THE ATMOSPHERE

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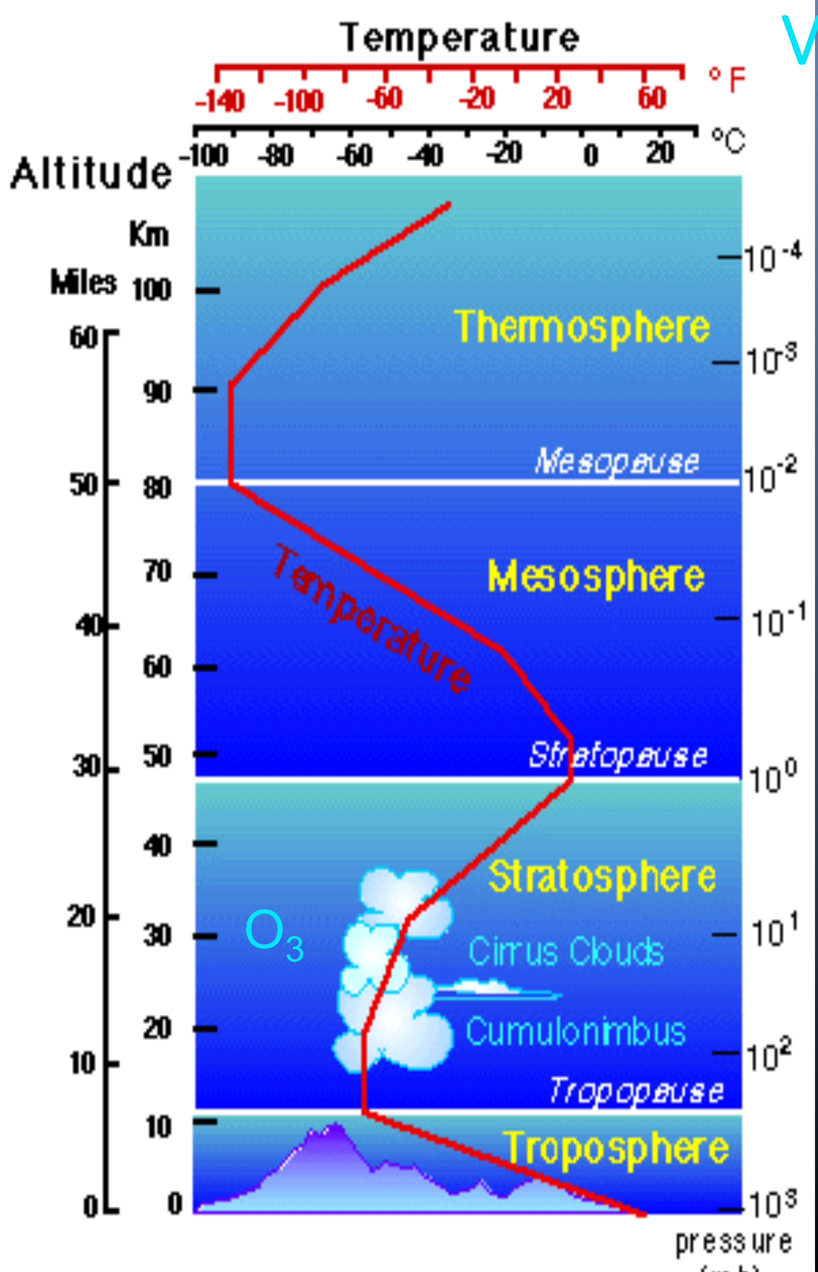
CICESE

The Abdus Salam International Centre for Theoretical Physics

The Science of Climate Change: a focus on Central America and the Caribbean Islands

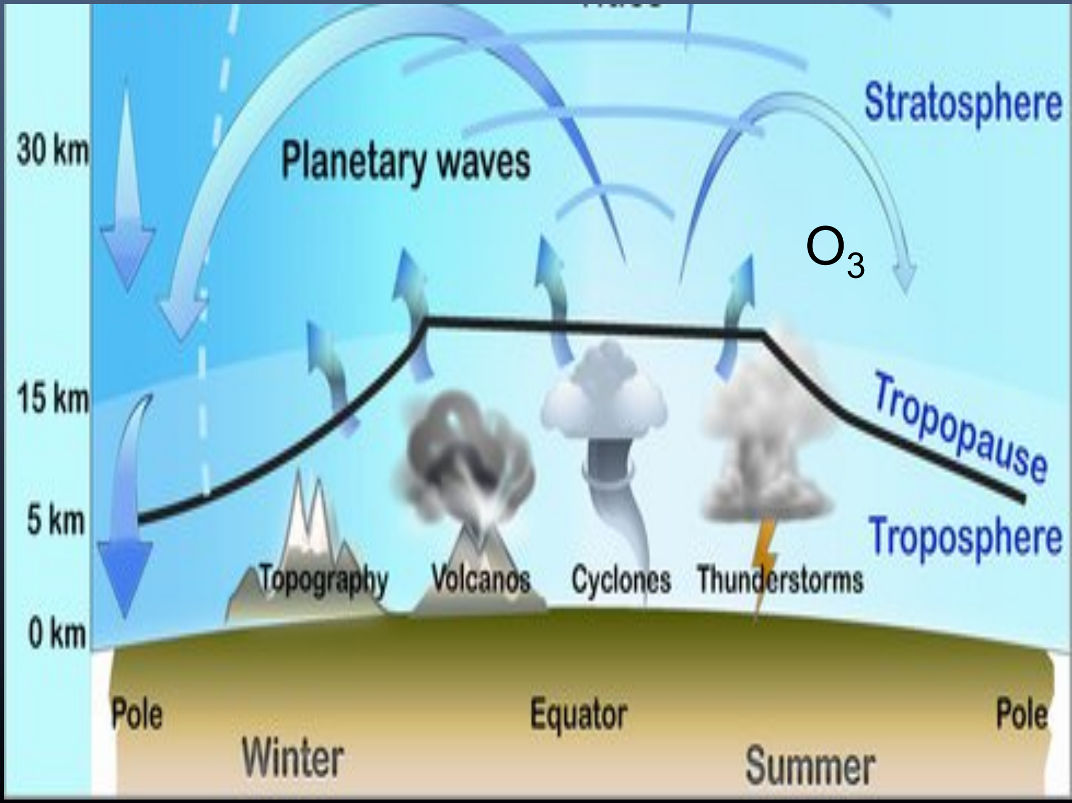
Antigua, Guatemala, 14-16 de marzo de 2017

Vertical Structure



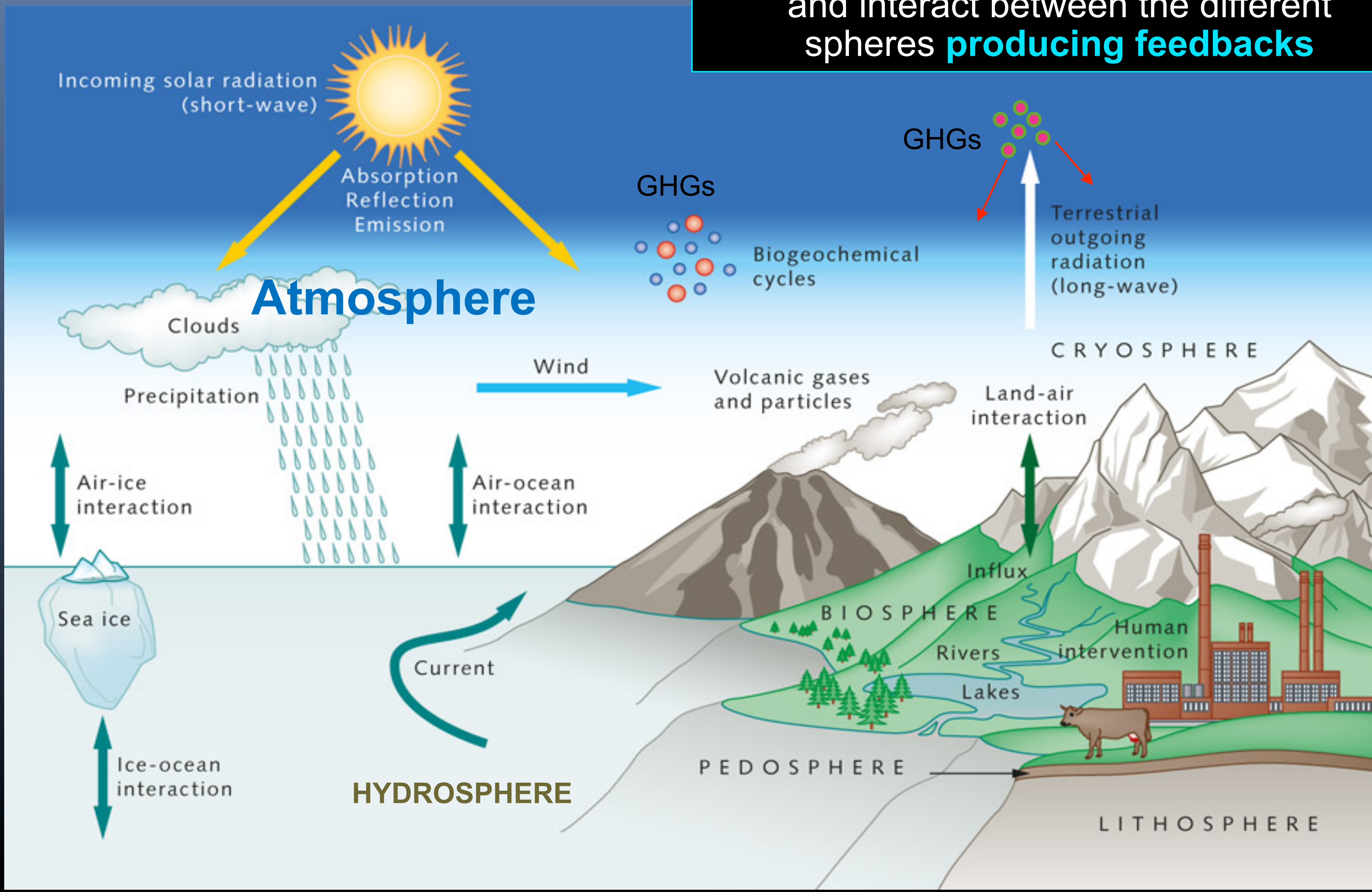
(Fig. 1.9, Wallace & Hobbs, 2006)

Atmosphere: is the layer of gases that surrounds the Earth and stays in place due to **gravity**. Up to 80 km the atmosphere is uniform: **AIR**



Earth's Climate System

Depends on many **processes** that occur and interact between the different spheres **producing feedbacks**



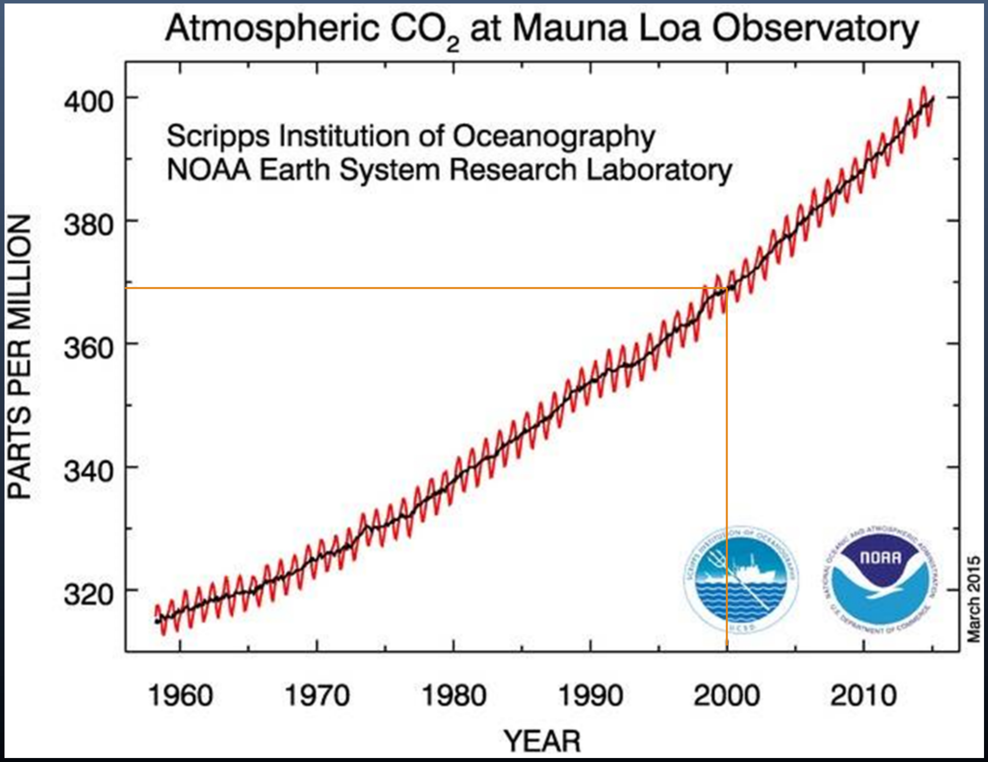
Earth's Atmosphere

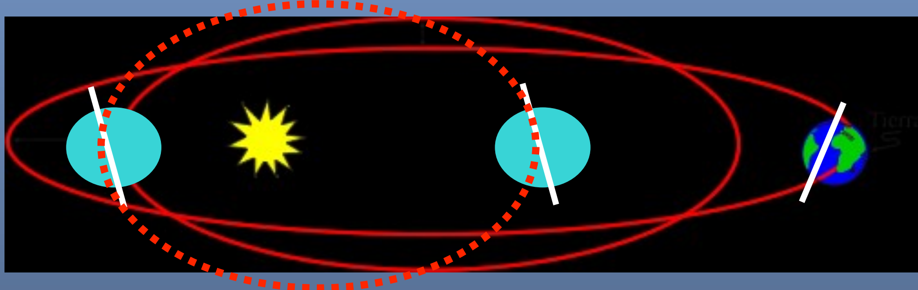
- Unique composition of gases (& GHGs) **favors life as we know it**
- **Unique weather & climate**
- **Transports heat, momentum, and humidity (hydrological cycle)**
- **Transports aerosols and other contaminants (O_3, CFC, NO_x, black carbon, etc.)**

GHGs: ➔ Global Ta = 15^oC

CO_2 (0.04%) CH_4, N_2O, water vapor

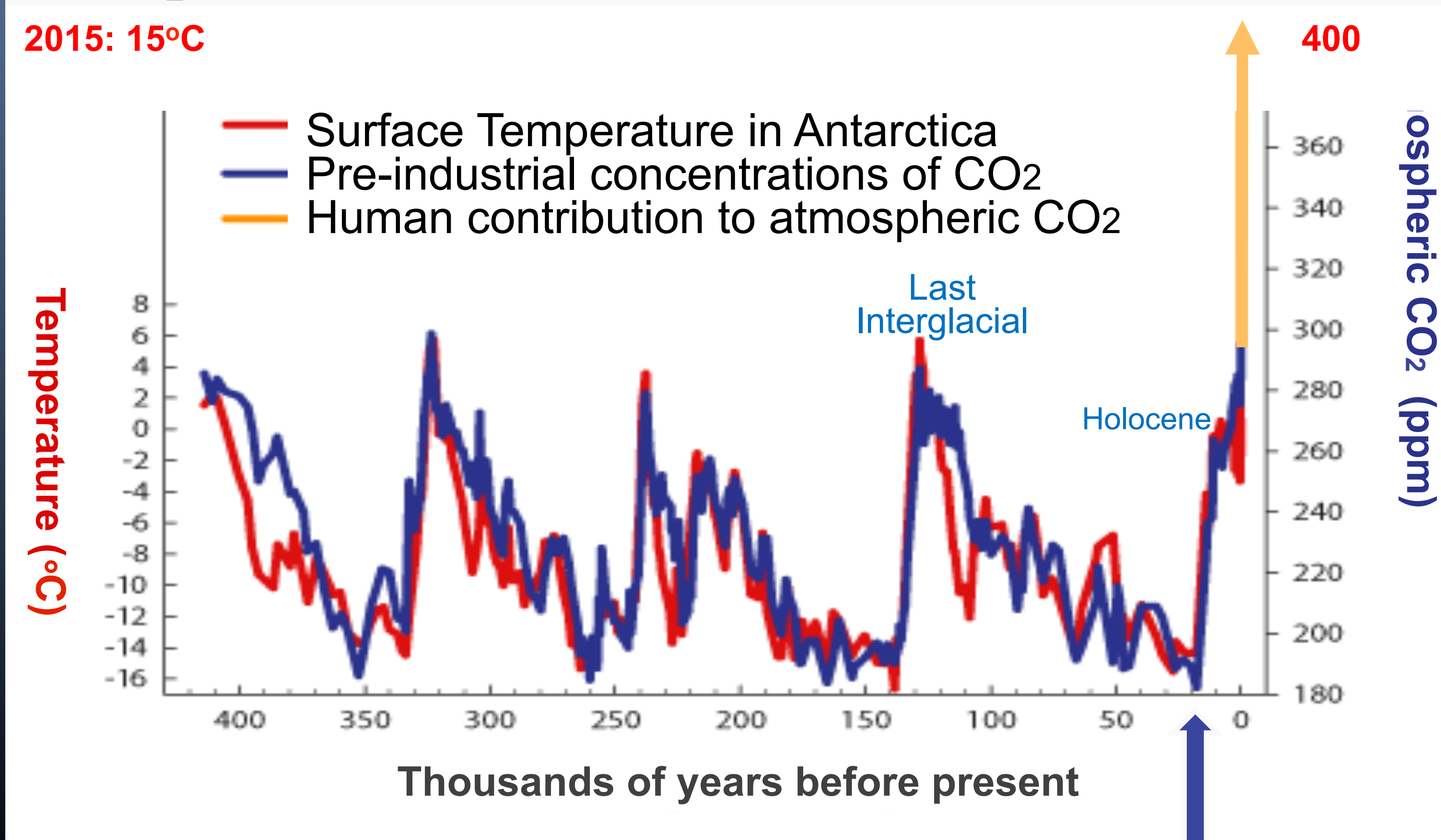
No GHGs ➔ T = -17^oC





← External Forcings

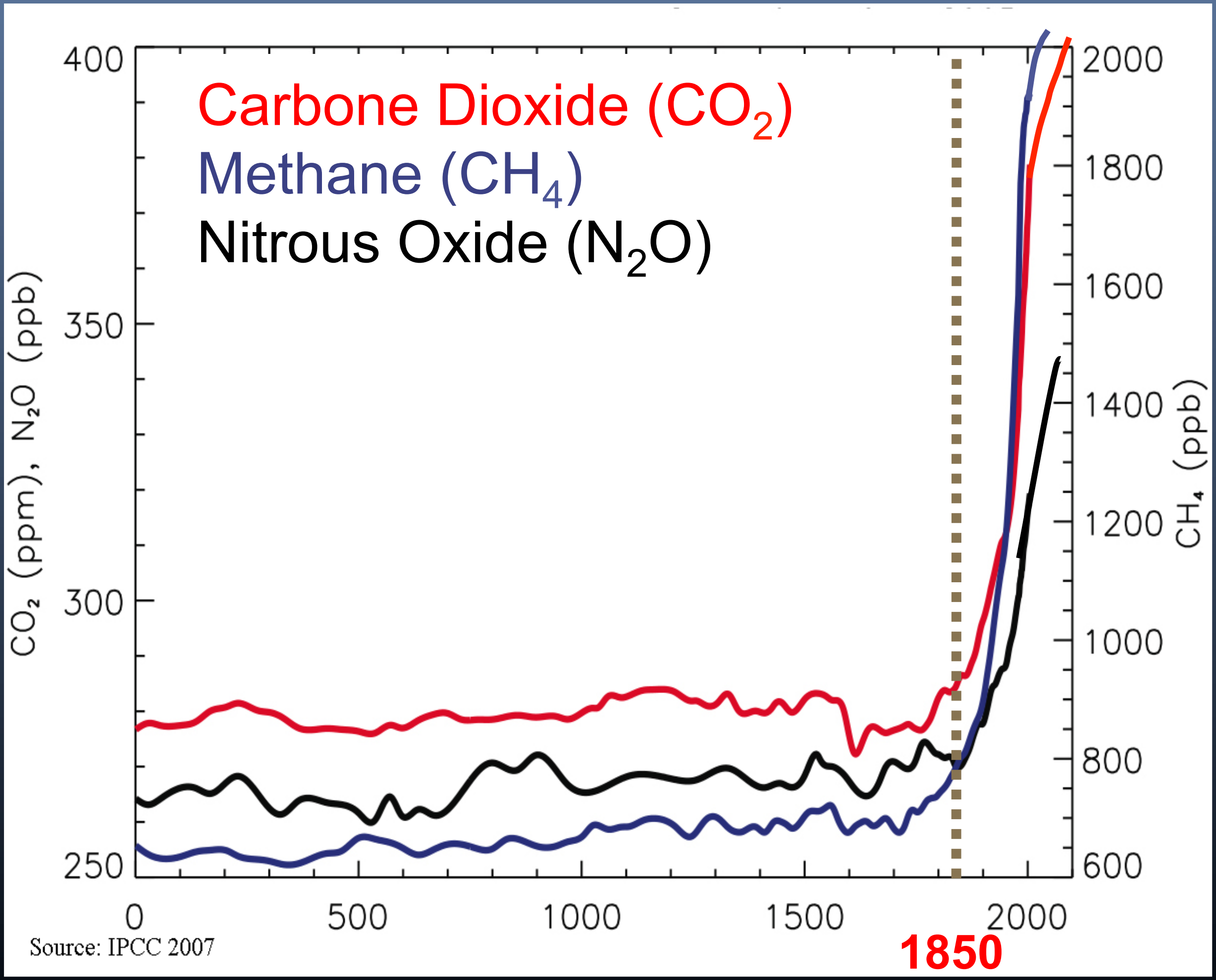
CO_2 & Temperature in Antarctica since 420,000 yr ago



