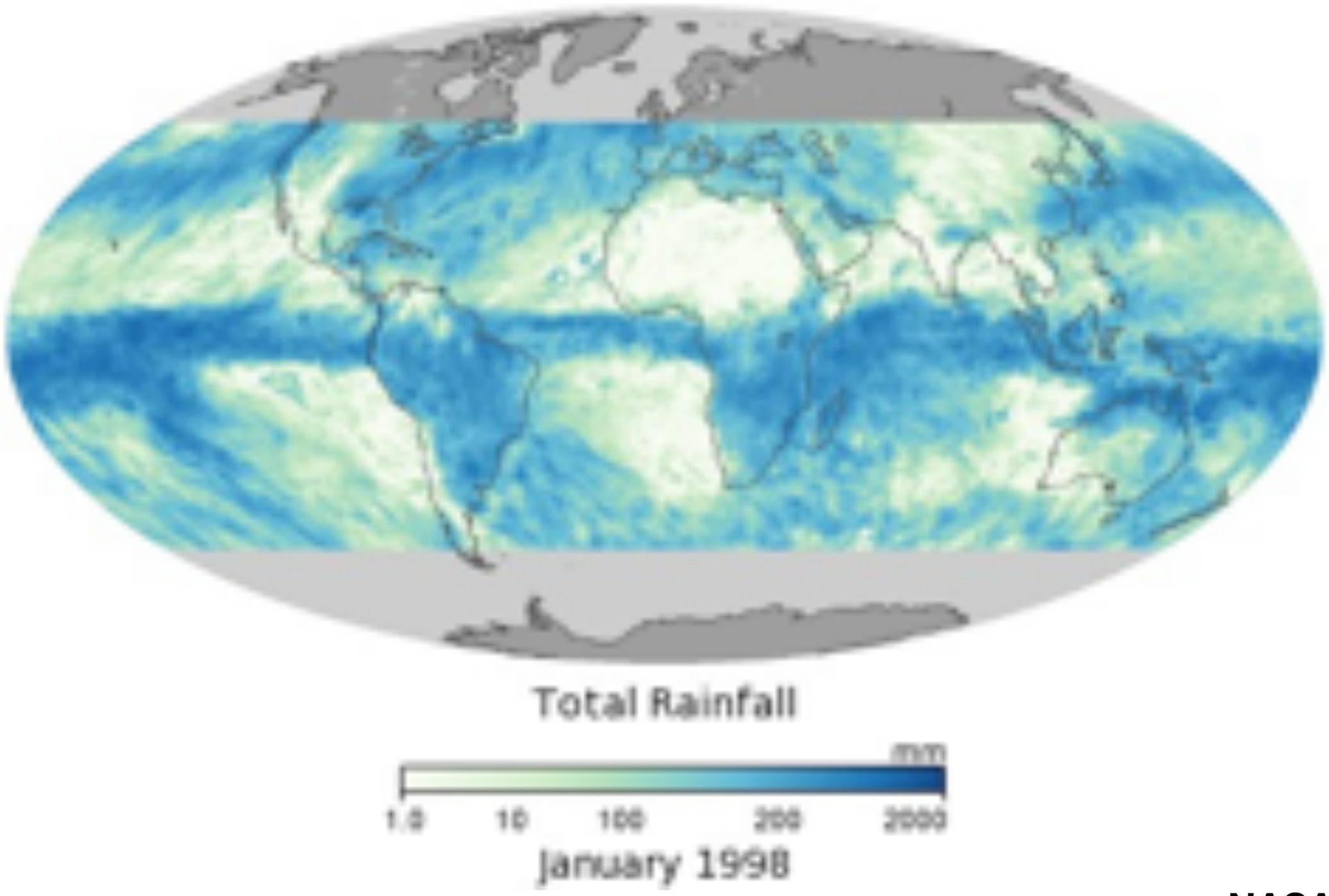
MONSOON

TRMM Precipitation-
make a small group of 2-4 people, talk about the signals that you see, make a list of three dominant patterns



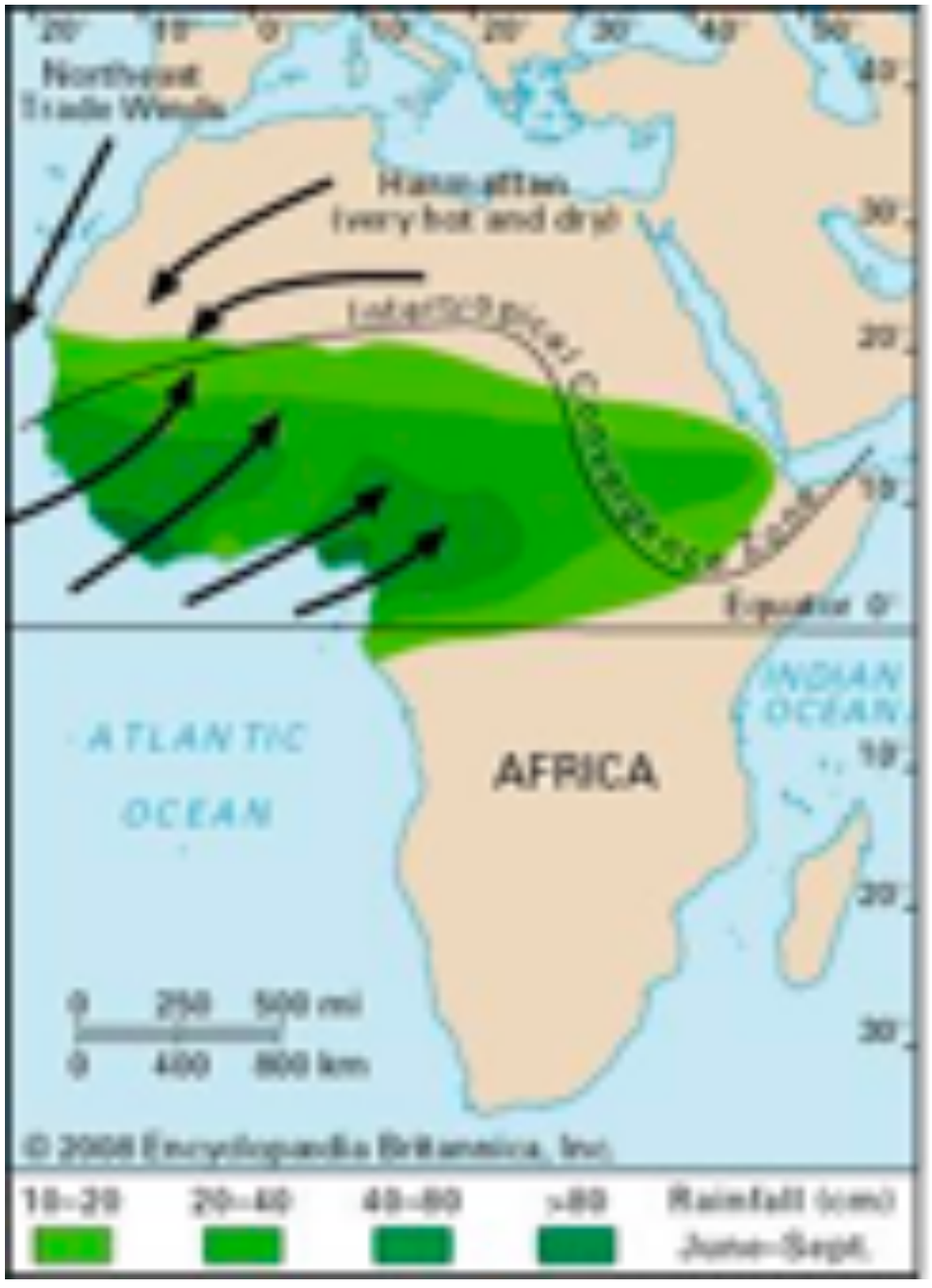
NASA

Some patterns that I see:

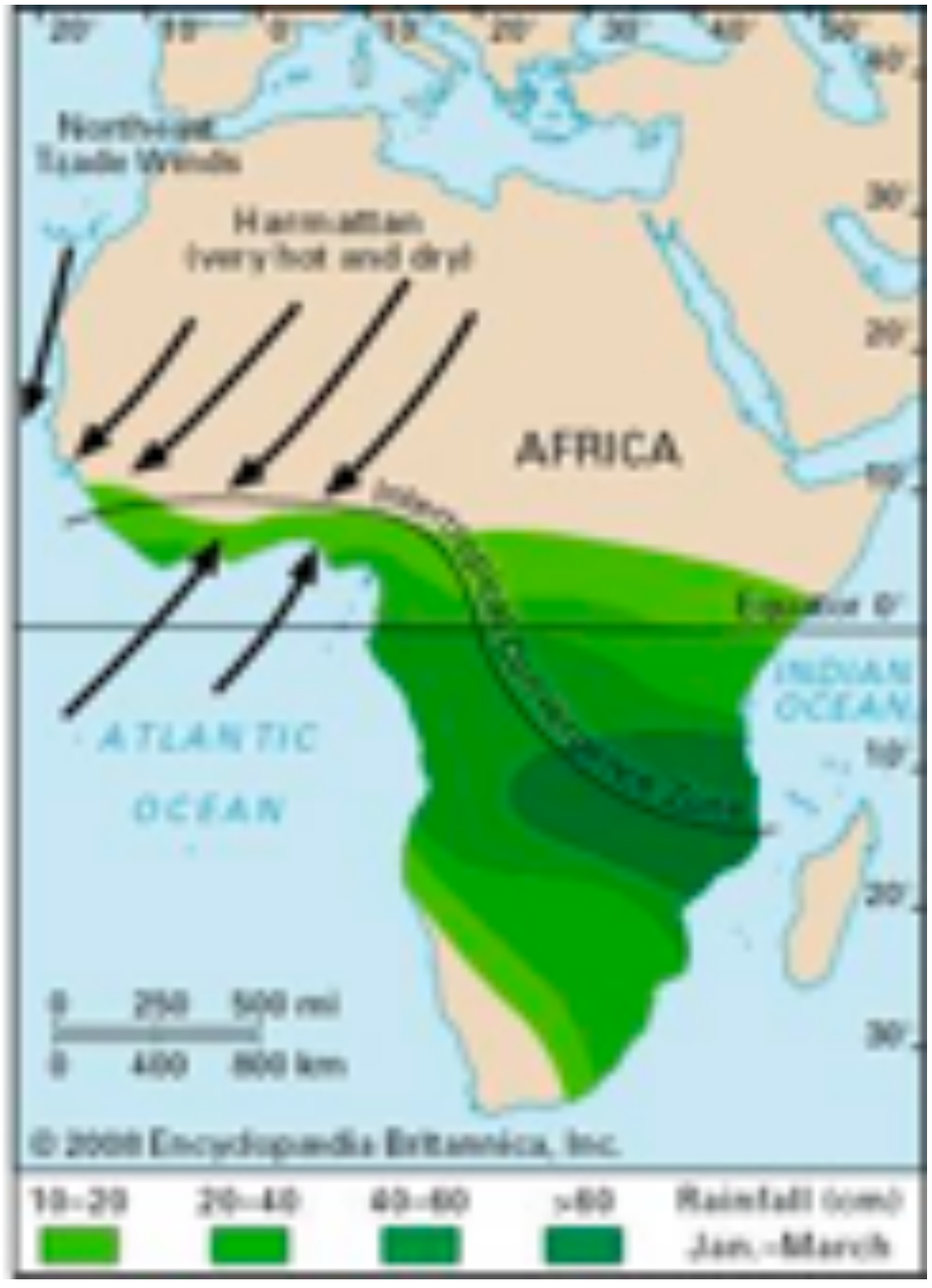
- **tight bands that migrate back and forth across the ocean near the equator**
- extratropical rain doesn't vary as much as rain in the tropics
- low precipitation regions in subtropical gyres and near deserts
- Equatorial upwelling and cold tongues suppress convection in the Pacific and a little bit in the Atlantic
- highest precipitation in tropics
- **tropical band displaced northward in the boreal summer, southward in the boreal winter**
- **displacement of tropical band largest over southeast Asia, moderate over Africa and west America, and not very noticeable over the central Pacific Ocean**

Monsoons!!! West African Monsoon

June-September



January-March



Our goal for today is to understand what causes the above wind and precipitation patterns.

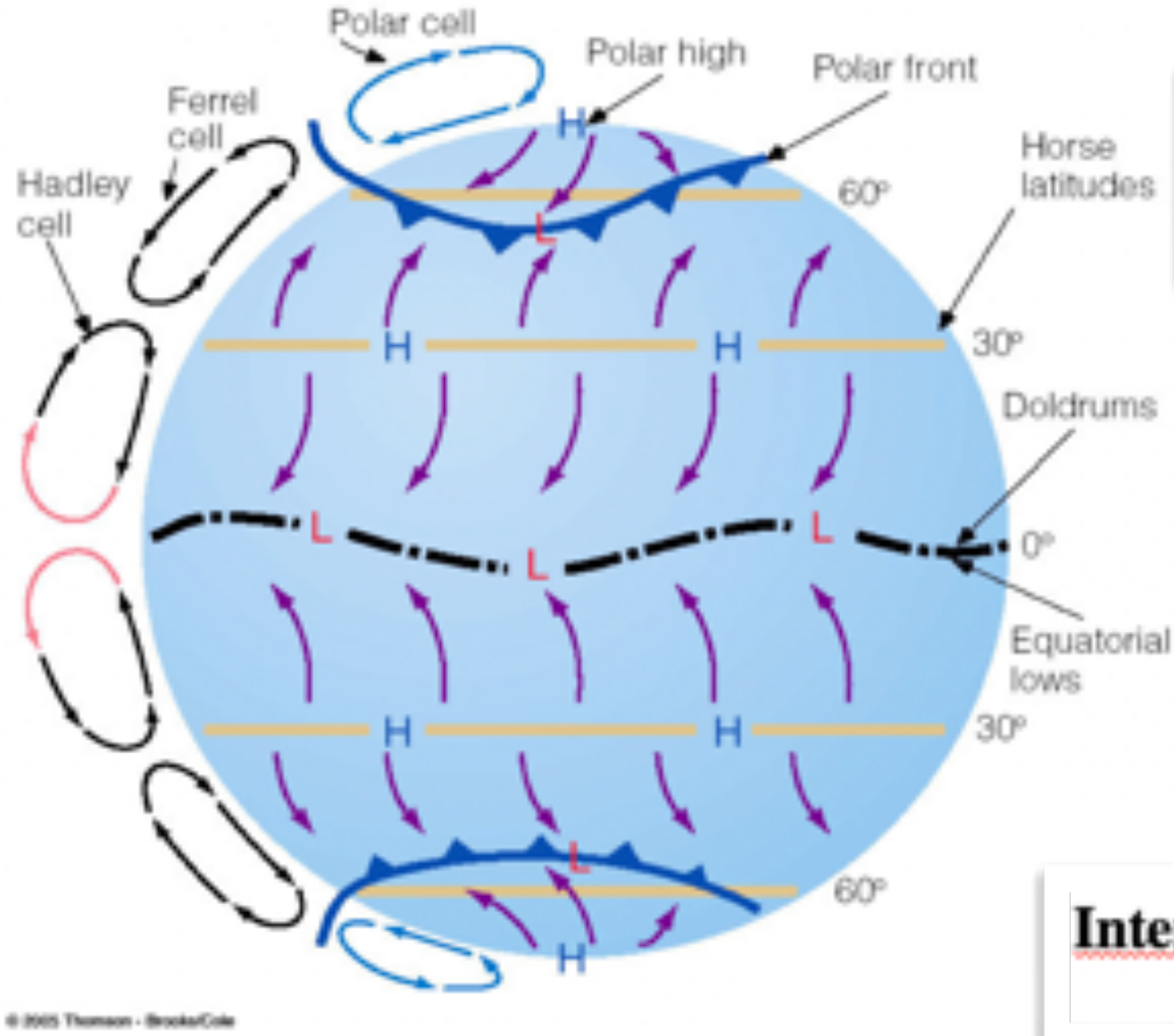
1. What processes drive monsoon circulations?

