TECHNICAL NOTE FOR DCPP-Component C

I. Definition of the Anomalous Sea Surface Temperature patterns

This short note documents in detail the suite of steps that have been followed to produce the anomalous sea surface temperature (SST) patterns from observations, which are representative of the Atlantic Multidecadal Variability and the Interdecadal Pacific Variability (hereafter AMV and IPV, respectively), and that are subsequently used in DCPP-Component C idealized model experiments.

1-Methodology

All the SST patterns have been extracted from the latest version of the Extended Reconstructed SST dataset (ERSSTv4, Huang et al 2016). Data are available at https://www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst-v4 . The steps to get the patterns are listed below:

1.1 Definition of the externally-forced component in observed SST

The AMV and IPV anomalies that are imposed in the proposed experiments correspond to an estimation of the internal component of the observed decadal variability. To get them, the externally forced signal, both natural (solar+volcanoes) and anthropogenic (GHG and aerosols), must be *a priori* removed and there is no unique way to estimate it. Here we follow the approach proposed by Ting et al (2009) that uses a signal-to-noise maximizing EOF analysis applied to global annual mean SST derived from the CMIP5 multi-model ensemble. Historical simulations and Representation Concentration Pathway 8.5 (RCP8.5) simulations are used for the 1870-2005 and the 2006-2013 periods, respectively. The principal component associated with the leading global signal-to-noise EOF corresponds to the annual temporal evolution of the radiatively forced component of the SST ($PC1_{for}$, Fig.1a). The spatial pattern of the forced component of the observed SST (SST_{for}, Fig 1b) is obtained by regressing the observed global annual SST onto $PC1_{for}$ (Fig.1b). The whole 1870-2013 period is used to estimate the externally forced component.

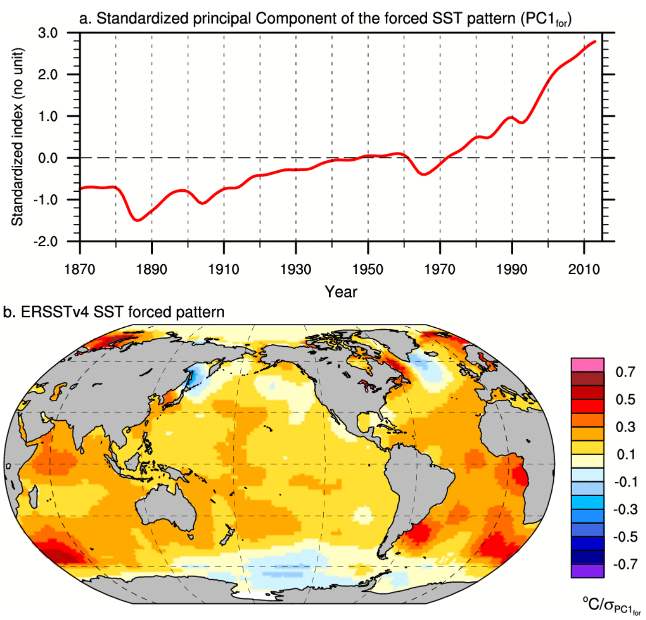

Figure 1: a. *Standardized principal component of the leading signal-to-noise EOF ($PC1_{for}$) computed from ERSSTv4 SST over 1870-2013 following Ting et al (2009) protocol.* ***b.*** *ERSSTv4 regressed SST pattern on $PC1_{for}$. Contour interval is $0.1^oC/\sigma$.*

1-2. Definition of the AMV and IPV internal components

The time series associated to the AMV and IPV patterns are defined as residuals of the forced components over the 1870-2013 period. The AMV and IPV SST patterns are then obtained by regression using the sub period of 1900-2013 during which observations are more reliable. The detailed procedure is described below:

<u>a) AMV patterns</u>

- Subtraction of the forced component from annual mean raw observed SST ---> SST_{int}

