The Global Observing System

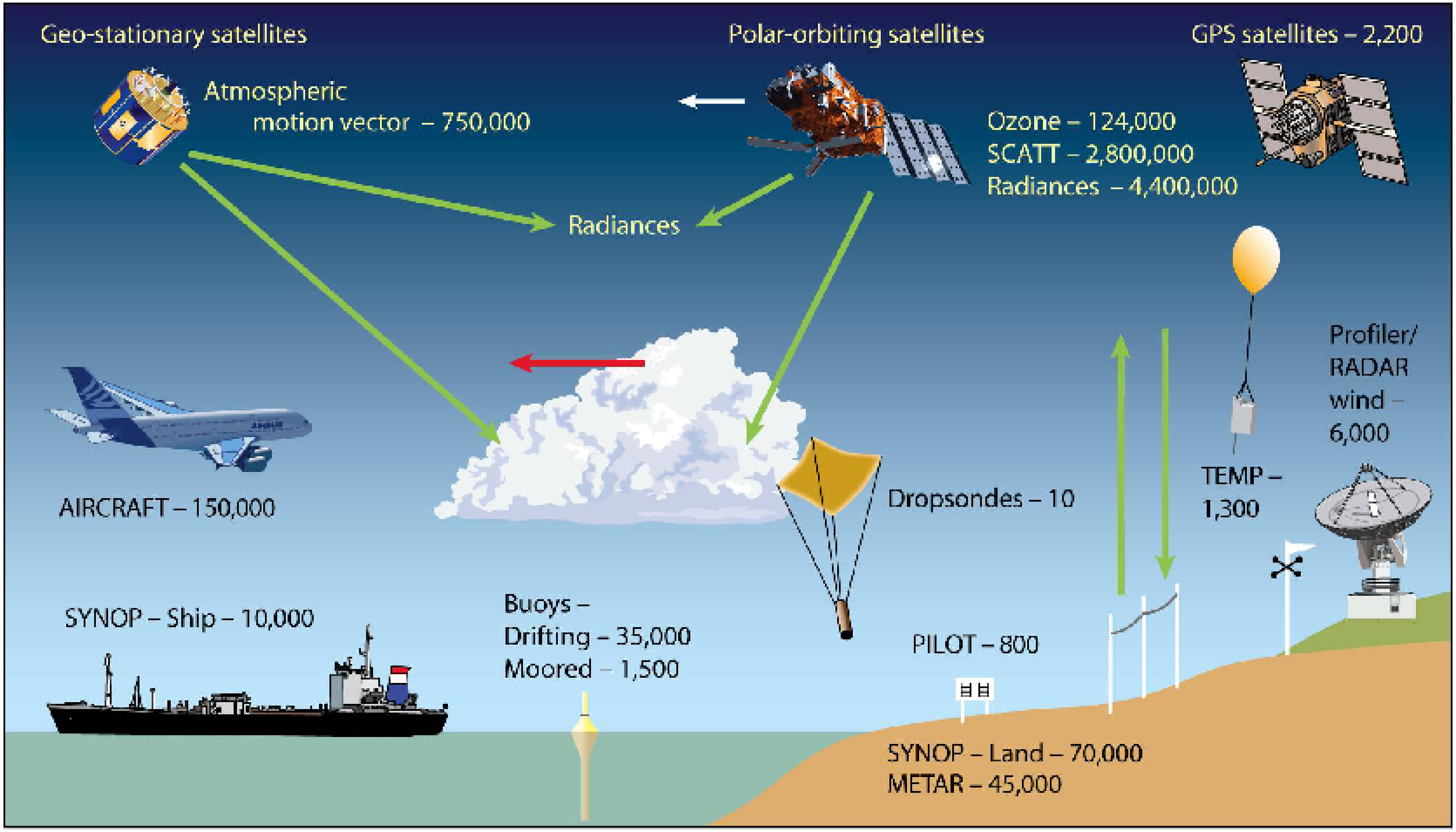
Tony McNally

DA Training Course 2015

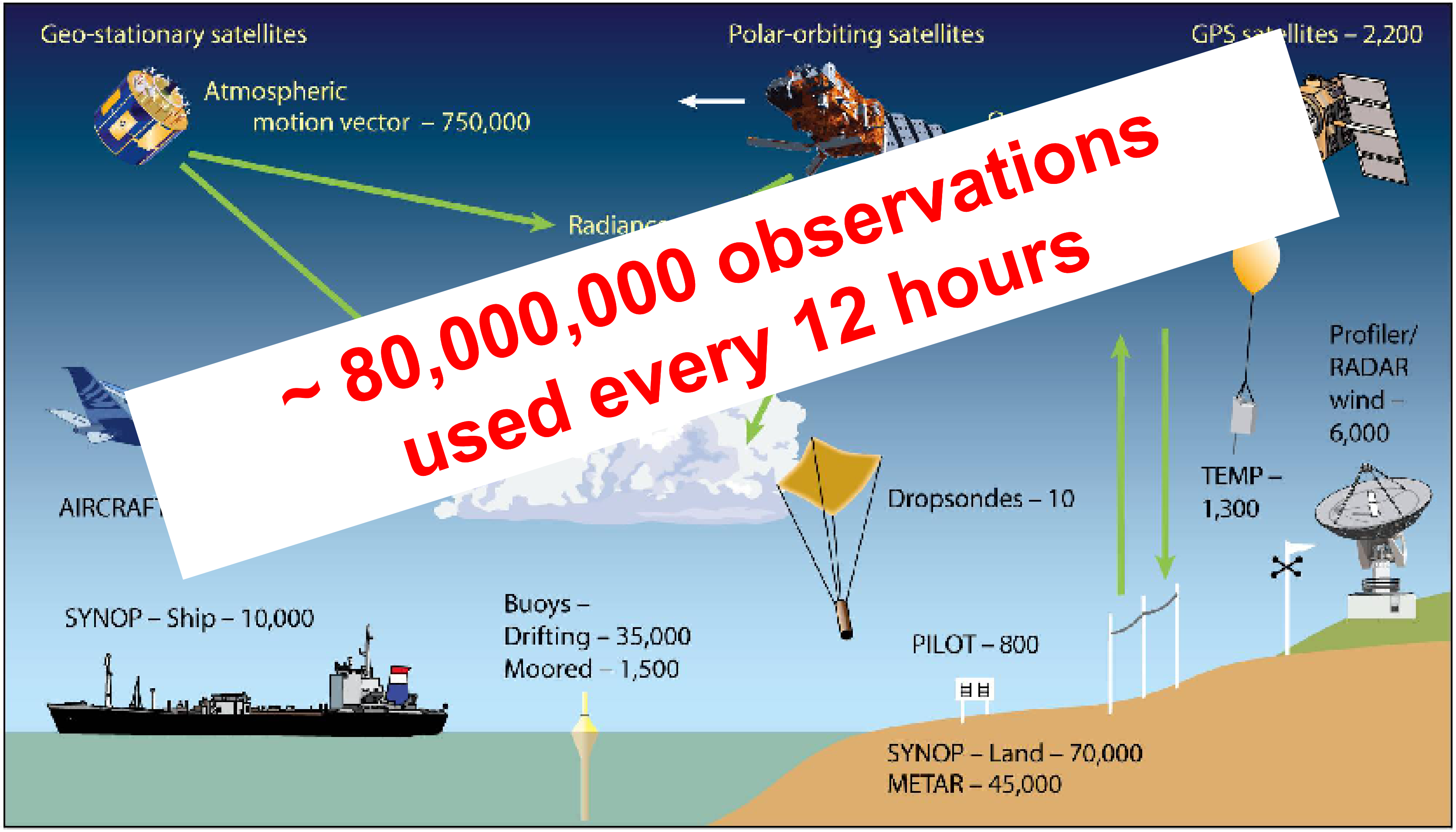
Overview

- Which observations do we have and what do they measure ?
- What are observations used for ?
- Assessing the impact of observations
- Which observations are most important ?
- Summary

Operational Global Observing Network



Operational Global Observing Network



~ 80,000,000 observations used every 12 hours

Conventional / in-situ observations

and

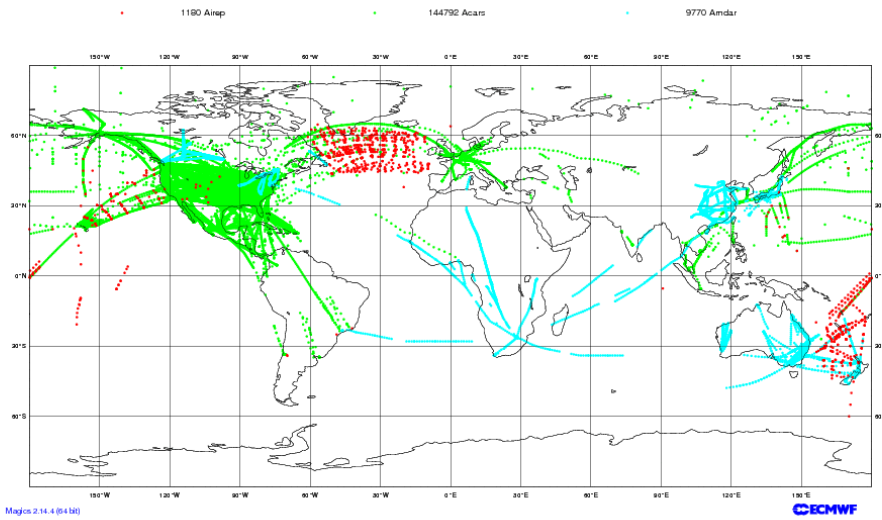
Satellite Observations

Conventional / in-situ observations

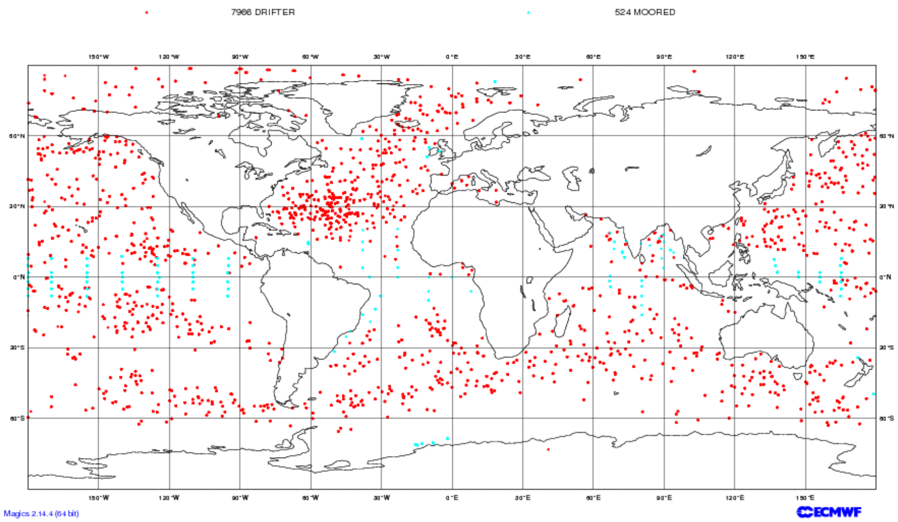
In situ Observations

Instrument	Parameters	Level
SYNOP **SHIP** **METAR**	temperature, dew-point temperature, wind	Land: 2m, ships: 25m
BUOYS	temperature, pressure, wind	2m
TEMP **TEMPSHIP** **DROPSONDES**	temperature, humidity, pressure, wind	Profiles
PROFILERS	wind	Profiles
Aircraft	temperature, pressure wind	Profiles Flight level data

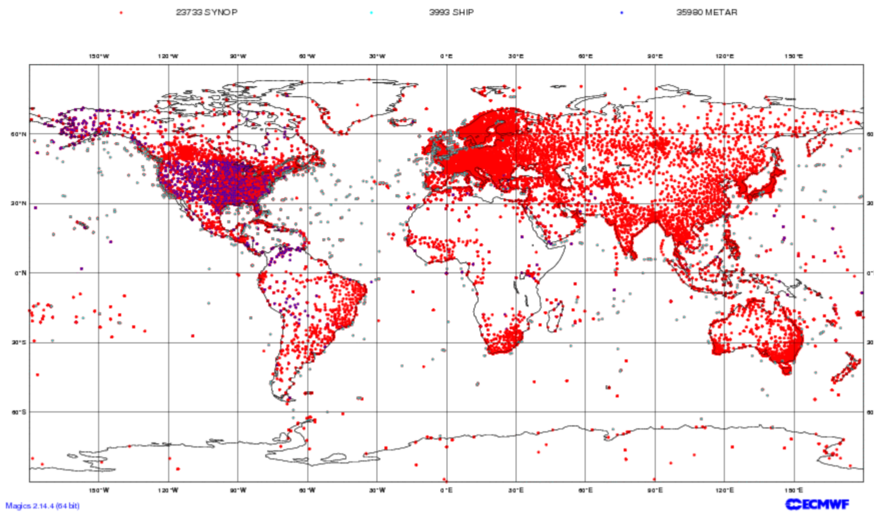
Snap-shot Example of 6hrs data coverage : 28 Jan 2015



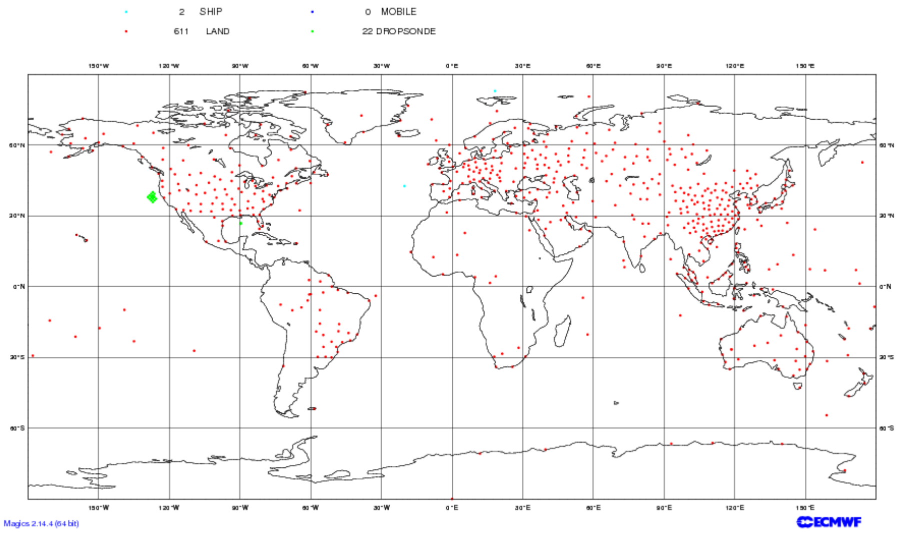
Aircraft



Buoy

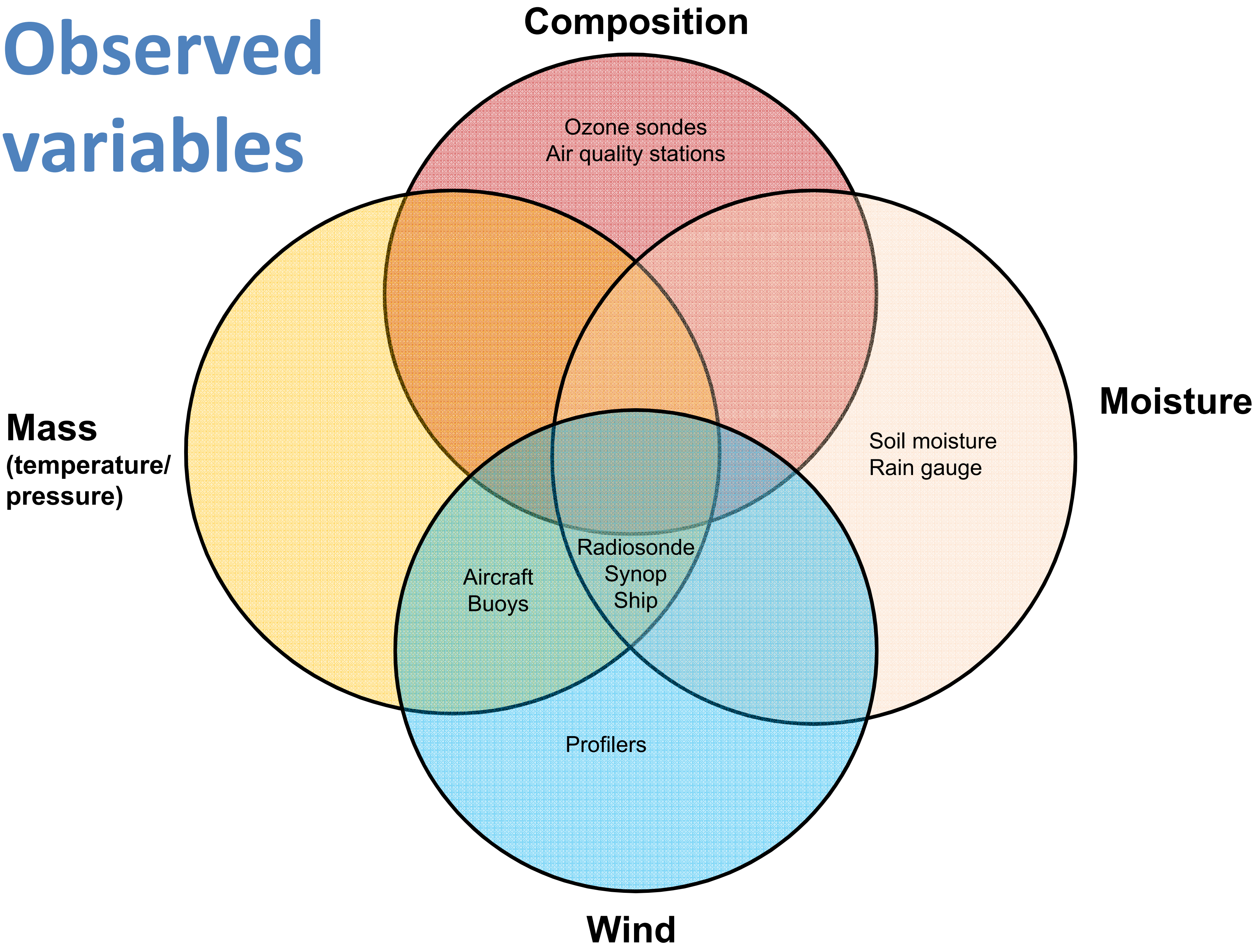


Surface (synop) + ship



Radiosondes

Observed variables



Issues related to in situ observations

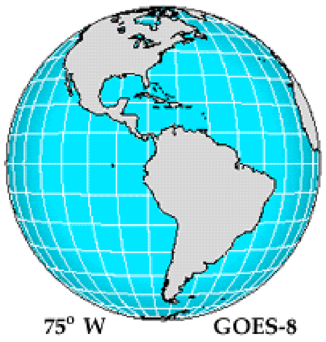
- Temporal and Spatial data voids
- If we measure temperature at a point location is it representative of model grid resolution?
- Non homogeneous data quality – some radiosondes are good quality, others less so; absolute calibration can vary with age

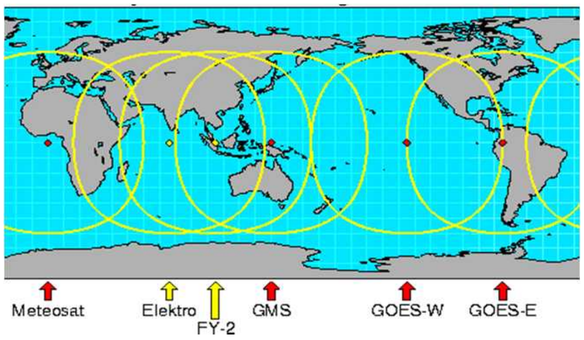
- But, they are a direct, in situ measurement
- Interpretation is usually more straightforward than for satellite observations

Satellite Observations

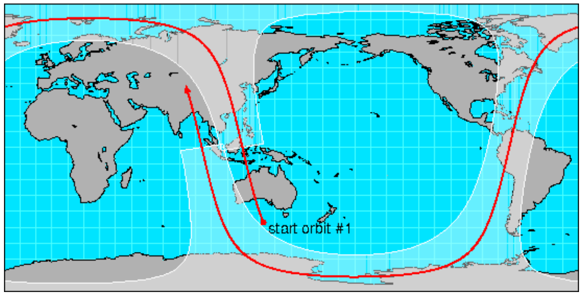
Geostationary and Low-Earth-Orbit Satellites

