Atmospheric circulation III

Reading: GPC Ch 6

Outline:

- Large scale circulation patterns and climate
- Surface pressure and winds patterns,
- Vertical motions
- Regional circulations
- Monsoons
- Zonal overturning circulation (Walker circulation)
- Deserts

Large-scale circulation pattern and climate

The circulation of the atmosphere is not zonally symmetric and east-west variations of wind and T are important for *regional climates*.

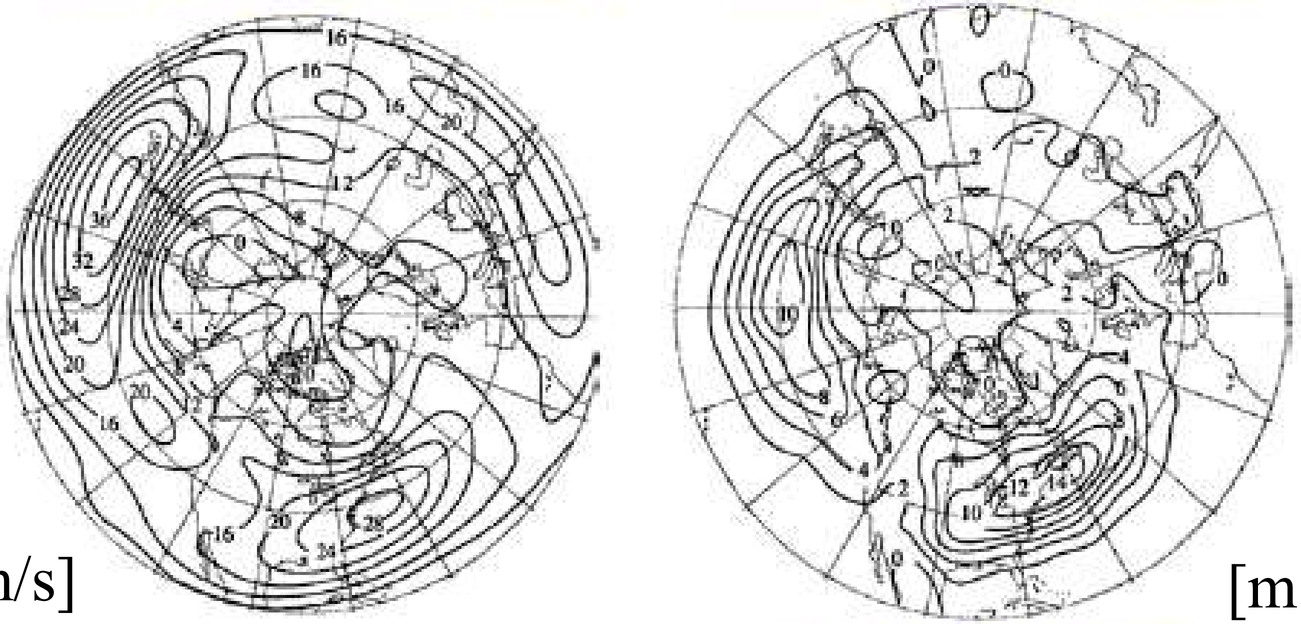
For example, the subtropical jet in midlatitudes is not equally strong at all λ but has local maxima associated with the distribution of land and ocean in the NH. During winter the subtropical jet stream has two local wind speed maxima downstream of the Tibetan plateau (over the Pacific) and downstream of the Rocky Mountains (over the Atlantic).

These maxima in the time-average wind speed are associated with maxima in the transient eddy activity and eddy fluxes of heat and moisture. They define the so-called *storm tracks*, where vigorous midlatitude cyclones are most frequently observed.

The seasonal migration of storm tracks plays a key role in the annual variation of precipitation in the areas affected by it.

Time-mean structure of upper tropospheric wind speed during winter and contours of northward T flux at 850 mb by transient eddies

500 mb wind speed (DJF) | 850 mb Heat Transport



[m/s] | [m K/s]

by eddies < 6 days

Very strong influence of "storm track" regions associated with air-sea temperature contrasts

Surface pressure and wind patterns

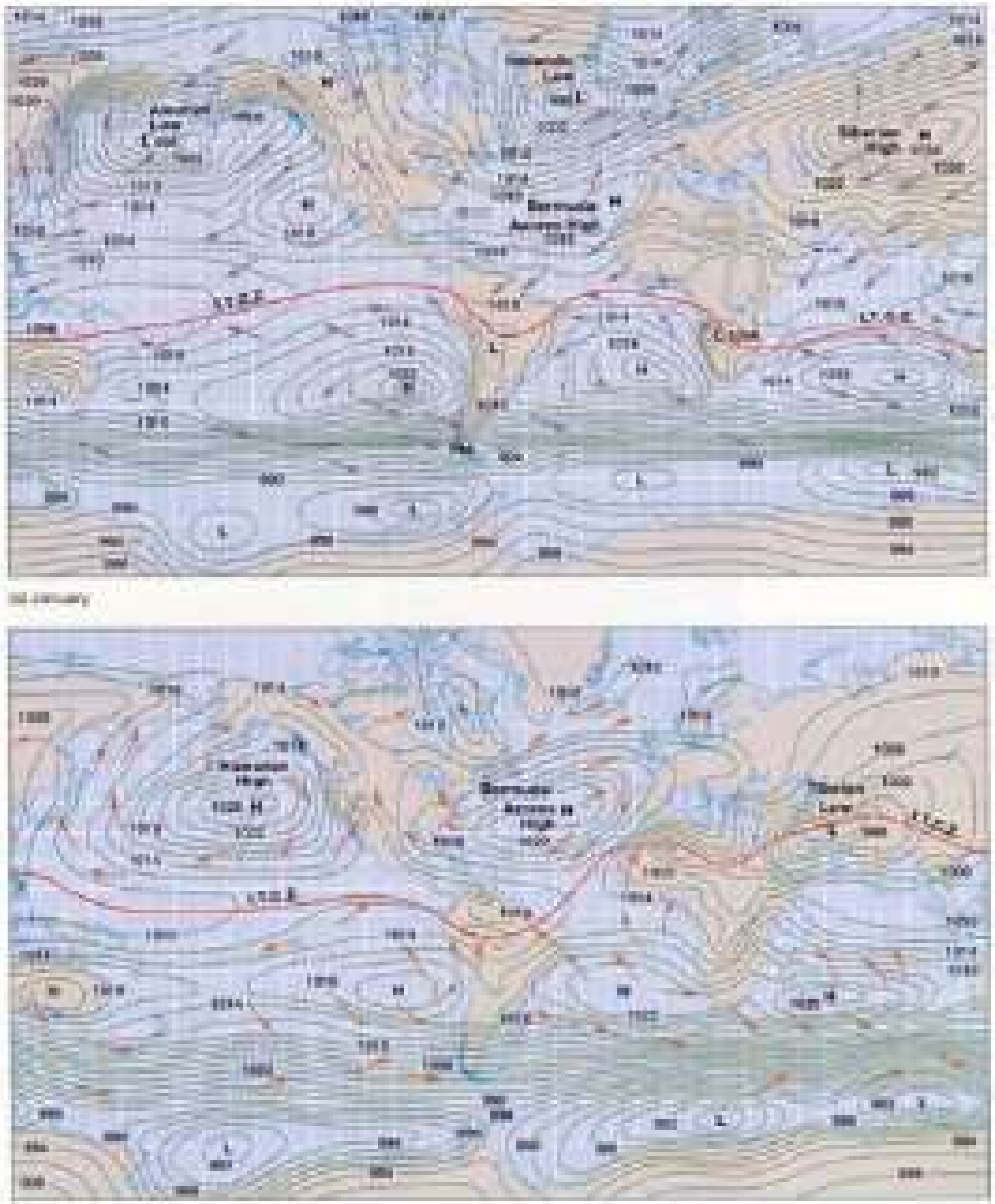
The spatial distribution of surface air pressure in the various months or seasons is an important indicator of the AGC.

Near the surface air tends to spiral inward toward low pressure centers (L). By the conservation of mass, this converging air must rise over the L centers, what means deep convection.

Conversely, the flow near the surface spirals outward from high pressure centers (H), causing subsiding motion above the PBL and suppressed convection.

The shifts in land-sea pressure distribution are driven by seasonal changes of insolation and the different responses of the land and ocean to heating.
Over the oceans the response of SST to seasonal variations of insolation is smaller because the energy is put into a deep layer of ocean with a large heat capacity and because evaporation consumes much of the heat input.
Land surfaces have a much smaller capacity for storing heat, and often are not sufficiently wet for evaporation to be important → land surfaces warm up dramatically in summer and cool in winter.

