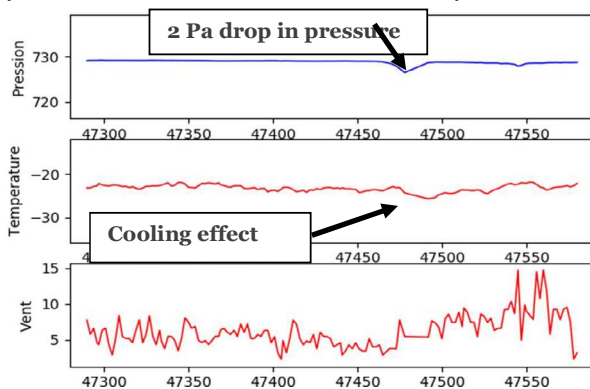
The thermal tides in the atmosphere of the planet Mars have a much higher amplitude than that of the Earth because thermal forcing is very strong due to the infrared absorption of atmospheric CO2, the absorbtion of infrared radiation emitted by the surface and the fact that the atmosphere on Mars is thinner.

The effect that atmospheric tides have on zonal and meridian average flow is therefore of great significance in the Martian atmosphere.

Comparison of the results obtained with data downloaded from Pathfinder website defining a Dust on Mars :

Pressure (hPa), wind (m/s) et temperature (K) measurements available on the Pathfinder site:

observations made by OMEG/Mars Express »
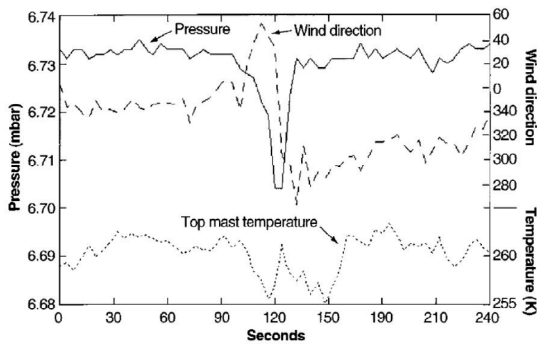
The data sampling rate is 4s. A dust devil passing through at cyclostrophic balance above the lander is reflected in a 2.5 Pa dew point depression and a decrease in temperature of approximately 5K. Wind's characteristic circulation was also recorded by the anemometers on Pathfinder, however the calibration issues didn't make possible to have an accurate measurement of the fluctuating wind amplitude. Image by Schofield et al. [1997].

Source : Thesis by M. Aymeric Spiga « Mesoscale dynamic model of the Martian atmosphere: defining a meteorological model and analyse of

Modelling the physical phenomena at the root of local whirlwind formation:

In an arid area, air close to soil surface is heated in a different manner. The heat will be transfered vertically by the radiation to a layer of colder dry air and will undergo an upward thrust according to Achimedes' principle and reach convection.

The arrival of a horizontal transport of air mass will generate a rotation in the air which will then confine all the dust in its proximity.

The altitude and diameter of a a whilwind depends on the air's instability and dryness.

Source : https://www.thoughtco.com/what-is-convection-4041318
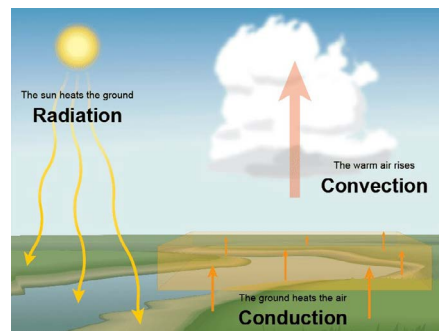
Plan three simple experiments to get a model for each heat transfer method: Convection – Conduction – Radiation. You can only use the materials provided for you.

11. Discussion of the results and conclusions

Martian weather resembles that of Earth in many ways. It is basically abundant in storms, tornadoes, dust...

And yet, Mars sets itself apart from planet Earth. Martian atmosphere is in fact not so thick, the phenomenon of diurnal wind variation, of so little significance on Earth, is identified by the great fluctuations in the day-night cycle.

The analysis of meteorological data allowed us to discover weak signals in the large-scale cosmic structure (thermal tides) and fast signals in the local scale (whirlwinds and convective turbulence).

En effet, les oscillations diurnes de la température et du vent à la surface excitent indirectement toutes les autres couches de l'atmosphère. Ce qui entraîne la vibration de la couche atmosphérique martienne ou plus exactement propage des ondes de de fréquence diurne (une oscillation par jour) appelée « onde de marée thermique ». Ces oscillations diurnes vont interagir avec les autres vents et influencer la circulation atmosphérique qui sera enregistrée inévitablement par le sismomètre SEIS.

In fact, diurnal variations of temperature and wind values found at the horizon indirectly stimulate other layers of the atmosphere. Which therefore stimulates the vibration of the Martian atmosphere or more precisely propagates waves of diurnal frequency (one amplitude per day) called « atmospheric thermal tides». These diurnal oscillations will interact with other winds and have an effect on atmospheric circulation inevitably captured by SEIS.

Once the data is continuously collected, meteorologists responsible for this mission will have to separate the thermal tides from the data provided by InSight's seismometer SEIS.

12. Explore More (additional resources for teachers)

- "Planet Mars" : Edition Belin – François Forget, François Costard – Philippe Lognonné

- M. Aymeric Spiga's Thesis « Mesoscale dynamic model of the Martian atmosphere: defining a meteorological model and analyse of observations made by OMEG/Mars Express »

Annex 11

SEIS, a securely-packed seismometer

1. Introduction & Pb

In 2018, NASA sent a new lander on Mars to explore for the first time the « depths » of the planet. To successfully carry out the mission that plans to record the seismic activity, meteorite impacts and thus determine the planet's internal structure: the robot is equipped with an ultrasensitive, but impervious seismometer called SEIS, constructed by CNES (The National Centre for Space Studies from Toulouse in partnership with IPG (Paris Global Institute).

In order to shield the seismometers from the environment, seismologists placed them in basements on Earth.

But to ensure SEIS' protection from the Martian environment, scientists designed a double protection: a Wind and Thermal Shield (WTS). To check its thermal resistance, the equipment was put in ovens and tested in high temperature conditions (up to 60 °C), before being placed in compounds that had glacial temperatures, down to -75°C.

Philippe Laudet, SEIS project manager at CNES

The Earth and Mars are greatly similar rocky planets. Certain people even call them « twin » planets.

Pb: **Yet why do scientists insisted to cover the seismometer with a protection dome?**

2. Age of students: 14 – 16 years

3. Objectives

The purpose of this activity is to determine how Mars' atmosphere and environment differ from those of the Earth and why the lander's construction needed really solid instruments to be tested repeatedly in extreme conditions on Earth?

4. Primary subjects

Chemistry – Earth Sciences

5. Additional subjects

6. Time required   1h30

7. Key terms

Atmosphere – Gas – Carbon cycle – Radiation balance – Solar radiation – Infrared.

8. Materials:

Atmospheric composition of the planets in the Solar System	Modelling of the Radiation balance of a planet	Modelling of the effect of variations in solar radiation on a planet	Modelling of the movement of air masses
– « Solar System» software : https://www.pedagogie.ac-nice.fr/svt/productions/systeme-solaire/	– Lab plate – Insulator – Thermometer – Glass	– Lamp – Planisphere – Plate pierced by holes	– Incense burner – Cold plate – Support stand – Black sheet of paper

9. Background

Solar radiation has a spectral range of ultraviolet radiation with wavelength below 0.4 mm and a range of infrared with wavelength greater than 0.8 mm.
Greenhouse gases (water vapour, carbonic acid gas, methane...) are basically transparent in the solar beams (visible light spectrum) and opaque in the infrared light emitted by the Earth.
Heating is thus averted.

10. Procedures

You will have to write a scientific paper on the specifics of Mars and of the Earth, in which you will integrate the arguments given by scientists to explain the process responsible for the loss of a great part of the atmosphere on Mars which would partly explain its hostile environment.
Lastly, you will deduct the arguments that scientists responsible for the InSight Mars mission took into consideration when developing very resistant measuring instruments to withstand the hostile environment of Mars.

     I.   <u>The atmosphere of rocky planets in the solar system:</u>

1. Fill in the following table using « The solar system » software.

	Thickness	Main components of the atmosphere	Water's states of matter	Presence of Ozone
Earth				
Mars				
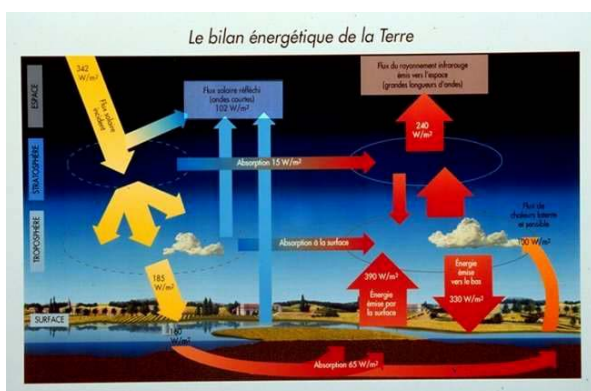
Mars has only half of the isolation on Earth.
The atmosphere's composition (95% CO2) makes is transparent in the visible light.
The atmosphere is therefore heated by the incident visible light and cooled down by the thermal infrared emission.
The radiation flux emitted by the surface in infrared light is partly absorbed by the atmosphere. The greenhouse effect has a very low amplitude on Mars: 5K due to low pressure and narrowness of the absorbtion/emission of CO2.

Image source: (CNES, scarab site):
http://scarab.cnes.fr:8020/

2. **Modelling of the Radiation balance of a planet with and without the greenhouse effect:**

Temperature in case of no greenhouse effect	Temperature in case of greenhouse gases
T° =	T°=
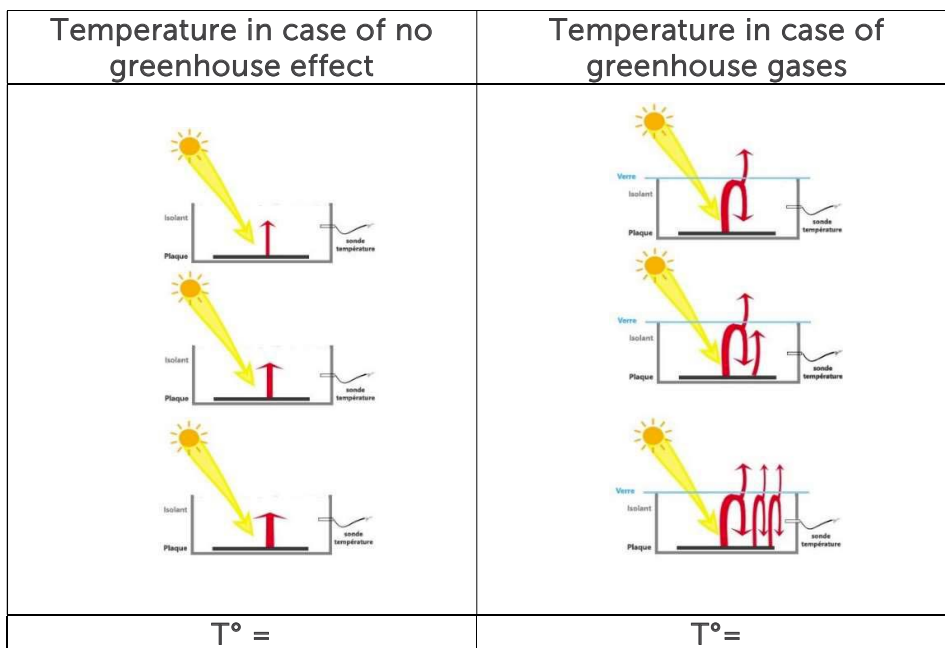
The plate that is exposed to the sun heats up. It receives energy from the Sun, therefore its T° increases. It will thus emit more radiation and will lose more energy in return.

The surface of glass allows the solar radiation to go through and absorbs all the infrared radiation. Glass therefore absorbs all the infrared radiation emitted by the plate and warms up. While it's warming up, the surface itself emits more infrared radiation and its temperature will increase up until the surface will lose as much energy as it receives.

The radiation that is emitted upwards by the glass is lost and the radiation emitted downwards is absorbed by the plate. The plate now receives more radiation than it loses, hence it's temperature will increase until the loss of energy will be equal to the amount of energy received by the plate.

We reach a balance, in which the temperature of the plate is higher than in the no-glass setup: that is the greenhouse effect.

II. **Circulation of wind on Earth and on Mars:**

Atmospheric circulation on Earth and on Mars is governed by the same laws.

Thermal contrasts in the atmosphere are interpreted as a large amplitude oscillation of pressure with altitude. Air masses from high pressure areas (warm regions) are drawn to areas of low pressure (cold areas).

They are set in motion and generate winds. We will plot the factors responsible for wind formation.

1. **Thermal contrasts:**

Solar radiation generates atmospheric circulation by creating contrasts in temperature. For the same pressure value on the surface we will find more air at higher altitudes because warm air masses take up more volume.
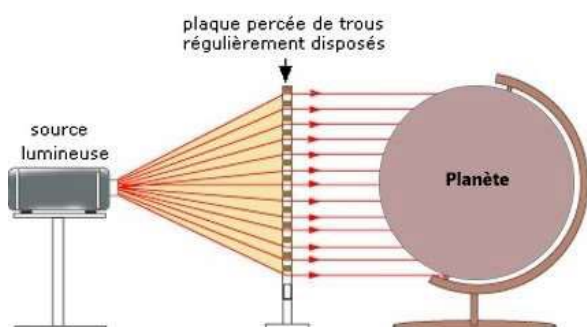
Tropical regions receive a greater amount of solar irradiation per unit area than polar regions.

On Earth, the average gap between two areas remains constant over time, there is thus a transfer of energy from the equator to the poles. This transfer is maintained by the two types of circulation of fluids of the planet, that is the atmosphere and the oceans.

The thermal contrast on Earth therefore takes place at low atmospheric pressure warmer in the sub-tropics than to the poles.

Whereas on Mars, the thermal contrast happens between the warm spring/summer hemisphere and cold autumn/winter hemisphere. Except during the equinox when the two poles, North and South, are cold.

- **Meridional circulation:**
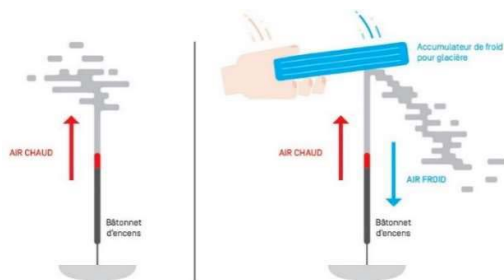
> We observe a meriodional flow circulation driven by the diferences in temperature and thus in the density of air (warm air dilates and goes up). Oscillations of atmospheric pressure are caused by this type of circulation.

Collective work "SVT, Cycle 4" 'Réseau Canopé', 2017

This flow transports hot air in the direction of the poles at high altitude and the cold air masses are transported towards the equator at low altitude levels on Earth: we mention Hadley Cells named after the English physicist (1735). This movement of warm and cold air masses generates winds.

On Mars, there is a single Hadley cell that joins the hemispheres together by transiting the equator.

2. **Planetary rotation:**

Air masses movement is also affected by the planetary rotation.

The rotation speeds of Mars and of the Earth as well as seasonal variations of insolation are identical, hence the similar meteorology.

As a matter of fact, we discover « jet stream » that meander round the planet from west to east in the southern and northern middle latitudes; the trade winds between the Tropics...
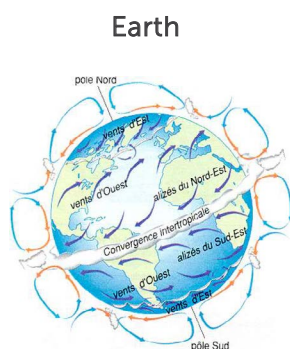
Earth

Source: eduscol.education.fr

11. Discussion of the results and conclusions

Earth's atmosphere is very different from the atmosphere of Mars: in terms of composition, thickness, radiation balance...

Earth absorbs a greater amount of energy that it reflects back in the atmosphere, the system pulls energy. Or, in the case of Mars, the radiation balance is negative and the planet losses energy. Thermal contrast is more significant on Mars than on Earth. The environmental conditions on Mars are: significant thermal gaps and violent winds.

Scientists had to design the SEIS seismometer both ultrasensitive and especially ultra-resilient to withstand the hostile environment of Mars characterised by extreme temperature oscillations, but also violent winds, atmospheric perturbations...

12. Explore More (additional resources for teachers)

- https://planet-terre.ens-lyon.fr/article/td-cycle-du-carbone2.xml
- "Planet Mars", Françoic Forget – François Costard – Philippe Lognonné, Belin Edition

- Paper in 'Sciences and Avenir' « Solar flares : why would they be devastating for our planet », by Erwan Lecomte on 25.07.2014

- Collective work « SVT, Cycle 4 » Canopé Edition Agir, 2017

Annex 12

Instruments to measure the speed of the Martian wind

1. Introduction & Pb

On Earth, the sensors used in the Météo-France network to measure wind force and direction are two types: mechanical sensors with a cup anemometer and a weather vane, and ultrasonic sensors.

Mechanical sensor Déolia 96   Ultrasonic sensor

For the Insight sensor, engineers chose TWINS (Temperature and Wind Sensors for InSight) sensors, very similar to the REMS (Rover Environmental Monitoring Station) sensors used for the Curiosity Rover, which has been operating since 2012 inside the Gale impact crater

TWINS sensors from the InSight weather station (© NASA)

NASA/JPL-Caltech

Insight has two sensors called « Twins ». They register air temperature, windspeed and wind direction 2 times per second. These data are recorded throughout all the mission, which will take one Martian year, equal to two terrestrial years

Pb : How can we determine the speed of the Martian wind despite a hostile environment?

2. Age of students 13-15 years

3. Objectives

The objective is to determine how the Twins sensors of the Insight probe work and why scientists need to know precisely the wind direction and the continuous temperature.

