16D.5

APPLICATION OF SPATIO-TEMPORAL PATTERN RECOGNITION TECHNIQUES TO PREDICTING EXTRATROPICAL TRANSITION OF TROPICAL CYCLONES

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1. INTRODUCTION

The method of Empirical Orthogonal Functions (EOFs) is a classic pattern recognition technique that has been used in a variety of meteorological applications in order to identify the important underlying spatial patterns in meteorological fields. In particular, authors have used EOFs in the analysis of the extratropical transition (ET) of tropical cyclones [Harr et al., 2000]. Typically, the EOFs are applied by comparing the spatial distribution of 500 mb geopotential heights from many similar cases spatially referenced to the geographical location of a defined ET point. Here, EOF analysis is used as a preliminary tool to define variability between cases of tropical cyclones in the western North Pacific during 1997 – 2002 that complete ET (positive cases) and those that fail to complete ET (negative cases).

2. EOF ANALYSIS

EOF analysis is another term for the more commonly used (in pattern recognition) principal components analysis (PCA) or Karhunen-Loeve (K-L) transform. We first assume that we have a particular observation that can be represented by the random vector $\mathbf{X}$. In our case, the observation of interest is the two dimensional distribution of 500 mb heights. If we have N observations (corresponding, say, to N storms), then we rearrange each of these $(m \times n)$ images into a single $(mn \times 1)$ column vector that we denote $\mathbf{x}_i$. We can arrange the N observations into a $(mn \times N)$ data matrix

$$\underline{\underline{\mathbf{X}}} = \left[\begin{array}{ccccc} \mathbf{x}_1 & \mathbf{x}_2 & \cdots & \mathbf{x}_{N-1} & \mathbf{x}_N \end{array} \right]. \quad (1)$$

We can estimate the $(mn \times mn)$ covariance matrix of the random variable $\mathbf{X}$ as

$$\underline{\underline{\mathbf{C}}}_{xx} = \frac{1}{N} \underline{\underline{\mathbf{X}}}\,\underline{\underline{\mathbf{X}}}^T = \frac{1}{N} \sum_{i=1}^{N} \mathbf{x}_i \mathbf{x}_i{}^T. \quad (2)$$

We can see from the last expression in (2) that even though $\underline{\underline{\mathbf{C}}}_{xx}$ is $(mn \times mn)$, the matrix is only rank N (assuming that the N observations are all linearly independent. $\underline{\underline{\mathbf{C}}}_{xx}$ is also by definition Hermitian and is positive semi-definite, which means that it is guaranteed to have mn real, non-negative eigenvalues (N of which are nonzero) and mn orthogonal eigenvectors. We can diagonalize the covariance matrix using standard techniques to write

$$\underline{\underline{\mathbf{C}}}_{xx} = \underline{\underline{\mathbf{V}}}\,\underline{\underline{\lambda}}\,\underline{\underline{\mathbf{V}}}^T, \quad (3)$$

where $\underline{\underline{\mathbf{V}}}$ is a matrix whose columns are eigenvectors of $\underline{\underline{\mathbf{C}}}_{xx}$ and $\underline{\underline{\lambda}}$ is a diagonal matrix with the corresponding eigenvalues. The important aspect of the eigenvector matrix is that it is a unitary rotation matrix. When we form the transformed data matrix $\underline{\underline{\mathbf{P}}} = \underline{\underline{\mathbf{V}}}^T \cdot \underline{\underline{\mathbf{X}}}$, we have

$$\begin{aligned} \underline{\underline{\mathbf{C}}}_{pp} &= \tfrac{1}{N} \underline{\underline{\mathbf{V}}}^T \underline{\underline{\mathbf{X}}}\,\underline{\underline{\mathbf{X}}}^T \underline{\underline{\mathbf{V}}} = \underline{\underline{\mathbf{V}}}^T \underline{\underline{\mathbf{C}}}_{xx} \underline{\underline{\mathbf{V}}} \\ &= \underline{\underline{\mathbf{V}}}^T \underline{\underline{\mathbf{V}}}\,\underline{\underline{\lambda}}\,\underline{\underline{\mathbf{V}}}\,\underline{\underline{\mathbf{V}}}^T = \underline{\underline{\lambda}}. \end{aligned} \quad (4)$$

This equation tells as that the transformed variable $\mathbf{P}$, which we call the principal components, are *uncorrelated*. Furthermore, they are typically ordered by decreasing variance. The eigenvectors that form the matrix $\underline{\underline{\mathbf{V}}}$ are usually referred to as EOFs in meteorology.

In all previous analyses, the EOFs have been applied at a specific time relative to the identified ET time of the storm. Such application neglects the temporal variations in the fields. In this study, we are searching for *spatio-temporal* patterns that can be used to differentiate ET cases that intensify from those that do not, preferably using field data from times much earlier than the ET time. Such a tool would help forecasters in predicting ET intensification.

3. DESCRIPTION OF THE DATA

The EOF analysis uses 500 mb height analyses from the Navy Operational Global Assimilation and Prediction System (NOGAPS) for all ET events in the western North Pacific from 1997 – 2002. The ET+00h fields were obtained by determining the time and location that stage 1 of ET is complete [Klein et al., 2000]. The NOGAPS analyses were then interpolated in space to a 121° longitude × 101° latitude grid, at a resolution of 2°, centered on the ET location given by the JTWC best track data. A similar process provided fields every 12 h for the 48 h preceding and subsequent to ET. Because some storms propagate north of 40°N during the 96-h period of interest, the latitudinal extent of the grids are truncated at later time periods. Here we present results for 1997, which includes 11 positive cases and 4 negative cases.

