Analysis of CMIP5 historical runs for precipitation in southwest North America

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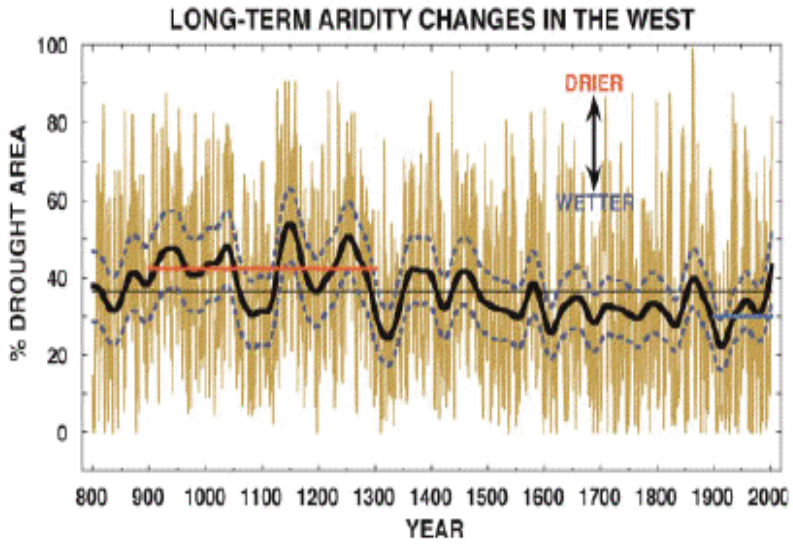
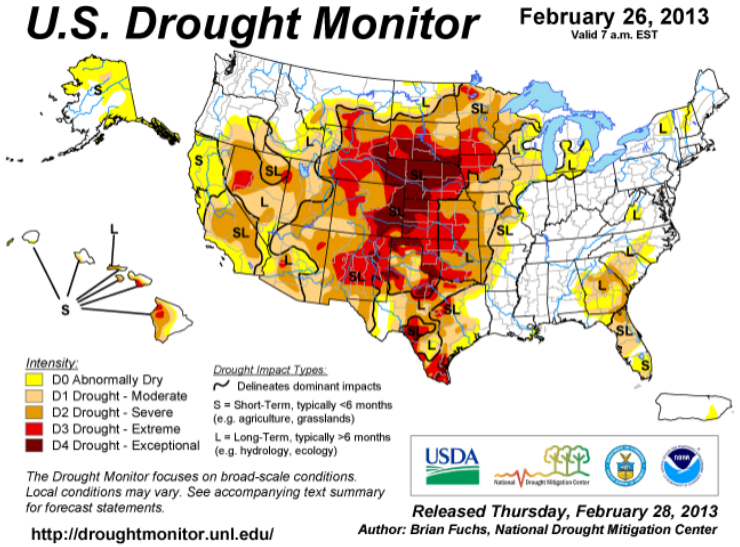
History of drought in southwest North America



Cook et al. 2009, J. Q. Sci.



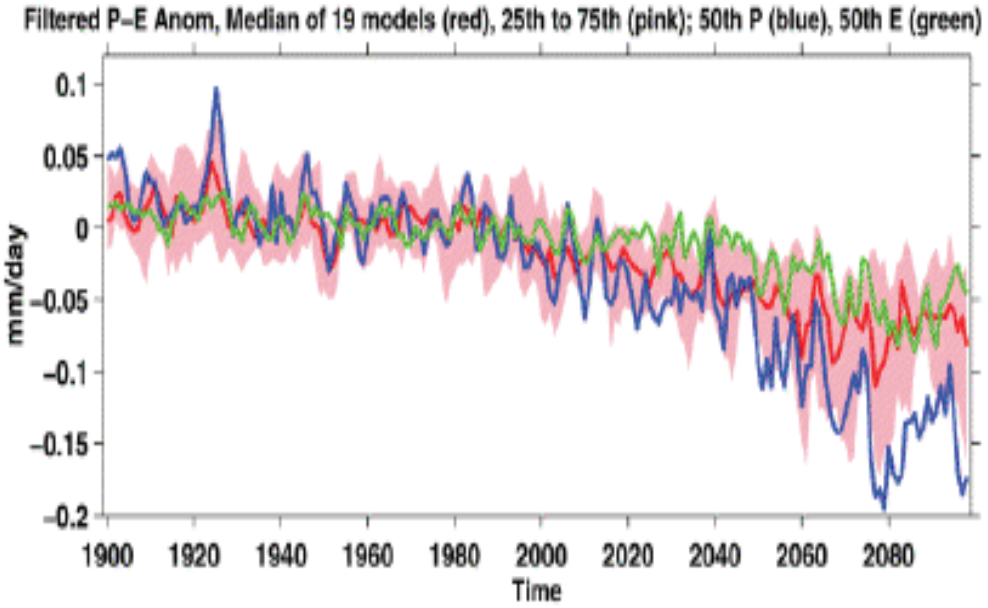
Records show periods of severe drought in the south and west of North America over past millennium - 'megadrought' longer than 20 years.

Droughts during past century -

Dust Bowl 1930s

Southwest 1950s, 2000s ...

Future drying trends in southwest US



For American southwest - Seager et al. 2007, Science 316

Runoff during spring at the head of the Colorado River catchment is expected to decrease by 25% by 2040 - decadal variability usually of order 10% (Seager et al. 2012, Nature Climate Change).

Ability to predict extreme events therefore assists in planning for variability around a drier climate.

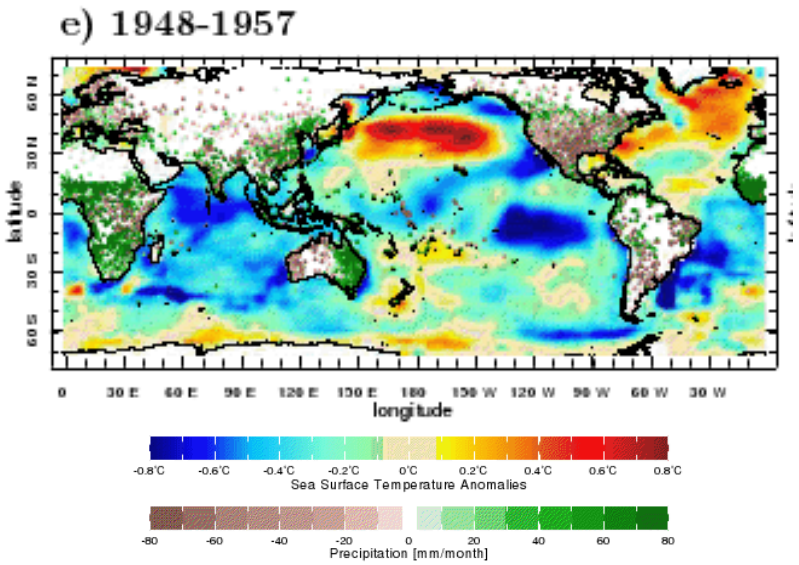
SST teleconnection to US precipitation

Connection between Pacific Ocean SST anomalies and precipitation over North America seen previously in literature.

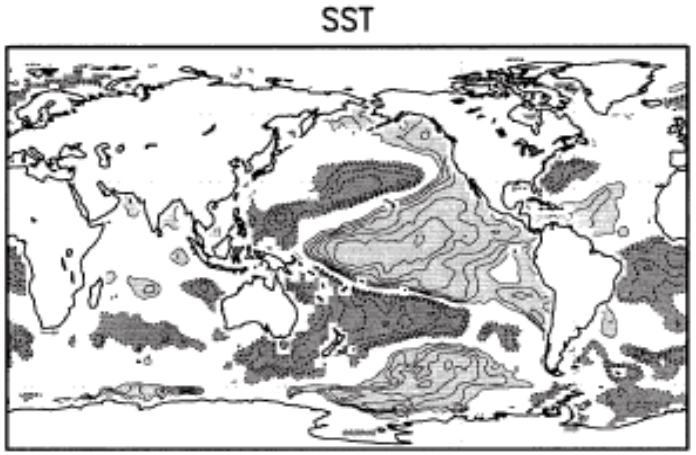
Equatorial Pacific Ocean SSTs tend to be cooler than average during case studies of recent North American droughts - Dust Bowl, SW drought etc.

Simultaneous correlation of Great Plains precipitation and SSTs show positive correlation over equatorial Pacific Ocean, negative correlation over north Pacific Ocean.

AMIP style runs forced with SST anomaly during drought consistent with decreased precipitation over US.



Seager and Cook 2007



Correlation of filtered (> 6 yrs) Great Plains precipitation with SST for 1930-2000.

Schubert 2004, J Clim 17.

