Clouds and turbulent moist convection

Caroline Muller
Laboratoire de Météorologie Dynamique
Ecole Normale Supérieure

Lectures Outline :

Cloud fundamentals - global distribution, types, visualization and link with large scale circulation

Cloud Formation and Physics - thermodynamics, cloud formation, instability

Organization of deep convection at mesoscales - MCSs, MCCs, Squall lines, Tropical cyclones, Processes, Self-aggregation

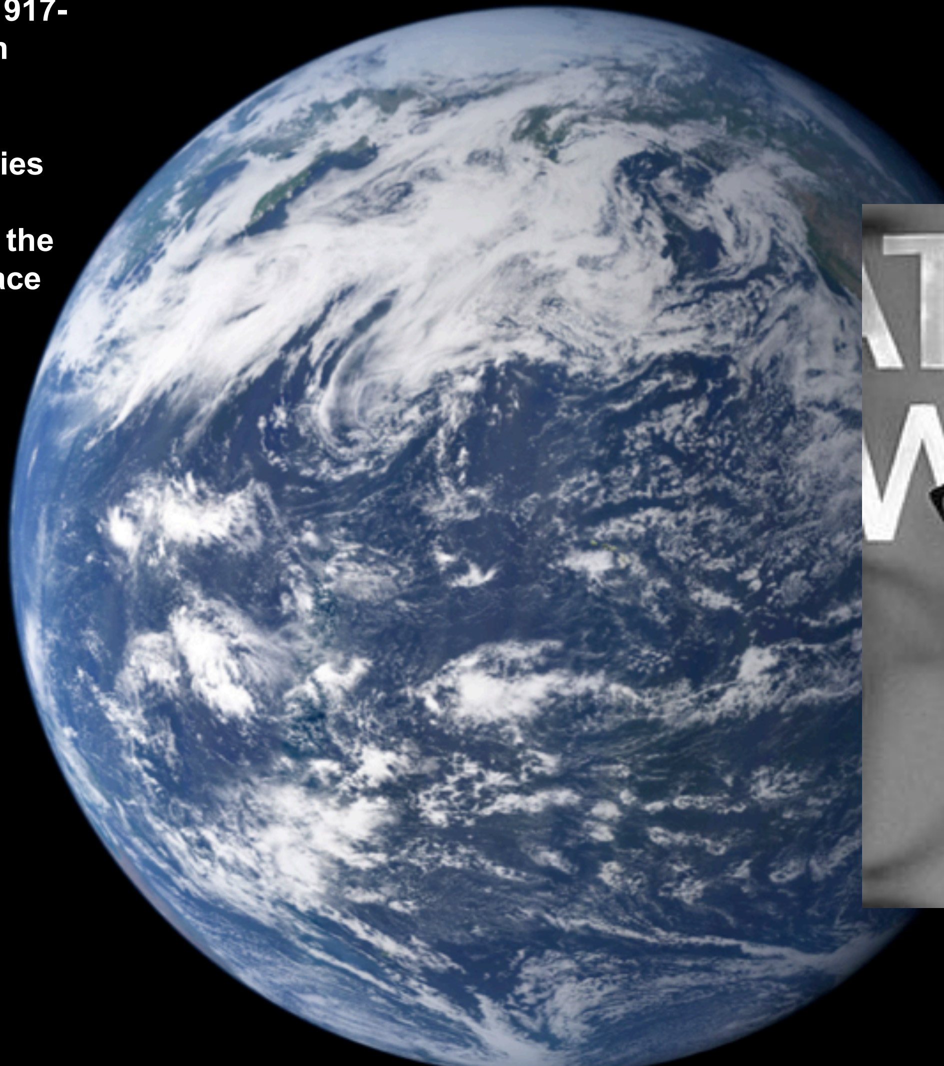
Response of the hydrological cycle to climate change - mean precip, precip extremes

Clouds in a changing climate – climate sensitivity, cloud effect, cloud feedback, FAT

What are clouds ?

Clouds and turbulent moist convection

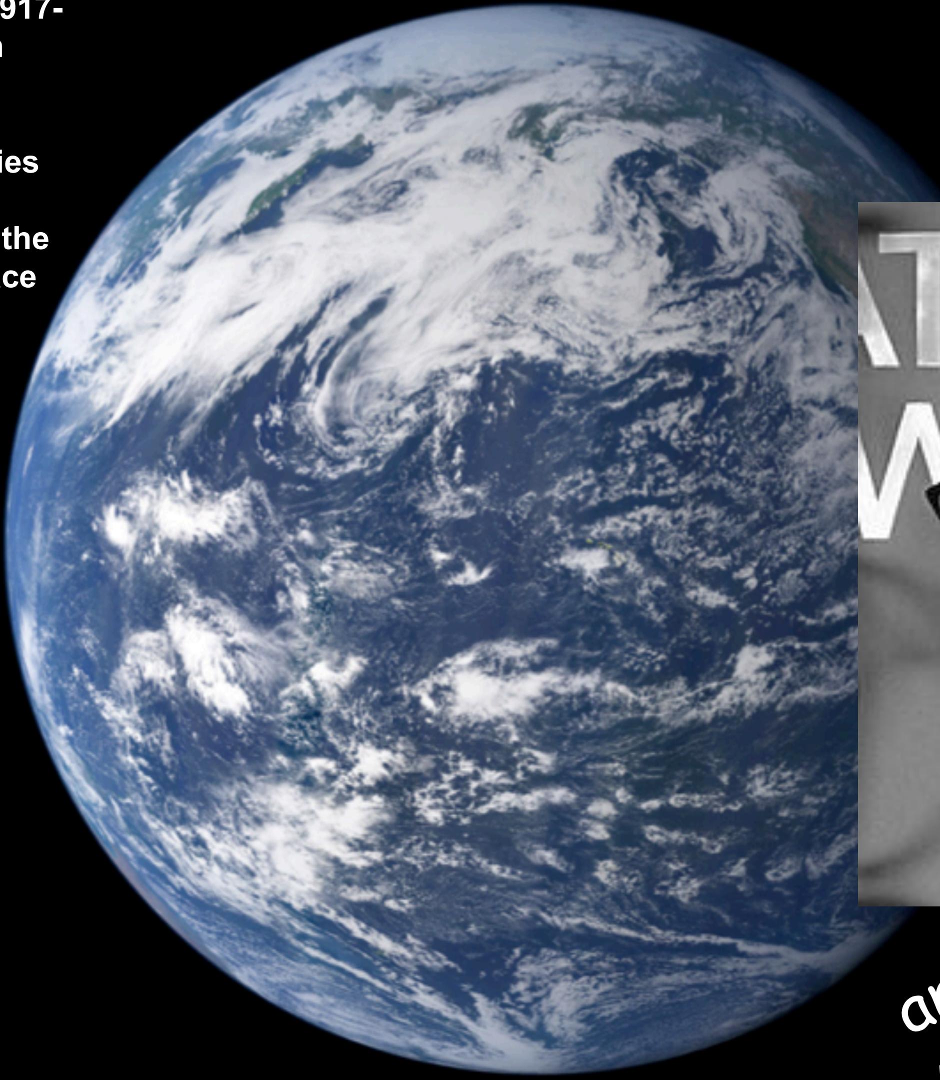
Sir Arthur Charles Clarke (1917-2008) British science fiction writer, science writer and futurist, inventor, undersea explorer amd television series host.
Most famous for co-writing the screenplay of « 2001: A Space Odyssey »



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

Clouds and turbulent moist convection

Sir Arthur Charles Clarke (1917-2008) British science fiction writer, science writer and futurist, inventor, undersea explorer amd television series host.
Most famous for co-writing the screenplay of « 2001: A Space Odyssey »

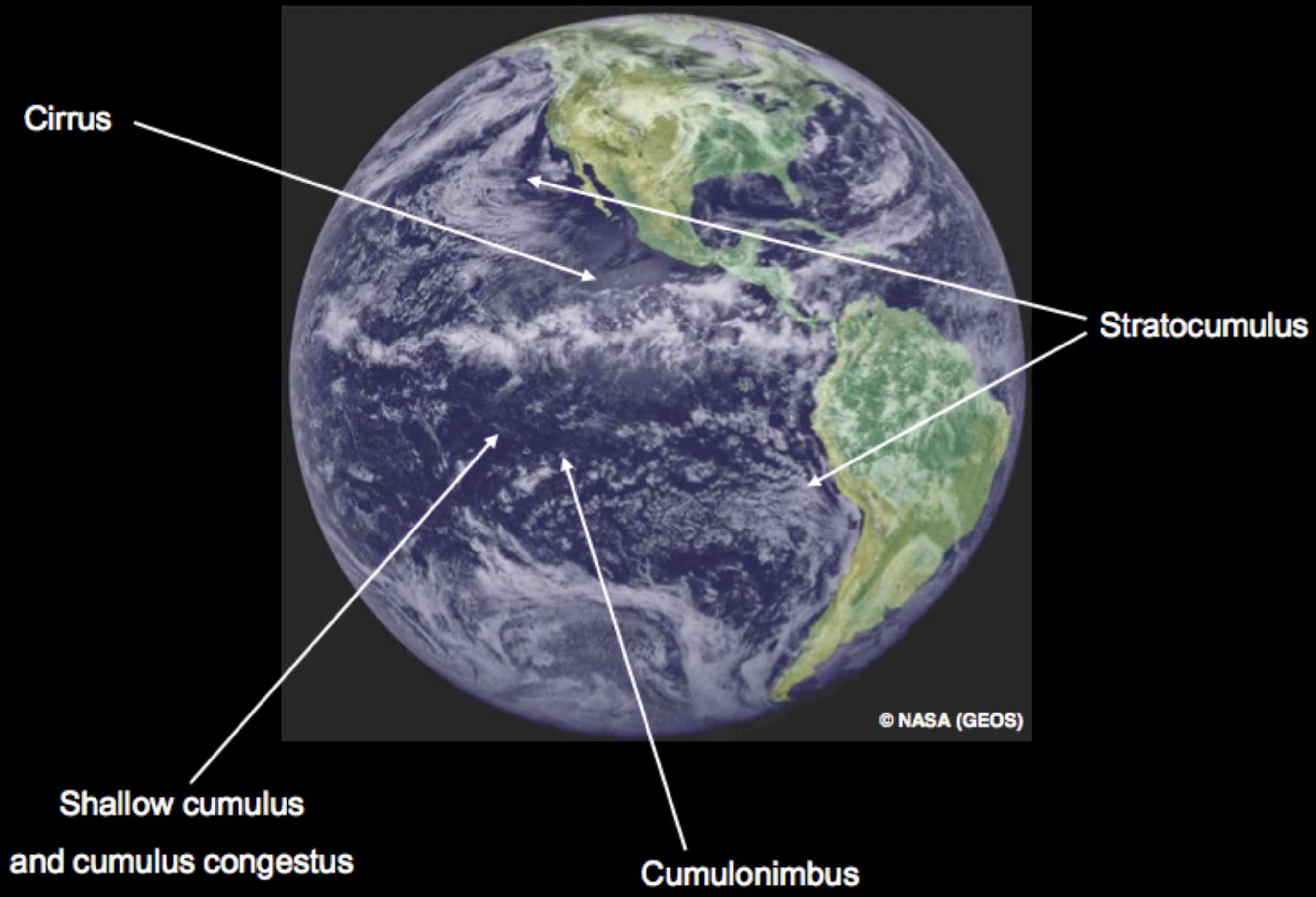


and clouds

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

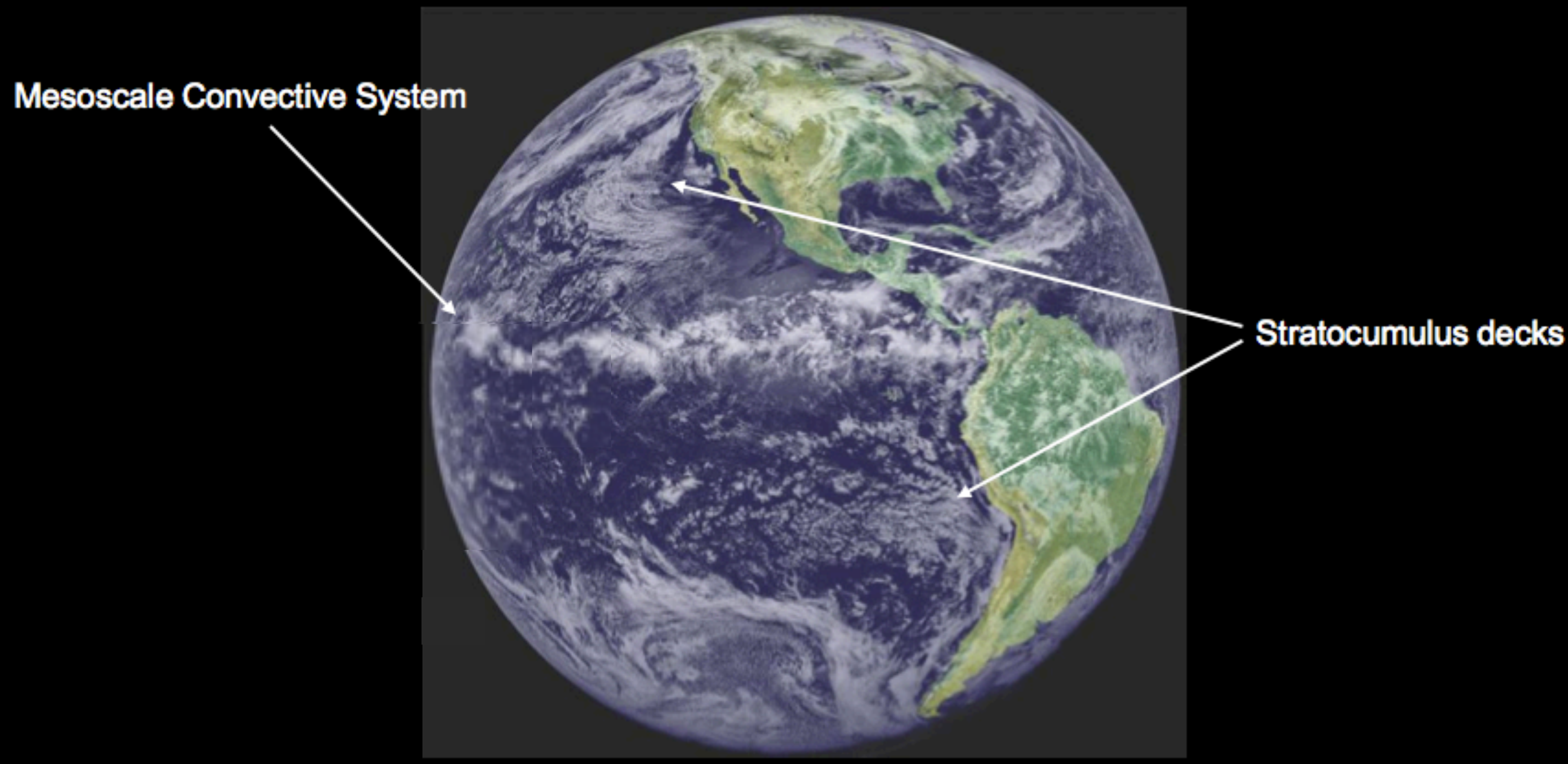
Clouds

Tropical and subtropical clouds are diverse, ...



