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6.6 LARGE-SCALE CIRCULATION ANOMALY INDICES IN RELATION TO COOL-SEASON PRECIPITATION EVENTS IN THE NORTHEASTERN UNITED STATES

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1. INTRODUCTION

Relationships between large-scale circulation anomaly indices (e.g., Wallace and Gutzler 1981), such as the North Atlantic Oscillation (NAO), Pacific-North American (PNA) pattern, and Southern Oscillation Index (SOI), and precipitation anomalies over the northeastern United States are hypothesized to exist. To test this hypothesis, we have calculated daily time series of these circulation anomaly indices. Daily, rather than monthly, values of the large-scale circulation anomaly indices are used to obtain a better understanding of the evolution of individual cyclone structure and life cycles in relation to changing large-scale circulation regimes. Specifically, we examine the relationship between two memorable East coast storms and the associated large-scale regime changes as measured by the NAO index.

2. DATA AND METHODOLOGY

To best represent regional-scale flow associated with large-scale circulation anomalies, such as the NAO, previous emphasis on NAO indices via sea-level pressure has shifted to an NAO index calculated from 500 hPa height data. This premise was established by Wallace and Gutzler (1981), who stated that regional representation of large-scale circulation anomalies is best defined at midtropospheric levels.

Two 500 hPa zonal domains, an Azores domain (30–45°N, 70–10°W) and an Iceland domain (55–70°N, 70–10°W), are used to define the NAO index. This definition matches that of the Climate Diagnostics Center (CDC). Daily NAO indices were computed by taking the difference of domain averaged 500hPa heights between the Azores domain and Iceland domain. Calculations of daily index values were made using NCEP/NCAR Reanalysis data for the 1953–1999 period. All 500 hPa height and height anomaly figures were produced using the CDC Daily Mean Composites Web page (www.cdc.noaa.gov). To filter out subsynoptic-scale influences on the NAO, a five-day running mean was applied to the daily values.

3. RESULTS

Figures 1 and 2 show daily and filtered NAO values encompassing the 12–14 March 1993 "Superstorm" (Kocin et al. 1995; Uccellini et al. 1995; Bosart et al. 1996; Dickinson et al. 1997), and the 5–9 January 1998 ice storm (Gyakum and Roebber 2001). The 12–14 March 1993 "Superstorm" (Fig. 1) matches up with a negative-to-positive NAO regime change, while the ice storm of 1998 (Fig. 2) matches up with a positive-to-negative NAO regime change.

The large-scale 500 hPa height and anomaly pattern prior to the Superstorm for 9–11 March 1993 (Figs. 3a,b) shows a large area of negative 500 hPa height anomalies associated with a trough over the North Atlantic bounded on the north by an area of positive 500 hPa height anomalies associated with a short-wave ridge over Iceland. The positive-north and negative-south anomaly pattern (Fig. 3b) is characteristic of the negative NAO values in Fig. 1 for this period.

Explosive cyclogenesis occurred during 12–14 March, coinciding with a negative-to-positive transition of the NAO (Fig. 1). Bosart et al. (1996) and Dickinson et al. (1997) showed that a strong downstream jet and ridge developed in conjunction with the Superstorm cyclogenesis. Development of a sharp downstream ridge over the NAO domain and the resulting intensification of the North Atlantic jet are indications of a strengthening positive NAO (not shown). From 14–16 March the remnant storm moved towards Greenland, as the 500 hPa downstream ridge and associated positive height anomalies reached western Europe (not shown). By 17–19 March 1993 (Figs. 3c,d) the 500 hPa short wave associated with the Superstorm had passed out of the domain while the large-scale trough, dominant prior to the event (Fig. 3a), had retracted poleward, resulting in a negative-over-positive 500 hPa height anomaly dipole that is characteristic of a positive NAO regime (Fig. 3d).

Unlike the 12–14 March 1993 " Superstorm," the 5–9 January 1998 ice storm coincided with a positive-to-negative NAO regime change (Fig. 2). The entire regime change consisted of two phases. The first phase included a change from positive to weakly negative NAO values. The weak negative NAO regime lasted for nearly two weeks before becoming more strongly negative. The absence of deep cyclogenesis during the first phase suggests that this process is not a factor in the initial NAO regime change. Prior to the ice storm, a very large 500 hPa height gradient and associated jet (Fig. 4a) over the North Atlantic was reflected in a textbook positive NAO pattern in the 500 hPa height anomaly field (Fig. 4b). As with the Superstorm, the regime change in the NAO occurred during the ice storm.

