Diagnosing the impact of Atmospheric Motion Vectors in the ECMWF 4D-Var Assimilation System

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Diagnosing the impact of Atmospheric Motion Vectors in the ECMWF 4D-Var Assimilation System

- Introducing of a new adjoint-based diagnostic tool:
  Forecast Sensitivity to Observations (FSO)
- FSO versus Observing System Experiments
- FSO evaluation of AMV impact in the 4D-Var at ECMWF
- Conclusions

FSO - Forecast sensitivity to observation: Equations

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

$\mathbf{x_a}$ is the analysis, **y** observations

J is a "dry energy norm" 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:

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

K is Kalman Gain matrix; **H** is obs.operator
R and **A** are obs./analysis covar. error matrices

Forecast error sensitivity to the analysis can be calculated using adjoint method: $\frac{\partial J}{\partial \mathbf{x}_a}$

F. Rabier *et al.* 1996.

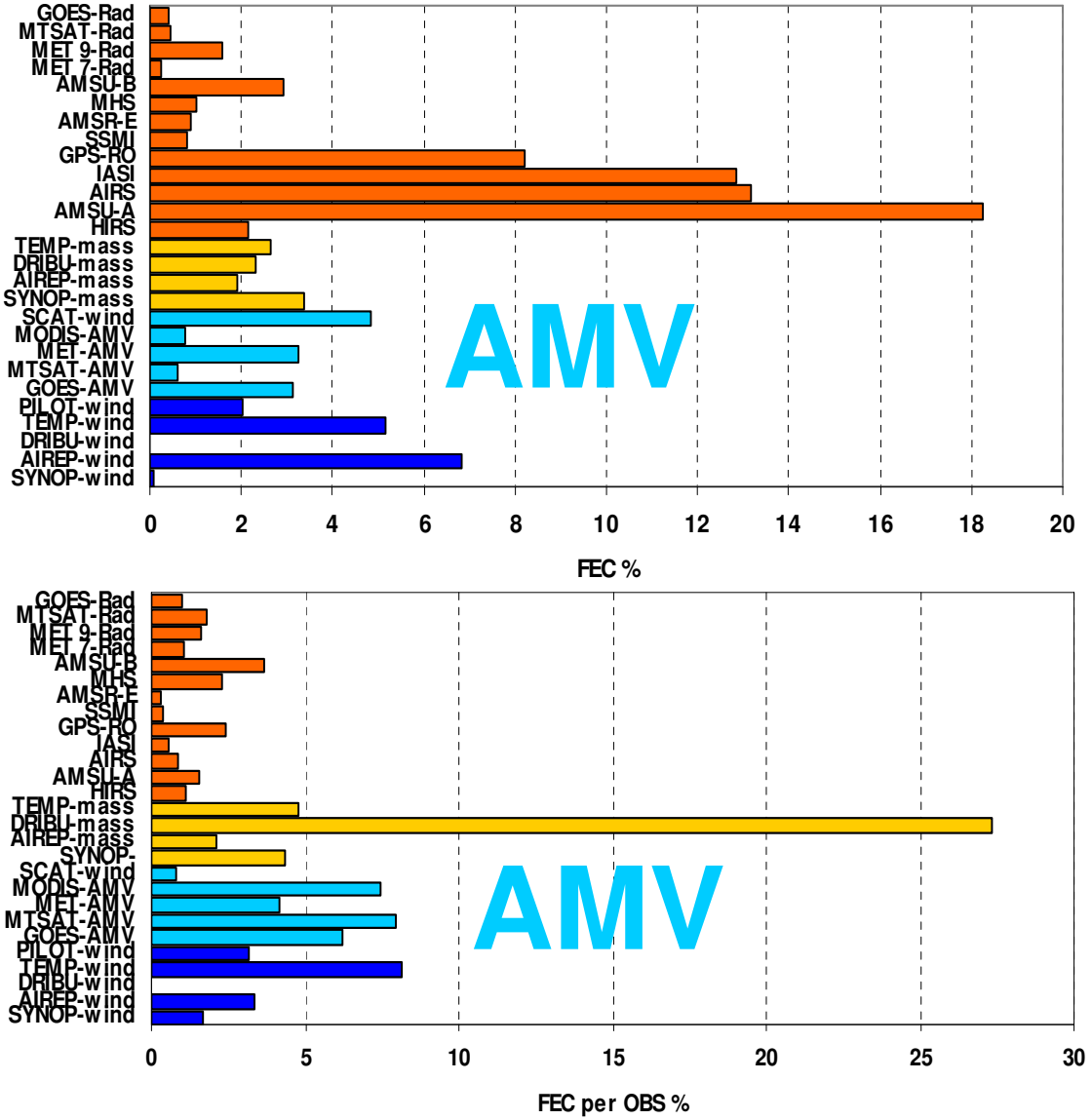
$$\frac{\partial J}{\partial \mathbf{y}} = \mathbf{R}^{-1}\mathbf{H}\mathbf{A}\frac{\partial J}{\partial \mathbf{x}_a}$$

