POLAR WINDS FROM VIIRS

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ABSTRACT

In 2001, an experimental polar wind product was developed using imagery from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite. Early the next year, two numerical weather prediction centers demonstrated a positive impact of the MODIS winds on forecasts not only in the polar regions, but globally. Since then, polar wind products based on data from the Advanced Very High Resolution Radiometer (AVHRR) on NOAA and Metop satellites have also been developed. Today the MODIS and AVHRR winds are produced operationally at NOAA/NESDIS and at six direct readout sites in the Arctic and Antarctic. These polar wind data are used in operational forecast systems at 13 NWP centers in nine countries. Given that the Terra and Aqua satellites have exceeded their life expectancies and that the Visible Infrared Imager Radiometer Suite (VIIRS) will eventually replace the AVHRR as NOAA's operational polar-orbiting imager, plans for polar wind products from new satellite systems have been developed. In the near-term, winds will be generated from VIIRS on the National Polar-orbiting Partnership (NPP) satellite in 2012. The VIIRS instrument will have new capabilities that will impact a polar wind product. These include constrained-growth pixels, where pixels toward the edge of the swath are significantly smaller than for MODIS and AVHRR, significantly greater swath width than MODIS, a visible day-night band (DNB) that provides the potential to track clouds in moonlight, and an improved network of ground receiving stations designed for lower latency. The algorithm developed for GOES-R Advanced Baseline Imager (ABI) will be used with VIIRS, which employs a nested tracking approach and the use of externally generated cloud mask, height, and phase products. These new instrument and algorithm features are expected to offer greater spatial coverage, improved accuracy, and earlier product availability. Unfortunately, VIIRS will not have a thermal water vapor channel as MODIS does, so clear-sky wind retrieval will not be possible.

INTRODUCTION

Satellite-derived wind fields are most valuable for the oceanic regions where few observations exist and numerical weather prediction model forecasts are therefore less accurate. Like the oceans at lower latitudes, the polar regions also suffer from a lack of observational data. While there are land-based meteorological stations in the Arctic and a small number of stations around the coast of Antarctica, there are no routine observations of winds over the Arctic Ocean and most of the Antarctic continent. Unfortunately, geostationary satellites are of limited use at high latitudes due to the large view angles and poor spatial resolution, resulting in significant uncertainties in the derived wind vectors at latitudes poleward of about 60 degrees.

Fully automated cloud-drift wind production from GOES became operational in 1996, and wind vectors are routinely used in operational numerical models of the National Centers for Environmental Prediction (NCEP) and other numerical weather prediction (NWP) centers. Winds over the polar regions have been generated with Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on NASA's Terra and Aqua satellites and the Advanced Very High Resolution Radiometer (AVHRR) on NOAA satellites at CIMSS since 2001, and by NESDIS operations since 2005 (MODIS) and later (AVHRR). A timeline of polar wind product development is shown in Figure 1.

