North Atlantic SST Impacts on U.S. Hydroclimate in Observations and CMIP5 Models

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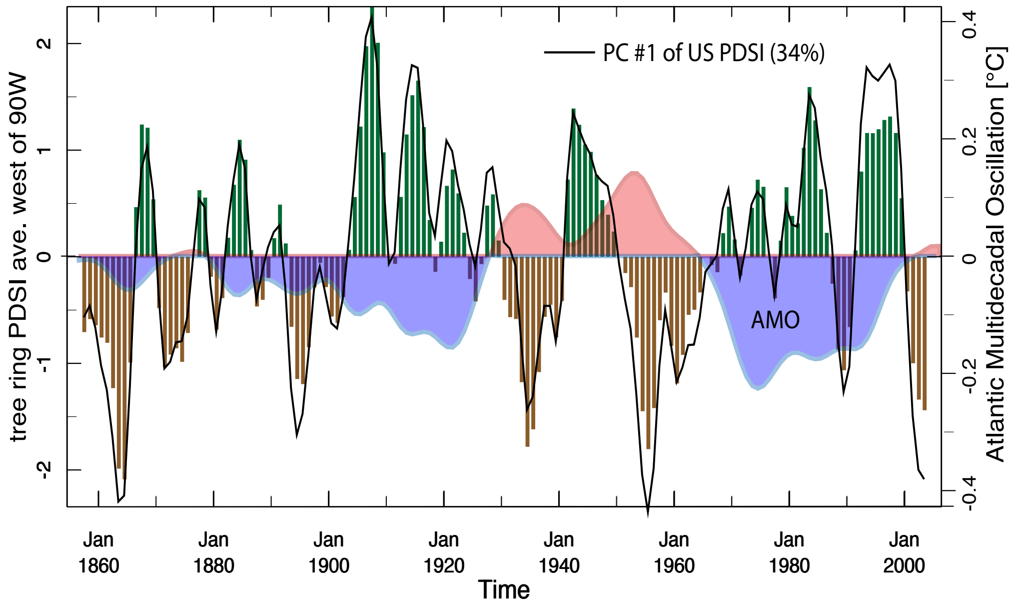
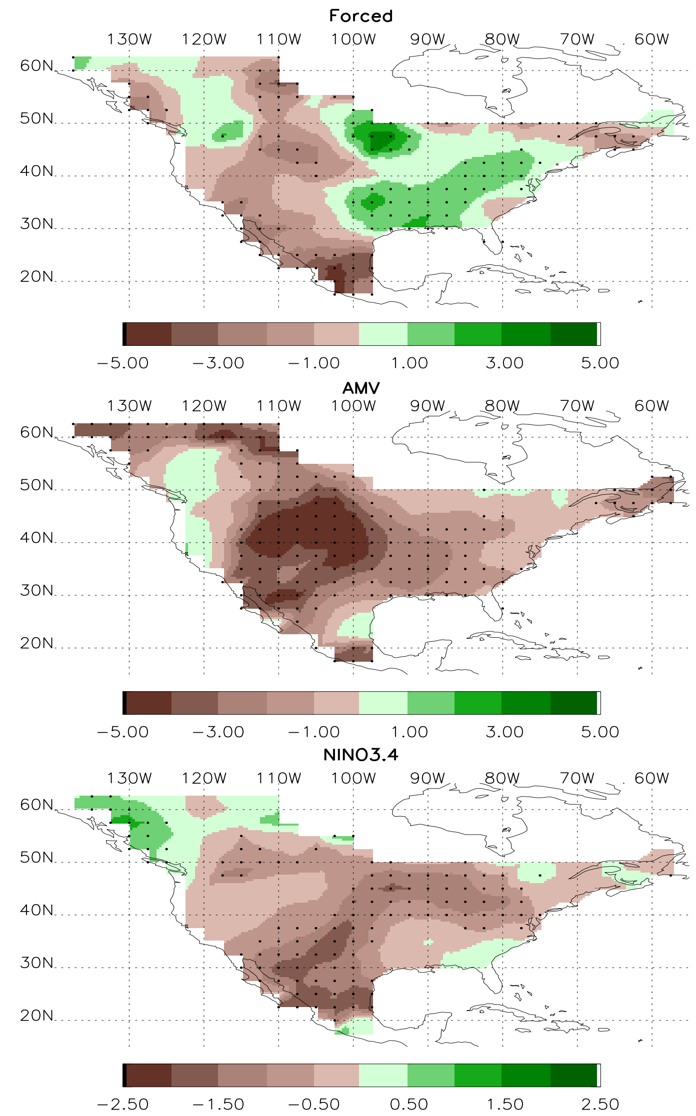
Palmer Drought Severity Index (PDSI) Versus AMV



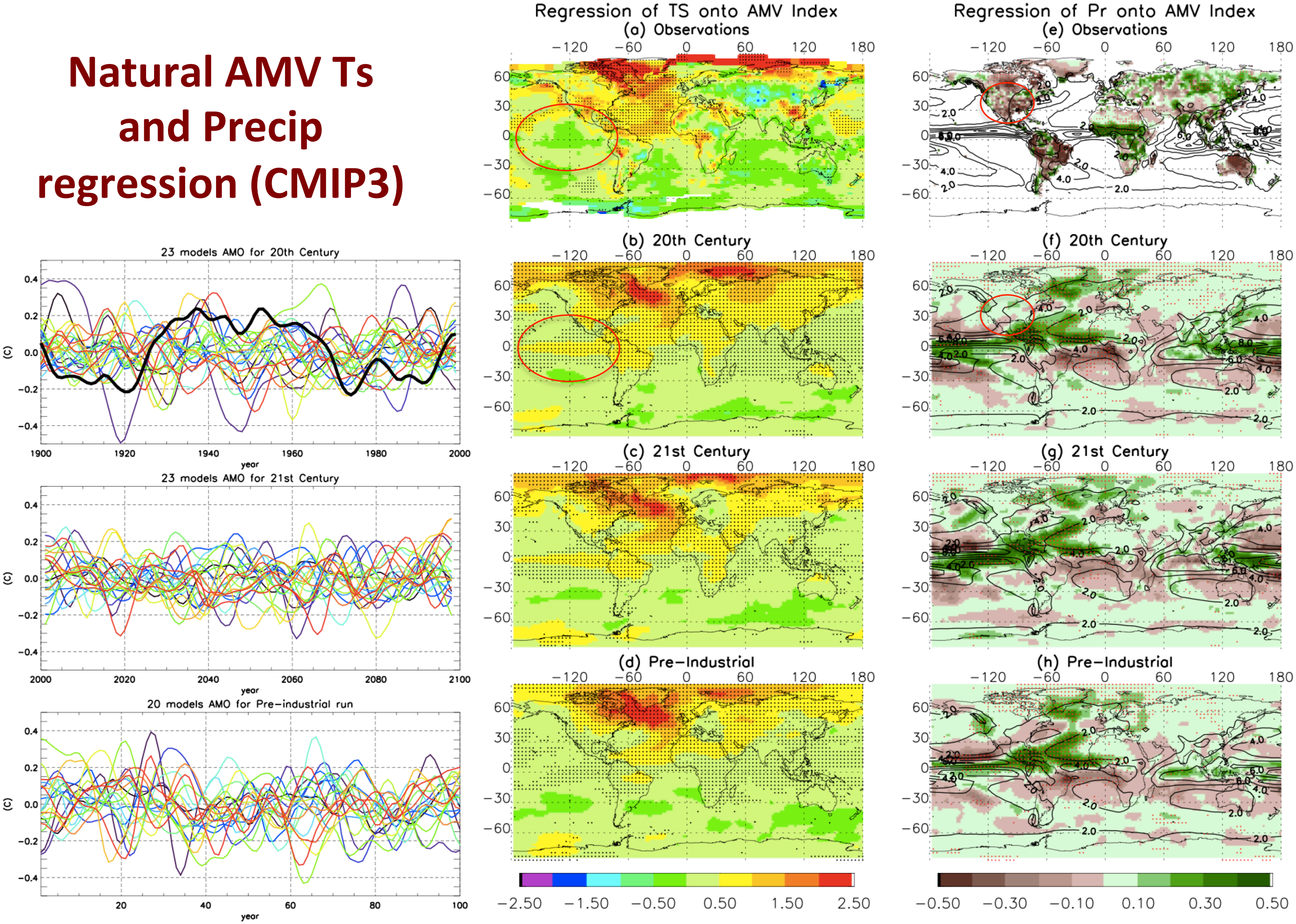
PDSI data from (Cook et al., 2004) North American Drought Atlas based on tree ring

- ***Forced warming, positive AMV and La Niña all contribute to drought conditions in the U.S., but the impact of AMV tend to be more significant and wide spread.***

Regression coefficients: PDSI onto radiatively forced SST (top), AMV index (middle), and negative NINO3.4 index (bottom)



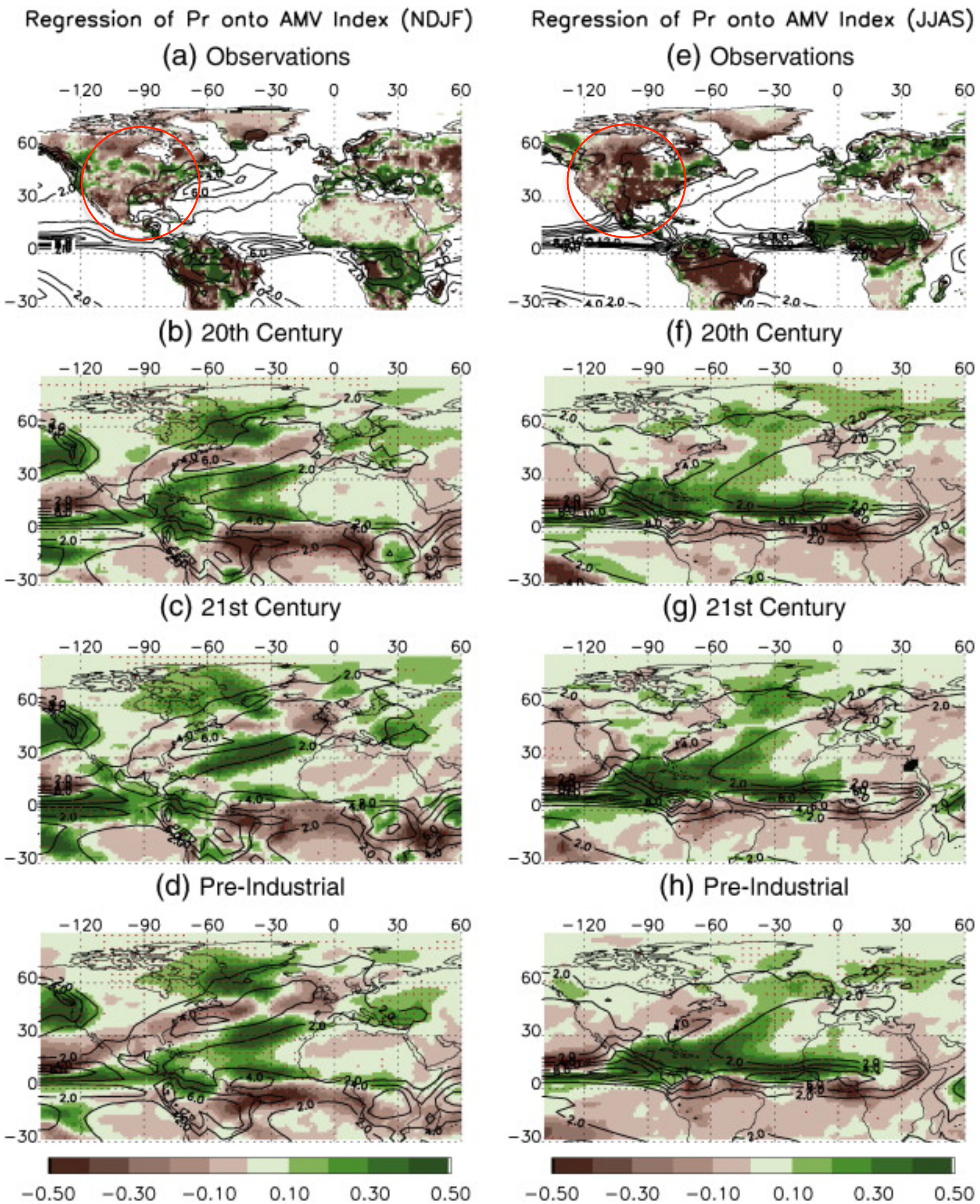
Natural AMV Ts and Precip regression (CMIP3)



Ting et al., 2011, GRL

AMV Impacts on Precip in Winter vs. Summer (CMIP3)

- *Impact on precip in North America much weaker in models than Obs. in both winter and summer*



Ting et al., 2014, J. Marine. Syst.

Questions

- How well is the positive AMV - North American drought relationship depicted in CMIP5 models?
- What is the interplay between ENSO and AMV in causing long-term US droughts?
- Given the importance of the stratospheric pathway in atmospheric teleconnection, what is the possible role of the stratosphere (high top models versus low-top models) in the AMV-NA Drought relationship?
- What are the possible mechanisms for the AMV-U.S. drought linkage?

