ATMOSPHERIC MOTION VECTORS AT ECMWF - OPERATIONAL STATUS AND RESEARCH ACTIVITIES

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Abstract

The paper delivers a brief update on the operational status of Atmospheric Motion Vectors (AMVs), monitored and assimilated operationally at the European Centre for Medium Range Weather Forecasts (ECMWF). AMVs from two new satellite instruments – FY2D and FY2E, became available and are now monitored. The instruments used for the current operational winds products have remained unchanged over the last 1.5 years. EUMETSAT and JMA implemented algorithmic changes – they are addressed in the first part of the paper.
A few new products were evaluated in the ECMWF data assimilation system and investigated in terms of quality and forecast impact. They reflect changes in the retrieval algorithms related to radiative transfer model calculations, surface emmissivity, target and search box sizes, and timeliness of the winds.

OPERATIONAL STATUS OF AMVs

NESDIS

Over the last one and a half years, there have been no operational changes to the wind products from GOES-11, GOES-12, MODIS and AVHRR. Their quality is stable and only the AMV count has varied slightly due to temporary data dissemination issues, instrument maintenance and manoeuvres, etc. NOAA NESDIS commenced the production and dissemination of AVHRR AMVs, however it was decided not to replace the currently used AVHRR AMVs produced by CIMSS/University of Wisconsin-Madison, before the product undergo extensive testing. Since December 2009, CIMSS/ University of Wisconsin-Madison is using a new Generating/Originating Centre code (176).

CMA

The Chinese Meteorological Agency (CMA) reported an overall improvement of their algorithm for FY2-C AMVs. It was first implemented in August 2009, and then in February 2010 with the beginning of disseminating winds from FY2-D and FY2-E. The new data streams replaced the FY2-C winds, and a quality evaluation is due in addition to the ongoing monitoring, which started in late February 2010.

JMA

The Japanese Meteorological Agency (JMA) introduced a couple of modification to their extraction algorithm. Since May 2009, a new height assignment routine was implemented – now they use the Cross-Correlation Contribution method for selecting pixels contributing to the height assignment. This change affected the high and middle level IR AMVs. A new template size of 16x16 pixels was adopted, and the derivation region was expanded with about 5 degrees in both latitude and longitude range. In August 2009 they added wind extraction at 03, 09, 15, 21 UTC. These AMVs are derived only over the Northern hemisphere, and the target size is 24x24 pixels. The new product is stored at ECMWF, but not assimilated yet. Finally, in September 2009 JMA implemented an improved tracking algorithm using nested target tracking (first a larger target box, and then a smaller one). All changes to the JMA AMV have been monitored closely, and although preliminary results from JMA show improvements of the AMV quality in terms of RAOBs collocation statistics, the background and analysis departures monitored at ECMWF do not show significant reduction of the departures.

EUMETSAT
Effective 1st August 2009, EUMETSAT replaced their SYNSATRAD radiative transfer model for Meteosat-8 and Meteosat-9 products with the Radiative Transfer for TOVS model (RTTOV) (Saunders, et. al.,2007). RTTOV is able to model the radiances observed by a wide range of satellite infrared and microwave sensors and is fast enough for operational use. EUMETSAT also introduced new monthly surface emissivity maps based on MODIS data. In terms of impact, they reported a slight vertical redistribution of AMVs counts.

The assessment of a month worth of IR AMVs (May 2009) using the RTTOV and their vertical distribution is summarised in Table 1. The First Guess and Analysis departures are comparable prior and after RTTOV, for low, mid-level and high winds. Only very small differences are observed for the winds at 100hPa, but the counts are very low, thus the statistics could be influenced by single observations. The similarity in quality is consistent globally with exception to the extratropics where the high level winds with RTTOV show slightly worse negative bias. Mean wind and geo-potential analysis were not impacted by the RTTOV implementation. Due to the restricted size of the test data set, forecast impact has not been investigated.

