REPROCESSING OF ATMOPHERIC MOTION VECTORS AT EUMETSAT

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Abstract

Imagers have been flying onboard polar and geostationary orbiting satellites for more than 30 years providing a suitable data source for climate research. The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) participates in the second European Re-Analysis of the global CLIMate system (ERA-CLIM2) project. The project contribution is dedicated to the "Preparation of satellite observations, boundary conditions, and forcing data" with the aim to improve the available observational record for the 20th century and to prepare data sets and assimilation tools needed for global reanalysis. One of EUMETSAT's contributions within the ERA-CLIM2 project is the generation Atmospheric Motion Vectors (AMVs) from polar and geostationary satellites. The polar AMVs are reprocessed using data from AVHRR instruments and derived from two independent algorithms. The first algorithm is the EUMETSAT operational algorithm and the second one is the algorithm developed at the Cooperative Institute for Meteorological Satellite Studies (CIMSS). The geostationary AMVs are reprocessed using MVIRI and SEVIRI images respectively onboard METEOSAT first and second generation satellites. The latest operational algorithm run at EUMETSAT is used for the reprocessing. The reprocessed products are validated through a comparison against radiosonde and NWP model analysis data. This paper presents the AMV dataset currently reprocessed at EUMETSAT and details the future AMV reprocessing plans.

EUMETSAT SATELLITES

EUMETSAT is the Europe's meteorological satellite agency. Its role is to establish and operate meteorological satellites to monitor the weather and the climate from space offering a 24/7 service. This information is supplied to the National Meteorological Services of the EUMETSAT 30 members and cooperative States in Europe, as well as other users worldwide. EUMETSAT also operates several Copernicus missions on behalf of the European Union and provide data services to the Copernicus marine and atmospheric services and their users.

EUMETSAT has now collected more than 30 years of consistent satellite data that are an asset for climate monitoring and understanding of our changing climate. Exploiting the potential of those data requires dedicated recalibration and reprocessing effort before making them available and usable for climate monitoring. Each satellite and instrument has its own characteristic such as sensitivity to the Earth signal, evolution of performance over time, or orbit stability. Calibration techniques and processing algorithms are constantly evolving with time, or orbit stability. Therefore a simple concatenation of data archived in real time would show jumps and/or artificial trends links with those changes and will not be useful for any climate analysis.

EUMETSAT has the capability to reprocess its data providing Fundamental and Thematic Climate Data Records (FCDR and TCDR), (*NRC, 2004*). This paper focuses on the first reprocessing of the polar and geostationary atmospheric motion vectors done at EUMETSAT during the last couple of years. Those TCDR contributed to the two European Union Framework 7 projects ERA-CLIM and ERA-CLIM2 (http://www.era-clim.eu). The project contribution is dedicated to the "Preparation of satellite observations, boundary conditions, and forcing data" with the aim to improve the available observational record for the 20th century and to prepare data sets and assimilation tools needed for global reanalysis. The AMV TCDR described in this paper can be ordered from the EUMETSAT data center (https://eoportal.eumetsat.int/).

GEOSTATIONARY ATMOSPHERIC MOTION VECTOR

Since 1982, AMVs are derived operationally at EUMETSAT using images acquired by the MVIRI imager onboard the Meteosat First generation satellites and then by the SEVIRI radiometer onboard the second generation of METEOSAT satellites. Each atmospheric wind vector is represented by its speed (m/s), direction (°) as shown in *Figure 1* and its height (given in hPa). The final hourly wind product is an average of three intermediate products derived every 15 minutes. Each wind vector is accompanied by a quality index as defined in Holmlund et al., 2001. The quality index takes into account the consistency between the three intermediate vectors and the consistency with the surrounding vectors.

