On Improving Precipitation Diurnal Cycle and Frequency in Global Climate Models

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Outline

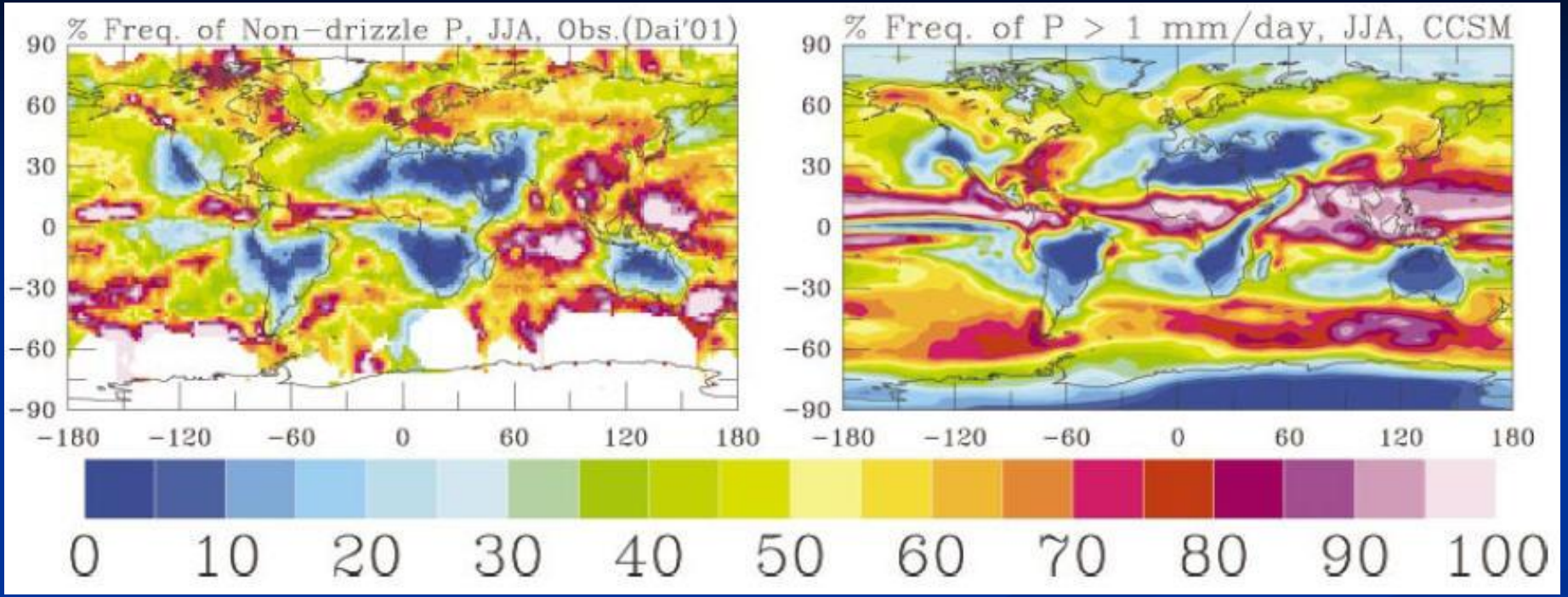
1. The Challenge
2. The Root of Problem
3. Methods
4. Simulations
5. Precipitation Characteristics
6. Summary and Remark

The Challenge

The intensity and variability of global precipitation will in no doubt greatly affect people and society in future climate change. However, the representation of precipitation processes in general circulation models (GCMs) remains a major challenge for climate prediction and research.

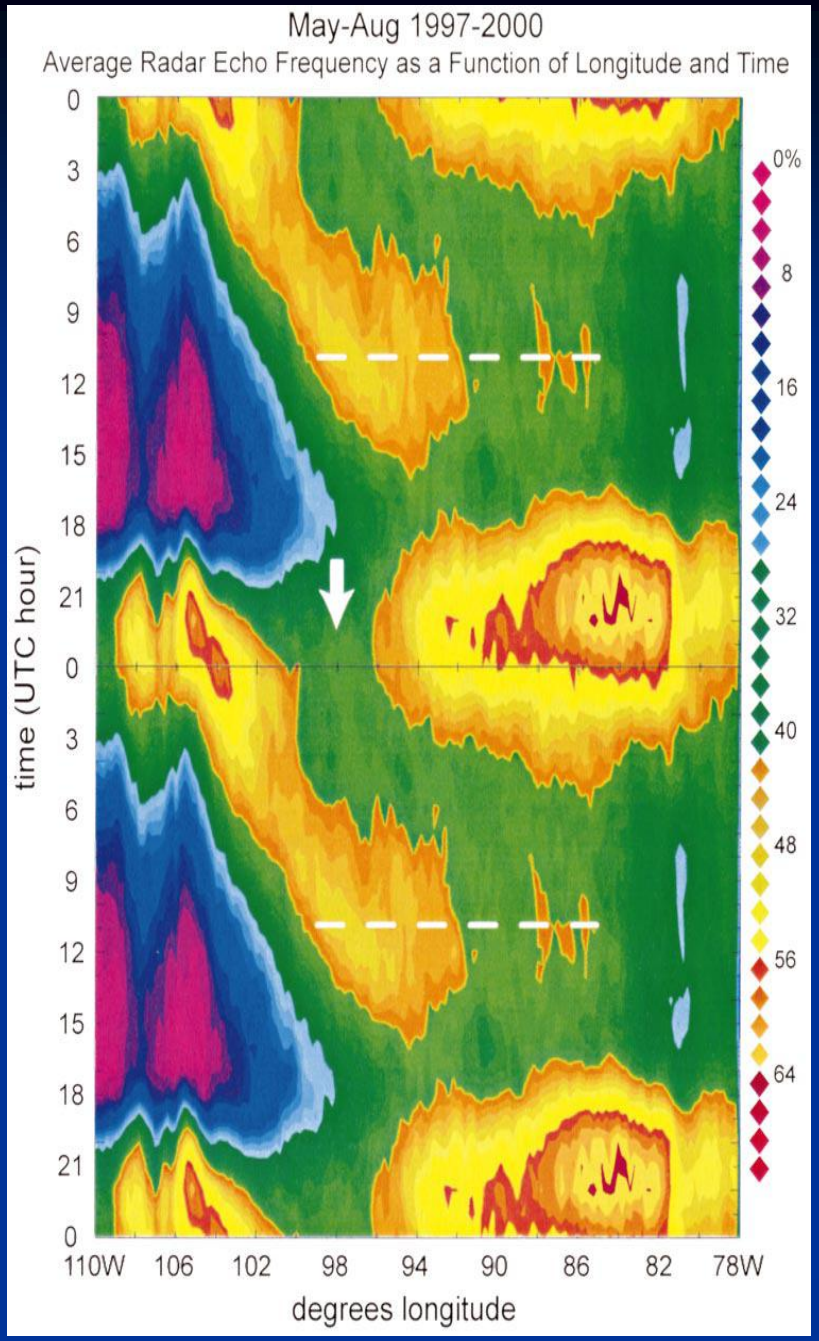
Most GCMs rain too often, overproduce light precipitation but underestimate heavy precipitation. The models do not reliably reproduce the observed diurnal cycle of precipitation with distinct geographic patterns over United States, China, and South America.

Hence the credibility of climate prediction or climate change projection made by GCMs is limited.

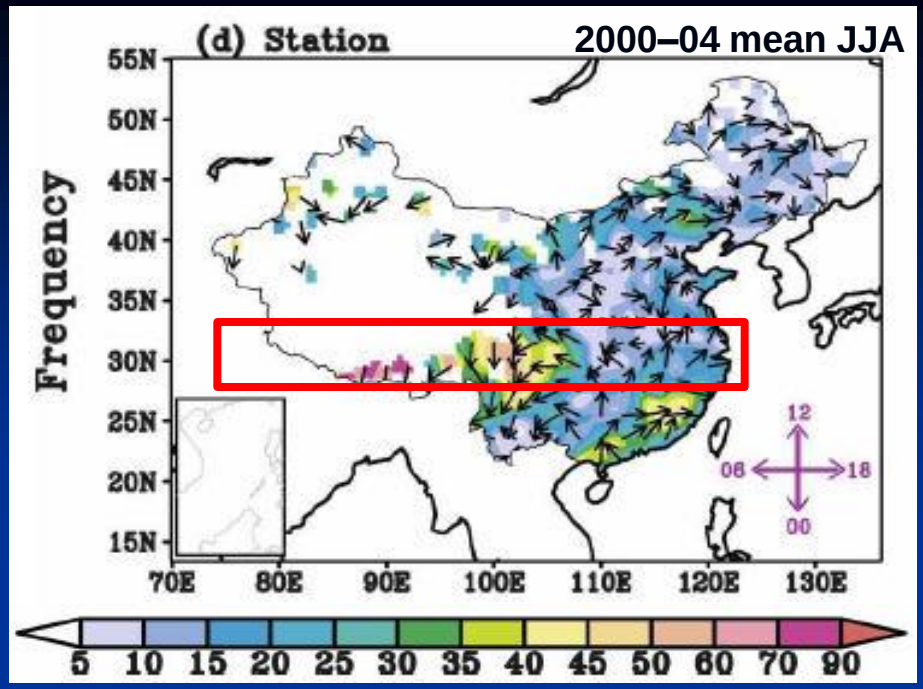


(left) Weather-report-based and (right) CCSM-simulated JJA precipitation frequency (%), which is defined as the percentage of the total number of days with one or more reports of nondrizzle precipitation for the left panel and with precipitation exceeding 1 mm/day in the CCSM for the right panel.

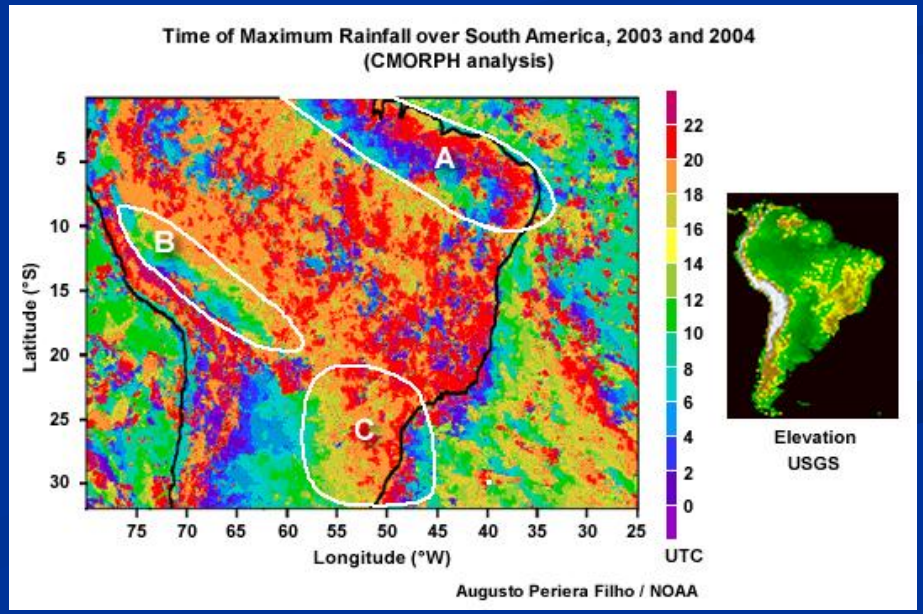
Dai and Trenberth (2004 JC)



Carbone et al. (2002 JAS)



Yu et al. (2007 GRL), Zhou et al. (2008 JC)



Courtesy of Augusto Periera Filho, NOAA

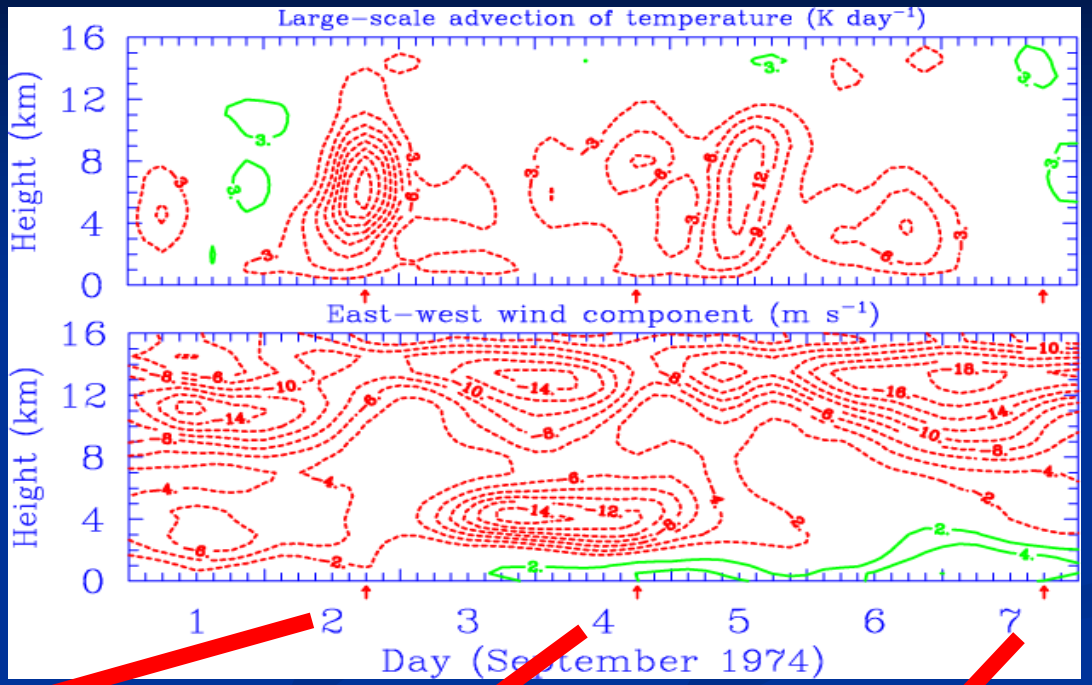
The Root of Problem

The precipitation process directly responds to cloud dynamics and physics, is associated with changes between vapor, liquid and solid water phases, and is a product of interaction between large-scale dynamics and cloud systems.

