SATELLITE DATA IMPACT STUDIES AT ECMWF

Outline of talk

- 1. Impact of early sounders (past and in reanalysis)
- 2. Problems with satellite retrievals
- 3. Direct use of radiances
- 4. Impact experiments with ERA reanalysis system
- 5. Data denial OSEs
- 6. Reference plus OSEs
- 7. Concluding remarks

1. Impact of early sounders

- **In 1973 Temperature Soundings were possible using the VTPR instrument flown on the Improved TIROS Operational Satellite series. The first satellite with VTPR was NOAA2.**

- **In 1975 the NASA environmental research satellite Nimbus 6 flew HIRS and SCAMS (later called MSU).**
-
- **In the future these two instruments were to be known as TOVS (TIROS N and NOAA6-14).**

VPTR retrievals from NOAA 2-5

This instrument measured surface temperature (11µ band)

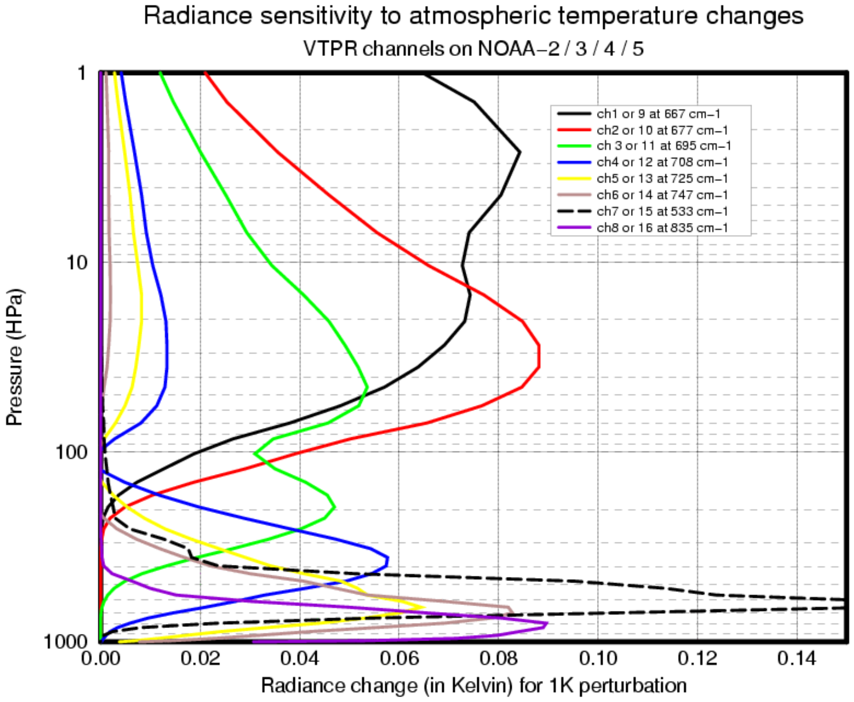
6 Channels for temperature and moisture (15µ band).