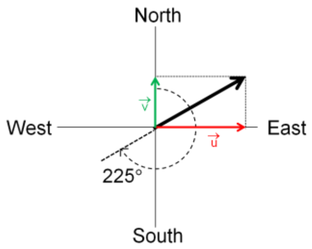


***Figure 1*: Wind direction measured in degrees in clockwise direction starting from the north. For example a direction of 225° represents a wind blowing from the south west. The altitude of the wind is expressed in hPa.**

Throughout the period, the sensors were replaced, aging, and various changes were introduced operationally at EUMETSAT in the AMVs derivation software. A climate change trend cannot be assessed using the AMV archive in real time at EUMETSAT knowing those changes. In 2013, EUMETSAT reprocessed the SEVIRI AMV using the last version of the algorithm available at that time (Version 1.5.3, 2013). Note that for time reprocessing constraints, the MSG winds were only derived every three hours and not hourly as the real time ones. Those data are identified by their unique digital object identifier (doi:10.15770/EUM_SEC_CLM_0006) and can be downloaded easily. Unlike the real time AMVs, the reprocessed AMV are now stable (*Figure 2*) and homogenous over the full reprocessed period and can be used for climate analysis or can be assimilated in reanalyses.

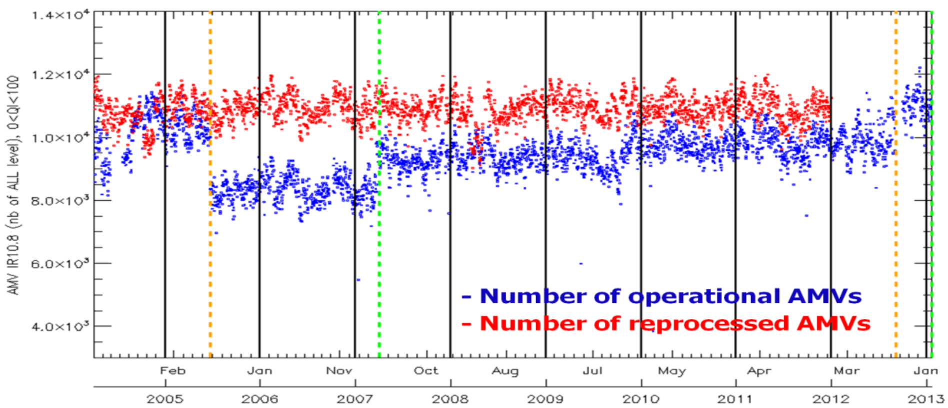


***Figure 2:* Number of hourly derived AMVs in the IR10.8 channel. Blue dots are the number of AMVs extracted operationally and stored in the MPEF database. Red dots are the number of reprocessed AMVs for the corresponding slots. The main changes in the algorithms are represented by the brown dashed lines; the changes in satellite are represented by the green dashed line. The benefit of the reprocessing is clear.**

The North Atlantic Oscillation (NAO) pattern is a climatic phenomenon in the North Atlantic Ocean of fluctuations in the difference of atmospheric pressure at sea level between the Icelandic and the Azores. It controls the strength and direction of westerly winds and storm tracks across the North Atlantic. The reprocessed AMV matches the general circulation pattern linked to NAO as shown on

Figure 3. This suggests a possible use of this CDR to study some possible changes in the general circulation patterns.

