Monitoring the observation impact in the ECMWF system and its variation with meteorological condition

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&
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Thanks to: Iliana Genkova, A. Garcia-Mendez

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Outline

- Forecast error sensitivity to the observation
  - Brief introduction to FSO tool
- Contribution to the forecast error of the operational assimilated observation in the ECMWF system
  - Summer 2006 and Winter 2007
  - Synoptic investigation

Motivation

- MetOps has the responsibility to monitor the operational forecast system which includes the quality control of obs, the analysis system but also forecast performance. This assessment is carried out on a daily basis by a group of Analysts and Assistants.
- …but nowadays the daily monitoring became less effective because the forecast system "has evolved towards very complicated system" over the past years (10^7 degrees of freedom and ~ $8*10^6$ observation in 12-h assimilation cycle)
- Any diagnostic tool that can provide information about the impact of the observation on the forecast performance in real time is a very exciting idea!

Forecast sensitivity to observation: Equations

$$\frac{\partial J}{\partial \mathbf{y}} = \frac{\partial \mathbf{x}_a}{\partial \mathbf{y}} \frac{\partial J}{\partial \mathbf{x}_a}$$

J is a measure of the forecast error

Analysis solution

$$\mathbf{x}_a = \mathbf{x}_b + \mathbf{K}(\mathbf{y} - \mathbf{H}\mathbf{x}_b)$$

Analysis sensitivity to observation and background

$$\frac{\partial \mathbf{x}_a}{\partial \mathbf{y}} = \mathbf{K}^T$$

$$\frac{\partial J}{\partial \mathbf{y}} = \mathbf{R}^{-1}\mathbf{H}\mathbf{A}\frac{\partial J}{\partial \mathbf{x}_a}$$

$$\delta J = \frac{\partial J}{\partial \mathbf{y}}(\mathbf{y} - \mathbf{H}\mathbf{x}_b)$$

$\delta \mathbf{y}$

Forecast error sensitivity to the analysis

$$\frac{\partial J}{\partial \mathbf{x}_a}$$

Rabier F, *et al*. 1996.

The tool provides information on the observation type, subtype, variable and level responsible for the forecast error variation

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Define Forecast Sensitivity

$$\frac{\partial J}{\partial \mathbf{y}} = \frac{\partial \mathbf{x}_a}{\partial \mathbf{y}} \frac{\partial J}{\partial \mathbf{x}_a}$$

Analysis sensitivity to the observation (observation space) Information Content

$$\frac{\partial \mathbf{H}\mathbf{x}_a}{\partial \mathbf{y}} = \mathbf{K}^T \mathbf{H}^T$$

Analysis sensitivity to the observation (model space)

$$\frac{\partial \mathbf{x}_a}{\partial \mathbf{y}} = \mathbf{K}^T = \mathbf{R}^{-1}\mathbf{H}(\mathbf{B}^{-1} + \mathbf{H}^T\mathbf{R}^{-1}\mathbf{H})^{-1}$$

$$\frac{\partial J}{\partial \mathbf{y}} = \mathbf{R}^{-1}\mathbf{H}(\mathbf{B}^{-1} + \mathbf{H}^T\mathbf{R}^{-1}\mathbf{H})^{-1} \frac{\partial J}{\partial \mathbf{x}_a}$$

$$\frac{\partial J}{\partial \mathbf{y}} = \mathbf{R}^{-1}\mathbf{H}\mathbf{A} \frac{\partial J}{\partial \mathbf{x}_a}$$

Equations

$$\frac{\partial J}{\partial \mathbf{y}} = \frac{\partial \mathbf{x}_a}{\partial \mathbf{y}} \frac{\partial J}{\partial \mathbf{x}_a} \longrightarrow \frac{\partial J}{\partial \mathbf{y}} = \mathbf{K}^T \frac{\partial J}{\partial \mathbf{x}_a} \longrightarrow \frac{\partial J}{\partial \mathbf{y}} = \mathbf{R}^{-1}\mathbf{H}\mathbf{A}\frac{\partial J}{\partial \mathbf{x}_a}$$

Solution for forecast sensitivity

$$1)\quad \mathbf{A}^{-1}\mathbf{z} = \frac{\partial J}{\partial \mathbf{x}_a}$$

Krylov Subspace Method

$$2)\quad \frac{\partial J}{\partial \mathbf{y}} = \mathbf{R}^{-1}\mathbf{H}\mathbf{z}$$

Equations

Compute the forecast impact or forecast error variation δJ

$$< \frac{\partial J}{\partial \mathbf{x}_a}, \delta \mathbf{x}_a >=$$

$$< \frac{\partial J}{\partial \mathbf{x}_a}, \mathbf{x}_a - \mathbf{x}_b >=< \frac{\partial J}{\partial \mathbf{x}_a}, \mathbf{K}(\mathbf{y} - \mathbf{H}\mathbf{x}_b) >=< \mathbf{K}^T \frac{\partial J}{\partial \mathbf{x}_a}, (\mathbf{y} - \mathbf{H}\mathbf{x}_b) >=$$

$$< \frac{\partial J}{\partial \mathbf{y}}, \delta \mathbf{y} >$$

$$\delta J = \frac{\partial J}{\partial \mathbf{y}} (\mathbf{y} - \mathbf{H}\mathbf{x}_b)$$

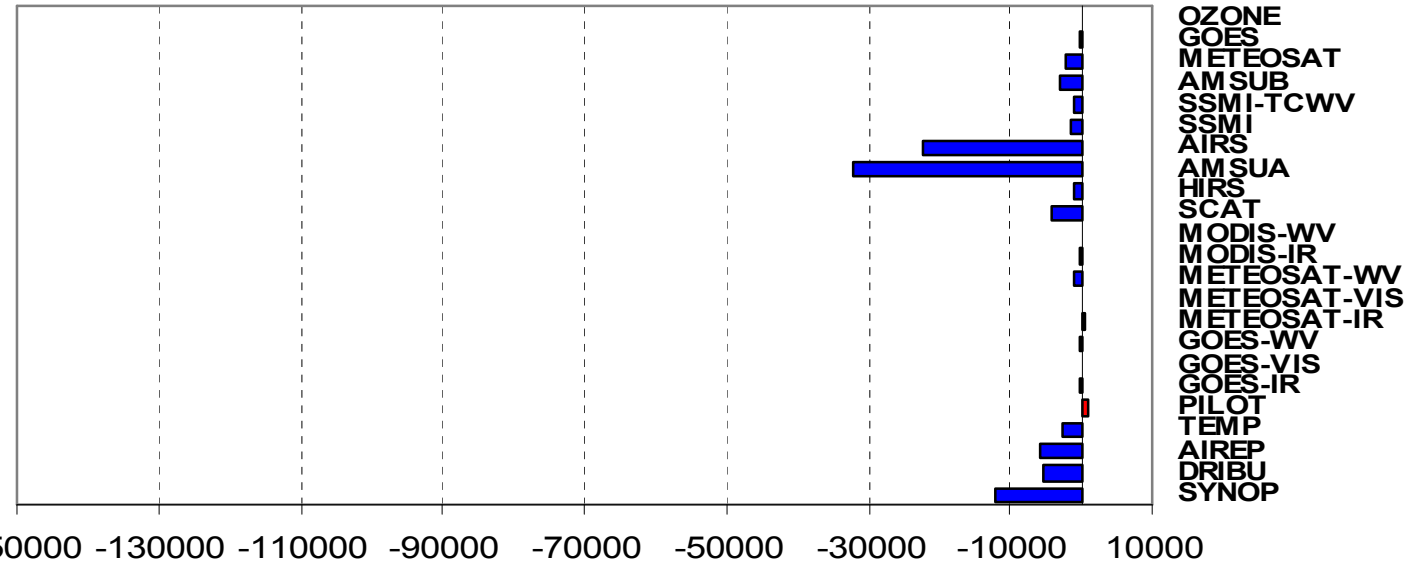
FSO tool and discussion of the results

- FSO was computed for two periods
  - Summer Case: 15 June to 15 July 2006
  - Winter Case: 5 January to 12 February 2007
- All computations were carried out on T511T159L60 for 00 & 12 UTC forecasts (24-h forecast range).
- The results will be presented together with an assessment of the synoptic weather conditions for both winter and summer cases.

