Use of DFS to estimate observation impact in NWP. Comparison of observation impact derived from OSEs and DFS.

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Outline

- Evaluation of the North American observing network applied to OSEs performed at the Meteorological Service of Canada
  - Method to calculate the DFS solely from a posteriori statistics
  - Assess the impact of the observing systems on the 4D-Var analyses of the various OSEs for three subregions of North America
  - Comparison of DFS with the observations' impact estimated from OSEs
- Assessing the benefits of assimilating cloud-affected SEVIRI radiances at ECMWF
  - Wind tracing with SEVIRI CSR and Overcast radiances
  - Impact of SEVIRI CSR and Overcast in ECMWF operations
  - Advanced diagnostics: DFS and 24-h forecast error contribution
- Summary

Estimation of the DFS

- Estimate of the information content is based solely on diagnostics from the assimilation process

$$\mathrm{d}_o^b = \mathrm{y} - \mathrm{Hx}_b \quad \mathrm{d}_a^o = \mathrm{y} - \mathrm{Hx}_a \quad \mathrm{d}_a^b = \mathrm{H}(\mathrm{x}_a - \mathrm{x}_b) = \mathrm{HKd}_b^o$$

$$DFS = tr(\mathrm{S}) = E\left[\mathrm{d}_b^{a\,T} \widetilde{\mathrm{R}}^{-1} \mathrm{d}_a^o\right]$$ (Lupu *et al.*, 2011)

- Case with consistent error statistics $DFS = E\left[\mathrm{d}_b^{a\,T} \mathrm{R}^{-1} \mathrm{d}_a^o\right]$

- Case with inconsistent error statistics

$$DFS = E\left[\mathrm{d}_b^{a\,T} \widetilde{\mathrm{R}}^{-1} \mathrm{d}_a^o\right] \cong E\left[\frac{\mathrm{d}_b^{a\,T} \mathrm{d}_a^o}{\widetilde{\sigma}_o^2}\right]$$

$$E\left[\mathbf{d}_a^o (\mathbf{d}_b^o)^T\right] = \widetilde{\mathbf{R}} = \mathbf{R}\mathbf{D}^{-1}\widetilde{\mathbf{D}}$$

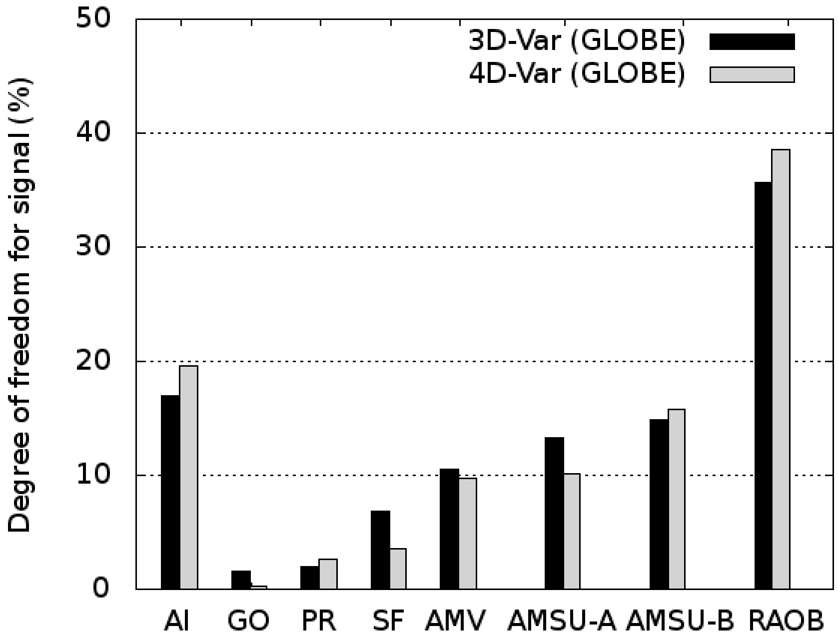
(Desroziers, 2005)

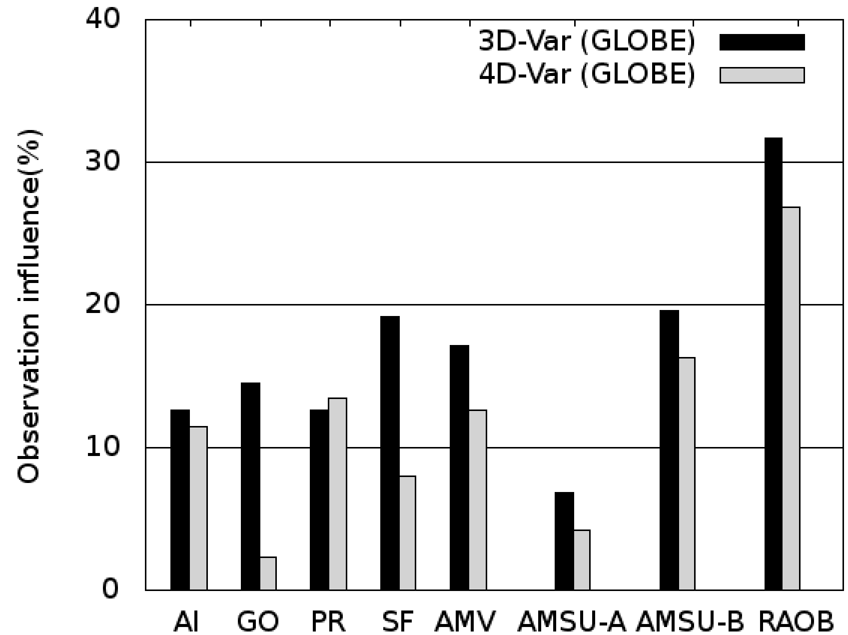
Data assimilation and forecast system

- Analysis scheme 4D-Var (6-h window) and 3D-Var (FGAT)
- Inner loop resolution T108 (180km); Outer loop resolutions: 100km and 33km;
- Observations assimilated at MSC in winter (Jan. and Feb. 2007) (Laroche and Sarrazin, 2010)

Network	Variables	Thinning
radiosondes/dropsondes	U, V, T, (T-T_d), p_s	28 levels
Surface reports (SYNOPS, SHIPS, BUOYS)	T, (T-T_d), p_s, (U, V over water)	1 report/6h
Aircraft (BUFR, AIREP, AMDAR, ADS)	U, V, T	1^o x 1^o x 50 hPa
ATOVS NOAA 15-16-17-18, AQUA	Ocean / Land AMSU-A: ch 4-10 / ch 6-10 AMSU-B: ch 2-5 / ch 3-4	250 km x 250 km
Water vapor channel GOES 11-12	IM3 (6.7 m)	2^o x 2^o
AMV (Meteosat 5-7-8, GOES 11-12, MTSAT-1R**)**	U,V (IR, WV, VI channels)	1.5^o x 1.5^o
MODIS (Aqua, Terra)	U,V	1.5^o x 1.5^o
Wind Profilers (NOAA Network)	U,V	(750 m) Vertical

Computation of DFS and OI for each type of observations in MSC's 3D-Var and 4D-Var systems



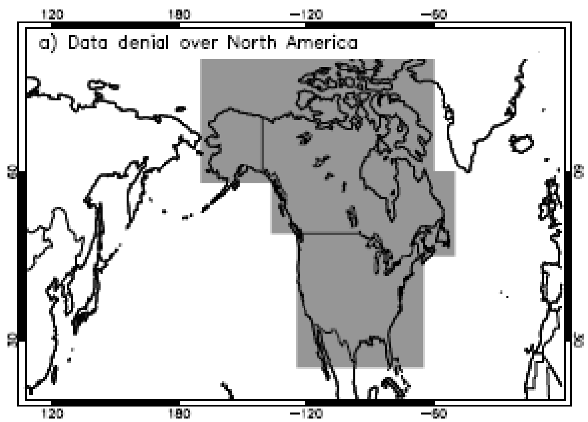


- The observation influence is larger for the RAOB data in both 3D- and 4D-Var; all other observations have less impact;
- AMSU-B data have a mean influence larger than AMSU-A data;

Latest upgrade (16/11/2011) include new data sources for the assimilation (see L. Garand talk): IASI (62 channels); SSMIS from DMSP-16 (over oceans); CSR from all 5 geostationary satellites; AIRS; Humidity data from aircraft. Other improvements include : Reduced horizontal thinning for all satellite radiance observations (150km); New SST analysis; Reduced background errors near the model top; Improved QC for AMV's and unified radiance bias correction scheme.

Observing System Experiments

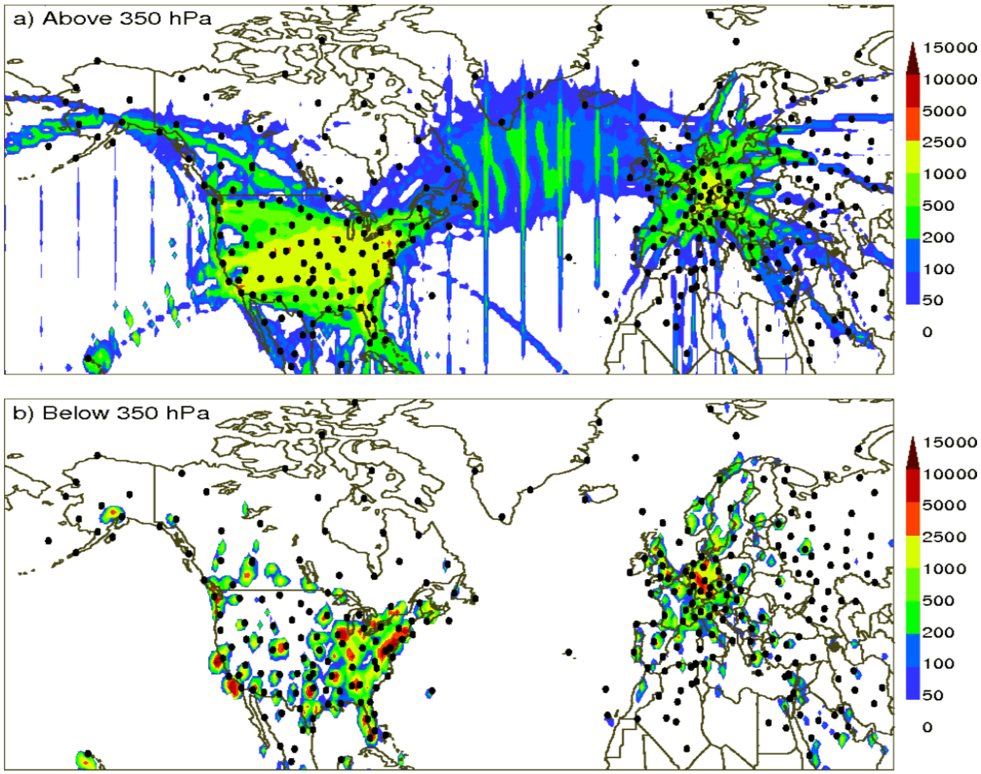
- Evaluation of the North American observing network through data denials experiments (Laroche and Sarrazin, 2010 a,b)
  - Take an analysis using all observations as a reference (CTRL) and then remove one observation type and measure the degradation

