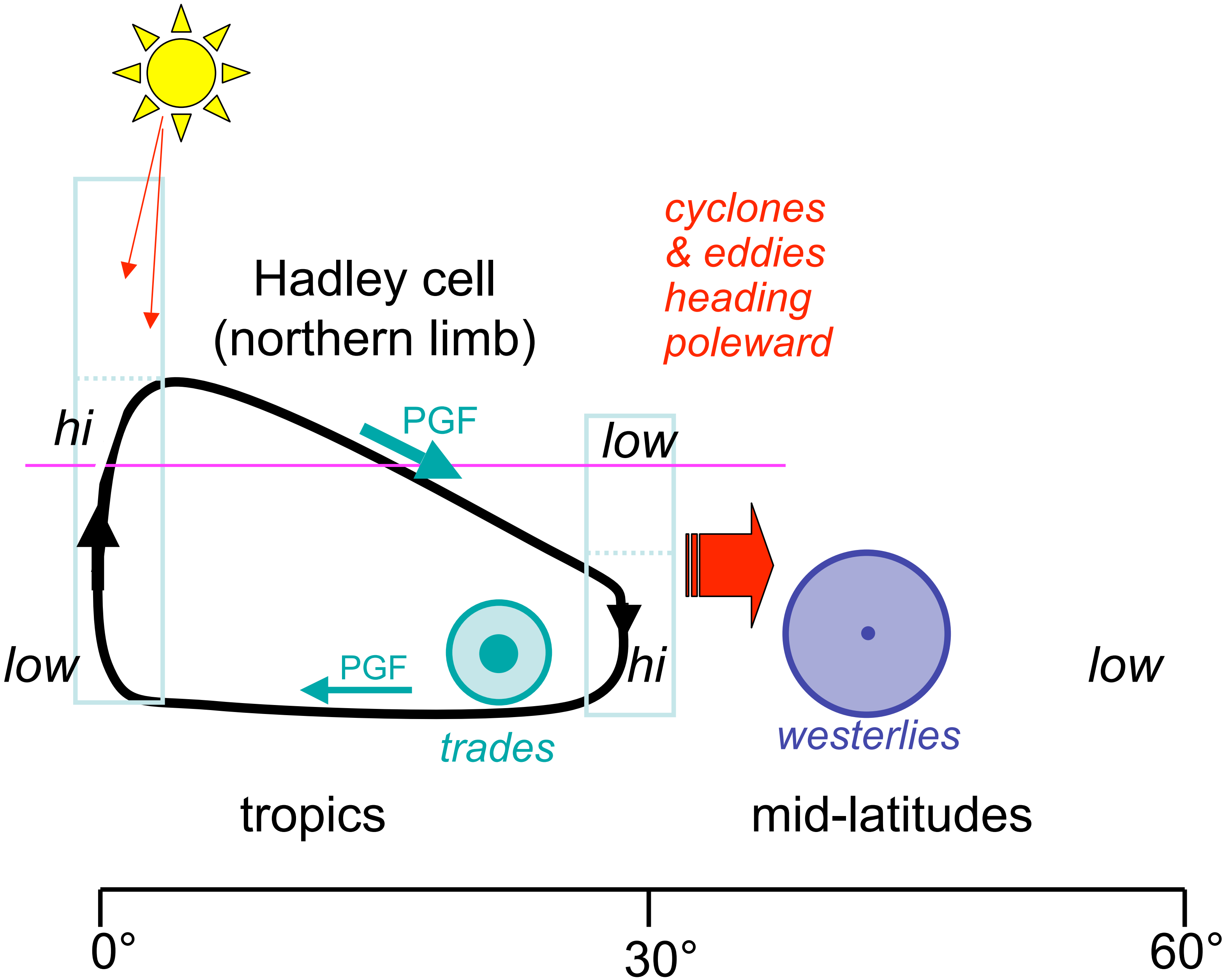
IIX. climate features of the hydrologic cycle

Hurricane Isabel from the International Space Station
Tuesday, 16 September 2003

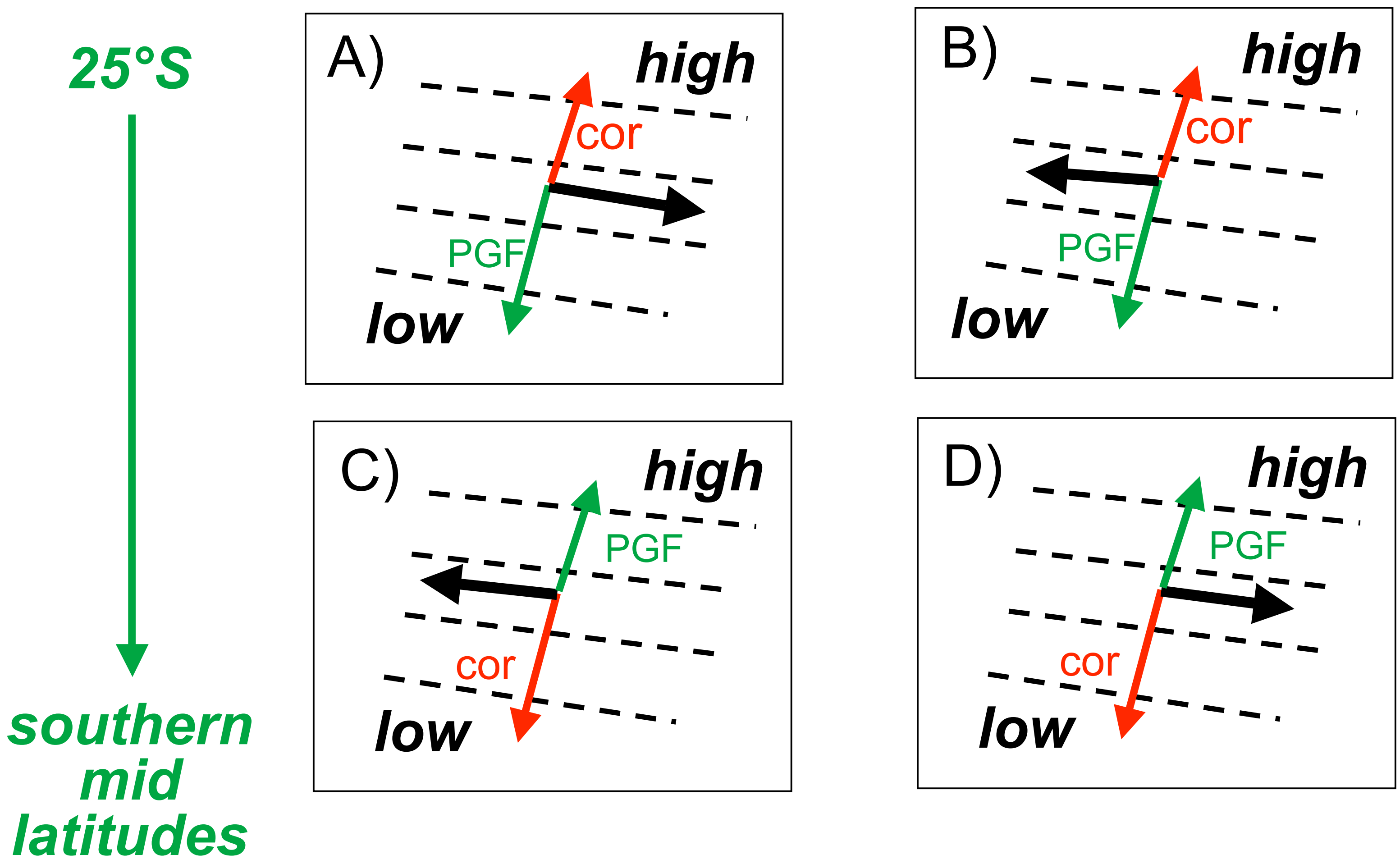
review



Hadley cell
(northern limb)
cyclones
& eddies
heading
poleward
hi
PGF
low
low
PGF
hi
low
trades
westerlies
tropics
mid-latitudes
0°
30°
60°

clicker question

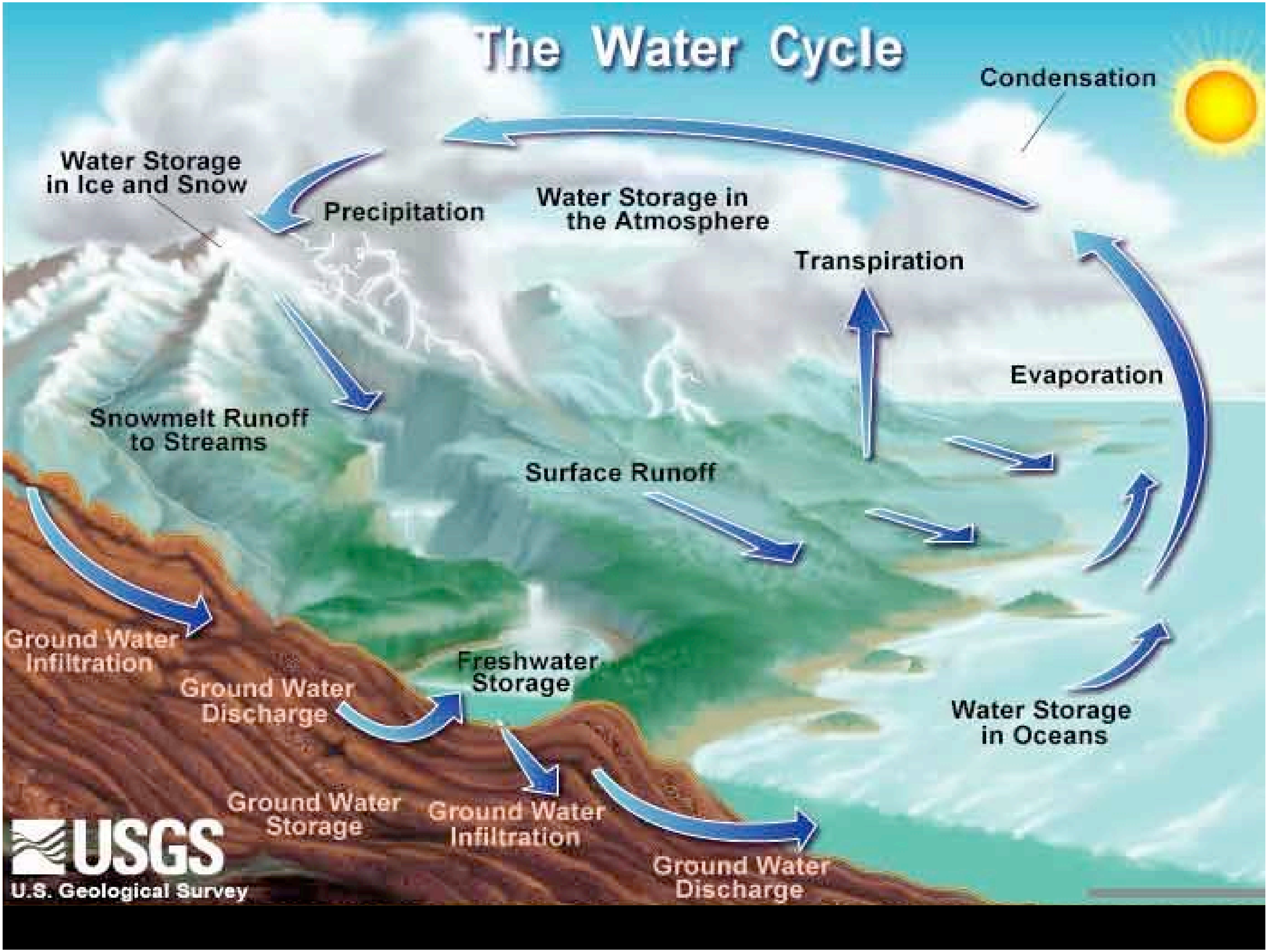
In the Southern Hemisphere, the geostrophic wind (the bold black arrow) would best be represented by diagram….



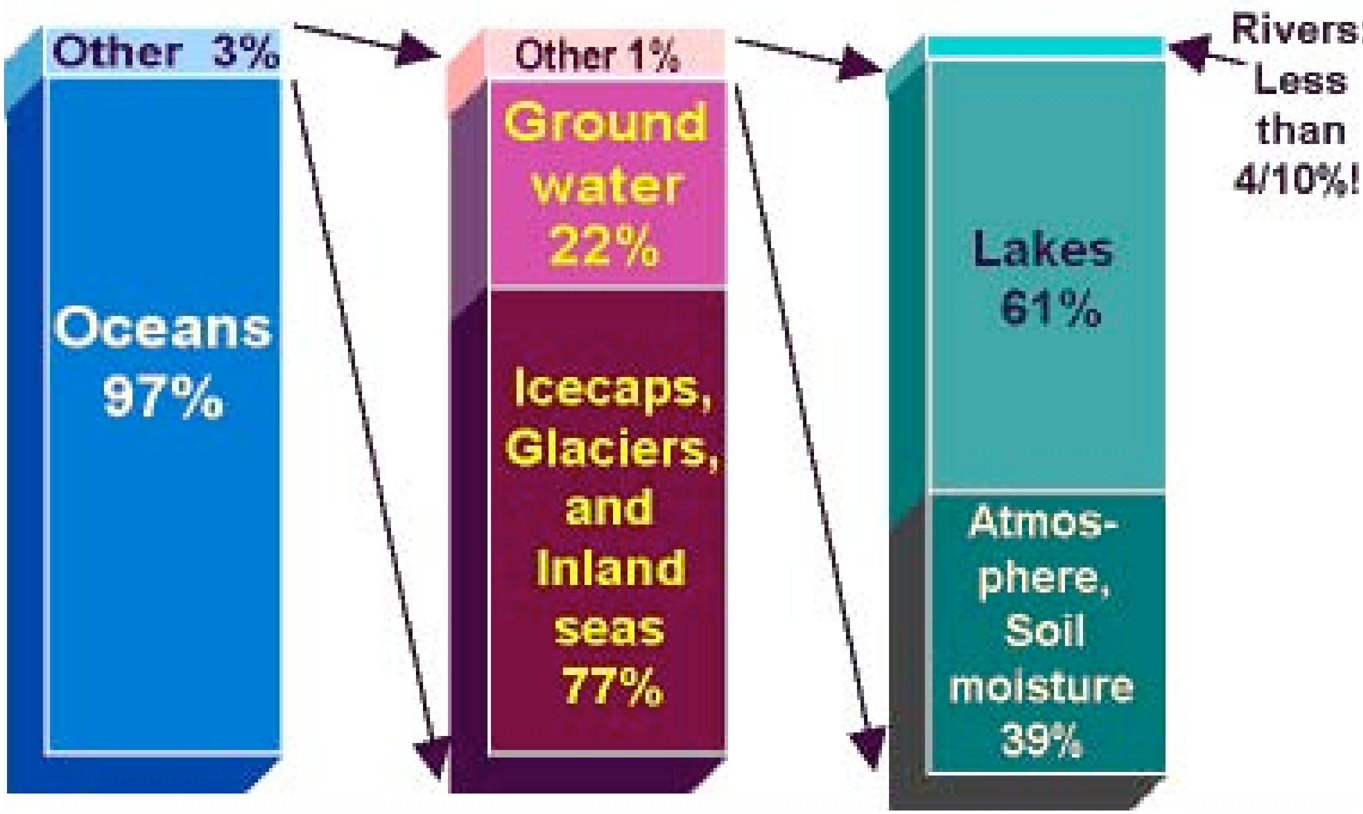
dashed lines are lines of equal pressure

today

- review major reservoirs and transfers of water in the climate system
- review the concept of latent or “hidden” heat
- look (one last time) at the role latent heat in moving energy from the equator to the poles
- seasonal migration of the ITCZ, monsoon climates and monsoon variability
- hurricanes and hurricane trends


The Water Cycle
Condensation
Water Storage in Ice and Snow
Precipitation
Water Storage in the Atmosphere
Transpiration
Evaporation
Snowmelt Runoff to Streams
Surface Runoff
Ground Water Infiltration
Freshwater Storage
Ground Water Discharge
Water Storage in Oceans
Ground Water Storage
Ground Water Infiltration
Ground Water Discharge
USGS
U.S. Geological Survey

Earth's water distribution

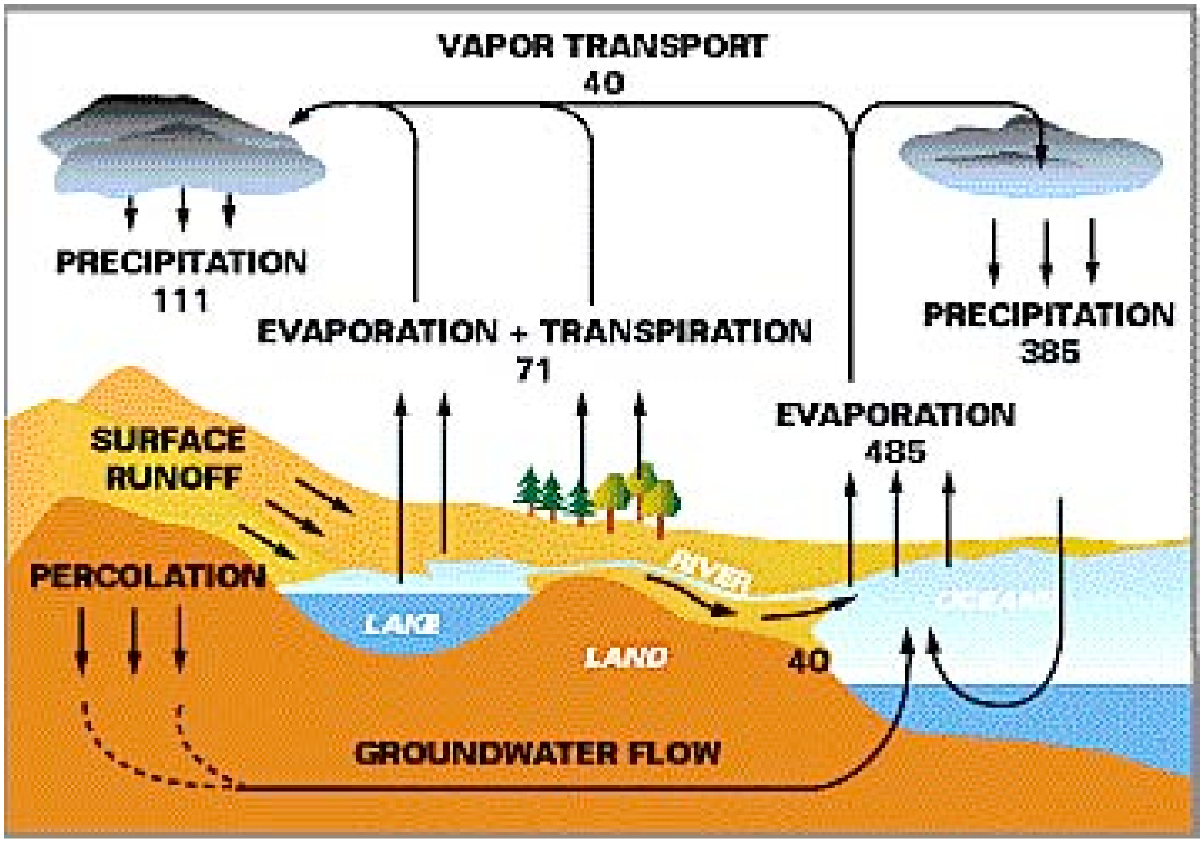


the oceans are by far the largest reservoir and are ultimately the source of water to the other reservoirs

this implies a transfer of water between reservoirs

transfer of water between reservoirs.....

