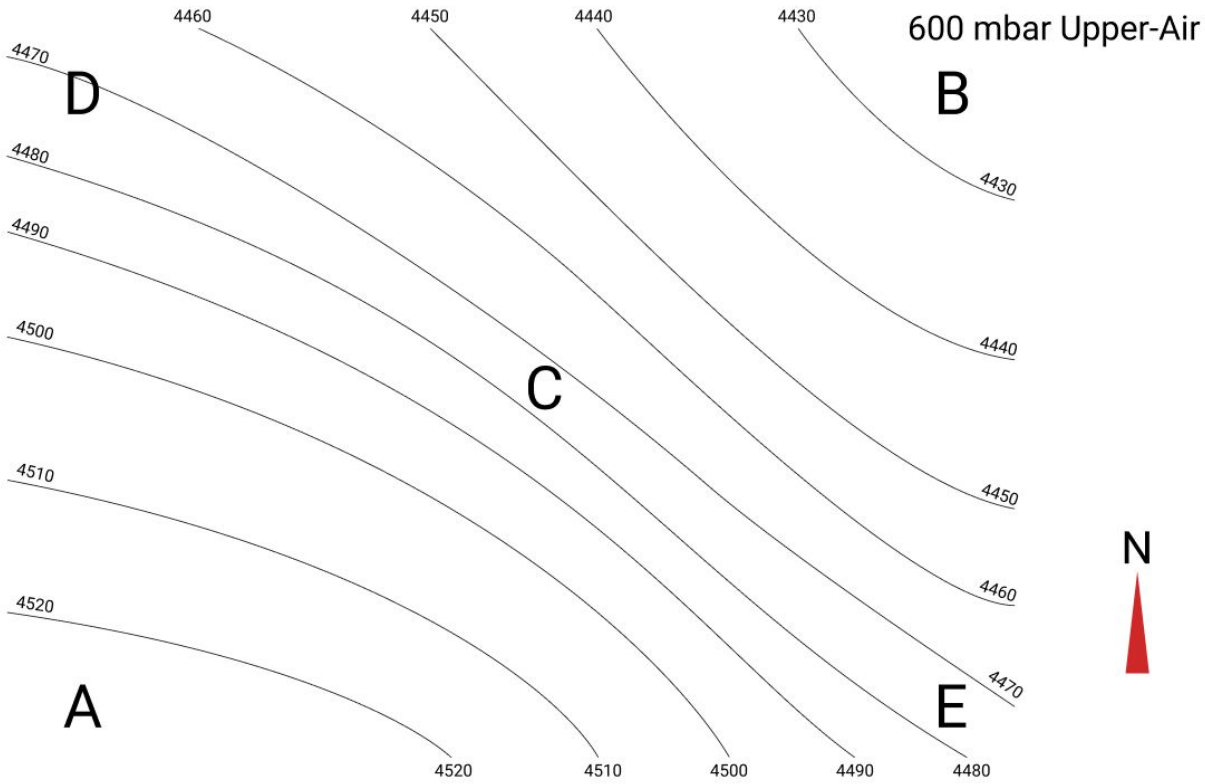
Atmosphere Exam

Key: (*) = none, one, or more than one answer possible (e.g. Answer: A, D, and E)
In questions with many pictures/text, the part requiring an answer is denoted with an arrow (→) to help differentiate from background information.

1. Use the diagram below to answer the following question. This question has four parts.



The figure above shows an isobaric (600 mbar) upper-air map in the **Northern hemisphere**. All elevations given are in meters, and assume that this is well above the planetary boundary layer such that there is no force of friction from the ground.

→ **Question 1, Part 1:** Which letter represents an upper-level high?

→ **Question 1, Part 2:** Which letter represents an upper-level low?

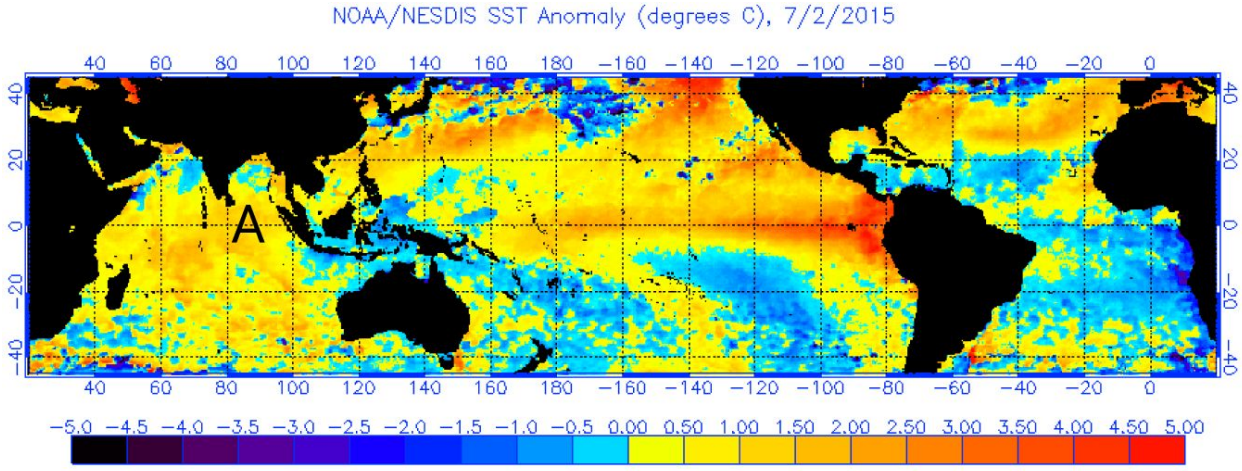
→ **Question 1, Part 3:** By referring to the figure above, identify the direction of flow for the geostrophic wind through point **C**. (*)

A) A geostrophic wind at **C** would flow **D** to **C** to **E**
B) A geostrophic wind at **C** would flow **A** to **C** to **B**
C) A geostrophic wind at **C** would flow **E** to **C** to **D**
D) A geostrophic wind at **C** would flow **B** to **C** to **A**
E) There are two possible directions of geostrophic flow through **C**

→ **Question 1, Part 4:** Now, assume that the planetary boundary layer is raised slowly, to well above the elevation of this upper-air map. This is accompanied with an increasingly significant force of friction from the ground, such that the wind at **C** deviates from geostrophic flow. Towards which point (letter) will the wind at **C** deviate towards?

