# CLOUD MOTION WINDS, VALIDATION AND IMPACT ON NUMERICAL WEATHER FORECASTS

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## ABSTRACT

A one year statistics set has been compiled assessing differences between ECMWF 6-hour forecasts and operational SATOBs for different satellites, height levels and areas. The quality of SATOBs was generally found to be satisfactory for the tropics (all height levels) and for low level data (all areas). In the extra-tropics severe biases for high level SATOBs in jet streams still exist, but monitoring results vary greatly between satellites. Results of SATOB/6-hour-forecast comparisons are supported by SATOB/AIREP collocations in the Atlantic. METEOSAT water vapour (WV) winds have also been monitored in the operational suite for the last few months and show promising results for high levels.

The impact of SATOBs and TOVS was separately assessed in a 14 day observing system experiment. A strong positive impact of SATOBs was found in the Northern Hemisphere extra-tropics, which surpassed scores for the operational system. To avoid negative impact of SATOBs in the Northern Hemisphere extra-tropics, severe quality control has to be applied in that area.

## 1 INTRODUCTION

Cloud motion winds represent an important data source to Numerical Weather Prediction (NWP) models, especially in otherwise data sparse areas like the tropics and the Southern Hemisphere. Earlier studies at ECMWF (Kelly and Pailleux, 1989; Eriksson, 1990) have shown that the analysis system reacts to SATOB quality control. To make best possible use of SATOBs statistical properties of each data set need to be known. Corrupted or severely biased observations need to be excluded from the analysis. The monitoring of each satellite performed by NWP centres can also serve as a guideline for SATOB producers where further improvement of their products might be required and in what areas efforts will be most appreciated.

Most of the monitoring results presented in this paper show differences between SATOBs and the 6-hour forecast of the ECMWF model (used as the First Guess (FG) for the analysis); the FG is interpolated to the position and level of the observation. Statistics are presented for all received SATOBs before they have undergone quality control. If not stated otherwise, results are given for the one year period from September 1990 to August 1991.

When comparing observations with the FG field one needs to consider that the accuracy of the forecast varies regionally. Also FG fields are not entirely unbiased themselves, as can be seen when comparing them with radiosonde and AIREP data. Accounting for these deficiencies in final evaluations, observation minus FG statistics can still provide a good transfer standard between satellites. The advantage of FG comparisons lies in computing the statistics at those positions (mostly over oceans) and levels where SATOBs are actually produced. The validity of conclusions drawn can be checked when comparing against collocated radiosondes or AIREPs (see 2.3).

## 2 QUALITY OF SATOB DATA

### 2.1 Low level data

Low level SATOBs generally are of quite good quality when compared to the FG (Table 1). Their quality does not vary greatly between different satellites. INSAT is the exception exhibiting large rms vector differences and directional differences. For GOES, METEOSAT and HIMAWARI agreement with the FG is actually better than for radiosondes. This is probably due to SATOBs representing an average over time and the low level wind showing less variability over oceans were most low level SATOBs are produced.

There is however evidence for some minor biases, especially for GOES and HIMAWARI in the Northern Hemisphere extra-tropics where the FG can be considered reliable when compared to radiosondes.

| | | rms vec. diff. (m/s) | speed bias (m/s) | mean abs. dir.diff. (degree) | mean FG speed (m/s) | No. of obser-vations |
|---|---|---|---|---|---|---|
| N. Hem. extra-tropics 1000-700hPa | radiosonde | 4.1 | 0.2 | 24.5 | 7.8 | 404477 |
| | METEOSAT | 3.0 | 0.0 | 11.0 | 9.8 | 60776 |
| | GOES | 3.6 | -0.8 | 18.7 | 7.5 | 80589 |
| | HIMAWARI | 3.9 | -0.6 | 19.3 | 9.4 | 113985 |
| S. Hem. extra-tropics 1000-700hPa | radiosonde | 6.1 | -0.1 | 31.9 | 9.1 | 22590 |
| | METEOSAT | 3.3 | 0.1 | 11.4 | 11.0 | 146855 |
| | GOES | 3.9 | 0.1 | 17.4 | 8.3 | 202210 |
| | HIMAWARI | 3.9 | -0.2 | 18.8 | 9.6 | 209573 |
| tropics 1000-700hPa | radiosonde | 4.2 | 0.1 | 30.2 | 6.2 | 57622 |
| | METEOSAT | 3.2 | 0.6 | 13.2 | 7.7 | 144592 |
| | GOES | 3.0 | -0.6 | 16.2 | 7.2 | 202210 |
| | HIMAWARI | 3.4 | 0.2 | 19.9 | 7.0 | 150429 |
| | INSAT | 6.2 | 1.1 | 40.9 | 5.9 | 26515 |

**Table 1:** September '90 - August '91; observation minus First Guess statistics for low level winds (all received data).

