NAM-WRF Verification of Subtropical Jet and Turbulence

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ABSTRACT

The Ellrod Index is a commonly used tool for diagnosing turbulence events across the National Airspace System (NAS). Aviation Weather Center (AWC) forecasters have observed Ellrod Index values that overestimate the potential for turbulence and its intensity in association with the subtropical jet (STJ). This overestimation was observed when the NAM-WRF model was used to calculate the Ellrod Index. Verification efforts have identified a problem with the NAM-WRF incorrectly forecasting winds aloft associated with the STJ. This over-forecast can be anticipated by detecting weather regimes that exacerbate this problem, and mitigated by augmenting the forecast with other data.

1. Introduction

The effects of turbulence on commercial air traffic are significant. An average of 18 injuries per year was reported during 1996–2000 due to turbulence (Baker 2004). It is important to the entire National Airspace System (NAS) that turbulence location and intensity be known at any given time to protect life and property, and to provide a safe environment. The National Weather Service (NWS) Aviation Weather Center (AWC) uses the Ellrod Index (Ellrod and Knapp 1992) to determine the potential for turbulence and its intensity.

The Ellrod Index is an objective technique for forecasting clear-air-turbulence (CAT). The index is calculated based on the product of horizontal deformation and vertical wind shear derived from numerical model u- and v-wind components, expressed in units of 10^{-7} s^{-2}. The resulting values represent the potential for turbulence (Ellrod and Knapp 1992). The output values at the grid spacing used in the present evaluation (i.e., 90 km) represent turbulence intensity as shown in Table 1.

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AWC forecasters have observed that these Ellrod Index values in the vicinity of the subtropical jet (STJ) are too high when using data from the North American Mesoscale (NAM) Weather Research and Forecasting (WRF) model (NAM-WRF). Even though the native grid of the NAM-WRF was 12 km as of June 2008, the Ellrod Index used at the AWC is computed using the NAM-WRF 200- and 250-hPa winds from a coarser 90-km polar stereographic grid (Grid #104, NCEP 2008). The NAM-WRF model has 22 vertical layers above 500 hPa (UCAR 2008). As alluded to above, verification efforts have identified a problem with the model incorrectly forecasting winds aloft associated with the STJ. This problem has led to extra time and resources to develop an accurate forecast of turbulence throughout the NAS.

2. Hypothesis

AWC forecasters have observed Ellrod Index values that overestimate the potential for any turbulence in association with the STJ. This forecasting problem is most evident over the southern United States. The Ellrod Index suggests the presence of turbulence on many days when no turbulence, or lower intensity turbulence, is reported. This discrepancy has brought up many questions regarding the validity of the Ellrod Index calculated from the NAM-WRF model in association with the STJ. The two most prominent questions follow: Why does the Ellrod Index indicate turbulence when no evidence of turbulence exists? Why does the Ellrod Index overestimate intensities of turbulence in association with the STJ?

The u- and v-wind components are the only inputs for the Ellrod Index, clearly making them the focus of any problems. Since it is difficult to verify u- and v-wind components in an operational setting, the total wind can be computed from the u- and v- components and subsequently compared to radiosonde and wind profiler data. Evaluation of the total wind at 200 and 250 hPa provides a more efficient way to determine if the NAM-WRF winds are the problem, since the STJ is primarily found near 200 hPa (Palmén and Newton 1969). It then can be deduced whether or not the NAM-WRF forecast winds at 200 and 250 hPa are the concern. A subjective verification scheme was devised to try to identify the problem.

3. Methodology

The General Meteorology Package (GEMPAK, Unidata 2008) software was used to display relevant fields from each forecast cycle of the NAM-WRF. The first display incorporated 12-h forecast winds at 200 and 250 hPa with winds from observed soundings, radar Velocity Azimuth Displays (VADs), and the wind profiler network for the corresponding time frame (e.g., Fig. 1). The 12-h model forecast was selected as it was deemed one of the most frequently used by AWC forecasters to aid in issuing turbulence Airmen's Meteorological Information (AIRMETs). An AIRMET is a concise description of the occurrence, or expected occurrence, of specified en route weather phenomena which may affect the safety of aircraft operations, but at intensities lower than those which require the issuance of a Significant Meteorological Information (SIGMET) bulletin (NWS 2008). A second display consisted of the 12-h forecast of the Ellrod Index from 200 through 400 hPa overlaid by pilot reports (PIREPs) that were within ±1 h of the valid time (e.g., Fig. 2). The last display (not shown) included cloud-to-ground lightning data overlaid by PIREPs to eliminate turbulence reports related to thunderstorms. The lightning data and PIREPs were displayed across the continental United States within ±1 h of the valid time.