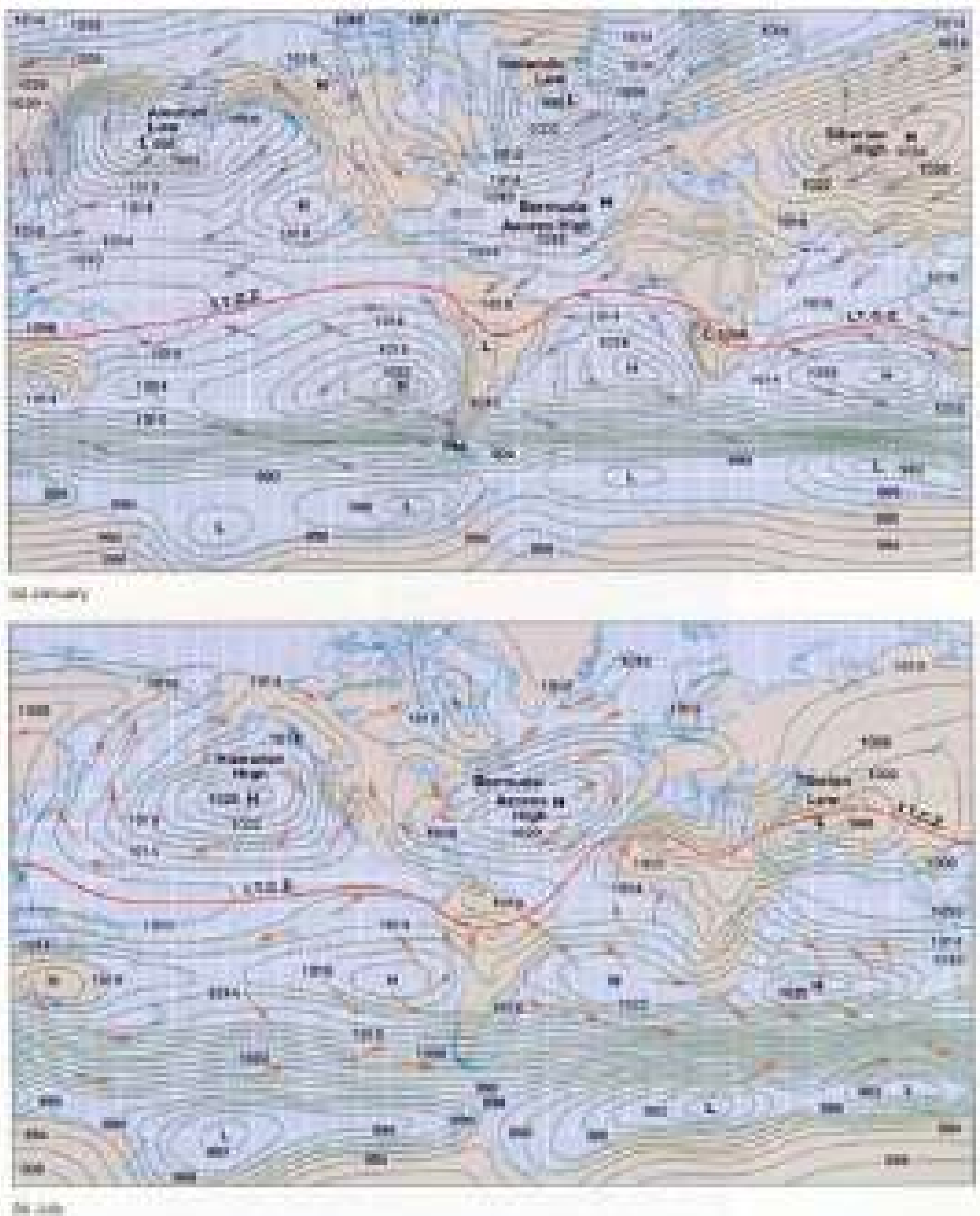
The pressure variations around latitude circles in midlatitudes are associated with the dynamical response to land-sea temperature and heating contrast. The L generally occupy the warm regions where the atmosphere is heated and the H occur where T is low and the atmosphere is being cooled. Land surfaces are warmer than adjacent oceans in summer and are colder than the oceans in winter.



- Midlatitude L over the Pacific and the Atlantic during winter: notice air convergence

- Surface pressure near 30^0 of ϕ generally higher than at the equator $\rightarrow$ tropical srfc tradewinds, which generally blow toward the equator from both hemispheres and meet in the *ITCZ = Intertropical Converg.Zone*

- ITCZ: srfc pressure is low and deep convection occurs with LH release and large-scale $\uparrow$ motion

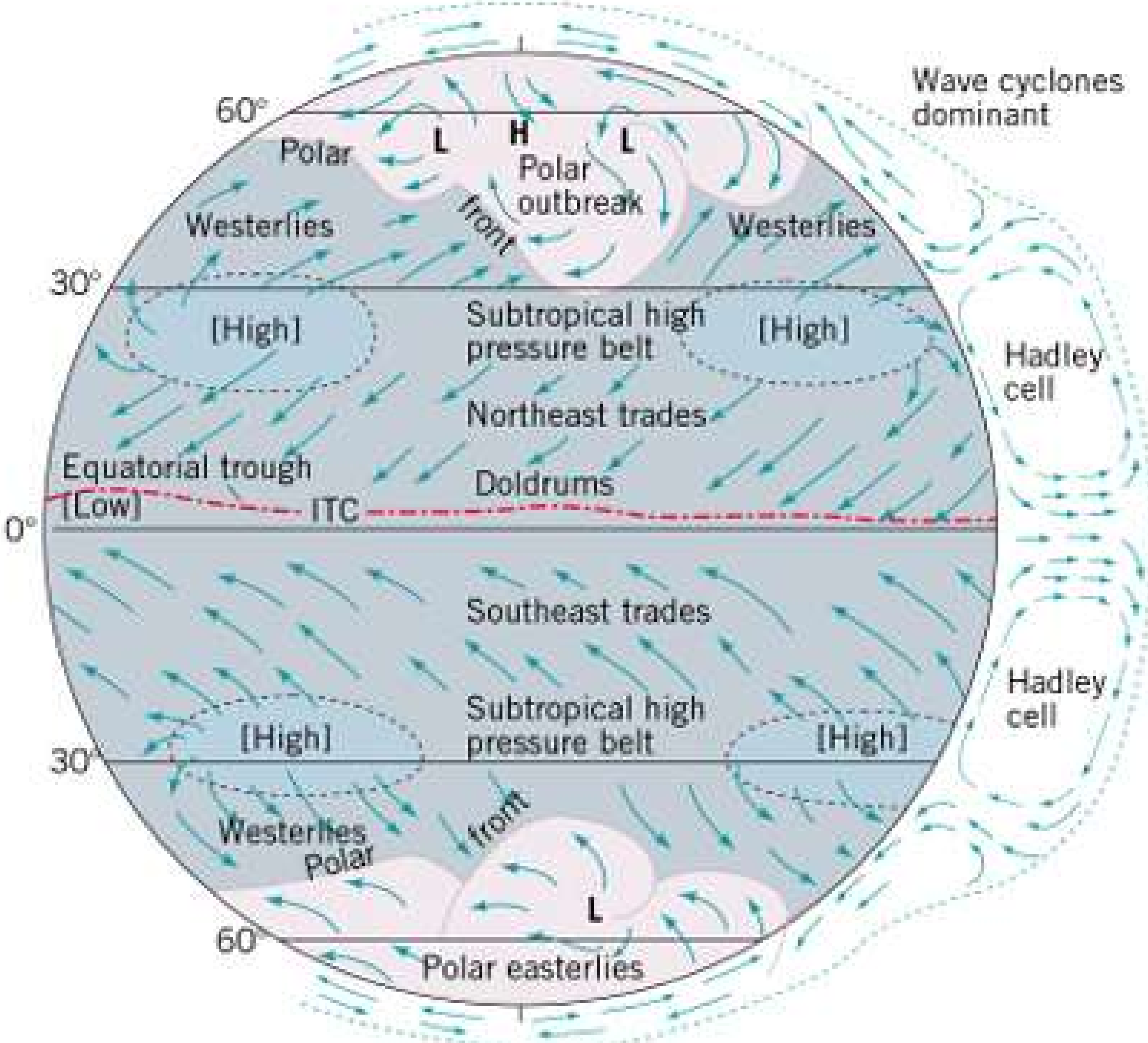


- Midlatitude westerlies in both hemispheres
- Strong semipermanent H and L areas (esp.in NH) assoc. w/ stationary waves
- Seasonal var. of srfc p most apparent in NH

Winter: Aleutian, Icelandic L high lat. oceans; Siberian H.

