The Impact of Satellite Atmospheric Motion Vectors in the U.S. Navy Global Data Assimilation System: The Superob Procedure

Patricia M. Pauley1, Nancy L. Baker1, Rolf Langland1, Liang Xu1, and Christopher Velden2

1Marine Meteorology Division, Naval Research Laboratory
7 Grace Hopper Avenue, Monterey, California, U.S.A. 93943-5502

2Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison
1225 West Dayton Street, Madison, Wisconsin, U.S.A., 53706

Abstract

This paper describes unique procedures developed to assimilate satellite-derived Atmospheric Motion Vectors (AMVs) in the U.S. Navy global forecast system. In the companion paper by Baker et al. (2012), it is suggested that the specific “superobbing” technique developed at NRL may help explain the relatively large beneficial impact of AMV data in the Navy model, compared to impacts of AMVs in other forecast systems, including ECMWF, UKMO and GFS. Here, we summarize the theory and application of the Navy superobbing technique, together with details of the quality control procedures applied to the AMV data. Experiments comparing superobbing with thinning are also summarized.

INTRODUCTION

As shown in our companion paper (Baker et al. 2012), Atmospheric Motion Vectors (AMVs) have a disproportionately large forecast impact in the U.S. Navy’s global operational numerical weather prediction system, which is composed of NAVDAS-AR (NRL Atmospheric Variational Data Assimilation System—Accelerated Representer), a 4DVAR (four-dimensional variational) global data assimilation system in observation space (Xu et al. 2005; Rosmond and Xu 2006; Chua et al. 2009), and NOGAPS (Navy Operational Global Atmospheric Prediction System), a global atmospheric model currently run with a resolution of 319 spectral triangular truncation on 42 levels (Hogan and Rosmond 1991; Peng et al. 2004). The goal of the present paper is to describe in detail the procedures that are used in NAVDAS-AR to process the AMVs, including quality control and averaging (“superobbing”) and to compare superobbing with thinning in our system. The description focuses on geostationary AMVs, but the procedures used for polar AMVs (both MODIS and AVHRR), AMVs from geostationary-polar composite imagery (LeoGeo), and surface AMVs (ASCAT and WindSat) are similar.

One way that the U.S. Navy's operational system differs from that at other operational centers is in its use of geostationary AMVs both from operational data providers (NESDIS, EUMETSAT, and JMA) and from the University of Wisconsin-Madison's Cooperative Institute for Meteorological Satellite Studies (CIMSS) (Fig. 1); most centers only use AMVs from the former providers. AFWA (Air Force Weather Agency) AMVs are also used as a back-up when CIMSS AMVs are not available, since AFWA uses the CIMSS software to generate their AMVs. AFWA winds, when used in NAVDAS-AR, are therefore handled in the same manner as CIMSS AMVs and so are not discussed as a separate category in this paper. In addition, the U.S. Navy has been using hourly AMVs operationally since 6 December 2010. The number of geostationary AMVs has nearly doubled since then, with the addition of hourly AMVs from more centers and more satellites. The December 2010 implementation used hourly AMVs only for the Northern Hemisphere for CIMSS MTSAT and GOES-West (and presumably EUMETSAT Meteosat 9) and 1.5-hourly or three-hourly AMVs for the remaining satellites and centers. CIMSS Meteosat 7 full-disk hourly winds went into use in mid-February 2011, followed by JMA MTSAT in late March, NESDIS GOES-13 and -15 in June, and CIMSS GOES-East Northern Hemisphere and Meteosat 9 full disk on 23 January 2012. The current temporal distribution of geostationary AMVs is shown in Fig. 2 for a 24-hour period with time relative to the four analysis times. Hourly AMVs are now being used for all satellites from all data providers, with the exception of EUMETSAT Meteosat 7, which is provided every 1.5 hrs. However, it should be noted that the August-September 2010 and December 2010-January 2011 International Winds Working Group (IWWG) study periods used in...
Baker et al. (2012) had far fewer hourly AMVs than are available at present. Counts as a function of time relative to the analysis times for 31 August 2010 (not shown) reveal that hourly AMVs were available only for EUMETSAT Meteosat 8 and 9 and for CIMSS MTSAT.

DATA QUALITY CONTROL

Before the AMV data are averaged ("superobbed"), a number of quality control procedures are applied. First of all, invalid observations are excluded from further consideration. An observation is considered to be invalid if its latitude, longitude, pressure, or time are missing, or if a background value interpolated from a short-term forecast to the observation location is unavailable, none of which occur very often. Observations that are flagged as bad or as having low confidence or quality are also excluded. The EUMETSAT-developed Quality Indicator (QI) is available for all of these AMV datasets, while CIMSS provides both QI and the CIMSS-developed RFF (Recursive Filter Flag). Both scores are described in Holmlund et al. (2001) and range from 0 to 100. AMVs are rejected when their QI is less than a threshold that either comes from the data provider or is specified locally. Current

Figure 1: Geographical distribution of geostationary AMVs prior to superobbing for the six-hour time window centered at 0000 UTC 13 January 2012 from (left) NESDIS (GOES-13 and GOES-15), EUMETSAT (Meteosat 7 and Meteosat 9), and JMA (MTSAT); and from (right) CIMSS (the same five satellites) for all levels and all channels.

