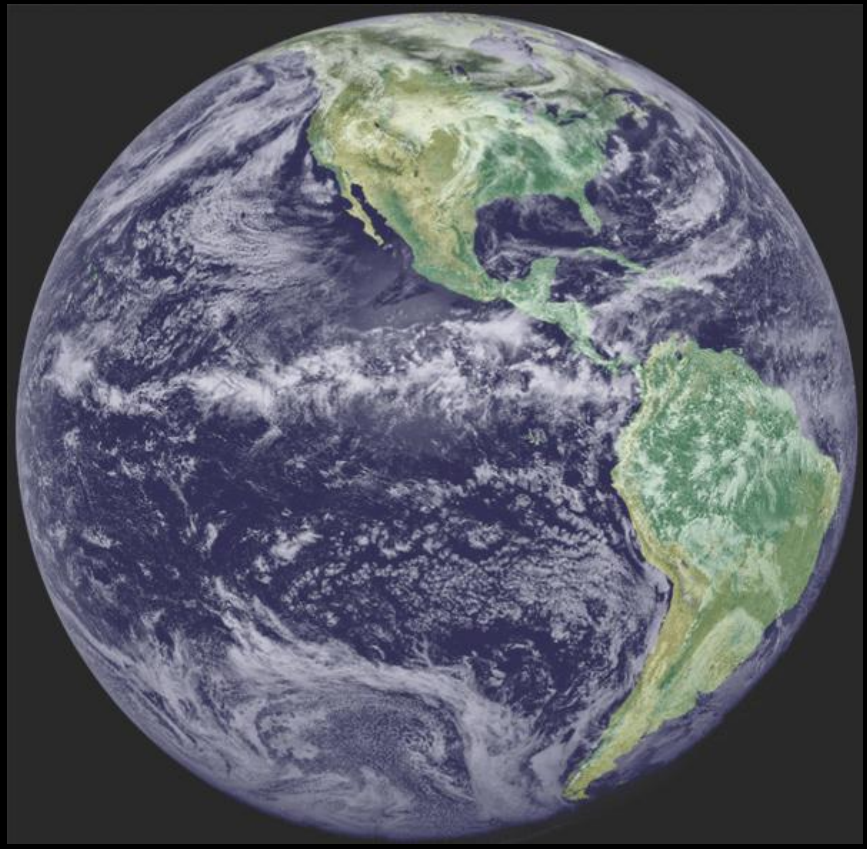
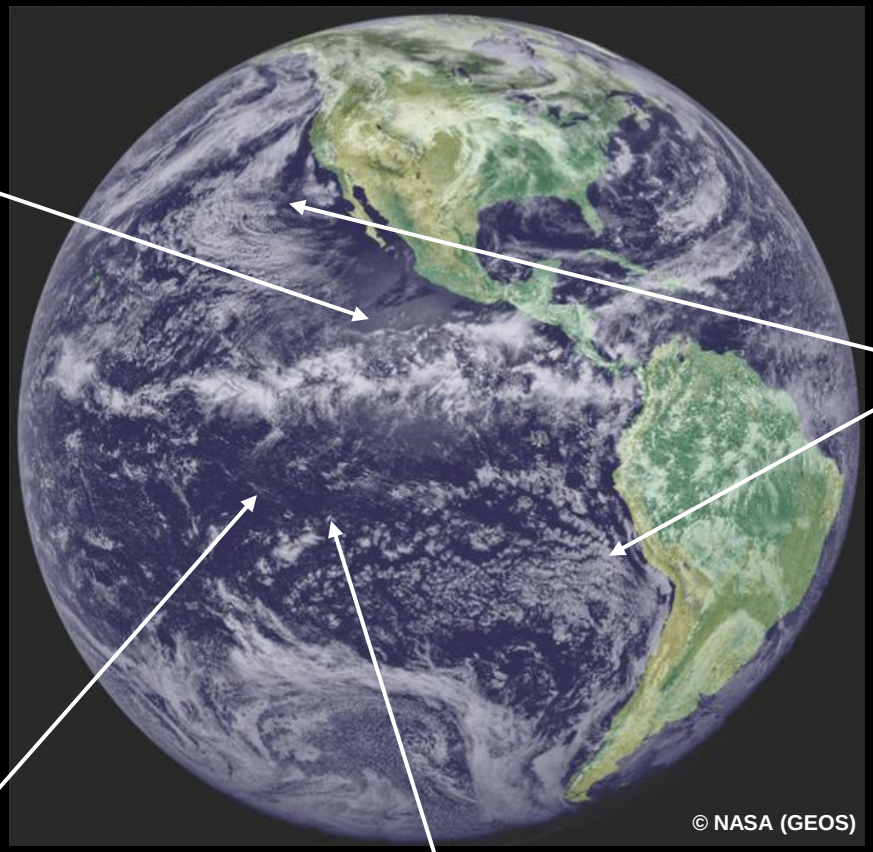


Tropical and subtropical cloud systems

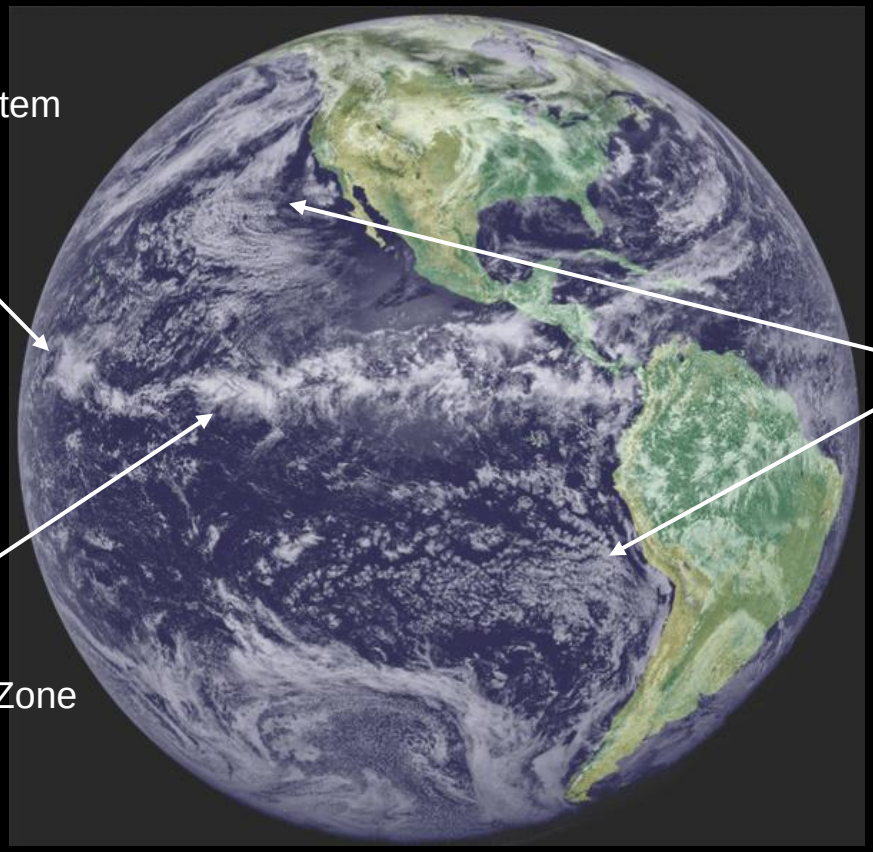
Gilles Bellon[1] & Sandrine Bony[2]

[1] CNRM (Toulouse) LMD, [2] IPSL (Paris)

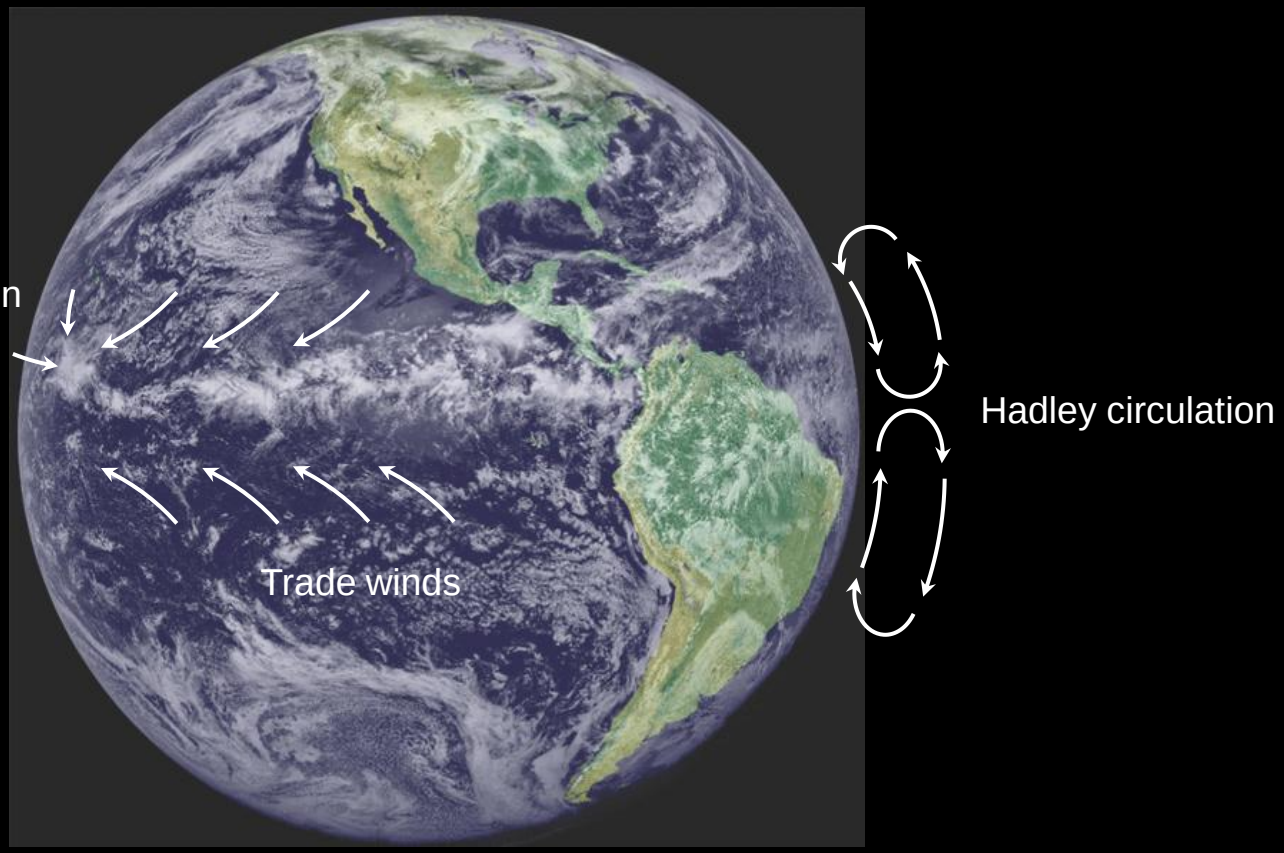
Tropical and subtropical clouds are diverse, …



… often spatially organized, …



… and coupled to circulations.



