The Relationship of the Asian Summer Monsoon to the Tropical Upper Troposphere and Lower Stratosphere

K. Mohanakumar

Department of Atmospheric Sciences
Cochin University of Science and Technology
Lakeside Campus, Cochin 682016, INDIA
E-mail:- *kmk@cusat.ac.in* *OR* *kmkcusat@gmail.com*

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Outline

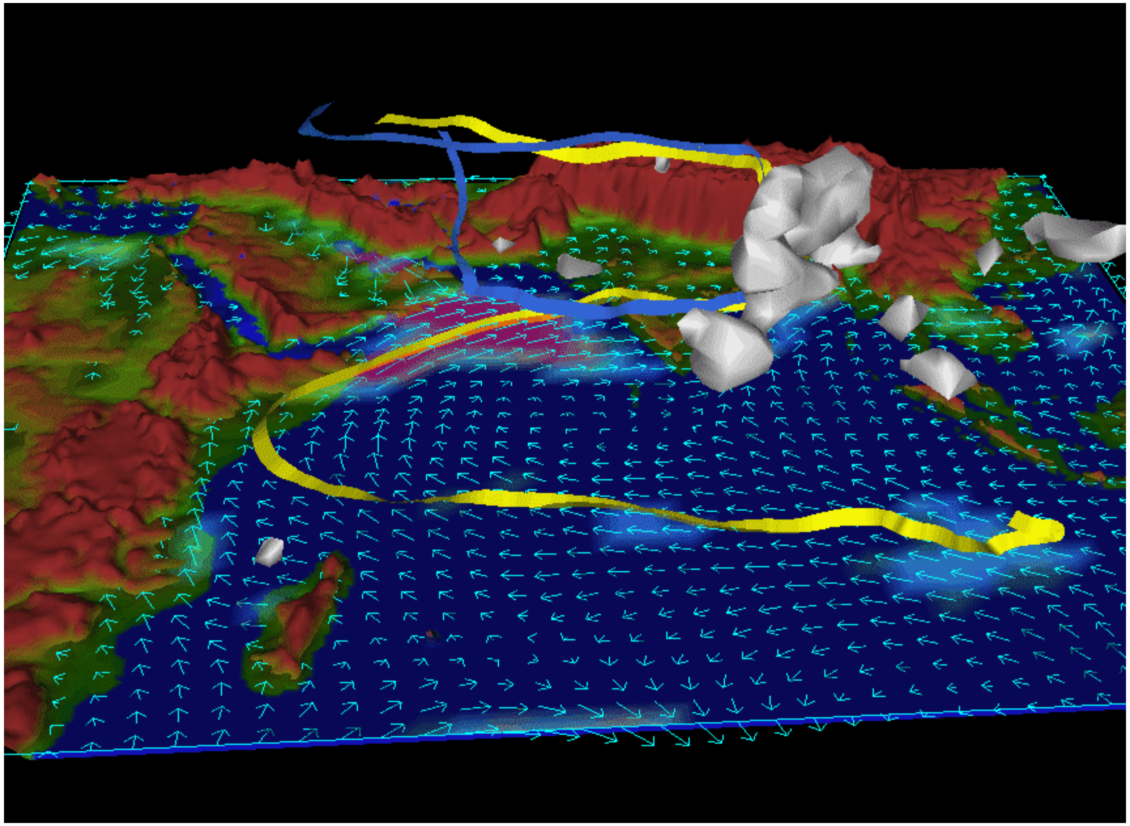
1. Asian Summer Monsoon – A Source of Moisture in the Lower Stratosphere.
2. Stratospheric QBO and its Influence on Summer Monsoon Rainfall over India
3. Effect of Global Warming on Indian Summer Monsoon Circulation.

ASIAN SUMMER MONSOON

Asian Summer Monsoon is a spectacular manifestation of regional scale anomalies of the general circulation of the atmosphere.

The basic origin of the Asian Summer Monsoon (ASM) lies in the differential heating of the land and the sea during the summer season.

The interesting feature of the ASM circulation is the development of the South Asian anticyclone in the Upper Troposphere over Tibetan Plateau



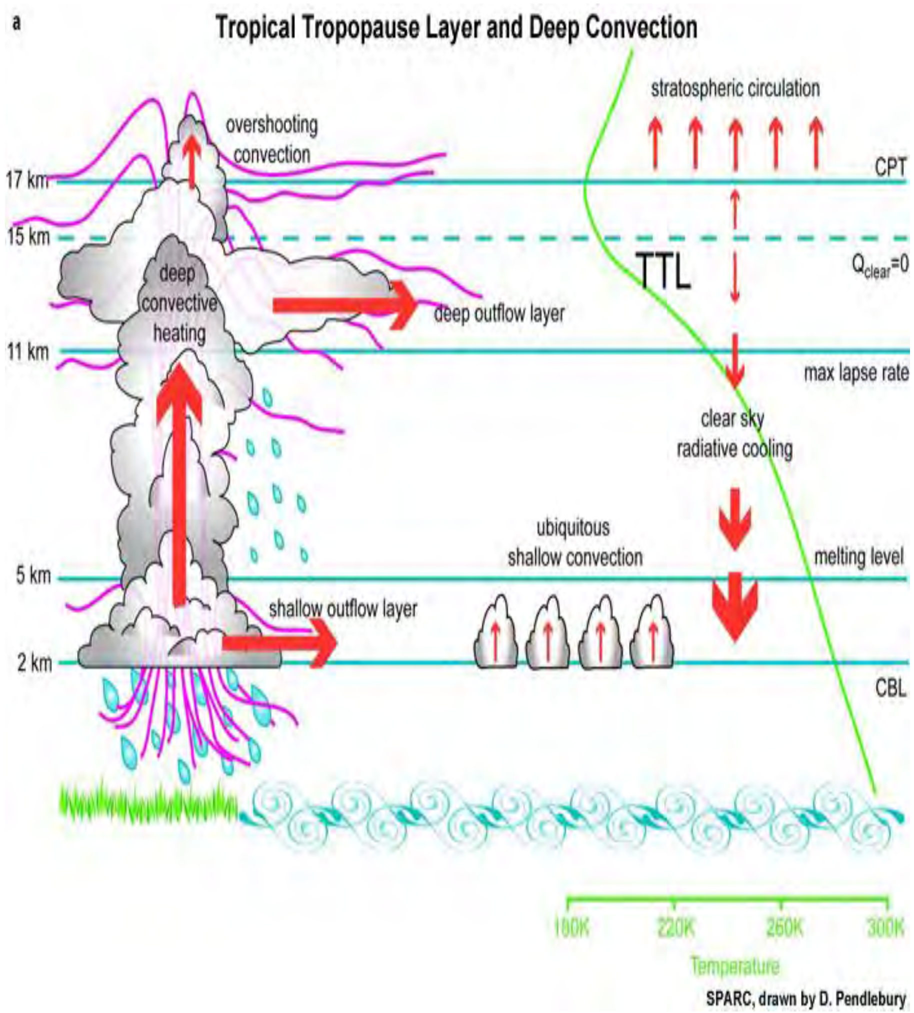
Asian Summer Monsoon Circulation Pattern
(www.tropmet.res.in/~kolli/mol/Links/index.html

Water Vapor in the UTLS over Asian summer Monsoon

The main sources of lower-stratospheric water vapour are the areas of deep convection in the tropics, especially over **Asian Summer Monsoon** region.

Upper tropospheric water vapor in the monsoon region is strongly coherent with deep convection, both spatially and temporally.

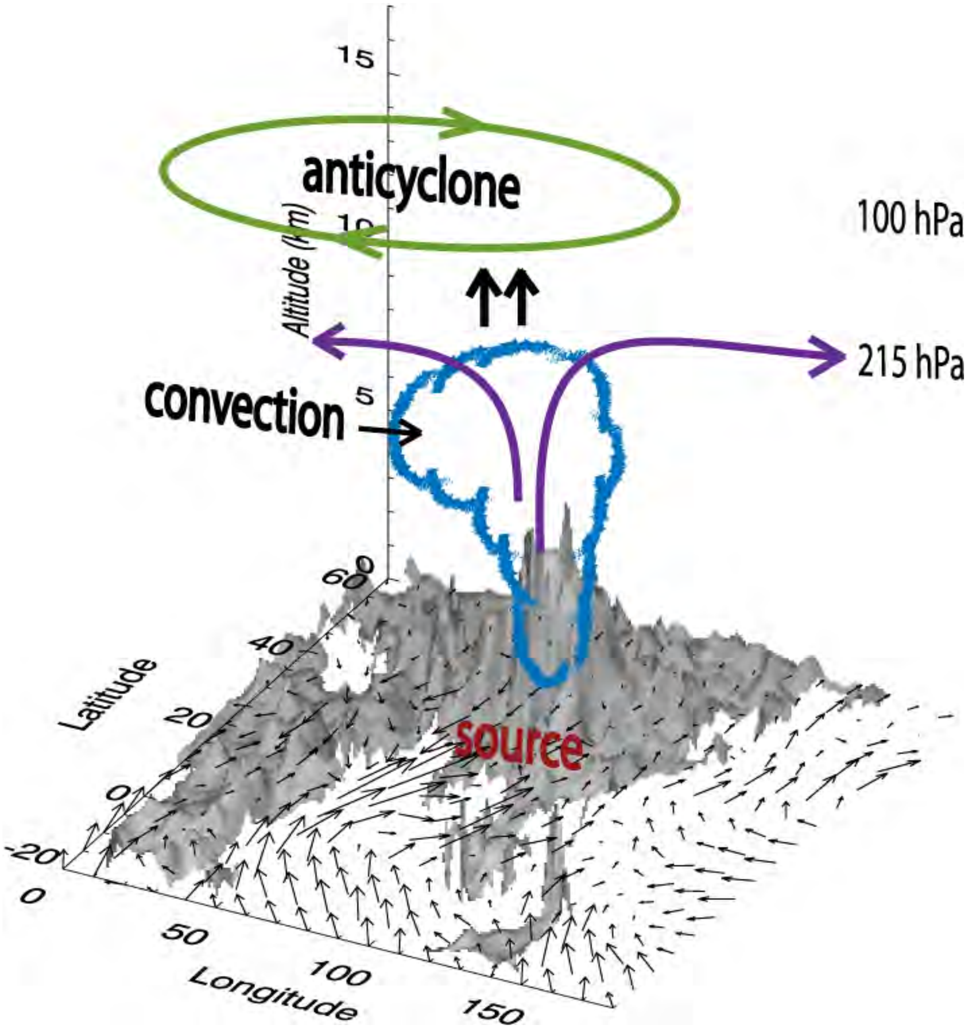
The wetter air intrudes into the tropical lowermost stratosphere (LS) over the convective region (70-180°E, 15-35°N) and extends to the extra-tropical LS along the isentropic surfaces below 380 K around the Asian subtropical jet.



Source: MetEd, UCAR

Regions of Intense Convection

Transport Pathways



Confinement by anticyclone

(Transport to stratosphere)

Transport above 200 hPa by large-scale circulation

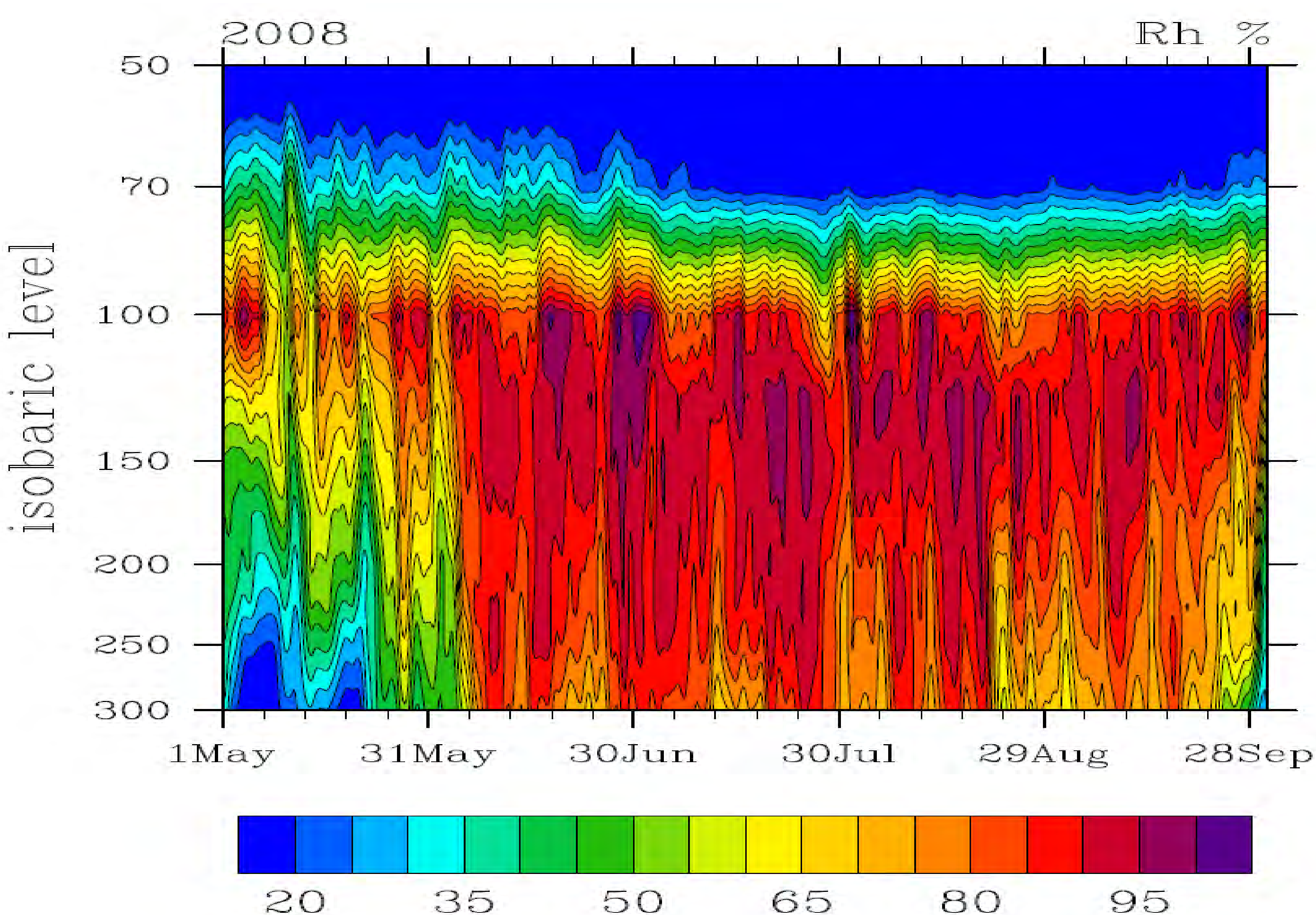
(Overshooting convection)