2. This question has two parts.

The Indian Summer Monsoon (ISM) is an important mesoscale system that provides the Indian subcontinent with significant rainfall in the months from June to September. First, we will consider the effects of the El Niño Southern Oscillation (ENSO) on the ISM. **Figure 1** shows the sea-surface temperature (SST) anomaly on July 2, 2015.

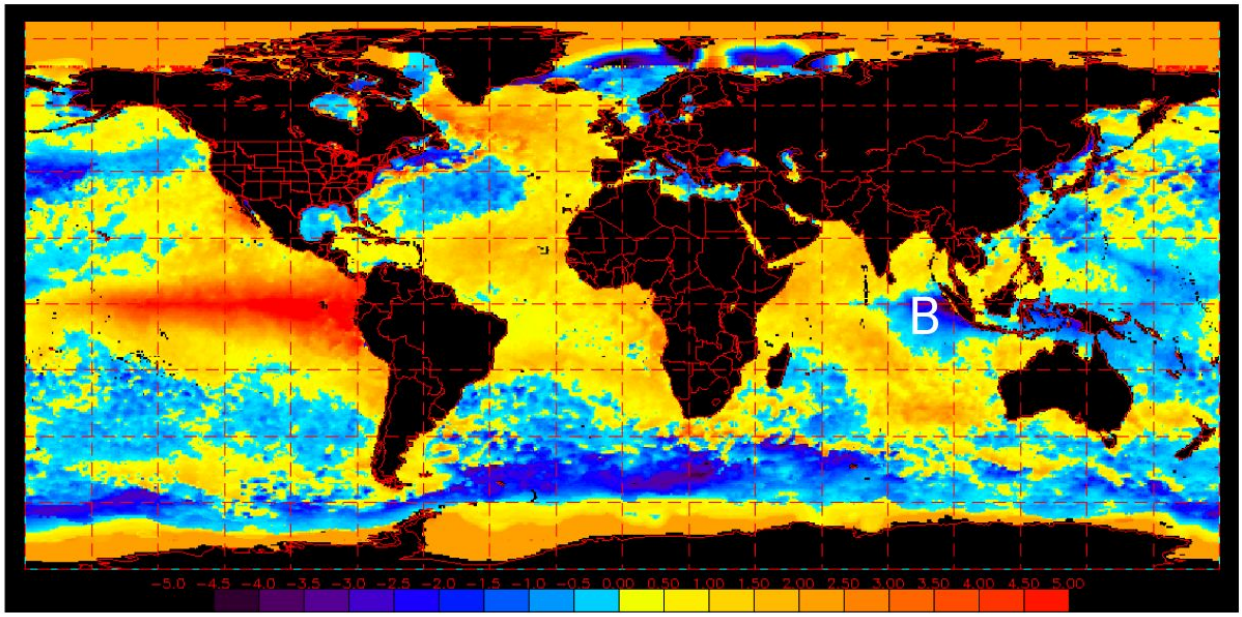


Question 2, Figure 1 [modified after NOAA/NESDIS]: Shows the global SST anomaly in July, 2015. Note location **A** in the eastern Indian Ocean.

→ **Question 2, Part 1:** Using **Figure 1**, identify all of the following statements that are likely **true** regarding the ISM in July 2015: (*)

A) There is anomalous surface divergence at **A**
B) There is anomalous surface convergence at **A**
C) Moisture flux is directed westward from Indonesia toward **A**
D) Moisture flux is directed eastward from **A** towards Indonesia
E) The ITCZ is located within 5 degrees of the equator (**A**)
F) The ITCZ is located greater than 5 degrees to the north of **A**
G) The ITCZ is located greater than 5 degrees to the south of **A**
H) The ISM is weakened by a positive ENSO phase
I) The ISM is strengthened by a positive ENSO phase

In 1999, an irregular oscillation of SST in the Indian Ocean, the Indian Ocean Dipole (IOD), was discovered. Since then, there has been research regarding the coupled effects of the IOD and ENSO on the ISM. A strong positive-phase IOD coupled with a positive-phase ENSO is shown in **Figure 2**.



