

- Overview and description of major tropical monsoons



***Goal: Describe the principal features and characteristics of monsoons***

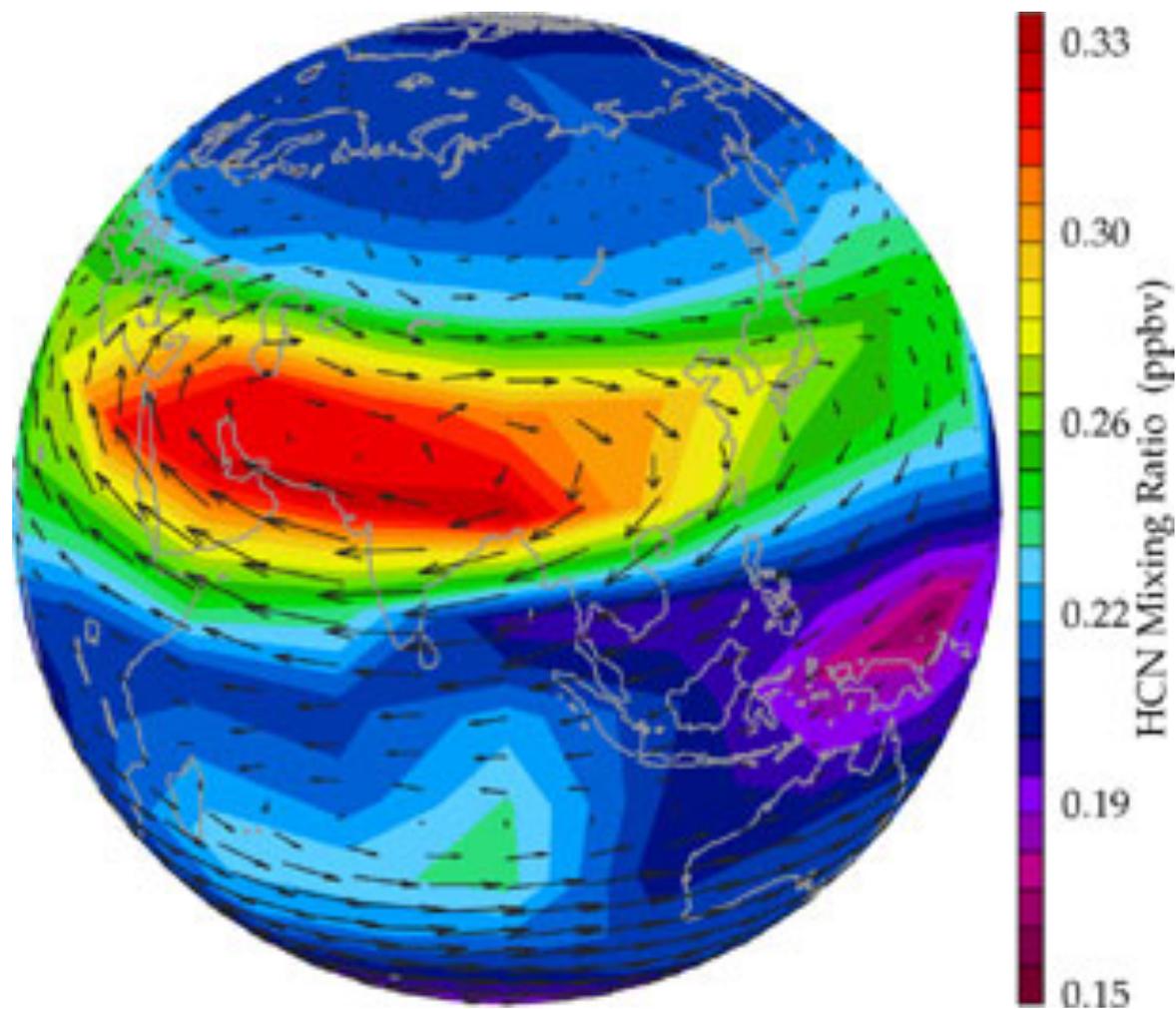
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REPORTS

## Asian Monsoon Transport of Pollution to the Stratosphere

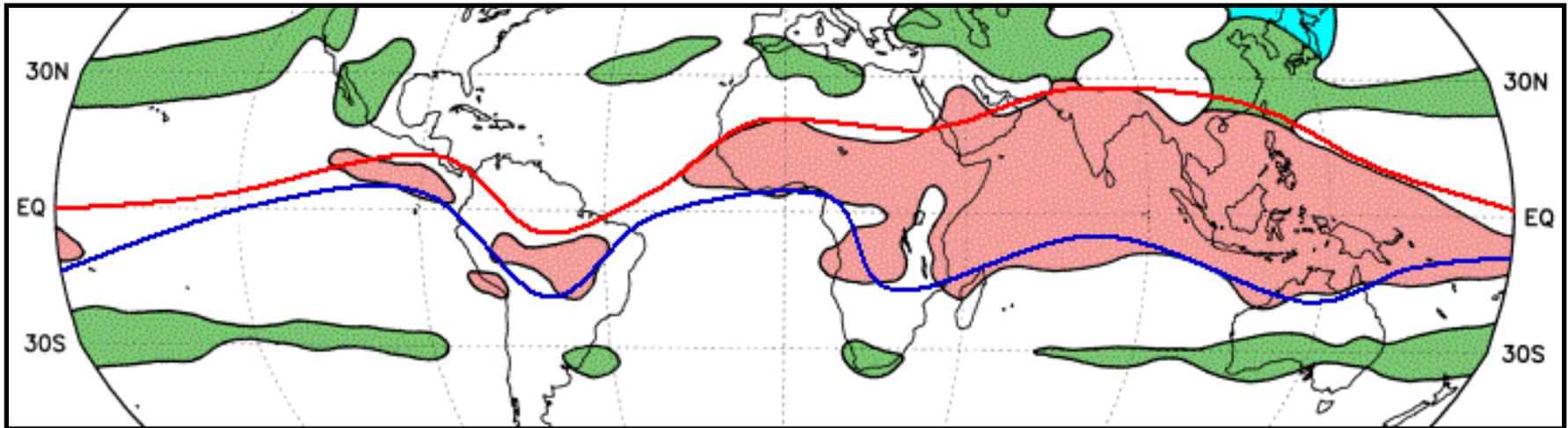
William J. Randel,<sup>1,\*</sup> Mijeong Park,<sup>1</sup> Louisa Emmons,<sup>1</sup> Doug Kinnison,<sup>1</sup> Peter Bernath,<sup>2,3</sup> Kaley A. Walker,<sup>4,3</sup> Chris Boone,<sup>3</sup> Hugh Pumphrey<sup>5</sup>



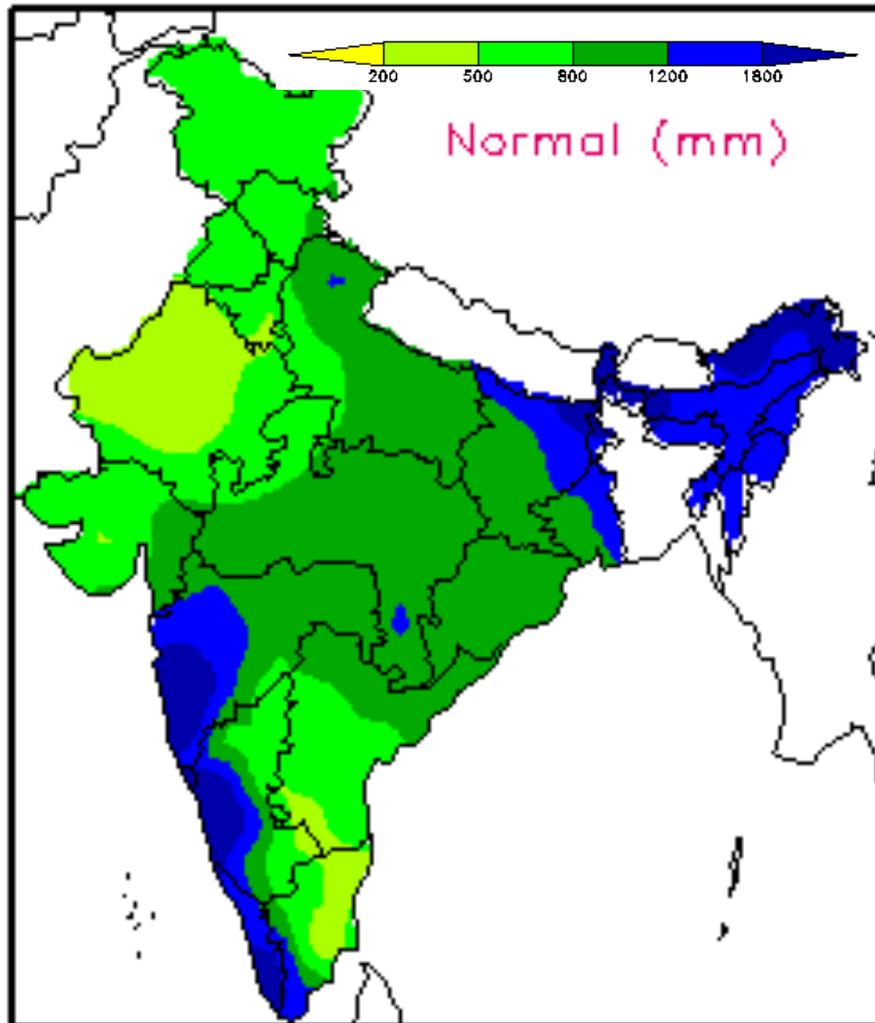
# Monsoons: Overview

- Traditionally any seasonally-reversing wind pattern with accompanying changes in precipitation
  - Thus: wet monsoons and dry monsoons
- Etymology:
  - From the Portuguese *monção*, and the earlier Arabic *mawsim*, meaning “season” [also: Arabic-origin *mausam* means “weather” in Hindi]
- Major monsoon systems:
  - Asian [Indian/South Asian, East Asian, Western Pacific]
  - Australian
  - West African
  - North American
  - South American