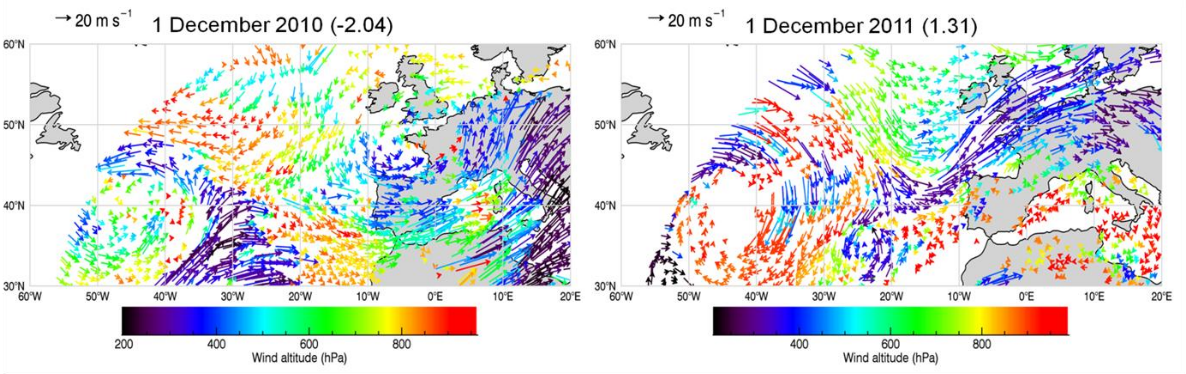


Figure 3: **Example of AMVs over Europe on the 1st of December 2010 for a negative (bottom left panel) positive (bottom right panel) NAO cases.**

POLAR AMV

EUMETSAT derives operationally since 2013 AMVs from its polar orbiting satellites using the images acquired by the AVHRR instrument (in the channel 4). In the framework of the ERA-CLIM project, EUMETSAT generated polar atmospheric motion vector CDRs using a single AVHRR instrument onboard the METOP-A satellite. Level 1 data at full Local Area Coverage (LAC) spatial resolution (1 km at nadir) were used with the aim to provide the data for assimilation into the new ECMWF reanalysis. This first reprocessing period of polar AMVs covers the period 2007-2014. The AMVs) were generated using two operational algorithms used at EUMETSAT and Cooperative Institute for Meteorological Satellite Studies (CIMSS). The ERA interim data were used by both algorithms as a model input (for radiative transfer calculations and height assignment). Those CDRs are publically available at no cost and can be ordered via the EUMETSAT Data Centre.

The idea behind the wind derivation is the same as for geostationary AMVs and is rather simple. The consecutive overpasses in Polar Regions are 102 minutes apart, which is quite long, compared to the 15-30 minute interval available from geostationary instruments. However, research has shown that a meaningful retrieval of AMVs is possible (*Dworak and Key 2009*).

Two algorithms were used to generate the polar wind data records:

- an adapted version of the algorithm used operationally by CIMSS (Version 1), and
- EUMETSAT operational algorithm (Version 2.4, 2013).

Details about those algorithms can be found in *Nieman et al. (1997)*, *Olander (2001)* and *Borde et al. (2016).* The main differences between the algorithms are summarised in *Figure 4.*

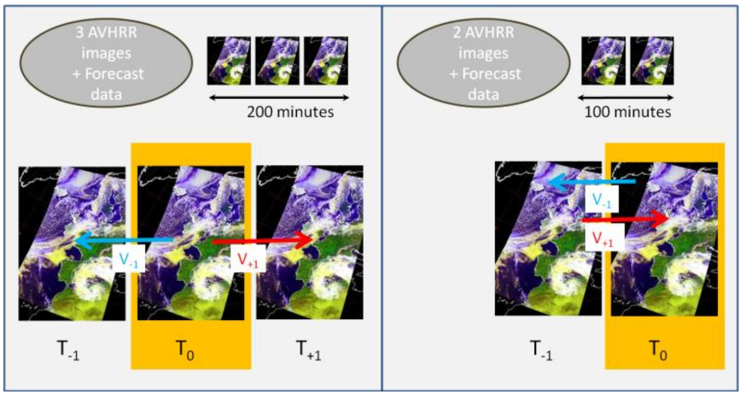


Figure 4: **AMV retrieval for CIMSS (left panel) and the EUMETSAT algorithms (right panel). The red arrows represent the forward tracking (V_{+1}) while the blue arrows represent the backward tracking (V_{-1}). The final vector (as reported in the product), at time T_0, is computed for CIMSS as the mean of V_{+1} and V_{-1} and is equal to V_{-1} for EUMETSAT.**

