Simulated U.S. Drought Response to Interannual and Decadal Pacific SST Variability

Robert Burgman and Youkyoung Jang

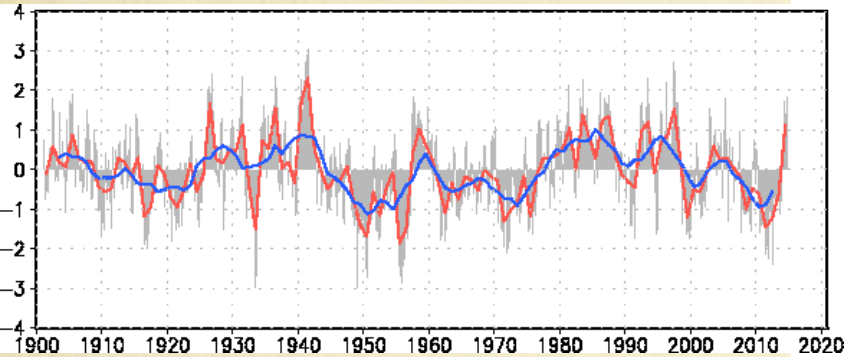
FIU FLORIDA INTERNATIONAL UNIVERSITY

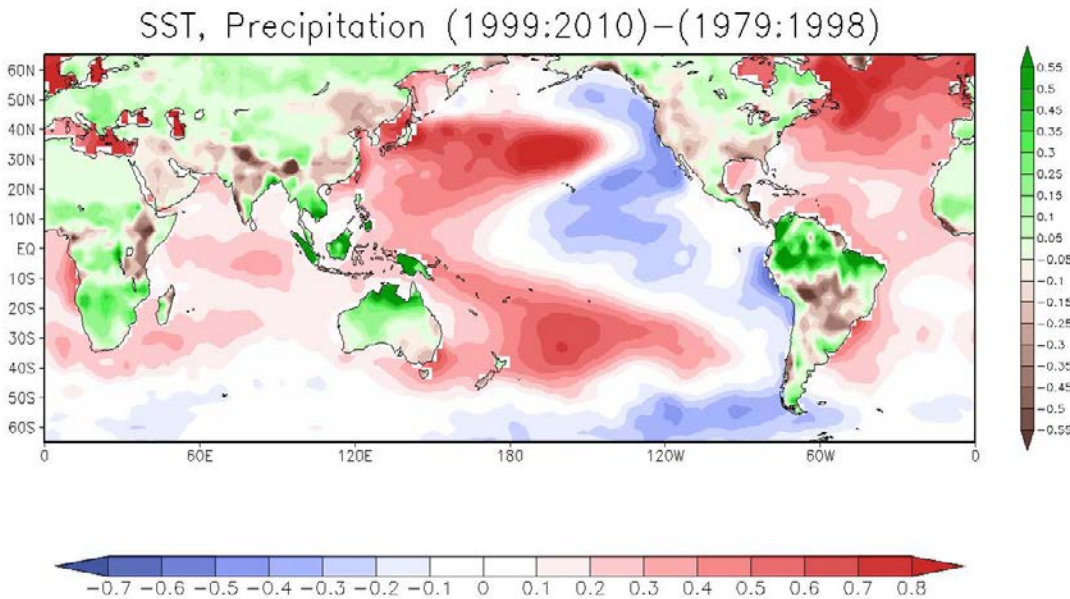
Outline

- Motivation
- USCLIVAR Drought Working Group
- DWG Pacific experiments
- Annual mean and regional precipitation response
- Spring and Summer response
  - Assess the relative role of SST forcing, relative amplitude of SST components, internal atmospheric variability and soil moisture feedback

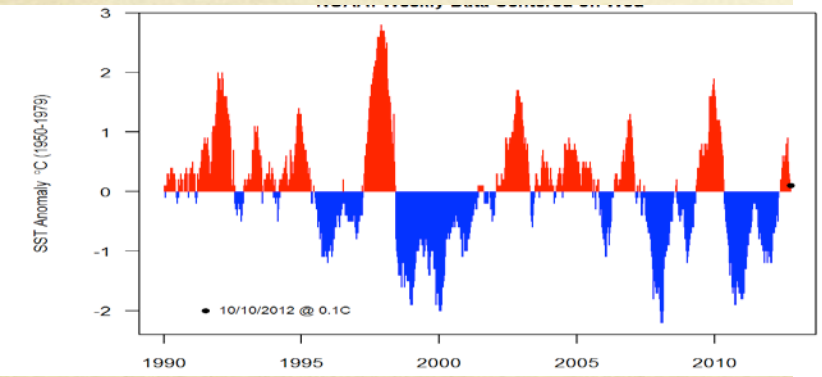
Motivation

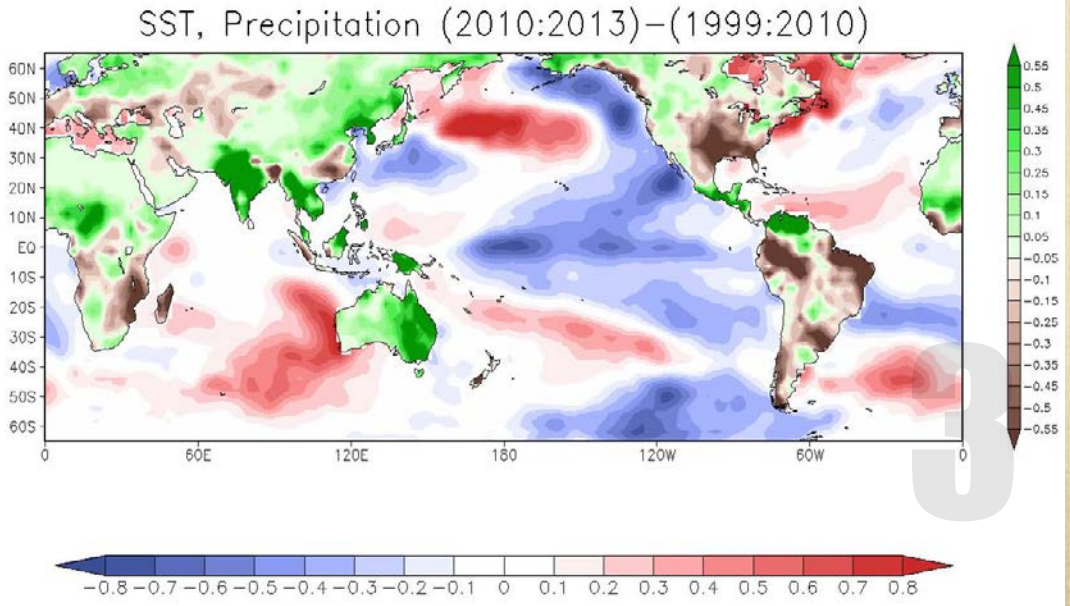
PDO index





Nino3.4 index





US Great Plains Drought

ENSO: e.g., Trenberth et al 1988; Lau and Peng1990; Cayan et al. 1999; Hoerling and Kumar 2003, and many many more.

Combined tropical Atlantic and Pacific: e.g., McCabe et al 2004; Hu and Feng2008; Seager et al (2005,2008), Mo et al. 2009; Schubert et al. 2009, Kushnir et al. 2010; Nigam et al. 2012

Atmospheric internal variability Seager et al. 2013; Hoerling et al. 2013, Wang et al. 2014.

Soil moisture/vegetation feedback Namias1959, 62, 82; 1991, Karl 1983; Carson and Sangster 1981, Rind 1982; Mintz1984; Ogelsby and Erickson 1989; Oglesby 1991, Dirmeyer 1994; Hong and Kalnay 2000; Schubert et al. 2004; Koster et al 2006)

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Model (reference)	Resolution	Convection scheme (reference)	Land surface model (reference)
AM2.1 (Delworth et al. 2006; GFDL Global Atmospheric Model Development Team 2004)	2° × 2.5°, L24	Relaxed Arakawa–Schubert (Moorthi and Suarez 1992)	Milly and Shmakin (2002)
GFS, version 2 (Campana and Caplan 2005)	T62 (~2° × 2°), L64	Simplified Arakawa–Schubert (Grell 1993; Pan and Wu 1995)	Ek et al. (2003)
NSIPP-1 (Bacmeister et al. 2000; Schubert et al. 2002)	3° × 3.75°, L34	Relaxed Arakawa–Schubert (Moorthi and Suarez 1992)	Mosaic (Koster and Suarez 1996)
CCM3.0 (Kiehl et al. 1998; Seager et al. 2005)	T42 (~2.8° × 2.8°), with 18 hybrid sigma levels	Zhang and McFarlane (1995) and Hack (1994)	Bonan (1996)
CAM3.5 (online at http://www.ccsm.ucar.edu/models/atm-cam/)	T85, with 27 hybrid sigma levels	Oleson et al. (2008)	Community Land Model (Oleson et al. 2008; Stockli et al. 2008)
CCSM3.0 (Collins et al. 2006)	AGCM: T85, with 26 levels; OGCM: 1° × 1°, telescoping to 1° × 1/2° in the deep tropics with 40 levels	Zhang and McFarlane (1995)	Community Land Model