Outline

A. Cloud spontaneous spatial organization
and resulting statistics

B. Cloud forced spatial organization
and geographical distribution

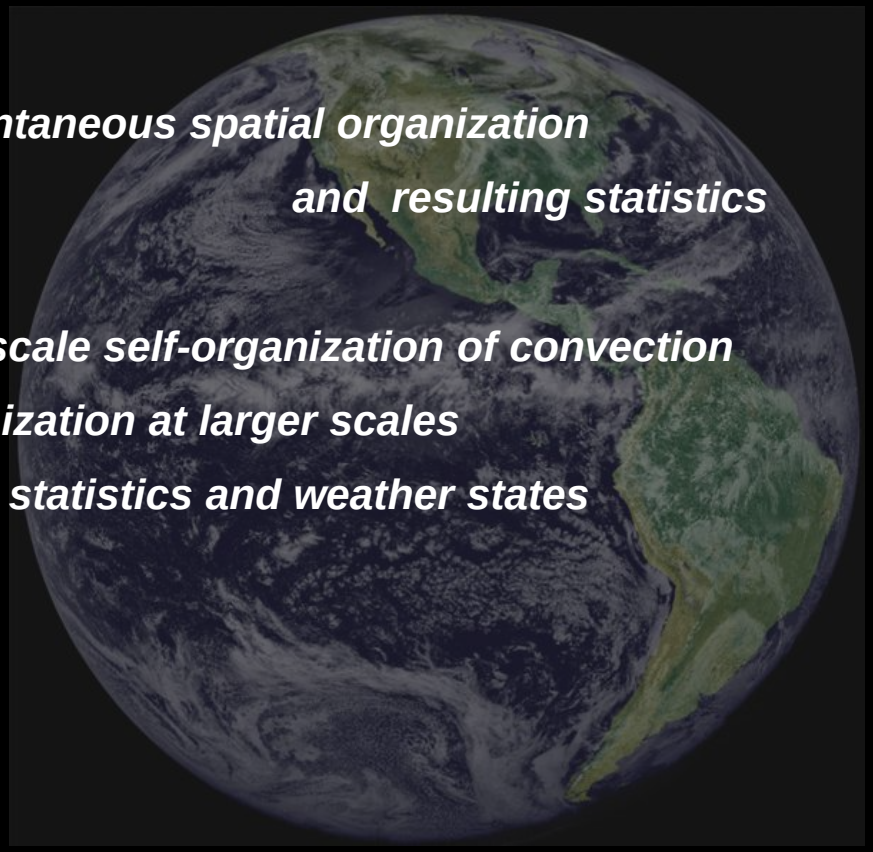
Lecture 1

C. Clouds and their environment:
a two-way interaction

D. Cloud mechanisms in the tropical climate

Lecture 2

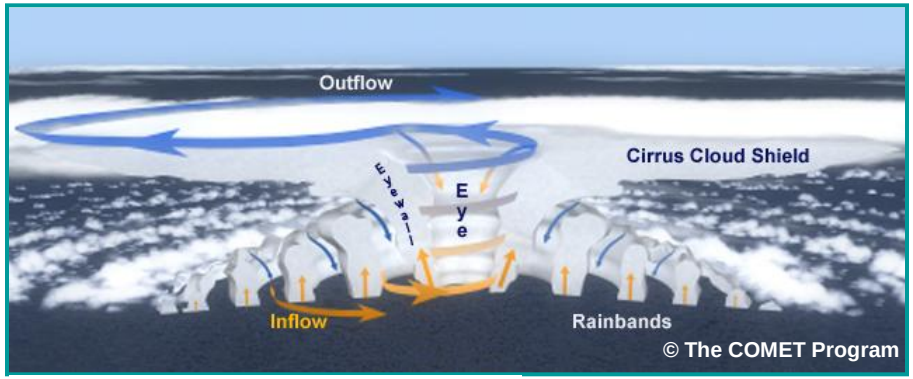
Outline

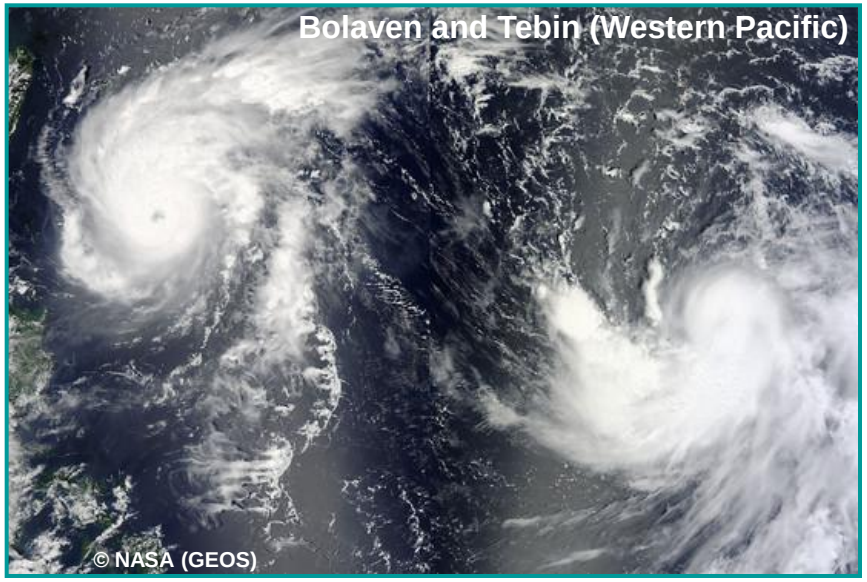


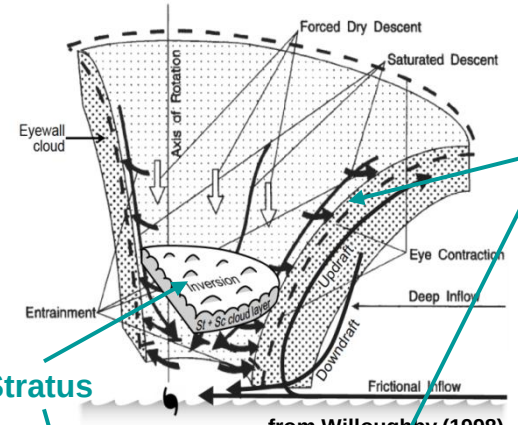
A. Cloud spontaneous spatial organization and resulting statistics

1. *Mesoscale self-organization of convection*
2. *Organization at larger scales*
3. *Cloud statistics and weather states*

Hurricanes!



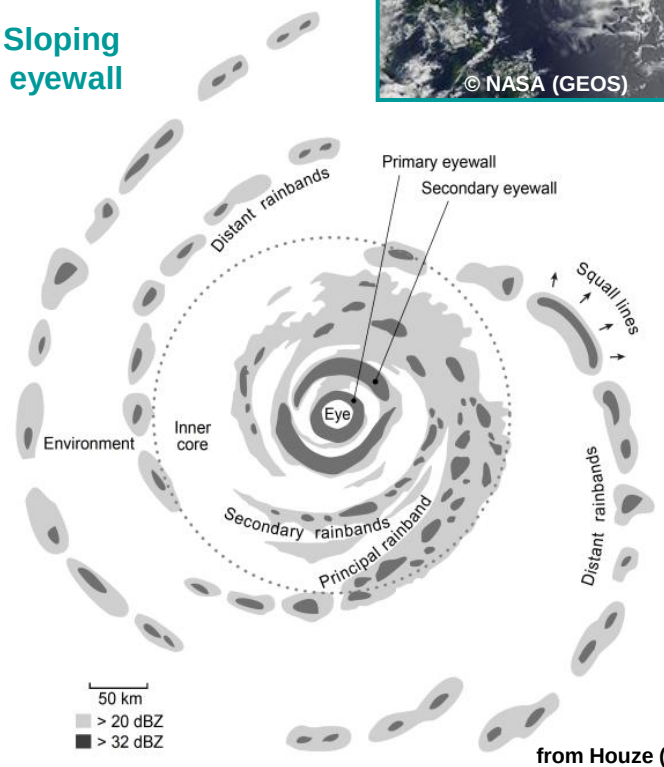




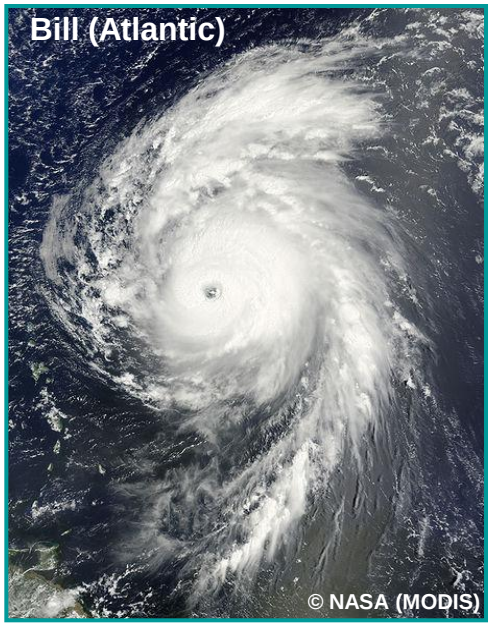
from Willoughby (1998)

Sloping eyewall

Stratus



from Houze (2010)

