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THE NORTH ATLANTIC OSCILLATION, AND REGIME TRANSITION DURING APRIL 1995

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1. Introduction

Another well documented spatial structure (pattern) that can be defined from a distribution of geopotential height anomalies (height departures from climatology) is called the North Atlantic Oscillation (NAO, Barnston and Livezey 1987, Wallace and Gutzler 1981, Lanzante 1990). The NAO is another atmospheric mode of low frequency variability (LFV--time-scales generally longer than 10 days, Holton 1992). Unlike the PNA (Berry 1995a) and TNH (Berry 1995b), the NAO can be observed during all 12 months. The NAO is more expansive during the colder part of the year (November through March) than during the warmer portion.

The purpose of this Technical Attachment (TA) is to briefly describe the NAO, and illustrate how this pattern may have contributed to a remarkable regime transition (pattern change) during April 1995. For greater detail than presented here, the reader is asked to study the referenced literature.

2. The NAO

Figure 1 is a schematic taken from Barnston and Livezey (1987), but slightly modified for our purposes. Isopleths can be thought as lines of constant 500-mb (our reference level) height anomalies. What is shown is the positive phase of the NAO, which favors enhanced westerlies across the North Atlantic Ocean basin.

Observe that there are two main centers of variability, one of them is near or just west of Greenland and the other around 35° North latitude/35° West longitude. It is important to remember that the NAO is essentially a meridionally oriented dipole of height anomalies. The response over the lower 48 states does vary. The center near the Texas Panhandle, shown in Figure 1, is statistically much less significant than the Atlantic centers. The NAO structure should be distinguished from a PNA pattern, the latter consisting of a zonally oriented curved Rossby wave train.

