Atmospheric Circulation and the Global Climate System

A map-based exploration

Name: Answer key

Introduction:
Exploration of Earth's radiation budget (Units 4 and 5) reveals regions of positive and negative radiation balance. In this activity we will explore how circulation in Earth's atmosphere acts to balance the global energy budget by transporting energy from regions of radiation excess (positive balance) to regions of radiation deficit (negative balance).

This activity employs a "jigsaw" approach where you will be assigned to a specialty group to study a single map in depth and then a synthesis group where you will present a summary of your specialty group's analysis and then work as a team to synthesize the data sets to generate map and cross section concept sketches illustrating the atmospheric circulation and its role in helping to balance the global radiation budget.

All of the data sets we will be analyzing come from the NCEP-NCAR Reanalysis Project (https://climatedataguide.ucar.edu/climate-data/ncep-ncar-r1-overview). This project was the first attempt to create a comprehensive record of weather and climate over a long period of time by integrating weather observations within a numerical forecast model. The original effort incorporated 40 years of data (1957-1996), but was extended back in time to 1948 and continues to the present day. Although newer reanalysis products have been created using more sophisticated models, the original NCEP/NCAR product has been widely cited and is often considered a baseline for many newer studies.

Learning Goals:
By the end of the unit, students will be able to:

- Explain how atmospheric circulation acts to balance the global heat budget.
- Analyze maps of global wind fields to infer patterns of atmospheric circulation.
- Attribute global circulation patterns to variations in the global heat budget observed in Units 4/5 (e.g. latitudinal gradients, land/sea differences).
- Predict how changes in the atmospheric circulation system might impact human society.

Groups:

Altitude Group (circle your assigned group):

Surface horizontal wind 5.5 km vertical wind 12 km horizontal wind

Latitude Synthesis Group (circle/complete assignment below):

Northern Hemisphere: 0-30° 30-60°

Southern Hemisphere: 0-30° 30-60°

Earth's Thermostat, an InTeGrate module Balancing Earth's Radiation Balance

Specialty Group Work

Task 1: Inspect your assigned specialty group map (assigned by altitude) and identify major wind patterns and infer their possible causes. *Be prepared to share your findings with your specialty group and the whole class.*

A few questions for guidance (modified from Unit 4)

1. What data does your map present? How were they collected?

- All data are from NCEP-NCAR Reanalysis Project. The raw data come from surface, balloon and satellite observations. The observational data are interpolated using an atmospheric model.

2. Wind has both speed and direction. The wind speed is the magnitude of the velocity vector and indicates how fast the wind is moving. The direction is the orientation of the velocity vector, which is typically measured relative to north and up in geographic coordinate systems.
    a. How are wind speed and direction represented on your map?

- Surface winds – speed is represented by color scale and arrow length. Direction is illustrated by arrow direction.
- Vertical winds – speed is represented by color shade. Direction is represented by sign.

    b. Where are the highest and lowest wind speeds, in an absolute sense, i.e. irrespective of direction, located (note latitude/longitude)?

- Surface: highest: North Atlantic Ocean ~45N 30W, lowest: tropics over land ~0N 60W/15E/110E
- 5500 m: highest magnitudes are at 35N 120E, lowest are widespread, but perhaps most obvious at 60S and most longitudes.
- 12 km: highest: western Pacific 35N 150E, lowest: Antarctica and tropics 10-15 S many longitudes

    c. What direction is the wind blowing at these locations?

- Surface: highest: toward NE (SW wind), lowest: variable
- 5500 m: highest: downward
- 12 km: Highest: toward east, lowest: variable

3. Now look for areas where the wind appears to be blowing in a similar direction. Do you see patterns related to:
    a. Latitude?

- Surface: winds blow toward equator and west from ~25S to ~20 N; winds blow toward poles and east between ~40S and 60S and 35N and 60N (winds appear to blow toward the equator from 70-75S and 70-75N, but this pattern is much less clear).
- 5500 m: upward from ~20S to 10N, downward from ~15N to ~30S and 50S to 30S.
- 12 km: strong eastward blowing winds at 60S-30S and 20N-45N (with slight equatorward component), (variable poleward? Winds from 30S to 20N)

    b. Landcover (water, bare earth, vegetation, snow/ice)?

- Surface: wind speeds are generally higher over water than land. Wind direction is more variable over land. (There appears to be some convergence over southern tropical land masses).
- 5500 m: generally upward winds over southern tropical landmasses downward over South Atlantic and Pacific oceans. Opposite pattern in northern hemisphere with upward winds over oceans and downward over land.
- 12 km: Little obvious

    c. Other factors?

- Surface: There are also longitudinal variations. The most obvious is the high wind in the North Atlantic (eddy effect), but there are also variations in the Pacific (Walker circulation) and elsewhere due to longitudinal (zonal) circulation

- 5500 m: There are addition al longitudinal variations that are not associated with land/sea such as the east/west changes in the Pacific.
- 12 km: some longitudinal variation

4. Compare your map to your final concept sketch from Units 4/5. How might the winds at your assigned atmospheric elevation act to transport radiation (heat)?