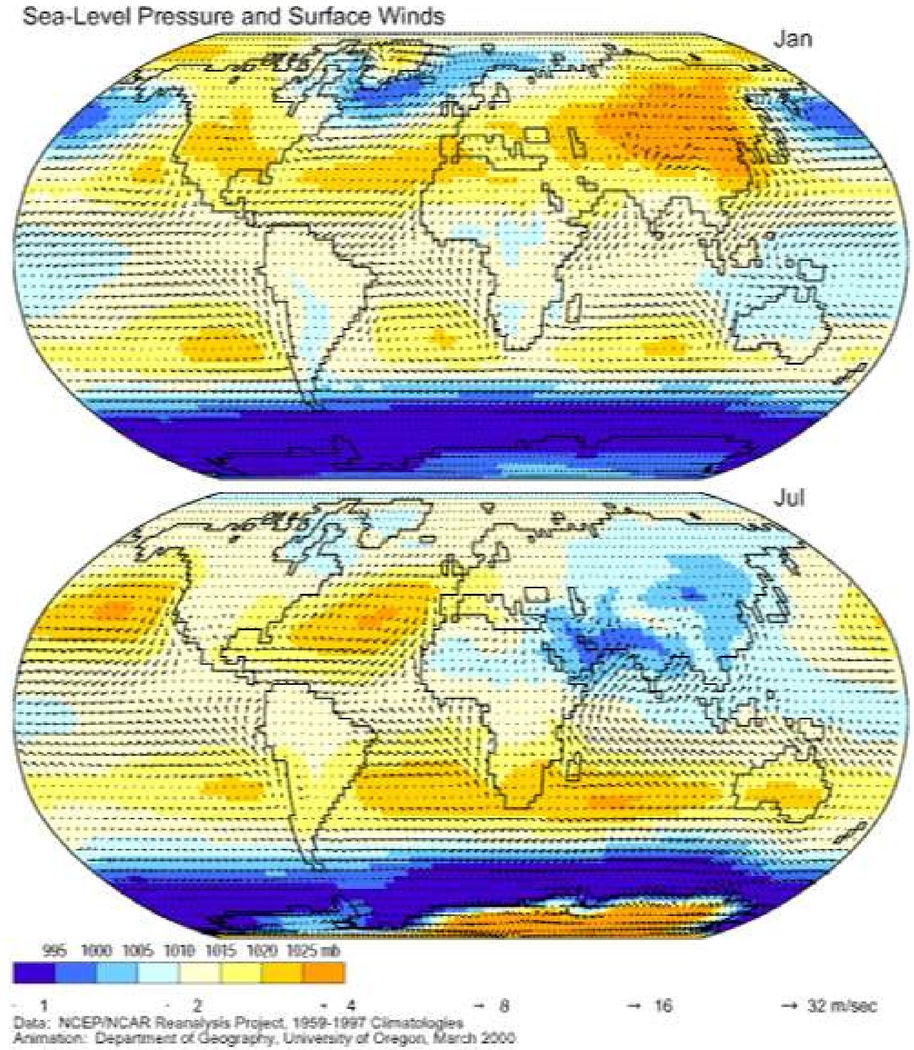
Summer: land-sea p contrast reversed in midlatit. (Hawaiian, Azores H; Tibetan L).

- Seasonal migration of ITCZ (monsoon)


Wave cyclones dominant
60°
Polar
L
H
L
Polar outbreak
front
Westerlies
Westerlies
30°
[High]
Subtropical high pressure belt
[High]
Hadley cell
Northeast trades
Equatorial trough [Low]
Doldrums
ITC
0°
Southeast trades
Hadley cell
Subtropical high pressure belt
[High]
[High]
30°
front
Westerlies
Polar
L
60°
Polar easterlies

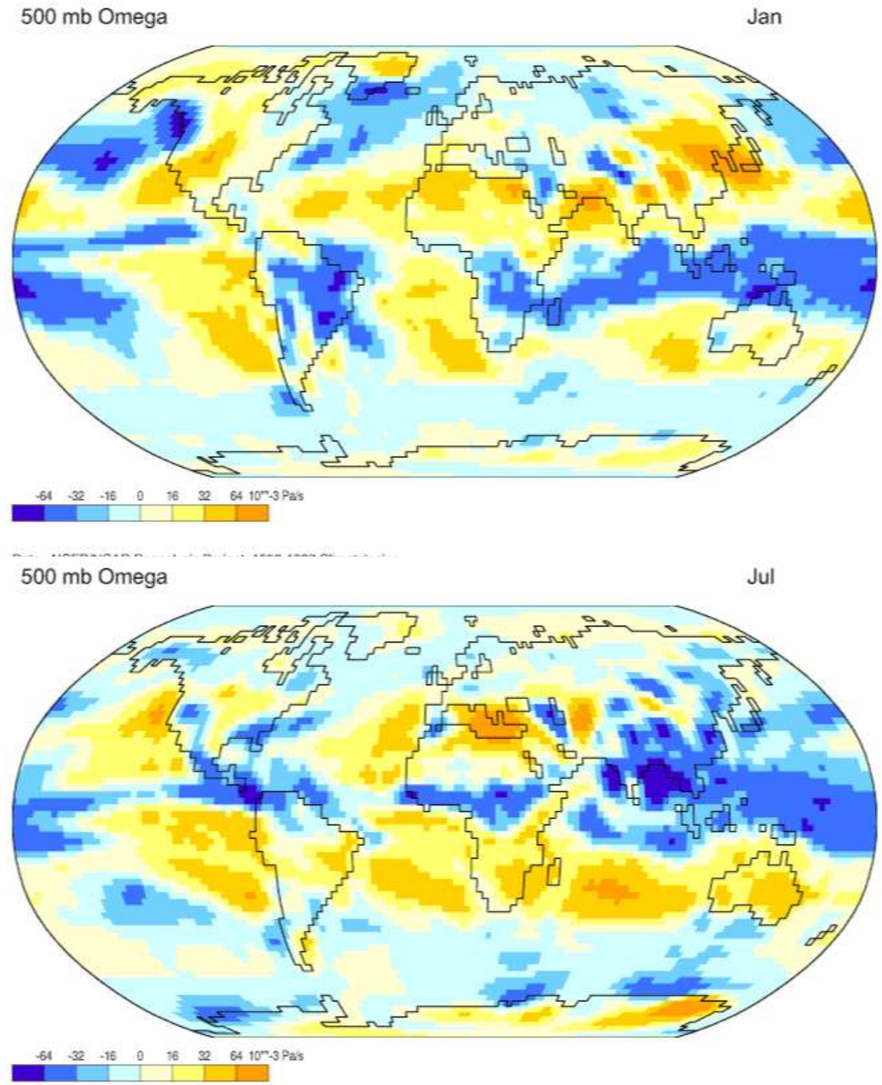
Regional circulations

Sea level pressure and surface winds: notice the low pressure zones in the tropics and high latitudes (in the NH, they are the Aleutian low in the Pacific, and the Icelandic low in the Atlantic); and the high pressure zones in the subtropics. Note correspondence between pressure and winds. Notice also the seasonal evolution - in particular, the strengthening of the NH subtropical high in summer, and the NH high latitude low in winter (why is this so?). Note also the contrast in sea level pressure between the land and ocean in the NH summer and winter.



500mb omega (pressure vertical velocity): positive values mean subsidence, -ve is uplift.

- The subtropical trades meet at the tropics at the ITCZ.
- Convection occurs all along the ITCZ, leading to uplift over the tropical belt. There is a tendency for convection over land regions, and over the warmest ocean waters.
- The air has to come down, and does so primarily over the subtropics. This inhibits convection, and over land regions results in deserts.
- Note the seasonal migration in the tropics.
- Also, the upward velocity in the high latitudes.
- How is uplift/subsidence related to sea level pressure?



Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies
Animation: Department of Geography, University of Oregon, September 2001

Monsoons (monsoon means ‘season’, from Arabic ‘mausim’)

•Describes complete reversal of wind regimes during the seasonal cycle in some regions of the tropics. In many parts of Asia, Africa and Australia seasonal changes in wind direction are accompanied by dramatic shifts in precipitation regime between very dry and very rainy. *The most pronounced is the Asian Monsoon*.