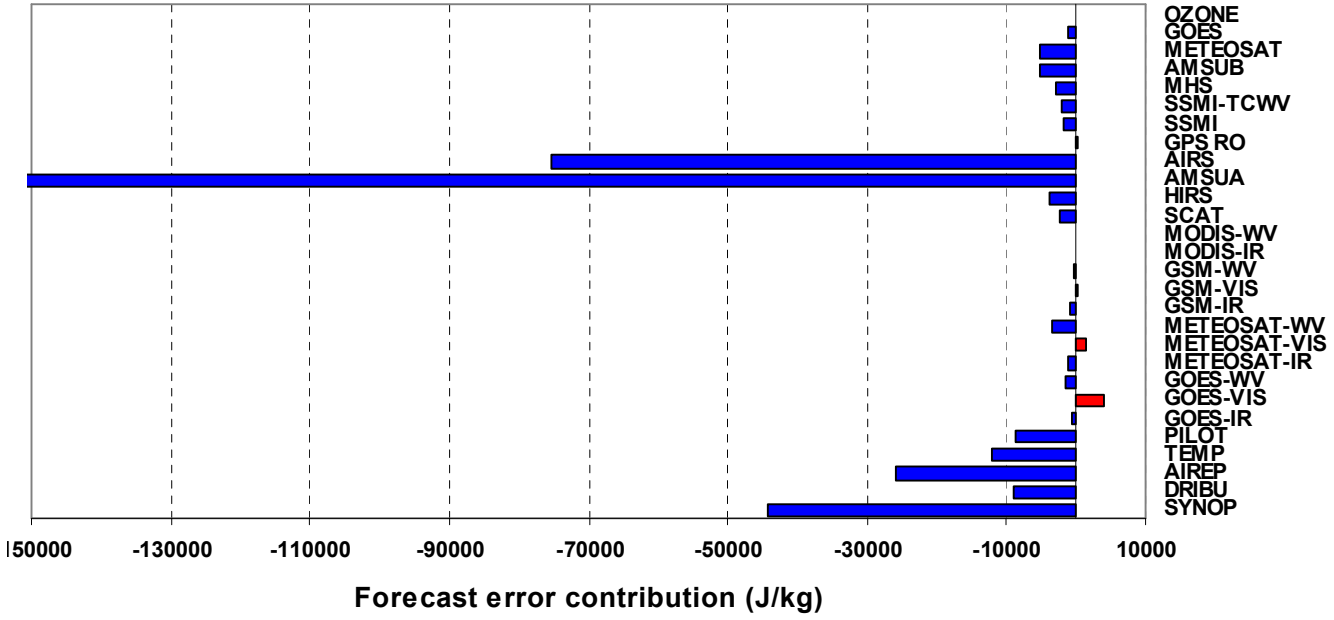
Monitoring ECMWF System

15 June-15 July
Summer 2006

Overall impact of the observations to total Fc error



5 January-12 February
Winter 2007



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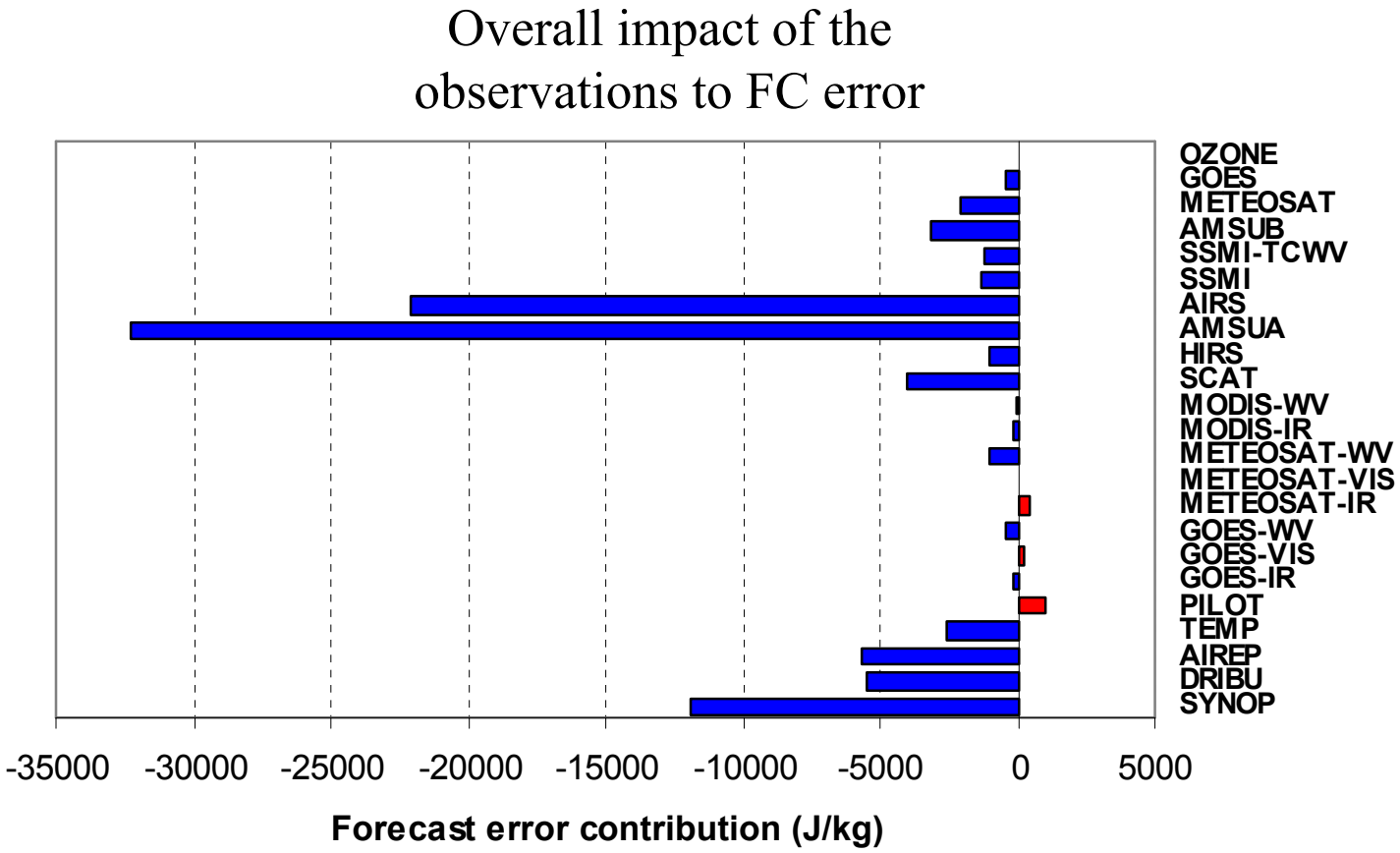
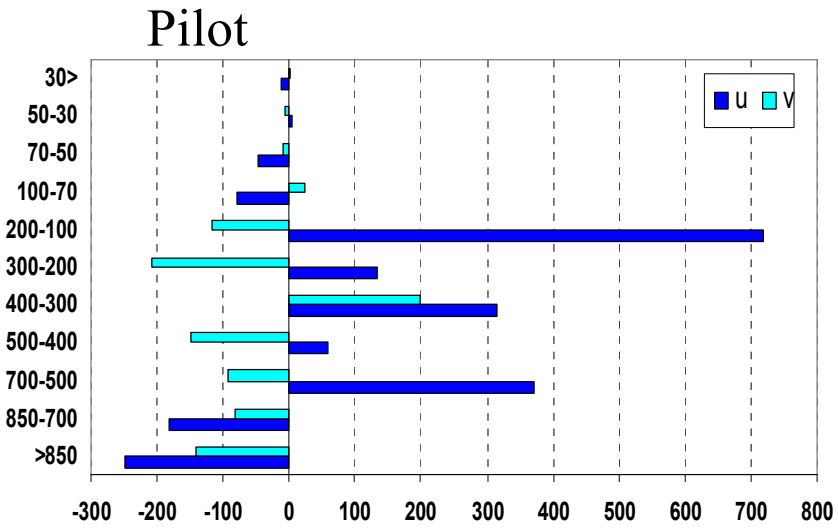
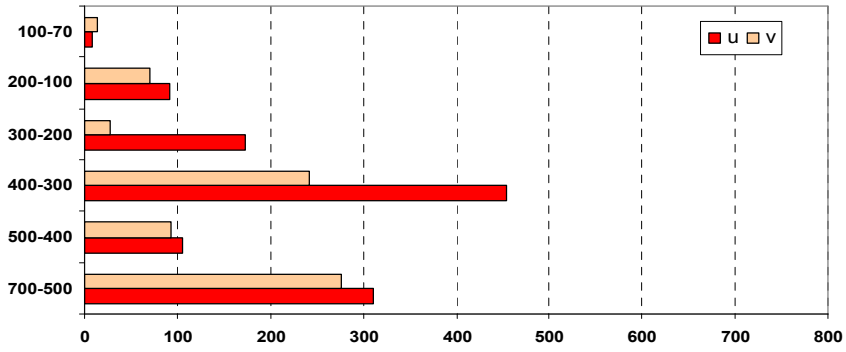
Monitoring ECMWF System: Summer 2006

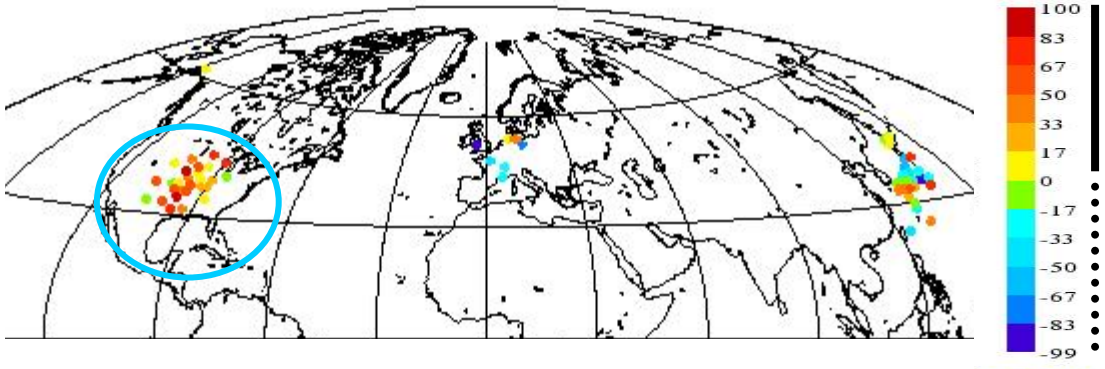


AMSUA & AIRS both contribute largely to forecast error decrease. PILOT as well GOES-VIS and MET-IR have a negative impact on the 24-h forecast error.

Pilot and Wind Profilers FcE contribution Summer 2006







Negative impact

Positive impact

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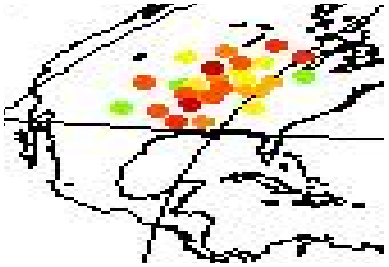
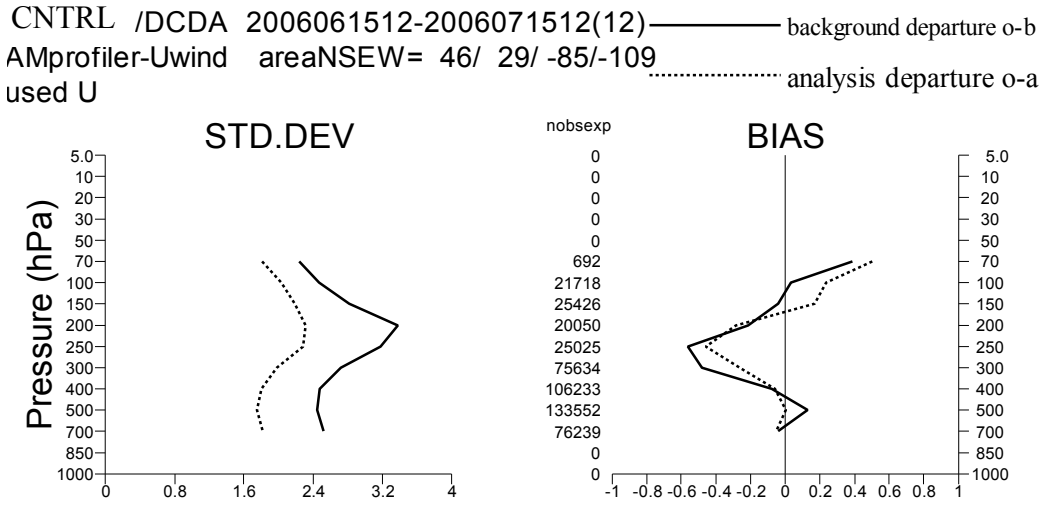
Wind Profilers North America Summer 2006

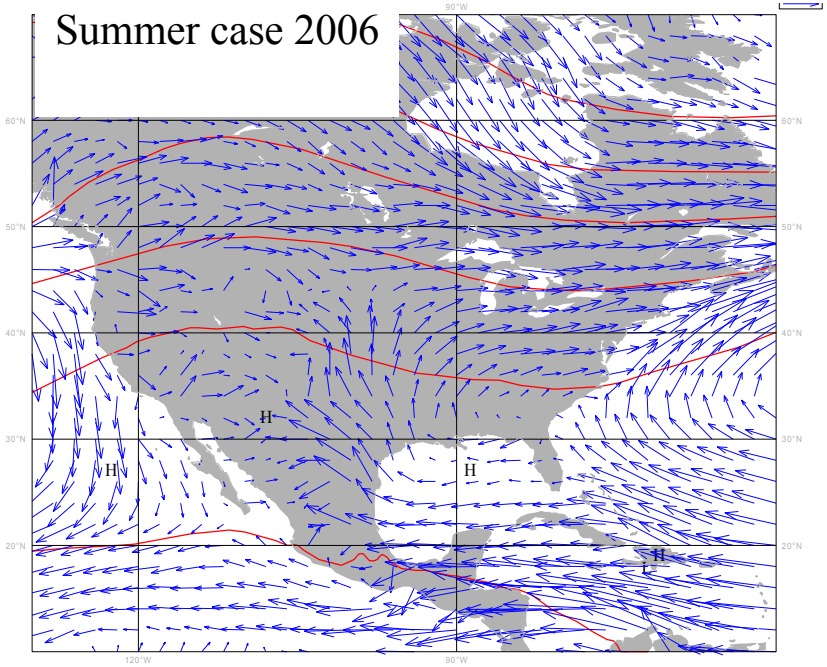


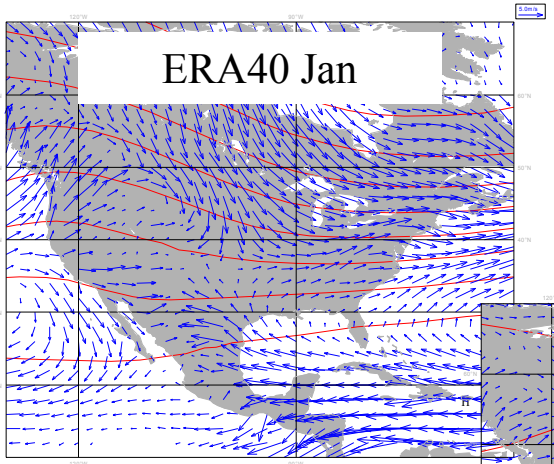


North America "Problem" (OD/RD special topic 2005)

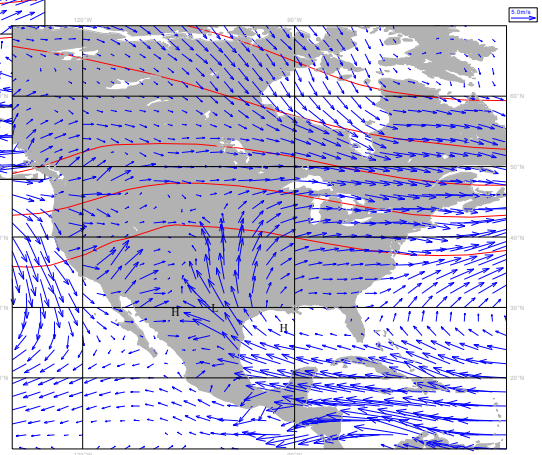
- **strong, moist warm flow from the Gulf of Mexico.**
- **Wind increments are huge and divergent at 150-250 hPa.**
- **The conclusion was that "increments are not related to bad observations or a poor 4D-Var performance".**

… but under certain meteorological conditions wind profilers measurements can be contaminated….(Ackley *et al*, 1998)





