Advancing Teleconnection Simulations

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Newman et al. (2016)

PDO in the CMIP5 historical runs, we fit each PDO time series with the extended AR1 model:

$$\text{PDO}(n) = r \text{PDO}(n-1) + a \text{ENSO1}(n) + b \text{ENSO2}(n) + \epsilon(n),$$

where $\text{PDO}$ is the PDO time series, $\text{ENSO1}$ and $\text{ENSO2}$ are the time coefficients of the leading two EOFs of tropical Pacific ($20^\circ S$–$20^\circ N$) SSTAs, $\epsilon$ is white noise, and $n$ is the time step. This model, estimated for detrended and normalized annual mean time series averaged from $F_{IG}$. The PDO over the historical record as simulated by coupled CGCMs. (a),(b) As in Fig. 1a,b. Shown are two selected members of the historical CMIP5 ensemble that are (a) closest and (b) farthest from the reference pattern in Fig. 2. (c),(d) As in (a),(b), but showing two selected members of the CESM-LE that are (c) closest and (d) farthest from the reference pattern in Fig. 2. (e) PDO times series from all ensemble members; all time series are smoothed with the Zhang et al. (1997) filter (used in Fig. 1c). Thin gray lines represent each ensemble member, the thin black solid (dashed) line in the CMIP5 panel represents model A (B), and the thick black line is the ensemble mean for each set of models.

a), b): PDO spatial structure in CMIP5 models closest to, farthest from observations.

c), d): Same as a), b) for members of the CESM Large Ensemble.

Issue: both structural, internal differences matter to teleconnections.
SLP composites during DJF of El Niño peak: CMIP5 historical, RCP4.5 projections

CMIP5 projections: shift in location of ENSO teleconnections

20th century (historical)

21st century (RCP 4.5)
Left: Regression of temperature onto NINO3.4 index in the CESM Large Ensemble (Kay et al. 2015)

Right: change in the regression coefficient between 2040-2100 and 1920-1980

Fasullo, Otto-Bliesner, & Stevenson 2017, Nature Climate Change, in revision
No agreement on future changes in ENSO amplitude

Running 20-year NINO3.4 variance, RCP8.5

Community Earth System Model (NCAR)

Earth System Model 2M (NOAA GFDL)

Fasullo, Otto-Bliesner, & Stevenson 2017, Nature Climate Change, in revision
CESM: differential ENSO response to anthropogenic forcings

2S-2N SST vs. lon, time: 0 = January of peak year
PI = 850-1849
20th c. = 1850-2005

Stevenson et al. (2017), Climate Dynamics
What new simulations and observations are needed to improve understanding of teleconnections in climate models?
### Simulations planned for CMIP6 (DECK)

<table>
<thead>
<tr>
<th>Experiment short name</th>
<th>CMIP6 label</th>
<th>Experiment description</th>
<th>Forcing methods</th>
<th>Start year</th>
<th>End year</th>
<th>Minimum no. years per simulation</th>
<th>Major purpose</th>
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<tr>
<td><strong>DECK experiments</strong></td>
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<tr>
<td>AMIP</td>
<td>amip</td>
<td>Observed SSTs and SICs prescribed</td>
<td>All; CO₂ concentration prescribed</td>
<td>1979</td>
<td>2014</td>
<td>36</td>
<td>Evaluation, variability</td>
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<td>Pre-industrial control</td>
<td>piControl or esm-piControl</td>
<td>Coupled atmosphere–ocean pre-industrial control</td>
<td>CO₂ concentration prescribed or calculated</td>
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<td>n/a</td>
<td>500</td>
<td>Evaluation, unforced variability</td>
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<tr>
<td>Abrupt quadrupling of CO₂ concentration</td>
<td>abrupt-4×CO₂</td>
<td>CO₂ abruptly quadrupled and then held constant</td>
<td>CO₂ concentration prescribed</td>
<td>n/a</td>
<td>n/a</td>
<td>150</td>
<td>Climate sensitivity, feedback, fast responses</td>
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<tr>
<td>1 % yr⁻¹ CO₂ concentration increase</td>
<td>lpctCO2</td>
<td>CO₂ prescribed to increase at 1 % yr⁻¹</td>
<td>CO₂ concentration prescribed</td>
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<td>n/a</td>
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<td>Climate sensitivity, feedback, idealized benchmark</td>
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<td><strong>CMIP6 historical simulation</strong></td>
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<tr>
<td>Past ~ 1.5 centuries</td>
<td>historical or esm-hist</td>
<td>Simulation of the recent past</td>
<td>All; CO₂ concentration prescribed or calculated</td>
<td>1850</td>
<td>2014</td>
<td>165</td>
<td>Evaluation</td>
</tr>
</tbody>
</table>
CMIP6: also supports “sub-MIPs” with specific scientific targets