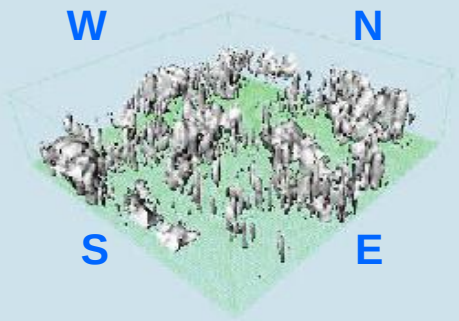
Therefore, the representation of convection and clouds is a key element for the accurate reproduction of precipitation characteristics in GCMs.

Methods

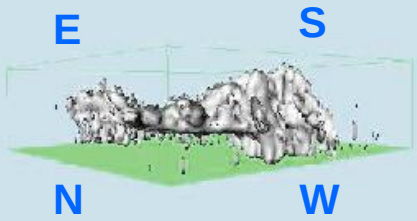
Cloud-Resolving Model (CRM) provides a tool to generate cloud and radiation properties over climate sensitive regions for improving the understanding and representation of cloud systems in GCMs.



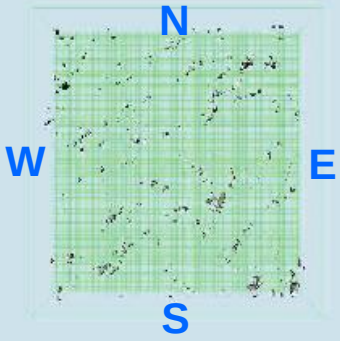
Non-squall cluster



Squall cluster



Scattered convection



Grabowski, Wu and Moncrieff (1996 JAS), Wu and Moncrieff (2001 JAS)

ISU General Circulation Model (GCM):

Based on a version of NCAR GCM, but with

1) Modified Zhang-McFarlane deep convection scheme

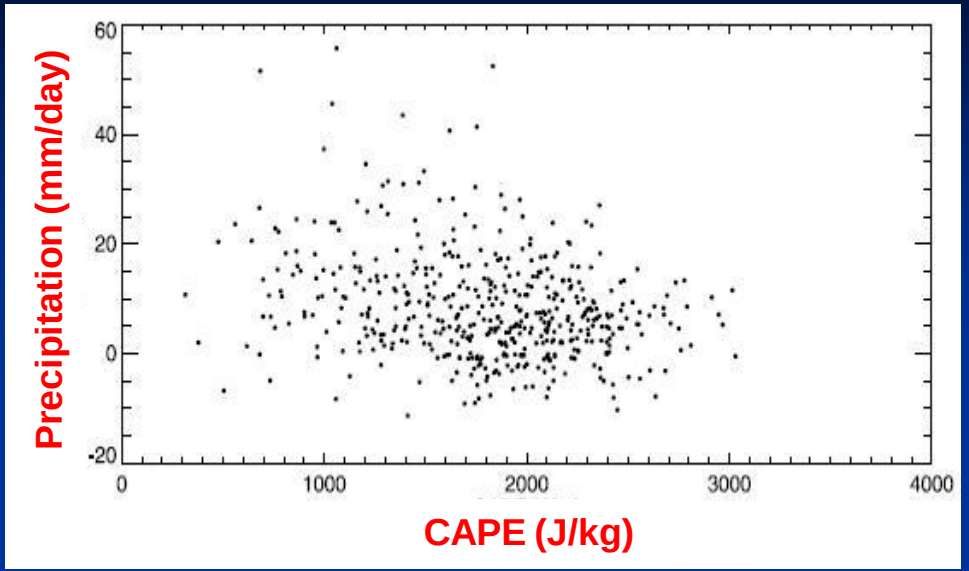
- Revised convection closure assumption consistent with CRM concept
- CRM-based trigger condition of deep convection
- CRM-validated convective momentum transport

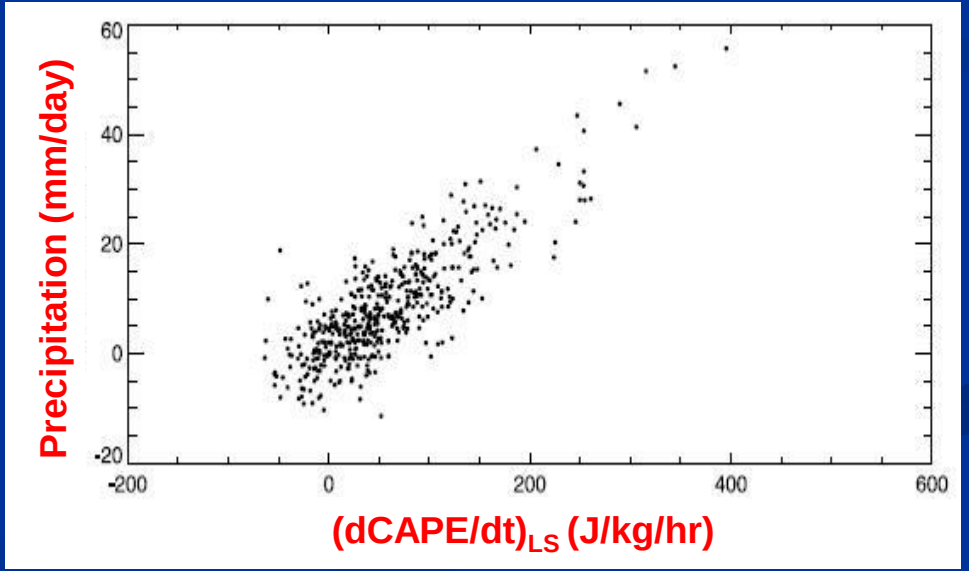
2) Modified cloud and radiation parameterization schemes

- CRM-validated mosaic treatment of subgrid cloud variability
- CRM-derived vertical scaling factor of in-cloud water content

Revised Zhang-McFarlane closure assumption

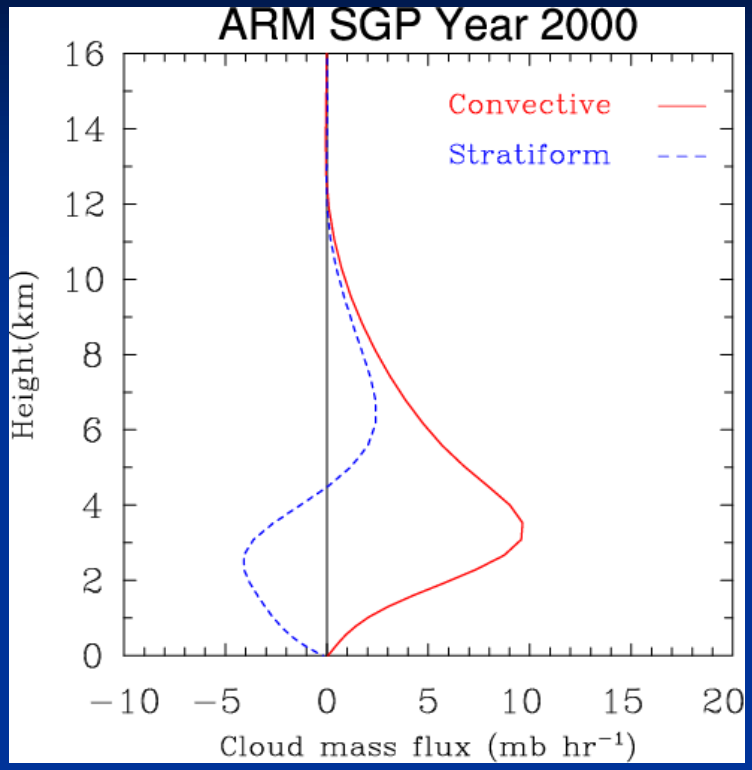
Convection is tied to the destabilization of the tropospheric layer above PBL by the large-scale processes, i.e., the change of Convective Available Potential Energy (CAPE) due to the large-scale temperature and moisture advection $(dCAPE/dt)_{LS}$.

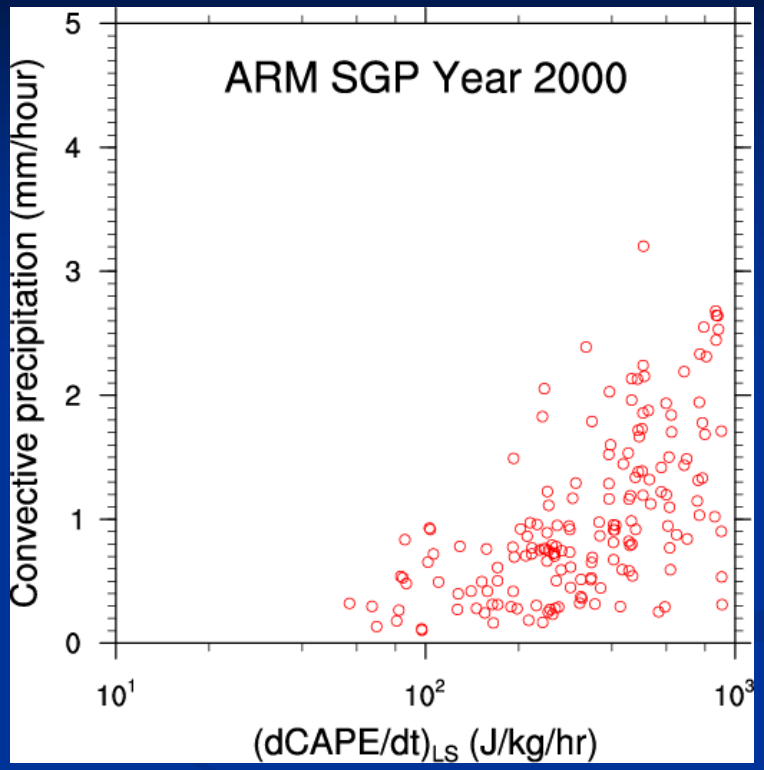




Zhang (2002, 2003 JGR)
Xie and Zhang (2000, JGR)

Trigger condition of deep convection





Convection is activated when the increase of CAPE due to the large-scale processes exceeds certain threshold (65 J kg^{-1} hr^{-1}) derived from year-long CRM simulations.