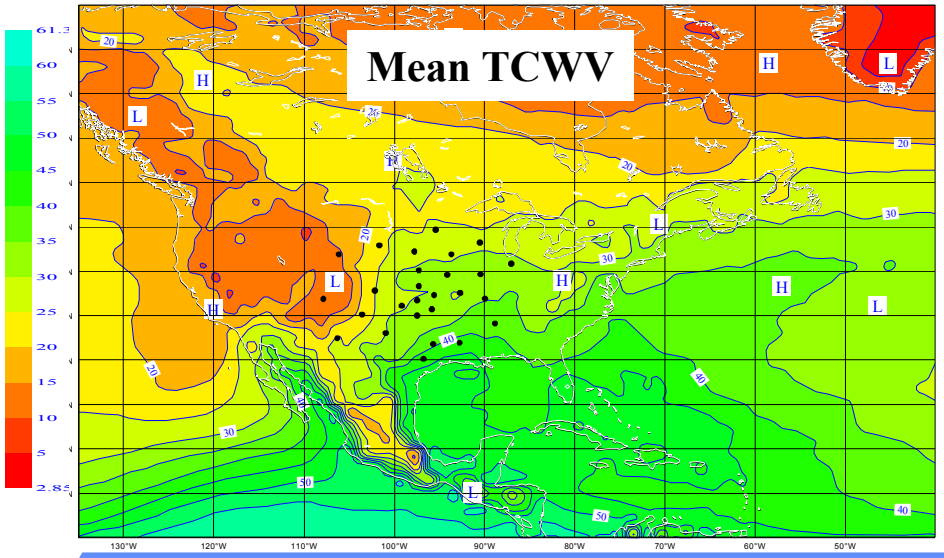
ERA40 Jun

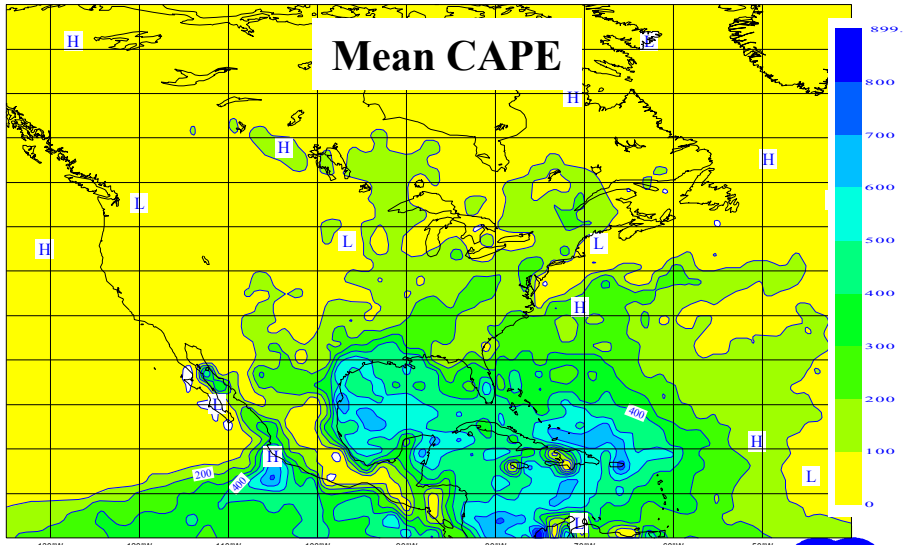


Mean 850-hPa Wind

&

Z500 hPa





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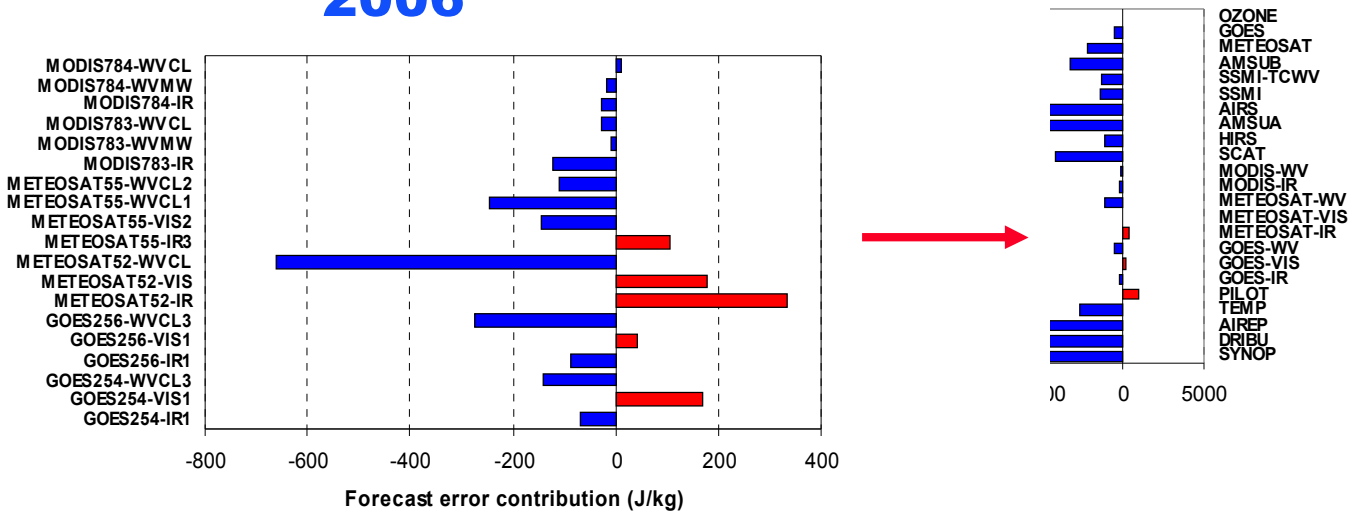
Summary FSO wind Profiler

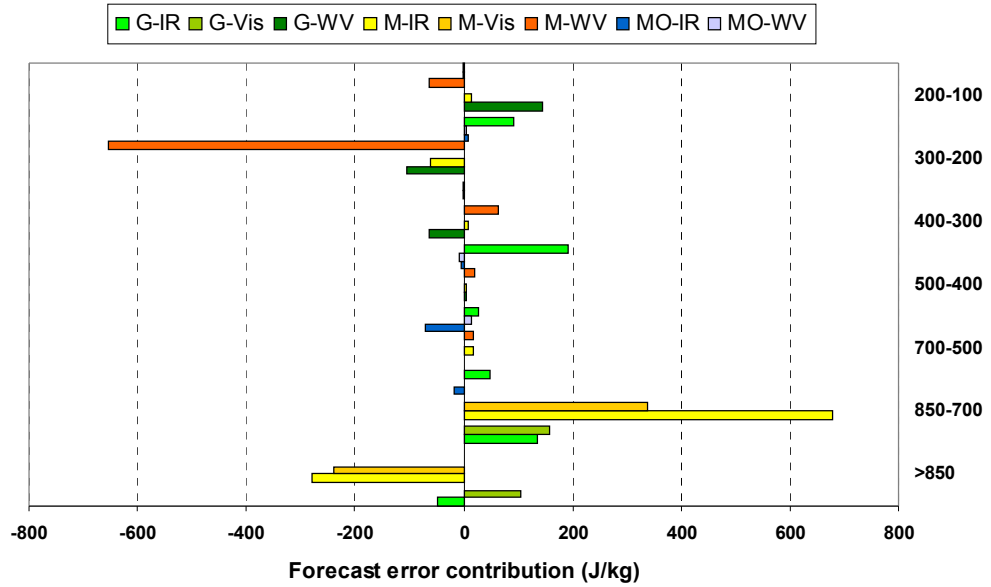
- FSO showed a Fc Error increase due to the American wind profilers observations for the summer case.
- Southerly flow across SE USA bringing warm and moist air from Gulf of Mexico produced strong convective instability in the region, a typical situation at this time of the year.
- Following Ackley *et al* report (1998) on wind profiler measurements validity “in strong unstable conditions (turbulence) the measure of the mean horizontal wind is corrupted affecting the measurements”. Suggesting that the forecast impact can change with the meteorological situation for the summer 2006 case.

Atmospheric Motion Vector FcE Contribution Summer 2006

Forecast error contribution of the observed wind grouped by satellite types- positive corresponds to an **increase** of Fc Error



Forecast error contribution of the wind on **pressures levels** & grouped by satellite types- largest degradation comes from the lower troposphere



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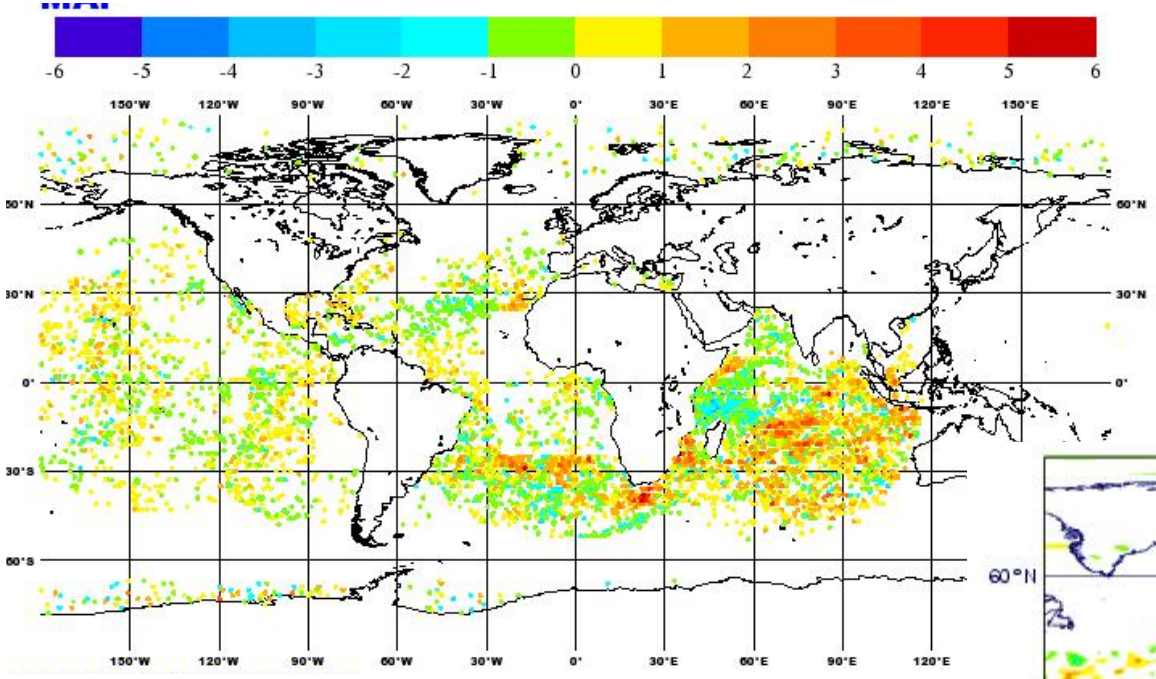
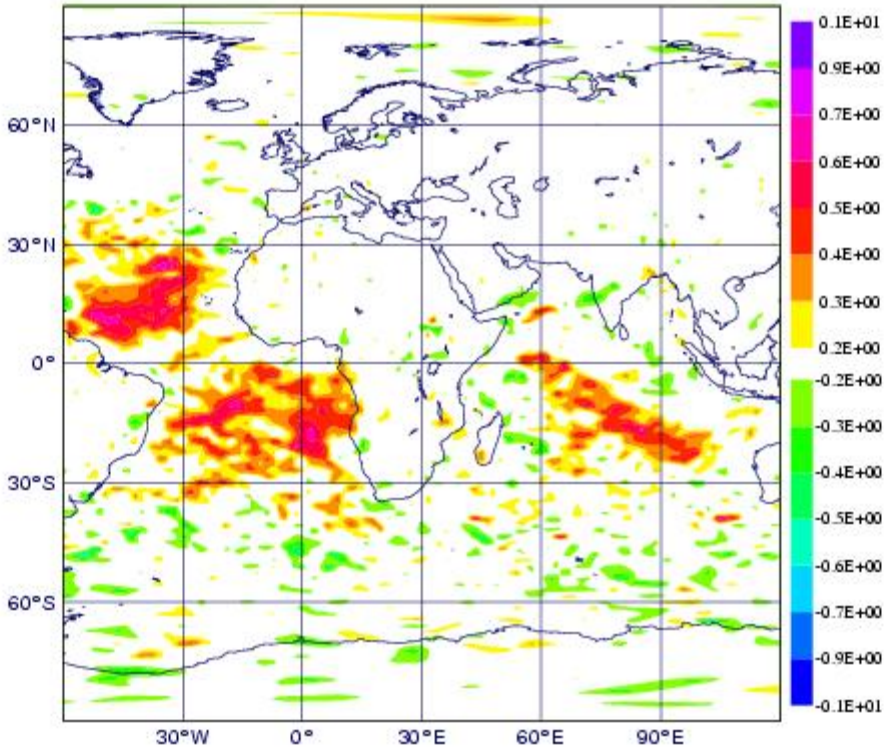
AMV OSE: Summer 2006 OSE & FSO