Unlike the CIMSS polar-orbiter wind algorithm that used an image triplet to track the AMVs, the EUMETSAT algorithm only uses two successive images to derive polar winds. This results in the

EUMETSAT algorithm deriving winds on a larger geographical area than the CIMSS algorithm (towards 50° latitude versus 65°), as shown in *Figure 5*. The larger area covers the location of the jet streams which represents an important element for studies of atmospheric dynamics and their potential changes with changing climate. The jet stream areas have almost no (southern hemisphere) or only limited observations (northern hemisphere), but are very important for the performances of Numerical Weather Prediction (NWP) models used for reanalysis. It has to be noted that the comparison of EUMETSAT and CIMSS AMV data records can only be done for the overlap region extending from the poles to 65° latitude north or south. Using only image pairs results in the loss of the temporal consistency test between the two consecutive wind vectors available from image triplets. This problem is mitigated by introducing a forward and backward tracking which consistency is taken into account for the final QI.

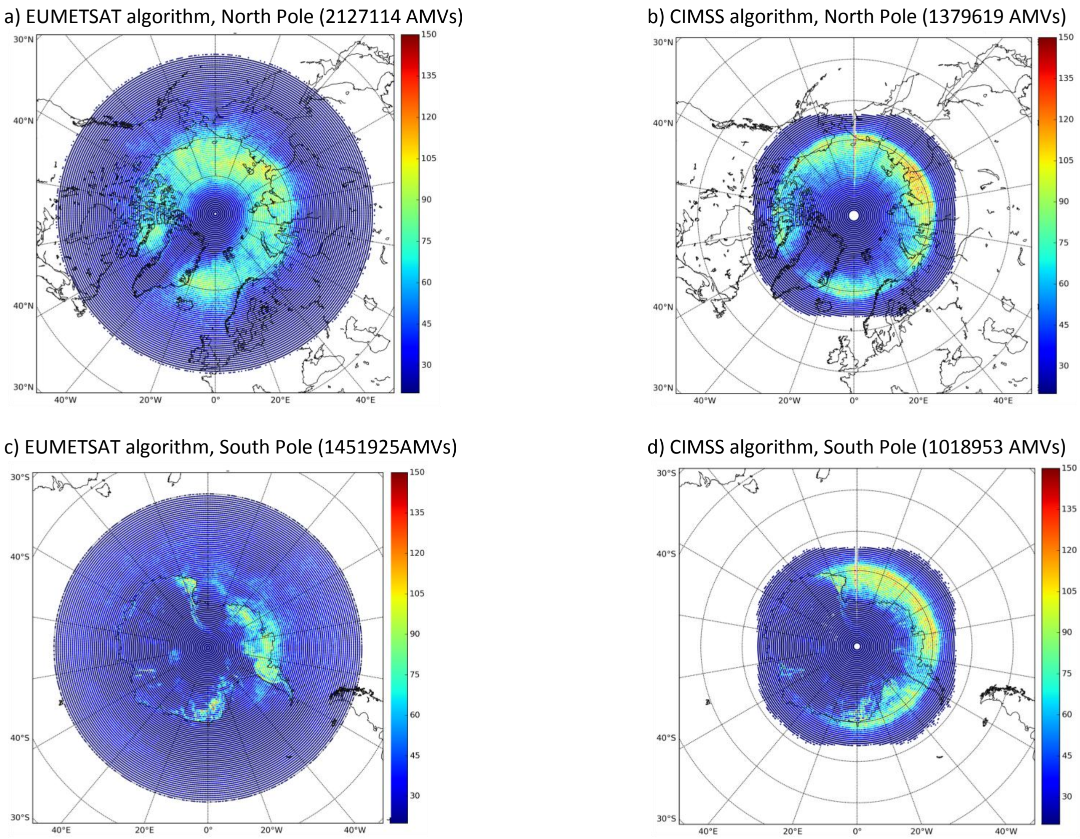


Figure 5: **Example of the mean number of AMVs (with a quality index QI > 50) retrieved over the North Pole (*a* and *b*) and the South Pole (*c* and *d*) for the month of August 2009. AMVs are gridded on a 0.5° × 0.5° regular grid to produce the plot. The total number of AMVs is indicated in brackets for each plot.**

