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EE 106 – Planetary Exploration

Problem Set V
Earth as a Planet
Cratered Worlds
Earth-Like Planets

Problem 7.7 – The Risk of Earthquake

Fault zones and subduction zones present two of the worst places to live if we wanted to avoid destructive earthquakes. In a subduction zone, the forceful submergence and subsequent melting of one plate can lead to violent earthquakes such as the 1923 Yokohama earthquake; meanwhile, along fault zones, where two plates slide and grind together, sudden releases after lengthy stagnation could lead to destructive earthquakes as well, especially when the forces accumulate over time.

Meanwhile, locations where the plates diverge rather than converge see much less violent activity. For example, volcanic regions are much safer residential areas, although earthquakes still occur due to magma flow, often in prelude to volcanic eruptions. The rise of magma in mid-ocean ridges, where tectonic plates move *apart from* rather than *against* each other, enables earthquakes as well during submarine volcanic eruptions, although their frequency and violence are unlikely to match fault zone and subduction zone earthquakes because the plates do not exert much force on one another. Similarly, volcanic islands such as Hawaii see constant volcanic activity, but most of the danger comes from lava flow rather than tremors accompanying eruption. Thus, Hawaii is a relatively safe locale.

On the other hand, the centers of tectonic plates represent the safest locations since most violent activity occurs at plate boundaries or edges, where friction and fragmentation precipitate the most destructive quakes. Thus, if we wanted to minimize the chances of a destructive earthquake, then choosing to live at the center of a tectonic plate would probably guarantee the fewest such events.

Problem 7.10 – Greenhouse Gases

We are concerned about increases in the amount of carbon dioxide (CO_2) and other greenhouse gases in the Earth's atmosphere because accumulation of these opaque gases will impede Earth's reradiation of light; by absorbing light of wavelengths at which Earth re-emits energy, the layer of gases in the atmosphere effectively traps this emitted energy close to Earth, leading to an increase in the equilibrium temperature across Earth's surface. Unable to escape Earth's atmosphere, this energy not only heats the surface but also precipitates other forms of positive feedback, such as gassing swamps that originally contributed little CO_2, melting ice caps that helped reflect incident sunlight, warming tundras and melting permafrost (both carbon sinks), stressing CO_2-absorptive trees and increasing the risk of forest fires, evaporating ocean water currently housing plankton and carbonate sediments, effectively adding to atmospheric greenhouse gas content. As seen on Venus, small perturbations in mean equilibrium surface temperature could pave the way for more drastic, irreversible alterations – potentially runaway effects.

To reduce the levels of carbon dioxide in our atmosphere, (1.) we could proliferate and preserve forestation to maximize production of oxygen and respiration of CO_2. (2.) Furthermore, our industry could scale back its use of fossil fuels since their burning ejects a lot of carbon dioxide into the atmosphere, and resort instead to solar, wind-powered, and/or nuclear energy sources; (3.) meanwhile, consumers of fuel-demanding products such as large cars and vans could carpool or consider biking or walking to work, reducing the amount of exhaust. (4.) More fuel-efficient alternatives such as electric cars have also tried to reduce the amount of fossil fuel consumption, but their popularity has waned; perhaps choosing vehicles that consume less gasoline would fuel the drive for more efficient standards, and the government could help the cause by taxing intensive gasoline usage. (5.) Domestically, families could curtail the amount of electricity use by shutting off appliances when not in use as opposed to leaving them on standyby, henceforth reducing the total power consumption. (6.) Levying electricity quotas on households might also encourage energy efficiency. (7.) Means also exist to capture and extract carbon dioxide from the atmosphere and return it into geological storage mechanisms under the ocean, so erecting more of these stations would expedite the quest for reduced CO_2 levels. At this point, trying to reduce carbon dioxide might be too difficult, but scaling its rapid increase would require only a change of lifestyle and economy.