### 2.2 Medium level data

Extra-tropics

Most medium level SATOBs (401-699hPa) in the extra-tropics are produced for METEOSAT (approx. 100000 per year) and show an agreement with the FG similar to radiosondes (Table 2). For GOES far fewer medium level winds are produced (approx. 10000 per year); they show a considerable slow bias (more than 2m/s) as well as much larger rms vector differences to the FG.

Tropics

In the tropics GOES medium level winds seem to be better, but few winds exceed 20m/s. On the other hand METEOSAT reports many tropical medium level winds of more than 30m/s and their FG/observation speed scatterplots resemble plots for radiosondes (not shown). METEOSAT winds also show a very good agreement with the FG. Finally, INSAT winds at medium levels display severe problems having mean absolute direction differences of 67.2° and large speed biases.

| | | rms vec. diff. (m/s) | speed bias (m/s) | mean abs. dir.diff. (degree) | mean FG speed (m/s) | No. of obser-vations |
|---|---|---|---|---|---|---|
| **N. Hem.** | radiosonde | 4.6 | 0.5 | 17.1 | 12.5 | 714652 |
| **extra-tropics** | METEOSAT | 5.6 | -0.3 | 11.5 | 16.4 | 42756 |
| **401 - 699hPa** | GOES | 7.8 | -2.3 | 19.4 | 15.9 | 7097 |
| **S. Hem.** | radiosonde | 6.5 | 0.6 | 26.1 | 12.5 | 44265 |
| **extra-tropics** | METEOSAT | 6.3 | -0.2 | 10.2 | 21.8 | 56430 |
| **401 - 699hPa** | GOES | 8.0 | -2.1 | 15.8 | 18.3 | 3616 |
| **tropics** | radiosonde | 4.7 | 1.0 | 33.5 | 5.9 | 80419 |
| | METEOSAT | 4.2 | 0.7 | 18.4 | 8.3 | 56763 |
| **401 - 699hPa** | GOES | 5.3 | 0.9 | 30.8 | 6.8 | 17795 |
| | INSAT | 10.4 | 3.5 | 67.3 | 5.5 | 14455 |

**Table 2:** September '90 - August '91; observation minus FG statistics for medium level winds (all received data).

## 2.3 Upper level data

Extra-tropics

In the extra-tropics at high levels the ECMWF FG exhibits a slow bias when compared to radiosondes (Figure 1a) and AIREPs (not shown). This bias increases from zero at speeds of 20m/s to a bias of more than 2m/s for high speeds. When evaluating SATOBs these FG biases need to be considered.

Density coded speed scatter plots (Figure 1b-d) for the Northern Hemisphere extra-tropics show that SATOBs are biased slow for speeds exceeding 20m/s. Biases vary considerably from satellite to satellite, with GOES being the poorest. High level HIMAWARI winds have improved since April '90 (Strauss, 1991, this volume), especially in the Northern Hemisphere extra-tropics. In the Southern Hemisphere HIMAWARI biases are unfortunately still severe (Table 4).

For single months the bias in the SATOB speed in high speed situations can be even much higher than the yearly average given in Table 4 (SH ext. tropic biases for June 1991: HIMAWARI: -6.2; GOES: -5.6; METEOSAT: -1.4).
The total bias at high speed classes can roughly be estimated when combining FG biases in Figure 1a with SATOB biases in Figure 1b-d. For the speed class of 30-40m/s in the Northern Hemisphere extra-tropics for example the total bias for METEOSAT would amount to 2-2.5m/s; for GOES it is a more severe bias of about 4m/s. This is in approximate agreement with collocations between AIREPs and SATOBs in the Northern Atlantic that were computed for January to March 1991 (Table 3):

| **AIREP speed class:** | **20-30m/s** | **30-40m/s** | **40-50m/s** |
|---|---|---|---|
| METEOSAT bias | 0.2m/s | -2.9m/s | -5.8m/s |
| (No. of collocations) | (1864) | (1952) | (1368) |
| GOES bias | -1.6m/s | -4.6m/s | -7.6m/s |
| (No. of collocations) | ( 657) | ( 677) | ( 447) |