A subjective analysis was done to find discrepancies along the STJ from August 2006 through September 2007. The various 200-hPa forecast wind images were evaluated against radiosonde, wind profiler, and VAD wind data. A deviation of ≥10 kts between the forecast and observed winds was designated as an erroneous forecast. The deviation of ≥10 kts was used because smaller values were not deemed operationally significant. This evaluation then was repeated for the 250 hPa level. If either the 200 or 250 hPa forecast winds were found to be in error, then both displays were examined further. The lightning–PIREP and Ellrod Index–PIREP displays for the corresponding time frame were also evaluated.

The 200–400-hPa Ellrod Index and PIREP displays were evaluated in the geographical area along the STJ where the winds were found to be in error based on the criteria above. The data were examined to determine if the forecast turbulence was observed at the location and at the predicted intensity. If PIREPs were available and none matched the forecast location or intensity of the turbulence, the forecast was deemed to be in error. The display of cloud-to-ground lightning and PIREPs was examined to determine if convective activity had any influence on the pilot reports in the area.

A composite analysis was made of the wind at 250 hPa based on the average position and intensity of the wind at each level over the days that the wind forecasts were found to be in error. These averaged values were then displayed across the United States. This composite aided in showing the different regimes—specifically, when and where the over-forecasting of turbulence and winds by the NAM-WRF were most prevalent. The Climate Diagnostics Center website was used to produce the analysis (http://www.cdc.noaa.gov/cgi-bin/Composites/printpage.pl).

4. Analysis and results

The NAM-WRF model had the tendency to over-forecast wind speeds at 200 and 250 hPa. These higher wind speeds were used in the Ellrod Index formula, resulting in increased forecasts of turbulence and at higher intensities with the STJ. The NAM-WRF shows the greatest likelihood of this over-forecasting when the winds associated with the STJ have an anti-cyclonic curvature. The model over-forecast the winds at these two levels by 7.5–10 m s^{-1} (15–20 kts) at times when this anticyclonic turning was taking place (e.g., Fig. 1). This happens most in a split flow regime at 200 and 250 hPa. In general, a mean trough is located over the western United States, and a second mean trough is located over the Great Lakes area (Fig. 3). Also at these levels, a confluent/convergent flow is observed over the Four Corners area in the southwestern United States. The surface analysis usually exhibits a low positioned near southern California, with a surface trough moving east-southeast from the northwestern United States (not shown). Other observations include:

- In the 13-month period of observations, 16 days were found to have discrepancies of greater than 5 m s^{-1} (10 kts) between forecast winds and observed winds at 200 and 250 hPa (Table 2).
- The composite of 250 hPa winds showed a speed maximum over northern New Mexico, the Texas panhandle, and western Oklahoma, and another speed maximum off Vancouver Island extending into the Washington state coastal waters (Fig. 3).

5. Case study: 29 October 2006

An example that is representative of situations where the Ellrod Index over-forecasts turbulence occurred 29 October 2006 around 1200 UTC. Similar to the composite, there was a trough centered along 130W and another center along 80W (Fig. 4). An observed area of higher wind speeds—according to observed soundings, VAD winds, and wind profiler data—extended from near Needles, CA, to Roswell, NM (Fig. 1, note the circles). The one circle shows the model forecast wind of 41 m s^{-1} (80 kts) compared to the observed wind of only 33 m s^{-1} (65 kts). The other circle shows the model forecast wind of 41 m s^{-1} (80 kts) and observed winds of only 23 m s^{-1} (45 kts). This led to forecast Ellrod Index values of 8 to 32 across northern Arizona into central New Mexico, suggesting moderate to severe turbulence (Fig. 2, Table 1). The "night shift" AWC forecaster recognized this as a potential problem pattern and used weaker forecast winds from the concurrent run of the Global Forecast System (GFS) model, resulting in considerably less turbulence, and an official forecast of only light-to-moderate turbulence at 1200 UTC. Available PIREPs between 1000 UTC and 1400 UTC showed only light turbulence, verifying the forecaster's downward adjustment, and allowing for normal NAS operations. It should be noted that the availability of PIREPs is limited at this time of day over the geographical area of this case study.

