Supplementary for: *The updated Multi-Model Large Ensemble Archive and the Climate Variability Diagnostics Package: New tools for the study of climate variability and change*

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1 CVDPv6 Output Fields

The diagnostics computed in the CVDPv6 are organized in a similar way to those in previous versions of the CVDP (see Phillips et al., 2020). They begin with general quantities (climatological averages, interannual standard deviations and linear trends; defined below) displayed in the form of global maps for each variable and season. The variable names are abbreviated following CMIP convention as follows: MSFTMZ for ocean meridional overturning mass streamfunction, PR for total precipitation, PSL for barometric sea level pressure, SICONC for sea ice concentration, TS (or SST) over ocean gridboxes for sea surface temperature, TAS for 2m air temperature and ZOS for sea surface height. The seasons are 3-month averages for: December-February (DJF), January-March (JFM), March-May (MAM), June-August (JJA), July-September (JAS) and September-November (SON). Annual means (January-December averages) are also shown. Next are the major modes of coupled (ocean- atmosphere) climate variability: El Niño Southern Oscillation (ENSO), Atlantic Multidecadal Variability (AMV), Pacific Decadal Variability (PDV), Interdecadal Pacific Variability (IPV) and the Atlantic Multidecadal Overturning Circulation (AMOC). These are followed by the dominant modes (8 in total) of large-scale atmospheric circulation variability. The final set of diagnostics is devoted to time series, including globally-averaged quantities, regional indices and a variety of sea ice extent measures. As described in the main text, the method of trend removal is set by the user and is applied to all computations other than climatological averages and linear trends. All of the diagnostics are defined in detail below, along with a description of the various metrics used to characterize the modes of variability. This information is also provided in the *Methodology and Definitions* link at the top of the CVDPv6 output webpage.

1.1 General Quantities

1. Climatological averages: averages over the time period specified by the user.
2. Interannual standard deviations: temporal standard deviations computed over the time period specified by the user.
3. Linear trends: linear least-squares best-fit trends over the time period specified by the user.

1.2 Coupled Modes of Variability

1. ENSO
   The CVDPv6 provides an extensive set of diagnostics on the El Niño Southern Oscillation (ENSO) given its central importance to the global climate system. These diagnostics are grouped into two categories: spatial patterns and temporal characteristics. The spatial patterns are based on compositing all El Niño events and all La Niña events using a +1 and -1 standard deviation threshold of the December Nino3.4 SST Index after smoothing the monthly anomalies with a 3-point binomial filter (SST anomalies averaged over the region 5N-5S, 170W- 120W) to define events, respectively, following previous studies (e.g. Deser et al., 2012). Global maps of SST, TAS, PSL and PR anomalies based on composite El Niño events, composite La Niña events, and their difference are shown for each season, along with Hovmöller diagrams of the longitude-time evolution of equatorial Pacific SST anomalies (averaged between 3N-3S) for the El Niño and La Niña composites. The seasons are labeled relative to December of the year used to define events (denoted year 0). Thus, JJA0 and SON0 correspond to year 0, and DJF1 and MAM1 correspond to year +1. Metrics of the temporal characteristics, based on the detrended monthly Nino3.4 SST Index, include standard deviations by month, power spectra (in variance preserving format), Morlet wavelets (Torrence and Compo, 1998), lag- autocorrelation curves, and time-evolving standard deviations based on running 30-year windows.

2. AMV
   The Atlantic Multidecadal Variability (AMV) Index is defined as monthly SST anomalies averaged over the North Atlantic region [0-60N, 80W-0W] following Trenberth and Shea (2006) (the global mean SST is not removed as in previous versions of the CVDP as his may introduce spurious effects (see Deser and Phillips, 2023); however, the user has the option to detrend the SST data used for the AMV index). Both unfiltered and low-pass filtered (based on 10-year running means) versions of the AMV Index timeseries are provided, along with the power spectrum (in variance preserving format) of the unfiltered timeseries. Global regression maps of monthly SST, TAS and PR anomalies onto the AMV Index timeseries are also provided for the unfiltered (“Regr”) and low-pass filtered (“Regr LP”) versions of the data.

3. PDV
   The Pacific Decadal Varaibility (PDV) Index is defined as the standardized principal component (PC) timeseries associated with the leading Empirical Orthogonal Function (EOF) of area-weighted monthly SST anomalies over the North Pacific region [20-70N, 110E-100W] following Mantua et al. (1997) (the global mean is not removed as in previous

versions of the CVDP due to the availability of user-defined trend removal methods). Global regression maps of monthly SST, TAS and PR anomalies onto the PDV Index timeseries, and power spectra are also provided.