4. Primary subjects

Earth Sciences - Physics - Computer Science

5. Time required   2hrs

6. Key terms

Anémomètre - Météorologie

7. Materials

- Hot wire anemometer sensor

V_{OUT} is the tension measured in volts at the OUT output of the sensor

$V_{no\ wind}$ is the tension measured in volts when the sensor is sheltered from the wind (for example, by a bell)

$Temp_C$ is the temperature of the room measured in °C

$Vwind_{ms}$ est is the wind unit measured in m/s

The sensor's analog output OUT provides a tension value that we can correlate with windspeed as follows :

$$Vent_{ms} = 0,44704$$
$$\times (\frac{(V_{OUT} - V_{sansVent})}{\frac{(3,038517 \times (temp_C)^{0,115157})}{0,0087288}})^{3,009364}$$

In case of a room temperature of 25°C, the website indicates a value $V_{no\ wind}$ = 1,3692 V. We can compare this value with that of our set up

TEMP sensor's output measures the ambient temperature.

$$Tmp = \frac{(V_{TEMP} - 0.400)}{0.0195}$$

To follow windspeed evolution, we will connect the sensor with an Arduino

8. Background

Assembling a sensor and simple programming Arduino.

9. Procedures

The Lander Insight is equipped with anemometers without mechanical parts to avoid wear problems (due to temperature differences, among other things).
We will use similar sensors for wind measurement and temperature measurement.
It is a hot wire anemometer: a resistance is heated by a 12V power supply, the higher the temperature of the wire the higher its electrical resistance. The wind will cool the resistance, it is this drop in temperature that makes it possible to know the wind speed.

To follow the evolution of the wind speed and temperature we will connect the sensor to an arduino

1. **Setting up the first sensor**

The cable connection for one cable is depicted in the picture below
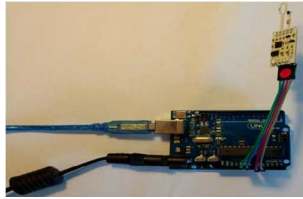
Sensor	Wire color in the image	Arduino
GND		GND
+12 V		Vin
OUT		A0
TEMP		A1

Below is the software that obtains the windspeed and temperature values in a Serial Monitor.

```
TP1
const int OutPin  = A0; // La sortie OUT du capteur sur la sortie analogique A0
const int TempPin = A1; // La sortie TEMP du capteur sur la sortie analogique A1
const int VSV = 284; // Valeur de la tension OUT en absence de vent
int OUT1;
int TMP1;
int ventms1; // valeur du vent en m/s
int temp1; // valeur de la température en °C

void setup() {
  Serial.begin(9600);
}

void loop() {
  // lecture des variables issues du capteur
  OUT1 = analogRead(OutPin);
  TMP1 = analogRead(TempPin);

  //Utilsation des formules pour donner les mesures en m/s et °C
  ventms1 = int(pow((((float)OUT1 - VSV) / 85.6814), 3.36814) / 0.44704); //conversion de la valeur du capteur en m/s
  temp1 = int (((((float)analogRead(TMP1) * 5.0) / 1024.0) - 0.400) / .0195);

  //affichage dans le moniteur des valeurs
  Serial.print(" Le vent est de ");
  Serial.print(ventms1);
  Serial.print(" m/s et la température est de ");
  Serial.print(temp1);
  Serial.println(" °C");
```

We then obtain

```
19:18:29.042 ->  Le vent est de 0 m/s et la température est de 25 °C
19:18:29.108 ->  Le vent est de 0 m/s et la température est de 25 °C
19:18:29.174 ->  Le vent est de 0 m/s et la température est de 25 °C
19:18:29.241 ->  Le vent est de 0 m/s et la température est de 25 °C
19:18:29.307 ->  Le vent est de 0 m/s et la température est de 25 °C
19:18:29.340 ->  Le vent est de 0 m/s et la température est de 25 °C
```

2. **Setting up the second sensor:**

The set-up of the second sensor is similar to the first example.
Presented below is the assembly diagram and the corresponding set up.

To obtain information from the second sensor, 2 new OUT2 et TMP2 variables need to be created which will further be integrated in the same way as in the previous software.
The layout in the serial monitor is similar to the previous example:

```
//affichage dans le moniteur série des valeurs
Serial.print(" Vent mesuré par capteur 1 : ");
Serial.print(ventms1);
Serial.print(" m/s et Vent mesuré par capteur 2 : ");
Serial.print(ventms2);
Serial.println(" m/s");
delay(1000);//pause d'une seconde
Serial.print(" température du capteur 1 : ");
Serial.print(temp1);
Serial.print(" ° c et celle du capteur 2 : ");
Serial.print(temp2);
Serial.println(" °C");
delay(1000);//pause d'une seconde
```

In no-wind conditions we obtain from the serial monitor the following :

```
18:09:19.514 ->  température du capteur 1 : 24 ° c et celle du capteur 2 : 24 °C
18:09:20.507 ->  Vent mesuré par capteur 1 : 0 m/s et Vent mesuré par capteur 2 : 0 m/s
18:09:21.534 ->  température du capteur 1 : 24 ° c et celle du capteur 2 : 24 °C
18:09:22.527 ->  Vent mesuré par capteur 1 : 0 m/s et Vent mesuré par capteur 2 : 0 m/s
18:09:23.554 ->  température du capteur 1 : 24 ° c et celle du capteur 2 : 24 °C
18:09:24.548 ->  Vent mesuré par capteur 1 : 0 m/s et Vent mesuré par capteur 2 : 0 m/s
```

3. Determining the direction

Now that the 2 sensors are set up, it's interesting to compare the windspeed values and find out the direction of the wind.

To do this, we will consider that the sensor 1 is placed to the left on the station and the sensor 2 to the right.

We will make a simple comparison between the sensor 1 output and the sensor 2 output.
Below is the part of the software that compares the values and displays the dominant windspeed.

```
// comparaison des sorties OUT des 2 capteurs
if (OUT2 > OUT1) {
  Serial.print("Le vent vient de la droite et il vaut : ");
  ventms2 = int(pow((((float)OUT2 - VSV) / 85.6814), 3.36814) / 0.44704); //conversion de la valeur du capteur en m/s
  Serial.print(ventms2);
  Serial.println(" m/s");
} else {
  Serial.print("Le vent vient de la gauche et il vaut : ");
  ventms1 = int(pow((((float)OUT2 - VSV) / 85.6814), 3.36814) / 0.44704); //conversion de la valeur du capteur en m/s
  Serial.print(ventms1);
  Serial.println(" m/s");
}
delay(1000);//pause d'une seconde
```

We will then determine the direction of wind and categorize wind data into 3 groups:
- Strong wind,
- Medium wind
- Feeble wind

In order to do this, we will obtain the maximum of windspeed achievable with our set up. This value will be memorized as a MaxWind constant and will help compare values.

- If the wind measured is lower than 33 % of MaxWind, we will then display "the wind is feeble"
- If the wind measured is lower than 66 % of MaxWind, we will then display "the wind is medium"
- If the wind measured is higher than 66 % of MaxWind, we will then display "the wind is strong"

Here is an exemple :

```
void loop() {
  // lecture des variables issues du capteur
  OUT1 = analogRead(OutPin1);
  OUT2 = analogRead(OutPin2);

  // comparaison des sorties OUT des 2 capteurs pour déterminer le vent dominant
  if (OUT2 > OUT1) {
    VentDom = OUT2;
    Serial.print("Le vent vient de la droite.");
  } else {
    VentDom = OUT1;
    Serial.print("Le vent vient de la gauche.");
  }

  // comparaison du vent dominant avec ventMax
  if (VentDom < 0.33 * ventMax) {
    Serial.print("Le vent est faible");
  } else if (VentDom < 0.66 * ventMax) {
    Serial.print("Le vent est moyen");
  } else {
    Serial.print("Le vent est fort");
  }
  delay(1000);//pause d'une seconde
}
```

10. Discussion of the results and conclusion

The determination of wind speed on Earth as well as on Mars is a determining factor in meteorology. This measurement can be made using different instruments depending on the accuracy of the measurement, the environment...
Seismologists on land do not need to equip seismic stations with meteorological stations because seismometers are stored in cellars protected from atmospheric disturbances.
On the other hand, the interaction of the Martian atmosphere with the ground leaves its mark on seismic recordings.
That's why the engineers designed and placed a weather station on the Lander Insight and placed the SEIS seismometer under a wind protection shield, the WTS, which effectively blocks most wind effects, but cannot completely cancel them out. We will therefore be able to record these gusts of wind and by combining the data from the WTS station and the SEIS recordings learn more about the Martian environment.

11. To follow up activities

Using an LCD display
If we use a computer to visualize wind speed, we can have the messages obtained on an LCD display rather than have them on the Arduino serial monitor. This can be easily obtained, as in the picture below, with an Arduino development environment. The example is available if we open the suggested software in File>examples>LiquidCrystal>Display.

 Set up with an LCD:
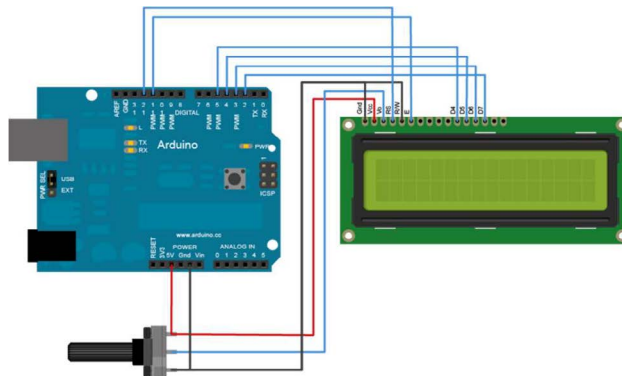
After having « HelloWorld » displayed, we can use the screen layout connected to our software.

The difference is in the displayed sequence, instead of Serial.print () we use lcd.print()

```
void loop() {
  // lecture des variables issues du capteur
  OUT1 = analogRead(OutPin1);
  OUT2 = analogRead(OutPin2);
  //On va d'abord effacer tout les caractères sur l'écran:
  lcd.clear();
  lcd.setCursor(0, 0); //ici, on se positionne en haut à gauche de l'écran

  // comparaison des sorties OUT des 2 capteurs pour déterminer le vent dominant
  if (OUT2 > OUT1) {
    VentDom = OUT2;
    lcd.print("Vent de droite");
  } else {
    VentDom = OUT1;
    lcd.print("Vent de gauche");
  }

  lcd.setCursor(0, 1); //On se place sur la deuxième ligne
  // comparaison du vent dominant avec ventMax
  if (VentDom < 0.33 * ventMax) {
    lcd.print("vent faible");
  } else if (VentDom < 0.66 * ventMax) {
    lcd.print("vent moyen");
  } else {
    lcd.print("vent fort");
  }
  delay(1000);//pause d'une seconde
}
```

12. Follow up activities (additional resources for teachers)

- Météo France : http://www.meteofrance.fr/prevoir-le-temps/observer-le-temps/moyens/les-stations-au-sol
- Météo à l'école : https://www.infoclimat.fr/pedagogie/
- Site Arduino

Annex 13

Erasmus+

This project is co-funded by the European Union

Saltwater - the source of ravines on Mars : Info or Hoax?

1. Introduction & Problem

Scientists believed that the process of soil liquefaction was responsible for the occurrence of ravines on Mars. That is, a process throughout which salts absorb atmospheric water-vapours when both temperature and humidity are elevated at the same time.

Such surface activity is also detected in the Antarctic, where similar water remnants are formed by trickling down brines on a shallow depth. But the night is a lot more cold on Mars than in the Antarctic and the active layer of ground that isn't freezing is a lot more shallow. This process, combined with the rarefied Martian air, can result in solely unnoticeable water quantities, certainly not enough for forming currents along the escarpment.

It seems that the process allowing ravines to be formed on Mars isn't due to the trickling of «saltwater » , but to another aspect.

Mars | Earth
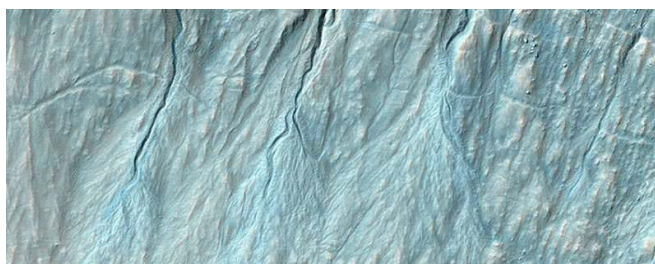
A New Gully Channel in Terra Sirenum
Source: *NASA/JPL/University of Arizona*

Gully erosion in mudstones, PACA region
Source: www.lithotheque.ac-aix-eille.fr/Affleurements_PACA

How are ravines formed on Earth and on Mars ? Is soil erodibility the same ?

2. Age of students   13 - 15

3. Objectives

Explain ravine shaping on Earth and Mars and determine the soil erodibility factor (also known as the k-factor) and explain the sediment transport and deposition process.

4. Primary subjects

Physics –Geoscience - Chemistry

5. Additional subjects

6. Time required: 2h

7. Key terms

Ravine – Erosion – Soil erodibility factor– Sediment transport and deposition

8. Materials
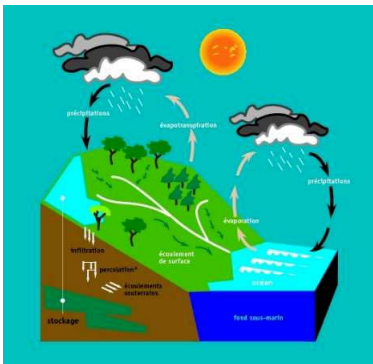
Ravine creation on Earth	Franklin Flask	Image processing
- Laboratory basin sink - Water - Wedge - Sand	- One Franklin flask (laboratory vessel) - Water - Arduino Temperature Sensor - Hot plate - Laboratory stopper - Support stand	- Qgis software - Satellite Images obtained from Hirise

9. Background

The fundamentals of the hydrologic cycle and CO2 cycle on Earth.

10. Procedures

<u>On Earth :</u>

Hydrologic Cycle	Ravines on Earth simulation:
	- Simulation protocol, in A. Prost, *The Earth, 50 experiments to discover our planet*, Belin, 1999. 1 – Equally spread the sand in the basin sink (0,2 mm) and level the surface. 2 – Give the bowl a slight slope by placing a wedge on one side. 3 – Place the hose at the highest point of the bowl. 4 – Gently turn on the tap and lead the water jet to the bottom of the basin (downstream) : the trickle of water infiltrates in the sand. Increase water flow until water stays on the surface.
Source : Water Cycle on Earth (© DocSciences – P. Veyret)	**Author :** *(Van Vliet-Lanoë, 2005)*

1. **Use the available documents and the modeling protocol for the process of ravine formation on Earth (Erosion – Transport - Deposition)**

<u>On Mars :</u>

Pressure-Temperature phase diagram for water and the position of planets:
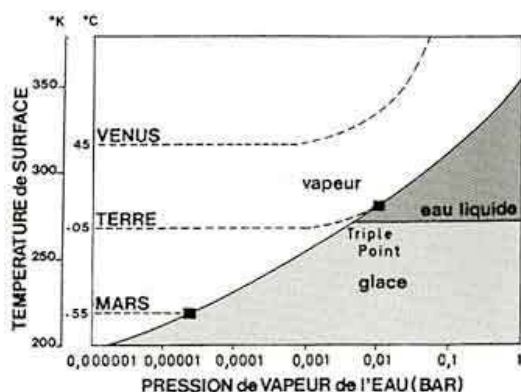
Author : *(Van Vliet-Lanoë, 2005)*

Tens of thousands of such ravine formations, having at times the length of many kilometers, cross slopes situated at Mars' mid-lattitudes. Their formation involved great quantities of liquid, which are very hard to explain. But the planet's atmospheric pressure is so low that any pure surface water inevitably freezes, evaporates or quickly boils. In fact, temperature and pressure conditions (see phase P° and T° diagram for water) are really close to pure water's critical point.

Isn't actually water that digs ravines on Mars ? What is in fact the factor responsible for this process ?

Martian atmosphere composition and Earth's atmosphere composition:

Gas	Mars (%)	Earth (%)
CO2	95,97 %	0,035 %
Ar	2 %	0,93 %
N2	1,89 %	78 %
O2	0,146 %	20,6 %
CO	557 ppmv	0,2 ppmv
H2O (varying)	0,021 %	0,4 %
O3 (varying)	0,01 – 5 Dobs	300 Dobs

CO2 cycle on Mars :
Source : doc. Lance Hayashida/Caltech
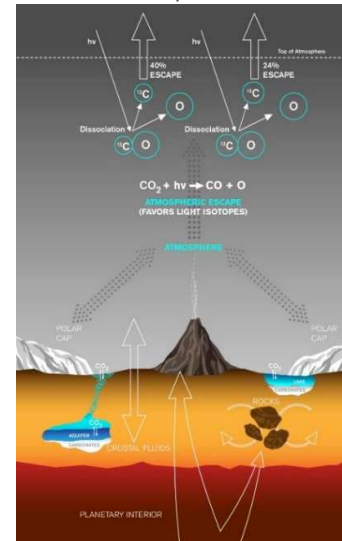
2. Formulate a plausible hypothesis:

Hypothesis : CO2 could be responsible for ravine creation on Mars.

Distribution of seasons during a Martian year:
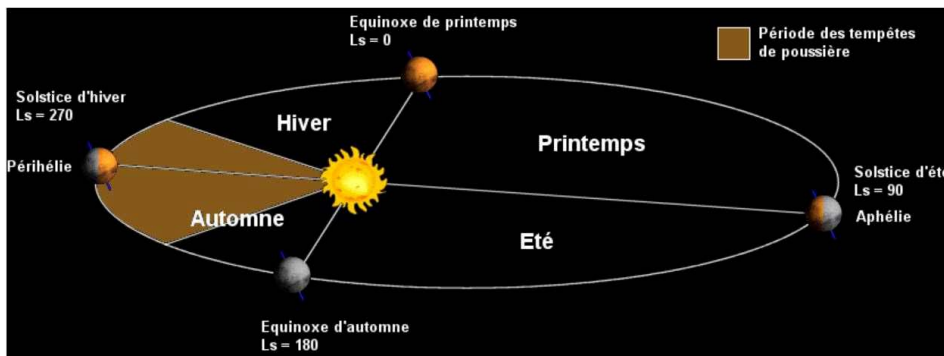
Sl : means Solar Longitude, measured using angles. One Martian year equals 360 degrees, i.e. one complete rotation around the Sun.

One degree in solar longitude matches the angle between the planet and the Sun on the day of Boreal spring equinox.