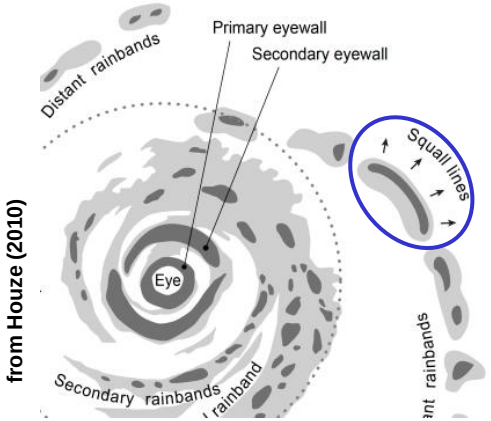


Mesoscale spontaneous organization

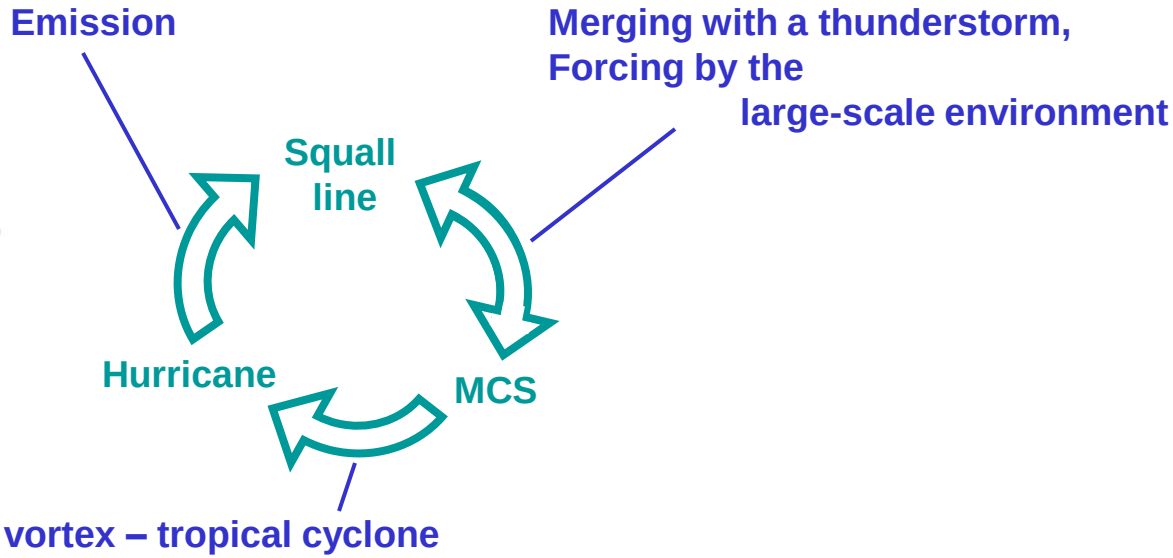
Squall lines

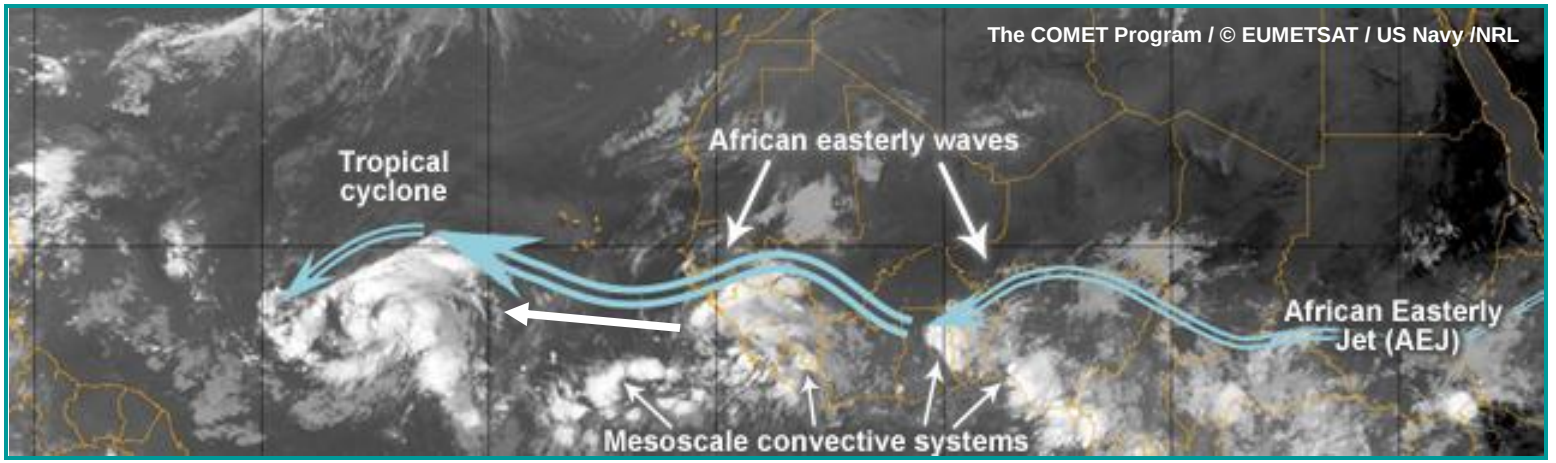
Mesoscale convective systems

Transitions between organized structures

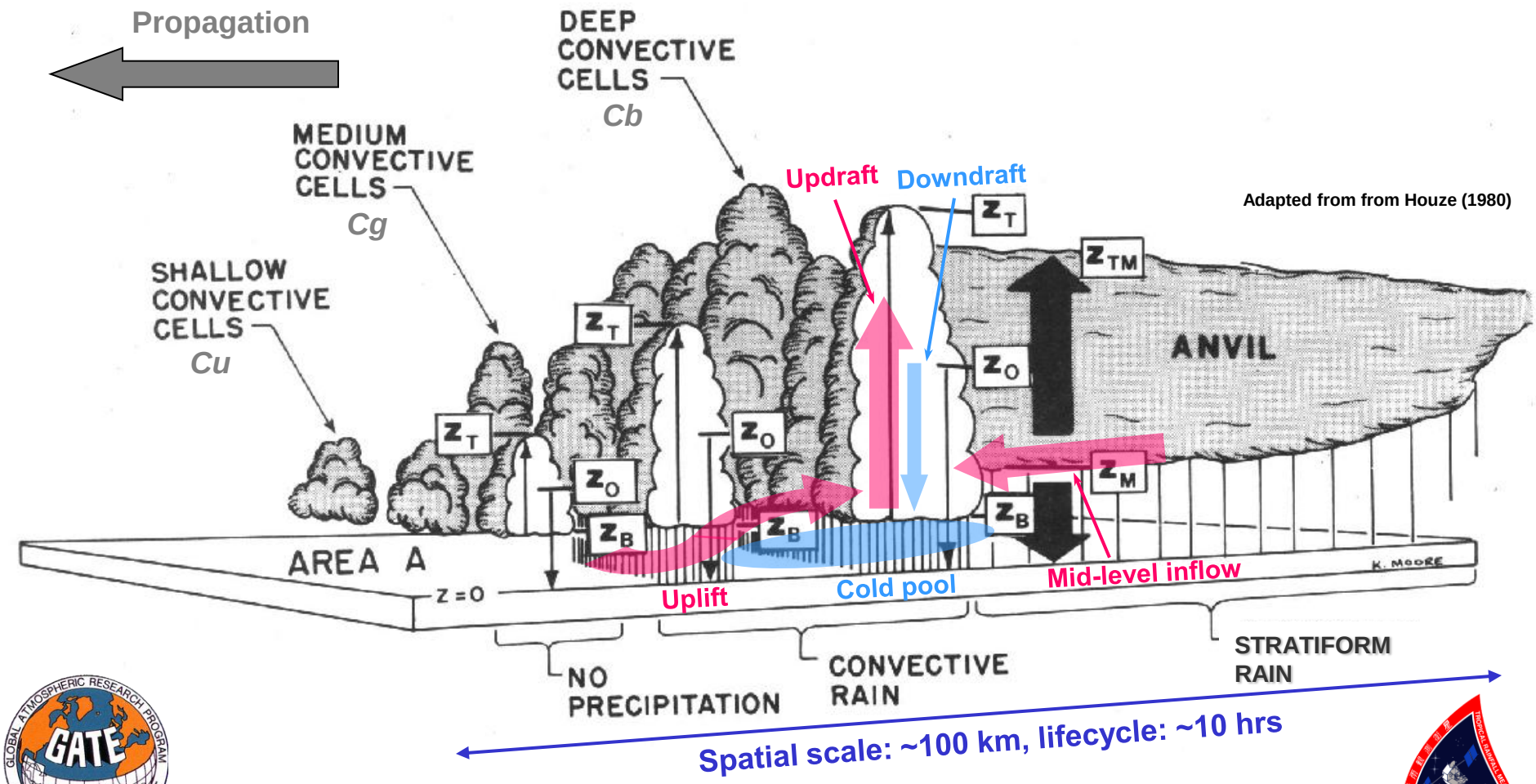


from Houze (2010)



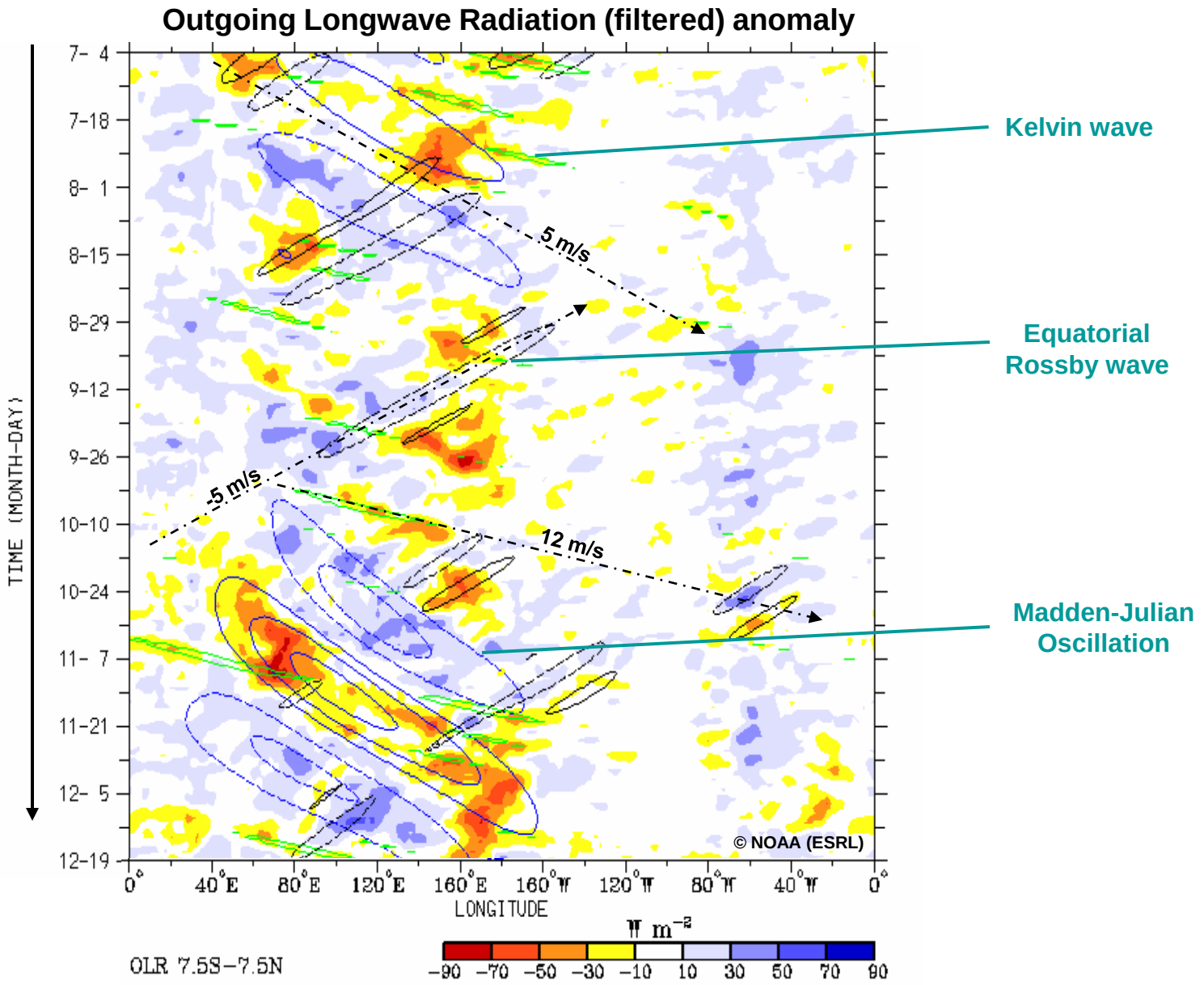


Dynamics of Mesoscale convective systems



- First documented during GATE (Atlantic,1974): spatial organization, role of cold pool;
- Observed during TOGA-COARE (West Pacific, 1992-1993): role of momentum transport;
- Satellite observations with TRMM (1997), Megha-Tropiques (2011), and soon GPM core (2014): population, precipitation.

Spontaneous variability at larger scales

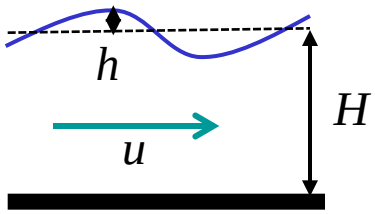


Tropical subseasonal variability

Linearized shallow-water equations on a β-plane:

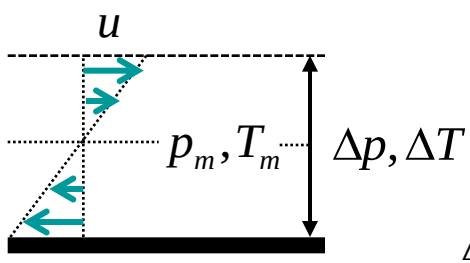
➢ **Classical formulation:**

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



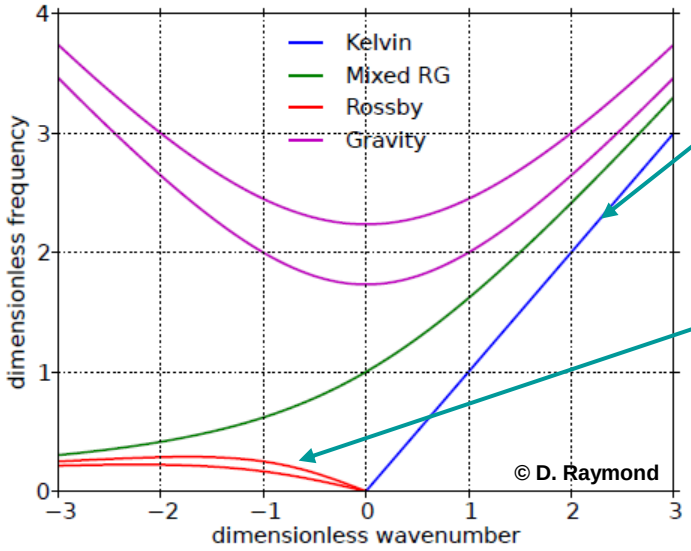
➢ **Tropical atmosphere:**

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

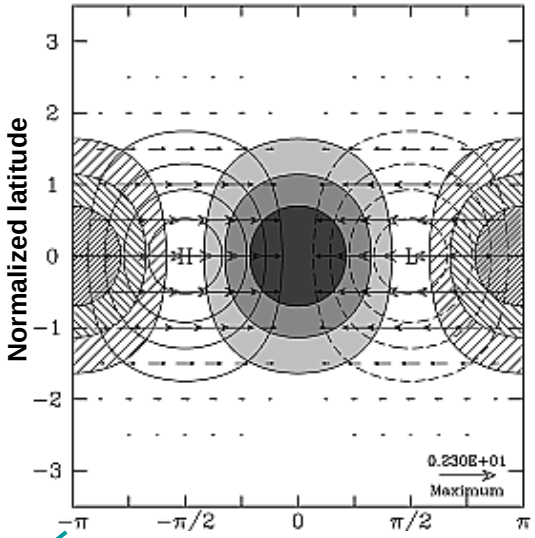


$$\alpha = \frac{\Delta p}{2\,p_m} R$$

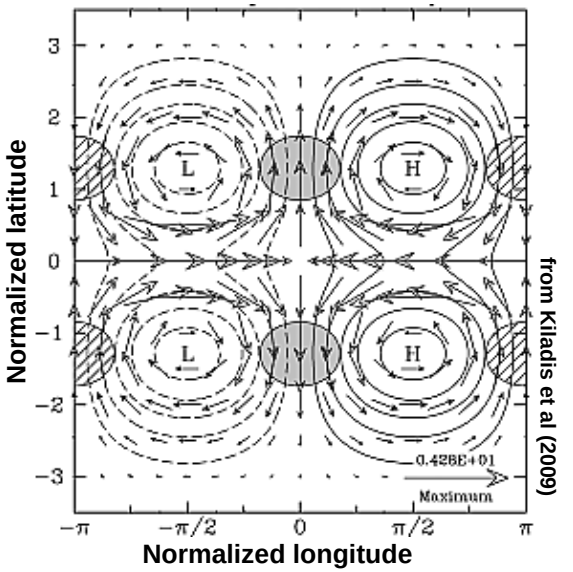
Dispersion diagram:



Kelvin wave



Equatorial Rossby wave

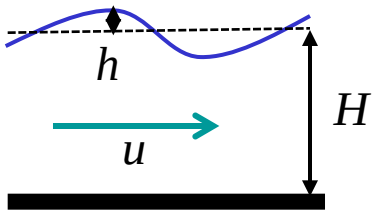


Tropical subseasonal variability

Linearized shallow-water equations on a β-plane:

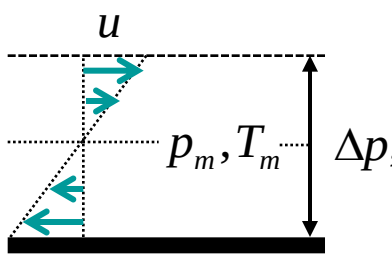
➢ Classical formulation:

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



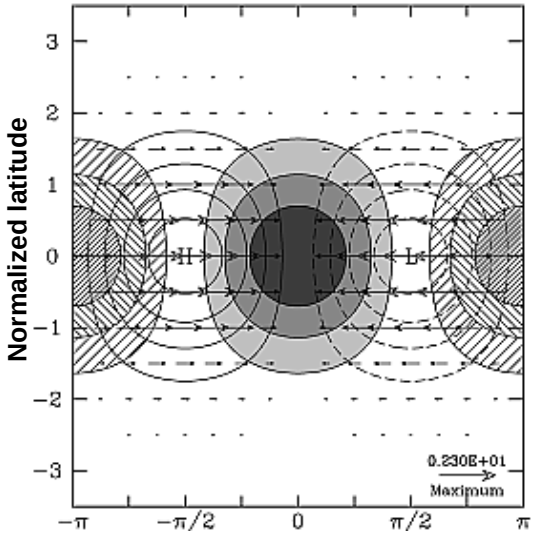
➢ Tropical atmosphere:

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

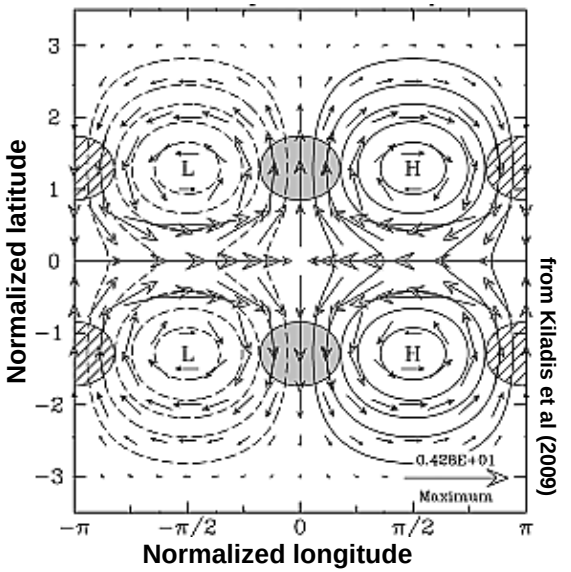


$$\alpha = \frac{\Delta p}{2\,p_m} R$$

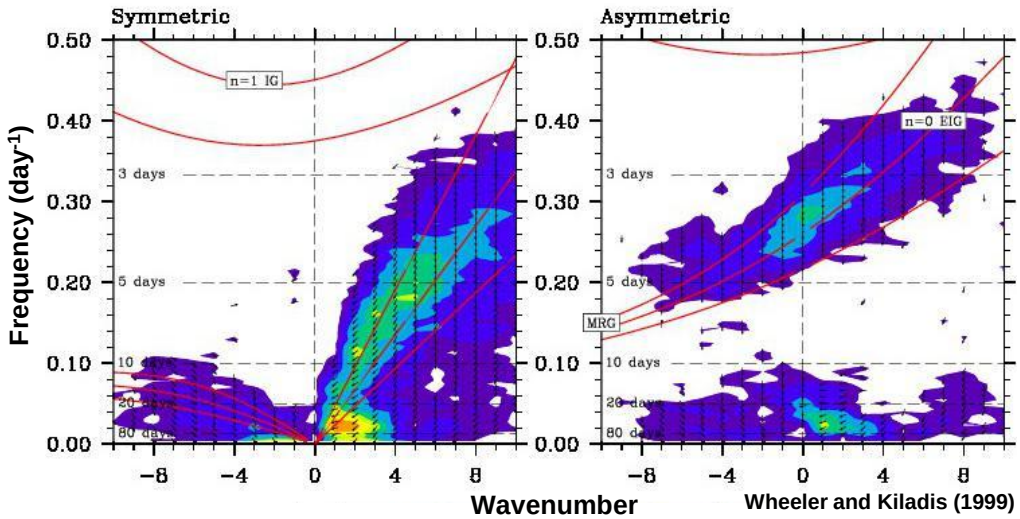
Kelvin wave



Equatorial Rossby wave



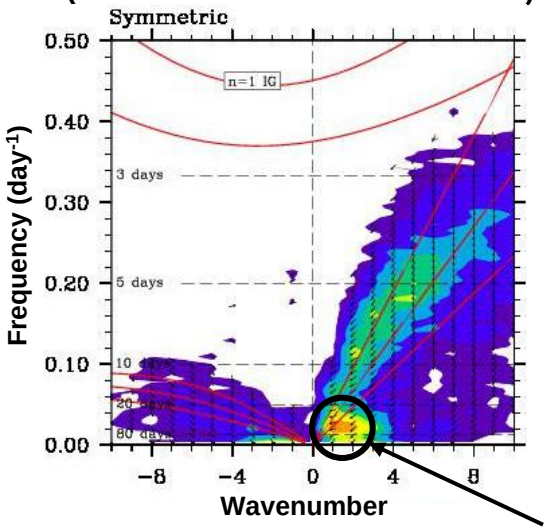
Coherence squared (NOAA OLR + ERA Interim winds)



Wheeler and Kiladis (1999)

Tropical subseasonal variability

Coherence squared
(NOAA OLR + ERA Interim winds)



MJO

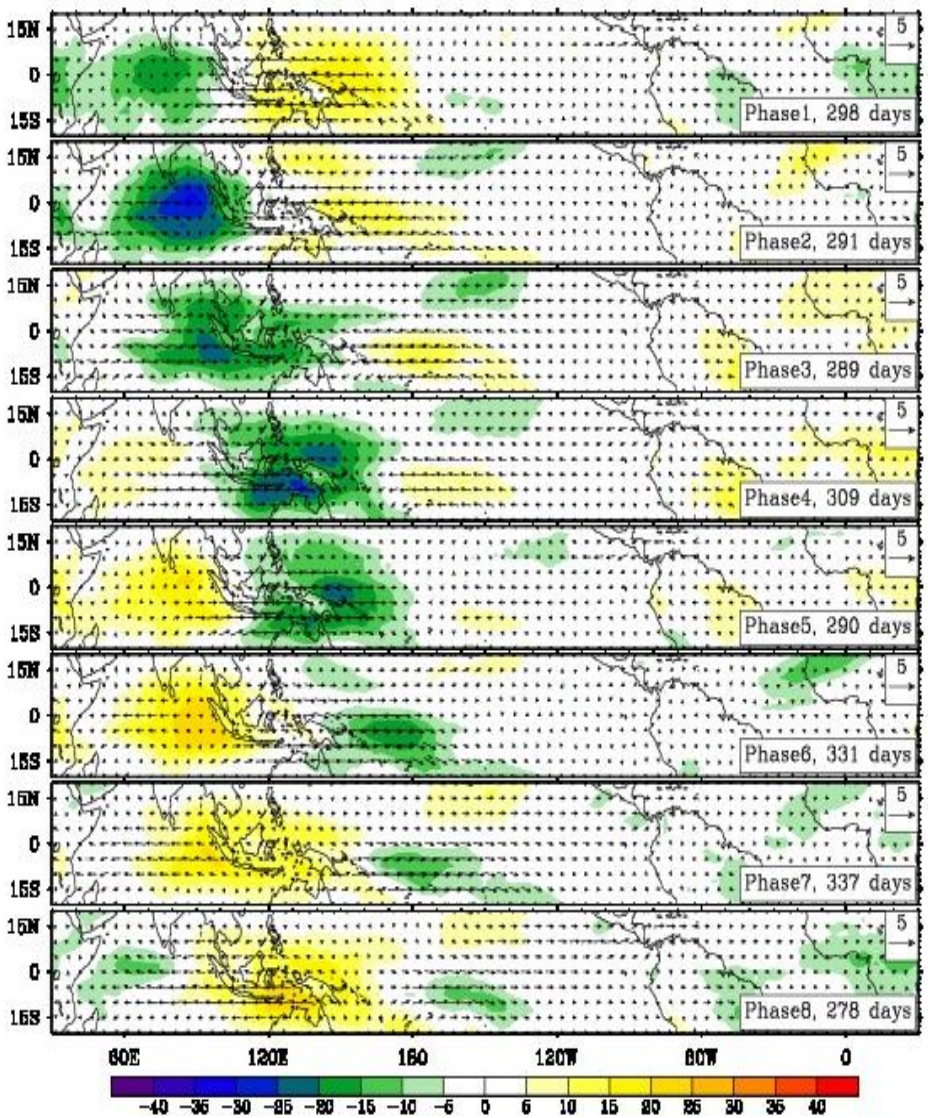
The MJO is a moisture mode ??

Current efforts:

- **Recent campaign**

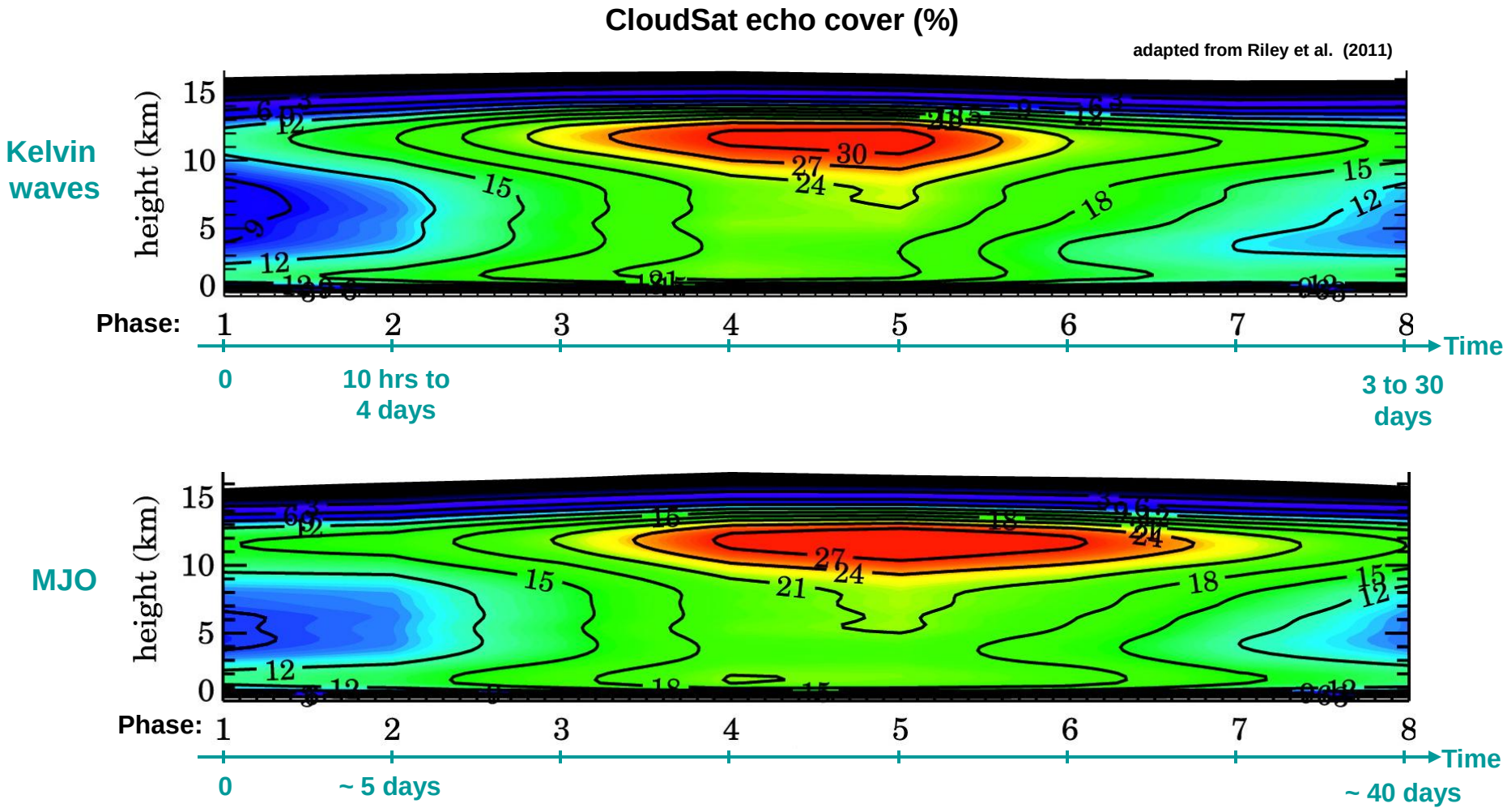
- **Modelling: diabatic structure**

MJO composite life cycle

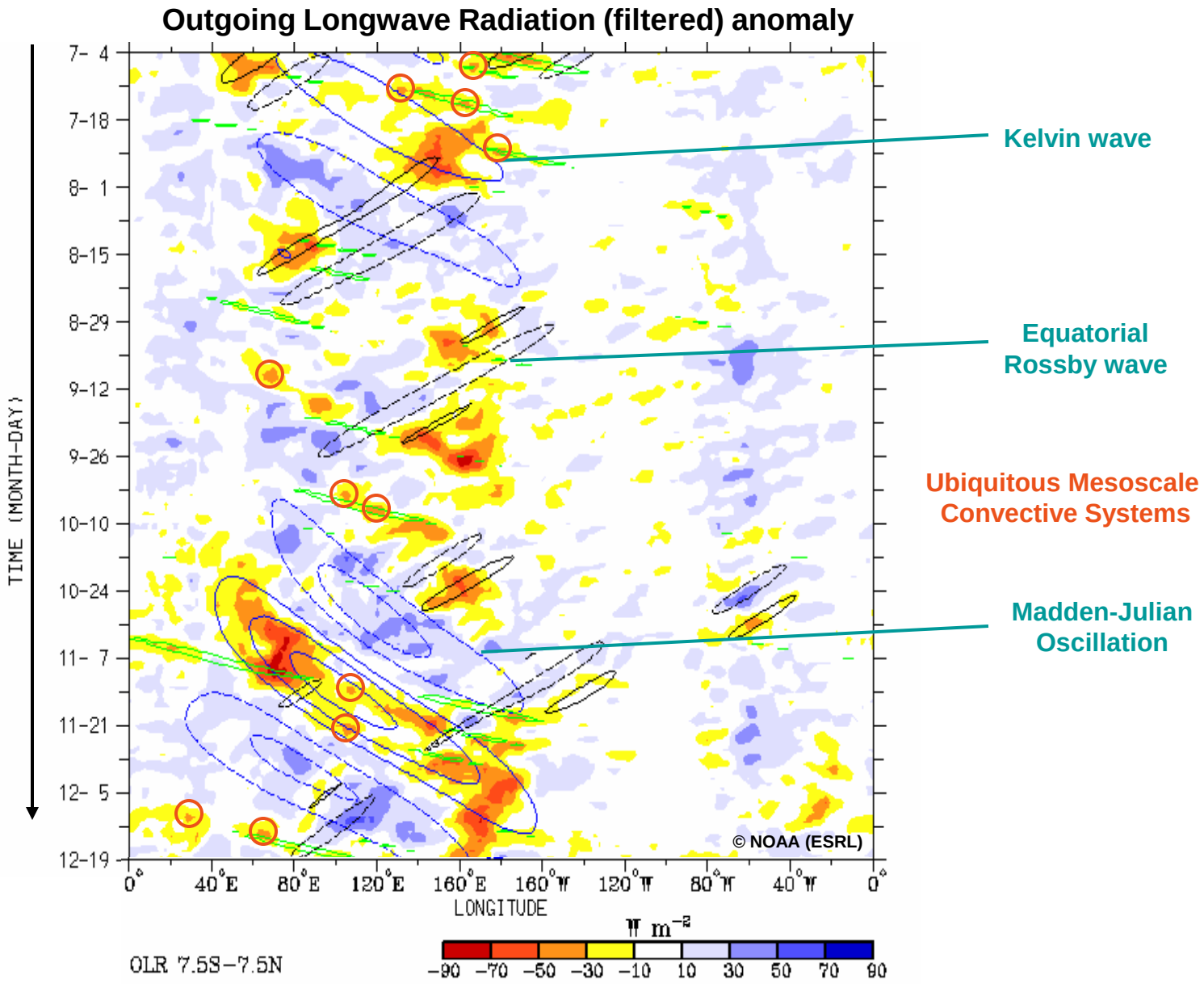


NOAA OLR anomaly (+ ERA Interim wind anomaly)

Cloud signature of Kelvin waves and MJO



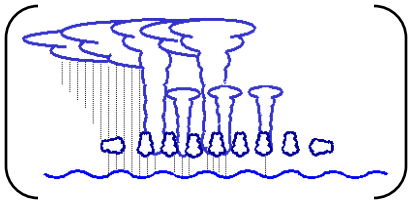
Spontaneous variability at larger scales



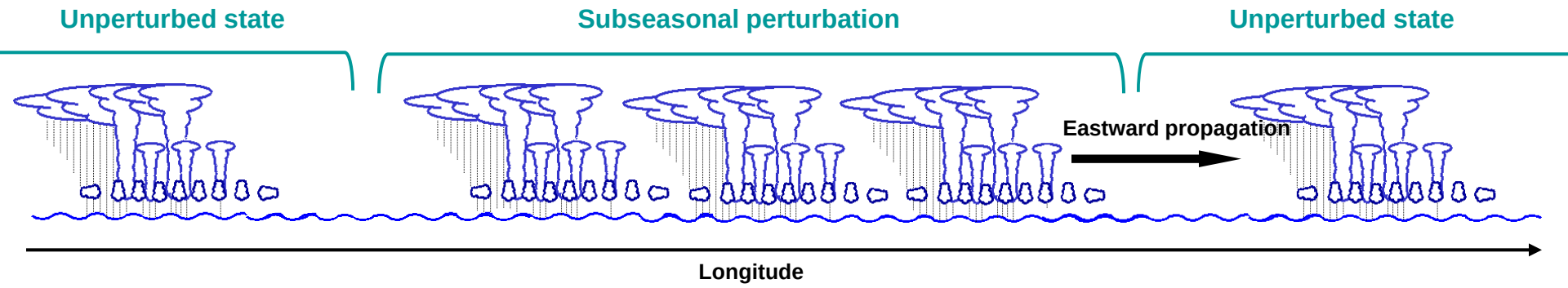
The ‘stretched building blocks’ hypothesis*

* Mapes et al. (2006)

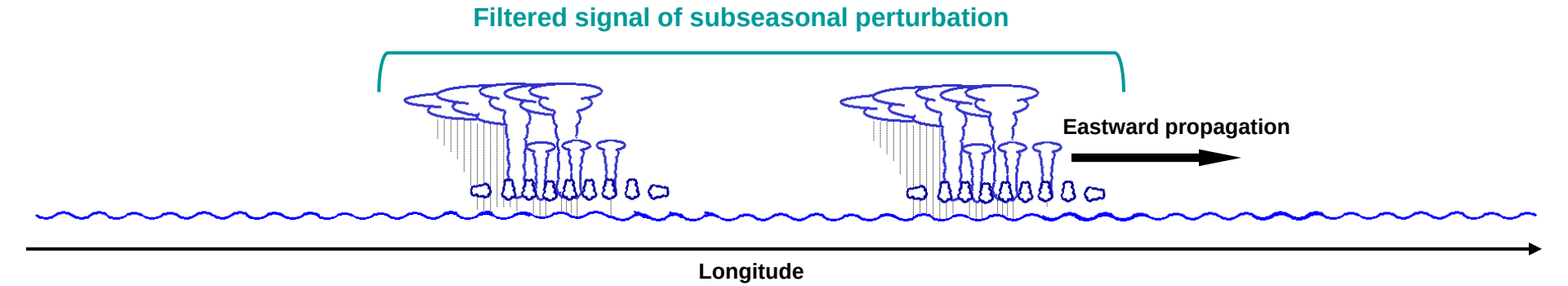
Initial ‘building blocks’ hypothesis:

- MCSs  are the building blocks of larger-scale variability:

- Intraseasonal variations result from piling up building blocks:



Problem: the filtered signal does not have the expected structure



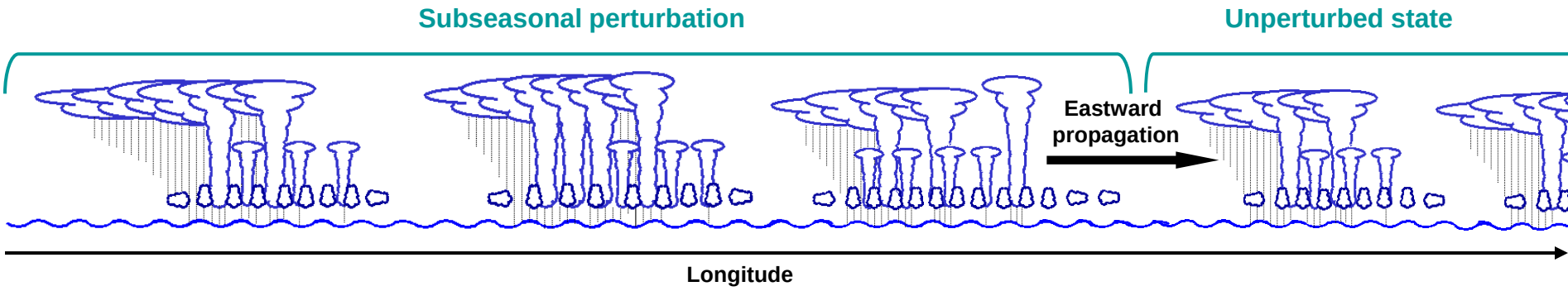
The ‘stretched building blocks’ hypothesis*

* Mapes et al. (2006)

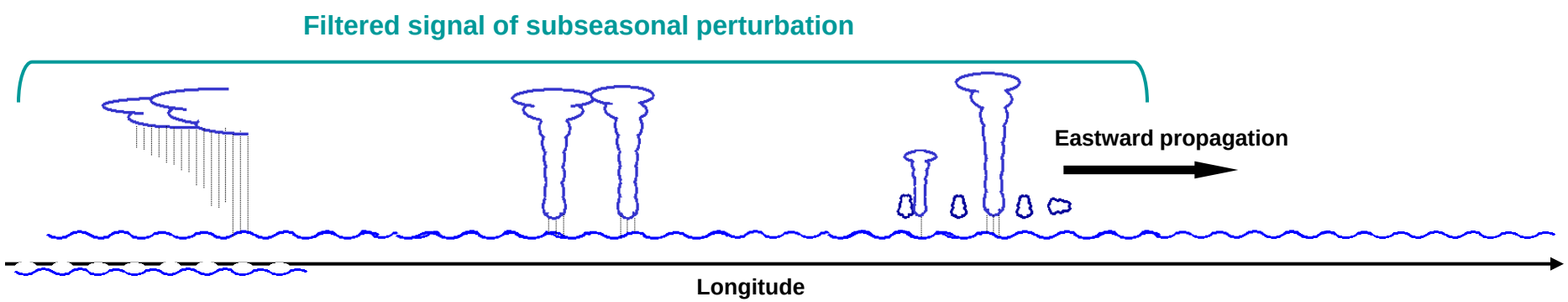
‘Streched building blocks’ hypothesis:

- **MCSs are the building blocks of larger-scale variability:**

- **Intraseasonal variations result modulating one phase of the life cycle (shallow, deep convective or stratiform) of these building blocks**



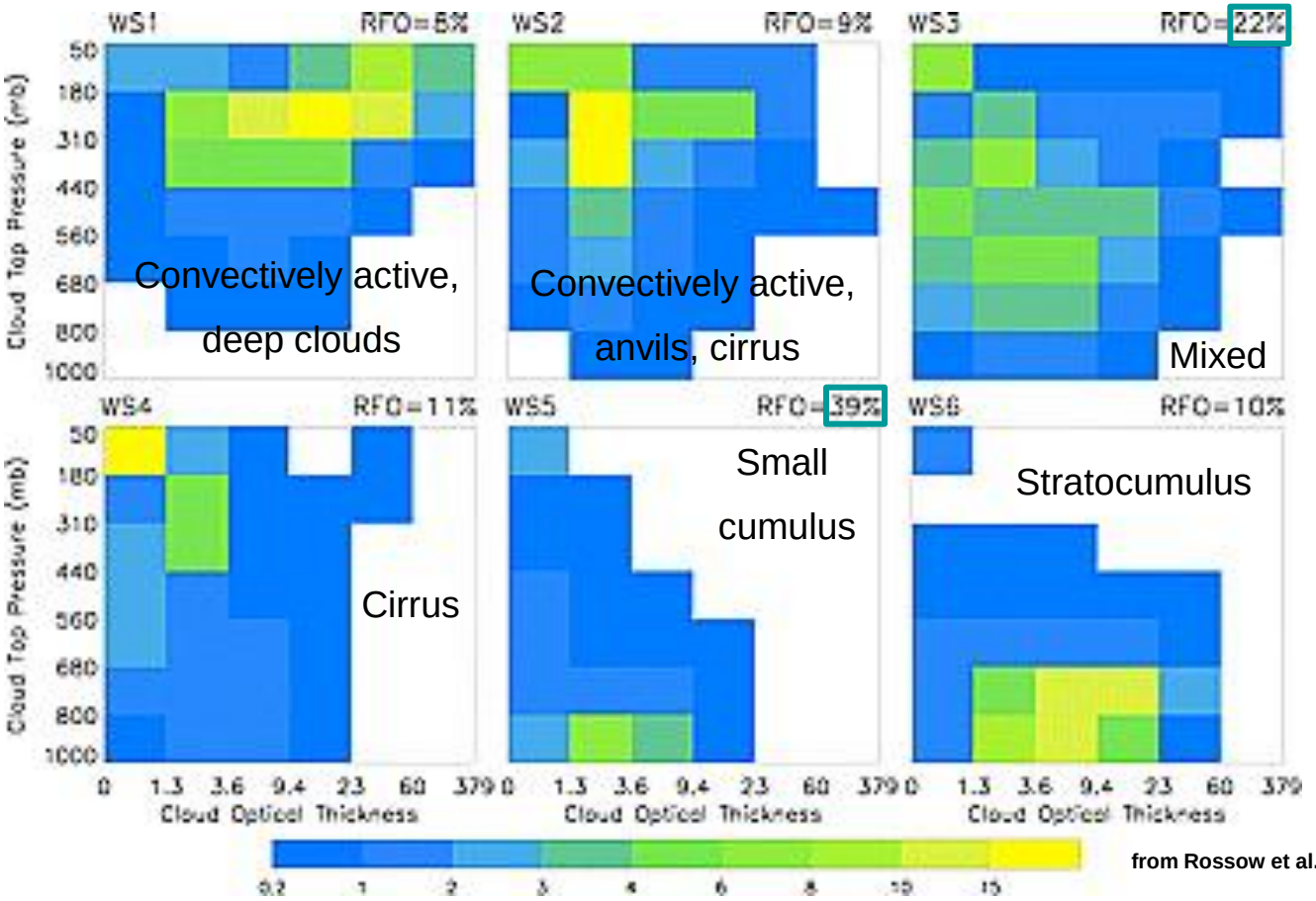
Filtered signal:



Weather states

In the distribution of cloud in terms of cloud-top altitude and cloud optical depth, six 'weather state' can be determined:

from ISCCP (satellite passive measurements):

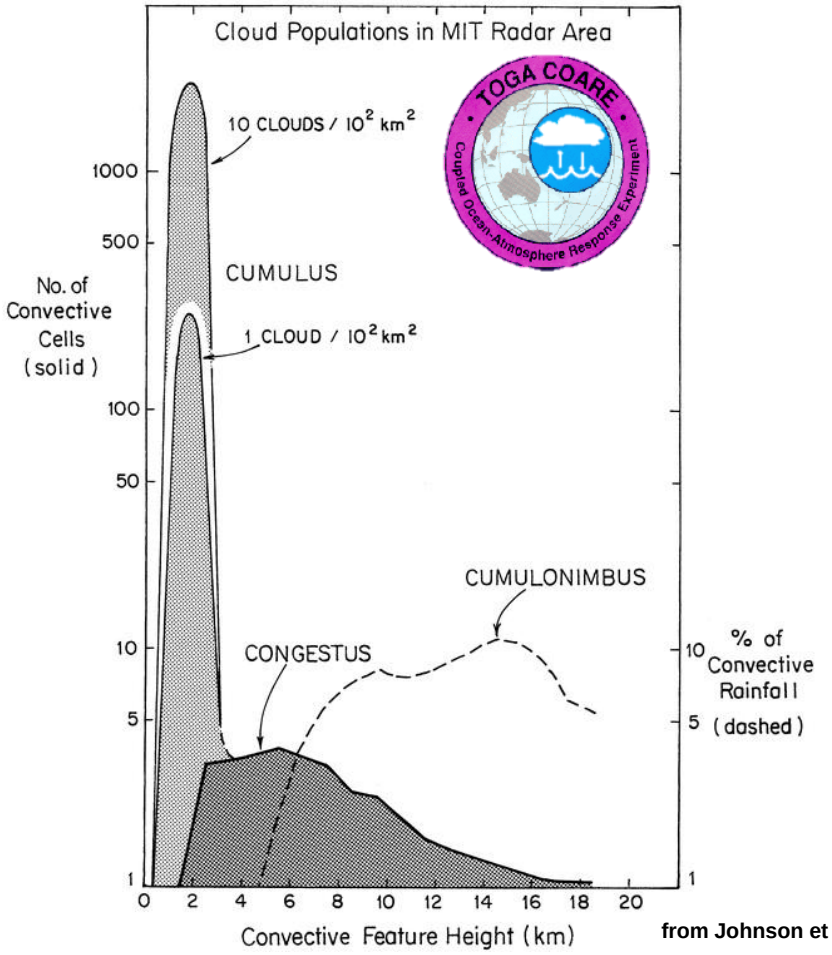


from Rossow et al. (2005)

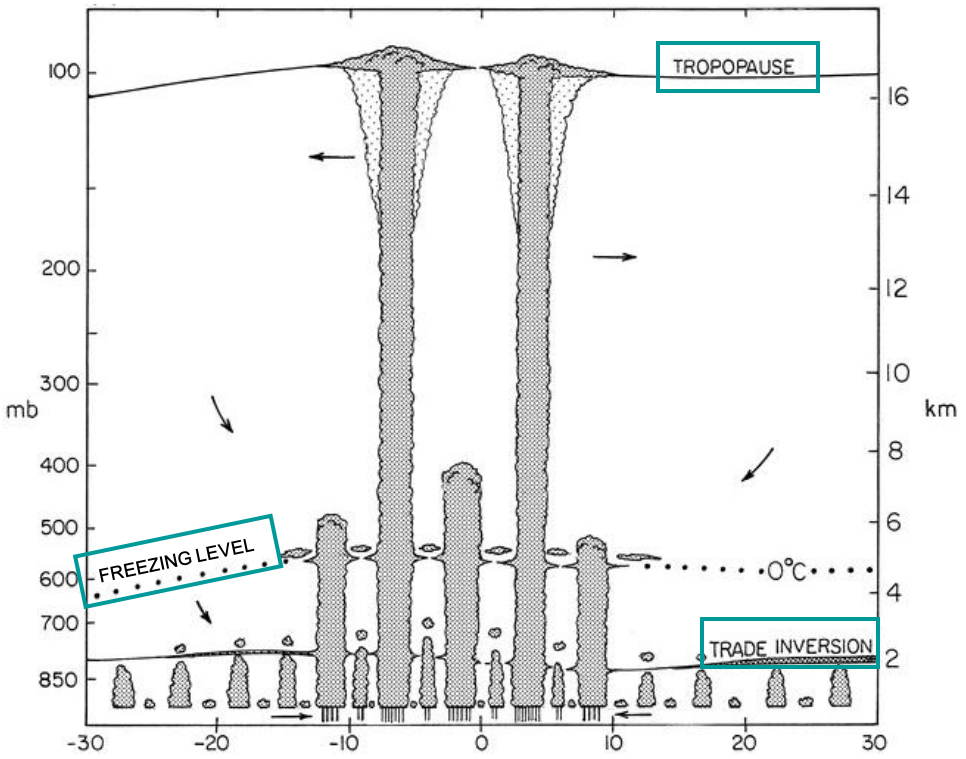
Distribution of cloud top altitudes

The distribution of cloud top altitudes is trimodal …

from radar measurements:

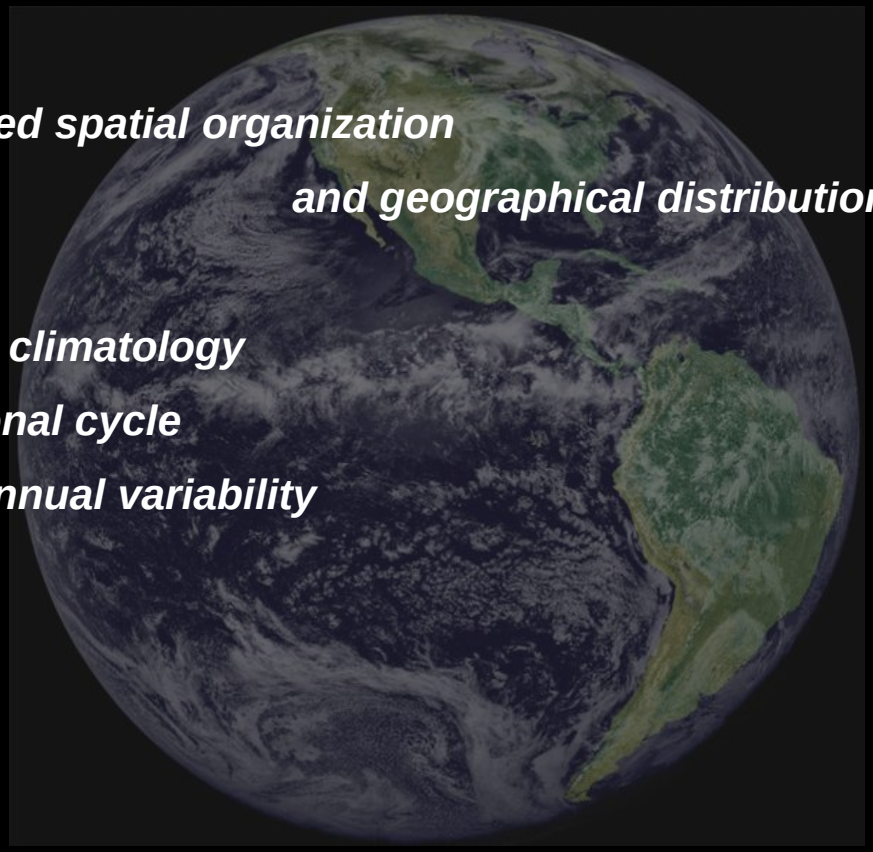


… with maxima at altitudes of enhanced stability :



from Johnson et al. (1999)

Outline

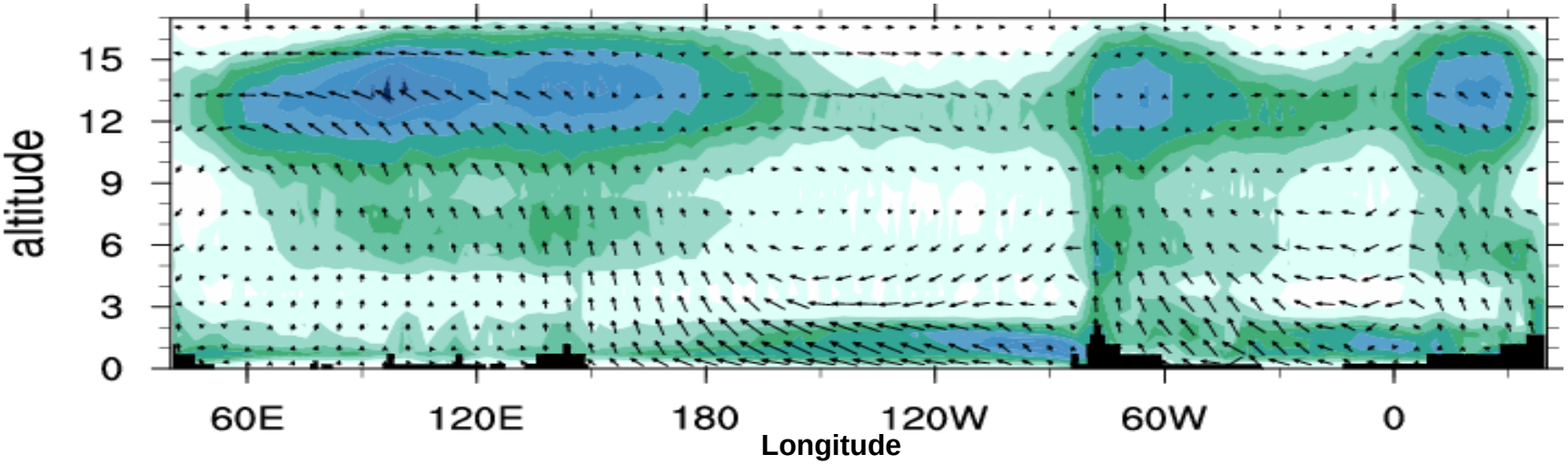


B. Cloud forced spatial organization and geographical distribution

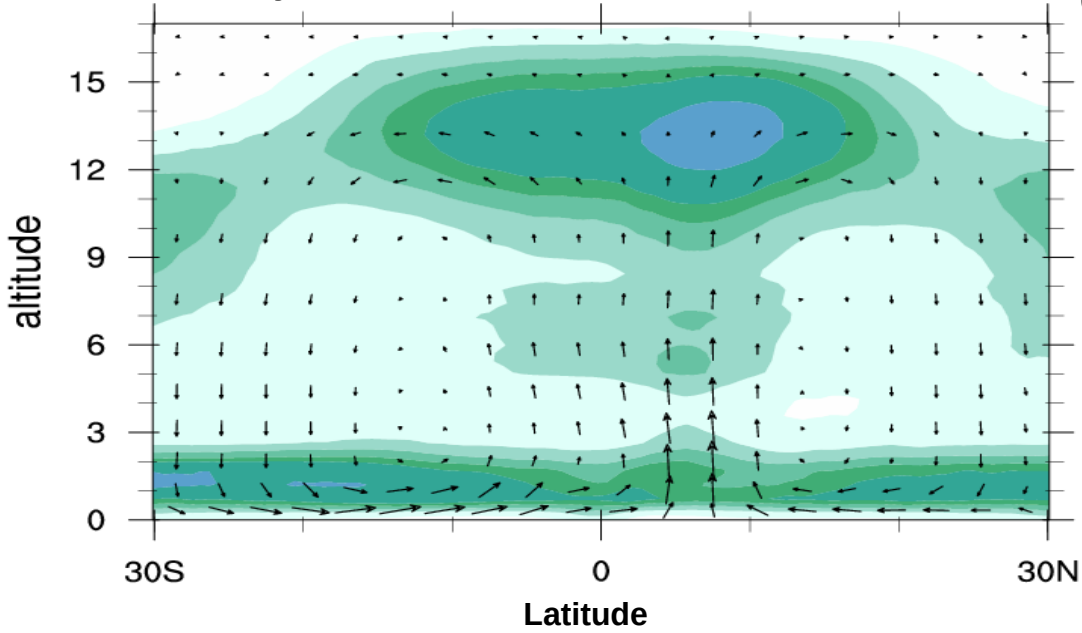
1. ***Cloud climatology***
2. ***Seasonal cycle***
3. ***Interannual variability***

