Data assimilation diagnostics: Assessing the observations impact in the forecast

Cristina Lupu

cristina.lupu@ecmwf.int

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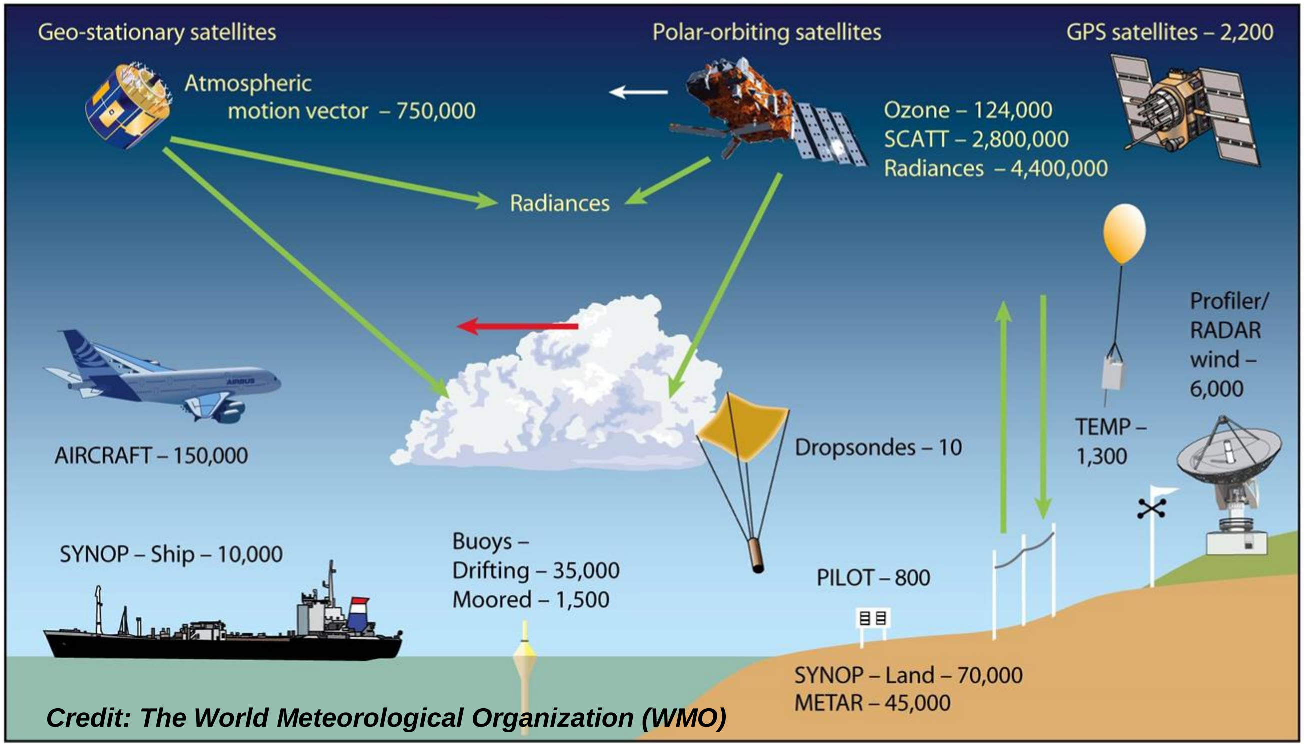
The Global Observing System Network

- ECMWF 4D-Var data assimilation system is assimilating ~10^7 observations per a 12-h assimilation window;



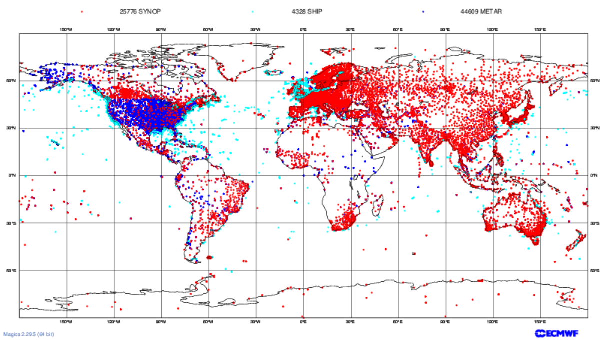
Credit: The World Meteorological Organization (WMO)

- Conventional observations
  - Surface-based
  - Upper-air

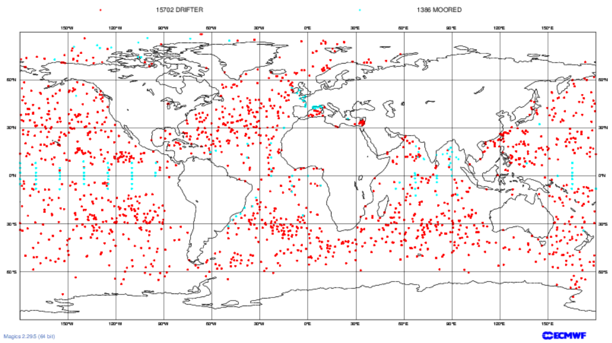
- Satellite observations
  - Infrared (IR) and Microwave (MW) radiances from polar and geostationary satellites
  - AMVs
  - Radio occultation (GPS-RO)
  - Scatterometer
  - Other (ozone, etc)

Data sources : Conventional observations

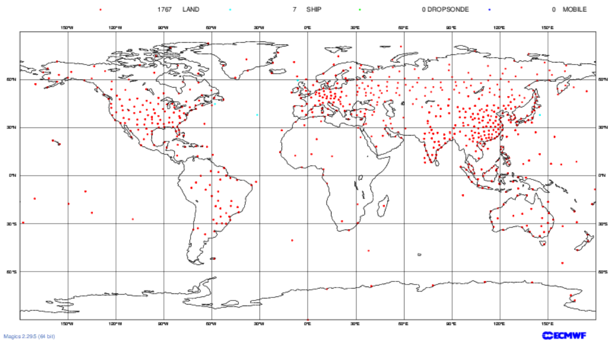
SYNOP-SHIP- METAR



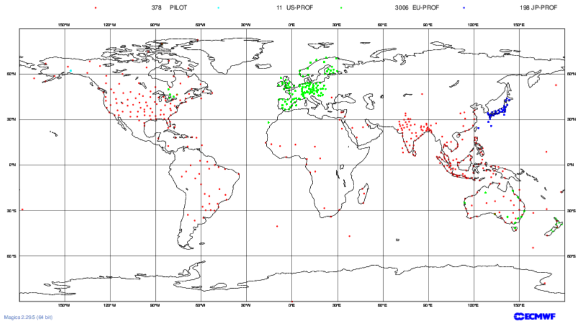
BUOY



TEMP

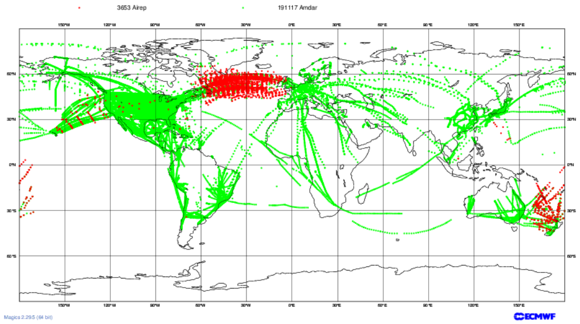


PILOT - PROFILER



Instrument	Parameters
SYNOP-SHIP- METAR	10-m wind, MSL pressure, 2m-rel humidity, temperature
BUOY	Wind, temperature, MSL pressure
TEMP **TEMPSHIP** **DROPSONDES**	Wind, temperature, spec. humidity
PROFILER	Wind
PILOT	Wind
AIRCRAFT	Wind, temperature, spec. humidity

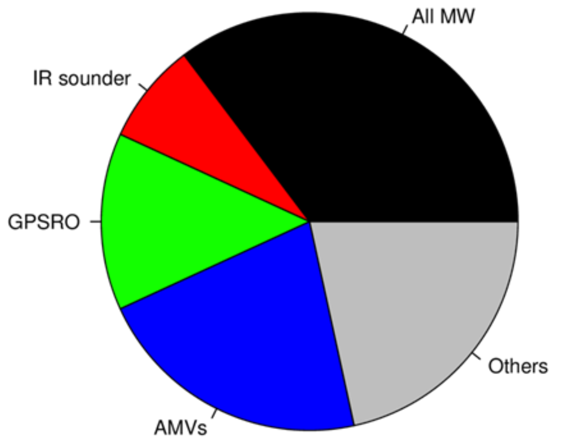
AIRCRAFT

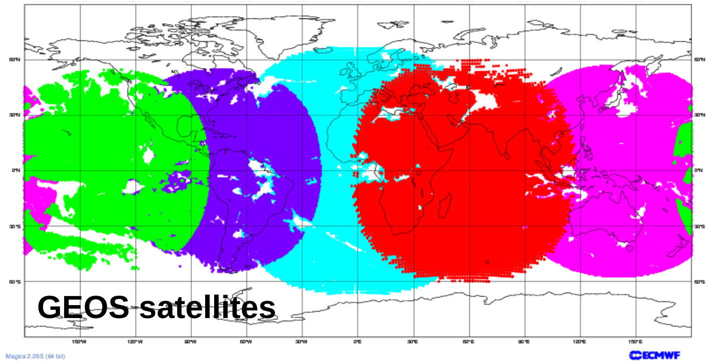


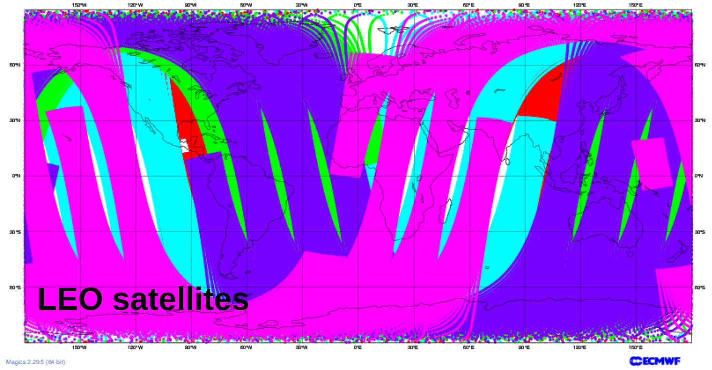
Data sources: Satellite observations

Observing system	**Instruments / Satellites**
High spectral resolution IR sounder	IASI from 2 satellites (MetOp-A, MetOp-B); AIRS on Aqua; CrIS from 2 satellites (S-NPP, NOAA-20);
Geostationary IR radiances	MET-8, MET-11, GOES-15, GOES-16, Himawari-8;
MW Temperature sounder	AMSU-A from 6 satellites (NOAA-15/18/19; Aqua, MetOp-A, MetOp-B); ATMS from 2 satellites (S-NPP, NOAA-20);
MW Humidity sounder	ATMS from 2 satellites (S-NPP, NOAA-20); MHS from 4 satellites (NOAA-18/19, MetOp-A, MetOp-B); MWHS on FY-3B; MWHS-2 on FY-3C;
MW Humidity imager	SSMI/S from 2 DMSP satellites (F17, F18); AMSR-2 on GCOM-W1; GMI on GPM; SAPHIR on Megatropiques
Atmospheric Motion Vectors (AMVs)	MET-8, MET-11, GOES-15, GOES-16, Himawari-8, NOAA-15/18/19 AVHRR, Aqua Modis, MetOp-A, MetOp-B, S-NPP, Dual-satellite AMVs from MetOp-A/B;
Scatterometer	ASCAT from MetOp-A and MetOp-B;
Radio occultation	MetOp-A, MetOp-B, TerraSAR-X, TanDEM-X, FY-3C, GRACE-A and COSMIC satellites
Ozone Ground-Based Radar	Aura OMI, NOAA-19 SBUV-2, MetOp-A+B GOME-2

Proportion of satellites/ instruments

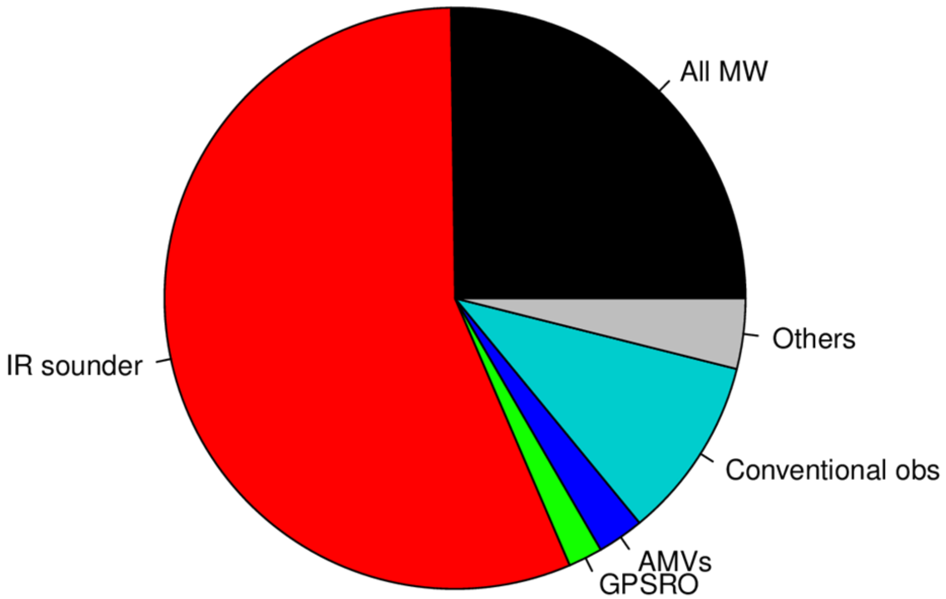






With millions of observations assimilated every analysis cycle, how do we quantify the value provided by all these data?

Proportion of assimilated observations
(Total number: ~ 20 Million per 24 h)



What diagnostics are available to measure impact?

Which observation types provide the largest total impacts, or largest impact per observation?

How do impacts vary by location or channel?

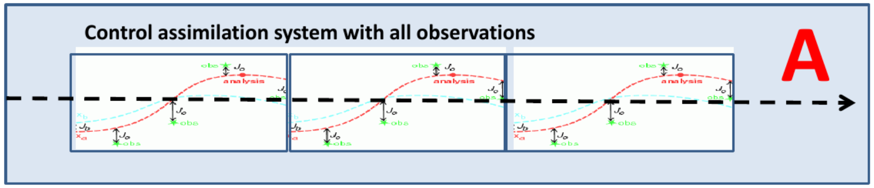
Do all observations provide benefit?

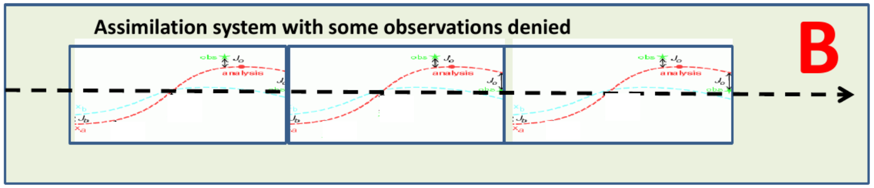
What diagnostics are available for evaluating observations impact on forecast?

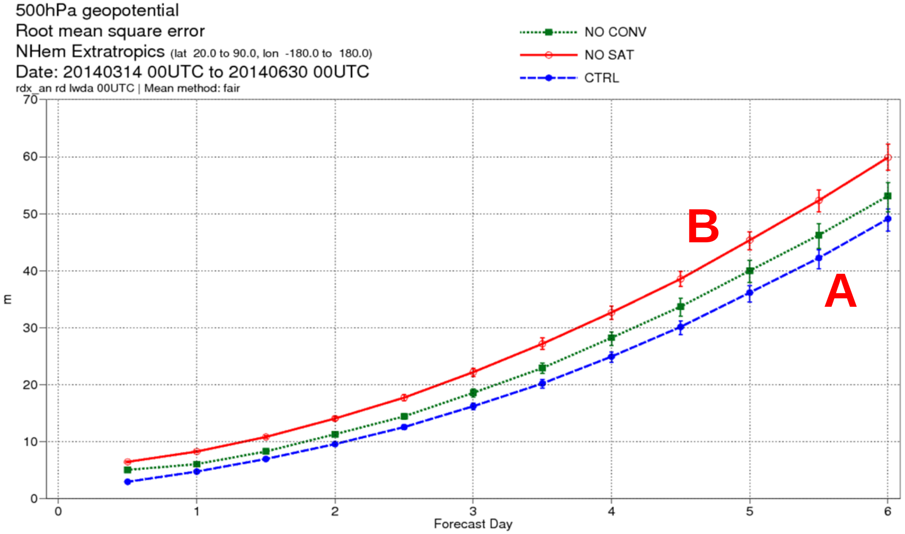
- Observing System Experiments - OSEs

- Adjoint-based diagnostic methods - Forecast Sensitivity Observation Impact

Observing System Experiments (OSEs)





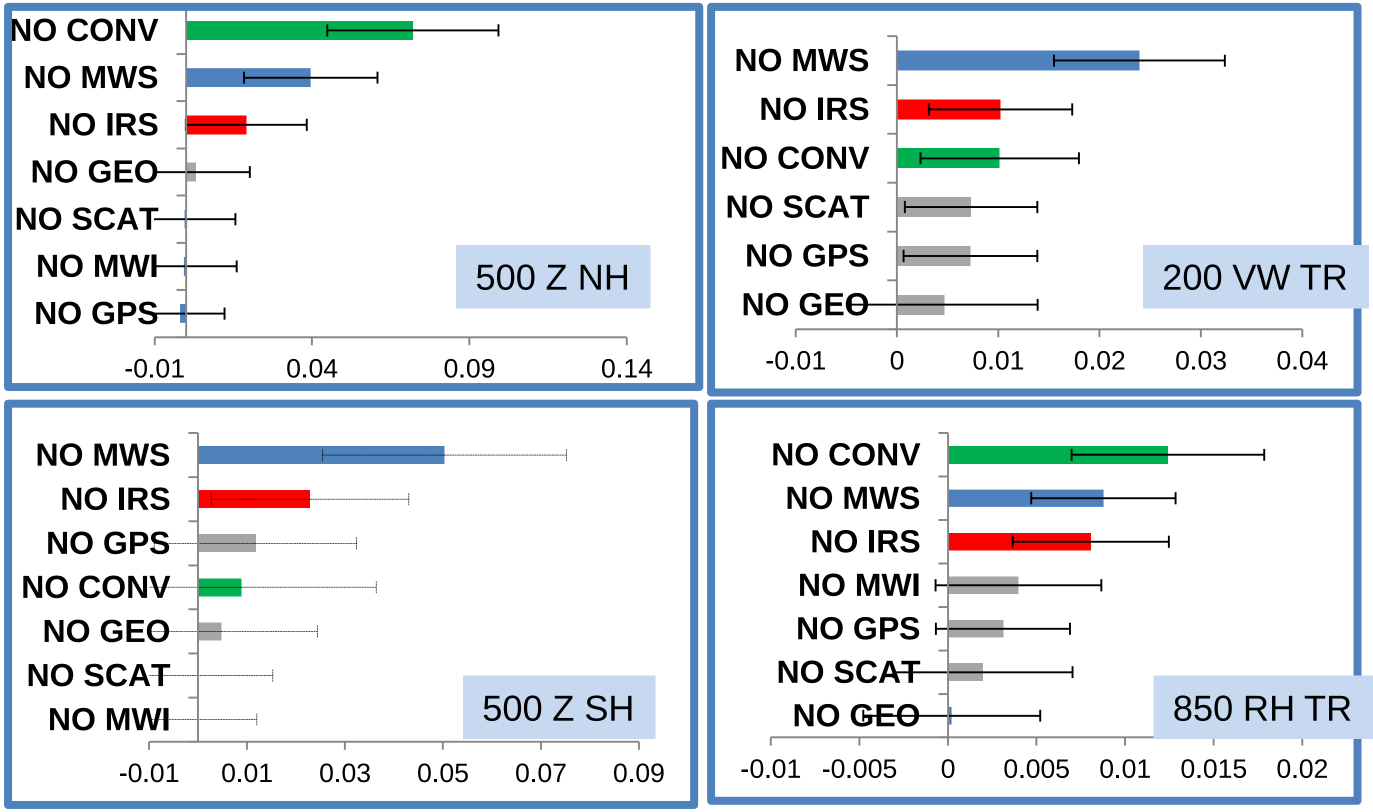


- Tell us what happens to forecast errors with / without a particular observation;
- Denial or addition experiments: subsets of observations are removed (or added) to the data assimilation system to assess their impact on any forecast metric;
- Valid for any forecast range or measure:
    - Range (12-h, 5 days, 10 days…)
    - Parameter (geopotential height, temperature, wind, humidity…)
    - Altitude (surface, 500hPa, 1hPa)
    - Region (global, NH, SH, Tropics, Europe)
- Requires re-running the data assimilation system for each subset of observations examined.
- Costly, because of the length of time required to get statistically significant results (Geer, 2016)
- OSEs run at ECMWF: Bormann *et al*., 2019; McNally, 2014; Radnoti *et al.*, 2010; Kelly *et al*., 2004.