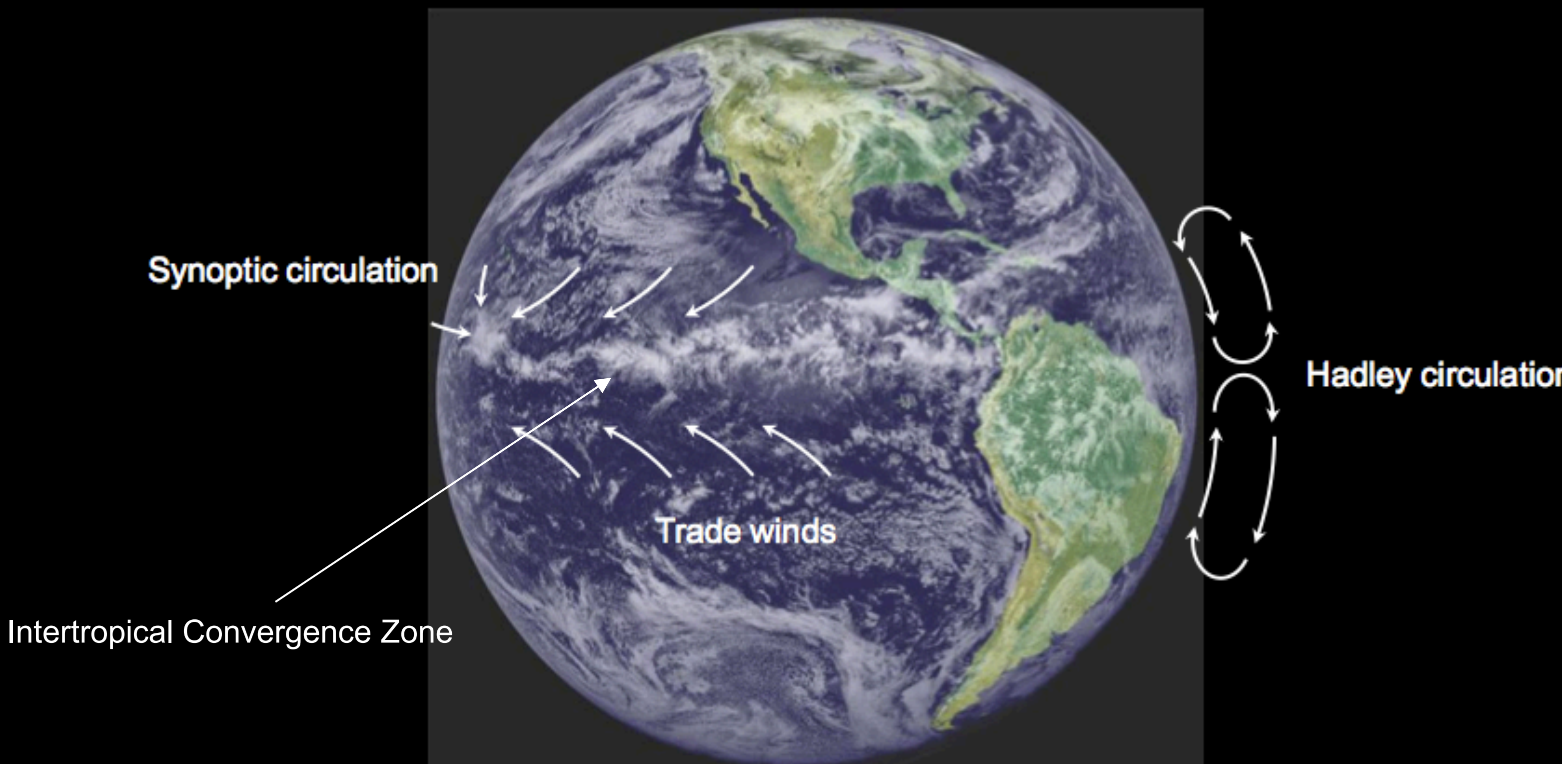
Clouds

… often spatially organized, …

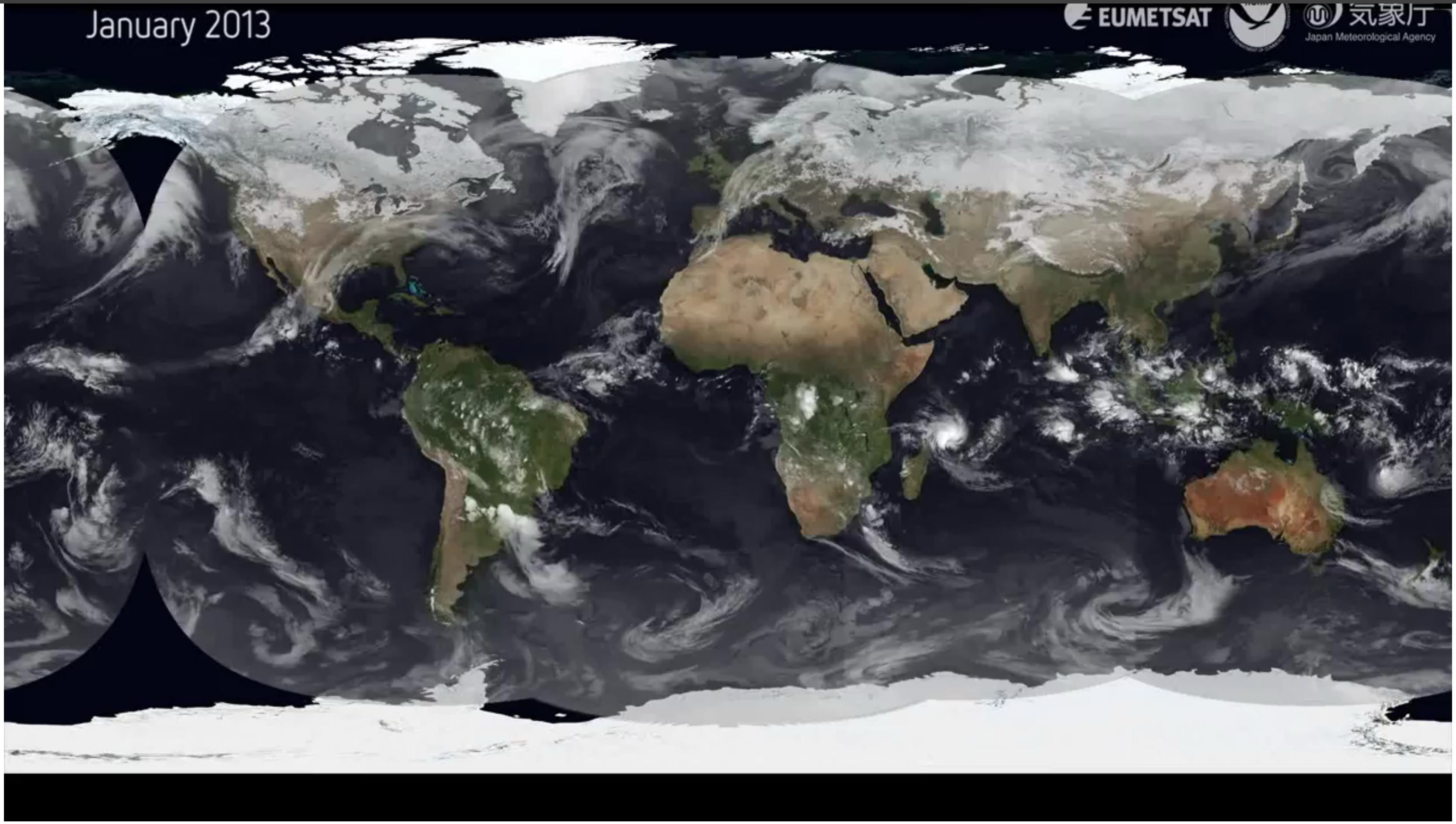


Clouds

… and coupled to circulations.



Distribution of clouds ?

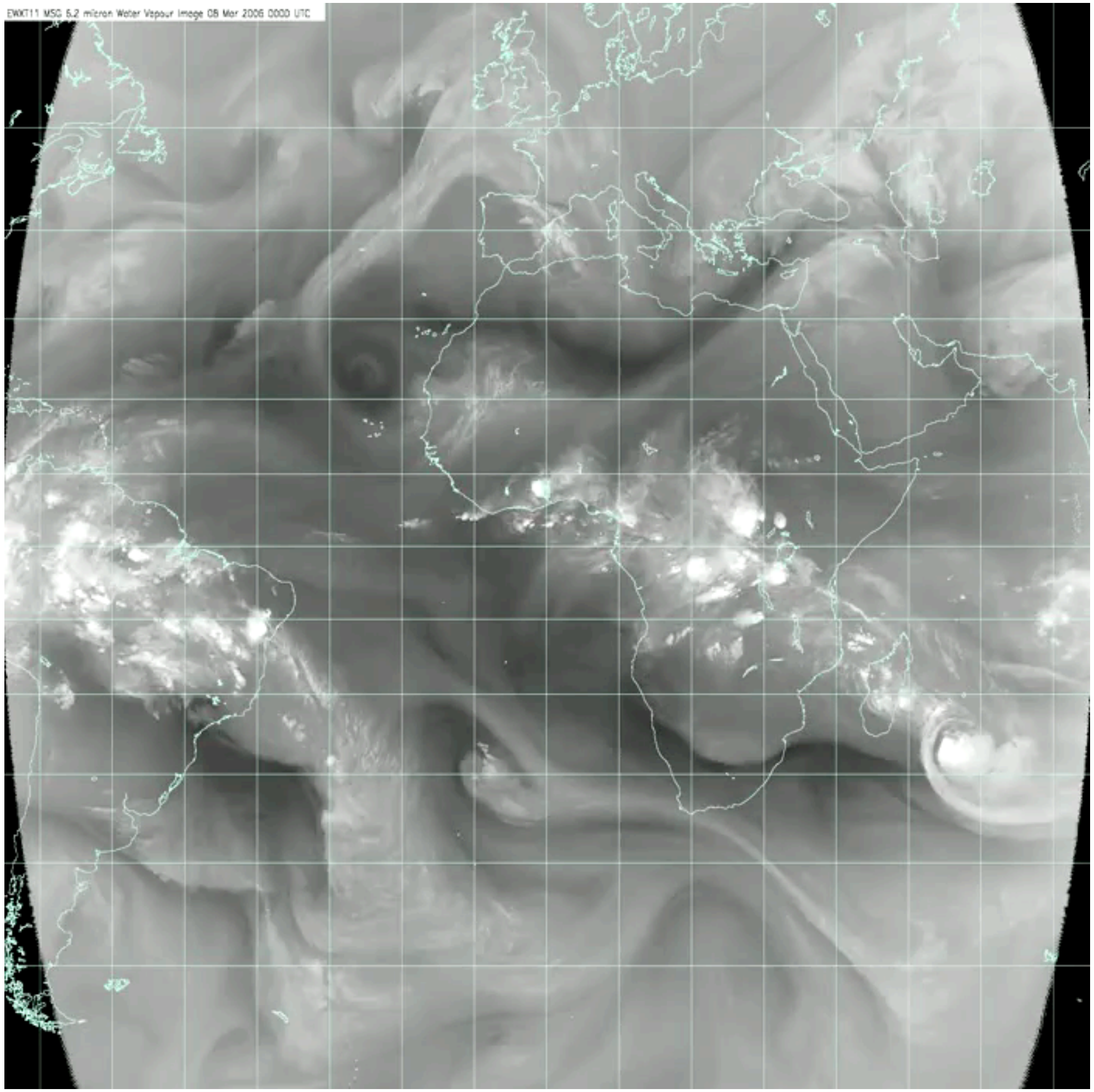


A Year of Weather 2015

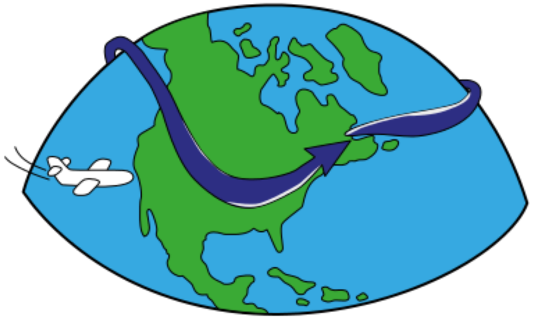
This visualisation, comprised of imagery from the geostationary satellites of EUMETSAT, NOAA and the JMA, shows an entire year of weather The satellite data layer is superimposed over NASA's 'Blue Marble Next Generation' ground maps, which change with the seasons.

=> Different characteristics at low and high latitudes

atmospheric water vapor (white=humid)



Low latitudes => convective « pop-corn » convection



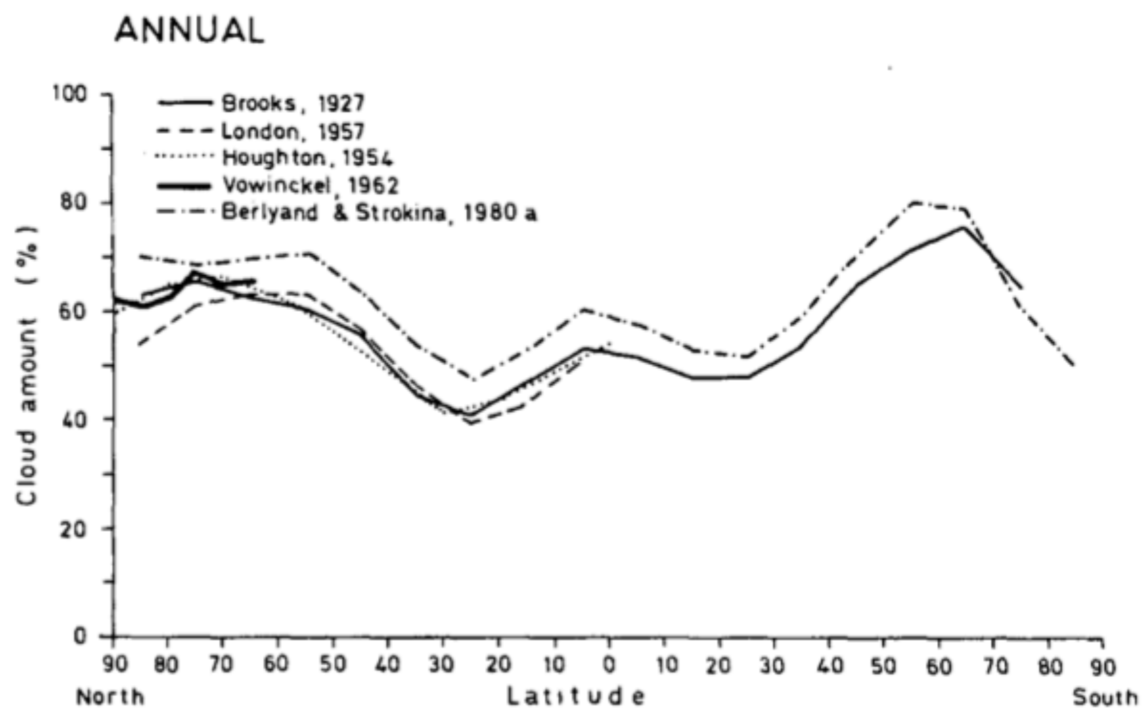
courant-jet polaire

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

NASA

Clouds and turbulent moist convection

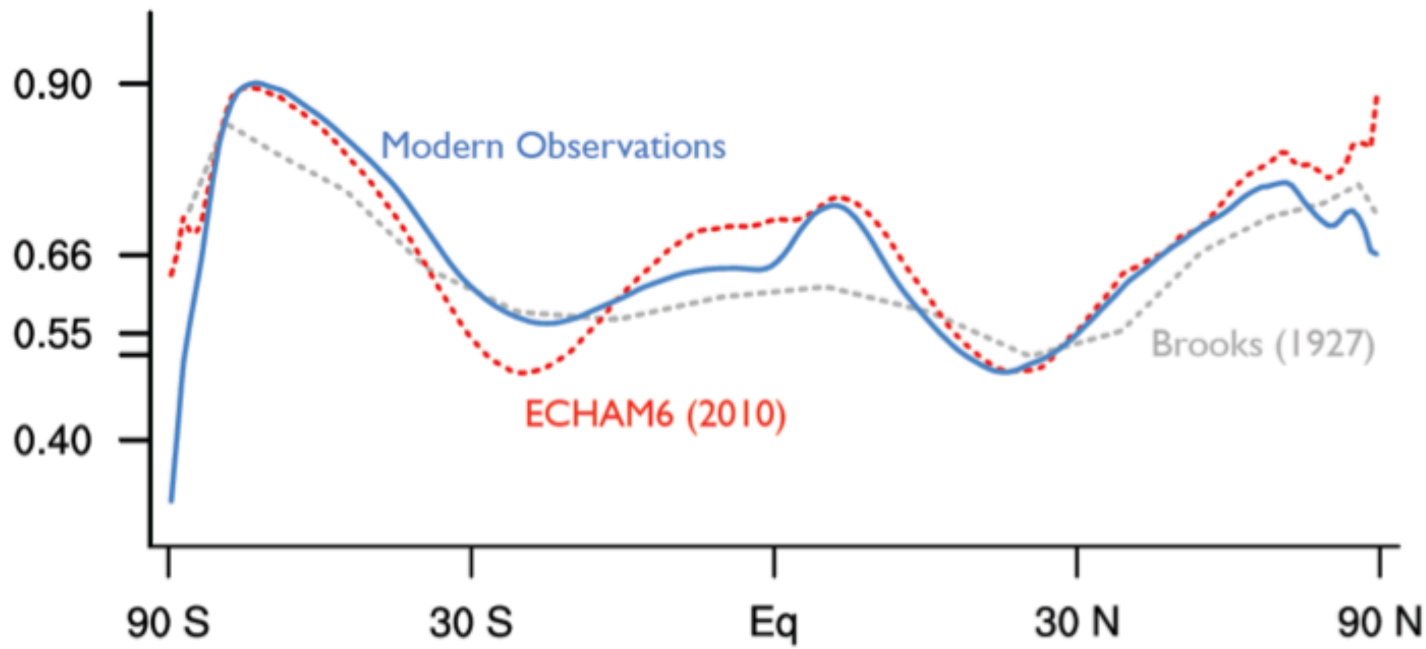
Distribution of cloud amount



[Hughes 84]

Clouds and turbulent moist convection

Cloud amount was underestimated



Courtesy Bjorn Stevens

Clouds and climate

An era of blooming cloud and climate science

BBC | Sign in | News | Sport | Weather | iPlayer

NEWS SCIENCE & ENVIRONMENT

Home | World | UK | England | N. Ireland | Scotland | Wales | Business | Politics | Health | Educa