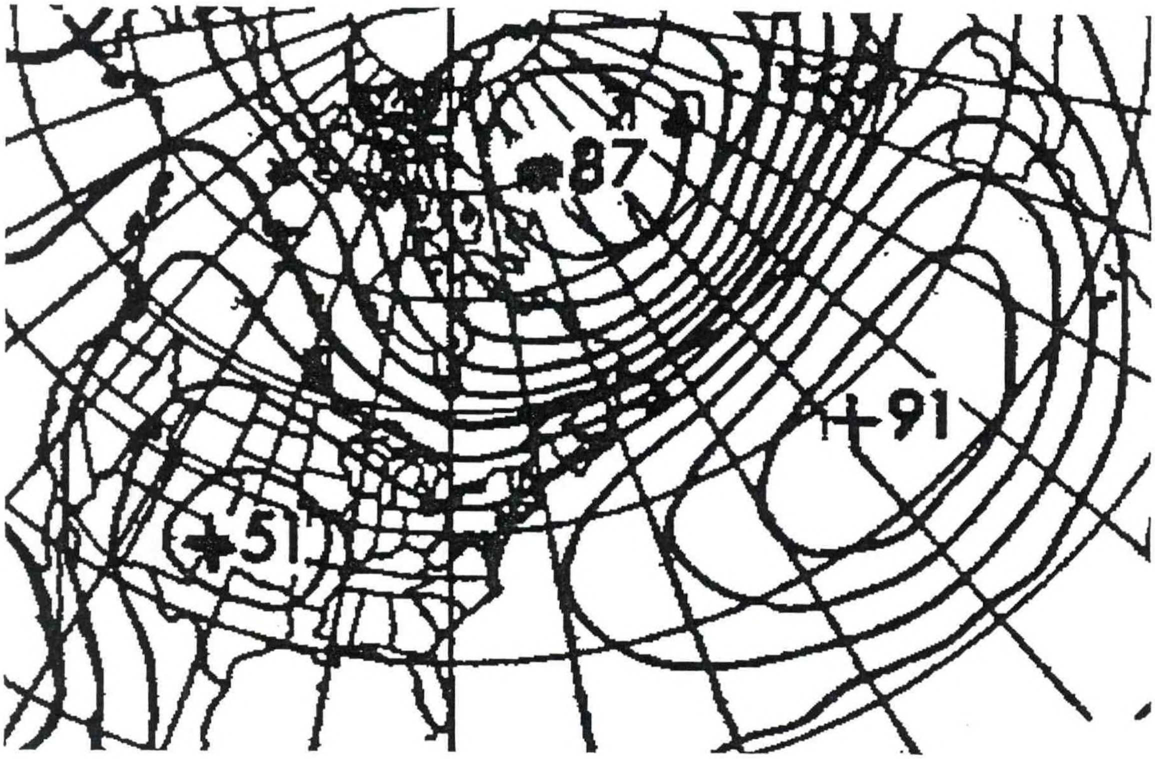

Figure 1: The positive phase of the NAO. Isopleths are lines of equal 500-mb height anomalies, every 15 meters. Algebraic signs are indicated. This figure is taken from Barnston and Livezey (1987).

Specifically, the positive NAO would feature large negative 500-mb height anomalies near Greenland, with reverse anomalies at the other two centers. If the signs of the height anomalies are reversed, that would be the negative phase of the NAO, with weaker than climatologically normal westerlies.

Figure 2 is a diagram taken from a paper by Lanzante (1990). This figure presents a good example of how a negative NAO could appear (or "project"). More detail is given in this figure for a response of the westerlies across the United States. Observe there would be negative height 500-mb anomalies across the western part of the country, with positive 500-mb height anomalies near Florida.

If there is a trough (ridge) in the 500-mb geopotential height field with negative (positive) height anomalies, shown in Figure 2 there is a storm track across the middle of the country. A storm track is a zonally elongated region of height field variabilities greater than climatology, for time-scales less than six days (Wallace et al. 1988). Referring to Figure 2, this would be the path that synoptic-scale cyclones and anticyclones would take, extending from the Southern Rockies northeastward to the Great Lakes states.