4. IPV

The standard Interdecadal Pacific Variability (IPV) Index is defined as the leading principal component (PC) of 13yr low pass filtered Pacific [40°S:60°N, 110°E:70°W] area-weighted SST anomalies following Meehl et al. (2009) (the global mean is not removed as in previous versions of the CVDP due to the availability of user-defined trend removal methods). A minimum of 40 years of data is required for the standard IPV index to be calculated. The Henley IPV Index is defined as the area-weighted SST anomalies of the Tropical Pacific [10°S:10°N, 170°E:90°W] minus the average of the area-weighted anomalies in the North [25°:45°N, 140°E:145°W] and South [15°:50°S, 150°E:160°W] Pacific following Henley et al. (2015). The diagnostics provided for both IPV indices are the same as those for PDV above.

5. AMOC

The Atlantic Meridional Overturning Circulation (AMOC) Index is defined as the standardized PC timeseries associated with the leading EOF of area-weighted annual mean oceanic meridional mass transport (Sv) in the Atlantic sector from 33°S to 90°N over the depth range 0 – 6km low-pass filtered with a 15-point Lanczos filter following Danabasoglu et al. (2012). Both the timeseries and power spectrum (in variance preserving format) of the low- pass filtered AMOC Index are displayed. The spatial patterns of oceanic meridional mass transport (Sv) associated with AMOC are shown as a function of latitude and depth for the climatological mean, interannual standard deviation, and regression patterns onto the AMOC Index. In addition, global regression maps (at zero lag) of annual low-pass filtered SST and TAS (in degrees Celsius) anomalies associated with a one standard deviation departure of the AMOC Index are displayed. Finally, lead/lag correlation curves from -15 years to +15 years between the low-pass filtered AMOC and AMV timeseries are shown.

1.3 Atmospheric Modes of Variability

The following modes of large-scale atmospheric circulation variability are included based on their regional importance; all modes are computed separately for each season and the annual mean using PSL anomalies:

- Southern Oscillation (SO): Difference between the Indian Ocean/Western Pacific [70-170E] and the Central/Eastern Pacific [160W-60W] averaged over the latitude band 30S-0 (see Trenberth and Caron, 2000).
- Northern Annular Mode (NAM): leading EOF north of 20N (Thompson and Wallace, 2000)
- North Atlantic Oscillation (NAO): leading EOF in the region [20-80N, 90W-40E] (Hurrell and Deser, 2009)
- Southern Annular Mode (SAM): leading EOF south of 20S (Thompson and Wallace, 2000)
- Pacific - North American Pattern (PNA): leading EOF in the region [20-85N, 120E- 120W]
- North Pacific Oscillation (NPO): second EOF in the region [20-85N, 120E-120W]

– Pacific – South American Pattern Mode 1 (PSA1): second EOF south of 20S (Mo and Higgins, 1998)

– Pacific – South American Pattern Mode 2 (PSA2): third EOF south of 20S (Mo and Higgins, 1998)

For the EOF-based modes, the Index timeseries are the associated PCs. All Index timeseries are standardized (i.e., divided by their standard deviations). The spatial patterns of the modes are displayed as hemispheric (global in the case of the SO) PSL regression maps upon the standardized Index timeseries.

Timeseries:

1. Global: Area-weighted global averages of SST, TAS and PR anomalies for each season and the annual mean. Land-only PR is also included, as many observational data sets before the satellite- era are land-only.

2. Regional: Area-weighted monthly SST anomaly timeseries as follows (see the cited references for information on their climatic significance):

   – Tropical North Atlantic [5N-23N, 15-60W]; (Enfield et al., 1999)
   – Tropical South Atlantic [0-20S, 30W-10E]; (Enfield et al., 1999)
   – Atlantic Meridional Mode; (Doi et al., 2009)
   – Atlantic Niño [3N-3S, 20W-0E]; (Zebiak, 1993)
   – North Atlantic; [0-60N, 80W-0W]
   – Tropical Indian Ocean [15S-15N, 40-110E]
   – Indian Ocean Dipole [10S-10N, 50-70E] minus [0-10S, 90-110E]; (Saji et al., 1999)
   – Niño1+2 [0-10S, 80-90W]; (Rasmusson and Carpenter, 1982)
   – Niño3 [5N-5S, 120-170W]]; (Rasmusson and Carpenter, 1982)
   – Niño4 [5N-5S, 160E-150W]; (Rasmusson and Carpenter, 1982)
   – North Pacific Meridional Mode; (Chiang and Vimont, 2004)
   – South Pacific Meridional Mode; Zhang et al. (2014)
   – Southern Ocean [50-70S, 0-360E]

   The North Pacific PSL Index (NPI; Trenberth and Hurrell, 1994) is also included. This Index is defined as the area-weighted PSL anomaly averaged over the region [30-65N, 160E-140W] and averaged over the months December-March.

3. Sea ice extent: Monthly, seasonal and annual averages of sea ice extent in the Northern and Southern Hemispheres (NH and SH, respectively). Sea ice extent is defined as the area of ocean with at least 15% sea ice. Monthly anomalies and the monthly climatology of sea ice extent are also included.

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