•Driven by changes in the distribution of heating driven primarily by the solar seasonal cycle.

•Requires a thermal contrast between land and sea to set up a monsoon.

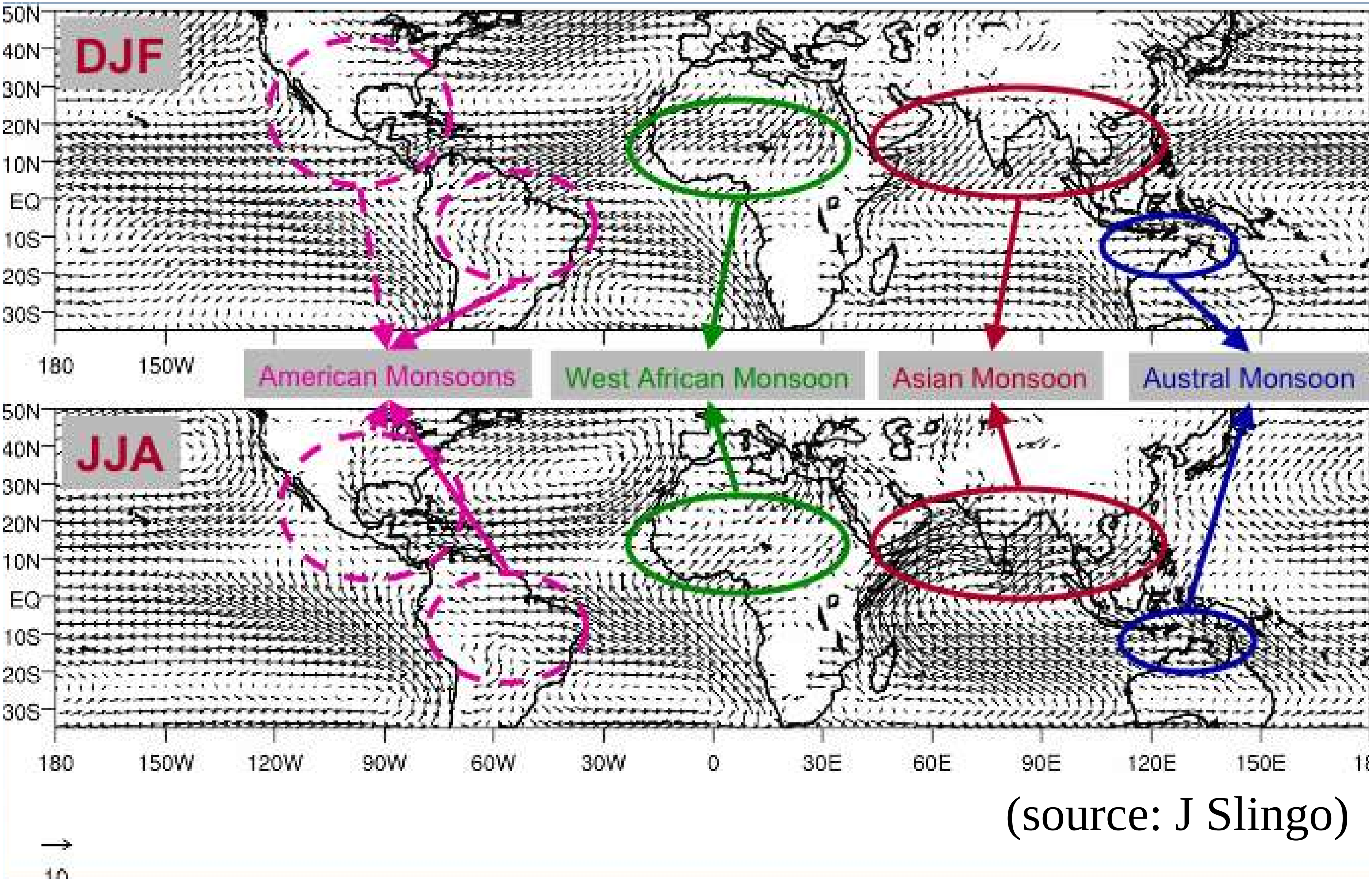
•Once established, positive feedback between circulation and latent heat release maintains the monsoon.

Asian Monsoon

- **Summer:** Tibetan plateau heated by insolation → atmosph. warms → srfc pressure decreases → low level flow of warm, moist air from the ocean to the land which causes intense precipitation over India and the slopes of Himalaya. The heating by insolation and LH release drives ↑ motion in the atmosphere, balancing the convergence of air at low levels.
- **Winter:** Himalayas cool dramatically → srfc pressure increases → air flows toward the Indian Ocean from the land at low levels and India and sorrounding lands experience a wintertime drought.

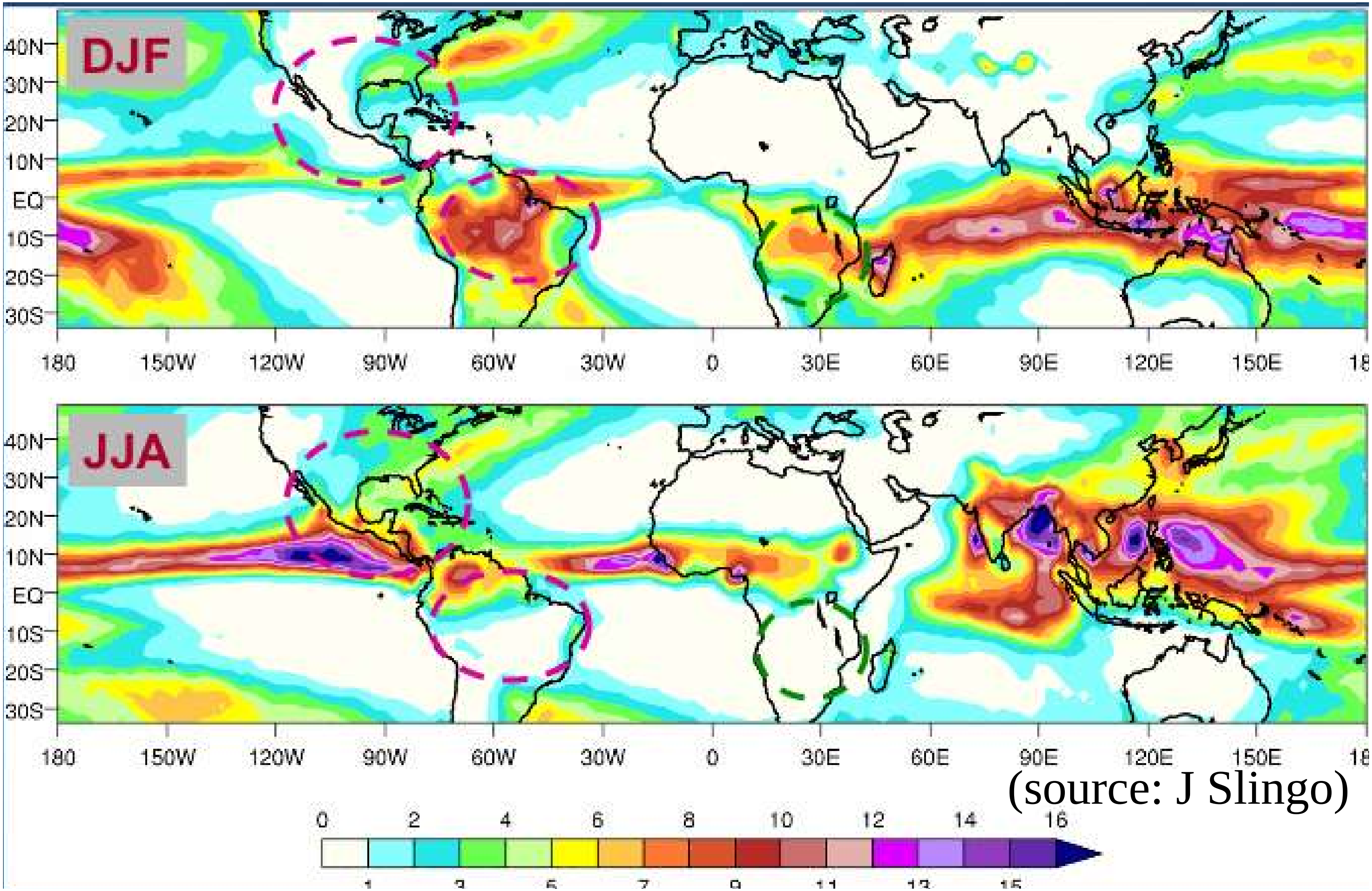
The switch from dry to moist conditions occurs abruptly at about the middle of June. The date of monsoon onset and the duration and intensity of rainfall vary from year to year. These fluctuations can produce either flood or drought.