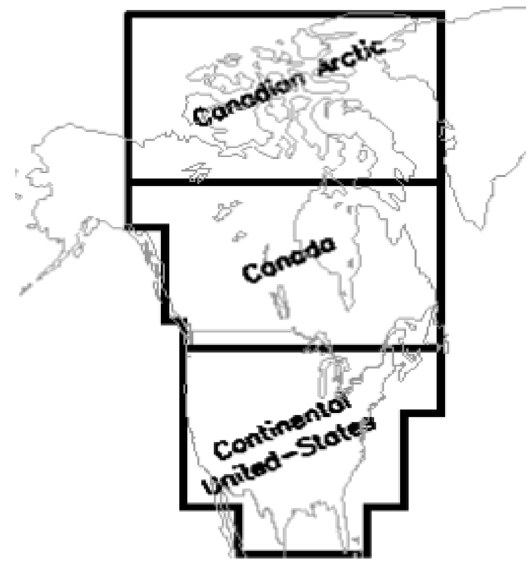


NO_RAOB: exclude all RAOB and PR data over North America
NO_AIRCRAFT: exclude all AI reports over North America
NO_ASC/DESC: exclude AI between the ground and 350 hPa
NO_RAOB+NO_AIRCRAFT

- How the absence of an observing system affect the information content supplied by different observation types to an analysis?
  - Comparison of the information content for these experiments gives a detailed view of the interactions between observations

Aircraft reports assimilated during winter 2007 and radiosonde stations (black dots)

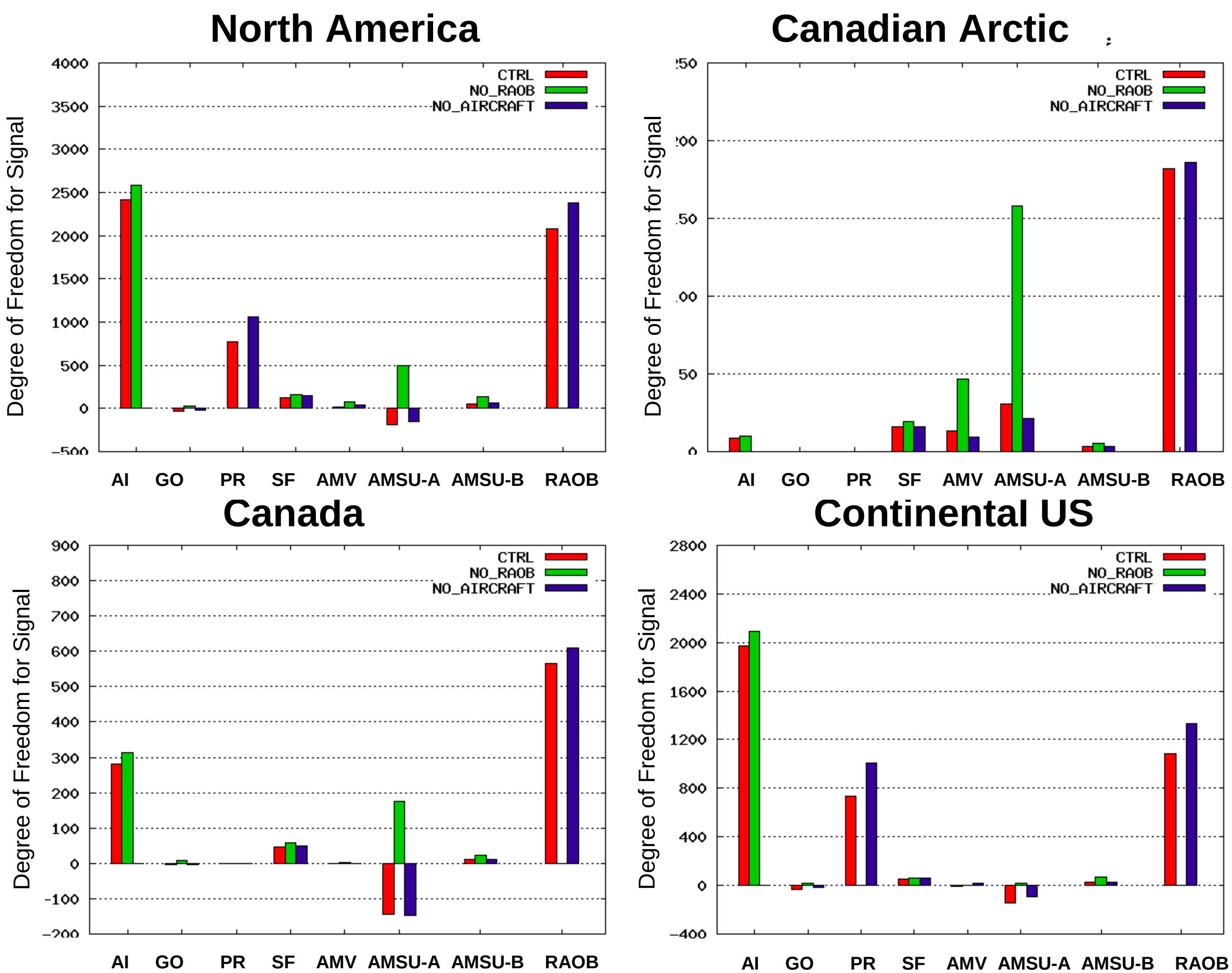




CanArc: radiosonde network has a low density and only a very small nb. of AI data from commercial aircraft were available;

Over Canada and continental US, the analyses are controlled by RAOB and AI data because of the higher density of the radiosonde network and the larger number of AI reports over this regions.

Observation impact estimated from DFS in OSEs



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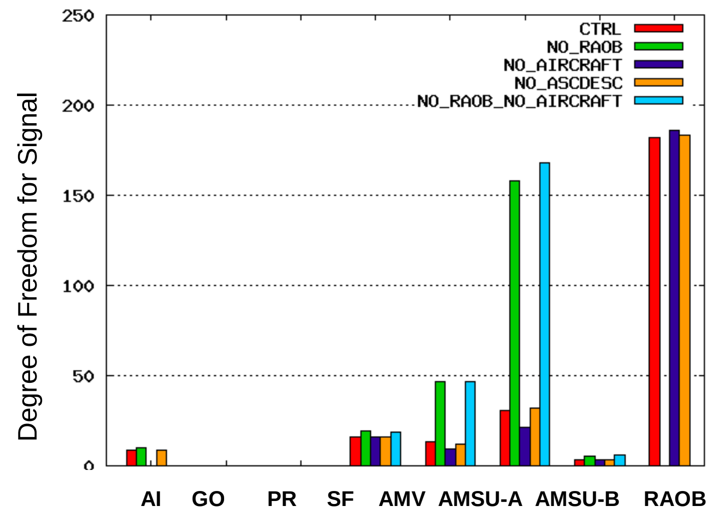
Observation impact estimated from DFS in OSEs

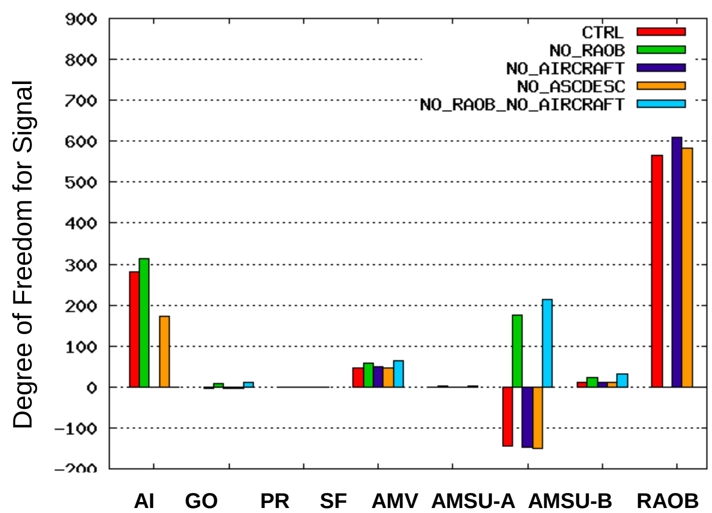
Over Canada and US, the DFS of ascent/descent AI reports, alone account for 40% of the impact of all AI data.

Relatively weak DFS of RAOB over US is explained by its collocation with profiling AI data.