Compute the δJ:

$$FEC = \delta J = \left\langle \frac{\partial J}{\partial \mathbf{y}}, \delta \mathbf{y} \right\rangle = \frac{\partial J}{\partial \mathbf{y}}(\mathbf{y} - \mathbf{H}\mathbf{x}_b)$$

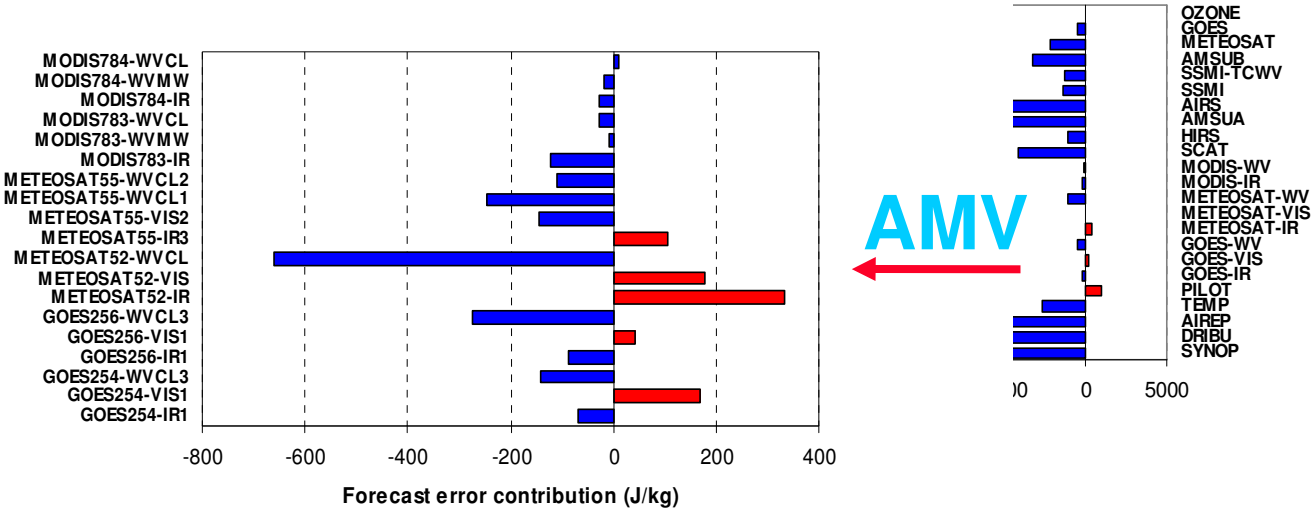
The tool provides the *F*orecast *E*rror *C*ontribution (*FEC*) for each assimilated observation, it can be accumulated by *observation type, subtype, variable or level*

FSO: 24h Forecast Error Contribution of 2009 Global Observing System in ECMWF's 4D-Var