FSO to AMV U
700-1000 hPa



850 hPa U-Comp
RMSE differences between AMV-Ref OSE

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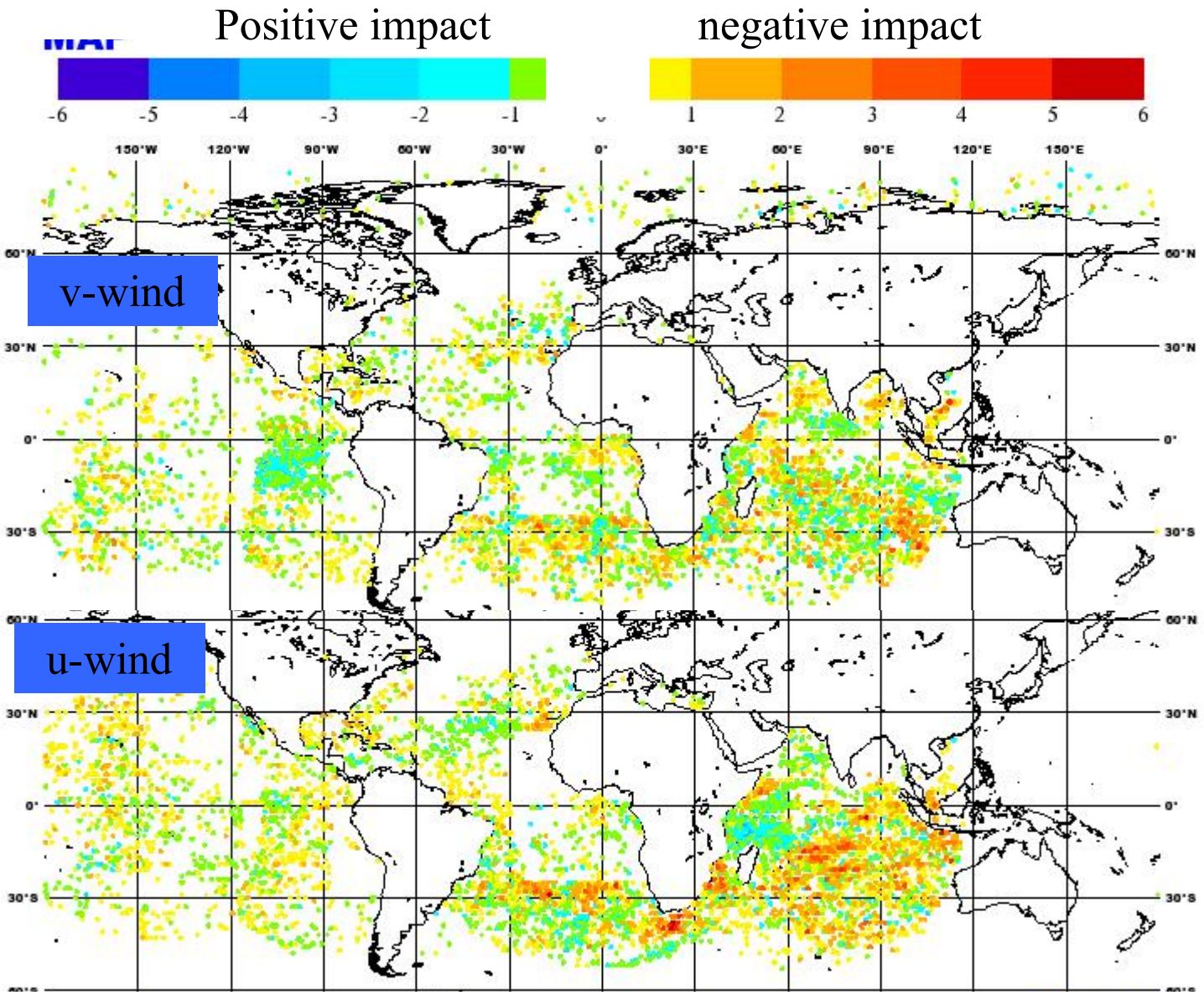
FSO AMV 700-1000 hPa: Summer 2006



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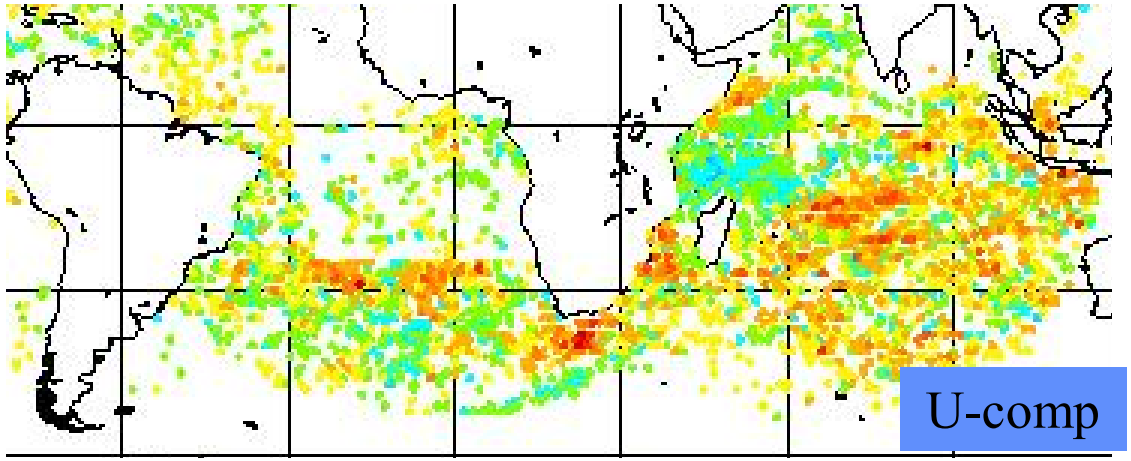
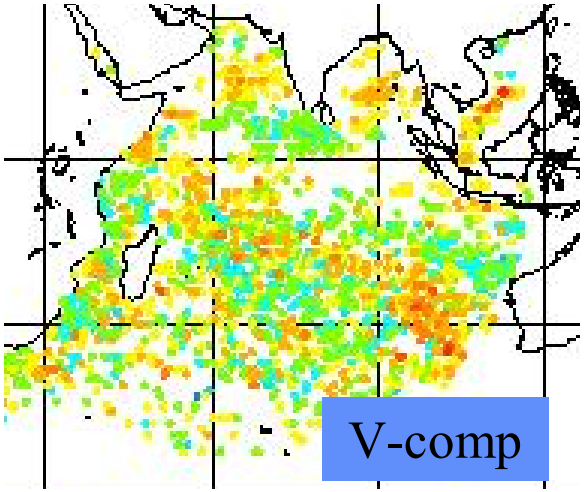
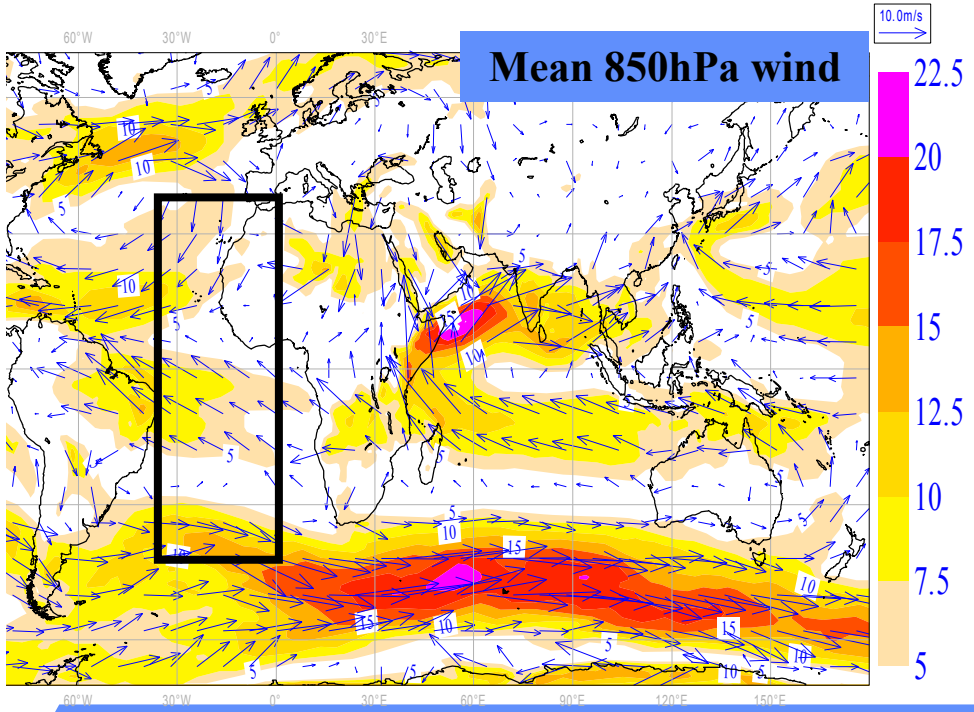
FSO AMV 700-1000 hPa: regional impact







Conditions affecting the HA of AMVs:

Weak winds, wind shear/curvature, presence of both opaque/transparent clouds (typical in the tropics) can have a large impact on the AMV height assignment.

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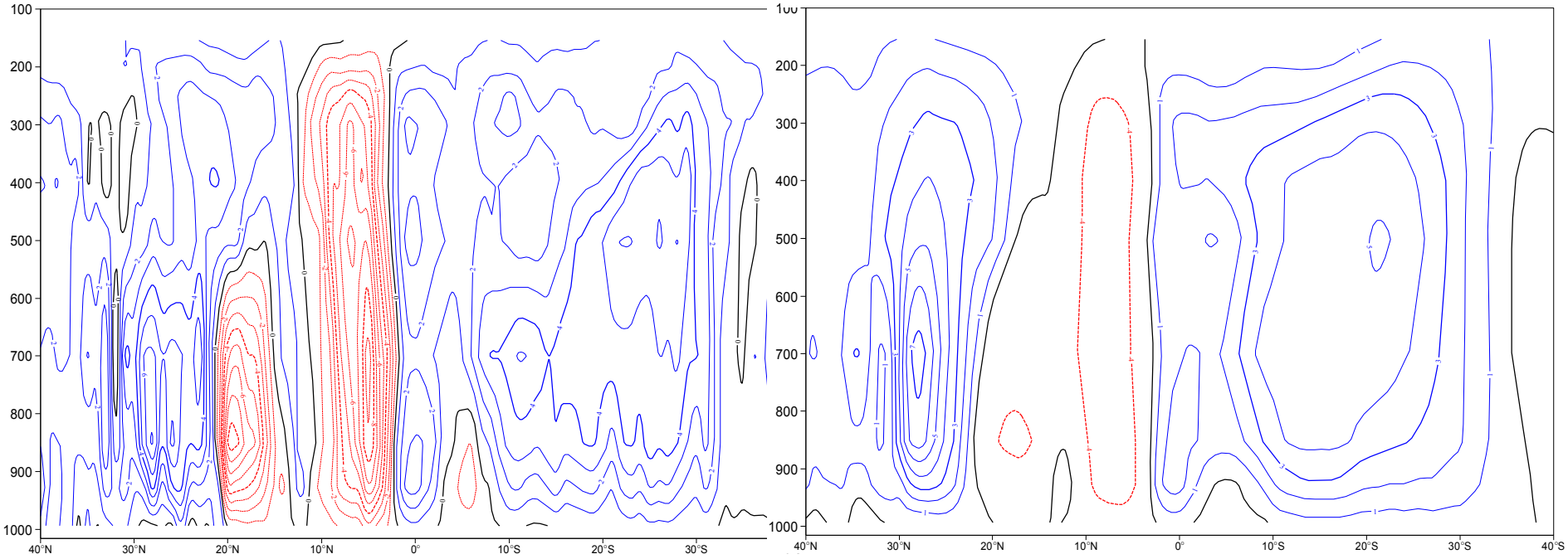
Cross Section [35W-0E] Summer 2006: Atlantic

AN mean vertical velocity (*0.01 Pa/s) **ERA40**



north **south** **north** **south**

The strong sinking motion in SH near 30S represents southern limit of the Hadley circulation (where the subtropical high cell is located) which coincides with the largest negative impact of AMV u-component below 700 hPa .

