

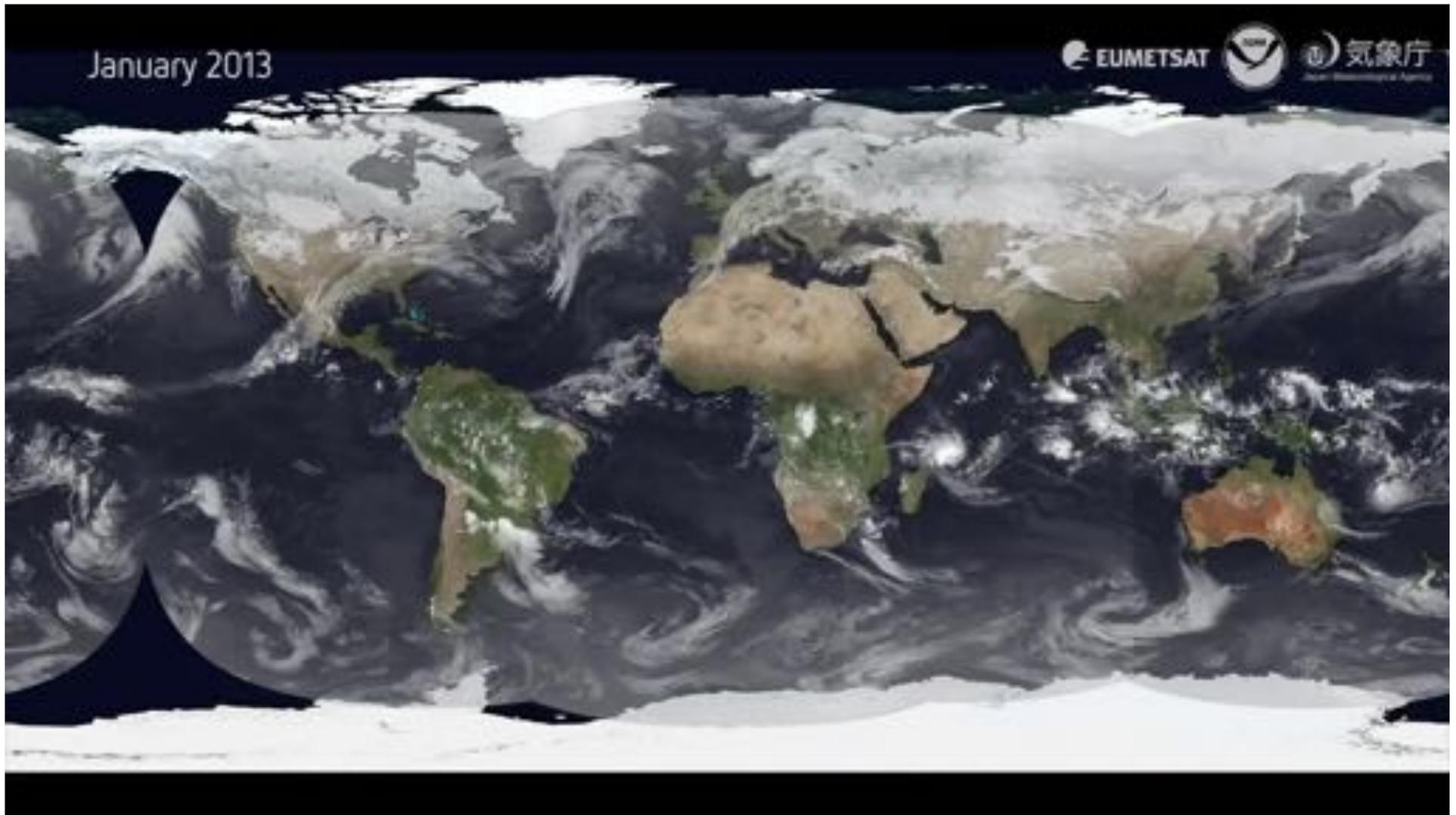
Clouds and Atmospheric convection

Caroline Muller

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E406





A Year of Weather 2013

This visualisation, comprised of imagery from the geostationary satellites of EUMETSAT, NOAA and the JMA, shows an entire year of weather across the globe during 2013, with audio commentary from Mark Higgins, Training Officer at EUMETSAT.

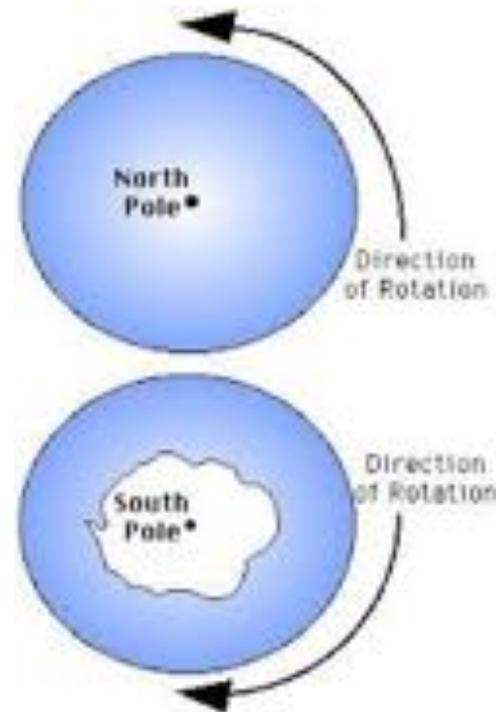
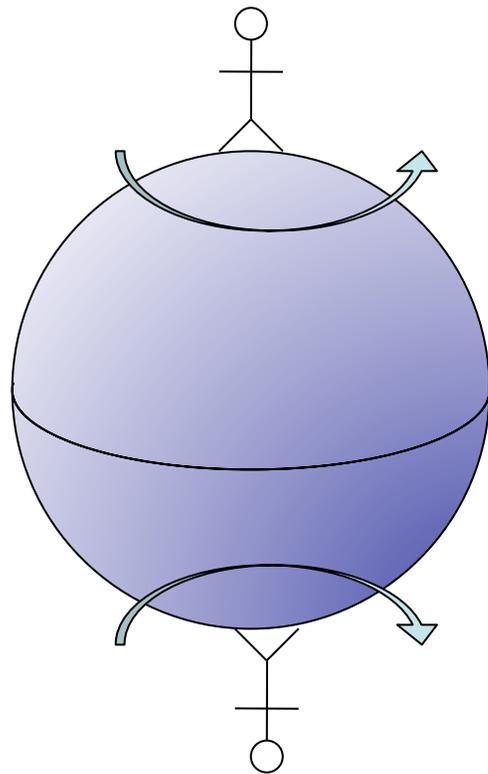
The satellite data layer is superimposed over NASA's 'Blue Marble Next Generation' ground maps, which change with the seasons.

Remarque :

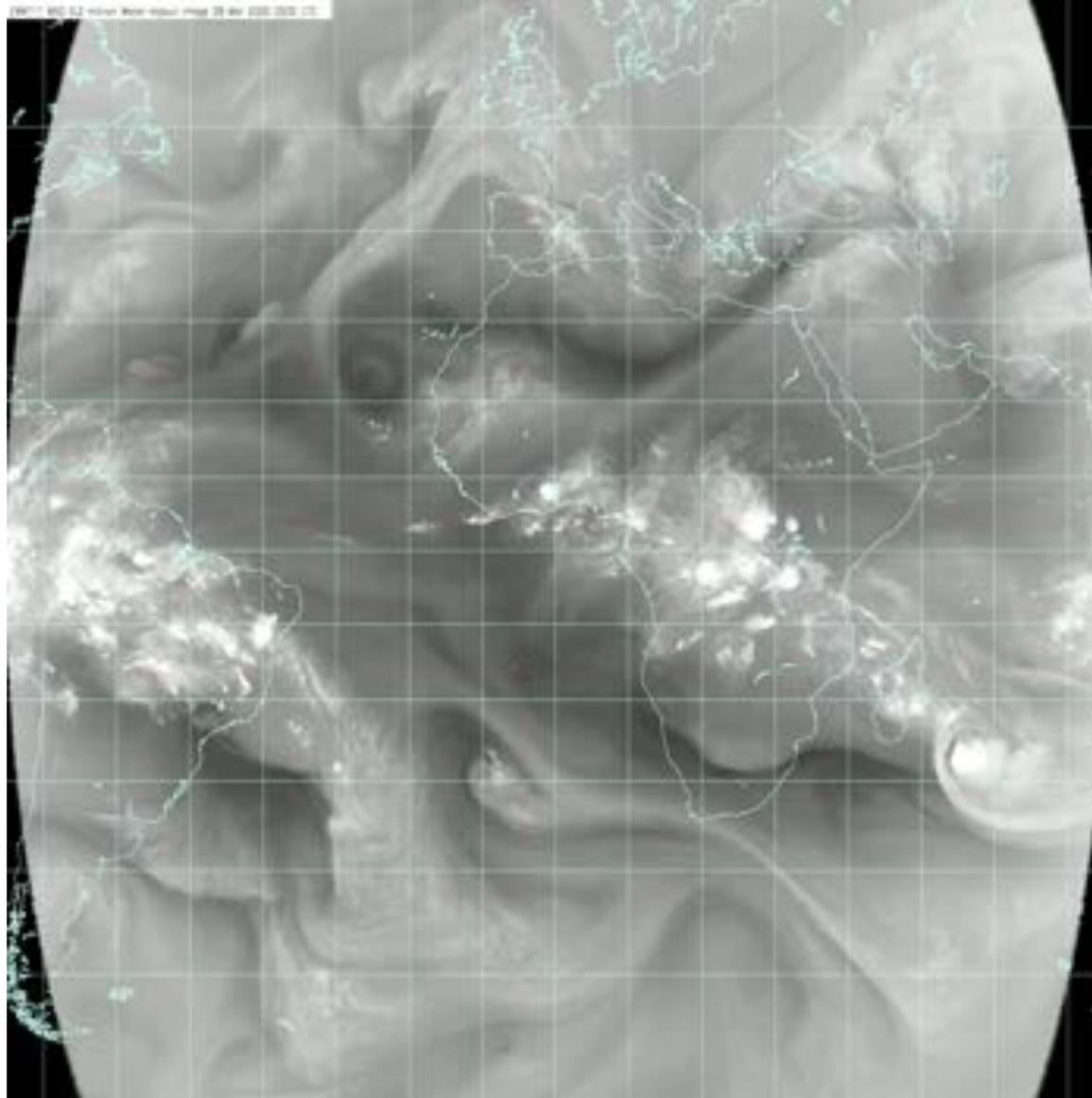
Pourquoi cyclone = sens inverse des aiguilles d'une montre dans l'hémisphère nord VERSUS sens des aiguilles d'une montre dans l'hémisphère sud?

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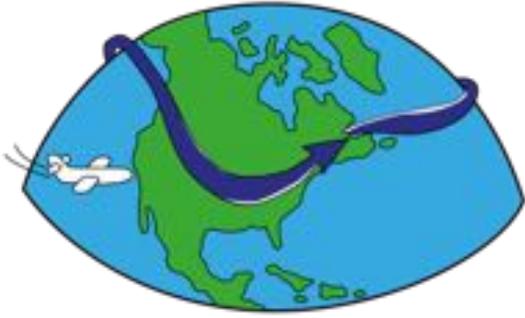
Pourquoi cyclone = sens inverse des aiguilles d'une montre dans l'hémisphère nord VERSUS sens des aiguilles d'une montre dans l'hémisphère sud?



atmospheric water vapor (white=humid)



