Clouds in our current, and in a warming climate

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Clouds and Climate

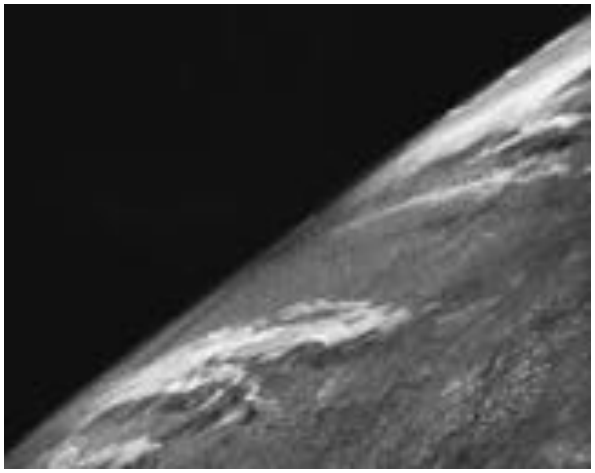
"How inappropriate to call this planet Earth, when clearly it is Ocean." - Arthur C. Clark

Clouds and Climate

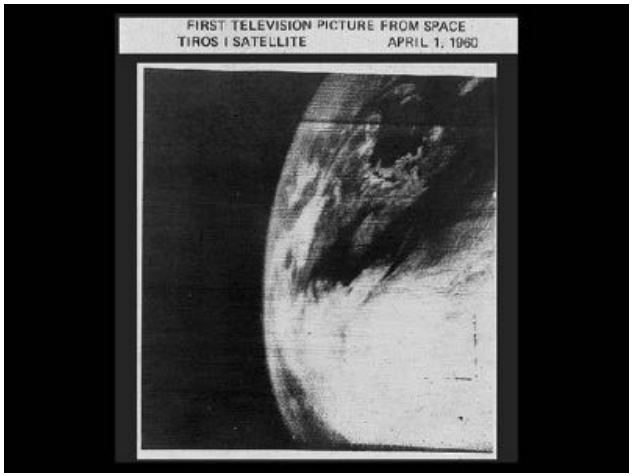
"How inappropriate to call this planet Earth, when clearly it is Ocean." - Arthur C. Clark

Clouds and Climate

Earth from rocket 1946



Earth From Weather Satellite 1960

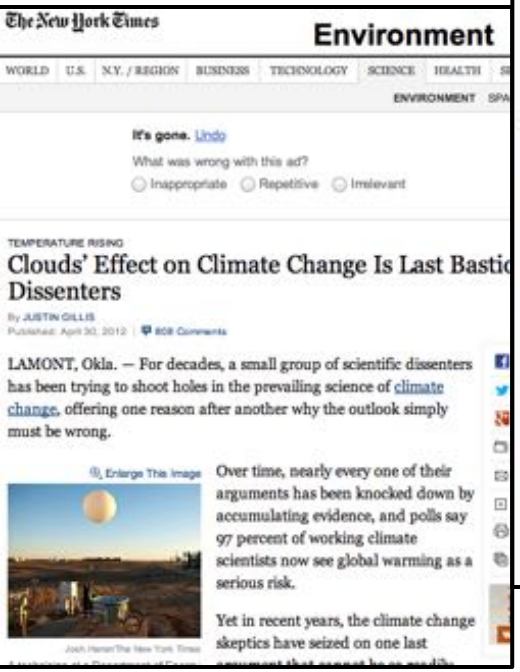


Blue Marble 1972

Tintin on the moon 1952

Key actors of climate

An era of blooming cloud and climate science



A Grand Challenge

Clouds, Circulation & Climate Sensitivity

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WCRP
World Climate Research Programme

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Clouds, Circulation and Climate Sensitivity

How do clouds couple to circulations in the present climate?
How will clouds and circulation respond to global warming or other forcings?
How will they feed back on it through their influence on Earth's radiation budget?

Limited understanding of clouds is the major source of uncertainty in climate sensitivity, but it also contributes substantially to persistent biases in modelled circulation systems.

As one of the main modulators of heating in the atmosphere, clouds control many other aspects of the climate system. Read more in the white paper.

Clouds, Circulation and Climate Sensitivity

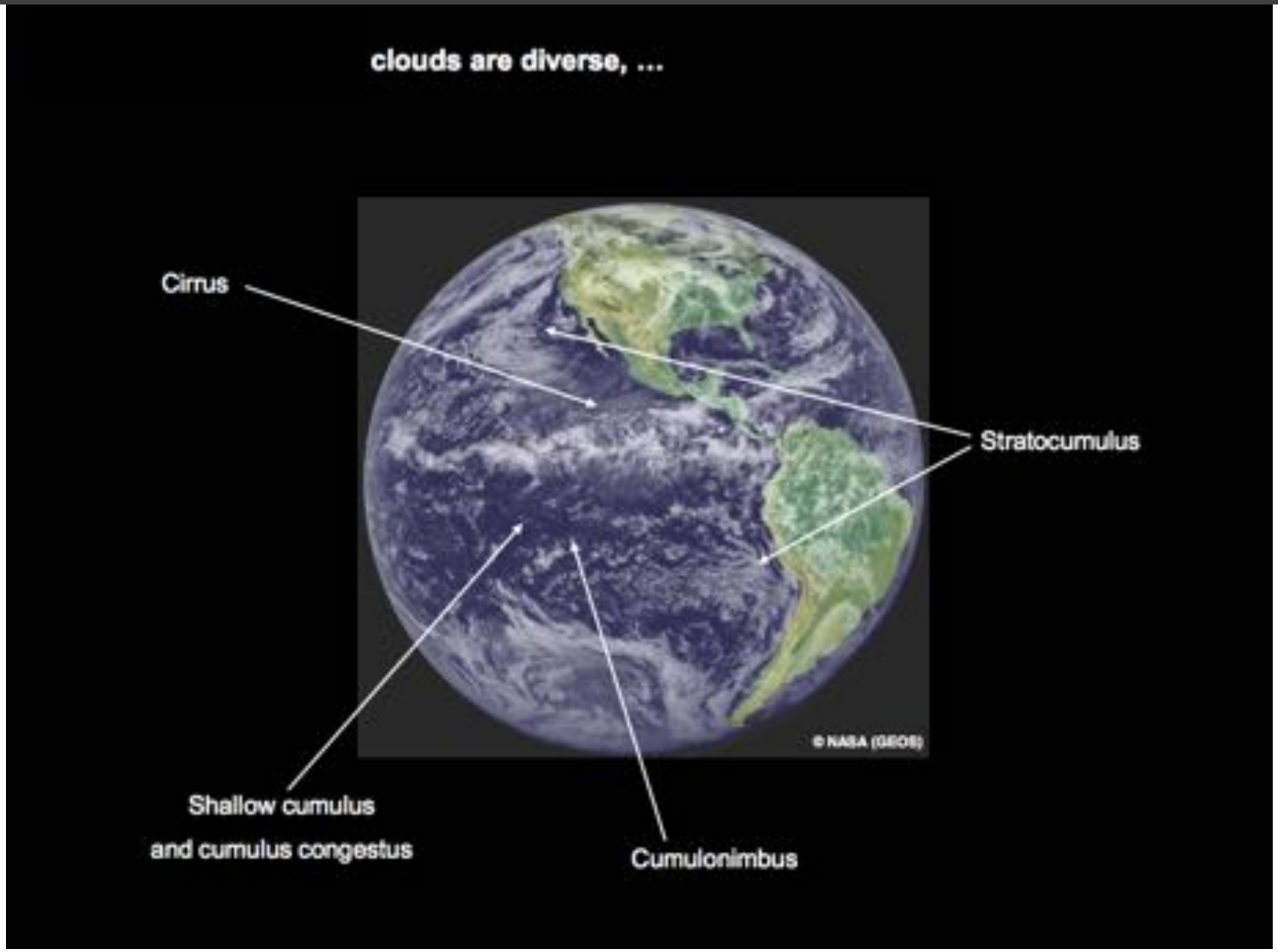
- Overview
- Leadership
- Activities
  - Initiatives
    - Projects
  - Meetings
- Documents

« Back to Grand Challenges Overview

Clouds in our current, and in a warming climate

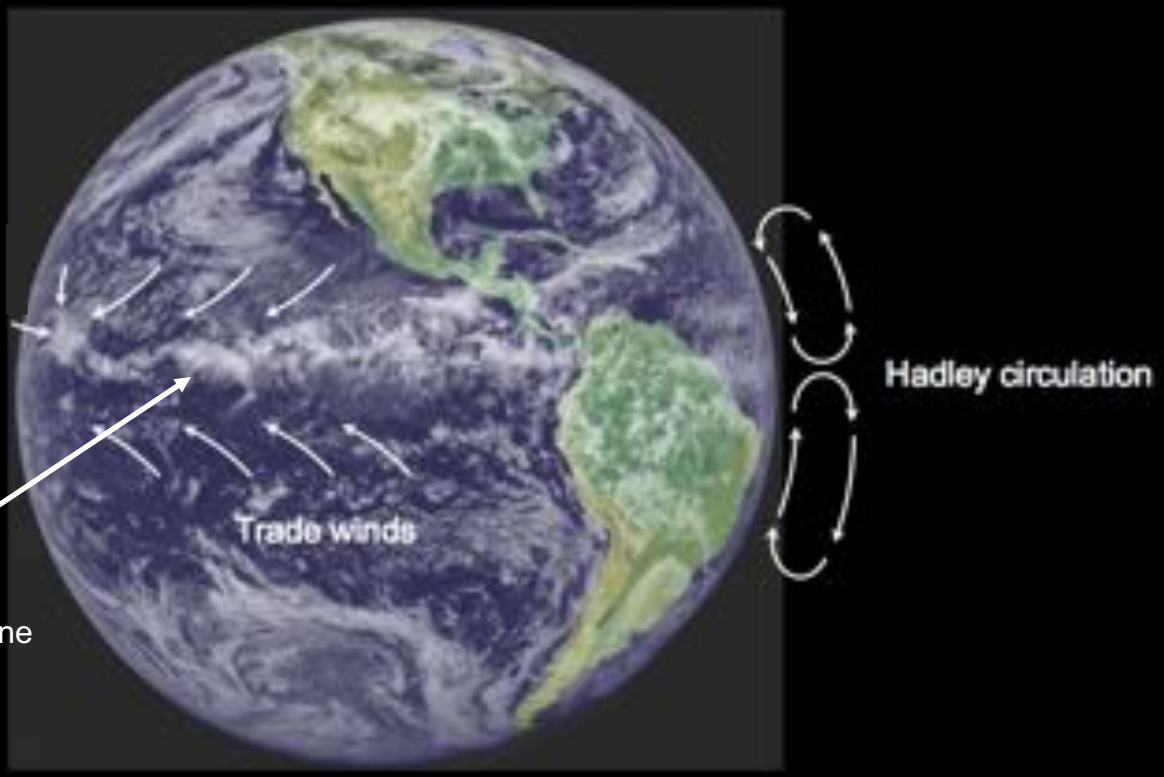
1. Clouds distribution
2. Coupling with circulation
3. Role in climate

Clouds distribution



Clouds distribution

… and coupled to circulations.



