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Potential Predictability of Southwest US Precipitation: Role of tropical and high-latitude variability

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Background, motivation

Seasonal prediction is a boundary value problem – it relies on predictability of the slowly evolving components of the climate system, especially sea surface temperature (SST)

Most predictability on the seasonal time scale comes from ENSO

El Niño years are generally associated with plentiful precipitation in the Southwest US (SWUS), and La Niña years are generally associated with dry conditions.

However, the teleconnection is non-stationary or intermittent. Example, WY 2016 compared to WY1998 and 1983

The strong El Niño in 2016, which was a bust in SWUS precip, was followed by a weak La Niña that produced record rainfall

Outline

Here we want to assess the level of predictability that may be gained for SWUS precip, from the S2S to multiyear time scales, in a “perfect-model” configuration where the tropics and/or the Arctic are nudged towards observed variability.

Want to assess what may have been the role of tropical and/or high-latitude variability on the SWUS precipitation observed over 1980 to 2016 using AMIP-style experiments with prescribed observed SST and sea ice

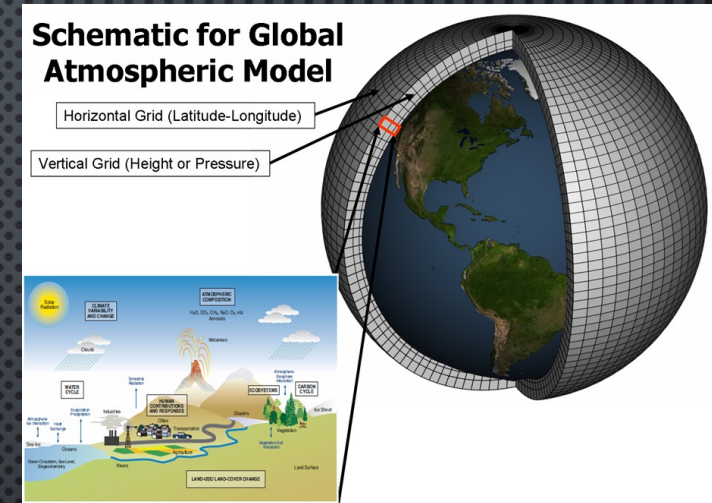
The AMIP-plus experiments reveal how perfectly predicting the tropics and/or the Arctic may benefit prediction of SWUS precipitation, at various time scales



The atmospheric model : WACCM

The Whole Community Climate Atmospheric Model (WACCM)

- $1.9^\circ \times 2.5^\circ$ horizontal grid
- 66 vertical levels, up to 140 km
- Specified chemistry
- External forcing (GHGs, aerosols etc) follows historical values
- Prescribed QBO



Four types of experiments over 1979-2016 (10 ensemble members each)

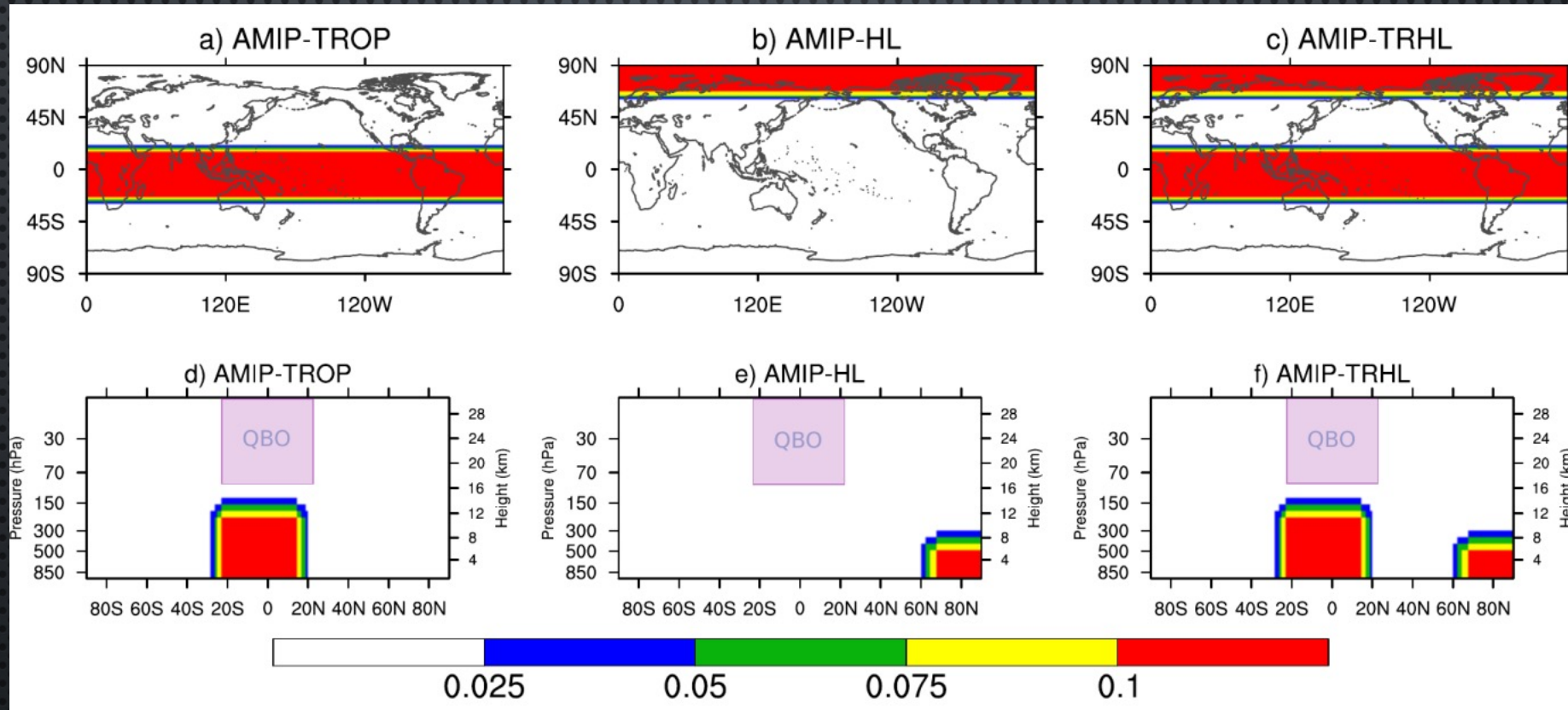
1) Prescribed observed SST/SIC : **AMIP**

2) AMIP with prescribed tropical variability : **AMIP-TROP**

3) AMIP with prescribed high-latitude variability : **AMIP-HL**

4) AMIP with prescribed tropical and high-latitude variability : **AMIP-TRHL**

Experimental setup for AMIP-plus experiments

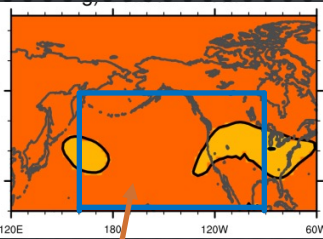


Value of the nudging coefficient along the horizontal and vertical in : a) and d) AMIP-TROP ; b) and e) AMIP-HL ; c) and f) AMIP-TRHL. The relaxation strength is linearly decreased from 0.1 to 0 at the edges of the nudging domain. The purple rectangle in the pressure versus latitude plots indicates the domain of relaxation of the QBO (horizontal wind only, and a nudging time coefficient of 10 days).