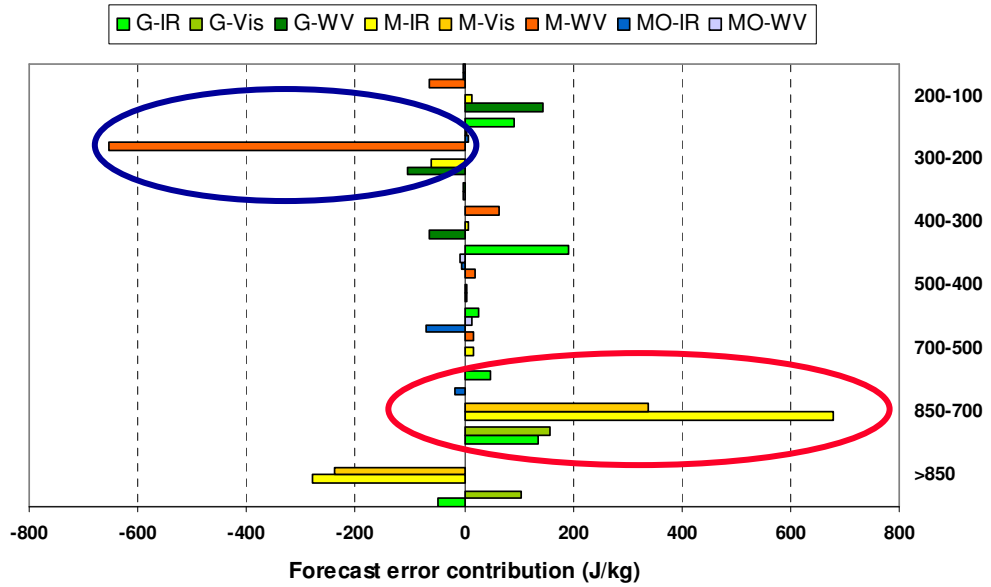


FSO: Atmospheric Motion Vector Forecast Error Contribution Summer 2006

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



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

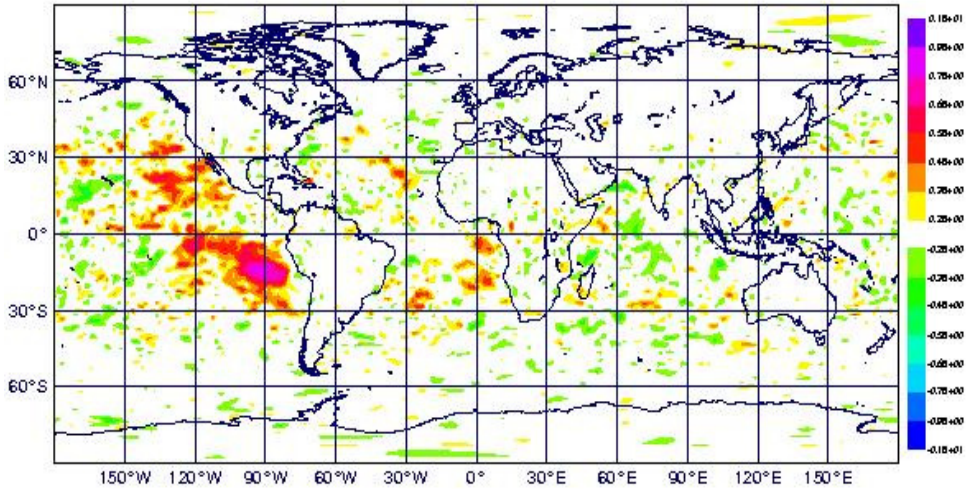


FSO versus OSEs (Observing System Experiments)

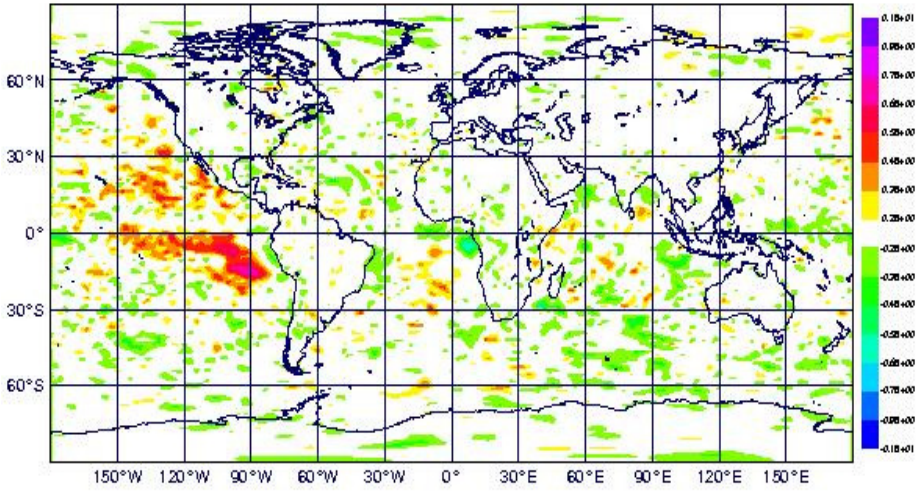
FSO	OSE
Measures the impact of an observation when entire observing system is used	Observation impact is evaluated by blacklisting observing system
Measures the response of a single forecast metric to all perturbations of observing system	Effects of a single perturbation on all forecast metrics
Tangent linear restrictions only allow short-range forecast 24-48h evaluation	Can measure data impact on long-range forecast
Measures impact of all observations assimilated in a single analysis	Accounts for combined effect of observations assimilated in all previous analyses

Impacts from OSEs: Fc RMS error T24h and T+72h Sept. 2008

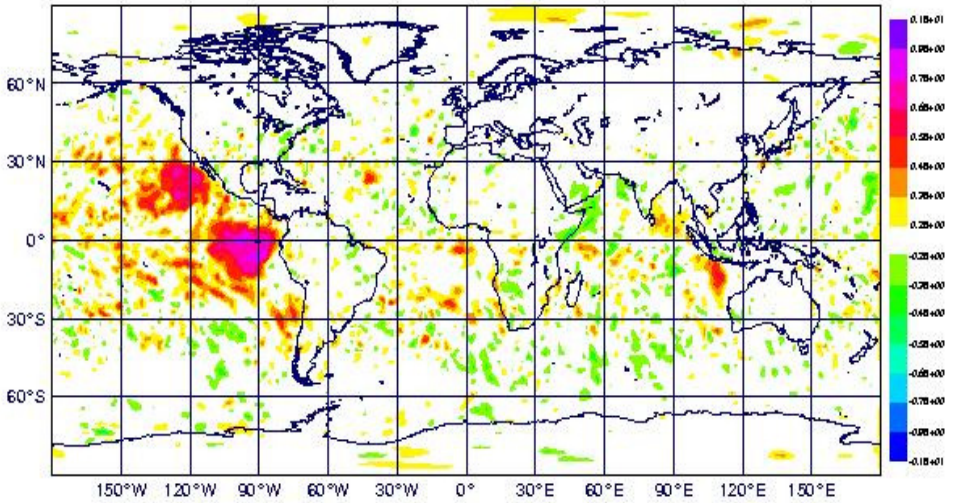
U-comp Fc T+24h error: AMV minus Baseline