# Global distribution of monsoonal climates



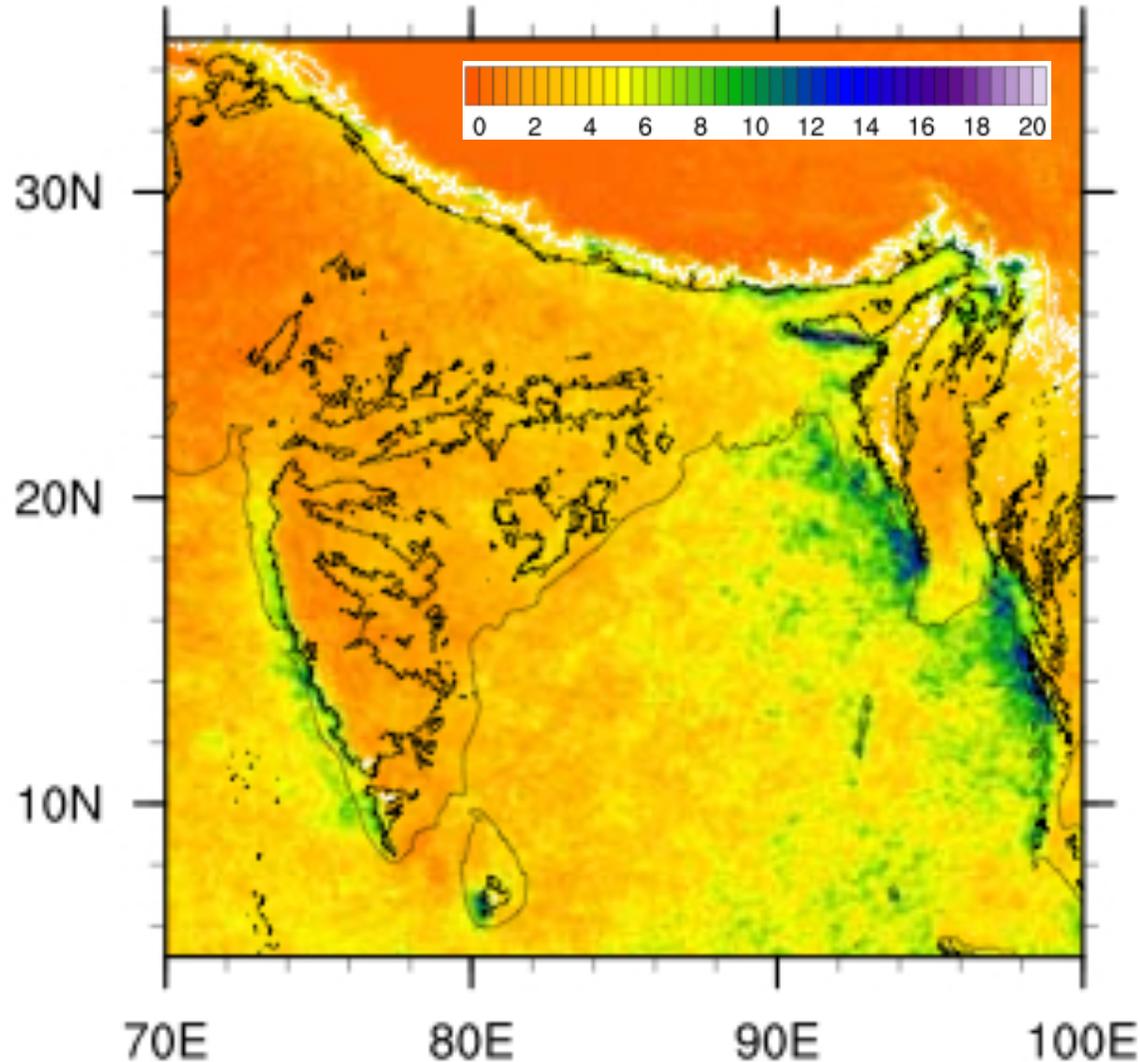
# Indian monsoon precipitation



- The Indian monsoon season is defined as June-September [the plot shown is the seasonal accumulation of rainfall in mm]
- The highest climatological rainfall totals are occur over the southwest Arabian Sea coast (i.e., to the west of the western Ghats mountains) and over extreme eastern India
- A commonly used monsoon measure is the All India Rainfall Index (AIRI)

*From the India Meteorological Department*

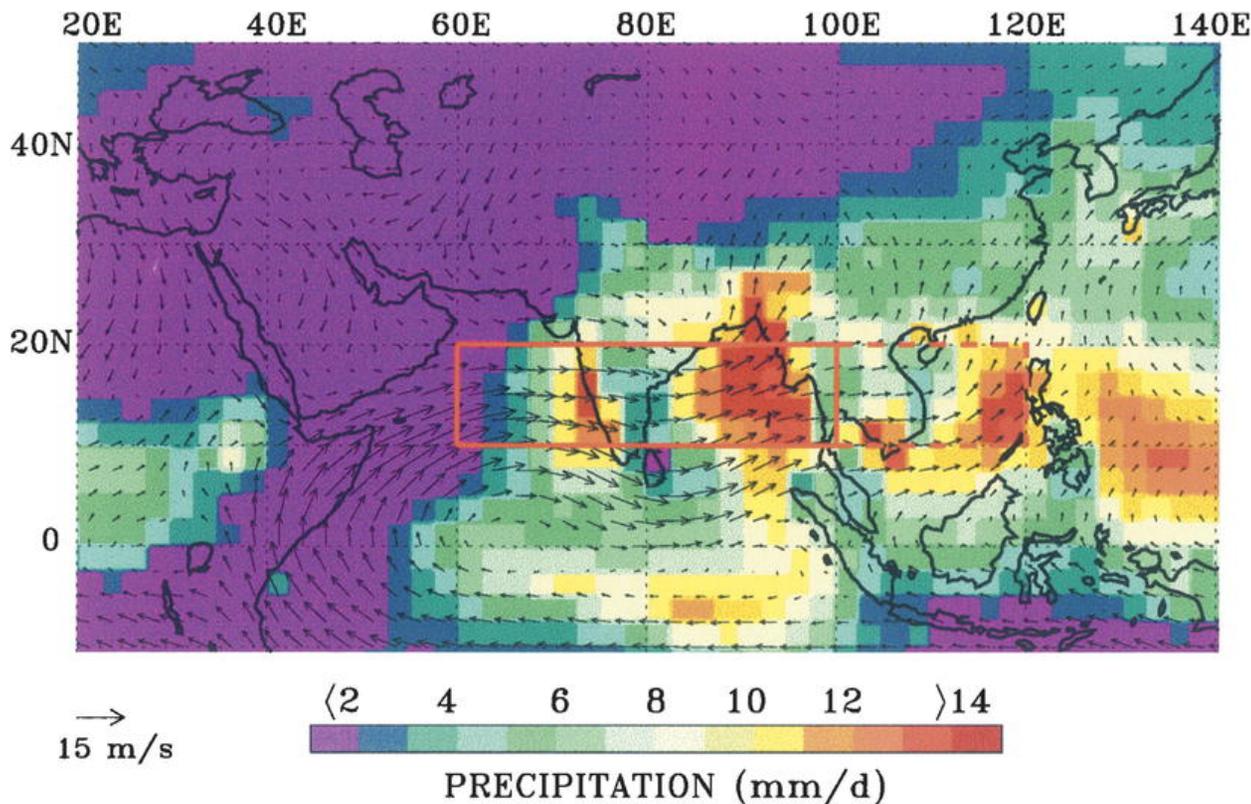
# Very hi-resolution precip climatology for India



- TRMM satellite retrievals at  $0.1^\circ$  resolution
- Precipitation (shaded, in mm) and 500 m and 2000 m topography (black and white contours, respectively)
- Prominent co-location of most intense precipitation with topography