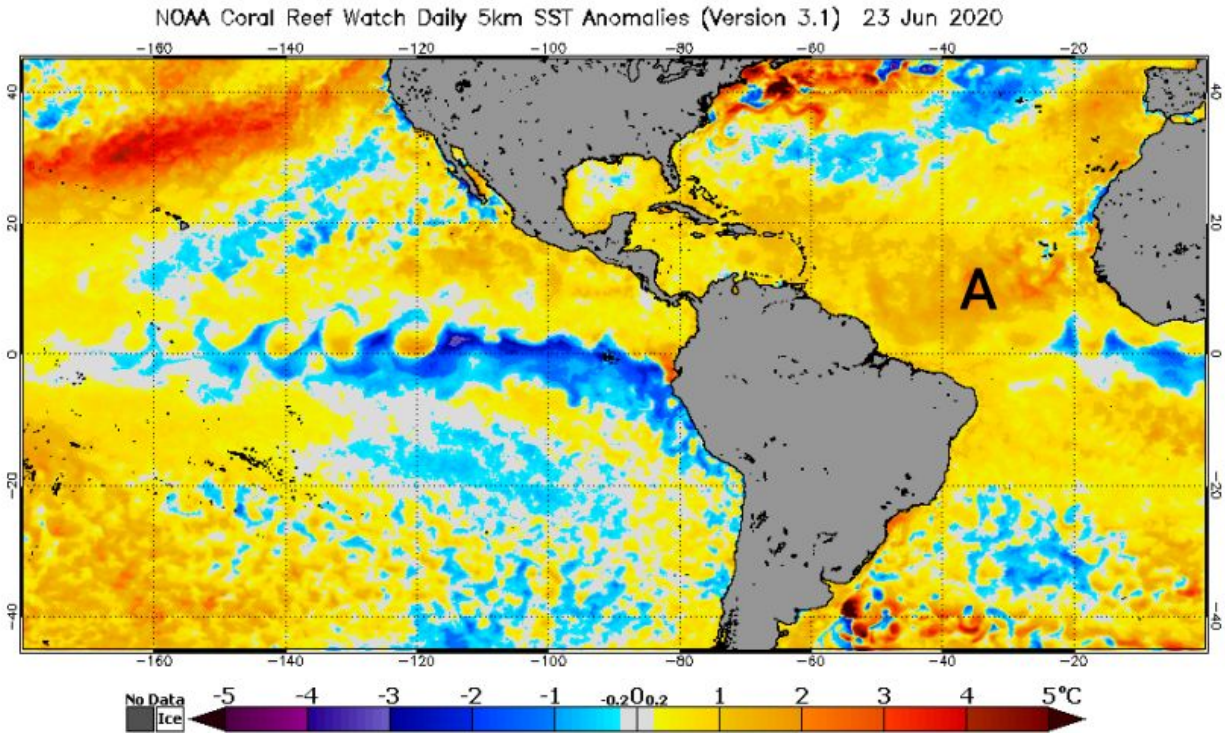
Question 2, Figure 2 [modified after NOAA/NESDIS]**:** Shows global SST anomaly during a strong positive IOD and positive ENSO in September, 1997. A positive-phase IOD, as shown in the figure, is characterized by a cold core anomaly in the eastern Indian Ocean, with a warmer anomaly in the western Indian ocean. Note location **B** in the eastern Indian Ocean.

→ **Question 2, Part 2:** Using **Figure 2** and **Figure 1**, identify all of the following statements that are likely **true** regarding a positively coupled IOD/ENSO phase on the ISM. (*)

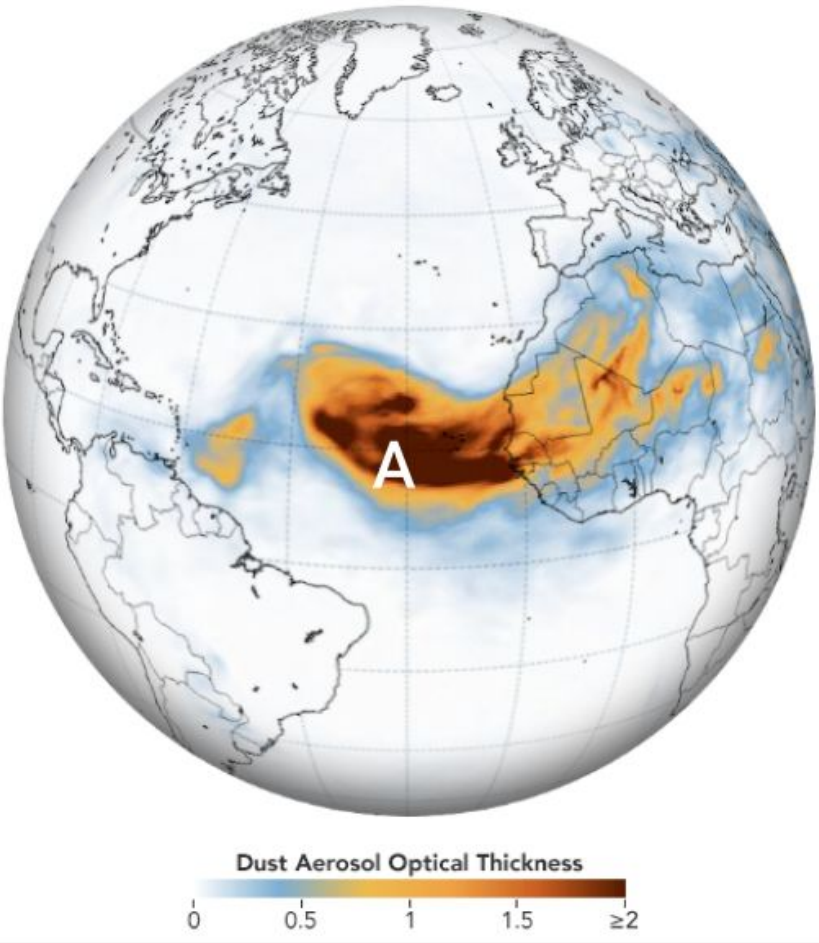
A) There is anomalous surface divergence at **B**
B) There is anomalous surface convergence at **B**
C) A positive IOD strengthens the effect of positive ENSO on the ISM
D) A positive IOD weakens the effect of positive ENSO on the ISM

3. This question has two parts.

The Atlantic hurricane season is affected by both the ENSO and the Saharan Air Layer (SAL), an exceptionally hot, dry, and dust-laden parcel of air that originates in Northwest Africa. Currently, a negative-phase ENSO (**Figure 1**) and an eastward-extended SAL (**Figure 2**) are present, which both affect Atlantic hurricane formation. Further, negative-phase ENSO is associated with the formation of a large-scale ridge in the tropical Atlantic, which directs the already-weakened subtropical jet to the north.



Question 3, Figure 1 [courtesy to NOAA/NESDIS]**:** Shows Pacific and Atlantic SST anomalies on June 23rd, 2020. Note location **A** in the tropical Atlantic.