OSEs denial experiments from McNally, 2014

- The impact of observations may change over time depending on the model / DA evolution and the availability of new data
- Important to explore resilience and redundancy to optimise the use of resources
- Useful for the long term planning of the global observing system

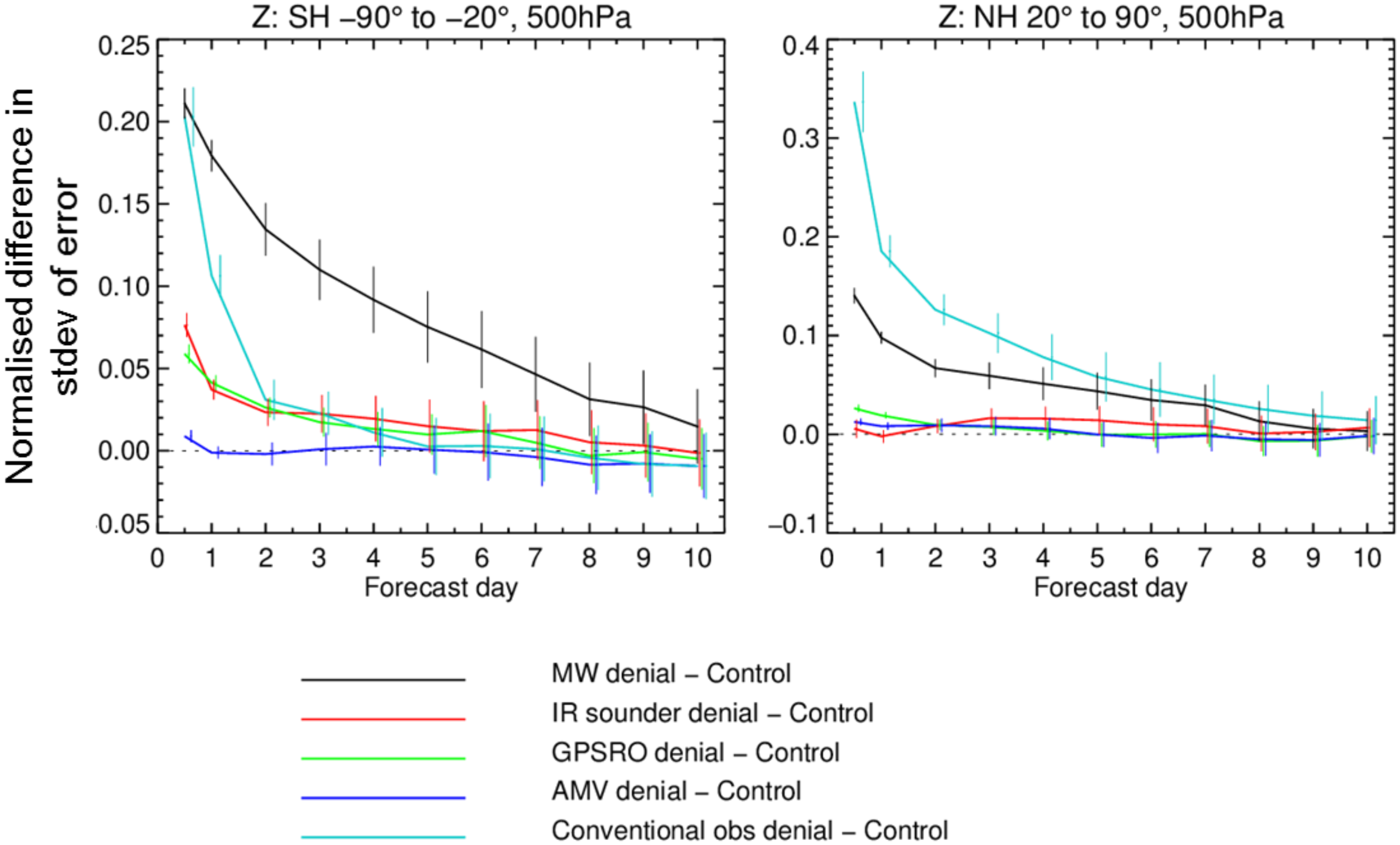
Day 6 fractional increase in RMSE compared to control



Current impact of various observing systems: Z 500 hPa

- NH: Conventional observations show the largest impact, followed by MW observations; statistically significant forecast impact out to day 7;
- SH: MW radiances show the dominant forecast impact (e.g., 11% degradation at day 3; see Bormann *et al*., 2019)

Periods: 1 June – 30 September 2016; 1 December 2017 – 31 March 2018;



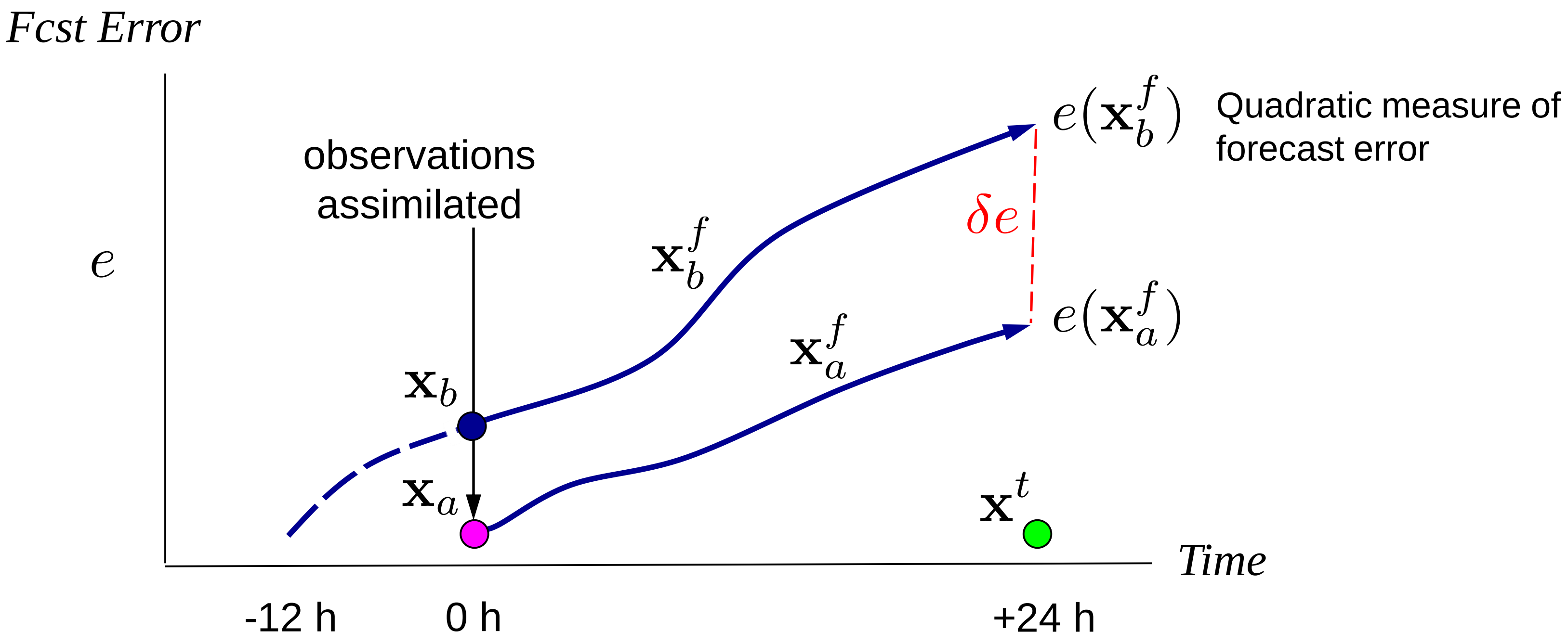
Adjoint-based diagnostic methods (FSOI)

- Estimates of observation impact using the **adjoint** (transpose) of the data assimilation system have become increasingly popular as an alternative/complement to traditional OSEs.
  - Enable a simultaneous estimate of forecast impact for any and all observations assimilated.
  - Impact assessed without denial - FSOI measures the impact of observations when the entire observation dataset is present in the assimilation system
  - Used at several centers now for routine monitoring or experimentation: ECMWF, Met Office; Meteo France, JMA, NRL, GMAO, Bureau of Meteorology
  - Implemented at ECMWF by *C. Cardinali (2009)*; FSOI statistics are published on the ECMWF monitoring website.

http://www.ecmwf.int/en/forecasts/charts/obstat/

Forecast Sensitivity Observation Impact Measure

Cardinali (2009) following Langland and Baker (2004)



Quadratic measure of forecast error

Observations move the forecast from the background trajectory to trajectory starting from the new analysis;

The difference $\delta e = e(\mathbf{x}_a^f) - e(\mathbf{x}_b^f)$ measures the collective impact at 24-h of **all observations** assimilated at 0-h. (model space)

Can we measure their individual contributions? (observation space)
Yes, using information from the model and analysis adjoints.

Observational impact on the analysis

Recall the analysis equation (Daley, 1991):

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

$$\boxed{\delta\mathbf{x}_a = \mathbf{K}\delta\mathbf{y}}$$

(model space) *(observation space)*

$\mathbf{x}_a$ - analysis vector
$\mathbf{x}_b$ - background vector
$\mathbf{y}$ - observation vector
$H(\mathbf{x}_b)$ - forward observation operator
H - Jacobian or tangent linear approximation of H
R – observation error covariance
B – background error covariance
$\mathbf{K} = \mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1}$ Kalman gain matrix
$\delta\mathbf{y} = \mathbf{y} - H\mathbf{x}_b$ is the innovation vector
$\delta\mathbf{x}_a = \mathbf{x}_a - \mathbf{x}_b$ is the analysis increment

- The sensitivity of the analysis to the observations is:
  DFS, Cardinali et al. 2004; Lupu et al., 2011; Daescu, 2008;

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

- Adjoint property for a linear operator: $\langle \mathbf{K}\delta\mathbf{y}, \mathbf{g}\rangle = \langle \delta\mathbf{y}, \mathbf{K}^T\mathbf{g}\rangle$

  For any vector **g** in model space, there is a corresponding vector $\mathbf{K}^T\mathbf{g}$ in observation space such that:

$$\boxed{(\delta\mathbf{x}_a)^T\mathbf{g} = (\delta\mathbf{y})^T\tilde{\mathbf{g}}}$$

Observational impact on the forecast

- Define a scalar cost function of the forecast error: $$e = (\mathbf{x}^f - \mathbf{x}_t)^T \mathbf{C}(\mathbf{x}^f - \mathbf{x}_t)$$

where $\mathbf{x}^f = M\mathbf{x}$ is the forecast model state, x_t is the truth atmospheric state, M is the nonlinear model and **C** **-** is a matrix of energy norm coefficients. The verifying analysis is a proxy for the truth atmospheric state.

- Energy norm based cost function:

u- is the zonal wind, v is the meridional wind,
R_d is the dry air constant, T_r is the reference temperature (350 K), p_r is the reference pressure (1000 hPa) and T is the air temperature, q specific humidity with a certain weight w_q, Lc is the latent heat of condensation.
ECMWF→ w_q=0 (dry energy norm)

$$e = \mathbf{x}^{\mathrm{T}}\mathbf{C}\mathbf{x} = \frac{1}{2}\int_{p_0}^{p_1}\iint_S \left(u^2 + v^2 + \frac{c_p}{T_r}T^2 + w_q \frac{L_c^2}{c_p T_r} q^2\right) dp\,dS + \frac{1}{2} R_d T_r p_r \int_S (\ln p_{sfc})^2 dS$$

- A dry norm based on own-analysis verification is used in the operational FSOI (w_q=0) , but **a moist norm** or **an observation-based error norm** have also been advocated (*Janisková and Cardinali, 2016; Cardinali, 2018)*

Observational impact on the forecast

- Define a scalar cost function of the forecast error:

$$\boxed{e = (\mathbf{x}^f - \mathbf{x}_t)^T \mathbf{C}(\mathbf{x}^f - \mathbf{x}_t)}$$

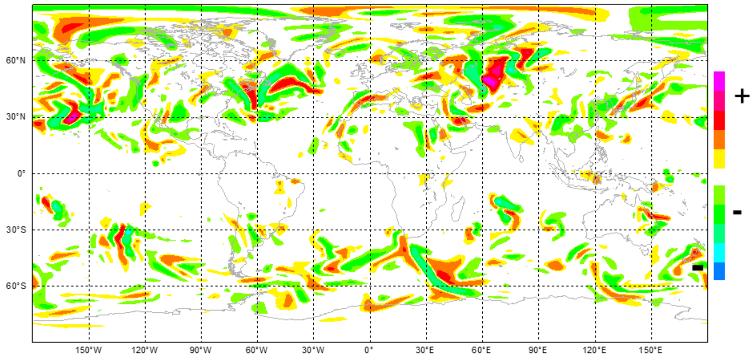
- Using the chain rule, the sensitivity of *e* with respect to observations is:

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

where the sensitivity of the forecast error to initial conditions is :

$$\boxed{\frac{\partial e}{\partial \mathbf{x}_a} = \mathbf{M}^T \mathbf{C}(\mathbf{x}^f - \mathbf{x}_t)}$$

The forecast error is mapped onto the initial conditions by the adjoint of the model, providing, for example, regions that are particularly sensitive to forecast error growth.



- The variation of the forecast error due to the assimilated observations is:

$$\boxed{\delta e = \langle \frac{\partial e}{\partial \mathbf{x}_a}, \delta \mathbf{x}_a \rangle = \langle \frac{\partial e}{\partial \mathbf{x}_a}, \mathbf{K}(\mathbf{y} - H\mathbf{x}_b) \rangle = \langle \mathbf{K}^T \frac{\partial e}{\partial \mathbf{x}_a}, \delta \mathbf{y} \rangle = \langle \frac{\partial e}{\partial \mathbf{y}}, \delta \mathbf{y} \rangle}$$

$$\boxed{\delta e = (\delta \mathbf{y})^T \mathbf{K}^T \frac{\partial e}{\partial \mathbf{x}_a}}$$

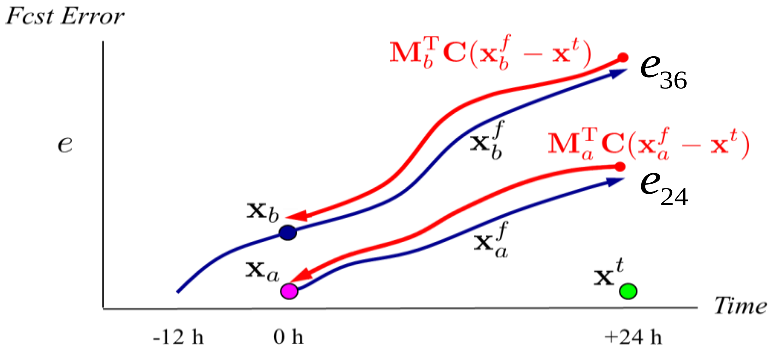
FSOI in the IFS - summary

- Given forecasts from an analysis and background state, use an *dry* energy-weighted forecast error norm as the measure of forecast error:

$$\mathbf{x}_a^f = M(\mathbf{x}_a) \longrightarrow e_{24} = e(\mathbf{x}_a^f) = (\mathbf{x}_a^f - \mathbf{x}_t)^T \mathbf{C}(\mathbf{x}_a^f - \mathbf{x}_t)$$

$$\mathbf{x}_b^f = M(\mathbf{x}_b) \longrightarrow e_{36} = e(\mathbf{x}_b^f) = (\mathbf{x}_b^f - \mathbf{x}_t)^T \mathbf{C}(\mathbf{x}_b^f - \mathbf{x}_t)$$

$$\longrightarrow \boxed{e = e_{24} - e_{36}}$$



Higher than first-order approximation of impact (e.g., second order) is required due to quadratic nature of e (*Errico, 2007);*

$$\boxed{\frac{\partial e}{\partial \mathbf{x}_a} = \frac{\partial e_{24}}{\partial \mathbf{x}_a} + \frac{\partial e_{36}}{\partial \mathbf{x}_b}}$$

Gradients evaluated along forecast trajectories initialized from background and analysed states.

$$\boxed{\delta e = (\delta \mathbf{y})^T \mathbf{K}^T \frac{\partial e}{\partial \mathbf{x}_a} = (\delta \mathbf{y})^T \mathbf{K}^T [\mathbf{M}_a^T \mathbf{C}(x_a^f - x_t) + \mathbf{M}_b^T \mathbf{C}(x_b^f - x_t)] = (\delta \mathbf{y})^T \tilde{\mathbf{g}}}$$

adjoint analysis scheme

adjoint forecast model

Summation of individual observation impacts

FSOI in the IFS - summary

$$\boxed{\delta e = (\delta \mathbf{y})^T \mathbf{K}^T \frac{\partial e}{\partial \mathbf{x}_a} = (\delta \mathbf{y})^T \tilde{\mathbf{g}}}$$

- FSOI is a function of sensitivity gradient, the adjoint of the gain matrix and the innovation vector;

- FSOI is computed at ECMWF for a 12-h window; The sensitivity gradient is valid at the starting time of the 4D-Var window, typically 9 UTC and 21UTC;

- The impact of observations can be summed up over time and space in different subsets to compute the total contribution of the different components of the observing system towards reduction of the forecast errors;

- FSOI is influenced by the simplified adjoint model used to carry the forecast error information backwards and by the selection of the total energy norm (dry/moist).

