Generation and Initial Evaluation of a 27-Year Satellite-Derived Wind Data Set for the Polar Regions

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David Santek, PI
Space Science and Engineering Center
University of Wisconsin-Madison
Madison, Wisconsin

Jeffrey Key, Co-I
NOAA/NESDIS
Center for Satellite Applications and Research
Madison, Wisconsin

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Proposed Work

We proposed to reprocess 27 years of NOAA's Advanced Very High Resolution Radiometer (AVHRR) data to generate a polar winds dataset for use in reanalysis efforts. There is much interest in this dataset from the retrospective modeling community, including the NASA Global Modeling and Assimilation Office (GMAO) and the European Centre for Medium-Range Weather Forecasts (ECMWF). In addition, we reprocessed Moderate Resolution Imaging Spectroradiometer (MODIS) polar winds for select time periods that overlap with the AVHRR data. We evaluated the impact of these polar winds through a collaboration with the GMAO, who ran short-term experiments using the Goddard Earth Observing System version 5 (GEOS-5) atmospheric model with the Grid-point Statistical Interpolation (GSI) analysis.

This resulted in a high-quality retrospective dataset for use in future reanalysis efforts and a proven technique to derive polar winds from the AVHRR and Visible/Infrared Imager/Radiometer Suite (VIIRS) instruments for the foreseeable future.

Project Goals

From the proposal, the plans for the first year were to:

- *Identify time periods for the GEOS-5 experiments.*
- *Reprocess MODIS and AVHRR polar winds for the selected time periods. This includes deriving winds from the other operational NOAA satellite during those times.*
- *Evaluate these cases.*

Year 2 plans from the proposal:

- *Reprocess a 27-year record of AVHRR data. This will be for the two operational NOAA satellites active during their respective years.*

Overall Accomplishments

The goals of the project have been satisfied:

- The NASA GMAO ran experiments with the AVHRR and MODIS polar winds. Unfortunately, there was a calibration error in the NOAA-18 data, which impacted the vector height assignment, resulting in a poor model impact. The error was corrected for the final winds dataset, but the GMAO was unable to rerun the experiments.
- The dataset of AVHRR winds from 1982 to 2010 can be found at: ftp://stratus.ssec.wisc.edu/pub/winds/histavhrr/
- Most importantly, the NASA GMAO and ECMWF are keenly interested in this dataset for their reanalysis efforts because "we view the AVHRR data as extending our window of interest for reanalysis further back in time…"[1]

Since we are able to easily reprocess the entire AVHRR dataset in three months, it is recommended to contact SSEC before downloading the satellite-derived winds to inquire about the current version of the dataset. Contact David Santek at the Space Science and Engineering Center, University of Wisconsin-Madison: dave.santek@ssec.wisc.edu.

[1] Ron Gelaro, NASA GMAO, personal communication.

Year 1 Details

During the first year we:

- Completed the addition of a 2nd operational NOAA polar orbiting satellite to our AVHRR dataset.
- Produced satellite-derived winds for the entire 27-year archive of AVHRR data.
- Consulted with the GMAO to identify two time periods to produce a test dataset of Atmospheric Motion Vectors (AMV) to include in assimilation and forecast experiments. A winds dataset was created for the two NOAA operational satellites, NOAA-17 and -18, for January/February and June/July 2009.
- Developed and modified many scripts to access, stage, and process historical MODIS image data to derive a MODIS winds dataset for the same time period as the AVHRR above. These changes were necessary since our current system only processed MODIS data in real-time. After these modifications, we are able to easily reprocess MODIS data for specific time periods.

Input datasets

The historical record of AVHRR data we obtained extends from NOAA-7 in 1982 through NOAA-18 into 2010. During most of that time period, two operational satellites are available at a given time from the AM and PM orbits. Since the 11 μm IR (channel 4) is used to track cloud features, we have only archived that channel.

The wind derivation process requires model output grids for a first guess in the tracking process and the temperature profile to assign a cloud height. Grids from the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis, available every 6 hours, from 1981 into 2010 are used.

Database

The entire 29-year AVHRR dataset along with NCEP/NCAR reanalysis grids are catalogued in a PostgreSQL database. This facilitates the access to the data and makes it possible to easily move the processing to our cluster computing facility, providing much faster reprocessing of the entire record.