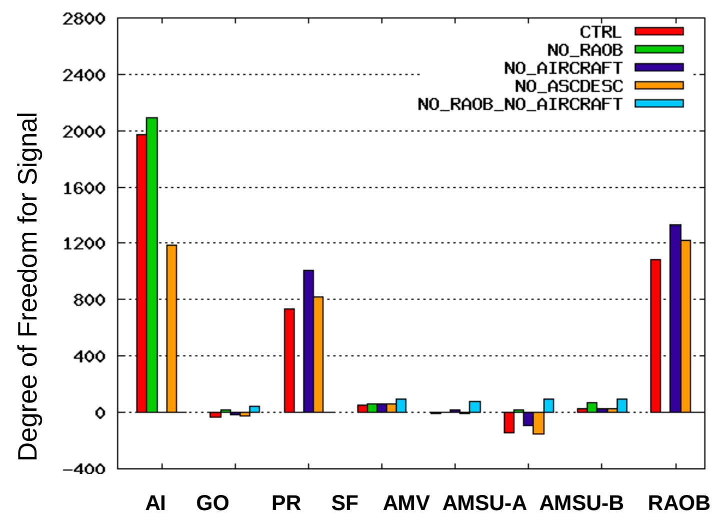
Canadian Arctic



Canada



Continental US



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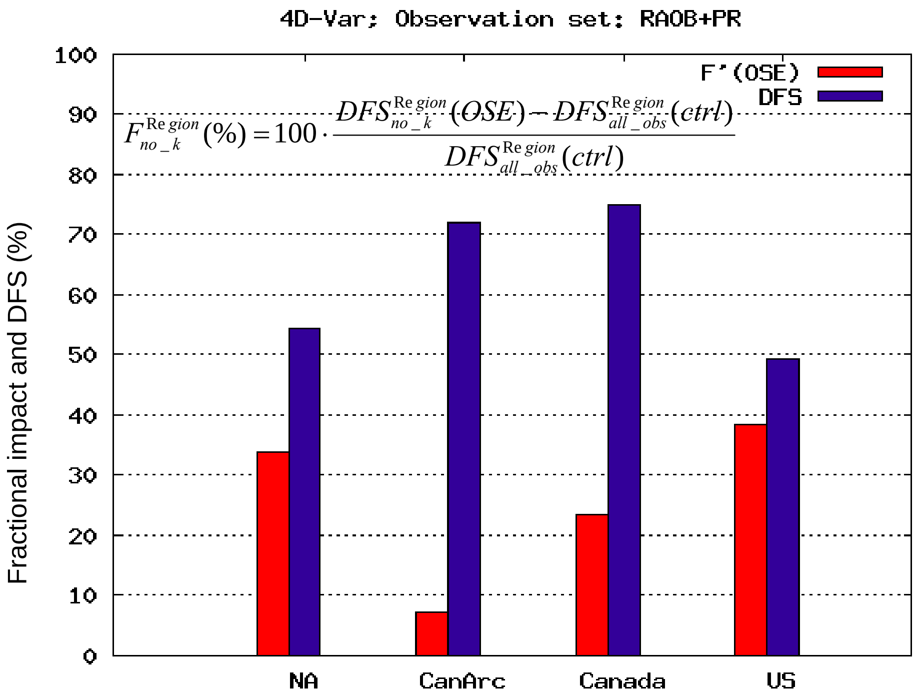
Interdependency of observing systems

DFS can be useful for assessing the complementarity and redundancy of observing networks.



Significant compensation for the loss of RAOB+PR over Canada and Canadian Arctic where RAOB data are the most informative data source:

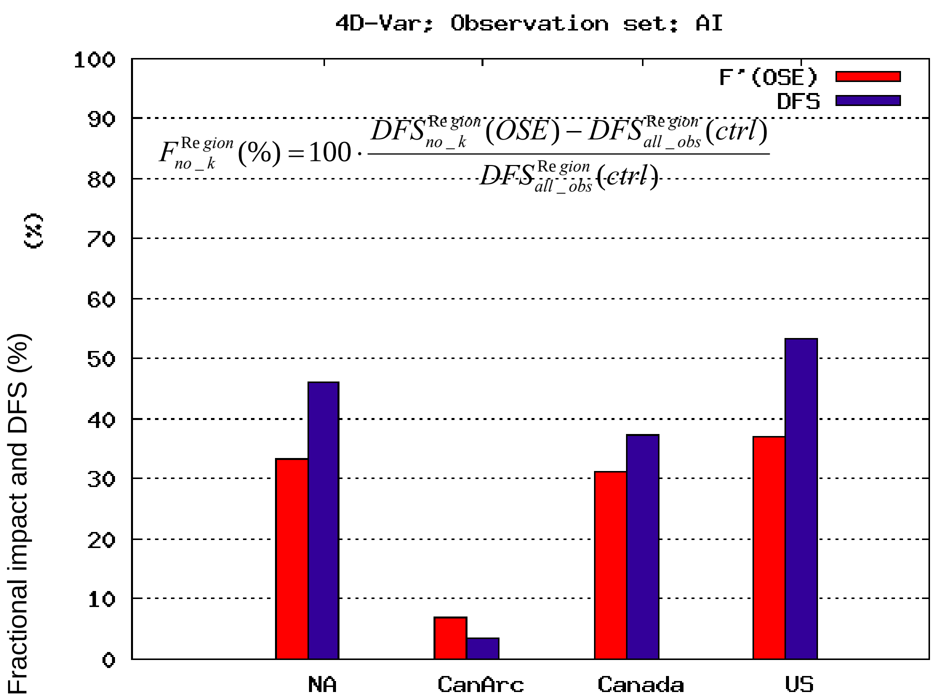
AMSU-A and AMVs MODIS winds have the most important compensation over CanArc;
AMSU-A and AI compensate over Canada;

Less significant compensation for the loss of RAOB+PR over continental US and North America

Over the continental US and North America the DFS is smaller, mainly because in these regions AI data are at least as informative as RAOB data.

Interdependency of observing systems

DFS can be useful for assessing the complementarity and redundancy of observing networks.



DFS for AI data is dominant over the continental US, mainly because of the larger number of AI data over this region.

DFS for AI data is small over the CanArc where the analysis relies on the radiosonde network.

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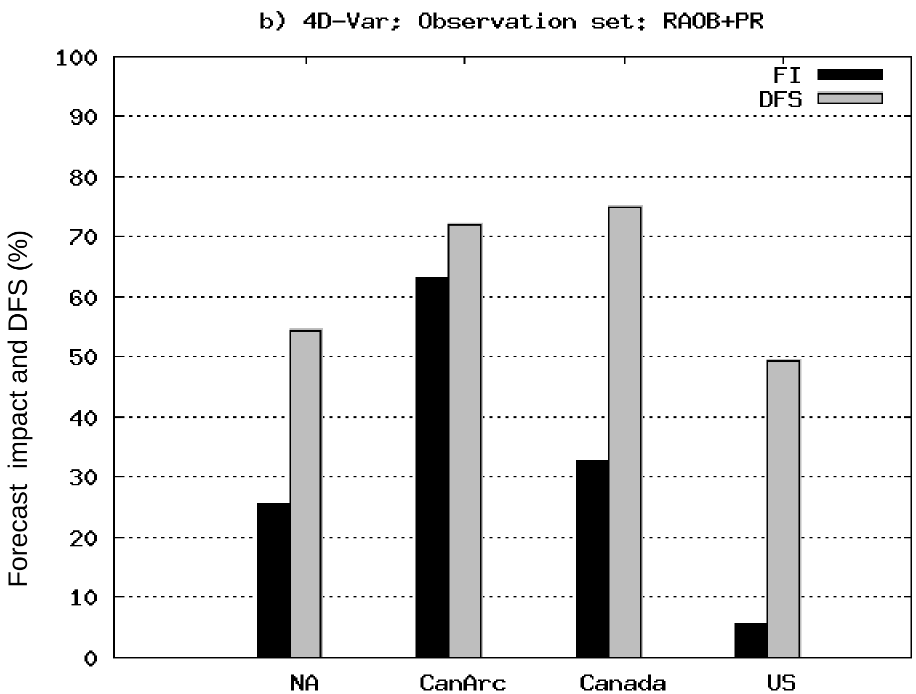
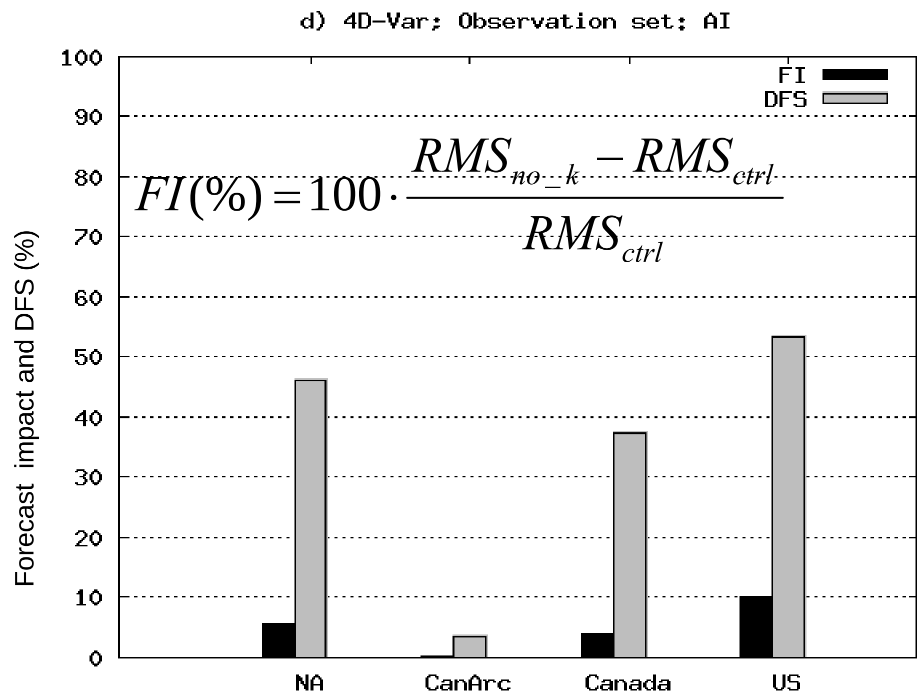
Comparison of observation impact estimated from OSEs and DFS

Evaluate how the forecast impact (500 hPa geopotential heights for the 12-h forecast) from the OSEs agree well with the observation impacts deduced from the DFS diagnostics. Positive FI score means that the forecast quality is improved when denied dataset is assimilated.





