Impact of satellite data on global NWP

Tony McNally

Thanks: **Cristina Lupu**, Carla Cardinali, Alan Geer, Richard Forbes, Katrin Lonitz, Michail Diamantakis, Carole Peubey

Where science meets politics and money!

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Overview

- What do we mean by impact (analysis / forecasts)
- What factors influence impact ?
- What diagnostics are available to measure impact and are they reliable ?
- An assessment of current satellite impact on NWP forecasts
- How satellite data impact model development

History of SAT impact

- Early experiments (FGGE ?) showing SAT data useful in the SH, but not the NH (early OPS configuration reflected these results)
- SAT data are currently the highest impacting OBS in all regions – how did we get here ?
- Clues from ERA FC scores ?
- Impacts from different components of the SAT network – can we reliably measure these ?
- Estimating impact of future systems ?

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What do we mean by impact ?

- For this talk we focus on **forecast** impact
  - Range (12hrs, 5 days, 10 days…)
  - Parameter (gp height, wind, temperature, humidty …)
  - Altitude (surface, 500hPa, 1hPa)
  - Region (global, NH, SH, Tropics, Europe)

Note: Observation impact has a sign ….it can be good and bad!

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Factors that determine impact ?

- Observation quality
- Observed quantity (important ? already known?)
- Observation usability (ambiguity)
- Observation spatial coverage
- Observation time
- Tuning of the assimilation system (correct specification of B, R, BC, QC)

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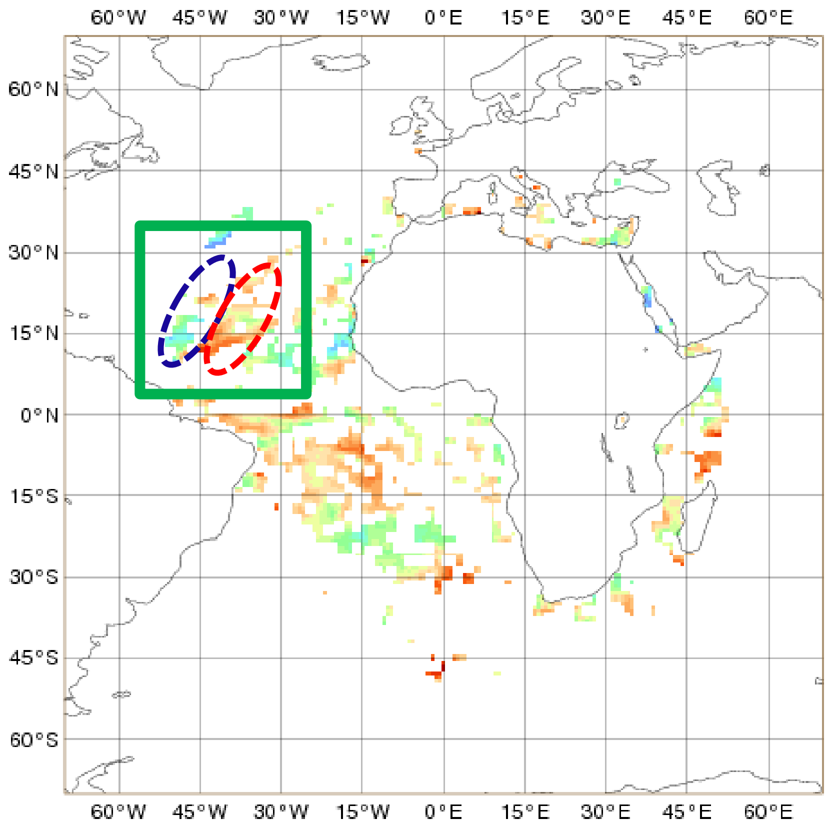
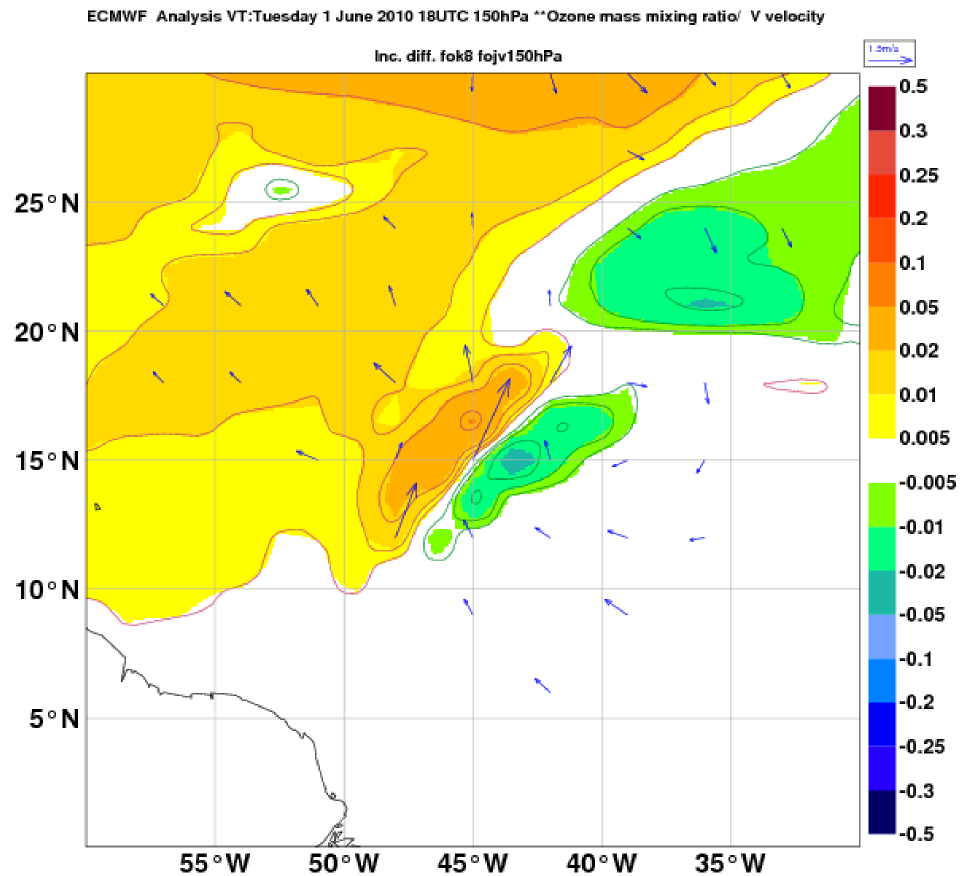
Observation time in 4D-Var window

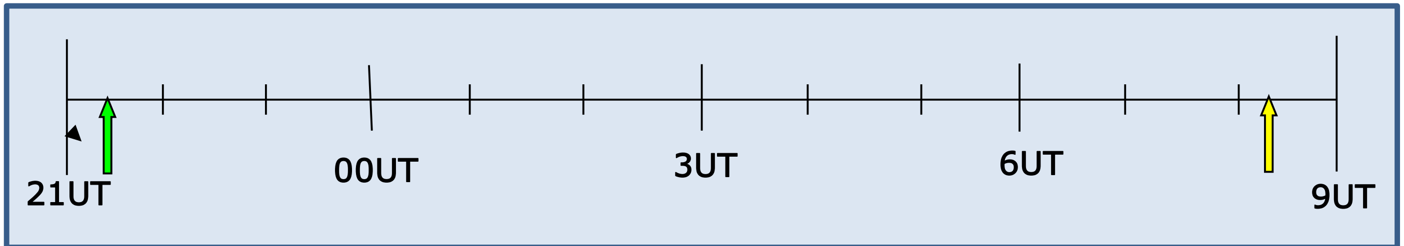
Instead of creating and destroying water vapour / ozone locally (to fit observations) 4D-Var can **change the wind field** to advect the misplaced feature

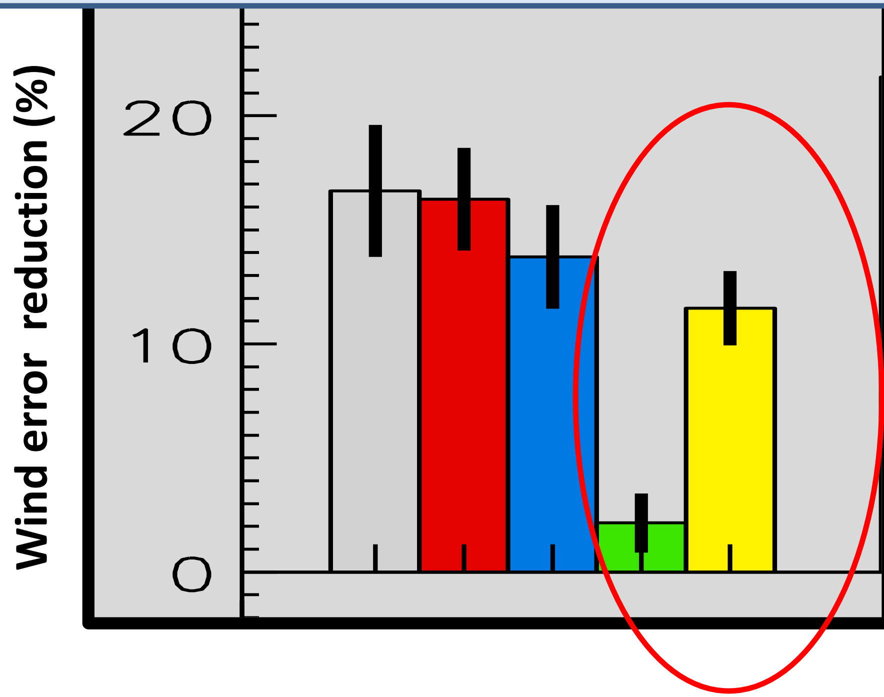


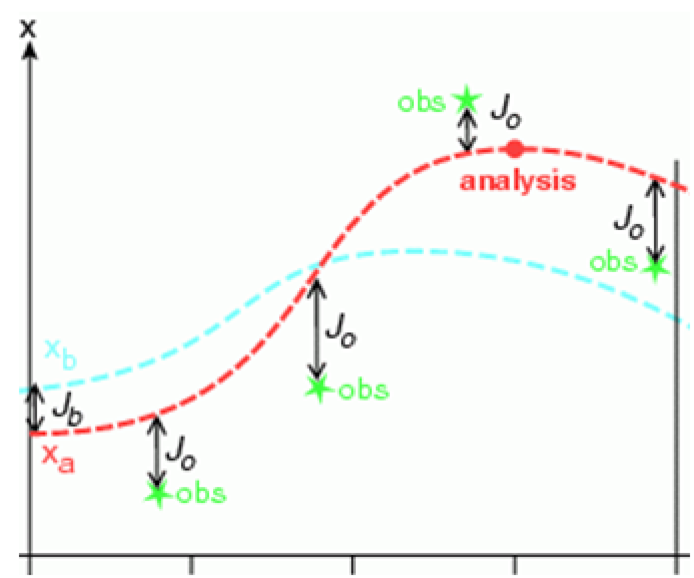


Observation time in 4D-Var window

The impact of the feature advection (wind tracing) depends on the location of the observation within the 4D-Var window



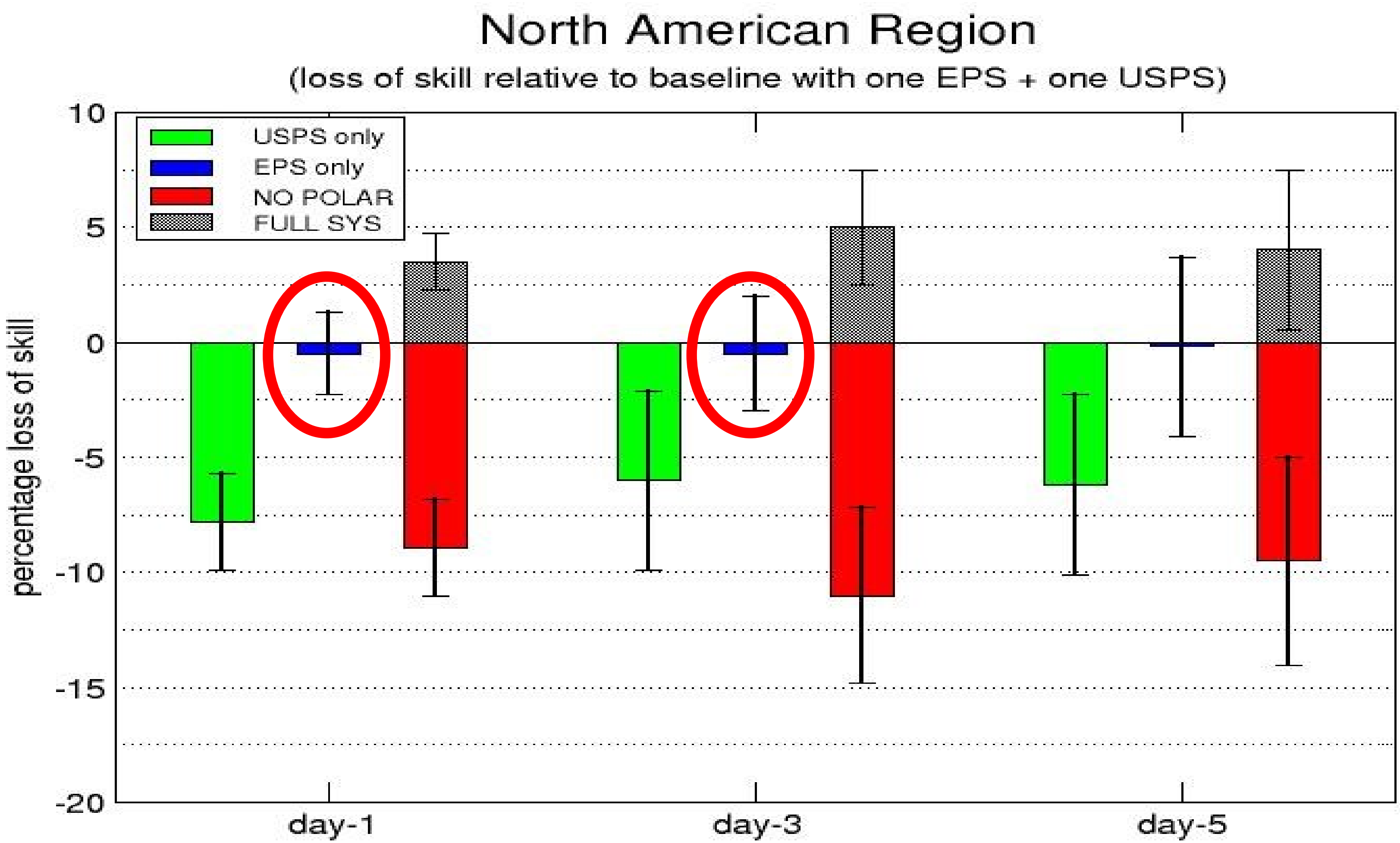




Observation location in 4D-Var window

Observing system	Baseline (EPS+USPS)	EPS only	USPS only	No Polar sounders
Conventional	Yes	yes	yes	yes
GEO (RAD+AMV)	yes	yes	yes	yes
IRS	Yes (AIRS+IASI)	Yes (IASI)	Yes (AIRS)	no
MWS	Yes (2 AMSUA/B/MHS)	Yes (AMSUA/MHS)	Yes (AMSUA/B)	no
MWI	Yes (AMSRE)	no	Yes (AMSRE)	no
SCAT	Yes (ASCAT)	Yes (ASCAT)	no	no
GPSRO	Yes (GRAS)	Yes (GRAS)	no	no

No impact of USPS over USA !



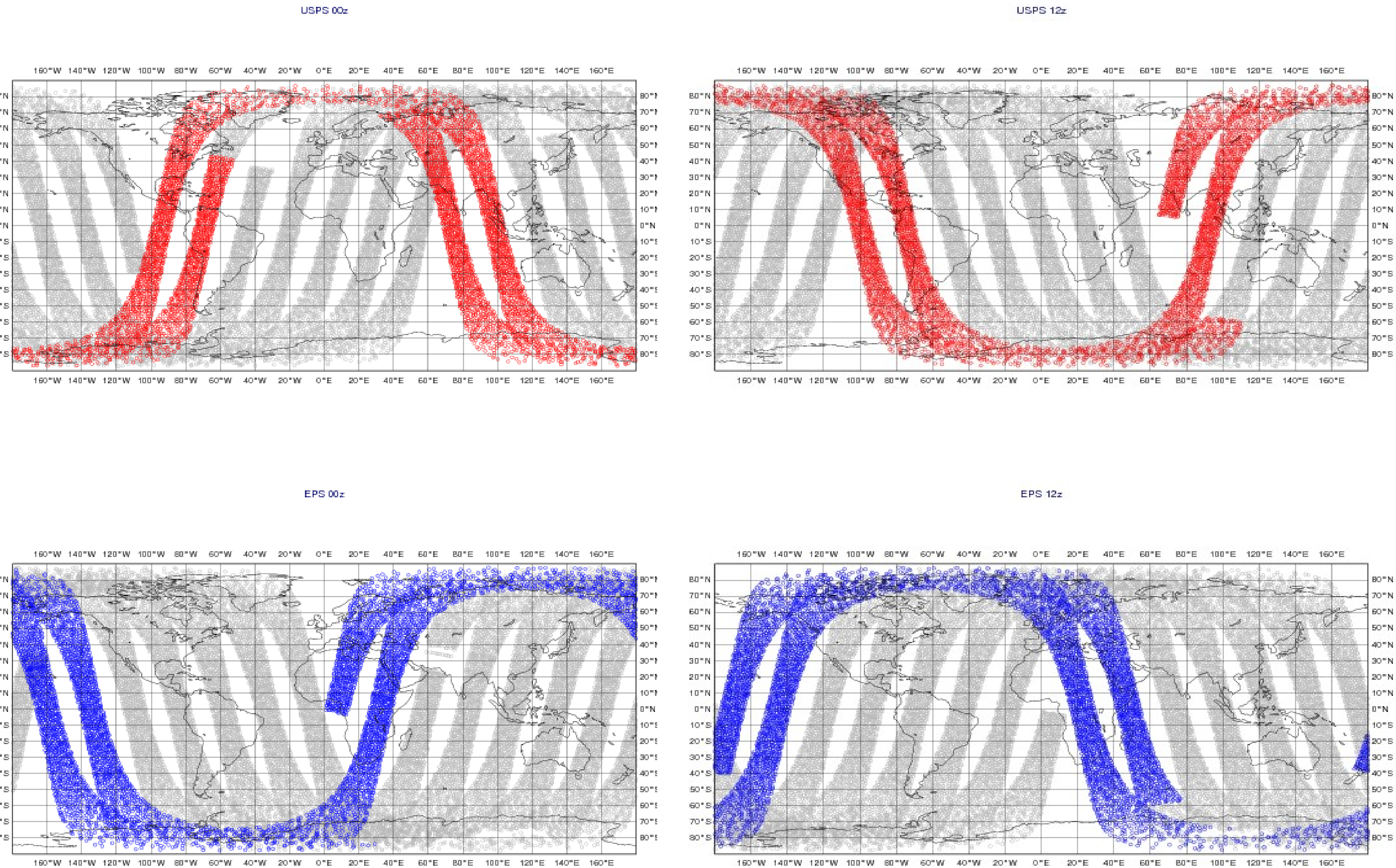
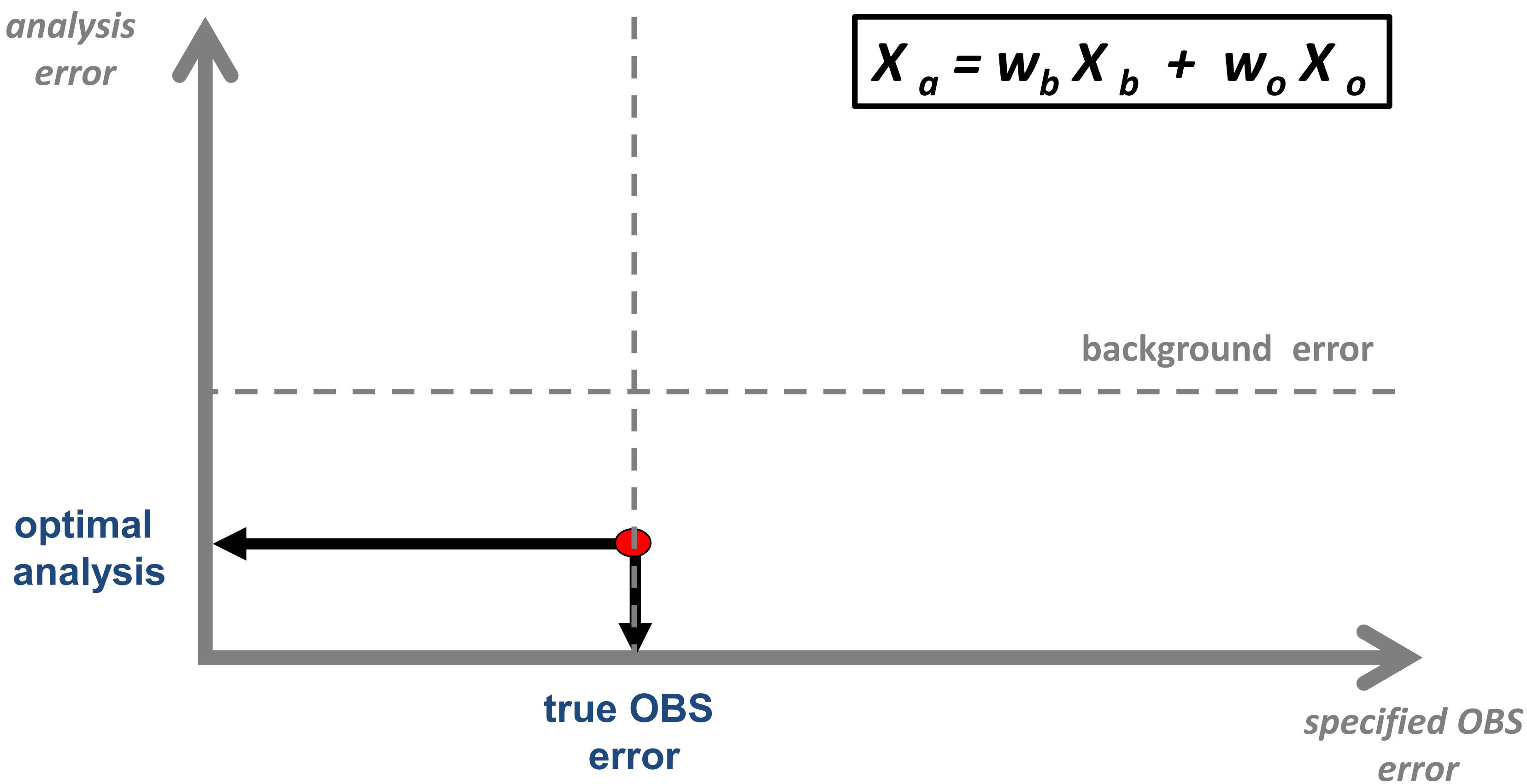


Figure 2. *Orbits of the EPS and USPS in the 00z (left) and 12z (right) 4DVAR 12 hour assimilation window. Those coloured red (for USPS) and blue (for EPS) are observed in the lattermost 3 hours of the assimilation window.*

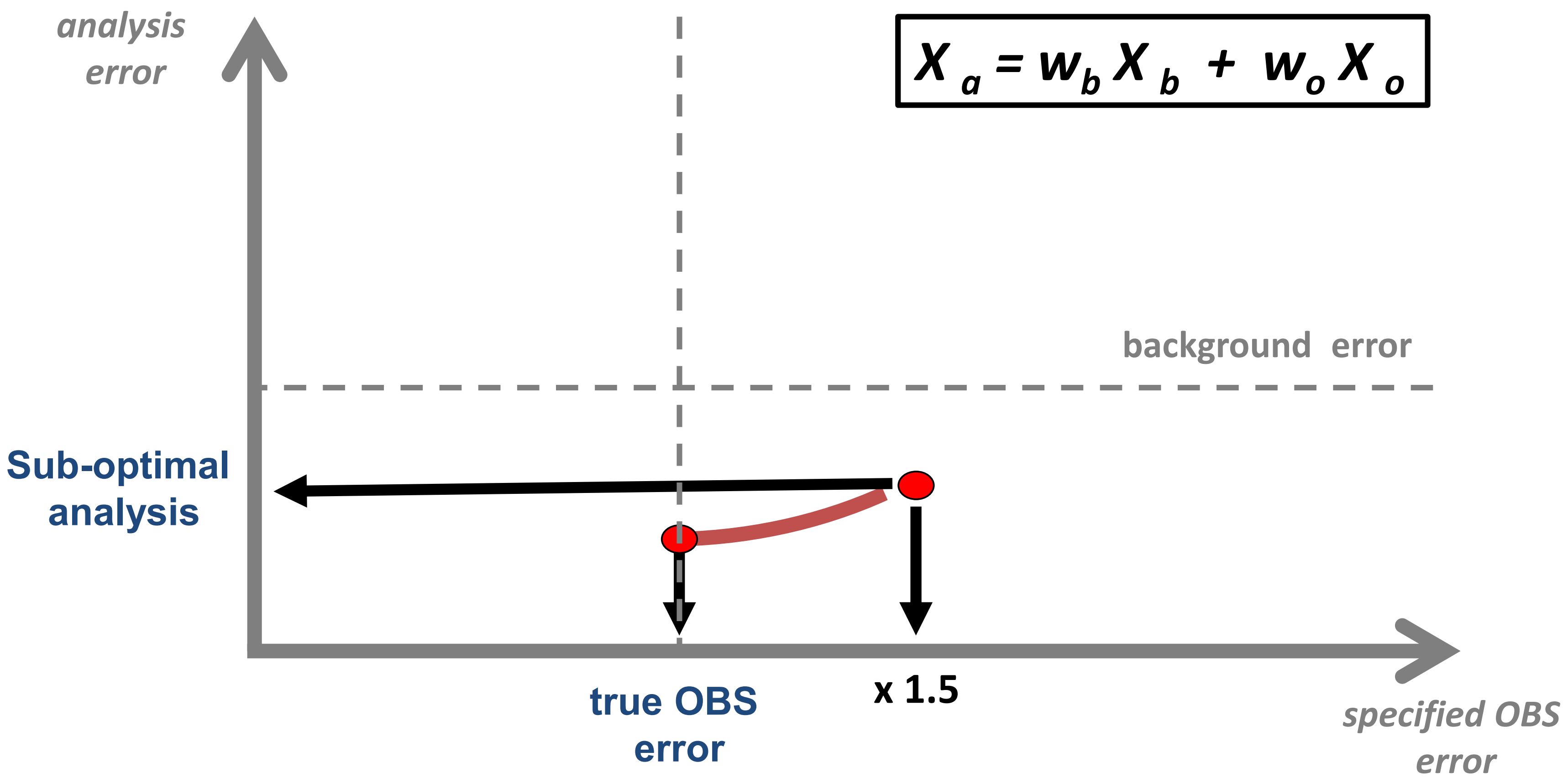
Factors that determine impact ?

- Observation quality
- Observed quantity (important ? already known?)
- Observation usability (ambiguity)
- Observation spatial coverage
- Observation time
- Tuning of the assimilation system (correct specification of B, R, BC, QC)

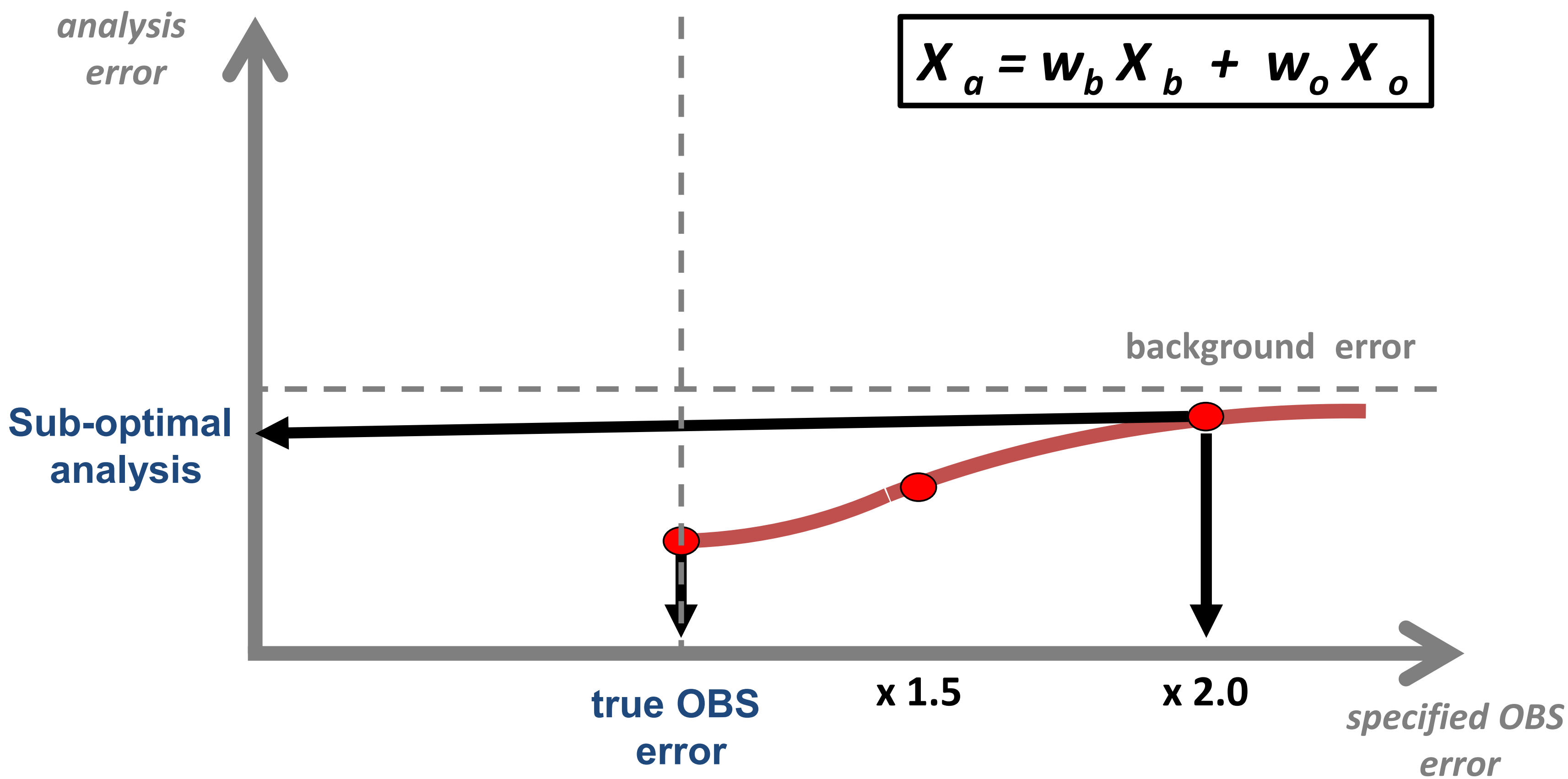
- Specifying the **correct** observation error produces an optimal analysis with minimum error.



- **Over-estimating** the observation error degrades the analysis…



- **Over-estimating** the observation error degrades the analysis, but the result will not be worse than the background.



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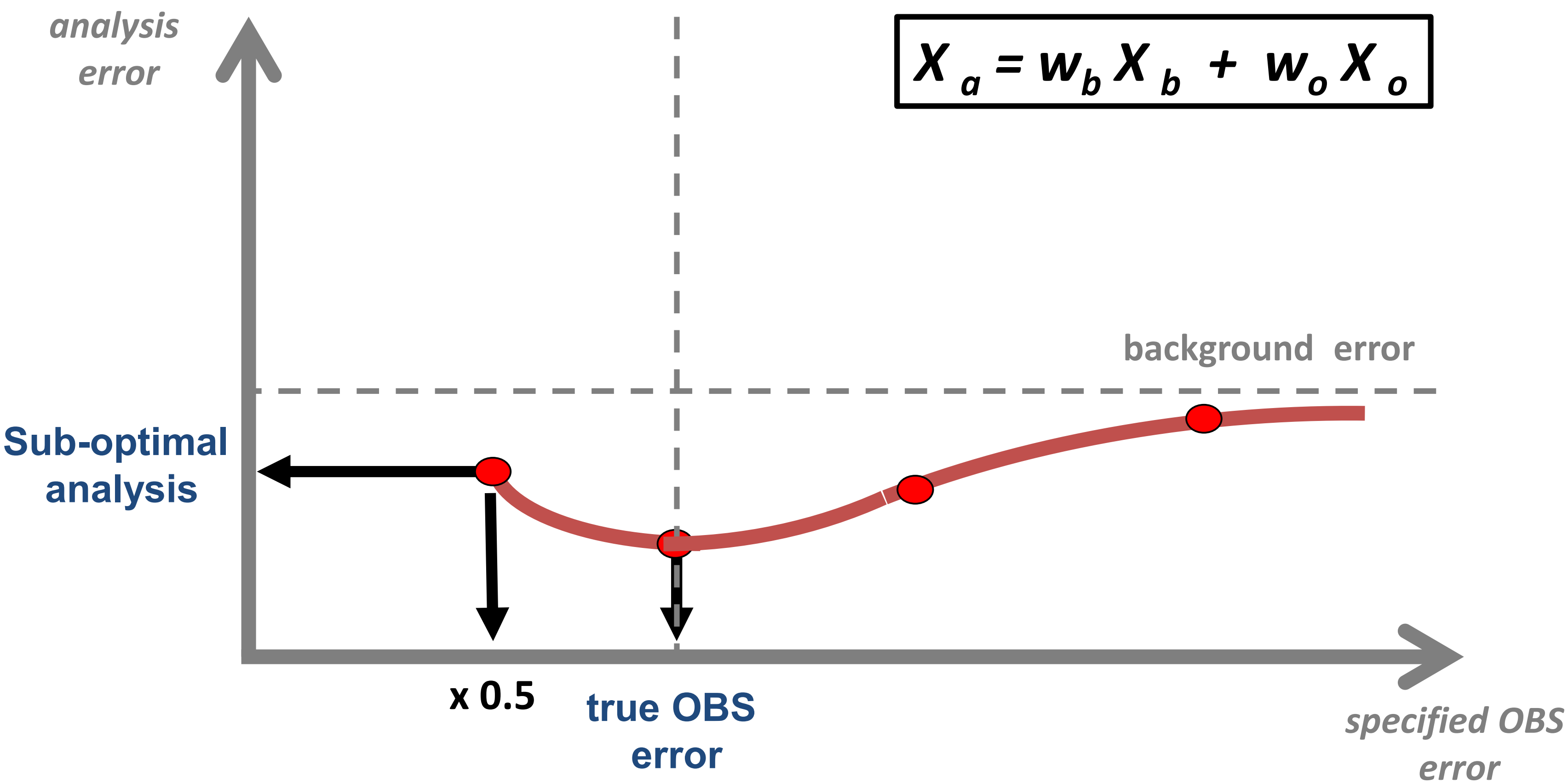
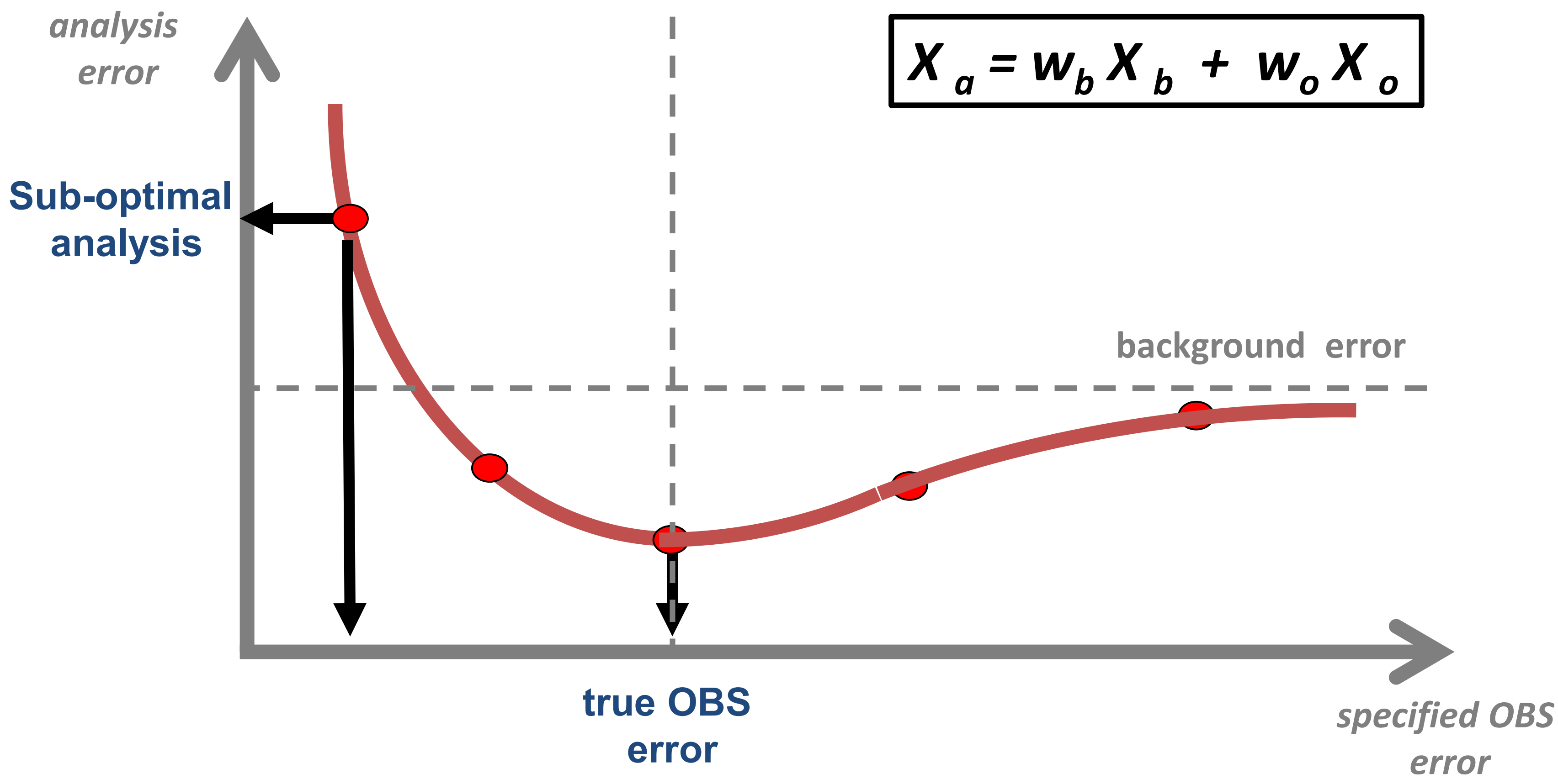


- **Under-estimating** the observation error degrades the analysis and the result can be **worse than the background!**



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Diagnostics Available

- **Observing System Experiments (OSE)**
  - Denial or addition experiments
  - Periodic statistical evaluations
  - Case studies

- **Adjoint Sensitivity Diagnostics (ASD)**
  - Impact assessed without denial
  - Periodic statistical evaluations
  - Case studies ?