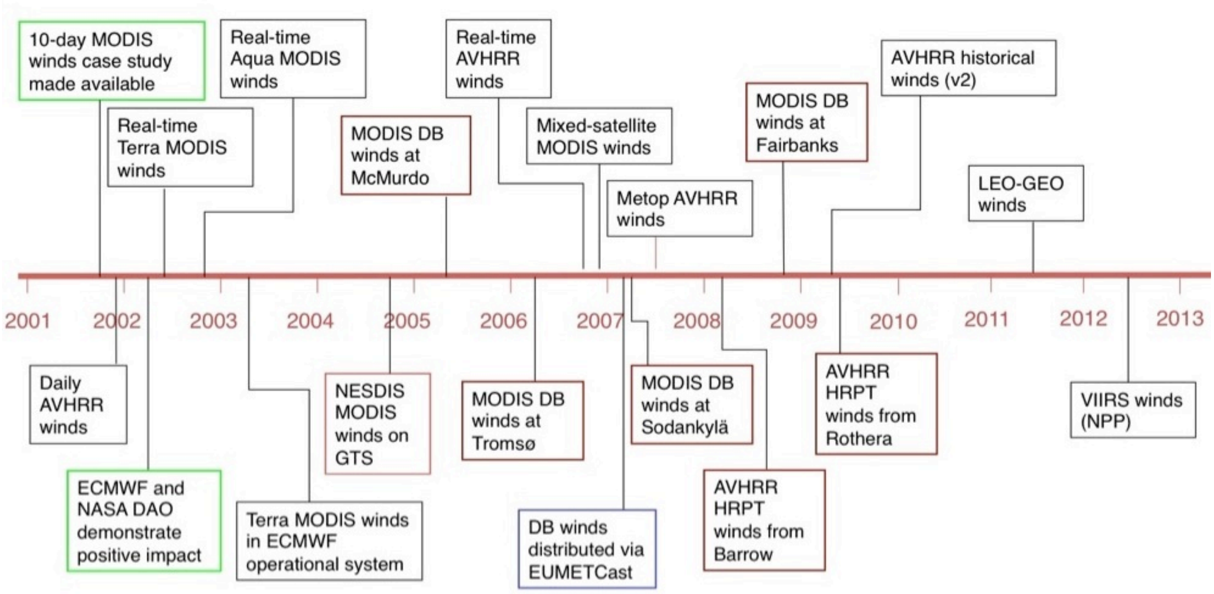

***Figure 1*. The polar winds product history, from 2001 to the present.**

The objective of this project is to develop a polar wind product using the Visible Infrared Imager Radiometer Suite (VIIRS) instrument on the Suomi National Polar-orbiting Partnership satellite (NPP, formerly the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project). NPP was launched 28 October 2011. The product will also be generated with the VIIRS instrument on future Joint Polar Satellite System (JPSS) satellites.

VIIRS CHARACTERISTICS

VIIRS is a 22-band imaging radiometer that, in terms of features, is a cross between MODIS and AVHRR, with some characteristics of the Operational Linescan System (OLS) on Defense Meteorological Satellite Program (DMSP) satellites. It has several unique characteristics that will have an impact on a VIIRS polar winds product. These include:

- a wider swath,
- higher spatial resolution (750 m for most bands; 375 m for some),
- constrained pixel growth: better resolution at edge of swath,
- a day-night band (DNB).

One disadvantage of VIIRS is that, unlike MODIS but similar to AVHRR, it does not have a thermal water vapor band. Therefore, no clear-sky winds can be retrieved.

VIIRS has a wider swath (3000 km) than MODIS (2320 km), so the coverage will be better. The AVHRR swath width is somewhere between that of VIIRS and MODIS (2600 km). A wider swath means more winds with each orbit triplet. Figure 2 shows the overlap of three orbits, which are needed for wind derivation, for MODIS and VIIRS. The figure illustrates the improved coverage of VIIRS, with a larger area of overlap. Consecutive VIIRS swaths overlap even near the equator, so the area for which polar winds can be derived will extend somewhat further south than for MODIS.

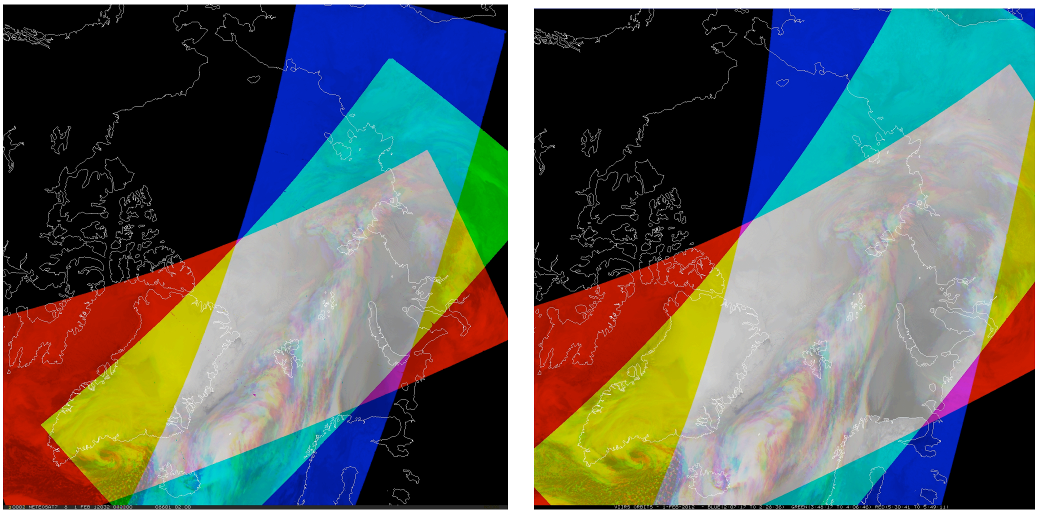

***Figure 2*. The gray region represents the overlap in three orbits where the polar winds are derived for MODIS (left) and VIIRS (right).**

