An Investigation of Extreme Wind Events in Extratropical Cyclones Using Innovative Satellite Techniques

Mallory K. Cato[1], Timothy P. Eichler[1], Emily B. Berndt[2], Michael J. Folmer[3]

[1]Saint Louis University, [2] NASA Postdoctoral Program Fellow MSFC Short-term Prediction Research and Transition Center, [3]University of Maryland, EESIC, CICS – NOAA/NWS OPC/TAFB/WPC and NESDIS/SAB

Introduction

- Stratospheric intrusions of subsiding high-potential vorticity (PV), warm, dry, ozone-rich air, that are often associated with intense extratropical cyclones, have been shown to be directly related to severe non-convective surface winds (Knox and Schmidt 2005, Goering et al. 2001).
- Due to the absence of convective features, the public tends to ignore high wind warnings (Ashley and Black 2008), resulting in significant societal and economic impacts.
- These localized, high surface wind events are extremely difficult to forecast due to their limited areal coverage and brief nature (Von Ahn 2005).

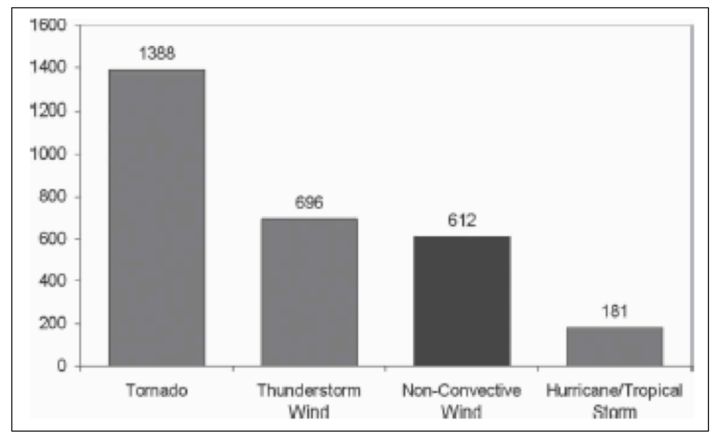

Fig. 1: Fatalities due to various wind-related hazards from 1980 to 2005 (Ashley and Black 2008).

- The purpose of this study was to investigate a new forecasting technique outlined in Zavodsky et al. (2013) that uses the Red, Green, Blue (RGB) Air Mass product developed by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) to identify regions susceptible to stratospheric intrusions, leading to strong non-convective high surface winds.
- The ultimate goal is to demonstrate the use of the EUMETSAT RGB Air Mass product for forecasting unique events as a proxy for the new RGB Air Mass product, available from GOES-R when it is launched.

Background

- The evolution of oceanic cyclones typically follows the Shapiro-Keyser cyclone model (Fig. 2).
- Non-convective winds can develop south of the low pressure center during stages III and IV.

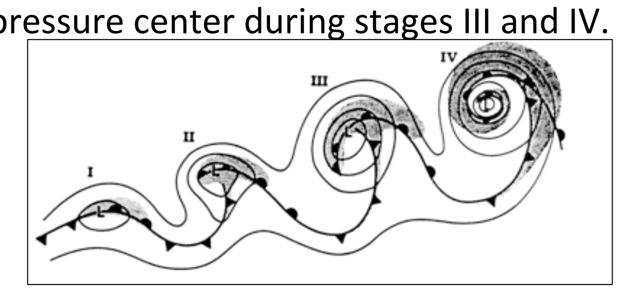

Fig. 2: The four stages of the Shapiro-Keyser cyclone model: (I) incipient frontal cyclone, (II) front fracture, (III) bent-back front and frontal T-bone, (IV) warm-core frontal seclusion (Shapiro and Keyser 1990).

