

# Clouds and turbulent moist convection

*Caroline Muller*  
*Laboratoire de Météorologie Dynamique*  
*Ecole Normale Supérieure*



What are clouds ?

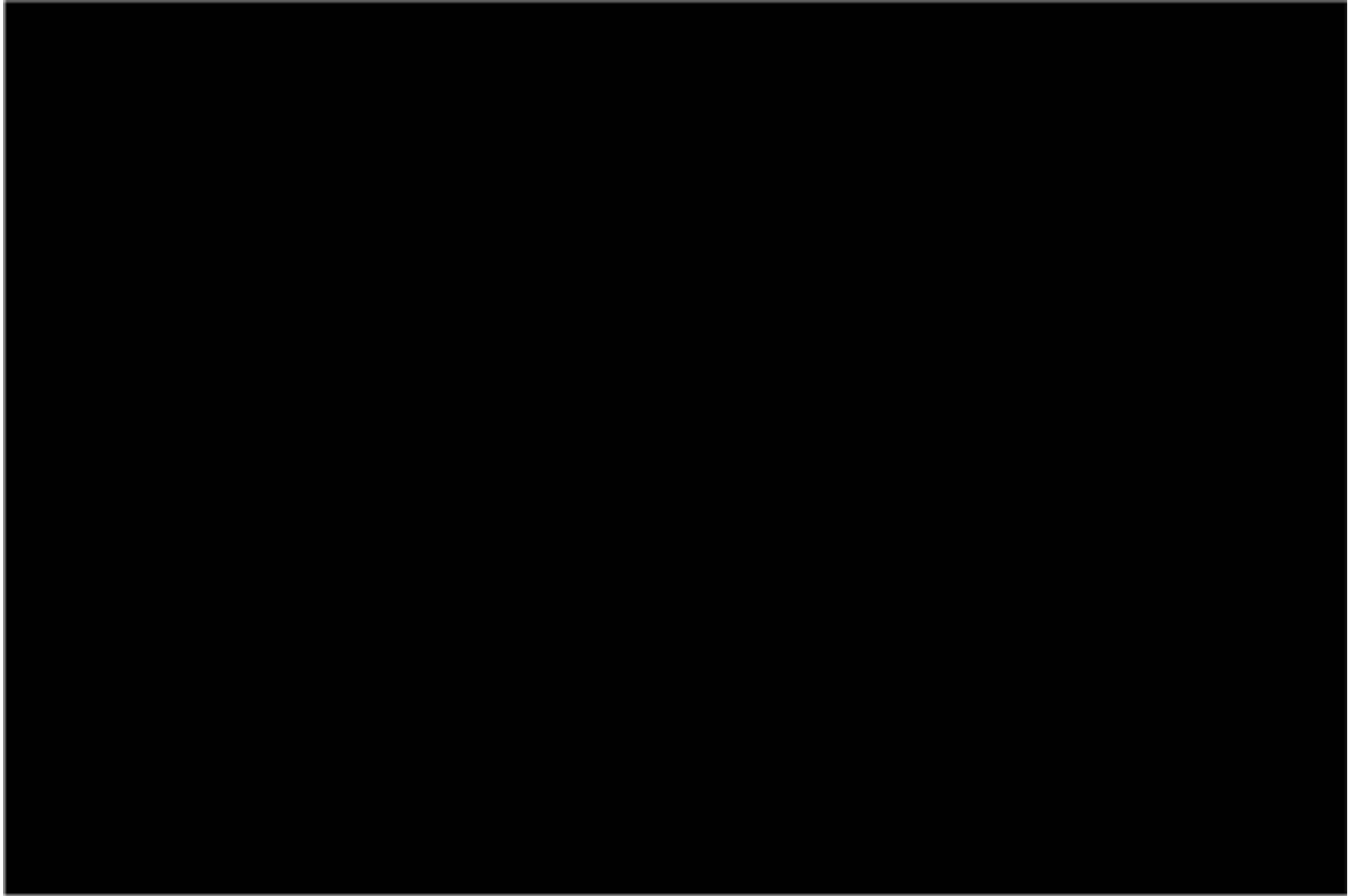


# Cloud formation



*Courtesy : Octave Tessiot*

# Cloud formation



*Courtesy : Octave Tessiot*

# Clouds and turbulent moist 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 turbulent moist convection

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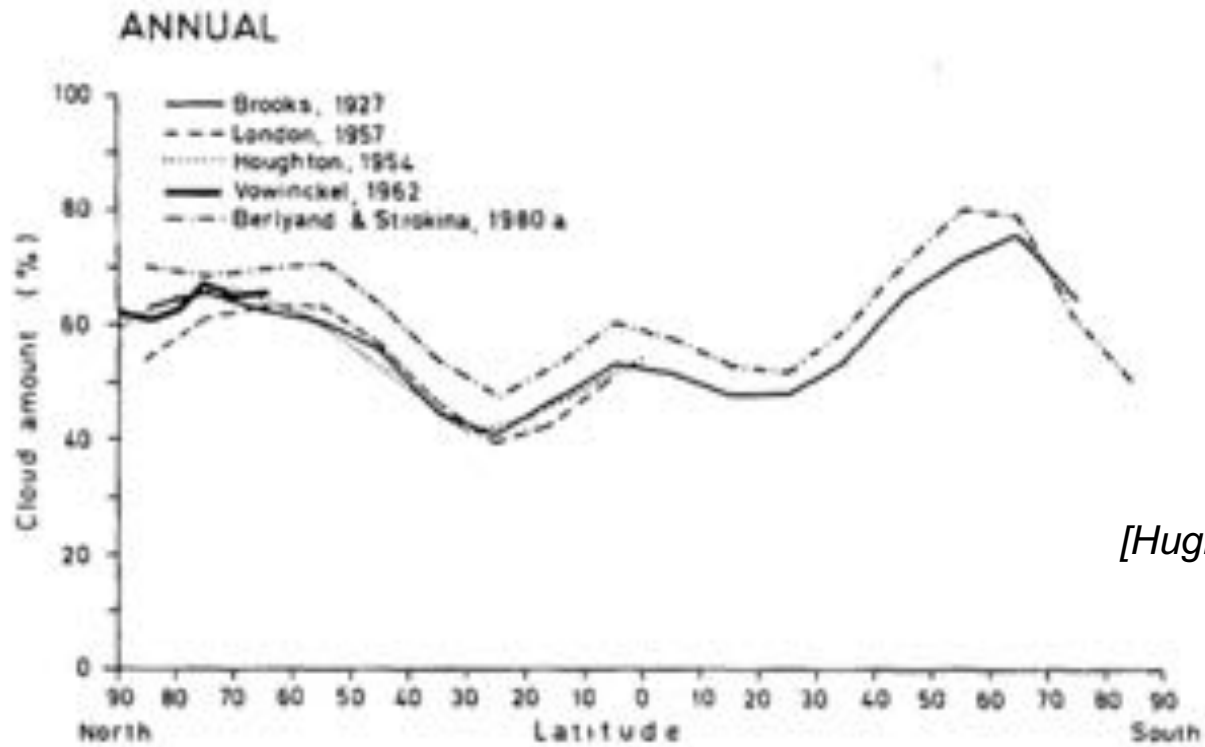


and clouds

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# What are clouds ?

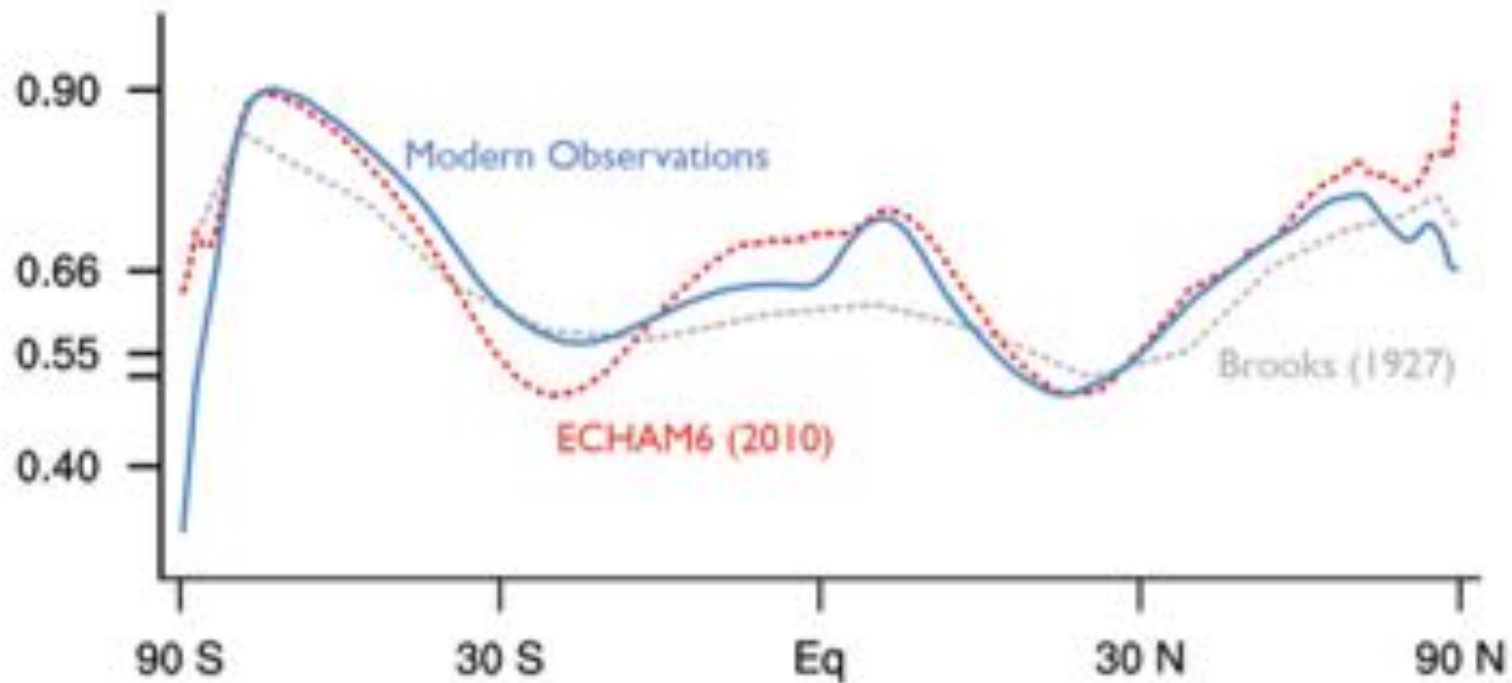
## Distribution of cloud amount



[Hughes 84]

# What are clouds ?

Cloud amount was underestimated



*Courtesy Bjorn Stevens*



# What are clouds? Key actors of climate

An era of blooming cloud and climate science

The New York Times

## Environment

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Inappropriate  Repetitive  Irrelevant

TEMPERATURE RISING


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

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 dismissed.



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Josh Harnett/The New York Times

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# CNN

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## Climate change: Can we even try? 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... We Do It? Should...

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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.

HOME SEARCH

## The New York Times

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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



# What are 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

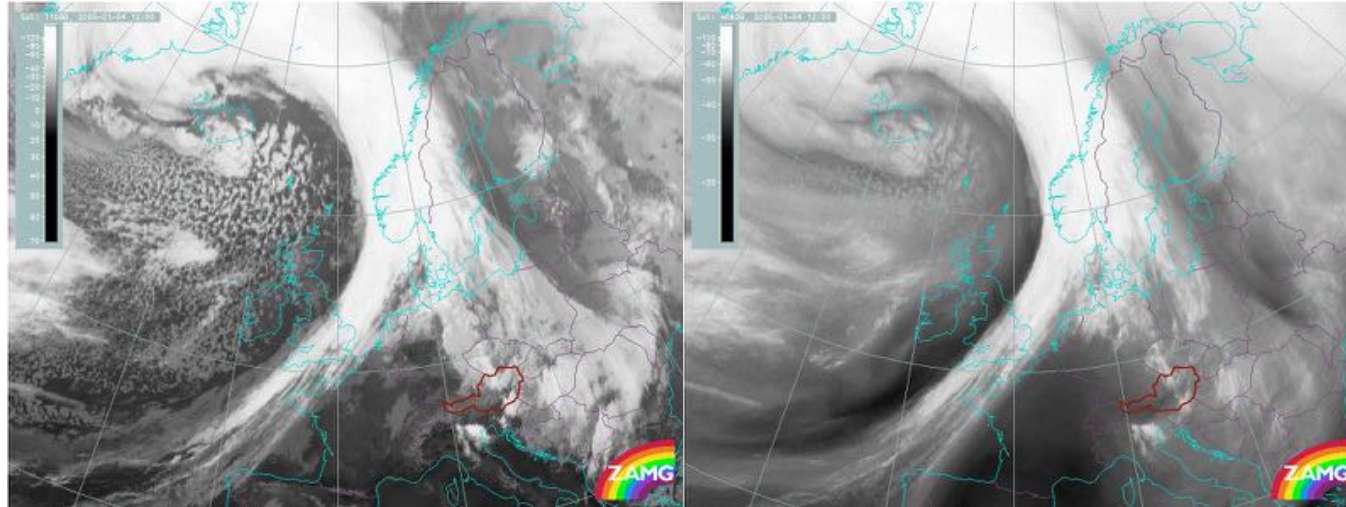
Documents

[← Back to Grand Challenges Overview](#)