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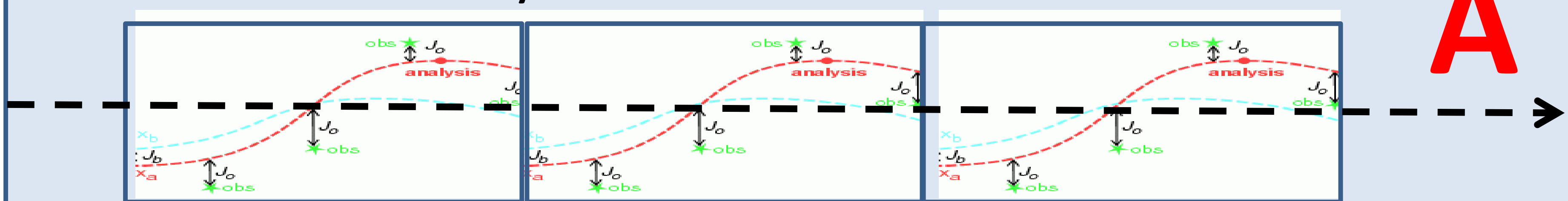
Observing System Experiments

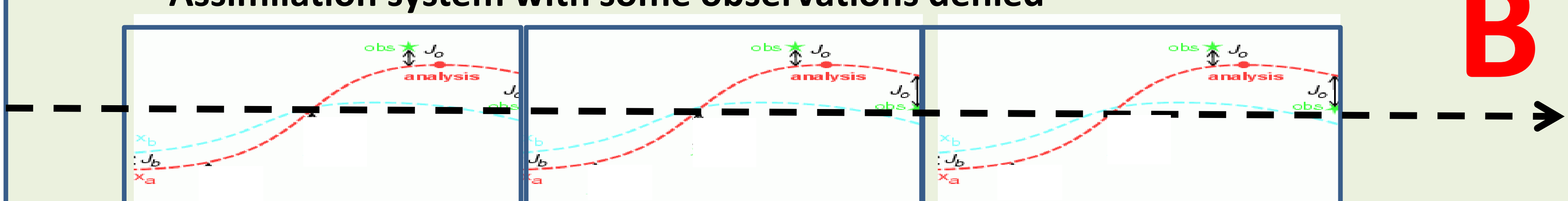
Control assimilation system with all observations

A



Assimilation system with some observations denied

B



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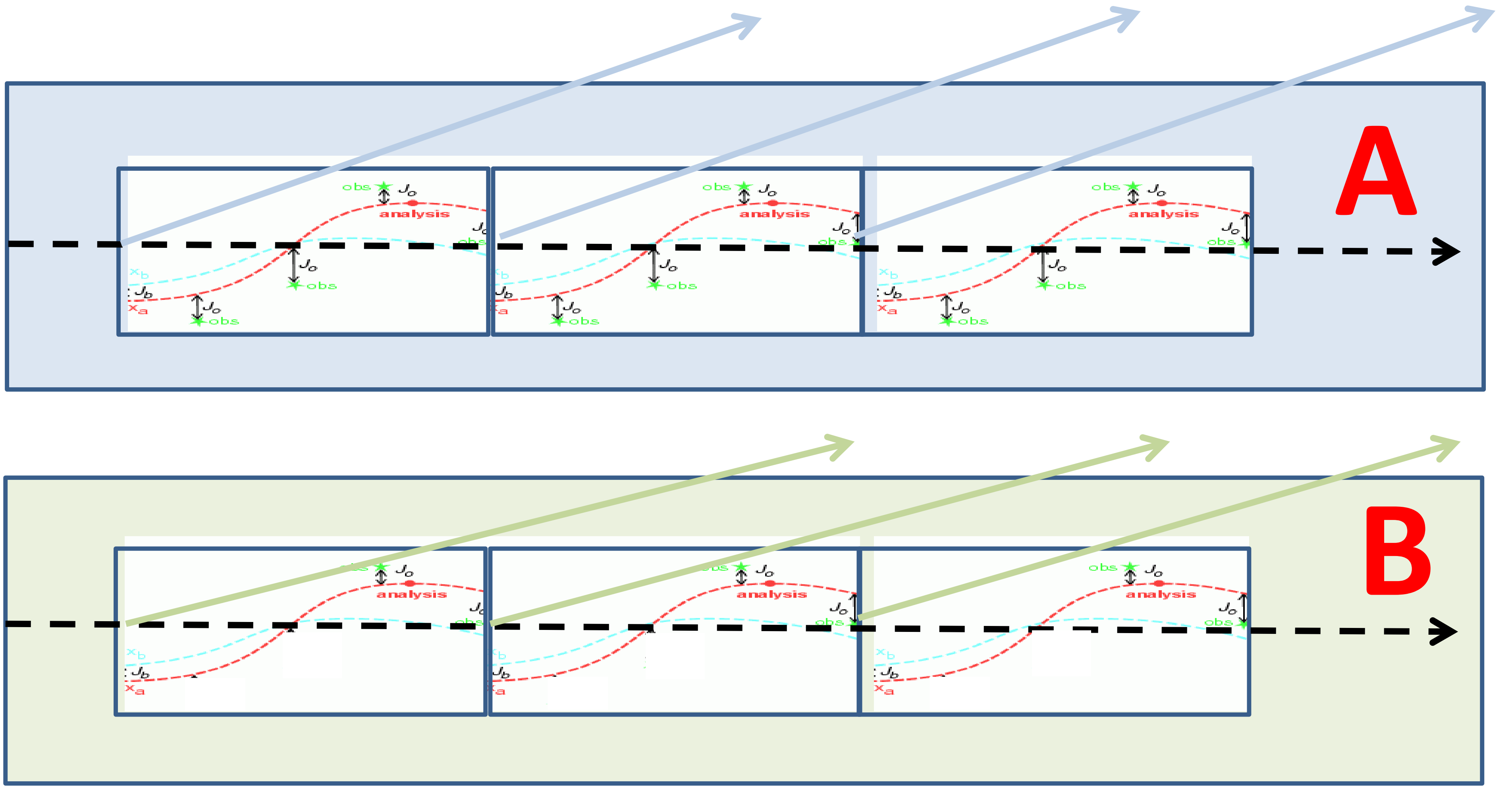

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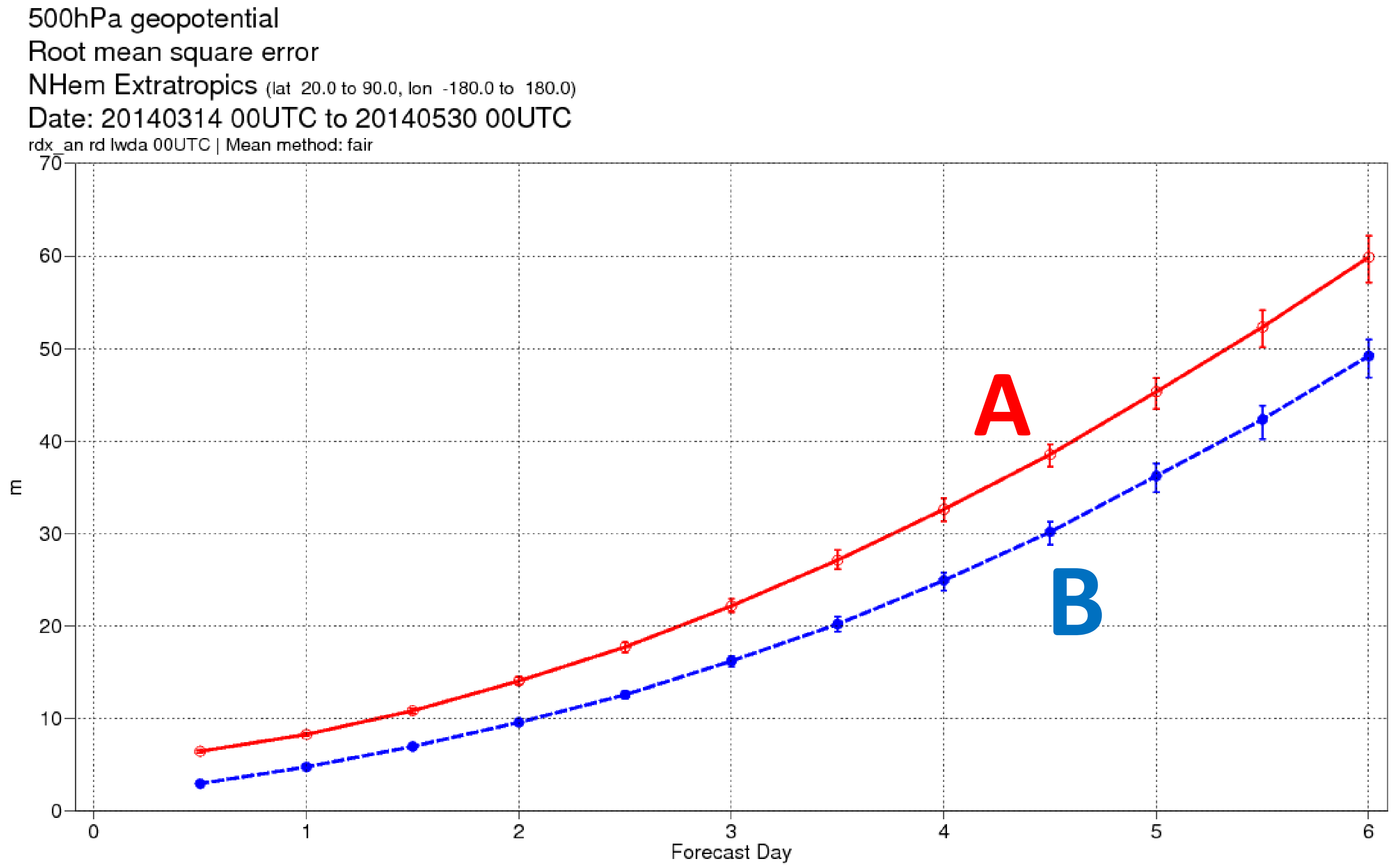

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Adjoint Sensitivity Diagnostics

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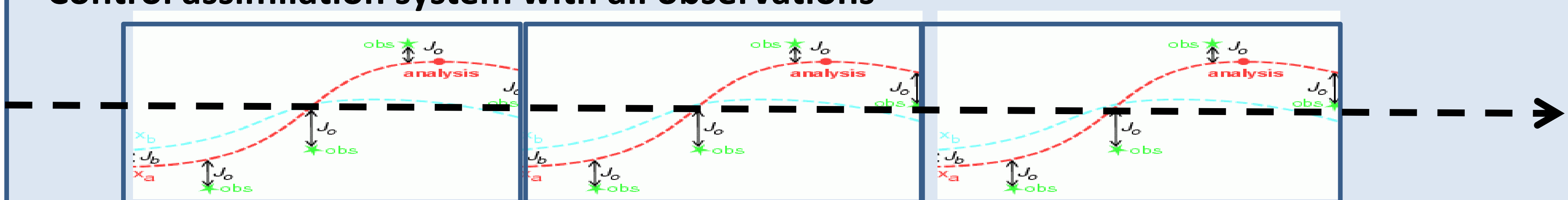
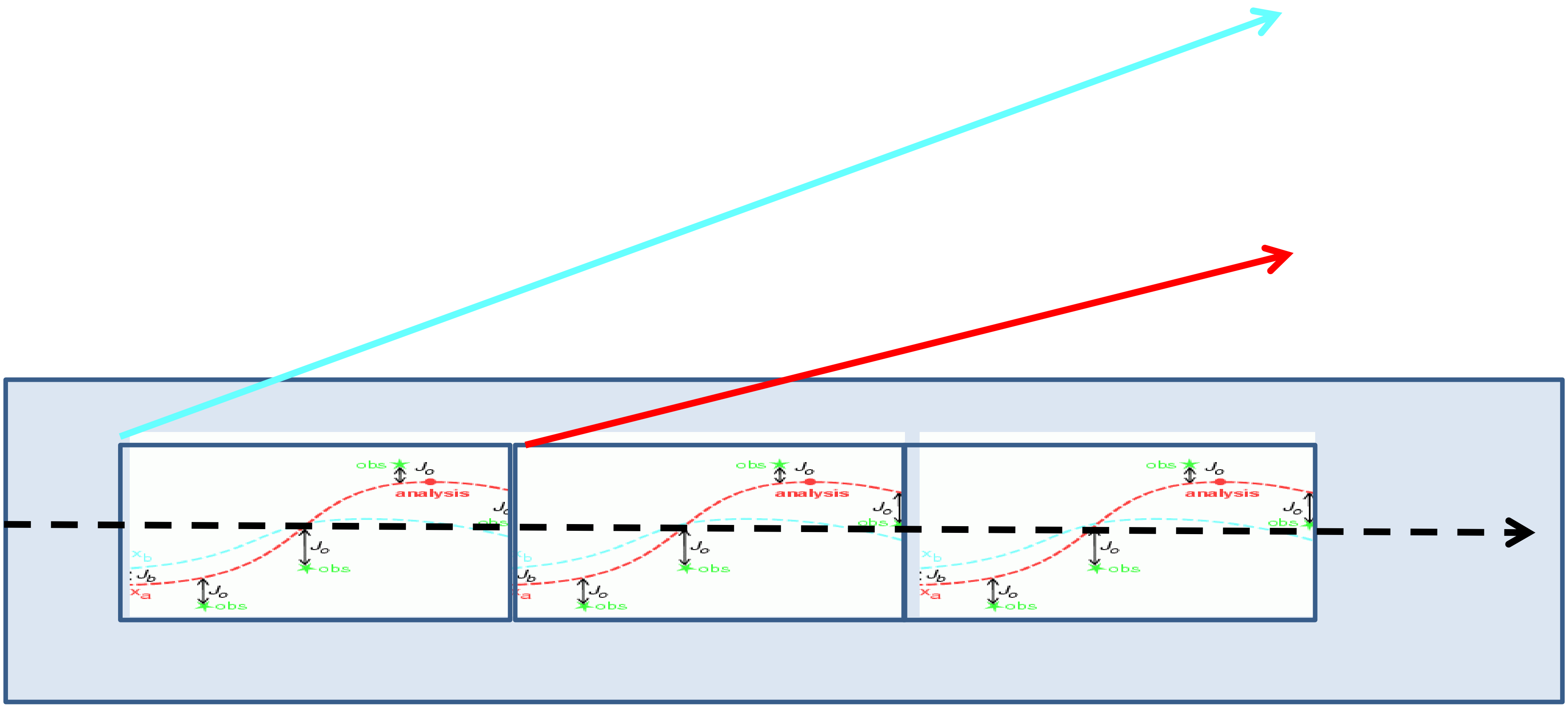


Adjoint Sensitivity Diagnostics



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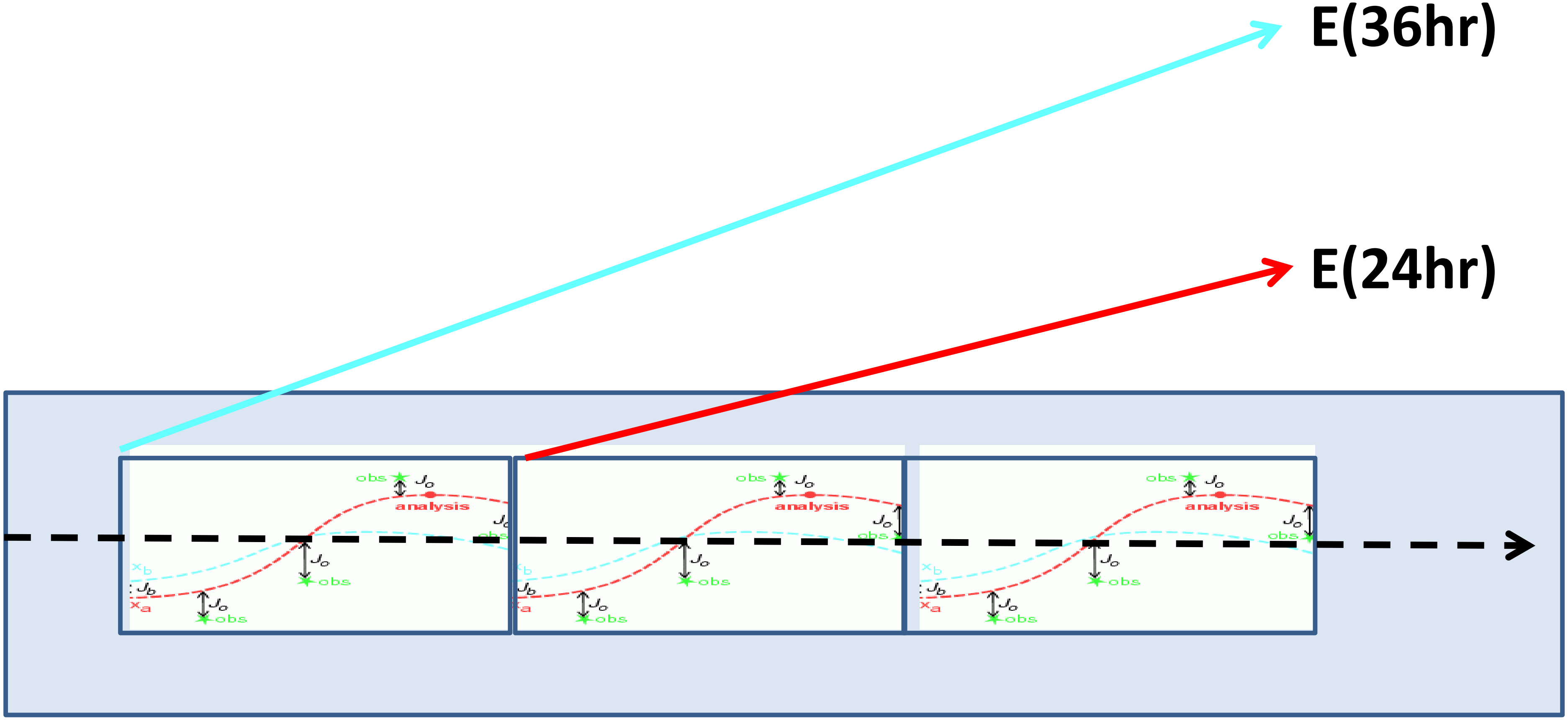
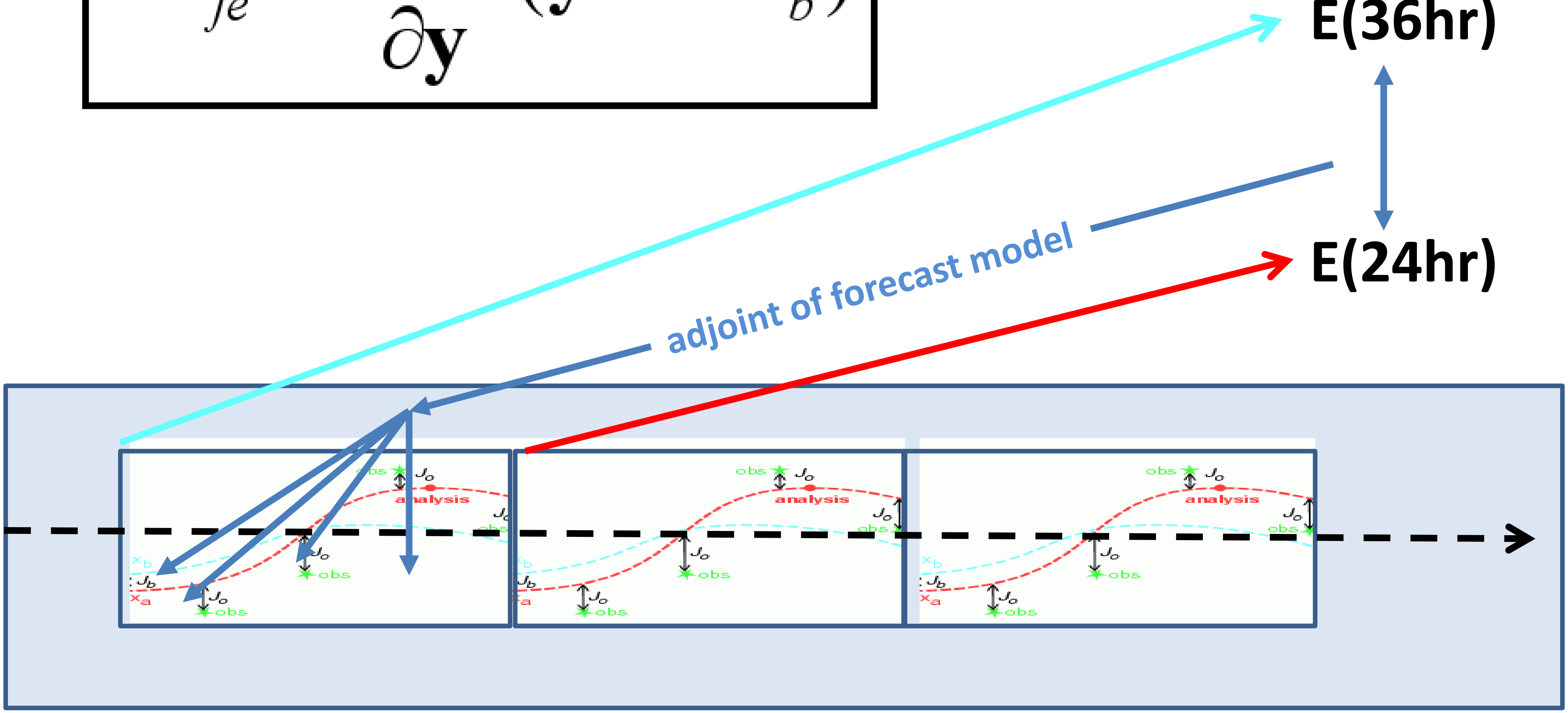


Adjoint Sensitivity Diagnostics

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



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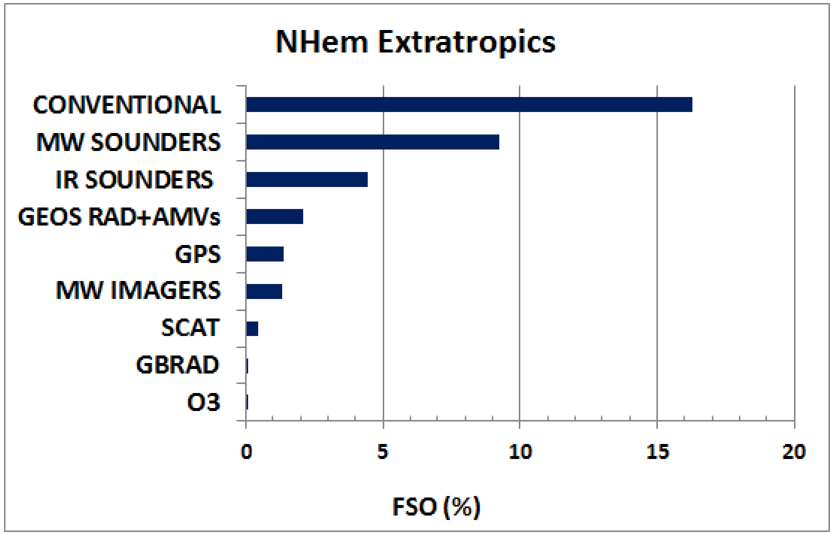
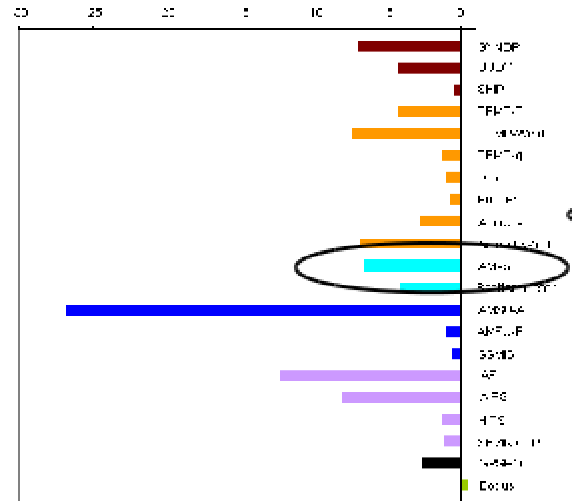
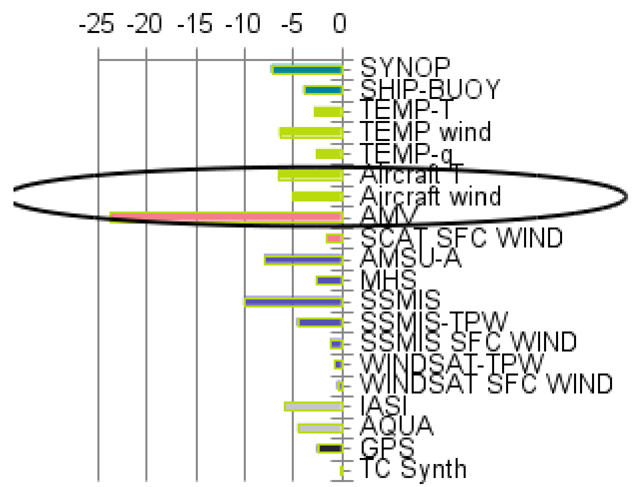




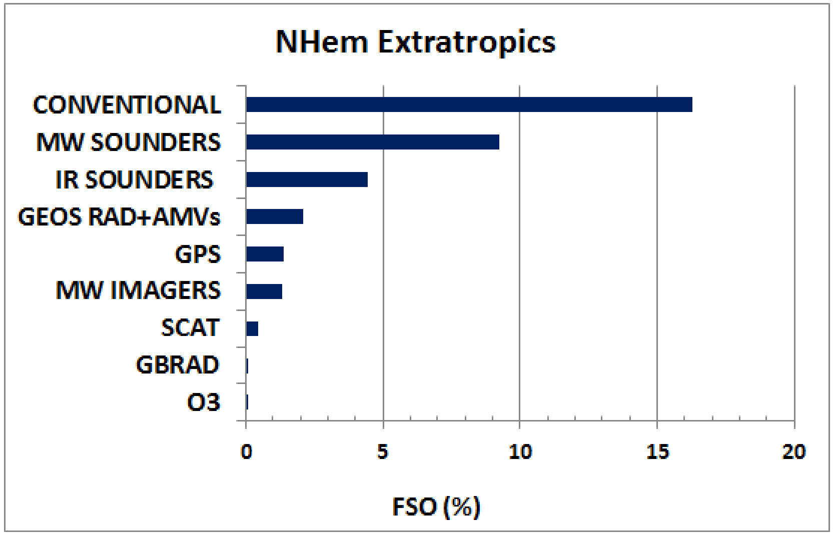
Met Office



NRL

We can measure impact by Observation type …

Adjoint Sensitivity Diagnostics



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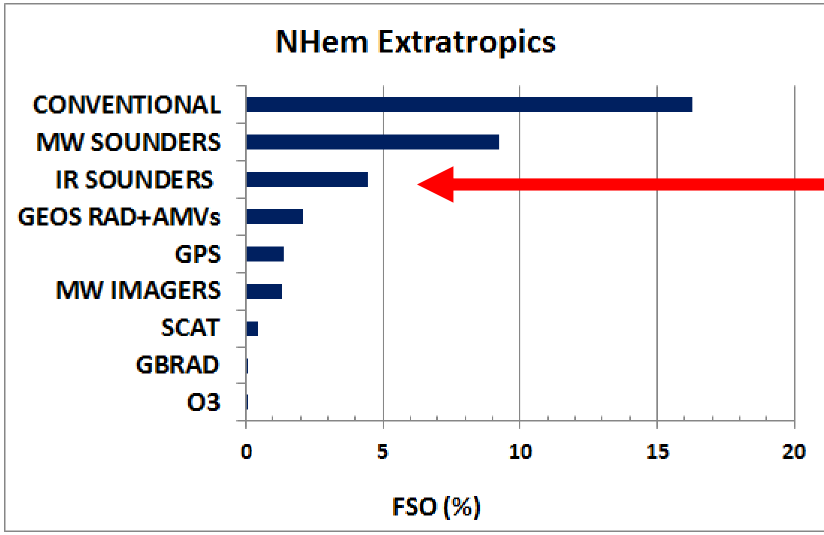
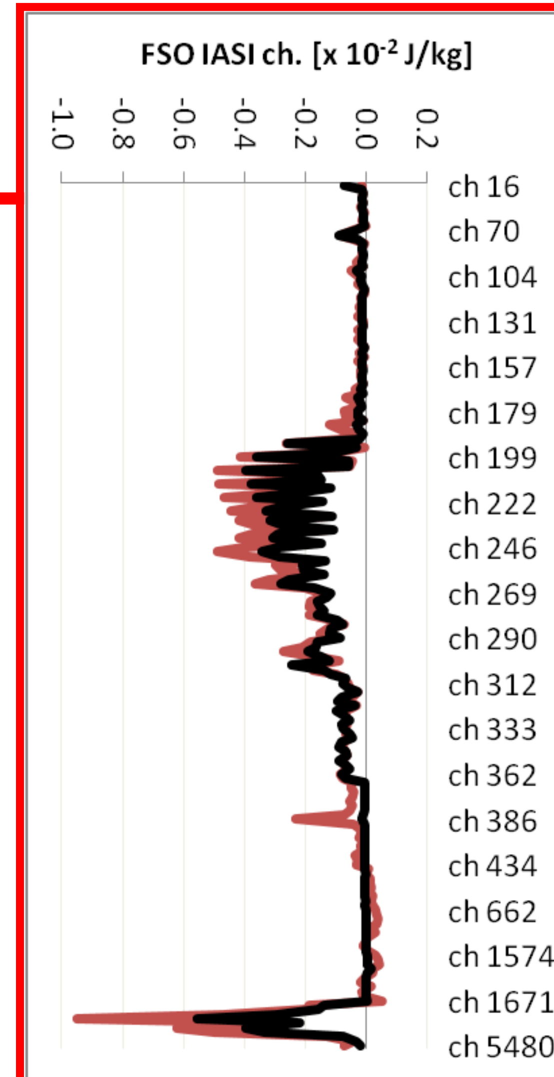




We can measure impact by Observation type…but also *drill down* to see the impact of individual channels

Are the diagnostics reliable ?

- All are reliable subject to :
  - The accuracy of the verifying state
  - Sampling noise (for statistical evaluations)
  - Correct specification of system parameters (B/R)
  - Appropriate interpretation !

Verification (what is truth?)

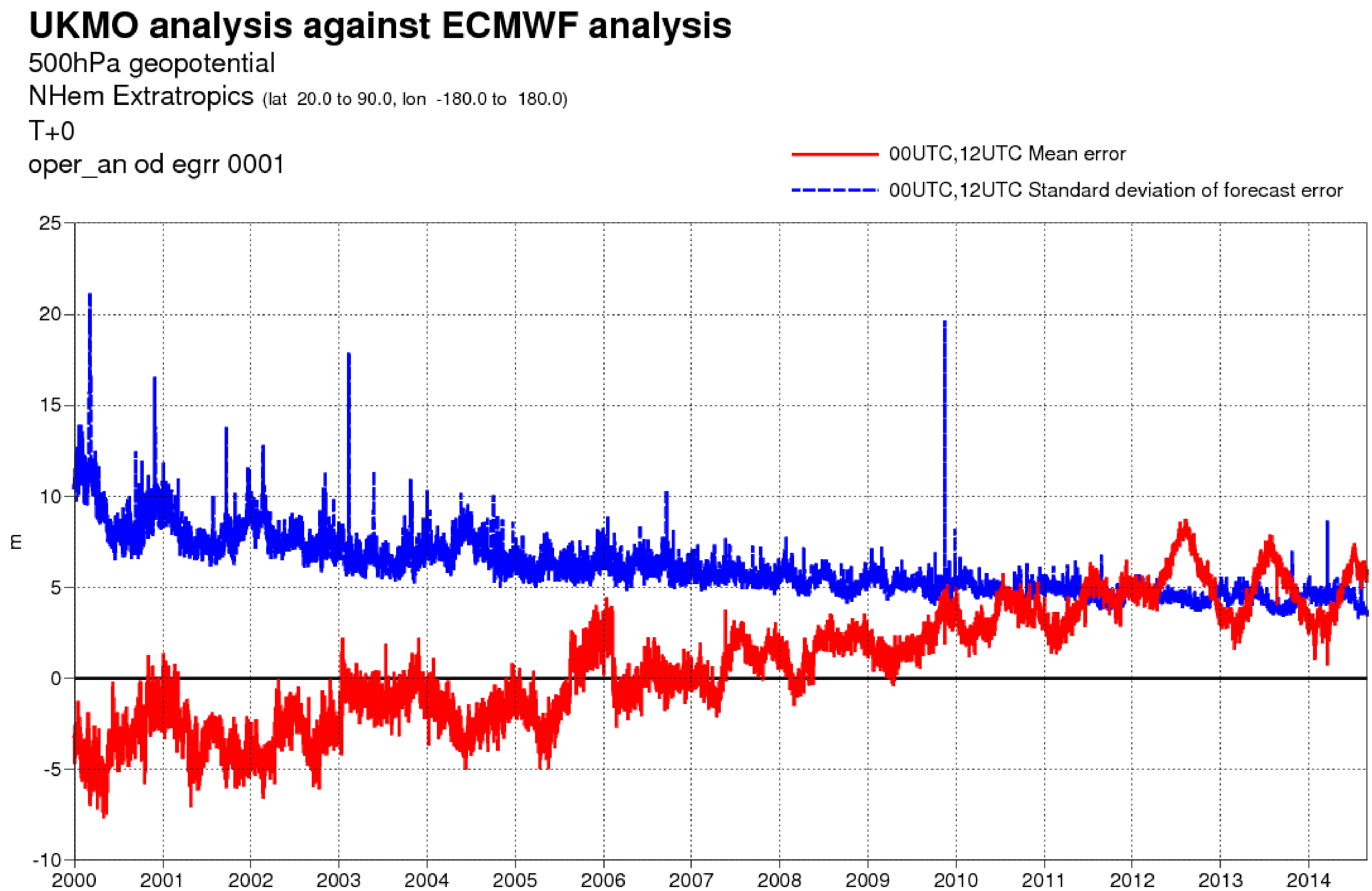
- Conventional (in situ) Observations ?
  - Poor (biased) spatial coverage
  - They have errors (RS z500 ~ 10m)
- Satellite Observations
  - Excellent unbiased spatial coverage
  - They have errors
  - Limited vertical resolution
- NWP analyses
  - They have errors

How accurate are NWP analyses ?