Color	Band/Band Diff.	Physically Relates to….	Little Contribution Indicates….	Large Contribution Indicates….
Red	6.7-7.3	Vertical water vapor difference	Moist upper levels	Dry upper levels
Green	9.7-10.8	Estimate of tropopause height based on ozone	Low tropopause, more ozone, polar air mass	High tropopause, less ozone, tropical air mass
Blue	6.7	Water vapor ~200-500 hPa layer	Dry upper levels	Moist upper levels

Table 1: RGB Air Mass product recipe based off EUMETSAT RGB guidelines (NASA/SPoRT).

- RGB Air Mass imagery is derived from multiple channels or paired channel differences (Table 1).
- The RGB Air Mass product is able to identify temperature and moisture characteristics surrounding synoptic features.
- Ozone anomalies were calculated as a percent of normal using the Atmospheric Infrared Sounder (AIRS) total column ozone and a satellite derived ozone climatology; stratospheric air had ozone values ≥ 125% of normal and is shaded blue.

- Red/Orange → Vorticity/Jet Streak, dry air pulled down on anticyclonic side of the jet
- Olive → Warm, mid-upper level dry air
- Green/Blue → warm (cool), mid-upper level moist air

Methodology

- This study analyzed three different North Atlantic extratropical cyclones with both a stratospheric intrusion and severe non-convective surface winds:
  - 23-25 November 2011
  - 25-26 January 2013
- Using the Grid Analysis and Display System (GrADS) with the Modern Era Retrospective-analysis for Research and Applications (MERRA) data and surface analysis charts from UK Met, a synoptic analysis was done for each case.
- Satellite analysis using the RGB Air Mass product developed by EUMETSAT, using the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on Meteosat-9, examined the evolution of the cyclones and identified regions susceptible to stratospheric intrusions, which were marked by red/orange coloring
- The RGB Air Mass imagery was compared to AIRS ozone data, MERRA 400-500 hPa layer PV, MERRA vertical cross sections, MERRA 925 hPa winds, and Advanced Scatterometer (ASCAT) wind retrievals.

Results

23-25 November 2011

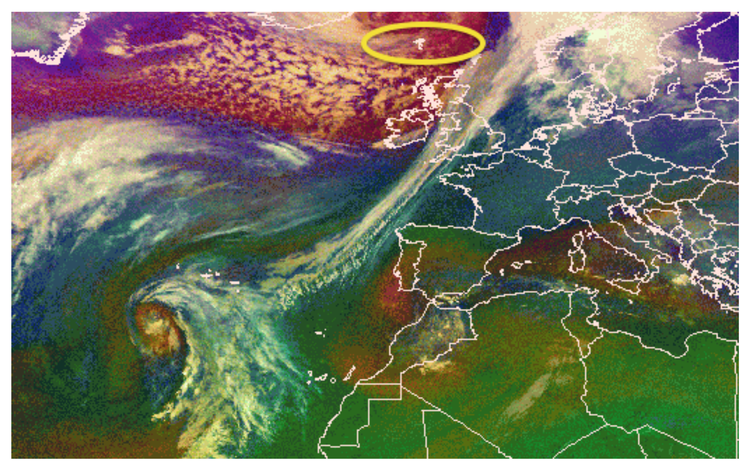

Fig. 3: Meteosat-9 SEVIRI RGB Air Mass imagery at 0000 UTC 25 November 2011. The yellow circle represents the region of highest surface winds in Fig. 5.