Cloud types

Cumulus: vertical extent

Stratus: horizontal extent

Cirrus: lock of hair

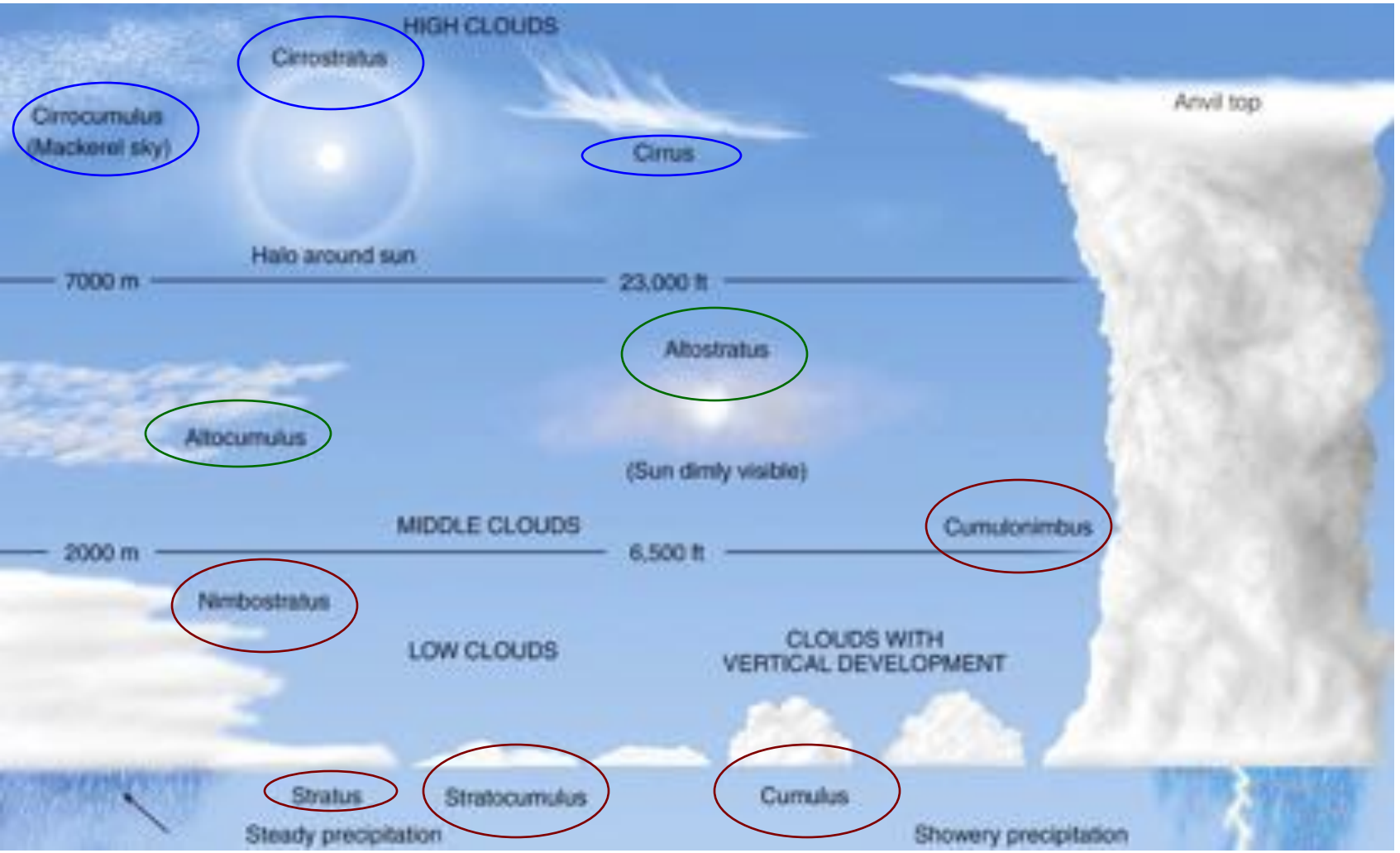
Nimbus: precipitating

Altum: height

Combined to define
10 cloud types

Cloud types

Clouds are classified according to height of cloud base and appearance



High clouds
Base: 5 to 12km

Middle clouds
Base: 2 to 6km

Low clouds
Base < 2km

High Clouds

Almost entirely ice crystals

Cirrus

Wispy, feathery

Cirrostratus

Widespread, sun/moon halo

Cirrocumulus

Layered clouds, cumuliform lumpiness

Middle Clouds

Liquid water droplets, ice crystals, or a combination of the two

Altostratus

Flat and uniform in mid levels

Altocumulus

Convective elements in mid levels

Low Clouds

Liquid water droplets, except during cold winter storms when ice crystals comprise much of the clouds.

Stratocumulus

Hybrid

Stratus

Uniform and flat

Nimbostratus

Thick stratus producing rain

Low Clouds

Liquid water droplets, except during cold winter storms when ice crystals (and snow) comprise much of the clouds.

Cumulus (humili)

with little vertical growth

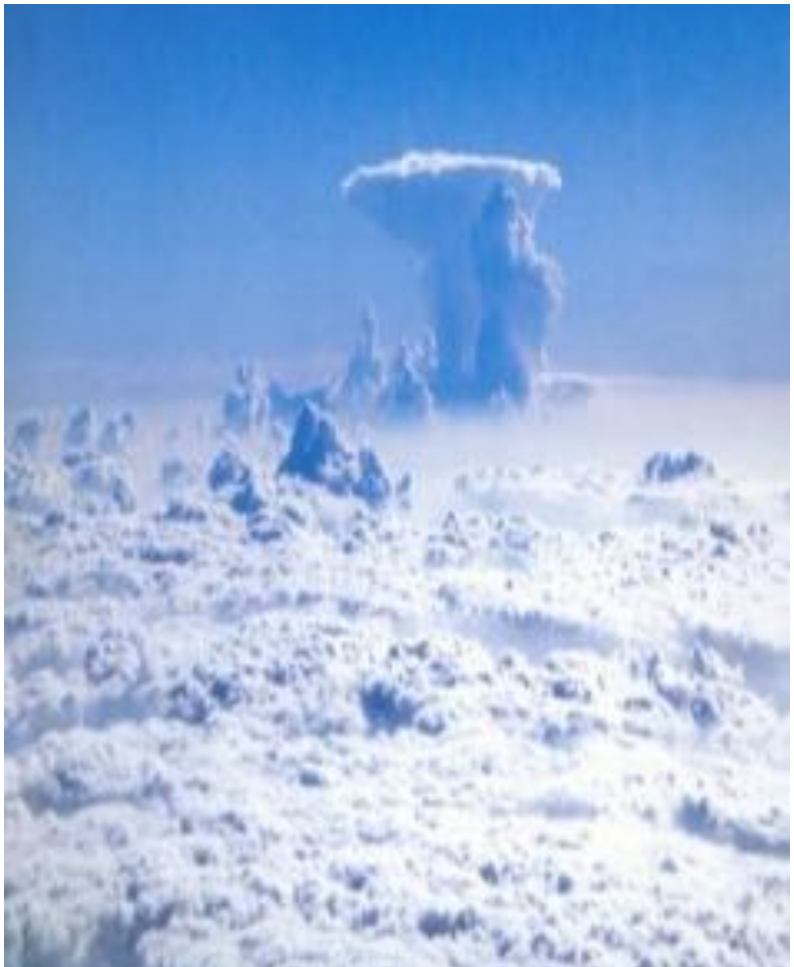
Also called "fair weather cumulus"

Cumulus (congestus)

Significant vertical development (but not yet a thunderstorm)

Cumulonimbus

thunderstorm producing heavy rain



Other spectacular Clouds…

Mammatus clouds (typically below anvil clouds)

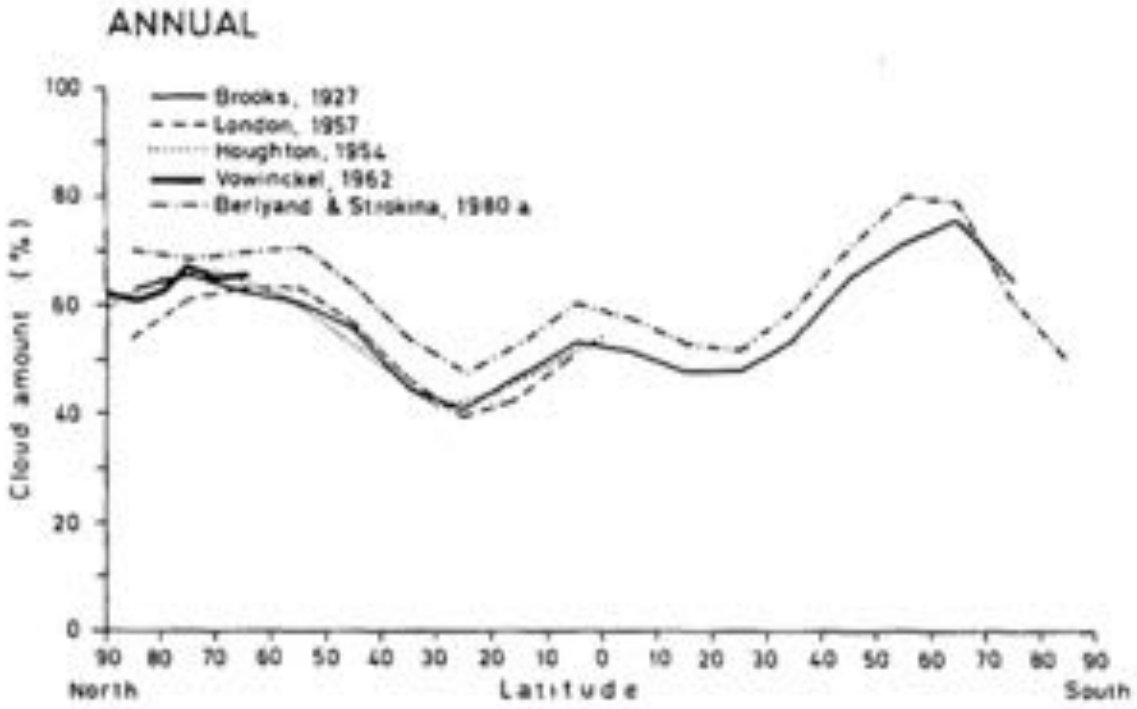
Shelf clouds (gust front)

Lenticular clouds (over orography)

Question: Global cloud cover (%)?

Clouds distribution

Distribution of cloud amount

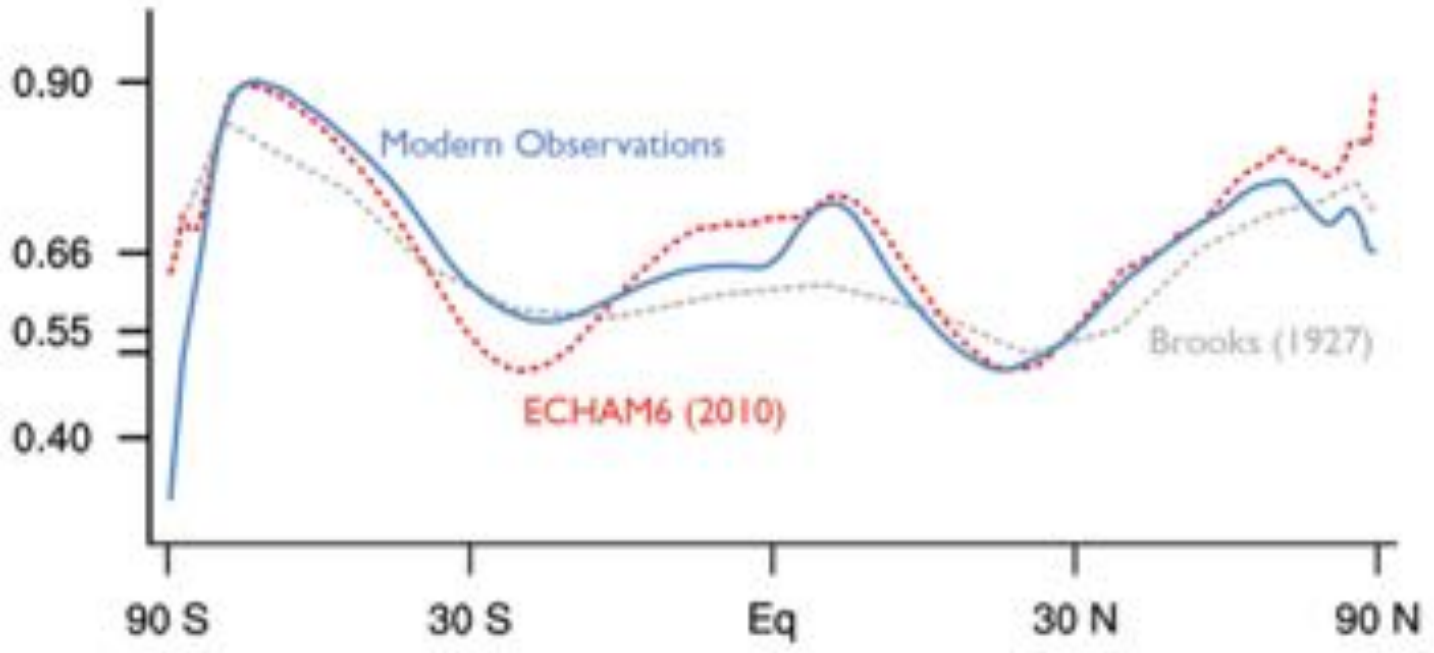


[Hughes 84]

