Estimating the regional response to global warming using pattern-scaled sea surface temperatures and sea ice

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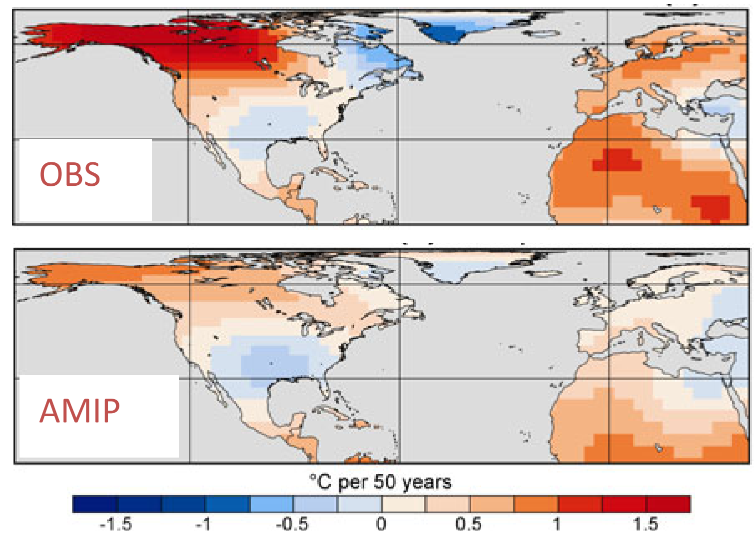
Bichet et al. 2015 and in prep

Support: NSERC CanSISE (Canada) and BNP-Paribas PRECLIDE (France)

- Prescribing SSTs for climate attribution and prediction.
- Method description.
- Applications to past regional climate.
- Key points.

The Ocean Controls Continental Climate

LST Trends (1951-1999)



Shin and Sardeshmukh 2011

The Ocean Controls Continental Climate

- Simulations that use observed global or tropical SSTs as boundary conditions can capture continental hydroclimate trends.

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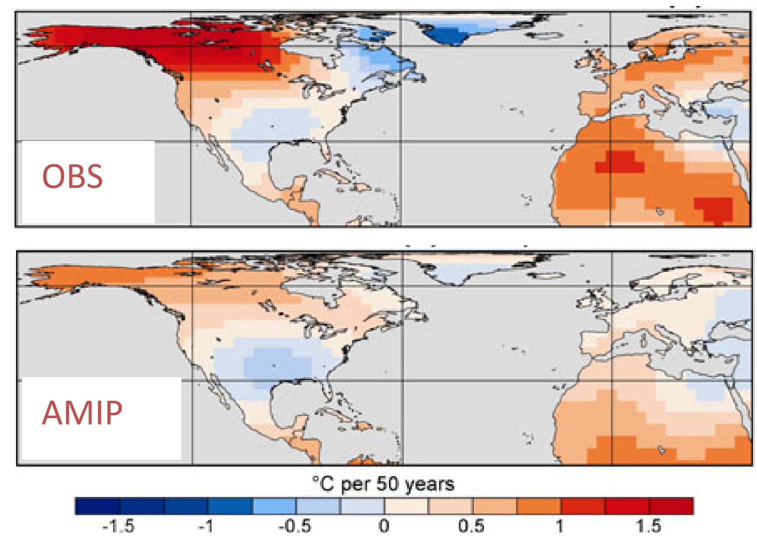

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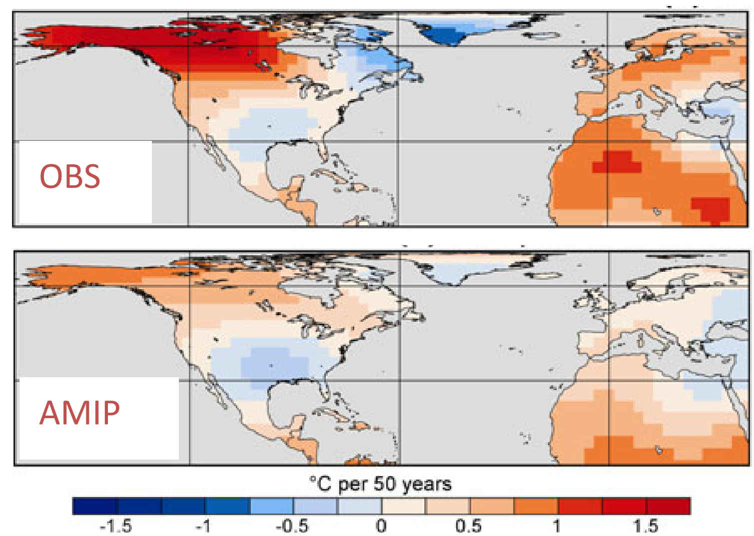
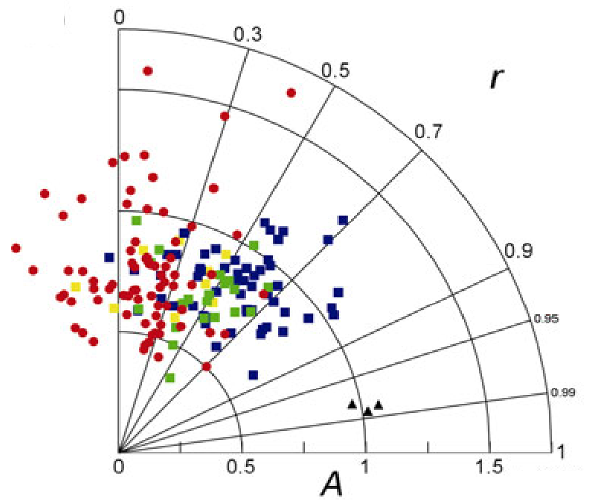


Global Land Surface Temperature



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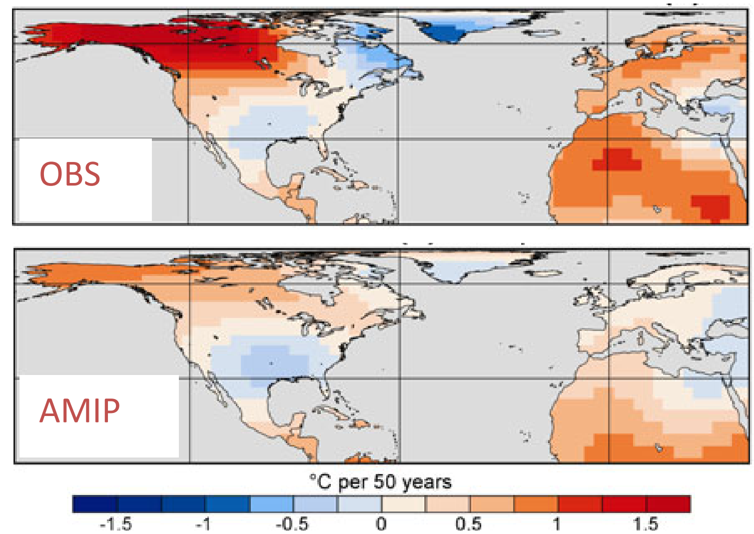

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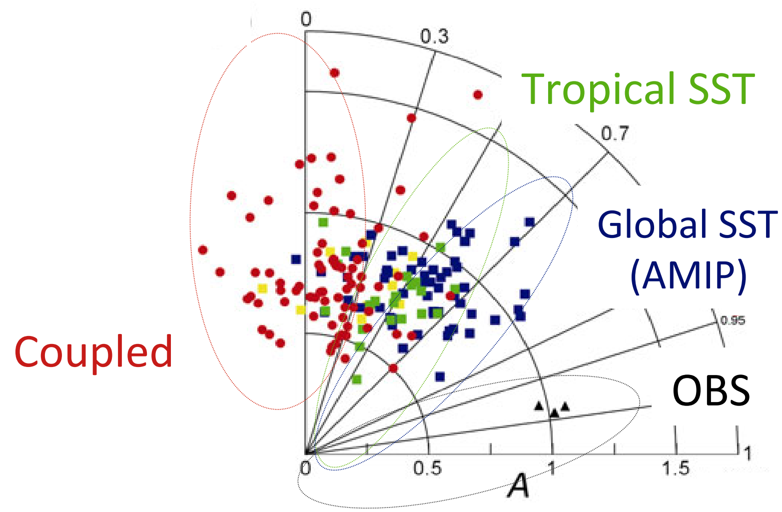

Shin and Sardeshmukh 2011

The Ocean Controls Continental Climate

- Simulations that use observed global or tropical SSTs as boundary conditions can capture continental hydroclimate trends.
- But coupled models struggle with tropical SST trends.
- This leads to poor coupled model simulation of continental trends.