2. Where do we find monsoons?

3. What does the monsoon mean for the Gulf of Guinea and West Africa?

Let's start with a global perspective of the Earth's atmospheric circulation and energy budget

Idealized atmospheric circulation



3 Cells:

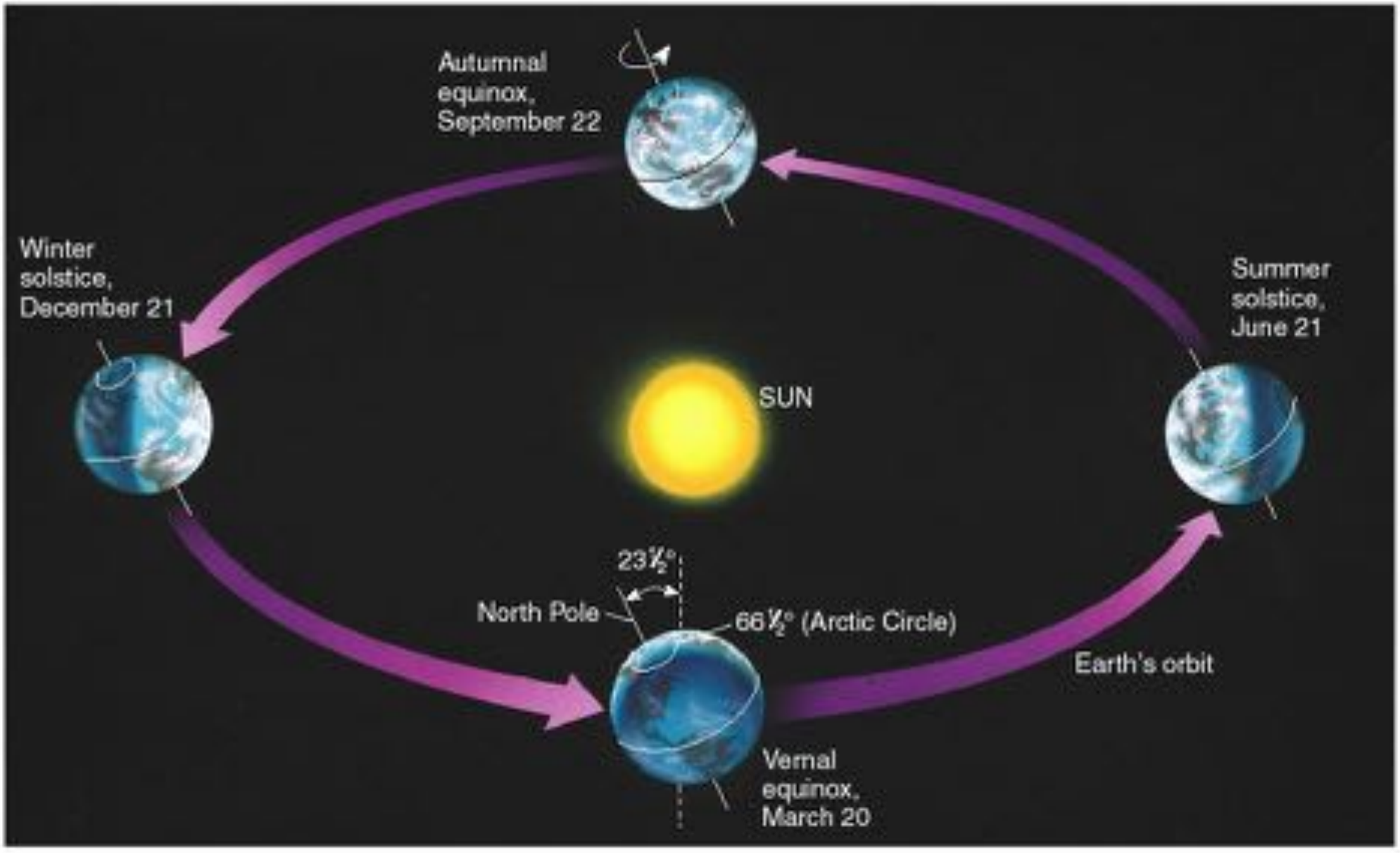
- **Hadley** (thermally driven from 0-30 degrees)
- **Ferrel** (between 30-60 degrees, driven by mid-latitude storm activity)
- **Polar** (between 60 and 90 degrees, north of polar front, linked with descent over cold poles)

Intertropical Convergence Zone (ITCZ. low pressure)

The ITCZ is associated with a 'convergence of trade winds', large-scale atmospheric upwelling and deep convection, heavy rainfall and weak winds.

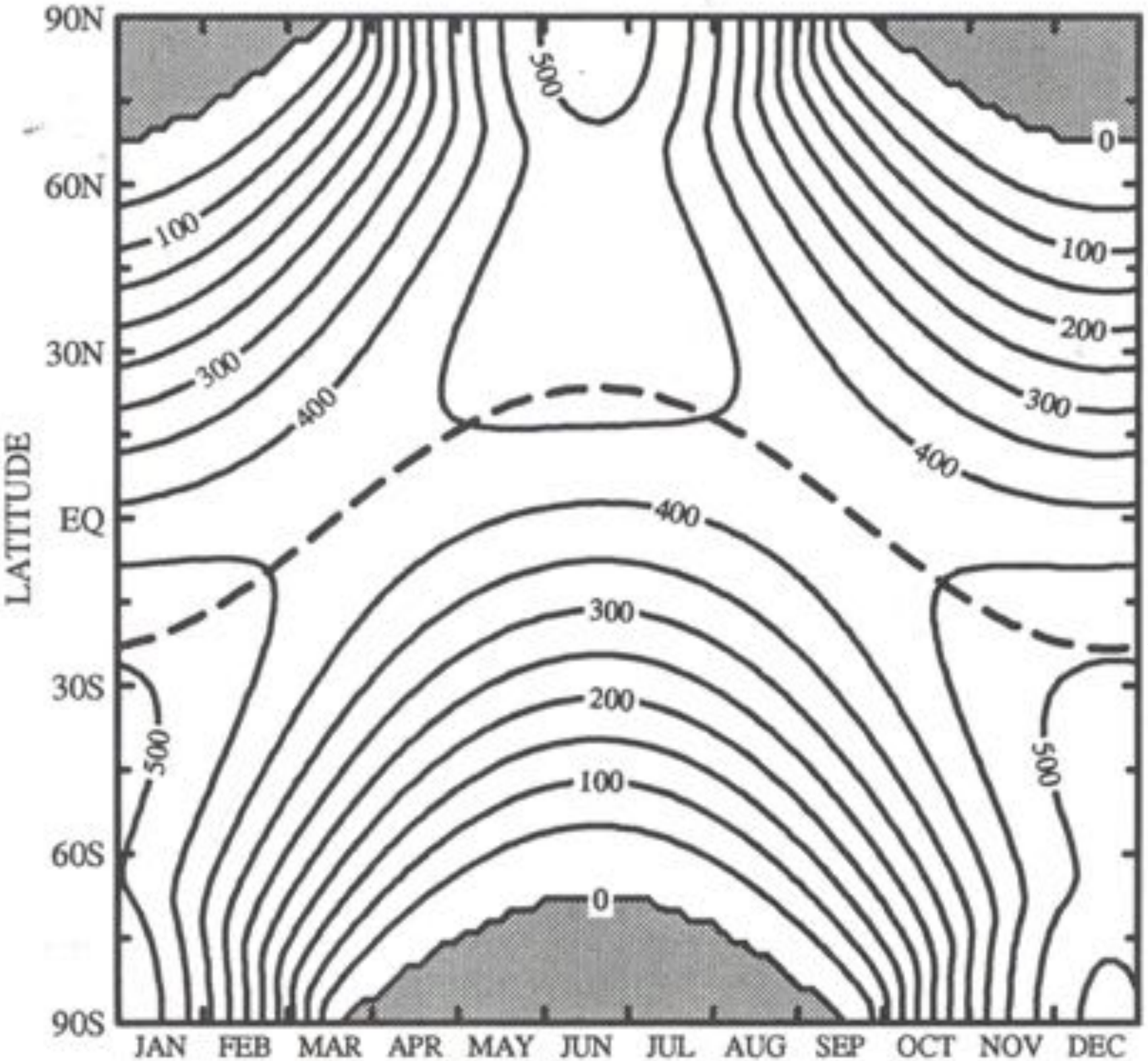
Monsoons are forced by the seasonal migration of the ITCZ, and the perturbations to this migration associated with differential heating of the land and ocean.

Seasons~ Earth's tilt + Revolution about the Sun



daily-averaged solar energy depends on hours of daylight and the angle at which the Sun hits surface… when is incoming solar energy a maximum in the Northern Hemisphere?

Total Daily Averaged Solar Insolation in W/m^2



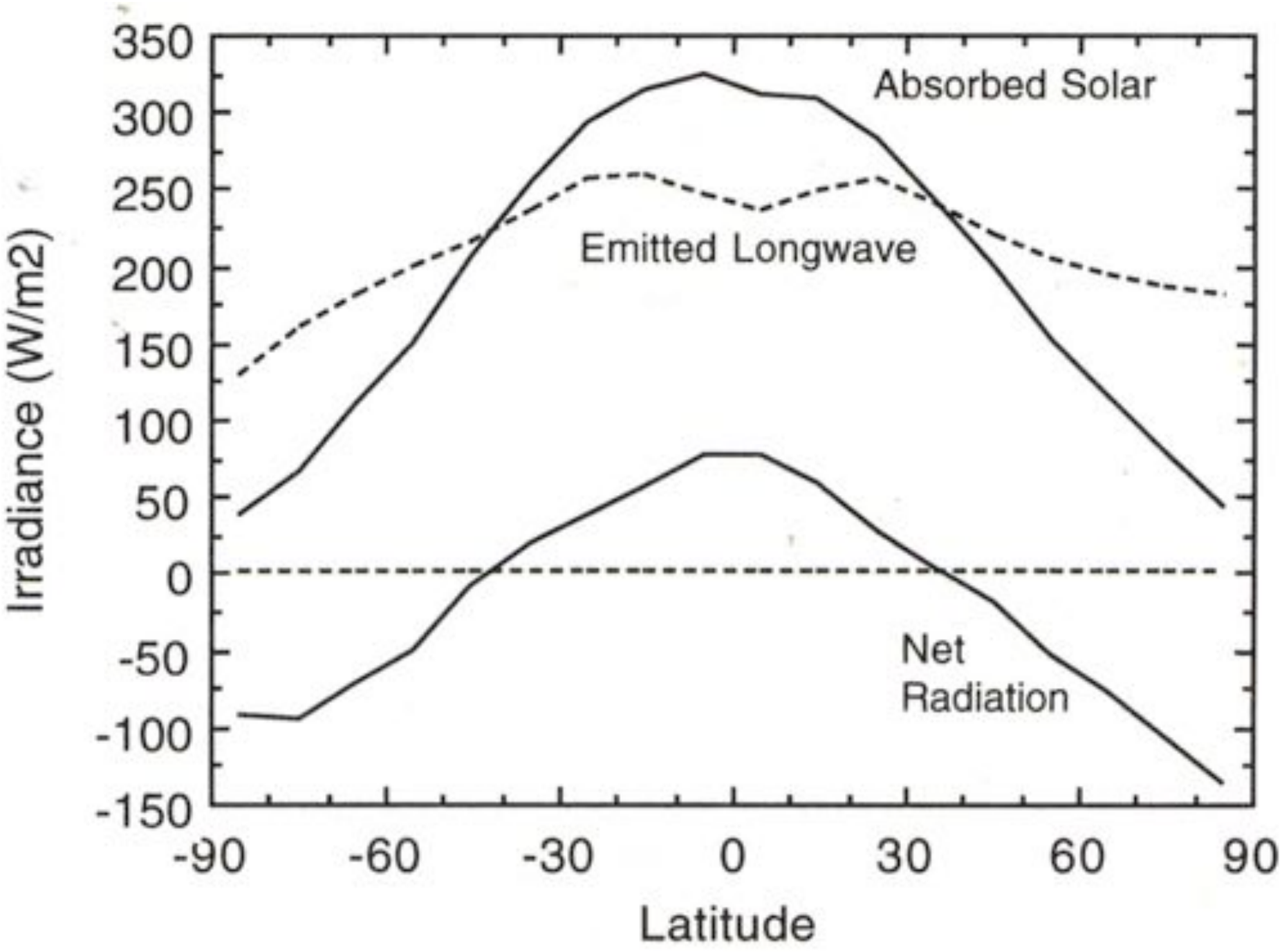
polar night and day 'strong seasonality'

continual heating near the Equator

dashed line- sun directly overhead at noon

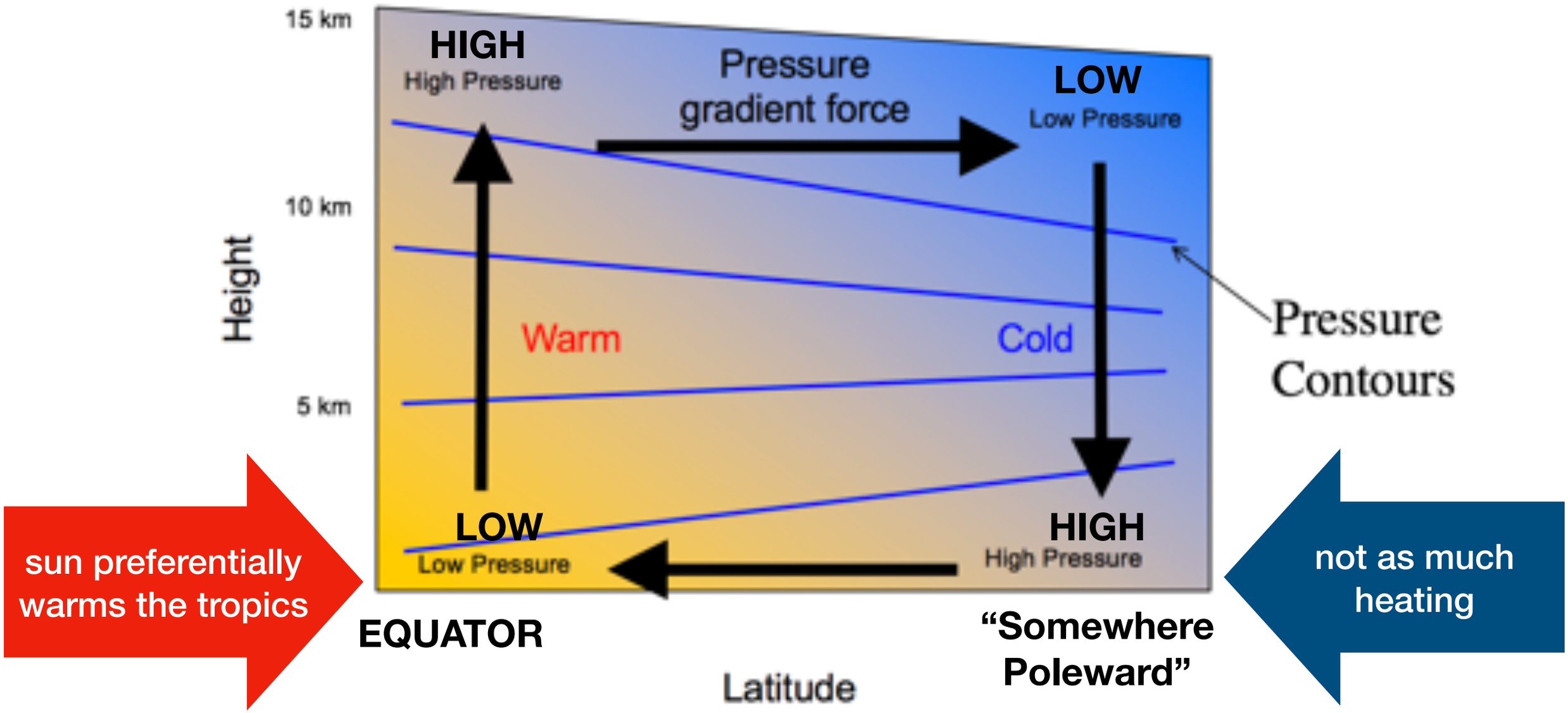
northern and southern hemisphere out of phase with each other

There is a net heating at the equator when averaged over a year. Incoming solar radiation in the tropics exceeds outgoing longwave radiation.