Photo Credit: © Philippe Labrot, according to the Dynamic Meteorology Laboratory diagram. Little by little by Calvin J. Hamilton
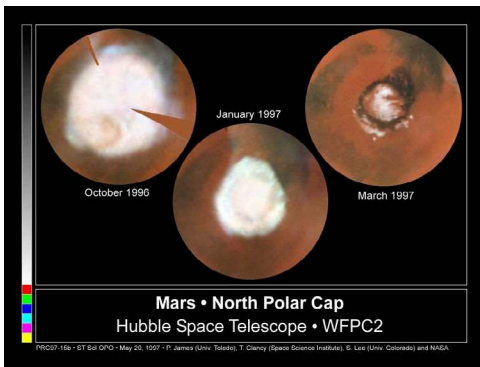
These white polar caps fluctuate in size depending on seasons. Towards the end of summer, only the so called **permanent** or **residual** polar caps remain, formed of "eternal ice fields". The surfaces of white polar caps grow in autumn and winter as they restore and surround by a layer of frost, frost that undergoes condensation in autumn and winter and then sublimation in spring and summer. We thus refer to them as **temporary or seasonal caps.**

Droits réservés - © 1996-1997 Phil James (Univ. Toledo), Todd Clancy (Space Science Inst., Boulder, CO), Steve Lee (Univ. Colorado), NASA

There is also the **seasonal variation of global surface pression**. Whenever there is a large residual cap to the north or to the south (winter and summer solstices), the pression is 75 Pa times weaker than the anual mean value. In absence of residual nothern or southern polar caps (spring and autumn equinoxes), the global pressure is 75 Pa times stronger than the mean value. This variation of 150 Pa between the equinox and solstice (25% of the average pression) shows that 25% of atmospheric CO_2 undergoes condensation and transforms into dry ice during winter and sublimes back the following spring. This transfer of 25% atmosphere between the north and the south that takes place 2 times during a martian year could be the cause of peculiar and generalized storms.

CO2 behaves differently on Mars because of T° and P° values.

Franklin Flask Experiment	Phase diagram for CO2
We will experiment with changes in the status of a chemical species, in this case water, to show students the effect of T° and P° on these changes. Source : https://applilocale.ac-besancon.fr/geogebra/labo/films/franklin/bouillant.htm	 H : average elevation of the surface P : equilibrium surface pressure *Source :* *Thesis « Seasonal condensates on Mars » Florence Grisolle.* **Frost** occurs when the **temperature** of air falls below **-125°C, temperature at which CO₂ changes its state of matter in this range of pressure.**
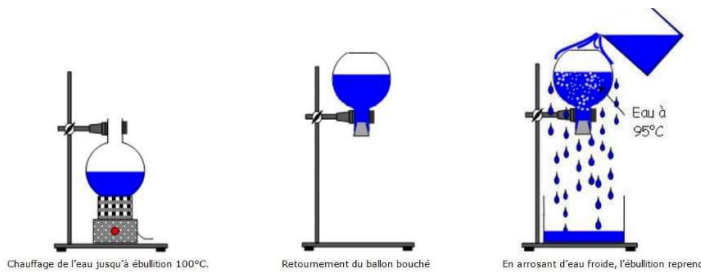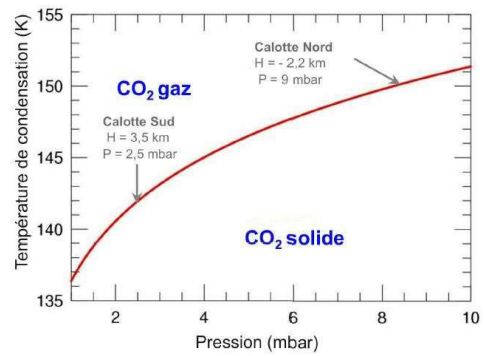
Temporary caps, thin layers of frost, seem mainly formed of dry ice (carbon dioxide ice). But what do those dry ice caps become and what do they transport?

In winter, a layer of carbonic frost forms on the martian regolith. During spring, this layer that is translucent to solar rays is heated from its base.

The ice sublimes: i.e. transitions directly to the gas phase. Gaseous CO_2, trapped underneath the ice layer, is dispersed into regolith pores where the pression increases. The pression can then generate the fracturing of the top ice layer and the swift decompression of the regolith made of broken rock and dust drifted CO_2 thus allowing the drainage of a part of soil by digging a network of channels more or less convergent (woven meshes).

Dust brought to the surface will be deposited in the surrounding area, shaped by the dominant winds. (les éventails).
Source : https://planet-terre.ens-lyon.fr
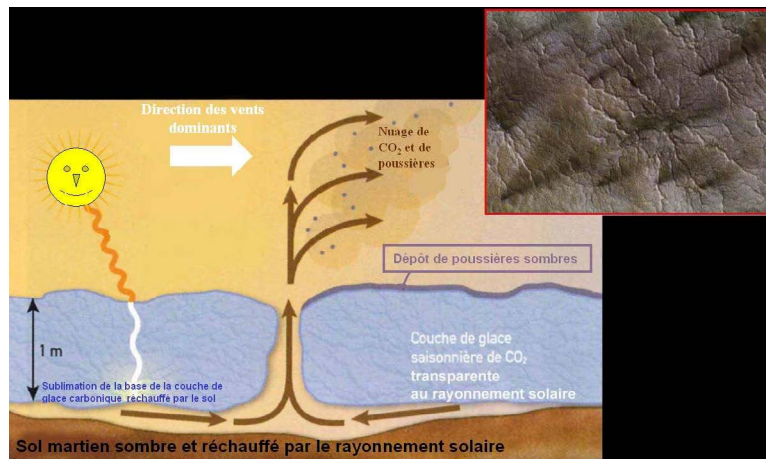
Rights reserved - © 2003 Piqueux et al. ;NASA/JPL/University of Arizona

To exemplify the phenomenon : Present the sequence of images using Qgis software
You can open these image from a Qgis rendered file and thus overlay the layers to see the evolution of woven webs.

End of Winter	Start of Spring	Middle of Spring	End of Spring	Start of Summer	Summer
 100 m					

This sequence is a part of a December 2007 AGU presentation : "Spring at the South Pole of Mars". The sequence of events is studied in a series of images taken during spring and summer in the southern hemisphere and depicts the sublimation of a specific woven web.

End of Winter: We zoom on a single "web". There is a bunch of channels radially organized on the surface, covered by a slab of seasonal translucent carbon dioxide ice (dry ice).

The "date" is Ls = 181.1 (Ls being the unit of time on Mars : at Ls = 180, the Sun crosses the Equator to the south ; at Ls = 270, the Sun reaches its southernmost latitude and Summer begins.)

Start of Spring: obtained at Ls = 195,4. Four dust winds escaped from the woven channels. Translucent ice is warmed from the ground up and evaporated under the seasonal frost layer. Gas finds a weak spot and escapes to the top of the frost layer, transporting the surface dust across the ice. Dust is then swept away by the dominant wind.

Middle of Spring: calculated at Ls = 199,6. The dust is stuck in the channels.

End of Spring: obtained at Ls = 226 shows that the winds' direction changed, that the existing "fan system" is now elongated and an increasing number of new dust winds (éventails) originate from the channels as the frost layer gets thinner.

Start of Summer: established at Ls = 233,1, when a great part of surface frost disappears. The channels are translucent because the Sun shines more directly on their walls. A slim layer of darker dust can be seen on the bottom of the largest channels.

Middle of Summer: calculated at Ls = 325,4, in the middle of austral summer. All seasonal ice disappeared. It's obvious that the channels were dug in the surface and not into the seasonal frost layer. The dust storms eventeils disappeared, meaning that they no longer contrast with the surface material from which they originated. The surface material is dirt solidified by iced water covered by a layer of approximately 5 cm of dried out silt, whici is redistributed every season within this process of éventail creation and transport.

Written by: Candy Hansen (12 December 2007) – **Source :** NASA/JPL/University of Arizona

11. Discussion of the results and conclusions

Water is the factor of erosion in the case of ravine creation on Earth; on Mars, that factor is CO2.
This activity allows students to understand that the action of chemical species depend on Temperature and Pression values.
It is important that students develop a sense of critical thinking so that they remain unbiased and inquiring with every paper published in the scientific field.
Science is not a fixed discipline, it rather evolves depending on technological and scientific progresses.

12. Follow up activities
Show the effect of erosion by CO2-enriched water: Karst landforms

Source : http://www.lithotheque.ac-aix marseille.fr/Affleurements_PACA/13_alla uch/carte_geologique_allauch250.htm

—Massive coherent, non-porous carbonate rocks form rocky slopes in the geological landscape. Vertical limestone walls and talus slopes of marly limestone are displayed in an alternate matter. These rocks are deeply eroded by the water flow and form the so called Pepino hills or Lapiaz: grooves with a circular shape formed on tilted slopes. The dissolution process is also the starting process for rock shelter formation or glacial potholes carved into the rocky bed of a watercourse. The erosion is caused by rock blocks transported by temporary water flows.

— Limestone erosion helps enlarge vertical or tilted joints that affect limestone bedding plane. The phenomenon causes rock blocks to detach from cliffs and collapse at the bottom of bedding planes. —The karst erosion depicted here formed under a vegetation cover, as water rich in carbon dioxide percolates the soil and slowly dissolves the chalk to give it the characteristic shaping of calcareous massifs. Nowadays, this chemical erosion has little to no effect on the rock outcrops.

13. Explore More (additional resources for teachers)

- https://www.uahirise.org/
- https://applilocale.ac-besancon.fr/geogebra/labo/films/franklin/bouillant.htm
- http://www.lithotheque.ac-aix-marseille.fr
- A. Prost, *La Terre, 50 expériences pour découvrir notre planète*, Belin, 1999.
- https://planet-terre.ens-lyon.fr/

Annex 14

Landscapes shaped by dust tornadoes

1. Introduction & Pb

Mars InSight lander captured a wind tornado that cleared the dust that has been piled on the lander's solar panels since its arrival.
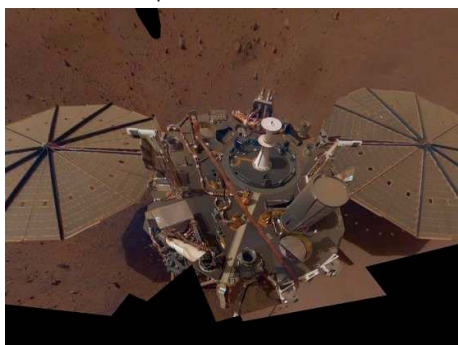
« On the 1st of February 2019, two solar panels of the InSight lander that investigate the geology of planet Mars regained their previous power. This event was associated to a wind tornado which lifted a part of the dust particles covering the panels. It isn't an isolated event on Mars, but it is the first time this has been studied having complete meteorological parameters. »

Source : *Sciences and the future « A Martian passing dust wind swept over the pannels of InSight's solar pannels »*

Source : NASA/JPL-Caltech

The meteorological station APSS (Auxiliary Payload Sensor Suite) recorded a maximum wind speed of 45km/h. As the same time as the dust devil, there was a 13% drop of in atmospheric pression. According to the scientists in charge of the sensor, those conditions are consistent with the passing of a so-called "dust devil".

These tornadoes leave highly visible traces of their crossing on the Martian landscape and thus contribute to the particular geomorphology of the planet Mars, which is not the case on Earth.

Traces left by Dust Devils in the Richardson crater :

The dunes in the image are situated 72° to the south; on Earth, they would have been beyond the Antarctic circle. Due to their position being too close to the pole, enormous temperature variations appear throughout the Martian year. The image on the left was captured at the vernal equinox in the Southern Hemisphere which marks the end of summer and the beginning of fall.

There are still many visible **whirlwind traces**, displayed as subtle intersecting lines, but they will gradually be covered anew by the dry ice layer as austral winter settles in.

NASA/JPL/University of Arizona

Pb : **How do these Dust Devil form on Mars ? Is there such a phenomenon on Earth?**

2. Age of students: 13 – 15 years

3. Objectives

Understanding the physical laws that govern the movement of Air Masses, i.e. atmospheric convection. But also the process underlining Dust Devils' formation to further deduct the causes of traces left on the soil so representative of the planet Mars.

4. Primary subjects

Physics – Earth Sciences

5. Additional subjects

6. Time required: 2h

7. Key terms.

Dew point depression – Atmospheric convection **–**

8. Materials

Dust vortex modeling
- Incense
- Plexiglass sheet
- Candle
- Ice cube tray
Pressure sensor (see: Arduino Technical Data Sheet)

9. Background

Displacement of stable air masses by atmospheric convection :

The ratio between pressure values and temperature values (Gay-Lussac's Law) underlying the atmospheric convection principle:

French chemist and physicist Louis Joseph Gay-Lussac (1778-1850) proved that there is a connection between the pression and temperature values of a gas. For a constant volume and a given quantity of a gas, he observed that pressure of a given gas increases directly with the absolute pressure of the gas and vice versa. The mathematical relationship he deducted from his experiments is called Gay-Lussac's law.
    « **Gay-Lussac's law** describes the relation between the pression and the temperature of a gas. It stipulates that, for a constant volume, pressure of a given quantity of gas is directly proportional to the absolute temperature of the gas. »

Temperature T   Temperature 3T

©F.Moujdi-F.Bouvet
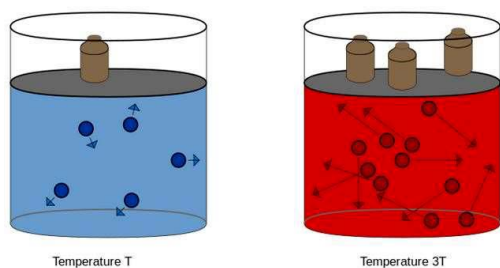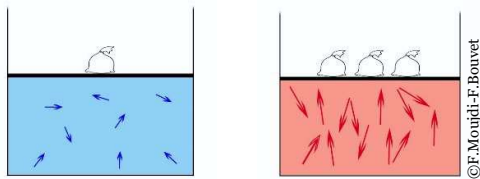
According to this kinetic-molecular theory of gases, an increase in temperature should cause an increase in the kinetic energy of particles.

The molecular collision risk is higher, which causes a change in pression. If volume of the gas remains constant, its pressure will increase.

10. Procedures

Same as on Earth, winds on Mars are powered by solar thermal energy. Observations made by the Viking landers show that atmospheric dust particles on both Mars and Earth can be lifted by dust storms. These phenomena can reach significant dimensions. A tornado draws in the surrounding air masses and concentrates them in its core.

Amazonis Planitia

A large dust whirl projects a serpentine shadow on the Martian soil.
The photo covers an 644m wide area. The North is facing upwards. The dust wind reaches 800m altitude and 30m in diameter.
A westerly breeze half as high as the dust whirl produced a slight curve in the middle. The photo was taken when the planet is at its aphelion (farthest point from the Sun).

Satellite: Mars Reconnaissance Orbiter
Copyright: NASA/JPL-Caltech/University of Arizona

The same phenomenon happens on Earth, generally during summer. A dust devil is formed from the soil up when certain criteria is met. Dust tornadoes are whirlwinds of air masses entraining dust particles.

Air masses dynamics model :
Conduct the following experiment to emphasize the movement of air masses.

P° sensor on the inside and on the outside :

Without external disturbing factor   With external disturbing factor
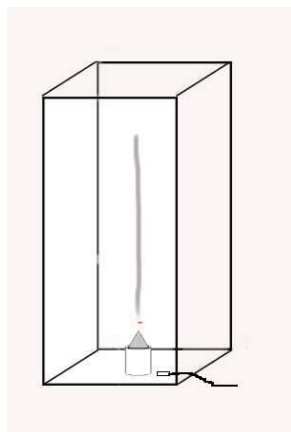
©F.Moujdi-
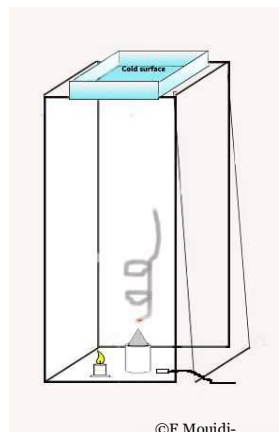
1. <u>Write down the results :</u>

	Experiment 1		Experiment 2	
	T=0	T=3'	T=0	T=3'
Pression inside the tube				
Pression outside the tube				
Interpretation of laboratory results				

2. Using the obtained results, **explain** the phenomenon that took place during the experiment and what exactly allowed the movement of warm air masses.

I.   <u>Tornado in action :</u>

We have just shown that the ascent of hot air is the trigger of a tornado. This updraft also allows horizontal rotations to become vertical because of the tangential shear of vertical winds.

Afterwards, when the tornado is produced, air rises to its core, generating the violent suction of surrounding air and sustains the dew point depression.

When a dust devil travels on the surface of Mars, it can gather and disrupt the detached dust layers, leaving behind darker trails.

<u>Dust in action, photographed on orbit by MGS on 11/12/1999 :</u>
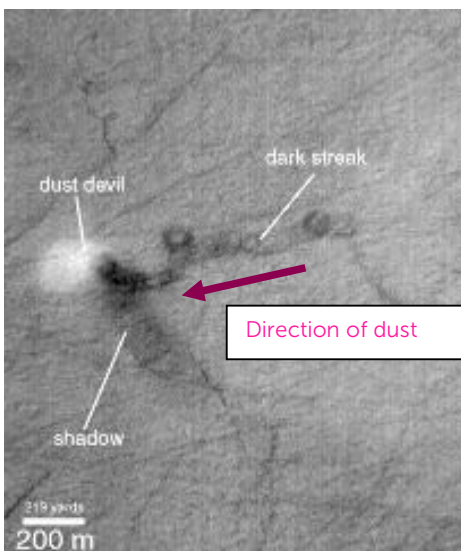
- Dark streak: The trace left by the passing of dust (70m wide) that swept the thin layer of clear dust particles covering the soil. Its sinuous form and dark color make the trace highly visible.

- Dust devil: Dust cloud

- Shadow: The shadow of the tornado on the soil.

11. Discussion of the results and conclusions

Dust devils on Mars are created in the same way they occur on Earth. The soil gets warmer during the day and heats the air just above the surface (through radiation). The mass of hot air rises and the colder mass of air above falls, thus creating vertical convection cells. A horizontal burst of wind will swirl the convection cells, which will then create a dust whirlwind.
Tornadoes that bring dust with them will contribute to the shaping of Martian landscape, leaving traces behind.
But these traces will gradually be covered once again by dry ice during austral winter. Mars' appearance changes depending on the season.