Embedded in planetary circulations

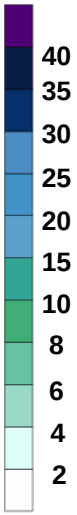
Walker circulation: Equatorial band



Hadley circulation: Zonal and time average



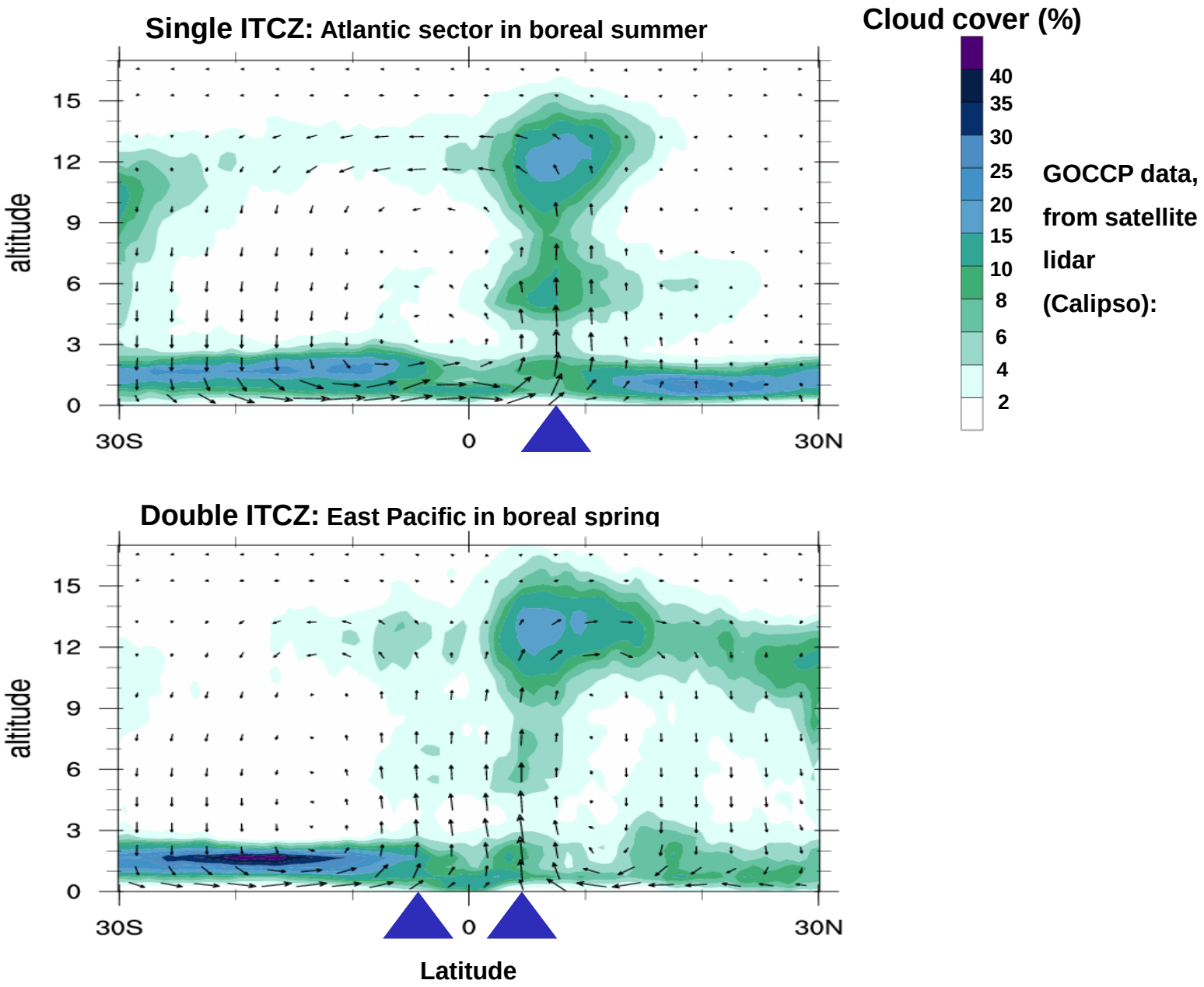
Cloud cover (%)



GOCCP data, from satellite lidar (Calipso):

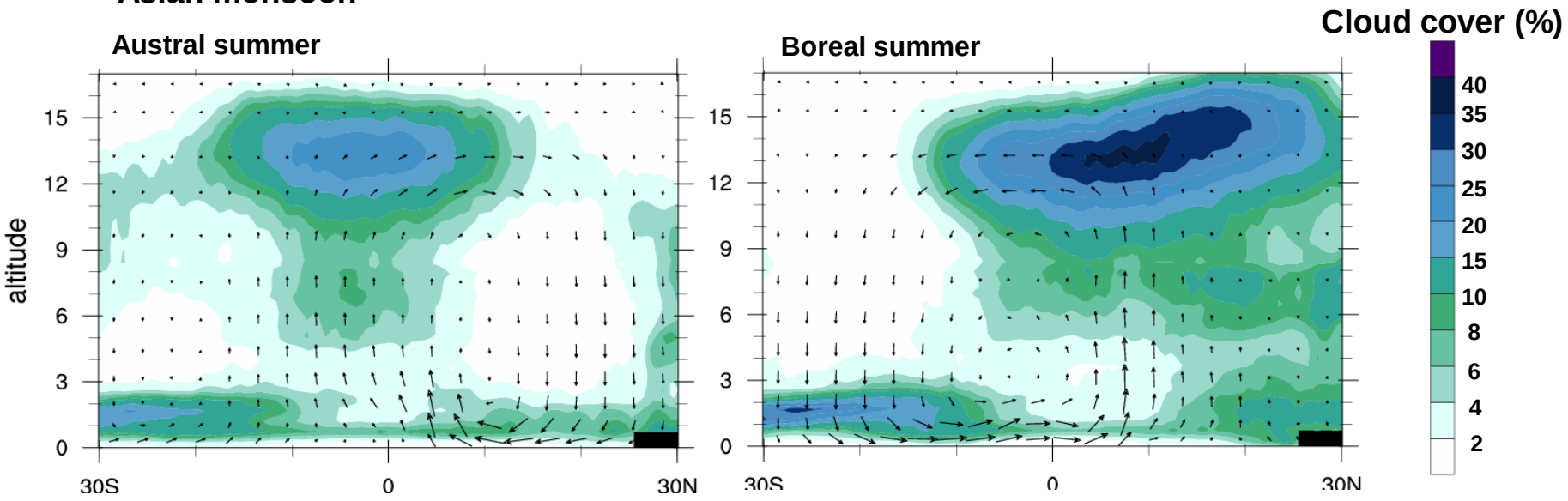
Latitude

Intertropical convergence zone(s)