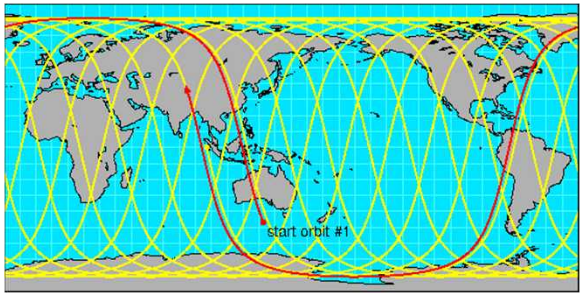
GEO





LEO





Sun-Synchronous Polar Satellites

Instrument	Early morning orbit	Mid Morning orbit	Afternoon orbit
High spectral resolution IR sounder		Metop-A+B IASI	Aqua AIRS NPP CrIS
Microwave T sounder	F17 SSMIS	Metop-A+B AMSU-A FY3C MWTS2 DMSP F18 SSMIS Meteor-M N1 MTVZA	NOAA-15, 18, 19 AMSU-A Aqua AMSU-A NPP ATMS
Microwave Q sounder + imagers	F17 SSMIS	Metop-A+B MHS DMSP F18 SSMIS FY3A MWHS2+MWRI	NOAA-18, 19 MHS FY3B MWHS+MWRI NPP ATMS GCOM-W/AMSR-2
Broadband IR sounder		Metop-A+B HIRS FY3C IRAS	FY3B IRAS
IR Imagers		Metop-A+B AVHRR Meteor-M N1 MSU-MR	Aqua+Terra MODIS NOAA-15, 16, 18, 19 AVHRR
Composition (ozone etc).			NOAA-19 SBUV AURA OMI, MLS GOSAT

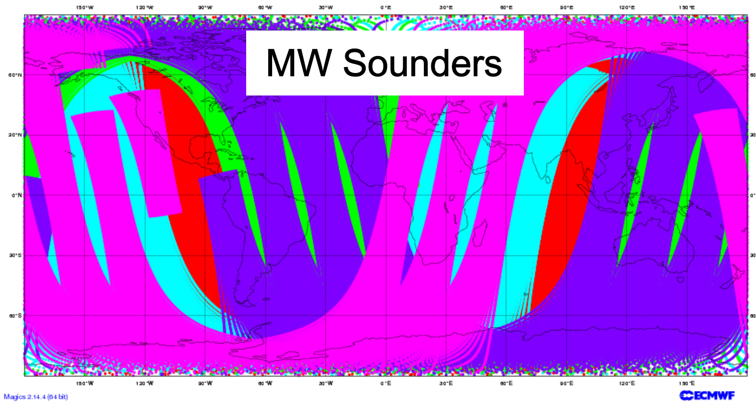
Sun-Synchronous Polar Satellites (2)

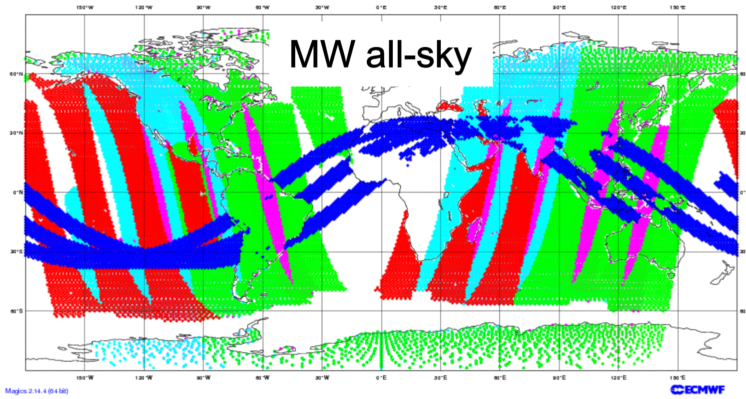
Instrument	Early morning orbit	Morning orbit	Afternoon orbit
Scatterometer		Metop-A+B ASCAT (Coriolis Windsat)	
Radar			CloudSat
Lidar			Calipso
L-band imagery	SMOS SAC-D/Aquarius		

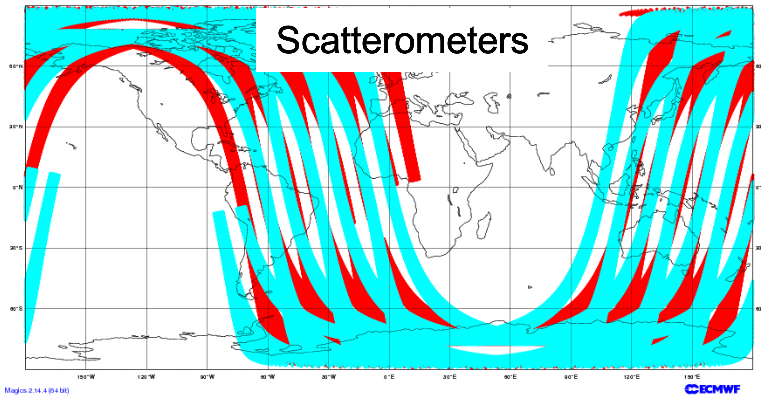
Non Sun-Synchronous Observations

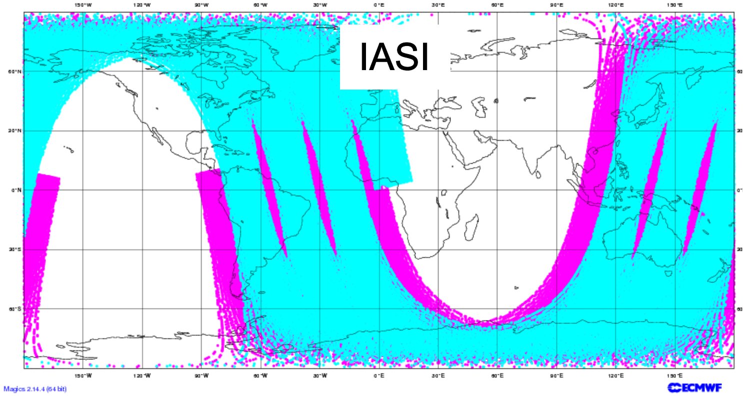
Instrument	High inclination (> 60°)	Low inclination (<60°)
Radio occultation	GRAS, GRACE-A, COSMIC	
MW Imagers		TRMM/TMI, GPM/GMI Meghatropics SAPHIR MADRAS
Radar Altimeter	JASON-2 RA + SAR Cryosat	

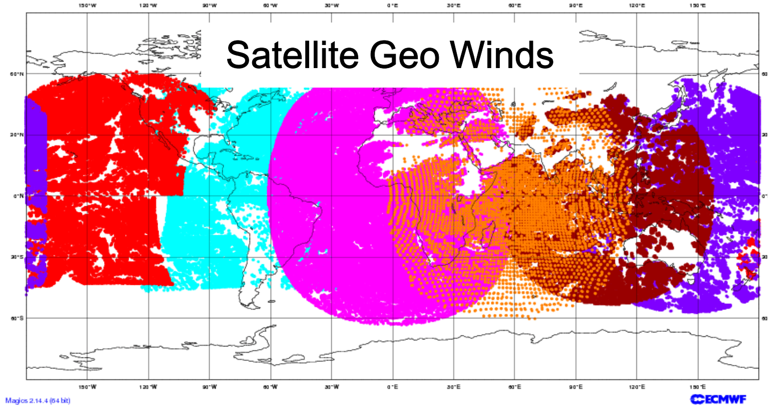
Example of 6hr satellite data coverage: 28 Jan 2015

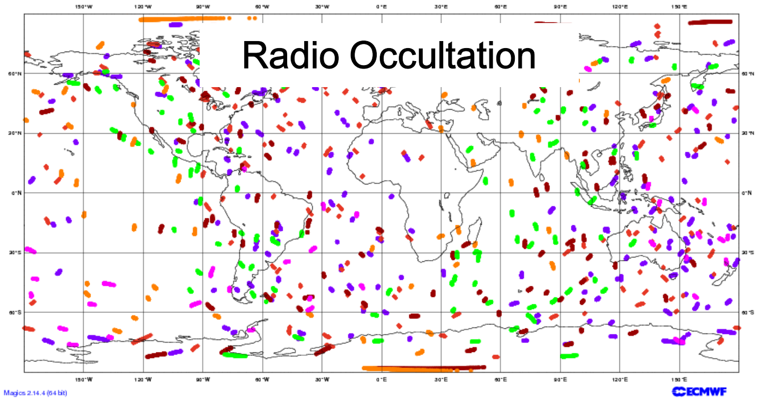




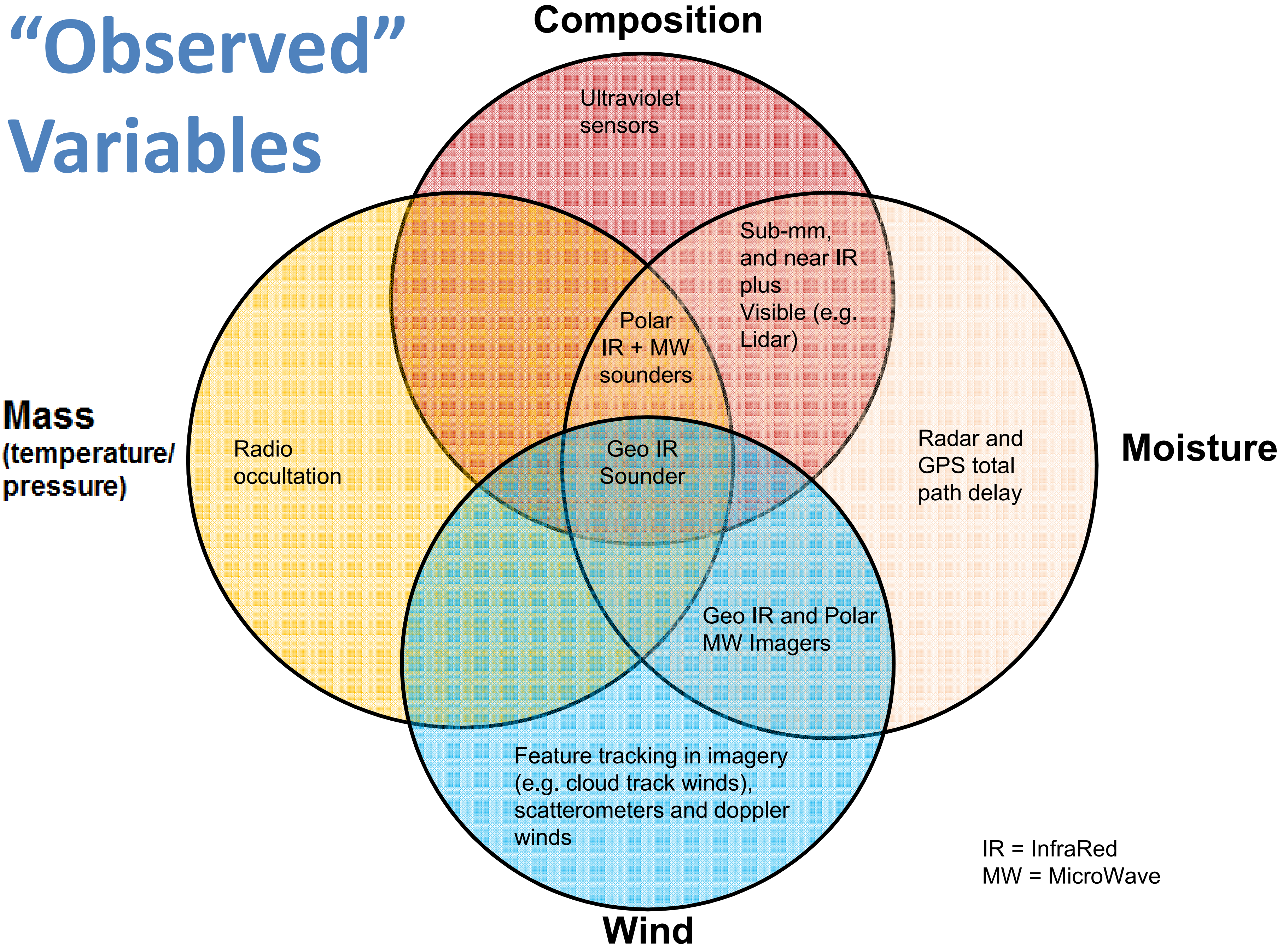








“Observed” Variables

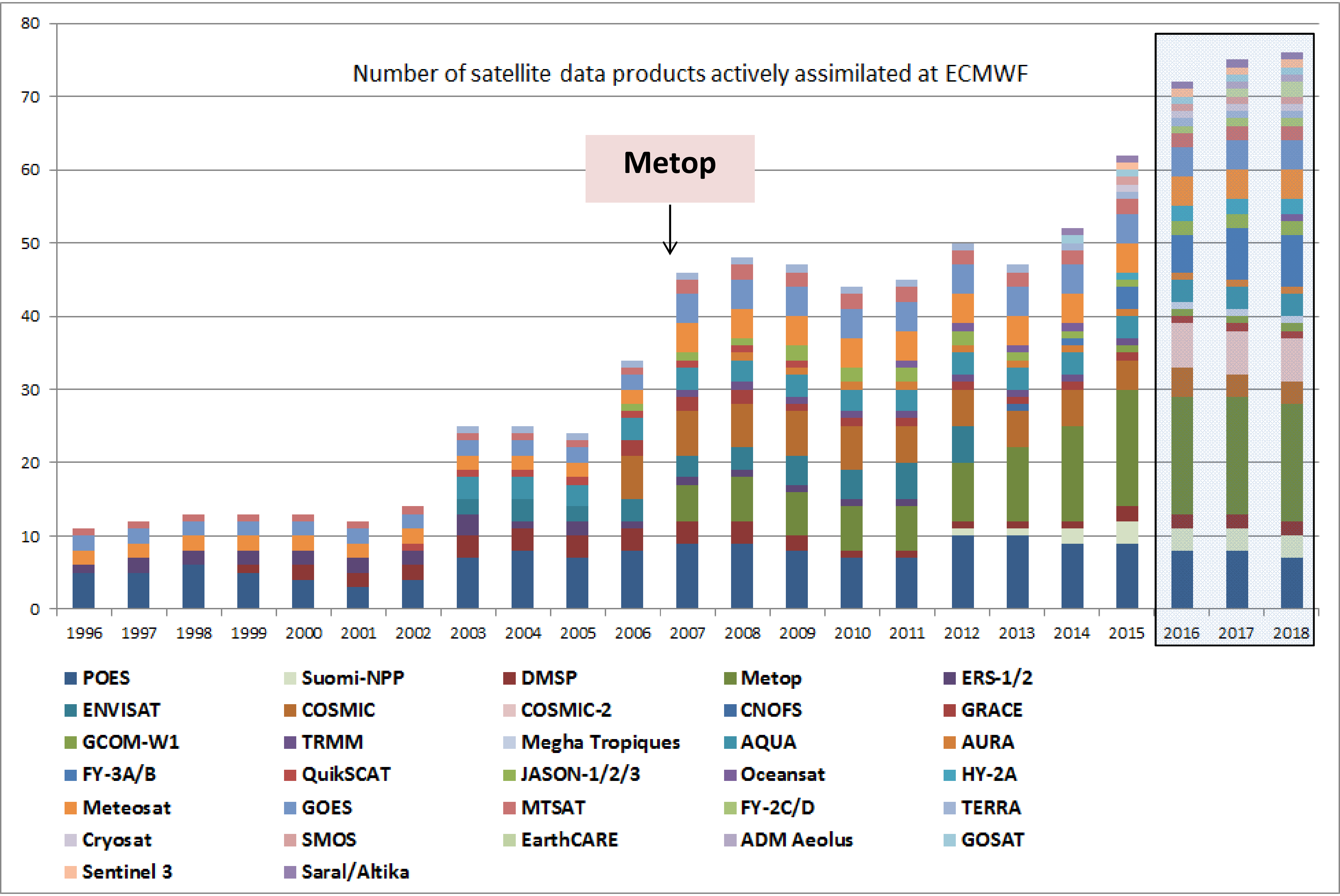


IR = InfraRed
MW = MicroWave

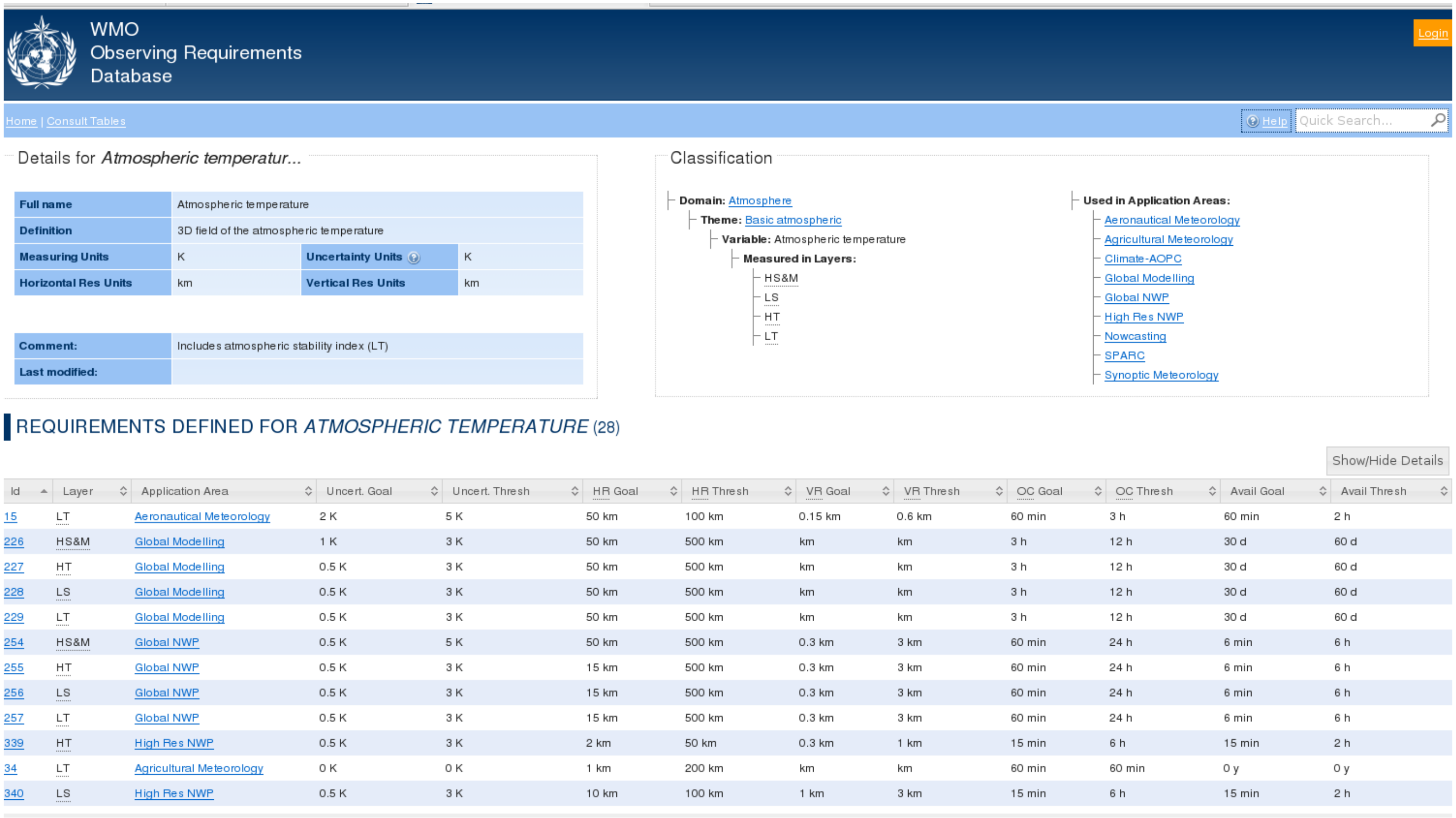
Issues related to satellite observations

- An indirect and potentially complex measurement that may be difficult to interpret (see lecture later this week)
- Nadir Sounders have degraded vertical resolution, limb sounders have degraded horizontal resolution
- No spatial or temporal data voids, but some conditions make observations difficult to use (e.g. clouds)
- Vast volumes of data must be handled

- Globally available measurements, often with good temporal repeat cycle.
- Satellite pixel footprints generally more representative of NWP model scales


Number of satellite data products actively assimilated at ECMWF
Metop
80
70
60
50
40
30
20
10
0
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
POES
Suomi-NPP
DMSP
Metop
ERS-1/2
ENVISAT
COSMIC
COSMIC-2
CNOFS
GRACE
GCOM-W1
TRMM
Megha Tropiques
AQUA
AURA
FY-3A/B
QuikSCAT
JASON-1/2/3
Oceansat
HY-2A
Meteosat
GOES
MTSAT
FY-2C/D
TERRA
Cryosat
SMOS
EarthCARE
ADM Aeolus
GOSAT
Sentinel 3
Saral/Altika

WMO OSCAR website



Details for *Atmospheric temperatur...*

Full name	Atmospheric temperature		
Definition	3D field of the atmospheric temperature		
Measuring Units	K	**Uncertainty Units**	K
Horizontal Res Units	km	**Vertical Res Units**	km

Comment:	Includes atmospheric stability index (LT)
Last modified:	

Classification

- **Domain:** Atmosphere
  - **Theme:** Basic atmospheric
    - **Variable:** Atmospheric temperature
      - **Measured in Layers:**
        - HS&M
        - LS
        - HT
        - LT

- **Used in Application Areas:**
  - Aeronautical Meteorology
  - Agricultural Meteorology
  - Climate-AOPC
  - Global Modelling
  - Global NWP
  - High Res NWP
  - Nowcasting
  - SPARC
  - Synoptic Meteorology

REQUIREMENTS DEFINED FOR *ATMOSPHERIC TEMPERATURE* (28)

Id	Layer	Application Area	Uncert. Goal	Uncert. Thresh	HR Goal	HR Thresh	VR Goal	VR Thresh	OC Goal	OC Thresh	Avail Goal	Avail Thresh
15	LT	Aeronautical Meteorology	2 K	5 K	50 km	100 km	0.15 km	0.6 km	60 min	3 h	60 min	2 h
226	HS&M	Global Modelling	1 K	3 K	50 km	500 km	km	km	3 h	12 h	30 d	60 d
227	HT	Global Modelling	0.5 K	3 K	50 km	500 km	km	km	3 h	12 h	30 d	60 d
228	LS	Global Modelling	0.5 K	3 K	50 km	500 km	km	km	3 h	12 h	30 d	60 d
229	LT	Global Modelling	0.5 K	3 K	50 km	500 km	km	km	3 h	12 h	30 d	60 d
254	HS&M	Global NWP	0.5 K	5 K	50 km	500 km	0.3 km	3 km	60 min	24 h	6 min	6 h
255	HT	Global NWP	0.5 K	3 K	15 km	500 km	0.3 km	3 km	60 min	24 h	6 min	6 h
256	LS	Global NWP	0.5 K	3 K	15 km	500 km	0.3 km	3 km	60 min	24 h	6 min	6 h
257	LT	Global NWP	0.5 K	3 K	15 km	500 km	0.3 km	3 km	60 min	24 h	6 min	6 h
339	HT	High Res NWP	0.5 K	3 K	2 km	50 km	0.3 km	1 km	15 min	6 h	15 min	2 h
34	LT	Agricultural Meteorology	0 K	0 K	1 km	200 km	km	km	60 min	60 min	0 y	0 y
340	LS	High Res NWP	0.5 K	3 K	10 km	100 km	1 km	3 km	15 min	6 h	15 min	2 h

http://www.wmo-sat.info/oscar/

What are observations used for ?

