Monsoons

https://vimeo.com/106827999

Monsoons

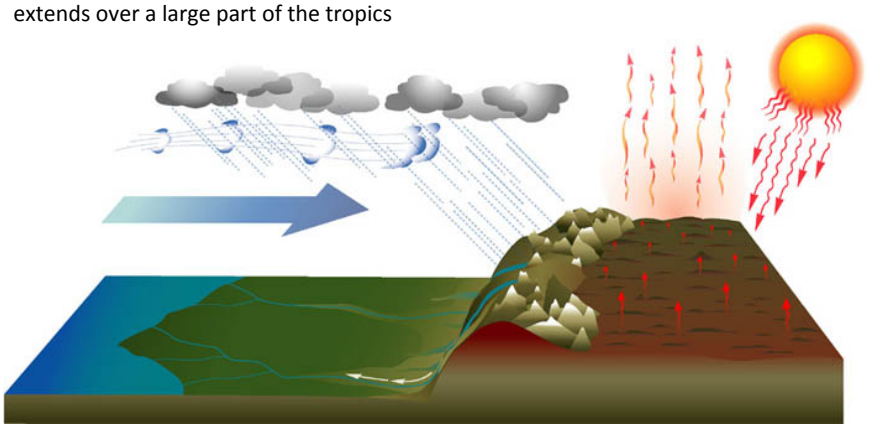
Affect more than ***3 billion people***
Critical for agricultural planning, flood and drought mitigation

Monsoons

- ***Mechanisms***
- How are monsoons defined?
- Regional monsoon dynamics:
  1. South Asian/ Indian
  2. East Asian
  3. Western North Pacific
  4. Asian-Australian
  5. American
  6. West African
  7. GLOBAL monsoons?
- ENSO – Monsoon
- Climate modeling / future monsoon?

"Monsoons"

- derived from the Arabic word for ***season***
- seasonal reversal in the direction of the wind
- monsoonal regions defined by a significant change in the wind direction between winter and summer
- extends over a large part of the tropics



Heat Capacity = the number of joules of energy required to heat one gram of a substance by one degree Kelvin
(or the capacity of a material to store heat)

Land heats and cools rapidly — Low heat capacity (Granite = 0.79 J/ g)

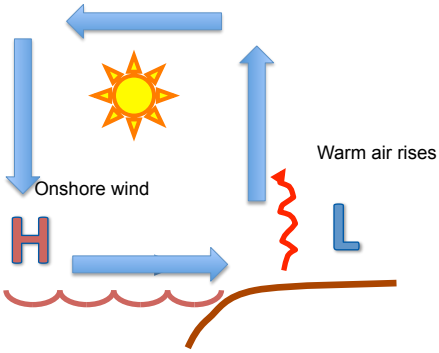
Water heats and cools slowly — High heat capacity (H_20 = 4.184 J/ g)

This is why the ocean says warm into fall even though the weather is getting cool

Local/regional geographic scale:

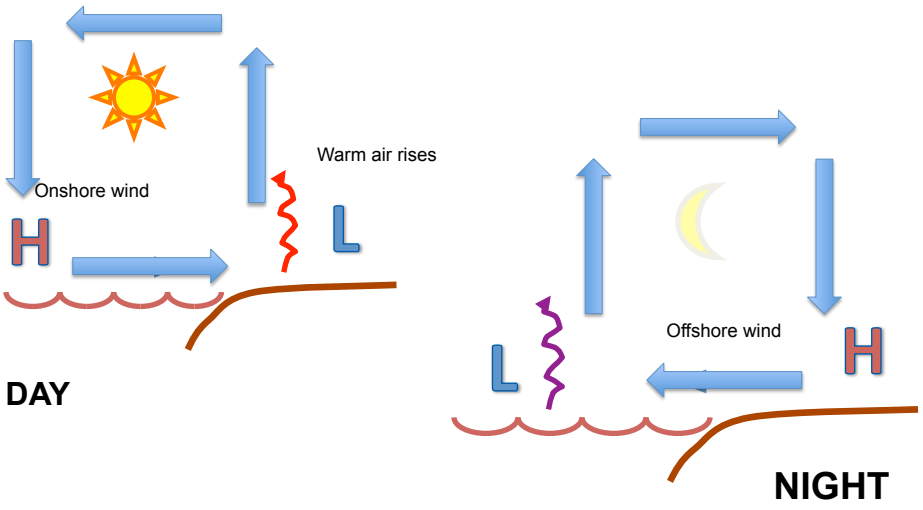
sea breezes
mountain-valley winds
AND MONSOONS!

Sea Breezes



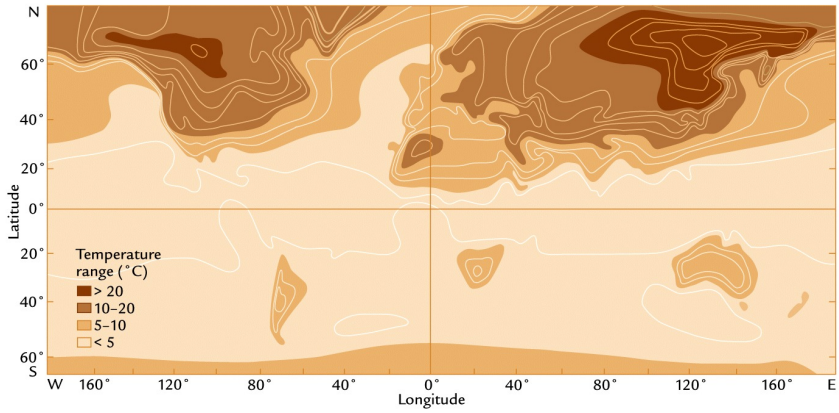
DAY

Sea Breezes



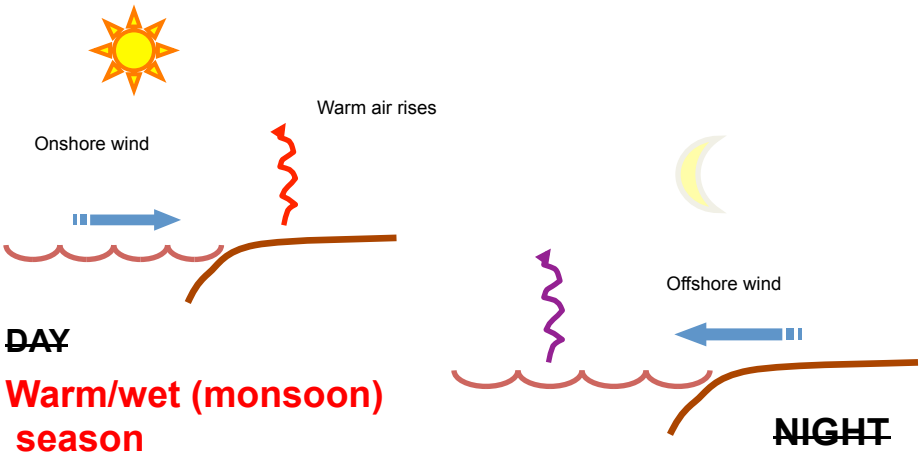
Continentality

The influence of land mass and distance from the ocean results in the diurnal (from night to day) range of temperatures, as well as the difference in temperature between summer and winter.