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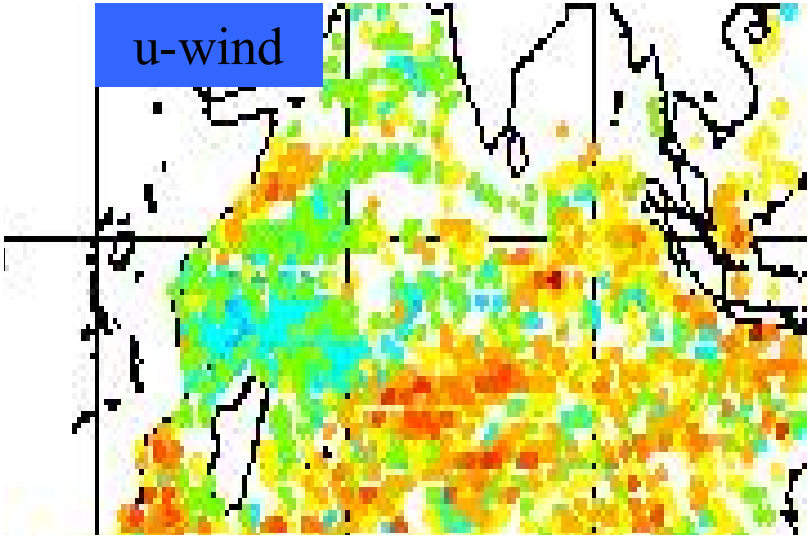
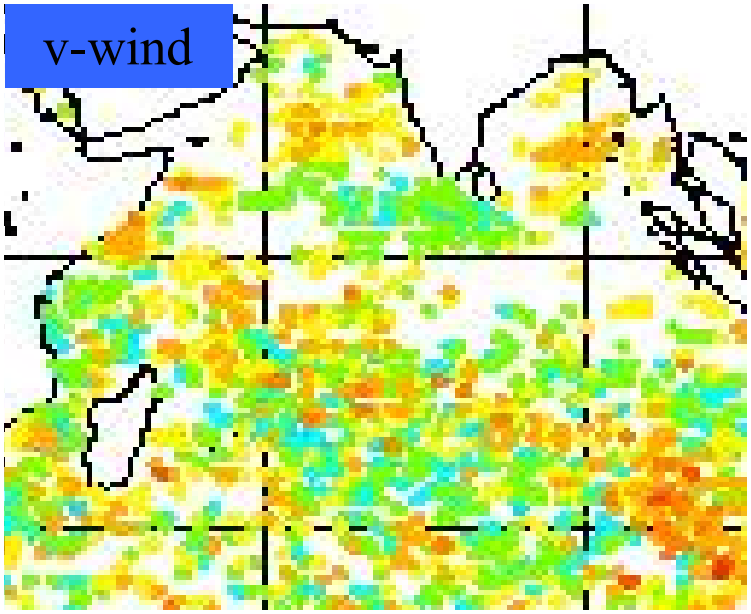
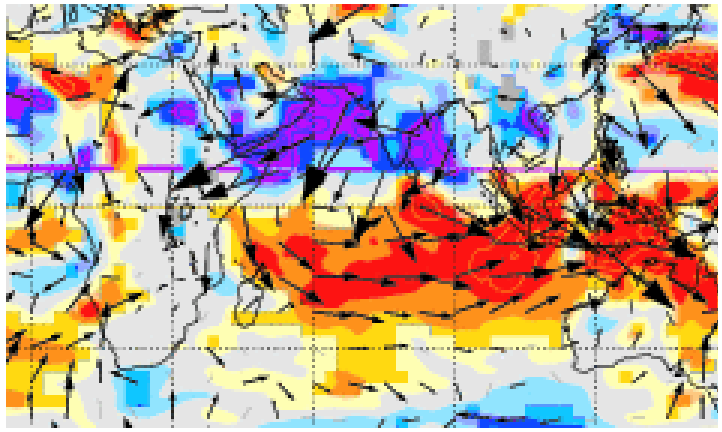
Indian Monsoon Summer 2006: Model bias



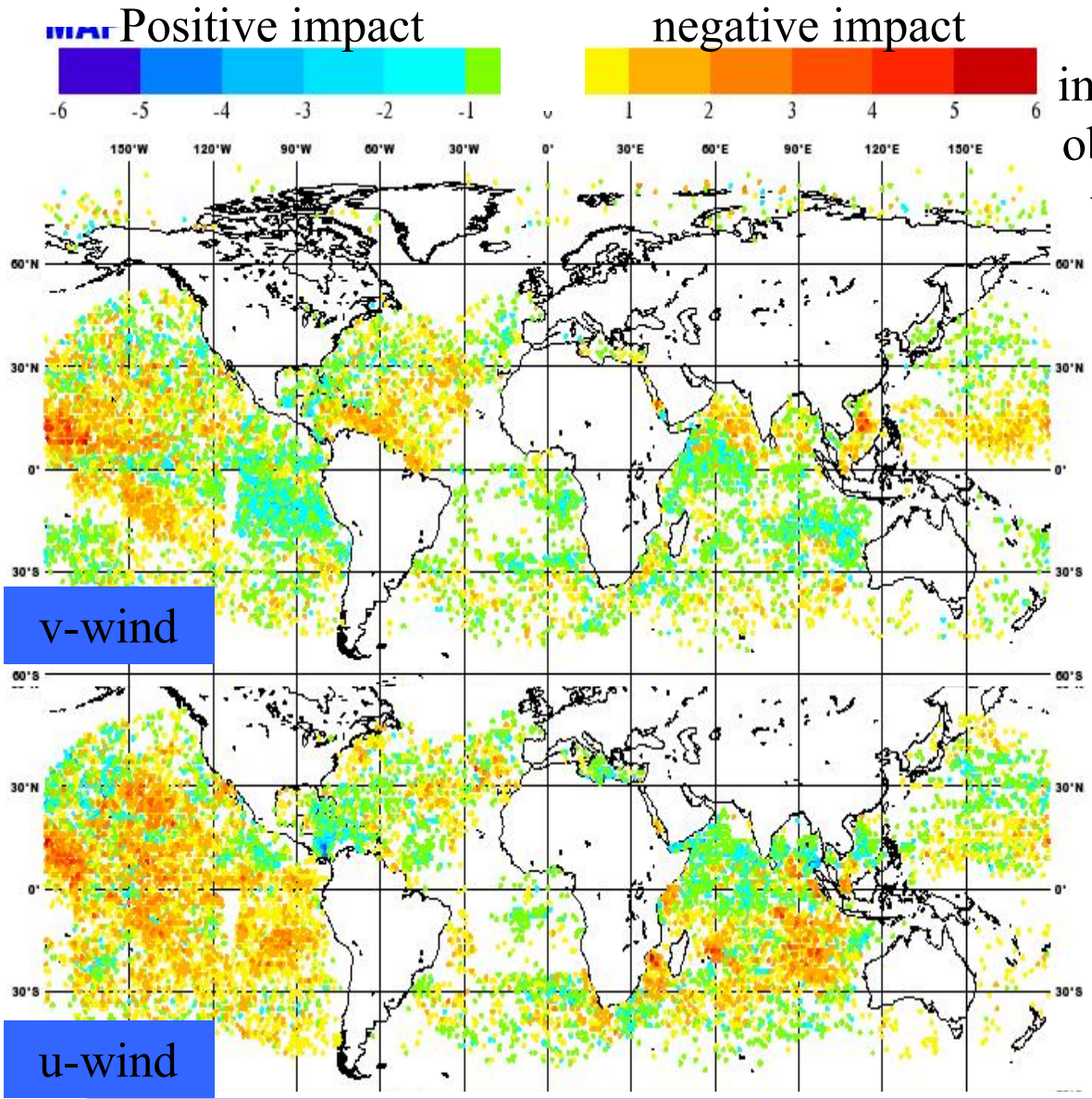


A too strong low level flow of Indian Summer Monsoon is a known problem in the model as is indicated by the JJA mean analysis increments (discussed in OD/RD last March)

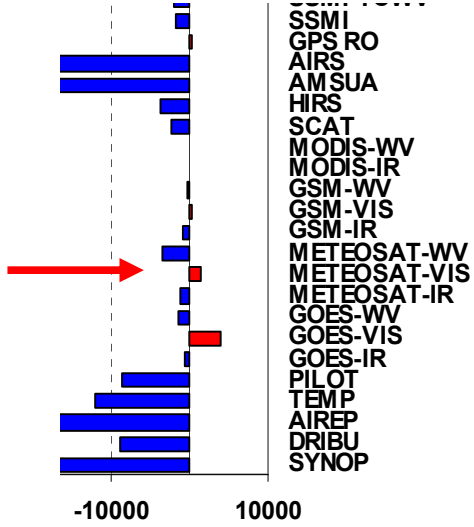


925-hPa JJA 2006 Diagnostic Explorer

AMV FSO 700-1000 hPa: Winter 2007



Overall impact of the observations to fcError



Largest negative impact of AMVs to Fc error can be seen in central/eastern Pacific (absent in summer case).

Negative impact seen during summer 06 in south Atlantic near 30S has disappeared in winter 07

In the Indian Ocean the degradation is mainly due to u-component of the wind

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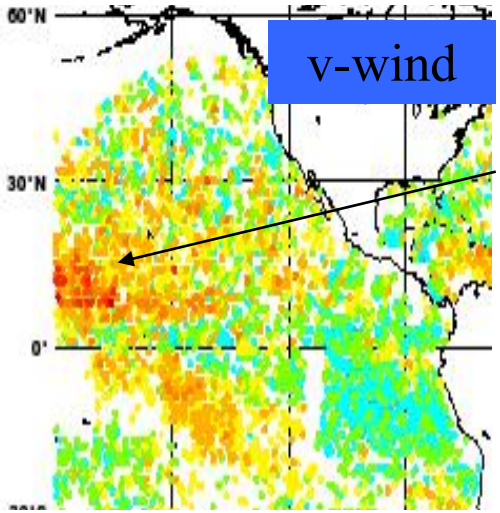
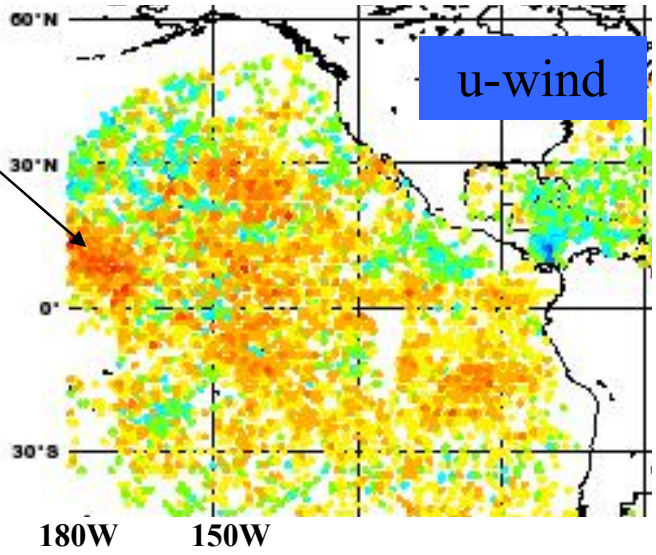
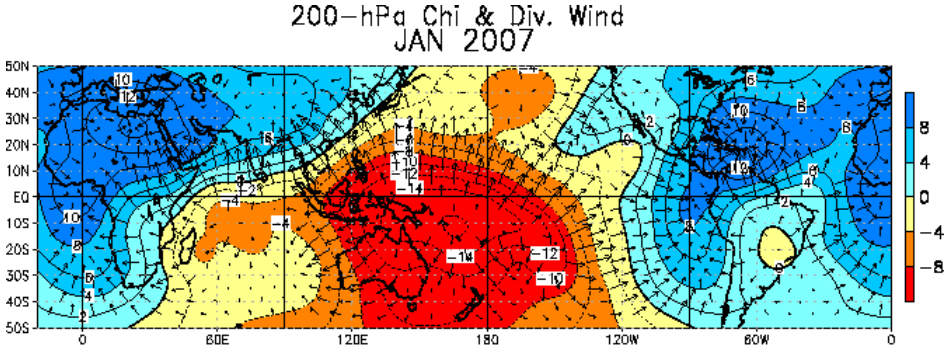
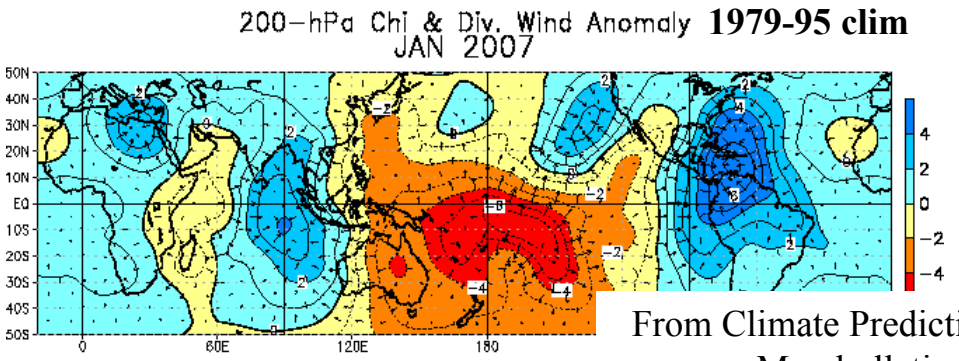
Winter 2007 Central/Eastern Pacific: weak El Nino



Largest degradation in central eastern PAC is located NE of the convective activity across central equatorial PAC







Enhanced convection in central & eastern Pacific due to El Nino conditions.

