

Nonlinear Paleoclimatology: Reconstructions in West Antarctica

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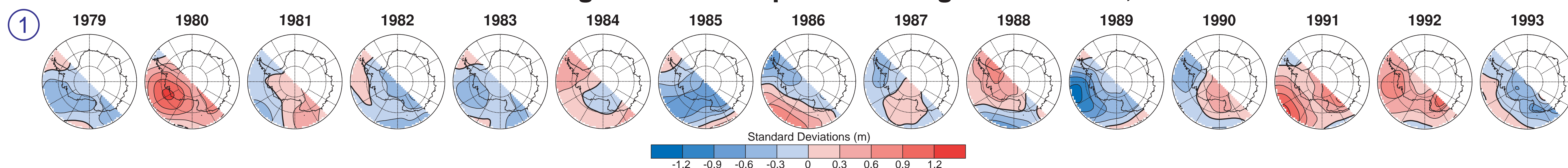
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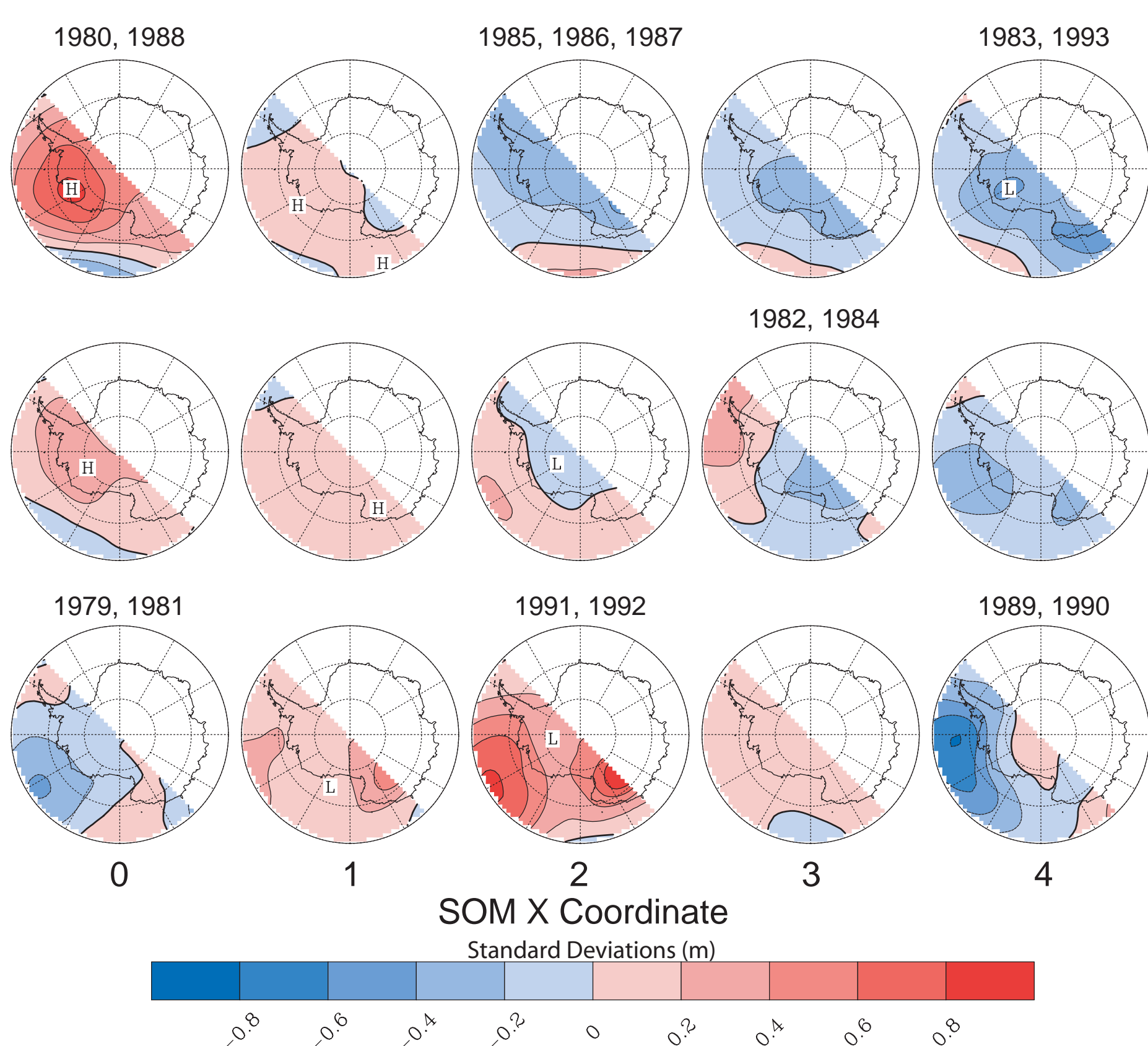
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I. Classifying the ERA-15 Circulation with Self-organizing Maps (SOMs)

