ASSIMILATION OF POLAR WINDS AND RECENT SATELLITE WINDS IMPACT STUDIES AT ECMWF

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ABSTRACT

Polar Winds derived at CIMSS (Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin, Madison) from Modis onboard the Terra platform have been used operationally at ECMWF since January 2003. Their optimal use is an ongoing issue especially when combining the wind products of both polar-orbiting satellites (Terra and Aqua) that carry Modis instruments. Very recently Polar Modis winds became available from NOAA/NESDIS. They show better agreement with the ECMWF model background compared with winds produced at CIMSS. In several assimilation experiments the observational error has been reduced in order to take into account the improved quality of the winds. This leads to more consistent analyses over the Poles, in particular when AMVs from Terra and Aqua are used. In general, the neutral to slightly positive forecast impact of Modis winds in 3DVAR low-resolution experiments remains over both hemispheres. None of the Modis experiment is clearly outperforming in terms of forecast scores, although the usage of Aqua and Terra Modis winds has an advantage over Southern Hemisphere.

We also present some of the most recent Global Observing System Experiments (OSEs) carried out at ECMWF. These show a positive impact of the satellite derived AMVs in the ECMWF system. The strongest impact is over the Tropics and Southern Hemisphere.

1. INTRODUCTION

Tropospheric wind information can be estimated by tracking characteristic atmospheric features in subsequent satellite images (hence Atmospheric Motion Vector (AMV)). These atmospheric features can be clouds or other highly absorbing tracers in the atmosphere, i.e. water vapor (*Menzel, 2001*). The full-automated techniques to derive winds from satellite images were mainly developed for the application to geostationary satellites (*Holmlund et al., 2001*).

Since mid of 2001 CIMSS (Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin, Madison) is deriving AMVs from Modis (Moderate Resolution Imaging Spectroradiometer) images in order to fill the gap of missing wind information over polar regions (*Key et al., 2003, Bormann and Thépaut, 2004*). Modis cloud features are tracked in the infrared (IR) window band at 11 µm, and water vapor (WV) features (clouds and clear sky) are tracked in the 6.7 µm band.

At present AMVs from Modis on-board the National Aeronautics and Space Administration's (NASA) polar-orbiting Terra and Aqua satellites are processed on a routinely basis at CIMSS.

As there is a high demand in NWP to use these data as an operational product, NOAA/NESDIS was asked to take over the processing and dissemination in the near future. Test data from NOAA/NESDIS is available since November 2003 and quality checks against ECMWF background fields have been made over several months. Assimilation and forecast experiments have been conducted with varying observation errors associated to the winds. The common usage of AMVs from Terra and Aqua has also been investigated.

Winds processed at CIMSS and NOAA/NESDIS will be called thereafter CIMSS and NOAA winds respectively.

2. DIFFERENCES OF QUALITY BETWEEN CIMSS AND NOAA MODIS WINDS

The main difference in the derivation process lies in the usage of forecast fields from the NCEP GFS (Global Forecast System) model in NOAA processing while CIMSS is using the NOGAPS model from the US-Navy. Another important issue is the different handling of forecast fields: NOAA/NESDIS is interpolating the available forecast fields to the actual tracer time while CIMSS does not and may also use older forecast fields. Another difference is that CIMSS is using the third Modis image for the targeting while NOAA is using the middle image. The real impact of each difference is not clear at the moment and is under investigation at the wind producers site.

All Modis experiments in this study are done with ECMWF's 3DVAR (First Guess at the appropriate time FGAT) system in low resolution (T95 (≈210 km) with 60 levels in the vertical). The forecast step has run with T159 resolution (≈125 km). The passive monitoring period of Modis winds from CIMSS and NOAA/NESDIS starts at 7 Nov. 2003 (18 UTC) and ends 16 Dec. 2003 (12 UTC).

The model background departure (OBS-FG) is computed and density plots over the vertical and latitude are showing slightly less biased winds over the South Pole for NOAA winds for each wind type. Figure 1 shows the IR channel as an example. The mean vector difference between observation and FG is also taking the deviation in wind direction into account. In the IR channel (and the other channels) the vector difference is roughly twice as high for CIMSS winds compared to NOAA winds (Figure 1).

A detailed study co-locating NOAA and CIMSS winds and comparing their assigned pressures shows that there are no systematic differences in assigned heights (Figure 2a). This is supporting the fact that the OBS-FG biases for NOAA and CIMSS winds are pretty similar (Figure 2b) compared to the large differences in vector difference (Fig. 2c). The variance in CIMSS AMV vector difference is much larger than for NOAA. Therefore it can be suspected that for CIMSS and NOAA not always the same targets were tracked. This would imply that the search area for targets is depending on the different forecasts that are used and their processing. As the usage of forecast data in the NOAA processing is more sophisticated, it is quite likely that this results in derived winds of higher quality.

