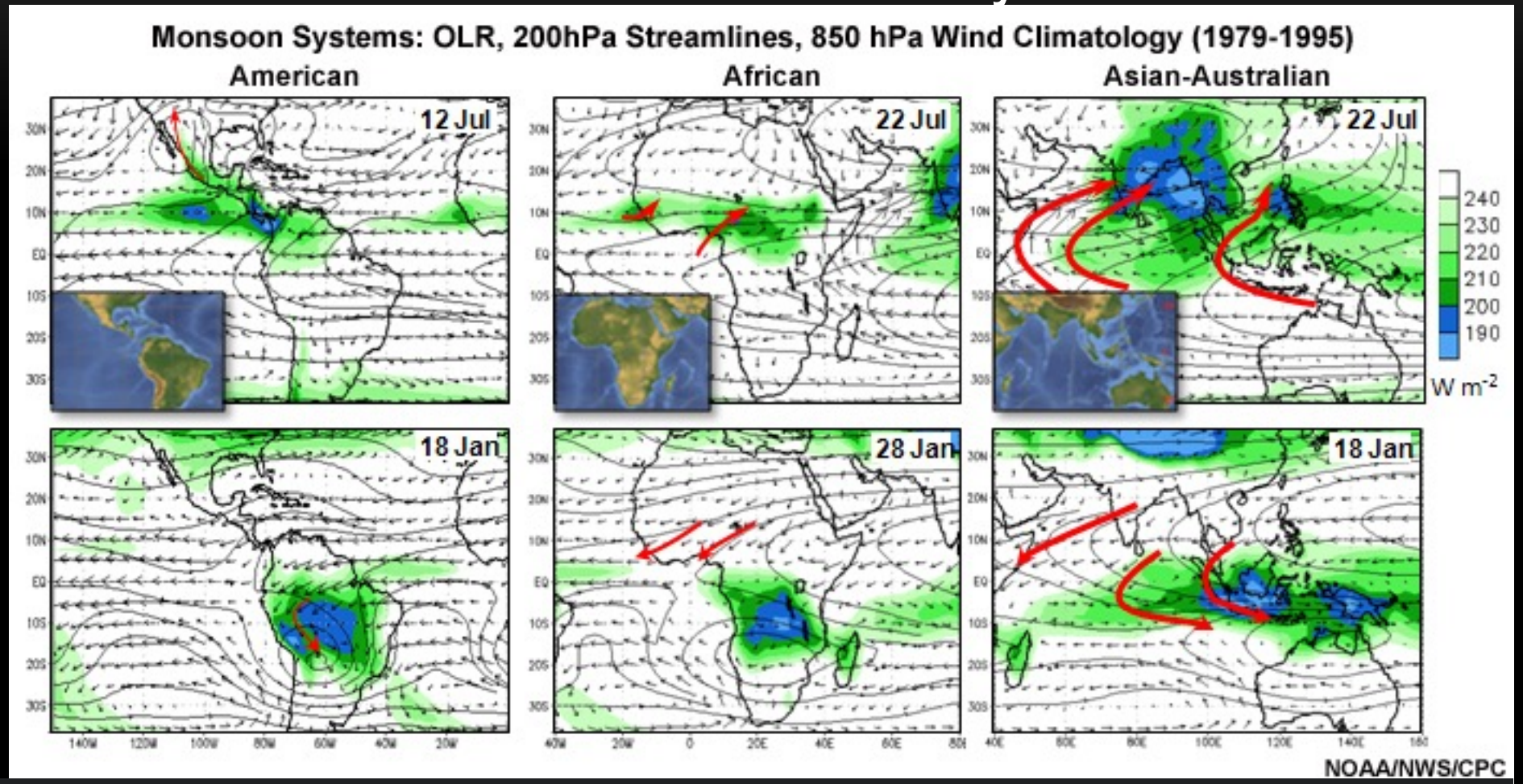
Monsoons, Stationary Eddies, and Transient Eddies

Monsoons

Monsoons

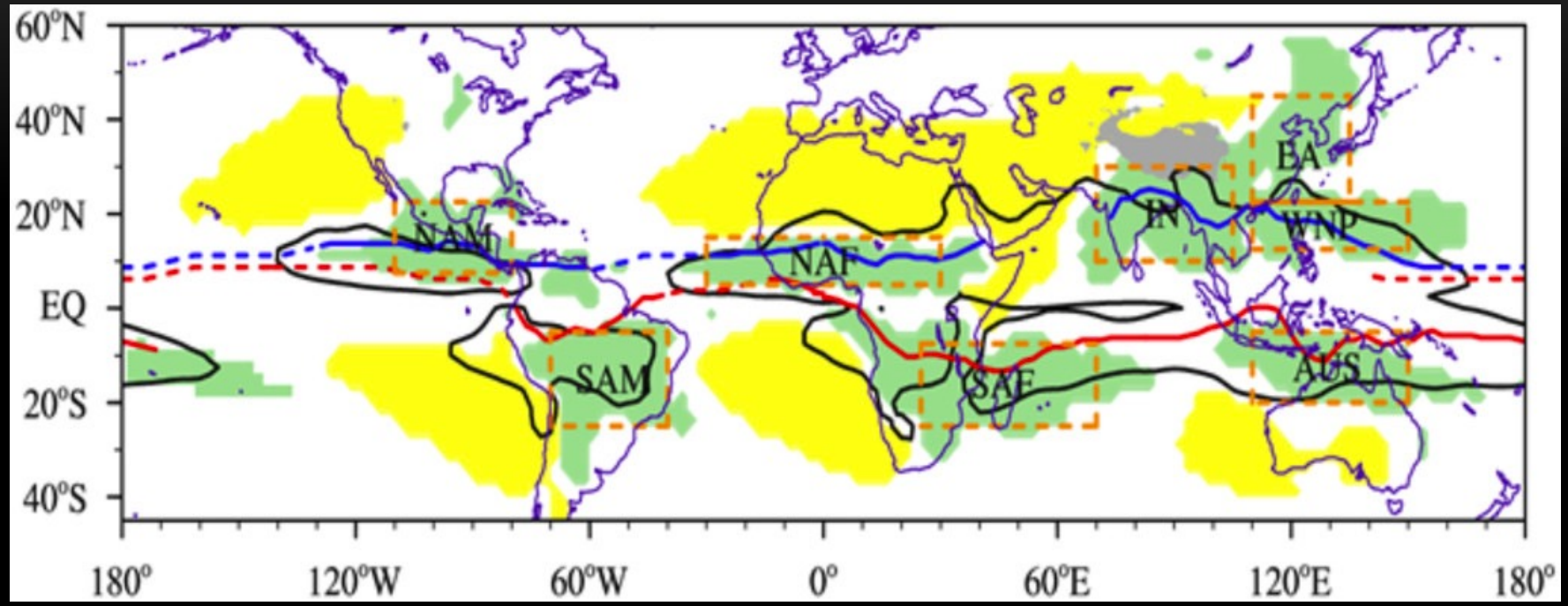
- Monsoons: the seasonal reversal in atmospheric low-level circulation, especially the surface winds, and the associated seasonal variations of precipitation (wet summer and dry winter).
- "*Monsoon was first applied to the winds over the Arabian Sea, which blow for six months from northeast and for six months from southwest, but it has been extended to similar winds in other parts of the world*." (AMS Glossary)
- The majority of Earth's populations live in monsoon regions.