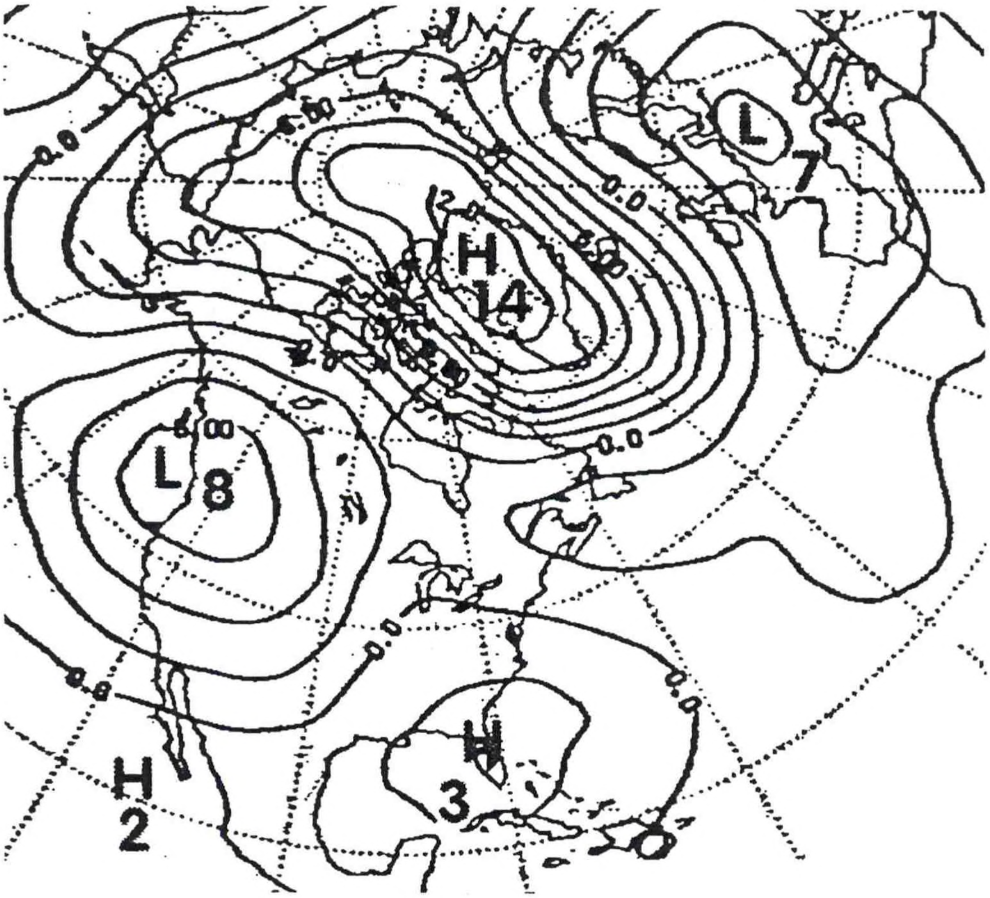

Figure 2: An example of a negative phase of the NAO, taken from Lanzante (1990). Isopleths can be thought of as every 20 meters for 500-mb height anomalies. H's (L's) are positive (negative) anomaly centers.

How is all the above relevant to operational forecasting, and the weather we experience? In what follows, some recent atmospheric events will be illustrated to help offer answers to these questions.

3. Circulation Changes During April 1995

Figure 3 is the AFOS graphic W5D, a chart generated by Western Region that displays averaged 500-mb height anomalies predicted from the MRF model over an upcoming five day period. This chart is from 0000 UTC 29 March to 0000 UTC 3 April 1995.

What can be observed, from Figure 3, is a positive PNA curved Rossby wave train, and a positive NAO. Figure 4 is the actual northern hemispheric 500-mb geopotential height analysis valid 1200 UTC 31 March 1995 (shown for just the western hemisphere). All features should be apparent to the reader, including the PNA and NAO patterns, such as the ridge over western North America and the deep cyclone near Greenland. Generally, the distribution of height anomalies shown in Figure 3 did approximately verify.

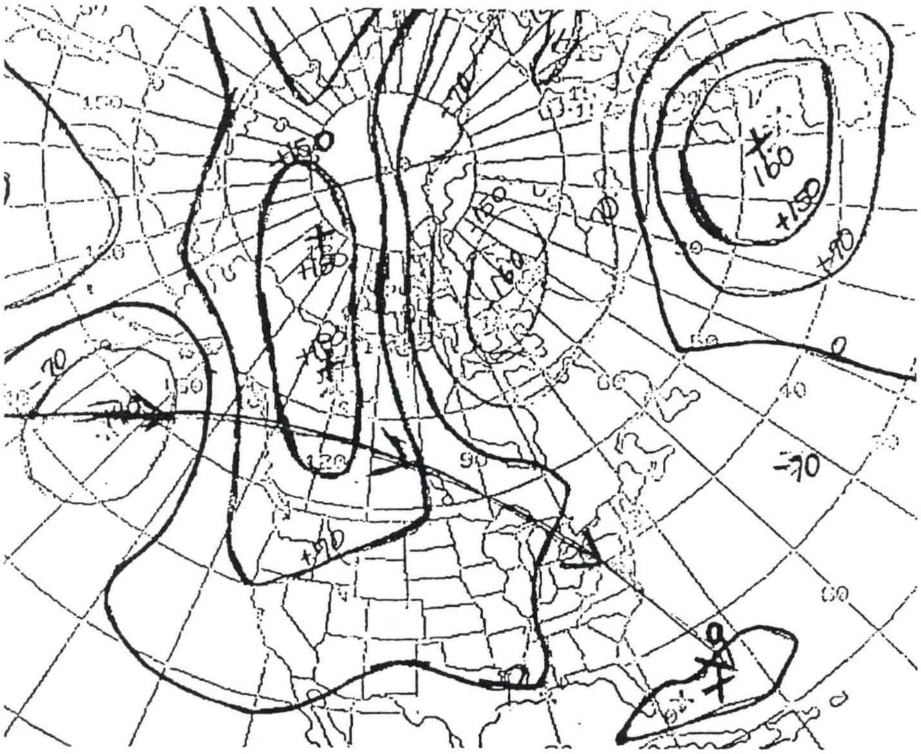

Figure 3: AFOS graphic W5D. Isopleths are analyzed every 70 to 80 meters, for the 500-mb MRF 5-day mean predicted geopotential height anomalies. Algebraic signs for the anomaly centers are indicated. Curved wave train was sketched in. This chart is the forecast valid from March 29 to April 3, 1995.