How accurate are NWP analyses ?

- Simmons and Hollingsworth (QJ 2001) diagnosed errors of 7m for ECMWF and 10m for the Met Office…
- Massimo Bonavita (2014 per com.) "…about 5m…"
- Very difficult question to answer!

How accurate are our analyses ?



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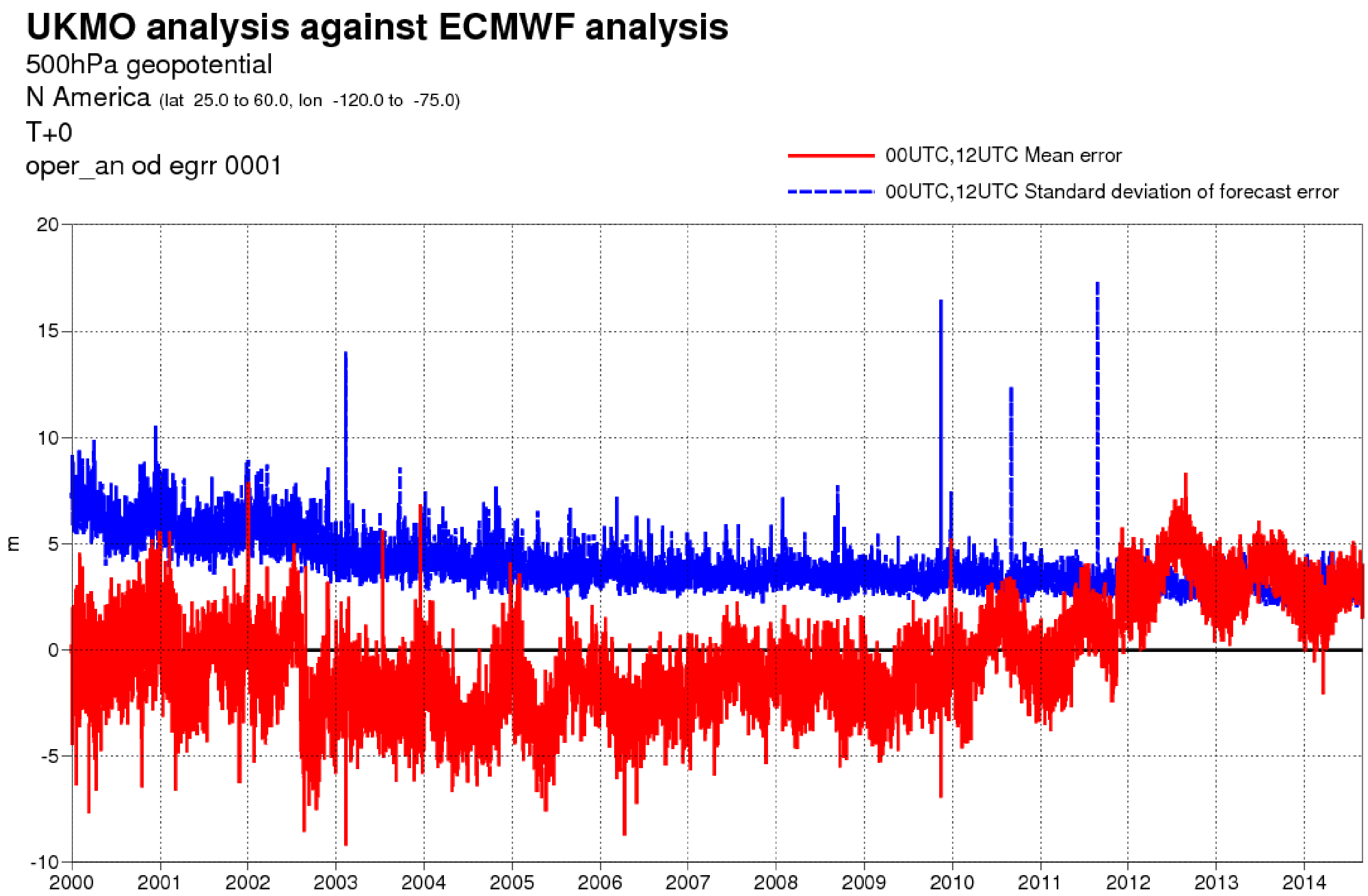

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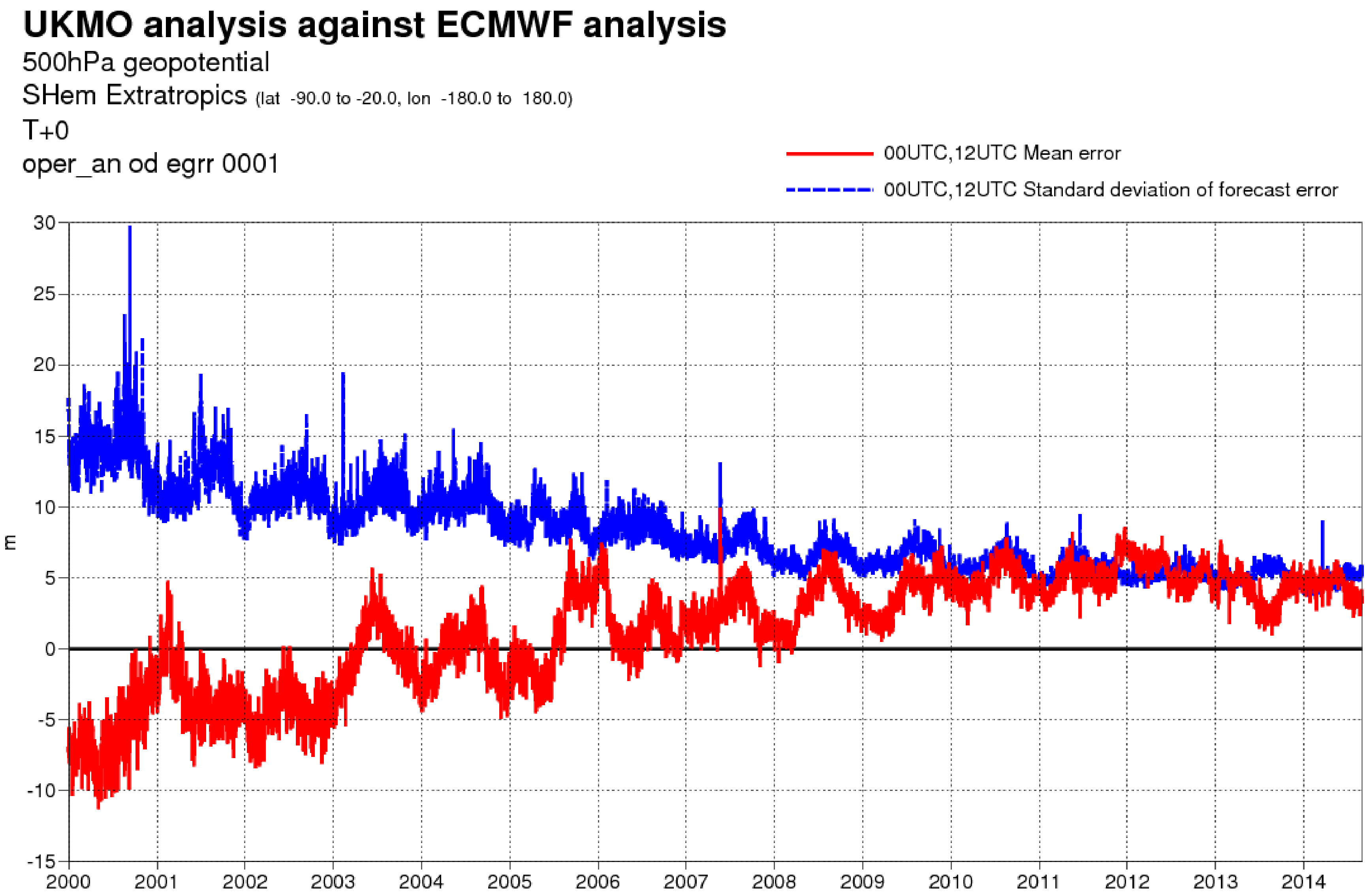
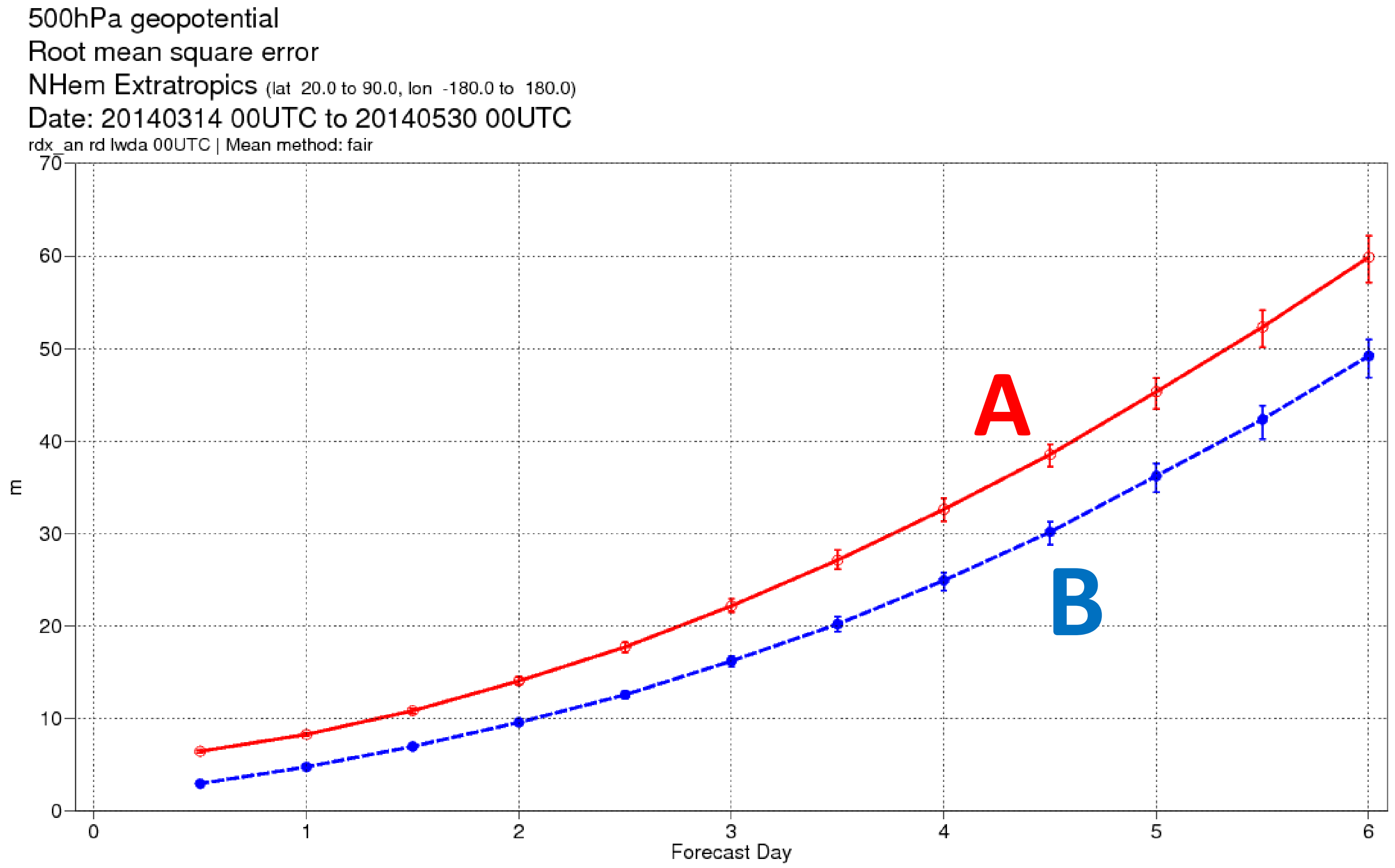
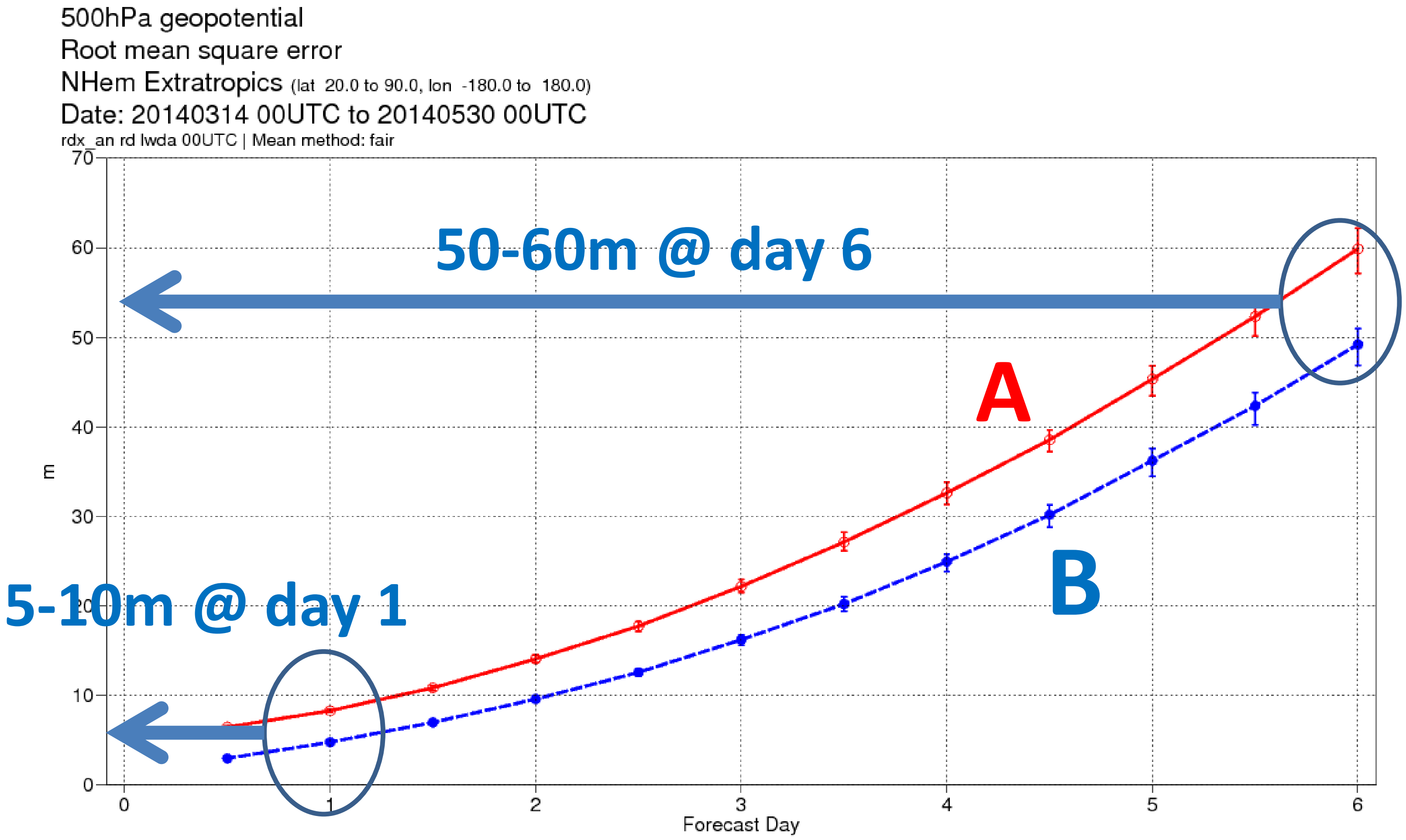


Observing System Experiments



Analysis uncertainty in verification



OSE vs ASD ?

Pros and Cons of OSE

- Extremely (prohibitively?) expensive to run long periods (needed for small signals)
- Adding or denying a data type may require background errors to be retuned*
- Verifying short-range forecasts is less reliable
- The only measure of medium-range observation impact
- They give the only clear definitive answer to the question "what if I did not have this satellite ?"

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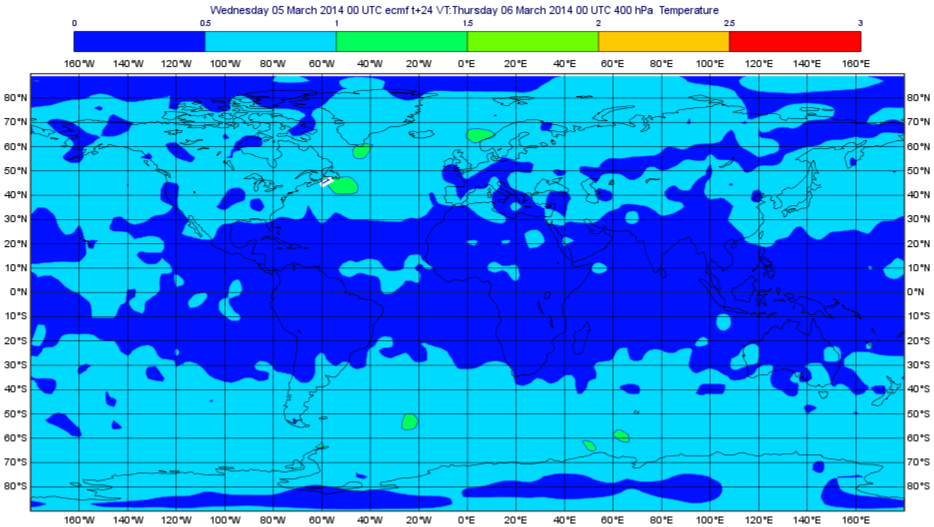
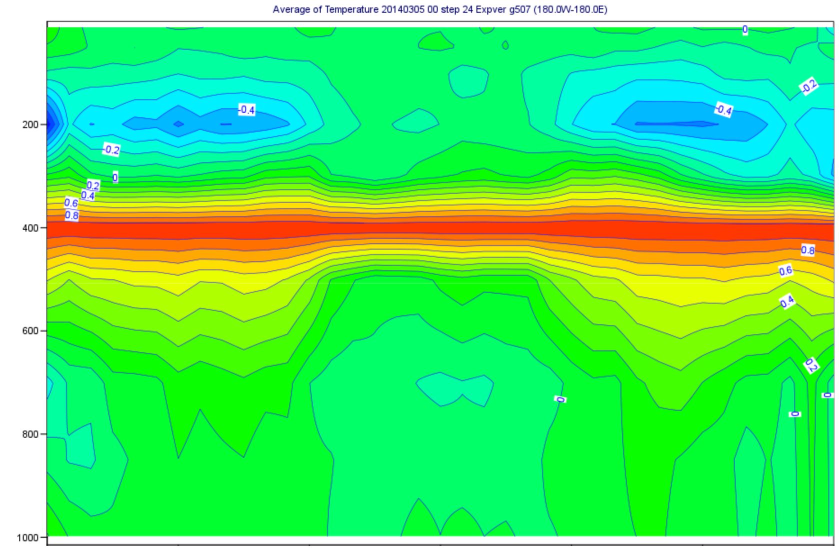
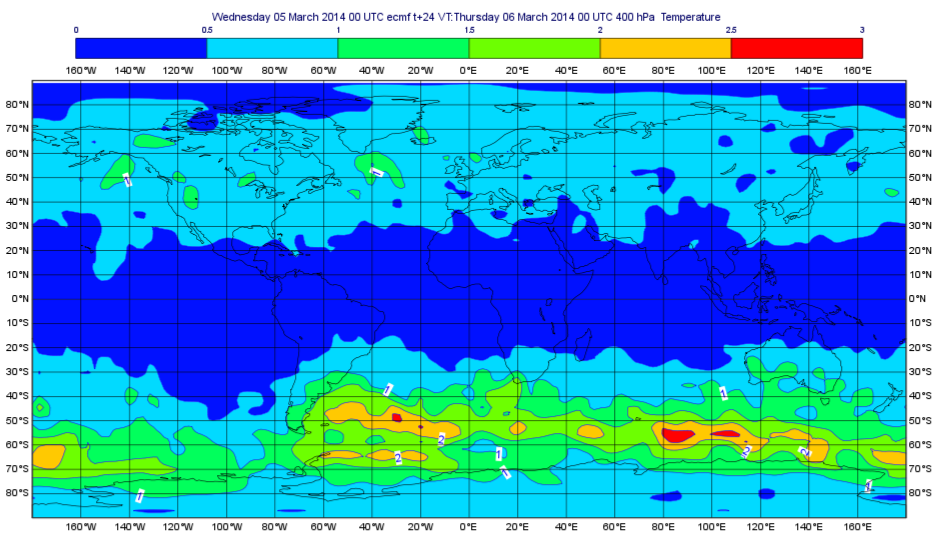
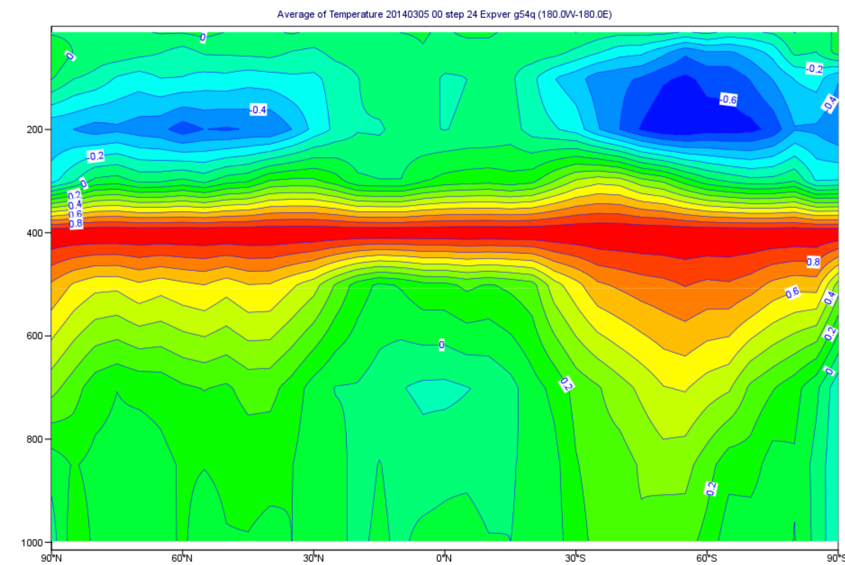
Retuning background errors for OSE

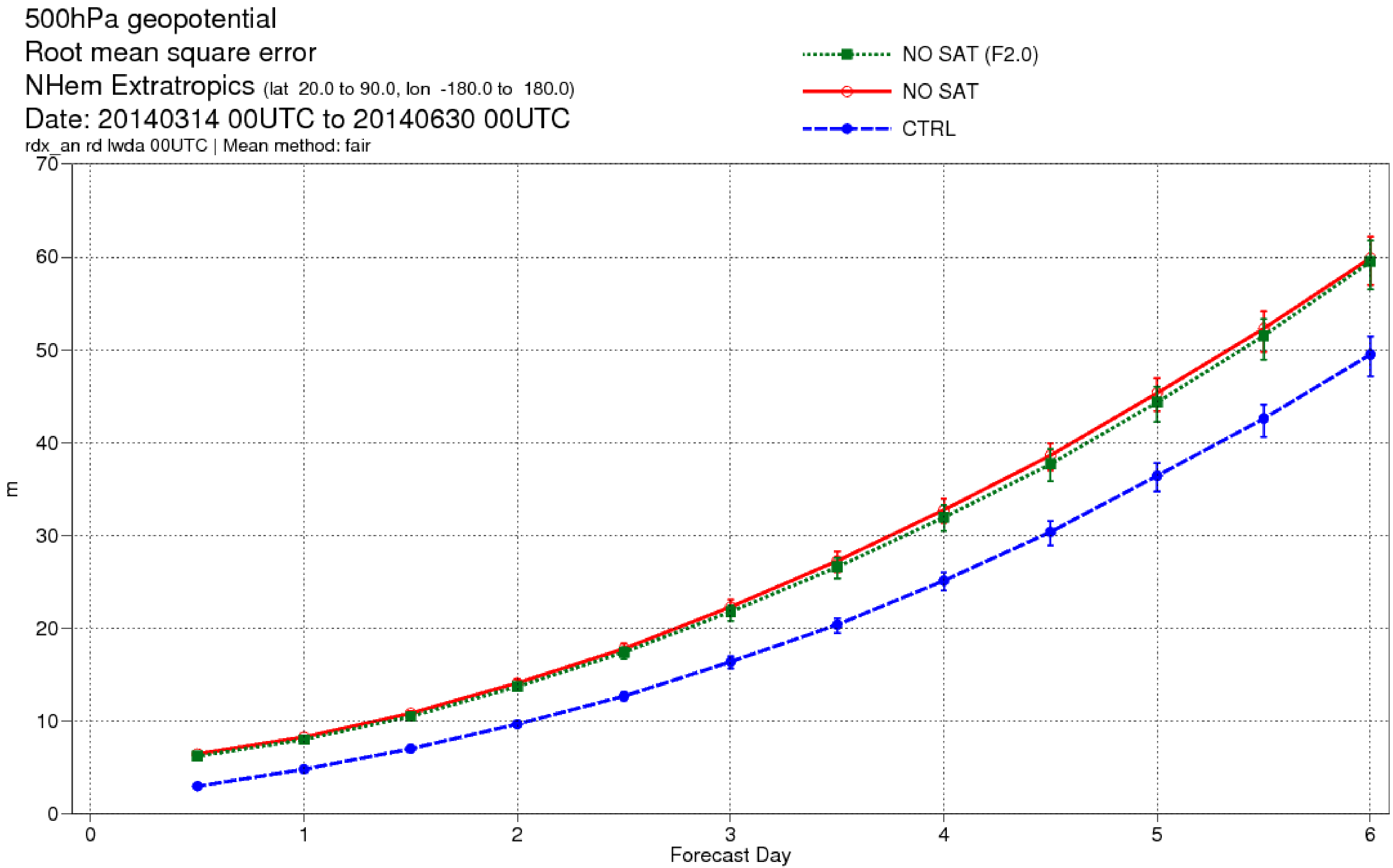








Retuning background errors for an extreme OSE



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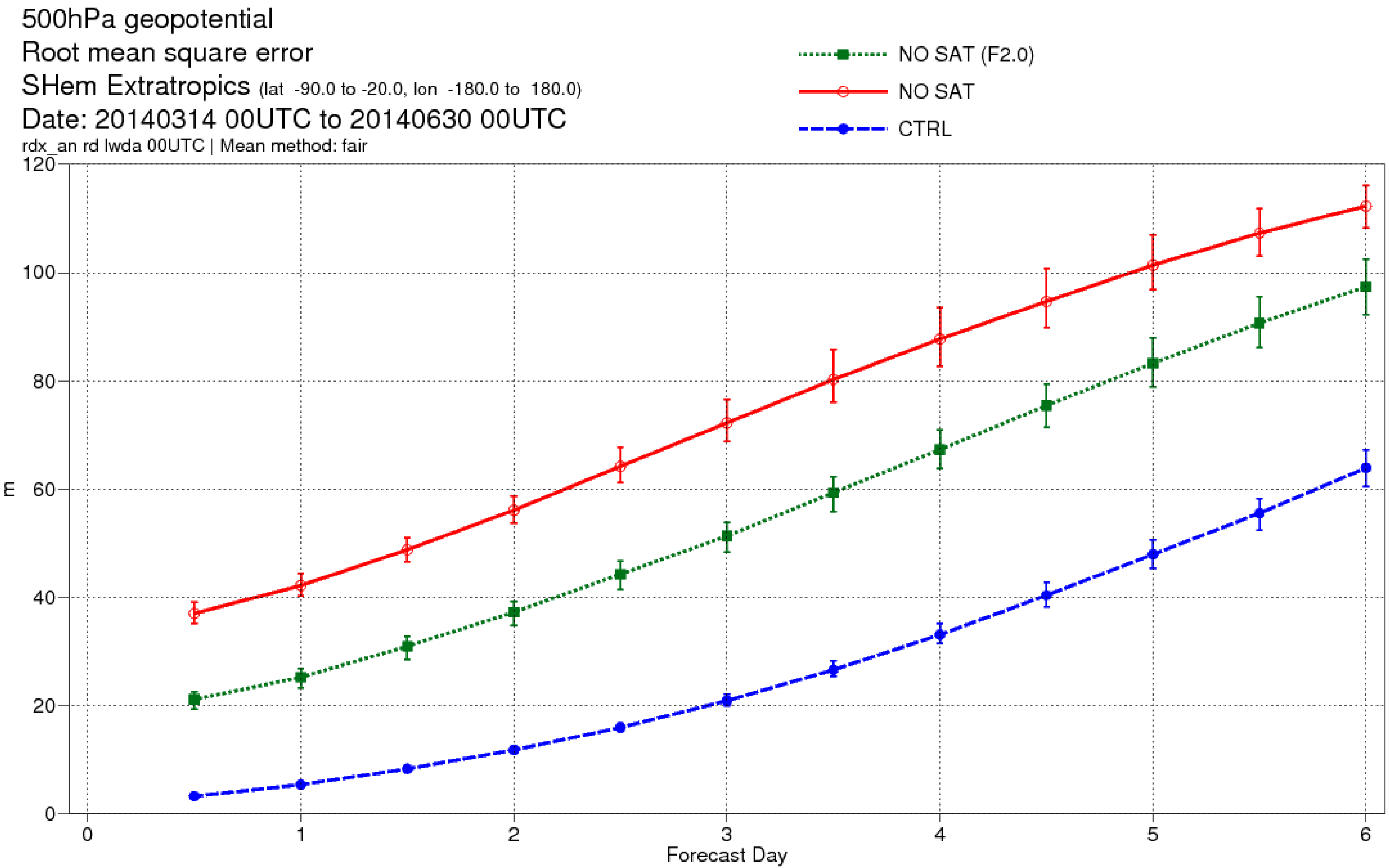

Pros and Cons of ASD

- Can only operate a short-range where verification is least reliable
- Problems relating TE metric to parameters and consistency of adjoint model (dry/wet)
- Poor observation error tuning can produce misleading results*
- Very affordable (compared to OSE)
- Allows detailed evaluation of individual channel impacts

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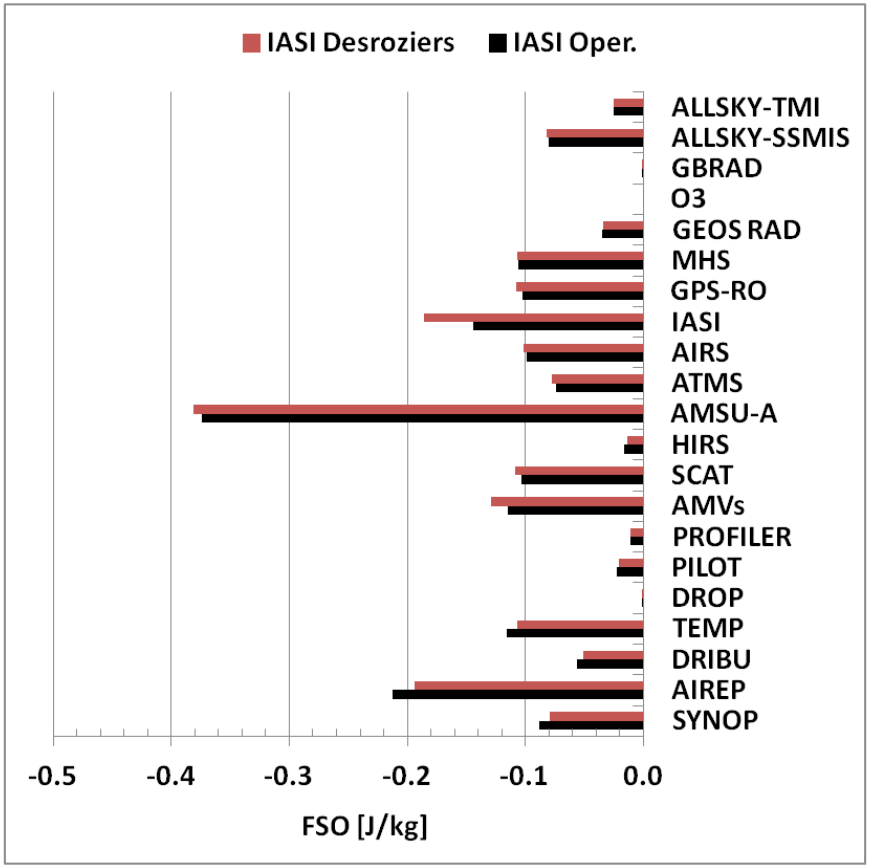
ASD sensitivity to observation error

Impact measured using operational observation error model (values 0.4K to 2K)

Impact measured using unrealistic observation error model (unscaled Desrosier values)



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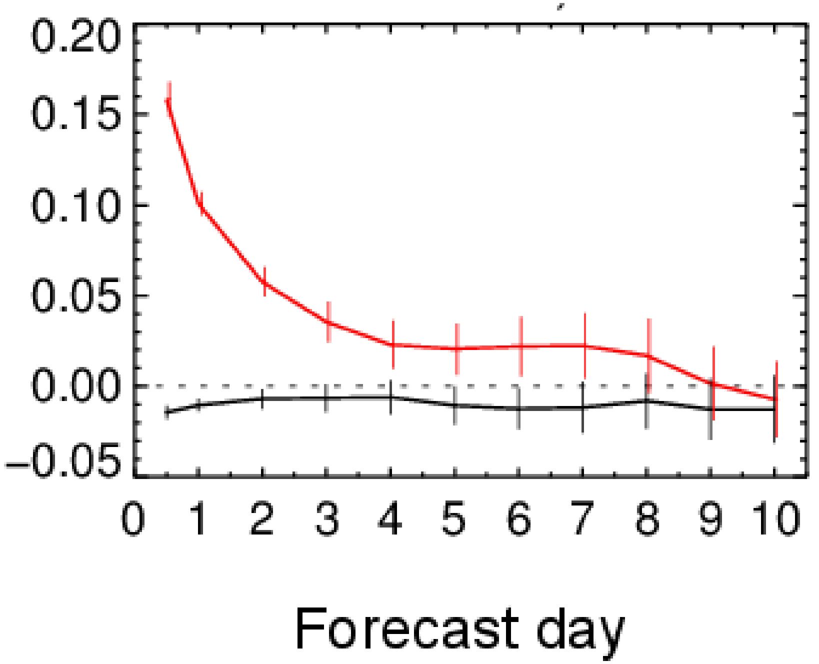
RMSE(IASI) minus RMSE(NO-IASI)

RMSE(IASI*) minus RMSE(NO-IASI)



