World Meteorological Organization

Working together in weather, climate and water

WMO

Wind Measurements in the WMO Global Observing System

ESA ADM/Aeolus Cal/Val Workshop
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Overview

1. The WMO Global Observing System (GOS) and the Rolling Review of Requirements
2. NWP-based Data Impact Studies and Diagnostics
   - OSEs
   - FSO
   - OSSEs
3. Role of the WMO Impact Workshops
4. Sample results from Fifth WMO Impact Workshop
5. Sample OSSE Results
6. Key guidance regarding wind observations
7. Final remarks

1. Rolling Review of Requirements

- WMO Congress: *All components of (WI)GOS shall use the RRR to design networks, plan evolution and assess performance* *(WIGOS is the WMO Integrated Global Observing System, of which the GOS is one element)*
- The RRR is the process used by WMO to collect, vet and record user requirements for all WMO application areas and match them against observational capabilities
  - Gap analysis results in *Statement of Guidance,* one per application area, that provides a narrative of how well a given application area is supported by WIGOS; to be supported by a quantitative gap analysis module (in development)

WMO Application Areas Supported by the RRR

1. Global numerical weather prediction (NWP)
2. High-resolution numerical weather prediction
3. Nowcasting and very short range forecasting
4. Seasonal and inter-annual forecasting
5. Aeronautical meteorology
6. Atmospheric chemistry*
7. Ocean applications
8. Agricultural meteorology
9. Hydrology
10. Climate monitoring
11. Climate applications
12. Space weather

Requirements in the RRR

- **Requirements are "technology free", specified in terms of geophysical variables rather than measurands (e.g. temperature rather than radiances)**
- **For** each variable and each application areas, requirements on:
  - Spatial (horizontal and vertical) and temporal resolution, uncertainty, data latency, required coverage area, source, and level of confidence
- Each requirement is expressed in terms of three separate values:
  - Threshold (observations not useful unless this is met)
  - Break-through (optimum cost-benefit ratio)
  - Goal (exceeding this provides no additional benefit)
- Requirement values are collected by Expert Teams operating under the Commission for Basic Systems and other WMO Technical Commission, and the process is informed by the wider community e.g. though the WMO Impact Workshops engaging the NWP and data assimilation community

			Area		/ decade	Res	Res	Cyc			Level	Date	
119	Wind (horizontal)	HS&M	Climate-AOPC	2 m.s^{-1} 3 m.s^{-1} 7 m.s^{-1}		100 km 200 km 500 km		3 h 4 h 6 h	3 h 6 h 12 h	Global	firm	2007-07-19	AOPC
120	Wind (horizontal)	HT	Climate-AOPC	2 m.s^{-1} 3 m.s^{-1} 5 m.s^{-1}		100 km 200 km 500 km		3 h 4 h 6 h	3 h 6 h 12 h	Global	firm	2007-07-19	AOPC
121	Wind (horizontal)	LS	Climate-AOPC	2 m.s^{-1} 3 m.s^{-1} 5 m.s^{-1}		100 km 200 km 500 km	0.5 km 0.65 km 1 km	3 h 4 h 6 h	3 h 6 h 12 h	Global	firm	2007-07-19	AOPC
122	Wind (horizontal)	LT	Climate-AOPC	2 m.s^{-1} 3 m.s^{-1} 5 m.s^{-1}		100 km 200 km 500 km		3 h 4 h 6 h	3 h 6 h 12 h	Global	firm	2007-07-19	AOPC
22	Wind (horizontal)	HT	Aeronautical Meteorology	2 m.s^{-1} 2.7 m.s^{-1} 5 m.s^{-1}		50 km 63 km 100 km	0.15 km 0.238 km 0.6 km	5 min 6 min 10 min	60 min 84 min 3 h	Global	firm	2000-06-23	ET ODRRGO
23	Wind (horizontal)	LS LT	Aeronautical Meteorology	2 m.s^{-1} 3 m.s^{-1} 5 m.s^{-1}		50 km 70 km 100 km	0.15 km 0.3 km 0.6 km	5 min 7 min 10 min	60 min 90 min 3 h	Global	firm	2000-06-23	ET ODRRGO
239	Wind (horizontal)	HS&M	Climate Modelling Research	3 m.s^{-1} 4 m.s^{-1} 5 m.s^{-1}		50 km 100 km 500 km	2 km 3 km 5 km	3 h 6 h 12 h	30 d 45 d 60 d	Global	reasonable	1998-10-29	WCRP
240	Wind (horizontal)	LS HT LT	Climate Modelling Research	1 m.s^{-1} 2 m.s^{-1} 4 m.s^{-1}		10 km 50 km 250 km	0.2 km 1 km 3 km	60 min 3 h 6 h	30 d 45 d 60 d	Global	reasonable	2012-12-01	WCRP
310	Wind (horizontal)	HS&M	Global NWP	1 m.s^{-1} 5 m.s^{-1} 10 m.s^{-1}		50 km 100 km 500 km	1 km 2 km 3 km	60 min 6 h 12 h	6 min 30 min 6 h	Global	firm	2009-02-10	John Eyre
311	Wind (horizontal)	HT	Global NWP	1 m.s^{-1} 3 m.s^{-1} 8 m.s^{-1}		15 km 100 km 500 km	0.5 km 1 km 3 km	60 min 6 h 12 h	6 min 30 min 6 h	Global	firm	2009-02-10	John Eyre
312	Wind (horizontal)	LS	Global NWP	1 m.s^{-1} 3 m.s^{-1}		15 km 100 km	0.5 km 1 km	60 min 6 h	6 min 30 min	Global	firm	2009-02-10	John Eyre

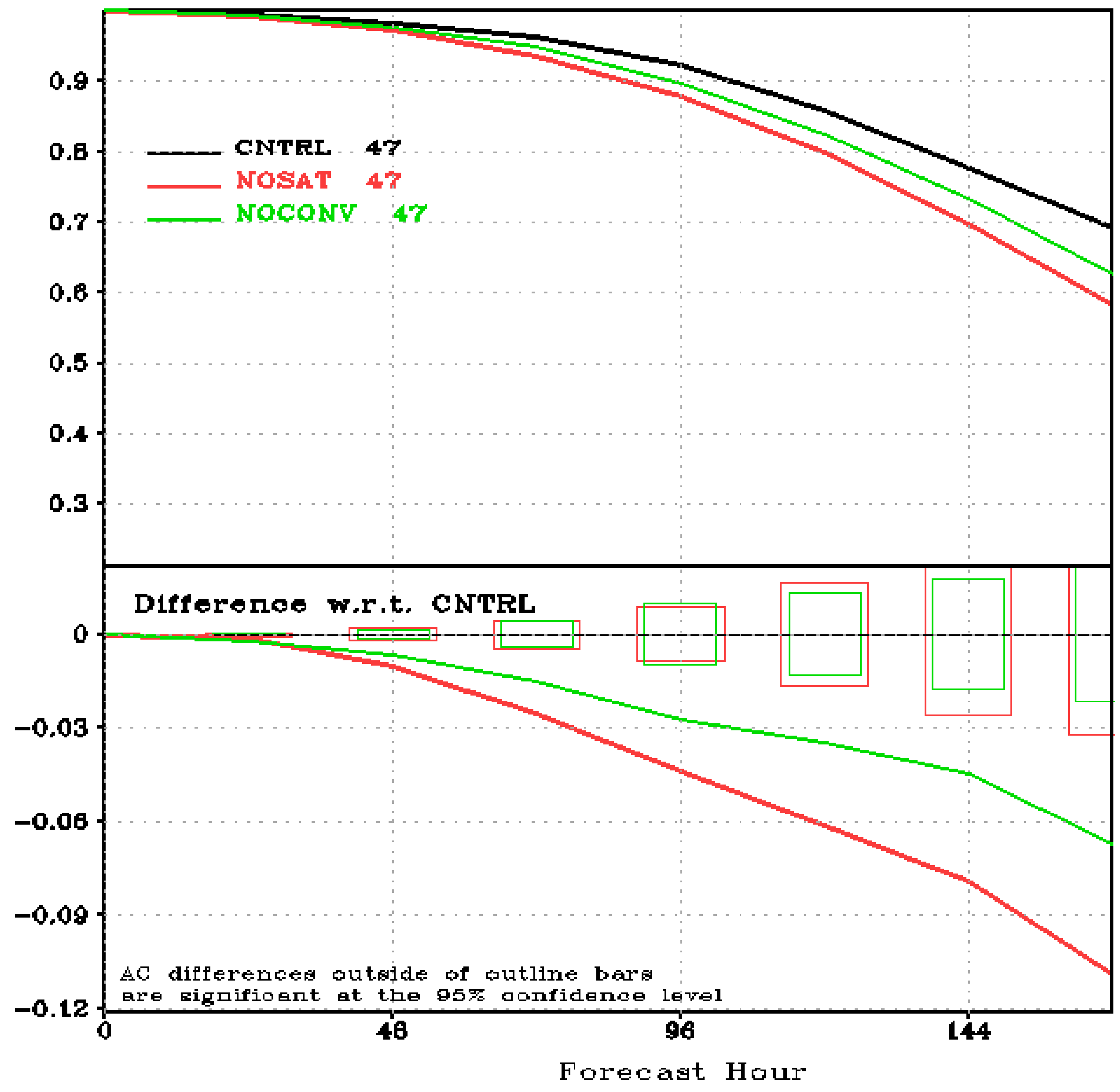
2. NWP-based Impact Assessment Methodologies

- Why use NWP-based assessment methods?
  - Objective, quantitative metrics:
  - NWP poses a well-defined prediction problem with a “right” answer
    - (and an infinity of wrong ones)
    - Well-defined measures for quality of output
    - Well-established methodologies for assigning merit (or blame) to individual observing systems

NWP-based Impact (I)
OSE (or data denial)

- OSEs (Observing System Experiments) are based on data denial (or addition):
  - 1. Run a control with operational data
  - 2. Add (or subtract) data to be tested
  - 3. Compare
- Impact focuses on the medium to long range
- Results show the impact of withdrawing (or adding) certain data