Convective transport

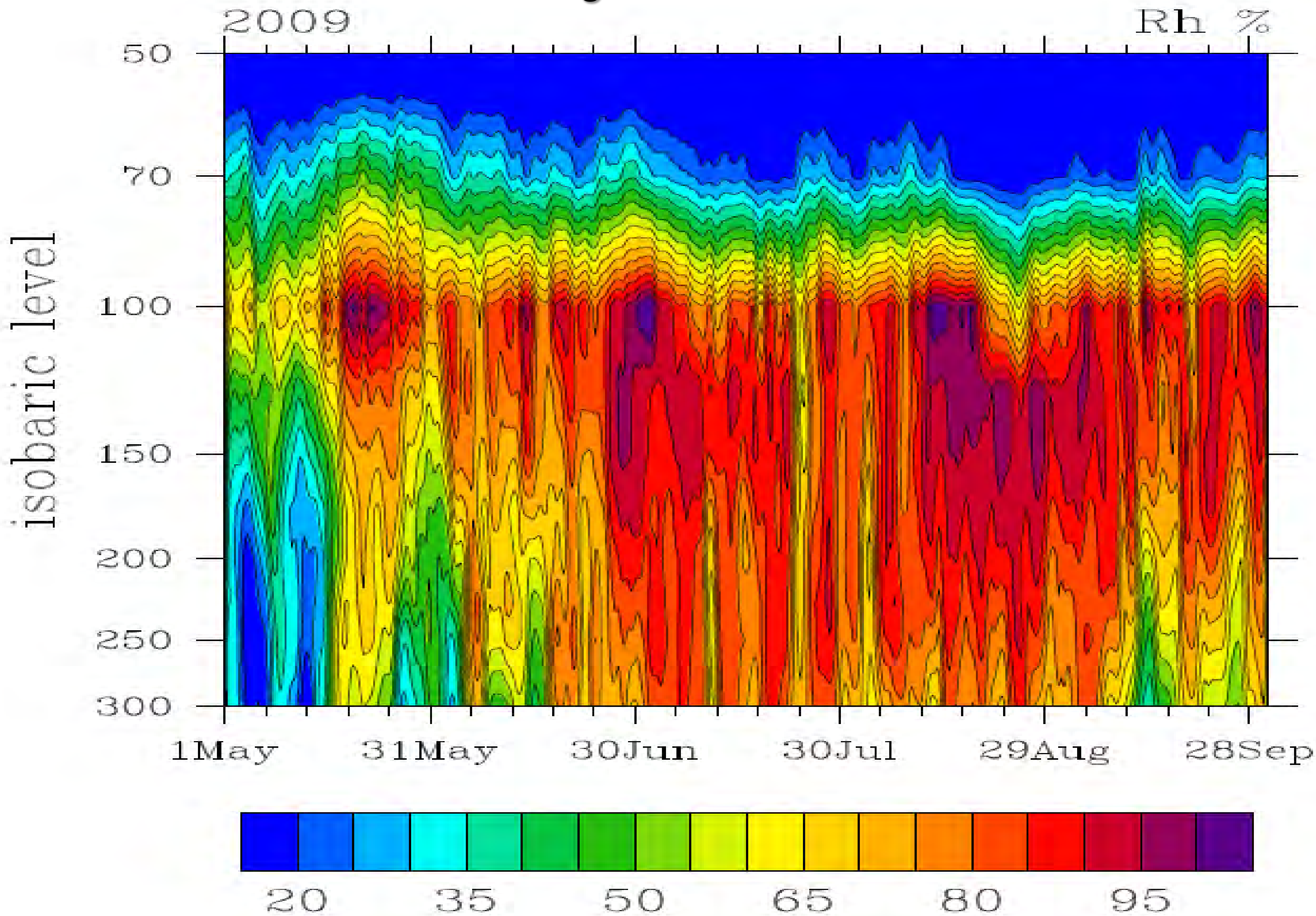
(Main outflow near 200 hPa)

Park et al, JGR, 2009

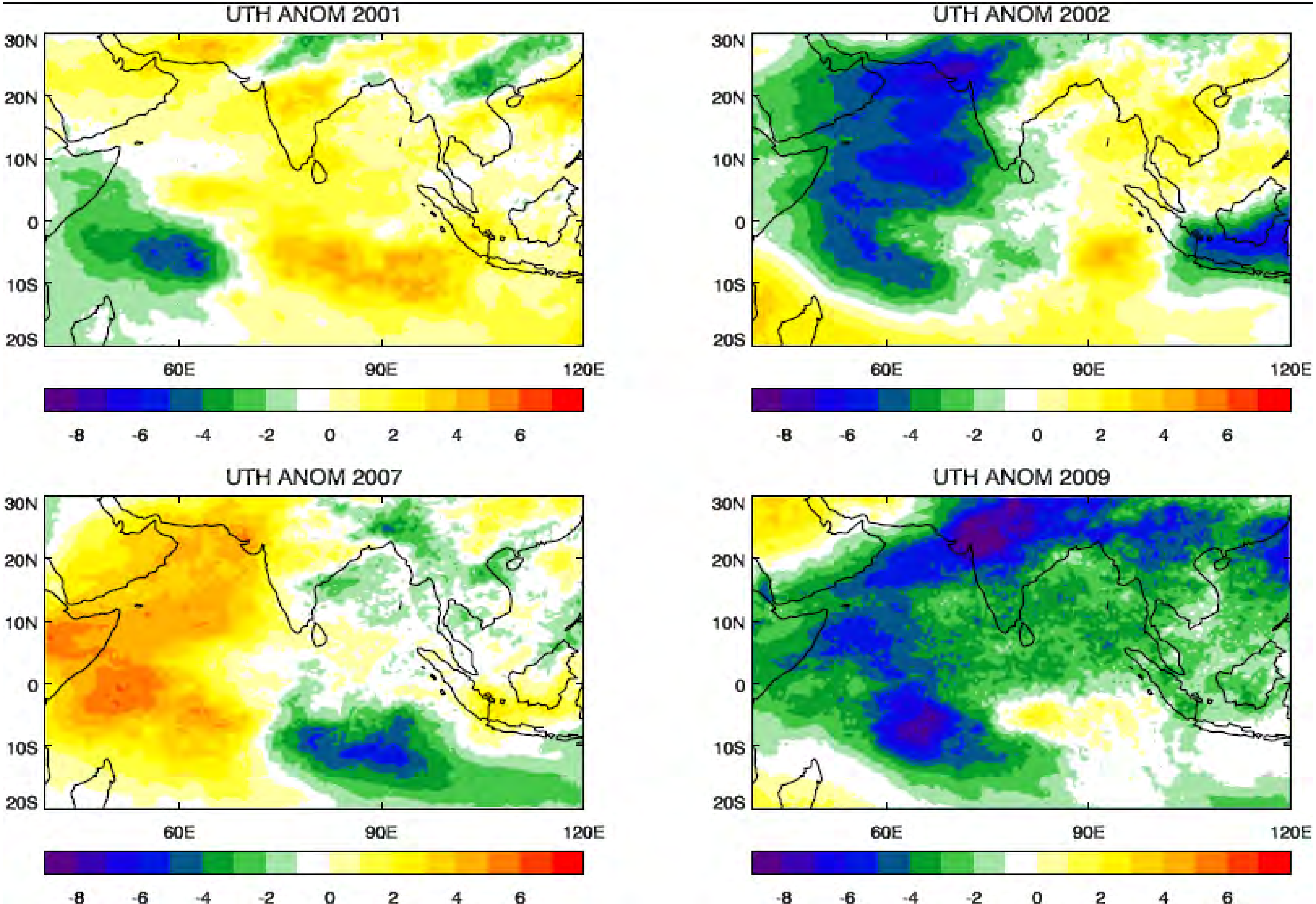
Distribution of Relative Humidity in the UTLS Region During a Normal Monsoon Year



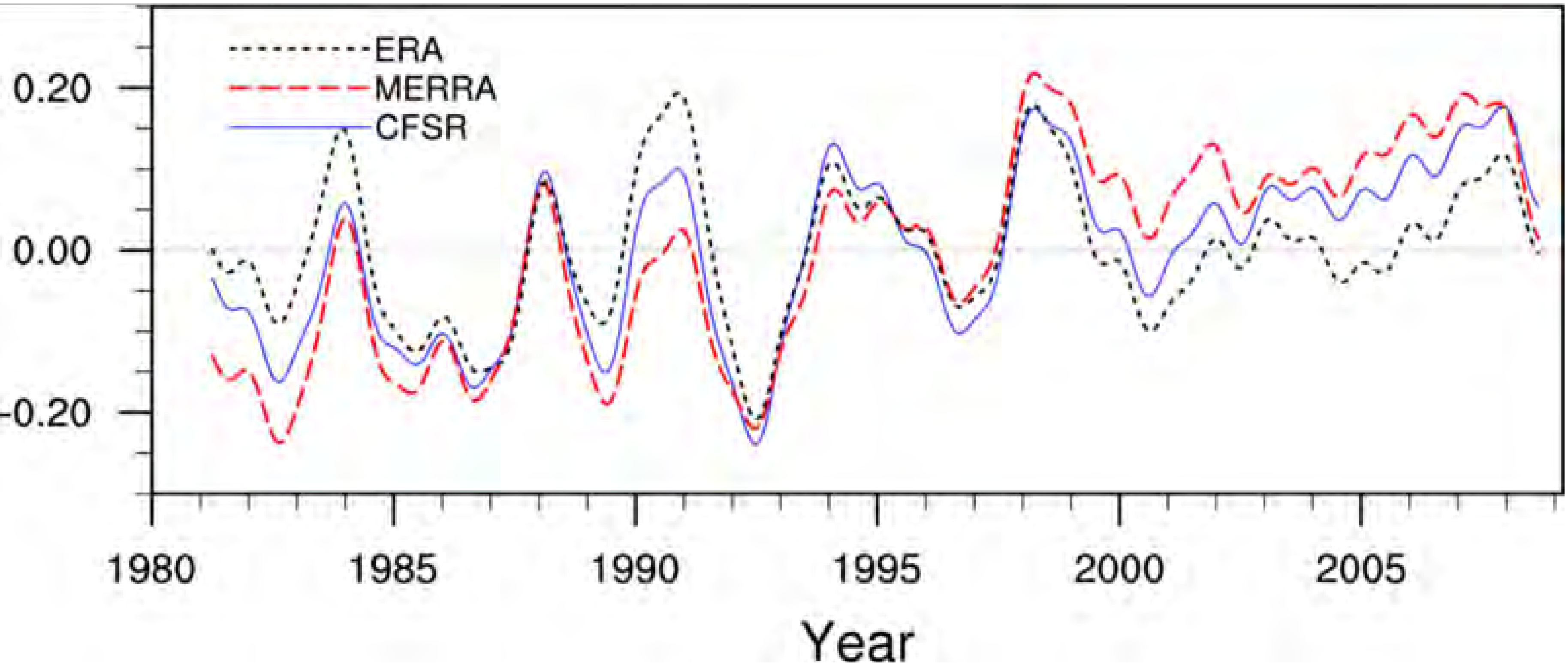
Distribution of Relative Humidity in the UTLS Region During a Weak Monsoon Year



Upper Tropospheric Humidity Anomaly During Strong and Weak Monsoon Years

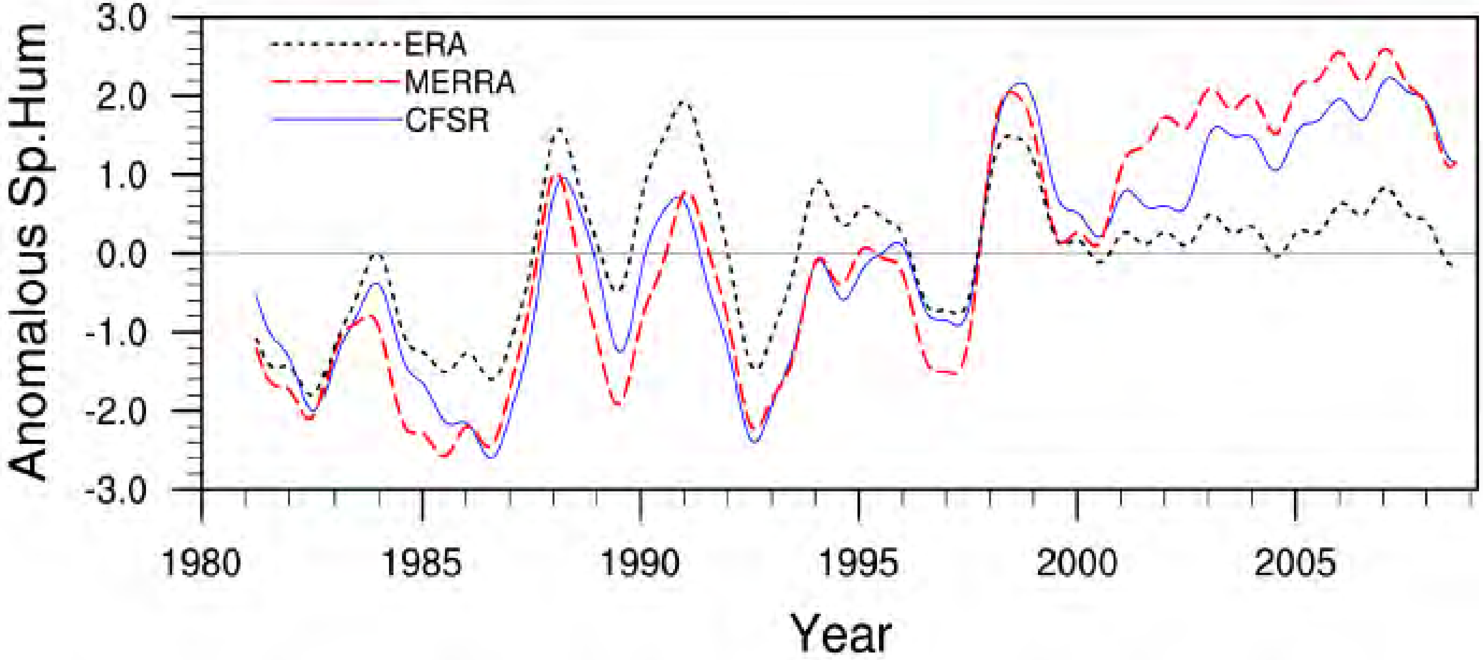


Integrated Water Vapour from Surface to 300 hPa (Lower Troposphere) over Monsoon region



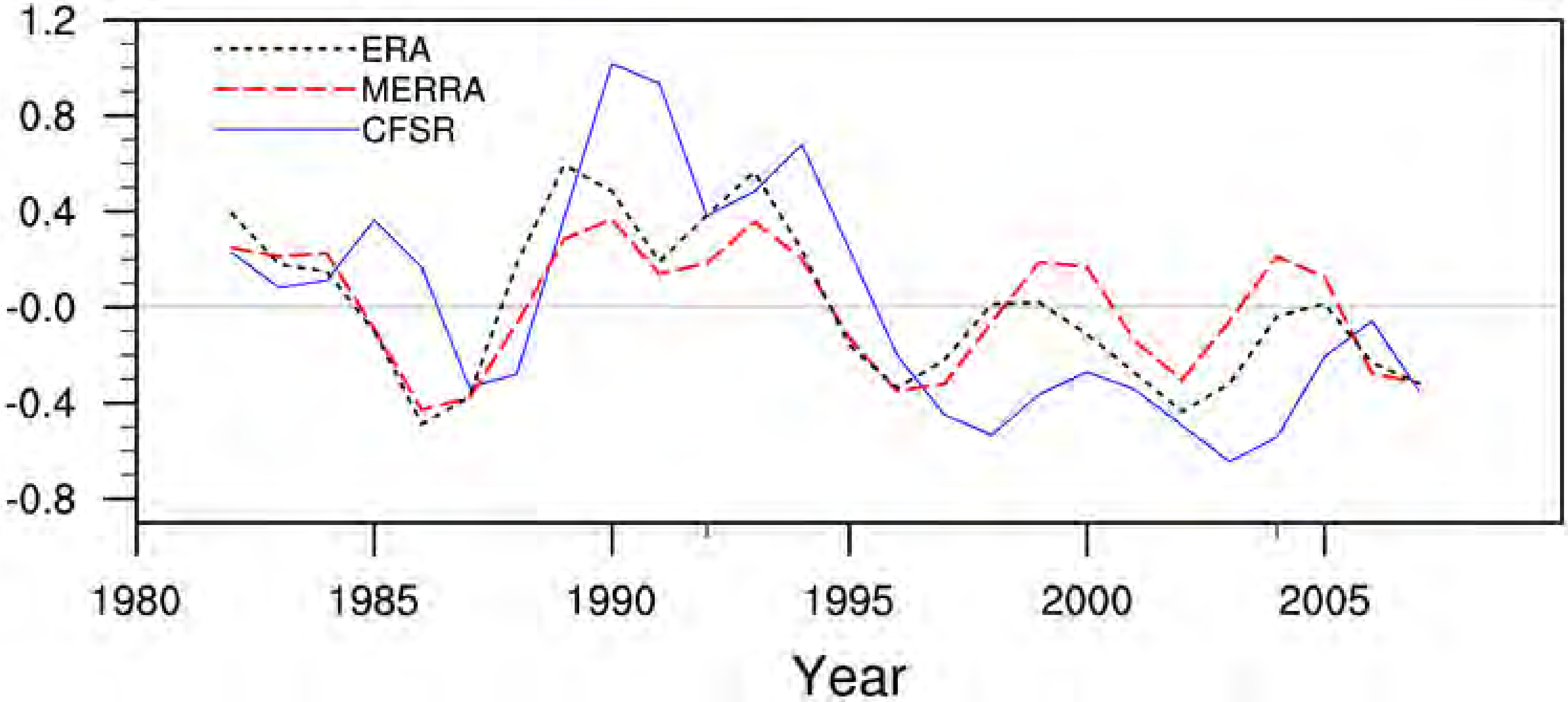
- Monthly mean specific humidity data filtered for periodicities less than two years.
- Strong interannaul variability is seen, especially ENSO influence.
- The year following strong El Nino shows increase in water vapour.
- Over the 30 year period, an increasing trend is observed in water vapour.

