GEOS 32060 – Winter 2020 – Homework 3

Due 5pm Thursday 13 February (in Kite mailbox on the 1st floor of the Hinds building, or by email to kite@uchicago.edu). No credit will be given for answers without working. It is OK to use e.g. Mathematica, but if you do, please print out the work.

Q1. Alternative fates of Venus.

a) The escape velocity from Venus is ~10^4 m/s, but in hydrodynamic escape models, both bulk and thermal velocities are <<10^4 m/s out to very large distances from the planet (example below). Explain qualitatively how gas might escape from the planet without ever reaching escape velocity.

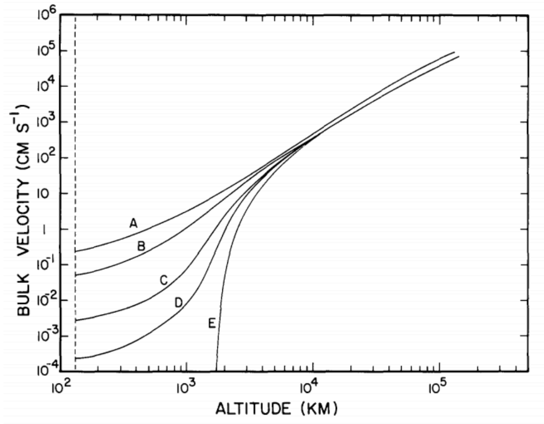


FIG. 6. Bulk velocities for the numerical solutions.

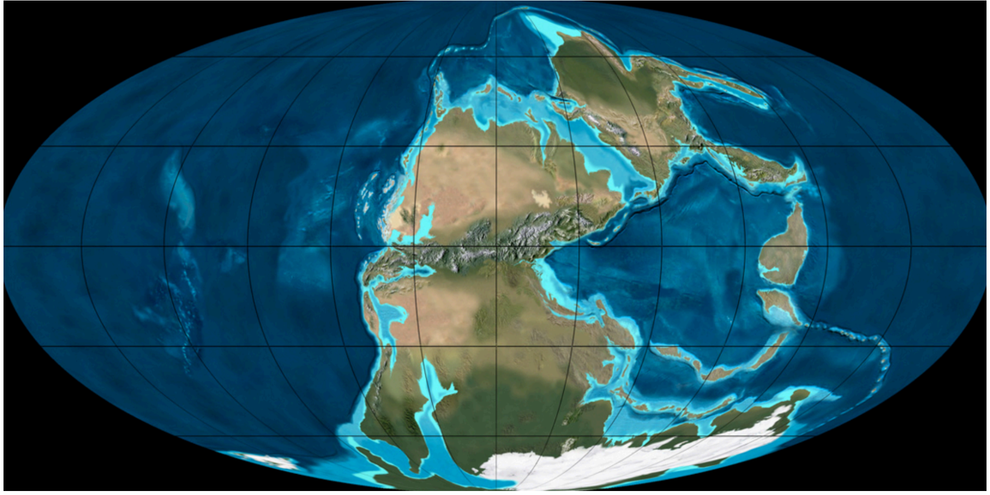
from Watson et al. Icarus 1981

b) We have seen that the basic equations for hydrodynamic escape have supersonic and sub-sonic solutions. Suppose that Venus was embedded in a gaseous nebula (e.g. during solar system formation). Explain, with reference to the basic equations for hydrodynamic escape as discussed in lecture, how this would affect the physical validity of the supersonic and/or sub-sonic solutions.

c) In the case of Venus, a runaway greenhouse is believed to have been followed by loss of almost all water from the planet. State and explain two circumstances under which a long-lived runaway greenhouse might *not* cause loss of much water from the planet.

Q2. Effect of Supercontinent Formation. Mountains are important to the global weathering budget. This is because mountain uplift increases the amount of material available for weathering per year (the sediment mass flux). Because the total planet-integrated weathering must be constant (averaged over >10^7 yr timescales) in order to avoid a climate runaway, the increase in material available for weathering must be compensated by a decrease in the amount of weathering per unit sediment. The easiest way to decrease the amount of weathering per unit sediment is to lower the planet temperature. (The lowering of temperature is accommodated by a transient pulse of increased weathering. This transient increase in weathering lowers the CO_2 concentration, which lowers temperature. The planet is now less efficient at weathering each sediment parcel, and so the climate re-equilibrates at a new, lower temperature).

The purpose of this question is to work through the order-of-magnitude effect on planetary climate of forming new mountain belts.



Earth 280 Ma. Credit: Ron Blakey (NAU).

The most recent global supercontinent, Pangea, was completed ~280 Ma by collision of North America with Africa. The collision (the Alleghenian orogeny) created a mountain chain, the Central Pangean Mountains. The Appalachian Mountains approximately correspond to a remnant of this mountain belt. In this question, use the paleogeographic reconstruction above (grid spacing 30 degrees) and Earth radius = 6×10^6 m.

Assume weathering efficiency (cations/yr/km^3 of sediment flux) scales as

$$\varpi \propto e^{-E/RT}$$

where E is activation energy and R is the gas constant, 8.314 J/mol/K, and surface temperature T is in K. Assume an effective activation energy for weathering ("effective" including the effect of temperature on rainfall) of E = 74 kJ/mol (West et al., Earth & Planetary Science Letters, 2005).

(a) Suppose paleomagnetic data[1] indicate Africa travelled N at 5 cm/yr and collided with a stationary North America. Assume continental crust is 35 km thick. Because continents are buoyant relative to the mantle, neither continent subducts. At steady state, continental crust is moving up to the surface at mountain belts, undergoing weathering and erosion, and the mass is being redistributed away from the mountain-belt, all at equal rates. What is the mass

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[1] Paleomagnetic data provide great constraints on latitudinal drift rates, but constraining paleo-longitudinal drift requires less direct methods such as matching up geologic provinces on either side of a rift zone, or looking for evidence of hotspot volcanism (hotspots are underlain by mantle plumes, which move slowly relative to plates and so define a "hotspot reference frame").

flux? Suppose the pre-collision eroded flux was equal to Earth's modern sediment flux of 8 km^3/yr; what is the fractional change in eroded flux (i.e., mass/volume available for weathering)?

(b) Assume an activation energy for the temperature effect on weathering of 74 kJ/mol (West et al., Earth & Planetary Science Letters 2005). What is the sign and magnitude of planetary temperature change?

(c) Suppose that the ice sheet in the S Hemisphere grows. Is this a positive or negative feedback on the change you calculated in part (b)? Why?

(d) It is often said of warming climates that "wet areas get wetter, dry areas get drier." [2] Given that weathering rate depends on both temperature and rainfall, explain qualitatively how changes in rainfall on the Central Pangean Mountains due to the warming you calculated in part (b) would feed back on (and thus modify) your answer to part (b).

(e) Suppose that collision had occurred in the desert belt at 25° N instead of at the humid equator. Explain how you answer to part (d) would differ.

The formation of the Himalayas and Tibet is one leading hypothesis for the cooling of Earth that led to the onset of ice sheets on Antarctica ~35 Myr ago.

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[2] This is not always exactly true. For example, an expanding Hadley cell under warming (the Hadley cells are currently expanding due to anthropogenic global warming) can turn the low-latitude edge of the desert belt into a wet zone.