The Abdus Salam International Centre for Theoretical Physics

2356-7

Targeted Training Activity: ENSO-Monsoon in the Current and Future Climate

30 July - 10 August, 2012

Introduction to American Monsoons

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Introduction to the American Monsoons

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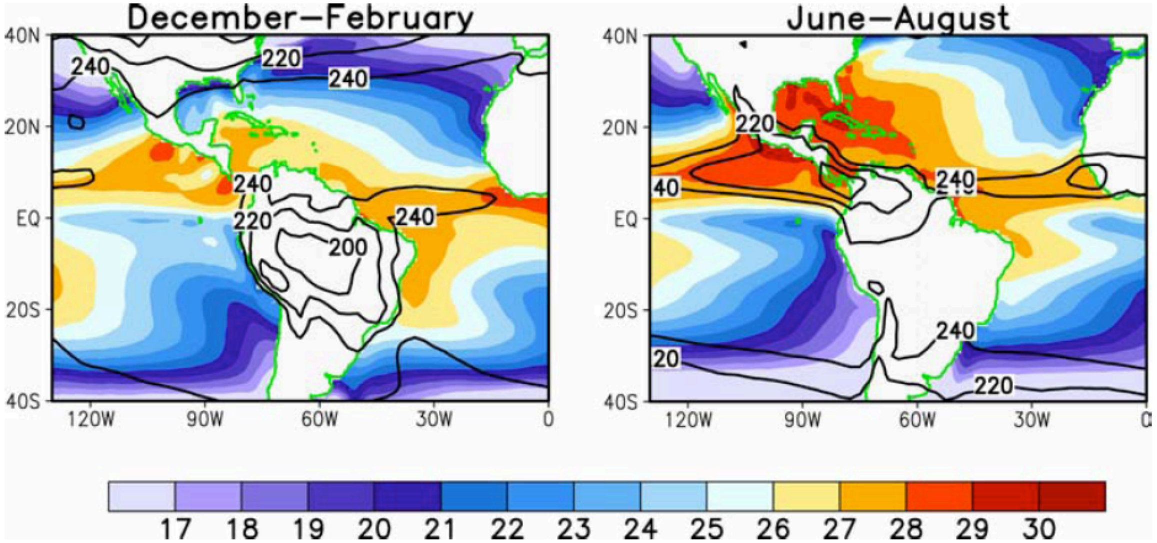
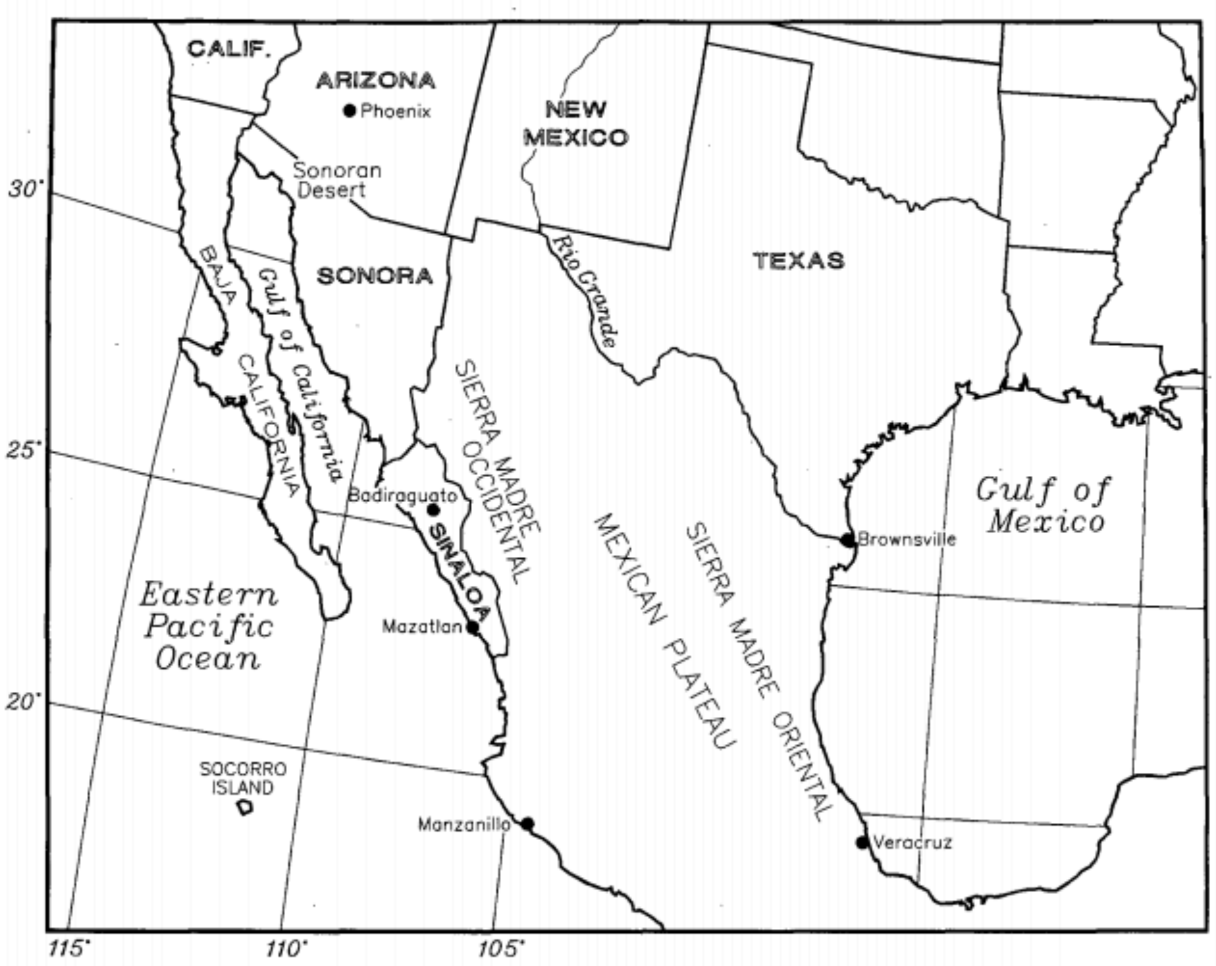


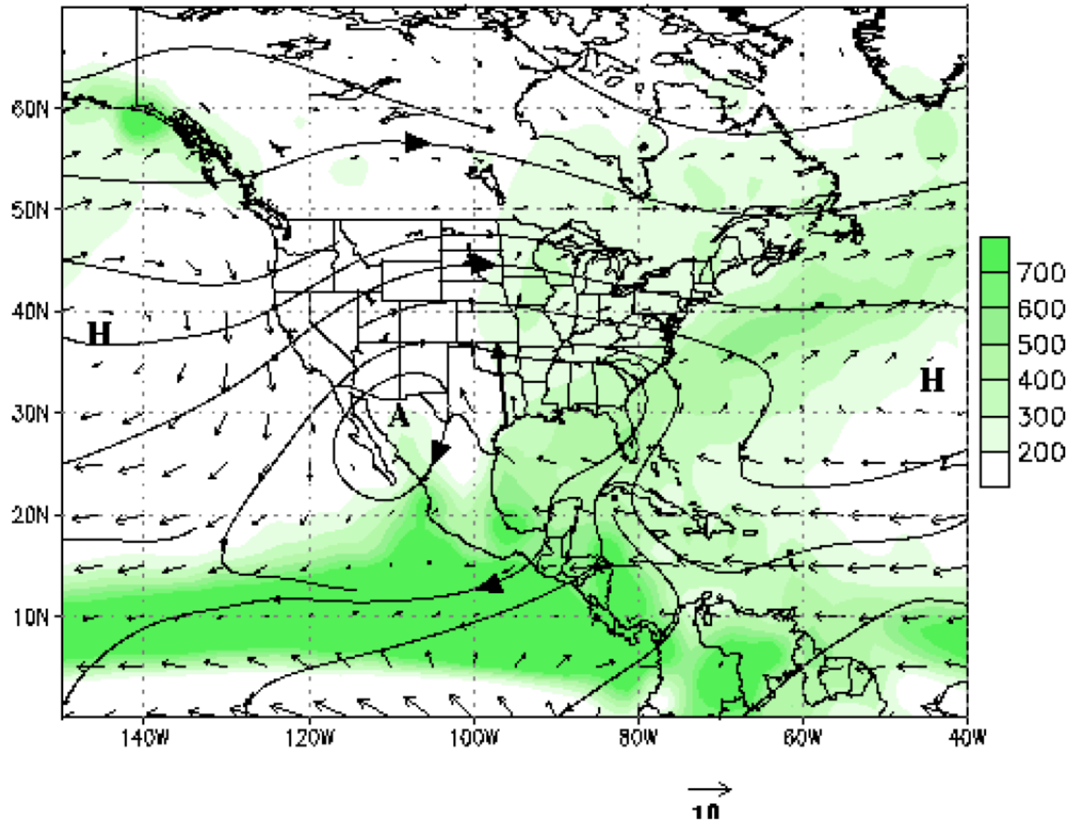
Distribution of SST (^{0}C; shaded) and OLR (Wm^{-2}; contoured)