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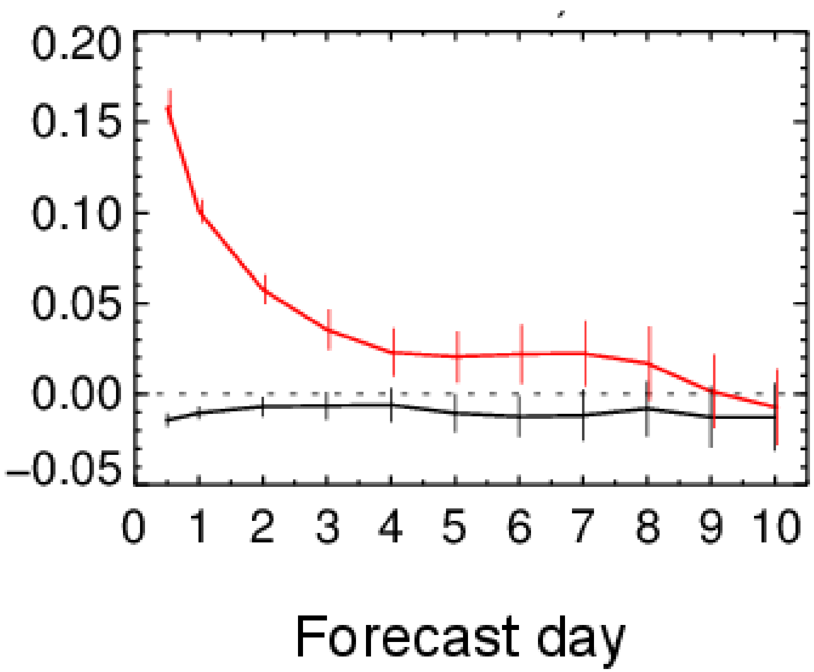

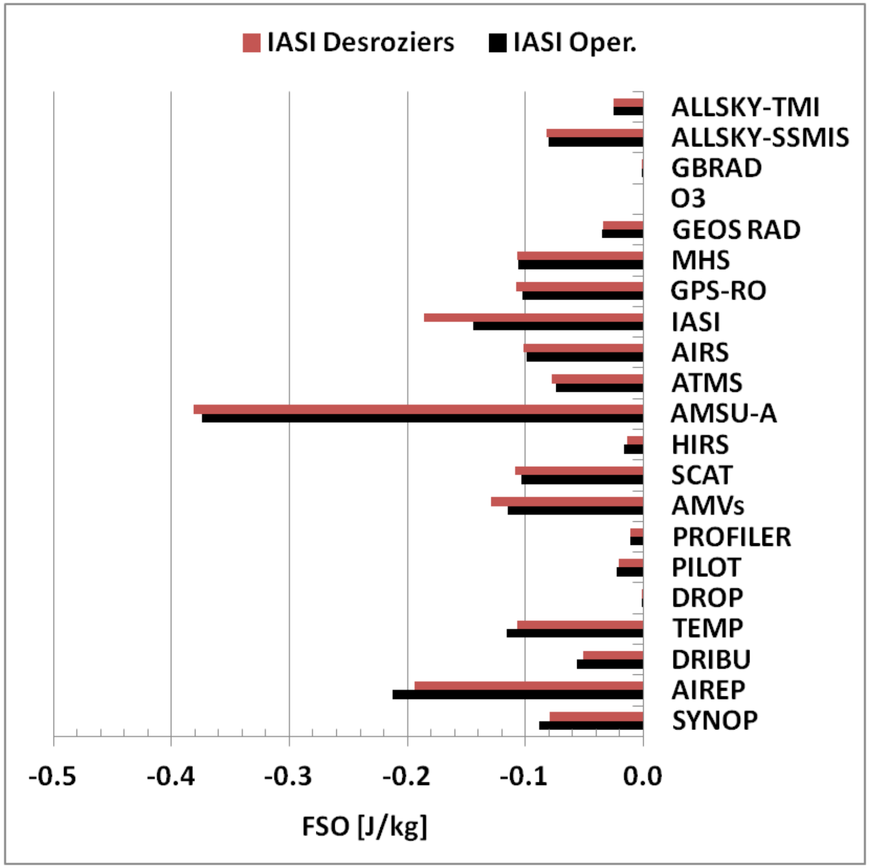

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Observations Considered

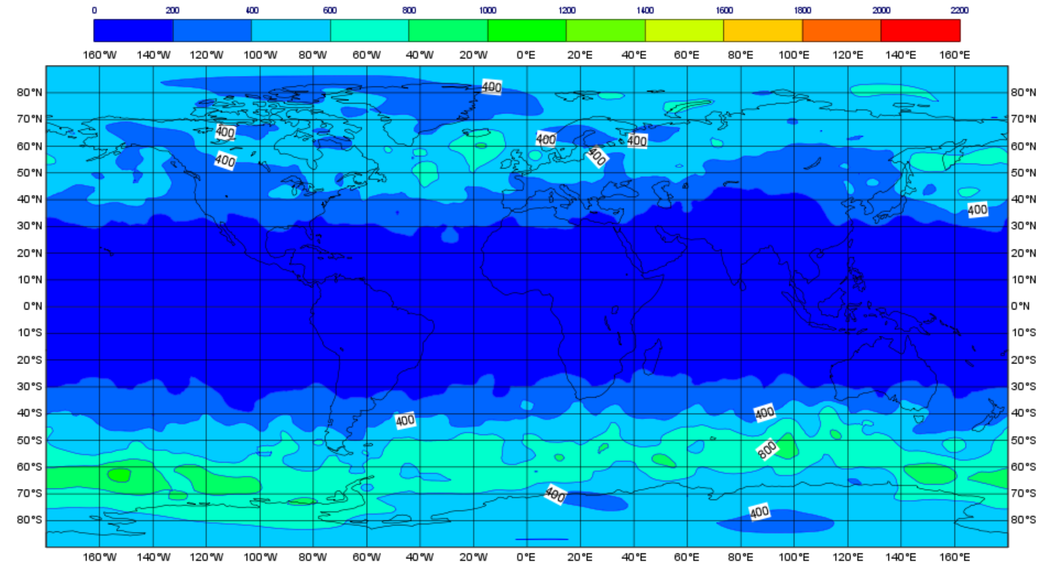
All conventional (in situ) data	CONV	TEMP/AIRCRAFT/SYNOP/SHIP
All Satellite Data	SAT	
Microwave sounding radiances	MWS	7 x AMSUA, 1 x ATMS, 4 x MHS
Infrared sounding radiances	IRS	2 x IASI, 1 x AIRS, 1 x HIRS
All GEO data (AMVs and radiances)	GEO	2 x GOES, 2 x METEOSAT, 1 x MTSAT, polar AMVs
GPS-RO bending angle data	GPS	COSMIC, 2 x METOP-GRAS
Microwave imager radiances	MWI	1 x TMI, 1 x SSM/IS
Scatterometer surface wind data	SCAT	2 x ASCAT

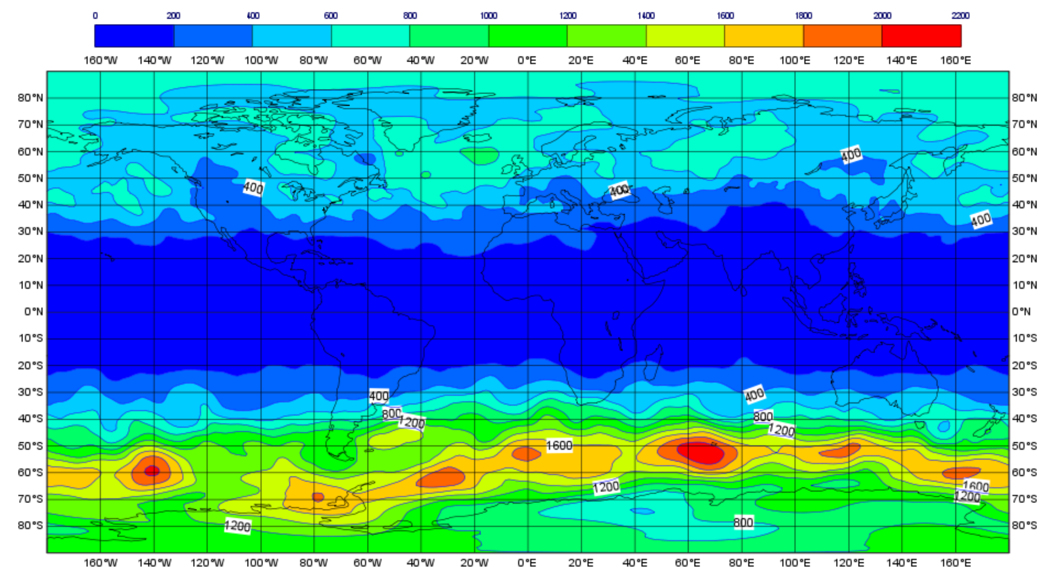
Experimental Setup

- Period covered (March 1st to June 30th 2014)
- Version 40R1 of the ECMWF analysis / forecasting system
- T511 Horizontal resolution (~40km) with 137 vertical levels (surface to 0.01hPa)
- For OSEs the various data types are **denied** from the system
- Verification is with the ECMWF operational analyses or in-situ observations (n/a AST)

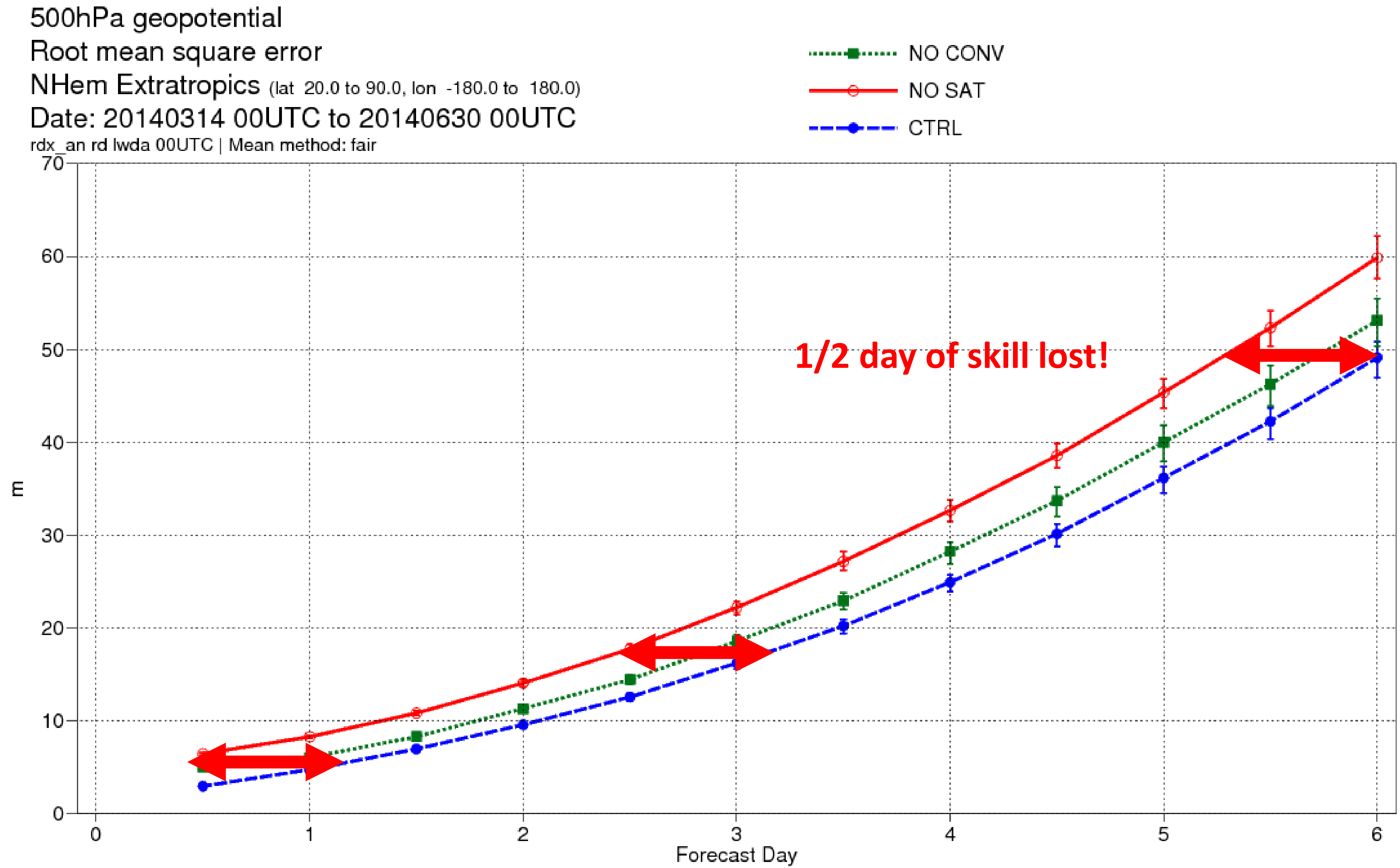
Results of OSE

Removing all Satellite Data





Importance of SAT v CONV data



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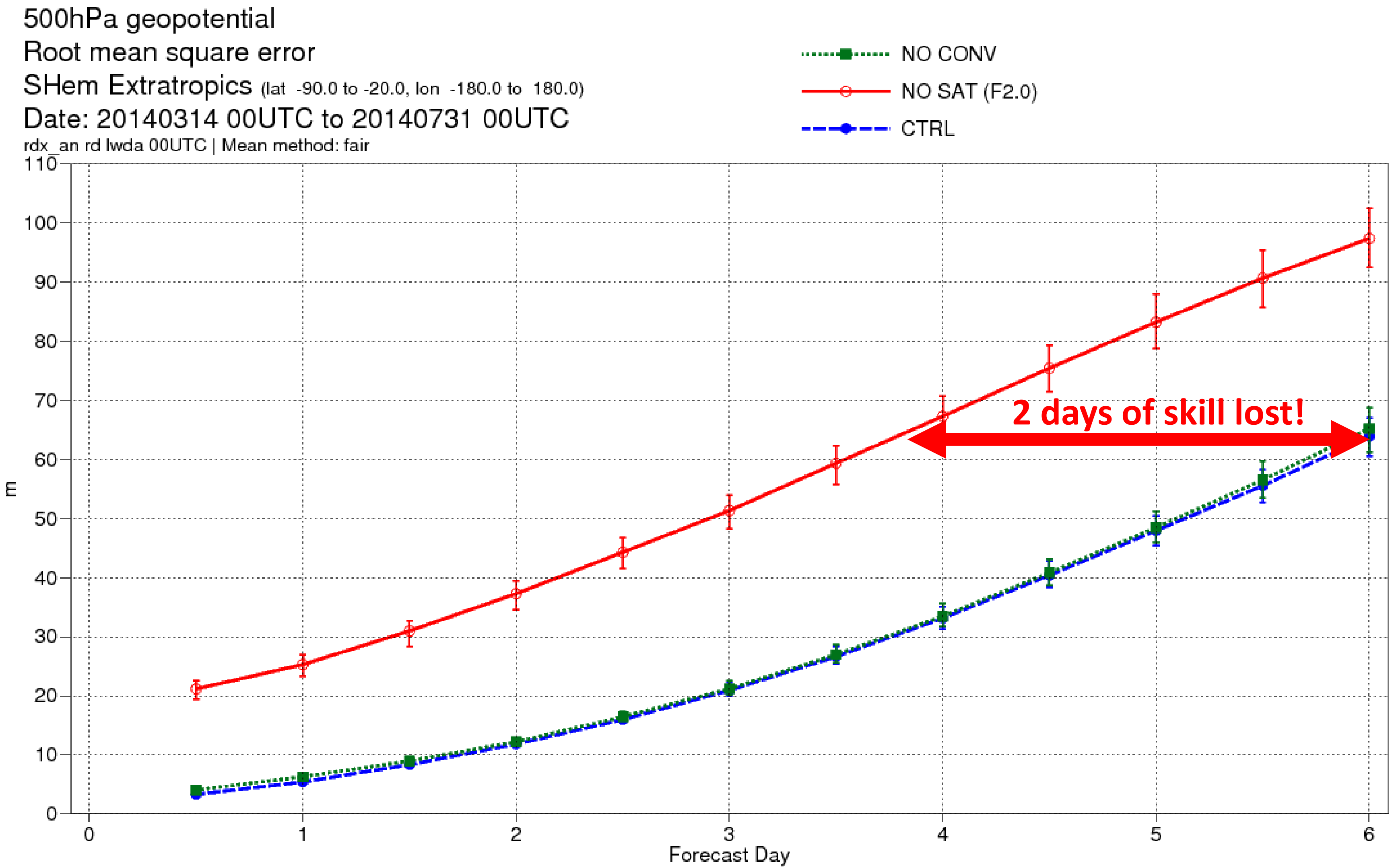

Impact of removing individual satellite observation types

Removed Observations

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Infrared sounding radiances	IRS	2 x IASI, 1 x AIRS, 1 x HIRS
All GEO data (AMVs and radiances)	GEO	2 x GOES, 2 x METEOSAT, 1 x MTSAT, polar AMVs
GPS-RO bending angle data	GPS	COSMIC, 2 x METOP-GRAS
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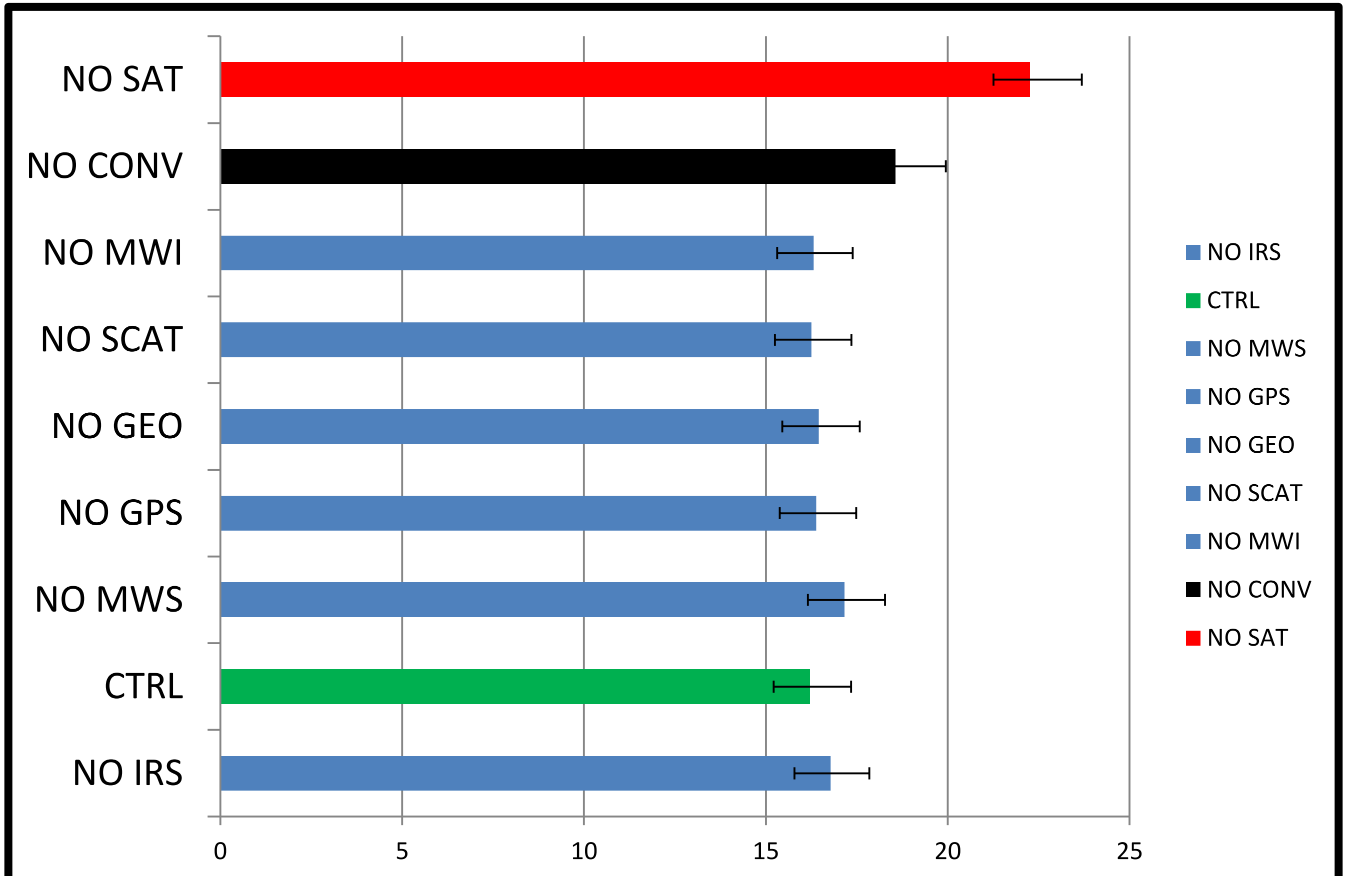
Day-3 Forecasts of 500hPa Z over NH



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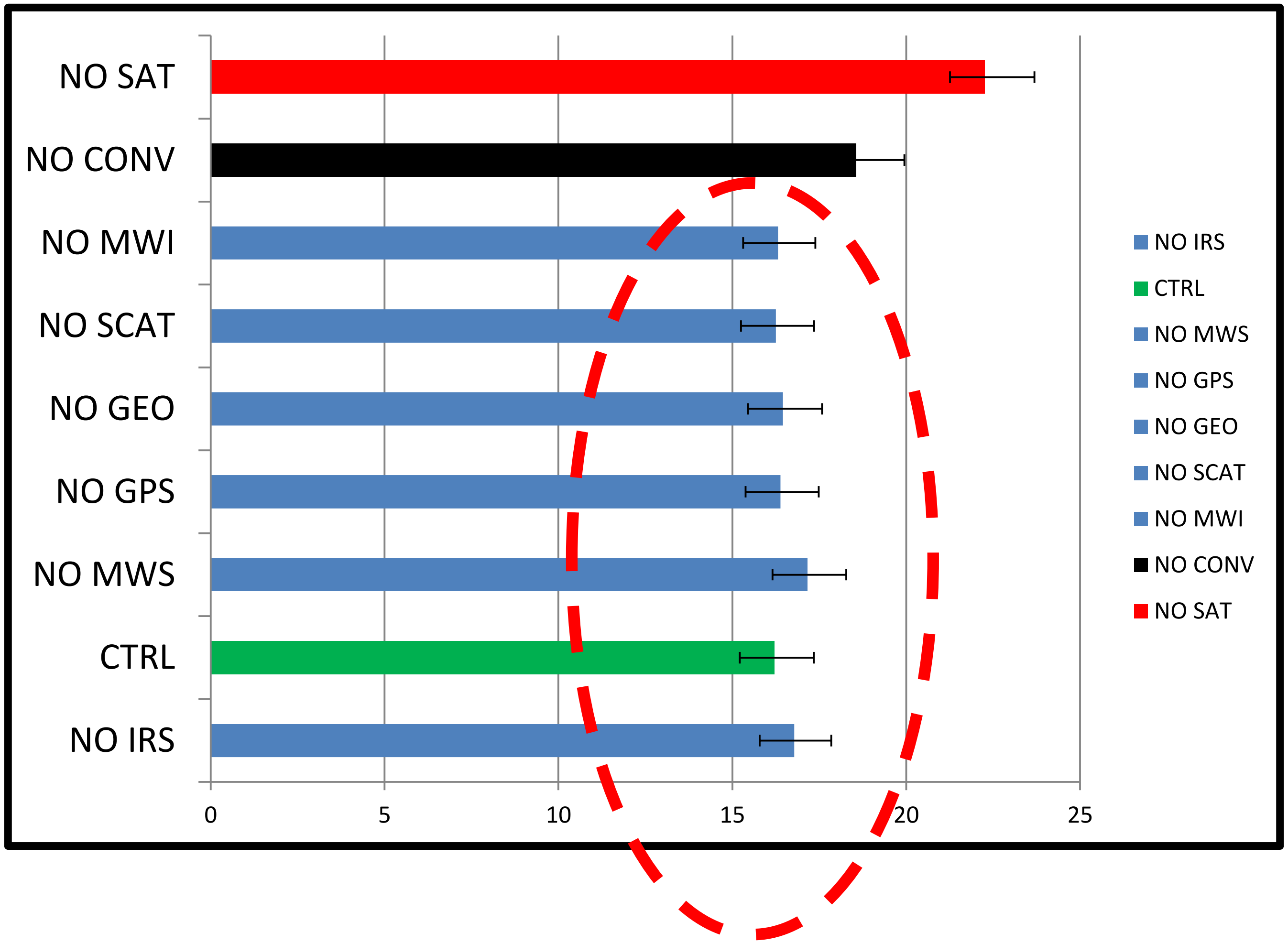
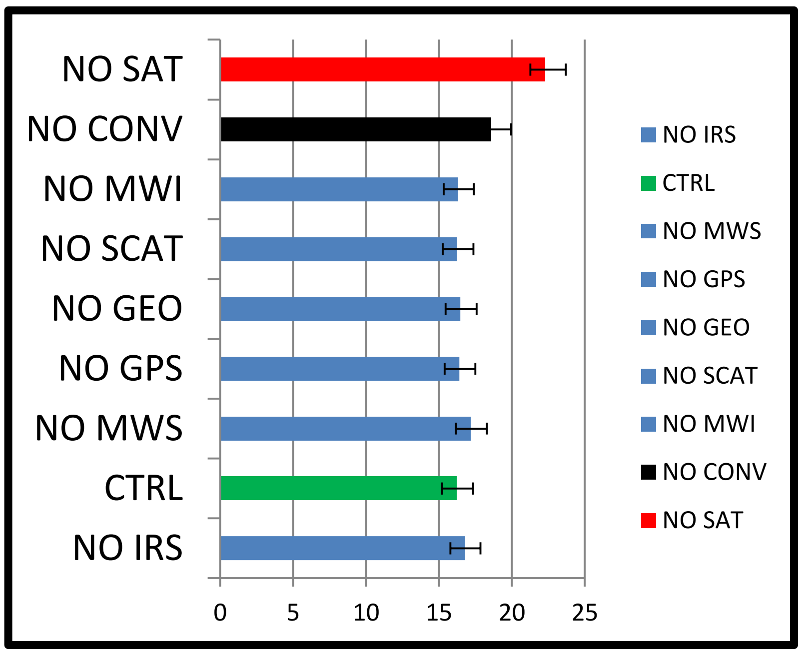
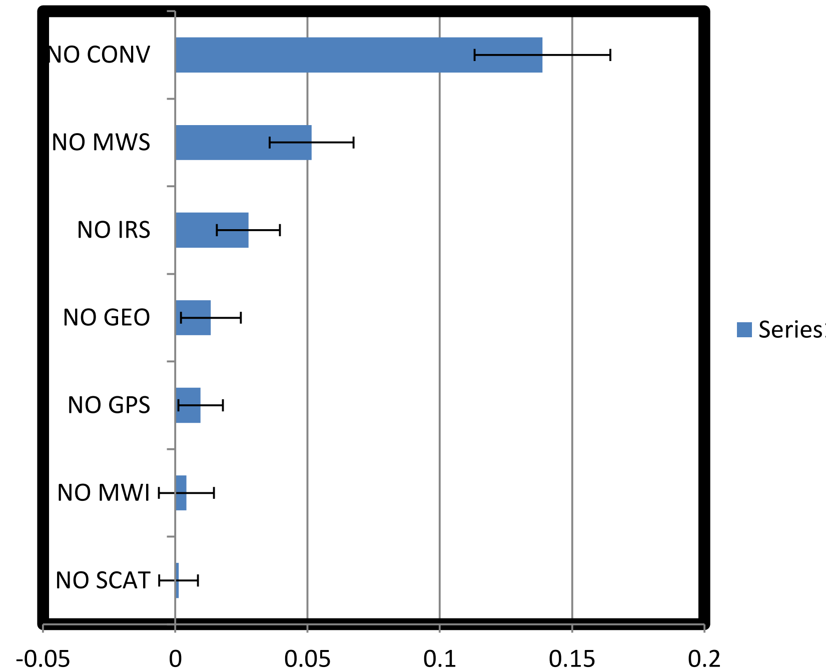


Day-3 Forecasts of 500hPa Z over NH

To see differences more clearly we need to **difference** with the errors of the CONTROL and **normalise** with the errors of the CONTROL



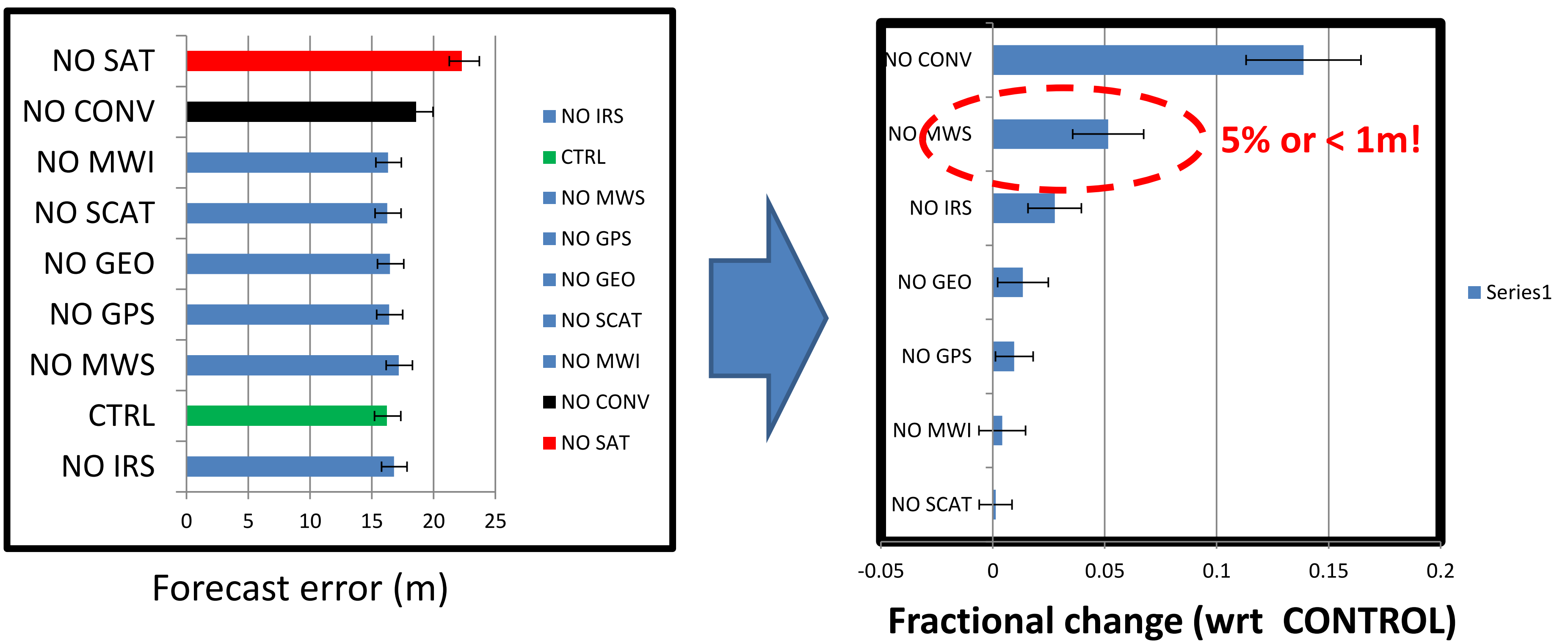
Forecast error (m)



Fractional change (wrt CONTROL)

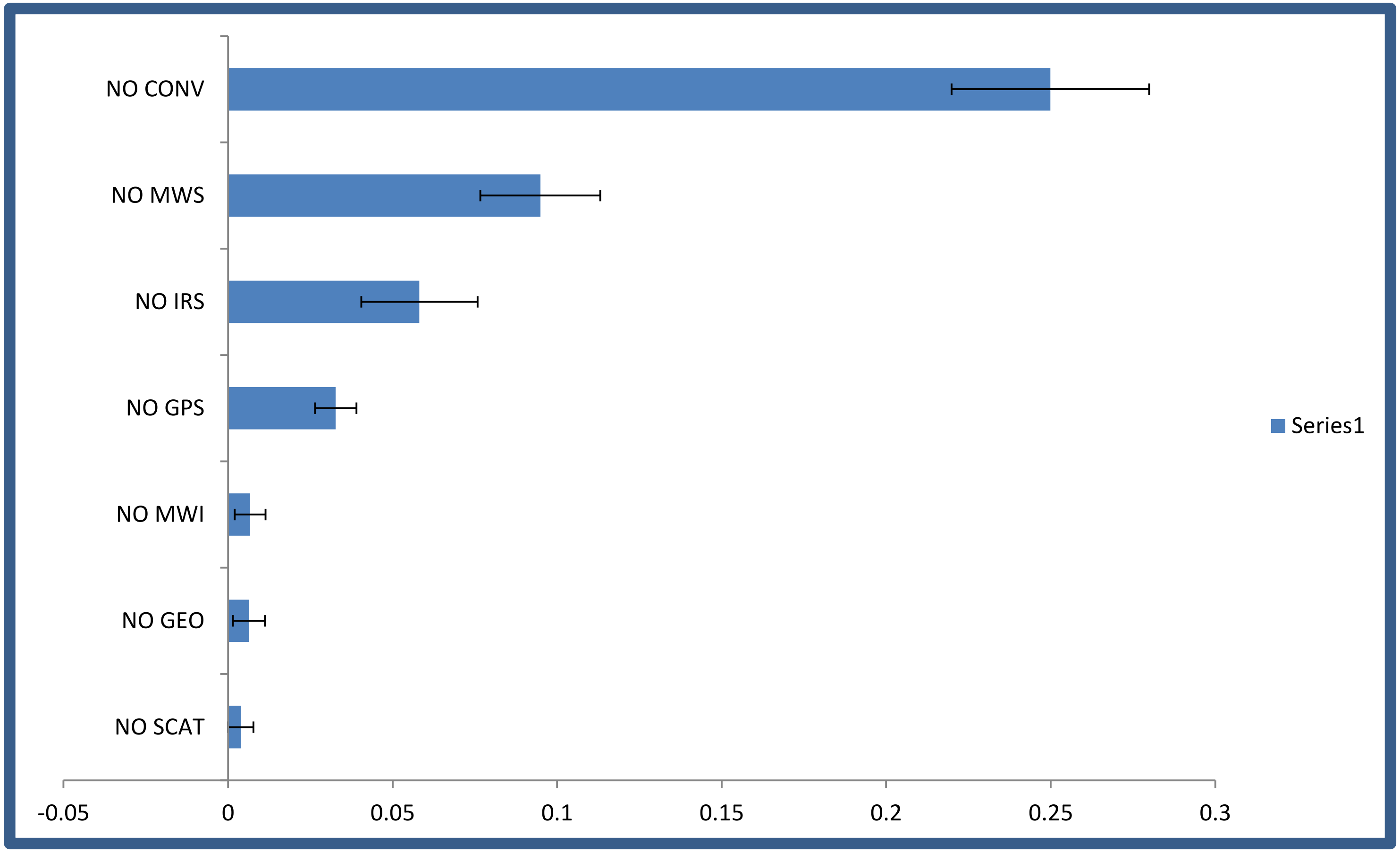
Day-3 Forecasts of 500hPa Z over NH

To see differences more clearly we need to **difference** with the errors of the CONTROL and **normalise** with the errors of the CONTROL