Seasonal Temperature RANGE greatest on land,
(even though most of the HEAT is in the oceans)

Monsoon circulation



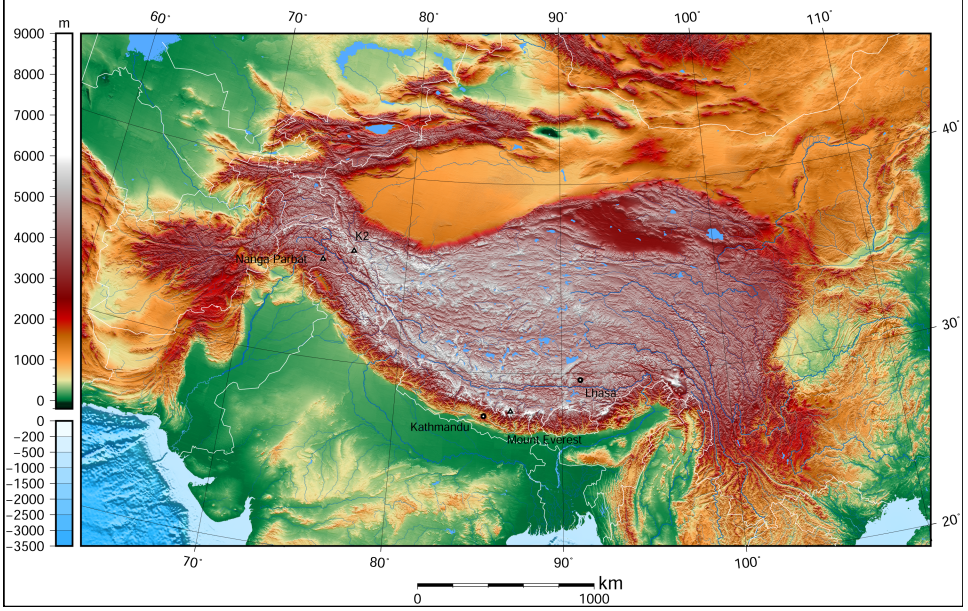
~~DAY~~

Warm/wet (monsoon) season

~~NIGHT~~

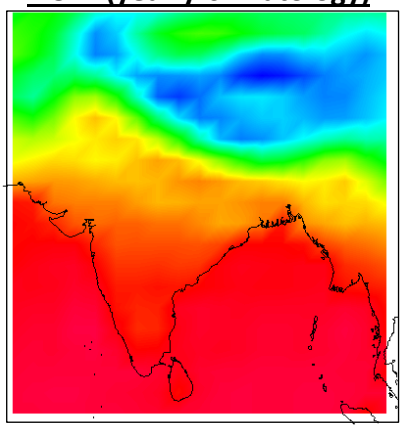
Cool season

Role of topography?

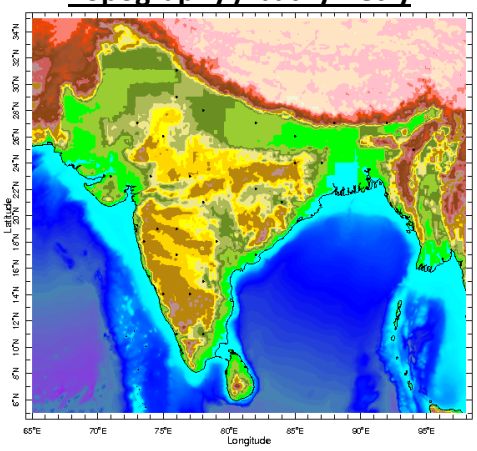


Role of topography?

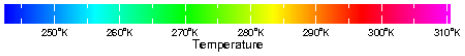
NCEP (yearly-climatology)

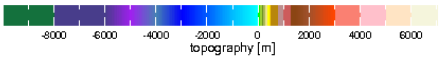


Topography / bathymetry



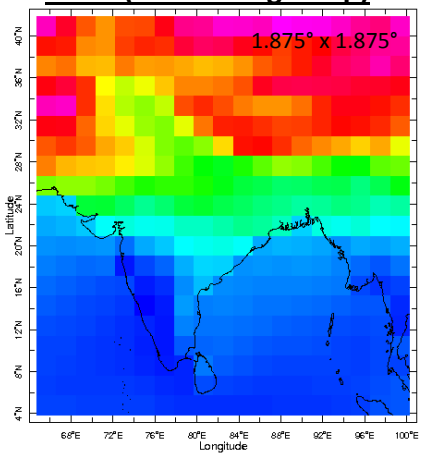
Jan



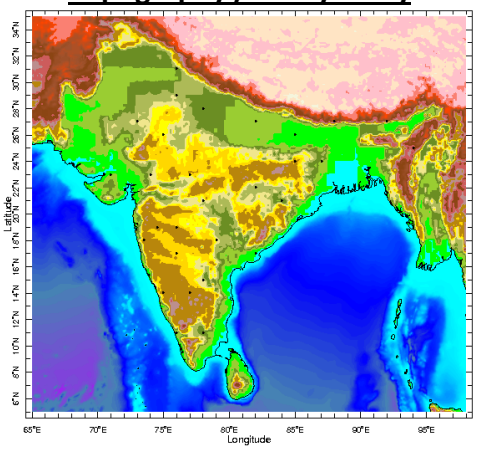


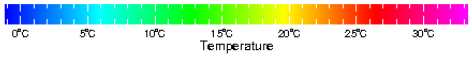
Role of topography?