Wu et al. (2007 GRL)

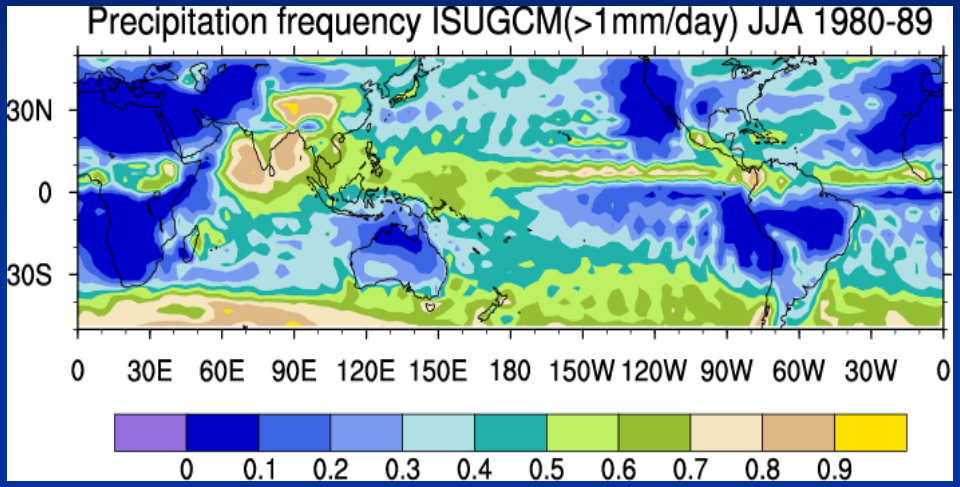
Simulations

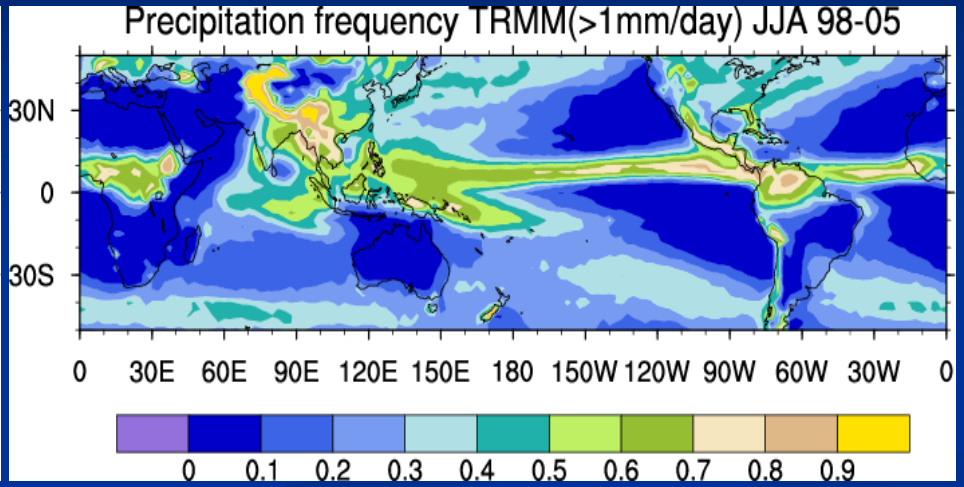
	Run	Runtime	Processor
ISUGCM	T42 AMIP 1979-	18h/10yrs	16
CCM3	T42 AMIP 1979-	15h/10yrs	16
CAM5	2º AMIP 1979-	90h/10yrs	32

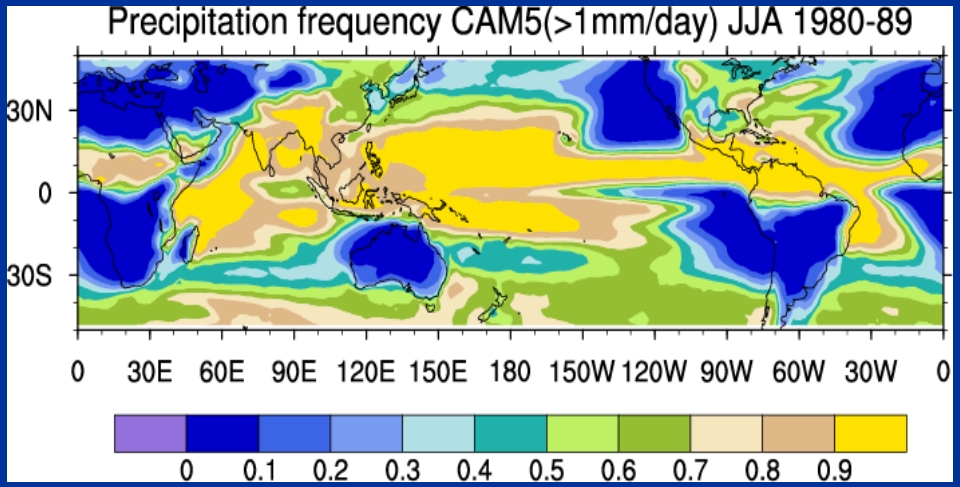
Precipitation Characteristics

- Frequency
- Diurnal cycle
- Annual mean
- Annual cycle
- MJO

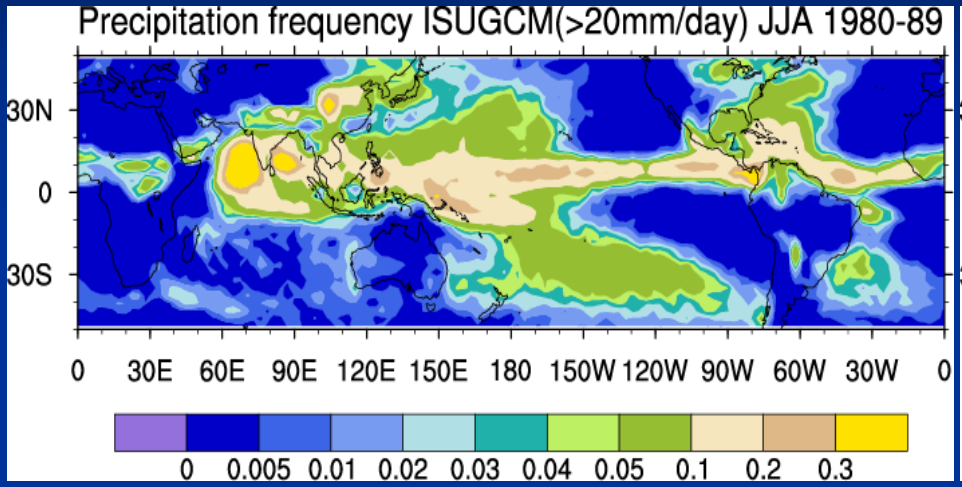
Precipitation frequency of rainfall > 1 mm/day

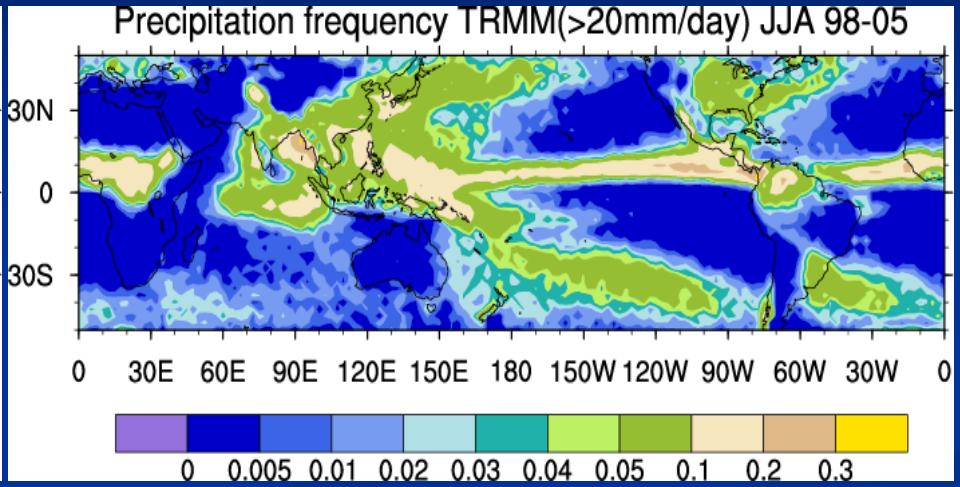


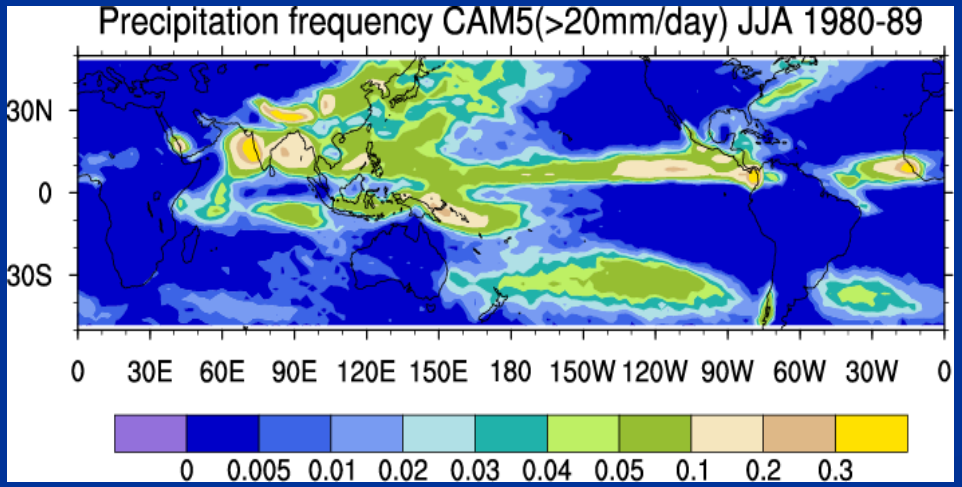




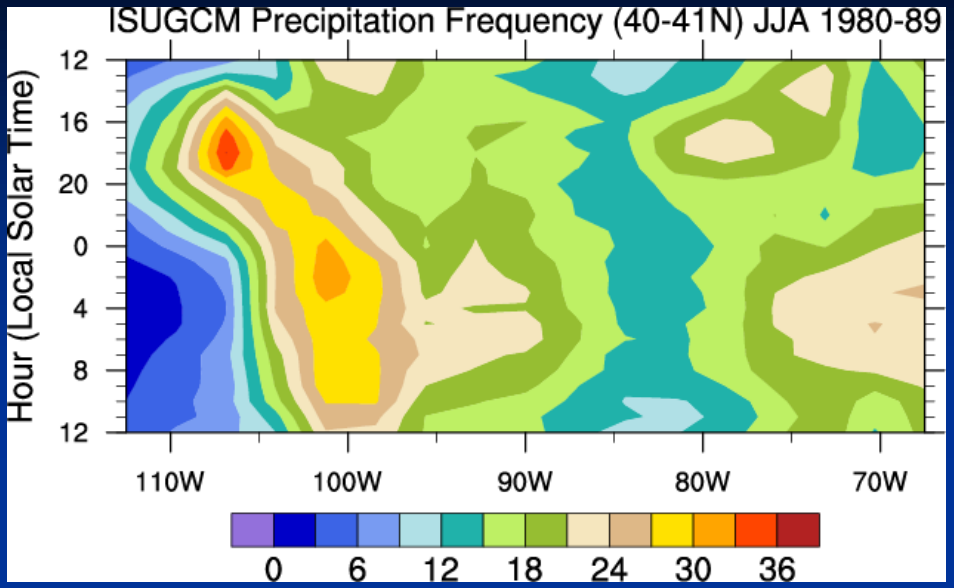
Precipitation frequency of rainfall > 20 mm/day