925mb winds



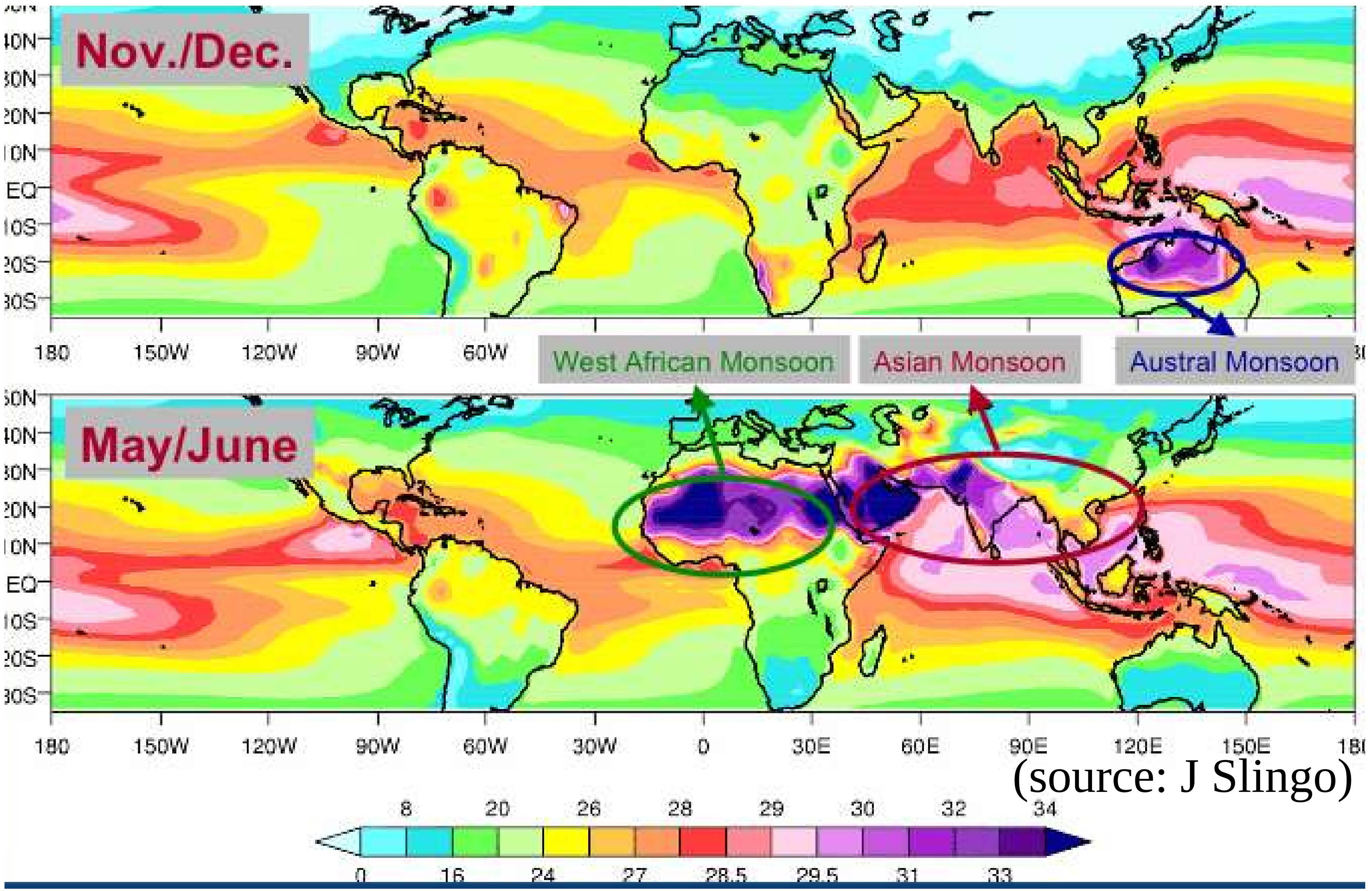
(source: J Slingo)

Rainfall



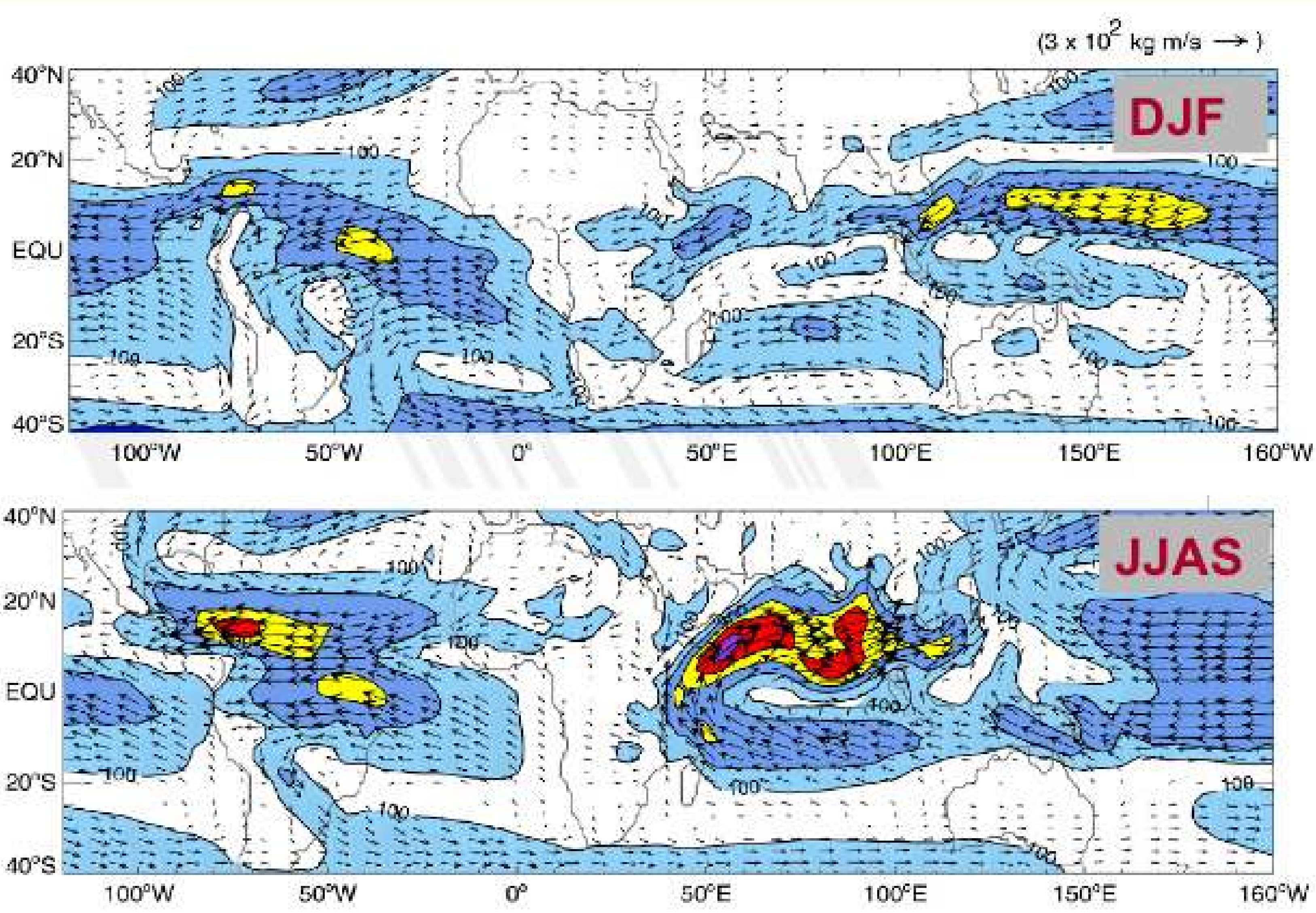
(source: J Slingo)

Land-sea temperature contrasts



(source: J Slingo)

Monsoon moisture supply - vertically integrated moisture flux



(source: J Slingo)