**Table 3**: SATOB-AIREP Collocations in the Northern Atlantic, January to March 91, speed bias for SATOB minus AIREP before quality control (collocation criteria: distance < 300km, pressure difference < 50hPa, time within one analysis cycle, typically less than 3h)

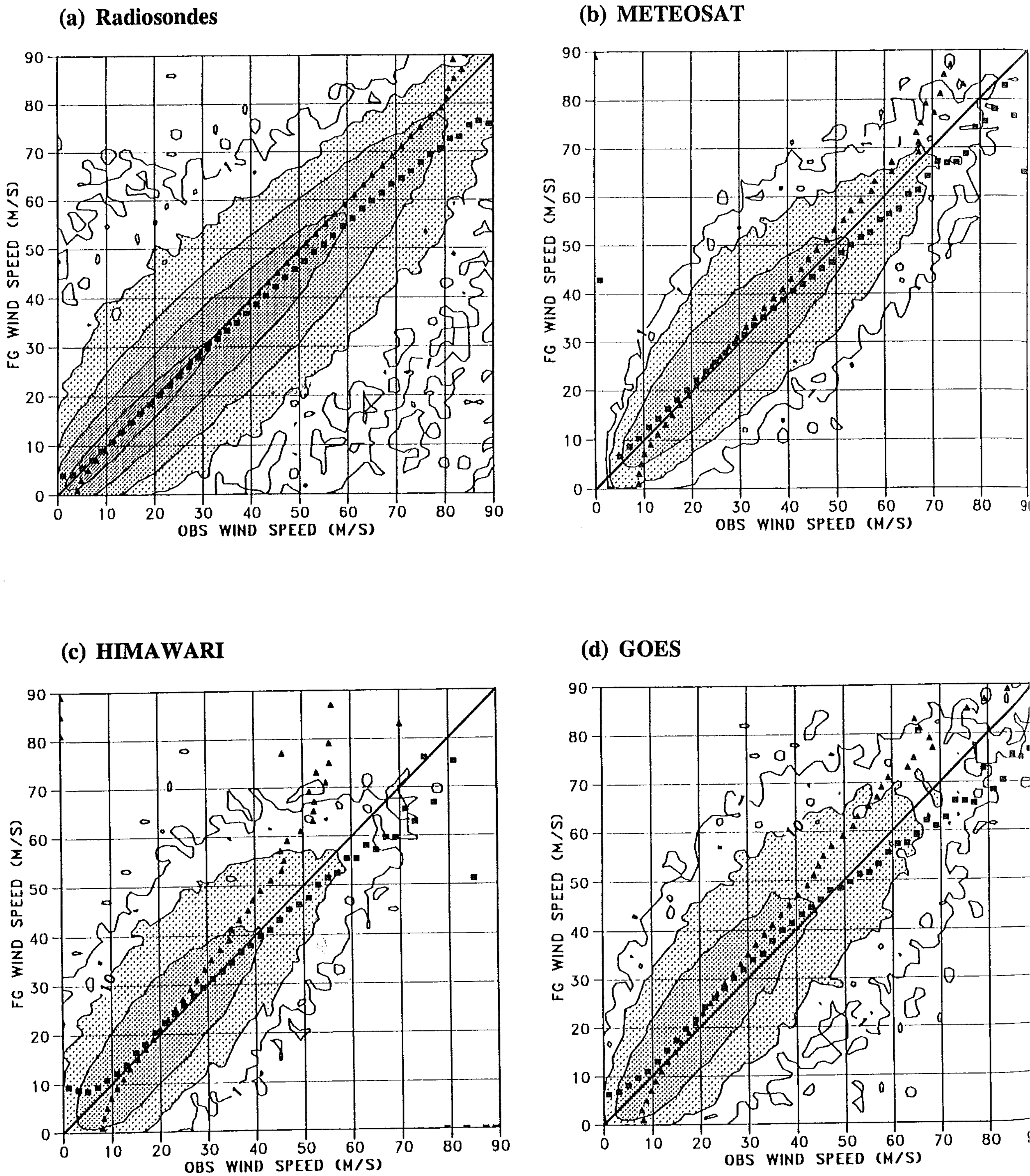


**Figure 1**: September 1990-August 1991. Density coded scatter plots of 6-hour forecast (FG) speed versus observation speed (all received data) for Northern Hemisphere extra-tropics (north of 20°N) high level winds (100-400hPa for SATOBs). The number of entries for each 2m/s*2m/s class is given, contouring is logarithmic (1,10,100... entries per class). Triangles denote average observation speed in FG speed classes; rectangles denote average FG speed in observation speed classes.
(a) radiosodes (150-400hPa), (b)METEOSAT, (c) HIMAWARI, (d) GOES