12. Follow up activities

- https://visionscarto.net/once-upon-a-thirst

13. Explore More (additional resources for teachers)

- **https://planet-terre.ens-lyon.fr/article/mars-2005-04-13.xml**

- https://www.nirgal.net/mars_science_atm.html

Erasmus+

This project is co-funded by the European Union

Volcanos compared: why a smaller planet has a bigger volcano?

1. Introduction & Pb

The size and shape of a volcanic cone on the Earth allows the volcanologists to learn many things of the

history of the volcano as well as to know about the composition and other related physical properties of the magma that originated it, as for instance, its viscosity.

Many students know that a volcano on the planet Mars, Olympus Mons, is the biggest mountain in the Solar System, or at least, its highest volcano. It size (almost 22,000 m high) more than doubles the highest mountain on the Earth: another volcano located in Hawaii (Mauna Kea, 10,000m high).

Figure 1: Olympus Mons
© NASA

2. Age of students 16 to 18 years old.

3. Objectives

Through this activity, students can:

- compare the sizes of the two planets (Earth and Mars);
- compare the sizes of the highest volcanoes on both planets, Mauna Kea on Earth and Olympus Mons on Mars;
- be aware that Olympus Mons is not only the biggest volcano in the Solar System, but also its biggest mountain;
- make calculations to calculate the volume, mass, density and weight of the two volcanoes;
- compare the eruptions of both volcanoes and to understand that both are shield volcanoes formed by lavas with a basaltic composition.

4. Primary subjects

General science, Geology, Maths, Physics, Geometry

5. Additional subjects

Arts (drawing)

6. Time required 30 minutes plus 30 minutes more for the "Follow up activities"

7. Key terms

Volcanoes, basalt, shield volcanoes, volume, density, gravity, weight, scale, equivalence of units, asthenosphere, deformation

8. Materials

- graph paper,
- ruler,
- compass,
- pencil

9. Background

Many students find difficult to compare the dimensions of the different planets in the Solar System, as well as the relative size of the volcanos of both planets.

Through a series of simple calculations, they learn about the size of its biggest mountains. From its volume, composition and density, they can calculate their respective weights.

They can produce, then, theories to explain the differences in size as well as to better understand the dynamics of a planet with tectonic plates moving upon a plastic asthenosphere compared to another one with no active tectonic plates in the present.

Figure 2: Olympus Mons compared to France. Published under Creative Commons Attribution-Share Alike 4.0 International

10. Procedures

Before starting the activity, ask the students to use an engine search (i.e. Google™) in order to find out which are the biggest mountains on Earth and Mars as well as its dimensions (height and maximum diameter.

Their results should be:

PLANET	MOUNTAIN	TYPE	HEIGHT	DIAMETER
Earth	Mauna Kea (Hawaii)	Volcano	about 9,100m*	about 180km*
Mars	Olympus Mons	Volcano	about 25,000m*	about 600km*

*Results may differ from one source to another because of the *reference surface* to calculate the height as well as the shape of the basis that is not circular and therefore the measure of the diameter approximates the *mean diameter*.
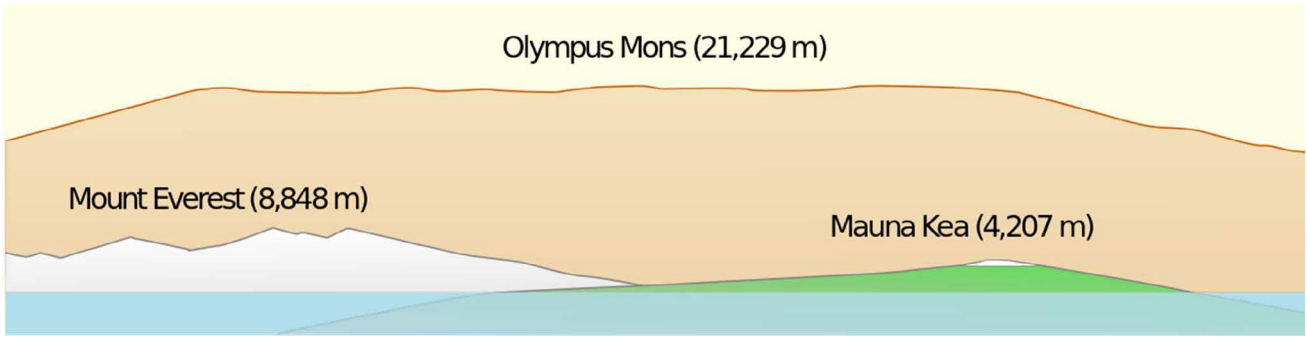
Figure 3: Olympus Mons compared to Mount Everest and Mauna Kea.
Published under Creative Commons Attribution-Share Alike 4.0 International

Now give them a graph paper and ask them to represent a cross section of both volcanoes.

Scales suggested are: - horizontal: 1:2,500,000;

- vertical: 1:1,000,000.

Then, ask the students to calculate the tangent of the slopes of both volcanoes using the following formula:

Tangent = height / radius

It is expected both results to be quite similar. As the Mauna Kea is a typical shield volcano formed by runny, basaltic high temperature lavas, with low angle slopes, we can find out that Olympus Mons is a Martian shield volcano also formed by basalt type lavas. The samples analysed in Mars confirm this theory.
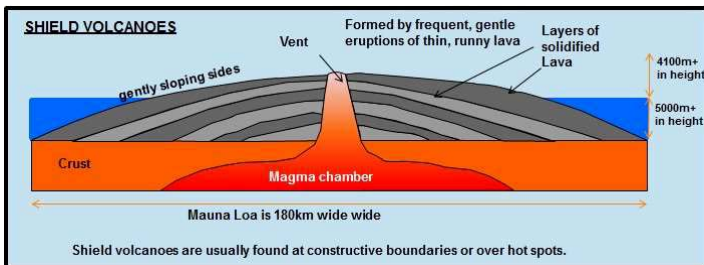
Shield volcano (Wikimedia commons)   Stratovolcano (Wikimedia commons)
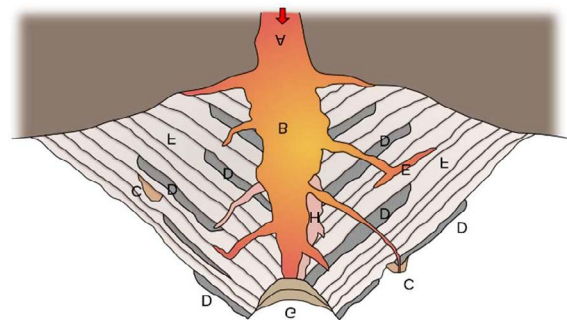
Figure 5: A shield volcanoes compared to a stratovolcano.
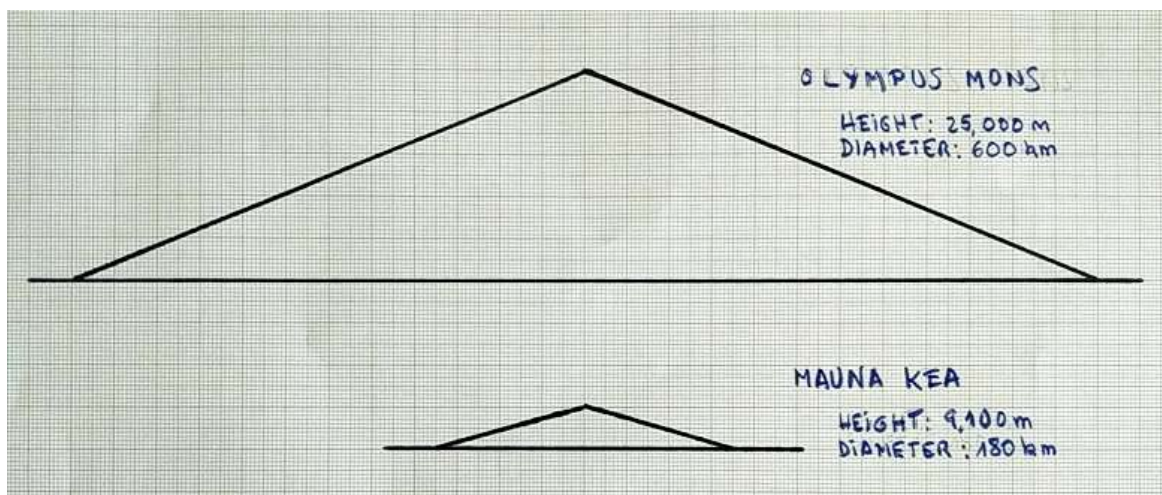
Figure 6: The two volcanoes plotted on a graph paper. Scales: horizontal 1:2,500,000; vertical: 1:1,000,0
Drawing: Xavier Juan

11. Discussion of the results and conclusions

A final discussion about the results should lead to the question: why Mars (a smaller planet than the Earth) has such an enormous volcano compared to the Earth volcanoes?

Possible answers are:

- *In Hawaii, the movement of the Pacific plate upon a unmoving plume causes the formation and extinction of successive volcanos that d0n't have time enough to grow very high.*

- *In Mars an unmoving plume feeding the volcano for a long time causes a higher volcanic building.*
- *A lower gravity in Mars seems to favour a higher volcanic activity.*

12. Follow up activities

Calculating the volume of the two volcanoes:

Accepting that the approximate shapes of the two volcanoes is a cone, and knowing its height and radius, students could calculate both volumes by using the formula:

$$V = 1/3 \ \pi r^2 h$$

Where r is the radius of the base an h, the height of the cone.

Calculating the mass of the two volcanoes:

Now, knowing the volume of both volcanoes and the average density of basalt (about 3,000 kg/m^3), the students should be able to calculate the mass of the two volcanoes by using the following formula:

$$\rho = m / V$$

where ρ is the density, m the mass and V the volume.

Calculating the weight of the two volcanoes:

Now, provided that the average gravity is for the Earth and Mars (9.8m/s^2 and 3.7 m/s^2, respectively), pupils should be able to calculate the weight of both volcanoes:

$$W = mg$$

Where W is weight, m the mass and g the acceleration of gravity.

Discussing the results:

Knowing the weight of Mauna Kea upon the Earth crust and Olympus Mons upon Mars, ask the students to propose explanations for the fact that the Earth's crust is depressed around Mauna Kea because of its weight and that there's no evidence of such a sinking of Mars surface around Olympus Mons.

Possible answers are:

- The pressure (= weight (force) / surface) is less on Mars than on the Earth.
- As the outer layer of the Earth (lithosphere) is broken in several tectonic plates, the Pacific plate behaves apart from the rest of plates to the pressure caused by Mauna Kea.
- Mauna Kea is not a single volcano in the Hawaii area, but one of a complex of volcanoes with a resulting weight bigger than the one that they have calculated.
- In the Earth, the existence of a plastic layer below the lithosphere (asthenosphere) allows the Pacific plate deformation because of the weight of
the Hawaii volcanoes. This is not the case for Mars where it seems that there's not a plastic layer like in the Earth.

All the possible answers could be true but, probably, the most significant is the absence of asthenosphere in Mars

13. Explore More (additional resources for teachers)

NASA Mars Exploration Program: https://mars.nasa.gov/

A flight simulation over Olympus Mons : https://www.youtube.com/watch?v=OTazRNGXSC8

Olympus Mons *(largest volcano in the solar system!)*: https://mars.jpl.nasa.gov/gallery/atlas/olympus-mons.html

Annex 16

How to estimate epicenter location with only one seismic station on Earth

1. Introduction & Pb

Usually, students work on epicenter location by using origin time of the earthquake and arrival time of seismic waves. With records from three seismic stations, it is possible to estimate the epicenter location.

On Mars, there is only one sensor to detect and to estimate the epicenter location. We propose here to invite students to estimate the epicenter of the Mw 9.0 Tohoku-Oki earthquake (Mars 11, 2011, Japan), with only one seismic station.

2. Age of students 15 – 17 years

3. Objectives

Use an approach similar to that used by researchers working on the mission insight to estimate the epicenter location of an earthquake with only one record from a three-components seismic station.

4. Primary subjects

Physics – Earth Science

5. Additional subjects

6. Time required: 2h

7. Key terms

Rayleigh waves, Epicentral distance, azimut

8. Materials

Supports used :

- Data from RESIF network
- SeisGram2K80_ECOLE© : To download free of charge from the Edumed website: http://edumed.unice.fr/fr/tools-lab

Data :

- The Mw 9.0 Mars 11, 2011 Tohoku-Oki earthquake (Japan), recorded at the station CALF (Observatoire de la Côte d'Azur, Calern, France).

9. Background

- Rayleigh waves detection:
    o They are low periods waves, the associated arks are longer than arks from body waves. They're also higher in amplitude.
    o If the earthquake has sufficient energy, the surface wave can pass several times at the station: packs of longer period signal can appear in the signal.
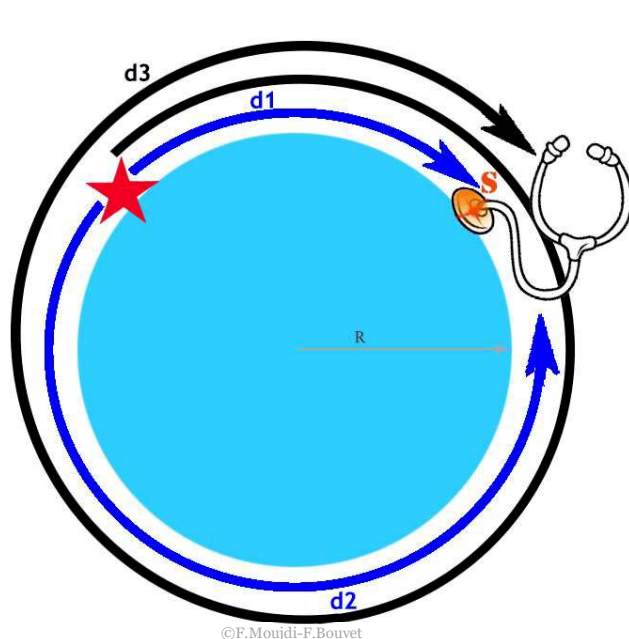
$$distance_{(source/station)} = \frac{t3 - t2}{2} \cdot \frac{2\pi R}{t3 - t1}$$

Figure 1. Theorical approach to estimate an epicentral distance from Rayleigh waves. White start seismic source. Black inverted triangle: Seismic station. d1: shortest distance between the source and the station. d2: longest distance between the source and the station. d3: travel along the d1 distance plus a complete rotation around the planet. t1: arrival time of Raleigh waves after the propagation along d1. d2: arrival time of Raleigh waves after the propagation along d2. T3: arrival time of Raleigh waves after the propagation along d3. R: radius of the planet.

10. Procedures

Students are then invited to pick Rayleigh waves from the Tohoku-Oki earthquake, recorded at the station CALF.

- **pick of the three arrival times, and compute of the epicentral distance.**

Here, the automatic tool provided by SeisGram2k is not used. Students read arrival times and compute manually the distance to the epicenter from the formula in Figure 1.
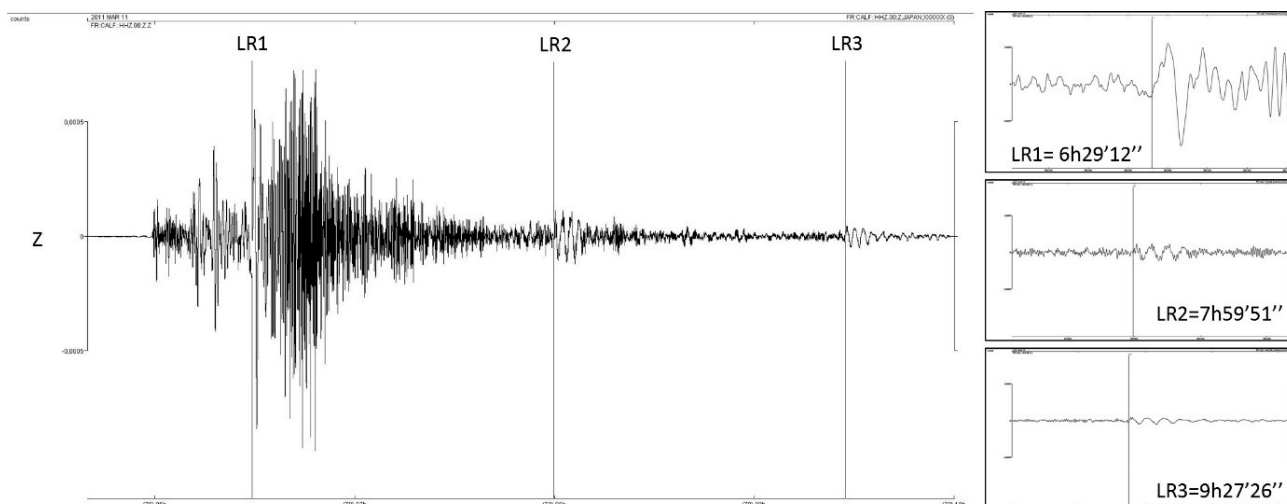
Figure 2. Pick of the three passage of Rayleigh waves (Tohoku-Oki earthquake) at the station CALF. Right column: zoom of each pick, with the observed arrival times (UTC).

10. Discussion of the results and conclusions

In this case, the epicentral distance computed is equals to 9841 km.

- **Estimate the backazimuth.**

The epicentral distance computed previously indicate that the epicenter is on a circle, which the radius is equals to 9841 km. Two parameters are required to find the correct position on this circle: the azimuth, and the backazimut. The azimuth gives the direction of the first ground motion in the horizontal plane at the station, positive clockwise. The backazimut gives the sense where the epicenter is. The polarity of the P wave from the vertical component is required: i) if the polarity is positive, the first motion is upwards, the backazimuth is equals to the azimuth plus 180°; ii) if the polarity is negative the first motion is downwards, the backazimuth is equals to the azimuth.