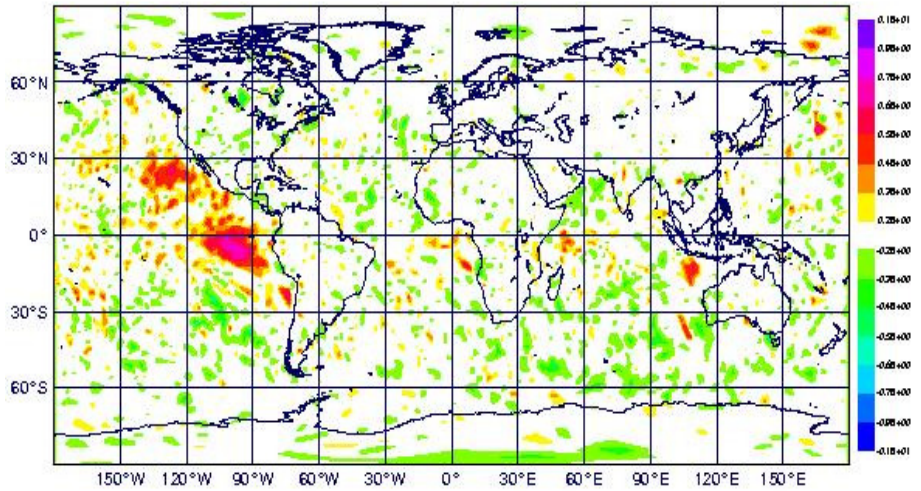
U-comp Fc T+72h error: AMV minus Baseline



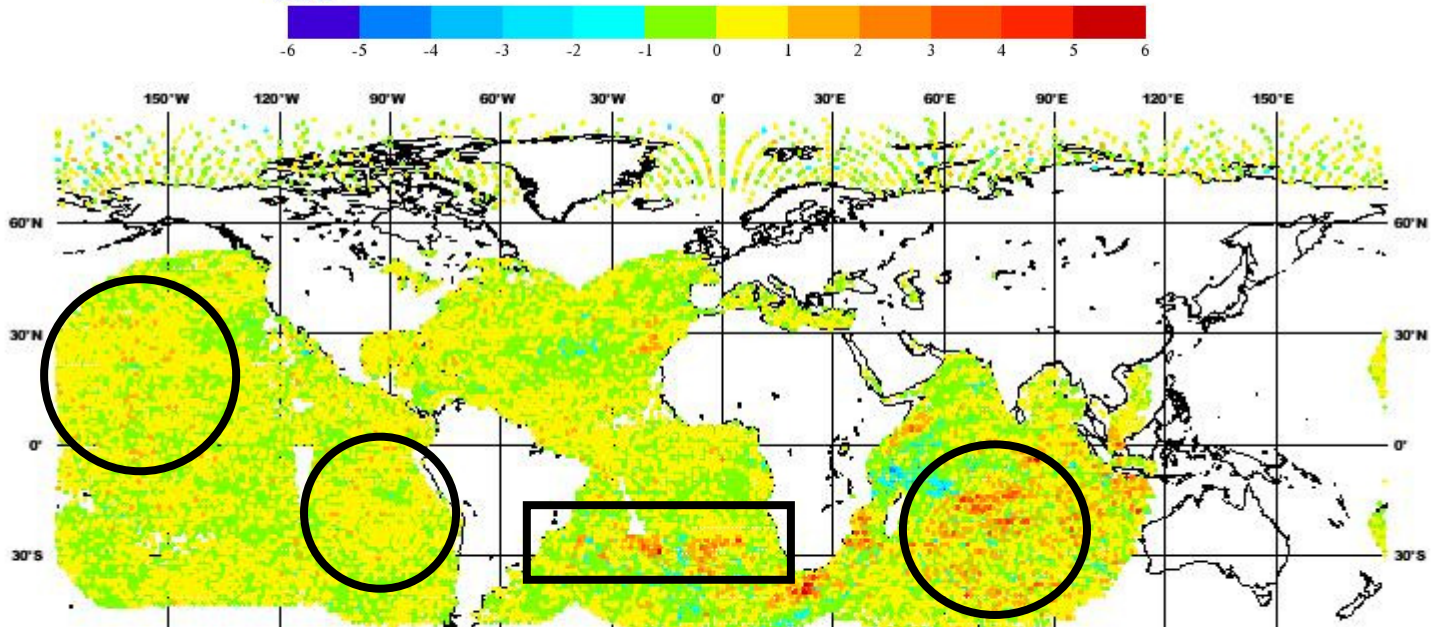
V-comp Fc T+24h error: AMV minus Baseline