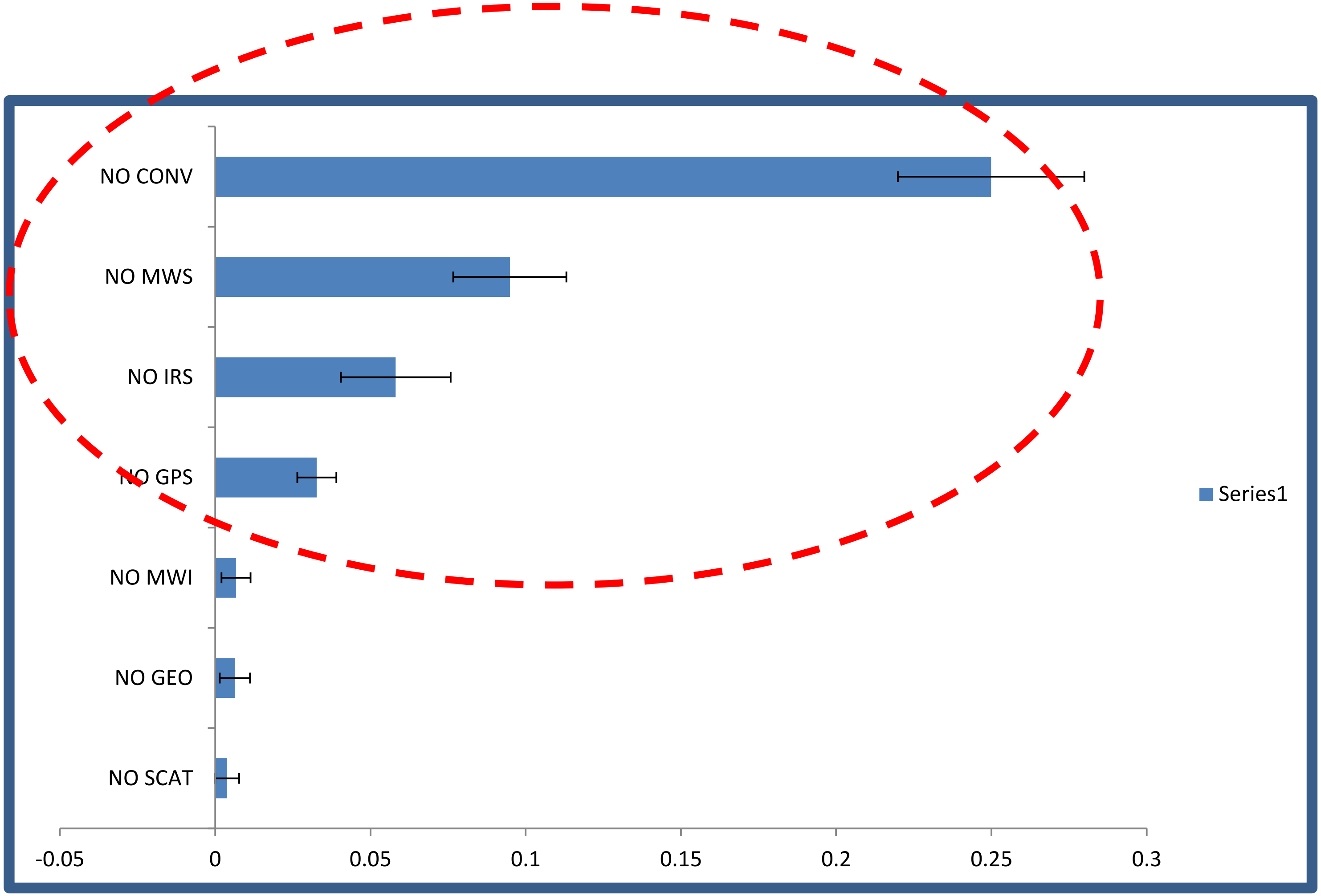


Geopotential (500hPa) forecasts in the extra-Tropics

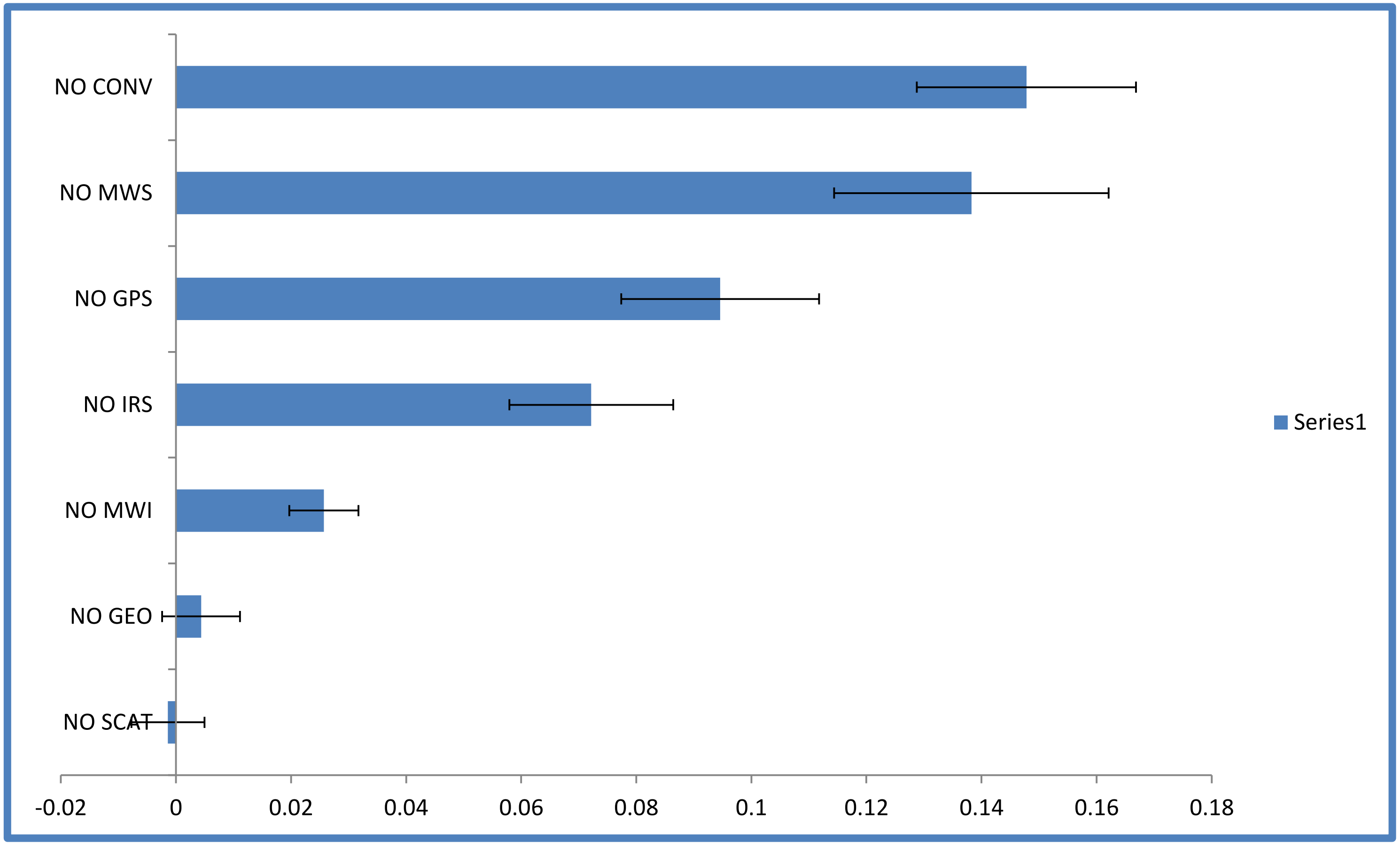
OSE 500z (NH-24h)



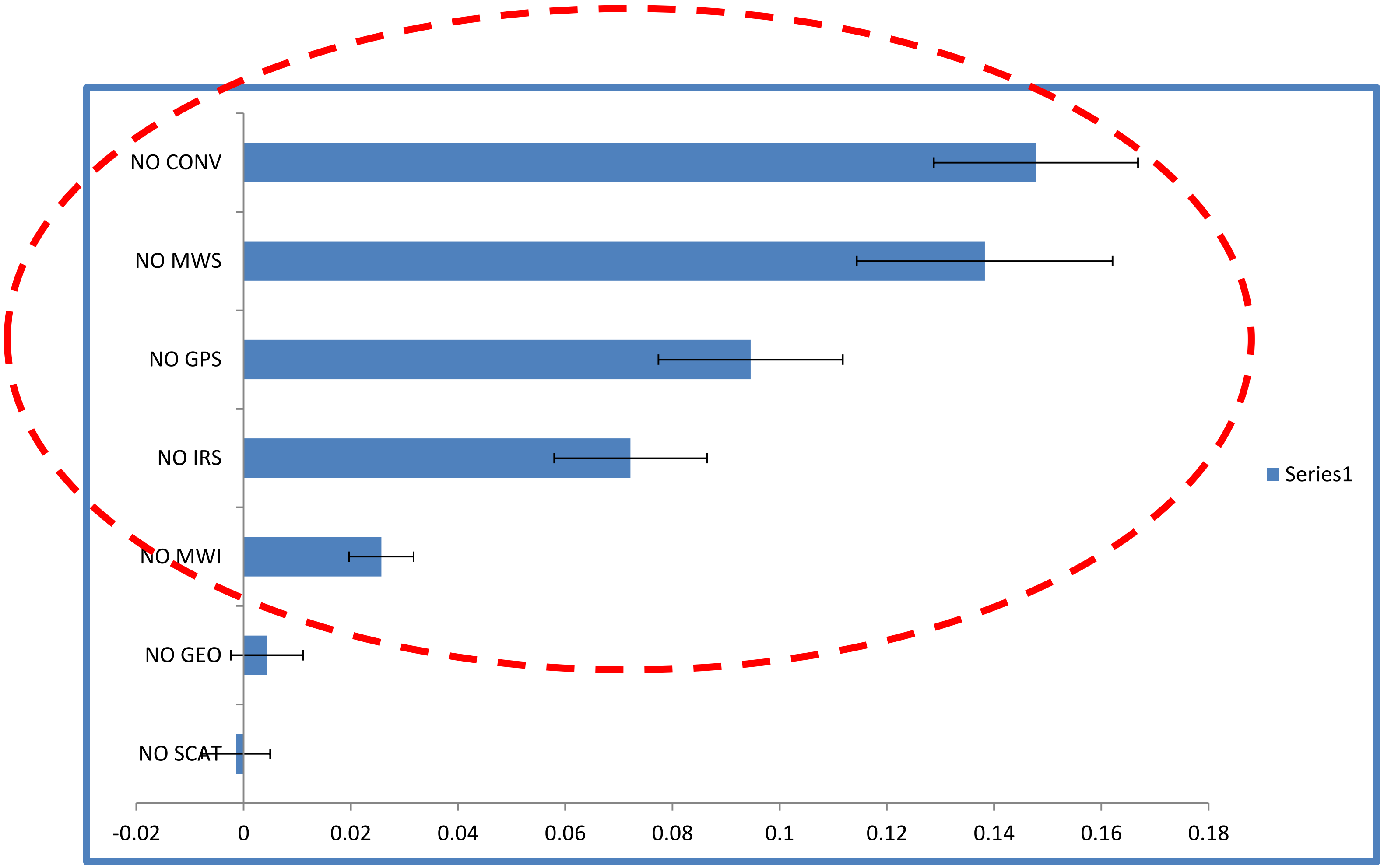
OSE 500z (NH-24h)



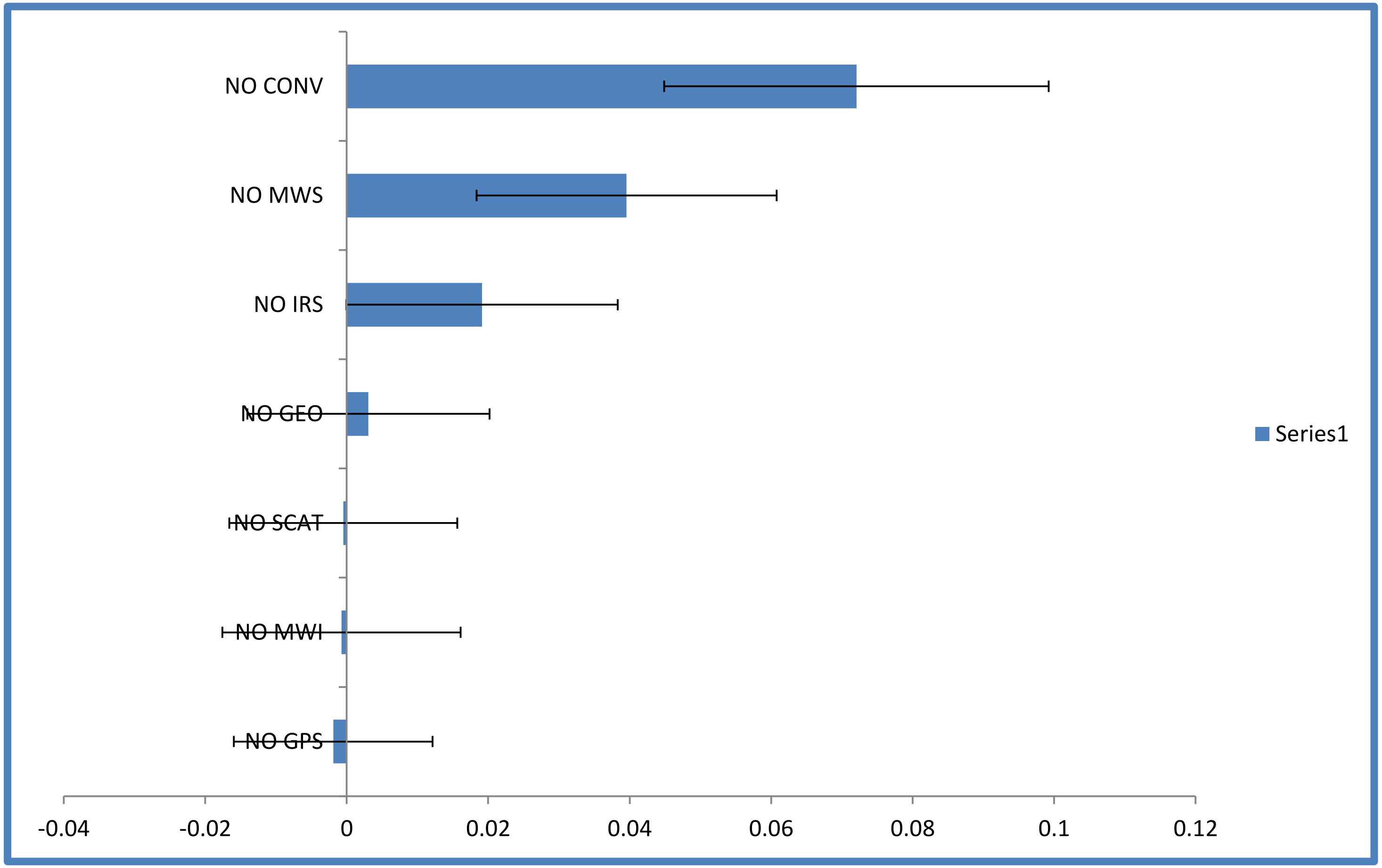
OSE 500z (SH-24h)



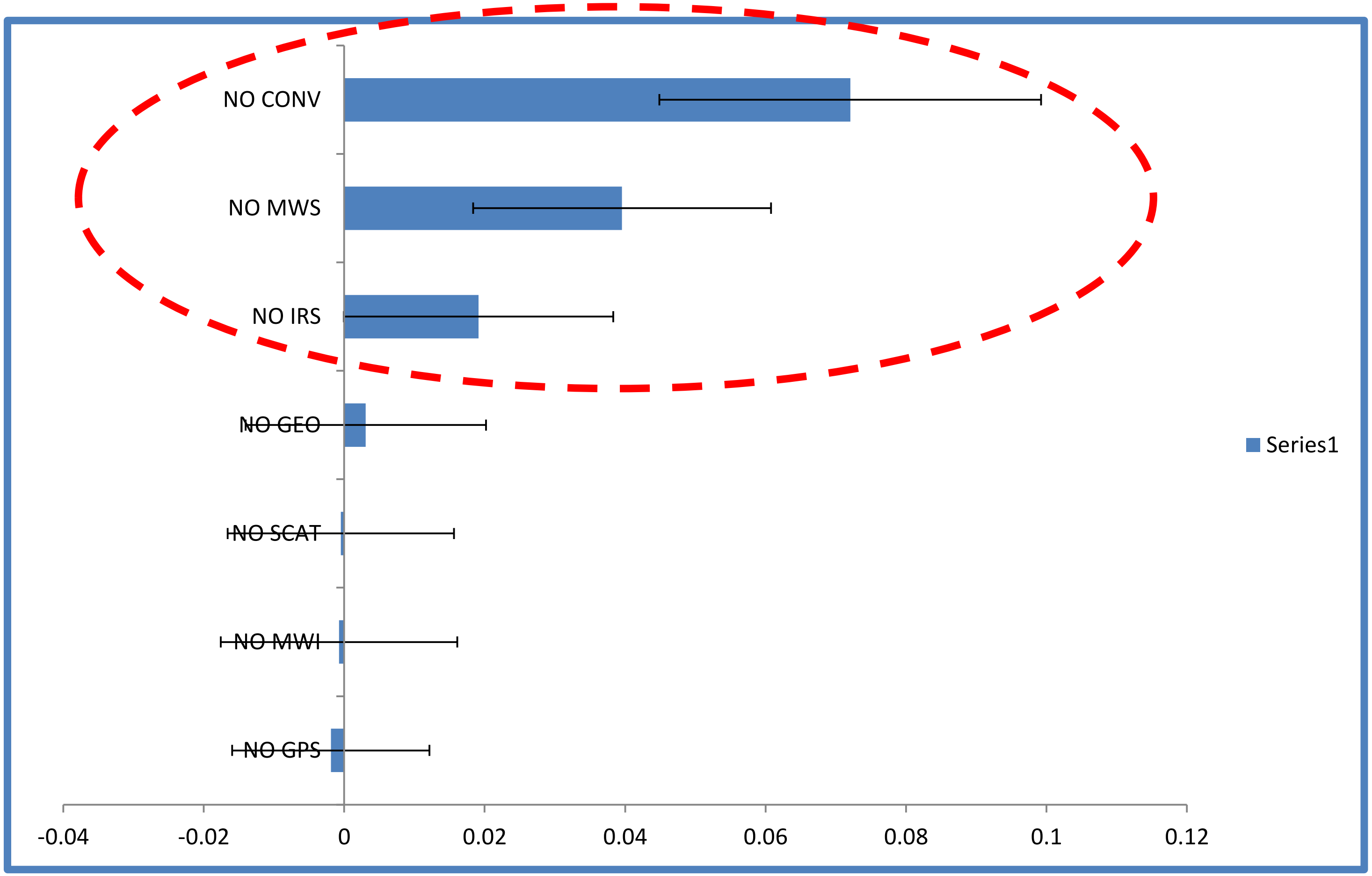
OSE 500z (SH-24h)



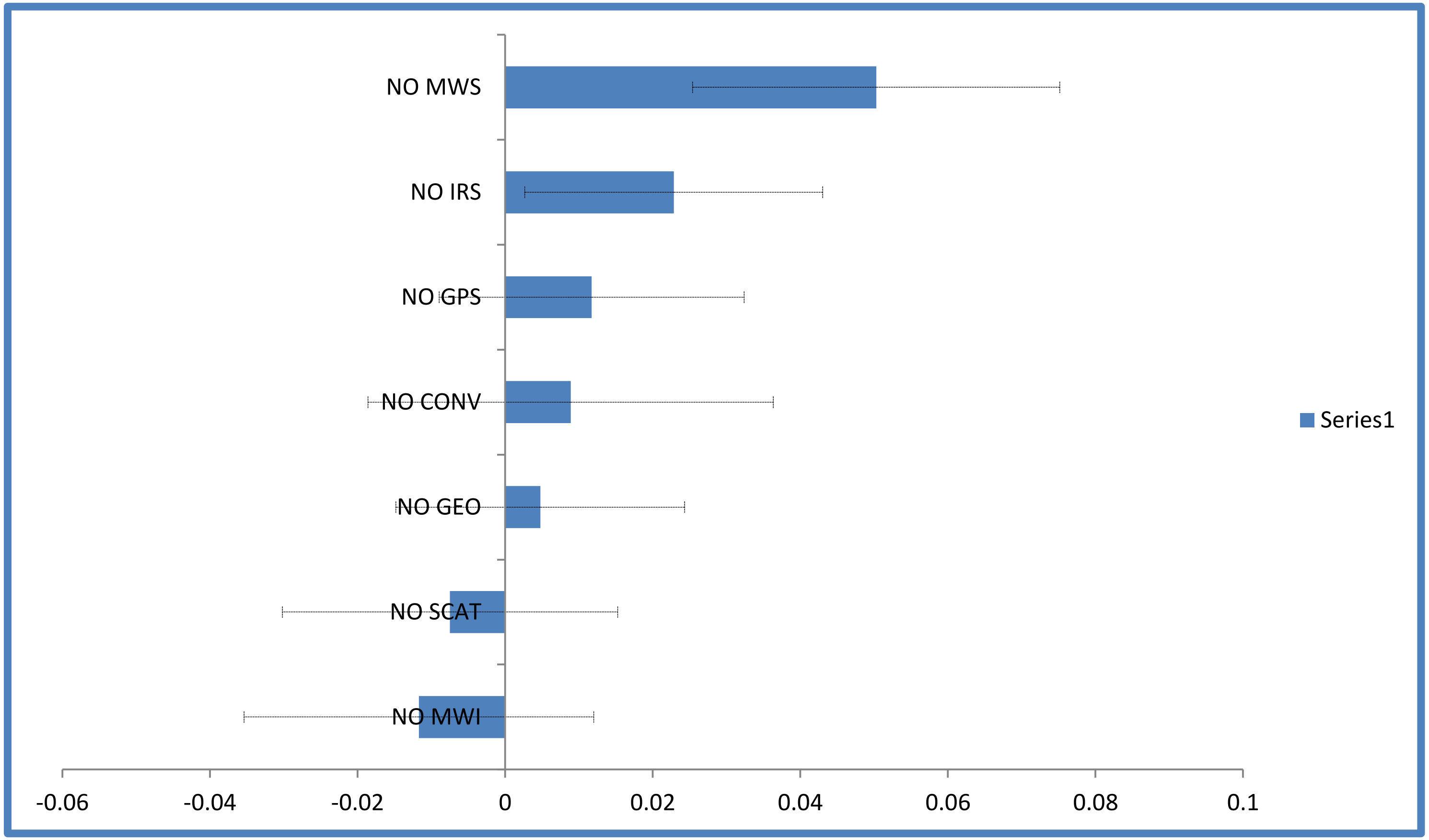
OSE 500z (NH-Day 6)



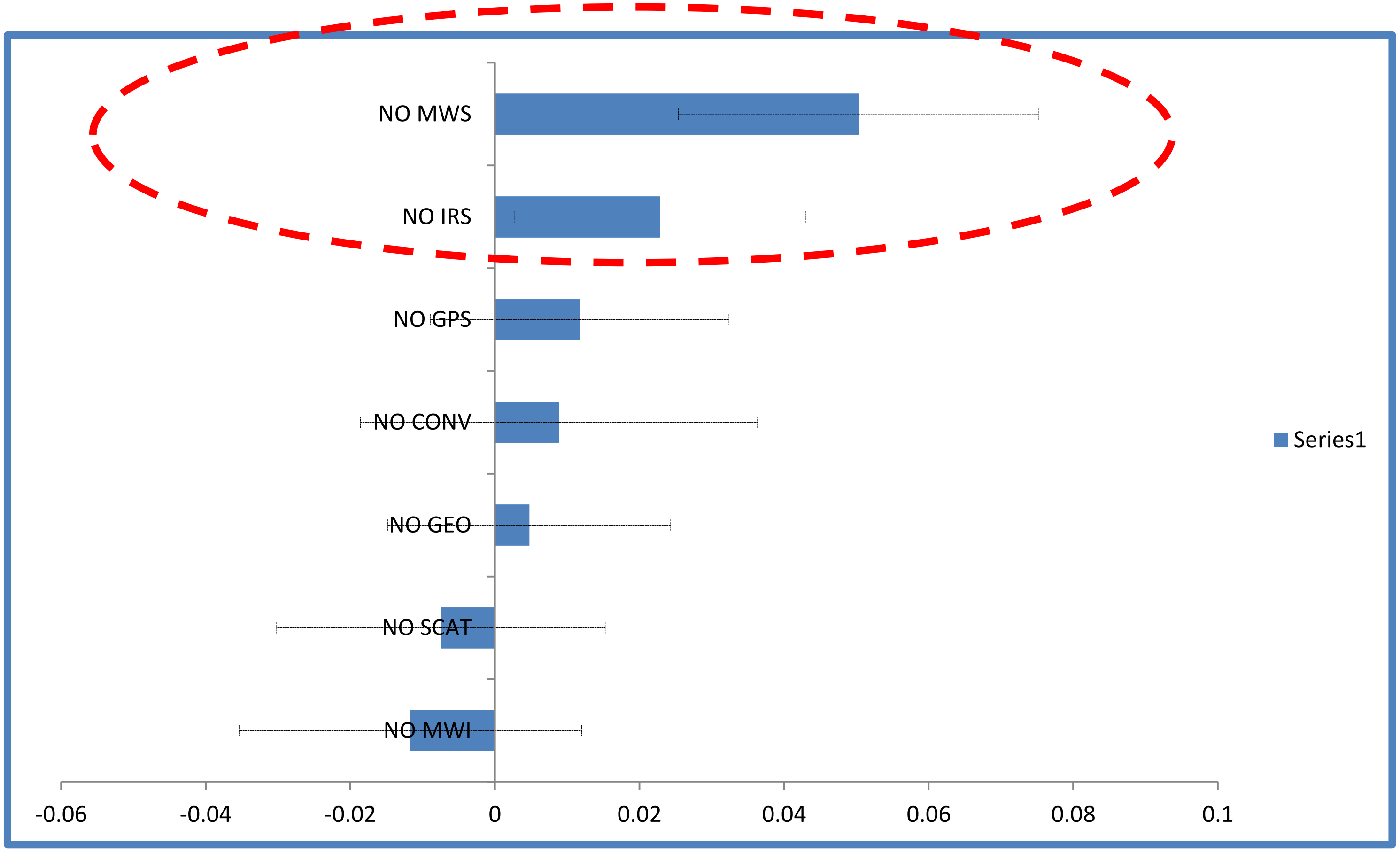
OSE 500z (NH-Day 6)



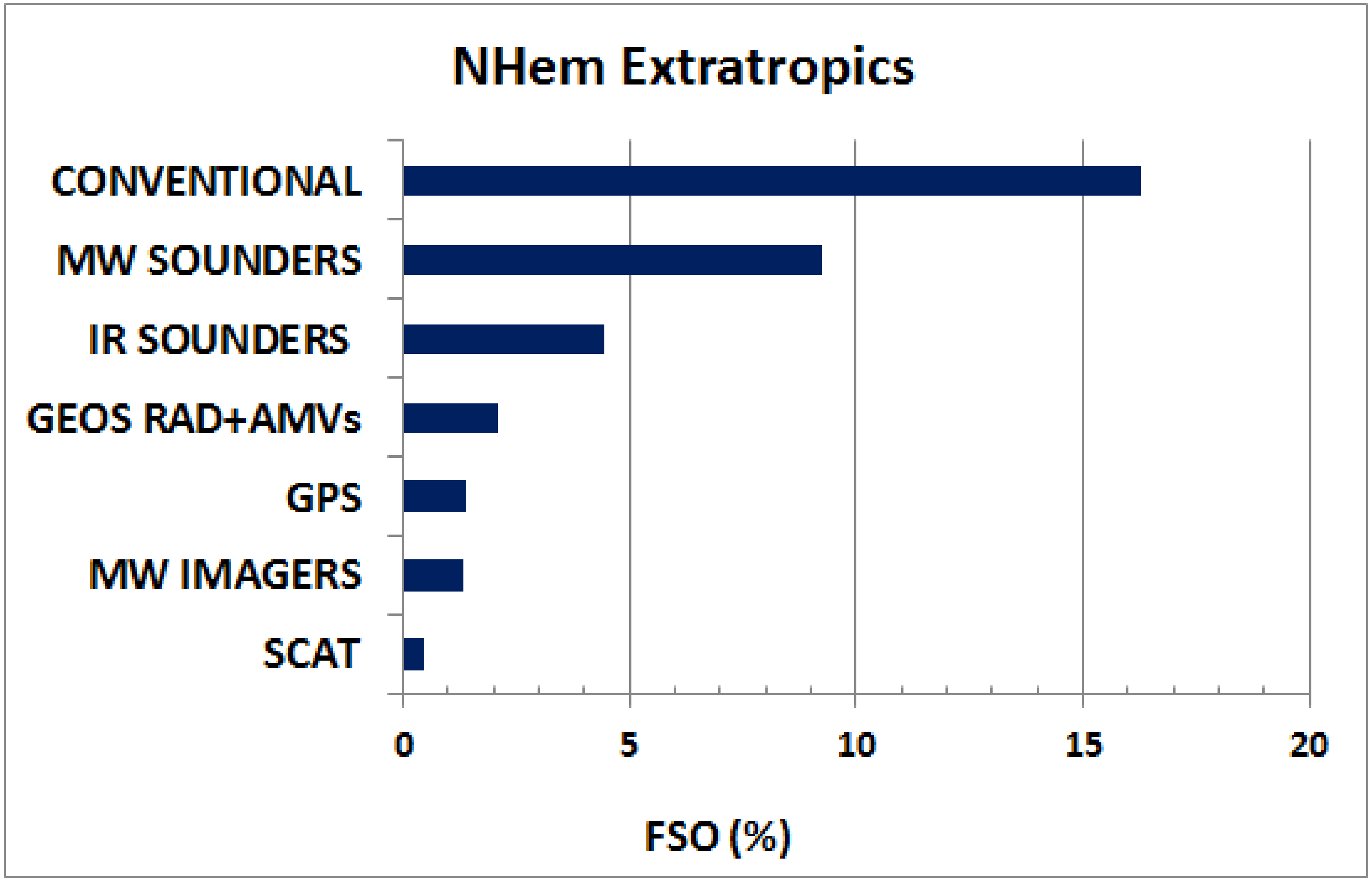
OSE 500z (SH-Day 6)



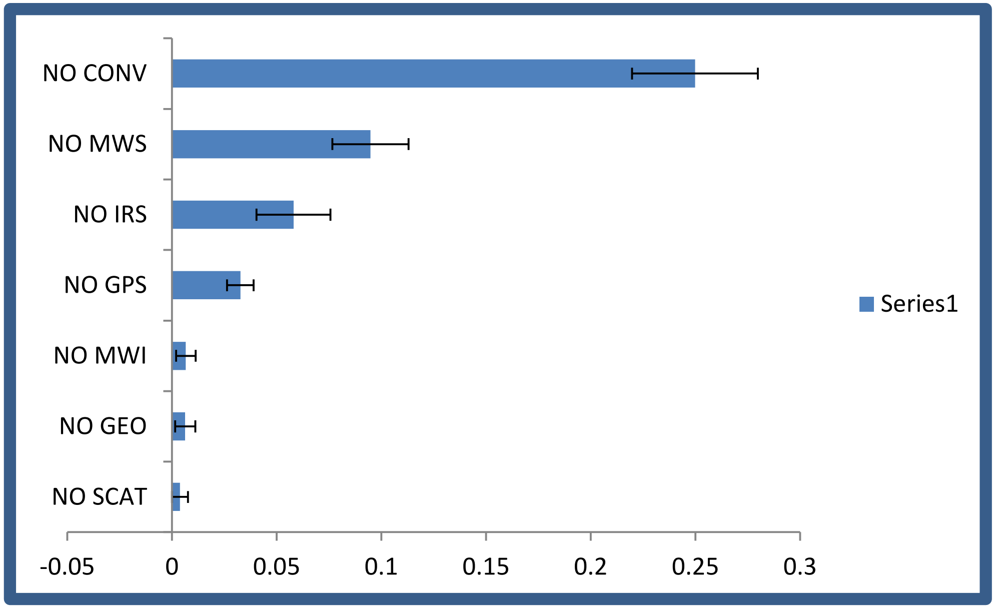
OSE 500z (SH-Day 6)

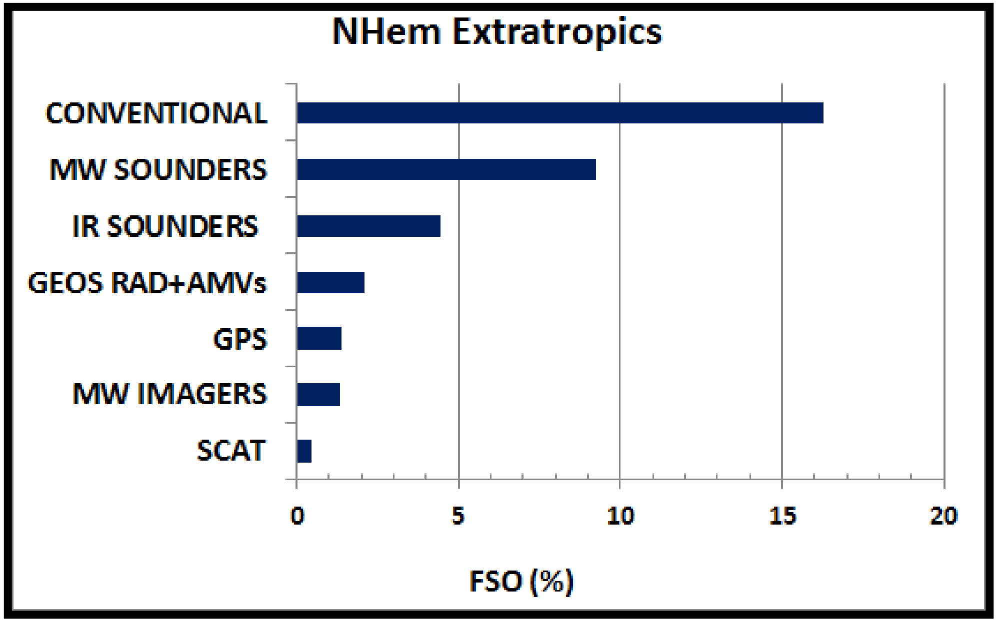


Comparing OSE results with ASD

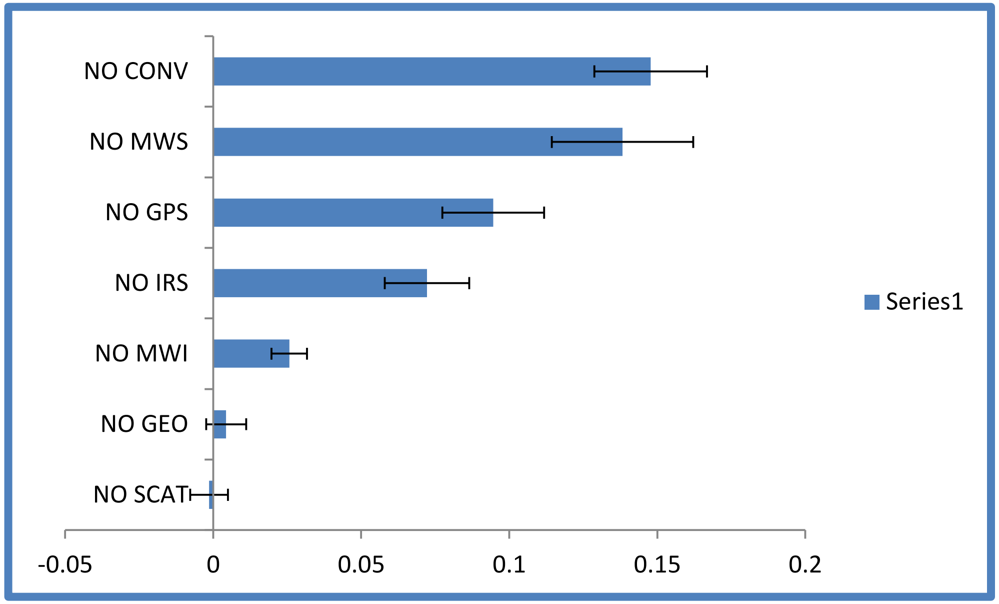


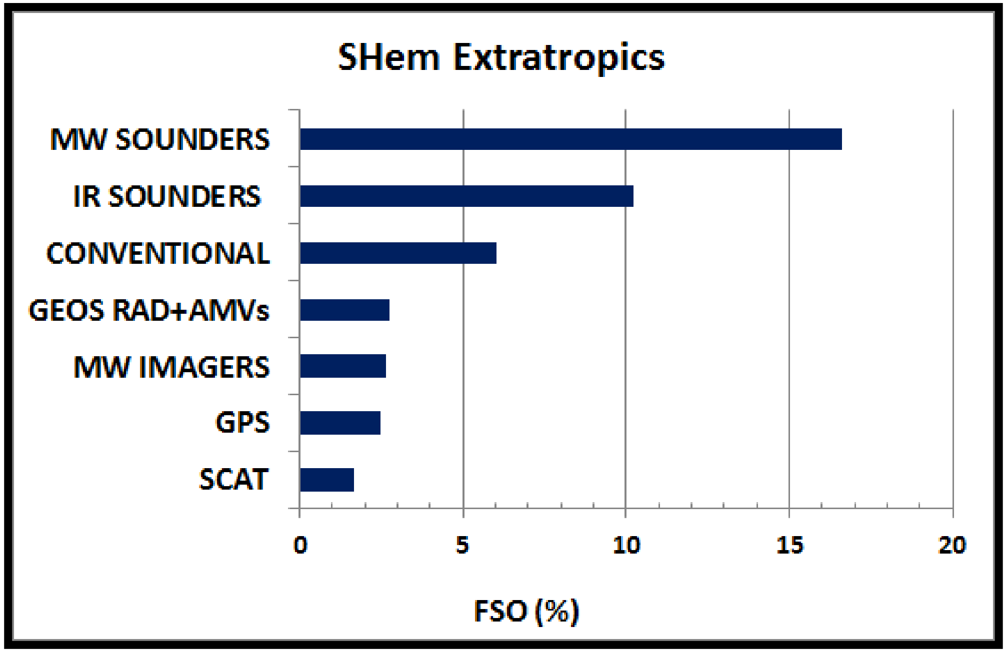
OSE 500z (NH-24h) v FSO (NH-24h)