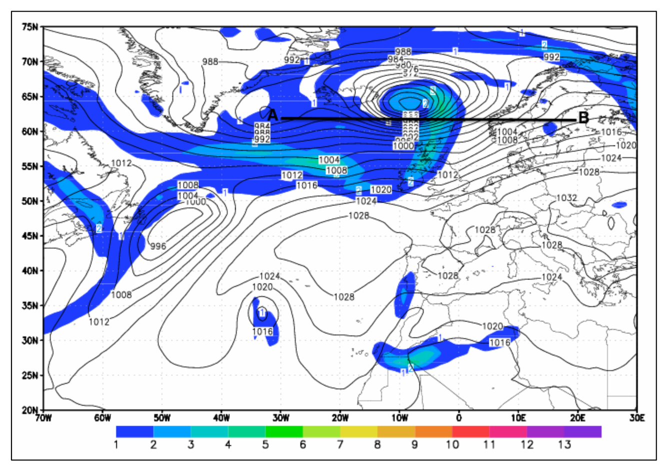

Fig. 4: MERRA 400-500 hPa layer PV (shaded) and sea level pressure (black contours) at 0000 UTC 25 November 2011. The black line (AB) represents the cross sections in Figs. 8 and 9.

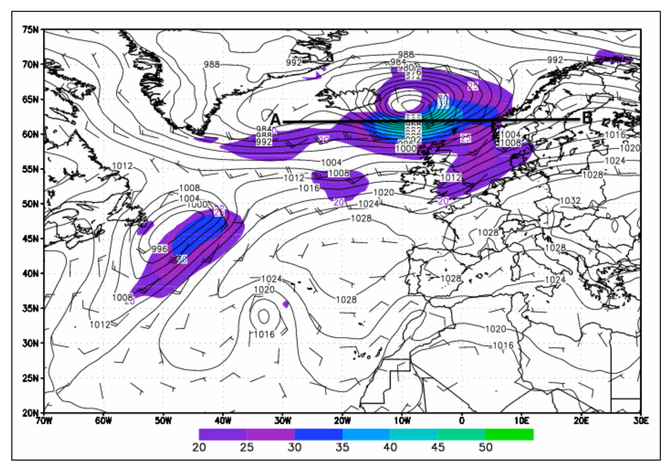

Fig 5: MERRA 925 hPa winds (shaded, barbs) and sea level pressure (black contours) at 0000 UTC 25 November 2011. The black line (AB) represents the cross sections in Figs. 8 and 9.

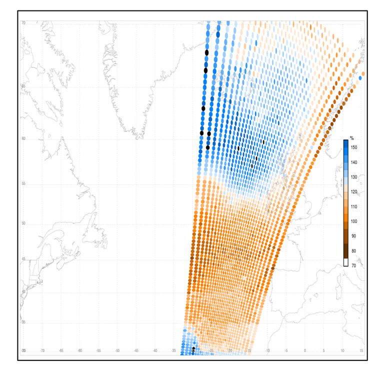

Fig. 6: The AIRS Ozone Anomaly product at approximately 0330 UTC 25 November 2011.

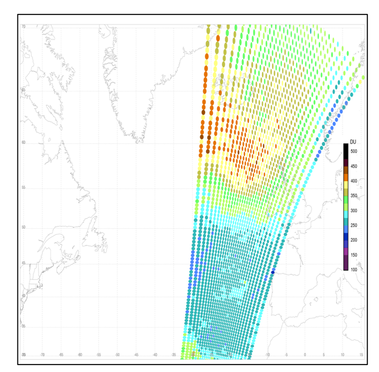

Fig. 7: AIRS total column ozone observations at approximately 0330 UTC 25 November 2011.

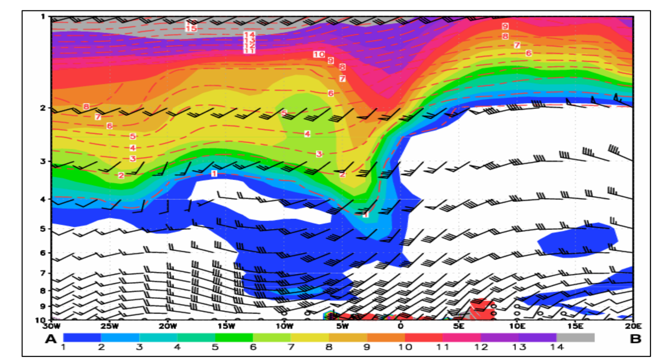

Fig. 8: MERRA vertical cross sections (extent represented by black line in Figs. 4 and 5) of PV (shaded), ozone (red dashed lines) and winds (barbs) at 0000 UTC 25 November 2011.