SeisGram2k allows to determine the azimut value, with the rotation tool. It's possible to virtually rotate the geographical frame and to compute amplitudes in the new frame. By rotating the frame, amplitude of the P wave vary between two maxima, passing by a null value, on each component. The rotation value which allows to cancel the P wave on the East component give the azimuth: the motion is only in the North direction of the new geographical frame.

a. **Detect the first P waves on each horizontal components.**

Use zoom tool of seismogram to select a time windows adapted to highlight the first P wave. The increase/decrease amplitude tool could be used.
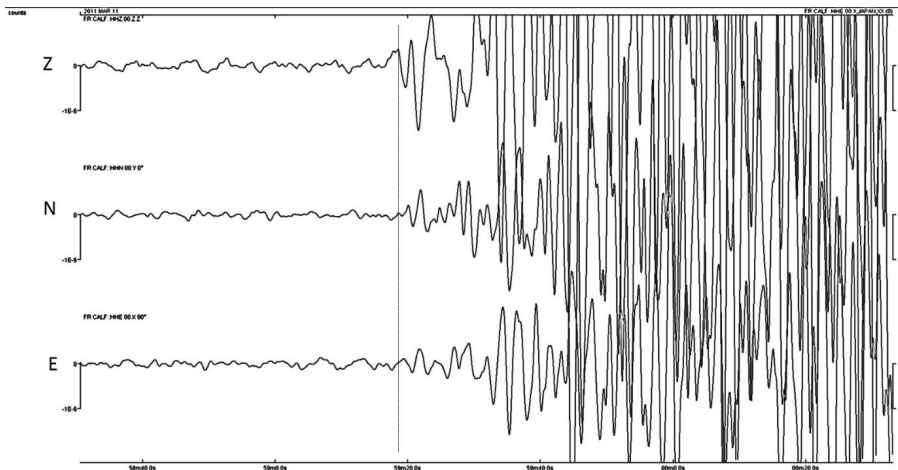
Figure 3. Records of the Tohoku-Oki earthquake. Vertical black dashed line: pick of the P wave. E: East component. N: north component. Z: vertical component.

b. **Rotate horizontal component (clockwise) to cancel the P wave on the East component**

In this case, a rotation equals to +30° allows to cancel the P wave amplitude on the East component. The first motion is in a direction equals to +30° (clockwise) from the North in the real geographic frame: it's the value of the azimuth.
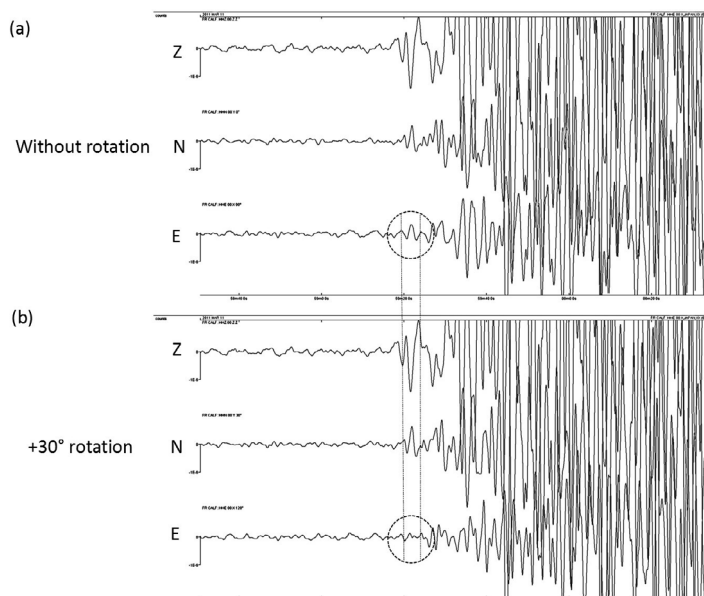
Figure 4. Records of the Tohoku-Oki earthquake. (a) Raw seismograms. Black dashed ellipse: identification of the P wave from the east component. (b) Seismograms after a rotation equals to +30°: the P wave amplitude is canceled. E: East component. N: north component. Z: vertical component.

c. **Estimate the backazimut value from the P wave polarity on the vertical component**

In this case, the P wave is downwards on the vertical component (Fig. 3): the backazimut is equals to the azimuth.

Information file in SeisGram2K indicate an azimuth equals to 329.5°. This azimuth is corresponding to the direction at the epicenter from the geographic North to the station: it is equals to the angle between the geographical north minus the backazimuth (counter-clockwise).

Determine the location of a Martian earthquake from a single seismometer

1. Introduction & Pb

Let's try to understand how with a single seismometer it will be possible to locate the origin of seismic waves created by a meteorite impact or an earthquake.

Theoretically, Mars having a small perimeter, scientists hope to record several wave trains, shifted in time corresponding to the same earthquake or impact.

The waves that can circle the planet several times are the Rayleigh surface waves.
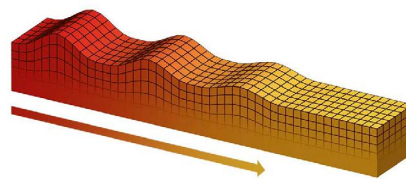
Principe de déplacement d'une onde de surface (© IPGP/David Ducros).
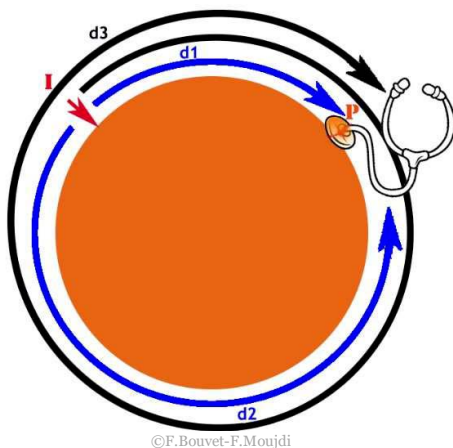
©F.Bouvet-F.Moujdi

I: point of impact, origin of the seismic wave.

P: seismometer

T1: the time taken by seismic waves to travel the distance **d1**

T2: the time taken by seismic waves to travel the distance **d2**

T3: the time taken by seismic waves to travel the distance **d2+2d1** or **d3**

2. Age of students 15 – 17 years

3. Objectives

The Insight mission aims to locate an earthquake on Mars using a single seismometer.
In this activity, students will use experimentation to better understand the scientific approach used by researchers to estimate the location of an epicentre of an earthquake with the recording of a single seismometer.
In our experiment we will use a piezo cell to simulate the work of the SEIS instrument.

4. Primary subjects

Physics – Earth Science – Mathematics

5. Additional subjects

6. Time required: 2h

7. Key terms.

Epicenter, surface waves, frequency, seismogram

8. Materials

- A pilates balloon, perimeter 250 cm
- Audacity 1.2.6
- 1 piezo cell
- 2 polystyrene bars
- 1 tape measure
- 1 ball of 11,5g and 1,4cm suspended from a 1m wire fixed to a protractor

9. Background

The notions of seismic wave propagation, the origins of an earthquake.

10. Procedures

Place the balloon on the polystyrene bars to avoid any contact with the ground
Tape a piezo cell onto the balloon
Determine a striking zone 93cm from the piezo cell
Hang the protractor so that the ball is level with the hitting area.

Let's experiment with a model to better understand the theory
Detail of the experimental device

Make several successive recordings with impacts of constant intensity. To do this, move the ball so that the wire faces an angle of 50° with the vertical.

Let's analyze the results obtained:
Several wave trains are observed as predicted by the scientists' simulations. Let's determine the time elapsed between the different wave trains.

Record 1
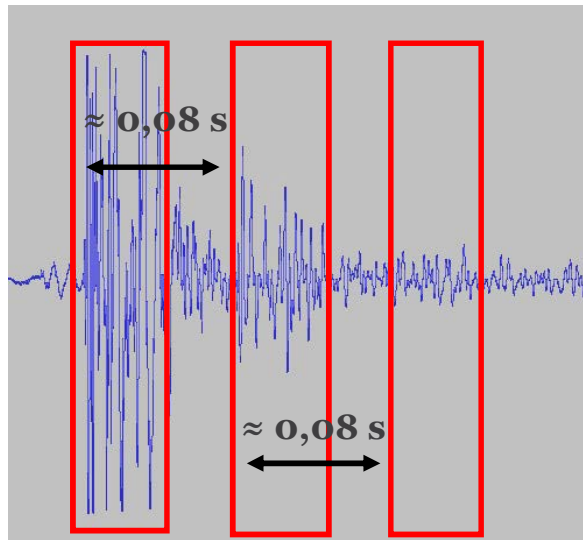
Record 2
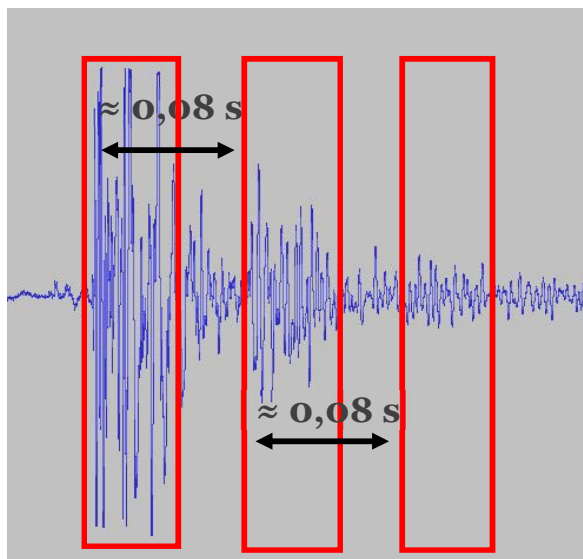
Record 3
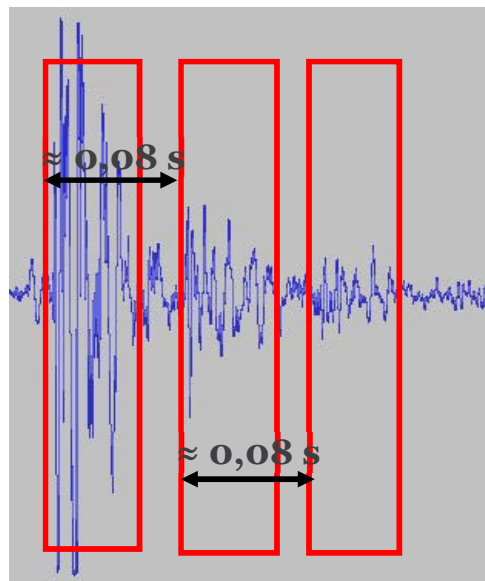
From the obtained results, let us assume that the time elapsed between each wave train corresponds to the time taken by the latter to complete a complete balloon revolution **d2+d1**

We can therefore determine an approximation for the speed of wave propagation on the surface of the balloon.

V=d /t =(d1+d2) /t
$\quad$ = 250 /0,08 = **3125 cm.s^{-1}**

Let's take a closer look at the first. We are trying to find out if the waves that travelled the distance d2 were detected by the piezo.
Record 1

Record 2

0,022 s

Record 3

0,02 s
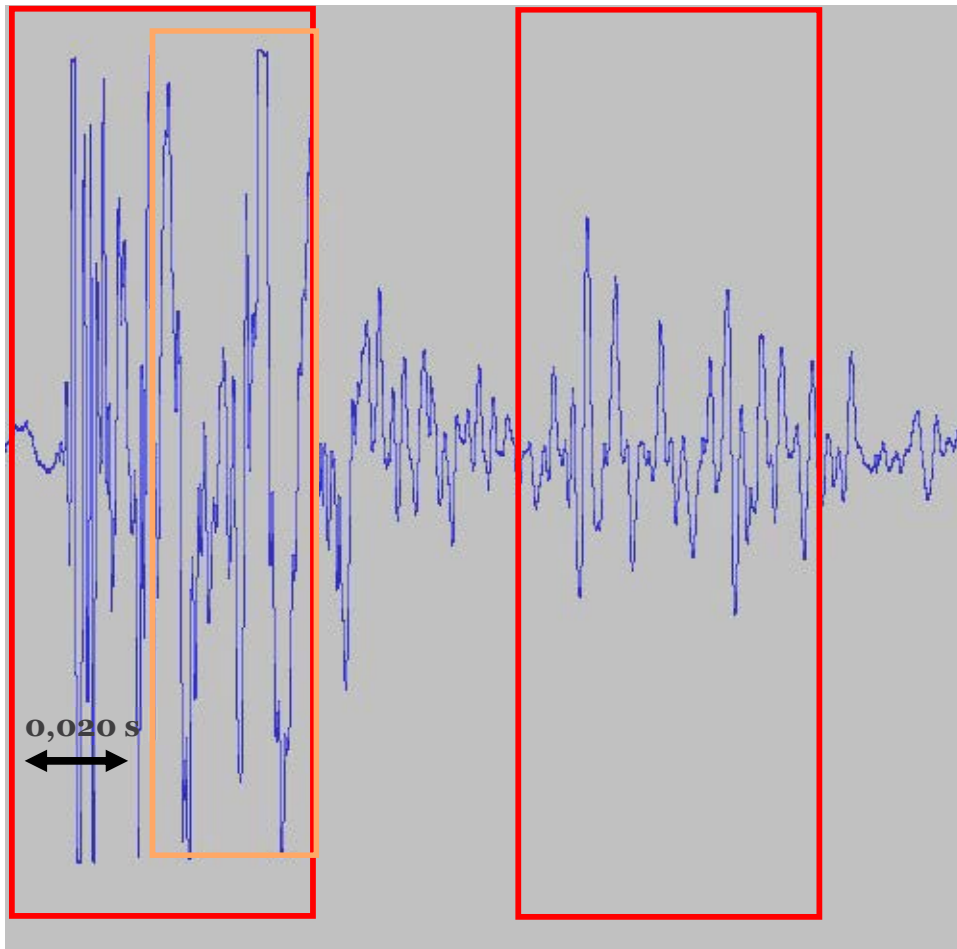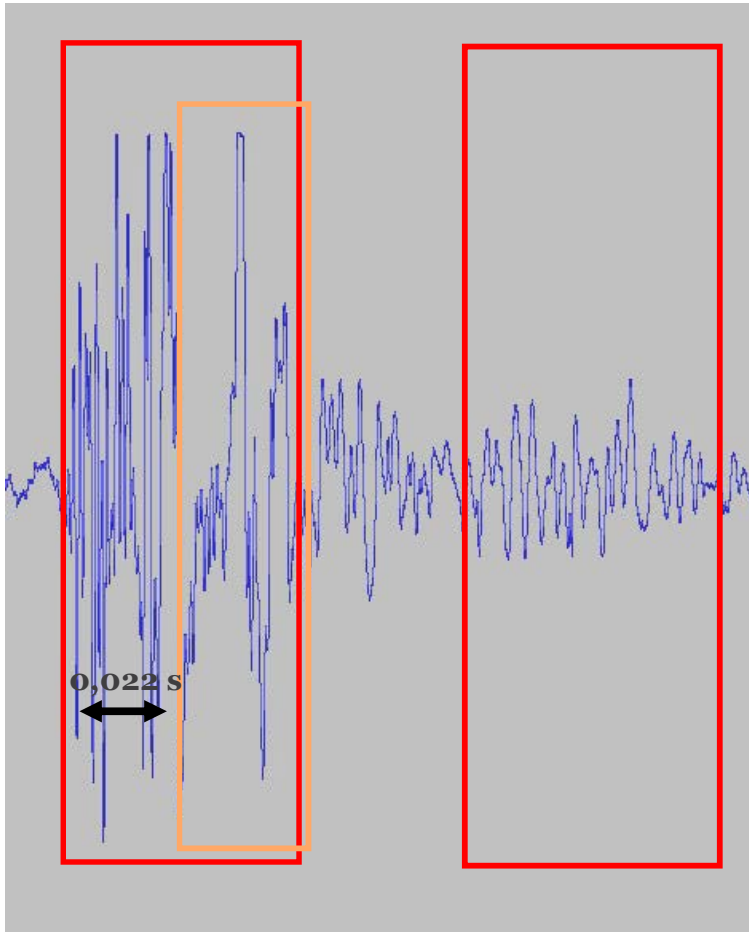
Let us suppose that this signal corresponds to the waves that travelled the distance d2.

We can estimate an impact area.

d2-d1 $= \Delta t \times$ **V**

 d2-d1 $=$ 0,02 x 3125 $=$ <u>62,5 cm</u>

 d1 $=$(250 -62,5)/2 $=$ <u>93 ,75 cm</u>

11. Discussion of the results and conclusions

The distance between the seismometer and the earthquake source, the time of the earthquake, and the average speed at which waves travel over the planet's surface can be estimated by combining the arrival times of waves R1, R2 and R3. Earthquakes of magnitude 4.5 or greater are relatively rare events on Mars, but geophysicists estimate that over the duration of the mission (one Martian year, or two terrestrial years), it should be possible to observe between about 3 and 5.

It is important to note that the effectiveness of the techniques that will be implemented for the InSight mission has been validated on Earth with data from unique stations. (cf: activity on the study of earthquakes on Earth from a single seismometer). These have led to the discovery of one of the Earth's internal structure models commonly used by geophysicists (PREM) with acceptable error bars.

However, there are unknowns, and the validity of the technique summarized above cannot be confirmed until scientists receive and analyze records from Mars.

12. Follow up activities

On the Moon geophysicists were astonished to discover that the lunar crust caused enormous diffraction of the seismic waves, preventing the existence of surface waves. Since the Martian crust, just like the lunar crust, was exposed to a massive bombardment of asteroids early on in the formation of the solar system, its pulverised nature and numerous craters, especially in the planet's southern hemisphere, could also cause seismic waves to be diffracted; seriously complicating analysis.

13. Explore More (additional resources for teachers)

- https://www.seis-insight.eu/en/public-2/martian-science/seismic-activity

- The geology of Mars, edited by Mary Chapman

Annex 18

Erasmus+   SCHOOLS TUNE INTO MARS   This project is co-funded by the European Union

Plasticine balls: how can we explore inside Mars?

1. Introduction & Pb

During the latest centuries, many geoscientists have been working to unveil the internal structure of the Earth. Apart from observing the rocks on the Earth surface and analysing and testing them using different methods, a wide range of tools to find out how it is the structure of the Earth have been developed.

In 1970, the Kola Superdeep Borehole failed to reach the depth it had been designed for: to drill a hole 15 km deep in the Kola Peninsula (ancient USSR). This deepest hole drilled in the Earth reached a depth of 12,262 metres. So, the geoscientists don't have direct access to any rock below this depth.

Once proven that direct methods like drilling the Earth could not provide information about the internal structure of the whole Earth (its radius being of about 6,400 km), the scientists focused on improving even more the indirect methods that had already being developed since the 19th Century. Refining these techniques and making them more precise has been a major contribution to our current knowledge of the internal structure of the Earth as well as the dynamic processes that take place deep in our planet.