- Surface: At the mid latitudes warm air travels poleward at the surface transporting heat from warmer to colder regions. (In the tropics, convergence of winds near the equator implies rising (warm) air. This air is replaced by cooler air blowing in from the north in the tropics.)
- 5500 m: heat rising at the equator, cooler air sinking at ~30N/S
- 12 km: poleward motion of warm air from equator

Specialty Group Work

Task 2: Work with your specialty group to create a concept sketch on the *specialty group base map* you have been provided that illustrates the patterns you observe in your data and how the winds might act to transport heat. Your map should include a title, author's names, an explanation, and graphic and text annotations that highlight key features and interpretations. Examples of features you might choose to annotate include high and low values, general patterns, and exceptions to these patterns. *You will use this map to explain your data, observations, and inferences to your synthesis group in the next task.*

Map-based concept sketch rubric

Level of achievement	Content/Comprehension	Communication/Presentation
Exemplary	- Map thoroughly illustrates the patterns in the data while not simply copying the original presentation - Map labels and symbols provide clear and correct explanation of underlying physical process(es) (8 points)	- Map clearly labeled with title, primary author's name and group member's names - Map elements clearly and accurately drawn and labeled directly or explained in legend (2 points)
Adequate	- Map illustrates primary patterns in data, but may miss secondary details - Labels and symbols capture main process(es), but may miss some details or contain some minor errors (6-7 points)	- Some basic map information missing - Map elements lack some detail or are not clearly drawn or labeled (1 point)
Needs improvement	- Map misses important patterns in data - Important processes are ignored or incorrectly explained (5-0 points)	- Map lacks detail or is uninterpretable (0 points)

Synthesis Group Work

Task 1: Begin by presenting each of your specialty maps to the group, explaining patterns and the processes that you infer to be responsible for creating these patterns.

Task 2: Work with your group to synthesize your specialty group observations into a concept sketch on the sheet that you have been provided. The sketch should illustrates atmospheric circulation and associated heat transport in your assigned latitudinal zone.

Your sketch should include:

- An annotated map synthesizing your various specialty group data sets into an integrated interpretation of atmospheric circulation and associated heat transport.
- A vertical cross section of the troposphere to help illustrate the 3D nature of atmospheric flow.

A few facts that may help you in your interpretation:

- For an ideal gas at fixed pressure (isobaric), the volume of the gas, and thus the density, is proportional to temperature, assuming the number of molecules of gas remains constant (i.e. no phase change).
- Converging flows indicate that material is moving away from the surface, while diverging flows suggest flow toward the surface in order to conserve mass.
- Winds and currents moving toward the equator [poles] will veer westward [eastward] due to the Coriolis effect.

Task 3: Class discussion of the global radiation budget.

For Thought: Compare the map of atmospheric circulation you made in this activity and the data maps we analyzed to maps of January precipitation rate and global landcover.

5. Which of the three wind maps (altitude groups) is most similar to (most correlated with) the patterns you observe in the precipitation map?
   - 5500 m vertical wind. Areas of high and low precipitation are correlated with upward and downward blowing winds, respectively.
6. Describe the location of anomalously high and low precipitation in terms of the global circulation patterns we described in class.
   - Precipitation is greatest in areas of upward winds (equator for Hadley cells and ~45-50 N for Ferrel cells (most obvious in northern hemisphere) and least in areas of downward winds (~30N and S).
7. How are these patterns of precipitation reflected in regional landcover and climate?
   - High precipitation areas are forested (tropical and temperate). Low precipitation areas are sparsely vegetated (deserts, grasslands, snow/ice).
8. One consequence of a warming climate may be an expansion of the tropical atmospheric circulation (Hadley) cells. What effect might this have on water supplies for human societies in the subtropics (e.g., southern United States, northern Mexico, North Africa, south-central Australia, Middle East, southeast China)?

- These areas are all located just north of 30N. If the Hadley cells expand, then these regions may become drier as the sinking winds on the north side of the cell move further north. Societies in this region may face shortages of water for drinking and agriculture.

Worksheet/Take Home questions rubric

Level of achievement	Content/Comprehension	Communication/Presentation
Exemplary	- Answers are accurate and complete. - Answers are supported by observations from data and student knowledge. (8 points)	- Answers address the questions directly. - Answers are justified with supporting arguments in a logical order. - Answers use acceptable style and grammar (no errors). (2 points)
Adequate	- Most answers are accurate and complete. - Most answers are supported by observations from data and student knowledge. - Minor misconceptions or misunderstandings. (6-7 points)	- Some answers incomplete or tangentially related to question. - Some explanations missing or unclear. - Minor issues (1-2) with grammar/style. (1 point)
Needs improvement	- Answers are inaccurate or incomplete. - Answers are not supported by observations from data and student knowledge. (5-0 points)	- Answers do not address the question asked. - Justification absent or unclear. - Answers do not use acceptable style and grammar. (0 points)

Annotated map/cross section rubric (specialty group task 2)

Level of achievement	Content/Comprehension	Communication/ Presentation
Exemplary	- Atmospheric circulation patterns are accurately sketched in map and cross section views. - Annotations clearly relate wind patterns to radiation excess/deficit and heat transport. (8 points)	- Map and cross section are neatly drawn and clearly labeled. (2 points)
Adequate	- Major atmospheric circulation patterns are sketched in map and cross section views, but features may be imprecisely located (within ~10%) and/or missing minor details. - Annotations relate wind patterns to radiation excess/deficit and heat transport, but some features may be missing or incorrectly attributed. (6-7 points)	- Map and cross section lack some detail or is not clearly labeled. (1 point)
Needs improvement	- Major atmospheric circulation patterns are imprecisely or inaccurately plotted. - Annotations relating wind patterns to radiation excess/deficit and heat transport are incorrectly identified/labeled. (5-0 points)	- Map and cross section lack detail or are uninterpretable. (0 points)