Shin and Sardeshmukh 2011

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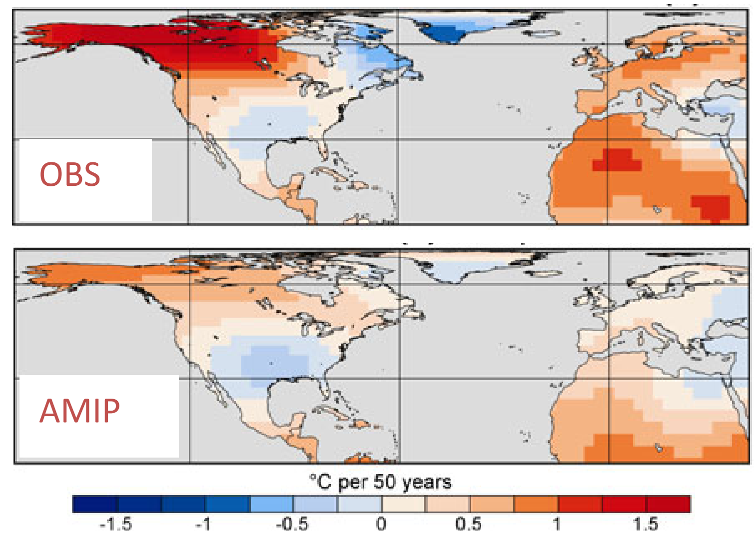

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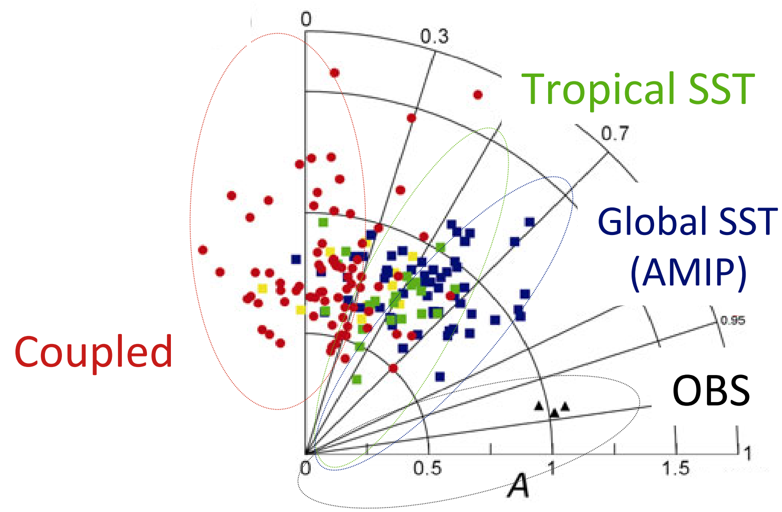
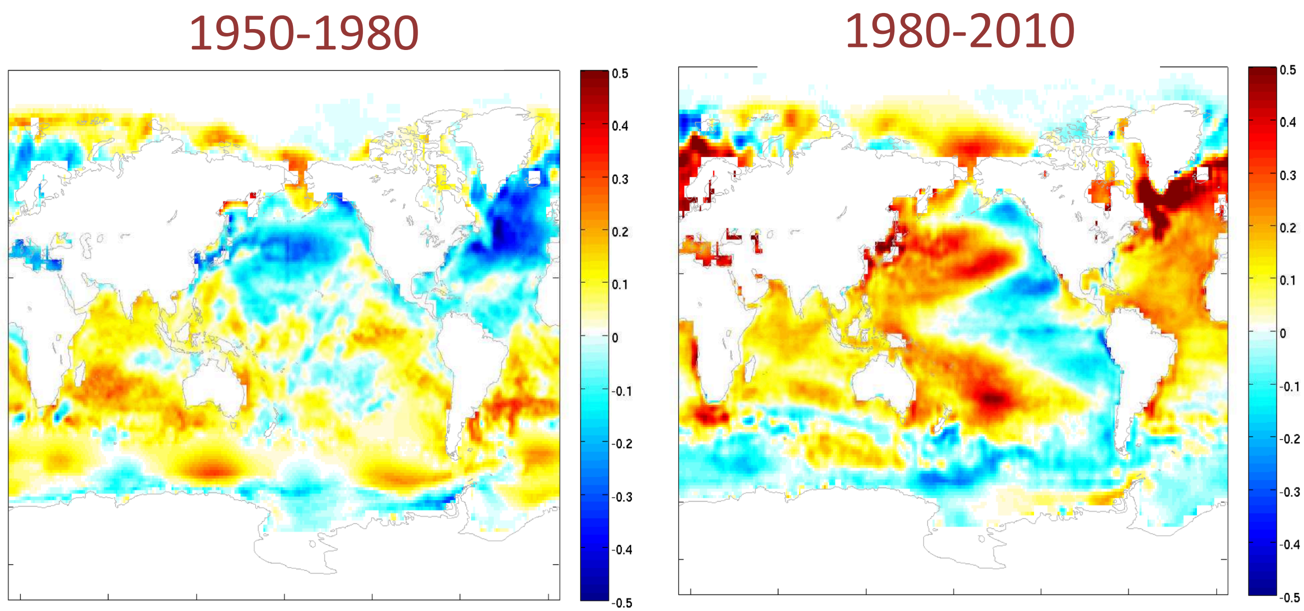


Using the time history of observed SSTs in atmospheric GCMs give us insight into continental hydroclimatic trends.

What other insight can we get from observed SSTs?

Separating Short- and Long-Term Variability



Hurrell SST

- SST decadal variability includes forced and internal parts.
- Can we estimate the long-term variability associated with global warming, S_{GW}, from obs?
- Can we use S_{GW} for attribution and near-term prediction? (Hoerling et al. 2011, Bichet et al. 2015)

- Observed SST decomposed into long term (GW) and residual:

$$S(x,t) = S_{GW} + S_{residual}$$

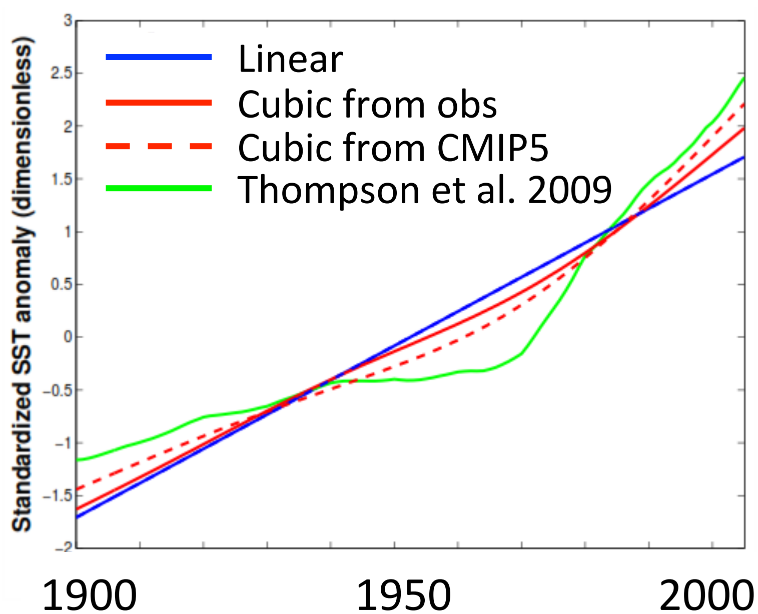
Residual includes internal variability and short-term forcings

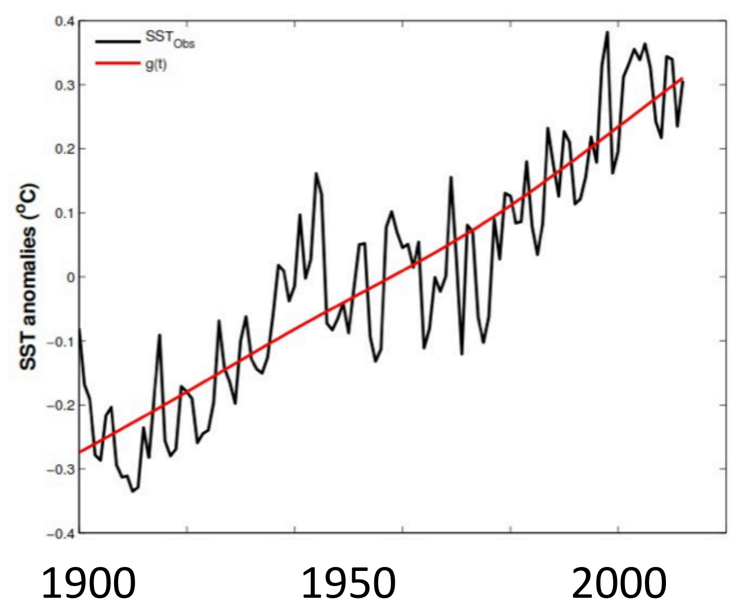
- S_{GW} modelled as time-independent pattern $h(x)$ scaled by time-dependent gain $g(t)$:

$$S_{GW} \approx h(x)\, g(t)$$

- $g(t)$ is low-pass filtered global mean SST from obs (Bichet et al. 2015) or from CMIP5 (Bichet et al. in prep)
  - Linear, cubic and Thompson et al. methods tested … Cubic used.