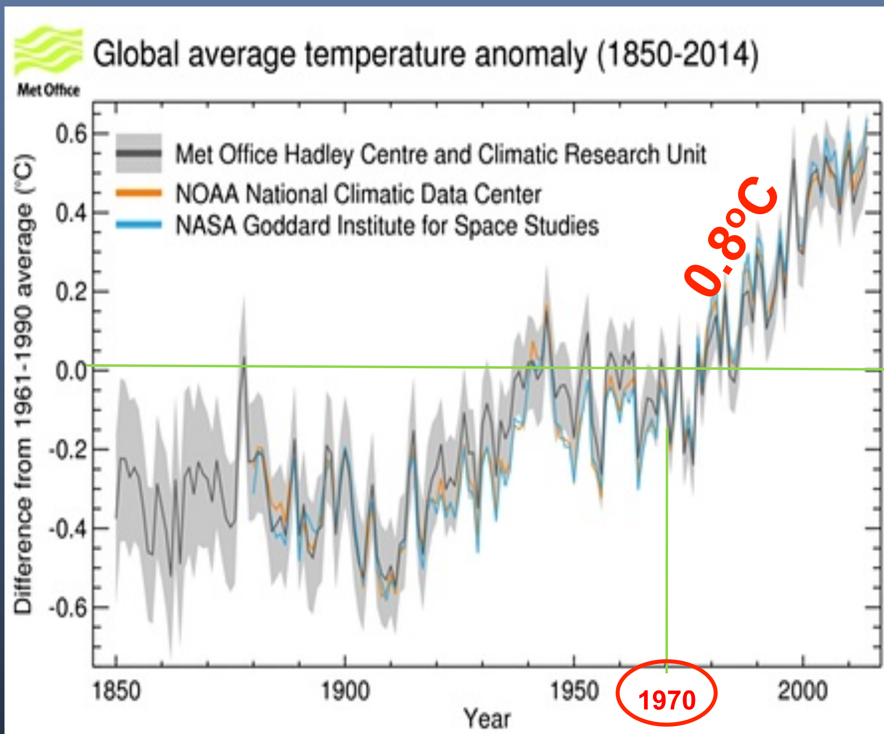
Last glaciation (Tan = -16°C)

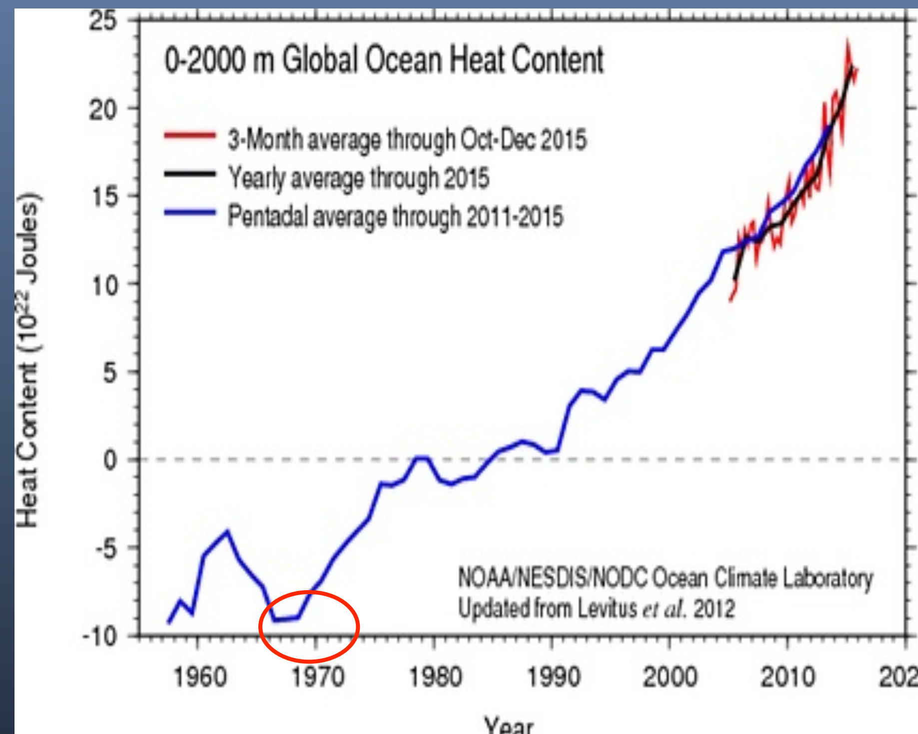
(Petit et al., 1999, *Nature*, 399, p. 431. Ver Fig. 2.31, W&H, 2006, p. 52)

Concentration of Greenhouse Gases (GHGs)

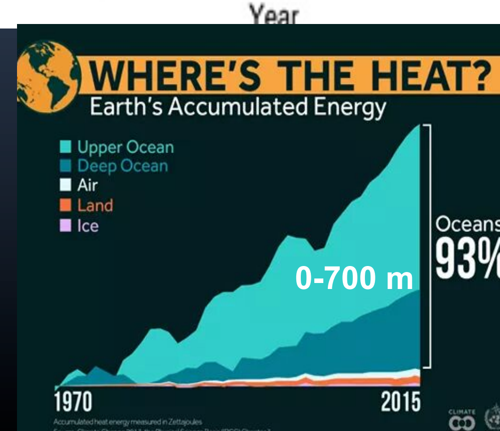


OBS: Global Air Temperature Anomaly and Ocean Heat Content





Global Air Tmean = 15oC



Radiative Forcings in the Atmosphere (Watts/m^2)
Attribution to climate change

Processes

ANTHROPOGENIC

- GHGs
- Land-use change
- Tropospheric Ozone

NATURAL

- Solar radiation
- Volcanoes
- Water vapor

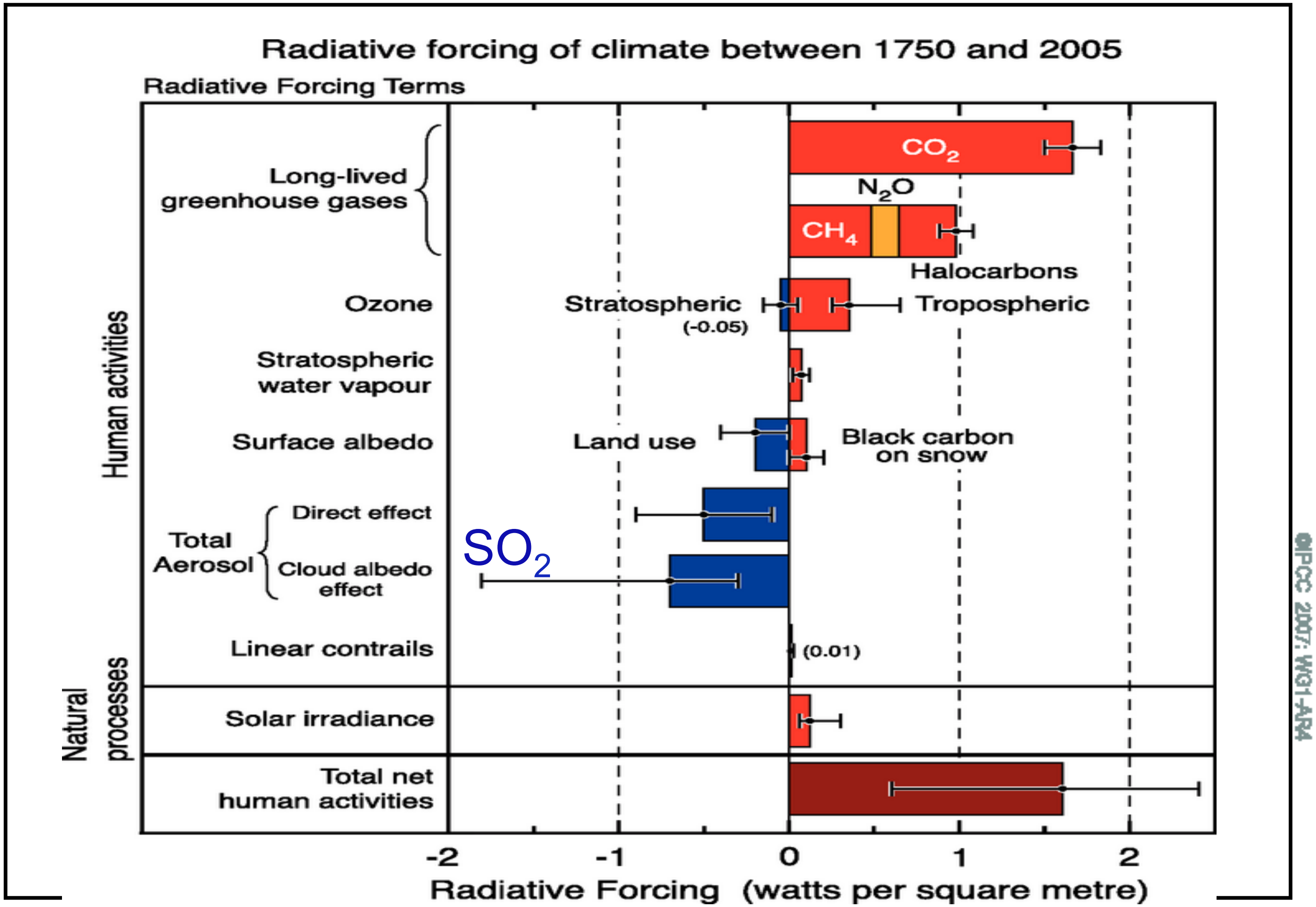
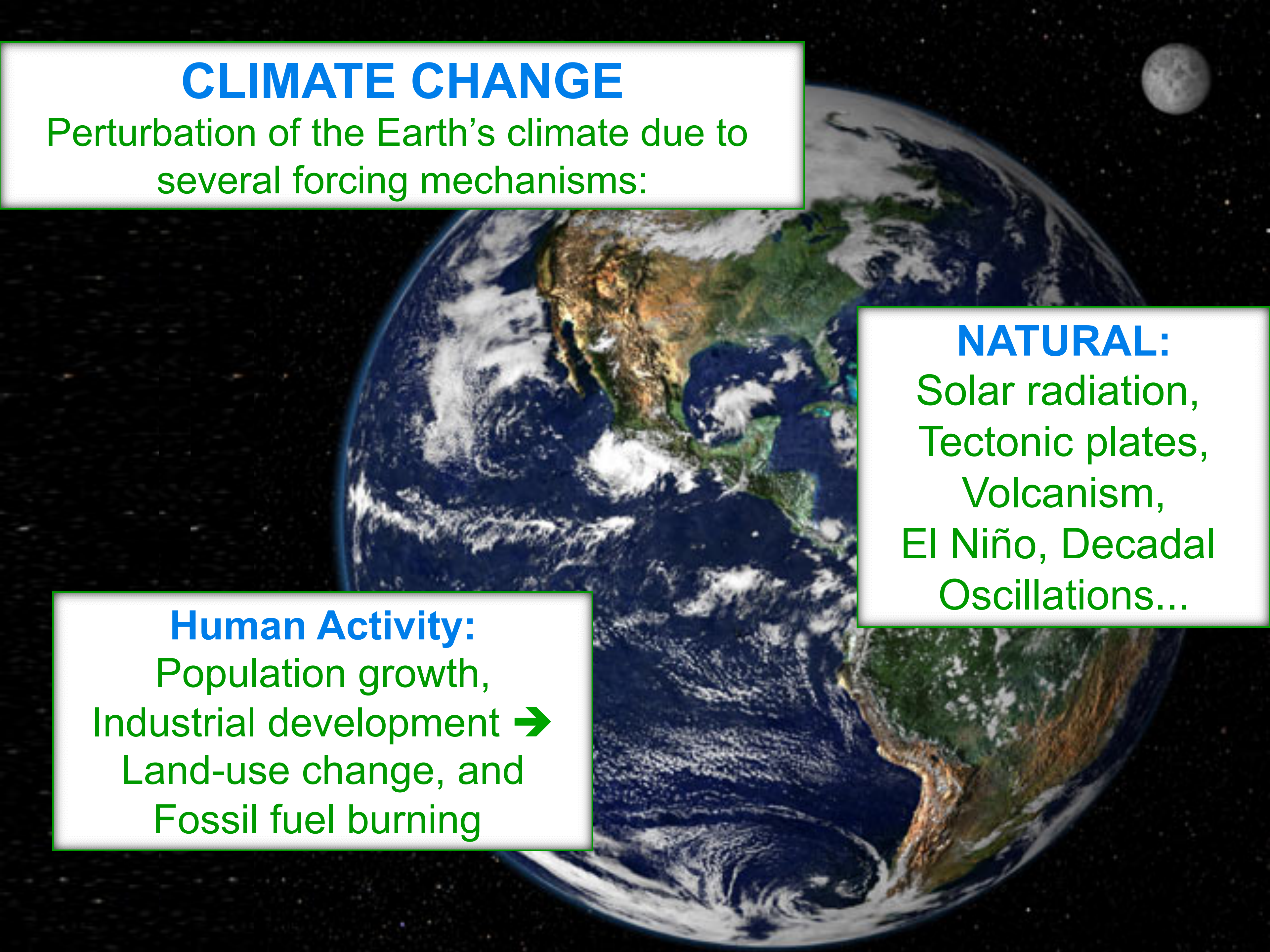


Figure SPM.2. *Global average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). The net anthropogenic radiative forcing and its range are also*

(AR4 WG1, IPCC 2007 – Sci Basis)



CLIMATE CHANGE

Perturbation of the Earth's climate due to several forcing mechanisms:

NATURAL:

Solar radiation,
Tectonic plates,
Volcanism,
El Niño, Decadal Oscillations...

Human Activity:

Population growth,
Industrial development ➔
Land-use change, and
Fossil fuel burning

Weather and Climate

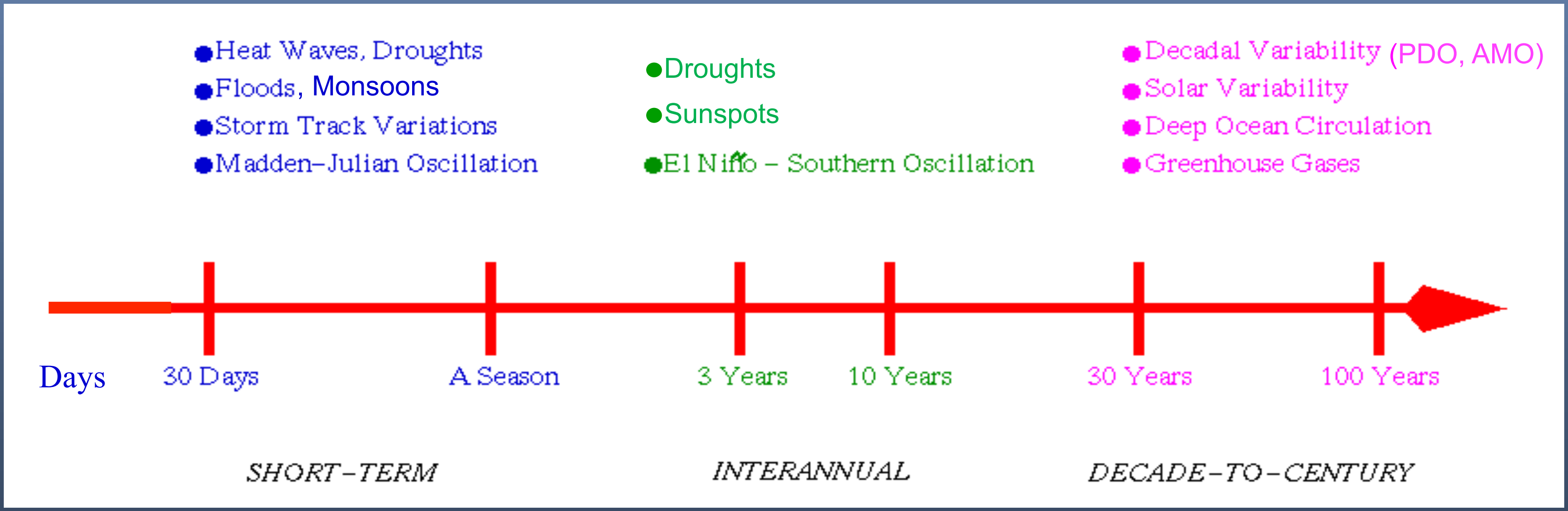
Weather: Atmospheric phenomena that occur from seconds to few weeks; this is the deterministic limit for weather forecast. It is the **state of the troposphere** at any moment.

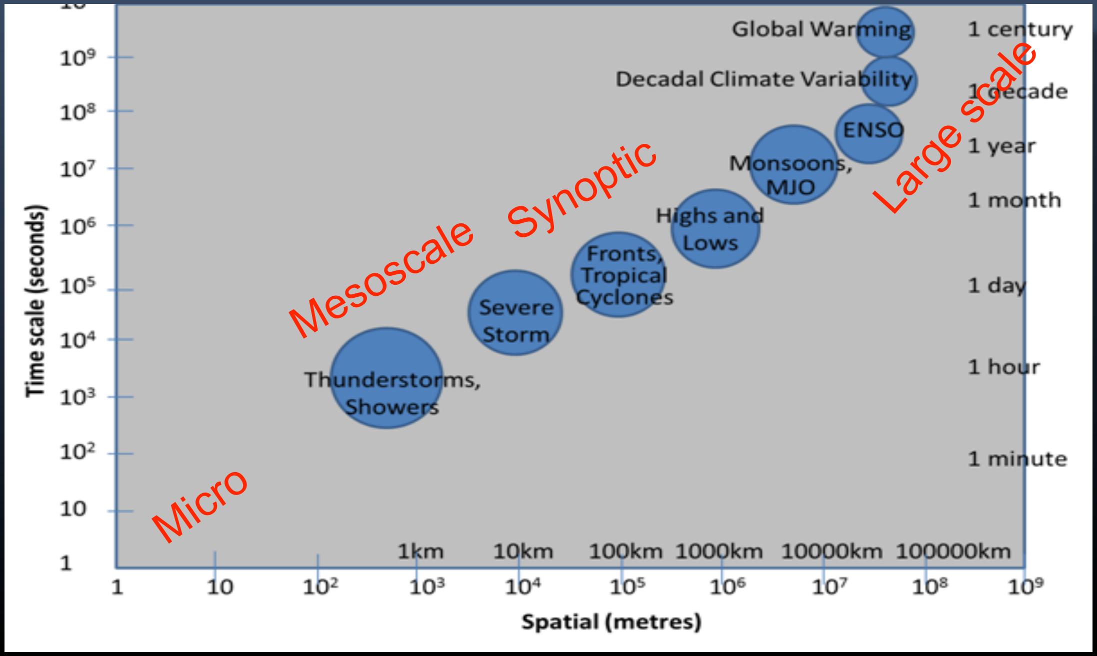
"Weather is what we feel right now"

Climate: Atmospheric phenomena that occur from one month to much longer time periods. It is the **average weather** in a place over more than thirty years.