CMIP5 models

How well do the CMIP5 models represent the SST anomalies?

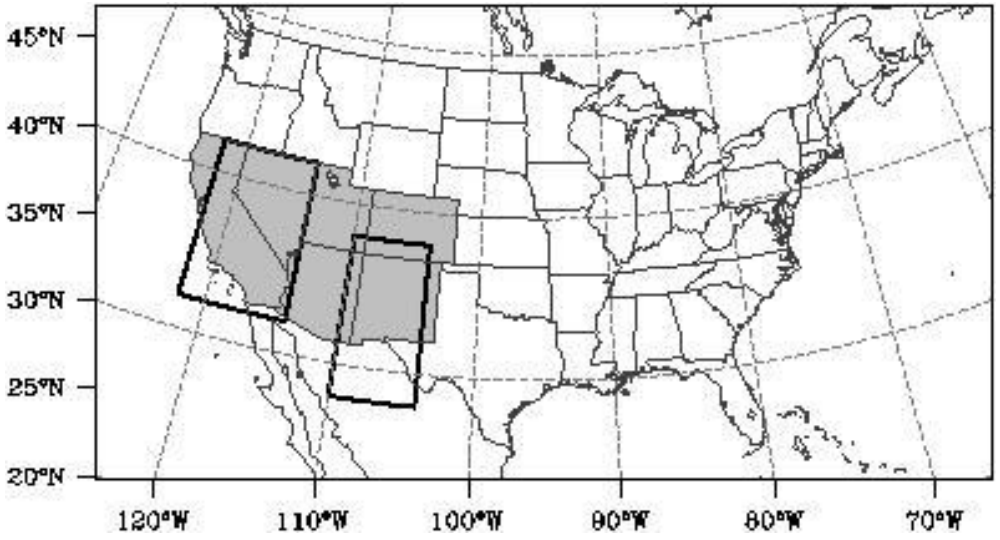
Is the North or Equatorial Pacific Ocean more dominant on decadal timescales?

How much low-frequency precipitation variability is associated with SSTAs?

First assess that models represent current hydroclimate of southwest North America - two main regimes:

California and Nevada

New Mexico/NA monsoon



CMIP5 -

47 historical runs

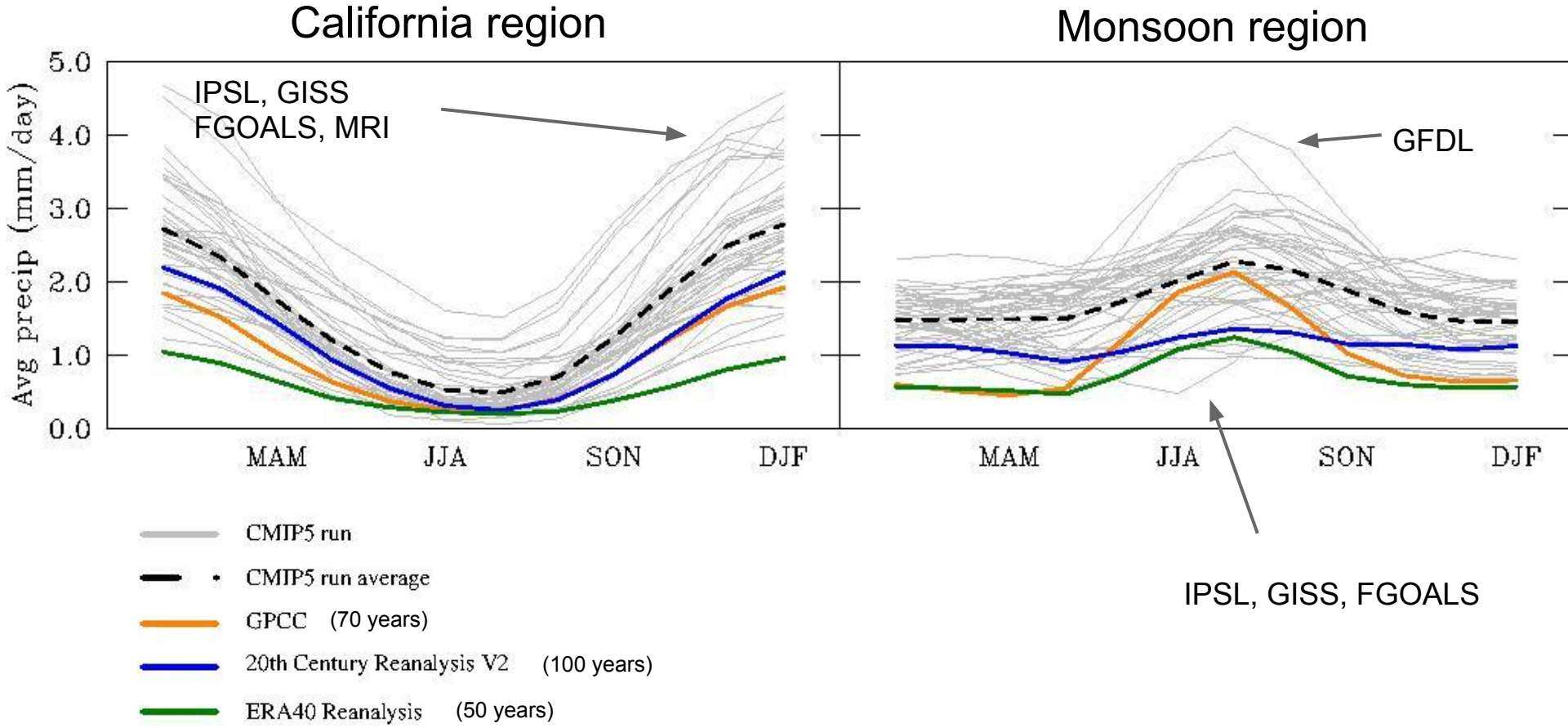
monthly output

150 year duration

first ensemble member

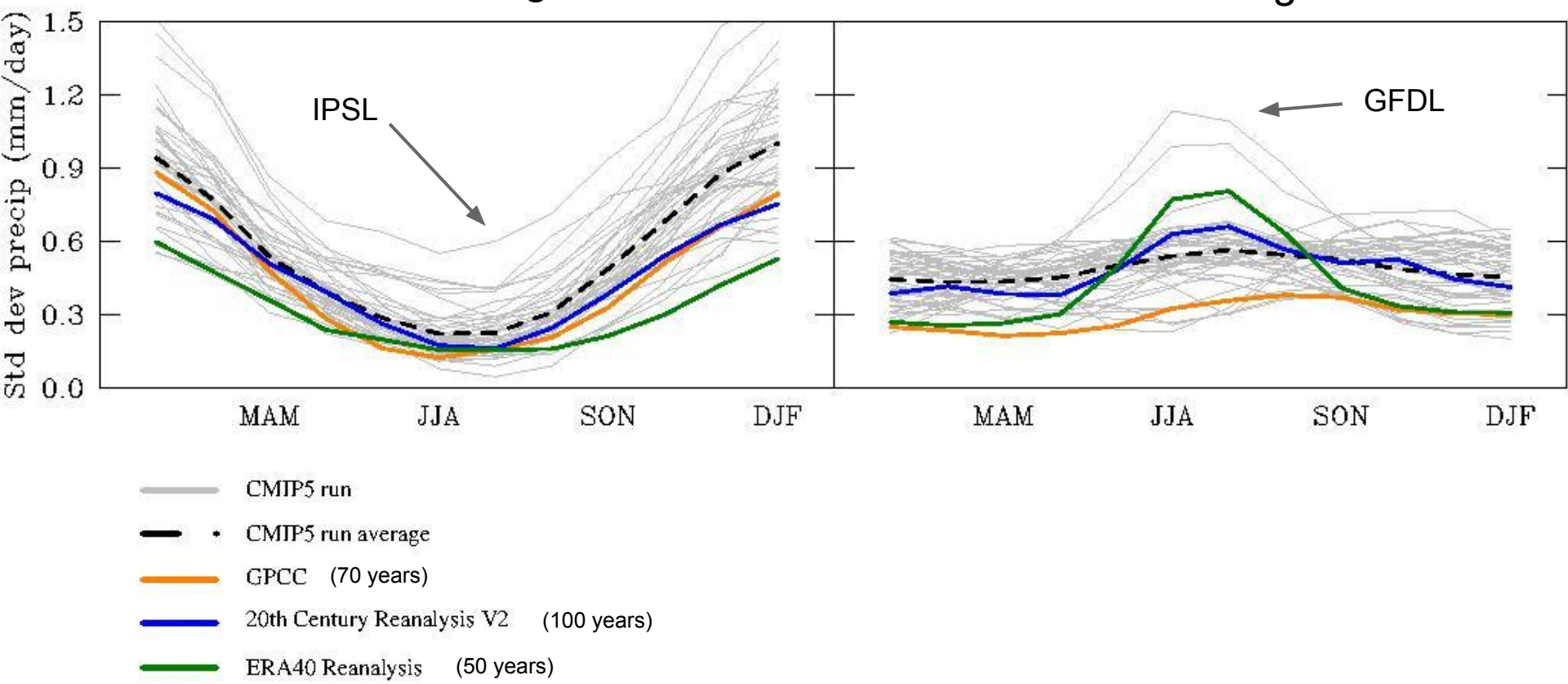
Precipitation climatology in CMIP5

Average precipitation -
models higher precip than gauge and reanalysis



Precipitation climatology in CMIP5

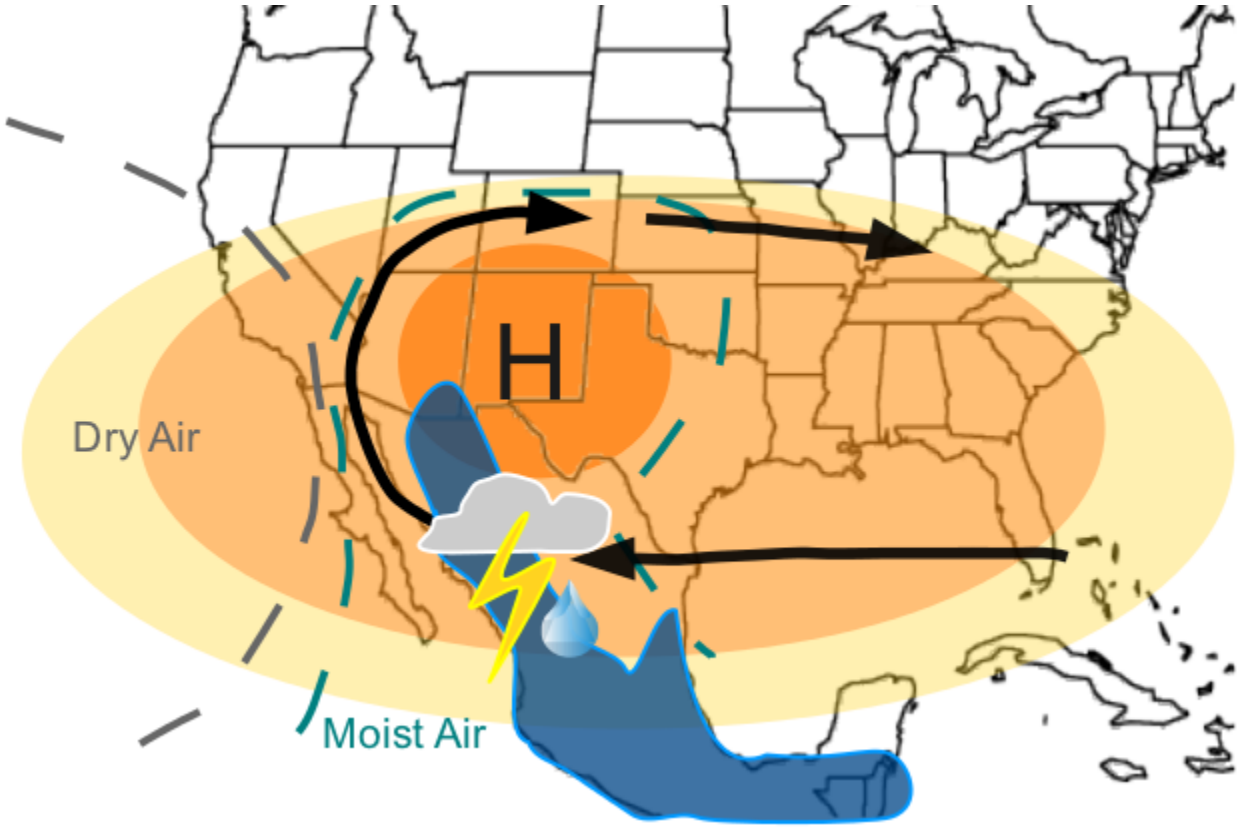
Standard deviation of precipitation -
models less variable in monsoon region



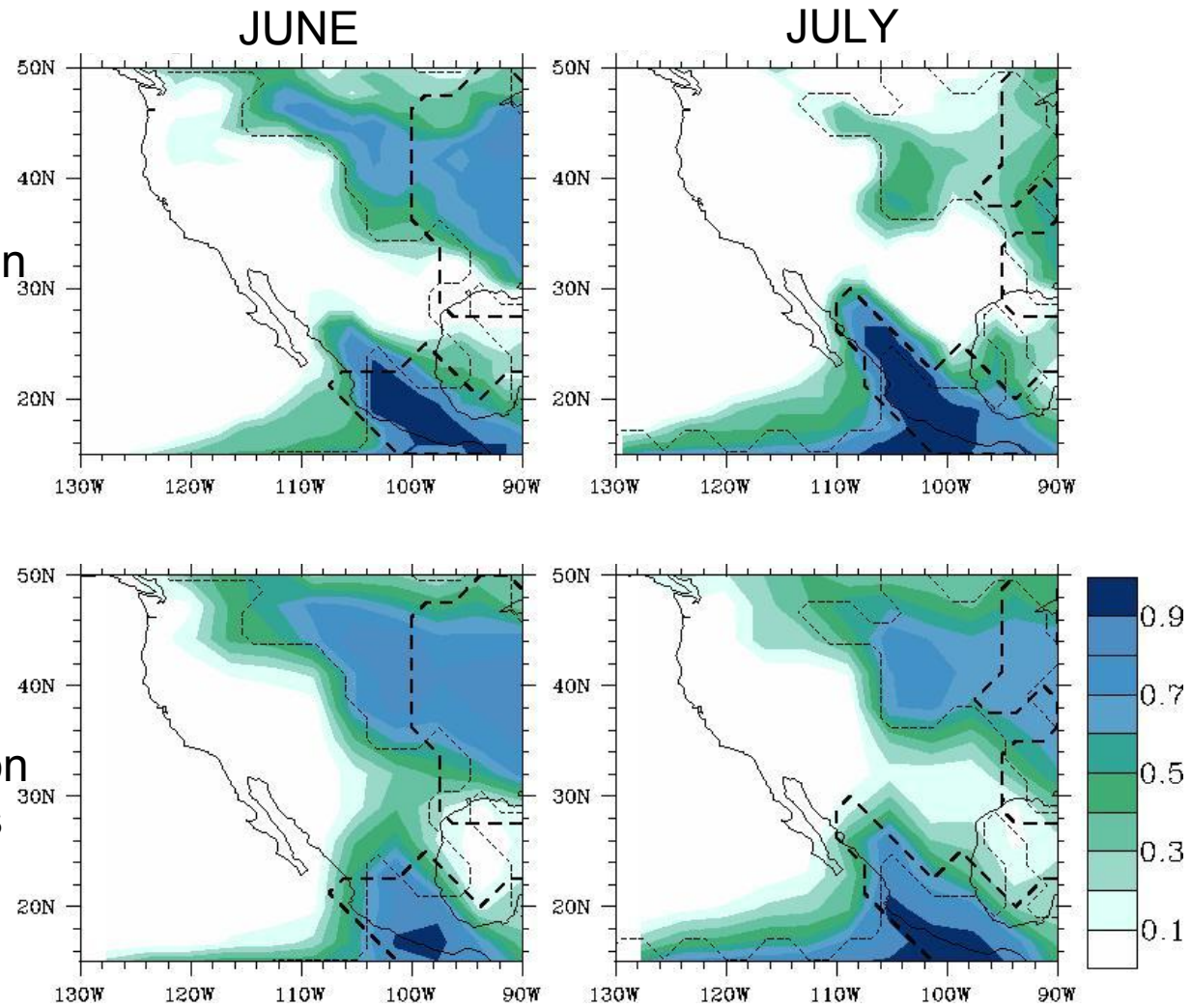
North American monsoon climatology

Characterize NA monsoon by -

- High pressure over Four Corners region
- Change in direction of wind across Gulf of California
- Moisture flux northwards over southwest North America



NA monsoon precipitaiton climatology



Higher resolution models < 2º more likely to have better topography.