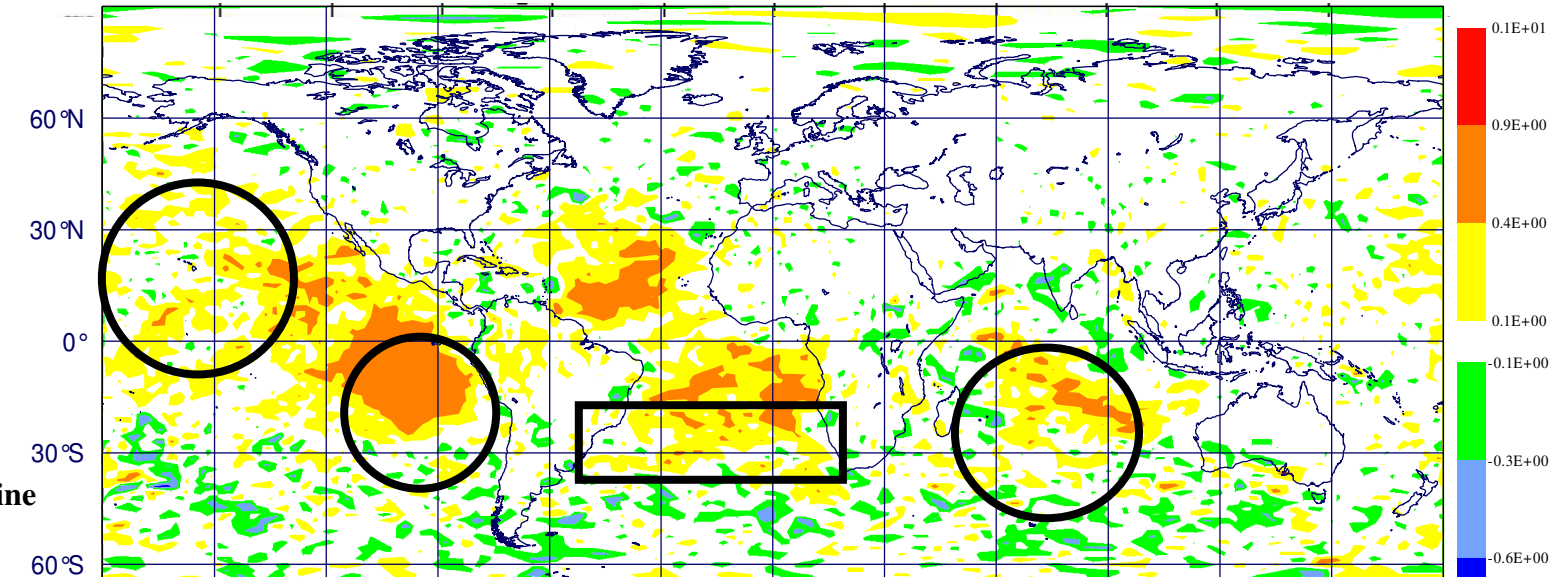
V-Comp Fc T+72h error: AMV minus Baseline