Observation impact calculation

1. Difference of nonlinear forecast error norm (model space)

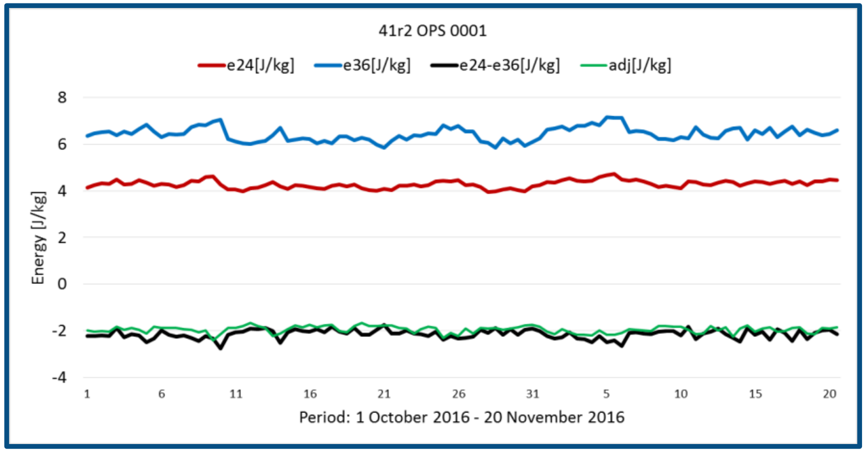
$$\boxed{\delta e = e_{24} - e_{36}}$$

2. FSOI (observation space) – adjoint-based estimate of δe

$$\boxed{\delta e = (\delta \mathbf{y})^T \frac{\partial e}{\partial \mathbf{y}}}$$

$\delta e < 0$ the observation is beneficial

$\delta e > 0$ the observation is non-beneficial



$\delta e < 0$ the assimilation of the complete set of observations consistently results in a more accurate 24-h forecast;

Average total observation impact is 95.4% of the total forecast impact.

e_{24}	e_{36}	e_{24}-e_{36}	adj
4.28	6.43	- 2.15	- 2.05

Observation impact calculation

1. Difference of nonlinear forecast error norm (model space)

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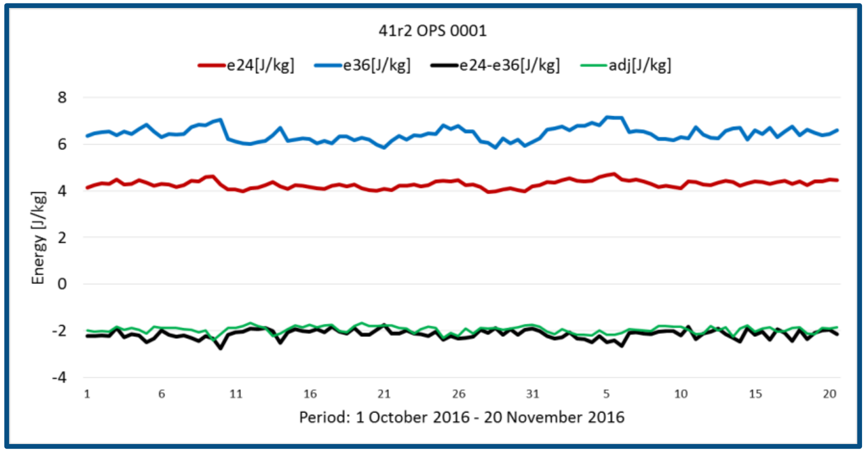
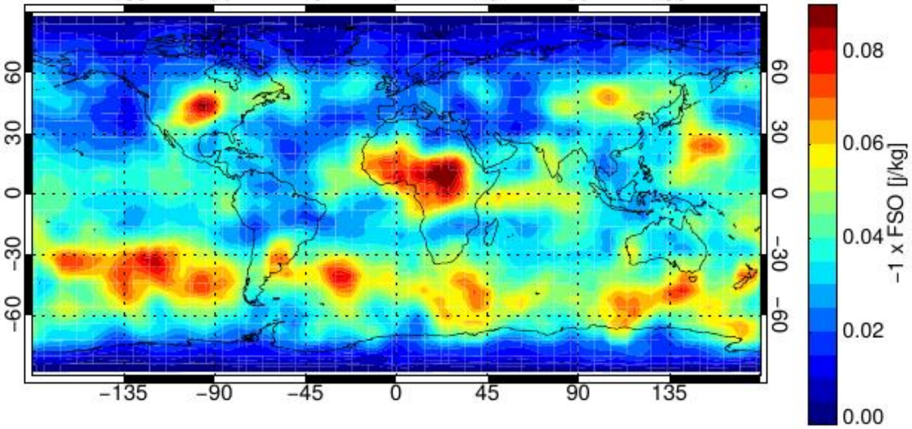


FSOI –all observations (July-August 2016)

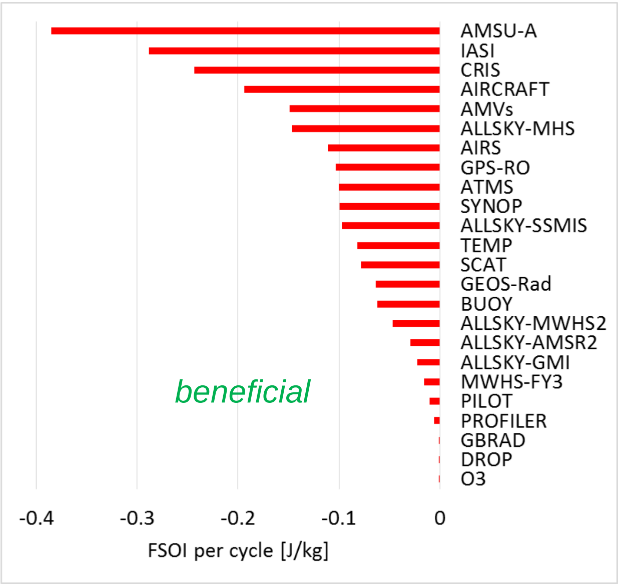


Largest FSOI values in the Southern extra-tropics ➔ consistent with faster error growth in the winter storm tracks;

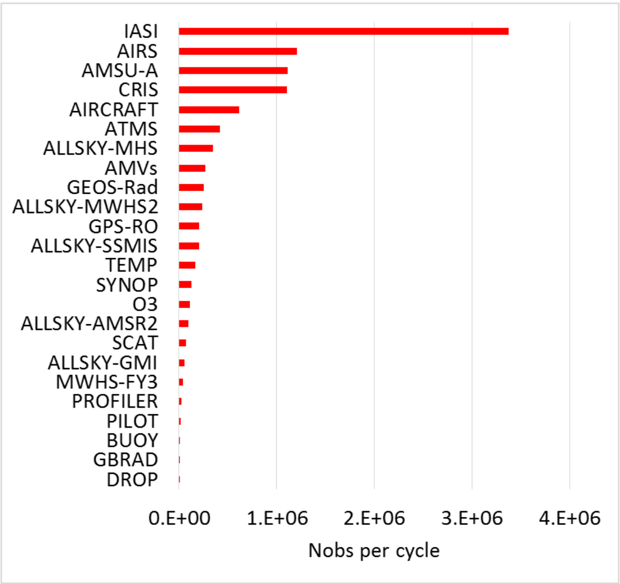
Impact of major observing systems on reducing 24-h forecast errors, May-Sept. 2016

- Measured using a global dry energy norm, surface to model top
- ***Negative*** *(positive)* **FSOI** indicate that the assimilation of an observation or subset of observations ***decreased*** *(increased)* 24-hour forecast error and will be referred as ***beneficial*** *(detrimental).*

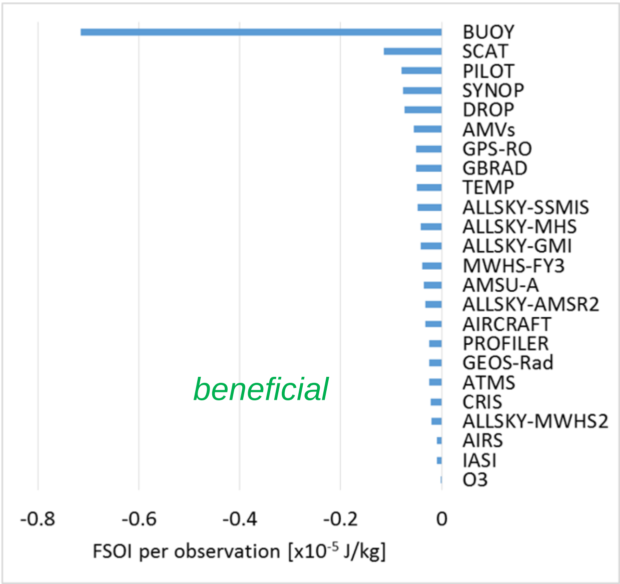
Total FSOI impact



Total data count



Impact per observation

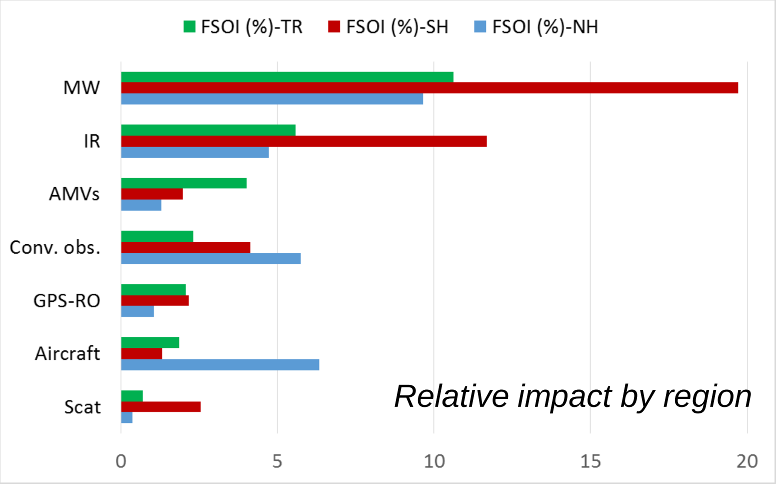


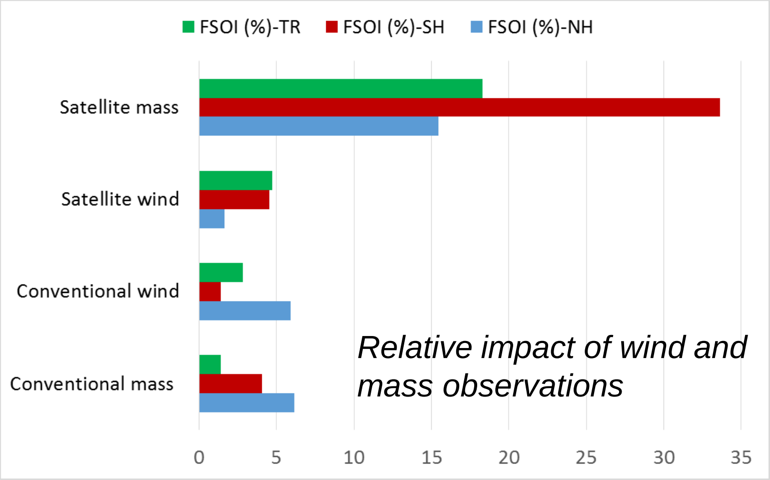
Report of 6th Workshop on the Impact of Various Observing Systems on NWP (WMO, 2016)

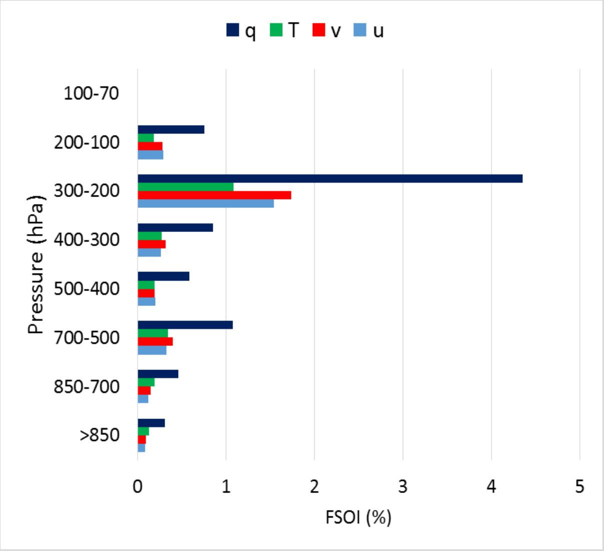
- Observing types with the most significant contributions to error reduction for global NWP: MW sounders (AMSU-A, ATMS), hyper-spectral IR sounders (IASI, CrIS, AIRS), radiosondes, aircraft data and satellite winds (AMVs).
- On a per observation basis, the impact is dominated by buoys, radiosondes, AMVs and aircraft observations.

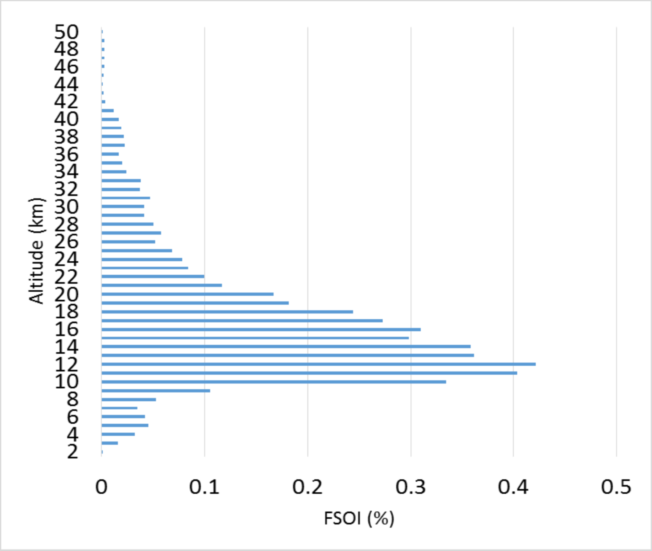
Examples of Observing System Impacts

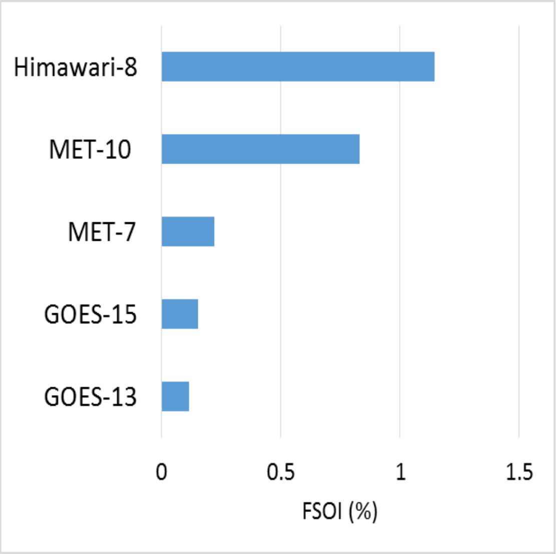
- Observation impacts can be sorted by conditional information (e.g. region, separate channels or separate satellites, wind and mass observations, etc)


Relative impact by region


Relative impact of wind and mass observations


Aircraft: Relative impact by parameter

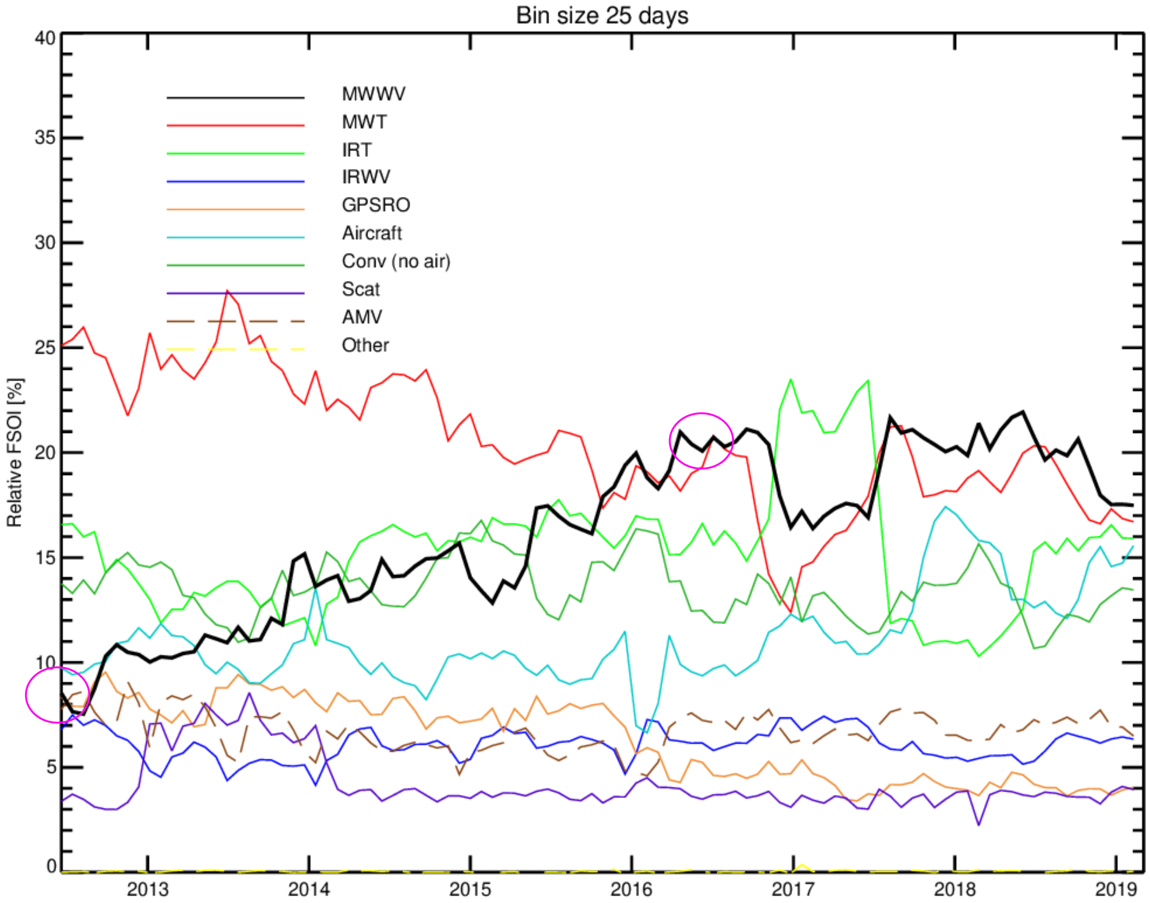

GPSRO: Relative impact by altitude


Geos Rad: Relative impact by satellite

FSOI of major observing systems in ECMWF operations

Summer 2006
(from Cardinali, 2009)

Microwave WV	6.2 %
Microwave T	35.5 %
Infrared	28.0 %



August 2016

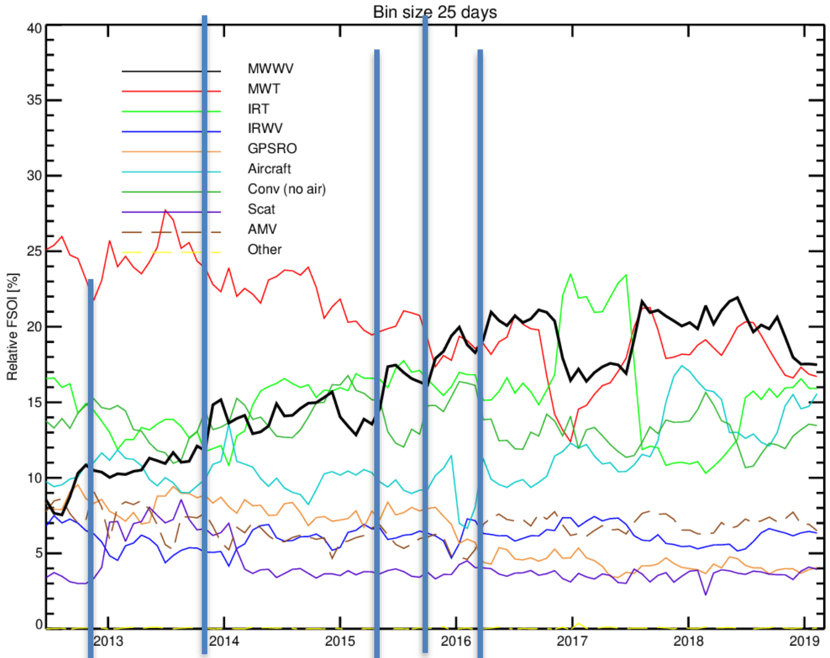
Microwave WV	20.4%
Microwave T	20.1 %
Infrared	21.9 %

- MW radiances are the satellite observing system with the largest forecast impact in the ECMWF system.
  - Used in a wide variety of conditions: all-sky for humidity-sensitive observations; clear and weakly cloudy for temperature-sounding data; land, sea, sea-ice for sounding data.
  - Microwave water vapour, cloud and precipitation observations (MWWV) now provide significant real benefits, equivalent to clear-sky MW temperature sounding (MWT) and IR sounding (IRT).

What’s happened recently?

