

USES0 2023

Open Exam



Section II

Instructions:

- Section II consists of 4 multipart questions that further assess geoscience knowledge in the form of free-response and multiple choice questions.
- A non-graphing, non-programmable calculator is allowed. Show all work for calculations.
- Any space on the page may be used for scratch paper, but only work on your answer sheet will be graded.
- Write your full name on every page of the answer sheet.

Problem 1

| Question | 1 | 2 | 3 | 4 | 5 | 6 | Total |
|----------|---|---|---|---|---|---|----------|
| Points | 4 | 2 | 2 | 2 | 2 | 3 | 15 (25%) |

On February 6, 2023, two major earthquakes shook eastern Turkey and Syria, killing tens of thousands and causing massive structural damage. These earthquakes took place at two different sites surrounding the city of Kahramanmaraş. Below is a diagram displaying the direction and magnitude of movement at each section of the fault during the main earthquake.

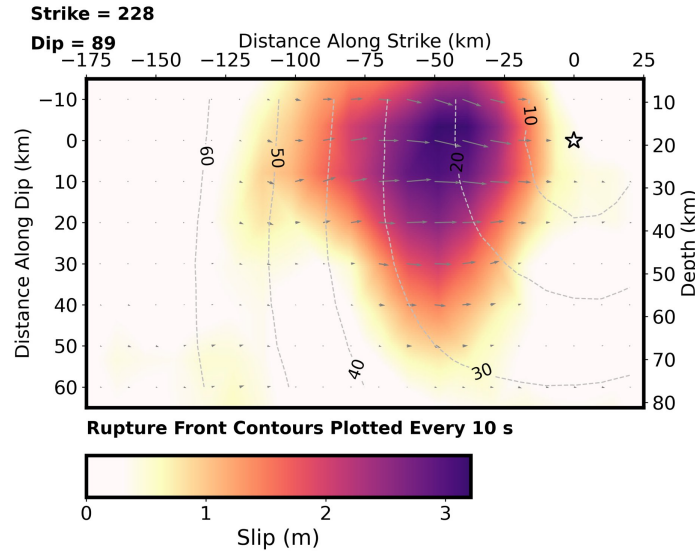


Figure 1: values for strike and dip of the fault are in the top left corner.

1. (a) (2 points) What does a dip of 89 indicate about the fault?
 - A. The fault runs almost perfectly north-south
 - B. The fault runs almost perfectly west-east
 - C. The fault plane is nearly horizontal
 - D. The fault plane is nearly vertical

- (b) (2 points) The fault strike is 228 as measured clockwise from north. If the fault is left-lateral, in what cardinal (e.g. north, west) or ordinal (e.g. northwest, southeast) direction is the region *north* of the fault moving? Briefly justify your answer.

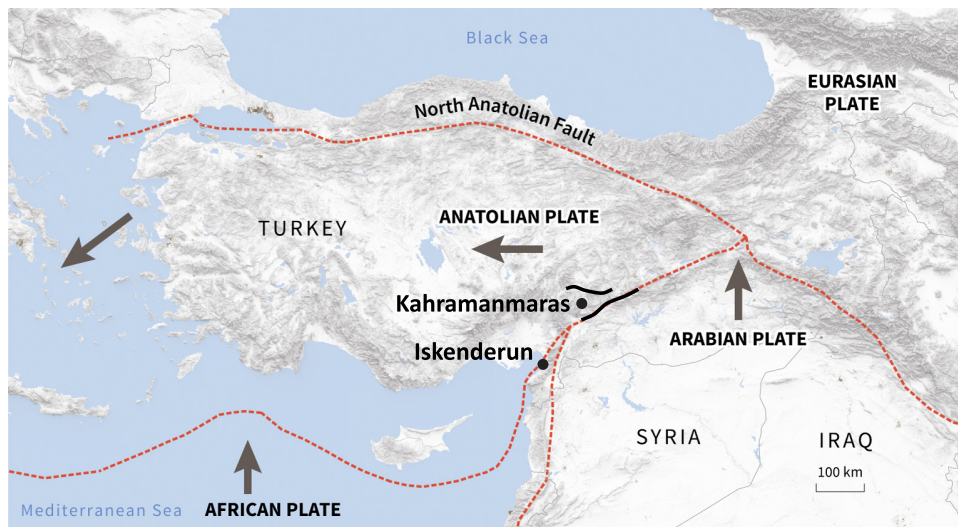


Figure 2: A map displaying the tectonic plates surrounding Turkey. The faults where the two earthquakes occurred are shown near Kahramanmaraş.