- Constraining model error growth for **data assimilation** and NWP
- Providing ground truth for improving model parameterisations

What are observations used for ?

- Constraining model error growth in **data assimilation** and NWP
- Providing ground truth for improving model parameterisations

What is Data Assimilation ?

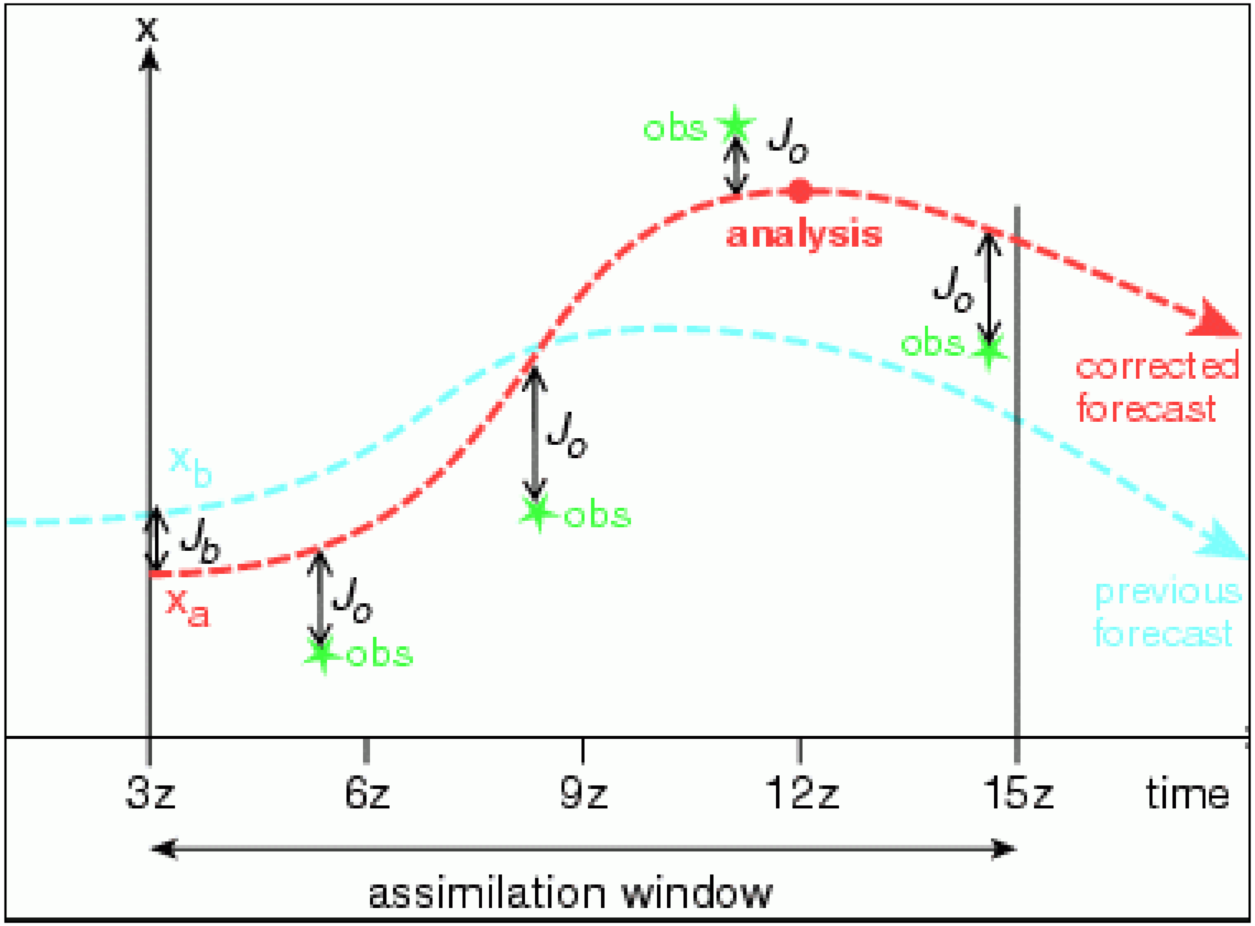
- Models give a complete description of the atmospheric, but **errors grow rapidly** in time

- Observations provide an **incomplete description** of the atmospheric state, but bring up to date information

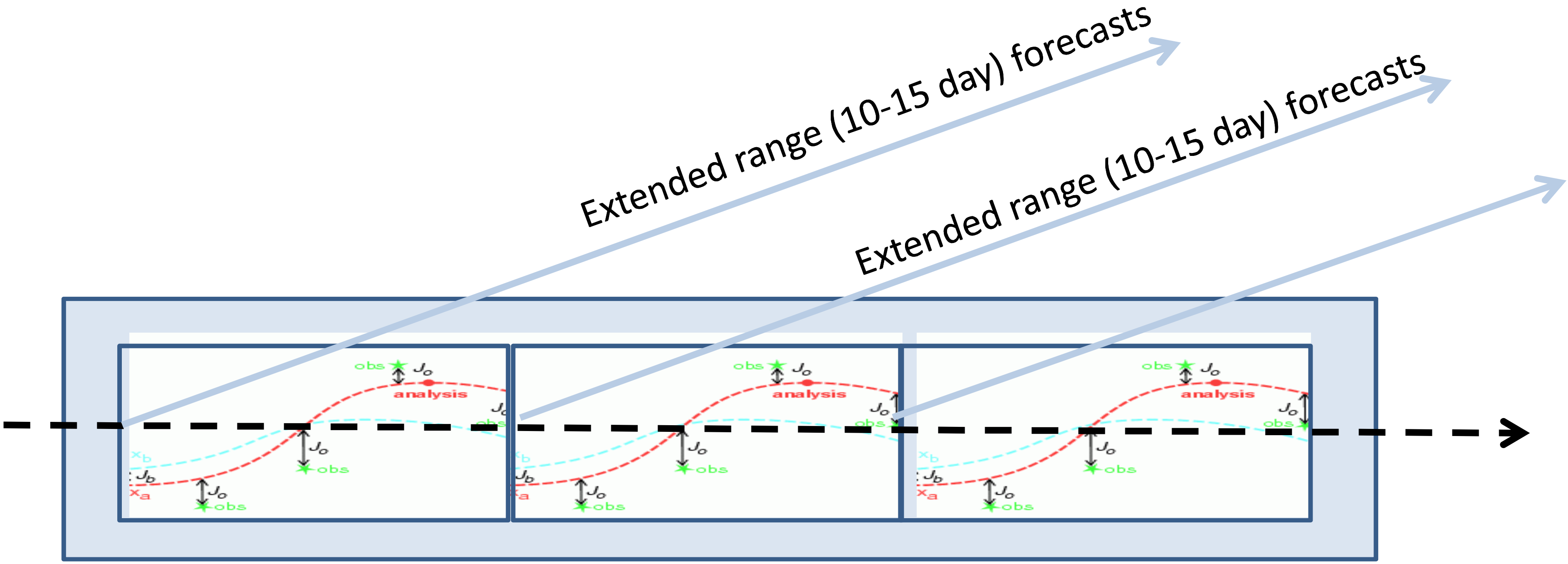
- Data assimilation **combines** these two sources of information to produce an optimal (best) estimate of the atmospheric state

- This state (the *analysis*) is used as **initial conditions** for extended forecasts.

Data Assimilation (single window)



Data Assimilation (quasi-continuous)



Extended range (10-15 day) forecasts

Extended range (10-15 day) forecasts

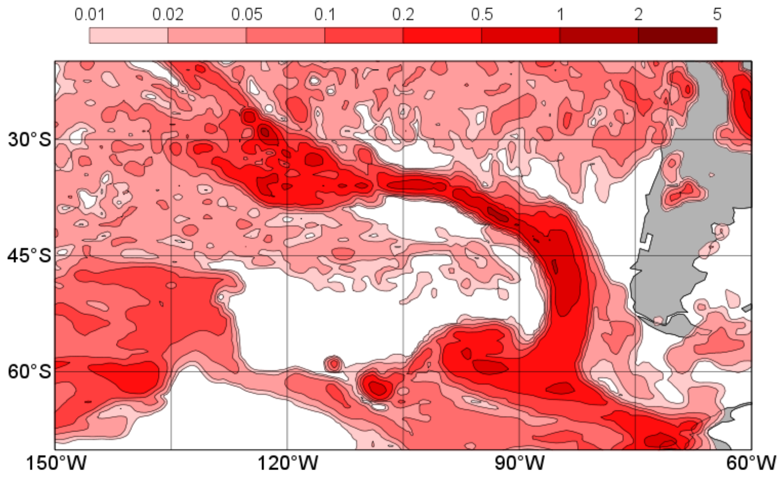
What are observations used for ?

- Constraining model error growth for data assimilation and NWP

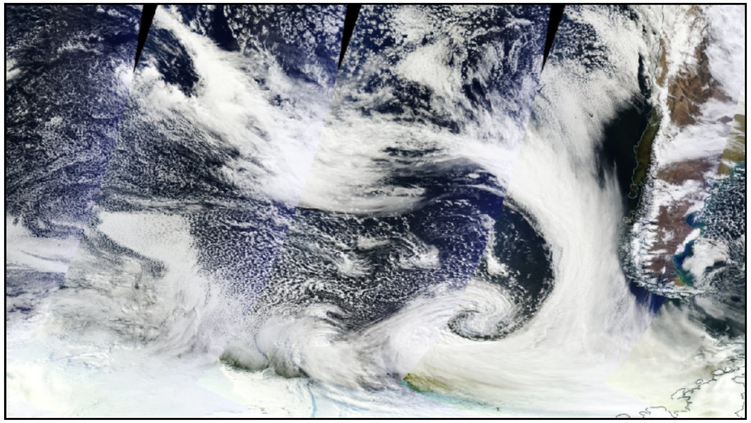
- Providing ground truth for improving model parameterisations

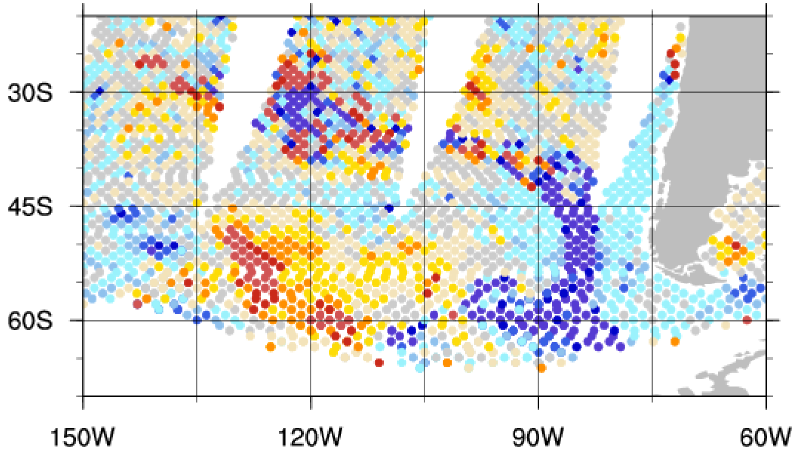
Using SSMIS to improve cloud physics

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



MODIS visible image of front / cold sector

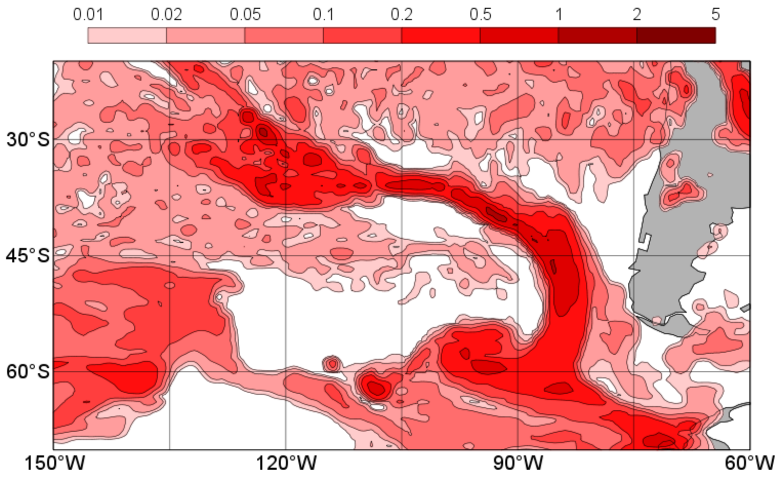




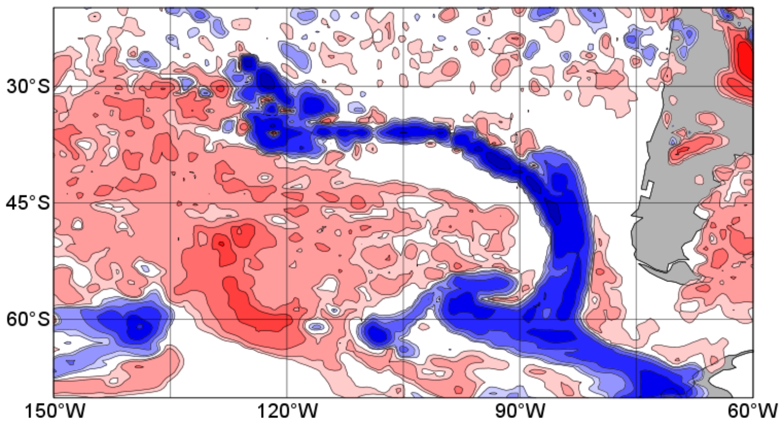
Comparing SSM/IS 37V observations with values simulated from the model fields suggest an excess of liquid water in the front and a deficiency of liquid water in the cold air outbreak behind

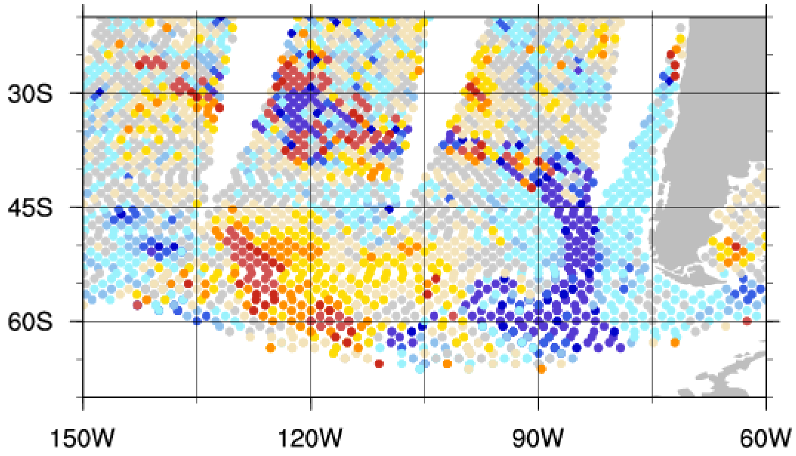
Using SSMIS to improve cloud physics

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



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

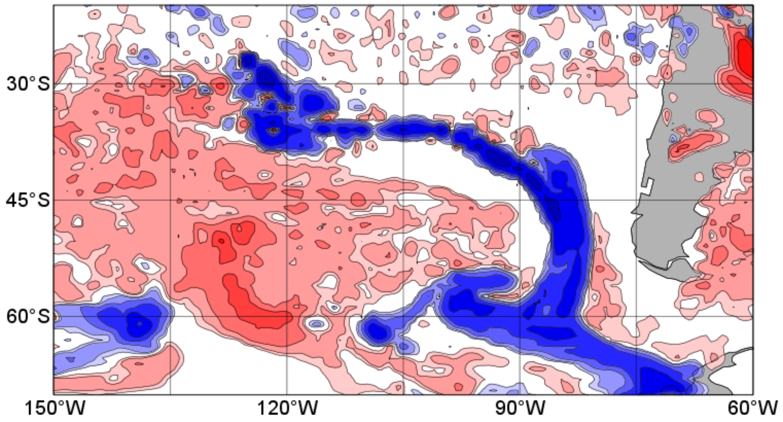


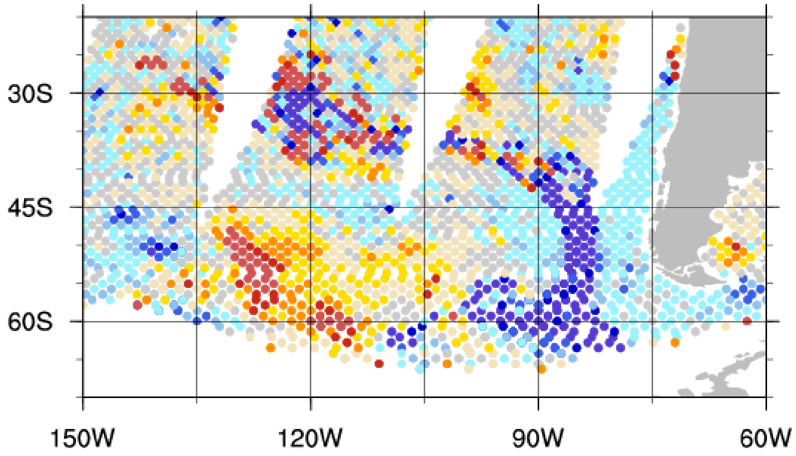


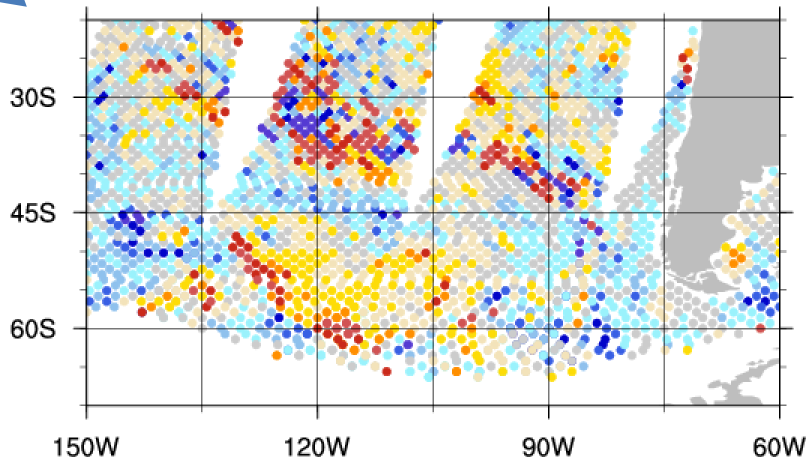
Changes to the modelling of super-cooled liquid water reduce values of LWP in frontal zones and increase LWP in the cold air convection regions

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







Assessing the impact of Observations on NWP systems

How do we measure observation impact ?

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

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

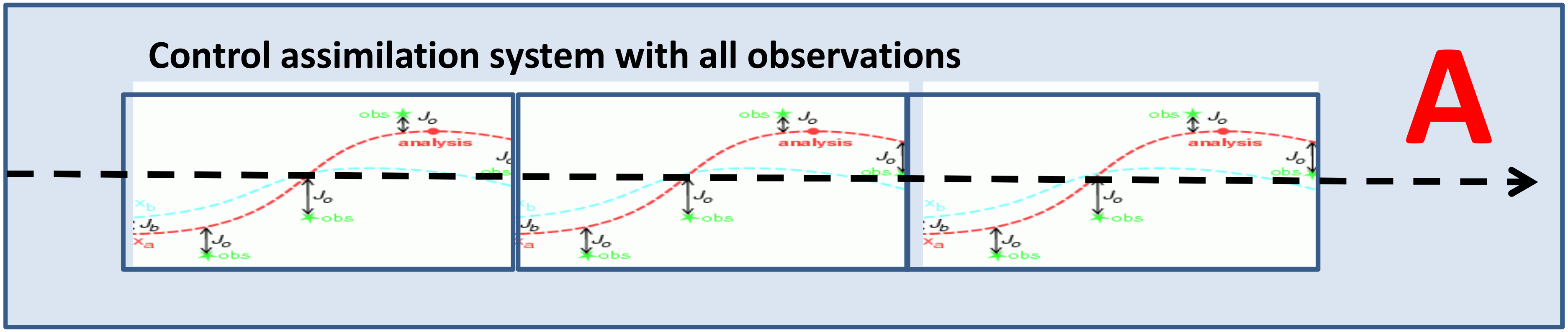
Measuring Observation Impact

- **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 ?