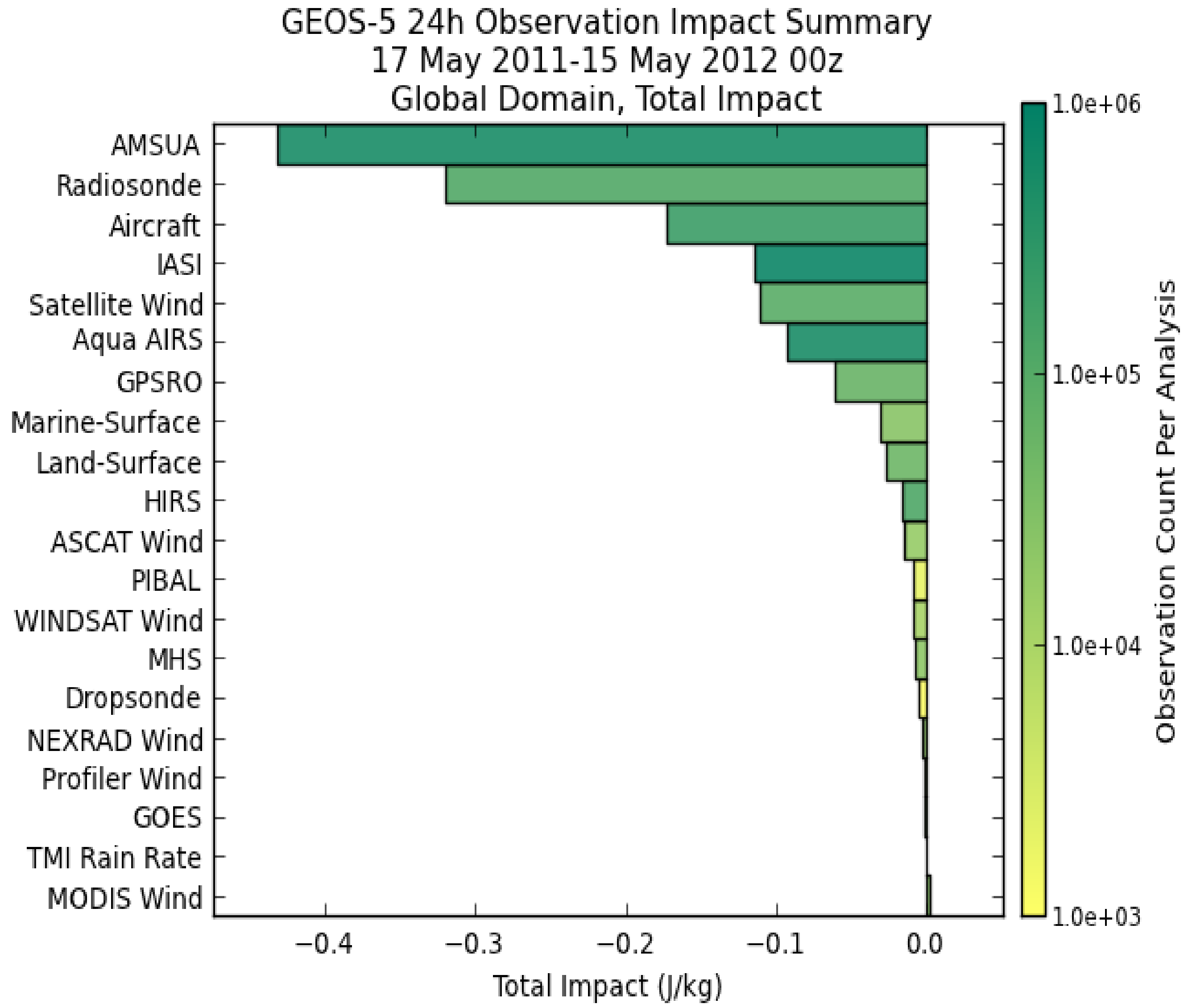
Jung et al., WMO Impact Workshop in Sedona, May 2012



NWP-based Impact (II)
FSO

Gelaro et al, Fifth WMO Impact Workshop, Sedona 2012

- FSO (Forecast Sensitivity to Observations) are based on the adjoint of the model/analysis system or an ensemble approach
- Measure of the contribution to the reduction of 24 h forecast error
- Approach focuses exclusively on the short (quasi-linear) range
- Results show the impact of observations <u>in the presence of all other observations</u>
- Relative rather than absolute measure of impact



NWP-based Impact (III)
OSSE

- Observing System Simulation Experiments
  - Assessment of new (simulated) observing systems

- Advantages
  - Only “truly objective” way of assessing the potential impact of new (potential) observing system
  - Assessment done with actual operational data assimilation/NWP systems

- Disadvantages
  - Costly to set up; EVERYTHING (including the atmospheric state and all other observations) must be simulated
    - Important to avoid conflict of interest
    - Somewhat tuneable
    - Difficult to project the state of the art of NWP and data assimilation - and the rest of the Global Observing System - several years ahead

3. WMO Impact Workshops

Five Workshops held so far:

- 1st - Geneva, 1997
- 2nd – Toulouse, 2000
- 3rd – Alpbach, 2004
- 4th – Geneva, 2008
  - Workshop Report available on
  http://www.wmo.int/pages/prog/www/OSY/Reports/NWP-4_Geneva2008_index.html
- 5th – Sedona (AZ, USA), May 22-25 2012
  -Workshop Report and all presentations available on
  http://www.wmo.int/pages/prog/www/OSY/Reports/NWP-5_Sedona2012.html

Workshops aim to bring together major NWP centers and representatives from the research community to discuss the contribution to forecast skill of various elements of the global observing system; guidance to participants provided well in advance of Workshop itself.

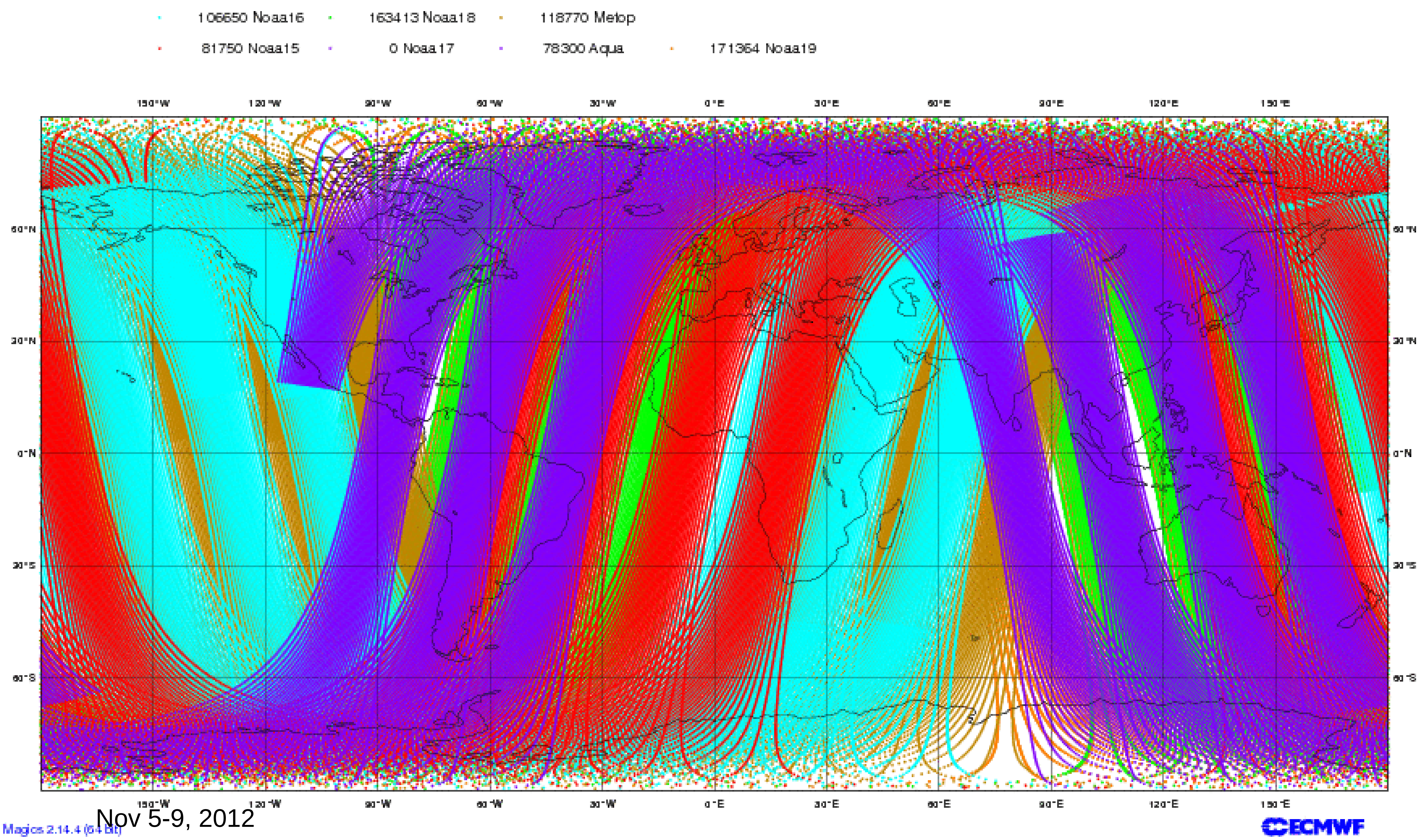
Sedona in brief

- The largest WMO Impact Workshop so far:
  - 3½ days
  - 59 participants from 13 countries
  - 40 presentations distributed in three sessions
- Ample discussion time during and after the sessions
- Very broad attendance from NWP community
- Space agencies and other observing system managers also represented
  - They are keenly aware of the power of NWP diagnostics as aids for decision making
  - Some trepidation among core participants about potential impact of results

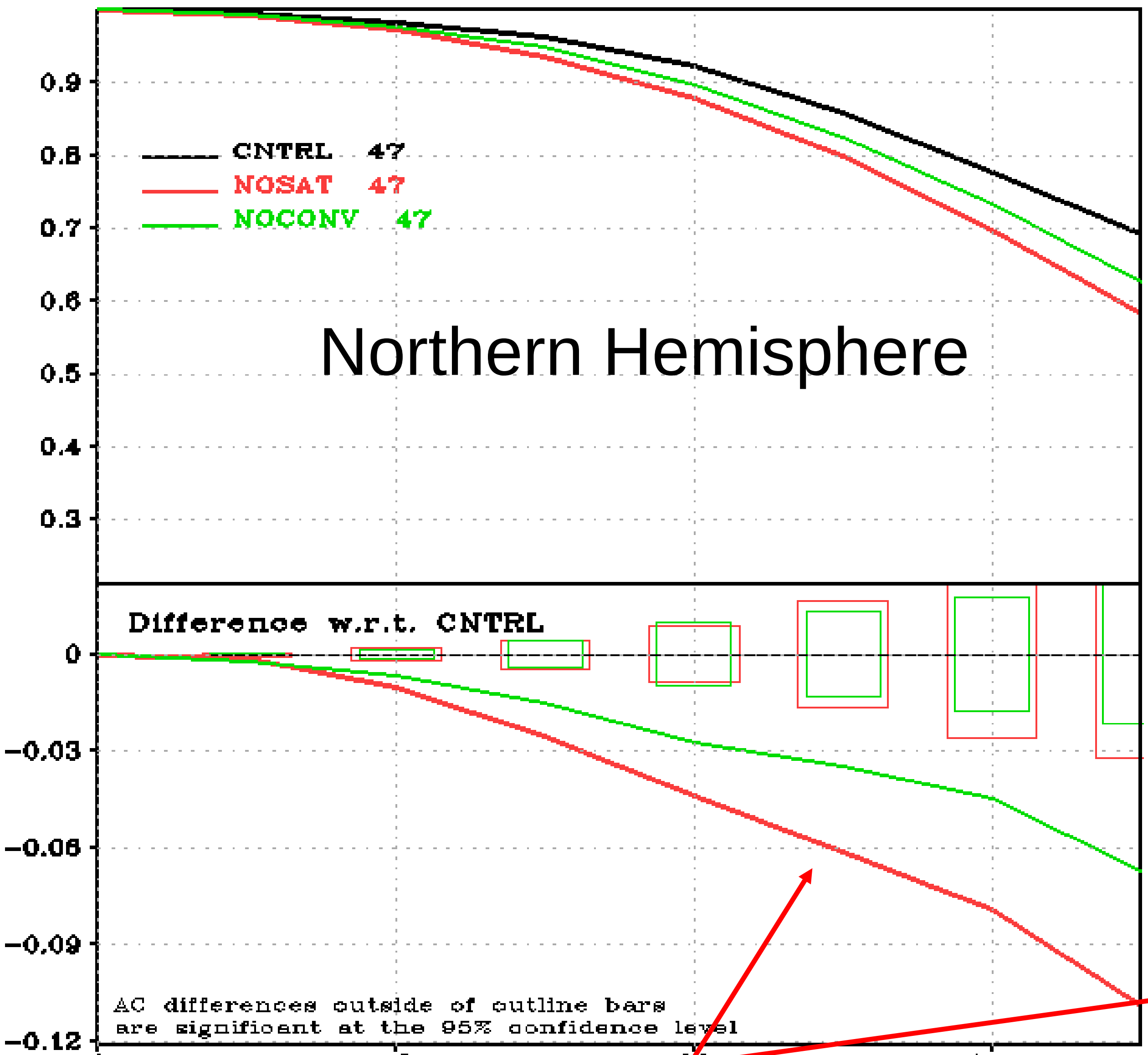
4. Sample Results from Fifth WMO Impact Workshop in Sedona, May 2012

