

# 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

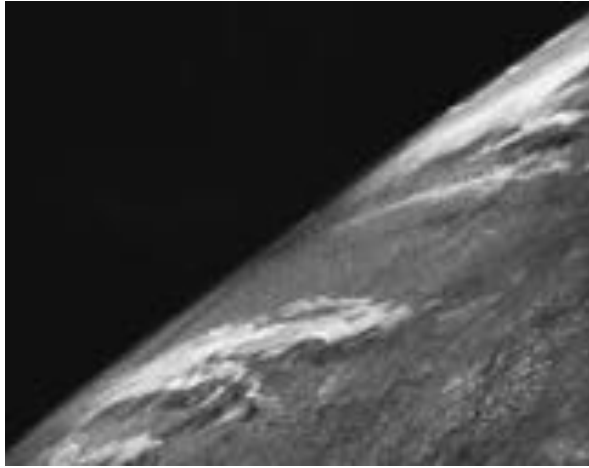


and clouds

*"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



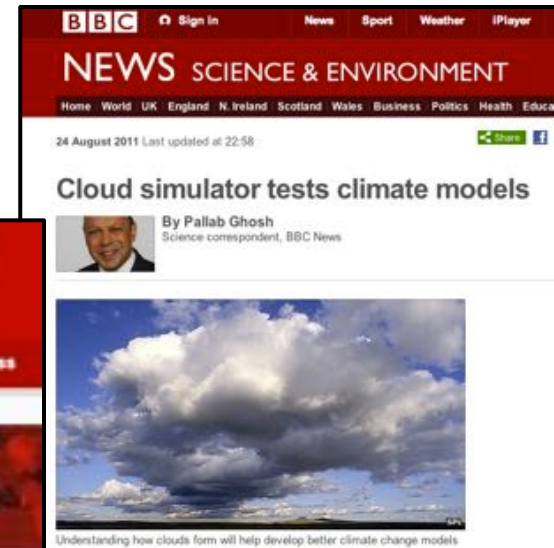
Tintin on the moon 1952





# Key actors of climate

## An era of blooming cloud and climate science




BBC NEWS SCIENCE & ENVIRONMENT

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24 August 2011 Last updated at 22:58

### Cloud simulator tests climate models

By Pallab Ghosh  
Science correspondent, BBC News



Understanding how clouds form will help develop better climate change models



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ENVIRONMENT SPA

It's gone. [Link](#)

What was wrong with this ad?

Inappropriate  Repetitive  Irrelevant

TEMPERATURE RISING

### Clouds' Effect on Climate Change Is Last Bastion of Dissenters

By JUSTIN GILLIS  
Published: April 30, 2012 | 128 Comments

LAMONT, Okla. — For decades, a small group of scientific dissenters has been trying to shoot holes in the prevailing science of climate change, offering one reason after another why the outlook simply must be wrong.



Enlarge This Image

Over time, nearly every one of their arguments has been knocked down by accumulating evidence, and polls say 97 percent of working climate scientists now see global warming as a serious risk.

Yet in recent years, the climate change skeptics have seized on one last argument that cannot be easily



### Climate change: Can we ever... Should we even try?

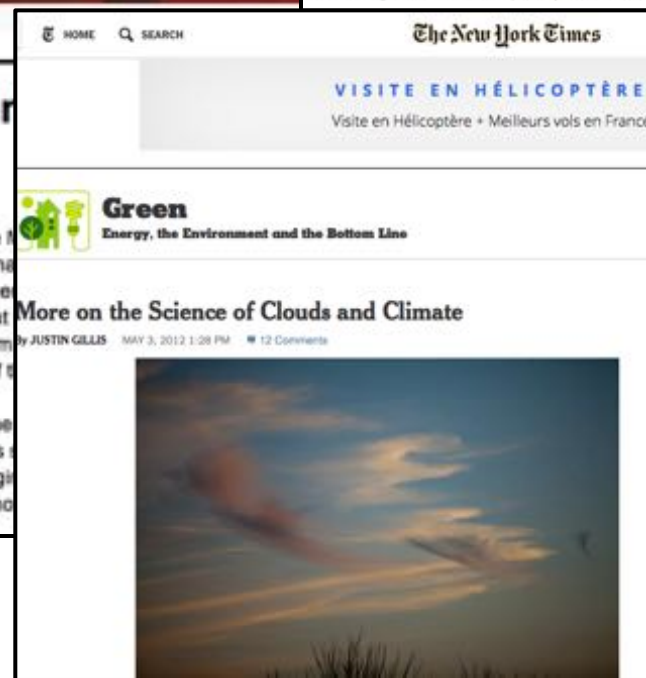
By Shelby Lin Erdman, CNN



Global warming and the resulting droughts help make climate manipulation a hotly debated issue.

(CNN) -- The... Technology ha... for its engine... symposium at... scientists from... a hot facet of...

The title of the... the questions... science; "Engi... We Do It? Sho...



The New York Times

VISITE EN HÉLICOPTÈRE  
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**Green**  
Energy, the Environment and the Bottom Line

### More on the Science of Clouds and Climate

By JUSTIN GILLIS MAY 3, 2012 1:28 PM 12 Comments



# A Grand Challenge



The screenshot shows a web browser window with the URL [www.wcrp-climate.org/grand-challenges/ge-clouds](http://www.wcrp-climate.org/grand-challenges/ge-clouds). The page features the WCRP logo (World Climate Research Programme) and a navigation menu with items: About WCRP, Core Projects, Unifying Themes, Grand Challenges, Initiatives & Activities, Events, News, and Resources. A search bar is visible on the right side of the header.

## 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

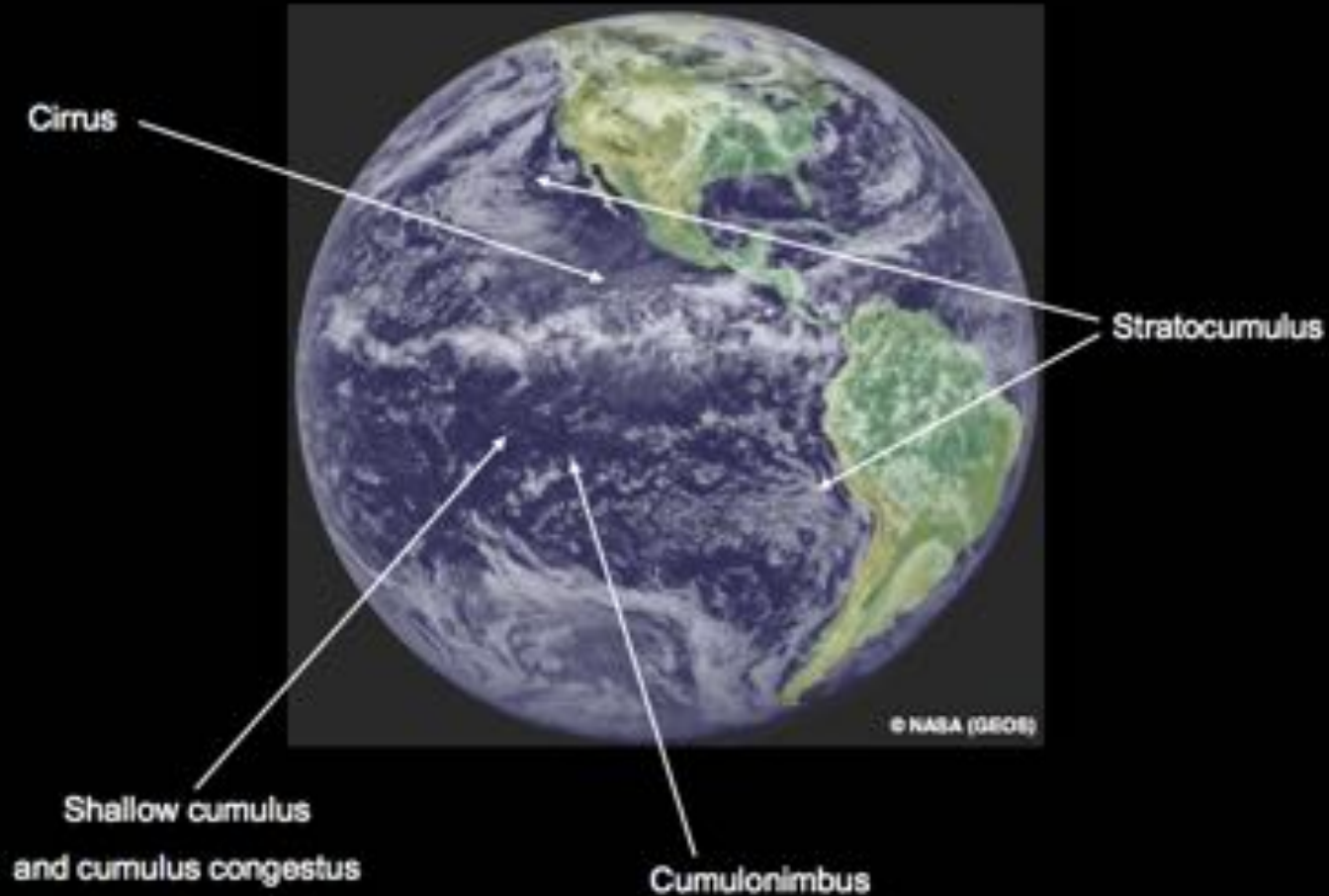
[← Back to Grand Challenges Overview](#)

# Clouds in our current, and in a warming climate

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

# Clouds distribution

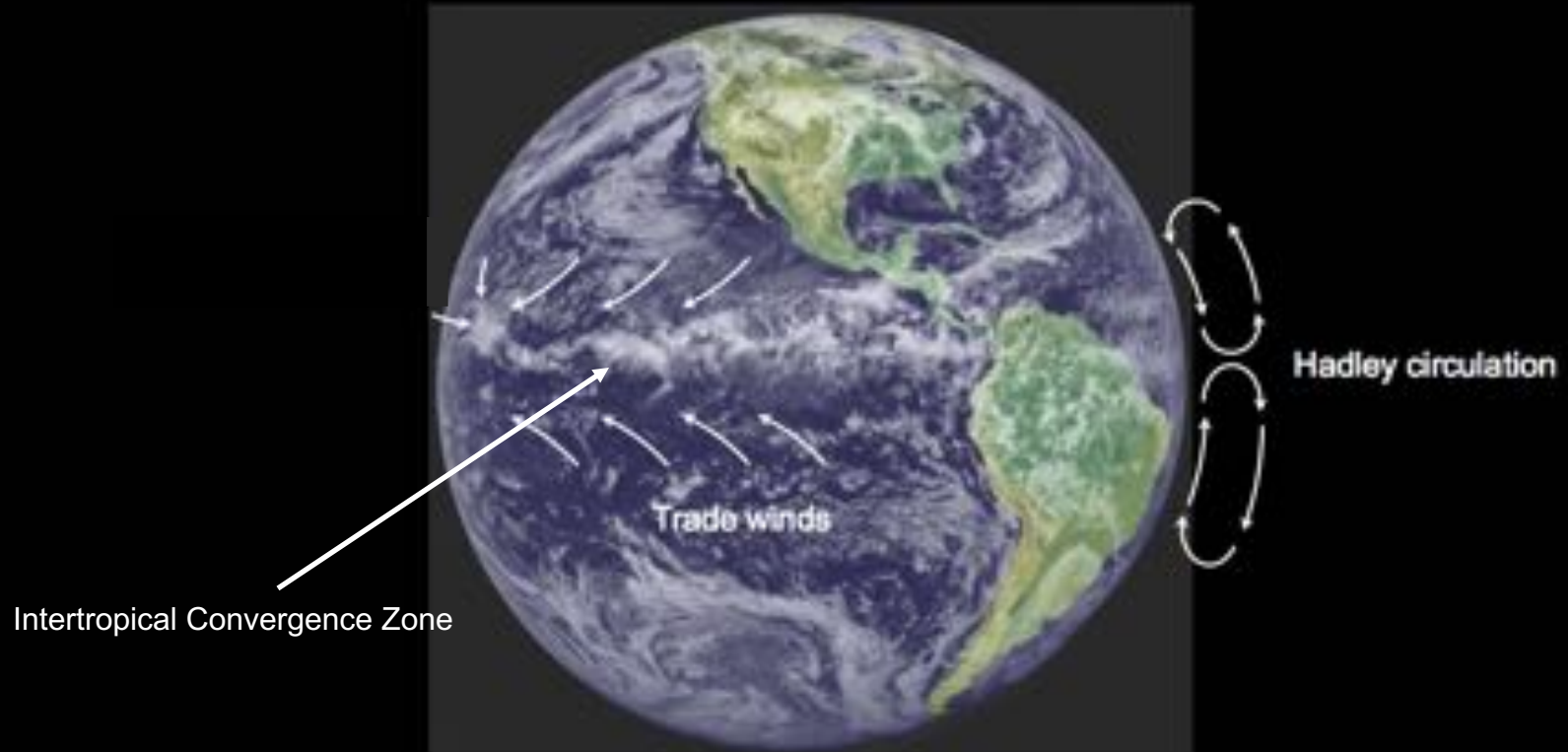
clouds are diverse, ...





# Clouds distribution

... and coupled to circulations.