1 Channel for upper level water vapour channel (18µ band).

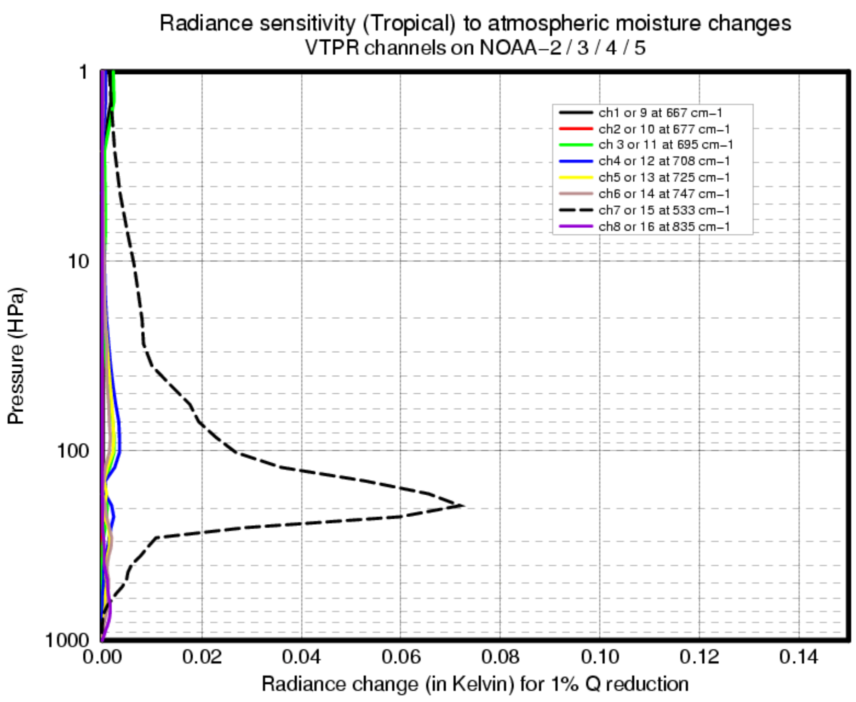
A complex regression retrieval method was developed to provide vertical profiles of temperature and moisture. The regression input was obtained from a global radiosonde/radiance match data set and a 1200 climate rocketsonde data set.

The bias correction made use of a discriminate analysis technique to relate radiance biases to synoptic patterns. (Kelly et al. 1978)