Data and Methods

- 15 historical CMIP5 model simulations with Penman-Monteith PDSI computed as in Cook et al. (2014, *Climate Dynamics)*
- Use S/N EOF on multi-model to define radiatively forced North Atlantic SST Index as in Ting et al. (2009, J Climate)
- Define AMV as residual of North Atlantic SST from the forced Atlantic SST index
- Use regression to attribute PDSI, precipitation, surface temperature, and atmospheric circulation and moisture budget terms to AMV
- Separate models with high top and those with low top to determine the role of stratosphere in the AMV impacts

15 CMIP5 Models Used

Six high-top models:

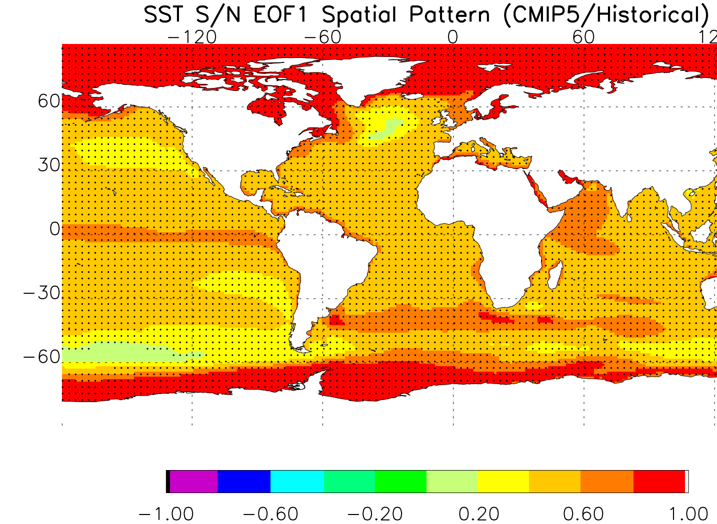
1. GFDL CM3 (0.01 hPa, 40 levels)
2. GISS-E2-R (0.1 hPa, 40 levels)
3. IPSL-CM5A-LR (0.04 hPa, 39 levels)
4. MIROC-ESM (.0036 hPa, 80 levels)
5. MIROC-ESM-CHEM (.0036 hPa, 80 levels)
6. MRI-CGCM3 (.01 hPa, 48 levels)

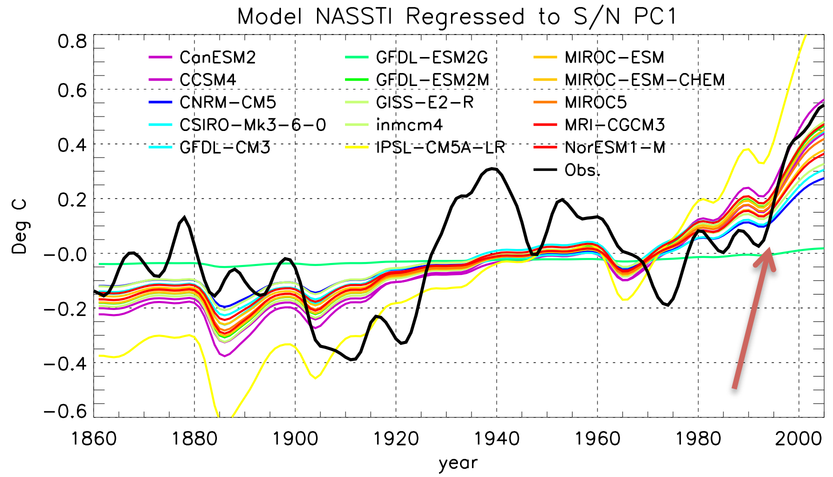
Nine low-top models:

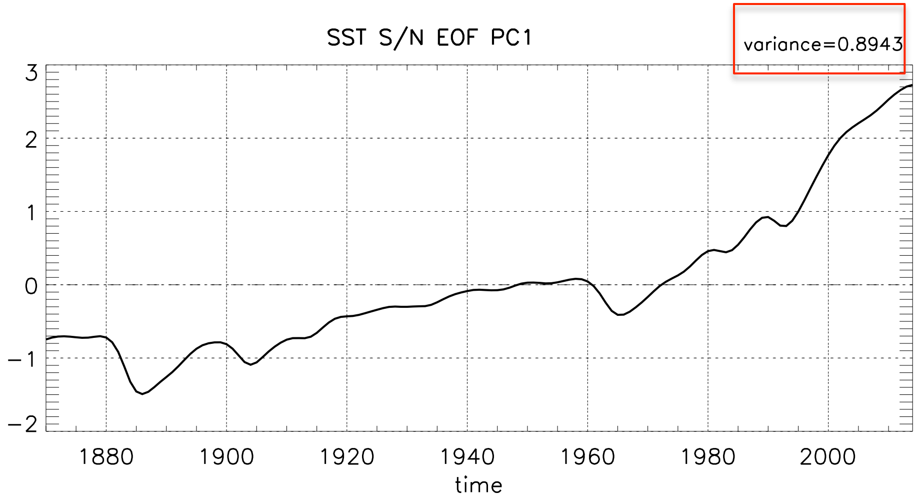
1. CanESM2 (1 hPa, 35 levels)
2. CCSM4 (2.19 hPa, 27 levels)
3. CNRM-CM5 (10 hPa, 31 levels)
4. CSIRO-Mk3-6-0 (4.5 hPa, 18 levels)
5. GFDL-ESM2G (3 hPa, 24 levels)
6. GFDL-ESM2M (3 hPa, 24 levels)
7. Inmcm4 (10 hPa, 21 levels)
8. MIROC5 (3 hPa, 40 levels)
9. NorESM1-M (3.54 hPa, 26 levels)

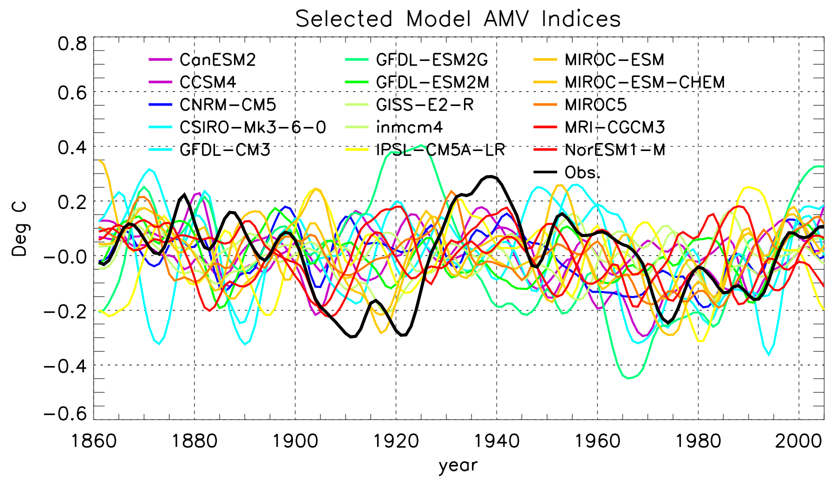
High Top Models: model top above 1 hPa
Low Top Models: model top at or below 1hPa
Similar to Charlton-Perez et al., 2013, J. Geophys. Res.

S/N EOF1/PC1 based on 15 CMIP5 Models



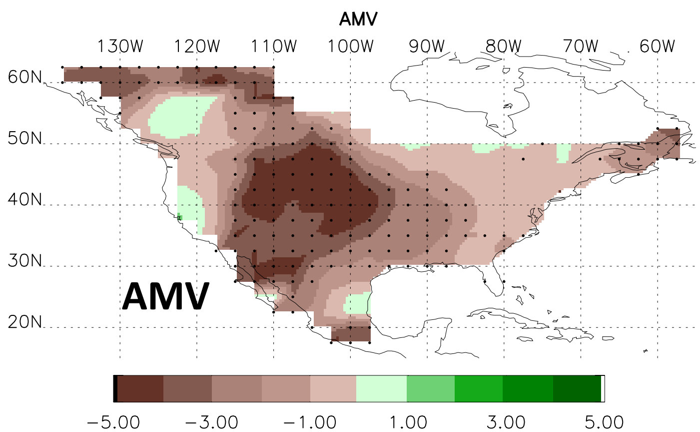


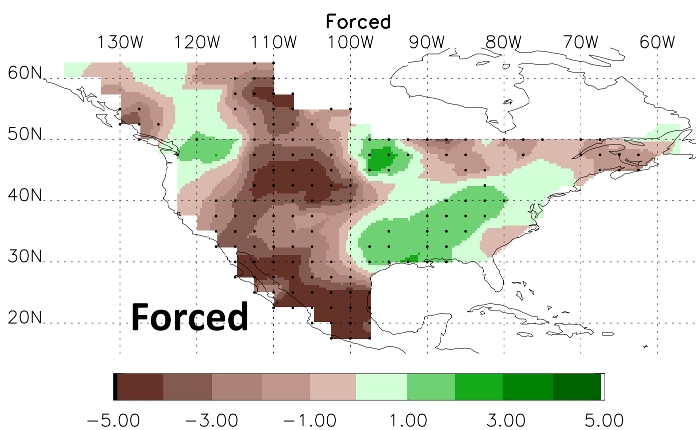




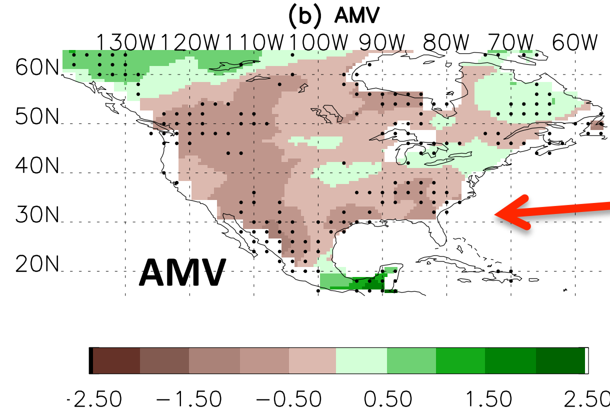
PDSI regressed to forced SST and AMV for Obs. (left) and CMIP5 Models (JJA, right)

Tree-Ring based PDSI (Cook et al., 2004)