At the moment the observation errors for all AMVs are much higher than for conventional (radiosonde, pilot, aircraft) wind observations and range from 2 m/s for low level winds to 5 m/s for high level winds. In order to take the increased quality of the NOAA winds into account, it was considered worthwhile to revise the observation error for those winds. It is assumed that the variance of OBS-FG for each wind component is the sum of background error covariance σ_E^2 and observation error covariance σ_O^2

$$\sum (OBS - FG)^2 \cong \sigma_O^2 + \sigma_E^2$$

The left side can be calculated from the data and σ_E^2 is known from the forecast model. The observation error covariance is the residium of both. For NOAA winds these calculated values of the observation error covariance are about 1 to 2 m/s less than for CIMSS winds. The given assumption is only valid for uncorrelated observation errors and the assumption also relies on the fact that background errors and observation errors are not correlated, which is probably also doubtful after *Bormann et al, 2003.* Bormann et al showed that observation error correlations are present in satellite derived winds from geostationary satellites. As this is probably also the case for Modis Polar winds, it is advisable not to lower the observation error too much. As a compromise the operational assigned observation errors are reduced by 1 m/s in each level and thinning has been increased from 140 to 200 km.

3. FORECAST EXPERIMENTS WITH CIMSS AND NOAA MODIS WINDS

In total five low-resolution 3DVAR FGAT experiments have been computed from 1 Jan. 2004 (00 UTC) to 24 Jan. 04 (12 UTC):

- **CTL**: no Modis winds used
- **T-NOAA**: Terra winds from NOAA
- **T-NOAA OE**: Terra winds from NOAA with reduced observation error
- **TA-NOAA OE**: Terra and Aqua winds from NOAA with reduced observation error
- **T-CIMSS**: Terra winds from CIMSS

10 day forecasts have been run from the 12Z analyses. Verification of the forecast was done against operational ECMWF analyses.

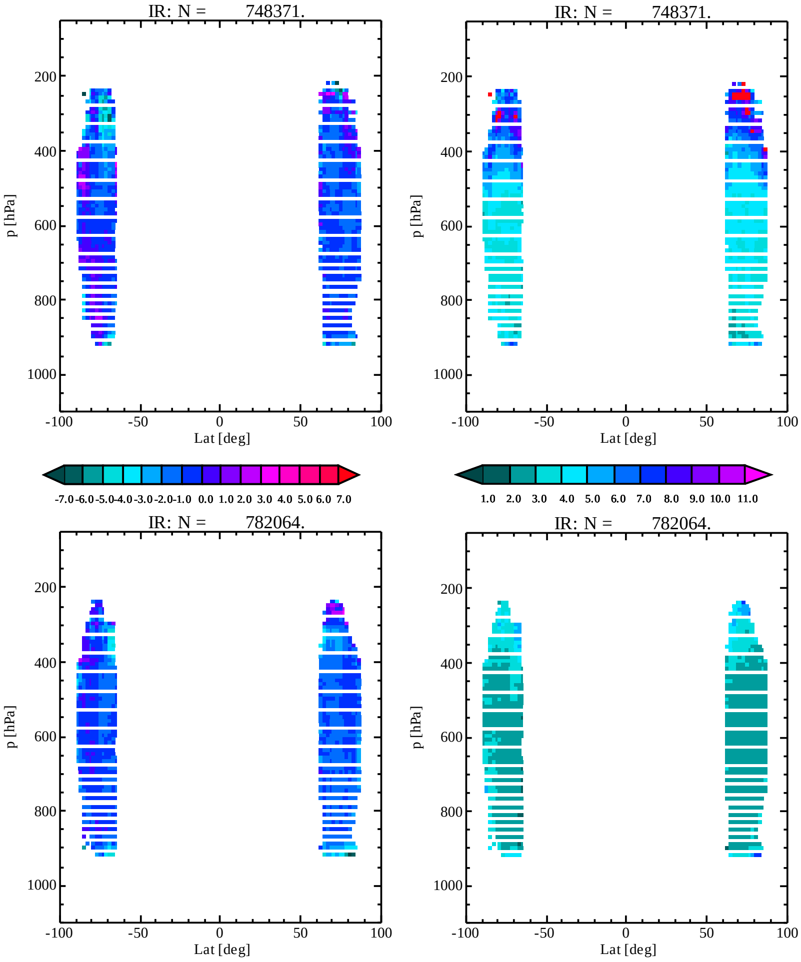

Figure 1: Density plots of OBS-FG bias (left) and vector difference (right) for CIMSS Terra Modis IR winds (top panels) and NOAA/NESDIS winds (lower panels) for 7 Nov. 2003 18UTC to 16 Dec. 2003 12UTC.