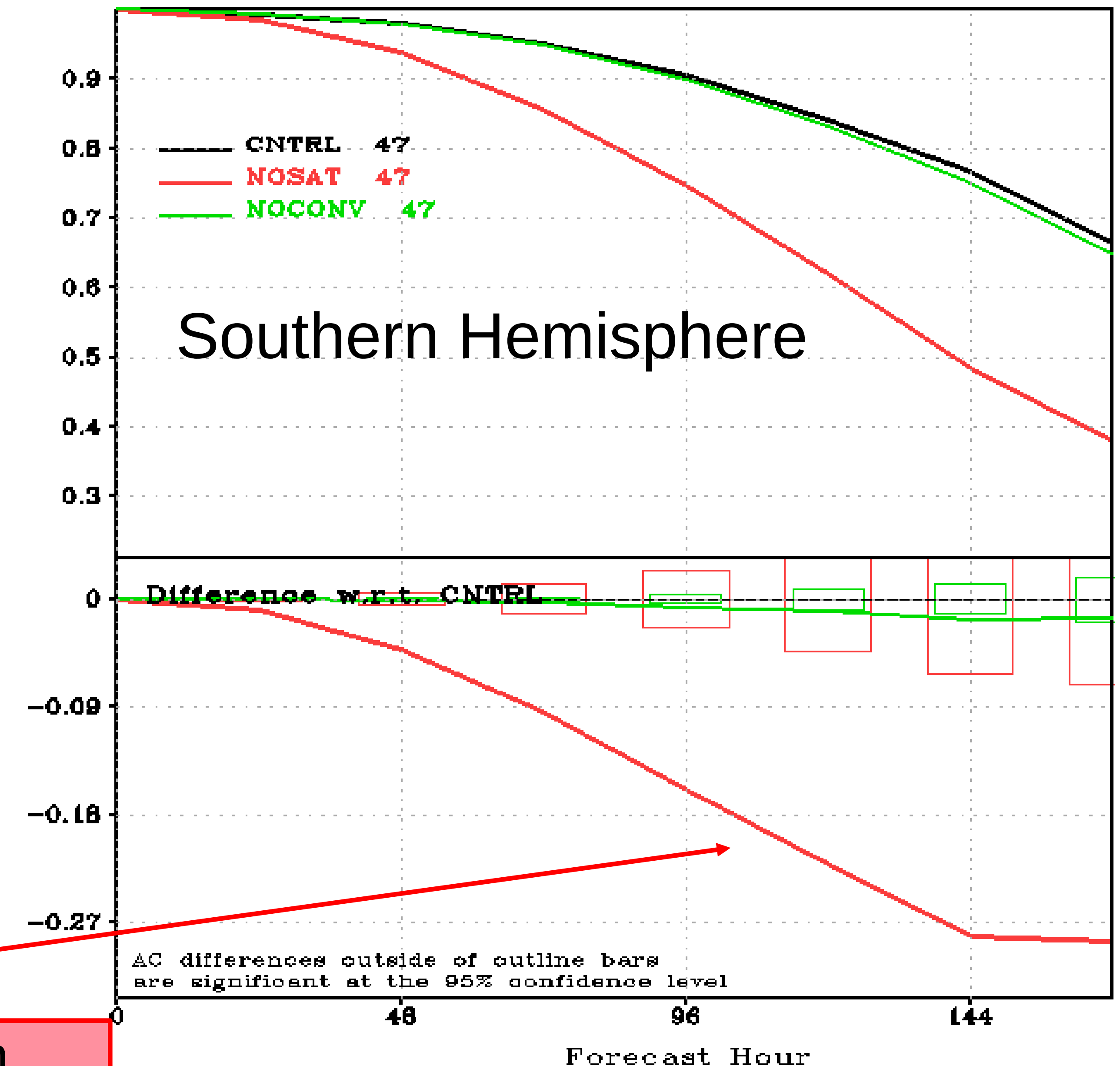
- Satellite data are important
- Conventional observations are re-emerging, especially RAOBs and aircraft observations (AMDAR)
- Wind observations of all kinds show a strong impact

ECMWF Data Coverage (All obs DA) - AMSU-A
25/Jul/2012; 06 UTC
Total number of obs = 720247



No Satellite / No Conventional Data
(JCSDA w/ NCEP GFS)

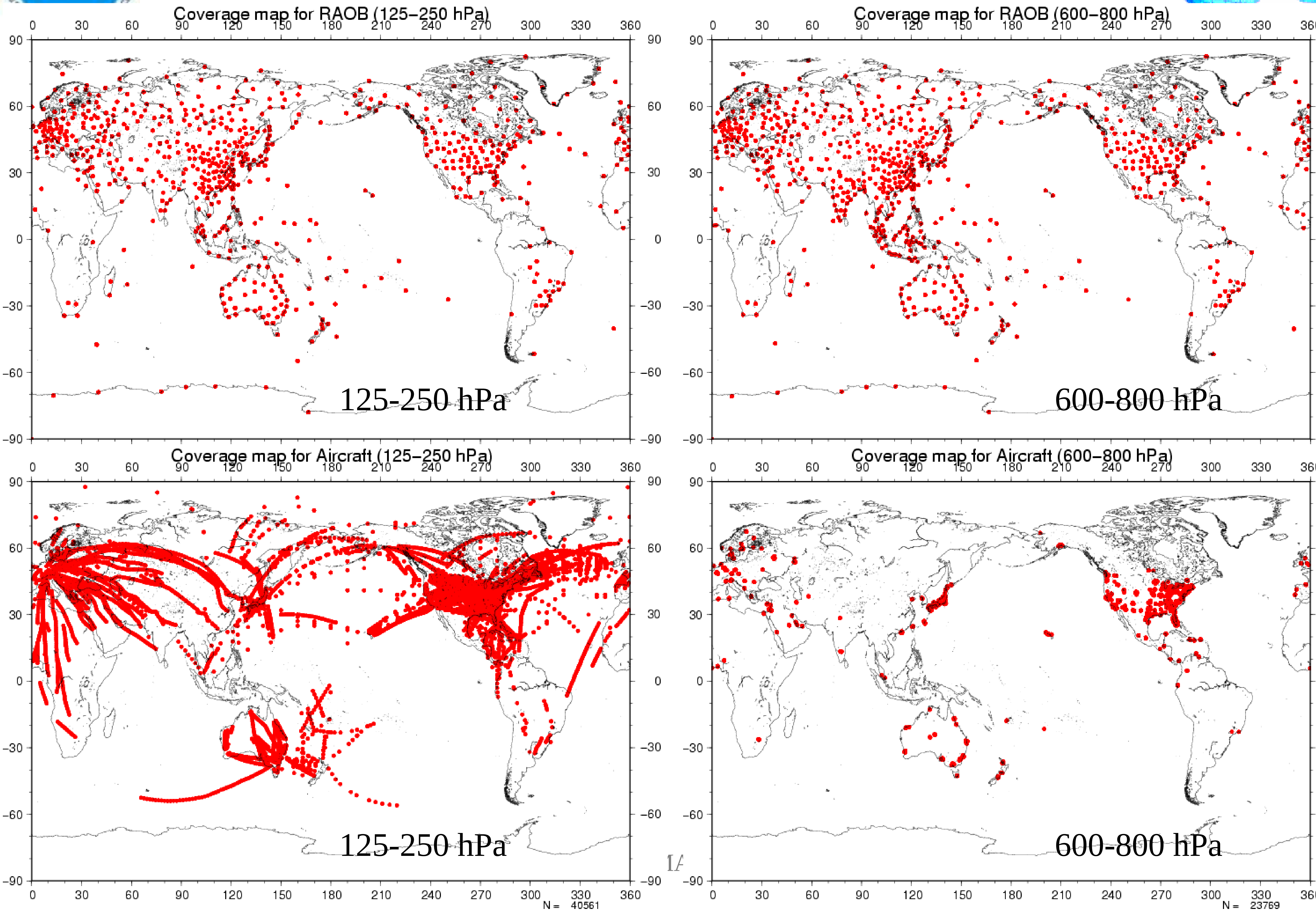




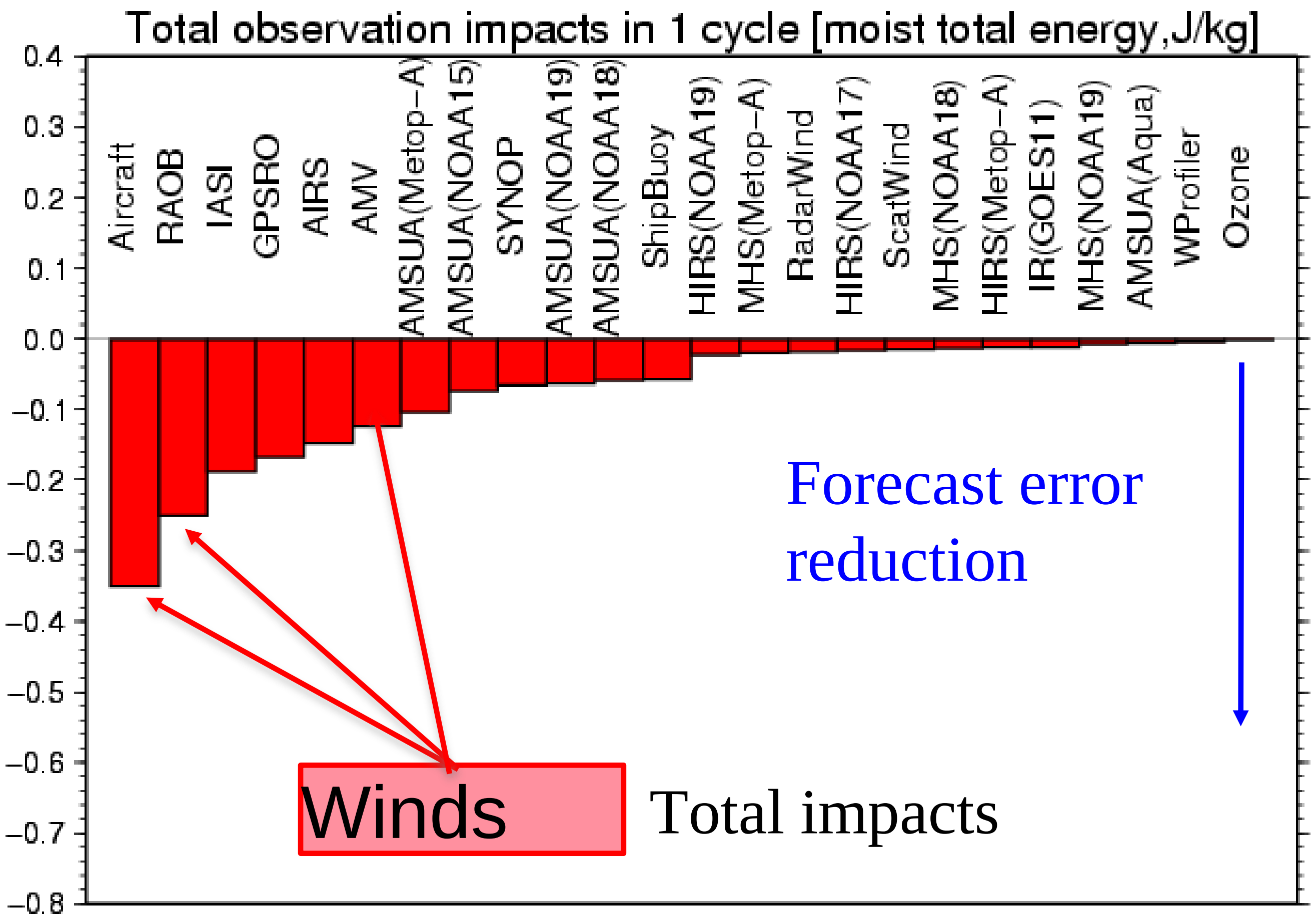
Strong impact of satellite data overall in both hemispheres