6.2_micron_wv_700-300-meteosat



courant-jet polaire

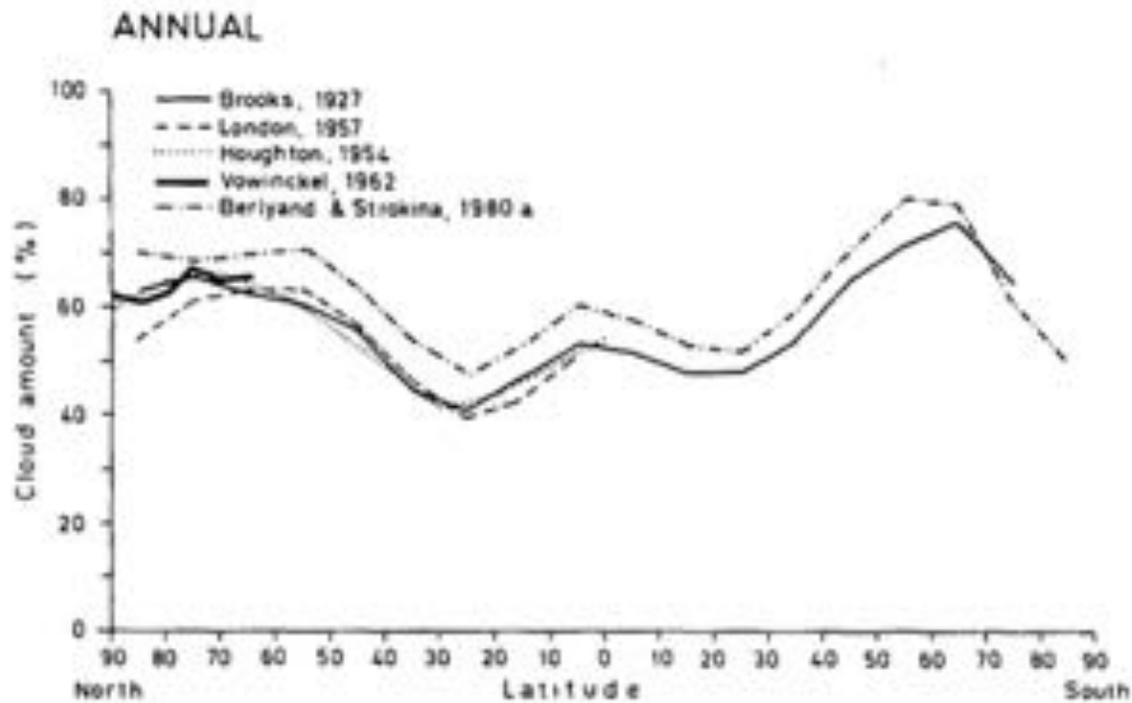


Clouds and Atmospheric convection



Clouds and Atmospheric convection

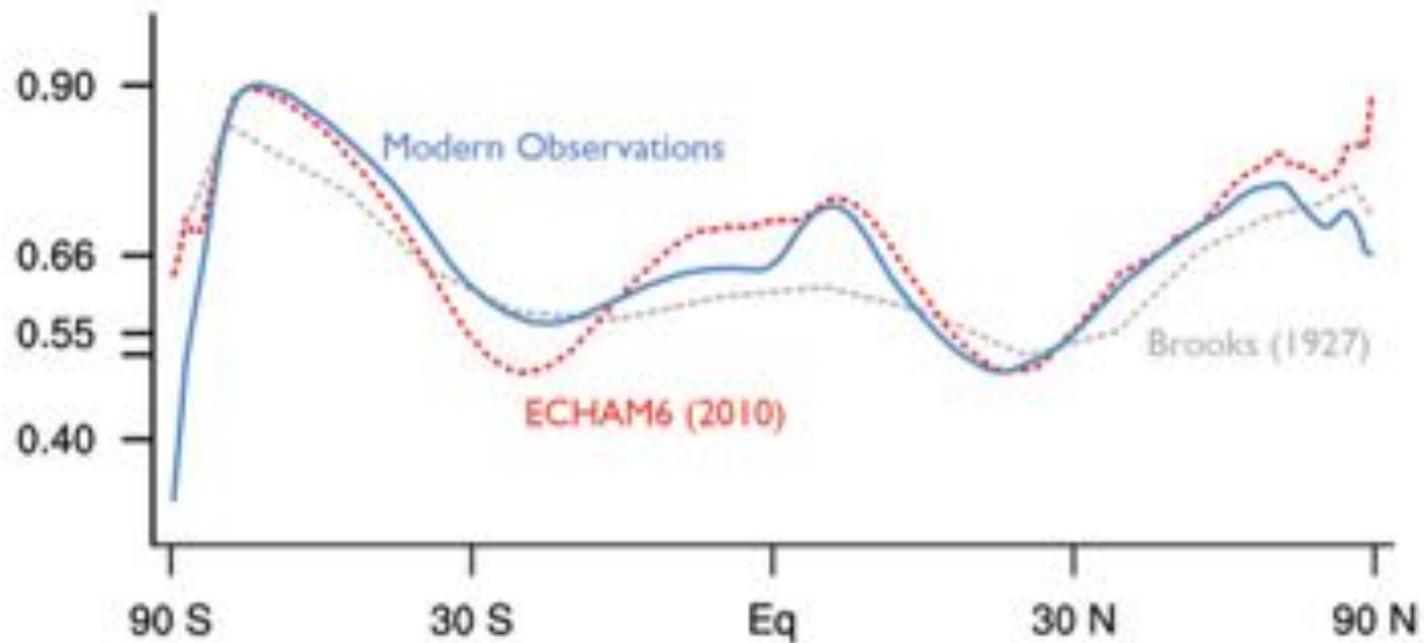
Distribution of cloud amount



[Hughes 84]

Clouds and Atmospheric convection

Cloud amount was underestimated



Courtesy Bjorn Stevens

Clouds and Atmospheric convection



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

Clouds and Atmospheric convection

Sir Arthur Charles Clarke
(1917-2008) British science fiction writer, science writer and futurist, inventor, undersea explorer and 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 Atmospheric convection



and clouds

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

Clouds and climate

An era of blooming cloud and climate science

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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

EDITION: INTERNATIONAL U.S. MÉXICO ARABIC

TV: CNN CNN en Español

CNN

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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 | 108 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.



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 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 Max Technology has been... for its engineering symposium at MIT... scientists from an... a hot facet of the... The title of the symposium... the questions surrounding... science: "Engineered... We Do It? Should

HOME SEARCH

The New York Times

VISITE EN HÉLICOPTÈRE
Visite en Hélicoptère + Meilleurs vols en France

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, 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](#)

Cloud types

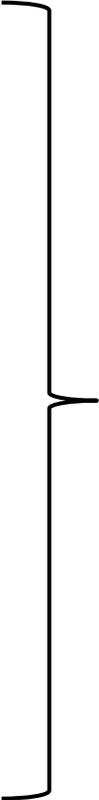
Cumulus: heap, pile

Stratus: flatten out, cover with a layer

Cirrus: lock of hair, tuft of horsehair

Nimbus: precipitating cloud

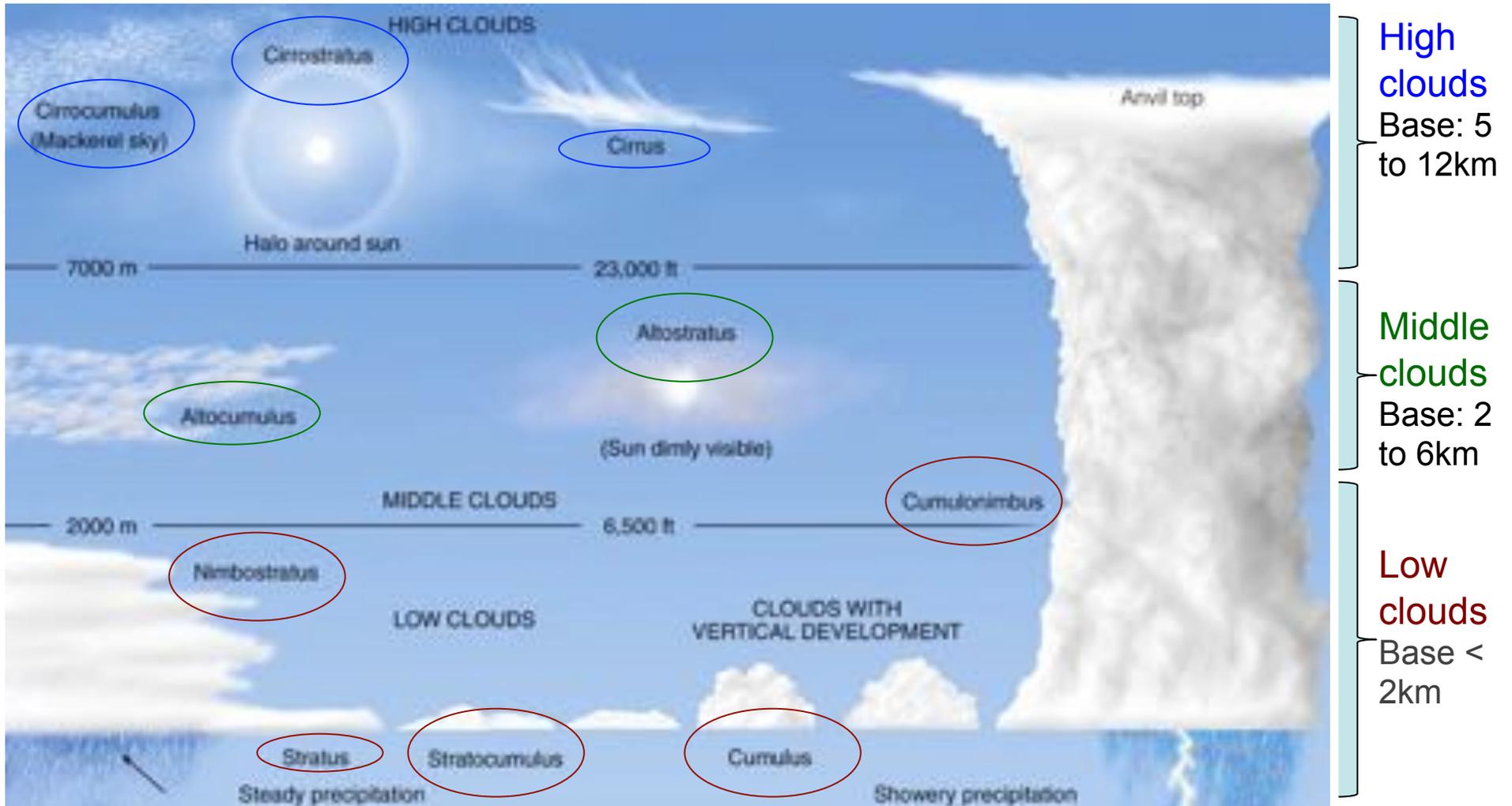
Altimus: height



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



Altostratus

Flat and uniform type texture in mid levels

Alto cumulus

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"



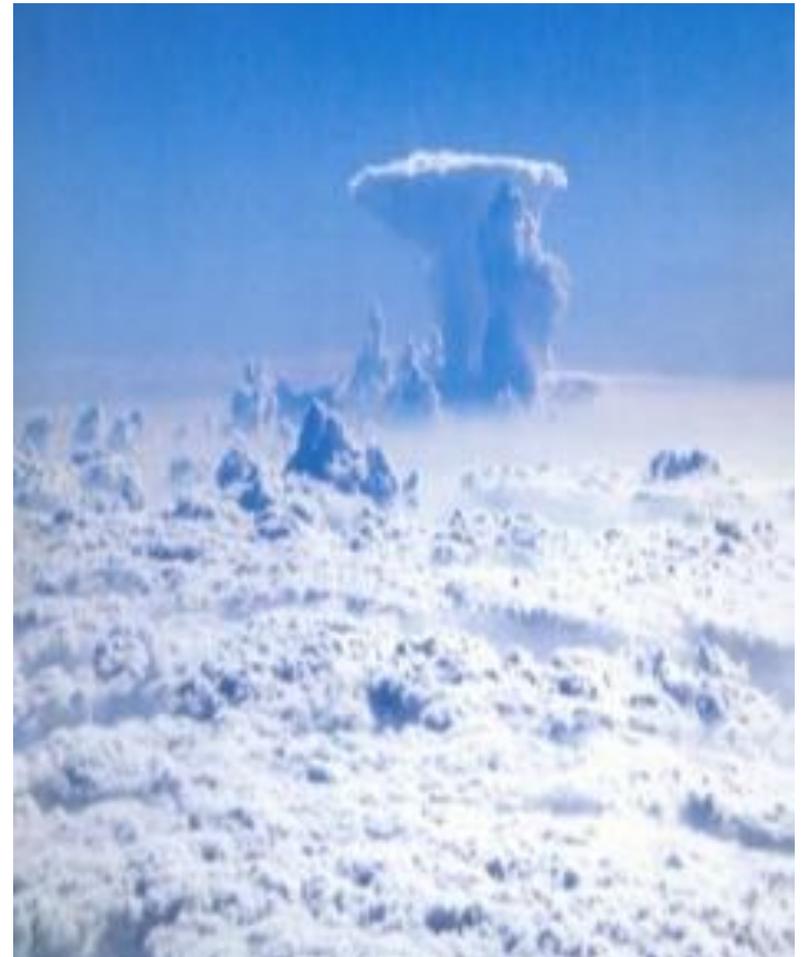
Cumulus (congestus)

Significant vertical development (but not yet a thunderstorm)

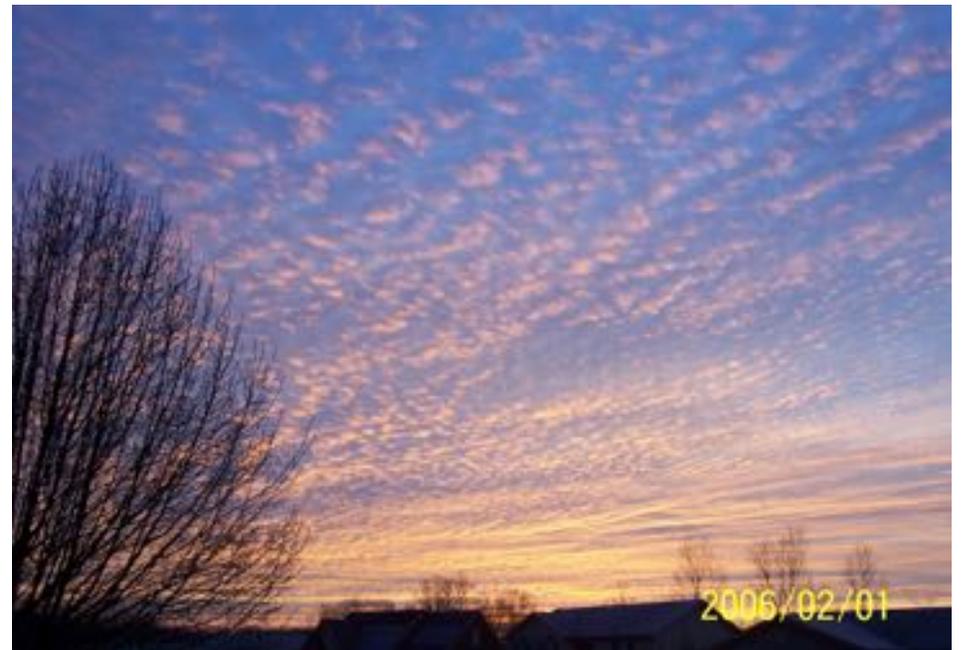


Cumulonimbus

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



High Clouds



High Clouds

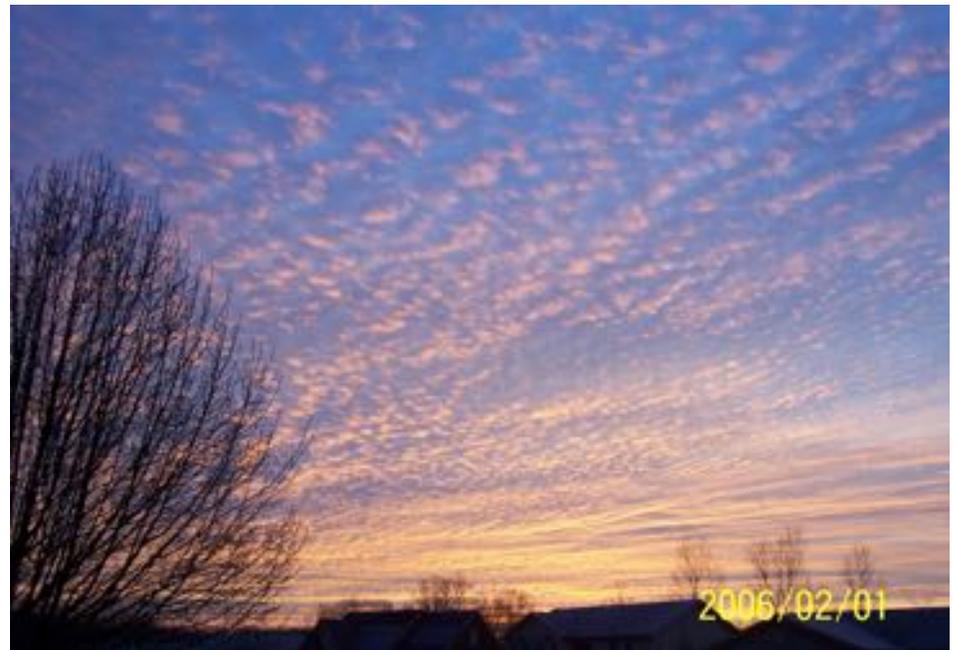
Cirrostratus



Cirrus



Cirrocumulus



Middle Clouds



Middle Clouds

Altostratus



Altostratus

Low Clouds



Low Clouds



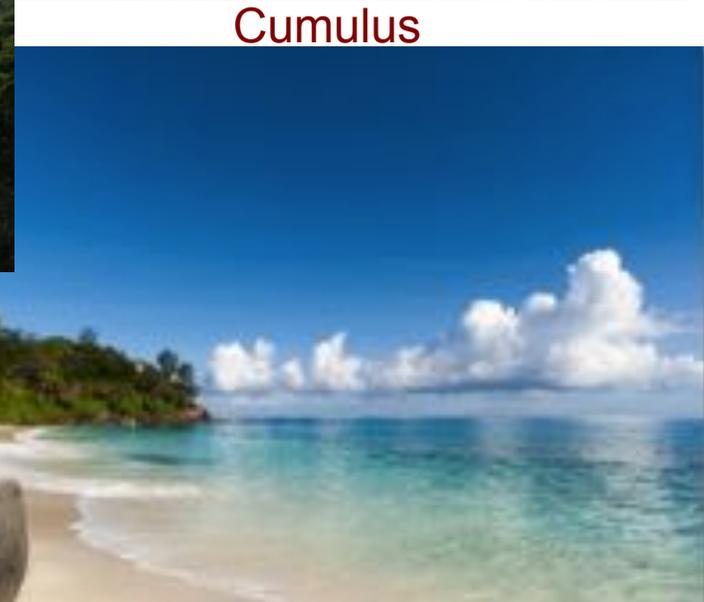
Stratocumulus



Cumulonimbus



Nimbostratus



Cumulus

Other spectacular Clouds...