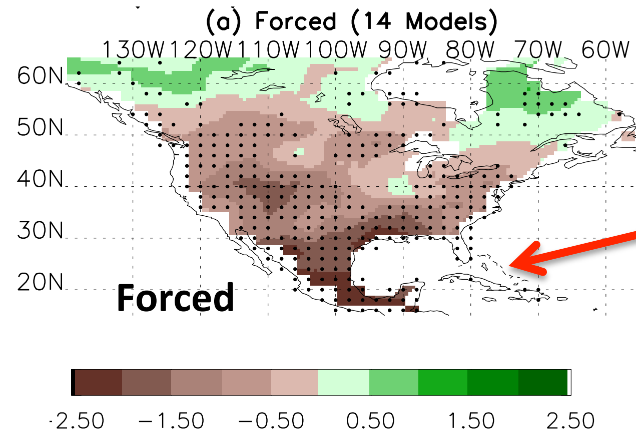




CMIP5 14 Models

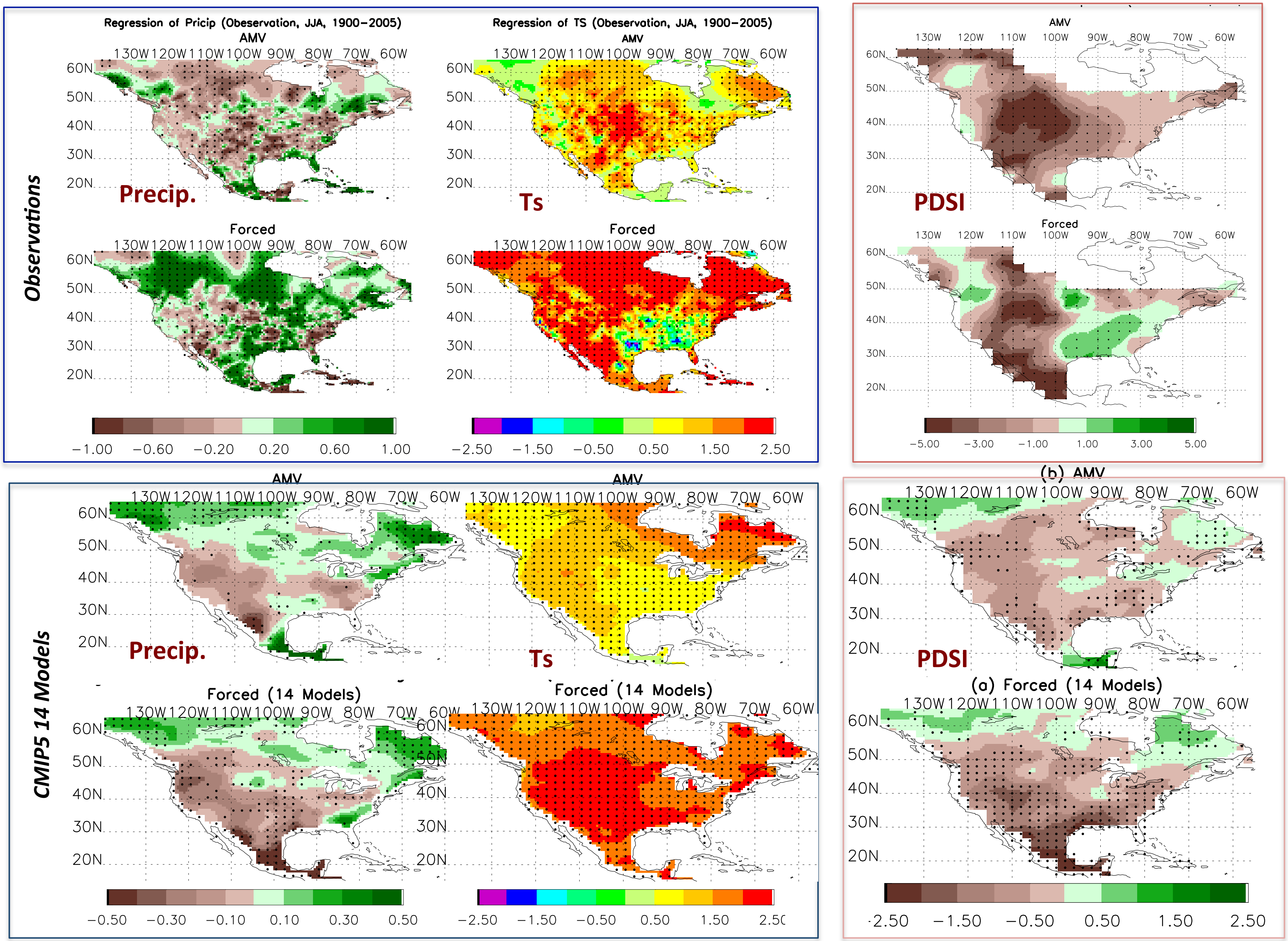


AMV-related Drought signal is somewhat weaker in models

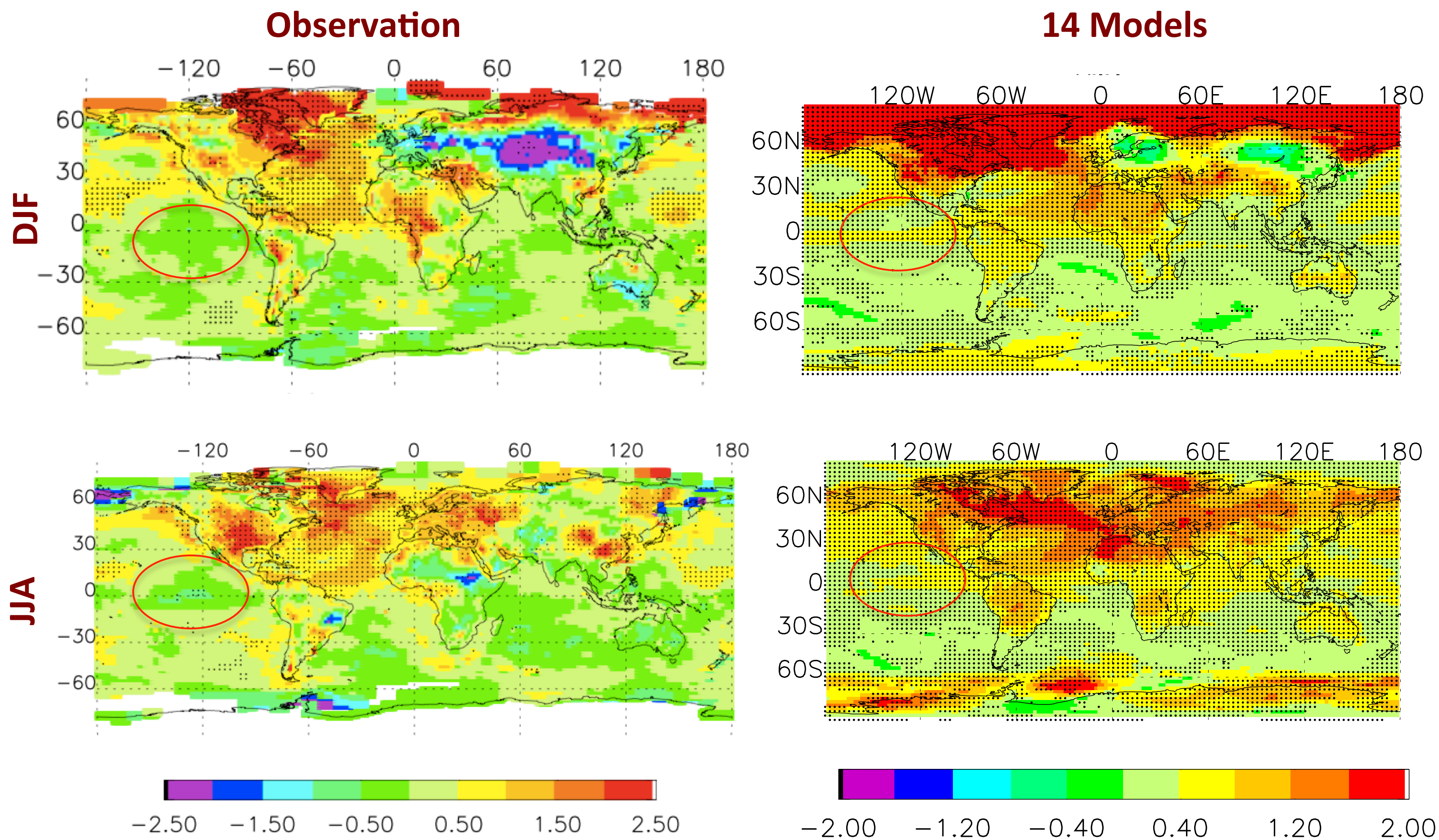


Forced Drought signal is more widespread in models

Forced vs. AMV Precipitation, Surface Temp and PDSI

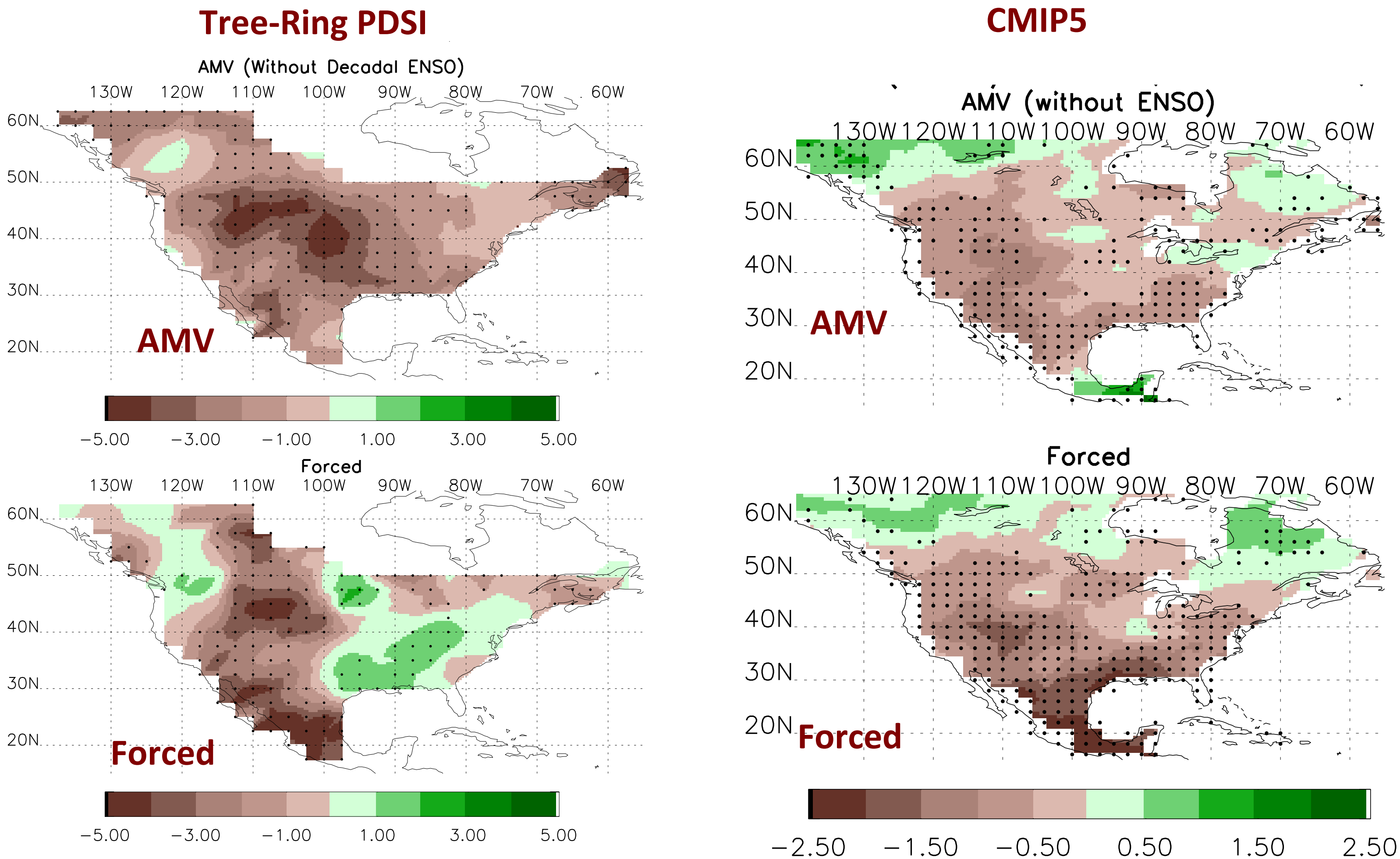


SST Regressed to AMV in Observations and CMIP5 Models (DJF and JJA)



- ***Positive AMV links to weak La Niña condition in observations, but El Niño in CMIP5 models***
- ***AMV-ENSO relationship is much improved in CMIP5 compared to CMIP3***

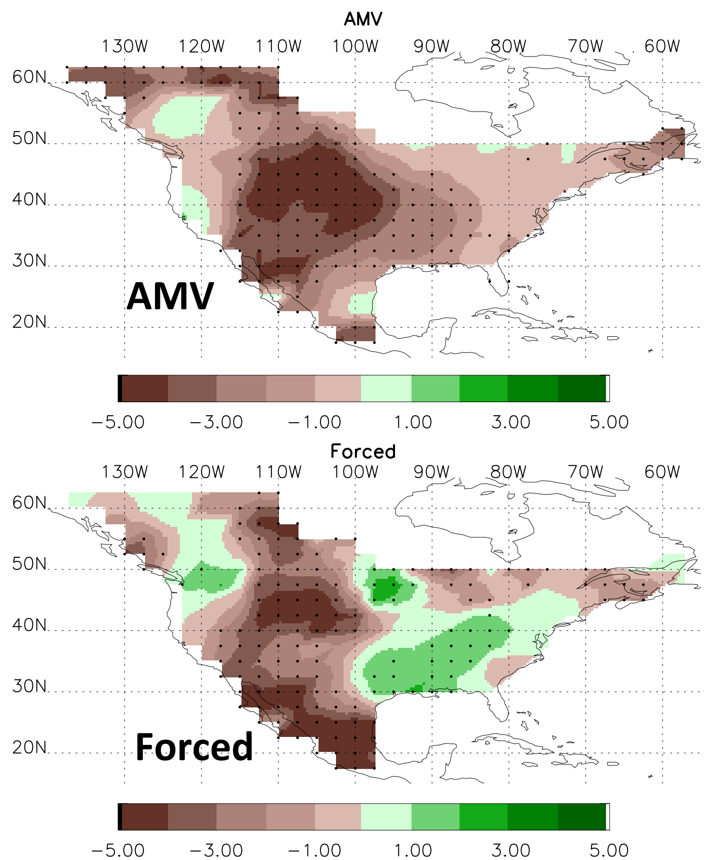
AMV versus Forced Impact on PDSI <u>without</u> Decadal ENSO



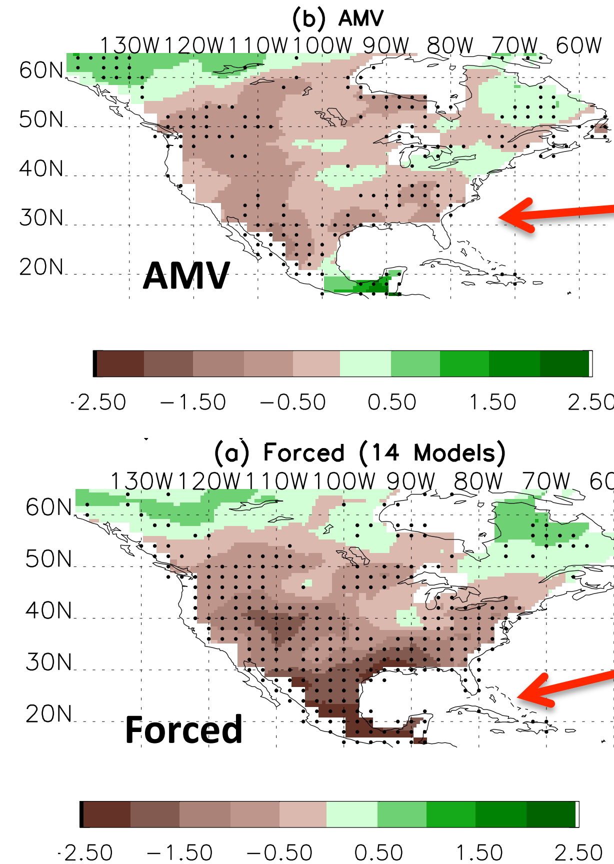
- ➢ *Removing decadal ENSO improved the AMV-U.S. Drought relationship*
- ➢ *It is still weaker compared to the observed relationship*