"Climate is what we expect"

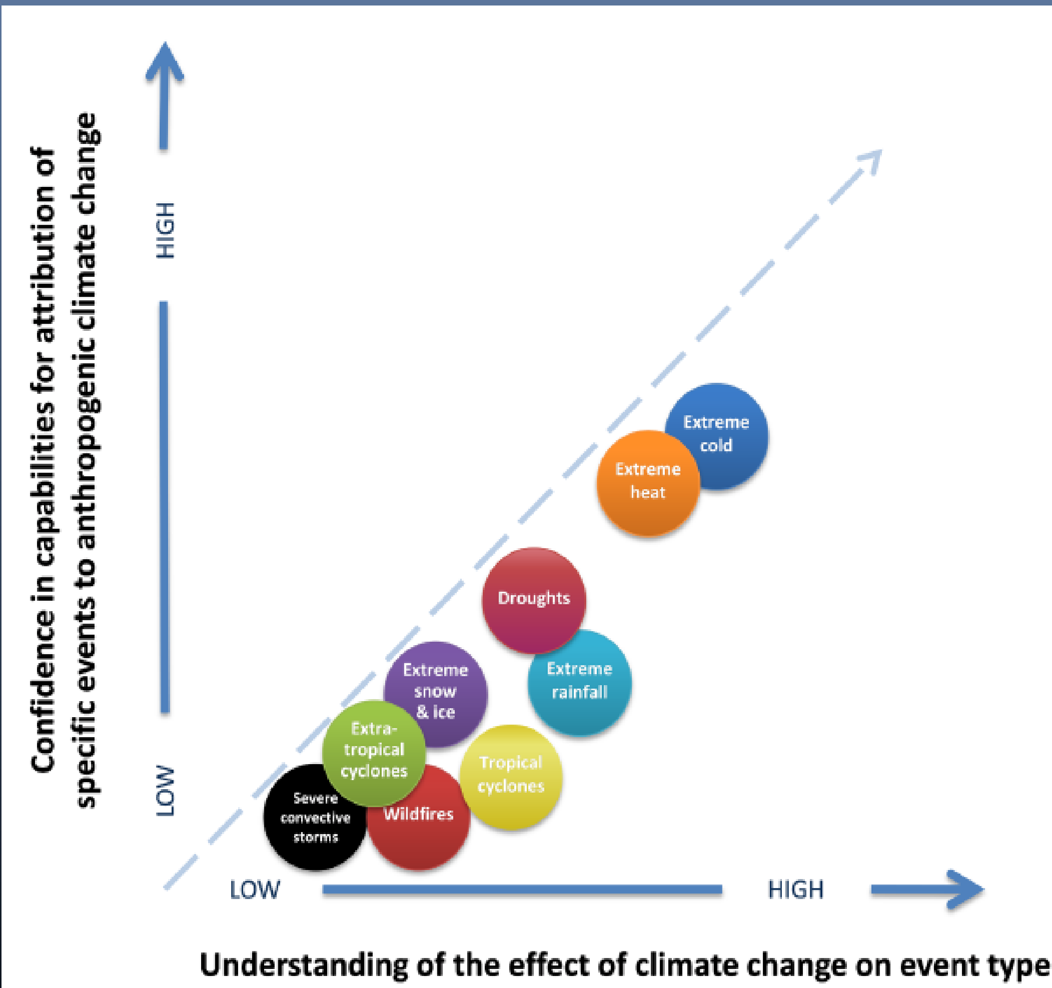
Scales of Variability of Weather and Climate





Planetary scale

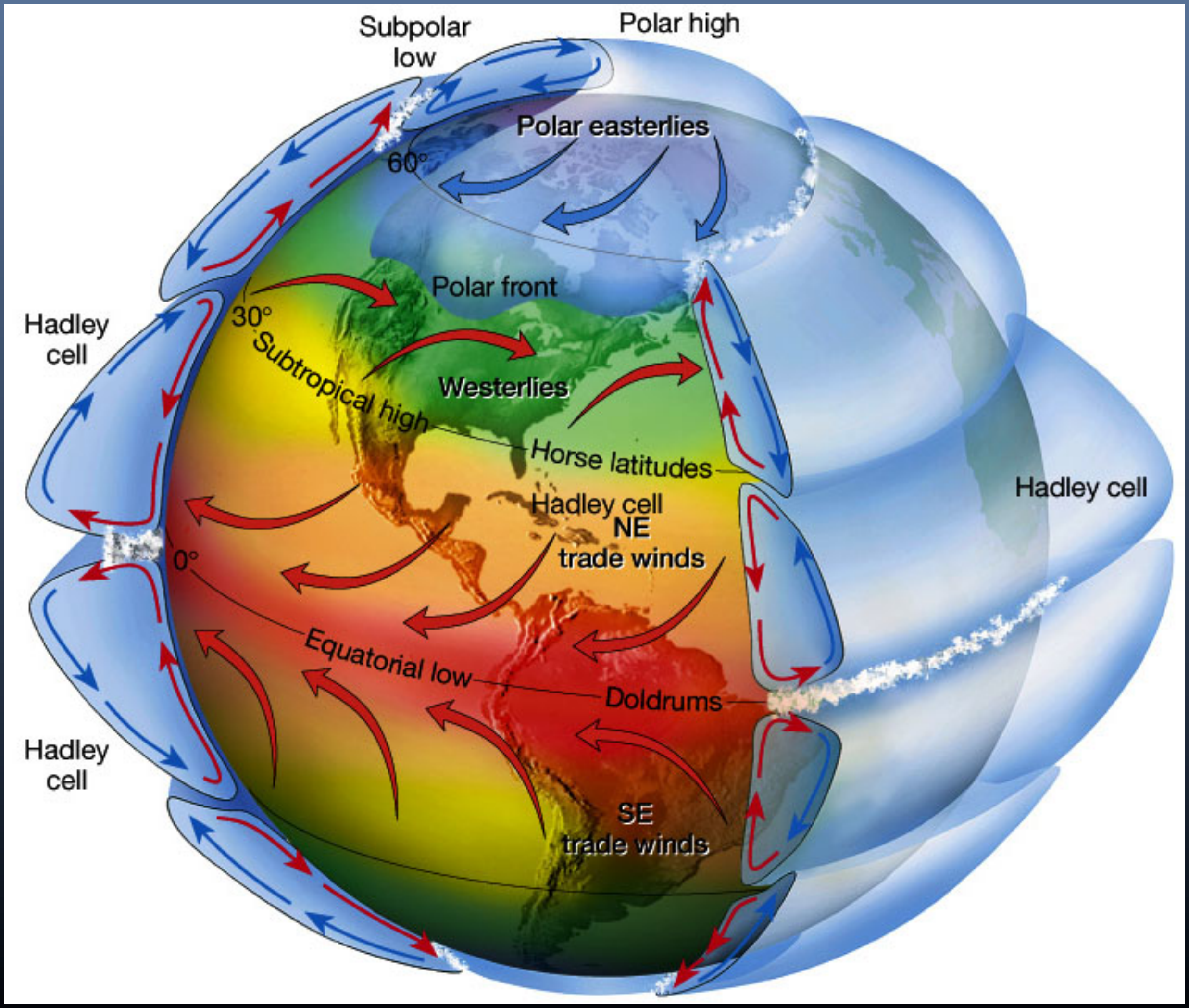
Scales of Variability and Attribution to Climate Change



● = high **o** = medium ○ = low	Capabilities of Climate Models to Simulate Event Type	Quality/Length of the Observational Record	Understanding of Physical Mechanisms That Lead to Changes in Extremes as a Result of Climate Change
Extreme cold events	●	●	●
Extreme heat events	●	●	●
Droughts	**o**	**o**	**o**
Extreme rainfall	**o**	**o**	**o**
Extreme snow and ice storms	**o**	○	**o**
Tropical cyclones	○	○	**o**
Extratropical cyclones	**o**	○	○
Wildfires	○	**o**	○
Severe convective storms	○	○	○

Attribution of Extreme Weather Events in the Context of Climate Change
National Academy of Sciences 2016

Atmospheric Circulation



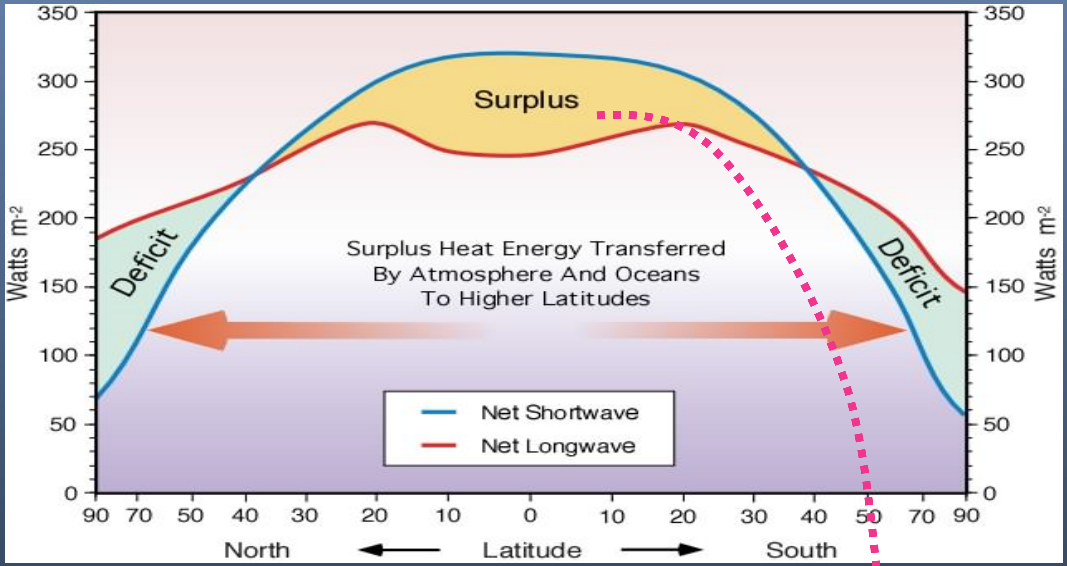
Ferrel Cell: Thermally indirect circulation

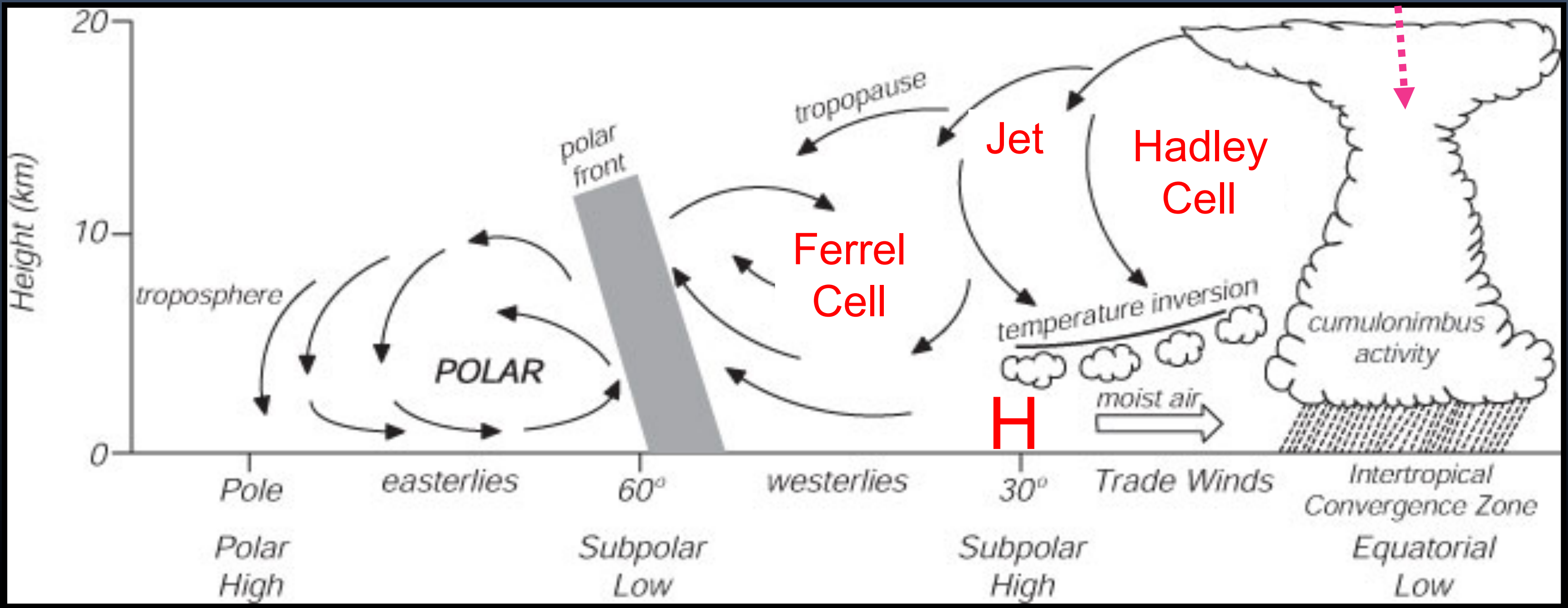
Jet Stream

Hadley Cell: Direct circulation

ITCZ

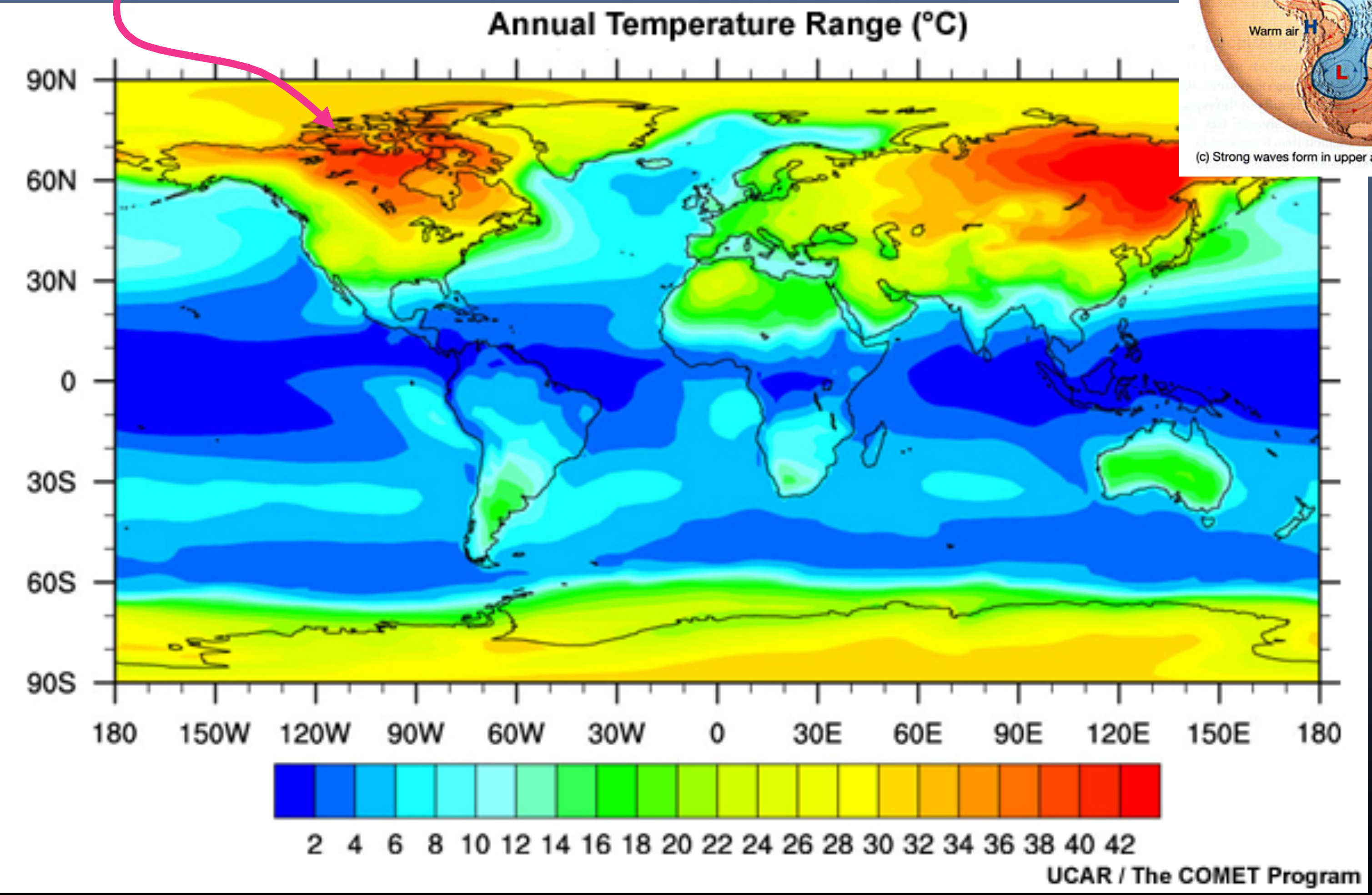
Meridional Circulation and Heat Transport

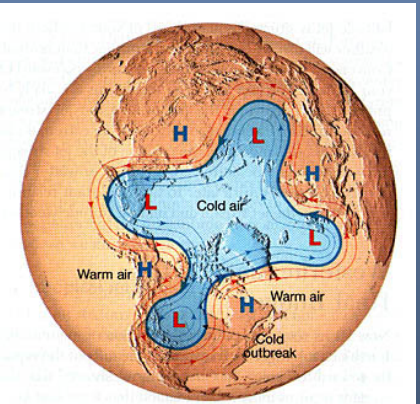




Annual Temperature Range

Large seasonal contrasts ➔ Rossby and planetary waves





(c) Strong waves form in upper airflow

Thermodynamic Equation

Local change T = Horiz ADV + vertical ADV + radiative + convective diabatic heating

$$\frac{\partial T}{\partial t} = -\mathbf{V}\cdot\nabla T + \omega\left(\frac{\kappa T}{p} - \frac{\partial T}{\partial p}\right) + \frac{\overline{Q}_{rad}}{c_p} + \frac{\overline{Q}_{con}}{c_p} + D_H$$

$$dQ = cpdT - \alpha dp$$

Warming/diabatic dissipation

(7.37 W&H)

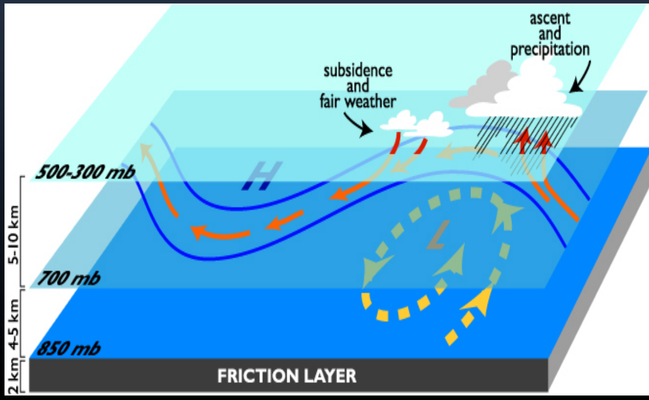
$$\frac{\partial T}{\partial t} = -\mathbf{V}\cdot\nabla T + \sigma\omega$$

➔ **Sigma (Static Stability):**

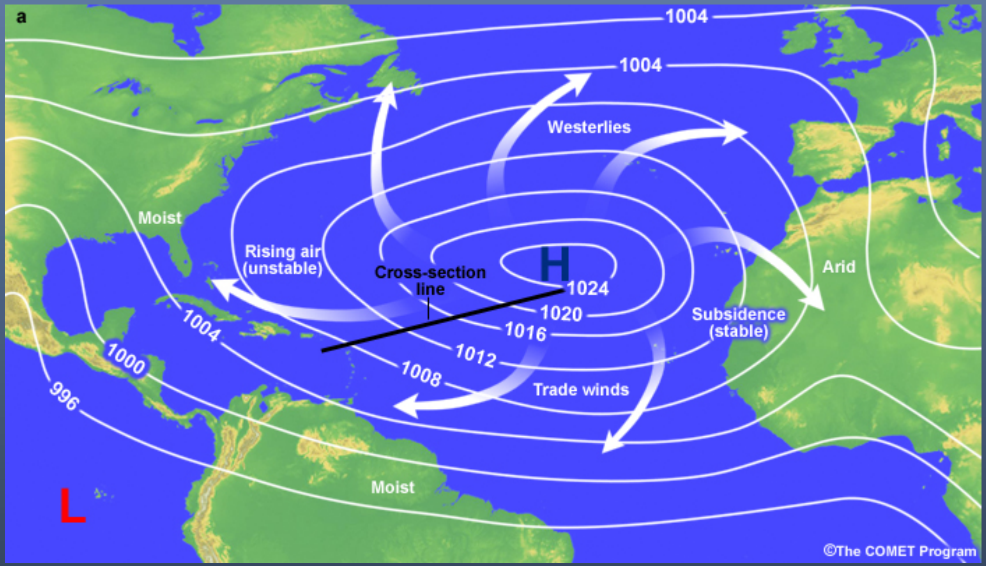
➔ **+ Stable, - unstable, 0 neutral**

MIDLATITUDES: Horiz ADVECTION of Temp dominates

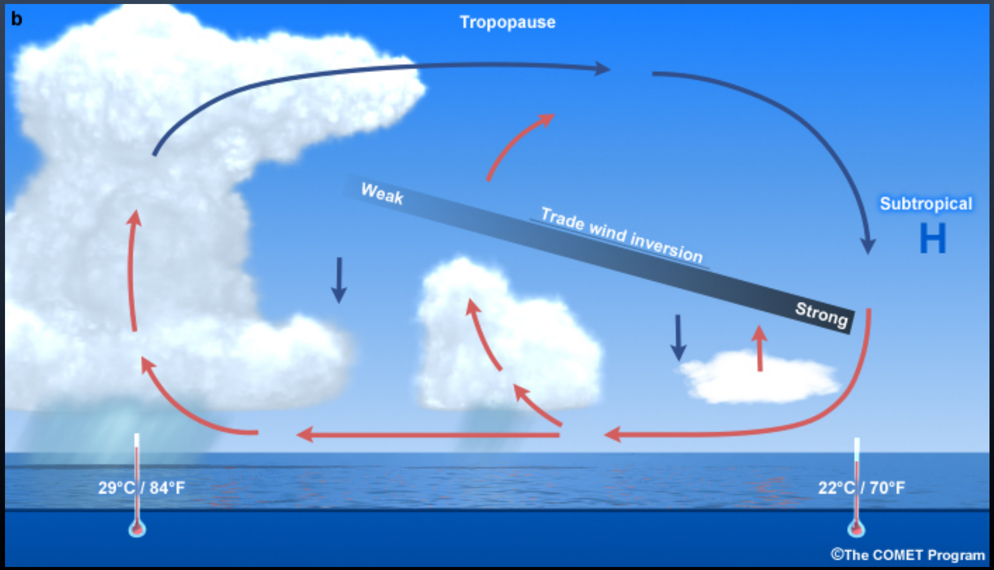
TROPICS: Vert ADV dominates (ω σ ➔ compression expansion). Local change and horiz ADV are small from day to day. Easterly waves ➔