Mammatus clouds (typically below anvil clouds)



Shelf clouds (gust front)



Lenticular clouds (over orography)



Other spectacular Clouds...



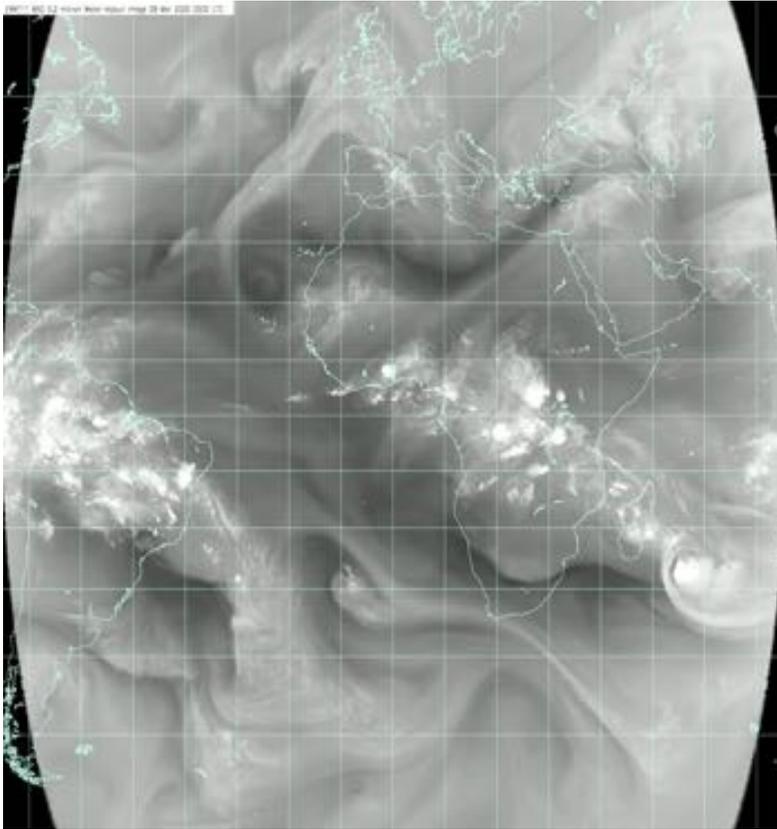
Courtesy: D.-D. Rousseau

Other spectacular Clouds...



Cloud types

Water vapor from satellite



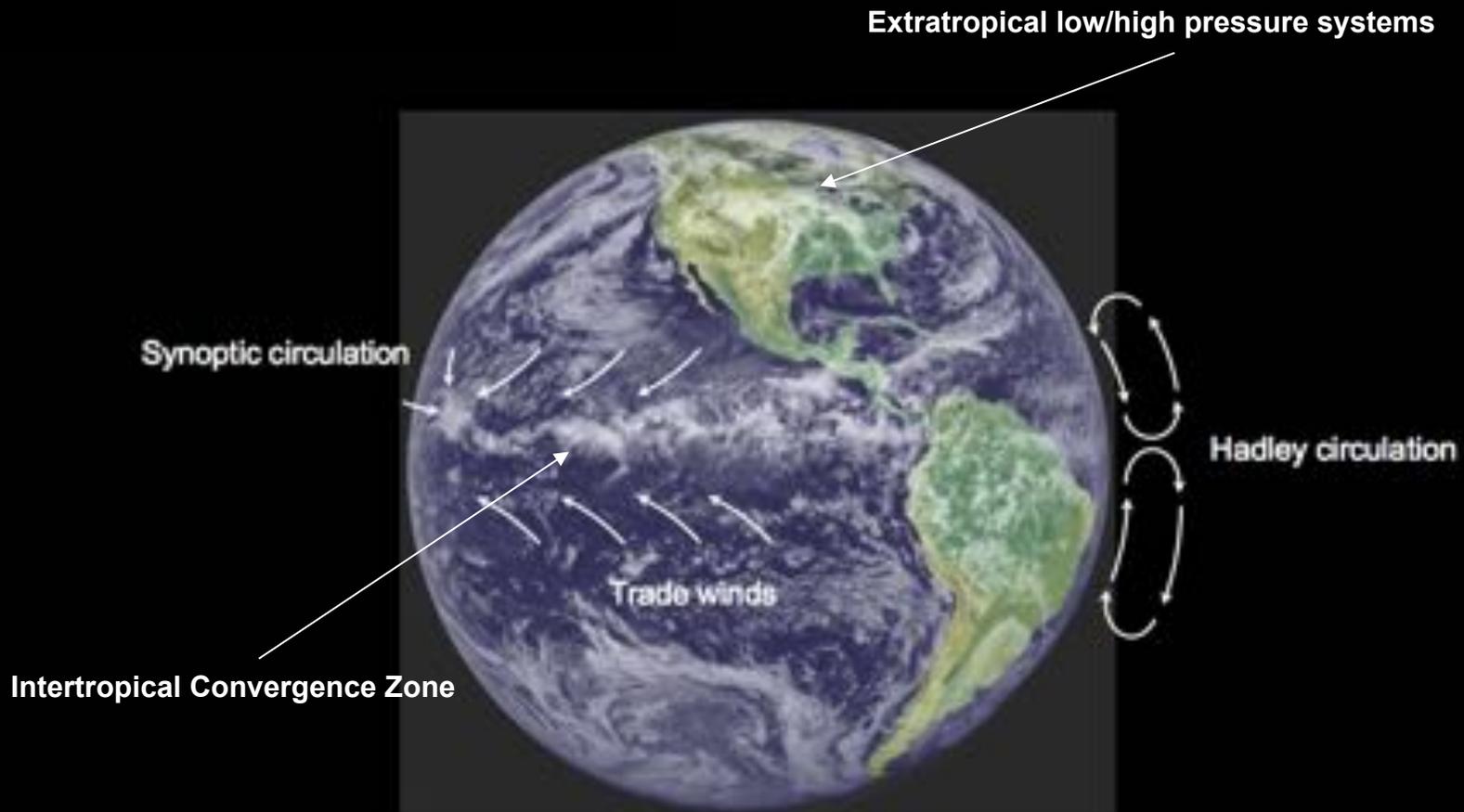
Larger-scale
extratropical
convection

Small-scale
tropical
convection

Deep convective system over Brazil

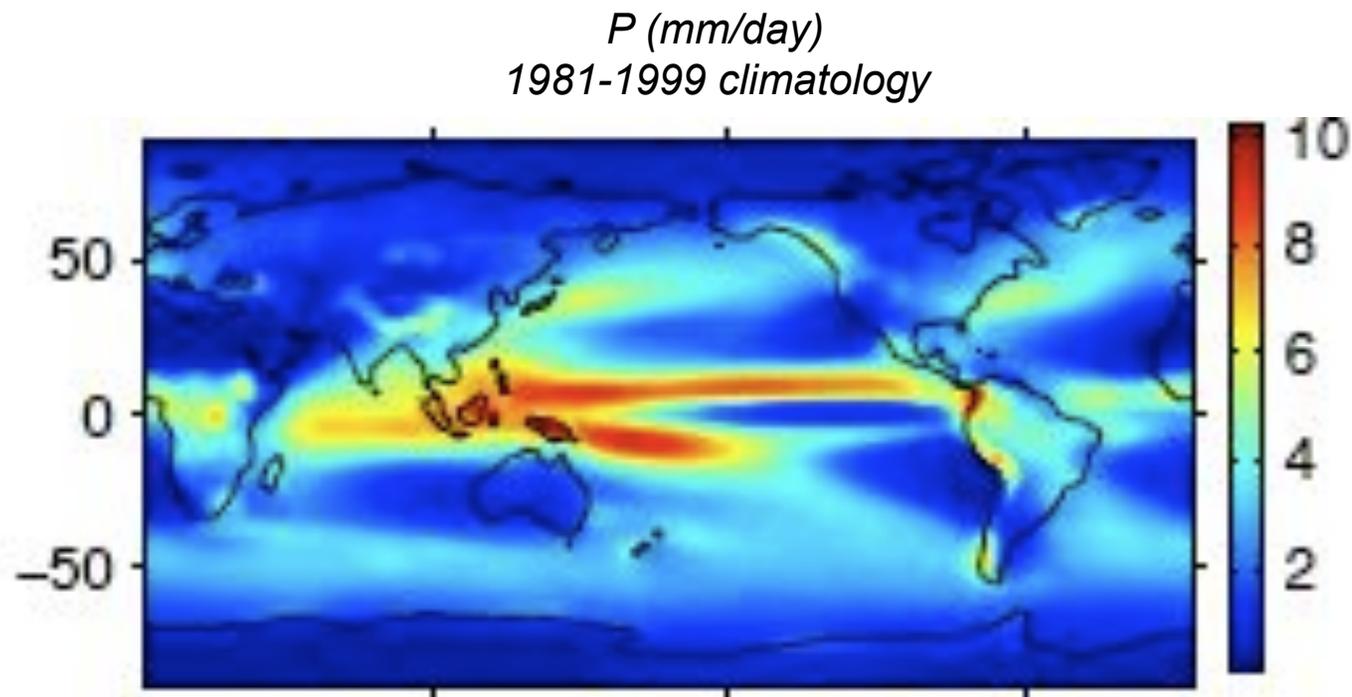


Coupled with circulation



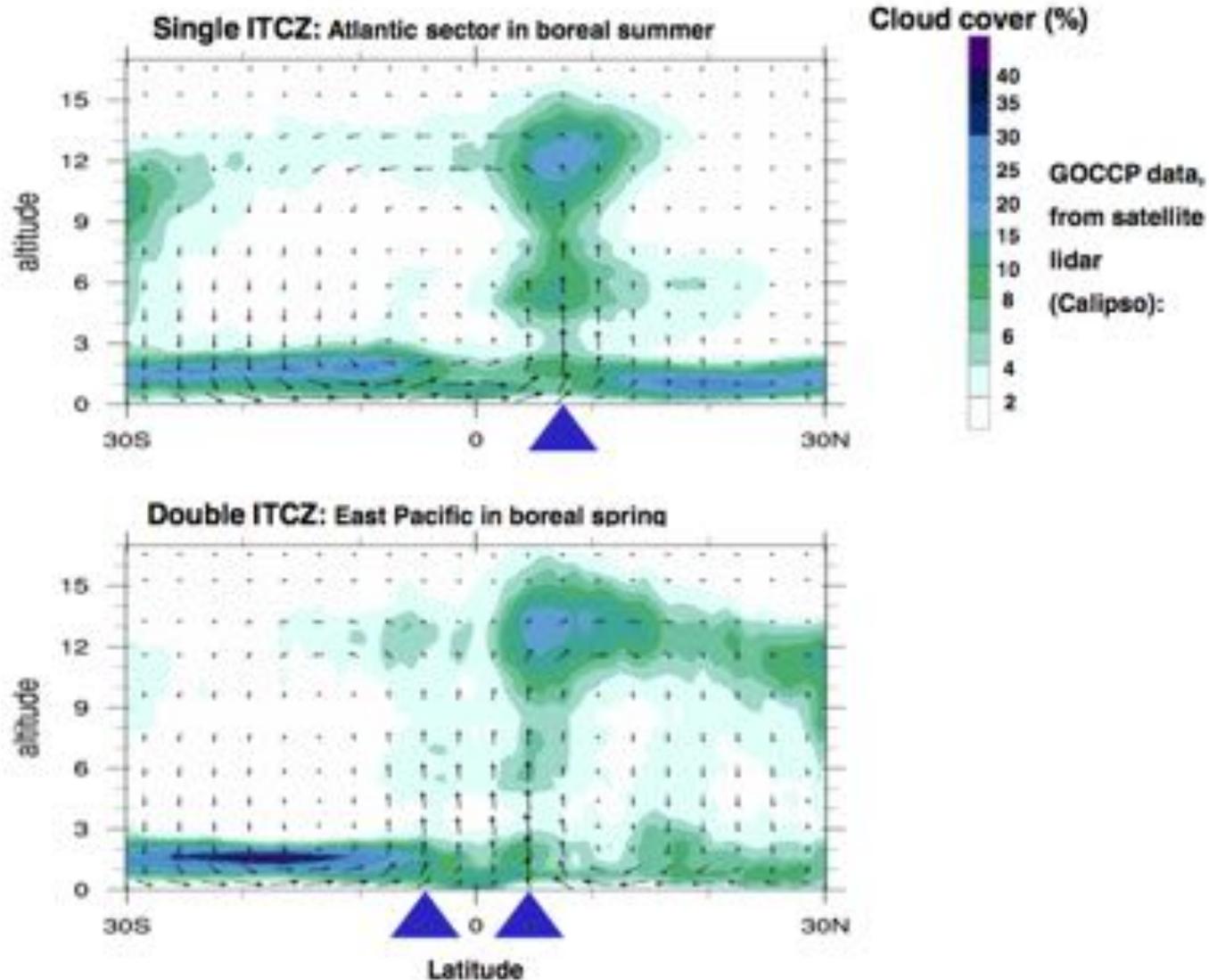
1. Tropics and subtropics : Hadley cell, ITCZ, Walker cell, El Nino, Monsoon, equatorial waves, Mesoscale Convective Systems, tropical cyclones
2. Extra tropics : Frontal systems, clouds embedded in cold and warm fronts