To generate a wind product AVHRR images are collected over 200 minutes for CIMSS (image triplets) and 100 minutes for EUMETSAT (two images). Further difference comes from the usage of different vertical resolution for the model forecast (60 model levels for EUMETSAT against 12 model levels for the CIMSS algorithm). Those model data are mainly used for the height assignment that is the biggest source of errors and uncertainties in the retrieval. The two algorithms use different methods to derive the height. Both algorithms used the Equivalent Black Body Temperature method assigning the wind vector to an initial height based on the cloud top temperature and the model temperature profile. EBBT heights are prone to biases in situations with semi-transparent or broken clouds, and in the case of low-level temperature inversions. In such situations the vector height is refined using additional corrections. EUMETSAT applies a correction that places the wind vector at the level of the temperature inversion if such an inversion can be diagnosed in the forecast temperature profile. CIMSS uses a best fit adjustment using the forecast model results and the cloud based method for low level vectors.

The climate data records were generated to provide a consistent AMV data record from Metop-A for the ERA-5 reanalysis in the framework of the ERA-CLIM project. This also provided AVHRR AMV data for the first time for the period before 2013 when the polar AMV product became operational at EUMETSAT. The data record generation allows the removal of breaks and discontinuities in the data record caused by algorithms and/or instrument changes.

For the validation, the two datasets were inter-compared and compared/validated to forecast data, radiosonde data and AMVs derived from Meteosat Second Generation in areas where both were available. The full validation report can be requested at EUMETSAT.

The various comparisons have shown that both data records are consistent which each other and with each other dataset used in the comparisons. The EUMETSAT algorithm retrieved more vectors than the CIMSS algorithm (*Figure 6*). The number of AMVs retrieved over the North Pole is higher than over the South Pole. This can be explained by the geographical characteristics of the two areas. For the EUMETSAT algorithm there is a seasonal cycle showing more winds retrieved in the summer hemisphere. This is probably because of the poor performance of the cloud mask scheme implemented on the operational AVHRR chain. The lack of information from the visible channel during night time and the simple threshold method used for cloudy pixels identification do not really allow distinguishing between clouds and ice pixels (*Borde et al., 2016*). The amount of cloudy pixels available for the tracking substantially dropped during the night time, reducing the number of retrieved AMVs.

Both data records show the same temporal variability with no obvious flaws or trends. The two algorithms detect similar characteristics in the data (*Figure 9*), e.g. they show an increase of the wind speed with altitude. In addition, there is a clear seasonal cycle being more pronounced over the South Pole (amplitude for North Pole 3-4 ms^{-1}, and South Pole 5-6 ms^{-1}). For both algorithms the average height (or pressure) of the AMVs over the South Pole also shows a seasonal cycle with winds derived at higher altitude during winter seasons. Over the North Pole, there is a double seasonal cycle with winds being assigned higher in the atmosphere in summer and winter and lower in spring an autumn. The amplitude of the wind seasonal cycle is around 150 hPa. On average, the winds retrieved using the EUMETSAT algorithm are located 20 hPa higher over the North Pole (because of the greater latitudinal coverage).