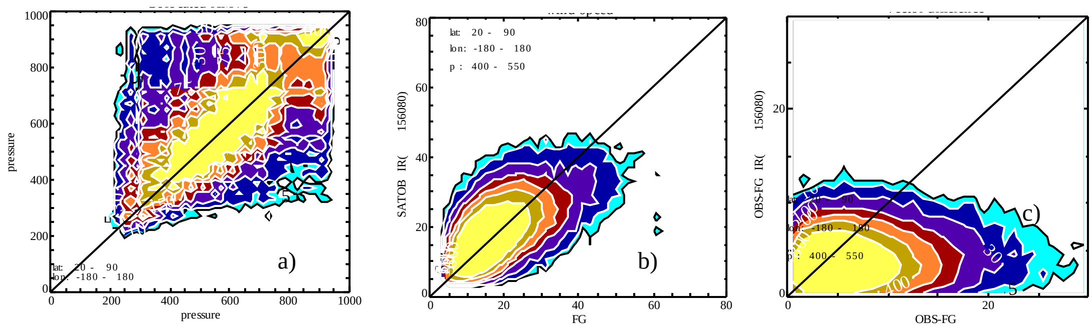

Figure 2: Density plots of IR winds from CIMSS (x-axis) and from NOAA/NESDIS (y-axis). From left to right are assigned pressure, observed wind speed and OBS-FG vector difference (7 Nov. 2003 18UTC to 16 Dec. 2003 12UTC).

The 500hPa geopotential height forecast scores over each hemisphere are slightly better for each experiment compared to CTL. The difference between the experiment with Terra NOAA winds with or without increased observation error is so small that **T-NOAA** is not depicted here. The inclusion of Aqua winds has a small but distinctively positive impact over both hemispheres. Over NH the positive impact on 500Z scores at day 7 and 8 is significant at the 98% level (or higher) compared to CTL. This supports previous results that the usage of Terra and Aqua (from CIMSS) has a slight positive impact (*von Bremen et al., 2003*) when thinning has been increased to 200km. **TA-NOAA OE** is significantly (95%) better than **T-CIMSS** at day 8 over NH. Over SH **TA-NOAA OE** is better than **T-CIMSS** at day 5 at the 95% significance level.

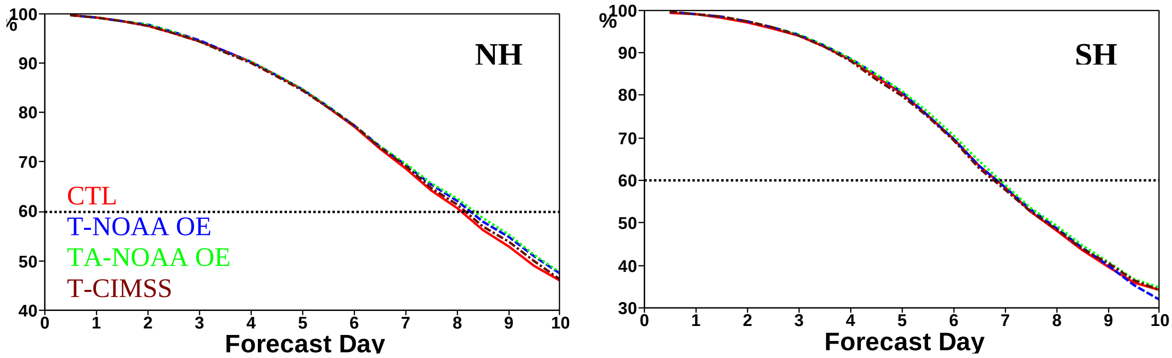

Figure 3: 500Z anomaly correlation forecast scores over Northern (left) and Southern (right) Hemisphere for three Modis experiments and no Modis CTL. T-NOAA_OE: Terra winds from NOAA with decreased observation error, TA-NOAA OE: Terra and Aqua NOAA winds with decreased observation error and T-CIMSS: Terra winds from CIMSS with original observation errors (24 cases in January 2004).