4. PRELIMINARY RESULTS

At this time we have not managed to apply a full spatiotemporal EOF analyses to these systems. Instead, we have created time series of EOFs for both the positive and the negative cases described above. We performed EOF

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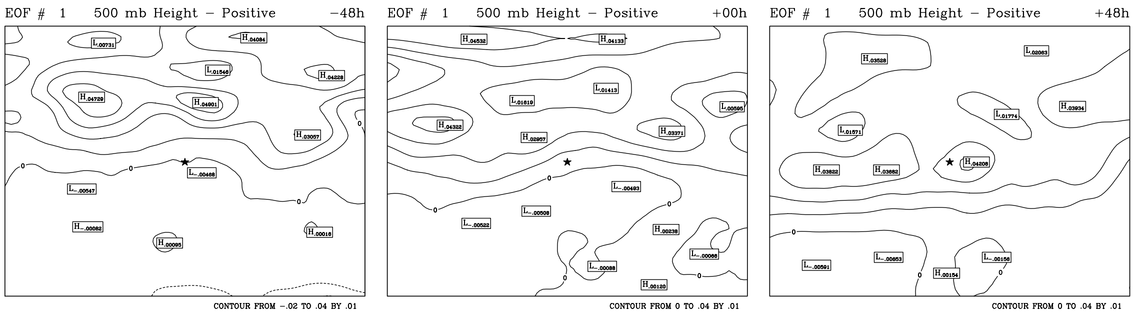

Figure 1: First EOF for the positive cases for -48 h, 0 h, and 48 h from ET. This function shows how the positive cases tend to deviate from the mean fields.

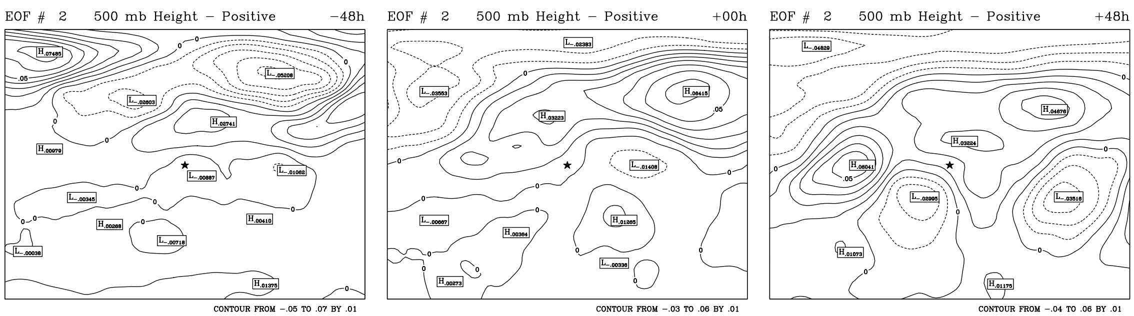

Figure 2: Second EOF for the positive cases for -48 h, 0 h, and 48 h from ET. This function shows how the positive cases tend to deviate from the mean fields.

analyses at 12-hour intervals from 48 hours before ET until 48 hours after ET. This covers the time when the storm is still a TC until well after the time of ET reintensification (if the storm is going to reintensify). Fig. 1 shows the 1st EOF and Fig. 2 shows the 2nd EOF for the positive cases for -48 h, 00 h, and 48 h from ET time. Next, we can project the individual storms into the reduced feature space represented by the EOFs. The projection onto the first two EOFs of the positive cases is shown in fig. 3. At the earlier times (-48 h, 00 h) there is some separation of the positive and negative cases. For the +48 h case, the separation is less clear. In the presentation, we will explore larger feature spaces for better separation.

References

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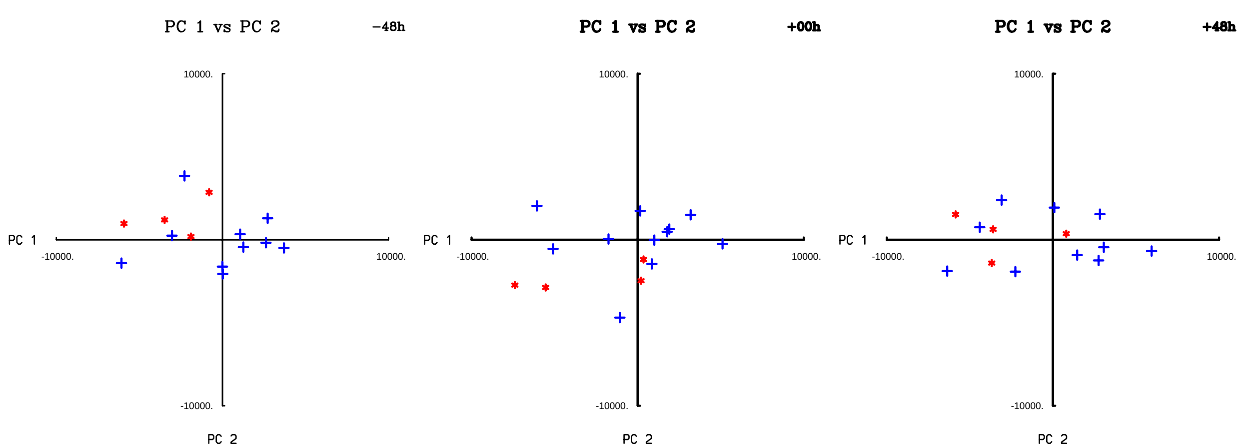

Figure 3: Projection of the positive (+) and negative (*) cases into the reduced feature space represented by the first two EOFs of the positive cases.