What does this mean for atmospheric circulation?

Thermal Cell Driven by Temperature Gradient between Tropics and Higher Latitudes

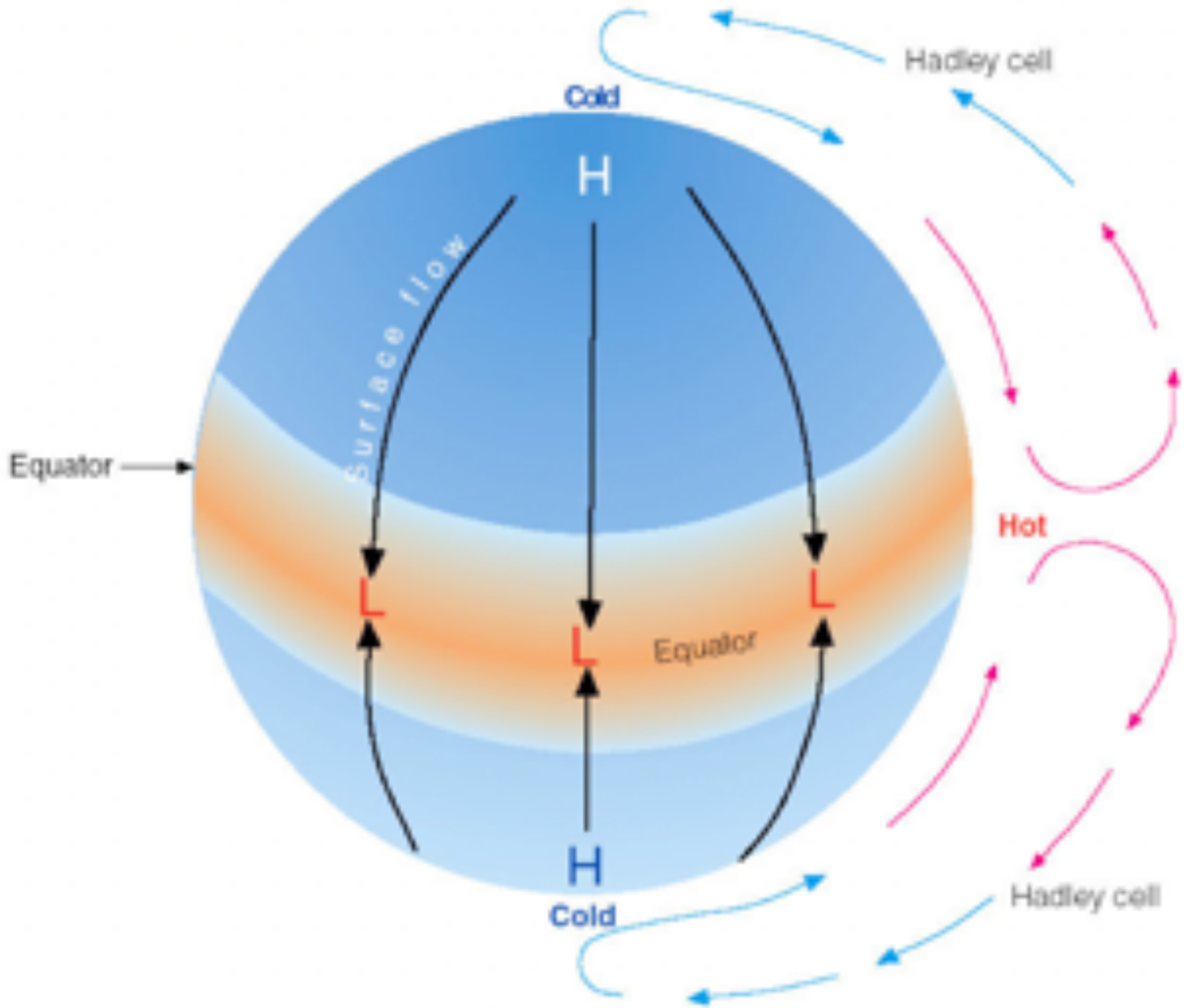


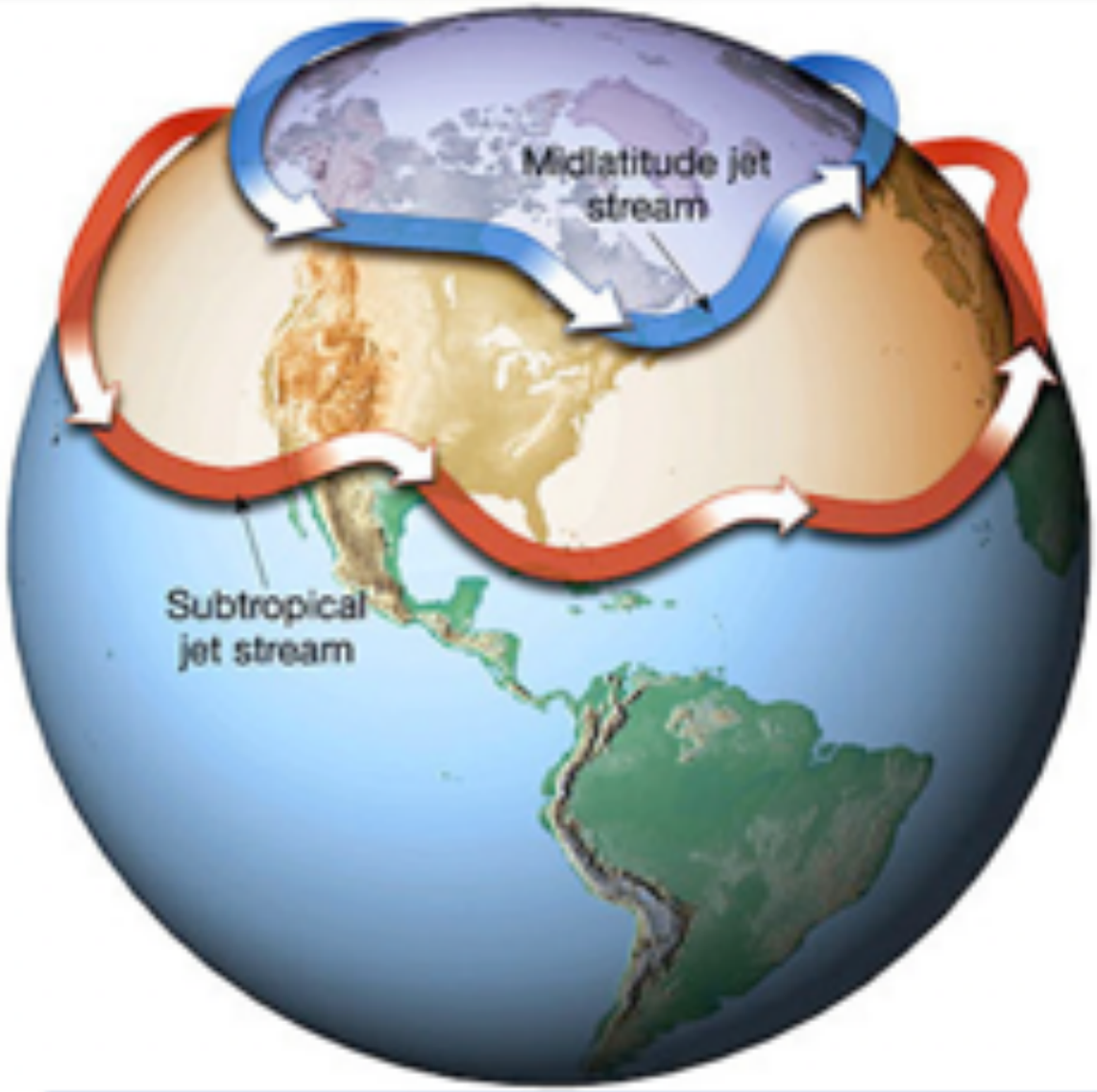
This global cell is an example of how a warmer atmosphere in one location relative to another can help drive a circulation. We will return to this in a few slides, but this particular thermally direct cell is called the **Hadley cell**.

One-cell model: the one envisioned by Hadley

- A thermal circulation extending all the way to the Poles from the equator.

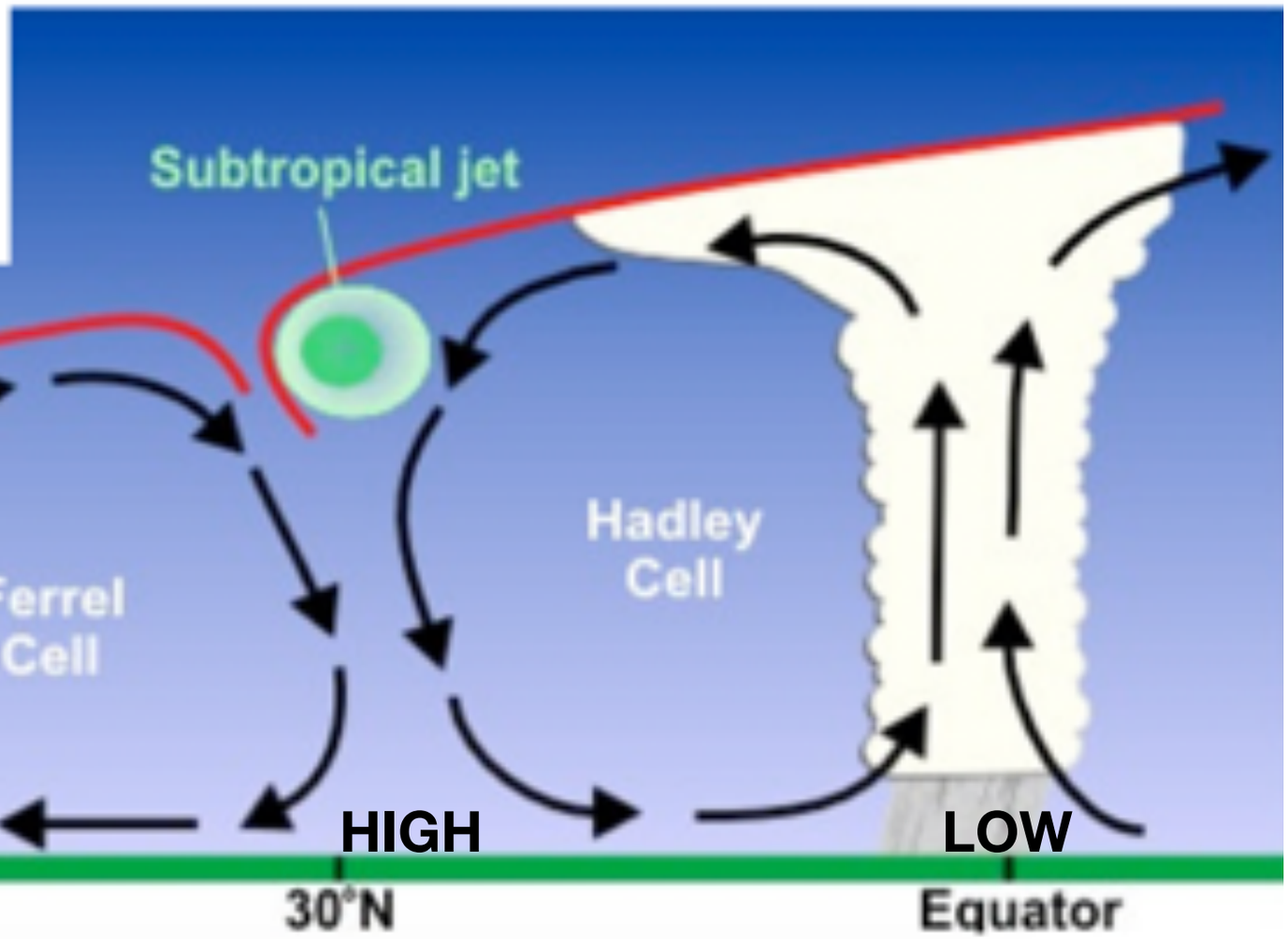
- ***If the Earth were not rotating***, this one-cell model would exist. i.e., the northernmost latitude would be 90 degrees N in the figure a few slides ago.



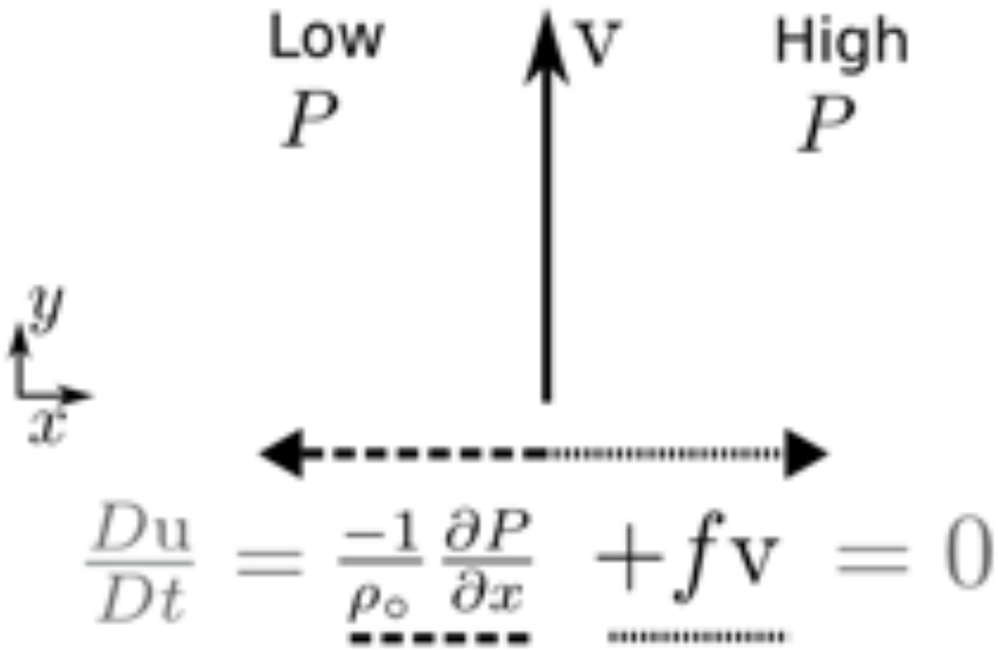


The ***Hadley Cell*** is thermally direct cells, i.e., it is associated with the rising of warm air and sinking of cool air.