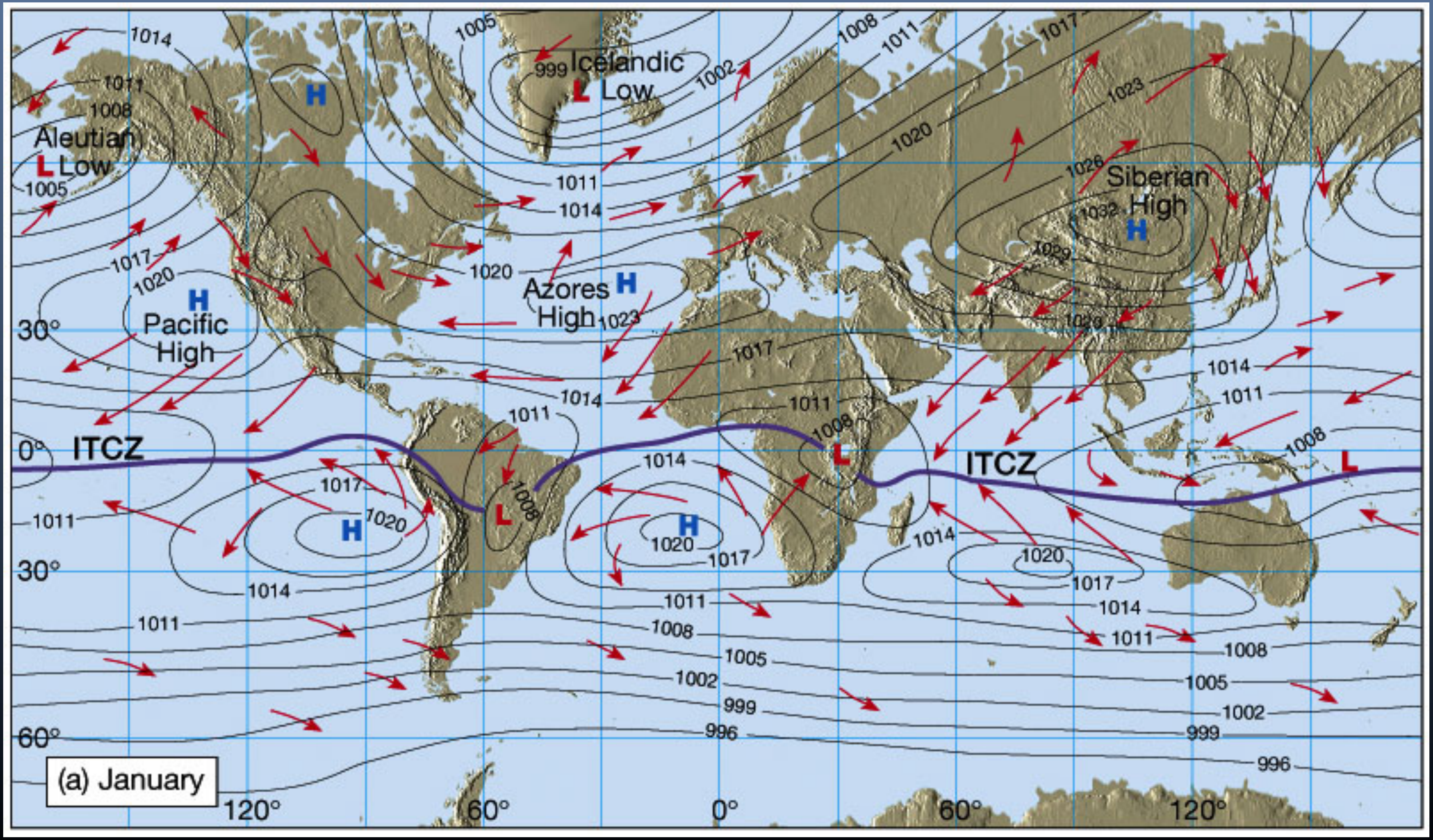
Tropical Atmosphere



30N

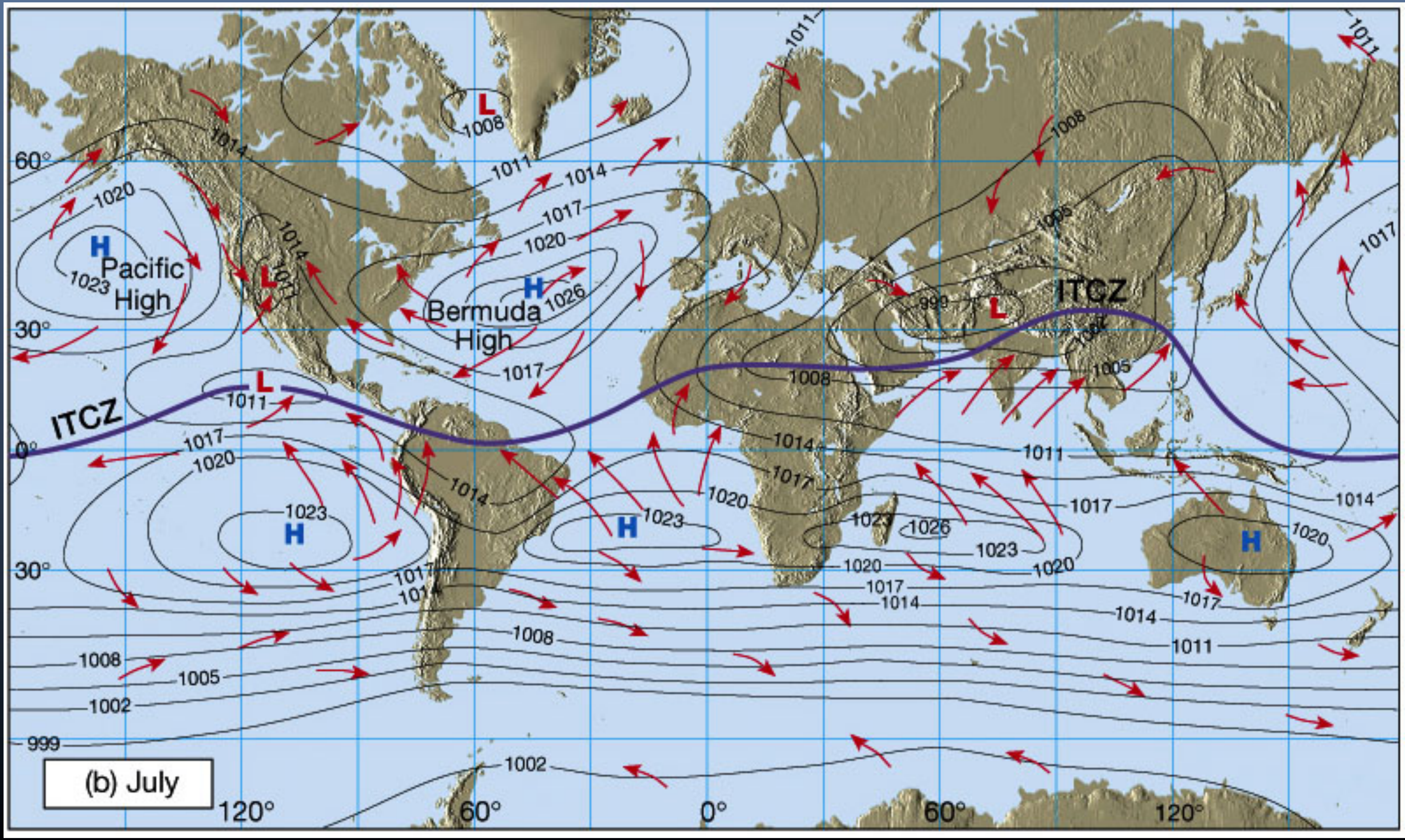


Semipermanent Highs and Lows
January SLP



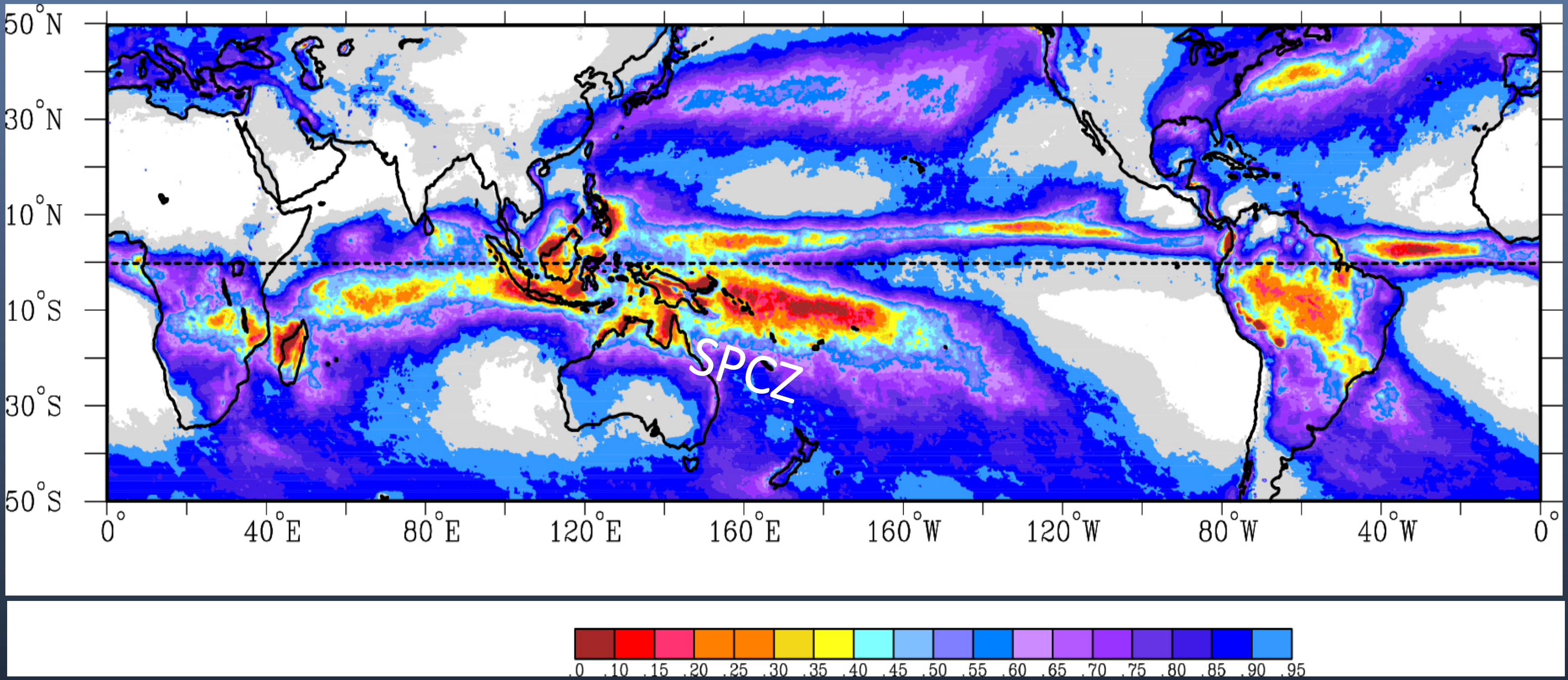
See Fig. 1.18, Wallace and Hobbs, 2006, p. 17

Semipermanent Highs and Lows
July SLP



See Fig. 1.19, Wallace and Hobbs, 2006, p. 17

January Precipitation Climatology 1998-2015, TRMM

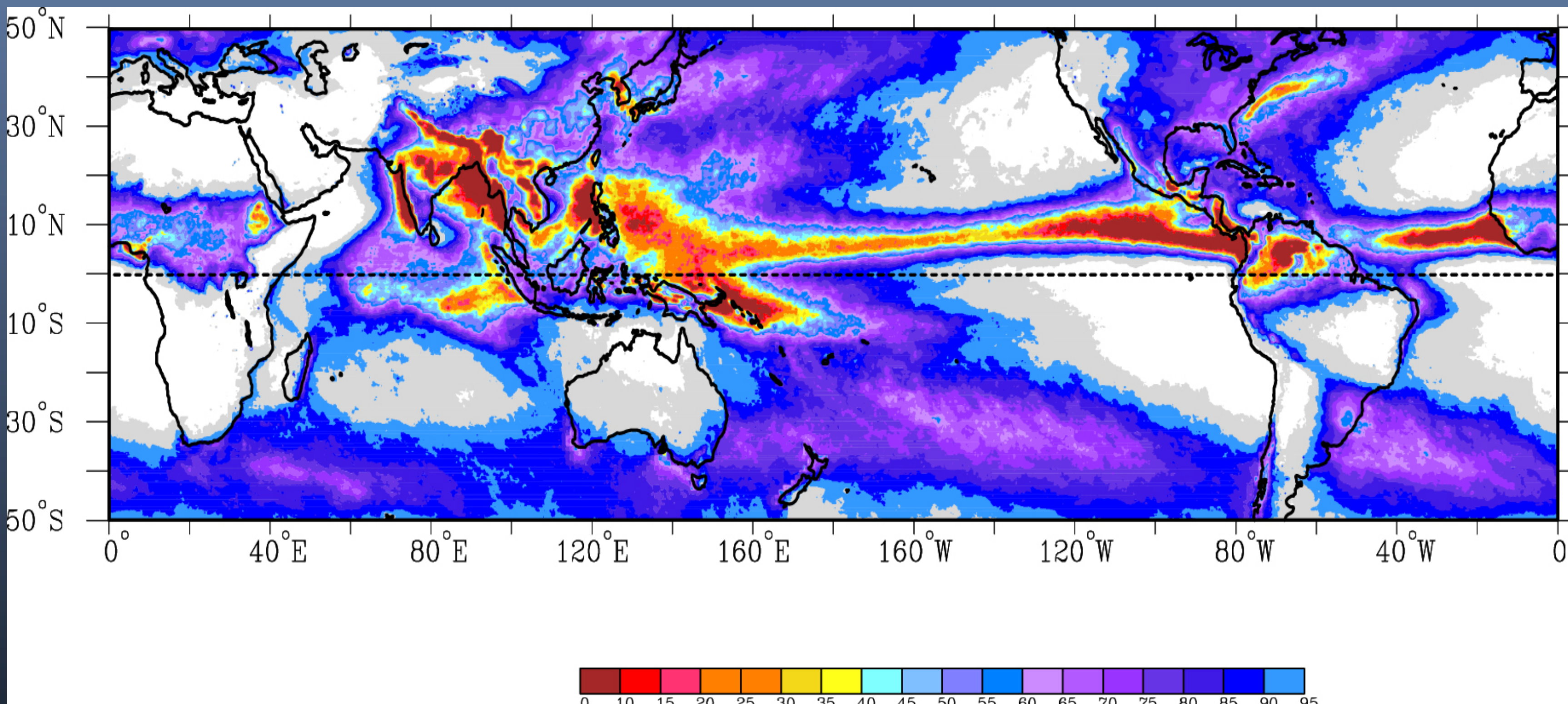


Precipitation (mm hr^{-1})

Figure from George Kiladis

July Precipitation Climatology

1998-2015, TRMM



Precipitation (mm hr^{-1})