# Cloud types

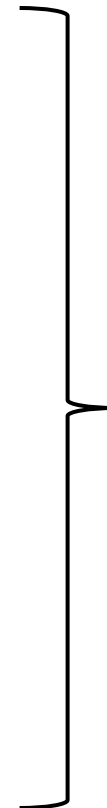
***Cumulus***: vertical extent

***Stratus***: horizontal extent

***Cirrus***: lock of hair

***Nimbus***: precipitating

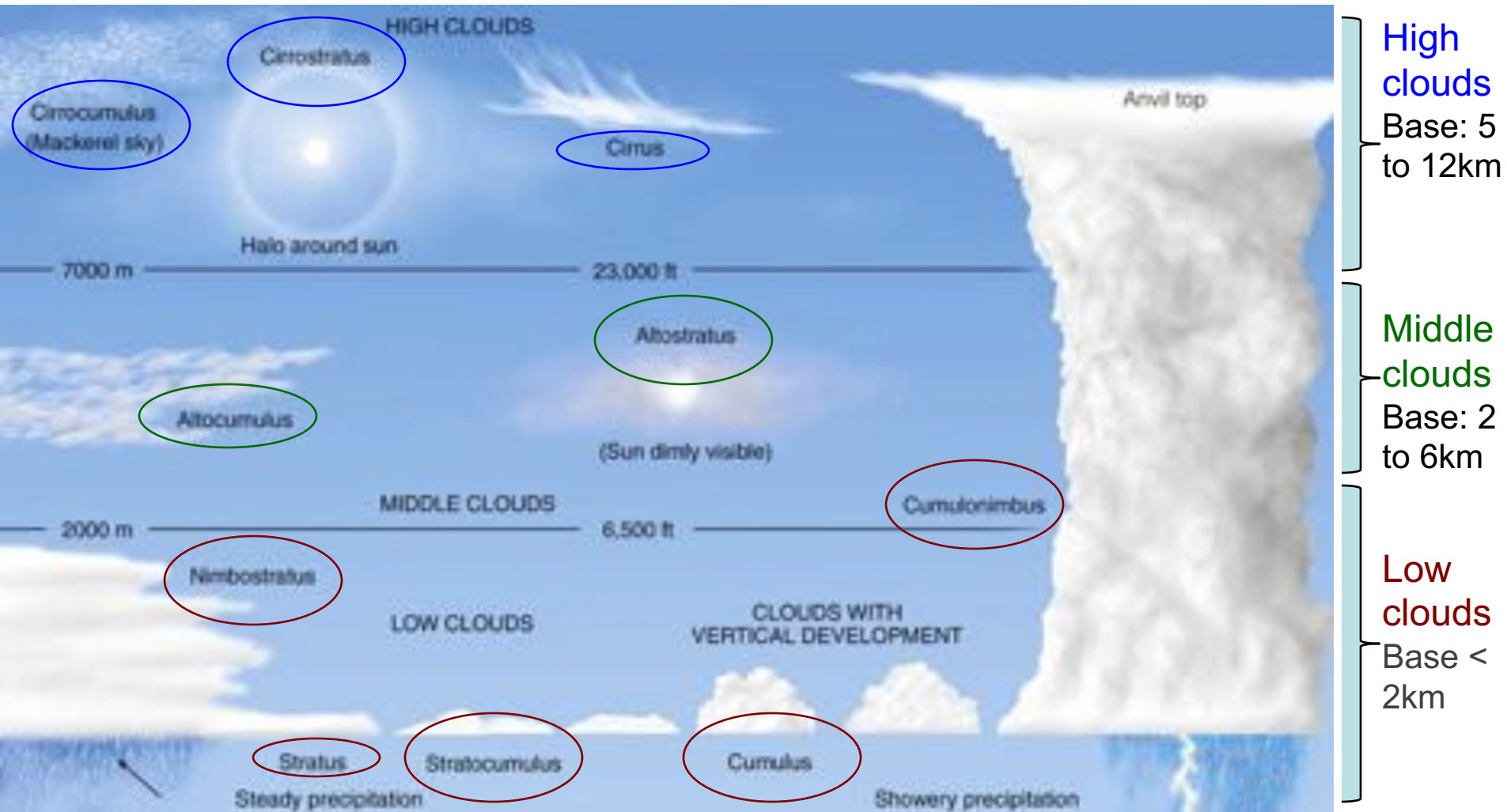
***Altim***: height



Combined to define  
10 cloud types

# Cloud types

Clouds are classified according to height of cloud base and appearance



# 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)

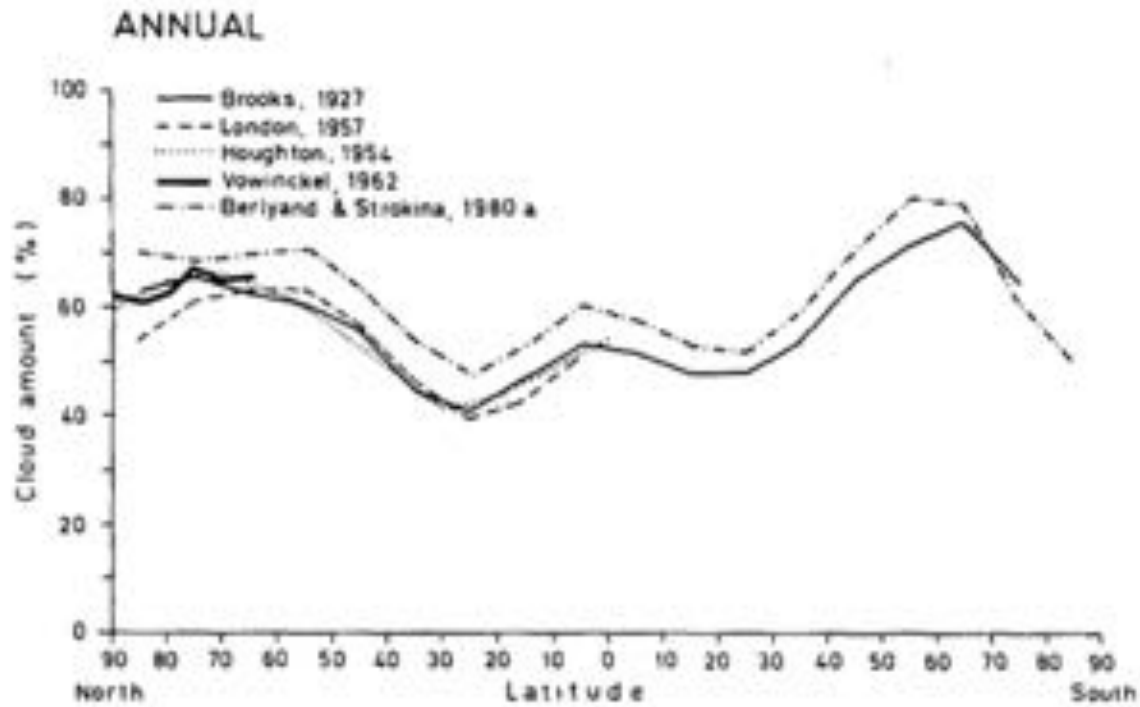


**Question:** Global cloud cover (%)?



# Clouds distribution

Distribution of cloud amount

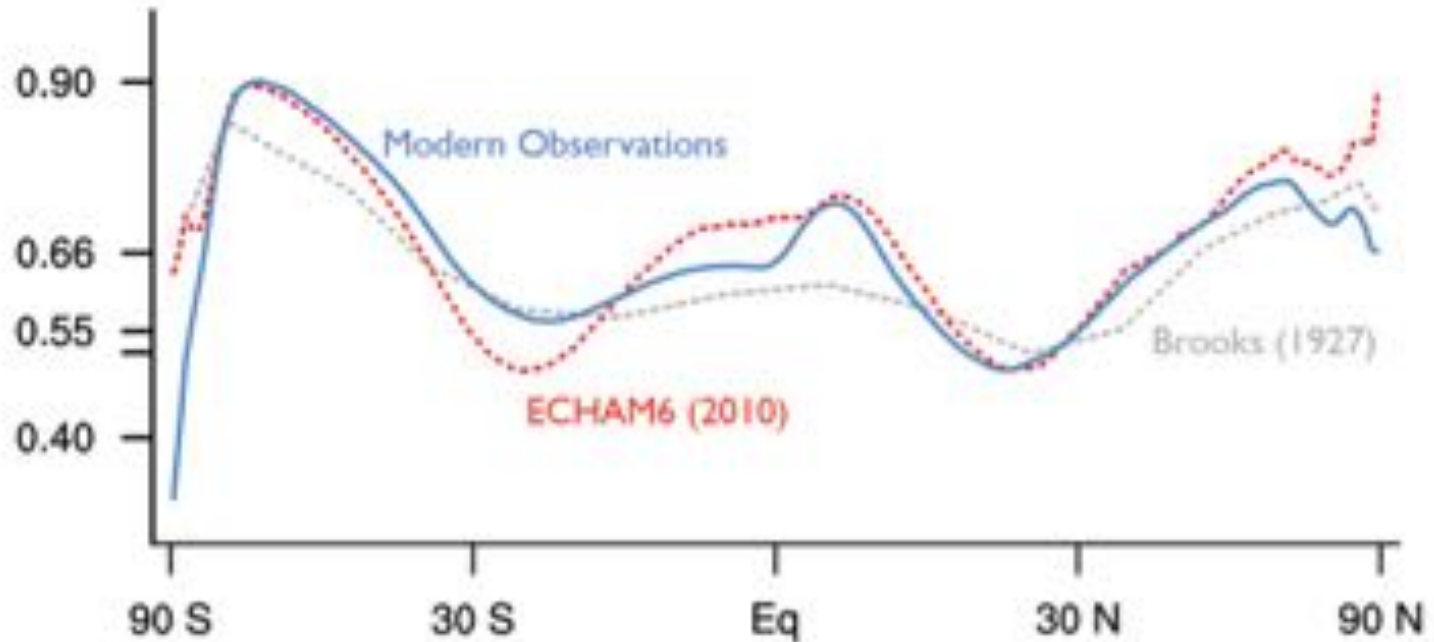


[Hughes 84]

# Clouds distribution

Cloud amount was underestimated

Also note the latitudinal distribution

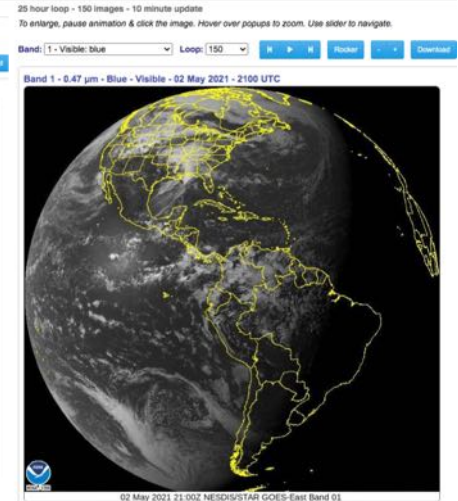
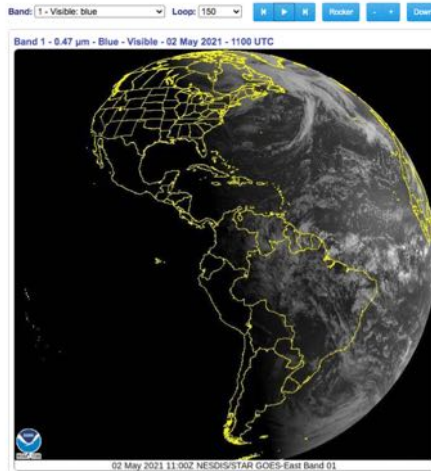


*Courtesy Bjorn Stevens*

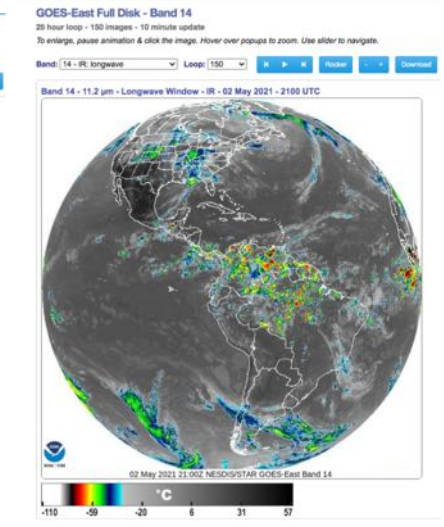
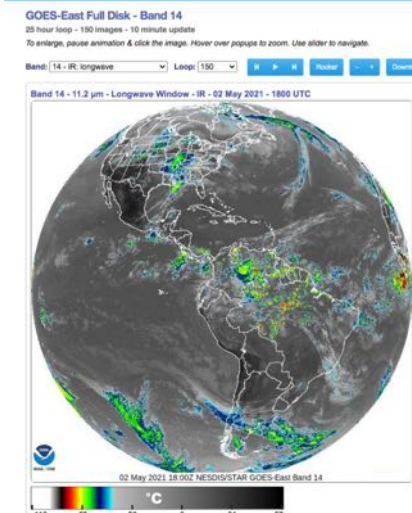
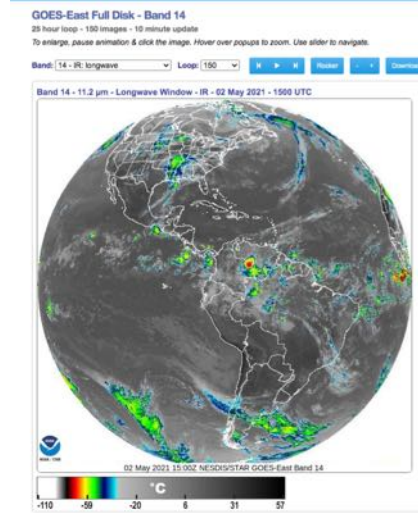
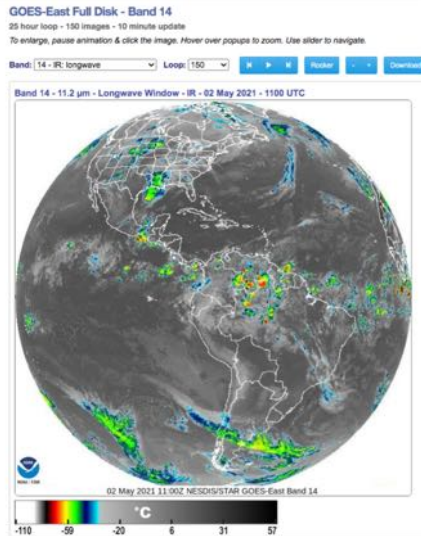
# GOES satellite imagery May 2<sup>nd</sup> @ 11,15,18,21 UTC

## Shortwave, or visible

25 hour loop - 150 Images - 10 minute update  
To enlarge, pause animation & click the image. Hover over popups to zoom. Use slider to navigate.