From Climate Prediction Centre –Noaa Mon bulletin Jan 2007

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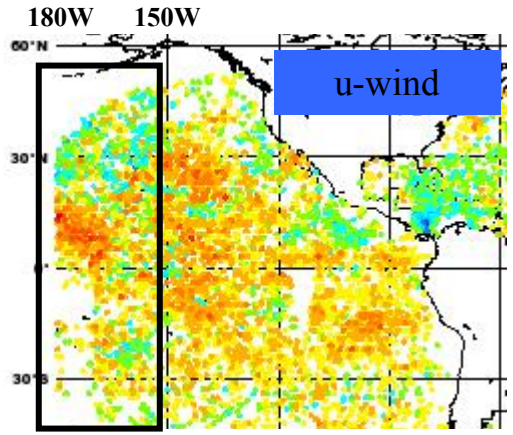
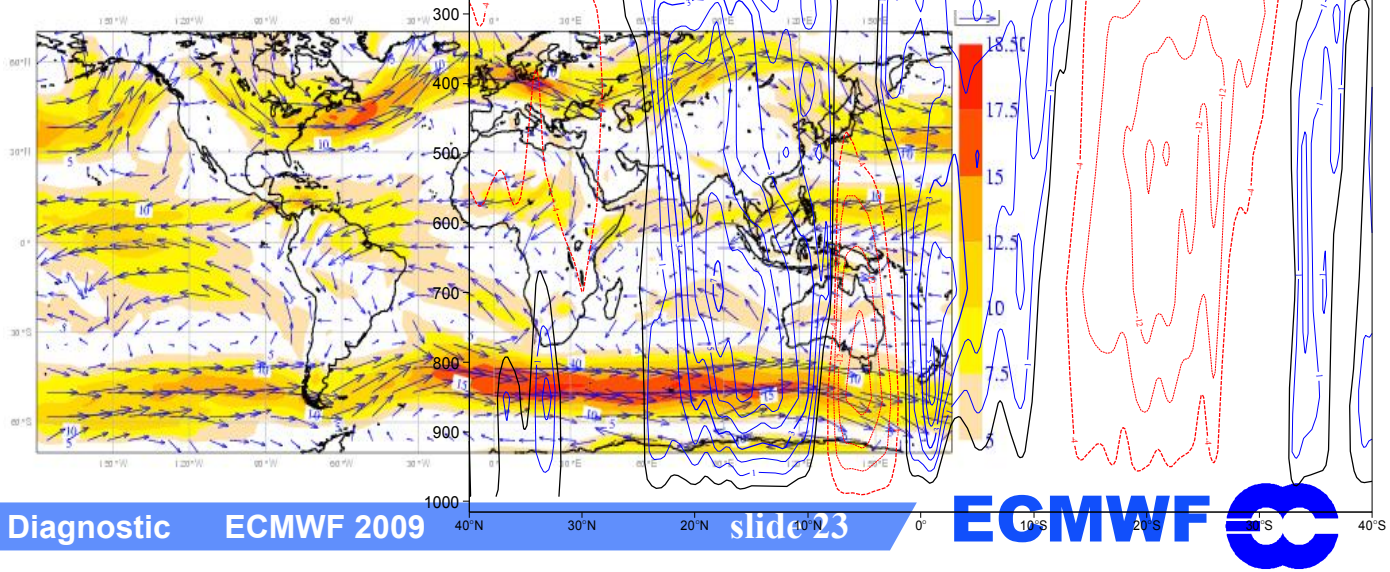
Winter 2007 central/eastern Pacific Cross Section [180W-150W]

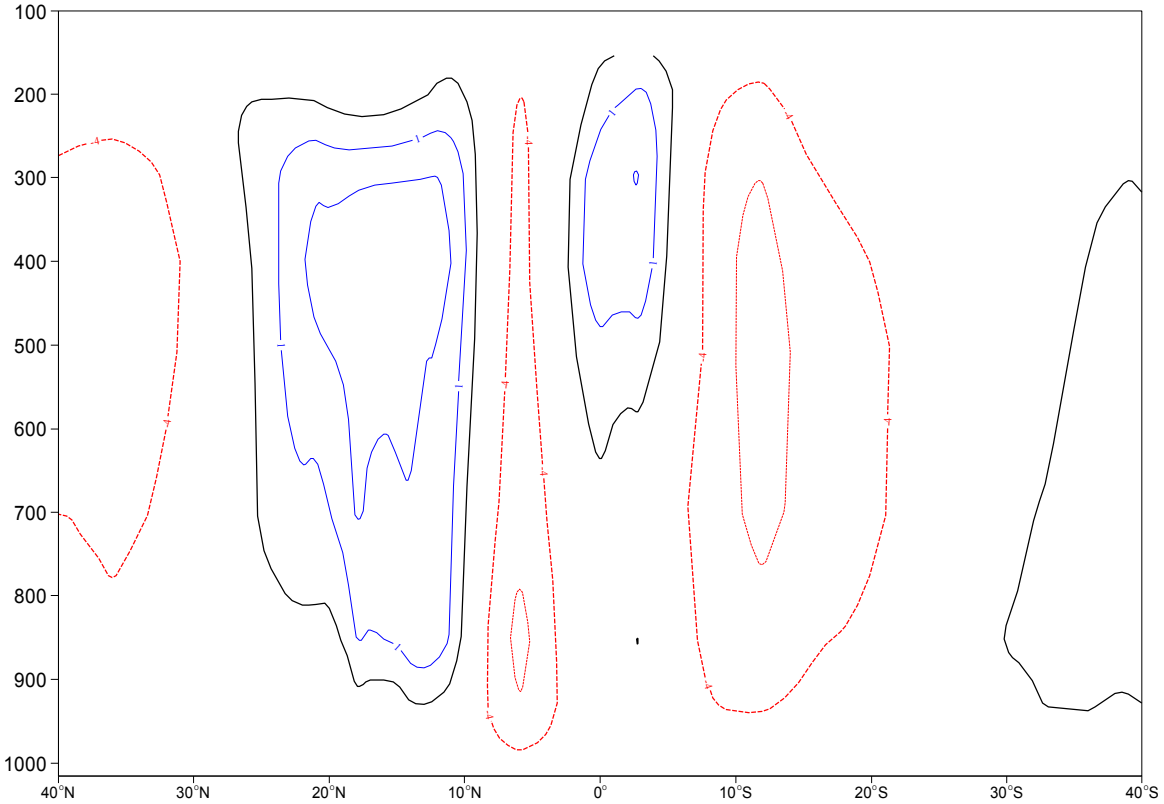
The largest negative impact of AMVs to the Fc error is found between 5N and 15N and coincides with a broad downward mean motion of the Hadley circulation (large departures were found below 700-hPa in the same region)

A second cluster of negative impact near 25N/140W is localized on top of a region of weak winds (strong sinking motion)





Average of vert vel 256550106 00 step 0 Expver 0011 (180.0W-150.0W)



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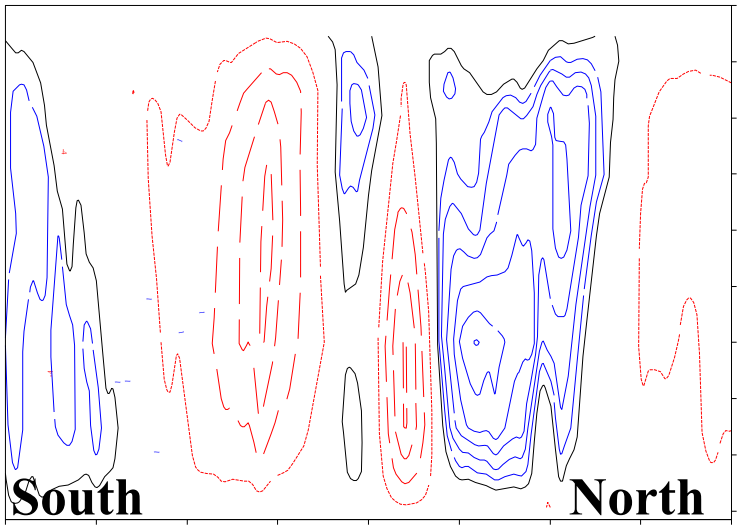
Mean ω