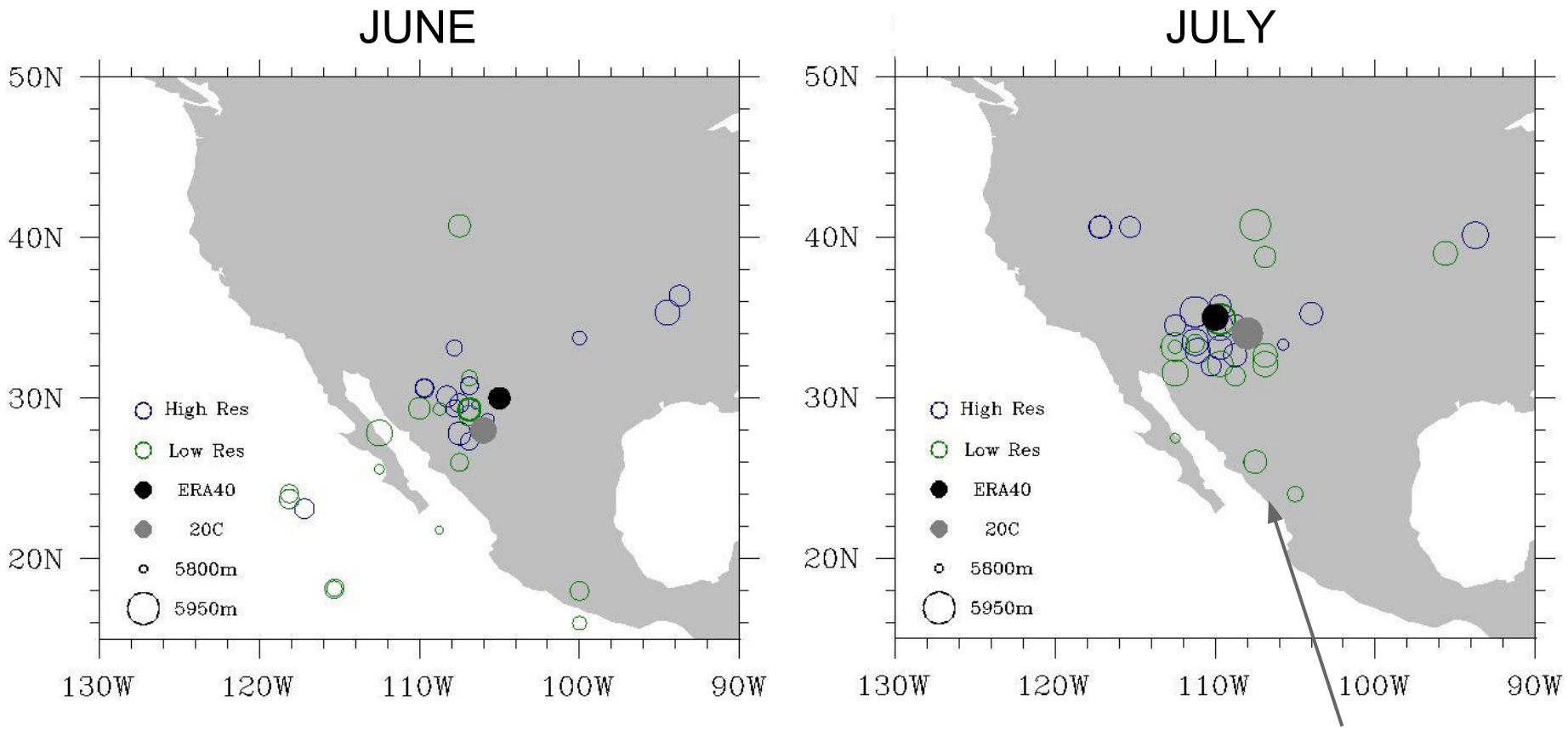
Lower resolution models > 2º do not capture precipitation along the west coast of Mexico.

Fraction of models exceeding threshold of 3 mm/day precipitation climatology

20th C GPCC

Location of NA monsoon ridge

Lower resolution models show greater spread in the location of the monsoon ridge - which affects the northward moisture flux

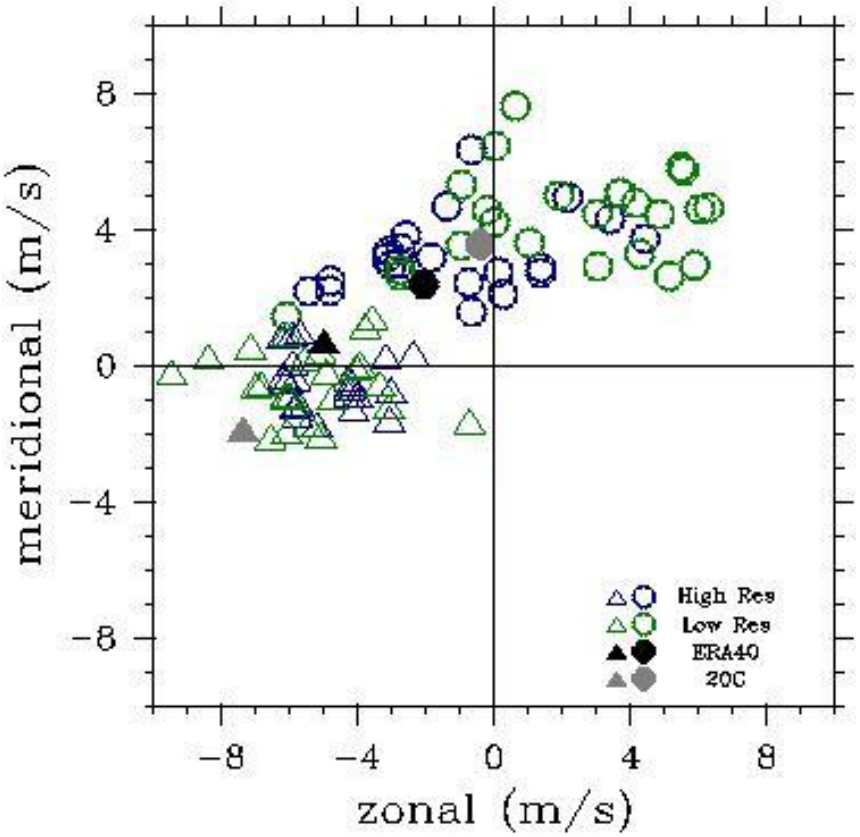


Average location of minimum vorticity at 500hPa.

IPSL, GISS, FGOALS

Gulf of California wind in NA monsoon

500hPa level winds at top (circles) and base (triangles) of Gulf of Mexico for July.



Winds along Gulf of Mexico bring moisture into Arizona and New Mexico

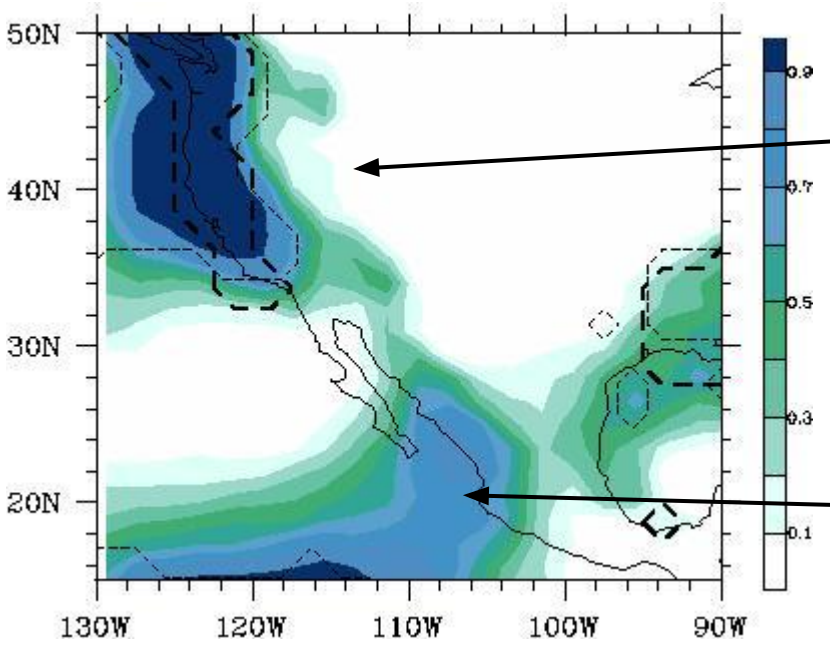
Models show offshore winds at base of Gulf.

Models show a range of onshore and offshore winds at top of Gulf - higher resolution models more consistent with reanalysis.

CMIP5 historical runs not capturing the dynamics of the NA monsoon, higher resolution models better at spatial pattern of precipitation climatology

California winter precipitation climatology

Precipitation climatology in California and Nevada is robust between models - all peak in DJF.



