Resent-From: <jkenyon@ALBANY.EDU>
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Subject: **Synopsis of Friday map discussion for 8 Feb 2013**
Date: 10 February 2013 7:09:55 PM EST
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Hi Everyone,

The focus of jam-packed Friday map discussion for 8 Feb 2013 was, not surprisingly, on the major Northeast coastal storm already in progress at that time. Because this storm involved the the rmerger/phasing of separate troughs and their associated vorticity maxima in the northern and southern branches of the westerlies, a longstanding operational challenge to forecasters and models alike, we began with a discussion of the trough merger/phasing problem. Synoptic experience indicates that when two upper-level disturbances (PV anomalies) located in separate branches of the westerlies come into relatively close proximity (i.e., merge/phase) their mutual interaction can induce explosive cyclogenesis.

Web links and papers referenced during the map discussion and added subsequently based on the discussion are contained in the map discussion link prepared by Philippe Papin and are available here: http://www.atmos.albany.edu/student/ppapin/mapdisco/20130208/ Philippe and Jaymes Kenyon also provided ample last-minute support for the discussion.

I. Brief Storm History:

The 8-9 Feb 2013 storm produced widespread snowfall totals from 0.5-1.0 m across parts of southern and eastern New England. This storm moved northwestward offshore, intensified rapidly south of New England, and was situated just east of Cape Cod, MA at 1200 UTC 9 Feb. The corresponding NCEP-OPC surface analysis showed this storm with a 970 hPa central pressure at this time (http://www.opc.ncep.noaa.gov/Loops/UA_East_coast_hires/UA_East_coast_hires_07_Day.shtml). The southern stream disturbance involved in the trough merger/phasing appears as a small area of relatively lower potential temperatures (314-318 K) on the dynamic tropopause (DT) west of Los Angeles, CA (near 36 N and 128 W) and as an area of cyclonic flow at 500 hPa (http://www.atmos.albany.edu/student/ppapin/mapdisco/20130208/images/dt_name

r.html;
http://www.atmos.albany.edu/student/ppapin/mapdisco/20130208/images/500vort_namer.html) at 0000 UTC 30 Jan.

Over the next few days this DT/500 hPa disturbance migrates slowly southward, turns northward ahead of a deepening trough in the eastern Pacific, and reaches coastal southern Oregon by 0000 UTC 3 Feb. Subsequently, the DT/500 hPa disturbance moves southward along the California coast, turns eastward across northern Mexico by 0000 UTC 5 Feb, and reaches south-central Texas by 1200 UTC 6 Feb. This DT/500 hPa disturbance reaches the East Coast by 0000 UTC 8 Feb as it turns northeastward. Cold-air damming east of the Appalachians and a strong 850 hPa baroclinic zone along the coast poleward of the coastal cyclone are in place by 0000 UTC 8 Feb (http://www.atmos.albany.edu/student/ppapin/mapdisco/20130208/images/850temp_namer.html).

The northern stream DT/500 hPa disturbance is situated over the southwestern Gulf of Alaska at 0000 UTC 4 Feb. It fractures from the main oceanic trough over the Gulf of Alaska and reaches Vancouver Island by 1200 UTC 5 Feb. Subsequently, this DT/500 hPa disturbance initially weakens as it crosses the Pacific Northwest and northern Rockies and restrengthens east of the northern Rockies by 0000 UTC 7 Feb. By 0000 UTC 8 Feb the northern stream DT/500 hPa disturbance is approaching the western Great Lakes. Trough merger/phasing of the northern and southern stream DT/500 hPa disturbances occurs over New England and the immediate coastal waters of the North Atlantic between 1800 UTC 8 Feb and 1200 UTC 9 Feb as the PV hook signature characteristic of intense cyclogenesis develops (http://www.atmos.albany.edu/student/ppapin/mapdisco/20130208/images/jet_namer.html; discussed more fully below).

II. Trough mergers/phasing:

Motivated by the forecast challenge of trying to predict trough merger/phasing, Gaza and Bosart (1990) conducted the first systematic study of the trough merger/phasing problem from a forecasting perspective. They showed that the then-NMC LFM model had a difficult time forecasting the merger/phasing of individual 500 hPa disturbances in separate branches of the westerlies more than 24 h in advance. Of the 21 cases studied, only 12 and 2 of them were correctly forecast in the 24 h and 48 h LFM forecasts, respectively. Hakim et al. (1995) conducted a case study Cleveland Superbomb of 25-26 January 1978 over North

America and showed that the ultimate storm intensity was strongly conditioned by the merger/phasing of northern and southern stream disturbance with the northern stream providing most of the baroclinicity and the southern stream providing most of the (tropical) moisture. Bosart et al. (1996) and Dickinson et al. (1997) found similar results for the 13-14 March 1993 Superstorm over eastern North America.