FSO AMV 700-1000 hPa U-Wind: Summer 2006



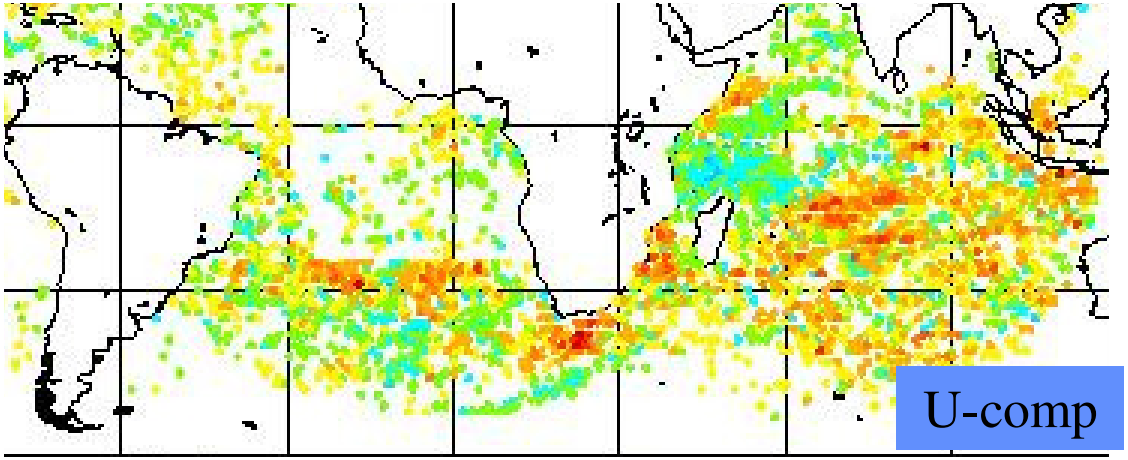
FSO

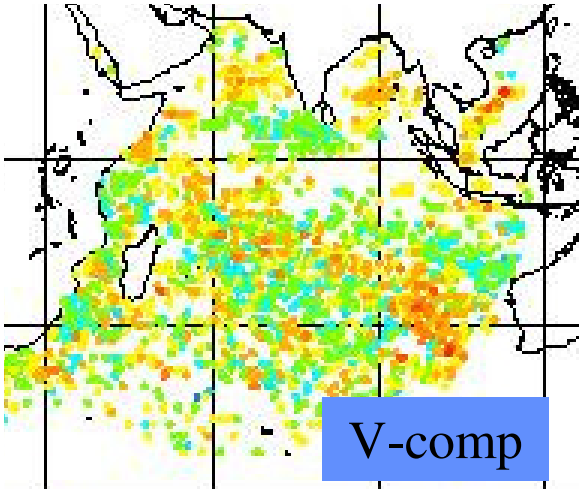


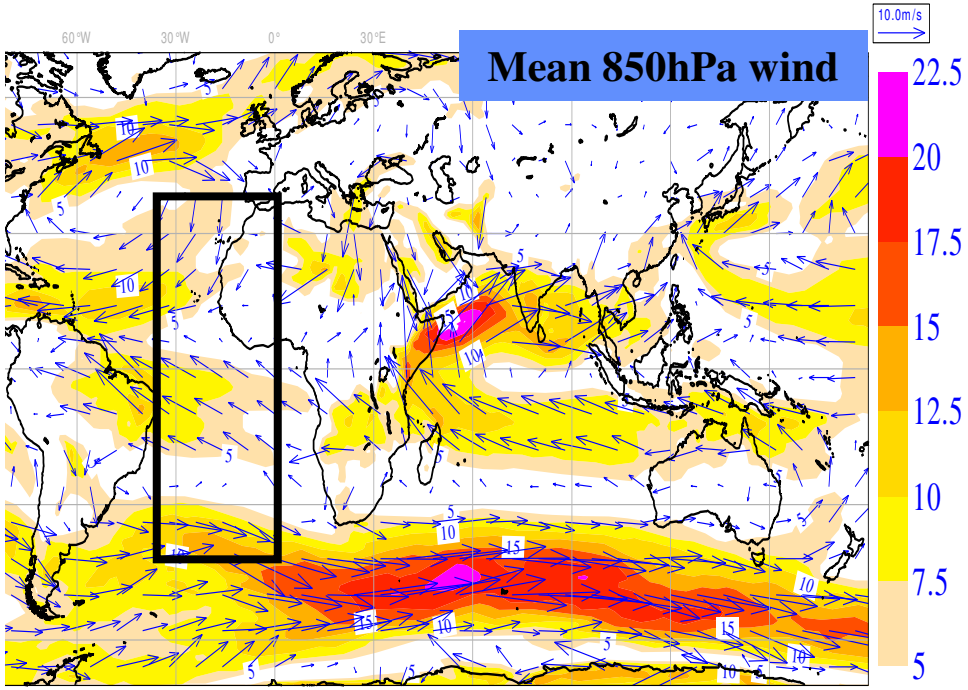
OSE

RMSE
AMV- Baseline
850 hPa U

FSO AMV 700-1000 hPa Summer 2006







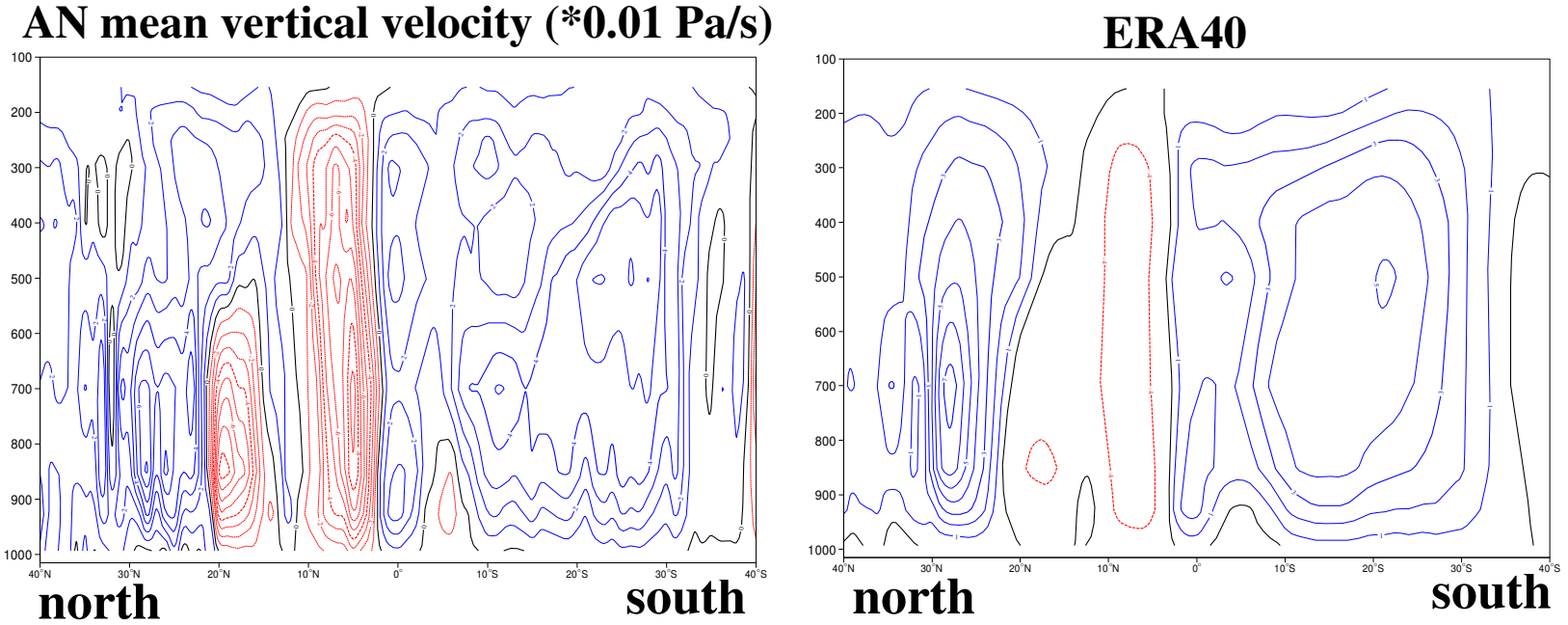
Atlantic Ocean: transition between sub-tropical and extra-tropical from weak to strong zonal flow