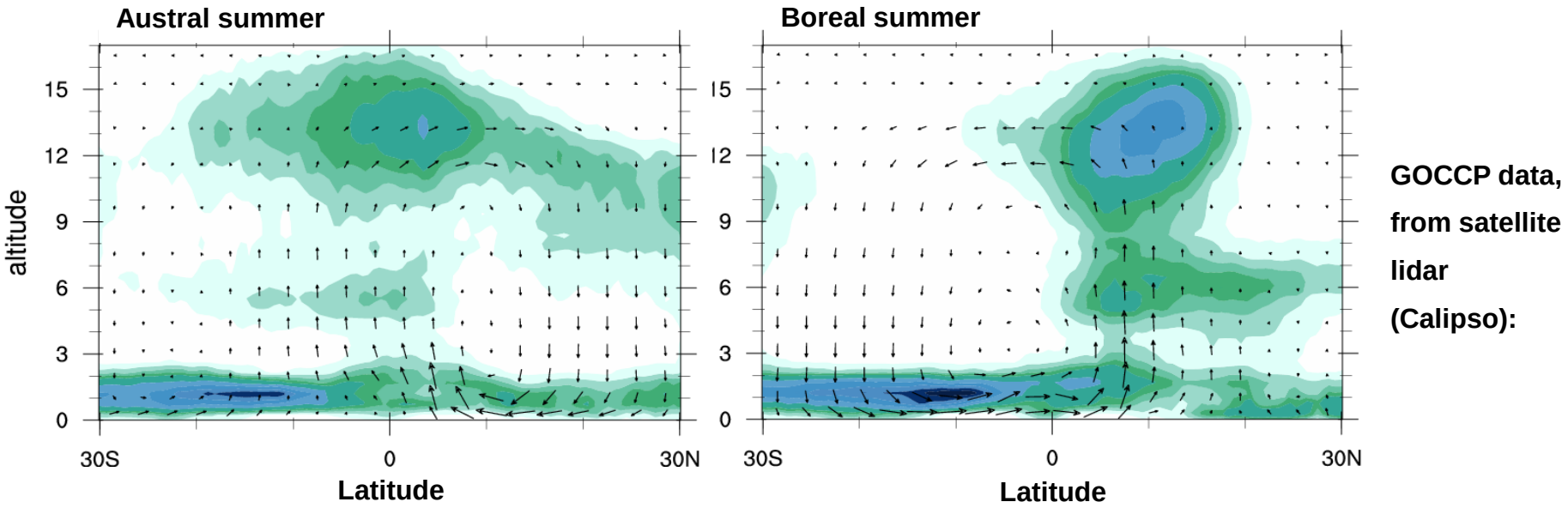


Monsoons

Asian monsoon

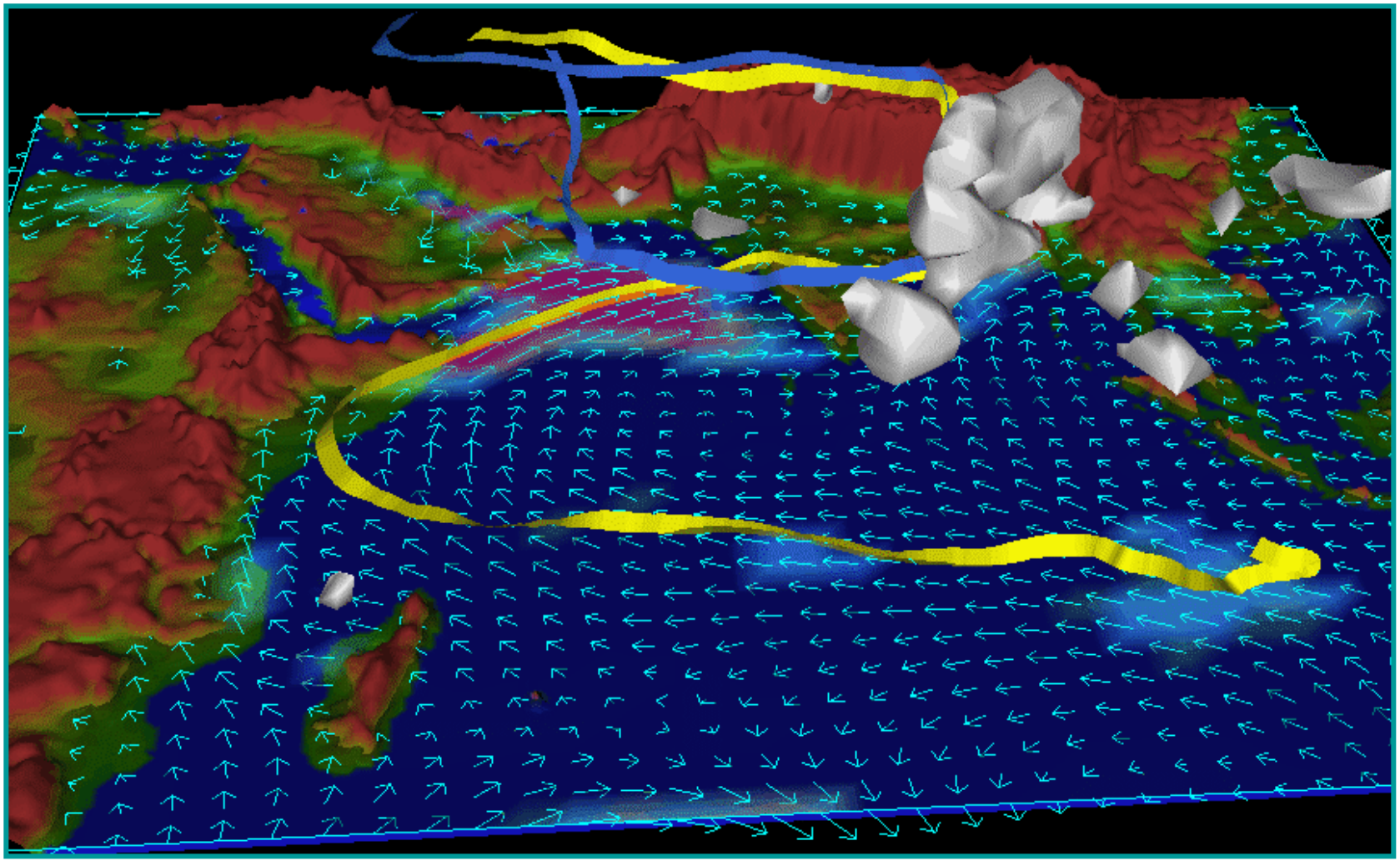


West African monsoon

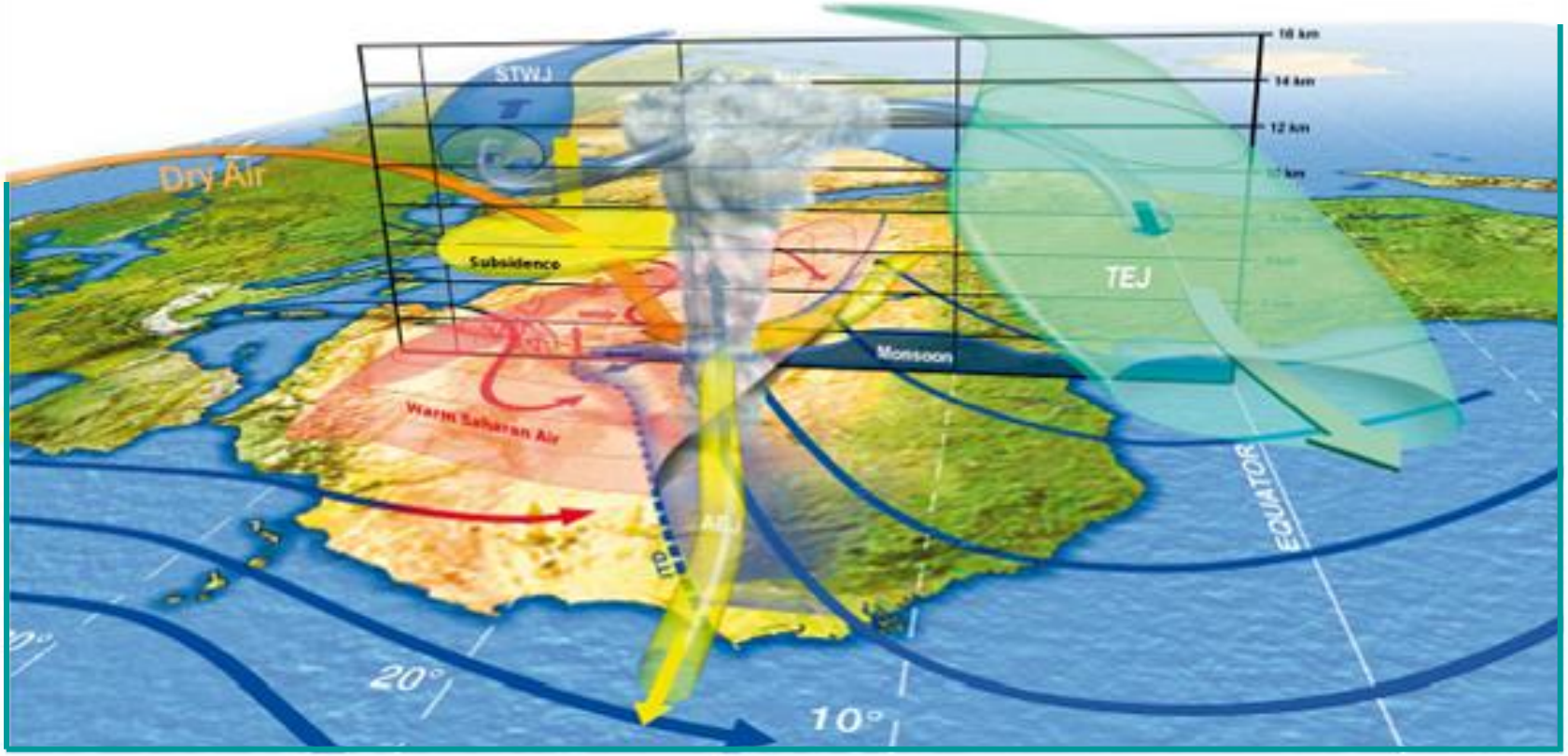


GOCCP data, from satellite lidar (Calipso):

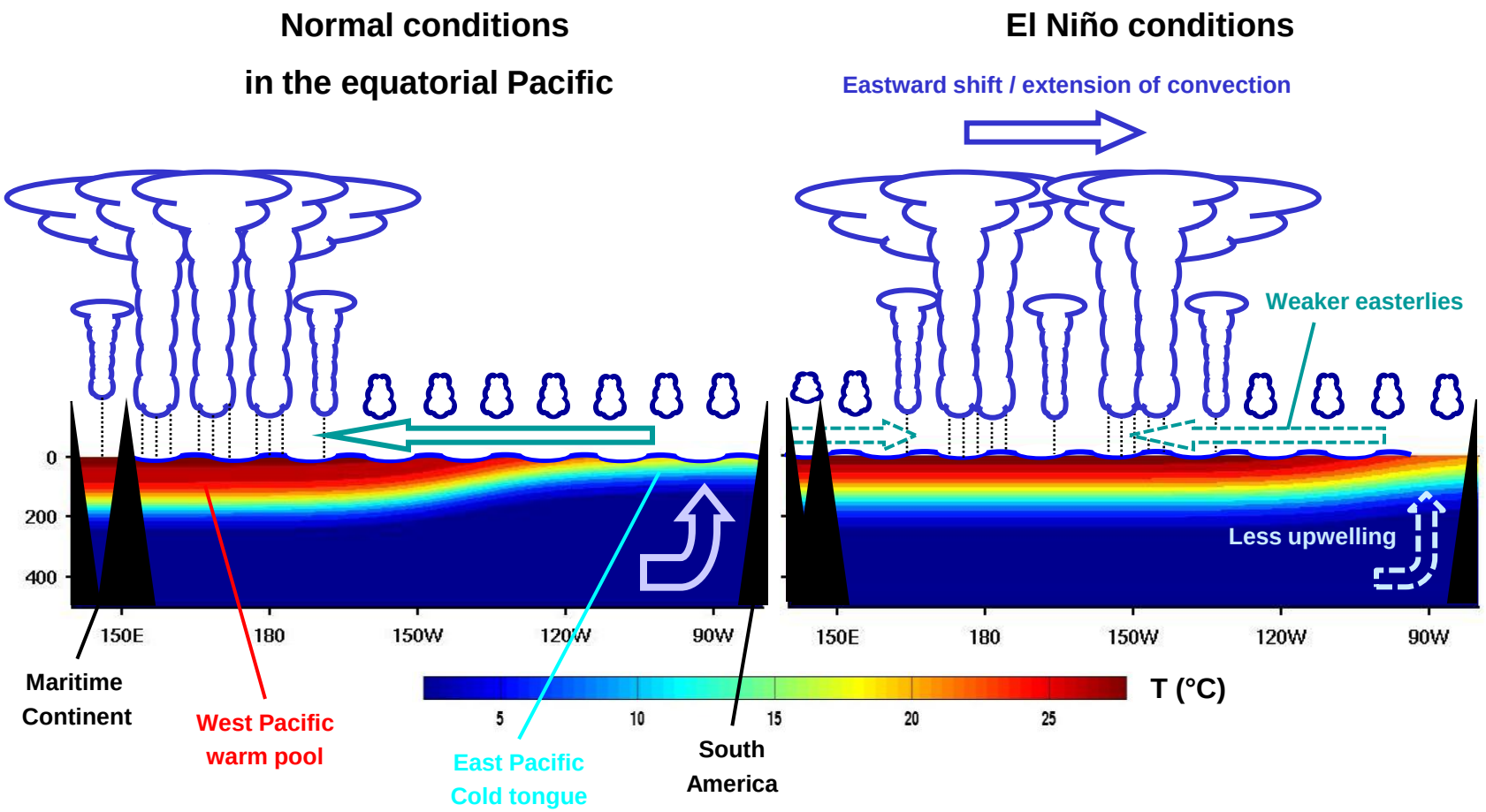
Asian Monsoon



African Monsoon

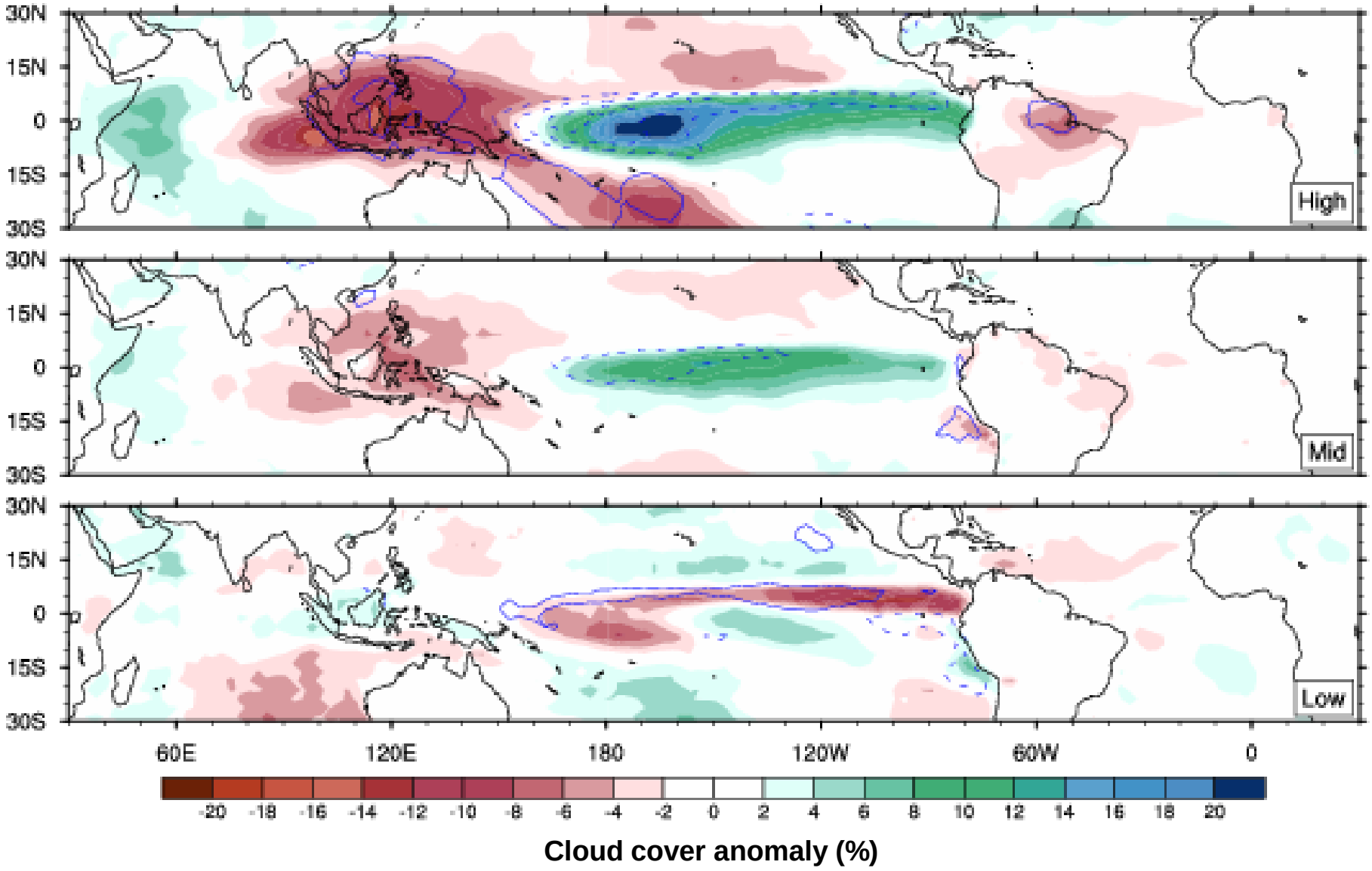


El Niño – Southern Oscillation



Cloud signature of ENSO

El Niño (shadings) and La Niña (contours) composite cloud anomaly (ISCCP)



Outline

A. Cloud spontaneous spatial organization
and resulting statistics

B. Cloud forced spatial organization
and geographical distribution

Lecture 1

C. Cloud and their environment:
a two-way interaction

D. Cloud mechanisms in the tropical climate

Lecture 2