As Dan Keyser reminded us during the discussion, Hakim et al. (1996) conducted a further theory-based diagnostic analysis of the Cleveland Superbomb. From their abstract: "A simple model is proposed that includes the three primary elements of this case: two vortices and a background flow. For a barotropic atmosphere on an *f* plane, the vortices are represented by rigid vortex patches and the background flow by a hyperbolic deformation field that is fixed in time. Solutions representative of observed parameters (from the Cleveland Superbomb storm) exhibit many of the properties of the observed case, including "merger." Solutions corresponding to merger are found to be extremely sensitive to small changes in the deformation field for a given set of initial conditions describing vortex position, size and strength, suggesting limitations to the predictability of the merger phenomenon." Current forecast experience with trough merger/phasing as typified by the current storm suggests that while there has been a vast improvement in model forecast capability since the old LFM days, important predictability issues still remain with respect to the proper simulation of the trough merger/phasing process. That said, important predictability issues remain with trough merger/phasing cases as is readily apparent from looking at Kyle Griffin's GFS-based d(prog/dt) loops (http://www.atmos.albany.edu/student/kgriffin/maps/ and my poor-man's ECMWF d(prog)/dt loops (http://www.atmos.albany.edu/student/ppapin/mapdisco/20130208/; select from the four options available on the map discussion home page).

A characteristic of explosively deepening cyclones associated with trough merger/phasing is that the SLP gradient around these storms is highly asymmetric with the strongest SLP pressure gradients….and highest surface wind speeds….found in the western and northern quadrants of the storm. The strong SLP gradient on the western and northern sides of the storm is usually associated with a bent-back warm front and a fractured cold front (Shapiro and Keyser 1990). The former feature was also called the "poisonous tail of the bent-back occlusion" by Gronas (1995) because it is often an area where destructive high wind events (amidst "tails" of woe) can occur in conjunction with frontogenetically forced vorticity concentration and vorticity roll-up along the bent-back front. The "poisonous tail" has also been called a "sting jet" by Browning (2004) and Browning and Field (2004) because damaging winds were observed to occur near the tip of the poisonous tail. Sting jets are described in more detail in an online powerpoint by Vaughan (2012).

III. Science Issues and Opportunities:

Science issues and opportunities discussed during the map discussion included the need to establish a benchmark global climatology of trough/merger and phasing. Although the preliminary and limited findings by Gaza and Bosart (1990) suggested that over North America trough merger/phasing was mostly a forecast issue east of the Rockies, their study was limited to two years and gridded data was unavailable to do a more general and longer study. It is important to establish the frequency of trough merger/phasing, its interannual and intraseasonal variability (e.g., does the frequency of trough merger/phasing depend on the phase and amplitude of ENSO or the MJO?), and the preferred regions of the globe where trough merger/phasing may be maximized. More generally, because many big memorable cold season storm have been associating with trough phasing/merger to some extent, one could ask the question how trough merger/phasing might change in a future warmer climate, what the consequences would be on future storm tracks, and what the impact would be on the future cold-season precipitation distribution. Once a trough merger/phasing climatology is available it should be possible to construct representative composite and case study analyses to help further understand the structure and evolution of trough merger/phasing and the relevant dynamical and thermodynamical processes at work.

There is also a good scientific opportunity to conduct more theoretical and idealized modeling studies of the trough merger/phasing process. Hakim et al. (1996) suggest that whether two barotropic vortices embedded in a background deformation flow will merge is very sensitive to small changes in the background deformation field for a specified set of initial conditions for the two vortices. Their results imply that significant predictability issues remain to be addressed in conjunction with the trough merger/phasing process because as we have seen, real cases of trough merger/phasing typically involve baroclinic weather systems in the presence of significant diabatic heating. The addition of baroclinicity and diabatic heating (stratiform and convective) to the trough merger/phasing mix is bound to add even more complexity and uncertainty to the forecasting process, making this a ripe topic for future predictability studies. Look no farther than the 8-9 Feb 2013 trough merger/phasing explosive cyclogenesis event (970 hPa cyclone of the New England coast at 1200 UTC 9 Feb) to see the importance of negative PV advection by the upper-level irrotational wind in forming the PV hook that is so characteristic of explosive cyclogenesis (compare Heather Archambault's loops of divergent outflow and jet-nteraction, and PV advection by the non divergent wind for the 8-9 Feb case [available at: http://www.met.nps.edu/~hmarcham/2013.html)] and note how PV advection by the diabatically driven irrotational wind preferentially opposes PV advection by the non divergent wind, leading to PV hook formation).

For possible guidance on how to conduct theoretical and idealized modeling studies of trough merger/phasing we might look to the work of Riemer and Jones (2010) who studied the interaction of recurving and transitioning tropical cyclones (TCs) with the baroclinic wave guide defined by the oceanic subtropical jet (STJ). A category of TC-STJ interaction exists that also involves additional interactions with midlatitude baroclinic disturbances. Although these kinds of tropical and midlatitude interactions may be "distant cousins" of midlatitude trough merger/phasing events, common physical processes may be in play for both types of interactions and warrant further scientific investigation.

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