See lecture by Carla Cardinali later this week

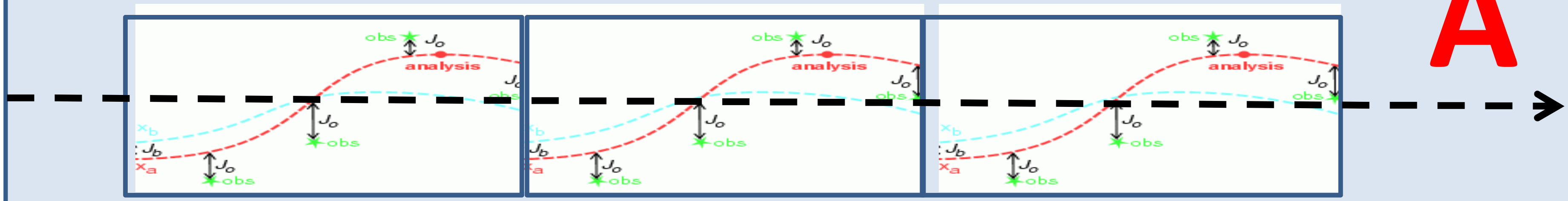
Observing System Experiments (we run a CONTROL system A)



Control assimilation system with all observations

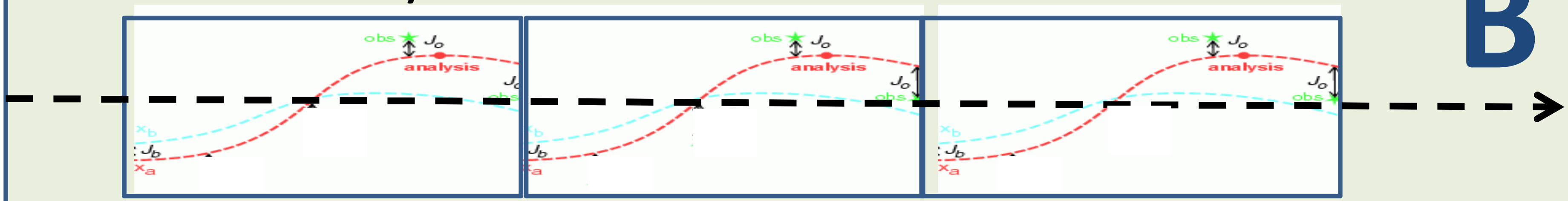
Observing System Experiments
(we run a reduced system **B**)

Control assimilation system with all observations



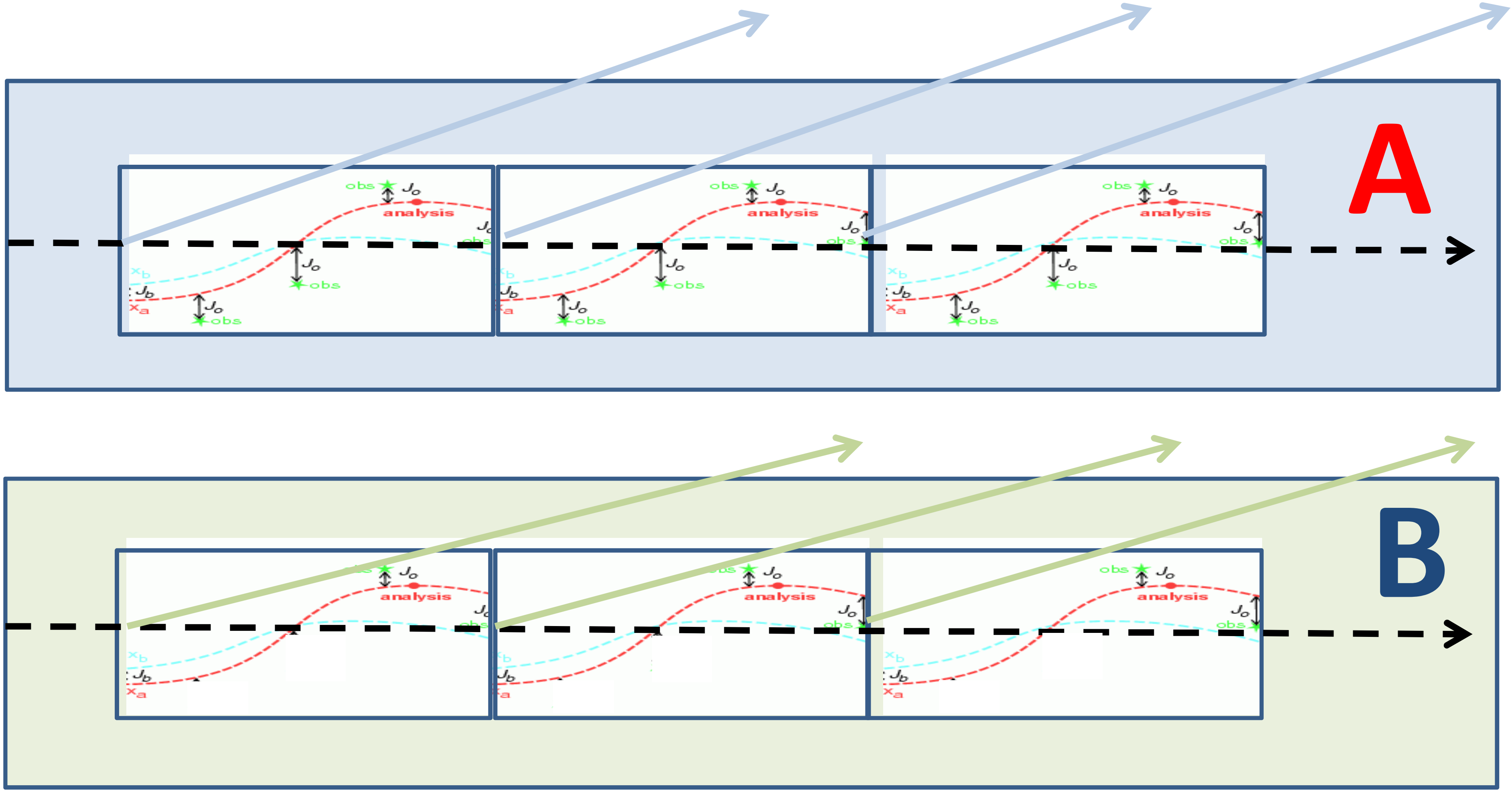
A

Assimilation system with some observations denied

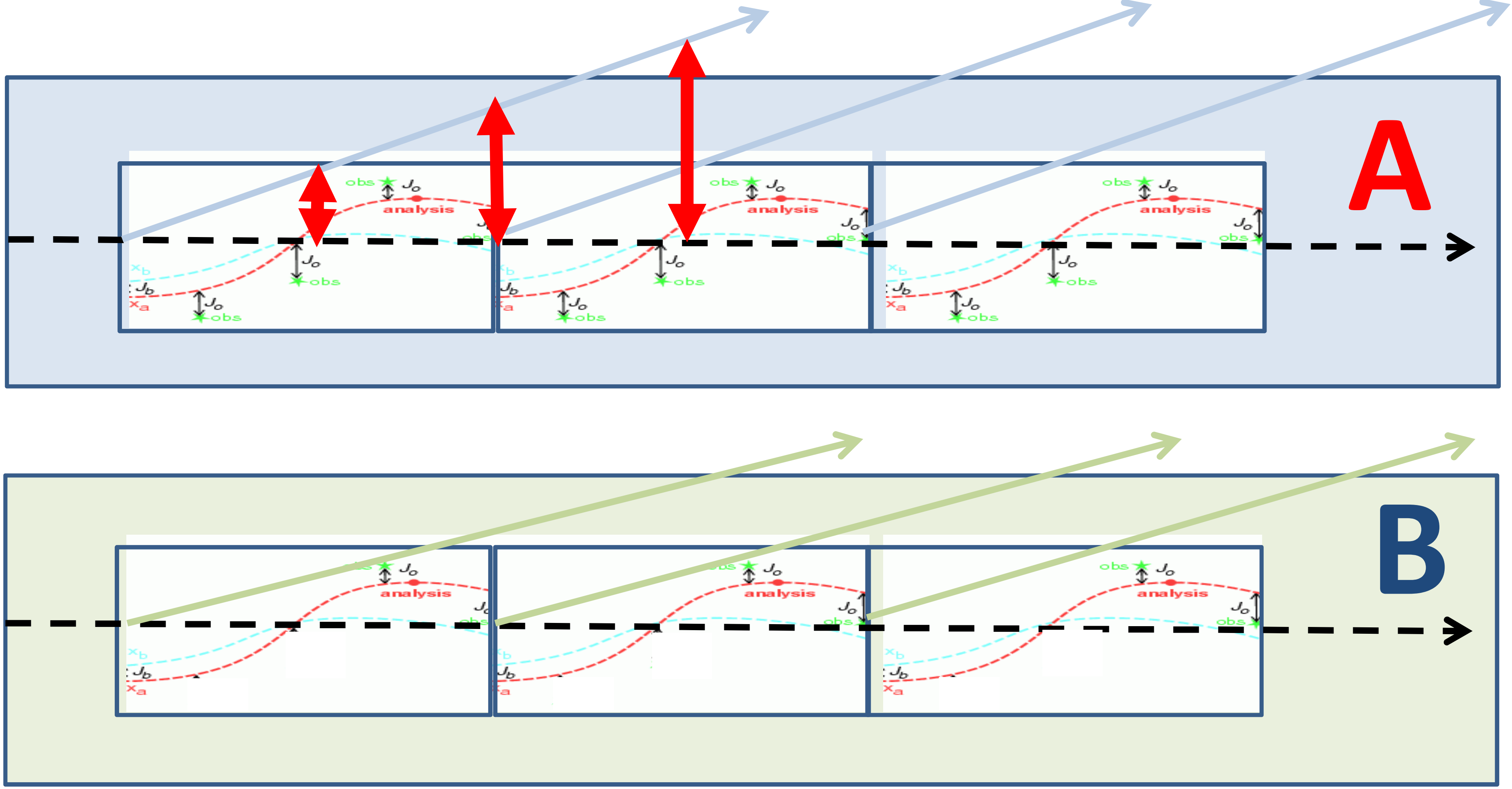


B

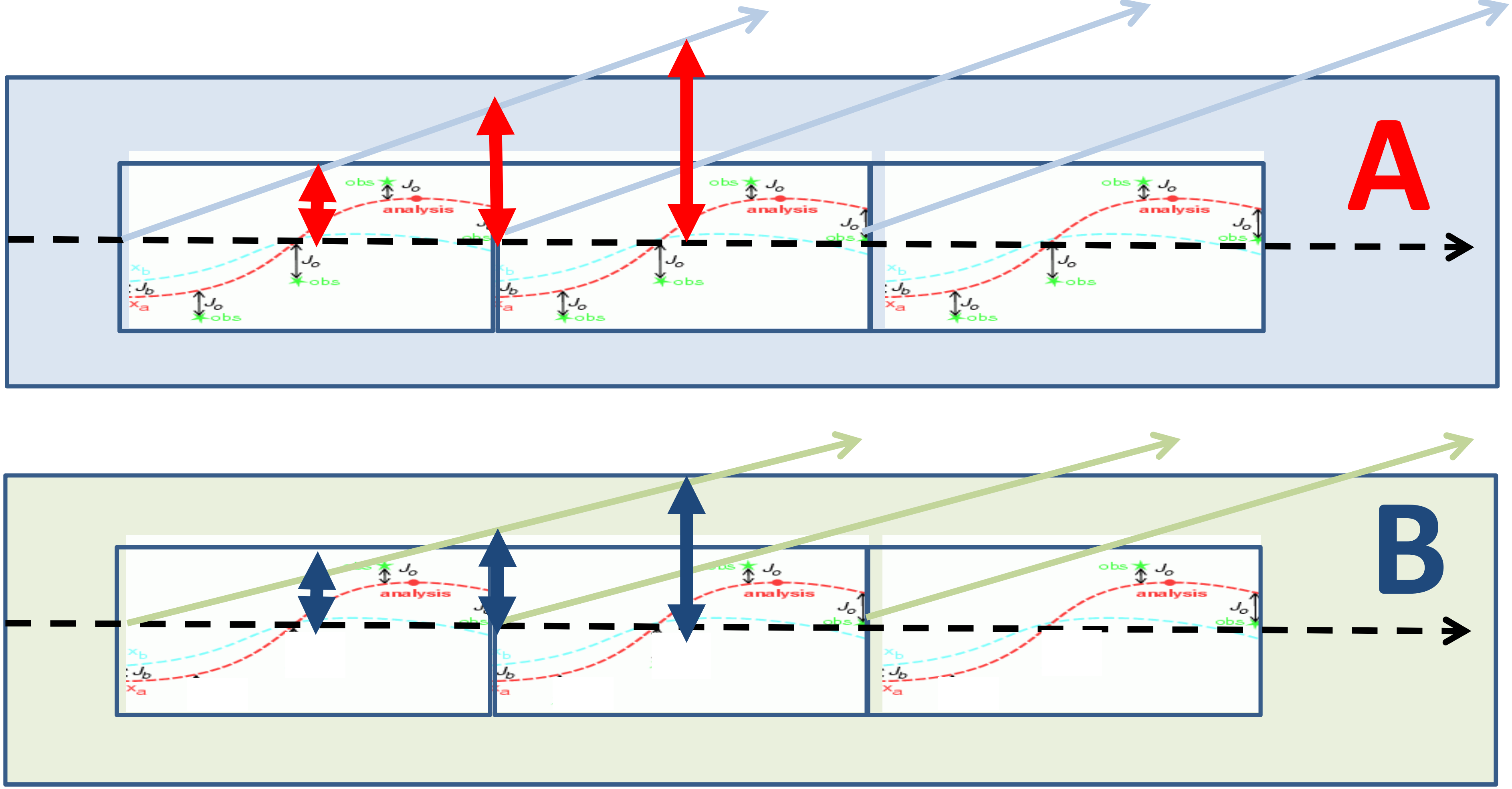
Observing System Experiments (we launch extended forecasts from both)



Observing System Experiments (we verify forecasts from A)



Observing System Experiments (we verify forecasts from **B**)



Then….

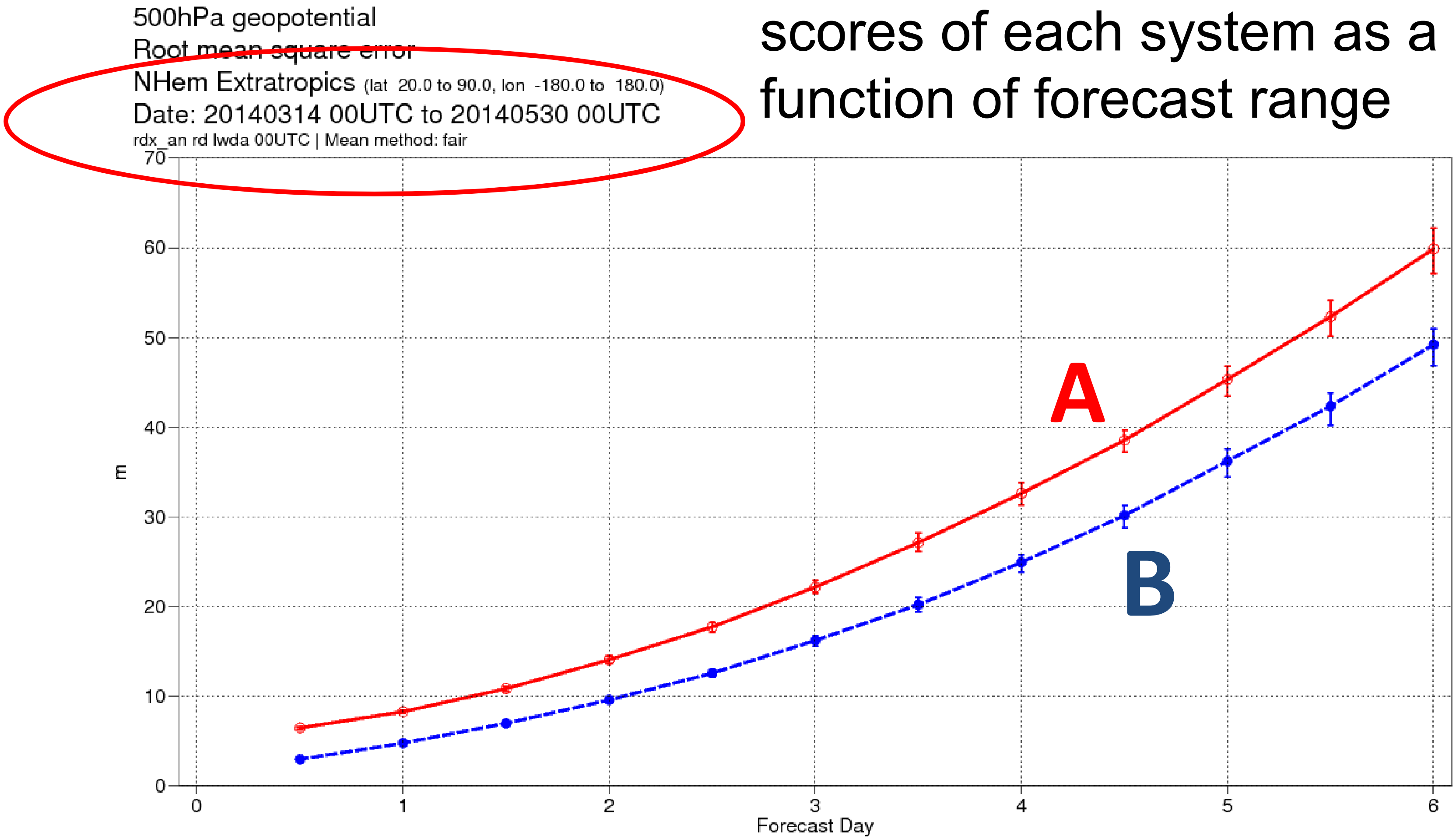
We can compare **statistics** of forecast scores from system **A** versus system **B** over a long period

Or…

We compare the performance of forecasts from system **A** versus system **B** in specific **case studies**

Statistics of Observation Impact

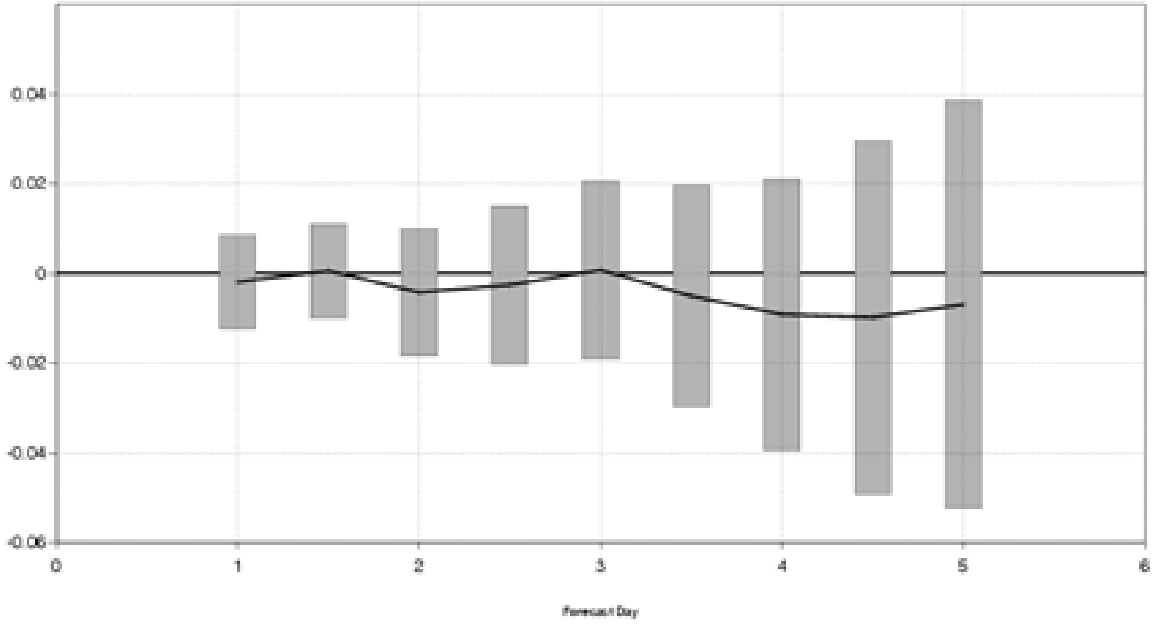
We can compare the average scores of each system as a function of forecast range