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Over the period 5–9 January, a 500 hPa short wave dug into the southeastern US, which resulted in the downstream development of a 500 hPa ridge–trough system (not shown). This evolution of the large-scale pattern broke down the positive NAO regime in place prior to the event. Positive 500 hPa height anomalies for this pattern were in the ridge, with negative anomalies in the trough. The meridional orientation of these anomalies resulted in a weak negative NAO signature. From 10–13 January, a deep trough resided over the eastern Atlantic with zonal flow upstream. The associated 500 hPa height anomalies were negative in the trough and positive in the zonal flow (not shown). The anomaly pattern retained a meridional orientation, consistent with a weak negative NAO.

By 13–15 January (Figs. 4c,d), the 500 hPa trough over the eastern Atlantic has been replaced by a cutoff low east of Labrador and a downstream high-amplitude ridge. The resulting 500 hPa height anomaly pattern features a large positive anomaly center in the northern domain over the Davis Strait and weak negative and positive height anomalies over the southern domain.

From 16–18 January the Labrador 500 hPa cutoff and associated high-amplitude ridge move eastwards. A weak high-latitude ridge associated with a negatively tilted short wave in the northern branch has built in behind the cutoff. The two ridges on either side of the cutoff show up as a southwest–northeast elongated positive 500 hPa height anomaly (not shown).

By 19–22 January, the easternmost cutoff low has moved out of the domain and a negatively tilted trough cuts off over the Northeast. The formation of the 500 hPa cutoff low allows a sharp downstream ridge–trough pattern to develop. The ridge and upstream cutoff are reflected as a positive-over-negative 500 hPa height anomaly pattern, suggesting an increase in the magnitude of the negative value of the NAO index (Fig. 2).

Finally, by 23–25 January a Rex-type blocking pattern is in place with a cutoff anticyclone (cyclone) situated over England (Spain) (Figs. 4e,f). This pattern arose as the high-latitude ridge near Greenland shifted eastward while a short-wave tough undercut the ridge, resulting in a strongly negative NAO pattern.

4. SUMMARY

A comparison of daily NAO values for two significant Northeast US precipitation events has revealed that a transition in the NAO regime accompanied both events. For the 12–14 March 1993 "Superstorm" event, the resulting downstream jet and ridge development was associated with a negative-to-positive NAO regime change. The 5–9 January 1998 ice storm, which coincided with a positive-to-negative NAO regime change, occurred in the absence of deep cyclogenesis. For both cases, changes in the NAO regime were triggered by changes in the upstream large-scale pattern.

5. ACKNOWLEDGMENTS

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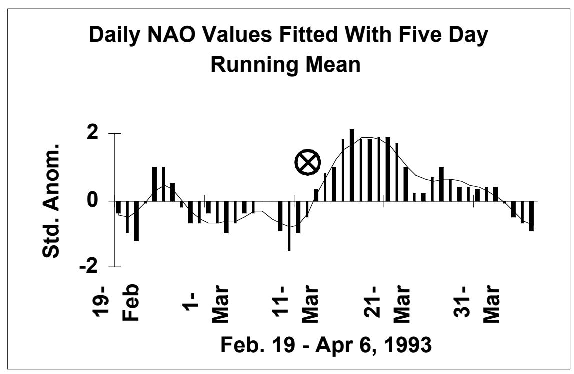

Fig. 1. Timeline of daily NAO index (bars) and five-day running mean of daily NAO index (thin solid line). The marker represents the 12–14 March 1993 "Superstorm." Ticks along the horizontal axis are spaced 10 days apart.

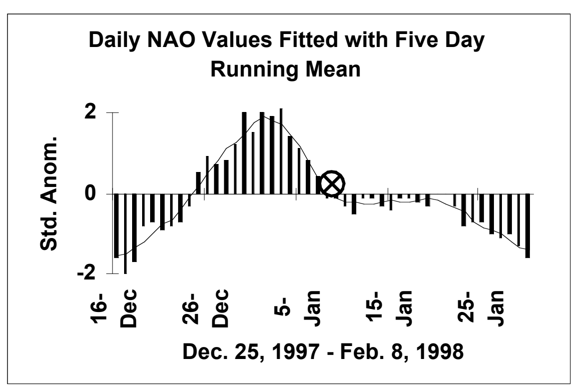

Fig. 2. Timeline of daily NAO index (bars) and five-day running mean of daily NAO index (thin solid line). The marker represents the 5–9 January 1998 ice storm. Ticks along the horizontal axis are spaced 10 days apart.