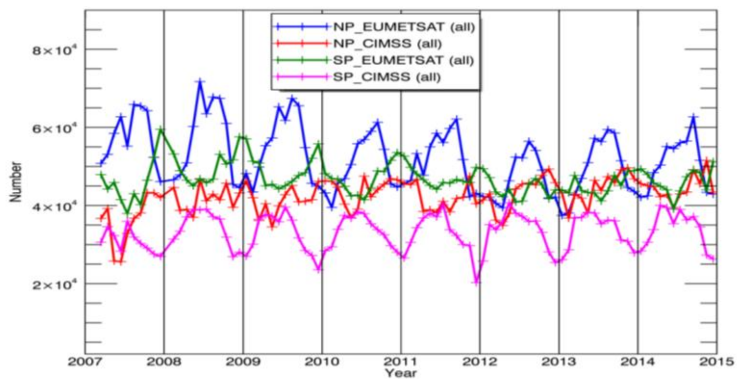
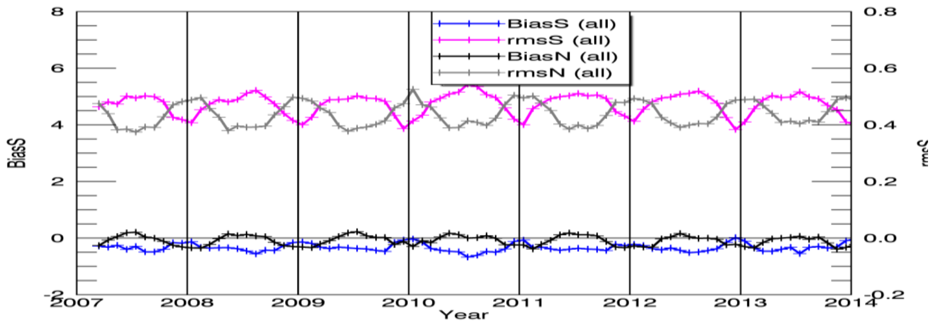


Figure 6: **Monthly averaged time series of the number of METOP-A winds retrieved using EUMETSAT (blue and green) and CIMSS (red and magenta) algorithms over the North (blue and red) and South Poles (green and magenta). Only AMV with a QI greater than 50 are considered.**

The strongest points regarding the EUMETSAT data record are as follows:

- Unlike traditional polar-orbiter wind algorithms such as the one developed by CIMSS that use image triplets for wind tracking, the EUMESAT METOP polar winds are extracted from a pair of Metop-A 10.8-μm images obtained approximately 100 minutes apart increasing the overlap area considerably, allowing wind retrievals pole wards from 50° instead of 65°. This is particularly important in the 50°-70° latitude band, where the polar winds help extending the spatial coverage of the date products derived from geostationary satellites.
- The EUMETSAT algorithm is less tight with the model forecast data especially to assign an altitude to the vector. This is particularly useful if the product is used in reanalysis as it provides a more independent information to the model. This can be seen from the fact that RMSEs with respect to the reanalysis forecast (*Figure 7*) are lower for the CIMSS algorithm but when compared to radiosonde data this seemingly better quality is not visible anymore and seems only due to the tighter relation with the model winds (*Figure 8).*

a) EUMETSAT AMVs



a) CIMSS AMVs

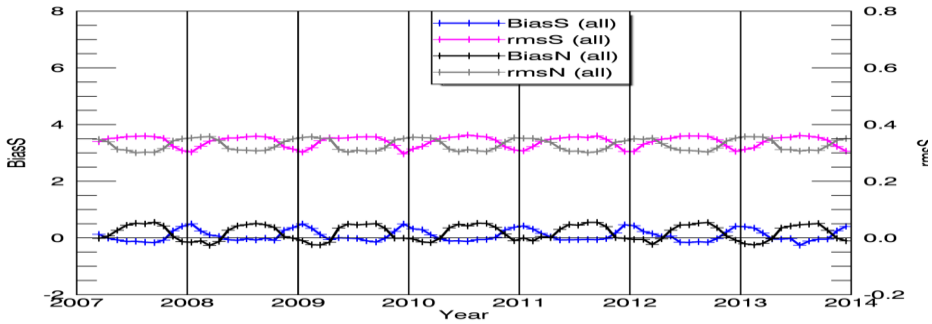


Figure 7: **Time series of bias (m/s) and RMSE (m/s) of EUMETSAT (a) and CIMSS (b) AMVs wind speed against the corresponding ECMWF ERA-Interim forecast for the North (black and grey) and South (blue and magenta) Poles.**