  SST_{int}(time, lat, lon) = SST(time,lat,lon) - $PC1_{for}$ (time) x SST_{for}(lat,lon)
- Weighted spatial average of annual SST_{int} over a broad North Atlantic domain (0^o-60^oN and from the American coast to Africa/Europe. The Mediterranean and Baltic Seas are excluded) ---> NASST(time). Weights correspond to the cosine of the latitude.
- Filtering of the NASST(time) ---> AMV(time) (Fig2.a). A zero-phasing Butterworth filter is applied using the `butter` and `filtfilt` matlab functions. The order of the filter is taken equal to 2 and the cutoff period is 10 years.
- Regression of global SST_{int}(time,lat,lon) on the AMV(time) index over 1900-2013.
- A posteriori application of masks to get the final AMV_{Full}, AMV_{Trop} and AMV_{Extrop} domains where restoring is active, such as AMV_{Full}(lat,lon) = AMV_{Trop}(lat,lon)+ AMV_{Extrop}(lat,lon), as displayed in Fig.2b-d, respectively.

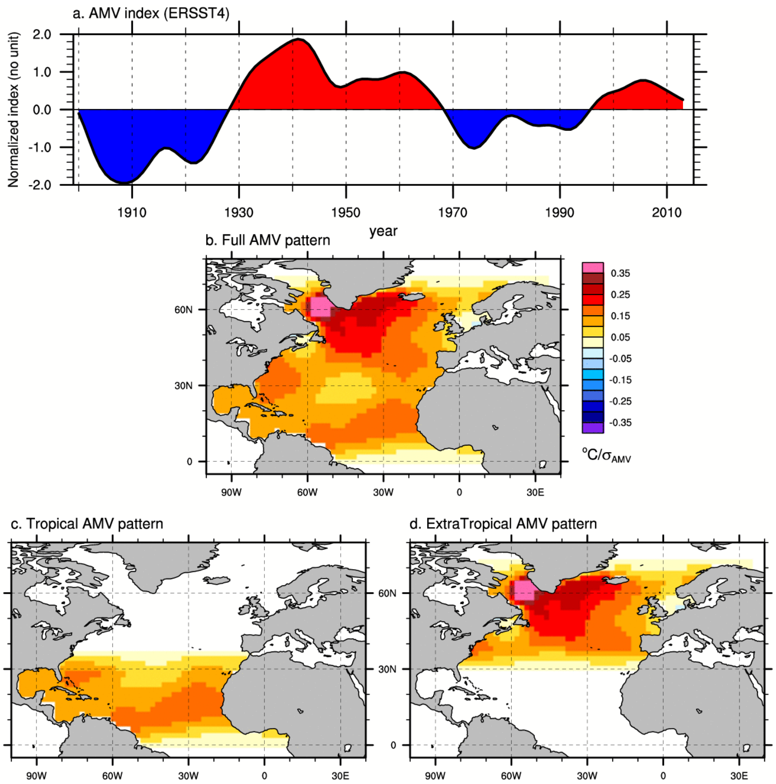

***Figure 2: a.** Normalized AMV time series after filtering. **b.** Full AMV SST anomalies obtained from regression of ERSSTv4 annual residual SST (i.e. forced component removed) on the AMV time series. Contour interval is $0.05^oC/\sigma$. **c-d.** Same as b. but showing the partition into **c.** tropical and **d.** extratropical domains to be applied in DCPP-Component C additional experiments in order to deconvoluate the respective role of the AMV regional anomalies.*

b) IPV patterns

- Subtraction of the forced component from annual mean raw SST ---> SST_{int} (similarly to AMV):

$$SST_{int}(time, lat, lon) = SST(time,lat,lon) - PC1_{for}(time) \times SST_{for}(lat,lon)$$

- EOF decomposition of annual SST_{int} weighted by the root-square of the cosine of the latitude over the IPV domain (40°S-60°N, from Indonesia to the American Coast).
- Extraction of the leading PC time series and filtering ---> IPV(time) (Fig.3a). Similarly to AMV, a zero-phasing Butterworth filter is applied using the `butter` and `filtfilt` matlab functions. The order of the filter is equal to 2 and the cutoff period is 13 years (see e.g. Henley et al. 2015, among others for the definition of the IPV).
- Regression of global SST_{int}(time,lat,lon) on the IPV(time) index over 1900-2013.
- Creation of buffer zones and a posteriori application of masks to get the final IPV_{Full} and $IPV_{NorthPac}$ patterns (Fig.3b-c, respectively).