Layer averaged (200 -100 hPa) specific humidity during 1980-2009 averaged over an area encompassing 5-25N and 70-90E for the three reanalysis NCEP-CFSR, MERRA and ERA-Interim. A low pass filter is applied to remove periodicities less than 2 years and the mean value of each data sets are also removed.



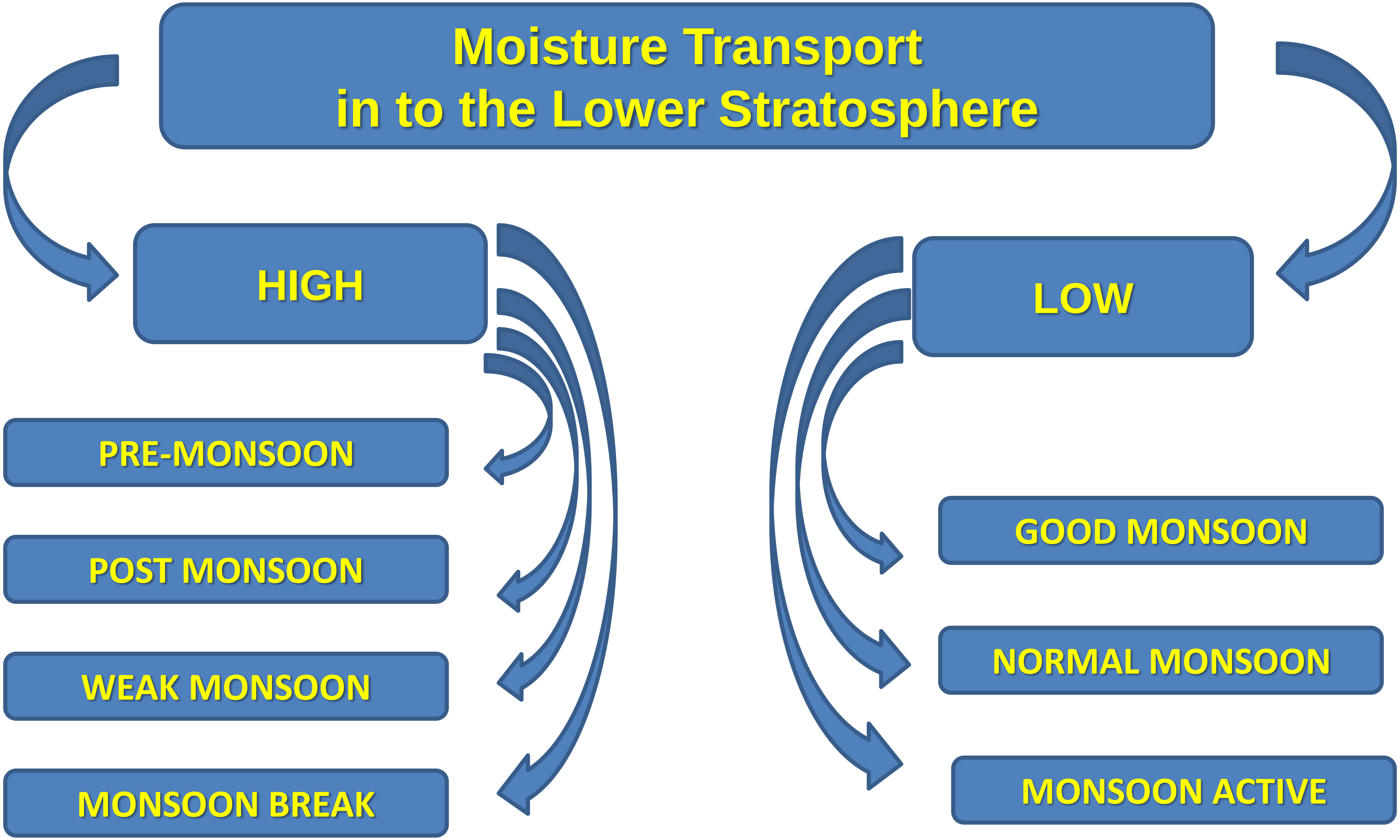
The variabilities are similar that observed with lower tropospheric specific humidity.
Good correlation with ENSO cycle. An increasing trend in specific humidity also observed

Layer mean (100 – 30 hPa) Specific Humidity Anomaly (Lower Stratosphere) over Monsoon region

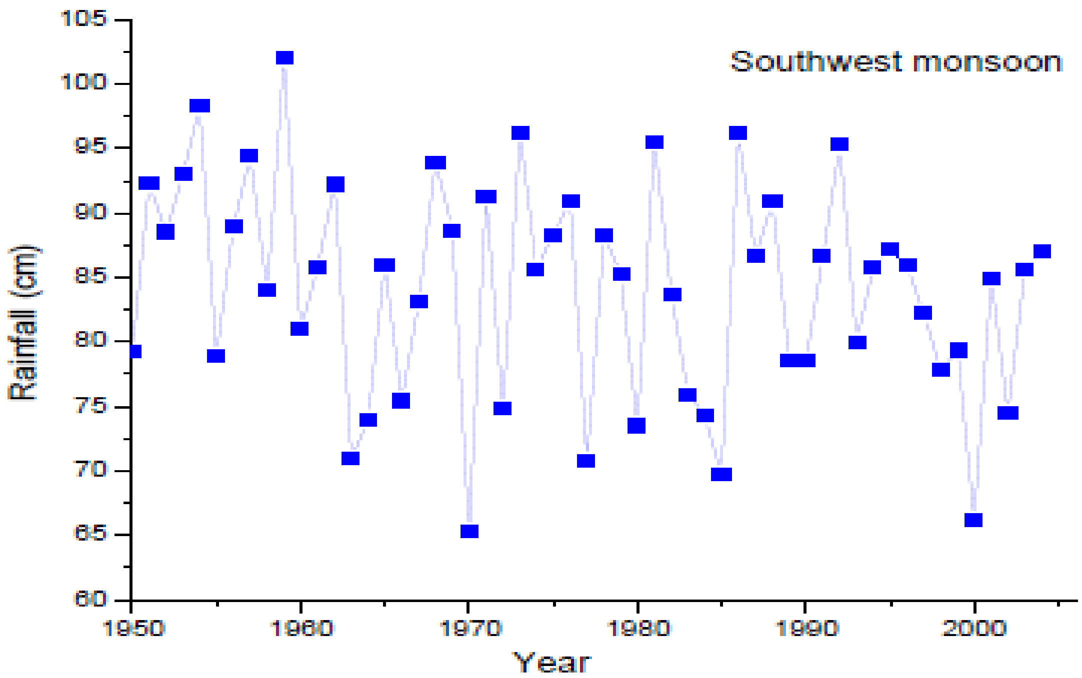


Water vapour in the Lower stratosphere is decreasing from 1990

In brief:


Moisture Transport
in to the Lower Stratosphere
HIGH
LOW
PRE-MONSOON
POST MONSOON
WEAK MONSOON
MONSOON BREAK
GOOD MONSOON
NORMAL MONSOON
MONSOON ACTIVE

Biennial Periodicity of Summer Monsoon Rainfall



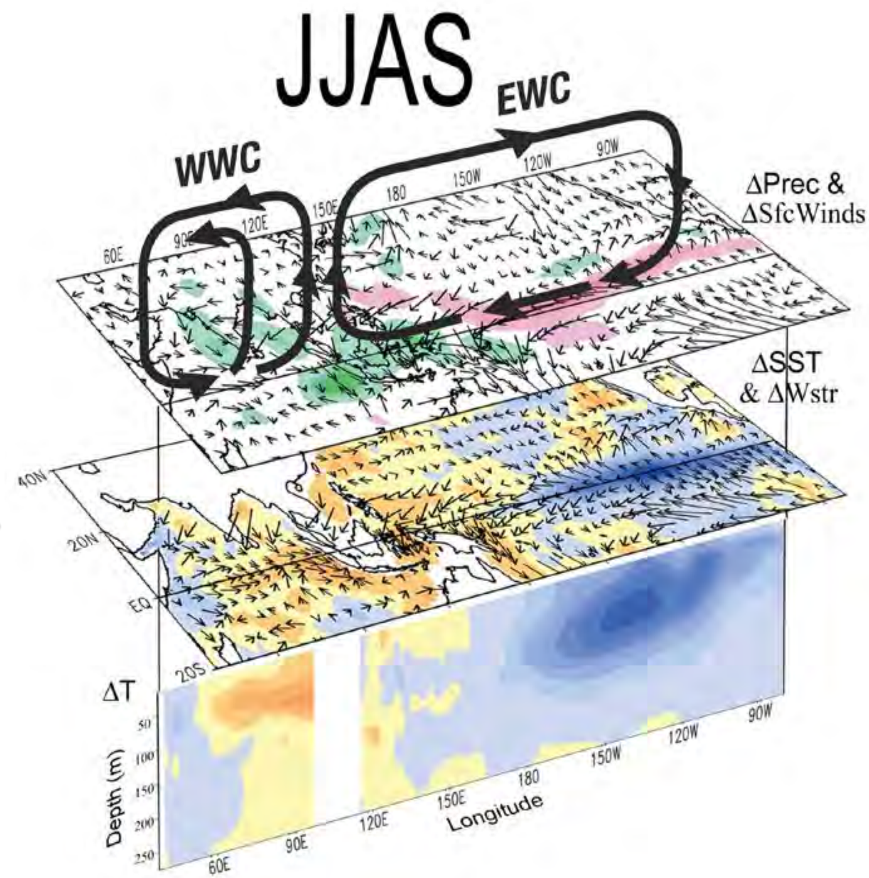
The interannual variability of monsoon rainfall over Asian region shows a biennial tendency

Strong and spatially persistent prominent peaks of 2-3 year oscillations are observed in the monsoon rainfall pattern, referred to as Tropospheric Biennial Oscillation (TBO).

The rainfall TBO appears as a part of the coupled Ocean-Atmosphere system of the monsoon region

TROPOSPHERIC BIENNIAL OSCILLATION (TBO)

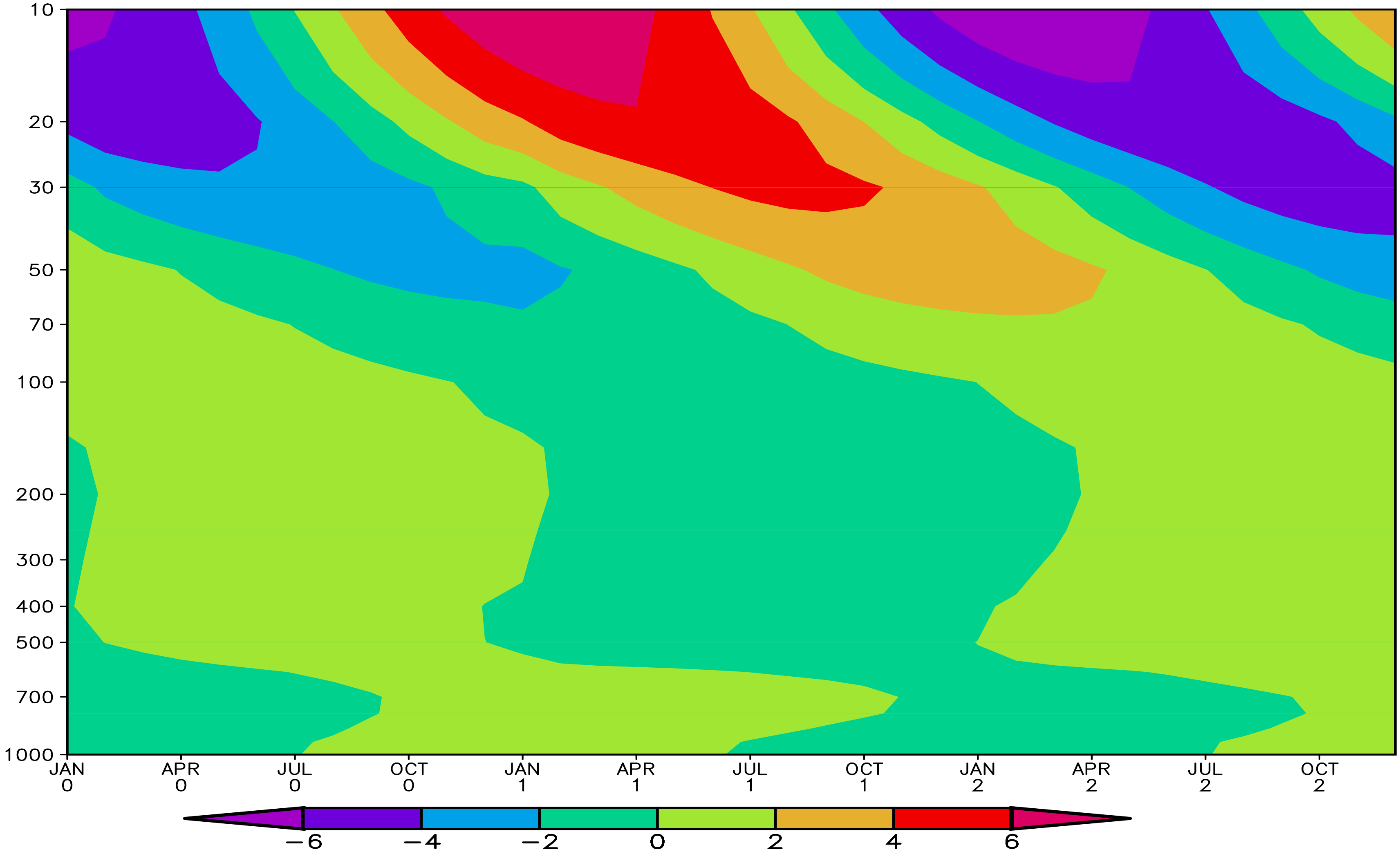
- TBO is the tendency of South Asian monsoon rainfall to 'flip-flop' in successive years
- TBO is associated with variations in the tropical atmospheric circulation and SST over the tropical oceans.
- Atmospheric convection associated with the TBO over the Asian-Australian monsoon sector exhibits a characteristic spatial structure and seasonality.