not quite there yet…



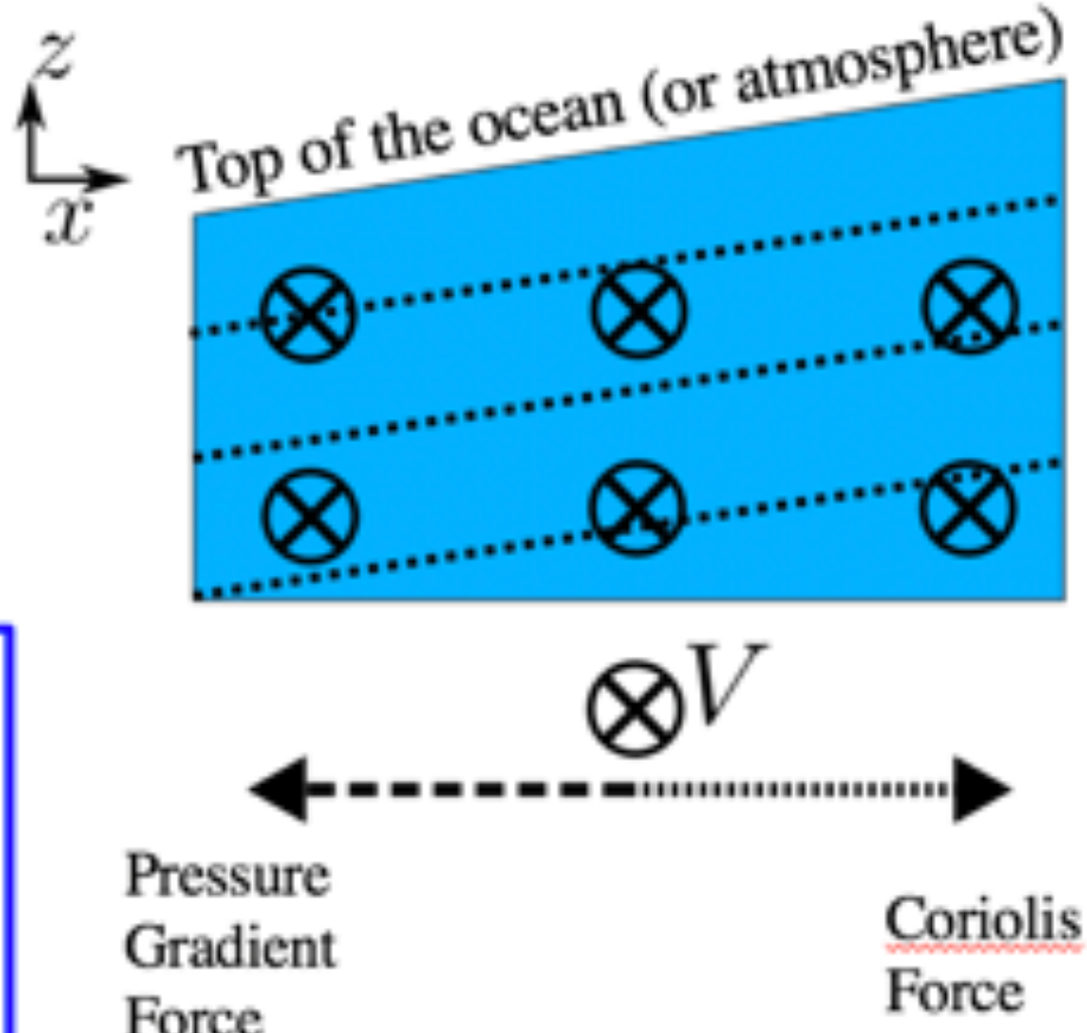
Geostrophic Balance



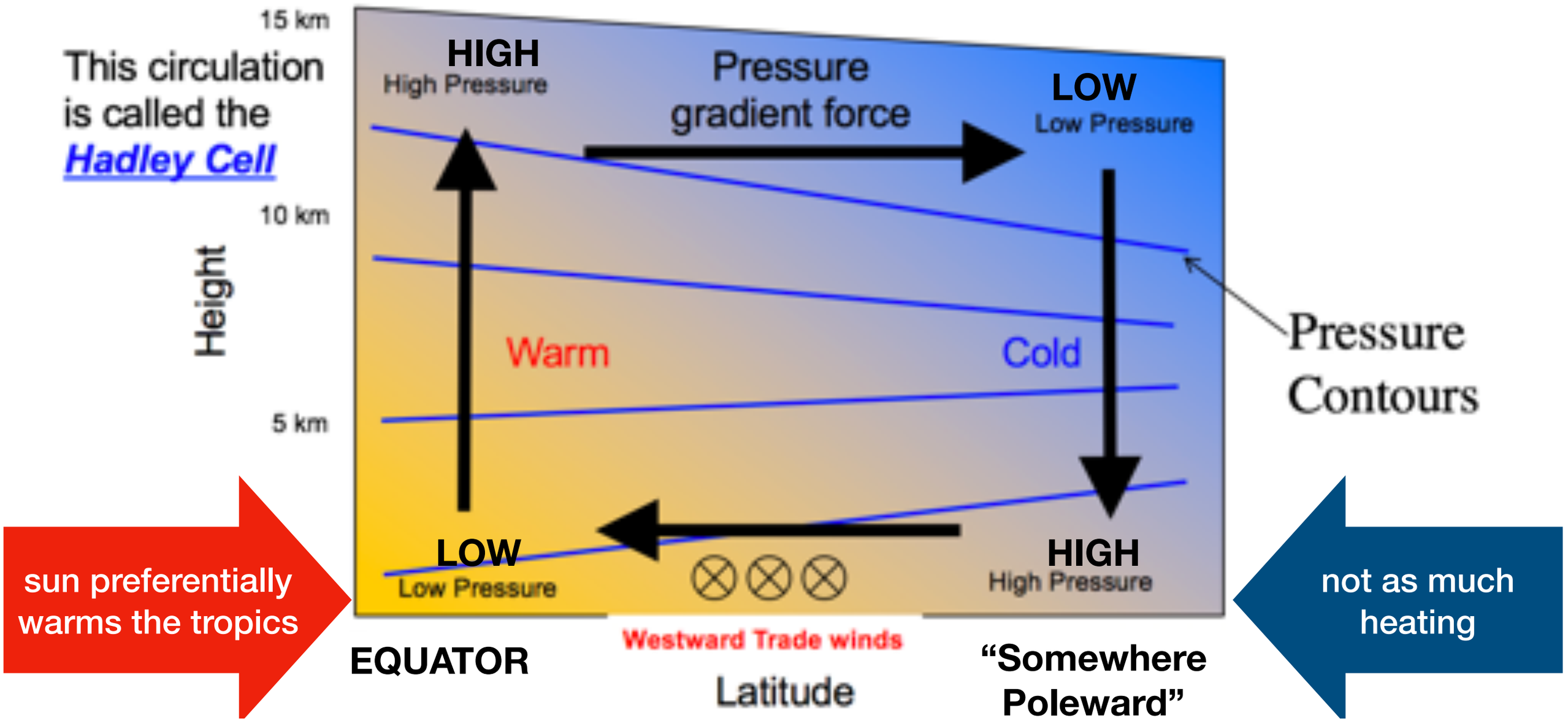
$$\frac{Du}{Dt} = \underbrace{\frac{-1}{\rho_\circ}\frac{\partial P}{\partial x}}_{\text{- - - -}} \underbrace{+fv}_{\cdots\cdots} = 0$$

- **High Pressure to RIGHT of velocity in northern hemisphere**
- **High Pressure to LEFT of velocity in southern hemisphere**

Barotropic Pressure Gradient



Thermal Cell Driven by Temperature Gradient between Tropics and Higher Latitudes



The Coriolis force strongly deflects the flow in the Hadley Cell setting up the trade winds.

One-cell model: the one envisioned by Hadley

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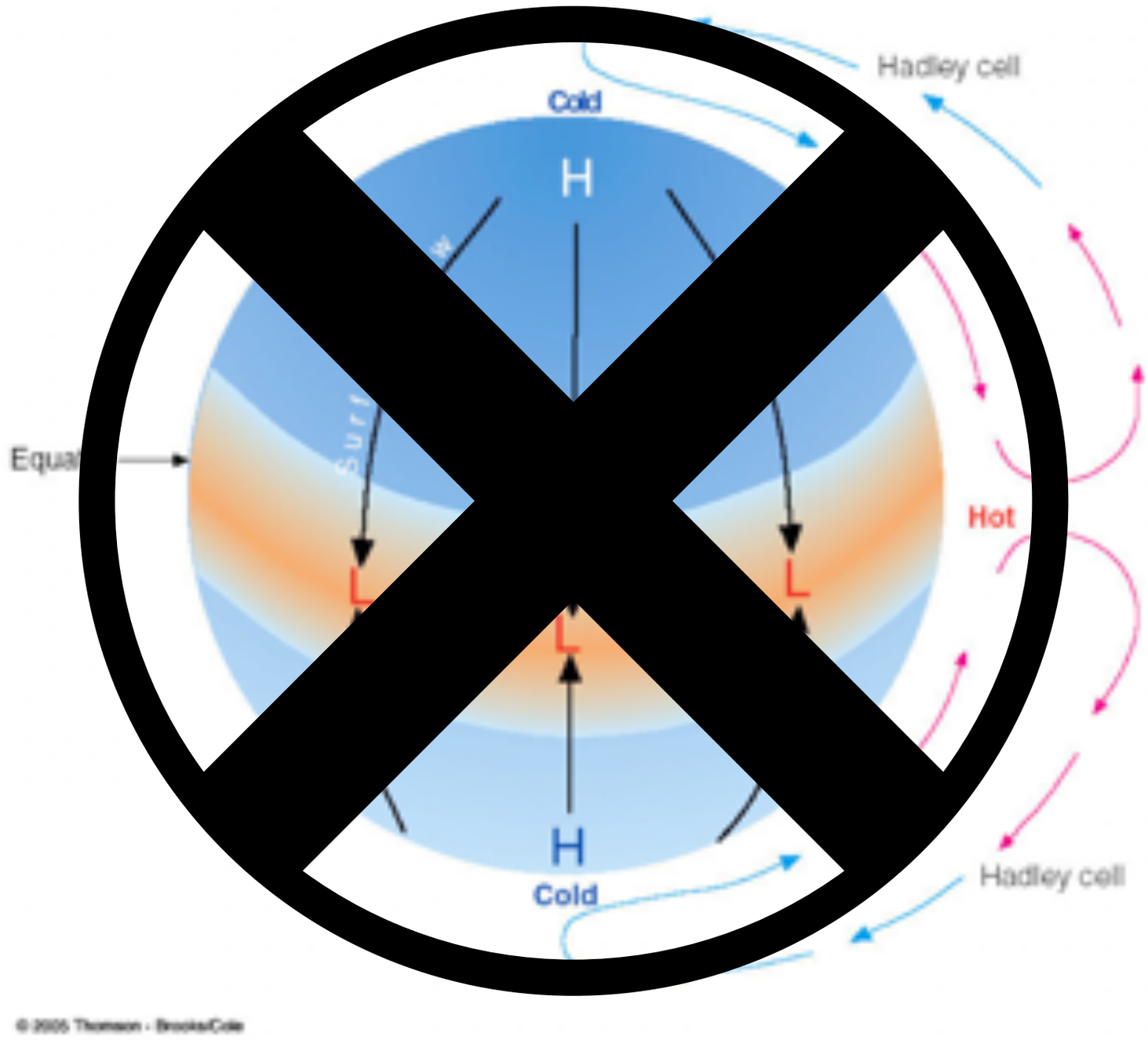
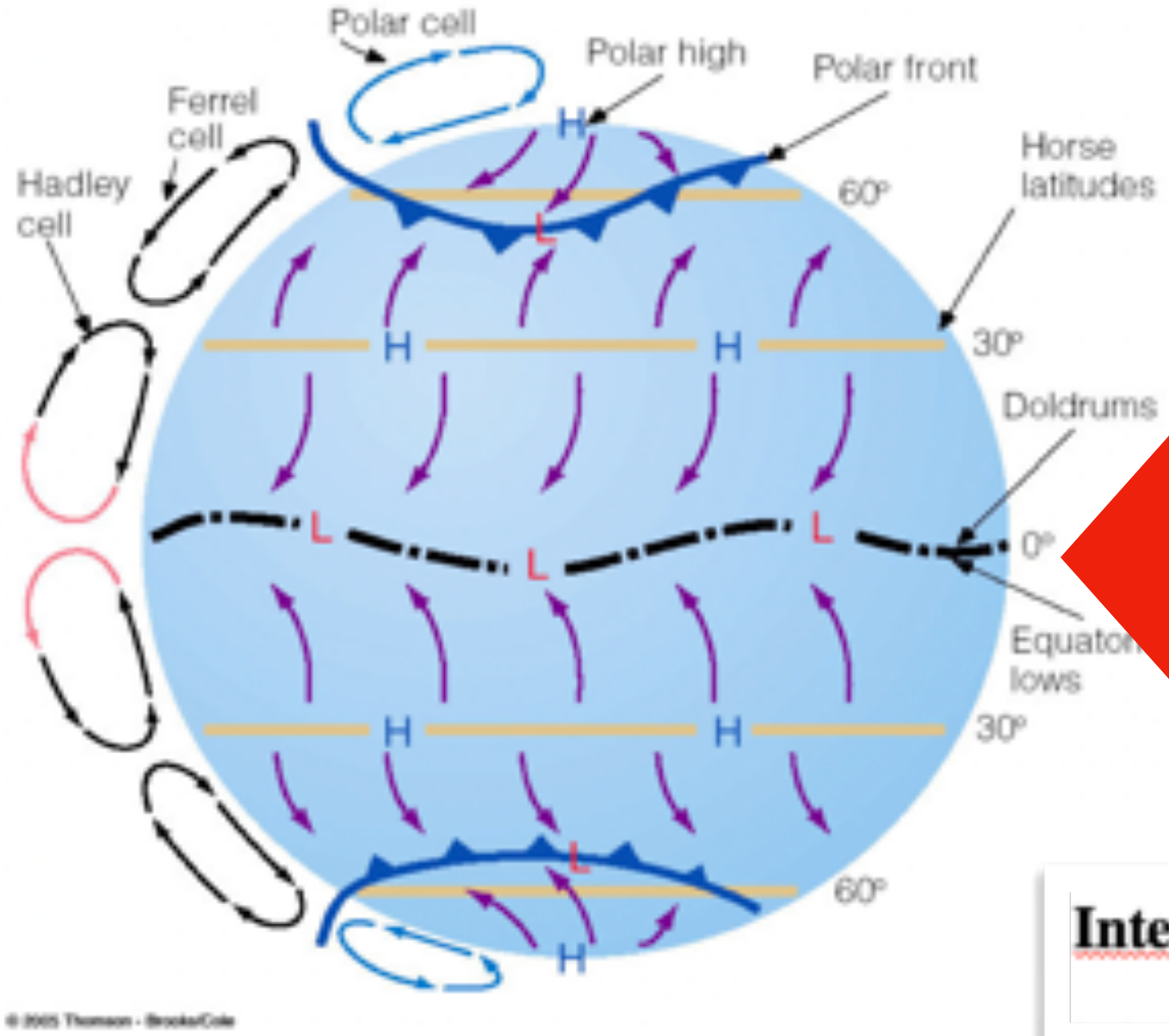