2. (2 points) Suppose a fault just south of Kahramanmaraş is oriented north-south. If plate movement caused this fault to rupture with the same magnitude of displacement as the faults in the image, would it likely have more or less vertical movement? Explain.
3. (2 points) After the earthquake, subsidence in İskenderun caused significant flooding. Which of the following can be inferred about the region as a result of this subsidence?
 - A. Saltwater intruded into previously fresh groundwater
 - B. The bedrock is loose and unconsolidated
 - C. The bedrock is primarily composed of carbonates
 - D. The water table is relatively low

Turkey's geologic setting is strongly influenced by the subduction of the African Plate beneath the Anatolian Plate.

4. (2 points) Much of Turkey's bedrock is *mélange*—mixed material scraped off of the subducting African Plate. Part of this material is derived from oceanic igneous activity. Does this material likely have a higher or lower silica content than surface volcanoes in Turkey? Briefly explain.
5. (3 points) Seismic tomography data is collected in the region underneath the Anatolian Plate. In this data, would the subducted slab from the African Plate have a higher or lower seismic wave velocity than the surrounding mantle? Explain.
6. (2 points) The Taurus Mountains in southern Turkey are dominated by karst topography and have bedrock primarily composed of limestone. **Briefly** propose a method by which this limestone could have been deposited.

Problem 2

| Question | 1 | 2 | 3 | Total |
|----------|---|---|---|----------|
| Points | 4 | 3 | 8 | 15 (25%) |

The Pliocene epoch, particularly the mid-Piacenzian warm period (3.0–3.3 Ma), was the most recent period of elevated global temperatures with near-present atmospheric CO₂ concentrations. The Pliocene is thus used as an analogue for the climate in the near future.

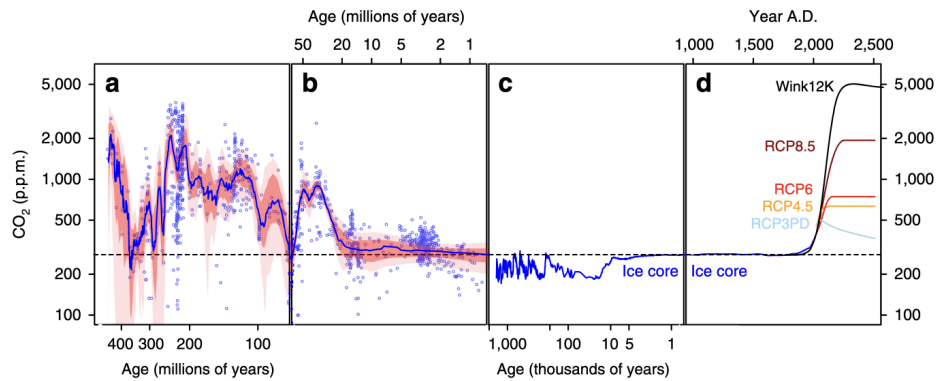
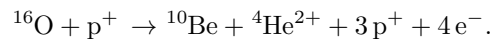


Figure 1: inferred CO₂ concentrations in the past half billion years, with the current level dashed.

- (4 points) There are many periods in Earth's past that resemble possible near-future climate conditions (see Figure 1). **Give two reasons** for why the Pliocene serves as a more useful analogue for studying near-future climate change than periods further in the past.
- (3 points) During the Pliocene, ice sheet melt caused global mean sea level rise dramatically. Give **one** reason why local sediment deposits in Greenland would seem to indicate much less sea level rise. In your answer, be sure to explain the physical processes in your reason.
- A geochemical method useful for studies of glacier retreat involves the production and radioactive decay of ¹⁰Be (beryllium-10) within quartz crystals.
 - (1 point) There is essentially no ¹⁰Be within quartz when it crystallizes from melt. Instead, ¹⁰Be forms in quartz *when it is exposed to the surface* via the following reaction:



Above, p⁺ and e⁻ refer to a proton and an electron, respectively. Surface materials also collect some ¹⁰Be from similar reactions occurring with atmospheric O₂ and N₂. **Name** or **describe** the physical phenomenon responsible for the production of ¹⁰Be in both of these cases.

- (5 points) ¹⁰Be is a radioactive isotope and decays to ¹⁰B (boron-10) with a half-life of 1.4 million years. The amount of ¹⁰Be in a quartz crystal is thus dependent on both the production process and the decay process.

Suppose we wish to infer the rate of retreat for an alpine glacier following the Last Glacial Maximum. If we know the constant rate of ¹⁰Be production for its location, then **qualitatively describe** how the rate of glacial retreat can be inferred by measuring ¹⁰Be concentrations in quartz samples. In your answer, be sure to comment on where/what your measurements are sampled from. (*Hint: the sample should be taken something that has not shifted or been overturned, since the rate of ¹⁰Be formation is dependent on the orientation of the sample*)

- (2 points) Is the method described above suitable for measurement of mid-Pliocene (3.0 Ma) episodes of glacial retreat? **Give one** reason why or why not.