24 August 2011 Last updated at 22:58

Share

Cloud simulator tests climate models

By Pallab Ghosh
Science correspondent, BBC News

Understanding how clouds form will help develop better climate change models

EDITION: INTERNATIONAL | U.S. | MÉXICO | ARABIC

TV: CNNI | CNN en EspaÃ±ol

Set edition preference

CNN

Home | Video | World | U.S. | Africa | Asia | Europe | Latin America | Middle East | Business

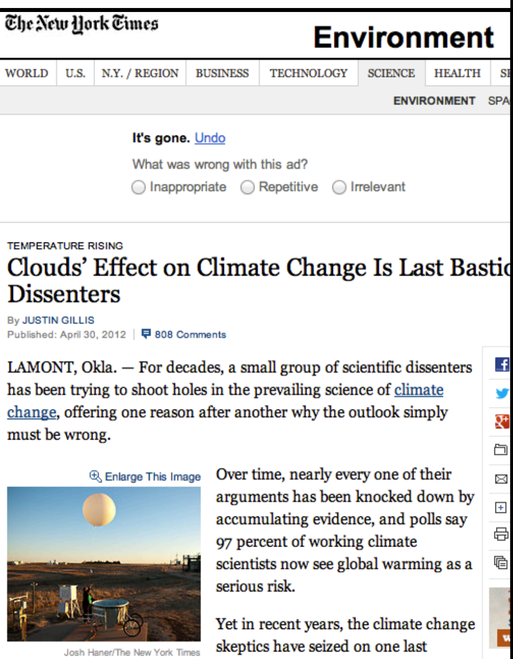
**Climate change: Can we even
Should we even try?**

By **Shelby Lin Erdman**, CNN

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

(CNN) -- The Mas
Technology has l
for its engineering
symposium at MI
scientists from ar
a hot facet of the

The title of the sy
the questions sur
science: "Enginee
We Do It? Should



The New York Times — Environment

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SI

ENVIRONMENT | SPA

It's gone. Undo
What was wrong with this ad?
Inappropriate | Repetitive | Irrelevant

TEMPERATURE RISING

**Clouds' Effect on Climate Change Is Last Bastic
Dissenters**

By JUSTIN GILLIS
Published: April 30, 2012 | 808 Comments

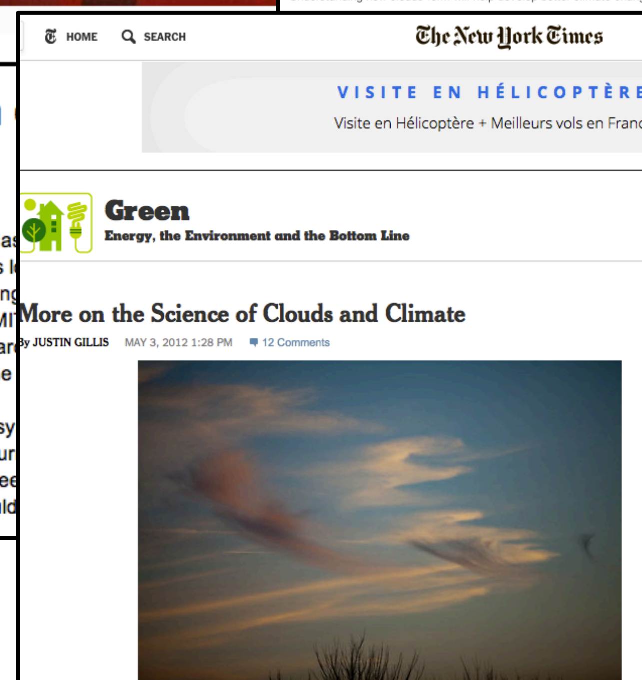
LAMONT, Okla. — For decades, a small group of scientific dissenters has been trying to shoot holes in the prevailing science of climate change, offering one reason after another why the outlook simply must be wrong.

Enlarge This Image

Josh Haner/The New York Times

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



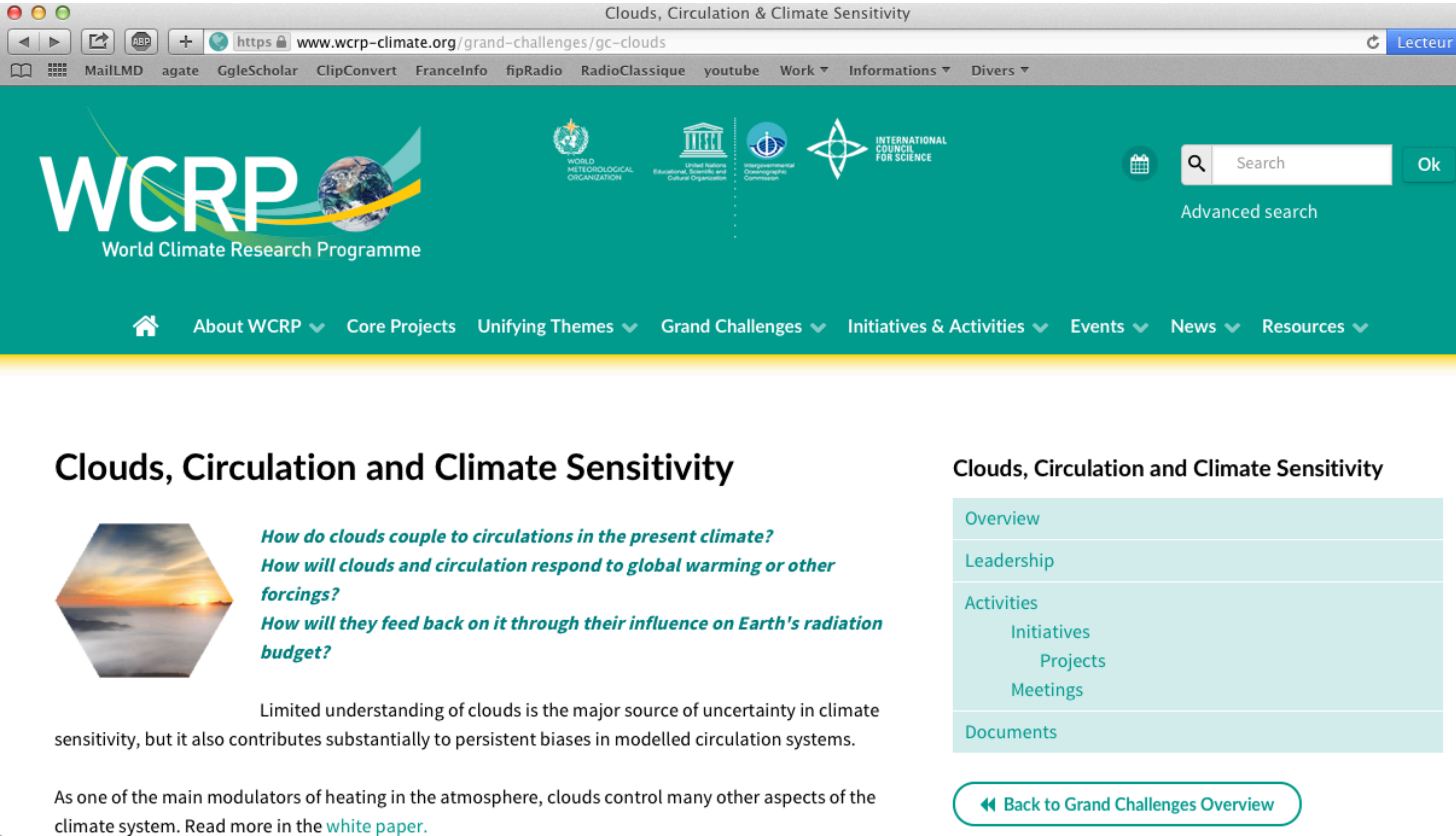
HOME | SEARCH — The New York Times

Green
Energy, the Environment and the Bottom Line

More on the Science of Clouds and Climate

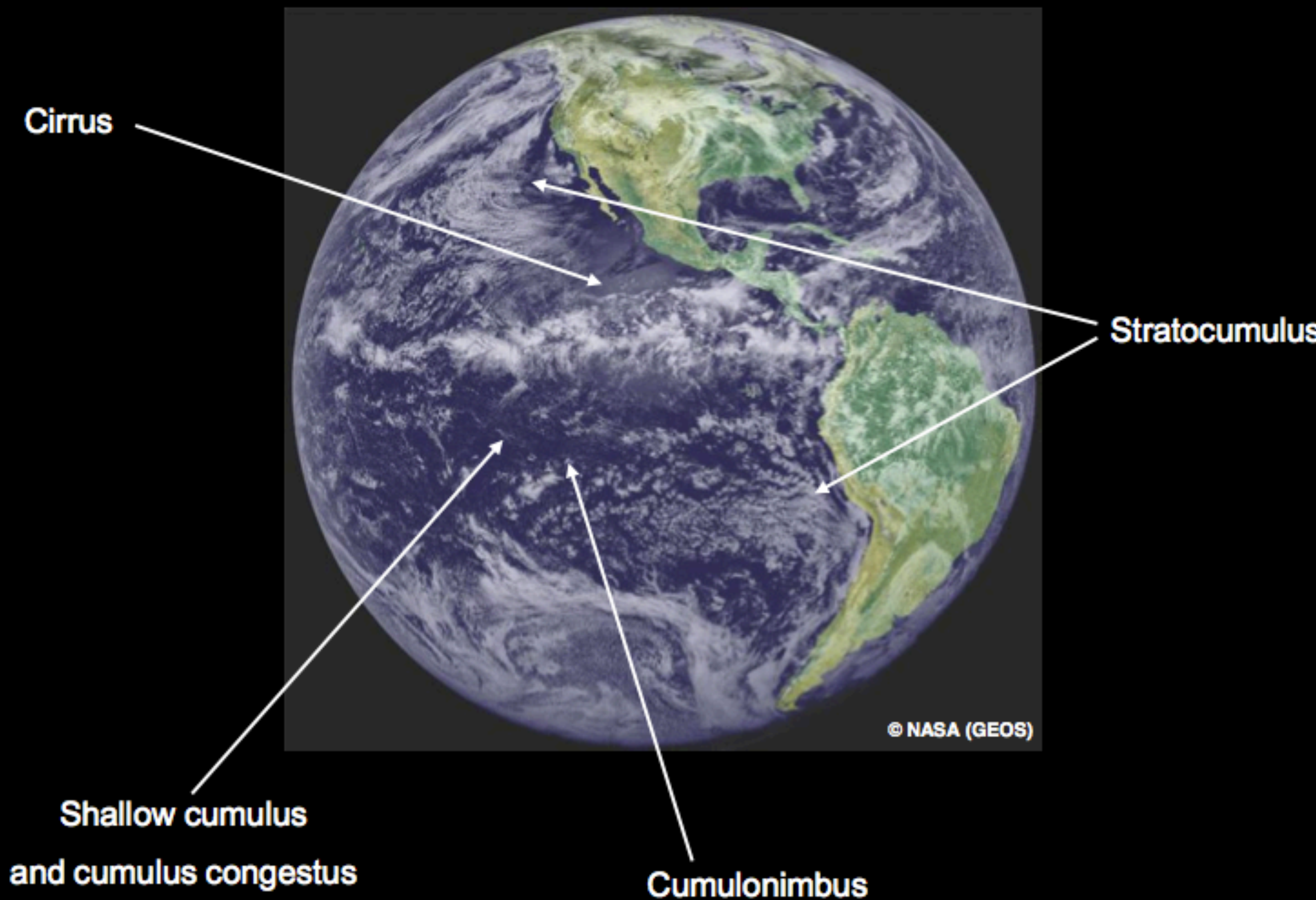
By JUSTIN GILLIS | MAY 3, 2012 1:28 PM | 12 Comments

Clouds : a Grand Challenge



Clouds

Tropical and subtropical clouds are diverse, ...



Cloud types

Cumulus: heap, pile

Stratus: flatten out, cover with a layer

Cirrus: lock of hair, tuft of horsehair

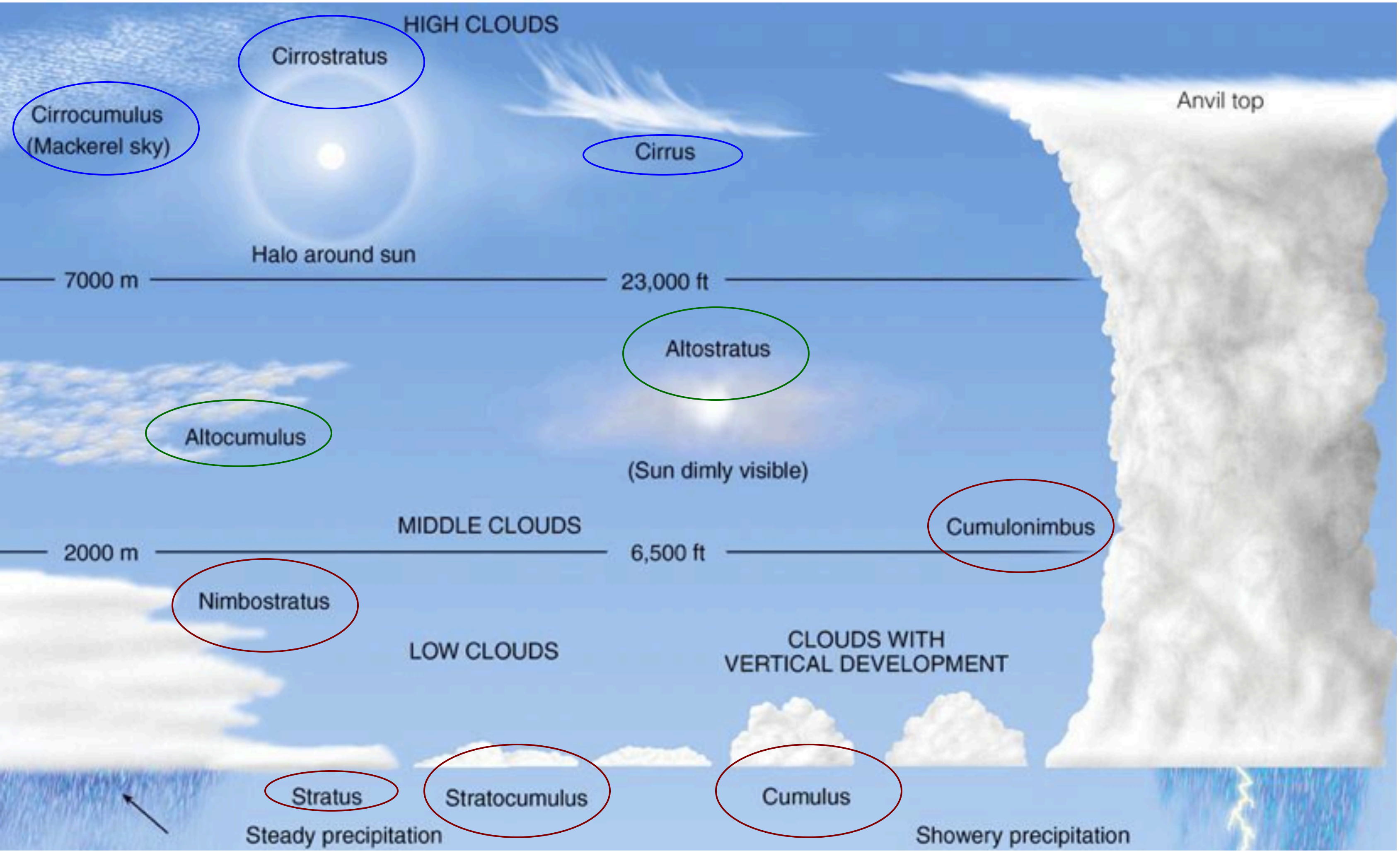
Nimbus: precipitating cloud

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, including supercooled droplets (i.e., liquid droplets whose temperatures are below freezing).

Altostratus

Flat and uniform type texture in mid levels

Altocumulus

Heap-like clouds with convective elements in mid levels
May align in rows or streets of clouds

Low Clouds

Liquid water droplets or even supercooled droplets, except during cold winter storms when ice crystals (and snow) comprise much of the clouds.
The two main types include **stratus**, which develop horizontally, and **cumulus**, which develop vertically.

Stratocumulus

Hybrids of layered stratus and cellular cumulus

Stratus

Uniform and flat, producing a gray layer of cloud cover

Nimbostratus

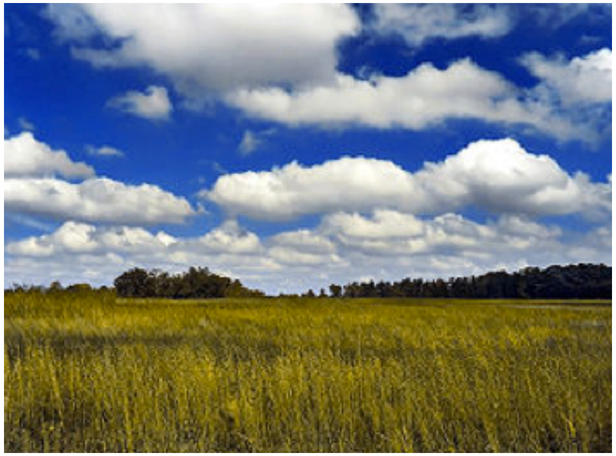
Thick, dense stratus or stratocumulus clouds producing steady rain or snow

Low Clouds

Liquid water droplets or even supercooled droplets, except during cold winter storms when ice crystals (and snow) comprise much of the clouds.
The two main types include **stratus**, which develop horizontally, and **cumulus**, which develop vertically.