These methods include:

- Calculating the average density of the Earth by knowing its mass and volume.
- Studying the seismic waves that travel through its layers every time an earthquake takes place anywhere on the Earth.
- Studying and analysing the meteorites falling on the Earth surface.
- Studying the general Earth's magnetic field and what causes it.
- Studying how the Earth spins (its rotational inertia).

2. Age of students   14 to 18 years old

3. Objectives

Students can:

- propose hypothesis and discuss them with the rest of students
- suggest methods for testing these hypothesis
- suggest which of these could be useful to probe the Earth
- suggest which of these could be used to probe Mars with the available technology

4. Primary subjects

- Earth science
- Physics
- Maths

5. Additional subjects Technology

6. Time required 30 minutes

7. Key terms

Internal structure, Earth, Mars, scientific hypothesis, testing, probing, density, seismic waves, magnetism, spheres, meteorites.

8. Materials

- plasticine™ of two colours
- small bar bearings
- several toothpicks
- a Magnaprobe™
- scale (optional)
- slide gauge (optional)

9. Background

Students have to face a problem when they are given two clay ball of the same size but different weight. They are asked to provide hypothesis that could fit with the fact that two spheres that look externally the same (apart from their colour) have a very different physical propertes (mass and, therefore their density).

Then they are asked to suggest methods to test what is the internal structure of both balls and to decide which of those could be useful when studying the internal structure of a planet like the Earth or Mars.

10. Procedures

Give to every group of three students two plasticine balls of different colours but the same size and ask them if they feel any difference between the two balls. They easily realize that the weight, and therefore, the density is different.

Figure 1: Two balls: the same size, different weight. Green lighter, red heavier

Ask them to suggest hypothesis that could explain the difference between the two balls. They can provide five different solutions:

- the two balls are made of two types of plasticine with different densities
- one of the balls has something heavier inside
- one of the balls has something lighter inside
- the density of one of the balls increases gradually as you go deeper in it
- the density of one of the balls decreases gradually as you go deeper in it

(The right answer is the that the heavier one contains a bar bearing inside)
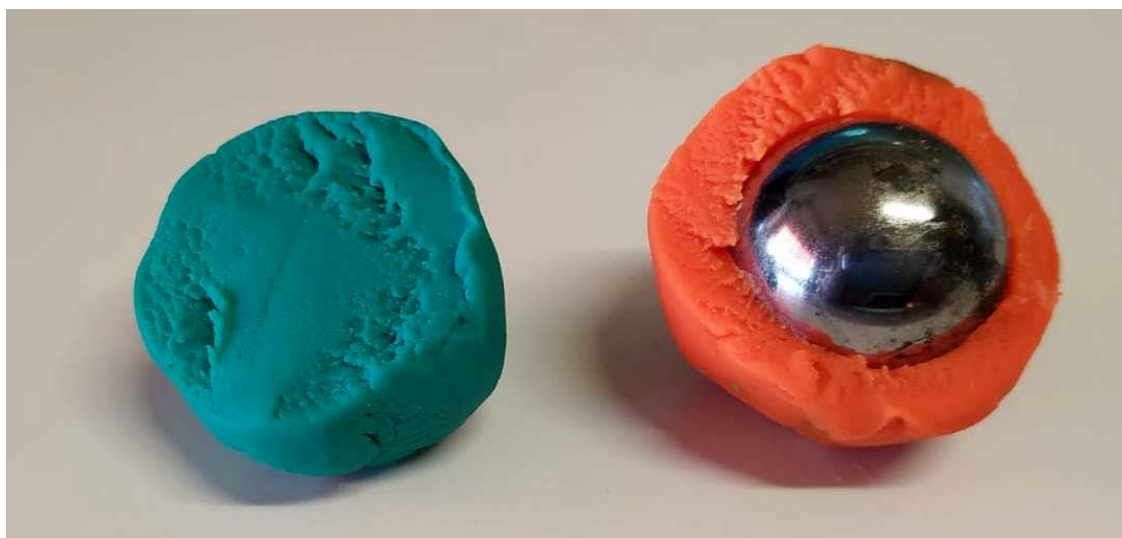
Figure 2: The two balls cut to show their internal structure: green, pure Plasticine™; red ball bearing inside.

Now ask them how, with all the apparatus and technologies available in the Earth, could they test which is the difference between the two balls.

Possible answers:

- weighting the two balls (with a scale) and calculating their density
- drilling them (with toothpicks, for example)
- testing its magnetism (with a small compass)
- using X-rays
- ultrasounds (like the one used to see embryos inside the uterus)
- electromagnetic resonance (EMR) like the ones used in many hospitals
- ionising radiation (alpha, beta or gamma radiation)
- how the Earth spins

Then, ask the students which of these methods are suitable for studying the internal structure of the Earth.

Possible answers:

- weighting the two balls (with a scale) and calculating their density. *Yes, astronomical calculations allow scientists to know the mass of the Earth and, knowing the Earth radius, its possible to calculate the volume, and therefore, the density of the Earth*.

- drilling them (with toothpicks, for example). *Not much, as we have not been able to drill more than 13 km deep.*
- testing its magnetism (with a small compass). *Yes, there's a general magnetic field in the Earth, related with its outer (liquid) and inner (liquid) iron core. It can be detected with a compass.*
- using X-rays. *No, they can't penetrate the Earth.*
- ultrasounds (like the one used to see embryos inside the uterus). *No, they can't penetrate the Earth. However, infrasounds or seismic waves can penetrate the Earth and provide a very useful information about its layers as well as their physical state (solid or fluid).*
- electromagnetic resonance (EMR) like the ones used in many hospitals. *No, they can't penetrate the Earth*
- ionising radiation (alpha, beta or gamma radiation). *No, only gamma radiation can penetrate a few meters into concrete.*
- How the Earth spins. *Yes, the way the Earth spins suggest a denser core inside it.*

Now provide the students with two more clay balls of different colours: one lighter than the lighter they already have (with a ball of expanded polystyrene, EPS, inside) and another one the same weight as the heavier they already have (with a magnet bar inside).

Ask them to order them by increasing density; the results should be:

1. EPS core
2. Plasticine™ core
3. Ball bearing and magnet cores (approximately the same density)

Now, ask them which of these four should be the less suitable to model the internal structure of a planet. (Answer: 1 and 2, as usually, gravity pushes the heaviest materials to "sink" deep in the core of the planets).

Provide them with a small compass and ask them wich of the balls 3 or 4 fits better with the internal structure of the Earth and which fits better with Mars. (*Answer: the one with the magnet inside fits better with the model of the Earth as our planet has a general magnetic field related to a liquid iron outer core, while Mars seems to have an iron core but completely solid and, therefore it has no general magnetic field*)

11. Discussion of the results and conclusions

Students can compare the physical properties both of Earth and Mars, discuss which methods are the best to study them, which are available in each planet and compare the degree of knowledge about the internal structure of the Earth and Mars.

12. Follow up activities

Students can use an Internet search engine to research for the equipment of the probe Insight landed on Mars. From this information they can discuss which of the methods suggested for studying the internal structure of the Earth could apply in Mars according with this equipment.

They can also, using a scale and a slide gauge, calculate the density of the four spheres knowing that the formula to calculate the volume of a sphere is:

$$V = \frac{4}{3} \cdot \pi \cdot r^3$$

... and that de density (D) is:

$$\rho = \frac{m}{V}$$

13. Explore More (additional resources for teachers)

- This activity has been developed from the Earthlearningidea "From clay balls to the structure of the Earth" in www.earthlearningidea.com.
- https://www.nasa.gov/. Official website of the National and Aeronautics Space Administration (NASA)
- All the relevant information about InSight Mission in https://www.nasa.gov/feature/jpl/for-insight-dust-cleanings-will-yield-new-science .

Annex 19

Plasticine balls: comparing planets

1. Introduction & Pb

This activity is intended to be carried out after "Activity 4A. How can we explore inside Mars" in which pupils have learned about the different methods for studying the internal structure of a planet. Nevertheless, this activity can be carried out individually and completely apart of the other one.

Two aspects of the study of the internal structure of a planet have been developed along this activity: the distribution of masses inside it and the presence or absence of a general magnetism.

2. Age of students   14 to 18 years old

3. Objectives

Students can:

- propose hypothesis and discuss them with the rest of students
- suggest methods for testing these hypothesis
- understand how these properties allow or not to distinguish between the Earth and Mars
- calculate the density of different clay balls and compare them
- decide which ball models better the Earth and Mars

4. Primary subjects

- Earth science
- Physics
- Maths

5. Additional subjects

Technology

6. Time required   20 minutes

7. Key terms.

Internal structure, Earth, Mars, scientific hypothesis, testing, probing, density, magnetism, spheres, meteorites.

8. Materials

- plasticine^{TM} of different colours
- small bar bearings
- magnets
- small balls of Expanded Polystyrene (EPS)
- a Magnaprobe^{TM}
- scale

9. Background

Students are given four plasticine balls of different colours and they are informed about the composition of the four balls.

They have to decide which of the four balls models better the features (distribution of masses and magnetism) of the two planets, Mars and the Earth.

10. Procedures

Provide your students with the four balls but without telling them which colour each sphere is. The four spheres are approximately the same size and their respective composition is:

- *sphere 1*: all of it is made of pure Plasticine™
- *sphere 2*: the Plasticine™ ball contains a ball of Expanded Polystirene (EPS) inside
- *sphere 3*: contains a ball bearing inside it
- *sphere 4* contains a magnet weighting about the same as the ball bearing of sphere 3

Balls 1 and 3 (green and red) as used in the Activity 3	
Ball 3 showing the EPS ball inside	Ball 3 showing the magnet inside
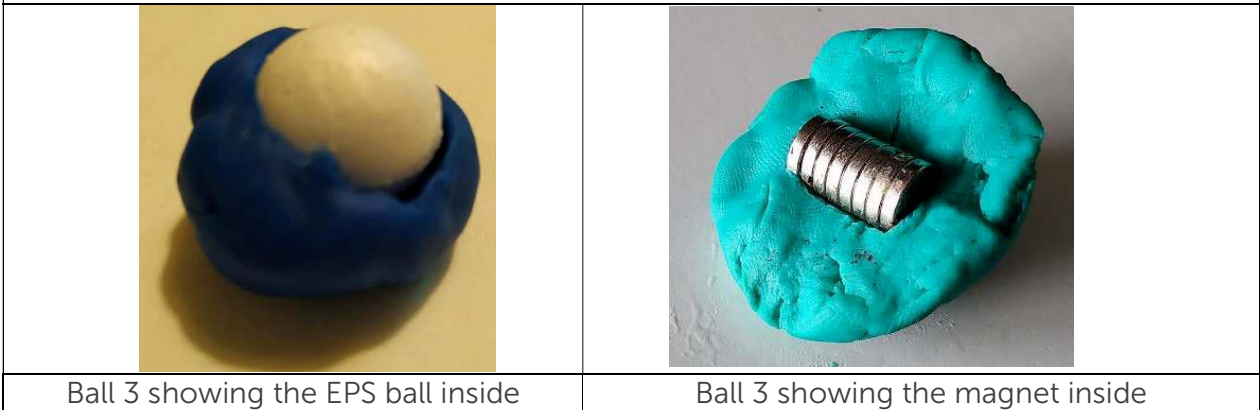
Now, ask them which of the four balls fit better with what is expected about the distribution of layers in any planet and which of the four fit better with the internal structure of the Earth and of Mars respectively.

(The right answer is the that the heavier one contains a bar bearing inside)

Now ask them how, all the apparatus and technologies available in the Earth, could they test which is the difference between the two balls.

Possible answers:

- weighting the two balls (with a scale) and calculating their density
- drilling them (with toothpicks, for example)
- testing its magnetism (with a small compass)
- using X-rays
- ultrasounds (like the one used to see embryos inside the uterus)
- electromagnetic resonance (EMR) like the ones used in many hospitals
- ionising radiation (alpha, beta or gamma radiation)
- How the Earth spins

Then, ask the students which of these methods are suitable for studying the internal structure of the Earth.

Possible answers:

- weighting the two balls (with a scale) and calculating their density. *Yes, astronomical calculations allow scientist to know the mass of the Earth and, knowing the Earth radius, its possible to calculate the volume, and therefore, the density of the Earth.*
- drilling them (with toothpicks, for example). *Not much, as we have not been able to drill more than 13 km deep.*
- testing its magnetism (with a small compass). *Yes, there's a general magnetic field in the Earth, related with its outer (liquid) and inner (liquid) iron core. It can be detected with a compass.*
- using X-rays. *No, they can't penetrate the Earth.*
- ultrasounds (like the one used to see embryos inside the uterus). *No, they can't penetrate the Earth. However, infrasounds or seismic waves can penetrate the Earth and provide a very useful information about its layers as well as their physical state (solid or fluid).*
- electromagnetic resonance (EMR) like the ones used in many hospitals. *No, they can't penetrate the Earth*
- ionising radiation (alpha, beta or gamma radiation). *No, only gamma radiation can penetrate a few meters into concrete.*
- How the Earth spins. *Yes, the way the Earth spins suggest a denser core inside it.*

Now provide the students with two more clay balls of different colours: one lighter than the lighter they already have (with a ball of expanded polystyrene, EPS, inside) and another one the same weight as the heavier they already have (with a magnet bar inside).

Ask them to order them by increasing density; the results should be:

1. EPS core
2. Plasticine™ core
3. Ball bearing and magnet cores (approximately the same density)

Now, ask them which of these four should be the less suitable to model the internal structure of a planet. (*Answer: 1 and 2, as usually, gravity pushes the heaviest material to "sink" deep in the core of the planets*).

Provide them with a small compass and ask them with of the balls 3 and 4 fits better with the internal structure of the Earth and which fits better with Mars. (*Answer: the one with the magnet inside fits better with the model of the Earth as our planet has a general magnetic field related to a liquid iron outer core, while Mars seems to have an iron core but completely solid and, therefore it has no general magnetic field*)

11. Discussion of the results and conclusions

Students can compare other physical properties both of Earth and Mars, discuss which methods are the best to study them, which are available in each planet and compare the degree of knowledge about the internal structure of the Earth and Mars.

12. Follow up activities

Students can, also, using a scale and a slide gauge, calculate the density of the four spheres knowing that the formula to calculate the volume of a sphere is:

$$V = \frac{4}{3} \cdot \pi \cdot r^3$$

... and that de density (D) is:
$$\rho = \frac{m}{V}$$

13. Explore More (additional resources for teachers)

- This activity has been developed from the Earthlearningidea "From clay balls to the structure of the Earth" in www.earthlearningidea.com.
- https://www.nasa.gov/. Official website of the National and Aeronautics Space Administration (NASA)
- All the relevant information about InSight Mission in https://www.nasa.gov/feature/jpl/for-insight-dust-cleanings-will-yield-new-science .

The seismogram: a complex signal

1. Introduction & Pb

The ground motion is the result of arrivals of many waves, which have their own frequency. Seismometers record ground motion continually and this continue signal, without arrival of seismic waves, is considered as the ambient seismic noise.

When an earthquake is well recorded, seismic waves are clearly identified relative to the continue seismic noise. But sometimes, these waves had been recorded, but they are not perceptible. Knowing frequencies ranges of seismic waves, it is possible to find an hidden earthquake in the seismic noise.

2. Age of students 15 – 17 years

3. Objective

Filtering a seismogram with adapted bandwidth to observe seismic waves.

4. Primary subjects

Earth science - Physics

5. Additional subjects

Informatics: Audacity software

6. Time required 2hrs

7. Key terms

Wave – Frequency - Seismograms

8. Materials

Supports used:

- Data from RESIF network
- SeisGram2K80_ECOLE© : To download free of charge from the Edumed website: http://edumed.unice.fr/fr/tools-lab

Data:

- The Mw 4.8 January 1, 2019 earthquake (Greece), recorded at the station CALF (Observatoire de la Côte d'Azur, Calern, France).
- The Mw 6.3 December First, 2018 earthquake (Indonesia), recorded at the station CALF.

9. Background Seismogram2K -

10. Procedures

Step one: processing of the Greek earthquake to display P waves

The raw seismograms are extractions of continuous seismic signal where seismic waves should be perceptible. On each component, no seismic waves are observable. Related to the magnitude (Mw 4.8) and the epicentral distance (15.87°). By considering an average P wave velocity of 8 km/s (related to the epicentral distance), first P wave should arrive on 11:45:43 a.m.

By providing the following frequencies scale to students, they can estimate a specific frequencies range for body waves.
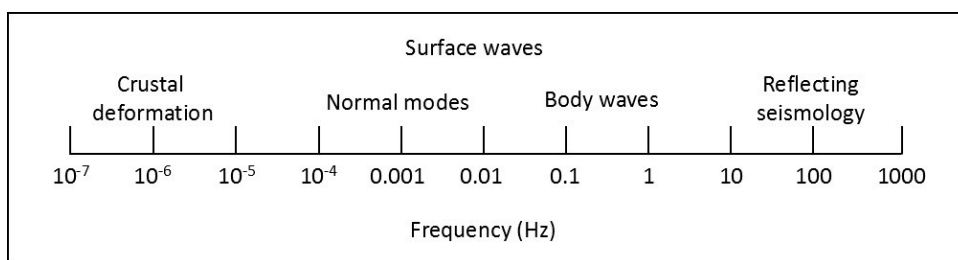
This scale (from Stein and Wysession, 2013) is an indicative scale. Student can observe that the body waves frequencies spread out from values lower than 0.01 Hz and upper than 1 Hz.

Exercise: test different bounding values for a bandpass filtering in order to highlight seismic waves.

In this case, the lower value for a bandpass filtering must be greater than or equal to 1 Hz. The greater value has no influence on the emergence of seismic waves.

<u>Results:</u>
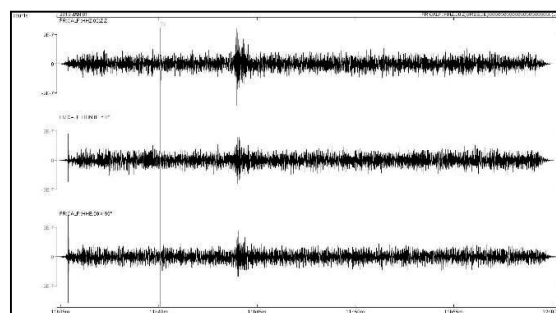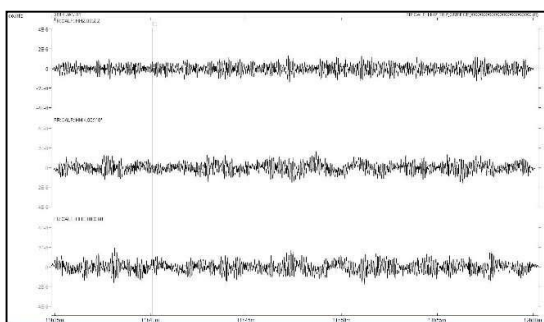
<u>Step two:</u> processing of the Indonesian earthquake to display P waves

As previously, no seismic waves are observable in raw data.