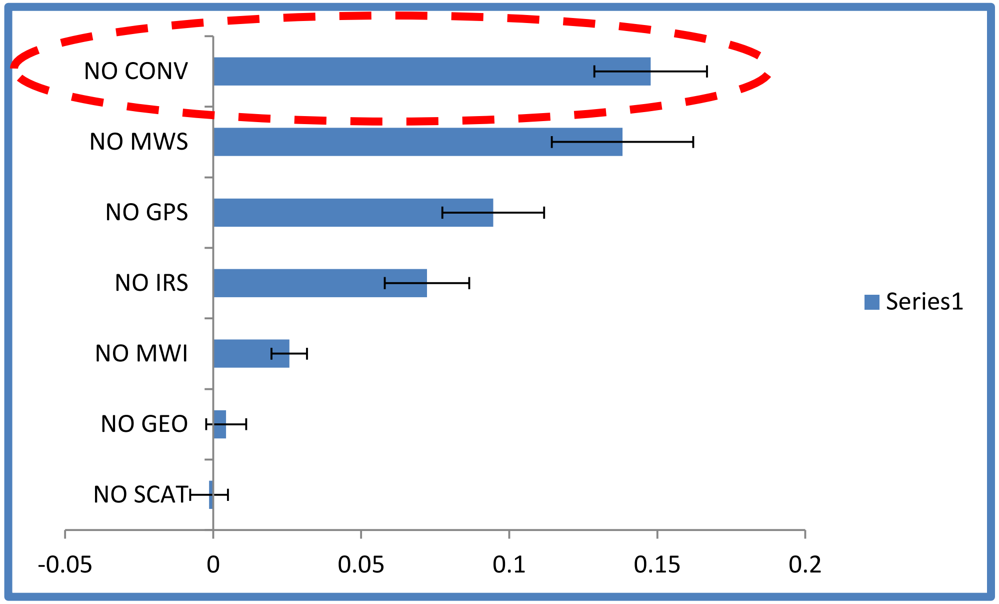


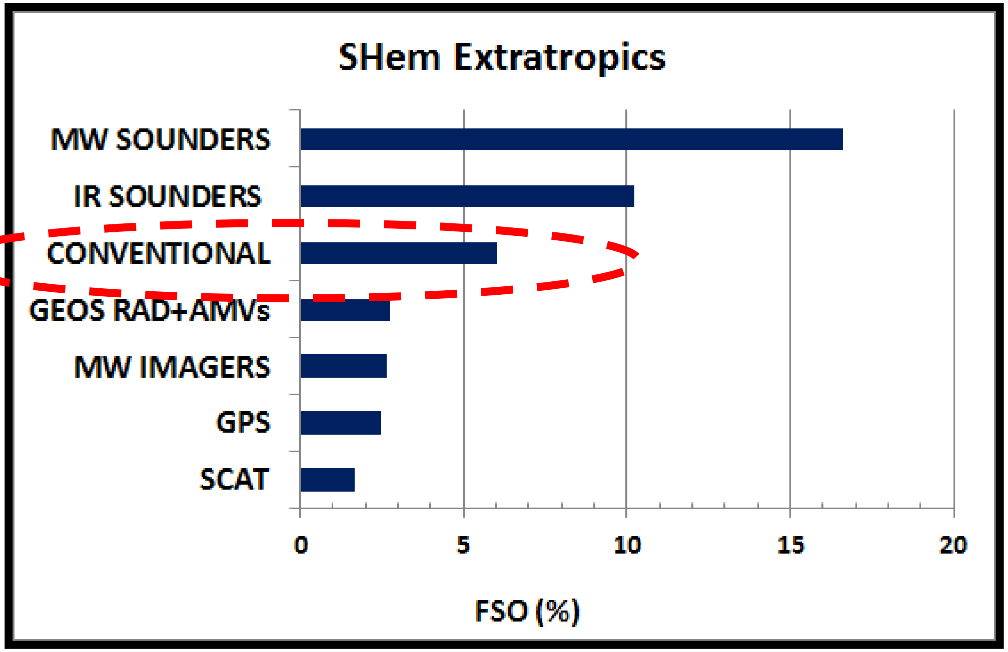
OSE 500z (SH-24h) v FSO (SH-24h)



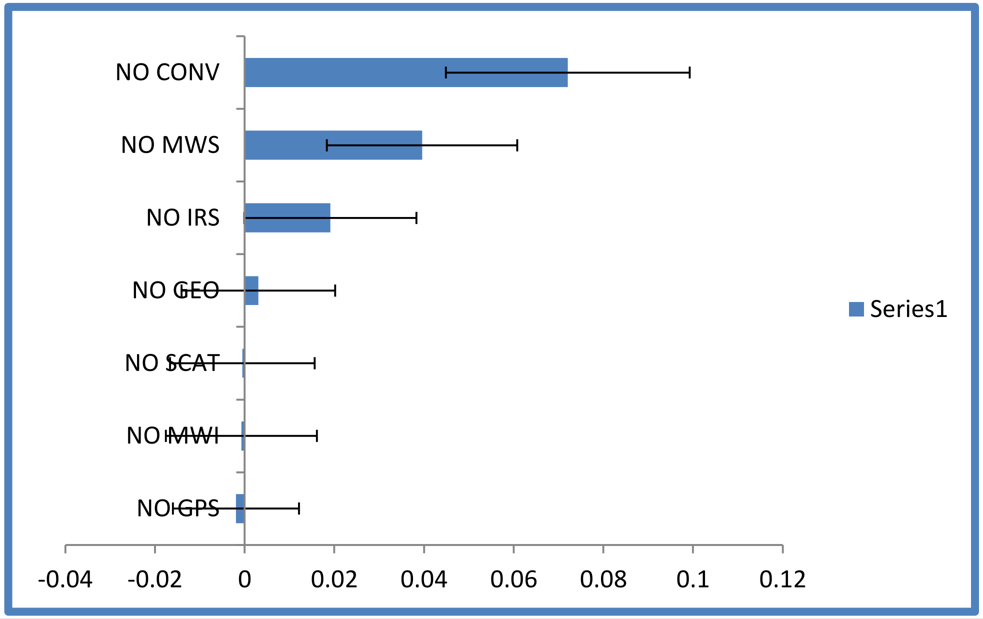


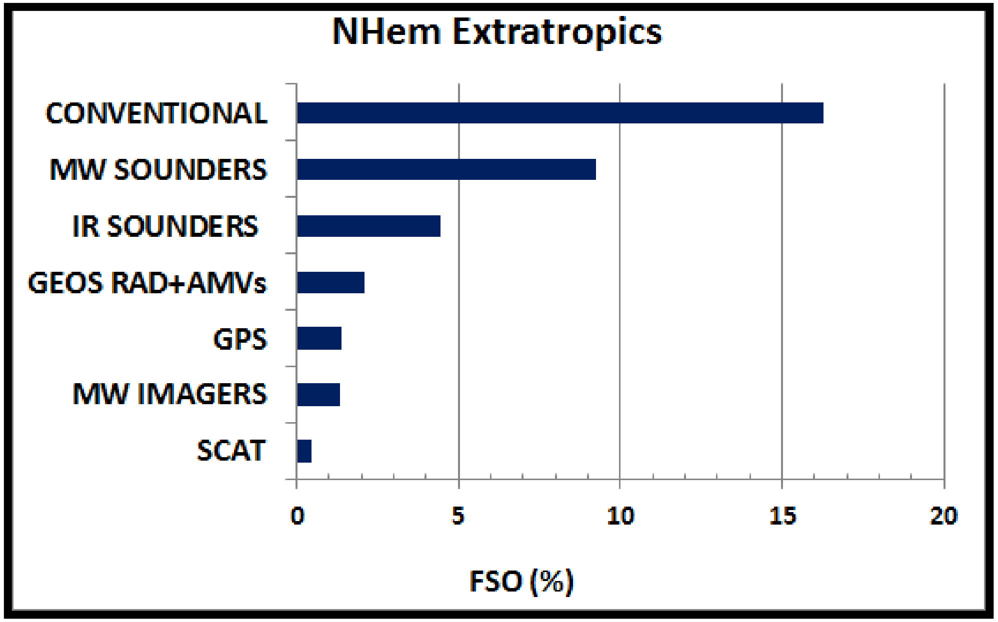
OSE 500z (SH-24h) v FSO (SH-24h)



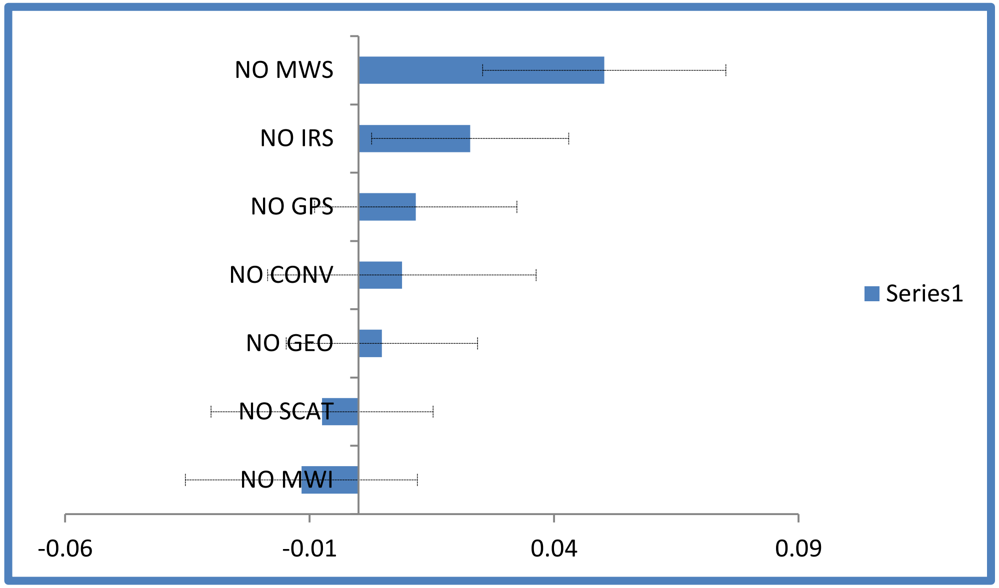


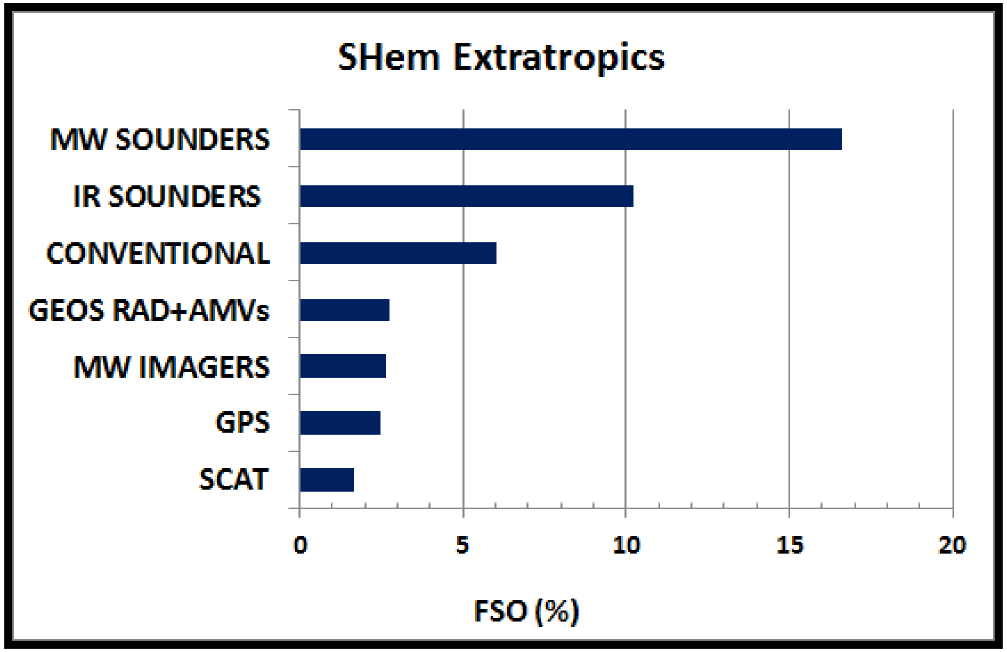
OSE 500z (NH-Day 6) v FSO (NH-24h)





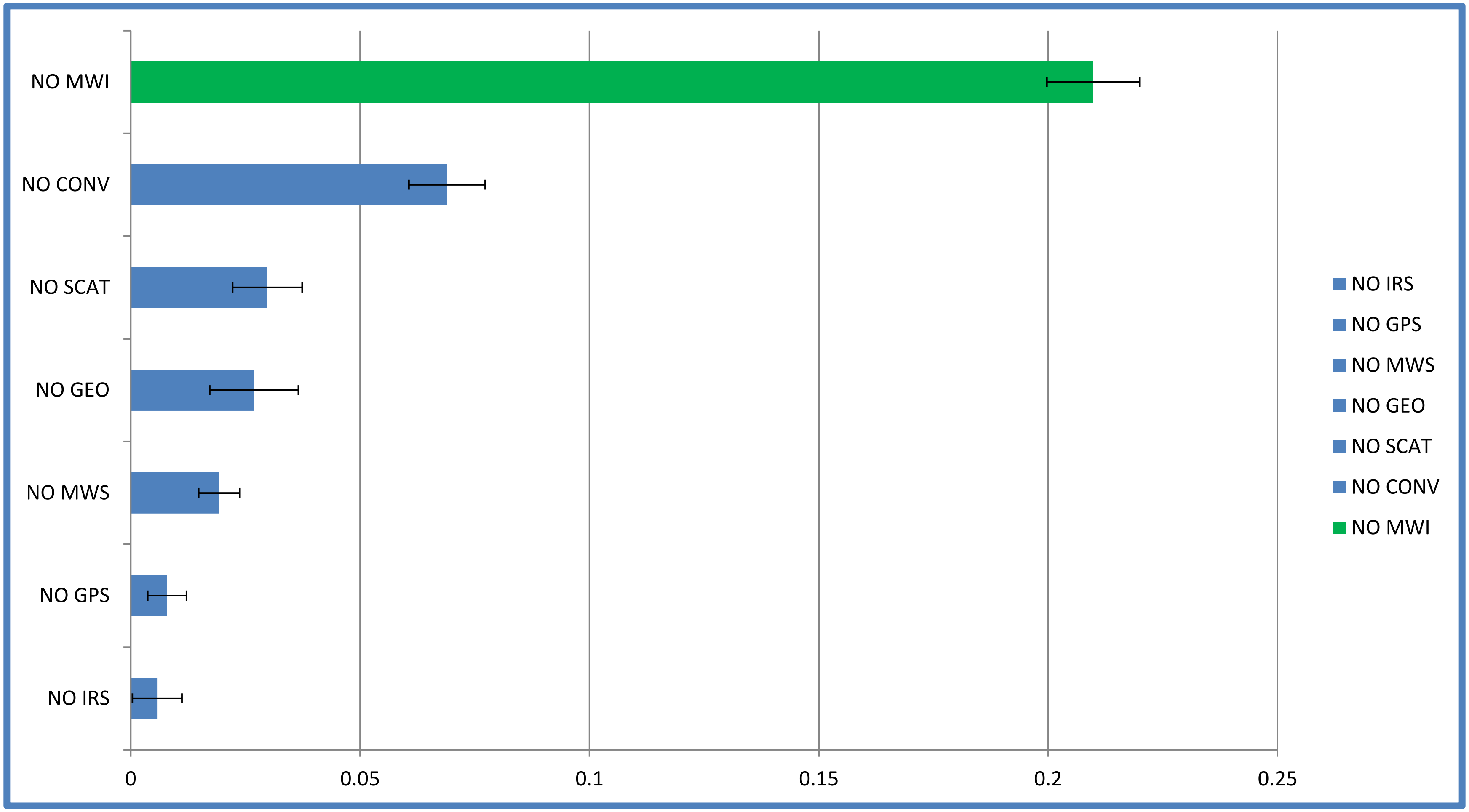
OSE 500z (SH-Day 6) v FSO (SH-24h)