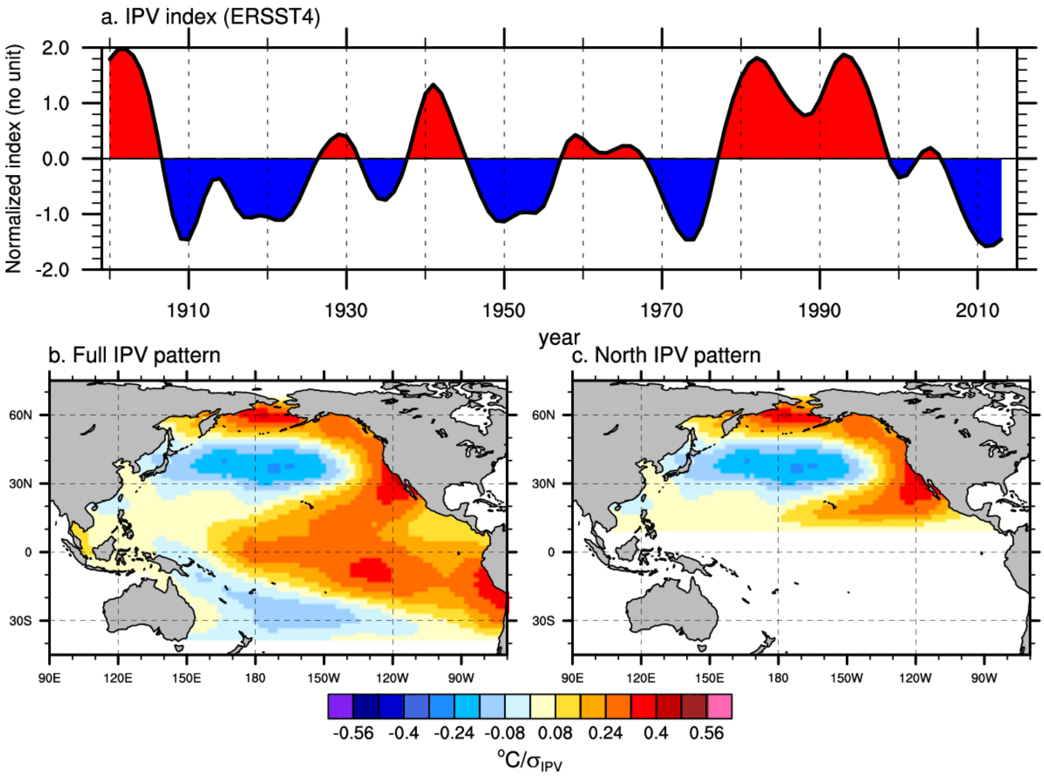

Figure 2: a. *Normalized IPV time series after filtering.* ***b.*** *Full IPV SST anomalies obtained from regression of ERSSTv4 annual residual SST (i.e. forced component removed) on the IPV time series. Contour interval is 0.08°C/σ.* ***c.*** *Same as b. but showing the region selected to isolate the role of the northern Pacific domain in additional DCPP-Component C experiments.*

Note that the AMV and IPV patterns provided in the netcdf files are given globally and have not been tapered by the masks. The reader is invited to check below section 2.2.4 for recommendation about masking and issues related to the interpolation from the ERSSTv4 source grid to the ocean model target grid.