Problem 3

| Question | 1 | 2 | 3 | Total |
|----------|---|---|---|----------|
| Points | 4 | 3 | 8 | 15 (25%) |

This question will explore several aspects of the El Niño Southern Oscillation (ENSO), which is the most prominent mode of climate variability.

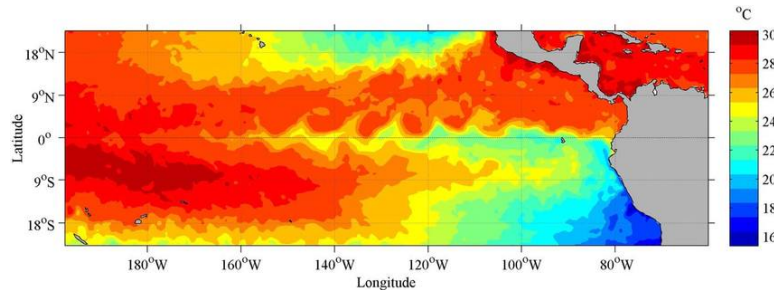


Figure 1: a snapshot of sea surface temperature in the tropical Pacific in June 2010.

- Explain how general atmospheric and oceanic circulation maintain the following aspects of the tropical Pacific’s mean state (a few sentences are sufficient).
 - (2 points) There is a band of relatively lower sea surface temperatures centered about the eastern equatorial Pacific.
 - (2 points) The thermocline of the equatorial Pacific is deeper in the west than the east.
- (3 points) ENSO is driven by the close coupling between the ocean and atmosphere. **Explain** how a positive sea surface temperature anomaly in the eastern Pacific generates an anomaly in the zonal (east-west) winds. Then, **explain** how that atmospheric response reinforces the sea surface temperature anomaly.
- While the growth-decay cycle of ENSO is well-understood, predicting the beginning of an El Niño event remains difficult. An existing theory for El Niño initiation is that short-lasting anomalies in the trade winds called *westerly wind bursts* cause warming in the eastern Pacific.
 - (4 points) Since westerly wind bursts occur on much shorter timescales (weeks) than the ENSO cycle (years), they might be considered to be forcing that is external to ENSO variability. Shown below is a composite of westerly wind burst events (measured by the westerly wind anomaly over the equatorial Pacific) and the western extent of the 29°C sea surface temperature isotherm (a proxy for the Pacific warm pool).

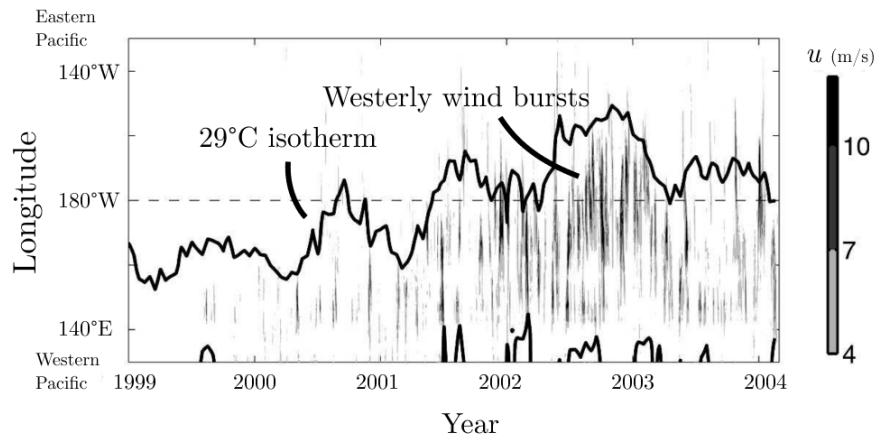


Figure 2: composite of westerly wind burst events and the extent of the 29°C SST isotherm. Note that 140°W corresponds to the **eastern** Pacific and 140°E corresponds to the **western** Pacific.

Using the observational evidence shown in Figure 2, **argue** why westerly wind bursts should **not** be considered to be external forcing that is decoupled (separate) from ENSO variability.

(b) (4 points) To test the possible two-way coupling between ENSO and westerly wind bursts, the following simulations were run using a climate model:

- **Experiment 1:** westerly wind bursts are artificially added to the simulated wind field when the Pacific warm pool extends past some threshold longitude.
- **Experiment 2:** westerly wind bursts are added randomly, while the amplitude and frequency of bursts are kept the same as experiment 1.