Fraction of models exceeding threshold of 1.5 mm/day standard deviation in precipitation

20th C GPCC

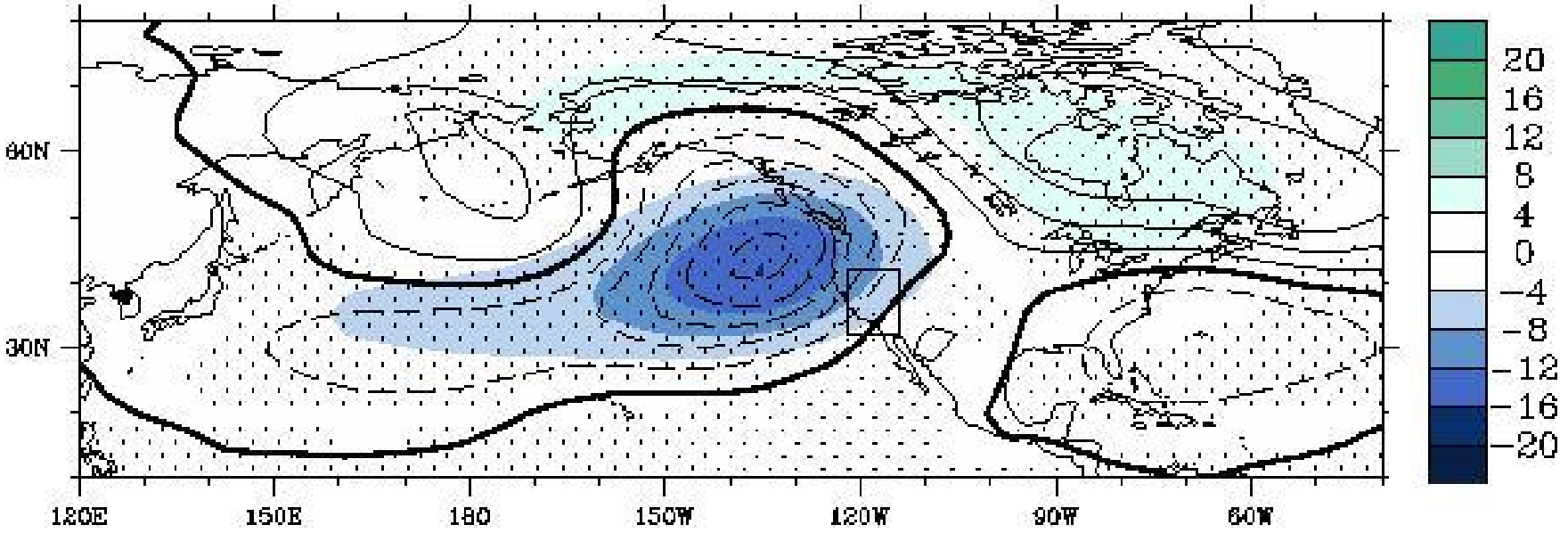
Consistent region of high variability and precipitation along California coast.

Some models fail to simulate the southward displacement of the ITCZ in winter.

Winter precip regression onto 500hPa height

Robust relationship between high precipitation in California in winter and low pressure anomaly over northeast Pacific Ocean -

consistent with southerly shift in jet stream, bringing more moisture to southwest North America.

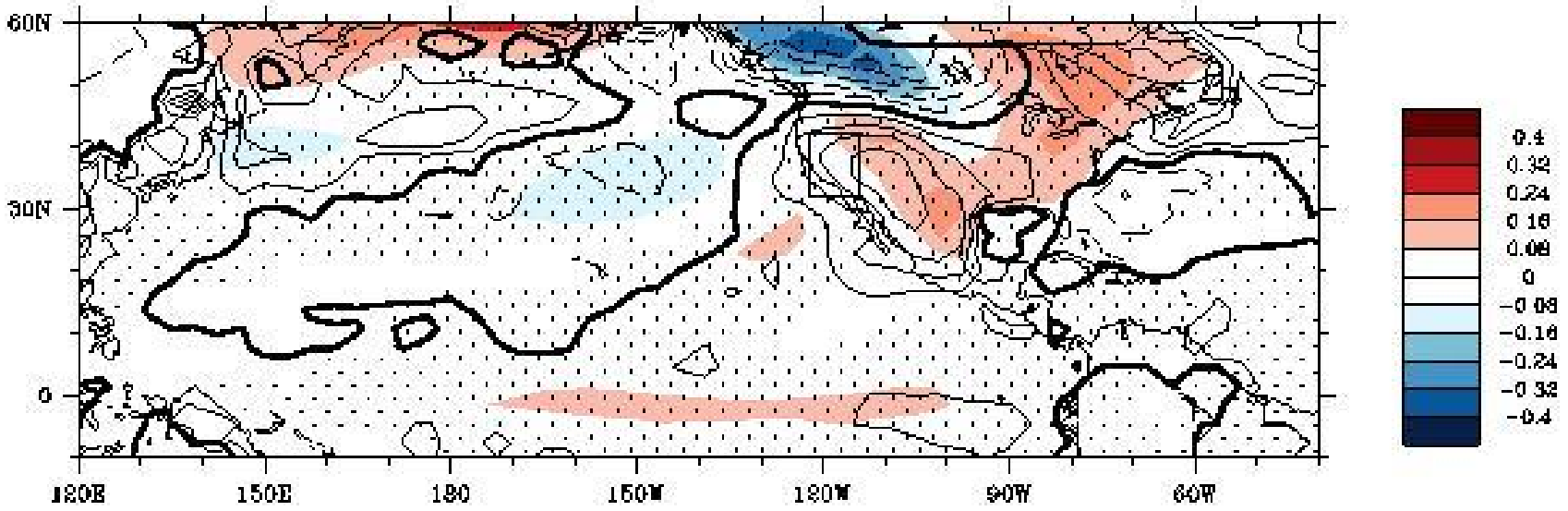


Simultaneous regression of 5-yr rolling average standardized California winter precipitation anomaly onto 500hPa geopotential height anomaly.

Contour interval 4 m per standard deviation change in precipitation.
Negative values indicated by dashed lines.
Lines GPCC and ERA40, colors average of model regression results.
Stippling indicated more than two-thirds of the models agree on the sign of the regression.

Winter precip regression onto surface temp

Weak relationship between high precipitation in California in winter and cool SST anomaly in northern Pacific and warm SST anomaly in equatorial Pacific - consistent with previous literature.

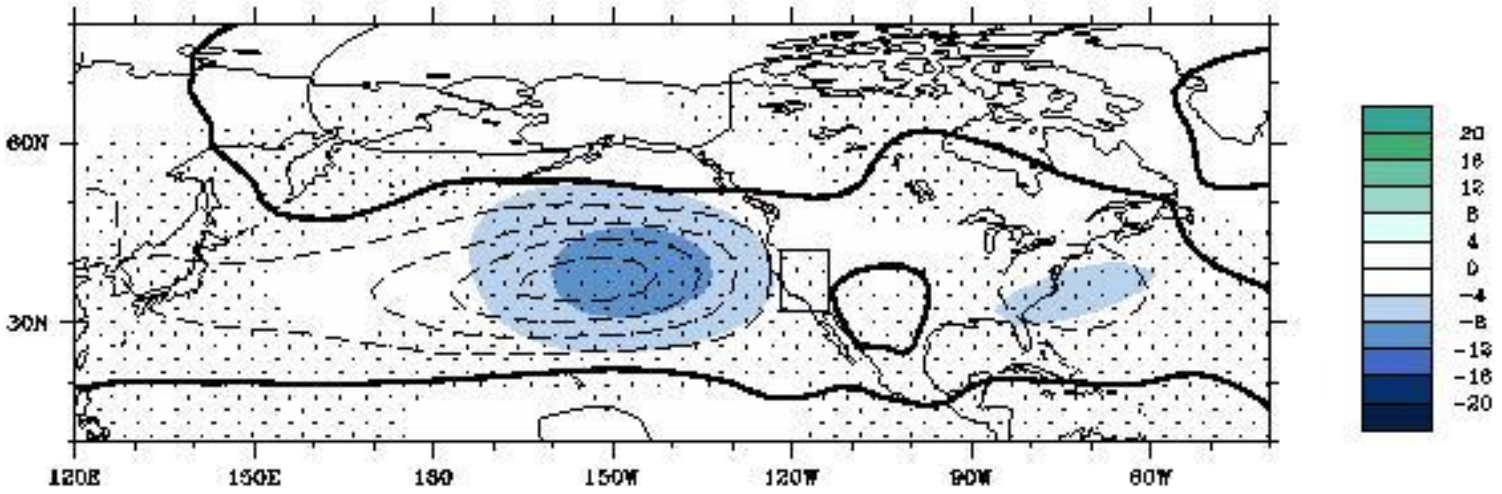


Simultaneous regression of 5-yr rolling average standardized California winter precipitation anomaly onto SST or land surface temperature anomaly.