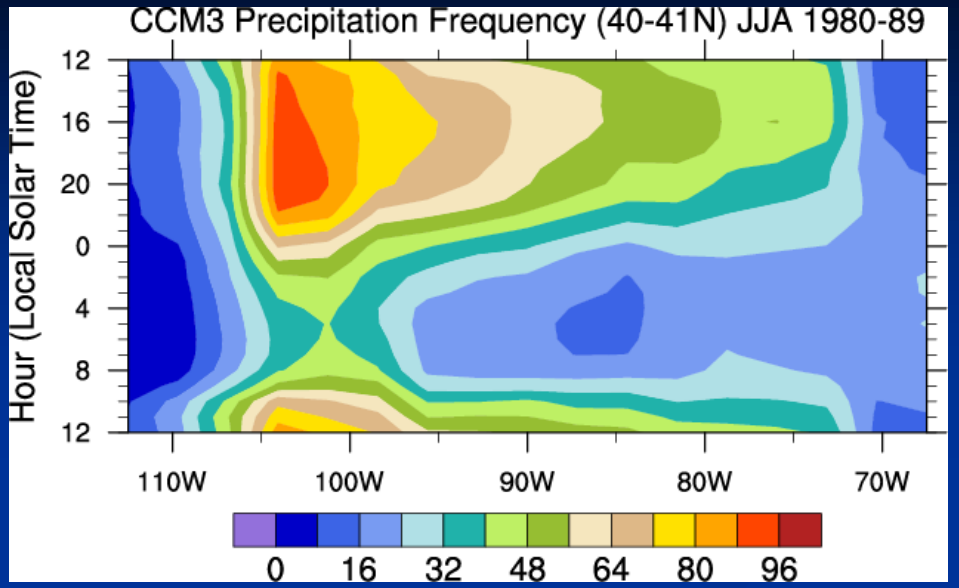


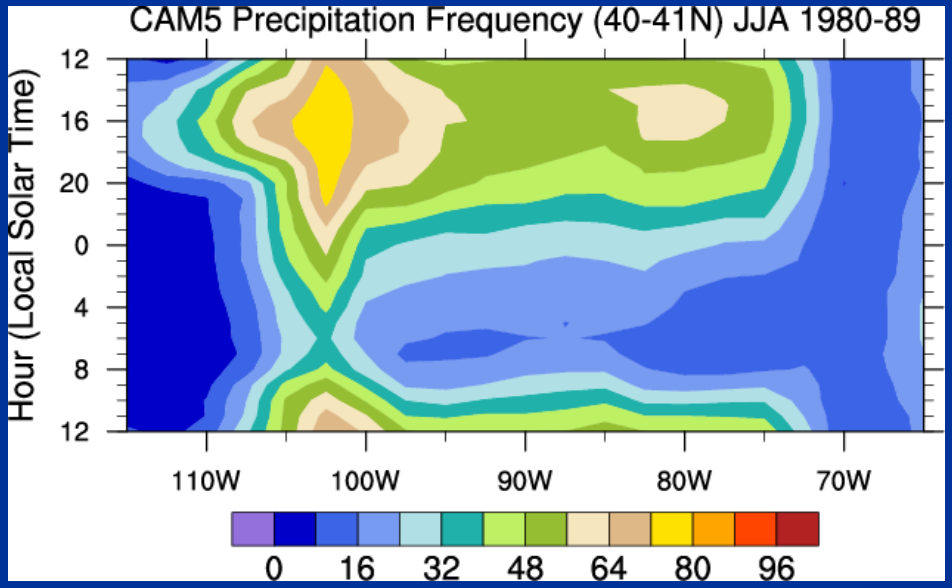




Diurnal cycle of summer precipitation over US







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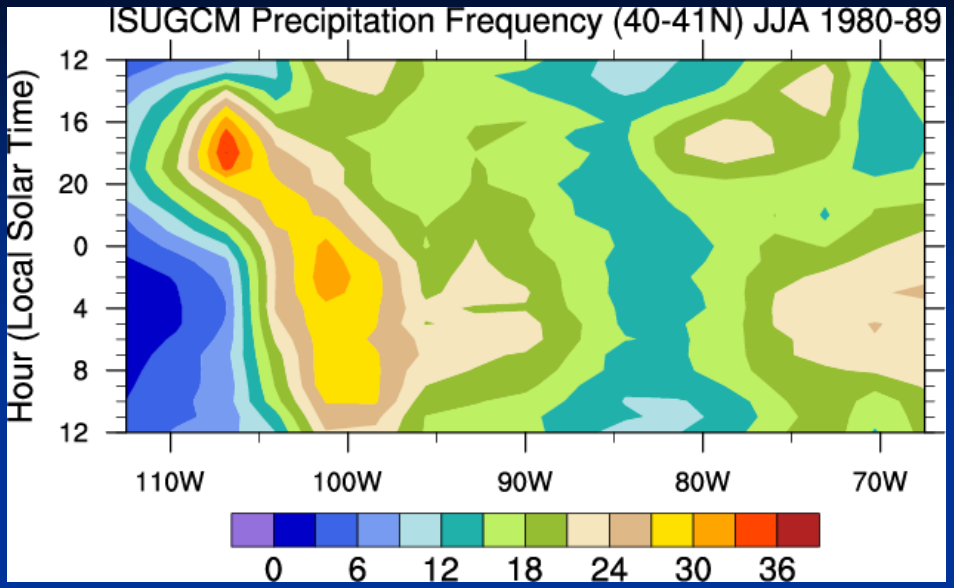
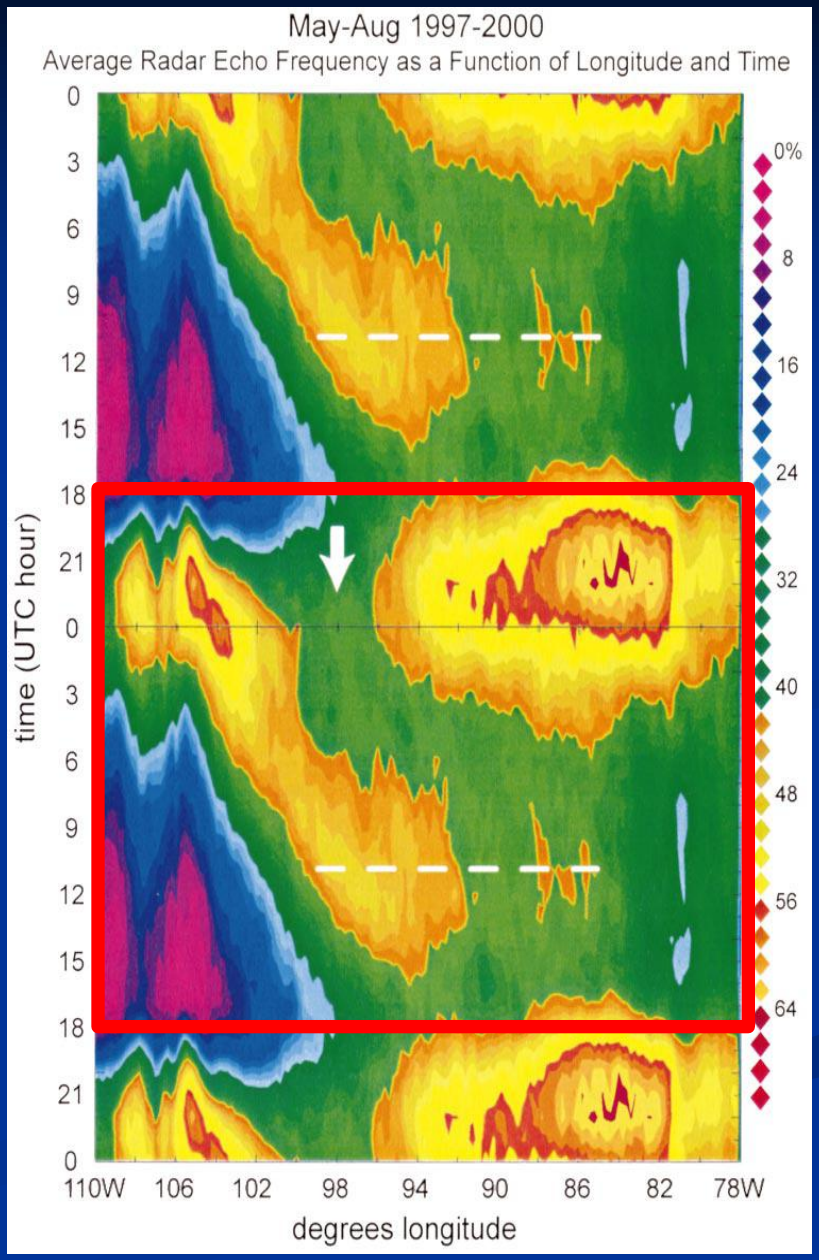
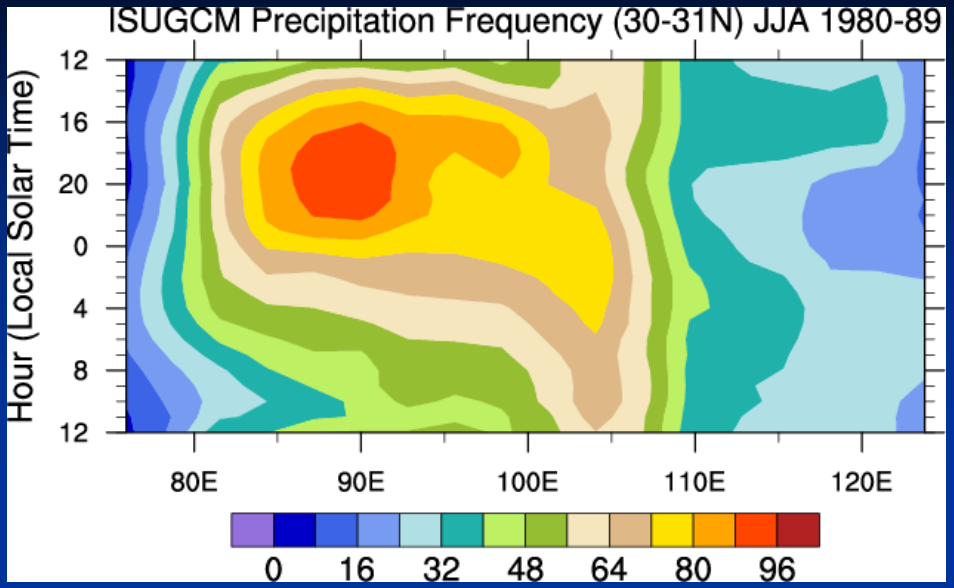
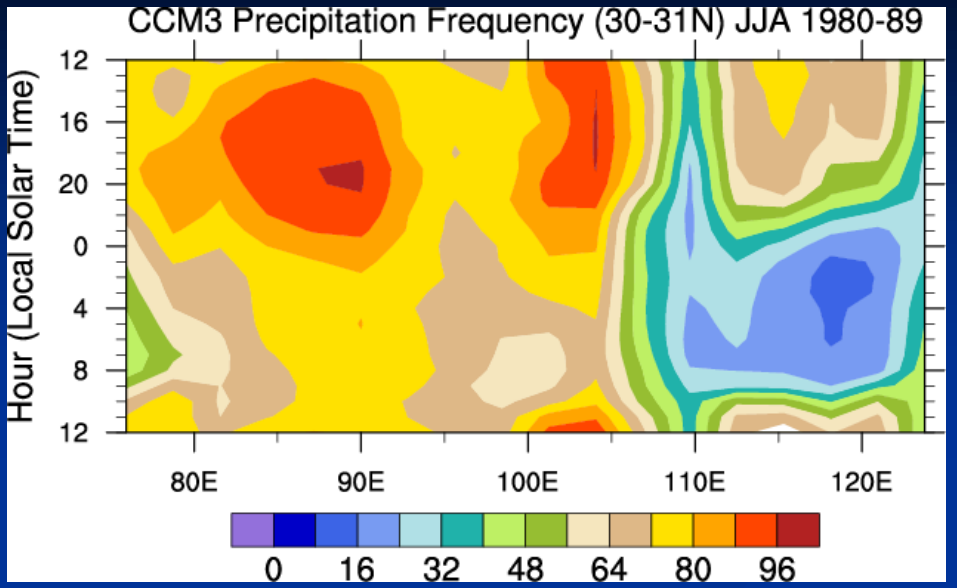


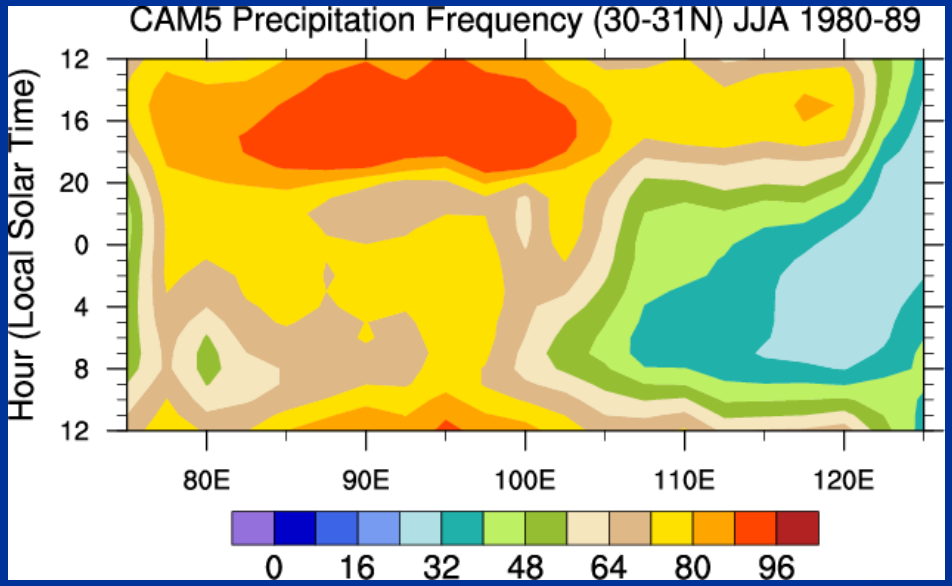


Carbone et al. (2002 JAS)