Different monsoon systems



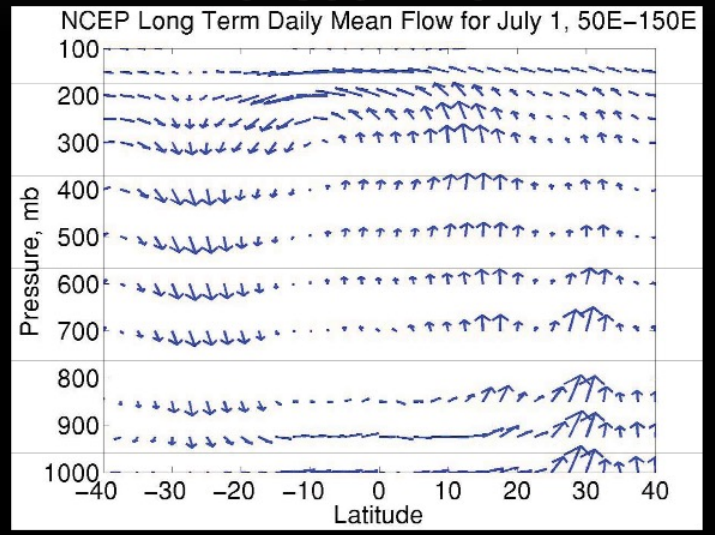
- The global monsoon systems now include regions of the Americas whose summertime precipitation and wind characteristics are similar to the Indian monsoons.

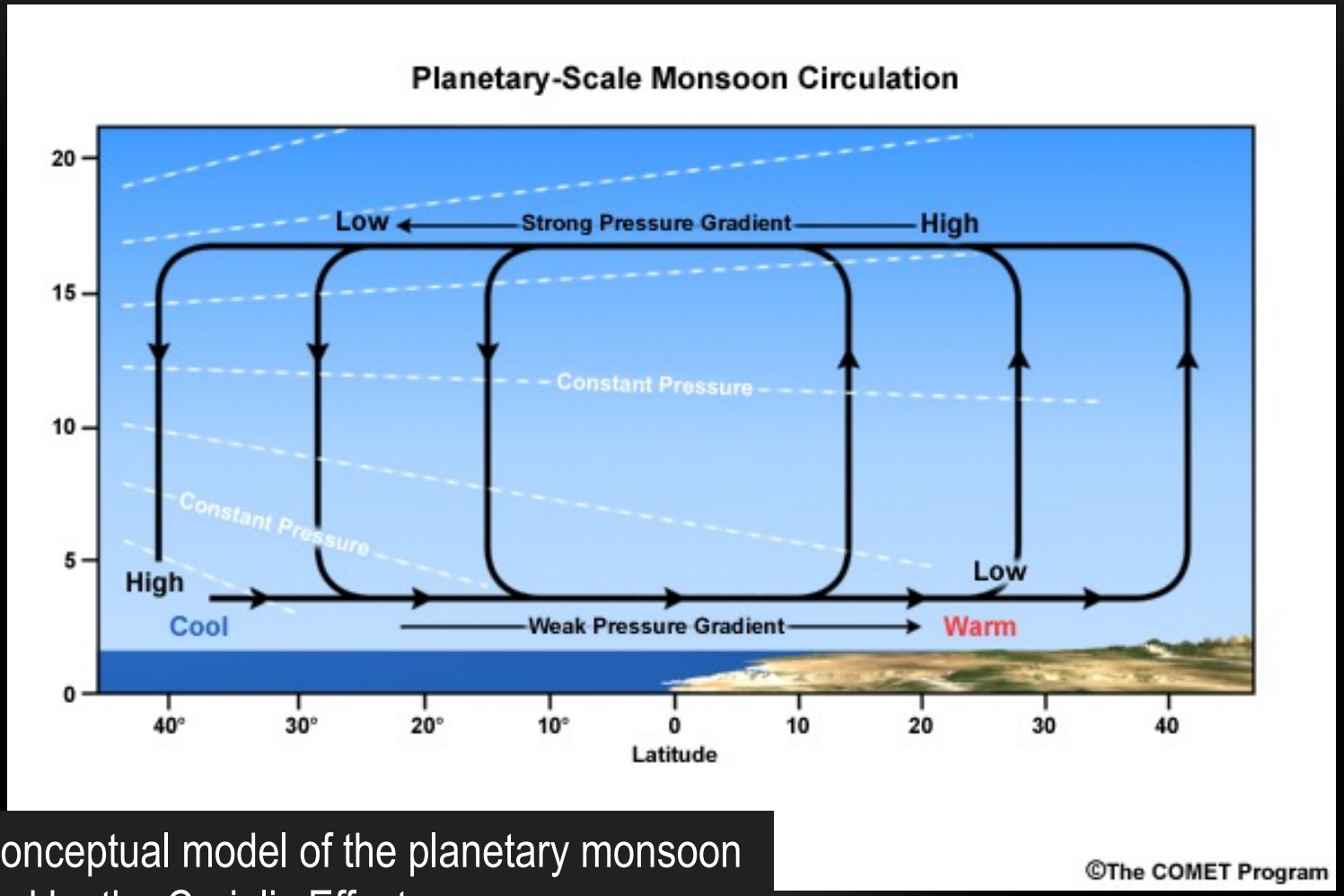
Global Monsoon Domains



The monsoon precipitation domains (green shading) defined as the regions where local summer-minus-winter precipitation exceeds 300 mm and the local summer precipitation exceeds 55% of the annual total. The dry regions (yellow shading) are regions where the local summer precipitation is less than 150 mm. The blue lines indicate the ITCZ position in August, and the red lines indicate the maximum monthly mean precipitation in February; solid lines denote monsoon troughs, and dashed lines show the trade wind convergence.