Now, refer to Figure 5, and compare that with Figure 3. Figure 5 is the W5D AFOS graphic valid from 0000 UTC 21 April to 0000 UTC 26 April 1995. Over a period of about three weeks (intra-monthly low frequency time-scale), the NAO changed phase, from positive to negative. The behavior of the NAO to change its phase during April has been suggested previously (see Barnston and Livezey 1987).

Observe the large 500-mb positive height anomalies predicted to be just to the west of Greenland. Also note that large positive height anomalies were forecasted to continue across western Canada, and even expand. End result, for all latitudes poleward of about 60° North, western hemisphere, large 500-mb

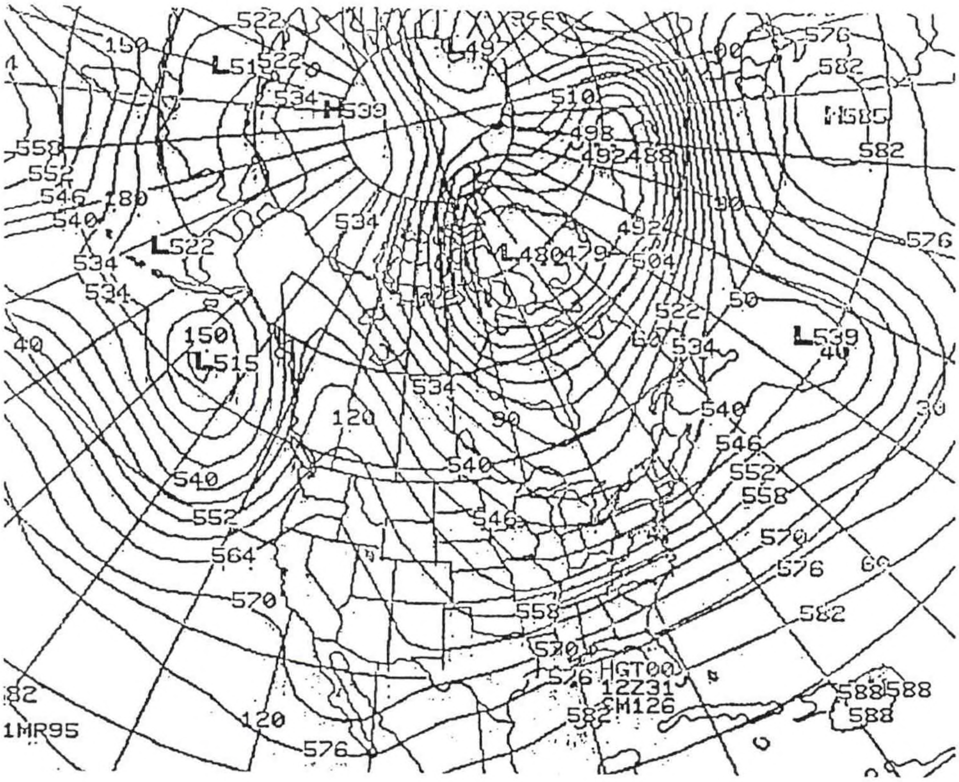

Figure 4. 500-mb northern hemisphere analysis valid 1200 UTC 31 March 1995. The western Hemisphere is shown, and the analysis is conventional.