Unfortunately, several obstacles impede such progress. For example, international disregard for quota-setting protocols (such as the Kyoto Protocol) make regulation of greenhouse gas production extremely difficult, especially when different countries are restricted inhomogeneously, inciting debate. Also, because so much of modern industry depends on power derived from fossil fuels, altering the mode of production at the sacrifice of profit seems an unfavorable exchange for money-hungry businesses that care little about the future of humankind – no monetary penalty currently exists to discourage cold-hearted companies from exploiting coal as the primary means for energy. Likewise, consumer lifestyle has grown so accustomed to driving these fuel-intensive cars in large burgeoning cities that any alternative seems restrictive and inconvenient, especially without individual incentive, common cooperation, or penalty; it is hard to respect a rule when so many others blatantly disregard it in an era of every-man-for-himself capitalistic competition. Finally, with little political support and few mandatory regulations or quotas for worldwide greenhouse gas prevention, and with so many belligerents still defending global warming's harmlessness, science has not been cogent enough to sway the masses and establish lasting rules; government officials have thus far seem concerned with too many other political issues to focus on the threat of rising greenhouse gas emission.

Problem 8.11 – The Impact Origin of Lunar Craters

Geologists failed to acknowledge the impact origin of lunar craters because such impact craters appear so rarely on Earth, with most of Earth's craters generated volcanically. Applying their knowledge of Earth to the moon, geologists simply concluded that, because most of Earth's craters appeared to be volcanic in origin, lunar craters must have originated similarly, mostly with volcanic rather than impact processes. Impact craters seemed too rare on Earth to appear with much frequency on the Moon, which many still link closely to the Earth in origin.

Problem 8.12 – The Impact Craters of Comets and Asteroids

The impact craters formed from comets and asteroids will depend primarily on the size, mass, and impact speed of the body. Larger, heavier, and faster asteroids and comets will carve out wider, deeper craters than their smaller, lighter, and slower counterparts. However, assuming that the size and speed of the asteroid and comet remain similar on average, the main visible difference between the two impacting bodies lies in the difference between the definitions – an asteroid comprises mainly solid rock or metal, whereas a comet, by definition, comprises frozen liquids and gases. Thus, the materials inside and the ejecta surrounding craters formed by asteroids likely comprise mainly rock fragments and metal shards, whereas comet impact craters likely exhibit more ice and frozen volatiles, either in the form of scattered remains, embedded pieces, or large quantities vaporized in the nearby atmosphere.

Because of the ease with which the contents of a comet vaporize in the inner solar system (due to the proximity of the Sun), we might also expect somewhat less remnant material in the crater formed by a comet than a crater formed by an asteroid, although both impact craters will still feature many pieces of the projectile. It is the chemical composition of these fragments that differentiates the two types of impact craters.