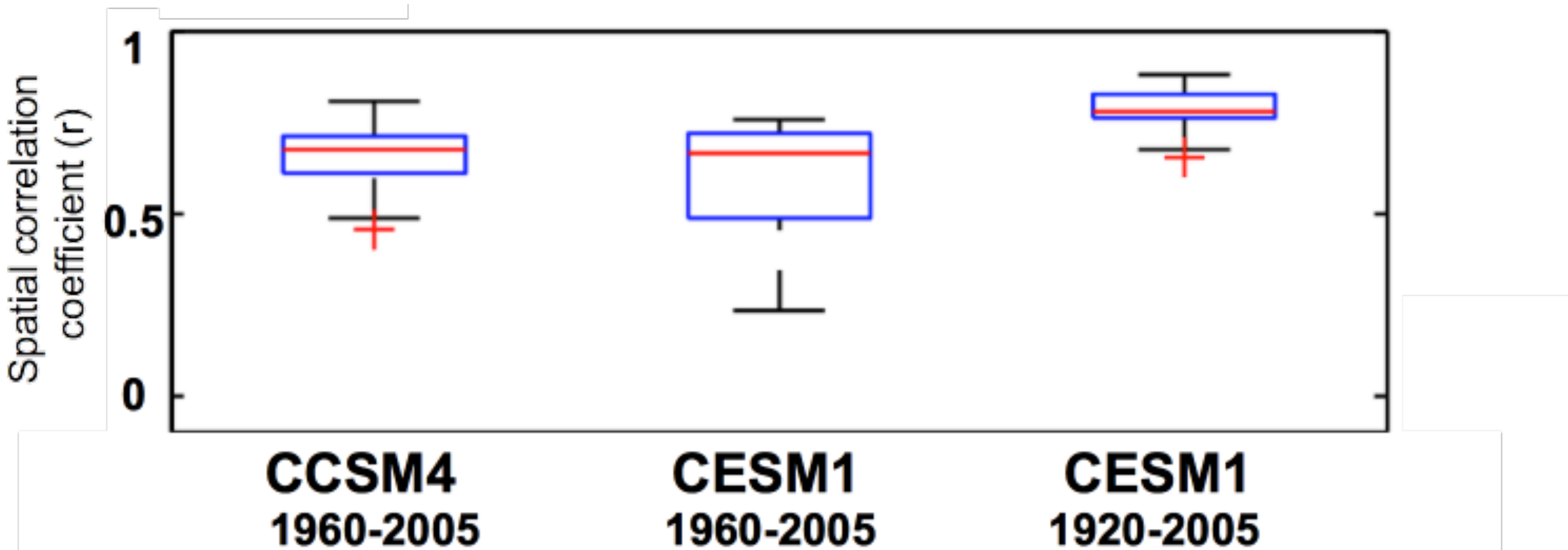
$g(t)$ from HadCRU and CMIP5





- $h(x)$: regression of Hurrell SST/SICE on $g(t)$

Testing our estimate of S_{GW} with large ensembles



Bichet et al. 2015

- Shown is spatial correlation of $h(x)$ of individual large- ensemble members with remaining members' ensemble mean $h(x)$.
- Using recent improvements, our estimate now captures over 70% of spatial variance of S_{GW}.

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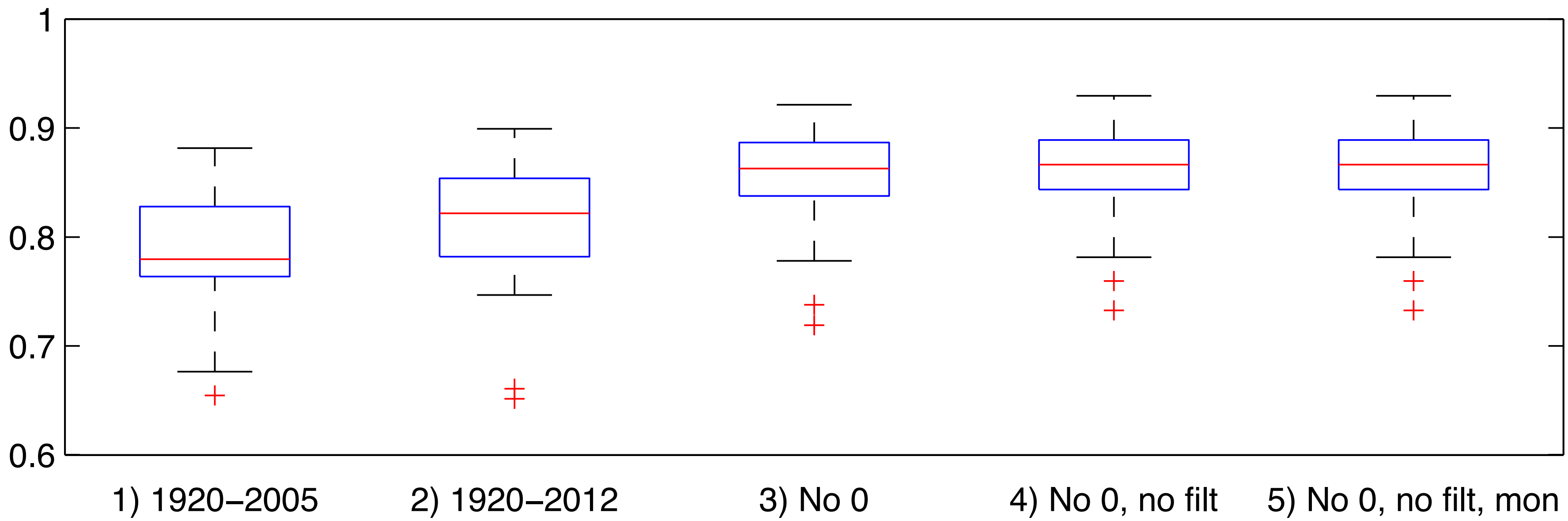

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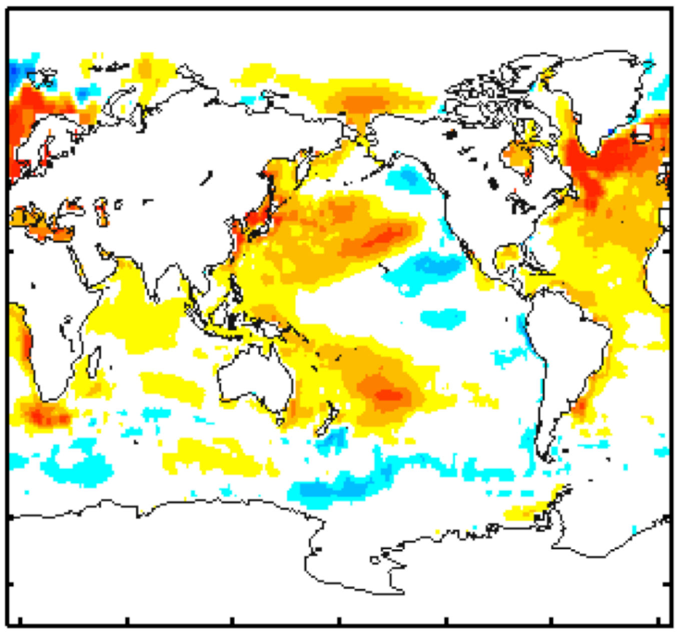
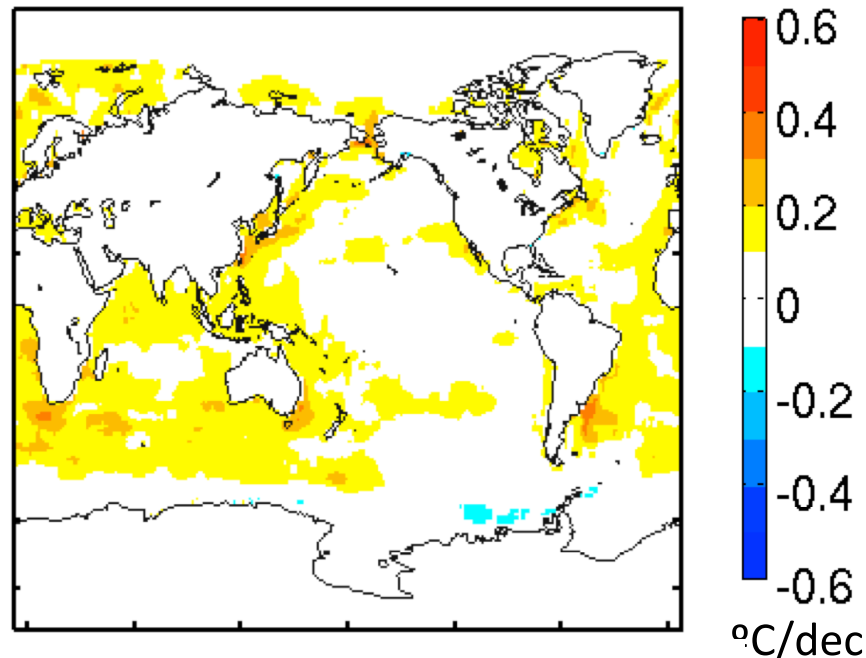
Global Warming Pattern of SST