units of transfer (flux) between reservoirs are 10^{12} m^3/year

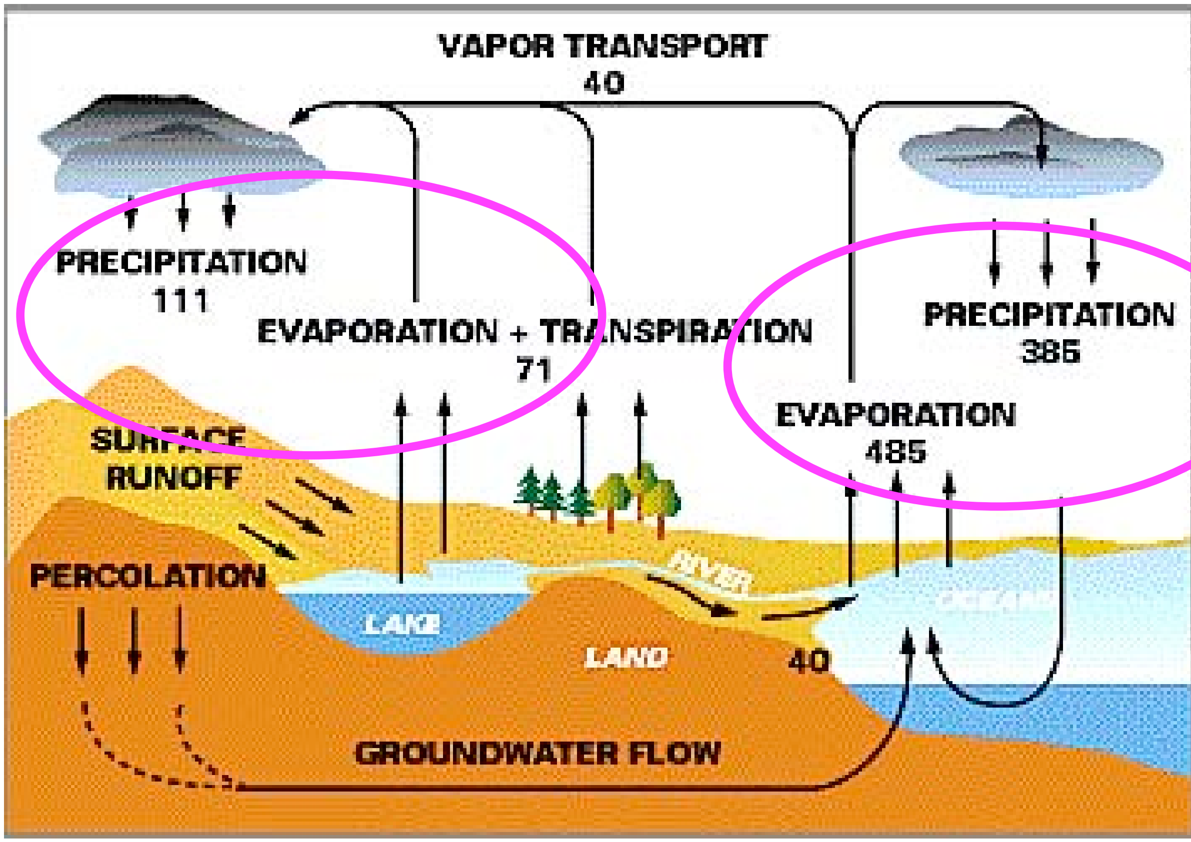


since water is largely neither created or consumed the transfers should balance, forming a continuous cycle

(note: 10^{12} m^3 water = 10^{15} kg water)

transfer of water between reservoirs.....

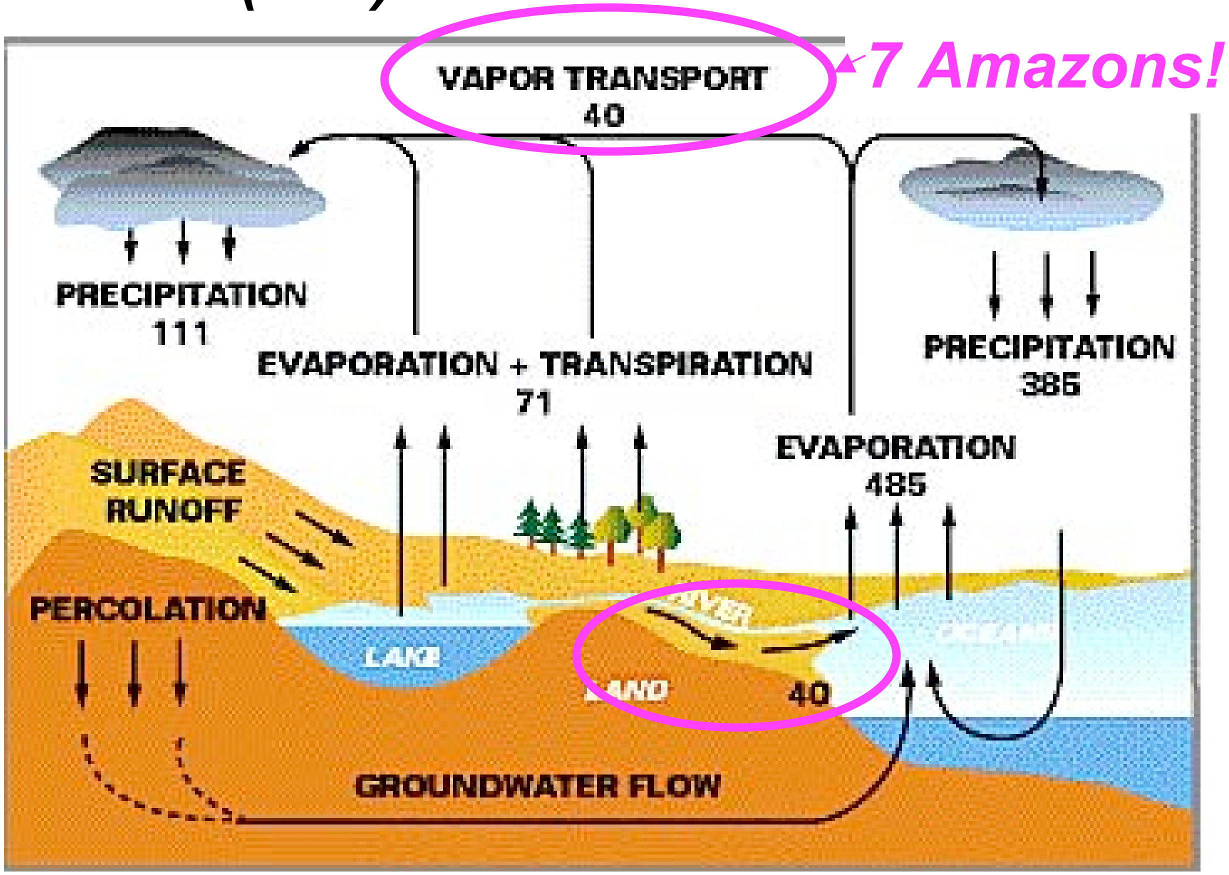
units of transfer (flux) between reservoirs are 10^{12} m^3/year



the excess of evaporation over the ocean is balanced by an excess of precipitation over land
a transfer from the ocean to land must take place in the atm.

transfer of water between reservoirs.....

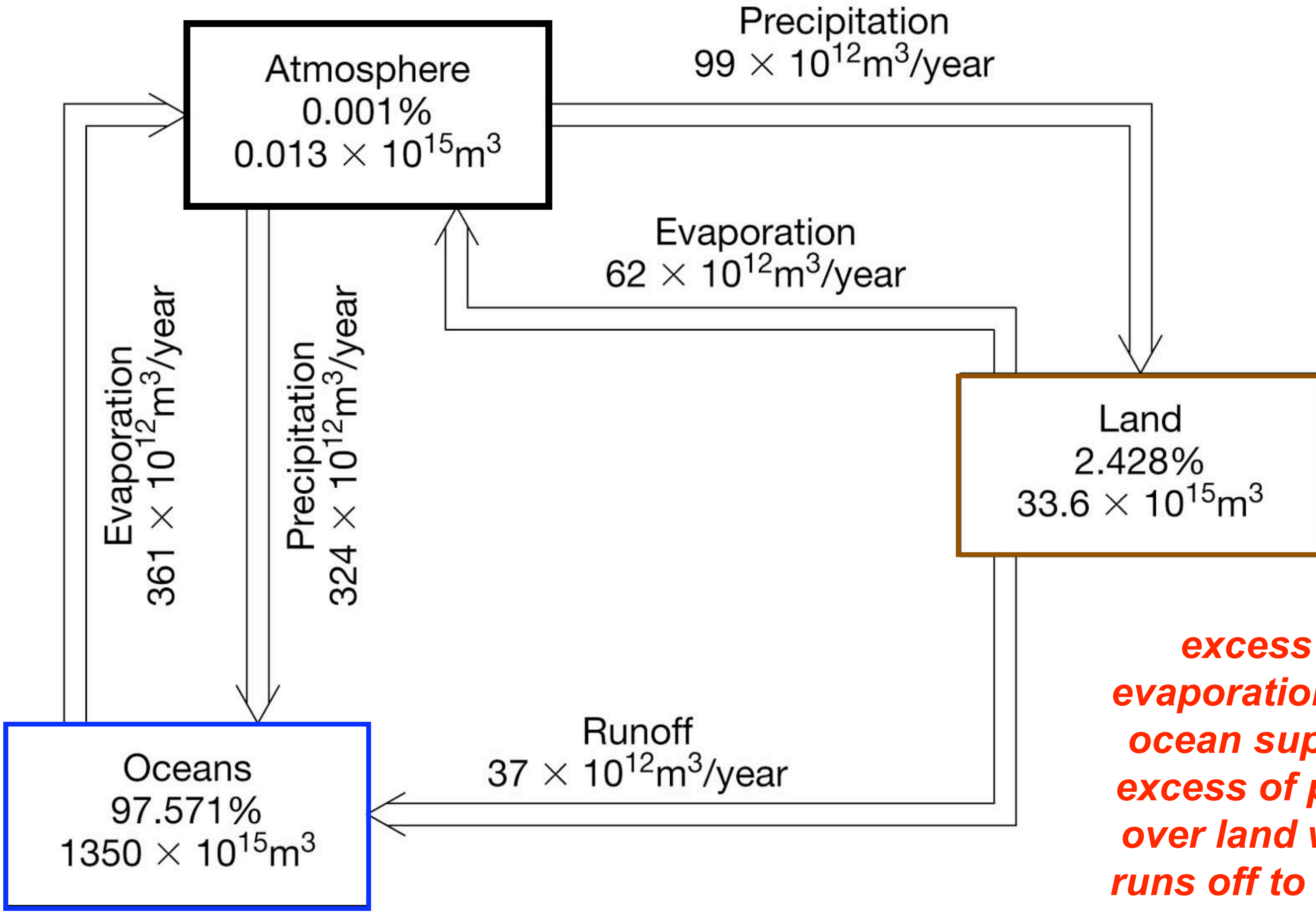
units of transfer (flux) between reservoirs are 10^{12} m^3/year



the transfer from the ocean to land must take place in the atmosphere

how big is this transfer?

simplified plumbing



excess of evaporation over ocean supplies excess of precip over land which runs off to ocean

(values differ slightly from those of previous slide)

how long does an average water molecule stay in the atmosphere?

- ***guess?***

- ***calculate?***

- ***how?***

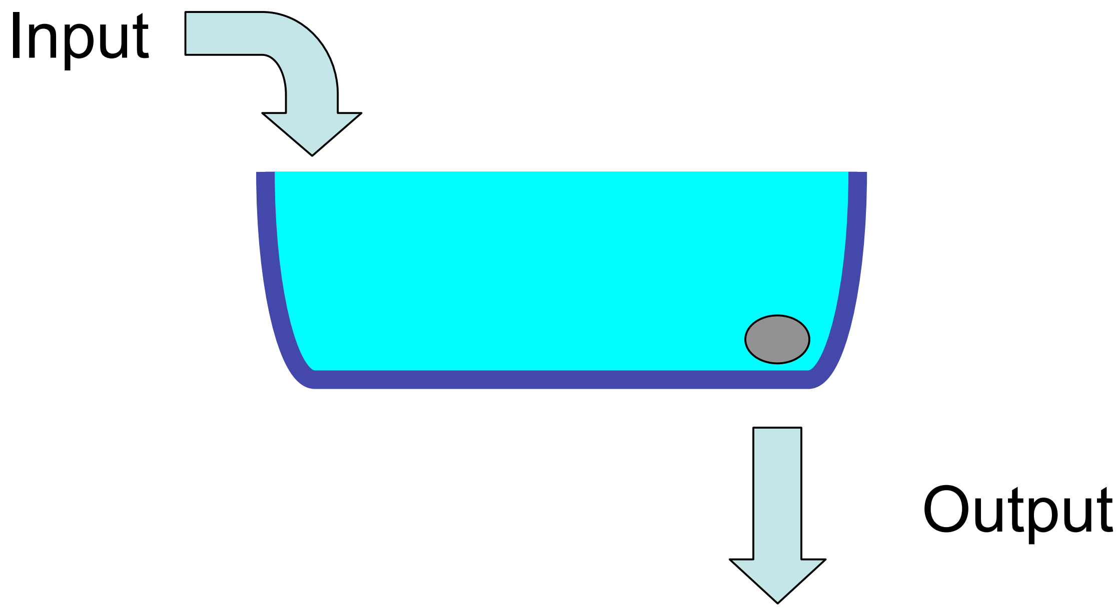
- ***recall concept of residence time***

- **consider the flow of matter (we have already looked at flows of energy, for ex.)**

= reservoir

= flux of material

consider your bathtub



when the flow of water into the tub equals the flow out of the tub, the water level does not change

steady state conditions:

input = output

residence time

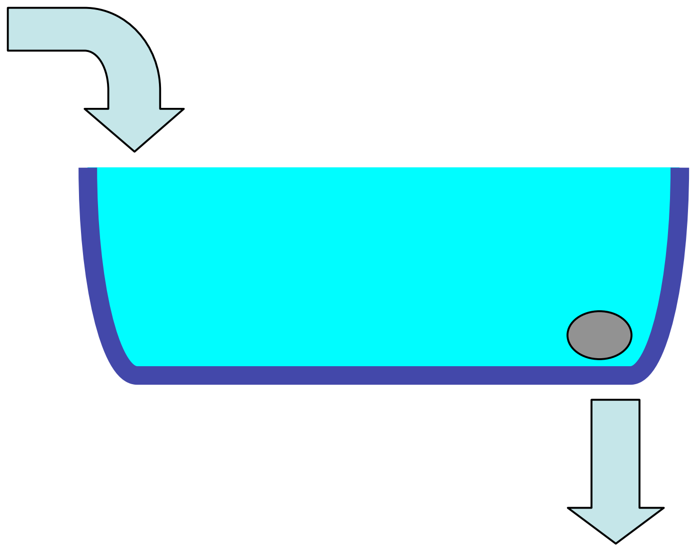
the <u>average</u> length of time matter spends in a reservoir

residence time = reservoir size / input

= reservoir size / output

bathtub again......

