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Separation of the low-frequency atmospheric variability into non-Gaussian multidimensional sources by Independent Subspace Analysis

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An efficient nonlinear method of statistical source separation of space-distributed non-Gaussian distributed data is proposed. The method relies in the so called Independent Subspace Analysis (ISA), being tested on a long time-series of the stream-function field of an atmospheric quasi-geostrophic 3-level model (QG3) simulating the winter's monthly variability of the Northern Hemisphere.

ISA generalizes the Independent Component Analysis (ICA) by looking for multidimensional and minimally dependent, uncorrelated and non-Gaussian distributed statistical sources among the rotated projections or subspaces of the multivariate probability distribution of the leading principal components of the working field whereas ICA restrict to scalar sources. The rationale of that technique relies upon the projection pursuit technique, looking for data projections of enhanced interest. In order to accomplish the decomposition, we maximize measures of the sources' non-Gaussianity by contrast functions which are given by squares of nonlinear, cross-cumulant-based correlations involving the variables spanning the sources. Therefore sources are sought matching certain nonlinear data structures. The maximized contrast function is built in such a way that it provides the minimization of the mean square of the residuals of certain nonlinear regressions. The issuing residuals, followed by spherization, provide a new set of nonlinear variable changes that are at once uncorrelated, quasi-independent and quasi-Gaussian, representing an advantage with respect to the Independent Components (scalar sources) obtained by ICA where the non-Gaussianity is concentrated into the non-Gaussian scalar sources.

The new scalar sources obtained by the above process encompass the attractor's curvature thus providing improved nonlinear model indices of the low-frequency atmospheric variability which is useful since large circulation indices are nonlinearly correlated. The non-Gaussian tested sources (dyads and triads, respectively of two and three dimensions) lead to a dense data concentration along certain curves or surfaces, nearby which the clusters' centroids of the joint probability density function tend to be located. That favors a better splitting of the QG3 atmospheric model's weather regimes: the positive and negative phases of the Arctic Oscillation and positive and negative phases of the North Atlantic Oscillation. The leading model's non-Gaussian dyad is associated to a positive correlation between: 1) the squared anomaly of the extratropical jet-stream and 2) the meridional jet-stream meandering. Triadic sources coming from maximized third-order cross cumulants between pairwise uncorrelated components reveal situations of triadic wave resonance and nonlinear triadic teleconnections, only possible thanks to joint non-Gaussianity. That kind of triadic synergies are accounted for an Information-Theoretic measure: the Interaction Information. The dominant model's triad occurs between anomalies of: 1) the North Pole anomaly pressure 2) the jet-stream intensity at the Eastern North-American boundary and 3) the jet-stream intensity at the Eastern Asian boundary.
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