Schubert et al (2009), J Climate

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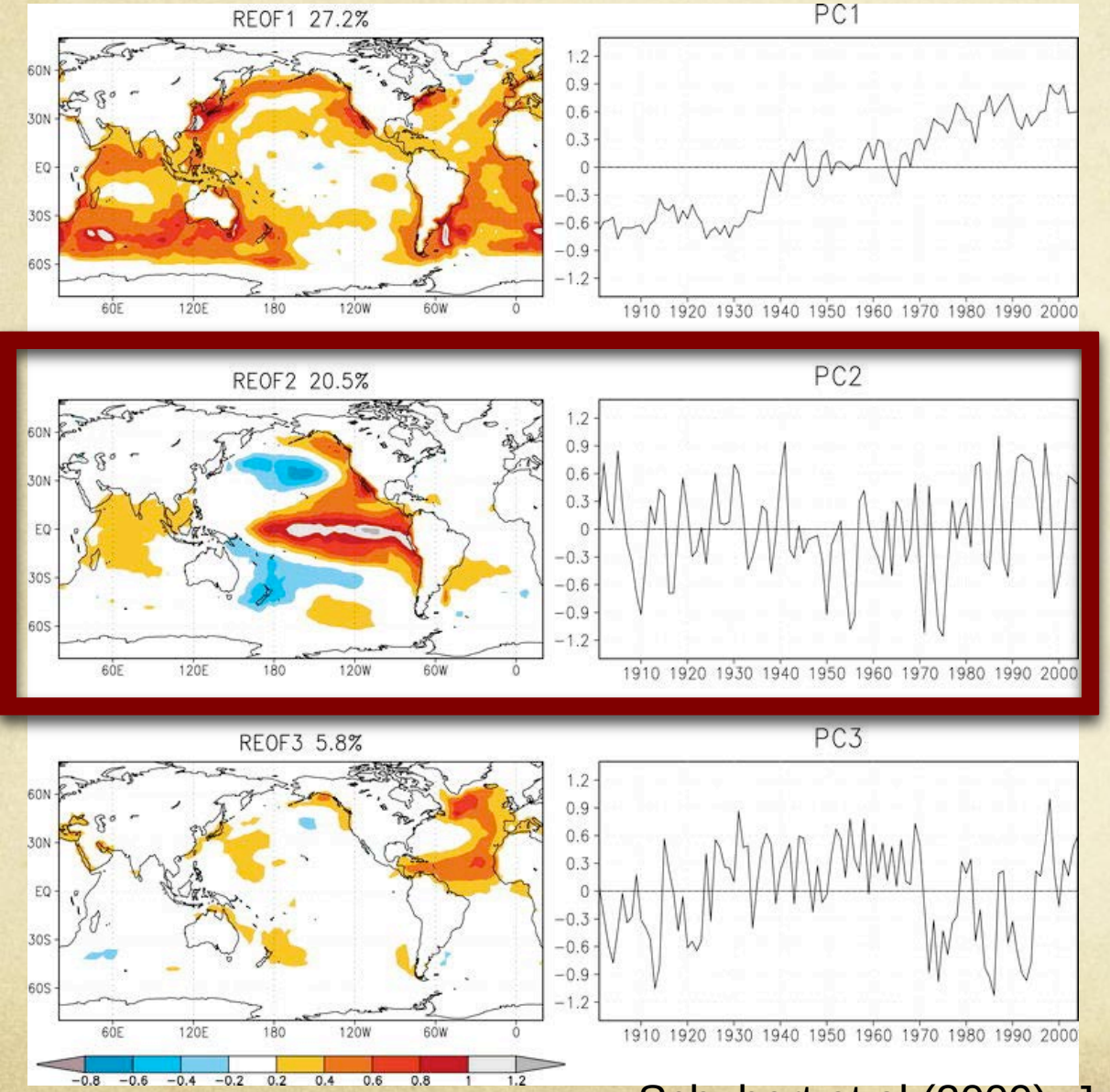

1900-2004 Annual SST

Patterns derived from REOF analysis

Pacific response largest
Broadly similar Drought Response to negative tropical SSTAs

Response to Atlantic pattern less robust, but constructive / destructive interference evident

Schubert et al (2009), J Climate

US CLIVAR Drought Working Group
Pacific simulations

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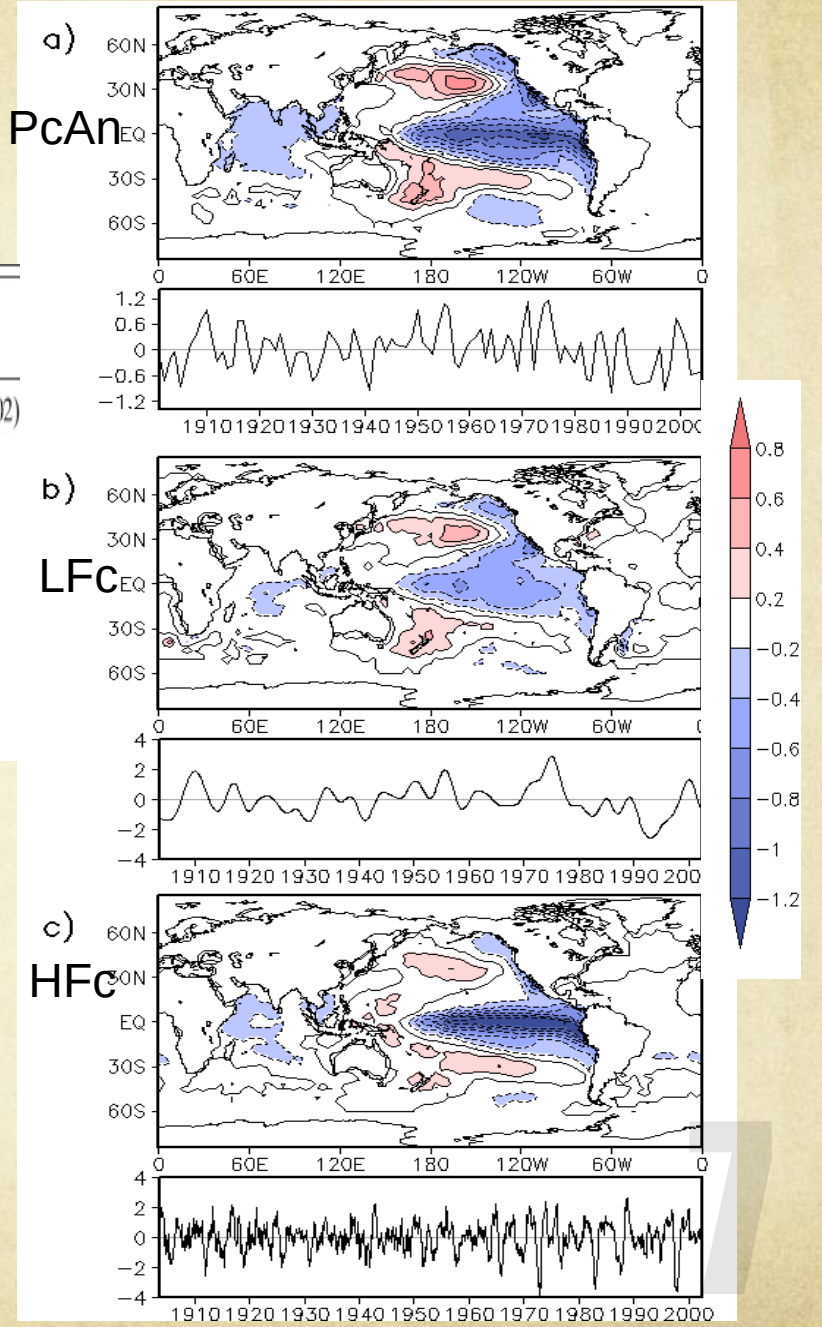


LFc and HFc pattern. Monthly data, REOF of lowpass filtered and residual anomalies

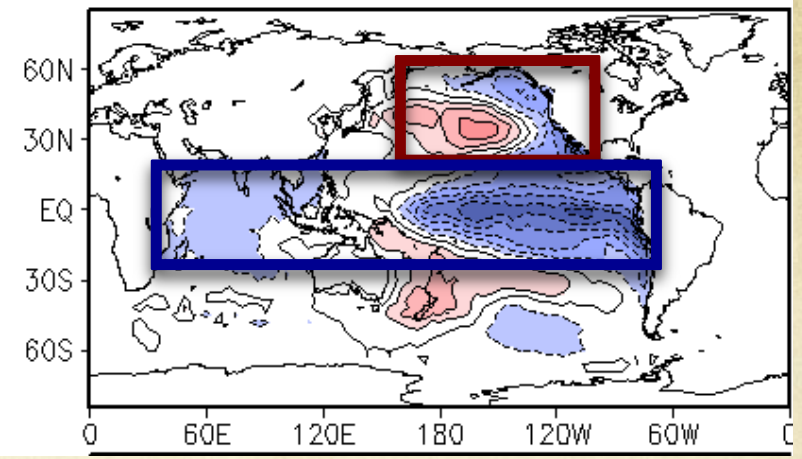
50 years (AM2.1, NSIPP1), 35 years (GFS)