Figure 4 shows the RMS of 500hPa geopotential height analysis increments for all Modis experiments. The increments in CTL have been substracted. For all NOAA Modis experiments the increments are smaller than for CTL (yellow to green color scale). This is also true over SH although the differences are much smaller. The RMS of increments is slightly smaller when more weight is given to the NOAA Terra winds (**T-NOAA OE**). This seems to indicate that the analysis increments introduced by NOAA Terra winds are very consistent. The additional use of NOAA Aqua winds has the largest impact north of Canada (for 12Z analysis) where it decreases the RMS of geopotential height increments considerably. In 00Z analysis the largest Aqua impact is north of Kara and Barentsea. In general, the areas that are most influenced by Terra and Aqua lay opposite of each other as the orbit of both satellites is different by 12 hours. The spatial coverage within a 12 hour assimilation window is therefore much better than using the winds from only one single platform.

The difference in size of analysis increments between CTL and the CIMSS Terra experiment is much smaller. Overall the 500hPa geopotential height increments are slightly reduced (Fig. 4).

The distinct influence of Aqua can also be viewed in Figure 5, which shows the difference in mean wind vector increments between the Modis experiments and CTL. Aqua introduces large mean increments in areas north of Canada that are nearly unaffected by Terra winds (12Z analysis).

CIMSS Terra winds are partially introducing increments in areas that are unaffected by NOAA Terra winds (e.g. north of Norway) and increments are lacking for example over Barentsea.

Conclusively the 500 hPa mean geopotential height analysis is quite different for NOAA and CIMSS winds (Fig. 6). The largest differences with respect to CTL analyses are centered quite exactly over the North Pole for CIMSS winds. No real structure can be recognized. For NOAA winds the change in mean analysis is very consistent when giving more weight to the winds, i.e. the difference to **CTL** over the Pole is intensified. When Aqua is included this anomaly is even more pronounced although the maximum is still smaller than for **T-CIMSS** over the Pole.

The fit of other wind observations (radiosondes, aircraft data, pilot) to the model background is unchanged throughout the different experiments. However, it can be noted that the number of used radiosonde winds over the whole Northern Hemisphere are increased considerably in **TA-NOAA OE** but are reduced over the Tropics (high levels) although the number of used AMVs over the Tropics are increased very much. The latter is also true for **T-CIMSS** but the number of used radiosonde winds over the Tropics has also increased.

These results are not very consistent and make any explanation doubtable.

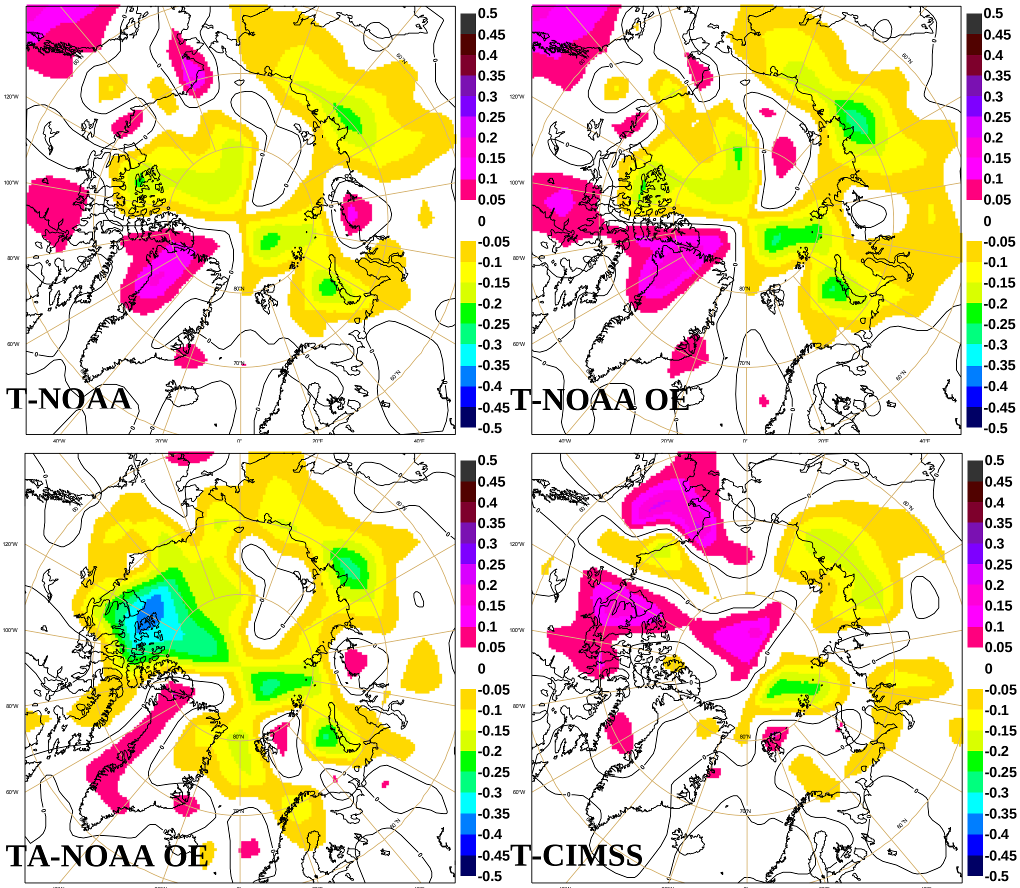

Figure 4: Difference of RMS of 500hPa geopotential height [gpdm] increments between the four Modis experiments and CTL. See text for explanation of Modis experiments. Negative values mean a reduction of increments (1 Jan – 24 Jan 2004, 12 UTC analysis).