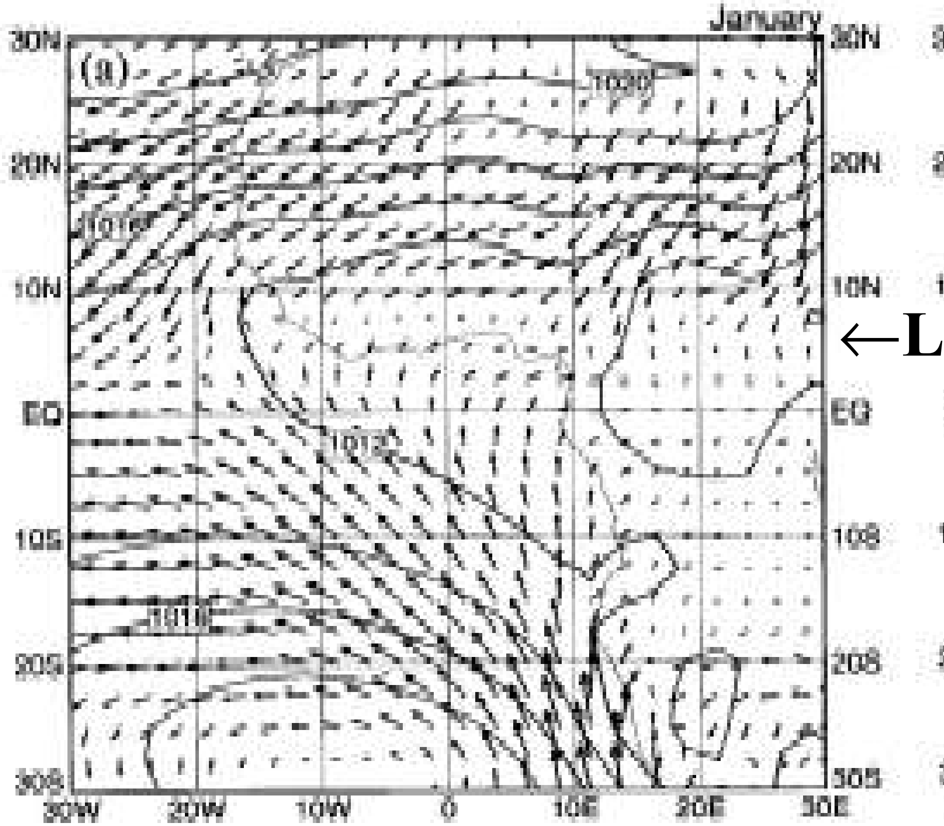
Tropical wet and dry climates: the West African Monsoon

Many tropical regions have a wet season and a dry season of varying length. Example: between the boundary of Sahara (~ 16^0N) and the equatorial belt the precipitation is seasonal.

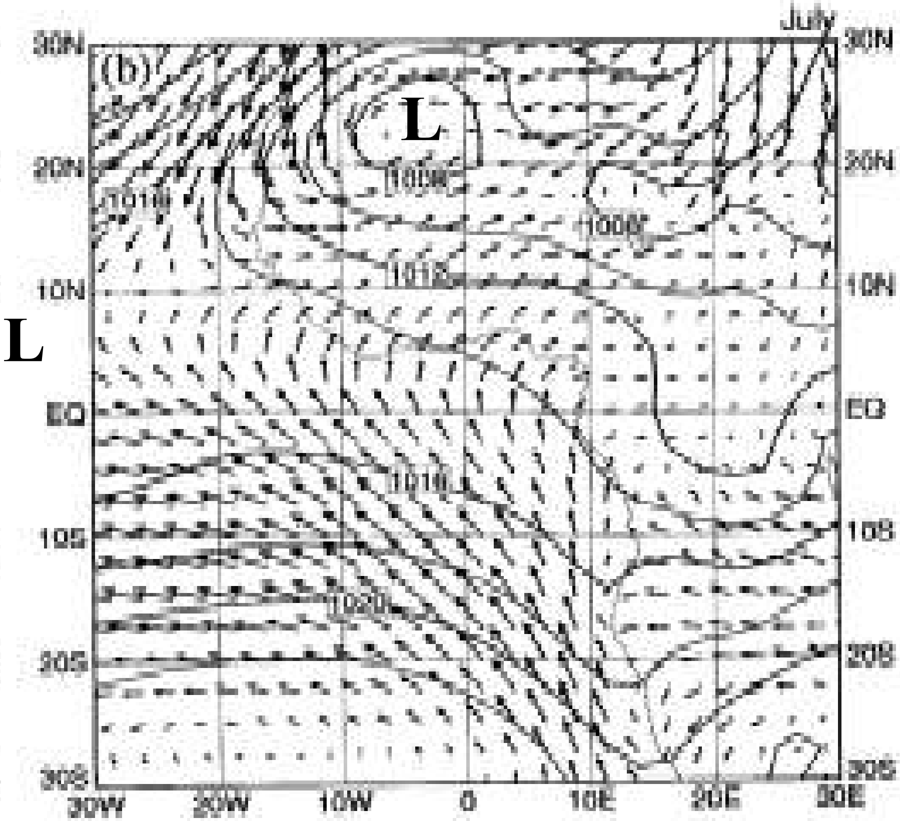
- **Jan-Dec (summer):** strong solar heating $\rightarrow$ air warms $\rightarrow$ upward motion (L at ~ 7^0 N) that draws moist low level air convergence from the south (origin: Gulf of Guinea and moist land areas of Central Africa) $\rightarrow$ precipitation.

- **July (winter):** the L occurs at 22^0 N, 5^0 W $\rightarrow$ the air must follow a long trajectory over dry lands $\rightarrow$ it is quite dry when it reaches the area where the low level winds converge $\rightarrow$ shallow rising motion, small precipitation.

Mean sea level pressure and 1000 mb winds over West Africa



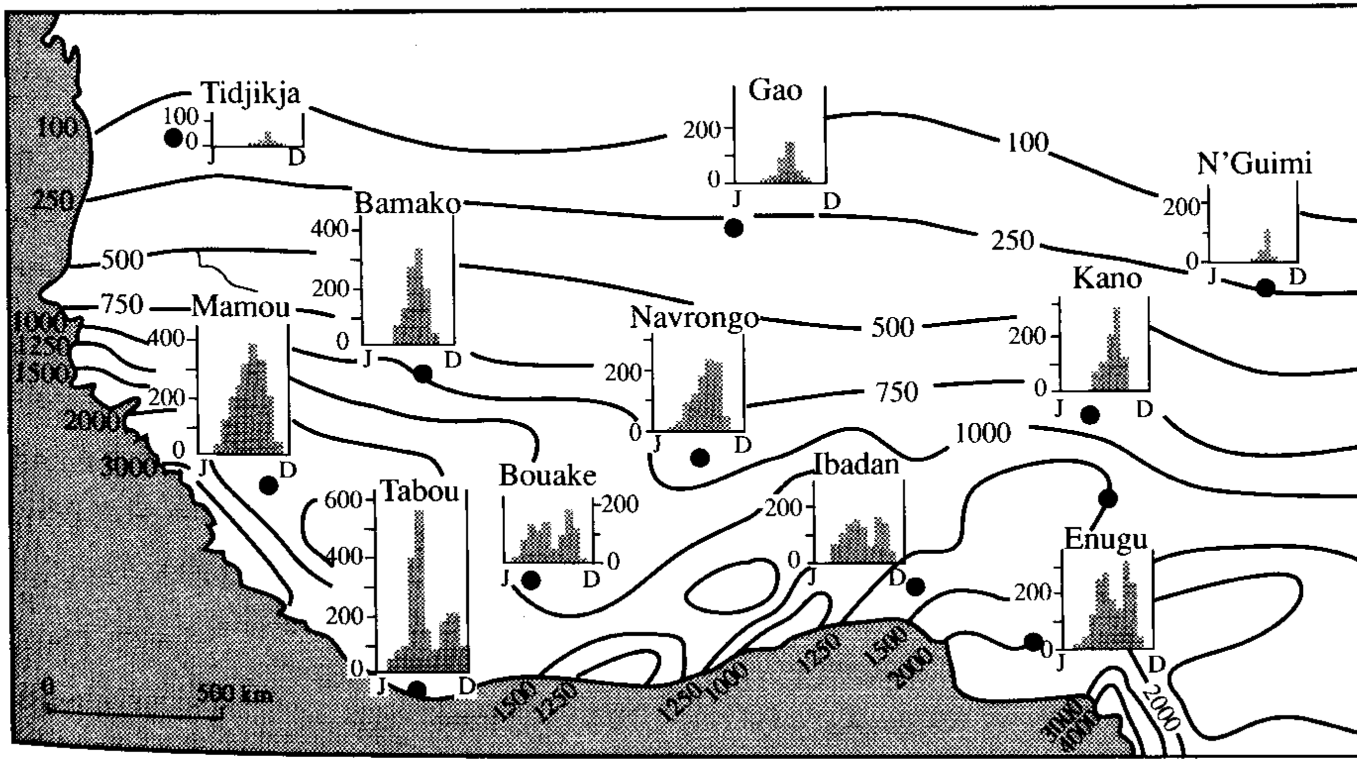
Summer - wet



Winter - dry

Seasonality of precipitation in NW Africa

Contours of annual mean precipitation in mm/y and bar graphs showing the monthly precipitation from Jan to Dec in mm/month.