Contour interval 0.08°C per standard deviation change in precipitation.
Negative values indicated by dashed lines.
Lines GPCC and HadISST, GISSTEMP, colors average of model regression results.
Stippling indicated more than two-thirds of the models agree on the sign of the regression.

Connection between SST and precip via atmos

Regression of negative of standardized area average north Pacific Ocean SST anomaly onto 500hPa geopotential height for winter and 5-yr rolling averages.

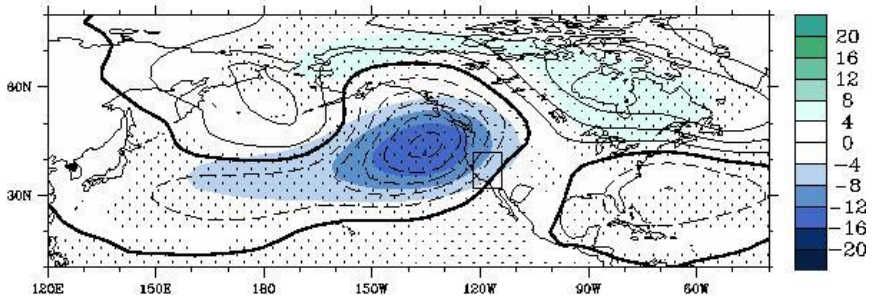


Pattern correlation with earlier figure -

0.75 average of model results

0.78 reanalysis

-> evidence of a bridge between north Pacific Ocean SST anomalies and low-frequency precipitation over California and Nevada.

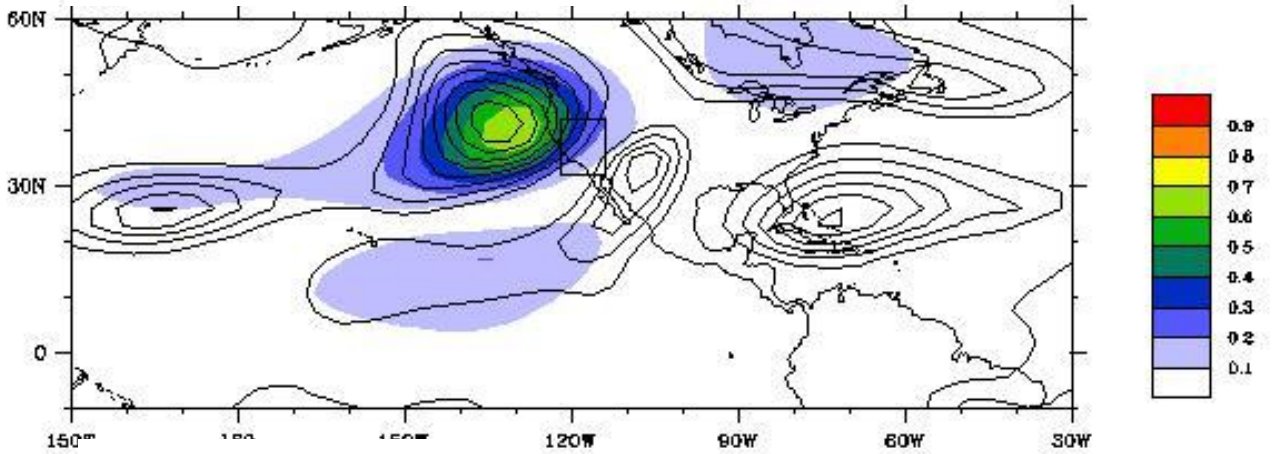


Variance explained by hgt/SST anomalies

Fraction of California winter low-frequency precipitation variance explained by 500hPa height or SST anomalies -

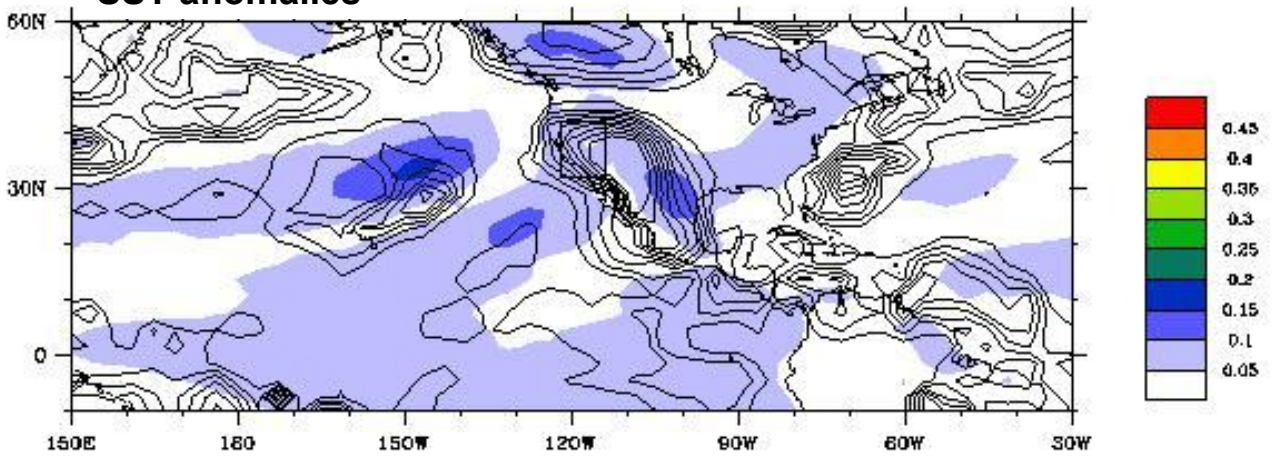
Model average shows up to **70%** of variance explained by pressure anomaly over northeast Pacific Ocean.

500hPa height anomalies



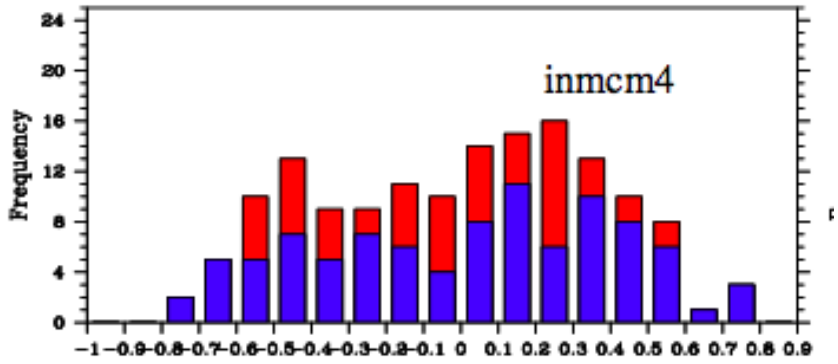
Model average shows up to **20%** of variance explained by SST anomaly in north Pacific Ocean.

SST anomalies

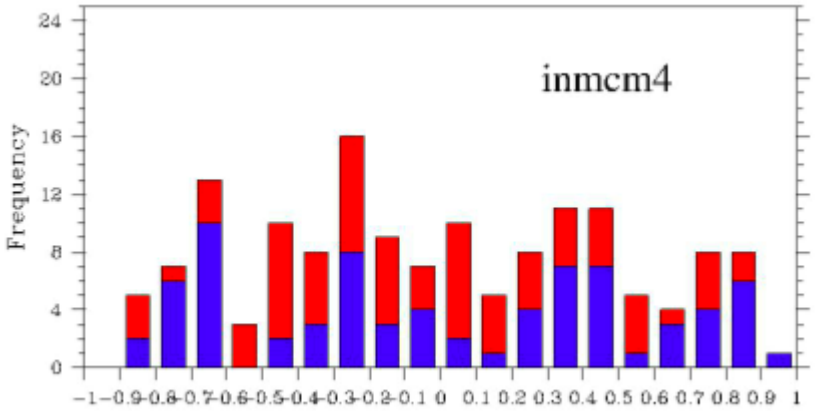


Drought occurring without SST anomaly

SST pattern correlation



500hPa height pattern correlation



Red bars -
SST anomaly pattern correlation with SST regression pattern onto California winter low- frequency precipitation (150 values)

Blue bars -
Subset of pattern correlations for years where the 500hPa height anomaly pattern correlation onto 500hPa height regression pattern is greater than 0.3.