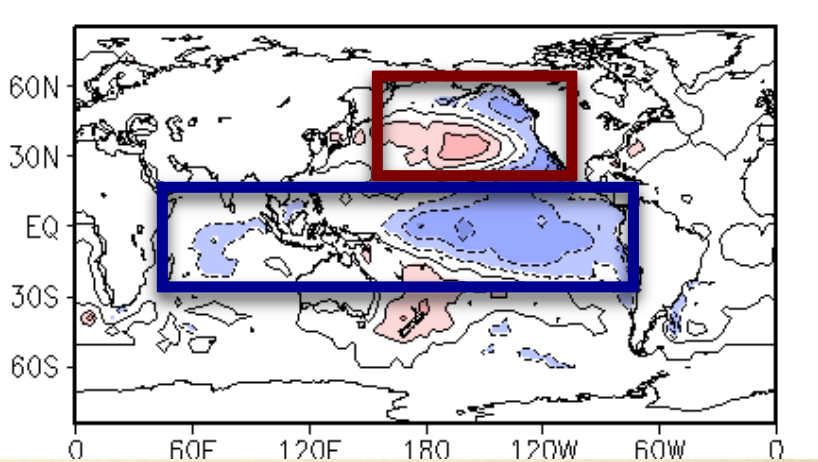
Burgman and Jang (2015) *J. Climate*, **28**

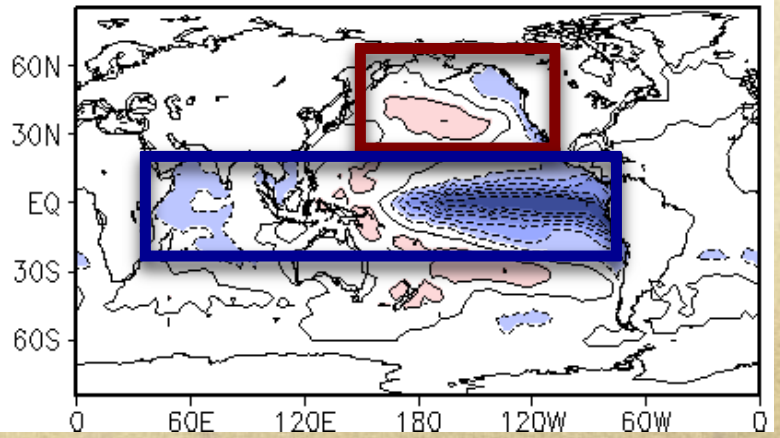
Pacific Patterns

- **Spatial Correlations**
- **PcAn and LFc, r = 0.93;**
- **PcAn and HFc, r = 0.9;**
- **LFc and HFc, r = 0.79);**

SSTA amplitude of the equatorial (mid-latitude) anomalies differ by up to 1°C (0.3°C)







Annual Mean Precipitation Response

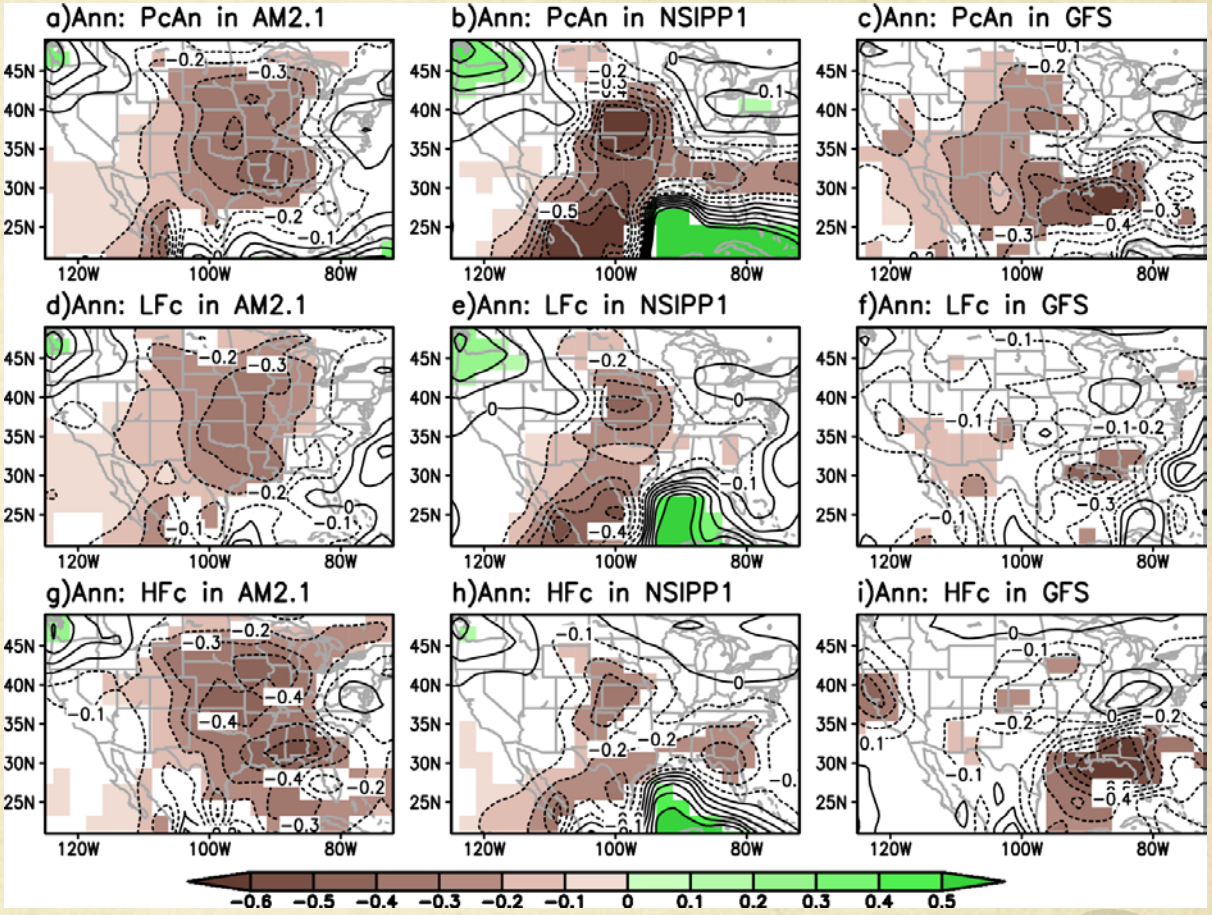
Broad agreement to PcAn pattern for all models

AM2.1
robust response to all forcing patterns, larger response to equatorial component

NSIPP1
largest response to PcAn,
LFc Pac NW, Northern Great Plains
HFc South and Southeast

GOM low influence (Wang et al 2010)

GFS
largest response to PcAn,
Larger internal atmospheric variability
HFc Southeast