Indian Ocean: Large errors associated with well established Monsoon circulation

courtesy by Fernando Prates, ECMWF

FSO Atlantic Ocean: Observation Quality

Cross Section [35W-0E]

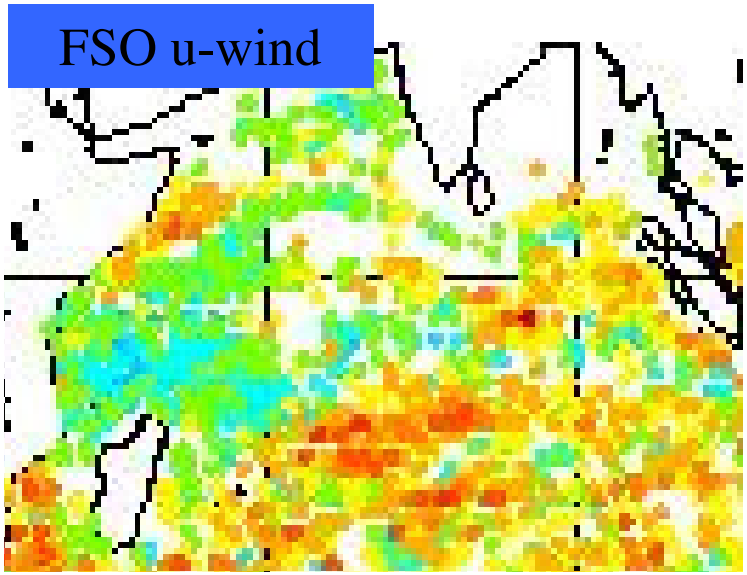


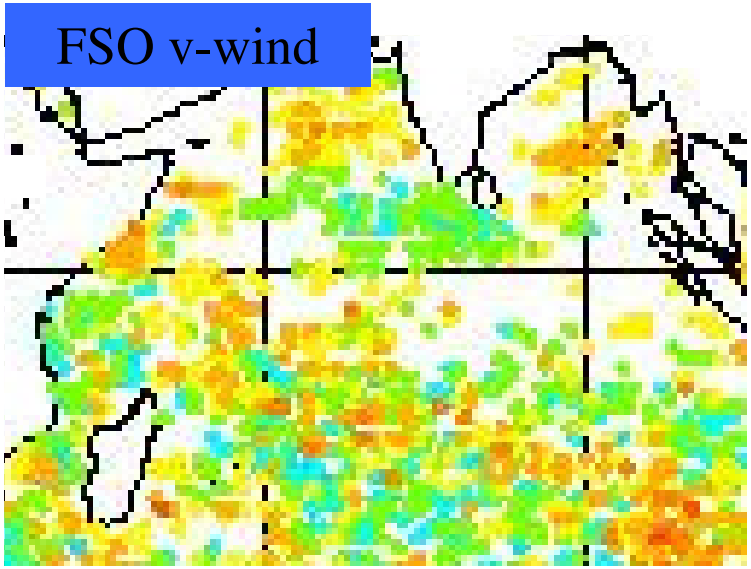
The strong sinking motion in SH near 30S represents the southern limit of the Hadley circulation where the subtropical high cell is located. Cloud suppression or low clouds.

AMV quality affected: it is difficult to assign the cloud top height

courtesy by Fernando Prates

FSO Indian Monsoon Summer 2006: Model bias





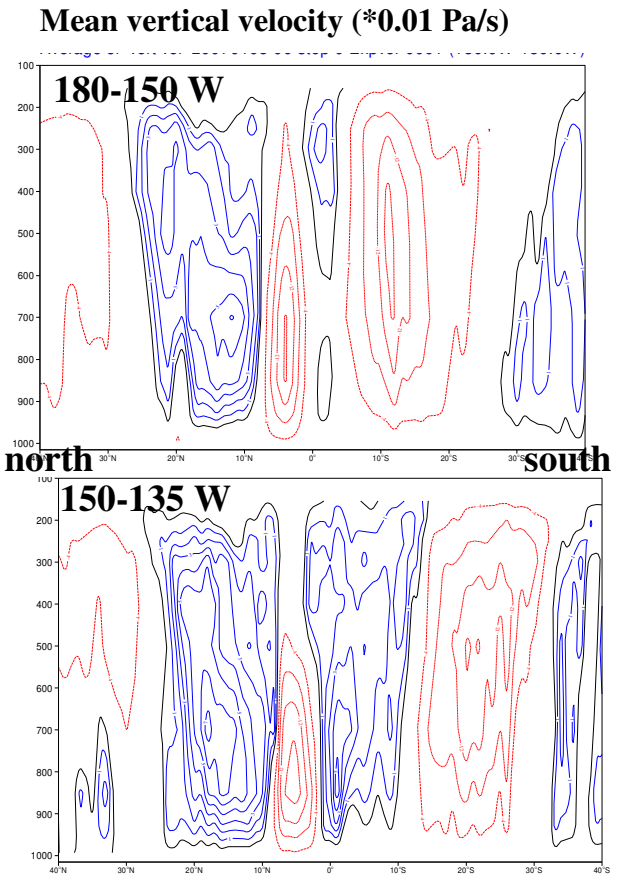
A too strong low level flow of Indian Summer Monsoon is a well known problem in the ECMWF model as is indicated by the June-July-August mean analysis increments