PDSI regressed to forced SST and AMV for Obs. (left) and CMIP5 Models (JJA, right)

Tree-Ring based PDSI (Cook et al., 2004)



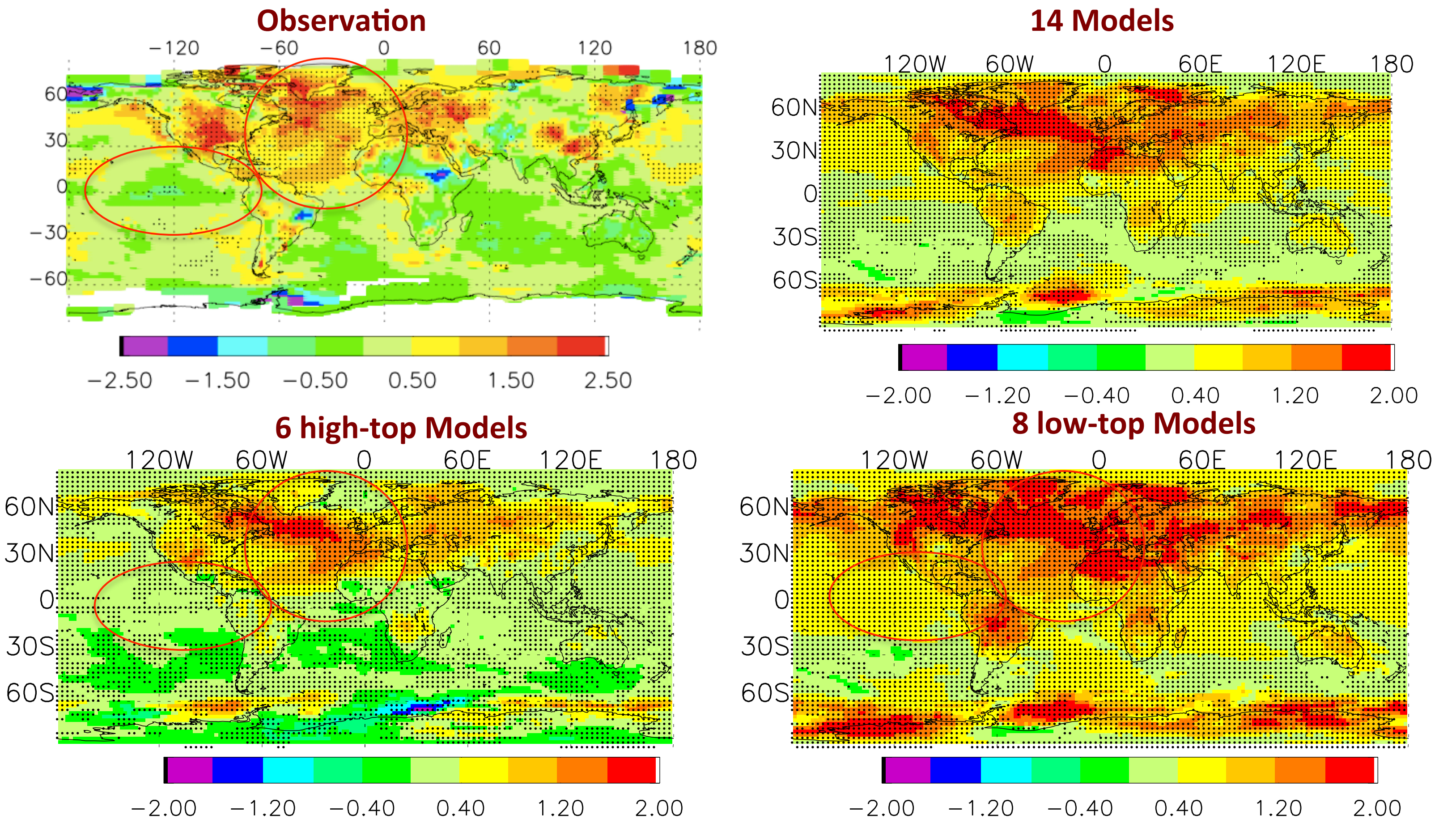
CMIP5 14 Models



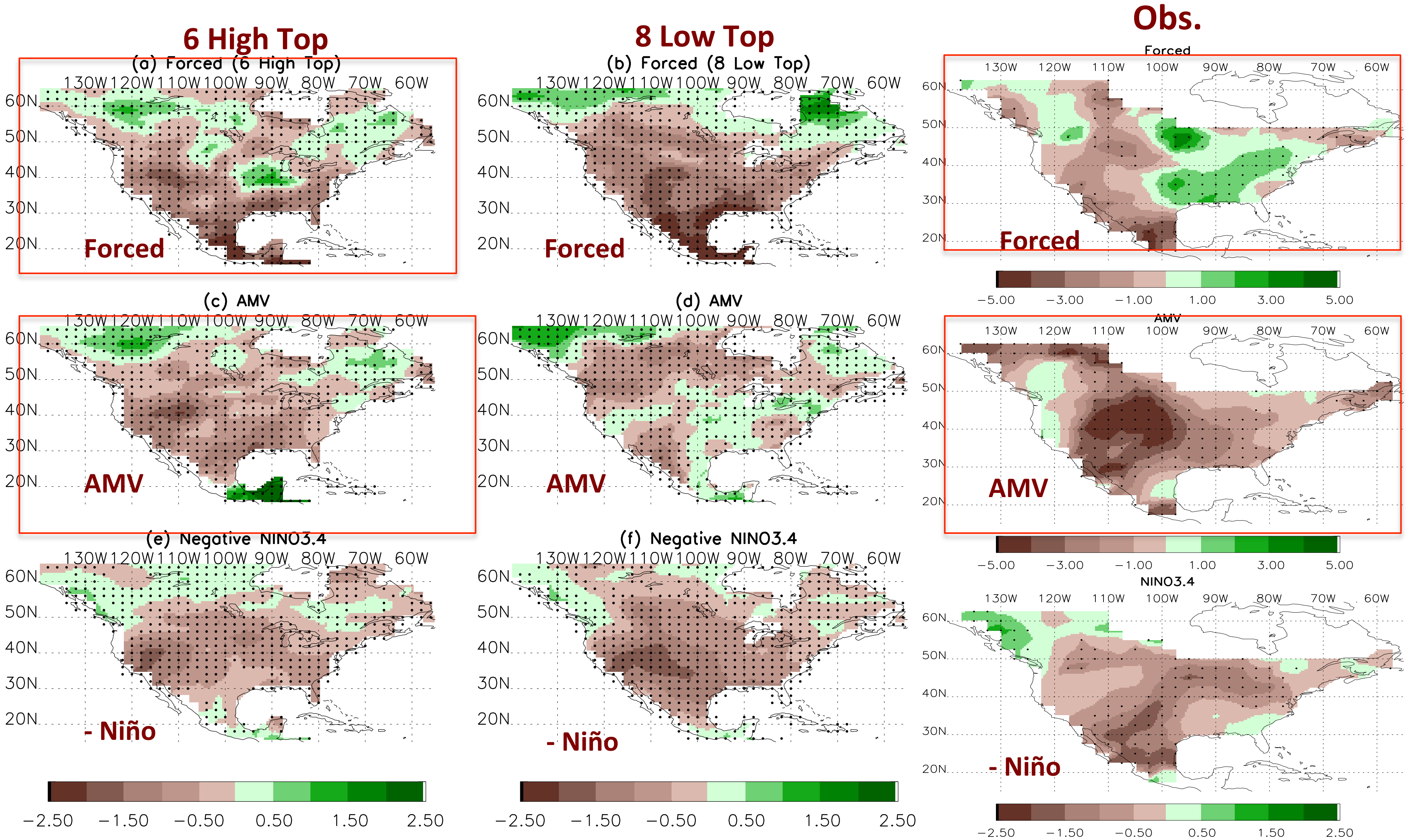
AMV-related Drought signal is somewhat weaker in models