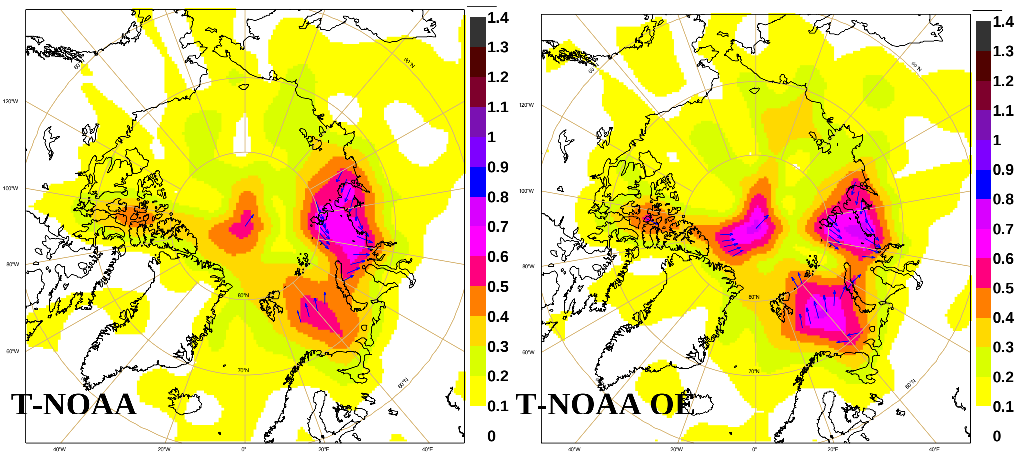

Figure 5: Difference of mean wind increments at 500hPa between the four Modis experiments and CTL. See text for explanation of Modis experiments. The color shading indicates the length of the diff- ence vector [m/s] (1 Jan – 24 Jan 2004, 12 UTC analysis).

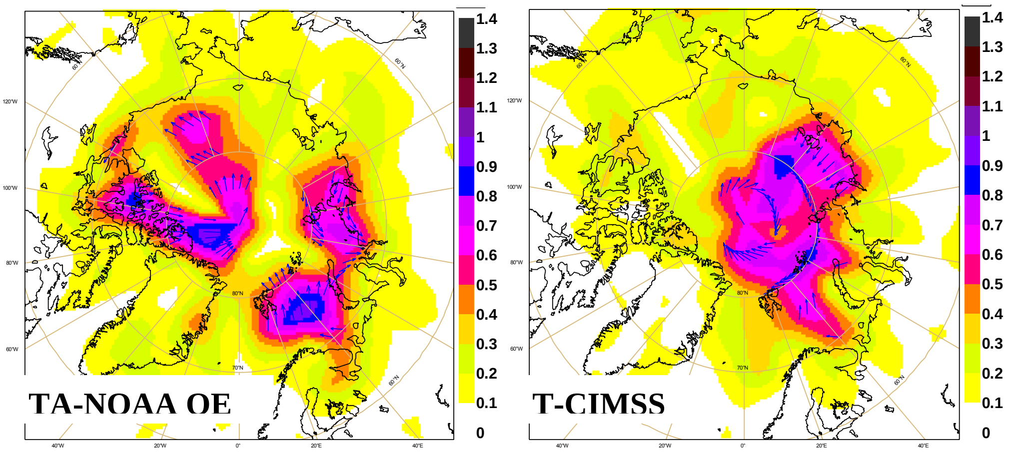

Figure 5: (continued).