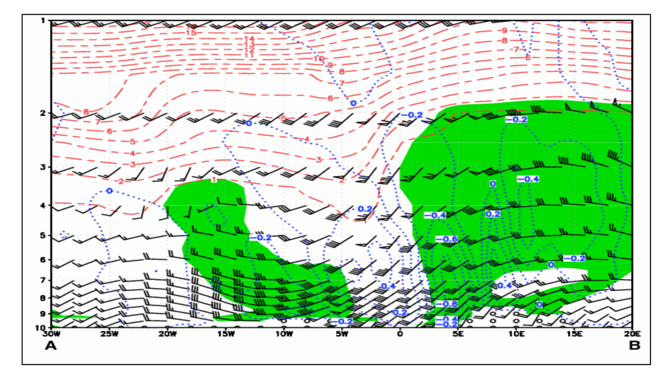

Fig. 9: MERRA vertical cross sections (extent represented by black line in Figs. 4 and 5) of relative humidity (green), ozone (red dashed lines) omega (blue dotted lines) and winds (barbs) at 0000 UTC 25 November 2011.

- The development of the 23-25 November 2011 cyclone was similar to the Shapiro-Keyser cyclone model and underwent explosive cyclogenesis.
- The region of red coloring in the RGB Air Mass imagery (Fig. 3), which represents dry, upper-level air, coincides with the MERRA 400-500 hPa layer PV (Fig. 4), with the PV maximum on the east side of the dry slot, east of the cyclone's center.
- Strong, non-convective surface winds are located in this same region over the North Atlantic Ocean, to the south of the center of the cyclone, as seen in the MERRA 925 hPa winds (Fig. 5)

- The high concentrations of total column ozone determined to be stratospheric by AIRS (Figs. 6 and 7) matched the high-PV, upper-level dry air shown as the red color in the RGB Air Mass imagery. The ozone anomaly (Fig. 6) confirms that the RGB Air Mass identification of stratospheric air.
- The MERRA vertical cross sections (Figs. 8 and 9) showed a stratospheric intrusion that extended into the mid-troposphere. Beneath and behind the stratospheric intrusion is an area of positive omega and hurricane-force surface winds, indicating that the two are related.

25-26 January 2013

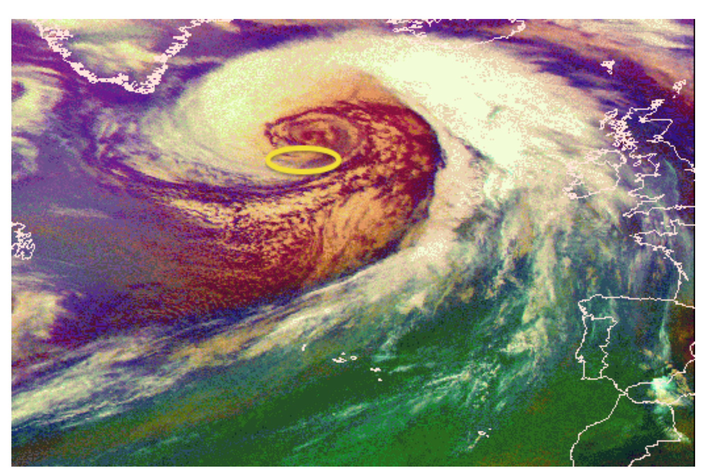

Fig. 10: Meteosat-9 SEVIRI RGB Air Mass imagery at 1200 UTC 26 January 2013. The yellow circle represents the region of highest surface winds in Fig. 12.