Forced Drought signal is more widespread in models

High vs. Low Top JJA AMV SST and Precip Patterns

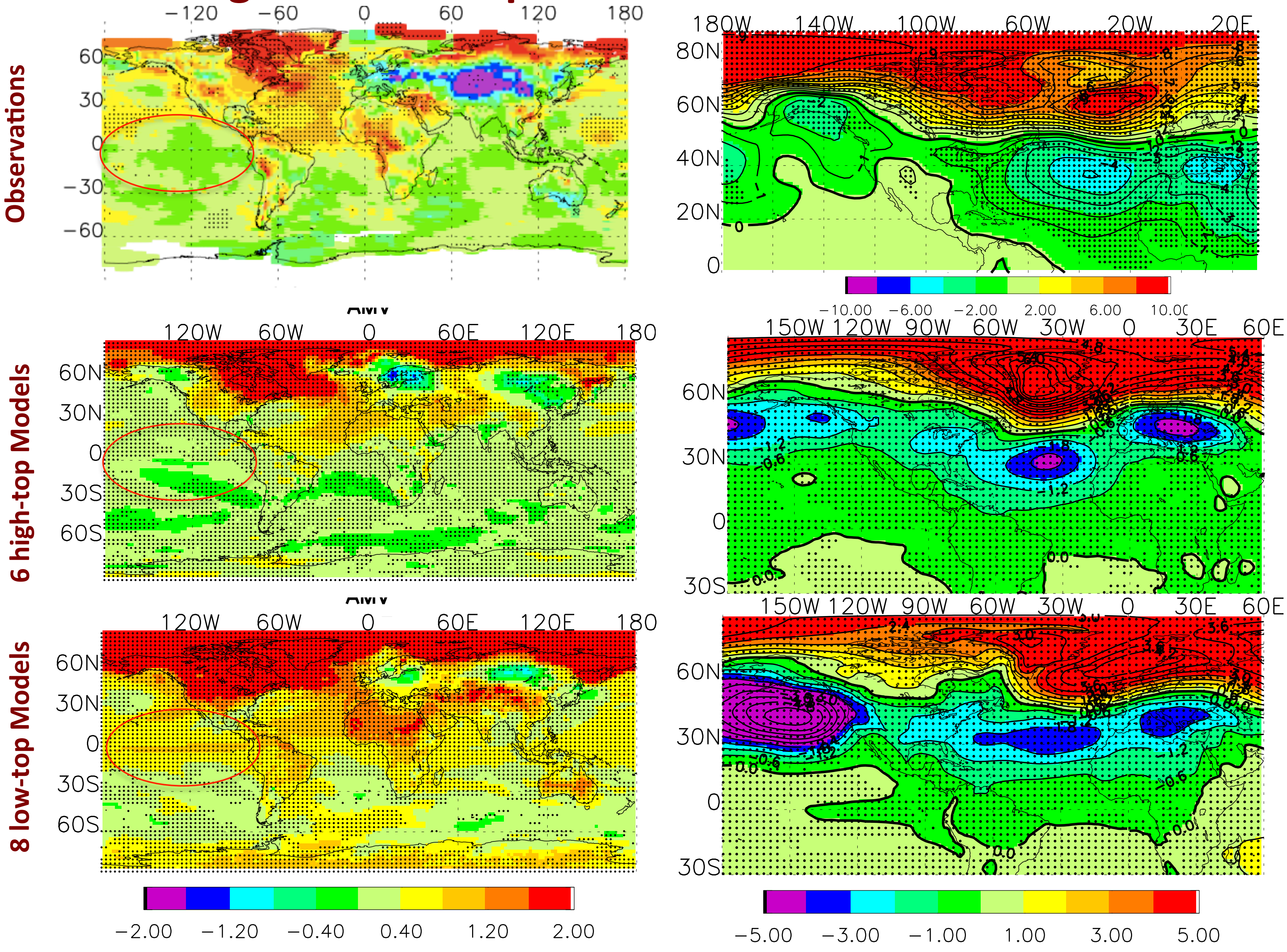


High top vs. Low Top Models PDSI

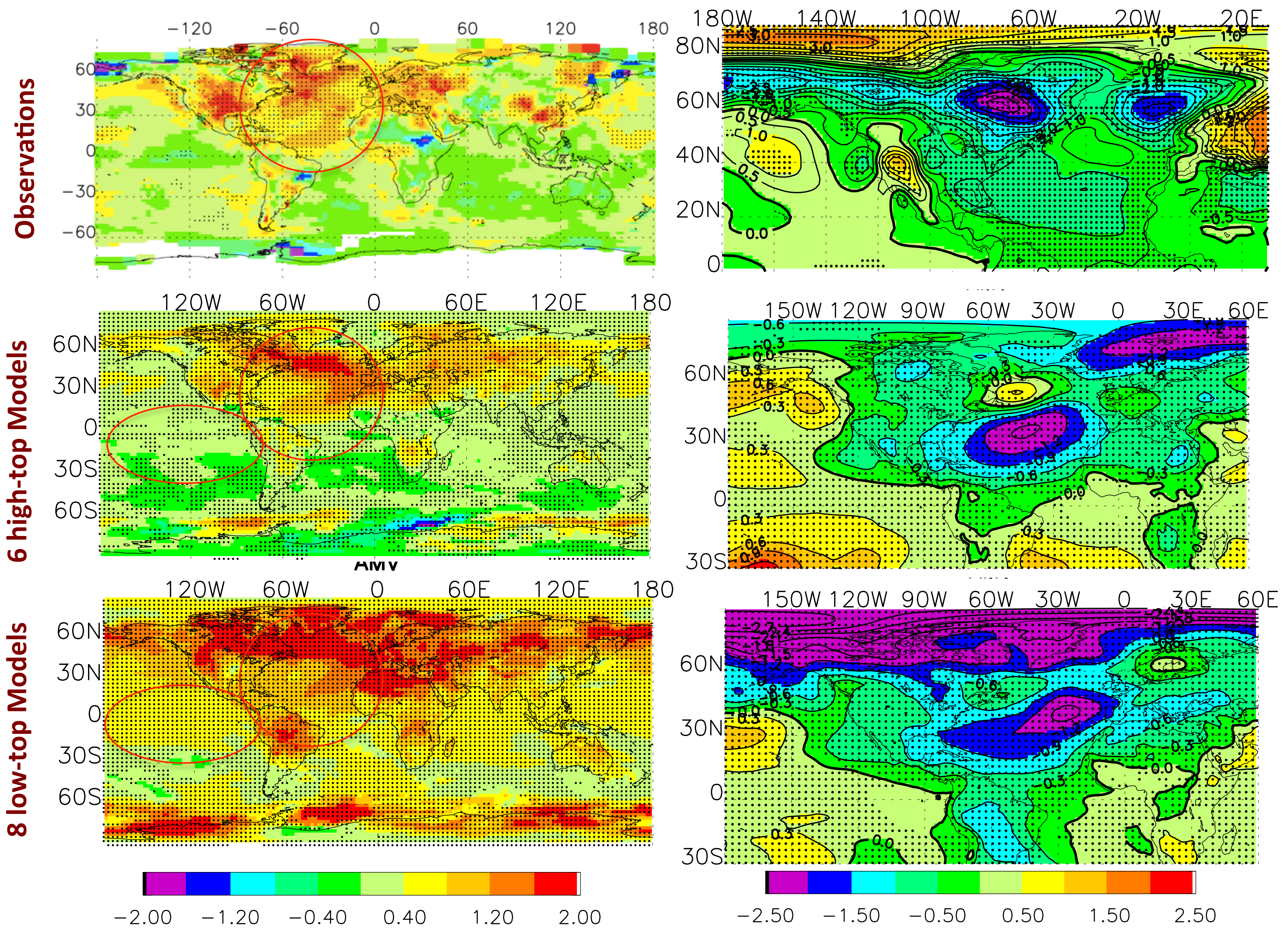


Stippling: 4/6 for high-top, 6/9 for low-top, 95% significance for obs

High vs. Low Top DJF AMV SST and SLP Patterns

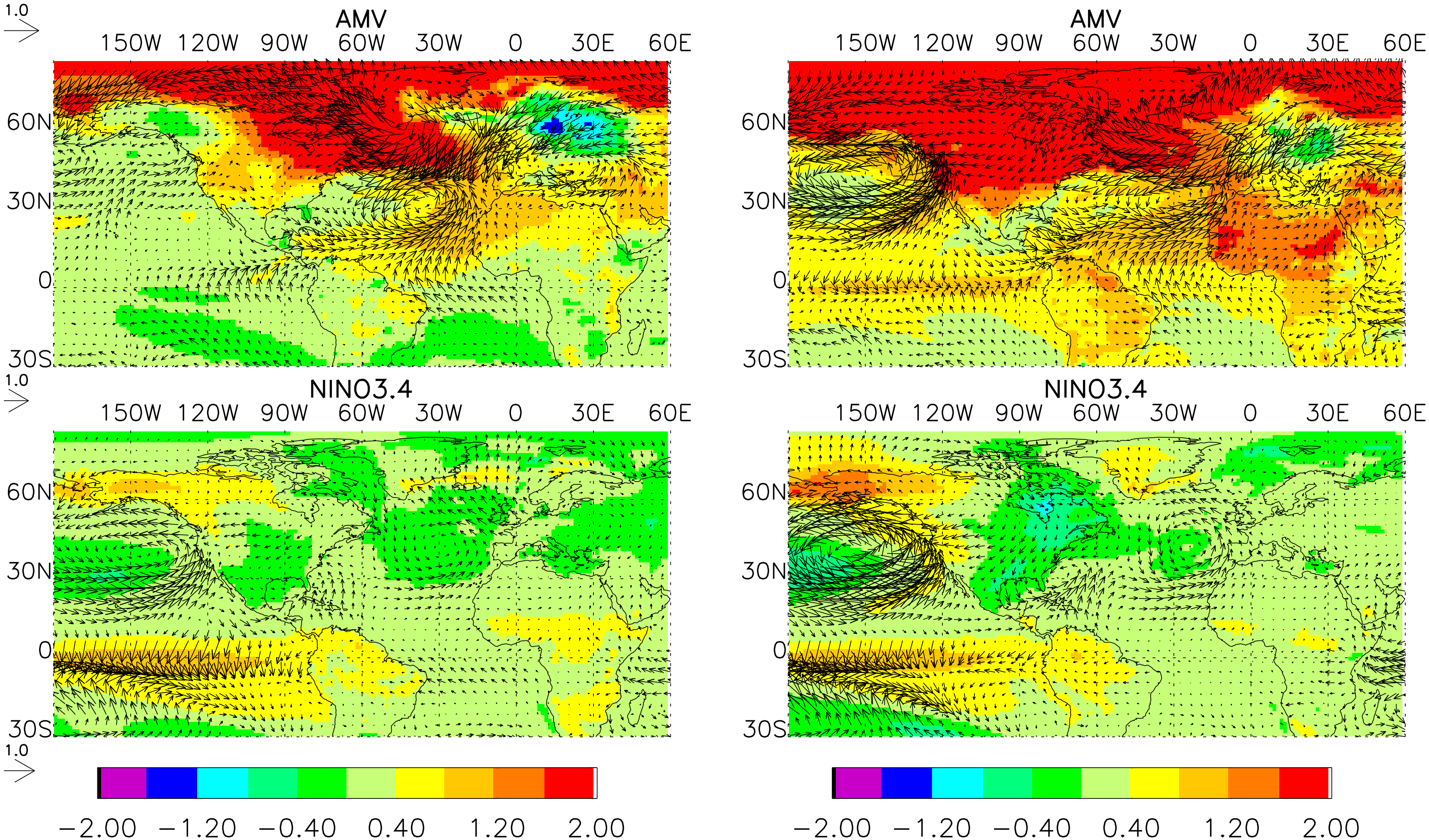


High vs. Low Top JJA AMV SST and SLP Patterns



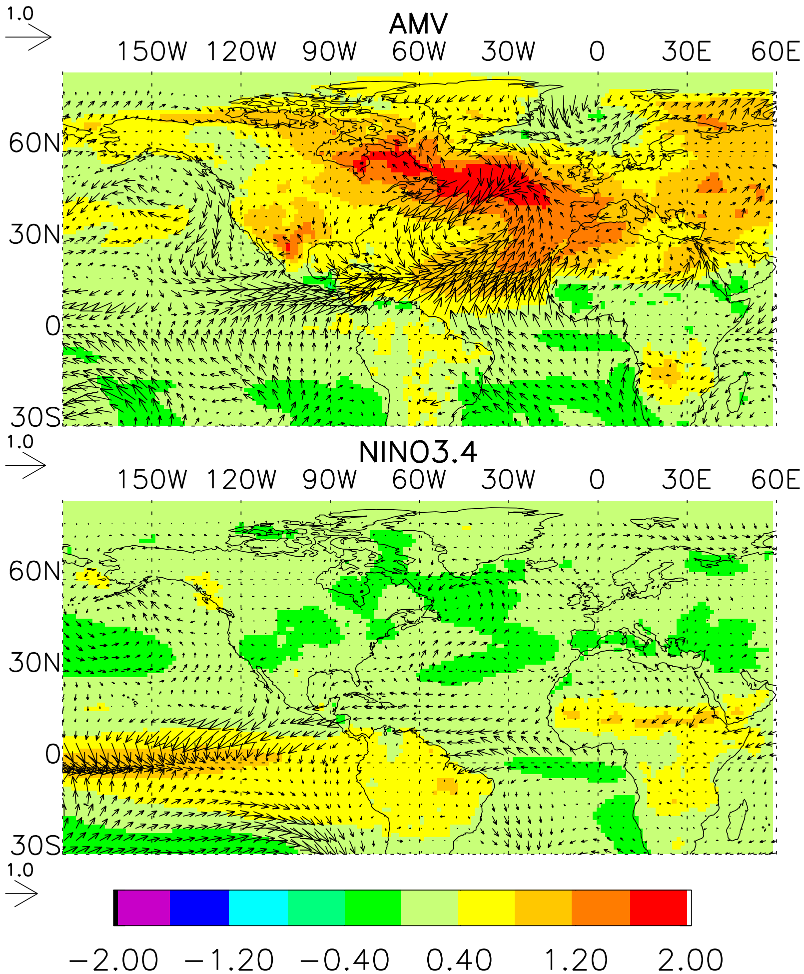
High vs. Low Top DJF AMV and ENSO SST and Surface Wind Patterns

6 high-top Models | **8 low-top Models**

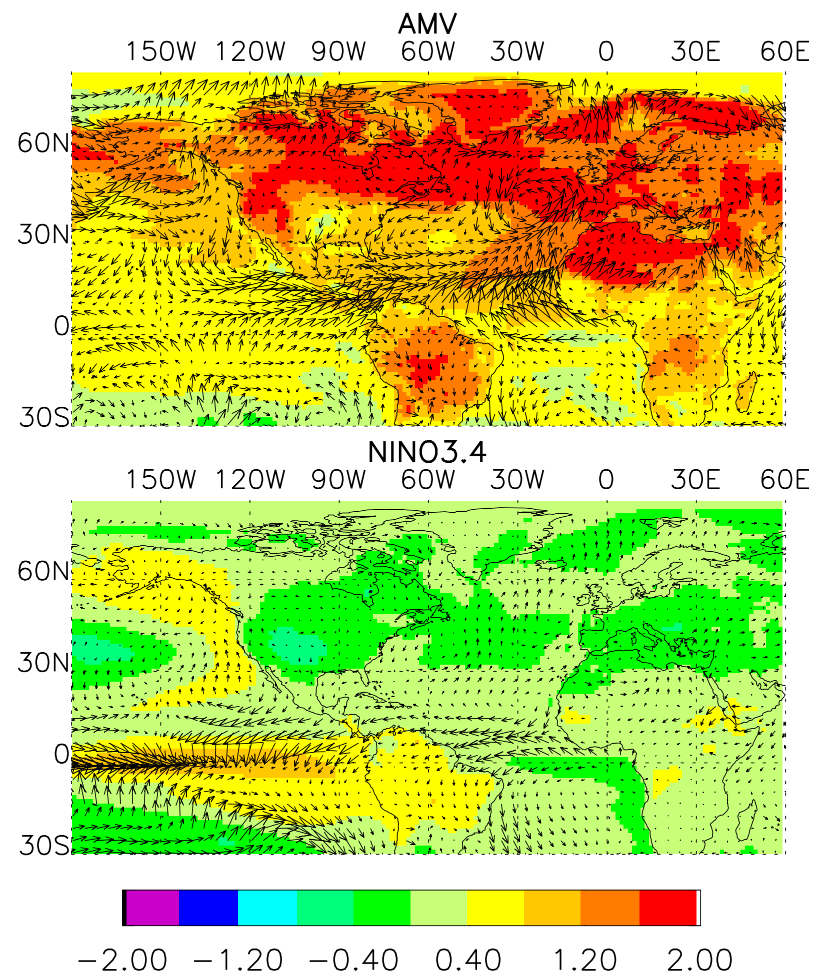


High vs. Low Top JJA AMV and ENSO SST and Surface Wind Patterns

6 high-top Models



8 low-top Models



- Why does warmer North Atlantic lead to dry North American climate?
  - Moisture budget analysis
  - Atmospheric GCM experiments

Moisture Budget Analysis

$$P - E = -\frac{1}{g\rho_w}\nabla \cdot \int_0^{p_s} \vec{u} q \, dp$$

Overbar represents monthly mean here

$$\bar{P} - \bar{E} = -\frac{1}{g\rho_w}\nabla \cdot \int_0^{p_s} \overline{\boldsymbol{u}q}\,\overline{dp} = -\frac{1}{g\rho_w}\nabla \cdot \int_0^{p_s} \bar{\boldsymbol{u}}\bar{q}\,\overline{dp} - \frac{1}{g\rho_w}\nabla \cdot \int_0^{p_s} \overline{\boldsymbol{u}'q'}\,\overline{dp}$$