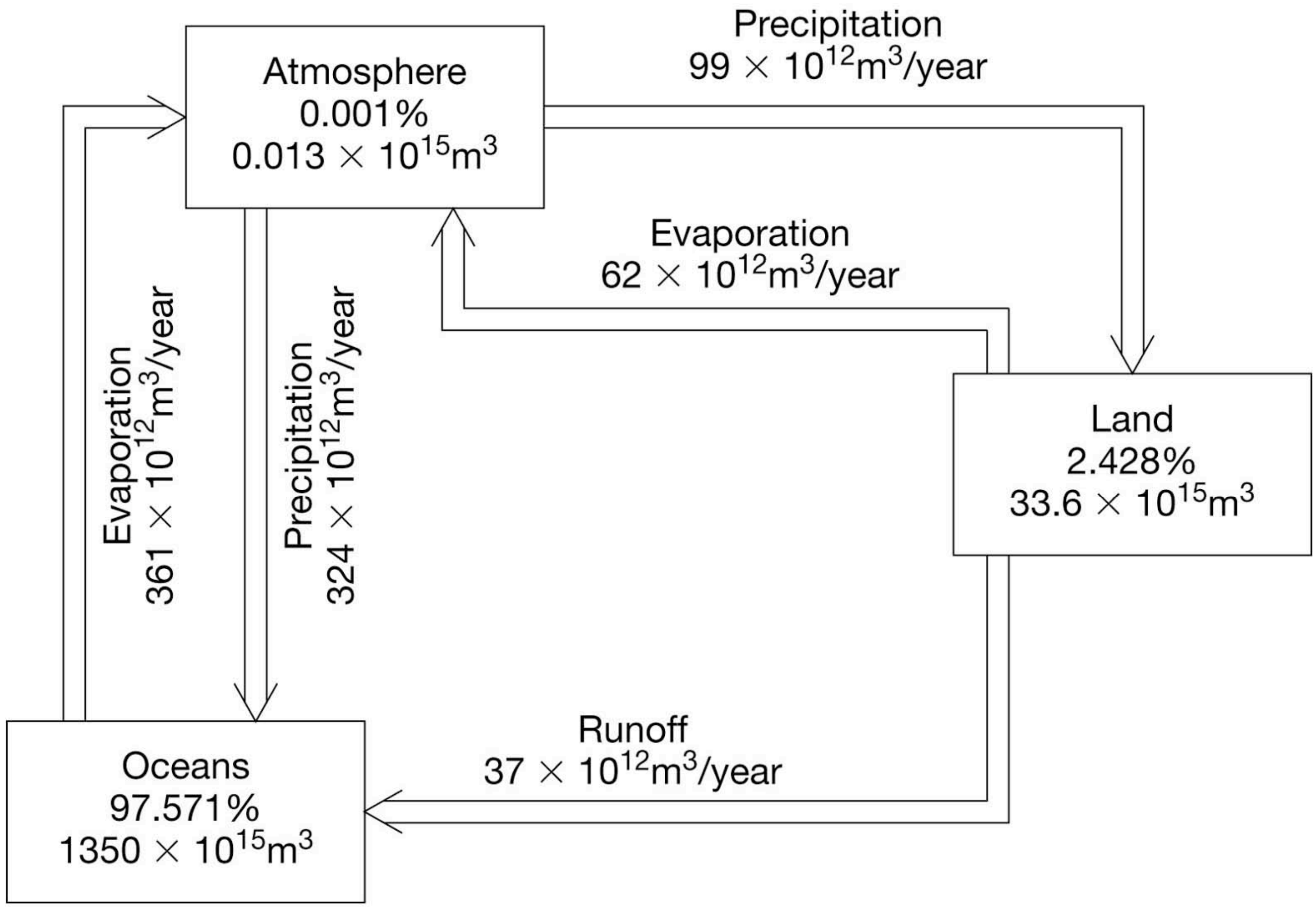
tub = 100 liters
input = 5 liters/minute



$$\text{residence time} = \frac{\text{100 liters}}{\text{5 liters/minute}}$$

= 20 minutes

in class exercise

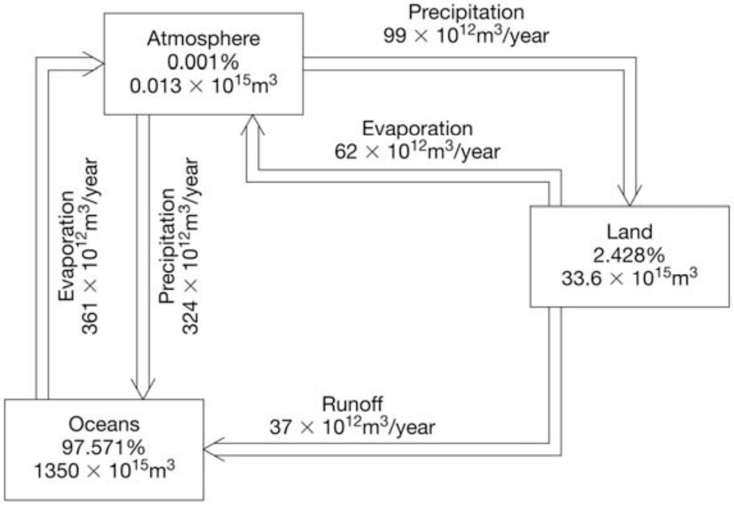


What is the residence time of water in the atmosphere w.r.t. fluxes coming in or out from the land and oceans?

clicker

The residence time of water in the atmosphere w.r.t exchange with the land and oceans can be calculated as…..

a) the size of the atm. res. /total evap over land and sea
b) the size of the atm. res. /total precip. over land and sea
c) the total evap. over land and sea/ the size of the atm. res.
d) <u>both a) and b)</u>
e) both a) and c)



atm. residence time of average water molecule

- **sum of evaporative fluxes:**

  $423 \times 10^{12}\ m^3/yr$
- **sum of precipitation fluxes:**

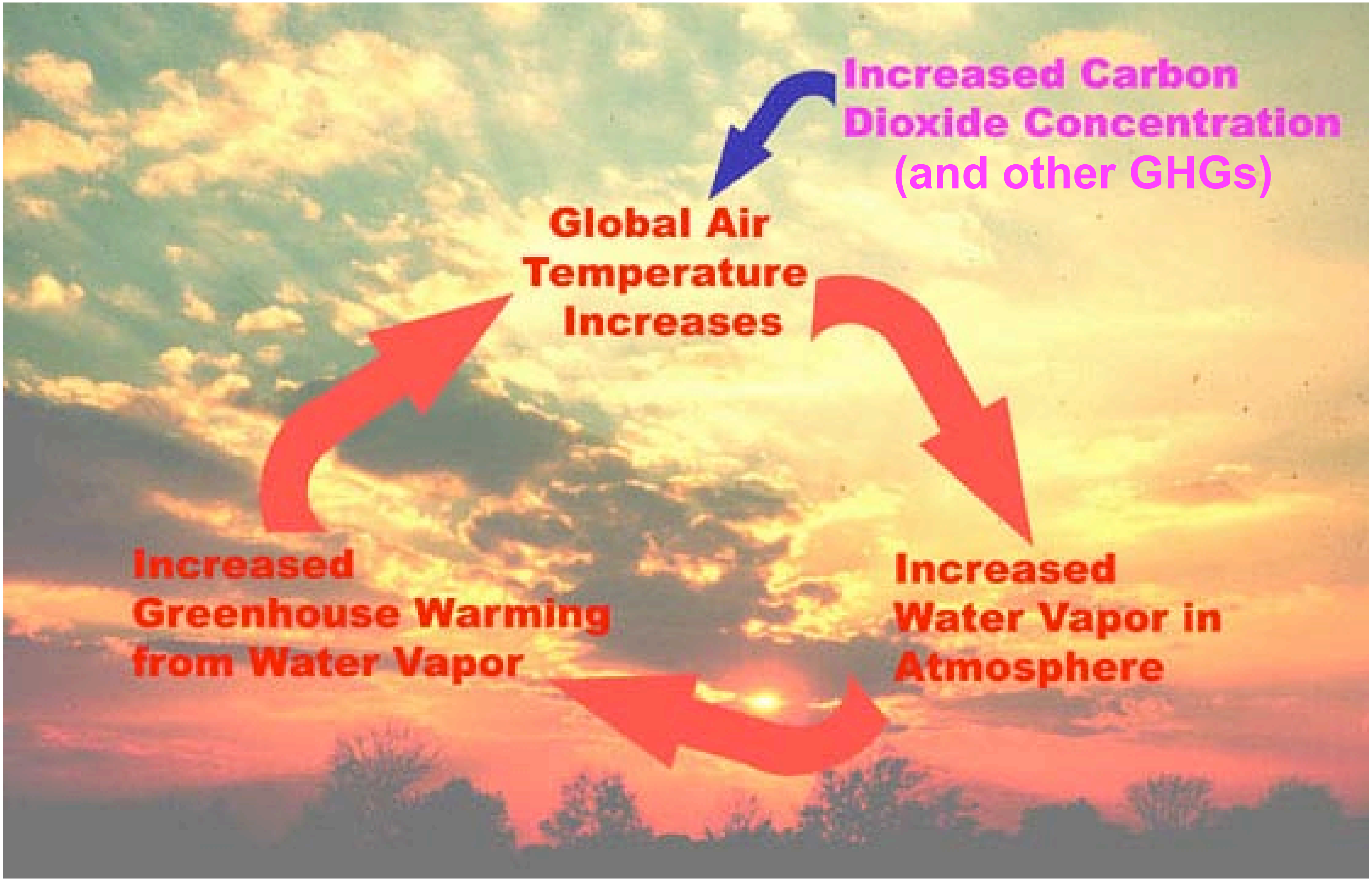
  $423 \times 10^{12}\ m^3/yr$
- **mass of atmospheric reservoir:**

  $14 \times 10^{12}\ m^3$
- **residence time:**

$$\frac{14 \times 10^{12}\ m^3}{423 \times 10^{12}\ m^3/yr} = \sim 0.03\ yr\ (365\ d/yr) = \sim 11\ d$$

this helps remind us that water vapor (as a GHG) is a climate feedback and not a primary forcing...

i.e. water vapor adjusts quickly to a change in GHGs in this system feedback



importance of the hydrologic cycle

- water is essential to life (so its distribution, or any change in its distribution, is important)

- extremes and changes in extremes have big impacts (*drought and flooding*)

- helps power the weather and the global transport of energy via latent (or hidden) heat that is stored and released as water changes state

let's first consider the energy carried as latent or "hidden" heat

latent heat

- **energy is required to change liquid to gas (i.e. for evaporation of liquid water to water vapor)**

liquid water ⟷ vapor

- **this energy is converted back to heat when the water vapor condenses back to liquid state**

- **this latent heat is "*hidden*" heat**

latent heat

- what happens when you heat water to 100 °C?

- what happens when you continue heating it?

- the extra energy goes to changing water to steam (vapor)...

- why does steam feel so hot?

  vapor = water + heat!

energy and evaporation

- *evaporation occurs when there is enough energy to allow the fastest moving molecules to break free of intra-molecular bonds at the liquid surface*

- *more evaporation can occur as more energy is applied because molecules move faster on avg.*

- *this energy is returned as heat when vapor condenses back to liquid water*

cooler molecules move more slowly on average

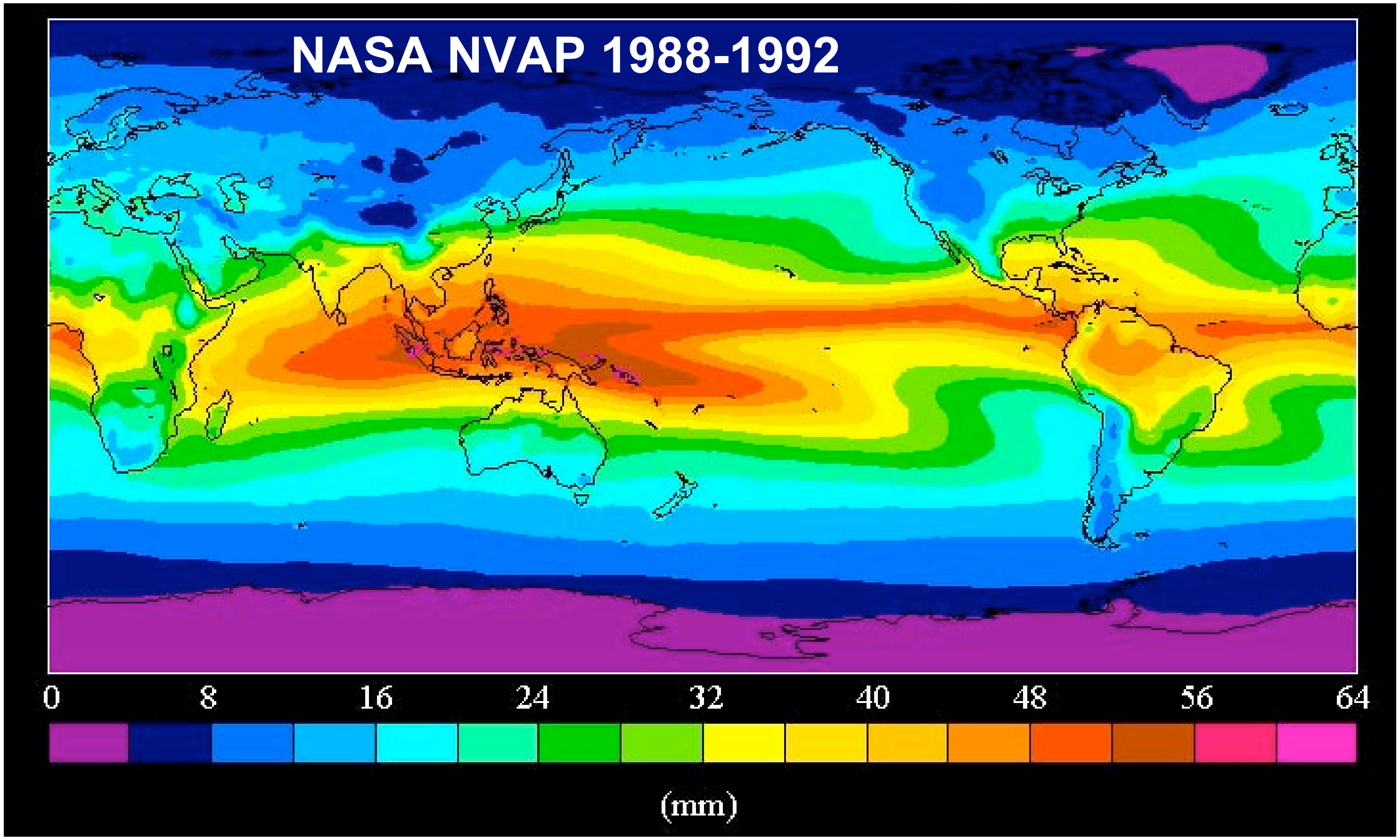
upon heating molecules move faster on average

which molecules are most likely to break free?

- **where and how does this play out in the climate system**

- **let’s start at the primary source...**

total column water vapor

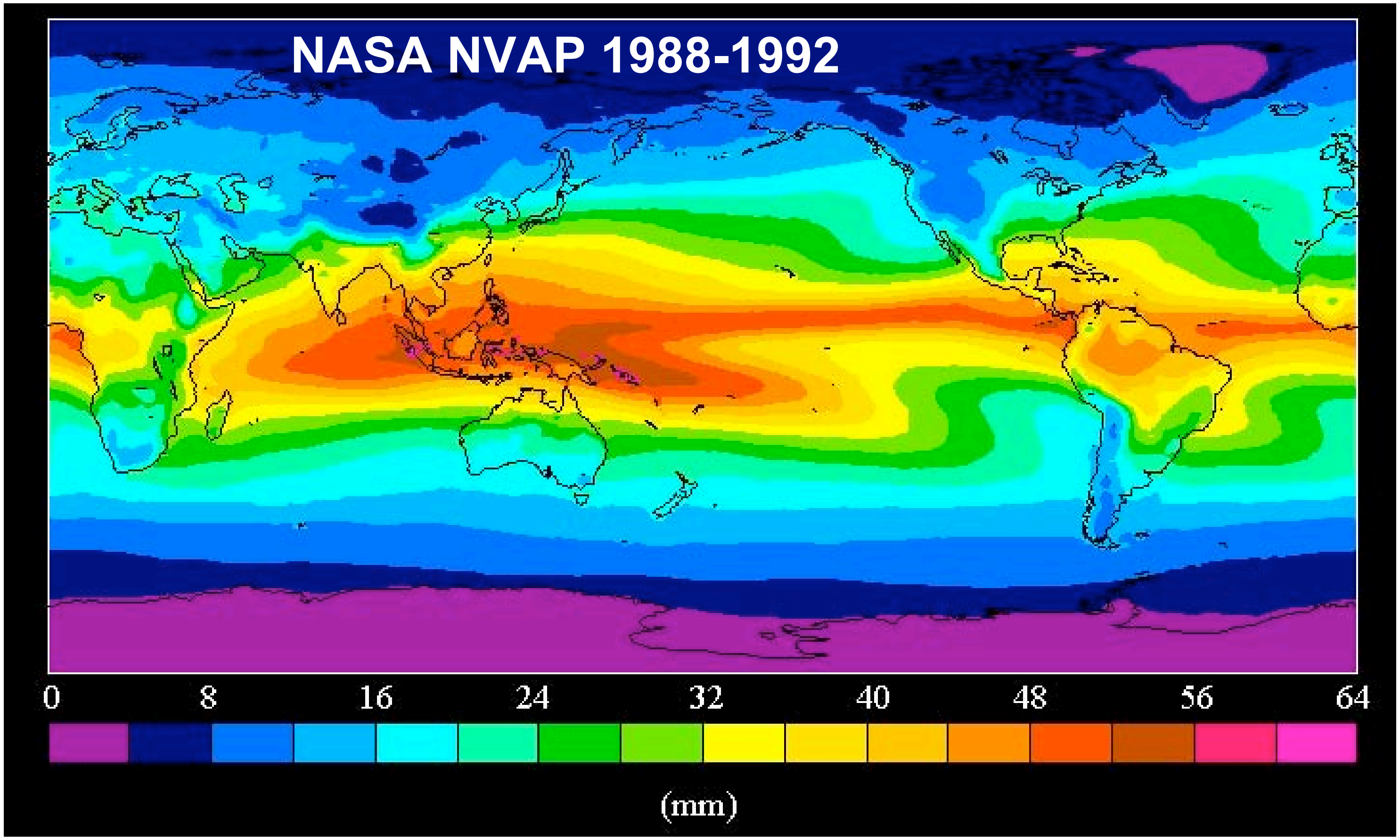


this is the amount you can "wring" out of the atmosphere

(the global mean is ~25 mm or 1 inch)