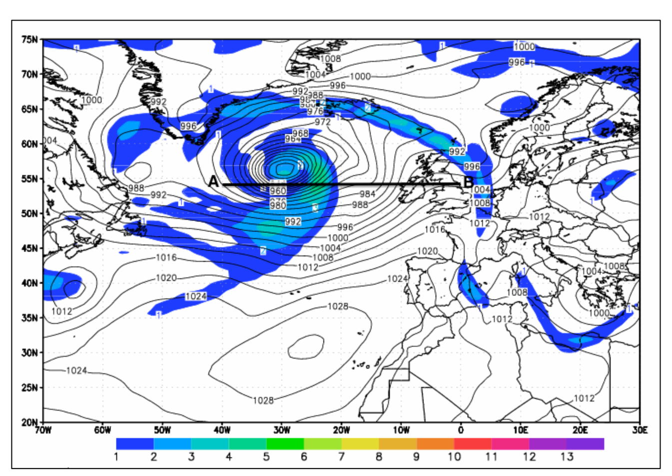

Fig. 11: MERRA 400-500 hPa layer PV (shaded) and sea level pressure (black contours) at 1200 UTC 26 January 2013. The black line (AB) represents the cross sections in Figs. 15 and 16.

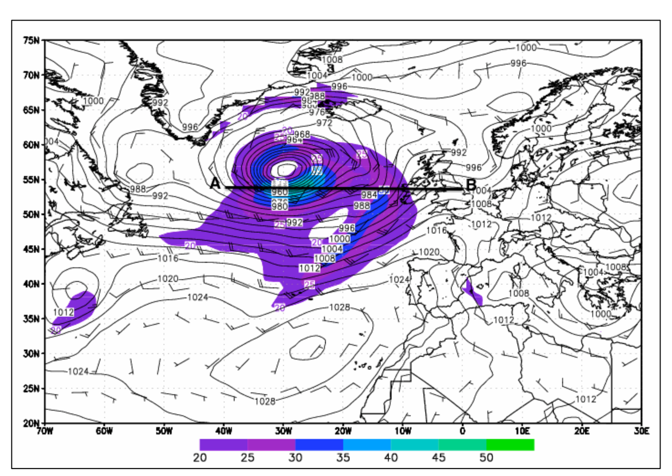

Fig. 12: MERRA 925 hPa winds (shaded, barbs) and sea level pressure (black contours) at 1200 UTC 26 January 2013. The black line (AB) represents the cross sections in Figs. 15 and 16.

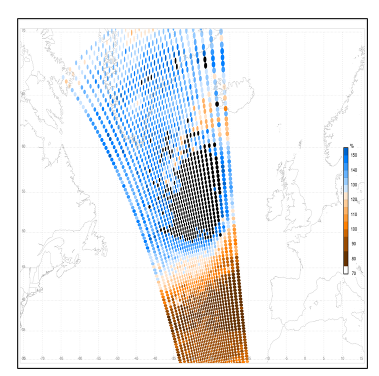

Fig. 13: The AIRS Ozone Anomaly product at approximately 1500 UTC 26 January 2013.

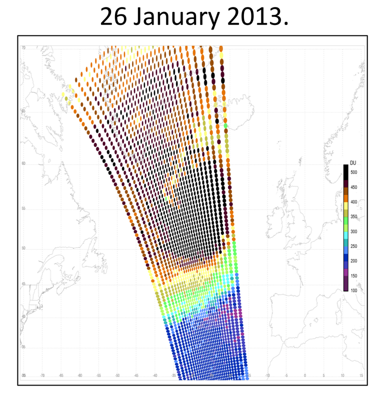

Fig. 14: AIRS total column ozone observations at approximately 1500 UTC 26 January 2013.