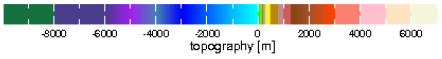
NCEP (JJA-DJF avg temp)



Topography / bathymetry

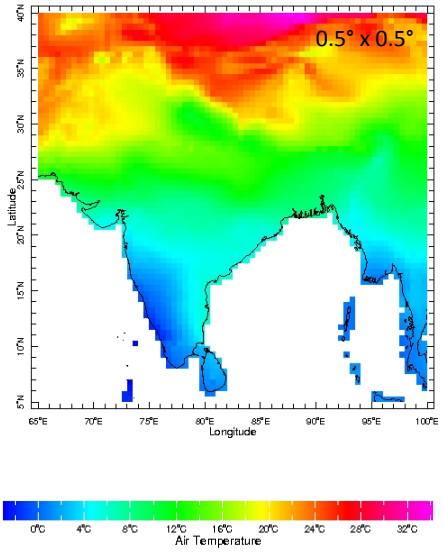




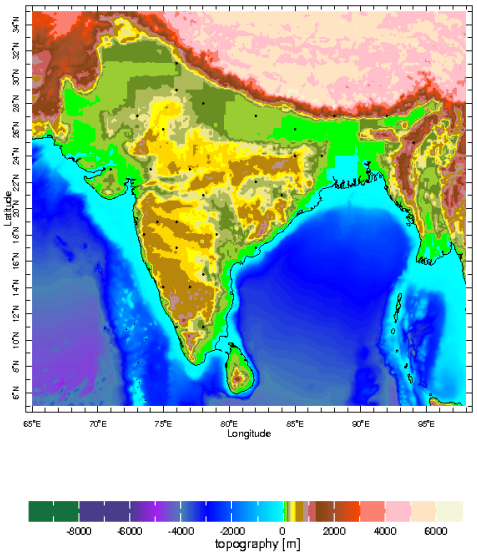


Role of topography?

NCEP (JJA-DJF avg temp)



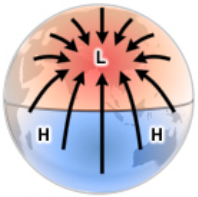
Topography / bathymetry



Monsoon circulation

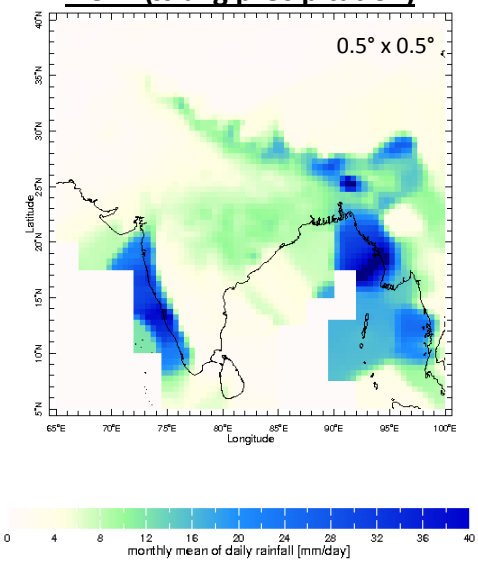
Thermal / SLP gradient **+** ***Coriolis deflection***

Non-rotating earth:

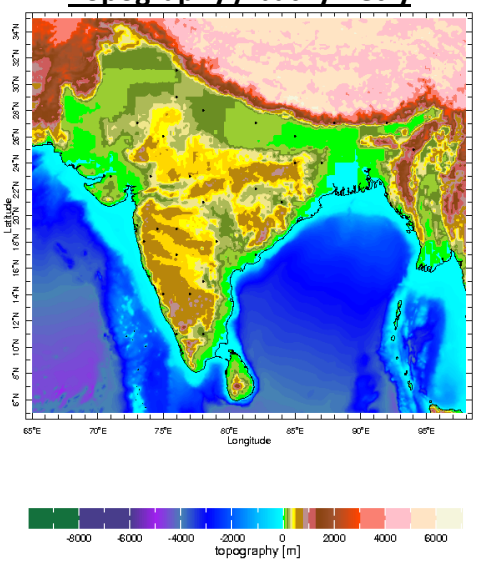


Role of topography?

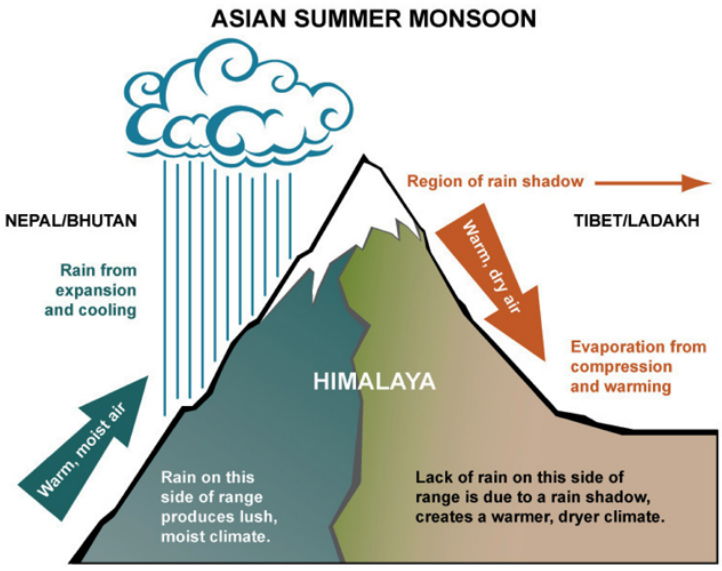
NCEP (JJ avg precipitation)



Topography / bathymetry



Monsoon circulation



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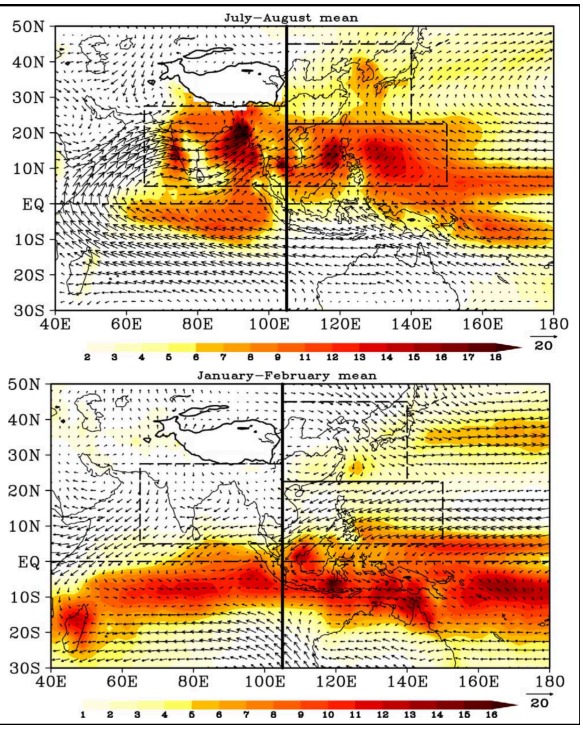
Monsoon "regions"?