All-sky assimilation of humidity sounding channels on SSMIS

GMI and AMSR-2 added in all-sky



F18, all-sky over snow, MWHS-2

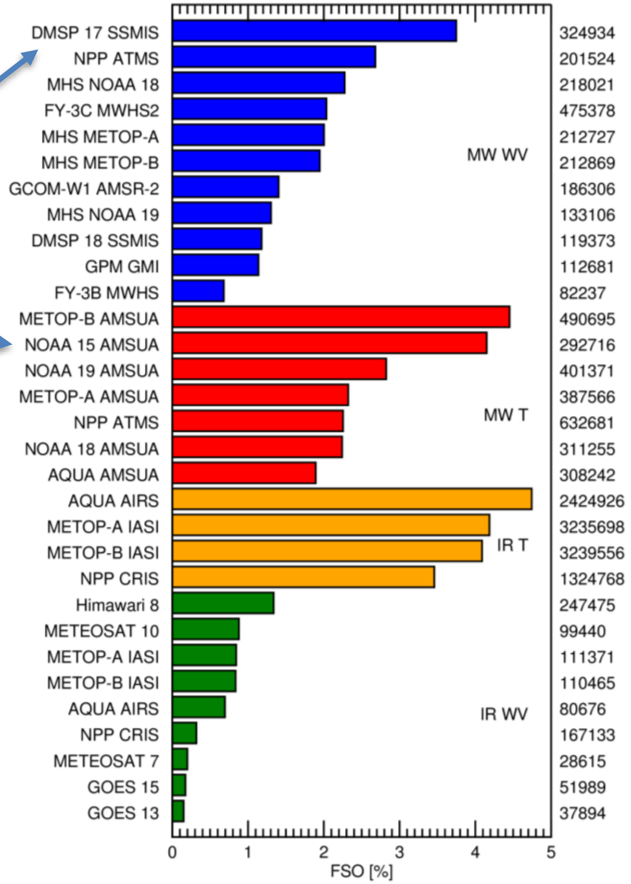
ATMS and Metop-B MHS added in clear skies

All-sky assimilation of all four MHS (transferred from clear-sky)

FSOI of satellite radiances, August 2016

100% = full operational observing system

An SSMIS (combining imaging and humidity sounding channels) is nearly equivalent to the best of the temperature-sounding AMSU-As



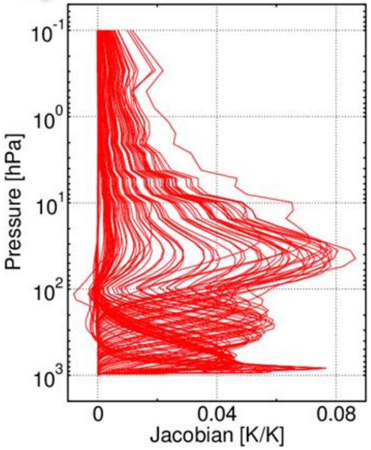
Microwave WV 20.4%

Amount of information coming from humidity/cloud/precip is equivalent to what's coming from T sounding

Microwave T 20.1%

Infrared T 16.5%

Impact of individual channels (e.g.,CrIS)

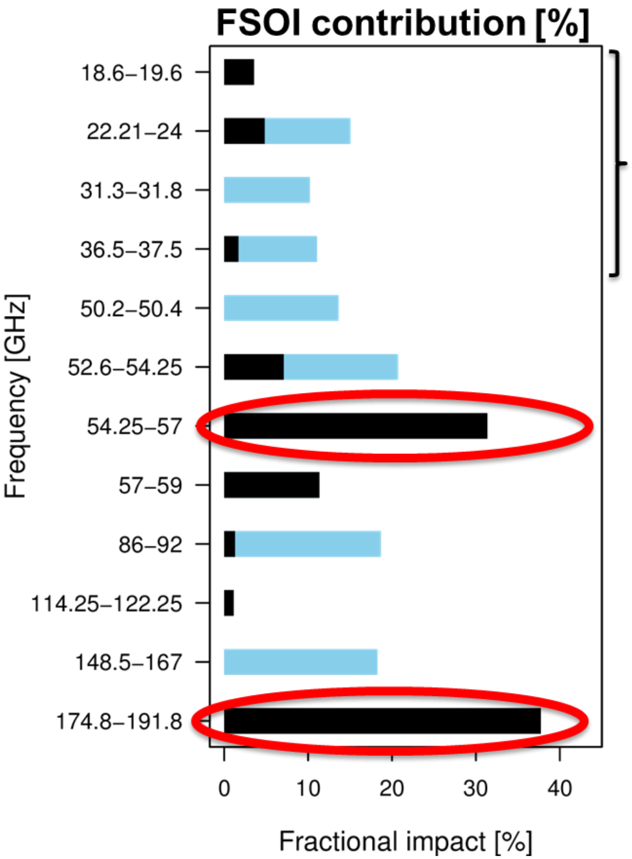


Infrared WV 5.4%

Geer *et al.*, 2017; Eresmaa *et al.*, 2017; Eresmaa and Lupu, 2017

Current value of individual MW bands

- The MW bands with the largest contribution are 52.6 – 59 GHz (T-sounding) and 183 GHz (Q-sounding). But all bands contribute significantly to the overall impact through various aspects.
- The impact of spectral bands will change, as we learn how to improve the use of certain bands.



TCWV, clouds, precip, ocean winds

Surface emission, clouds

Lowest T-sounding, clouds

Mid/upper tropospheric T-sounding

Stratospheric T-sounding

TCWV, clouds, precip, surface emission

T-sounding, clouds

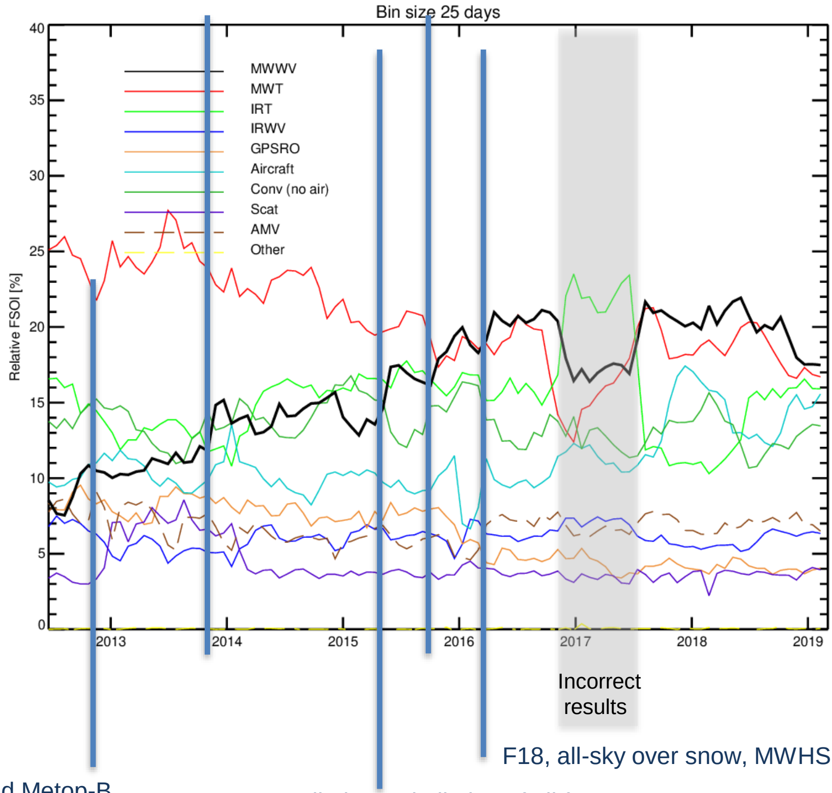
TCVW, clouds, precip, surface emission

Q-sounding, clouds, precip

What’s happened recently?

All-sky assimilation of humidity sounding channels on SSMIS

GMI and AMSR-2 added in all-sky



F18, all-sky over snow, MWHS-2

ATMS and Metop-B MHS added in clear skies

All-sky assimilation of all four MHS (transferred from clear-sky)

Since Nov. 2016, fully correlated error covariance estimates are used at ECMWF for hyper-spectral IASI and CrIS observations.

Explicit treatment for correlated error made it possible to use a large number of CrIS channels.

Early 2018, activate non-surface-sensitive IR channels over land.

Data events: highlights

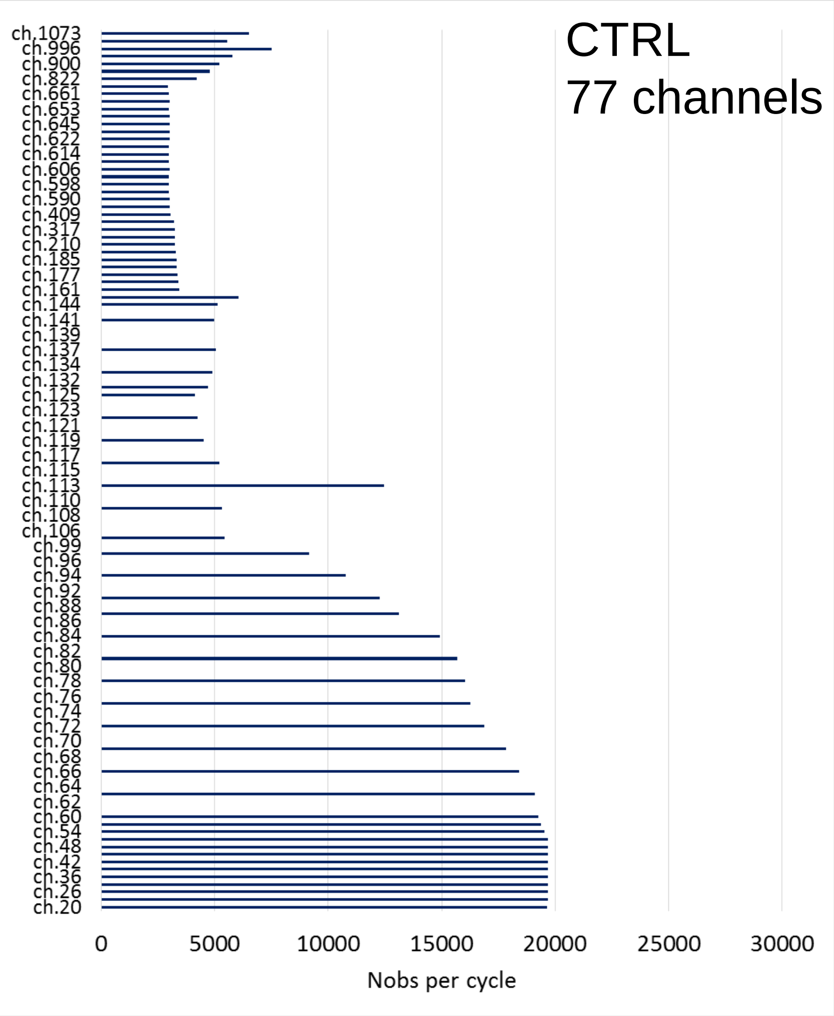
- Activation of ATMS on NOAA-20 (MWT, early May 2018);
- Activation of GOES-16 clear-sky radiances (IRWV, July 2018)
- Activation of CrIS on NOAA-20 (IRT, Sept 2018)
- Outage of SAPHIR (MWWV, Dec 2018)
- Outage of NOAA-15/AMSU-A (MWT, Jan 2019)
- …

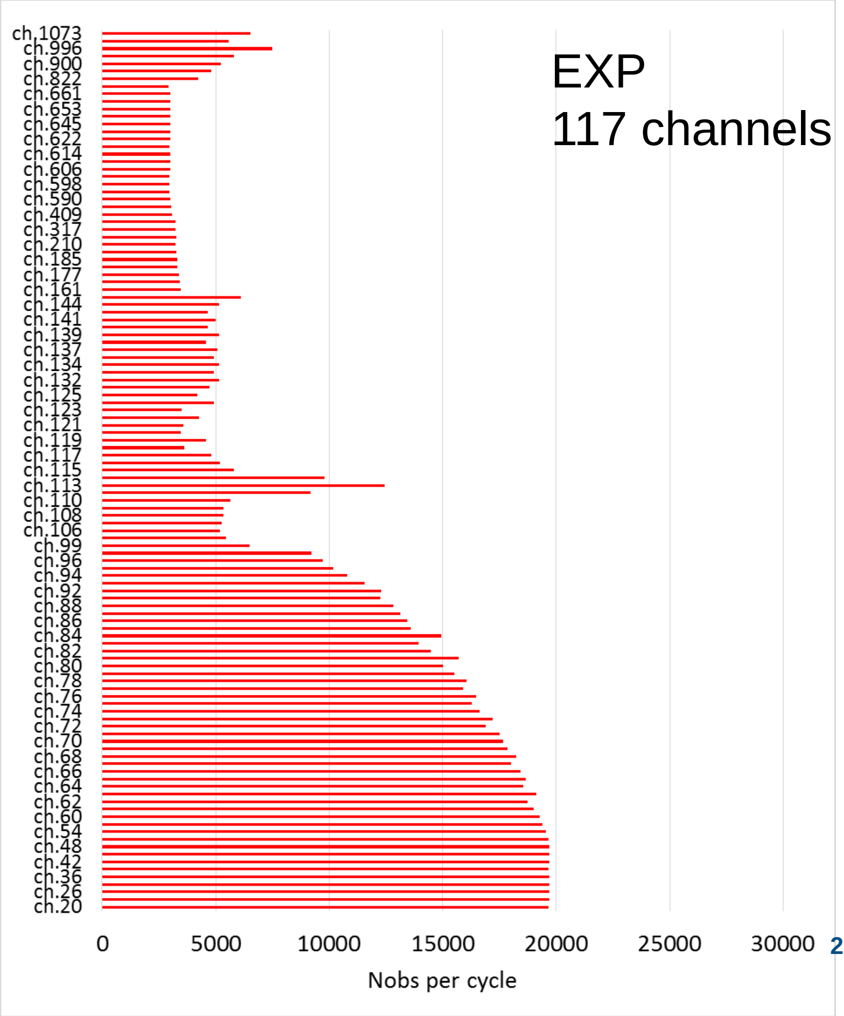
Explicit treatment for correlated error made it possible to use a large number of CrIS channels

Evaluate the new CrIS operational set-up for the period 2/5/2016 - 30/9/2016;

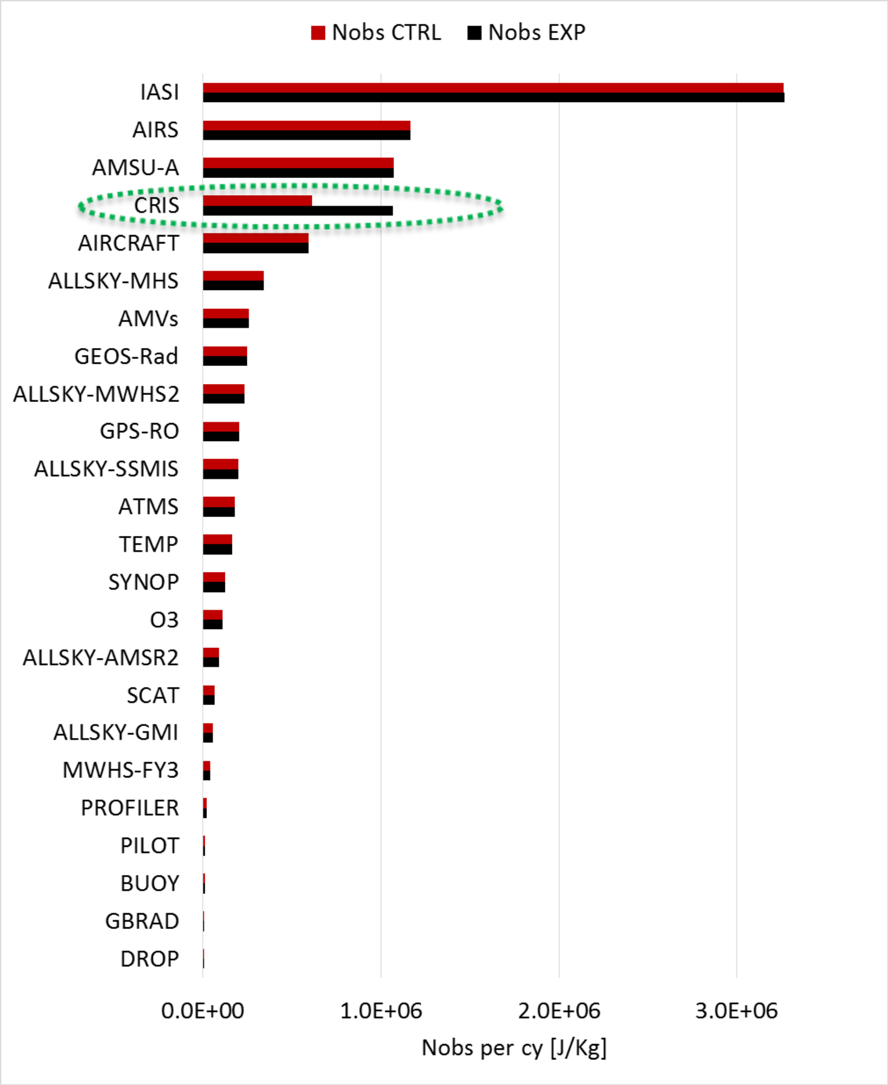
CTRL : as Ops, but only 77 assimilated CrIS channels

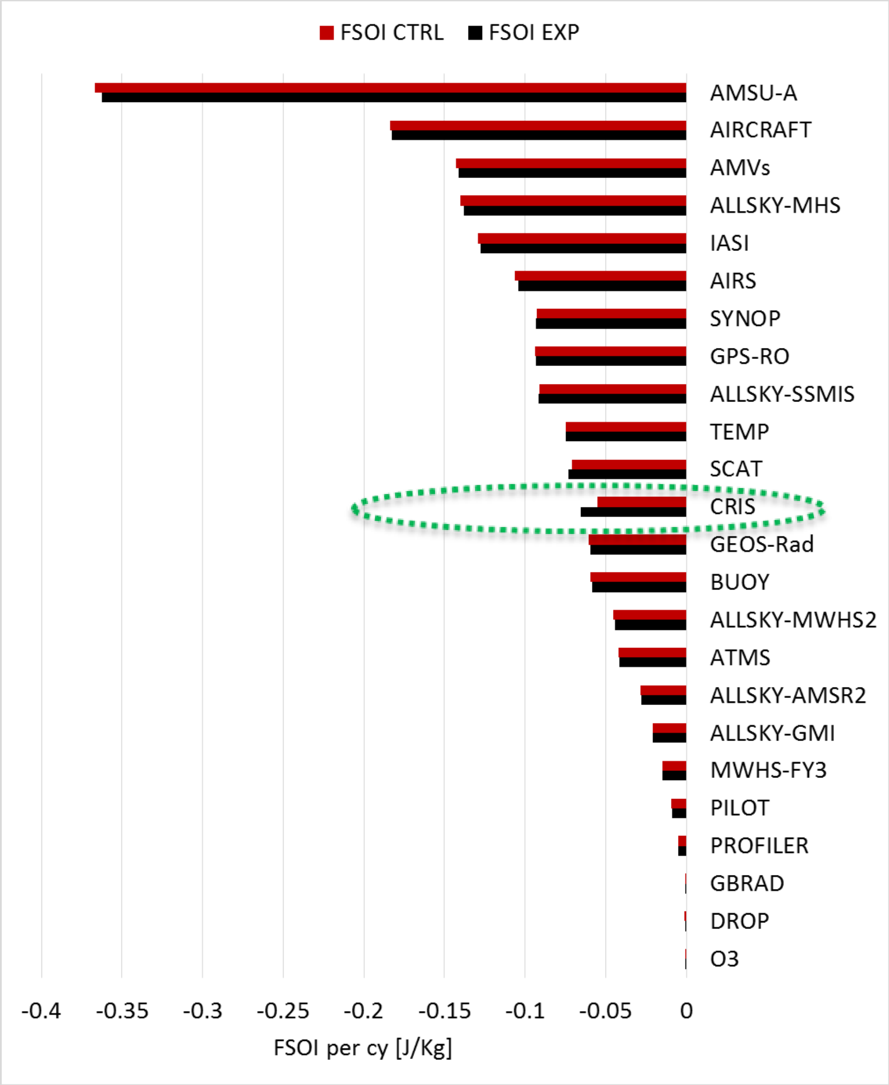
EXP : as Ops, but with 117 assimilated CrIS channels