6. Conclusions

The NAM-WRF wind and turbulence forecasts associated with the STJ must be used with a great degree of caution. A composite analysis for 16 days with significant errors in upper-level winds resulted in a pattern with two long wave troughs (one over the western U.S. and the second over the Great Lakes) and confluent/convergent flow over the Four Corners area at 200 and 250 hPa. This situation should be considered as suspect, such that winds and resulting turbulence may be over-forecast. Also, anytime the STJ has anti-cyclonic curvature anywhere over the southern United States, the winds and turbulence should be analyzed further. It is during these specific weather regimes that the 200 and 250 hPa forecast winds from the NAM-WRF model must be verified before turbulence guidance can be used in conjunction with the STJ. It is in the best interest of the forecaster to examine how well the model was initialized via comparison with radiosonde, profiler, and VAD wind data. Further research should be focused on other model output to see if those models have a better forecast of winds and turbulence associated with the STJ. The problem has been brought to the attention of the programmers and developers of the NAM-WRF model through examples and conference presentations; they are currently diagnosing the problem.

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TABLES AND FIGURES

Table 1. Ellrod Index intensity thresholds in units of 10^{-7} s^{-2} (based on model output with 90-km grid spacing).

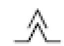
Threshold Value	Category	Symbol
4	Moderate	
8	Moderate-Severe	
12	Severe	

Table 2. Dates, times, and geographical areas for 16 days in which a wind error of ≥5 m s^{-1} (≥10 kts) was observed at 250 hPa.

Date	Time	250-hPa Obs. Wind (kts)	250-hPa Fcst. Wind (kts)	Wind Speed Error (kts)	Geographical Area
9/26/07	12Z	90	116	26	Southern OK
9/26/07	00Z	80	102	22	Northeast TX
2/28/07	12Z	150	185	35	AZ NM Area
12/27/06	12Z	95	114	19	Central TX
12/19/06	12Z	120	162	42	Southwest TX
12/5/06	12Z	80	97	17	Southwest TX
10/29/06	12Z	45	80	35	AZ NM Area
10/24/06	00Z	80	95	15	4-Corners Area
9/25/06	12Z	80	94	14	Central TX
9/20/06	12Z	100	122	22	4-Corners area
9/20/06	00Z	85	101	16	CO
9/17/06	12Z	70	81	11	GA area
9/17/06	00Z	60	76	16	Southwest TX
9/16/06	00Z	35-40	50	10-15	Southwest TX
9/12/06	12Z	40	55	15	Southern AZ
8/31/06	00Z	40	56	16	TX