NAM: North American Monsoon

SAM: South American Monsoon

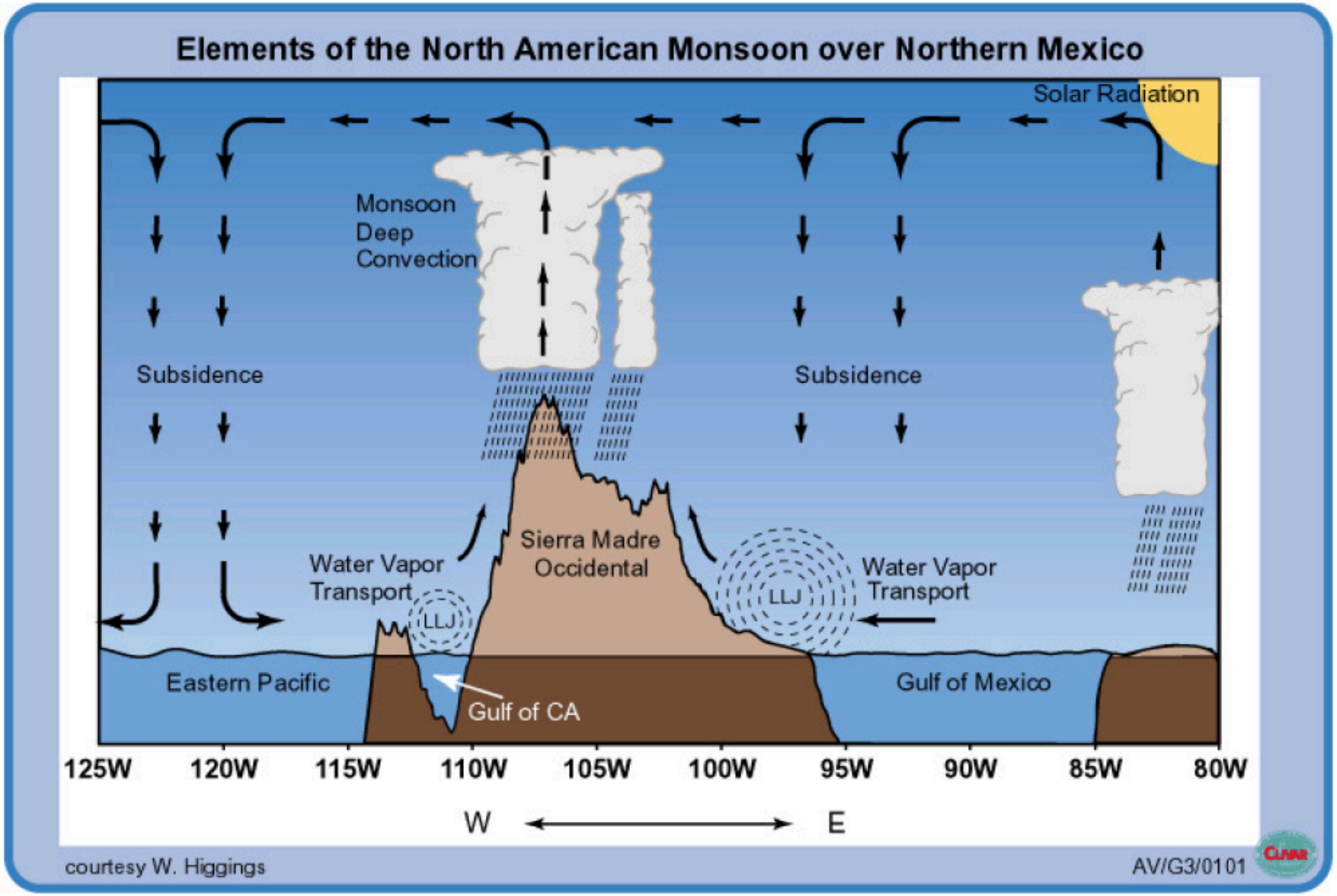


Geography of the North American Monsoon

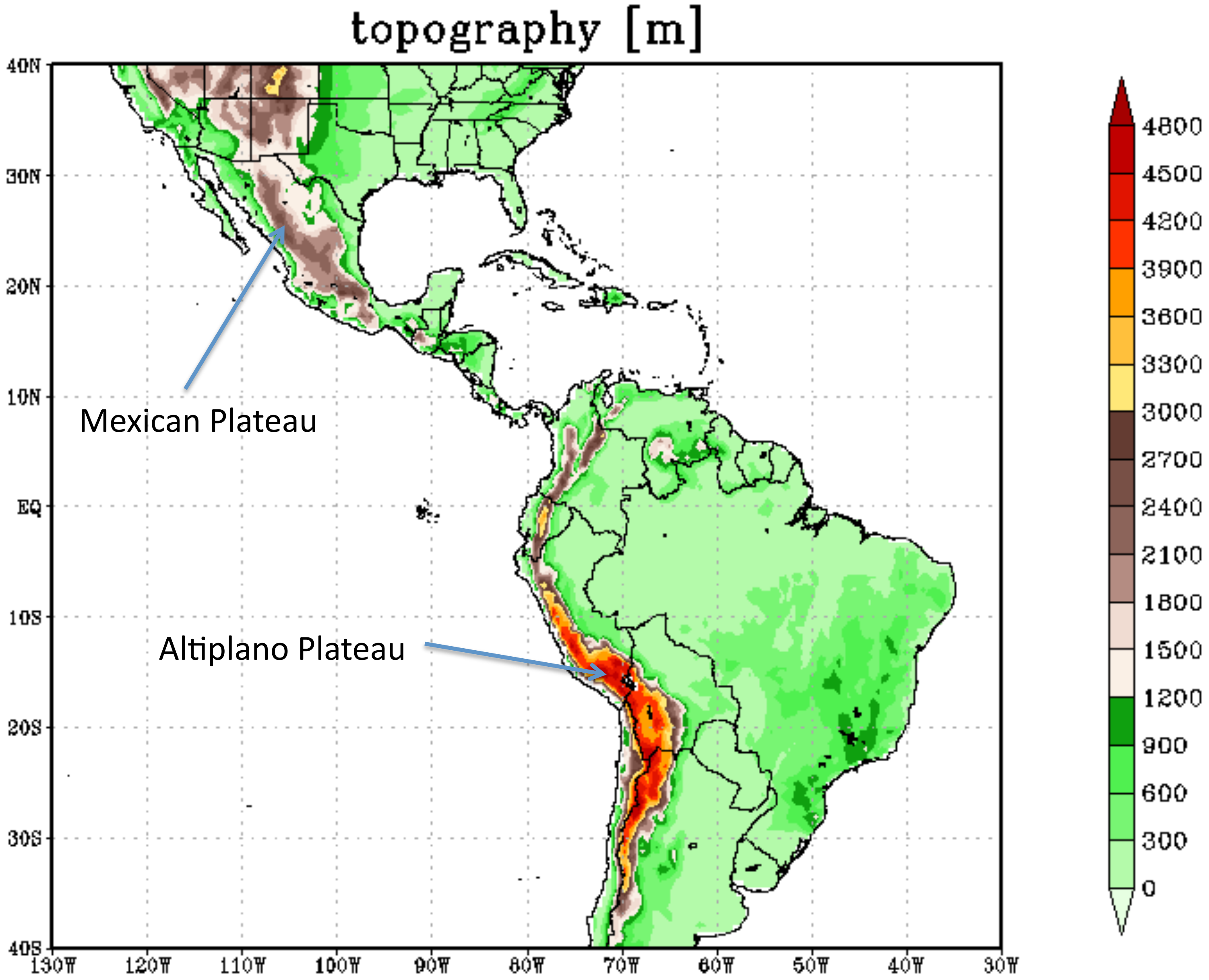


Schematic Illustrating the key features of the North American Monsoon system. The schematic shows mean (July-September 1979-1995) precipitation (shading) in millimeters, lower-tropospheric (925-hPa) vector wind (m s-1) and upper-tropospheric (200- hPa) circulation pattern (contours). The position of the upper-tropospheric monsoon anticyclone is indicated by "A". The mean direction of the circulation is indicated by the large arrows on the contours. The lower tropospheric Bermuda and North Pacific subtropical high pressure centers are indicated by "H". The approximate location of theGreat Plains low-level jet is indicated by the heavy solid arrow.

Note that bulk of the rainfall falls over the ocean ITCZ—however it is an example of a classic thermally direct monsoon circulation with warm (cold) SST's to the north (south) of the equator in the Pacific.