A strong TBO year monsoon season pattern

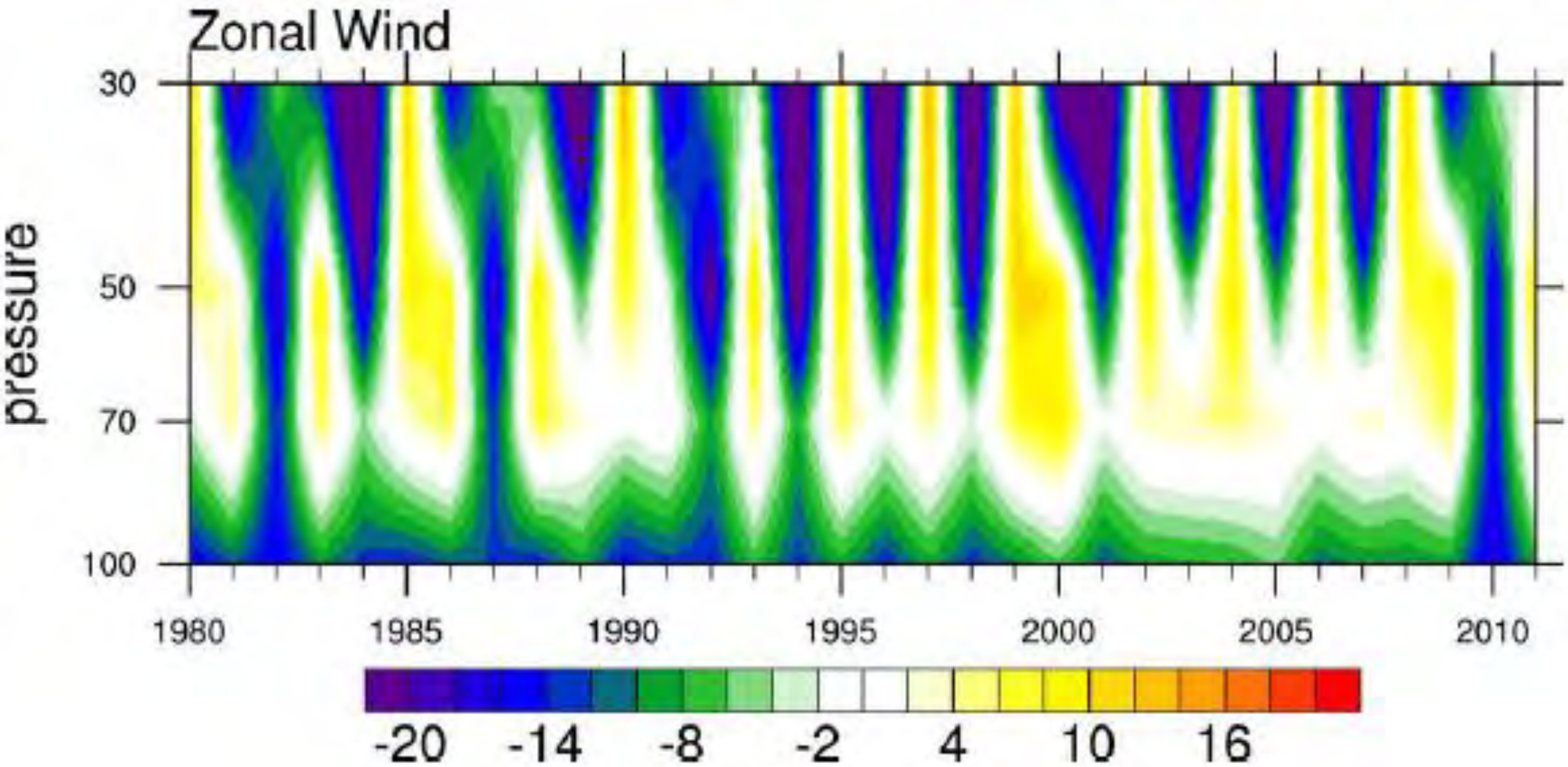
(Meehl et al, 2003)

Intrusion of Stratospheric QBO to Troposphere

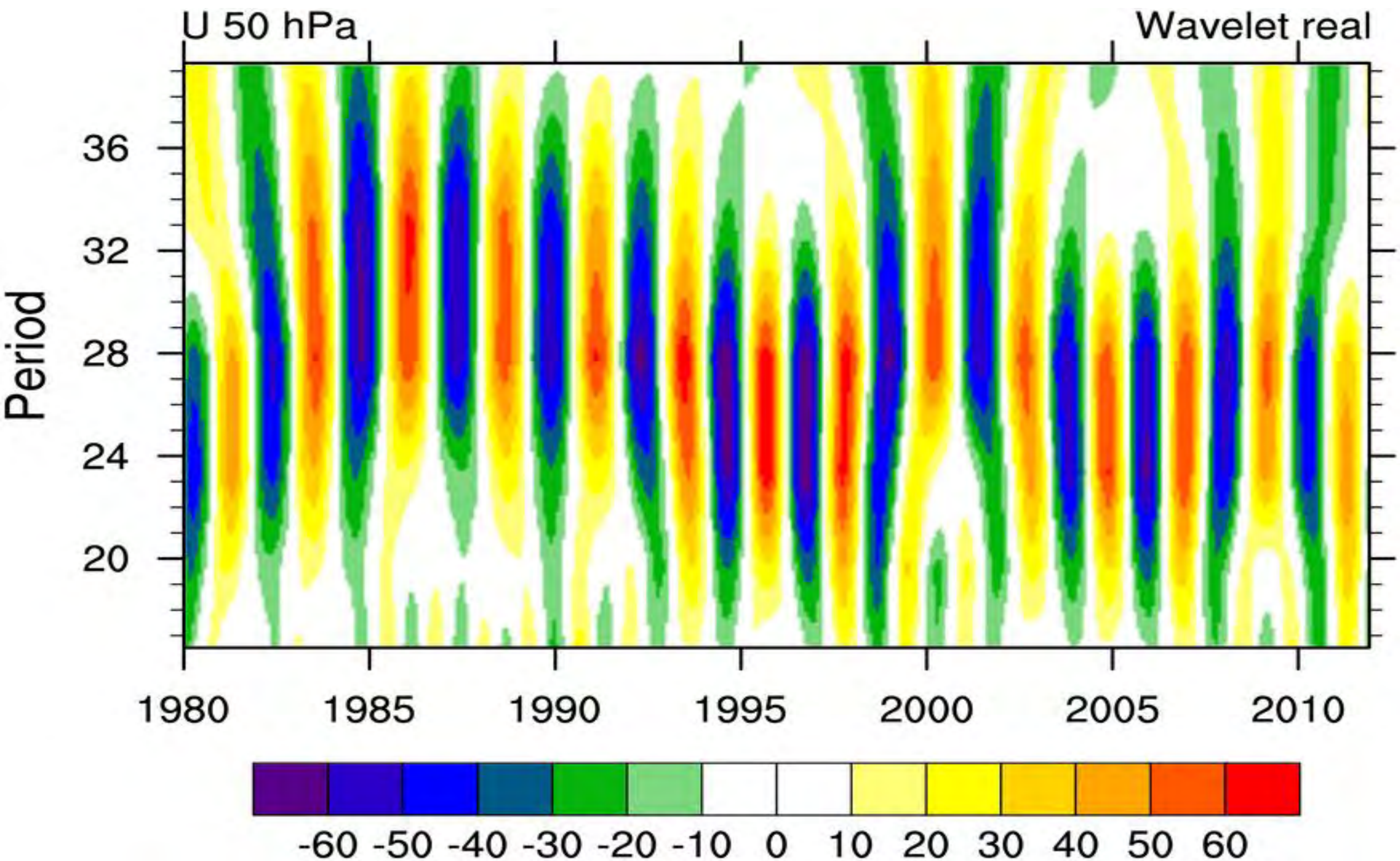


Zonal wind at TBO cycle (MONSOON)

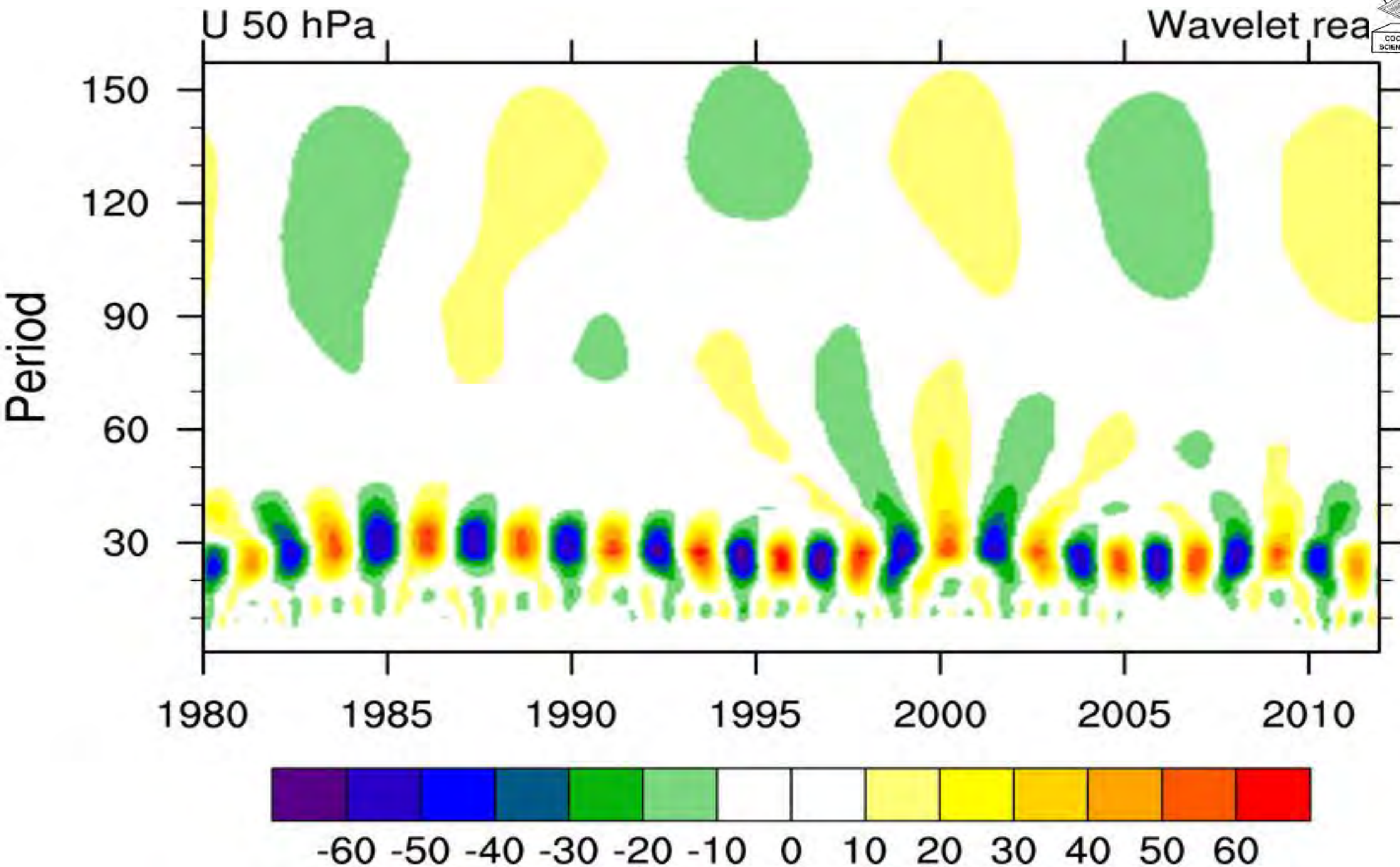
Monthly mean Zonal wind in the Lower Stratosphere



- Intrusion of westerlies in to the lower altitudes
- Weakening of easterlies after 1995
- Zonal wind at 100 hPa level shows weakening of TEJ

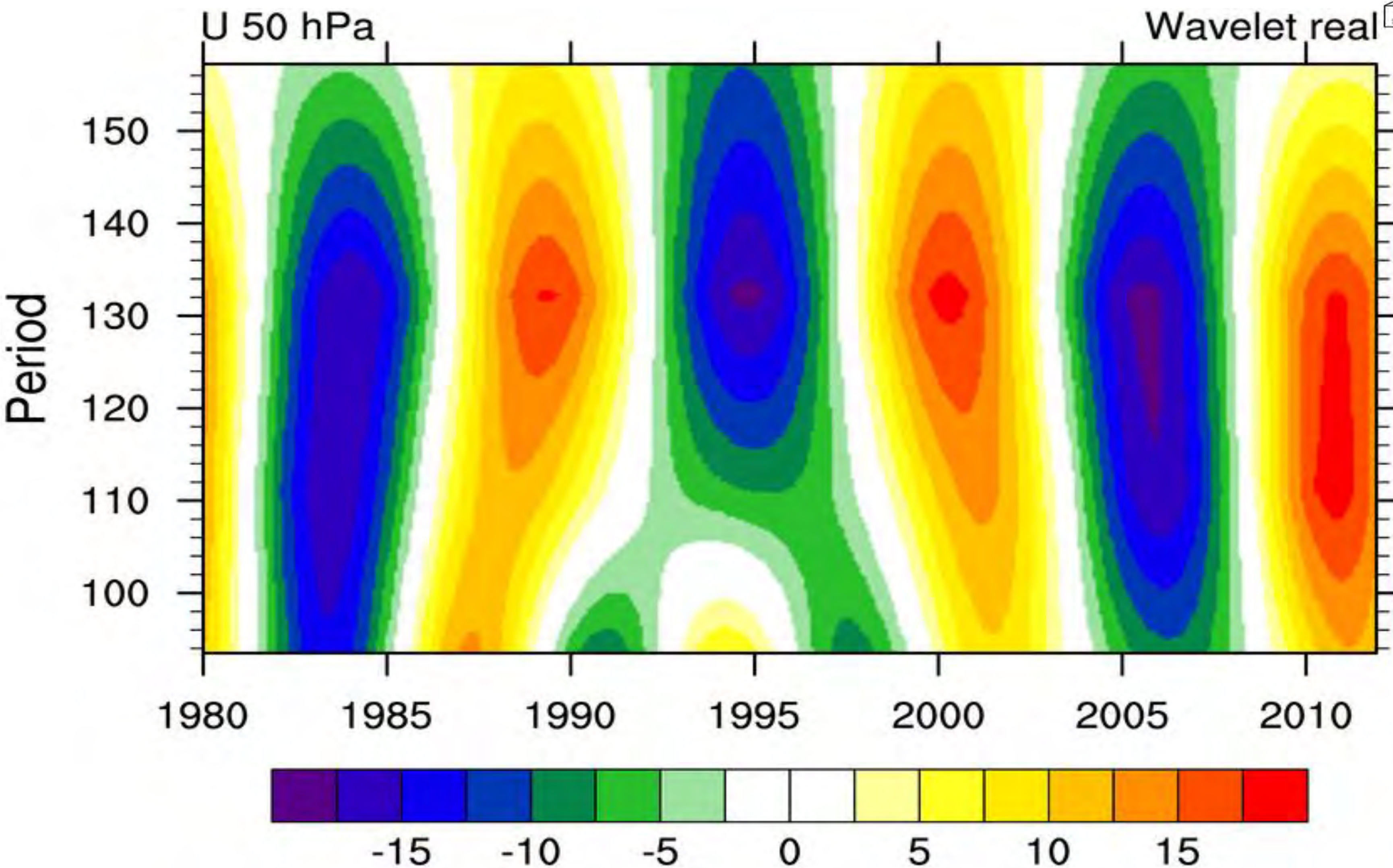


Wavelet analysis of monthly mean zonal wind averaged over Monsoon Region zooming only to QBO periodicities



Wavelet Analysis of the monthly mean zonal wind at 50 hPa is averaged over 5S-5N latitude and whole longitudes.