Question 3, Figure 2 [courtesy to NASA Visible Earth]**:** Shows the dust aerosol optical thickness of the extended SAL, which contains lots of dust. Location **A** is marked again.

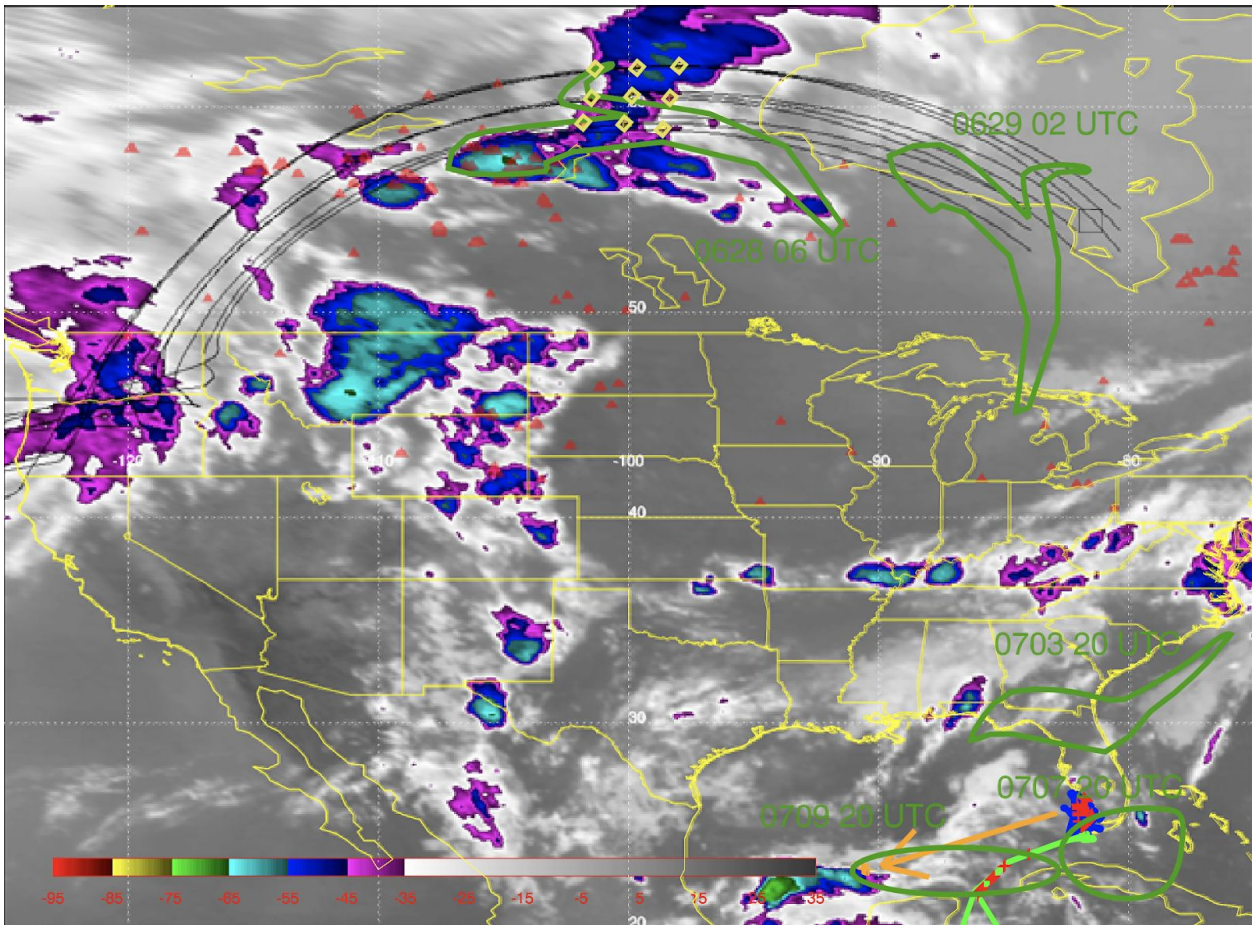
→ **Question 3, Part 1:** Using the information provided, as well as **Figures 1** and **2**, identify all of the following conditions that are likely present during the current state of an extended SAL and a negative-phase ENSO. (*)

A) Strong Pacific Walker circulation
B) Weak Hadley circulation in the eastern Pacific
C) Lower vertical wind shear in the tropical Atlantic
D) Higher vertical wind shear in the tropical Atlantic
E) Temperature inversion over location **A**

→ **Question 3, Part 2:** Finally, using the information provided, as well as **Figures 1** and **2**, infer the effects of negative-phase ENSO and an extended SAL on the upcoming Atlantic hurricane season. (*)

A) Negative-phase ENSO enhances the formation of Atlantic hurricanes
B) Negative-phase ENSO inhibits the formation of Atlantic hurricanes
C) Extended SAL enhances the formation of Atlantic hurricanes
D) Extended SAL inhibits the formation of Atlantic hurricanes