Diurnal cycle of summer precipitation over China







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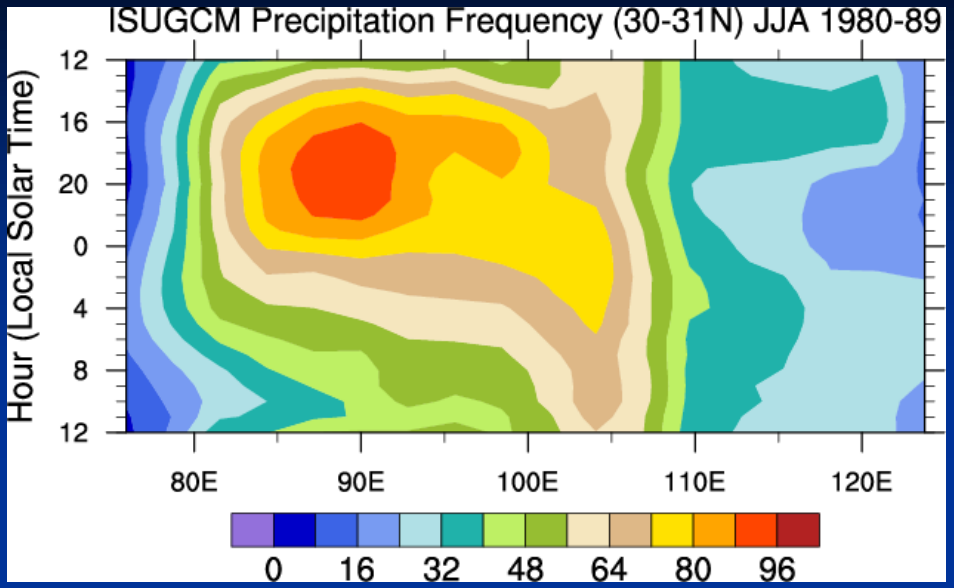
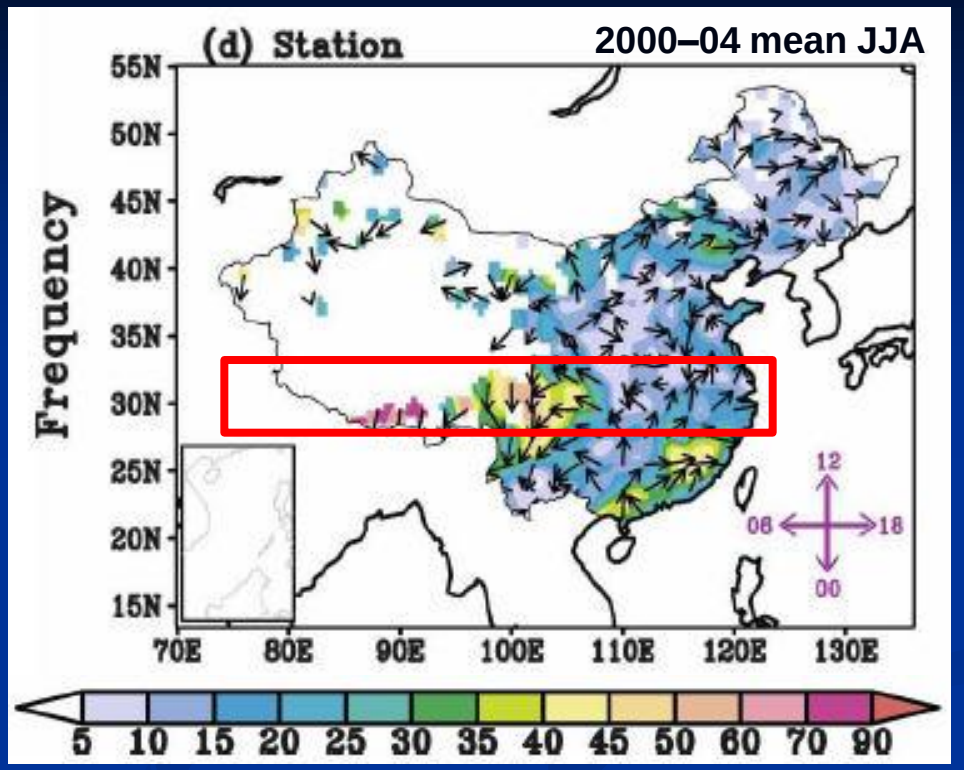
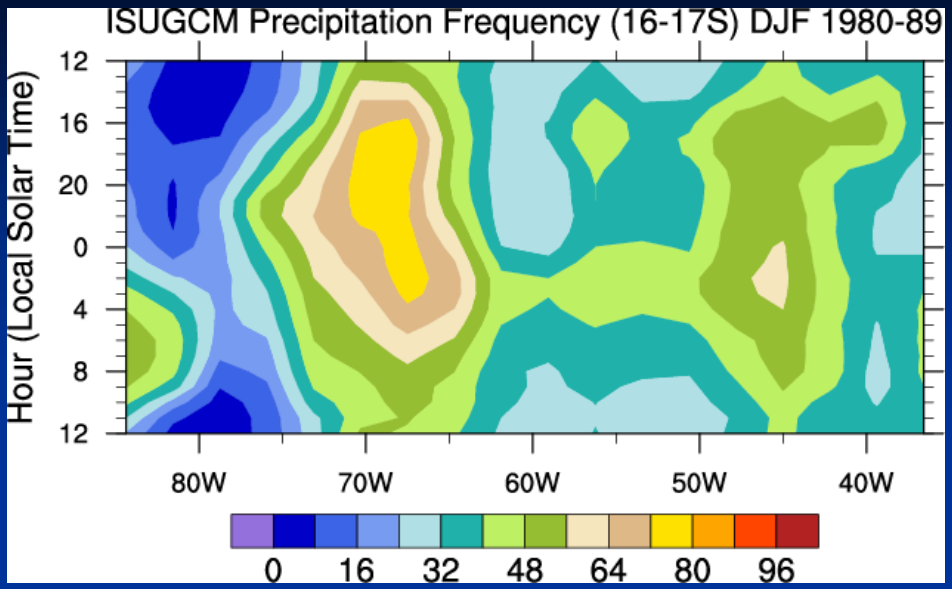
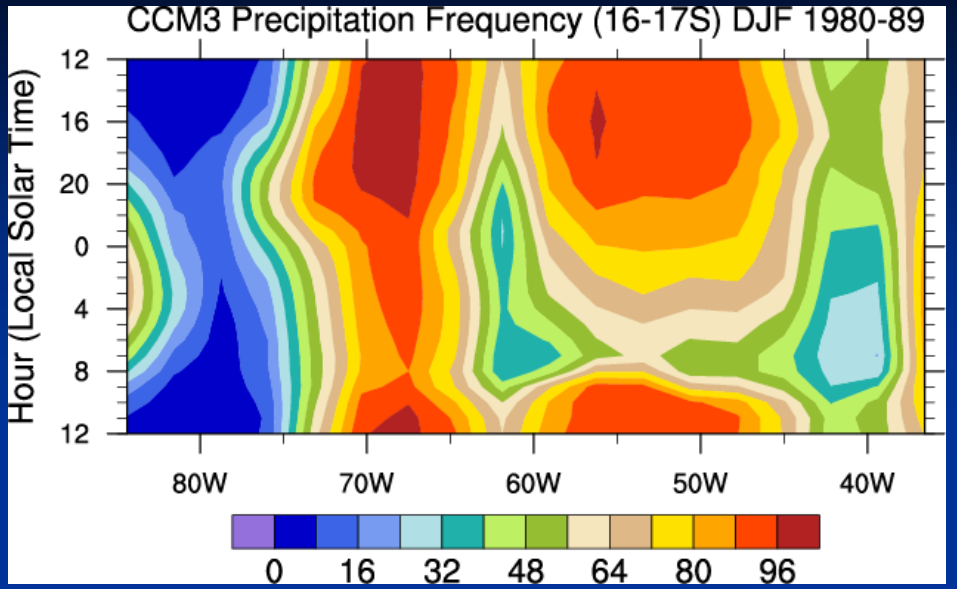


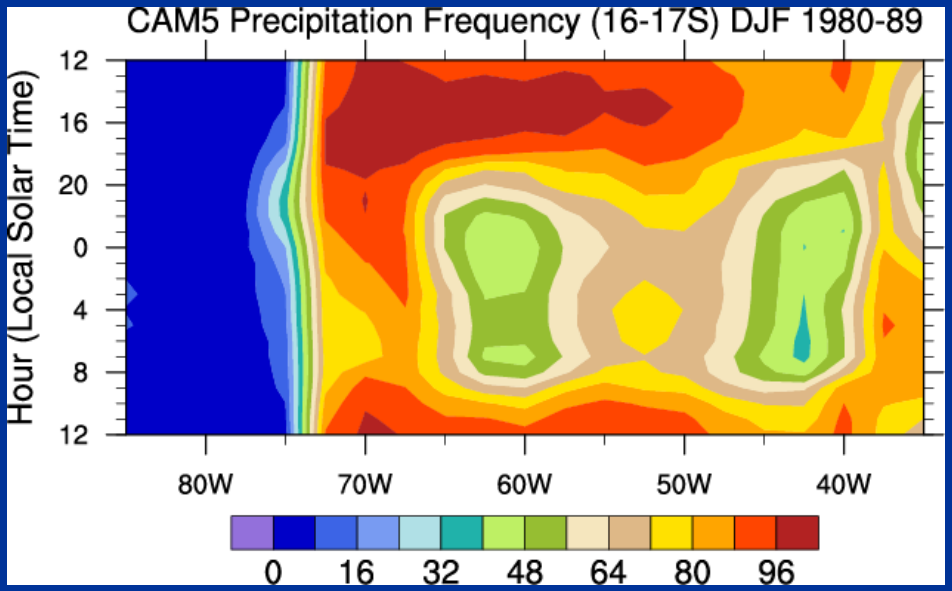


Yu et al. (2007 GRL), Zhou et al. (2008 JC)

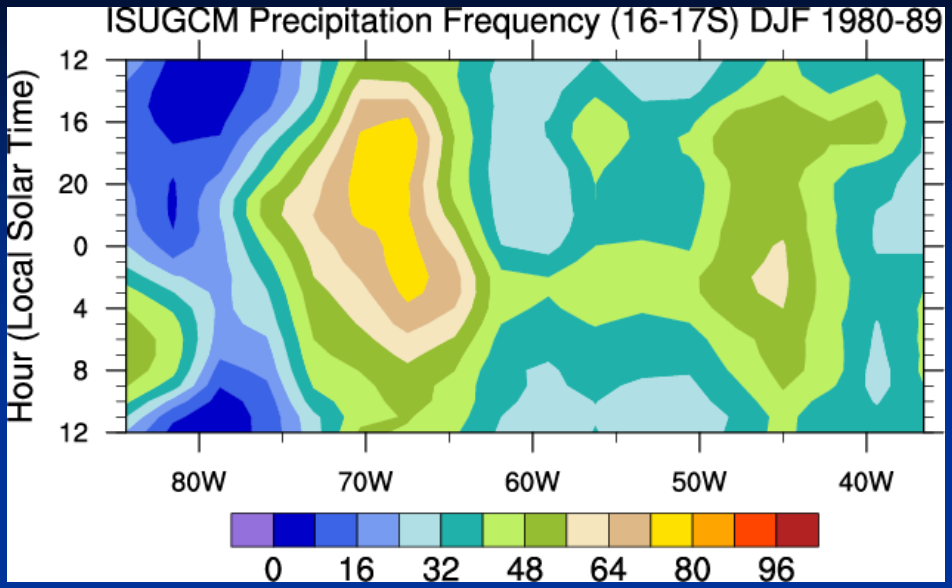
Diurnal cycle of summer precipitation over South America



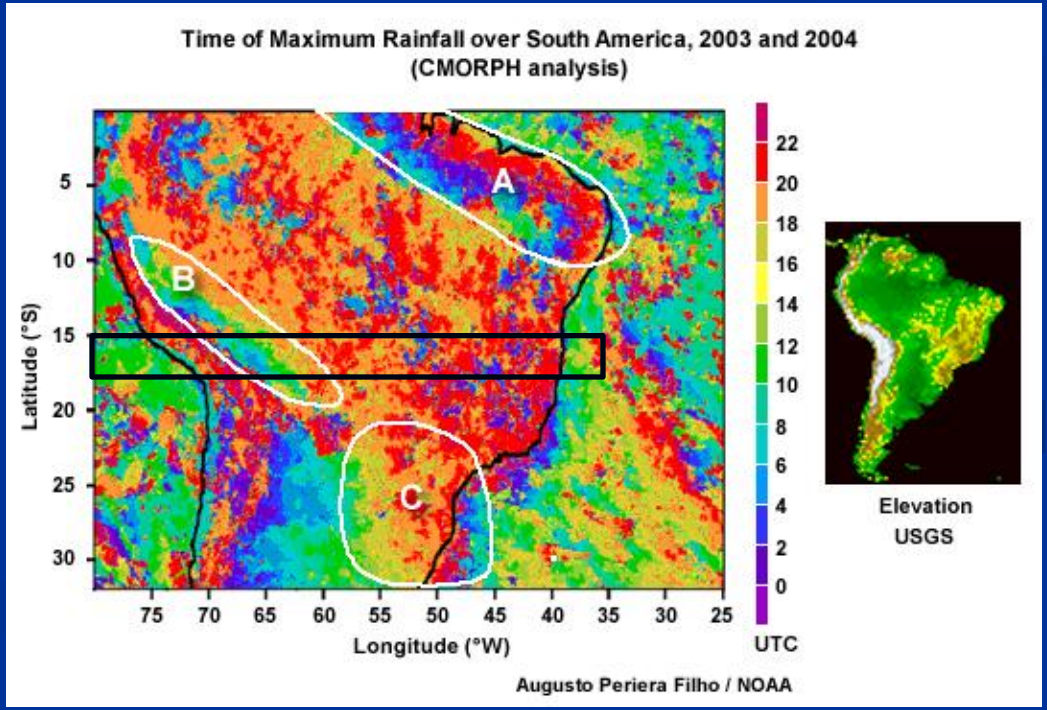




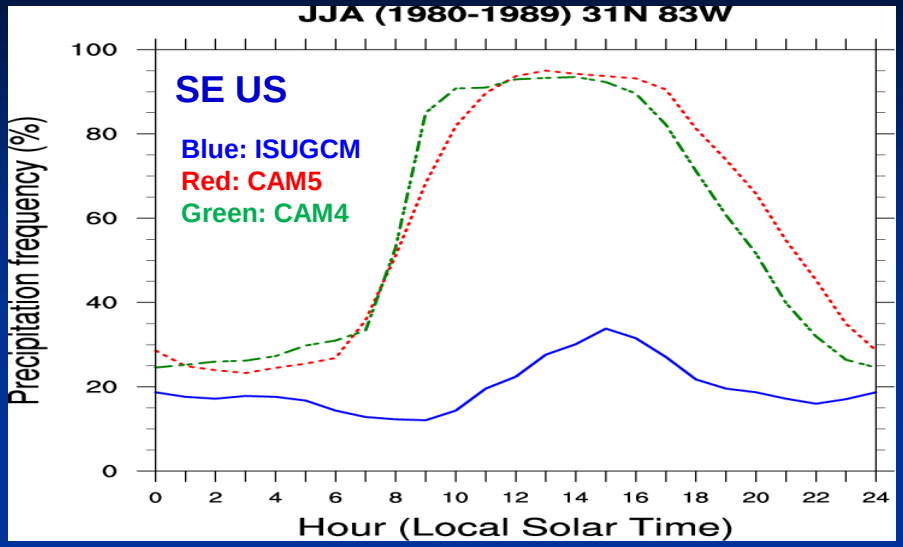
Diurnal cycle of summer precipitation over South America