- On most basic level: monsoonal regions defined by a ***significant change*** in the ***wind direction*** between winter and summer
- More complex spatial patterns/ dynamics

→ Divided into monsoon sub-regions by ***source, timing and location*** of precipitation

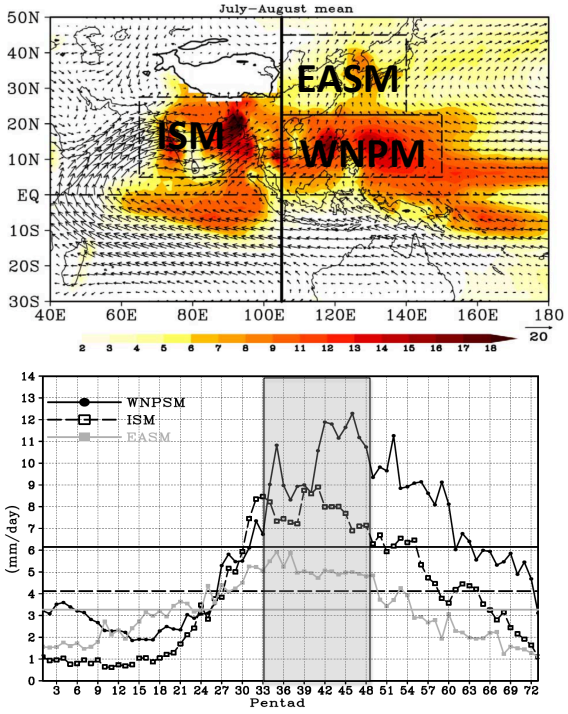


E.g., Asian monsoon "system"

1. *Indian Summer Monsoon/ South Asian monsoon*
2. *East Asian monsoon*
   a. East Asian
   b. Western North Pacific monsoon

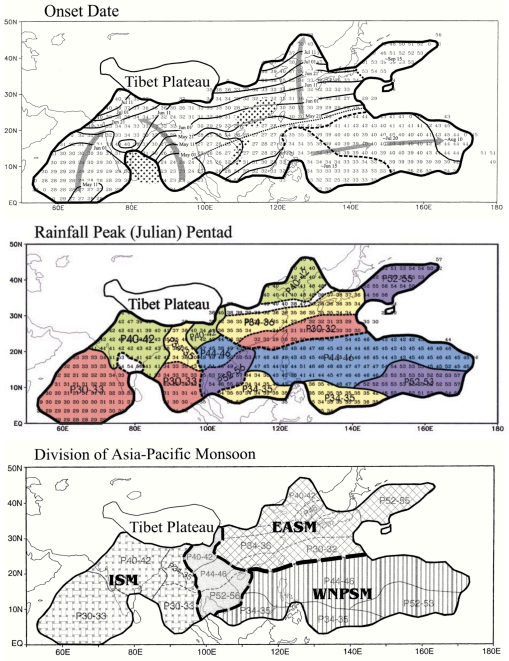
Note: pentad 1 (January 1-5) to pentad 73 (December 27-31).

Wang et al. 2003



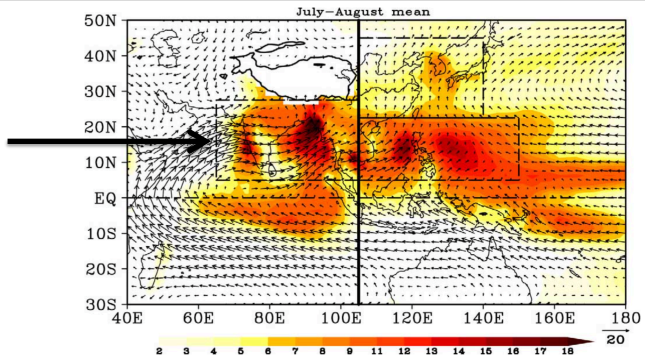
Asian Monsoon System

- earliest onset: southern Bay of Bengal in late April
- over the Indo-Chinese peninsula and south India in early May
- progresses north and northwestward into the continent reaching Japan by late June to July
- By the end of the peak season over Japan, the monsoon is already retreating over India



Wang and LinHo 2002

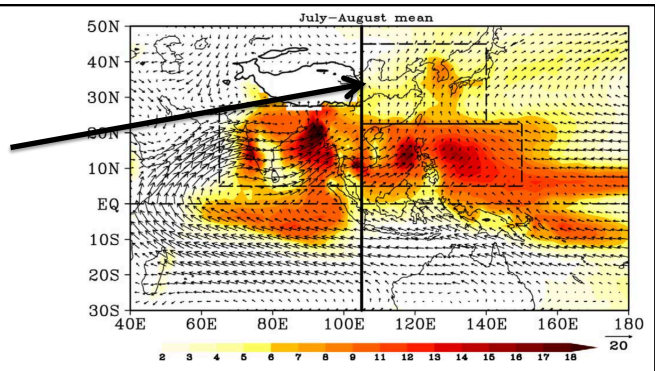
Indian Summer / South Asian



- Strongest and best known of the regional monsoons
- Carries moist air from the Indian Ocean to South Asia
- Accounts for approximately 80% of the rainfall in India
- Driven by strong heating over the Tibetan Plateau, which reverses the low-level pressure gradient