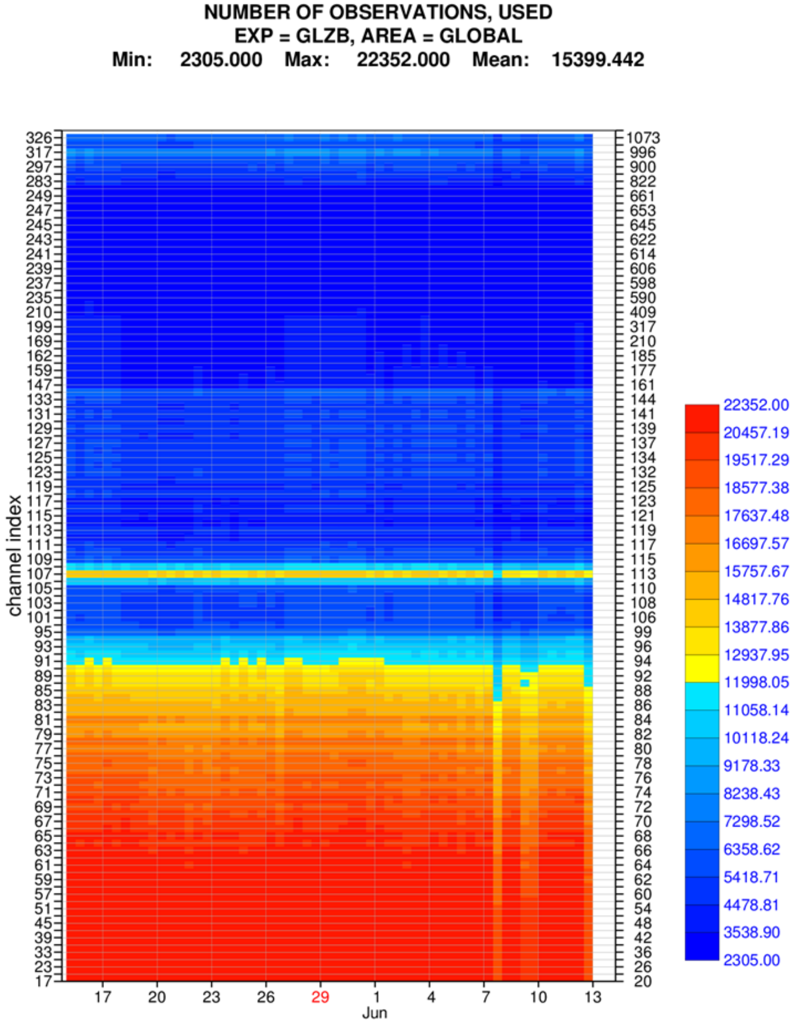


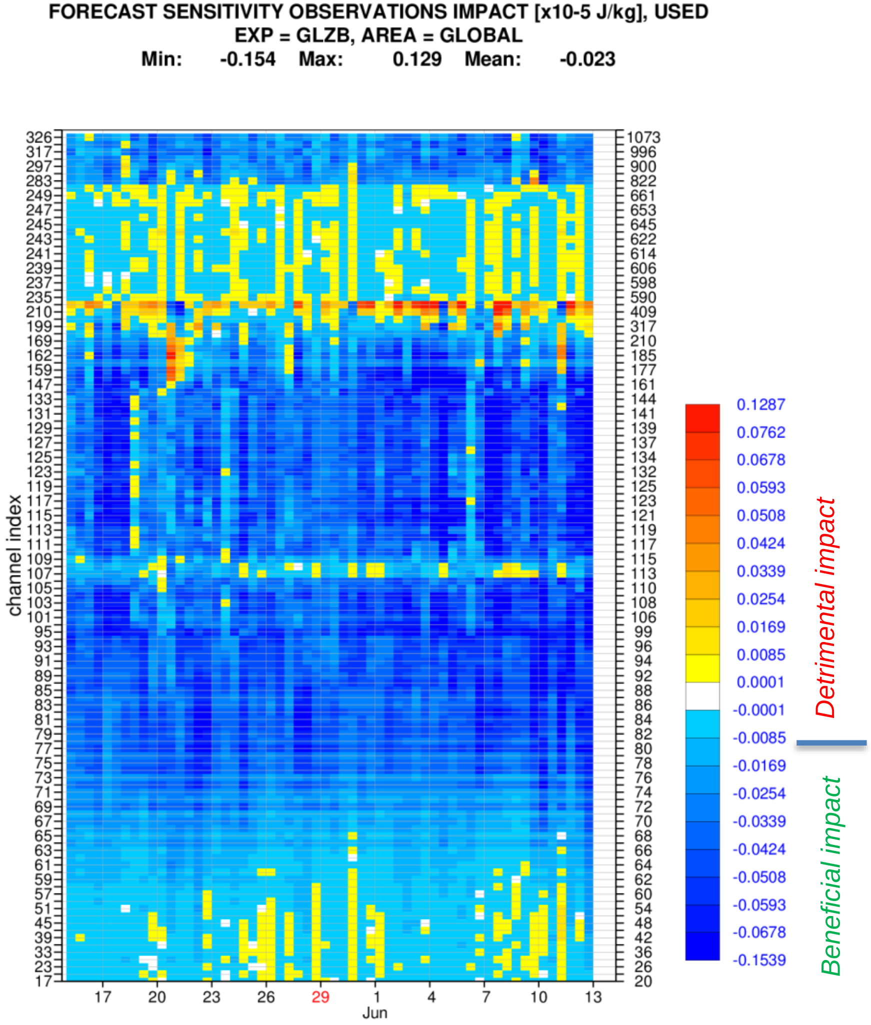
Nobs & FSOI results: additional CrIS channels





CrIS Hovmoeller Channels vs time: Nobs & FSOI

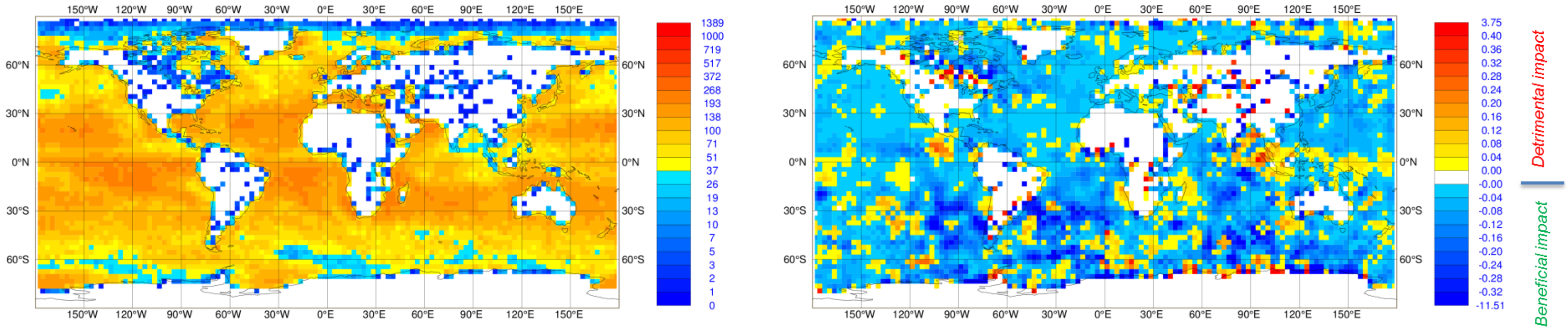

NUMBER OF OBSERVATIONS, USED
EXP = GLZB, AREA = GLOBAL
Min: 2305.000 Max: 22352.000 Mean: 15399.442


FORECAST SENSITIVITY OBSERVATIONS IMPACT [x10-5 J/kg], USED
EXP = GLZB, AREA = GLOBAL
Min: -0.154 Max: 0.129 Mean: -0.023

- The subset of CrIS stratospheric-sensitive sounding channels (wavenumbers range 690-710 cm^{-1}) give the greatest impact followed by the subset of tropospheric-sensitive sounding channels (wavenumbers range 720-760 cm^{-1}).
- The water-vapour and ozone sensitive channels show a very small but positive impact on improving the short-range forecast.

Data coverage and FSOI [J/kg]

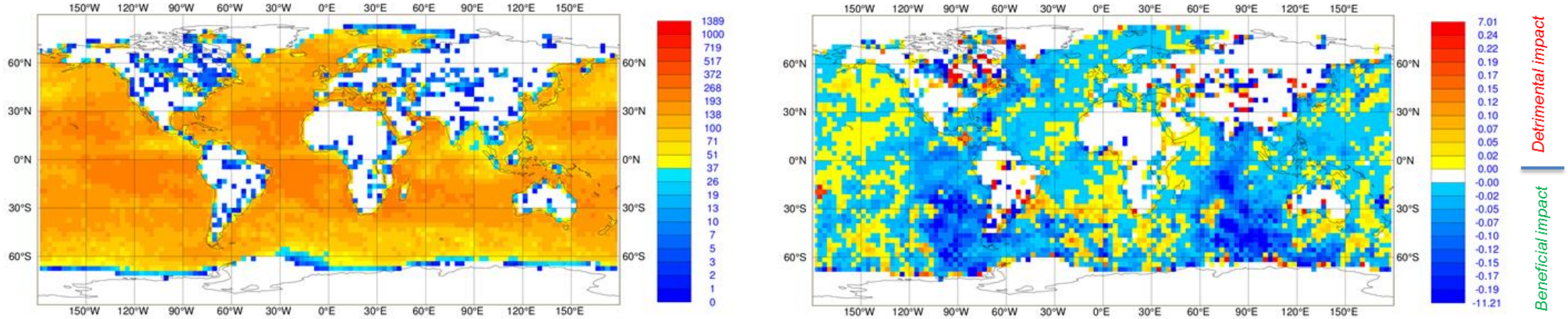
Mid-tropospheric (ch. 105 @ 715 cm^{-1})



Nobs

FSOI

Water vapour (ch. 1073 @ 1658.75 cm^{-1})

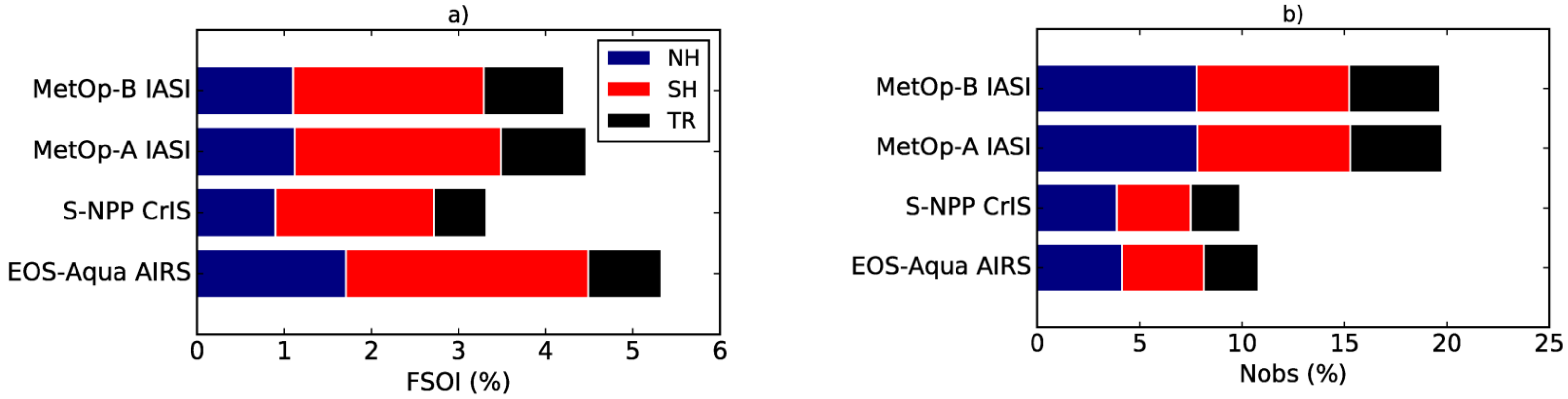


- Global sums are beneficial (negative), but many obs degrade the forecast!

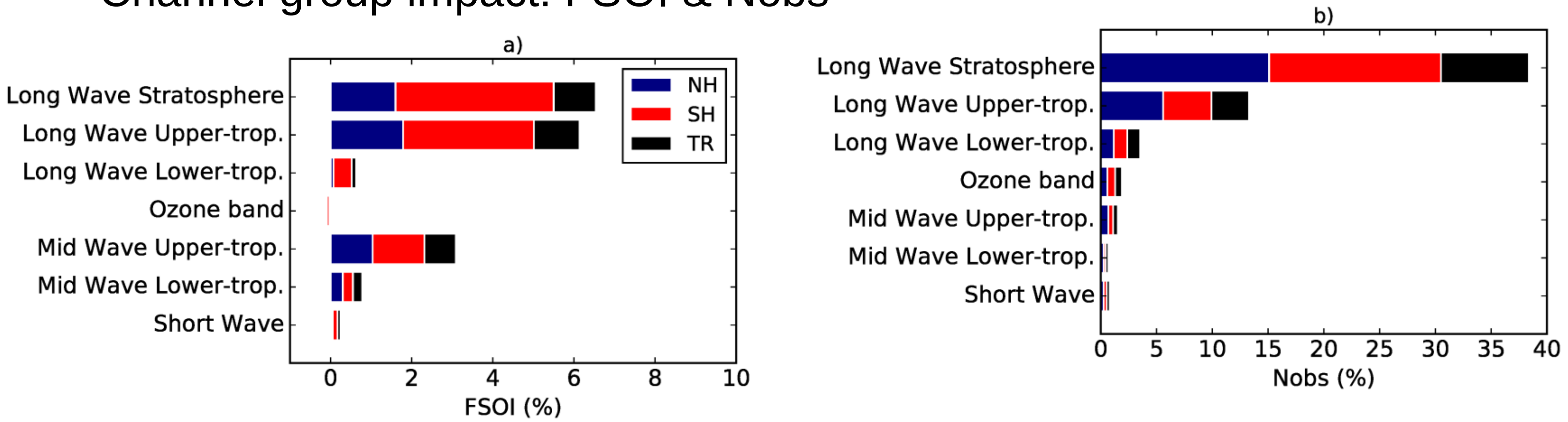
Current impact of hyperspectral IR radiances

- All infrared sounders produce a positive impact in short range forecast. The impact comes primarily from the use of stratospheric and upper-tropospheric channels in the long-wave infrared (LWIR) band and upper-tropospheric channels in the mid-wave infrared (MWIR) band.