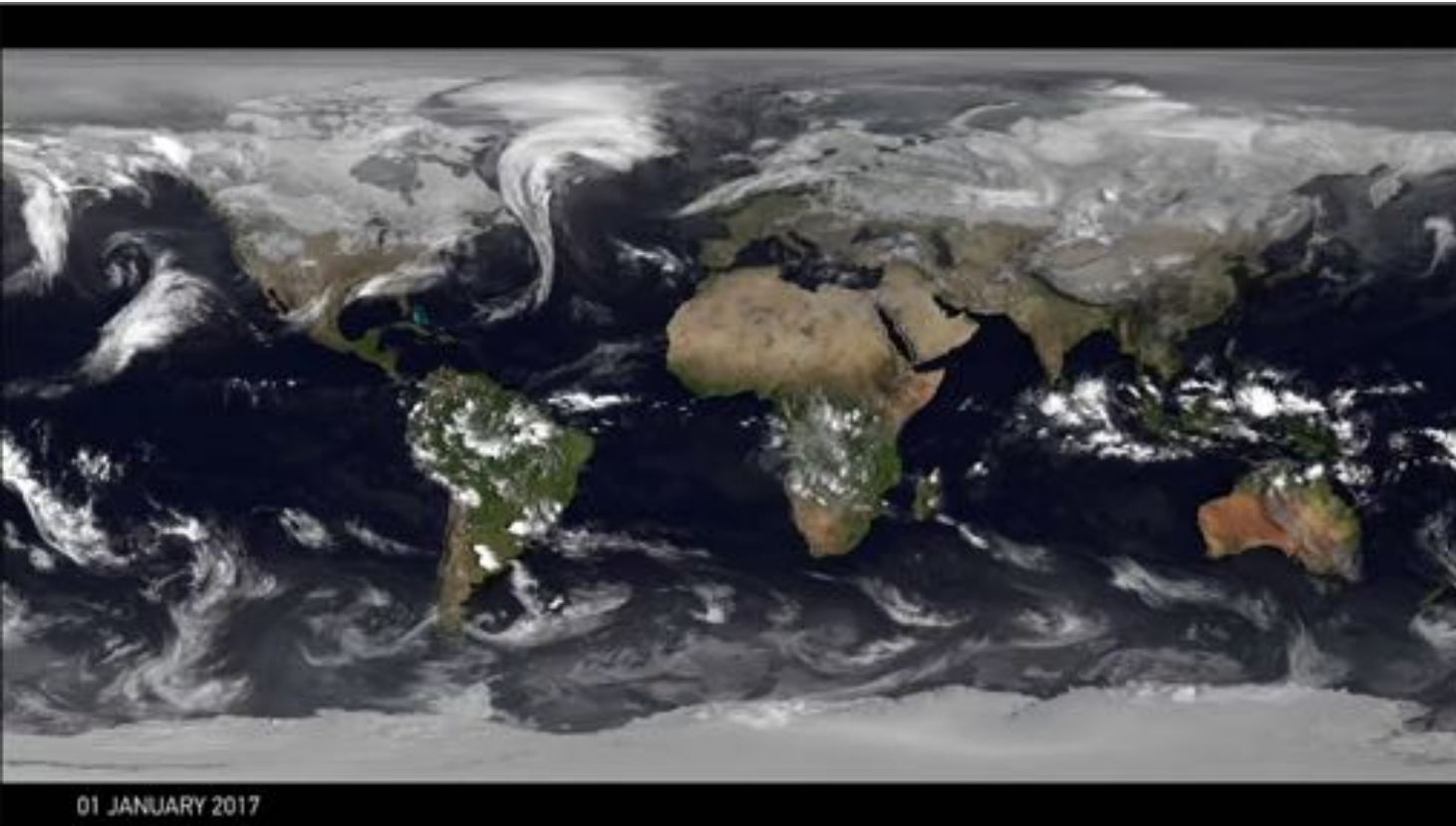


## Longwave, or infrared (emission temperature)



# Clouds distribution

Brightness temperature from satellite (white ⇔ cold cloud tops)



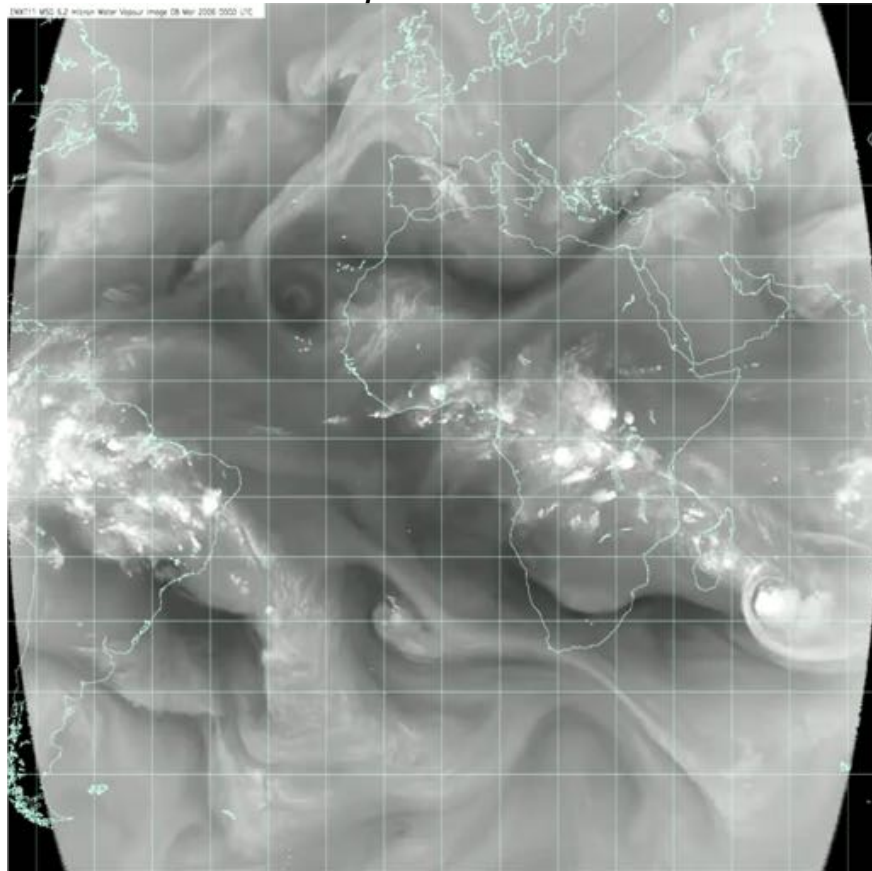
- Large extratropical storm systems
- subtropics: ~no high clouds
- ITCZ = Intertropical convergence zone

« 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

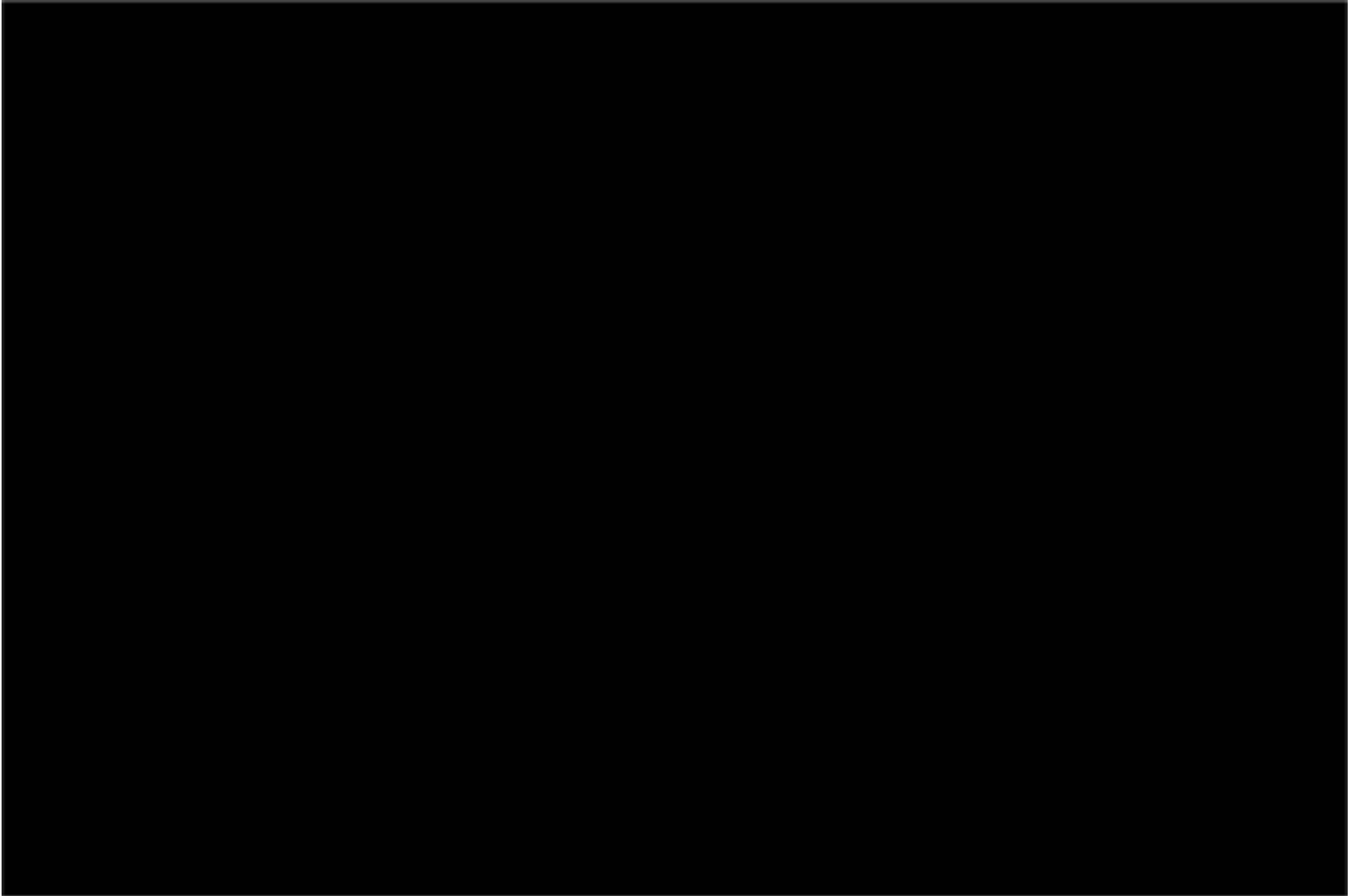
1. Clouds distribution
2. Coupling with circulation
3. Role in climate