Figure from George Kiladis

Mean Annual Precipitation, 1998-2012, TRMM

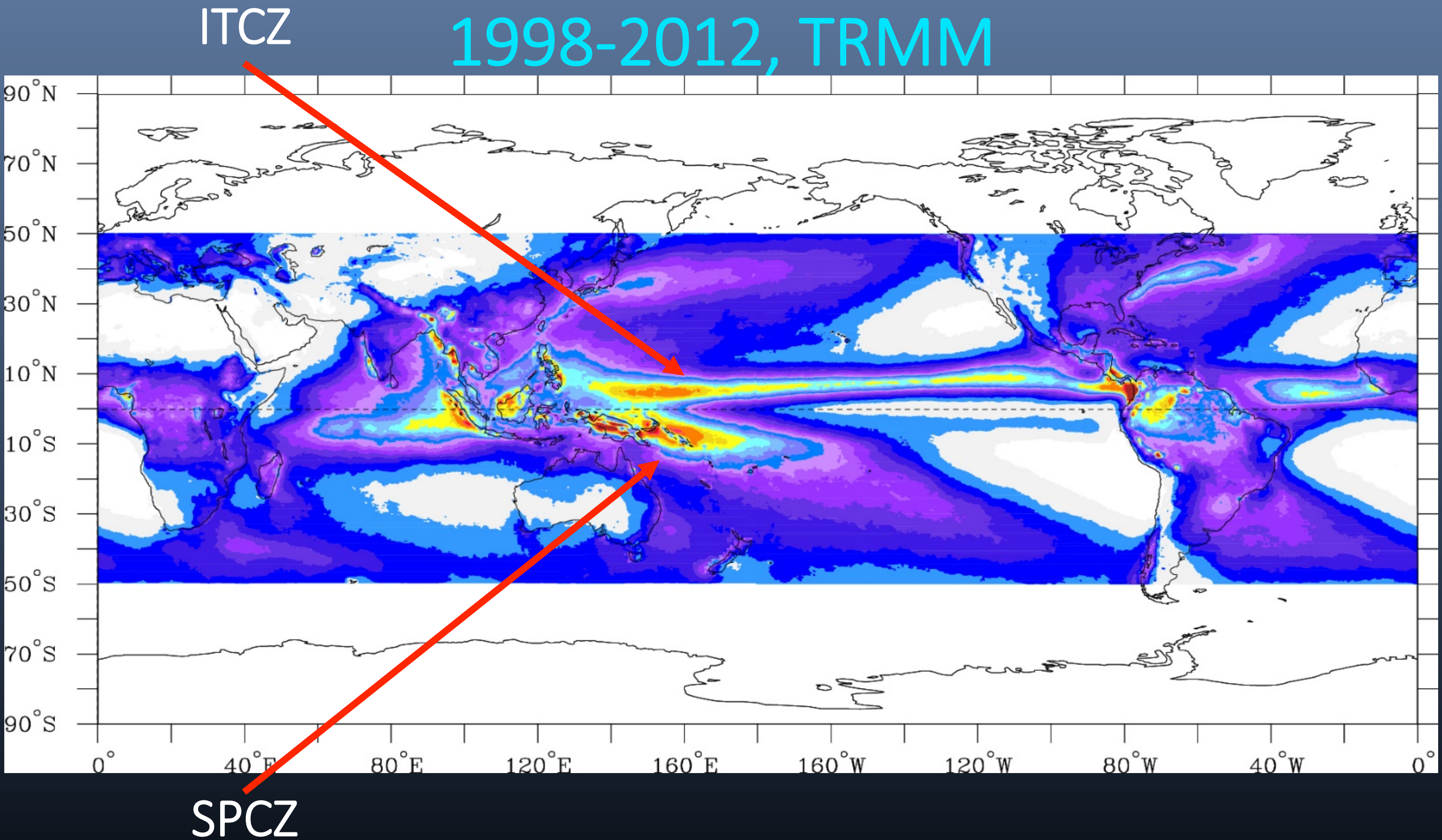


Figure from George Kiladis

January and July Precipitation (mm) derived from CMAP

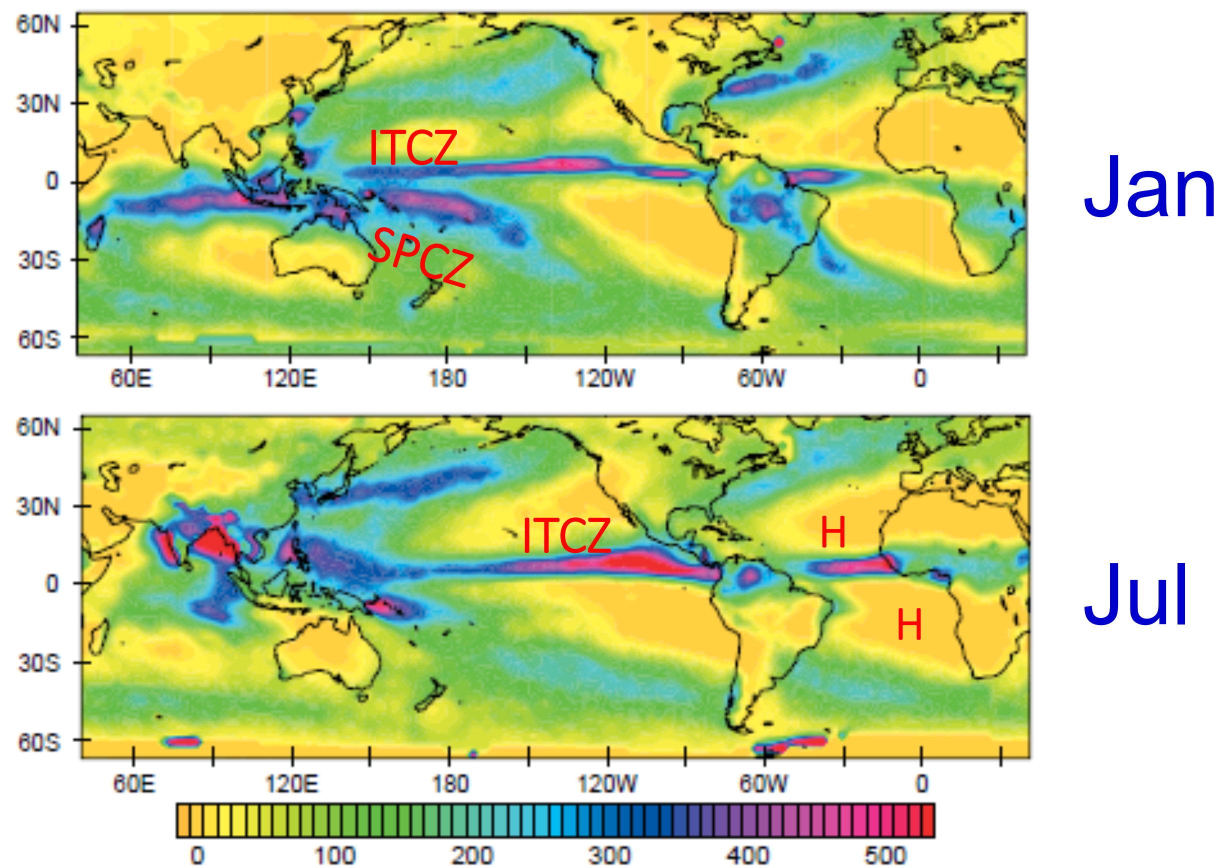
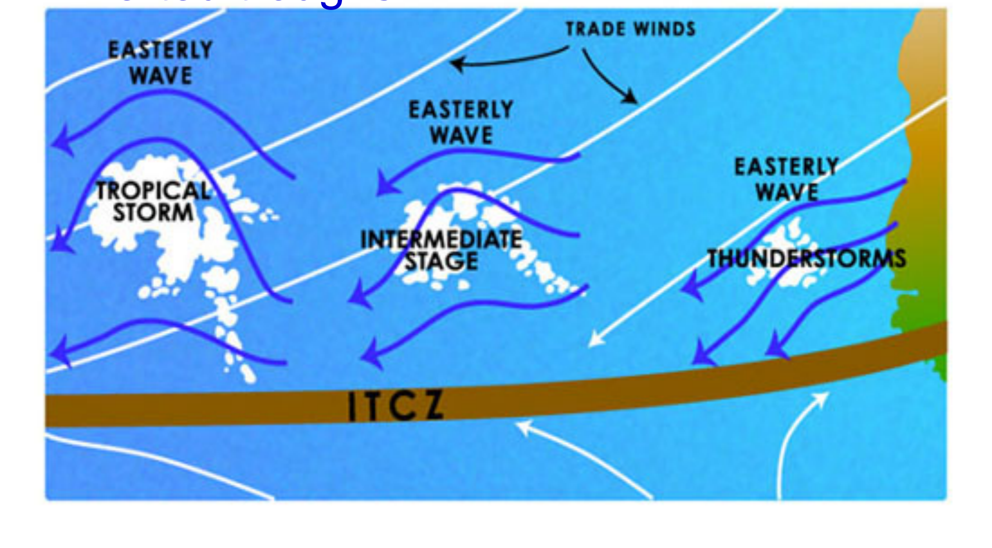


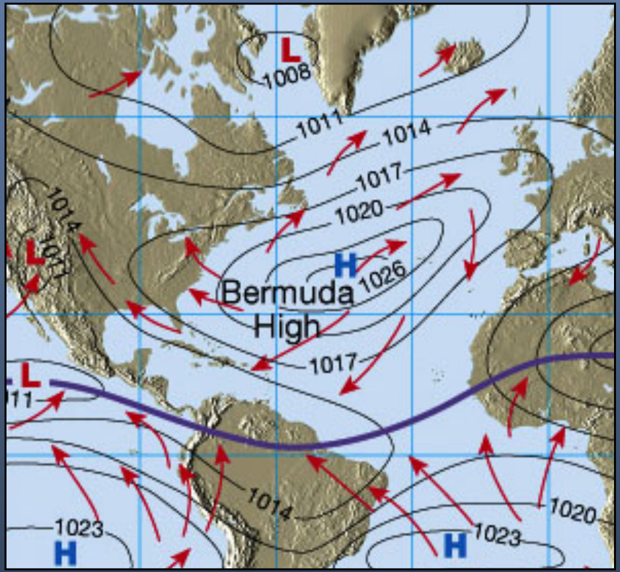
Fig. 1.25 January and July climatological-mean precipitation. [Based on infrared and microwave satellite imagery over the oceans and rain gauge data over land, as analyzed by the NOAA National Centers for Environmental Prediction CMAP project. Courtesy of Todd P. Mitchell.]

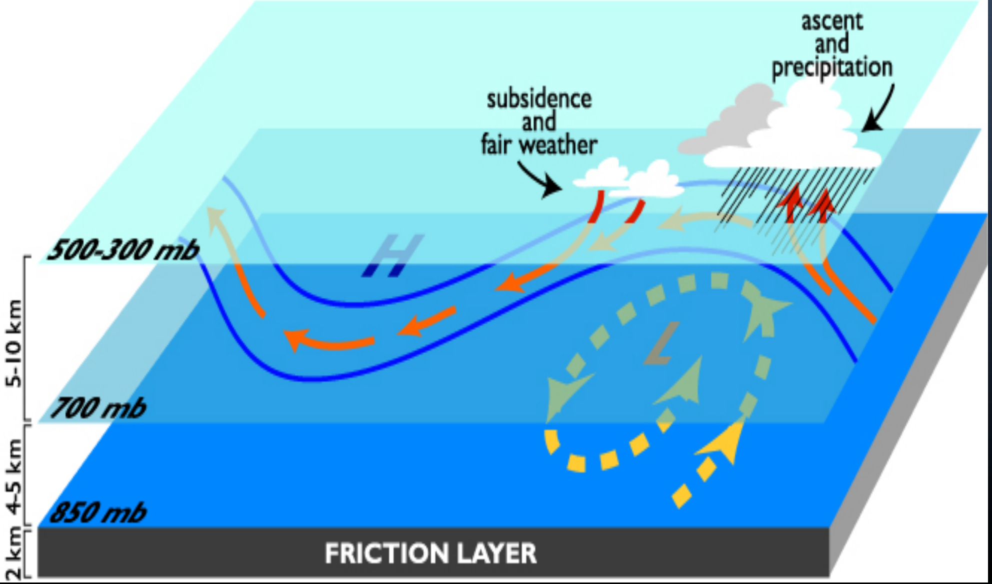
Fig. 1.25, Wallace & Hobbs, 2006, p. 20.

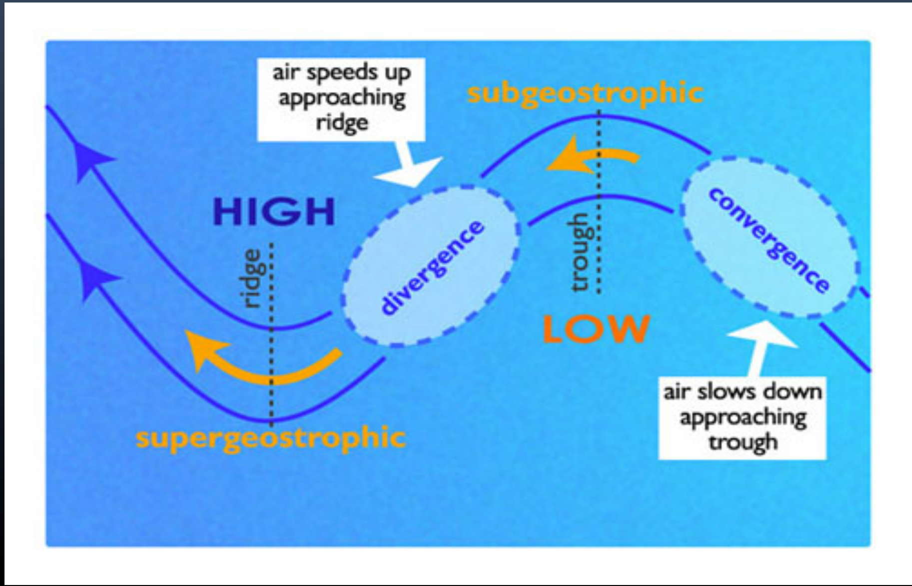
Easterly Waves in the Trade Winds

Inverted troughs

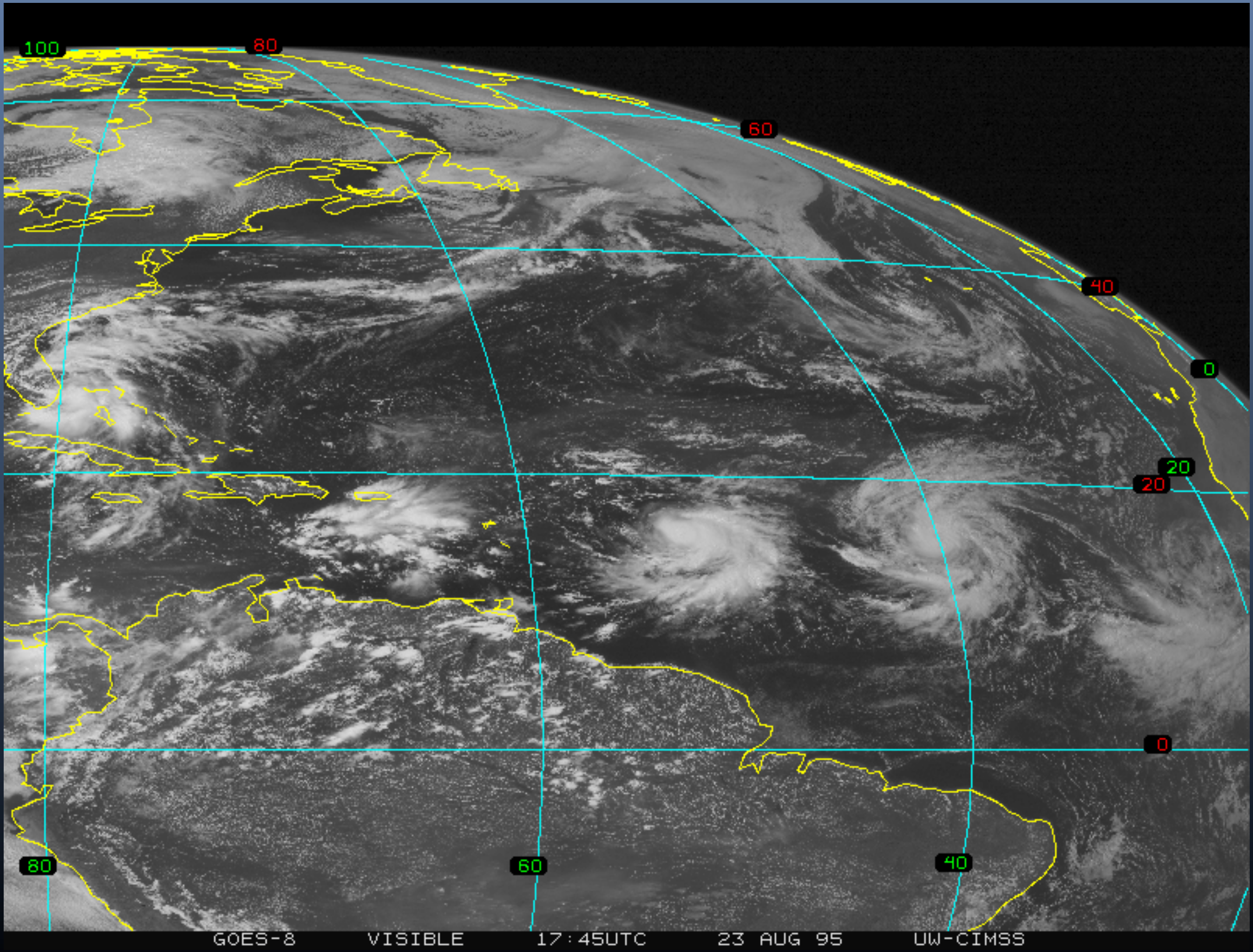






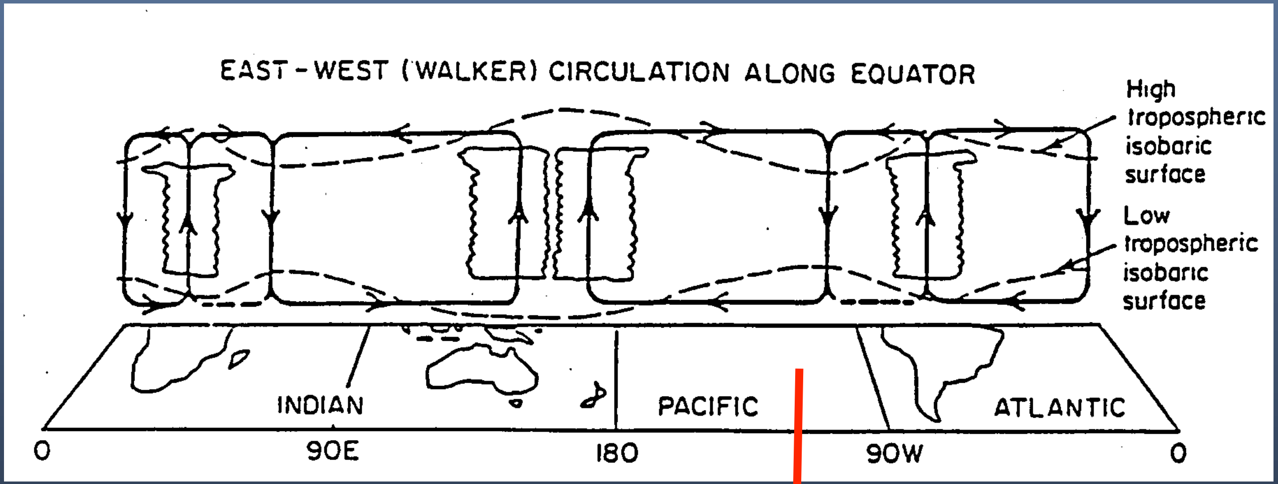


Easterly Waves 23 Aug 1995



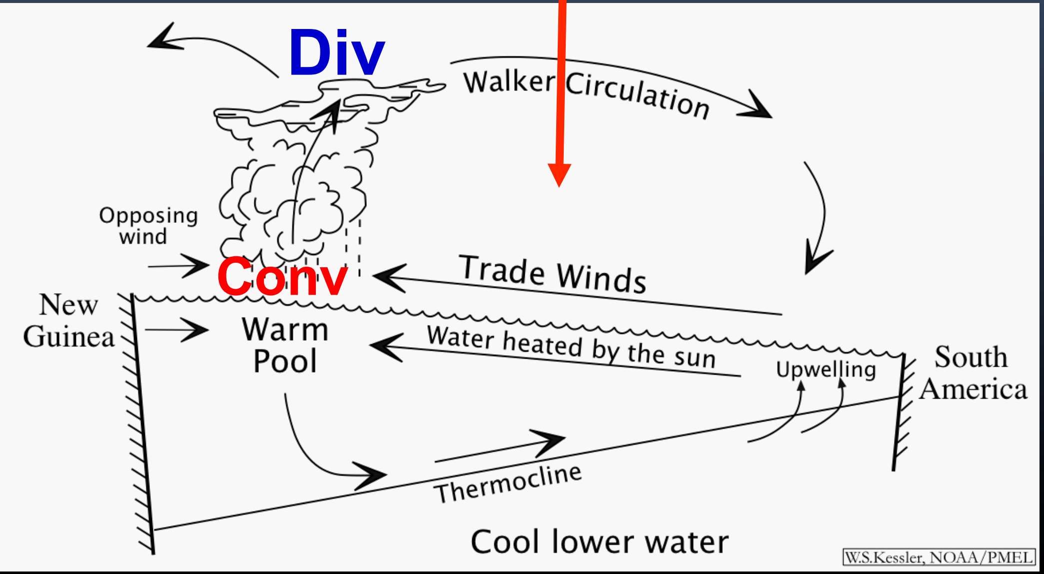
http://apollo.lsc.vsc.edu/classes/met130/notes/chapter15/graphics/ATL_WAVES_VIS.gif

Zonal Walker Circulation During Normal to La Niña Conditions

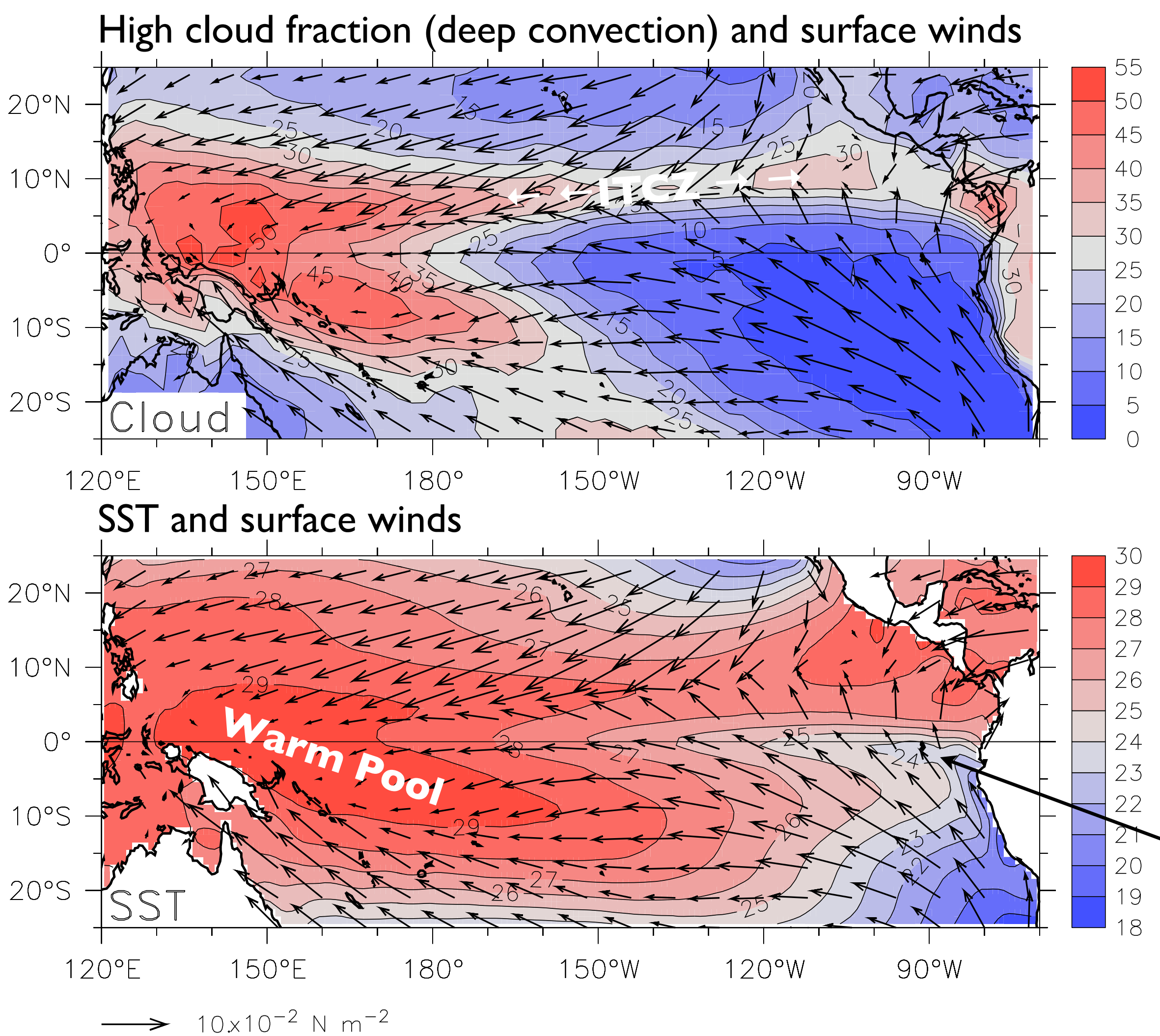


← Low level Easterlies

Pacific Ocean: the tropical climate is coupled (+ feedback)



Close relation among SST, convection and winds



In the tropics, convection coincides with warm SST and surface wind convergence.