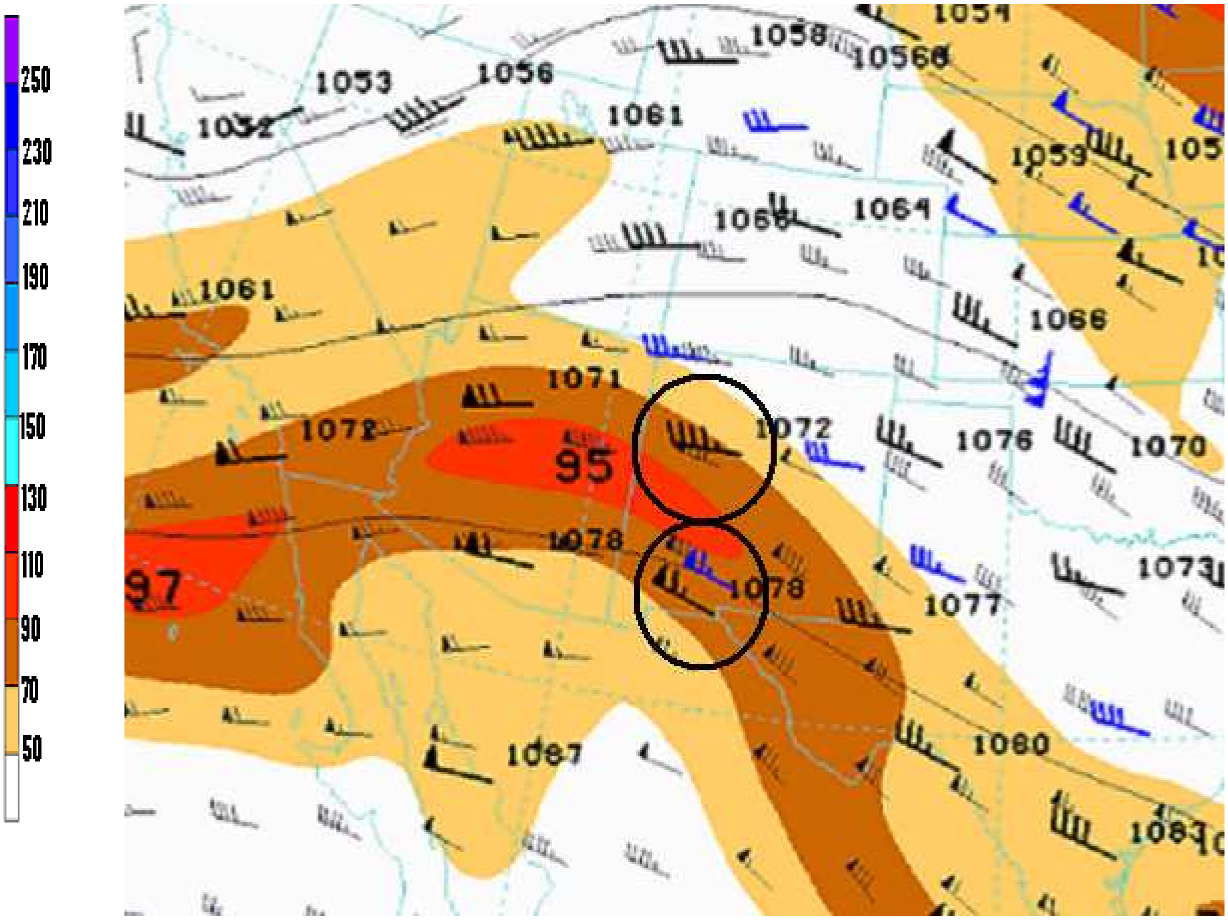


Figure 1. NAM-WRF 12-h forecast of 250-hPa isotachs (shaded, kts) and wind barbs (black, kts) valid 1200 UTC 29 Oct 2006. Also shown are the concurrent 250-hPa observed profiler winds (blue, kts) and observed sounding winds (large black, kts). Circles highlight areas with relatively large forecast errors.