Results

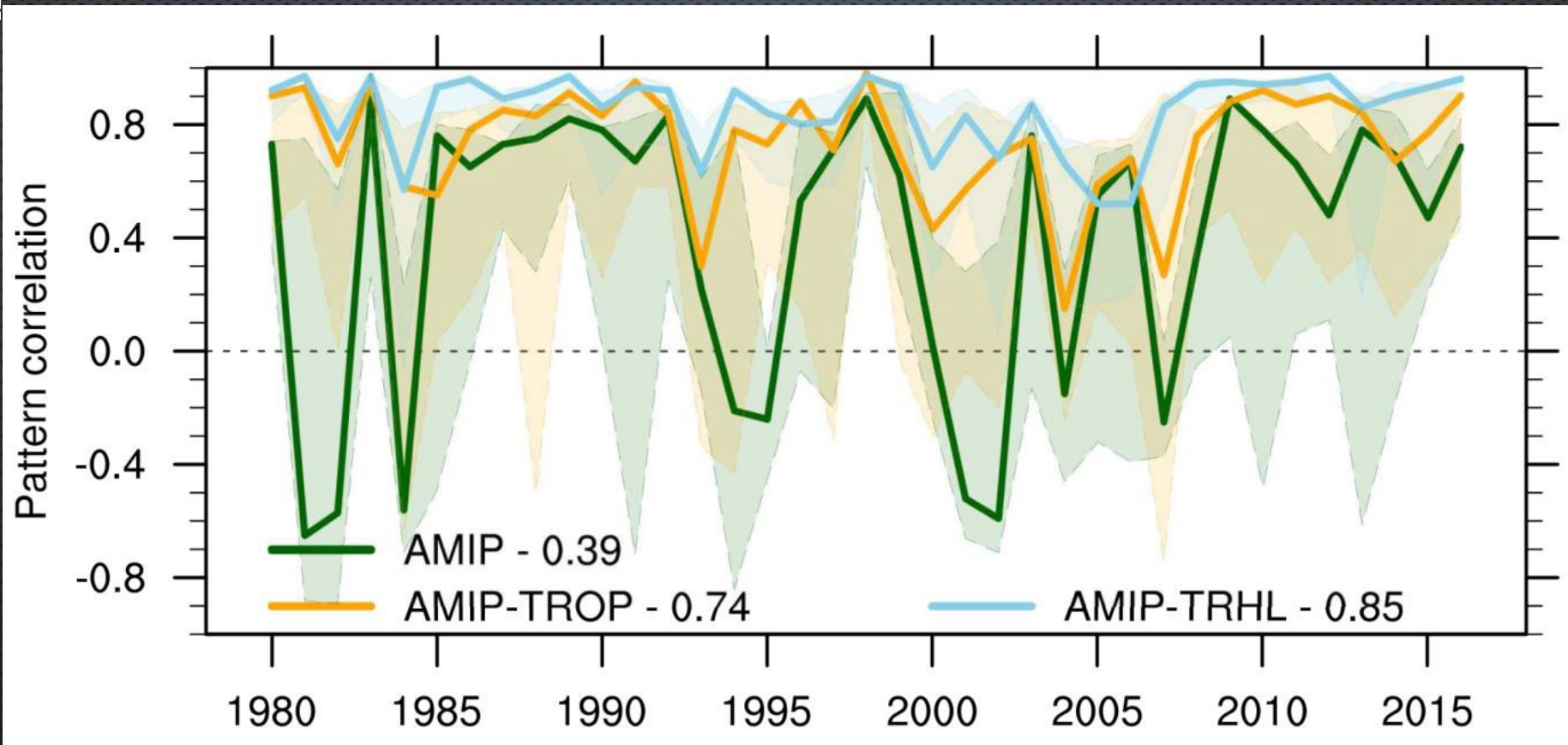
Interannual variability in Z500 anomalies

AMIP, AMIP-TROP (tropics nudged) and AMIP-TRHL (tropics and Arctic nudged)



North-Pacific/
North America
domain

[160°E /90°W;
20°N/60°N]



Pattern correlation of Z500 anomalies in the North Pacific - North America domain [160°E/90°W, 20°N/60°N] between MERRA-2 and ensemble means of AMIP (green), AMIP-TROP (orange) and AMIP-TRHL (blue) and MERRA-2, for each NDJFM season of 1980-2016. The 1980-2016 average correlation is given in caption. For each experiment, the envelope represents max/min values of the spatial correlation among the 10 ensemble members.

Decompose into different timescales using daily data

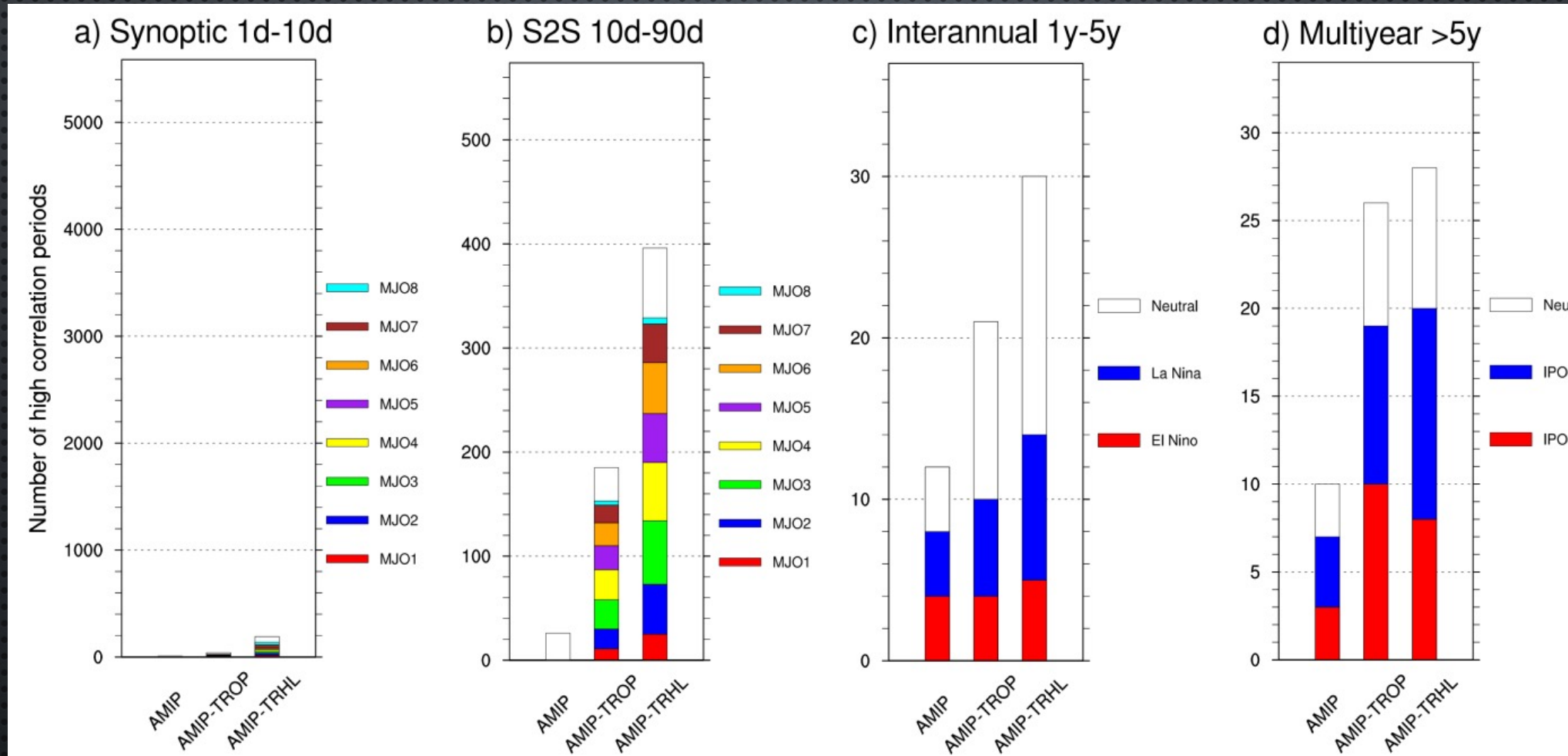
Synoptic (1-10 days), S2S (10-90 days), Interannual (1-5 years), Multiyear (>5 years)

Compute spatial correlations between the observed and simulated Z500 anomaly in the NP-NA domain, after time filtering the daily data

If the correlation is greater than 0.7, the event is classified as *accurately represented* in the experiment.