4. Use the image below to answer the following question.

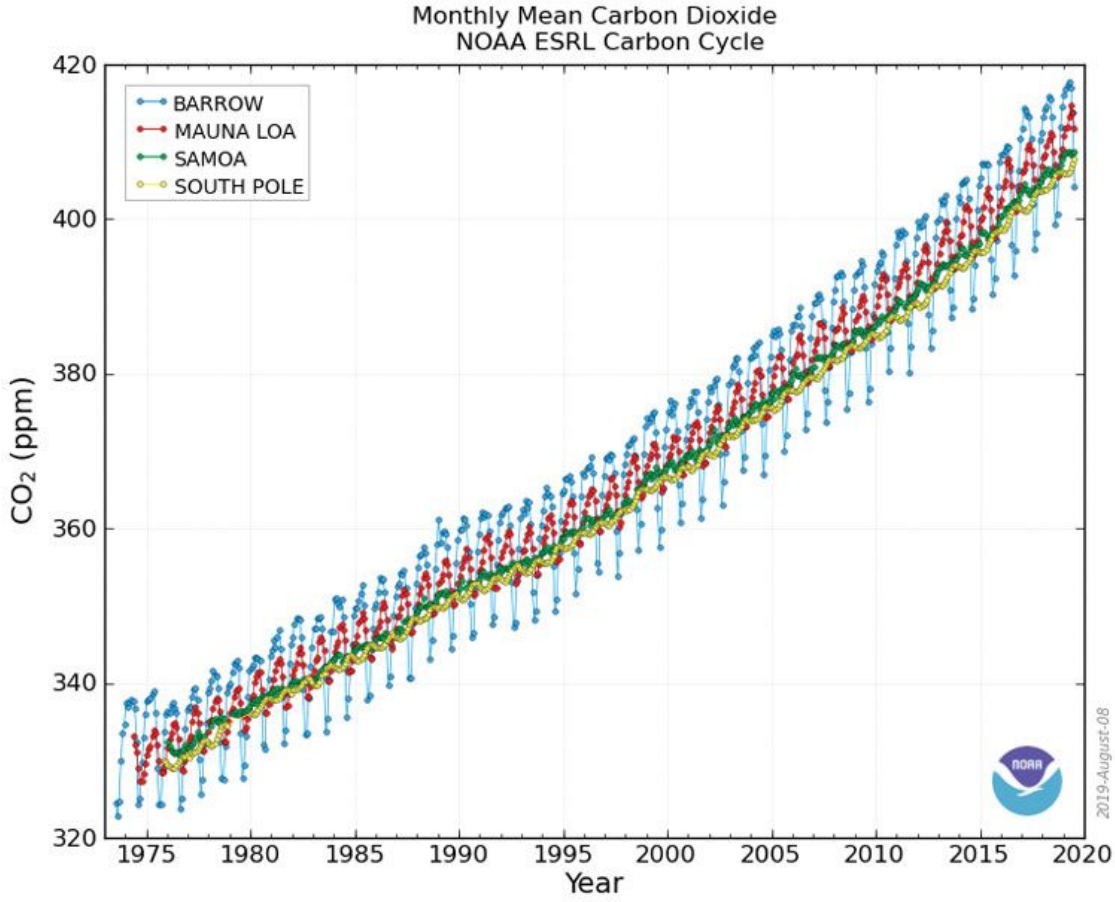


The image above shows cloud infrared brightness temperatures sourced from the GOES weather satellite. The color scale at the bottom of the image is measured in degrees Celsius.

→ Question 4: Which of the following is true regarding the image above? (*)

A) In visible satellite images, cirrus clouds appear brighter due to their thin structure.
B) In visible satellite images, cumulus clouds appear brighter due to their thick structure.
C) Using visible satellite images, cloud height can be determined but cloud thickness cannot.
D) The clouds over Washington and Oregon are higher in altitude than the clouds over Montana.
E) The clouds over Washington and Oregon are lower in altitude than the clouds over Montana.
F) The clouds over Washington and Oregon are approximately at the same altitude as the clouds over Montana.

5. Use the diagram below to answer the following question.



The diagram above shows the carbon dioxide concentrations measured at Barrow (Alaska), Mauna Loa, Samoa, and the South Pole. In addition to the overall upward trend in CO_2 concentration, a seasonal variation pattern is also evident.

→ Question 5: Based on the diagram above, which of the following is likely true? (*)

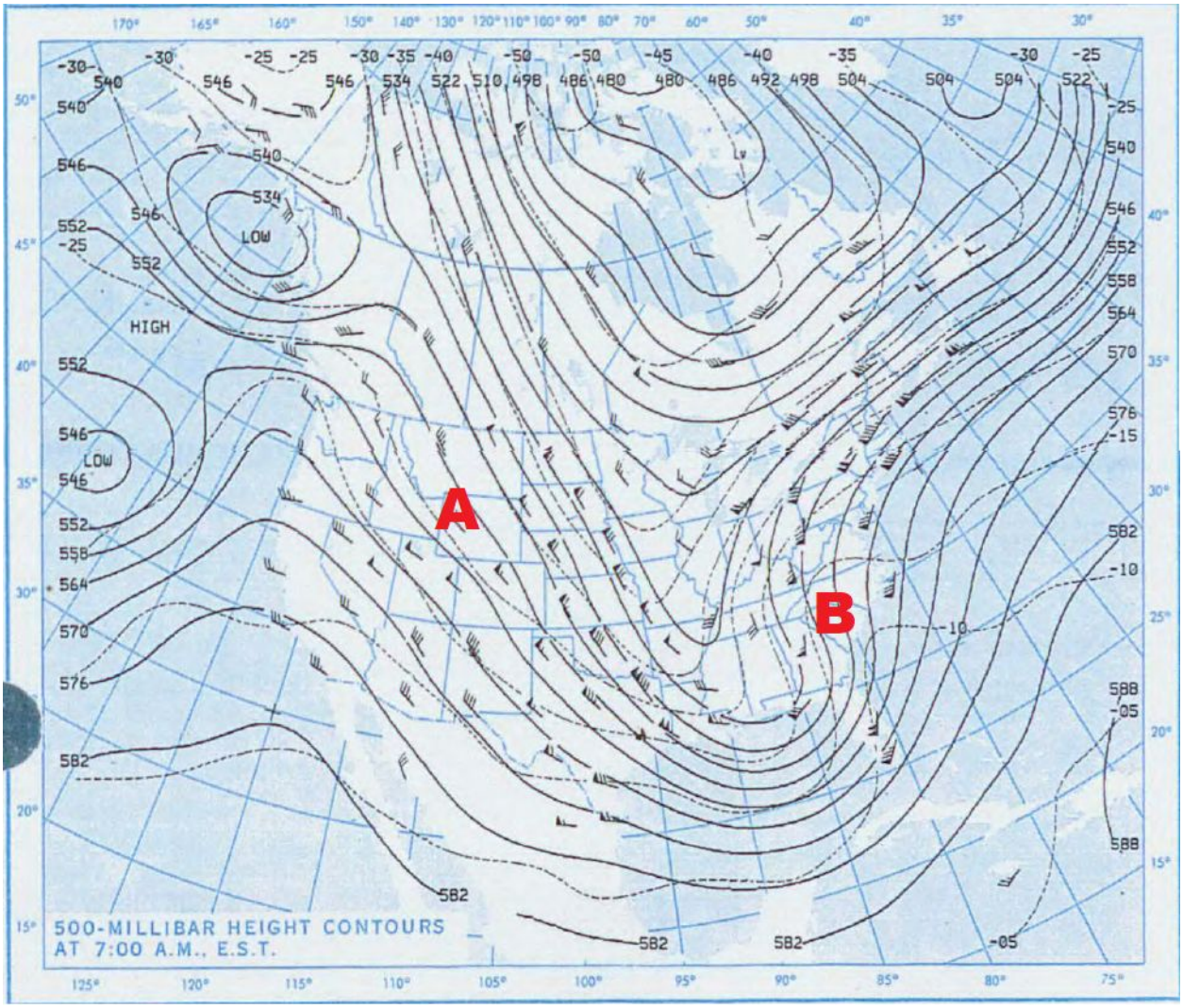
A) Fossil fuel combustion weakens seasonal CO_2 variations.
B) The large area covered by deciduous forests in the Northern Hemisphere accounts for the more prominent seasonal cycle of CO_2 concentration than in the Southern Hemisphere.
C) The seasonal variations are due to greater amounts of CO_2 being dissolved in the oceans during the summer.
D) The seasonal variations are due to the greater amount of insolation received in the Northern Hemisphere.