VTPR Radiance Sensitivity

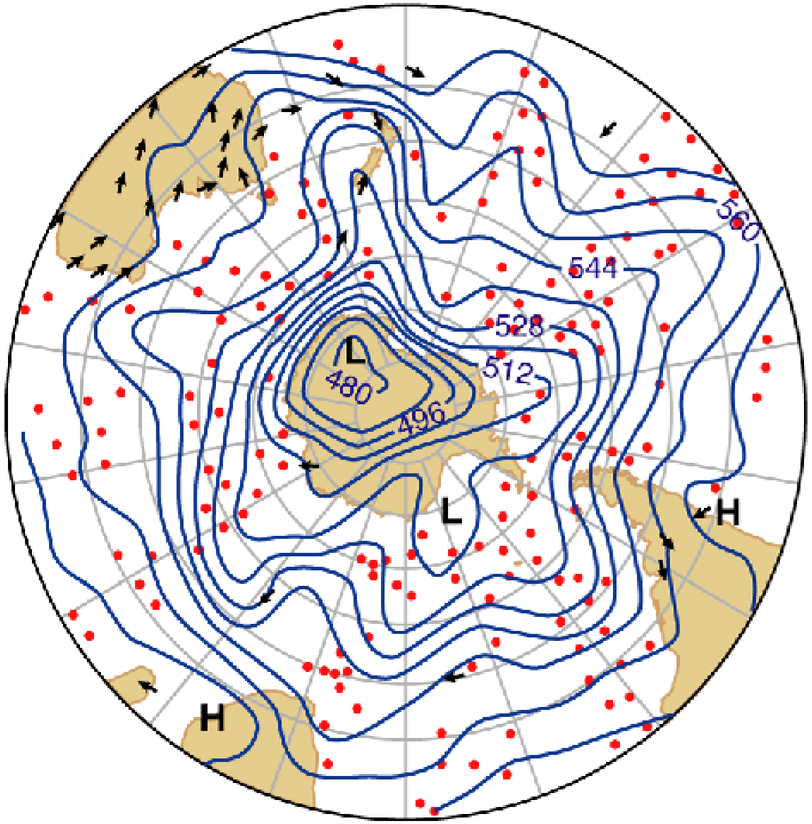


Temperature/humidity

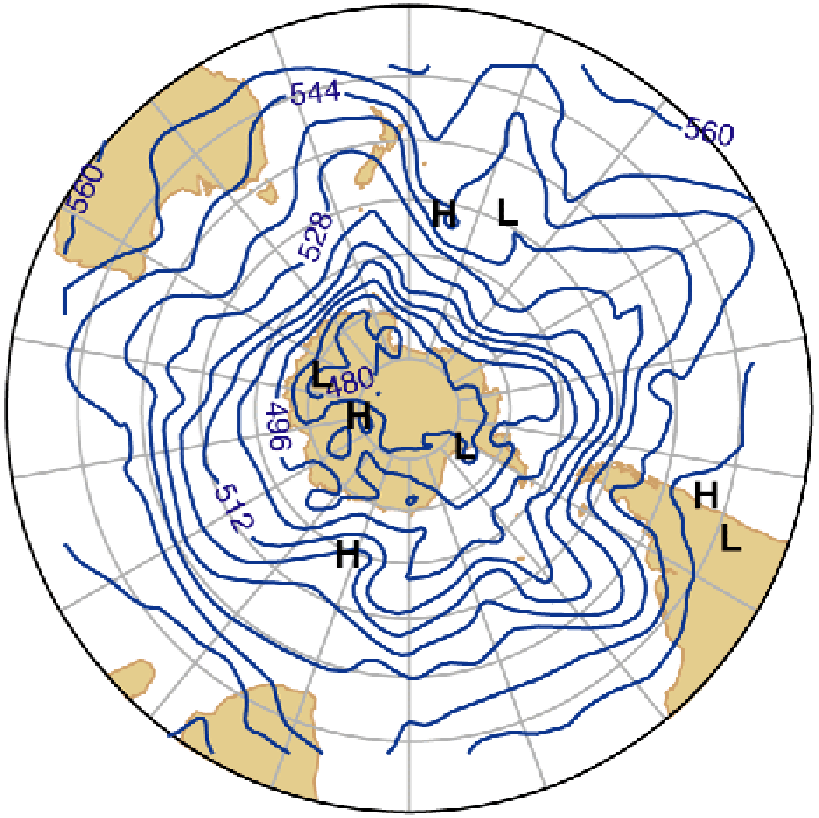


Upper level humidity

Comparison of two Southern Hemispheric analyses 17 years apart



1000 / 500 mb thickness VTPR analysis



1000 / 500 mb thickness ERA-40 analysis

It is interesting to compare the VTPR analysis, from Kelly 1976, with the same case from ERA-40 re-analysis. This ERA 40 production was completed in April 2003 using a reduced resolution of the ECMWF operational assimilation system (TL159/L60 3DVAR).

1975 the concept of the TOVS (package) began using the combination of the HIRS and SCAMS (later MSU) instruments onboard NIMBUS 6

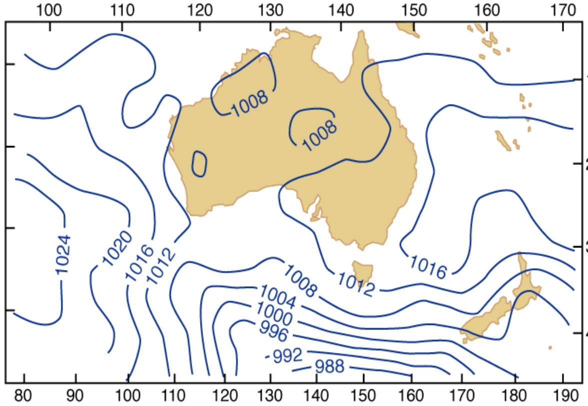
In 1977 two series of two parallel experiments were run using the BOM operational limited area data assimilation system (Kelly et all 1978).

The control used conventional data, Australian Region PAOBs (bogus from cloud imagery for surface pressure and 1000/500 thickness).