Monsoon as a Moist Land-sea Breeze

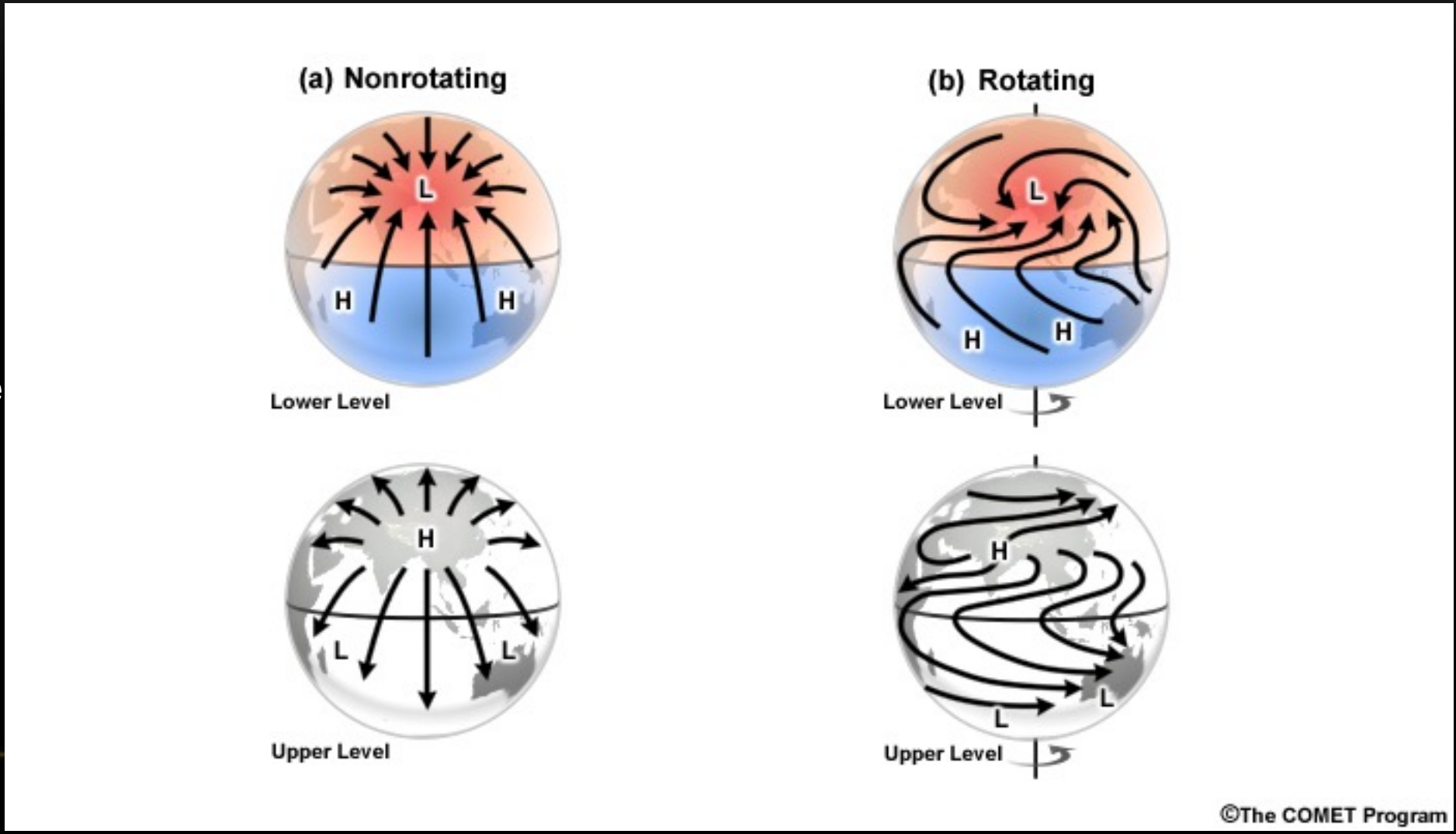




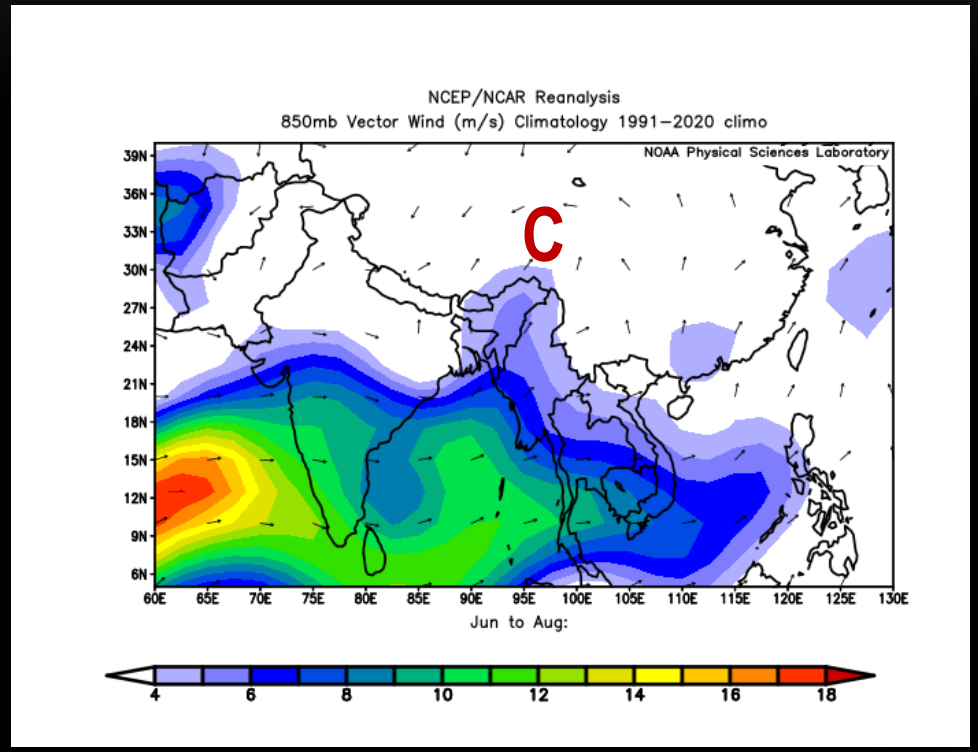
- Webster (1987) proposed a conceptual model of the planetary monsoon as a moist sea-breeze modified by the Coriolis Effect.