Annual Average 700 mb Geopotential Height Anomalies, 1979-1993



SOM of Annual Average 700 mb Geopotential Height



SOMs and West Antarctic Circulation 1979-1993

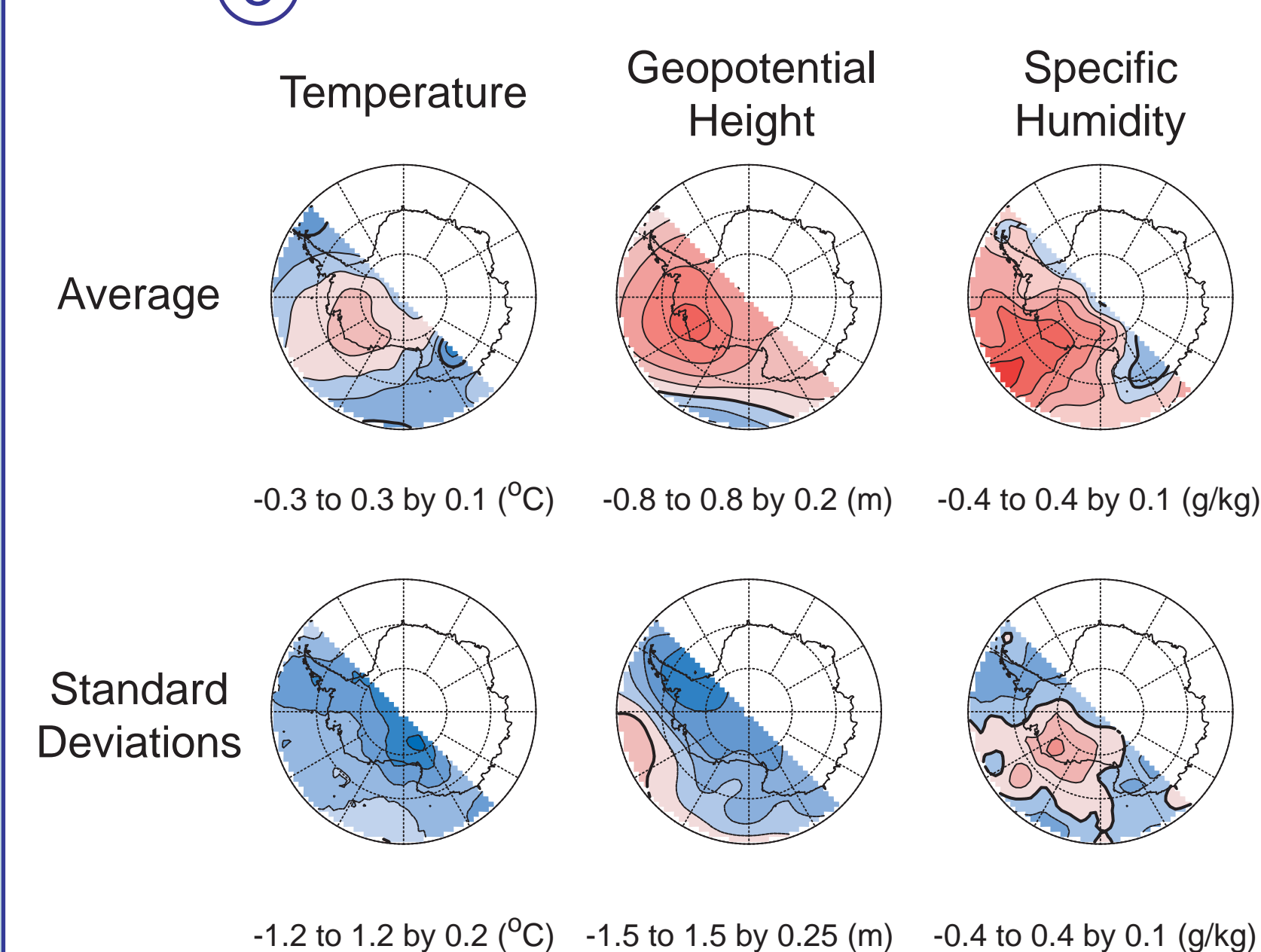
Self-organizing maps (Kohonen, 1990, 1995), or SOMs, provide an alternative method to do unsupervised classification of large, multivariate data sets into a fixed number of distinct generalized states or modes. A SOM analysis effectively projects multidimensional data onto a two-dimensional map composed of a set of generalized patterns (typically) arranged in a rectangular grid. The grid includes a spatial relationship such that similarity decreases with distance with opposite corners being least similar. The grid starts with uniform spacing with equal distances between randomly initialized patterns. Training of the SOM iteratively adjusts the patterns based on how close each input record is to the closest matching pattern. After training, each input record will match one pattern most closely and the input can be classified into groups based on this mapping to the closest pattern. Training also distorts the grid spacing (not shown) based on the similarity of adjacent patterns. Depending on the size of the SOM and input data set, training may also produce patterns not mapped by any input data. Such patterns represent intermediate states not seen in the input.