Idealized atmospheric circulation



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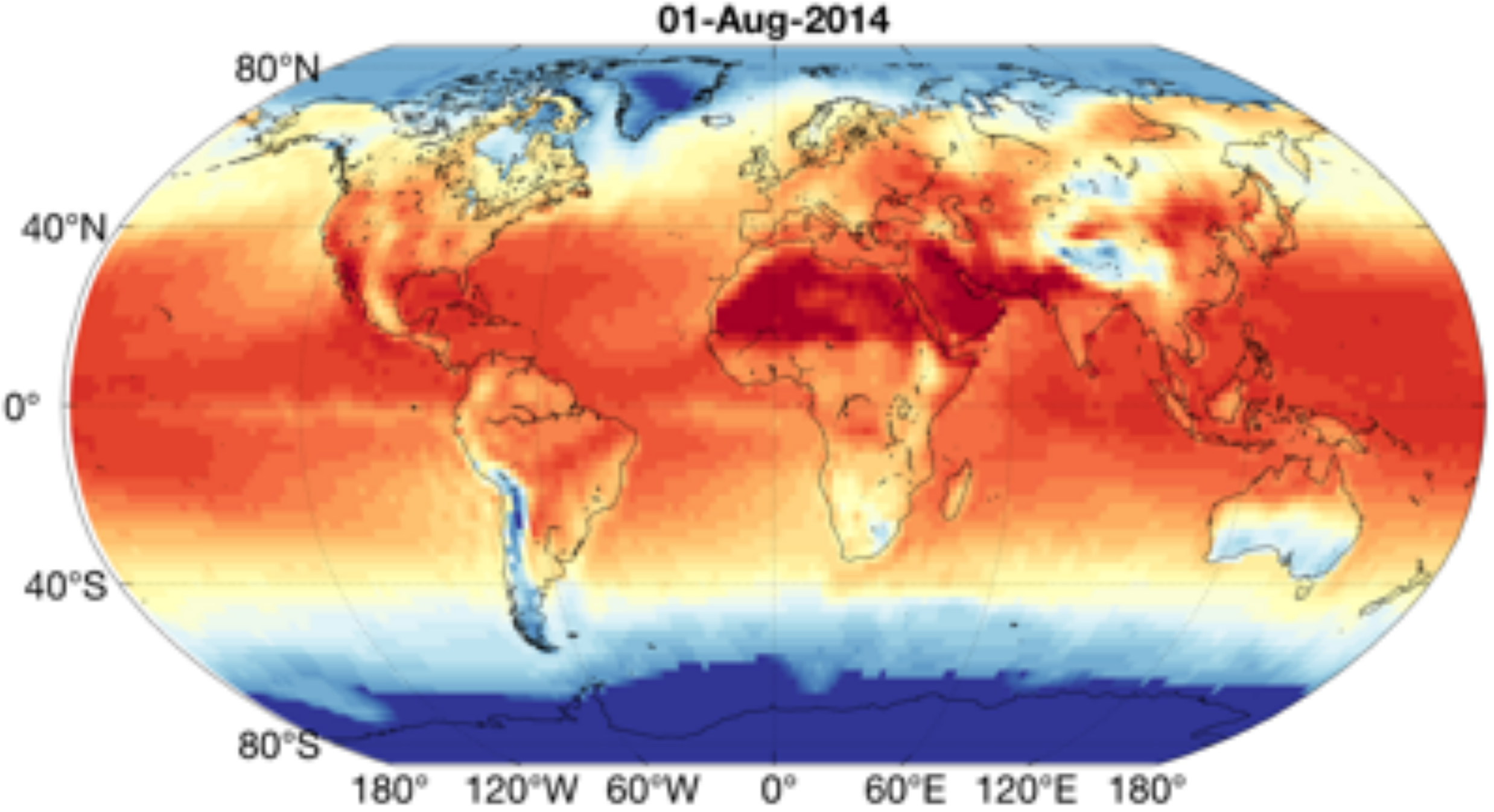
90 front, r cold

What's missing in this schematic?

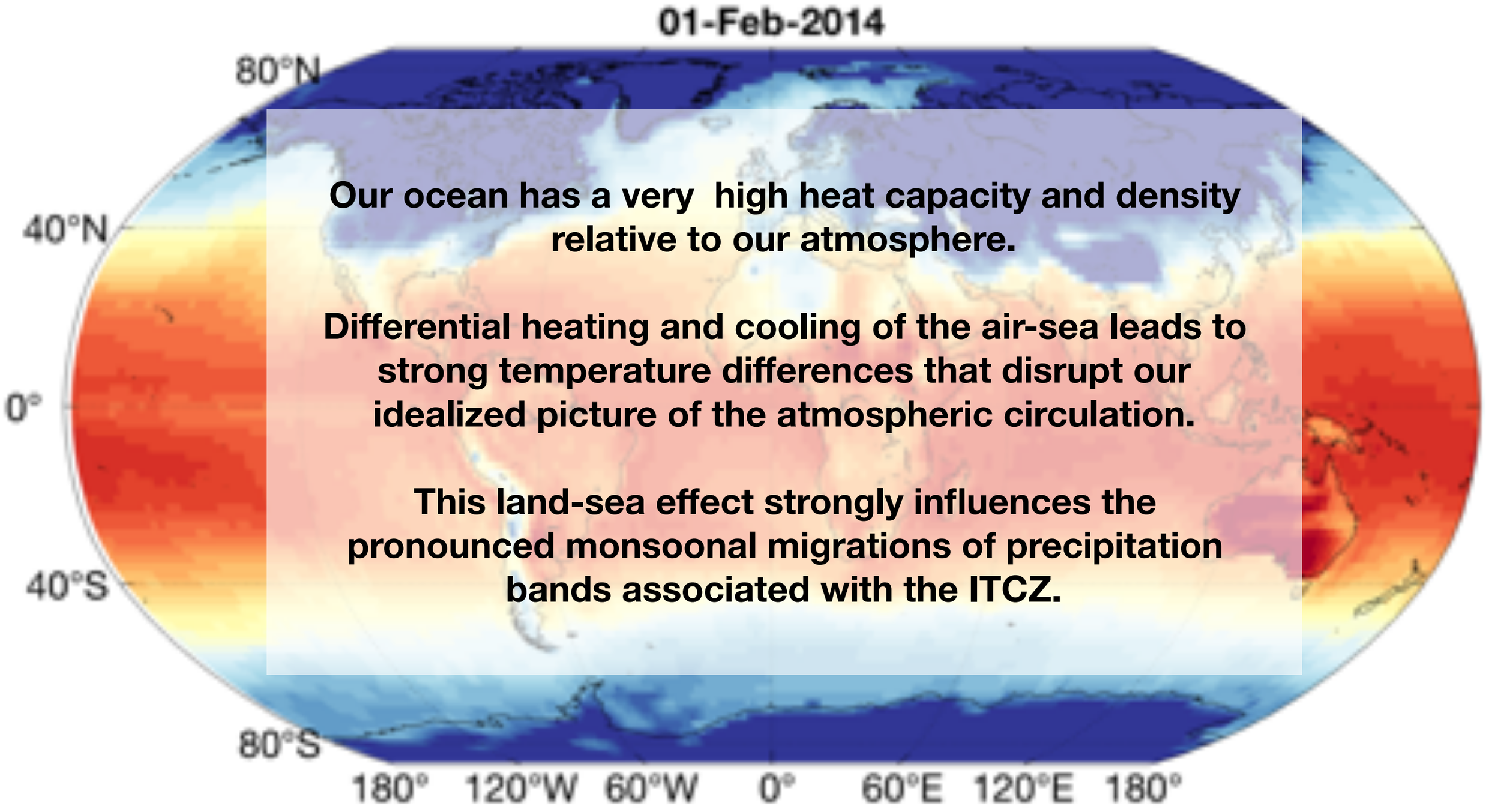
Intertropical Convergence Zone (ITCZ. low pressure)

The ITCZ is associated with a 'convergence of trade winds', large-scale atmospheric upwelling and deep convection, heavy rainfall and weak winds.

Monsoons are forced by the seasonal migration of the ITCZ, and the perturbations to this migration associated with differential heating of the land and ocean.



surface temperature- dark red near 35C, dark blue near or less than 0C



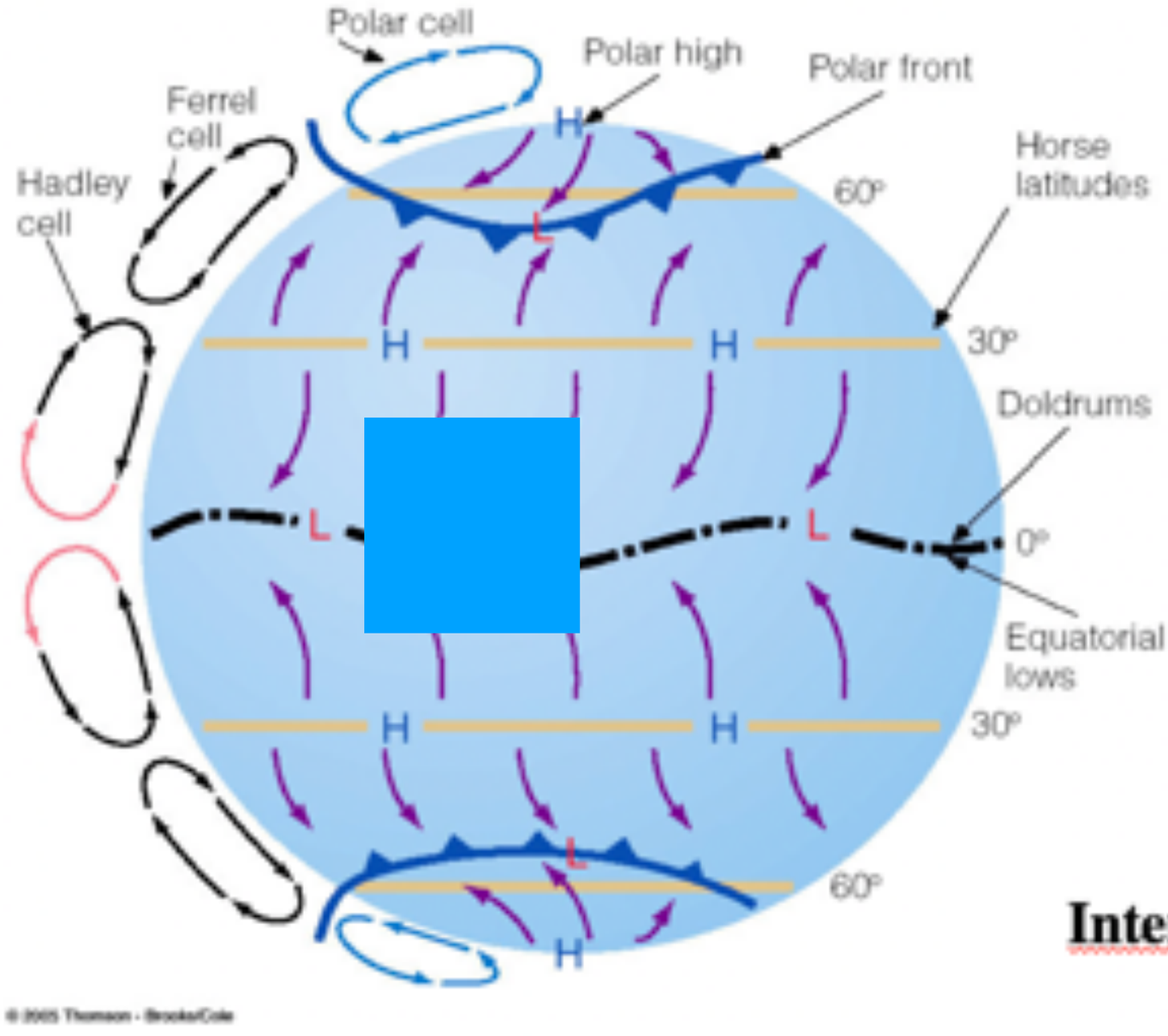
Our ocean has a very high heat capacity and density relative to our atmosphere.

Differential heating and cooling of the air-sea leads to strong temperature differences that disrupt our idealized picture of the atmospheric circulation.

This land-sea effect strongly influences the pronounced monsoonal migrations of precipitation bands associated with the ITCZ.

surface temperature- dark red near 35C, dark blue near or less than 0C

Idealized atmospheric circulation



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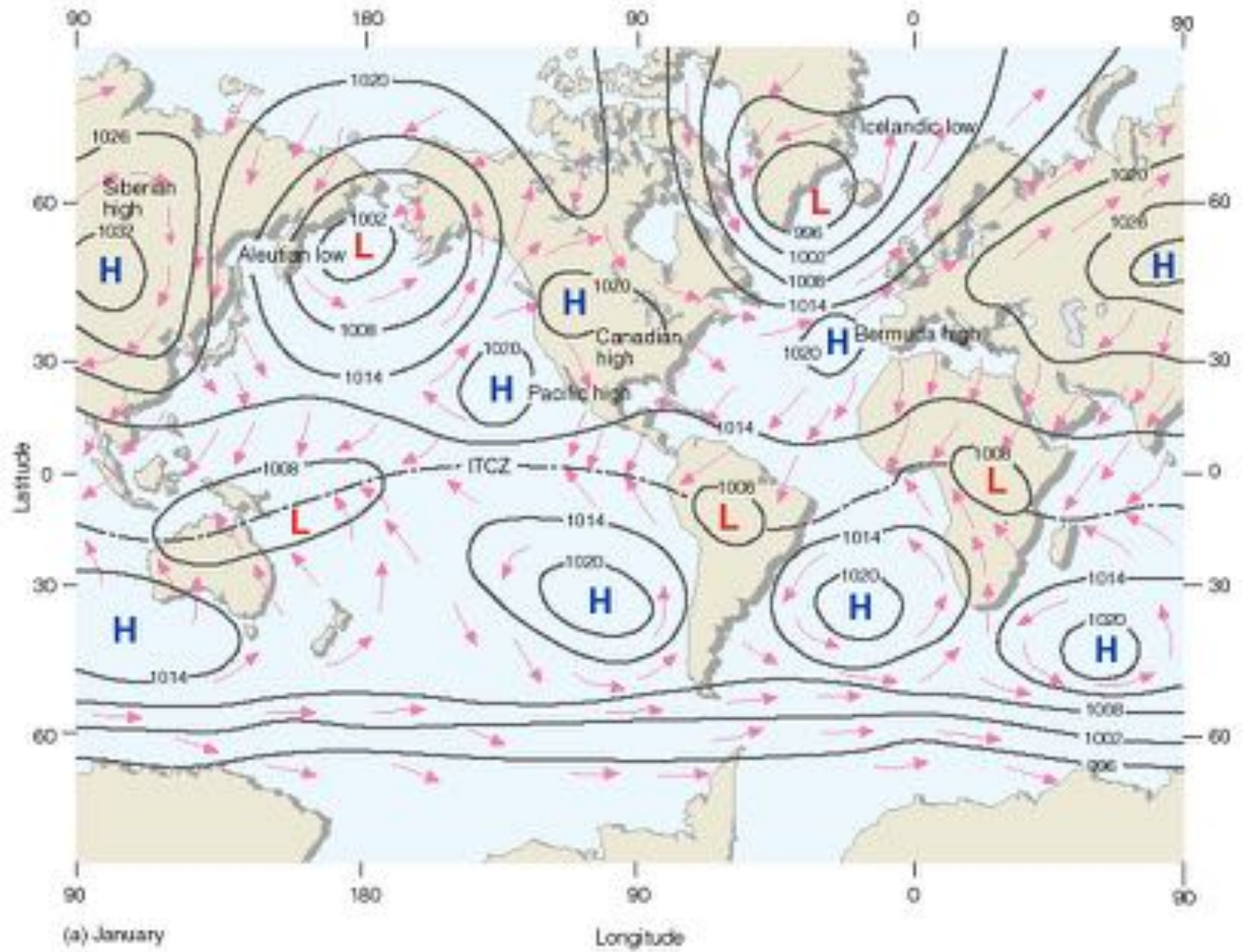
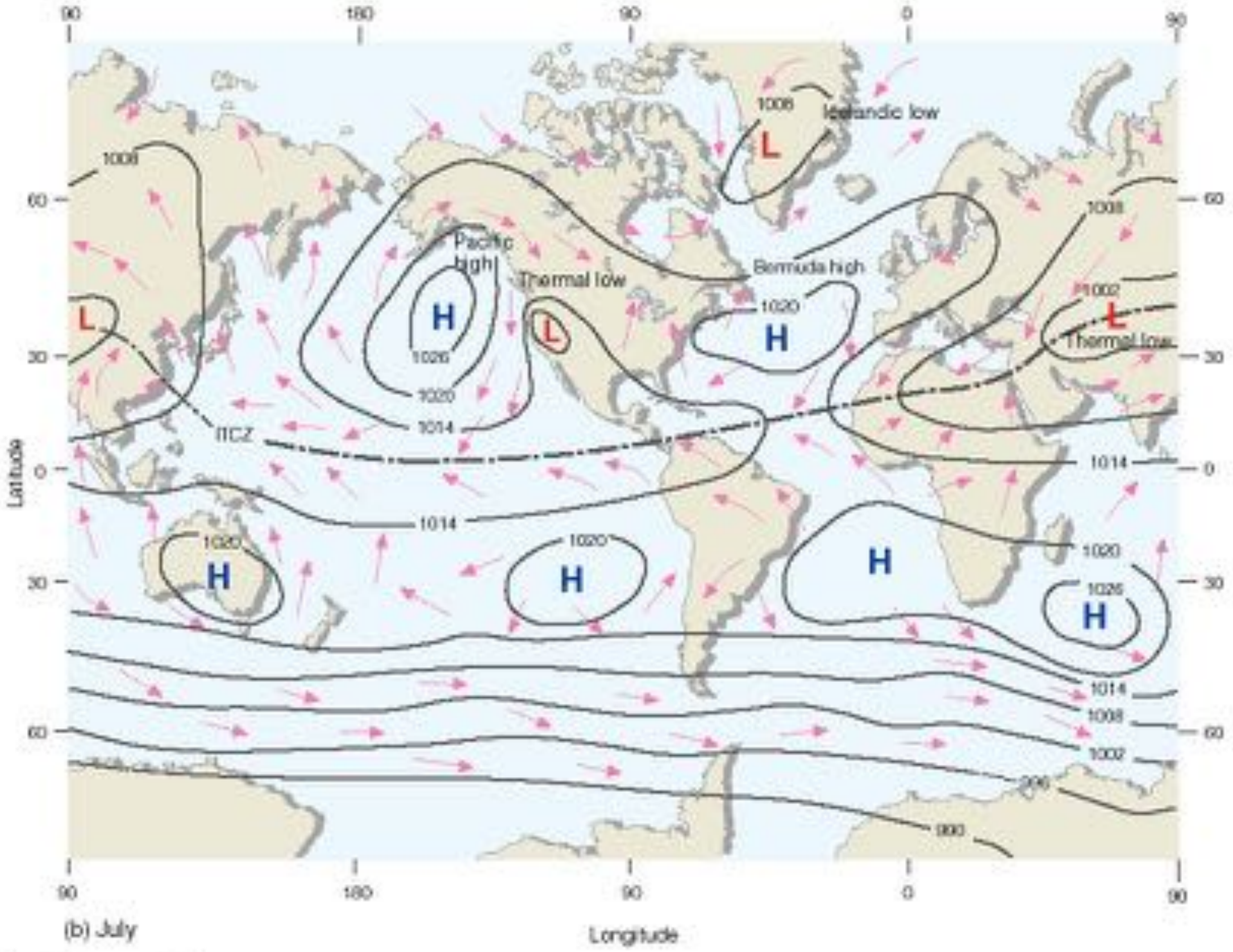
JANUARY

