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SIGNAL AND NOISE IN GLOBAL WARNING DECTECTION

Final Progress Report

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1.One of our studies considers the mean squared error (MSE) incurred in estimating an idealized earth's global average temperature with a finite network of point gauges distributed optimally over the globe. We use a spectral MSE formalism to find the optimal locations for N gauges in the problem of estimating the earth's global average temperature. Our technique calls for the examination of the MSE for realizations of N gauges randomly distributed on the sphere. To get the minimum MSE configuration we simply pick out the limiting least error case for each N. Our results suggest that for $NS greater than about 50 one can obtain estimates such that the amount of measured variance due to sampling error is less than about 15%, a result likely to be acceptable by climatologists. (North, G. R., S. S. Shen, J. W. Hardin, 1992: Estimation of the Global Mean Temperature with Point Gauges. Environmetrics, 3, 1-14. Also: Hardin, J. W. , G. R. North and S. S. Shen, 1992: Minimum error estimates of global temperature through optimal arrangement of gauges. Environmetrics, 3, 15-27.

2. A continuation of this work to the real geography of Earth and realistic placement of gauges: Making use of EOF analysis and statistical optimal averaging techniques, the problem of random sampling error in estimating the global average temperature by a network of surface stations has been investigated. The EOF representation makes it unnecessary to use simplified empirical models of the correlation structure of temperature anomalies. If an adjustable weight is assigned to each station according to the criterion of minimum mean square error, a formula for this error can be derived which consists of a sum of contributions from successive EOF modes.The EOFs were calculated from both observed data and a noise-forced EBM for the problem of one year and five year averages. The mean square statistical sampling error depends on the spatial distribution of the stations, length of the averaging interval and the choice of the weight for each station data stream. Our examples include four symmetric configurations of 4 by 4, 6 by 4, 9 by 7 and 20 by 10 stations and the Angell-Korshover configuration. Comparisons with the 100 year UK data set show that correlations for the time series of the global temperature anomaly average between the full data set and our sparse configurations are rather high. For example, the 63 station Angell-Korshover network with uniform weighting explains 92.7% of the total variance, whereas the same network with optimal weighting can lead to 97.8% explained total variance. (See Spectral approach to optimal estimation of the global average temperature. J. Clim., 7, 1999-2007.)

3. The following is a description of our work on detection of forced climate change. We consider the construction of a

linear smoothing filter for estimation of the forced part of a change in a climatological field such as the surface temperature. The filter is optimal in the sense that it suppresses the natural variability or 'noise' relative to the forced part or 'signal' to the maximum extent possible. The technique is adapted from standard signal processing theory. The present treatment takes into account the spatial as well as the temporal variability of both the signal and the noise. In this paper we take the signal's waveform in space-time to be a given deterministic field in space and time; however, we can allow it to be uncertain in some interesting cases. Formulation of the expression for the minimum mean squared error for the problem together with a no-bias constraint leads to an integral equation whose solution is the filter. The problem can be solved analytically in terms of the frequency dependent empirical orthogonal function (fdEOF) basis set and its eigenvalue spectrum for the natural fluctuations and the projection amplitudes of the signal onto these eigenfunctions. The optimal filter does not depend on the strength of the assumed waveform used in its construction. A lesser mean squared error in estimating the signal occurs when the space-time spectral characteristics of the signal and the noise are highly dissimilar; for example, if the signal is concentrated in a very narrow spectral band and the noise in a very broad band. Some special cases are discussed in which the signal is also allowed to be stochastic; this latter may be used in the Bayesian sense that we may introduce an uncertainty in our prior knowledge of the signal (thereby necessarily increasing the mean square error). Consideration is given to the tradeoffs offered by the use of a biased estimator which has a lower mean square error. We present some numerical examples of forced climate signals to give an idea of the effectiveness of the technique. A few pedagogical exercises suggest that some forced climate signals (such as greenhouse warming over the last century) are very likely to be detectable with large signal to noise ratio. (See North et al., 1995: Detection of Forced Climate Signals. Part I: Filter Theory. March issue J. Climate. see also Part II in the same issue.)

See also:

Kim K.-Y. and G. R. North, 1991: Surface temperature fluctuations in a stochastic climate model. J. Geophys. Res., 96, 18,573-18,580.

K- and -, 1993: EOF analysis of surface temperature field in a stochastic climate model. J. Climate, 6, 1681-1690.