Schematic cross-section of the North American Monsoon system at 27.5^{0}N



topography [m]
40N
30N
20N
10N
EQ
10S
20S
30S
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130W
120W
110W
100W
90W
80W
70W
60W
50W
40W
30W
Mexican Plateau
Altiplano Plateau
4800
4500
4200
3900
3600
3300
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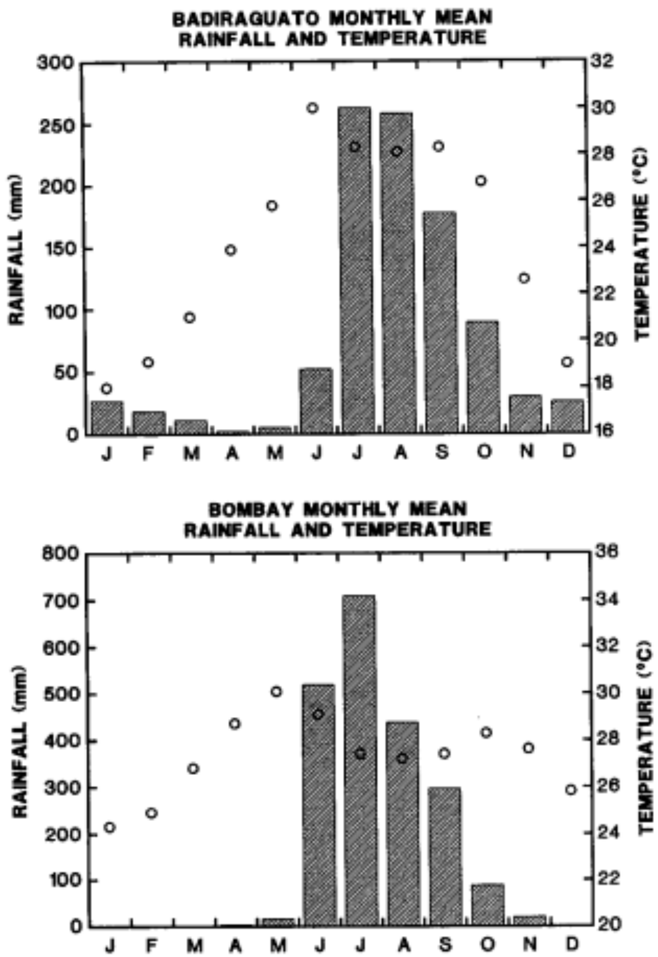
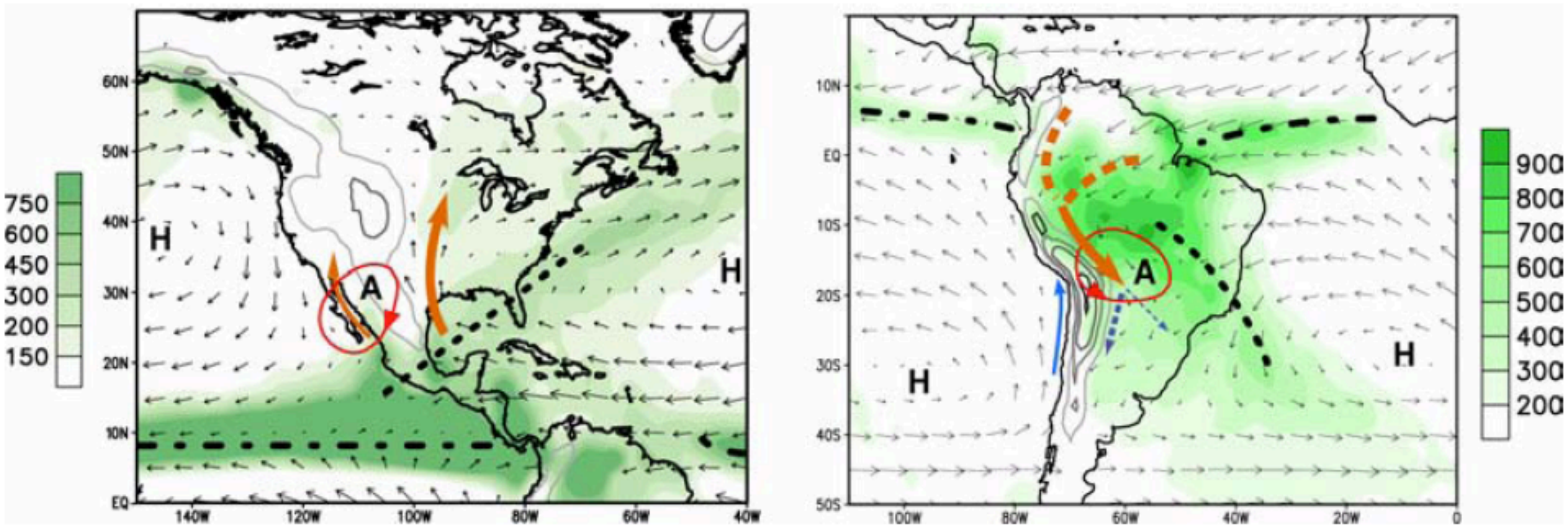


Rainfall histograms for a station in (top) Sonora and (bot) along west coast of India showing similar pattern of mean monthly precipitation (bars, mm) and temperature (open dots). From Douglas et al. 1993

- Both NAM and SAM in the first order are manifestation of reversal of temperature gradients that is associated with temperature contrast between land and adjacent oceans
- The concomitant development of surface low is accompanied by upper level anticyclone and summer rainfall



Precipitation (shaded), convergence zones (dashed lines), low level jets (thick red arrow), overlaid on 925hPa winds and A indicates upper level monsoon anticyclone and H low level subtropical highs.

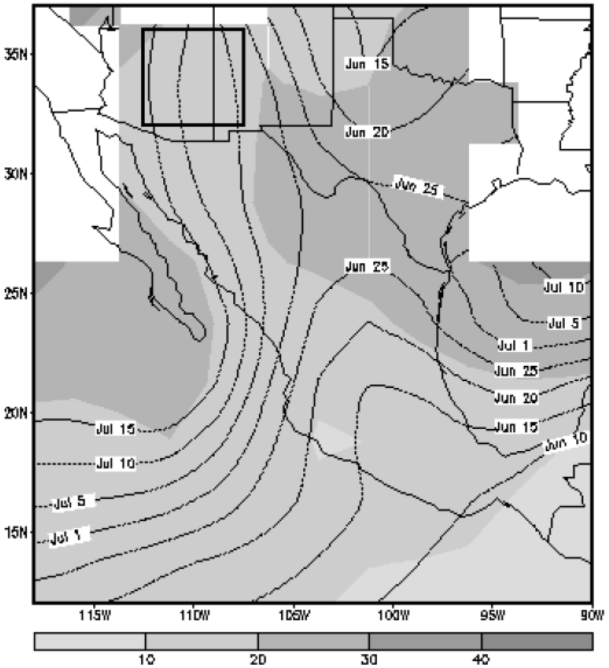
NAM is characterized by a region of intense precipitation extending from E. Pacific ITCZ , extending northward over Mexico-Southwest US, northeastward over Gulf of Mexico and finally merging with North Atlantic storm track.

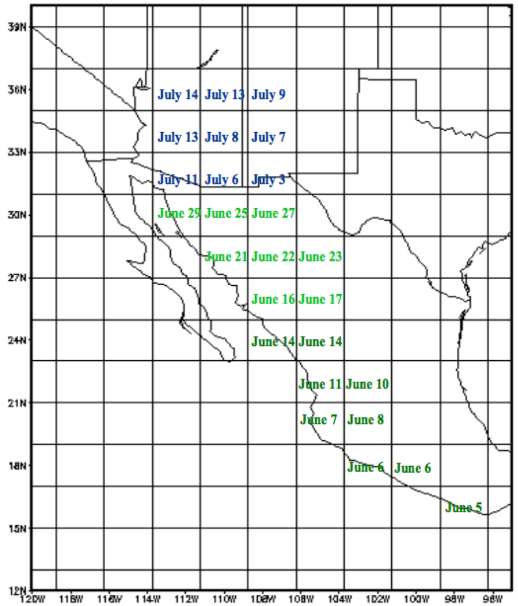
SAM is characterized by intense precipitation over central Brazil and Bolivia, linked with Atlantic ITCZ, extending to the south Atlantic convergence zone.

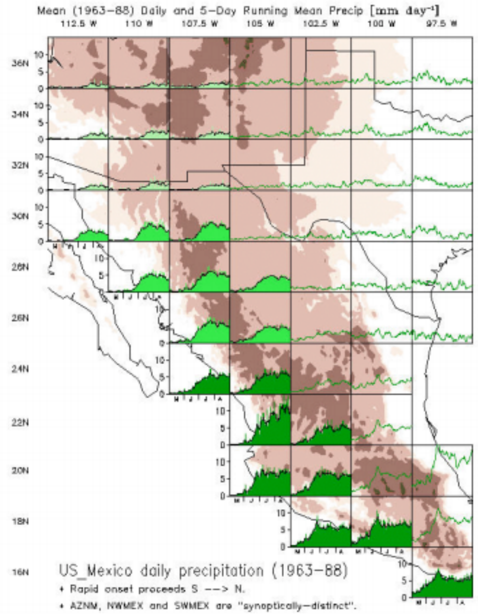
NAM features

- Bulk of the monsoon falls from July through September
- The continental component of the NAM is a relatively small fraction of the total rainfall that is over the neighboring ocean—the oceanic monsoon is from the meridional migration of the ITCZ