Clouds and Circulation: Hadley cell & ITCZ



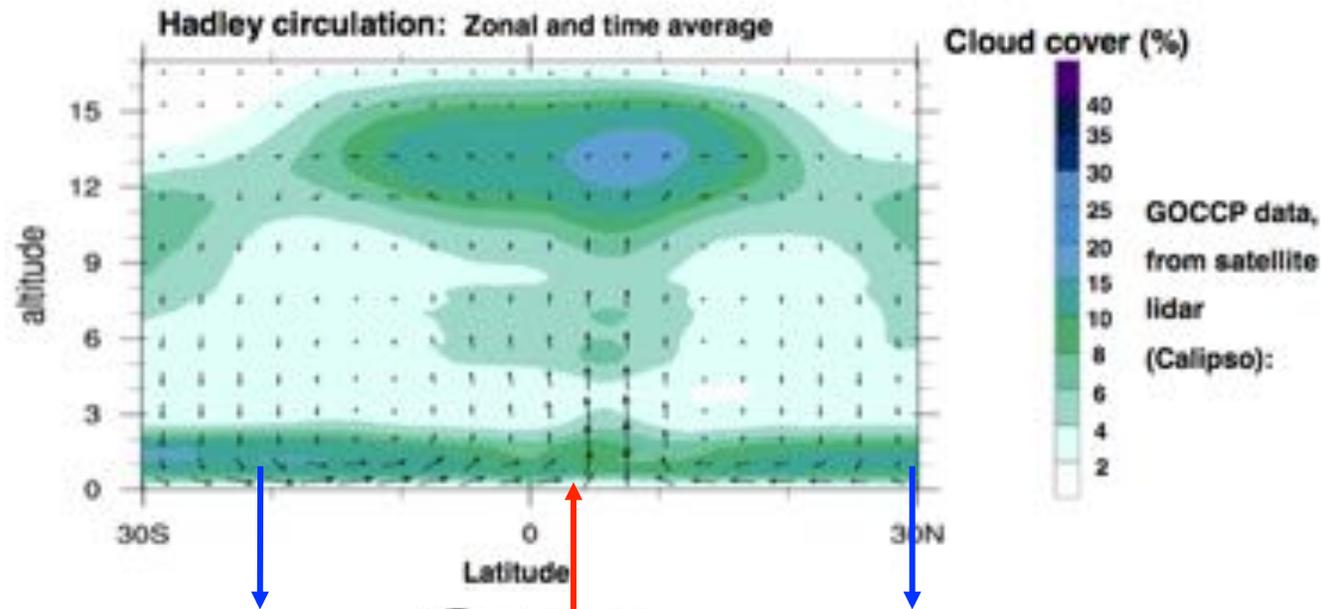
[Muller & O’Gorman, 2011]

Clouds and Circulation: Hadley cell & ITCZ

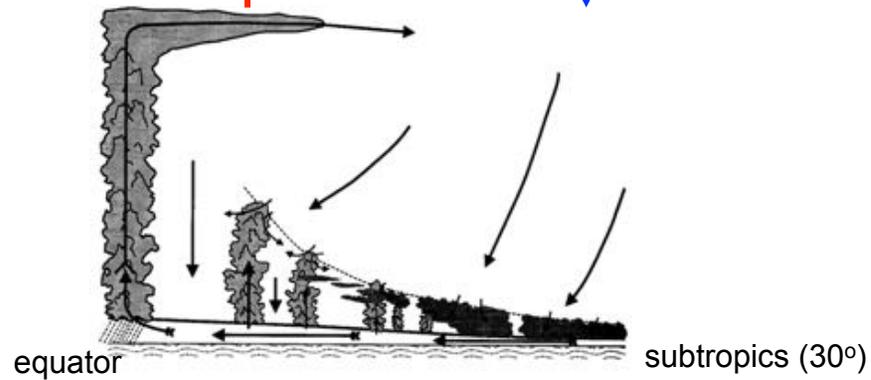


Courtesy Gilles Bellon

Clouds and Circulation: Hadley cell & ITCZ



Cloud types:



Deep cumulonimbus



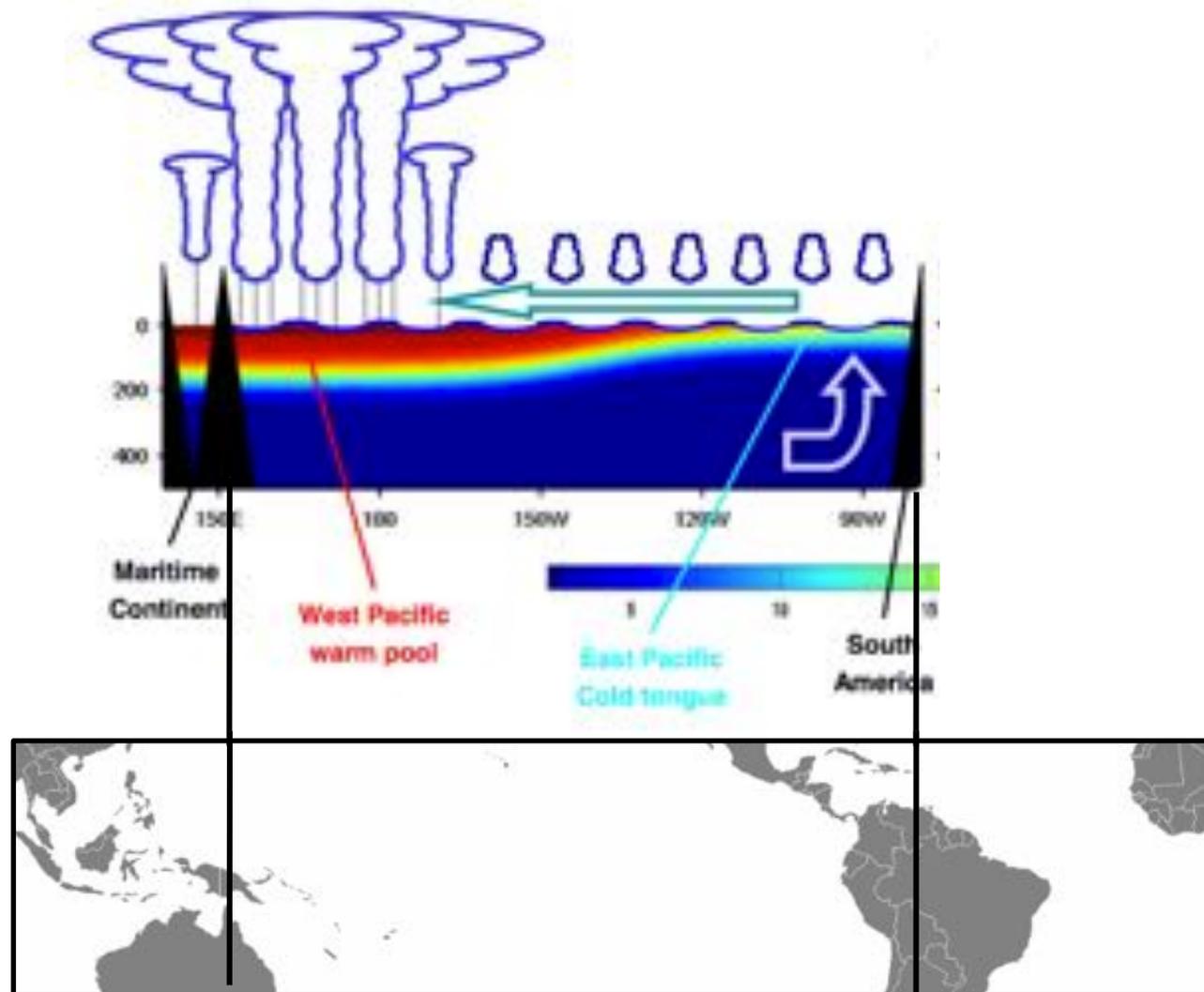
Fair weather cumulus



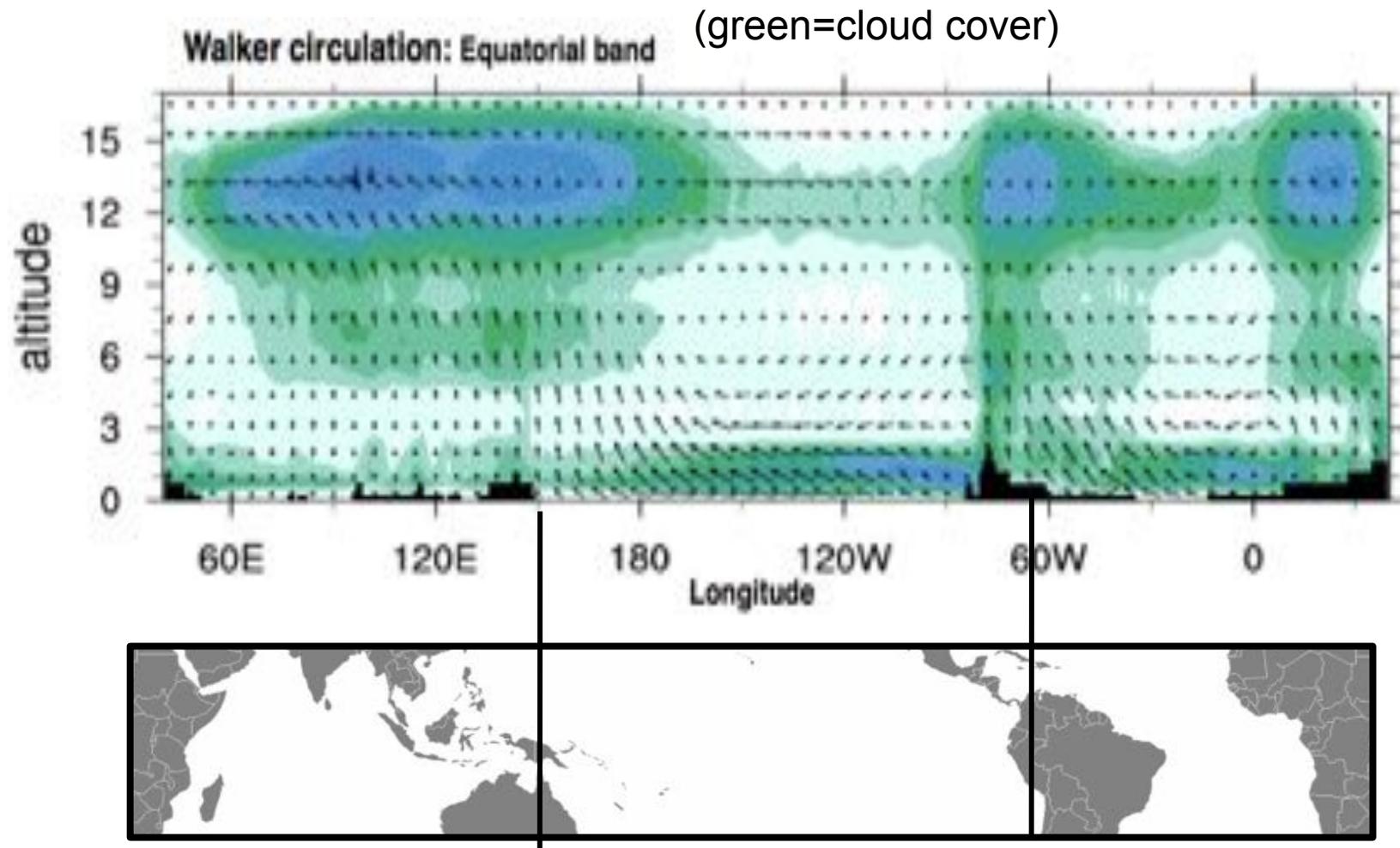
stratus

Clouds and Circulation: Walker cell

in the equatorial Pacific



Clouds and Circulation: Walker cell

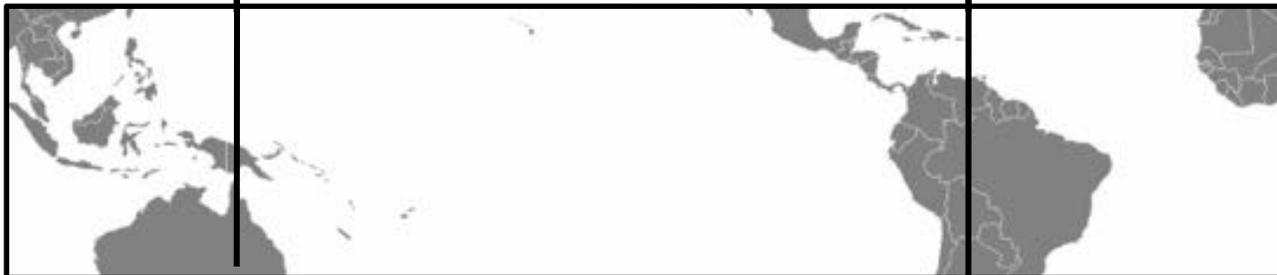
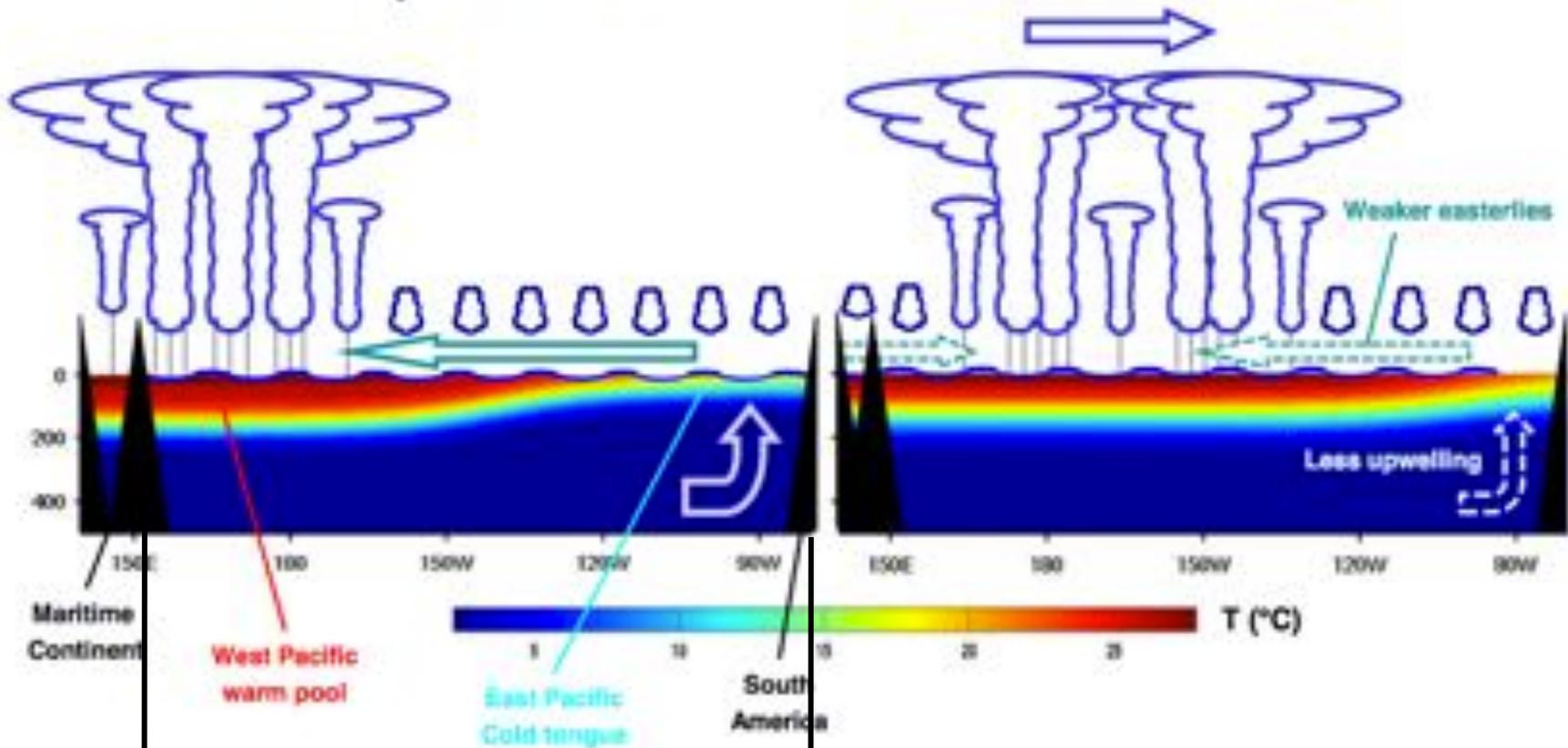