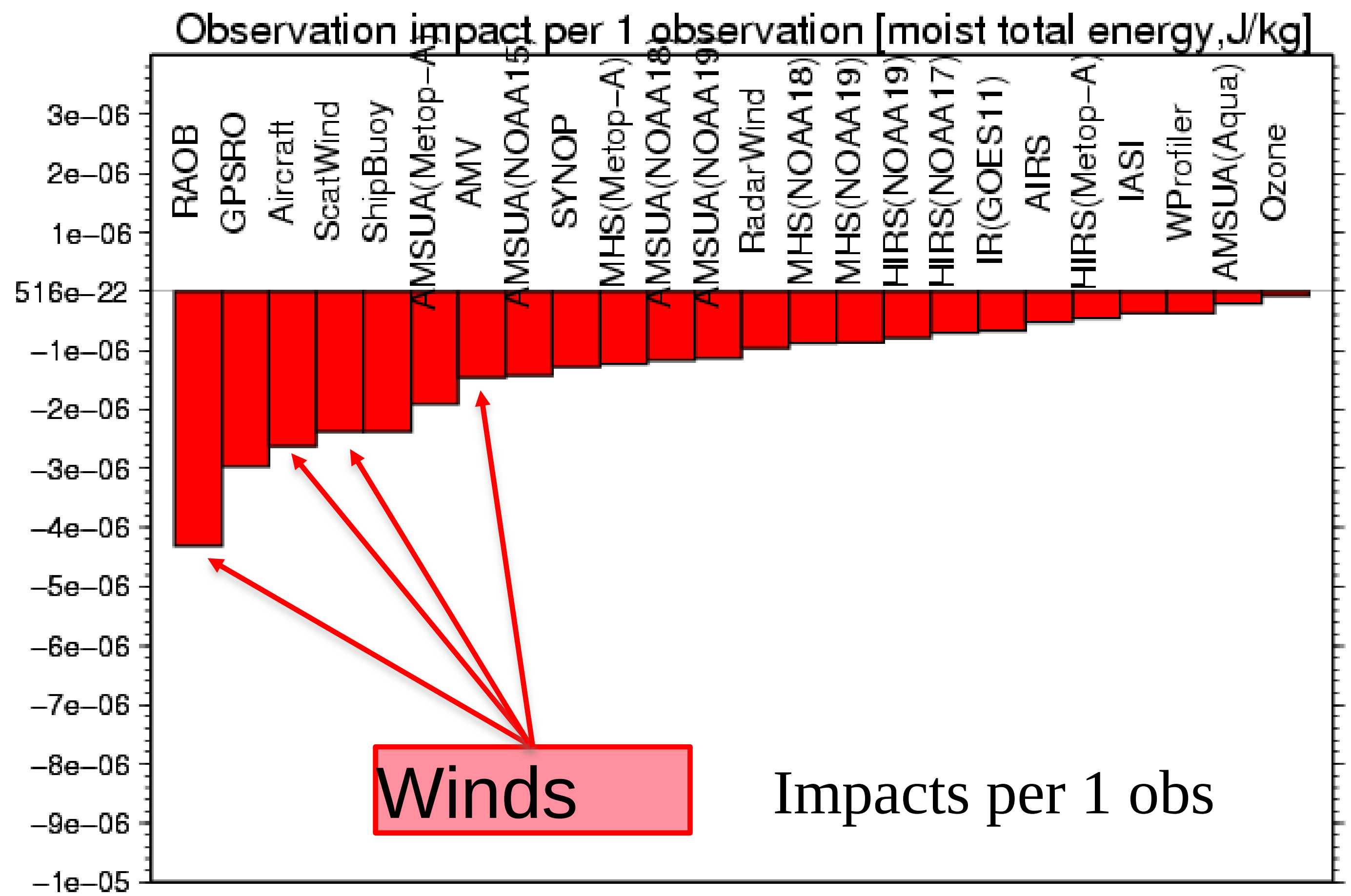
th WMO Impact Workshop, Sedona 2012

Radiosonde and aircraft



Impact summary

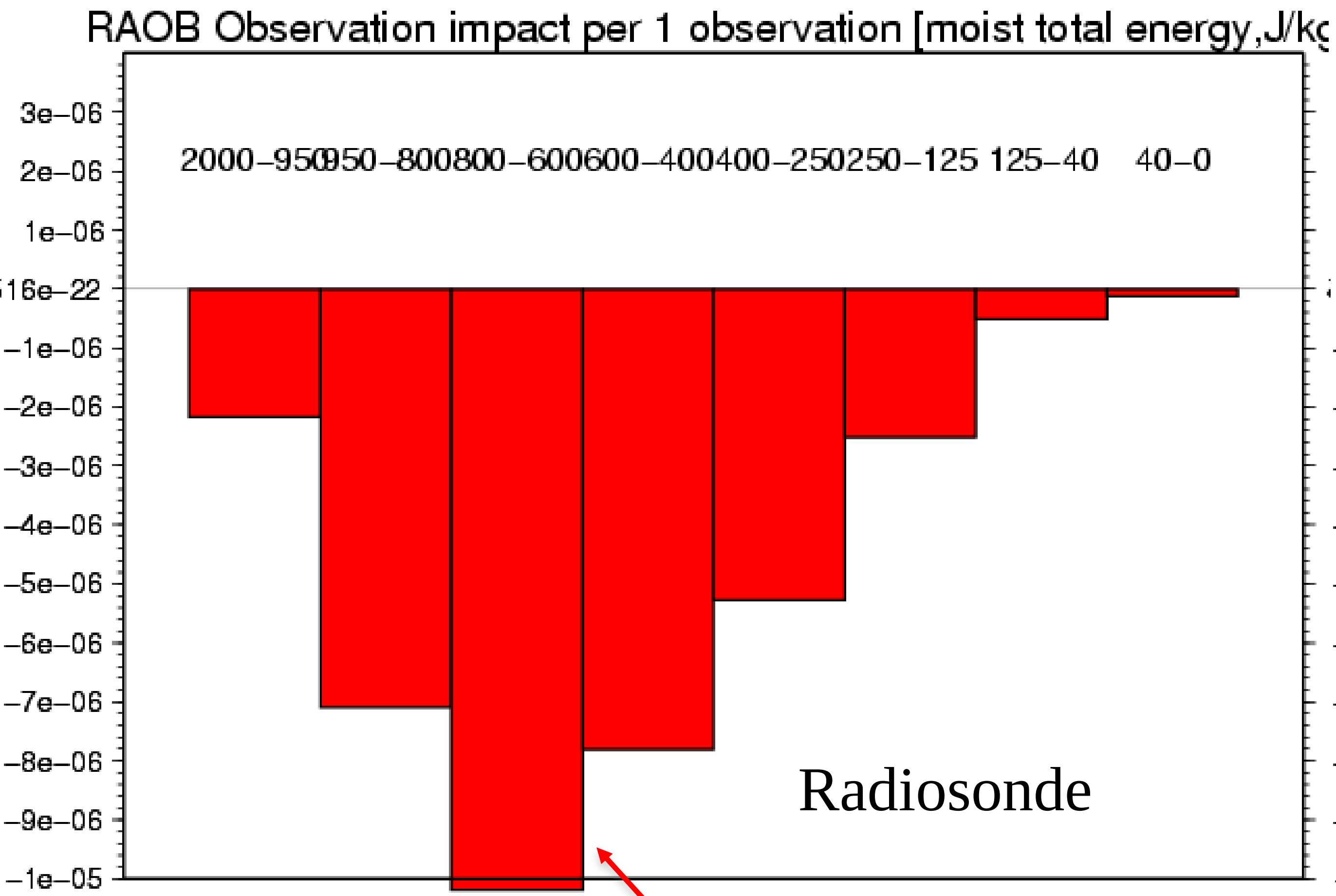


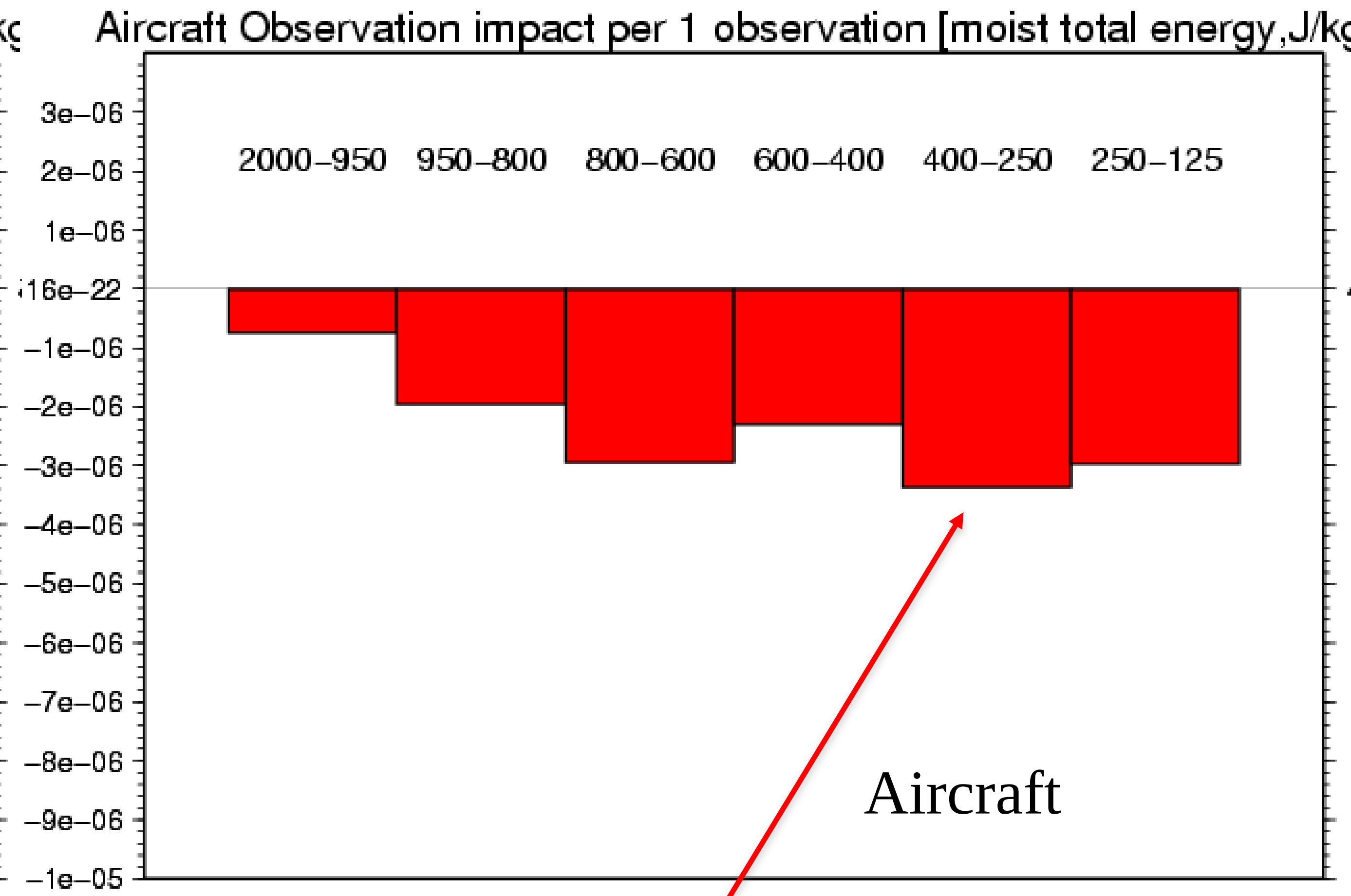


All observation types have positive impacts on average.
For the total impact, 1: aircraft, 2: AMSU-A, 3: radiosonde, 4: IASI, 5: GPSRO
For impact per 1 obs., 1: radiosonde, 2: GPSRO, 3: aircraft, 4: Scatterometer wind, 5: marine surface observation

Ensemble-based FSO diagnostics, NCEP GFS, Ota et al., WMO, Sedona, May 2012