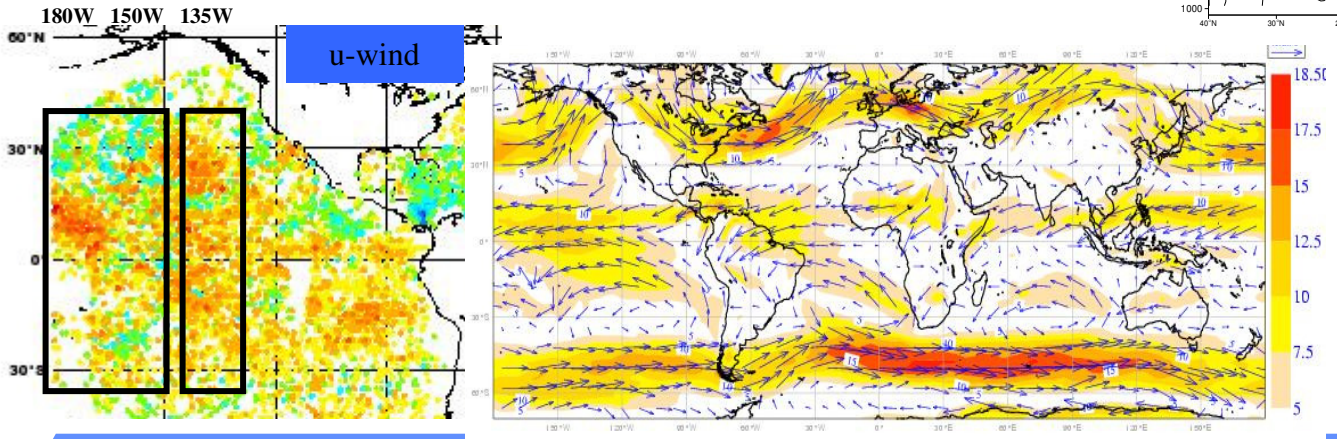
Mean Analysis increments 925hPa JJA 2006

Winter 2007 central/eastern Pacific Cross Section

• The largest negative impact of AMVs to the forecast error is found between 5N - 15N coinciding to a broad downward mean motion of the Hadley circulation.
Large departures were also found below 700hPa in the same region.

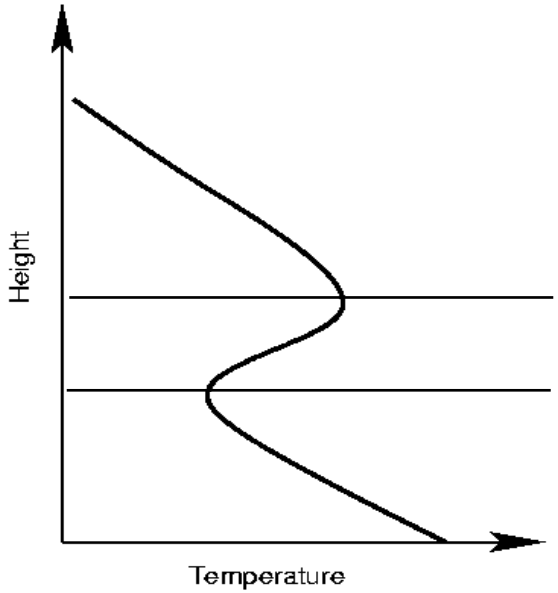
• A second cluster of negative impact near 25N/140W is localized on top of a region of weak winds (strong sinking motion/ high pressure system)





Reassigning low-level AMVs in inversion regions

- For low-level AMVs, EUMETSAT has shown benefits from assigning AMVs to the inversion base, if an inversion is detected in a forecast profile.
- Vertical resolution of ECMWF forecast data used at EUMETSAT is 50 hPa, so the inversion height assignment may be better done within the IFS.
- For GOES, no inversion height assignment is used, and forecast data is coarser.



Inversion base

Conclusions

- FSO method provide us with a useful and economic diagnostic tool. It can make design of OSEs more efficient.
- FSO and OSE give qualitatively similar results
- FSO show that AMVs cause increased forecast error in some regions
- The location of the largest negative impact of the AMVs in Atlantic (Summer 2006) and in pacific (Winter 2007, El Nino) is found close to the region of strong sinking mean motion embedded in the Hadley circulation
  - Observation quality problem due to the height assignment
- Detrimental effect is also observed in the Indian ocean associated with a too strong Indian monsoon circulation developed by the model
  - Model bias likely cause