Courtesy Gilles Bellon

Clouds and Circulation: Walker cell & El Niño

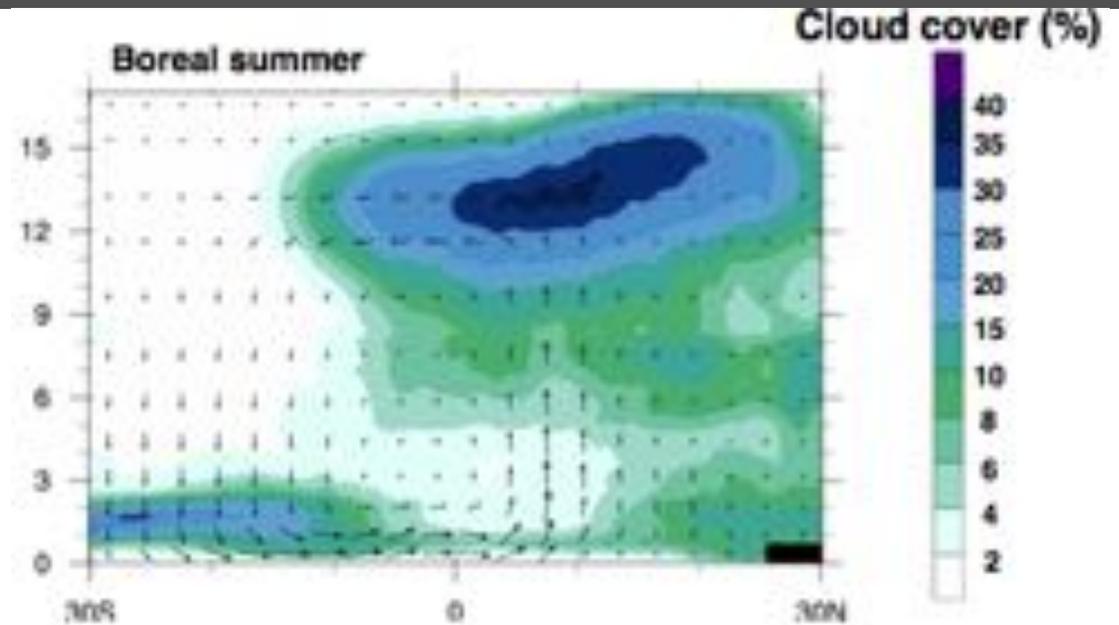
Normal conditions
in the equatorial Pacific

El Niño conditions
Eastward shift / extension of convection

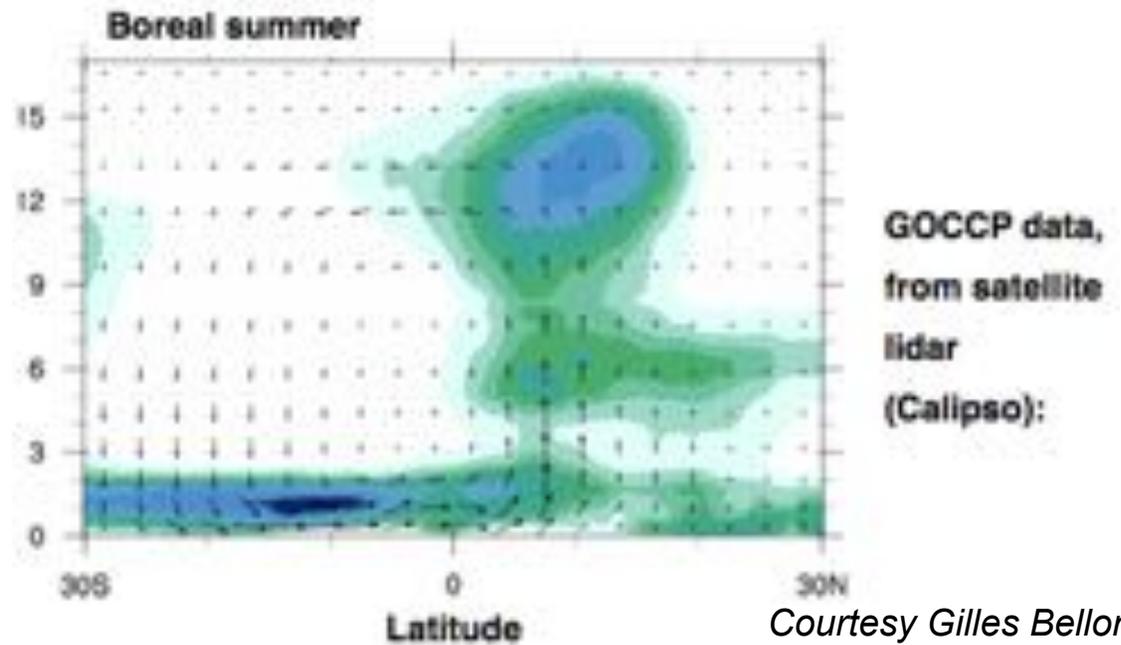


Clouds and Circulation: Monsoon

Asian monsoon



West-African monsoon



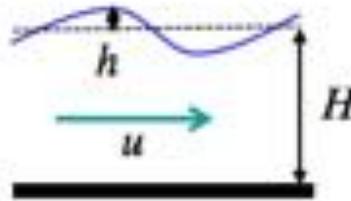
Courtesy Gilles Bellon

Clouds and Circulation: equatorial waves

Linearized shallow-water equations on a β -plane:

> Classical formulation:

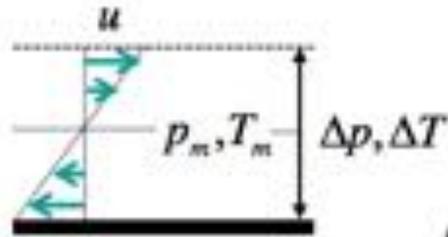
$$\begin{cases} \partial_t u - \beta y v = -g \partial_x h \\ \partial_t v + \beta y u = -g \partial_y h \\ \partial_t h + H(\partial_x u + \partial_y v) = 0 \end{cases}$$



[Matsuno 66]

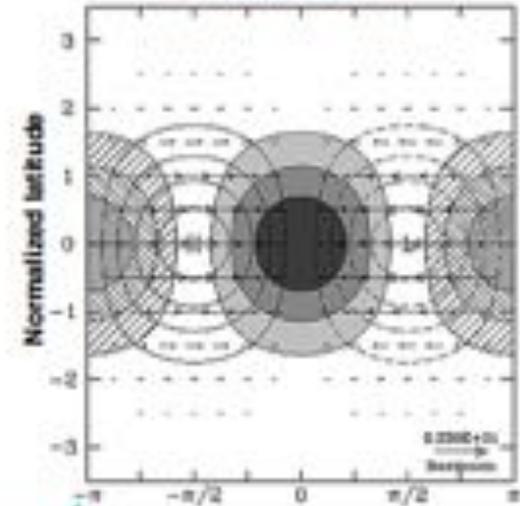
> Tropical atmosphere:

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

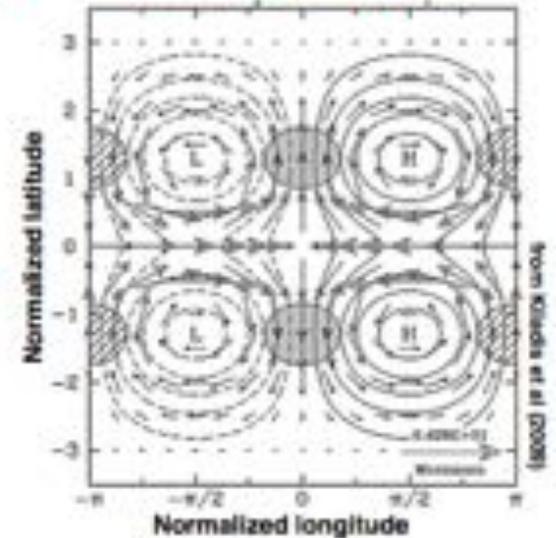


$$\alpha = \frac{\Delta p}{2 p_m} R$$

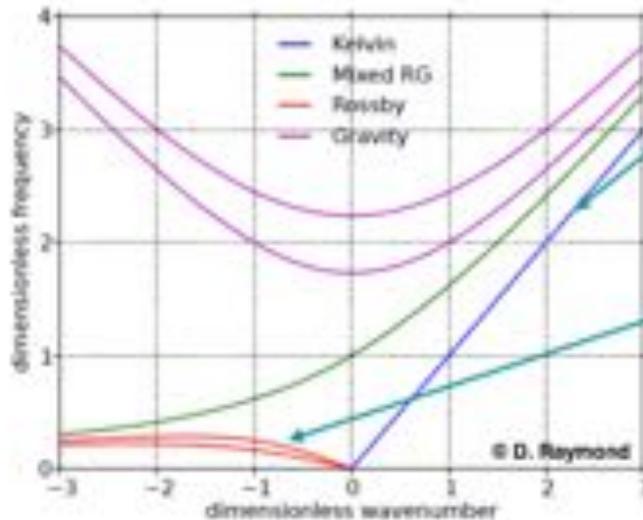
Kelvin wave



Equatorial Rossby wave



Dispersion diagram:

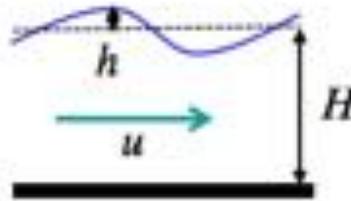


Clouds and Circulation: equatorial waves

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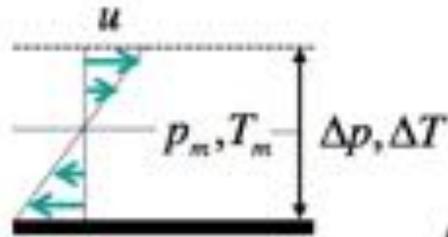
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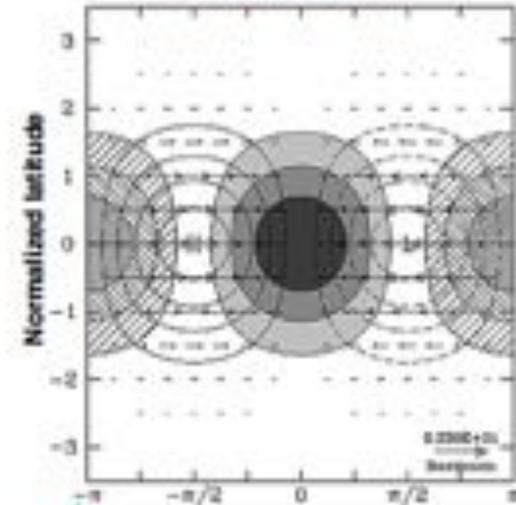
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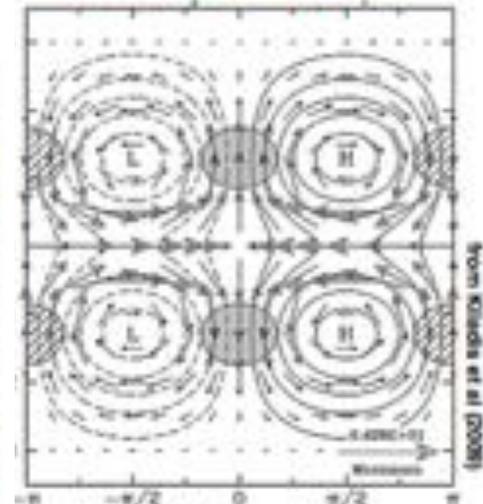