*Nesbitt and Anders 2009*

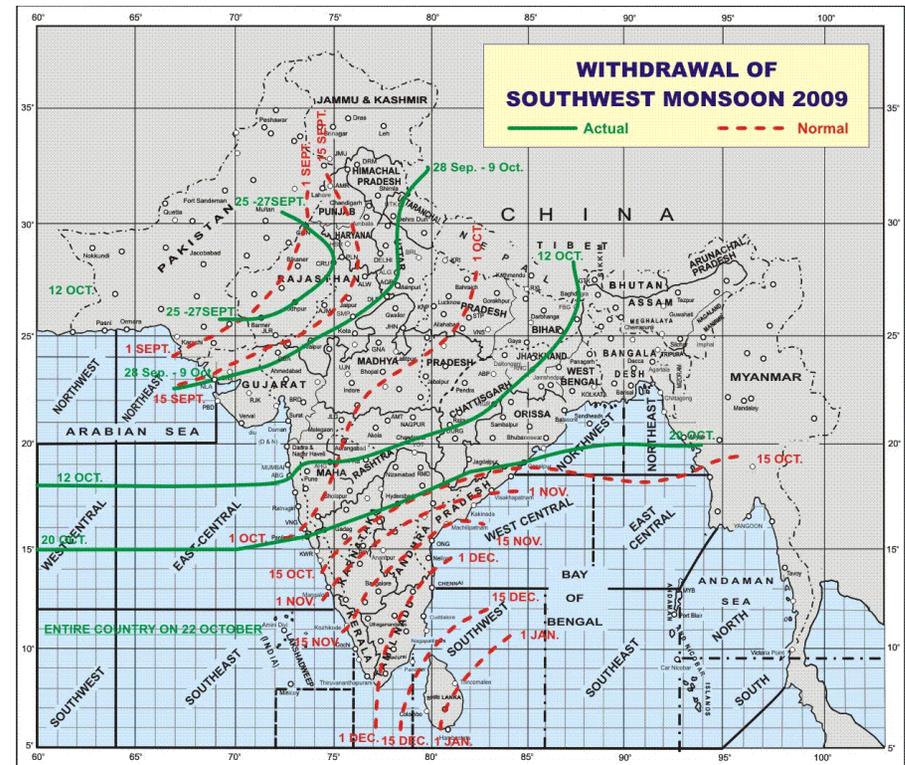
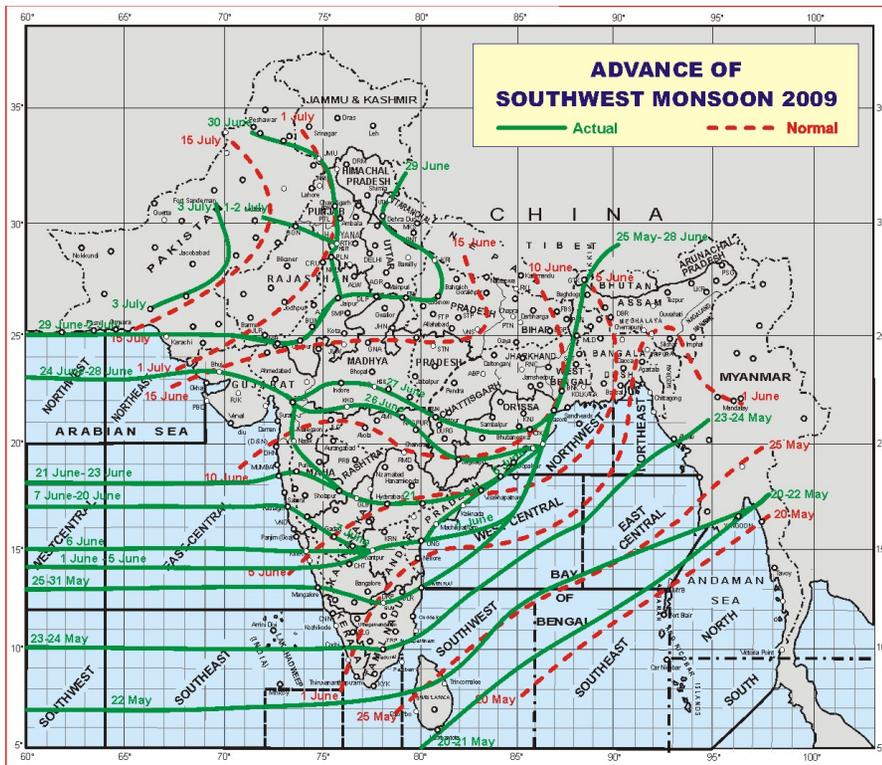
# Broader structure of the Indian monsoon



*From Buermann et al. 2005*

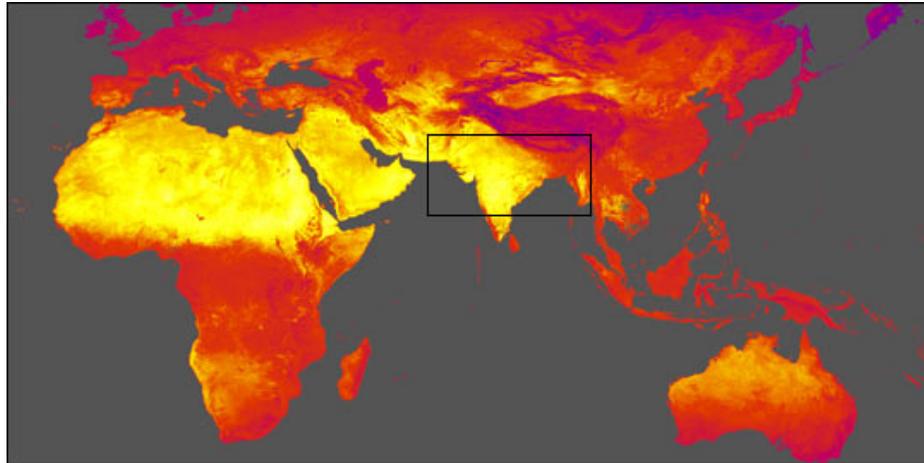
- 1979-1999 mean JJA CMAP precipitation (contours) and NCEP Reanalysis 850 mb horizontal winds (arrows) at 2.5° x 2.5° horizontal resolution
- The precipitation features previously evident over the Indian subcontinent are continuous with centers in the Arabian Sea and Bay of Bengal
- Note the low-level easterlies near the equator, westerlies over South Asia, and the southerly “Findlater” jet along the Somalian coast
- Extension of the monsoon into the western Pacific

# Advance & retreat of the Indian monsoon

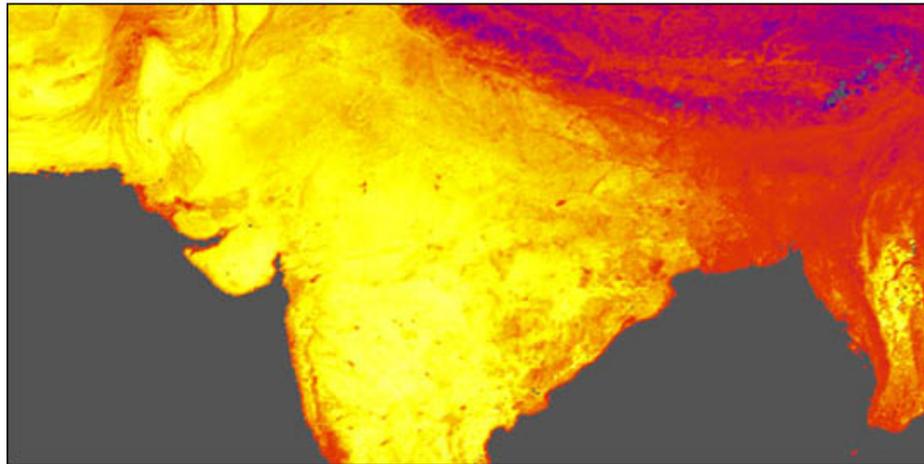


*From the India Meteorological Department*

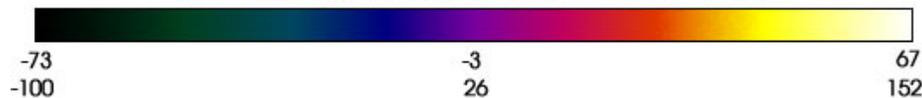
# 2003 Heatwave: A delay in monsoon advance



MODIS Land Surface Temperature May 2003



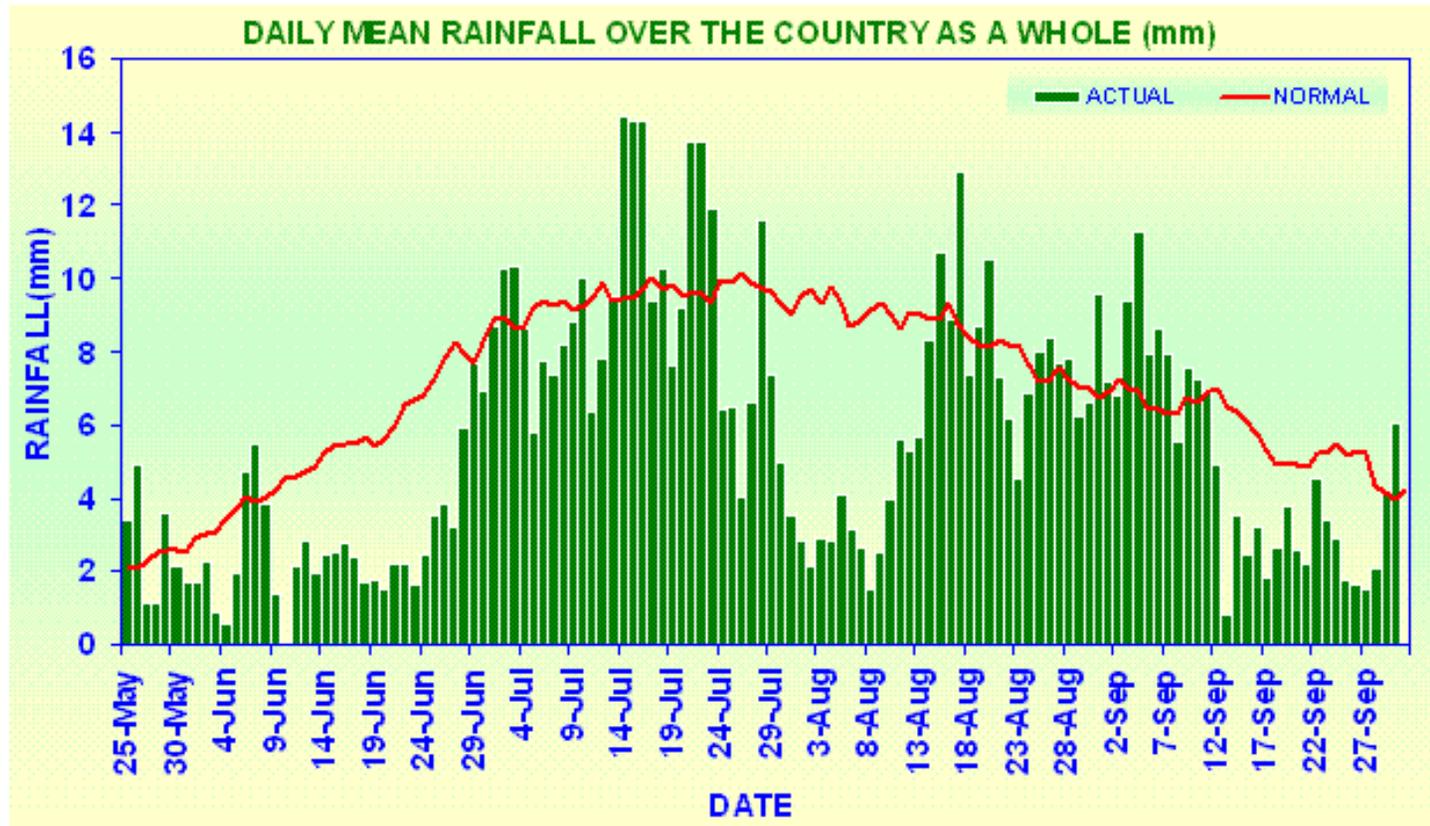
Land Surface Temperature (degrees Celsius/Fahrenheit)