Table 1 Vertical distribution of AMVs after the RTTOV implementation

EUMETSAT				ALL	||			QI>80	
IR10.8	Total	High	Mid	Low	||	Total	High	Mid	Low
OPER	10254	4629	998	4627	||	5056	2348	316	2392
		45%	10%	45%	||		46%	6%	48%
OPER-RT	29	58	-100	70	||	-23	8	-64	33
% of OPER	0.3	1.3	-10	1.5	||	-0.5	0.4	-20.2	1.4

RESEARCH ACTIVITIES ON AMVs

Monitoring and forecast impact of MODIS Direct Broadcast (DB) AMVs on ECMWF's Data Assimilation System

Winds from the MODerate-resolution Imaging Spectroradiometer (MODIS) have been generated since 2002 for the high-latitude polar areas (Key et al., 2003). Both Terra and Aqua MODIS imagery are used to produce ~3.5 hourly winds from successive pole overpasses every ~100 minutes. The European Centre for Medium Range Weather Forecasting (ECMWF) demonstrated a positive impact of the MODIS polar winds on short-range forecasts, particularly over the Arctic but also in the mid-latitudes in the northern-hemisphere (Bormann and Thepaut, 2004). Forecast improvement was quantified in terms of geopotential height forecast accuracy. Because much of the MODIS wind data is not available soon enough for use in the numerical weather prediction data assimilation cycles, MODIS wind processing systems have been implemented at a few direct broadcast sites to improve timeliness. Currently, ECMWF receive (from Univ. of Wisconsin / CIMSS via ftp) MODIS Direct Broadcast (DB) AMVs generated at the following direct broadcast sites: McMurdo, Antarctica (Terra and Aqua MODIS); Tromsø, Norway (Terra MODIS); Sodankylä, Finland (Terra MODIS); Fairbanks, Alaska (Terra MODIS). The wind products from these stations arrive much earlier than the global ones - about 100 minutes lead time for the Artctic and 150 minutes for the Antarctic. There is variation in terms of latency and coverage, but passive product monitoring at ECMWF (since 2006) shows significant improvement in terms of temporal coverage (Delsol, 2008). First guess and analysis departures show comparable quality to the MODIS global winds. Because of their earlier arrival time, it is hoped that MODIS DB AMVs will be beneficial to the "early delivery" assimilation cycle, but also good to include in the "delayed cut-off" cycle.

Two sets of experiments have been run to assess the impact of MODIS DB AMVs in ECMWF's 4DVAR Data Assimilation System. All experiments cover two months each, with one set for the winter season

(December 2008-January 2009), and another for the summer season (August-September 2008). They all run the 35R2 model cycle 4D-VAR at T_L255 spatial resolution with an incremental analysis resolution of T_L159. Winds are screened by their forecast independent quality indicator (QI) applying a threshold of 50%, for consistency with the already assimilated MODIS global winds. All winds are thinned in 200km by 200km by 50-175 hPa boxes, in 30 min slots. The following experiments are performed: i) a control experiment (ctrl); ii) an experiment assimilating MODIS DB AMVs with observation errors (OE) equal to what is used for MODIS global winds (oprOE); iii) an experiment assimilating the MODIS DB AMVs, but with increased observation error values for all MODIS AMVs - 1 m/s is added to the operational polar winds OE making it equal to the one used for geostationary AMVs (incOE).
For the summer season experiments MODIS DB winds are available only for the Arctic.
It is important to clarify that the MODIS DB winds are extracted from the same images as the global winds, only earlier, thus they would have the same observation time as the global winds extracted later from the same images. 'Duplicate' wind vectors are removed during thinning as long as they fall within the same 30 min thinning window and as long as the DB processing assigns the same observation time to the product. In the Arctic region there are three DB stations overlapping in spatial coverage. Each assigns its own observation time stamp, but they are never more than 15 min apart, thus the thinning will remove most of the duplicates.
Other AMVs assimilated in these experiments are from Meteosat, MTSAT-1R and GOES VIS, IR and WV (cloudy) AMVs; MODIS global Terra and Aqua (IR and WV); all subject to quality control and thinning as described on the NWP SAF web-page. The experiments are run in an early delivery IFS mode, where the improved timeliness of the MODIS DB winds is anticipated to contribute most to.