# Cloud visualization from space

IR

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

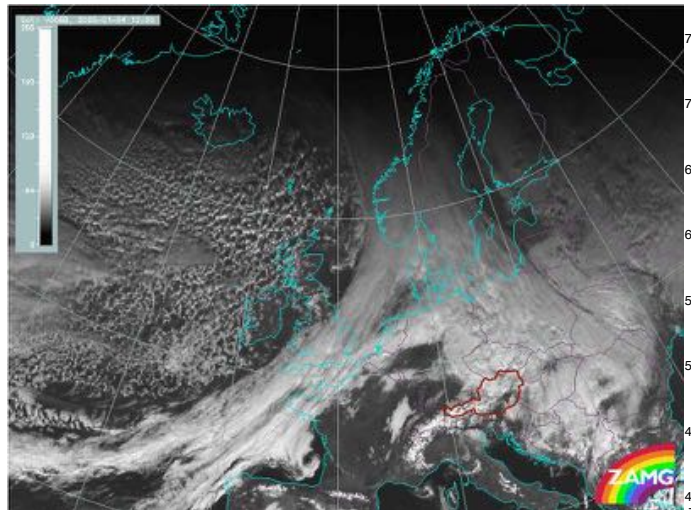


WV

Info on flow and water vapor **advection**.  
Smooth field

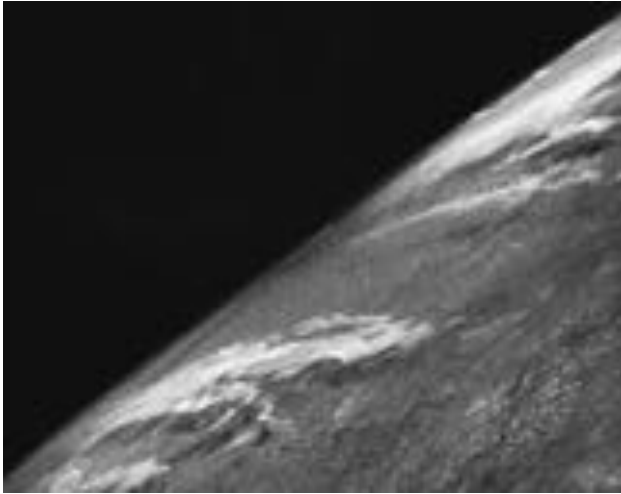
VIS

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



# Cloud visualization from space

Earth from rocket 1946



Earth From Weather Satellite 1960



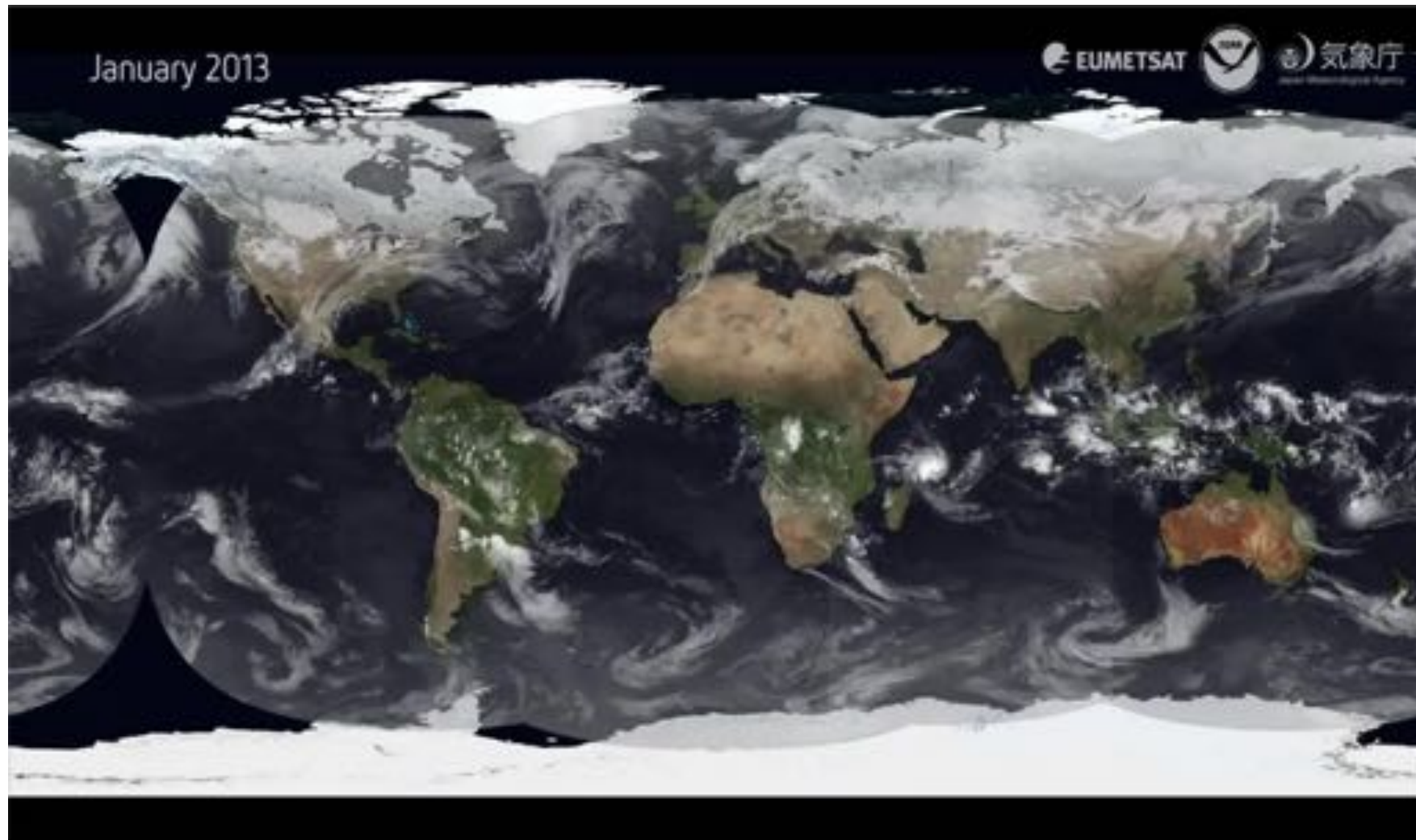
Blue Marble 1972



Tintin on the moon 1952



# Distribution of clouds



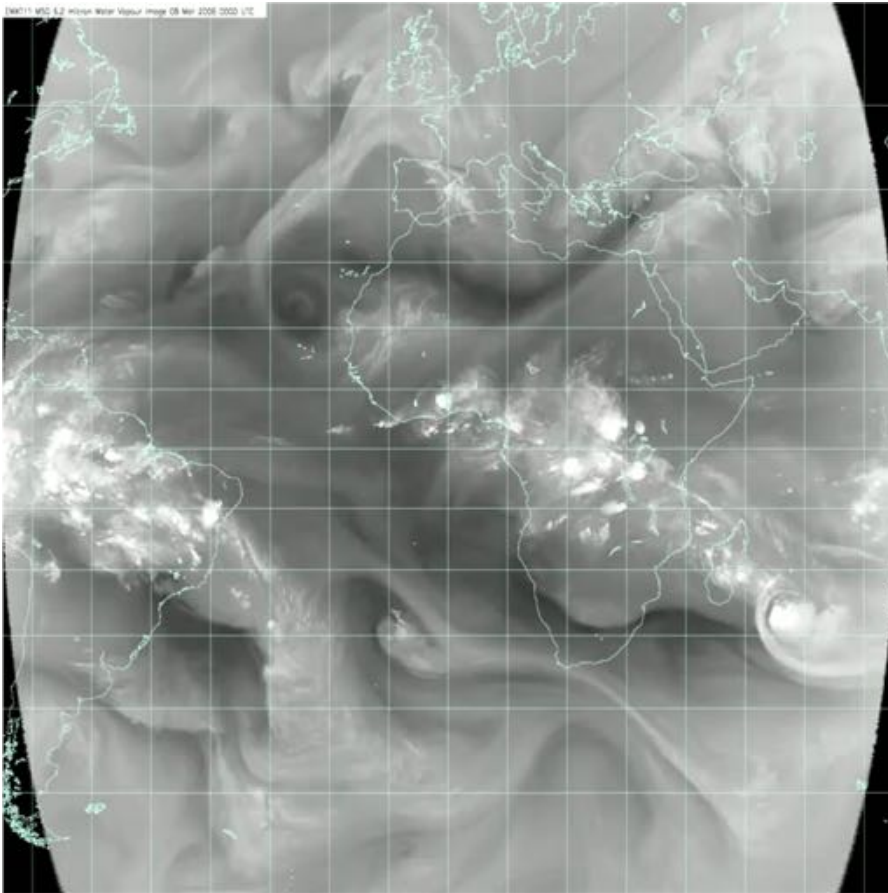
## **A Year of Weather 2015**

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

# Distribution of clouds

*Water vapor from satellite*



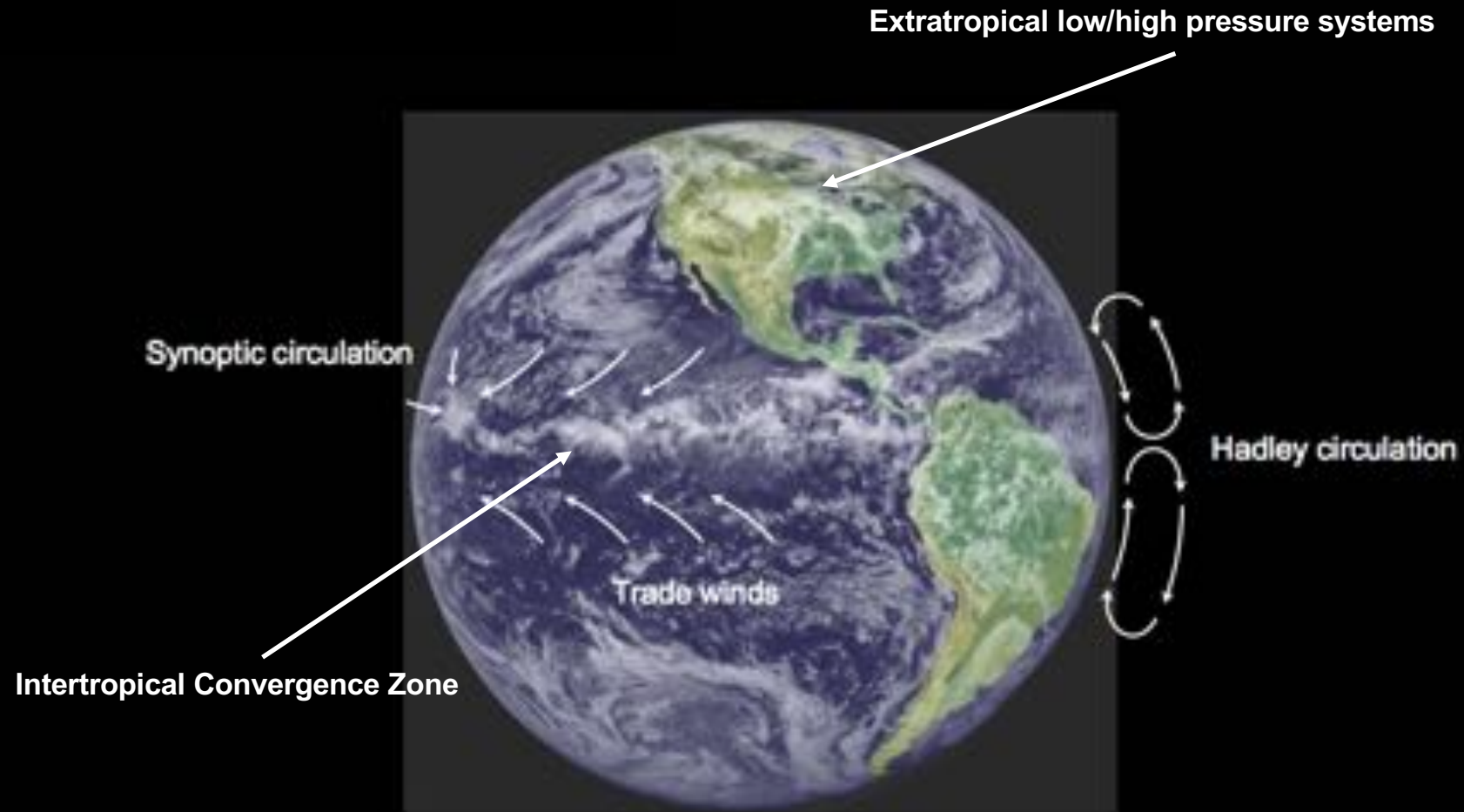
Larger-scale  
extratropical  
convection