FI: Large positive impact of RAOB+PR over CanArc and Canada and a smaller positive impact over the continental US;The positive impact of AI data over US is larger than that of RAOB, while is the oposite over the Canada and CanArctic.

Variation of DFS percentages and FI from one region to another agrees better for AI data;

Summary

- Evaluation of the information content of observations can be obtained from simple diagnostics using information generated by any assimilation system.

- The response of the remaining observations when a given set of observations is denied was illustrated comparing DFS calculations with the fractional impact.

  Over all regions of NA the values of DFS are larger than those obtained for the fractional impact. The difference between these values is attributed to the fact that the remaining data types compensate for the loss of denial data.

- On the short range forecast DFS and OSEs provide somewhat comparable assessment of the impact of RAOB or AI observations.

Assessing the benefits of assimilating cloud-affected SEVIRI radiances at ECMWF

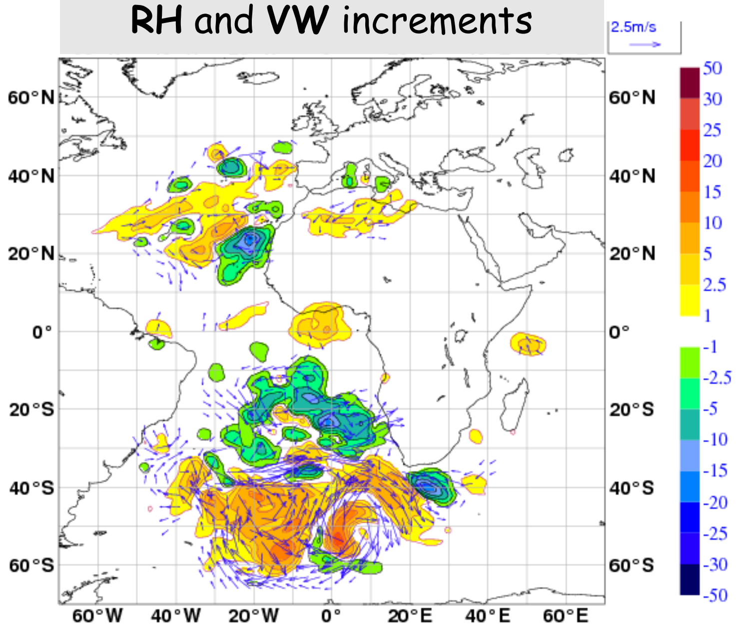
Wind tracing with SEVIRI CSR and OVERCAST radiances

ECMWF

Motivation

- WV Clear-sky radiances (CSR) from geostationary satellites provide humidity information in the middle and upper troposphere;
- CSR influence the wind fields via *humidity tracer advection* induced by 4D-Var (Peubey and McNally, 2009);

RH and **VW** increments



In 4D-Var, a humidity increment due to the assimilation of humidity sensitive radiances will be accompanied by an increment in temperature and wind;

Any changes to the humidity field, will result in the adjustements to other variables (for example, the wind field can be changed to advect humidity to and from other areas).

SEVIRI CSR leads to an improvement in ECMWF's 4D-Var wind analyses throughout the troposphere, with the strongest signal at 300 hPa and 500 hPa.

Objective

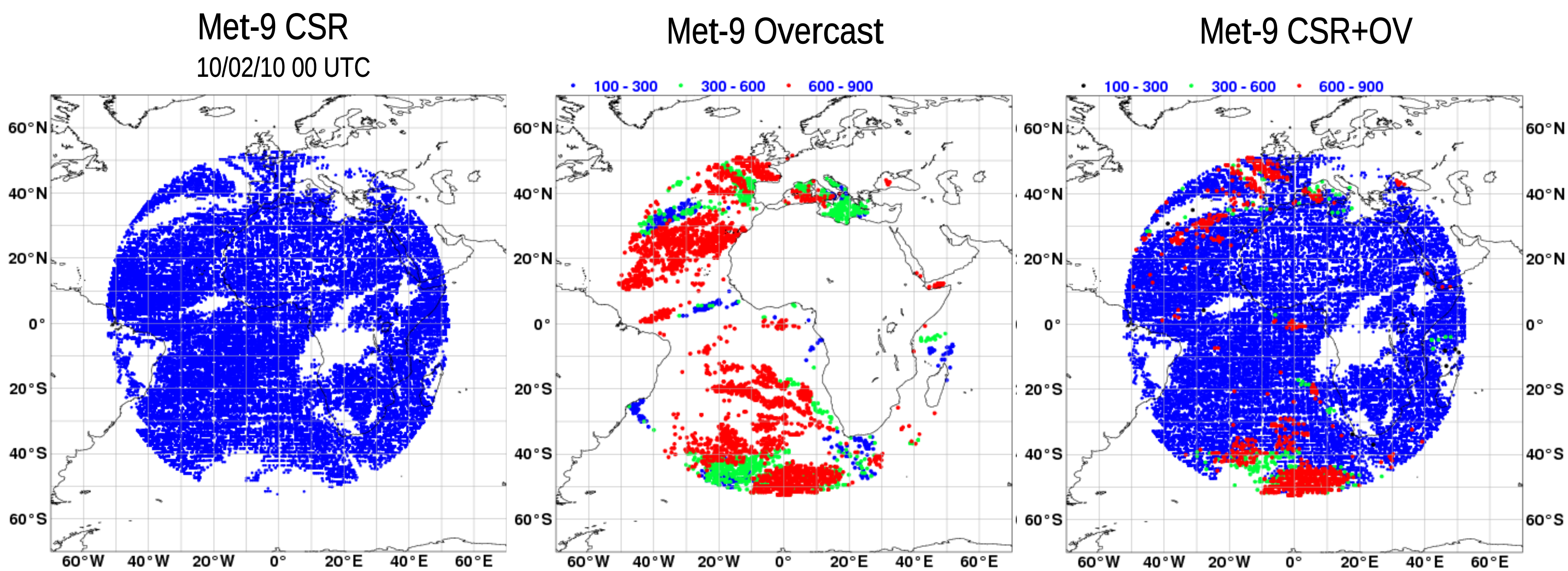
- Extend the humidity tracing capability to cloudy regions - to obtain an all-sky constraint on the atmospheric wind field with geostationary radiances.

- Exploit geostationary radiances in cloudy conditions in a similar manner to those of IR sounders on polar orbit;

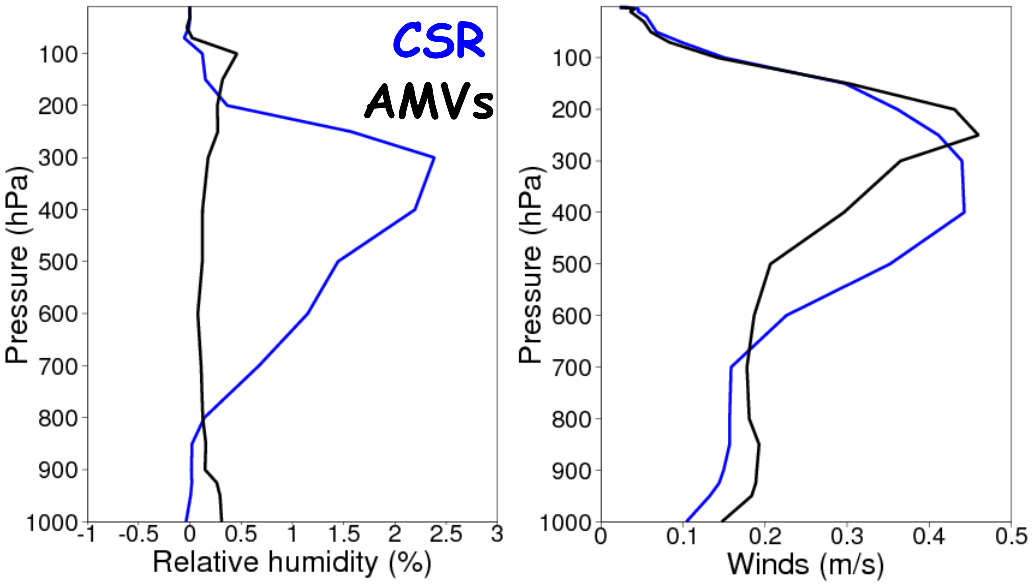
- Simplified overcast approach (McNally, 2009): clouds treated as a single-layer emitter characterized by cloud top pressure and effective cloud fraction; The cloud parameters are simultaneously estimated together with T and RH inside the main analysis;

Wind tracing with SEVIRI CSR and overcast radiances

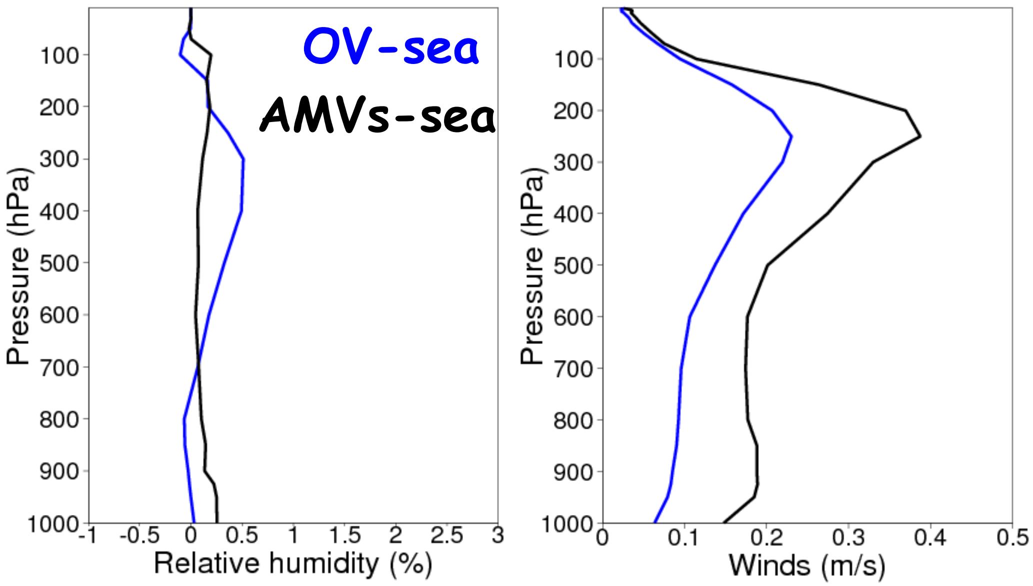
- CSR, OV, CSR+OV and AMVs from SEVIRI were each added to a Base experiment which uses a baseline system with conventional observation only. All experiments were run at T511L91 (12-hour 4D-Var), 10th February – 10th March 2010;
  - Quantify the magnitude of each of the CSR, overcast (OV) and CSR+OV wind impact on isolation and compare results with the cloudy AMVs wind impact.
  - The analysis impact of each datasets is shown in terms of the root-mean-square of wind speed increments differences with respect to the Base, averaged inside Meteosat-9 disc over 1-month period;



Analysis impact: SEVIRI CSR and OV vs.cloudy AMVs



- SEVIRI CSR and AMVs impact is complementary with respect to the magnitude of wind increments and the altitude range at which each observation type has maximum impact (CSR@500hPa; AMVs@200, 850hPa).