Parallax correction

Software was written to apply a parallax correction to the calculation of the wind vectors. This is done by adjusting the cloud's latitude/longitude based on the satellite viewing angle and cloud height, before determining the displacement of the cloud over time.

Winds processing

Four months of data were selected to run at the NASA GMAO. These are January/February and June/July 2009 for NOAA-17 and NOAA-18, with additional processing to account for parallax.

Also, the MODIS winds were reprocessed for the same four-month period. This dataset will be superior to our real-time product because:

a) parallax correction is included

b) detector variation in the MODIS images is reduced through a destriping algorithm
c) the vector times are corrected to the satellite pole-crossing time
d) output to BUFR files is added

Winds generated from the entire 29-year AVHRR dataset is available at:
ftp://stratus.ssec.wisc.edu/pub/winds/histavhrr/

The output wind files are in the following formats:

- Binary Universal Form for the Representation of meteorological data (BUFR)
- ASCII text
- Man computer Interactive Data Access System (McIDAS) Meteorological Data (MD) files

along with individual GIF images of the satellite data overlaid with wind vectors (Figure 1).

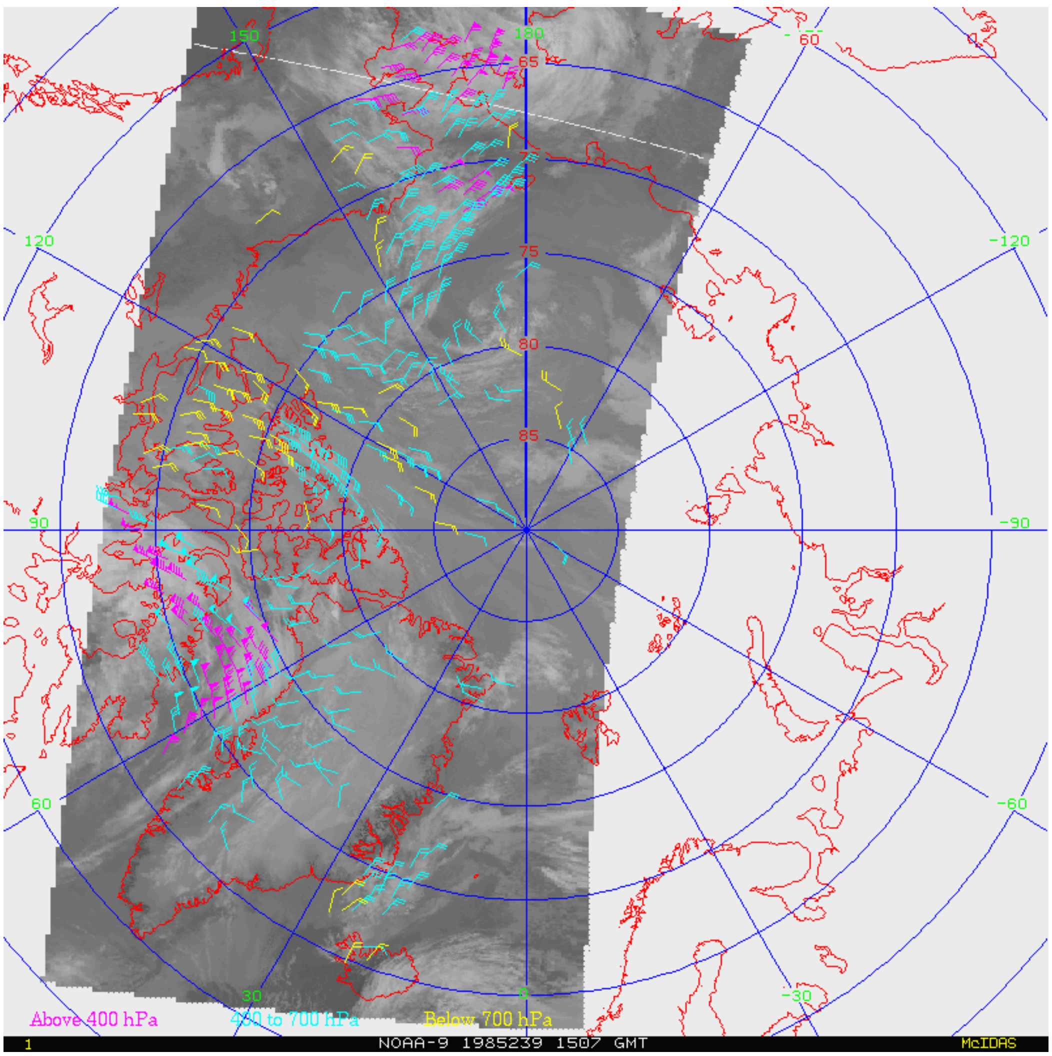

Figure 1: An example of the derived wind vectors over the Arctic. The satellite image is a NOAA-9 pass from 1507 UTC on 27 August 1985.