Clouds distribution

Cloud amount was underestimated

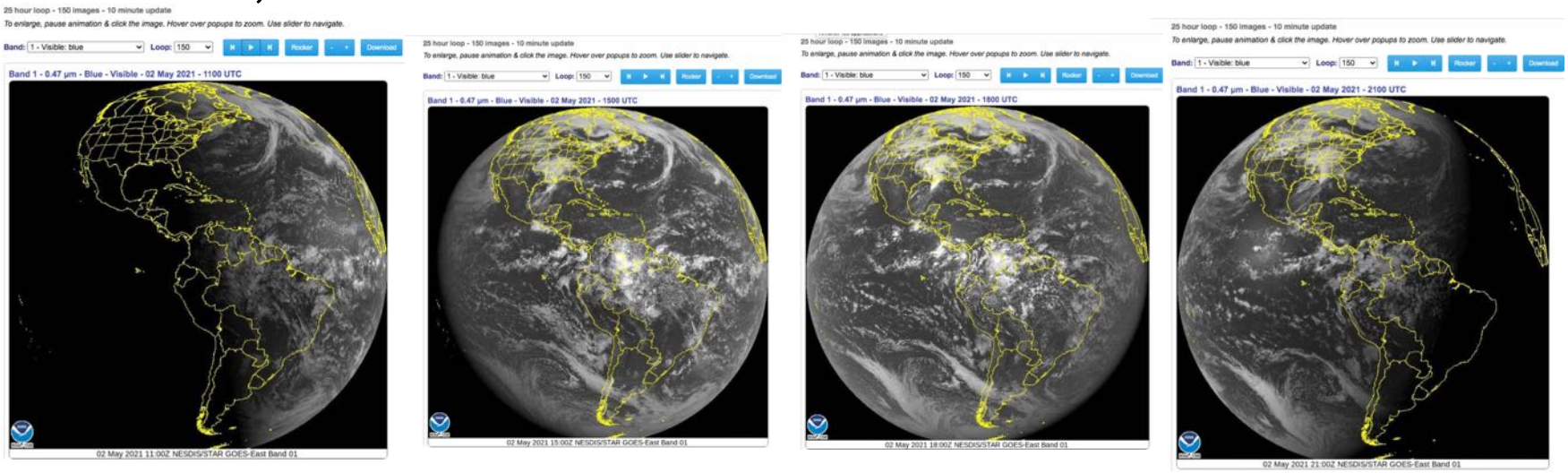
Also note the latitudinal distribution



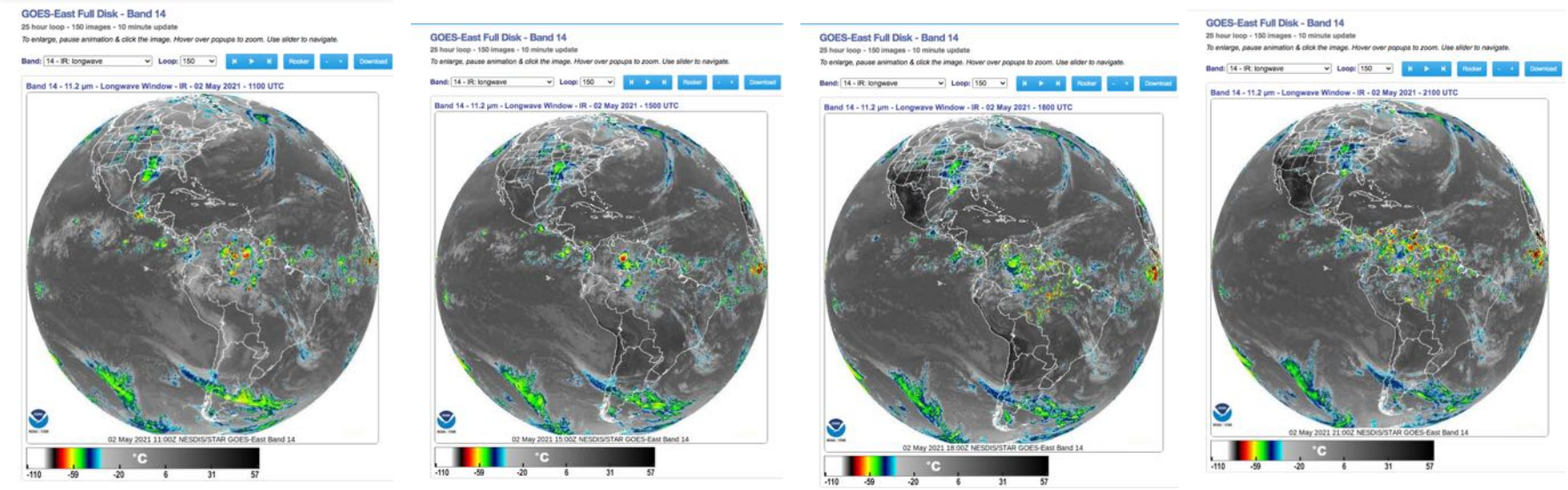
Courtesy Bjorn Stevens

GOES satellite imagery May 2nd @ 11,15,18,21 UTC

Shortwave, or visible

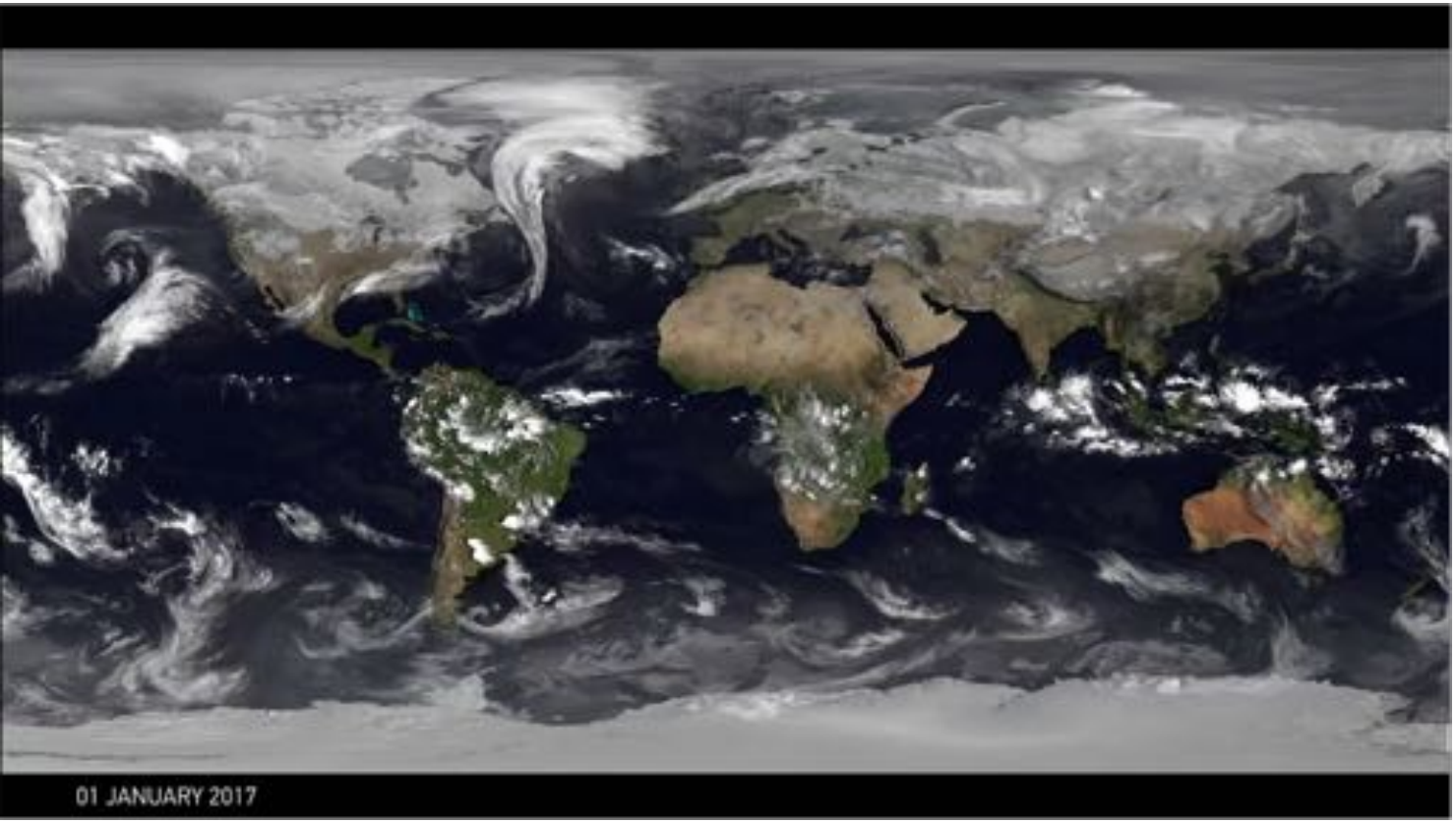


Longwave, or infrared (emission temperature)



Clouds distribution

Brightness temperature from satellite (white ⇔ cold cloud tops)



Large extratropical storm systems

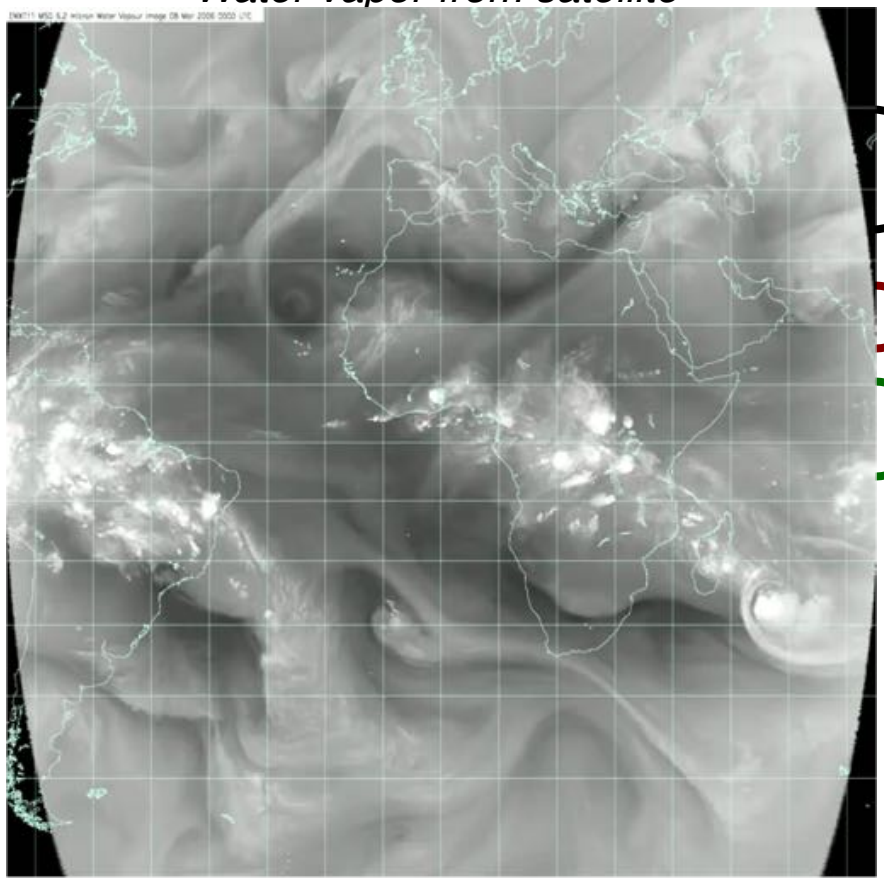
subtropics: ~no high clouds

ITCZ = Intertropical convergence zone

« A year of weather »

Clouds distribution

Water vapor from satellite



Large extratropical storm systems

=> Large-scale extratropical convection

subtropics: ~no high clouds

=> shallow clouds

ITCZ = Intertropical convergence zone

=> Small-scale tropical convection

… but not always that small!

Deep convective system over Brazil:

Clouds in our current, and in a warming climate

1. Clouds distribution
2. Coupling with circulation
3. Role in climate

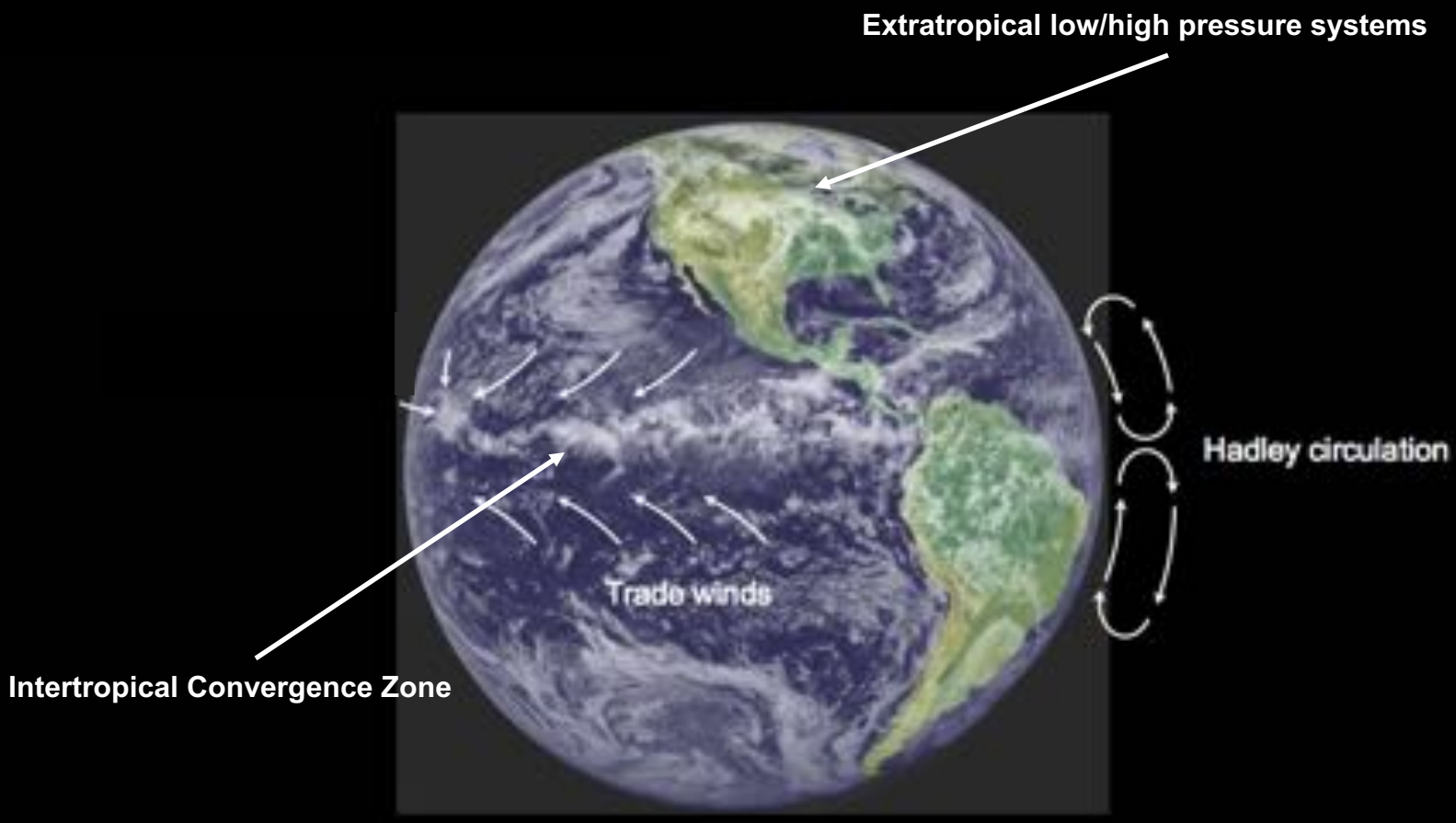
Cloud formation

Courtesy : Octave Tessiot

Cloud formation

Courtesy : Octave Tessiot

Clouds are coupled with circulation



Tropics and Subtropics : ITCZ, Hadley, Walker (ENSO), monsoon

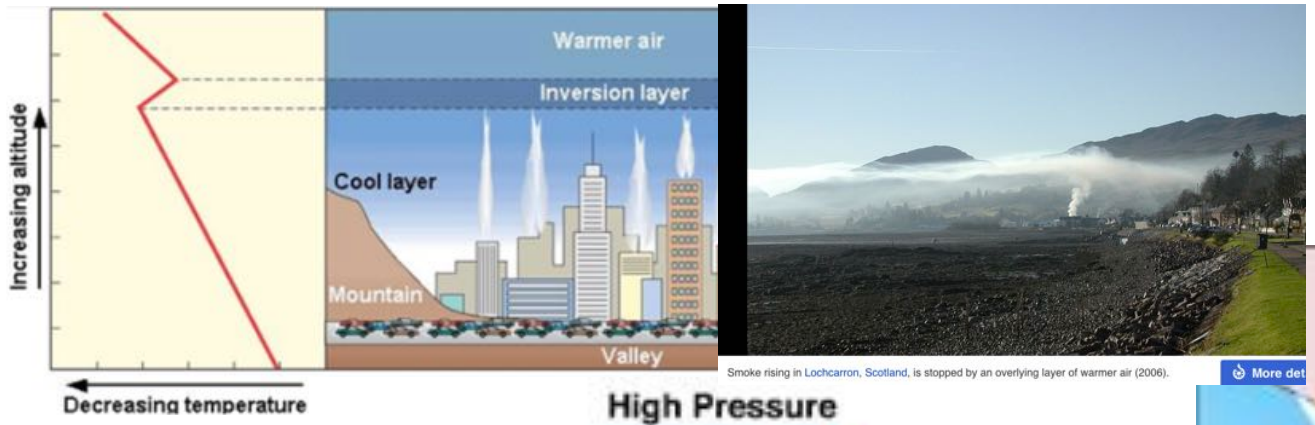
Mid-latitudes : Extratropical frontal systems

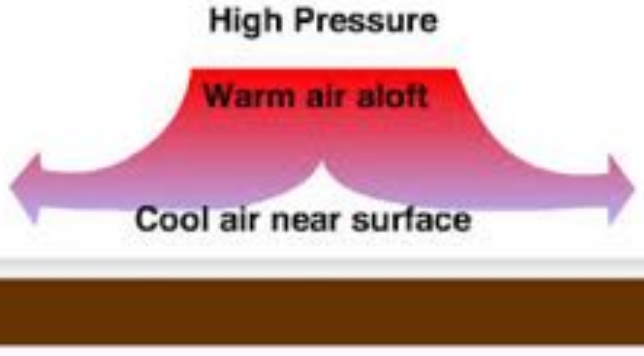
Clouds and Circulation

Air gradually sinking opposes cloud development:

air is **dry** and is **warmed** by adiabatic compression (increased pressure)

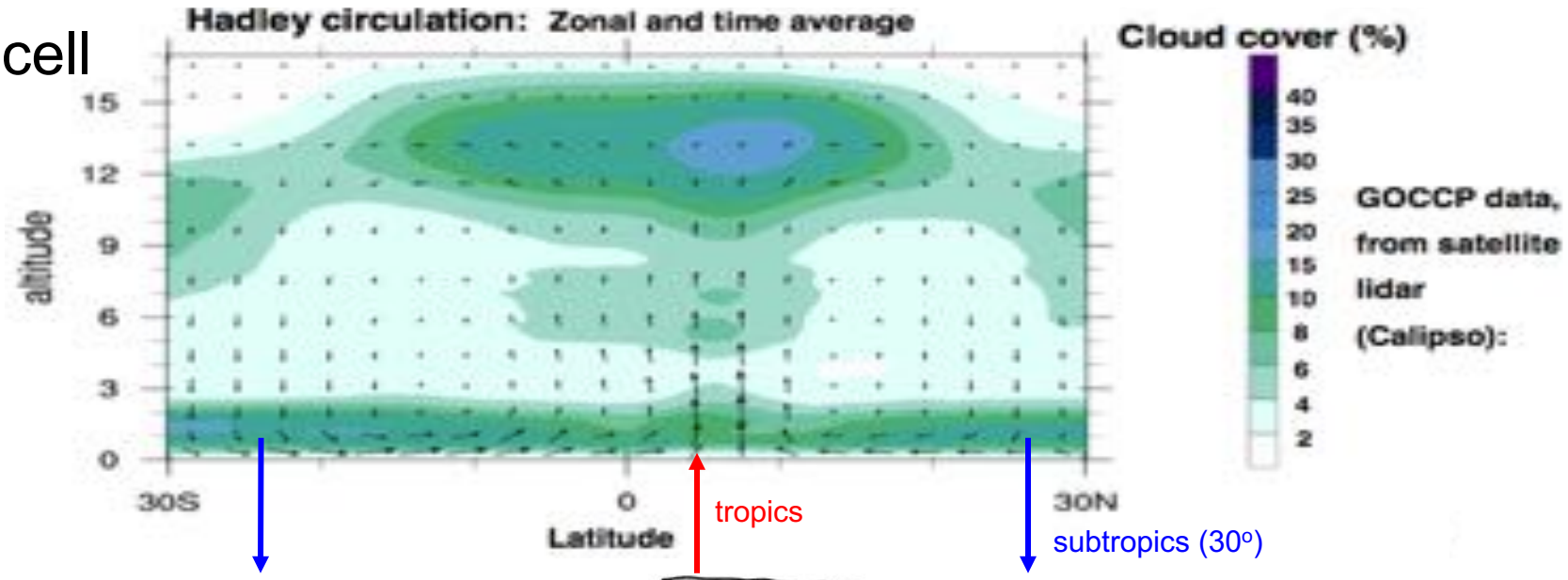
$\Rightarrow$ unstable layer capped by stable layer



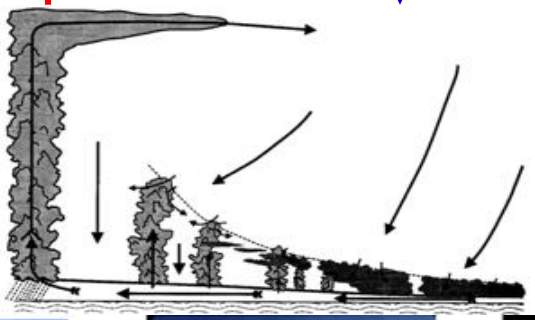


Clouds and Circulation: Tropics and Subtropics

Hadley cell



Cloud types:



Deep cumulonimbus Fair weather cumulus stratus

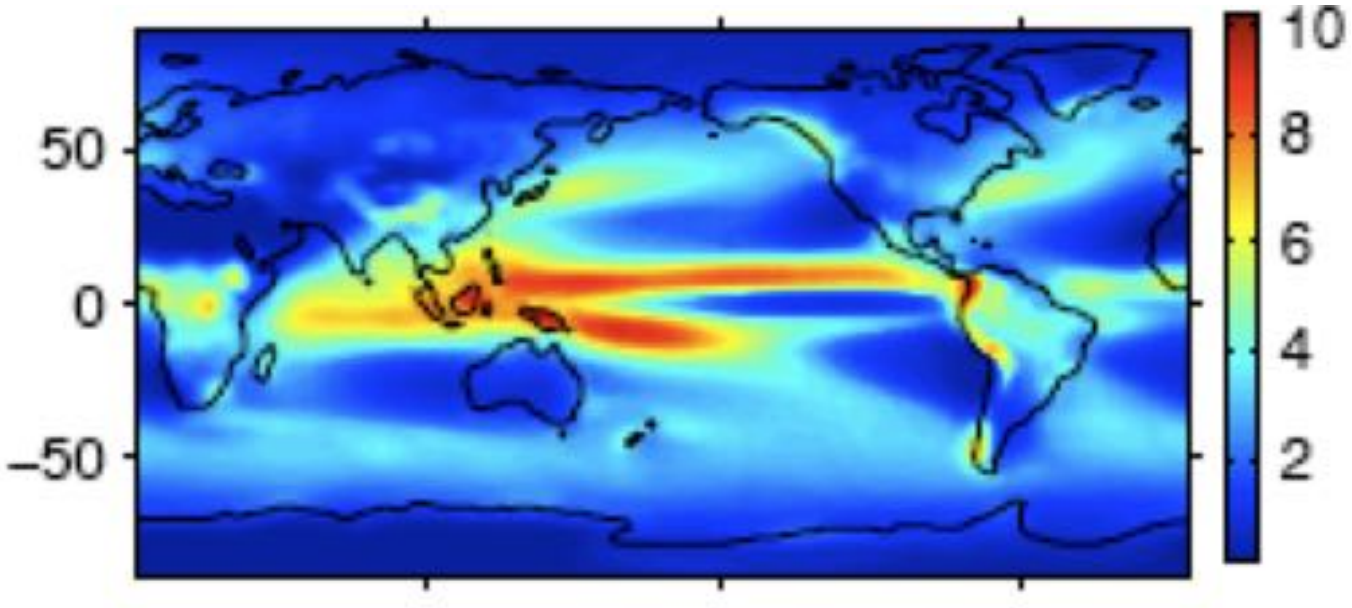
⇒**On average:**

Deep clouds are favored where there is large-scale ascent ;

Shallow clouds are favored where there is descent.

Clouds and Circulation: Tropics and Subtropics

P (mm/day)
1981-1999 climatology, multimodel mean



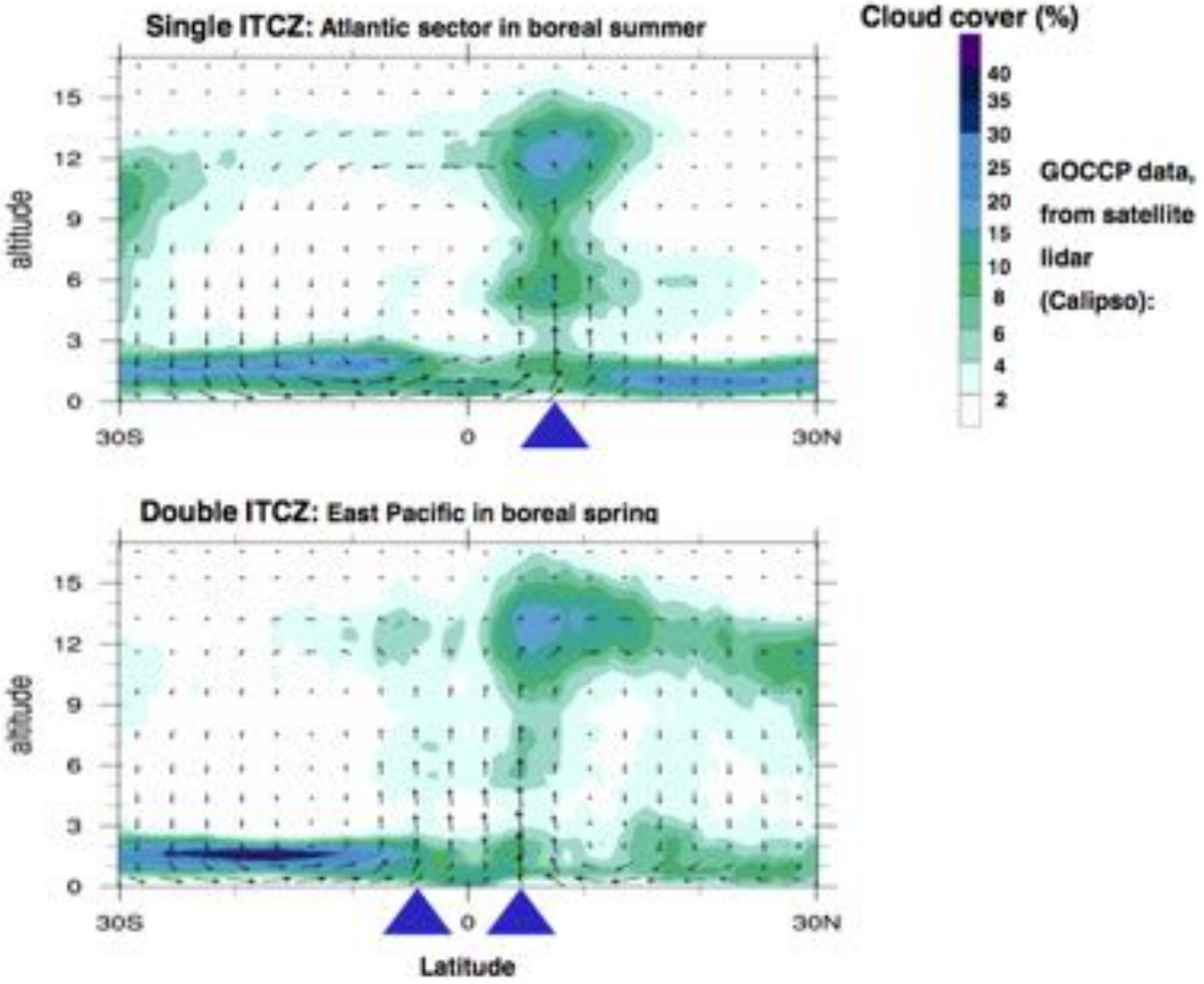
Small in Subtropics (descent)