Small-scale tropical  
« pop corn » convection

*Deep convective system over Brazil*



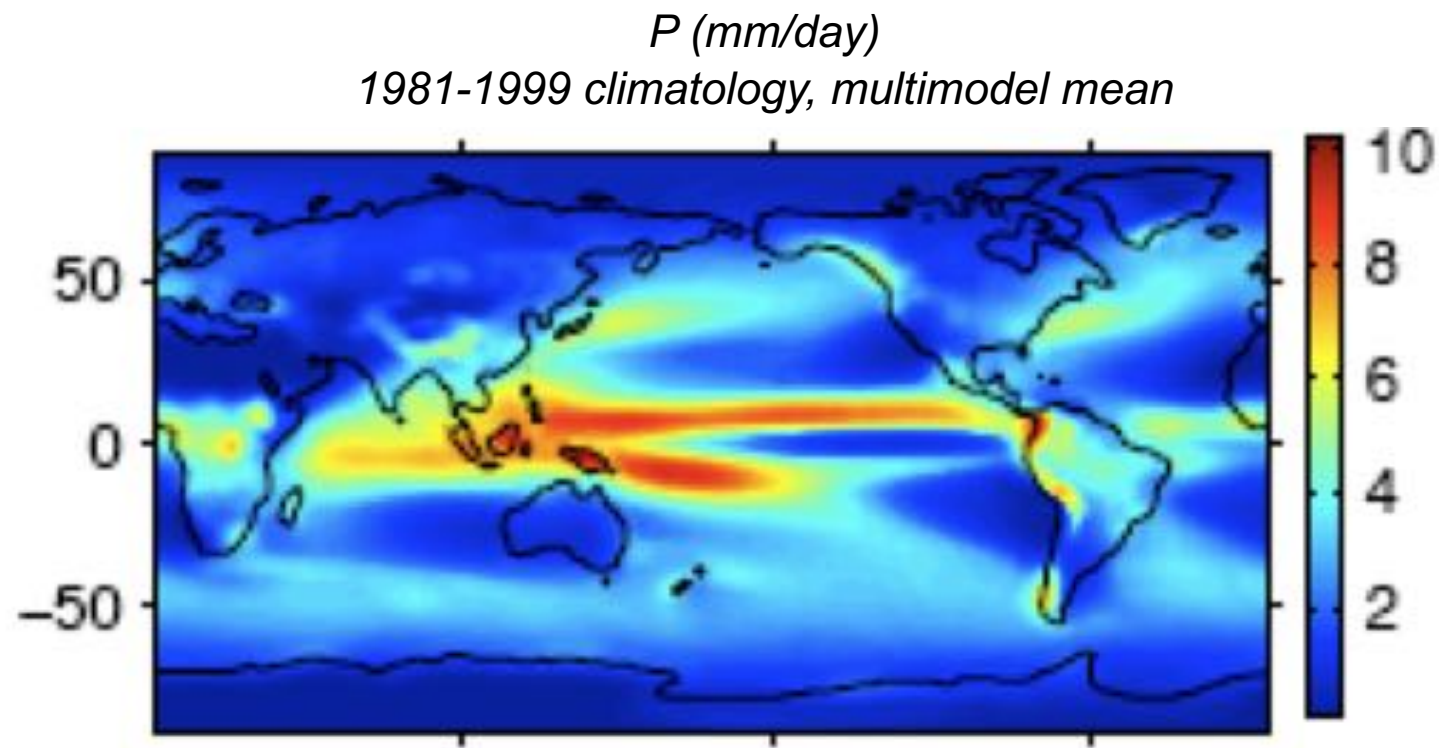
# Clouds are coupled with circulation



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

Synoptic scale : Equatorial waves, Extratropical frontal systems

# Clouds and Circulation: ITCZ

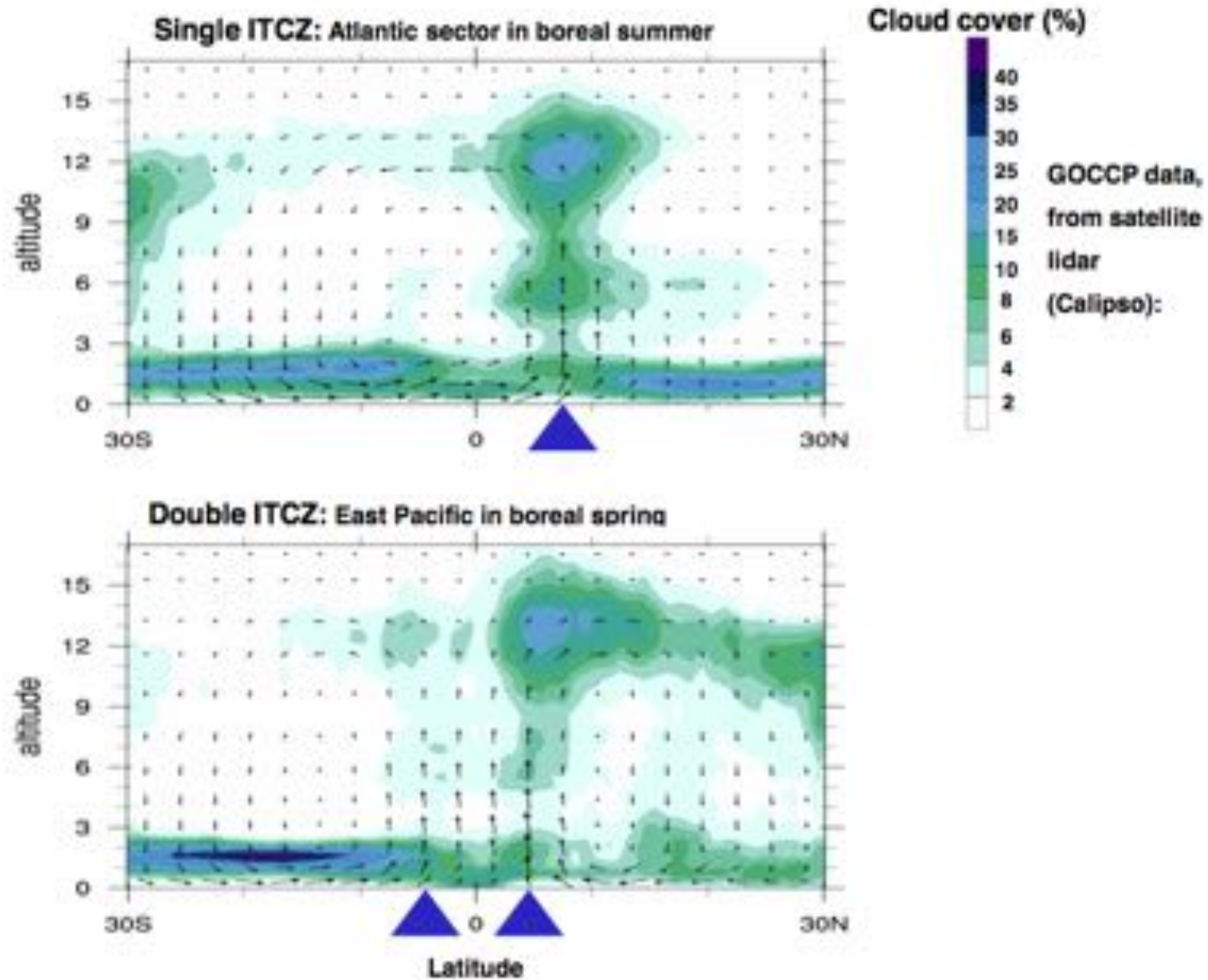


[Muller & O’Gorman, 2011]



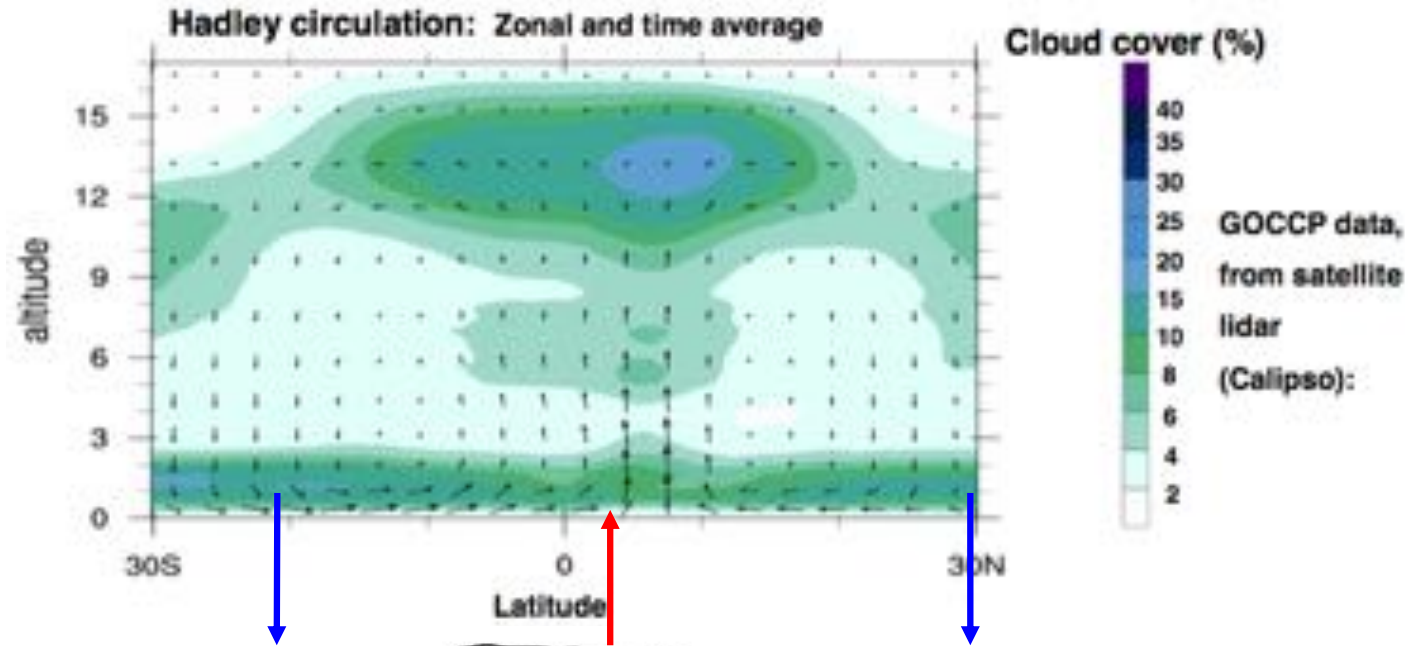


# Clouds and Circulation: ITCZ

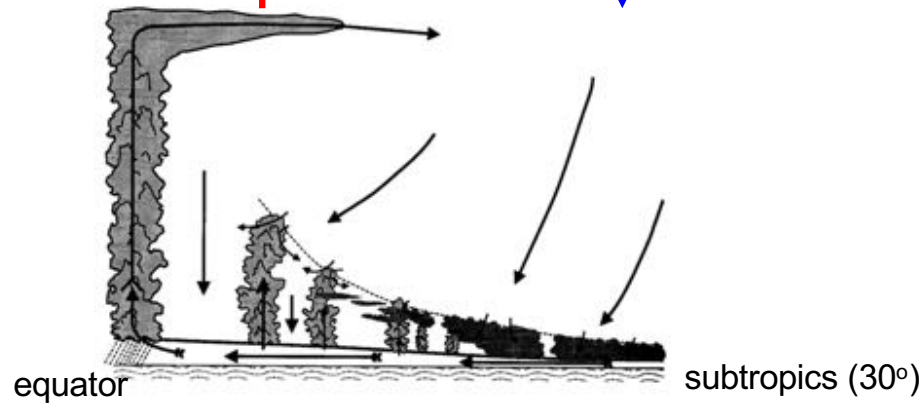


*Courtesy Gilles Bellon*

# Clouds and Circulation: Hadley cell



Cloud types:



Deep cumulonimbus



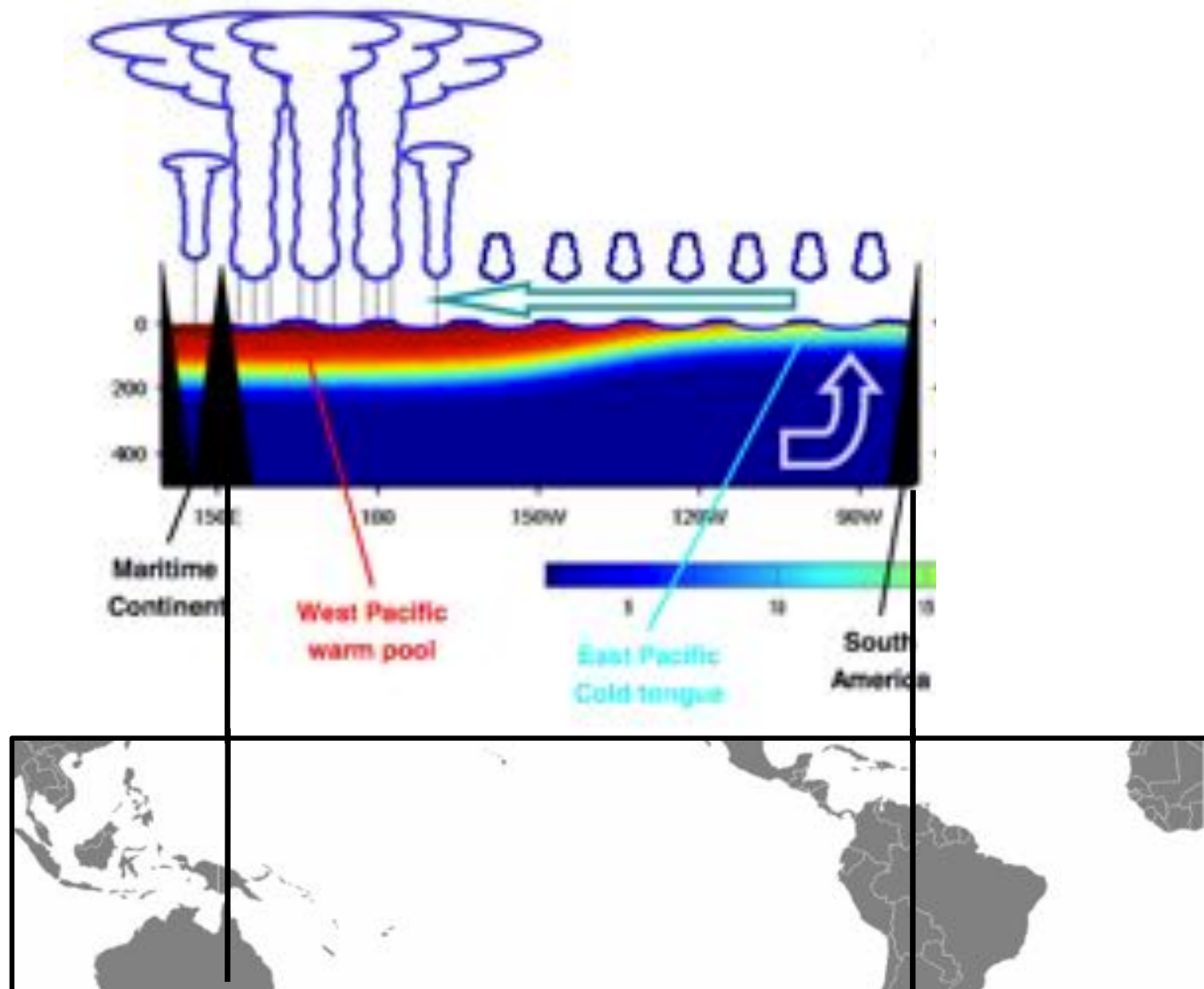
Fair weather cumulus



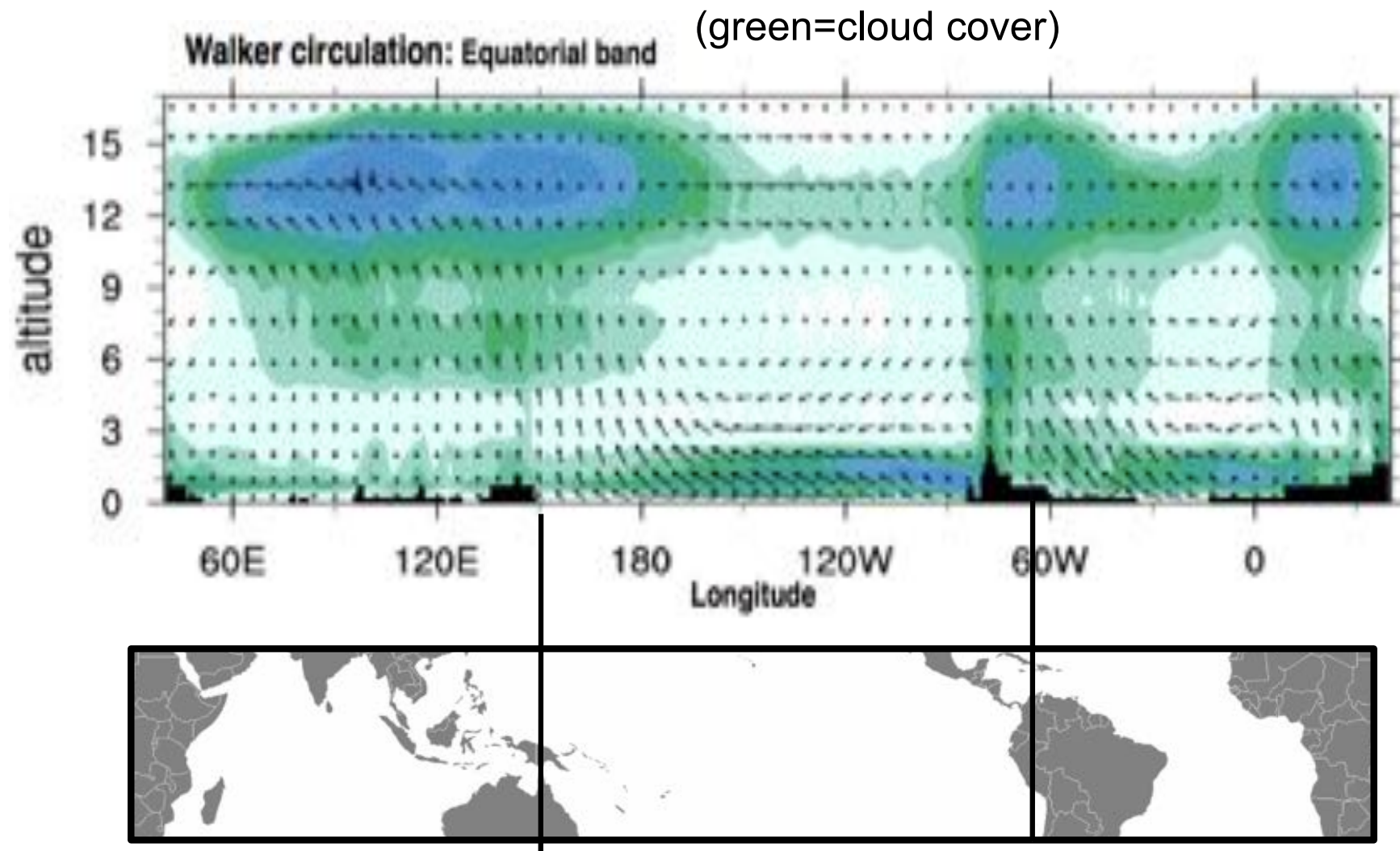
stratus

# Clouds and Circulation: Walker cell

in the equatorial Pacific



# Clouds and Circulation: Walker cell



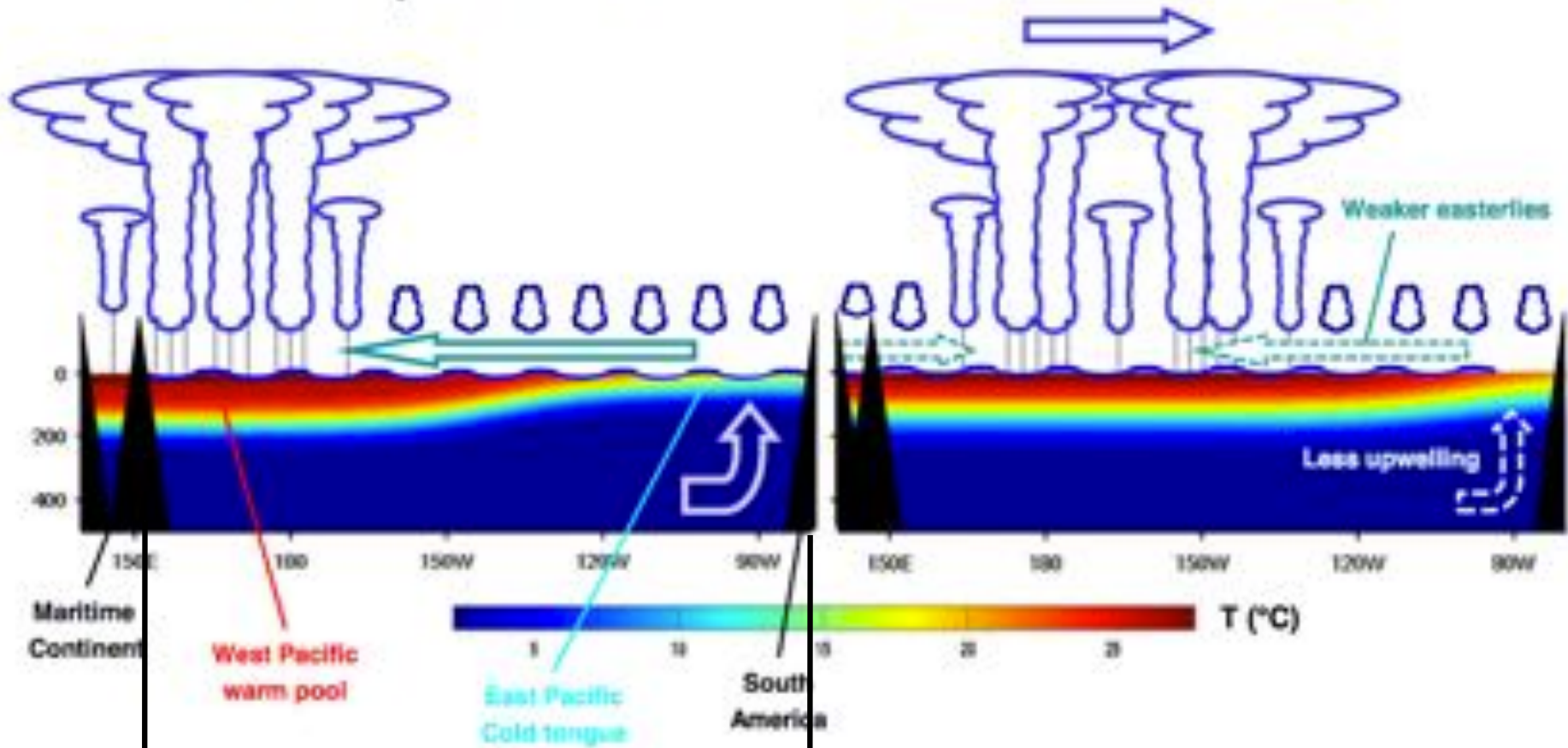
*Courtesy Gilles Bellon*

# Clouds and Circulation: El Niño

Normal conditions  
in the equatorial Pacific

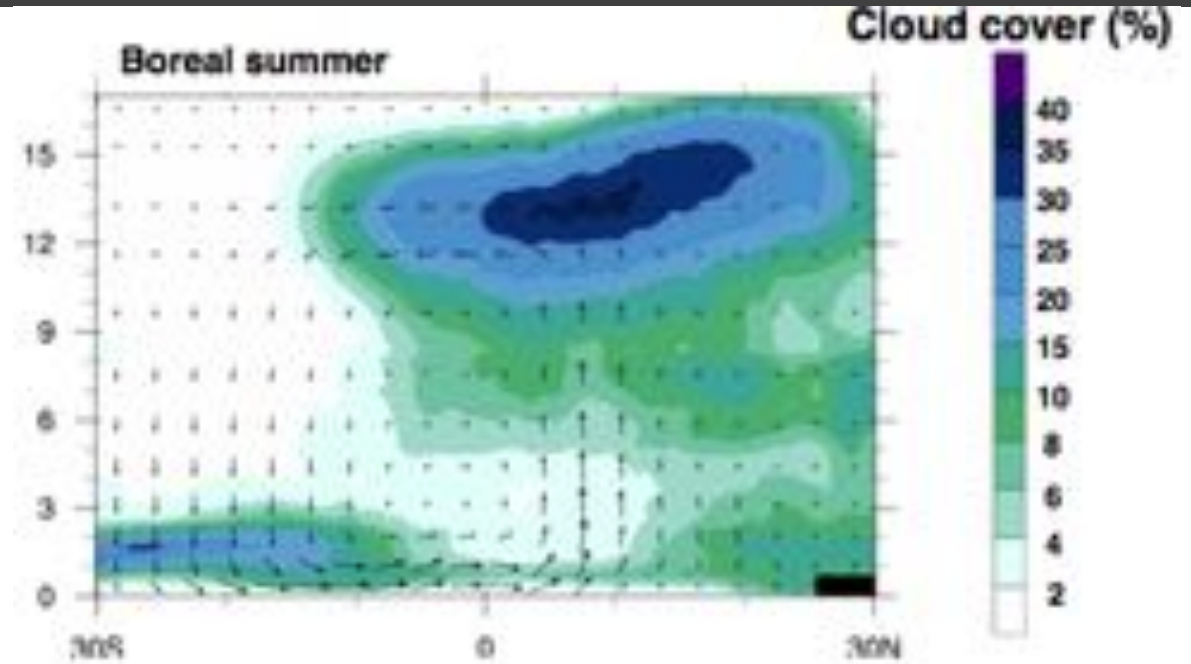
El Niño conditions

Eastward shift / extension of convection

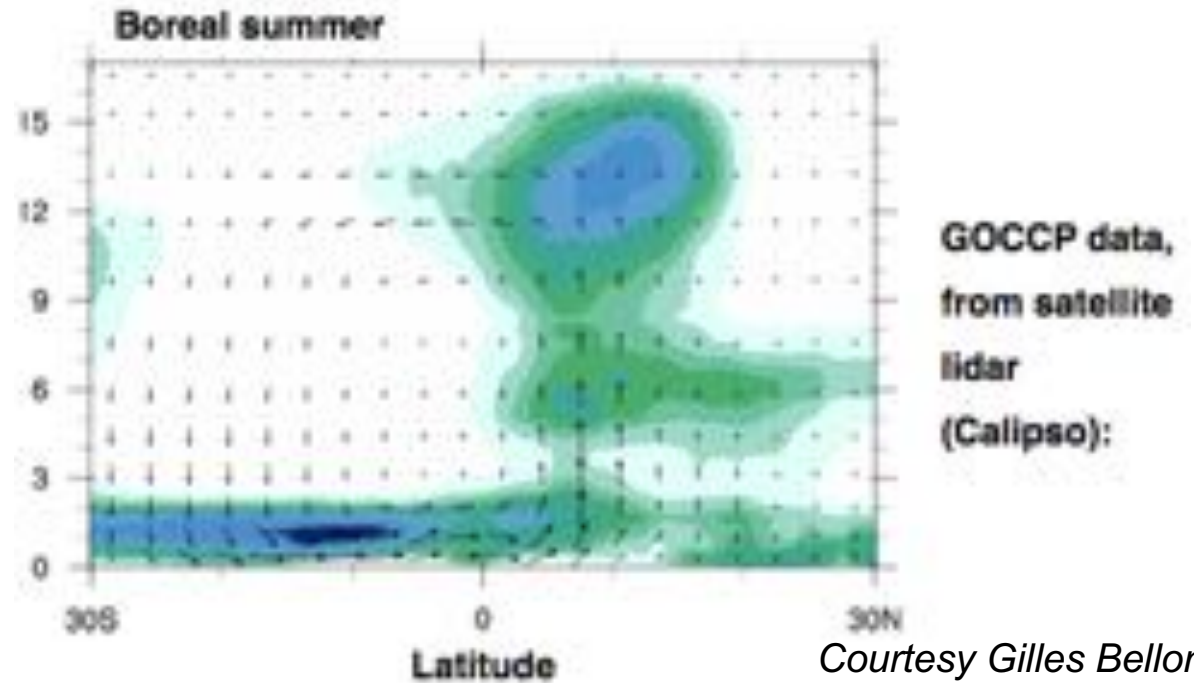


# Clouds and Circulation: Monsoon

Asian monsoon

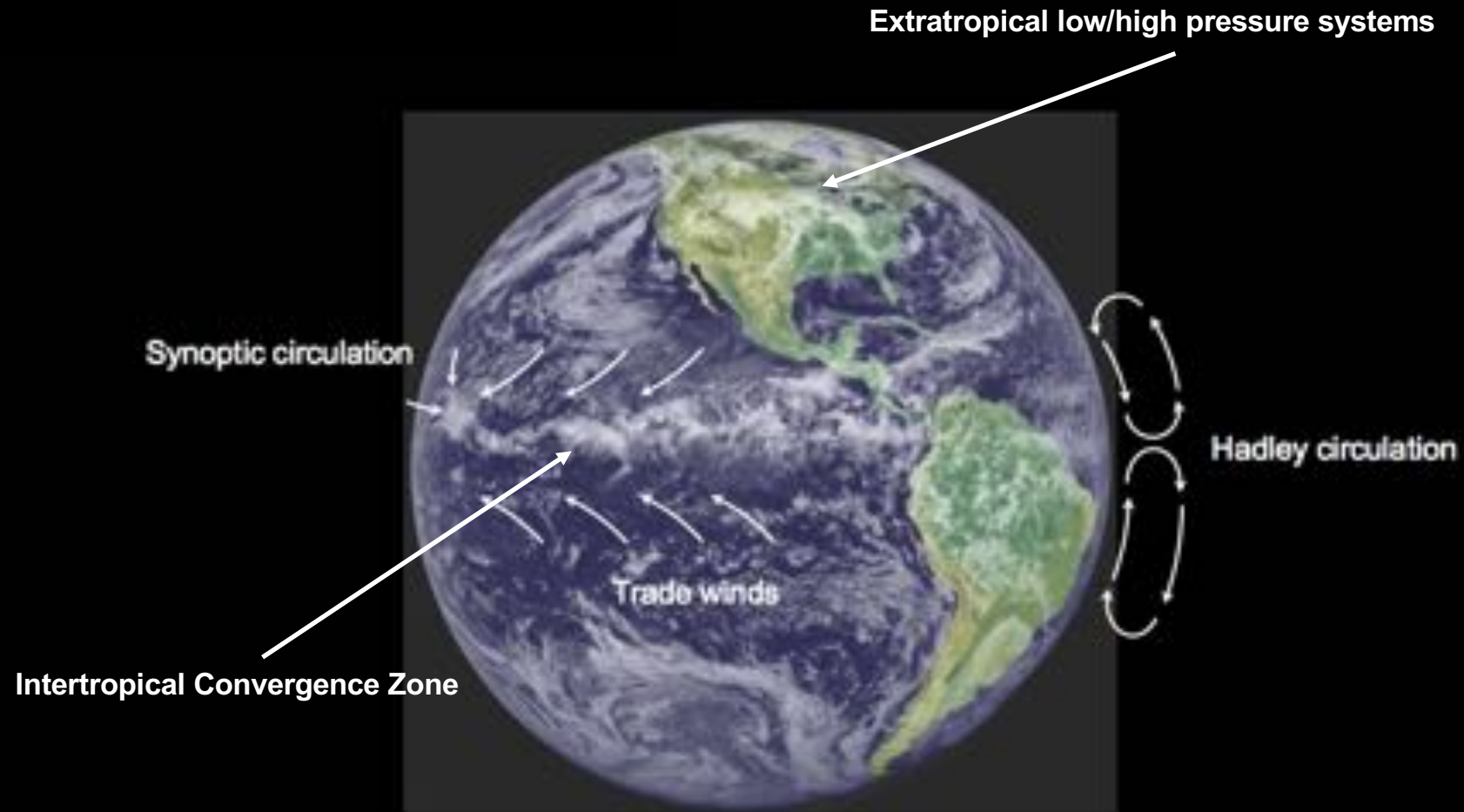


West-African monsoon



Courtesy Gilles Bellon

# Clouds are coupled with circulation



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

Synoptic scale : Equatorial waves, Extratropical frontal systems

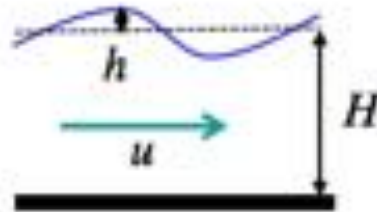


# Convective organization: equatorial waves

Linearized shallow-water equations on a  $\beta$ -plane:

> Classical formulation:

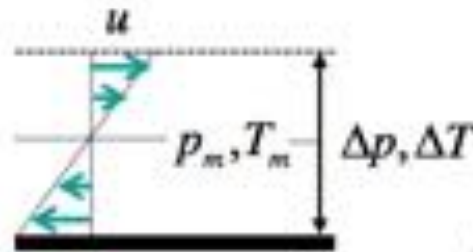
$$\begin{cases} \partial_t u - \beta y v = -g \partial_x h \\ \partial_t v + \beta y u = -g \partial_y h \\ \partial_t h + H(\partial_x u + \partial_y v) = 0 \end{cases}$$



[Matsuno 66]

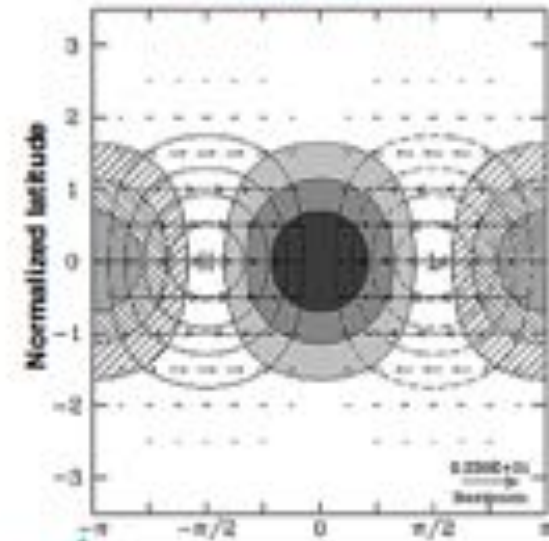
> Tropical atmosphere:

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

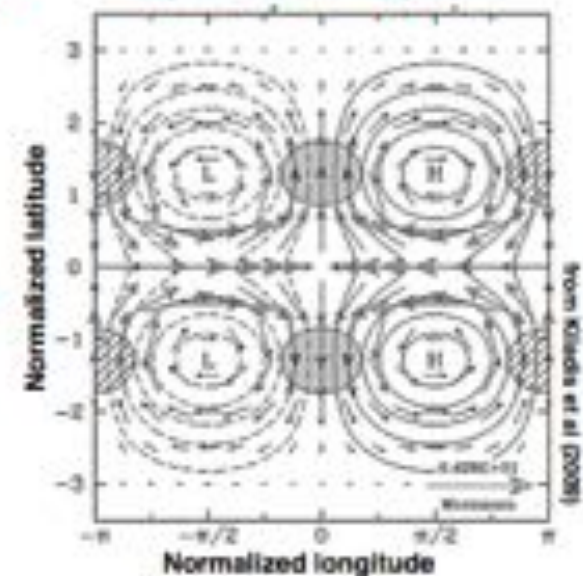


$$\alpha = \frac{\Delta p}{2 p_m} R$$

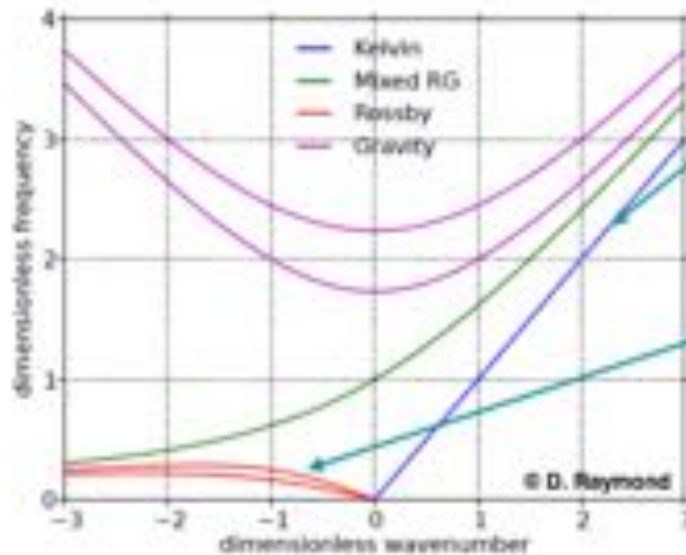
Kelvin wave



Equatorial Rossby wave



Dispersion diagram:

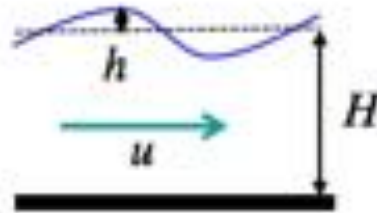


# Convective organization: equatorial waves

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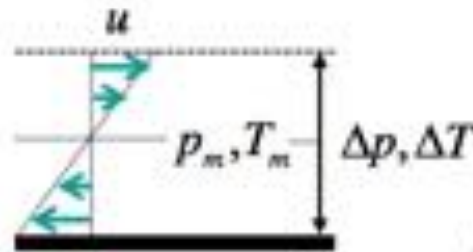
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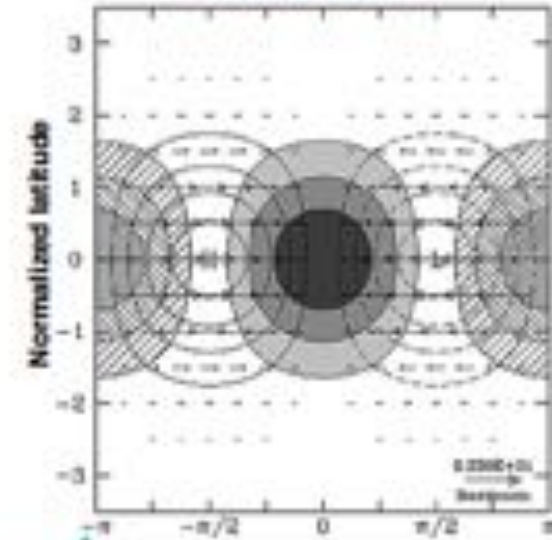
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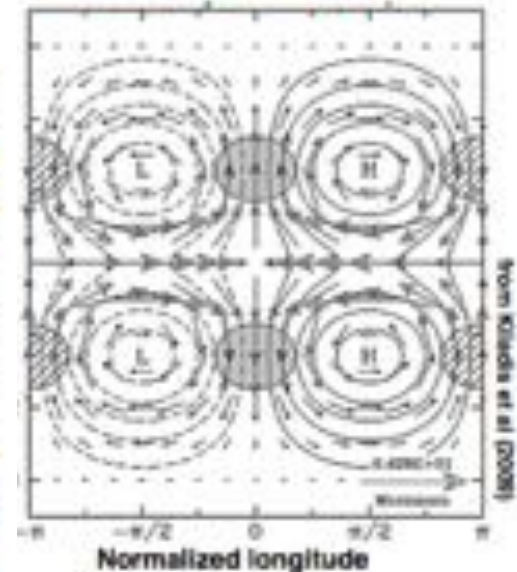


$$\alpha = \frac{\Delta p}{R} R$$

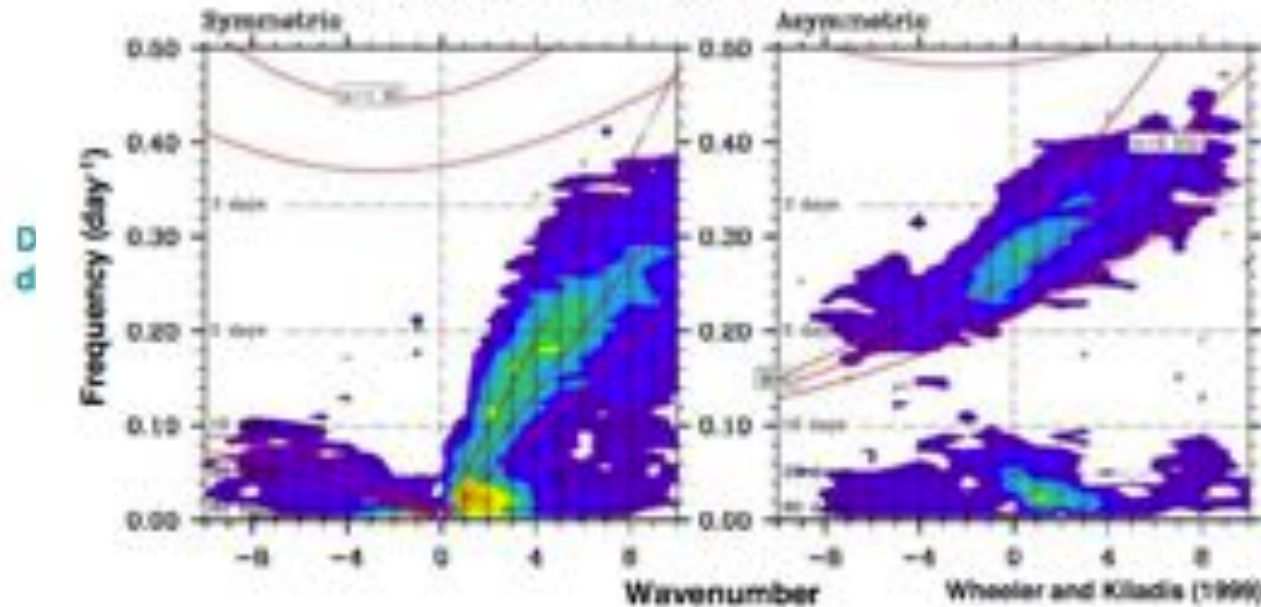
Kelvin wave



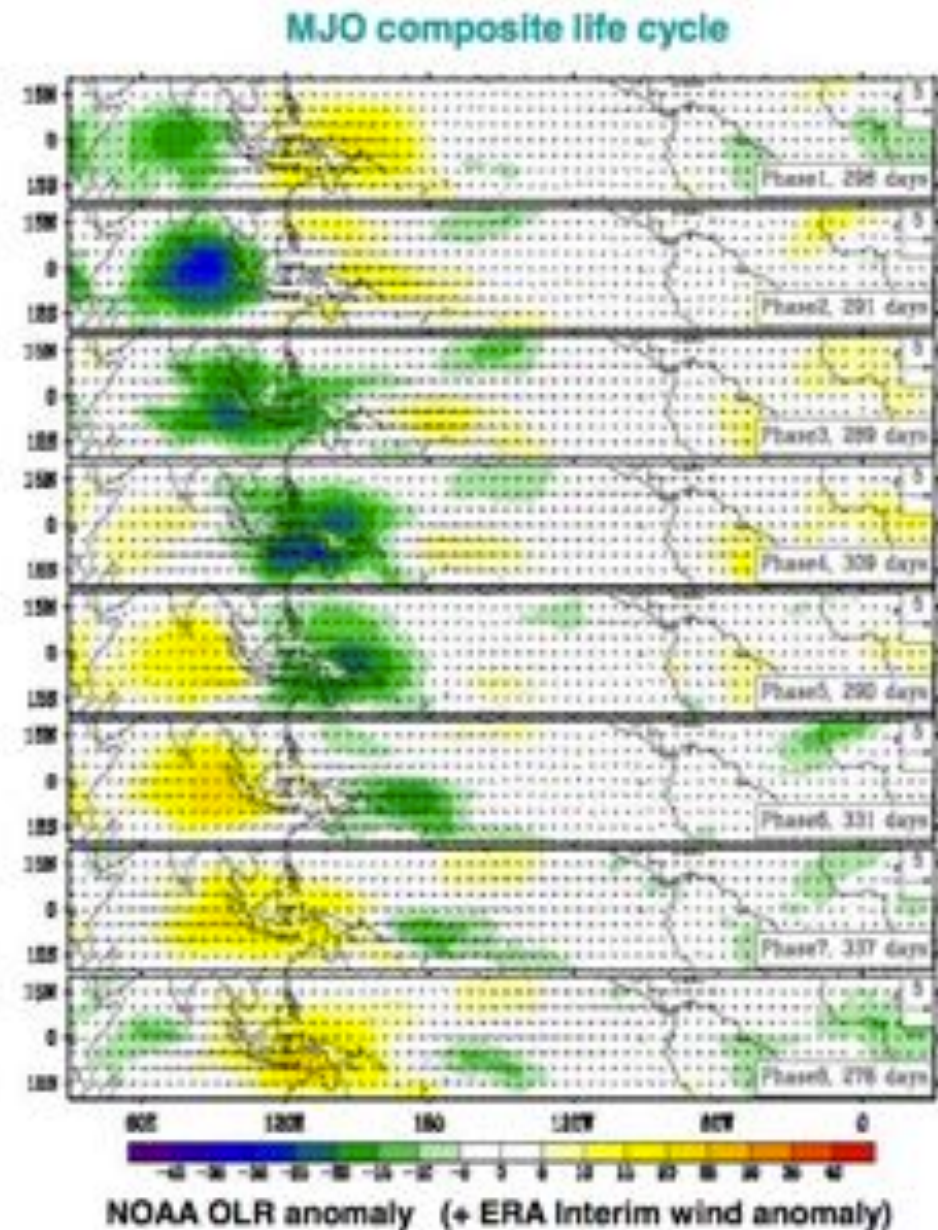
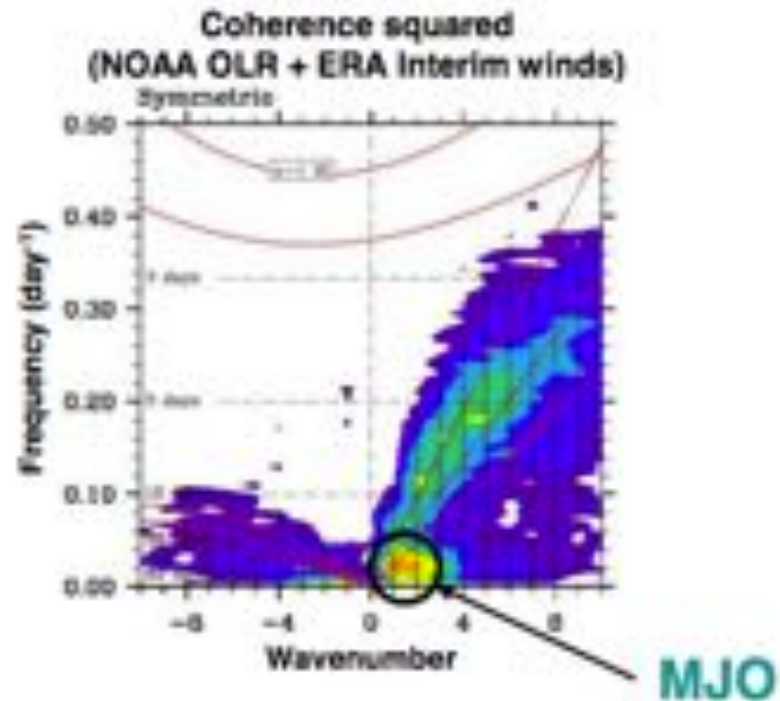
Equatorial Rossby wave