The wet season decreases in duration and reliability moving northward.The Sahel is the margin between the dry Sahara and the summer rainfall belt over West Africa. Variations in circulation lead to substantial changes to the Sahel rainfall from year to year.

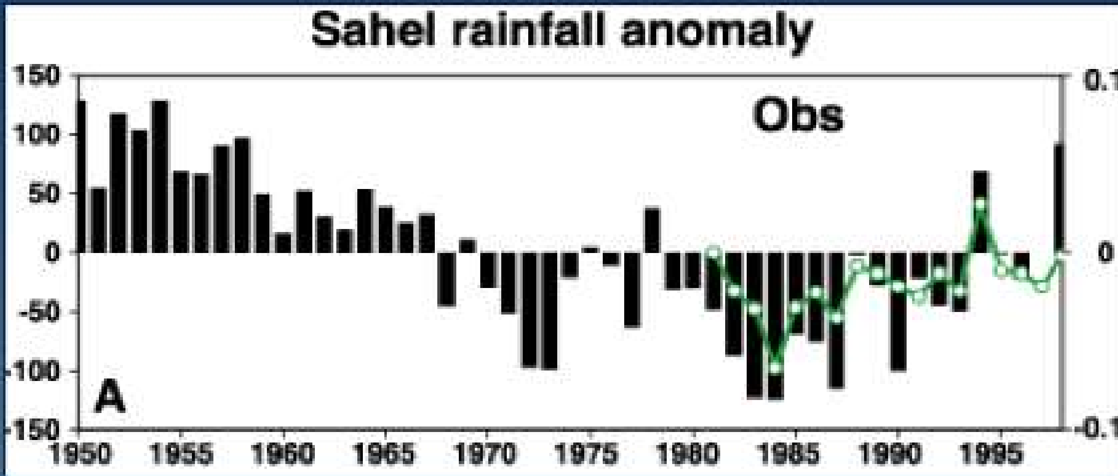
In **Sahel**, at the southern margin of the Sahara Desert, life is particularly sensitive to unusually dry or wet years. Rains may fail for several years. The effects of drought may be made worse by surface changes by humans (firewood) or domestic animals (vegetation to eat): land is denuded of vegetation (slow growth rate during drought!) and the *desert may advance into regions that were previously semiarid* →

- increased albedo
- heating rate for low level convergence not attained
- less rain

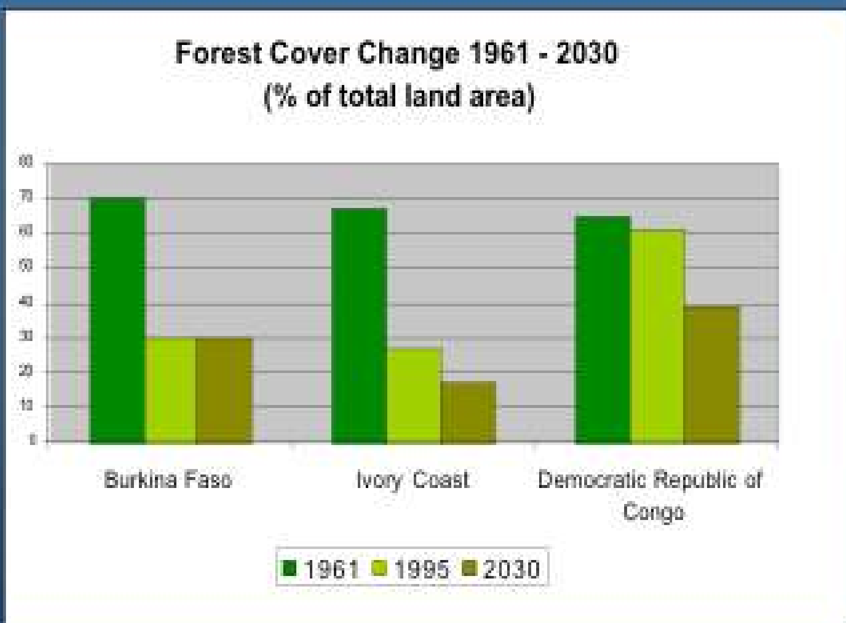
The reverse feedback process is also possible: succession of wet years → surface vegetation → additional wet years.

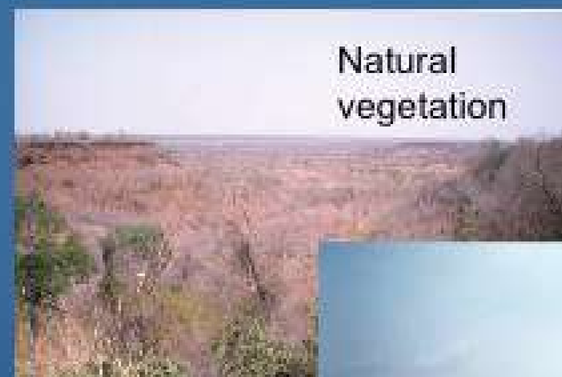
The desert margin is thus a sensitive region and can be altered by modest forces driving it toward greater or lesser aridity.

Sahel rainfall and land use change



Sahel summer rainfall (mm) displays huge decadal variations not seen in other tropical regions.





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Recent and projected deforestation in Africa shows land use change set to continue

Wet climates

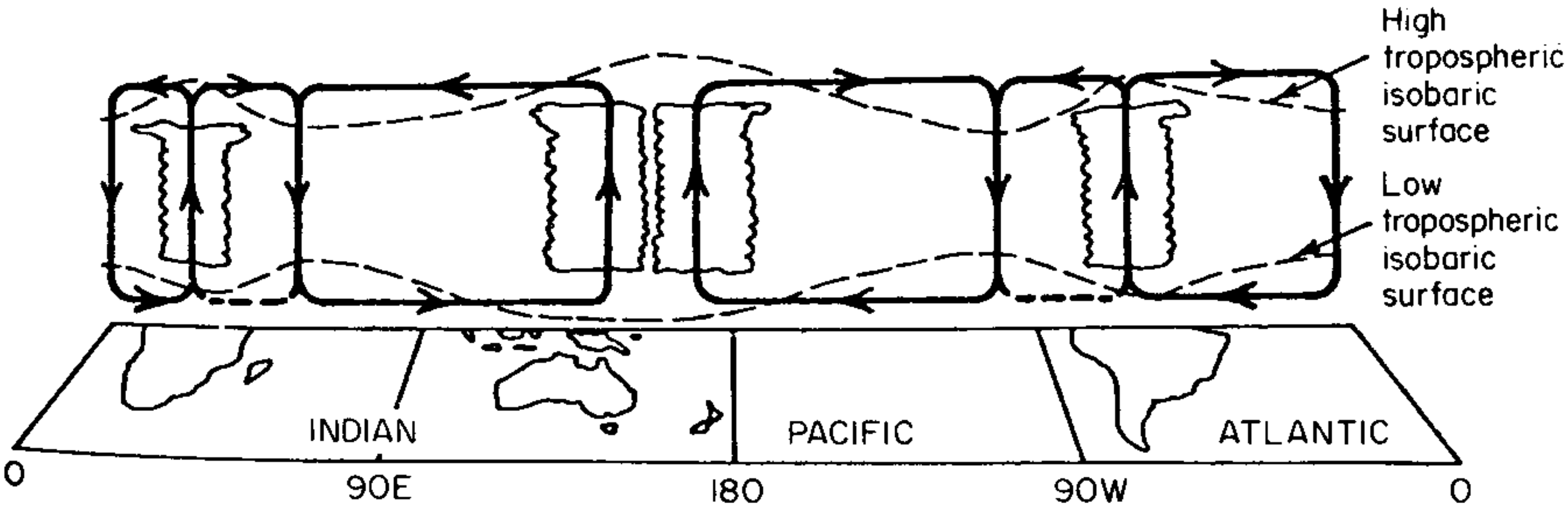
Wet climates occur when the precipitation is heavy and exceeds the evapotranspiration for much of the year.