The annual average 700 mb geopotential height time series (1) was part of a six variable (3) SOM analysis that used a 5x3 grid (2) to extract 15 generalized patterns from the European Centre for Medium-Range Weather Forecasts (ECMWF) 15-year reanalysis (ERA-15) dataset. Figure (2) shows annual geopotential height patterns as standardized anomalies from the 15-year mean. Each year's closest pattern is shown by the labels over selected patterns, e.g., 1980 and 1988 both map to the pattern of anomalous high pressure at upper left. Transitional patterns without labels are also present.

Figure (3) shows all six variables used in the SOM analysis for one group of years, 1980 and 1988, with the relevant contouring data underneath each pattern. This example shows that the average 700 mb temperatures, geopotential heights and specific humidities were all above normal over West Antarctica during these years. Variability, as shown by the standard deviation, was below normal except for specific humidity. Similar figures for the other groups from the SOM analysis provide further information on the 700 mb circulation for 1979-1993.

Future applications of this technique will be using both longer reanalysis records and higher time resolution (for an example of a daily analysis, see Part III) as we seek to improve understanding of Antarctic climate and how ice cores can help us reconstruct past climates.

1980 and 1988



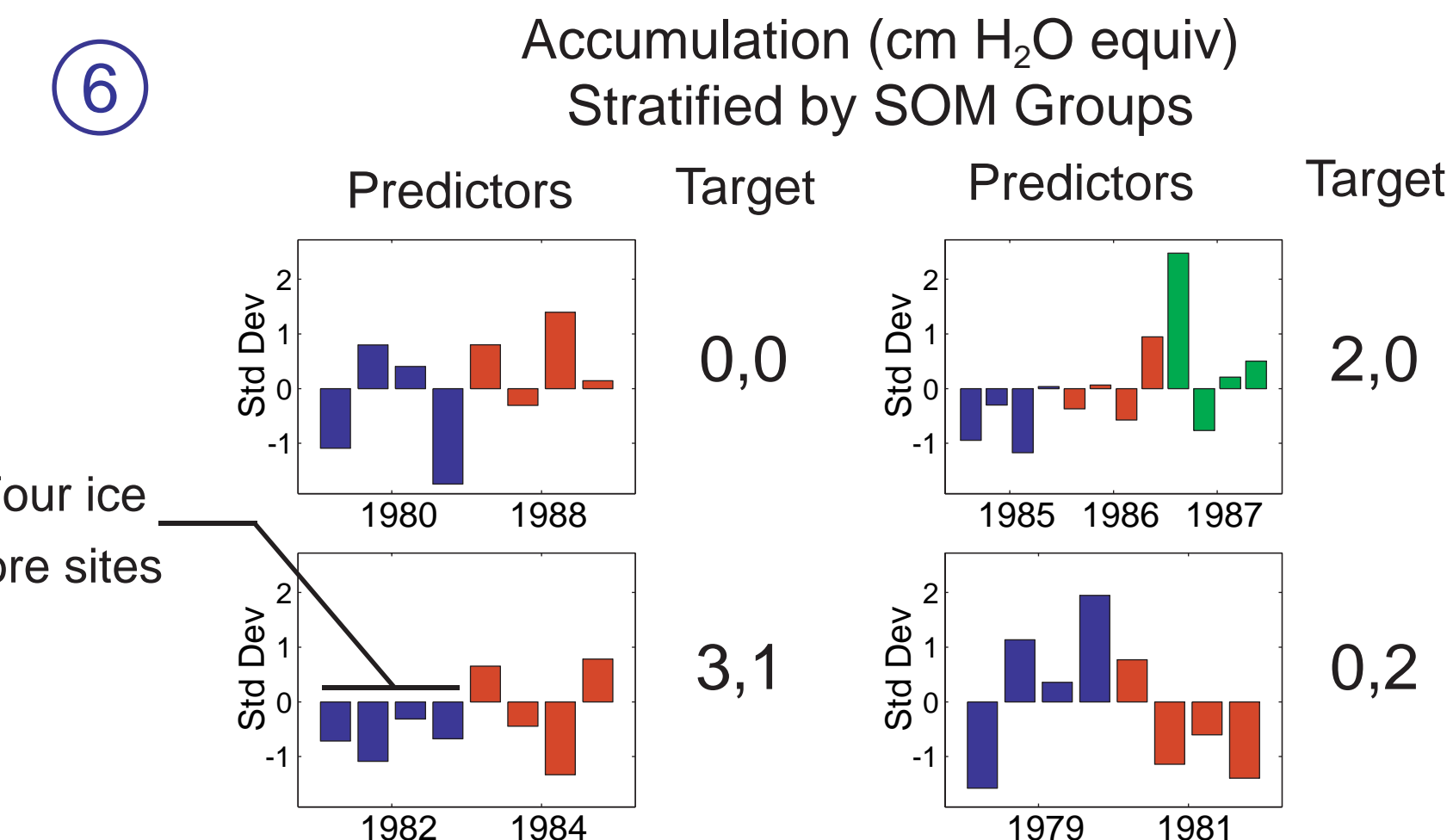
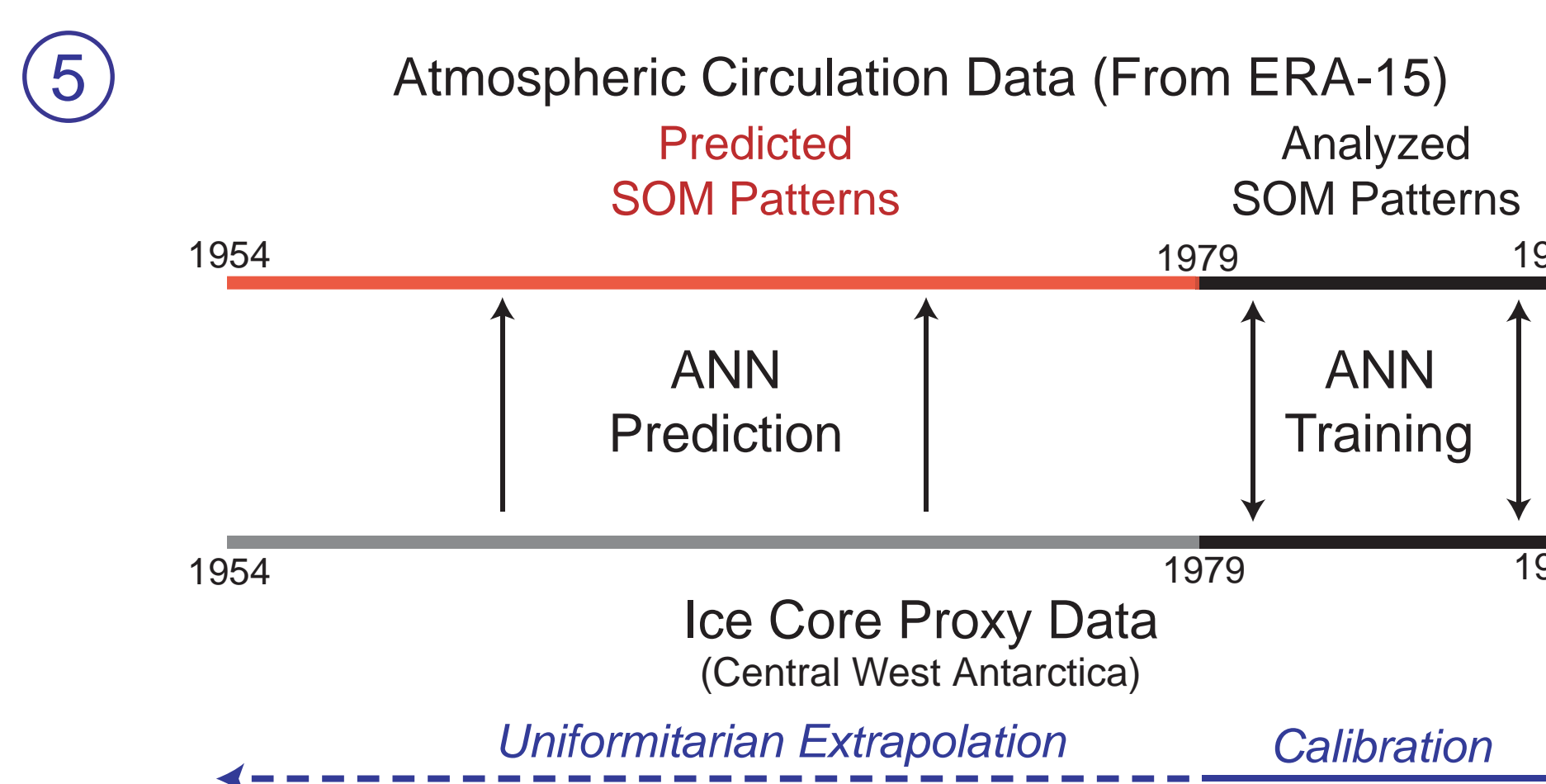
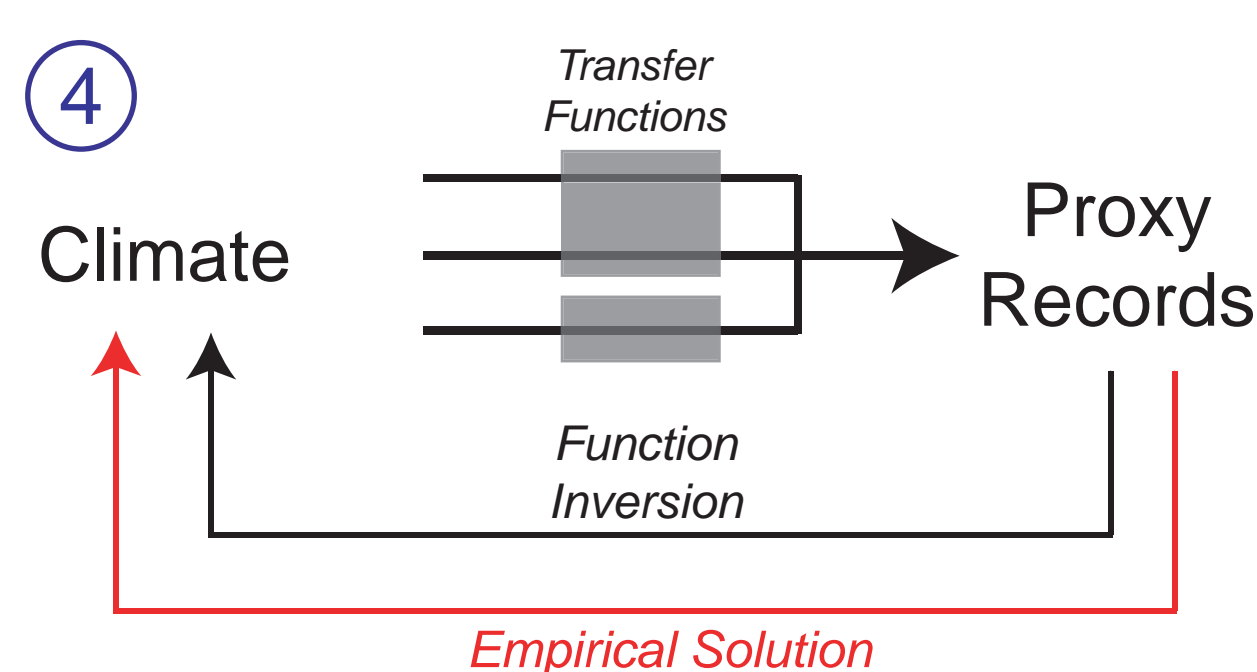
Selected SOM References
Boschetti, F., C. Wijns, and L. Moresi, Effective exploration and visualization of geological parameter space, *Geochem. Geophys. Geosyst.*, 4, 2003.
Hewitson, B.C., and R.G. Crane, Self-organizing maps: applications to synoptic climatology, *Climate Research*, 22 (1), 13-26, 2002.
Kohonen, T., *The Self Organizing Map*, *Proceedings of the IEEE*, 78 (9), 1464-1480, 1990.
Kohonen, T., *Self-Organizing Maps*, 362 pp., Springer-Verlag, Berlin, 1995.