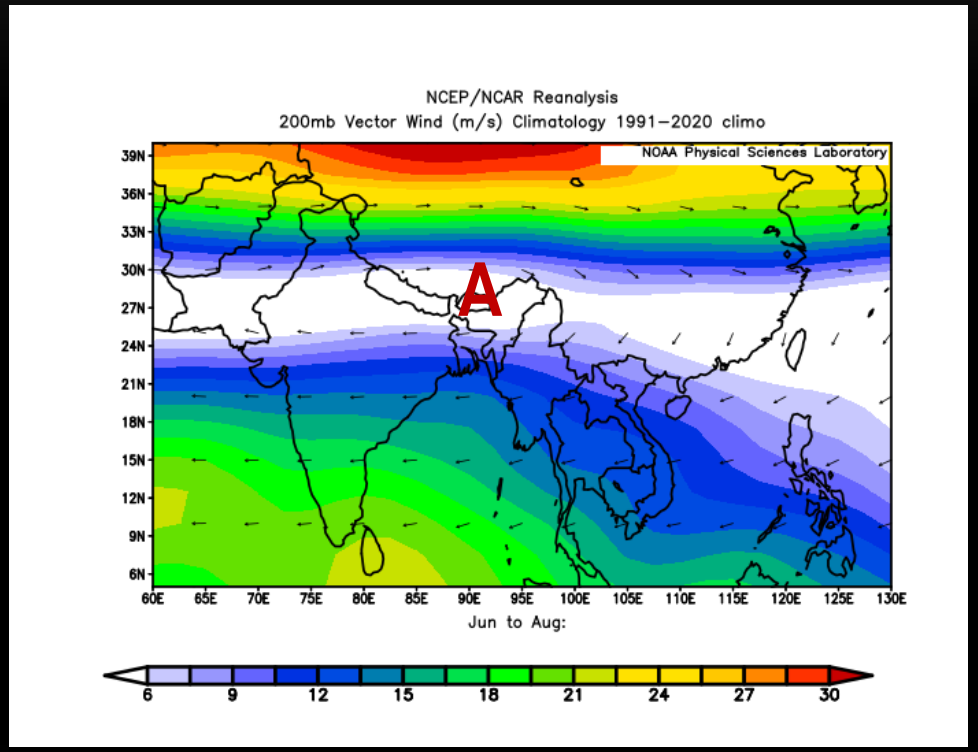
With and without the Coriolis effect

Warm land and cool ocean in summer → upper-level high pressure system and low-level low-pressure system over land



Observed Monsoon Circulations: Long-term mean wind (Jun-Aug)





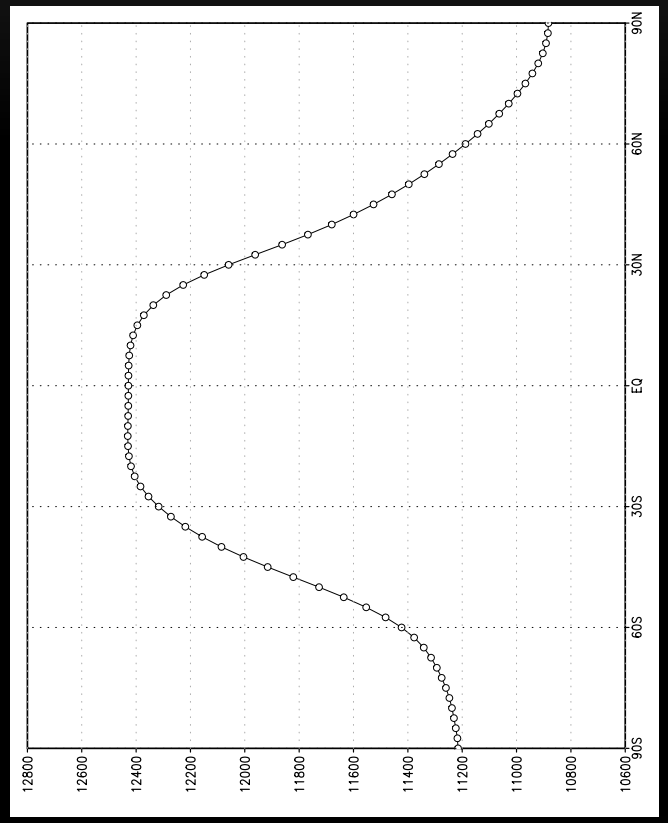
- the low-level cyclonic circulation and upper-level anticyclonic circulation over the Asian summer monsoon region

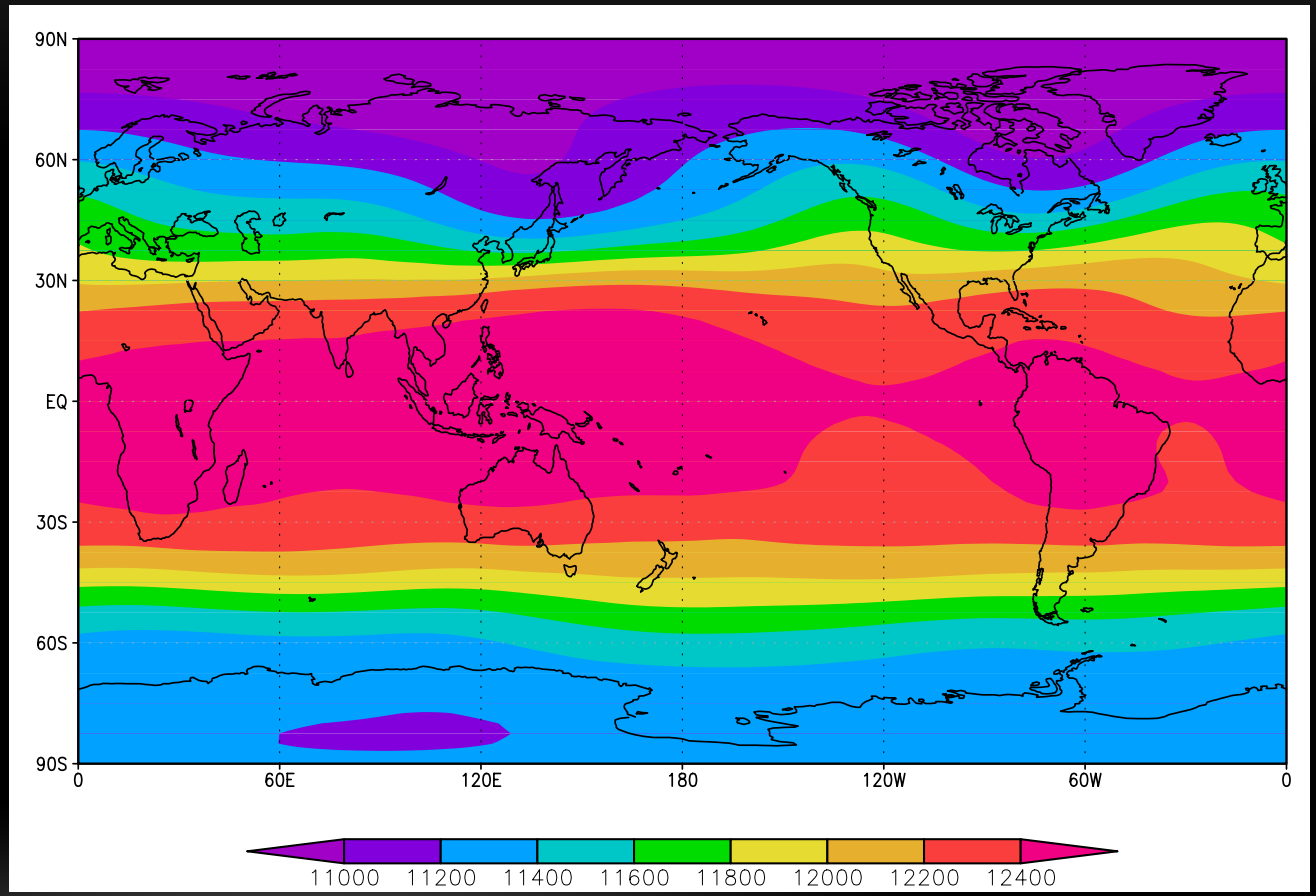
Plots produced at https://psl.noaa.gov/cgi-bin/data/composites/printpage.pl

Stationary Eddies (i.e., Stationary Waves)

Eddies refer to departures from the zonal mean

Long-term Mean 200-mb Geopotential Height: Zonal Mean and Total Field (Jan)





What if we remove the zonal mean from the total long-term mean field?