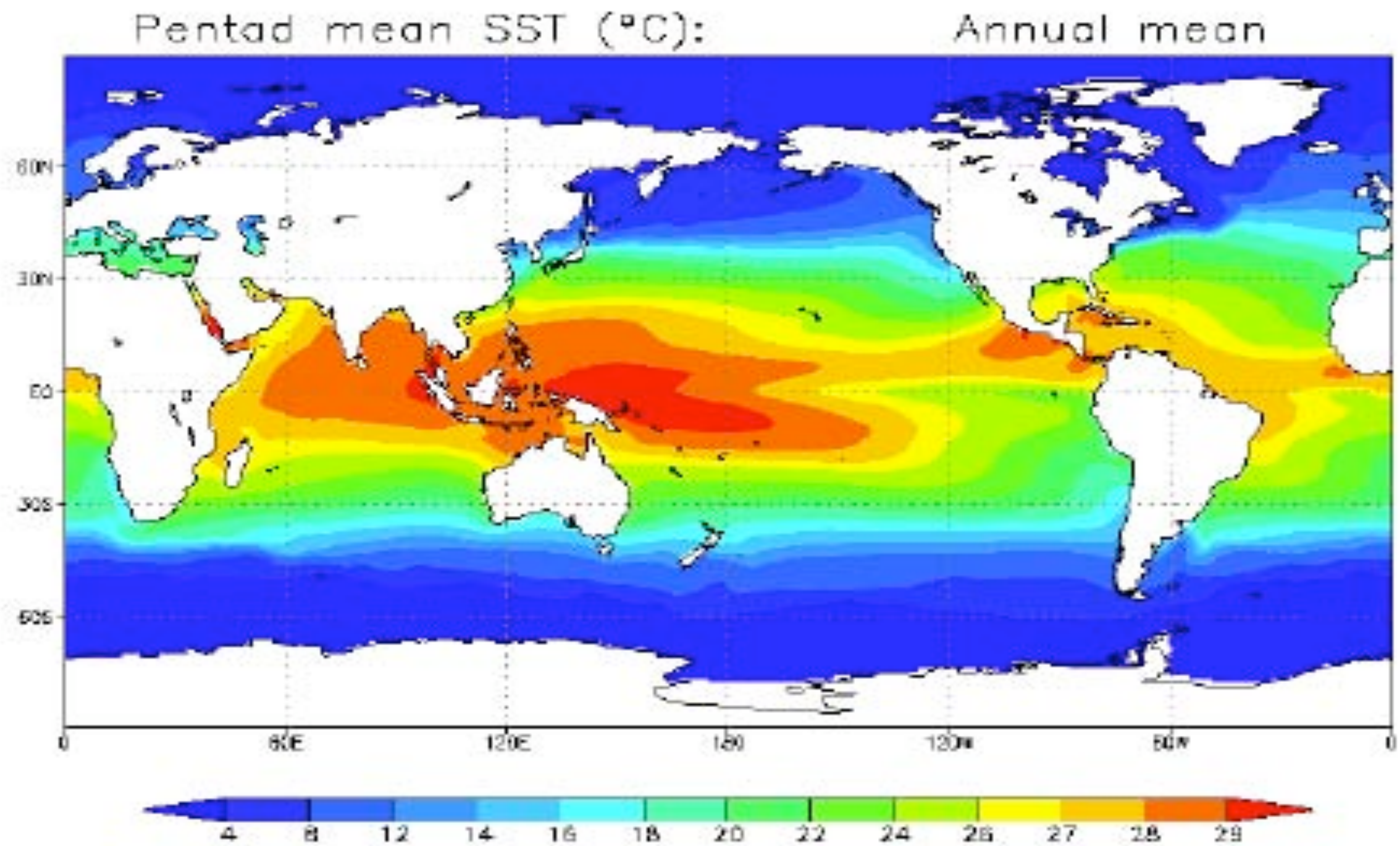
(and 90% is in lowest 5 km of atmosphere)

total column water vapor



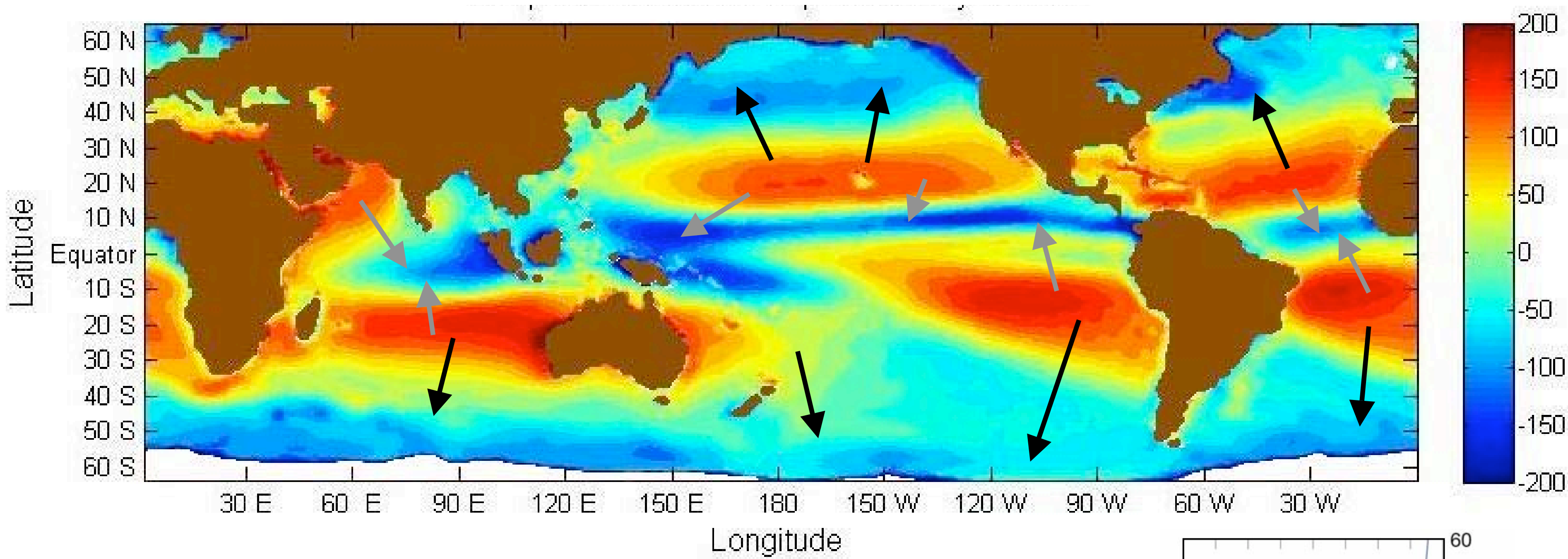
the water vapor is where the heat and water is

annual mean sea surface temp.

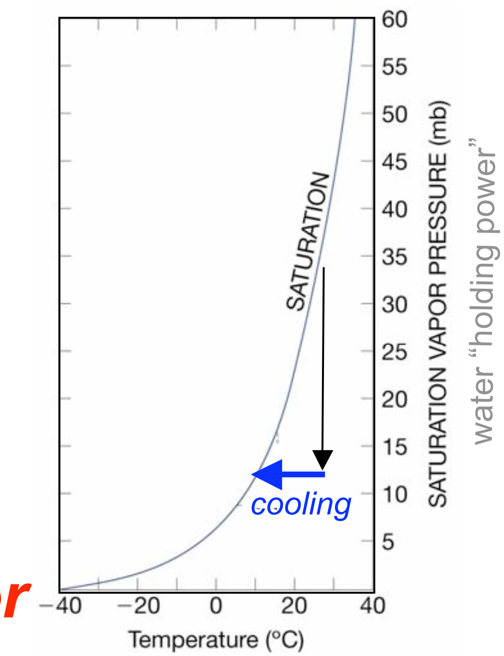


i.e. over or near the warmest parts of the ocean

evaporation minus precipitation (cm/yr)

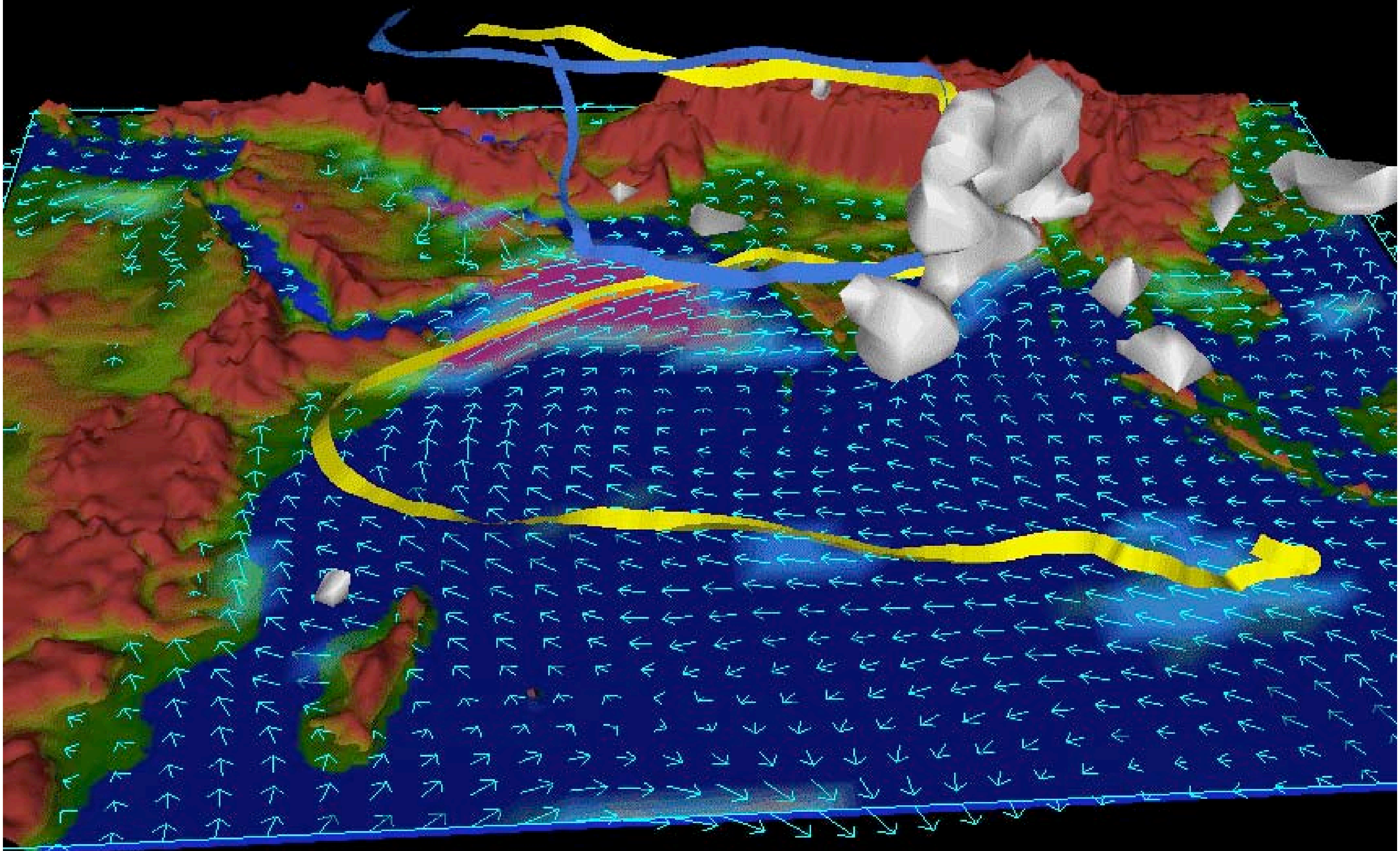


- *water enters atmosphere at low latitudes (i.e. source)*
- *exits at high latitudes (i.e. sink)*
- *must therefore have water vapor moving toward the poles* (& some towards ITCZ…)
- *this is part of the poleward energy transpor*



- **This reminds of the poleward heat heat transport needed to satisfy the latitudinal imbalances or received and emitted radiation…**

monsoon climates

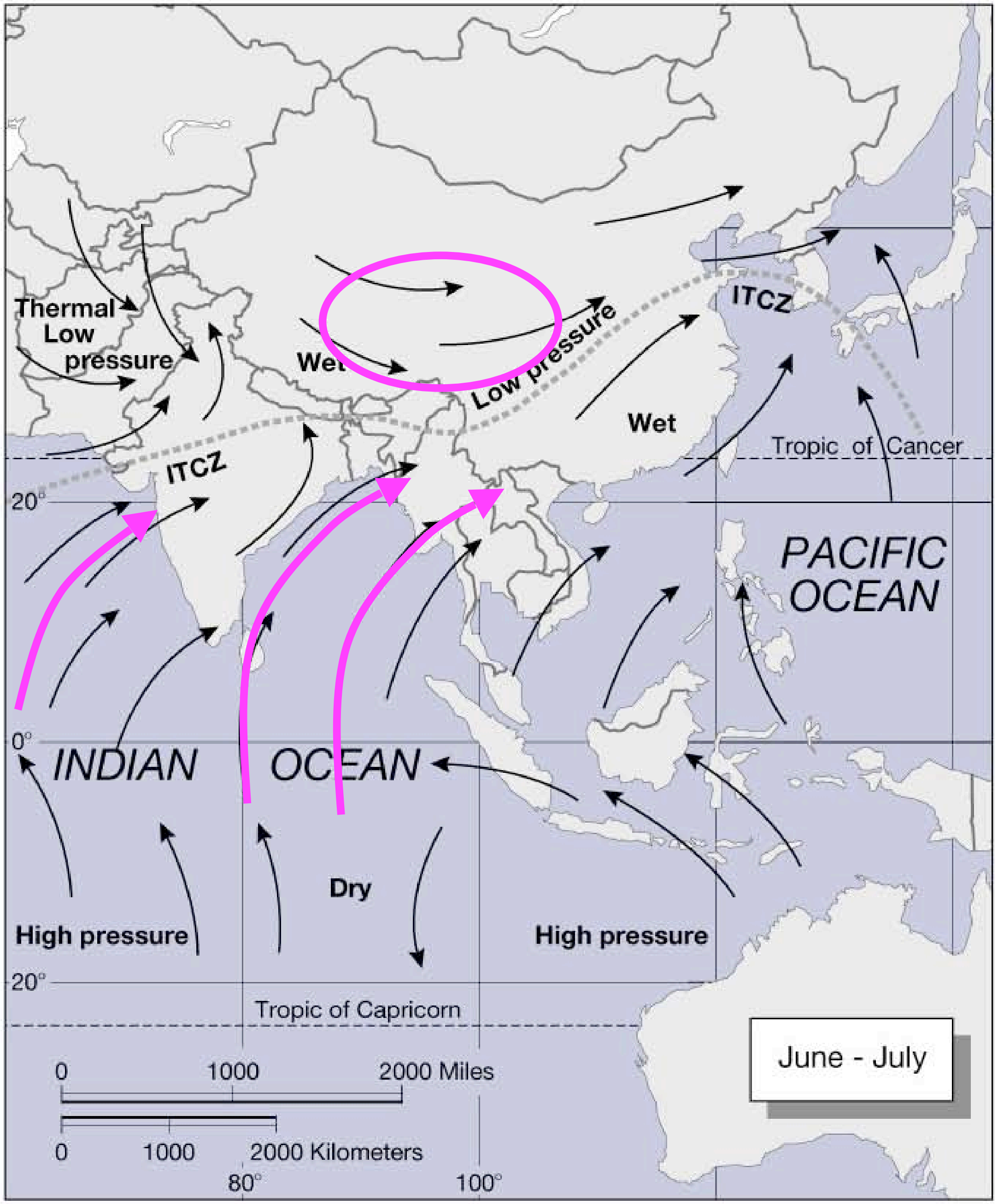


monsoon rains feed (and flood) a large part of the world population

monsoon climates

- “monsoon” refers simply to a strong seasonal change in wind direction
- such a change generally requires heating of a large landmass near the ocean
- i.e. India, SE Asia, Tropical Africa & Australia
- can think of these tropical monsoons as connected with the ITCZ
- monsoons also influence the SW US

India/SE Asia

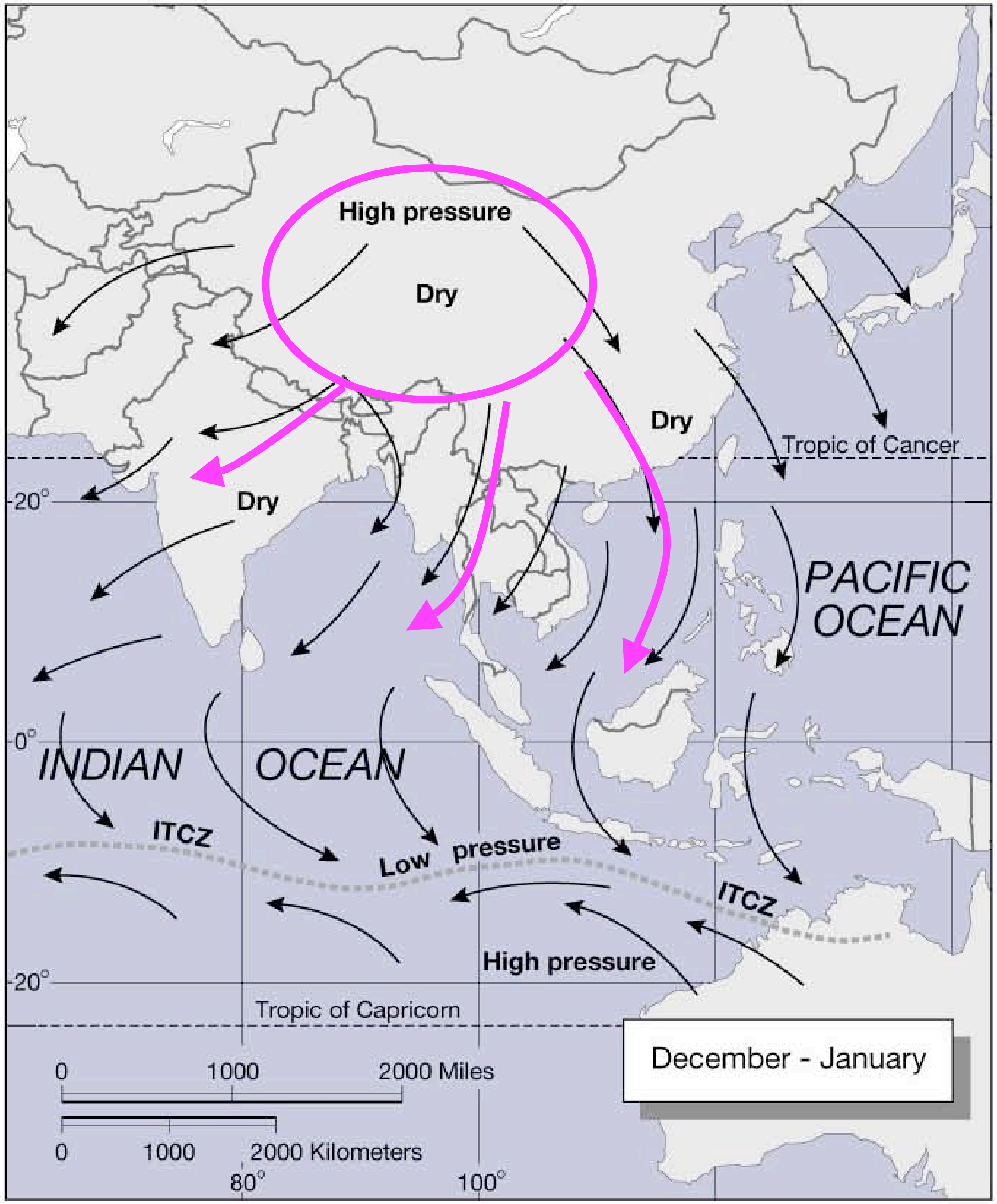


intense summertime heating of Tibetan Plateau creates buoyancy

rising air is replaced by moisture laden air from the warm Indian Ocean

similar to day time coastal "sea breeze" process

India/SE Asia

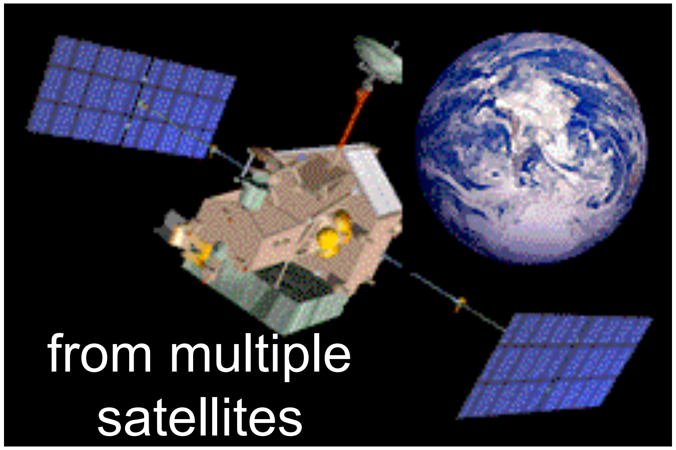


rapid wintertime cooling of Tibetan Plateau creates high surface pressure

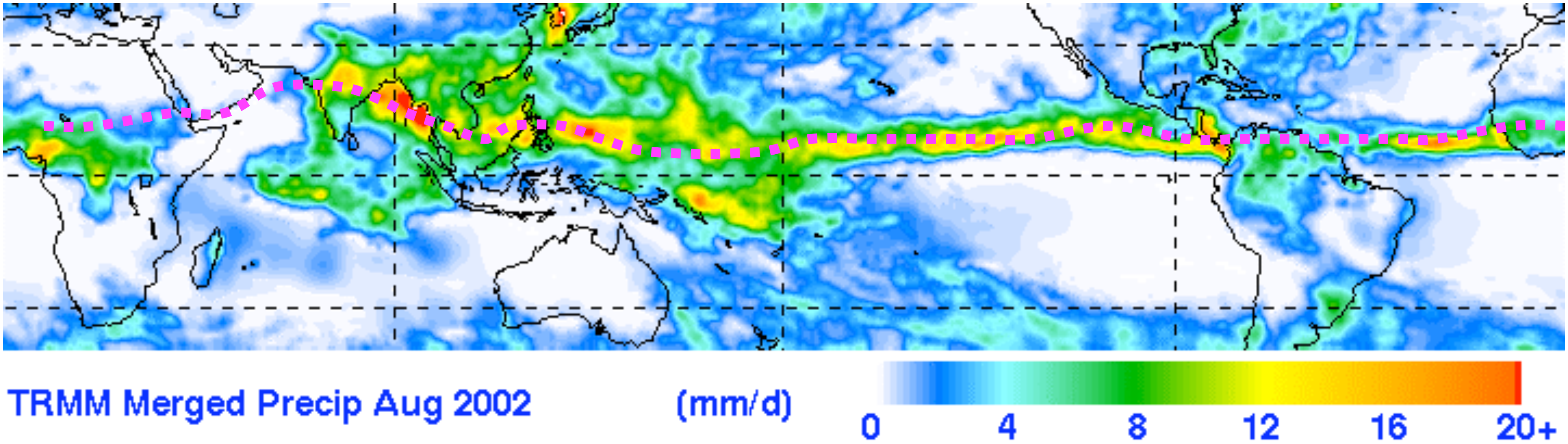
air flows toward lower pressure over ocean (i.e.reverses direction)