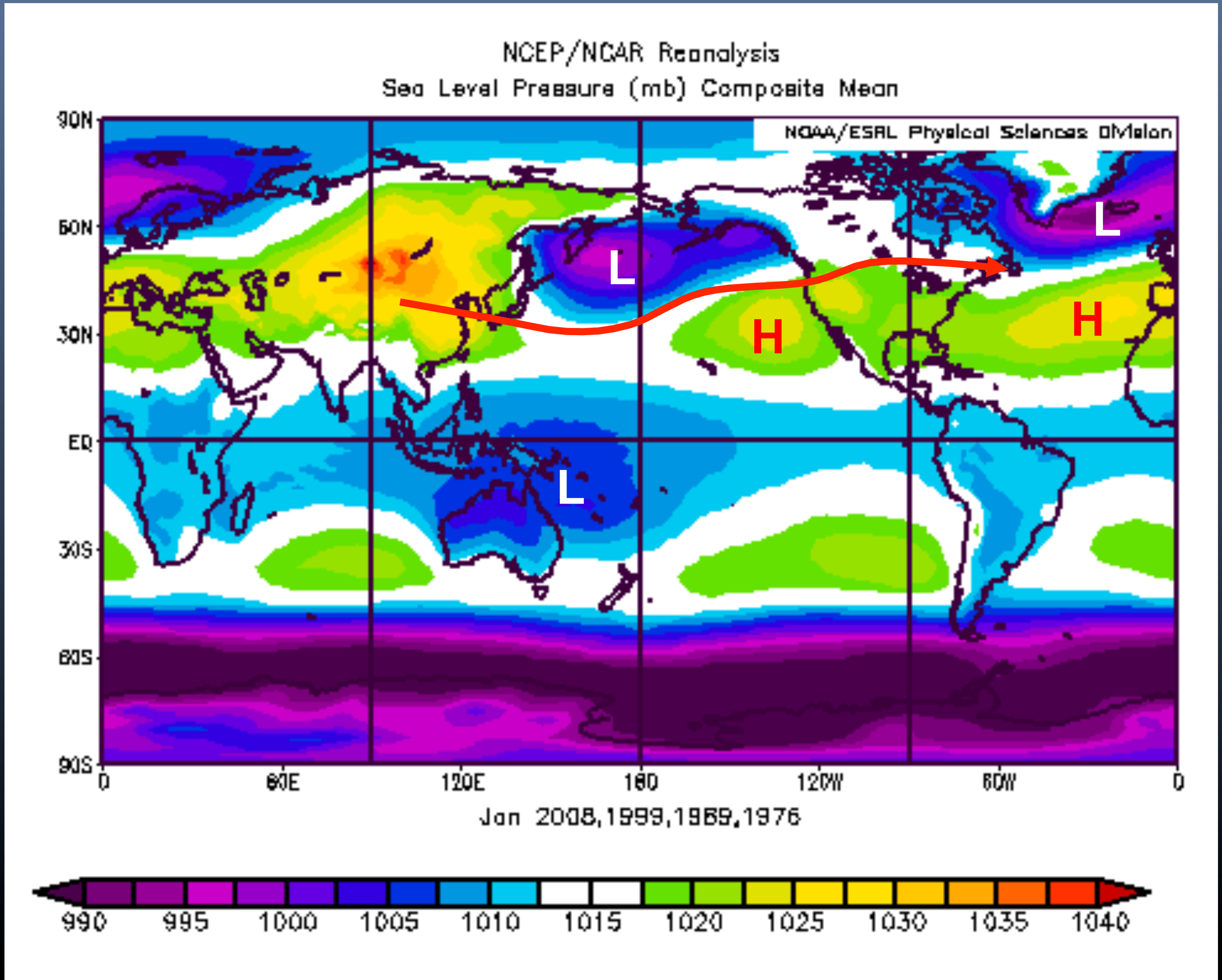
All three define the West Pacific warm pool and the Intertropical Convergence Zone (ITCZ).

(Reynolds SST, ISCCP high clouds, Quikscat winds)

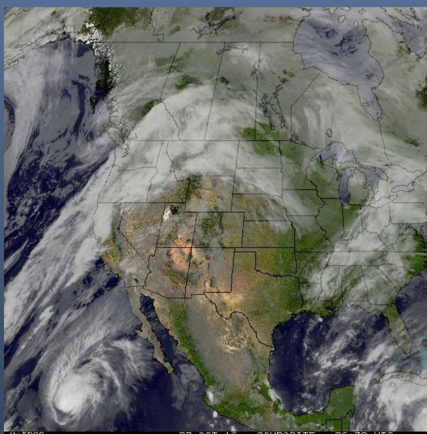
January Mean SLP during La Niña winters

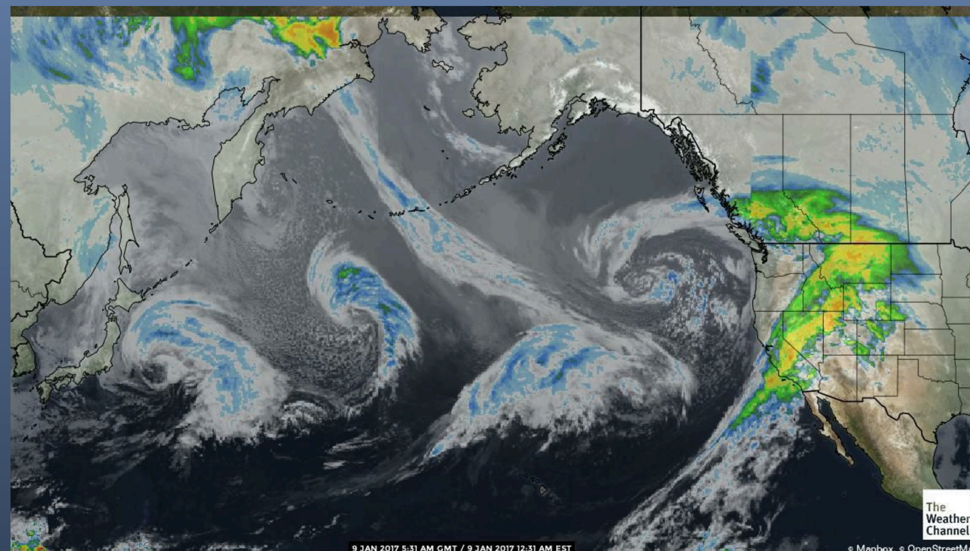
Dry in Mexico, the Caribbean and southern US ➔ Zonal circulation

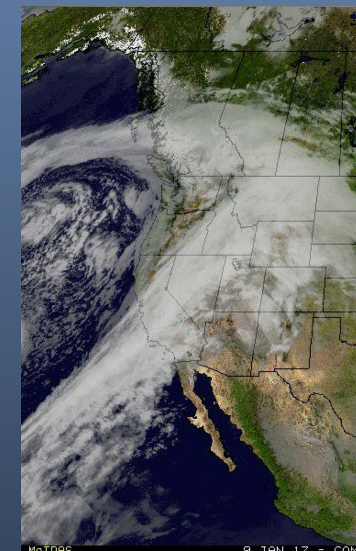
(e.g., 2008, 1999, 1989 y 1976)

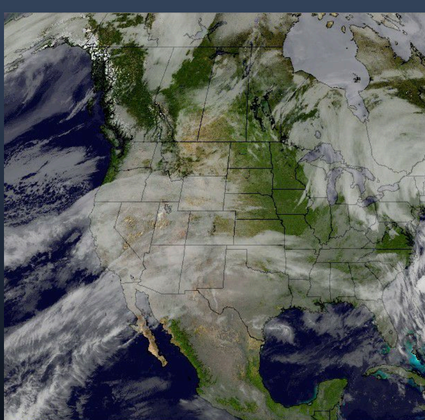


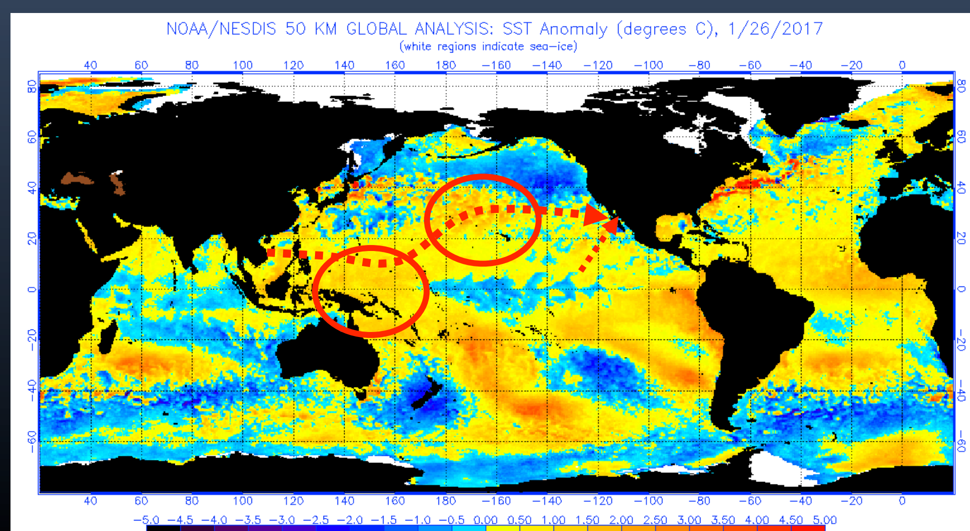
Atmospheric Rivers and Storms Autumn-Winter 2016-2017 during a very unusual La Niña (La Niña Modoki?)

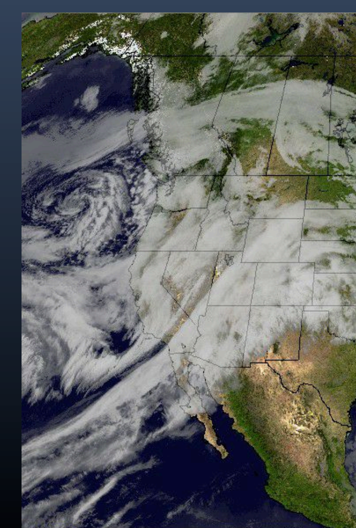


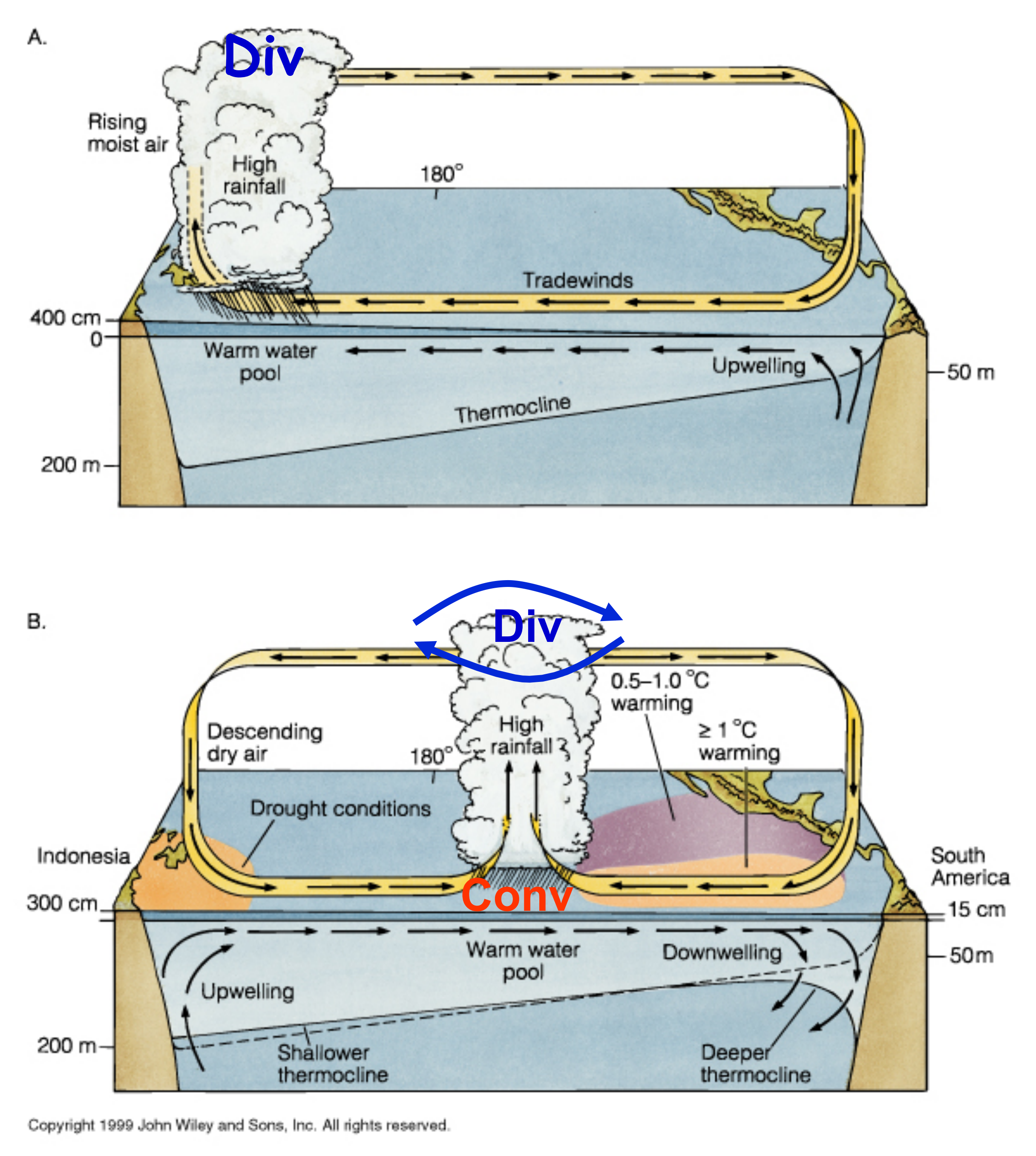










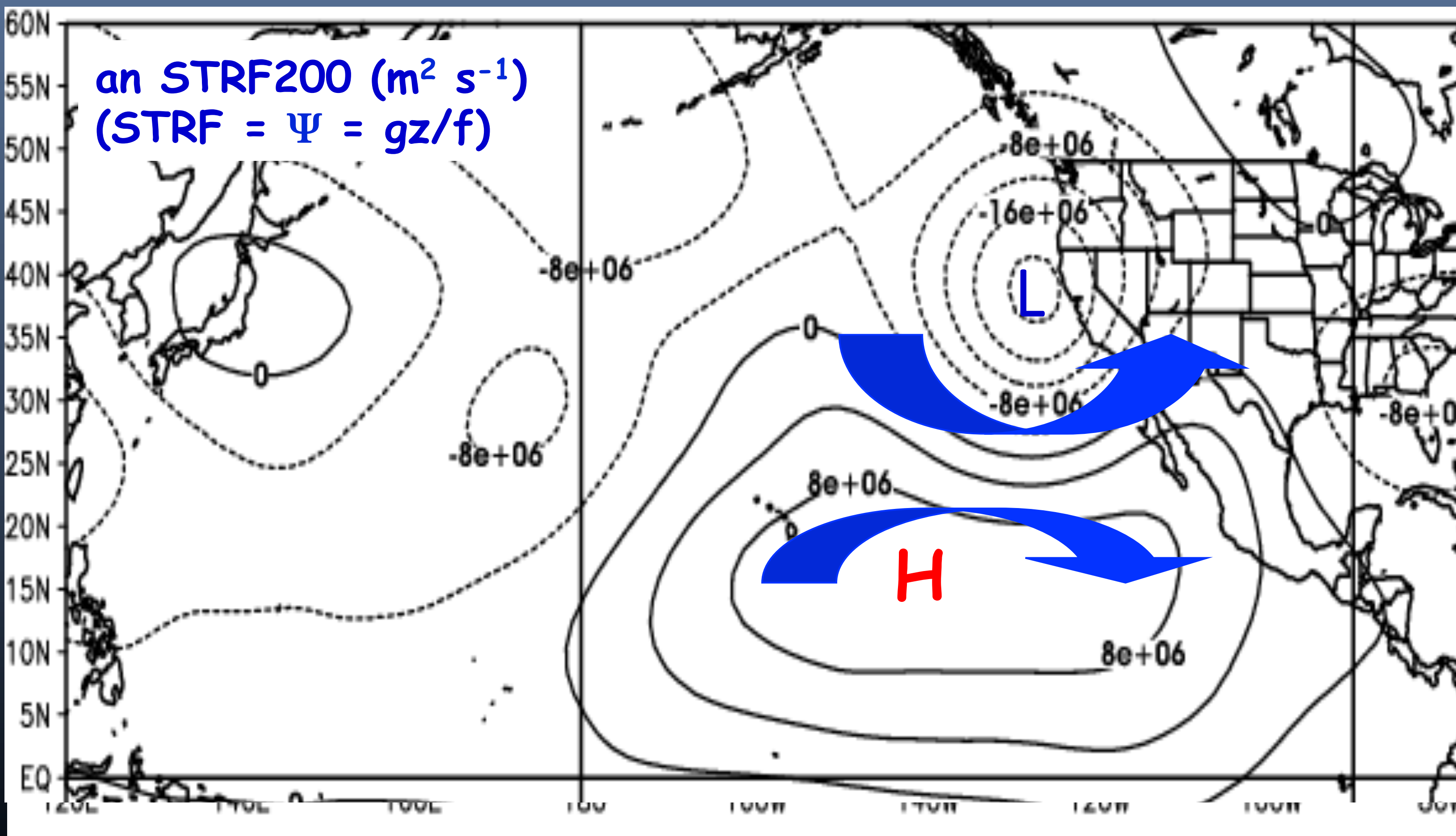


Canonical

La Niña

El Niño

Teleconnection during Strong El Niño winters
(Strong subtropical jet and extreme rainfall, 1976-2000)



(Cavazos and Rivas, 2004)