Large in Tropics (ascent)

[Muller & O'Gorman, 2011]

Clouds and Circulation: Tropics and Subtropics

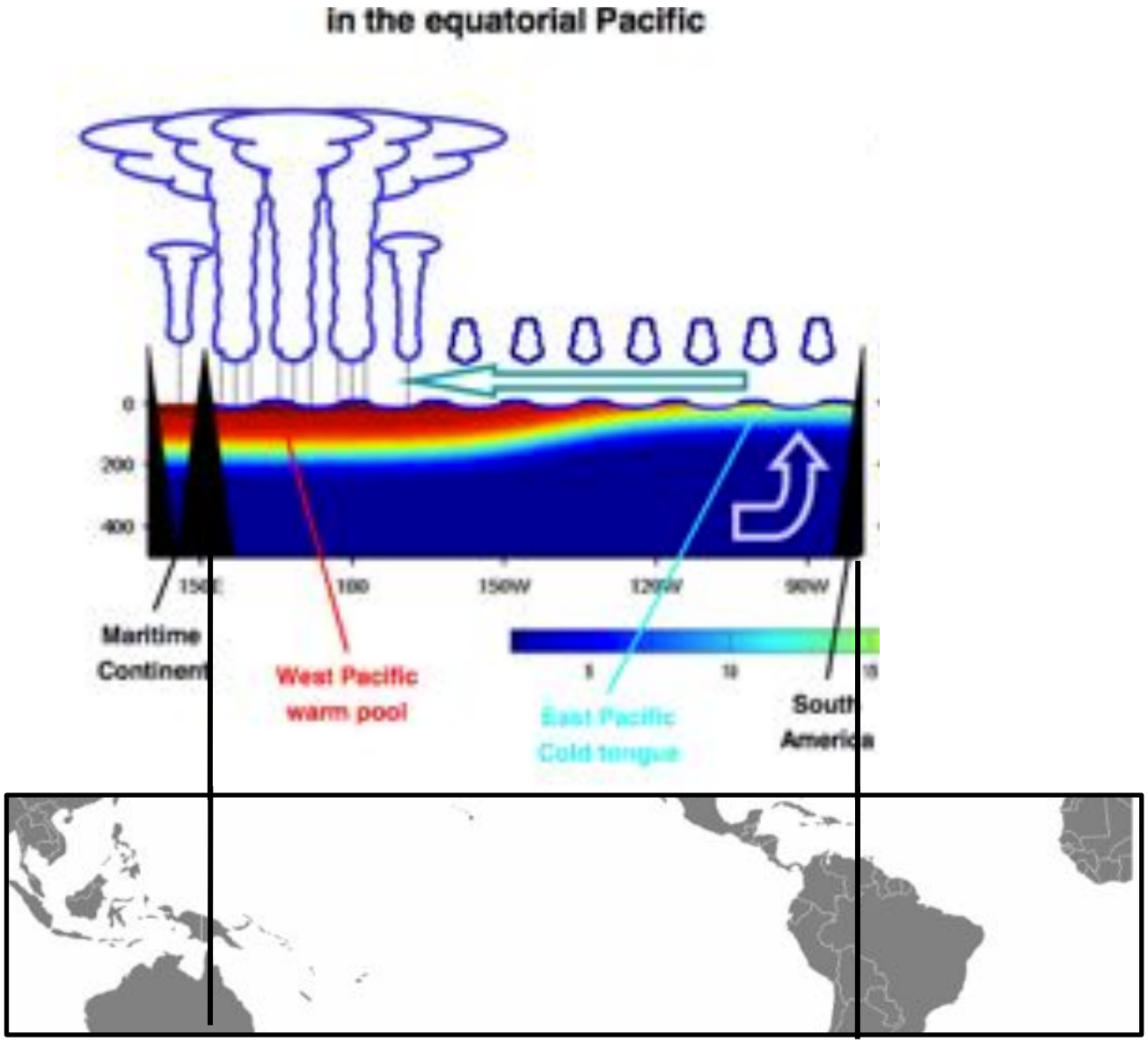
double ITCZ



Courtesy Gilles Bellon

Clouds and Circulation: Tropics and Subtropics

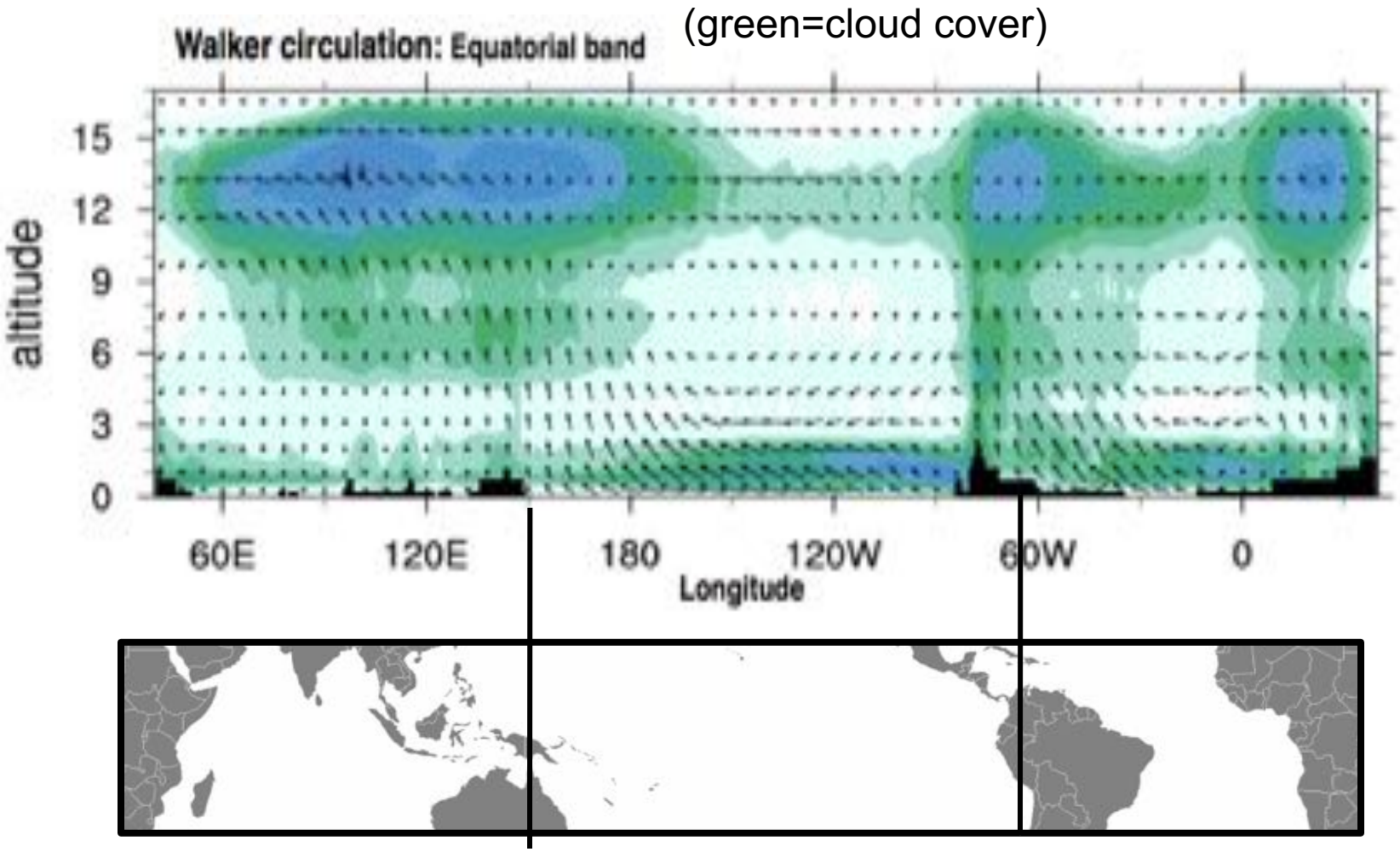
Walker cell



Clouds and Circulation: Tropics and Subtropics

Walker cell

(green=cloud cover)



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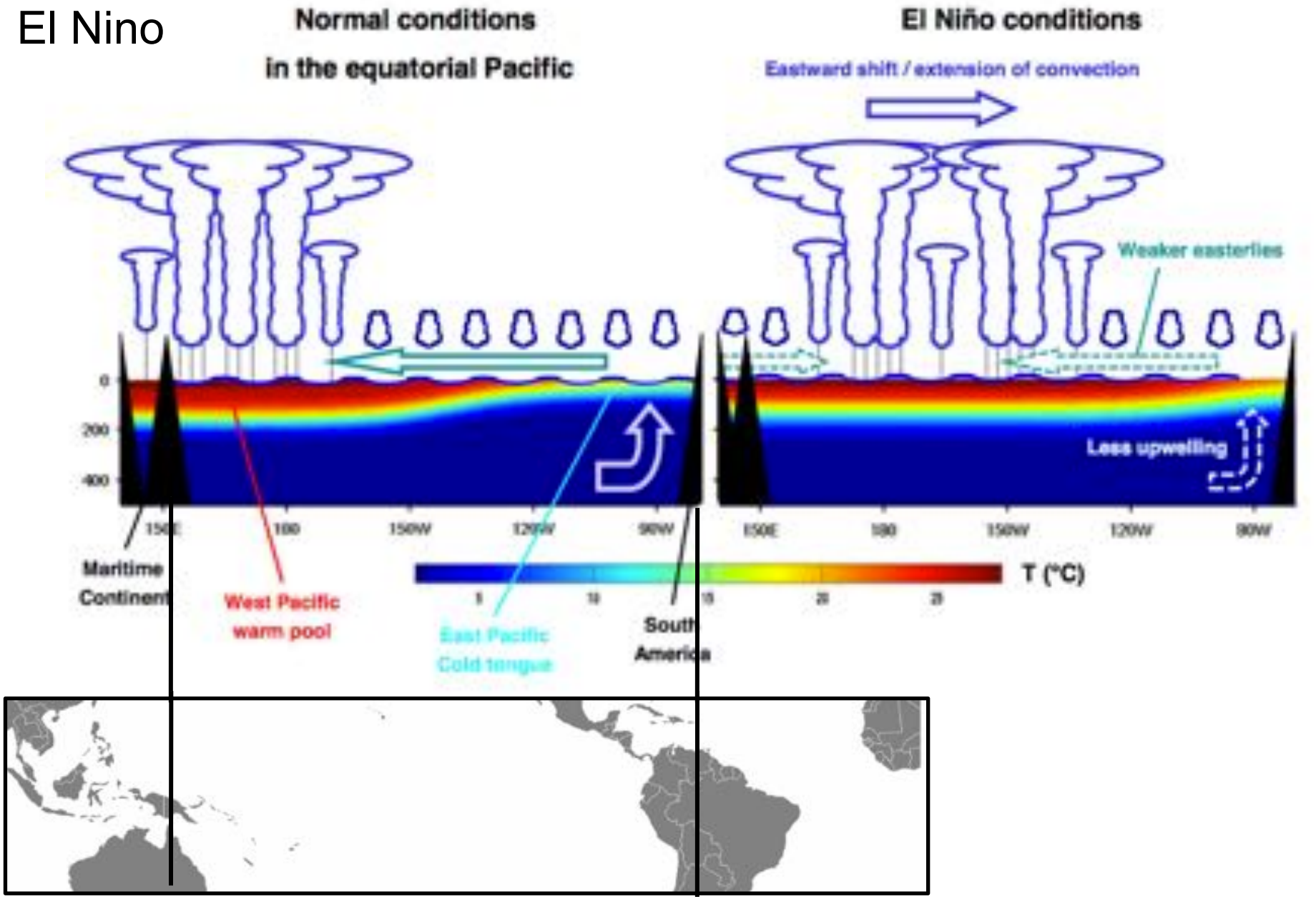
Clouds and Circulation: Tropics and Subtropics