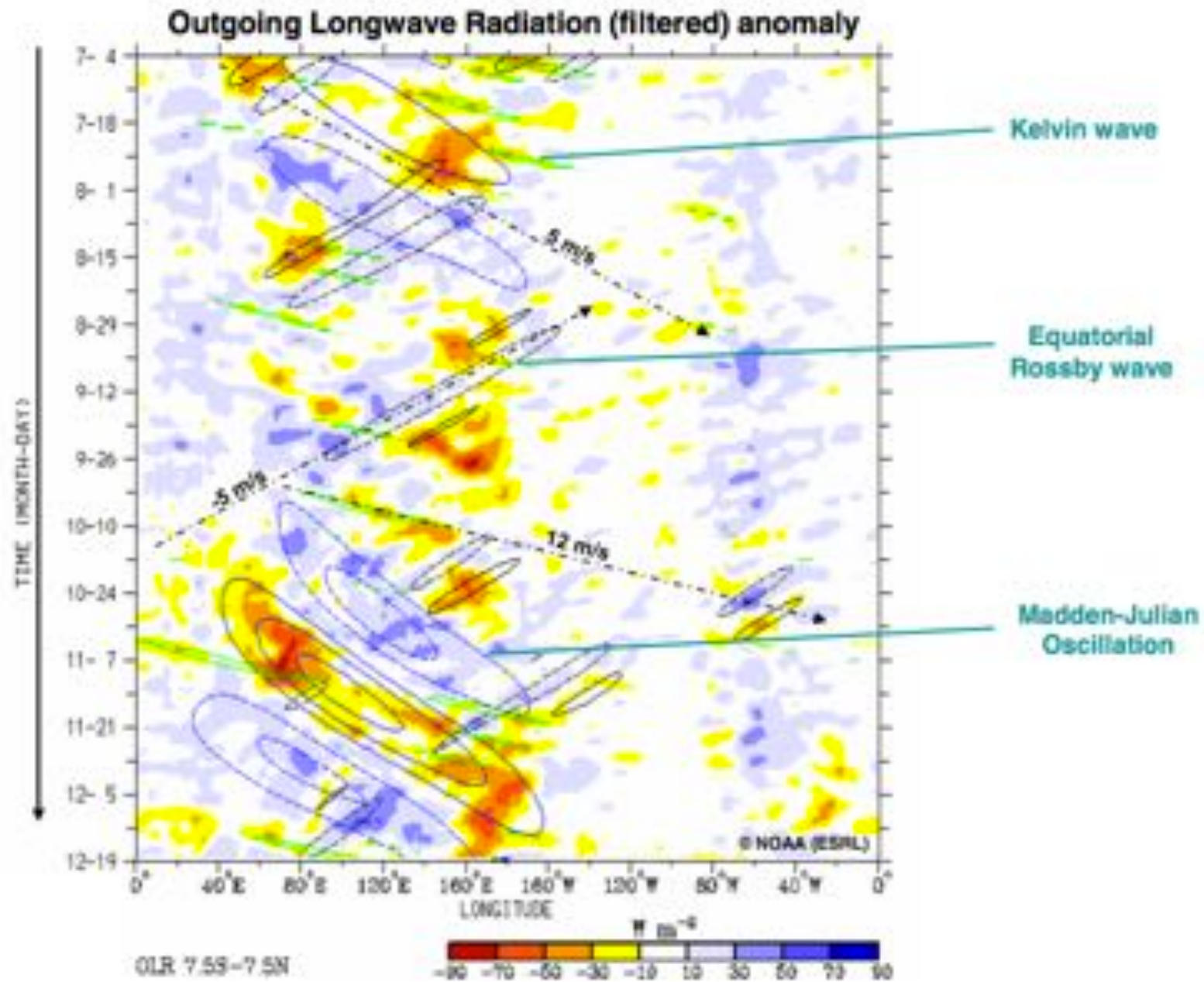
Coherence squared (NOAA OLR + ERA Interim winds)



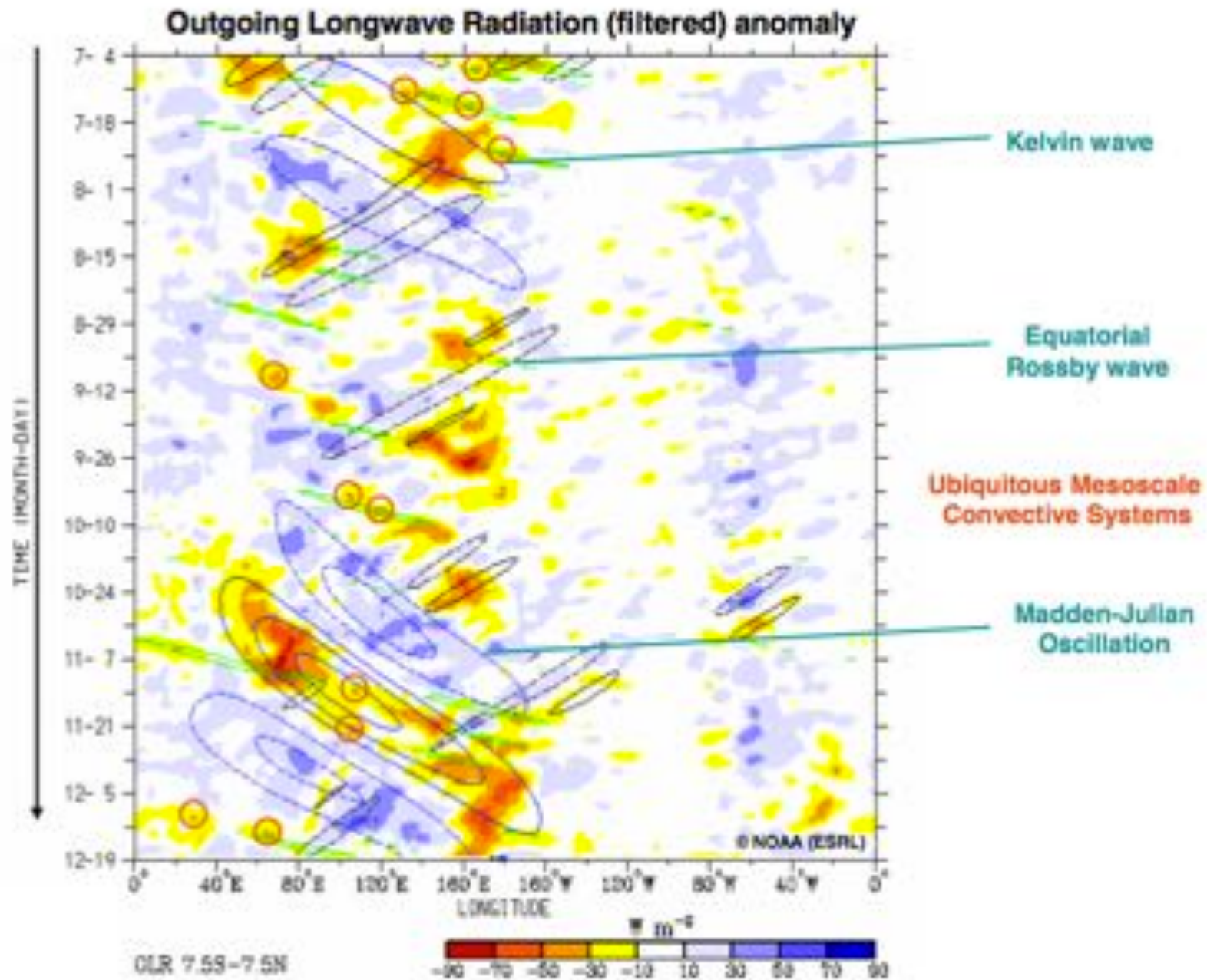
# Convective organization: MJO



# Convective organization: equatorial waves



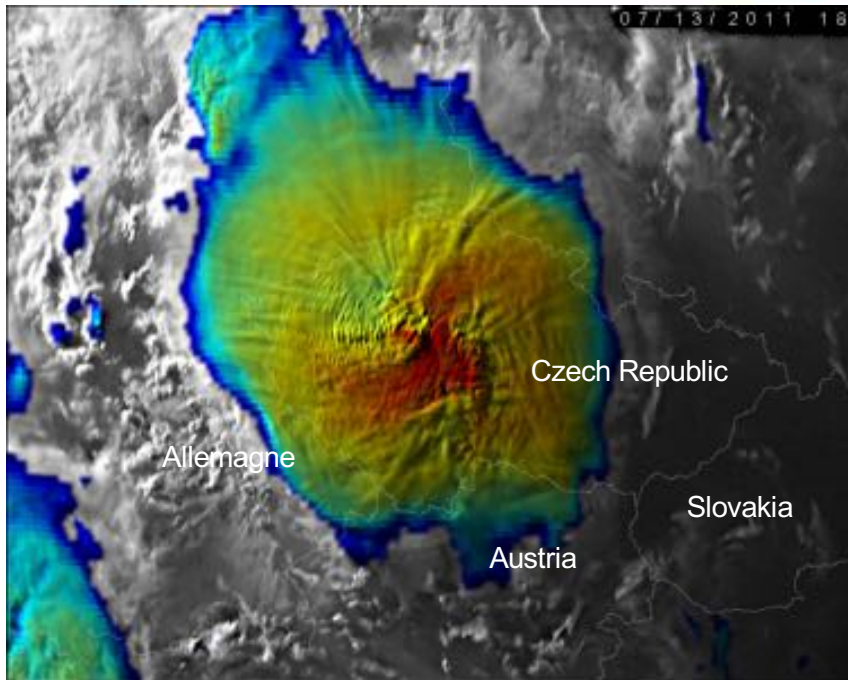
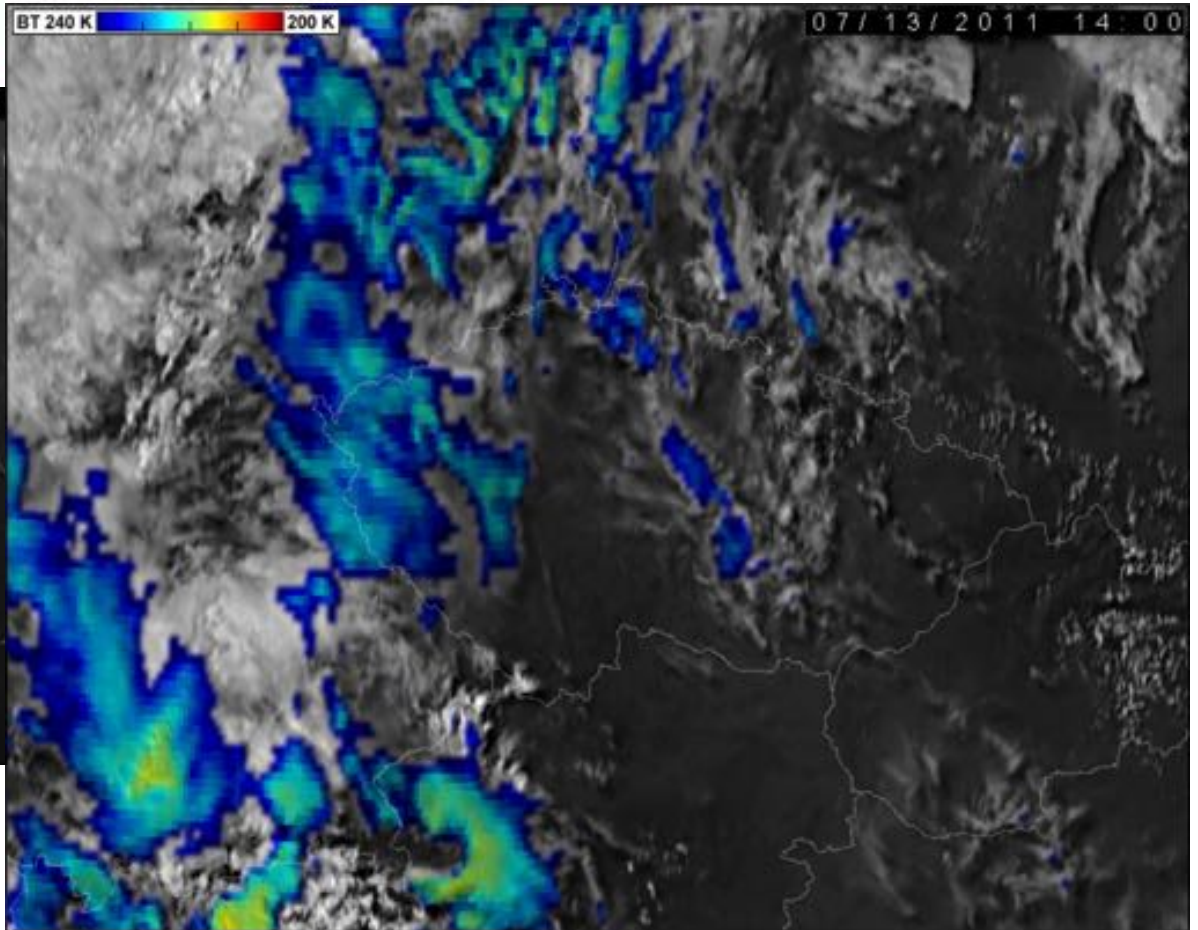
# Convective organization: equatorial waves