IR sounder impact: FSOI & Nobs

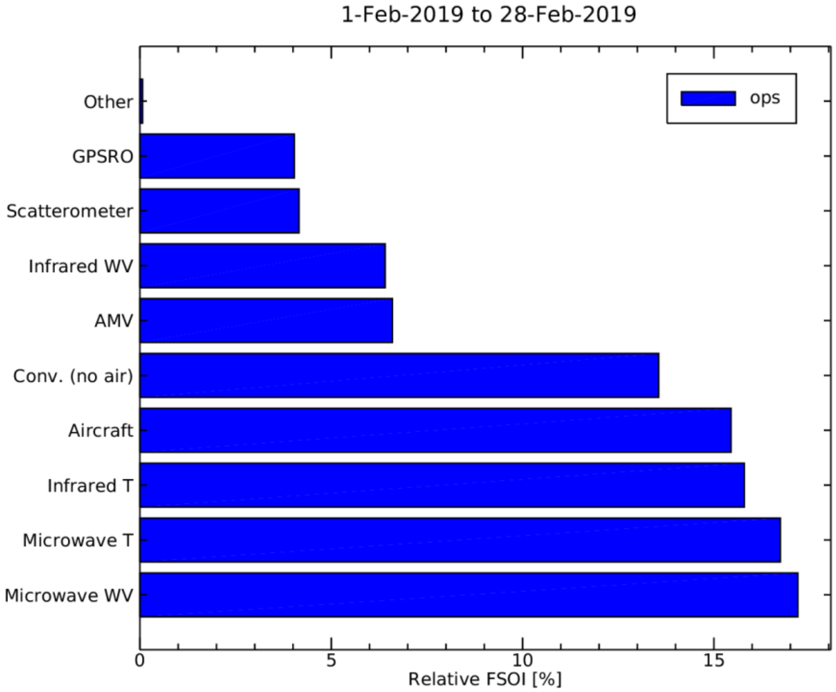


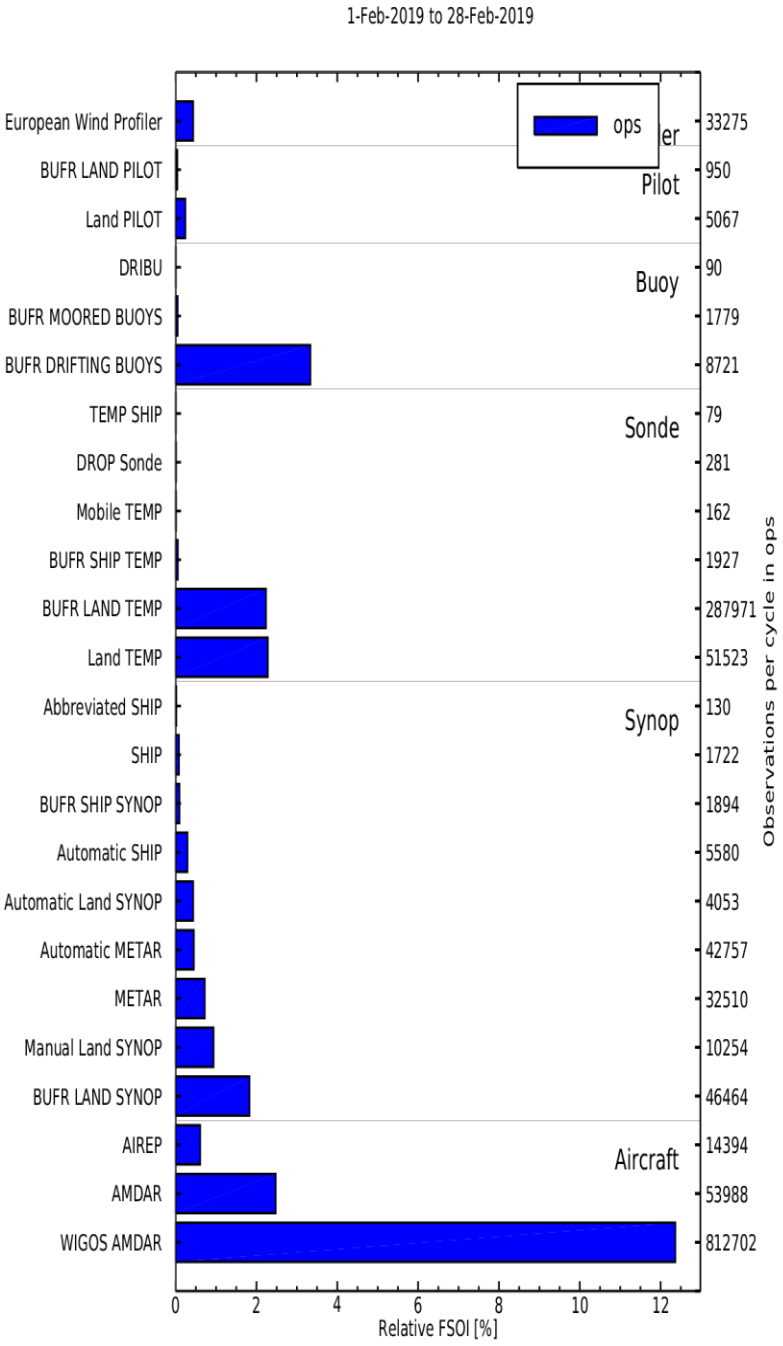
Channel group impact: FSOI & Nobs



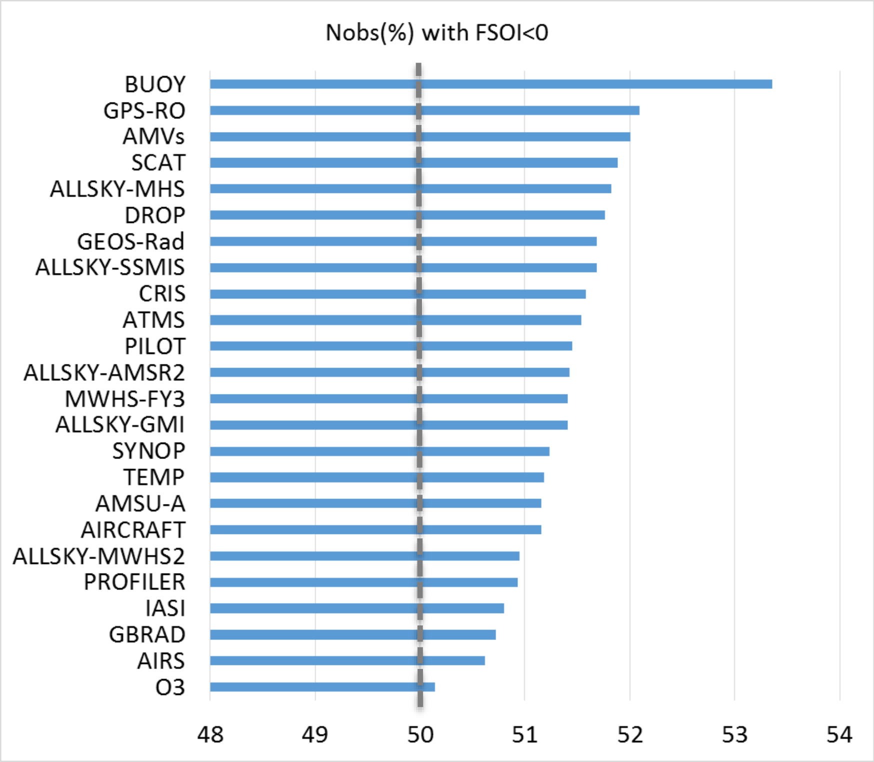
ECMWF FSOI February 2019

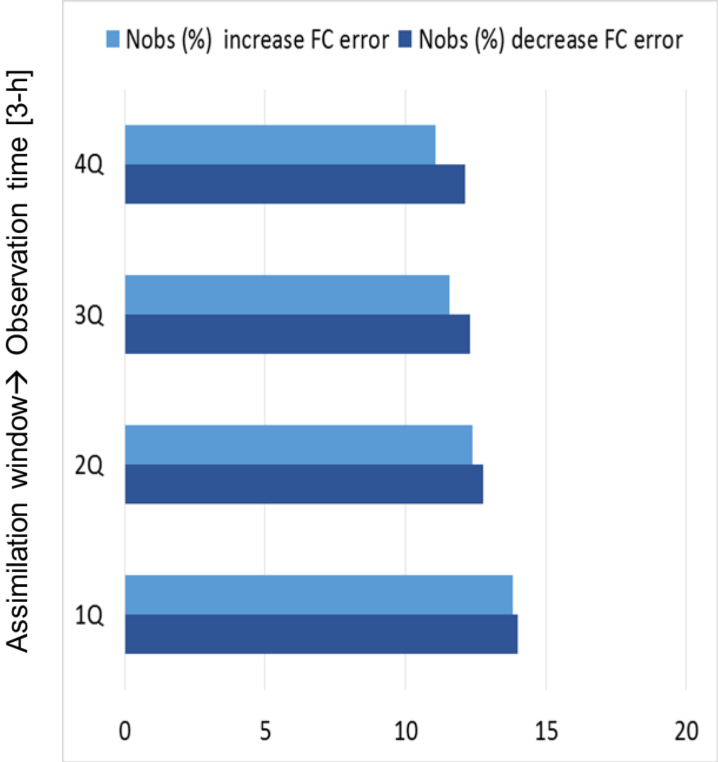
- Satellite observations, are critical for global NWP, but conventional data remain very important.





What fraction of the assimilated observations improve the forecast ?



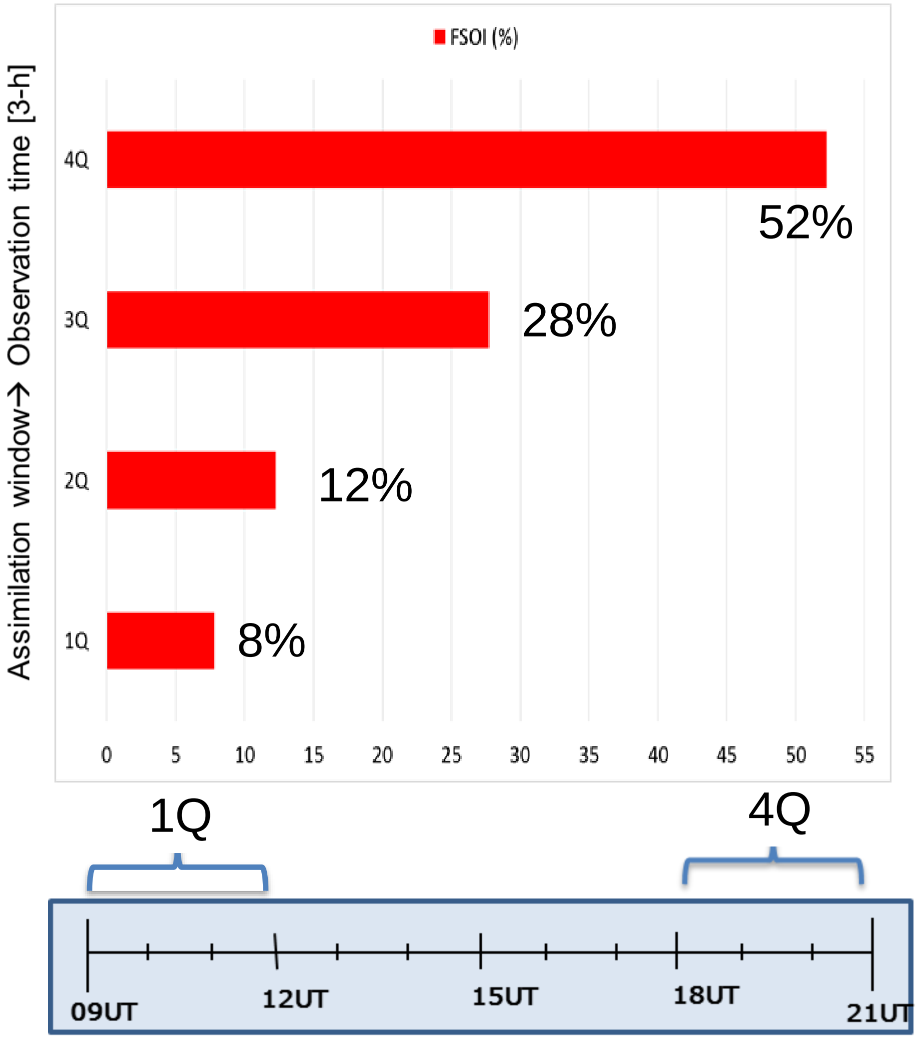


- For all data types, only 50-52% of the observations lead to positive impact on the 24-h forecast!

- The numbers of observations that improve or degrade the forecast are both large.

- Observations assimilated towards the end of the window are more beneficial than the observations assimilated at the beginning of the window.

FSOI depend on observation time in the 4D-Var window

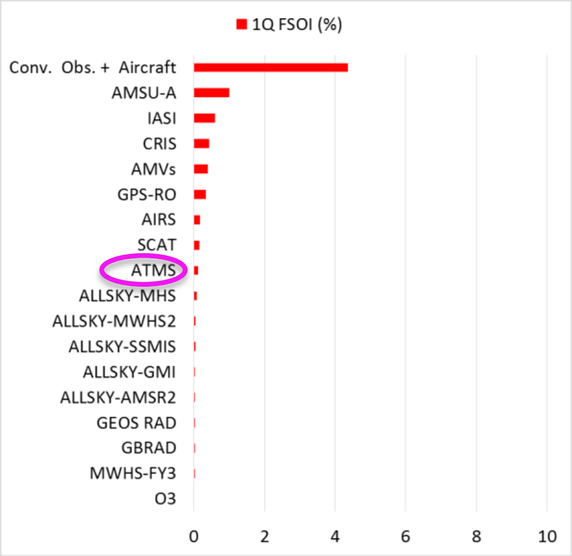


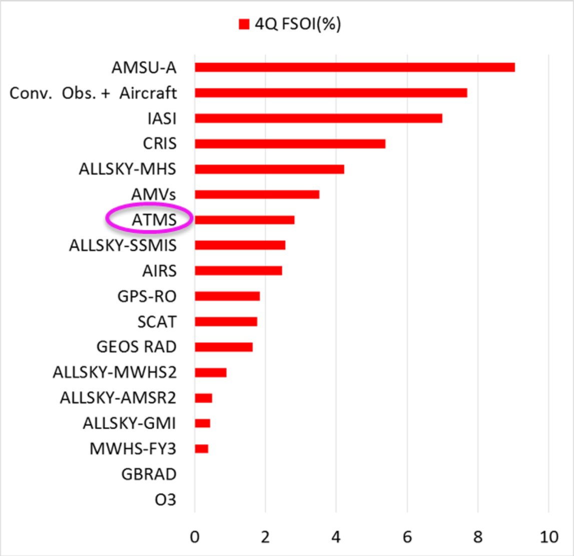
FSOI (4Q) >FSOI (1Q)

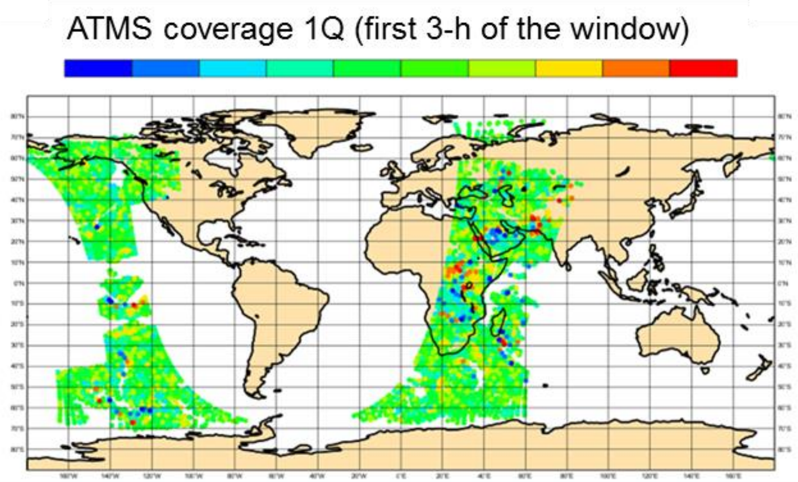
Observations late (4Q) in the 4D-Var window are more influential than data early (1Q) in the window.

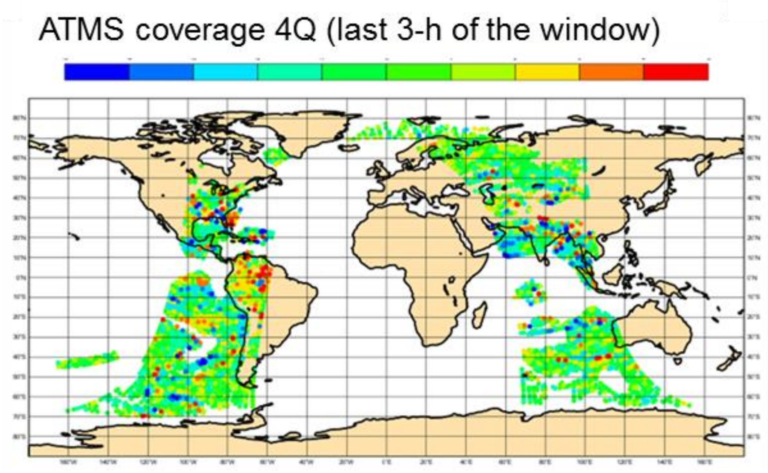
This is because the forecast model can evolve numerous atmospheric variables over time to fit the data at the end of the window.

FSOI by instrument in the 4D-Var window





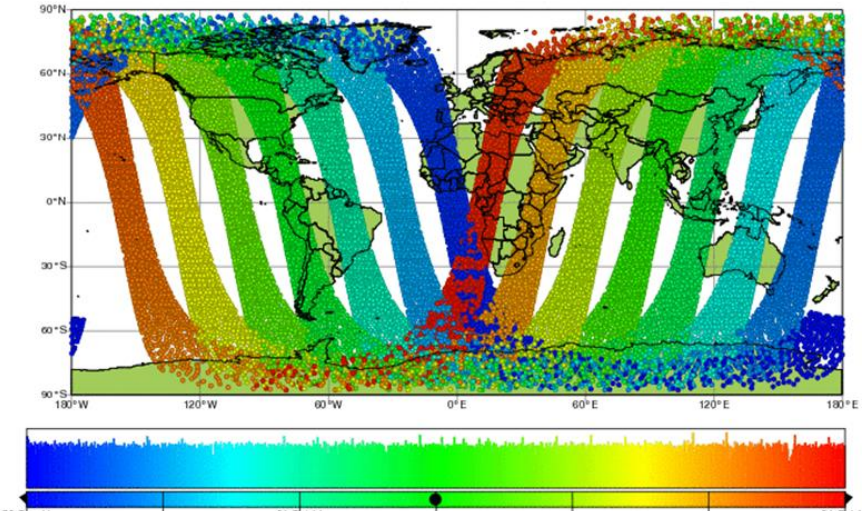

ATMS coverage 1Q (first 3-h of the window)


ATMS coverage 4Q (last 3-h of the window)

Observing the Atlantic: AMSU-A MetOp-A versus NOAA-15

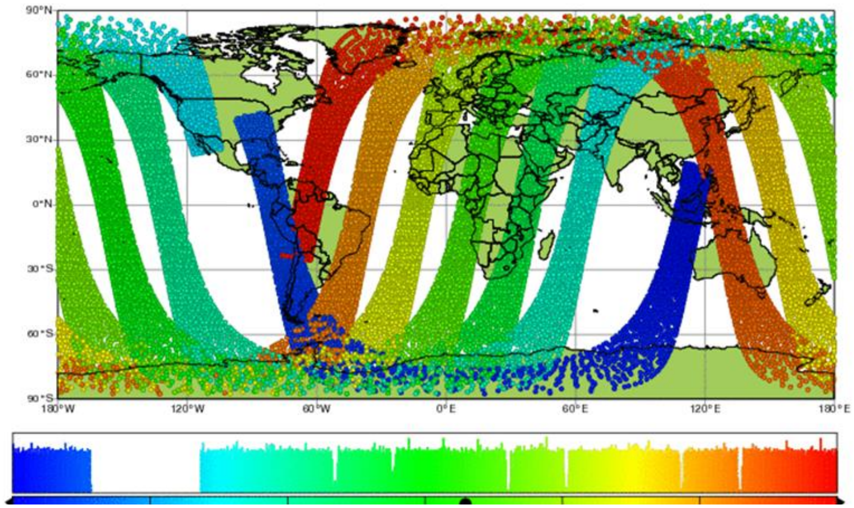
Satellite data (in LEO orbit) typically observe the same location at the same local time each day

…at the beginning of the 4D-Var window (MetOp-A)



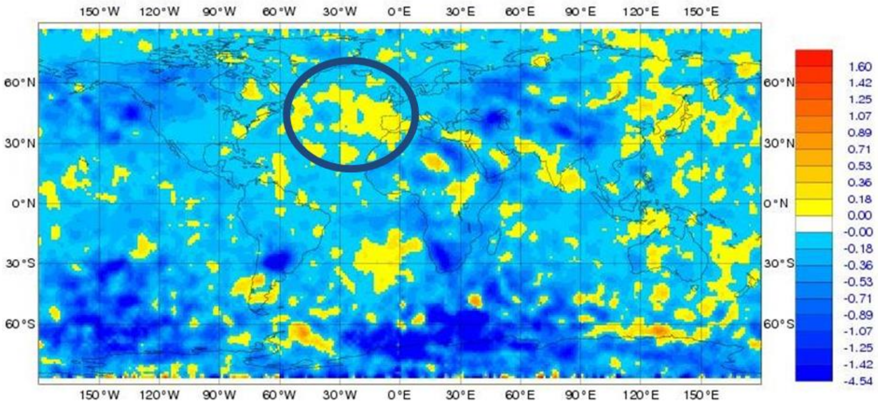
21 23 1 3 5 7 9

…at the end of the 4D-Var window (NOAA-15)

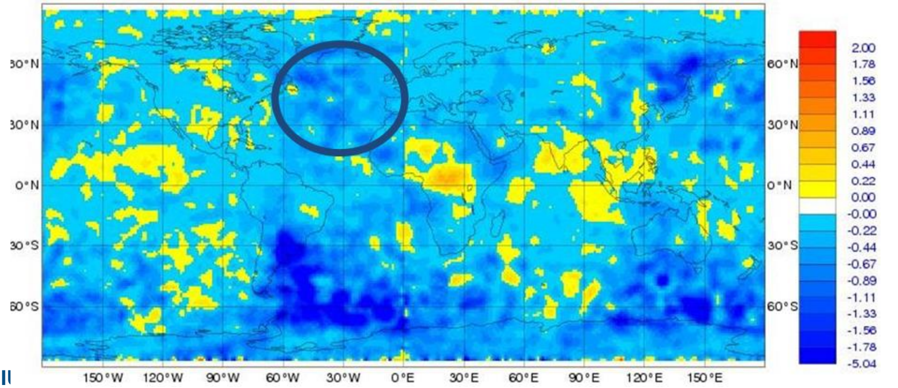


21 23 1 3 5 7 9

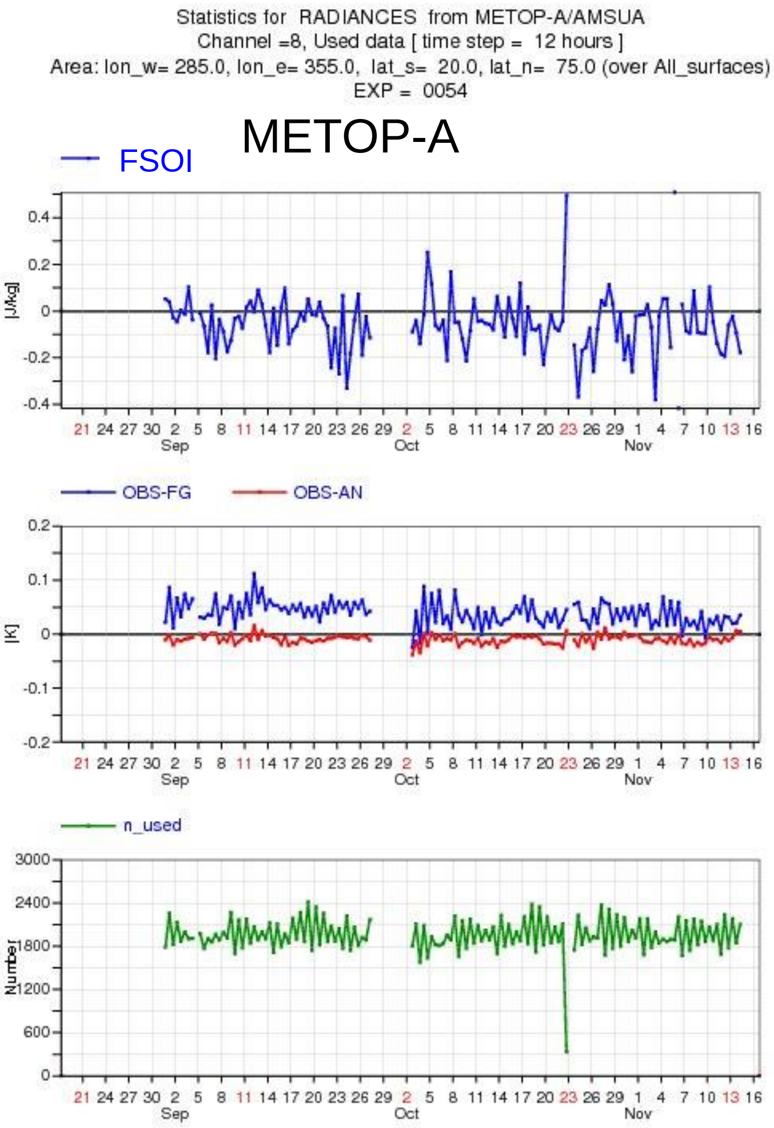
FSOI-negative impact over the N. Atlantic