2- Comments

The above-documented procedure mostly follows the methodology described in Ruprich-Robert et al (2016, hereafter YRR) for the AMV. However, we have purposely made some changes with respect to YRR including:

a) The SST dataset has been updated to a more recent version (ERSSTv4 instead of ERSSTv3)

b) The SSTs are not filtered before the final regression step; raw annual mean SST are used instead.

These changes in the methodology yield some differences in the resulting SST patterns and in the associated time series as described below:

2-1. Sensitivity to datasets

To assess the sensitivity to the SST dataset, the procedure documented in section 1 has been applied to the ERSSTv3b product used in YRR. The comparison between the two dataset versions is displayed in Fig.4 for both AMV and IPV time series and spatial patterns.

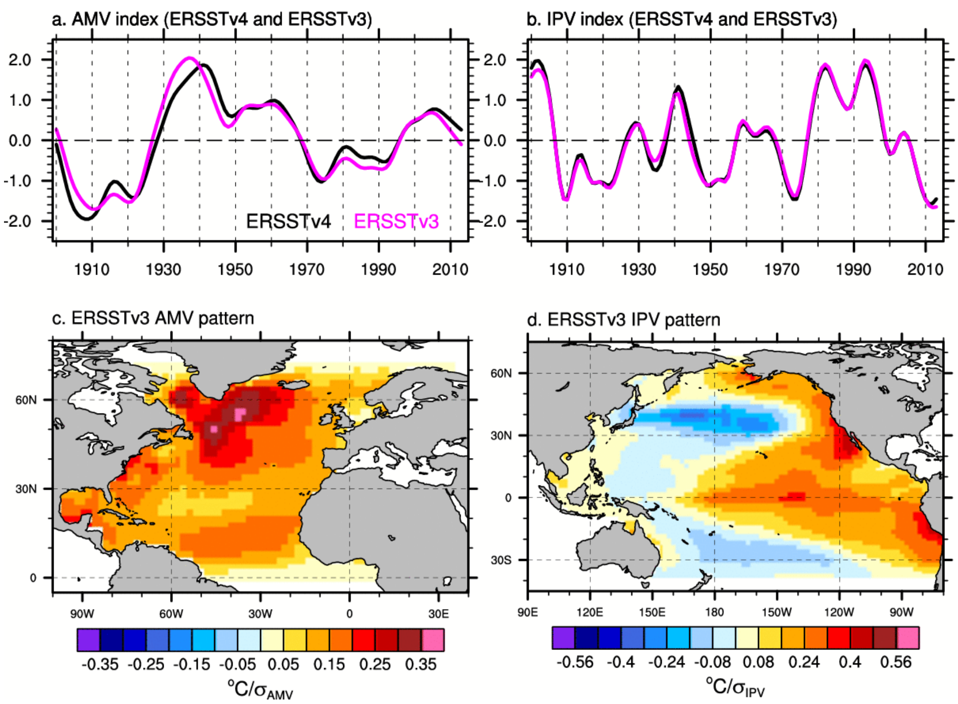

Figure 4: *Normalized* ***a.*** *AMV and* ***b.*** *IPV indices for ERSSTv4 (in black) and ERSSTv3b (magenta). Full* ***c.*** *AMV and* ***d.*** *IPV SST anomalies for ERSSTv3b to be directly compared to Fig.2b and Fig.3b, respectively. Contour interval is* $0.05^oC/\sigma$ *and* $0.08^oC/\sigma$ *for AMV and IPV, respectively.*

Both AMV and IPV time series are very similar with the two datasets. The largest differences are found during the 1930-1950s period consistently with the corrections applied in the observed ocean measurements during those decades (Huang et al. 2016). The main differences in the spatial pattern of the AMV are located in the subpolar gyre. Maximum loading in ERSSTv3b extends from the Irminger Sea to Newfoundland while the greatest anomalies are more confined in the Labrador Sea in ERSSTv4 (compare Fig.2b with Fig .4c). As to the IPV, tropical anomalies are narrower and more centered along the equator in

ERSSTv3b, while they are broader and southward displaced in ERSSTv4 around 140°W (compare Fig.3b with Fig.4d). In addition, the North Pacific negative anomalies are reinforced and constricted along 40°N in ERSSTv3b whereas weaker values are found in the Bering Sea and along the Northern American Pacific coast in ERSSTv4.