mm day^{-1} , Shading 90% confidence

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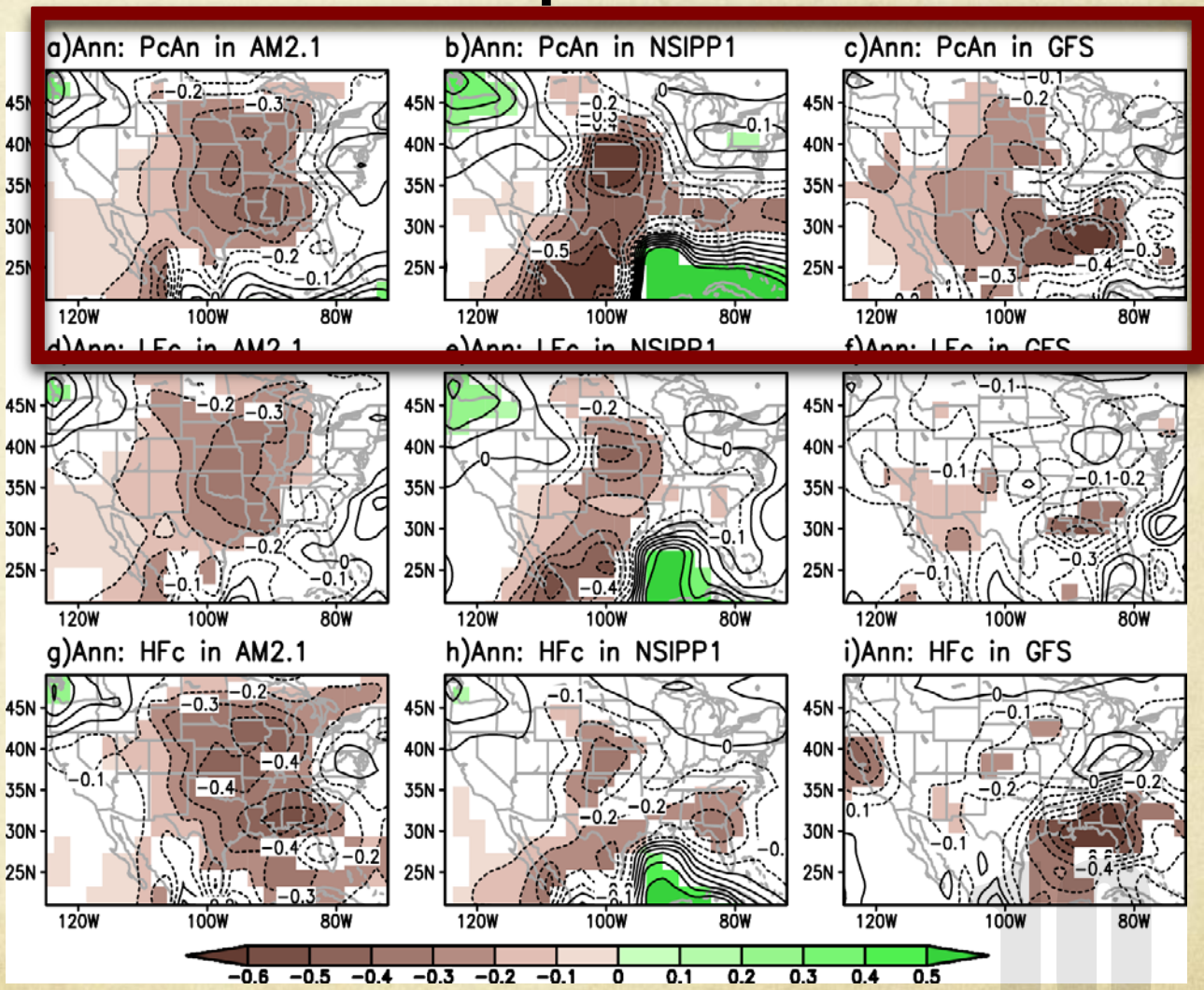

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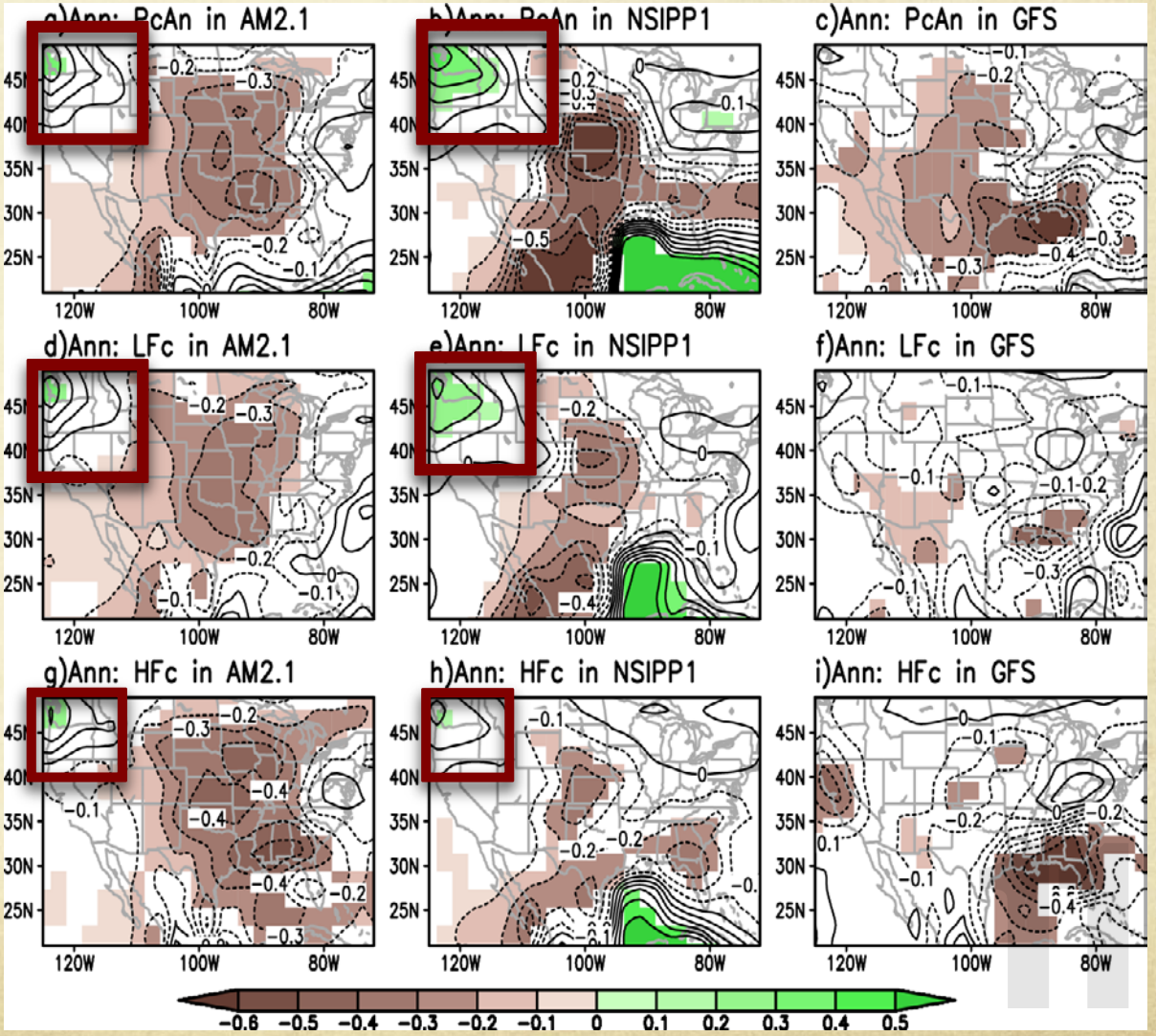

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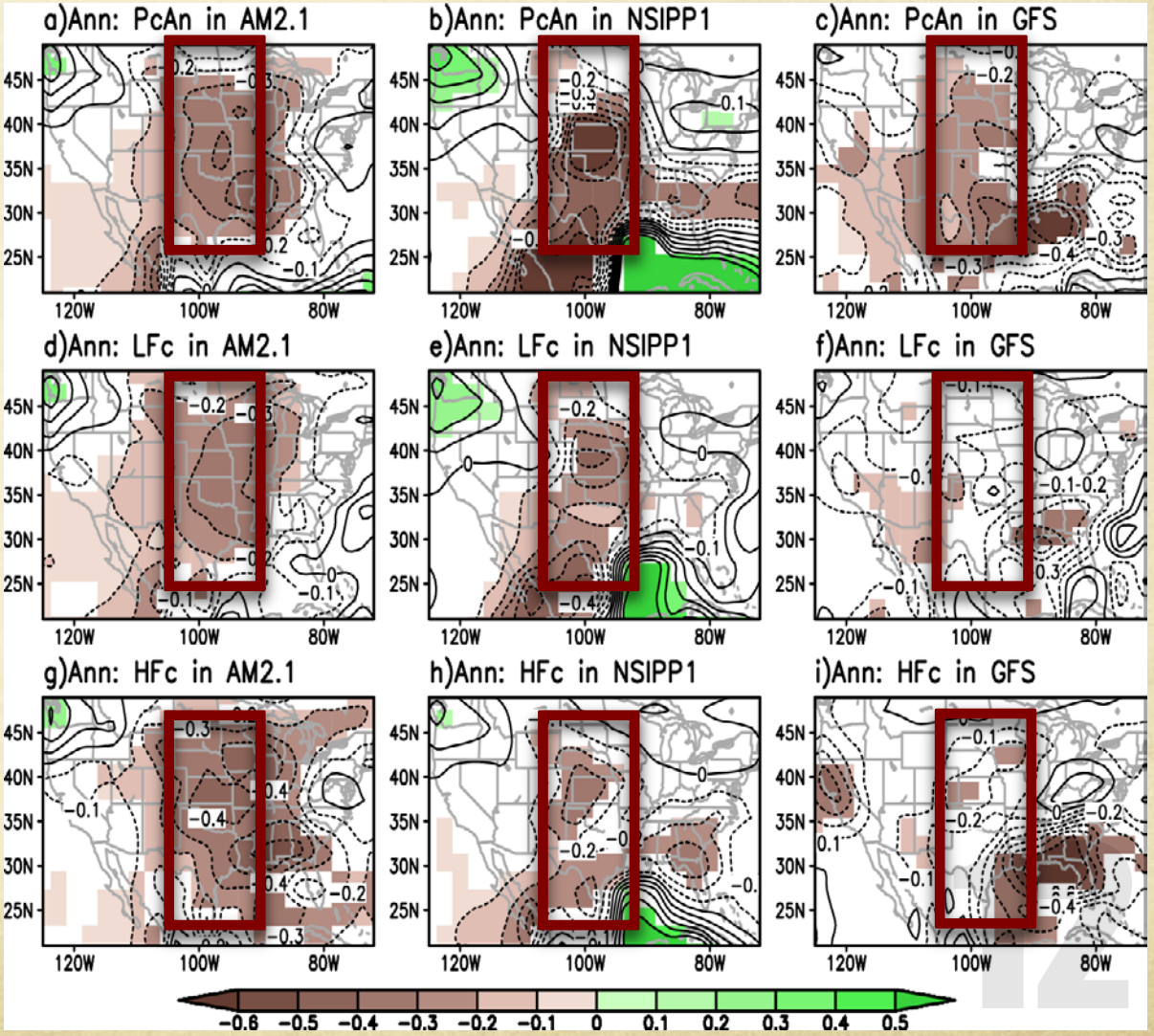