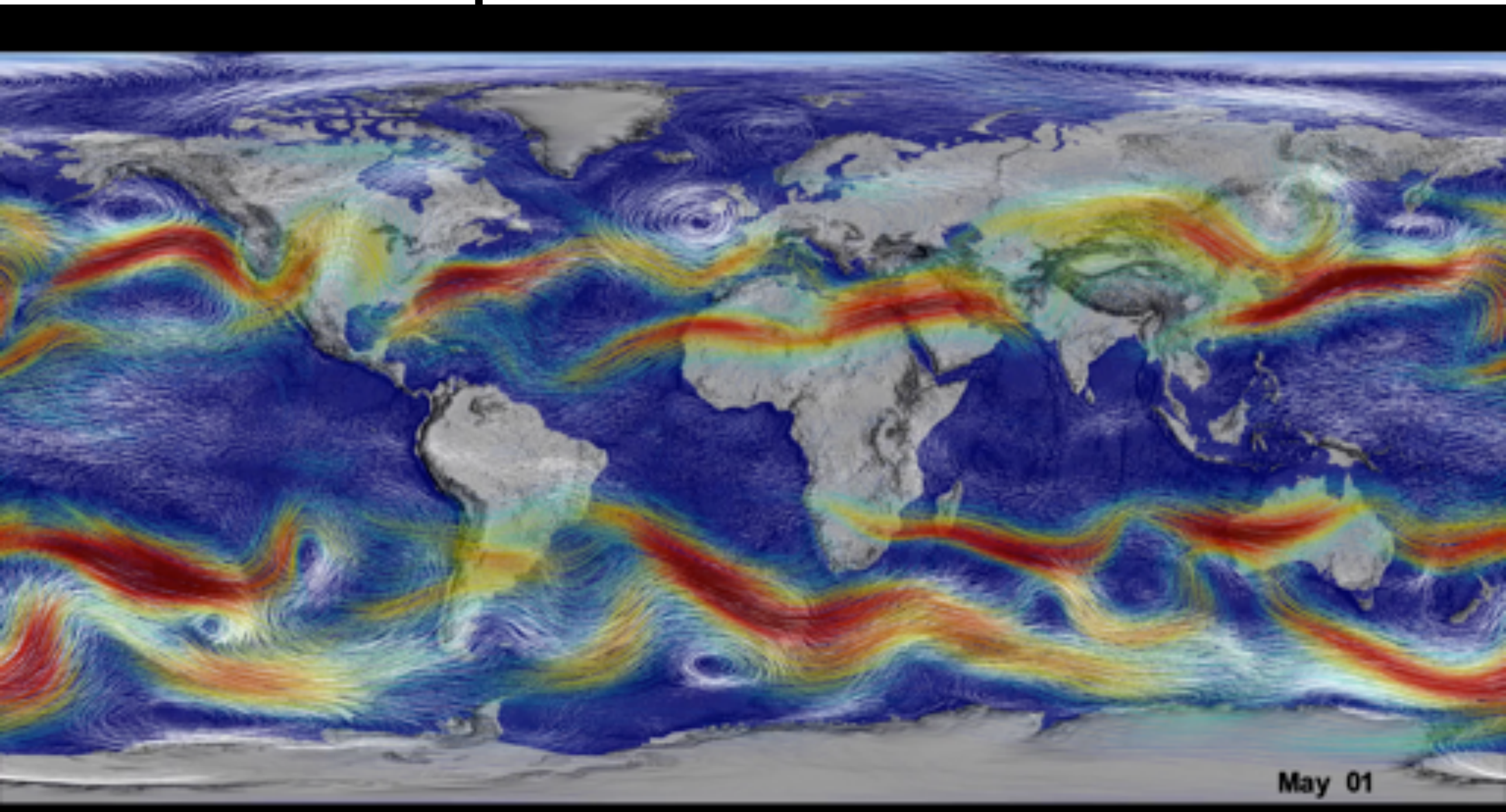


(a) January

JULY

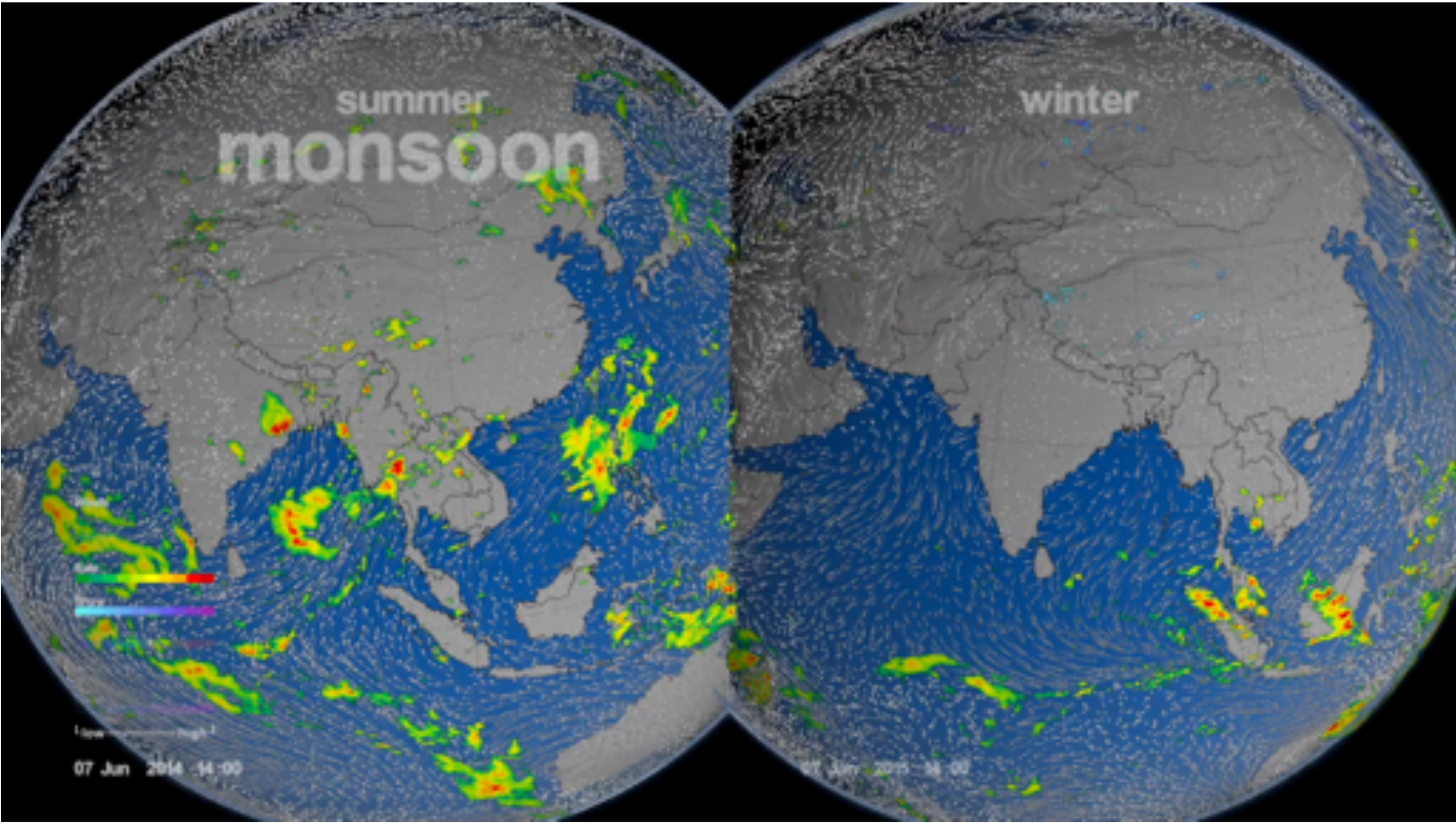


Realistic atmospheric circulation



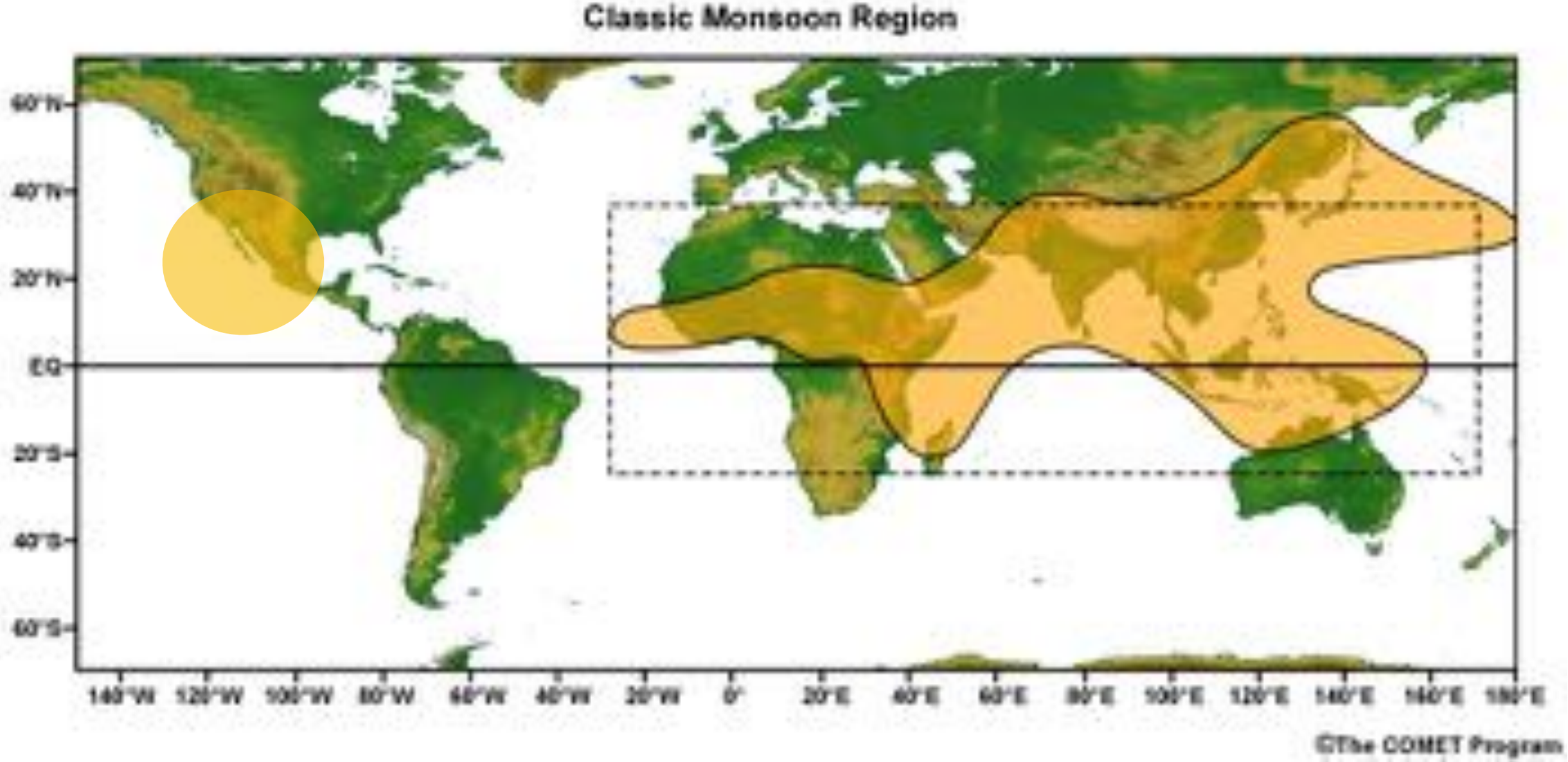
NASA MERRA

What does the monsoon look like?



NASA
Precipitation (GPM/IMERG), Winds (MERRA), Temperature (MERRA)

Where do monsoons occur?