2-2. Sensitivity to filtering

In YRR, a band-pass filter is applied not only to the AMV time series but also to SST_{int} prior regression on the index, whereas raw interannual SST_{int} are used in our proposed methodology. There is no consensus in the literature about the necessity for filtering the SST before regression. For the IPV, however, the traditional way is to use even higher-frequency data (monthly) than the annual means proposed in our methodology. We chose to use annual means both for the AMV and IPV to be consistent with the definition of the forced component that is based on annual average following Ting et al. (2009). We repeated the procedure with and without filtering and found that the main effect of the filter is to reduce the amplitude of the SST anomalies, whereas the spatial patterns are virtually unaffected (spatial correlation equal to 0.92 and 0.95 for the AMV and the IPV, respectively, between SST_{int} and $SST_{int\_filtered}$, not shown).

2-3. Time period issues

The definition of the SST forced response and the computation of the AMV and IPV indices have been performed over a period that maximizes the data availability, namely 1870-2013. The regressed anomalous patterns are however calculated over a restricted period, namely 1900-2013. The reason to limit the period for the last regression step is to exclude the spurious values generated by the zero-phase filtering at the beginning of the time series as illustrated for the IPV in Fig.5. The contamination by end-points is less critical for the AMV because of less extreme values at the beginning of the period, but to be consistent, we chose the same 1900-2013 period for both regression patterns following YRR. In addition, due to very sparse data coverage, observational uncertainty is very large before 1900 and restricting the period as proposed helps reducing the sensitivity of the final SST anomalous patterns to the choice of the dataset (ERSSTv3 vs ERSSTv4, not shown).

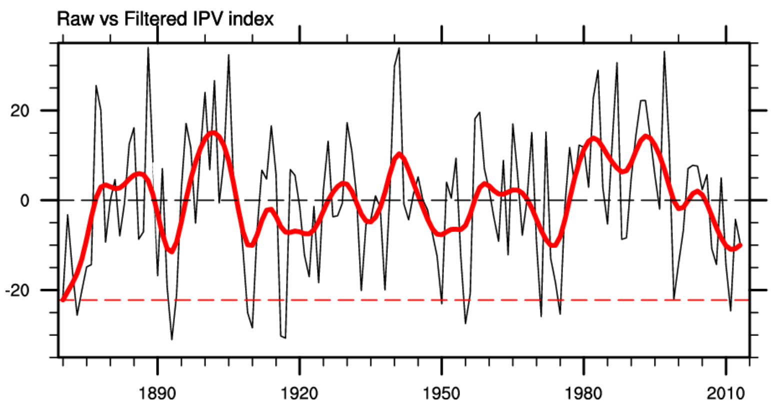

Figure 5: *Raw IPV annual index (in black) and 13-yr band pass filtered IPV index based on a zero-phasing Butterworth filter. The 1870-1877 filtered IPV values materialized by the horizontal red line are well outside the range of variability of the index (they correspond to about -3 standard deviation) and are sensitive to the the filter end-points.*

2-4. Recommendation for interpolation

The SST anomalies are provided globally on the ERSSTv4 grid and masks are given to define the regions where the restoring needs to be applied for each experiment. Modeling groups should interpolate the global SST patterns on their own ocean model grid. Regional masks can be either redefined by each modeling group on their own ocean model grid (see GMD paper for the precise definition of the mask extension) or interpolated from the provided netcdf files.