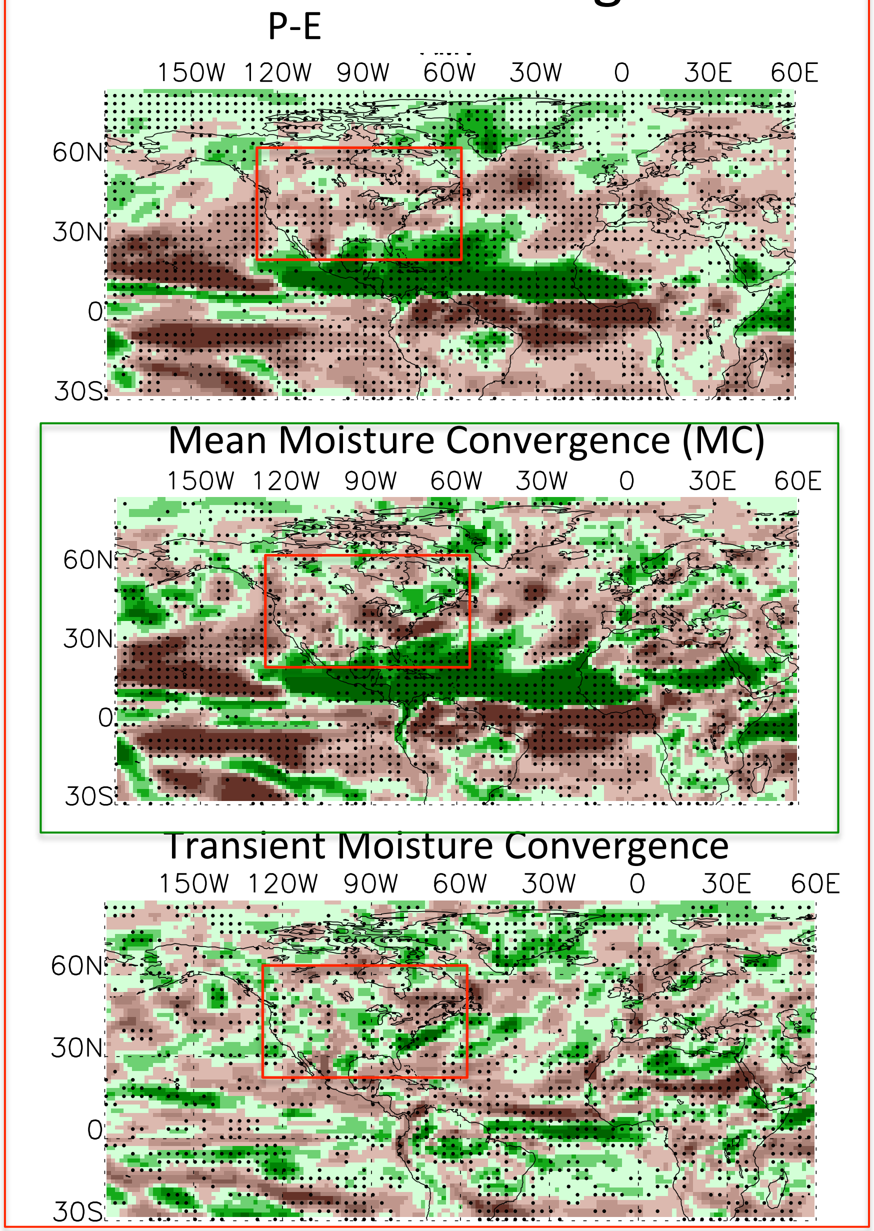
Mean flow MC (first term on the right) — **Transients MC** (second term on the right)

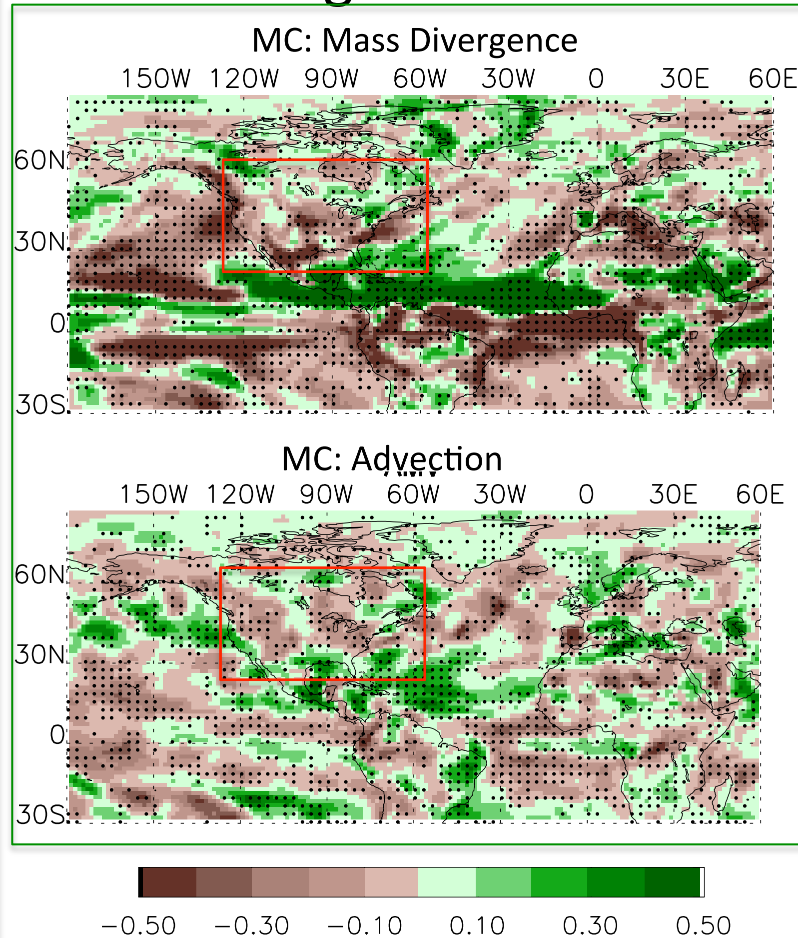
$$\delta(\bar{P} - \bar{E}) = -\frac{1}{g\rho_w}\delta\left(\nabla \cdot \int_0^{p_s} \bar{u}\bar{q}\,\overline{dp}\right) - \frac{1}{g\rho_w}\delta\left(\nabla \cdot \int_0^{p_s} \overline{u'q'}\,\overline{dp}\right)$$

$$-\frac{1}{g\rho_w}\delta\left[\int_0^{p_s} \bar{u} \cdot \nabla\bar{q}\,\overline{dp}\right] - \frac{1}{g\rho_w}\delta\left[\int_0^{p_s} \bar{q}\,\nabla \cdot \bar{u}\,\overline{dp}\right]$$

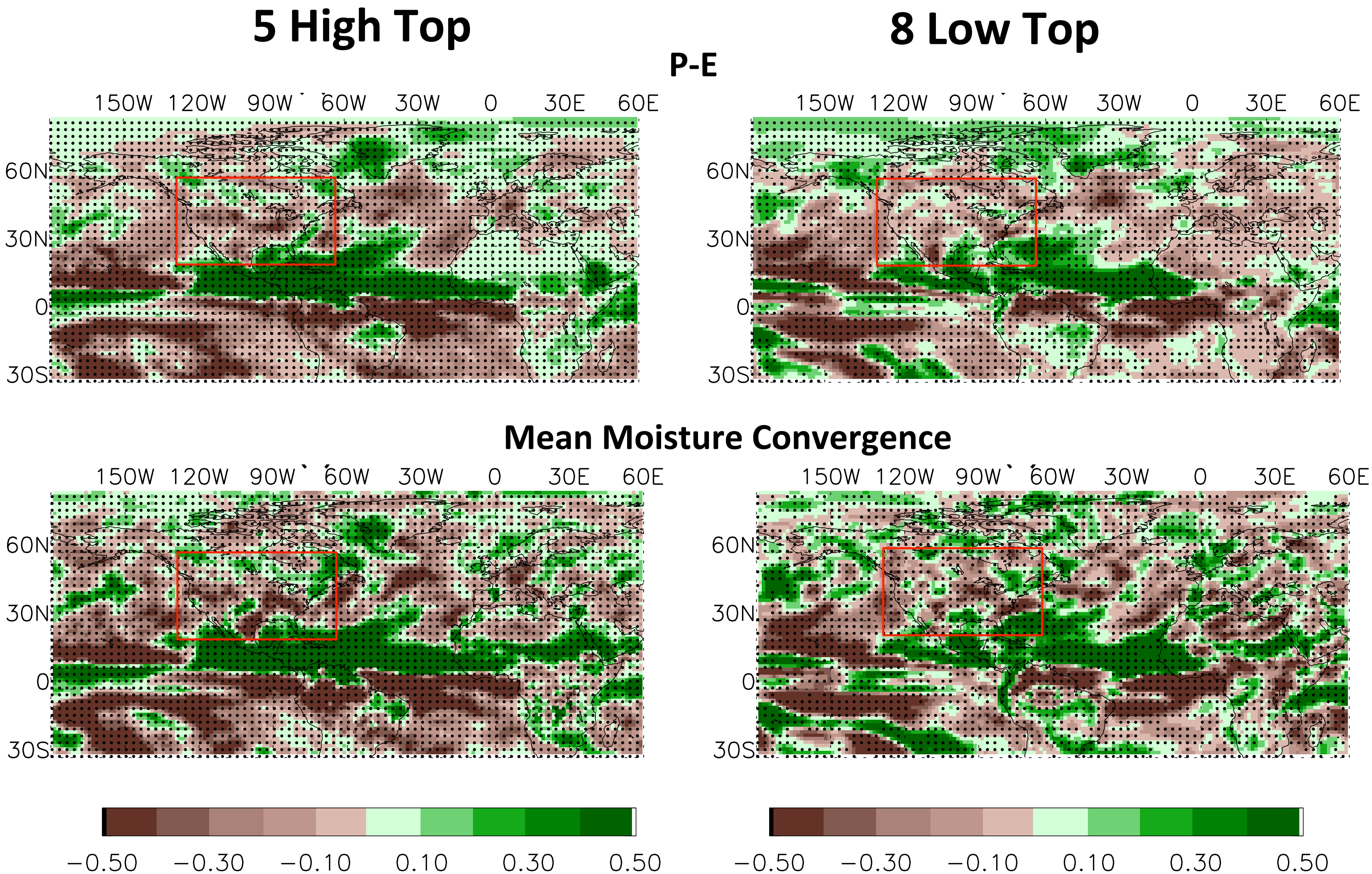
Mean moisture advection (first term) — **Mass divergence** (second term)