It was found that the simulated ENSO cycle in experiment 1 had twice the amplitude than that of experiment 2, shown below.

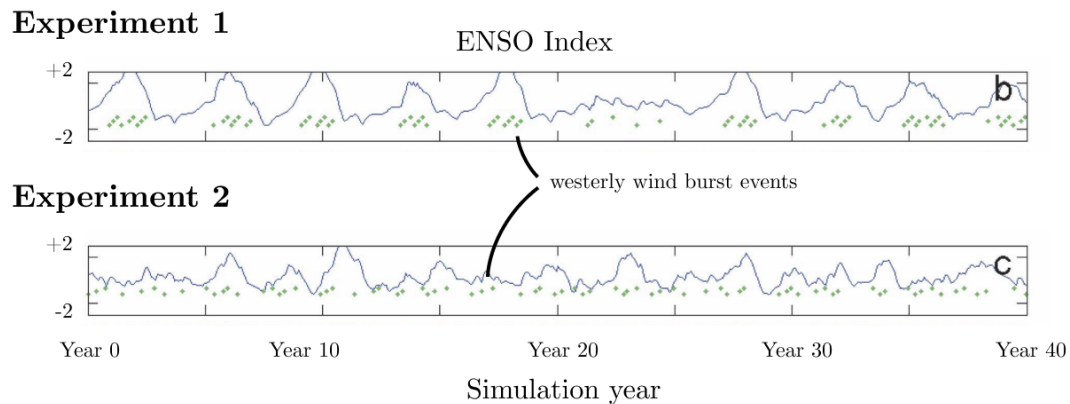


Figure 3: for both experiments, the ENSO index is shown by the line and westerly wind bursts are denoted by dots.

Justify why these results imply that westerly wind bursts are coupled with the ENSO cycle. In your answer, briefly explain how the experimental setup itself is important for making this conclusion. Here, coupling refers to a two-way causal relationship. (*Hint: how might the ENSO cycle and westerly wind bursts feed back on each other?*)

Problem 4

| | | | | |
|----------|---|---|---|----------|
| Question | 1 | 2 | 3 | Total |
| Points | 2 | 4 | 9 | 15 (25%) |

This question will explore several aspects of Saturn's rings.

- (2 points) A recent theory suggests that Saturn's rings were created early in its lifetime from the stripped outer layers of a large, differentiated moon that fell inwards towards the planet. Using this information, explain why Saturn's rings are mostly composed of water ice.

There are gaps within Saturn's rings that are caused by orbital resonances with its many moons. The largest gap is called the Cassini Division. Its inner edge includes the Huygens Gap, which is in a 2:1 resonance with Mimas (for every two orbits of an object within the gap, Mimas orbits once).

| | |
|--------------------------------|--|
| Mass of Saturn | 5.68×10^{26} kg |
| Semi-major axis of Huygens Gap | 1.18×10^8 m |
| Gravitational constant (G) | 6.67×10^{-11} N m ² kg ⁻² |

- (4 points) Using the parameters above, **calculate** the period of Mimas's orbit, in hours. **Show your work!**

The main rings are within Saturn's *Roche limit*, defined as the distance from the center of a celestial body at which an orbiting satellite will disintegrate due to tidal forces. You will derive a simplified equation for the Roche limit d by considering a spherical, rigid moon orbiting at exactly the Roche limit. For this question, let the mass of Saturn be M , the orbital radius of the moon be d , and the radius of the moon be r .

- (a) (2 points) The derivation of the formula involves the tidal force. In this case, we define the tidal force on a mass m as the positive difference between the gravitational force exerted by Saturn on a mass at the center of the moon and the same mass at a point on the moon's surface closest to Saturn. (It may help to draw a picture.)

Give an algebraic expression of the tidal force F_T in terms of M , m , d , r , and the gravitational constant G . Since the tidal force is a positive difference of gravitational forces, give your answer in the form of $F_T = F_2 - F_1$ where $F_2 > F_1$.

- (b) (3 points) The expression above can be simplified by assuming that $r \ll d$. Using the fact that for small x , $(1+x)^n \approx 1+nx$, **derive a simplified expression** for tidal force in terms of the same variables as above. (*Hint: rewrite one of the terms involving r and d in the form $(1-x)^n$.*)

If you cannot obtain an answer for (b), use $F_T = \frac{GMmr}{d^3}$ for (c).

- (c) (4 points) **Derive an algebraic expression** for the Roche limit d in terms of Saturn's mass M and the density of the moon ρ . (*Hint: recall that the moon disintegrates within the Roche limit because the tidal force exceeds its own self-gravitation.*)

END OF SECTION II