Additional experiments (not presented in detail in this document) assimilating MODIS global winds, but only passively monitoring the DB winds show comparable quality between the two polar wind data sets in terms of first guess and analysis departures. This is not a surprising finding because they are extracted with the same AMV retrieval algorithm. In the experiments presented here, as illustrated in Figure 1, the MODIS DB winds show better agreement with the background than the global AMVs. Even for the control experiment, the standard deviations are smaller for the DB wind background departures. Figure 1 also shows slightly smaller FG departures standard deviations when the MODIS DB winds are assimilated, i.e. short term forecasts with MODIS DB winds are in better agreement with MODIS global winds. When assimilated in the 4D-VAR system, the MODIS DB AMVs manifest better agreement with the analysis than the global winds, especially in terms of standard deviation, see Table 1 (only winter experiment is reported, but results are valid for the summer experiment too). Since the extraction algorithms are the same at NOAA/NESDIS (producing the global winds) and UW/CIMSS (producing the DB winds), the reduced departures could be attributed to the increased number of observations leading to more weight in the analysis.

Within each set of experiments, the statistics from used winds show that assimilating the MODIS DB winds leads to about thrice as many winds used. Throughout all pressure levels the standard deviation and the bias of the analysis departures have been reduced.

It is interesting to note that in the experiment assimilating polar winds with increased observation error the departures bias and standard deviation remain the same compared to the control. This can be explained with the link between observation error and first guess check, i.e. the larger the observation error, the more relaxed the first guess check becomes. Thus more winds with a larger departure pass the quality control. The effect compensates for the reduction in the standard deviation noted earlier. Consistent with this, even more MODIS DB AMVs were assimilated when the increased OE is used. The reduced analysis departures (compared to the control experiment) are an indication for an improved analysis in the sense of performing a better fit to the observations; however it is important to make sure that the large number of DB winds is not drawing the analysis away from other observations. Sonde measured U and V are such independent observation and results show the analysis has not been biased towards the AMVs. The numbers of used TEMPs remain unchanged.