Climatological onset dates of NAM







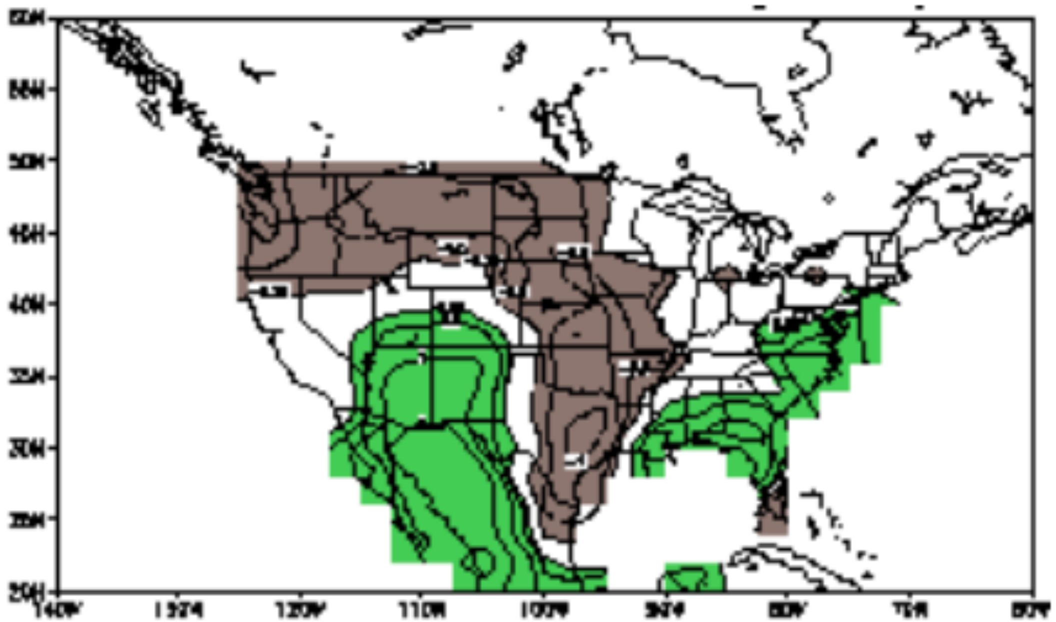
i) The monsoon rainfall progresses along Sierra Madre Occidental toward the east.

ii) The June rainfall is relatively modest even in Mexico.

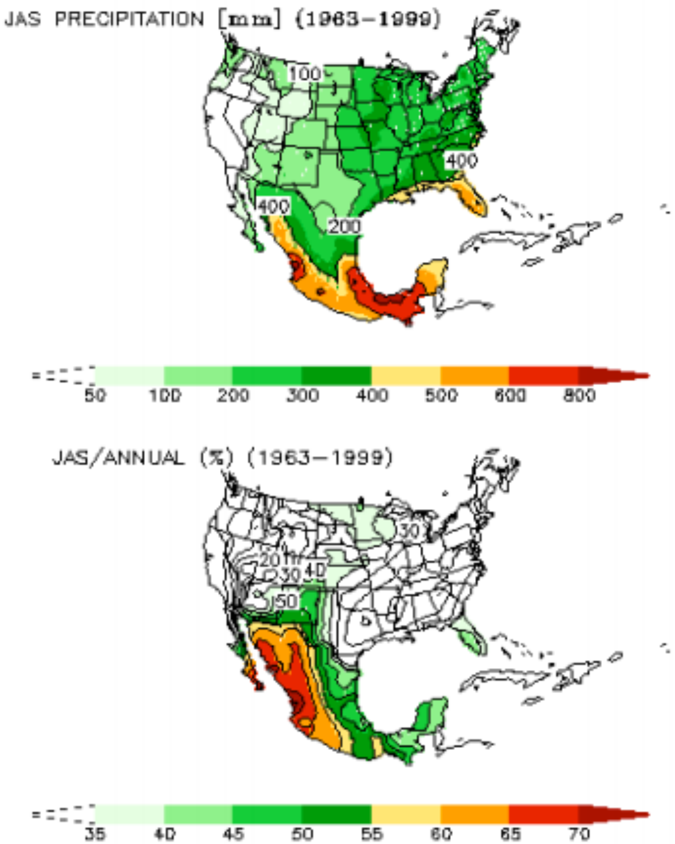
iii) In July rainfall has lined up from west-central Mexico northward into southwest US.

iv) August is rainiest month over much of the region

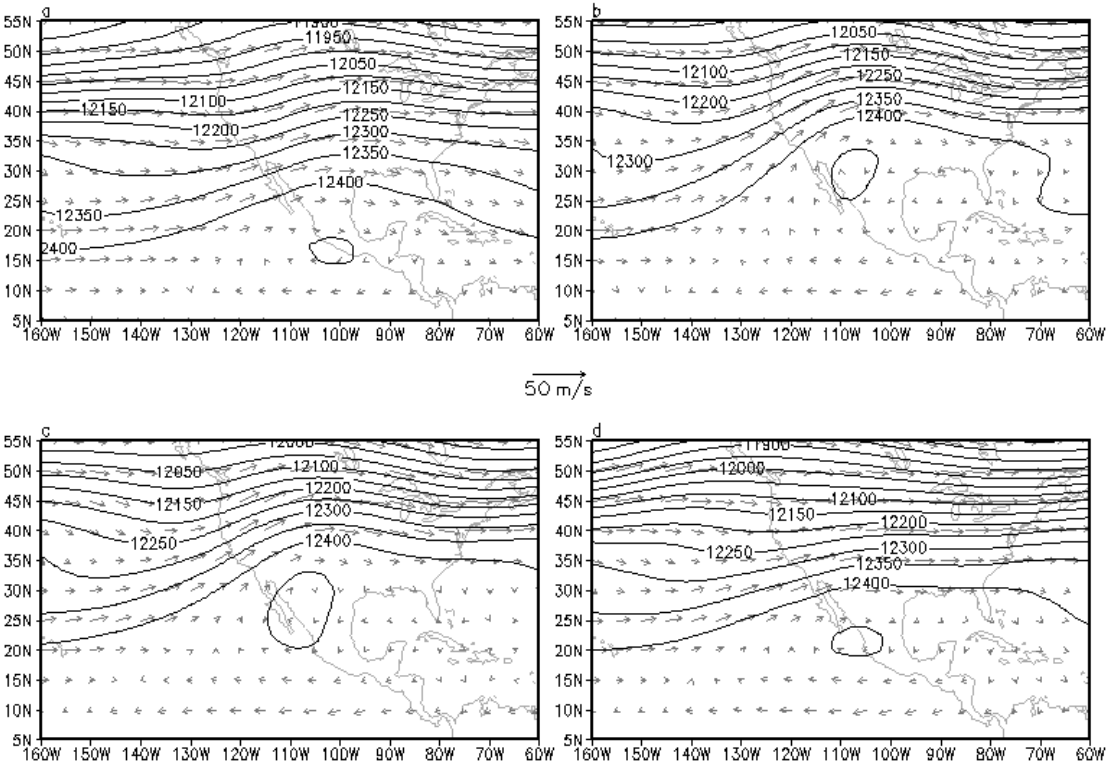
v) The rapid June to July increase in monsoon rainfall is coincident with dramatic decreases in US central Plains



Mean climatological difference between July and June. Values greater than 0.25mm day^{-1} (less than -0.25mm day^{-1}) are shaded green (brown). The climatological onset of summer rains in Northern Mexico and Arizona coincides with a decrease of rainfall over the Great Plains and increase over the east coast.

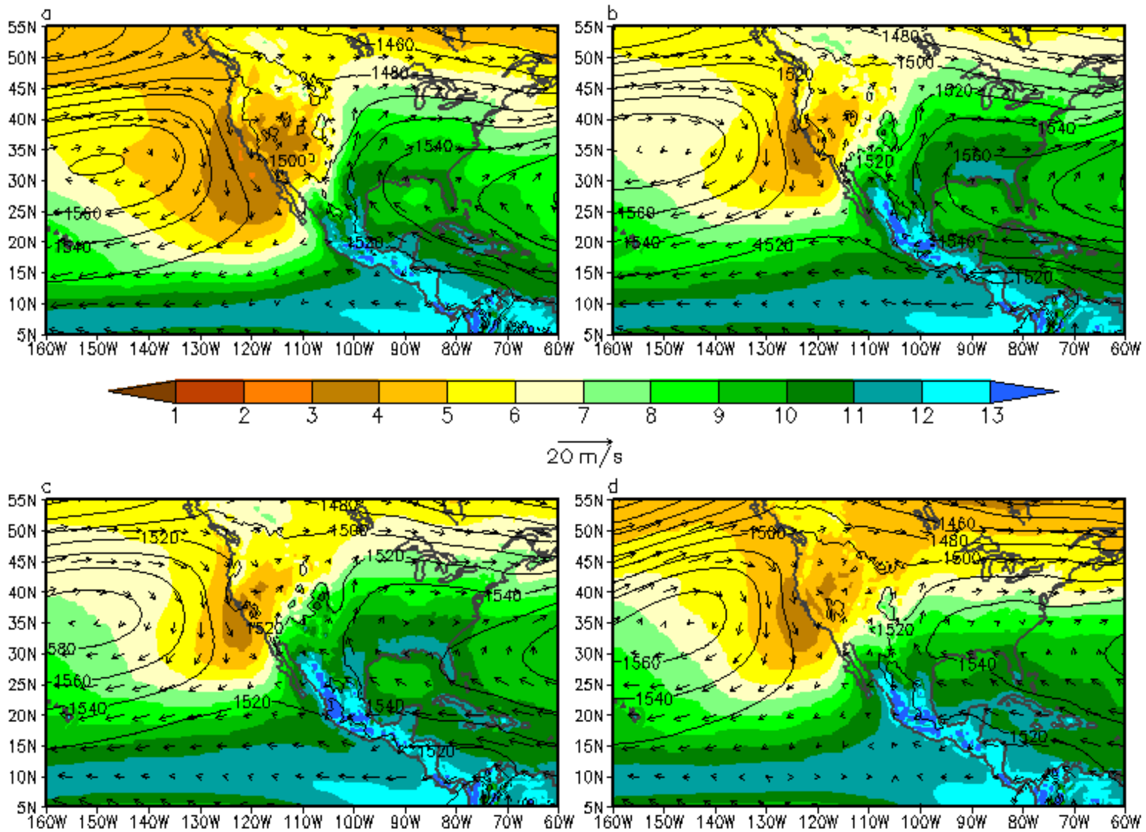


(Top) Mean seasonal precipitation (mm) for July-September. (Bottom) Percent of annual rainfall falling in July-August-September.