The VIIRS method of aggregating detectors and deleting portions of the scans near the swath edge results in smaller pixels at large scan angles. For thermal bands, VIIRS pixels are 0.56 km^2 (0.75 x 0.75 km) at nadir and 2.25 km^2 at the edge of the swath. Imager bands are 0.37 km at nadir and 0.8 km at the edge; the day-night band (DNB) is 0.74 km and both nadir and at the edge of the swath. In contrast, AVHRR and MODIS are 1 km^2 at nadir and 9.7 km^2 at edge of swath. Additionally, VIIRS scan processing reduces the bow-tie effect. The impact of this on a wind product is that tracking features will be better defined, resulting in more good winds toward the edges of the swath. Figure 3 gives an example of the deleted portions of scans for reducing the bow-tie effect, and the high resolution at the edges of the swath.

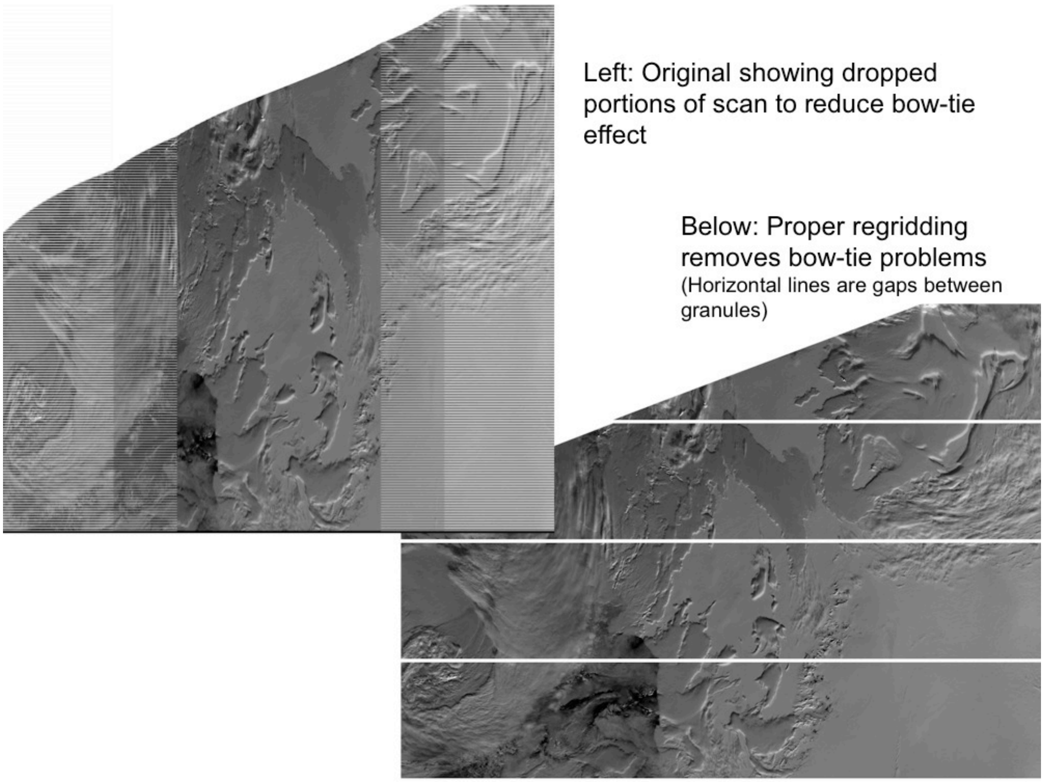

***Figure 3*. VIIRS visible imagery illustrating the deleted portions of scan lines in order to reduce the bow-tie effect when mapped (upper left), and the remapped and interpolated image with high resolution toward the edges of the swath (lower right).**

The effect of scan angle, and therefore pixel size, on the wind retrieval can be seen through an examination of the number and quality of winds away from nadir. For MODIS, Figure 4 shows that (a) the number of retrieved wind vectors below a Quality Indicator (QI) threshold value of 0.6 increases toward 50^o, with a drop off above 50^o due to poor viewing geometry, and (b) the quality of those vectors does decrease toward swath edge. One can infer, therefore, that a higher spatial resolution away from nadir will yield less degradation in the tracers, and therefore more good winds. This hypothesis needs to be tested with VIIRS data, of course.