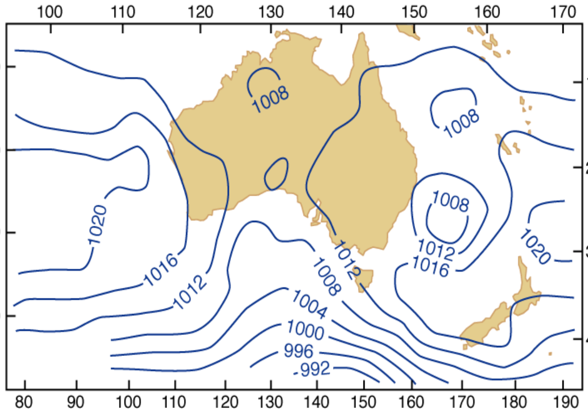
In the TOVS experiment mean layer thicknesses were obtained by eigenvector regression using radiances from both HIRS and SCAMS. (Smith et 1978)

Comparison of operational(BoM) ,NIMBUS 6(TOVS) and ERA40(VTPR) analyses and 24 HR forecasts in September 1975.

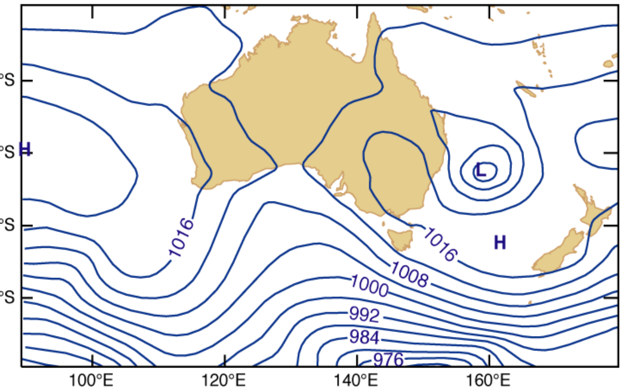
NIMBUS MSL analysis. Valid 12Z 31 August 1975



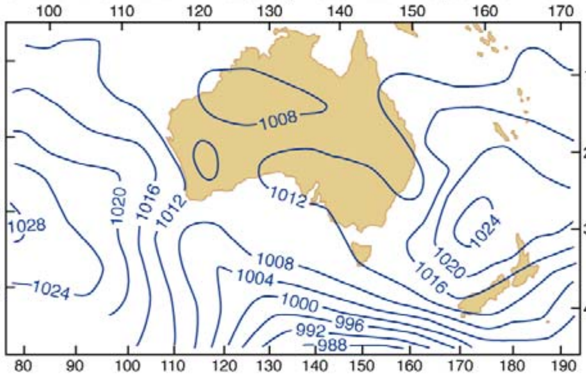
NIMBUS MSL analysis. Valid 12Z 1 September 1975



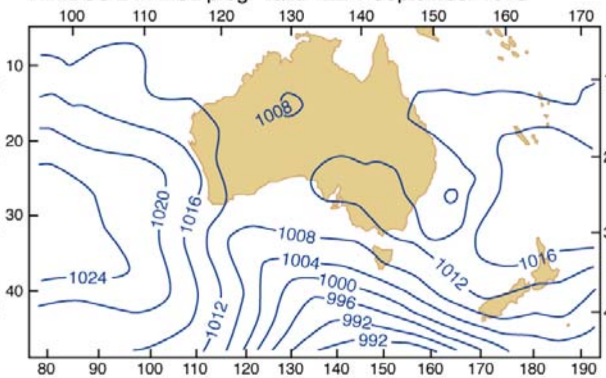
ERA-40 MSL analysis. Valid 12Z 1 September 1975



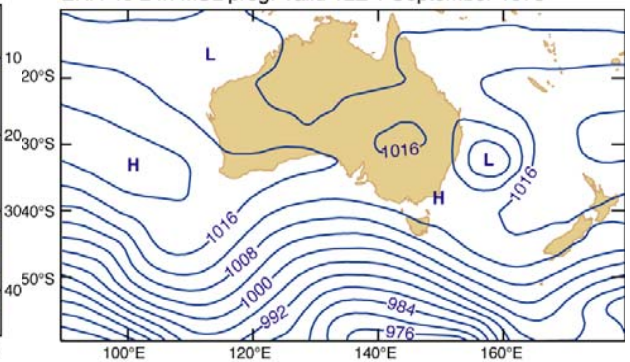
OPERATIONAL 24h MSL prog. Valid 12Z 1 September 1975