Categorize by phases of MJO (synoptic, S2S), ENSO (interannual) and IPO (multiyear)

Counts of periods of accurate representation of NP circulation patterns



Count of periods of accurate representation of the North Pacific circulation pattern in AMIP, AMIP-TROP and AMIP-TRHL, for a) the synoptic (1d-10d) timescale (5587 NDJFM days over 1980-2016) ; b) the S2S (10d-90d) timescale (574 pentads) ; c) the interannual (1y-5y) timescale (37 years) ; d) the multiyear timescale (37 years with 5-yr lowpass filter, i.e. 33 years). Events of “accurate representation” are based on a spatial correlation of Z500 anomalies, in the ensemble mean of experiments versus reanalysis, greater than 0.7. In a and b, the events are categorized based on the concomitant MJO phase. In c, the events are categorized in El Niño/La Niña/Neutral events based on the average Niño-3 index over NDJFM. In d, the events are categorized based on the sign of the IPO.

Key Take-aways

Clear improvement at S2S. AMIP can reproduce ~5%, AMIP-TROP ~30% and **AMIP-TRHL ~70%**

At longer timescales, the ocean exerts a stronger effect.

Interannual timescales:

AMIP ~30%, in AMIP-TROP up by ~25%, in AMIP-TRHL a further 25% increase

Note that most of the skill comes in ENSO neutral years

Multi-year timescale:

AMIP ~30%, AMIP-TROP ~80% and no further improvement in AMIP-TRHL

No dependence on IPO index

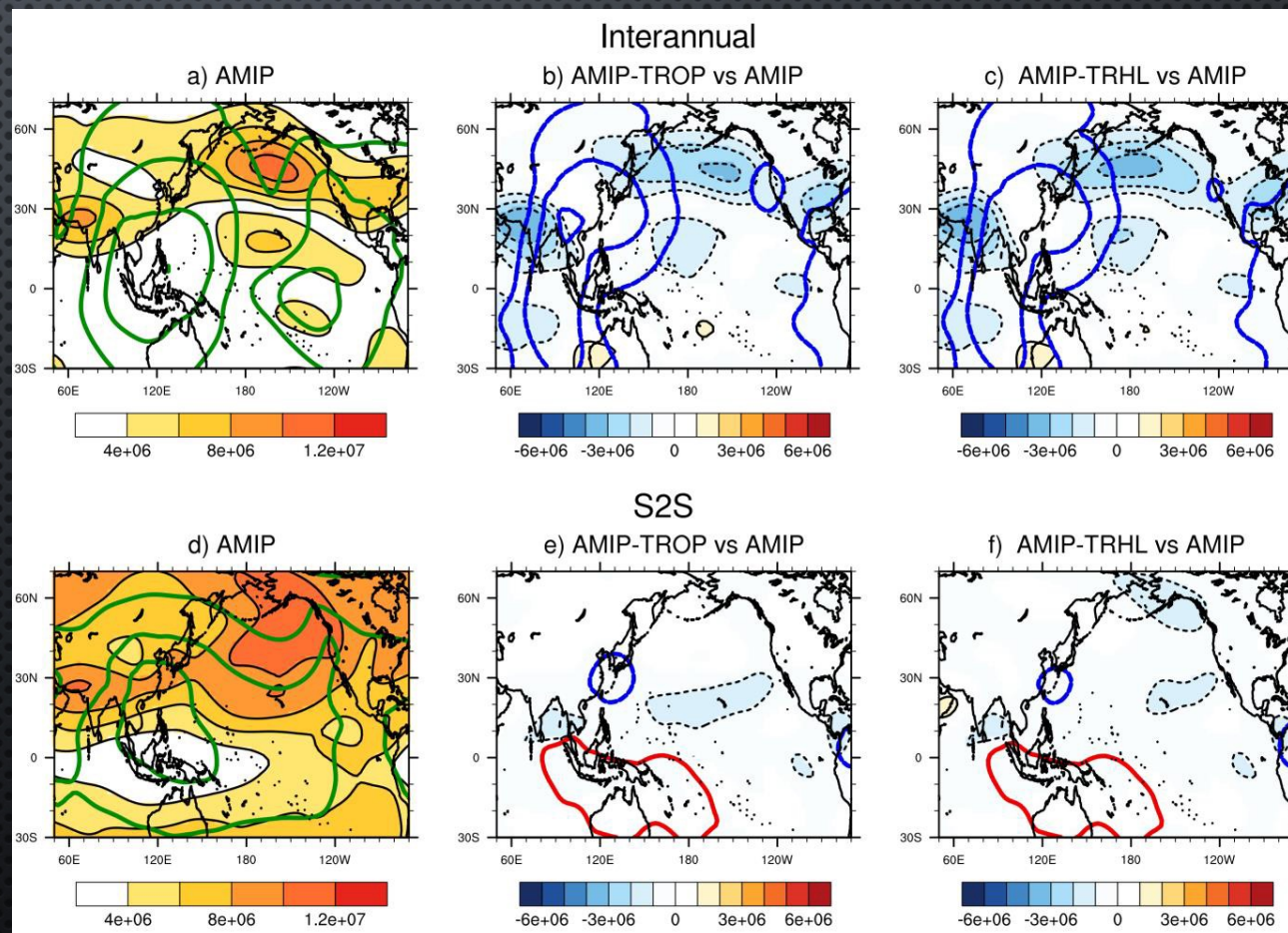
Focus on S2S and interannual timescales

Velocity potential at 850 hPa VP850; anomalies are indicative of large-scale convective activity

Streamfunction at 250 hPa SF250; anomalies highlight wave trains

Plotted here are absolute values of VP850 anomalies (contours, blue-neg, red-pos) and SF250 anomalies (shading)