Cumulus (humili)

Scattered, with little vertical growth on an otherwise sunny day
Also called "fair weather cumulus"



Cumulus (congestus)

Significant vertical development (but not yet a thunderstorm)

Cumulonimbus

Strong updrafts can develop in the cumulus cloud => mature, deep cumulonimbus cloud, i.e., a thunderstorm producing heavy rain.

High Clouds

High Clouds

Cirrostratus

Cirrus

Cirrocumulus

Middle Clouds

Middle Clouds

Altocumulus

Altostratus

Low Clouds

Low Clouds

Stratocumulus

Cumulonimbus

Stratus

Cumulus

Nimbostratus

Other spectacular Clouds…

Mammatus clouds (typically below anvil clouds)

Shelf clouds (gust front)

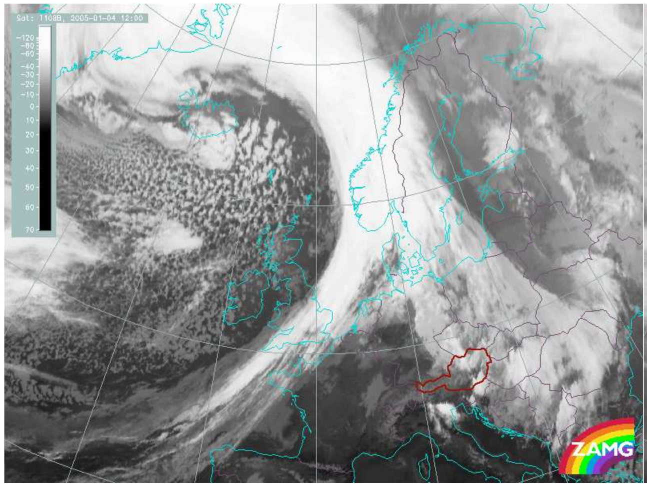
Lenticular clouds (over orography)

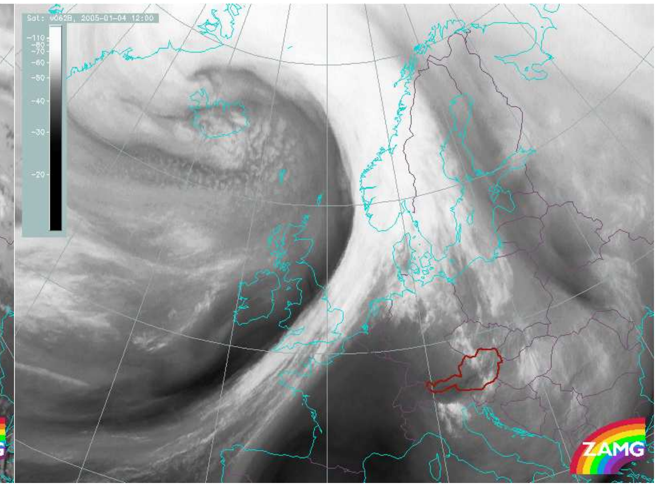
Other spectacular Clouds…

Cloud visualization from space

IR

Info on temperature => indicates high-level clouds and deep clouds



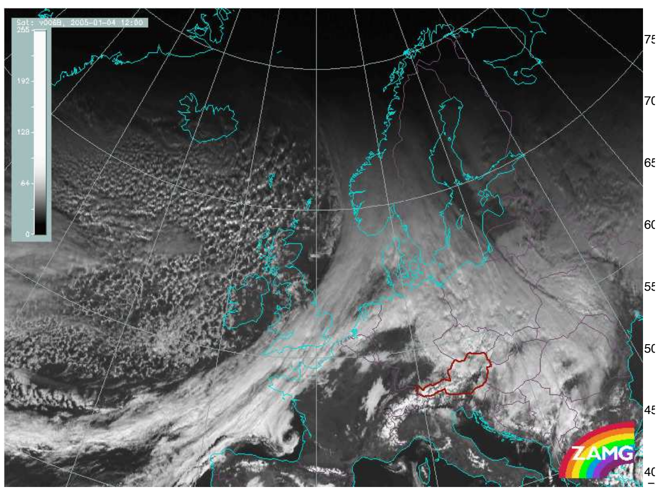


WV

Info on flow and water vapor advection. Smooth field

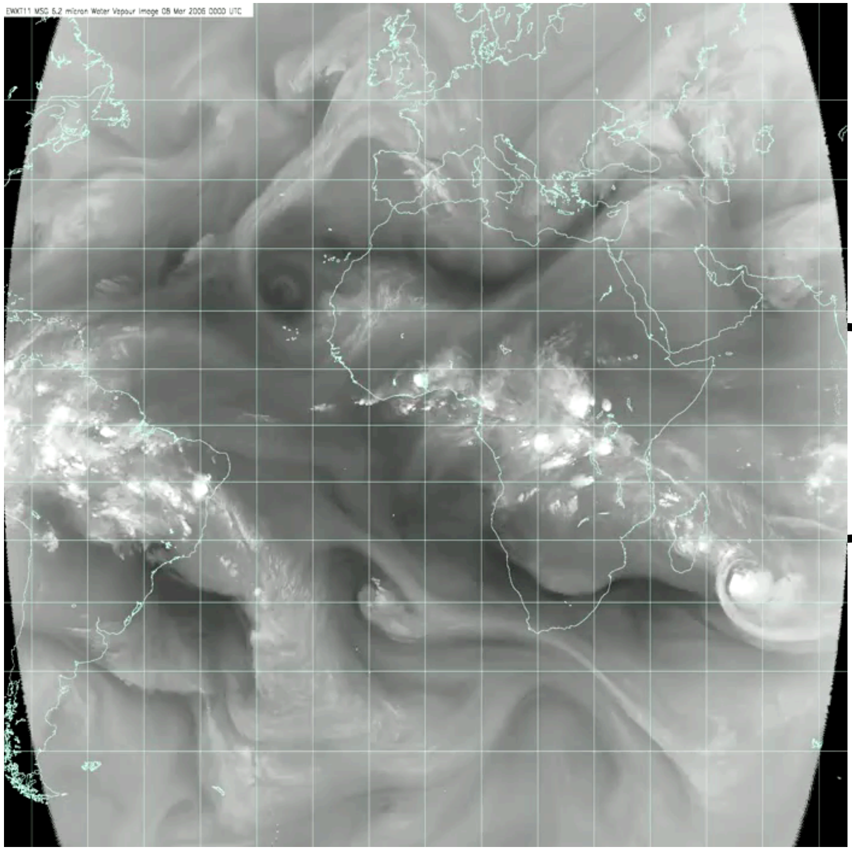
VIS

Info on clouds, low and high, thick enough to impact visible light. Partial coverage



Cloud types

Water vapor from satellite

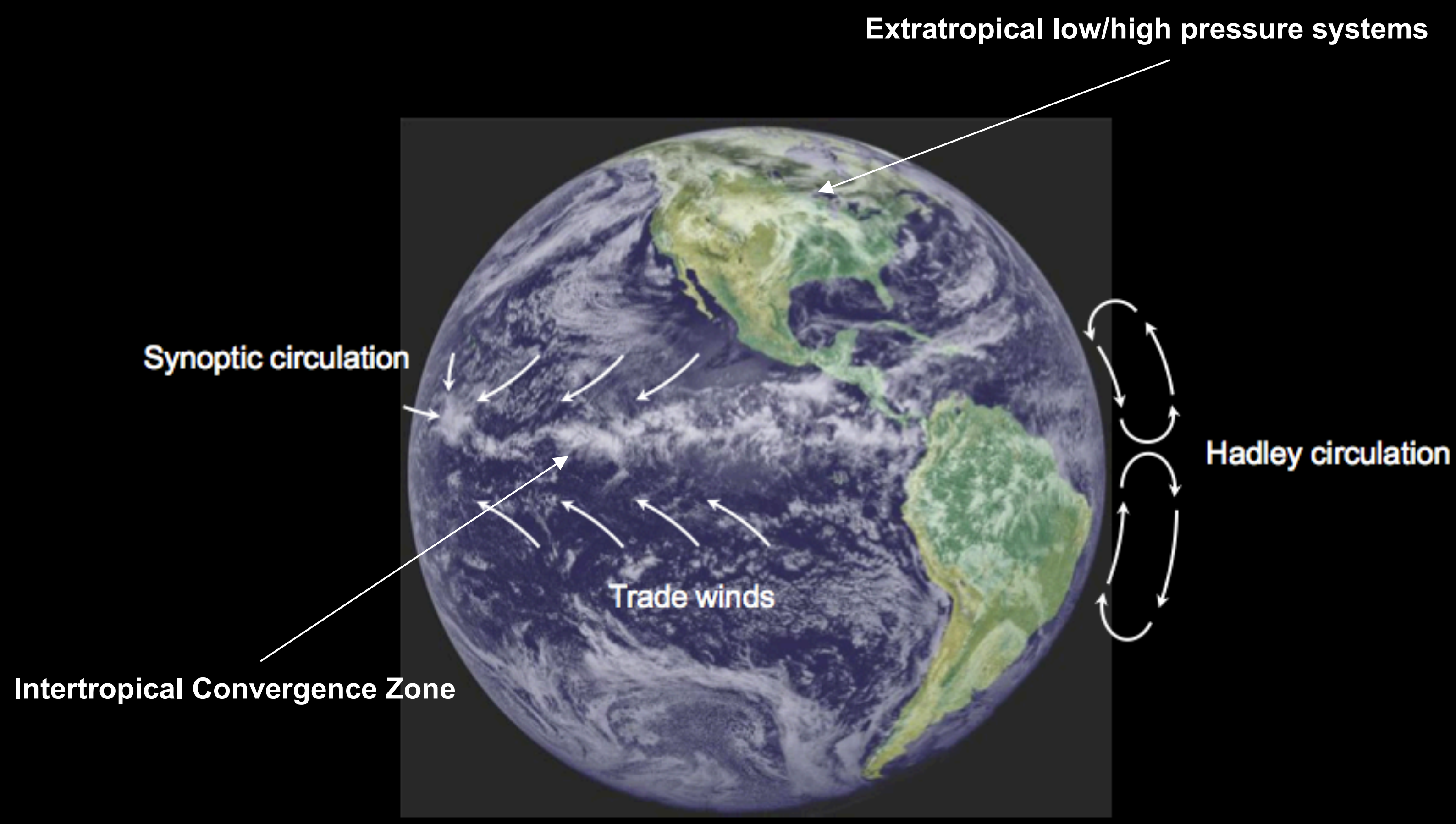


Larger-scale extratropical convection

Small-scale tropical convection

Deep convective system over Brazil

Clouds are coupled with circulation



Planetary scale : ITCZ, Hadley, Walker (ENSO), monsoon

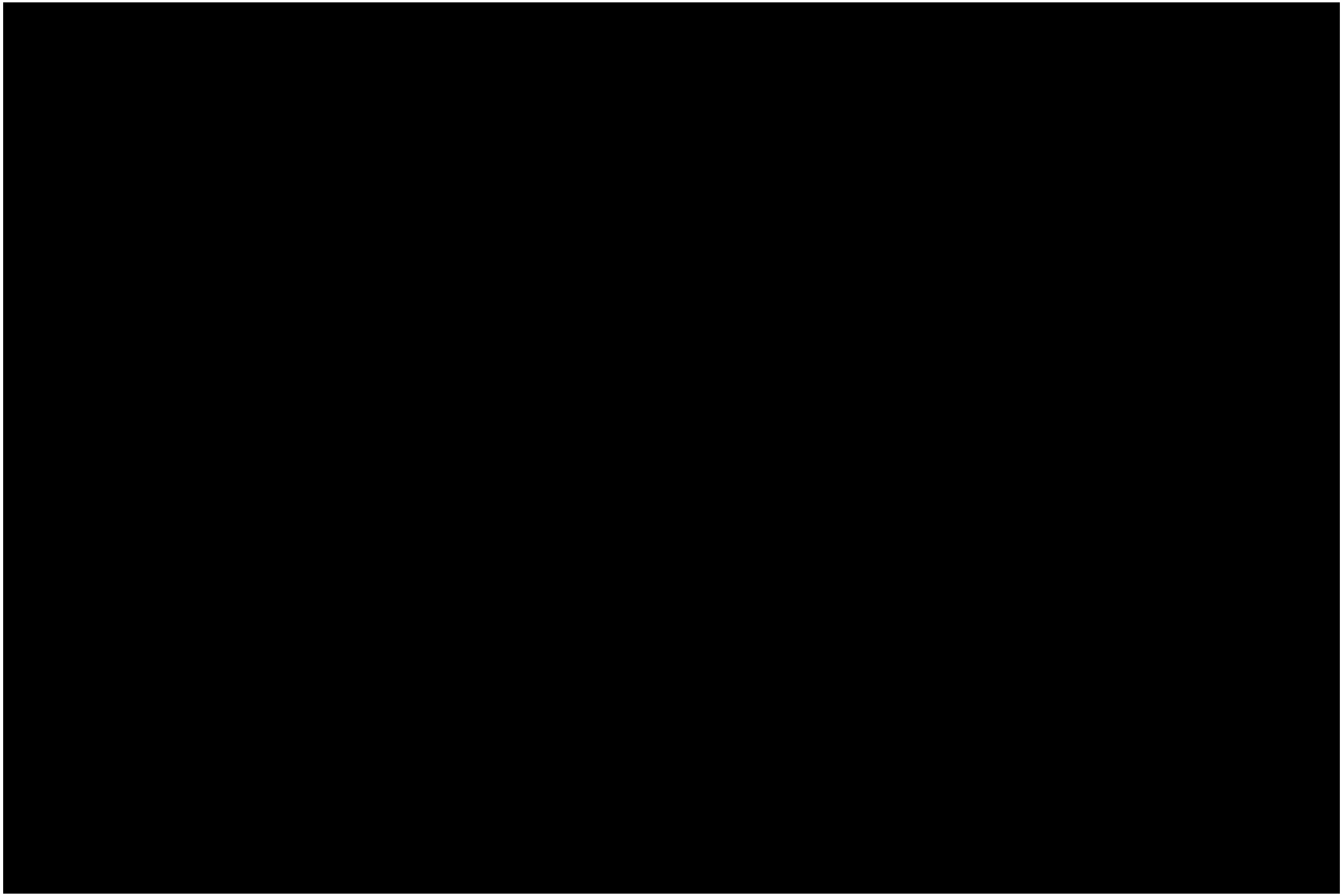
Synoptic scale : Equatorial waves, Extratropical frontal systems