1961-1990 average from NCEP-NCAR reanalysis of 200hPa winds and geopotential heights for a) June, b) July, c) August, d) September

i) Because of complex terrain, evolution of NAM best seen at 200hPa.
ii) Notice gradual increase in strength of upper level anticyclone and its weakening by September



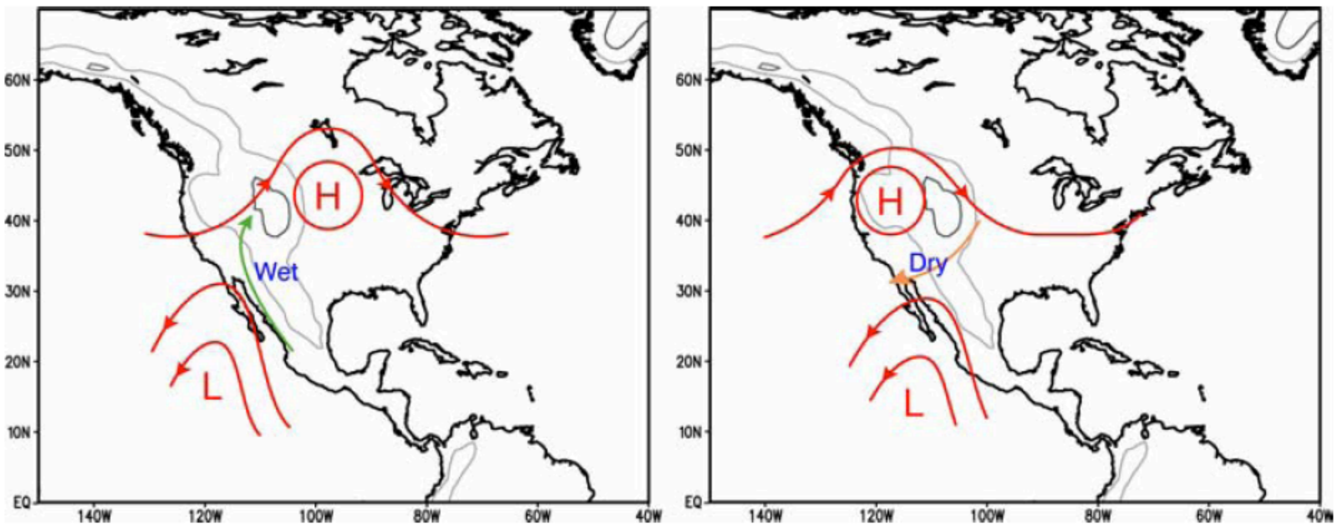
1961-1990 average from CFSR reanalysis of 850hPa wind, specific humidity (shaded; g/kg) and geopotential heights (contoured) for a) June, b) July, c) August, d) September

i) The northerlies on the eastern edge of the north Pacific subtropical high diminishes in strength in spring and summer and are well off the coast.
ii) In spring and early summer the southeasterly and southerly flow from Gulf of Mexico feed moisture to Great plains, lee side of the Rockies.
iii) The mean low level winds are strongest in regions of relatively weak moisture gradients i.e. to the east of the Sierra Madre mountains and, in contrast, strong low level moisture gradients appear along the west coast of Mexico in a region where the CFSR Reanalysis shows the mean wind fields to be near zero during each month of the monsoon season.

Gulf Surges

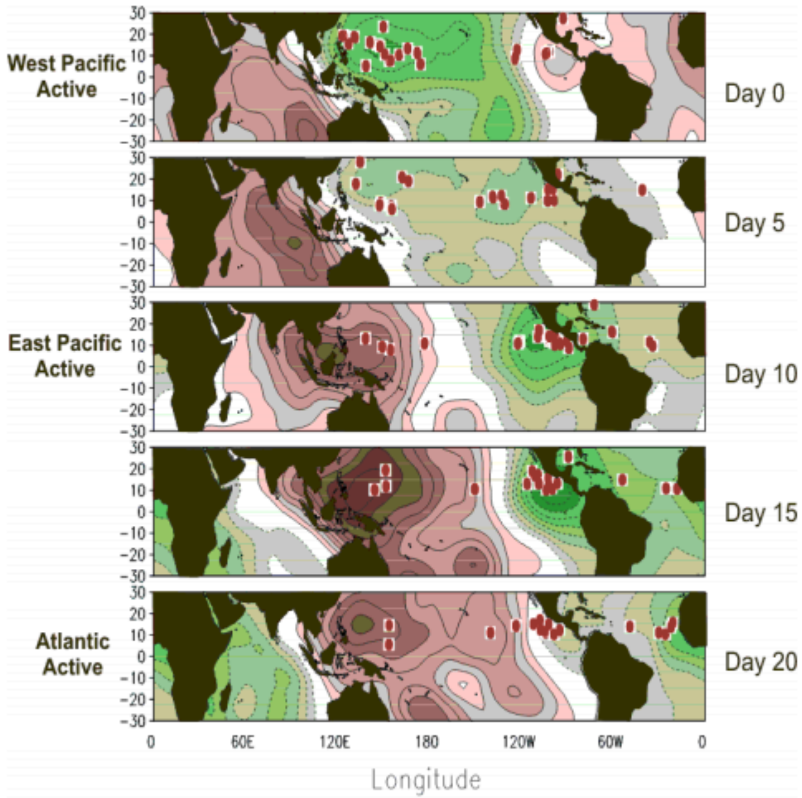
- Gulf surges are pulses of strong southerly winds that transport moisture up Gulf of California
- The link between Gulf surges and rainfall anomaly of NAM is not strong
- Surges are related to propagation of easterly waves across Gulf of Mexico
- Gulf surges are characterized by changes in surface weather including rise in dewpoint temperature, warm (cold) nighttime (daytime) temperatures, increased cloudiness and precipitation and shift of the winds to southerly or southeasterly.

Intra-seasonal variations of the NAM



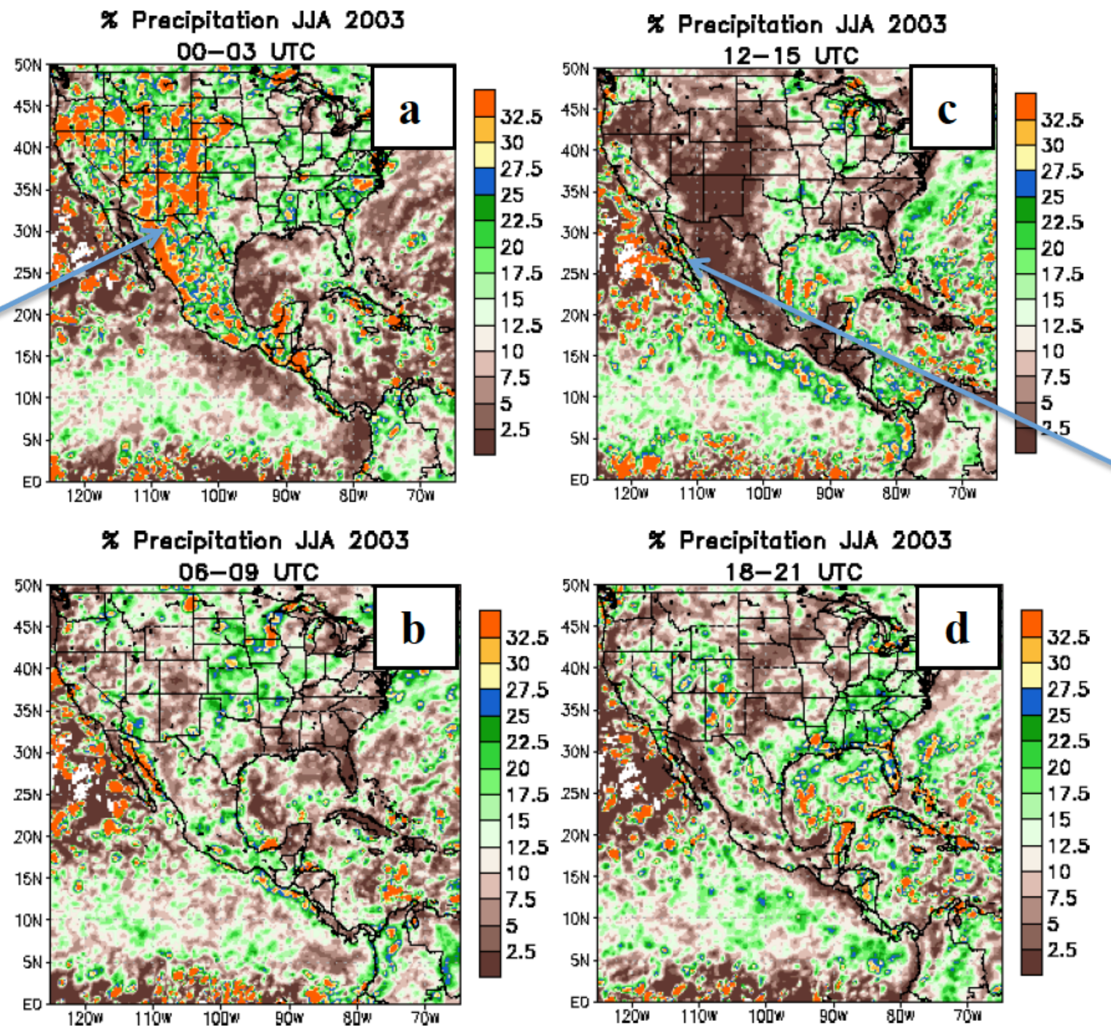
700hPa schematic of the wet (left) and dry (right) Gulf of California moisture surge event for Arizona.