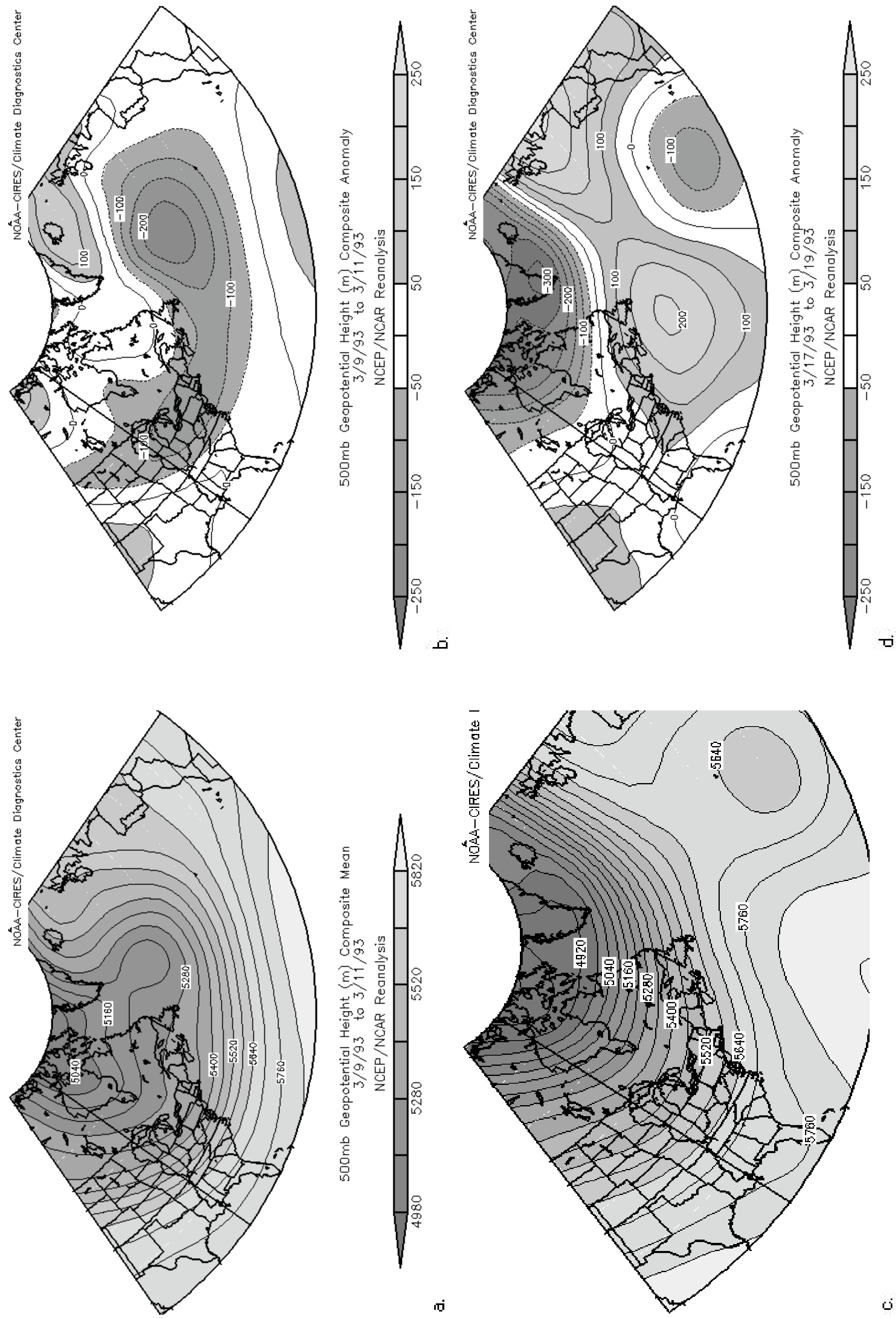

Fig. 3. 500 hPa analyses showing: (a) geopotential height (m) for 9–11 March 1993. (b) geopotential height anomalies (m) for 9–11 March 1993. (c) geopotential height (m) for 17–19 March 1993. (d) geopotential height anomalies (m) for 17–19 March 1993.