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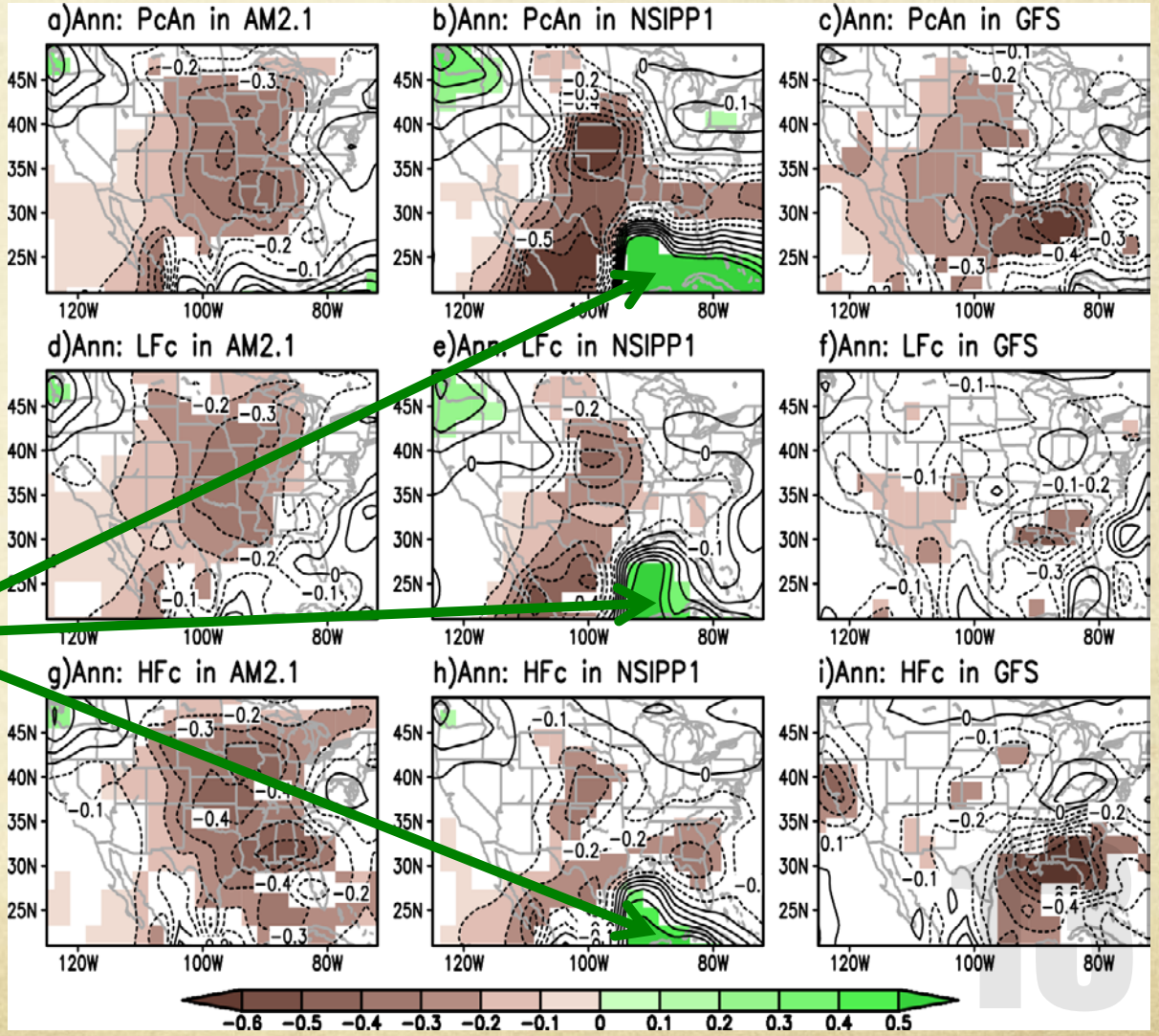
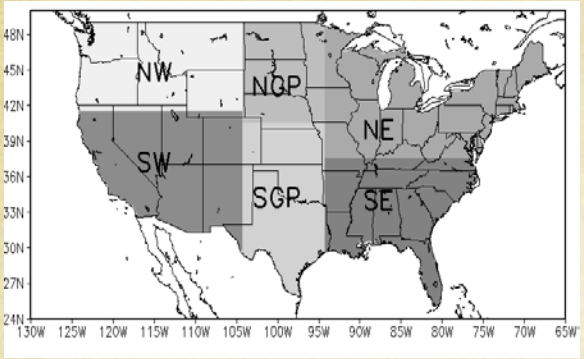


mm day^{-1} , Shading 90% confidence

Annual Mean Regional Response



NW, mixed +/- , extra-tropical influence

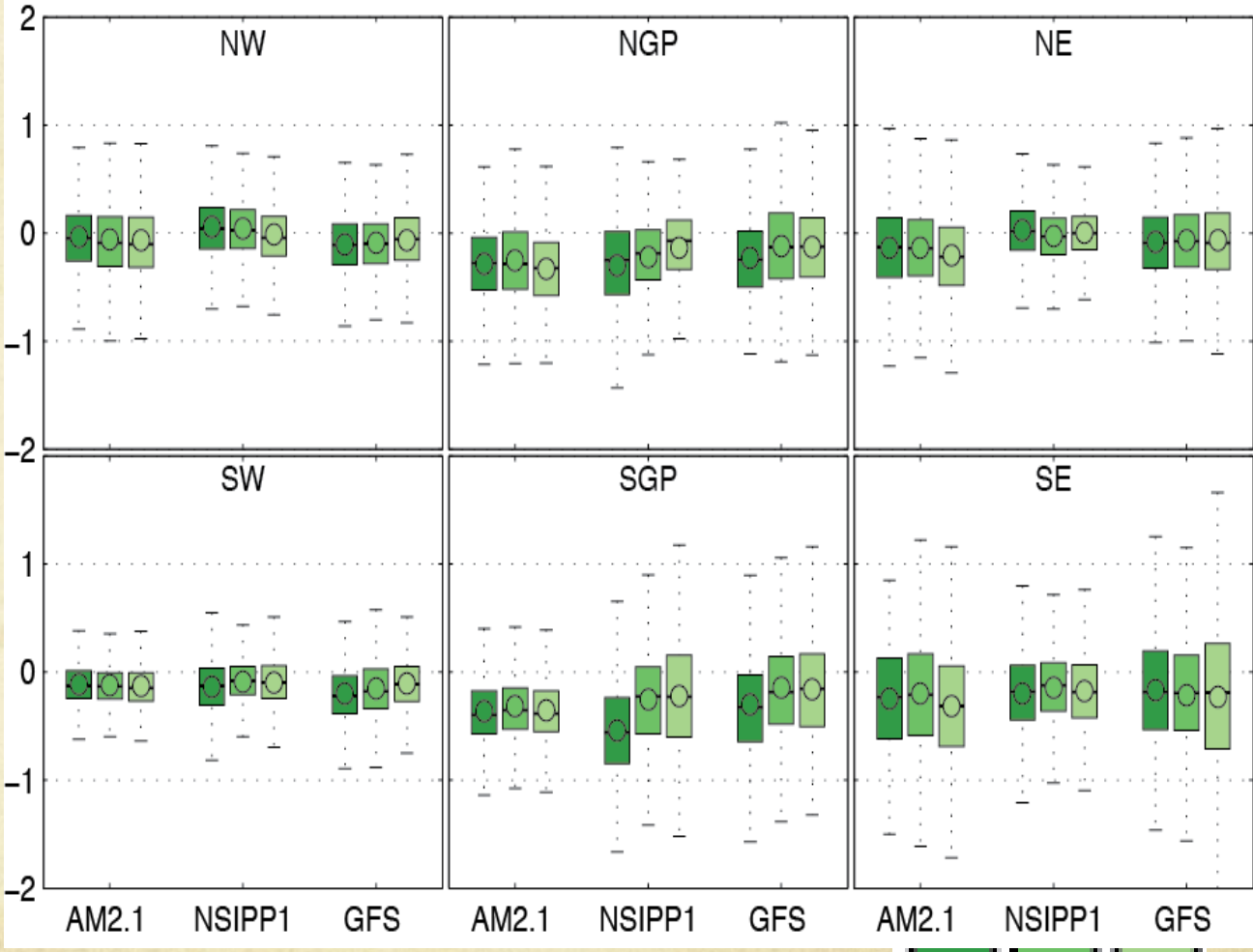
SW, robust drought, reduced variability, short tails