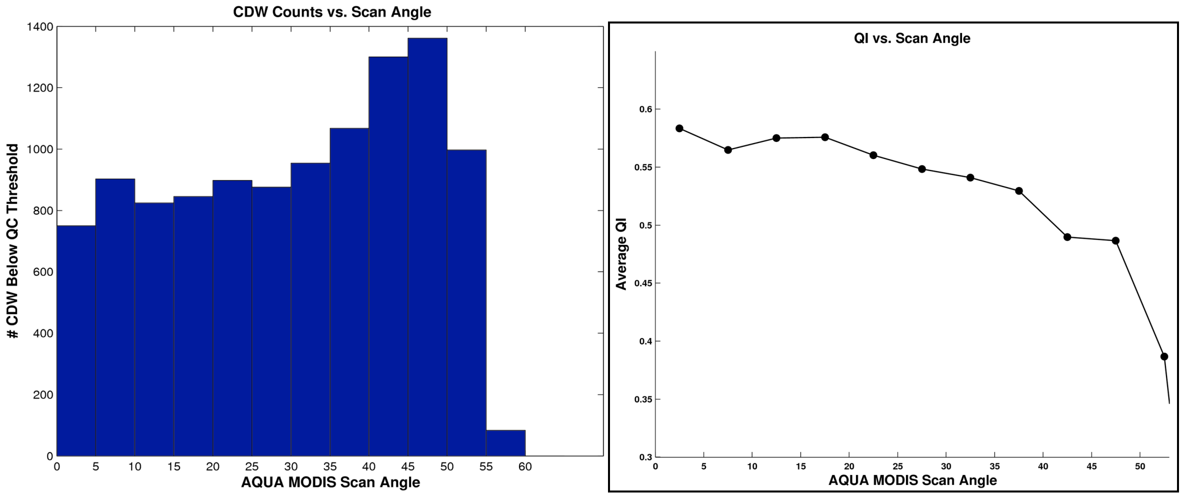

***Figure 4*. Left: The number of cloud drift wind vectors below a QI threshold of 0.6 as a function of scan angle for a sample of MODIS images. Right: The average quality indicator value as a function of scan angle for the MODIS sample.**

VIIRS polar winds processing will utilize the new GOES-R Advanced Baseline Imager (ABI) atmospheric motion vector (AMV) algorithm. Unique features of the ABI wind retrieval methodology include:

- Feature Tracking - The Sum-of-Squared Differences (SS) method is used in conjunction with a “nested tracking” algorithm that is very effective at capturing the dominant motion in each target scene being tracked to track the feature backward and forward in time.
- Target Height Assignment - Externally generated cloud heights are used. This approach
  - leverages experience and expertise of those involved in cloud property retrievals,
  - takes advantage of pixel-level cloud heights contained within a target scene that offer the best opportunity to assign the most representative heights to targets being tracked in time, and contain diagnostic performance metrics, and
  - offers potential for future enhancements to target height assignment algorithm.

The first polar winds case study generated using the ABI algorithm with MODIS data is shown in Figure 5.

The VIIRS day/night band offers an intriguing possibility for wind retrieval during the long polar night (winter). Visible information exists at night, but requires highly sensitive instrumentation to measure it. Satellite-based low light detection was pioneered by the Operational Linescan System (OLS), which has flown continuously on the Defense Meteorological Satellite Program (DMSP) since 1967. An example of the VIIRS DNB over the Arctic is given in Figure 6, which clearly illustrates clouds, surface features, and the aurora borealis.