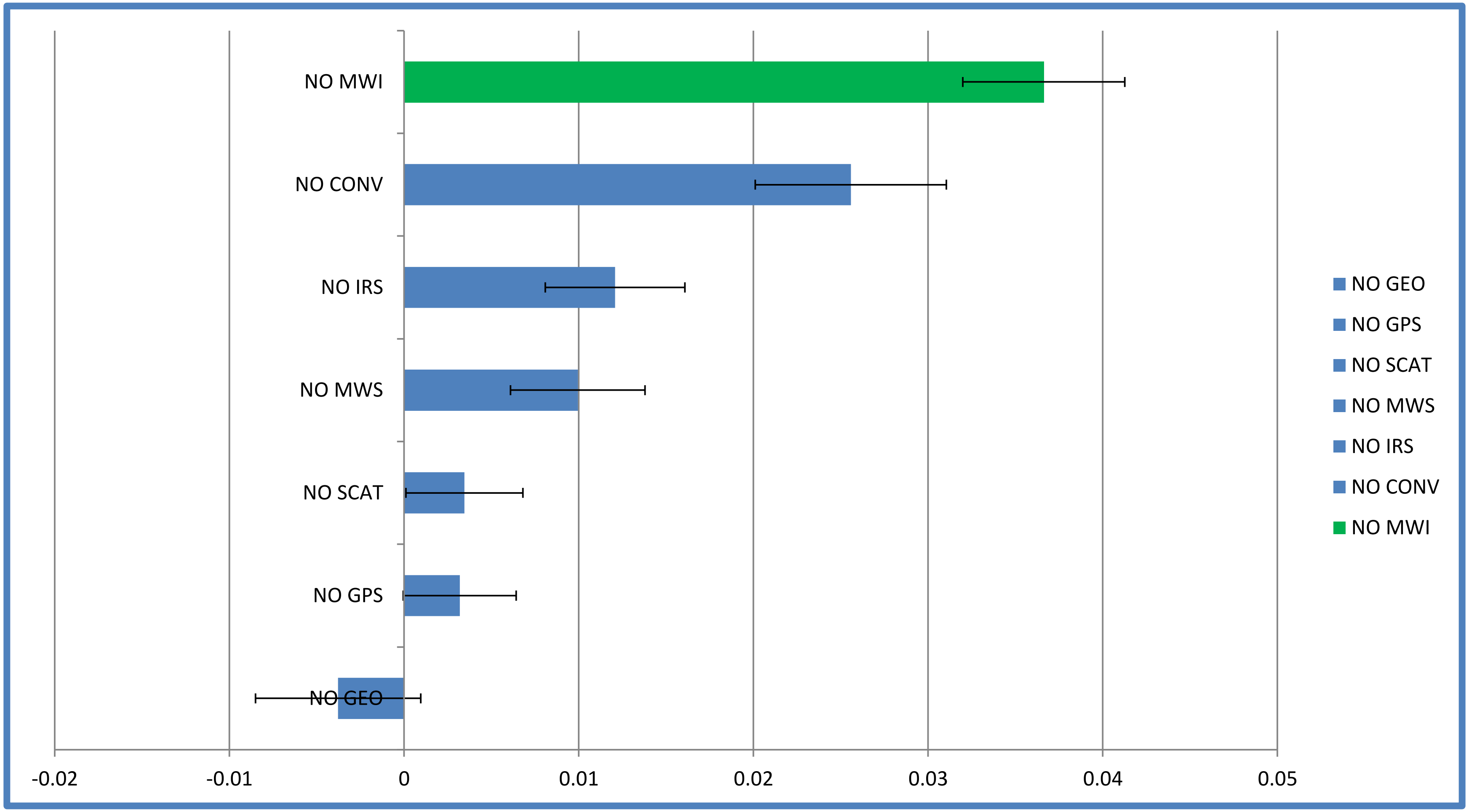


Lower level humidity in the Tropics

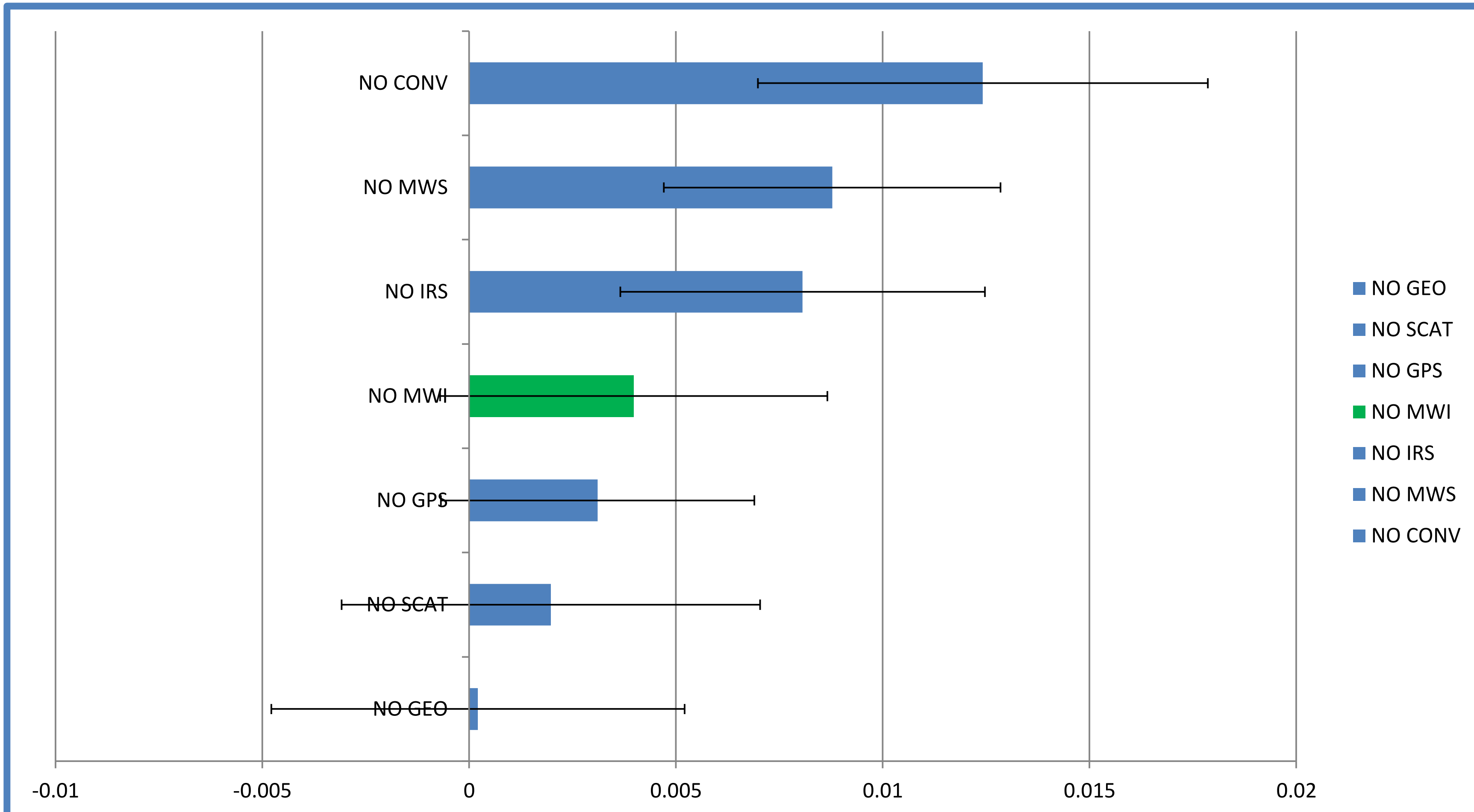
24hr 850RH in the Tropics



72hr 850RH in the Tropics

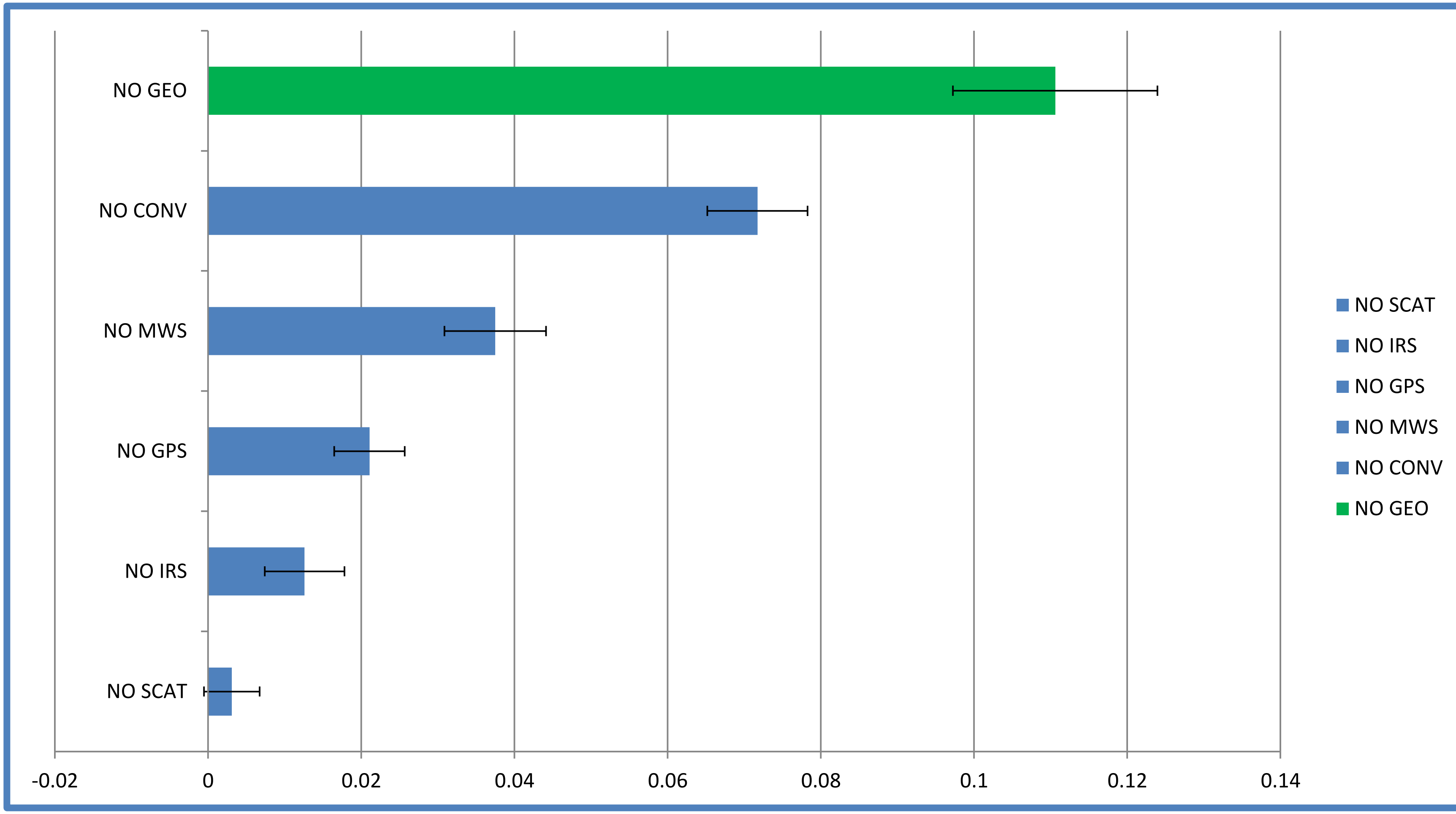


144hr 850RH in the Tropics

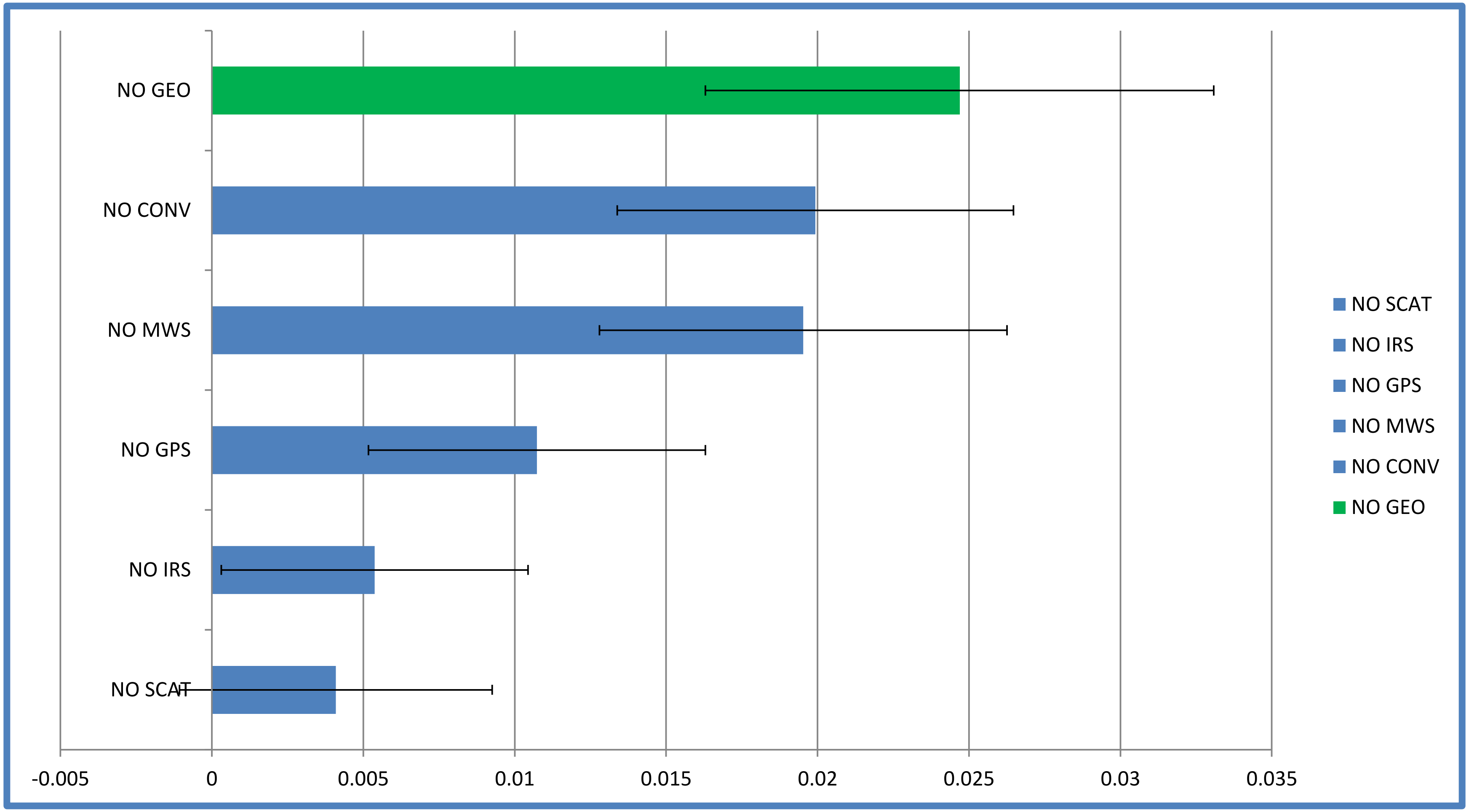


Upper level winds in the Tropics

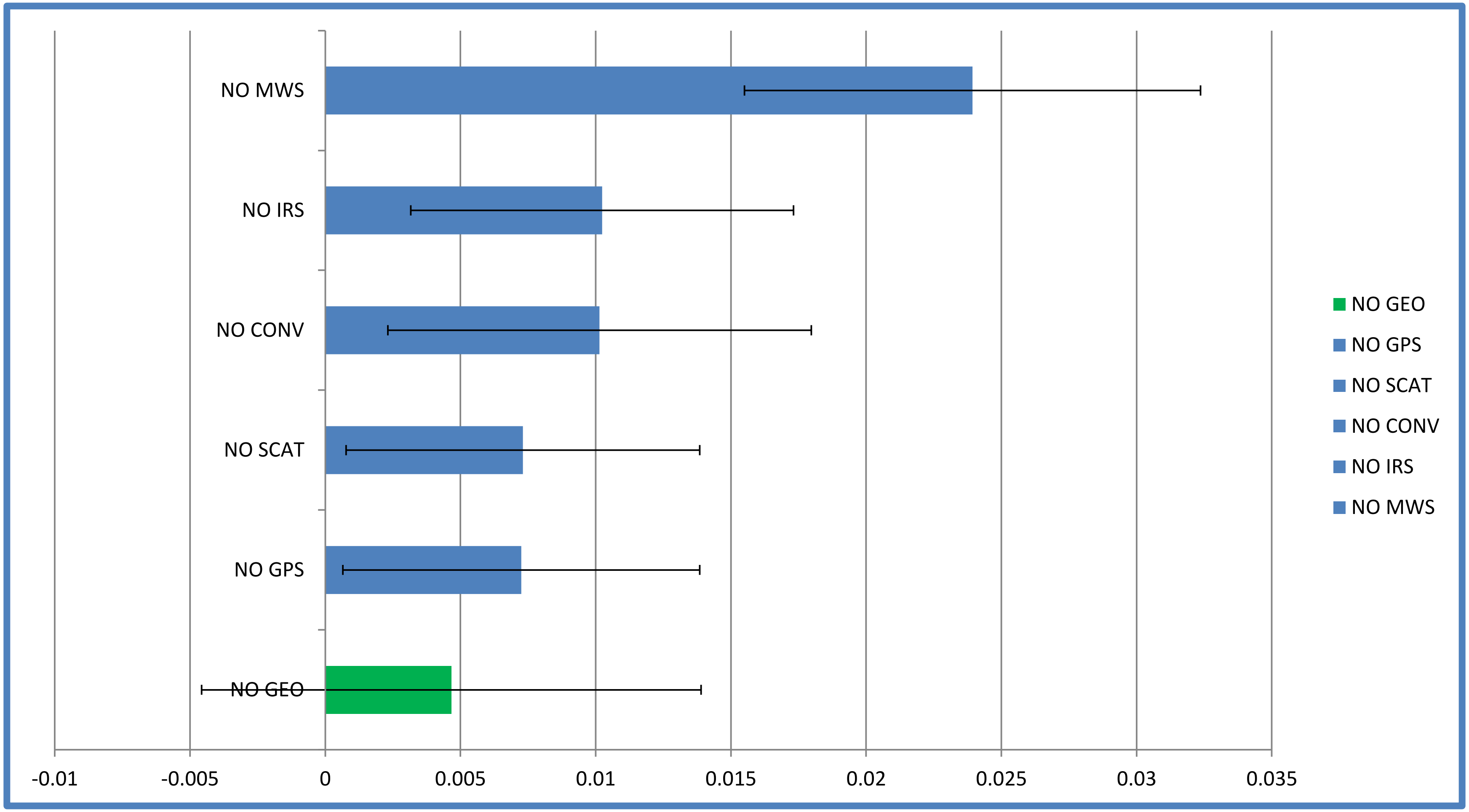
24hr Tropics 200hPa VW



72hr Tropics 200hPa VW

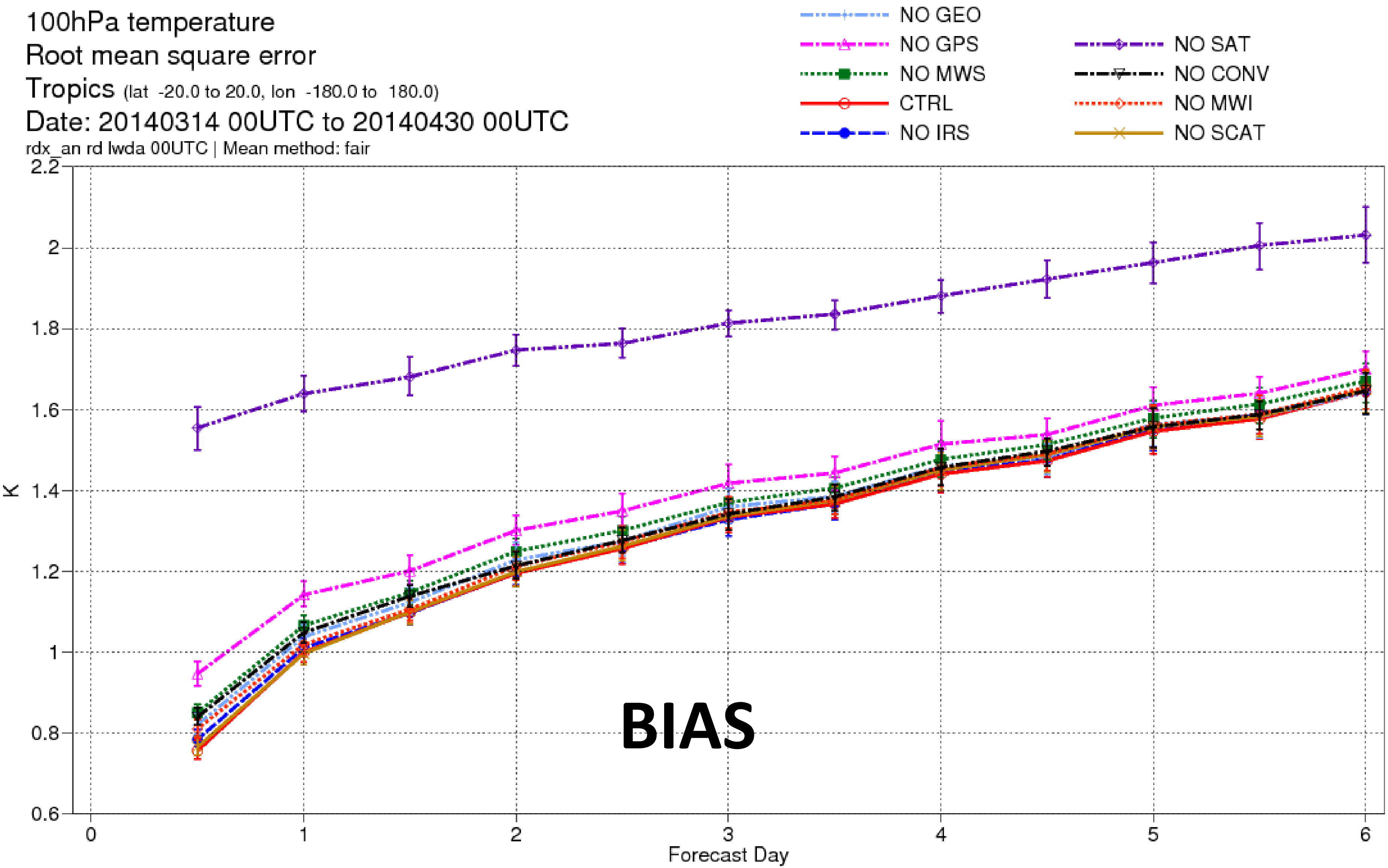


144hr Tropics 200hPa VW

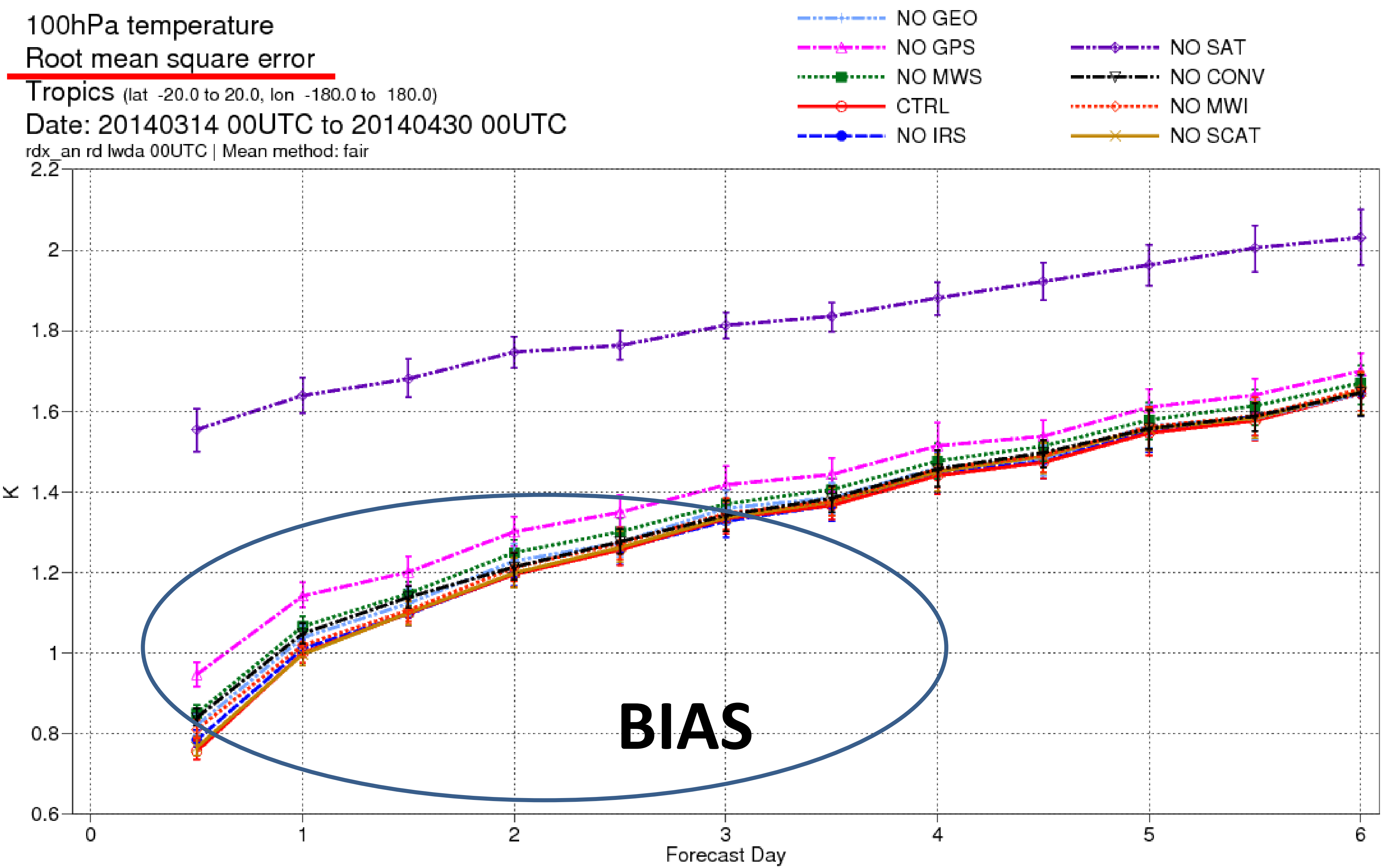


Upper level temperatures

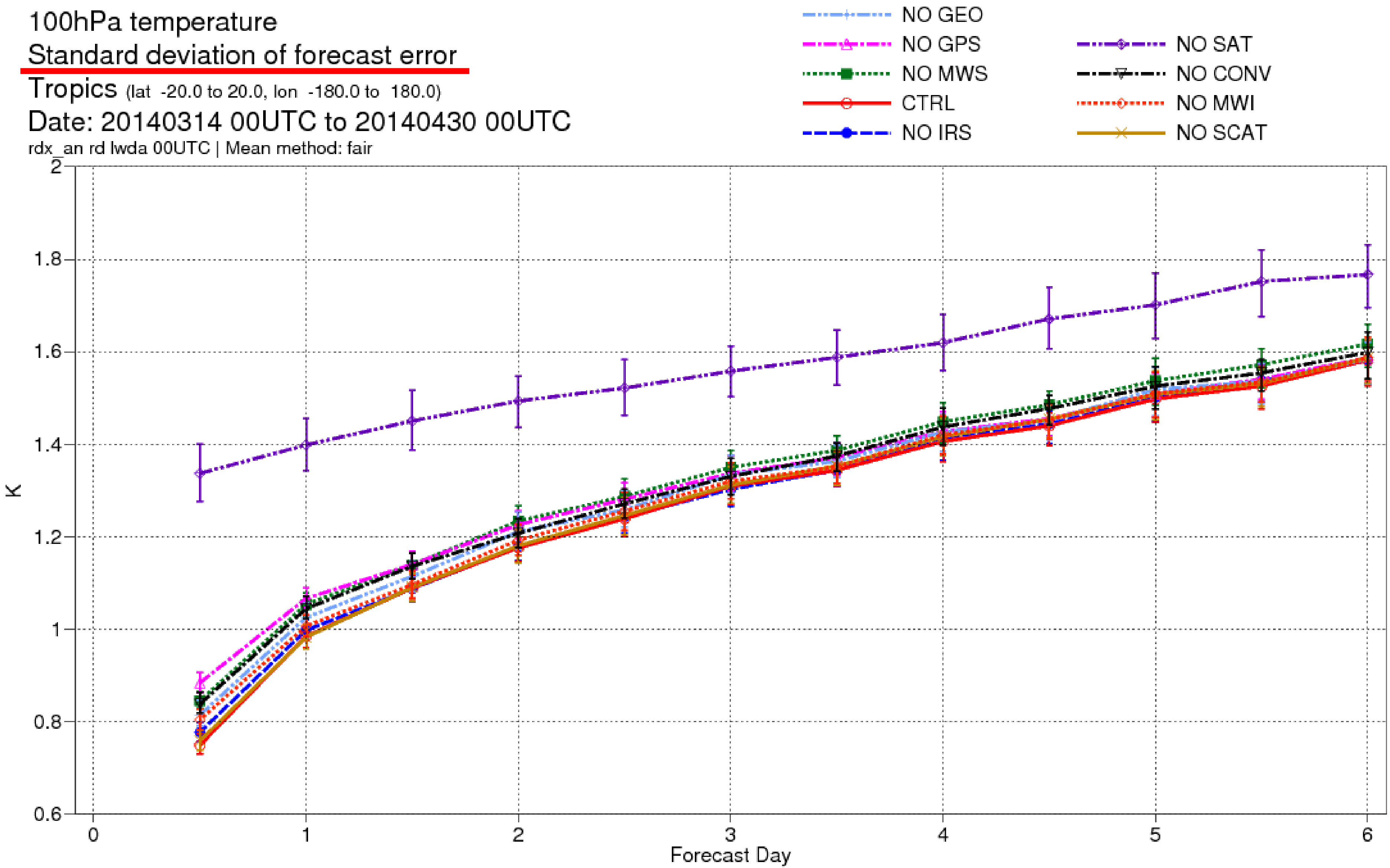
GPS-RO impact on temperature



GPS-RO impact on temperature



GPS-RO impact on temperature



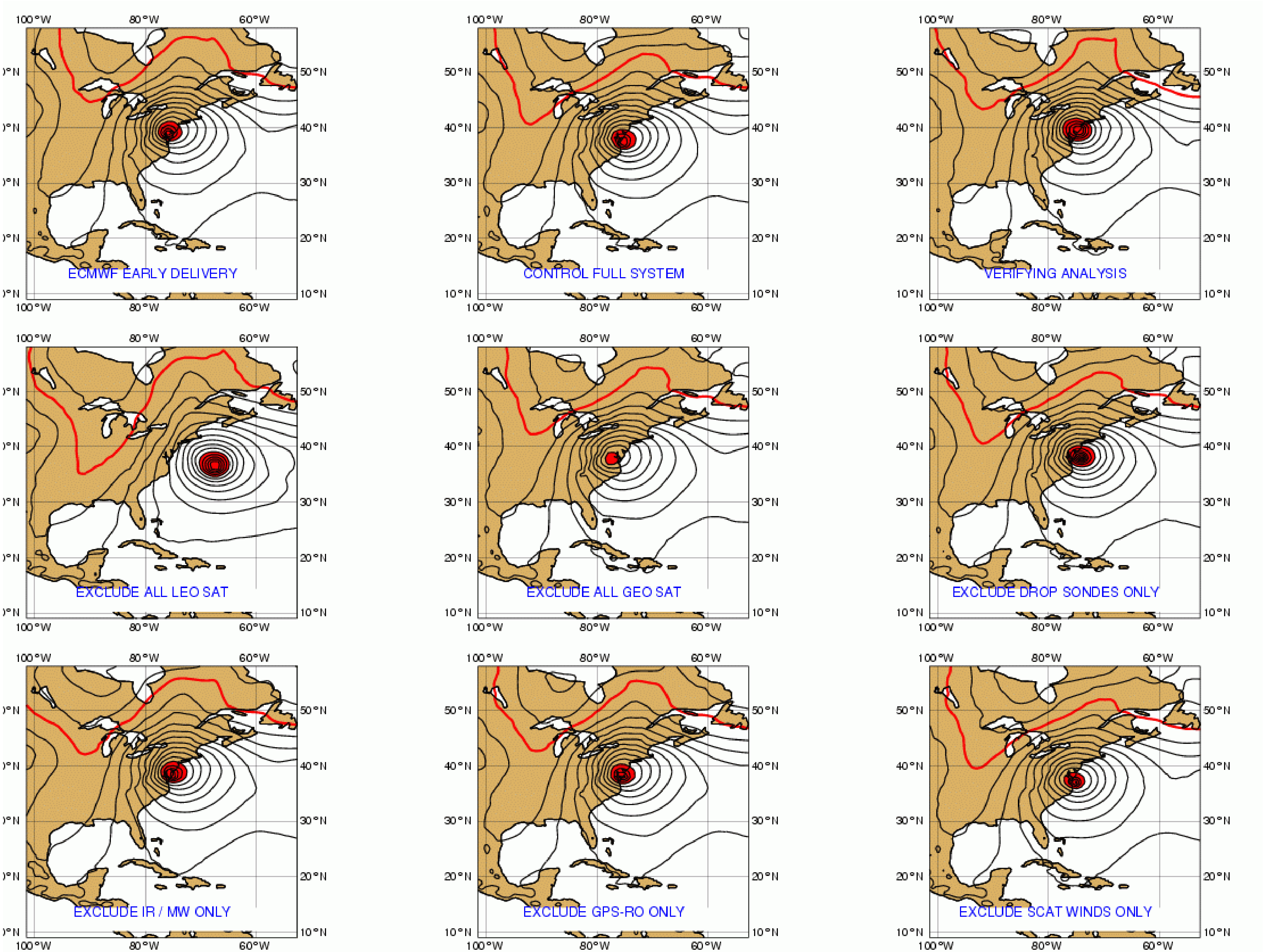
Case Studies

Are case studies valuable ?

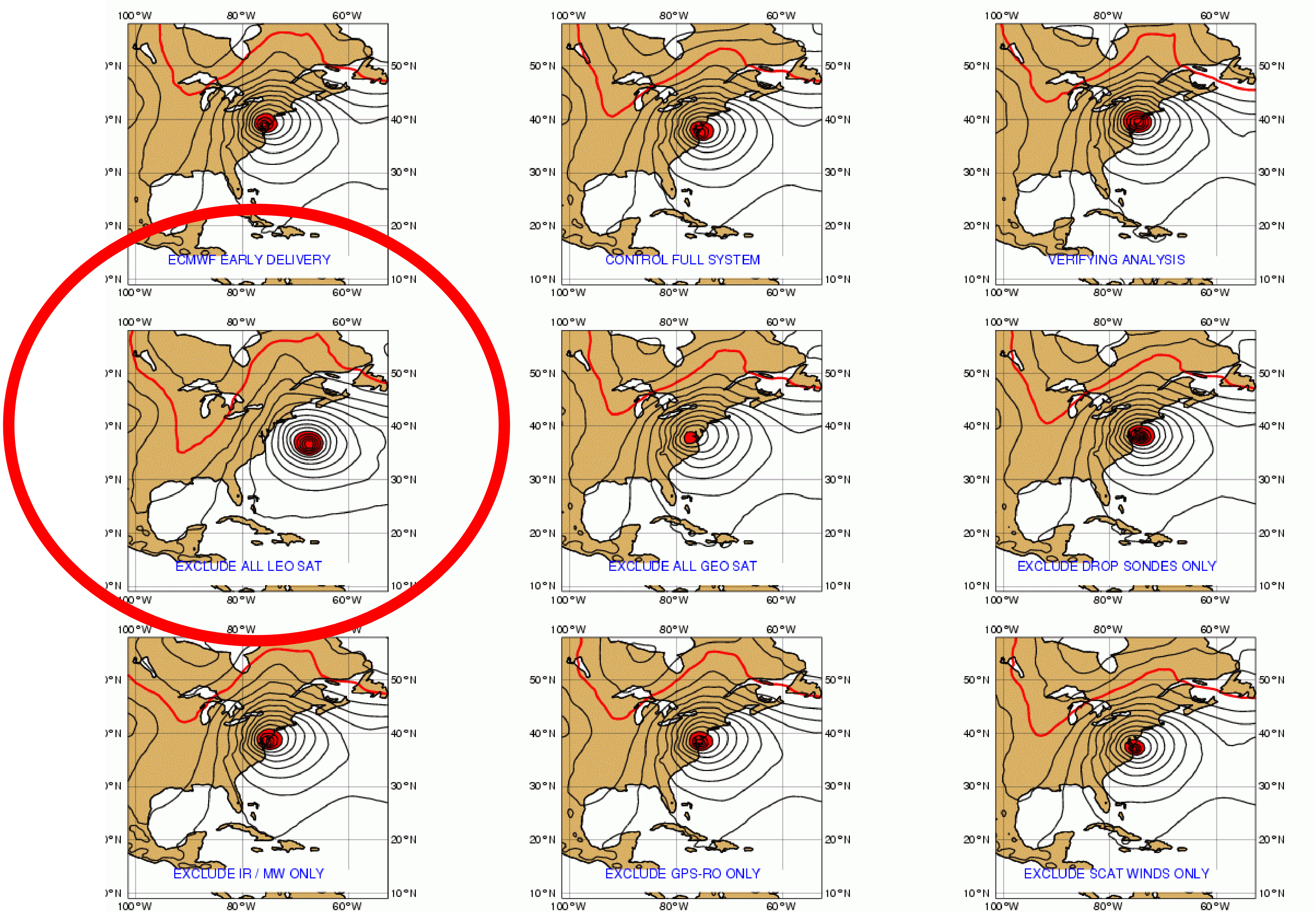
- Yes – they are typically the only thing that can actually convince decision makers !
- Yes – if the case is representative of a very common meteorological regime
- Yes – if the case is an extremely high impact event (e.g. Sandy)
- Yes – if we show (and publish) the good **and** the bad!!

Hurricane Sandy

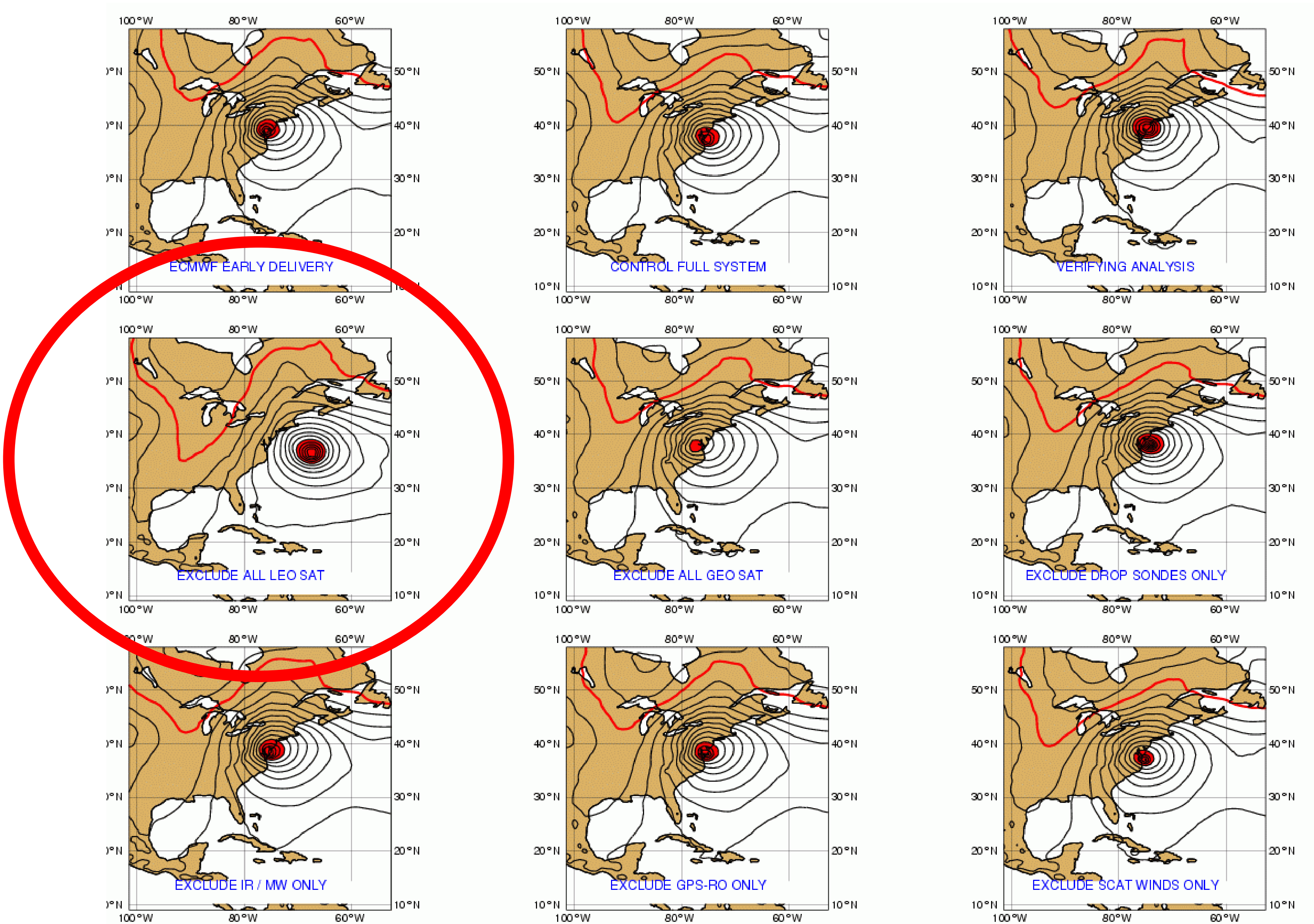
Hurricane Sandy



Hurricane Sandy

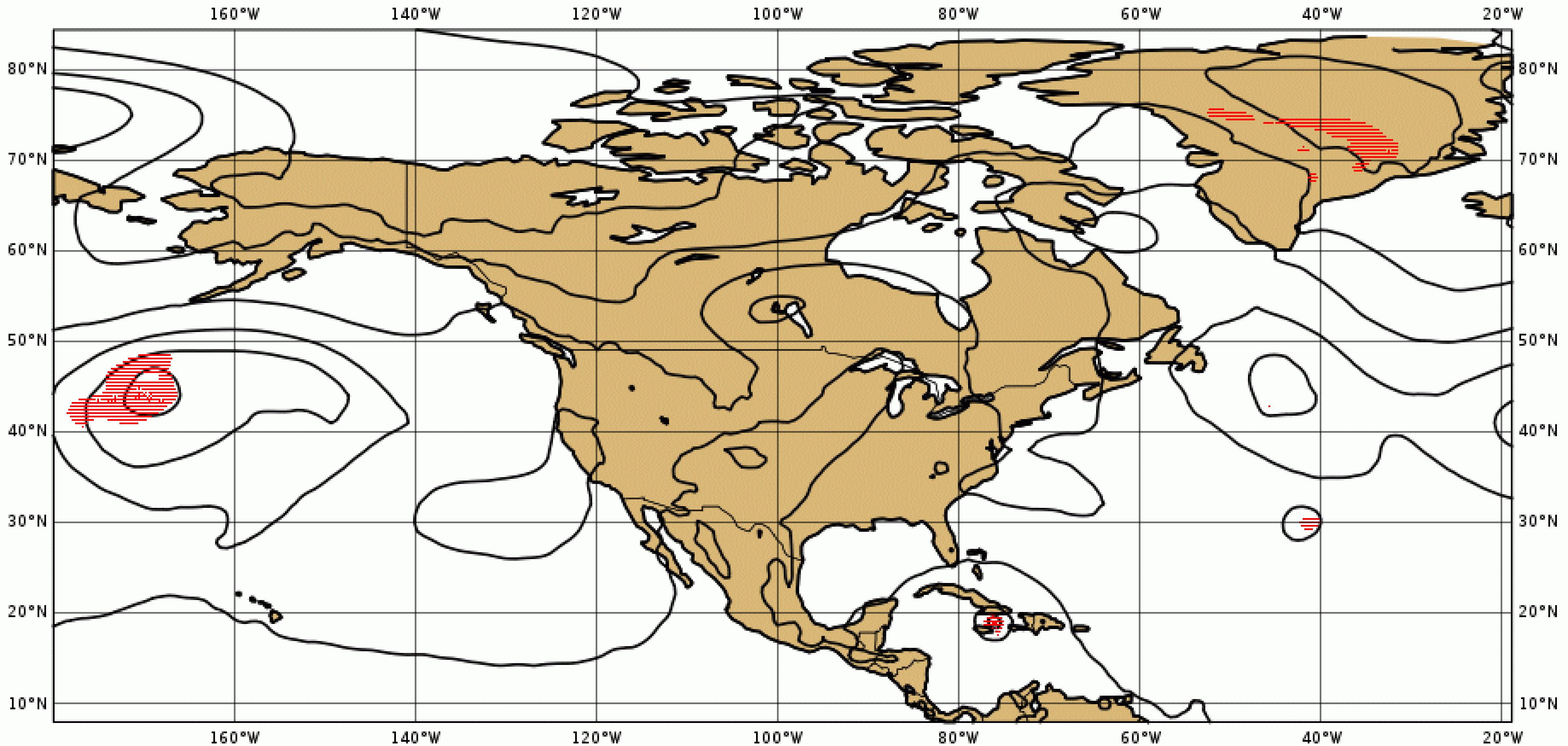


Forecast verification

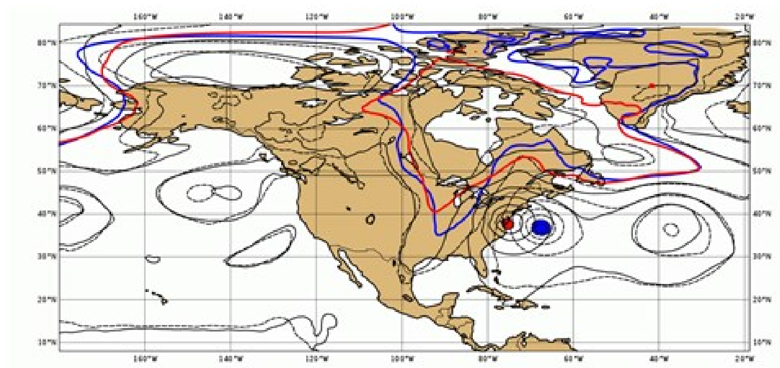


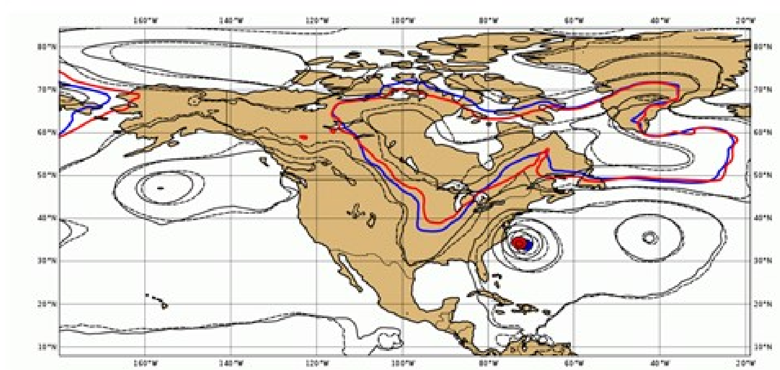
Analysis differences that led to failed (NO –LEO SAT) forecast

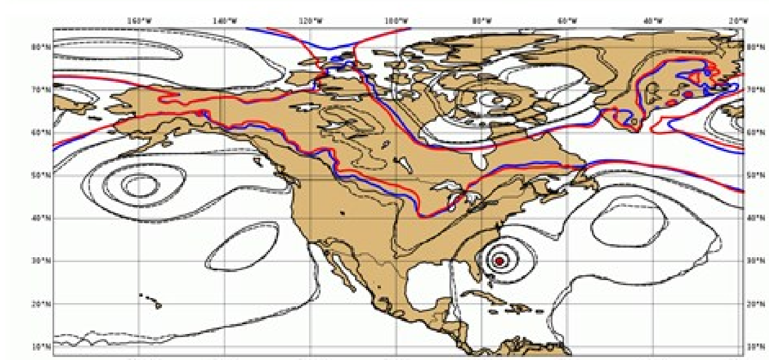
Control minus NO-LEO SAT MSLP

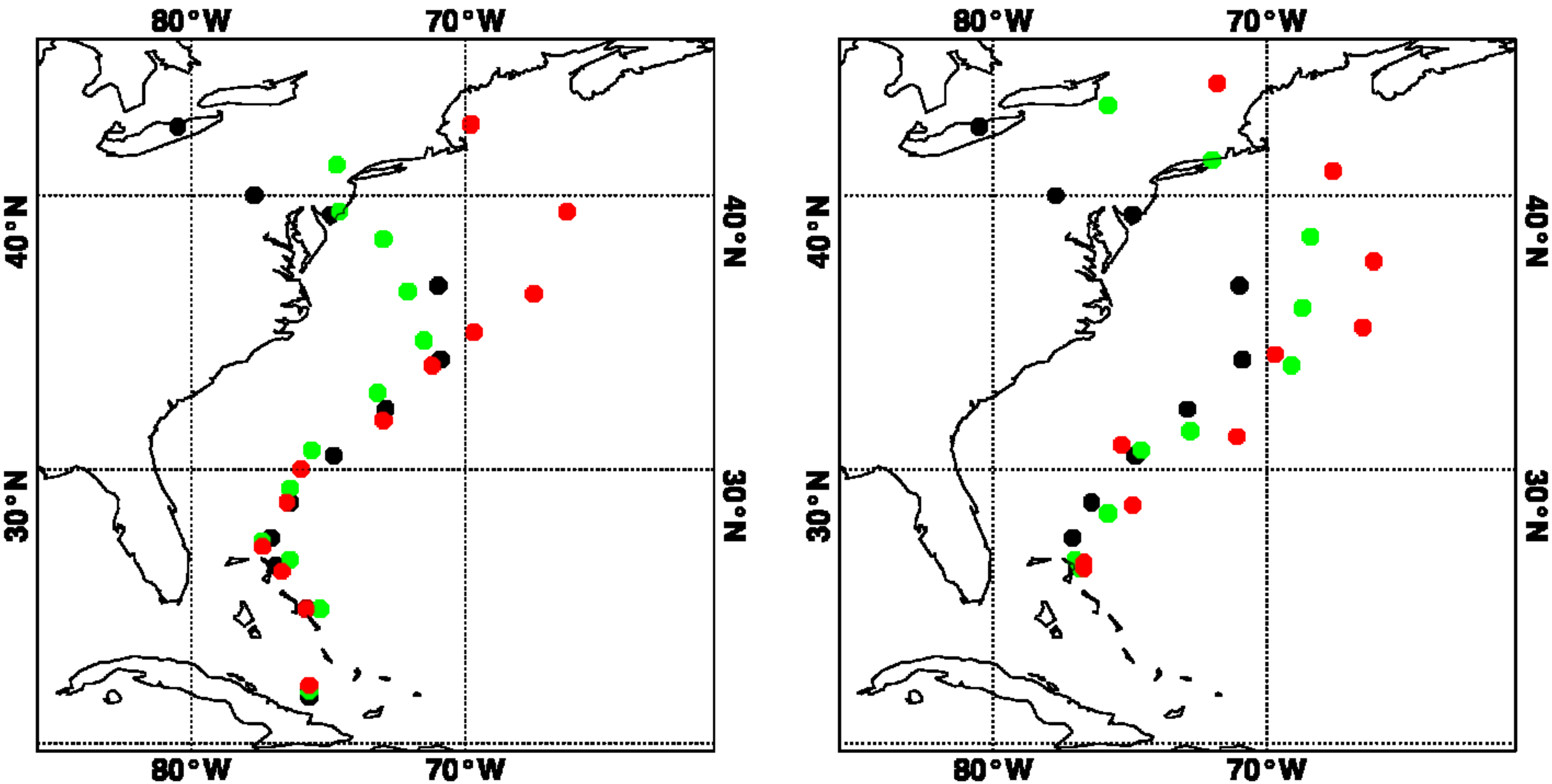


Hurricane Sandy



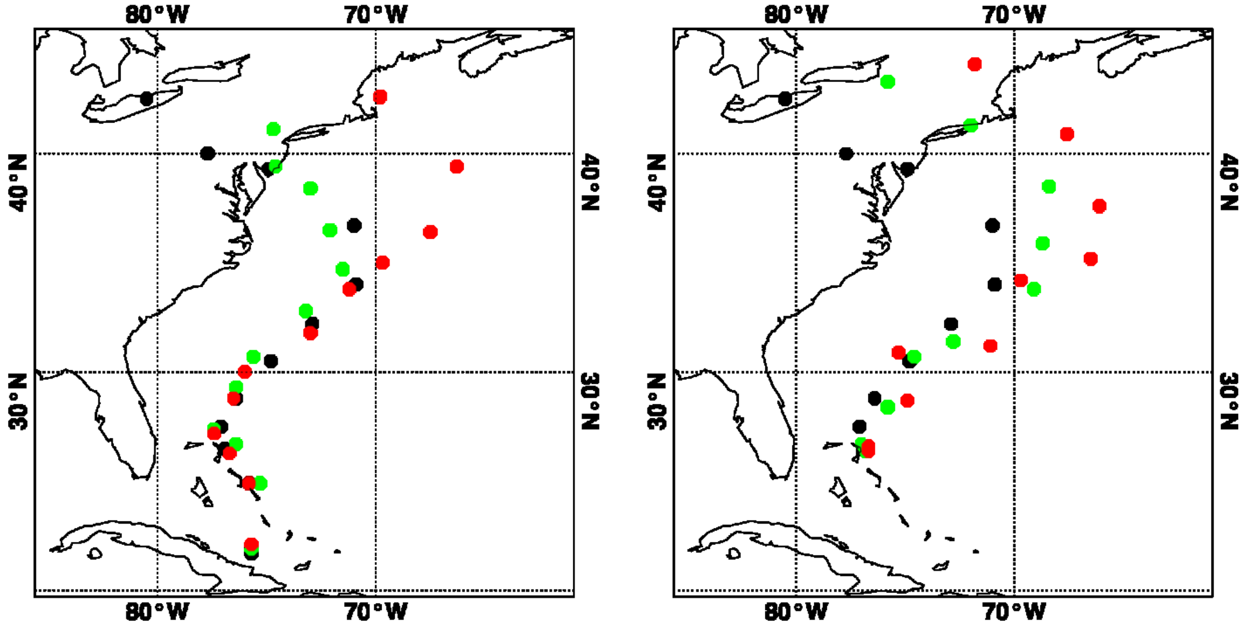






80°W
70°W
40°N
30°N
80°W
70°W
40°N
30°N

The importance of BG errors

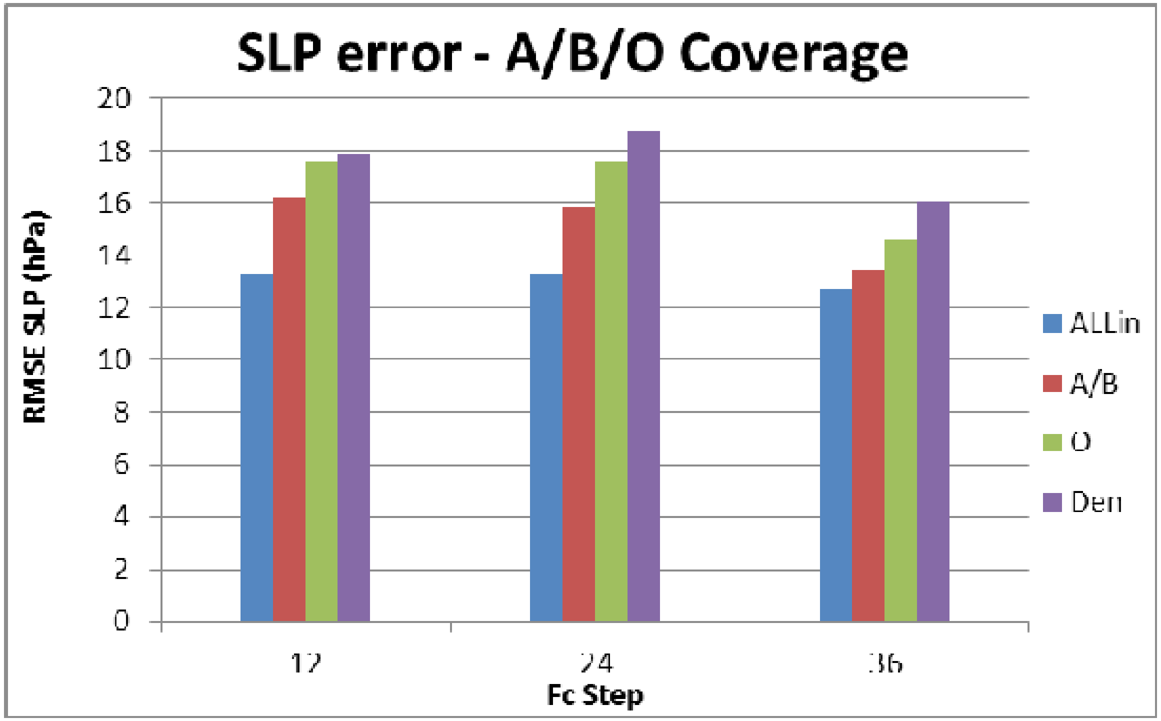


Tropical Cyclones

Impact of scatterometer winds

...on Tropical Cyclone FC

- For each storm the min SLP have been detected from the ECMWF model fields
- SLP have been compared to observation values (from NHC and JMA)