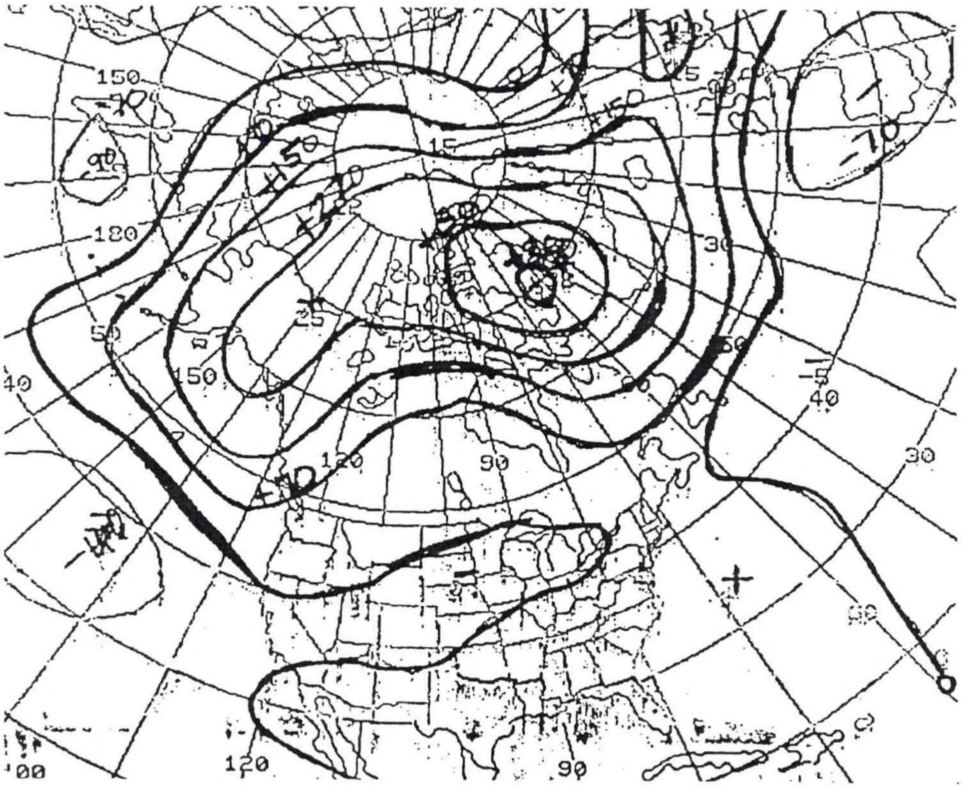

Figure 5. Same as Figure 3, but valid April 21 to 26, 1995.

positive height anomalies were predicted. To sum up, in the presence of the NAO changing polarity, the regime across North America went from one dominated by a curved Rossby wave train to one dominated by a meridionally oriented dipole of height anomalies. Put another way, a Rex-blocking like structure became established across much of Canada.

Again, Figure 5 shows a forecast, not an actual analysis. We are assuming (for our purpose) this prediction did approximately verify. This point will be addressed in the next section.

Perhaps because of the NAO changes, the polar jet stream westerlies were depressed southward across the lower 48 states. Furthermore, observationally, a storm track became established from the Southern Rockies to the Upper Mississippi Valley. To show this quantitatively, a proxy, such as 500-mb high frequency height variability, needs to be calculated. Indeed, from about April 7 to 25, several cyclones undergoing significant baroclinic development traversed the center part of the US, each accompanied with a variety of significant weather and substantial precipitation.

Figure 6 is the 500-mb geopotential height analysis valid 0000 UTC 21 April 1995. This "snapshot" is to give the reader a sense of the orientation of the storm track across the central US. Again, this type of track would be suggested by Figure 2 (although Figure 5 does not quite "match" Figure 2 across the US; there are other behaviors going on that are beyond the scope of this TA to address).