Cloud formation

More lecture 2 …

Courtesy : Octave Tessiot

Cloud formation

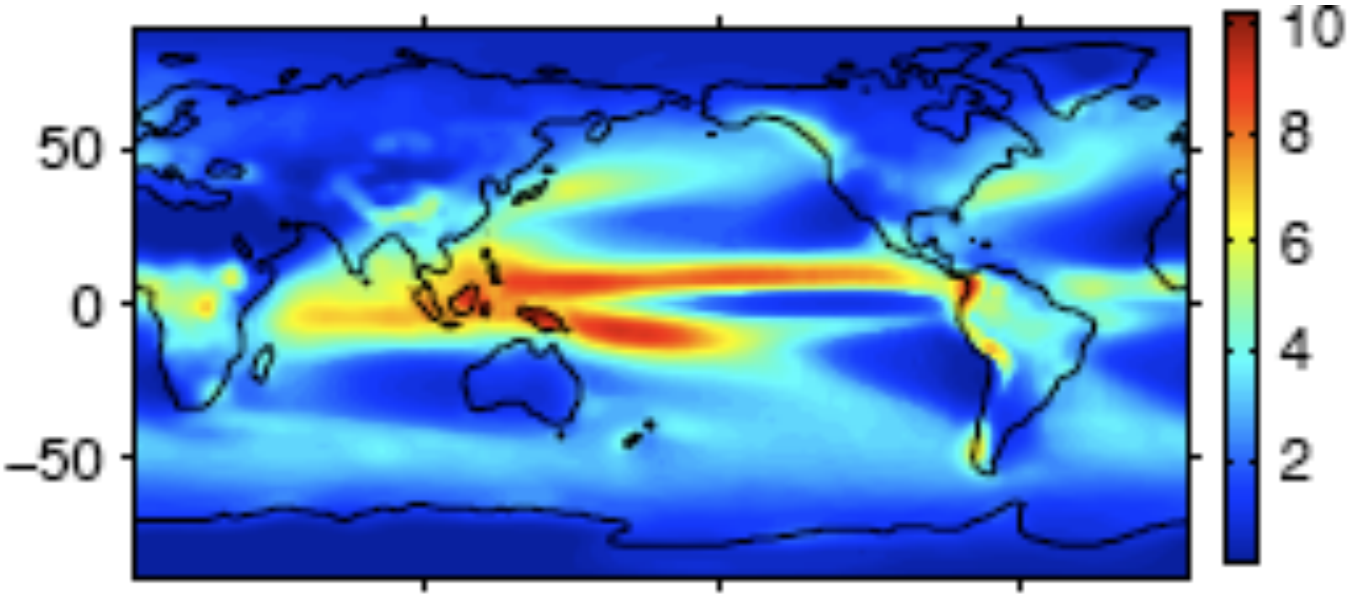


More lecture 2 …

Courtesy : Octave Tessiot

Clouds and Circulation: ITCZ

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

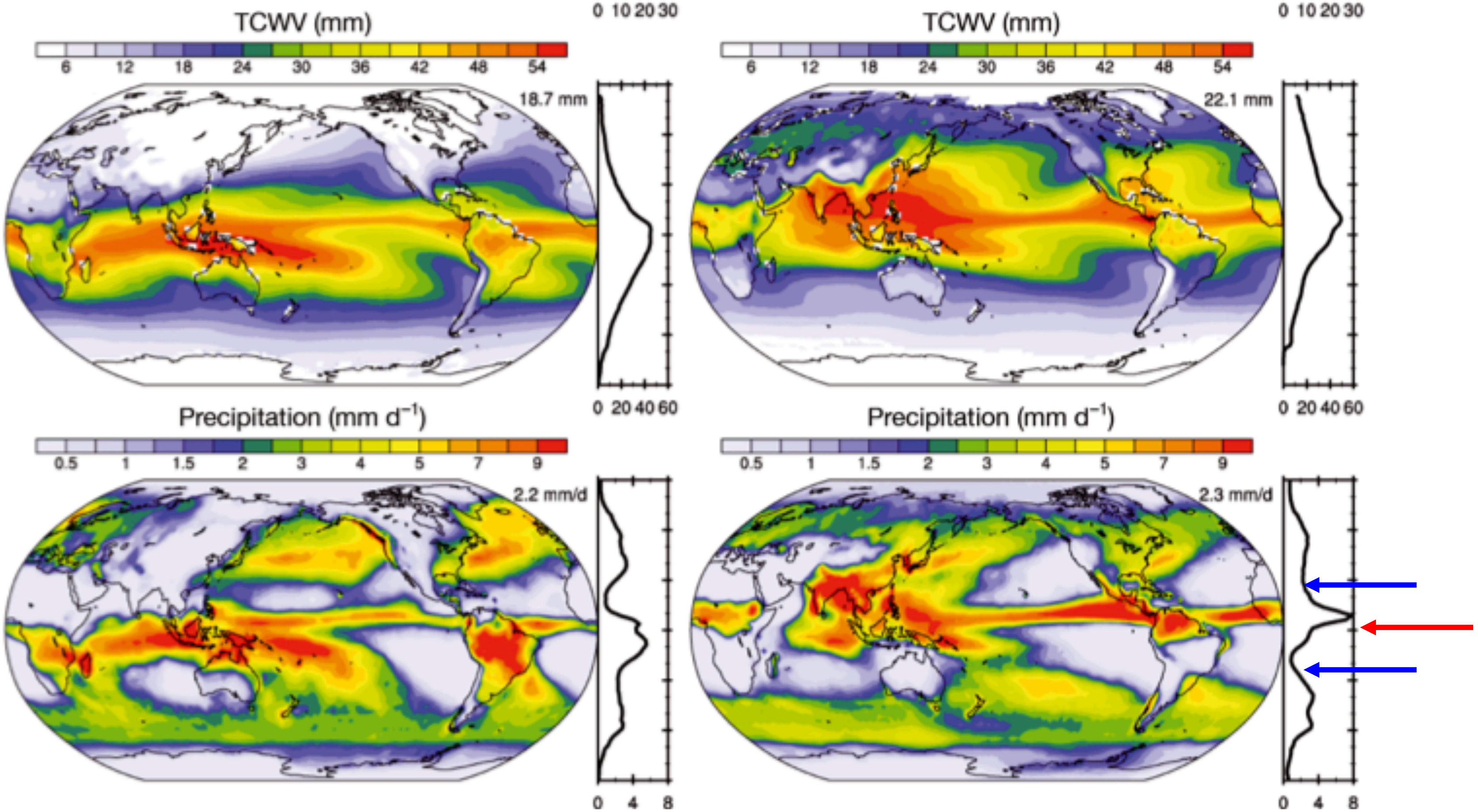


[Muller & O'Gorman, 2011]

Clouds and Circulation: ITCZ

Total column water vapor (TCWV) and precipitation (mm/day)

January (left) *July (right)*

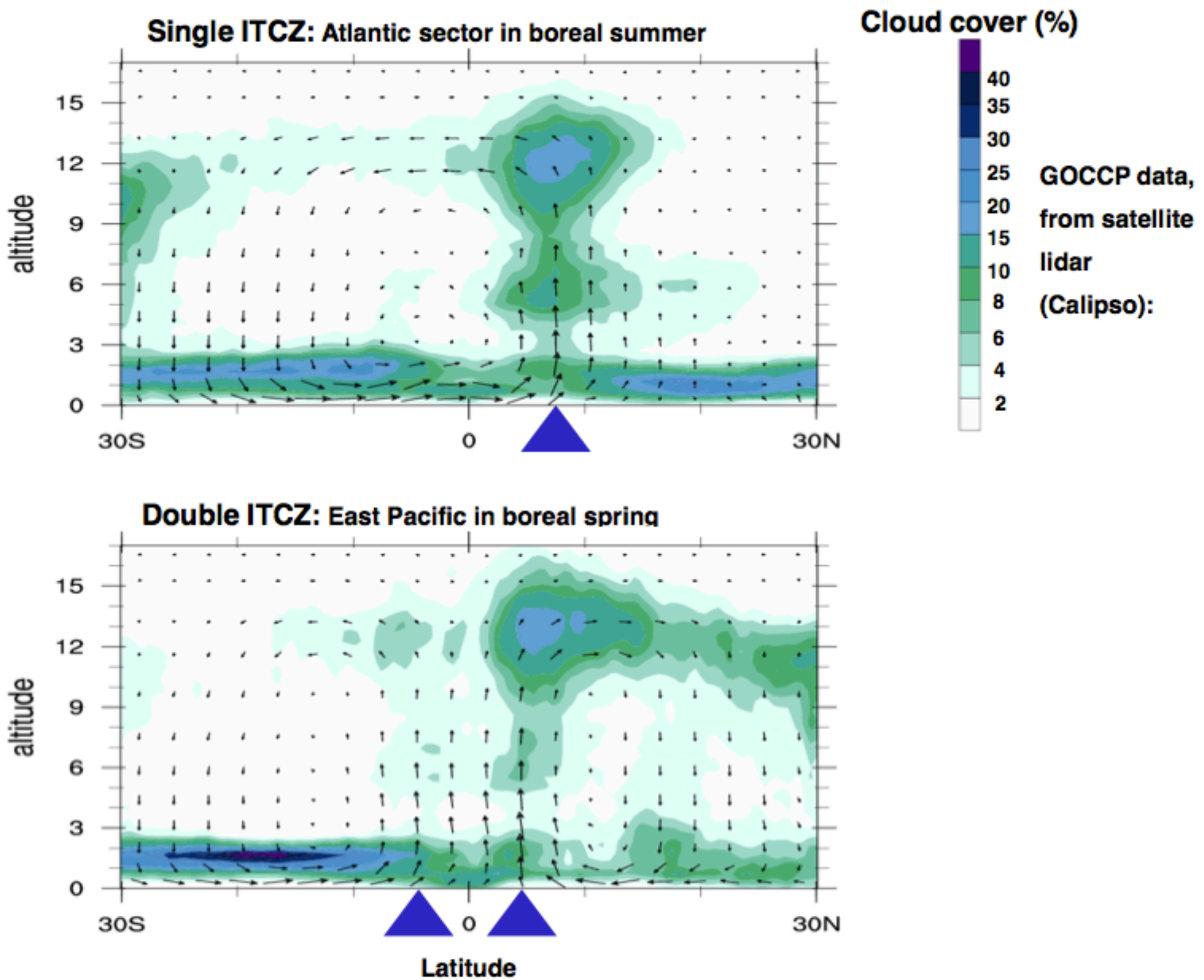


Small in Subtropics (descent)

Large in Tropics (ascent)

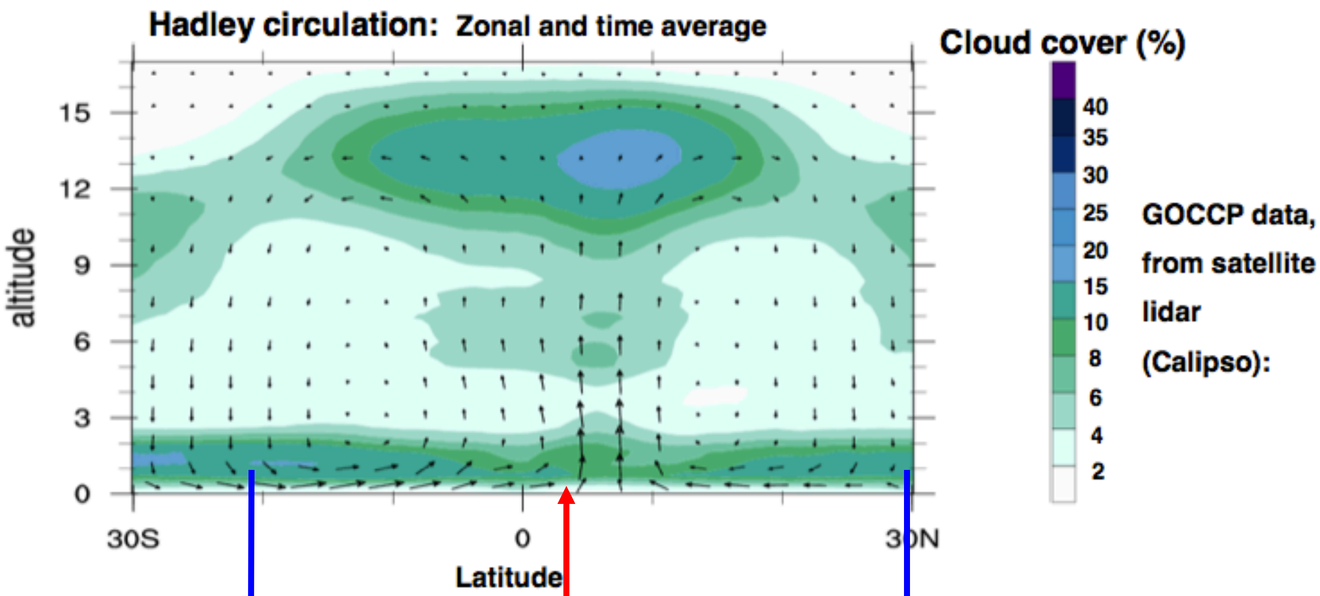
[Trenberth 2011]

Clouds and Circulation: ITCZ

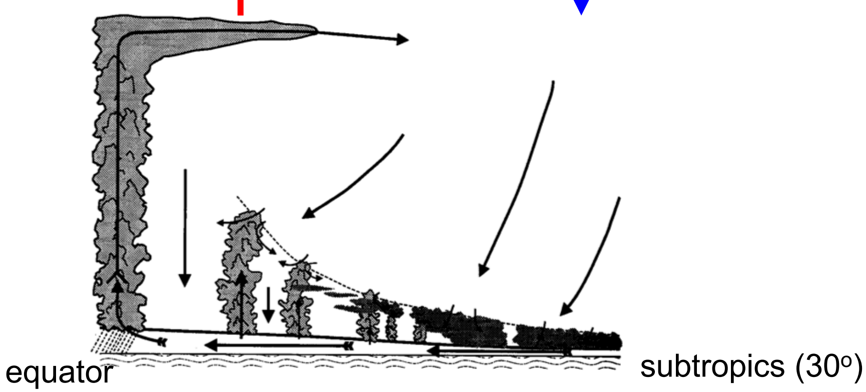


Courtesy Gilles Bellon

Clouds and Circulation: Hadley cell



Cloud types:

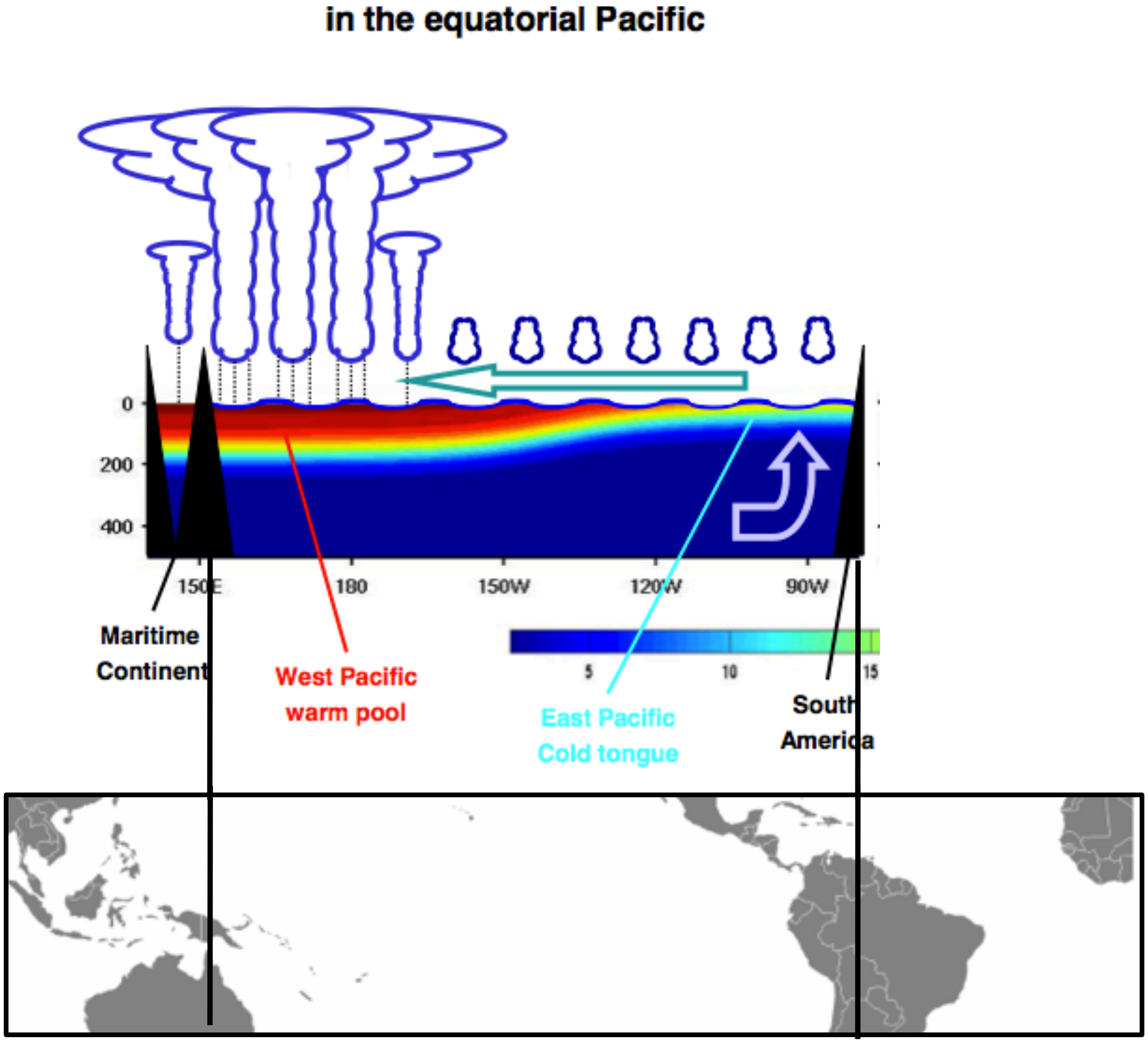


Deep cumulonimbus

Fair weather cumulus

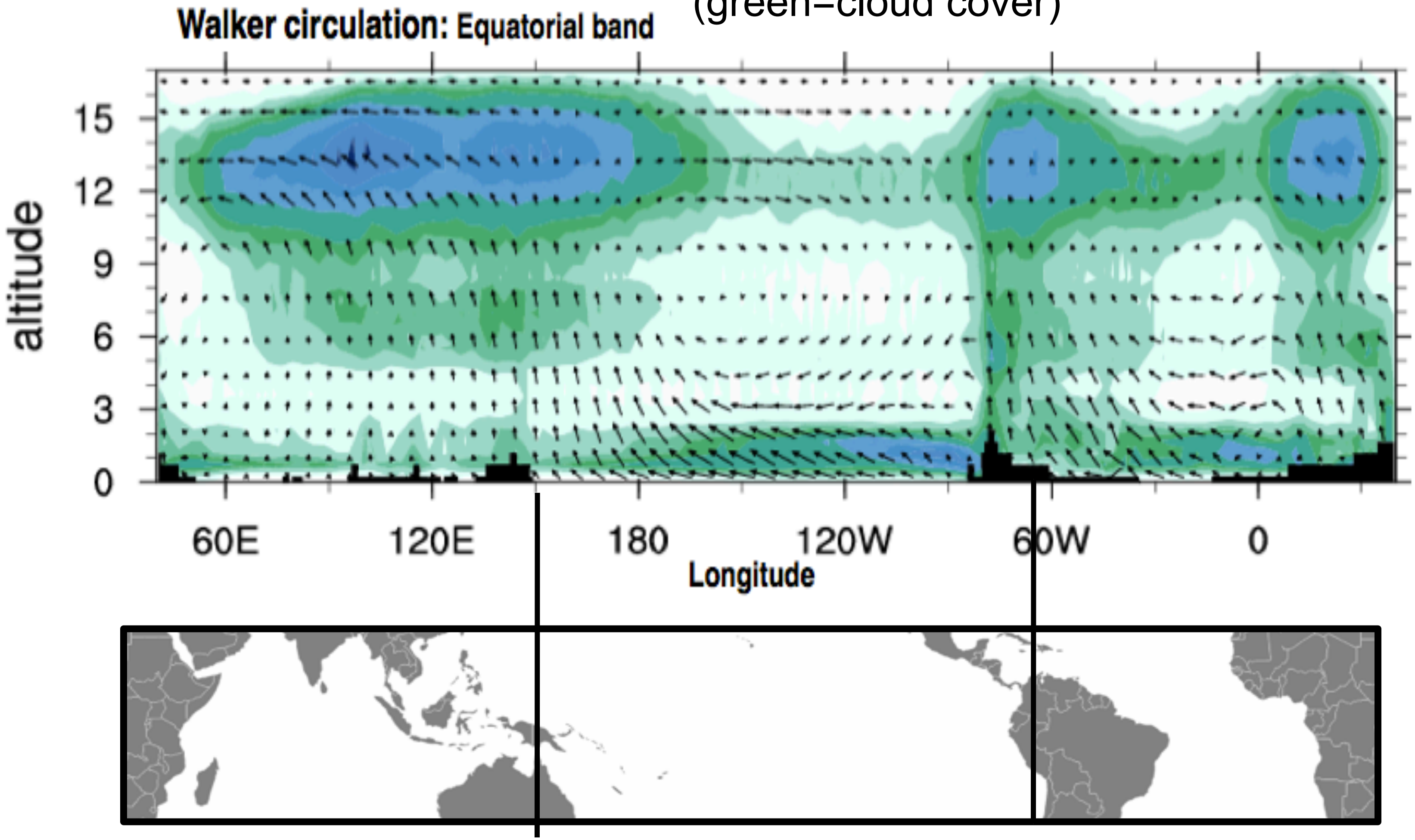
stratus

Clouds and Circulation: Walker cell



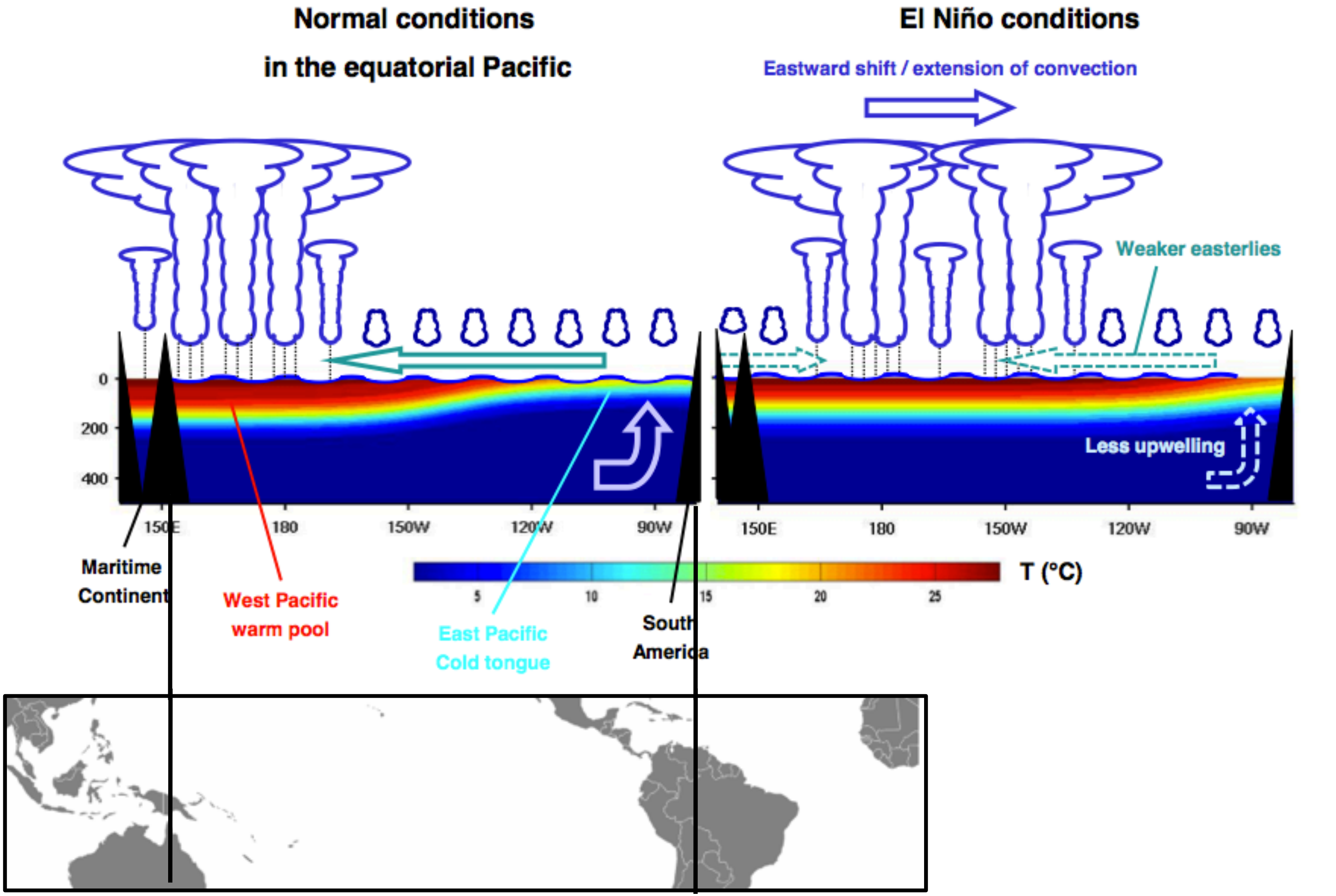
Clouds and Circulation: Walker cell

(green=cloud cover)



Courtesy Gilles Bellon

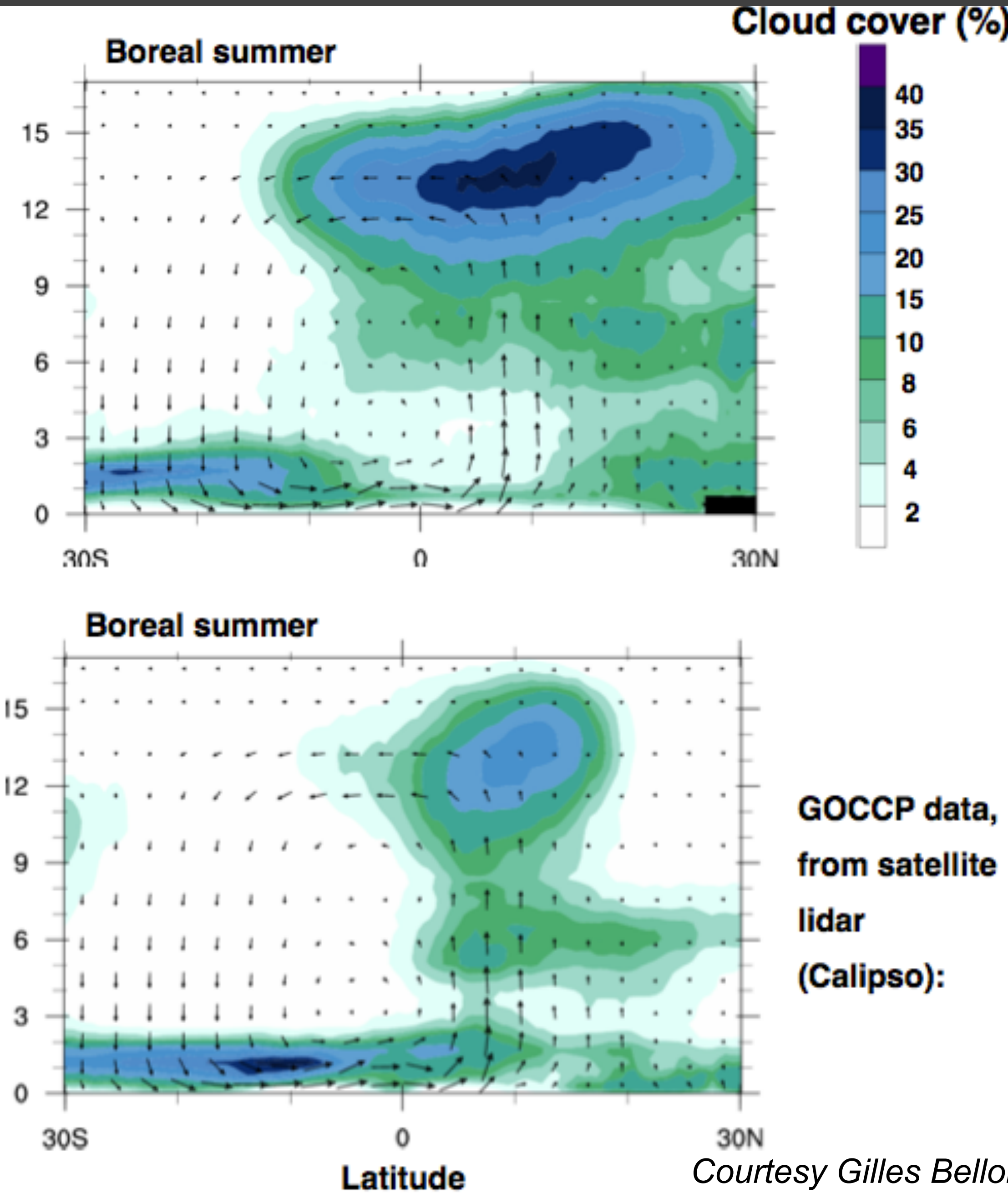
Clouds and Circulation: El Nino



Clouds and Circulation: Monsoon

Asian monsoon

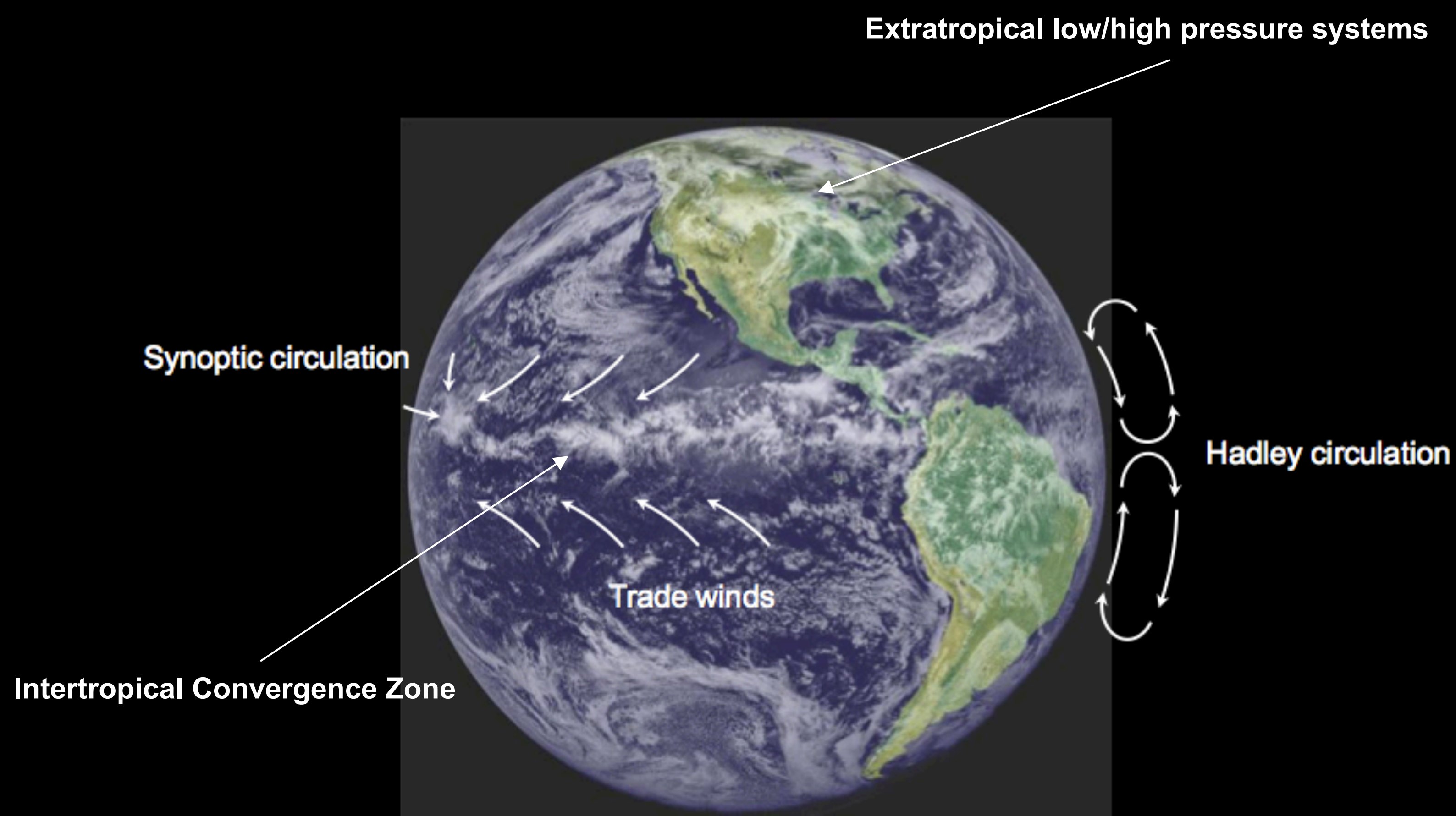
West-African monsoon



GOCCP data, from satellite lidar (Calipso):

Courtesy Gilles Bellon

Clouds are coupled with circulation



Planetary scale : ITCZ, Hadley, Walker (ENSO), monsoon

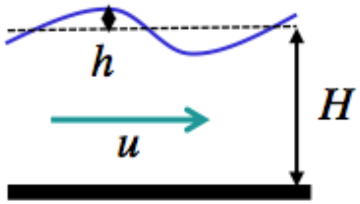
Synoptic scale : Equatorial waves, Extratropical frontal systems

Convective organization: equatorial waves

Linearized shallow-water equations on a β-plane:

➢ **Classical formulation:**

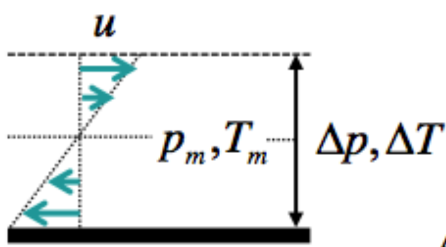
$$\begin{cases} \partial_t u - \beta y v = -g \partial_x h \\ \partial_t v + \beta y u = -g \partial_y h \\ \partial_t h + H\left(\partial_x u + \partial_y v\right) = 0 \end{cases}$$



[Matsuno 66]

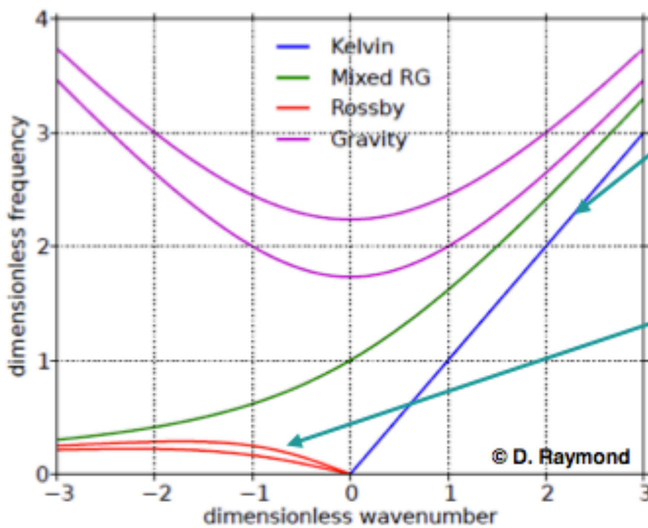
➢ **Tropical atmosphere:**

$$\begin{cases} \partial_t u - \beta y v = -\alpha \partial_x T_m \\ \partial_t v + \beta y u = -\alpha \partial_y T_m \\ \partial_t T + \Delta T\left(\partial_x u + \partial_y v\right) = 0 \end{cases}$$