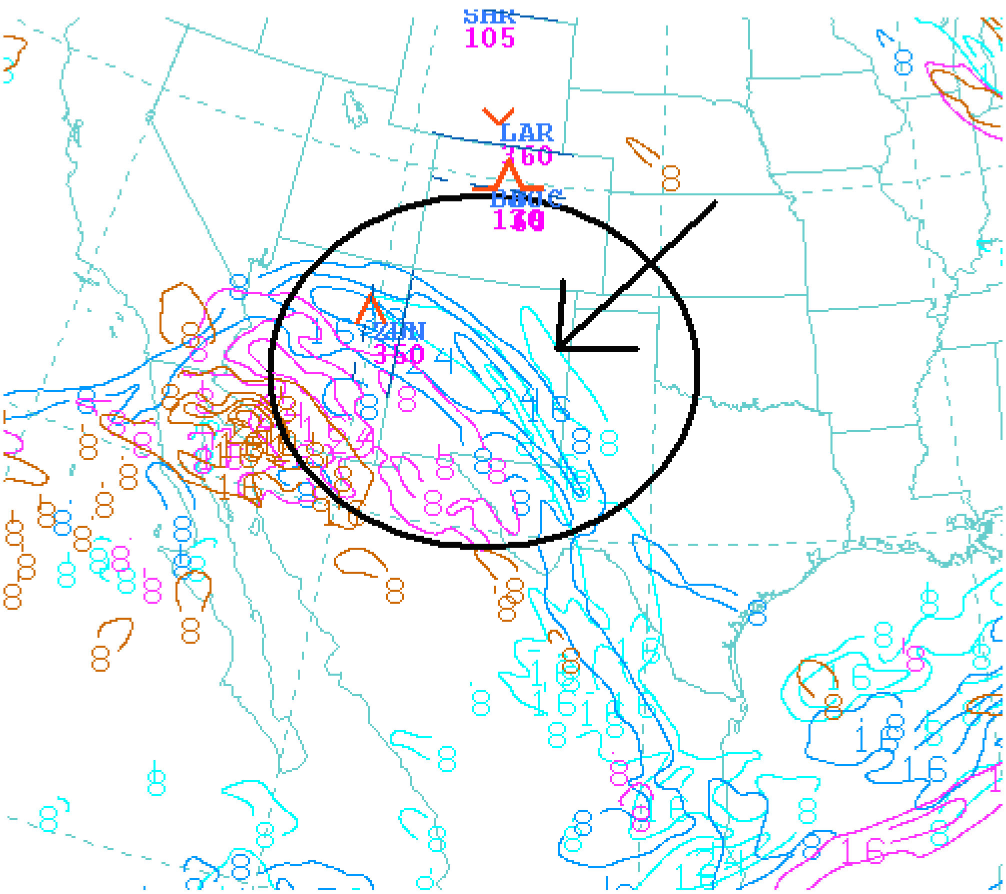


Figure 2. NAM-WRF 12-h forecast of 200 through 400 hPa Ellrod Index valid 1200 UTC 29 Oct 2006 (turquoise 200-250 hPa, blue 250-300 hPa, pink 300-350 hPa, brown 350-400 hPa). Also overlaid are pilot reports (PIREPs) within ±1 h of the valid time. The circle and arrow highlight an area of over-forecast Ellrod Index values.

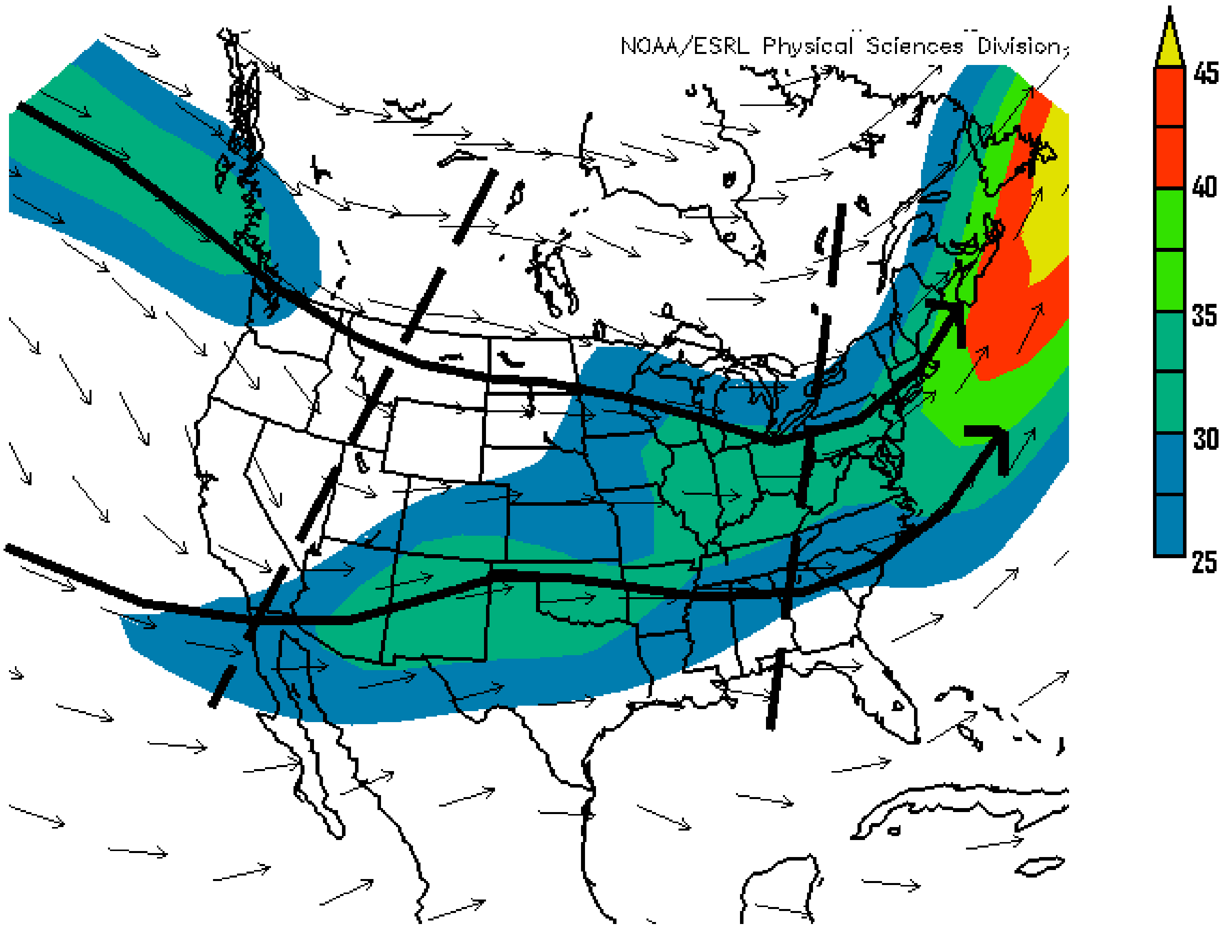


Figure 3. Composite analysis of 250-hPa wind (kts) for the 16 days with large wind errors listed in Table 2. Arrows show split flow, and dashed lines show mean troughs. Image courtesy of the Climate Diagnostics Center (http://www.cdc.noaa.gov/cgi-bin/Composites/printpage.pl).