# Cloud formation



*Courtesy : Octave Tessiot*

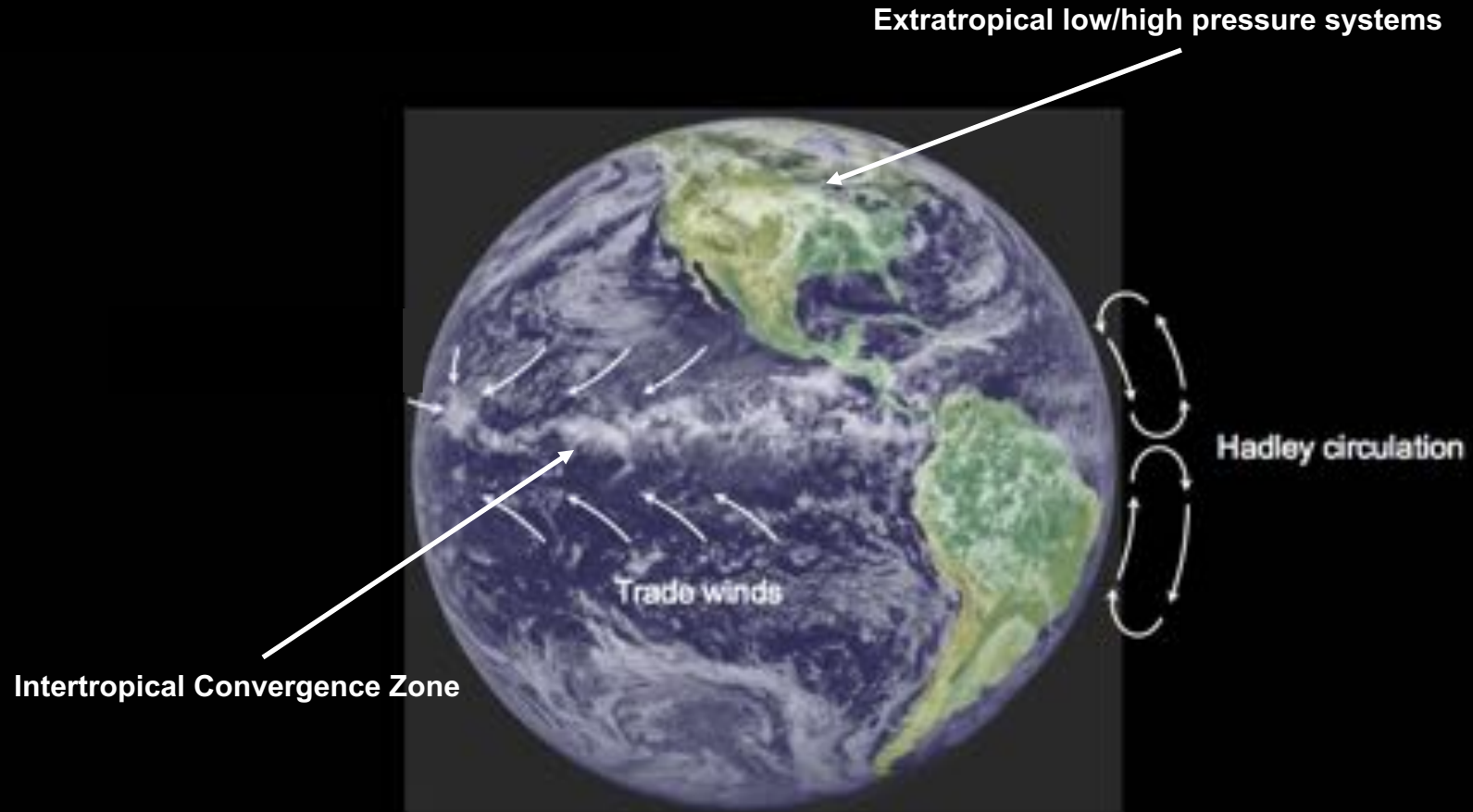
# Cloud formation



*Courtesy : Octave Tessiot*



# Clouds are coupled with circulation

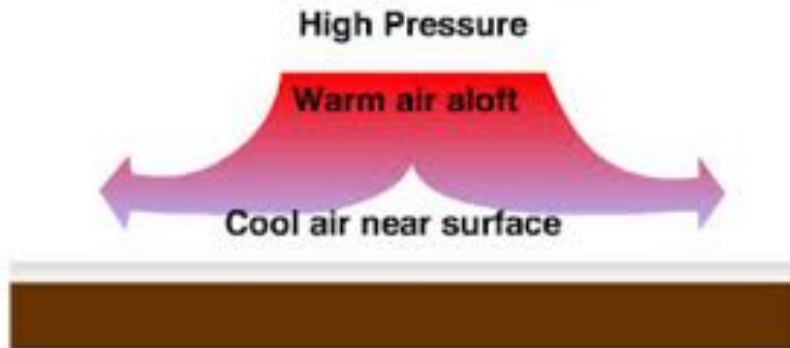
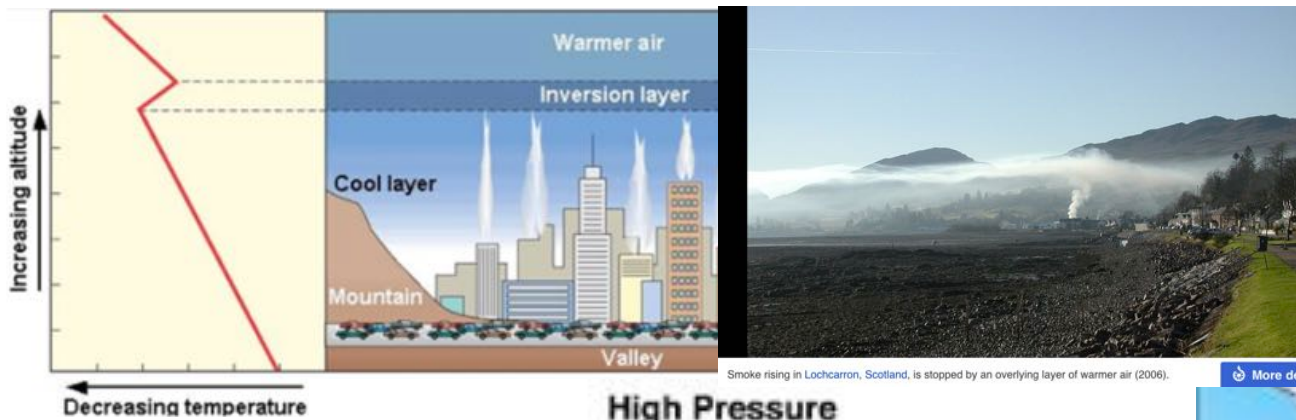


Tropics and Subtropics : ITCZ, Hadley, Walker (ENSO), monsoon

Mid-latitudes : Extratropical frontal systems

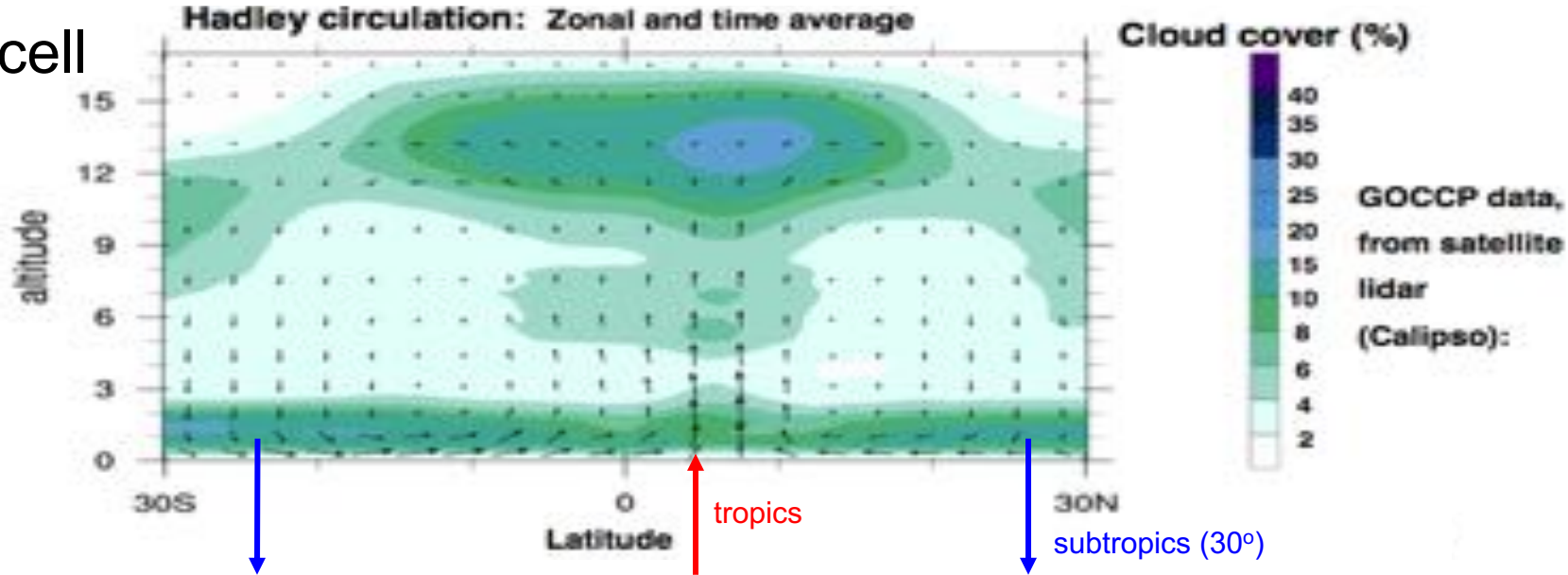
# Clouds and Circulation

**Air gradually sinking opposes cloud development:**  
air is **dry** and is **warmed** by adiabatic compression  
(increased pressure)  
⇒ unstable layer capped by stable layer

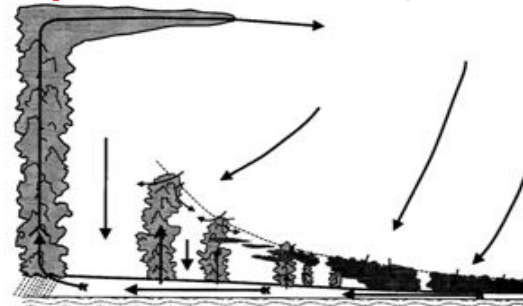


# Clouds and Circulation: Tropics and Subtropics

## Hadley cell



Cloud types:



Deep cumulonimbus



Fair weather cumulus

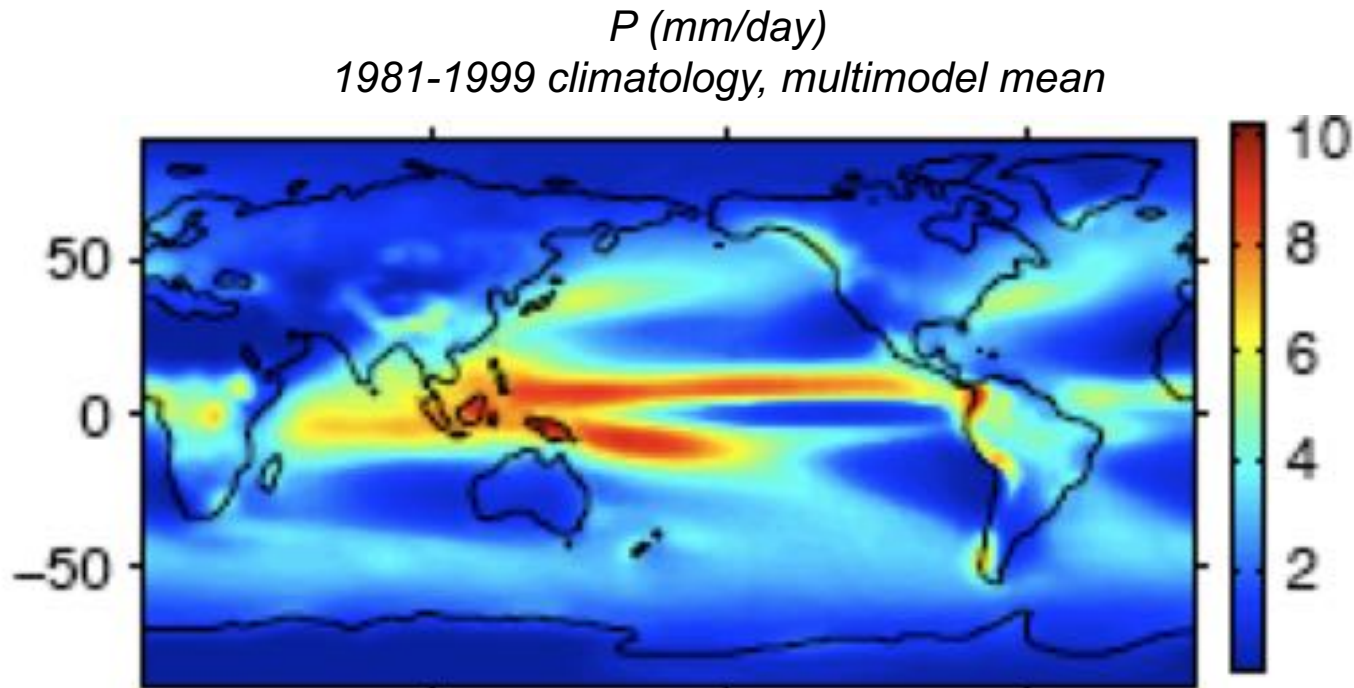


stratus

⇒ 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



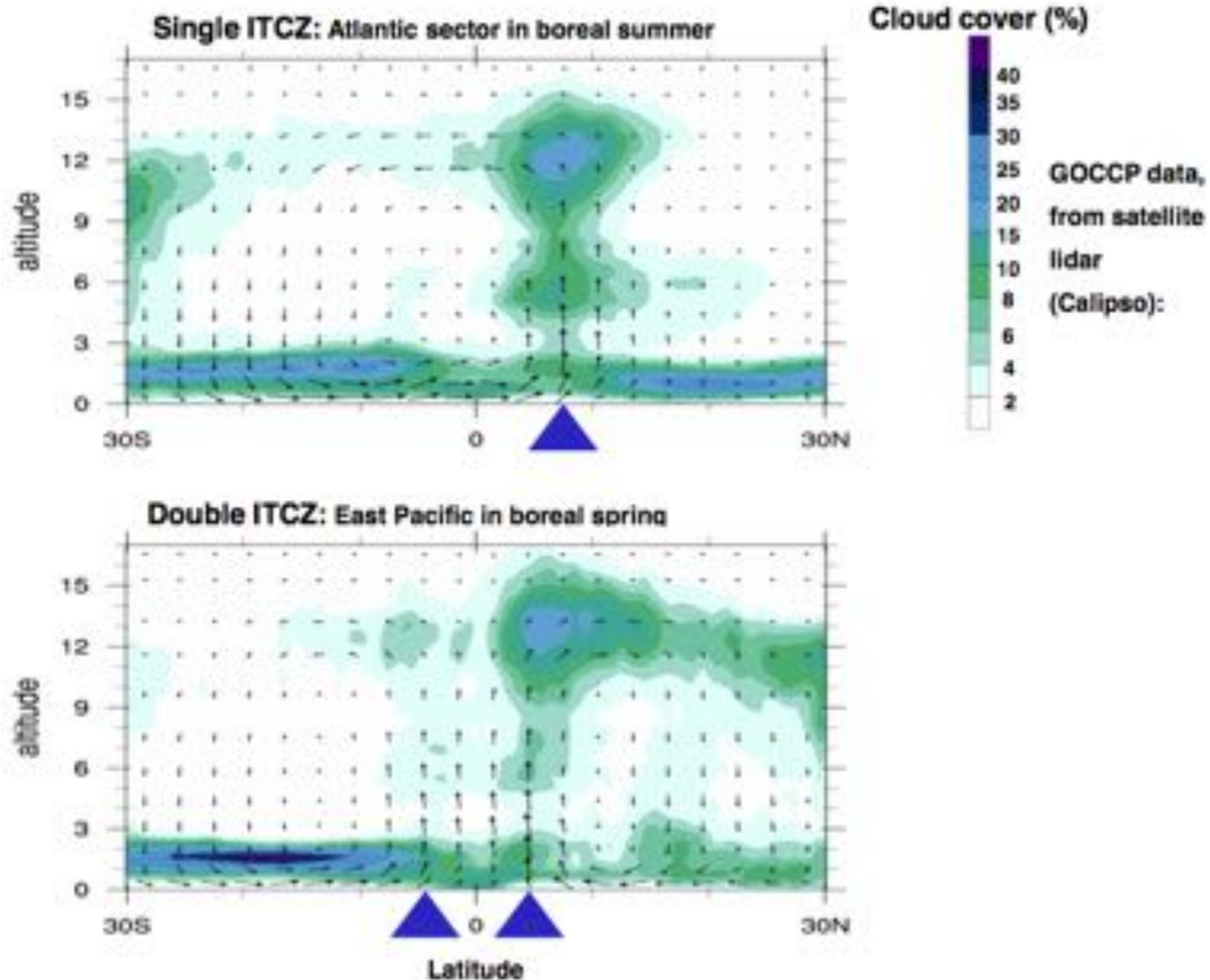
Small in Subtropics (descent)

Large in Tropics (ascent)

[Muller & O’Gorman, 2011]