Exercise: students are again asked to found adapted values for bandpass filtering which allow highlighting seismic waves.

In this case, the lower value for bandpass filtering to display P wave can be greater than or equal to 0.5 Hz.

First conclusion: although seismic waves are not observable in seismograms, they can be highlighted with an adapted processing. These two steps show that P waves are easly observable in frequencies range greater than 1 Hz.

But what about S waves and surface waves ?

Results:
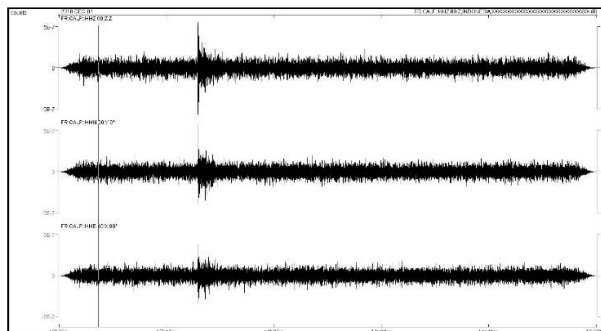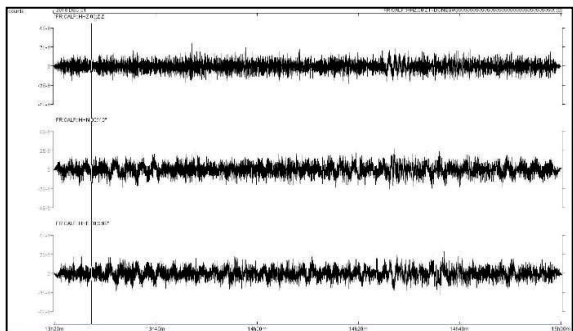
Step three: processing of the Indonesian earthquake to display P, S and surface waves

Exercise: students are asked to find adapted values in order to highlight P, S, and surface waves.

In this case, range values between 0.01 and 0.1 Hz allows displaying body and surface waves. Pick of theorical arrival times with SeisGram2K allows to easy identifying the different waves packs. For this teleseismic event P waves are in fact PKIKP waves, and S waves are SS waves. Rayleigh waves are well display and easly identifying.
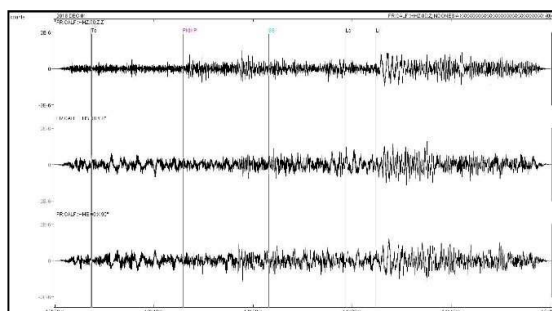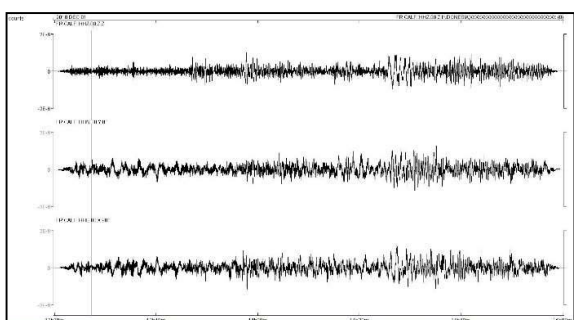
11. Discussion of the results and conclusions

Seismograms contain a large frequency content, and seismic waves could be hidden in the seismic noise, on Earth as on Mars. Scientists will have to process future data with accuracy in order to detect waves from future impacts and marsquakes.

Main conclusion:

Seismograms contain a large frequency content, and seismic waves could be hidden in the seismic noise, on Earth as on Mars. Scientists will have to process future data with accuracy in order to detect waves from future impacts and marsquakes.

Annex 21

Atmospheric parameters and impact on seismic records

1. Introduction & Pb

A seismic station is designed to detect infinitesimal ground motions. Its electronic devices can be impacted by ground motions, and also by atmospheric parameters. We proposed here seismograms where the continuous signal is not flat: day after day big daily arks are observed.

2. Age of students   15 – 17 years

3. Objective

Filter seismic noise by detecting atmospheric variations in the signal

4. Primary subjects

Earth science - Physics

5. Additional subjects

Informatics: SeisGram2K80_ECOLE©

6. Time required   2hrs

7. Key terms

Seismograms – Frequency - Waves

8. Materials

Supports used:

- Data from RESIF network
- SeisGram2K80_ECOLE© : To download free of charge from the Edumed website: http://edumed.unice.fr/fr/tools-lab

Data:

- Continuous seismic signal from February 3 to February 7, 2019, recorded at the station MYLF (Forcalquier, Alpes de Haute Provence, Observatoire de la Côte d'Azur).

9. Background

Using the SeisGram2K80_ECOLE© software

10. Procedures

Step one: Analysis of the continuous signal.

Students have to describe continuous signals from the picture in Figure 1.
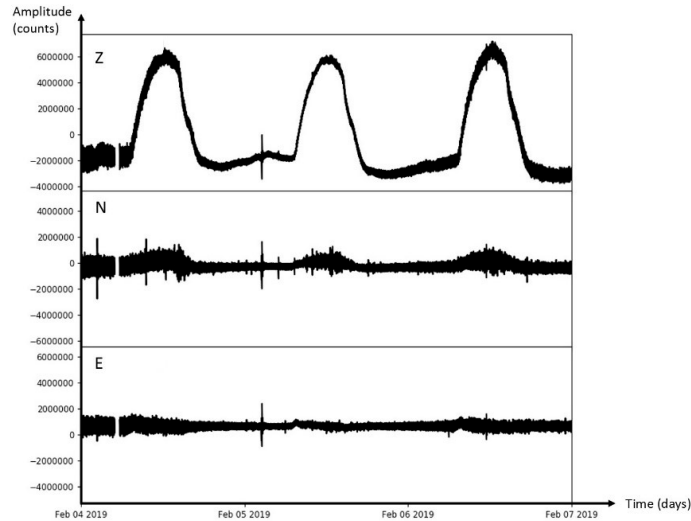
Figure 1. Records from the station MLYF (from February 4 to February 7, 2019). E: East component. N: North component. Z: vertical component.

In this case, students must highlight that the signal from the Z component is clearly daily disturbed: each day, the signal form an ark which increase till midday, and decrease after. This phenomenon is also observed in signal from the north component. The East component seems less impacted.

Step two: Find a physical parameter which can induce this drift of the continuous signal.

The seismogram from the vertical component can be used to ease analyse the continuous signal.

Step three: Find remarkable event except the daily arks.

In this case, an earthquake is recorded on 02h29m06s.

But in this continuous signal four others earthquakes are recorded (Fig. 2).
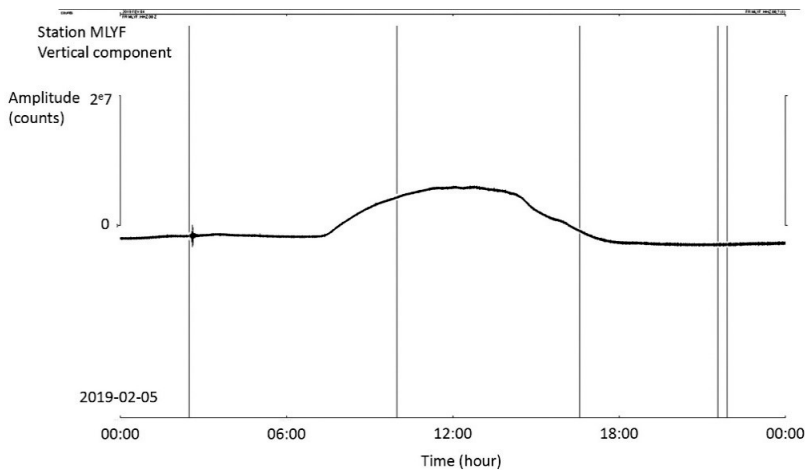
Figure 2. Continuous signal from the station MLYF (February 5, 2019). Vertical black lines: pick of earthquakes recorded this day.

Step four: Observation of these earthquakes

With SeisGram2K and the zoom and scroll tools, try to identify seismic waves recorded at each pick marker on Figure 2, and find the corresponding earthquake in Table 1.

time	Latitude (deg)	Longitude (deg)	Depth (km)	Magnitude
02/05/2019 02:23:20	44.623	6.999	5.22619	1.10
02/05/2019 02:59:21	44.620	6.996	5.90243	0.98
02/05/2019 03:14:54	44.627	6.995	3.97904	1.05
02/05/2019 03:24:12	44.632	6.994	4.50887	0.67
02/05/2019 03:30:24	44.622	7.002	5.23938	0.78
02/05/2019 03:46:13	44.631	7.004	5.74260	0.99
02/05/2019 06:40:26	44.321	7.203	2.69562	0.89
02/05/2019 11:08:10	43.431	6.337	3.15283	1.66
02/05/2019 16:33:52	43.600	5.367	0.00	2.20
05/02/2019 02:19:15	44.510	10.100	22.00	2.3
05/02/2019 06:54:58	43.420	12.470	9.00	2.1
05/02/2019 08:30:59	45.860	7.050	2.00	3.1
05/02/2019 08:31:00	45.850	7.080	10.00	3.1
05/02/2019 09:02:50	45.840	7.030	5.00	2.4
05/02/2019 09:52:45	45.970	6.970	8.00	3.0
05/02/2019 09:55:54	45.880	7.040	8.00	1.5
05/02/2019 11:47:51	44.440	12.190	32.00	2.2
05/02/2019 21:32:59	46.030	5.600	5.00	3.4
05/02/2019 21:52:57	45.980	5.580	10.00	3.2

Table 1. Catalog of seismicity on February 5, 2019 (From the catalog of European Mediterranean Seismology Center and the catalog of the laboratory Géoazur). The covered area is centered on the Region PACA, and North Italy.

11. Discussion of the results and conclusions

Meteorological parameters can have an influence if the sensors is not well isolated from its close environment. On Mars, the seismometer SEIS is protected by a dome against atmospheric activity as daily variation of the temperature and the wind. This dome could withstand squalls of 216 km/h and should even be able to survive winds of 360 km/h (https://www.seis-insight.eu/en/public-2/seis-instrument/wts).

Annex 22

Egg drop

1. Introduction & Pb

The landing phase of a probe is one of the most critical phases of a mission. This is why scientists model these phases in the laboratory before launching. We will take the case of the Insight mission that landed on Mars a few months ago.

To survive the intense friction forces that characterize entry into the atmosphere, the InSight probe is protected by a large diameter heat shield. The latter is covered with tiles made of a special material, which will absorb the impressive amount of energy due to the resistance of the atmosphere to the passage of InSight.

After atmospheric entry, the second stage of InSight's landing consists of a parachute descent. The latter will be deployed at an altitude of about 9 kilometres.

Finally, at an altitude of about 1.3 kilometres, while still flying at a speed of 224 kilometres per hour, InSight separated from its parachute, and found itself in free flight, falling like a rock towards the rusty surface of Mars and quickly moving away from the rear shield it had left behind (and to which the parachute had remained attached).

But very quickly, half a second after this event, the landing gear turns on its retrorockets, to brake and stabilize.

Drawing showing the InSight probe during the final (propelled) stage of landing on the equatorial plain of Elysium.

(© IPGP/Manchu/Bureau 21).

Engineering activities give kids a chance to develop problem solving and observations skills, to work with interesting and engaging tools and materials, and to learn how to work as a member of a team. When you drop something, it falls to the ground. This is because it is pulled by the gravity of the Earth. You'll notice that some things drop faster than others, this is because of air resistance. Try dropping a piece of paper and a lego brick. Which drops the fastest?

2. Age of students   6-17 years

3. Objectives

-   Describe and define material properties.
-   Identify the forces of gravity, drag, and the term air resistance
-   Design and build a system that will protect an egg from a 1-meter drop.

4. Primary subjects   Physics

5. Additional subjects

6. Time required

 1 hour

7. Key terms.

design process, landing, egg drop competition

8. Materials

eggs
big zip bags
cotton-wool
pencils/paper or computer
any construction materials from students' homes

9. Background

When you drop something, it falls to the ground. This is because it is pulled by the gravity of the Earth. You'll notice that some things drop faster than others, this is because of air resistance. Try dropping a piece of paper and a lego brick. Which drops the fastest?

If you tried dropping paper and a lego brick or similar, the paper should have dropped to the floor more slowly than the brick, this is because the paper has a larger surface area, so has to push against more air as it drops, which means the air resistance is greater and it drops more slowly.

You need to create something that can absorb the energy the egg gathers as it accelerates towards the ground. A hard surface will crack the egg so you have to think carefully about how you can protect it. Something that will cushion the egg at the end of its fall is a good place to start, you want the egg to decelerate slowly so it doesn't crack or smash all over the ground. You'll need to run a few trials so have some eggs.

10. Procedures

The idea is to wrap the egg in a layer of cotton-wool that will protect it from landing. Put the egg wrapped in cotton-wool in a zippered bag and allow it to fall from about 1 m high. If the cotton layer is thin the egg will crack.

11. Discussion of the results and conclusions

After the experiment, analyze your data. In an egg drop project, you will determine how well your design performed. If the egg broke after the first drop, you know that revisions need to be made. However, this does not mean the experiment was a bad one. In science, all results are good results, because all results offer an opportunity to learn. When something goes wrong or does not work the way it is expected, it provides a chance to find out why and correct it. If an egg breaks, look at the data, assess the performance of your design and use it to figure how it can be made better.

12. Follow up activities

13. Explore More (additional resources for teachers)

STEM activities websites

- https://www.seis-insight.eu/fr/public/la-mission-insight/atterrissage

- "Mars in a minute" du Jet Propulsion Laboratory (© JPL-Caltech/IPGP).

Going to Mars

1. Introduction & Pb

Finding the relative position of Earth and Mars which correspond to the optimal spacecraft travel path in terms of energy consumption, using planetary position data and advance algebra concept, all in order to determine the next launch opportunity to Mars.
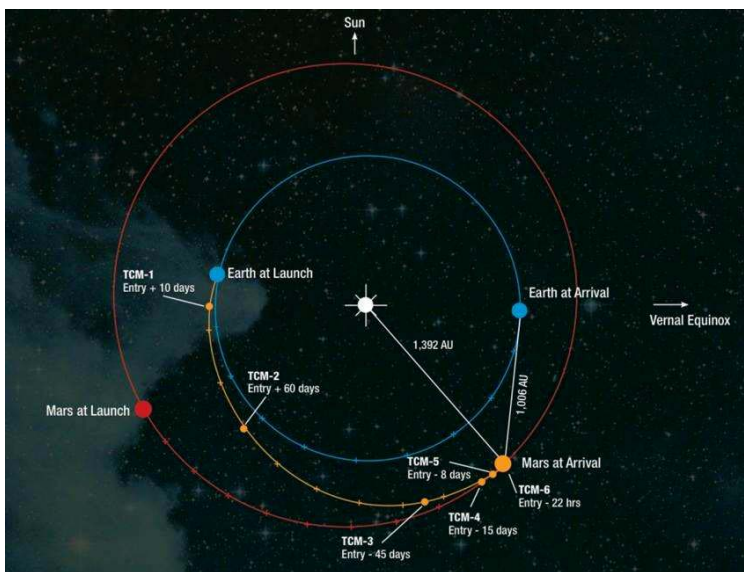
Orbit followed by the InSight probe between Earth and Mars (© NASA)

2. Age of students 15-17 years

3. Objectives

The objective is to determine the next launch window to Mars from the relative position of Earth and Mars that corresponds to the optimal trajectory of the spacecraft in terms of energy consumption and using planetary position data and the concept of advanced algebra.

4. Primary subjects

Mathematics - Physics – Earth and Space Science

5. Additional subjects

6. Time required

30 min – 1 hour

7. Key terms.

Orbits, Earth, Mars, space missions, launch windows, graph

8. Materials

Calculator, push-pins, graph paper, quadrille ruled, planetary heliocentric longitudes data sheet

9. Background

To get a spacecraft from Earth to any planet, you need to consider the curved travel path resulted as a combination of spacecraft velocity and planet gravitational pull. To get the most from this scenario scientists need to "work" with these forces and travel as much as possible with engines off, so lowering the cost of the mission.

As in many similar scenarios (e.g: passing a ball to a running football teammate) what essentially need to be considered is the initial impulse given to the spacecraft (the launch equivalent to the ball throw) the position of the targeted planet in any moment (described by its orbit) and then the gravitational pull.

Even if the spacecraft could take a variety of curved paths from the launching point to the landing planet, one is considered to be the most efficient in terms of energy consumption -   Hohmann transfer orbit.

In the case of Earth to Mars travel path, the Hohmann transfer is an elliptical orbit with the sun at one focus of the ellipse that intersects the orbit of the target planet. Launch occurs when Earth is at Hohmann perihelion (the point of the Hohmann orbit that is closest to the sun). Arrival occurs when Mars is at Hohmann aphelion (the point of the Hohmann orbit that is farthest from the sun).

This is a simple explanation for a far more complex scenario where scientists need to take into account a variety of parameters that are more or less constant. What need to be clearly understood is that a specific launching time window have to be calculated and validated through multiple simulation way before the launching. This will allow a proper launch window, so the spacecraft will arrive in the planet's orbit just as the planet arrive at the same place.