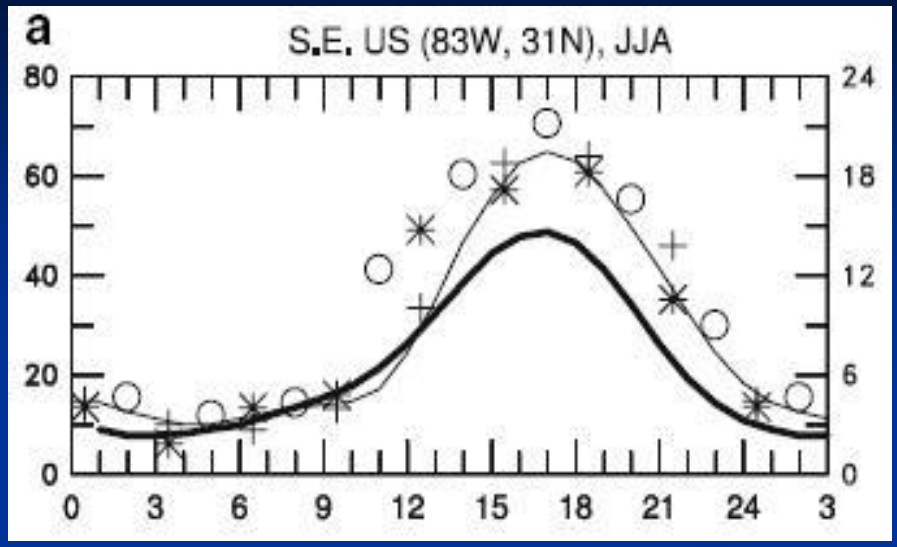


Courtesy of Augusto Periera Filho, NOAA

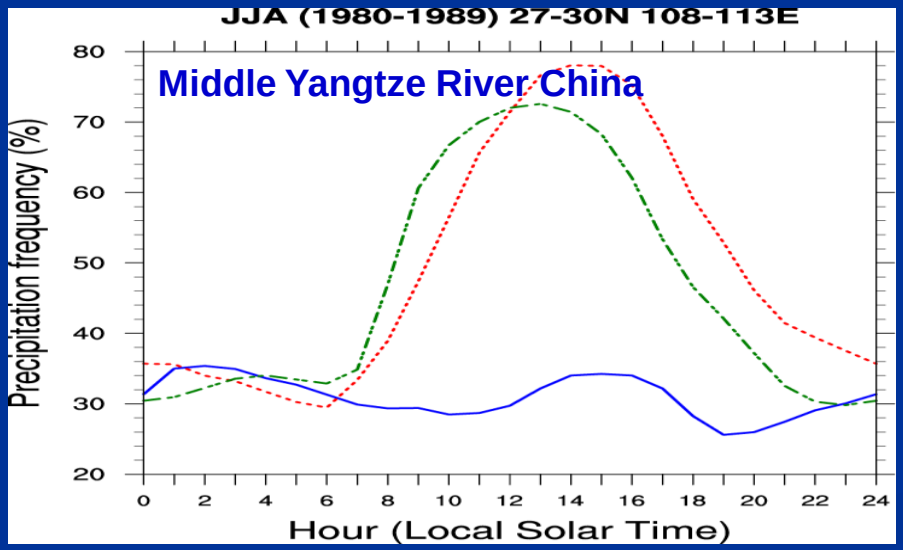


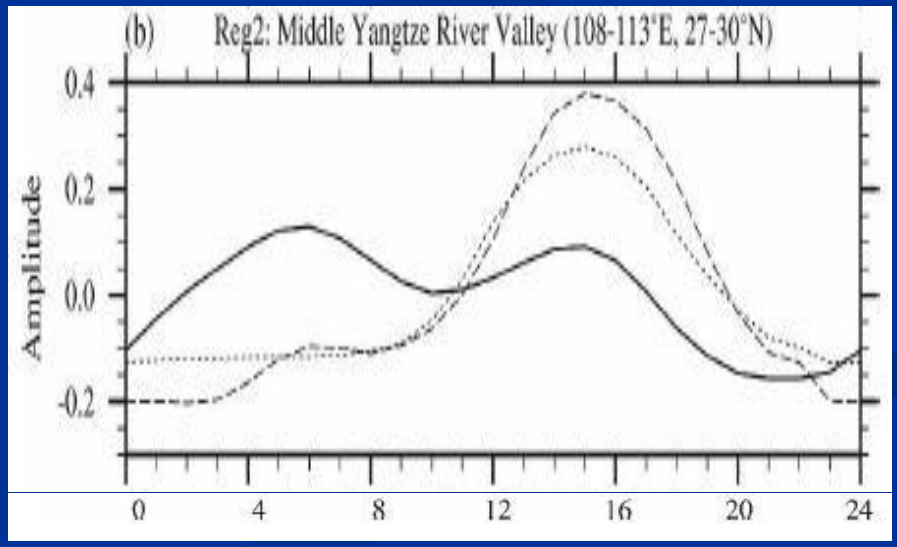
Diurnal cycle of summer precipitation





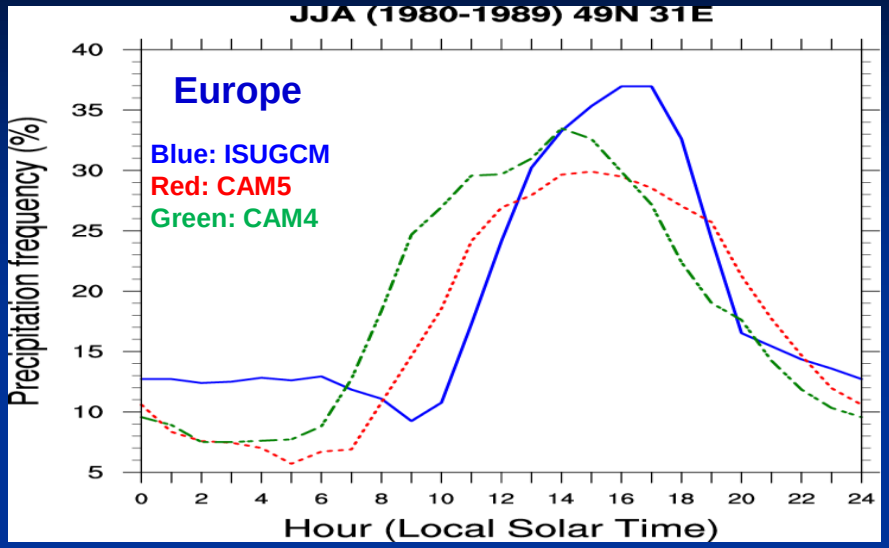
Dai et al. (2007 CD)

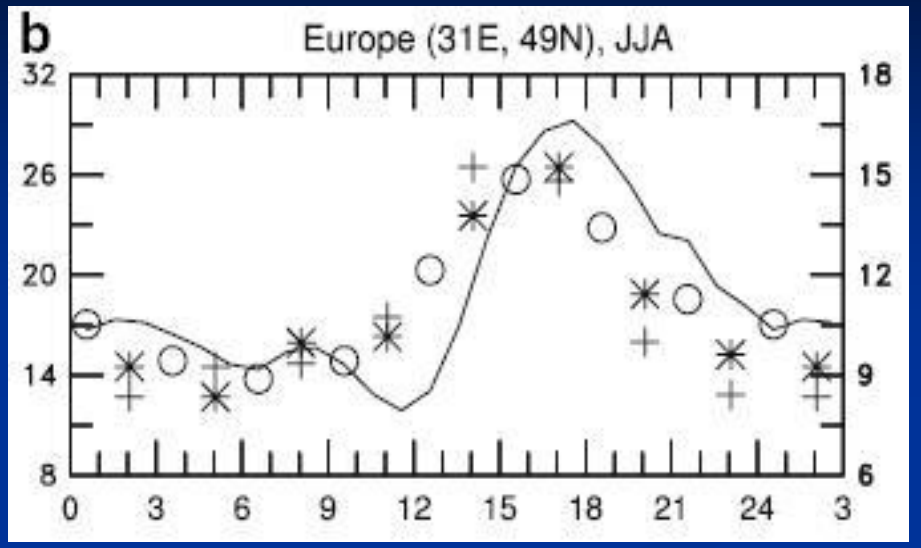


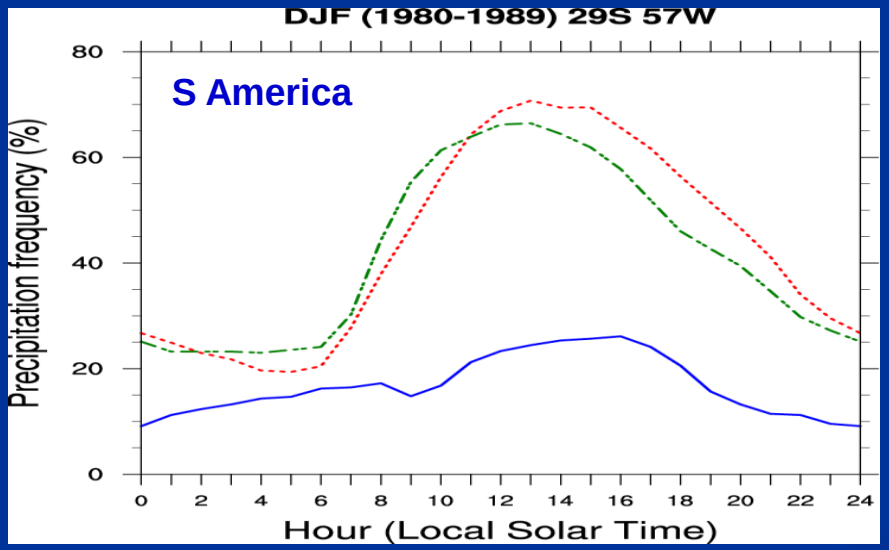


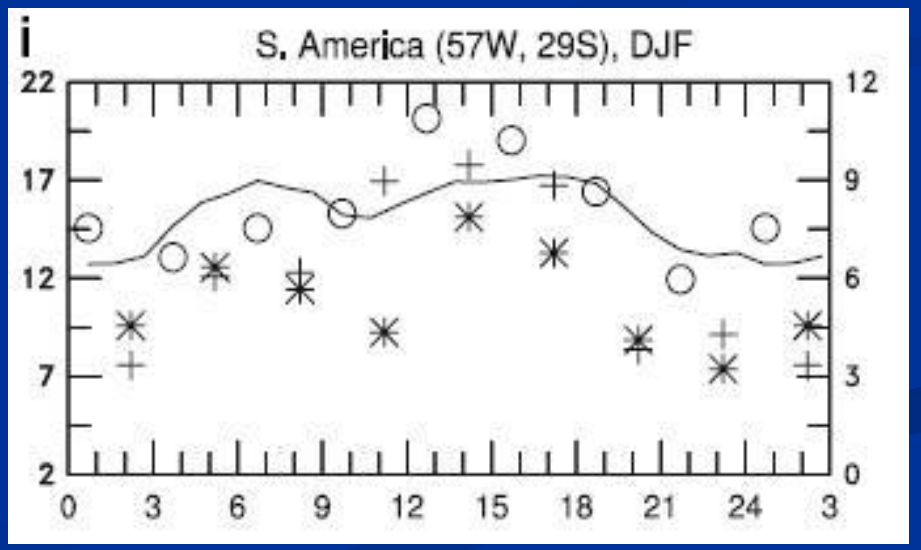
Zhou et al. (2008 JC), Yu et al. (2007 GRL)