$$\alpha = \frac{\Delta p}{R}$$

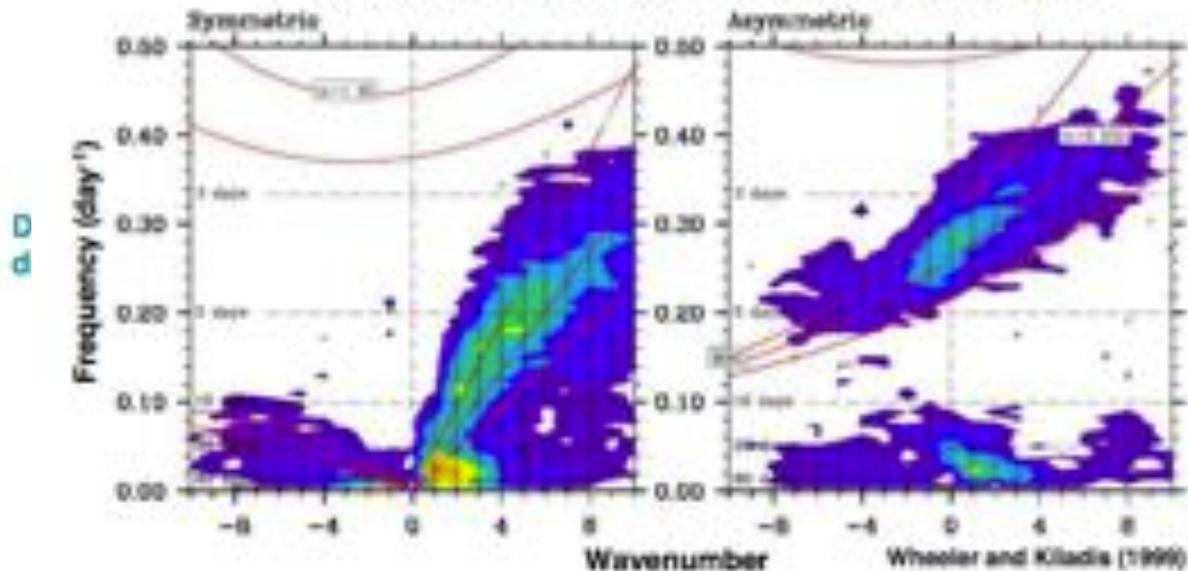
Kelvin wave



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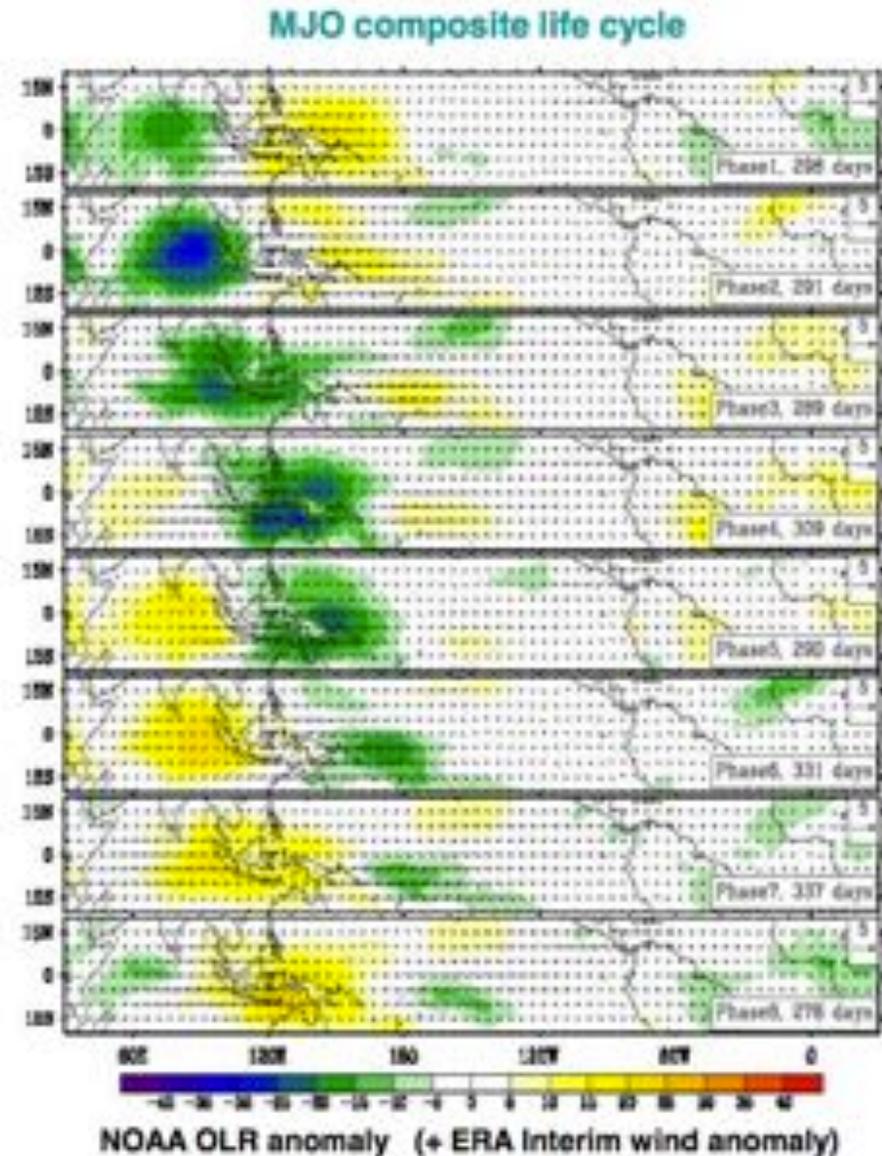
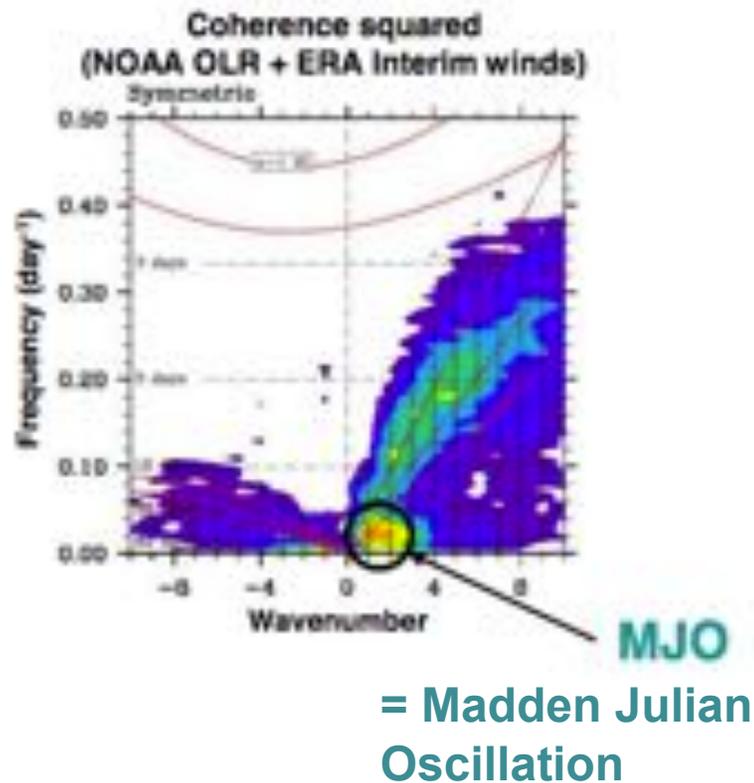


Coherence squared (NOAA OLR + ERA Interim winds)

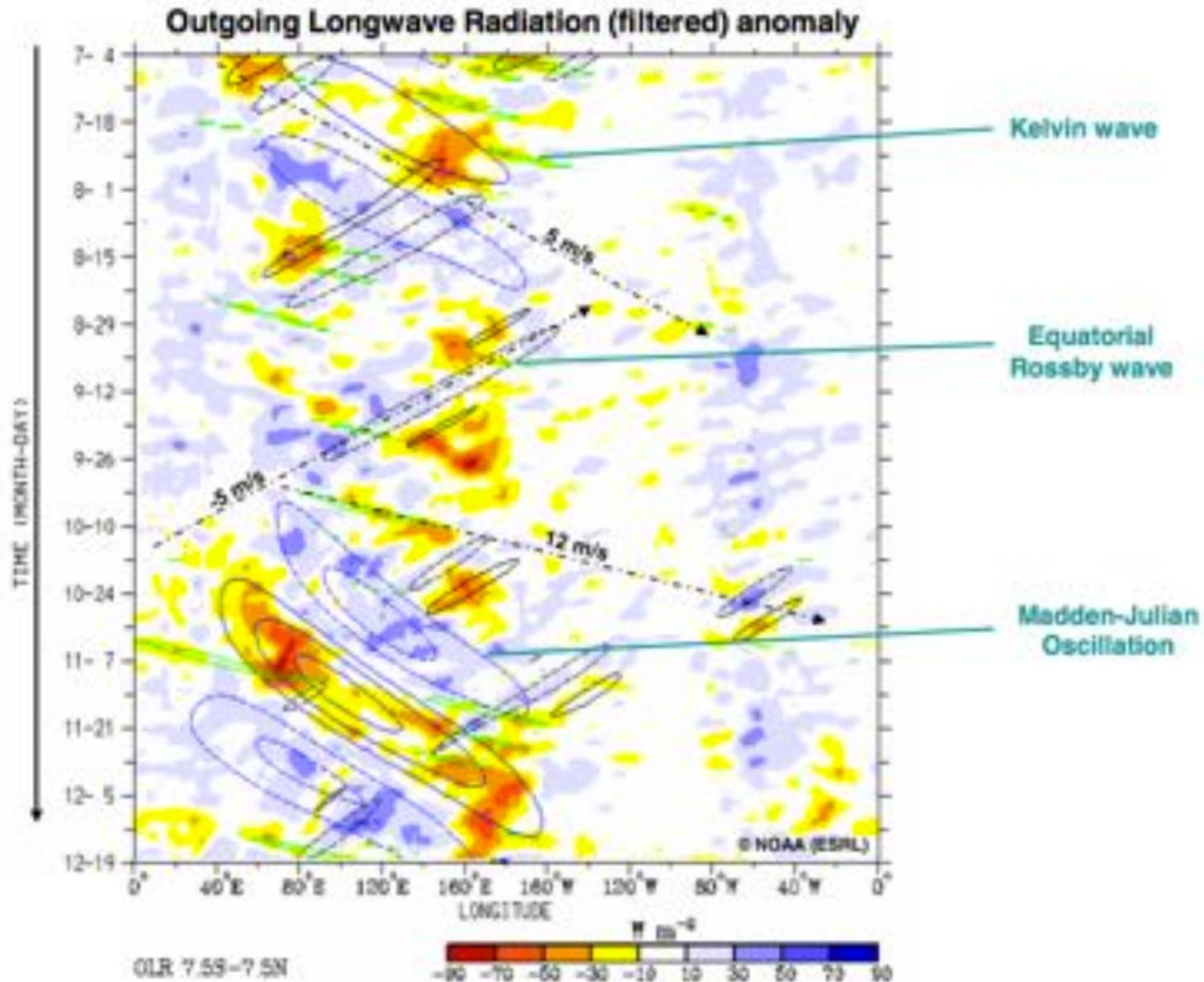


from Kiladis et al (2008)

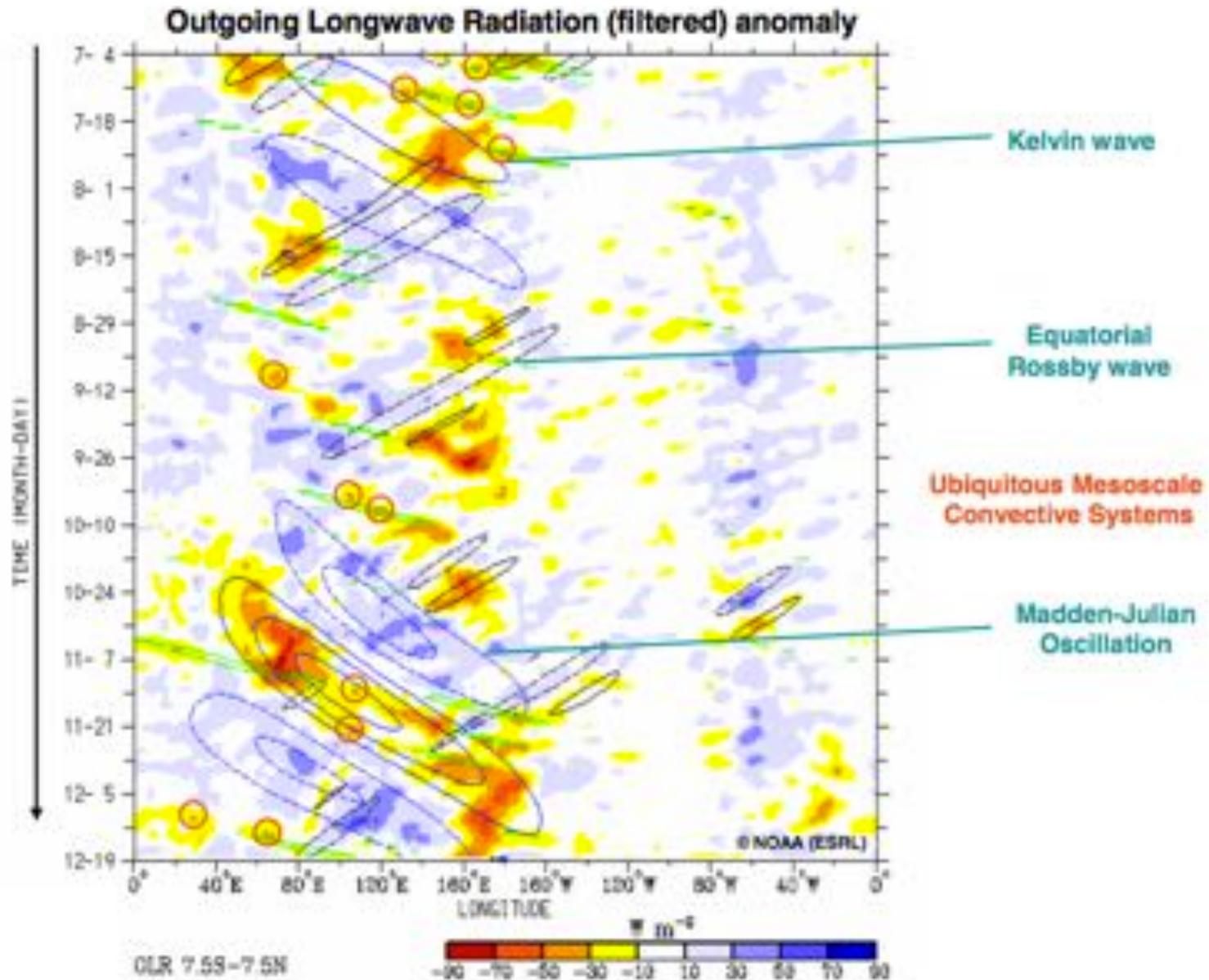
Clouds and Circulation: equatorial waves