Interannual



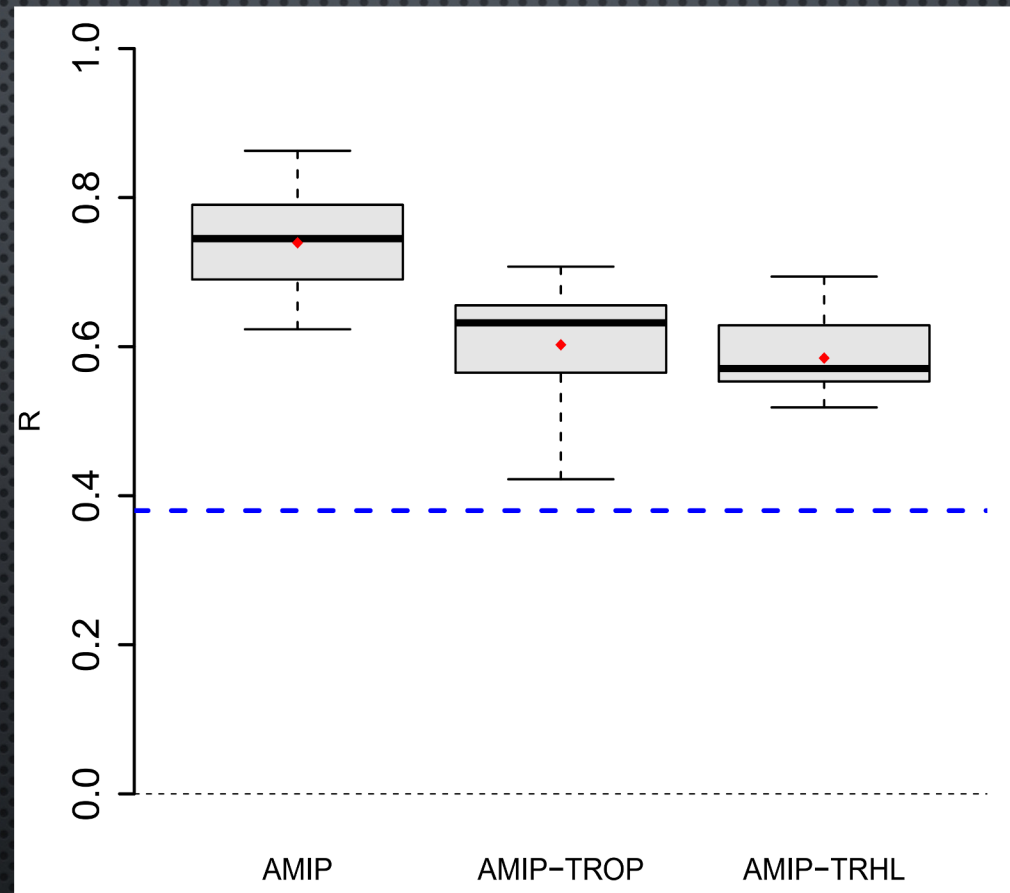
S2S

Interpretation

The seasonal convection anomalies are too strong (or too persistent) in AMIP. Thus the influence of tropical SST anomalies is too large and the tropics-extratropics teleconnection is too “ENSO-like” compared to the real world.

Put another way, because there is not enough subseasonal variability in tropical convection in AMIP (e.g., doesn't capture MJO) the teleconnection is too ENSO-like

Correlation between SWUS rainfall and the Nino-3 index in NDJFM

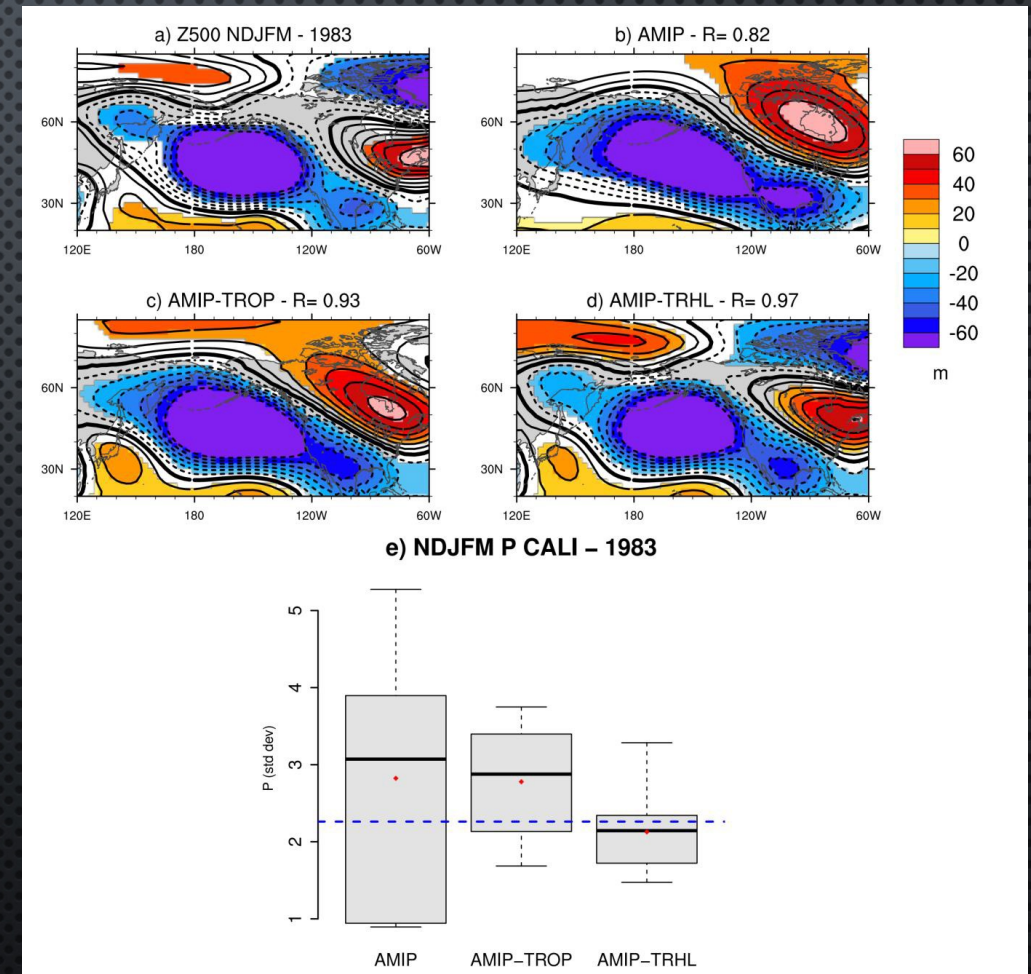
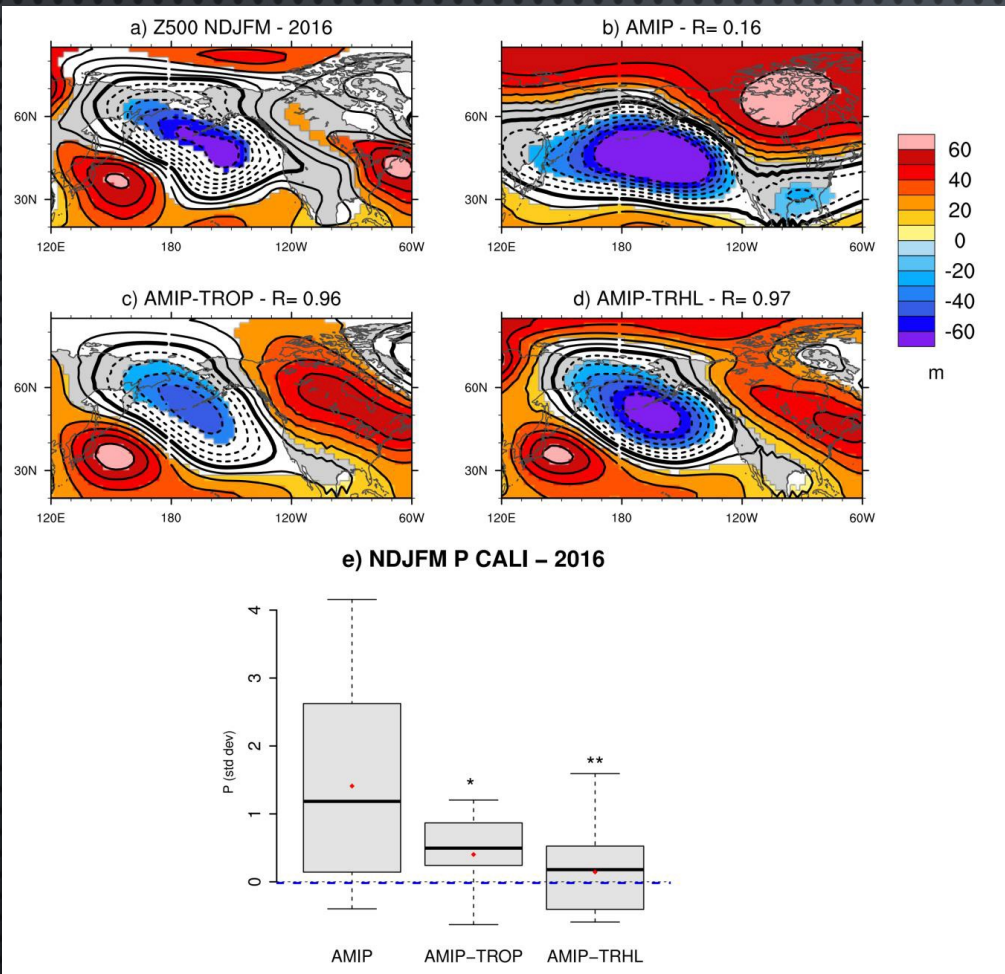