Statistics of Observation Impact

A > B

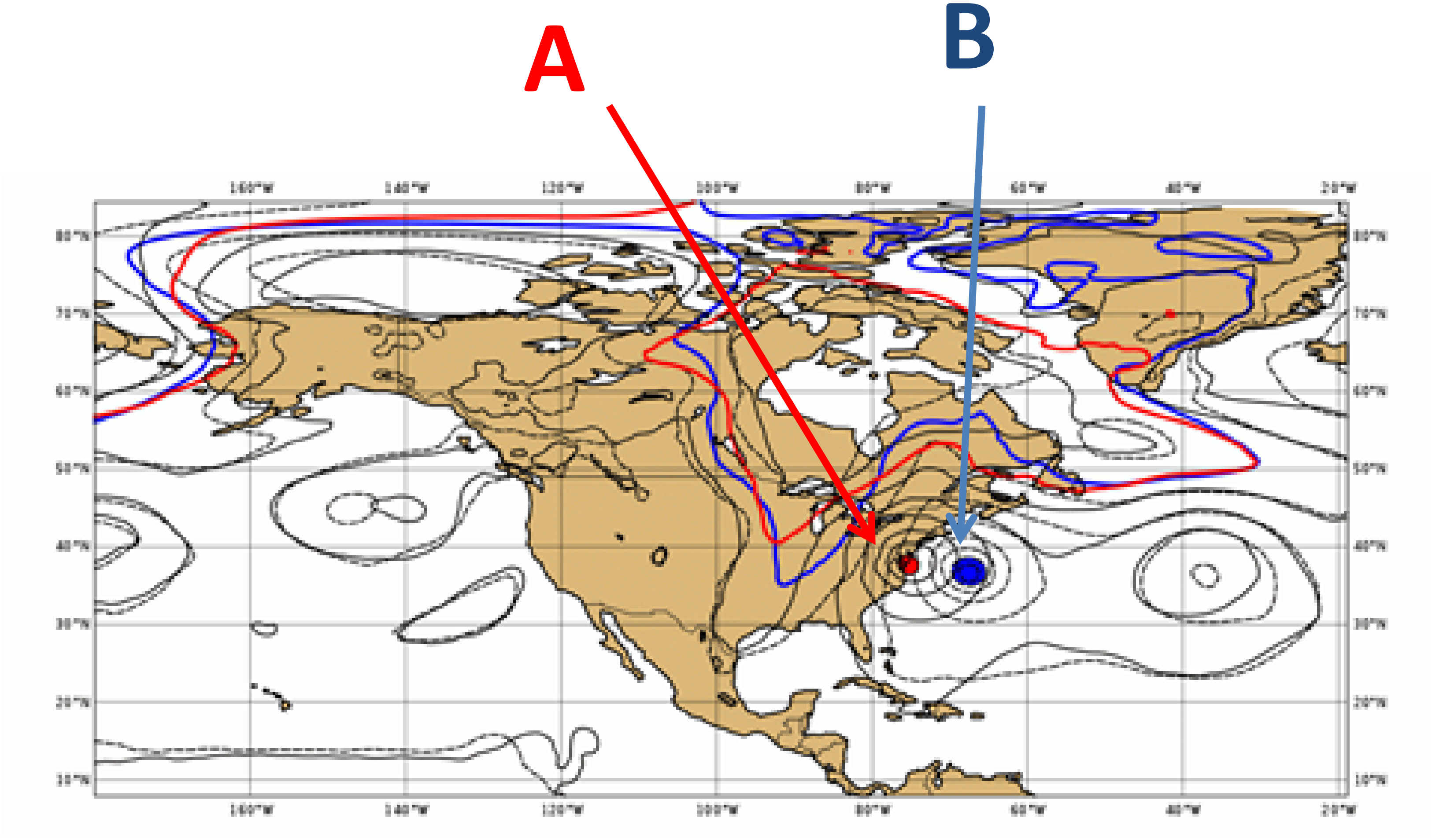
Or (increasingly) we can compare normalised score differences as a function of forecast range



B > A

Observation impact determined from individual case studies for important events

Case Study Observation Impact



Results from the most recent statistical evaluation of Observation Impact in the ECMWF NWP system

Observations considered in the study

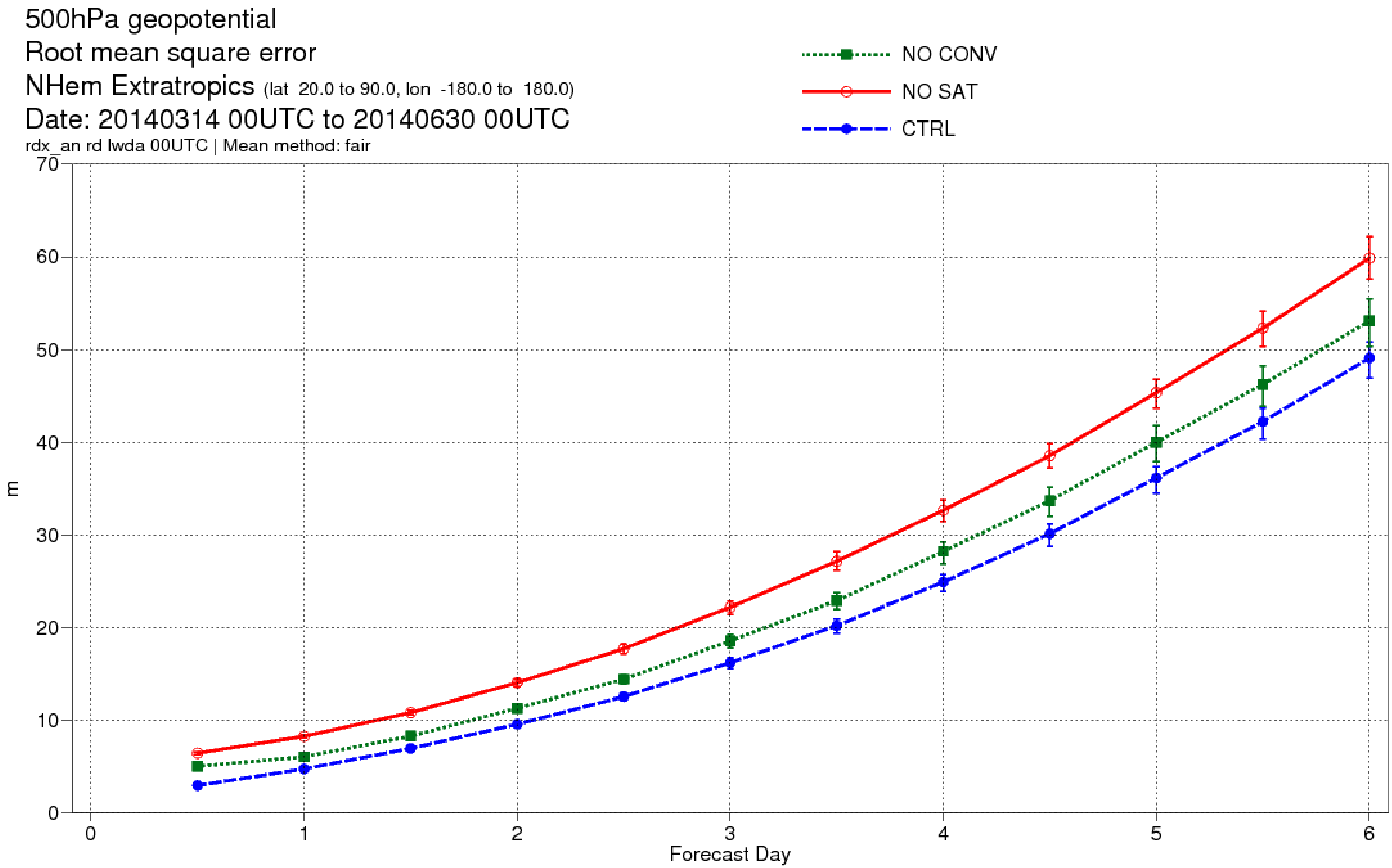
All conventional (in situ) data	CONV	TEMP/AIRCRAFT/SYNOP/SHIP/ BOUY/PROFILERS
All Satellite Data	SAT	
Microwave sounding radiances	MWS	7 x AMSUA, 1 x ATMS, 4 x MHS
Infrared sounding radiances	IRS	2 x IASI, 1 x AIRS, 1 x HIRS
All GEO data (AMVs and radiances)	GEO	2 x GOES, 2 x METEOSAT, 1 x MTSAT, polar 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

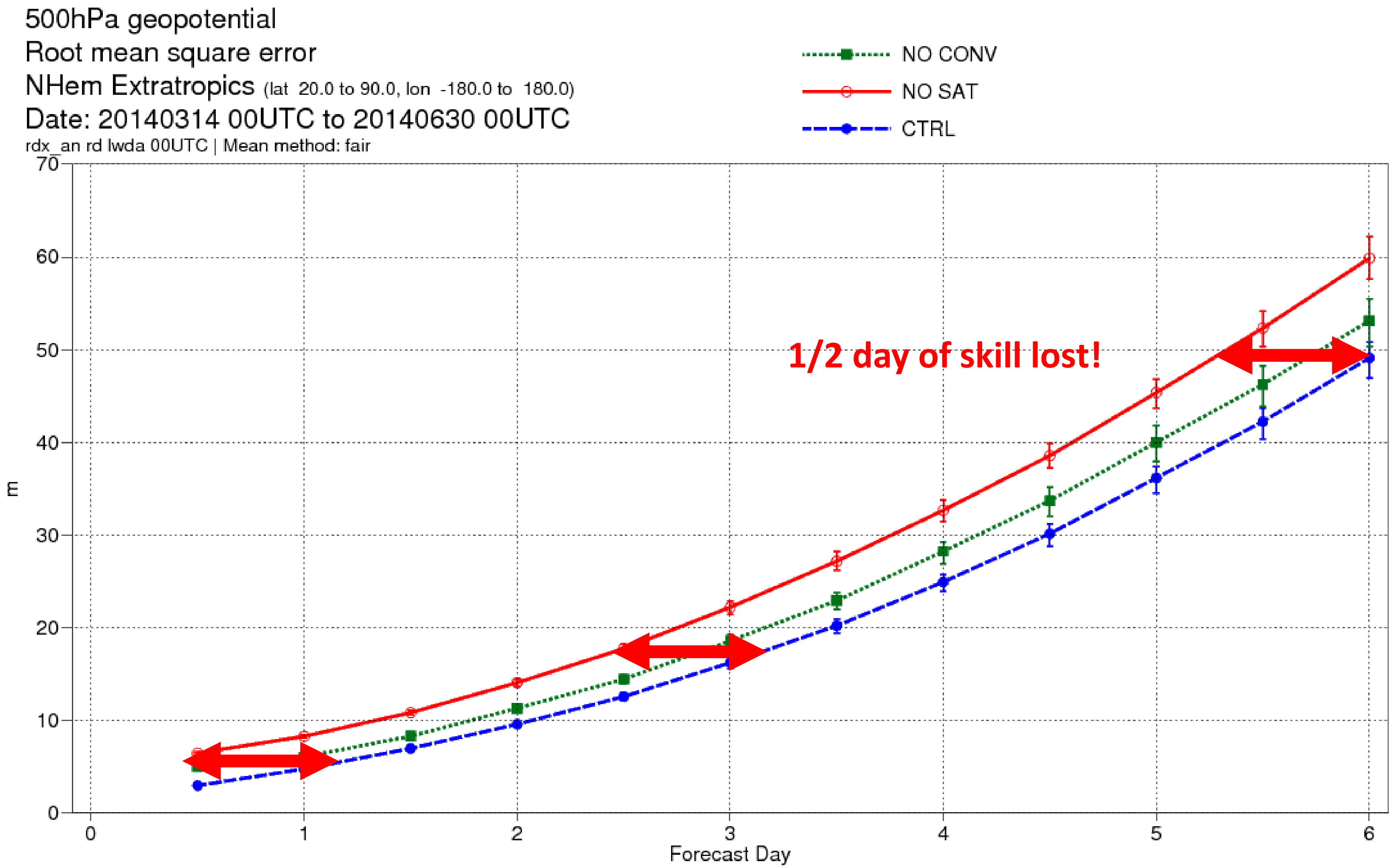
- Period covered (March 1st to June 30th 2014)
- Version 40R1 of the ECMWF analysis / forecasting system
- T511 Horizontal resolution (~40km) with 137 vertical levels (surface to 0.01hPa)
- For OSEs the various data types are **denied** from the system
- Verification is with the ECMWF operational analyses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

Satellites observations
v
Conventional (in situ) data

Importance of Satellites versus Conventional (in situ) data N.Hemis

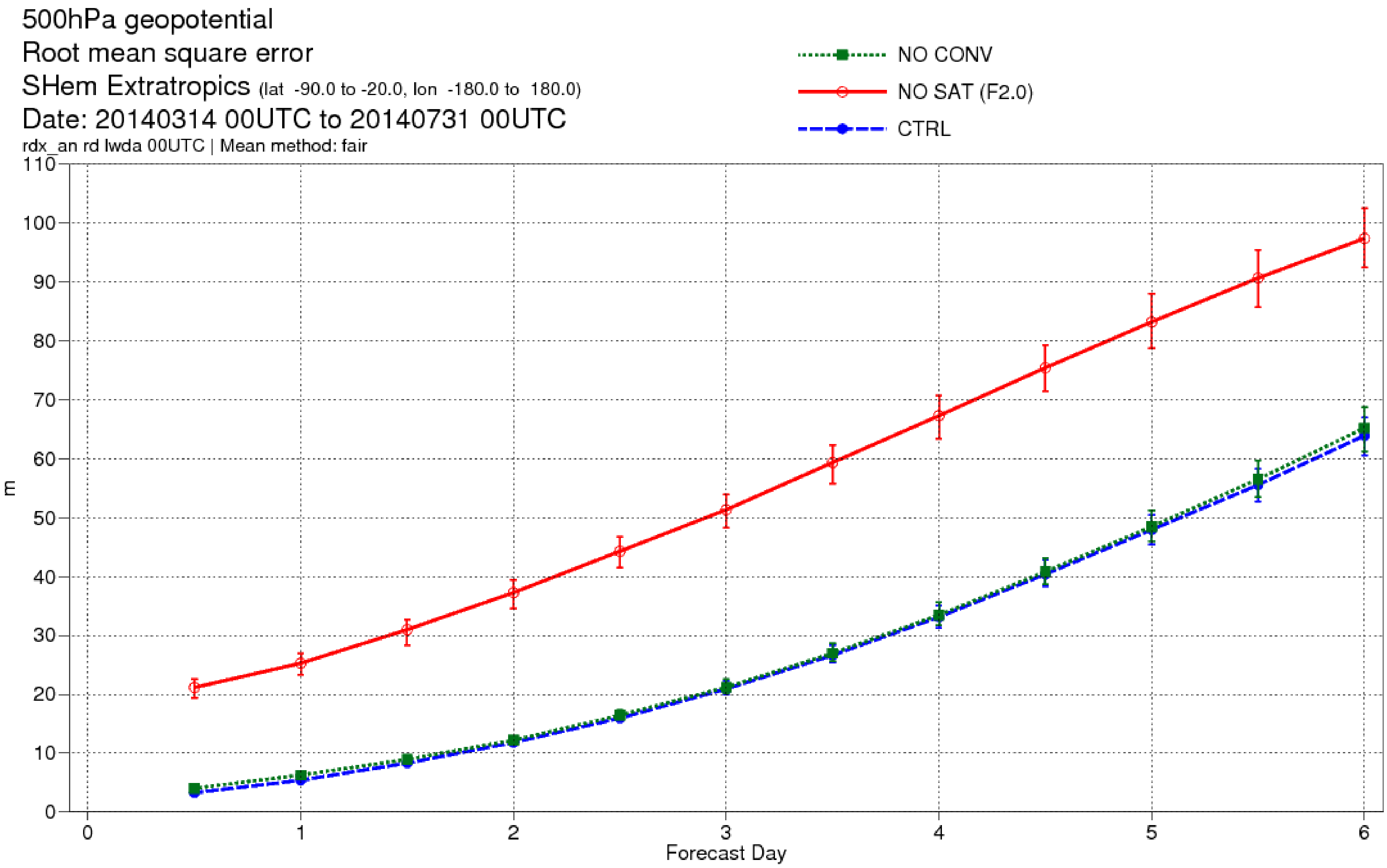


Importance of Satellites versus Conventional (in situ) data N.Hemis

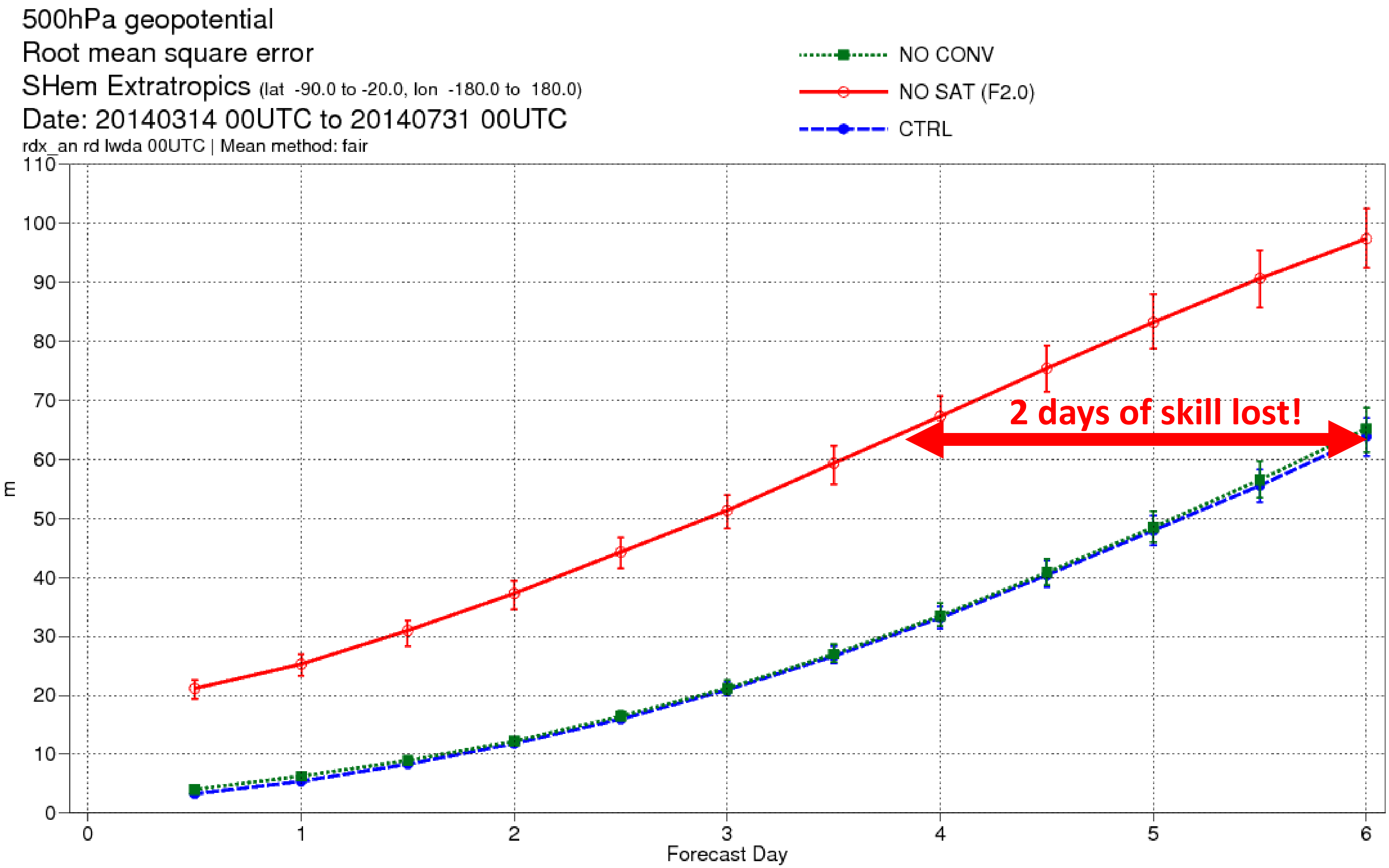


1/2 day of skill lost!