These GCs will be using the full spectrum of observational, modelling and analytical expertise across the WCRP, and in terms of modelling most GCs will address their specific science questions through a hierarchy of numerical models of different complexities. Global coupled models obviously constitute an essential element of this hierarchy, and CMIP6 experiments will play a prominent role across all GCs by helping to answer the following three CMIP6 science questions: How does the Earth system respond to forcing? What are the origins and consequences of systematic model biases? How can we assess future climate change given internal climate variability, climate predictability, and uncertainties in scenarios?

These three questions will be at the centre of CMIP6. Science topics related specifically to CMIP6 will be addressed through a range of CMIP6-Endorsed MIPs that are organized by the respective communities and overseen by the CMIP Panel (Fig. 2). Through these different MIPs and their connection to the GCs, the goal is to fill some of the main scientific gaps of previous CMIP phases. This includes, in particular, facilitating the identification and interpretation of model systematic errors, improving the estimate of radiative forcings in past and future climate change simulations, facilitating the identification of robust climate responses to aerosol forcing during the historical period, better accounting of the impact of short-term forcing agents and land use on climate, better understanding the mechanisms of decadal climate variability, along with many other issues not addressed satisfactorily in CMIP5 (Stouffer et al., 2015). In endorsing a number of these MIPs, the CMIP Panel acted to minimize overlaps among the MIPs and to reduce the burden on modelling groups, while maximizing the scientific complementarity and synergy among the different MIPs.

4.2 The CMIP6-Endorsed MIPs

Close to 30 suggestions for CMIP6 MIPs have been received so far, of which 21 MIPs were eventually endorsed and invited to participate (Table 3). Of those not selected some were asked to work with other proposed MIPs with overlapping science goals and objectives. Of the 21 CMIP6-Endorsed MIPs, 4 are diagnostic in nature, which means that they define and analyse additional output, but do not require additional experiments. In the remaining 17 MIPs, a total of around 190 experiments have been proposed resulting in 40,000 model simulation years with around half of these in Tier 1. The CMIP6-Endorsed MIPs show broad coverage and distribution across the three CMIP6 science questions, and all are linked to the WCRP Grand Science Challenges (Fig. 3).

Each of the 21 CMIP6-Endorsed MIPs is described in a separate invited contribution to this special issue. These contributions will detail the goal of the MIP and the major scientific gaps the MIP is addressing, and will specify what is new compared to CMIP5 and previous CMIP phases. The contributions will include a description of the experimental design and scientific justification of each of the experiments for Tier 1 (and possibly beyond), and will link the experiments and analysis to the DECK and CMIP6 historical simulations. They will additionally include an analysis plan to fully justify the resources used to produce the various requested variables, and if the analysis plan is to compare model results to observations, the contribution will highlight possible model diagnostics and performance metrics specifying whether the comparison entails any particular requirement for the simulations or outputs (e.g. the use of observational simulators). In addition, possible observations and reanalysis products for model evaluation are discussed and the MIPs are encouraged to help facilitate their use by contributing them to the obs4MIPs/ana4MIPs archives at the ESGF (see Sect. 3.3). In some MIPs, additional forcings beyond those used in the DECK and CMIP6 historical simulations are required, and these are described in the respective contribution as well.
CMIP6: also supports “sub-MIPs” with specific scientific targets

- **Aerosols & Chemistry MIP**
  - AerChemMIP
  - C4MIP
  - CFMIP
  - DAMIP
  - DCPP
  - FAFMIP
  - GeoMIP