Tropical wet climates are supported by the natural tendency of the atmospheric circulation to bring warm moist air to the equator. Zones of heavy rain (South America, Africa, Indonesian – West Pacific regions) move north and south with the season and tend to occur in the summer hemisphere.

The combination of equatorial location, shallow seas and relatively small land masses in Malaysia, Indonesia and New Guinea gives rise to the biggest region of intense precipitation on Earth.

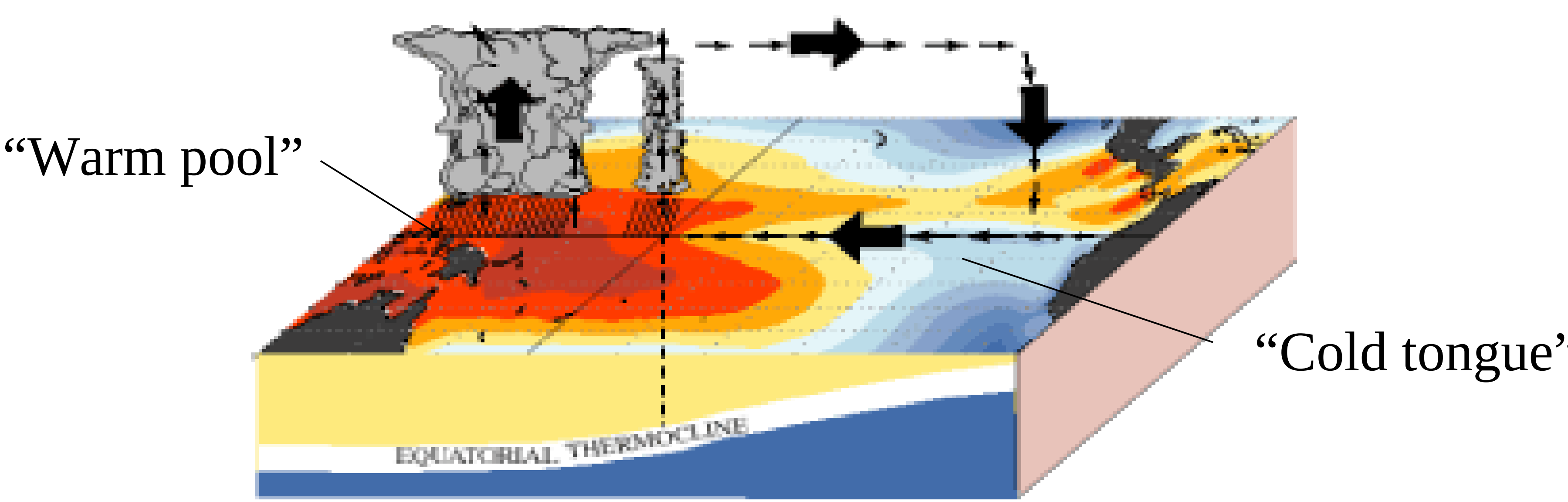
Zonal overturning circulation in the tropics

The non-uniform arrangement of convection over the tropical regions give rise to localized regions of uplift and subsidence: the ***zonal overturning circulation.*** As with the Hadley circulation, it transports energy from the uplift regions to the subsidence regions.

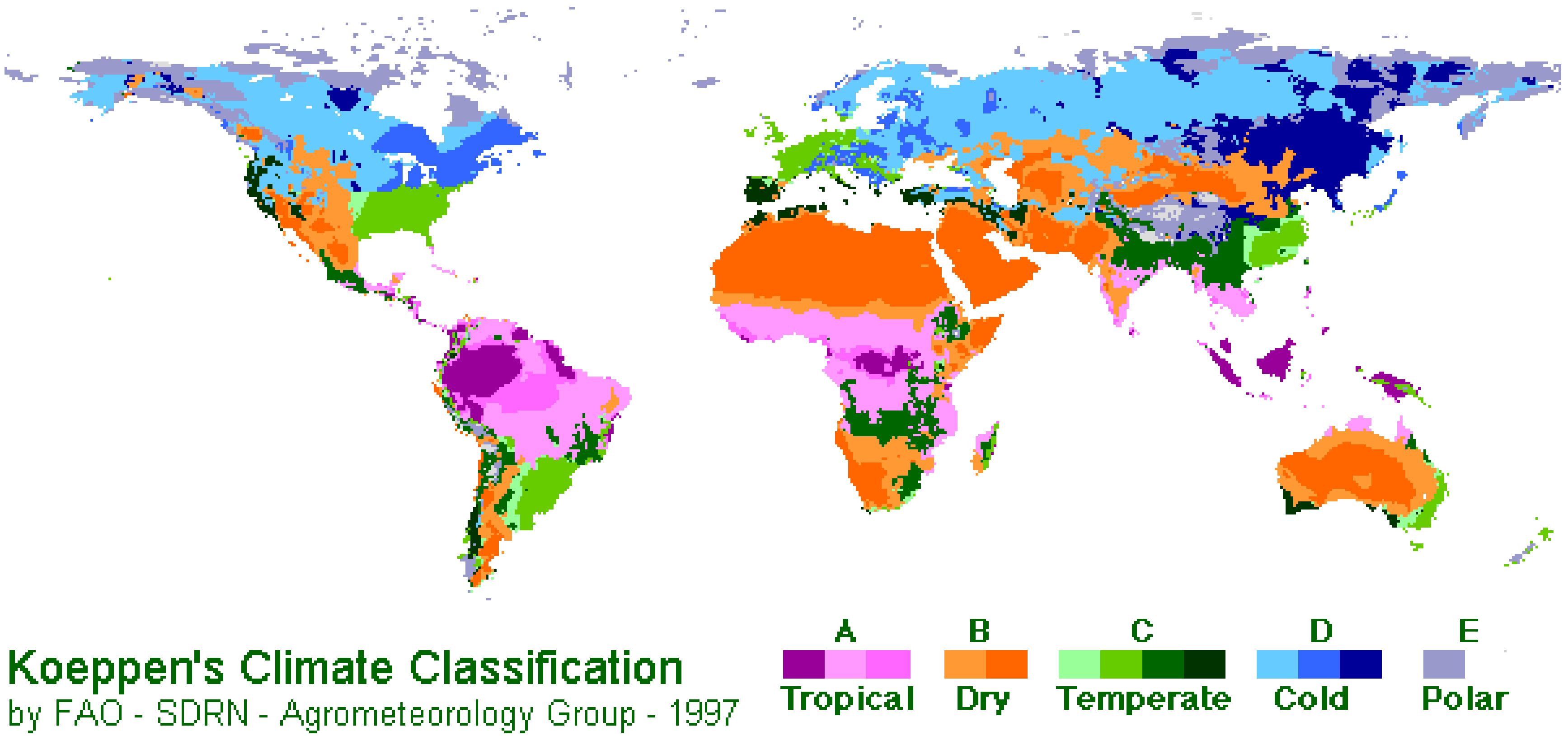


East-west cells along the equator associated with convective regions over South America, Africa and Indonesia.

The overturning circulation over the Pacific has a special name: the ***Walker circulation***. It is associated with a zonal contrast in sea surface temperatures (the Western Pacific warm pool and the eastern Pacific cold tongue), convection (and low pressure) over the warm waters and subsidence over the cold waters. This circulation arises as a result of an ocean-atmosphere interaction known as the ***Bjerknes feedback.*** Interannual variability of the Walker circulation brings about the ***El Niño*** phenomenon.



Desert climates occur in land areas where the precipitation is significantly less than the potential evapotranspiration, so that the surface becomes dry.



Aridity can be caused by a variety of mechanisms, all associated with GCA.

1. Associated with ***widespread, persistent subsidence*** e.g.

•Downbranch of the Hadley/Walker circulation (e.g. Sahara). Many of the world's greates deserts are found in the belt $\phi=10^0-40^0$ in both hemispheres.

•Downwind side of mountain ranges (e.g. North American desert east of the Rockies; Patagonia desert east of the Andes), in which localized subsidence takes place.

2. Adjacent cold coastal waters (e.g. coastal deserts of Peru and Chile adjacent of the Pacific cold tongue). Three causes: large-scale subtropical subsidence (Walker); localized subsidence associated with easterly flow over the Andes; cold SST. When warm air flows over cold waters, the air is cooled and becomes stable, suppressing moist convection.

3. Far from moisture source (e.g. Gobi desert). If air is forced to cross a mountain range, its humidity is reduced as the air stream is uplifted on the windward side: the air cools and water vapor condenses out as precip. On the leeward side, the air sinks and warms. The deserts of Central Asia are either very distant from the ocean or separated from it by a major mountain range.