Importance of Satellites versus Conventional (in situ) data S.Hemis



Importance of Satellites versus Conventional (in situ) data S.Hemis

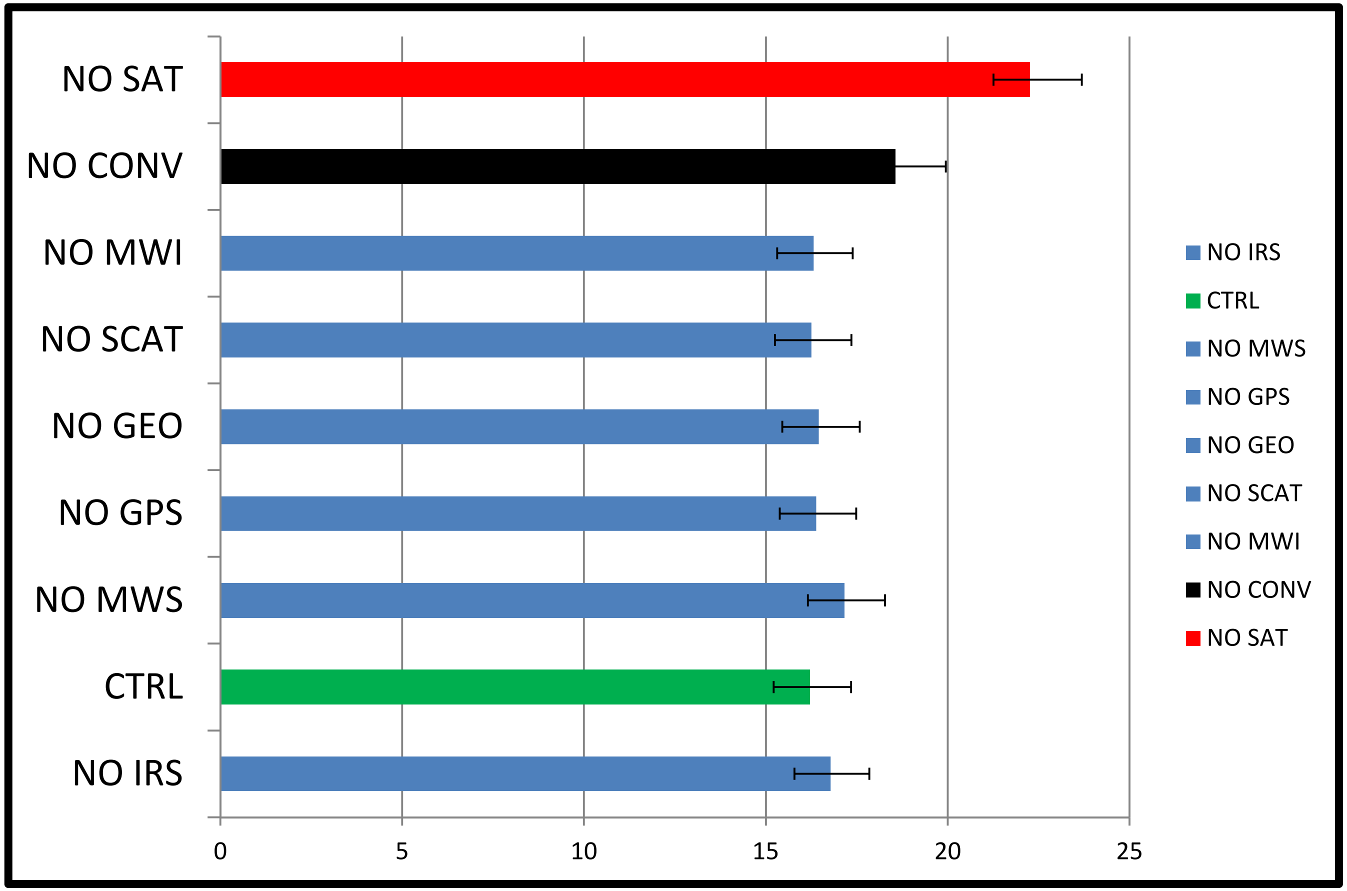


Which individual satellite observation types are most important ?

Observations considered in the study

All conventional (in situ) data	CONV	TEMP/AIRCRAFT/SYNOP/SHIP/ BOUY/PROFILERS
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

Day 3 Forecast Errors when Different Observations are denied
500hPa Z over NH



Day 3 Forecast Errors when Different Observations are denied
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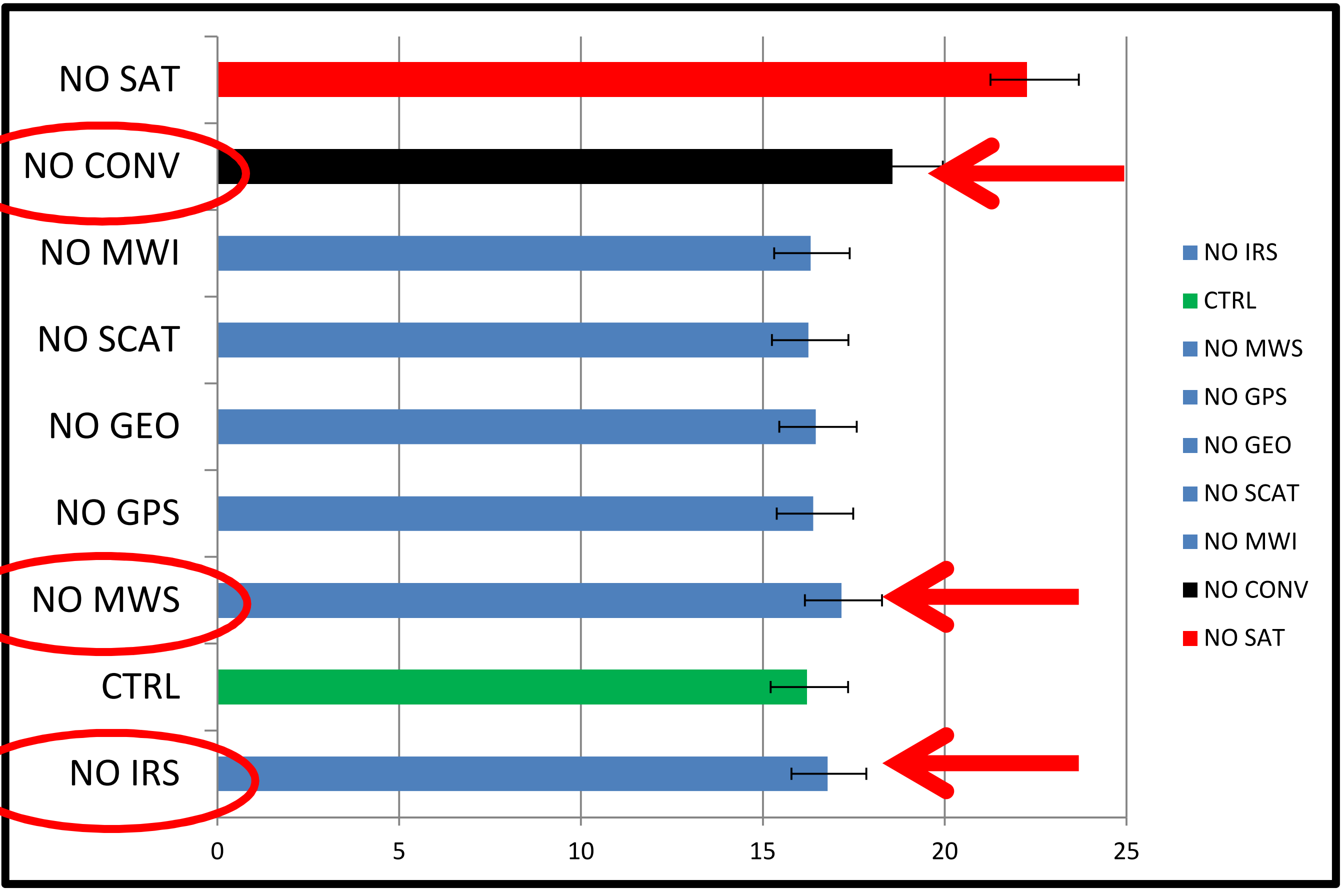
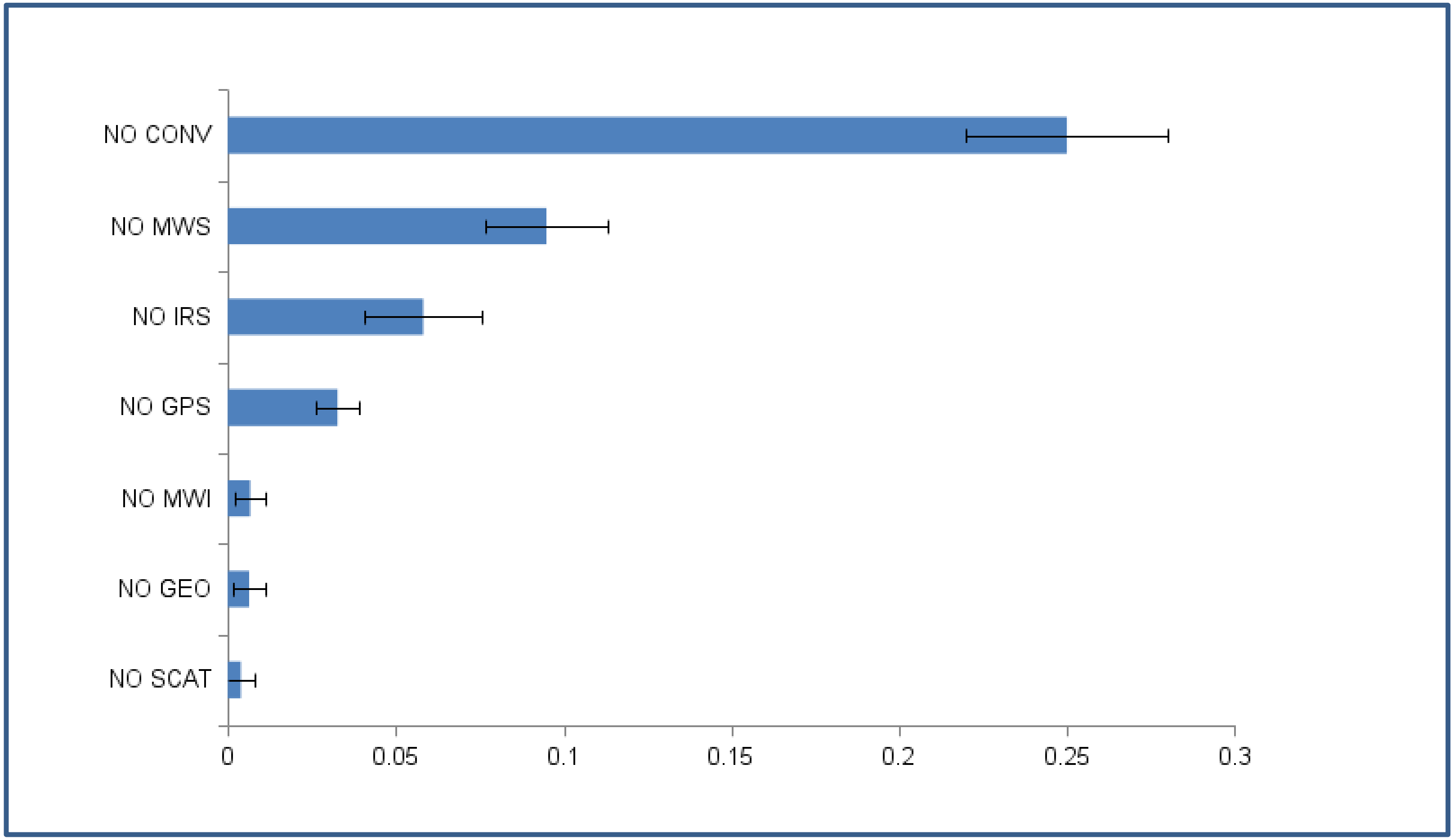
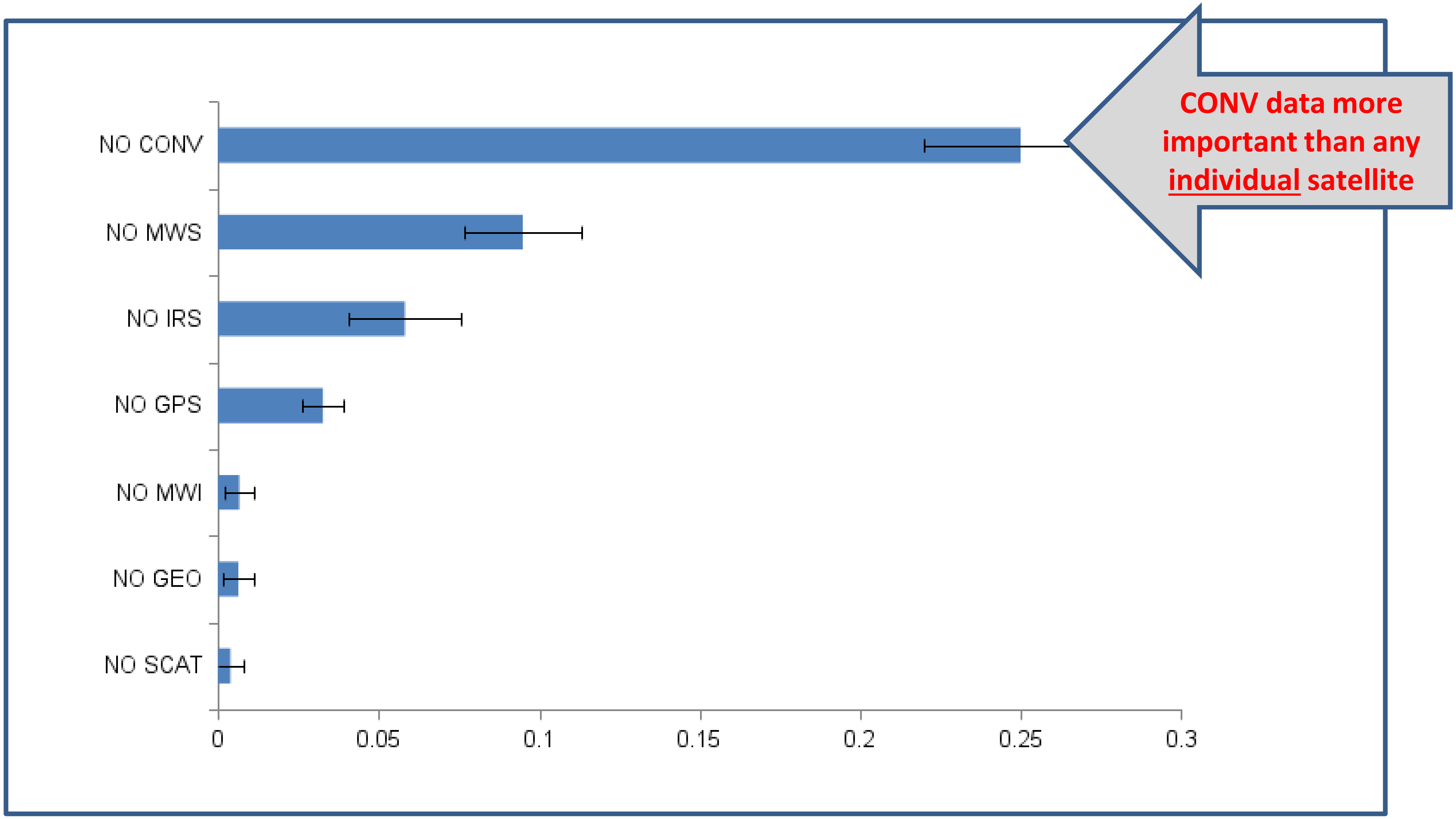


Observations ranked by impact upon day-3 NH forecasts of Z500

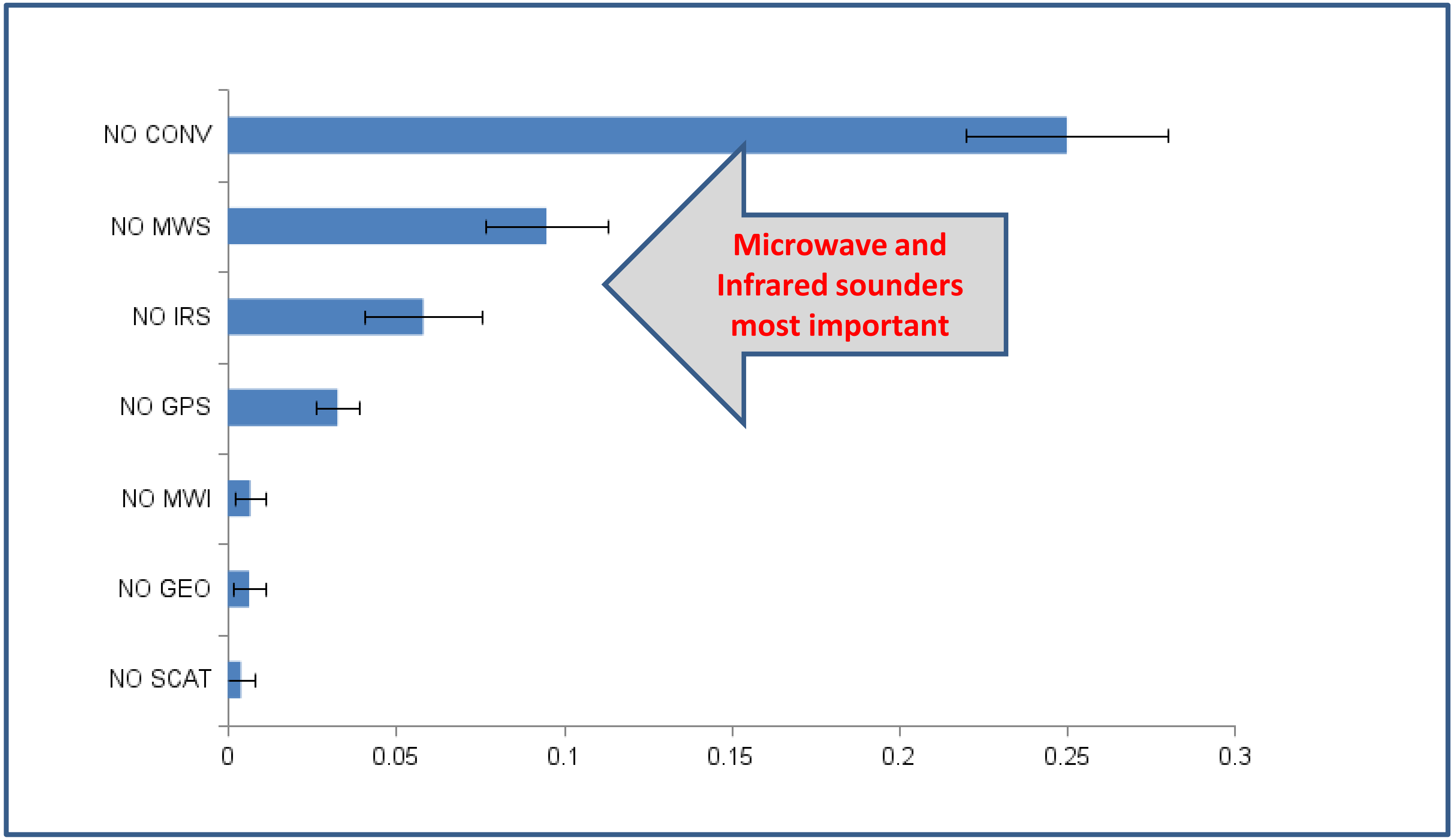


Ranked percentage loss of skill in day-3 Forecasts of 500hPa Z over NH



CONV data more important than any <u>individual</u> satellite

Ranked percentage loss of skill in day-3 Forecasts of 500hPa Z over NH



Microwave and Infrared sounders most important

Summary of overall ranking of Observations

1. All satellite observations
2. All conventional observations
3. Microwave Sounding Radiances
4. Infrared Sounding Radiances
5. GPS RO data
6. GEO/SCAT/MWI (niche impacts on other parameters)

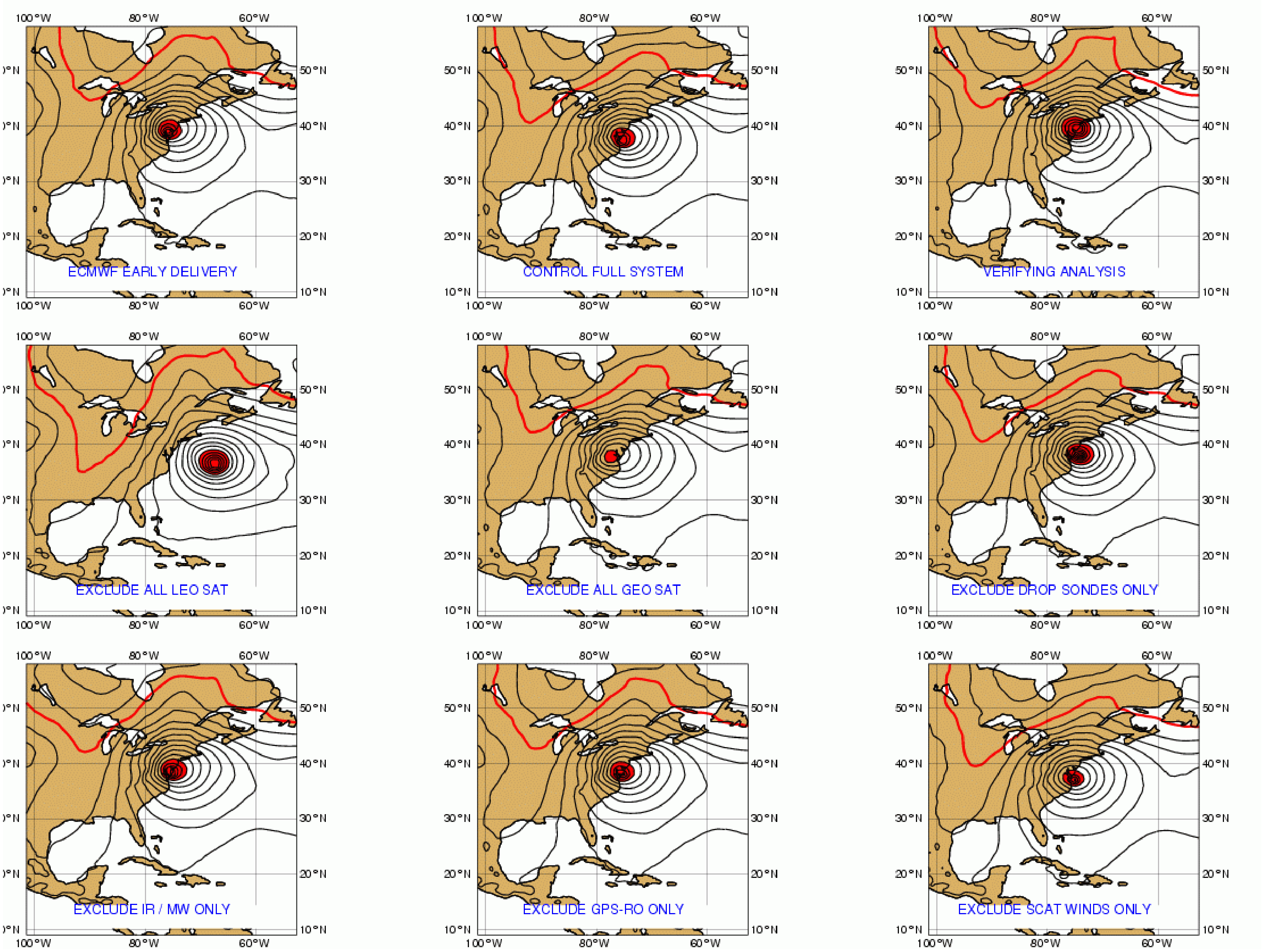
Observation impact determined from individual case studies for important events