Diurnal cycle of summer precipitation









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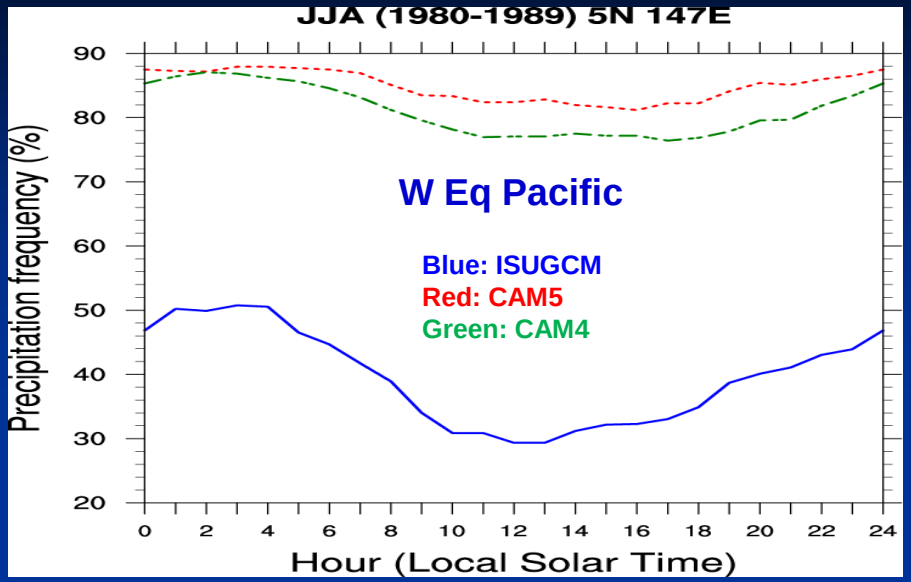
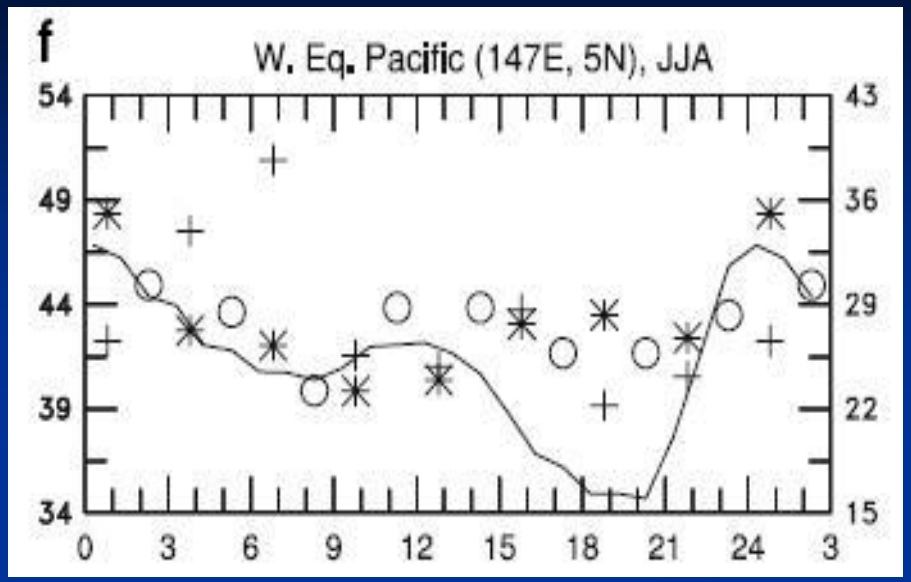
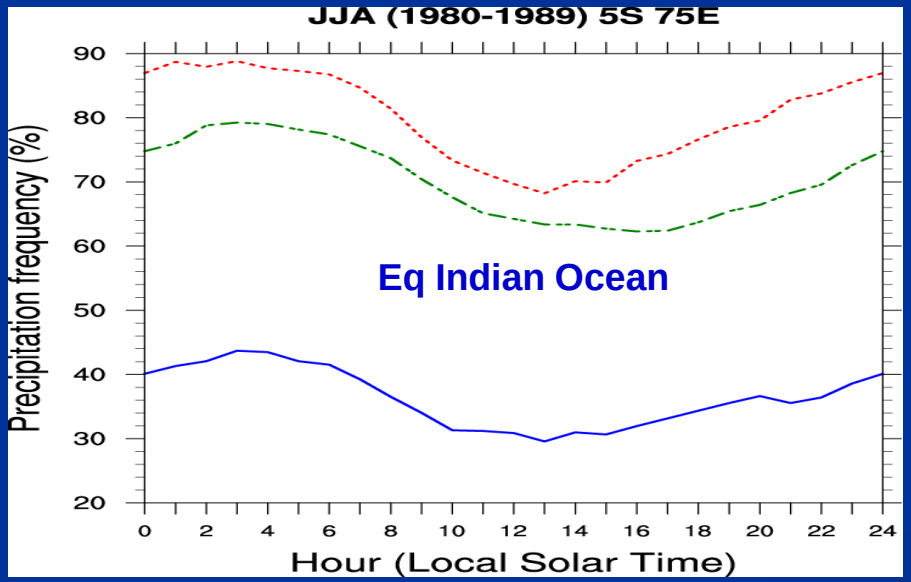
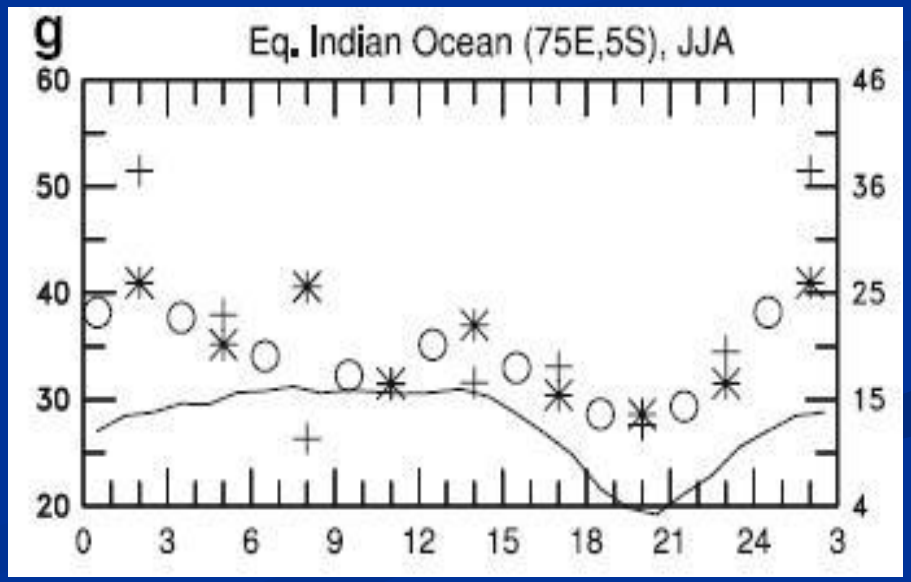
Diurnal cycle of summer precipitation



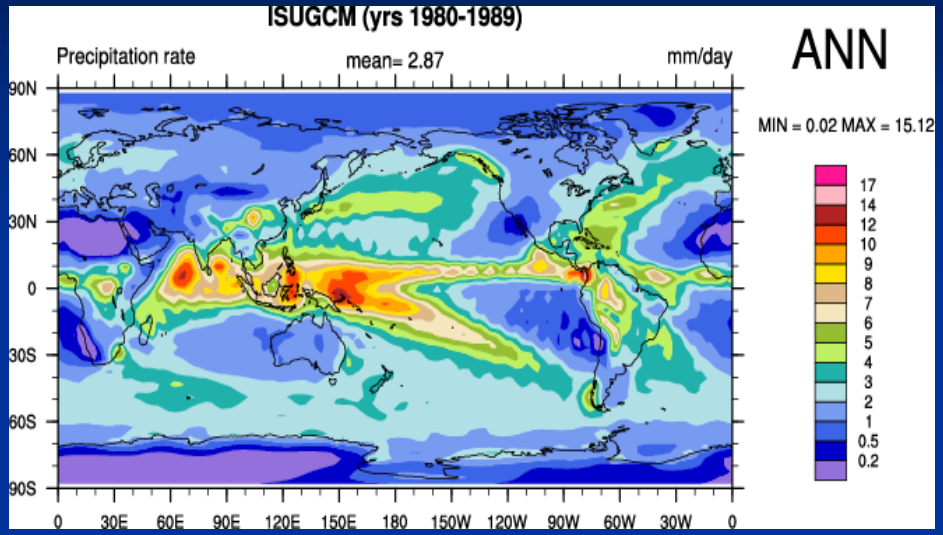


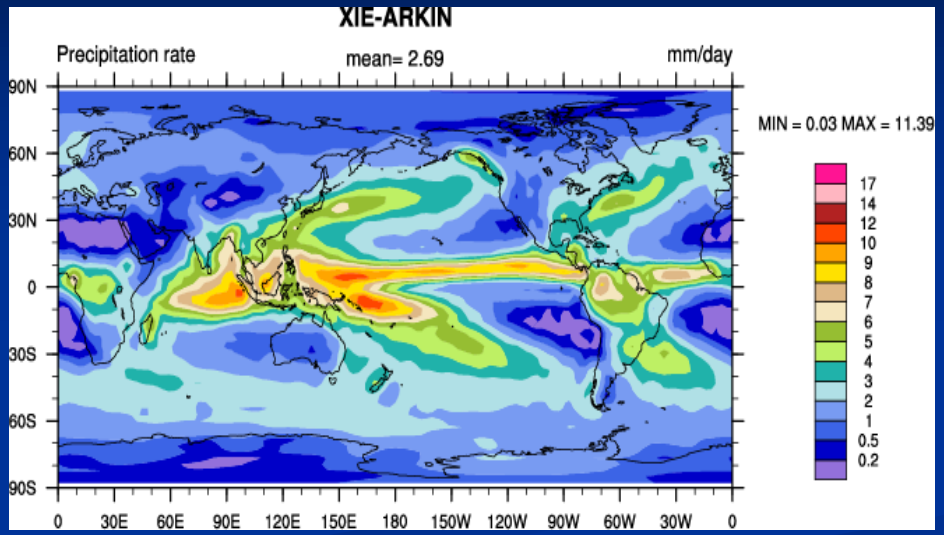


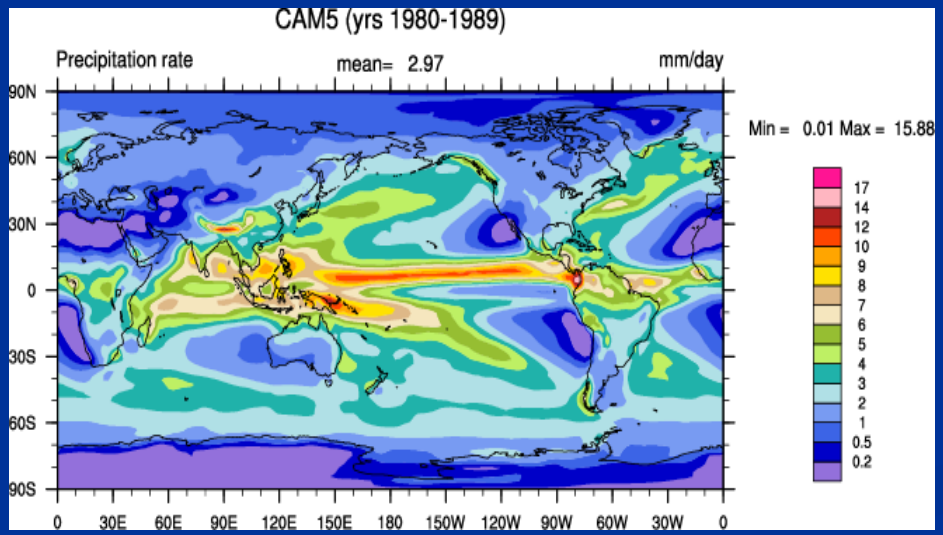


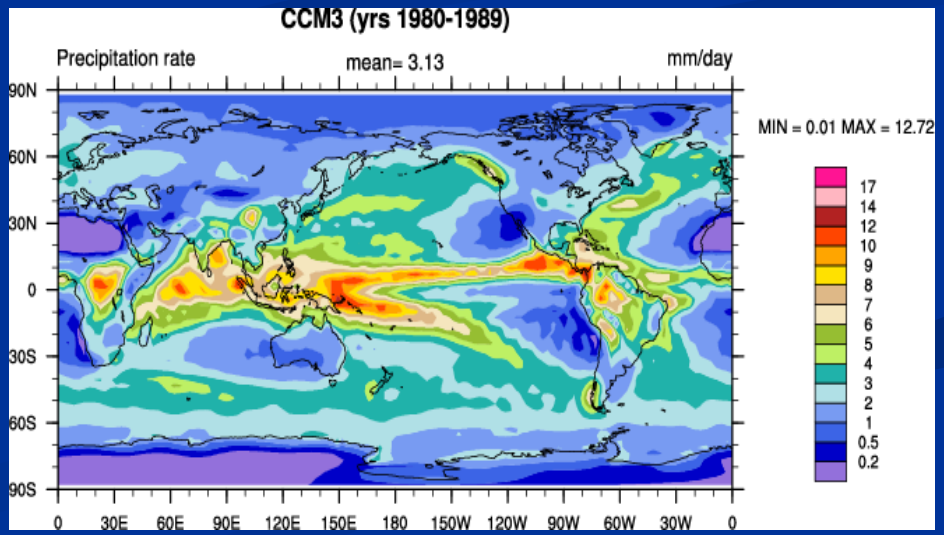
Dai et al. (2007 CD)