Statistics based only on cases where ASCAT-A, ASCAT-B and OSCAT passes were available
Dec 2012/ Feb 2013

Giovanna De Chiara

Overview

- What do we mean by impact (analysis / forecasts)
- What factors influence impact ?
- What diagnostics are available to measure impact and are they reliable ?
- An assessment of current satellite impact on NWP forecasts
- How satellite data impact model development

Satellite Data and Model Development

- Example of Satellites being used to improve Sudden Stratospheric Warming model numerics

- Example of MW imager data improving cloud micro-physics

Satellite Data and Model Development

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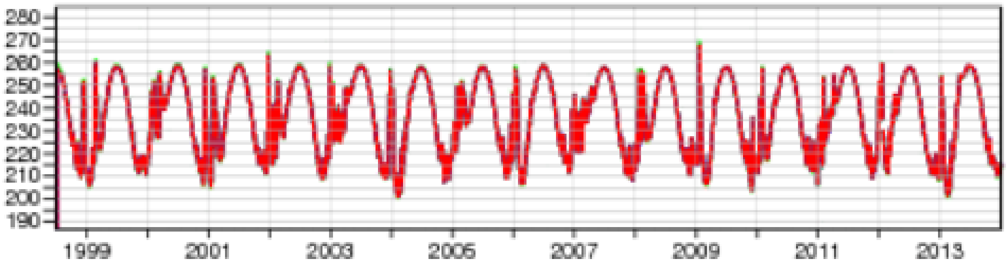
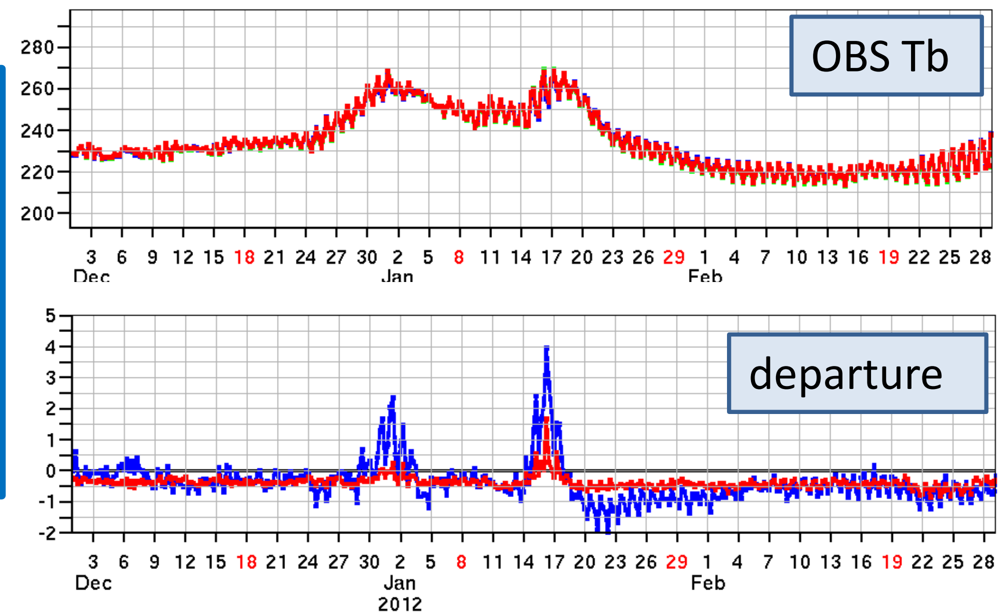
Sudden Stratospheric Warming



Temperature changes associated with SSW (up to 40K) are well observed by stratospheric channels satellites such as AMSUA

Comparing observations (e.g. in AMSUA channel 14) with values simulated from the model suggest that – while much of the warming amplitude is well represented – there are significant errors during the onset and decay of the event…



Sudden Stratospheric Warming

Asymptotic error analysis

Taylor expansion of d.p. (arrival point: $\eta \equiv \eta^{n+1}$):

$$\eta_d = \eta^{n+1} - \Delta t \left(\frac{d\eta}{dt}\right)^{n+1} + \frac{\Delta t^2}{2}\left(\frac{d^2\eta}{dt^2}\right)^{n+1} + O(\Delta t^3)$$

Standard 2-iteration SETTLS ($\ell = 2$) applied on vertical d.p.:

$$\eta_d^{(1)} = \eta^{n+1} - \Delta t\, \dot\eta(\eta^{n+1}, t^n) \quad (1)$$

$$\eta_d^{(2)} = \eta^{n+1} - \frac{\Delta t}{2}\left[\dot\eta\left(\eta_d^{(1)}, t^n\right) + 2\dot\eta\left(\eta_d^{(1)}, t^n\right) - \dot\eta\left(\eta_d^{(1)}, t^{n-1}\right)\right] \quad (2)$$

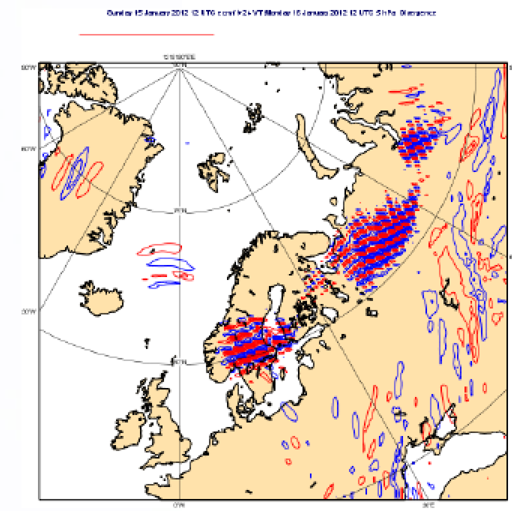
Substitute (1) to (2) and expand to obtain:

$$\eta_d^{(2)} = \eta^{n+1} - \Delta t \left(\frac{d\eta}{dt}\right)^{n+1} + \frac{\Delta t^2}{2}\left(\frac{d^2\eta}{dt^2}\right)^{n+1} + O(\Delta t^3)$$

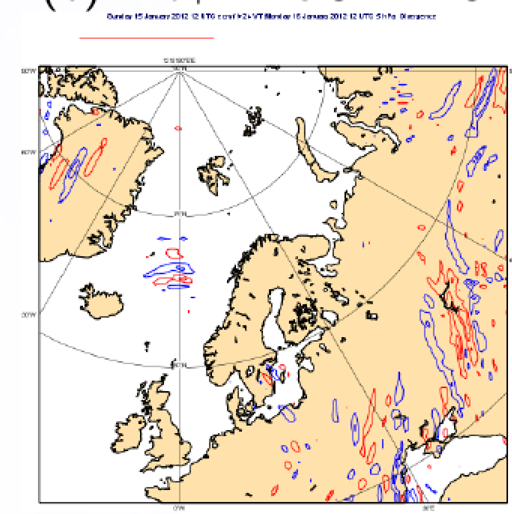
Non-extrapolated scheme in modified SETTLS:

$$\eta_d^{*(2)} = \eta^{n+1} - \Delta t \left(\frac{d\eta}{dt}\right)^{n+1} + \frac{\Delta t^2}{2}\left(\frac{d^2\eta}{dt^2}\right)^{n+1} + \frac{\Delta t^2}{2}\left(\frac{\partial\dot\eta}{\partial t}\right)^{n+1} + O(\Delta t^3)$$

Principal term difference: $\eta_d^{*(2)} - \eta_d^{(2)} = \frac{\Delta t^2}{2}\left(\frac{\partial\dot\eta}{\partial t}\right)^{n+1}$



(b) D t+24hrs SETTLS



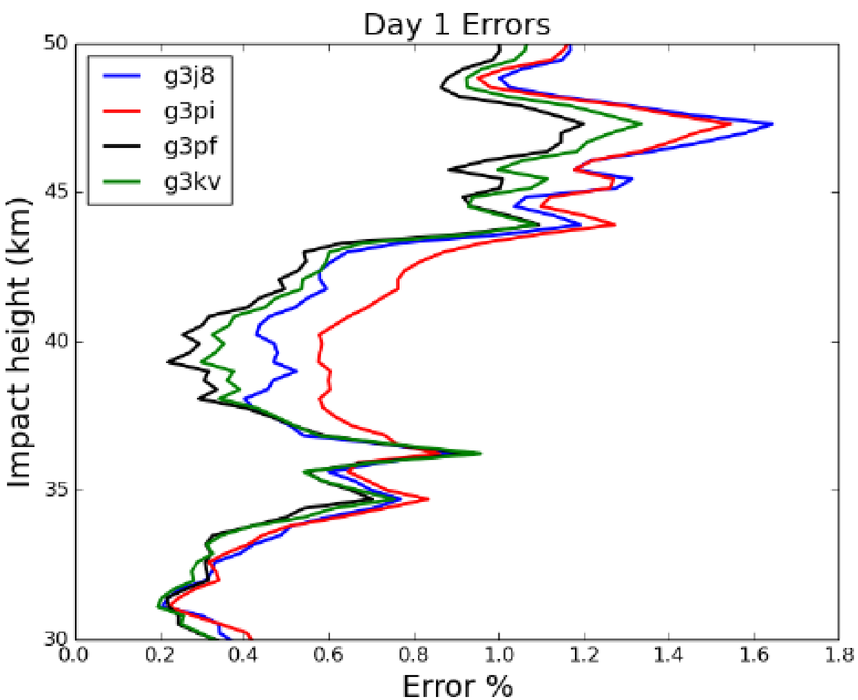
(d) D t+24hrs SETTLSTF

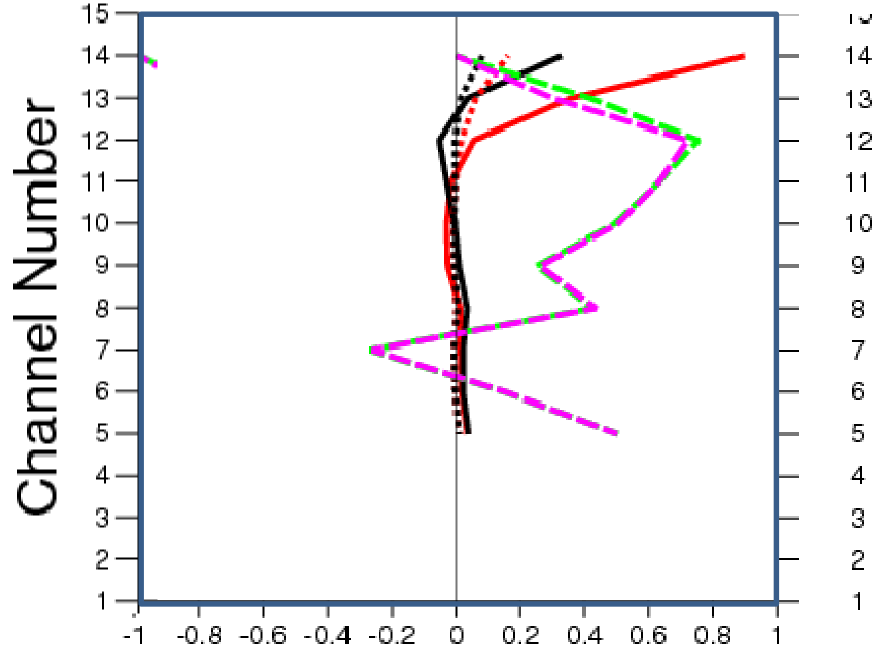
From Michail Diamantakis

Sudden Stratospheric Warming (impact of new numerics)

Fit to GPS

Fit to AMSUA



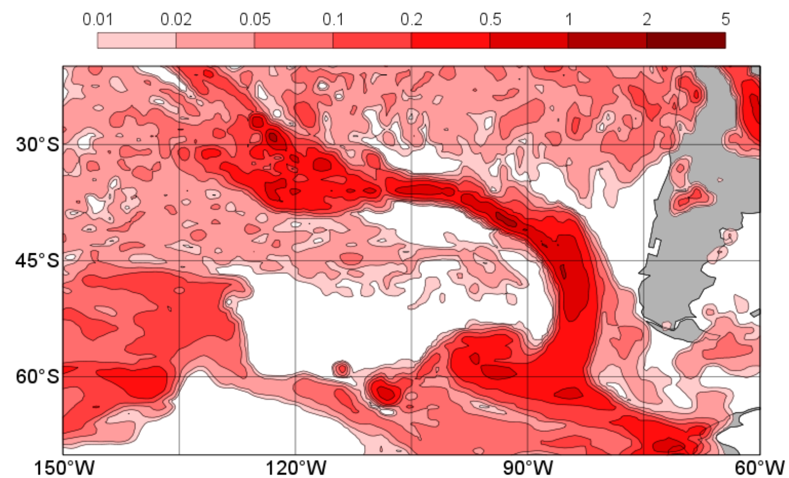


Satellite Data and Model Development

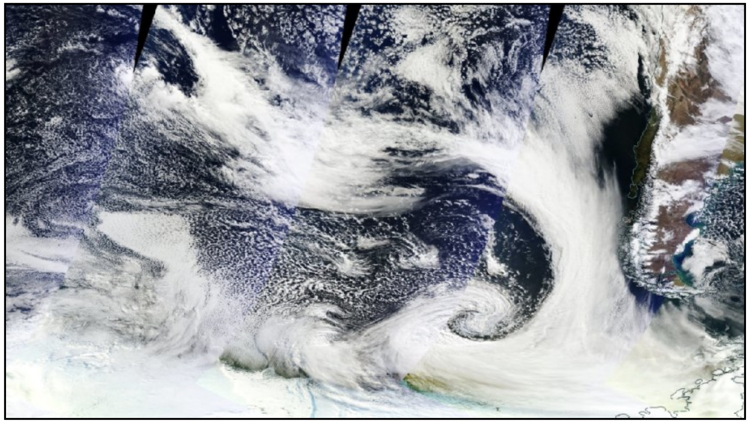
- Example of Satellites being used to improve Sudden Stratospheric Warming model numerics
- Example of MW imager data improving cloud micro-physics

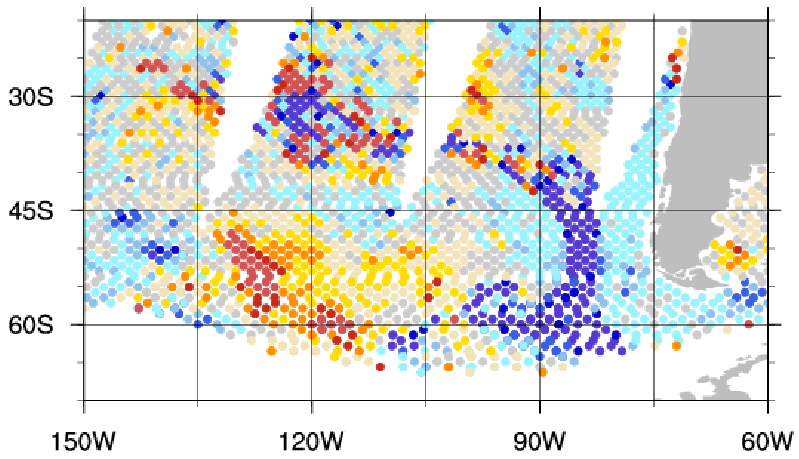
Using SSMIS to improve cloud physics

Model (40R1) liquid water path (Kgm-2)



MODIS visible image of front / cold sector

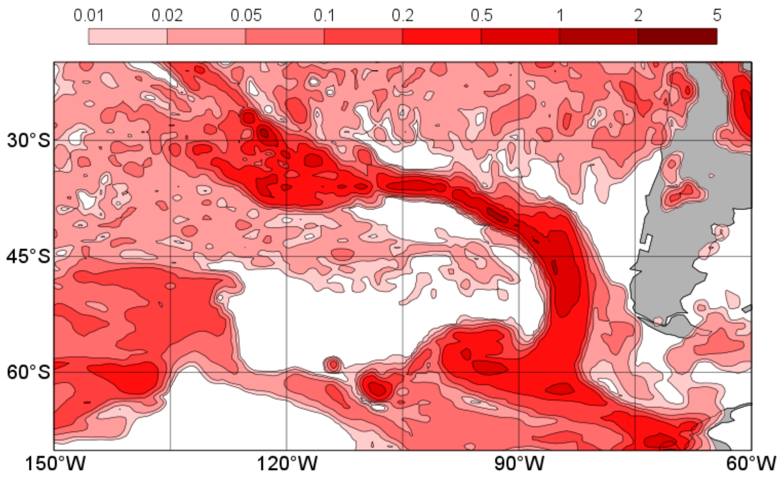




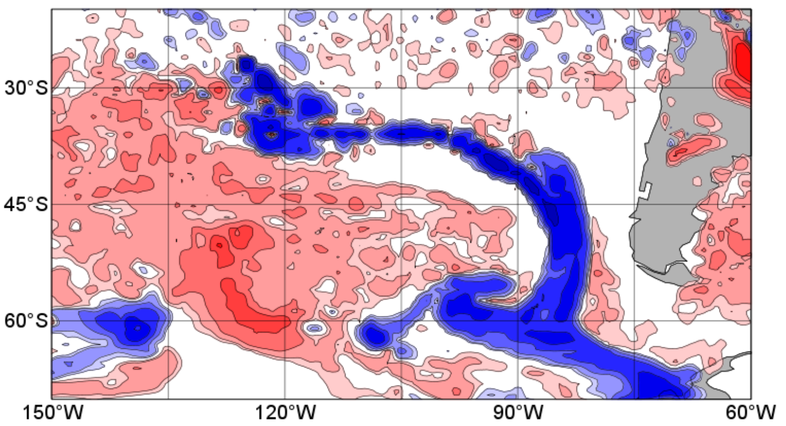
Comparing SSM/IS 37V observations with values simulated from the model fields suggest an excess of liquid water in the front and a deficiency of liquid water in the cold air outbreak behind

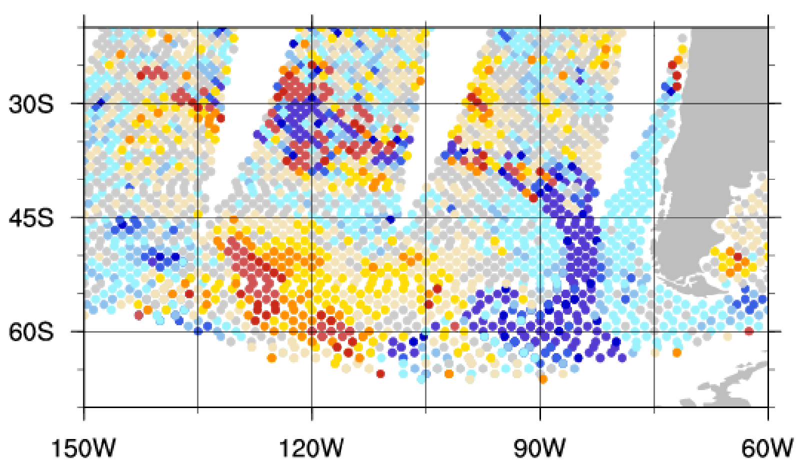
Using SSMIS to improve cloud physics

Model (40R1) liquid water path (Kgm-2)



Model (NEW) liquid water path (Kgm-2)

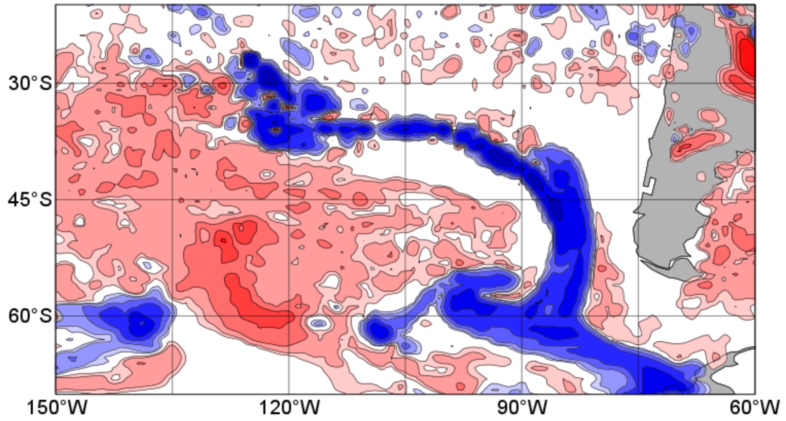


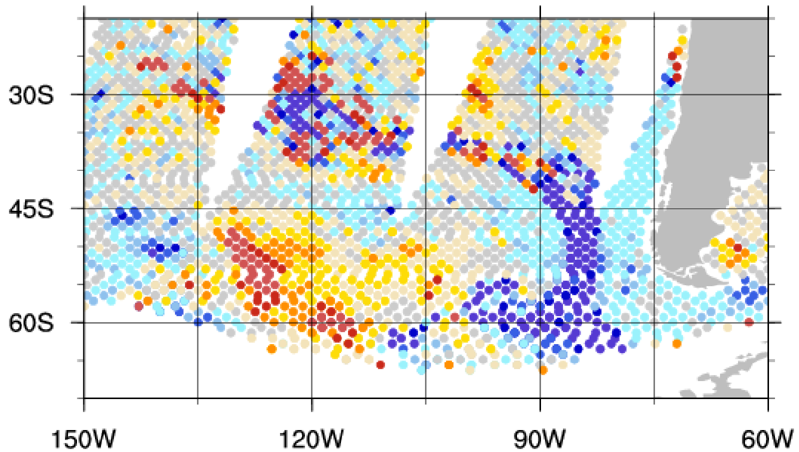


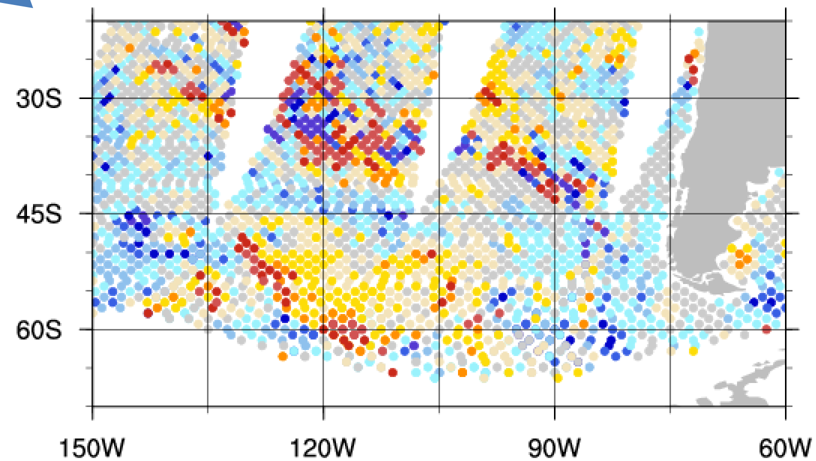
Changes to the modelling of super-cooled liquid water reduce values of LWP in frontal zones and increase LWP in the cold air convection regions

Using SSMIS to improve cloud physics

Comparing SSM/IS 37V observations with values simulated from the model fields suggest an excess of liquid water in the front and a deficiency of liquid water in the cold air outbreak behind



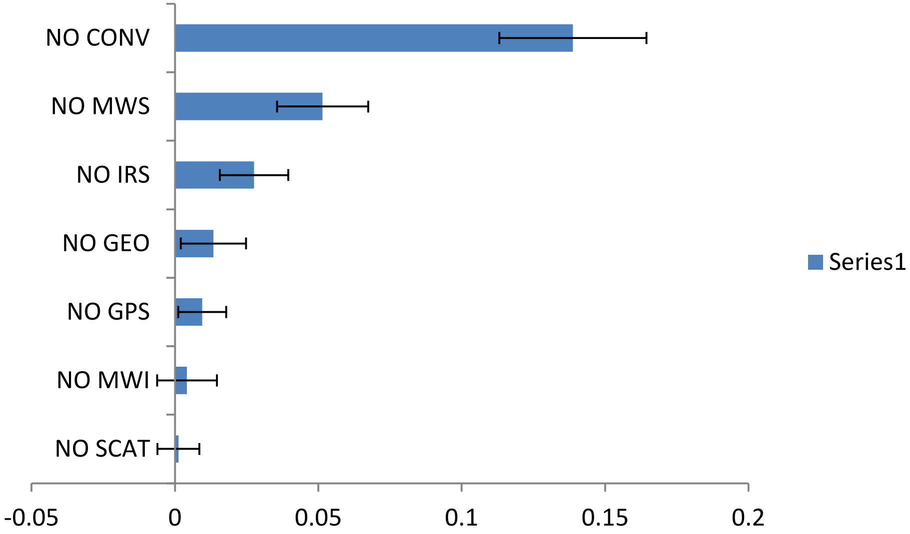


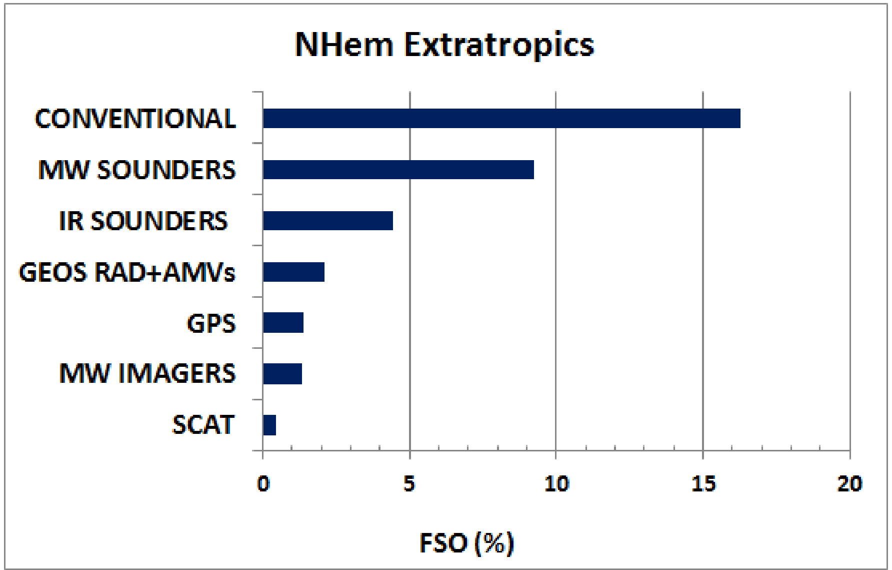


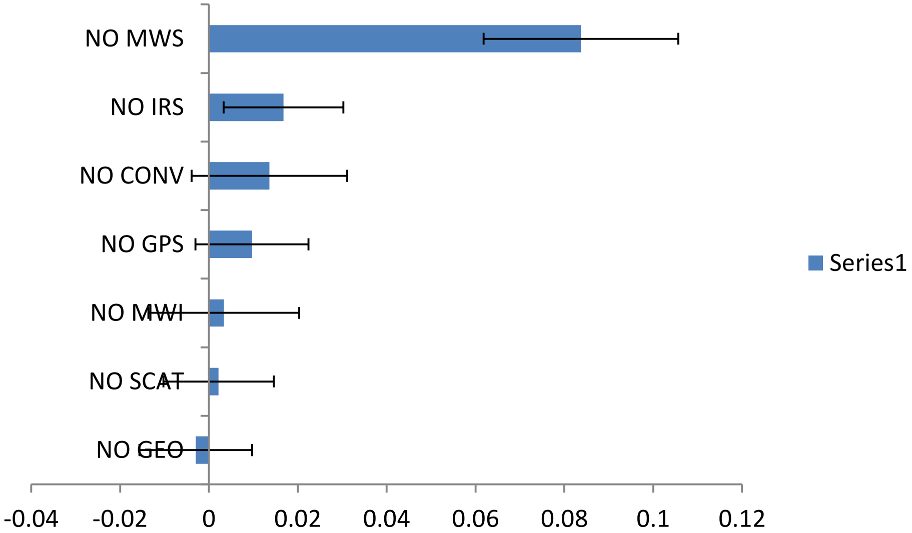
Summary

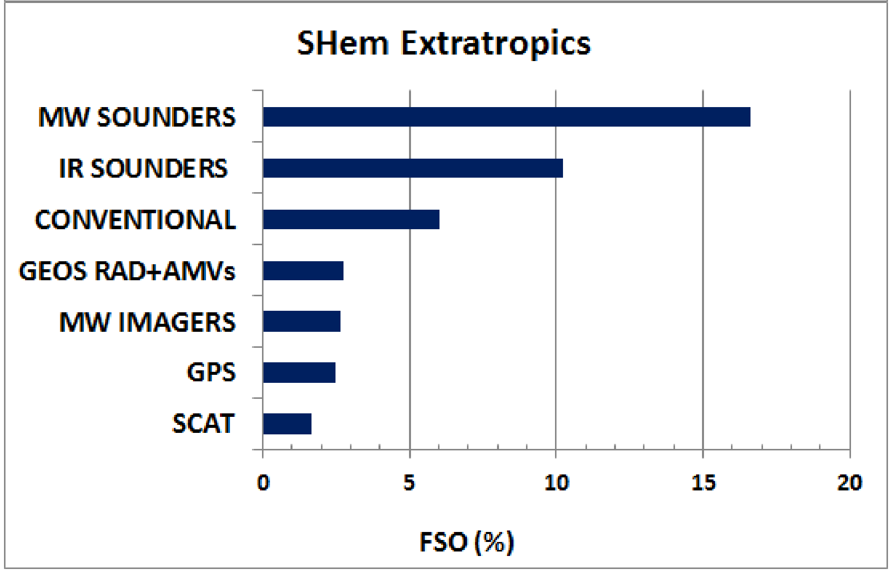
- Many factors influence satellite impact that are unrelated to the quality of the observations.
- Collectively satellite data dominate NWP forecast accuracy everywhere, but conventional data are still important (more than any single SAT system).
- Of these microwave and infrared sounding dominate the headline scores, but other have impact on other parameters
- Case studies are valuable and a very potent tool to convince decision makers
- Satellite have impact upon model development

OSE 500z (72h) v FSO (24h)



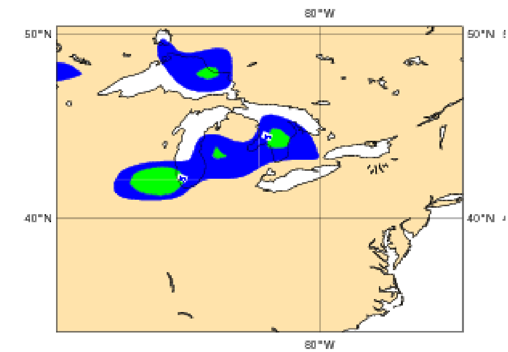




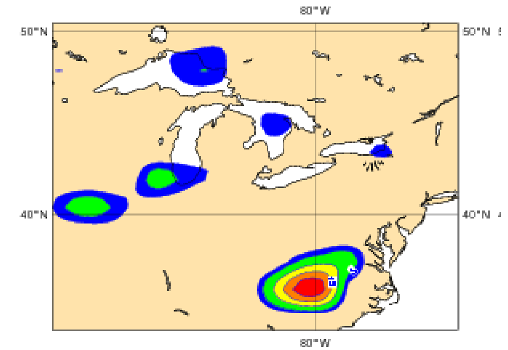


US Snowstorm (2009)

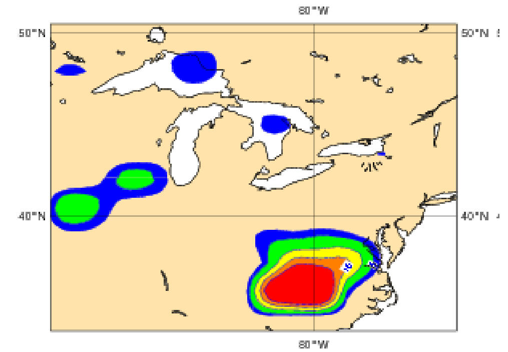
3 day forecast **without** POLAR satellites



3 day forecast **with** POLAR satellites

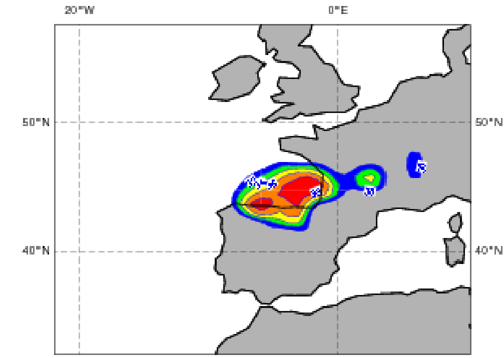


Verifying analysis

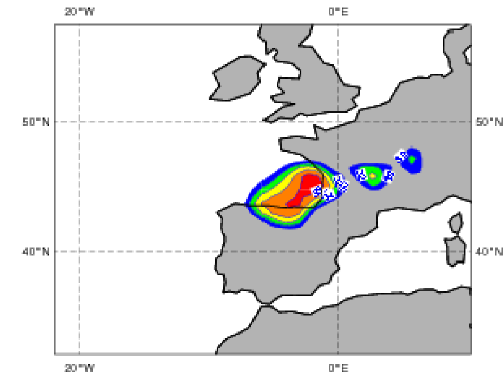


French Windstorm (2010)

3 day forecast **without** POLAR satellites



3 day forecast **with** POLAR satellites



Verifying analysis