Clouds and Circulation: equatorial waves



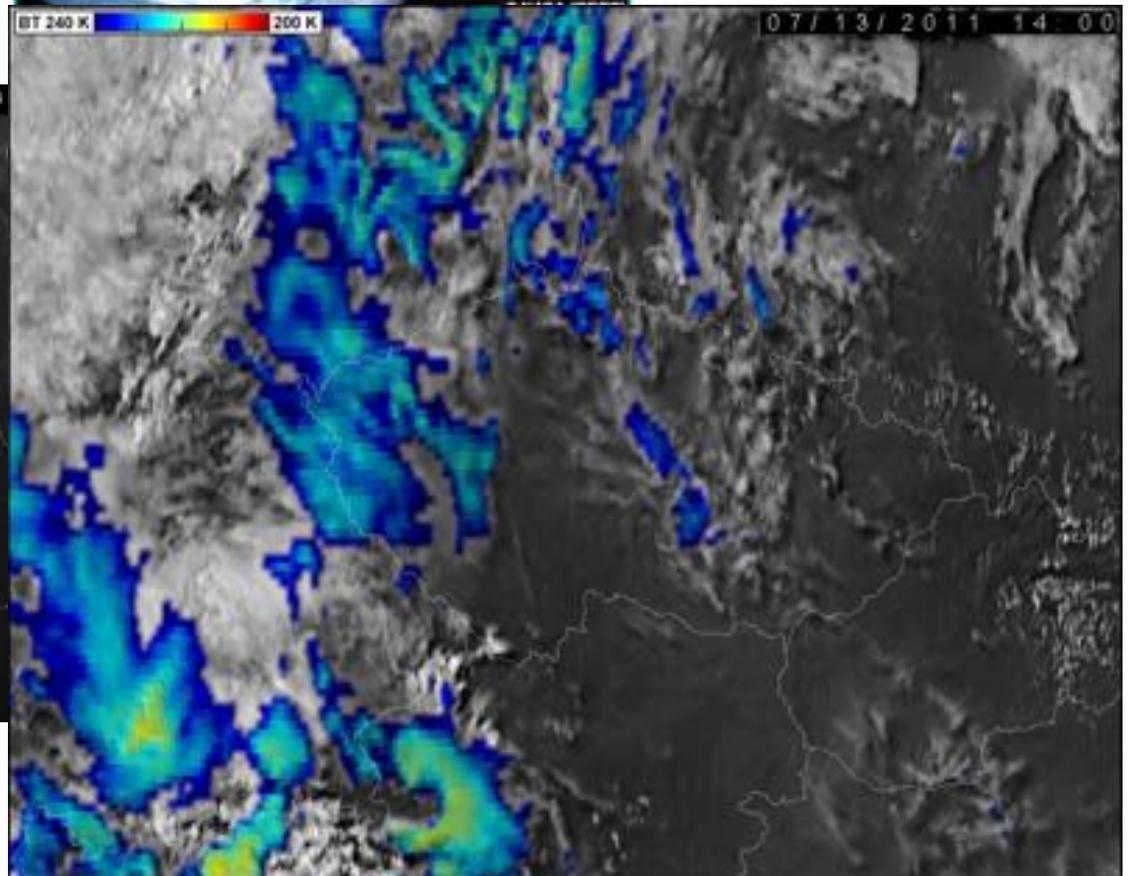
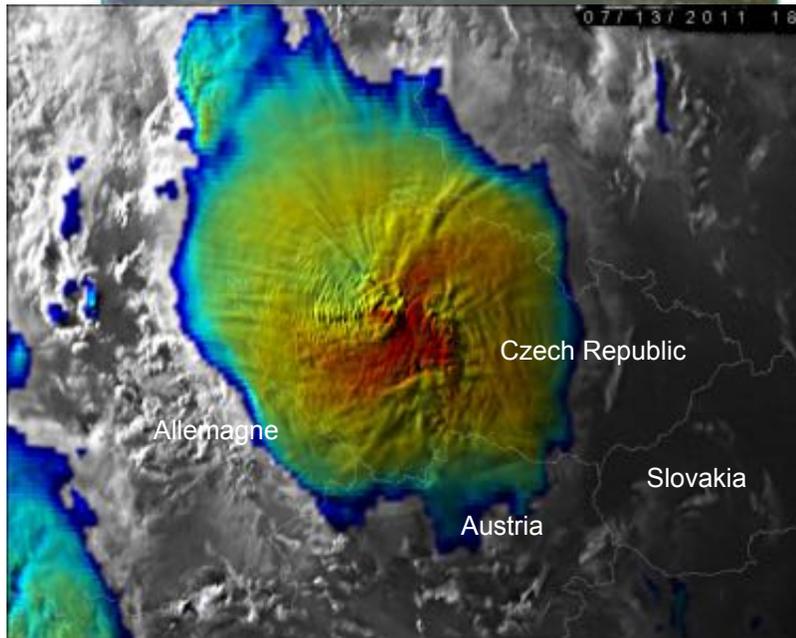
Clouds and Circulation: equatorial waves



Convective organization: mesoscale convective systems

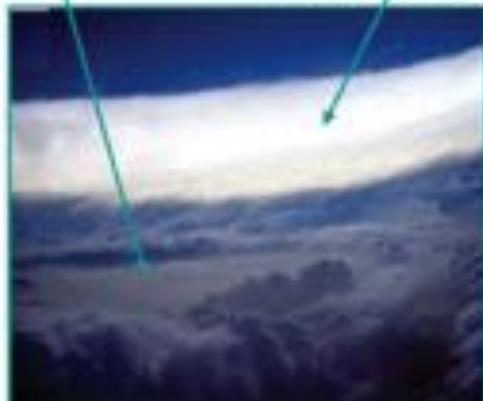
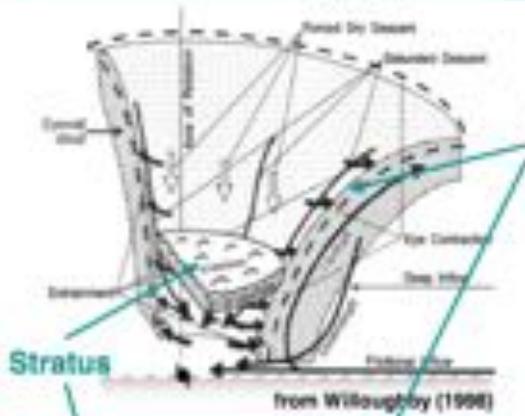


Mesoscale convective systems (MCSs)



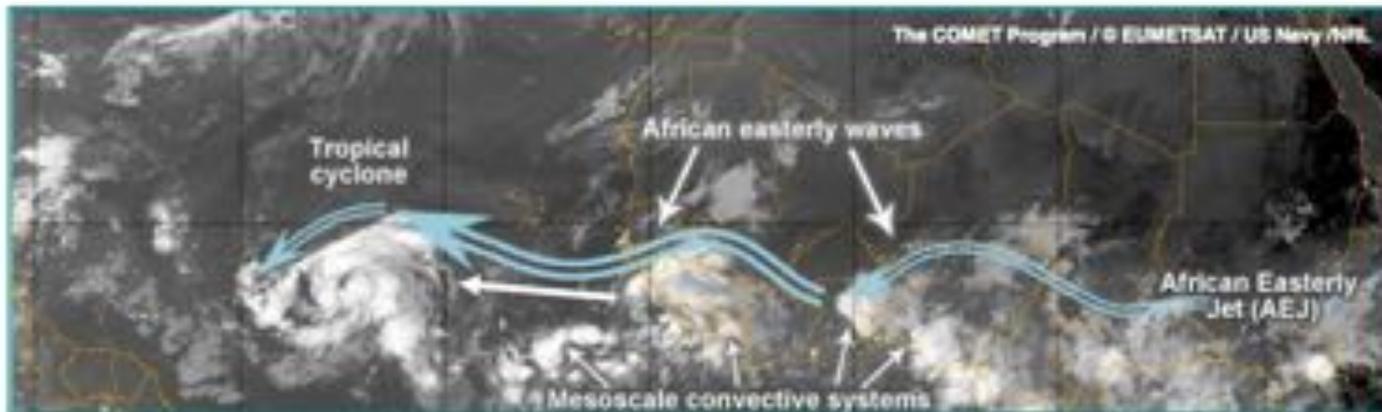
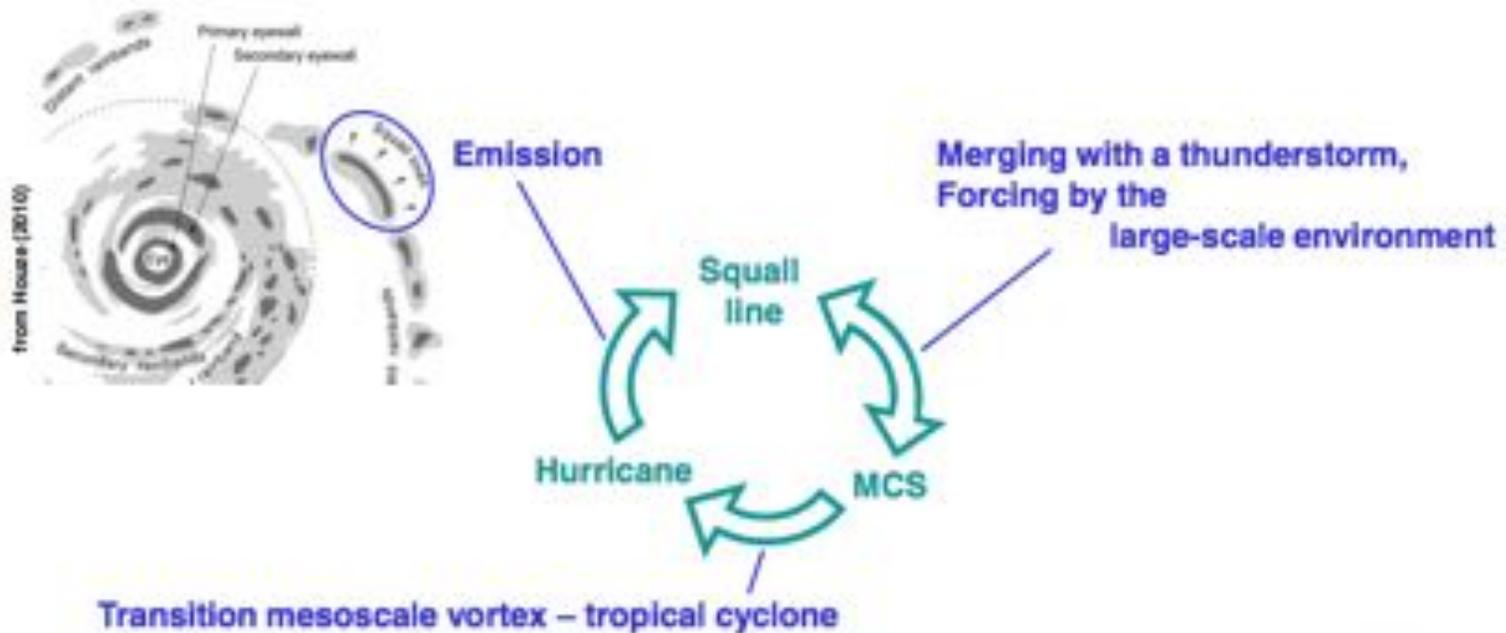
Convective organization: tropical cyclones

Tropical cyclones

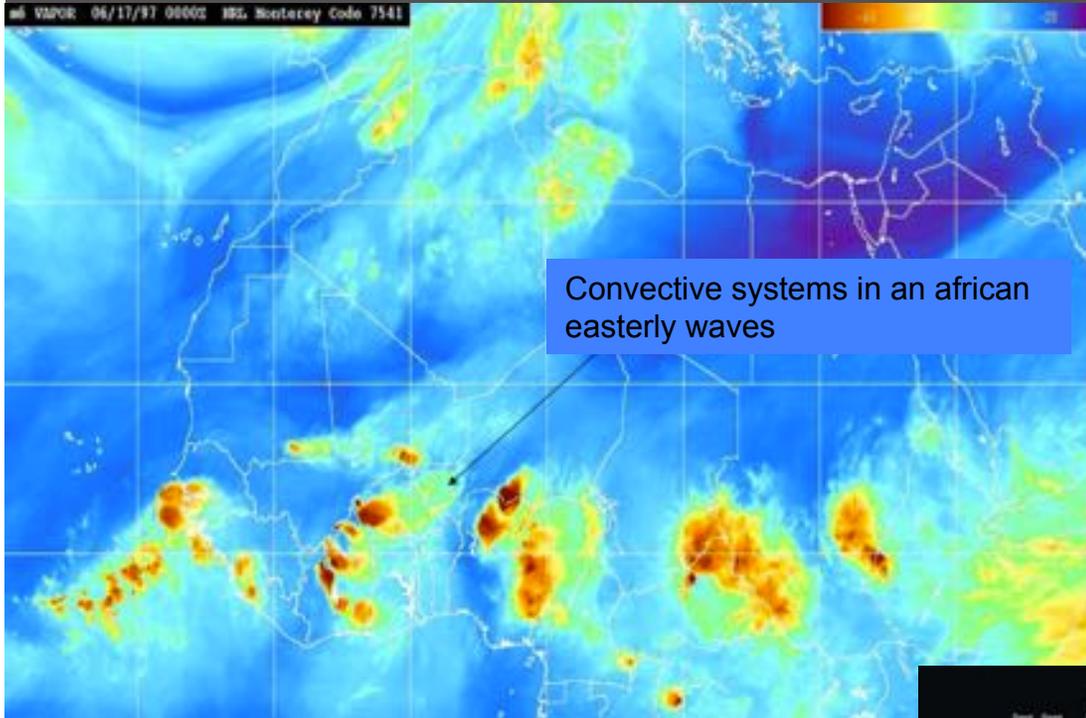


Convective organization: tropical cyclones

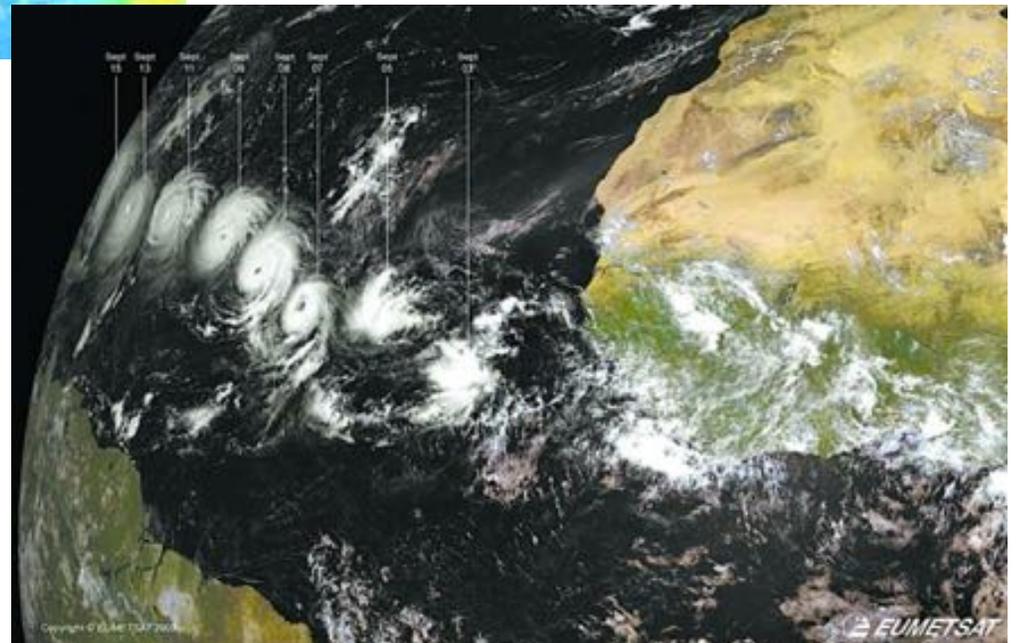
Transitions between organized structures