# (mesoscale organization)

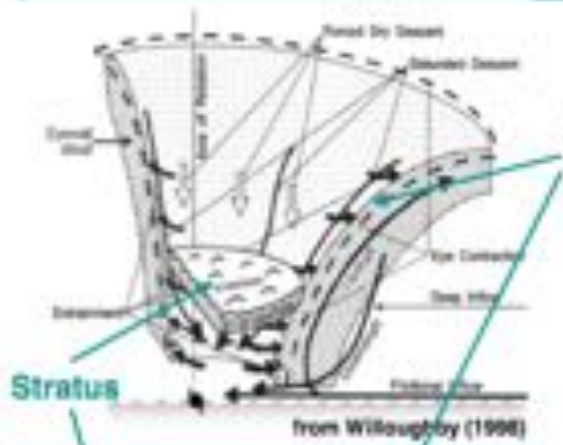


Mesoscale convective systems



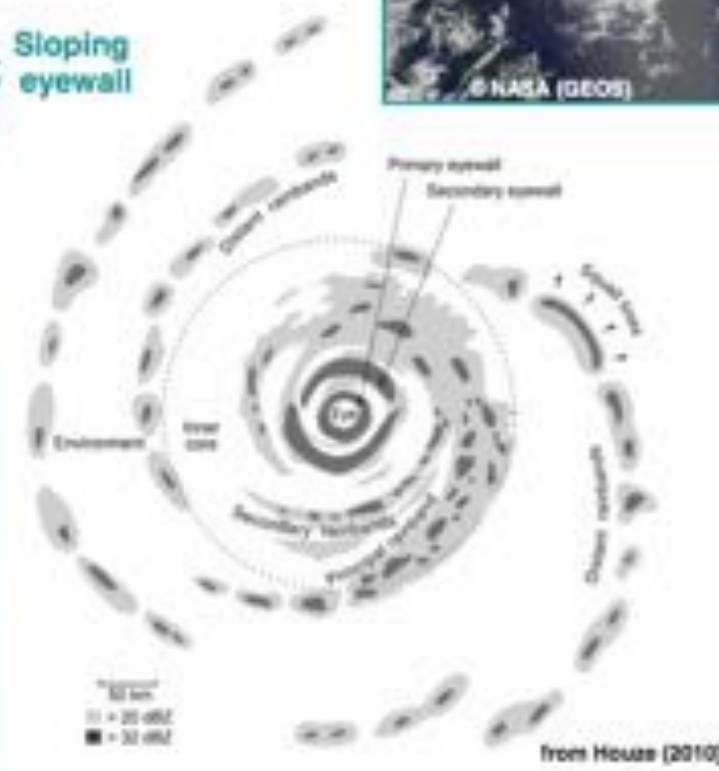
# (mesoscale organization)

## Tropical cyclones



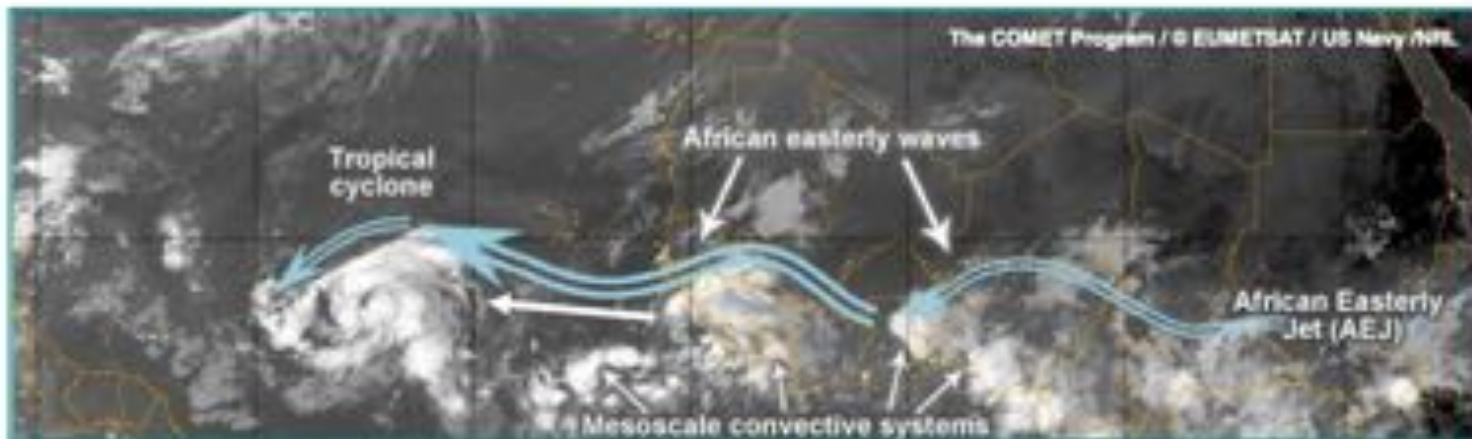
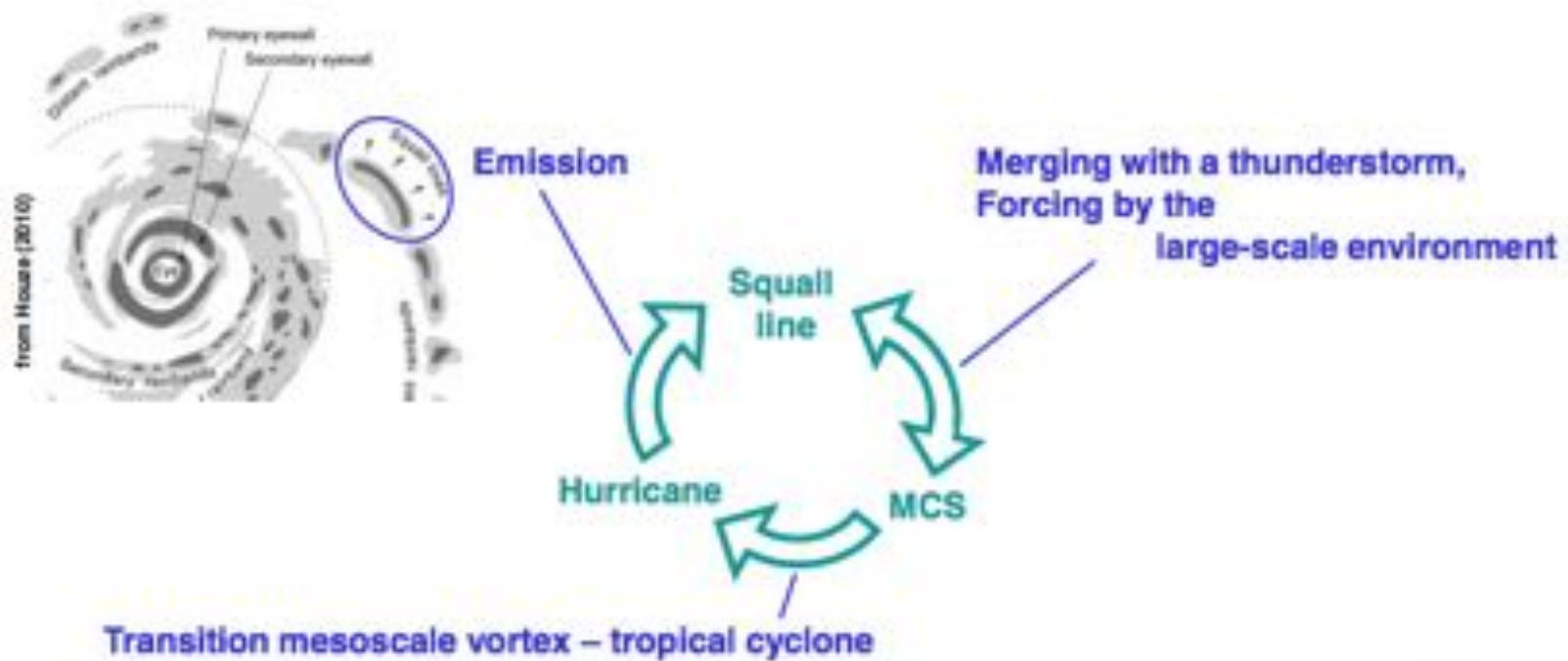
Sloping eyewall

Stratus



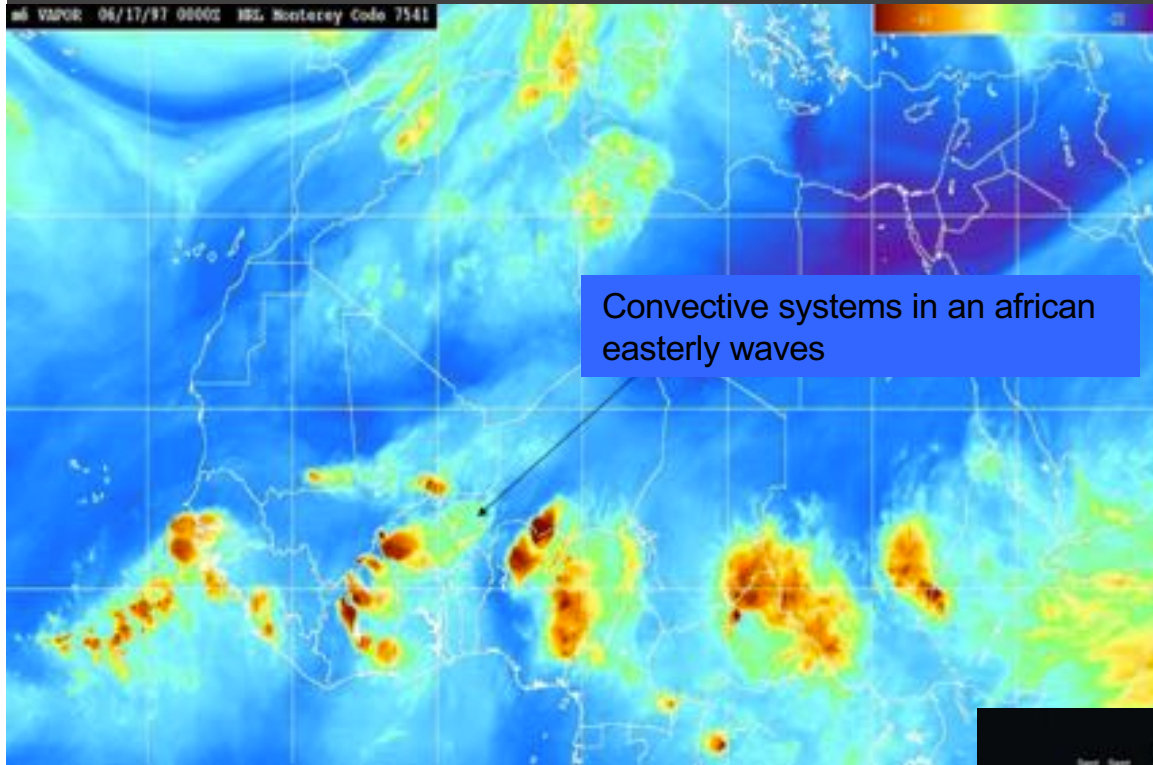
# (mesoscale organization)

## Transitions between organized structures

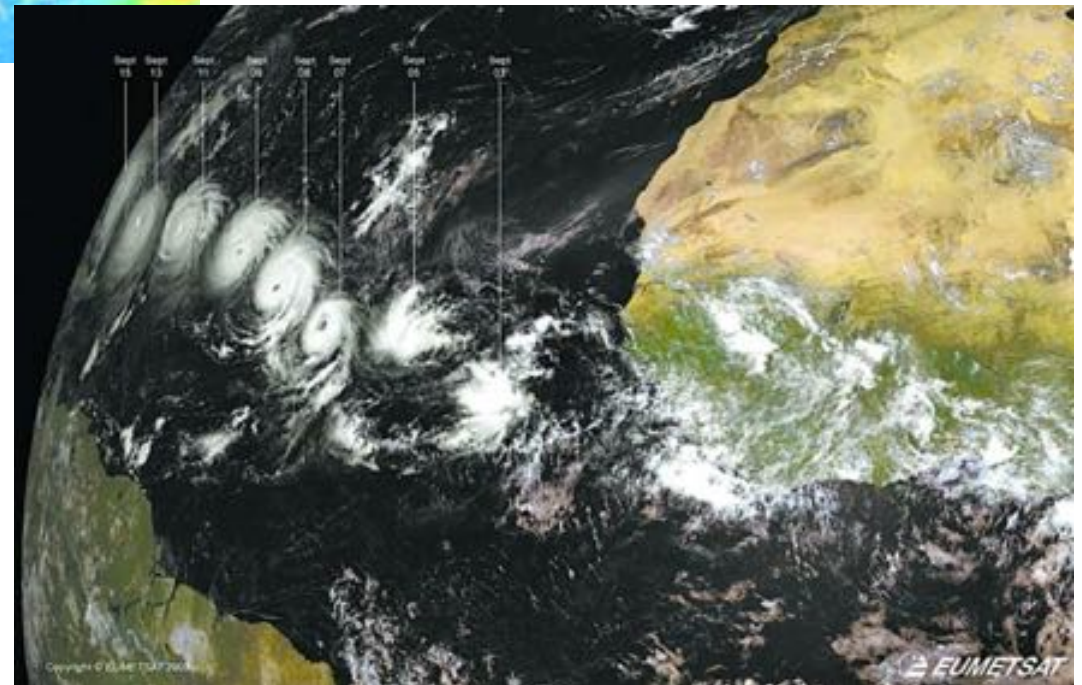




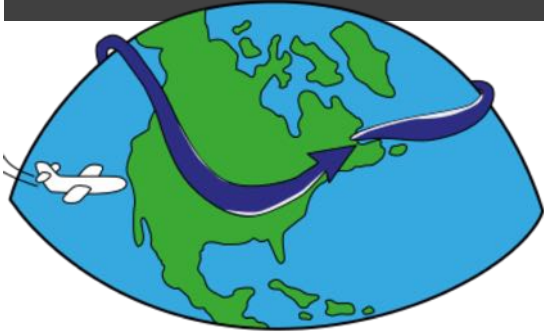
# (mesoscale organization)