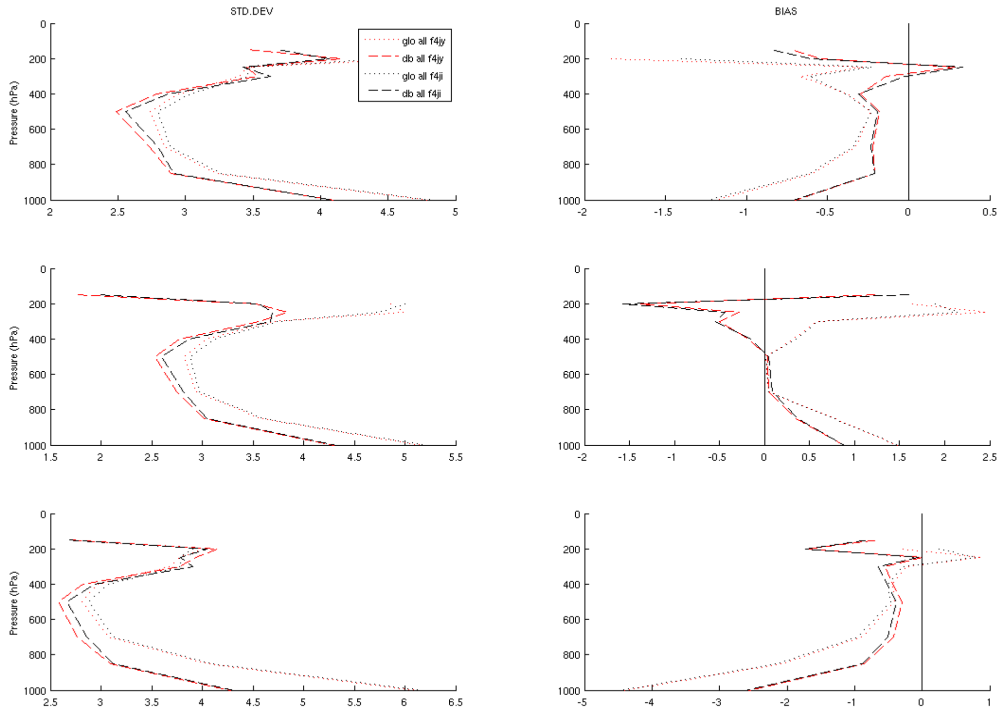

Figure 1: Profile of standard deviation and bias statistics of background departures [m/s] (u - top panel, v-middle panel, speed - bottom panel) for the global (dotted line) and Direct Broadcast (dashed line) Arctic AMVs shown separately for the control (f4ji - black) and the experiment assimilating MODIS DB AMV (f4jy - red line), for the early delivery analysis. Data period: 2008-12-01 - 2009-01-31.

Table 1: MODIS global and Direct Broadcast Speed statistics [m/s] for all spectral type and pressure level winds, for DA analysis. Data period: 2008-12-01 - 2009-01-31

		Speed			FG Speed Departure		AN Speed Departure	
		NumObs	Mean	Std	Mean	Std	Mean	Std
Global								
Arctic	All	333989	17.6	9.29	-0.513	2.94	-0.552	2.77
	Used	22056	17.0	9.55	0.248	2.37	0.223	1.97
Antarctic	All	93366	13.1	6.22	-0.103	2.66	-0.212	2.55
	Used	4374	13.9	7.92	0.693	2.33	0.522	1.99
DB								
Arctic	All	425088	17.0	8.71	-0.358	2.68	-0.319	2.43
	Used	40926	16.2	9.34	0.046	2.25	0.068	1.85
Antarctic	All	195362	12.8	6.15	-0.180	2.47	-0.234	2.36
	Used	10401	13.9	7.3	0.299	2.31	0.255	1.86

In general the MODIS DB winds are complimentary in terms of time of arrival and spatial coverage to the global winds. When there is partial spatial overlap, the two data sets are still distinguished in the 4D-VAR system by their observation time. On the rare occasions when MODIS DB and global winds are from the same areas and have similar (but never the same) time stamp, the MODIS global winds will be preferred in the DA system, due to the fact that only they have a forecast independent Quality Indicator. A request has been sent to UW/CIMSS (the producer of MODIS DB winds) to add the forecast independent QI to the MODIS DB data set. Furthermore, the mean vector wind analyses for 850, 500 and 200 hPa (not shown here) show that the assimilation of the MODIS DB winds is not altering the mean analysis locally to the poles, and that the differences are small in magnitudes, ±0.3m/s, thus there is little change to any wind analysis biases.

The impact of the assimilation of MODIS Direct Broadcast AMVs on the forecast performance is assessed through verification against the operational and the own analyses. Results from verification against the own analysis is shown, because it seems a better choice when a new data set is introduced to the system. Scores from the summer and winter experiments were merged in order to increase the sample volume and to eliminate possible seasonal dependence.

As Figure 2 shows, the assimilation of MODIS Direct Broadcast AMVs has a mostly neutral impact on the forecast. Globally this could be due to the limited region over which this additional data is available, despite the significant number of vectors. In the Southern Hemisphere there is barely any impact, due to receiving data only from one station, but most importantly, because all winds over land and below 400 hPa are blacklisted. Most impact is expected in the Northern Hemisphere. Days 1 through 3 forecasts, at pressure levels 850, 500 and 200hPa, show a slight degradation, which may merely reflect the added variability in the experiment with the additional MODIS winds, given the lack of other wind observations in the polar regions.