El Nino

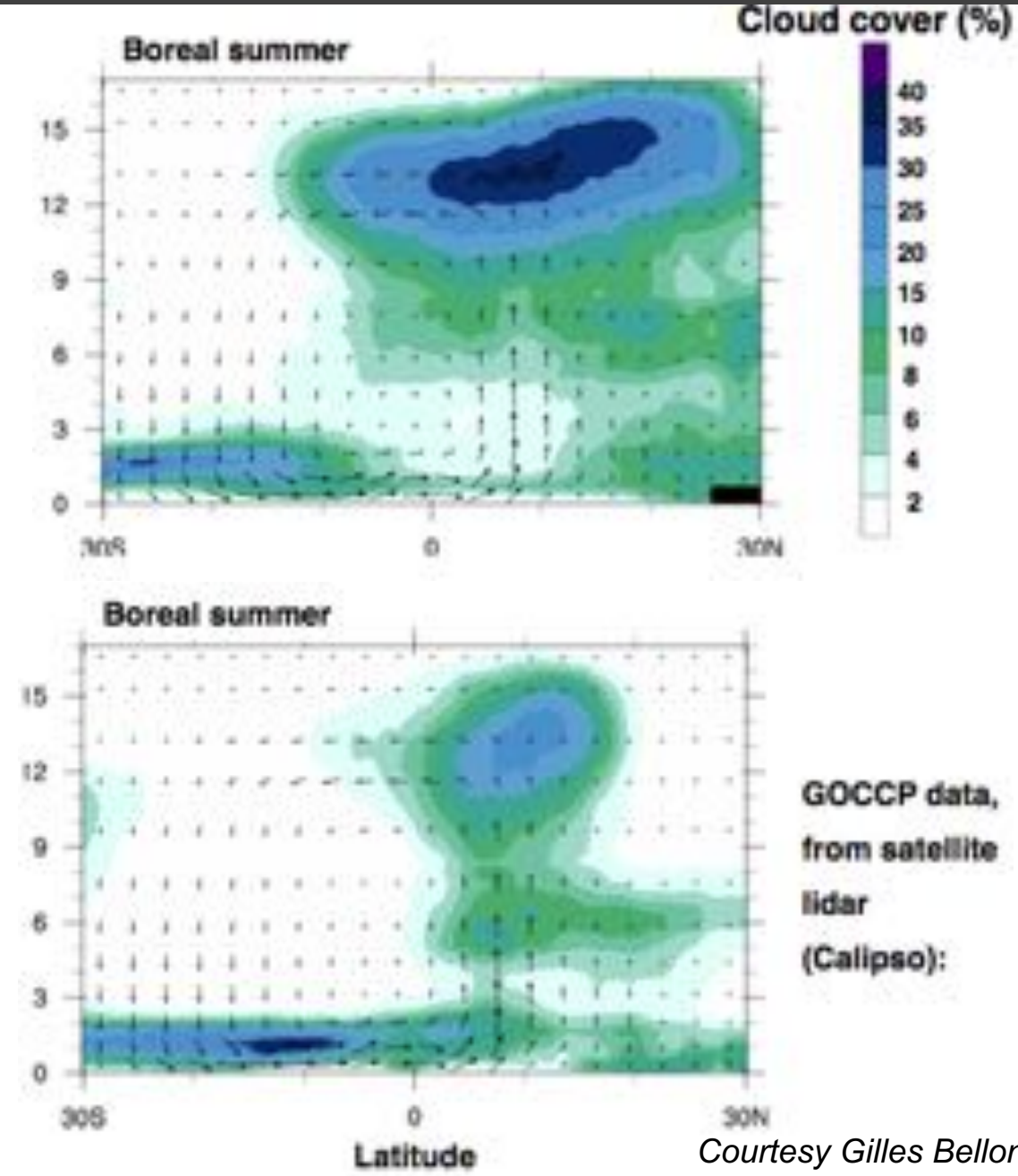


Clouds and Circulation: Tropics and Subtropics

Monsoons

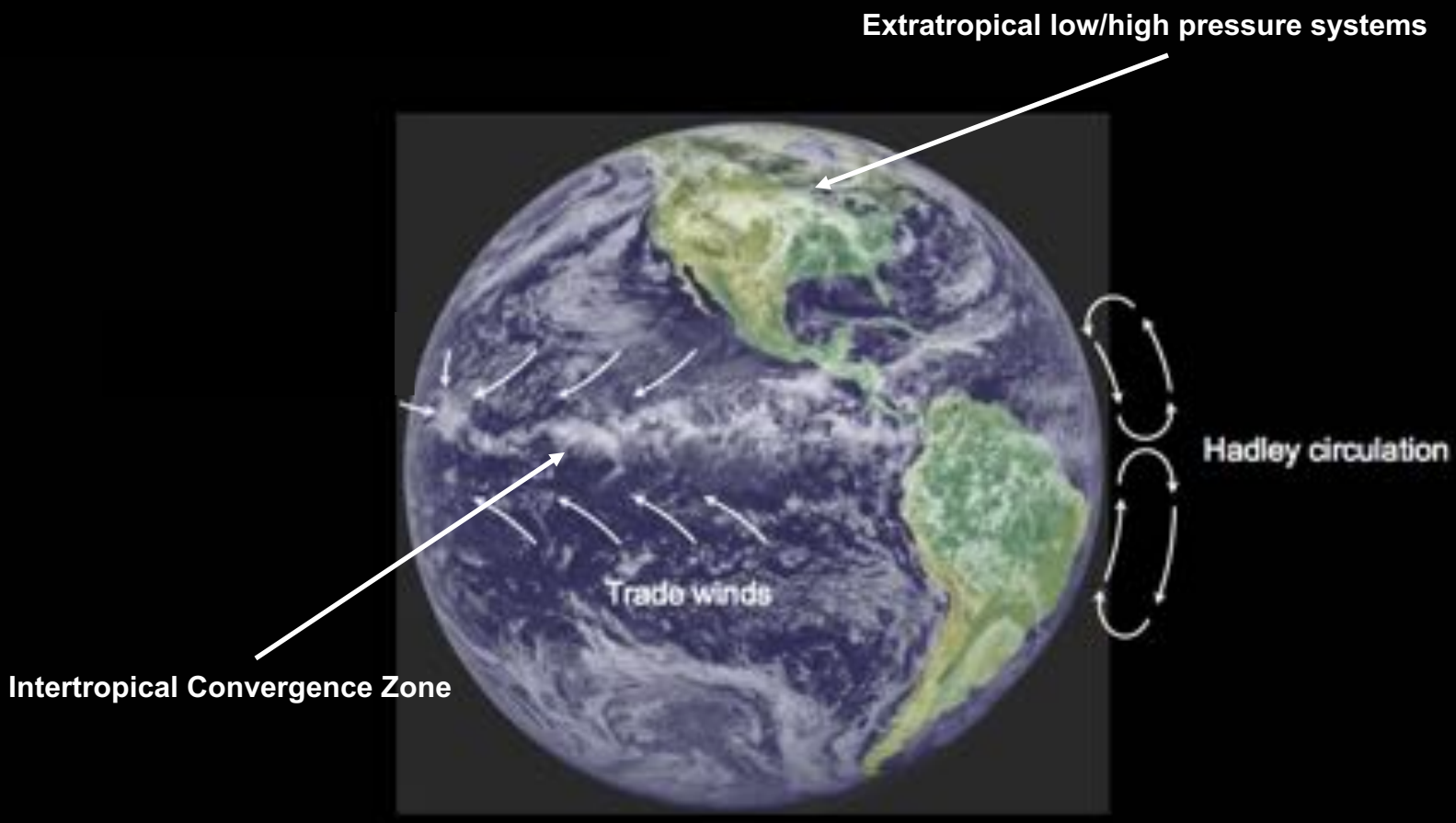
Asian monsoon

West-African monsoon



Courtesy Gilles Bellon

Clouds and Circulation: Extratropics



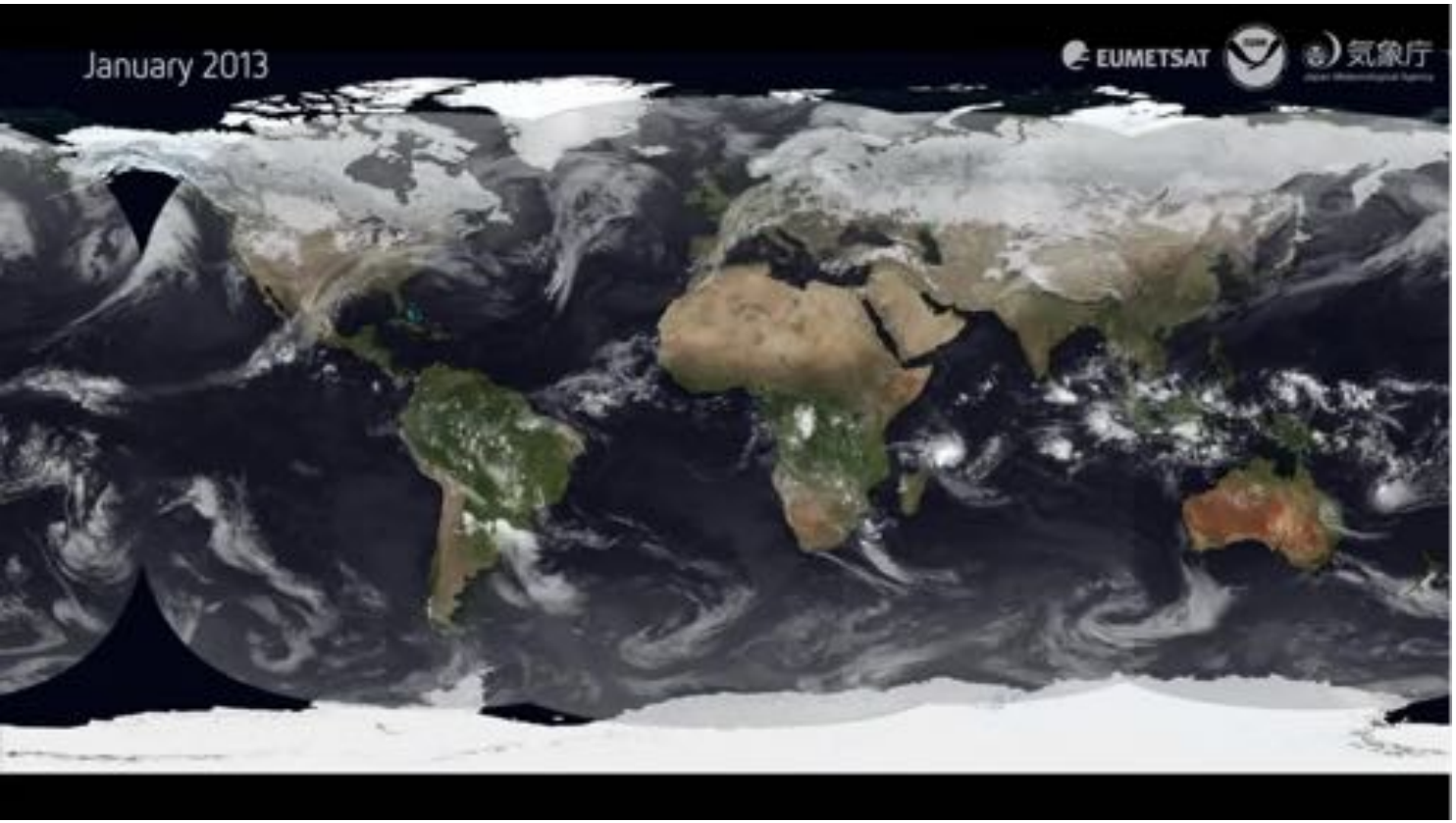
Tropics and Subtropics : ITCZ, Hadley, Walker (ENSO), monsoon

Mid-latitudes : Extratropical frontal systems

Clouds and Circulation: Extratropics

Recall : spatial distribution

Brightness temperature from satellite (white ⇔ cold cloud tops)



Large extratropical storm systems

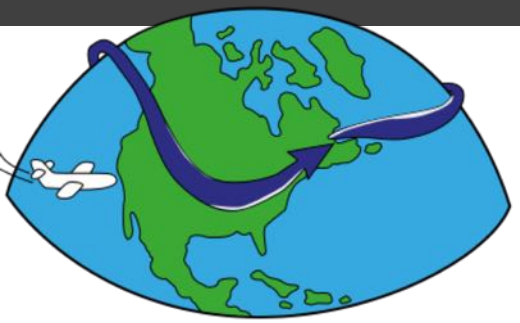
subtropics: ~no high clouds

ITCZ = Intertropical convergent zone

« A year of weather »

Extratropics: low and high pressure systems within the polar jet

Clouds and Circulation: Extratropics



courant-jet polaire

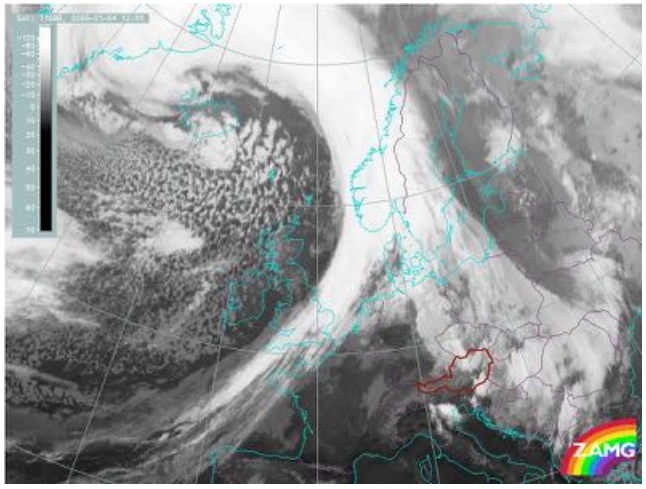
High latitudes => clouds embedded in low/high pressure systems and associated fronts