Radiosonde and aircraft



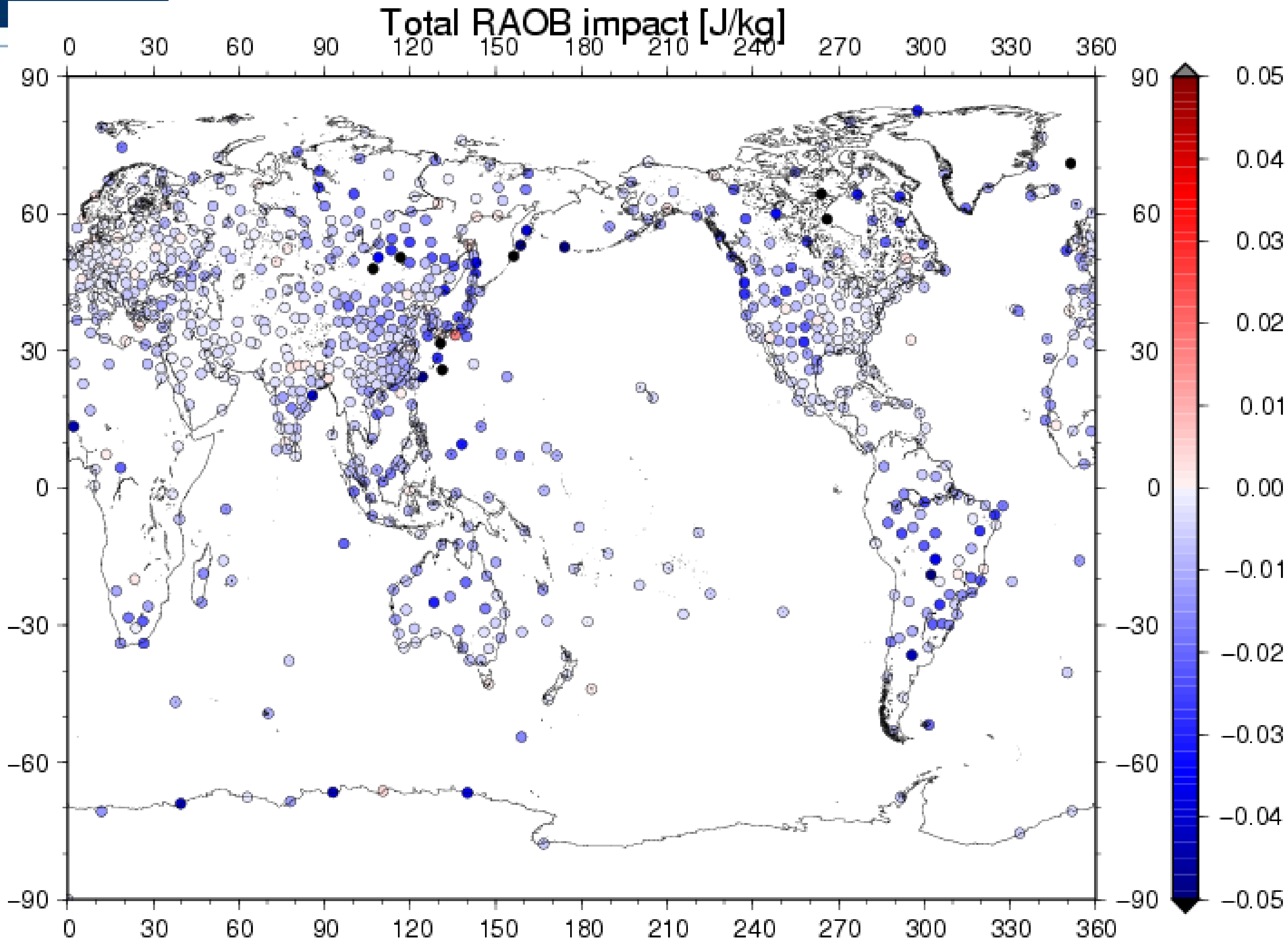


Radiosonde observations on mid- to lower tropospher
aircraft observations.

Aircraft: Upper troposphere; this is where we have data!

RAOBs: Mid- to lower troposphere; as expected based on sensitive structures

Radiosonde impacts



Total impacts of radiosonde (12UTC October 21 to 06UTC October 28)

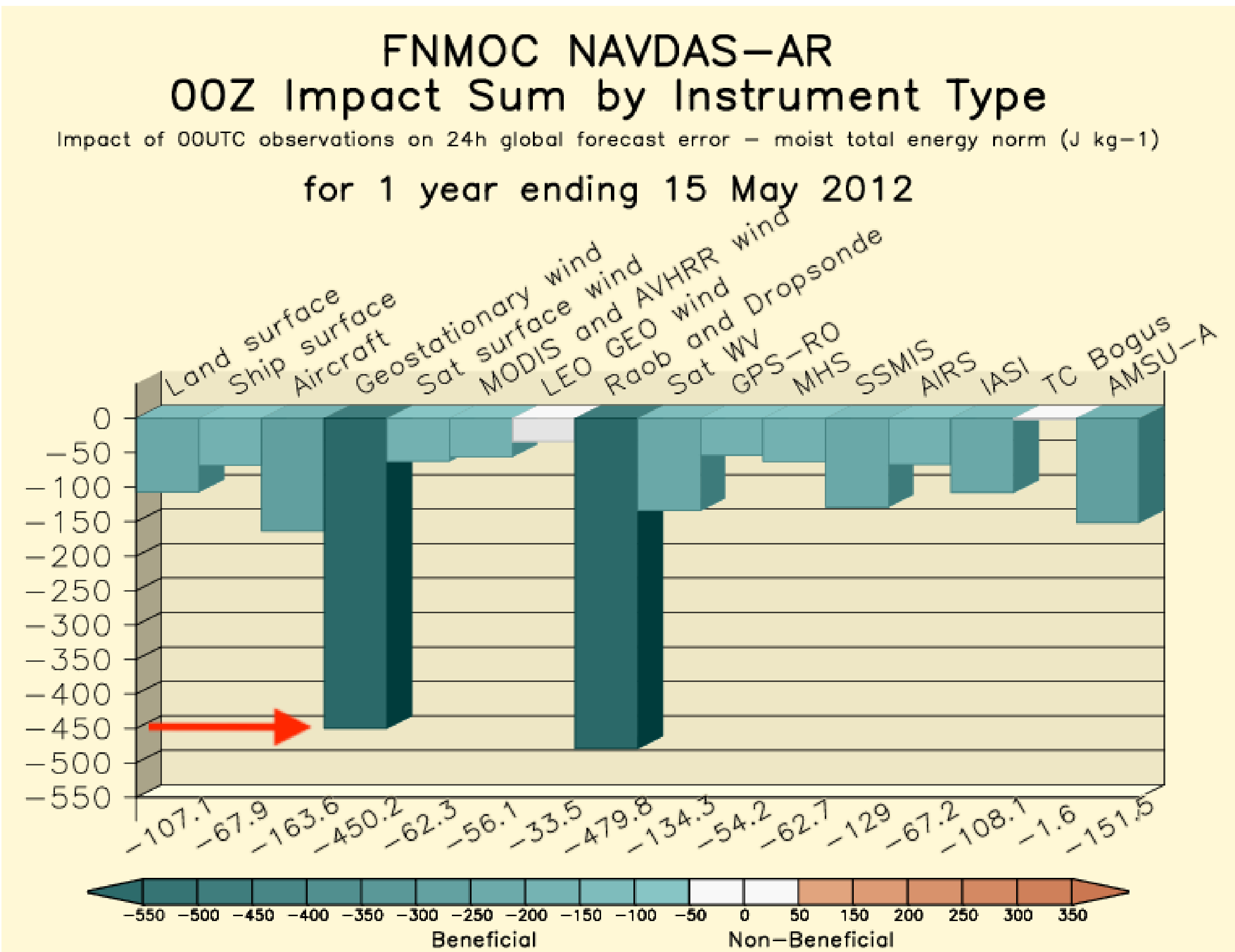
Most observations have positive impacts on average

Relatively large impacts for East Asia, Western US, Canada, and South America.