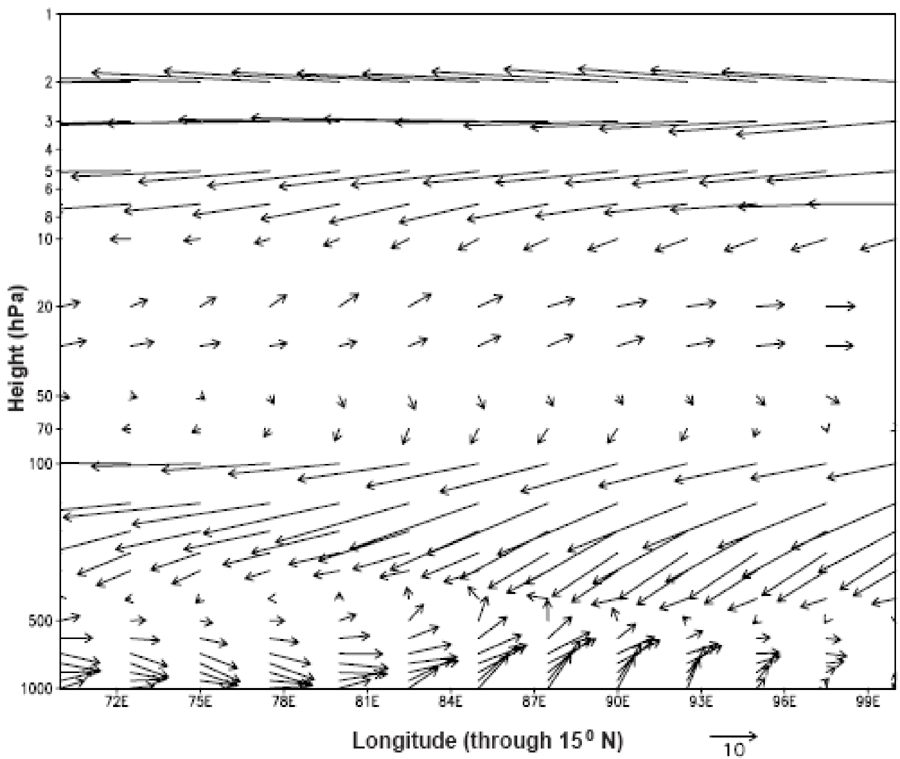
QBO (~30 months) and solar cycle (~ 130 months) signals are dominant



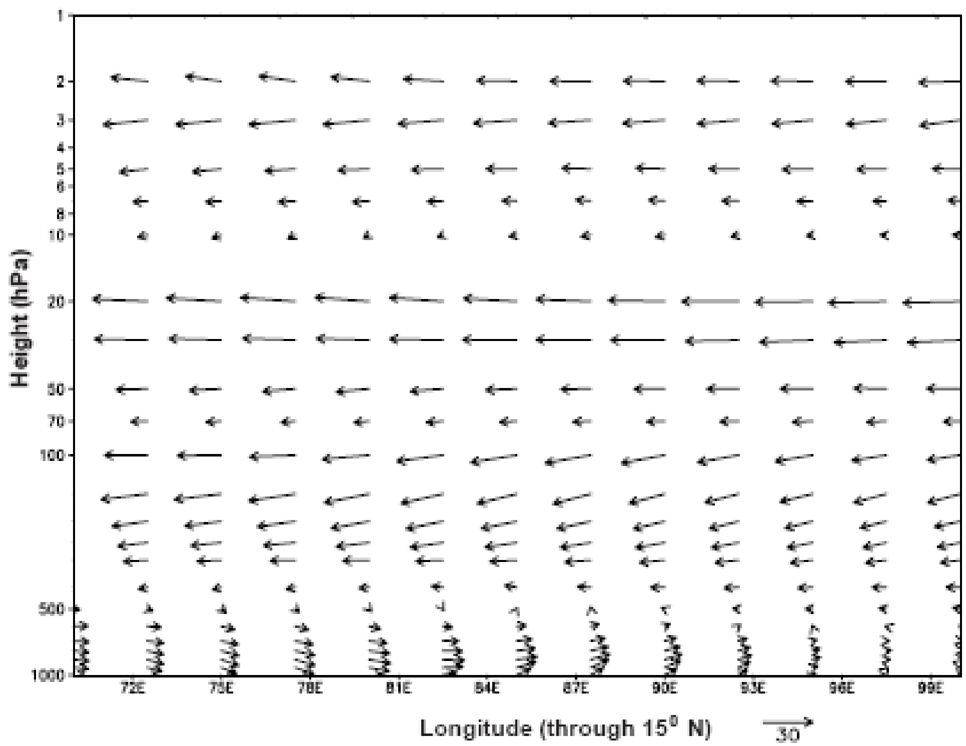
Wavelet Analysis for the monthly mean zonal wind at 50 hPa, averaged over 5S-5N latitude and whole longitudes, Zooming 11-Year Solar Cycle

Vertical Zonal Wind Pattern During QBO West and QBO East Phases Composites over Monsoon region

QBO WEST



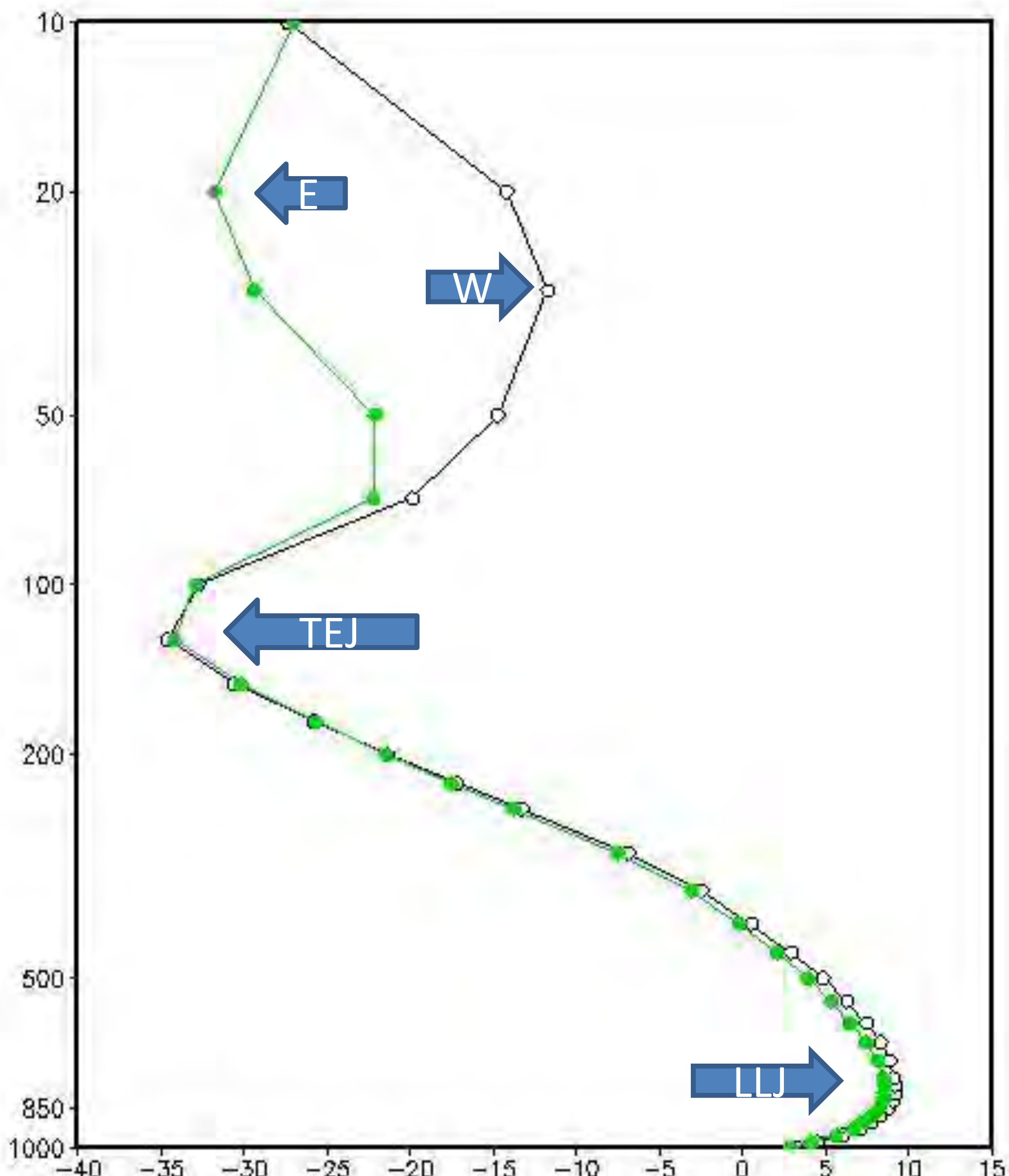
QBO EAST



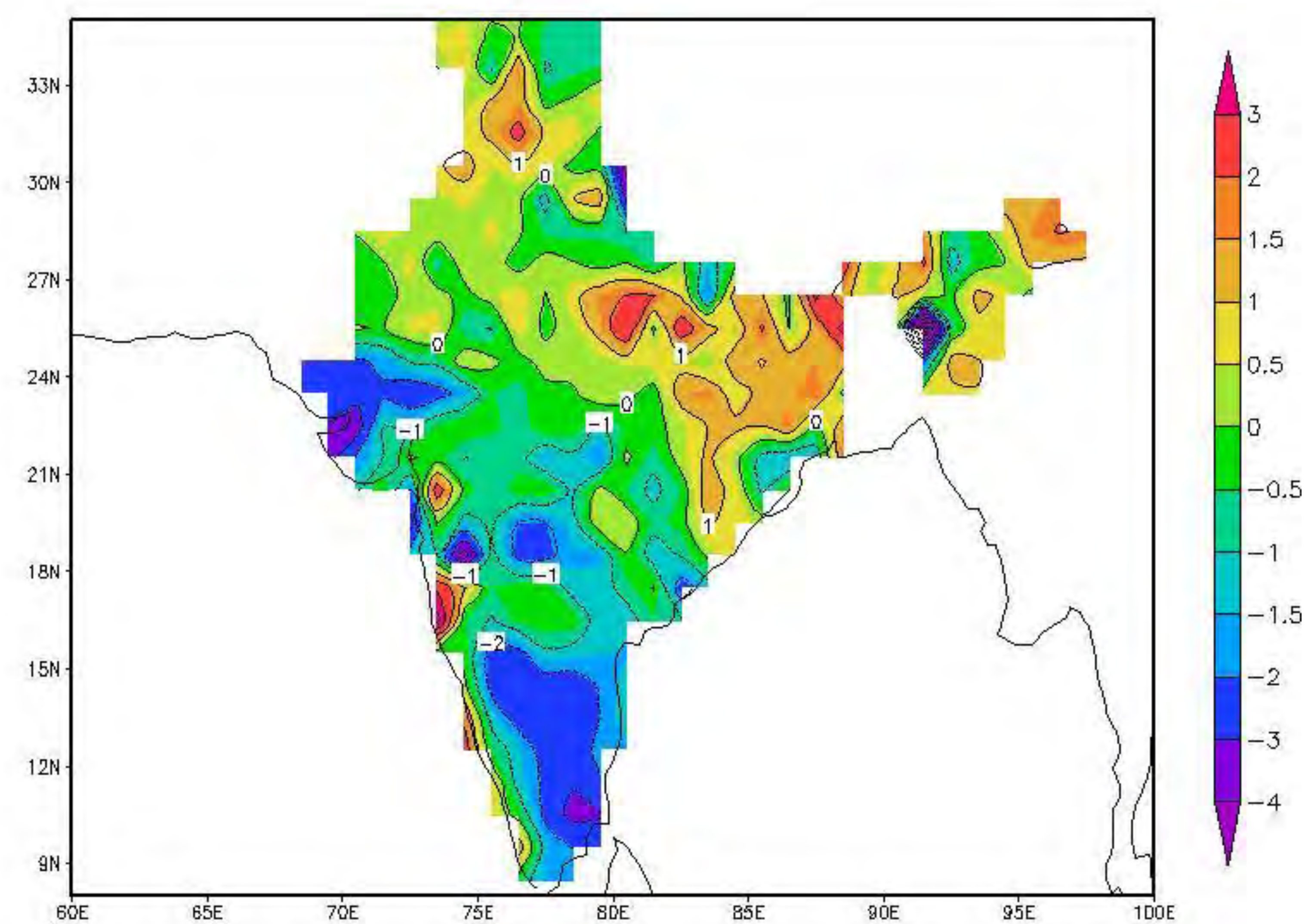
MONSOON-Active

MONSOON-Weak

Vertical Distribution of Zonal Wind During the Westerly and Easterly Phases of Stratospheric QBO



Composite Difference in rainfall between East and West Phases of Stratospheric QBO



In brief:

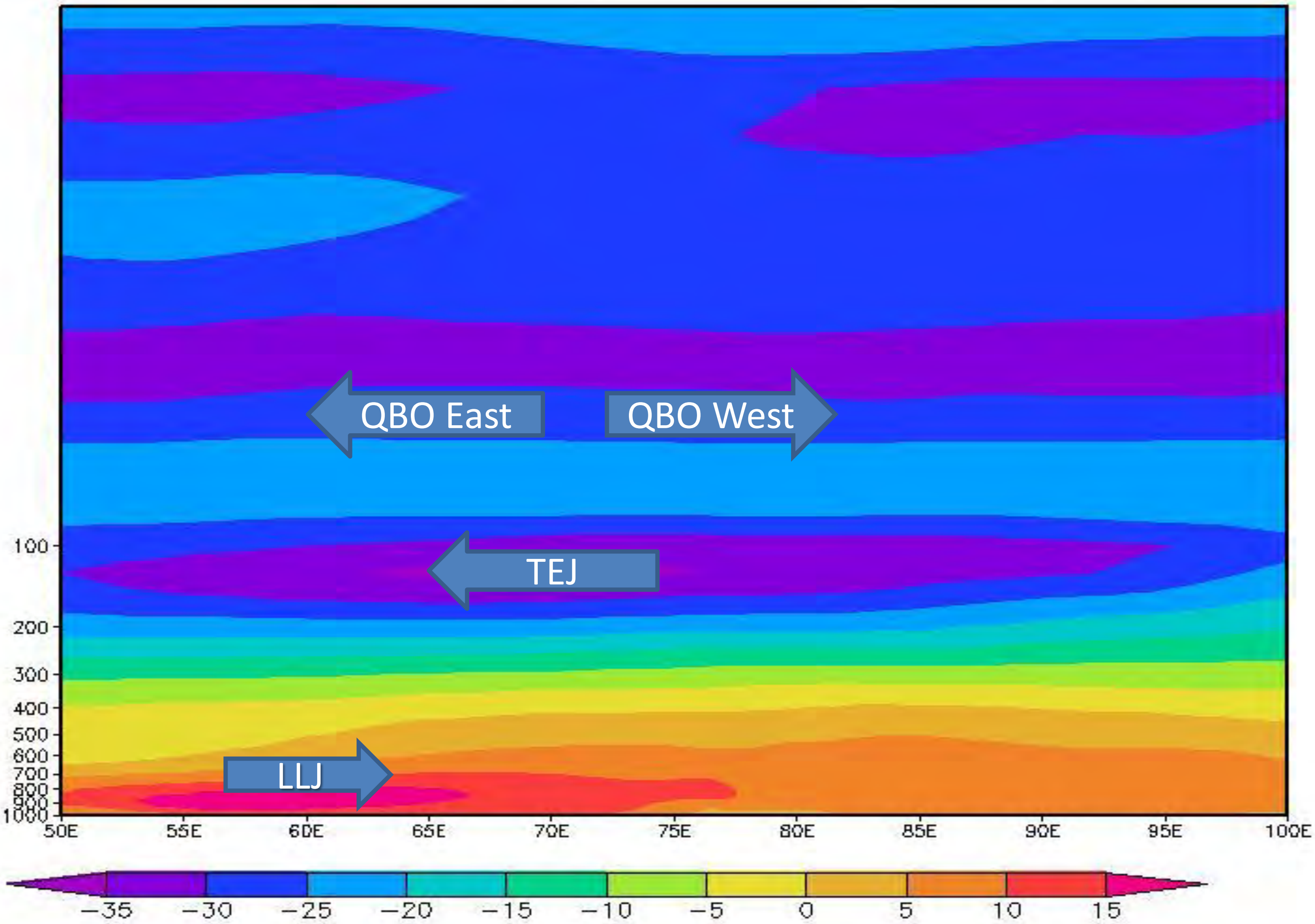
West Phase of QBO → **Enhances LLJ**

- Increases Cloud stratification
- Widespread rainfall
- Small Cloud droplets
- Longer duration of rainfall

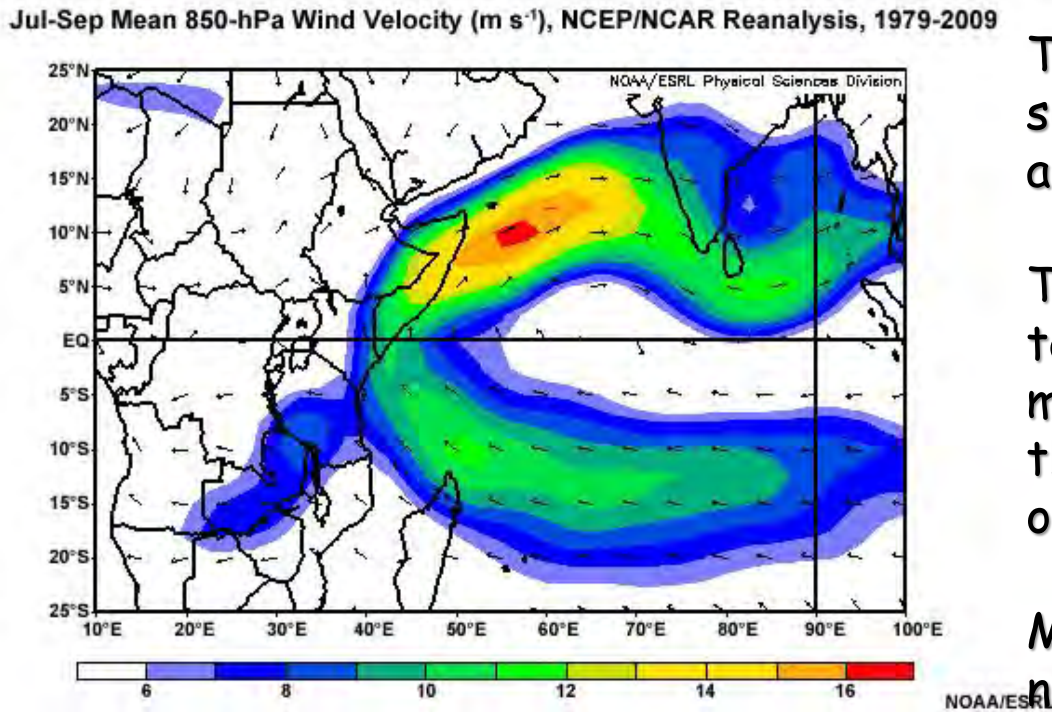
East Phase of QBO → **Weakening of LLJ**

- **Convective Activity dominates**
- **Large cloud droplets**
- **Heavy rainfall in localised regions**
- **Short spells**

Zonal Wind Distribution in the Troposphere and Stratosphere over Asian Summer Monsoon



Monsoon Low Level Jetstream



The Somali jet occurs during the summer over northern Madagascar and off the coast of Somali.