The wet and dry surge depends on the location of the upper level ridge axis. If it is located further eastward (westward) then it is wetter (drier) than seasonal average over Arizona.



Evolution of MJO events during the summer months together with points of origin of tropical cyclones that developed into hurricanes/typhoons (red dots). The green (brown) shading roughly corresponds to regions where precipitation is enhanced (suppressed). Results are based on 21 MJO events over 19 summers. Tropical cyclone data for Indian Ocean is not included.

Diurnal variations



Late afternoon maxima

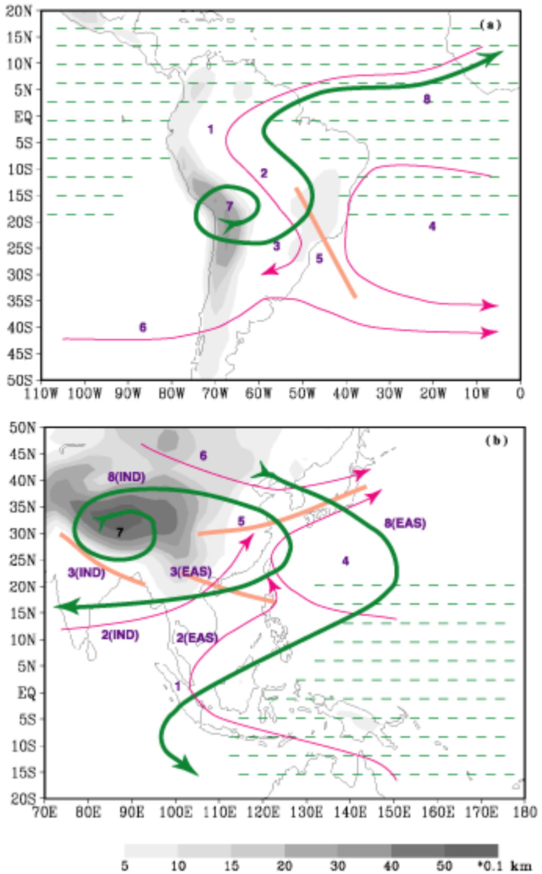
Local mid-night maxima in Gulf of California

South American Monsoon System

South American Monsoon System Components

South American

Asian

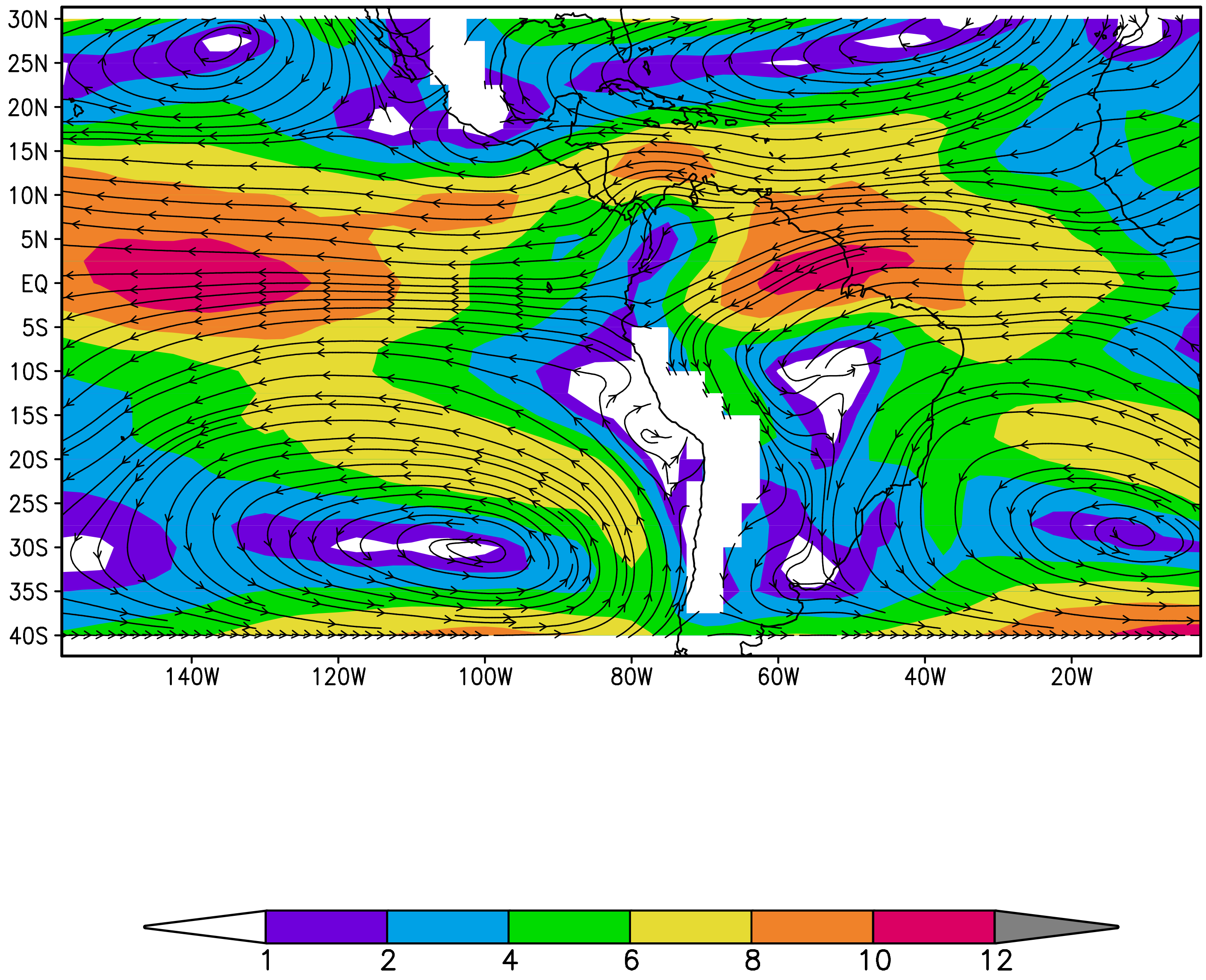


From Zhou and Lau, 1998

- 1-Low level cross-equatorial flow
- 2-Northwesterlies vs. Southwesterlies
- 3-GC low vs. EASM trough
- 4-subtropical high
- 5-SACZ vs. Mei-Yu Front
- 6-Mid-latitude westerlies
- 7-Bolivian High vs. Tibetan High (*Upper level*)
- 8-Upper level return flow