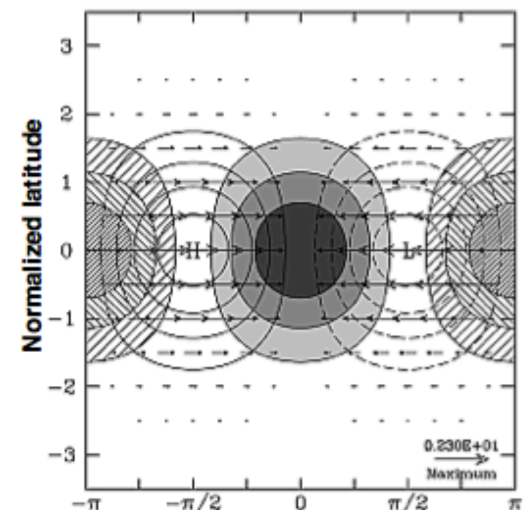


$$\alpha = \frac{\Delta p}{2 p_m} R$$

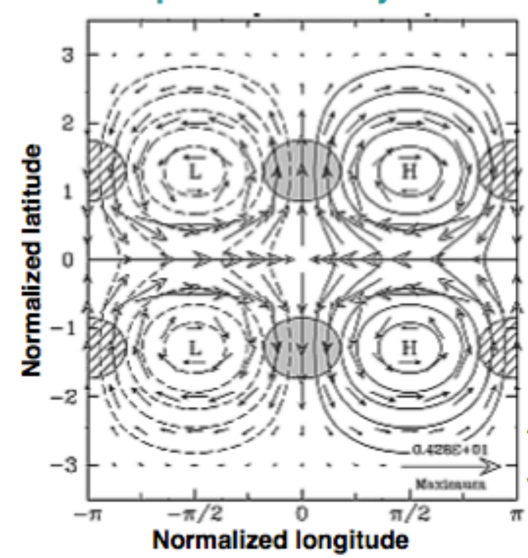
Dispersion diagram:



Kelvin wave



Equatorial Rossby wave



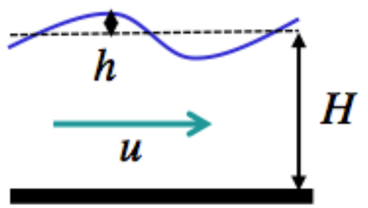
from Kiladis et al (2009)

Convective organization: equatorial waves

Linearized shallow-water equations on a β-plane:

➢ **Classical formulation:**

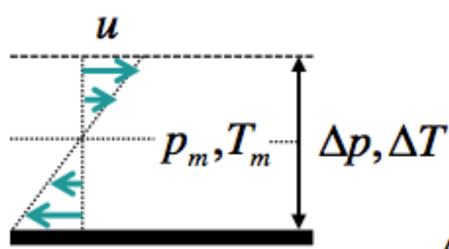
$$\begin{cases} \partial_t u - \beta y v = -g\partial_x h \\ \partial_t v + \beta y u = -g\partial_y h \\ \partial_t h + H(\partial_x u + \partial_y v) = 0 \end{cases}$$



[Matsuno 66]

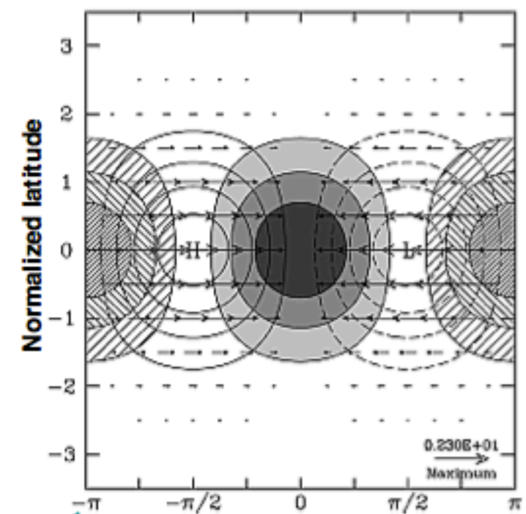
➢ **Tropical atmosphere:**

$$\begin{cases} \partial_t u - \beta y v = -\alpha\partial_x T_m \\ \partial_t v + \beta y u = -\alpha\partial_y T_m \\ \partial_t T + \Delta T(\partial_x u + \partial_y v) = 0 \end{cases}$$

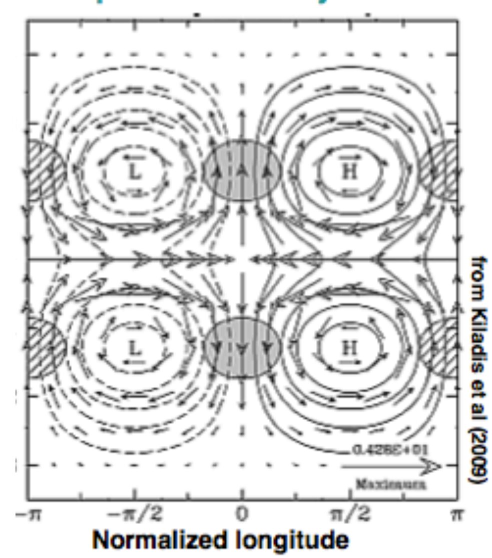


$\alpha = \frac{\Delta p}{} R$

Kelvin wave

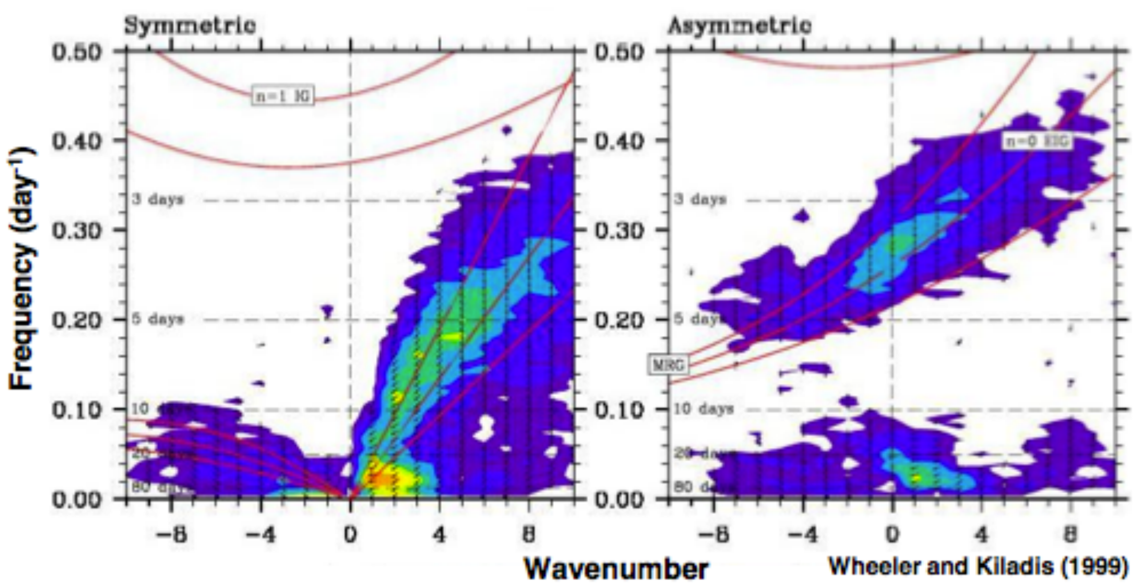


Equatorial Rossby wave

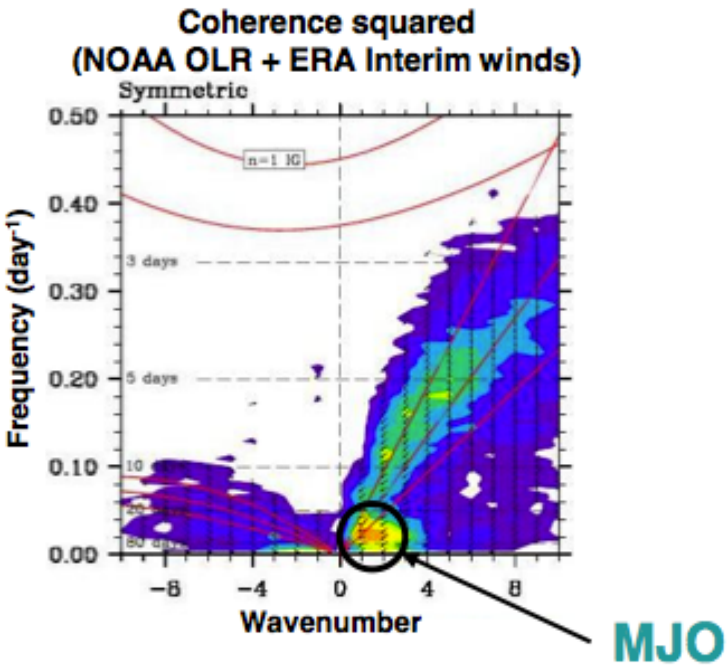


Coherence squared (NOAA OLR + ERA Interim winds)