Wang et al. 2003

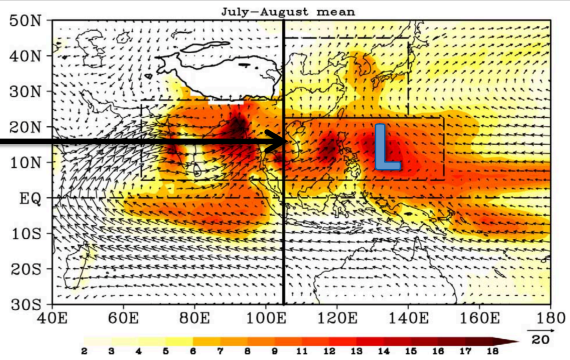
East Asian Monsoon



1. Carries moist air from South Asia to East Asia
2. Affects approximately one-third of global population (China, Korea, Japan)
3. Driven by temperature differences between (warm) Asia and the (cool) Pacific Ocean & N-S gradients between (cool) Australia and (warm) western North Pacific

Wang et al. 2003

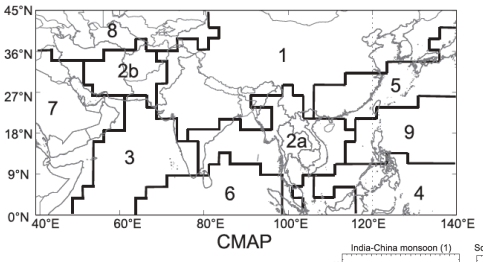
Western North Pacific



1. An oceanic component of the Asian monsoon system
2. Important for tropical cyclone tracks in the Pacific (tracks determined by location of monsoon trough – convergence of low-level westerly and easterly trade winds winds)

Wang et al. 2003

Regionalization



- empirical orthogonal function (EOF)-based regionalization of gridded precipitation value
- A robust way of dividing a large area into coherent sub-regions with similar variability

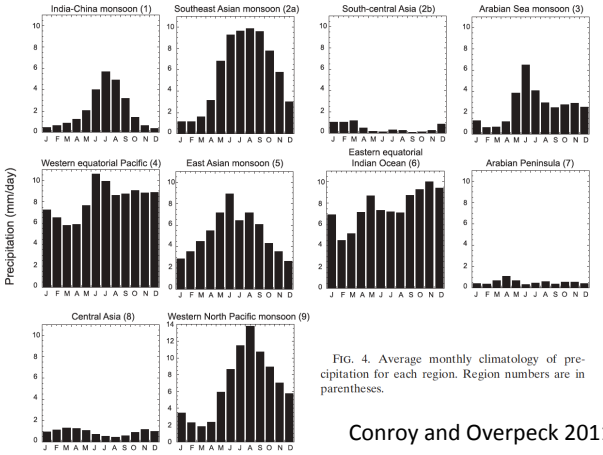
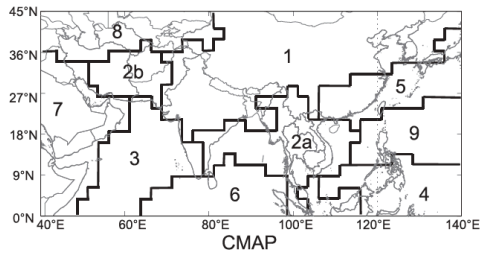


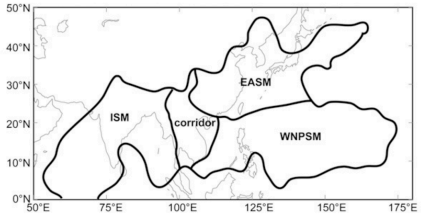
FIG. 4. Average monthly climatology of precipitation for each region. Region numbers are in parentheses.

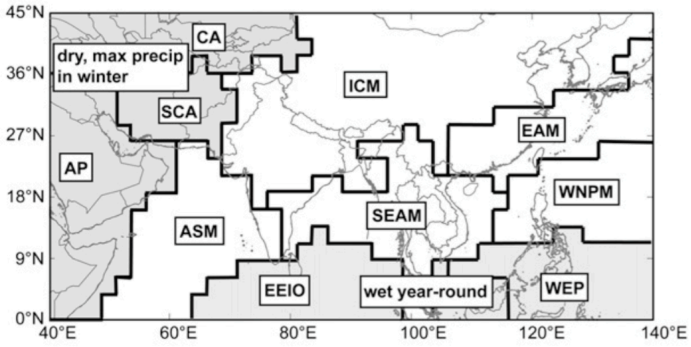
Conroy and Overpeck 2011



CMAP

Bin Wang Monsoon regions

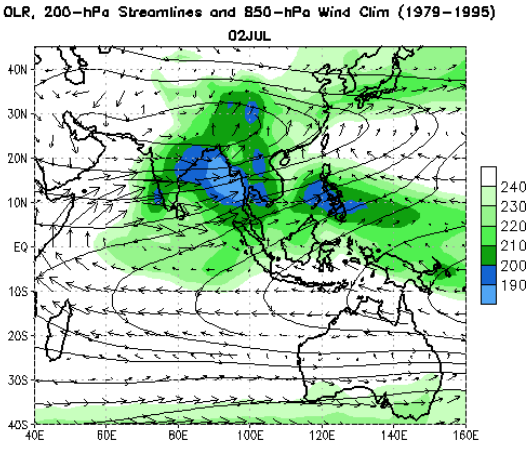




Conroy and Overpeck 2011

Asia-Australian Monsoon

Associated with the seasonal migration of heating between the northern and southern hemispheres