Figure 2: Temporal distribution of geostationary AMVs prior to superobbing and relative to the analysis times (0000, 0600, 1200, and 1800 UTC) for a 24-hour period on (left) 16 January 2012 for NESDIS (GOES-13 and GOES-15), EUMETSAT (Meteosat 7, Meteosat 8, and Meteosat 9), and JMA (MTSAT2); and on (right) 26 January 2012 for CIMSS (GOES-13, GOES-15, Meteosat 7, Meteosat 9, and MTSAT). Counts are binned by half hours. Channels are identified as “VIS” for visible, “SWIR” for short-wave infrared (3.9 μm), “IR” for infrared (10.8 μm), and “WV” for water vapor (approximately 6.5 μm). The WV counts in the left panel are the sum of the “WVCLR” (clear sky water vapor) and “WVCLD” (cloudy sky water vapor) counts. The distinction between WVCLR and WVCLD is different for different satellites and is not examined here.

Baker et al. (2012) had far fewer hourly AMVs than are available at present. Counts as a function of time relative to the analysis times for 31 August 2010 (not shown) reveal that hourly AMVs were available only for EUMETSAT Meteosat 8 and 9 and for CIMSS MTSAT.
thresholds are listed in Table 1. Only CIMSS AMVs have an RFF score; they are rejected when either RFF is less than 40 or QI is less than the value in the table.

Table 1: Quality Indicator (QI) thresholds applied to geostationary AMVs prior to superobbing. Note that the NESDIS, EUMETSAT, and JMA water vapor AMVs are categorized as “WVCLR” (clear sky) or “WVCLD” (cloudy sky), while the CIMSS water vapor AMVs are just labeled “WV” and not separated into clear and cloudy sky categories.

<table>
<thead>
<tr>
<th>Data provider/Satellite</th>
<th>VIS</th>
<th>SWIR</th>
<th>IR</th>
<th>WV</th>
<th>WVCLR</th>
<th>WVCLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>NESDIS GOES-13</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>NESDIS GOES-15</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>EUMETSAT Meteosat 7</td>
<td>70</td>
<td>80</td>
<td>60</td>
<td>60</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>EUMETSAT Meteosat 9</td>
<td>70</td>
<td>80</td>
<td>60</td>
<td>60</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>JMA MTSAT2</td>
<td>70</td>
<td>70</td>
<td></td>
<td>70</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>CIMSS all satellites</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In addition, vertical limits are imposed on the raw data as a function of channel and satellite type (Fig. 3, left panel). Most geostationary AMVs in the data-sparse layer between approximately 675mb and 450mb are excluded, as are AMVs below 975 mb and above 175 mb. Land masking is also used in three regions with ample conventional data, specifically Northern Europe, North America, and Australia/New Zealand (Fig. 3, right panel). Land masking is also performed in an additional rectangle over Greenland for Polar and LeoGeo AMVs. Note that the land masking doesn't affect the ocean AMVs within these rectangles; it merely rejects over-land AMVs.

Two final pre-superobbing quality control checks are then performed. The first excludes exact duplicates from further consideration, while the second excludes AMVs with large vector innovations, where the vector innovation is defined as the observed wind vector minus the background wind vector. At present, the background values used in this check are interpolated in time and space from 3, 6, and 9 hour NOGAPS forecasts rather than the actual 4DVAR background values. This allows the quality control and superobbing to be performed in a pre-processor outside of the 4DVAR. The vector innovation limits are imposed on the magnitude of the vector innovation and are set to 8 m/s below 425 mb with a stepwise increase to a maximum of 12 m/s at 250 mb and with a stepwise decrease from there to 10 m/s at 100 mb.

Figure 3: Spatial limits imposed on AMVs vertically as a function of pressure (left) and over land within three data-rich geographic regions (right). AMVs outside of the limits shown by the red bars in the left panel are excluded, as are AMVs over land within the three rectangles indicated by heavy black lines in the right panel.
SUPEROBBING PROCEDURES

The averaging or superobbing begins with binning AMVs that passed quality control into latitude-longitude “prisms” in 50 mb layers. The size of the prism is specified as the size at the equator, which currently is set to 2.0° latitude by 2.0° longitude for geostationary AMVs. In an effort to keep the horizontal area of a prism approximately constant with the latitudinal extent kept constant, the longitudinal extent of the prisms is allowed to vary, subject to the further constraint that the number of prisms in a particular latitude band is an integer. Figure 4 shows the distribution of prisms in the northern hemisphere, with the dots in the figure located at prism centers. To reduce any problems with collocated superobs, CIMSS AMVs are superobbed in prisms centered on even latitudes and odd longitudes at the equator (as in Fig. 4), while NESDIS, EUMETSAT, and JMA AMVs are superobbed in prisms centered on odd latitudes and even longitudes at the equator. AMVs within a prism are further divided among 50 mb layers, beginning with the 1000mb layer, which extends from 1025 mb to 975 mb.