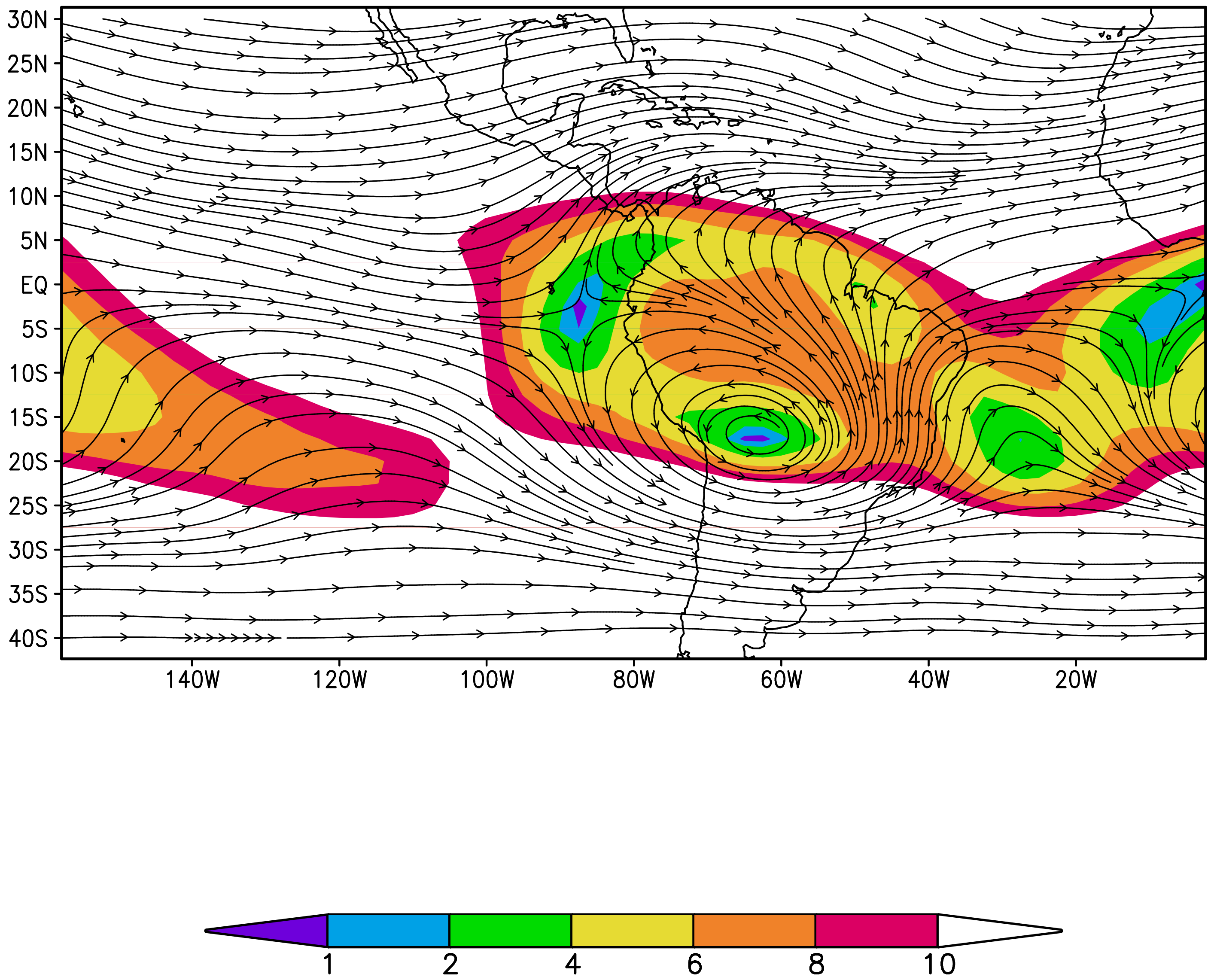
850hPa Circulation (NCEP Reanalysis, ms^{-1})

DJF Climatology

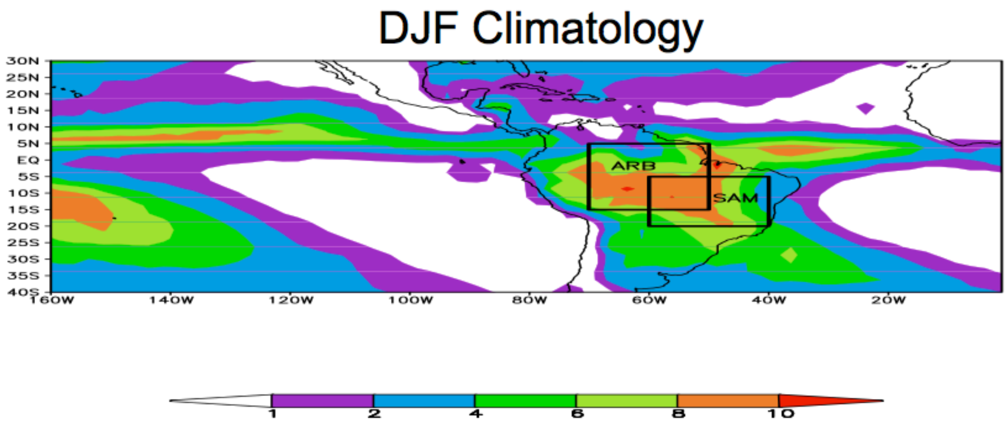


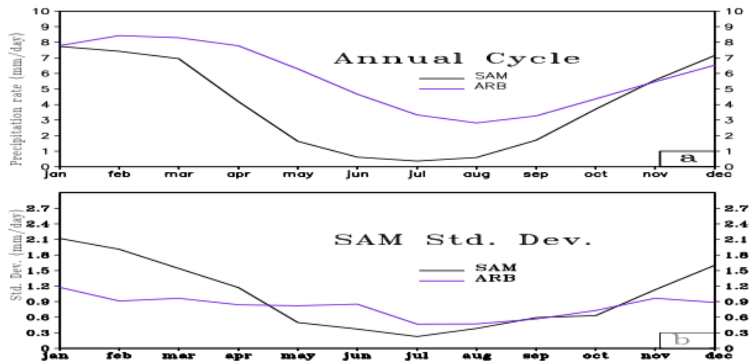
200hPa circulation (NCEP Reanalysis, ms^{-1})

DJF Climatology



Precipitation (mm/day) from Obs (CMAP)



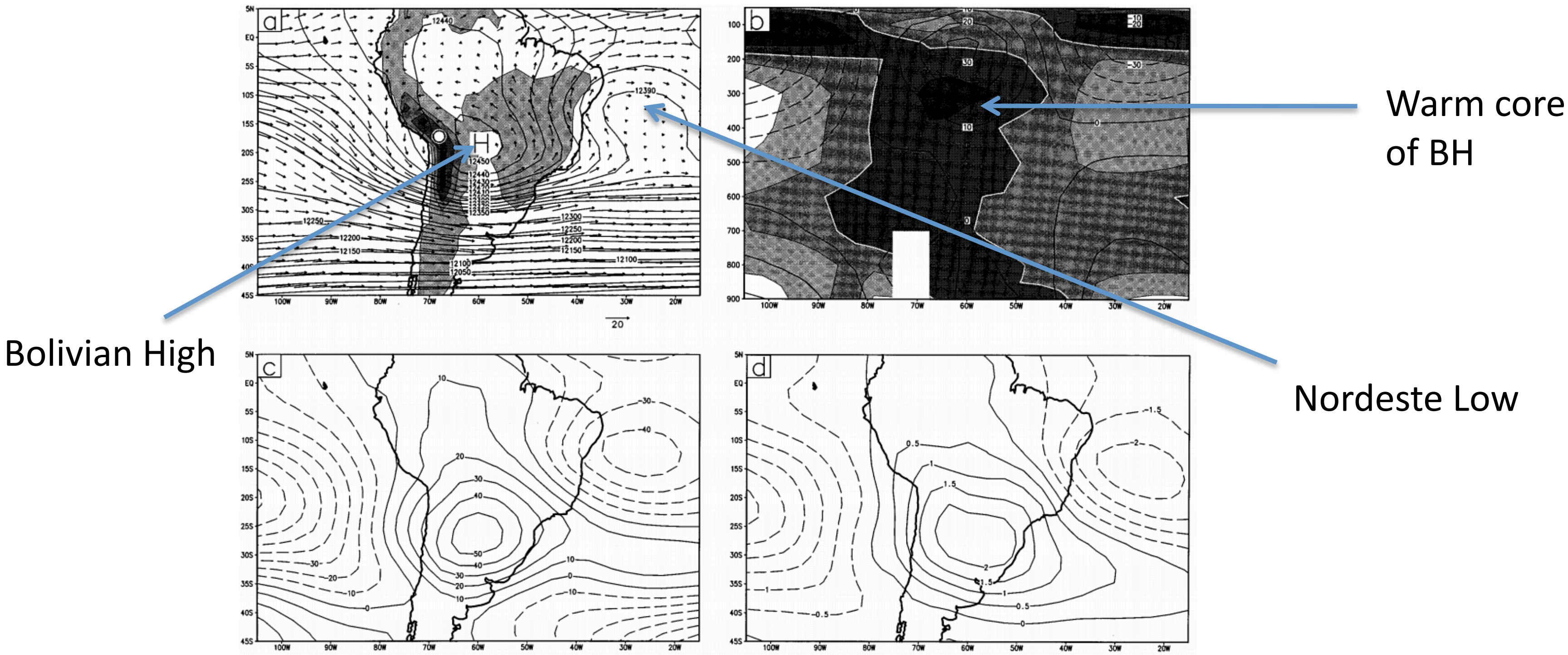


The seasonal cycle of the SAM domain has a larger amplitude than that over ARB. More importantly the interannual variations of SAM are phase locked with the seasonal cycle like rest of the monsoons.