NGP, robust drought, PcAn (extra-tropics) NSIPP1, GFS

SGP, robust drought NSIPP1, GFS PcAn, larger variability

NE, mixed +/-

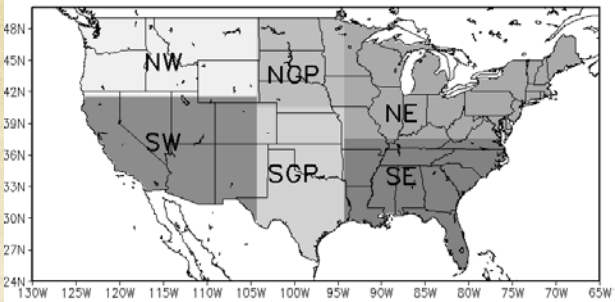
SE, robust drought large variability and tails



PcAn LFc HFc

mm day^{-1} Whiskers @2.698 stdev

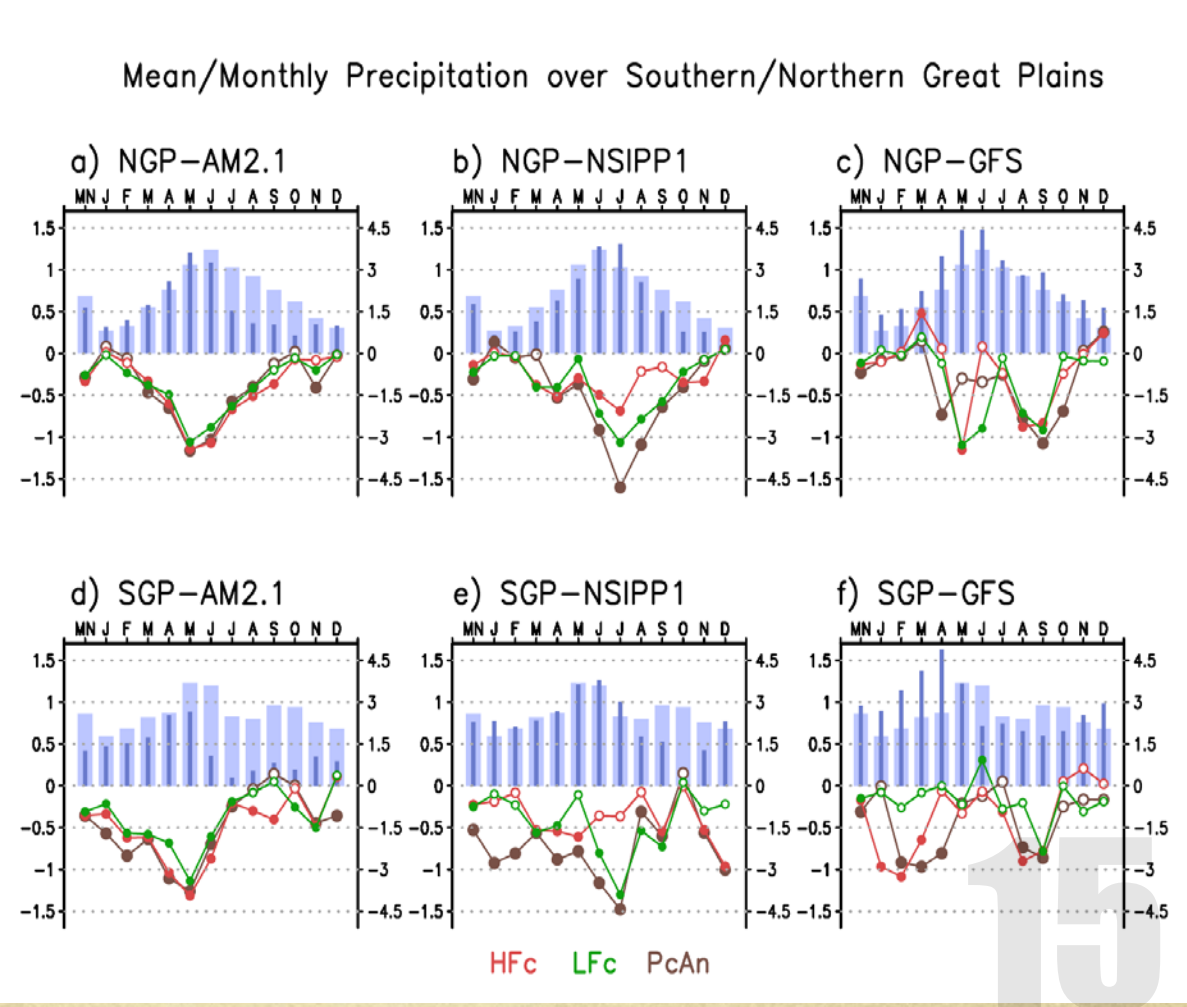
Great Plains Seasonal Precipitation Response



AM2.1
Comparable annual means
Seasonal Coherence, relative maximum climatology and Peak Drought in May

NSIPP1
PcAn largest in annual mean, relative maximum climatology Peak Drought in July.
Constructive interference of equatorial and extr-tropical components.

GFS
PcAn largest in annual mean, Bimodal drought, weakest in MJJ
Soil Moisture feedback and strong internal atmospheric

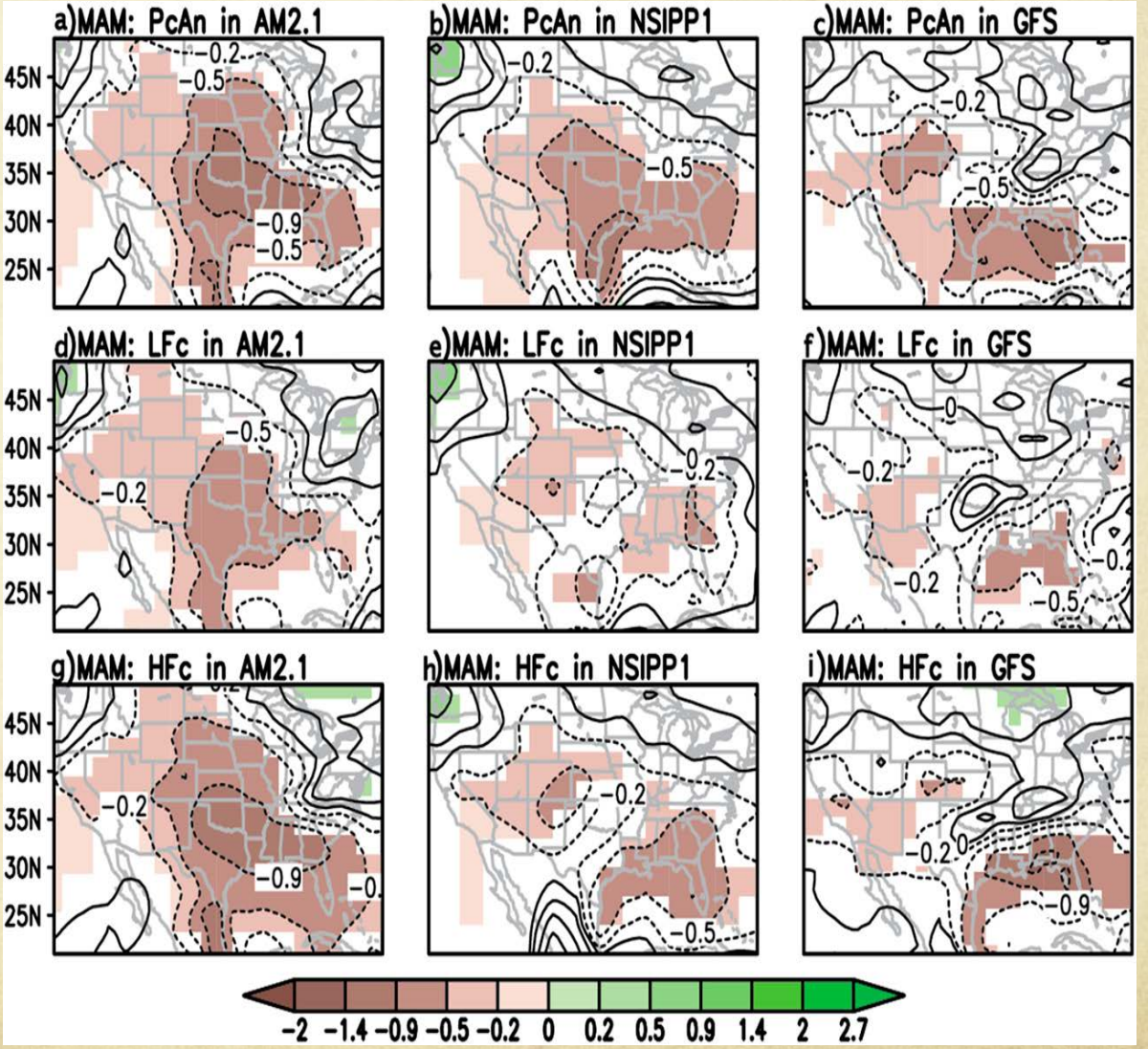


mm day $^{-1}$, Light Blue=GPCP climatology; Dark Blue=Model climatology; Only filled circles significant