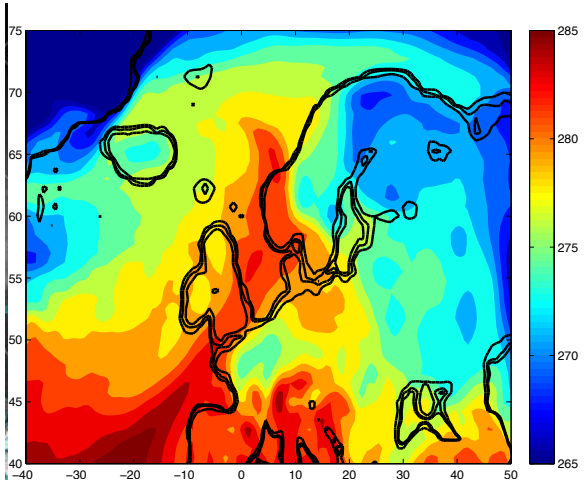
NASA

Clouds and Circulation: Extratropics

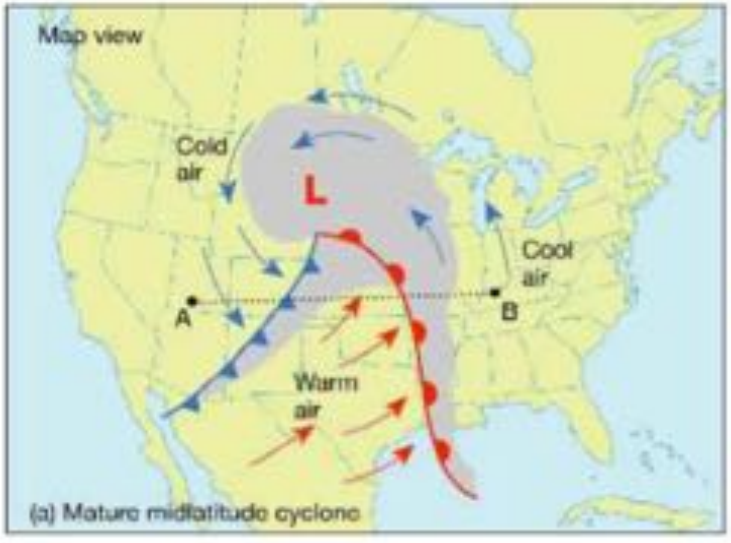
Clouds in frontal systems

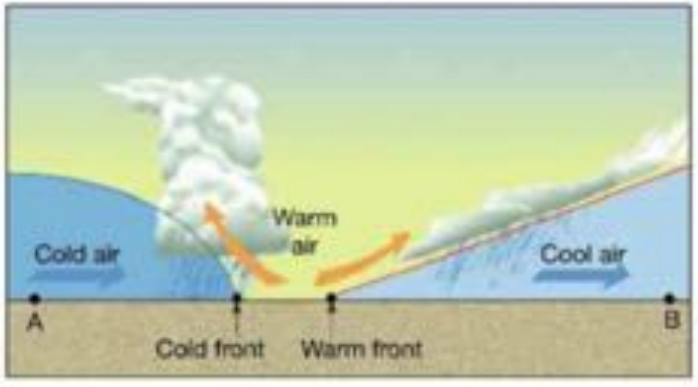
IR



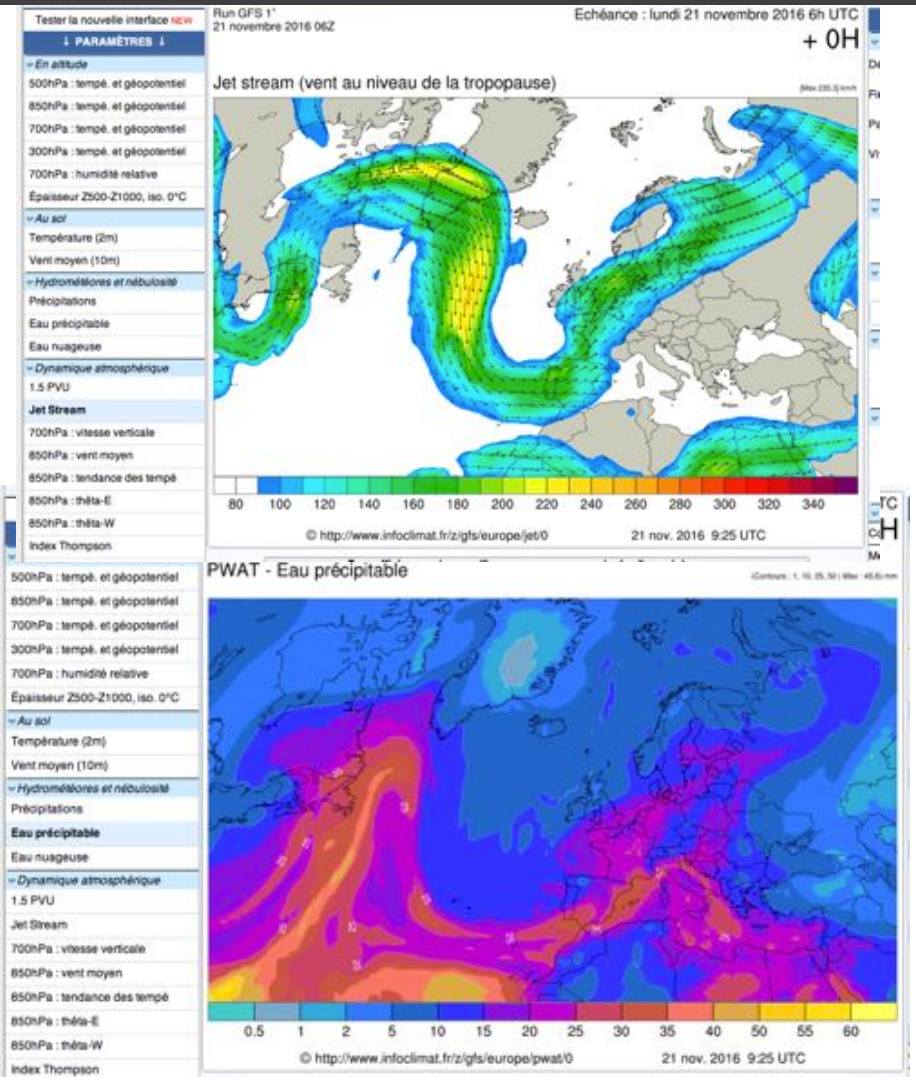


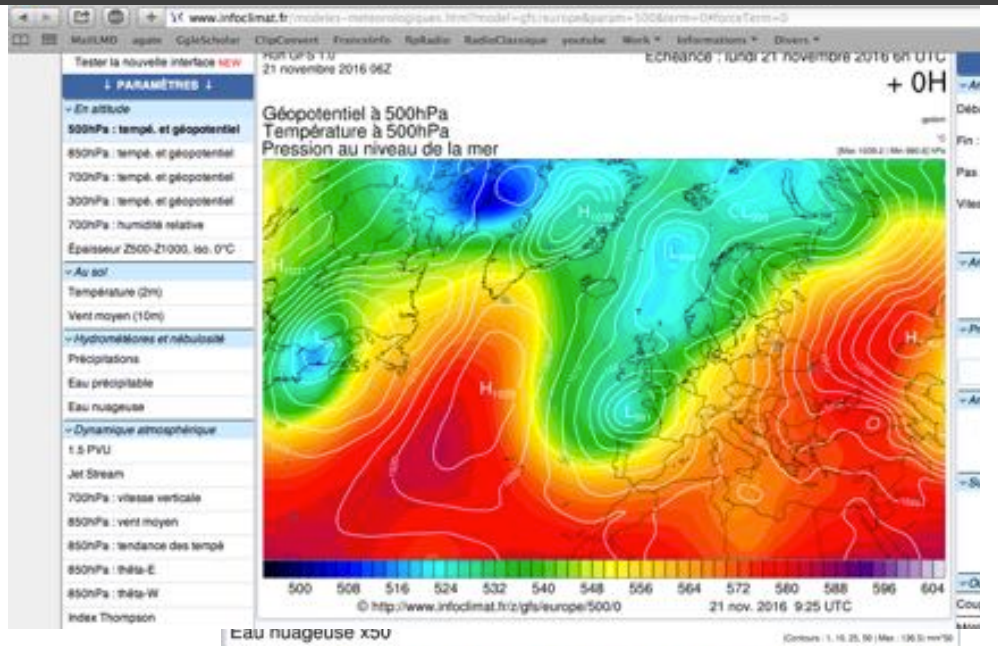
Corresponding T field
Clouds are clearly linked to the dynamics of frontal systems

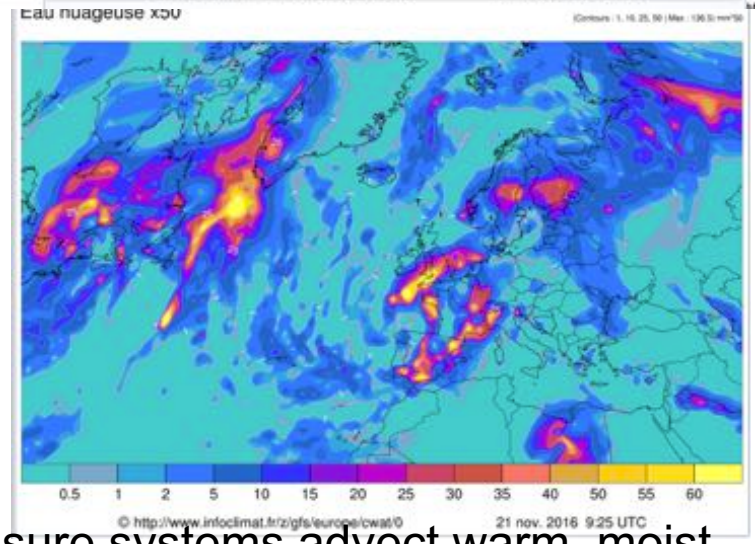




Clouds and Circulation: Extratropics







Weather map :

- Clouds and precip are found where low/high pressure systems advect warm, moist air into northern colder latitudes

Clouds in our current, and in a warming climate

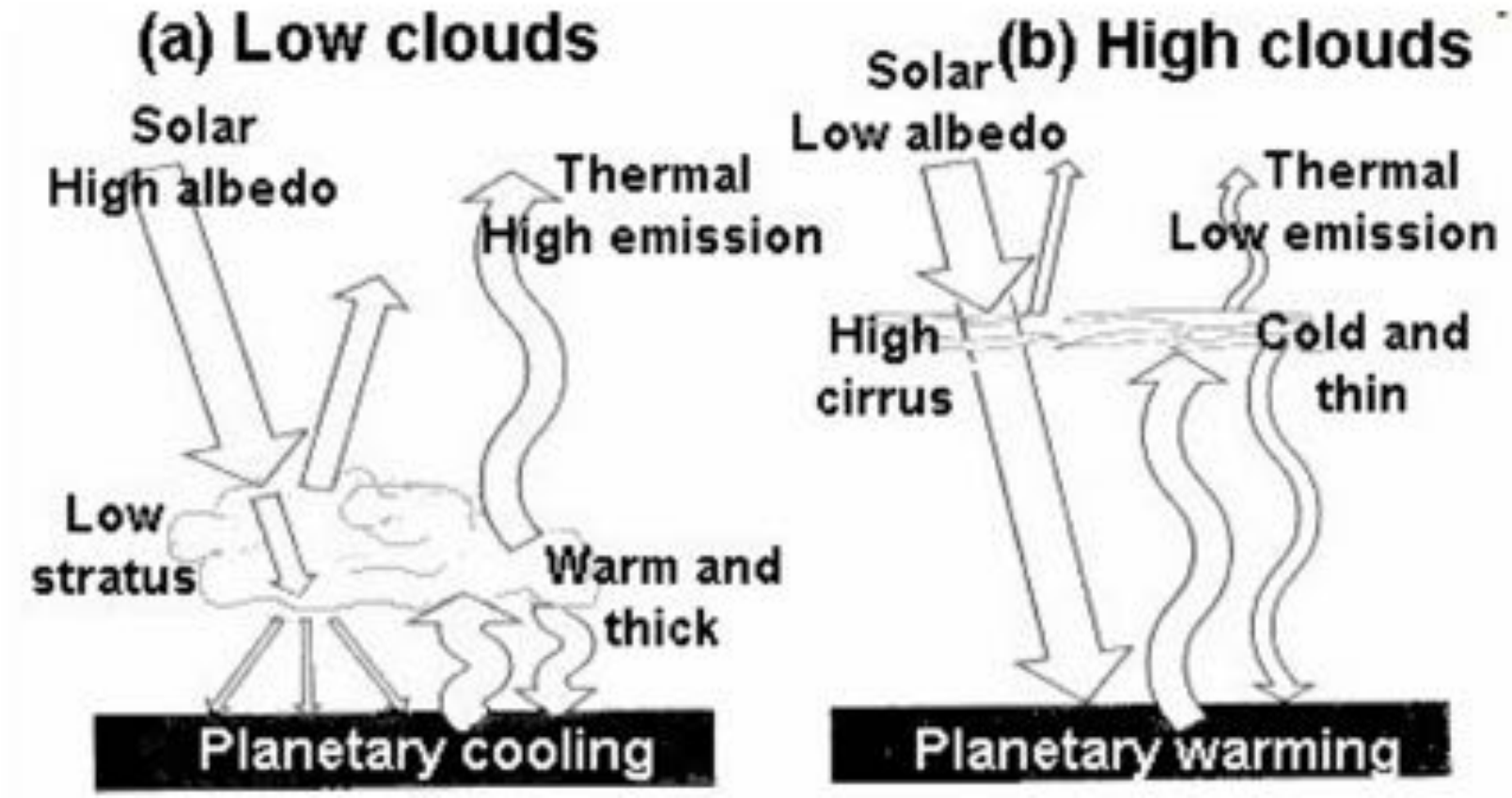
1. Clouds distribution
2. Coupling with circulation
3. Role in climate

Climate sensitivity

Climate sensitivity: equilibrium change in global mean surface temperature ΔT_s when atmospheric CO_2 is doubled.