Results from a recent Case Study
Hurricane Sandy

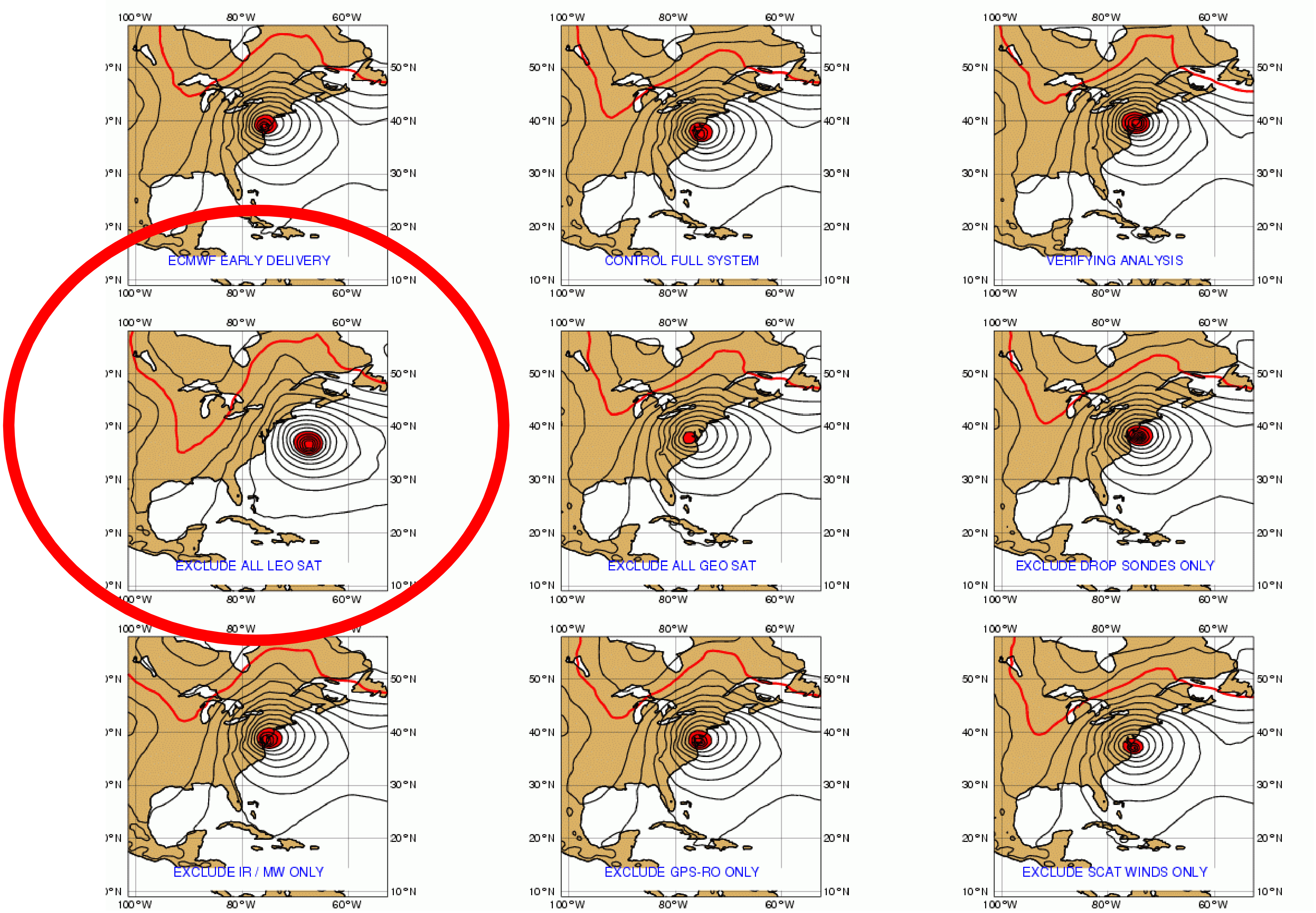
Experimental setup

- re-run ECMWF operations from the 20th October at full resolution (T1279)
- The denial experiments are identical to the control - except that different satellite observations are deliberately withheld
- Key day five forecasts launched from the 25th

Hurricane Sandy



Hurricane Sandy


ECMWF EARLY DELIVERY

CONTROL FULL SYSTEM

VERIFYING ANALYSIS

EXCLUDE ALL LEO SAT

EXCLUDE ALL GEO SAT

EXCLUDE DROP SONDES ONLY

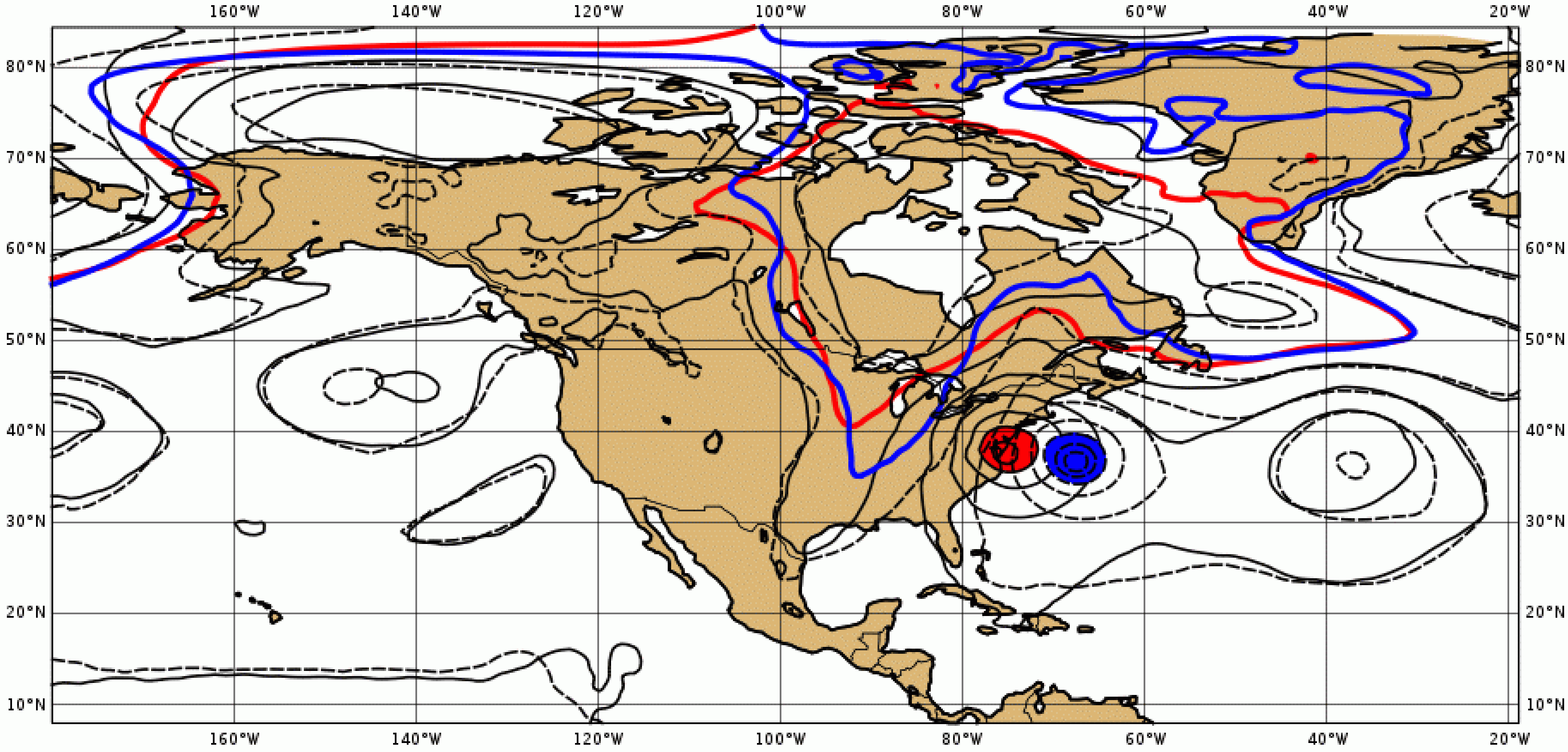
EXCLUDE IR / MW ONLY

EXCLUDE GPS-RO ONLY

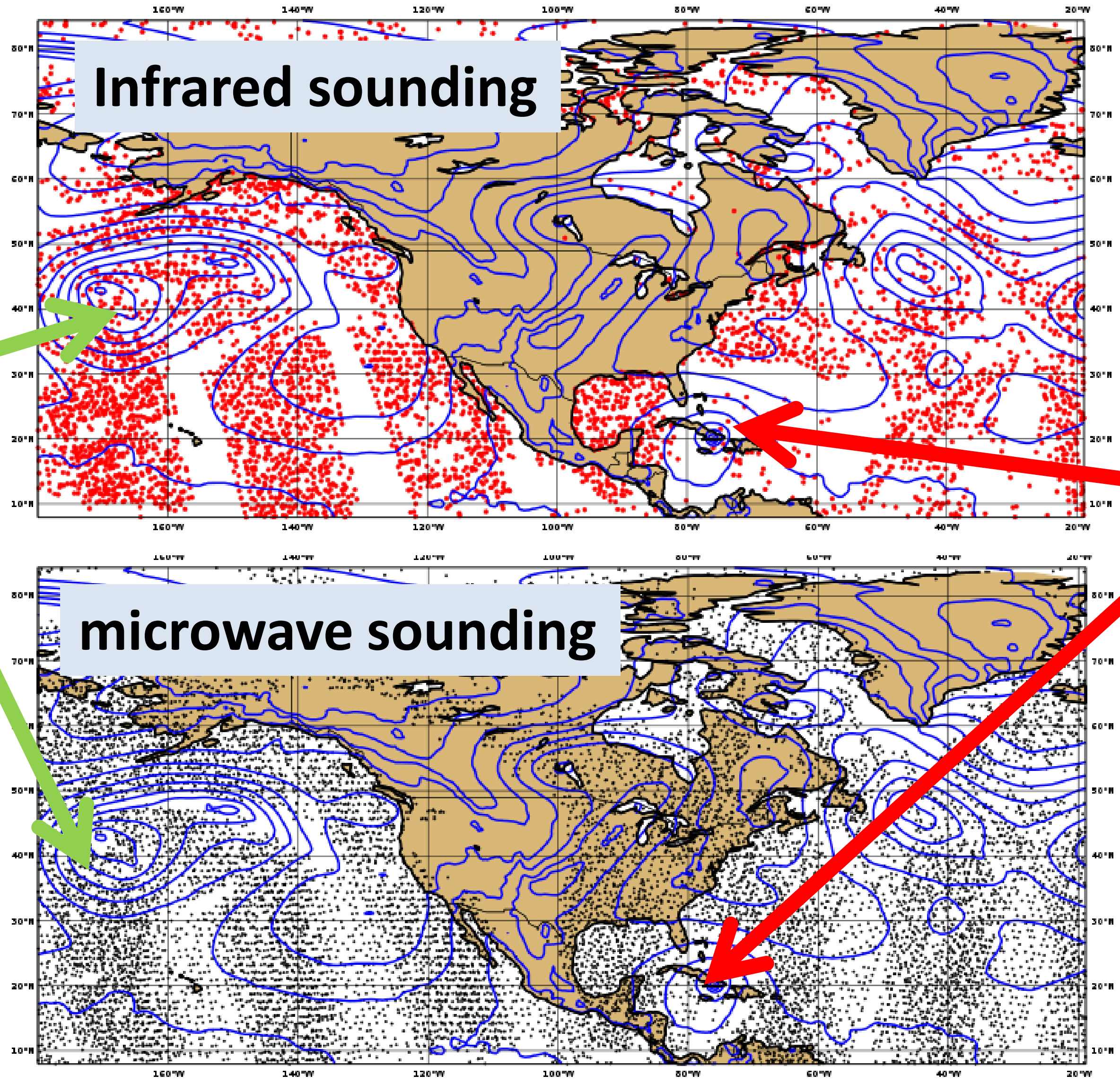
EXCLUDE SCAT WINDS ONLY

Forecast differences of failed (NO –LEO SAT) forecast

MSLP in Control (red and black solid)
NO-LEO SAT (blue and black dash) VT:2012103000z



LEO satellite data coverage (2012102500z)



Infrared sounding

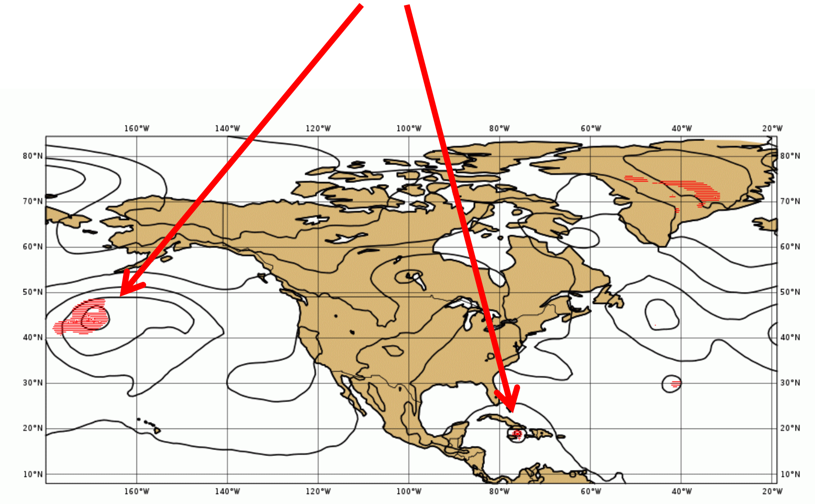
microwave sounding

Good in the N.Pacific

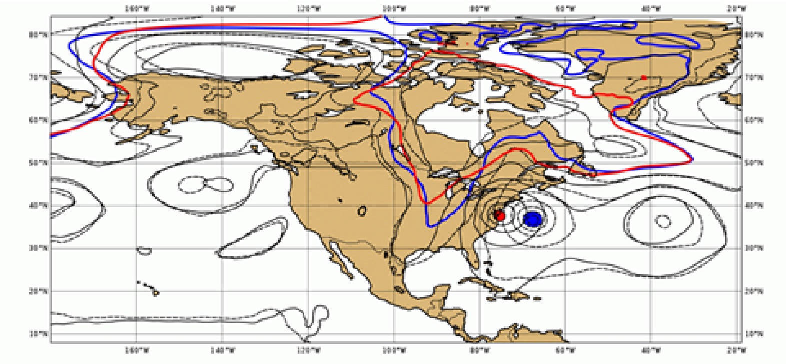
Bad in the immediate vicinity of the storm due to cloud

Satellite impact on Hurricane Sandy

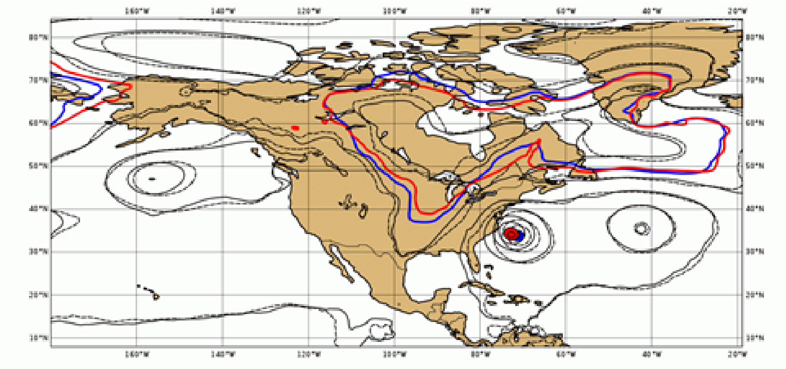
Changes to the initial conditions from removing LEO satellite data were small and located **far from the storm**



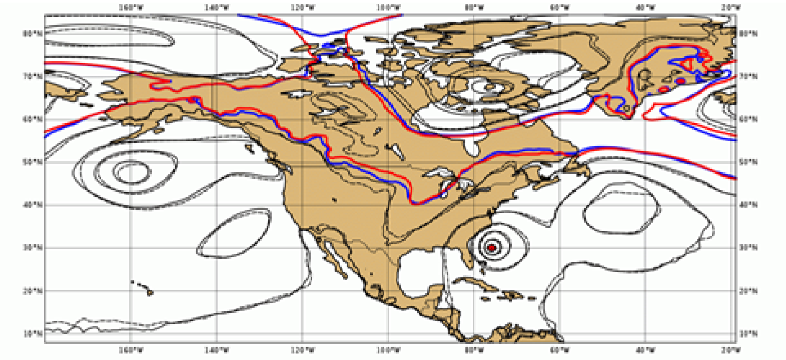
Forecasts **with** / **without** LEO data



Day-5



Day-4



Day-3

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 **<u>and</u>** the bad!!

But we need to take great care when making statements about the importance of different observations!

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)
- Reliability of verification!!

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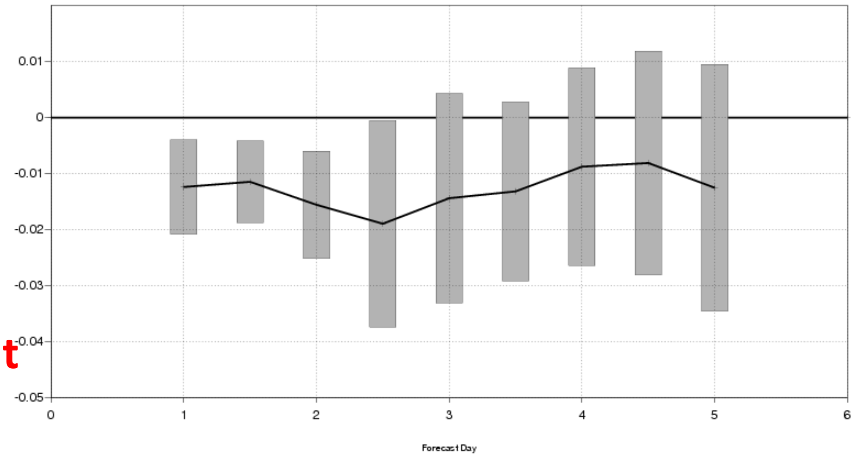
Putting the same satellite in a different orbit (13:30 compared to 07:30 orbit)

In the context of considering which orbit a new Chinese satellite should occupy, OSE studies showed that putting a microwave sounder in a morning orbit (07:30) meant it had a much bigger impact than if exactly the same data were obtained from an afternoon orbit (13:30).