Spring Precipitation Response

For the Spring Season, Stronger SST forced response

Tropical component (PcAn and HFc) dominates in the Southeast



mm day^{-1} , Shading 90% confidence

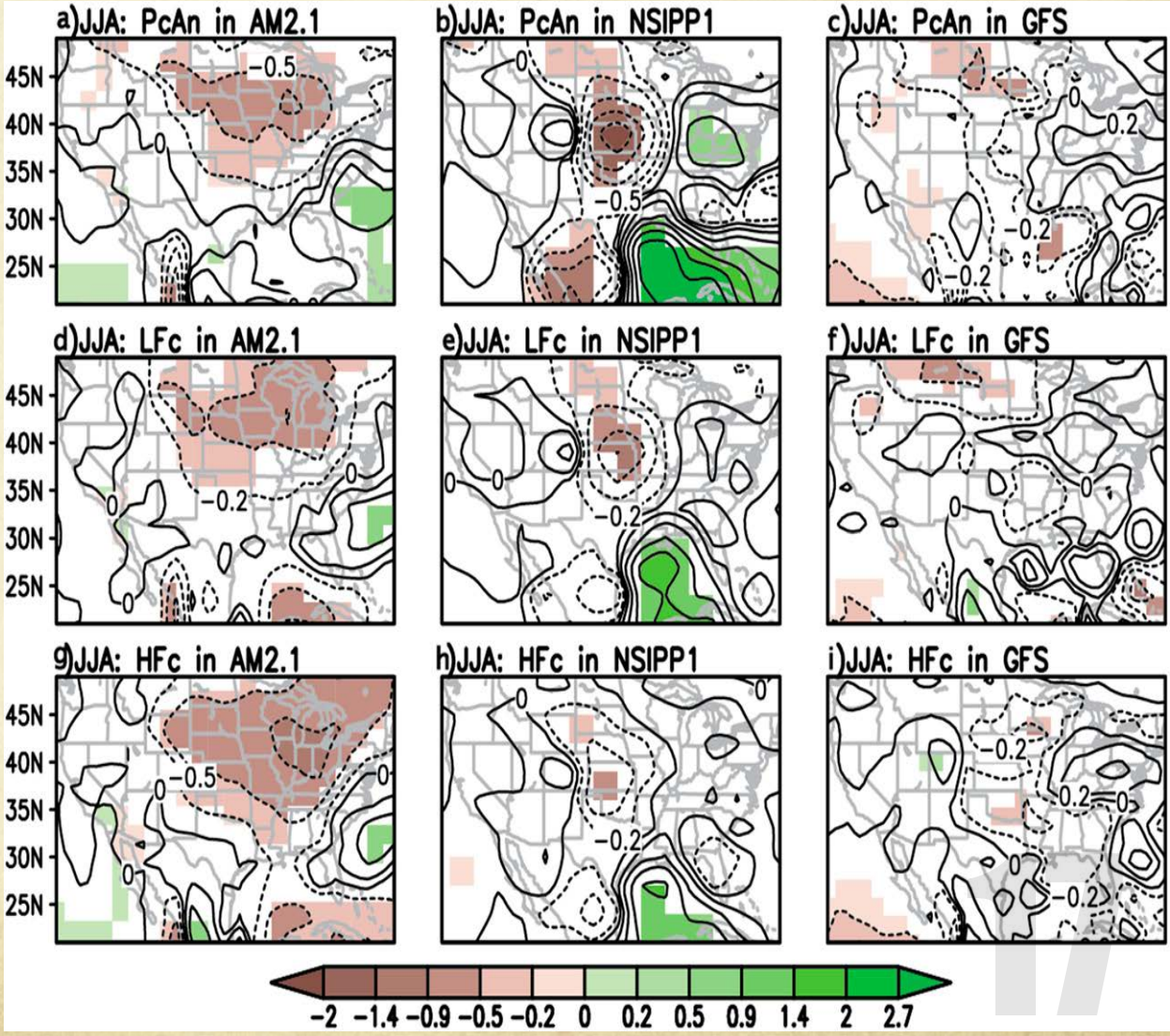
Summer Precipitation Response

For Summer Season, Internal atmospheric variability , soil moisture feedback play a larger role

AM2.1
Robust drought signal migrates to the northeast

NSIPP1
SST forced signal strongest in PcAn, reduced in HFc
GOM low contribution

GFS
Little significant drought.
Strong internal atmospheric variability, weak soil moisture feedback
Limited data (35 years)



mm day^{-1} , Shading 90% confidence

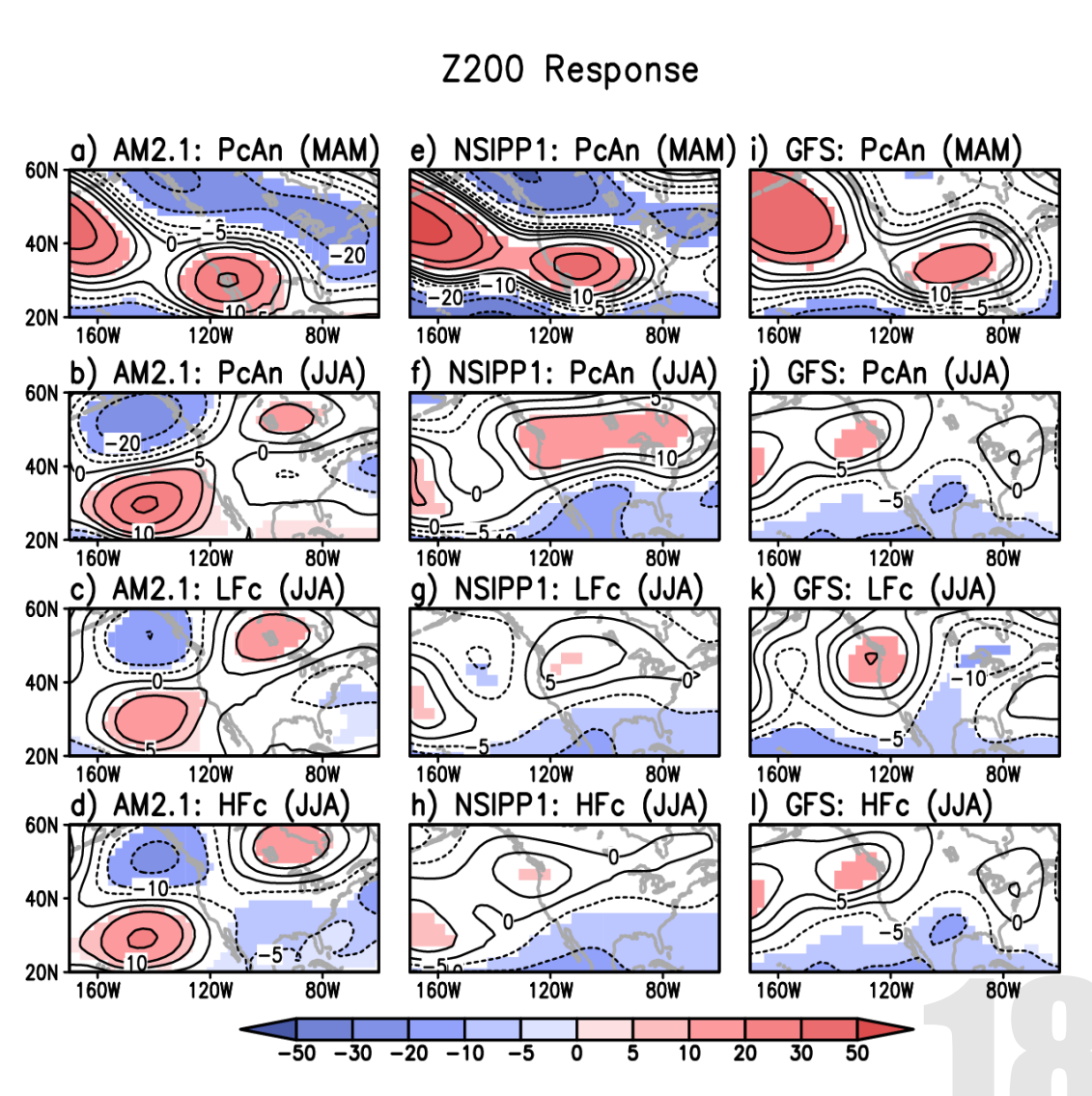
Spring / Summer Z200 hPa response

Spring: Ridge over the North Pacific that extends eastward across the United States

Summer:
AM2.1
Ridge over the N Pacific shifts to the South **Ridge over United States shifts to the Northeast**

NSIPP1
Ridge over the United States shifts to the North and weakens from **PcAn -> LFc ->HFc**

GFS
Ridge over the United States shifts to the Northwest and



5m, and shading denotes 90% confidence.