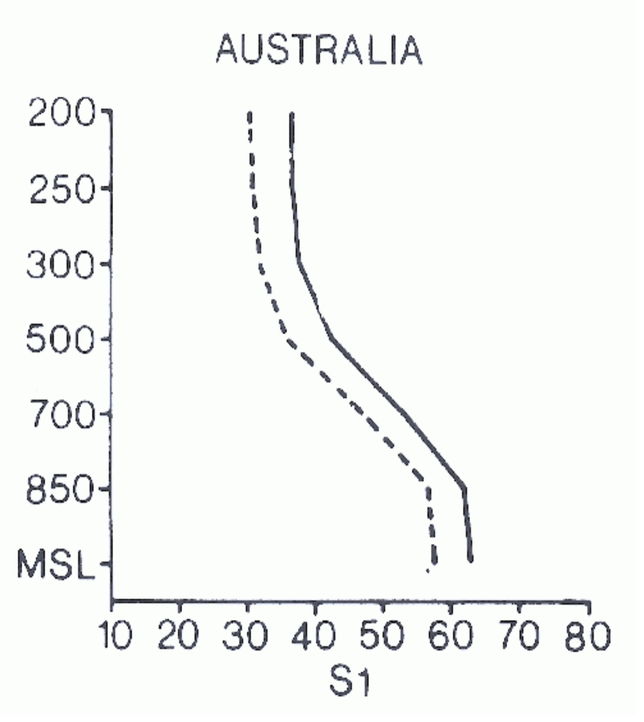
NIMBUS 24h MSL prog. Valid 12Z 1 September 1975



ERA-40 24h MSL prog. Valid 12Z 1 September 1975



S1 skill sores for Australian Region
14 cases (1 – 14 Sept 1975)
Solid operations
Dashed Nimbus 6 experiment



2. Problems with satellite retrievals

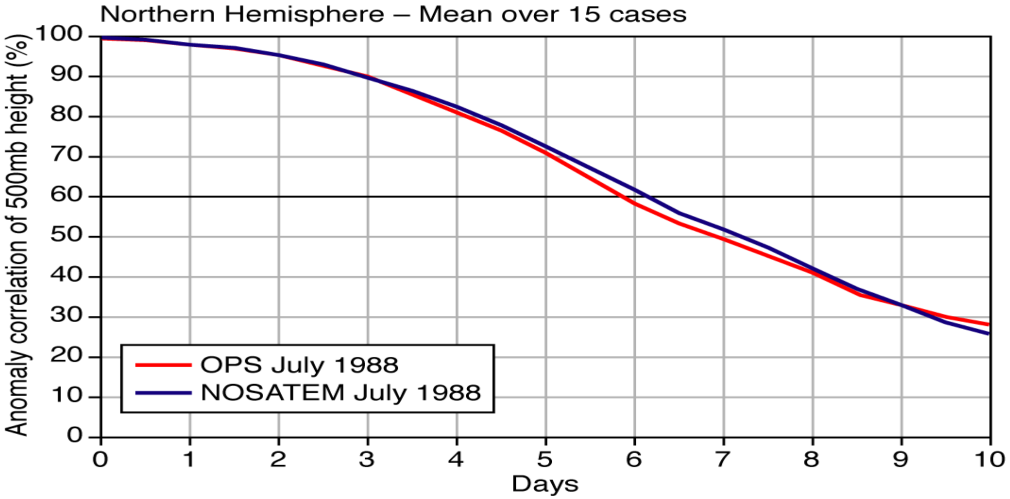
The meteorological community requested that satellite retrievals be produced to look like radiosondes with retrieved profiles of temperature and humidity produced on standard pressure levels.