Year 2 Details

1. Several experiments were run at the GMAO using the AVHRR and MODIS winds in combination and separately. These are detailed in the next section.

2. The Expected Error (EE) is gaining acceptance in the numerical weather prediction community as it better characterizes the errors in the AMVs. The EE is based on multiple linear regression coefficients derived from wind quality indicators, vector wind speed, and the vertical wind and temperature shear as compared to nearby radiosondes measurements. These coefficients are then applied as a post-process step to the entire winds dataset and made part of the final output files. The GMAO has requested the EE parameter to be included in the AVHRR winds dataset. Currently, the EE coefficients as determined from MODIS winds are applied to the AVHRR winds.

3. Since the beginning of the project, an additional two years of AVHRR data were added (see Table 1 for complete list of satellites and years processed). Therefore, the last reprocess was for the nearly 29-year record of AVHRR data. Improvements to the processing include a parallax correction and providing additional error information with the EE.

Table 1: NOAA satellites and years processed.

NOAA Satellite	Years
7	1982-85
9	1985-88
10	1986-91
11	1988-94
12	1991-98
14	1995-00
15	1999-02
16	2001-07
17	2002-09
18	2009-10

GMAO experiments

The following discussion is edited from this web page:
http://gmao.gsfc.nasa.gov/research/atmosphericassim/AVHRR/

with sample figures.

A series of experiments were conducted to test the impact of assimilating high-latitude AMVs on the quality of analyses and forecasts produced by the GEOS-5 atmospheric data assimilation system. Among other things, the study compares the impact of the AVHRR observations with the impact of polar winds based on the Moderate Resolution Imaging Spectroradiometer (MODIS), which are assimilated routinely in GEOS-5 and in most operational forecast systems.

The experiments were conducted for the period June-July 2009 using version 5.6.1p4 of the GEOS-5 atmospheric data assimilation system at 1/2-degree horizontal resolution with 72 vertical levels. A control experiment (including MODIS winds but no AVHRR winds) was run, as well as experiments with both MODIS and AVHRR winds, and no polar winds.

Observation increments

The distributions of observation-minus-background forecast (OMF) and observation-minus-analysis (OMA) departures (often referred to as observation increments) provide an indication of the relative agreement between the observations and model background state before and after the assimilation procedure. Ideally, the background state should provide a reasonably accurate estimate of the analyzed state, and the observation and analysis increments should provide only a minor adjustment to the background state. The OMF and OMA values should be unbiased and normally distributed, with the OMA having smaller standard deviation than the OMF reflecting the improved "fit" of the observations to the analyzed state.

The figures below show results for the experiment in which both AVHRR and MODIS winds are assimilated. Overall, the OMF and OMA values for both data types have reasonable distributions, although the distributions for the AVHRR winds (Figure 2) have longer tails and larger standard deviations than those for the MODIS winds (Figure 3), indicating a slightly worse fit between the AVHRR winds and other sources of information in the analysis compared with the MODIS winds. This is expected for at least two reasons: (a) the AVHRR global data is at a lower resolution compared to MODIS (4 km vs. 1 km); (b) the geolocation accuracy for AVHRR is lower than MODIS.