Data Sources: OLR – NESDIS/ORA, Winds – NCEP CDAS/ Reanalysis

Boreal winter vs summer monsoons

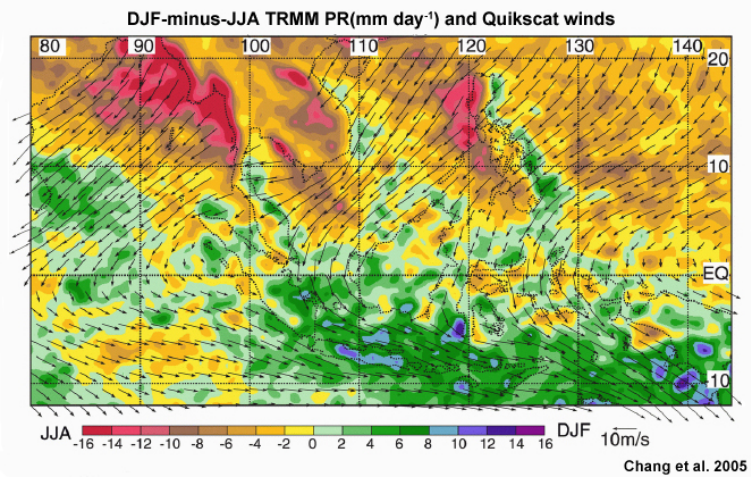
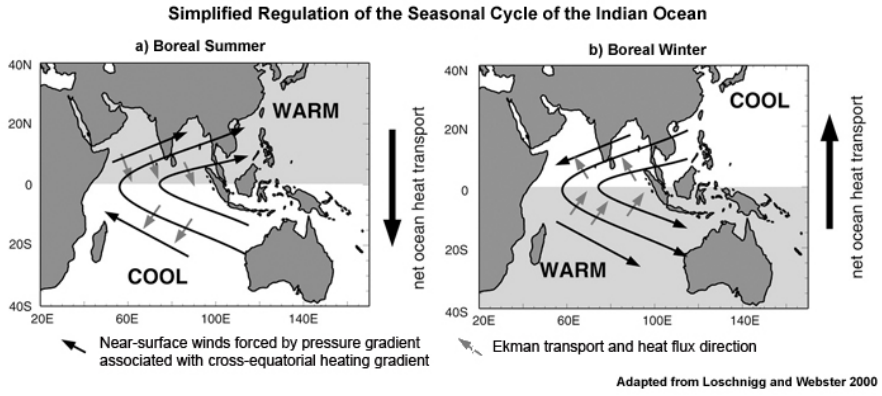


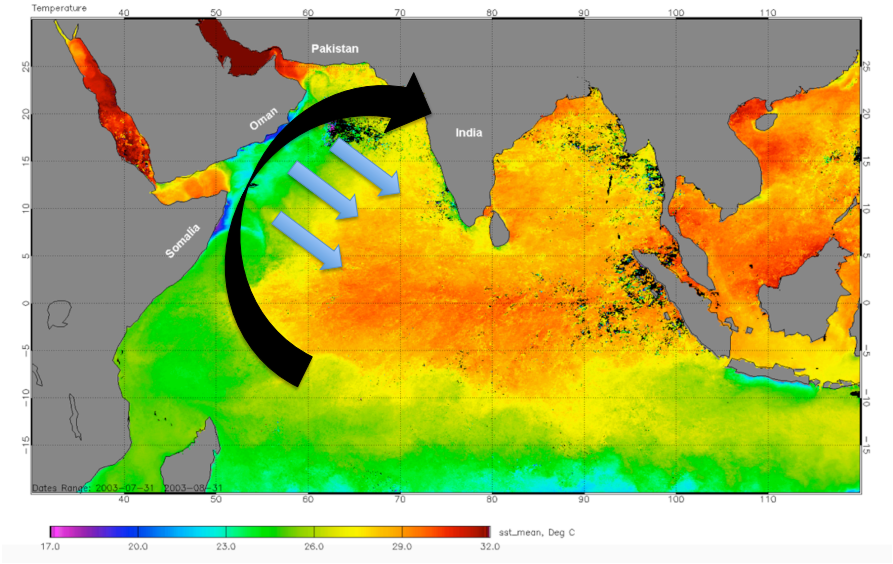
Fig. 3.43. Differences of TRMM PR rainfall and QuikSCAT winds between boreal winter and boreal summer (DJF minus JJA). Warm colors are the boreal summer monsoon regime and cool colors are the boreal winter monsoon regime. (Chang et al. 2005)

Ocean-atmosphere feedbacks

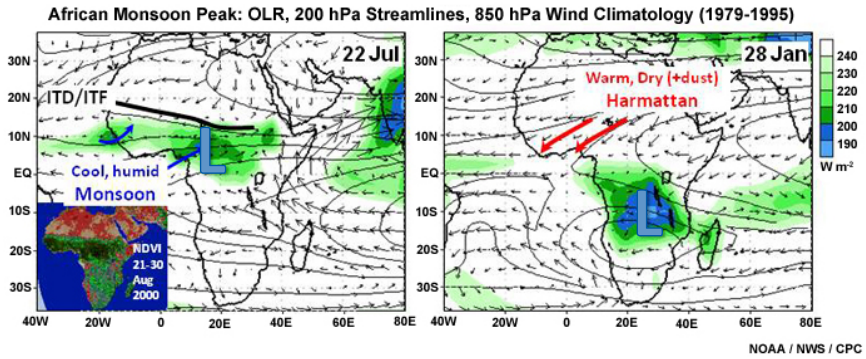
- *the ocean moves energy from summer hemisphere to winter hemisphere, while the atmosphere moves energy from winter hemisphere to summer hemisphere*
- monsoon seasonal cycle modulated by ***negative atmosphere–ocean feedback*** associated with Ekman transport



MODIS SST July 2003



West African Monsoon

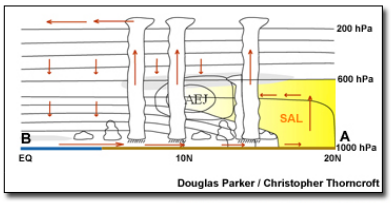


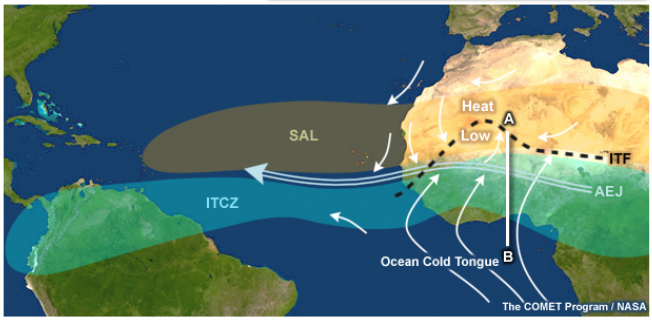
Intertropical Front (ITF) or Intertropical discontinuity (ITD):
boundary between the moist southwesterly monsoon flow and the hot, dry northeasterly wind from the Sahara.