# Clouds and Circulation: Tropics and Subtropics

## double ITCZ

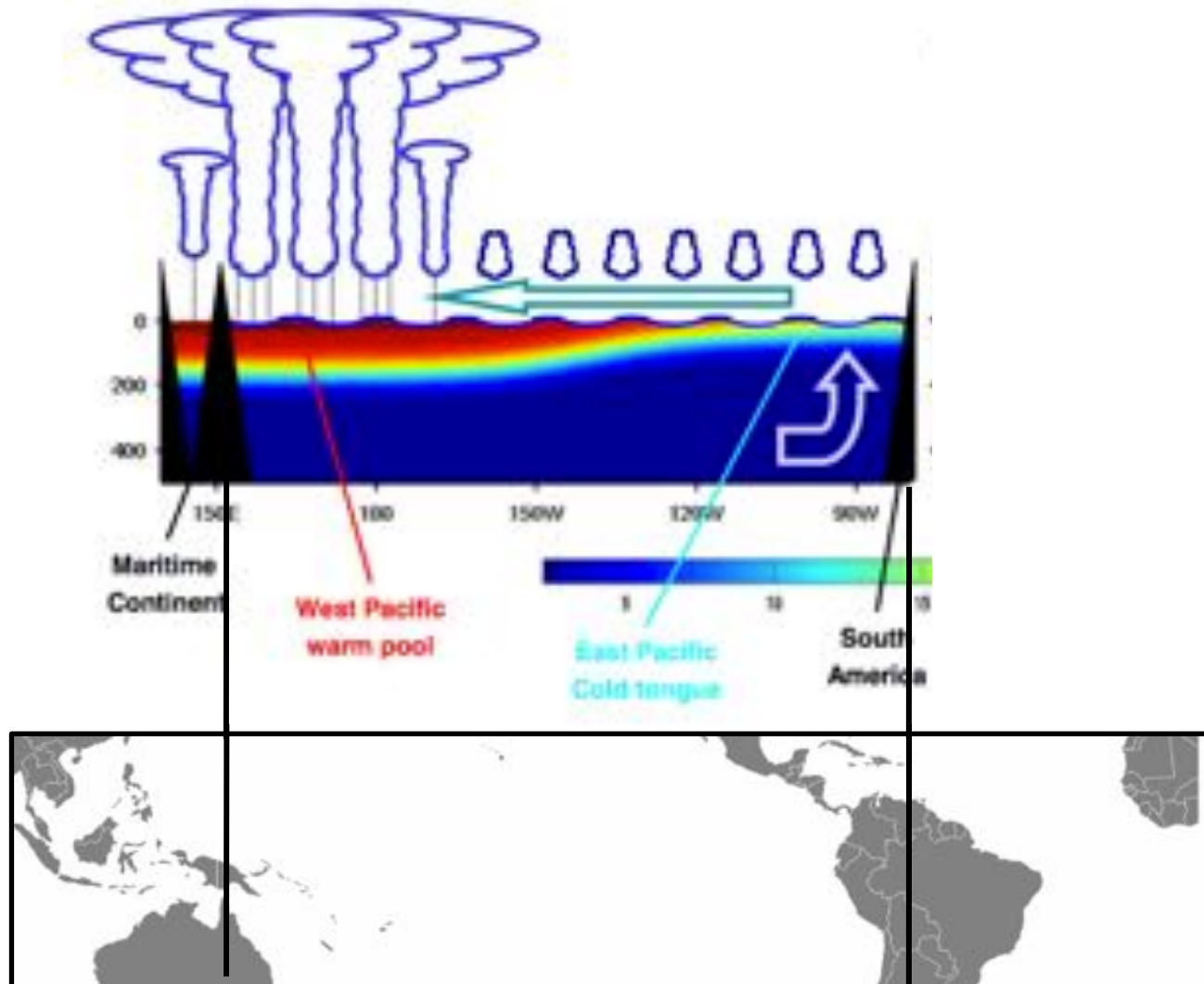




# Clouds and Circulation: Tropics and Subtropics

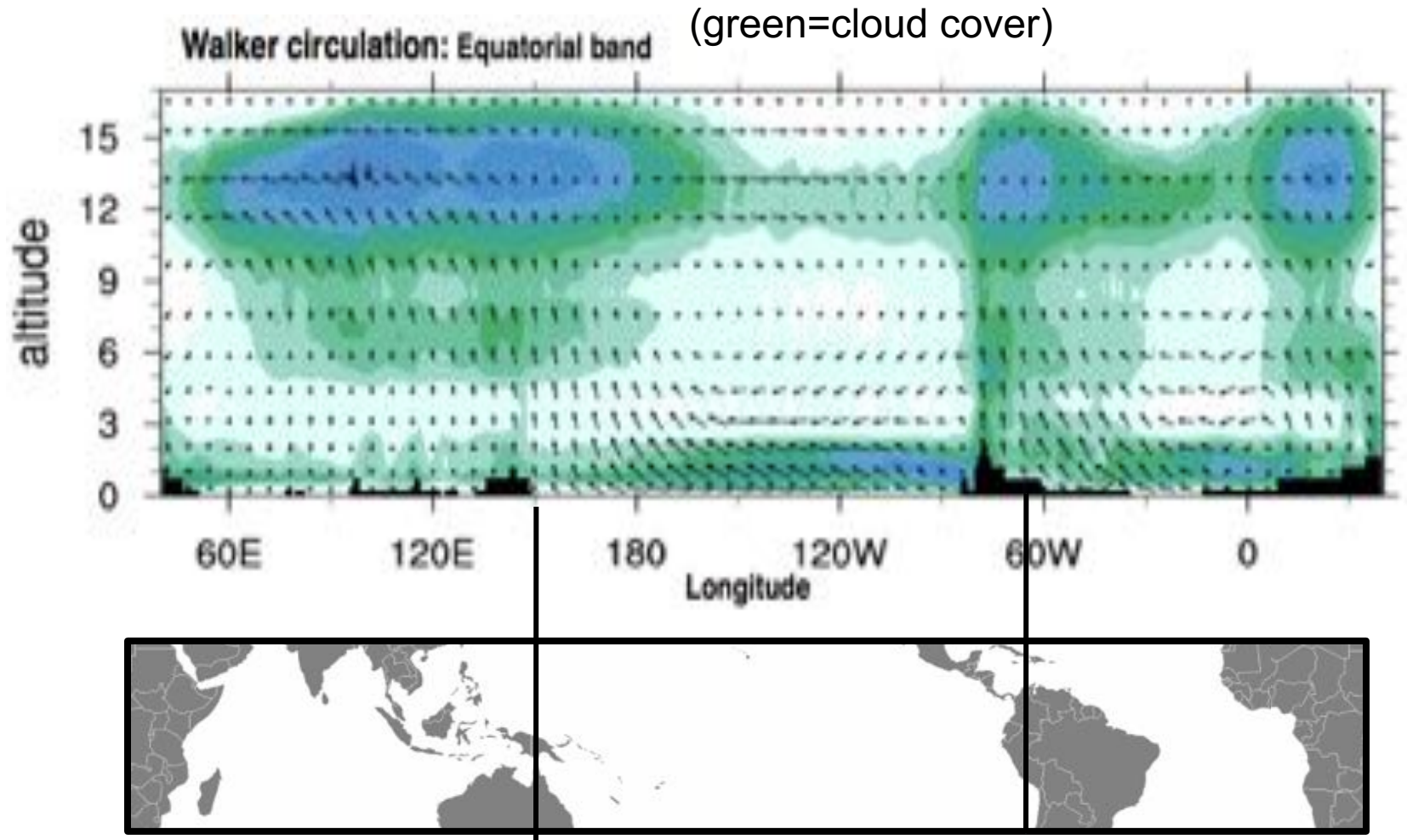
## Walker cell

in the equatorial Pacific



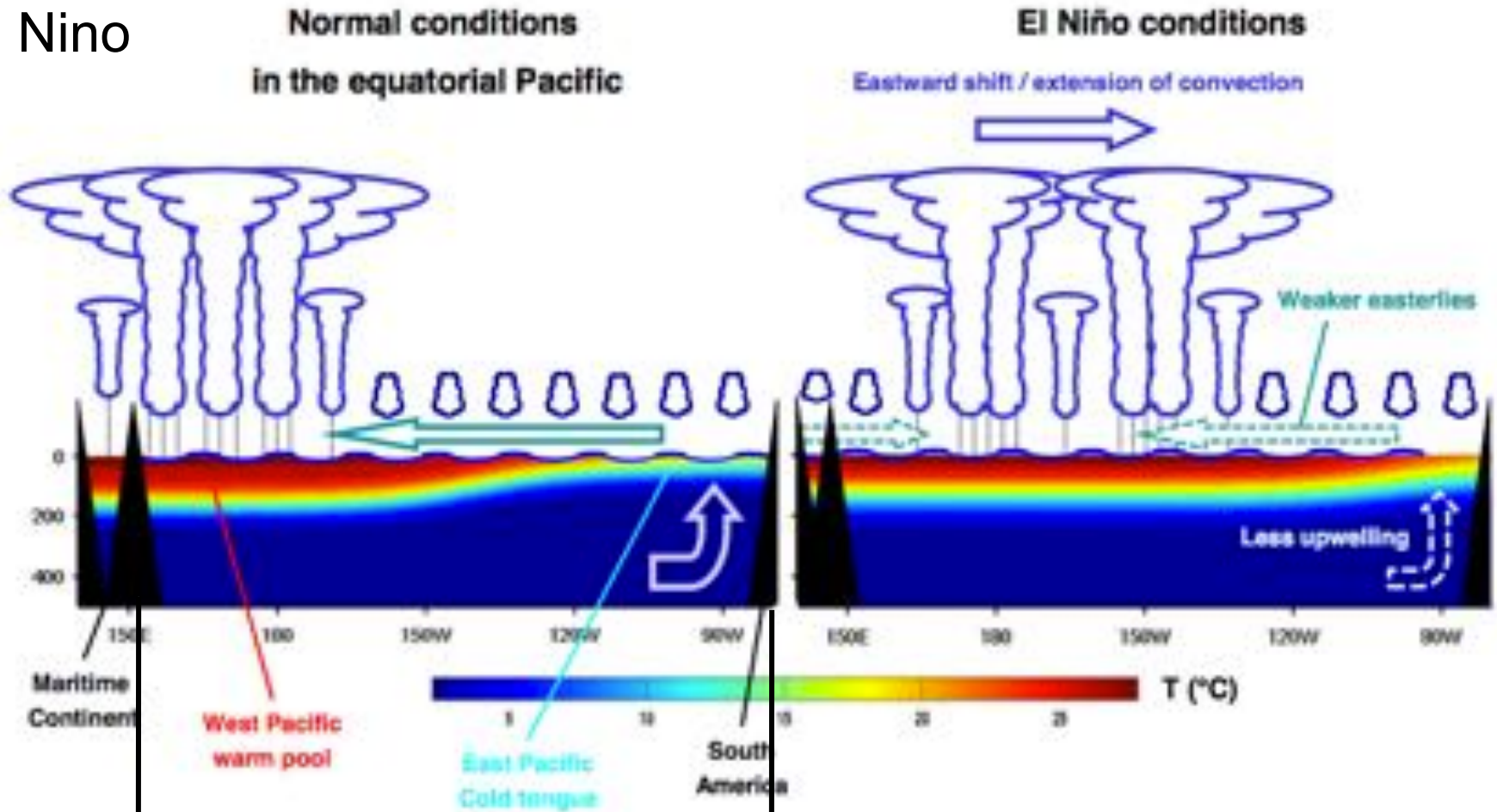
# Clouds and Circulation: Tropics and Subtropics