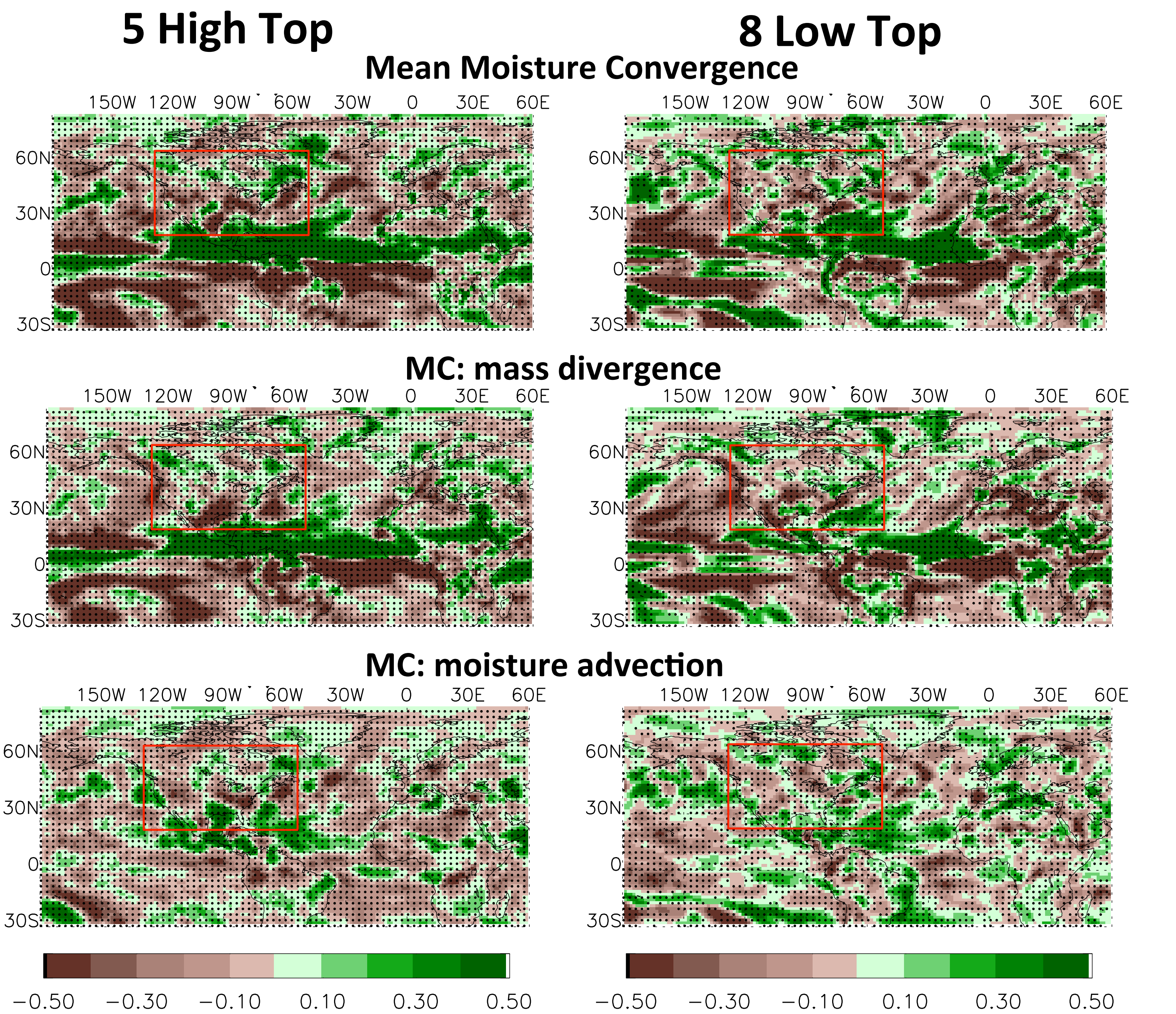
AMV Regression: Moisture Budget Terms



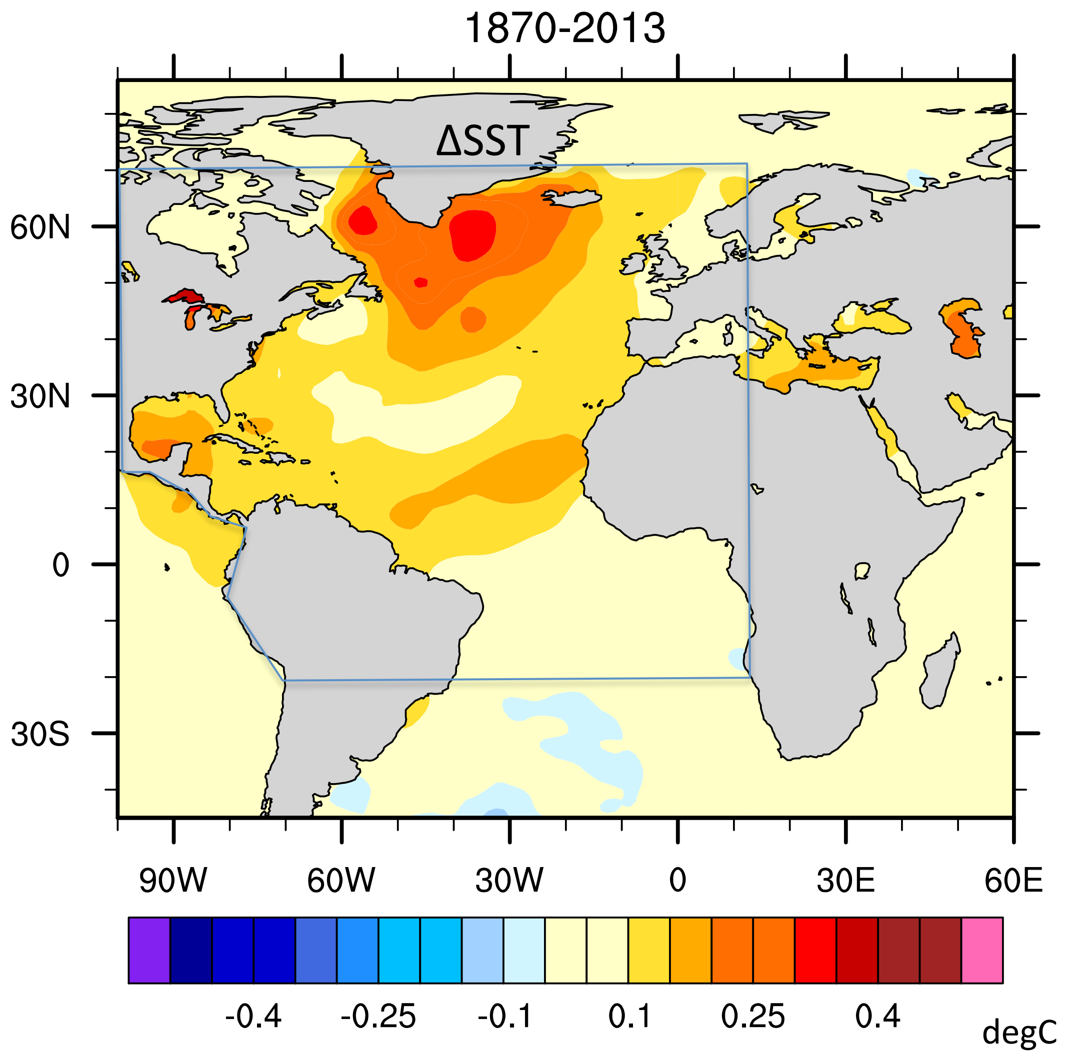


- Mean moisture convergence dominates the total MC
- Tropical NA region is dominated by mass divergence while moisture advection contributes to the drying in the extratropical NA as well


5 High Top
8 Low Top
P-E
Mean Moisture Convergence
150W 120W 90W 60W 30W 0 30E 60E
60N
30N
0
30S
−0.50 −0.30 −0.10 0.10 0.30 0.50


5 High Top
8 Low Top
Mean Moisture Convergence
MC: mass divergence
MC: moisture advection
150W 120W 90W 60W 30W 0 30E 60E
60N
30N
0
30S
−0.50 −0.30 −0.10 0.10 0.30 0.50

AMV experiments

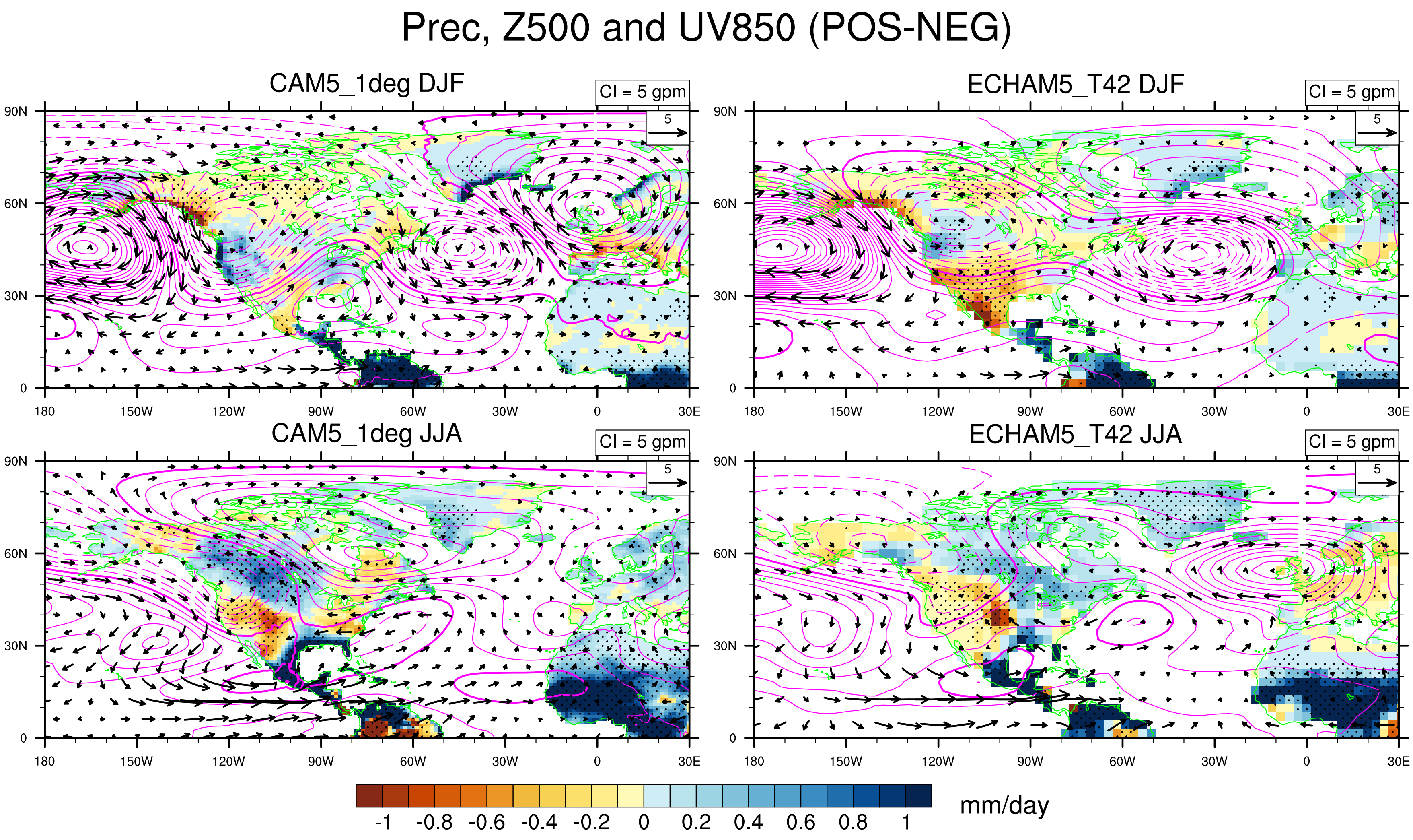


Regression coefficients for SST anomalies against the standardized AMV index by Ting et al. (2011)

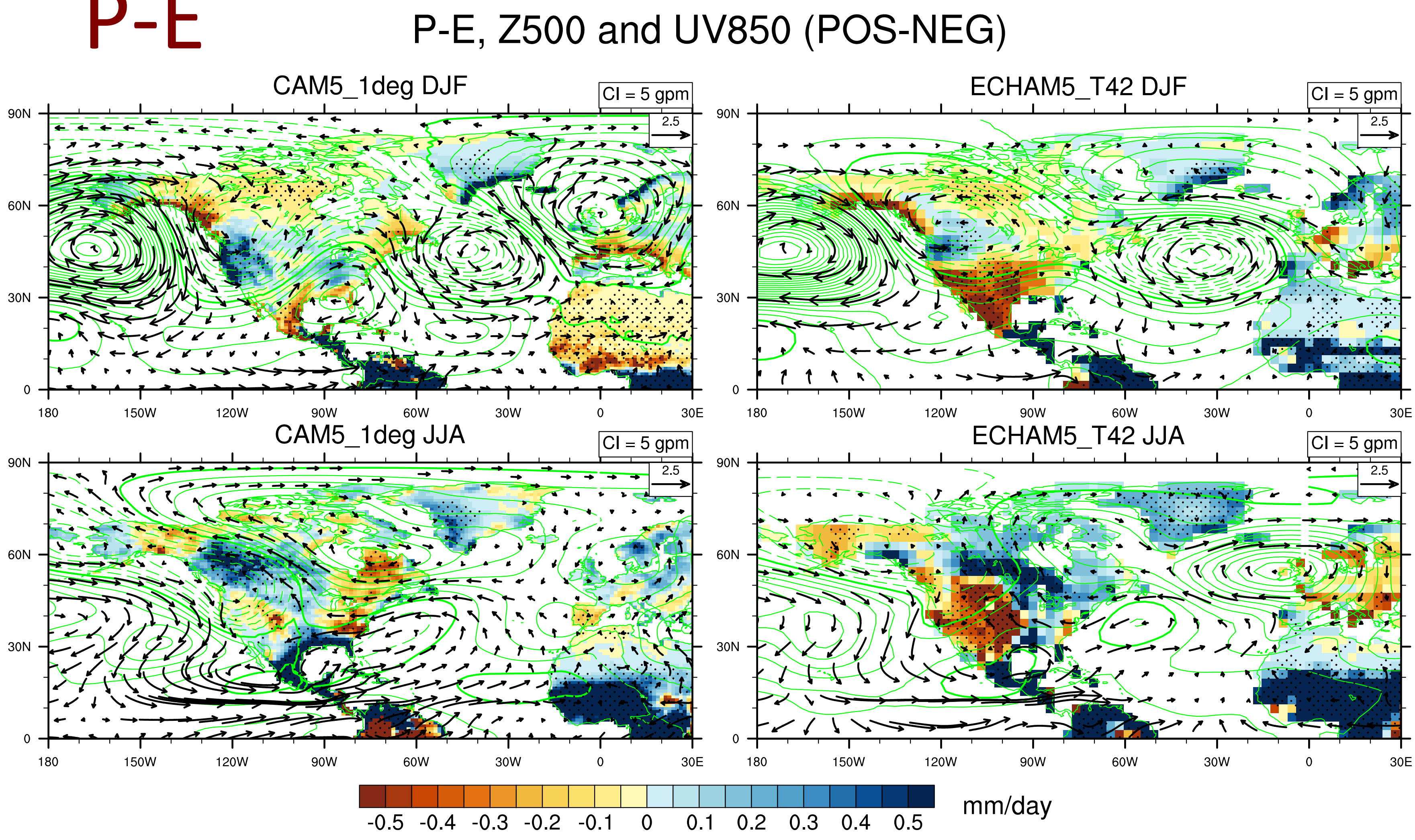
POS = ΔSSTx(+2.5)
NEG= ΔSSTx(-2.5)