West African Monsoon

AEJ: African Easterly Jet
SAL: Sahara Air Layer

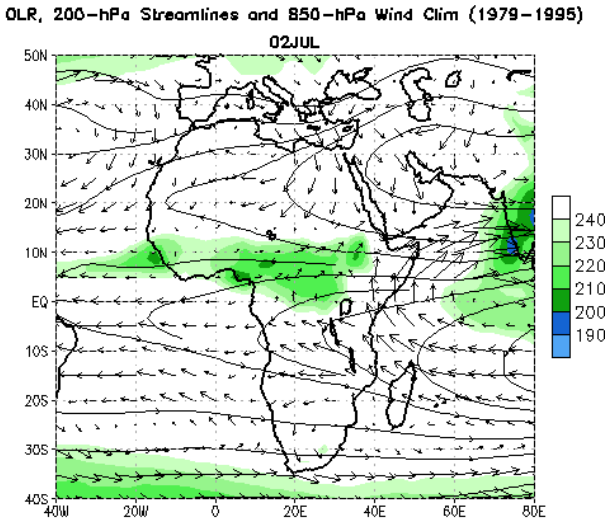
a Large-scale Features of the West African Monsoon and the Tropical Atlantic





Seasonality of West African Monsoon

1. Begins along the Guinea coast in early May
2. late June into early July– the maximum in rainfall shifts to the Sahel
3. Begins its southern retreat in late August and the coastal rainy season ends in early November



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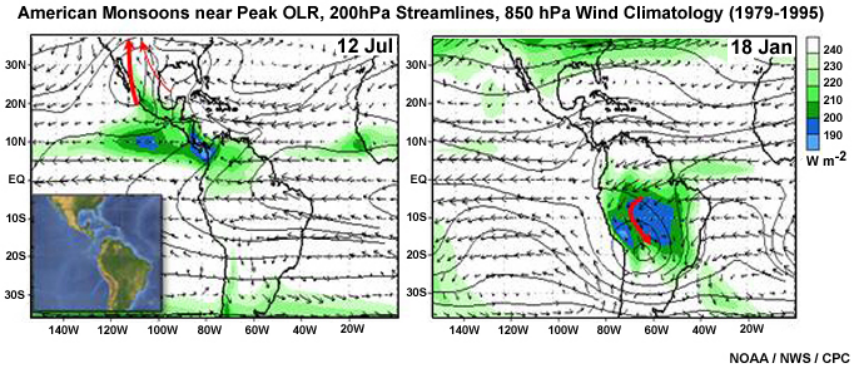
American Monsoons



**do not meet the classical criteria for monsoon as there is no oppositional wind shift during the winter (but there ARE wind anomalies relative to annual mean)

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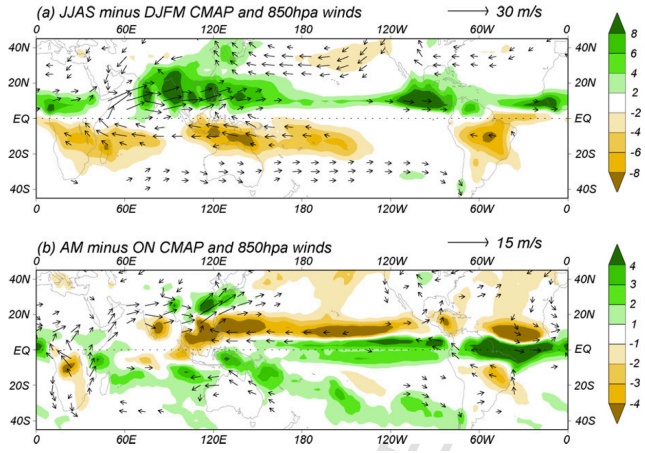
The Global Monsoon

1. Monsoon climates characterized by seasonal reversal of winds. This reversal is global, not just regional
2. Regional monsoons are coordinated primarily by the annual cycle of solar heating

"Solstice Mode"

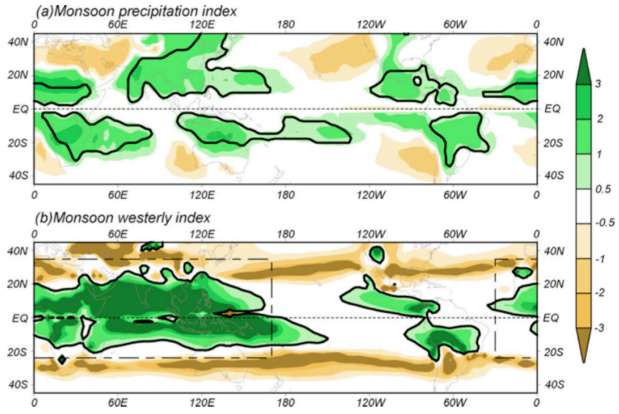
Explain 84% of precipitation variance!!

"Equinox Mode"



Wang and Ding (2008)

Global monsoon regions



$$\text{MPI} = \frac{\text{annual range of precipitation}}{\text{annual mean precipitation}} > 0.5$$

(provided annual mean precipitation > 300 mm)

Wang & Ding, *Dyn. Atmos. Oceans* 2008

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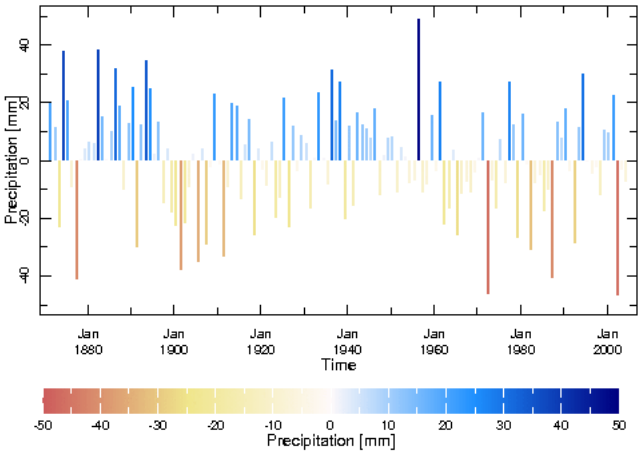
Temporal variability

biweekly, intraseasonal (30-60 days), interannual (e.g., ENSO), interdecadal (and longer!)