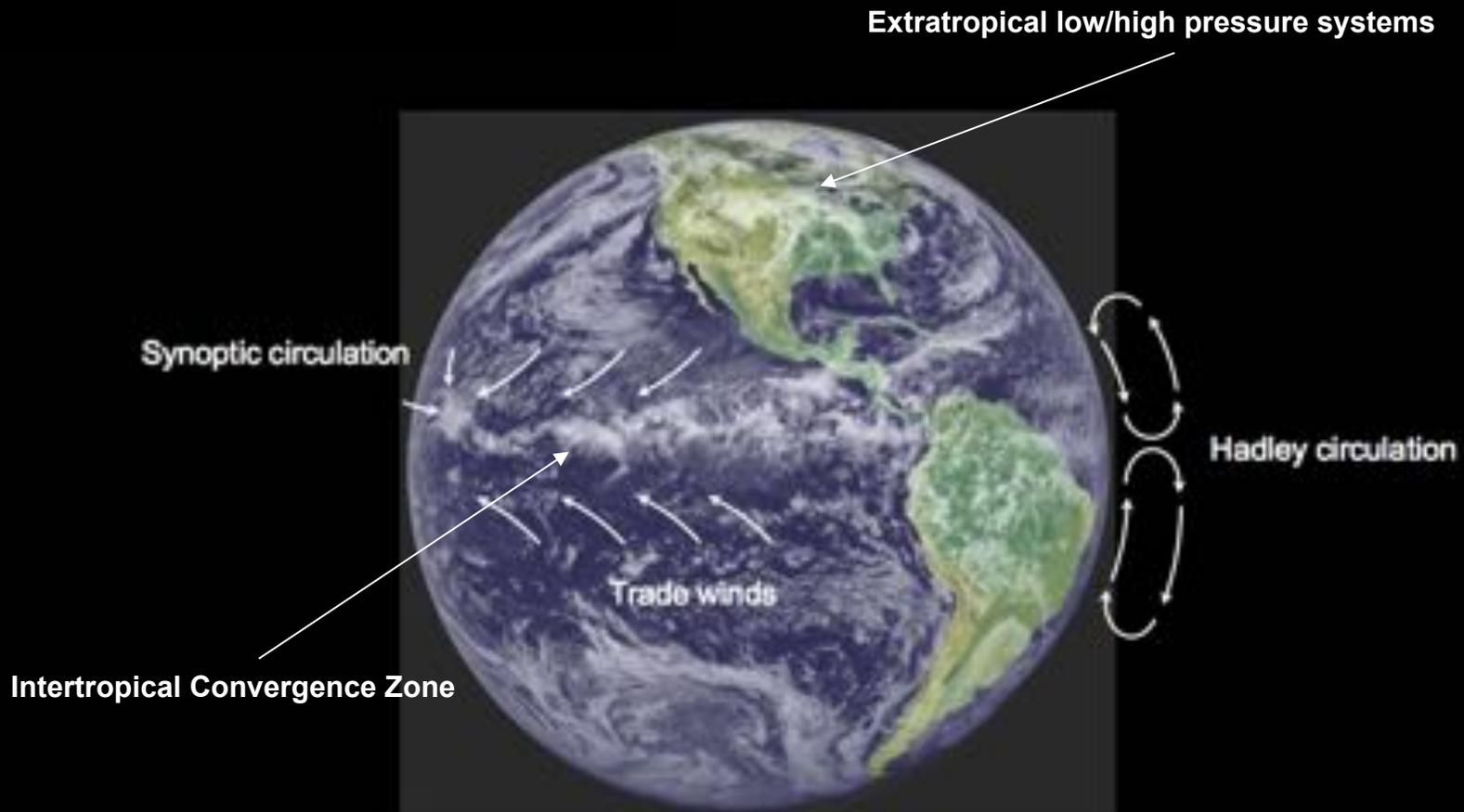
Convective organization: tropical cyclones



Hurricane Isabel off the coast of Africa



Coupled with circulation



1. Tropics and subtropics : Hadley cell, ITCZ, Walker cell, El Nino, Monsoon, equatorial waves, Mesoscale Convective Systems, tropical cyclones
2. Extra tropics : Frontal systems, clouds embedded in cold and warm fronts

Extra tropics : Clouds in frontal systems

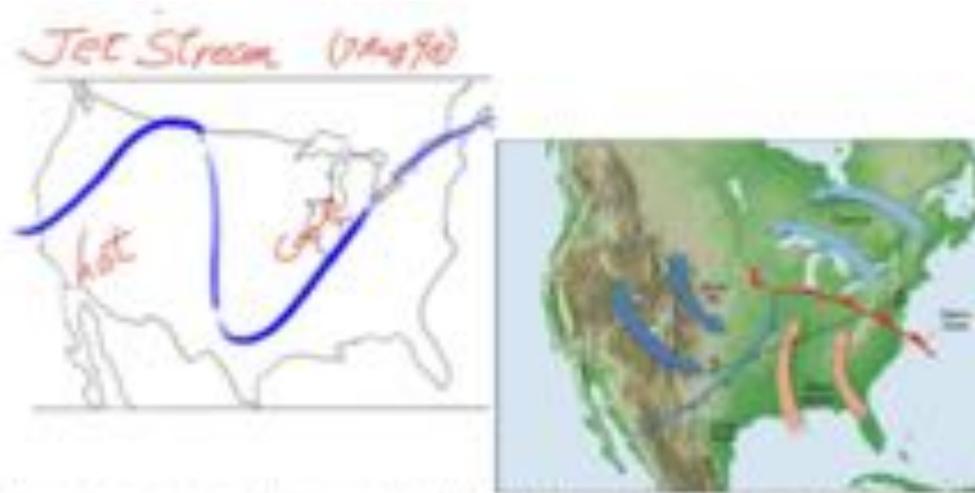
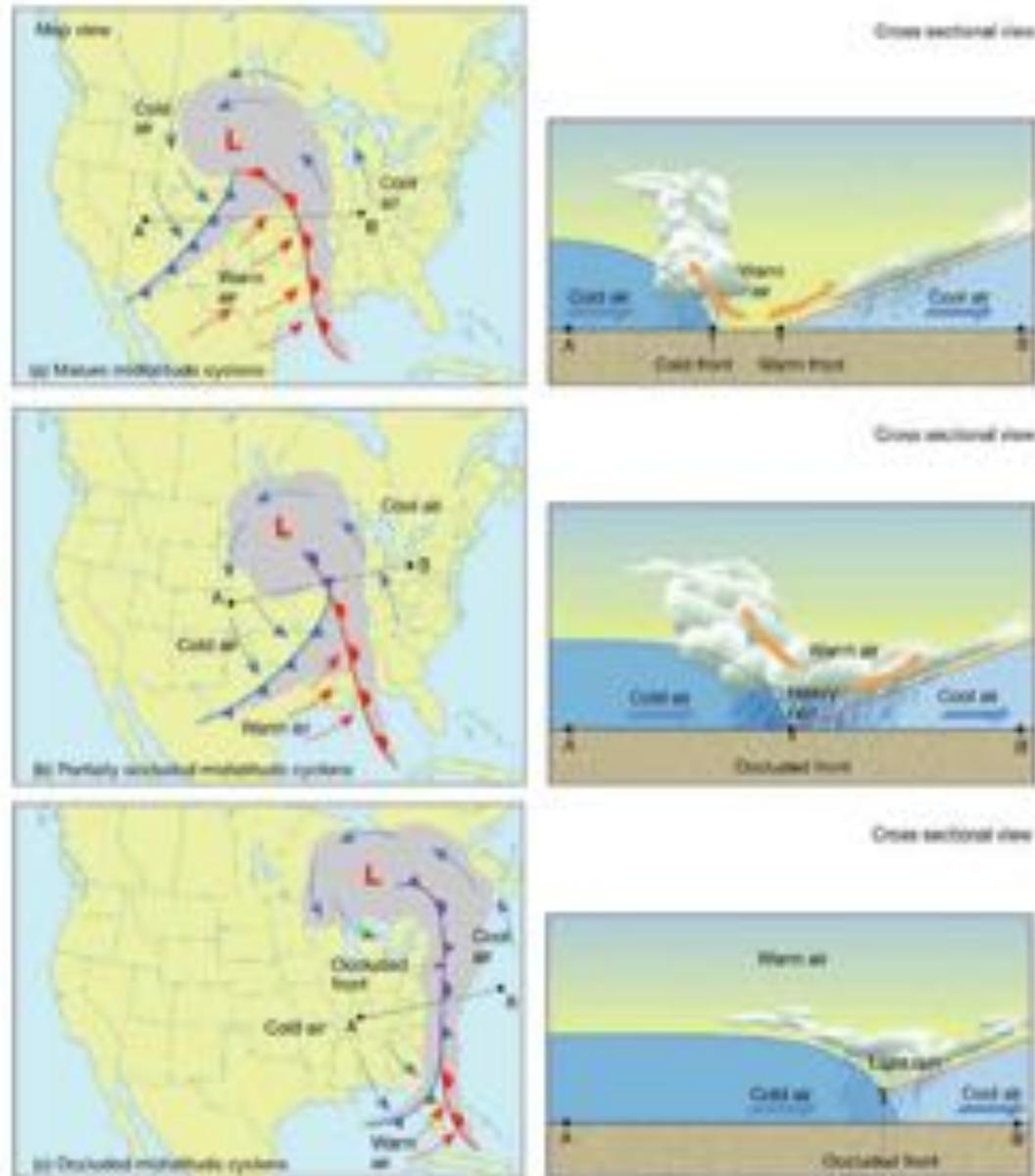


Figure 6 : représentation d'un courant-jet d'altitude. Figure 7 : représentation d'une dépression et ses fronts associés.



Figure 8 et 9 : cartes atmosphériques d'une situation météorologique (pression de surface et brises).

Extra tropics : Clouds in frontal systems



Clouds from space

Clouds from space

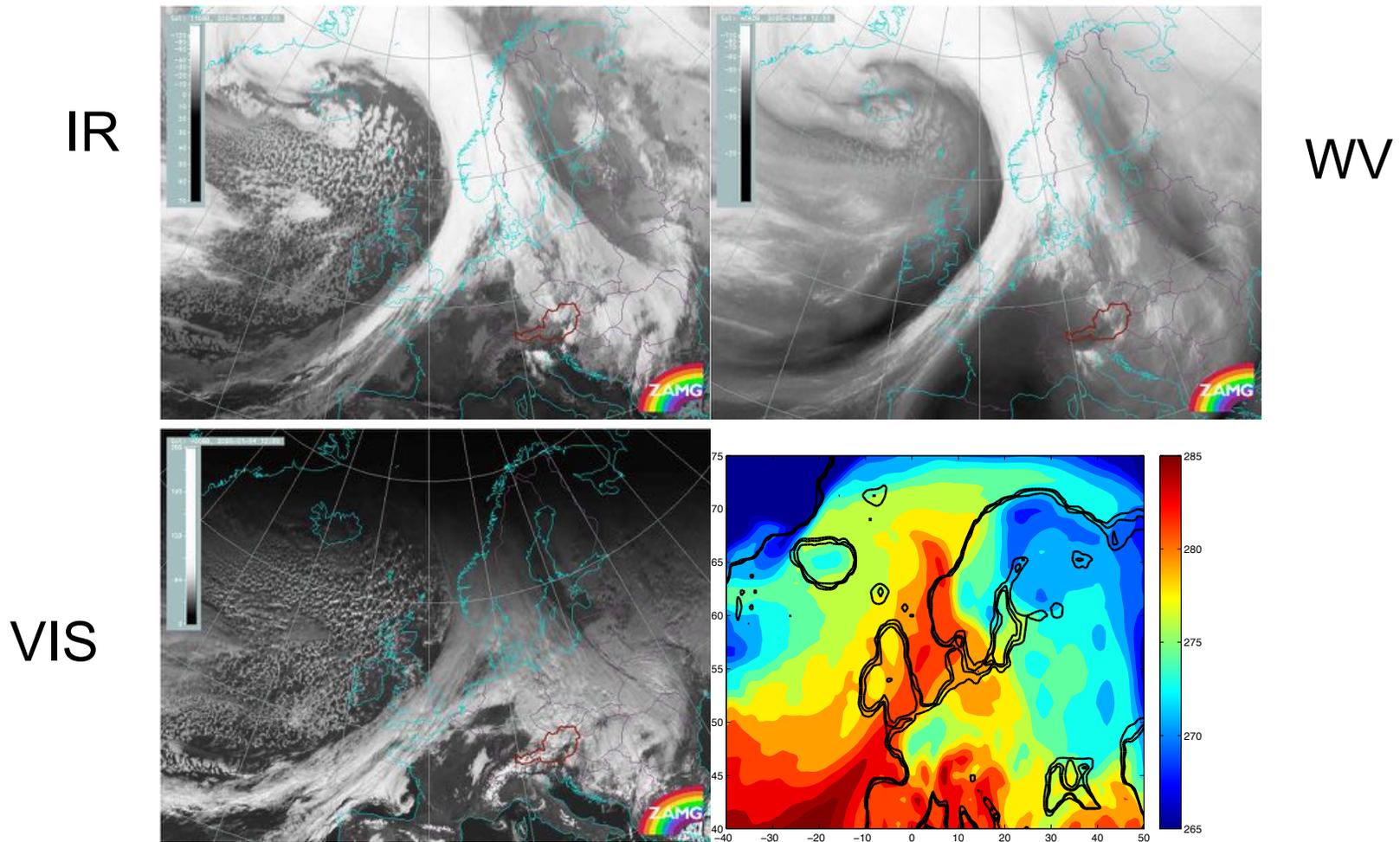


Figure 16 : image satellite (canal infrarouge) correspondant à un front froid et un front chaud.
Figure 17 : canal vapeur d'eau. Figure 18 : canal visible.