Hurricane Isabel off the coast of Africa



# Extratropical frontal systems



courant-jet polaire

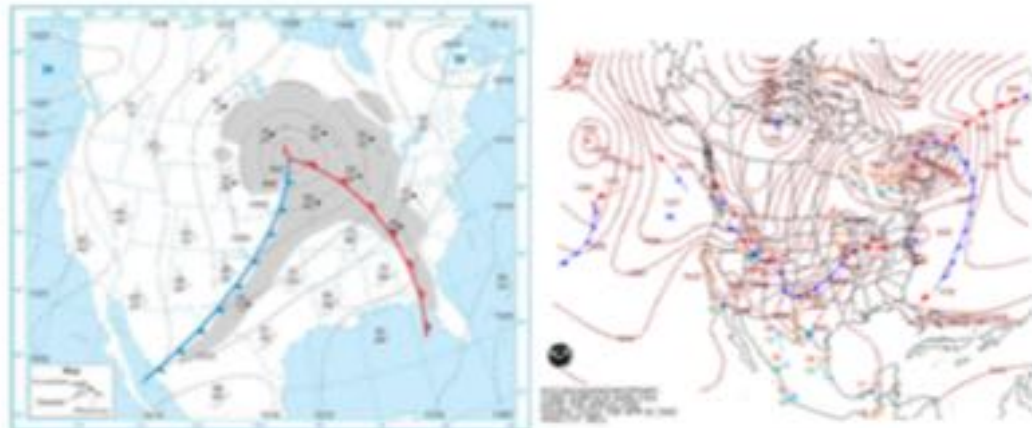


High latitudes => clouds embedded in low/high pressure systems and associated fronts

# Extratropical frontal systems



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

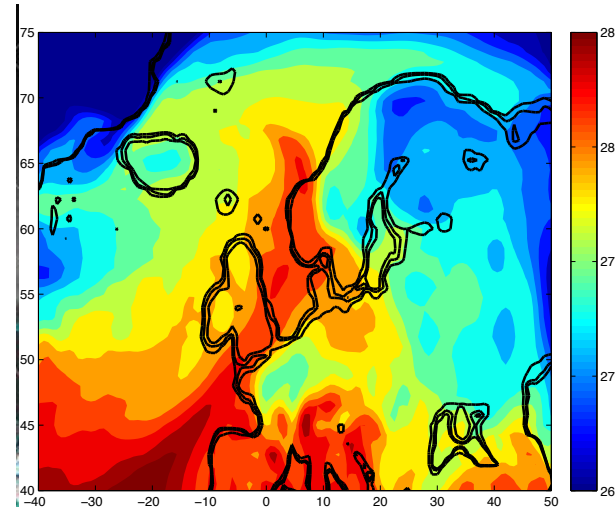
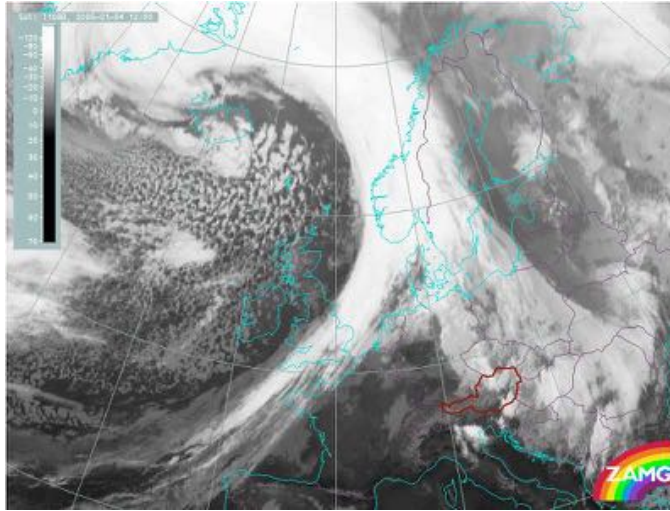


Figures 8 et 9 : cartes atmosphériques d'une situation météorologique (pression de surface et fronts).

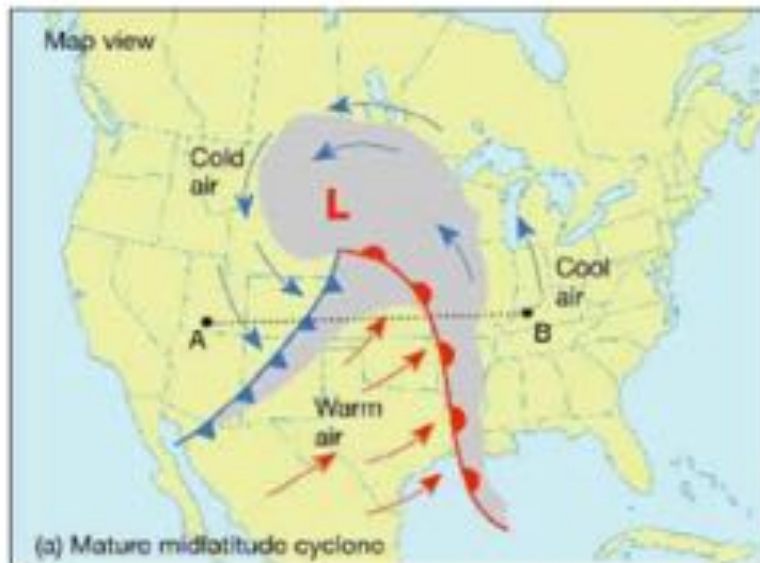
# Extratropical frontal systems

## Clouds in frontal systems

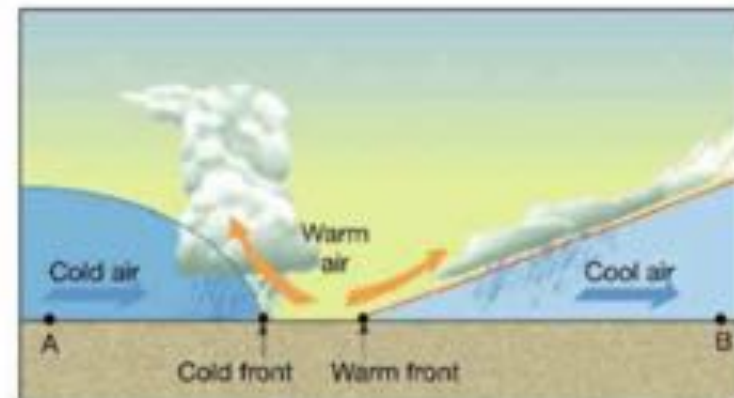
IR



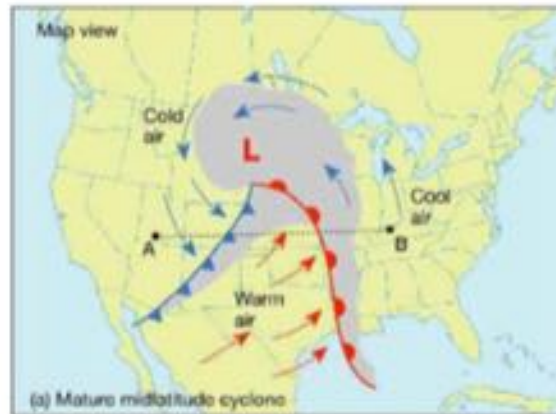
Corresponding  
T field  
Clouds are  
clearly linked to  
the dynamics  
of frontal  
systems



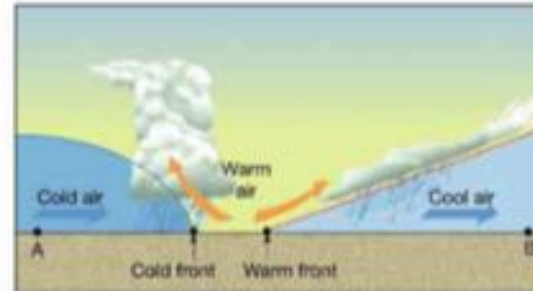
Cross sectional view



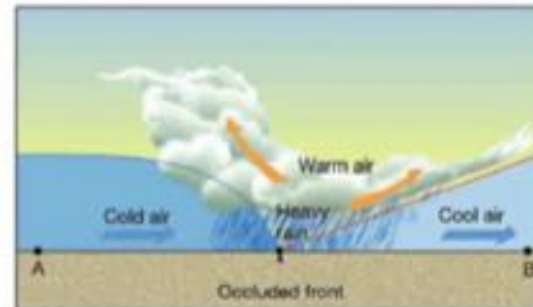
# Extratropical frontal systems



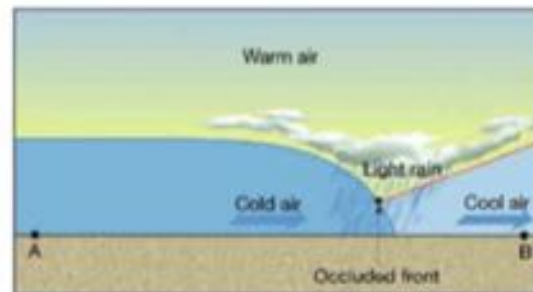
Cross sectional view



Cross sectional view

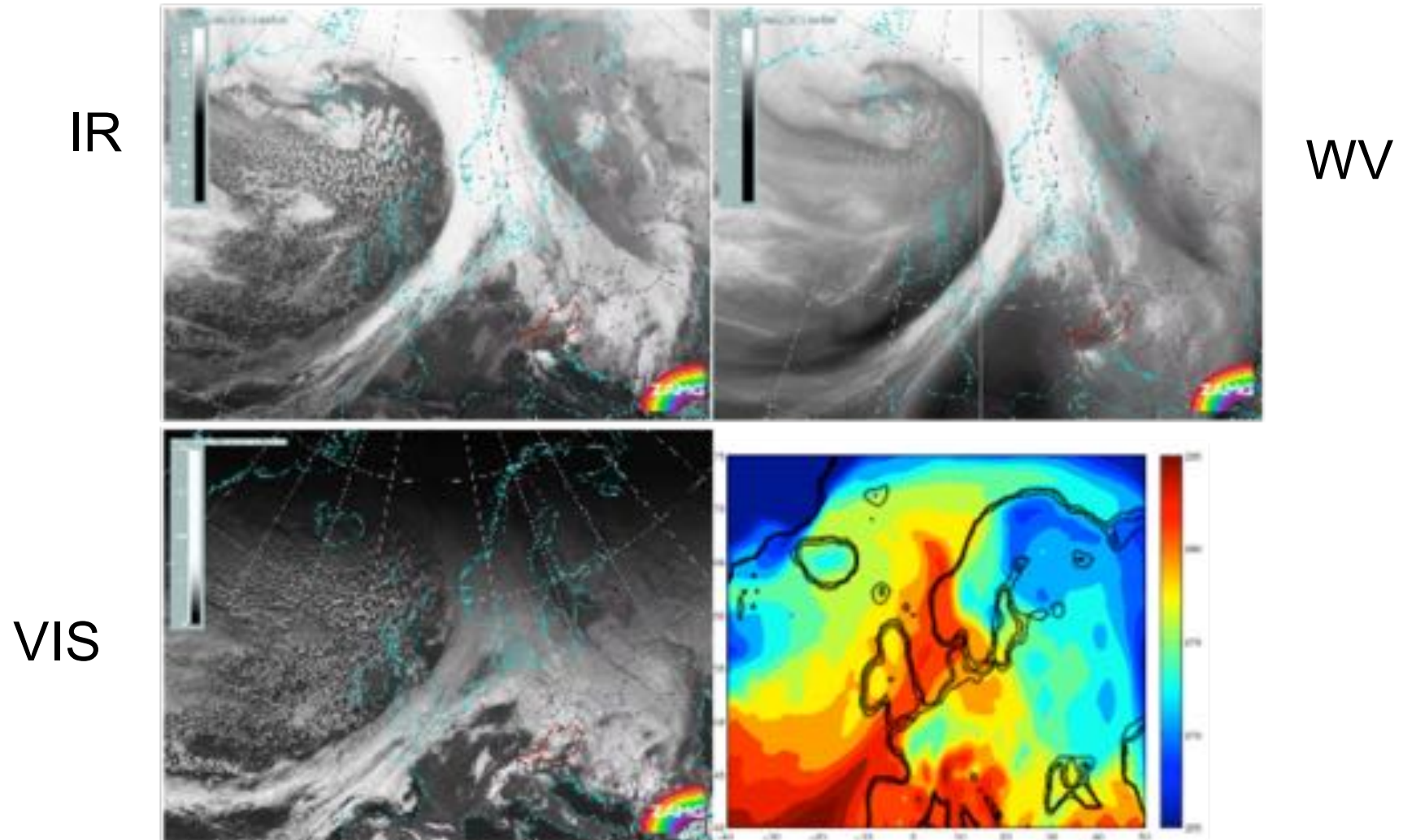


Cross sectional view



# Extratropical frontal systems

## Clouds from space



IR

WV

VIS

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.