Modeling groups are strongly encouraged to check the quality of the interpolated SST and mask fields before running the experiments and use ad-hoc corrections (especially along the coast and in the buffer zones) if necessary. For example, attention should be paid for the AMV (IPV) experiments on possible undesirable masked grid points that may appear in the Pacific (Atlantic) due to interpolation effects (especially off the coast of Central America) and because of the very coarse resolution of ERSSTv4 compared to most ocean model grids now used in CMIP6. The ideal steps to follow are given and illustrated below (Fig.6) for the AMV_{Full} mask interpolation:

- Extrapolation of the original mask (Fig.6a) over land on the source grid (Fig.6b) to minimize interpolation errors
- Interpolation on the ocean model grid (Fig.6c)
- Ad-hoc (often manual point-by-point) correction to remove spurious values due to interpolation along the coast (e.g. central America), to obtain the final mask on ocean target grid (Fig.6d).

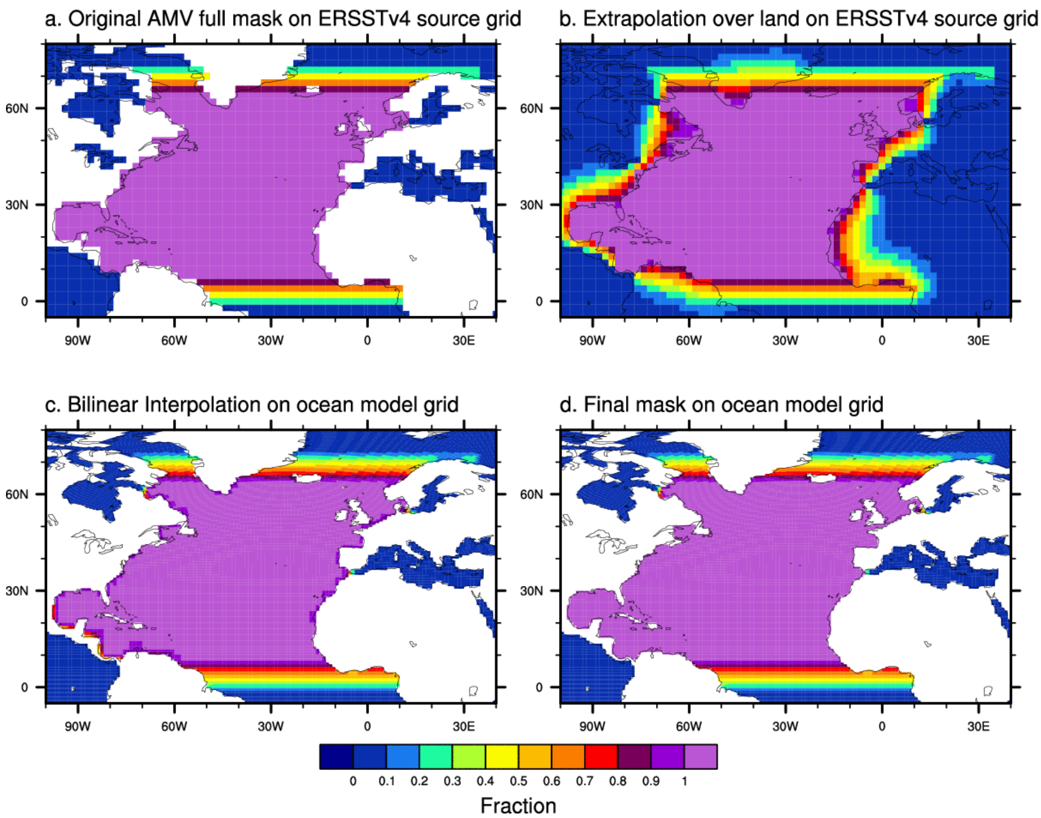

Figure 6: a. *Original AMV_{Full} mask on ERSSTv4 grid. b. Extrapolation of the mask over land. c. Interpolation on the ocean model ORCA1 grid. d. Final mask after correction of spurious points along continents.*

For group using a flux formulation restoring, mask should be ideally applied on the flux term and not on the SST to avoid spurious effects along the buffer zones.

References

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