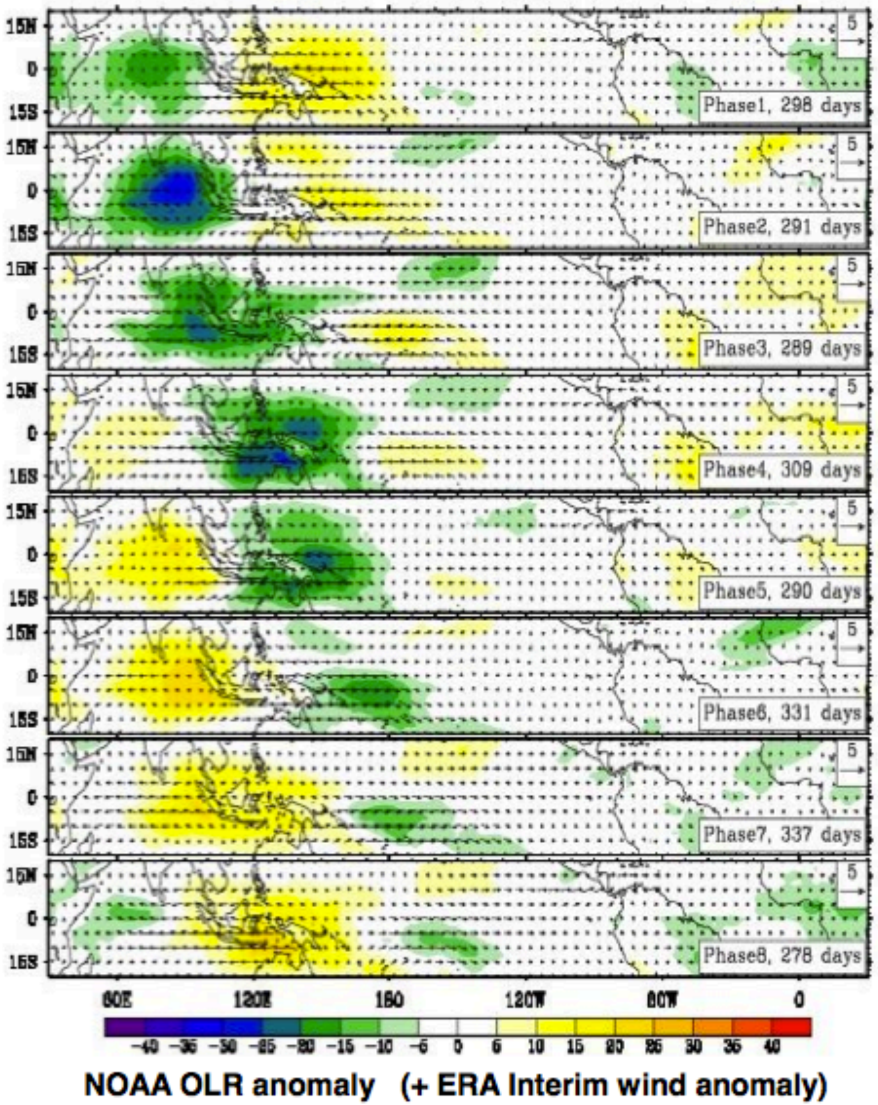
D
d



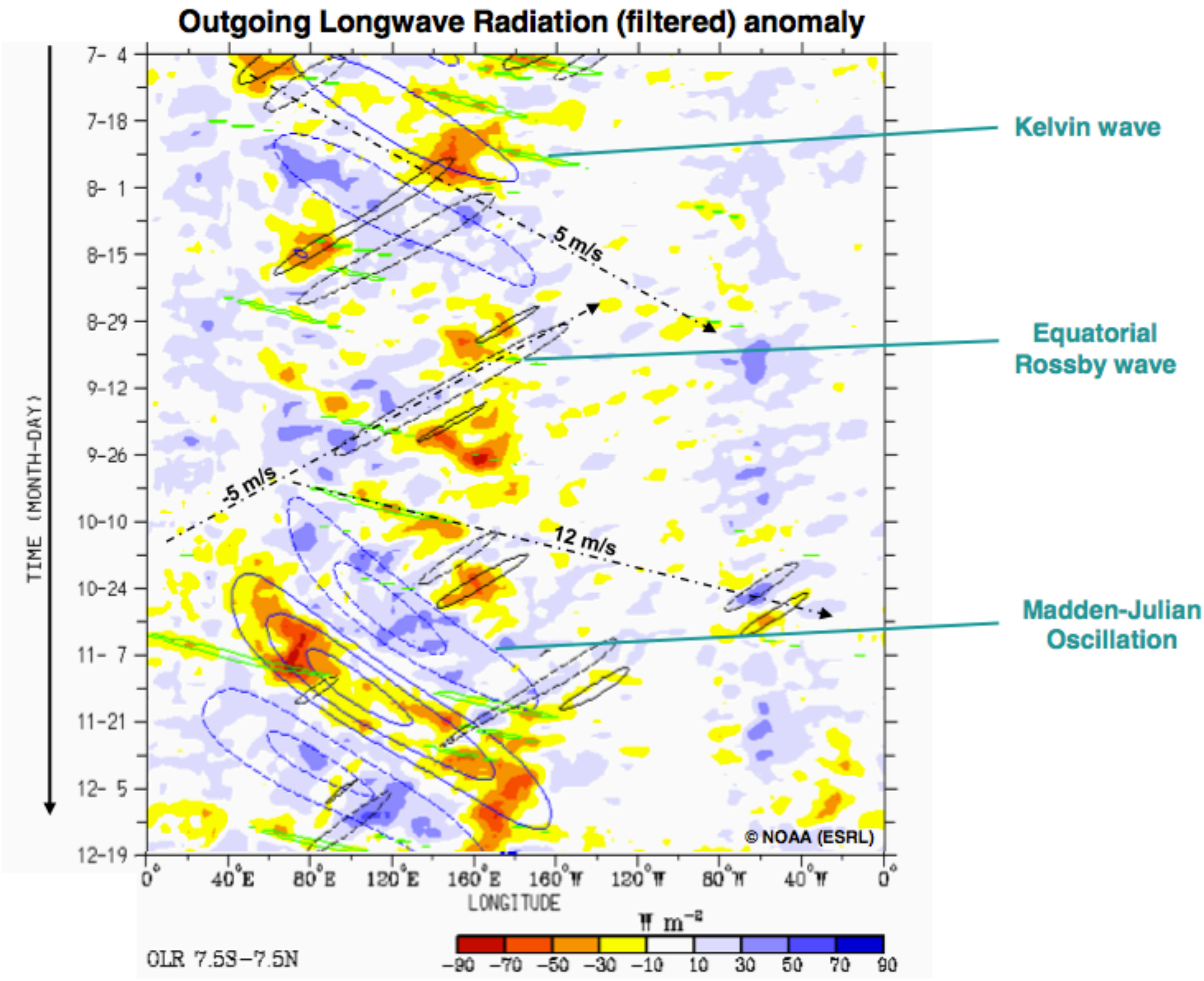
Convective organization: MJO



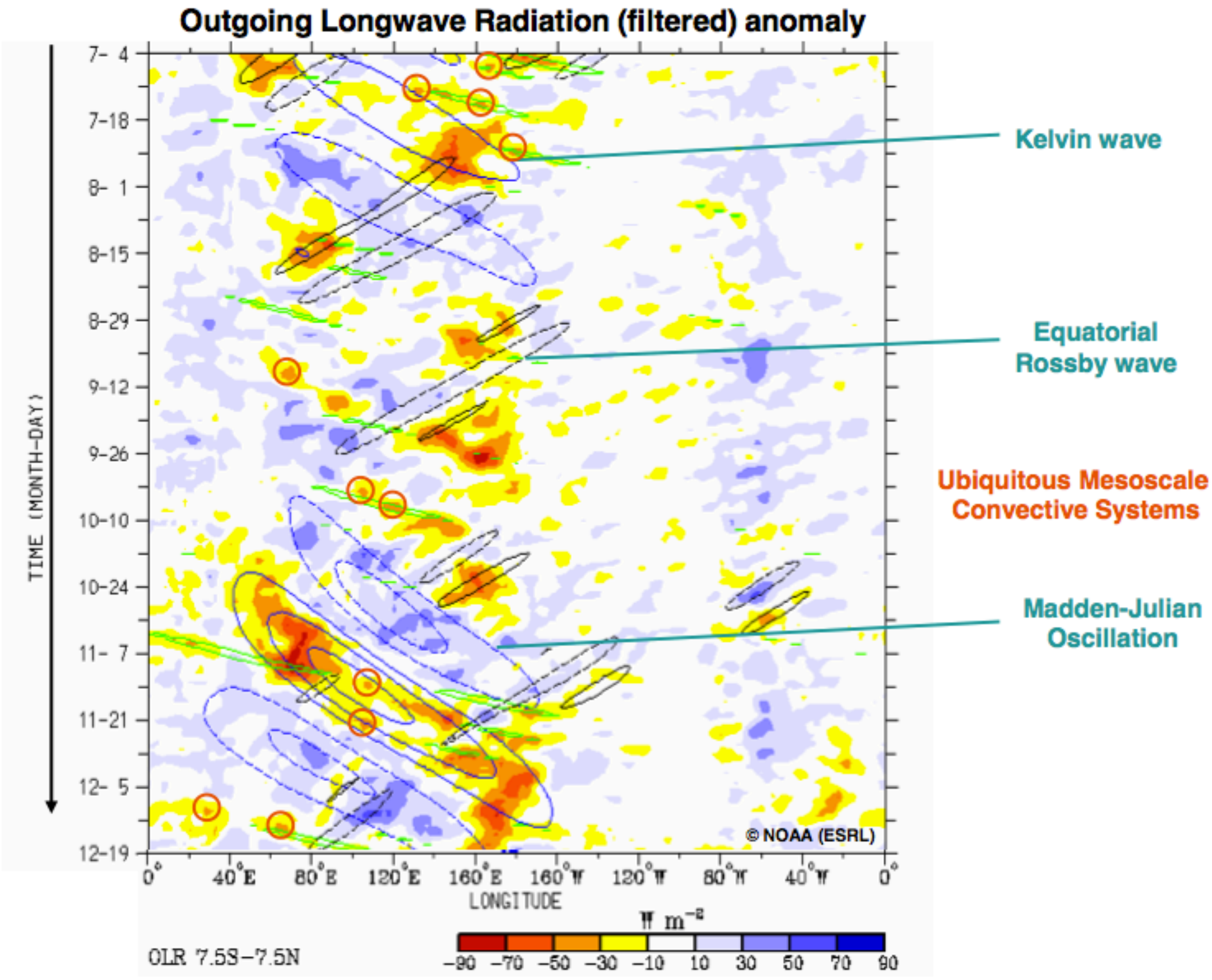
MJO composite life cycle



Convective organization: equatorial waves

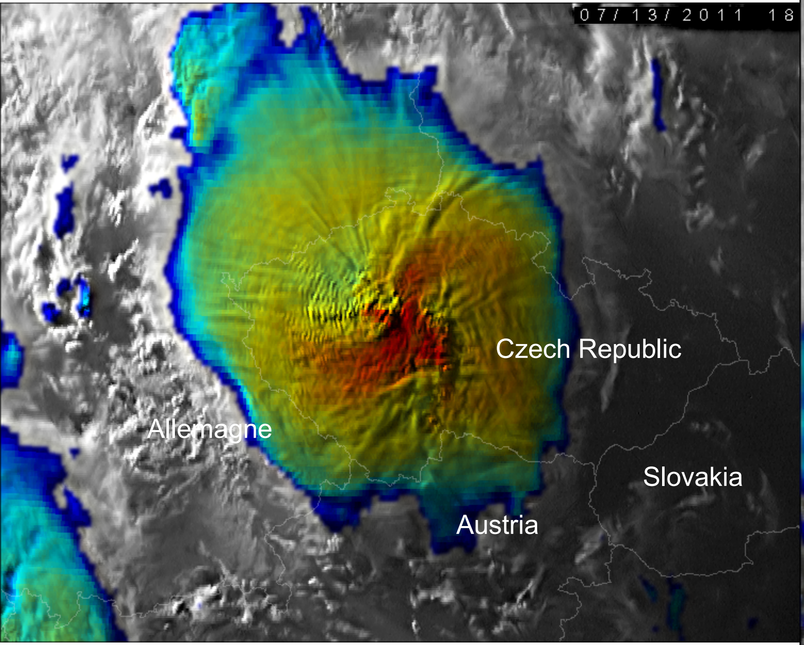


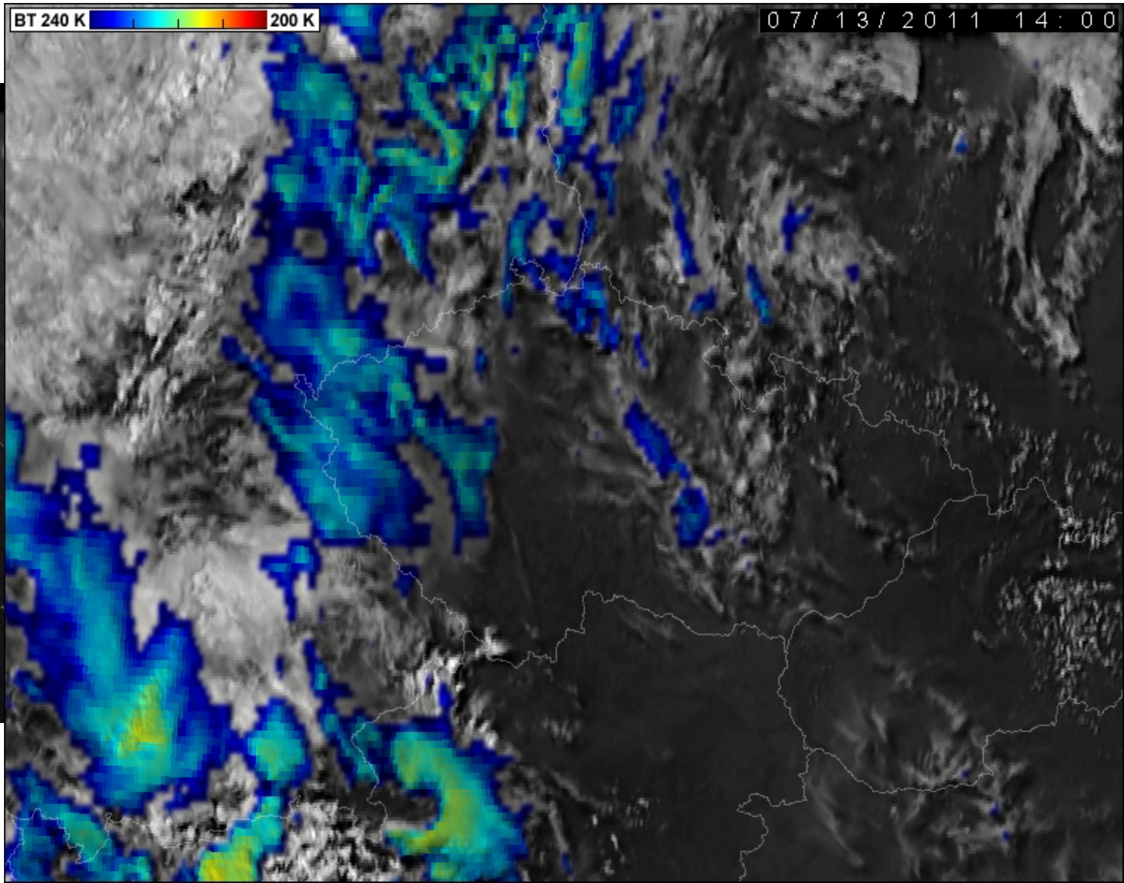
Convective organization: equatorial waves



Convective organization: MCS

Mesoscale convective systems

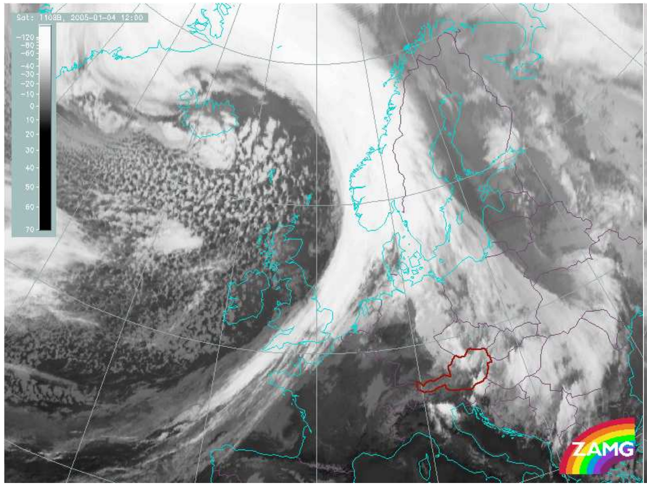


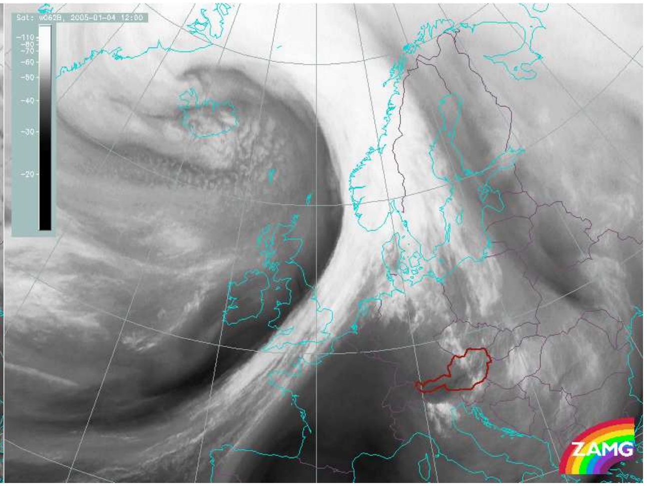


More lecture 3 …

Frontal systems and clouds

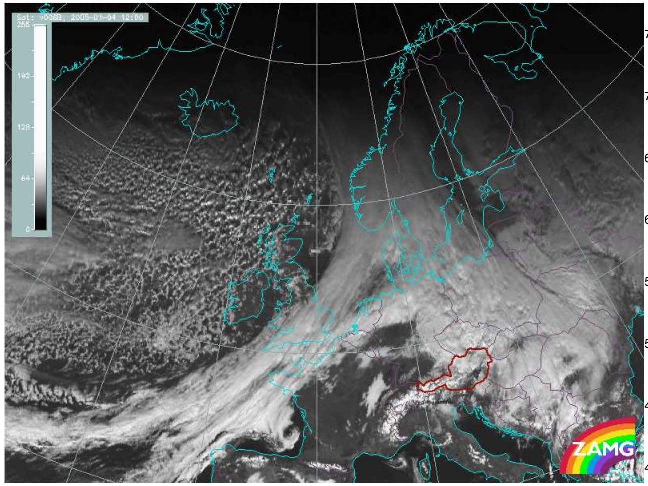
IR

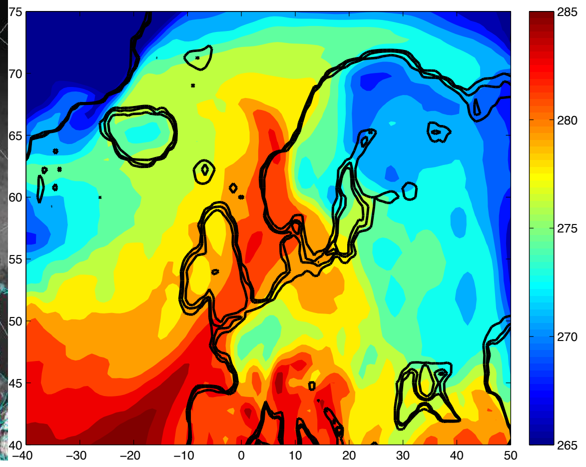




WV

VIS

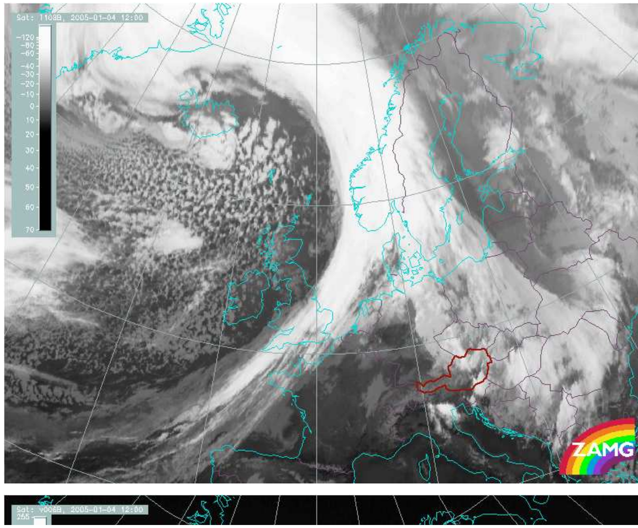


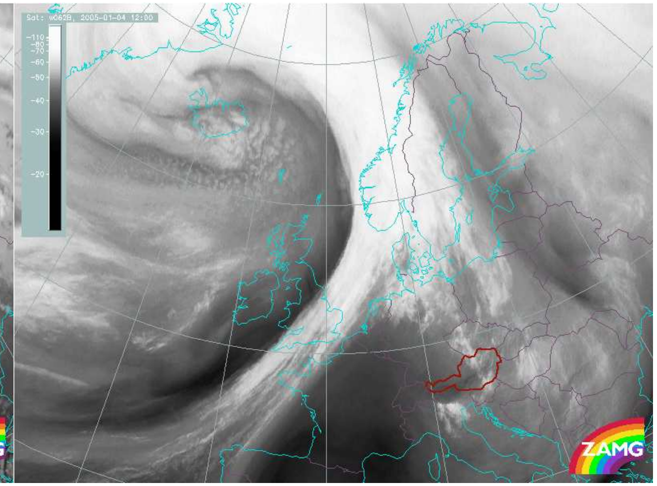


Corresponding T field
Clouds are clearly linked to the dynamics of frontal systems

Frontal systems and clouds

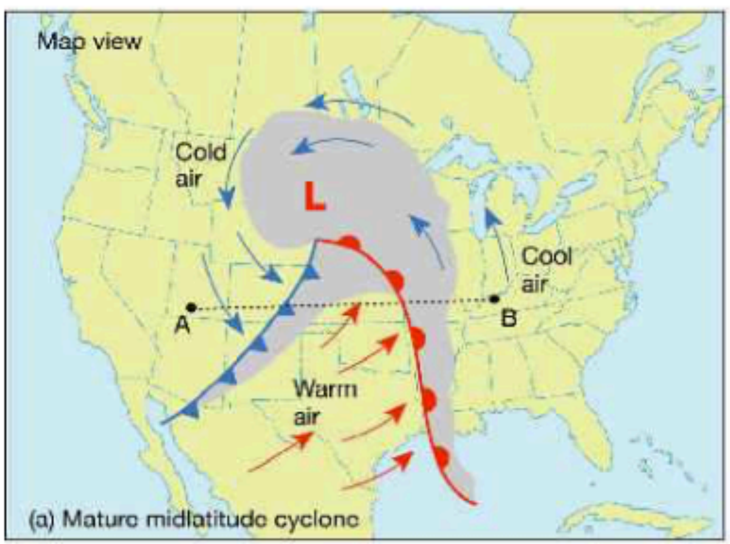
IR

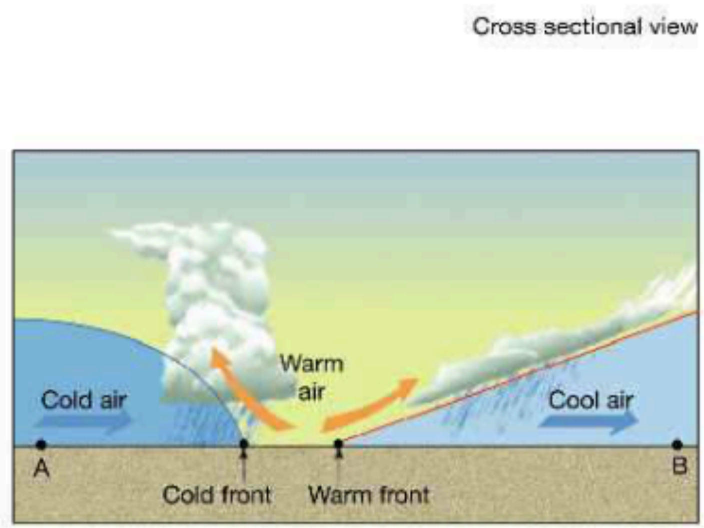




WV

VIS





Lectures Outline :

Cloud fundamentals - global distribution, types, visualization and link with large scale circulation

Cloud Formation and Physics - thermodynamics, cloud formation, instability

Organization of deep convection at mesoscales - MCSs, MCCs, Squall lines, Tropical cyclones, Processes, Self-aggregation

Response of the hydrological cycle to climate change - mean precip, precip extremes

Clouds in a changing climate – climate sensitivity, cloud effect, cloud feedback, FAT