Since the Charney Report, clouds have always been recognized as a key source of uncertainty for climate sensitivity

Clouds and radiation



More low clouds:

Little LW effect (~σT^4, T~Tsfc)

Strong SW cooling

More high clouds:

Strong LW warming (~σT^4, T<<Tsfc)

Little SW effect

Clouds and radiation

Cloud radiative effect: measure of cloud impact on earth energy budget (incoming radiation at TOA - *or tropopause*)

Difference between all- and clear-sky flux (> 0 ⇔ warming):

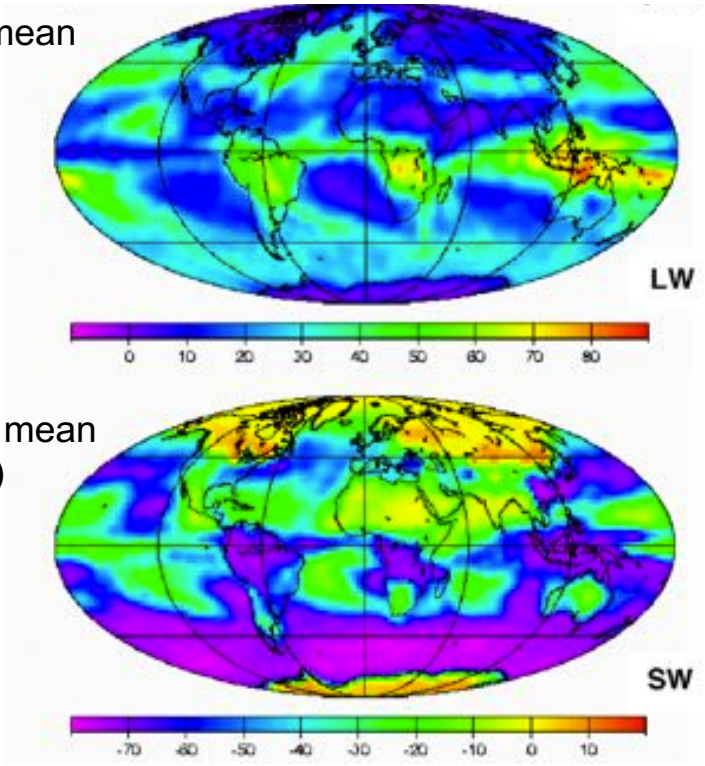
SW_{in} all sky – SW_{in} clear sky (< 0 due to low clouds cooling)

LW_{in} all sky – LW_{in} clear sky (> 0 due to high clouds warming)

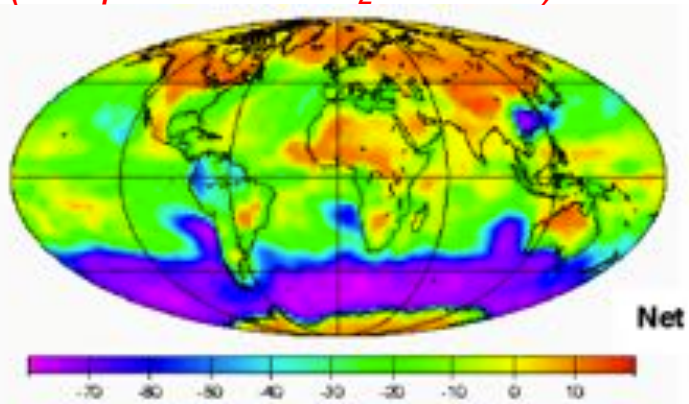
Cloud radiative effects in present-day climate (maps for JFM):

LW (annual mean ~ + 30W/m2)

SW (annual mean ~ - 50W/m2)



Net (annual mean ~ - 20W/m2)
(compare to $2xCO_2$: 4 W/m^2)



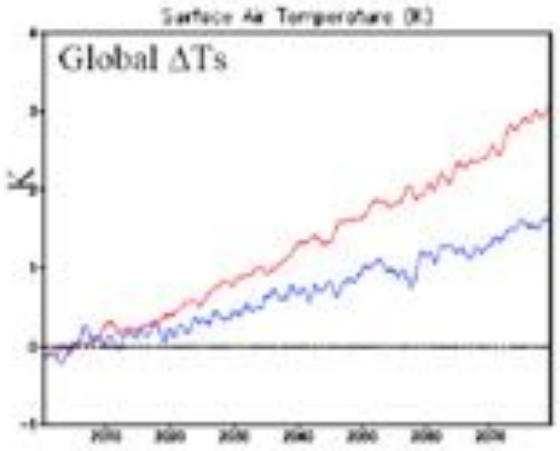
Clouds and radiation

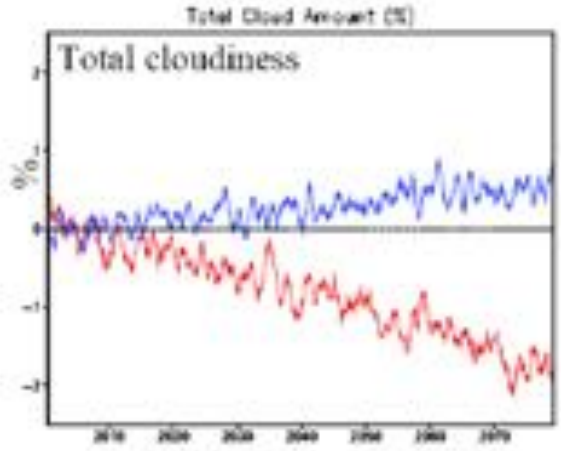
Cloud radiative forcing: difference between all- and clear-sky flux changes providing a measure of the contribution of clouds to the climate sensitivity.

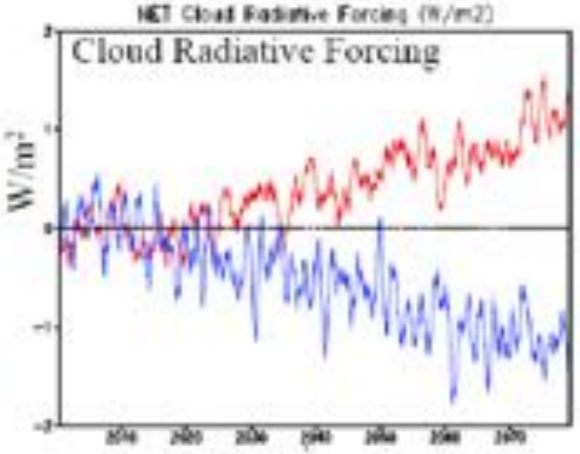
Net CRF = LW CRF + SW CRF
- < 0 : clouds oppose warming
- > 0 : clouds strengthen warming

How will clouds respond to increased CO_2 ?
How will that feed back on climate ?

Results from 2 different climate models (+ 1% CO_2/yr) MIROC and NCAR



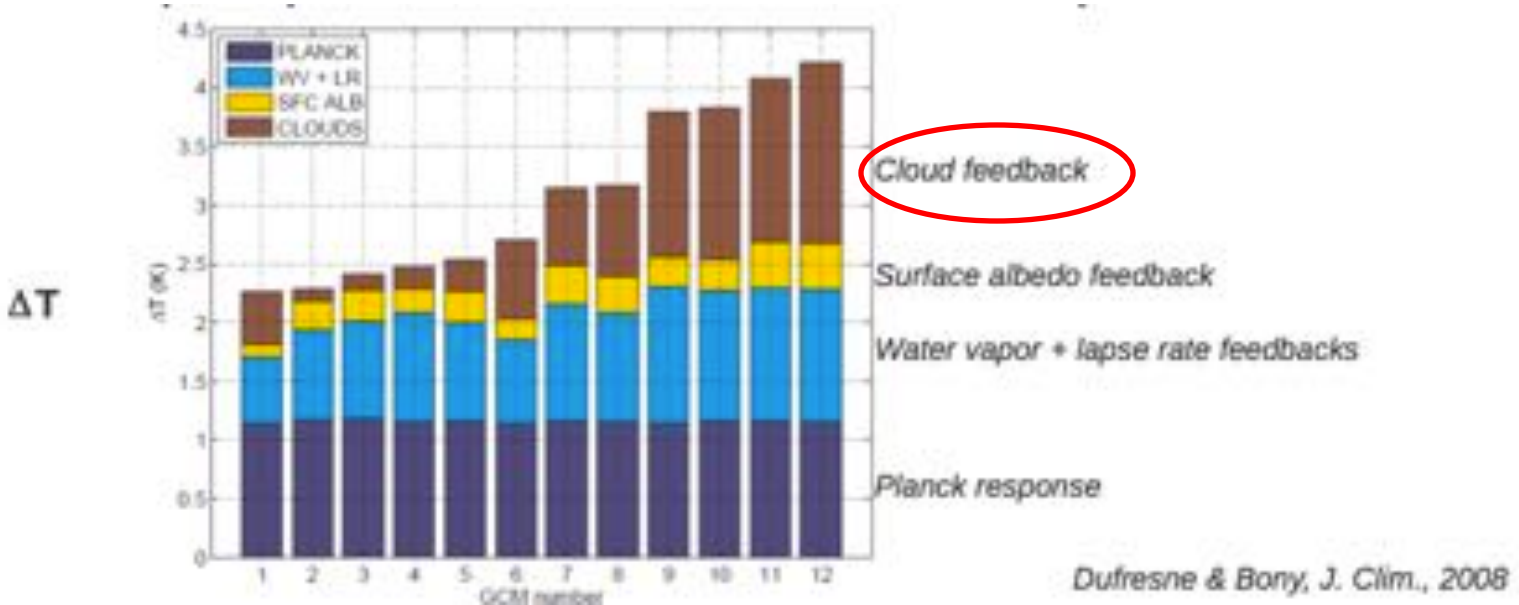




Quantifying Climate Feedbacks

We have methods to quantify various contributions to climate sensitivity

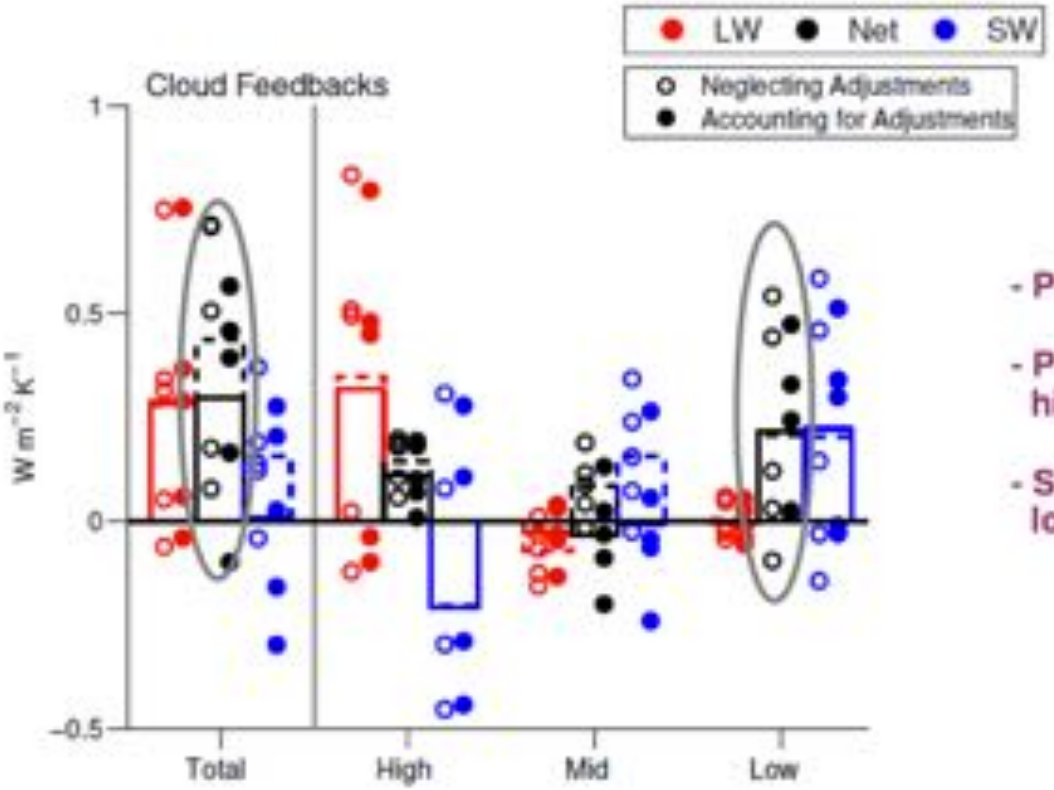
Helps interpret inter-model differences in climate sensitivity :



Cloud Feedback Processes

How do the different cloud types contribute to global cloud feebdacks ?
=> **Low-cloud feedbacks dominate the spread of model cloud feedbacks**

CMIP5 Cloud Feedbacks



- Positive cloud feedback
- Primarily arises from low-level and high-level cloud feedbacks
- Spread primarily arises from low-level cloud feedbacks

Zelinka et al., J. Climate, 2013

Clouds in a changing climate

Many remaining questions …

What controls the low cloud fraction ?

What determines the spatial organization of low clouds ?

What determines the spatial organization of deep clouds ?

Clouds in our current, and in a warming climate

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