The jet is most intense from June to August with average monthly maximum speeds of 18 ms^{-1} even though daily speeds can reach the order of 50 m s^{-1}.

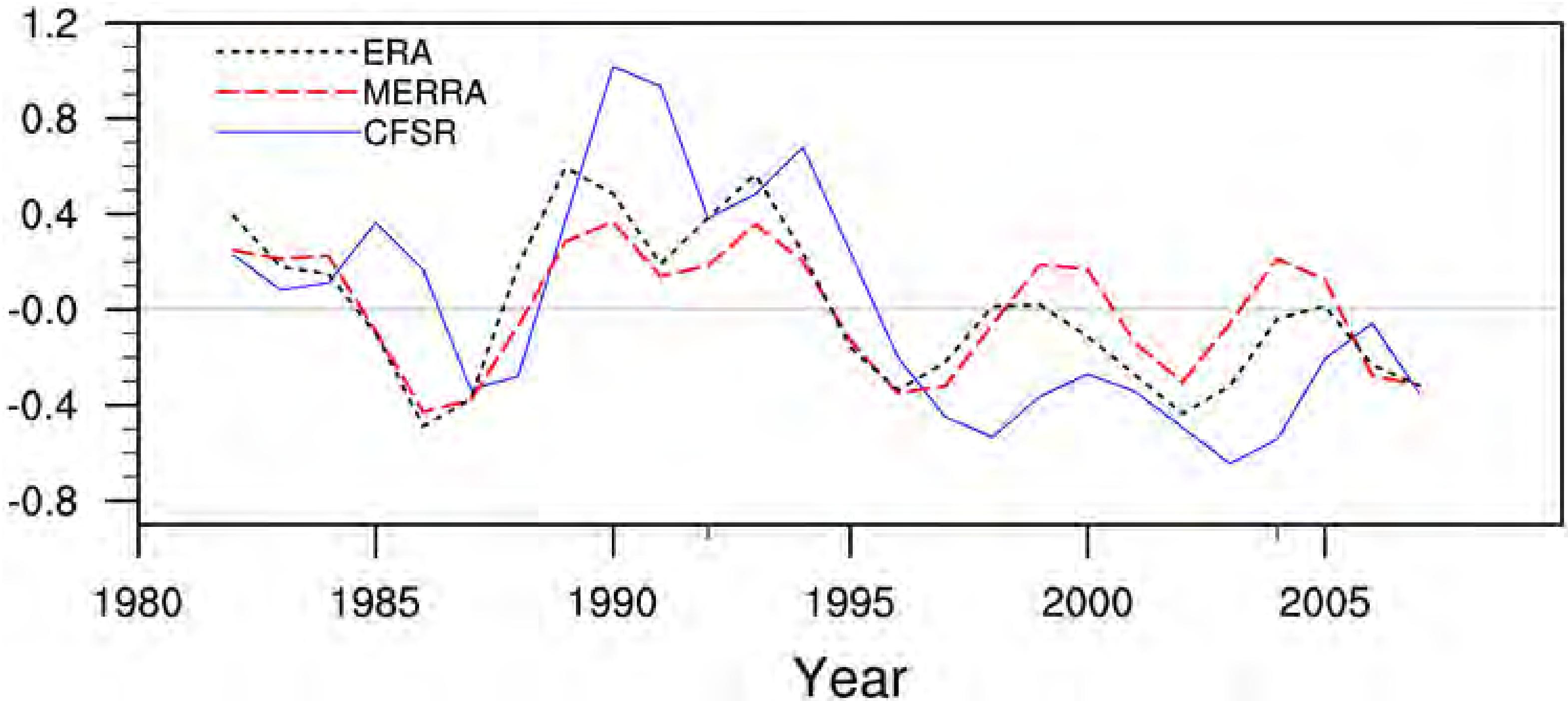
Maximum wind speed near the northern tip of Madagascar and off the Somali coast.

Key features are:

- A split in the axis of the jet over the Arabian Sea, the northern branch intersecting the west coast of India near 17°N, while the southerly branch moves eastward just south of India

- The jet remains relatively steady from June to September before moving southward to the southern Indian Ocean during the winter.

Weakening of LLJ



- Seasonal mean (JJAS) zonal wind at 850 hPa averaged over Indian region (10-20N,70-90E) for the period 1980-2009.

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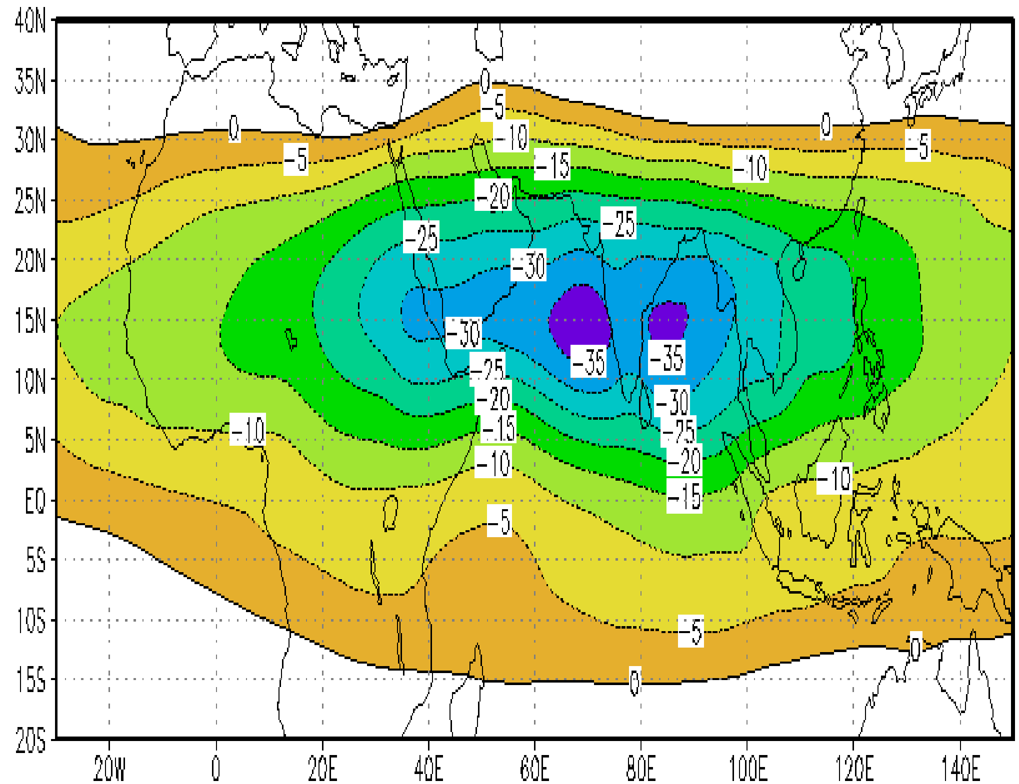
- Low pass filter is applied to remove periodicities less than three years. A decreasing wind speed is observed after 1995.

Tropical Easterly Jet (TEJ) Stream

TEJ is an inherent feature of the Asian summer monsoon.

It is a belt of strong easterly winds, which is a part of the southern periphery of an upper tropospheric anticyclone.

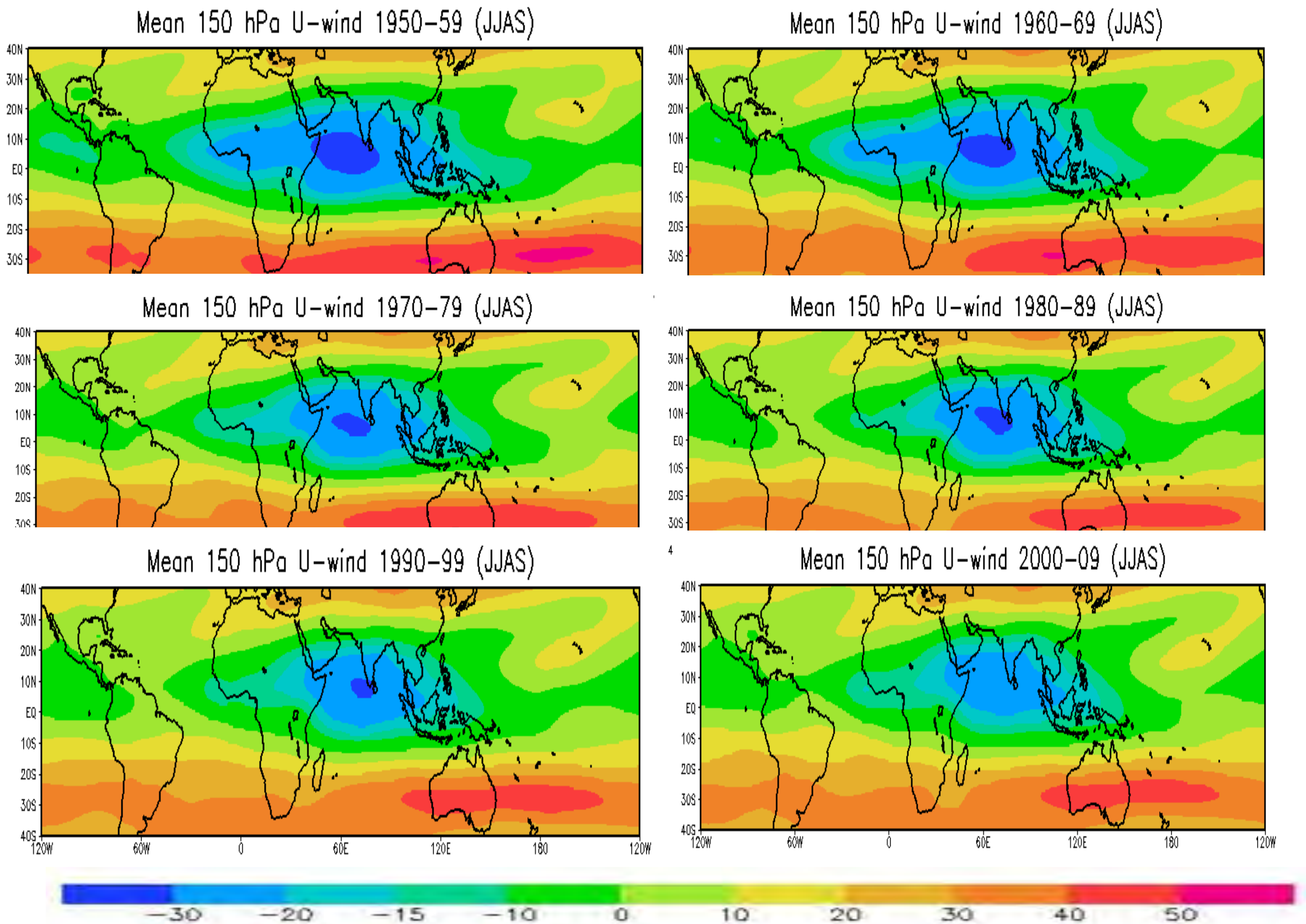
The easterly jet is observed between 200 and 100 hPa and has speeds often exceeding 100 knots.



The TEJ can be traced in the upper troposphere right up to the west coast of Africa.

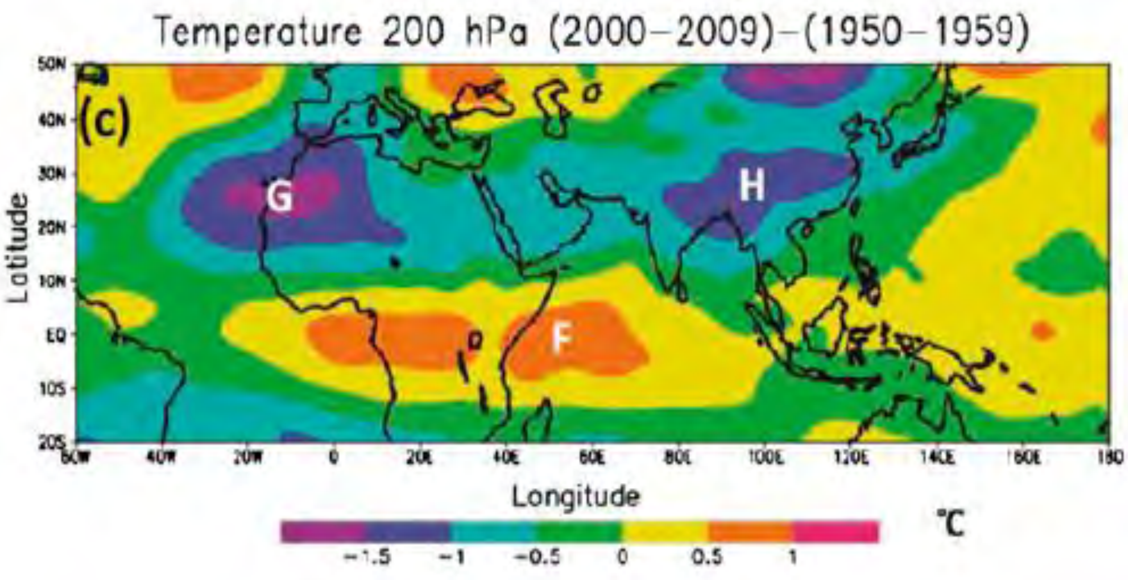
The location of the easterly jet moves north and south in phase with the northward and southward movement of the monsoon trough

WEAKENING OF TROPICAL EASTERLY JETSTREAM



Decadal Mean June-September Zonal Wind at 150 hPa *Abish et al, J. Climate, 2014*

Temperature Change at 200 hPa [(2000-’09) – (1950-’59)]



G and **H** denotes Subtropical Cooling and **F** represent Equatorial warming

Recent studies (Abish et al, 2014)reported that the TEJ in the UT region over the Asian Summer Monsoon is weakening.

The Weakening of TEJ is due to due to the decreasing trend in the UT temperature gradient over the Monsoon region.

The UT over the equatorial Indian Ocean has warmed due to enhanced deep moist convection associated with the rapid warming of the Equatorial Indian Ocean.