II. Upscaling from Ice Cores to Generalized Circulation Patterns

The Problem (4):

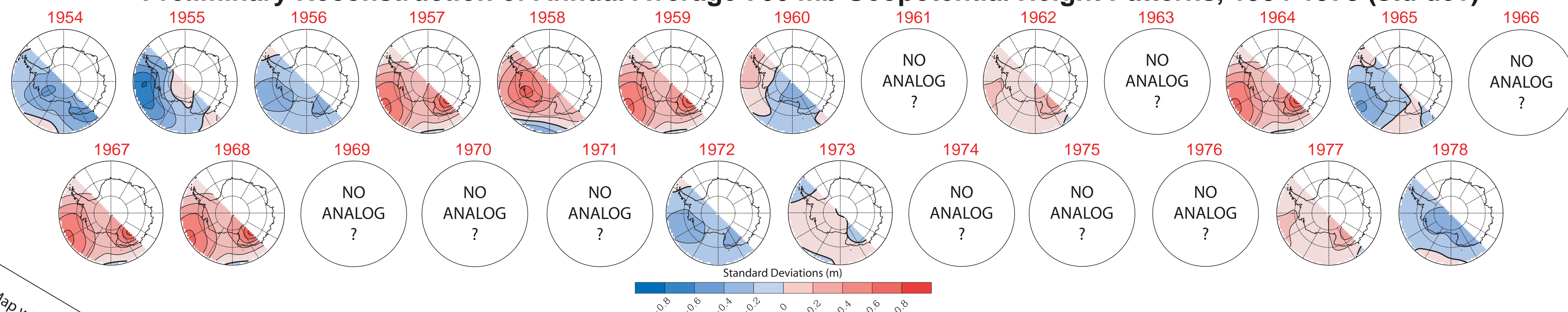
We know that ice core records of accumulation rate, stable isotopes and ion chemistry encode a filtered record of past climate but the processes involved remain too complex and the process data too incomplete to readily translate these proxies back to past climate. We still need a better understanding of the forward processes, or transfer functions, (e.g., transport strength, firm column wind pumping, source strength) before we can reliably and confidently invert our proxies back to past climate. In short, we still have too many black (or sometimes gray) boxes to properly use the analytical approach.

Empirical approaches, such as artificial neural networks (ANNs), bypass the physical processes and let us develop climate records in a world of imperfect knowledge. The empirical approach has weaknesses (e.g., assumption of stationarity, substituting one black box for one or more old ones) but these are not necessarily unique and a valuable contribution still results.



Our empirical approach (5) uses ANNs to relate ice core proxies to generalized patterns of the atmospheric circulation developed from our SOM analyses (2). SOM analysis associates each year with a generalized pattern that has an x,y coordinate in the SOM grid (2). Proxy data (6) for each year are used by the ANN to predict the associated x,y coordinates and, indirectly, the generalized pattern related to the proxy data. ERA-15 provides a 15-year overlap with our ice core data for training the ANN (5). Pure ANN prediction extends back to 1954 (7). The small size and noise of the training data limits the confidence we can place on the ANN predictions. The "No Analog" cases in (7) are those predictions outside the SOM grid that may represent conditions completely outside the training set or they may just reflect a poorly trained ANN. Additional training data (i.e., ERA-40) are needed to improve our confidence in this technique. Additional ice core data will also help by capturing a larger spatial domain.

Preliminary Reconstruction of Annual Average 700 mb Geopotential Height Patterns, 1954-1978 (std dev)



III. Analyzing Monthly Temperature Patterns in ERA-40

Larger input datasets tend to support more robust SOM analyses and also support additional analyses and larger grid sizes than are possible with just 15 years of annual averages. An analysis of monthly 500 mb temperature anomalies with a 6x5 grid (8) provides 30 generalized patterns summarizing the 1977-2001 period of the ERA-40 data set over the Peninsula. Figure 8 also incorporates the spatial nature of the SOM analysis by showing the patterns overlaid on a Sammon map (a projection of multidimensional vectors into 2-D) of the SOM reference vectors. This format highlights the greater differences between the warm/cold patterns versus the smaller differences between the half-warm/half-cold patterns. Clustering of some patterns (e.g., the lower right) is also evident.

Mapping all or part of the input data to the SOM and tracking which nodes are the best matches produces frequency maps. Figure 9 shows the most frequent patterns, month by month, and highlights how the most common patterns change over the annual cycle. Black lines surround patterns with a frequency greater than 10%. Unmapped patterns are dimmed. Following the most frequent patterns through the cycle suggests that both autumn (Mar/Apr/May) cooling and spring (Sep/Oct/Nov) warming tend to begin in the Weddell Sea sector with the Amundsen/Bellingshausen sector following behind. There are exceptions, such as the pattern for May where cooling could be in either sector.