- The pre-monsoon period (especially May) in India is typically characterized by high surface temperatures
- Especially hot conditions were in place in May 2003, resulting in nearly 1300 deaths
- The persistence of this event has been linked to a delay of ~1 week of monsoon advance

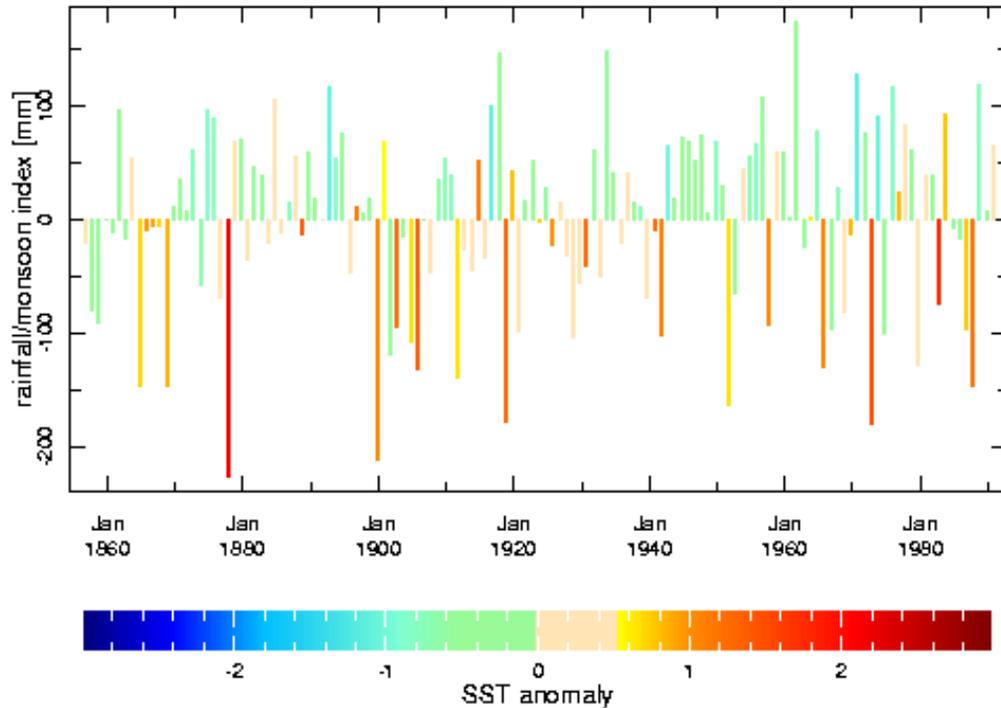
*From NASA Earth Observatory Image of the Day (EOIOD) Gallery*

# AIRI for 2009



- Daily mean climatological AIRI is shown in red; daily mean values for 2009 are shown in green.
- Significant intraseasonal variability, with both “active” and “break” phases [Overall, 2009 was a below-average monsoon].

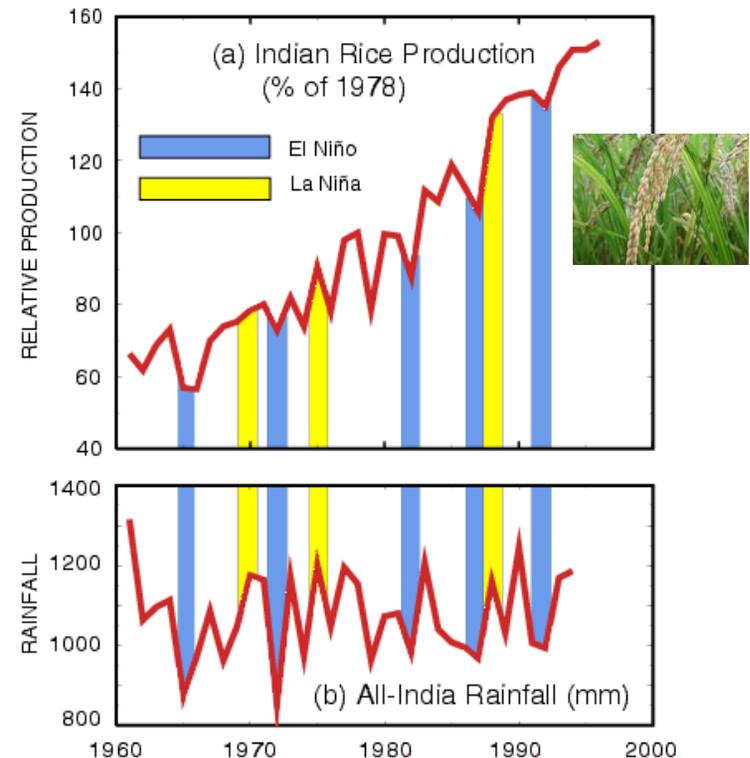
# AIRI interannual variability



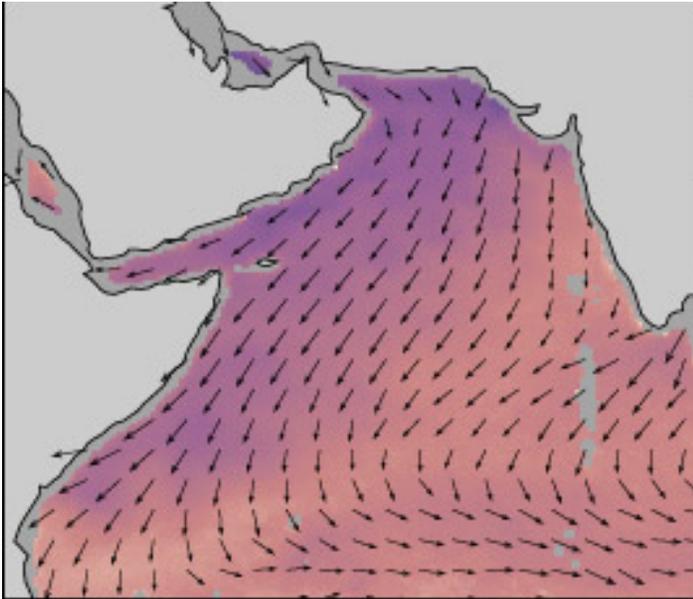
- **Kaplan et al. 1998** illustration of AIRI interannual anomalies (in mm) color coded by SSTs in the “NINO3” region [red = strong El Niño]. Note the mean value is ~850 mm, with a standard deviation of 80 mm.