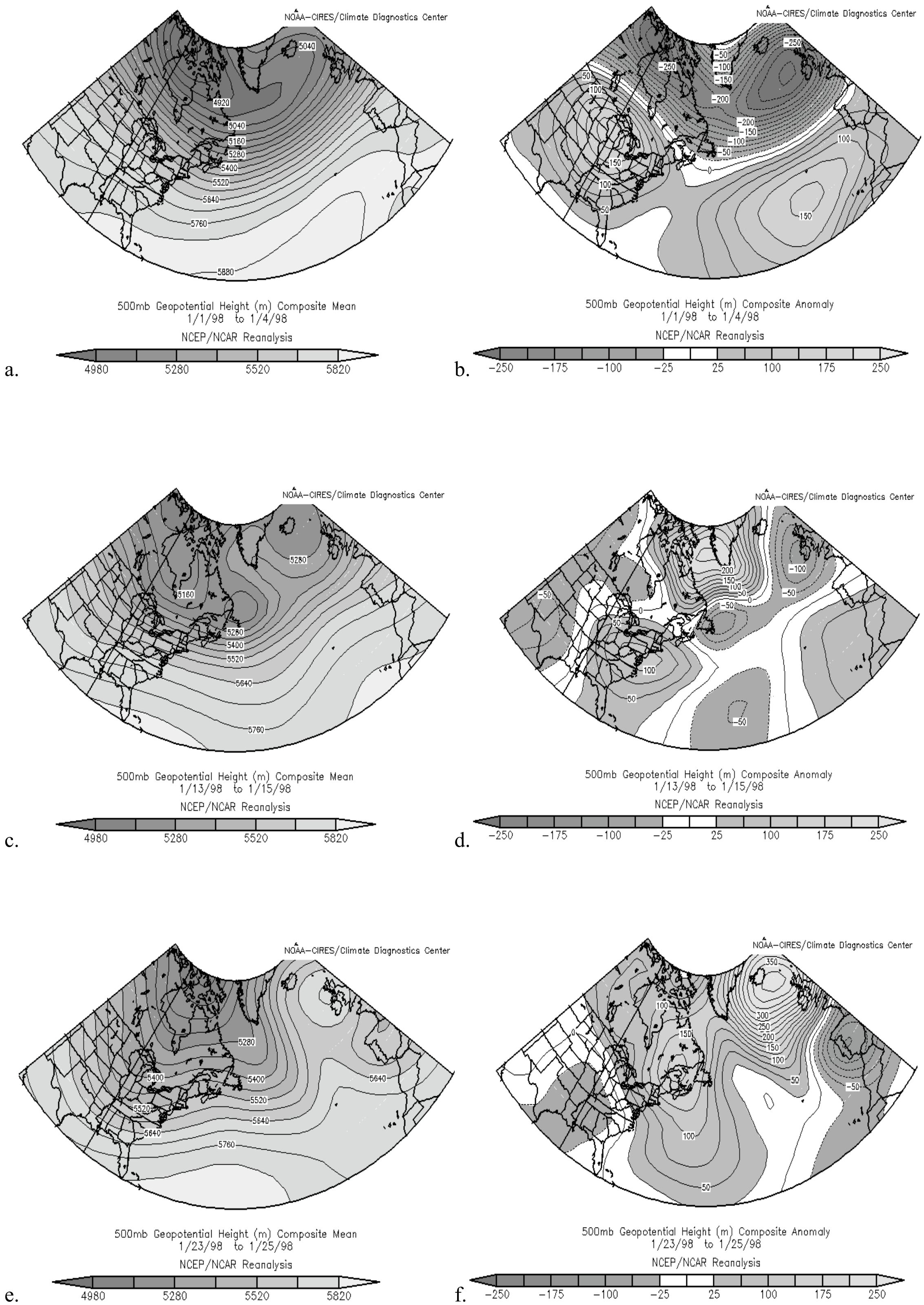

Fig. 4. 500 hPa analyses showing: (a) geopotential height (m) for 1–4 January 1998. (b) geopotential height anomalies (m) for 1–4 January 1998. (c) geopotential height (m) for 13–15 January 1998. (d) geopotential height anomalies (m) for 13–15 January 1998. (e) geopotential height (m) for 23–25 January 1998. (f) geopotential height anomalies (m) for 23–25 January 1998.