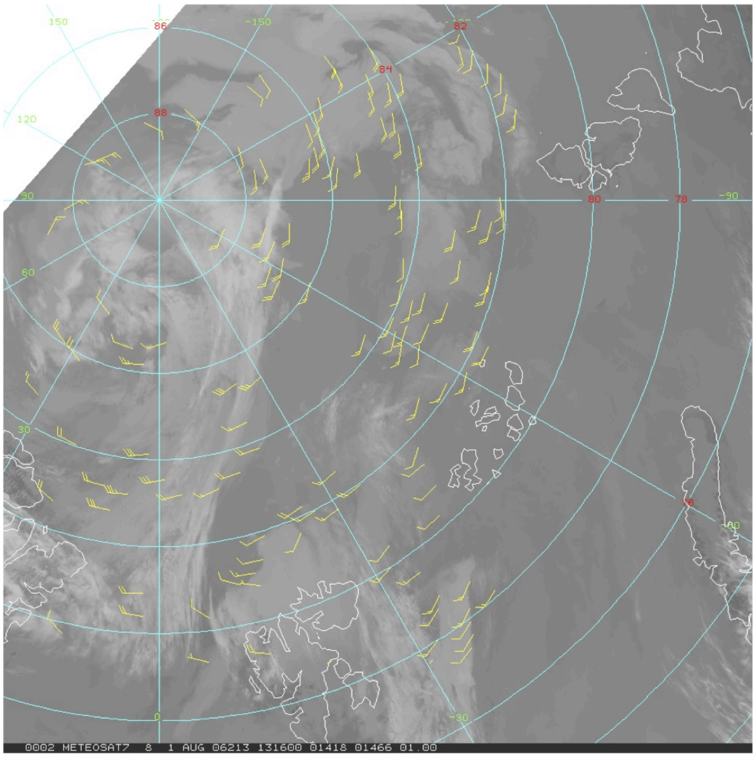

***Figure 5*. Polar winds based on MODIS data using the VIIRS/ABI processing system.**

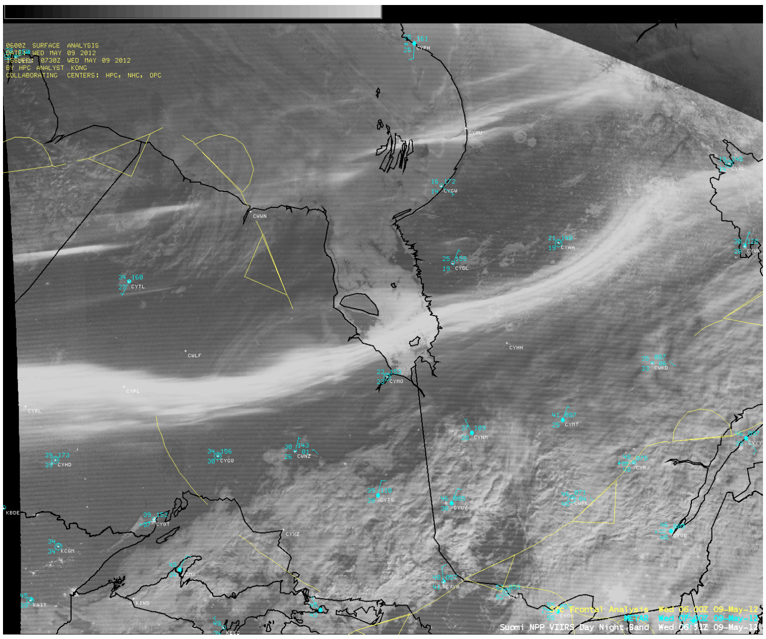

***Figure 6*. Suomi NPP Day/Night Band (DNB) image showing ribbons of the aurora borealis, which appear as bright west-to-east oriented features on the DNB image over Ontario and Quebec, Canada on May 9, 2012. Clouds can also be seen throughout the image. (Courtesy of S. Lindstrom and S. Bachmeier, CIMSS)**

USE OF POLAR WINDS IN NWP

We continue to work with numerical weather prediction (NWP) centers regarding product quality, use, and future enhancements. At present, MODIS and AVHRR polar wind products are used operationally by 13 NWP centers in nine countries:

- European Centre for Medium-Range Weather Forecasts (ECMWF)
- NASA Global Modeling and Assimilation Office (GMAO)
- Japan Meteorological Agency (JMA), Arctic only
- Canadian Meteorological Centre (CMC)
- US Navy, Fleet Numerical Meteorology and Oceanography Center (FNMOC)
- (UK) Met Office
- Deutscher Wetterdienst (DWD)
- National Centers for Environmental Prediction (NCEP/EMC)
- Meteo France
- Australian Bureau of Meteorology (BoM)
- National Center for Atmospheric Research (NCAR, USA)
- China Meteorological Administration (CMA)
- Hydrological and Meteorological Centre of Russia (Hydrometcenter)

Many of these centers will include the VIIRS winds in their operational systems after testing.

SUMMARY AND CONCLUSIONS

Several unique characteristics of VIIRS are expected to influence the quality of the polar winds product:

- A **wider swath** gives greater coverage and therefore more winds for each orbit.
- **Higher spatial resolution at nadir and across the swath** will result in better-defined tracking features and therefore more good winds toward the edges of the swath.
- The **day/night band (DNB)** provides intriguing possibilities for the long polar night.
- Unfortunately, VIIRS, like AVHRR, does not have a thermal water vapor band so no clear-sky winds are possible.
- The VIIRS polar winds processing is being built on the **GOES-R AMV algorithm**, utilizing a nested-tracking approach and externally generated cloud properties.

The VIIRS polar winds product is scheduled to be operational in late 2012.

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