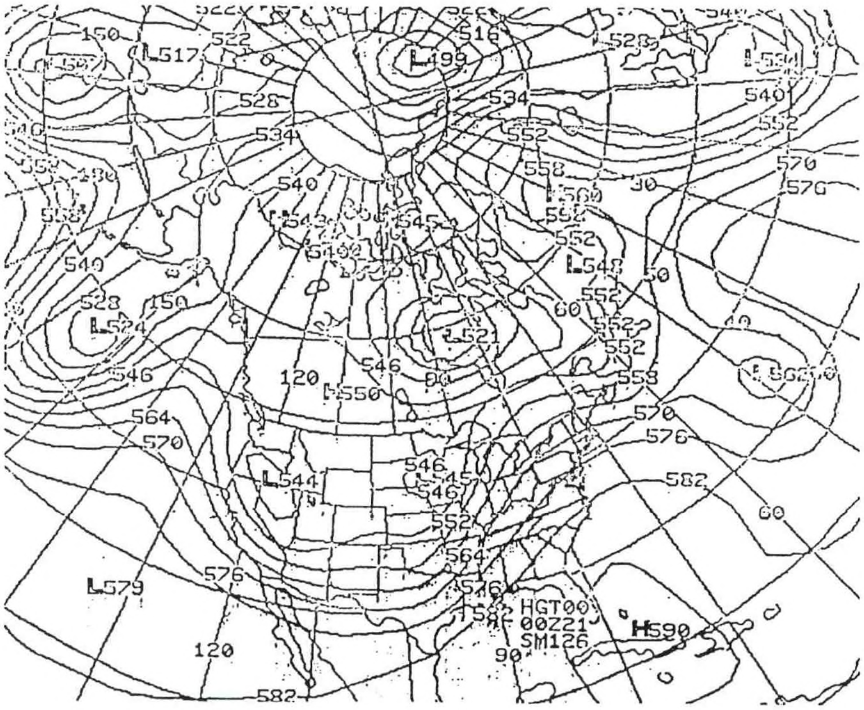

Figure 6. Same as Figure 4, but valid 0000 UTC 21 April 1995.

4. Tools to Observe and Predict the NAO

In all of the above discussion, except Figures 1 and 2, which were used for definitions, all reference was made to AFOS graphics. That is because, for the purposes of the topics discussed in this text, most operational forecasters only have AFOS. As stated in TA 95-09 (Berry 1995b), there are many far more sophisticated diagnostic and prediction tools that can help operational forecasters understand and predict LFVs in real-time (TA 95-09 shows some examples). Work is ongoing to make some of these tools available to the field in the future.

AFOS graphic W5D was used because it is a chart of 5-day mean 500-mb geopotential height anomalies, centered on day plus three (or D+3, as sometimes seen in the NMC PMDHMD and PMDEPD messages). The W5D charts shown above did verify well enough for our purposes. Having said that, the point is that 5-day mean charts are useful for extracting low frequency signals, much of the "synoptic-scale noise" will be filtered out.

For completeness, mention should be made that NMC does generate their own 5-day mean 500-mb geopotential height anomaly charts for the past five days (centered on day minus 3, or D-3), roughly centered on day zero (plus or minus 2.5 days, or D+0) and the next five days (D+3). The MRF model is used for the forecasts. These are charts that the field does not see at this time, but mention is often made of them in their discussions.

What an operational forecaster can do, with W5D, for example, is run an AFOS loop of about the past five to ten days worth (until the most recent initial conditions), and check for continuity, movement of anomaly centers, etc. That would be enough of a time history to assess something like the NAO changing phase.

If there is good continuity in the loop, then greater reliability for the prediction of planetary-scale (or "long-waves") features could be put in the actual MRF model output, for, say, days four through seven. The latter would be true for predicting a feature such as the orientation of a storm track, not the movements of individual cyclones and anticyclones. For much of April 1995, especially from about April 14 to 24, there were generally good agreement and continuity among the operational ECMWF, UKMET and MRF models with respect to the prediction of the storm track across the central US. The latter was true because the models "locked onto" the NAO phase change, a planetary-scale behavior.

5. Conclusion

A brief discussion of a mode of atmospheric low frequency variability (LFV), the North Atlantic Oscillation (NAO), was just given. Unlike the wave train patterns of the PNA and TNH teleconnections, the NAO is characterized by a dipole of height anomalies, with one center of action near Greenland and other near 35° North latitude/35° West longitude. The NAO is also observed during all 12 months. The behavior of the NAO can have a significant impact on the weather across the lower 48 states.

Two main points were made. First, observationally, during April 1995, the NAO changed phase, from positive to negative. That may have resulted in an energetic storm track becoming established from the Southern Rockies to the Upper Mississippi Valley.

Secondly, it was demonstrated that by simply using AFOS graphic W5D, it was possible to predict the behavior of the NAO in real-time. Furthermore, since 5-day mean charts are useful for extracting LFV signals, if there is continuity of features shown on W5D, greater reliability can be placed in the operational global models for storm track prediction.

6. Acknowledgements

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7. References

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