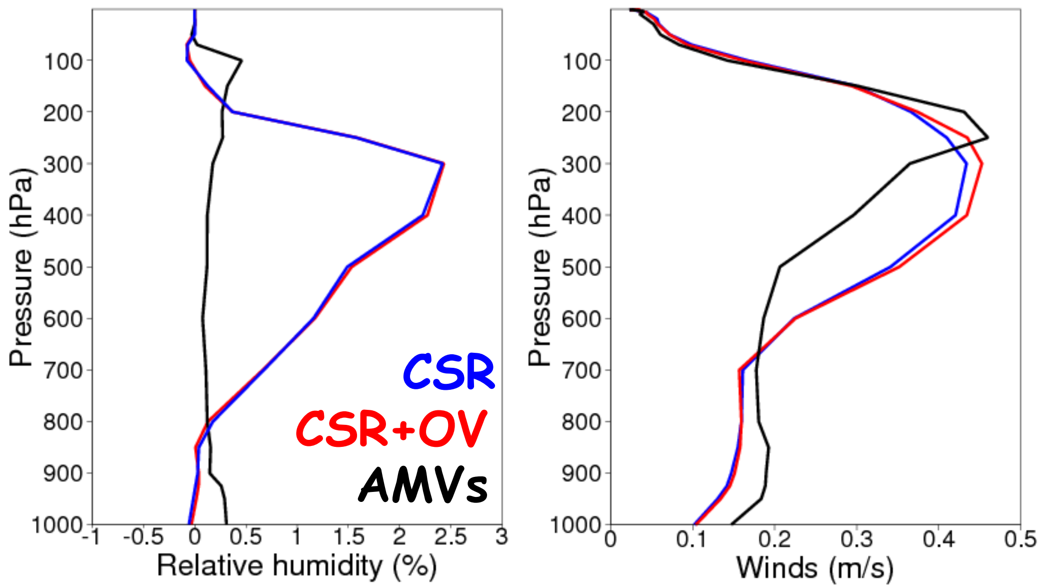


- Wind speed vertical profiles from OVERCAST radiances and AMVs assimilated over sea, are similar in shape, showing a main peak at 250-300 hPa.

- Larger impact of AMVs owing to the large number of AMVs assimilated.

- Relative-humidity changes are only restricted to above the cloud top.

Analysis impact : extend SEVIRI CSR to CSR+OV usage



CSR+OV and CSR wind speed increments are very similar in structure; a larger magnitude with a maximum at 300 hPa is obtained from CSR+OV;

- A 4D-Var assimilation system can derive useful tropospheric wind information from geostationary humidity-sensitive SEVIRI radiances by advecting humidity features to improve the analysis fit to observations.
  - The additional use of overcast data in CSR+OV experiment improves the wind analysis via tracing (maximum impact 300hPa).

ECMWF

Wind analysis scores from SEVIRI observations

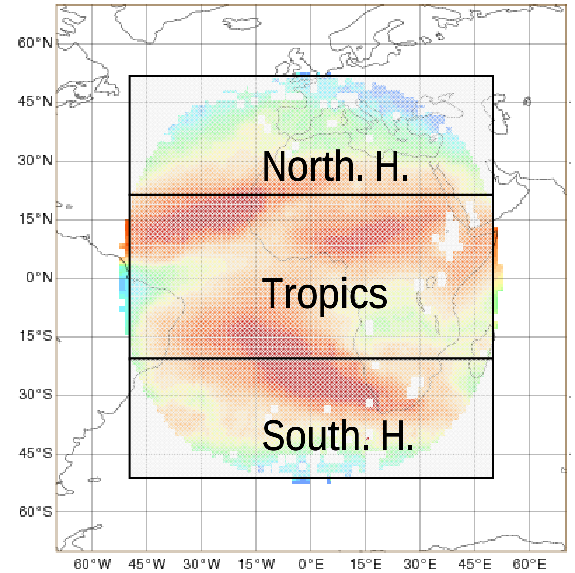
- Wind analysis errors are calculated as departures from the ECMWF operational analysis (T1279L91, full observing system), considered as the best estimate of the true wind field:

$$RMSE_j = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\left(u_i - u_i^r\right)^2 + \left(v_i - v_i^r\right)^2\right]}$$

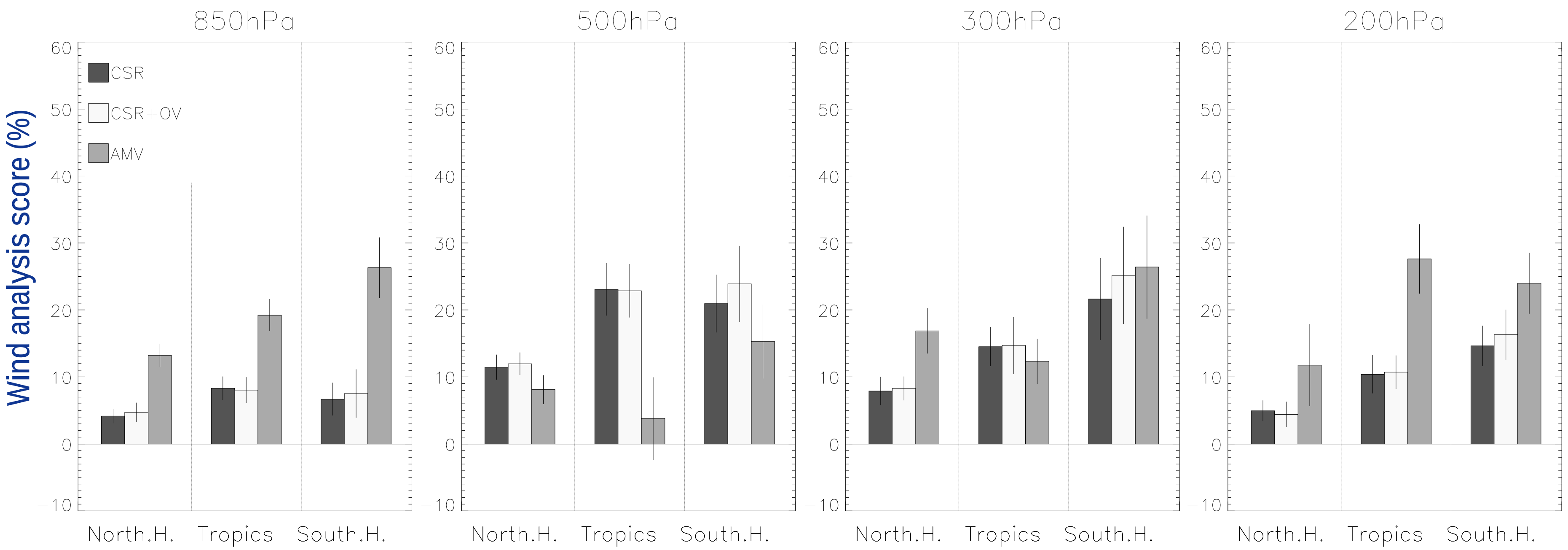
- For each experiment (e.g., CSR, CSR+OV and AMVs) the analysis error is compared to that of Base to provide an "Wind analysis score":

$$\Delta RMSE = \frac{\sum_{j=1}^{m}\left(RMSE_j - RMSE_j^{Base}\right)}{\sum_{j=1}^{m} RMSE_j^{Base}}$$

- An analysis score equal to zero means no improvement over the base, while a value of 100% correspond to an analysis that has no error with respect to the high resolution oper. analysis;



Wind analysis scores from SEVIRI observations



- CSR+OV have a large positive impact on wind analyses than CSR over the South. H.;
- Over North. H. and Tropics, the number of overcast scenes assimilated is limited and wind analyses only get benefits from the CSR assimilation;