Figure produced using NNR2 reanalysis

200-mb Geopotential Height: stationary eddies (Jan)

- Stationary waves or stationary eddies: waves with nodes that are stationary relative to the given coordinate system (or "geographically fixed").

- In meteorology the coordinate system is usually fixed with respect to the earth, so that a stationary wave usually refers to one that is stationary relative to the earth's surface.

  -- AMS Glossary

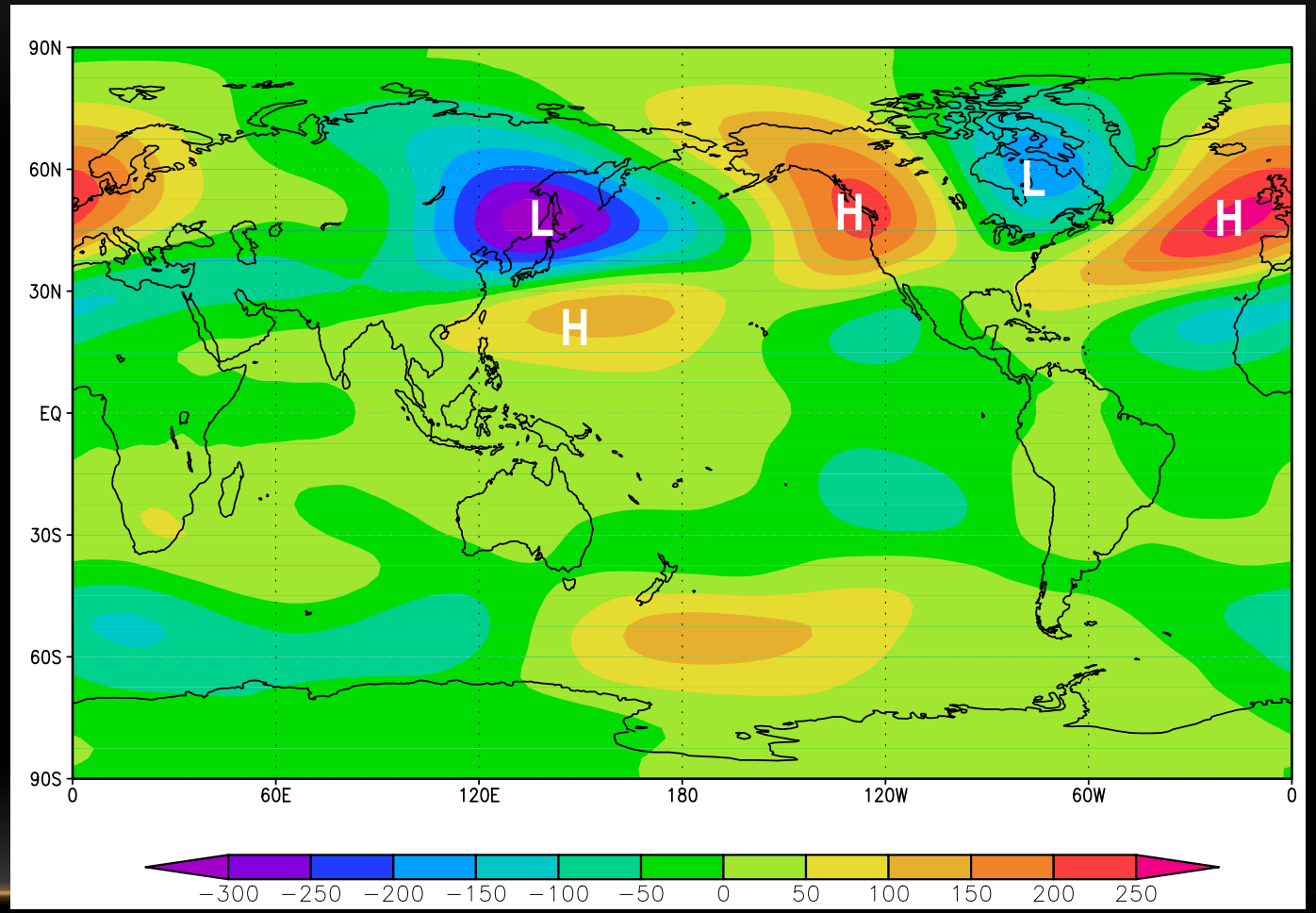
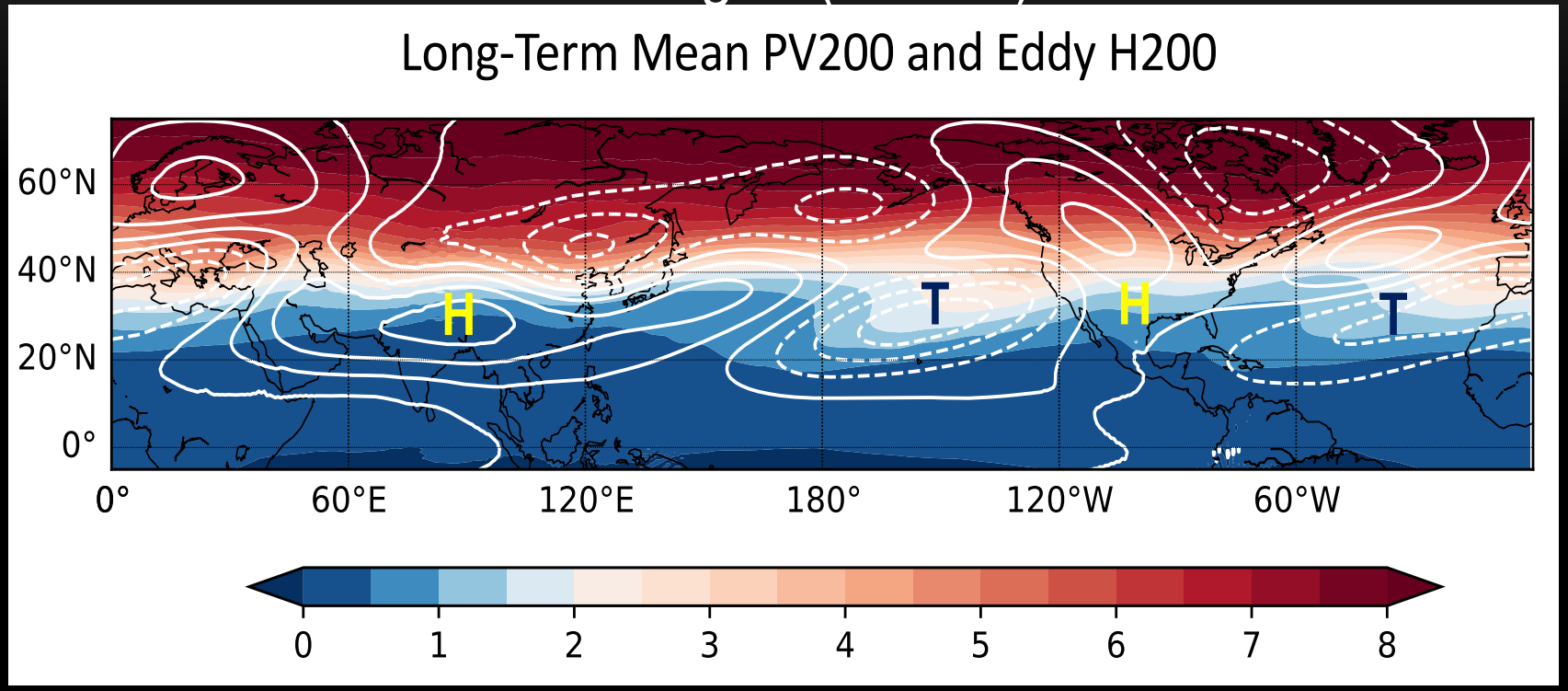