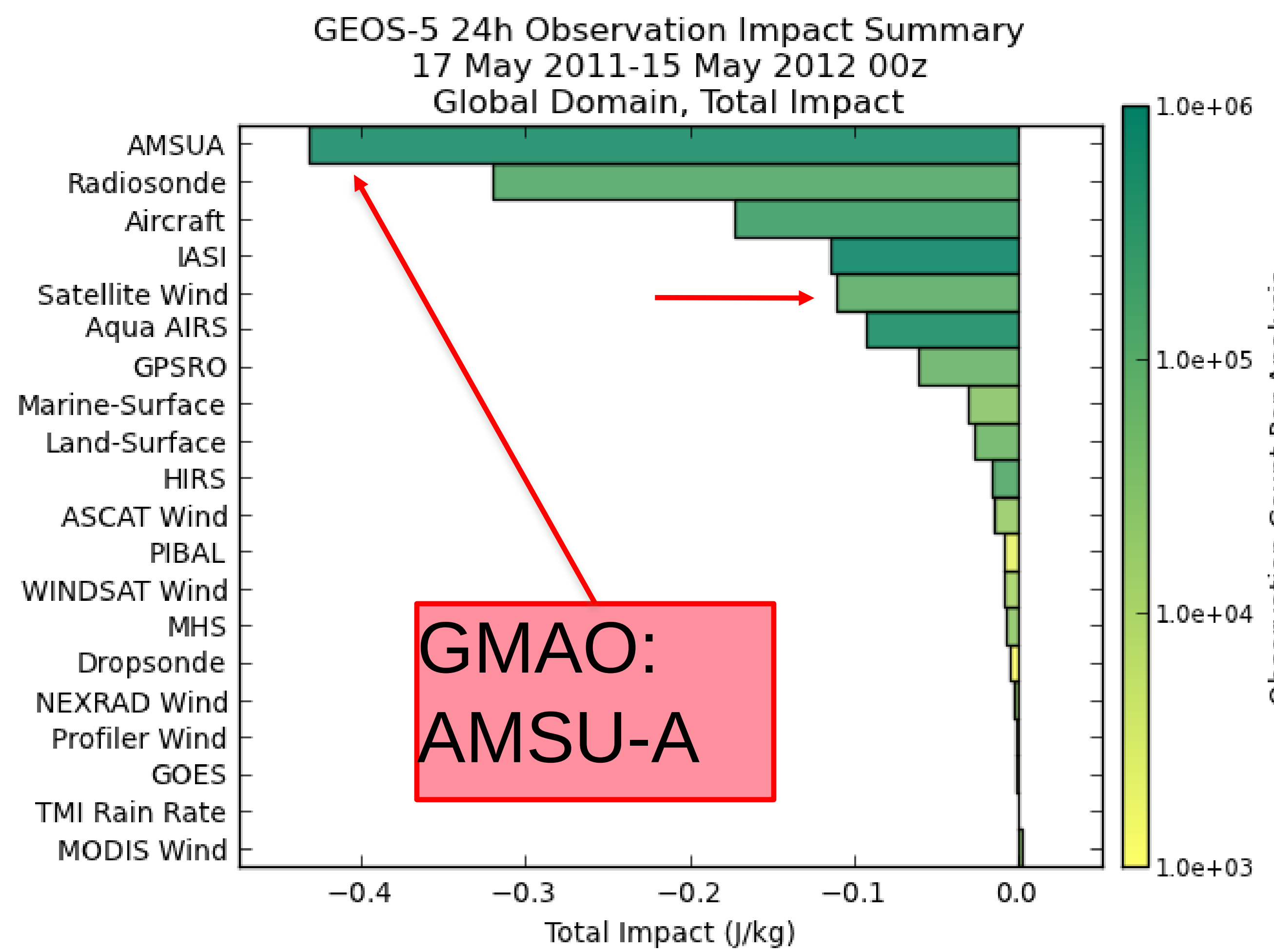
FNMOC and GMAO Observation Impact Monitoring

Current Operations

Gelaro et al. , Sedona May 2012



http://www.nrlmry.navy.mil/obsens/fnmoc/obsens_main_od.html



http://gmao.gsfc.nasa.gov/products/forecasts/systems/fp/obs_impact/

→ much larger relative impact of AMVs in Navy system

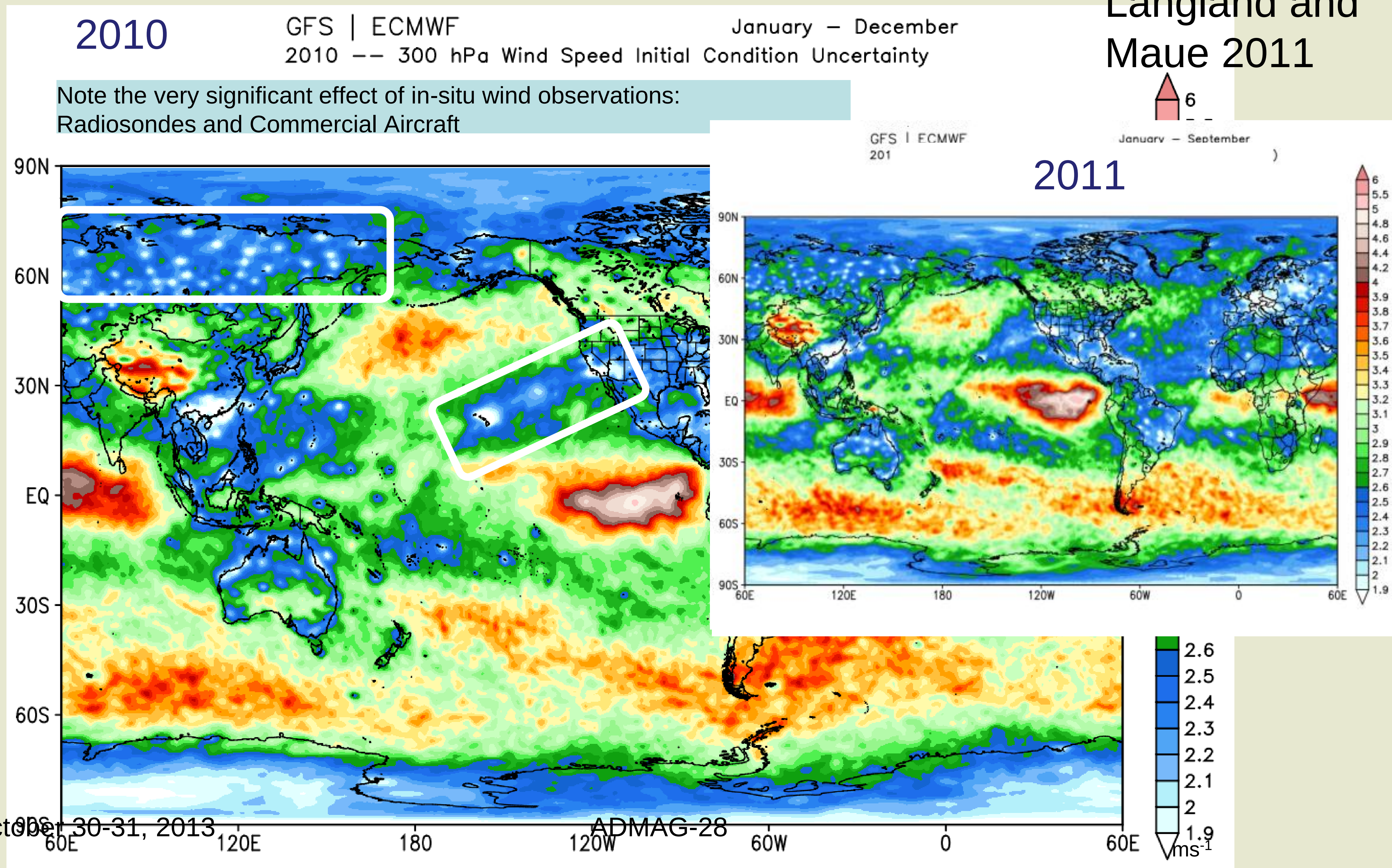
300mb Wind Speed (2010) GFS / ECMWF

Langland, Sedona 2012

Root-Mean Square of Analysis Differences: 300mb Wind Speed

Langland and Maue 2011

Note the very significant effect of in-situ wind observations:
Radiosondes and Commercial Aircraft



Observation impact in global NWP

(slide shown by Erik Andersson, Workshop Chair, at EMS, September 2012)

- **The highest ranked contributors for the forecast error reductions are:**
  - **AMSU-A, AIRS/IASI, radiosonde, aircraft, AMVs**
  - **GPS-RO also has substantial impact, but the data volume is declining approaching the end of COSMIC lifetime.**
- **Several satellite sensors contribute to forecast skill. There is not a single, dominating one**
  - **More complementarity is seen, c… previous years.**
  - **The GOS has become more resilient, but this resilience is threatened by expected decline of the operational polar orbiting satellites**
  - **When one observation type is missing or removed the contribution of other systems tend to increase without fully compensating**

These are (or include) wind measurements!

Workshop Recommendations

(slide shown by Erik Andersson, Workshop Chair, at EMS, September 2012)

- **Augment the profiling network e.g. by extending coverage of ascending and descending aircraft observations to regional airports**
- **There is a need to invest in enhanced wind observations in the tropics and over the oceans especially.**
- **Study observation impact that is more closely related to high-impact weather (including TCs) and service delivery to customers and forecast users**
- **Encouraged studies of impact per observing system or per observation linked to their cost**
- **Define appropriate impact metrics for**
  - **humidity and**
  - **regional NWP including precipitation and other surface weather elements**

5. Sample OSSE Results

- JCSDA has conducted a series of OSSEs to study the impact of potential configurations of a space-borne wind liar mission on the forecast skill of NCEP's Global Forecast System
- Standard OSSE set-up using ECMWF-provided Nature Run, complete simulated Global Observing System, including candidate Doppler Wind Lidar observations
- Perturbation experiment in which DWL observations were withheld from the assimilation

Types of simulated observations included in JCSDA OSSE

Set A (2005-6 period)

AIRS (Aqua),
AMSU-A (Aqua, NOAA-15, 16, 18),
AMSU-B (NOAA-15, 16, 17),
HIRS2 (NOAA 14),
HIRS-3 (NOAA 15, 16, 17),
HIRS-4 (NOAA-18),
MSU (NOAA-14),
MHS (NOAA-18)
GOES sounder (GOES-10, 12)

All conventional data available in 2005-2006

Set B (2011-12 period)

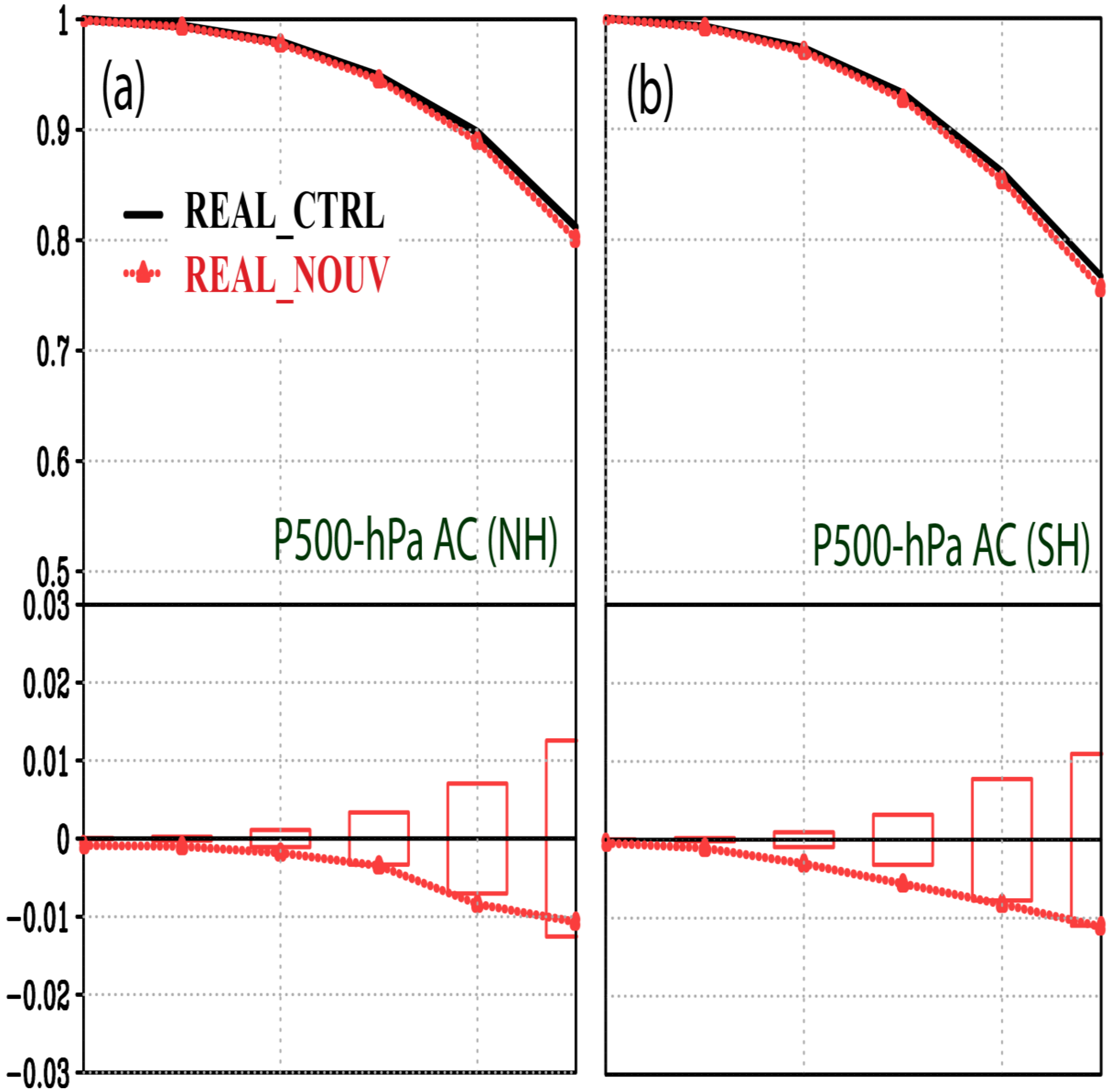
IASI(METOP-A), AIRS(AQUA),
ATMS(NPP), CrIS(NPP)
HIRS-2(NOAA14),
HIRS-3(NOAA 15, 16,17),
HIRS-4(NOAA 18, 19, METOP-A),
AMSUA(NOAA 15, 16, 17,18,19, AQUA, METOP-A),
AMSUB(NOAA 15, 16, 17),
MSU(NOAA 14), HSB(AQUA),
MHS(METOP-A,NOAA18,19),
SSMIS(DMSP F16), SEVIRI(MSG)
GOES sounder (10,12, and 13)
GPSRO
ASCAT
WINDSAT