Boxplot-whisker representation of the 10-member distribution of the correlation between SWUS rainfall and the Nino-3 index in NDJFM in AMIP, AMIP-TROP and AMIP-TRHL for the 1980-2016 period. The boxplot indicates the median, upper and lower quartile of the distribution. The whiskers indicate the minimum and maximum values. The ensemble mean is marked by a red diamond. The horizontal dashed blue line indicates the equivalent observed correlation.

A tale of 2 strong El Nino winters: 2016 and 1983

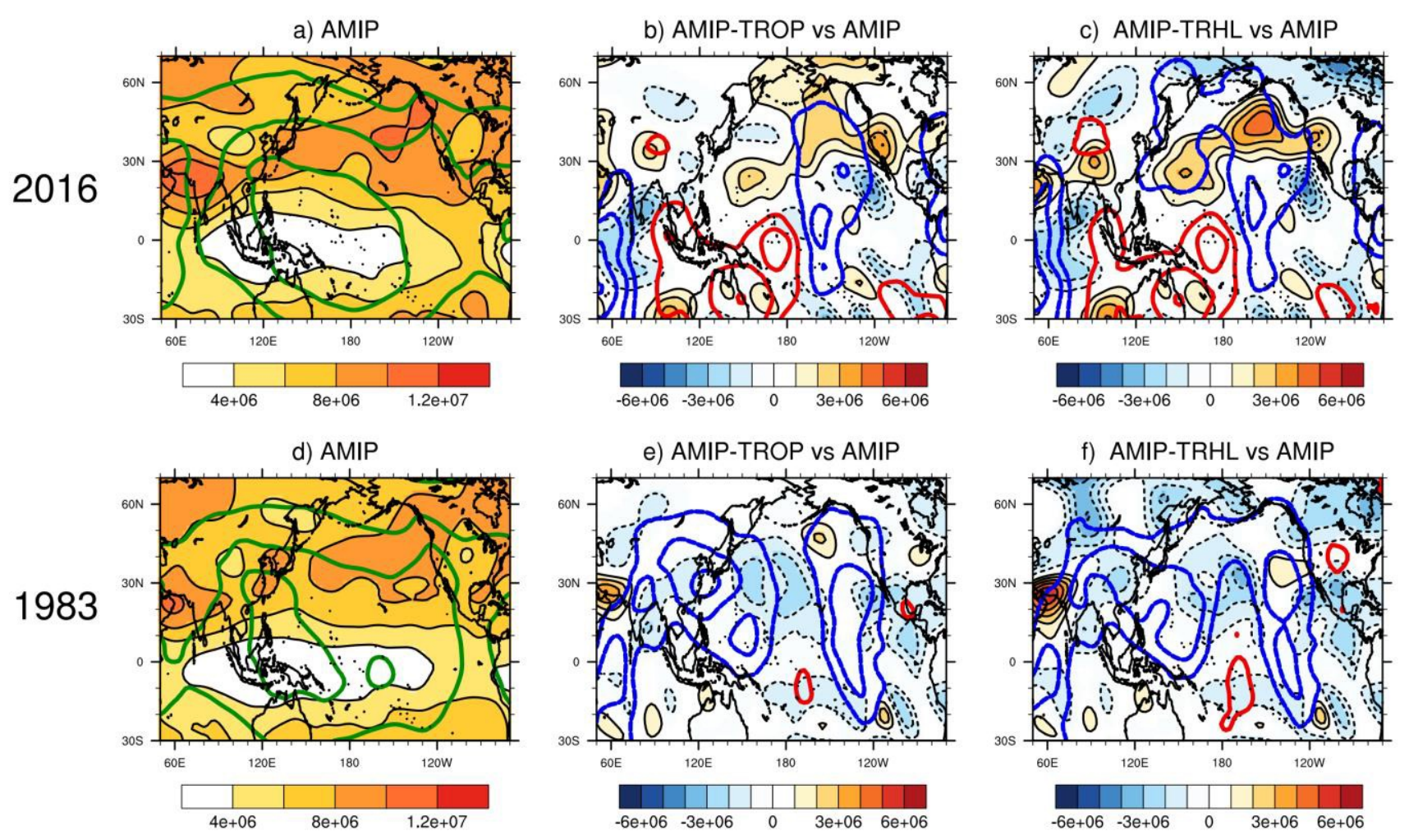
NDJFM 2016
Z500 anomalies

NDJFM 1983
Z500 anomalies



R=0.96

precip



NDJFM standard deviation of subseasonal (10d-90d) 850 hPa potential velocity (green, blue and red contours, kg/s) and 250 hPa streamfunction (shading, kg/s) in (Top) 2016 : a) AMIP, contour interval for VP850: $0.10E-5$ kg/s. b) AMIP-TROP minus AMIP difference. Contour interval for VP850: $2.5.10E-5$ kg/s (blue is negative, red is positive). c) Same as b) but for AMIP-TRHL. (Bottom) 1983 ; d-f) Same as a)-c) but for year 1983.