AMIP SST Trends 1980-2010



Hurrell SST trends

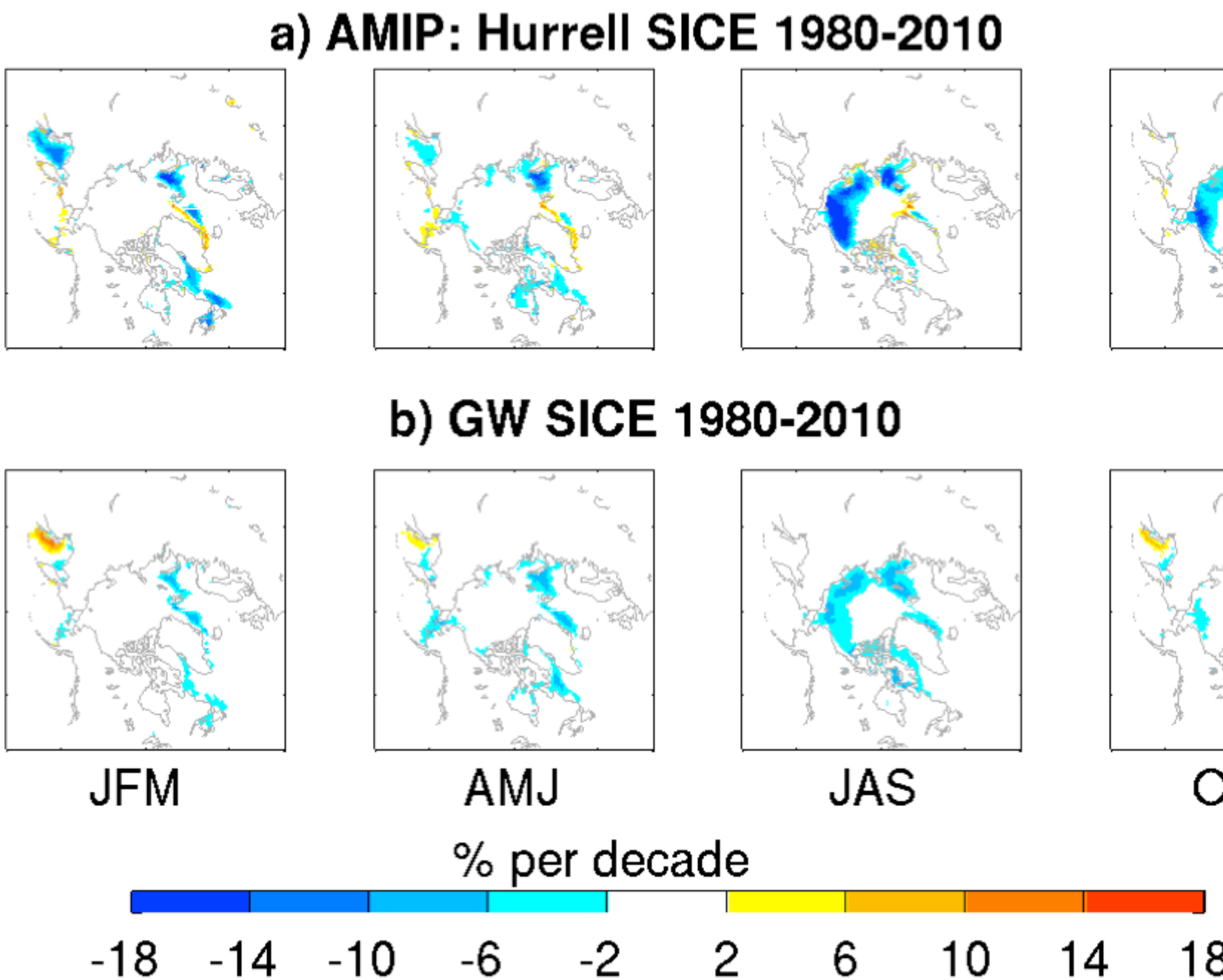
GW SST Trends 1980-2010



The pattern of S_{GW} is also from Hurrell SST

- S_{GW} *pattern* is from obs (20th century Hurrell SST). S_{GW} *scale* is from models [CMIP5 g(t)].
- S_{GW} features broader warming, relatively warm SH, coastal hot spots, no PDO trend (reduced east Pacific cooling), relatively weak AMO trend (reduced North Atlantic warming).

S_{GW} for sea ice



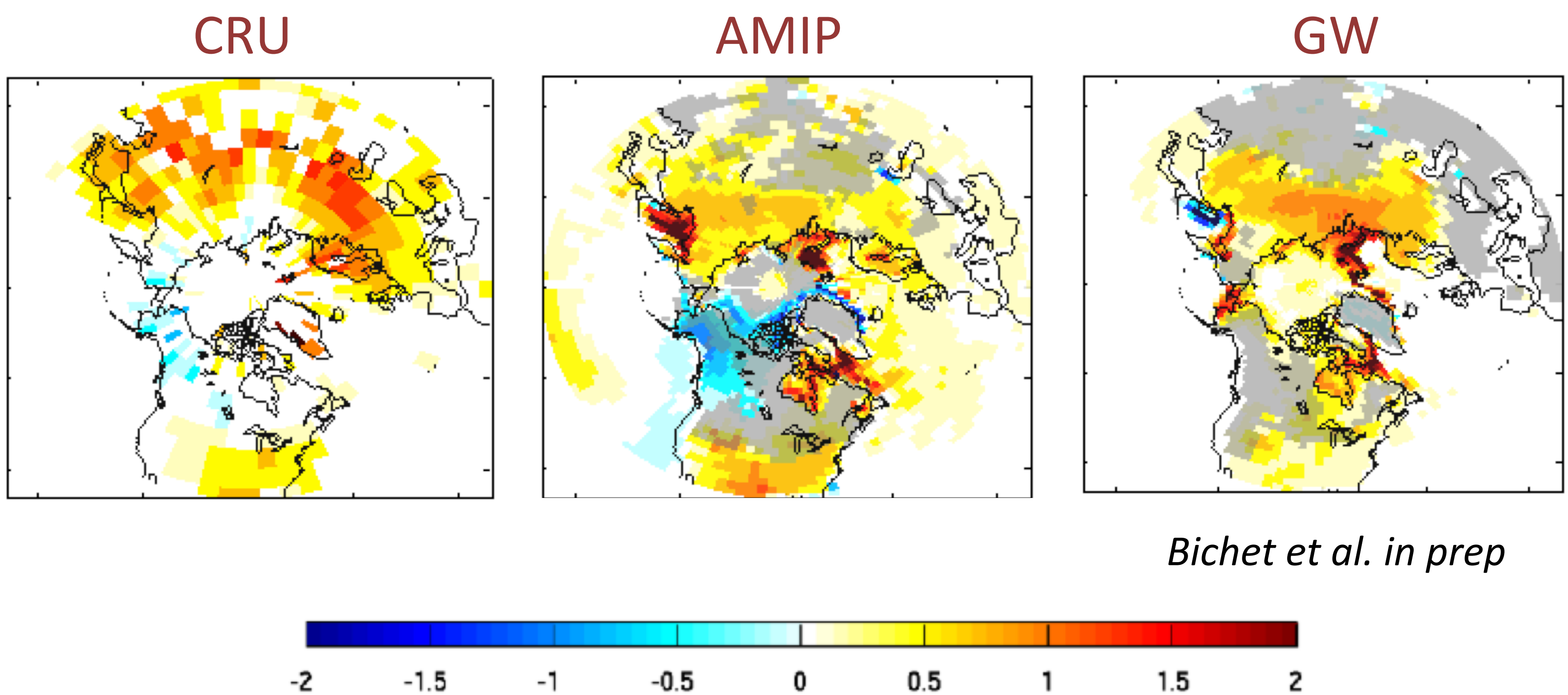
Using S_{GW} in Practice: AGCM Experiments

- CAM5, 2^0, 1980-2010, `historical` forcing, $N = 10$.
- **AMIP**: Observed SST and sea ice
- **GW**: Our estimate of GW SST and sea ice (S_{GW}).

★ We now survey regions and variables where

1. AMIP resembles observations and
2. Where trends are consistent across ensemble (signal-to-noise > 1).
   - Gray shading indicates signal-to-noise<1.
   - Trends aren't typically locally significant for this short period.

1980-2010 JFM Temperature



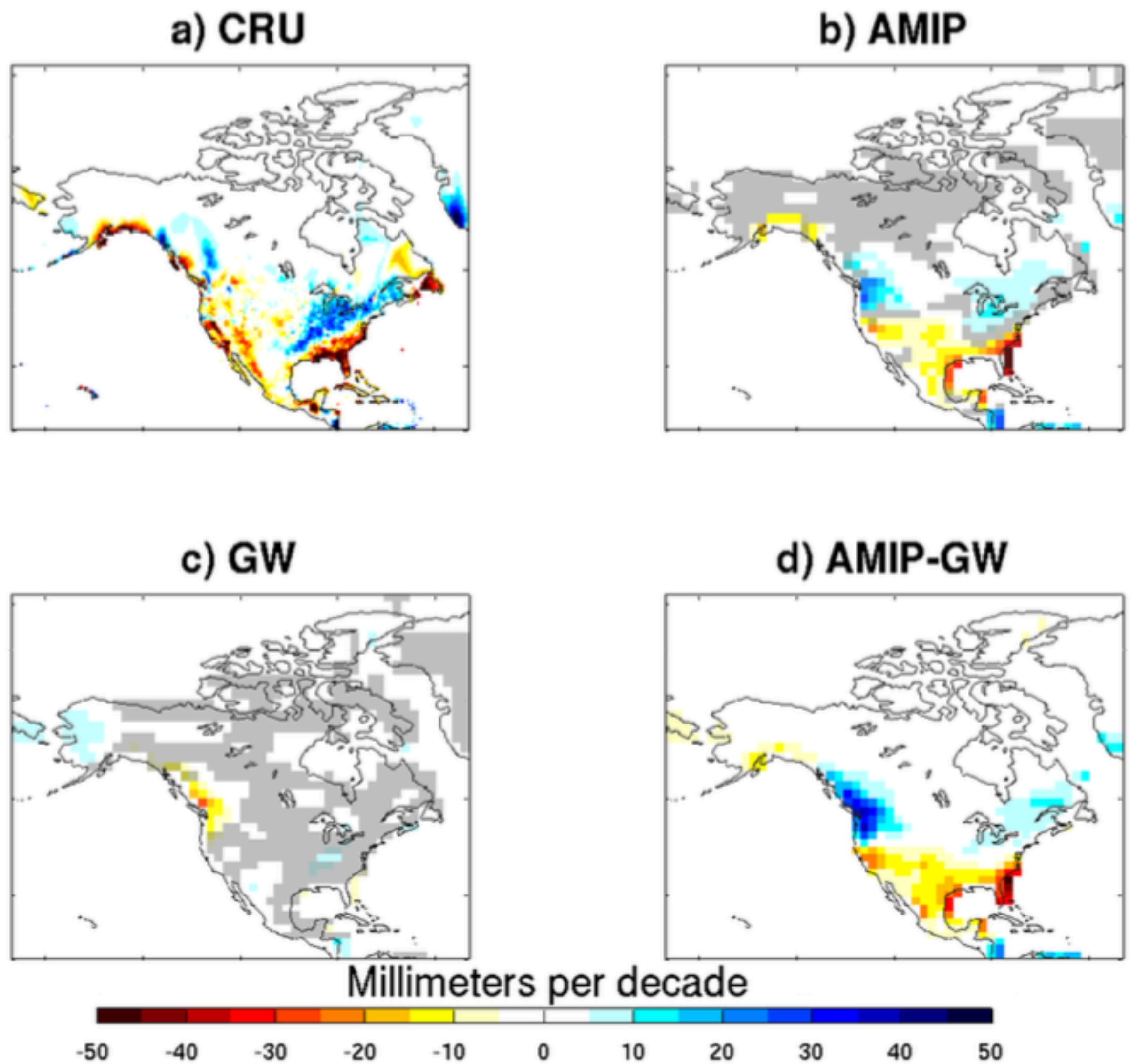
Bichet et al. in prep

- AMIP simulation captures basic obs pattern.
- GW signal shifts peak warming to central Eurasia
- Western North American cooling attributable to PDO-related East Pacific cooling.