200hPa signal to noise

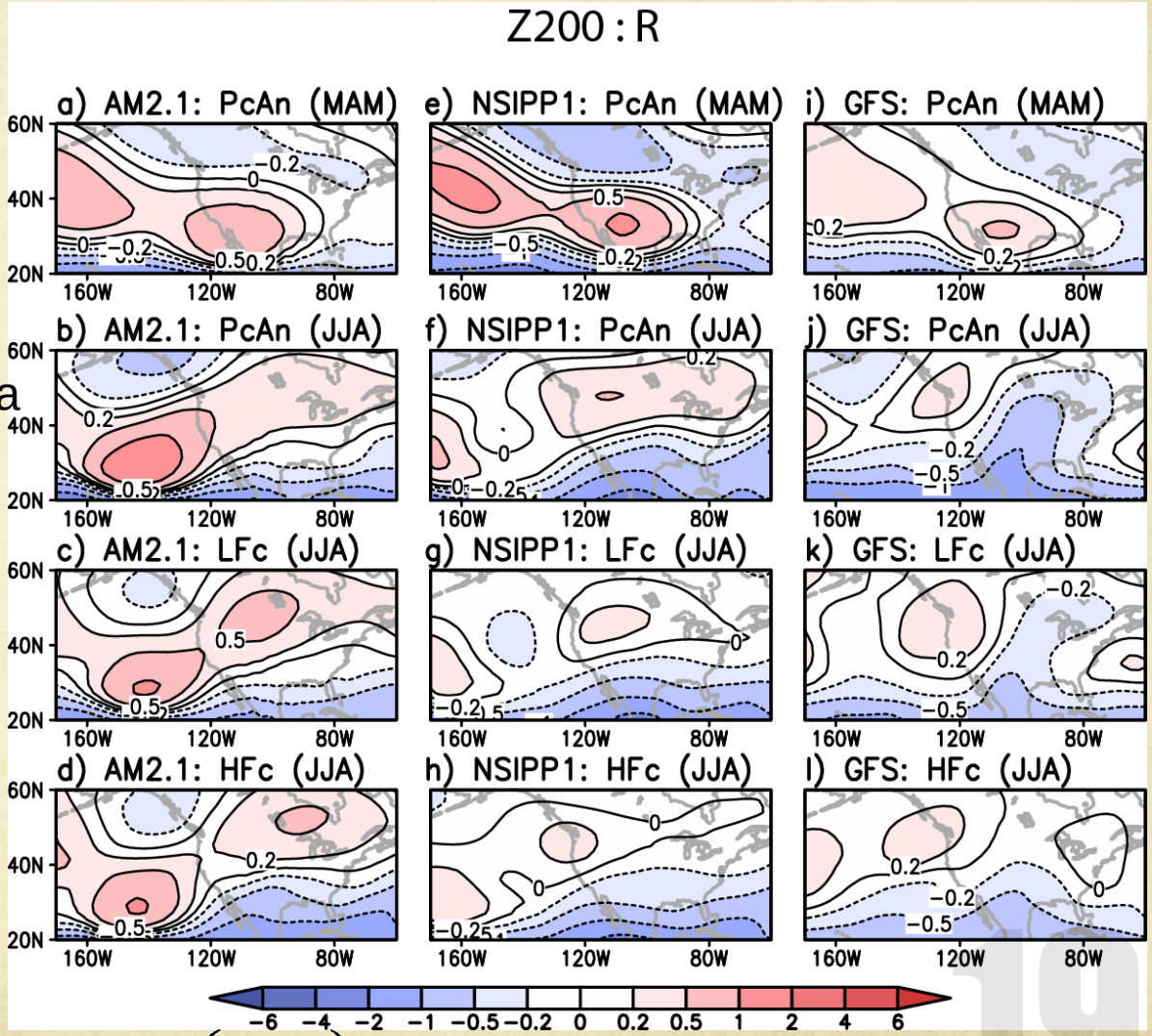
For Spring Season, PcAn signal to noise is strong in all simulations

JJA Internal atmospheric variability is stronger
Soil moisture feedback plays a larger role

AM2.1
Signal to noise remains strong,
Over-predicting SST response?

NSIPP1
signal strongest in PcAn,
LFc strong over NW Us and NGP

GFS



$$R = \left(\frac{\bar{x} - \bar{y}}{s_{xy}} \right)$$

Overbars 50yr mean of monthly mean
$S^2_{xy} = (S^2_x + S^2_y)/2$, variances of x and y

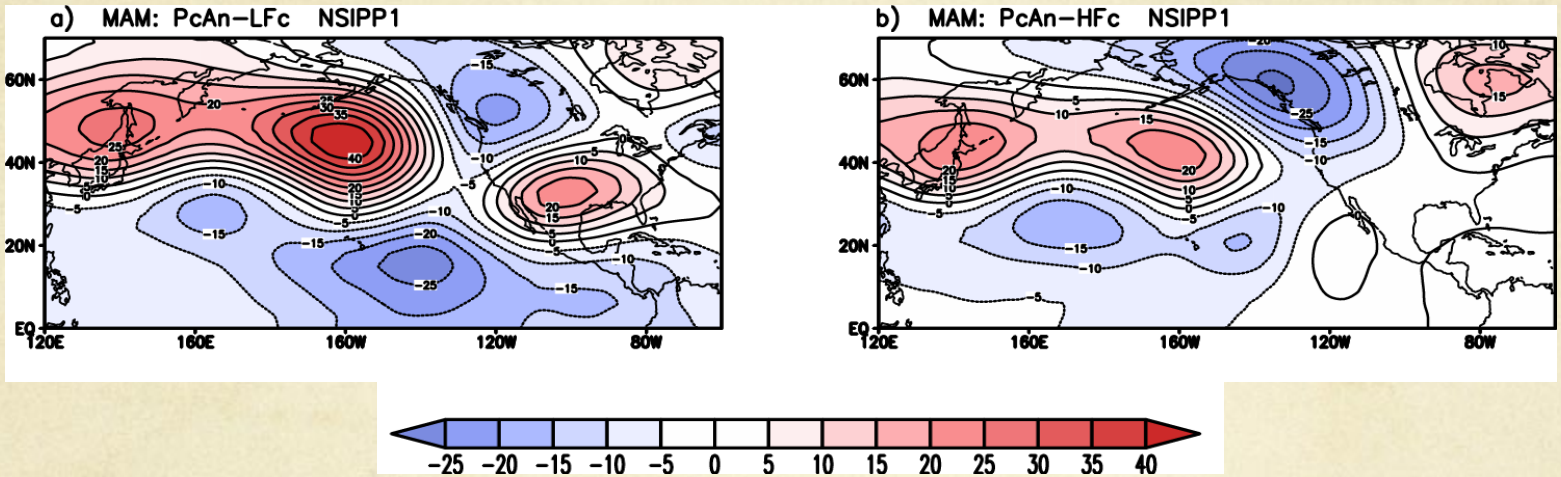
Summary

- **Overall agreement** with previous results using the DWG model data
- **Sensitivity to regional differences** in the amplitude of the prescribed Pacific SST forcing patterns with respect to internal atmospheric variability in the three AGCMs.
- The coherence of the AM2.1 (across patterns and seasons) responses suggests the model is **over-predicting the strength of the tropical SST signal.**
- Internal **atmospheric variability and land–atmosphere interactions influence the GFS model response**, though the shorter simulations also play a role in the reduced significance of the results presented.
- The SST forced response in the **NSIPP1 AGCM** is **a function of the relative amplitude of the SST forcing in the tropics and middle latitudes**, with detectible constructive interference between the two signals.
- The current study points to a more **significant role for the extratropical component of the SST** in forcing the precipitation response; particularly

Thank you!

Extra Slides

Tropical vs extra-tropical teleconnections



PcAn ≠ LFc + HFc

PcAn – LFc , Captures response to common forcing components in PcAn and HFc forcing , Equatorial (PNA)

PcAn-HFc, Captures response to common forcing components in PcAn and LFc forcing , Extra-tropical