6. Thunderstorms are important phenomena that have very significant effects on weather. At the most basic level, they consist of a convective system with a rising warm updraft and sinking cold downdraft. The downdrafts generally reach the ground and spread out, forming a boundary between cold and warm air known as a gust front. Despite their importance, most thunderstorms are 'unsustainable' - they dissipate quickly, maybe even within an hour.

→ Which of the following statements is/are true regarding thunderstorm development and "sustainability" (ability of the thunderstorm to endure over time)? (*)

A) Most thunderstorms are "unsustainable" because the downdraft cuts off upward air flow
B) Vertical wind shear can tilt thunderstorms in a way that a new convective cell can form
C) If a thunderstorm has only one cell, then it is likely to last for a long time and is "sustainable"
D) Intense downdrafts in large thunderstorms can cause turbulent and dangerous conditions for air traffic

7. Shown below is a map of upper-level weather conditions at 7 AM EST on March 13, 1993 during the "Storm of the Century":



(map for Question 7 courtesy NOAA Central Library Data Imaging Project) Dashed lines are isotherms while solid lines are 500 mb contour lines. The 500 mb lines show a deep trough (elongated region of low pressure) of an atmospheric longwave (also known as a Rossby wave.)

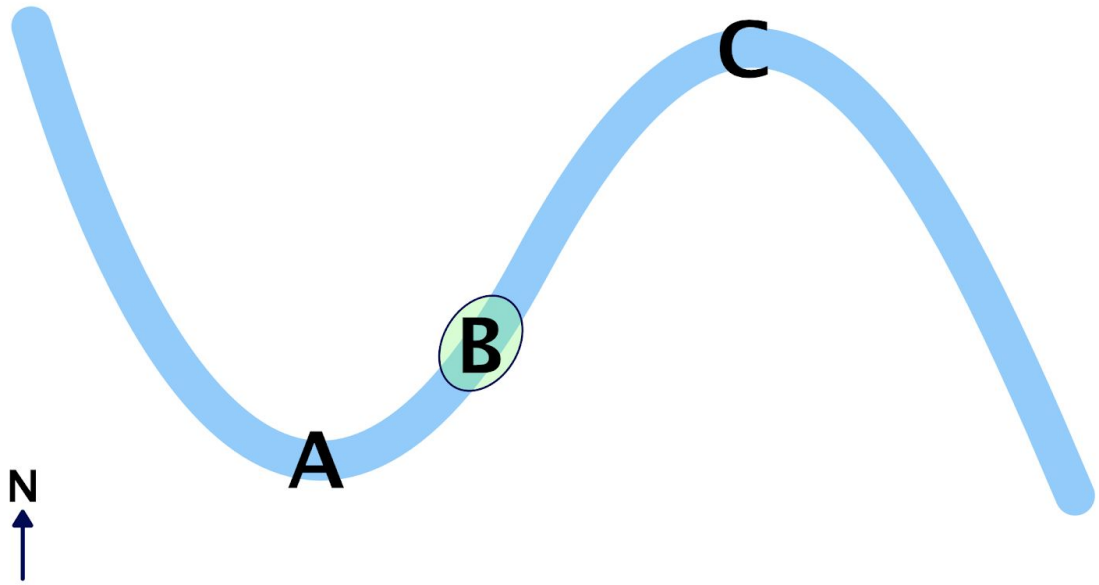
→ Question 7: Using this map and your knowledge of meteorology, which of the following is/are true? Assume all of the winds shown are geostrophic (flow parallel to isobars/contour lines). Consider what divergence and convergence aloft mean for air flow at the surface. (*)

A) There is an area of surface convergence at point B
B) There is warm advection (horizontal transport of warm air) occurring at point A
C) There is warm advection (horizontal transport of warm air) occurring at point B
D) There is an area of upper-level convergence at point A
E) Mid-latitude cyclones such as the one in 1993 are sustained by convergence aloft occurring directly above surface convergence
F) There is cold advection (horizontal transport of cold air) occurring at point A

8. Which of the following statements is true about the usage of ice cores in developing past climate records.

A) The thickness of ice core layers can be used to directly calculate past climatic temperature.
B) The presence of a bubble-free ice layer indicates a lack of a period of ablation or melting that year.
C) A large $^{16}O/^{18}O$ ratio in glacial ice is indicative of a glacial period.
D) Air bubbles are not accurate measures of past atmospheres due to impurities that seep in through the ice.