Our basic philosophy in superobbing AMVs is to only average similar observations. After AMVs have been binned horizontally and vertically into averaging volumes, they are separated by time, satellite, channel, and processing center. One-hour time bins are used with consideration given to the times that are available in a given averaging volume rather than using fixed time bins. Except for Meteosat data, at least two AMV obs are required to form a superob. The Meteosat exception was originally established to accommodate the thinned data that had been disseminated from the first-generation Meteosat satellites. This exception needs to be re-examined, given the much higher data density currently being disseminated for Meteosat satellites.

Once a group of AMVs have been assembled in a 50 mb layer and a one-hour time bin for a particular prism, satellite, channel, and processing center, they are further examined for consistence with each other. In order to form a superob, the speeds (or speed innovations) must be within a speed-dependent threshold that ranges from 7 to 14 m/s, and either have directions (or direction innovations) within 20° or have u and v components (or innovations) within 5 m/s. One or two outliers can be rejected to meet these criteria if a sufficient number of AMVs are available. If the criteria cannot be met, the prism is quartered horizontally, and an attempt is made to form superobs within each quarter. If the AMVs in a quarter fail to meet the criteria, they are rejected.

An example of this process is shown in Fig. 5, for CIMSS GOES-11 VIS AMVs from 1722 UTC 31 August 2010 in a prism centered at 42°S, 122.24°W, in the 50 mb layer centered at 850 mb. The wind directions for these AMVs range from 281° to 296°, within the 20° threshold. However, the speeds range from 10.9 to 22.9 m/s, well beyond the 7 m/s threshold on speeds. Since there are several AMVs with speeds greater than 20 m/s and several with speeds less than 13 m/s, rejecting one or two outliers is insufficient to meet the criteria. The prism is therefore subjected to quartering. The left panel in Figure 5 shows that rejecting one AMV as an outlier in the northeastern quarter allows the formation of a superob from the other three AMVs, with a speed of 13.3 m/s and a location at the average location of the contributing observations (blue square). The four AMVs within the northeastern quarter have a smaller range and so can be averaged to form the superob located at the orange square, which has a speed of 19.7 m/s. The southwestern quarter has no observations and the southeastern quarter has only one, so no further superobs are formed. As this example shows,
the quartering procedure yields additional superobs in regions of horizontal (and sometimes vertical) wind shear.

One final procedure is applied to the superobbed AMVs. In order to avoid the loss of kinetic energy brought about by averaging winds with directional shear, an adjustment is made to the $u$ and $v$ components of the superob so that the magnitude of the superob vector is equal to the mean speed of the obs used to form the superob. The above example had relatively low directional shear, so the adjustment increased the speeds by only 0.02 m/s. However, in a different example from the same dataset, three Meteosat 9 IR AMVs in a prism centered at 4°S, 39°W at 850 mb had speeds and directions of 7.4 m/s at 115°, 7.8 m/s at 150°, and 5.3 m/s at 158°. The resulting superob had a speed and direction of 6.5 m/s at 140°. In this case, the adjustment increased the speed to 6.8 m/s.

SUPEROBBING VS. THINNING

An experiment was performed for the 1 December 2010 – 15 January 2011 IWWG winter study period to compare superobbing with thinning. A control model run using superobbing as described in this paper was compared with a thinning run to investigate to what extent superobbing contributes to the enhanced observation impact AMVs have in the U.S. Navy global NWP system. The thinning experiment was designed to present essentially the same number of AMVs to the 4DVAR as the superobbing control run, in order to isolate the effect of averaging from that of observation count. The superobbing code was allowed to run through until the point at which the superob is written to the output file. At the point, the unrejected AMVs used to form the superob are examined, and the one with the smallest horizontal distance to the superob location is chosen and written to the output file in place of the superob.

The results from this experiment show little difference between these two model runs using standard statistical measures. Superobbing has a slight advantage in terms of 500 mb geopotential height anomaly correlation in the southern hemisphere at longer forecast ranges, but the differences are not statistically significant. In a verification against radiosondes, the wind speed error at both 850 mb and 200 mb is slightly less negative for superobbing in the northern hemisphere at longer forecast ranges with a small reduction in RMS as well. However, thinning led to a slightly less negative speed error in the tropics. Superobbing therefore seems to have a slight edge, but further work needs to be done to
examine the details of analysis differences and to use other statistical measures to compare these two model runs. However, based on these results, we see no compelling reason to change our methodology. A further experiment is planned in which the thinning procedure is independent of the superobbing procedure. We plan to follow the suggestion that Niels Bormann (ECMWF) made at the 11th IWWG Workshop by using the ECMWF method of selecting the AMV with the highest QI value in the thinning volume.

Acknowledgements: The authors gratefully acknowledge support from the Naval Research Laboratory under program elements 0601153N and 062435N.

REFERENCES