<center>A   B</center>
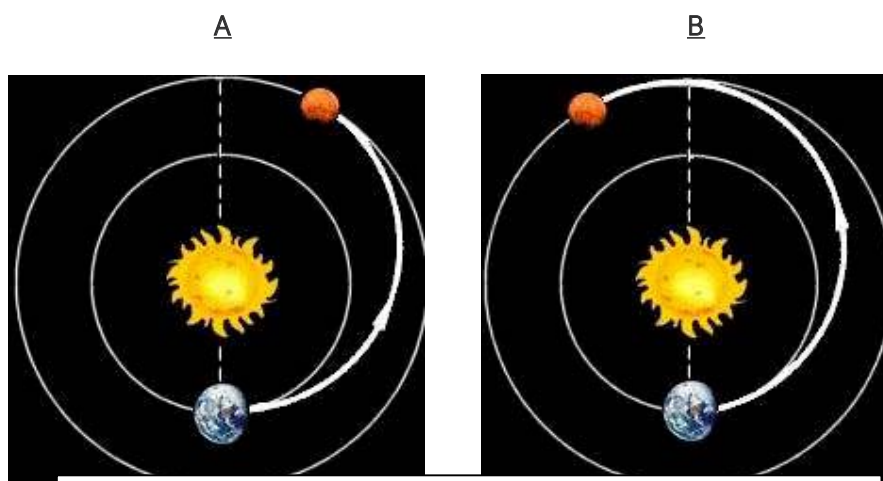
In A, the respective positions of Mars and Earth at the time of launch. In B, the respective positions of Mars and Earth during landing (Crédit photo : © Philippe Labrot).

10. Procedures

Students will be explained that a space station must have an elliptical trajectory around the sun to reach the same point at the same time as the planet Mars. What they should do next is to figure out what the launch time should be so that this intersection will take place.

Students will be explained that the most efficient orbit from the point of view of energy consumption needed for the trip must be calculated, called the Hohmann transfer, in which the spacecraft will travel half of one orbit about the sun, leaving Earth at the orbit's perihelion and arriving at Mars (or any outer planet) at the orbit's aphelion.

Bring into discussion the Kepler's Second Law also tells us that planets travel at different rates of speed in their elliptical orbits, moving faster when they are closer to the sun and slower when they are farther from the sun.

To make possible the complex mathematical task of launching a spacecraft while considering he orbital dynamics of the planets, mention to students three assumptions, actually some unrealistic simplifications but that will allow us a sufficiently accurate calculation of the launch window

The orbits of Earth and Mars are circular and centered on the sun. (Earth's orbit is more circular than Mars' orbit, but they are both slightly elliptical.)

Earth and Mars travel at constant speeds. (They do not. See Kepler's Second Law).

The orbits of Earth and Mars are in the same plane. (They are close but slightly out of plane with one another).

Explain to students the concept of heliocentric longitude. Just as longitudes on Earth measure position with respect to a fixed point (the prime meridian), heliocentric longitudes measure position in space along the ecliptic with respect to the vernal equinox.

Knowing that Earth is, on average, 1 astronomical unit (AU) from the sun and Mars is, on average, 1.52 AUs from the sun have students find the length of the semi-major axis of the transfer orbit in astronomical units (AU).

Using the string and pushpins have students draw the assumed-circular orbits of Earth and Mars about the sun, and the approximation of the Hohmann transfer orbit on graph paper

Determine the period of the Hohmann transfer orbit and then the travel time to Mars along this orbit using Kepler's Third Law (Law of Harmony)

Kepler's Third Law states that the square of the period of any planet is proportional to the cube of the semi-major axis of its orbit. An equation can represent this relationship:

$P^2 = ka^3$ with k being the constant of proportionality

Using Earth as an example, we can measure P in years and a in astronomical units so P = 1 year and a = 1 AU. Thus, $P^2 = ka^3 \rightarrow k=1 => P^2 = a^3$

$P^2 = (1.26\ AU)^3 => P \sim 1.41$ years ~ 517 days

The full period of this Hohmann transfer orbit is 517 days. Travel to Mars encompasses half of one orbit, so approximately 259 days.

Considering the daily motions of Earth and Mars, compute the ideal relative position of both planets during the launch.

1 Mars revolution = 687 days => 0.524 degrees/day => 136 degree/259 days

To calculate the position of Mars at the time of launch, subtract the amount of its motion during the spacecraft's travel time (136 degrees) from its point of arrival (180 degrees). 180 degrees – 136 degrees = 44 degrees.

Using the planetary heliocentric longitudes, approximately when is the next opportunity for a launch to Mars?

11. Discussion of the results and conclusions

What happens if the estimation of the launching window is shorter or longer that it should be? Can we estimate an average length?

Do you know how these launching windows have been calculated in the early times of space missions?

12. Follow up activities

Make a short phyton script that will subtract heliocentric longitudes for Earth and Mars to simplify launch window calculations.

13. Explore More (additional resources for teachers)

Stomp Rockets Activity

https://www.jpl.nasa.gov/edu/teach/activity/stomp-rockets/

When Computers Were Human https://www.jpl.nasa.gov/edu/news/2016/10/31/when-computers-were-human/

Mars in a Minute Video Series https://www.jpl.nasa.gov/edu/teach/activity/mars-in-a-minute/

Acknowledge This activity was inspired from the JPL Education Program

Annex 24

Solar energy, a sustainable source of energy

1. Introduction & Pb

NASA uses several different technologies for providing energy for space exploration. Each technology meets the requirements for different types of exploration. For space exploration close to the Sun (near the inner planets—Mercury, Venus, Earth, and Mars), solar power with battery backup is often an optimal option. This problem-based learning PBL will explore the use of solar panels as a power source. In the process, students will learn core classroom concepts related to energy, energy transformation, electricity, and circuits.

Solar cell technology is improving rapidly. The solar cells used on the ISS are about 12 percent efficient. Those developed for the Mars Rovers are about 26 percent efficient. Current solar cells have higher efficiency. The students will have to do some research to determine the efficiency. When NASA engineers plan a mission, they have to know all the specifications for all of the components, and the components have to be space tested. Sizes, electrical characteristics, masses, and connections must be known at the beginning of the planning. Since a mission might take 10 years to plan and construct, equipment might be 10 or more years "outdated." Your students will have to work with the same restrictions. They will be required to use solar cells that are currently available. They will have to research current technology.

NASA's InSight lander, which touched down on Mars Nov. 26 and successfully extended its large solar arrays hours later, is already setting records. During its full first day on the Red Planet, the solar-powered lander generated more electrical power in one day than any previous Mars vehicle has, mission team members said. "It is great to get our first 'off-world record' on our very first full day on Mars," Tom Hoffman, InSight project manager at NASA's Jet Propulsion Laboratory (JPL) in California, said in a statement. "But even better than the achievement of generating more electricity than any mission before us is what it represents for performing our upcoming engineering tasks," Hoffman added. "The 4,588 watt-hours we produced during sol 1 means we currently have more than enough juice to perform these tasks and move forward with our science mission." The 4,588 watt-hours InSight generated on its first sol, or Martian day, from solar power is well over the 2,806 watt-hours generated in a day by NASA's Curiosity rover, which runs on a nuclear system called a radioisotope thermoelectric generator. Coming in third was the solar-powered Phoenix lander, which generated around 1,800 watt-hours in a day, according to NASA officials.

2. Age of students

15-17 years

3. Objectives

1. Given solar cells or panels, students list variables that affect the operation of solar panels and explain how these variables affect the power production of solar panels.

2. Through computer simulations or laboratory investigations with electricity, students create parallel and series circuits, calculate power, and apply this knowledge to solve a theoretical problem.

3. By analyzing the power requirements of their own homes, students design a solar system that could supply the power to their home.

4. Using their own models, students propose and defend a design to provide power for a Martian research habitat for six explorers.

4. Primary subjects

Mathematics - Physics – Earth and Space Science

5. Additional subjects

Computer Science

6. Time required

1 hour – 2 hours

7. Key terms

Solar panels, Solar energy, Earth, Mars, space missions

8. Materials

Solar panel. Solar charger (optional). Voltmeter. Calculator. Red, Green, and Blue transparency film. Electrical wire to connect solar cell and the electric devices.   Notebooks and pencils. 12v bulb and battery (optional).

9. Background

A number of variables affect solar cell operation. Students will brainstorm, predict, and test variables in **Activity 1: Investigating Solar Cells.** The critical variables that affect solar cell performance—other than the efficiency of the cell itself—affect the intensity of light on the solar cell.

There are several factors that affect intensity:

Blocking - Natural conditions can block solar radiation from reaching the solar cells. Earth's atmosphere can partially block incoming solar radiation. The amount of light reaching Earth above the atmosphere is about 1366 Watts per square meter. When the Sun is directly overhead at the Equator, the intensity of solar radiation reaching Earth's surface is between 800 and 1,000 Watts per square meter. On the Moon and on Mars, solar panels can be blocked by dust. It was expected that the solar panels on the NASA Mars Rovers would become covered with dust and cease to provide energy for the systems. A chance dust devil swept the panels clean. Dust devils occur frequently enough on Mars that Rover panels are kept relatively clean.

Angle - The angle between the Sun and the solar panel is critical. The intensity of light is measured in Watts (power) per square meter. You can experimentally quantify how the angle changes the intensity. Hold a flashlight directly above a sheet of graph paper. The light source is at 90° to the paper. Count the number of squares illuminated. Keep the flashlight at the same distance from the paper, but tilt the flashlight so that it is at an angle to the paper. This represents a lower Sun angle. Count the squares illuminated again. More squares will be illuminated at the lower angle. The power of the light stays the same, but the area lit increases as the angle gets lower. When the same amount of power is spread over a larger area, the intensity decreases. The 23.5° tilt of the Earth's axis determines the angle of sunlight. The Sun is overhead in June in the Northern Hemisphere at the Tropic of Cancer at 23.5° N. latitude. The Sun is overhead in January in the Southern Hemisphere at the Tropic of Capricorn at 23.5° S. The GEMS (Great Explorations in Math and Science) Guide, The Real Reasons for the Seasons, could be used during this lesson to help students understand how the tilt of the Earth's axis affects the light intensity and the seasons. The axis of Mars is tilted at 25°, so very similar conditions prevail on Mars except the year is longer and each season is longer than Earth's. During the winter on Mars, the Rovers are parked on the slope of a hill to point the solar panels more directly at the Sun. As the International Space Station orbits Earth, the solar panels can be rotated to point more directly at the Sun. At times, the entire space station is pointed in a different direction to improve the angle between the panels and the Sun. For more information see:

What are ISS Attitudes? http://spaceflight.nasa.gov/station/flash/iss_attitude.html.

Distance from the Sun - As you know, the further you are from a light source, the dimmer (less intense) the light is. Students can confirm this experimentally and discover that the intensity (I) of light is inversely proportional to the square of the distance (r) from the light source ($I \propto 1/r^2$). You will need a light bulb, a meter tape measure, and a light intensity probe. In a dark room, measure the intensity of light at 10 cm, 20 cm, 40 cm, and 80 cm from the light. Plot Intensity versus distance. If you plot this curve on a graphing calculator, you can also obtain the equation for the curve. The intensity decreases because the light spreads out farther away from the source. The Sun emits light energy in all directions. The light of the Sun is spread out over the surface of an imaginary (hollow) sphere with its center at the Sun. The farther the sphere is from the Sun, the bigger the sphere is and the more surface it has (surface area of a sphere = $4\pi r^2$). So, the power (energy per second) emitted by the Sun as light spreads over the surface of this imaginary sphere. Close to the Sun, the sphere is small. There is a lot of power per square meter (Intensity). Farther away, the sphere is big. There is less power per square meter. There is an equation that lets us calculate the intensity of light at a distance from a light source.

The equation is: **Intensity = Power/(4πr2)** But how can you measure the power of the Sun at its source? You can't. However, scientists have measured the intensity of light at Earth and we know the distance from the Sun to Earth. The intensity of sunlight outside the Earth's atmosphere is 1366 Watts/m2 (It varies slightly with solar output). The distance (r) from the Sun to Earth is 150,000,000 km (kilometers). If you substitute these values into the equation above and solve for Power, the value for the power of light from the Sun is 384.6 x 1024 Watts (Joules/second). Now we can use this value for Power in the equation above and calculate the intensity of light at Mars. The average distance from the Sun to Mars is 227,900,000 km. You can calculate that the intensity of light at Mars is 589.2 W/m2. That is less than half of the intensity at Earth!

 But wait! The orbit of Mars is less circular than Earth's orbit. It is more elliptical.   At perihelion (closest to the Sun), Mars is 206,600,000 km away from the Sun, and the intensity is calculated to be 717.1 W/m2. At aphelion (farthest from the Sun), Mars is 249,200,000 km away from the Sun, and the intensity drops to 492.9 W/m2.

 These differences could be significant to the design of a solar energy system.

 You will have to judge whether your students will be able to understand the math involved.

Crédit : Lockheed Martin

NASA/JPL-Caltech/Lockheed Martin

Activity 2: Solar Panels on Earth.

SOLAR ELECTRICITY Solar energy can also be used to produce electricity. Two ways to make electricity from solar energy are photovoltaics and solar thermal systems. The word photovoltaic comes from the words photo meaning light and volt, a measurement of electricity. Photovoltaic cells are also called PV cells or solar cells for short. You are probably familiar with photovoltaic cells. Solar-powered toys, calculators, and roadside telephone call boxes all use solar cells to convert sunlight into electricity. Solar cells are made of two thin pieces of silicon, the substance that makes up sand and the second most common substance on earth. One piece of silicon has a small amount of boron added to it, which gives it a tendency to attract electrons. It is called the p-layer because of its positive tendency. The other piece of silicon has a small amount of phosphorous added to it, giving it an excess of free electrons. This is called the n-layer because it has a tendency to give up electrons, a negative tendency. When the two pieces of silicon are placed together, some electrons from the n-layer flow to the p-layer and an electric field forms between the layers. The p-layer now has a negative charge and the n-layer has a positive charge. When the PV cell is placed in the sun, the radiant energy energizes the free electrons. If a circuit is made connecting the layers, electrons flow from the n-layer through the wire to the p-layer. The PV cell is producing electricity--the flow of electrons. If a load such as a lightbulb is placed along the wire, the electricity will do work as it flows. The conversion of sunlight into electricity takes place silently and instantly. There are no mechanical parts to wear out. Compared to other ways of producing electricity, PV systems are expensive. It costs 10-20 cents a kilowatt-hour to produce electricity from solar cells. On average, people pay about eight cents a kilowatt-hour for electricity from a power company using fuels like coal, uranium or hydropower. Today, PV systems are mainly used to generate electricity in areas that are a long way from electric power lines.

Global horizontal irradiation — Europe

Average annual sum (4/2004 - 3/2010)

< 700   900   1100   1300   1500   1700   1900 >   kWh/m²

© 2011 GeoModel Solar s.r.o.

10. Procedures

Activity 1: Investigating Solar Cells.

Questions (students will answer these questions after doing the investigation)

1. What happened when you covered part of the solar cell with black paper? Why?

....
....
....

2. What is the relationship between the amount of solar cell that is covered and the functioning of the powered electrical devices? Explain.

....
....
....

3. How did the colored transparencies affect the solar cells ability to function?

....
....
....

4. What happens when you connect in series multiple solar panels compared with the initial specifications of one solar panel? What about connecting them in parallel?

....
....
....

Activity 2: Solar Panels on Earth.

➢ On the map find your location and determine what color your area corresponds to. Use the Legend to find out the energy range in "kWh/m^2/Day" from the "average annual sum kWh/m^2". Once you have the range, you will average the highest and lowest values on the range to get your energy estimate. For example, in France, the range is 2.7 – 4.4 kWh/m^2/Day, the average value is 3.55 kWh/m2/Day.

Energy range for your location:_____ _____ kWh/m^2/Day

Average energy:_____ kWh/m^2/Day

➢ Next, find the amount of solar energy available per unit area of your solar module (for example, a solar water heater), which depends on the time you expose your module to the sun. If you want to test your solar water heater for 1 hour, your duration of sun exposure is '1 hour' (this can be less than one if you test for less than an hour → 45 minutes = 0.75 hours). If you do not already have these values for a solar module, just use the following example values.

Duration of sun exposure:_____ hours   (example: 1 hour)

Now you will need to find the energy in units of Watt-hours/m^2, referred to as '**insolation**':

(kWh/m^2/day) x (1 day/24 hours) x (duration of sun exposure [hours]) x (1000 Wh/1 kWh) =

(__ kWh/m^2/day) x (1 day/24 hours) x (__ hours) x (1000 Wh/1 kWh) =

_____ Watt-hours/m^2

➢ To find the solar energy used by your solar module you will also need its surface area (m^2). Say you have a solar water heater that is 1 meter by 1.5 meters, the surface area would be 1.5 m^2 (you may need to convert feet to meters).

   Solar module surface area:_____ m^2 (example: 1.5 m^2)
Next, you need to use your surface area and **insolation** value to find out how much energy enters your solar module. This incoming energy is called **heat energy (Q_{in})** and is in units of Watt-hours:

   Q_{in} = [Insolation (Watt-hours/m^2)] x [Surface Area (m^2)]

   Q_{in} = (_____ Watt-hours/m^2) x (_____m^2)

   Q_{in} = _____ Watt-hours

➢ What would be the '**tilt angle**' of your solar module? Why do you want your solar module to face south?

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....
....

➢ How do you think the amount of solar energy available in Arizona for the same month would compare to the value for your location? (Hint: check out the maps, you don't need to calculate anything https://www.nrel.gov/gis/images/solar/solar_ghi_2018_usa_scale_01.jpg) What about the solar energy available in Alaska?   In which location (Arizona or Alaska) would it be easier for engineers to use the solar energy available for heating or electricity?

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11. Discussion of the results and conclusions

How does dust affect solar panels on Mars?

How are the scientists dealing with this challenge?

What really happened on Mars with the Insight Lander's solar panels?

What can and can't be done for future space missions in this matter?

12. Follow up activities

Challenge: Solar Energy for Moon and Mars. Working in small groups, students will choose either the Moon or Mars as the location for a NASA research habitat. Each group will estimate the requirements for the research habitat using what is known about home power requirements and the power requirements for the ISS. Then, each group will propose a design for a solar energy system to meet the energy requirements. This activity could be used as an assessment.

13. Explore More (additional resources for teachers)

Solar Maps

These solar maps provide average daily total solar resource information on grid cells.

https://www.nrel.gov/gis/solar.html

https://earsc-portal.eu/pages/viewpage.action?pageId=16548947

TeachEngineering is a digital library comprised of standards-based engineering curricula for K-12 educators to make applied science and math come alive through engineering design.

https://www.teachengineering.org/

https://www.nasa.gov/

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Project Partners