Figure produced using NNR2 reanalysis

Summertime Stationary Waves and Tropical Upper-Tropospheric Troughs (TUTTs)



Shading: PV200
Contours: eddy H200

- Subtropical stationary waves = monsoon anticyclones + TUTTs
- TUTTs: regions of reduced PV gradient and “windows” for active tropical-extratropical interaction
- TUTTs: preferred region of extratropical Rossby wave breaking

Z. Wang et al. (2020)

Why do stationary waves matter?
-Regional Variability of the Jet Streams/Storm tracks

- Midlatitude stationary waves are tied to the regional variability of the jet streams and storm tracks
- *Where do you expect the jet to be enhanced?*
- The jet is enhanced over the East Asian coast and the east coast of North America

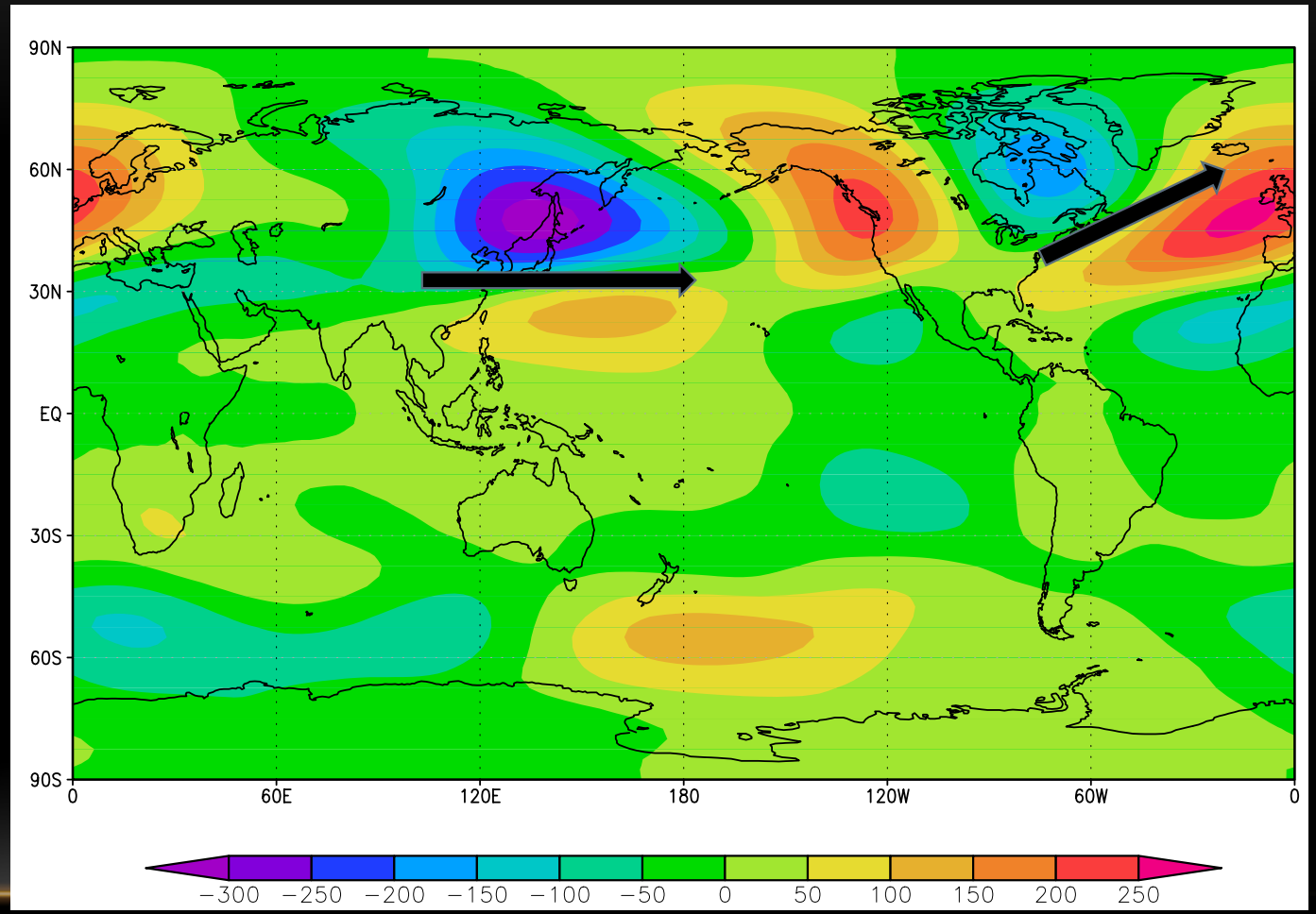
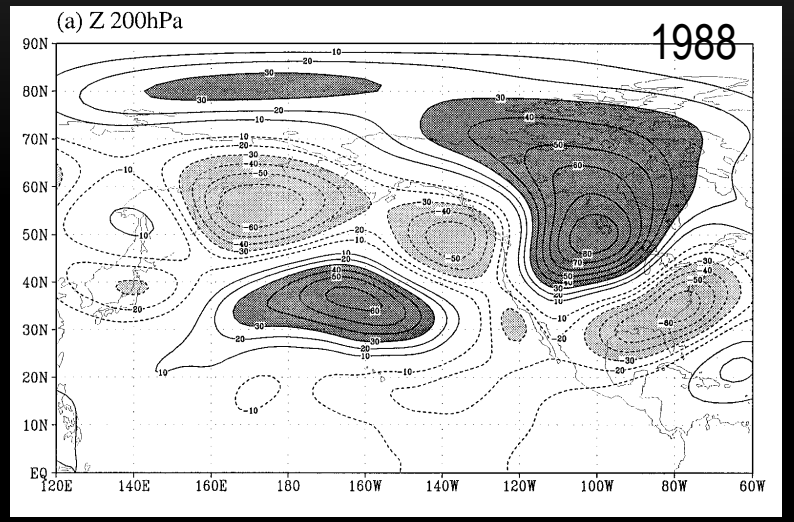
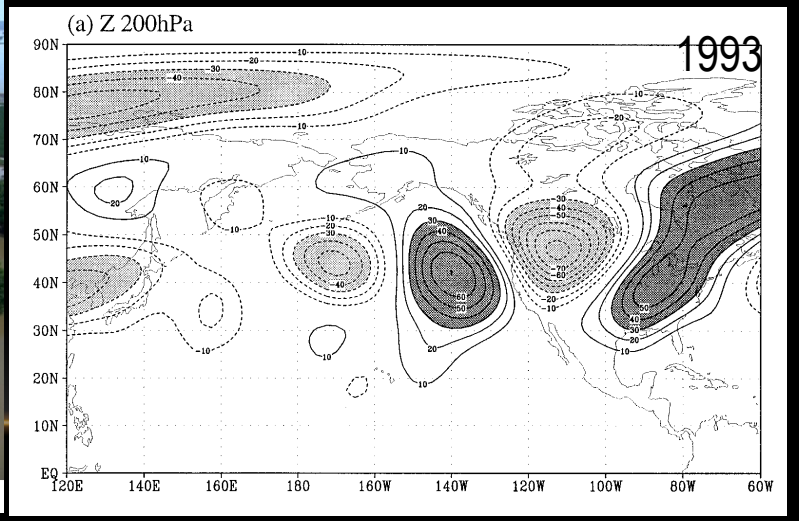