- **Global Monsoons MIP**
  - GMMIP
  - HighResMIP
  - ISMIP6

- **Land Surface, Snow and Soil Moisture MIP**
  - LS3MIP
  - LUMIP
  - OMIP
  - PMIP

- **Radiative Forcing MIP**
  - RFMIP
  - ScenarioMIP
  - VoMIP

- **Dynamics & Variability MIP**
  - CORDEX
  - DynVarMIP
  - SIMIP
  - VIACS AB
Major feedbacks relevant to the ENSO cycle

(a) Atmos. Bjerknes feedback

(b) Surf. Fluxes feedback

(c) Shortwave feedback

Bjerknes: sensitivity of SST to wind stress

Surf. fluxes: damping of SST by latent heat flux

Shortwave feedback: damping of SST by shortwave fluxes

Bellenger et al. (2014)
Important observational target: air-sea fluxes

Off-equatorial air/sea fluxes in precursor regions

Precise mooring locations to be determined during the evolution

Near-equatorial moorings (2°S, Eq, 2°N)

Red shading indicates TMA
Blue shading indicates Argo (enhanced 10°S-10°N)

The eventual configuration of the sustained moored and Argo networks. Red shading indicates TMA moorings, blue indicates Argo, enhanced within 10°S-10°N (darker blue shading; section 7.4.3). The reconfigured TMA consists of near-equatorial sites (broad red stripe centered on the equator), plus several extensions to cross the ITCZ and SPCZ (section 7.4.4.4). Precise sites are “fuzzy” (green shading) in some details, for example, how far north and south the extensions will go and whether the SPCZ line will be along 165°E or along 180°. Two extra moorings at 1°S and 1°N will increase the equator-spanning meridional resolution at 140°W (bright red square; section 7.4.4.1).

The focus of the future TMA sampling should be shifted up toward the near-surface layer. More capable moorings will:

a. include more complete measurements of air-sea flux variables;

b. enhance sampling of the rapidly-varying mixed layer, including some near-surface velocity; and

c. reduce temperature sampling below 300 m, except on the equator.

Argo

The observational requirements outlined in section 5.9 and addressed by Recommendation 17 demand a doubling of the number of Argo profiles in the 10°S-10°N band. As discussed below, this implementation will be staged; there will also be specific actions targeting improved resolution in the equatorial region. Within the staged increase of Argo density, some increases are designed to compensate for loss of subsurface data where the TMA is or will be reduced (see above), to ensure that subsurface sampling provides:

a. seamless or improved subsurface data for assimilation and forecast systems; and

b. continuation of credible climate records of subsurface conditions.
CESM: zonal SST gradient weakens, vertical stratification increases.

ESM2M: zonal SST gradient strengthens, vertical stratification doesn’t increase as much as CESM.

Stevenson et al. (2017b), in prep.
Nonlinear zonal advection: anomalous advection of anomalous gradient

**NINO3**: Eastern Pacific El Niño

\[-u' \cdot \nabla T'.\]
Also critical: improving long-term 20th c. estimates

3. Results

3.1. Data Coverage

In order to discriminate between secular climate change and naturally occurring multi-decadal variability, it is important to consider as long a period of record as possible. Seeking a balance between adequate data coverage (see Figure S1 in the auxiliary material) and length of record, we have examined SST trends using a variety of start dates (1900, 1910 and 1920) and data sampling thresholds; all of the results discussed below are robust to the different choices.

In the figures that follow, we show trend maps based on the period 1900–2008 using a 3 month per decade threshold; trends based on 1920–2008 using a 24 month per decade threshold are shown in Figure S2 of the auxiliary material. We emphasize that although our sampling criterion is lenient, we rely on additional factors such as regional coherency (note that no additional spatial smoothing has been applied to any of the data sets) and consistency with independently measured marine air temperatures to assess the reality of the SST trends.