At the same time a cooling of in the UT region is seen over Tibetan Plateau

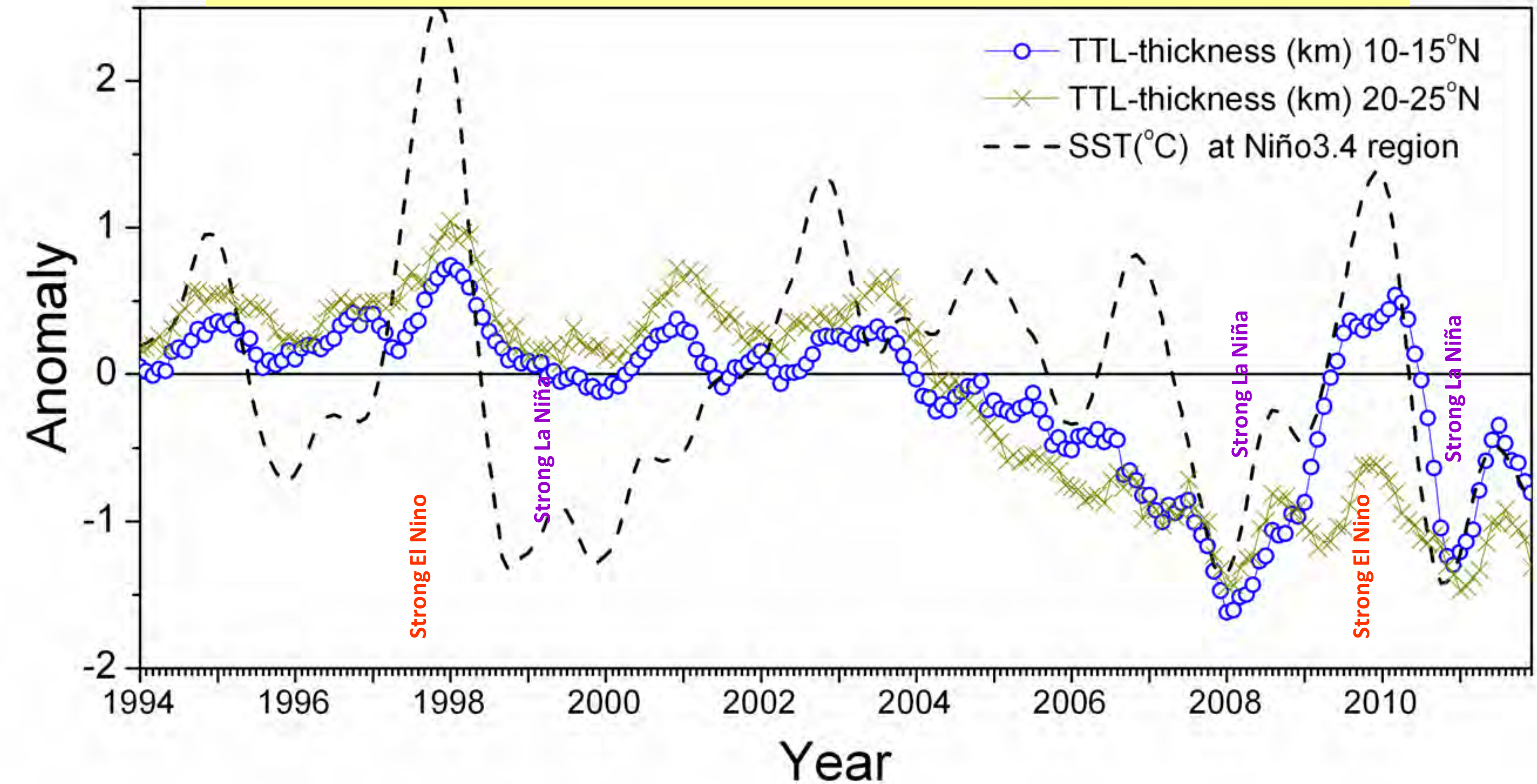
This causes a decrease in meridional temperature gradient in the UT region, which results the weakening of TEJ

(Abish et al, 2014)

Inter-annual variations: Tropical Tropopause

Tropical Tropopause: Relationship with ENSO

Anomaly of TTL-thickness and SST



TTL-thickness and SST anomalies show a good correspondence, **most notably the crests during 1997-1998 and 2009-2010 are associated with strong El Niño events** and **troughs during 2007-2008 and 2010-2011 are associated with La Niña events**

Sunilkumar et al., Climate Dynamics, 2013

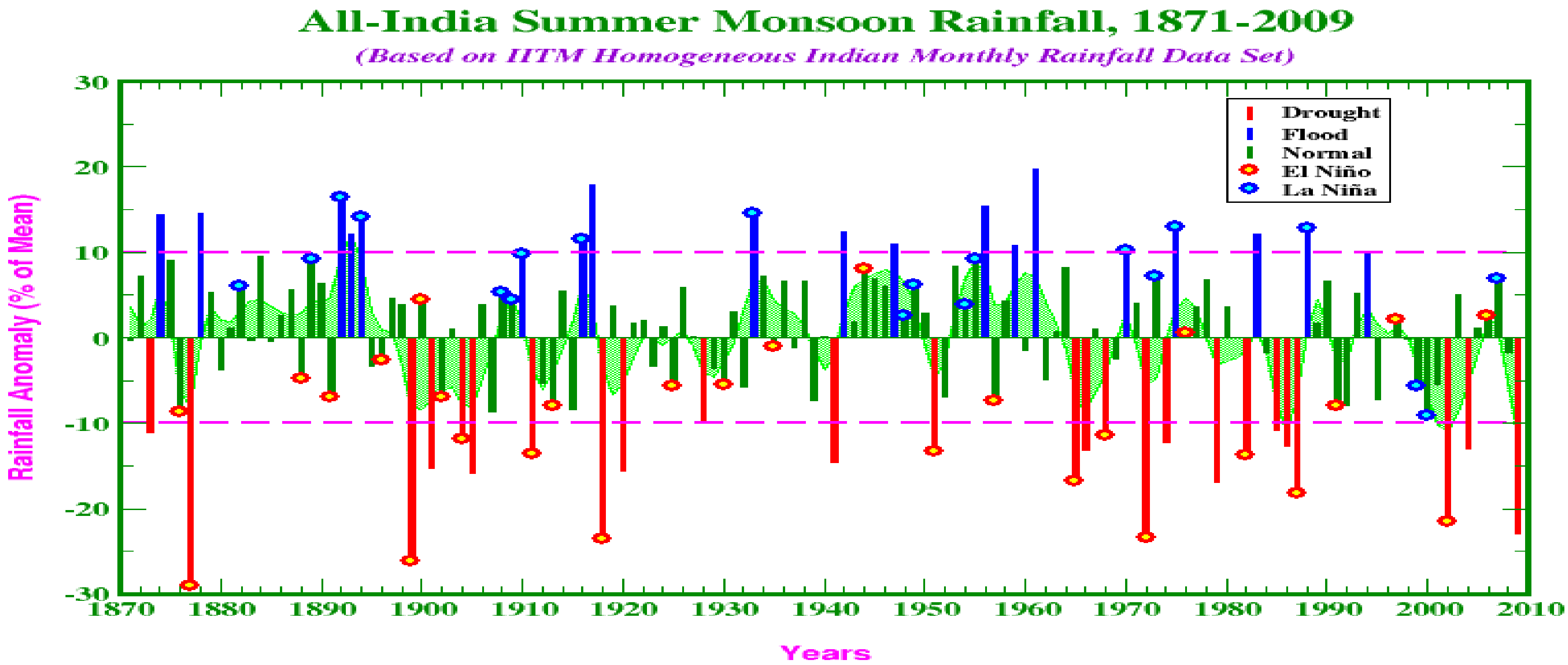
Association Between SST and Temperatures in the UTLS Region

- An earlier study (Saini et al, 2011) using chemistry-climate model demonstrates that the (SST) trends are driving the zonal asymmetry in upper tropospheric and lower stratospheric temperature trends in tropics.
- Warming SSTs in the Indian Ocean and in the warm pool region have led to enhanced moist heating in the upper troposphere that extends into the lower stratosphere.
- The anomalous circulation has led to zonal structure in the ozone and water vapor trends near the tropopause, and subsequently to less water vapor entering the stratosphere.

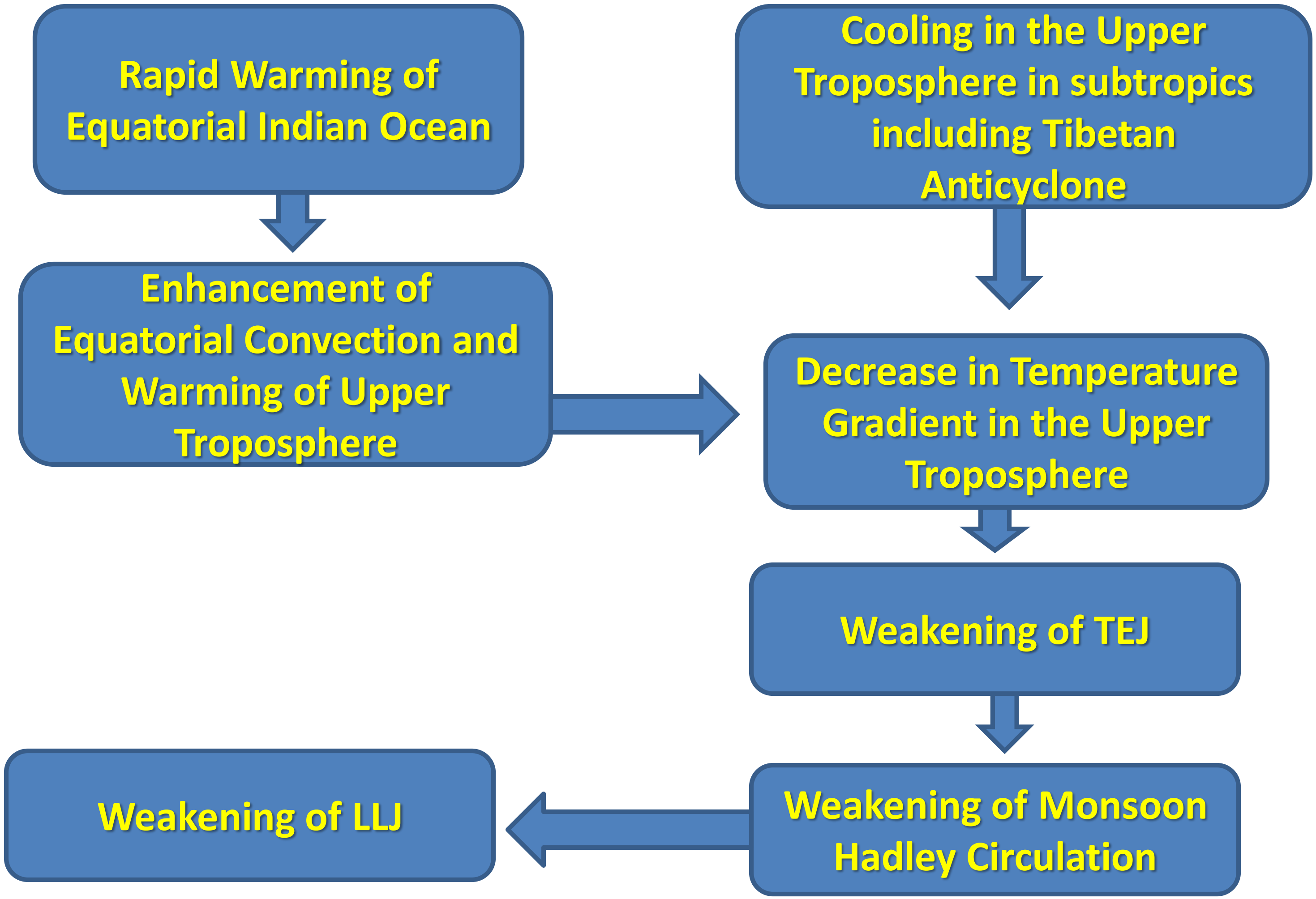
Saini et al, Journal of Climate 2011

The Indian summer monsoon rainfall averaged over the whole country is found to be stable over the last century, without any significant long-term trend, but is dominated by high interannual variability.

This variability is generally attributed to the slowly varying surface boundary forcings of sea surface temperature, soil moisture, snow cover, and the circulation features of the upper troposphere and the mid-troposphere.



Possible Mechanism



Summary

- Asian Summer Monsoon shows a source of water vapour to the lower stratosphere with large scale spatial and temporal variabilitiy.

- Stratospheric QBO seems to be modulating the monsoon circulation, by enhancing the monsoon low level jet during its westerly phase

- Due to the rapid warming of the Equatorial Indian Ocean and the Upper Tropospheric cooling in the Tibetan anticyclone region causes a decrease in the strength of Tropical Easterly Jetstream in the Upper Troposphere, causes a change in the Monsoon rainfall pattern.

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THANK YOU

- *Additional Slides*

- **Relationship water vapor transport from Indian monsoon and that over East Asia**
- Water vapor transport from Indian monsoon is inverse to that over East Asia.
- More (less) Indian monsoon water vapor transport corresponds to less (more) water vapor transport over East Asia.
- The stronger (weaker) the Indian summer monsoon water vapor transport, the weaker (stronger) the western Pacific subtropical high in its southwestern part, which leads to less (more) water vapor transport to East Asia.

Zhang Renhe, Adv. Atmos. Sci., vol.18, 2001

In Active Monsoon Rainfall season, widespread rainfall, continue for longer duration, consistent rainfall, with smaller drop sizes and coming mainly from Stratoscumulus clouds.

Westerly monsoon low level jet and the upper tropospheric TEJ circulation become intense and shifts northward over the Indian Subcontinent.

Due to the strong horizontal circulation, the convective type of clouds are transformed into stratified clouds, which provides widespread rainfall without regional torrential/ heavy rainfall events.

During the westerly phases of QBO, the LLJ become enhanced, which provide widespread rainfall.

- In weak monsoon years, rainfall is highly localised, short duration, heavy rainfall for short spells, with large raindrops, mainly from convective type of clouds.

- During this period, the LLJ in the lower troposphere and TEJ in the upper troposphere becomes weaker and shifts southward.

- As a result, high surface temperature with larger moisture content will generates intense convective thunder clouds, which penetrates into the lower stratosphere.

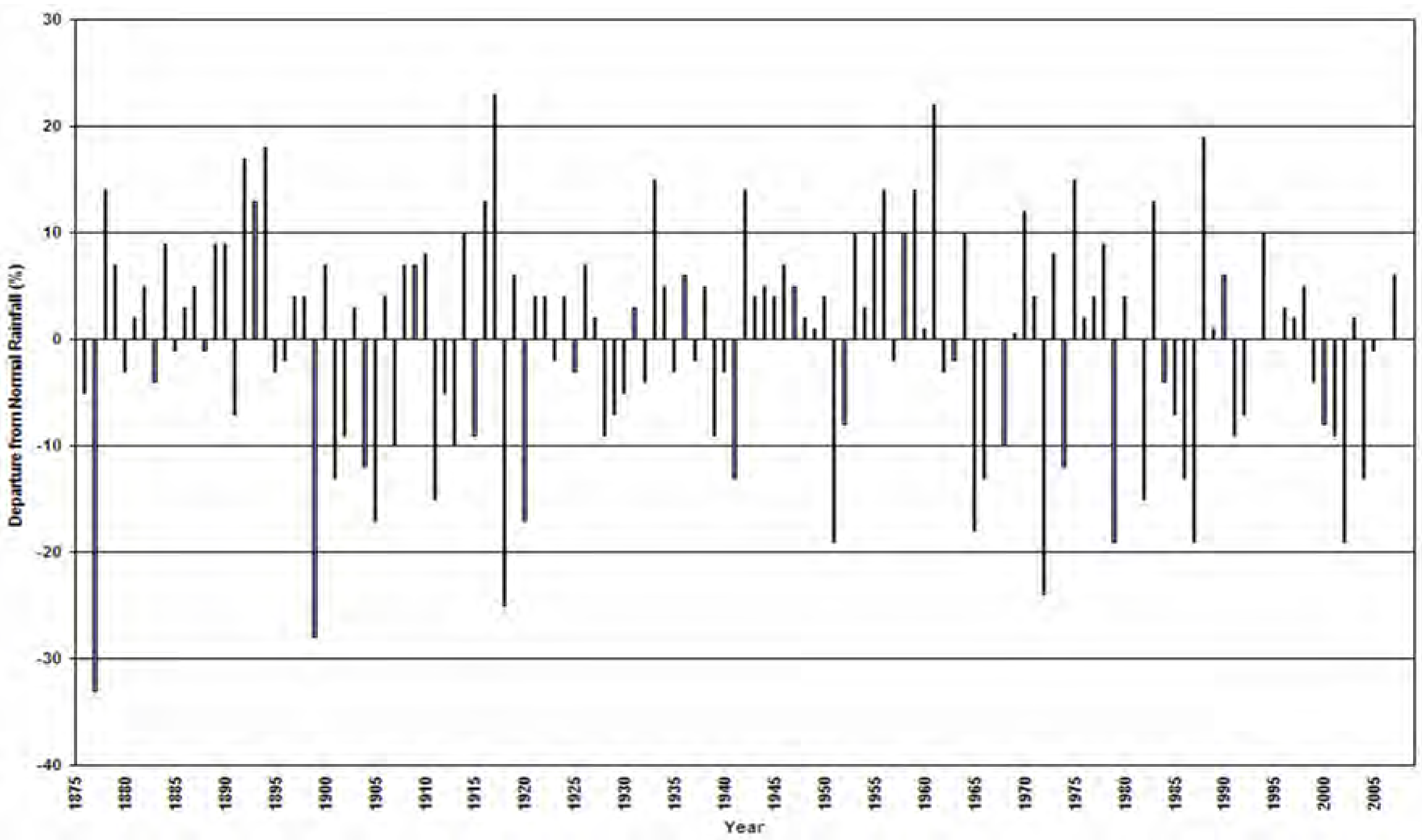
In the lower stratosphere, RH is seen to be more in the months of May & June, the period before the monsoon sets fully over India. Higher concentratio of RH can been in the first two months, and shows a gradul decrease in the remaining years.