All conventional data available in 2011-12

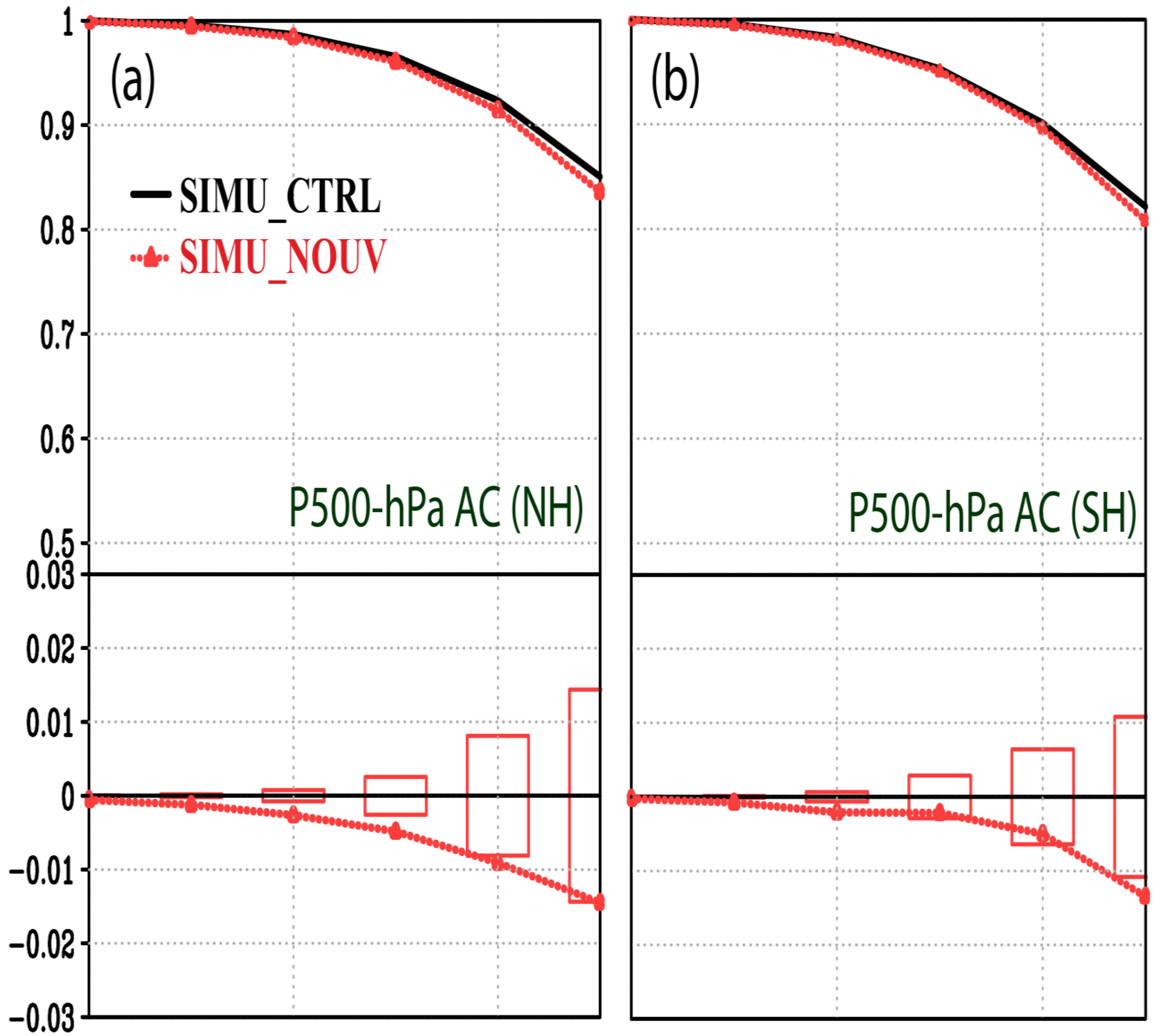
JCSDA Calibration Experiments

Compare impact of removal of RAOB wind in real and simulated experiments

REAL



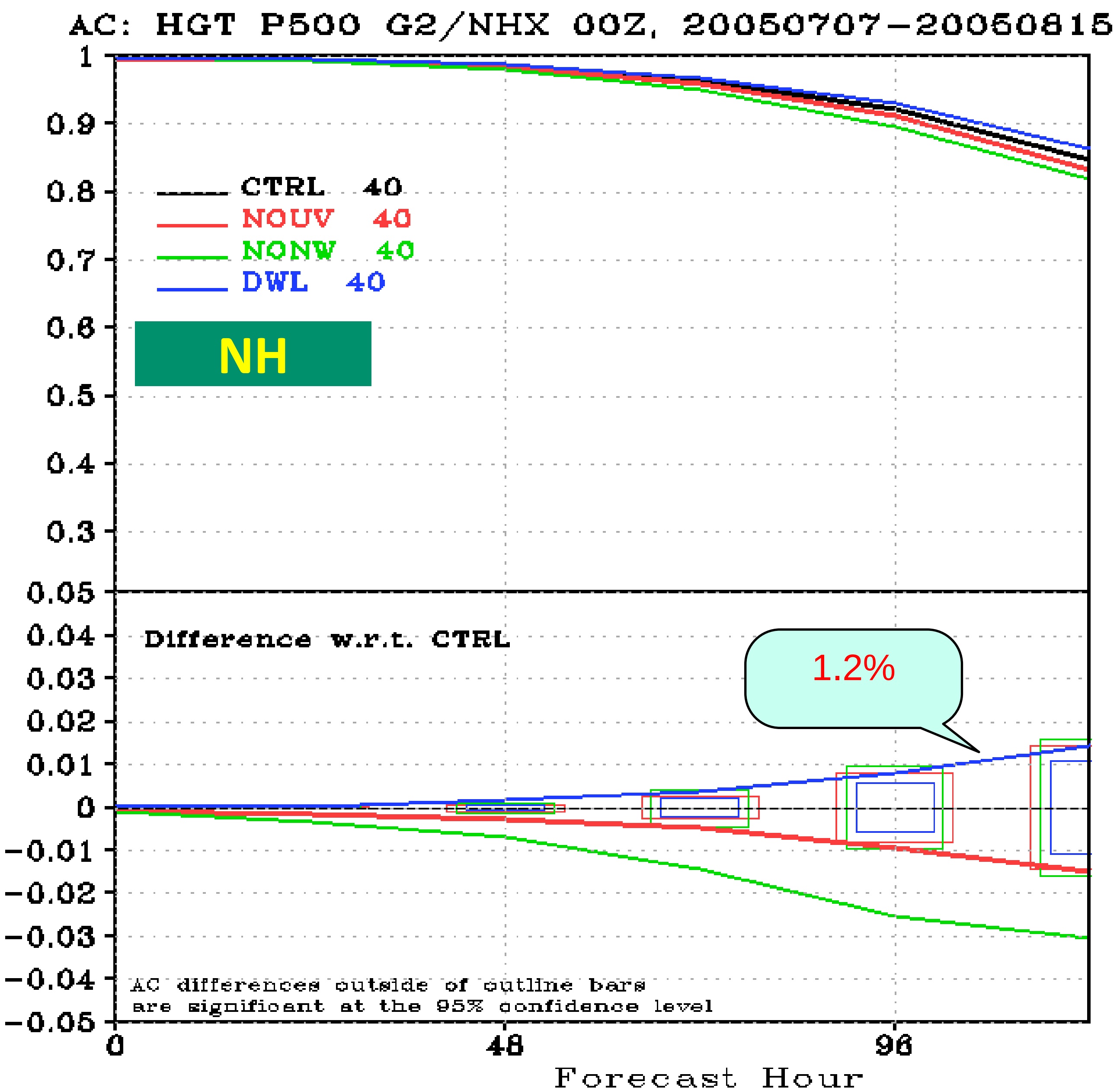
Simulated

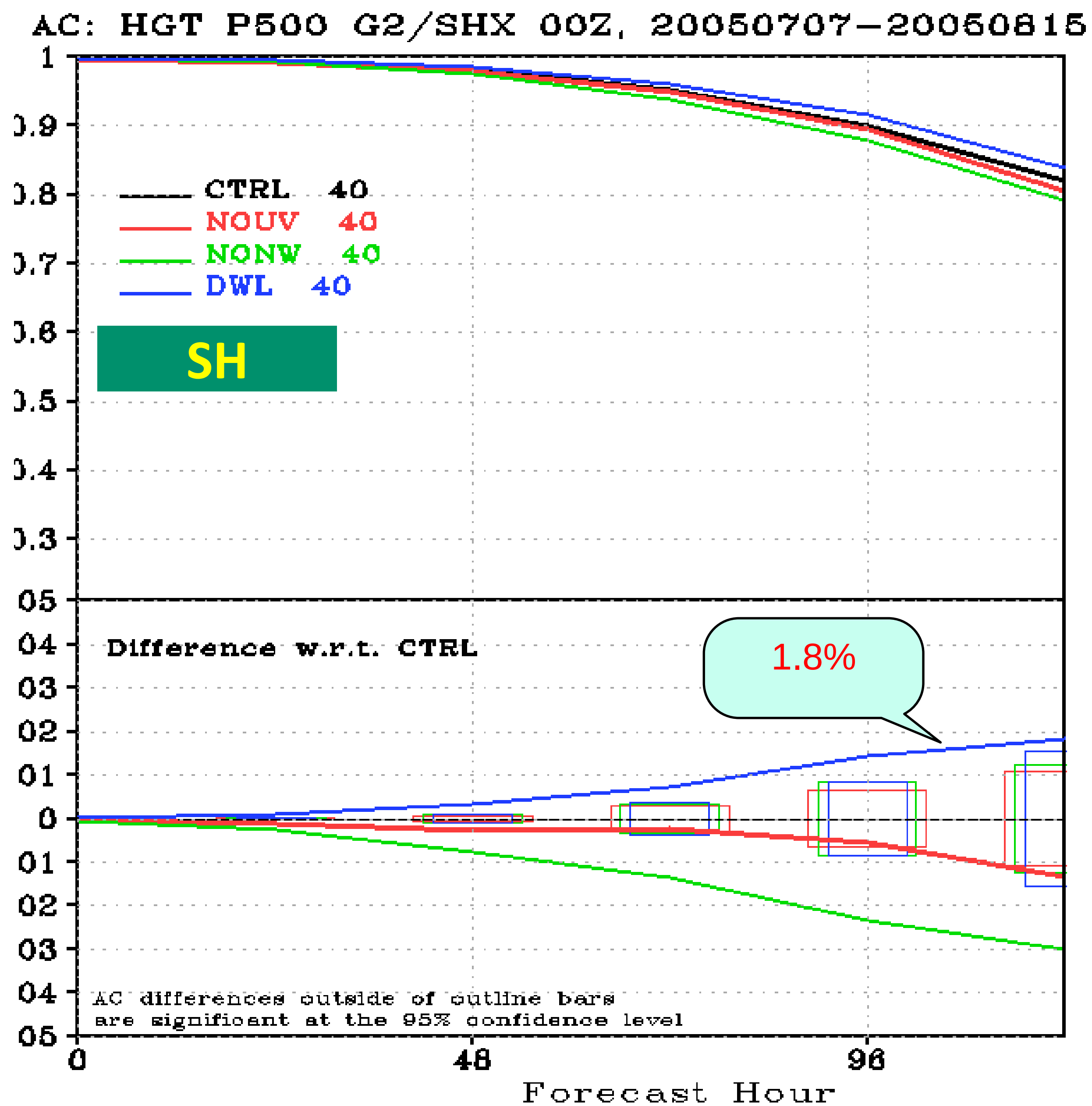


Wind Lidar OSSEs

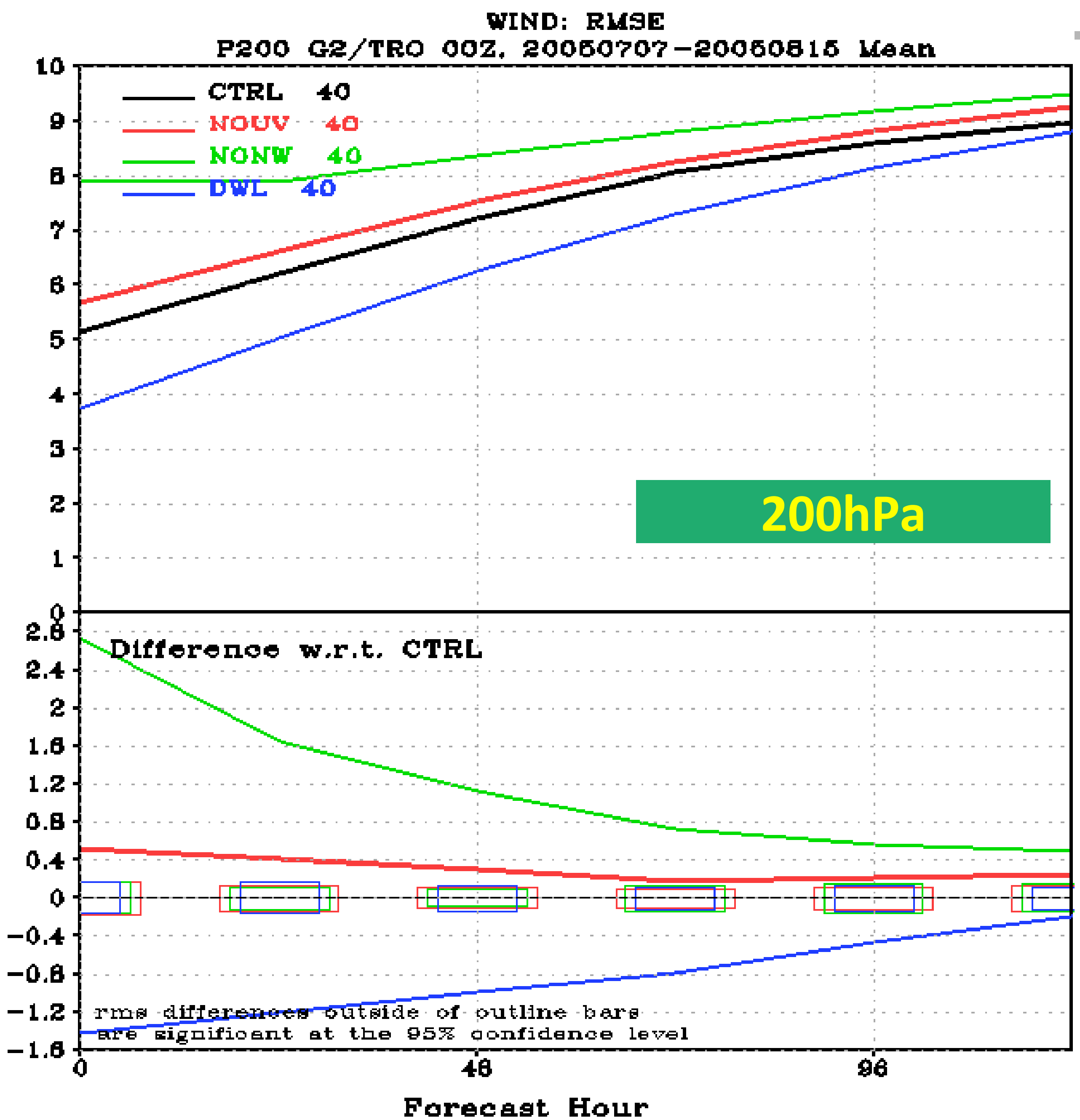
- Impact experiments for GWOS mission concept
  - NASA Tier-3 Decadal Survey mission concept
  - Four telescopes, full vector winds on either side of spacecraft
  - Two technologies, direct and coherent detection
- Experiments funded under Wind Lidar Science element of NASA's ROSES 2007 (Kakar)
- GWOS observations simulated by Simpson Weather Associates using DLSM

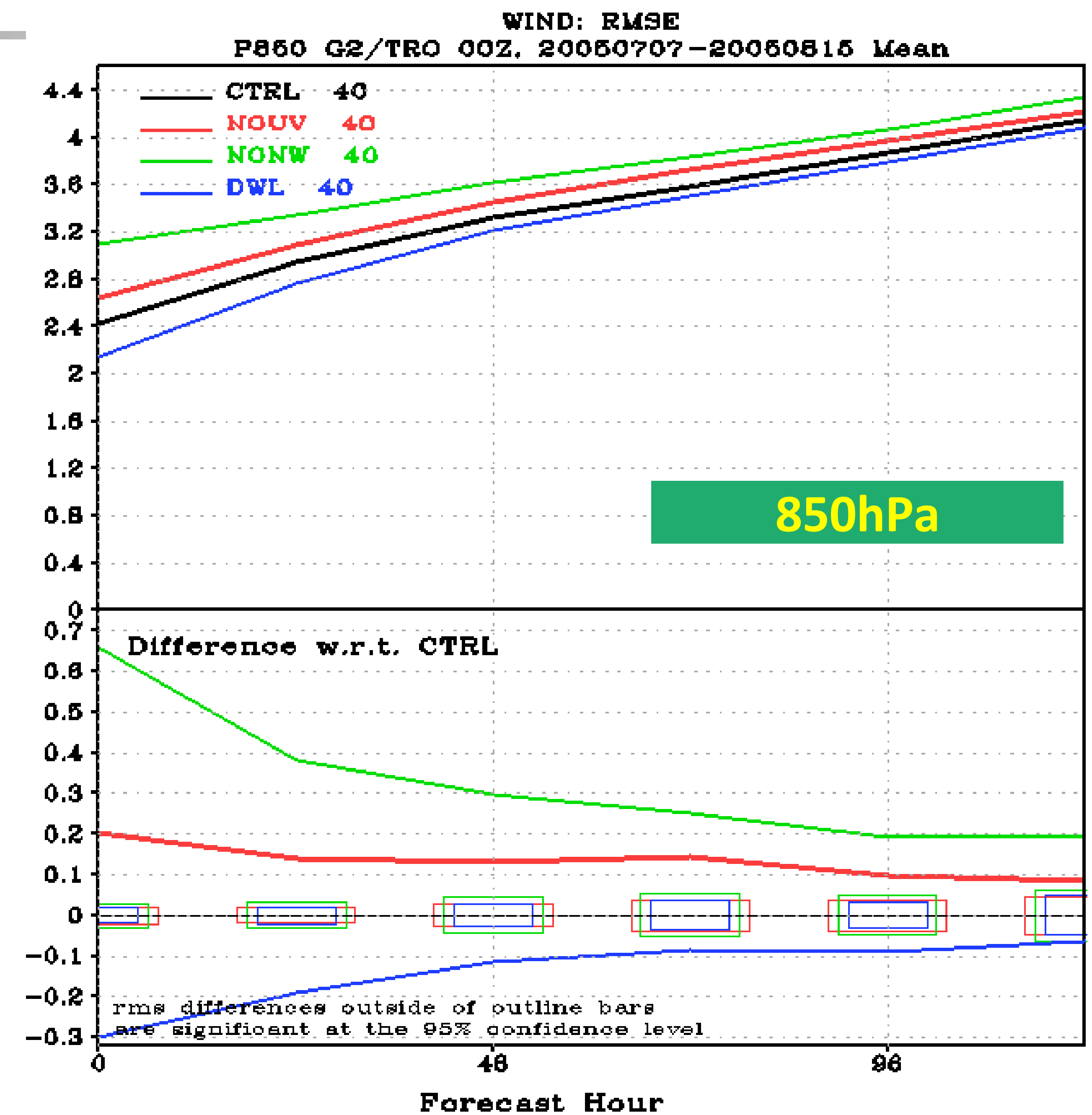
500hPa HGT anomaly correlation coefficients (T382)





RMSE: 200, 850hPa Wind error in tropics (T382)





6. General guidance regarding wind observations

- Wind observations are still very much needed
- … and not just for NWP
  - NWP is a foundational activity for most (all?) forecast application with a range beyond 6 hours
- Climate application; e.g. monitoring and understanding

- The lack of vertically resolved wind observations remains the most serious shortcoming of the WMO Global Observing System

7. Final Remarks

- The WMO Rolling Review of Requirements is a structured process for collecting, vetting and recording user requirements for all WMO application areas, and for matching them against observational capabilities (both conventional and space-based)
- Both subjective (user consultation) and objective (mostly NWP-based) methods are used for collecting user requirements
- The resulting guidance from WMO has been very consistent for more than two decades: *Global coverage of vertically resolved wind observations remains at the top of the list of*