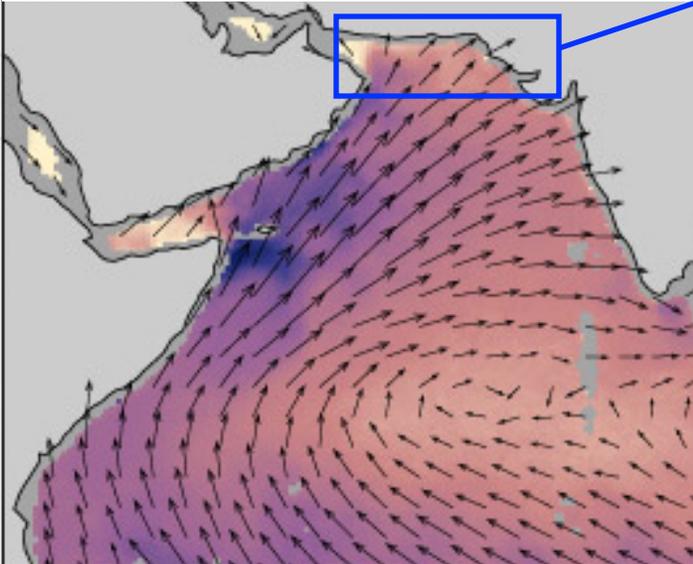
- Indian rice production (upper red curve; in % relative to 1978) and AIRI (lower red curve; in mm)



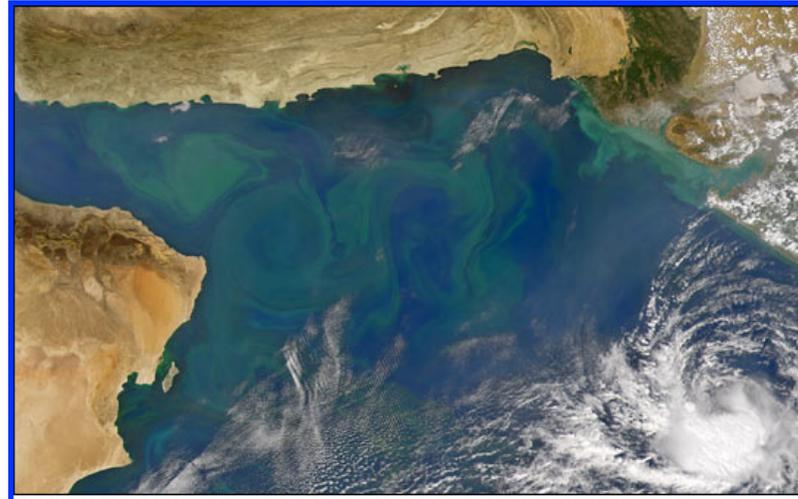
# Seasonal wind reversal



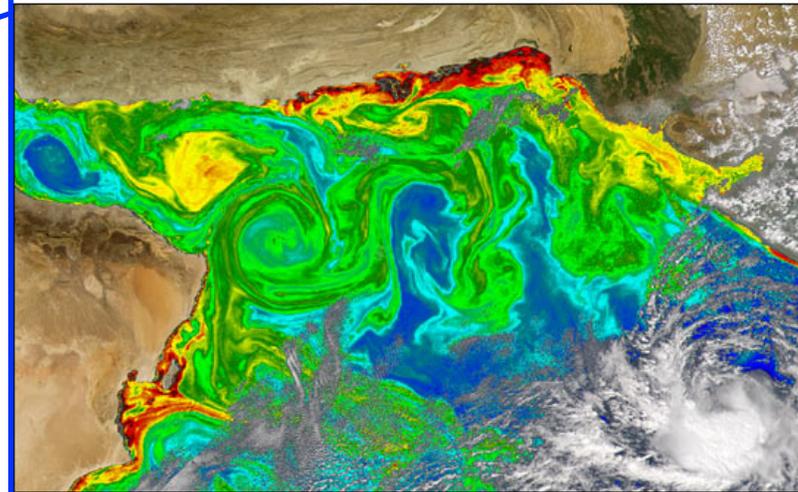
Winter Monsoon



Summer Monsoon



Natural Color

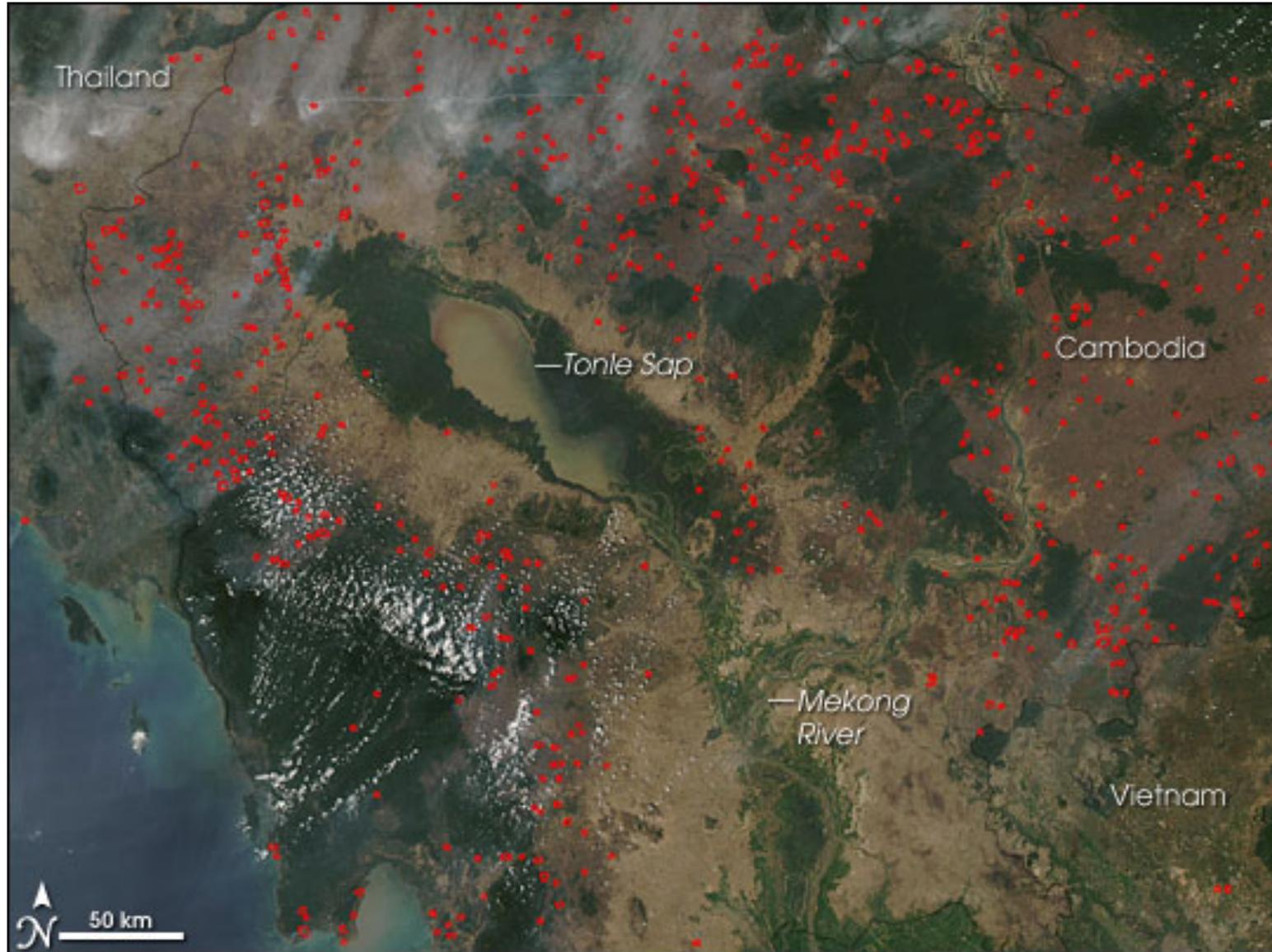


Chlorophyll Concentration

Ocean Chlorophyll Concentration (mg/m<sup>3</sup>)  
0.05 1.0 10 50

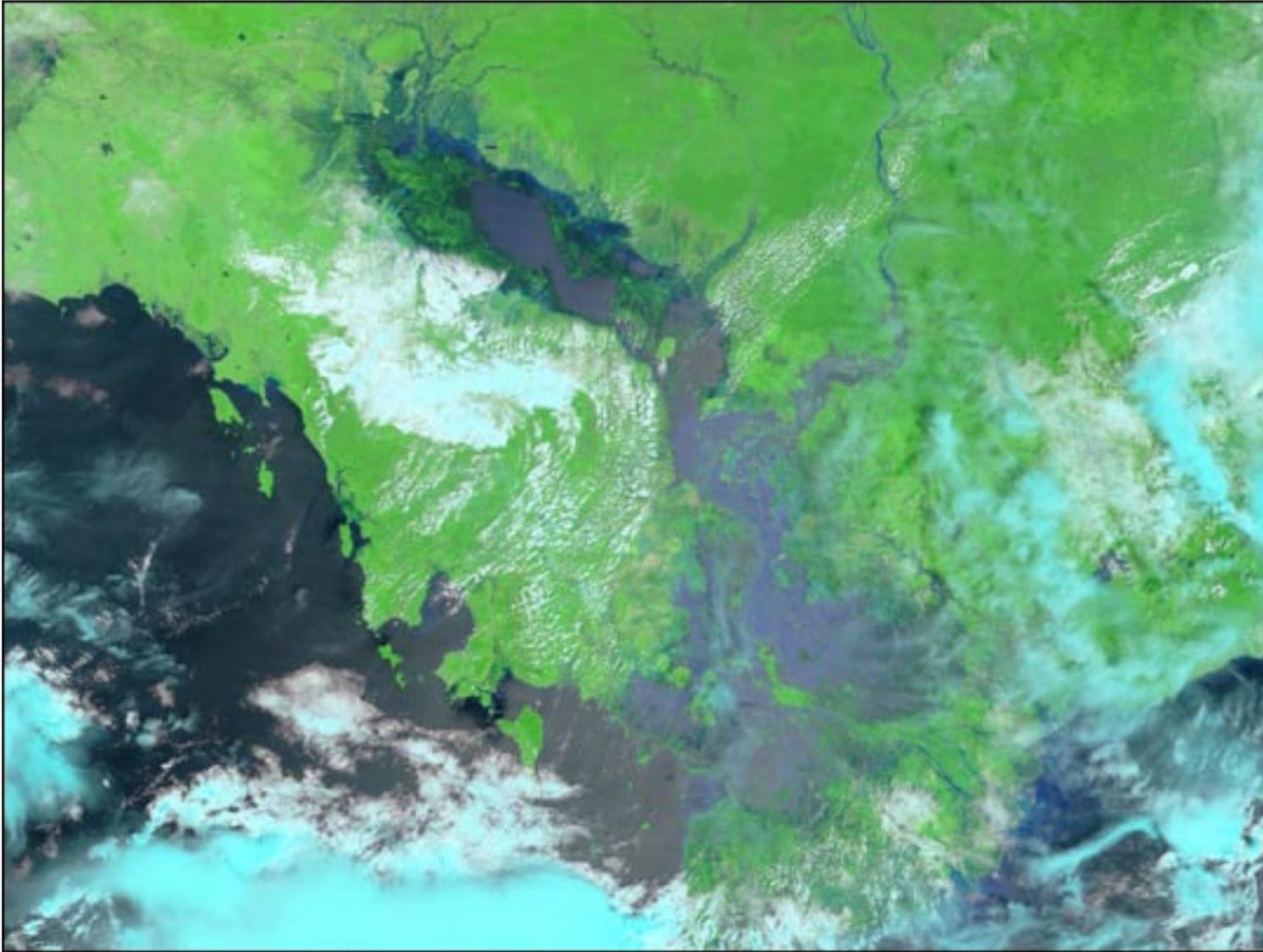
*From NASA EOIOD*

# SE Asia dry monsoon



*From NASA EOIOD*

# Seasonal change: Tonle Sap



Wet Season (October 9, 2002)