Figure produced using NNR2 reanalysis

Why do stationary waves matter? - 1988 drought and 1993 flood

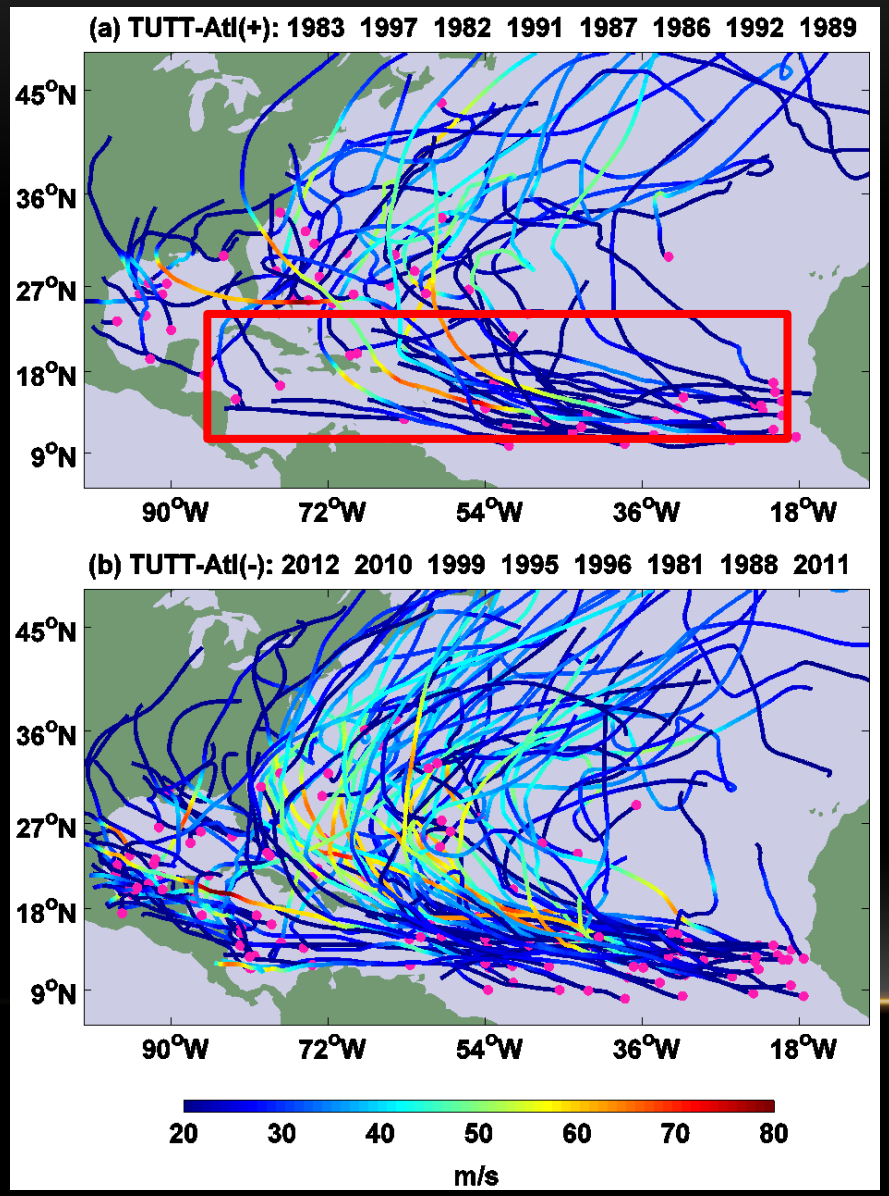
- Stationary waves play an important role in regional climate anomalies and extreme events.
- Examples include the 1988 drought and 1993 flood, which were associated with anomalous stationary waves.





Two figures on the left from NOAA for unknow years. The two plots on the right are from Liu et al. (1998) © American Meteorological Society. Used with permission

Atlantic Tropical Cyclones (TCs) and the North Atlantic TUTT



- TUTT: Tropical Upper-Tropospheric Trough, part of the subtropical stationary waves
- Atlantic TC activity is reduced when the North Atlantic TUTT is anomalously strong.
- A similar relationship between TUTT and TCs is also found over the North Pacific.

Corr. with Atlantic TCs (1979-2018)

Corr	TC	HURR	ACE
TUTT_Atl	-0.73	-0.76	-0.75
MDR_SST	0.59	0.56	0.55
Nino3.4	-0.34	-0.38	-0.32