Conclusions

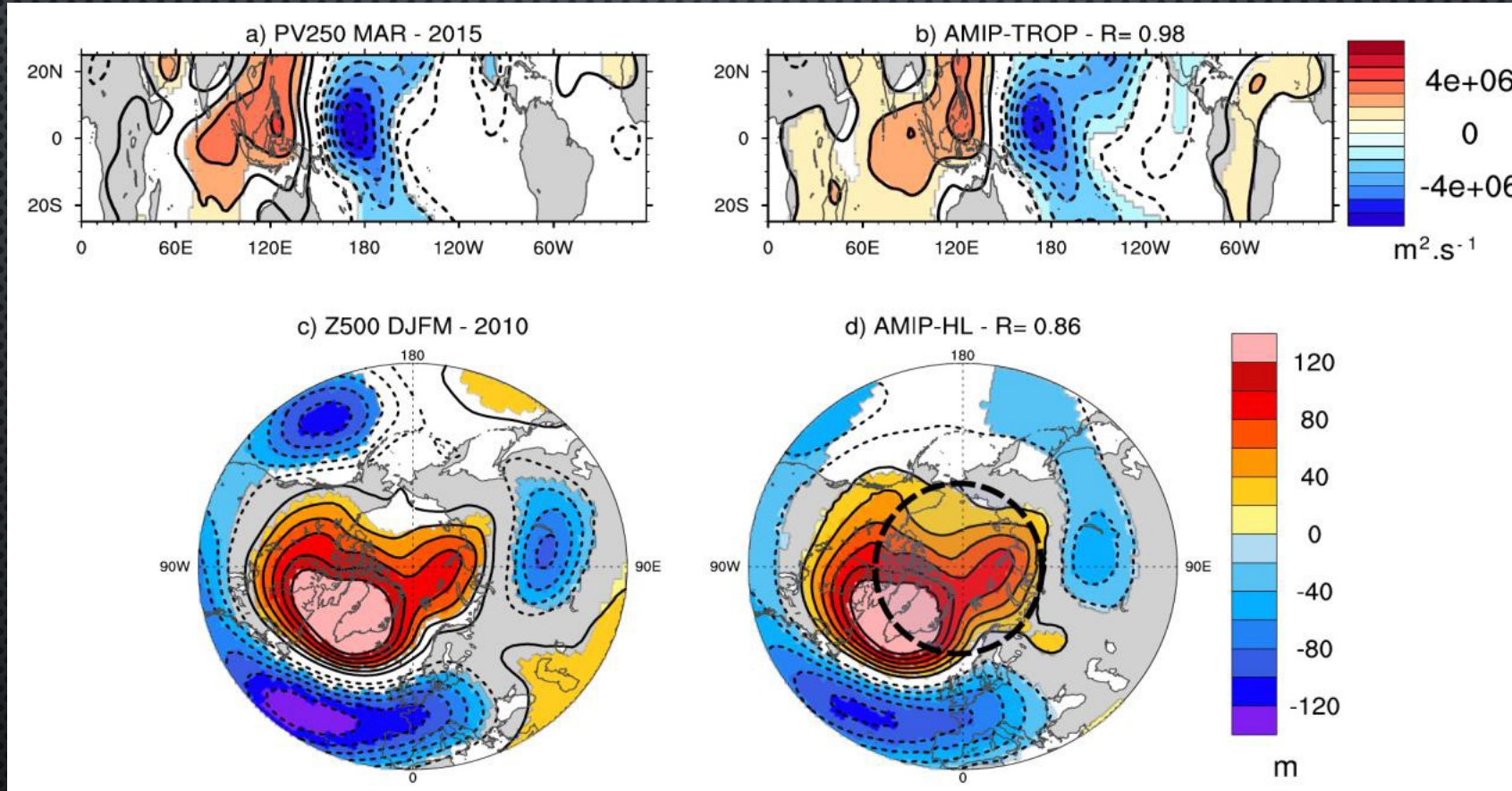
- Potential predictability of SWUS precipitation exists at the S2S, seasonal and multiyear time scales in the tropics and high-latitudes, which is independent of SST and sea ice variability.
- Most of the predictive signal comes from the tropics, but there may be additional skill when a good prediction of Arctic climate variability is combined with a good prediction of tropical variability.
- Subseasonal variability seems to be a source of noise for longer-term seasonal forecasting. In the AMIP configuration when the model lacks subseasonal variability, the seasonal SWUS rainfall exhibits stronger correlation with ENSO, i.e., is more predictable. Prescribing the observed tropical variability allows the model to better reproduce the observed variability, but it decreases the SWUS rainfall-ENSO teleconnection.

Verification of nudging protocol

MERRA-2

AMIP-plus experiment

Velocity potential
anomaly at 250 hPa,
March 2015



AMIP-TROP

AMIP-HL

DJFM-2010
anomaly in Z500

Verification of the nudging protocol. a) March 2015 anomaly of the 250 hPa velocity potential ($m^2.s^{-1}$) in MERRA2. b) Same as a) but for the ensemble mean anomaly in AMIP-TROP. c) December-March 2010 anomaly of the 500 hPa geopotential height (Z500, m) in MERRA2. d) Same as c) but for the ensemble mean anomaly in AMIP-HL. Anomalies that are significant at the 95% confidence level are shaded. The spatial correlation between MERRA2 and the simulation is given on top of the right panel (correlation on full domain shown).

ACC

Seasonal

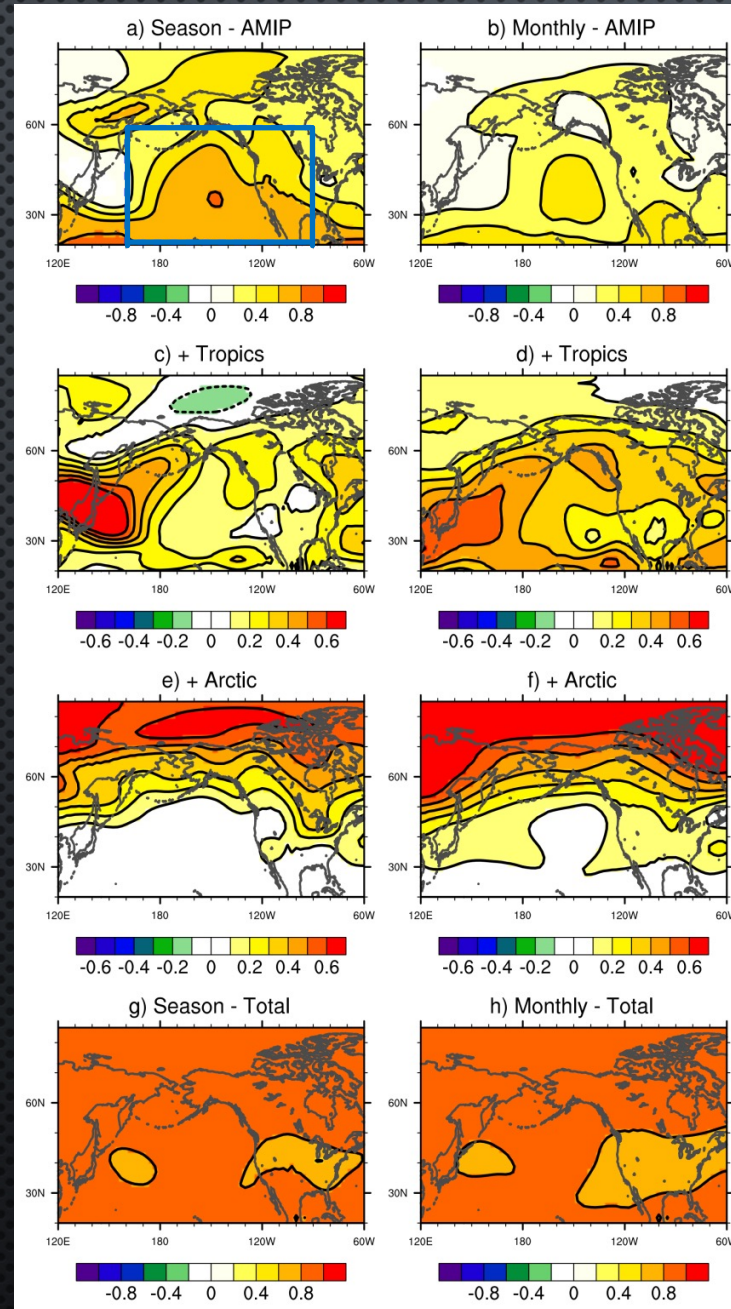
Monthly

1. just AMIP

2. gain by AMIP-TROP

3. gain by AMIP-TRHL

Total ACC for AMIP-TRHL



“Skill” associated with each exp

ACC: Anomaly Correlation Coefficient (pointwise)

a) Anomaly Correlation Coefficient (ACC) between 1980-2016 seasonal (NDJFM) Z500 anomalies of AMIP and MERRA-2. b) Same as a but for monthly (NDJFM only) Z500 anomalies. c) Difference in seasonal ACC when nudging the tropical troposphere towards MERRA-2 (i.e., $PP_{AMIP-TROP}$ minus PP_{AMIP}). d) Same as c but for monthly ACC. e) Difference in seasonal ACC when adding nudging of the Arctic troposphere towards MERRA-2 (i.e., $PP_{AMIP-TRHL}$ minus $PP_{AMIP-TROP}$). f) Same as e but for monthly ACC. g) Total seasonal ACC in AMIP-TRHL. h) Same as g but for monthly ACC. The blue box in a) is the domain we define as the “North Pacific – North America” domain.