Impact of SEVIRI CSR and overcast in ECMWF operations

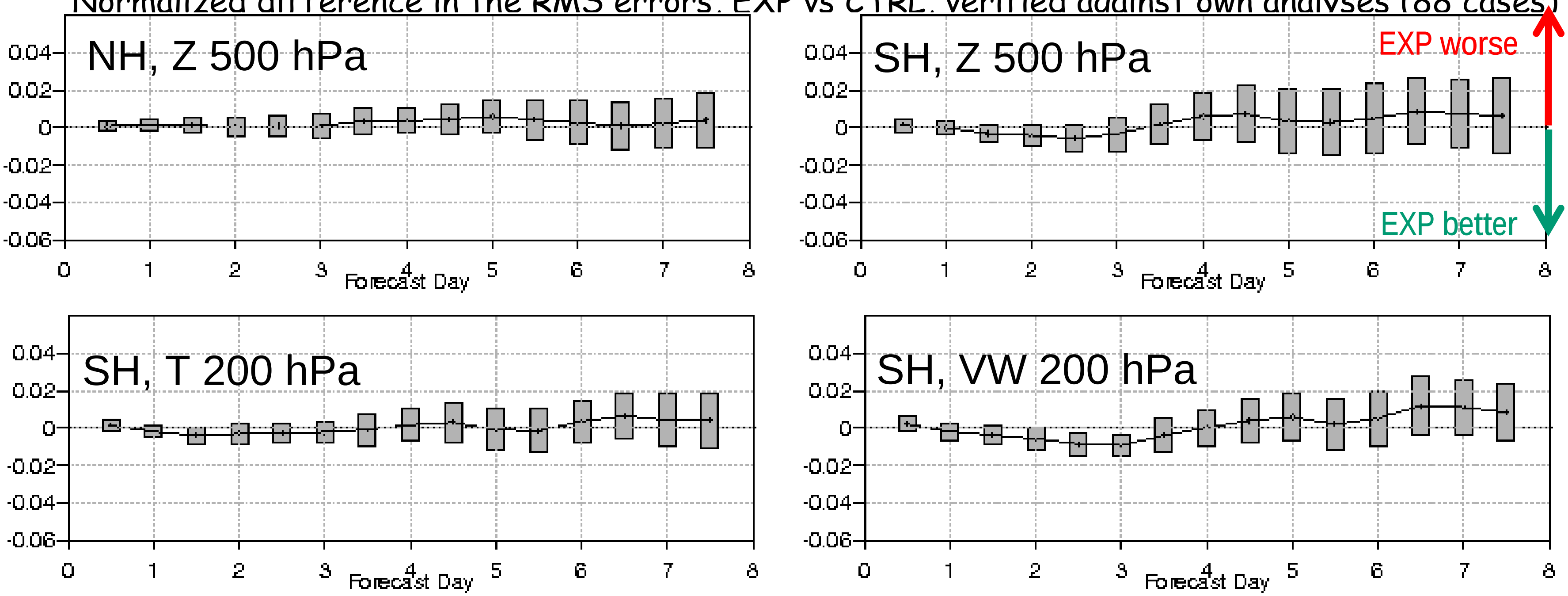
Full System Experiments: T511L91, 1 January – 29 March 2011

CTRL : CY37R3 full operational system with Met-9 WV CSR

EXP : CY37R3 full system with Met-9 WV Clear-sky and Overcast Radiances

The forecast impact on the Z 500 hPa is neutral with Meteosat-9 CSR+OV ;
The VW forecast error in the upper troposphere in the SH are reduced;

Normalized difference in the RMS errors, EXP vs CTRL, verified against own analyses (88 cases)



Monitoring the assimilation and forecast system performance

Sensitivity of the analysis with respect to the observations:

$$\frac{\partial \mathbf{x}_a}{\partial \mathbf{y}} = \mathbf{K}^T \Rightarrow OI = (\mathbf{HK})_{ii}$$

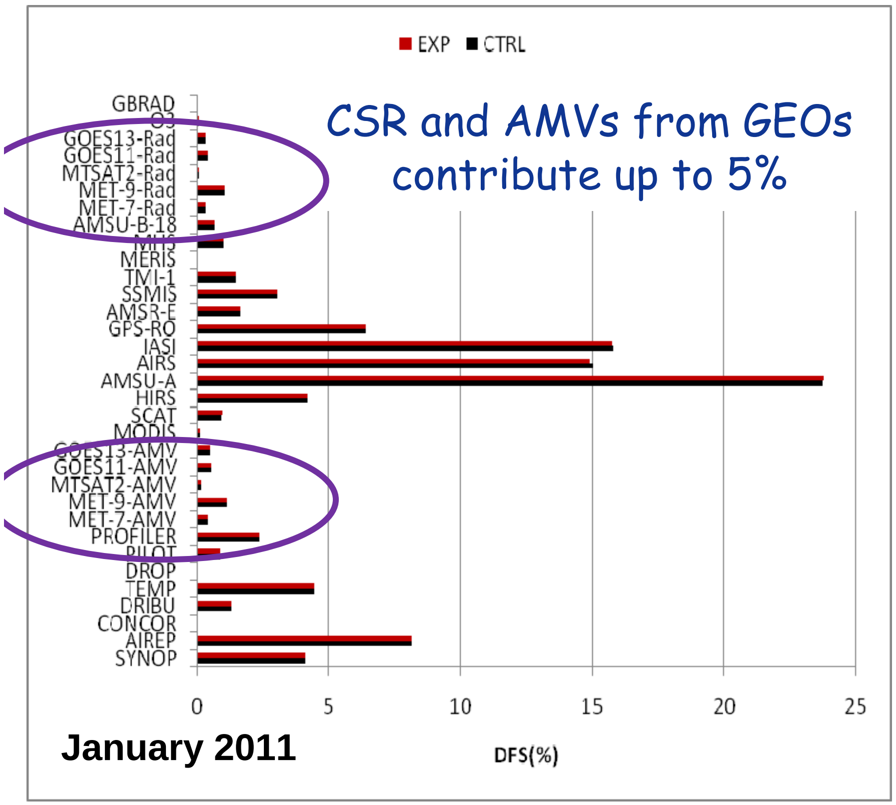
Cardinali et al., 2004

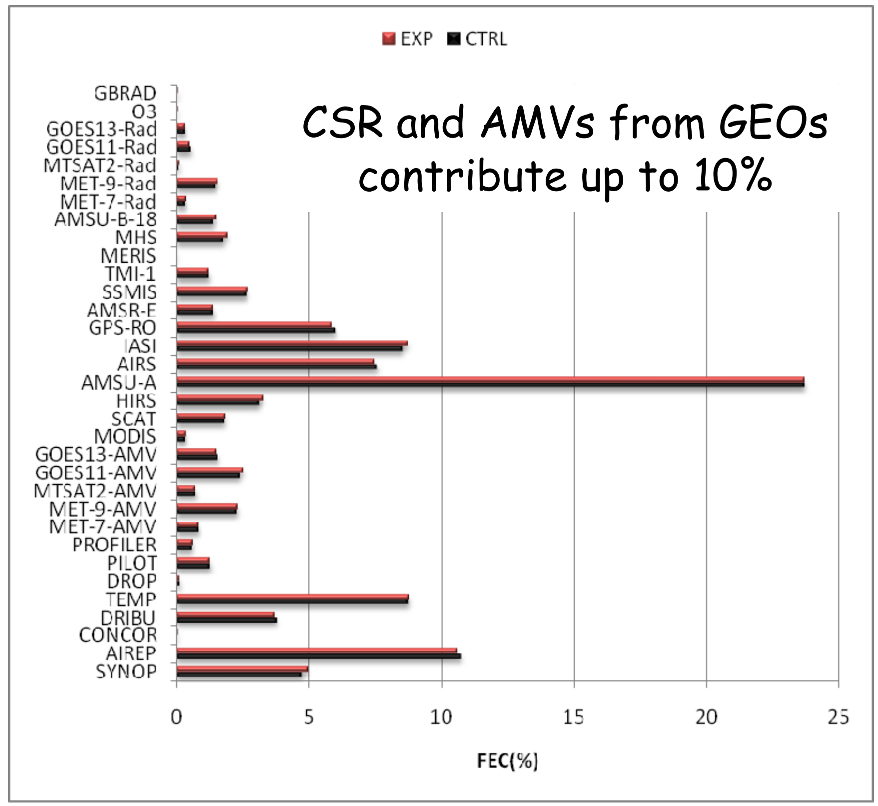
$$DFS = tr(\mathbf{HK})$$

Forecast sensitivity to observations:
J_e measure of the forecast error, e.g. Energy norm

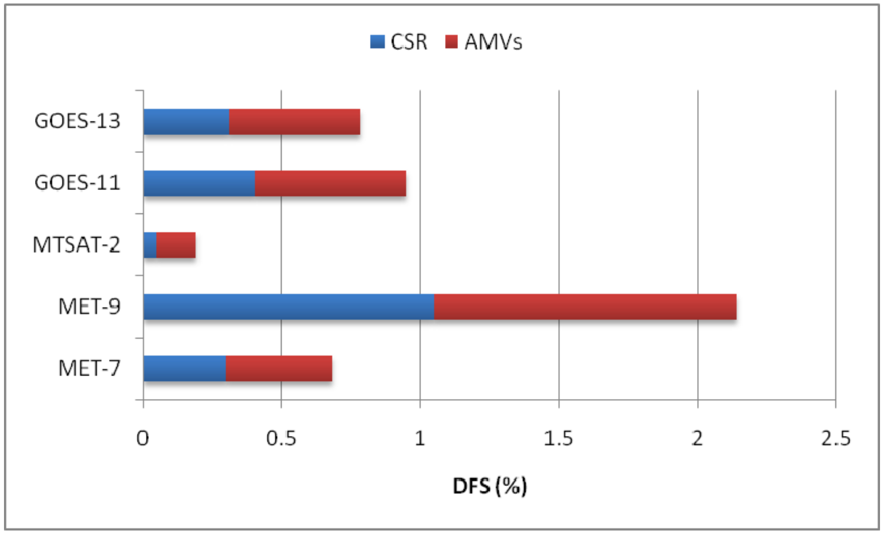
$$\delta J_e = \frac{\partial J_e}{\partial \mathbf{y}}(\mathbf{y} - \mathbf{H}\mathbf{x}_b)$$