Departures

Cross section

AMV GO11-IR10.6

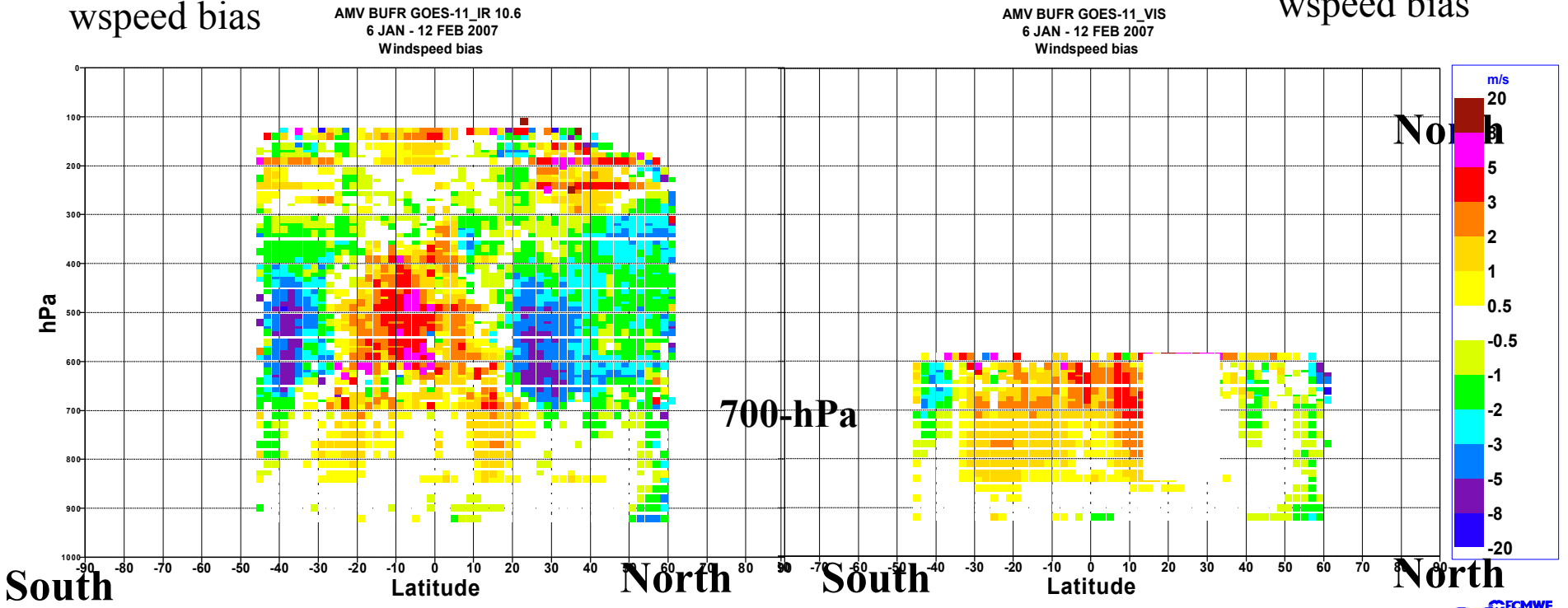
wspeed bias

Departures

Cross section

AMV GO11-VIS

wspeed bias



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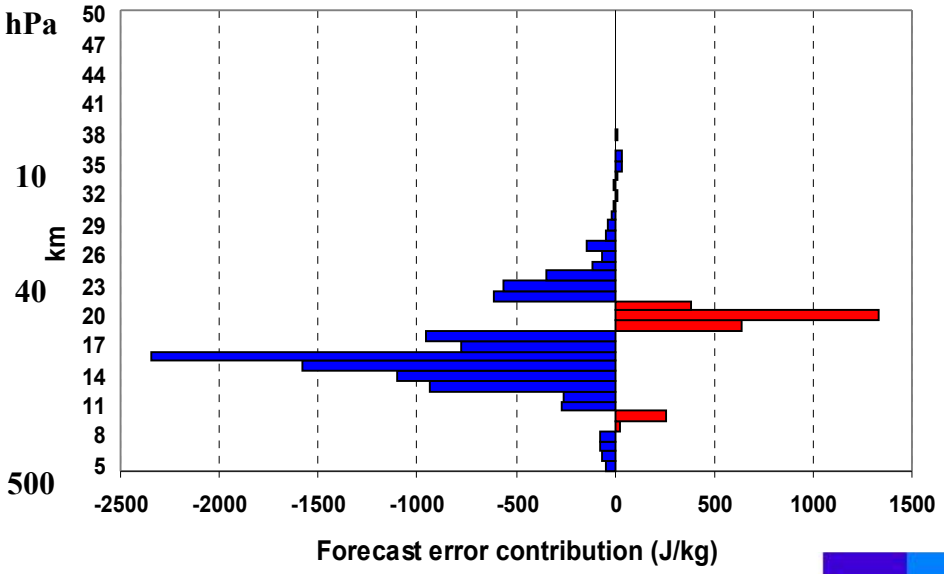
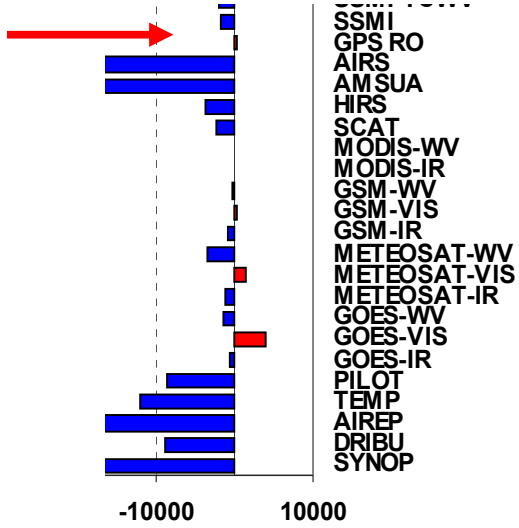
Summary FSO AMVs

- FSO showed a Fc error increase due to AMVs in both summer and winter cases. The impact of AMVs to the forecast varies from summer to winter.
- The location of the largest negative impact of the AMVs in Atlantic (summer) and Pacific (winter, El Nino) are found close to the region of strong sinking mean motion embedded in the Hadley circulation. Larger error in the height assignment on which AMVs measurements accuracy depends.
- Detrimental effect is also observed in the Indian ocean (summer) associated with too strong Indian monsoon circulation developed by the model.

GPS RO Impact on Forecast Error Winter 2007

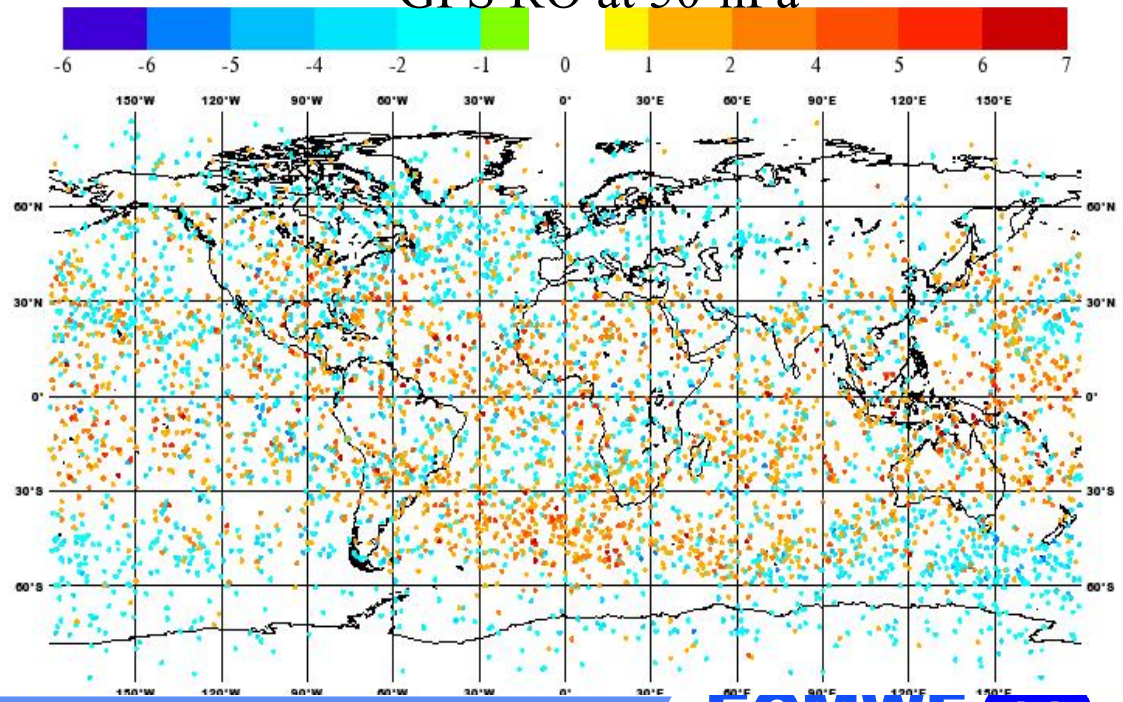


Overall impact of the observations to fc error



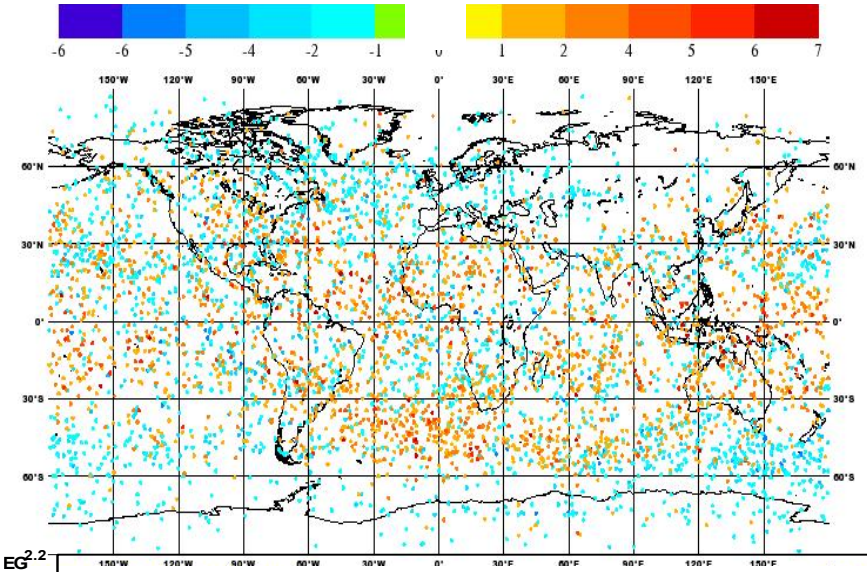
The negative impact is more pronounced in the tropics & subtropics

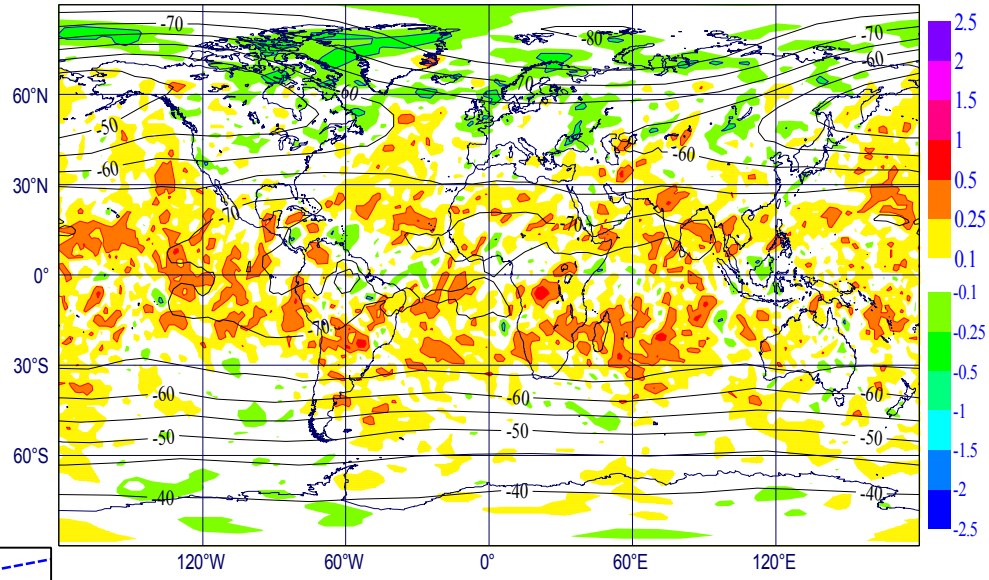
GPS RO at 50-hPa

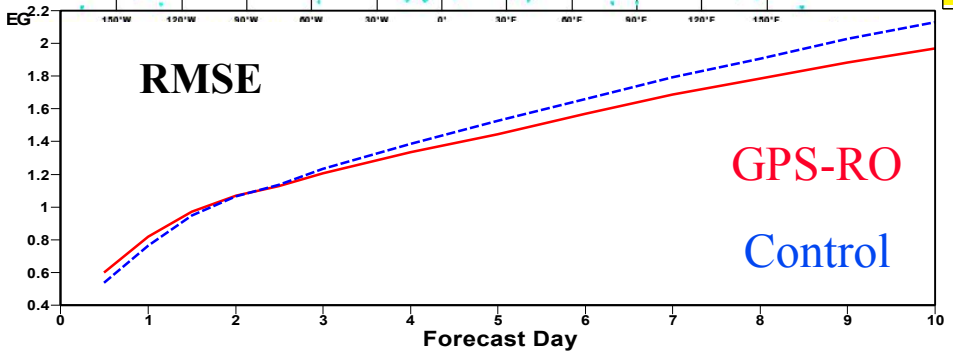


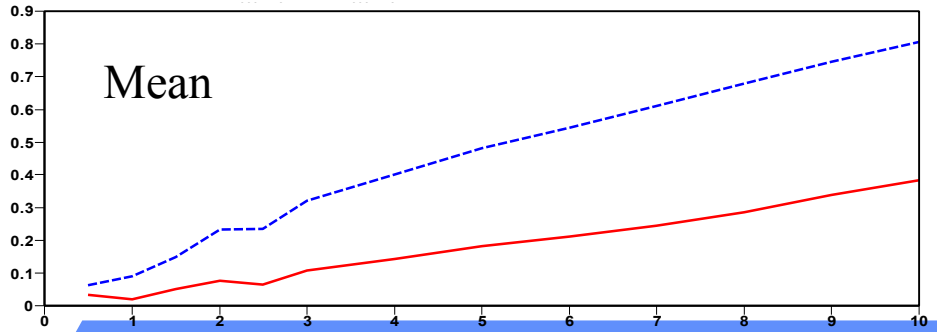
ECMWF

50 hPa RMSE Temperature GPSRO-Control Winter 2007









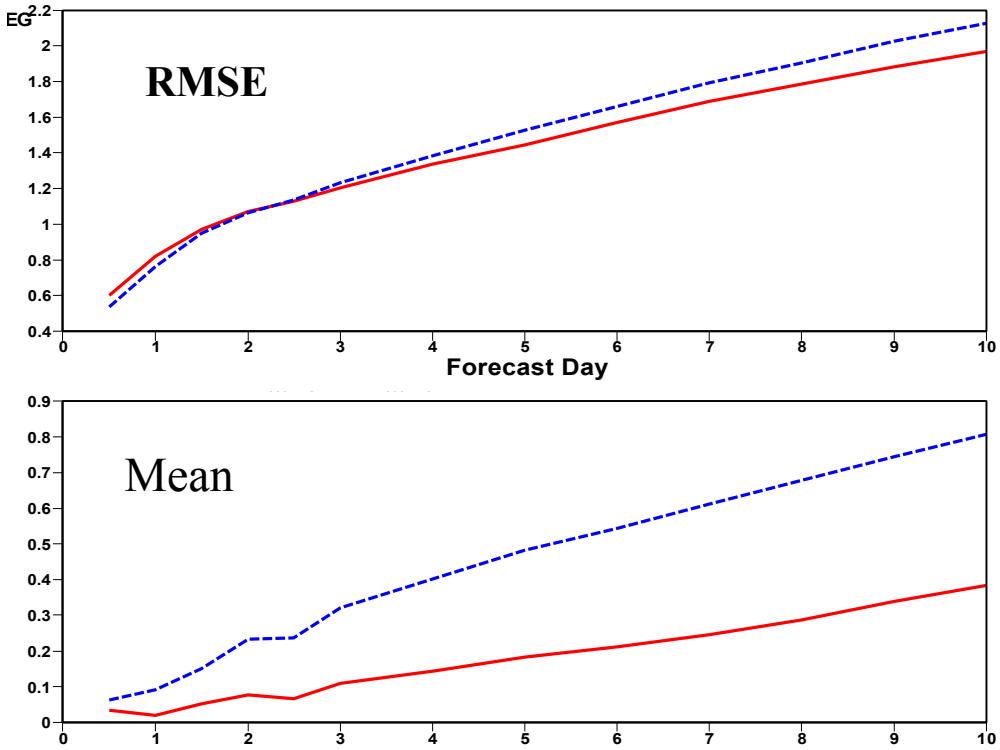
50-hPa Temp RMSE differences between GPS RO-Control OSEs (24-hrs Fc)

The degradation (positive values) are found mainly in the tropical belt which is consistent with the geographical distribution obtained from the FSO

The OSE shows a positive impact for the GPS-RO for the 10-days forecast with the exception of the first 24hrs forecast.