note ITCZ has moved to "summer hemisphere"

the tropical monsoon in India, SE Asia, and Africa



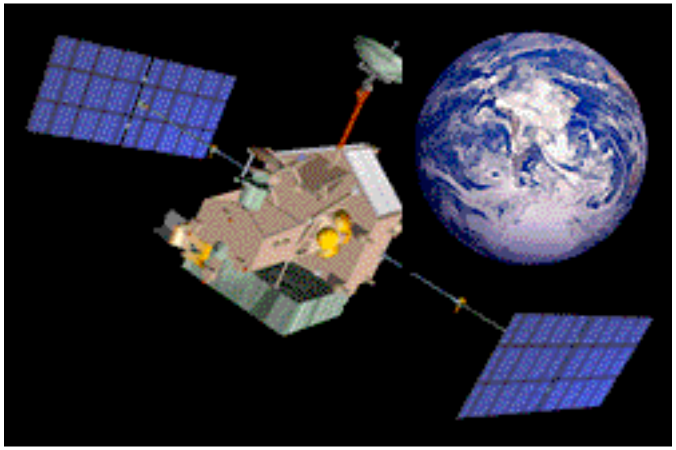
precipitation amount



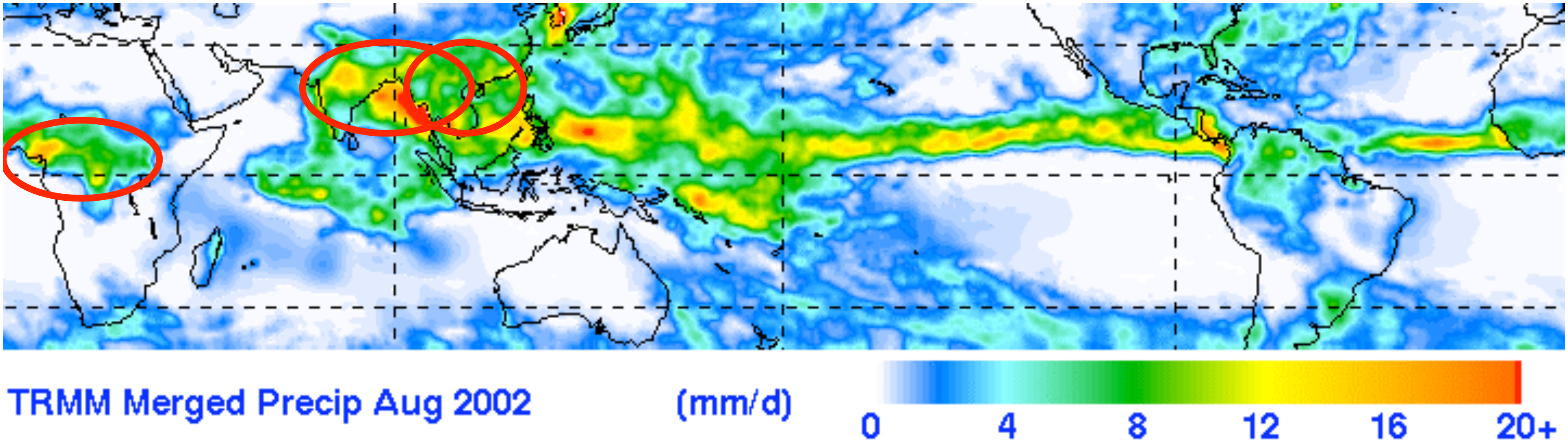
what is dashed pink line?

NASA's Tropical Rainfall Monitoring Mission (TRMM)

the tropical monsoon in India, SE Asia, and Africa



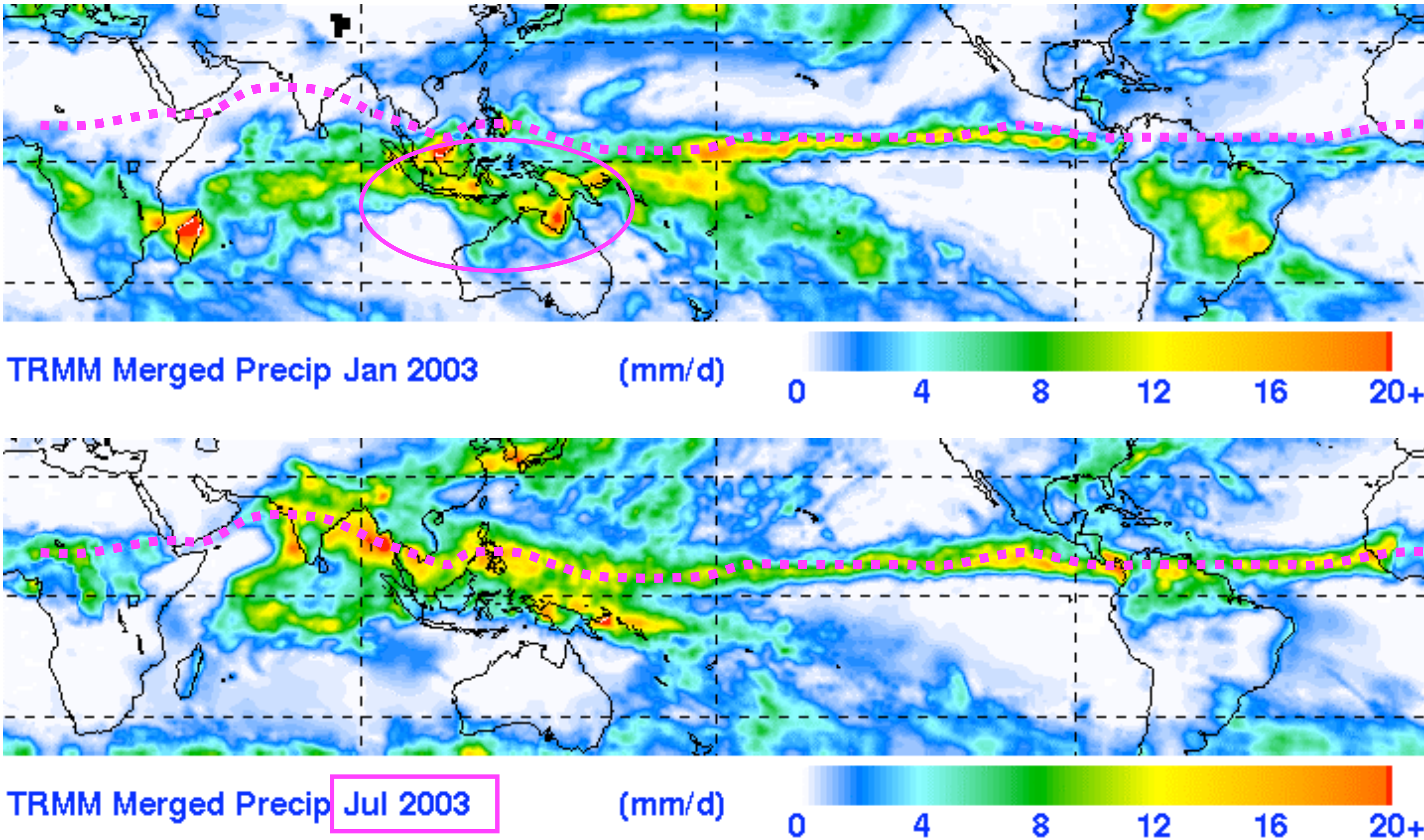
precipitation amount



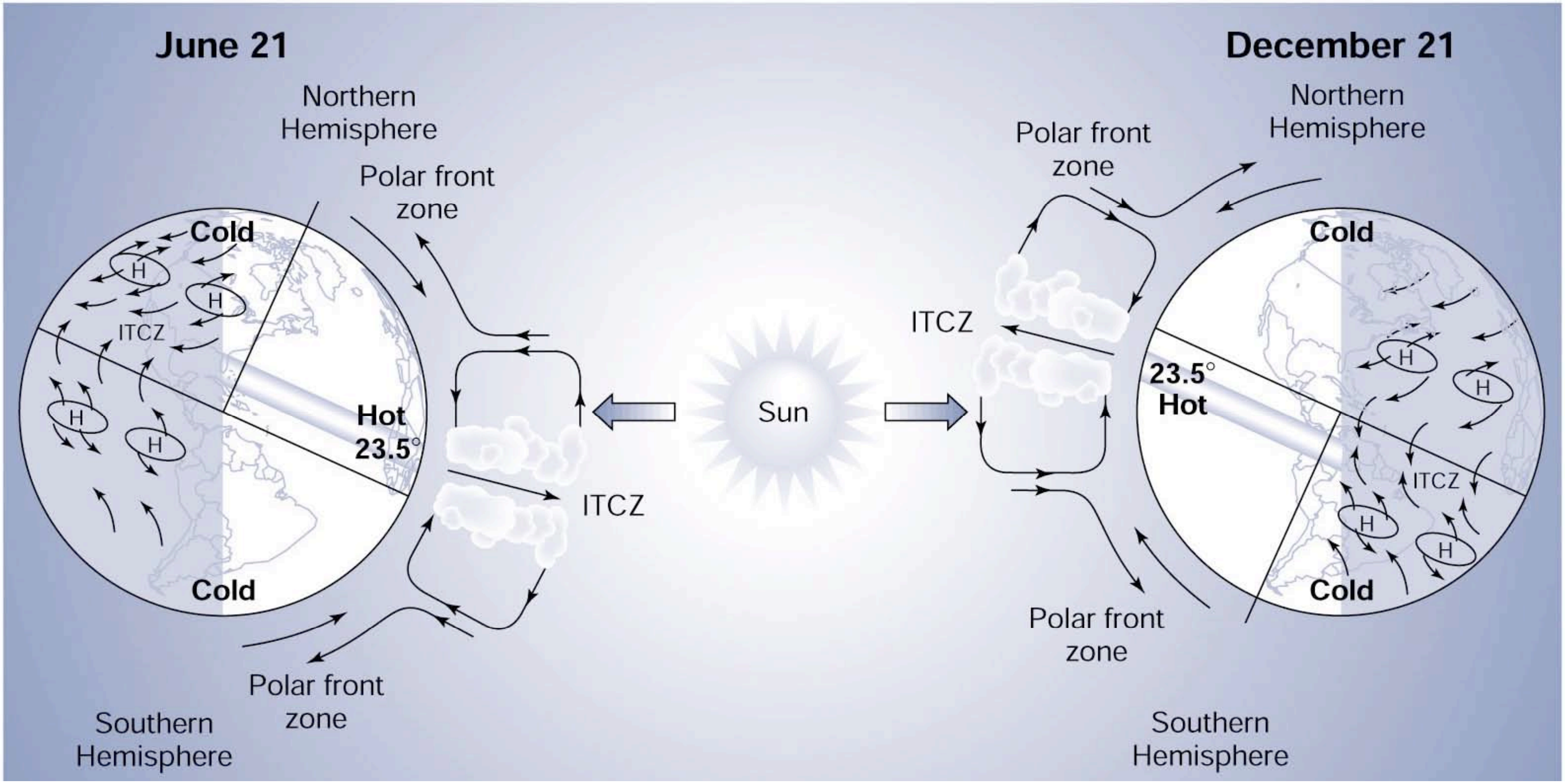
notice that the monsoon precip is the ITCZ over land
in the case of SE Asia and India it has a northward deflection
in NH summer due to Tibetan "hot plate"

the monsoon as a seasonal migration of the ITCZ and rains toward the warmer hemisphere

dashed line= July position

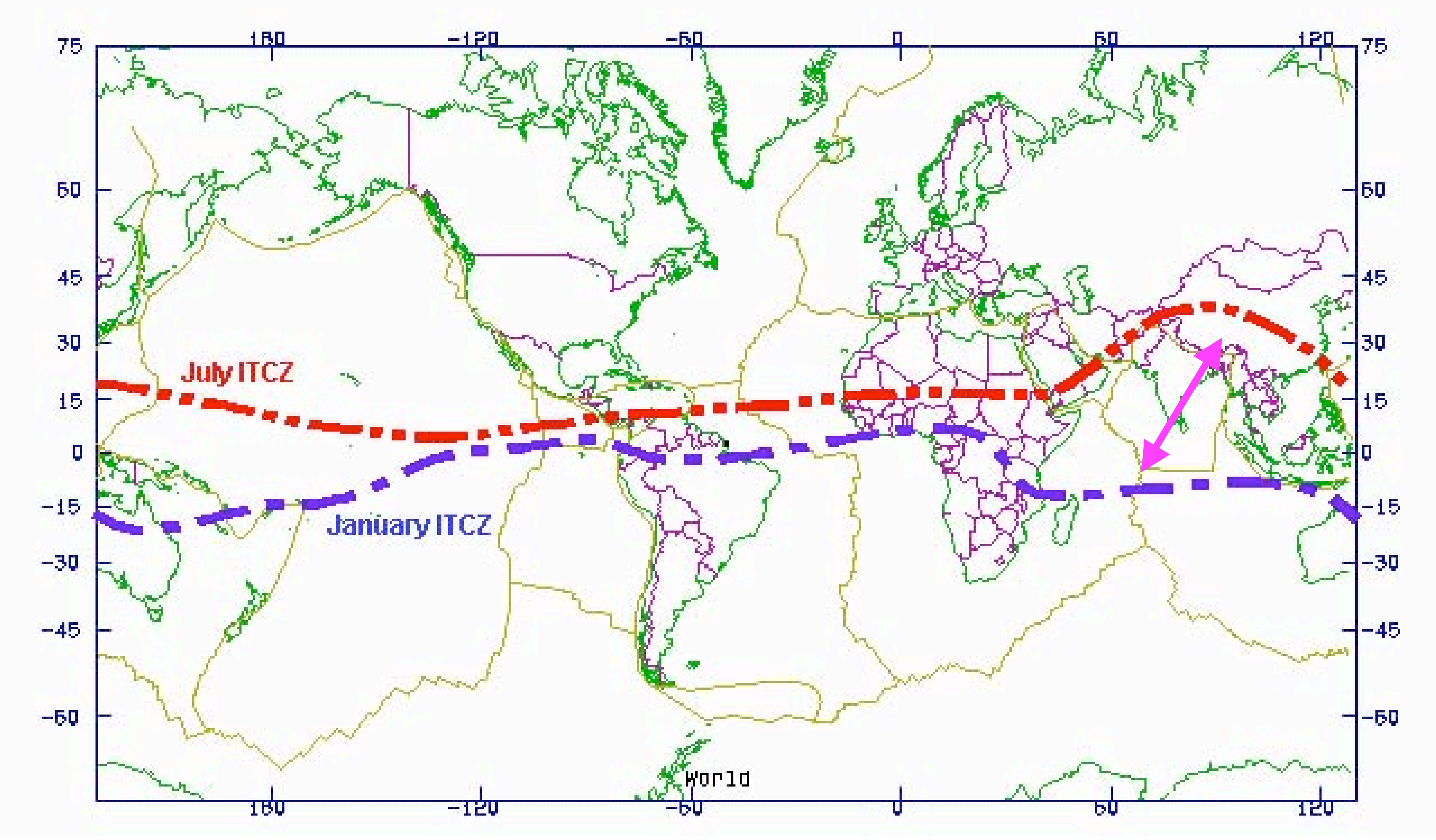


ITCZ follows the sun



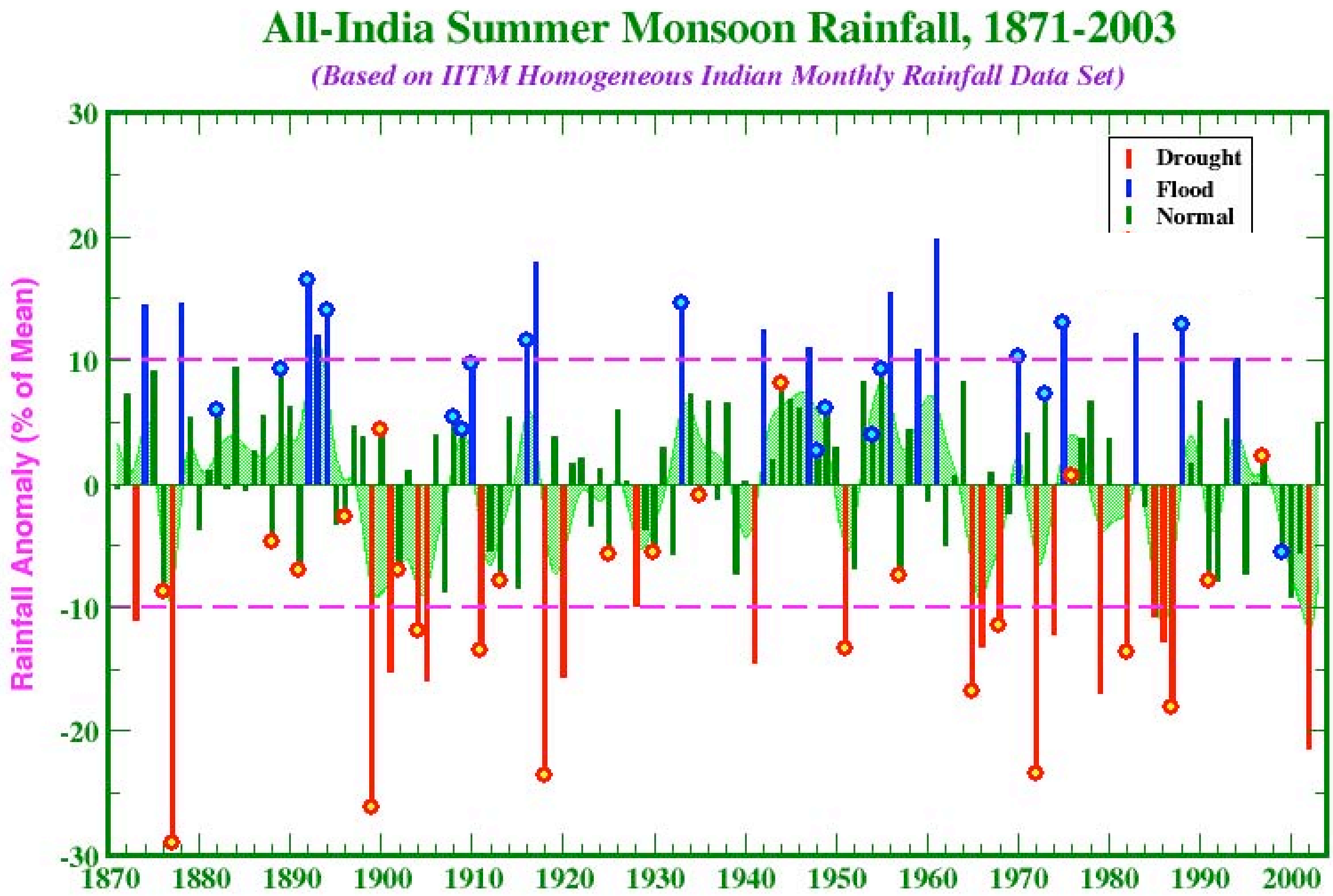
i.e. rainy season in tropics during summer