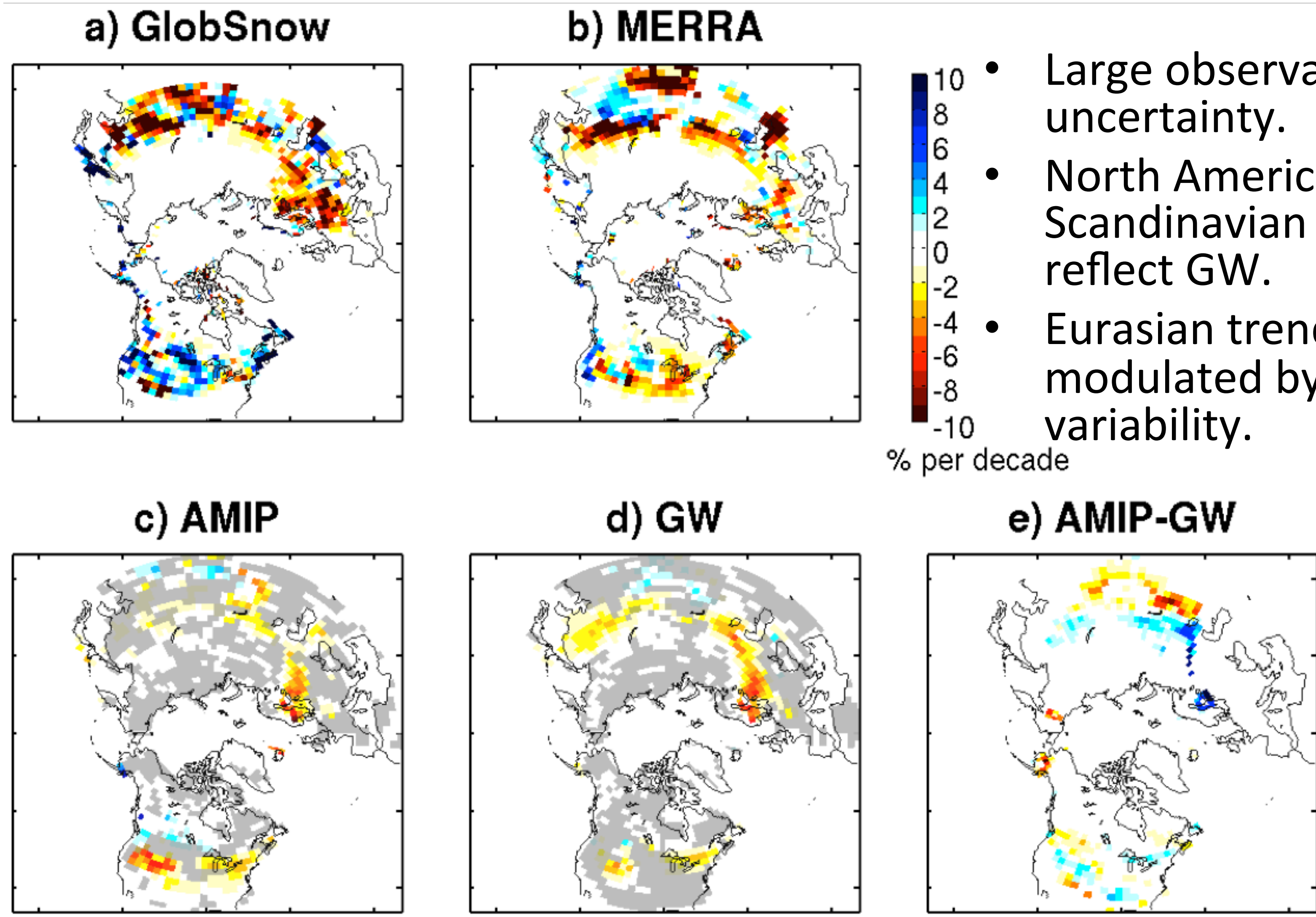
PDO = Pacific Decadal Oscillation

1980-2010 JFM Precipitation

- AMIP captures some of CRU.
- Internal variability, short-term forcing drive much of recent precip trend.



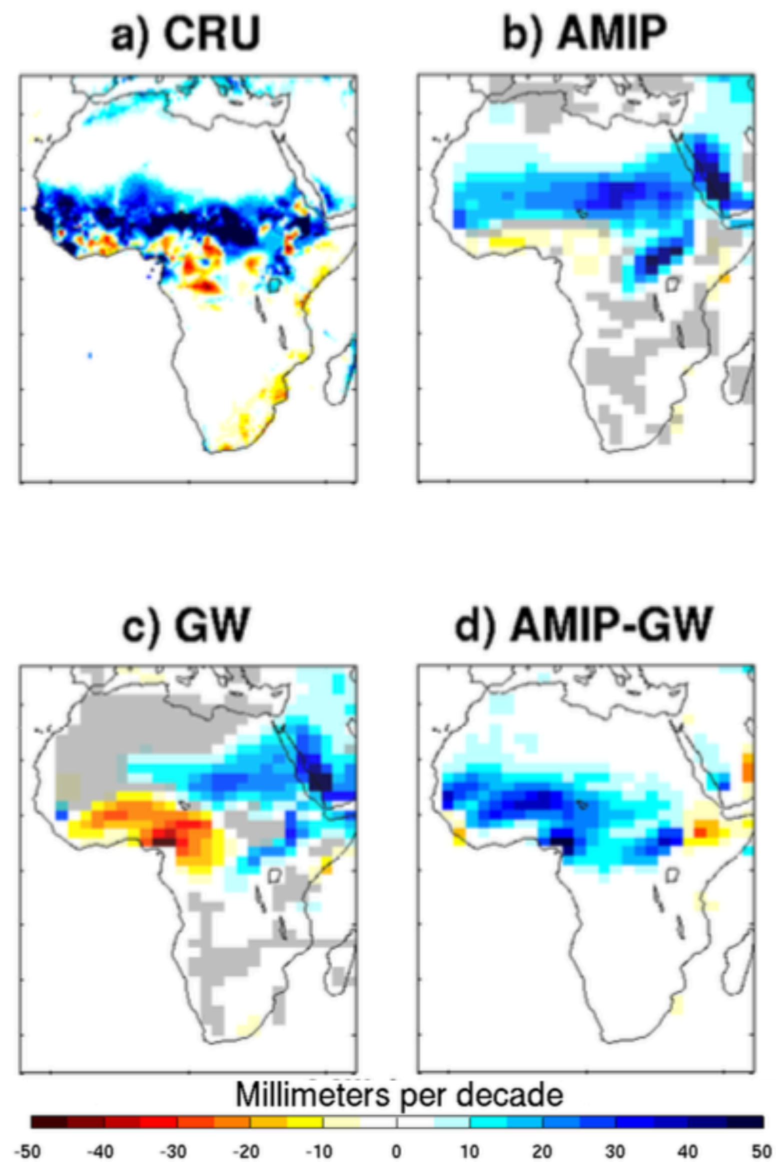
1980-2010 JFM Snow Cover Fraction



- Large observational uncertainty.
- North American and Scandinavian trends reflect GW.
- Eurasian trend modulated by internal variability.

1980-2010 JAS African Precip

- AMIP captures observed trends.
- Increase in precip in central Africa attributable to AMV+, whether forced or internal.
- GW signal in West Africa is a drying that opposes some of the AMV effect.