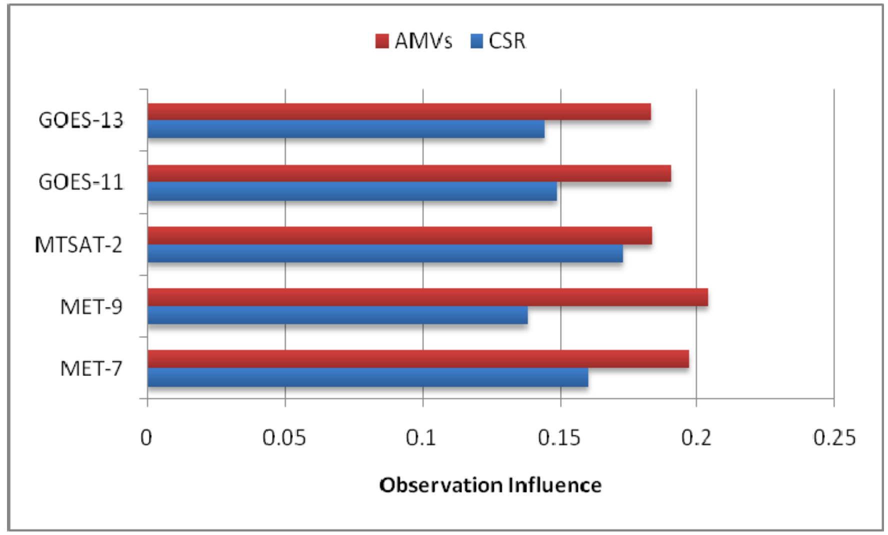
Langland and Baker, 2004; Cardinali, 2009

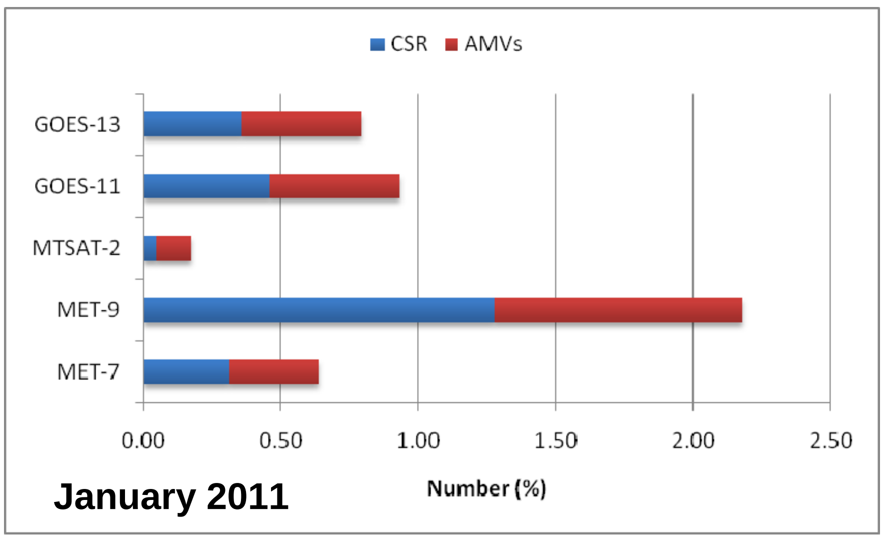




GEO satellites: DFS in the CTRL analysis





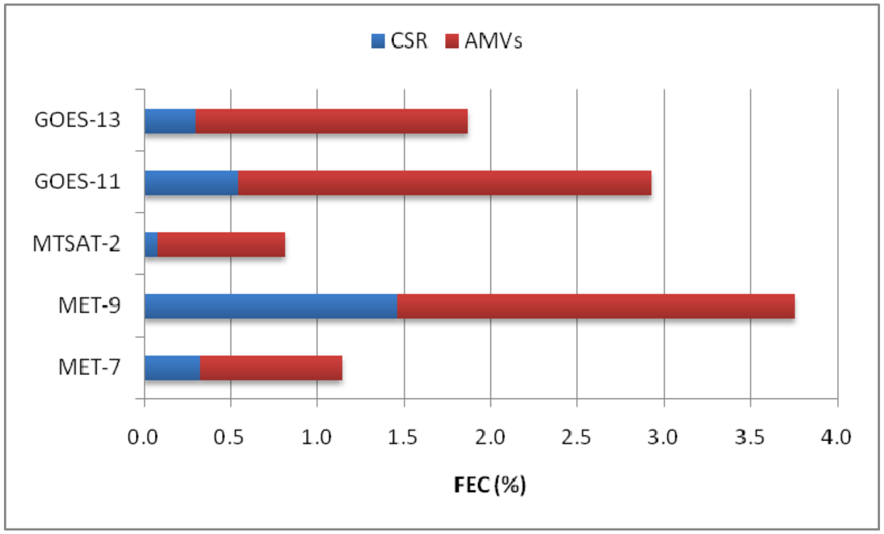


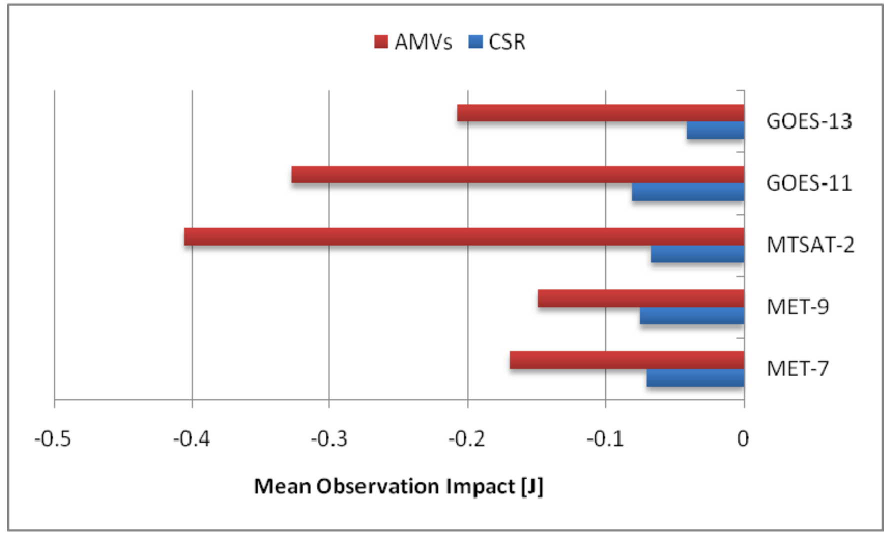
Met-9 show the strongest DFS among GEO satellites and this is due to the large nb. of observations assimilated;

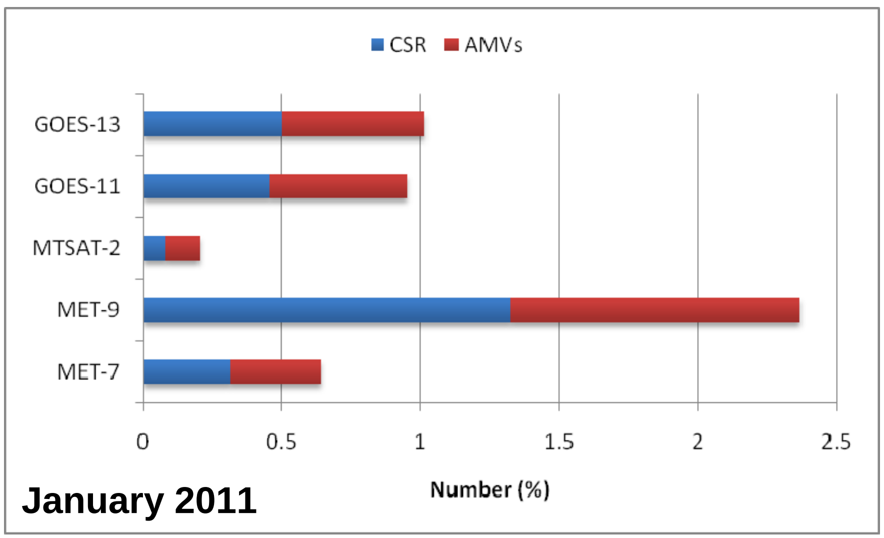
The CSR and AMVs observation influence show quite similar values for all GEO sat.;

AMVs observation influence is larger than the CSR observation influence;

GEO satellites: Forecast sensitivity to observations (CTRL)