ITCZ follows the sun



i.e. ITCZ (and terrestrial monsoon) moves to "summer hemisphere"

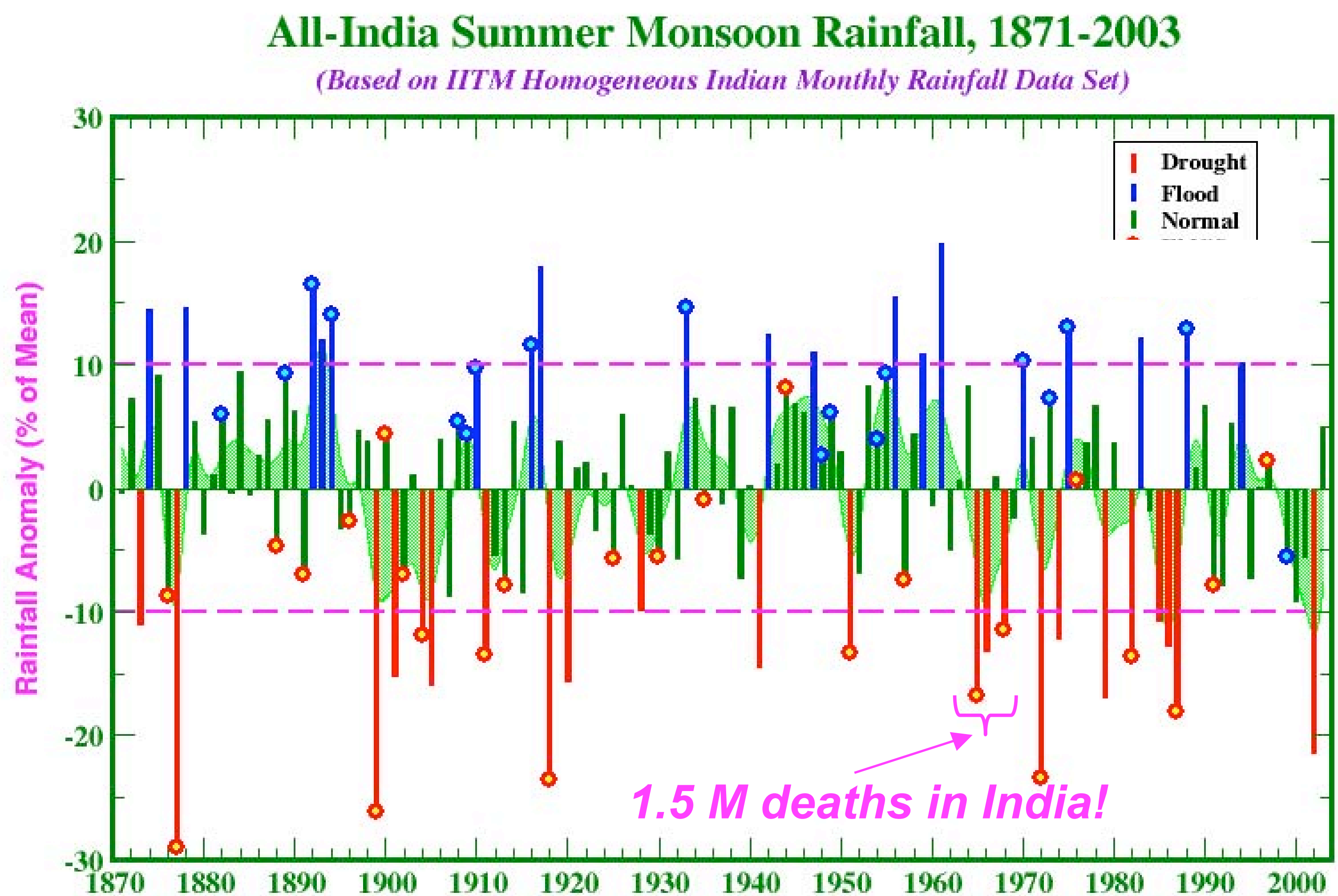
historic monsoon variability (India)



% deviations from long term mean of 85 cm (local/regional deviations would be larger)

why worry about it?

historic monsoon variability (India)

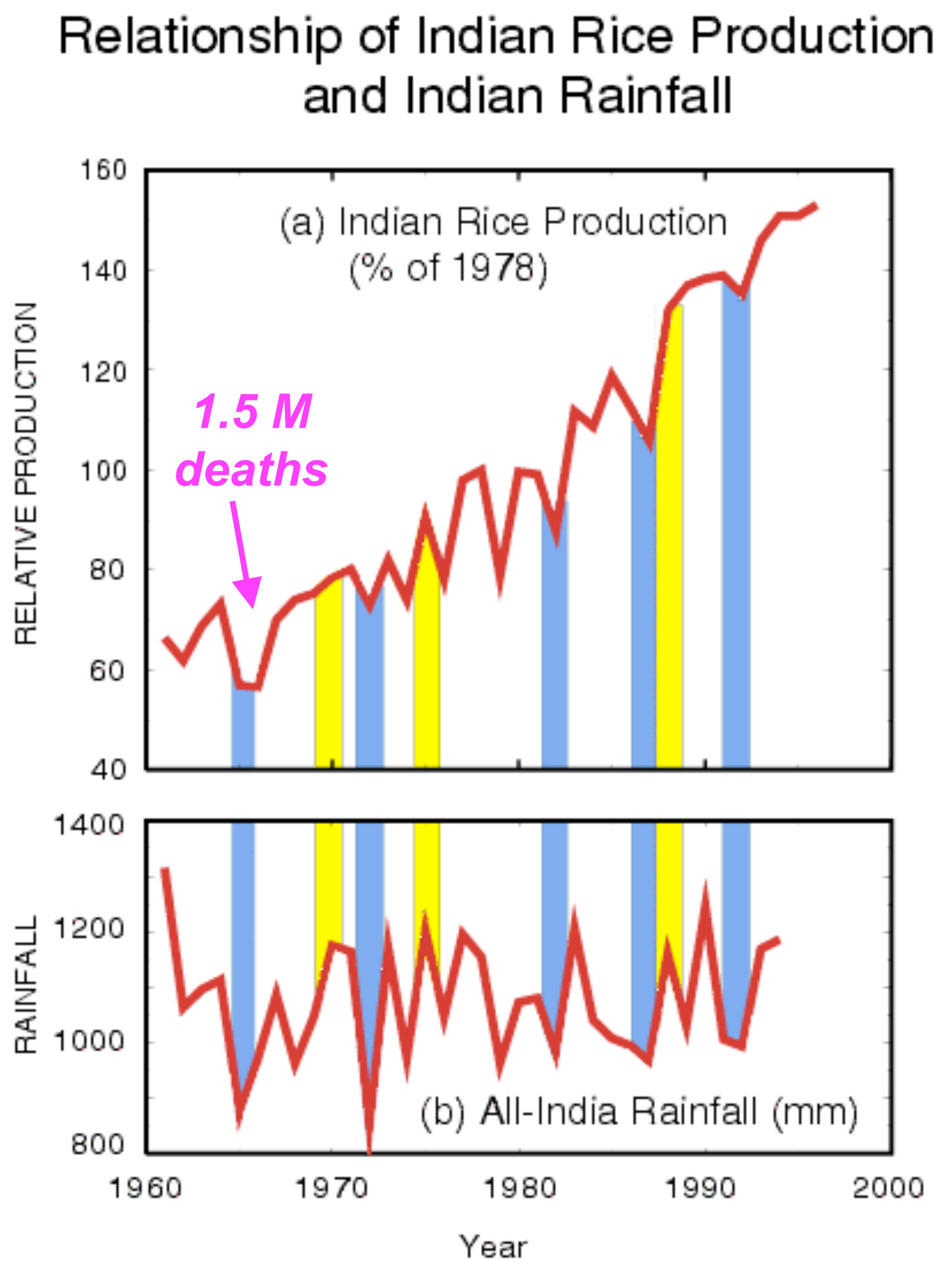


local/regional failures of the monsoon lead to famine!

(Brits create the field of tropical meteorology to deal with this issue)

1.5 M deaths following 3 “failed seasons” as recently as late 1960’s

rain fall and rice production



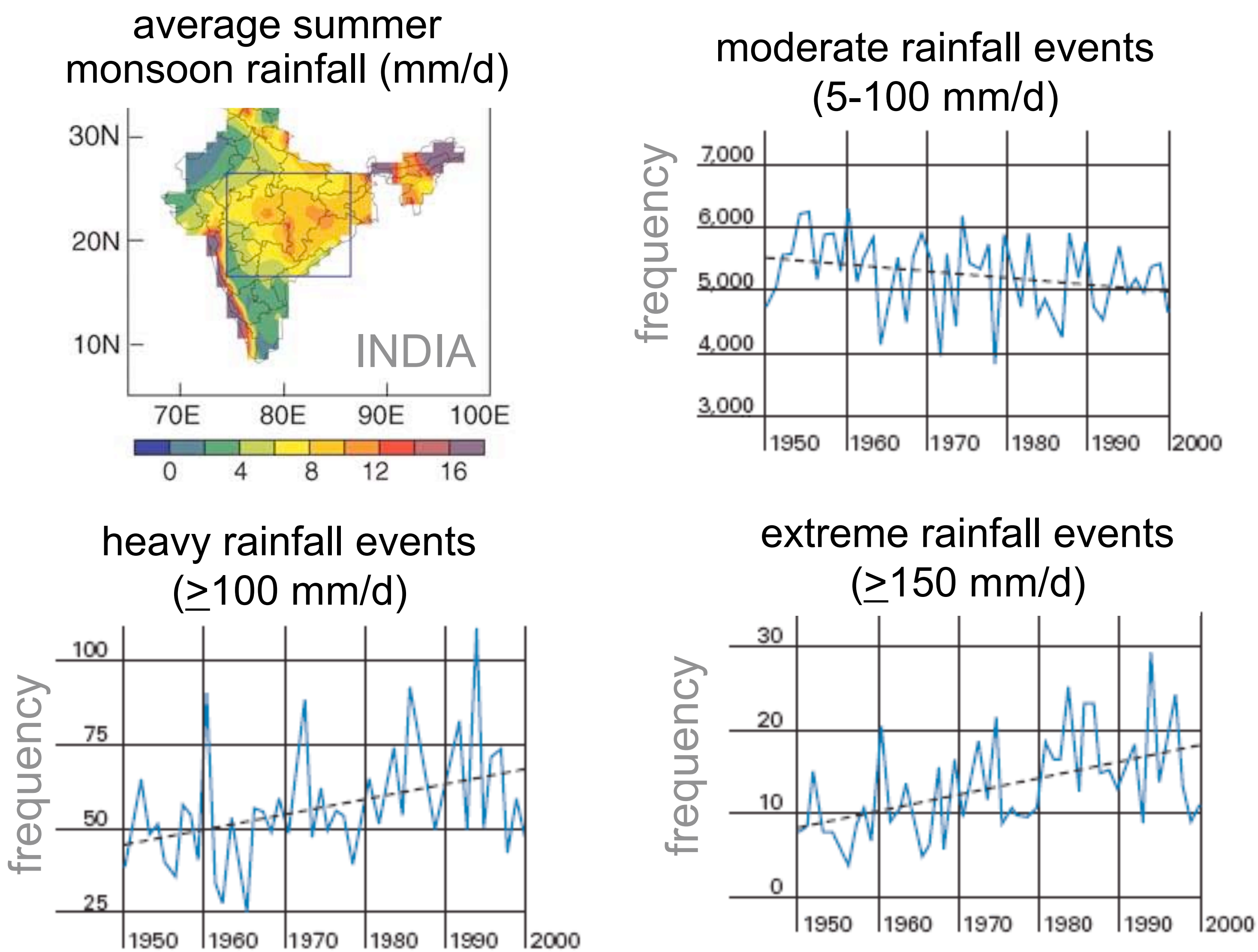
better farming practices and technology have increased rice production overall, but year-to-year fluctuations are still determined by the success or failure of the monsoon…..

monsoon variability

and, the flip side is…

feast? No, flooding……

the way rain “falls” is changing

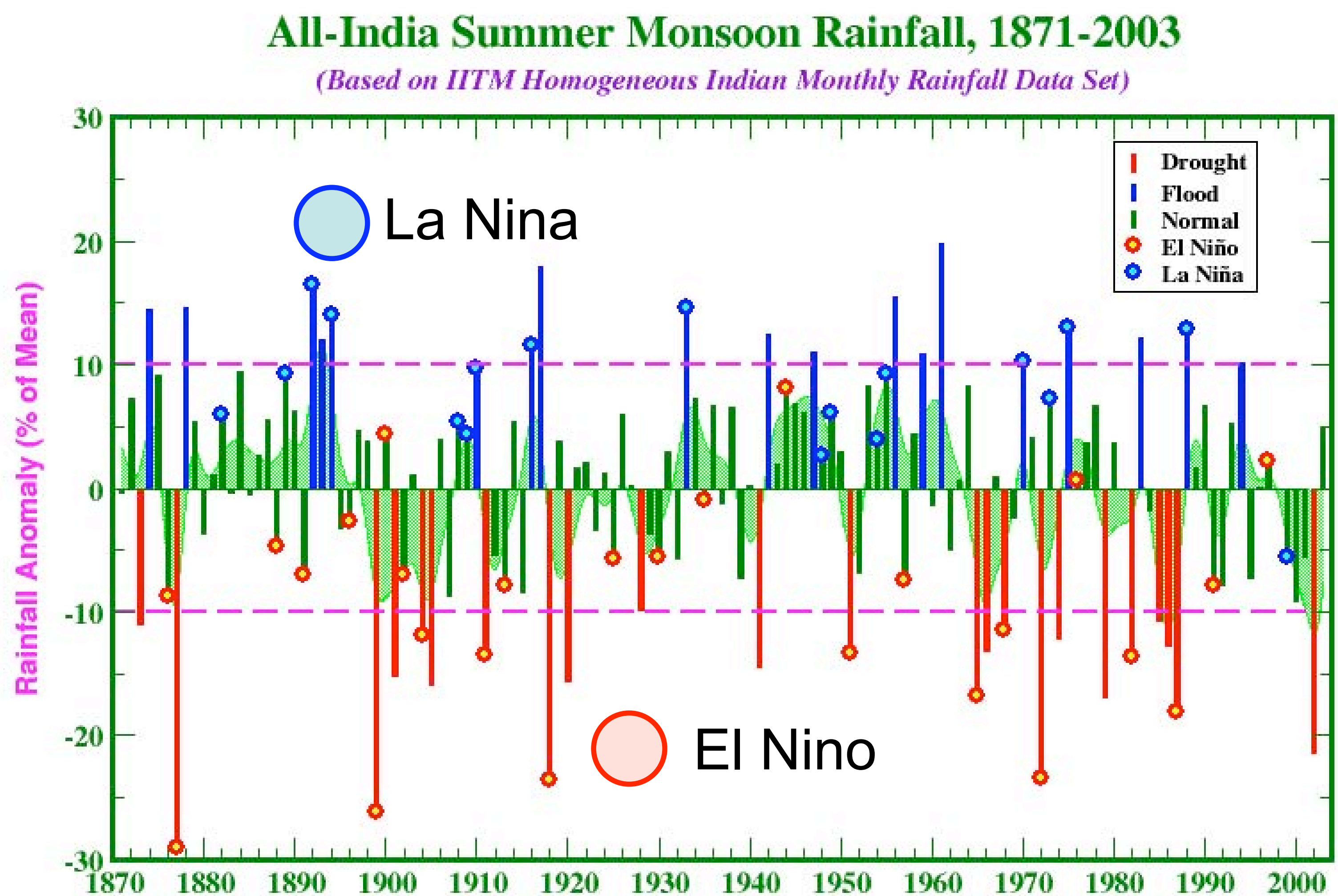


hard rain, hard to use

a shift toward fewer, bigger rainfall events since 1950, attributed to warming of the Indian Ocean

Goswami et al. 2006

historic variability (India)



Extremes of the Indian Monsoon connected to El Nino - La Nina oscillation in the Pacific, half a world away!

