Instructions for Rossby wave sources (RWS) Process-oriented diagnostics (POD)

The diagnostics package termed RWS-POD consists of four "levels" that are sequentially performed with monthly variables either from reanalysis or model integrations. With a focus on identifying leading processes that determine ENSO-induced global teleconnection, particularly the Pacific North American (PNA) pattern, main module of the POD estimates basic state flow properties at an appropriate tropospheric upper-level and solves barotropic vorticity equation to estimate various terms that contribute to the total anomalous RWS. To attain robust "composite" results a reasonable sample of ENSO winters is needed. However, the POD can be applied even for a single El Niño winter (e.g., when applied to seasonal prediction models). Similarly, the POD is applicable to any number of pressure levels (e.g., to identify the level at which maximum upper-level divergence and associated RWS are located). Here, reanalysis products (e.g., ERA-interim) is "considered" as "observations" and diagnostics obtained from multitude reanalysis products are used for model validation. In this general README document, brief descriptions of the four levels are provided but detailed information is provided at each level.

Level 1 – Basic ENSO diagnostics

Identify ENSO winters and construct seasonal composite anomalies for relevant variables (e.g., anomalous precipitation, circulation, geopotential height to estimate standardized PNA index). Also, seasonal climatology required for other Levels are computed here.

Reference index (e.g., Nino3.4 SST)

- Seasonal averages

Note: Level 1 diagnostics (ENSO-related anomalies and seasonal climatology) are required to perform Levels 2-4 diagnostics

Level 2 – Climatological flow and wave properties (basic-state/ambient flow) diagnostics

- Meridional curvature of upper-level zonal wind ($\partial^2\overline{U}/\partial y^2$) or gradients in relative vorticity of the climatological zonal wind
- Restoring effect for Rossby waves $\beta_* = \beta - \partial^2\overline{U}/\partial y^2$ where β meridional gradient in planetary vorticity
- Stationary wave number $K_s = (\beta_* / \overline{U})^{1/2}$

Level 3 – Anomalous Rossby wave source (RWS') diagnostics

- Explicitly solves barotropic vorticity budget and the leading terms contributing to the total (RWS') are quantified. RWS' is given by:

$$RWS' = -\bar{\xi}\nabla \cdot v'_\chi - v'_\chi \cdot \nabla\bar{\xi} - \xi'\nabla \cdot \bar{v}_\chi - \bar{v}_\chi \cdot \nabla\xi' \qquad (1)$$

Here, ξ and v_χ correspond to absolute vorticity and divergent component of the wind, respectively. The overbar represents seasonal mean and the prime refers to seasonal anomalies. The first term in

RWS' corresponds to stretching due to anomalous divergence, and the second term accounts for advection of climatological β by the anomalous divergent wind. The third and fourth terms account for transient eddy convergence of vorticity, and their contributions to RWS' is small but non-negligible.

Level 4 – RWS scatter plots (Metrics).

At this level, results from Levels 1-3 (AMIP/CMIP-era models) are condensed into scatter plots. Specifically, the sequential plots illustrate the "chain of processes" in ENSO-induced teleconnection. For example, model simulated equatorial Pacific precipitation anomalies (forcing) are examined against simulated subtropical divergence anomalies (response) that are subsequently assessed with estimates of leading RWS terms. Then, forcing due to RWS on the models' efficacy in representing PNA index (response), and the dependence of PNA index to models' ambient flow properties are examined. In summary, these scatter plots reveal models' fidelity in representing the essential ingredients that are deemed necessary for realistic representation of ENSO-induced teleconnection during boreal winters.

Level 4 requires pre-calculated results from Levels 1 - 3.

Contact Information:

PI: Dr. H. Annamalai,
International Pacific Research Center,
University of Hawaii at Manoa
E-mail: hanna@hawaii.edu

Programming: Jan Hafner
Email: jhafner@hawaii.edu

References:

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