El Niño 2015-2016: An unusual event

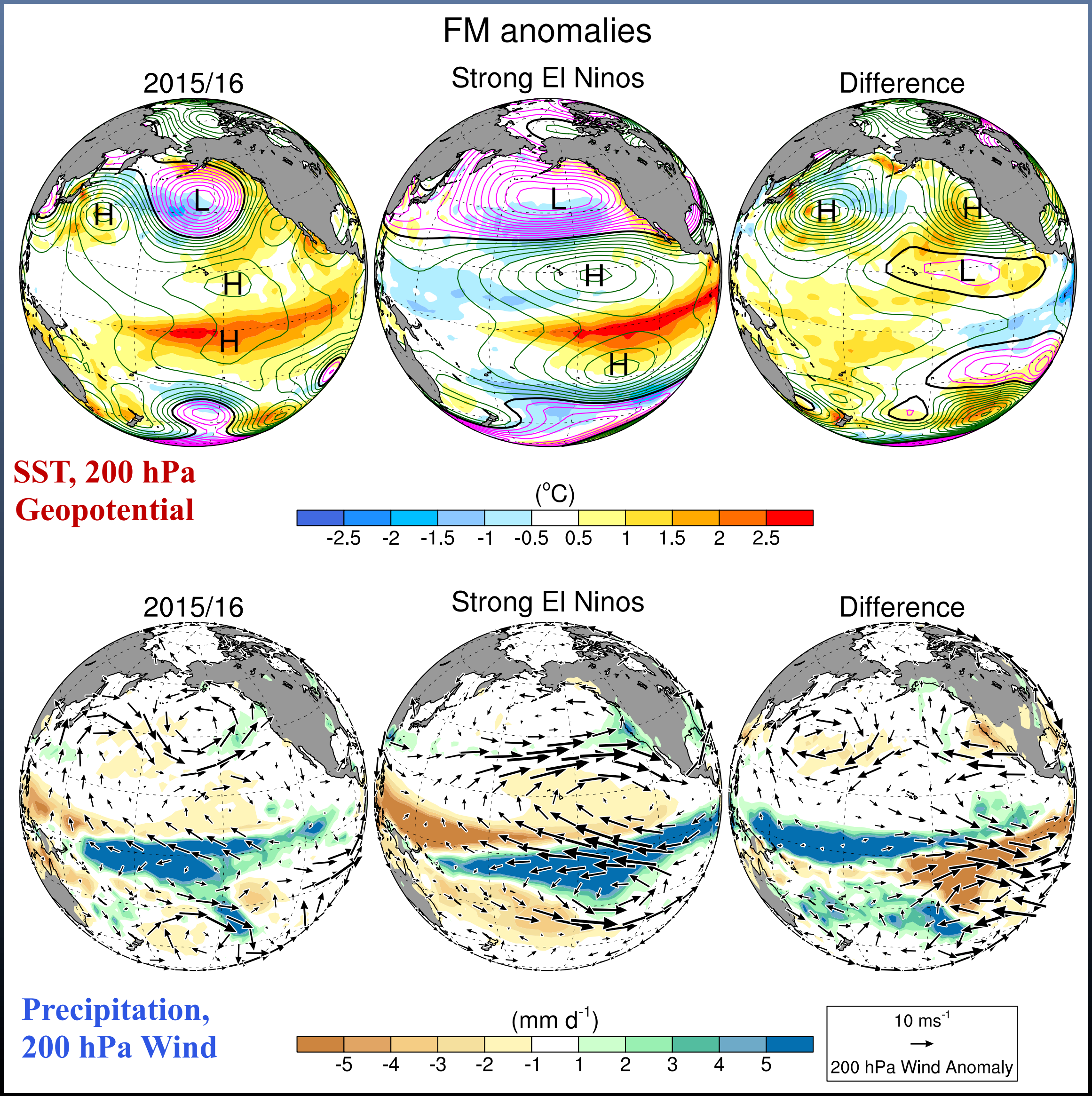
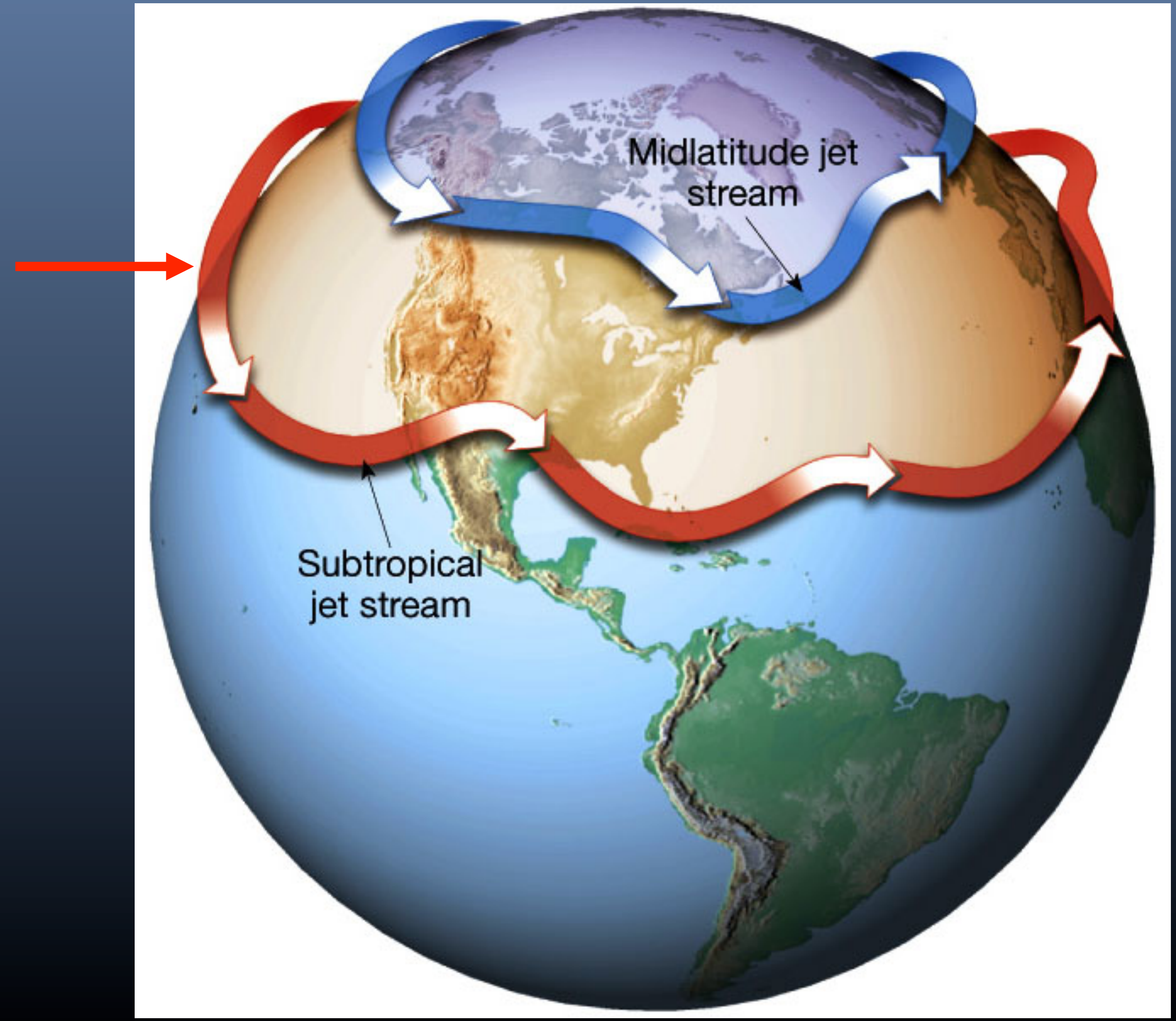


Figure from George Kiladis. Courtesy Tao Zhang, PSD ESRL

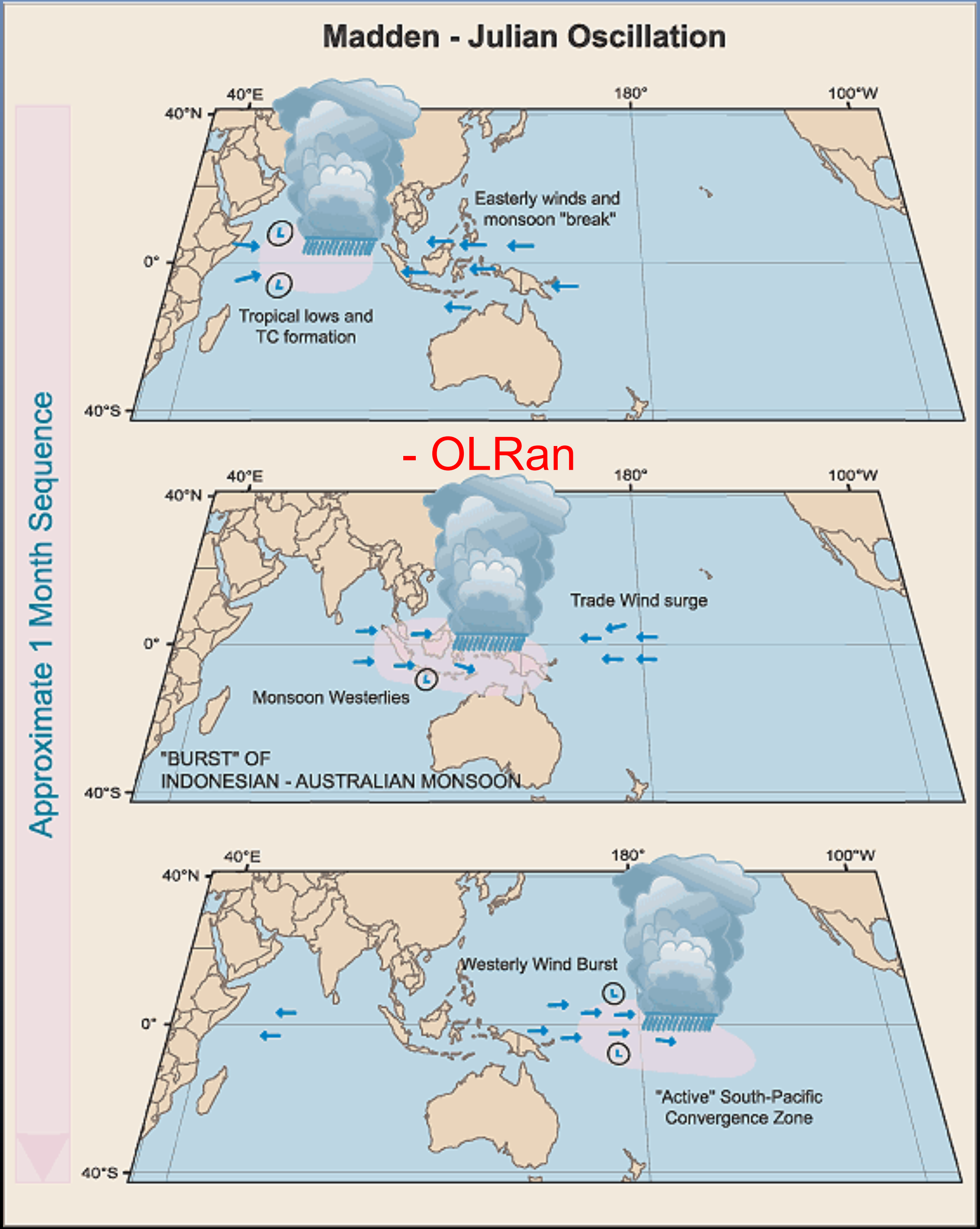
Subtropical Westerly Jet during El Niño



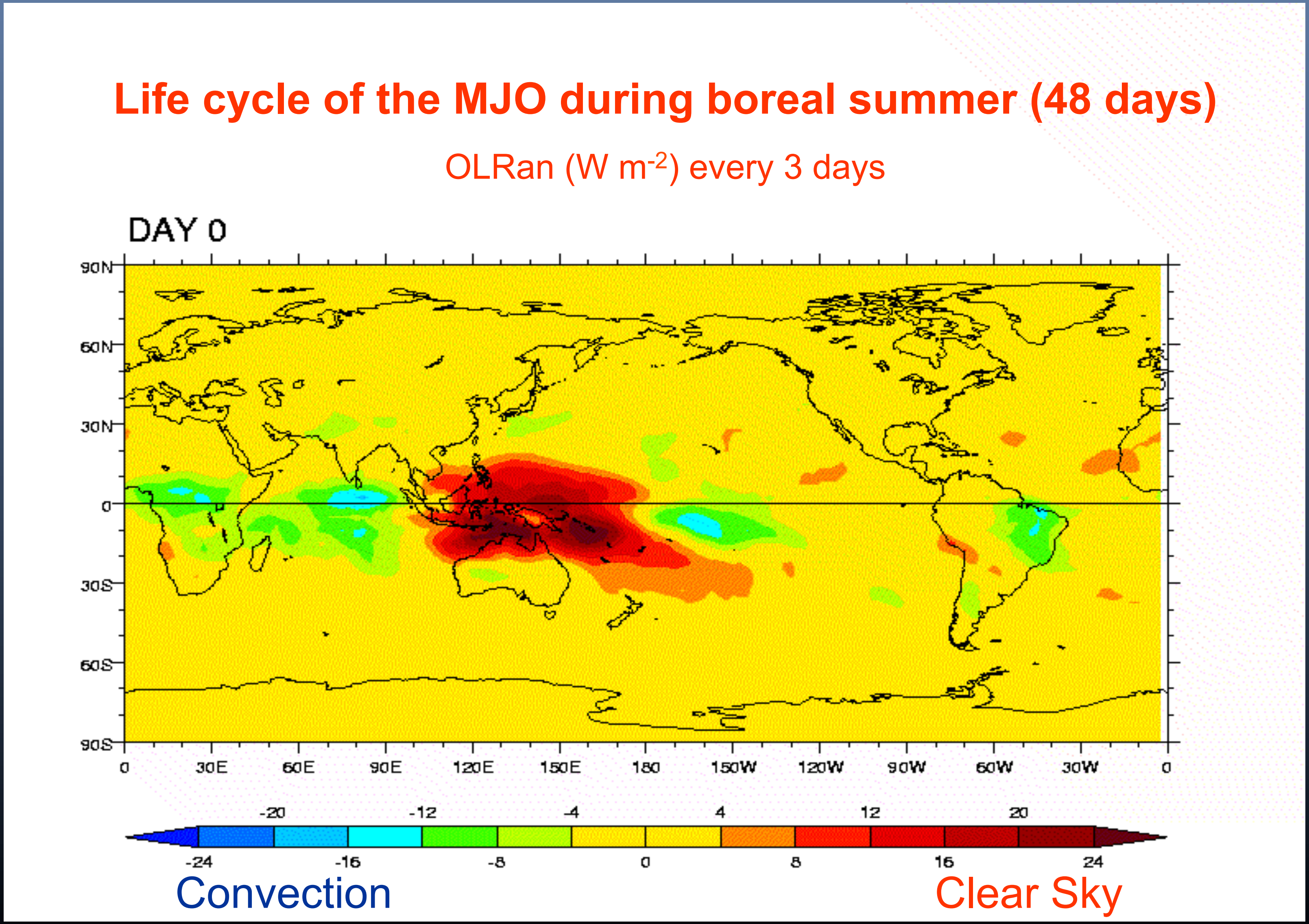
The Madden-Julian Oscillation (MJO) and Kelvin Waves

The MJO is also referred to as the 30-60 day or 40-50 day oscillation and is the main intraseasonal/intra-annual fluctuation that explains weather variations near the equatorial regions.

It may also affect weather systems in the extratropics, such as the west coast of the U.S. in winter. In its simplest form, the MJO consists of coherent variations



Atmospheric Kelvin Waves and the MJO



http://envam1.env.uea.ac.uk/met_ocean_climate.html (Matthews 2000)

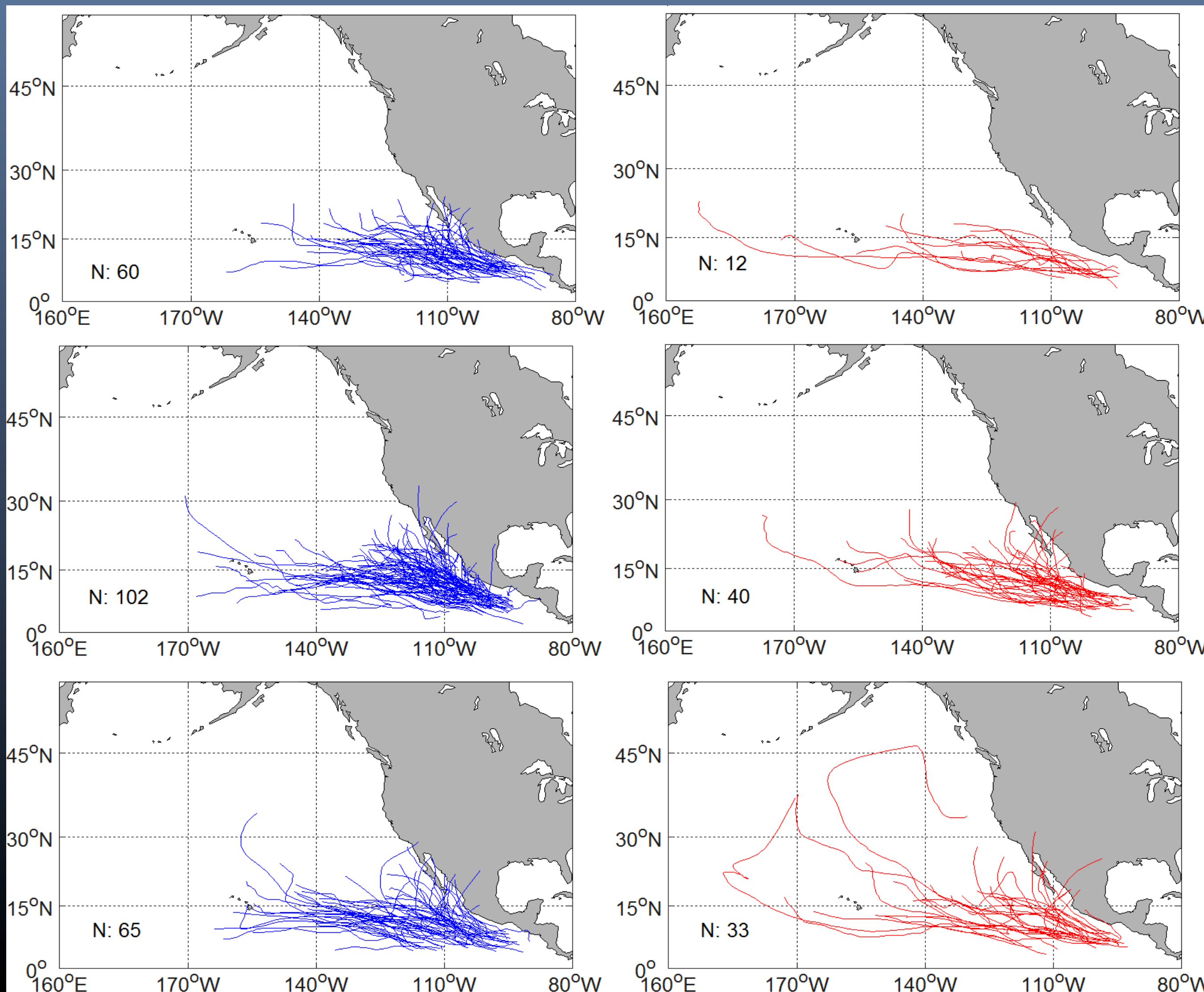
ENSO and EPAC Tropical Cyclones

HUR1-3 May-Nov HUR4-5

LN (72)

N (142)

EN (98)



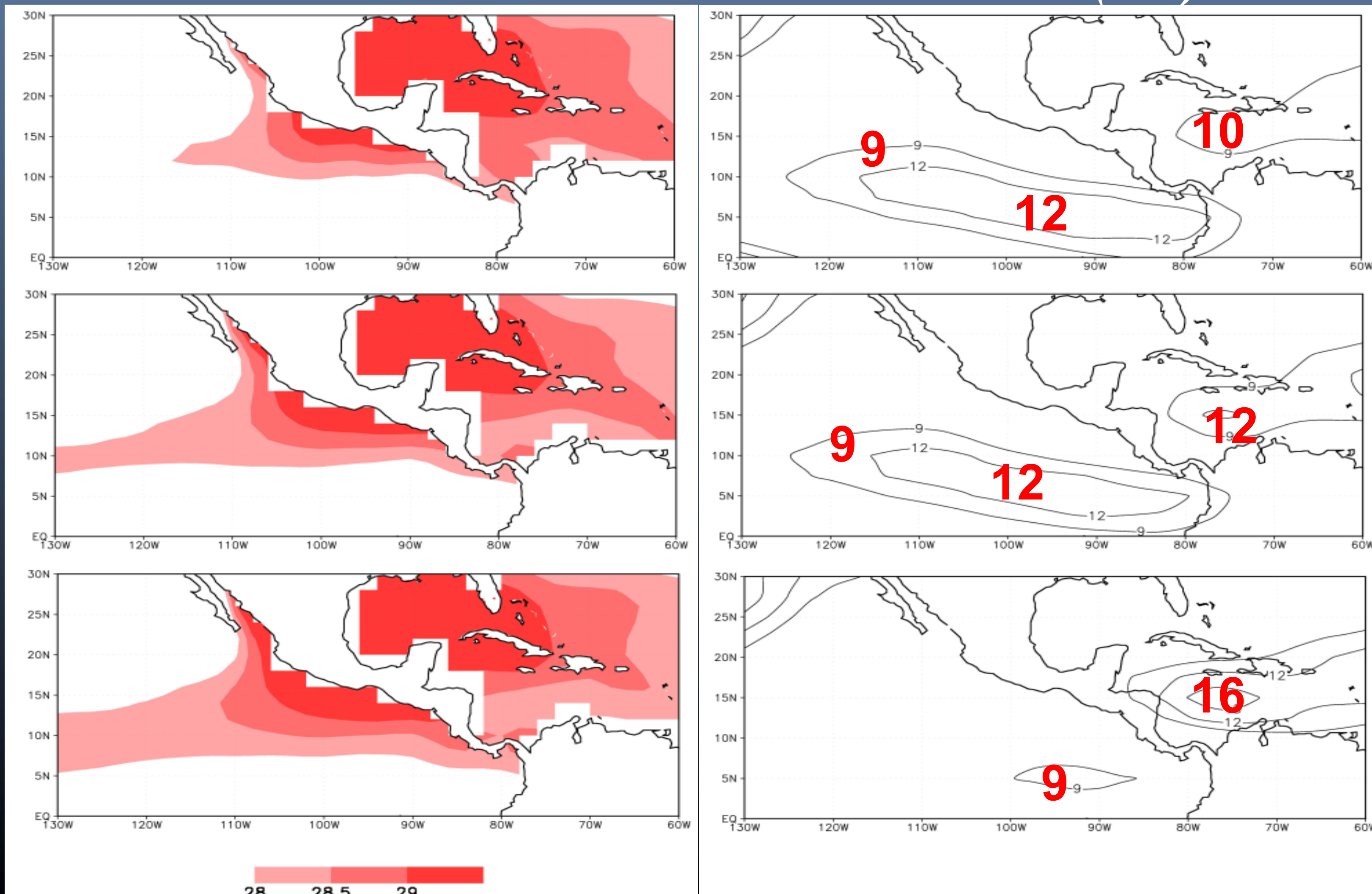
ENSO and EPAC Tropical Cyclones
May-Nov 1979-2010