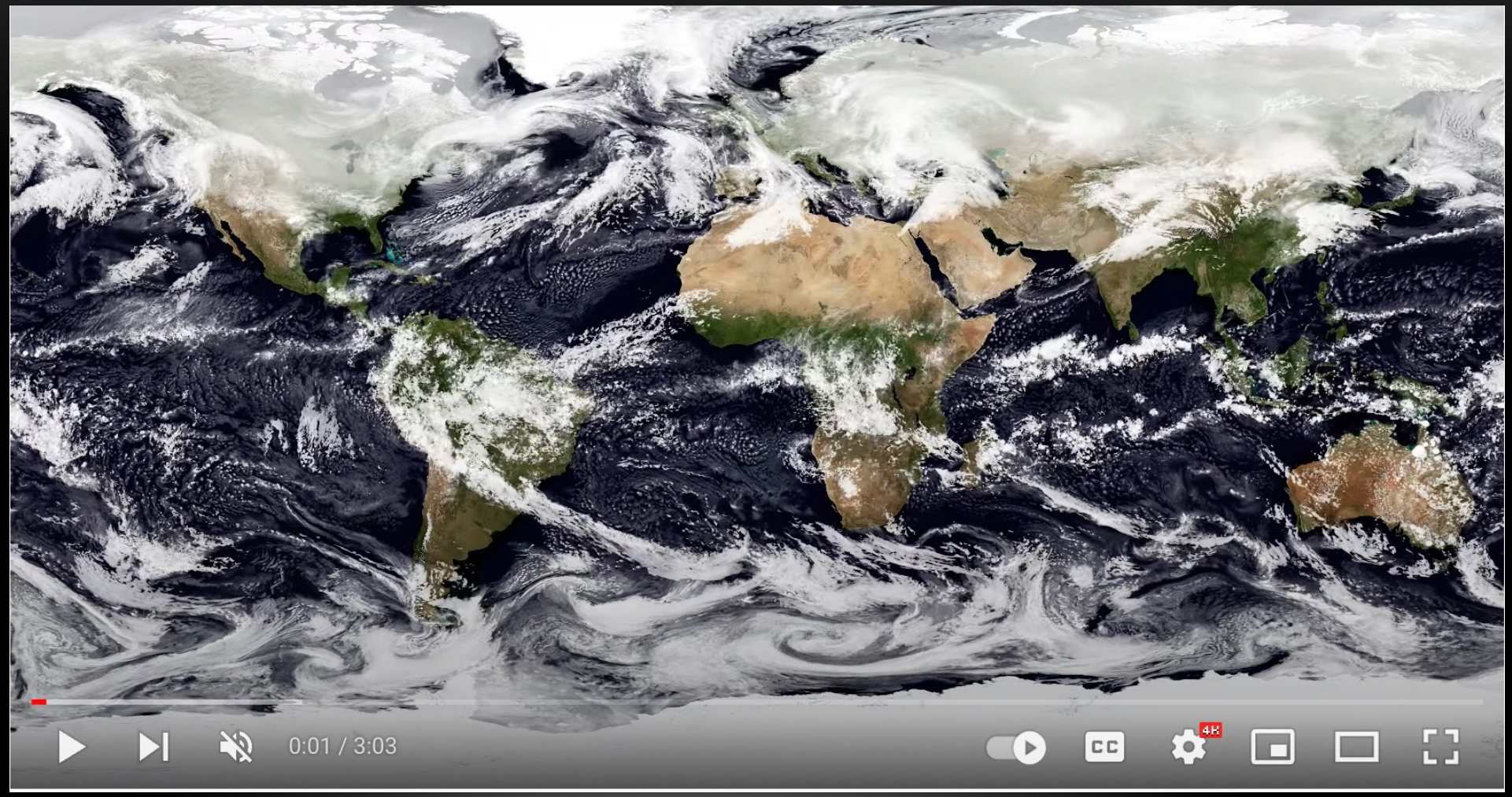
MDR: Main Development Region

Z. Wang et al. (2020)

Transient Eddies

In contrast to stationary eddies, transient eddies refer to the component of the eddy field that varies with time, such as the migratory cyclones and anticyclones in the extratropics. (AMS Glossary)

Transient Eddies: Midlatitude Cyclones and Anticyclones



The energy and track of cyclones are strongly modulated by the mean flow (baroclinic instability, steering flow…)

A map of Earth showing the global cloud cover on July 11, 2005
From https://earthobservatory.nasa.gov/blogs/earthmatters/tag/clouds/

Lorenz Energy Cycle

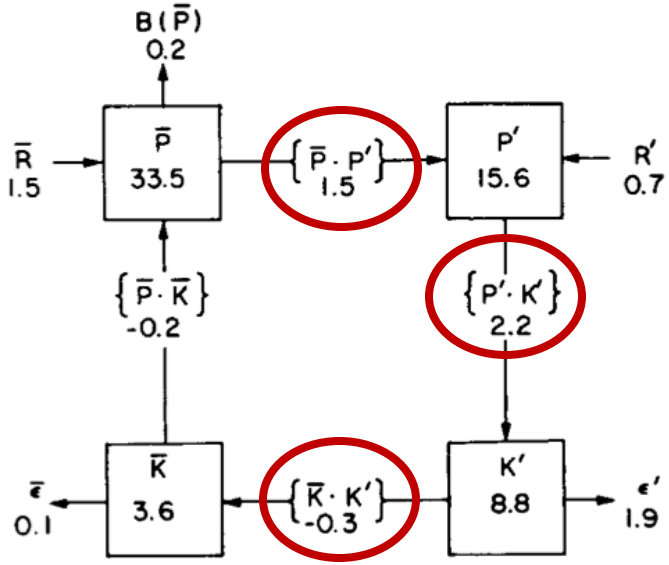


Fig. 10.13 The observed mean energy cycle for the Northern Hemisphere. Numbers in squares are energy amounts in units of 10^5 J m^{-2}. Numbers next to arrows are energy transformation rates in units of W m^{-2}. $B(\overline{p})$ represents a net energy flux into the Southern Hemisphere. Other symbols are defined in the text. (Adapted from Oort and Peixoto, 1974.)

- The zonal-mean diabatic heating generates mean zonal available potential energy through a net heating of the tropics and cooling of the polar regions (R_bar→P_bar).
- Baroclinic eddies transport warm air poleward, cold air equatorward, and transform the mean available potential energy to eddy available potential energy (P_bar→P').
- At the same time eddy available potential energy is transformed into eddy kinetic energy by the vertical motions in the eddies (P'→K').
- The zonal kinetic energy is maintained primarily by the conversions from eddy kinetic energy eddy momentum flux u'v' (K'→K_bar).
- The energy is dissipated by surface and internal friction in the eddies and mean flow.
- High-frequency eddies thus play an important role in the global climate system.

P_bar: mean zonal available potential energy
K_bar: zonal kinetic energy
B: a net energy flux into the Southern Hemisphere.

P': eddy available potential energy
K': eddy kinetic energy

Holton, 2004: Section 10.4

References

- Cook, K. H., 2013: Section 2.1
- Holton, 2004: An Introduction to Dynamic Meteorology, Section 10.4 “The Lorenz Energy Cycle”
- Liu, Z., M. Ting, and H. Wang, 1998: Maintenance of circulation anomalies during the 1988 drought and 1993 floods over the United States. J. Atmos. Sci.,55, 2810–2832.
- Wang, B., C. Jin, and J. Liu, 2020: Understanding future change of global monsoon projected by CMIP6 models. *J. Climate,* 33, 6471-6489. doi:10.1175/JCLI-D-19-0993.1.
- Wang, Z., G. Zhang, T. Dunkerton, and F. Jin, 2020: Summertime Stationary Waves Integrate Tropical and Extratropical Impacts on Tropical Cyclone Activity, Proceedings, National Academy of Sciences, 202010547; DOI: 10.1073/pnas.2010547117.
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