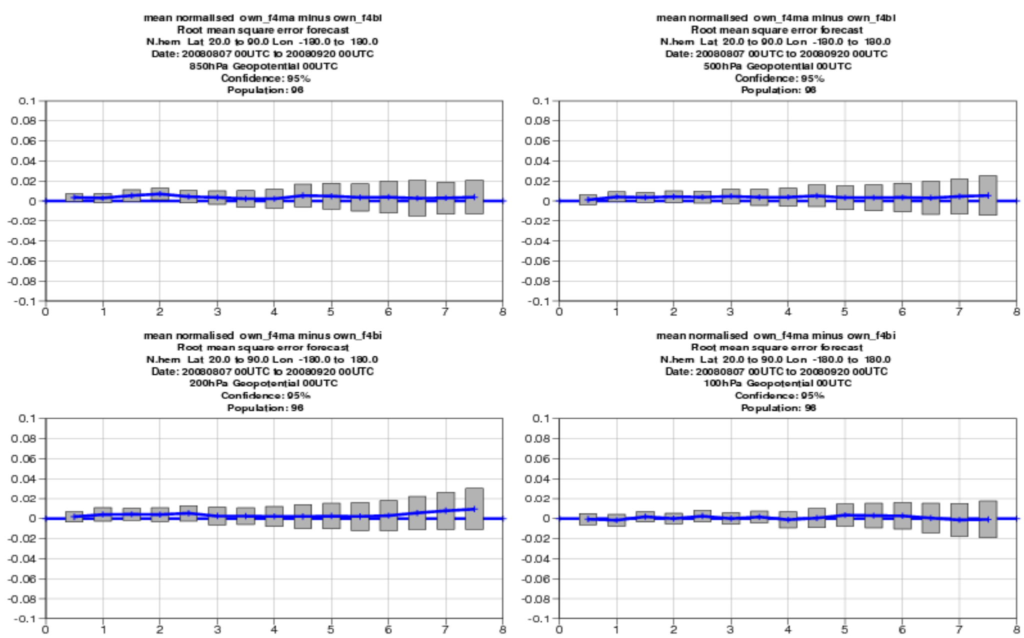

Figure 2: Normalised difference of the RMS of FC Error as a function of forecast range for the geopotential height (f4iu - with MODIS DB AMVs, f4bi - control), i.e. negative differences show benefit from assimilating DB winds). The grey error bars indicate the 95% confidence range based on the standard statistical test for the difference in the mean of two populations (in this case each consists of 96 cases). 850hPa, 500hPa, 200hPa and 100hPa pressure levels are shown for Northern Hemisphere. Verification is against own analysis.

The global distribution of the normalized difference in the RMS of the T+48 FC error for 850, 500, 200 and 100 hPa Geopotential Height with and without DB winds is presented in Figure 3. The largest error differences are observed in the tropics, however due to their small magnitudes and the distance from the MODIS DB winds observation location, there is not enough evidence for correlation between the two.