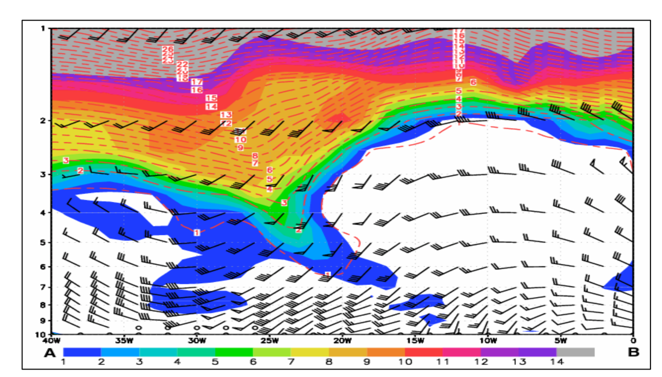

Fig. 15: MERRA vertical cross sections (extent represented by black line in Figs. 11 and 12) of PV (shaded), ozone (red dashed lines) and winds (barbs) at 1200 UTC 26 January 2013.

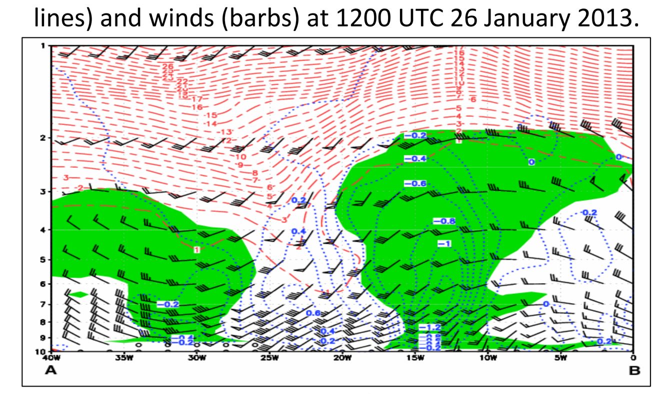

Fig. 16: MERRA vertical cross sections (extent represented by black line in Figs. 11 and 12) of relative humidity (green), ozone (red dashed lines), omega (blue dotted lines), and winds (barbs) at 1200 UTC 26 January 2013.

- The 25-26 January 2013 cyclone originally developed following the Norwegian cyclone model, but after undergoing explosive cyclogenesis, it looked similar to the Shapiro-Keyser cyclone model
- The dry air observed in the RGB Air Mass imagery, designated by the red color (Fig. 10), corresponds with the MERRA 400-500 hPa layer PV (Fig. 11). The 400-500 hPa layer PV maximum was to the east of the surface low center, on the eastern side of the dry slot.
- This region also coincides with the location of maximum non-convective surface wind speeds over the North Atlantic, just south of the center of the cyclone, shown in the MERRA 925 hPa winds (Fig. 12).

- The extremely high concentrations of stratospheric ozone observed by AIRS (Figs. 13 and 14) corresponded with the red coloring seen in the RGB Air Mass imagery that marked a region of high-PV, upper-level dry air, which confirms the identification of stratospheric air by the RGB Air Mass product.
- The MERRA vertical cross sections (Figs. 15 and 16) showed a strong stratospheric intrusion that extended into the low-troposphere. Beneath and behind the stratospheric intrusion is an area of strong surface winds and positive omega, indicating that the surface winds are linked to the intrusion.

Conclusions

- Both extratropical cyclones had the non-convective surface wind speed maximum in the same location, relative to the cyclone's center, at the time of each cyclone's peak intensity.
- The RGB Air Mass imagery identified stratospheric air, marked by the red color, and MERRA cross sections confirmed stratospheric intrusions were present and correlated with the strong non-convective surface winds in both cases.
- Both cases underwent explosive cyclogenesis and had a similar upper-level PV pattern, marked on the RGB Air Mass imagery by the red color.
- The RGB Air Mass imagery is a tool that can be used to forecast intense extratropical cyclones and strong non-convective winds.

Future Work

- Since the 25-26 January 2013 case began as a Norwegian cyclone, further examination of more cases of both Shapiro-Keyser and Norwegian cyclones that develop over land and oceans with the RGB Air Mass imagery is needed.
- A mesoscale analysis of higher resolution data is necessary to determine the exact link between stratospheric intrusions and non-convective surface winds.

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