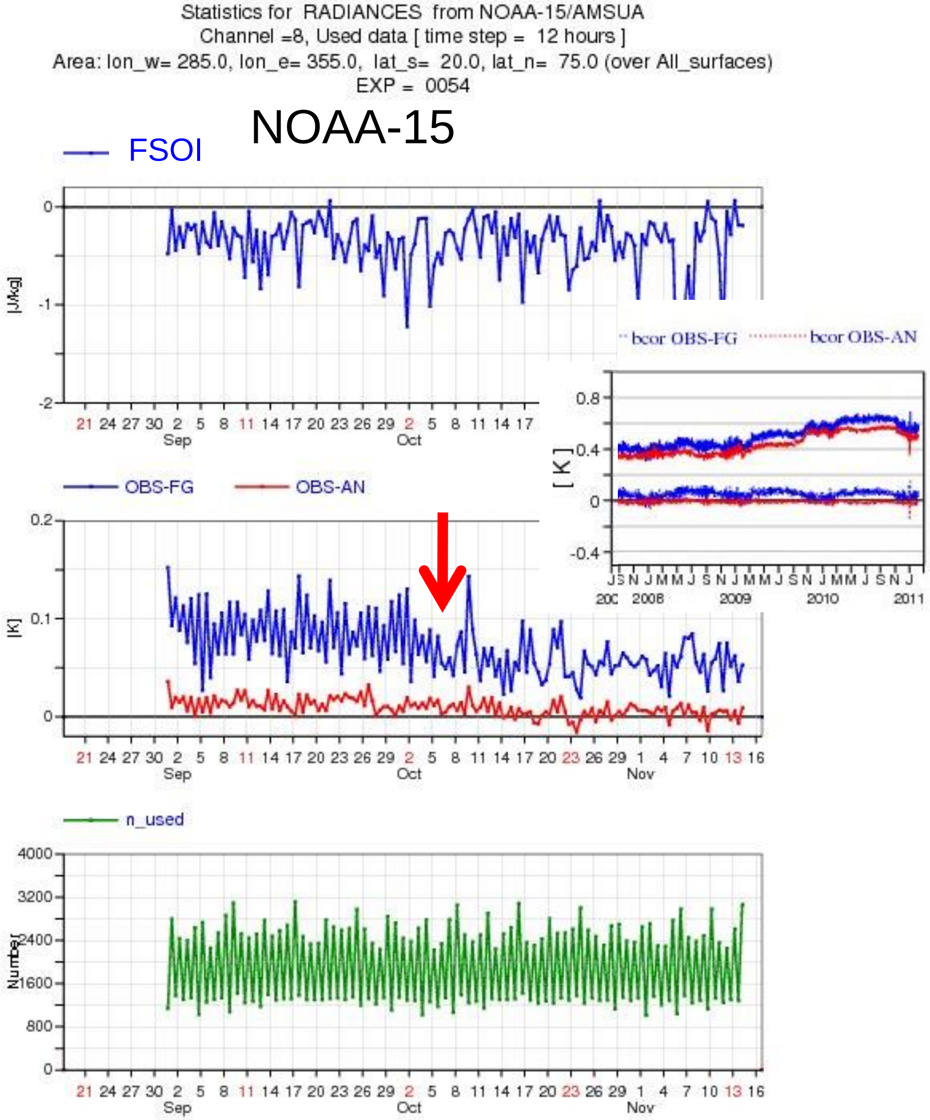


FSOI-positive impact over the N. Atlantic



AMSU-A ch8: FSOI Time series over N. Atlantic





Closing remarks

- **Methods to measure the observation contribution to the forecast quality**

  - **OSEs** give the only clear definitive answer to the question “what if I did not have this satellite ?”
    - The only measure of medium-range observation impact
    - Extremely expensive to run long periods

  - **FSOI Adjoint-derived observations impact**
    - Allows detailed evaluation of observations impact (e.g., individual channels, different regions or separate satellites); Very affordable (compared to OSE)

    - Scientific discussion over the interpretation of FSOI
      - Reliance on norm that has no connections to the DA problem
      - Reliance on validation that is expected to be uncorrelated with initial analysis
      - Reliance on validity of TL approximation
      - FSOI is affected by the optimality of the system - use of incorrect B, R, or an inadequate bias correction, for example, will make the results very difficult to interpret *(e.g., Lupu, 2013, 6th WMO Symposium on Data Assimilation)*

  - **FSOI extends, not replace OSEs** (applicable forecast range, metrics differ)

Closing remarks

- Satellite observations, especially radiance data, are critical for global NWP, but conventional data remain very important.
  - Observing types with the most significant contributions to error reduction for global NWP: MW sounders, hyper-spectral IR sounders, radiosondes, aircraft data and AMVs.
  - On a per observation basis, the impact is dominated by buoys, radiosondes, AMVs and aircraft observations.
  - At ECMWF, the extension of the use of MW humidity-sounding radiances to all-sky leads to a significant improvement of the forecast impact in the ECMWF system (Geer *et al.*, 2017)
- Only a small majority (50-52%) of observations improves the forecast, and most of the overall benefit comes from a large number of observations having small-moderate impacts
  - Reliance on statistics of background and observation errors implies a distribution of positive and negative impacts, regardless of data quality.
  - Imperfect DA method, errors in the verifying analysis may contribute to the number of observations harming the forecast.
- Observations late in the 4D-Var window are more influential than data early in the window.
- Interpretation of forecast improvement or degradation as depicted by the FSOI tool is necessary.

Closing remarks

- Several NWP centres are computing FSOI (Forecast Sensitivity Observation Impact) routinely, although different methodologies are used for different data assimilation systems:

  - **adjoint-based** FSOI (e.g., ECMWF, Met Office, Meteo France, NRL, GMAO, JMA, Bureau of Meteorology)
  - **ensemble-based** FSOI (e.g., NCEP, JMA)
  - **hybrid FSOI for 4DEnVar** (e.g, Env. Canada)

- Aspects of adjoint- vs. ensemble-based results are to be investigated further.

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Thank you for your attention !

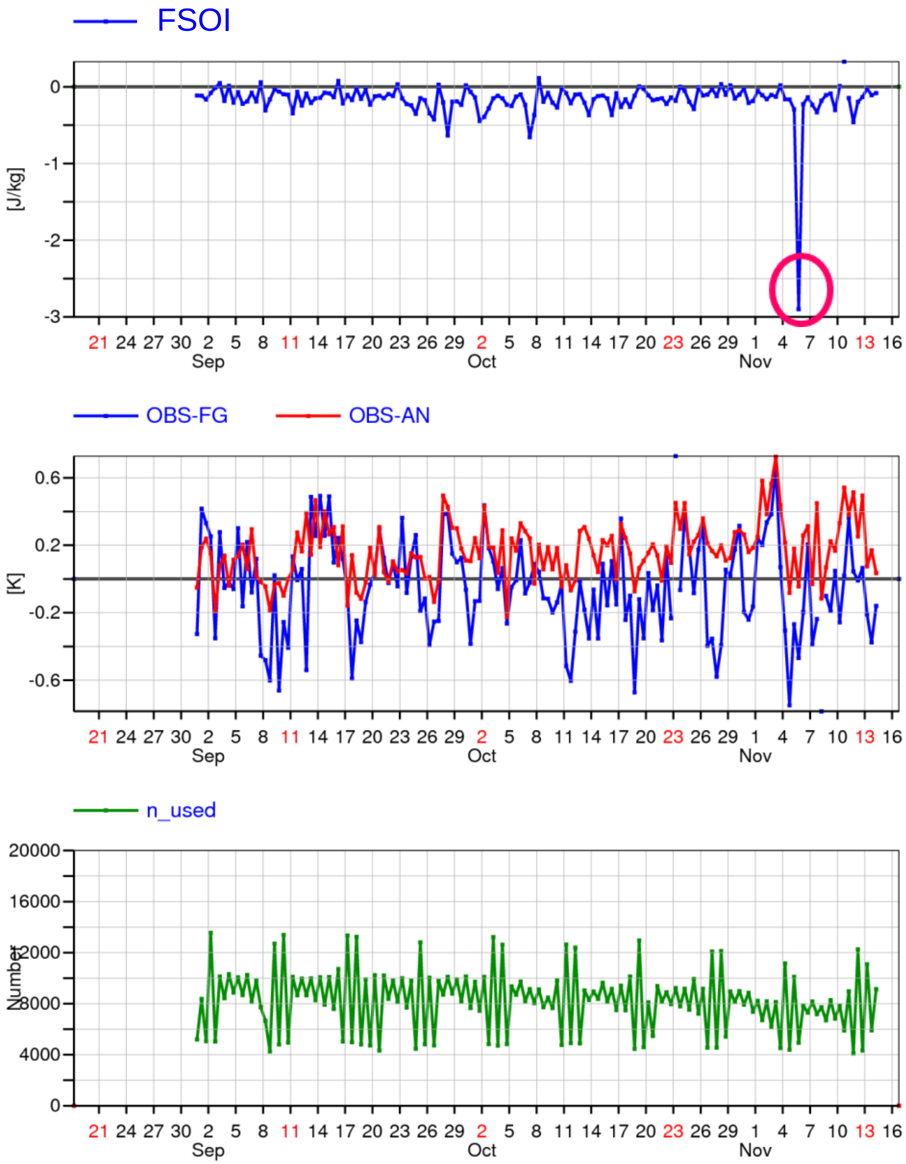
Questions?

A case study of a FSOI spike in the North Atlantic

- Forecast sensitivity monitoring shows a spike in the North Atlantic at 00Z on 6th November 2011
  - A storm develops rapidly, from 990hPa to 950hPa in 42h
  - Increments at 00Z cause the storm to shift to the NW, both at analysis time and through the forecast.
  - Evolved increments at T+24 are as large as 10hPa
- 90% of the forecast sensitivity in the vicinity of the storm comes from DRIBU, ship, AIREP and all-sky SSMIS
  - 50% from DRIBU alone
- SSMIS observes cloud and precipitation in the storm that is 250km too far to the south-east in the first guess
  - This is corrected in the analysis
- OSEs validate the forecast sensitivity diagnostic
  - DRIBU, AIREP and SSMIS are real contributors to the pattern of increments that shifts the storm

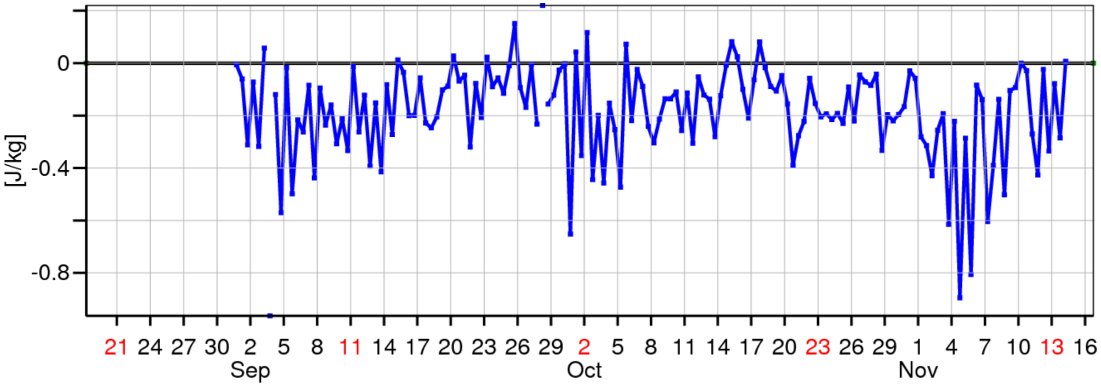
Operational FSOI monitoring
SSMIS, N Atlantic, autumn 2011

- A case study of a FSOI spike in the North Atlantic on 6th Nov. 2011

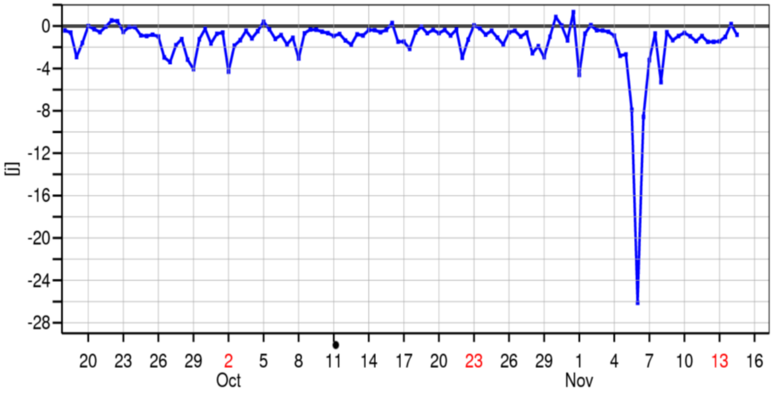


FSOI North Atlantic, autumn 2011

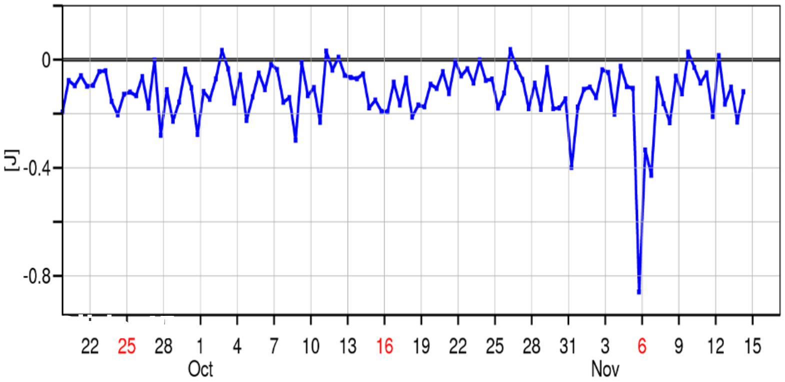
AMSU-A on NOAA-19



DRIBU

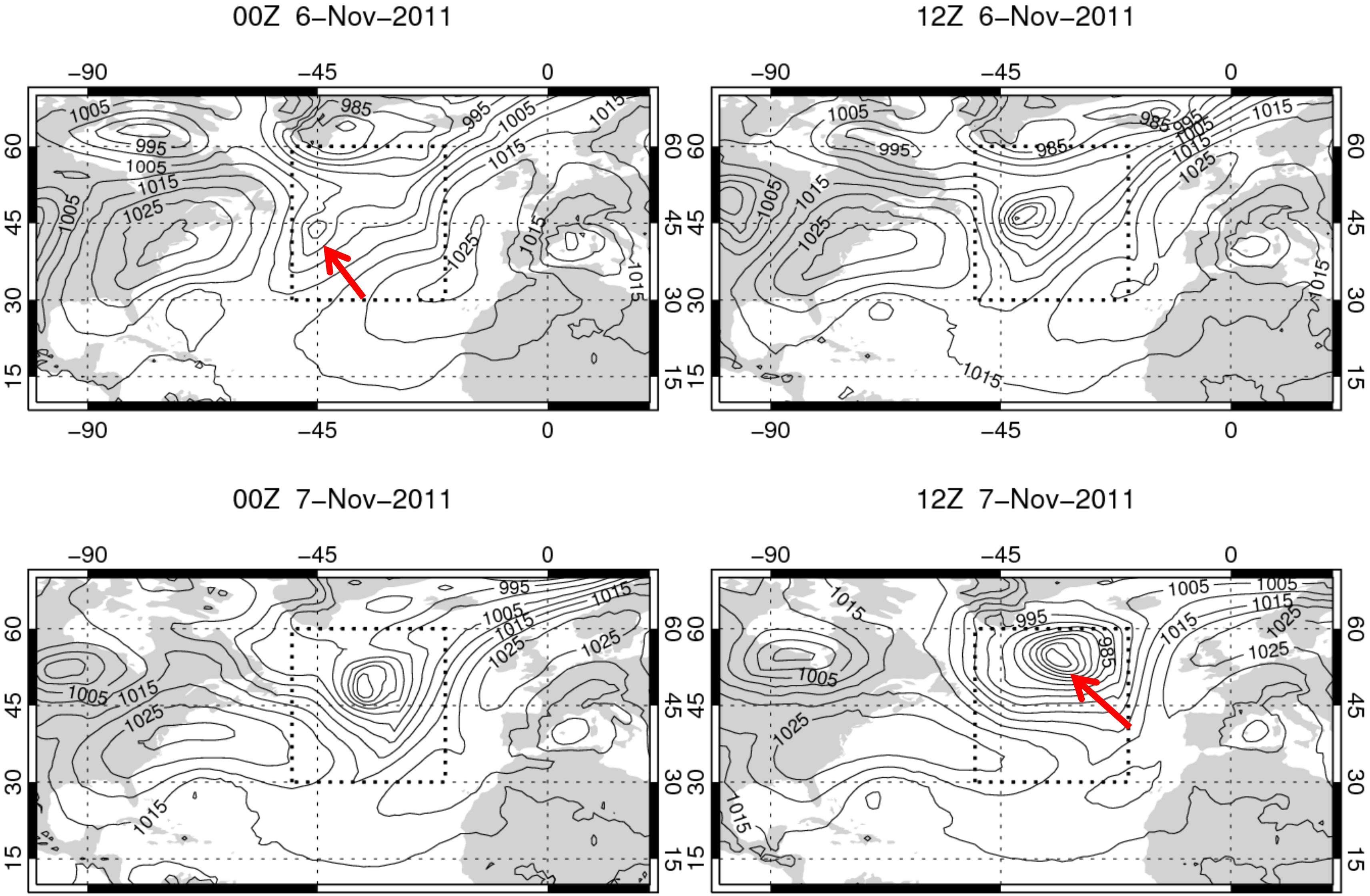


Aircraft



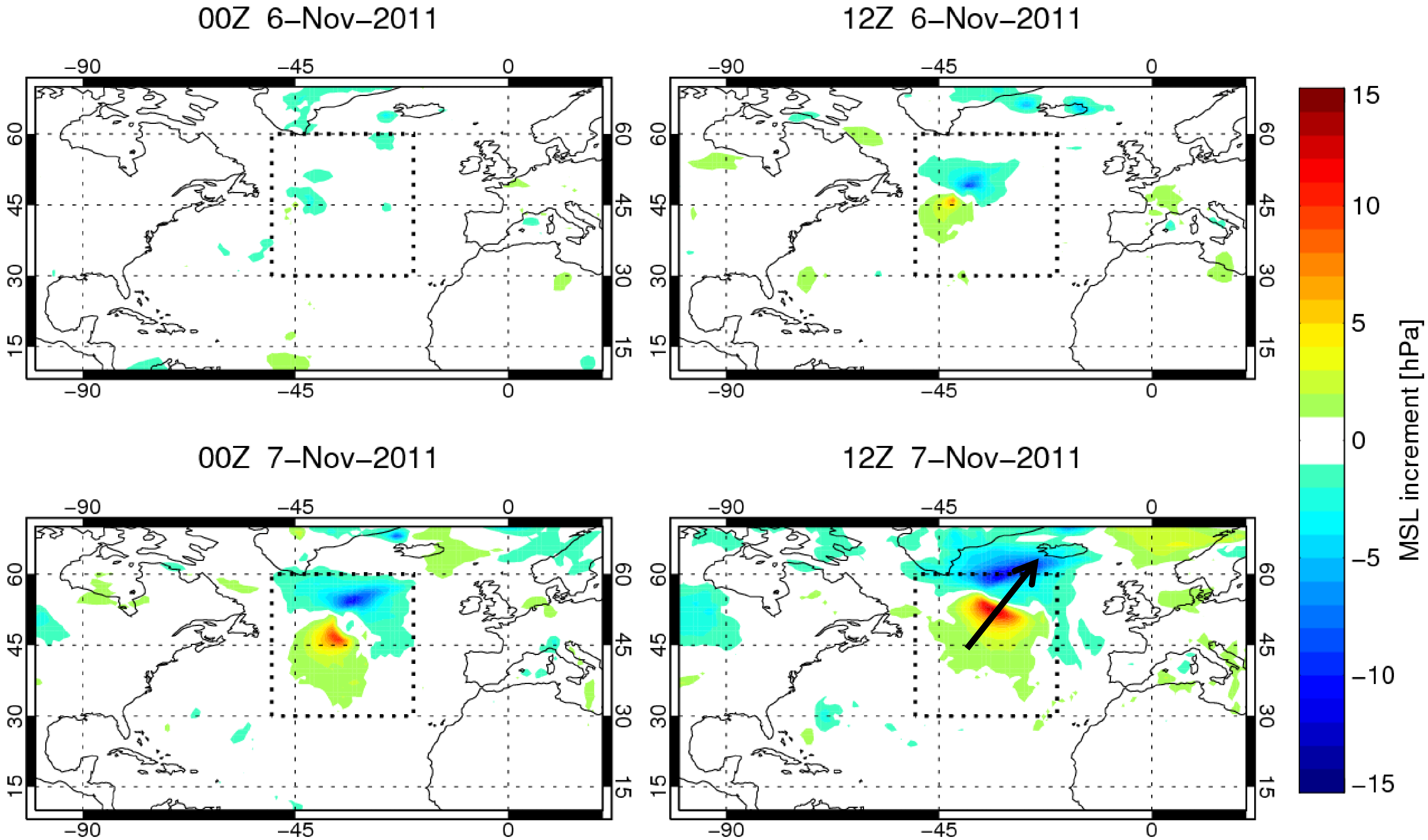
6th November: a rapidly developing storm