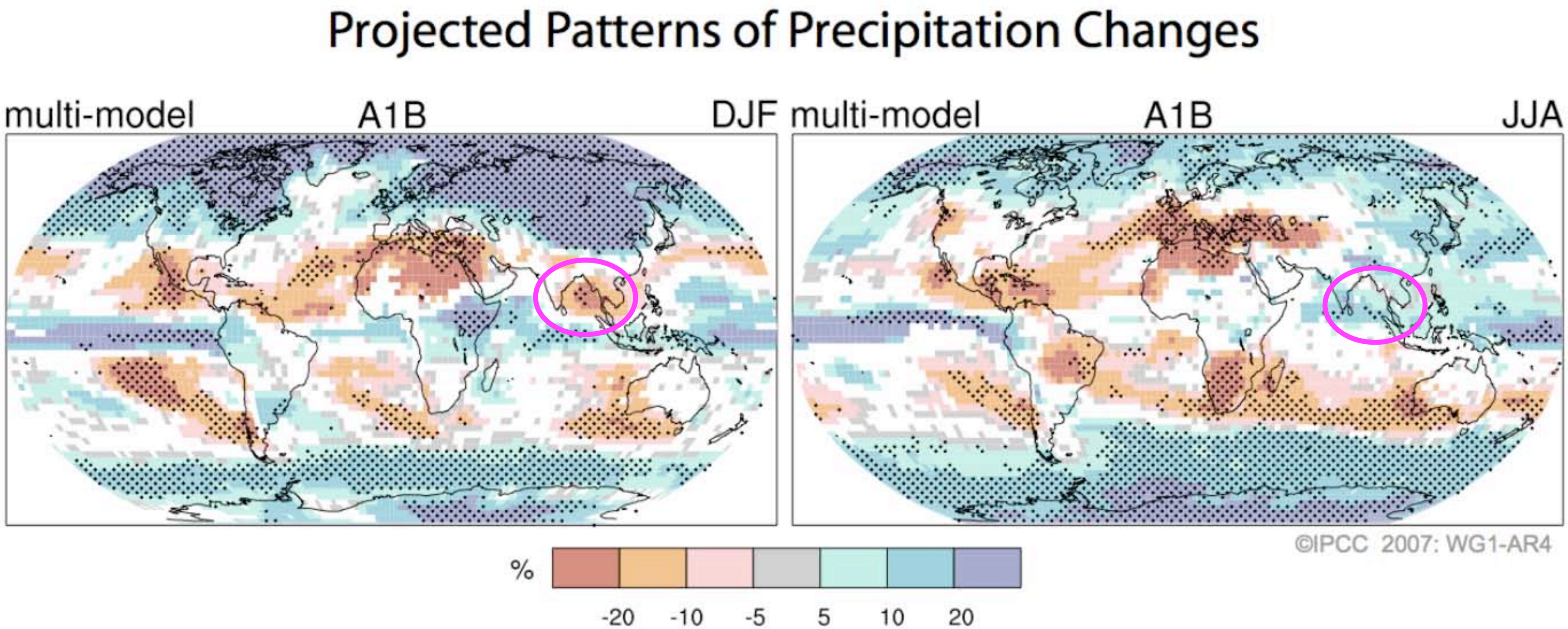
(we will study El Nino next week, when we begin ocean circulation)

tropical climate

- today the tropics are marked by large seasonal changes in precipitation (not temperature…..)

- we might conclude that some of the greatest impacts of any future climate changes in the tropics will be associated with timing and intensity of rainfall

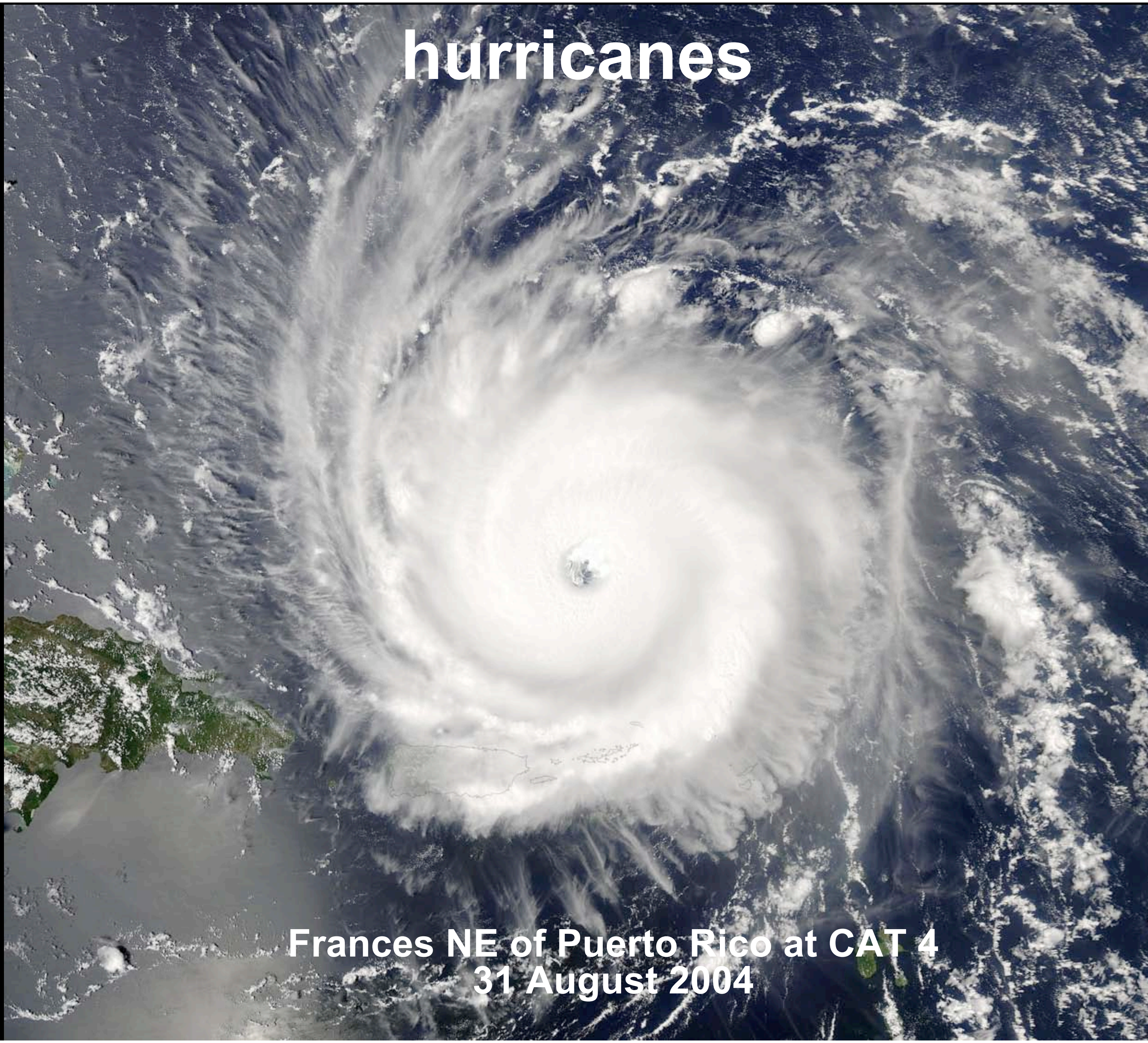
recall latest from IPCC



Seasonal 2090-99 projection vs. 1990-99 for average of many models. White areas are where less than 66% of models agree. Stippled areas are where more than 90% of models agree. All for same GHG scenario.

10 - 20 % is scale of historic variability in Asian monsoon

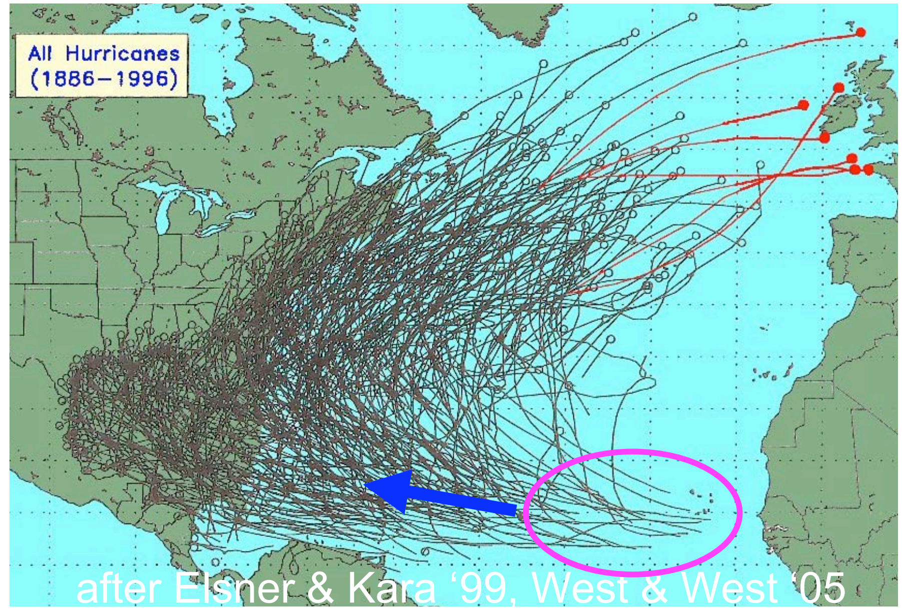
hurricanes

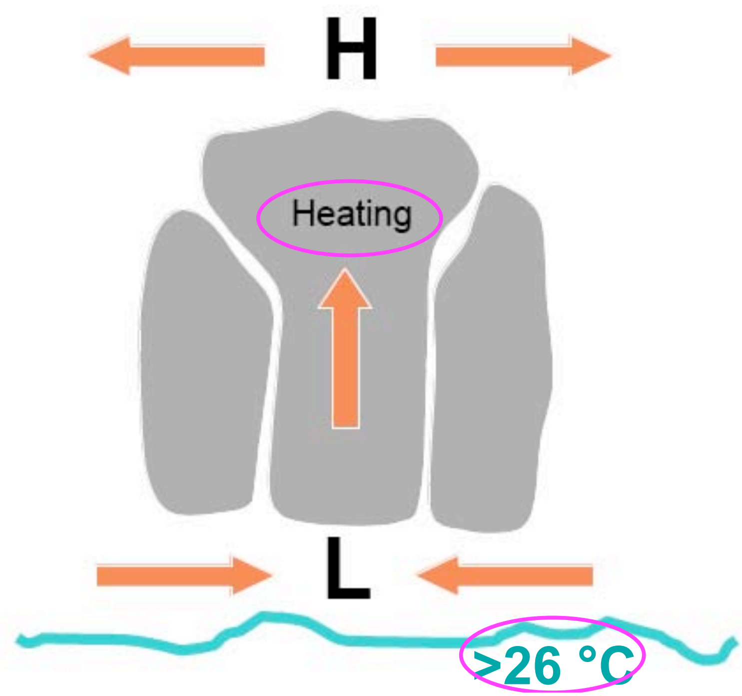


Frances NE of Puerto Rico at CAT 4
31 August 2004

hurricanes

- large topical storm systems that form and develop over warm waters near equator from small tropical depressions
- brought westward by gentle steering winds (trades)
- fueled by sensible and latent heating from warm ocean and moisture convergence
- generally require waters warmer than 26 °C to form and develop



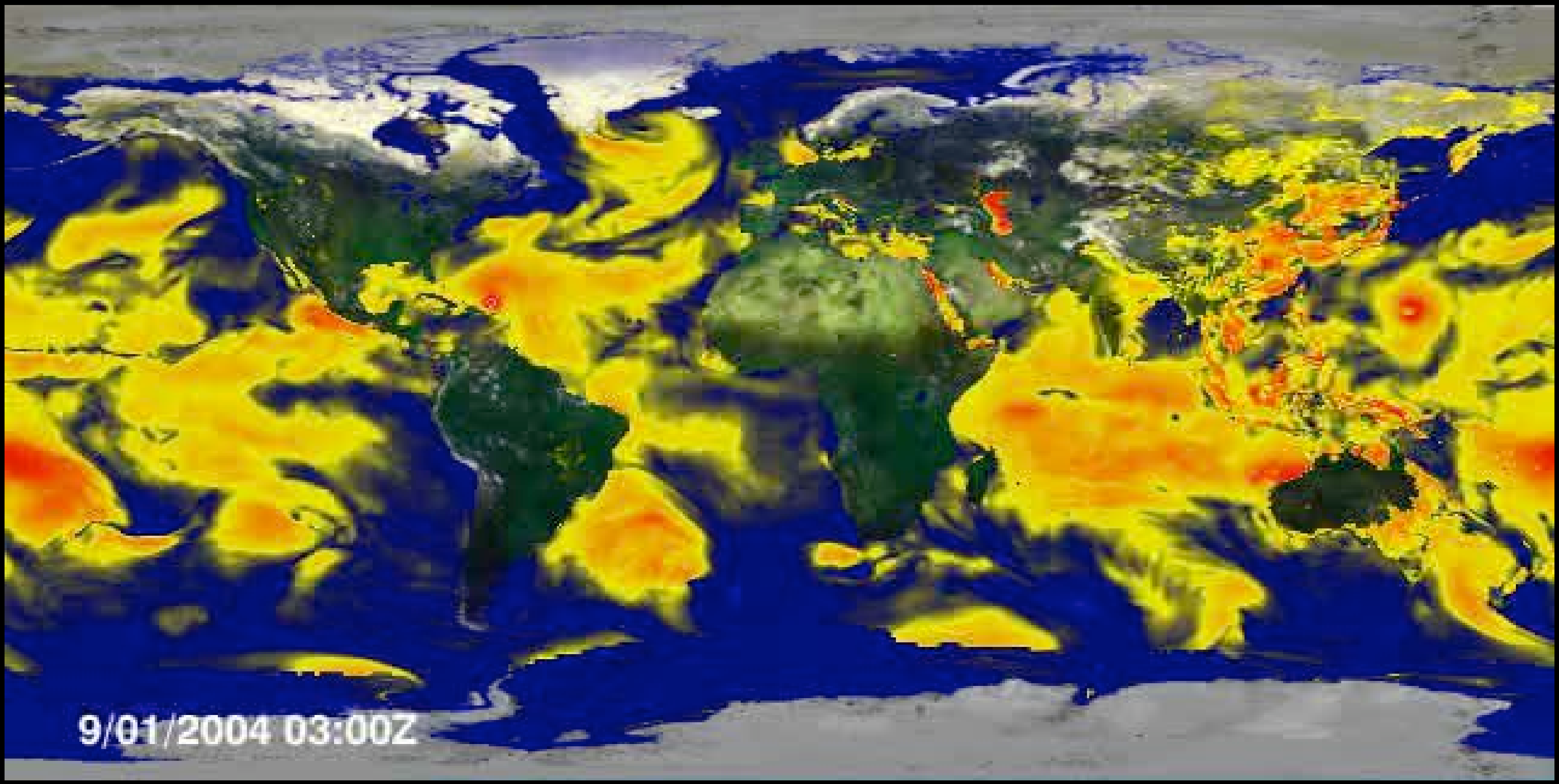


what makes a strong hurricane season

- *gentle steering winds (trades) from Africa*
- *little vertical wind shear (shear often assoc. w/ El Nino in Pacific, shear impedes “spin”)*
- *warmer sea surface (natural cycles, global warming)*

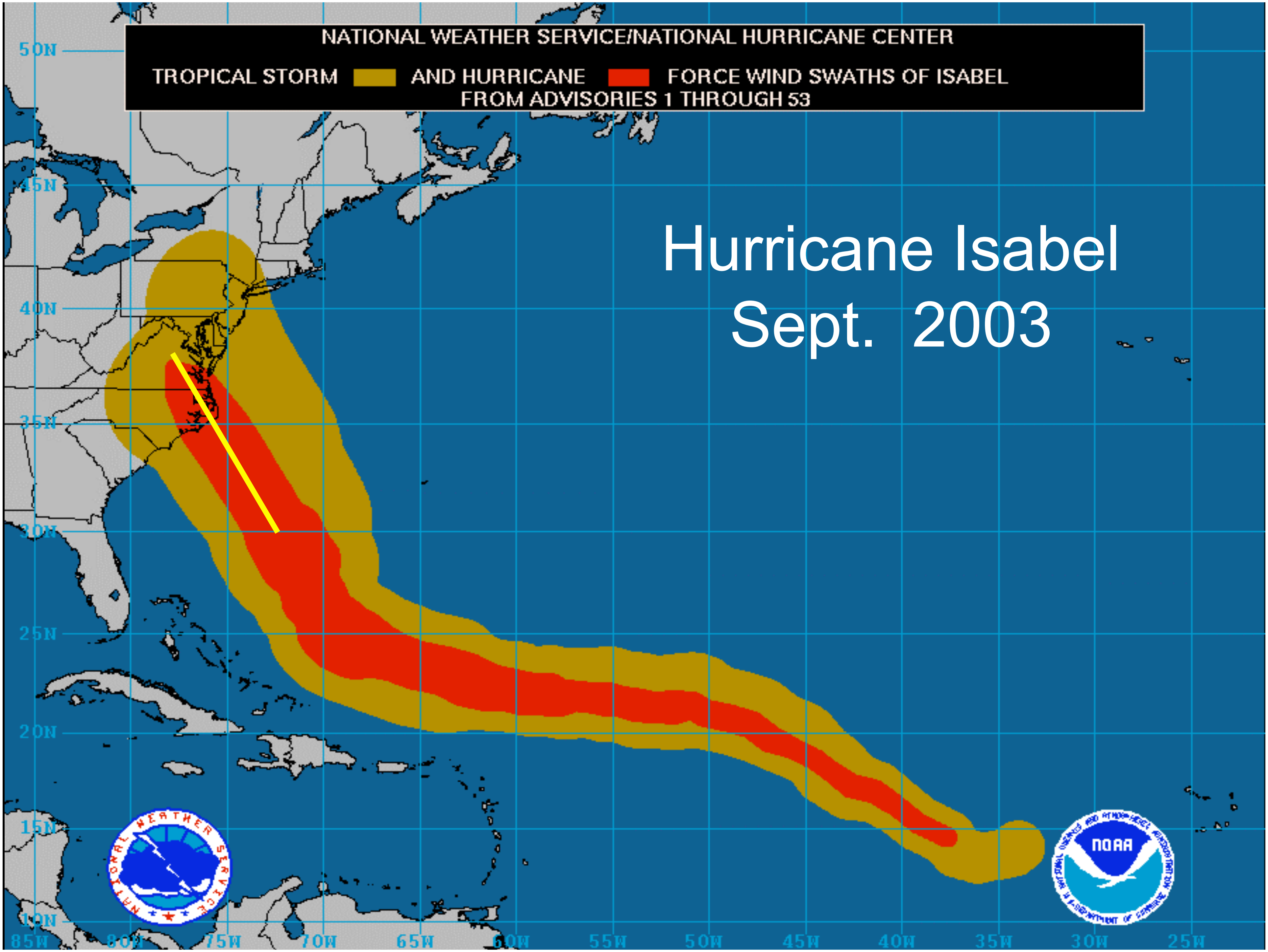
- *remember warm water and latent heat are food for hurricanes!*