9. Use the figure below to answer the following question.

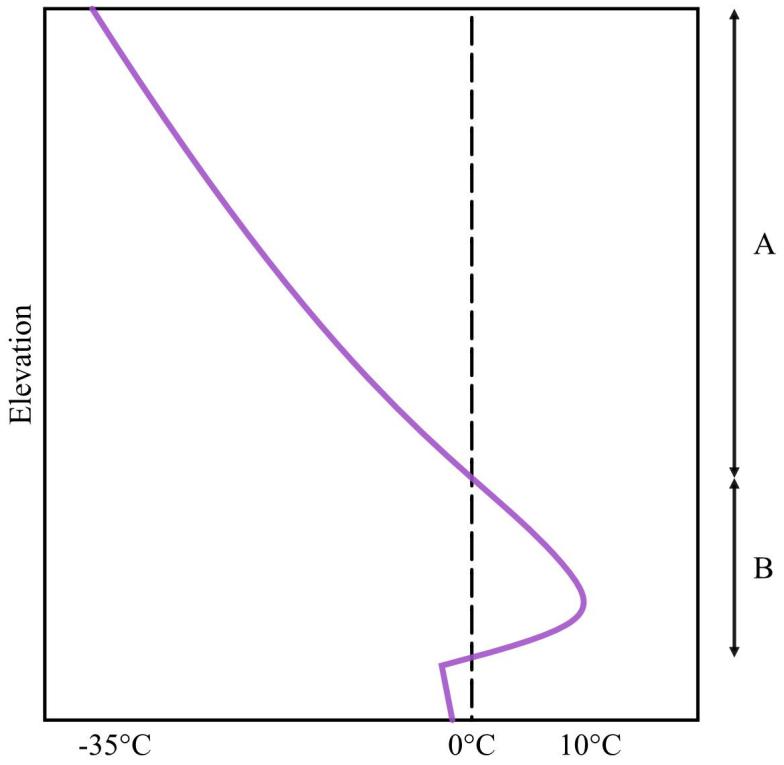


The figure above is a section of a hypothetical jet stream in the northern hemisphere of an unspecified planet. Analogous to the polar jet on Earth, it lies on the boundary between colder air to the north and warmer air to the south.

→ Select all of the following situation(s) that may be represented by the figure. (*)

A) The pressure-gradient force at point A is directed to the *north*.
B) The pressure-gradient force at point A is directed to the *south*.
C) The pressure-gradient force at point A is directed to the *east*.
D) The pressure-gradient force at point A is directed to the *west*.
E) The planet rotates *counterclockwise* and the jet is *easterly*.
F) The planet rotates *counterclockwise* and the jet is *westerly*.
G) The planet rotates *clockwise* and the jet is *easterly*.
H) The planet rotates *clockwise* and the jet is *westerly*.
I) Upper-level *divergence* occurs as air parcel B increases in latitude (in a westerly jet).
J) Upper-level *convergence* occurs as air parcel B increases in latitude (in a westerly jet).
K) The jet is *westerly* and wind speed at point A is greater than at point C.
L) The jet is *easterly* and wind speed at point A is greater than at point C.

10. Use the diagram below to answer the following question.

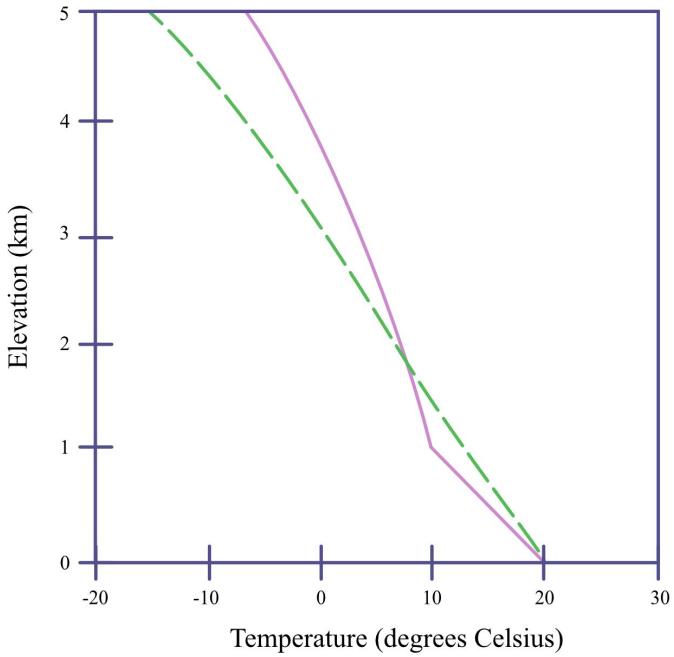


The temperature profile of a cloud, such as the one above (not to scale), may be useful for determining the type of precipitation that reaches the ground as well as its formation. Note that precipitation formation is controlled by the Bergeron process within A.

→ Select all of the following that are likely true about the conditions this profile depicts. (*)

A) A is predominantly composed of ice crystals.
B) B is predominantly composed of liquid water droplets.
C) The vapor pressure of water is greater than the local saturation vapor pressure over water droplets in B but not A.
D) The vapor pressure of water, in A, is greater than the local saturation vapor pressure over water droplets but not over ice crystals.
E) Precipitation remains liquid before freezing upon contacting the ground because the water droplets themselves are kept above 0°C by the warm air in B.
F) Precipitation reaches the ground as snow because ice falling through B does not have sufficient time to completely melt.
G) Precipitation accretes multiple layers of ice to form hailstones with alternating laminae of clear and opaque ice.