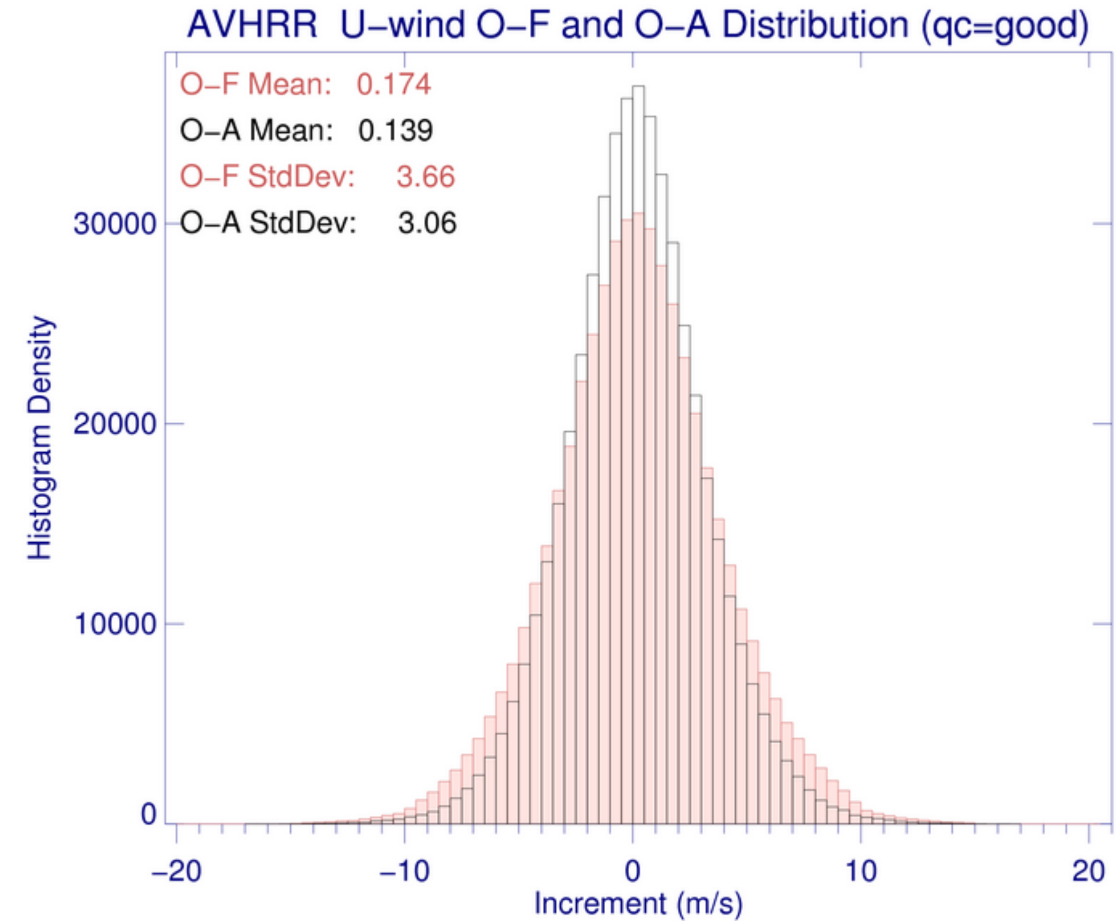

Figure 2: U-component OMF (red) and OMA for June 2009. These are all AVHRR winds that pass quality control.