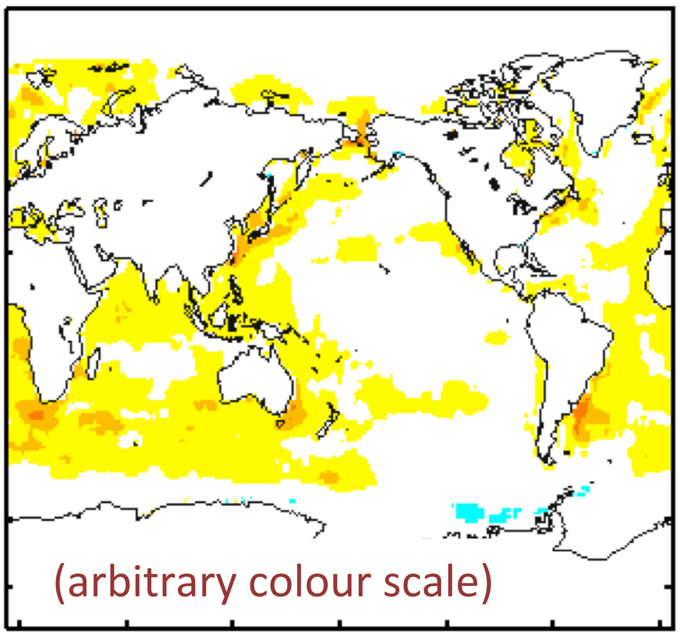


Summary

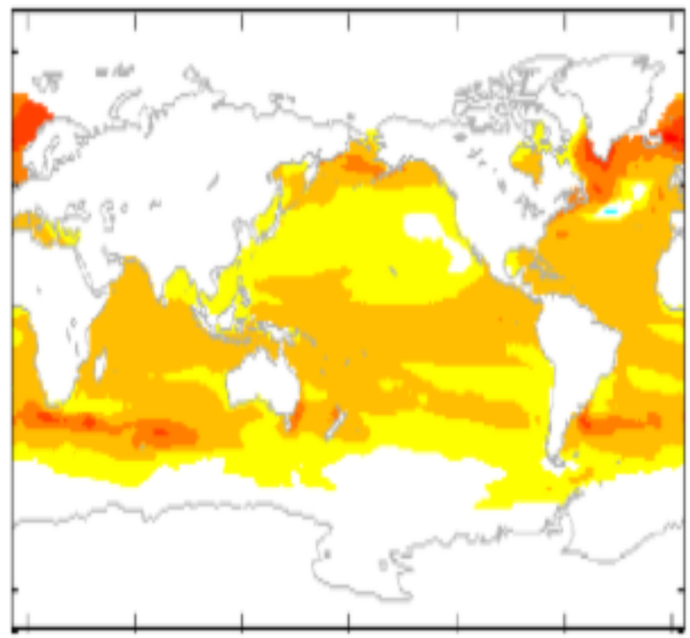
- We test and extend Hoerling et al.'s method to estimate the global warming part of SST variability in observations.
- We use the resulting S_{GW} in AGCMs to attribute regional responses in various regimes (high latitude temperature, snowcover, tropical precip, etc.)
- Much of the North American winter hydroclimate signal appears to be linked to PDO - internal variability.
- Recent wetting trends in sub-Sahel Africa run counter to long-term GW signal.

Why not use coupled models to estimate S_{GW}?

Hurrell SST S_{GW}



CMIP5 MMM S_{GW}



- CMIP5 multimodel mean S_{GW} is large in the tropics and the North Atlantic.
- It's quite distinctive from the pattern we get from obs.

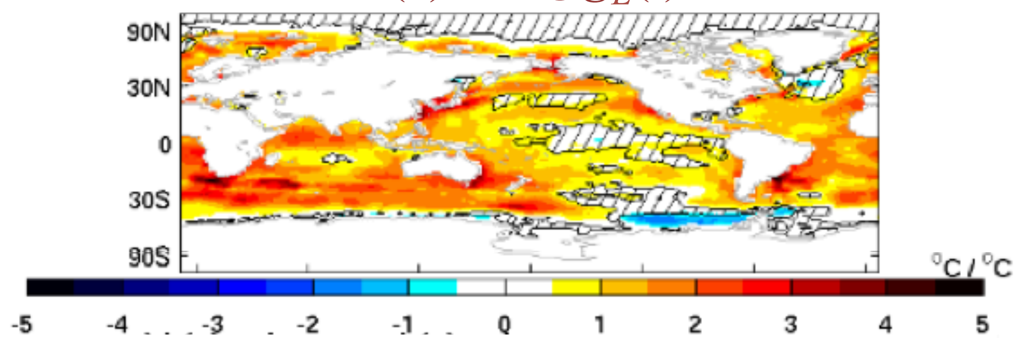
Key Points

- We can reliably estimate the observed pattern of long-term (>70 y) SST response to global warming.
- This pattern allows us to attribute GW related component of past hydroclimatic trends.
- We are also able to use the same method for regional climate projections of the forced component (Bichet, 5 p.m. Thursday)
- This pattern of observed long-term SST trends is different from those simulated in coupled ocean atmosphere models
- **There is a lot of insight to be gained on forced DCV from existing SST observations!**

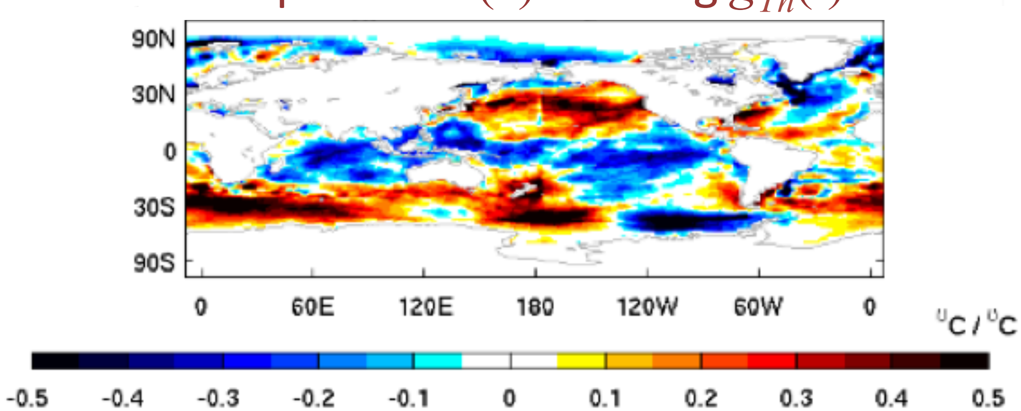
Extra Slides

Initial Tests of the Method

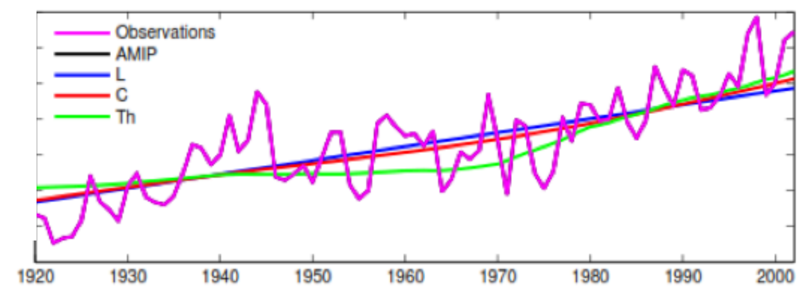
$h(x)$ using $g_L(t)$



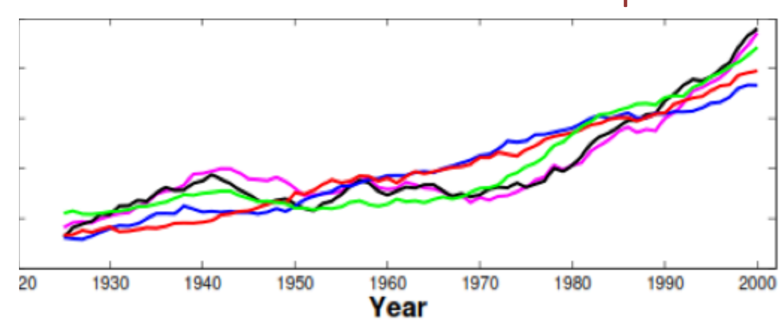
Impact on $h(x)$ of using $g_{Th}(t)$



Observed, Prescribed SST for Simulations



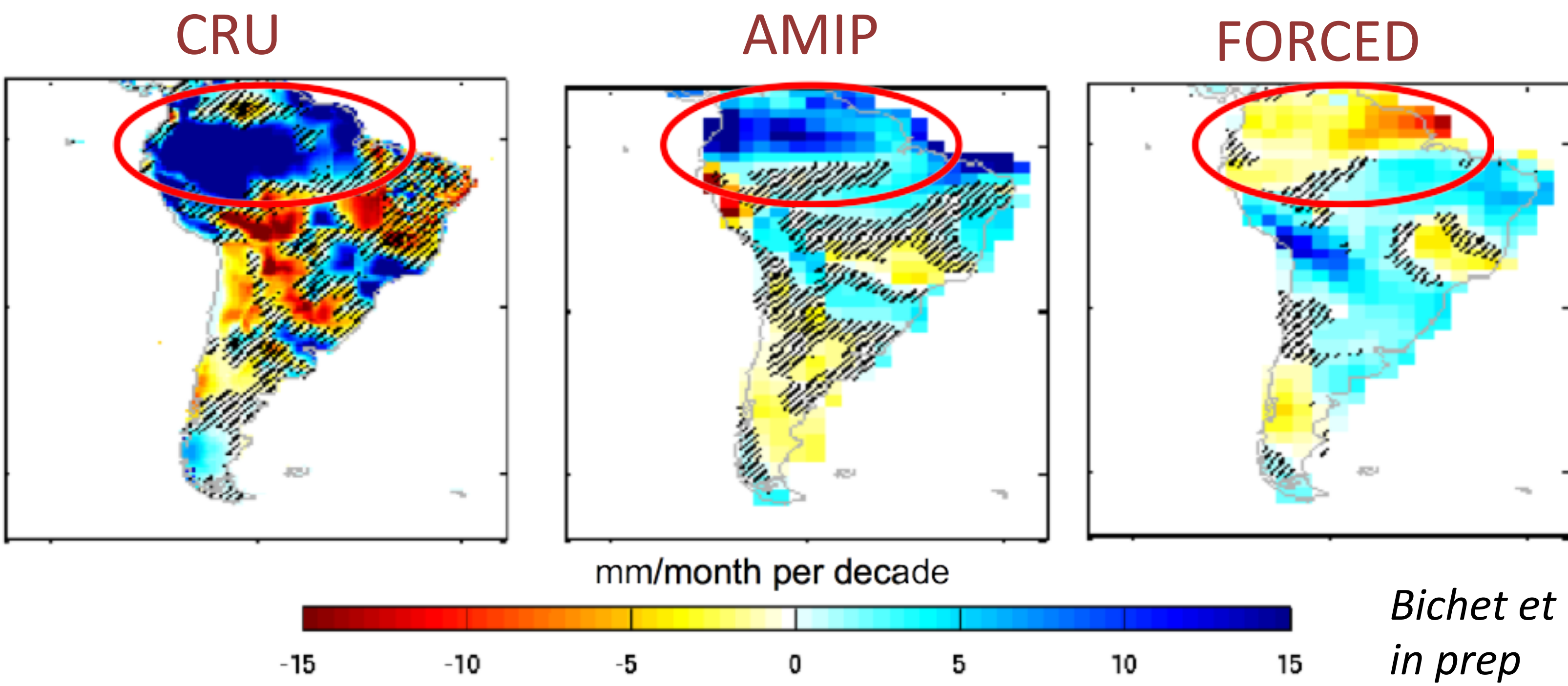
Observed and Predicted Land Temperatures



Bichet et al. 2015

- Spatial patterns obtained from different methods are similar.
- The gain factor affects the timing of the hydroclimate response to the SST forcing.