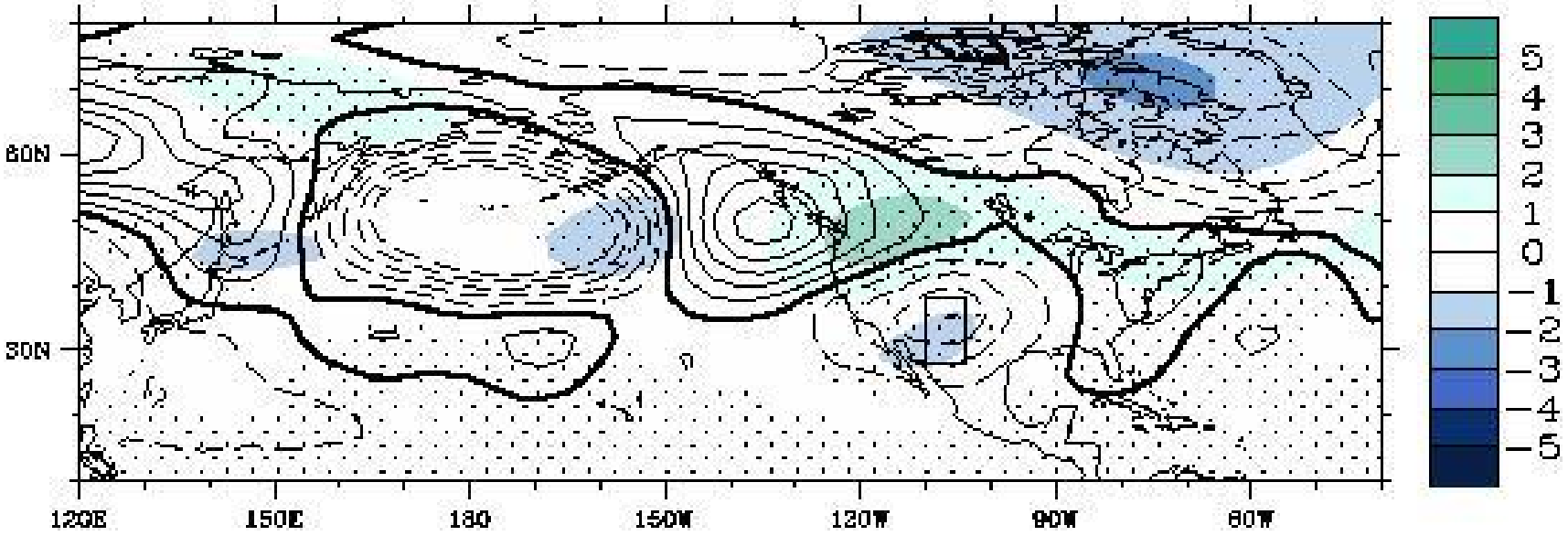
-> When the SST anomaly shows high correlation with the SST regression pattern, 500hPa height anomaly also shows high correlation with the height regression pattern.

But the height pattern is not always associated with the SST anomaly.

Summer precip regression onto 500hPa height

High precipitation in monsoon region associated with positive height anomaly over northeast Pacific Ocean and negative height anomaly over southern North America -

consistent with a northward shift of monsoon ridge.



Simultaneous regression of 5-yr rolling average standardized monsoon JAS precipitation anomaly onto 500hPa geopotential height anomaly.

Contour interval 1 m per standard deviation change in precipitation.

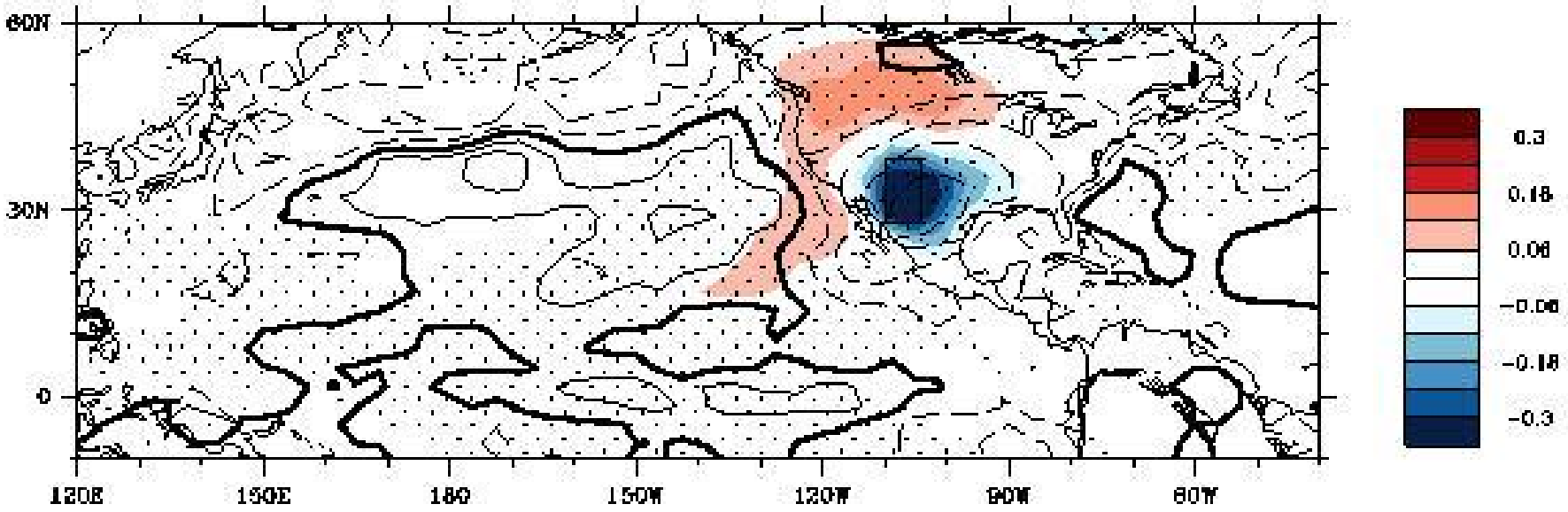
Negative values indicated by dashed lines.

Lines GPCC and ERA40, colors average of model regression results.

Stippling indicated more than two-thirds of the models agree on the sign of the regression.

Summer precip regression onto surface temp

Strong cooling feedback over North American monsoon region - evaporative cooling and reduced incoming shortwave radiation.

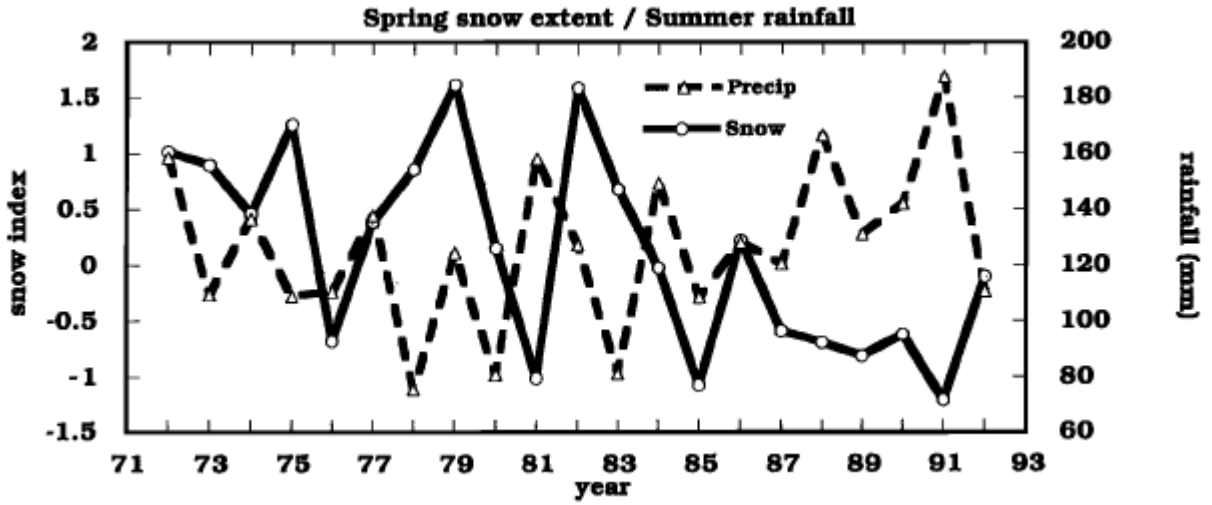


Simultaneous regression of 5-yr rolling average standardized monsoon JAS precipitation anomaly onto SST or land surface temperature anomaly.

Contour interval 0.06ºC per standard deviation change in precipitation.
Negative values indicated by dashed lines.
Lines GPCC and HadISST, GISSTEMP, colors average of model regression results.
Stippling indicated more than two-thirds of the models agree on the sign of the regression.

Lagged relationship with snow pack

Negative correlation between monsoon precipitation and spring snowpack in southern Rocky Mountains over past 50 years suggests memory in system between winter and summer.