| | | rms vec. diff. (m/s) | speed bias (m/s) | mean abs. dir.diff. (degree) | mean FG speed (m/s) | No. of obser-vations |
|---|---|---|---|---|---|---|
| **N. Hem.** | radiosonde | 6.0 | 0.4 | 11.2 | 22.5 | 1724489 |
| **extra-tropics** | METEOSAT | 7.8 | -0.8 | 9.3 | 28.4 | 64536 |
| **p < 401hPa** | GOES | 10.3 | -3.0 | 13.6 | 27.1 | 53149 |
| | HIMAWARI | 8.9 | -1.4 | 15.3 | 23.4 | 49471 |
| **S. Hem.** | radiosonde | 8.9 | 0.9 | 15.8 | 23.4 | 107411 |
| **extra-tropics** | METEOSAT | 8.3 | -0.7 | 8.7 | 32.4 | 82677 |
| **p < 401hPa** | GOES | 10.9 | -3.2 | 11.6 | 30.8 | 45451 |
| | HIMAWARI | 10.0 | -2.5 | 12.8 | 25.8 | 50881 |
| **tropics** | radiosonde | 7.2 | 1.3 | 30.5 | 10.8 | 184265 |
| | METEOSAT | 6.1 | 0.7 | 16.7 | 14.8 | 135238 |
| **p < 401hPa** | GOES | 7.3 | 0.6 | 22.1 | 14.1 | 80969 |
| | HIMAWARI | 6.5 | 0.8 | 28.3 | 9.7 | 164684 |
| | INSAT | 11.0 | 4.8 | 50.9 | 6.8 | 1653 |

**Table 4:** September '90 - August '91; observation minus FG statistics for high level winds (all reiceived data).

<u>Tropics</u>
In the tropics high level METEOSAT, HIMAWARI and GOES have similar characteristics to radiosondes (scatterplots not shown) and are generally of satisfactory quality (Table 4).

## 3 METEOSAT WV WINDS

ESOC has been producing WV winds operationally twice daily (00Z and 12Z) for several months (Laurent, 1991). These winds are being passed to ECMWF for monitoring purposes since June 1991. No manual quality control has been applied to these data and the only automatic quality control applied is a symmetry check of each vector pair. Thus the wind set is independent of ECMWF forecasts. Monitoring results are presented for July '91.

<u>High level</u>
The METEOSAT WV winds for upper levels are generally computed in lower speed regions than high level IR winds ( Table 5) and show an increased coverage. Speed scatterplots in Figure 2 show that the core of the distribution, also at high speeds, is quite similar to METEOSAT IR winds. This indicates a high potential of METEOSAT WV winds considering they have not undergone strict quality control by ESOC yet.
There is however evidence that for some situations WV winds seriously underestimate the wind speed (WV < 20m/s with FG being 10-20m/s faster; this result is apparent in all areas). With a more refined quality control on the production side, these winds could certainly be rejected and the overall scatter could be reduced.

<u>Medium level</u>
Medium level WV winds were few and of much inferior quality than IR winds (Table 5). Considering the nature of medium level WV winds, they should better be attributed to a layer rather than to a single level. More fundamental research needs to be carried out, before operational use can be considered.

| | | rms vec. diff. (m/s) | speed bias (m/s) | mean abs. dir.diff. (degree) | mean FG speed (m/s) | No. of obser-vations |
|---|---|---|---|---|---|---|
| global | MET.SAT WV | 9.4 | 1.0 | 24.4 | 15.8 | 25911 |
| | MET.SAT IR | 7.1 | -0.6 | 11.7 | 23.0 | 16848 |
| p < 401hPa | GOES | 8.6 | -1.4 | 19.9 | 18.6 | 14414 |
| | HIMAWARI | 7.7 | -0.2 | 18.6 | 16.6 | 17145 |
| global | MET.SAT WV | 13.4 | -0.7 | 37.3 | 16.4 | 2716 |
| | MET.SAT IR | 5.5 | 0.3 | 14.1 | 14.9 | 16769 |
| 401-700hPa | GOES | 5.6 | -0.5 | 22.6 | 10.4 | 3297 |