30 ens for CAM5
60+ ens for ECHAM5

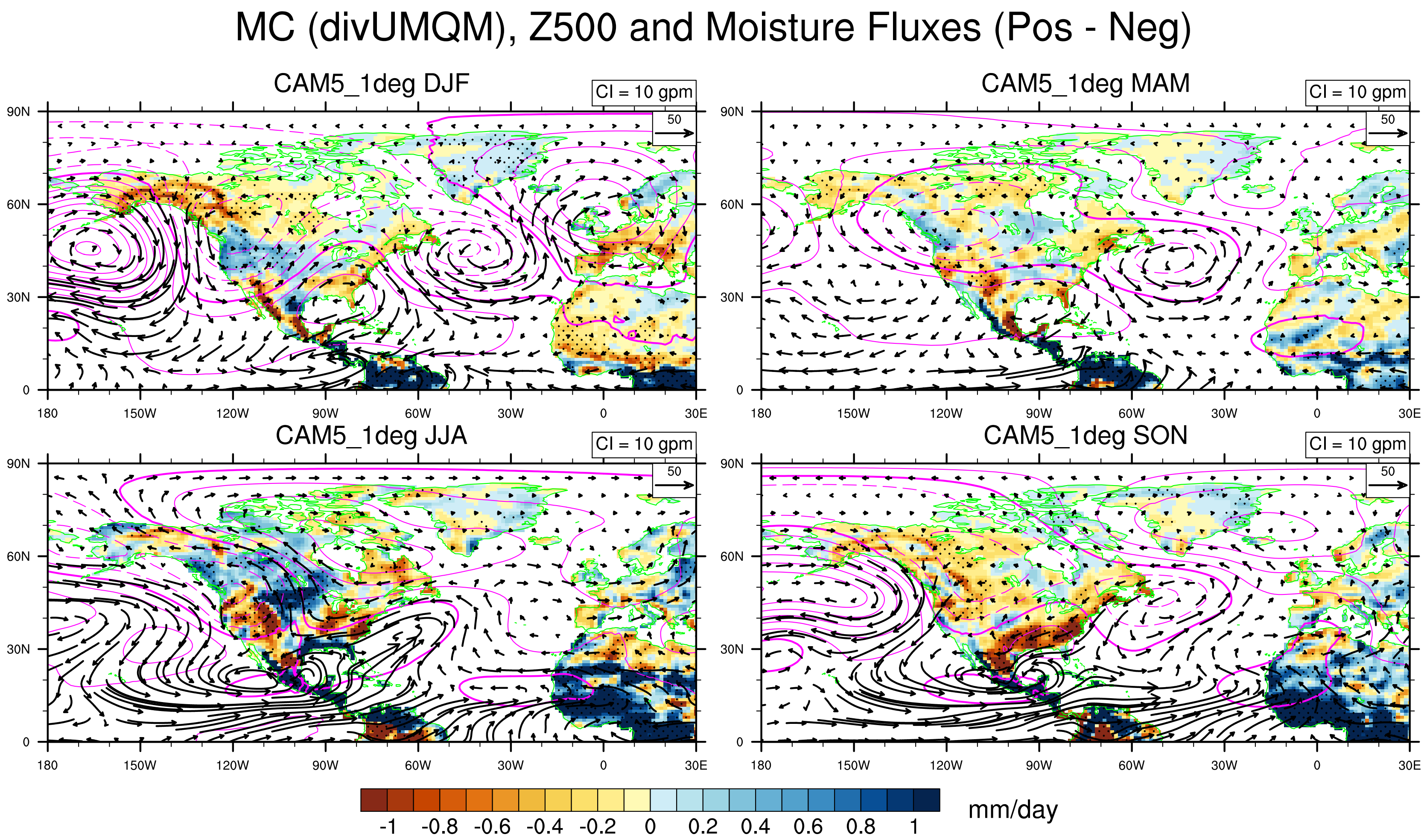
Precipitation



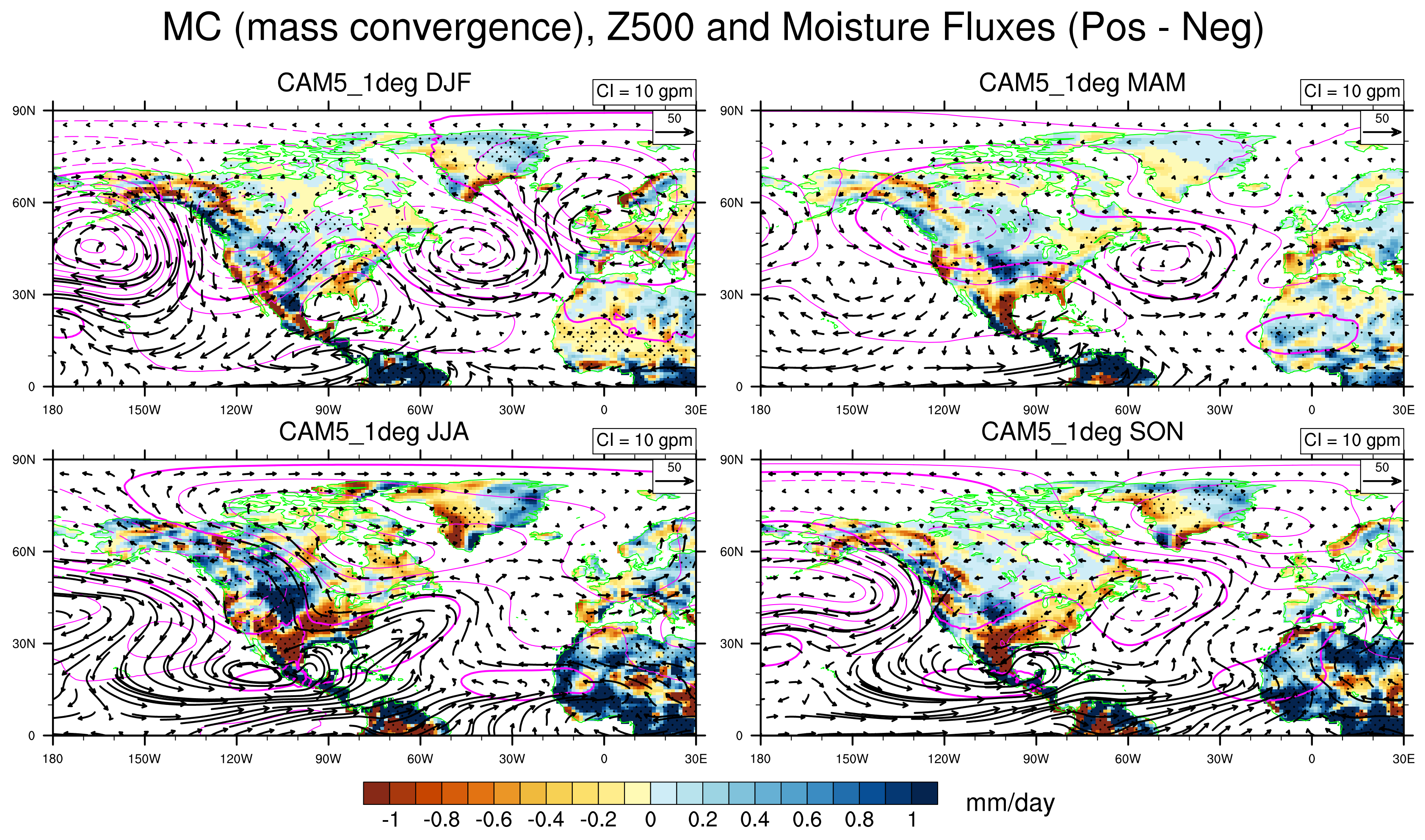
P-E


P-E, Z500 and UV850 (POS-NEG)
CAM5_1deg DJF
ECHAM5_T42 DJF
CAM5_1deg JJA
ECHAM5_T42 JJA
CI = 5 gpm
2.5
90N
60N
30N
0
180
150W
120W
90W
60W
30W
0
30E
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
mm/day

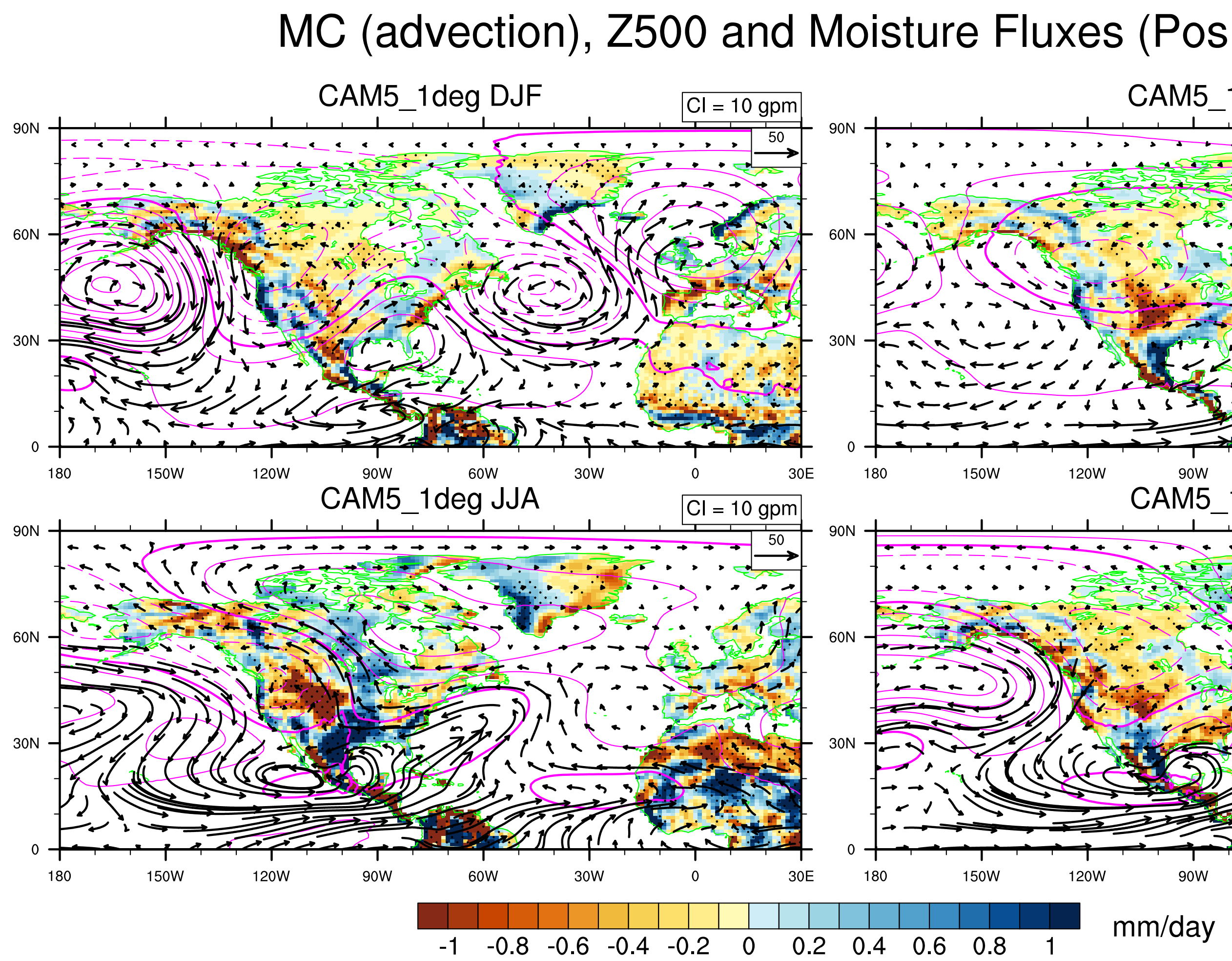
By Monthly Mean Flow



By Convergence



By Advection



Summary

- Radiatively forced SST warming, positive AMV and La Niña all contribute to drought conditions in the U.S., but the impact of AMV tend to be more significant and wide spread in historical observations, particularly in summer.
- CMIP5 models historical simulations overestimate the forced drought signal while underestimate the positive AMV- drought signal in the U.S.
- CMIP5 models tend to link positive AMV to weak El Niño condition in the tropical Pacific
- When decadal ENSO signal is removed, the CMIP5 models' representation of the forced and AMV drought signals improved slightly
- High-top models represent better the forced and AMV drought signals over the U.S. than the corresponding low-top models.
- The difference between the high and low top models seem to be related to the difference in the ENSO – AMV linkage: no significant El Niño in high-top models, but there is substantial tropical Pacific warming in low-top models associated with positive AMV.
- Mechanisms for warm AMV-NA Drought connection seems to be more due to local Hadley/Walker circulation: rising motion in tropical Atlantic and sinking in North American land mass, and less due to change in circulation and associated moisture advection change