*From NASA EOIOD*

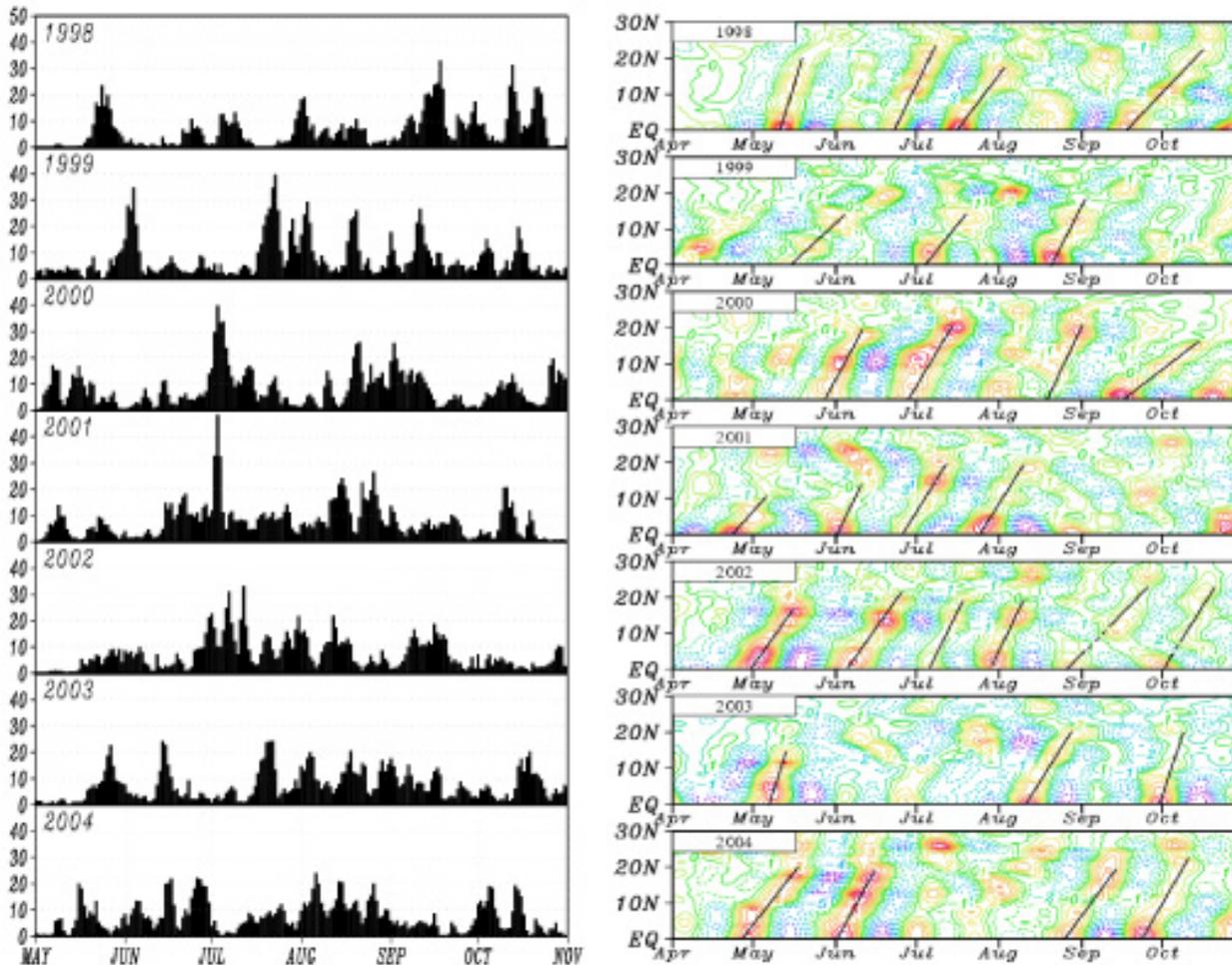
# Seasonal change: Tonle Sap



Dry Season (January 29, 2003)

*From NASA EOIOD*

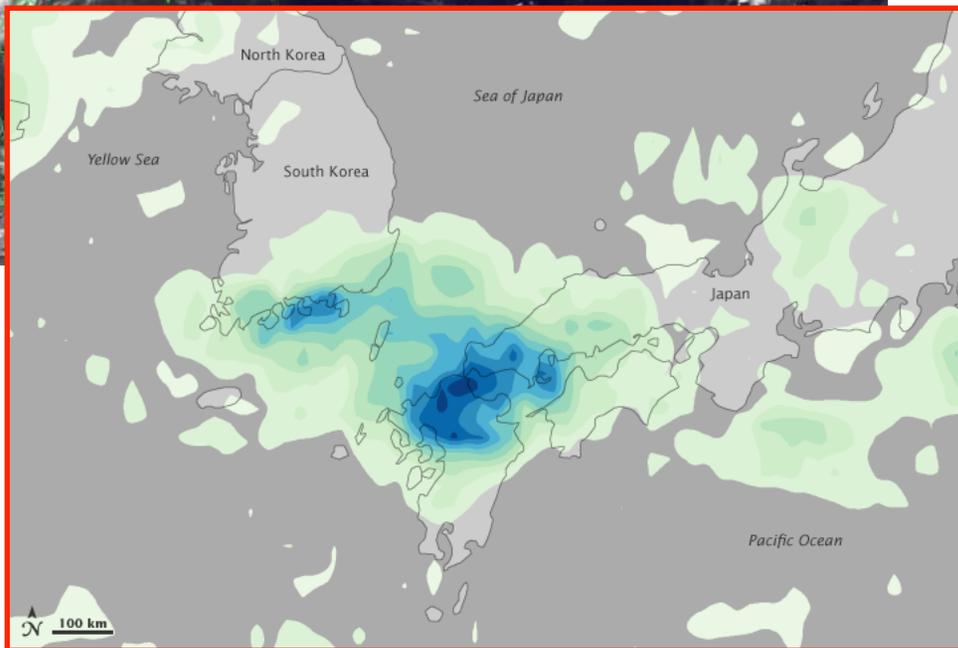
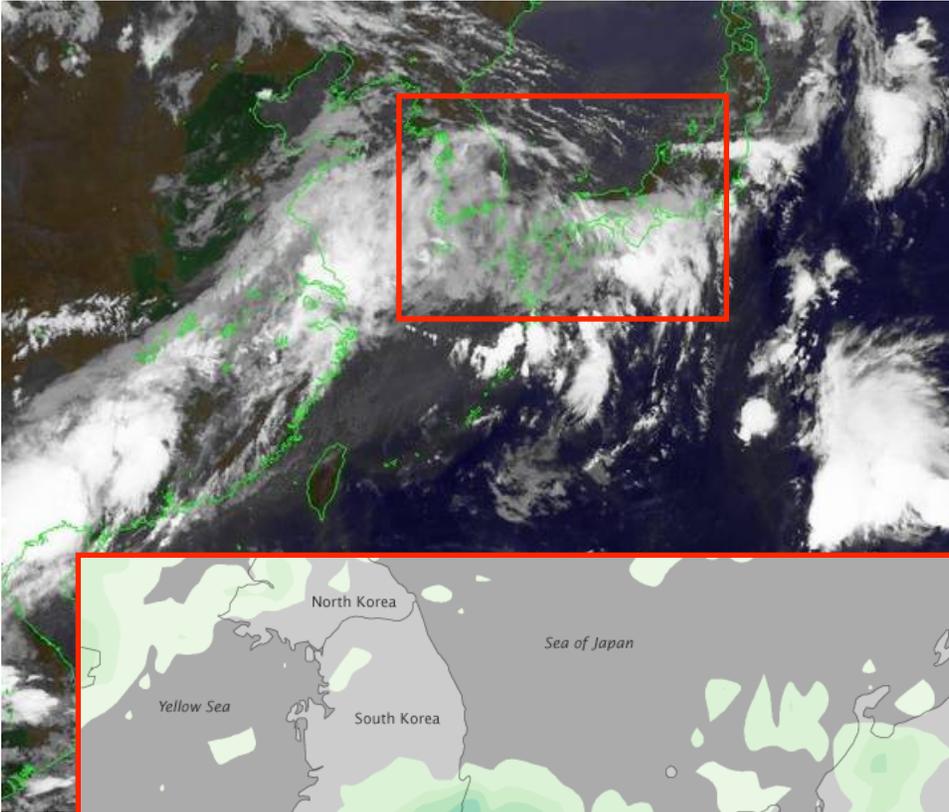
# Western Pacific, 1998-2004



- Left: TRMM daily precipitation averaged over 115°E-140°E, 10°N-20°N
- Right: 20-50 day filtered precipitation averaged over 75°E-100°E
- Intraseasonal north(west) ward propagating features seen on the right, active/break periods on the left suggestive of monsoon modulation by MJO[?]