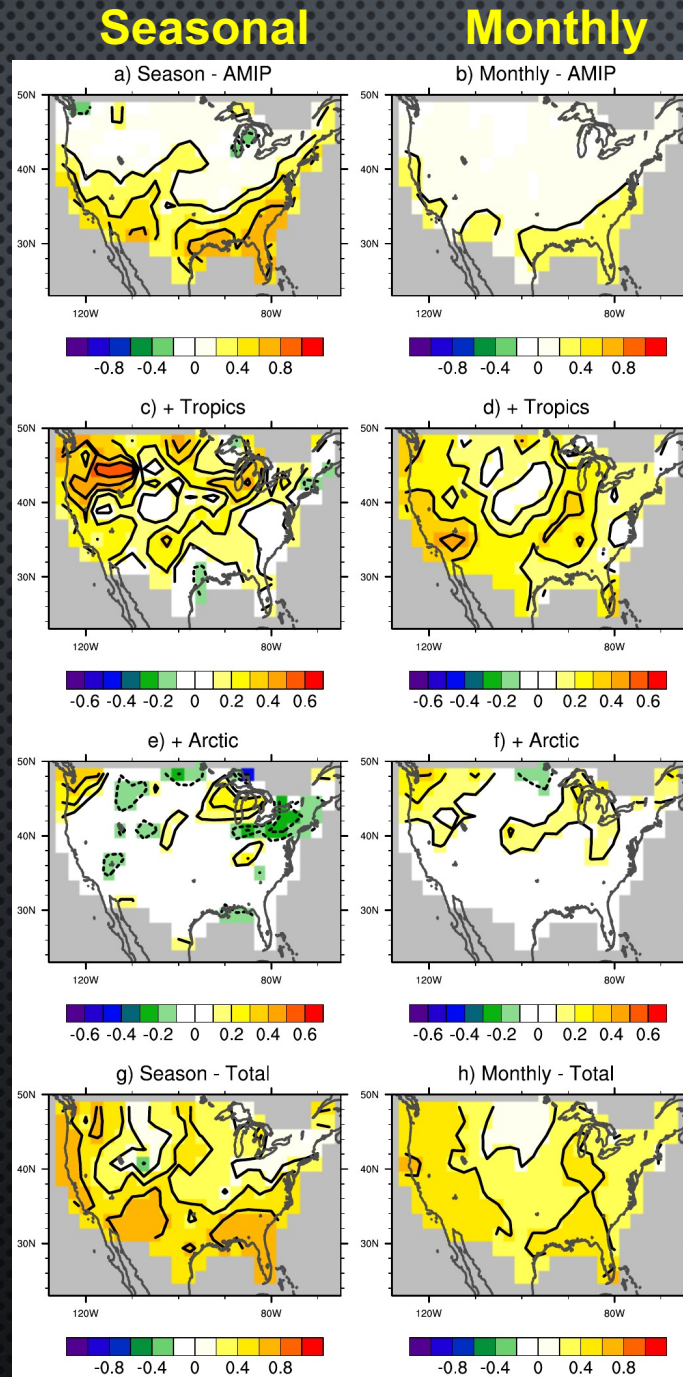
ACC

1. just AMIP

2. gain by AMIP-TROP

3. gain by AMIP-TRHL

Total ACC for AMIP-TRHL



Same as previous figure but for seasonal/monthly NDJFM US precipitation anomalies (observations are from the CPC dataset).

a) Anomaly Correlation Coefficient (ACC) between 1980-2016 seasonal (NDJFM) US precipitation anomalies of AMIP and observations (CPC). b) Same as a but for monthly (NDJFM only) precip anomalies. c) Difference in seasonal ACC when nudging the tropical troposphere towards MERRA-2 (i.e., $PP_{AMIP-TROP}$ minus PP_{AMIP}). d) Same as c but for monthly ACC. e) Difference in seasonal ACC when adding nudging of the Arctic troposphere towards MERRA-2 (i.e., $PP_{AMIP-TRHL}$ minus $PP_{AMIP-TROP}$). f) Same as e but for monthly ACC. g) Total seasonal ACC in AMIP-TRHL. h) Same as g but for monthly ACC. The blue box in a) is the domain we define as the “North Pacific – North America” domain.