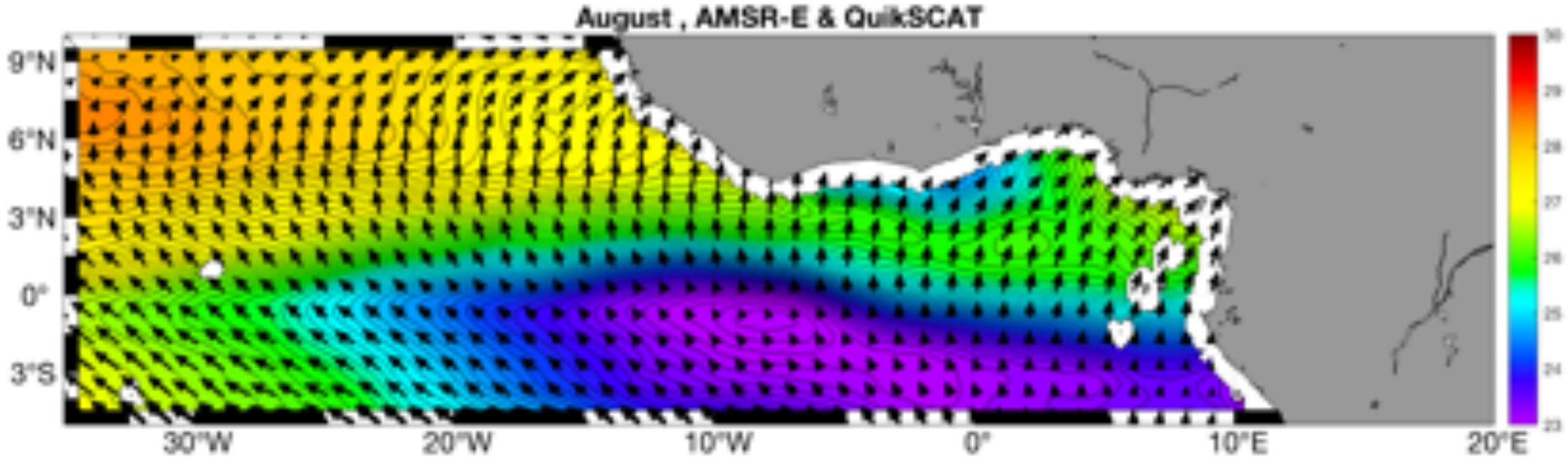


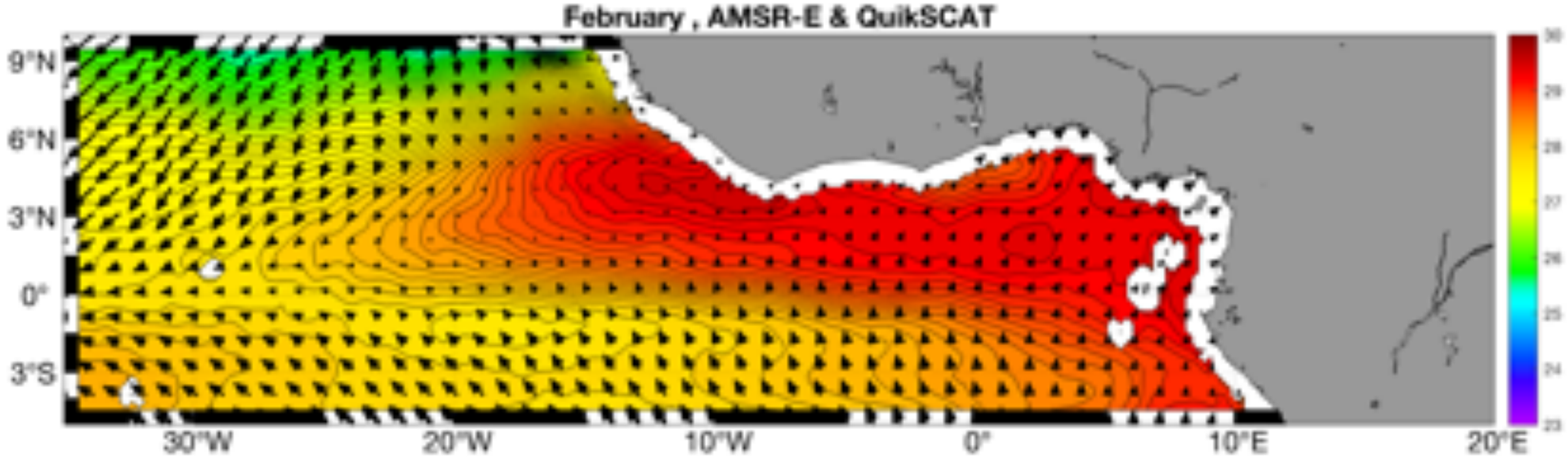
Monsoon regions as defined by Ramage 1971 (plus North America)

Definition based on the following criteria:

- Seasonal Reversal of Winds
- Mean speed of winds exceeding 3 m/s
- Pressure pattern Satisfy a steadiness criterion

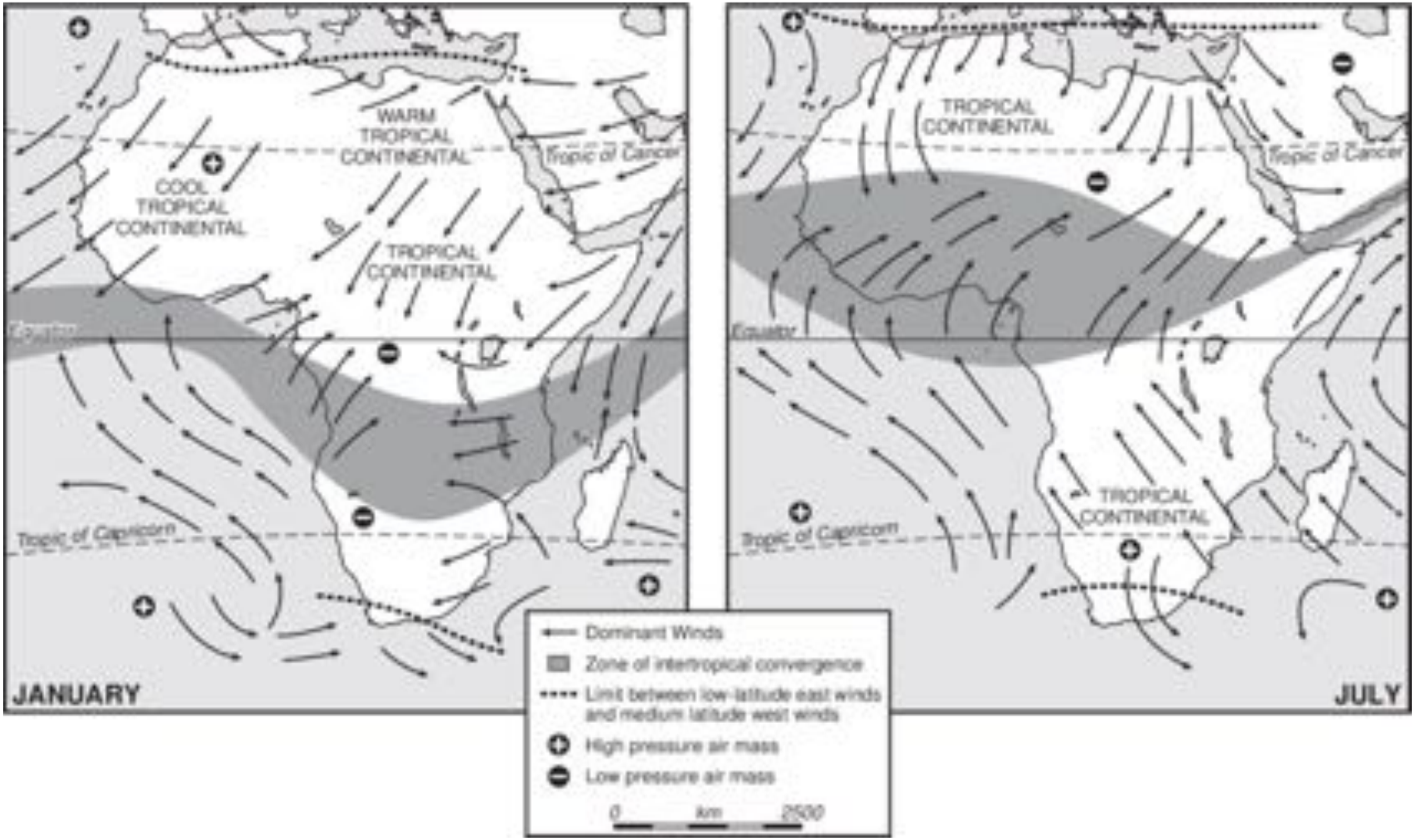
Remotely-Sensed Mean Winds/SST in the GoG





Risien & Chelton Climatology, 2008

The West African Monsoon



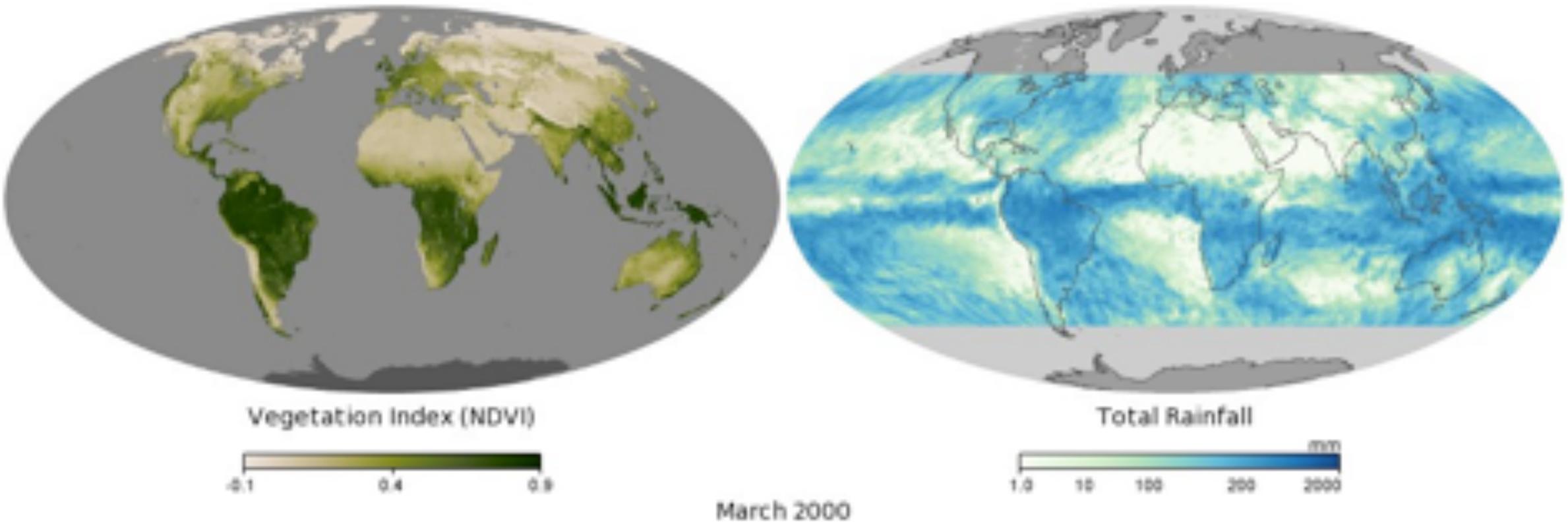
1. What processes drive monsoon circulations?

2. Where do we find monsoons?

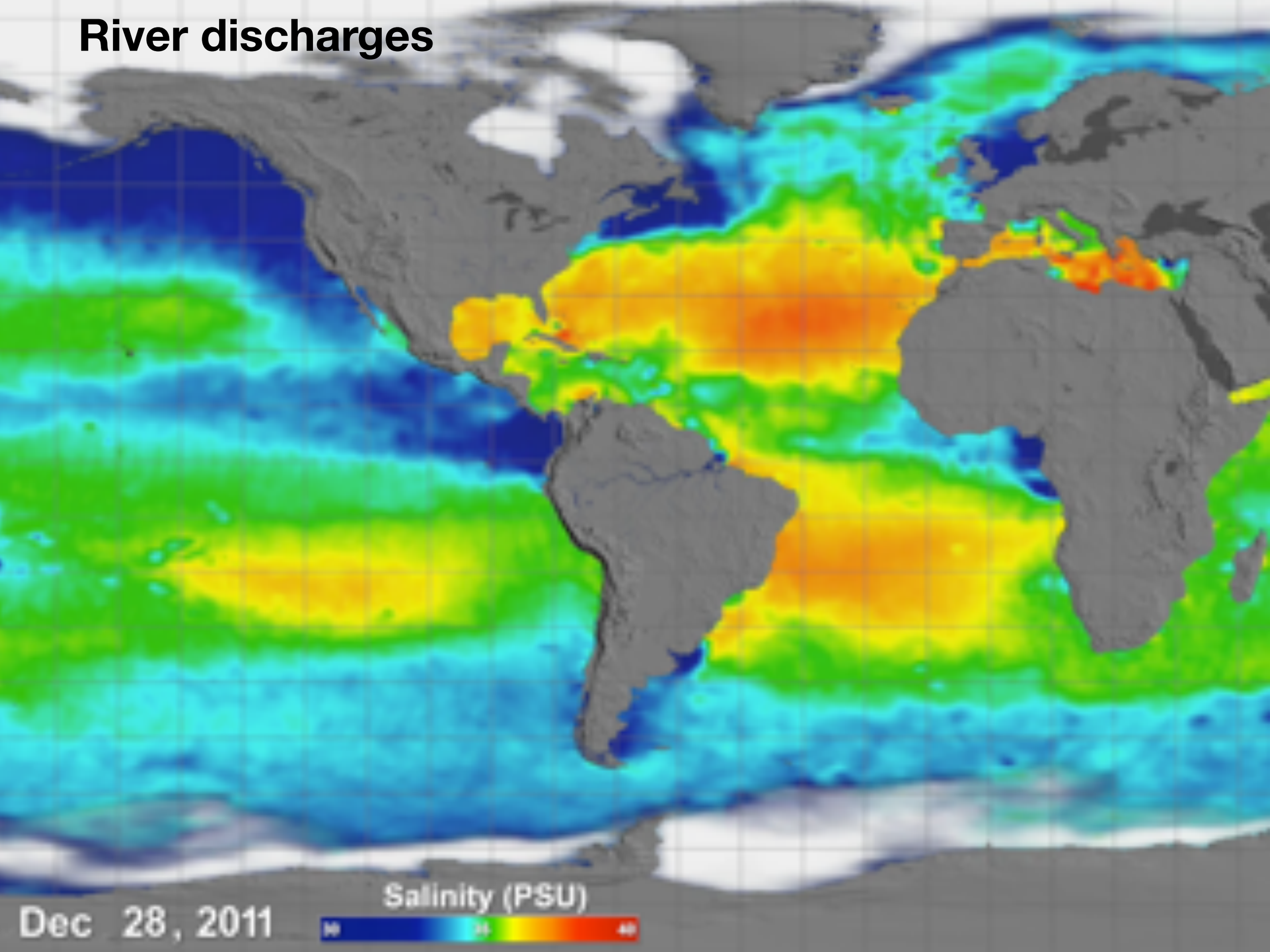
3. What does the monsoon mean for the Gulf of Guinea and West Africa?

Seasonality in solar insolation is small (~20 W/m2) near the Equator, however this variability leads to a pronounced seasonality associated with the monsoon with strong changes in SST, winds, and convection.