Mean sea level pressure: analysis and subsequent forecasts



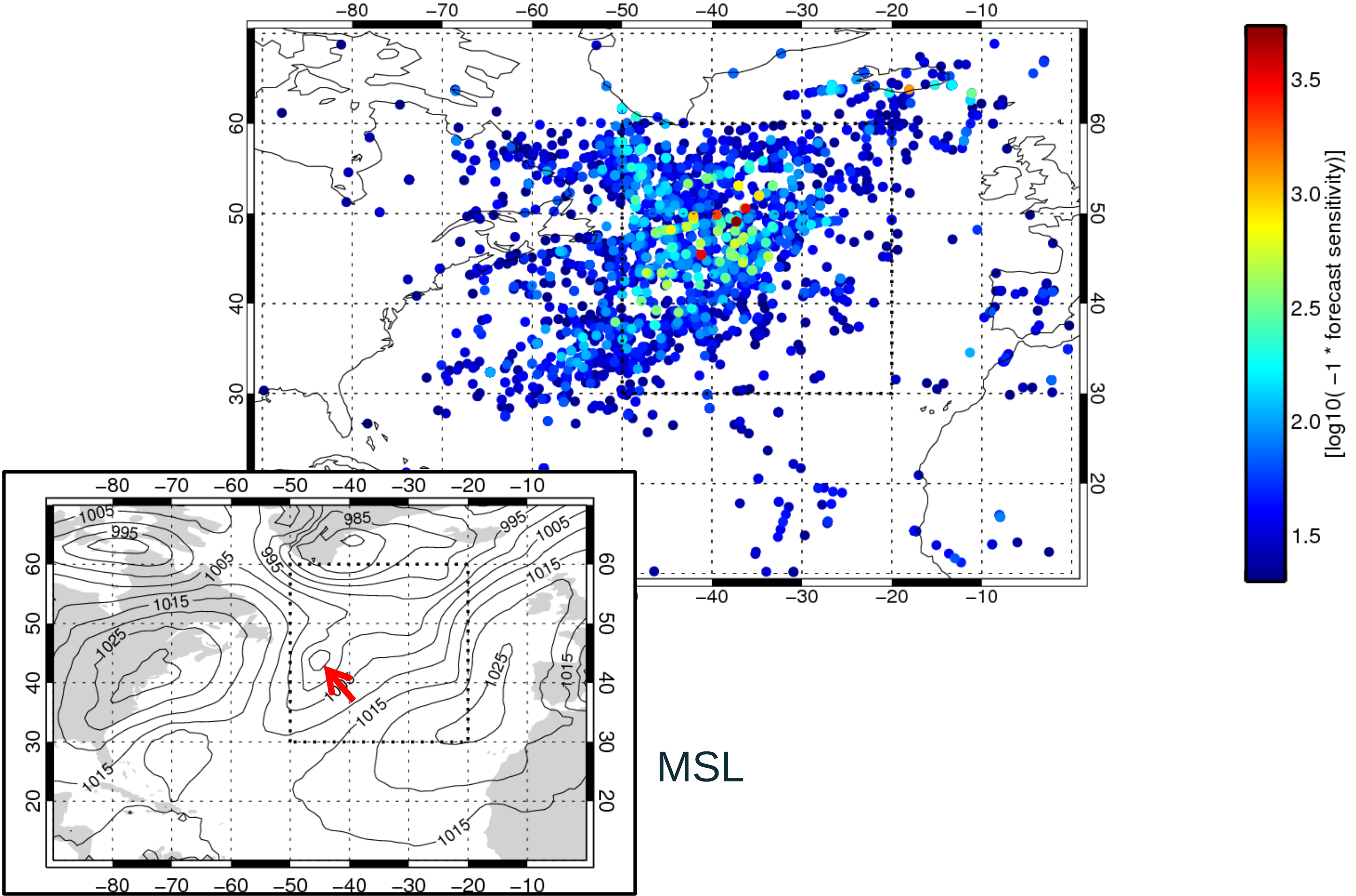
Minimum pressure goes from 990hPa to 950hPa between 00Z, 6/11 and 18Z, 7/11

Mean sea level pressure: evolved increments
(forecast from 00Z 6th Nov minus forecast from 12Z 5th Nov)



00Z 6th Nov analysis shifts the storm to the NW

Forecast sensitivity 00Z 6th November

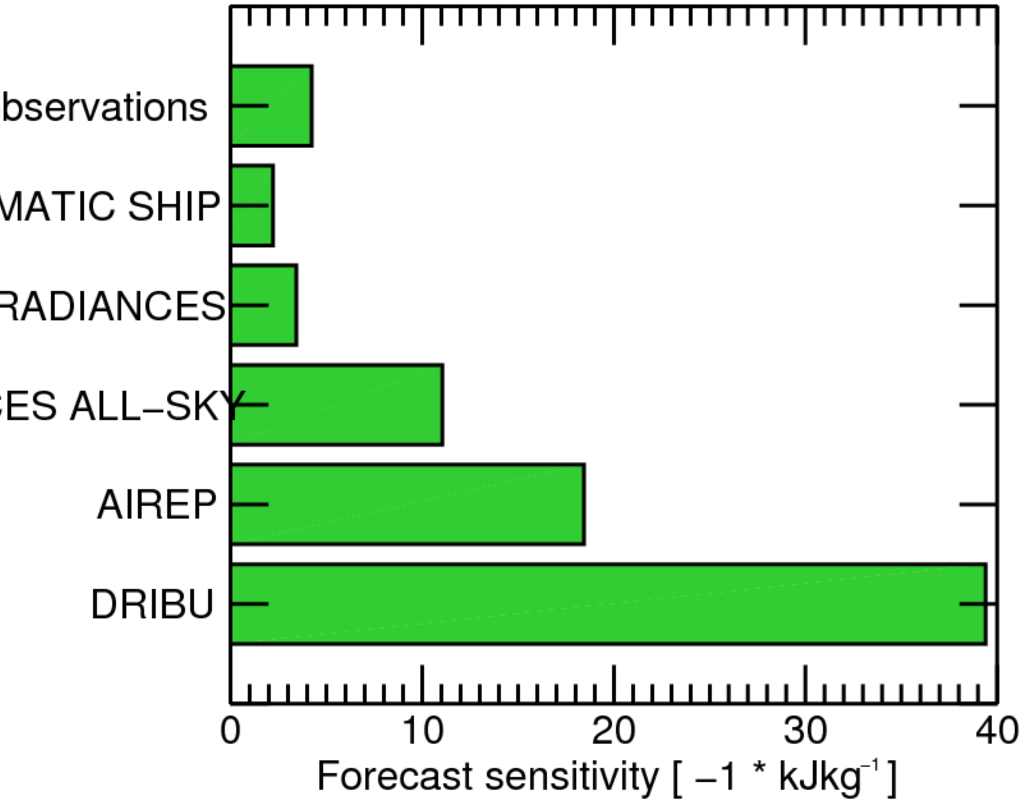


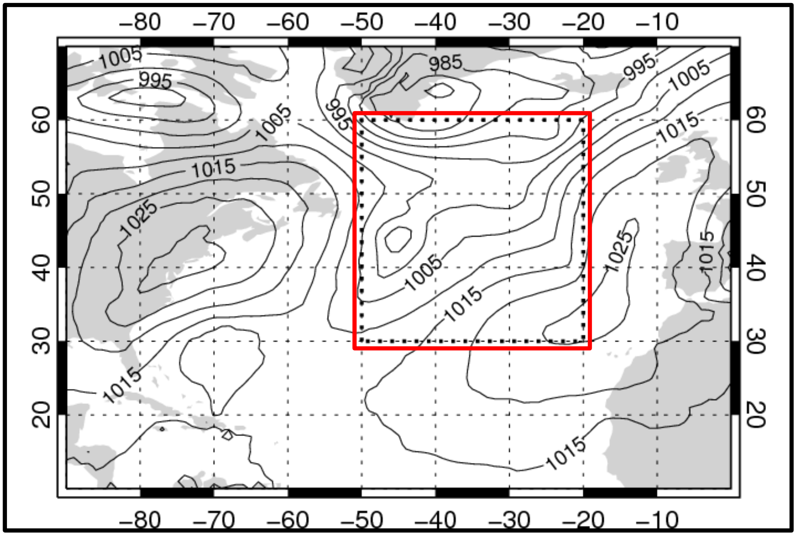
FSOI
:log
scale

MSL

Forecast sensitivity: 00Z 6th November

Total in the 30 by 30 degree box, by report type

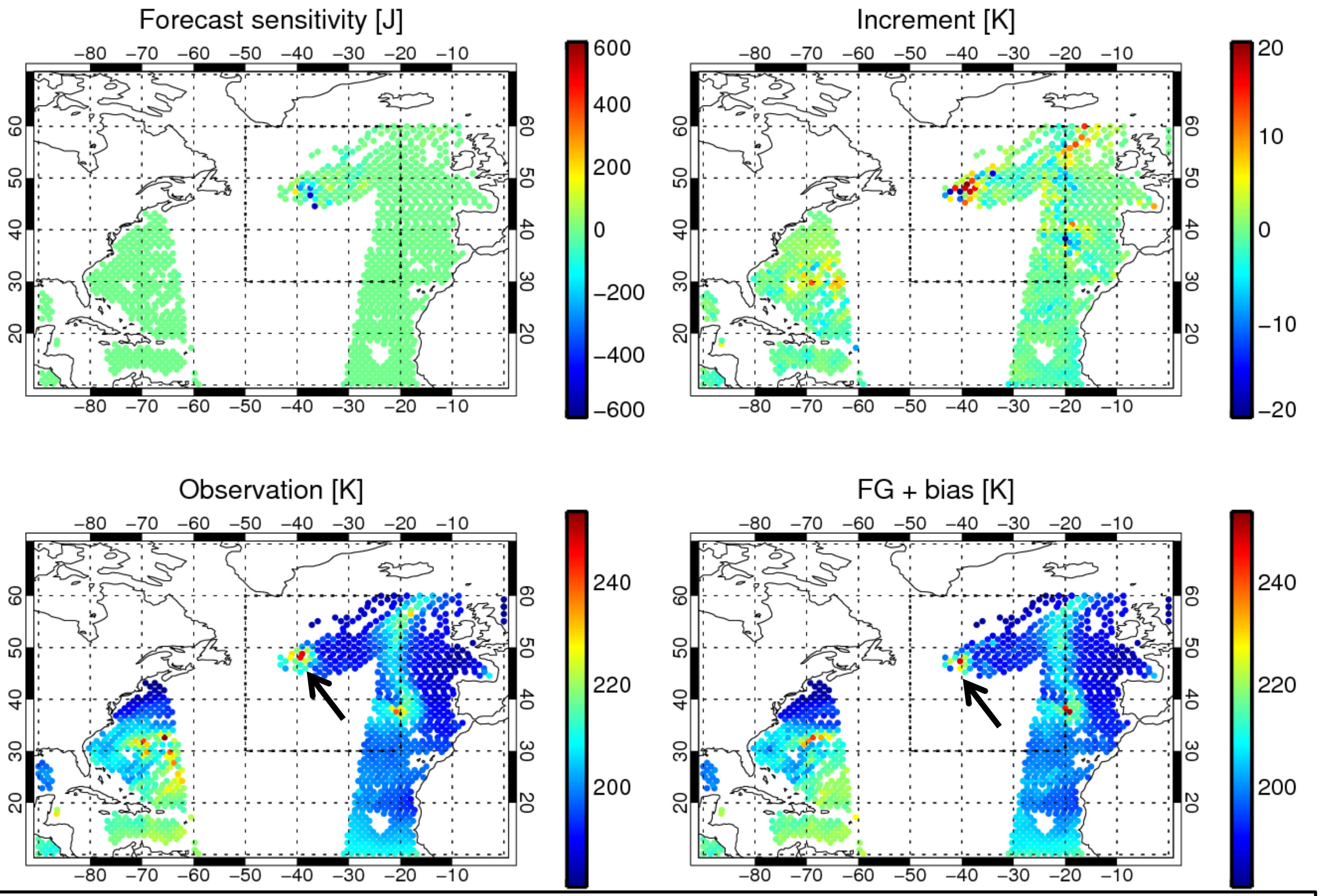




MSL

EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

All-sky SSMIS: channel 19v


Forecast sensitivity [J]

Increment [K]

Observation [K]

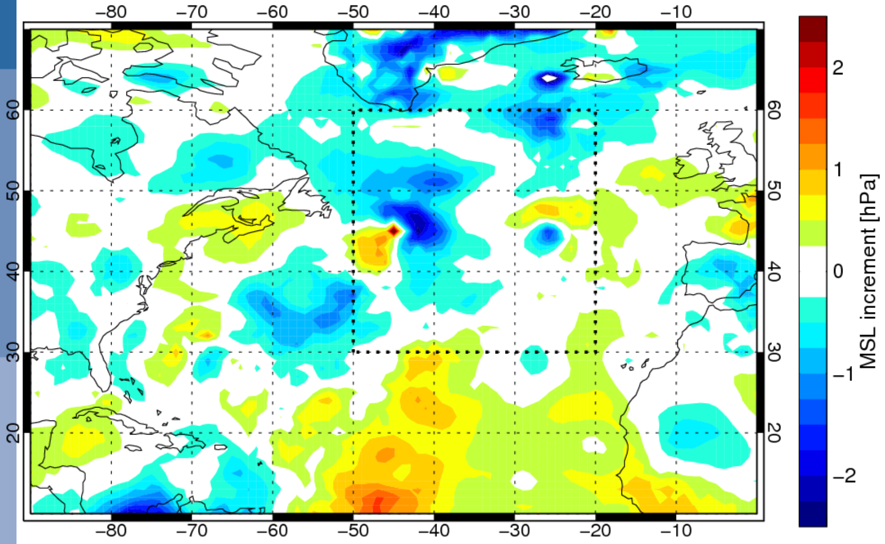
FG + bias [K]

Cloud and precip shifted ~250km to the NW in accordance with observations

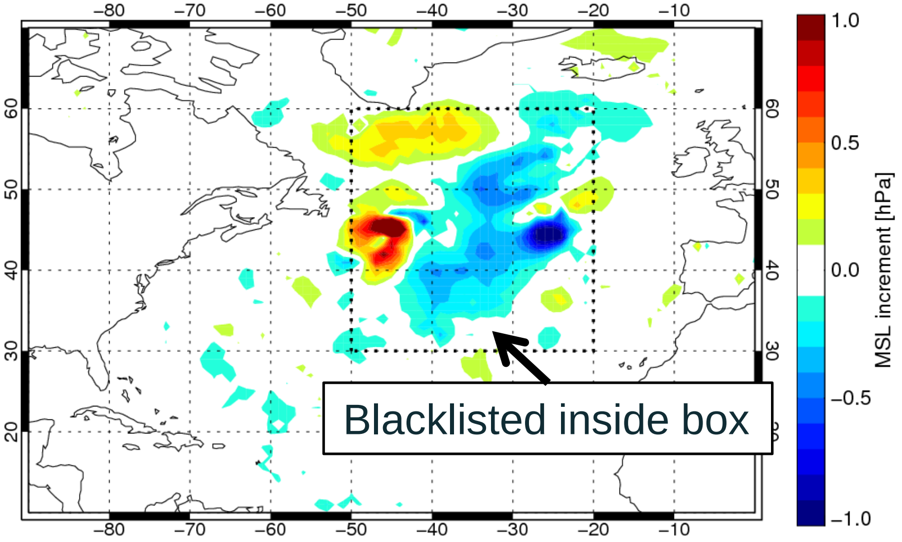
Denial OSEs vs. operations

Mean sea-level pressure increment at 00Z, 6th November

Operations: total increment

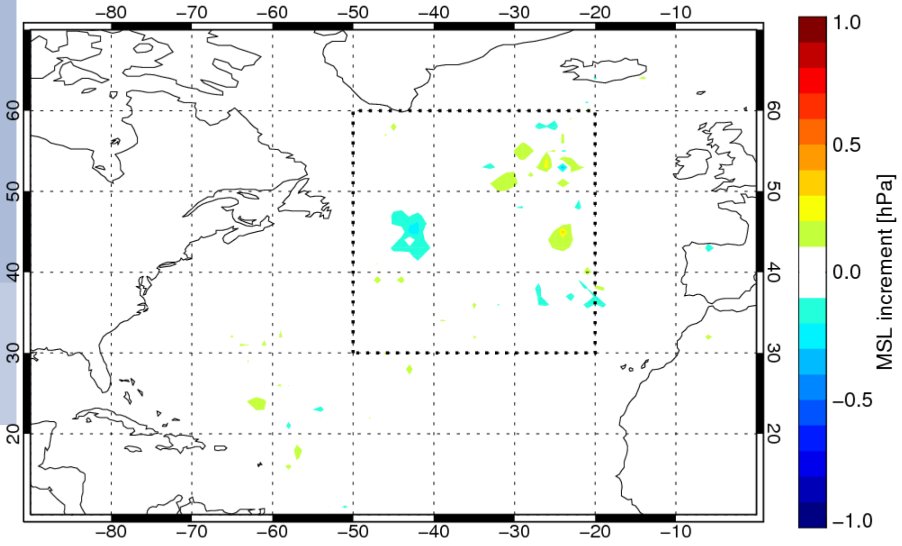


Ship and DRIBU: change in increment



Blacklisted inside box

All-sky SSMIS F-17 (change)



AIREP (change)