1980-2010 JFM Precipitation



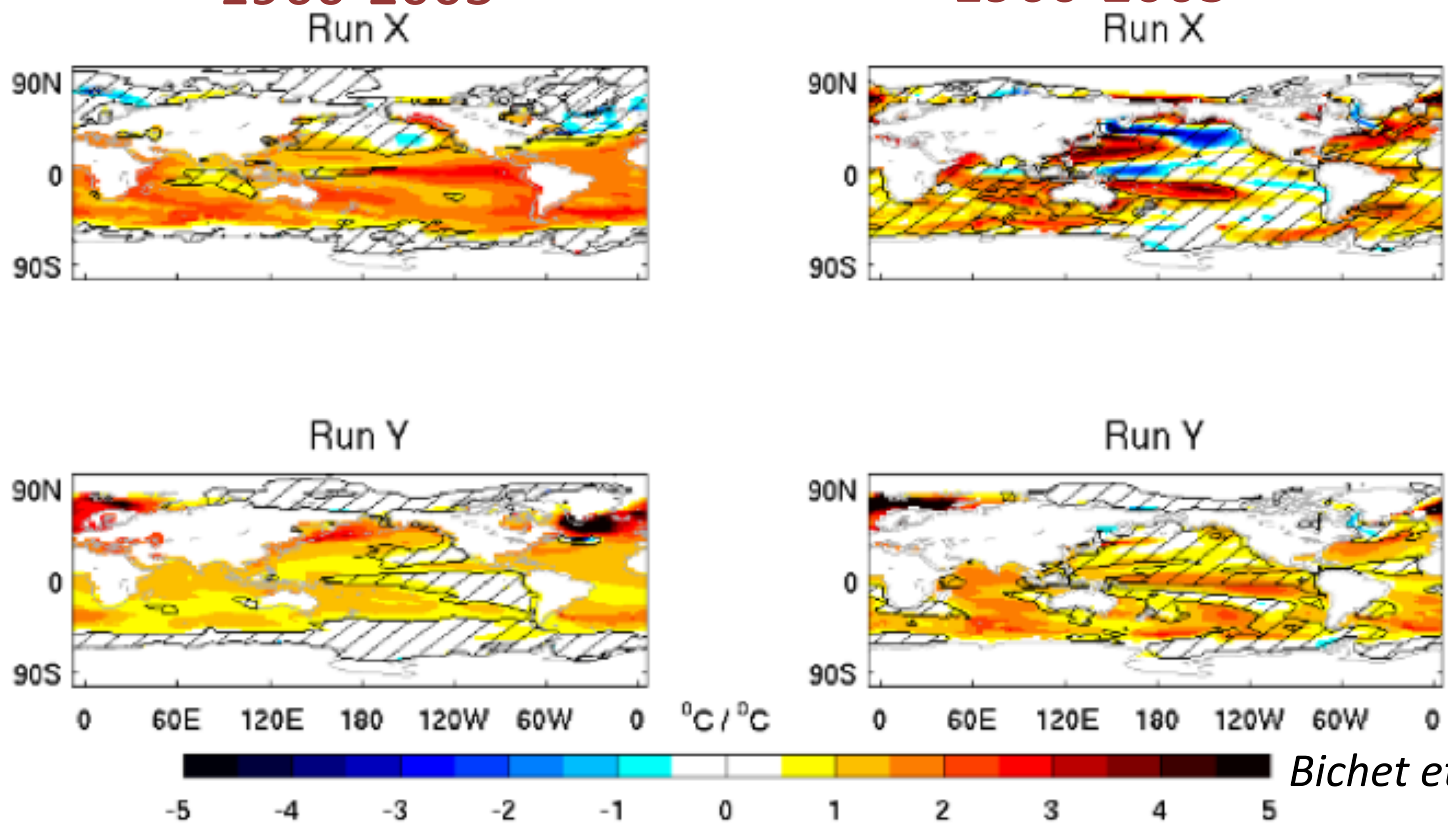
Bichet et al. in prep

- Increased precip in northern South America attributable to PDO-related variability.