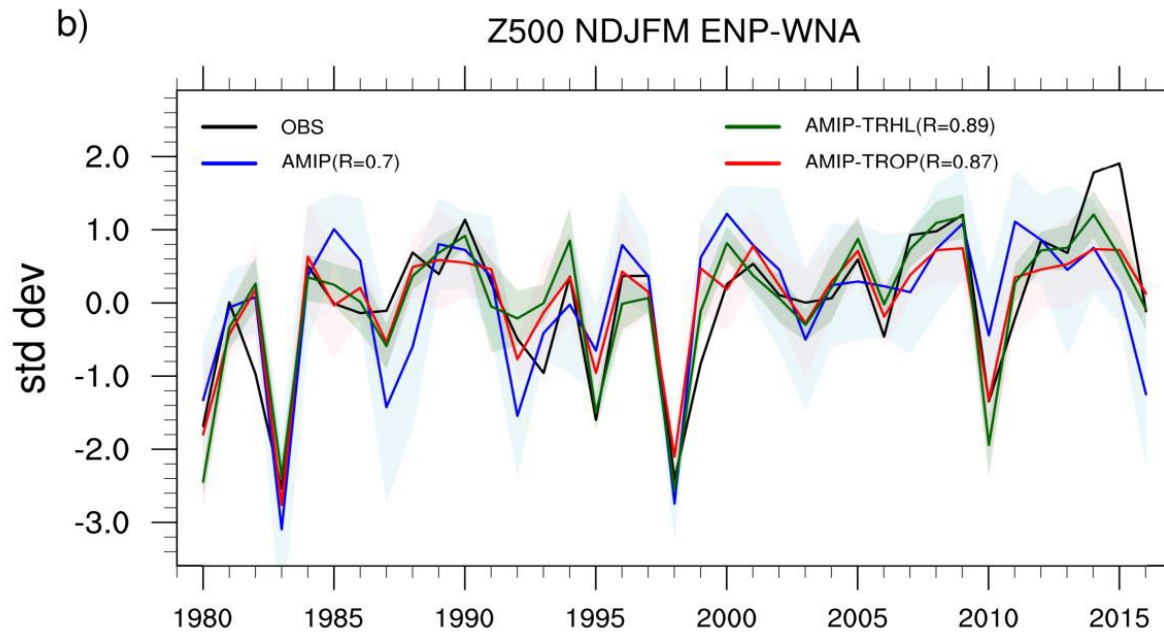
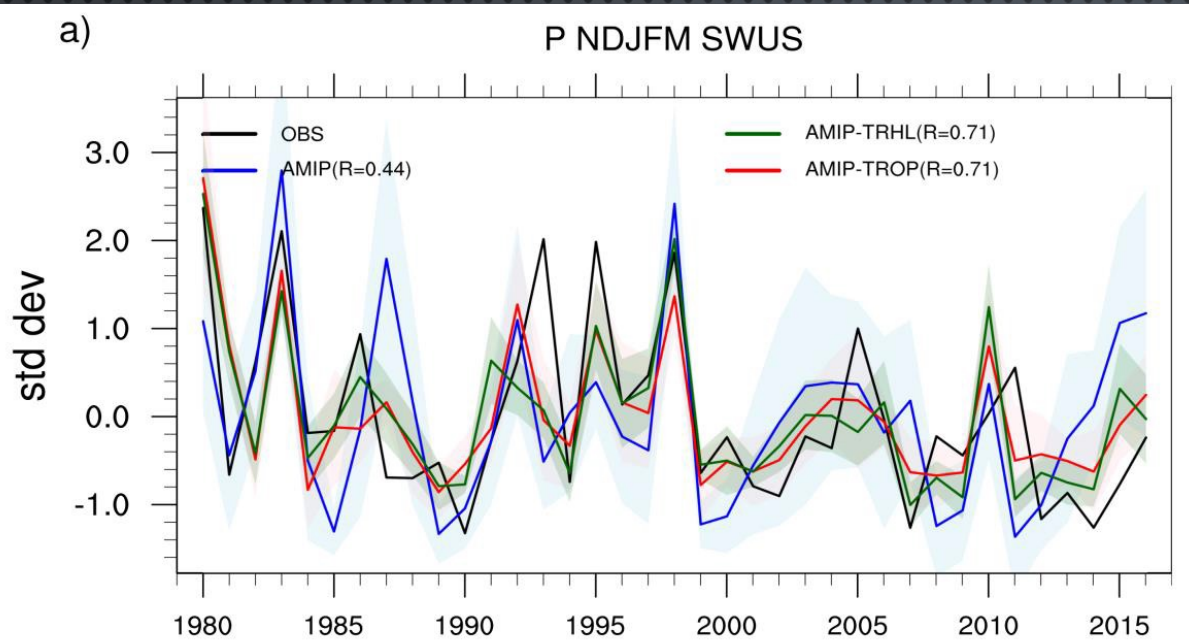
Timeseries of NDJFM rainfall

SWUS rainfall index

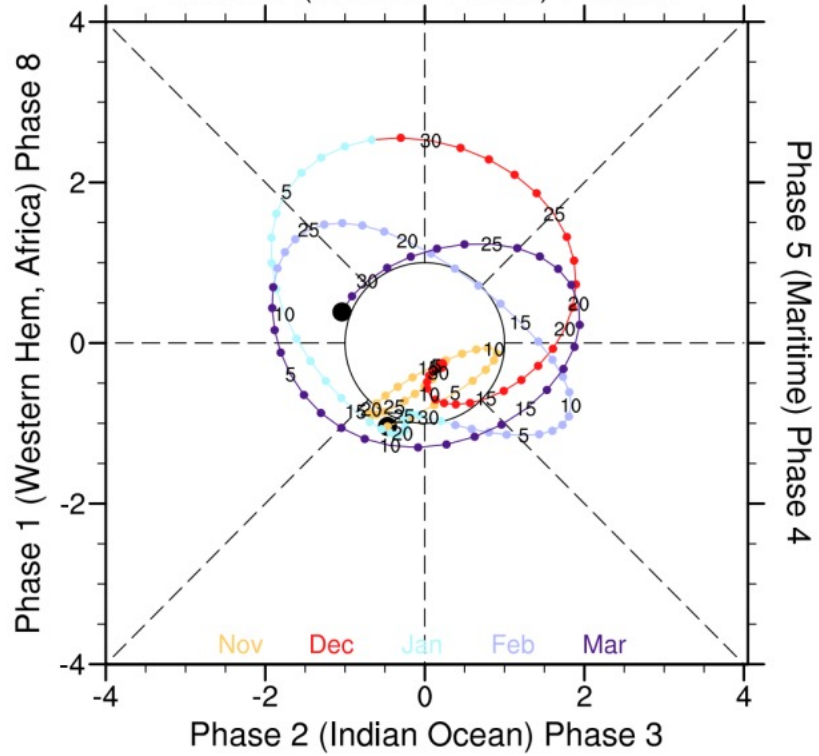
a) Timeseries of the NDJFM SWUS rainfall index in observations (CPC, black), AMIP (blue), AMIP-TROP (red) and AMIP-TRHL (green). For the experiments the envelope shows the +/- one standard deviation of the 10-member ensemble. The correlation with observations is indicated.

ENP Z500, a proxy index for rainfall

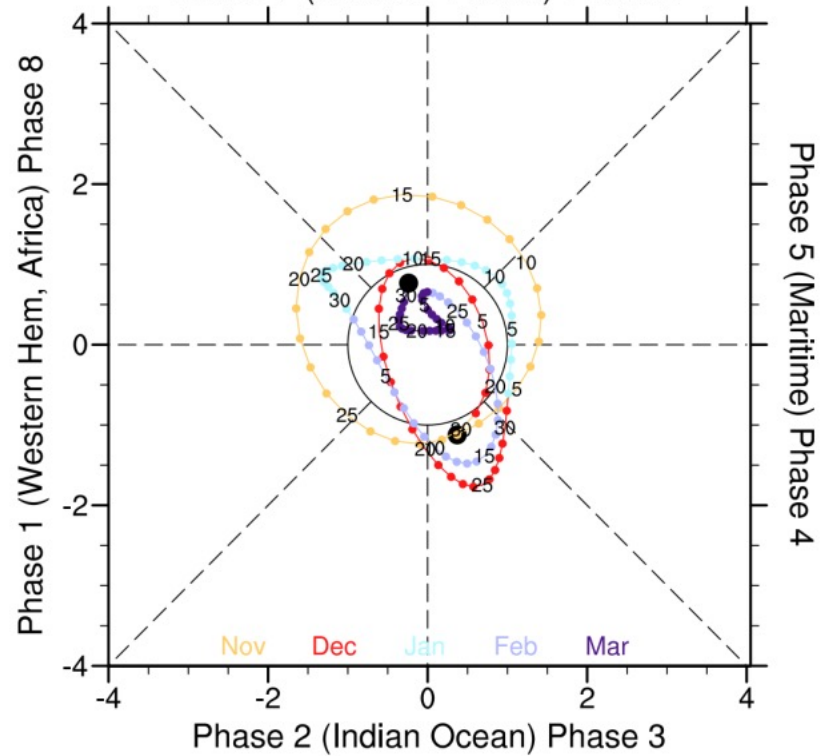
b) Same as a) but for the ENP Z500 index (a proxy for SWUS rainfall).



a) 2015/16
 MJO Phase: 15S-15N: 20151101-20160331
 Phase 7 (Western Pacific) Phase 6



b) 1982/83
 MJO Phase: 15S-15N: 19821101-19830331
 Phase 7 (Western Pacific) Phase 6



MJO phase from November to March for : a) the 2015/16 winter ; b) the 1982/83 winter.

Interannual variability in Z500 anomalies

AMIP, AMIP-TROP and AMIP-HL (only Arctic nudged)