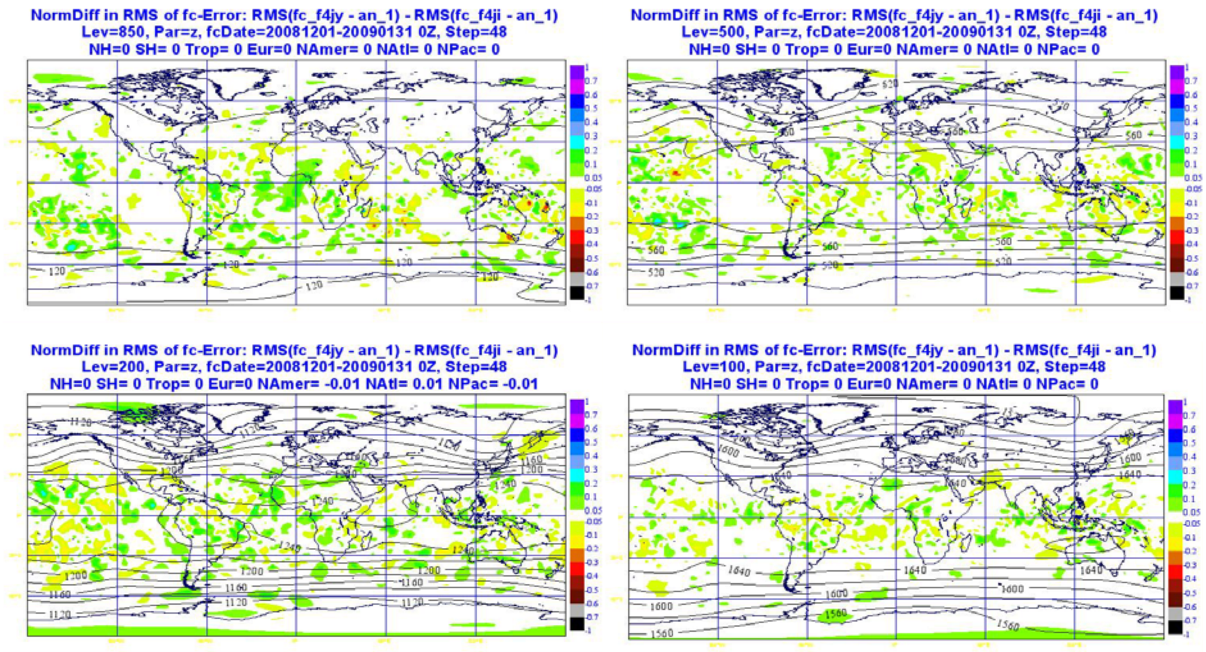

Figure 3: Normalized difference in the room mean square T+48 FC error for 850, 500, 200 and 100 hPa Geopotential Height with and without MODIS DB AMVs (f4jy - with, f4ji - without), i.e. yellow/red/black colouring shows benefit from assimilating the MODIS Direct Broadcast winds. Own analysis is used for the verifying analysis.

The experiment assimilating MODIS AMVSs with increased observation error show little difference in terms of FC error compared to assimilation using the current OE (used operationally for MODIS global winds). Despite the small magnitude in terms of impact, the MODIS DB winds add to both the temporal and spatial coverage of observation in an otherwise observation sparse region.

This study investigates the use of MODIS Direct Broadcast AMVs in the ECMWF 4D-VAR assimilation system. MODIS DB winds improve the timeliness and add a significant amount of observations to the early delivery cycle, thus the analysis is fitting better to the MODIS DB than to the global winds. It is encouraging that the analysis is not drawn away from the other sparse observations in the Polar Regions.
Two two-month experiments show mostly neutral forecast impact. In the northern hemisphere a slight positive impact is noticed for days 6-8. A slight degradation in the forecast is evident for days 2-3, but at this time there is no sufficient evidence for the causes of it.
One future work direction aiming to improve the use of MODIS DB winds could be to revise the thinning routines, both spatially and temporally, and in terms of increasing the QI threshold. This could be done in the course of revising all winds quality control routines.

Meteosat-9 AMVs using Cross-Correlation Contribution (CCC) Height Assignment (HA) approach

Presently, EUMETSAT's AMV retrieval algorithm assigns an AMV altitude using a histogram of the cloud top pressures within a target and selecting the coldest/highest peak. (EUM.MSG.SPE.022) A similar approach is used at NESDIS and JMA (until September 2009). However, there is no evidence that the coldest pixels in a target box are necessarily the ones that are tracked. Thus, a new way to select pixels for the AMV height assignment routine has been developed. It is calculating the contribution of each target pixel towards the cross-correlation during the tracking. The pixels which contribute most to the correlation are then used for the height assignment (Borde et al, 2008). At this stage, EUMETSAT's Cloud Analysis (CLA) product is providing the individual pixel cloud top height.

The effect of the CCC HA approach was investigated in conjunction with the performance of a new CLA prototype product developed by Borde and Dew (Borde,R., Dew,G., personal communication). Two sets of experiments were conducted. In the first set a control (f7dc) is compared to an experiment (f6p2) assimilating the CCC AMVs using the operational CLA product. The experiments last from 24 December 2008 till 21 January 2009. In the second set a control (f7dd) is compared to an experiment (f6p4) with CCC AMVs using the new CLA product. It lasts from 22 January 2009 till 18 February 2009. A third run was conducted as a part of each set as well, aiming to address the impact of the image enhancement (IE) on the 10.8 channel (f6p1 and f6p3, correspondingly). This is needed because the CCC AMVs do not use IE. All experiments used the 35R2 PrepIFS cycle 4D-VAR DA at TL255 spatial resolution and incremental analysis resolution of TL159.