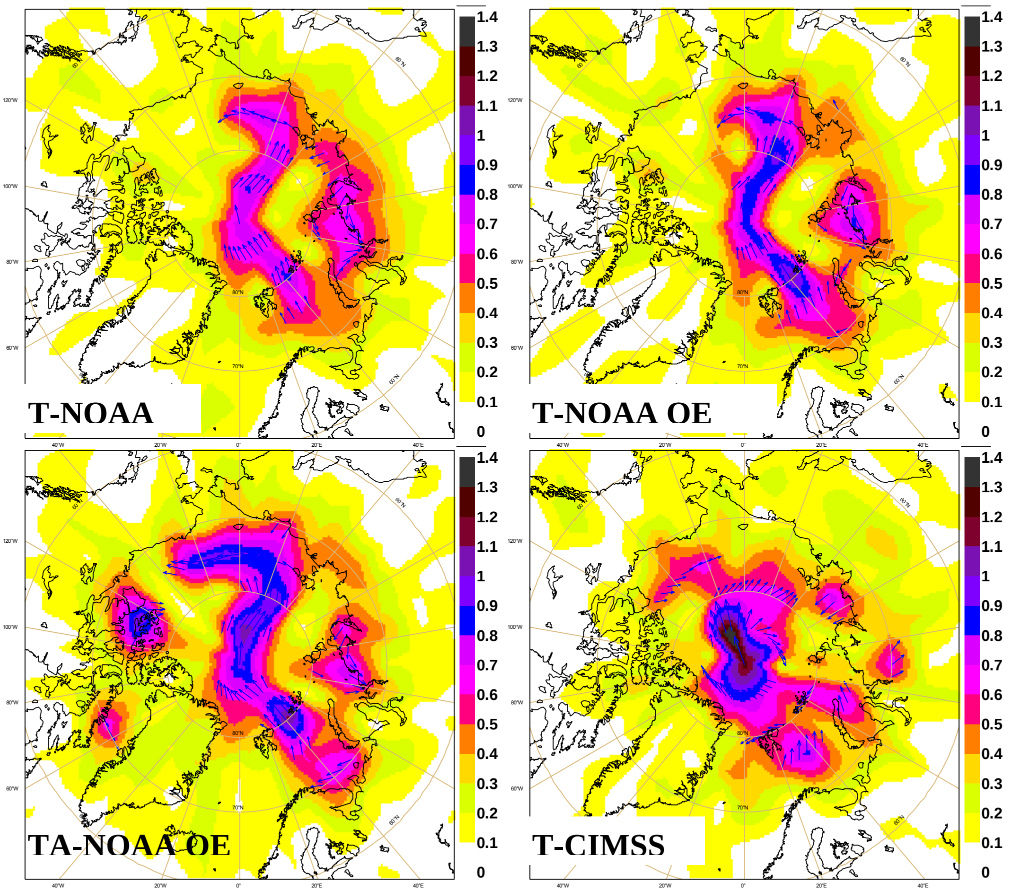

Figure 6: Difference of mean 500hPa wind analysis [m/s] between the four Modis experiments and CTL. See text for explanation of Modis experiments. The color shading indicates the length of the difference vector (1 Jan – 24 Jan 2004, 12 UTC analysis).

4. SATELLITE WINDS IMPACT STUDIES

A series of Observing System Experiments (OSEs) were run with the ECMWF Integrated Forecast System (IFS, Cycle 25R4) that had been operational between January and October 2003 (T511 (40km) forecast model and T159 (120km) 4DVAR analysis (*Rabier et. al 2000*)). Two summer (1 August - 30 September 2002) and two winter months (11 December 2002 - 9 February 2003) have been considered (122 cases). For a full description of the OSEs the reader is referred to *Kelly et al, 2004*. The impact of several data types of the Observing System has been evaluated by excluding only them from the analysis. This report will only cover the experiment (**no sat**) without any satellite data (radiances) or derived product from satellite data (i.e. winds) and the experiments without any AMV data (**no satob**). The **CTL** experiment contains all data that had been used in the operational forecast at that time.

Figure 7 shows the 500Z anomaly correlation forecast scores over NH and SH for the three experiments. The impact of AMVs is slightly positive over NH but not significant. Over SH the positive impact is larger and significant at day 3 in the summer experiment only and at day 8 in both seasons (95% significance level or higher). The general impact of satellite data over SH is overwhelming and is increasing the predictability over SH to the same level as over NH.

Satellite winds have the largest positive impact in high levels over the Tropics (both seasons) and over SH (summer season). In the summer season the significance level of improvement in vector wind forecast (200 hPa) is 99.8 % or better for each forecast day. The combined forecast scores for both seasons are drawn in Fig. 7 for the 200hPa vector wind.

The mean 850 and 200hPa wind vector analysis for August 2002 is shown in Fig. 8. The differences between **CTL** and **no satob** are largest over the Tropics and over SH in the GOES-10 and MET-5 disk. The south-east trade winds are more pronounced at 850hPa and the Indian monsoon is strengthened.