Upper level circulation features of the South American Monsoon

- Bolivian high is a warm core anticyclone with a maximum anomaly at 300hPa and is capped by a cold anomaly at 100hPa
- Much of the Bolivian high is produced in absence of Andes.
- Bolivian high is collective response to latent heat release in Amazon, central Andes and SACZ

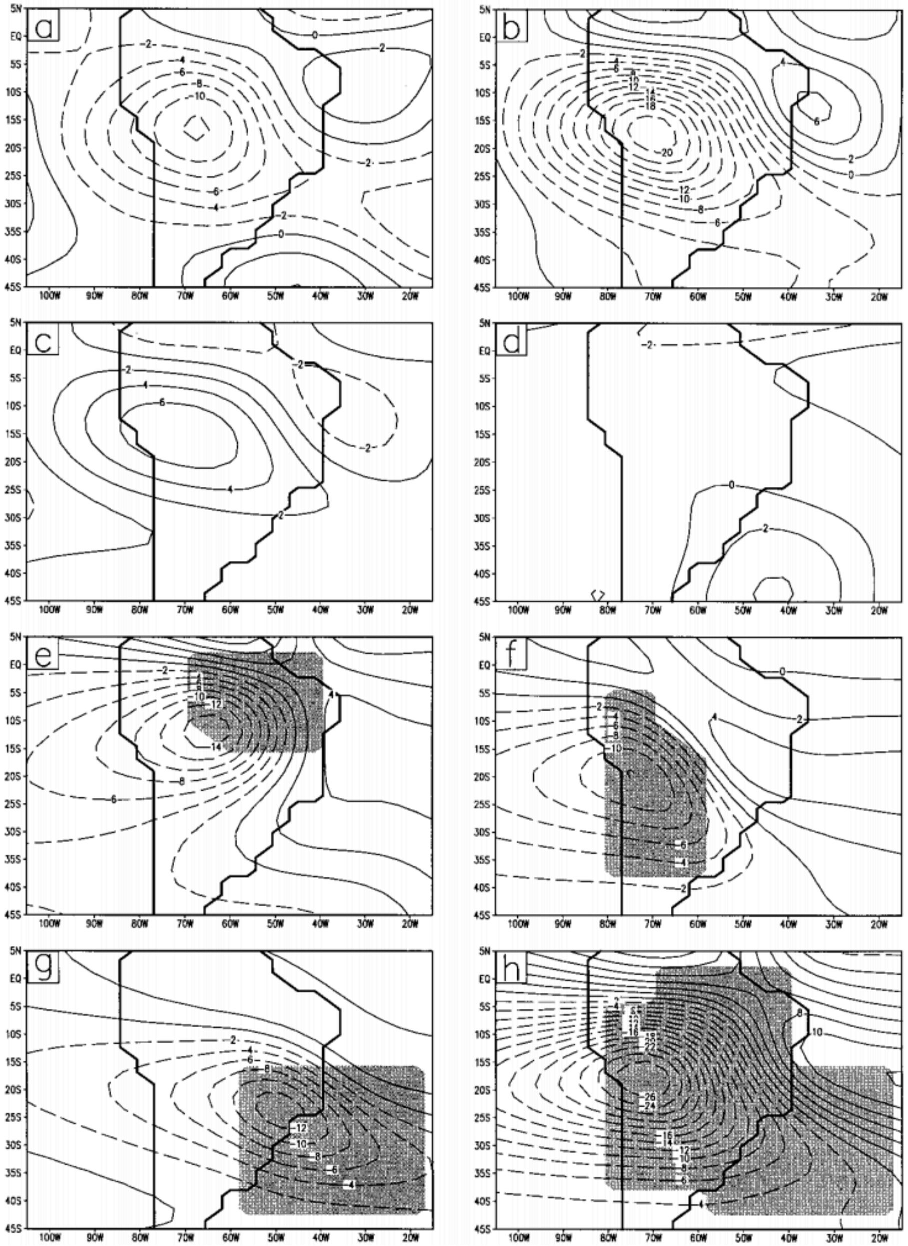
Warm core structure of Bolivian high and cold core structure of Nordeste low



Eddy Geopotential height at 200hPa

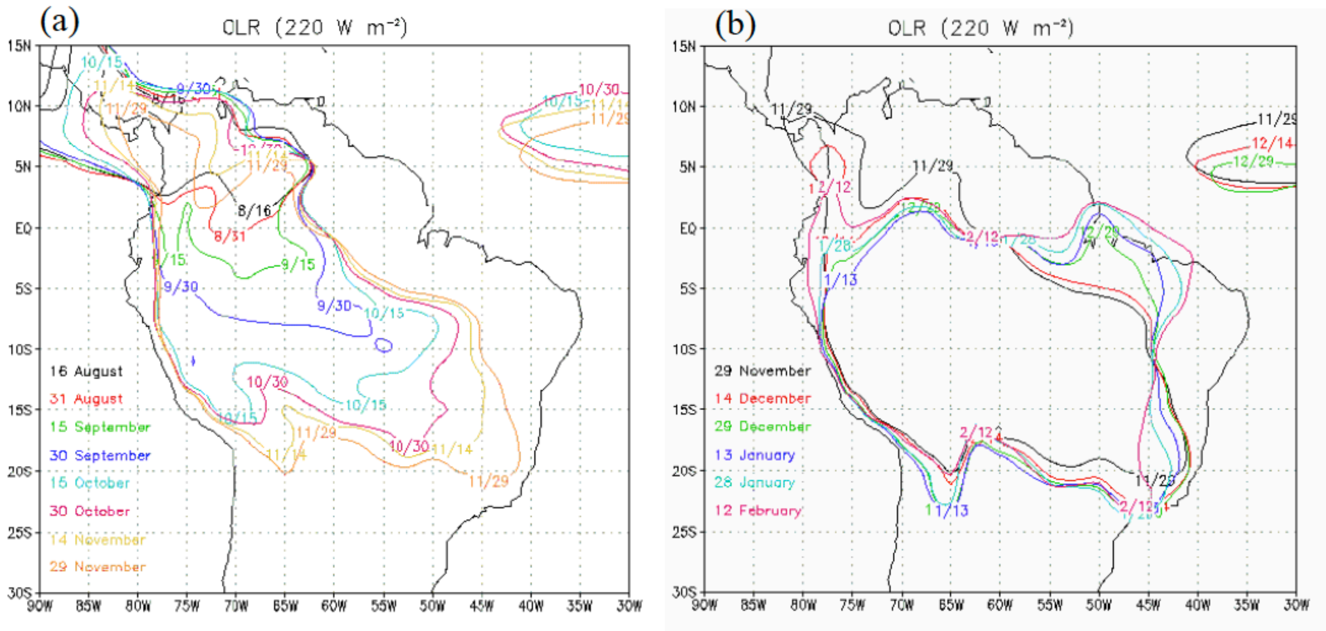
Eddy temperature at 300hPa

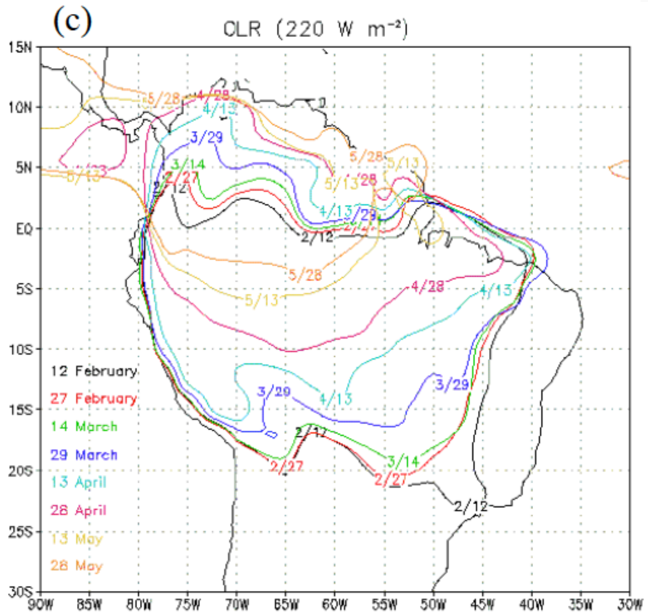
(a) Geopotential height (maximum denoted by ''H'') and wind vectors at 200 mb from NASA/DAO observations. Above 12350m the contour interval is 10 m, while below it is 50 m. Shading denotes topography (contour interval 1000 m, starting at 250 m), and the vector in the lower right corner indicates a wind speed of 20 ms^{-1}. The approximate location of the Altiplano is shown with a white circle. (b) Vertical cross section of eddy geopotential height (contour interval 10 m, negative contours dashed) and eddy temperature (shaded, 1-K interval; white contour denotes the 0-K line and darker shading denotes higher temperature), averaged from 10 to 25S. (c) Eddy geopotential height at 200 mb (contour interval 10 m, negative values dashed). (d) Eddy temperature at 300 mb (0.5-K contour interval, negative values dashed). From Lenters and Cook (1997).



Results from a steady state and a linearized about a zonally uniform basic stateGCM

Eddy streamfunction at around 350hPa from the linear model with (a) full forcing, (b) condensational heating, (c) thermal transient forcing (eddy terms), (d) mechanical forcing by topography, and condensational heating restricted to (e) the Amazon basin, (f) the central Andes, (g) the SACZ, and (h) all three regions. Contour interval is 2 $x10^6 m^2 s^{-1}$, and shading in (e)–(h) indicates the geographic extent of the imposed forcing.





Mean evolution of the 220 Wm^{-2} OLR contour for the (a) onset, (b) mature phase, and (c) decay phase of the South American Monsoon (from Grimm et al. 2000).

References

- Douglas, M. W., R. A. Maddox, and K. Howard, 1993: The Mexican Monsoon. J. Climate, 6, 1665-1677.
- Lenters, J.D. and K. H. Cook, 1997: On the origin of the Bolivian High and related circulation features of the South American Climate. J. Atmos. Sci., 54, 656-677.
- Misra, V., 2007: Coupled Air, Sea, and Land interactions of the South American Monsoon. J. Climate,21, 6389-6403.