**Table 5:** July '91; observation minus FG statistics for METEOSAT WV winds and operational SATOBs (all received data).

(a) METEOSAT WV

(b) METEOSAT IR

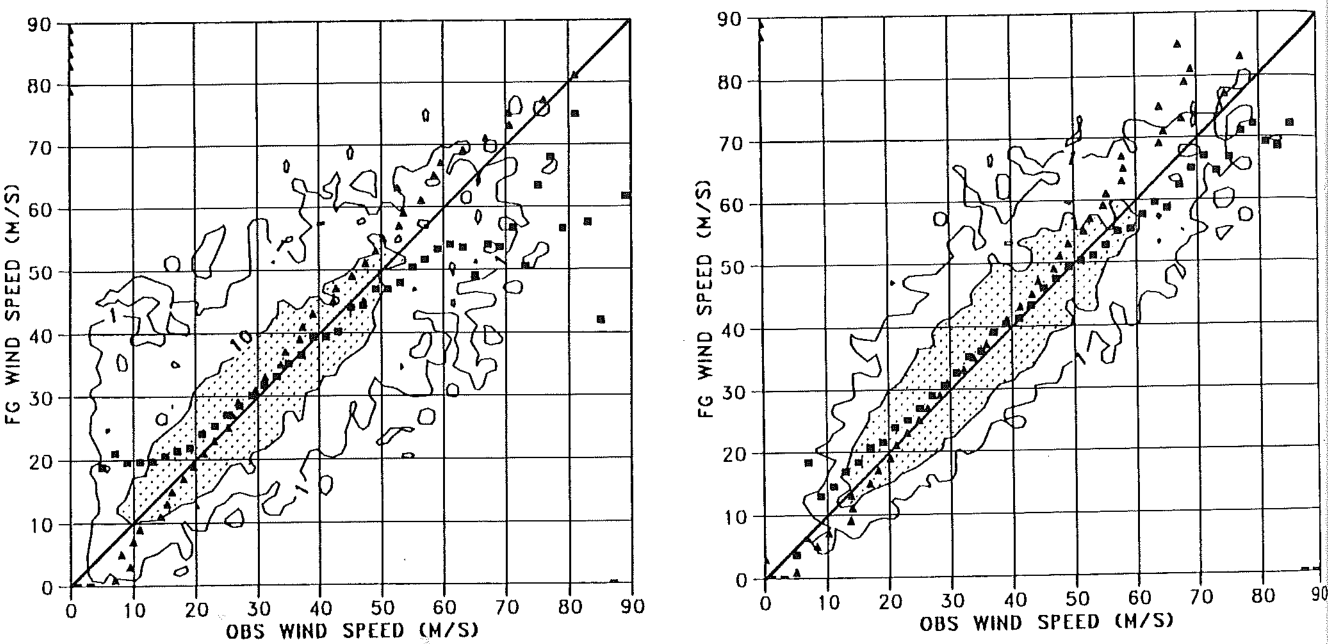


**Figure 2:** Like Figure 1, but for July 1991, Southern Hemisphere extra-tropics (south of 20°S) high level winds (100-400hPa). a) METEOSAT WV versus FG, b) METEOSAT IR versus FG.

## 4 IMPACT and QUALITY CONTROL CONSIDERATIONS

With improving forecast skill, numerical models have become very sensitive to quality control decisions. Care has to be taken to detect biased and erroneous data.

The sensitivity of the analysis to badly biased SATOBs in the Northern Hemisphere extra-tropics has made severe quality decisions necessary, which result in only 15% of high level extra-tropical SATOBs being used by ECMWF (overall about 70% of the SATOBs are used). With help of these drastic measures a negative impact of SATOBs in the Northern Hemisphere extra-tropics has been eliminated (Eriksson, 1990).

A recent comprehensive set of impact studies conducted by Kelly (1992) was separately assessing the impact of space (TOVS and SATOB) observations in the ECMWF analysis/forecast system for a 14 day period in February '89. Large positive impacts in the Northern Hemisphere extra-tropics were found for both observing systems when added separately to the conventional data, showing most positive impact for SATOBs. Adding both space data sets simultaneously, space impact was still positive, but did not reach the scores of either SATOB or TOVS data alone (Figure 3). These results have not been fully understood yet, but some adverse coupling effects in the tropical analysis are suspected. Consequently, the use of TOVS has been modified. Part of the positive impact of SATOBs in the Northern Hemisphere extra-tropics can probably be attributed to the highly beneficial impact of SATOBs on the tropical analysis as it occurs after day four in the forecast period.