The usage of satellite winds reduces the RMS of 500hPa geopotential increments mainly over the southern MET-5 area, the northern MET-7 area and over the southern Pacific (Fig. 9, August 2002). This indicates that the winds have a consistent impact on analyis. In particular over these areas the satellite winds introduce larger mean geopotential height increments (Fig. 9). In the winter season the difference in RMS of geopotential height increments between CTL and the experiment without AMVs is minor. The difference in mean geopotential increments is also smaller.

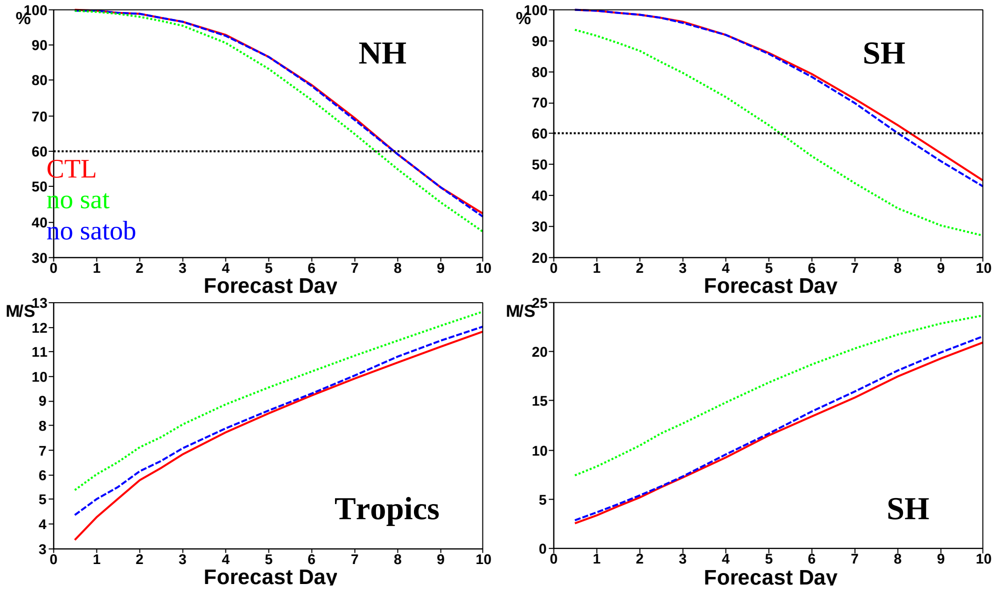

Figure 7: 500Z anomaly correlation forecast scores over Northern (top left) and Southern (top right) Hemisphere for CTL, no sat and no satob experiment. RMS of wind forecast error at 200hPa over Tropics (bottom left) and Southern Hemisphere (bottom right). 122 cases have been considered.