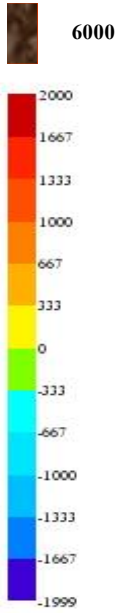
ECMWF

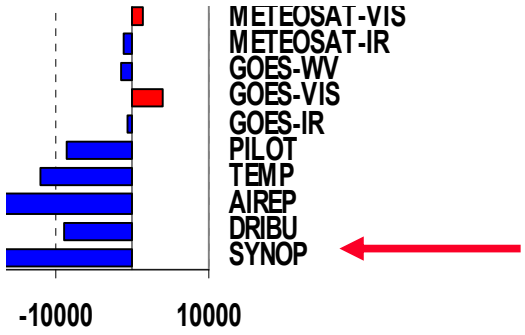
GPS RO Winter 2007: 50 hPa RMSE Temperature GPSRO-Control

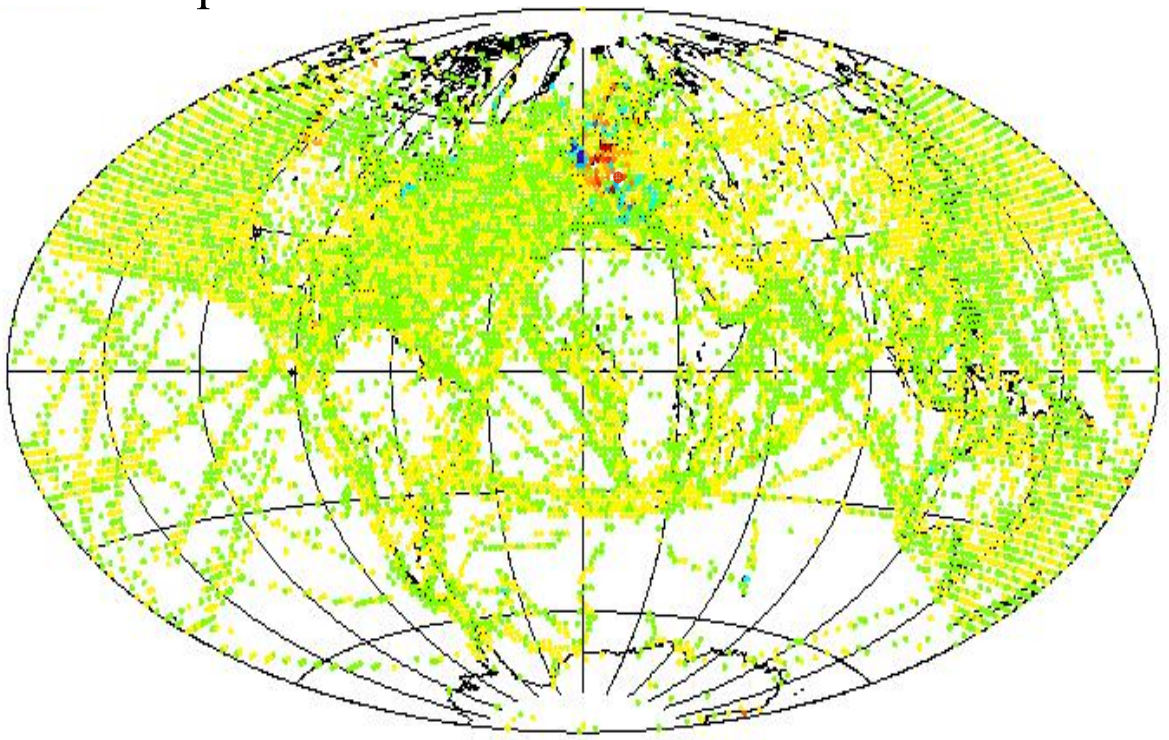


Automatic&Manual Surface Press SYNOP FcE Conribution winter case

SYNOP sfc-press observations shows an overall globally positive impact to the forecast error but not over Europe.



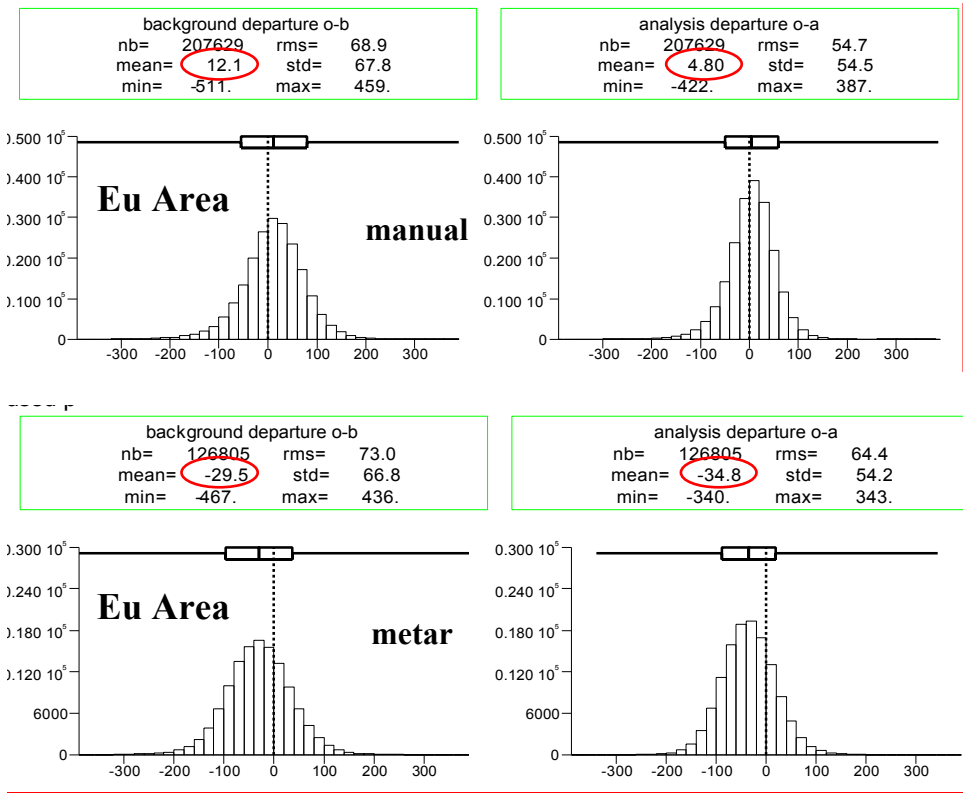


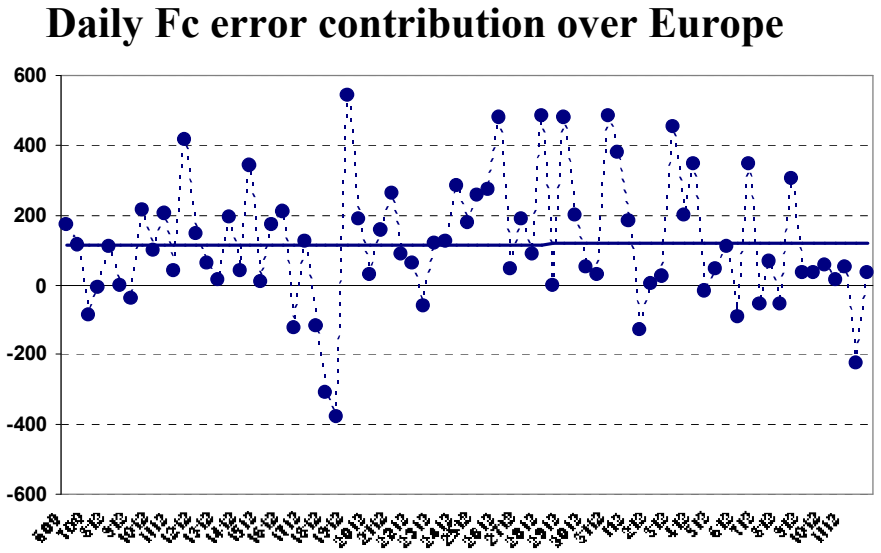


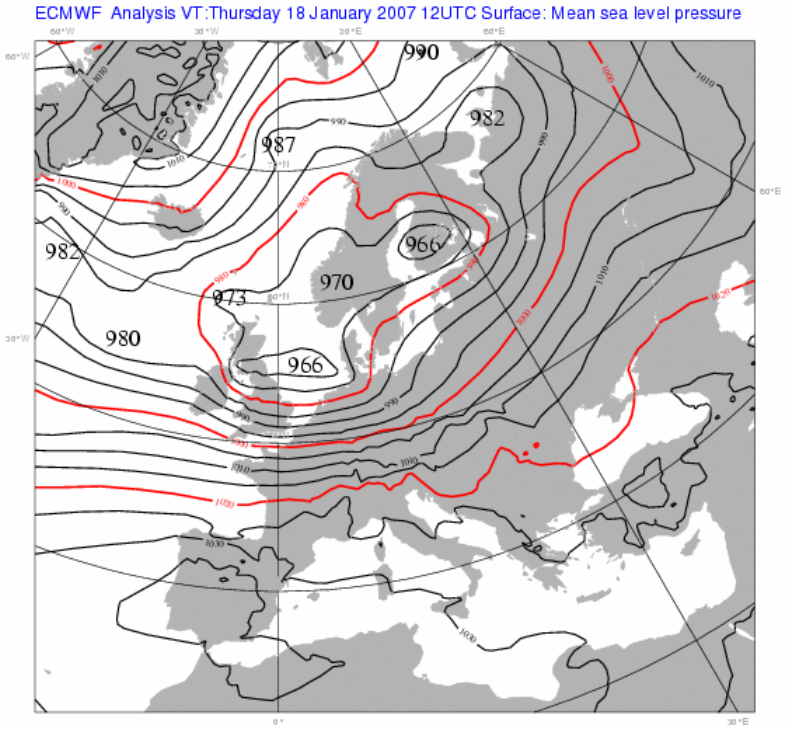
ECMWF

Automatic Surf Press SYNOP FcE Contribution time series - Winter 2007

Storm Kyrill – 18 -20 Jan







Summary FSO GPS-RO and SYNOP/METAR sfc-pressure

- A negative impact to Fc error due to GPS-RO is found in the lower stratosphere and mainly in the tropical belt which is related with temperature model bias. OSE showed the same impact for the first 24hrs forecast but also the positive impact for longer time ranges.
- The overall decrease of Fc error due to SYNOP (man. & auto.) contrasted with the degradation over Europe. Adverse weather conditions over Europe (strong pressure gradient) for several weeks would require a higher resolution analysis system.

Conclusion&Remarks

- Forecast sensitivity to observations allow to monitor the observation forecast impact on the 24 range
- The tool provides information on the observation type, subtype, variable and level responsible for the forecast error variation. Causes must be found that explain the failure
- Failures can be due to the data quality or some characteristics of the assimilation system and can highly depend on the weather situation
- A joint effort blending different expertises, tool developers and meteorologists, is necessary to produce a comprehensive investigation and understanding of forecast failures
- The assessment should be carried out on a daily basis (operational implementation)