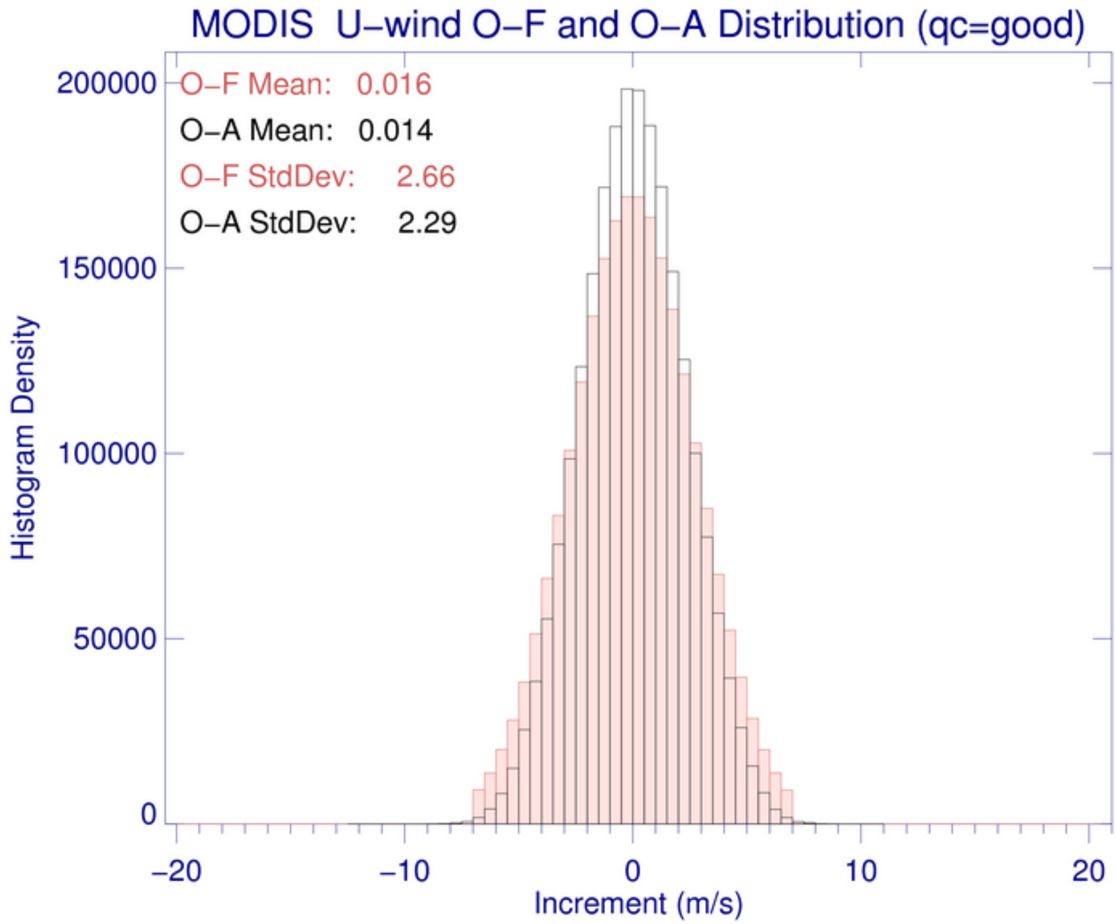

Figure 3: U-component OMF (red) and OMA for June 2009. These are all MODIS winds that pass quality control.

Forecast skill scores

The forecast scores in terms of the anomaly correlation coefficient (ACC) for 500 hPa height is a standard metric for measuring the skill of numerical weather forecasts. An ACC=1 denotes a perfect forecast relative to the GEOS-5 analysis valid at the same time as the forecast. The "die-off" curve in Figure 4 shows the average ACC values of the different experiments as a function of forecast lead time for the Northern Hemisphere during June 2009. The lower portion of these figures shows the statistical significance of the experimental results in terms of their difference from the control run.

Overall, the forecast skill scores show small but insignificant differences between the experiments. In most cases, the experiment without polar winds exhibits the largest ACC skill score at a forecast lead time of five days although there are some cases where using the AVHRR winds, or using both sets of polar winds, perform better than the 'no polar' or control experiments (Figure 4).