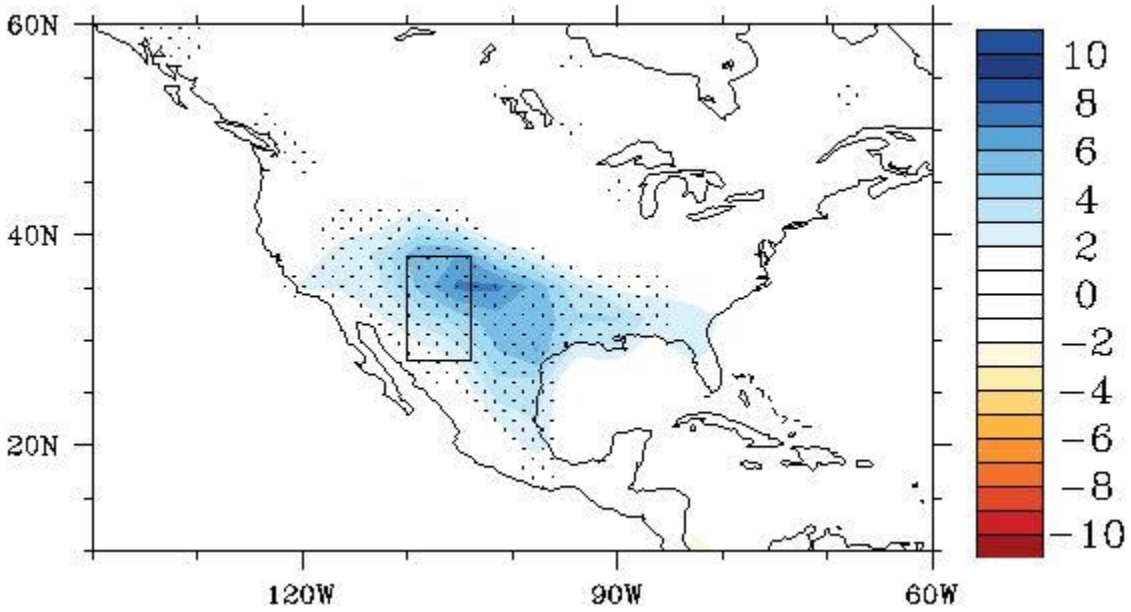


Gutzler and Preston 1997, GRL 24

However, relationship is not robust for past century -

No significant correlation found in CMIP5 historical runs for winter or spring precipitation and following summer monsoon precipitation.

Lagged relationship with soil moisture



Average of 20 model results for regression of standardized precipitation anomaly in monsoon region (rectangle) in JAS onto top 2m total soil water anomaly from the previous April.
Units are in kg/m^2, stippling indicates two-thirds of the models agree on sign.

Late summer monsoon precipitation shows a relationship with soil moisture conditions in Texas and Oklahoma in the previous April in the majority of the 20 model runs where soil water to a depth of 2m was available.

More detailed analysis of the role of antecedent conditions requires sensitivity analysis with models.

Teleconnection between north Pacific Ocean SST anomaly and low-frequency southwest US precipitation robust in CMIP5 models.

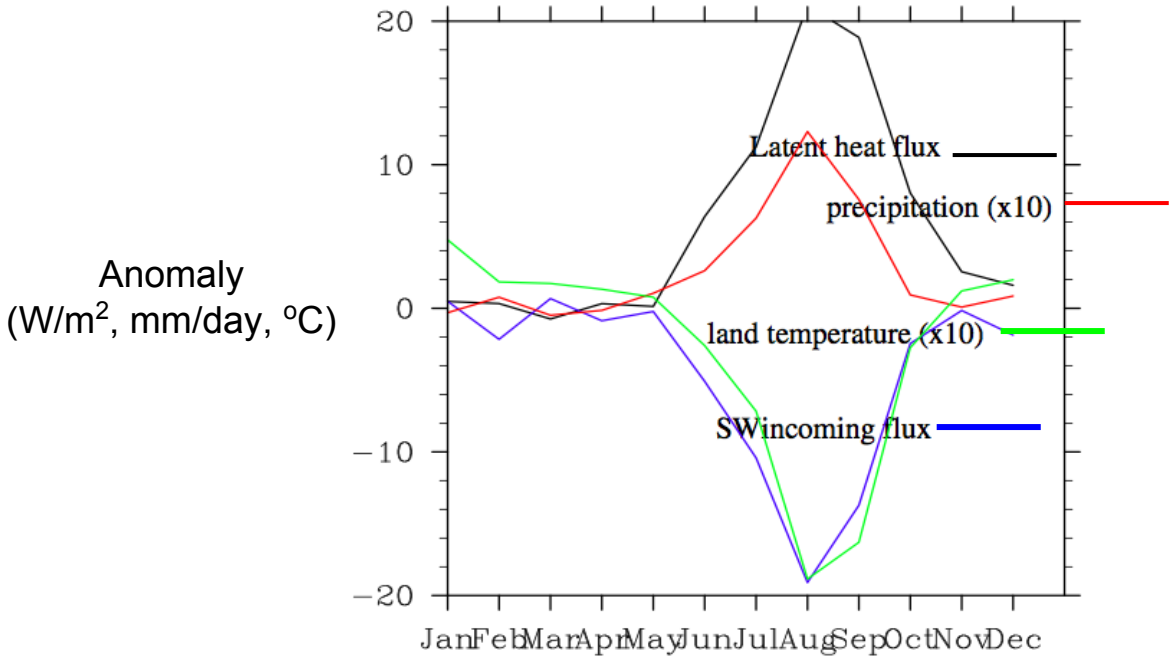
However, SST anomaly accounts for only 20% of the variability -> important for drought research that we understand what accounts for the rest of the variability.

CMIP5 models fail to capture dynamics of NA monsoon - but higher resolution models more accurate spatial representation of the precipitation climatology.

Models show strong land-atmosphere feedbacks within summer monsoon region, possible connection with antecedent soil moisture in Texas and Oklahoma, no correlation with spring snowpack - requires sensitivity studies.

Summer land-atmosphere feedback

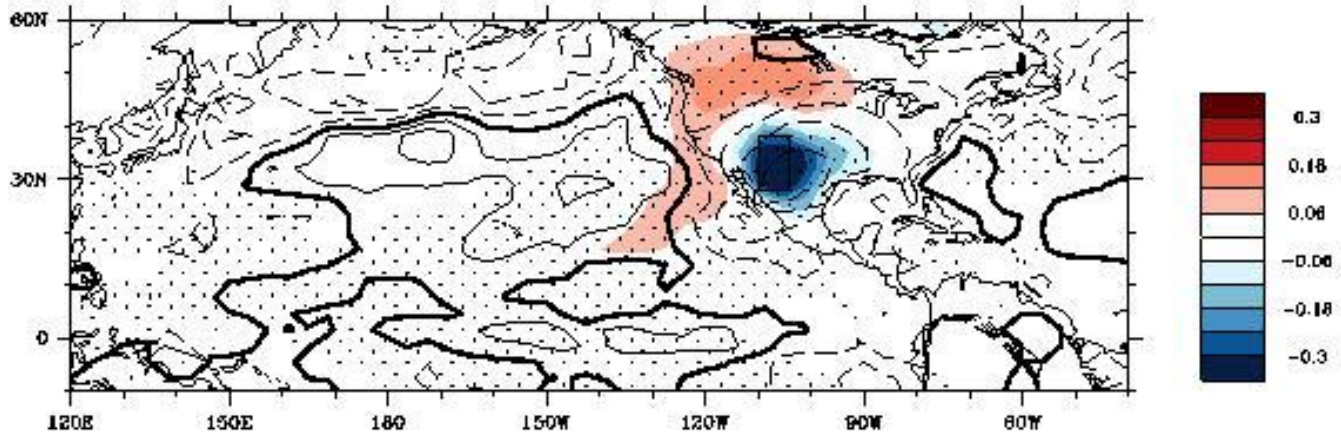
Increase in precipitation and decrease in land temperature in monsoon region occur simultaneously at the start of summer - with a positive latent heat flux and negative SW incoming flux anomaly.
Unable to distinguish the role of antecedent local conditions on strength of the monsoon.



Example for wet monsoon composite for ACCESS1-0 model
- dry monsoon composite shows opposite sign anomalies.

Summer precip regression onto surface temp

Strong cooling feedback over North American monsoon region - evaporative cooling and reduced incoming shortwave radiation.



Simultaneous regression of 5-yr rolling average standardized monsoon JAS precipitation anomaly onto SST or land surface temperature anomaly.

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Lines GPCC and HadISST, GISSTEMP, colors average of model regression results.
Stippling indicated more than two-thirds of the models agree on the sign of the regression.

As above for temperature at 500hPa.