Estimating the Regional Response to Global Warming Using Pattern-Scaled SSTs

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Bichet et al. in press, J. Climate; and in prep.

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

• Motivation, method, and method evaluation
• Survey of applications to regional hydroclimate
Sea Surface Temperature (SST) Trends

1950-1980

1980-2010

• AMIP framework gives good sense of the ocean’s impact on continental climate.

• Is there a global warming pattern in SSTs, separable from internal variability and short-term forcing?

• Can this pattern be used to drive AGCMs for physical attribution and hydroclimate prediction?
Approach: Estimate and Use the Global Warming Signal in SST/Sea Ice

1. Estimate SST/sea ice change coherent with global warming from observations using pattern scaling (Hoerling et al. 2010): “$S_{GW}$”

2. Evaluate the quality of this estimate using the CESM large ensemble (Bichet et al. in press).

3. Assess regional impacts on simulations driven with the observational $S_{GW}$ (Bichet et al. in prep).
Method Description and Evaluation
• Observed SST decomposed into forced and internal parts:
  \[ S(x,t) = S_{GW} + S_{\text{residual}} \]
  
  \[ S_{GW} \] modelled as time-independent pattern \( h(x) \) scaled by time-dependent gain \( g(t) \):
  \[ S_{GW} \approx h(x) g(t) \]

• \( g(t) \) is derived from global mean observed SST (HadCRU, starting from 1900)
  – Linear, cubic and Thompson et al. methods tested ... Cubic used.

\[ \begin{align*}
  1900 & \quad 1950 & \quad 2000 \\
  \text{Thompson et al. 2009} & \quad \text{Cubic from obs} & \quad \text{Cubic from CMIP5} \end{align*} \]

• \( h(x) \): regression of Hurrell SST/SICE on \( g(t) \)
Using Large Ensembles as a Testbed

- 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 $S_{GW}$.

_Bichet et al. in press_
Shown are the linear 1980-2010 SST trends for $S$ and $S_{GW}$, updated from Bichet et al. in press.

By construction, net SST warming is similar, but $S_{GW}$ redistributes it into SH, removes structures like PDO.
Application to Regional Climate

- CAM5, $2^0$, 1980-2010, historical forcing, $N=10$.
- **AMIP**: Observed SST and sea ice ($S$)
- **GW**: Our estimate of forced SST and sea ice ($S_{GW}$) using cubic $g(t)$ to calculate $h(x)$

★ We highlight regions where 1) AMIP resembles observations and 2) where trends are consistently reproducible in the simulations (trends aren’t significant for this short period).
1980-2010 JFM Temperature

- AMIP simulation seems to capture basic obs pattern.
- Forced signal shifts peak warming to central Eurasia
- Western North American cooling attributable to internal variability: PDO-related East Pacific cooling.

Hatching represents “low-threshold” significance test.

°C per decade

Bichet et al. in prep
• Southwestern U.S. snowcover decrease linked to global warming.
• Western Canada/U.S. increase attributable to internal PDO-related variability.
Southwestern wintertime precip reduction and northwestern increase attributable to internal PDO variability.

Bichet et al. in prep
1980-2010 JAS African Precip

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

Shading here represents signal to noise measure.

Bichet et al. in prep
Conclusion/Discussion

• We test and extend Hoerling et al.’s (2011) 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 internal linked to PDO - internal variability.
  – Recent wetting trends in sub-Saharan Africa run counter to long-term GW signal.
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.).
1980-2010 AMJ Snow Water Equivalent

- Much of spring SWE trend in North America probably also reflects internal variability.

*AMIP* GW

*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

- Internal variability interferes with our ability to confidently estimate $S_{GW}$ from observations.
1980-2010 JFM SLP

- Part of anomalous northerly flow over Western Arctic is possibly forced.

Bichet et al. in prep
Shown are the linear sea ice trends for $S$ and $S_{GW}$.

$h(x)$ comes from regressing $g(t)$ on Hurrell sea ice.

Forced sea ice ice trends are positive and weak.
Method assessment

- **Obs** $p(x)$ show more spatial structure than CMIP5 $p(x)$:
  - **Similarities**: Warmer western boundary currents (SH), Bering Sea, and North Sea
  - **Differences**: Tropical Pacific Ocean and Kuroshio current
Method assessment

CMIP5 $p(x)$ vs. Obs $p(x)$

- Individual CMIP5 models $p(x)$ show:
  - large spread in standard deviations
  - poor correlation with Obs $p(x)$

- CMIP5 multimodel mean $p(x)$ show poor correlation with Obs $p(x)$: $\sim 0.4$
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- Including indirect aerosol effects does not improve the comparison
Results: Attribution of snow trends at high northern latitudes

- Attribute parts of recent increase in JFM sea level pressure over North Pacific (AMIP) to oceanic internal variability
- Resemble PDO<0 pattern, fit with SST