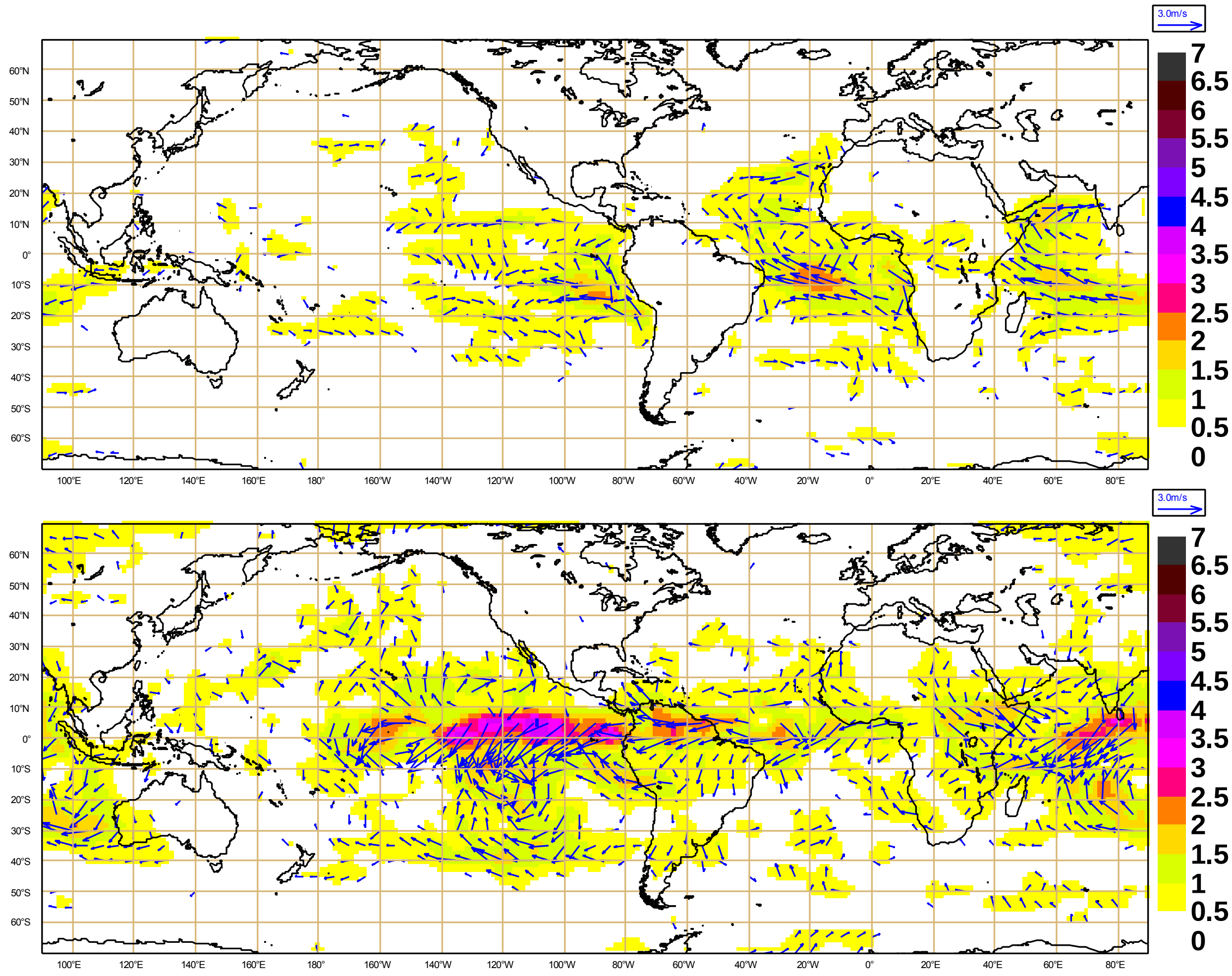

Figure 8: Mean wind analyis difference at 850hPa (top) and 200hPa (bottom) between CTL and no satob experiment for August 2002.

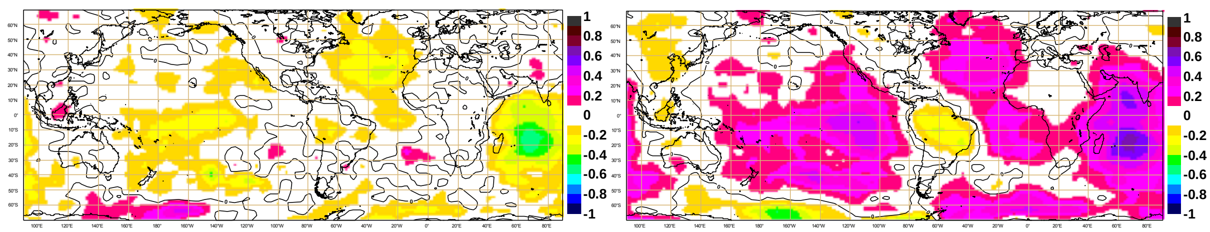

Figure 9: Difference of RMS of 500hPa geopotential height increments (left) between CTL and no satob experiment for August 2002 and difference of mean 500hPa geopotential height increments (right)

5. SUMMARY AND PROSPECTS

Observing System Experiments show a substantial positive forecast impact of satellite derived winds (AMVs) over the Tropics and Southern Hemisphere. Important parts of the general atmospheric circulation (trade winds, Indian monsoon) are strengthened when satellite winds are used. The impact on analysis is very consistent and leads to considerable reduction in RMS of increments and larger mean increments. It has to be mentioned that Modis Polar winds have been only included for 4 weeks at the end of the winter study period.

Modis Polar winds are produced at the moment by CIMSS and NOAA/NESDIS. Both centres use different forecast models for the processing. The NOAA/NESDIS winds agree much better with the ECMWF model background in terms of bias and vector difference. It can be suspected that the different forecast models used play an important role in the wind processing, especially when setting the target area.

The improved fit to the ECMWF model background has encouraged the assimilation of NOAA/NESDIS winds with reduced observation errors. It has been shown that this increases mean increments and reduces variance of increments. The additional usage of Aqua data gives a consistent impact to the Polar wind analysis and also reduces wind increments. The usage of Terra data from CIMSS seems to have a less consistent impact on the analysis as increments are nearly unchanged compared to the no Modis control experiment. In terms of forecast scores all Modis experiments are doing better than the no Modis control, although the common use of Terra and Aqua winds is performing best. The impact of NOAA Terra and Aqua winds is currently evaluated in high resolution 4DVAR experiments. In case of comparable results to the study presented here, it is hoped that the NOAA/NESDIS processing will be used in the near future.

6. ACKNOWLEDGEMENTS

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