PM orbit better

AM orbit better

Change in Northern Hemisphere Forecast accuracy for Z500



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- Tuning of the assimilation system (correct specification of B, R, BC, QC)
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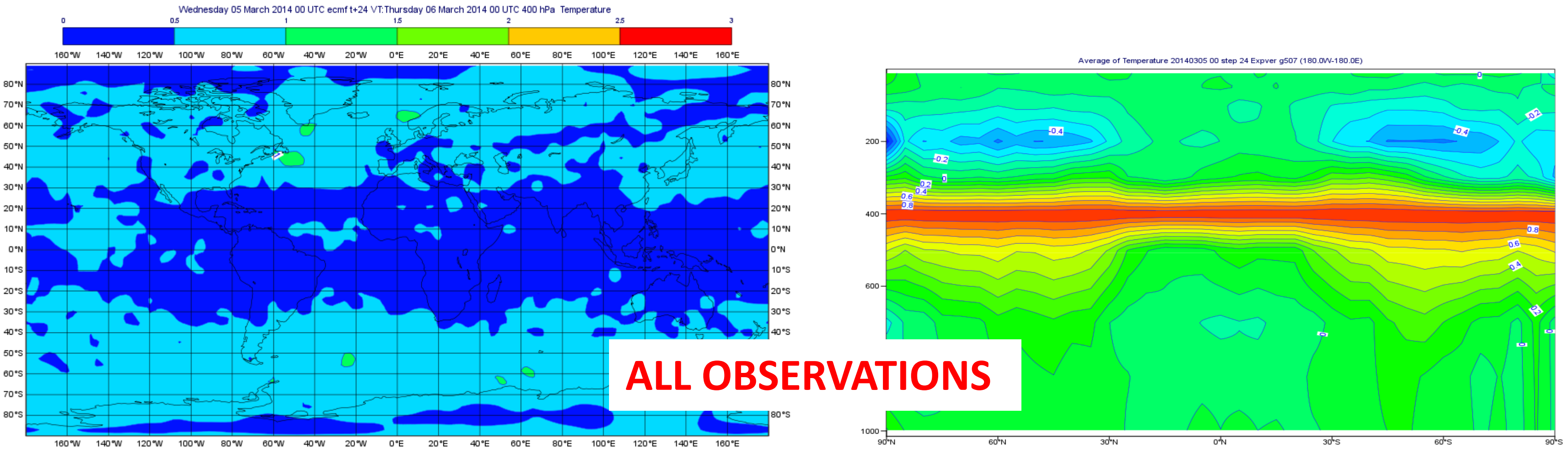
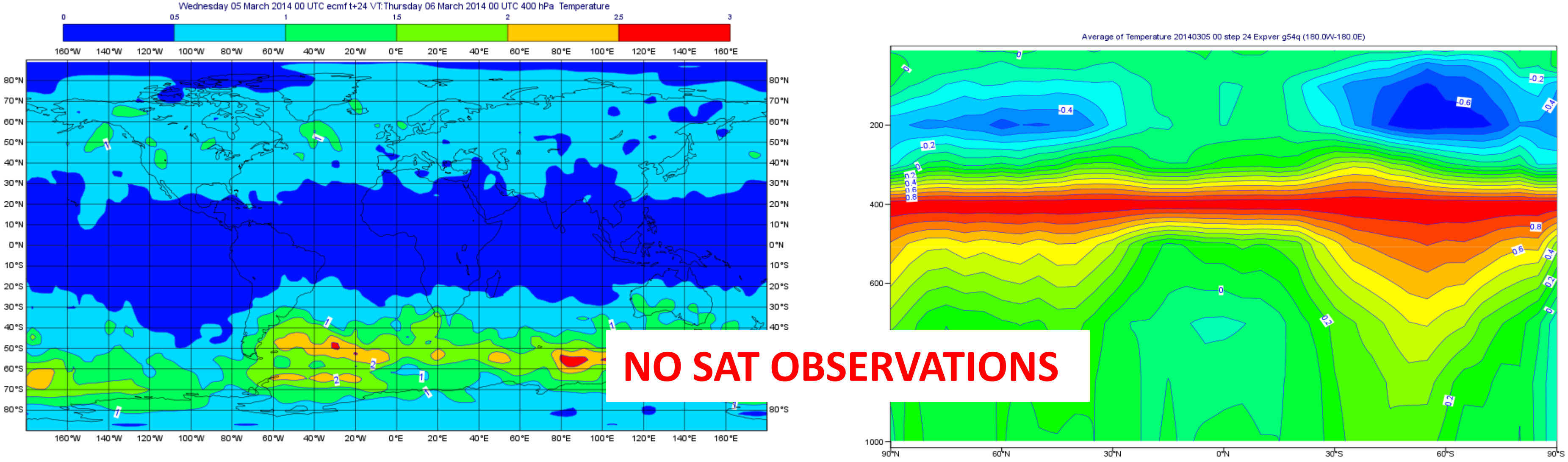
Correct tuning of the assimilation system (e.g. background errors)

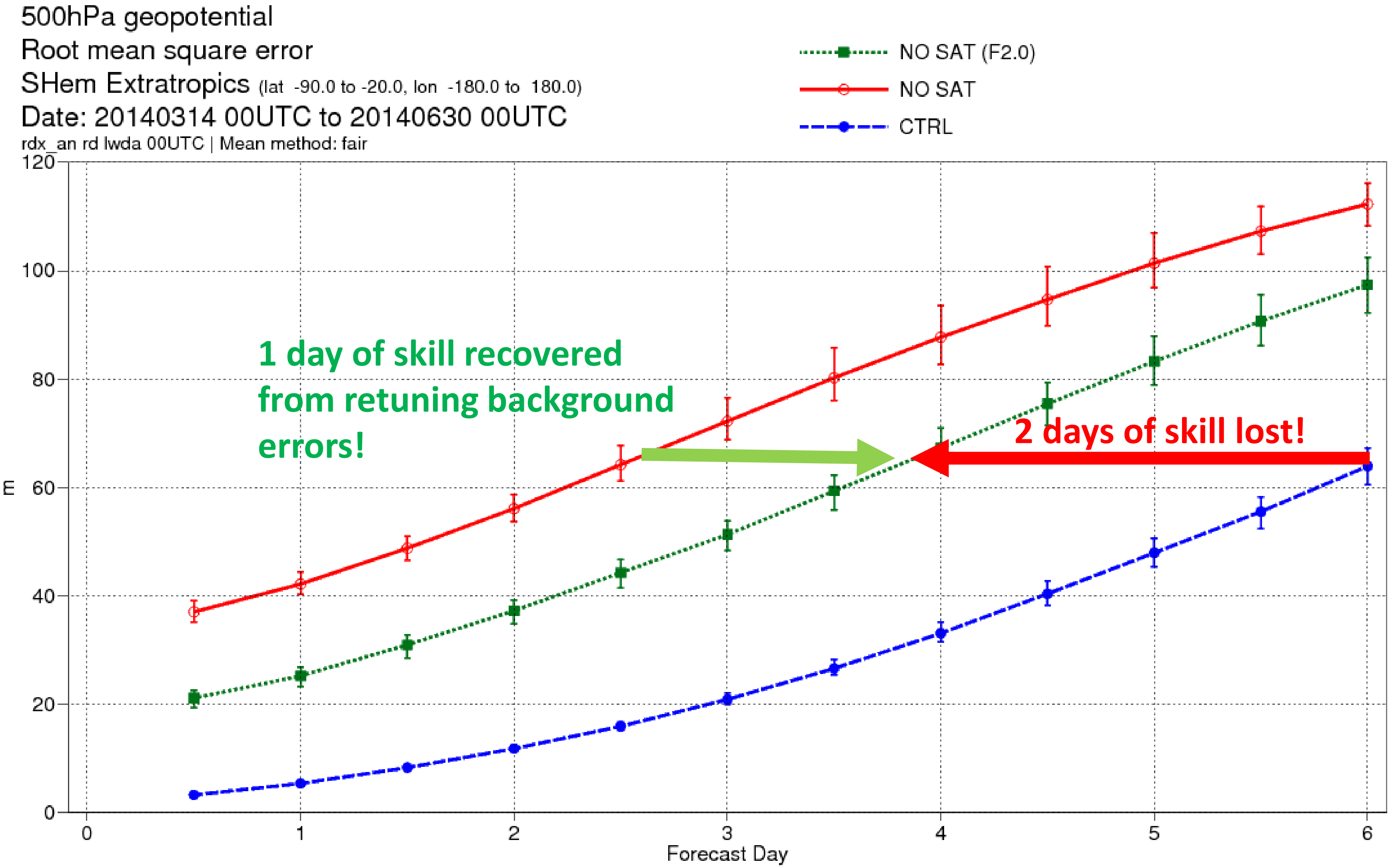


ALL OBSERVATIONS



NO SAT OBSERVATIONS

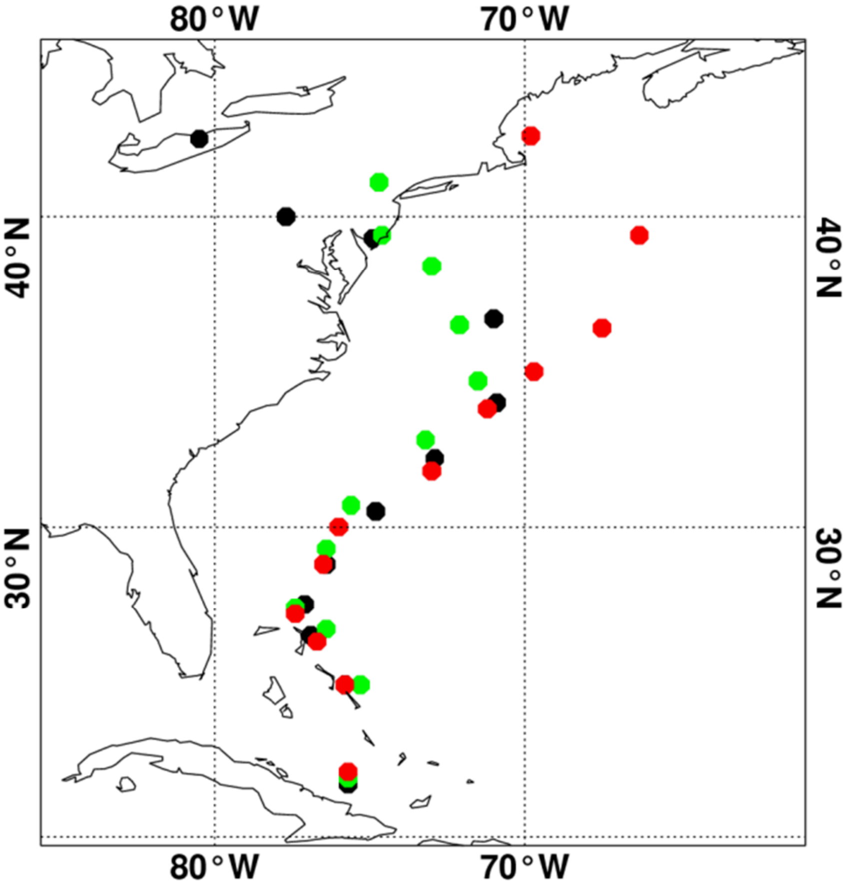
Retuning background errors for an extreme OSE

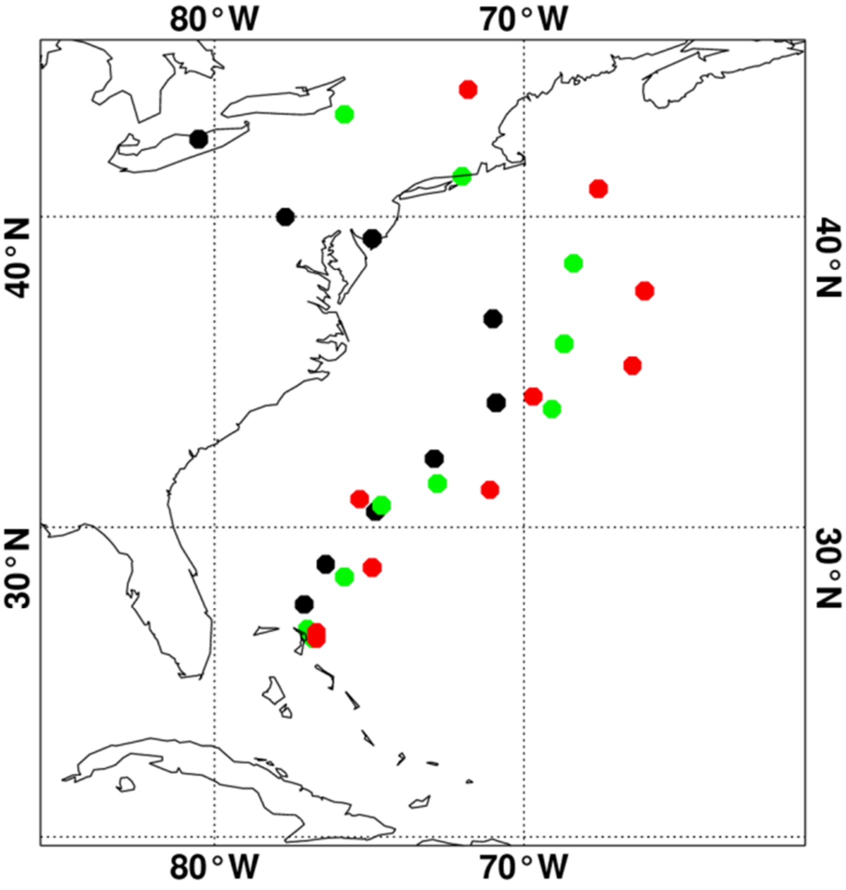


1 day of skill recovered from retuning background errors!

2 days of skill lost!

Sensitivity to Background Errors





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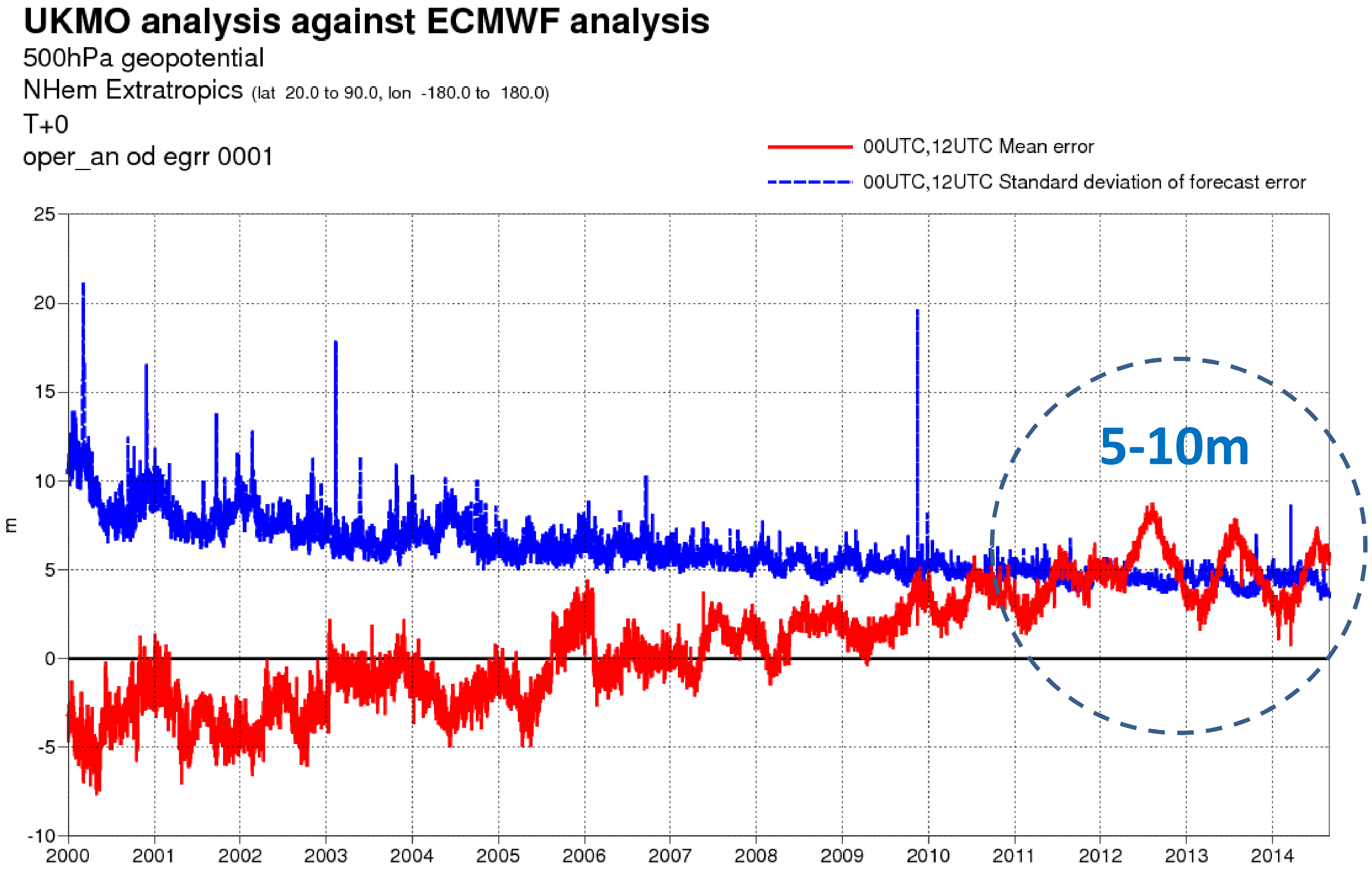
- Tuning of the assimilation system (correct specification of B, R, BC, QC)
- Reliability of verification!!

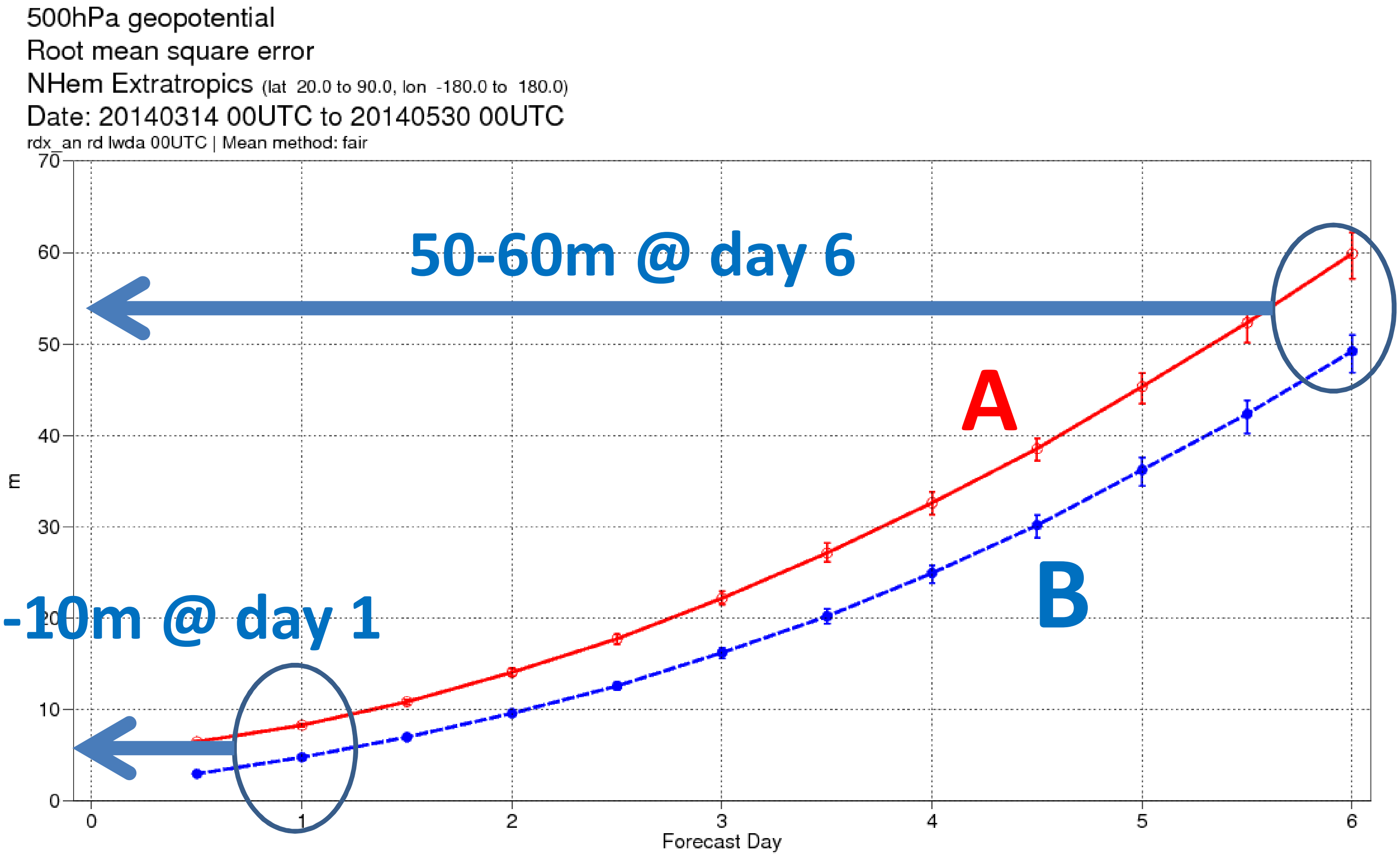
Verification (what is truth?)

- Conventional (in situ) Observations ?
  - Poor (biased) spatial coverage
  - They have errors (RS z500 ~ 10m)
- NWP analyses
  - They have errors (z500 ~ ??)

How accurate are our analyses ?



Analysis uncertainty in verification



50-60m @ day 6

5-10m @ day 1

Summary

- NWP systems rely completely on observations to make usable weather forecasts (either for DA or model development)
- Collectively satellite data dominate forecast accuracy everywhere, but conventional data are still important (more than any single SAT system).
- Of these, microwave and infrared sounding dominate the medium-range headline scores, but other SAT observations have impact on other parameters (and ranges)
- Case studies are valuable and a very potent tool to convince decision makers

Thank you for your attention
(questions ?)

Anomaly correlation of 500hPa height forecasts