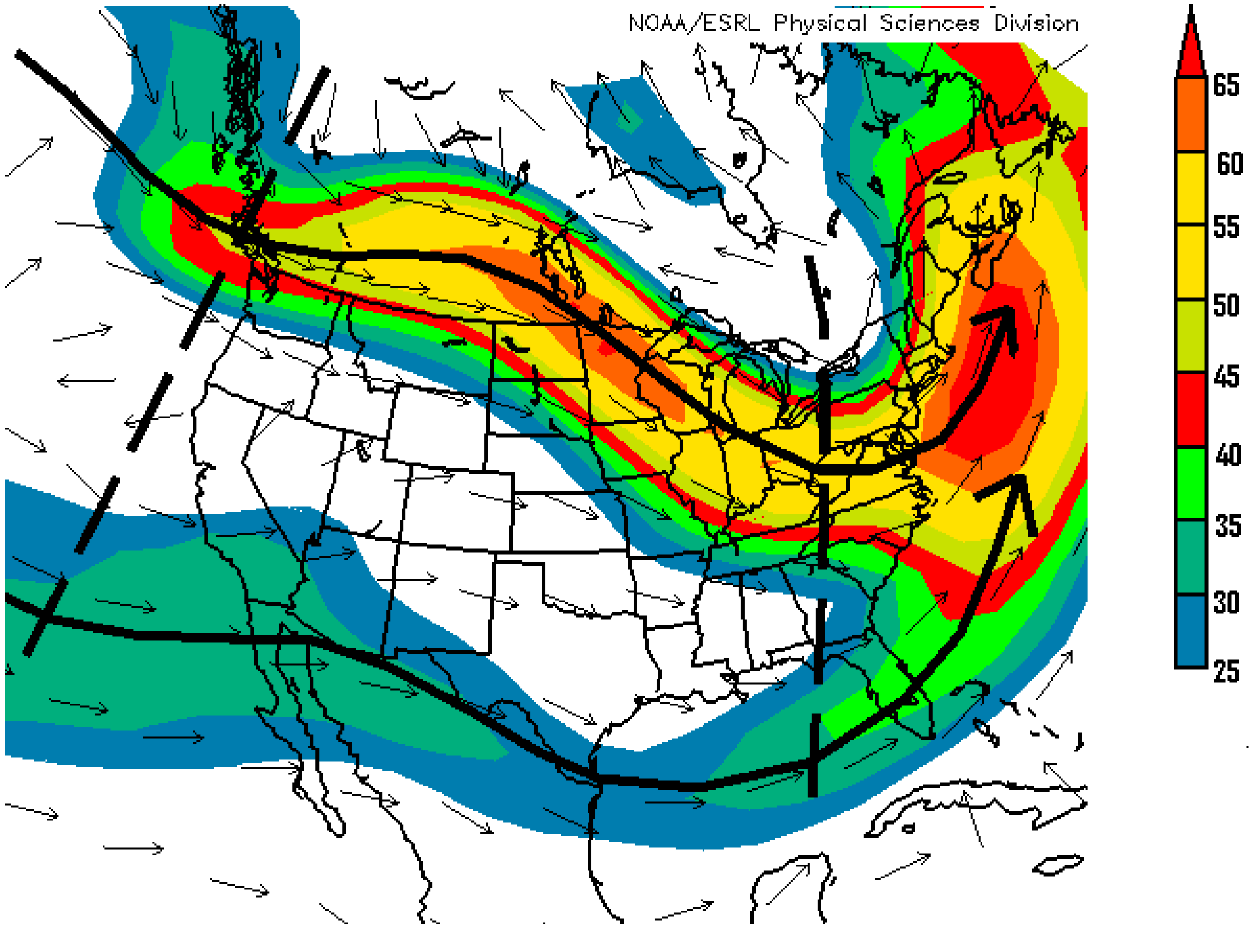


Figure 4. Observed 250-hPa wind (kts) valid 1200 UTC 29 Oct 2006. Dashed black lines show long-wave troughs and arrows show the split flow.