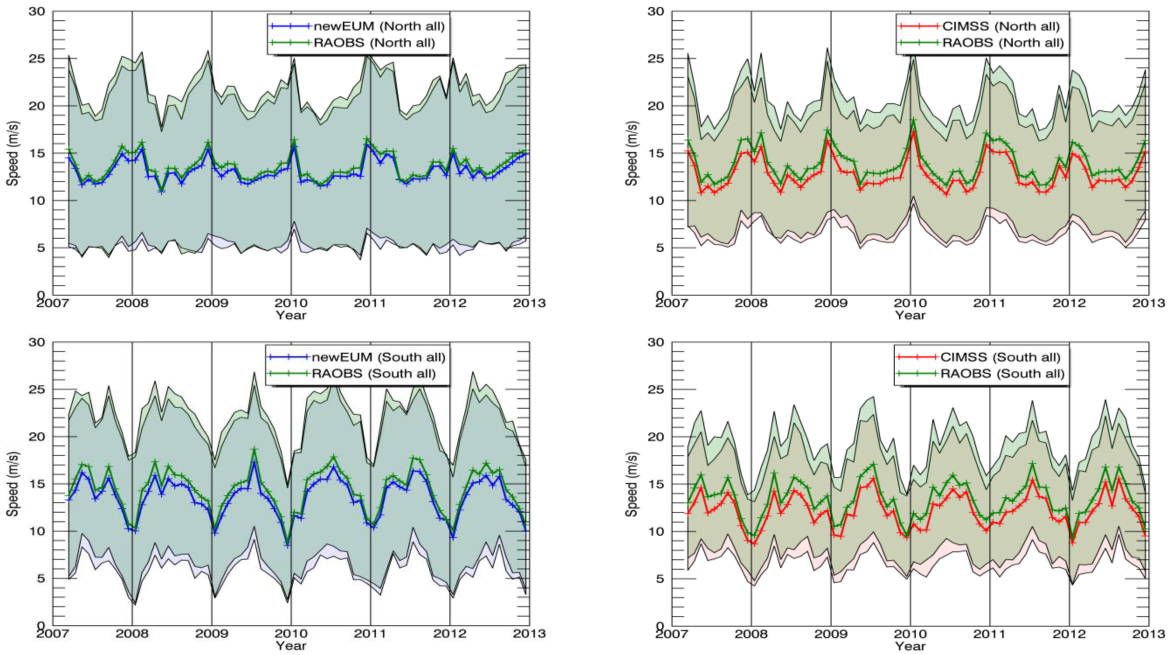


Figure *8*: Monthly statistics of the wind speed (m/s) for collocated satellite AMVs and RAOBS data.