## Walker cell



# Clouds and Circulation: Tropics and Subtropics

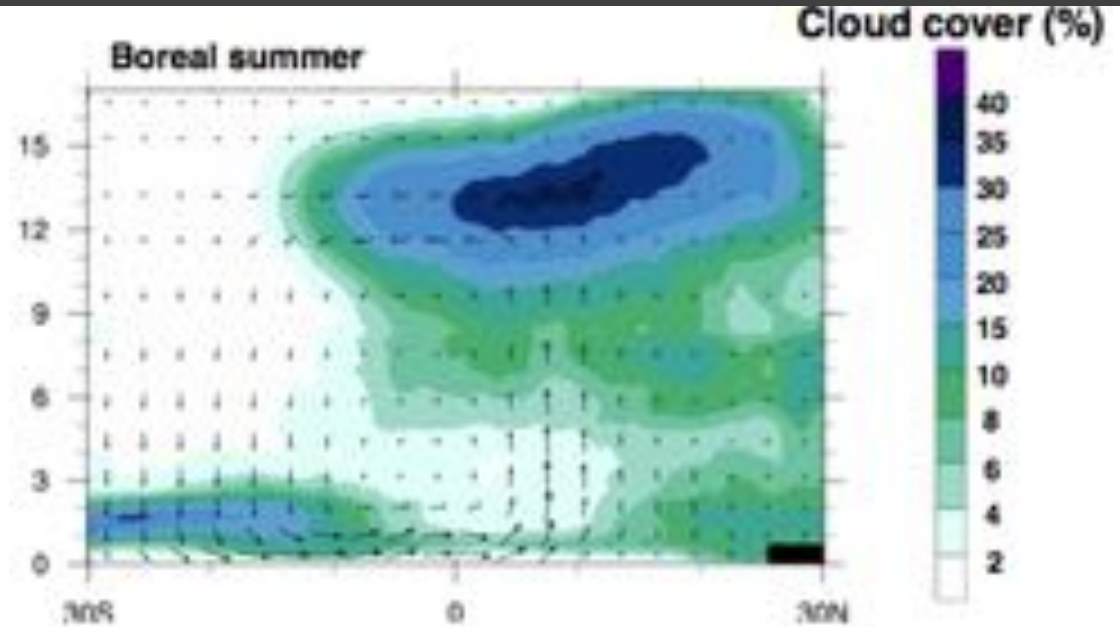
## El Niño



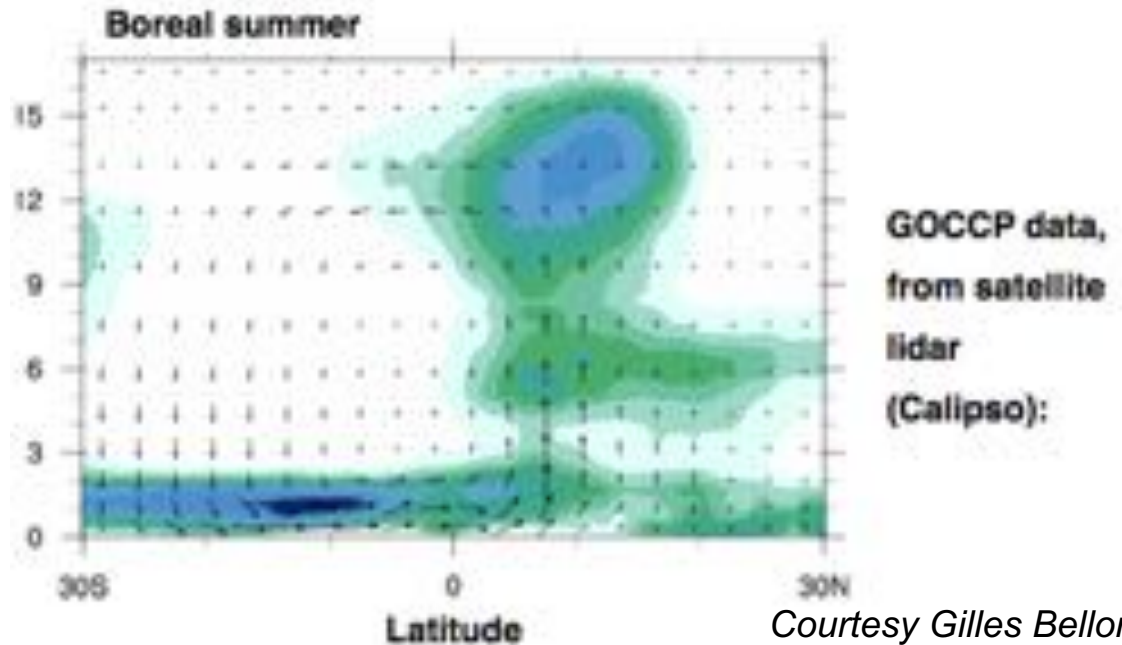
# Clouds and Circulation: Tropics and Subtropics

## Monsoons

Asian monsoon



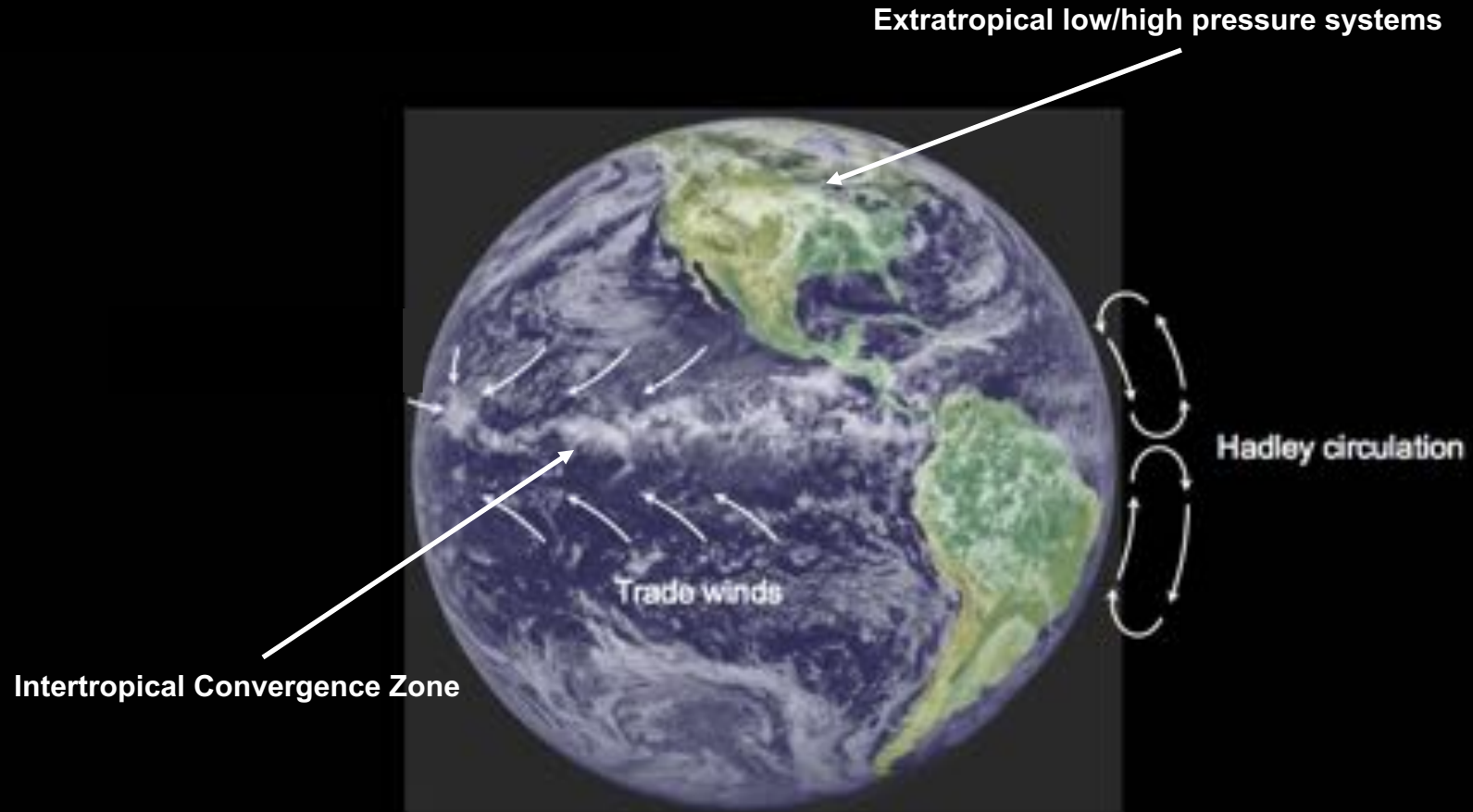
West-African monsoon



Courtesy Gilles Bellon



# Clouds and Circulation: Extratropics



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

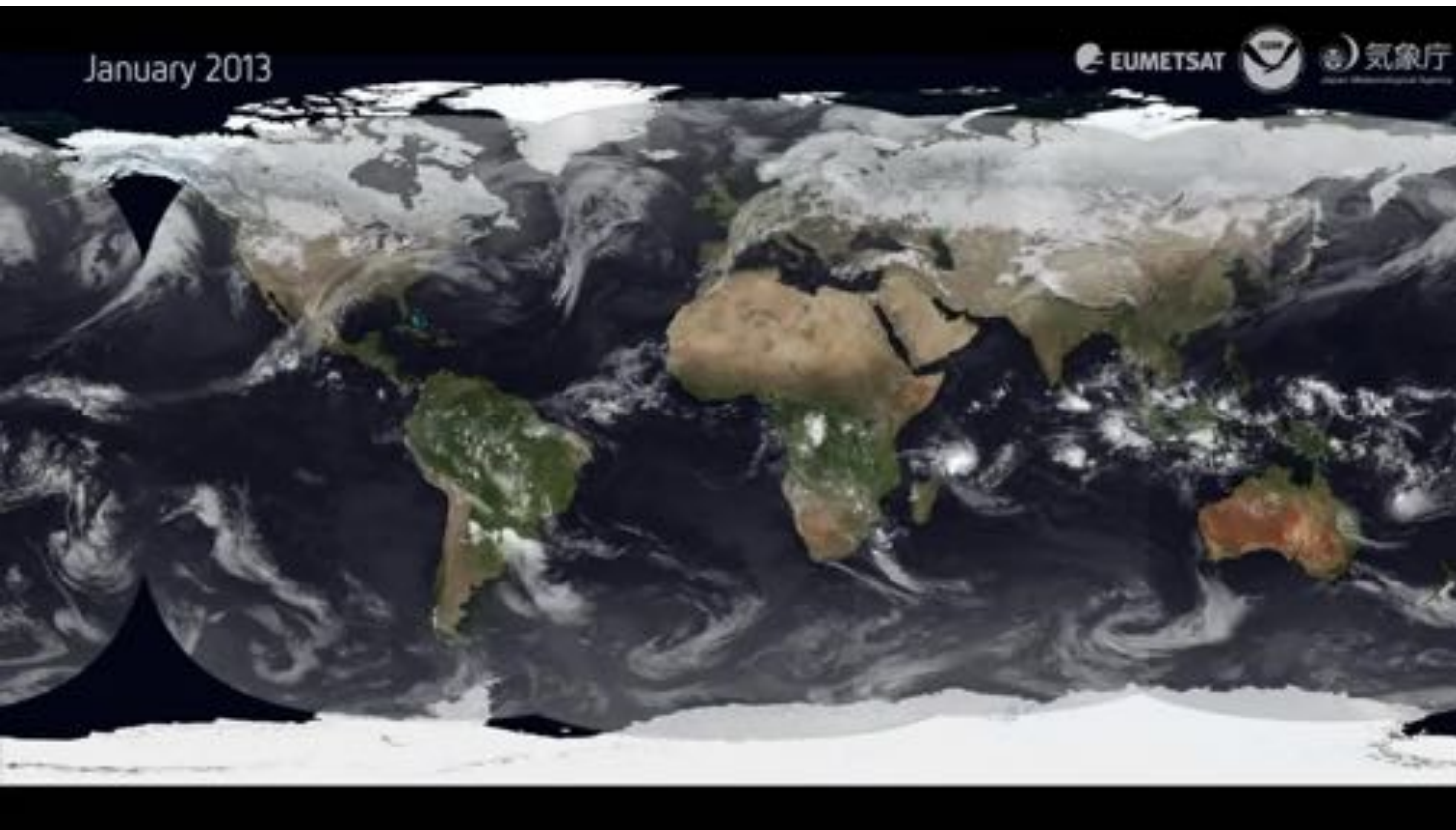
Mid-latitudes : Extratropical frontal systems



# Clouds and Circulation: Extratropics

## Recall : spatial distribution

Brightness temperature from satellite (white ⇔ cold cloud tops)

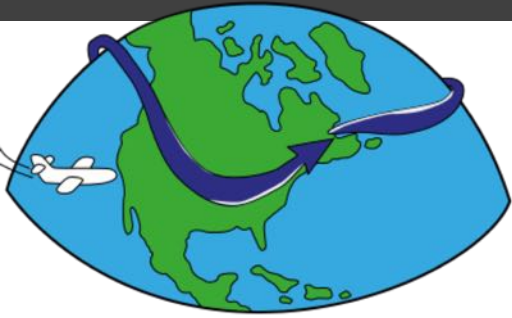


- Large extratropical storm systems
- subtropics: ~no high clouds
- ITCZ = Intertropical convergent zone

« A year of weather »

Extratropics: low and high pressure systems within the polar jet

# Clouds and Circulation: Extratropics



courant-jet polaire

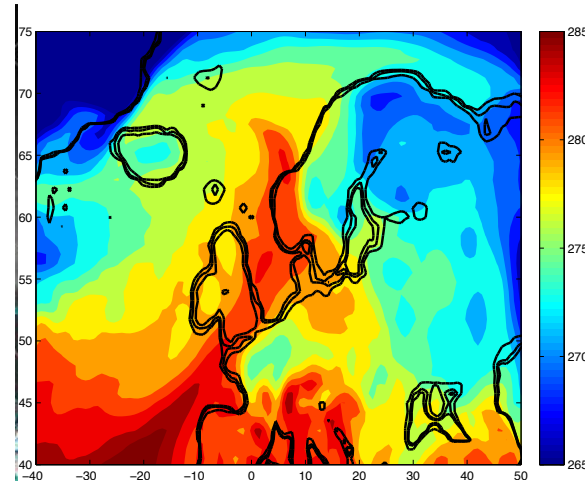
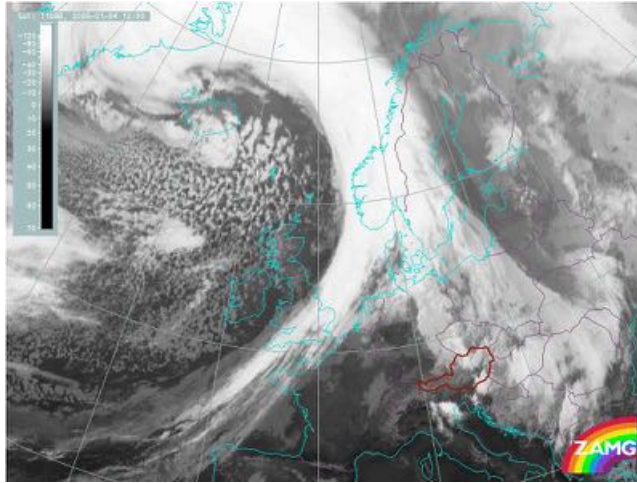


High latitudes => clouds embedded in low/high pressure systems and associated fronts