Warm Pool: SST > 28°C | *U200-U850mb (m/s)*

LN

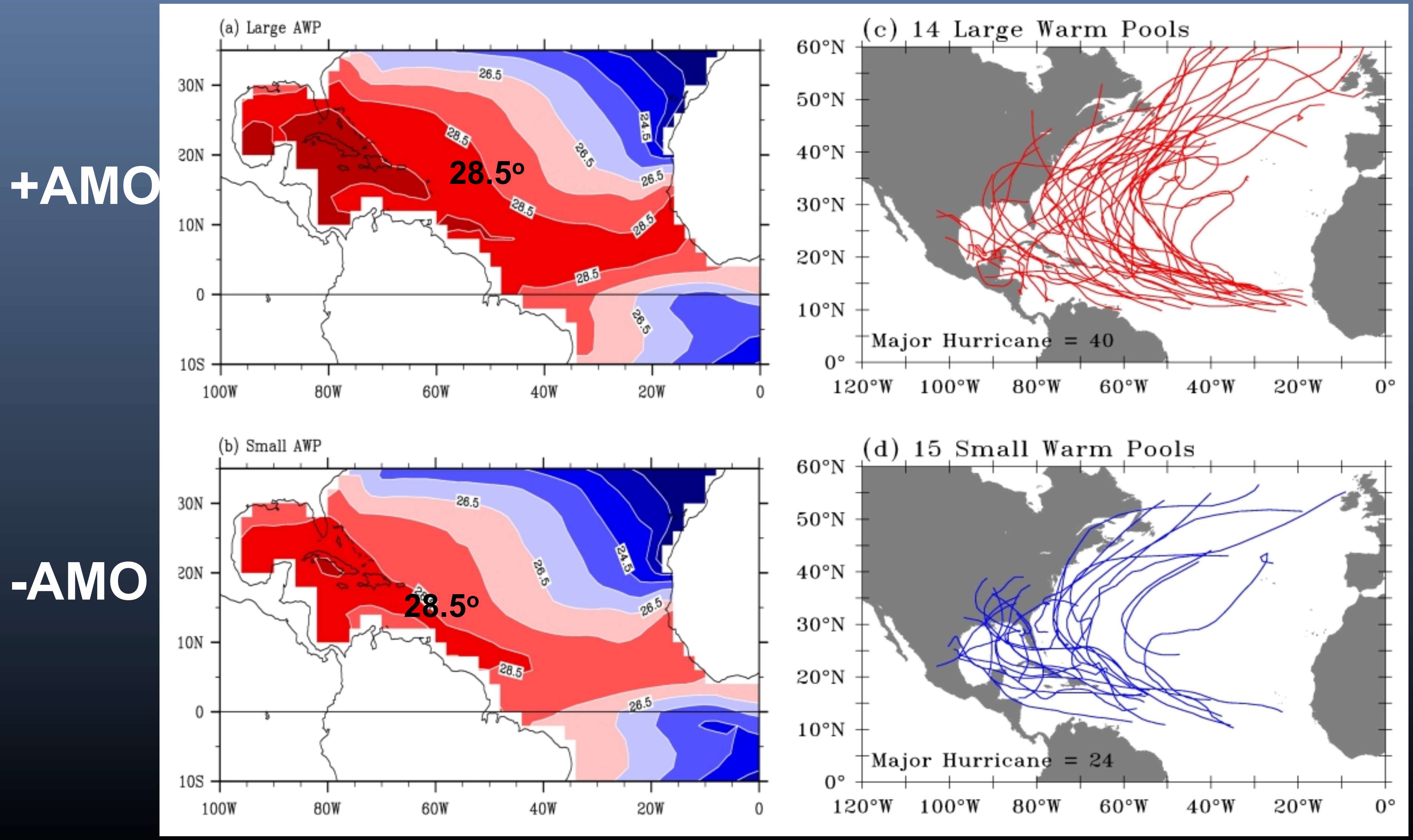
N

EN



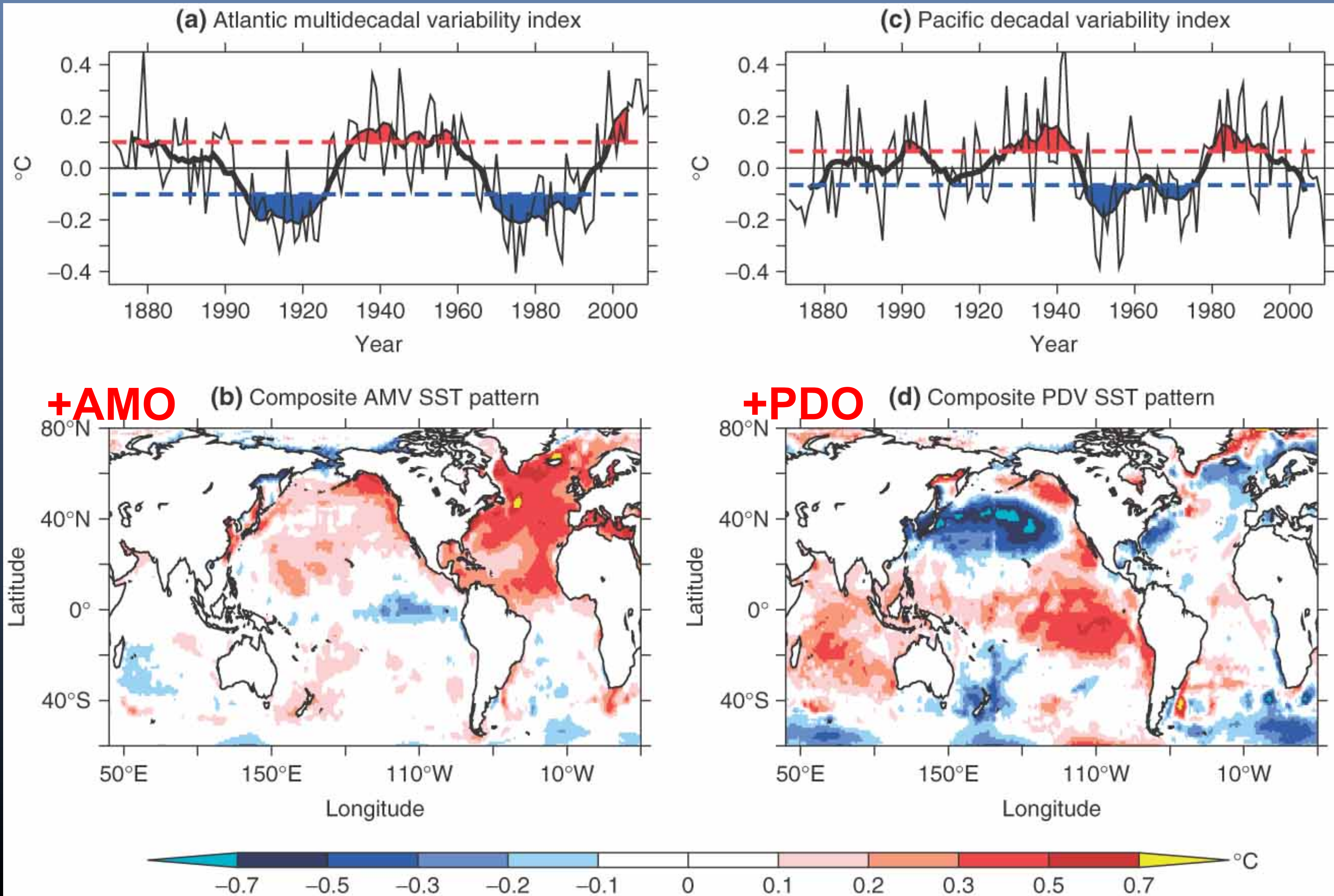
Martinez-Sanchez y Cavazos 2014

AMO and NAT Tropical Cyclones

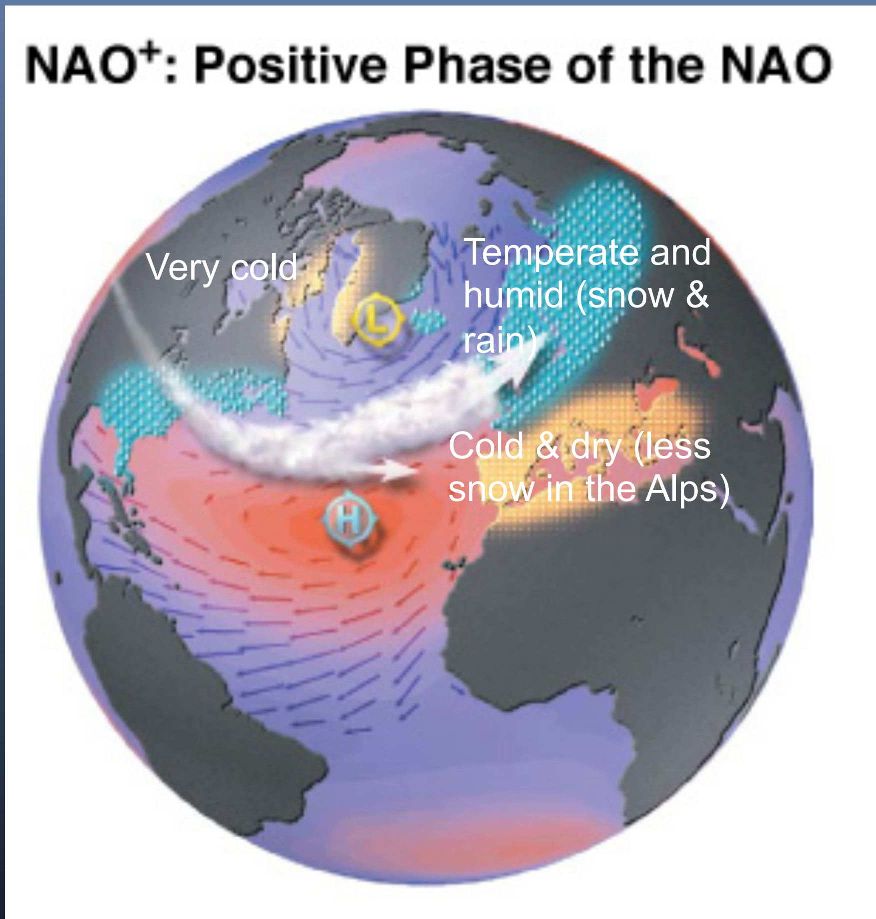


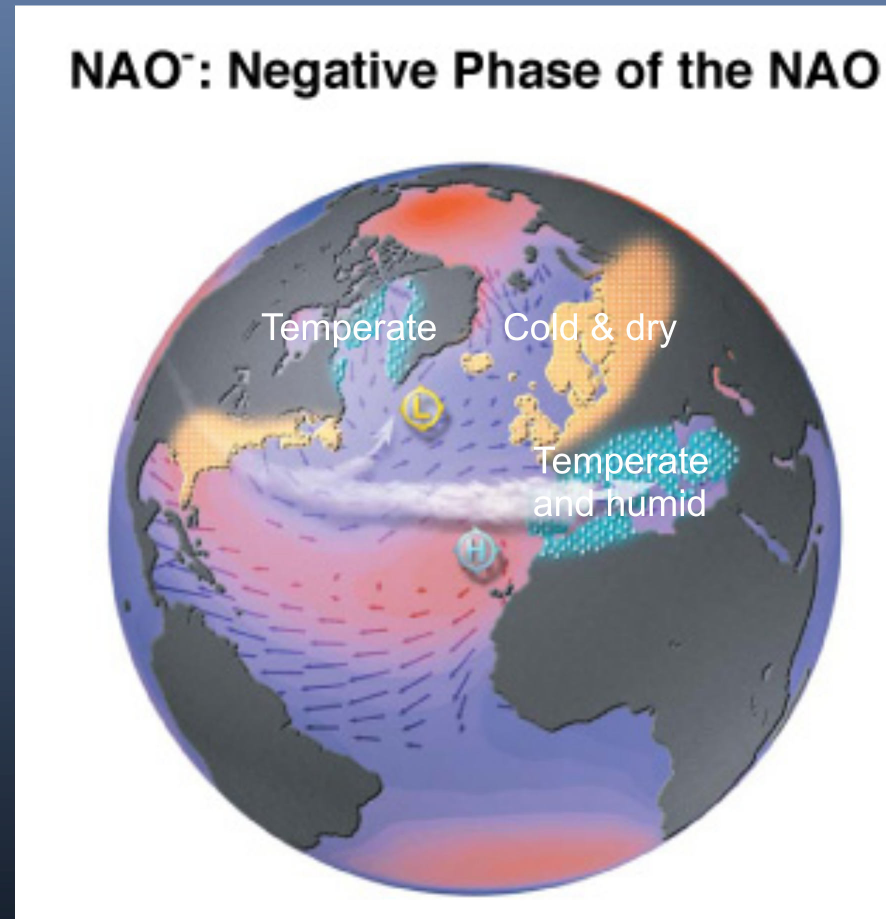
http://www.aoml.noaa.gov/phod/research/tav/awp/

Decadal Patterns of the Atlantic and Pacific



Teleconnection Pattern: The North Atlantic Oscillation



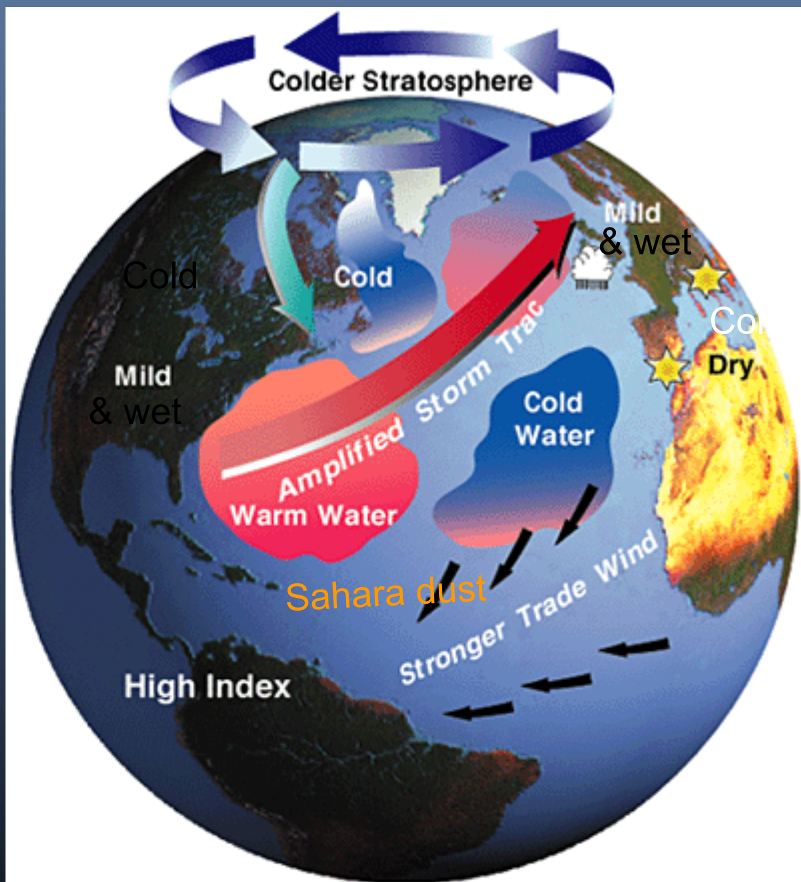


The two extreme phases of the North Atlantic Oscillation (NAO) and some climatic impacts. Courtesy of Lamont Doherty Earth Lab./NOAA).

AV/D1/001

Teleconnections of the North Atlantic Oscillation

NAO Pos



NAO Neg

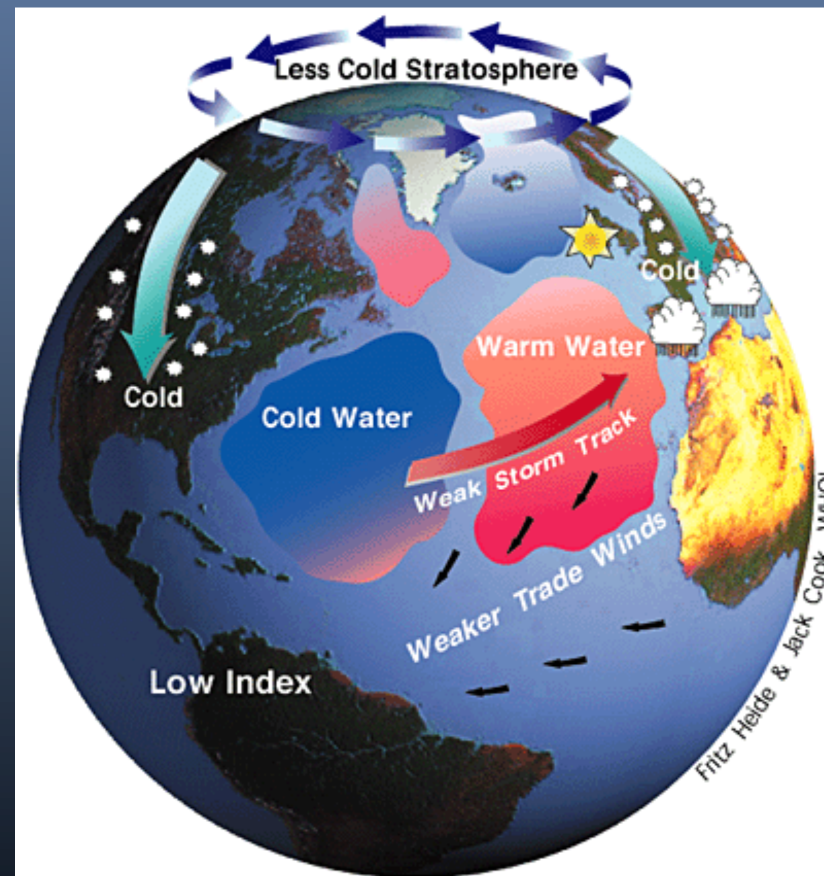
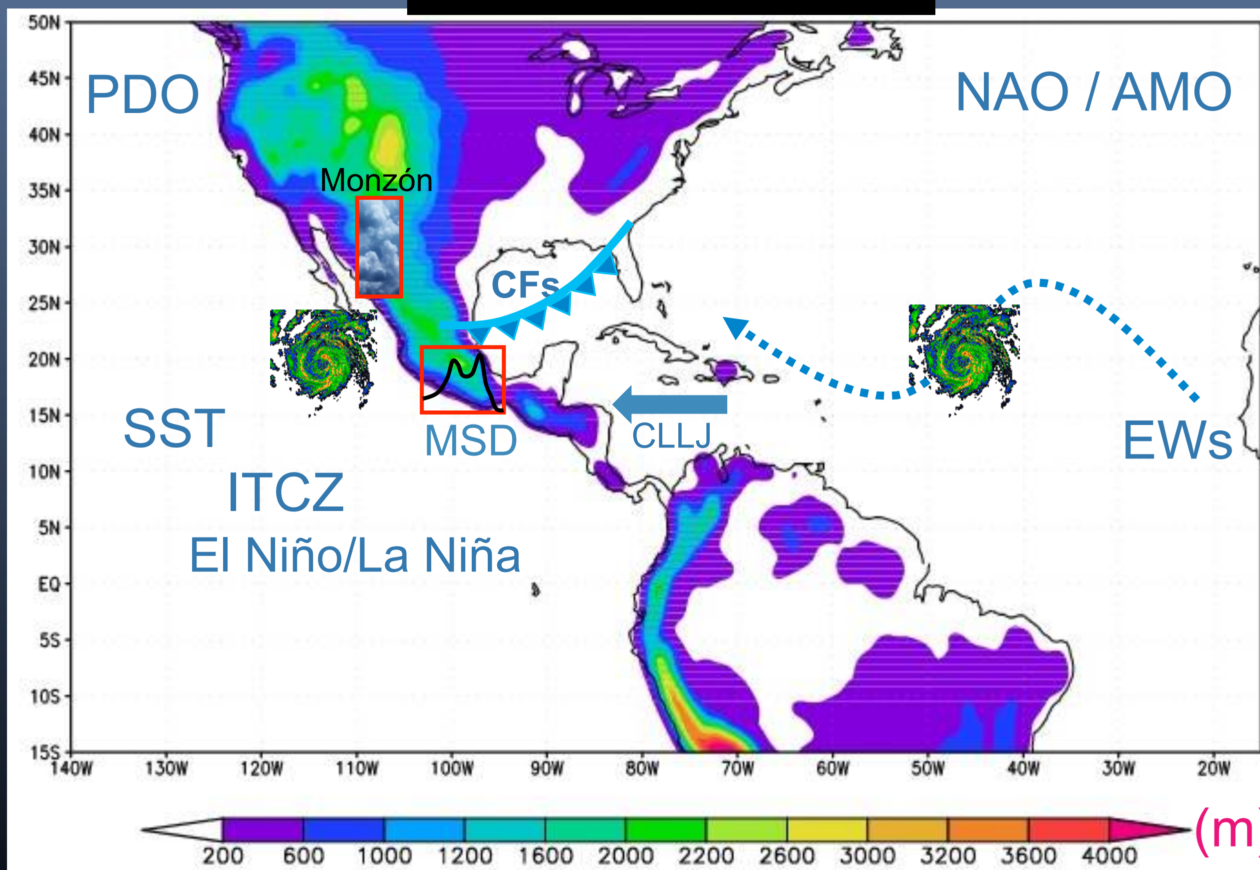


Figure 2A. The North Atlantic Oscillation (NAO). Its "high index" state is shown above, this corresponds to particularly high atmospheric pressure over the Azores, an intense low over Iceland. Ocean winds are stronger and winters milder in the eastern U.S. When the NAO index is low, ocean winds are weaker and the U.S. winter more severe. Changes in ocean temperature distributions are also observed. (Illustration by Fritz Heide & Jack Cook, WHOI)

Relevant Phenomena
for the Central American – Caribbean Region

[redacted]



Thank You

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