Annual mean precipitation rates (mm day^{-1})



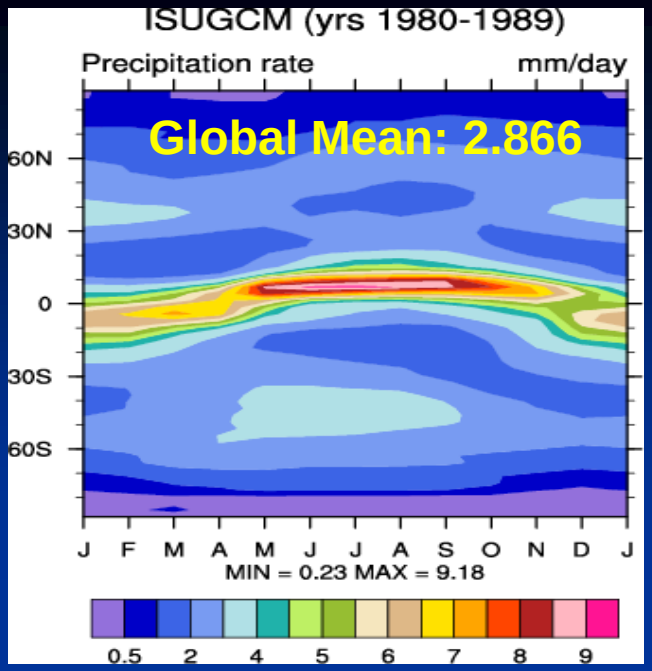


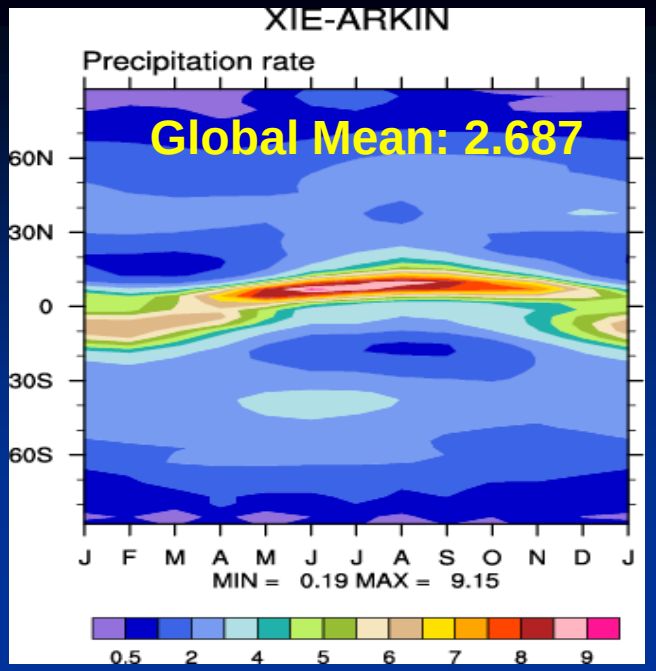


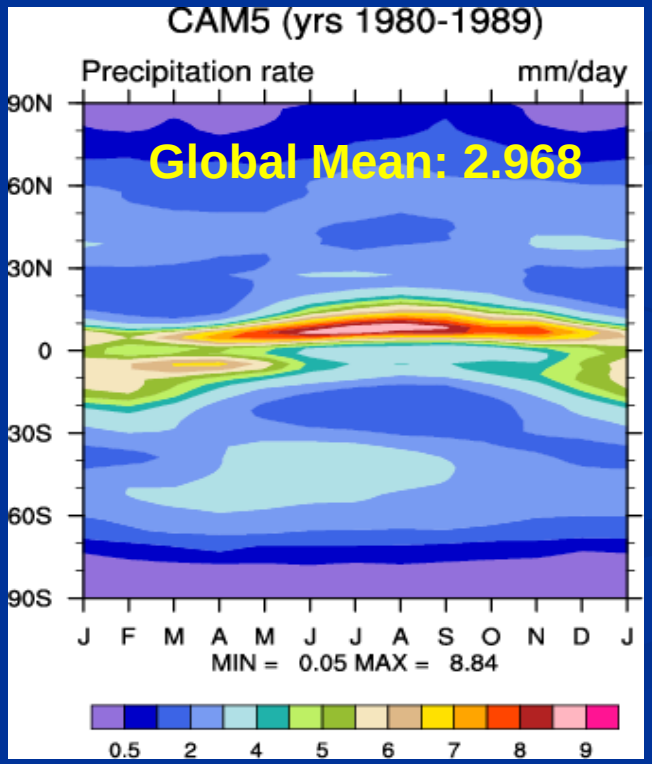


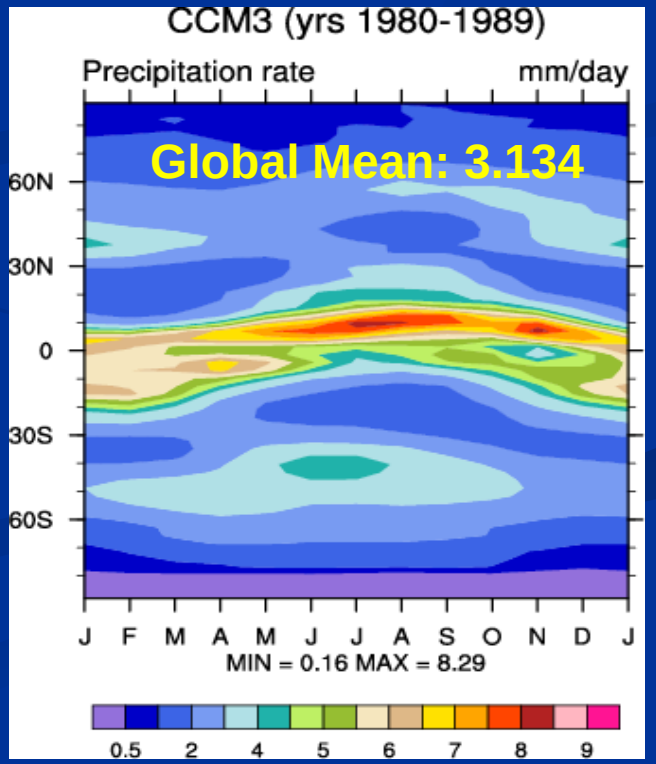
Annual cycle of zonally averaged precipitation

Seasonal migration of ITCZ

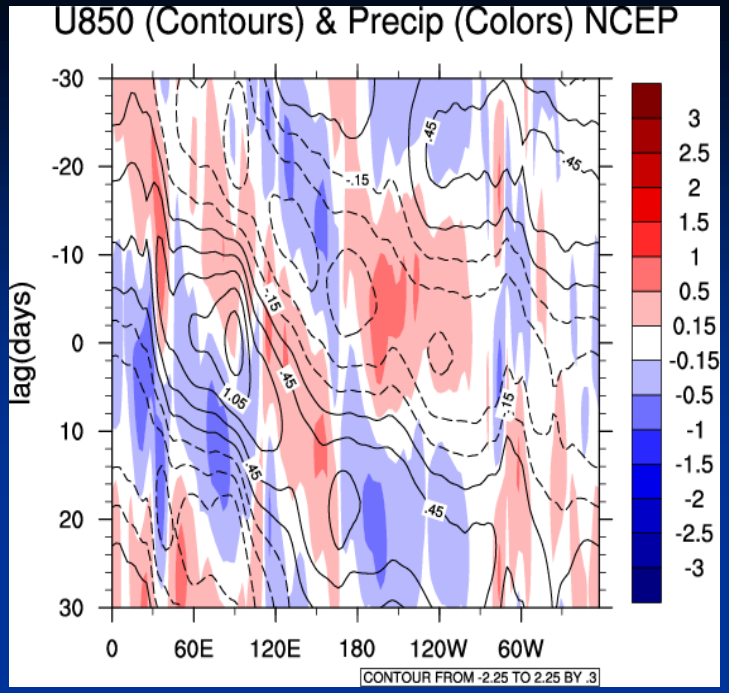


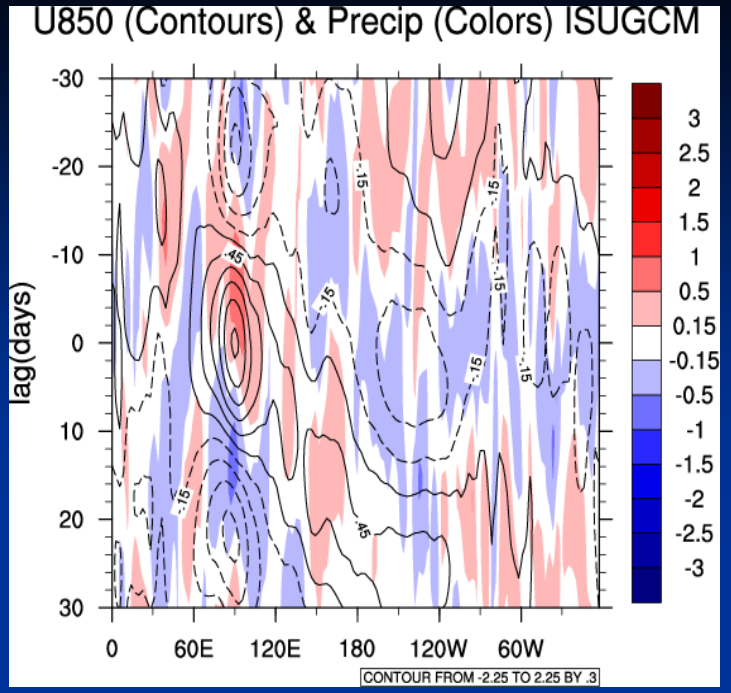


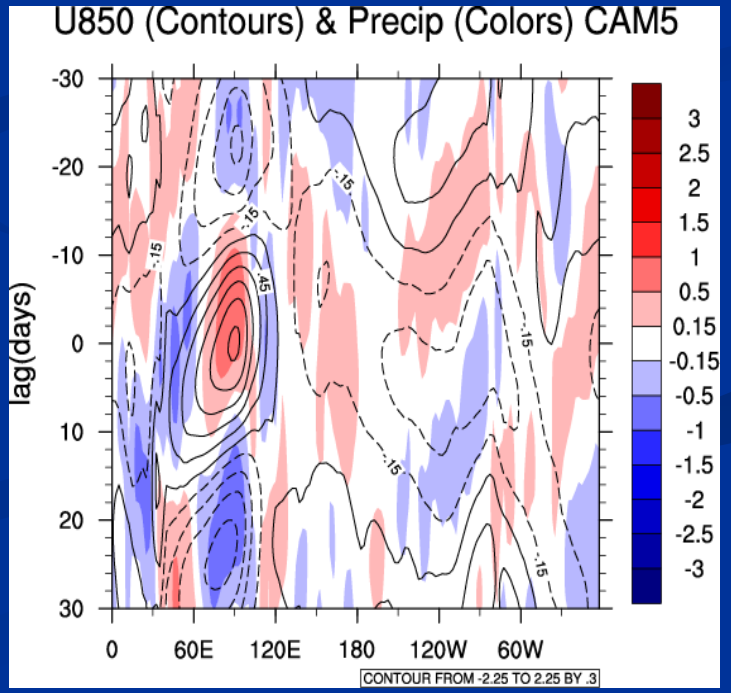




MJO over
Indian Ocean







Ten-years (1980-89 October-April) lag correlations of 30-90-day band-passed daily equatorial (5ºS-5ºN averaged) 850-hPa zonal wind (contours) and precipitation (colors) onto the daily equatorial 850-hPa zonal wind time series at 90˚E

Summary and Remark

- **The diurnal cycle and frequency of precipitation are controlled by the ensemble effects of cloud systems that are in response to the CAPE change due to the large-scale temperature and moisture advection, and how the deep convection is triggered.**

- **With the CRM-derived trigger condition, the energy is released less frequent, which allows more vigorous precipitating cloud systems and consequently leads to better MJO simulations.**

- **Observed diurnal cycle, frequency and mean state of precipitation can be reproduced simultaneously without degrading one or the other by GCMs that include the knowledge transferred from field experiments and CRM simulations.**