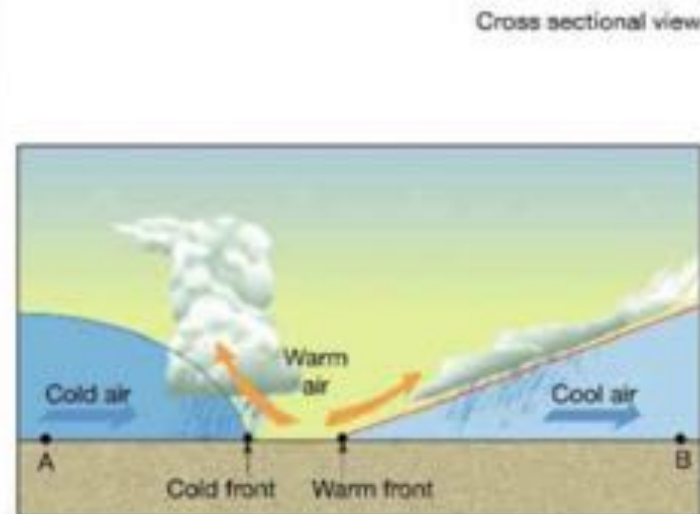
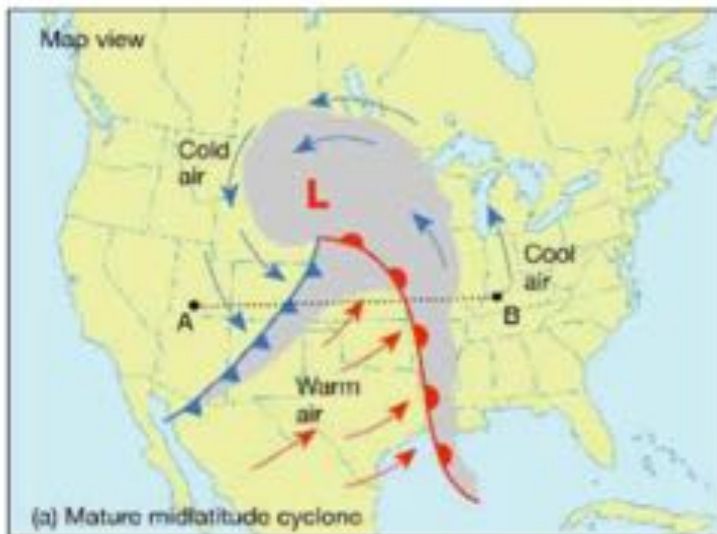
# Clouds and Circulation: Extratropics

## Clouds in frontal systems

IR

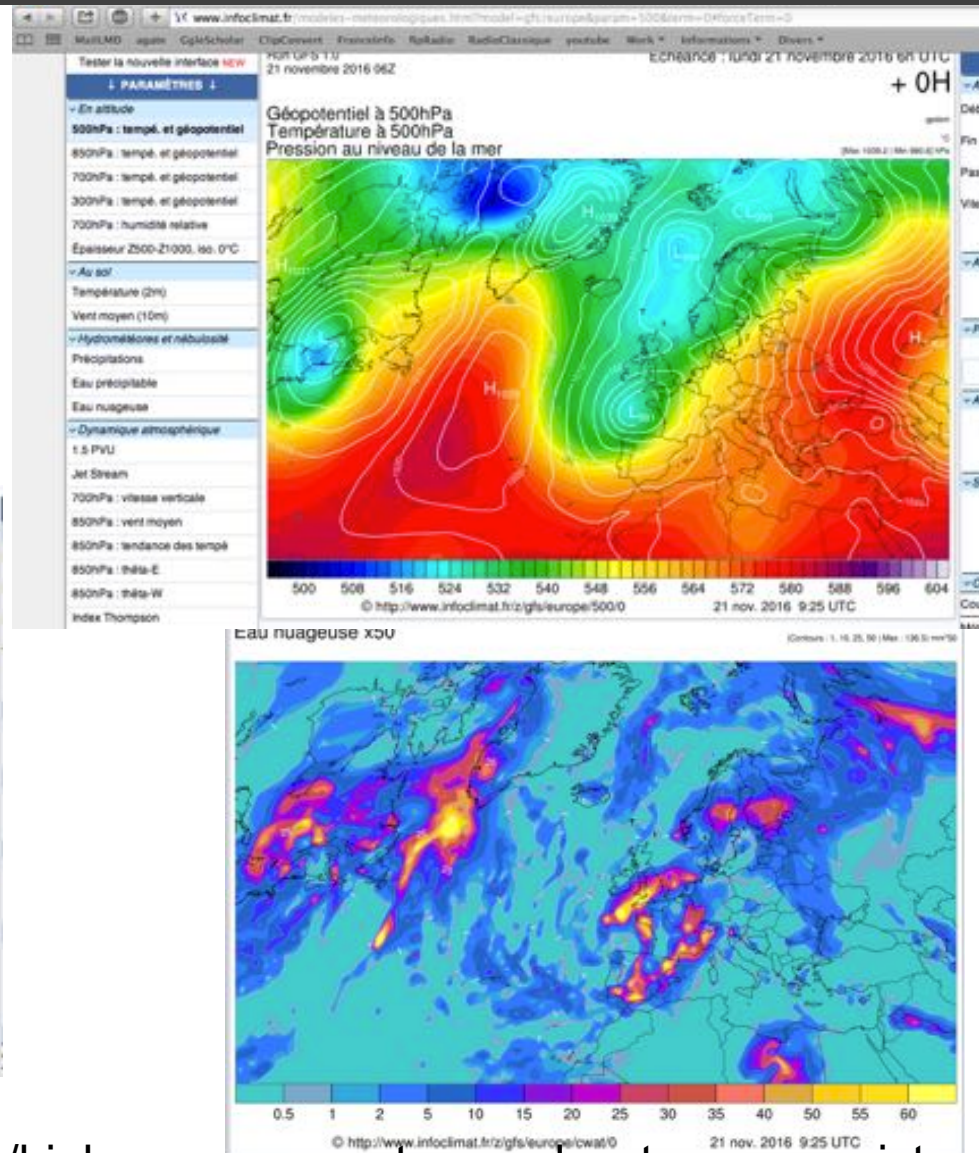
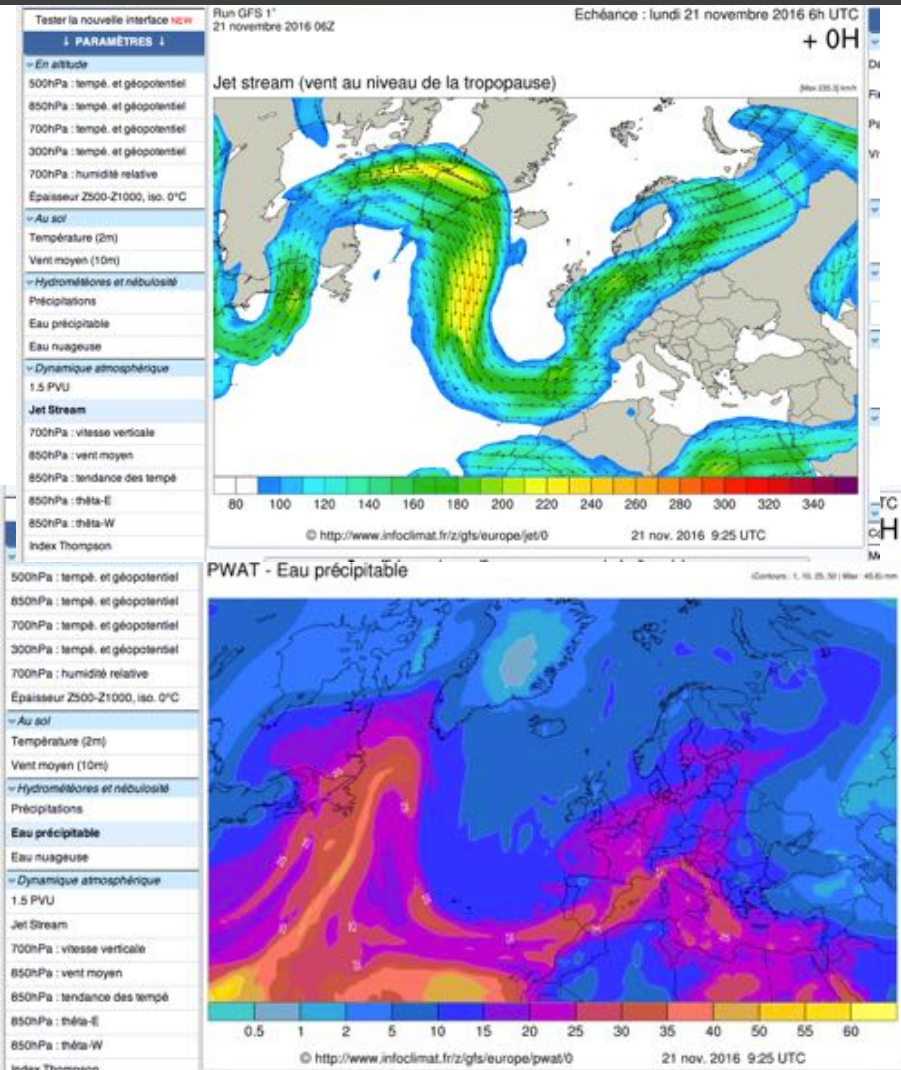


Corresponding T field  
Clouds are clearly linked to the dynamics of frontal systems





# 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

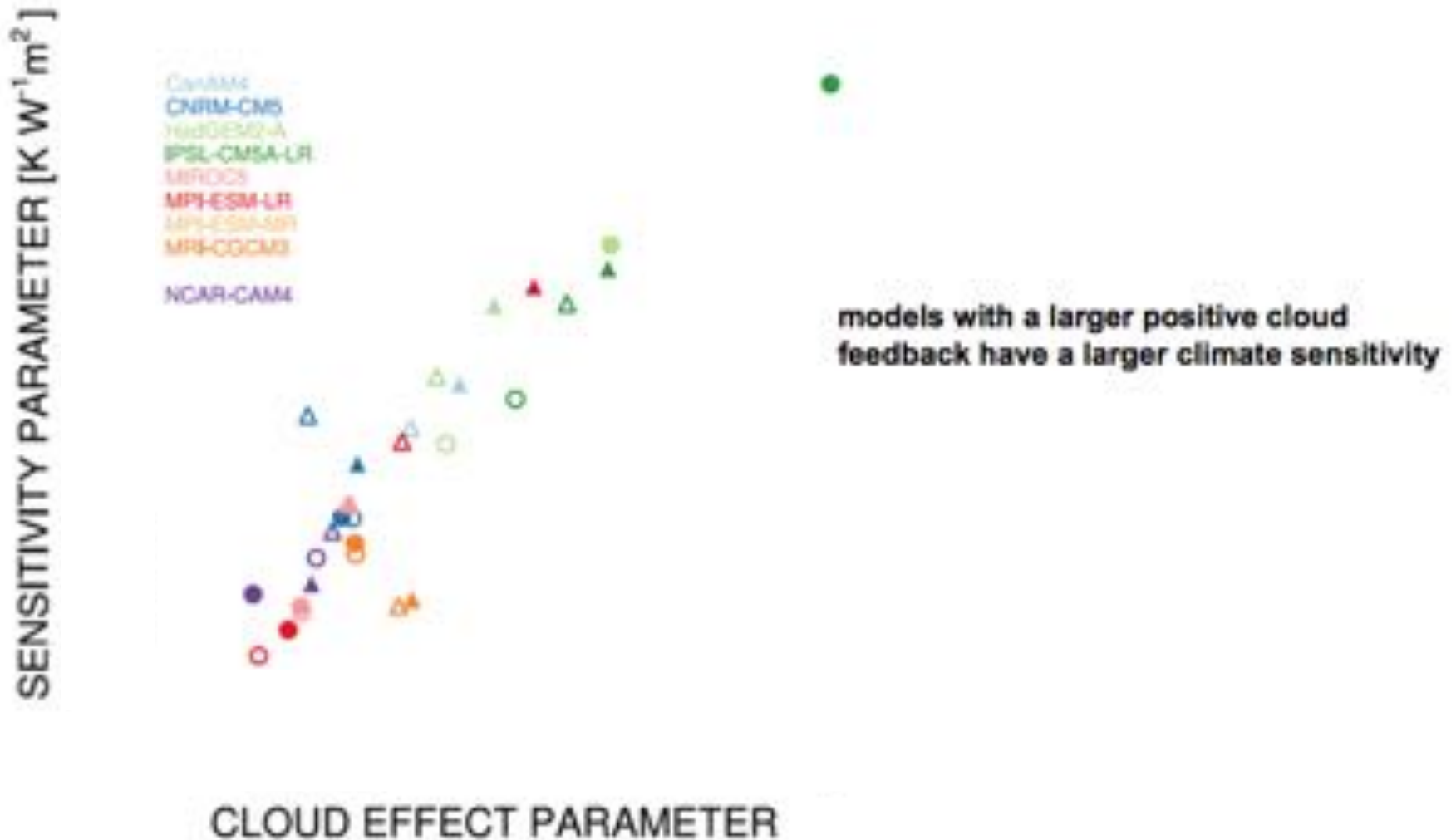
1. Clouds distribution
2. Coupling with circulation
- 3. Role in climate**