11. Use the diagram below to answer the question that follows.



The atmospheric vertical temperature profile above includes the environmental lapse rate in a dashed green line and the adiabatic lapse rates of a lifted air parcel in a solid pink line. Assume equal moisture content for air parcels within the question.

→ Select all of the following that are true of this particular situation. (*)

A) Overall, the atmosphere shown is in a state of *absolute stability.*
B) Overall, the atmosphere shown is in a state of *conditional instability.*
C) Overall, the atmosphere shown is in a state of *absolute instability.*
D) An air parcel lifted *0 km* will continue rising on its own.
E) An air parcel lifted *1 km* will continue rising on its own.
F) An air parcel lifted *2 km* will continue rising on its own.
G) An air parcel lifted *3 km* will continue rising on its own.
H) The dew point of the air parcel at 1 km is *20°C.*
I) The dew point of the air parcel at 1 km is *18°C.*
J) The dew point of the air parcel at 1 km is *10°C.*
K) The dew point of the air parcel at 1 km is *8°C.*
L) A cloud base would form at an elevation of about *0 km*.
M) A cloud base would form at an elevation of about *1 km.*
N) A cloud base would form at an elevation of about *2 km.*

12. Use the diagram below to answer the following question.

The Santa Ana winds that rush into the LA basin, and even past the coast, from the pressure system located in the Great Basin (the white circle, approximately), creating warm conditions that range from unpleasant to dangerous.

→ Considering the elevation map above, select all of the following that are **true** about the formation and effects of these winds. (*)

A) The white circle is a surface high.
B) The average velocity of the Santa Ana winds is increased when air within the circle is relatively warm.
C) The migration of the pressure system over LA drives sinking air to warm over the region.
D) The experience of the Santa Ana winds is part of a passing warm front.
E) The maximum temperature of the Santa Anas is likely within the LA basin.
F) Moisture content of the Santa Anas decreases as air warms, thus increasing the likelihood of wildfires.
G) Offshore flow of the Santa Anas results in cooler waters at the coast.

13. Atmospheric circulation in a simplified model of a non-rotating planet with a uniform surface features Hadley cells spanning from the equator to either pole.

    → Which of the following best explains the discrepancy between this model and real observations on Earth?

    A) The subtropical jet streams, which require rotation in being geostrophic, in each hemisphere inhibit further poleward movement of upper-level flow.
    B) Earth's non-uniform surface creates pressure gradients that do not necessarily direct winds towards the poles.
    C) The presence of the Ferrel cell drives the sinking of air within the subtropical ridge, resulting in the restriction of the Hadley cell to within about 30 degrees latitude.
    D) The flow of poleward winds, influenced by the Coriolis force, gradually decreases in their meridional component before reaching the poles.

14. Some studies suggest that the poleward extent of Hadley circulation is correlated with height of the tropopause.

    → Identify all of the following that would likely increase tropopause height in the subtropics. (*)

    A) Greater vertical mixing in subtropical oceans.
    B) Increased stratospheric nitrous oxide.
    C) Warmer mean global temperature.
    D) Denser pressure gradients about the Intertropical Convergence Zone.
    E) Greater temperature difference directly above and below the tropopause.

15. Choose all of the following statements that are true about land and sea breezes. (*)

    A) Land breezes blow towards land.
    B) At night, a low surface pressure zone is created above the ocean.
    C) Significant cloud cover would strengthen land and sea breezes.
    D) Ignoring physical obstructions, areas with coastal cities experience stronger sea breezes than similar rural coastal areas.
    E) Ignoring physical obstructions, areas with coastal cities experience stronger land breezes than similar rural coastal areas.
    F) Ignoring physical obstructions, areas with coastal cities experience weaker sea breezes than similar rural coastal areas.
    G) Ignoring physical obstructions, areas with coastal cities experience weaker land breezes than similar rural coastal areas.

16. Which of the following is NOT a process that causes air to rise upward?

    A) Orographic Lifting
    B) Frontal Wedging
    C) Convergence Aloft
    D) Adiabatic Heating

17. An air parcel decreases in temperature with increasing elevation at a rate of 10 degrees Celsius per kilometer. Venkat the meteorologist measures the dew point to be 16 degrees Celsius, and the air parcel temperature to be 24 degrees Celsius. Knowing that an air parcel must equal the dew point to achieve a cloud, Venkat is so excited about the prospect of making a cloud that he wills the air parcel to rise until it has cooled to 16 degrees Celsius. To his great dismay, no cloud forms. What is the most likely explanation?

    A) The air parcel actually decreases in temperature at the wet adiabatic lapse rate, which is 6 degrees Celsius per kilometer
    B) The air parcel actually decreases in temperature at the environmental lapse rate, which is 8 degrees Celsius per kilometer
    C) The dew point has decreased due to decreasing air pressure
    D) Air is not necessarily saturated with respect to water when air parcel temperature is equal to the dew point

18. Yuchen the weatherman gives two weather reports per year, once in July, and once in January. A meteorology student compiles all of Yuchen's reports across multiple years, and notices that January reports tend to be relatively rainy, while July reports tend to be very dry. Where is Yuchen most likely located? (*)

    A) Peru
    B) Florida
    C) Italy
    D) Arctic Ocean
    E) Antarctica

19. Vivek the glaciologist moves to the South pole to conduct research on the Antarctic marine ecosystem. At 90 degrees South, one would expect to find:

    A) Relatively clear skies year round
    B) Wet summers, dry winters
    C) Dry summer, wet winters
    D) Large amounts of snowfall year round