In stratospheric levels, a regular periodicity of RH changes can be seen.

RH in certain periods show larger values in the upper stratosphere for a short period, which repeats nearly 35--40 days. This phenomena can be verified with the 30-40 day oscillations in the lower troposphere.

In some years, we can se see that lower stratospheric water vaour decreases. Abrupt decrease in RH is visible in some years.

All-India monsoon rainfall has not shown any increasing or decreasing trend so far

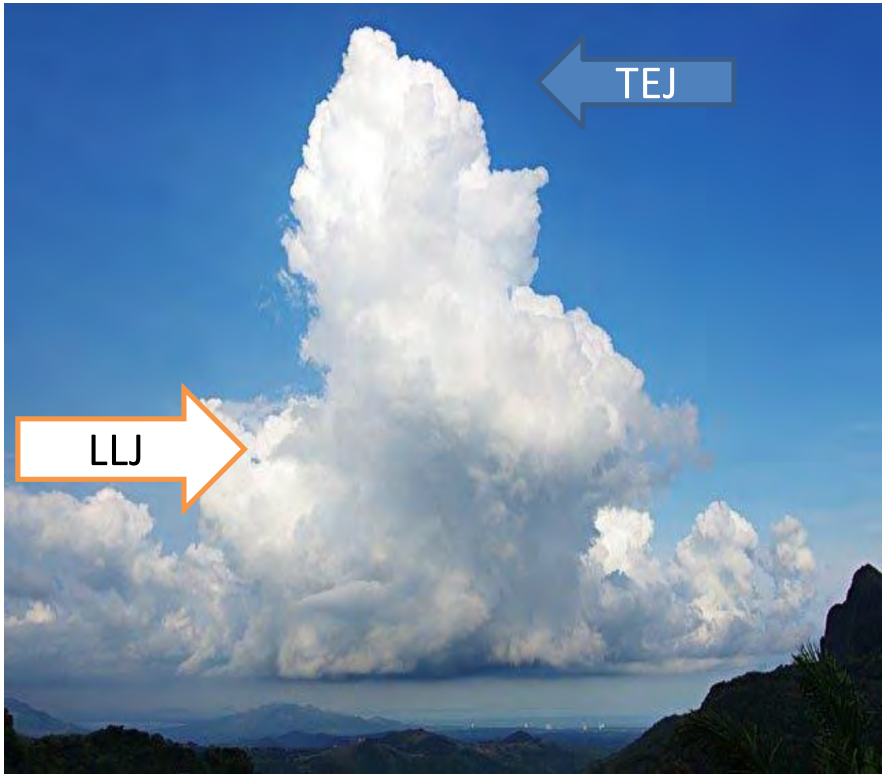


FLOOD YEARS: During the period 1871-2009, there were 19 major flood years, defined as years with AISMR in excess of one standard deviation above the mean (i.e., anomaly exceeding +10%; blue bars above):
1874, 1878, 1892, 1893, 1894, 1910, 1916, 1917, 1933, 1942, 1947, 1956, 1959, 1961, 1970, 1975, 1983, 1988, 1994.

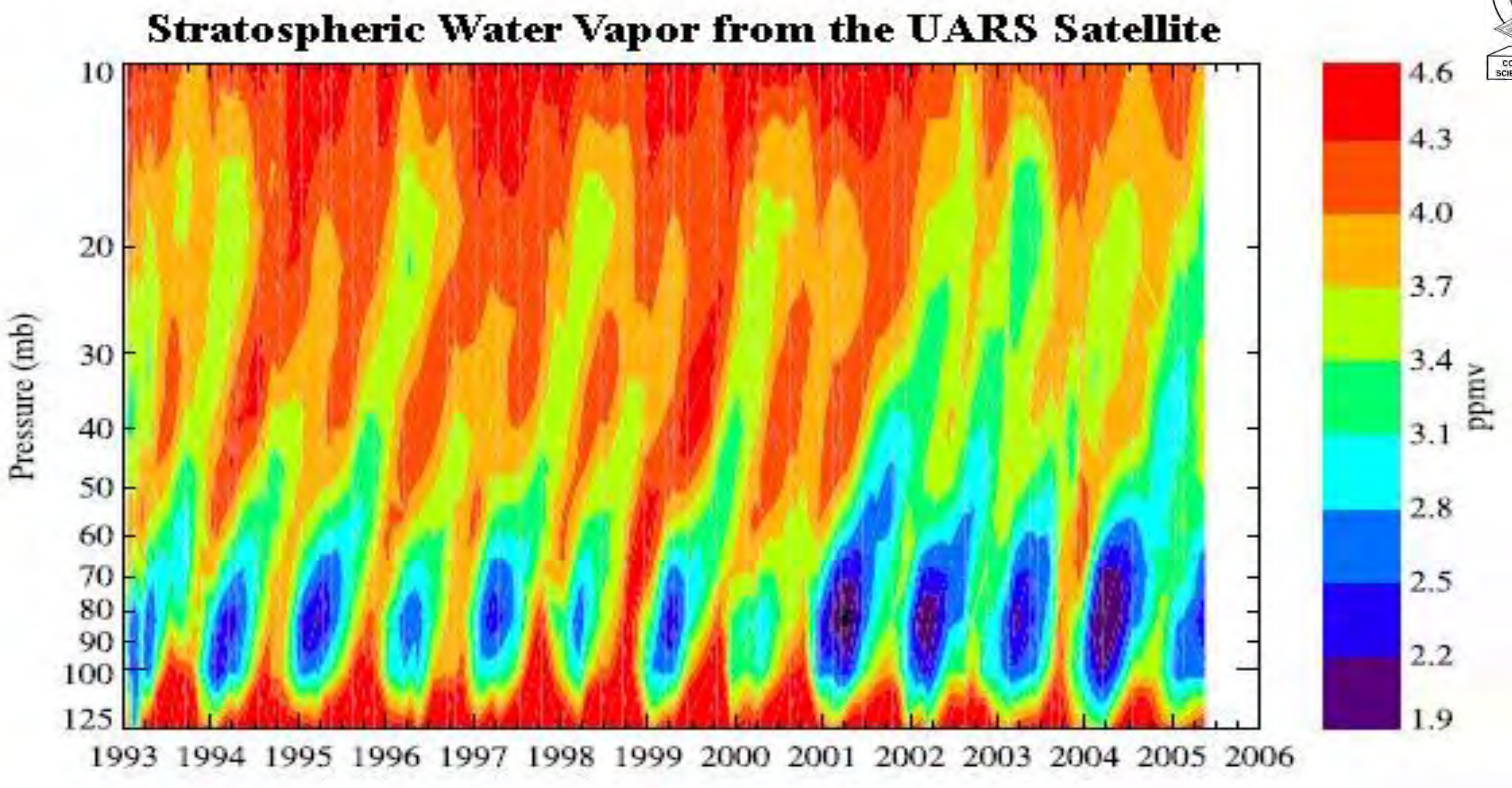
DROUGHT YEARS: During the period 1871-2009, there were 24 major drought years, defined as years with AISMR less than one standard deviation below the mean (i.e., anomaly below -10%; red bars above):
1873, 1877, 1899, 1901, 1904, 1905, 1911, 1918, 1920, 1941, 1951, 1965, 1966, 1968, 1972, 1974, 1979, 1982, 1985, 1986, 1987, 2002, 2004, 2009.

It is interesting to note that there have been alternating periods extending to 3-4 decades with less and more frequent weak monsoons over India. For example, the 44-year period 1921-64 witnessed just three drought years; during such epochs, the monsoon was found to be less correlated with the ENSO. During the other periods like that of 1965-87 which had as many as 10 drought years out of 23, the monsoon was found to be strongly linked to the ENSO (Parthasarathy et al., 1991).

How the LLJ and TEJ Suppresses Convective Clouds During Monsoon?

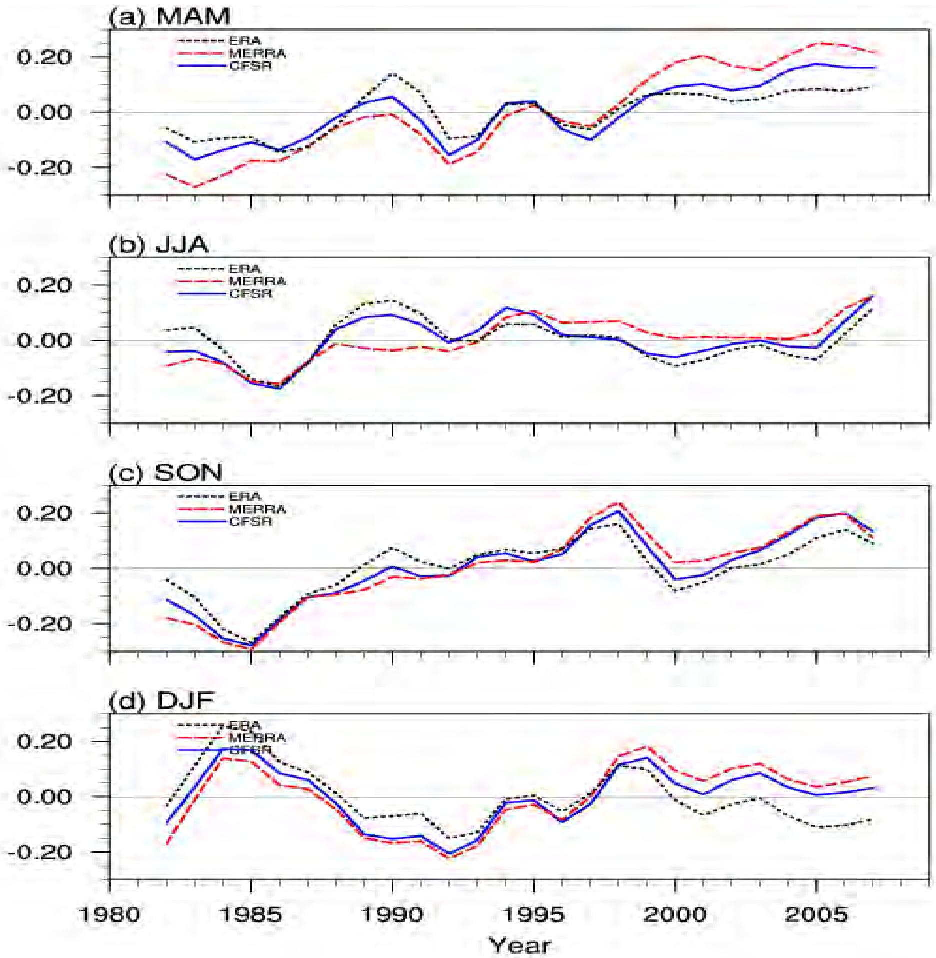


El Niño			La Niña		
Weak	Mod	Strong	Weak	Mod	Strong
1952	1951	1957	1950	1955	1973
1953	1964	1965	1954	1970	1975
1958	1968	1972	1956	1998	1988
1969	1986	1982	1964	2007	1999
1976	1987	1997	1967		2010
1977	1991		1971		
2004	1994		1974		
2006	2002		1983		
	2009		1984		
			1995		
			2000		
			2005		
			2008		
			2011		



- Stratospheric water vapor showed an increase of about 0.5 parts per million by volume (ppmv) during the 1990s.
- After 2000, a sudden drop of 0.4 ppmv was observed, and this decrease has persisted in 2009.
- High resolution model computations shows that the increase in stratospheric water vapor in the 1990s led to about a 30% increase in the amount of global warming observed during that decade, and the decrease of 0.4 ppmv since 2000 led to a 25% reduction between 2000 - 2009. (***Source: Jeff Masters, 2010***)

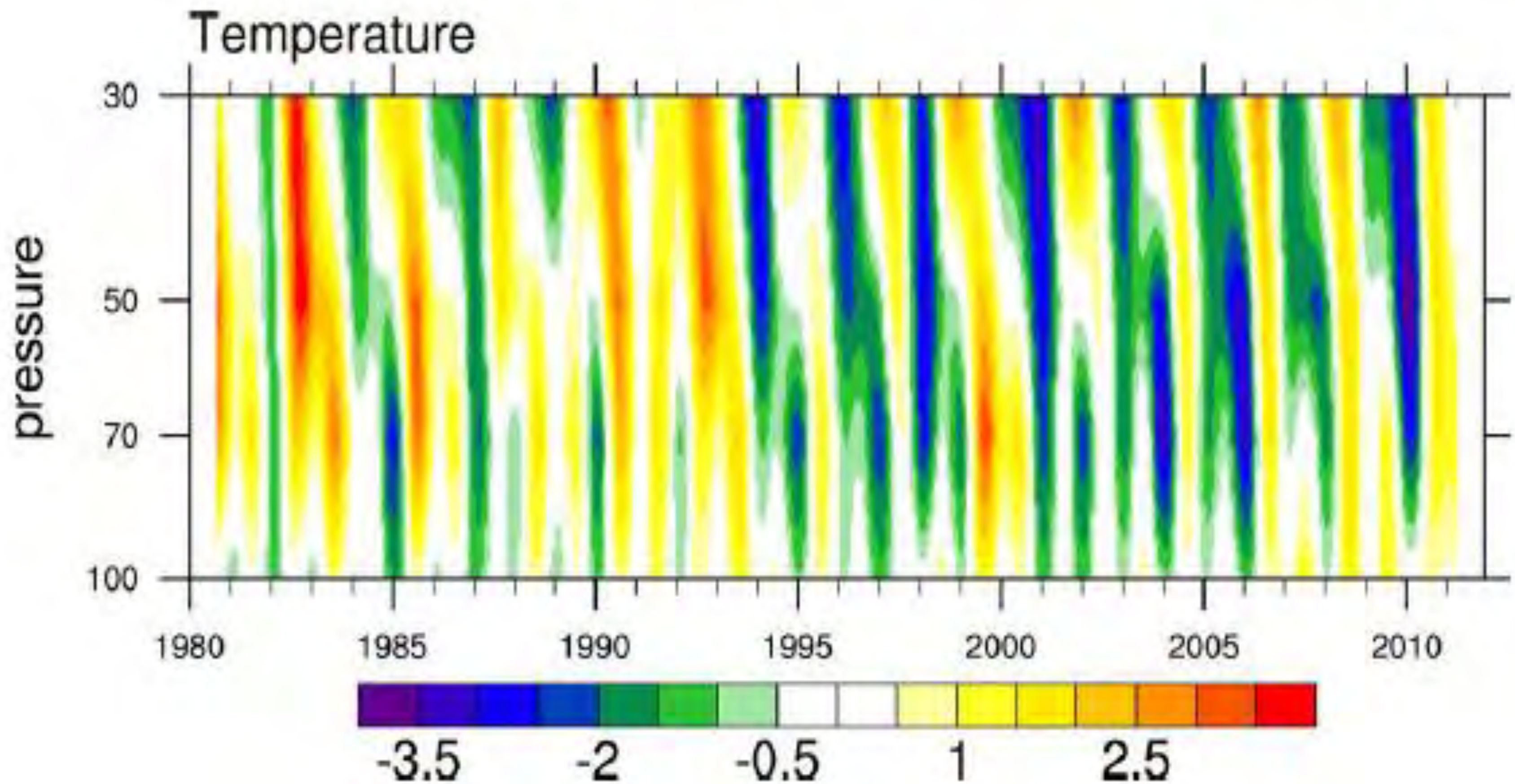
Seasonal variability of water vapour in the Lower Stratosphere



Pre- and Post Monsoon seasons show an increasing trend in Moisture

No clear trend in water vapor is seen during the Monsoon season.

Monthly Mean Temperature in the Lower Stratosphere over Monsoon Region



Temperature in the LS region is decreasing