Since the CCC HA method will change the heights of the AMVs, the discussion below will focus on the vertical redistribution of AMVs, and its impact on the STD and BIAS. It is worth mentioning two characteristics of the experimental data sets. First, due to a set up deficiency the AMV BUFR files had lost about 3% WV winds compared to the operational data sets. Second, the runs simulating operational winds, but with turned-off image enhancement, are lacking the VIS channel for unknown reason.

Experiments using operational CLA cloud top heights

A comparison of the 'used' IR AMVs in operations (f7dc) and after turning off the image enhancement (f6p1) shows that much more AMVs have been assimilated in the experiment, without a degradation in the First Guess (FG) departures. However, in the BUFR files there is a 10% increase in AMVs with QI > 80% due to the turned-off IE. Further investigation implies that the thinning is causing the increased counts of assimilated IR winds. The thinning works on all AMV channels together, and the vector with highest QI is selected (among all AMVs within 200x200km/ ~75 hPa box). As WV images are smoother than IR images, the WV AMVs have in general a better vector consistency, i.e. higher QI. The effect of this is that for high and medium levels mostly WV AMVs (80%) are assimilated. This however seems not to be optimal because the WV AMVs have a worse STD on all levels despite the higher QI values, except around 200 hPa where it is quite similar to IR. As the channels are "competing" with each other, the big increase we get in used IR AMVs by disabling the I.E. is balanced by a similar decrease in used WV AMVs, reducing the ratio of used WV AMVs to about 75%. The quality of the IR winds looks quite similar for the experiment and the control, thus we can conclude that the IE only impacts the tracking and the QI values without a clear advantage. The 30% increase in used low level 10.8 AMVs is not significant as there are no VIS AMVs available in this experiment, hence IR AMVs are used instead through the combined thinning.

For the experiment using the CCC HA winds (f6p2), and no IE we see less used IR AMVs than in the experiment using operational AMVs with disabled IE. More CCC HA winds are used (compared to the control) only at around 500 hPa and above 200 hPa, however they have worse STD and BIAS. The WV winds show the same tendency - increased counts around 500 hPa and above 200 hPa, and heavily reduced numbers around 300 hPa, together with worse Std. In conclusion, the CCC method does not perform well with the operational CLA product.

Experiments using new CLA cloud top heights

A new CLA was developed to be more consistent with the current operational AMV height assignment method, i.e. it favors the CO2 slicing height assignment method over other methods. Two low level clouds height assignment corrections are applied as well - cloud base height assignment and inversioan cloud height.

For the experiment turning off the IE (f6p3) we see an increase in used IR AMVs with small and random impact on STD and BIAS, but in contrary to the experiment using the operational CLA (f6p1) there is no corresponding reduction for WV AMV counts. In total, there are 6% more used medium/high level AMVs just by turning off the IE. Results also shows the IR AMVs based on CCC height method and new CLA, look better, and now we see a positive impact on STD for high and medium levels. However, STD for low levels is still significantly worse. The WV AMVs are also indicating a better quality, although the upwards movement of heights is here even more emphasized. More winds are used in the experiment with CCC heights and new CLA, compared to the experiment with CCC and operational CLA, and it is due to the increased counts of all winds with high QIs. Overall the statistics indicate that the CCC method works well with the new CLA, but further work is required for low levels.

The high amount of data close to 100 hPa, where OPE have hardly any AMVs, needs investigation, but these AMVs can easily be filtered out. It probably indicates that the new CLA needs further tuning.

Low level height assignment

In both experiments using CCC HA AMV (with operational and new CLA), there is a significant loss of used AMVs around 850 hPa and huge increase at 1000hPa. This is not related to the CCC height assignment method, but to changes in the Cloud Base Height reassignment (CBH) implemented at the same time as the CCC HA. This issue will be addressed further.

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