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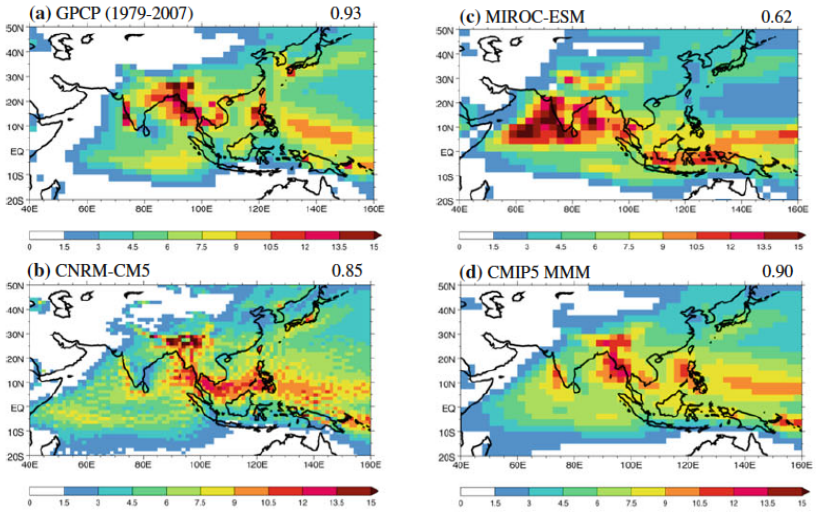
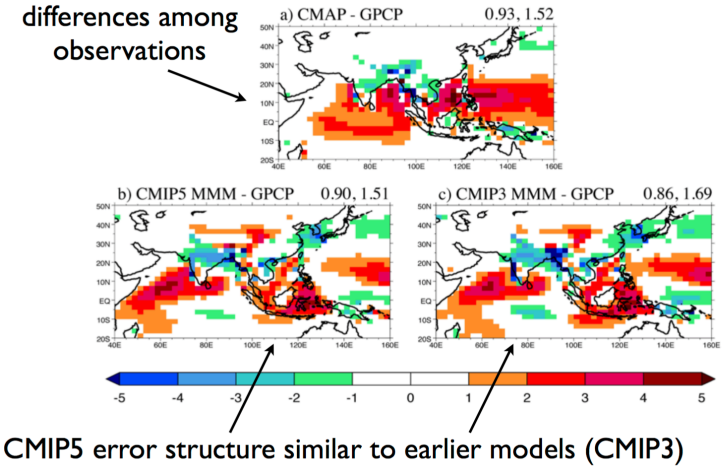
- ***Climate modeling / future monsoon?***

Simulating the Asian Monsoon



Sperber et al. 2013

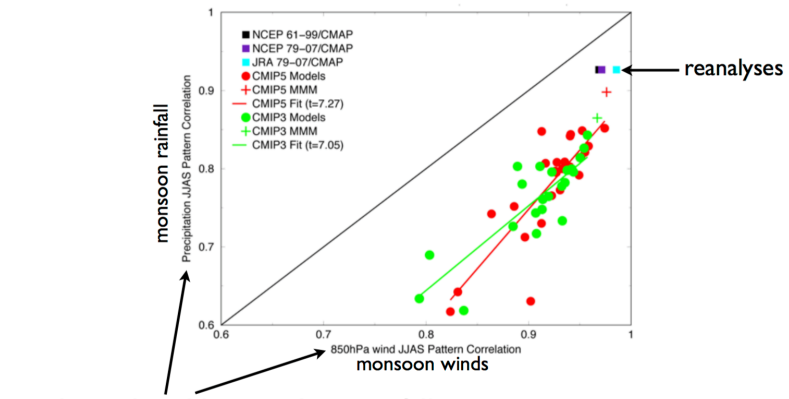
Simulating the Asian Monsoon



Sperber et al. 2013

What are we looking at?

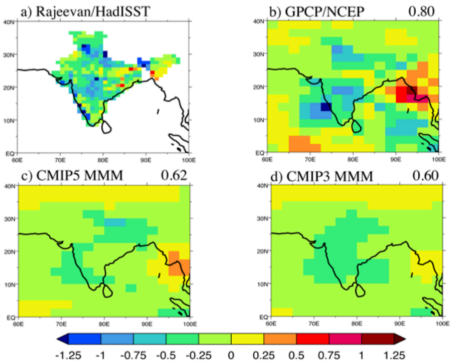
Simulating the Asian Monsoon



Sperber et al. 2013

Simulating the Asian Monsoon

monsoon rainfall during El Niño



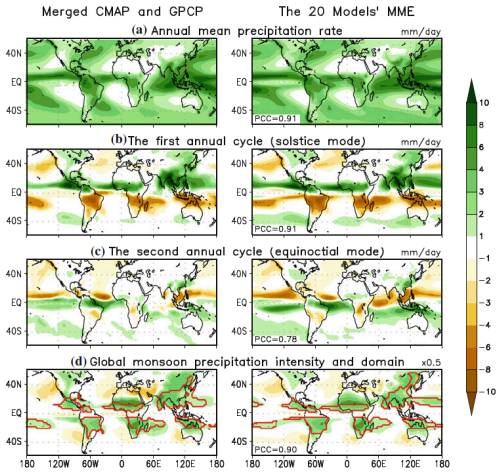
newer models slightly better, but amplitude is still too weak

Sperber et al. 2013

Simulating the global monsoons

Problem areas:

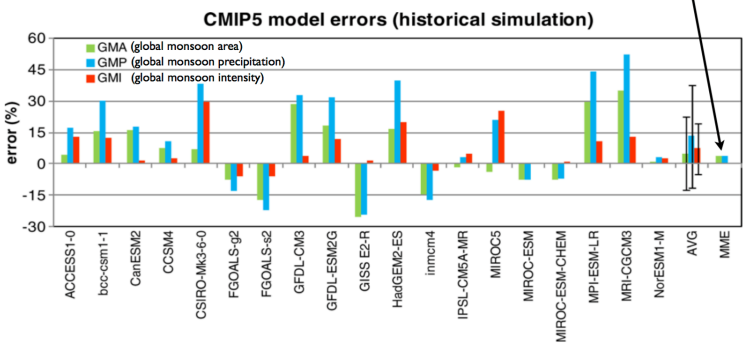
- Eastern Indian Ocean
- Bay of Bengal
- equatorial western Pacific
- tropical Brazil
- Maritime Continent
- Philippines
- high-elevation areas like the Andes and the Tibetan Plateau



Lee and Wang 2014

Simulating the global monsoons

multi-model mean reproduces the global monsoon, but the inter-model spread is large



CMIP5 projects future increases in area, precipitation, and intensity

Hsu et al. 2013

Summary

- Seasonal variations in winds and precipitation due to seasonal variations in heating and T, p gradients
- Can be defined either regionally or globally
- Monsoons arise from coupled interactions between the atmosphere and ocean
- Coupled models are often able to capture the basics of monsoon dynamics, but the multi-model ensemble mean generally performs 'better' than any individual models
- Model representations of the monsoon have improved over the past decade