Large Ensemble Evaluation of Method

$h(x)$, CCSM4 LENS 1960-2005

$h(x)$, CESM1 LENS 1960-2005



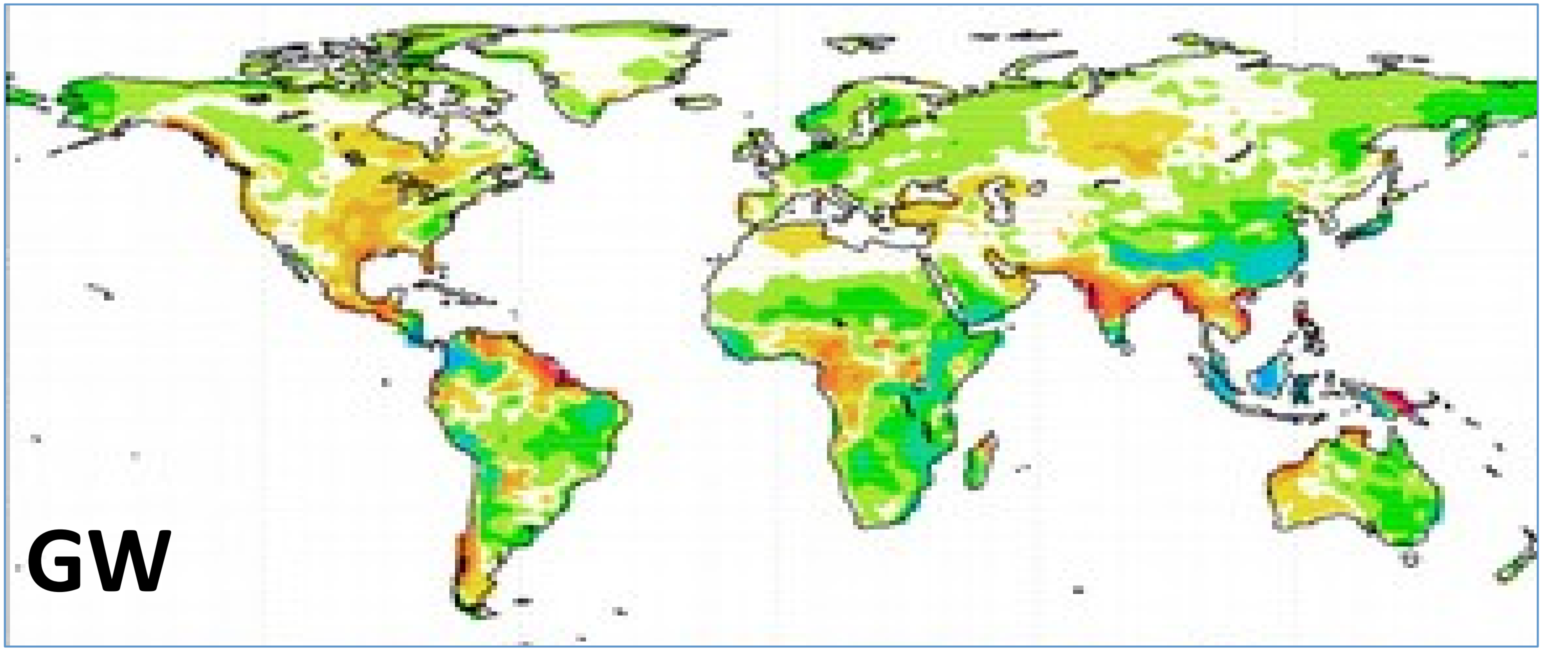
Bichet et al. 2015

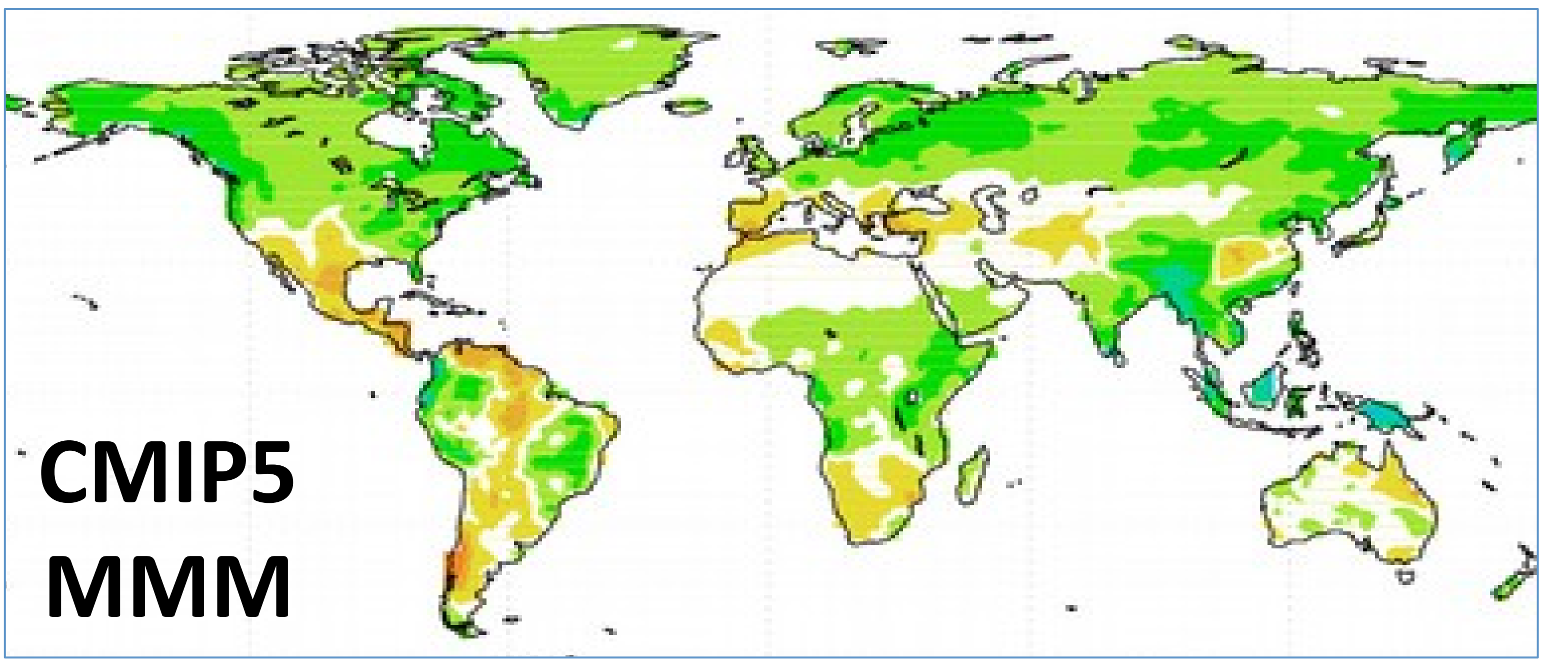
- Internal variability interferes with our ability to confidently estimate S_{GW} from observations.

Preliminary Results on Near Term Climate Projections

- We have extended the GW integrations to 2010-2040 and expect the forced trends to be quite similar to the past GW trends, by construction.
- The trends we obtain form an interesting point of comparison to CMIP5 trends.

ANN Precip 2010-2040

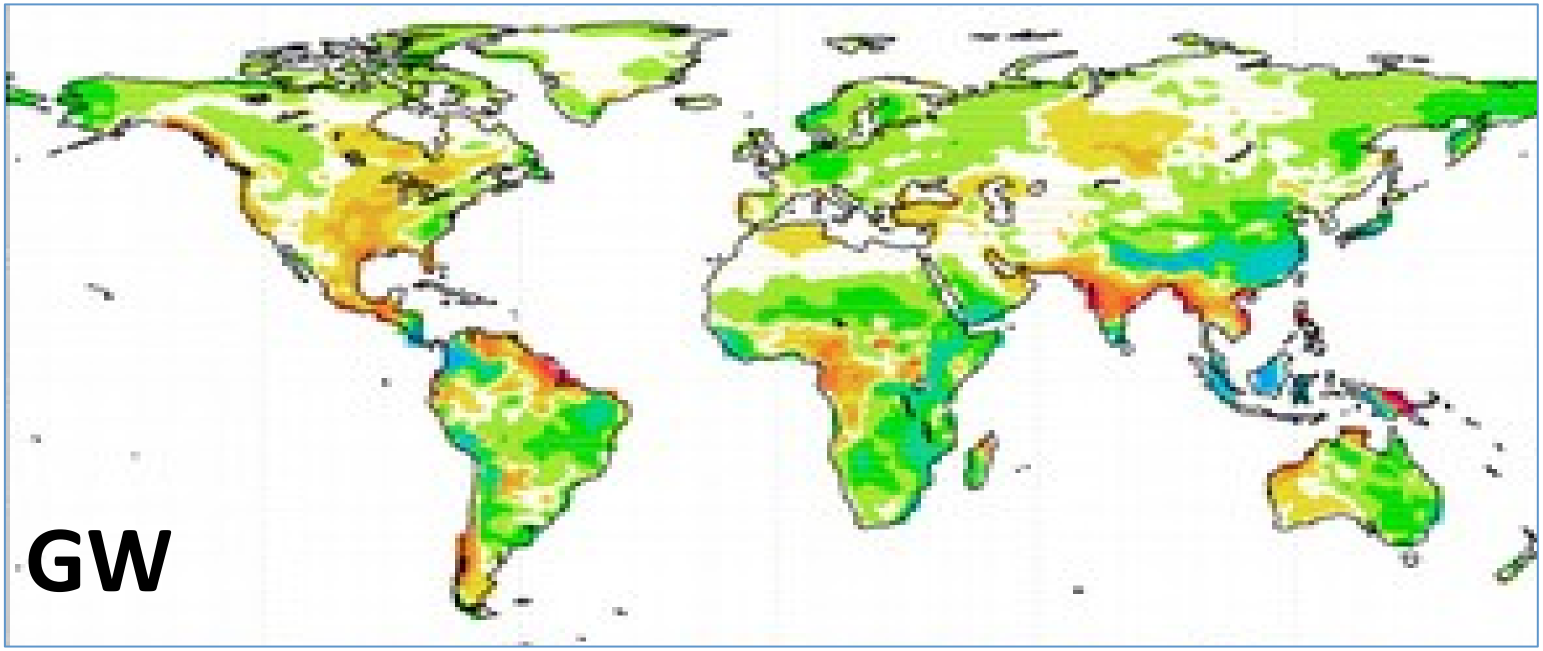


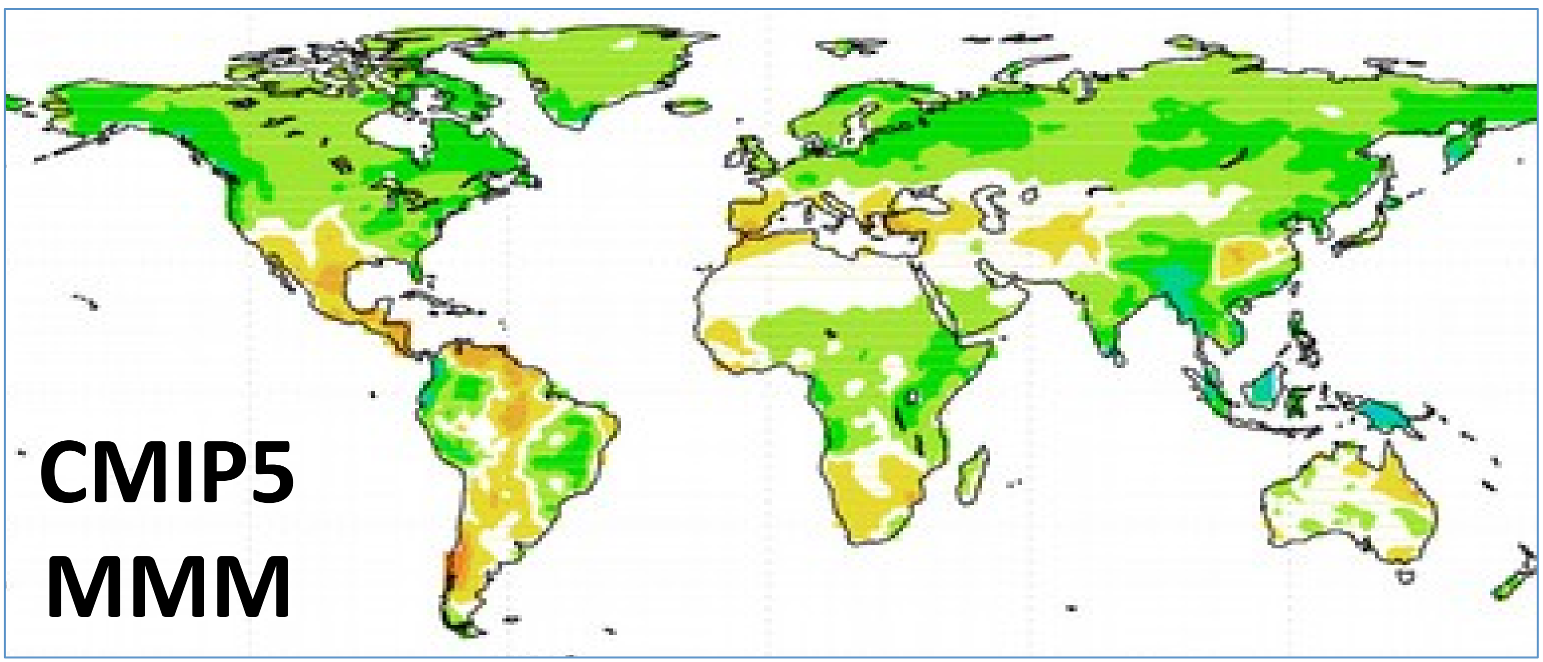


ANN Precip 2010-2040

GW v. CMIP5:

- More North American drying
- Less South American drying
- West African drying
- Indian subcontinent drying





Conclusion/Discussion

- The framework could help quantify how internal variability of SSTs in PDO and AMO interferes with the hydroclimate response to global warming.

- We can also tweak the *timing* of regional responses based on different $g(t)$.

- We are exploring this method for purposes of decadal prediction.

★ Extensions of framework: moving beyond prescribed SSTs, distinguishing different radiative forcings (ANT vs. historical), applying to other models (CanESM, etc.).