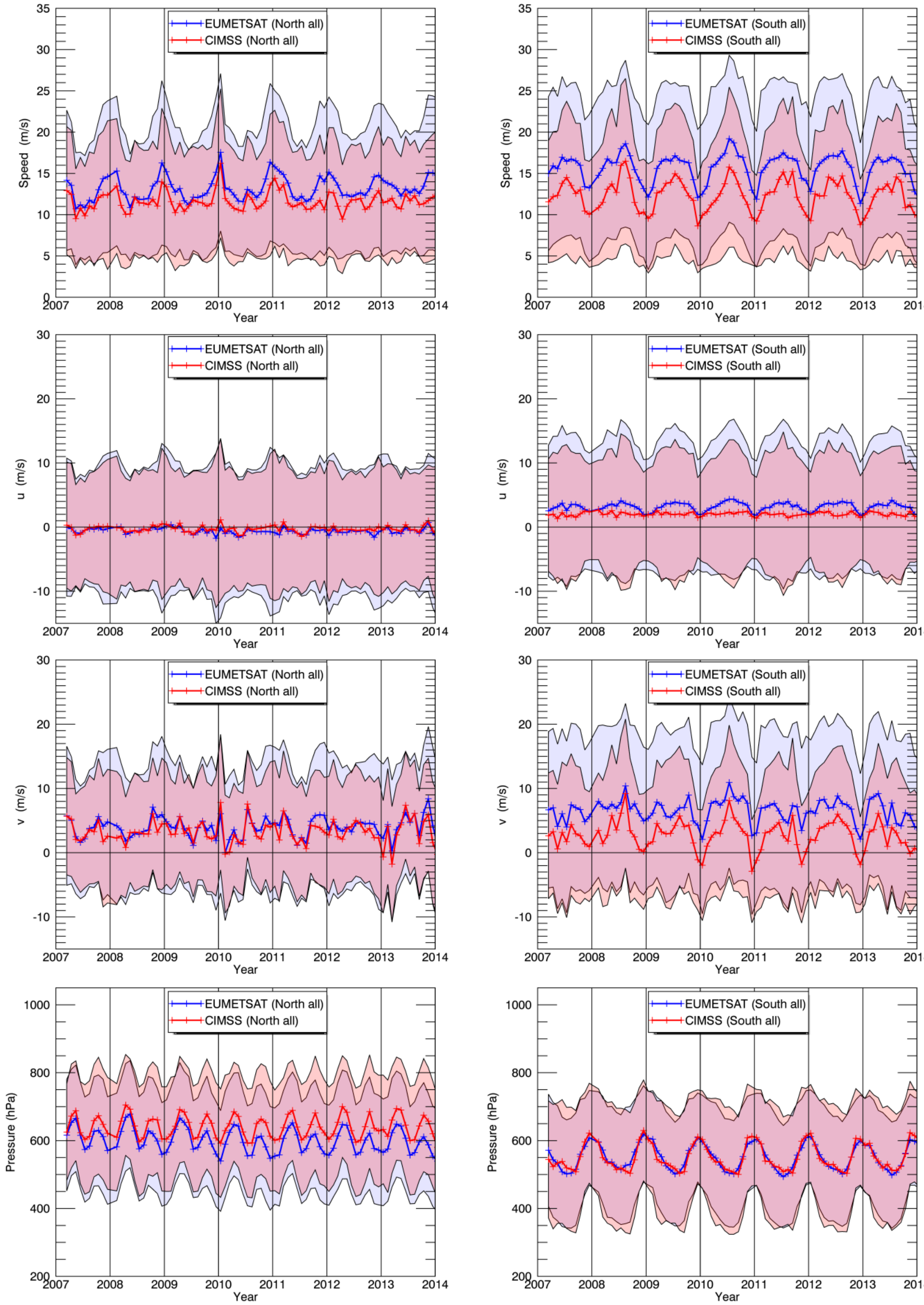


Figure 9: **Monthly mean of time series of speed (m/s), u and v components (m/s), pressure (hPa) over the period 2007-2013 for non collocated vectors over the North Pole (left) and the South Pole (right). The blue and pink envelopes correspond to ± one standard deviation. Only AMVs with a QI greater than 50 are considered.**

FUTURE

EUMETSAT has now gained experience in reprocessing FCDR and TCDR. The usefulness of reprocessed satellite climate data record is now recognised. The Meteosat first and second generation FCDR will be produced. The second release of the MFG and MSG geostationary AMVs derived using the same unified algorithm for both dataset should be released in 2017. The Release 2 of the polar AMV products will be generate from NOAA AVHRR-GAC imagery data back to 1982 using both EUMETSAT and CIMSS algorithms and will be delivered to ERA-CLIM2 project also in 2017.

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