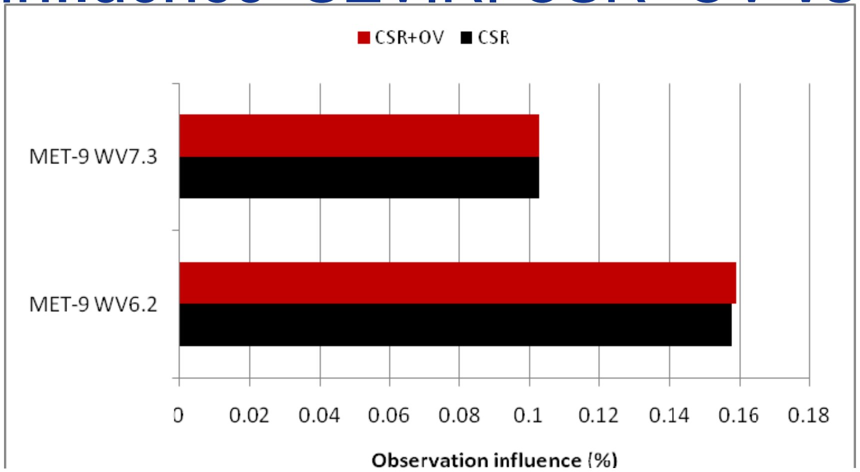


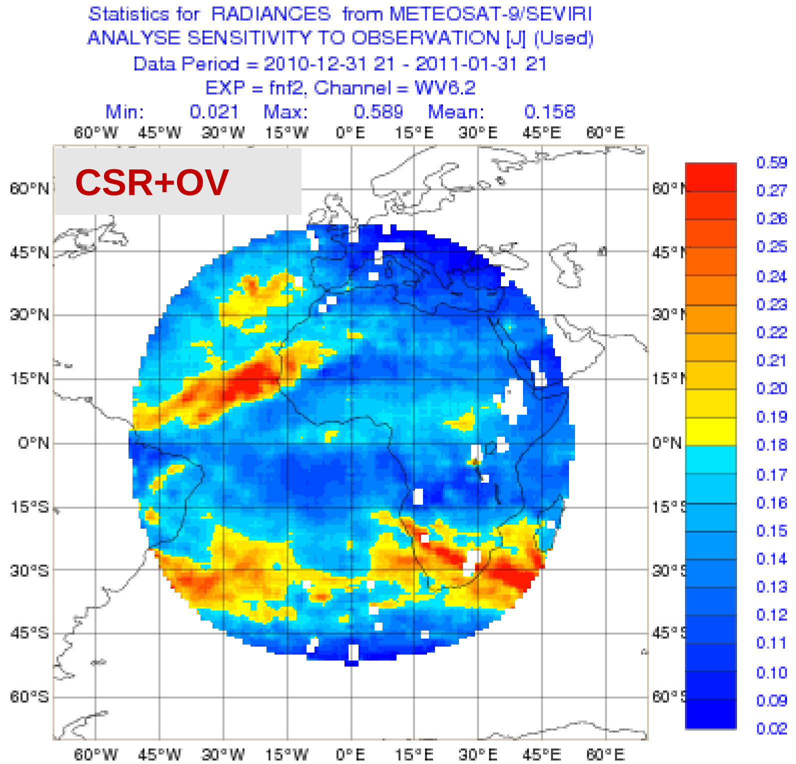


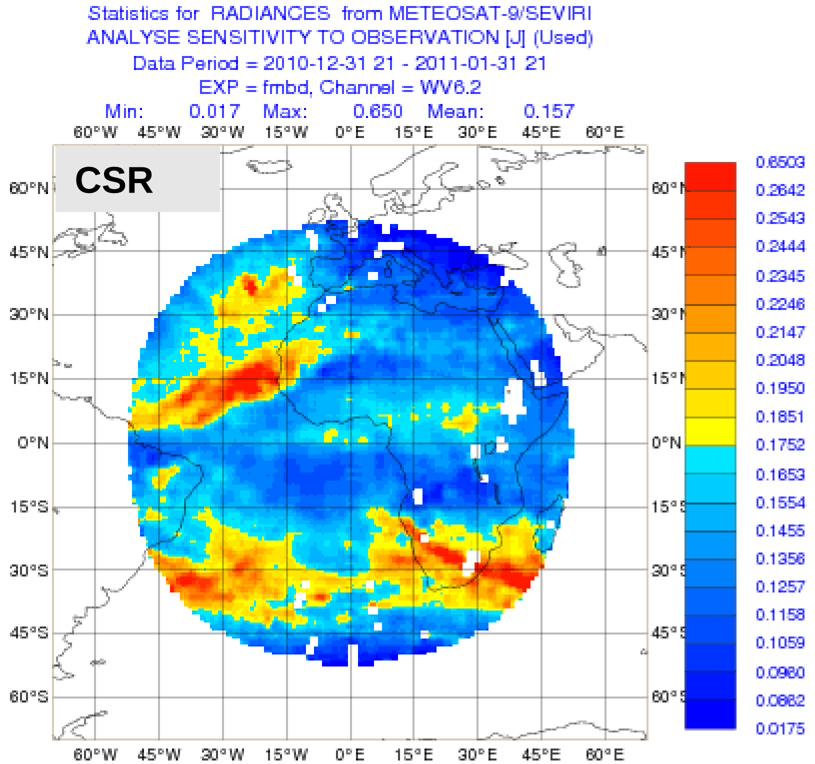
Met-9 is measured as having the largest contribution to the decrease of 24-h forecast error contribution.

AMVs mean observation impact is larger than the CSR mean observation impact;

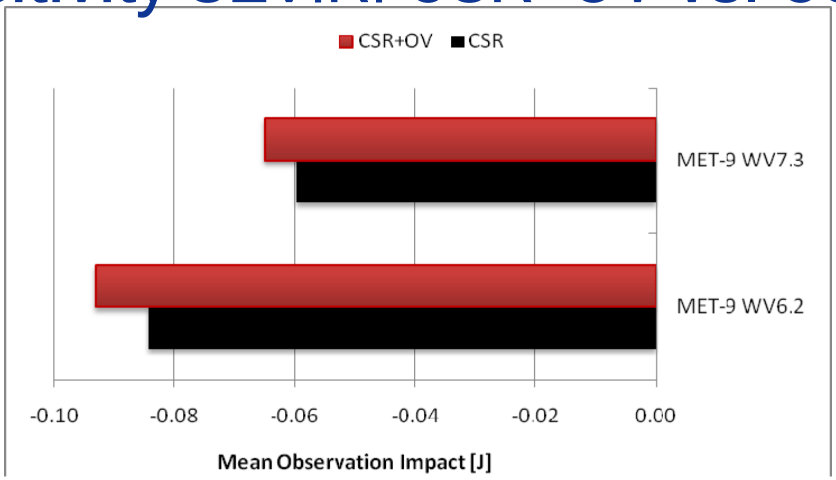
Observation Influence SEVIRI CSR+OV vs. CSR

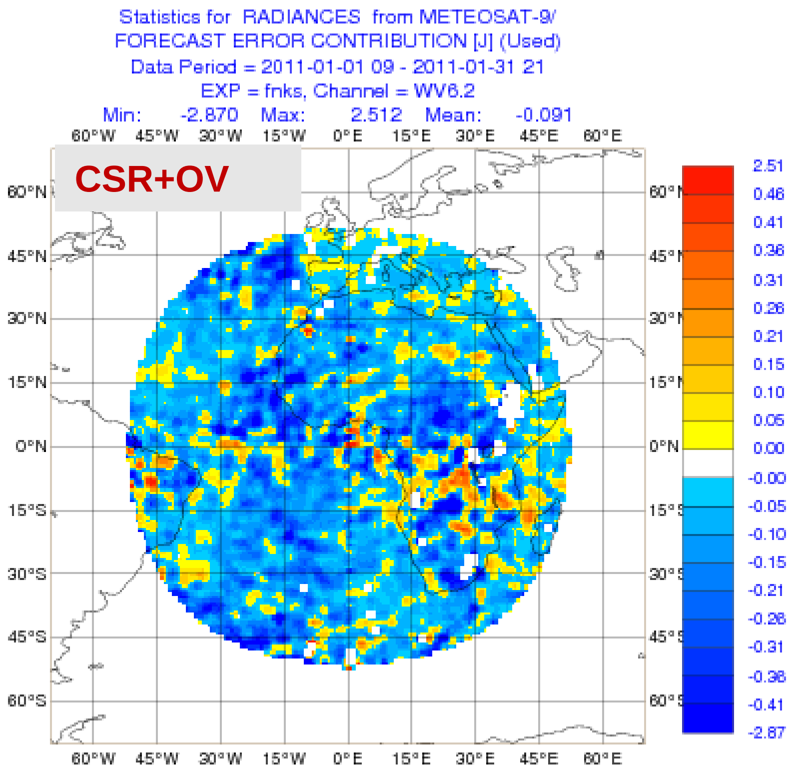


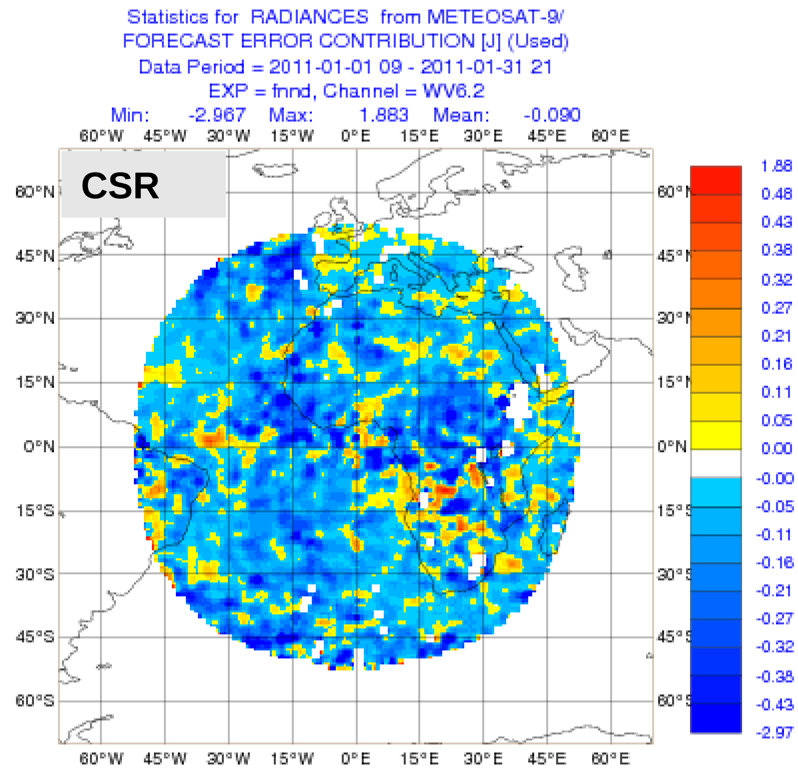




Forecast sensitivity SEVIRI CSR+OV vs. CSR







Summary

- **A 4D-Var assimilation system can derive useful tropospheric wind information from geostationary humidity-sensitive SEVIRI radiances by advecting humidity features to improve the analysis fit to observations.**
  - SEVIRI CSR and AMVs impact is complementary with respect to the magnitude of wind increments and the altitude range at which each obs. type has maximum impact;
  - SEVIRI OV and AMVs impact show a very good agreement with a maximum impact in the upper troposphere (250-300 hPa).
  - The additional use of overcast data in CSR+OV experiment improves the wind analysis via tracing (maximum impact 300hPa).
  - **In the context of no-satellite baseline experiment, CSR+OV have a positive impact on wind analyses through the troposphere, with better performance than CSR over the Southern Hemisphere.**

  - **WV CSR+OV from Meteosat-9 will be operational assimilated at ECMWF with CY38R1 (June 2012).**

  - **The ranking of 24-h forecast error contribution from geostationary satellites is led by Met-9; the largest contribution comes from the combined CSR+OV rad**

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Thank you !

Questions ?