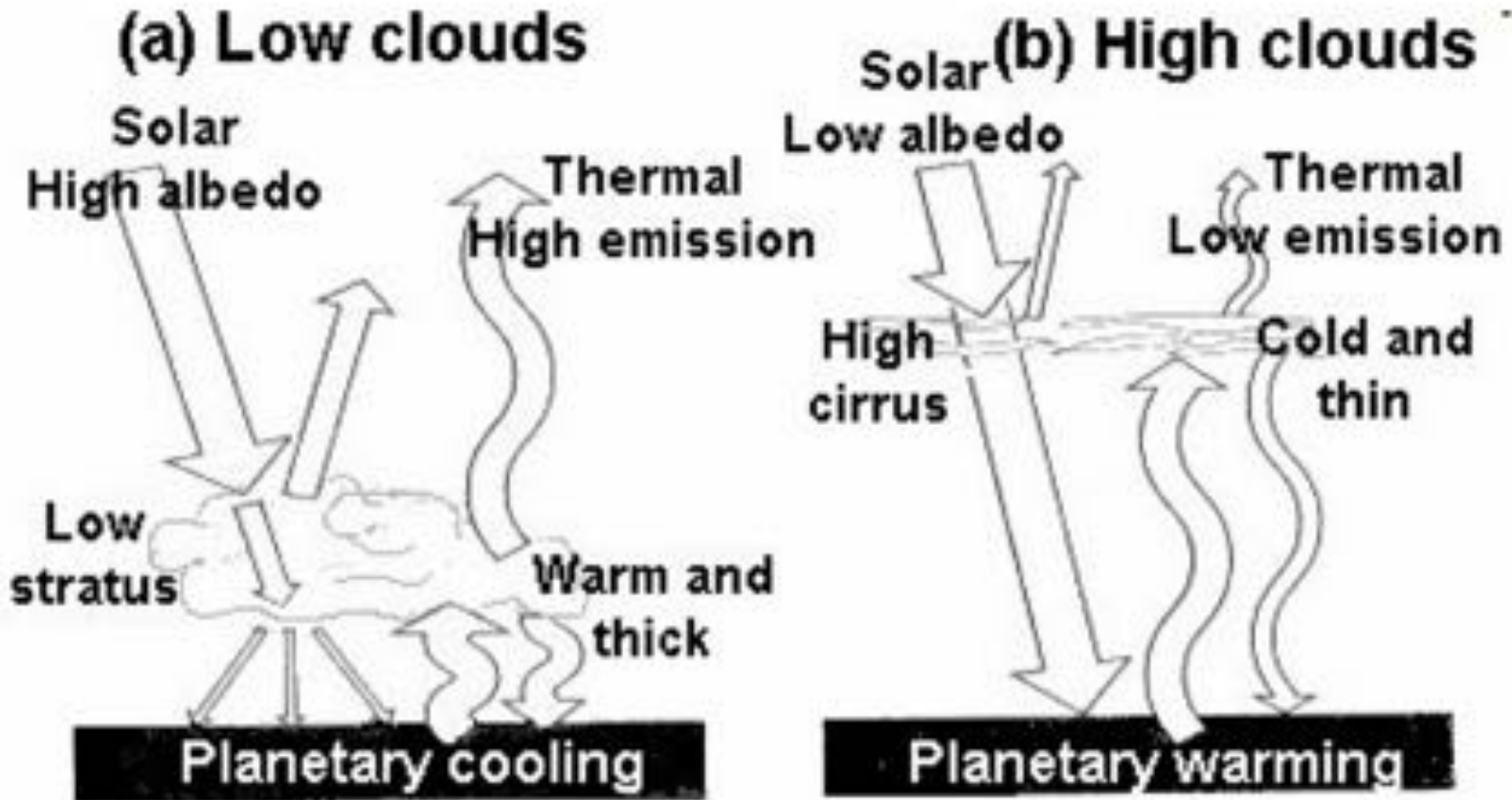
# Climate sensitivity

**Climate sensitivity:** equilibrium change in global mean surface temperature  $\Delta T_s$  when atmospheric  $\text{CO}_2$  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 ( $\sim\sigma T^4$ ,  $T\sim T_{sfc}$ )

**Strong SW cooling**

More high clouds:

**Strong LW warming** ( $\sim\sigma T^4$ ,  $T\ll T_{sfc}$ )

Little SW effect

# Clouds and radiation

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

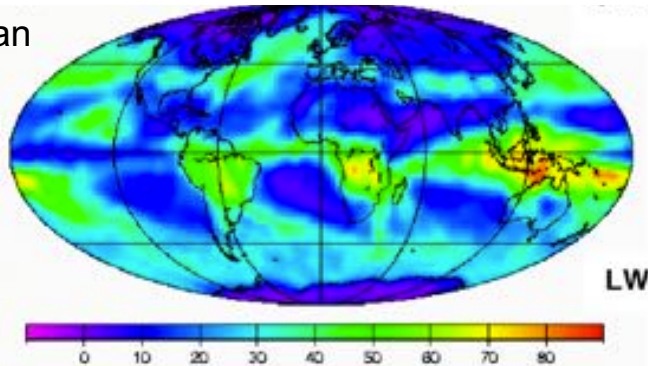
Difference between all- and clear-sky flux ( $> 0 \Leftrightarrow$  warming):

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

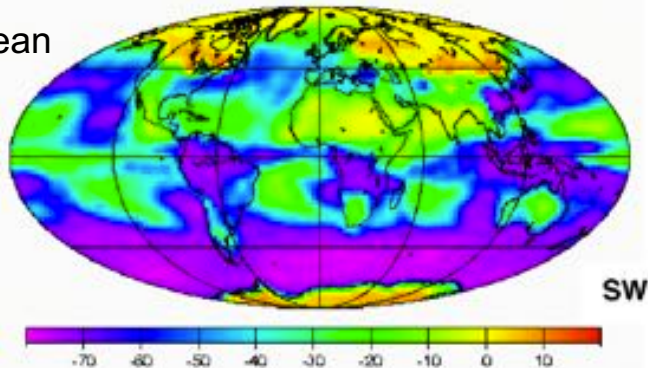
$LW_{in}$  all sky  $- LW_{in}$  clear sky ( $> 0$  due to high clouds warming)

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

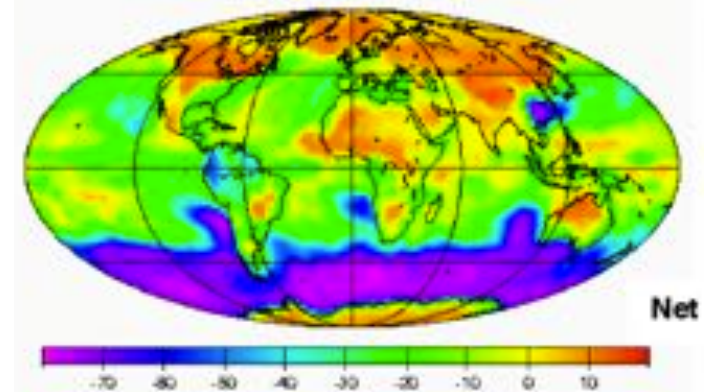
LW (annual mean  
 $\sim + 30W/m^2$ )



SW (annual mean  
 $\sim - 50W/m^2$ )



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



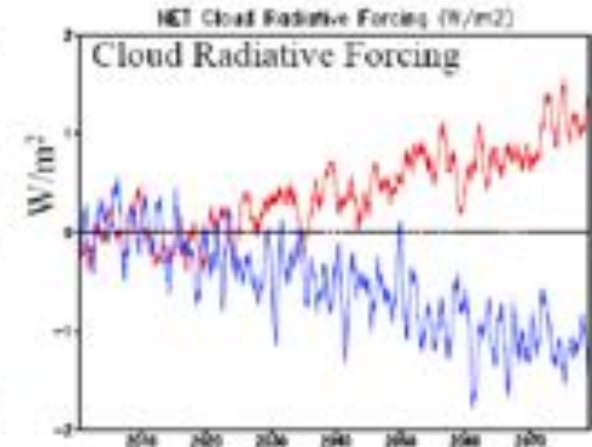
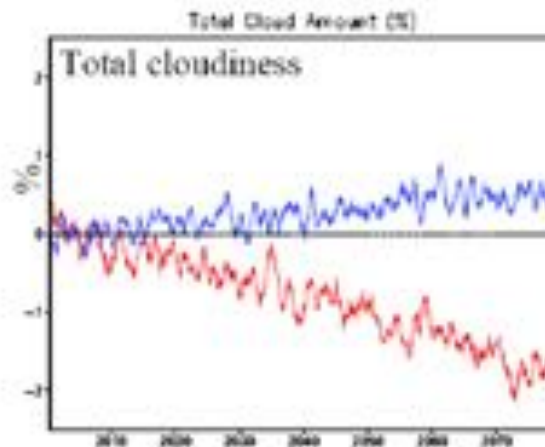
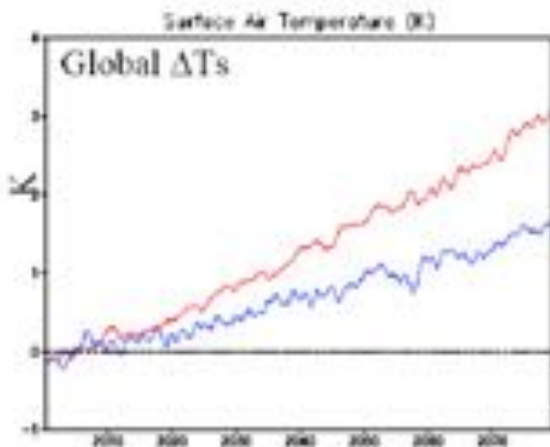
# Clouds and radiation

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

$$\text{Net CRF} = \text{LW CRF} + \text{SW CRF} \begin{cases} < 0 : \text{clouds oppose warming} \\ > 0 : \text{clouds strengthen warming} \end{cases}$$

How will clouds respond to increased  $\text{CO}_2$  ?  
How will that feed back on climate ?

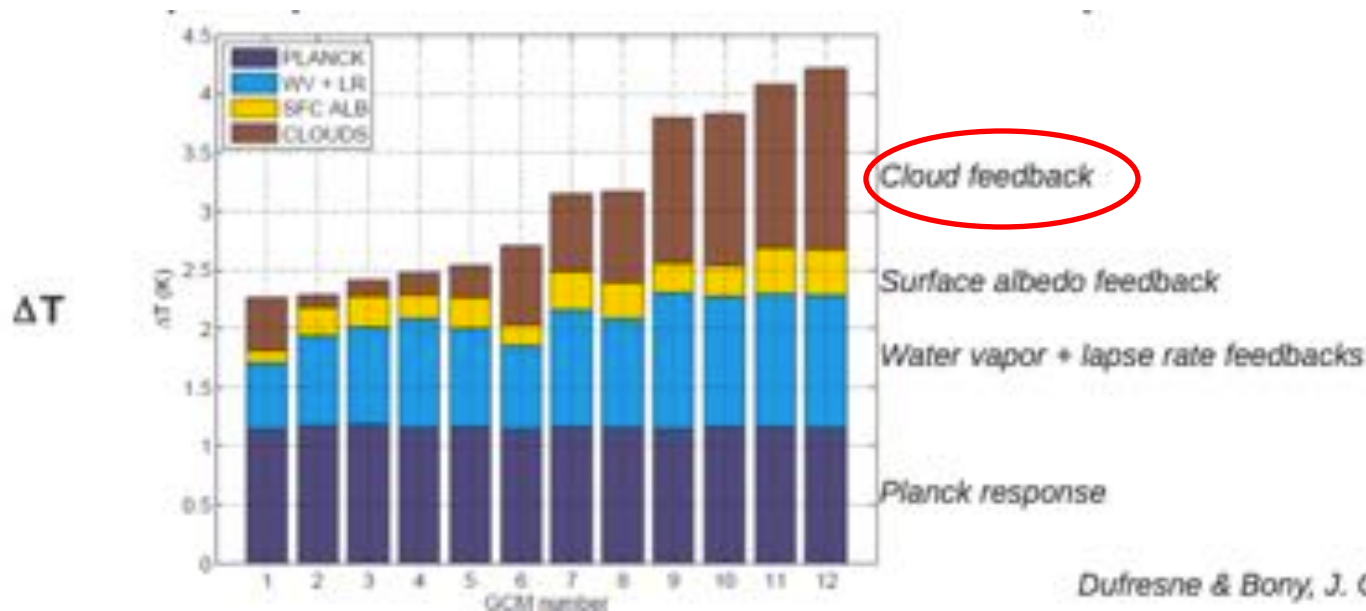
Results from 2 different climate models (+ 1%  $\text{CO}_2/\text{yr}$ ) **MIROC** and **NCAR**



# Quantifying Climate Feedbacks

We have methods to quantify various contributions to climate sensitivity

Helps interpret inter-model differences in climate sensitivity :

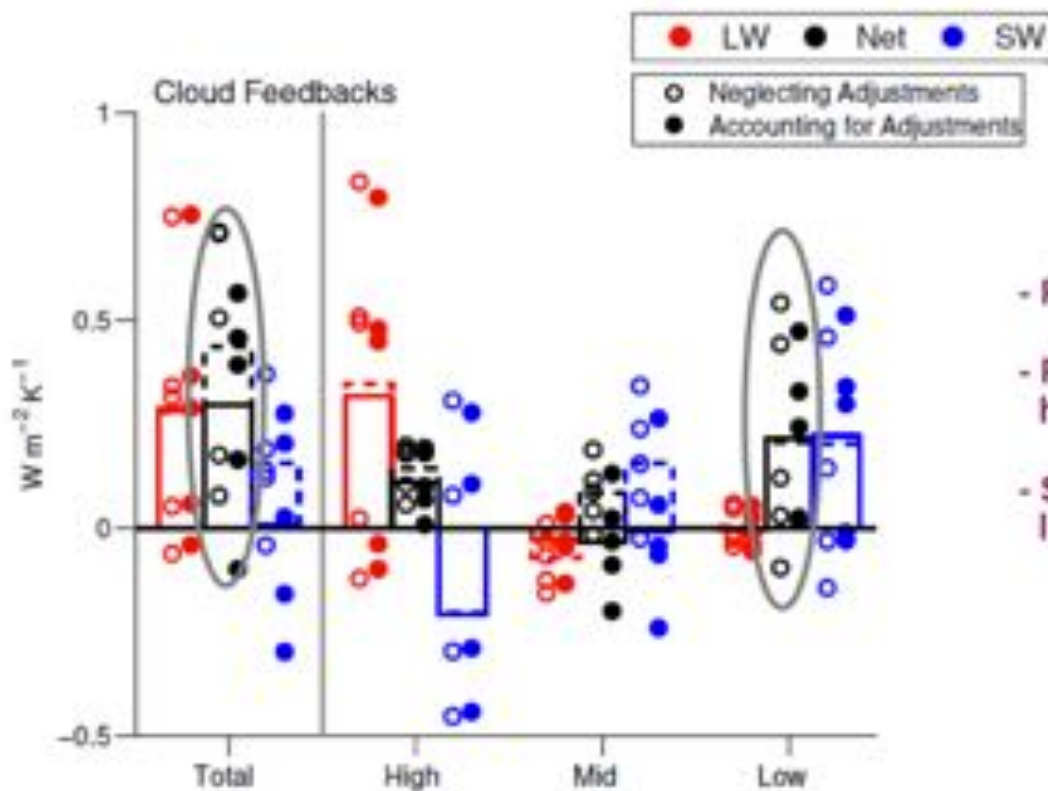




# Cloud Feedback Processes

How do the different cloud types contribute to global cloud feedbacks ?  
=> **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

# 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

A photograph of a single water droplet suspended in mid-air above a splash of water. The background is a soft, light blue gradient. The text "Thank you!" is overlaid in white on the blue background.

Thank you!

*Caroline Muller*  
CNRS, Laboratoire de Météorologie Dynamique  
Ecole Normale Supérieure Paris