3.2. Global SST Trends

The 20th century SST trend distributions from the 5 different data sets are compared in Figure 1 for the period 1900 to 2008 (2002 for Minobe/Maeda, the latest year available), along with air temperature trends based on HadCRUTv3 over land and MOHMAT4 over the oceans for the period 1900 to 2005 (the latest year available). The SST trends from the uninterpolated HadSST2 and Minobe/Maeda archives are similar, exhibiting positive values everywhere except the western portion of the northern North Atlantic. The largest warming trends (approximately 1.2–1.6°C per century) occur directly east of the continents in the northern hemisphere, in the Southern Ocean and the eastern tropical Atlantic. The eastern tropical Pacific warms by approximately 0.8–1.0°C per century, similar in magnitude to the tropical Indian Ocean and the central tropical Atlantic.

Figure 1. Twentieth century SST trends (°C per century) computed from monthly anomalies since 1900 for various data sets as indicated. White grid boxes denote insufficient data, and gray boxes indicate trends that are not statistically significant at the 95% confidence level. See text for additional information.

Auxiliary materials are available in the HTML. doi:10.1029/2010GL043321.

Deser et al. (2010)
Paleoclimate: key piece of the puzzle

Cook et al. (2015)

or modern period, considerably adding to the previous report of an MCA megadrought in southern Finland (29), and it now more completely defines the spatial pattern and extent of dryness during that time.

In contrast, the Romania and Ukraine regions of eastern Europe have more similar patterns of dryness, and northern Fennoscandia and Russia have more similar patterns of wetness, in all three epochs. Notably, the overall timing of MCA dryness in north-central Europe is consistent with that described for large areas of North America (26, 27) (see later discussion).

A summary of the history of drought and wetness since 870 CE in the core region of Old World MCA drought (Fig. 3A, yellow rectangle) is presented in Fig. 3B. The overall mean ± 1σ error is −0.44 ± 0.04 scPDSI units from the expected mean of zero for the 1928–1978 calibration period, which reflects the general tendency for drier conditions in the preindustrial past. In contrast, the most recent period (1998–2012) has been anomalously wet (+0.97 ± 0.24). It is necessary to go back to 1721–1739 to find a wetter period of comparable duration (+1.55 ± 0.24). As a relative index of drought, scPDSI has a high degree of spatial comparability across a broad range of precipitation climatologies (30). This allows us to compare this drought to another reconstructed megadrought occurring at around the same time in western North America (26).

The 1000–1200 CE megadrought over north-central Europe has a reconstructed mean of −0.72 ± 0.10 scPDSI units. By comparison, the worst megadrought in the California and Nevada regions of the NADA (26) lasted from 832 to 1074 CE (−0.84 ± 0.09, calculated after adjusting the mean of the California/Nevada series to match that of the north-central Europe series over their 870–2005 common interval). Thus, in terms of relative dryness as modeled by the scPDSI, this MCA megadrought in the OWDA is comparable to one of the more exceptional MCA megadroughts in the NADA.

Besides the MCA, Fig. 3B also reveals the occurrence of a mid-15th-century megadrought in north-central Europe. The most intense drought phase lasted for 37 years from 1437 to 1473 CE (−1.84 ± 0.20), with only two isolated years of positive scPDSI. The timing of this megadrought is similar to that of the worst drought reconstructed to have occurred over the past 1000 years in the southeastern United States (27). This suggests the existence of some common hydroclimate forcing across the North Atlantic, perhaps related to Atlantic Ocean sea surface temperature variations and/or the North Atlantic Oscillation (31, 32).

Finally, a third megadrought occurred from 1779 to 1827 (−1.34 ± 0.16). This period has as a period of "major long-duration drought" (33) from 1798 to 1808 (−1.89 ± 0.38) in England and Wales identified from early instrumental NADA records.
Paleoclimate: key piece of the puzzle

![Map and graph showing correlation and SST anomalies over time]

- Significant correlations between our ENSO reconstruction and tropical records.
- Marked decadal variability in Indo-Pacific regions.
- SST anomalies relative to the mean of observed SSTs during 1971–2000.
- Data from 1300 to 2005 with a focus on interannual to interdecadal timescales.

Li et al. (2013)
21st c. teleconnected responses governed by changes to modal amplitude, atmospheric responses to SST variability

- Some teleconnection responses are robust across models (El Nino impacts), some may not be
- Anthropogenic forcing is extremely complex, implemented differently across models: e.g. details of land-use changes, aerosol microphysics
- CMIP6-endorsed MIPs may help clarify some issues, as may observational process studies