*Fu et al , US CLIVAR [courtesy Dr. K. Kikuchi]*

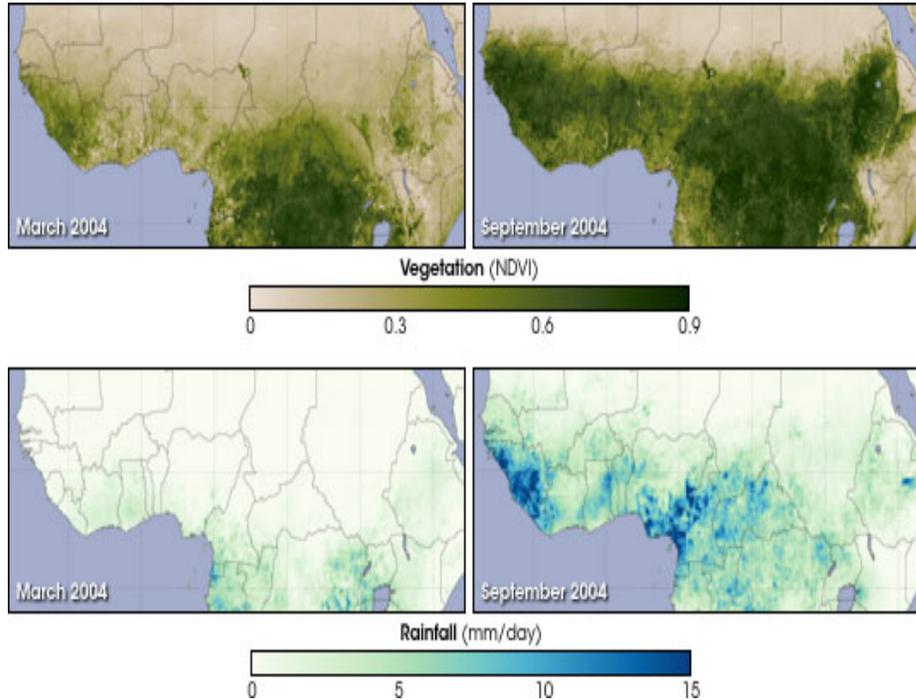
# Mei-yu/bai-u front



- Quasi-stationary zonal rainfall feature on the northeast margin of the Asian monsoon
- Mei-yu means “plum rain” in Chinese, because of the arrival of rain in mid June: “When the rain falls on the ripe plums, there follows 40 days of rain.”
- While the rainy season is short (~30 days), it may account for 20% of the annual precipitation

*From NASA EOIOD*

# West African monsoon

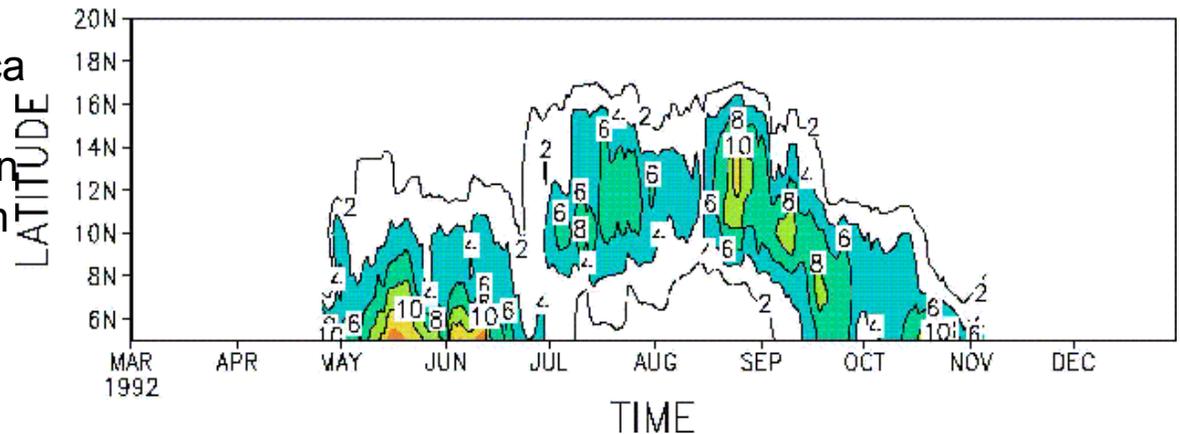


- Top panels: NDVI [satellite-derived measurement of “green-ness”] for March 2004 and September 2004
- Bottom panels: TRMM rainfall for March 2004 and September 2004

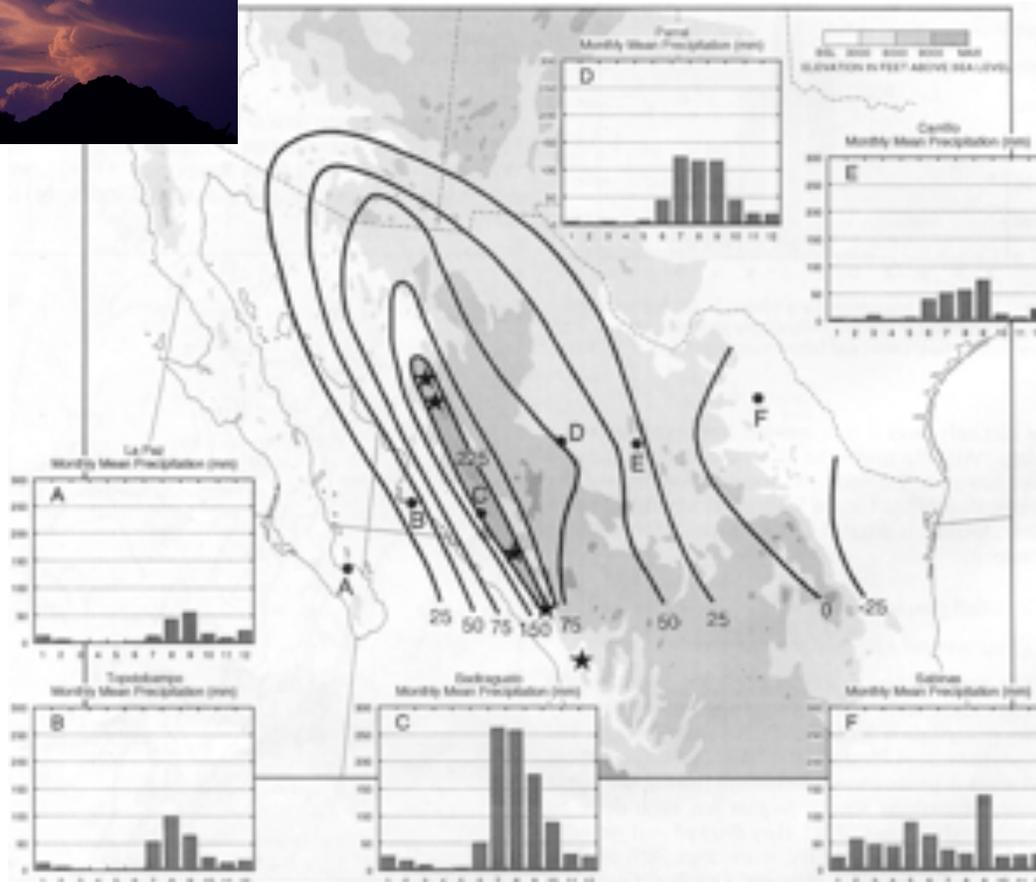
## From NASA EOIOD

- Daily mean rainfall over West Africa shows a pronounced tendency to “jump” from an early season location close to the coast and a later season land region maximum
- Models have difficulty reproducing this jump

## IRD DAILY RAINFALL DATABASE OVER WEST AFRICA 1992 MEAN 10W–10E



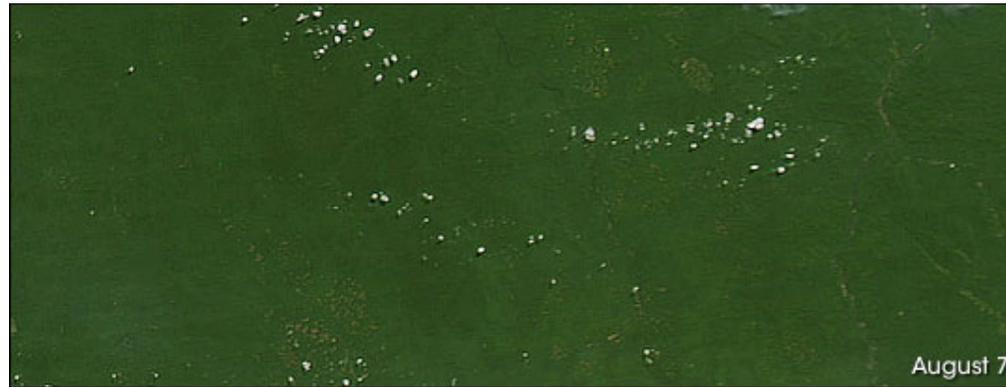
# North American monsoon (NAM)