A considerable portion of high quality SATOBs in the extra-tropics currently gets rejected by the ECMWF analysis system. This was evident when the positive impact of SATOBs in the Southern Hemisphere extra-tropics was slightly reduced with the introduction of a more severe quality control against the FG (Eriksson, 1990). The FG field often represents the only independent source of information in data sparse areas but is of inferior quality to the FG field in data richer areas. In trying to prevent erroneous data entering the analysis, strict quality control against the first guess sometimes rejects the most valuable data (see Kelly 1991, this volume).

More information on the quality of each individual SATOB would be needed in order to refine quality control decisions especially in data sparse areas. It would be of great value if SATOB producers could pass several estimates of the quality of each individual SATOB along with the wind. These quality flags should clearly identify channel and processing used, as well as separate flags for the confidence in height assignment, tracking, quality of the tracer etc. A more detailed knowledge about each individual wind would eventually also make it possible to reassign heights to more adequate levels or, in the context of variational analysis, make use of directional information alone for certain winds.

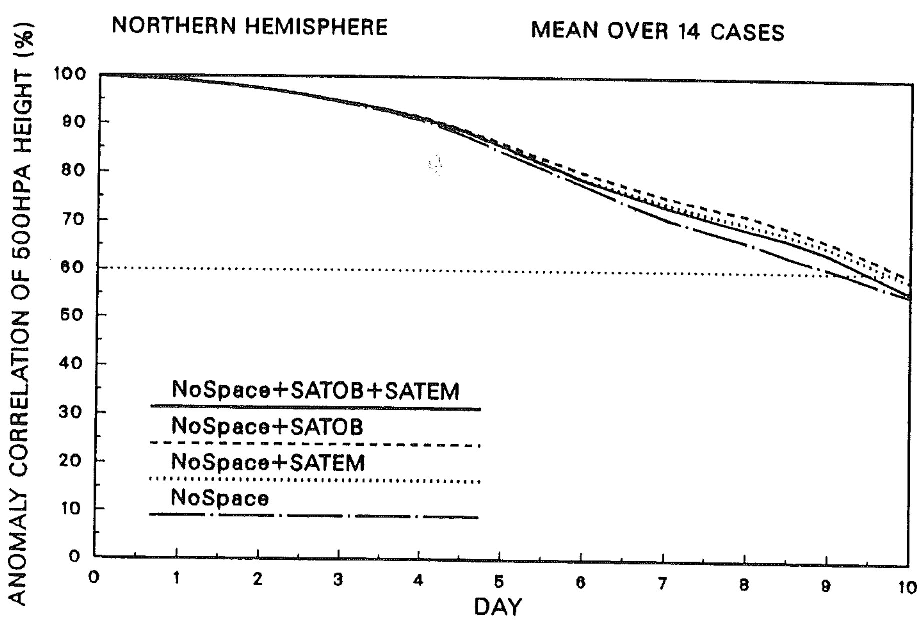


**Figure 3:** Northern Hemisphere extra-tropics anomaly correlations of 500hPa height for a 14 day period in February '89. Impact of space observing systems on top of conventional data assessed separately for TOVS and SATOB.

## 5 CONCLUSIONS and RECOMMENDATIONS

The quality of operational SATOBs varies significantly for different height levels, areas and satellites. The quality of low level SATOBs is generally satisfactory. For INSAT low level winds there is scope for considerable improvement.

In the extra-tropics there are still serious slow biases for high level winds in high speed situations and efforts to improve these winds are needed for all satellites. It is hoped that GOES products will be improved soon by introducing the new Wisconsin software. For HIMAWARI efforts should be undertaken to bring high level Southern Hemisphere winds up to the same quality as achieved in the Northern Hemisphere. For high level tropical winds monitoring results appear satisfactory.

The monitoring of METEOSAT WV winds showed very promising results. Implementation of a more refined quality control would be welcomed.

The impact of SATOBs on NWP models largely depends on sensible quality control and proper use of the data. Given adequate quality control, the impact of SATOBs is positive, also in the Northern Hemisphere extra-tropics. In the tropics SATOBs are indispensible to assure realistic analysis.

To make best possible use of SATOBs in the analysis, quality indicators should be passed with each individual SATOB. Research on suitable quality indicators should start now. Close cooperation in this matter will be needed between SATOB producers and users.

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