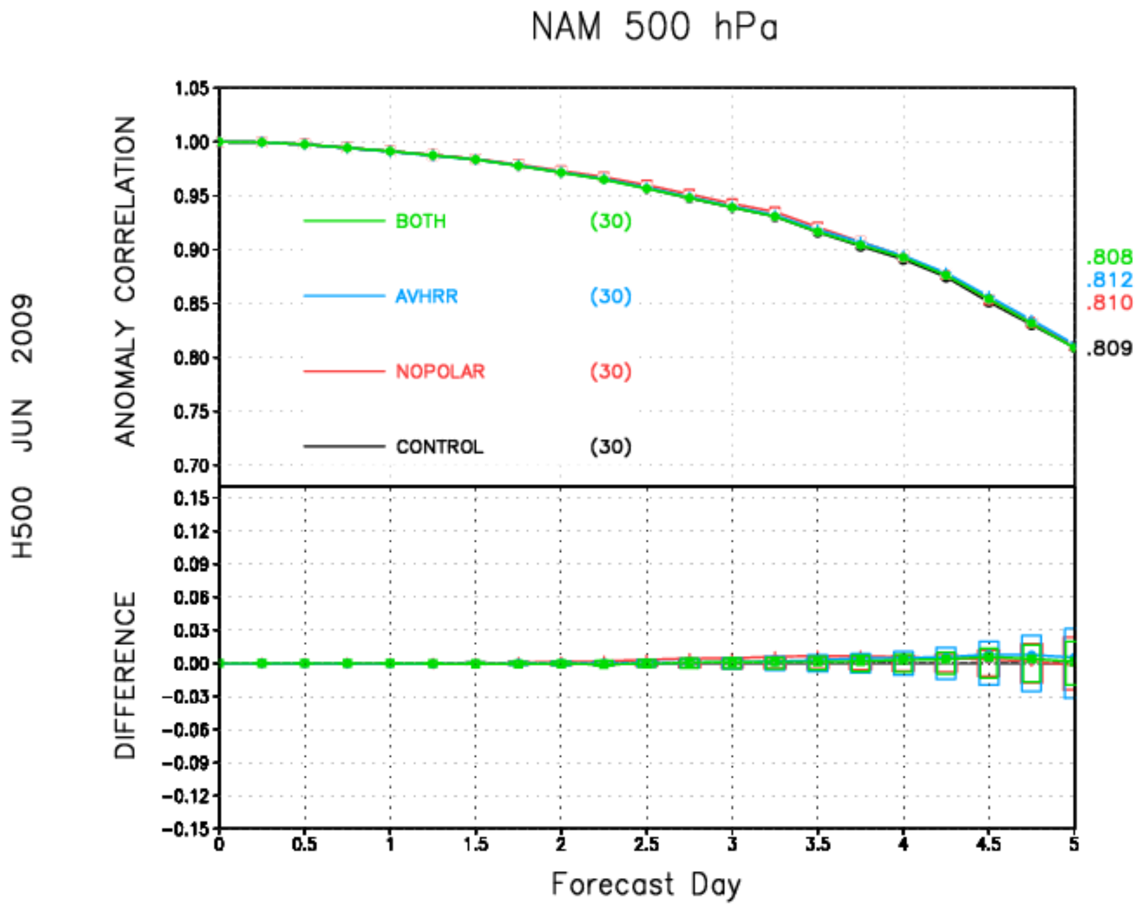

Figure 4: ACC score at 500 hPa over North America for June 2009. Both AVHRR and MODIS (green), AVHRR only (blue), no polar winds (red), control (black).

<u>Adjoint-based observation impacts</u>

The adjoint of a data assimilation system provides an accurate and efficient means of estimating the impacts of any or all assimilated observations on measures of short-range forecast skill. The impacts are computed for all observations simultaneously, without having to add or remove selected subsets of observations from the data assimilation system.

The adjoint of the GEOS-5 data assimilation system was used to compute the impact of observations on 24-h forecasts during the study period in terms of the reduction of a global (energy-based) measure of error combining temperature, wind and surface pressure from the surface to 150 hPa.

In June 2009, the AVHRR winds have near zero impact globally, although the majority of the observations have a beneficial impact on (reduce the error of) the 24-h forecast. It should be kept in mind that, being restricted to the polar region, the AVHRR (and MODIS) winds might have a larger impact in terms of regional (high-latitude) forecast measures as opposed to the global measure used here.

In July 2009, the AVHRR winds do not perform as well as in June and the statistics show that, overall, they increase the 24-h global forecast error measure. Also, the majority of the AVHRR observations during July degrade the forecast, indicating that the overall negative impact during this month is not likely attributable to just a few "outlier" observations with unusually large negative impacts. This negative impact is likely due to the error in height assignment, which was due to mis-calibrated NOAA-18 AVHRR data.

Conferences and workshops

Santek, D., J. Key, R. Dworak, and M. Rienecker, 2010. A 27-year record of satellite-derived polar winds for retrospective analyses. *Proc. of the Fourteenth Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface (IOAS-AOLS)*. American Meteorological Society, January 2010, Atlanta, GA. http://ams.confex.com/ams/90annual/techprogram/paper_165519.htm

Santek, D., J. Key, R. Dworak, M. Rienecker, and R. Gelaro, 2010. A 27-year record of satellite-derived polar winds for retrospective analyses. *Proc. of the Tenth International Winds Workshop*. February 2010, Tokyo, Japan. http://cimss.ssec.wisc.edu/iwwg/iww10/iww10_programme.html

ECMWF visit

As part of a visit by D. Santek to ECMWF in October 2011, a presentation was given that included information on this project. Afterward, a meeting with Dick Dee and Paul Poli (of ECMWF's Reanalysis Team) was arranged to discuss their data needs in regards to their next reanalysis project. They are also interested in an additional reprocessing of the AVHRR data using the ERA-Interim grids, instead of the NCEP/NCAR reanalysis grids.

EUMETSAT visit

In July 2011, D. Santek met with Jörg Schulz of EUMETSAT and discussed their Metop AVHRR winds reprocessing efforts. These winds would also be included in ECMWF's reanalysis project.