- Commences in southern Mexico in late May/early June and spreads northwestward along the western slope of the Sierra Madre Occidental
- The southwestern US (Arizona and New Mexico) is impacted by mid-to-late July
- Complex moisture source: Gulf of California/eastern Pacific (low levels) and the Gulf of Mexico (upper levels); potentially also the Great Plains

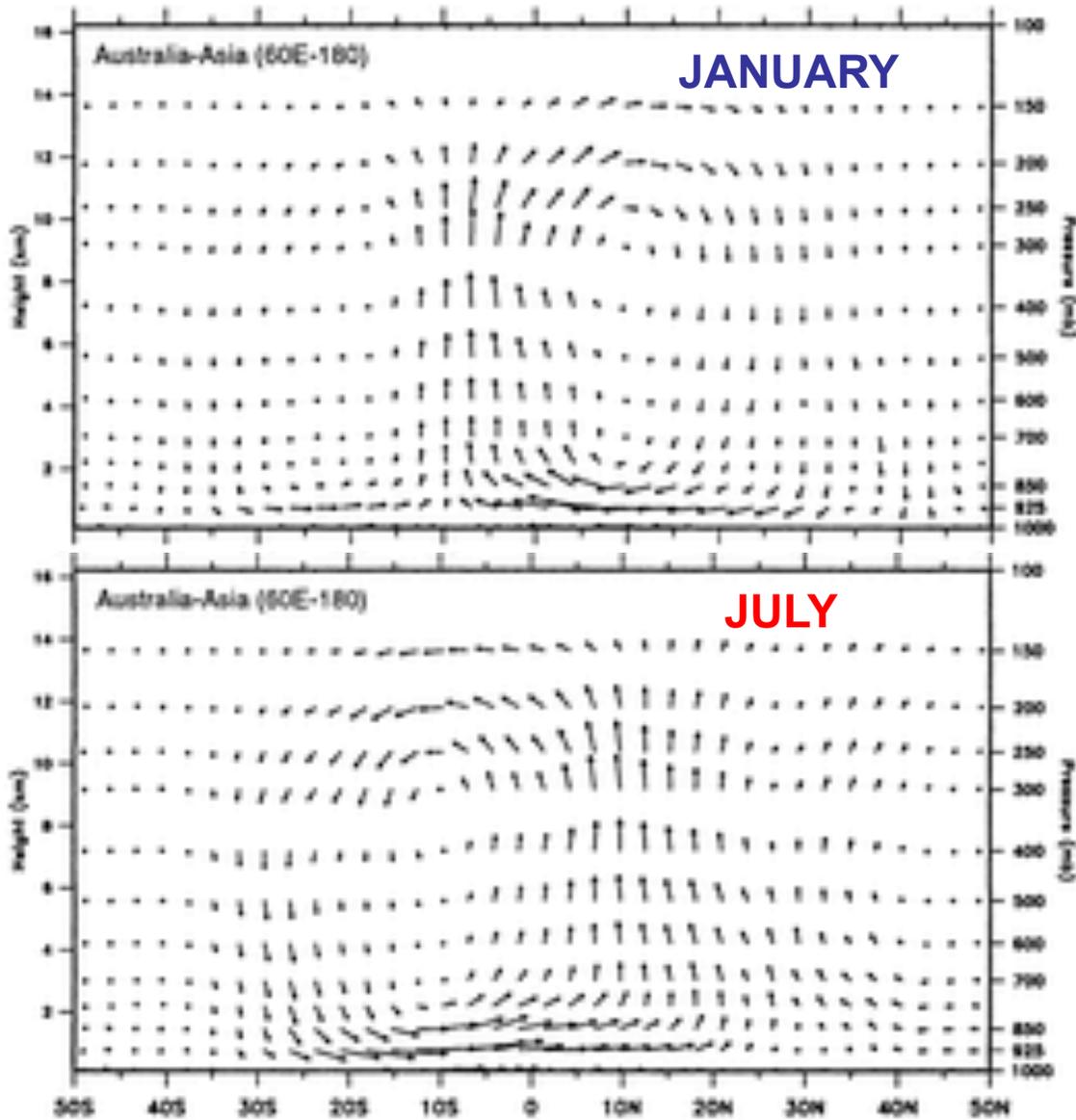
*Climatological NAM rainfall from Douglas et al., 1993.  
Contours show July-June rainfall in mm.*

# Developing South American wet monsoon



*From NASA EOIOD*

# Monsoon vertical structure



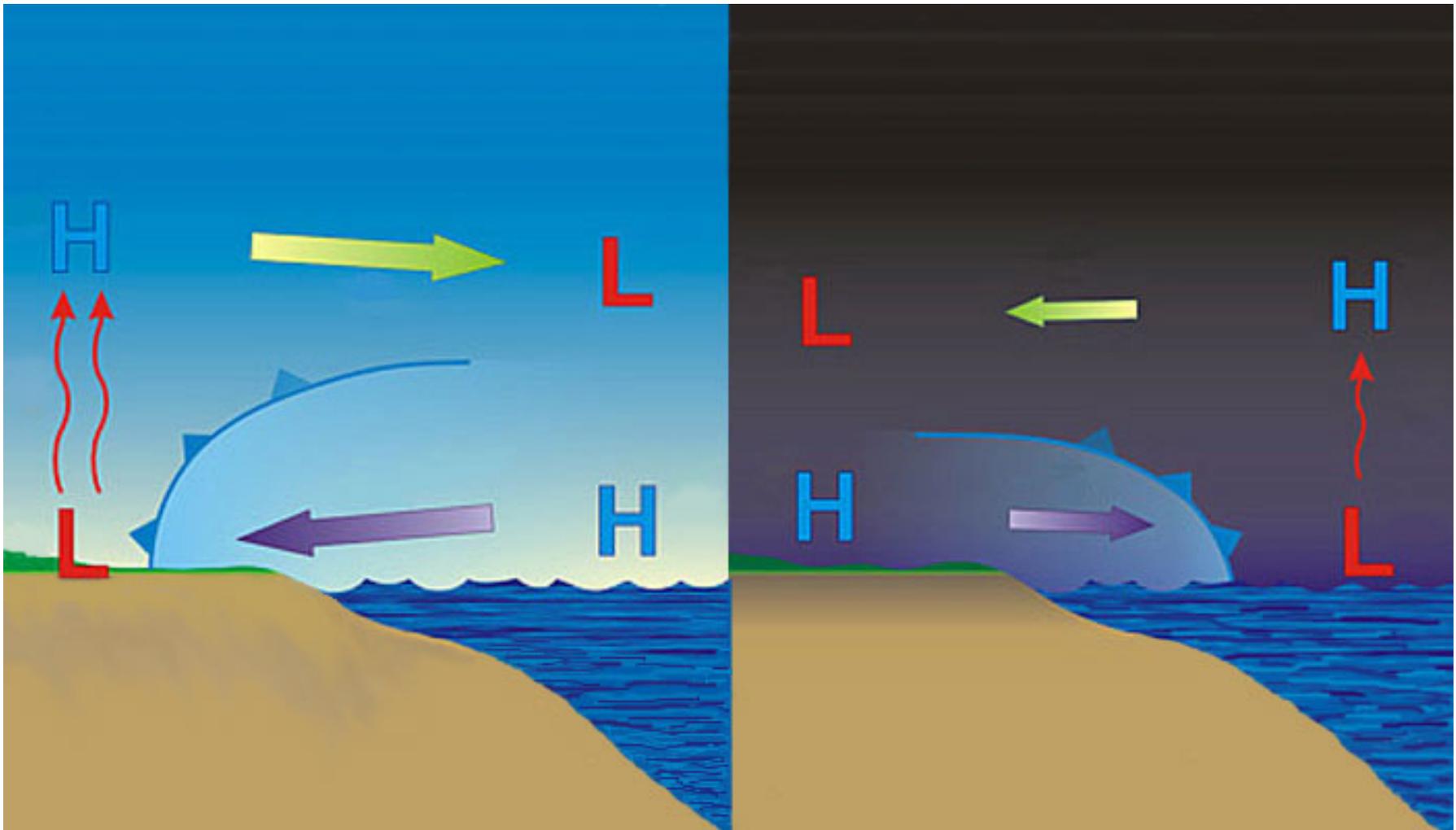
*Trenberth et al. 2000*

- Mean divergent  $v$ ,  $\omega$  averaged over 60°E-180°E
- January rising branch to the south of the equator; July rising branch to the north of the equator
- “Local Hadley circulation”: in fact, in NH summer, the Hadley circulation defined as the zonally-averaged overturning circulation is largely accounted for by the South Asian monsoon

# Simple view: monsoons as “land-sea breeze”\*

Day or “Summer”

Night or “Winter”



\*This view posited by Halley in 1686

# Beyond the simple view [next time]

- The land-sea breeze view fails to account for:
  - Tendency for rapid monsoon onset even while large-scale forcing [top-of-atmosphere radiative heating] varies smoothly
  - Active/break cycles
  - Effect of rotation at large-scales
- An alternative view is of the monsoon as a seasonal displacement of Intertropical Convergence Zones (ITCZs) toward the subtropics
- A significant aspect is how monsoonal convection feeds back onto circulation