Precipitation Patterns-
Greening of the Sahel



River discharges



Coastal Circulation and Upwelling

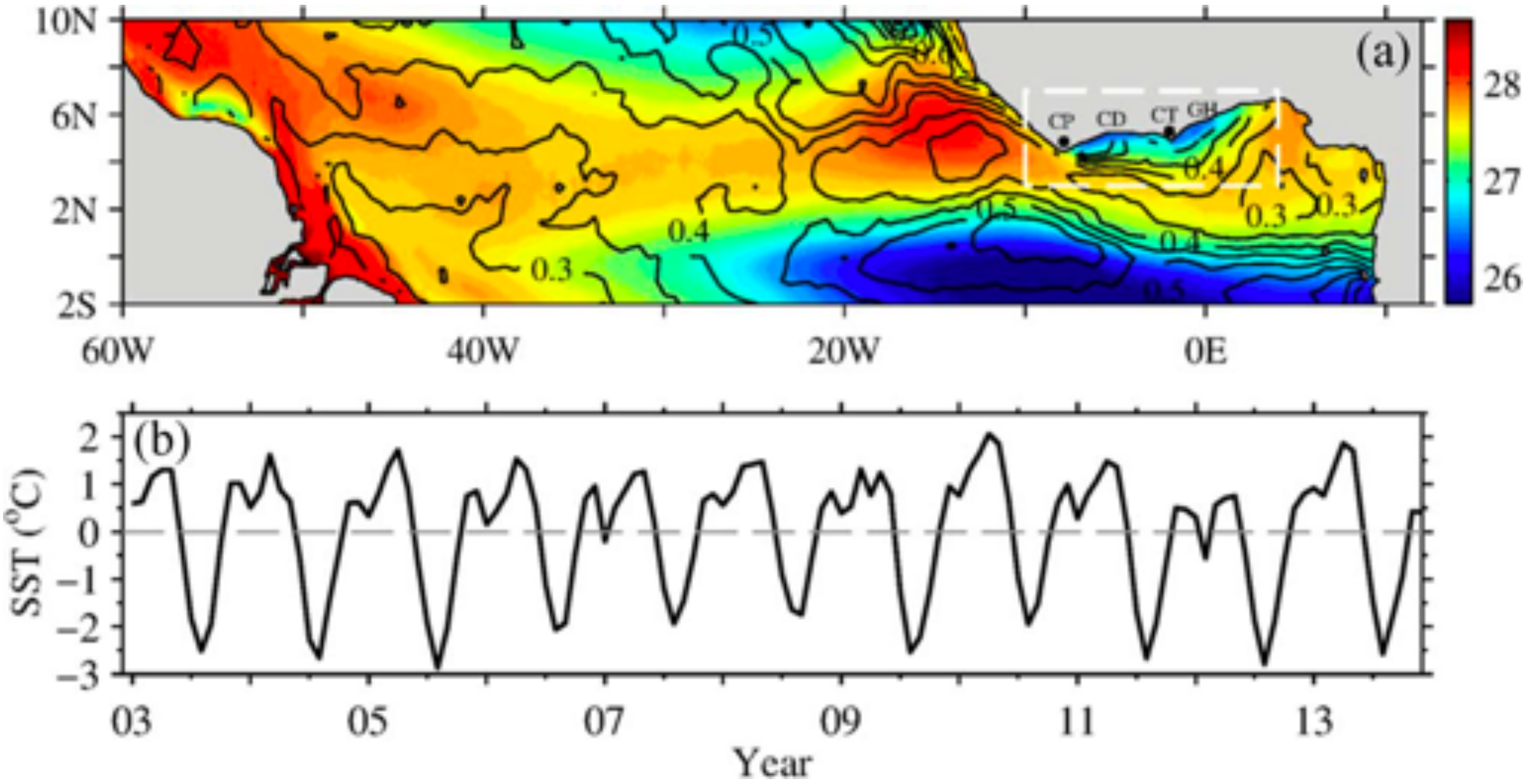


Fig. 1. (a) Annual mean SST (in degrees Celsius) (color shaded) in the Central Atlantic Ocean. Contours show standard deviation of SST. Contour interval is 0.05C. White box (10W–4E, 3N–7N) shows the northwestern GoG region, our primary area of focus: CP, Cape Palmas; CD, Côte d'Ivoire; CT, Cape Three Points; GH, Ghana. (b) Seasonal variation of SST spatially averaged in the northwestern GoG box region from 2003 to 2013. **Waife and Nyardo**

Modern day climate models have varying success at simulating monsoon circulation and precipitation.

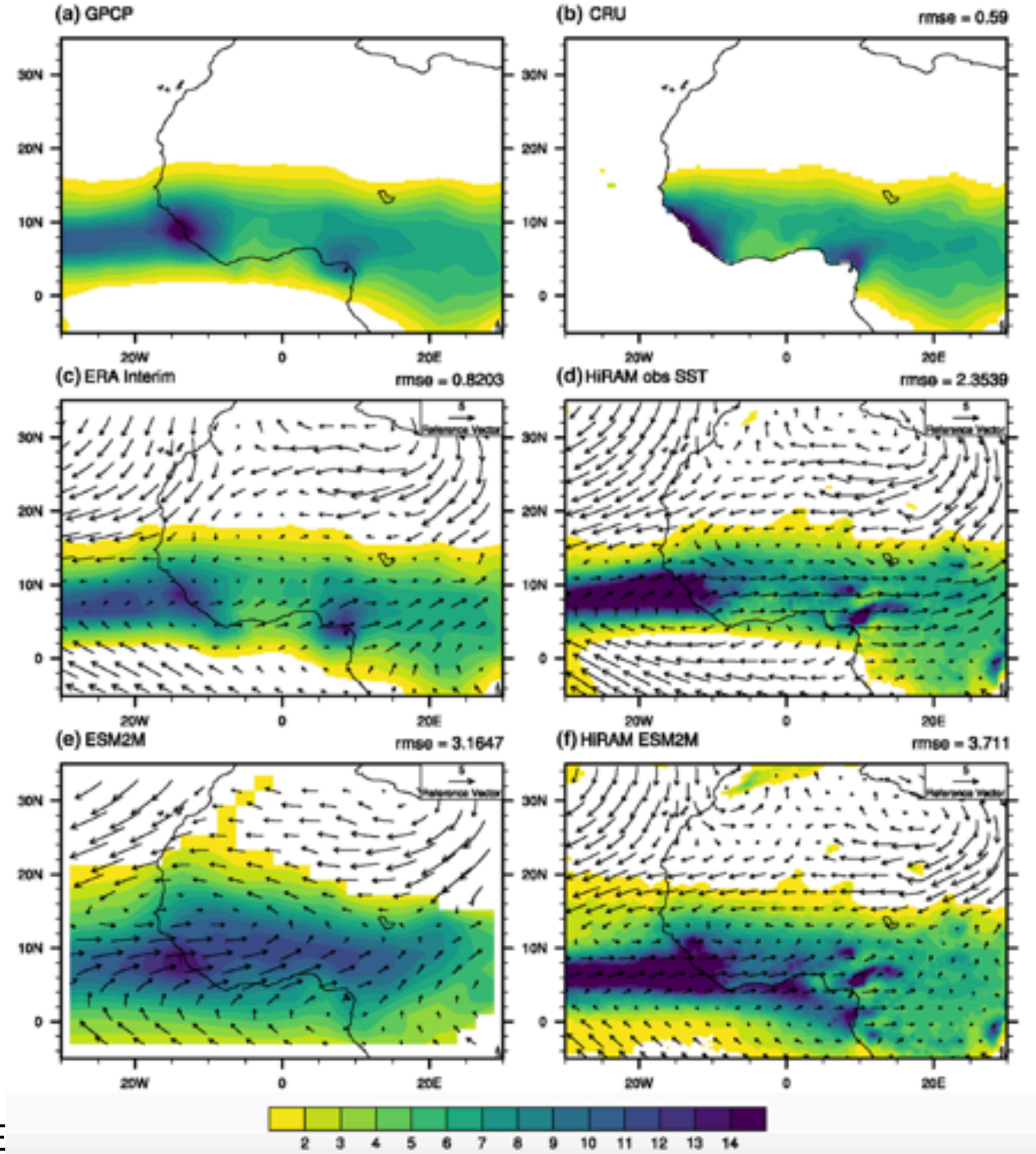
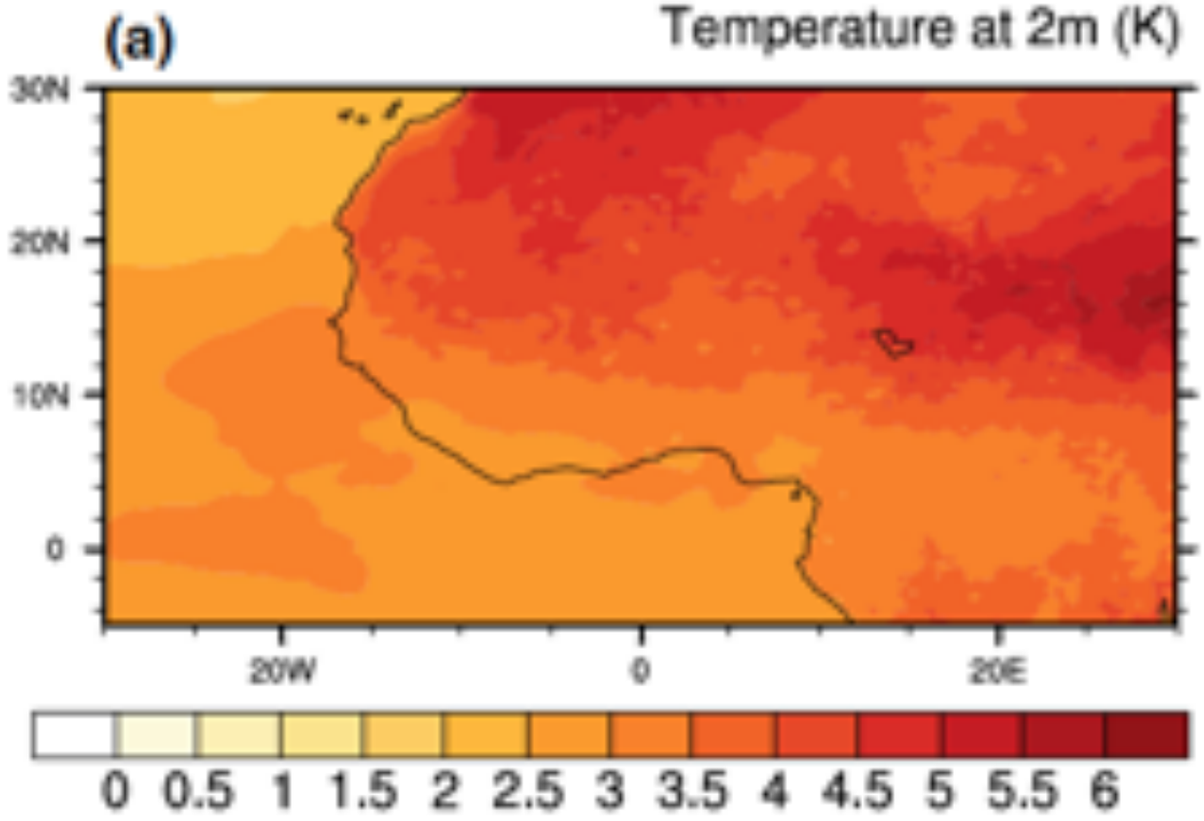


Fig. 1 Seasonal mean precipitation rate (filled contours; mm/day) and 850 hPa wind (vectors, m/s) from a GPCP; b CRU; c ERA Interim; d HiRAM-obsSST; e ESM2M; f HiRAM-ESM2M averaged over June–September (JJAS) for the period 1974–2004. Wind reference vector is 5 m/s. Precipitation RMSE is calculated with respect to GPCP.

Raj et al, Climate Dynamics (2019)

"The future projection of the WAM exhibits warming over the entire domain, decreasing precipitation over the southern Sahel, and increase of precipitation over the western Sahara."
Raj et al, Climate Dynamics (2019)



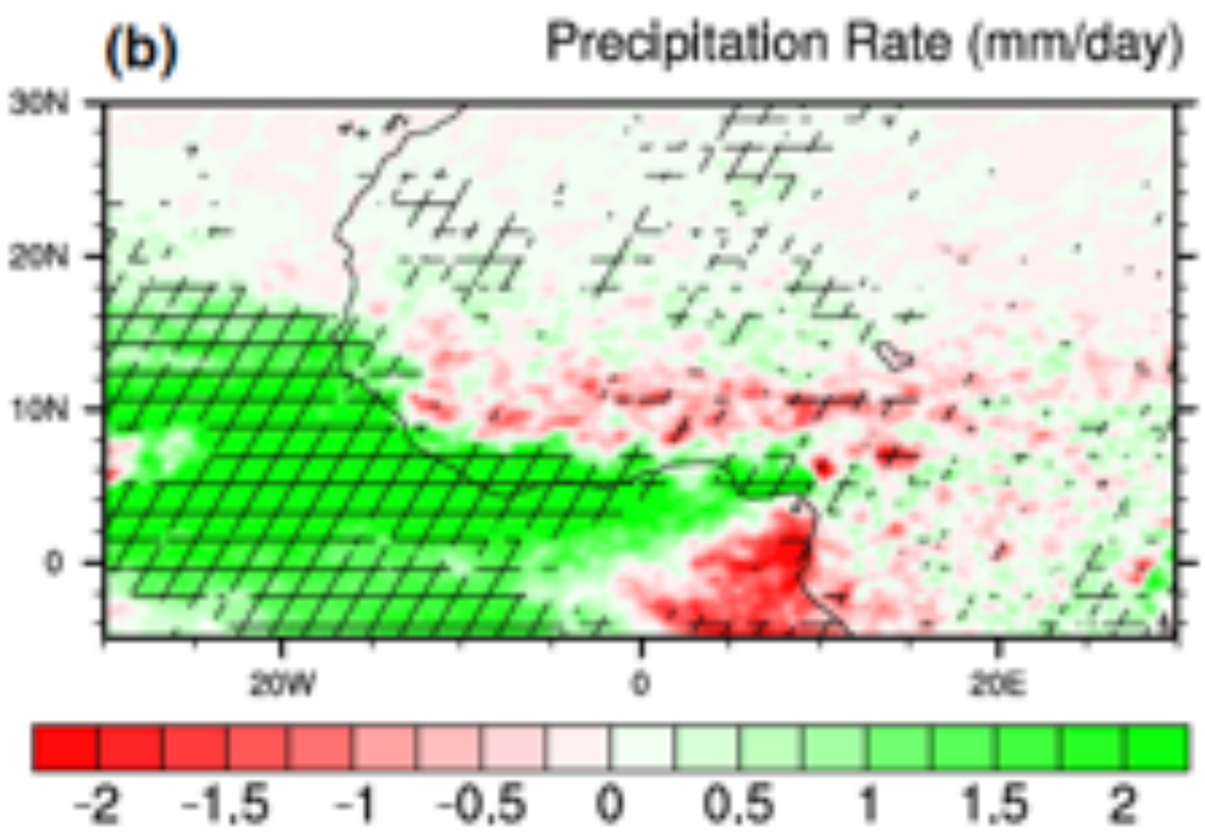


Fig. 13 Projected changes in HiRAM RCP 8.5 by the end of 21st century in, a mean summer (JJAS) 2-m temperature (K), only values with at least 95% significance level are plotted; b mean summer (JJAS) precipitation rate (mm/day), hatching shows the areas where the anomalies are statistically significant at least at 95% level. Anomalies are calculated by subtracting mean of variables in the historical period (1985–2004) from that of future (2080–2099)

1. What processes drive monsoon circulations?

Monsoons are forced by the seasonal migration of the ITCZ, and the perturbations to this migration associated with differential heating of the land and ocean.

2. Where do we find monsoons?

Throughout the tropical band— including Southeast Asia, West Africa, western United States, and northern Australia.

3. What does the monsoon mean for the Gulf of Guinea and West Africa?

rain!!, vegetation growth, changes in winds and coastal circulation

need projections for monsoon under a warming climate