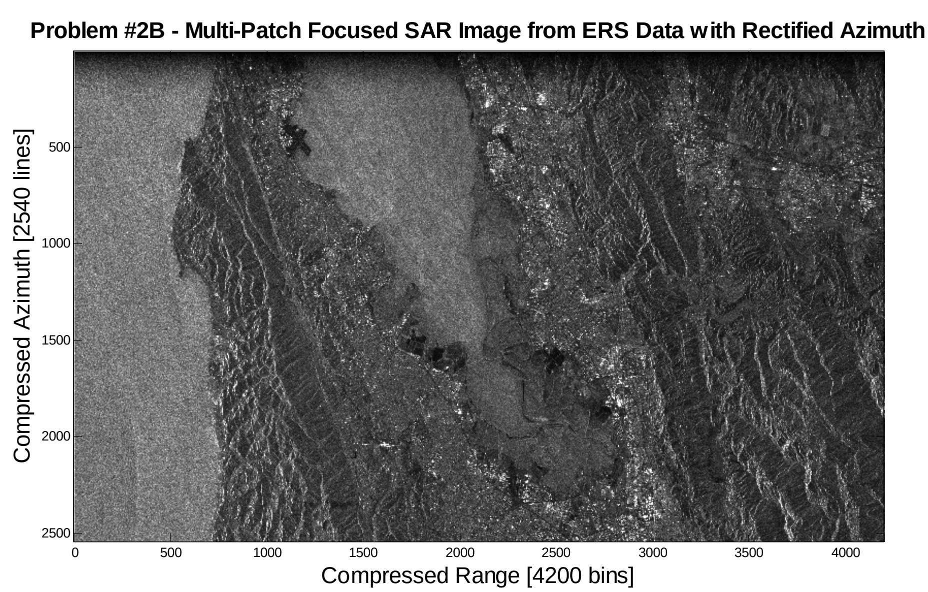
Problem 8.14 – The Lunar Highlands

The lunar highlands contain approximately ten times more craters on a given area than do the lunar maria. However, the tenfold proportion of crater count on the highlands does not guarantee tenfold proportion of age, because the rate at which these craters formed could have differed over time; for example, radioactive dating of highland matter reveals that the highland craters are approximately 4.2 billion years old, whereas the lunar maria are only 3.8 billion years old. The lunar highlands are not ten times older because impacts on the Moon likely occurred much more frequently prior to the formation of the maria, and that increased frequency led to the dramatic difference in crater count. When counting craters, we must be careful not to assume that bombardment remains uniform throughout all time.

Problem 9.9 – Radar Imaging

Radar imaging dwarves optical imaging of the Venusian surface because Venus' thick atmosphere is opaque to optical wavelengths; such wavelengths of light are too short to penetrate the atmosphere and return, as the obscuring layer absorbs most of these wavelengths. Thus, unless the camera operates from the surface of Venus, optical wavelengths can inform only the atmosphere, and nothing about the surface topography; because most of the devices dropped through the atmosphere to the surface of Venus die quick deaths due to the dry conditions on the Venusian surface, a global mapping of Venus is unfeasible with optical wavelengths alone. Meanwhile, radar imaging, at much longer wavelengths, provides a way to penetrate Venus' atmosphere and collect information from surface incidence; furthermore, using the signal processing techniques inherent in synthetic aperture radar, we can improve radar resolution beyond even optical limits.

The atmospheric advantage no longer applies when studying Earth or Mars, because optical wavelengths can penetrate the terrestrial and Martian atmospheres; for Earth in particular, we can even healthily image the surface from within the atmosphere, without any need for an outer space probe. However, the resolution improvement in synthetic aperture radar still holds, regardless of the presence of a thick, opaque atmosphere. For example, we can obtain very fine detail through signal processing:



In fact, we can perform range compression and azimuth beam focusing on any planet; all we need is remote connection to a powerful machine (try `bramble.stanford.edu` or `cardinal-best`), some caring help from the most awesome teaching assistant ever, and a bevy of EE 355 knowledge (Curlander is recommended, but not required). ☺

Furthermore, with its own light source, radar imaging allows operation during both daytime and nighttime, without any dependence on incident sunlight. Thus, radar approaches to mapping Earth or Mars are still advantageous in many ways, albeit not because of atmosphere.

Problem 9.11 – Atmospheric Carbon Dioxide

The Venusian atmosphere contains much more carbon dioxide than the terrestrial atmosphere because Venus has no oceans and no surface water available to hold sedimentary carbonate rocks and plankton, both of which contain much of Earth's carbon dioxide content; furthermore, Venus' surface also boasts no plant life capable of absorbing carbon dioxide, so the gas runs rampant without any use or storage on the extremely dry surface, whereas terrestrial forests and oceans sink much of Earth's carbon dioxide, preventing the gas from dominating the atmosphere.

Mars, on the other hand, has much less atmospheric carbon dioxide (and much less atmosphere in general) because its weaker gravitational field more readily permits escape of gases, leading to lowered surface temperatures and frequent condensation of carbon dioxide into solid form, as seasonal dry ice caps as well as permanent residual caps. Much of the gaseous carbon dioxide that would reside in the atmosphere under Venusian conditions are instead sustained as clouds of dry ice crystals or deposited as solid surface caps under Martian conditions. Thus, Venus' domination in atmospheric carbon dioxide stems primarily from its dry conditions and lack of surface storage mechanisms; Earth boasts flora and ocean carbonate sediments, while Mars' surface temperature has grown low enough to permit the formation of stable dry ice caps.