global surface flux of latent heat
Sep. 1-4 '04

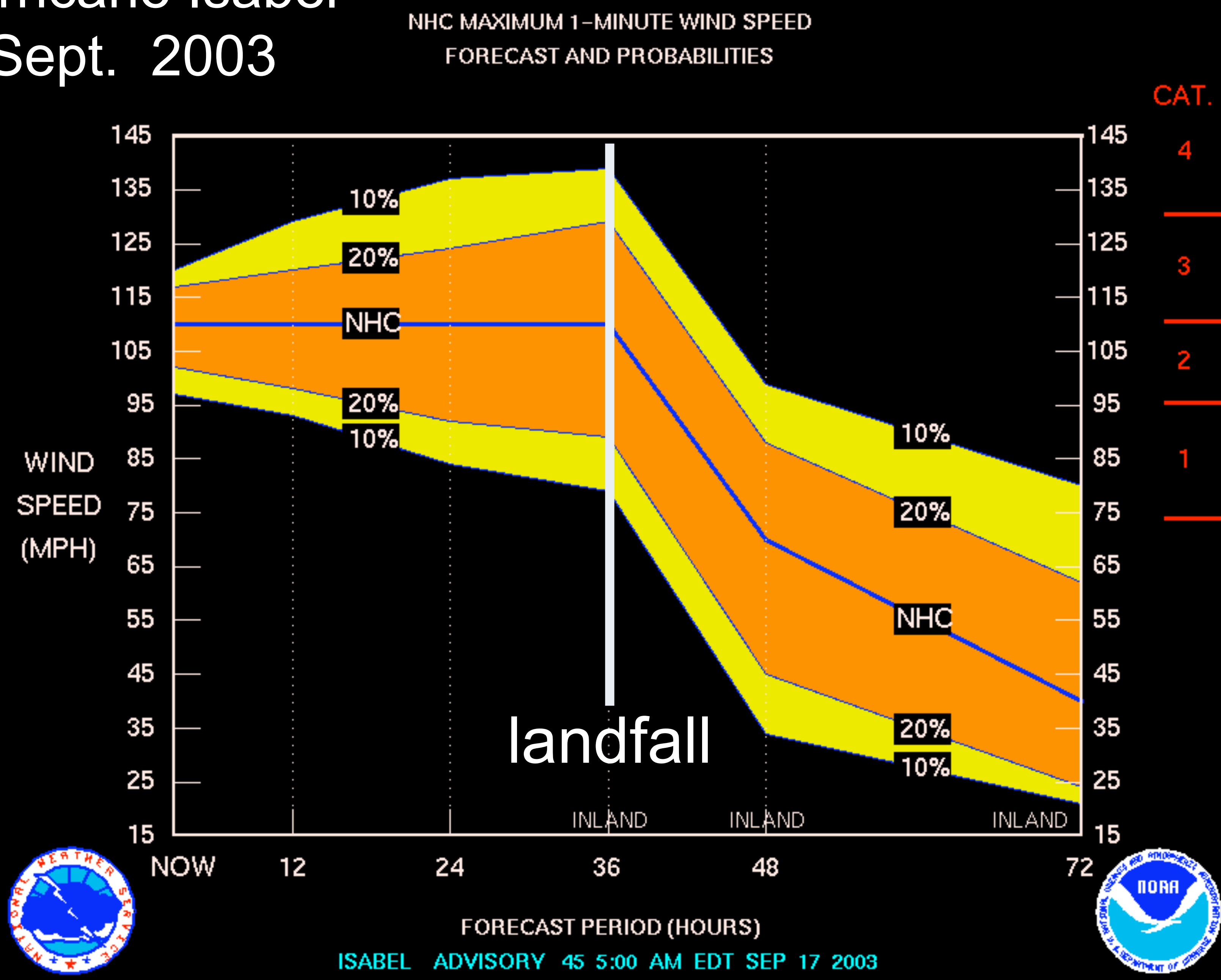


Hurricane Isabel, Sept. 2003

from the International Space Station
Tuesday, 16 September 2003


NATIONAL WEATHER SERVICE/NATIONAL HURRICANE CENTER
TROPICAL STORM AND HURRICANE FORCE WIND SWATHS OF ISABEL
FROM ADVISORIES 1 THROUGH 53
Hurricane Isabel
Sept. 2003
50N
45N
40N
35N
30N
25N
20N
15N
10N
85W
80W
75W
70W
65W
60W
55W
50W
45W
40W
35W
30W
25W

Hurricane Isabel
Sept. 2003



- ***warm water and latent heating fuel hurricanes***

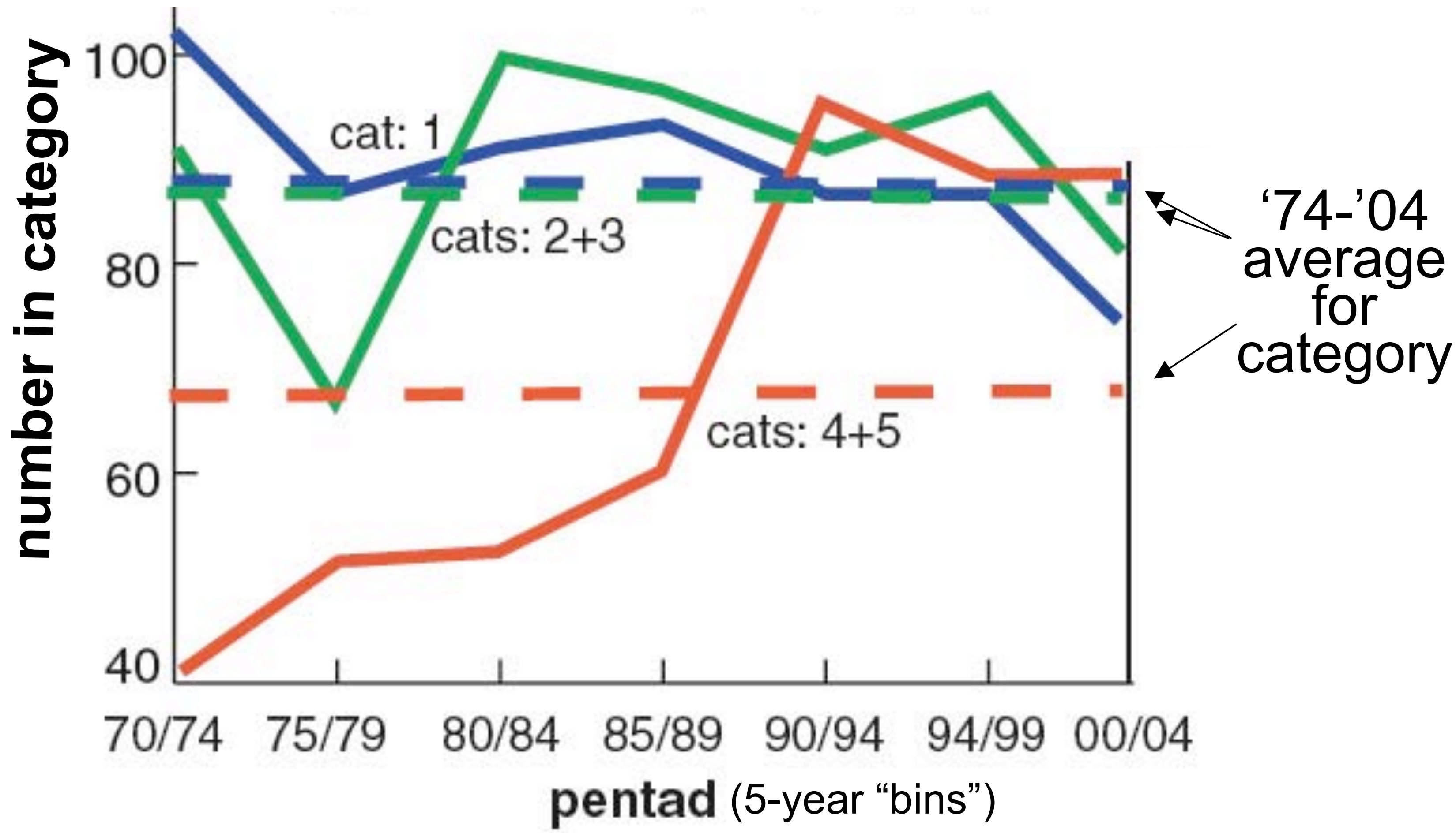
- ***storm strength therefore diminishes significantly at landfall***

hurricane strength

SAFFIR/SIMPSON DAMAGE POTENTIAL SCALE

CATEGORY	WINDSPEED (MPH)	PRESSURE (MB)	SURGE (FT)
1	74 – 95	> 980	4 - 5
2	96 – 110	965 – 979	6 - 8
3	111 - 130	945 – 964	9 - 12
4	131 - 155	920 - 944	13 - 18
5	> 155	< 920	> 18

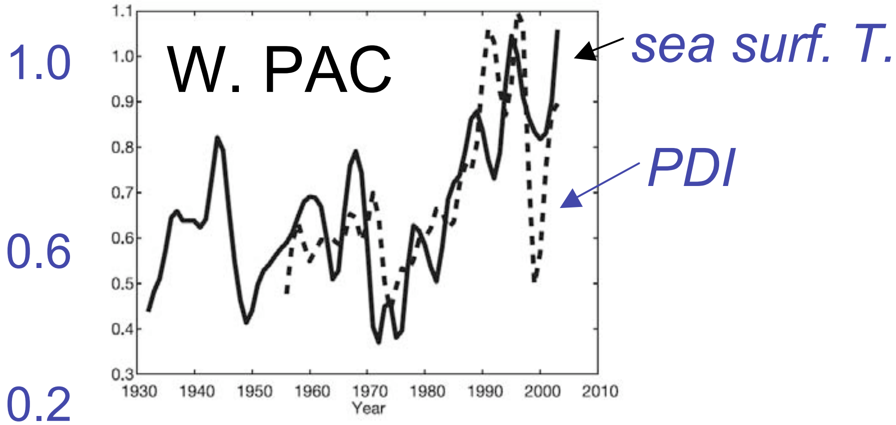
number of intense hurricanes



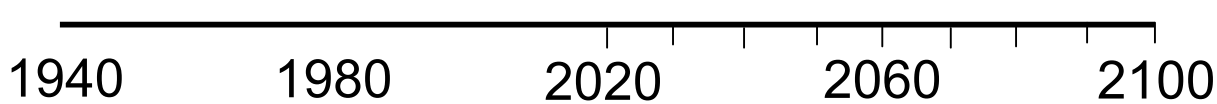
the frequency of the most powerful (category 5) hurricanes has doubled in the last 30 years.....

Webster et al. '05

destructive power (PDI) and SST

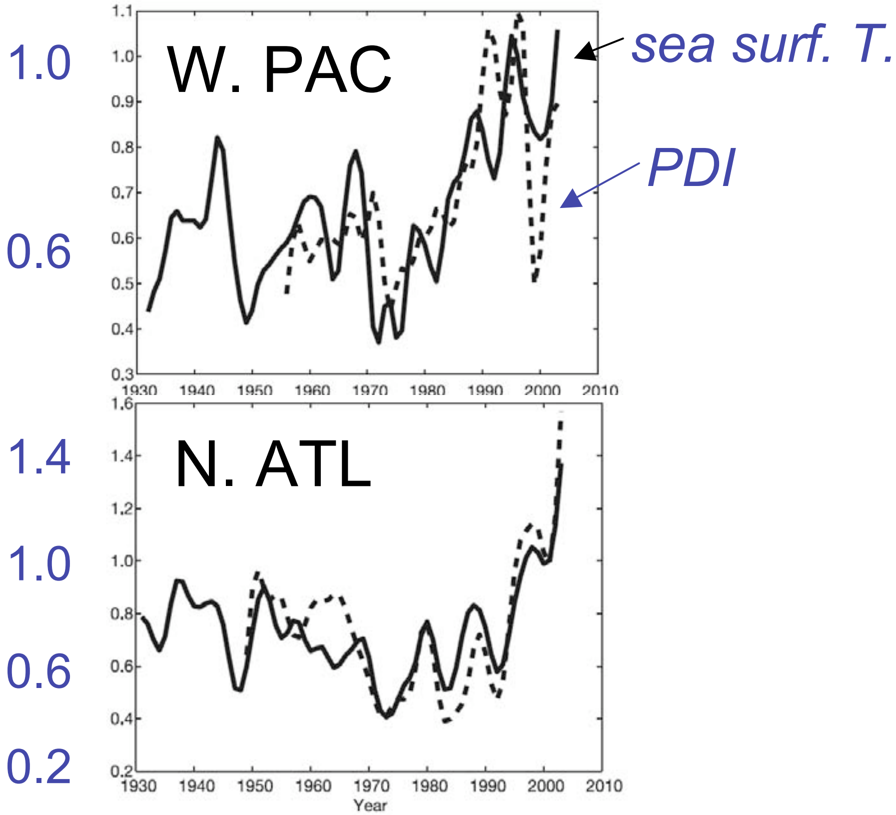


destructive power of cyclones doubled in assoc. with a 0.5 °C increase in temperature



after Archer '07
data of Emanuel '05

destructive power (PDI) and SST



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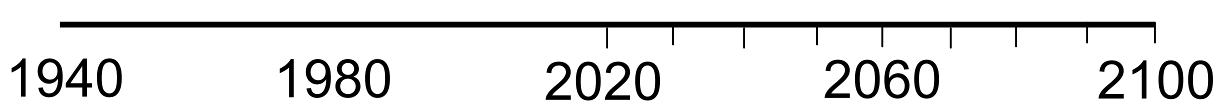
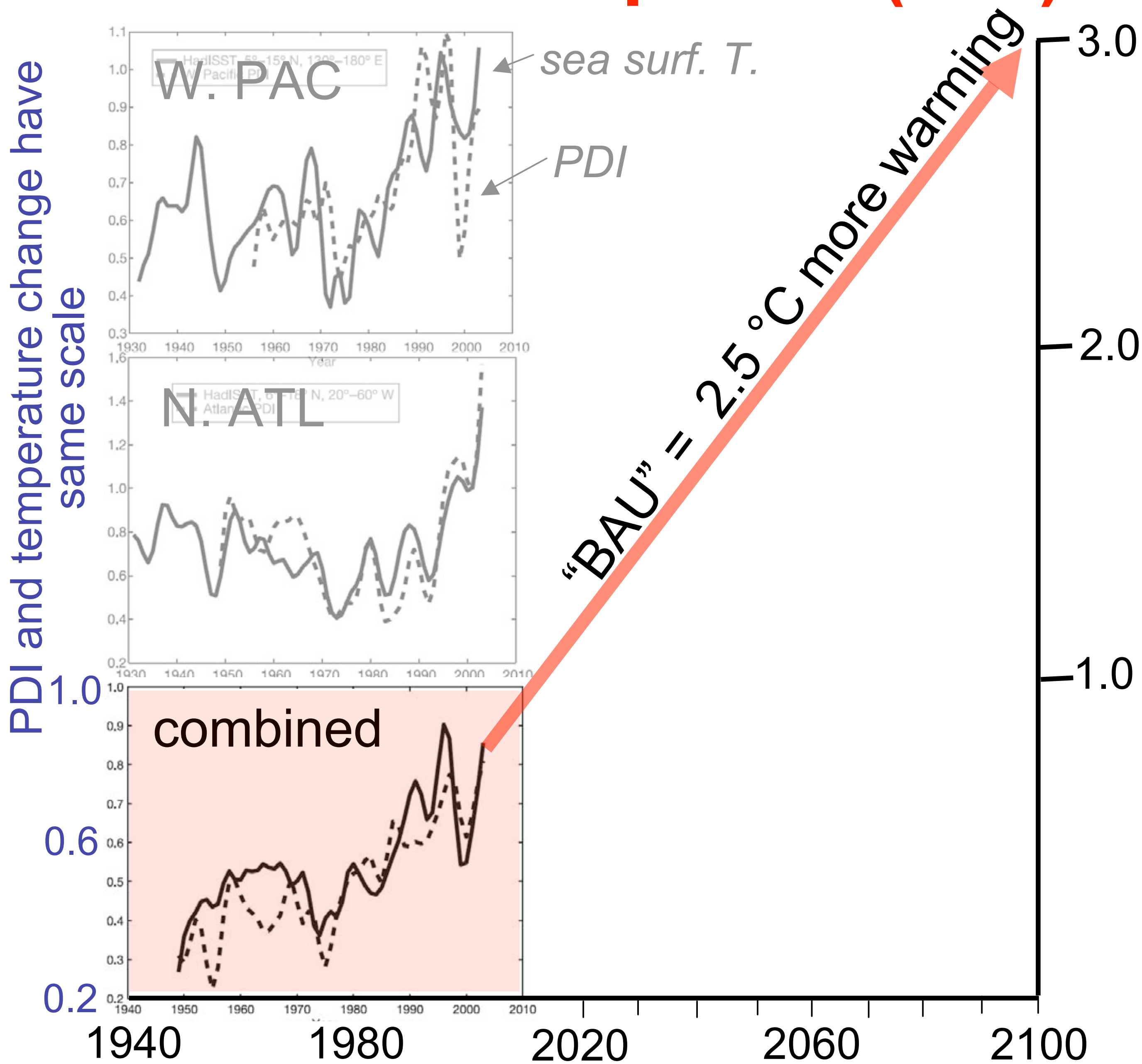


after Archer '07
data of Emanuel '05

destructive power (PDI) and SST



destructive power of cyclones doubled in assoc. with a 0.5 °C increase in temperature

what will happen with another 2.5 °C warming in a "BAU" scenario

after Archer '07
data of Emanuel '05

learning goals

- explain the large scale transfers of water within the climate system and how the excess of evaporation over the oceans relates to the excess of precipitation over land
- describe the process by which latent or hidden heat is created and released
- explain how the movement of water vapor from areas of net evaporation to areas of net precipitation influences the poleward transport of energy within the atmosphere
- be able to describe the seasonal movement of the ITCZ and its relationship with the tropical monsoon
- be able to describe a simple mechanism explaining the seasonal change in wind direction and the monsoon over India and SE Asia
- describe the conditions that allow hurricanes to develop and strengthen