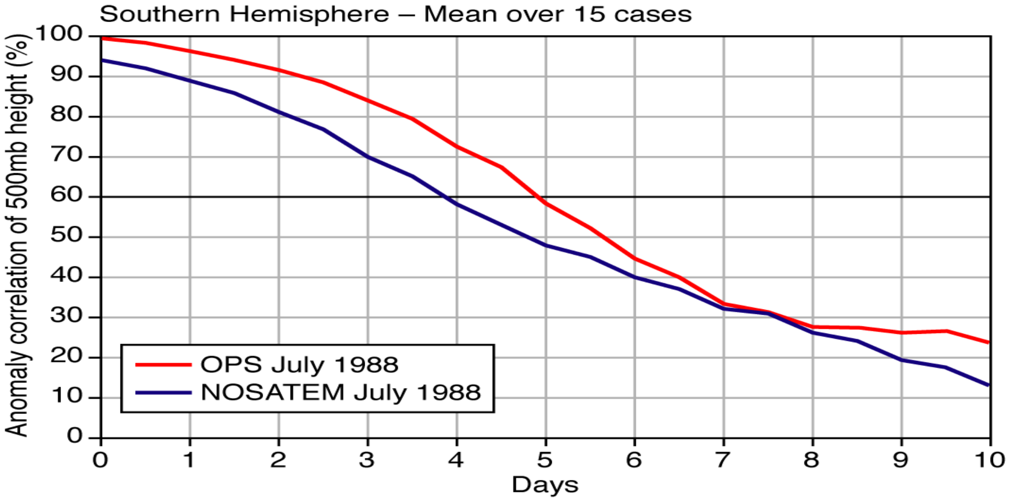
This was not a problem in early numerical analysis schemes which used a limited number of levels and simple analysis methods.

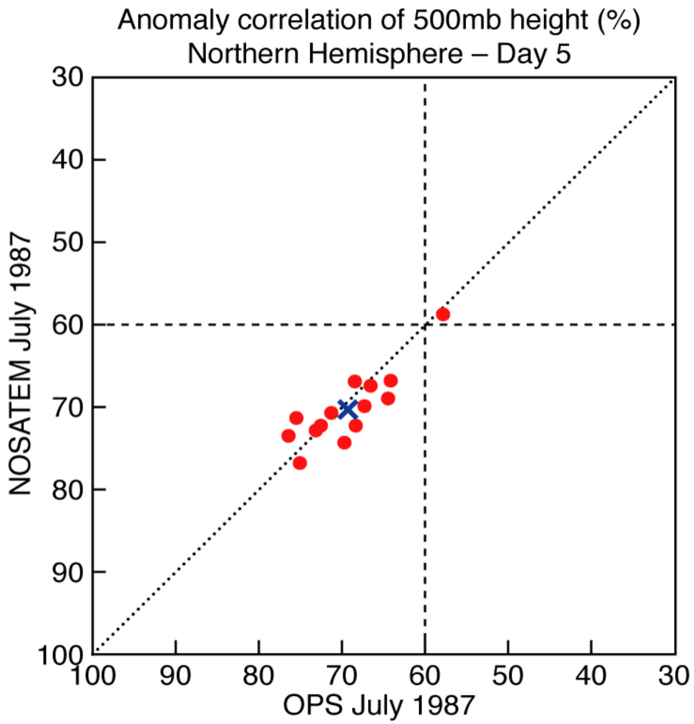
As analysis methods improved (using OI and more vertical levels) the error structure of the satellite retrieval was required.

This error structure was difficult to obtain from statistical retrievals and not easy to apply in the OI framework for computational reasons.

ECMWF TOVS impact experiments in 1987,1988 found small negative impact in the N. H.
This lead to the removal of TOVS retrievals from the N. H.

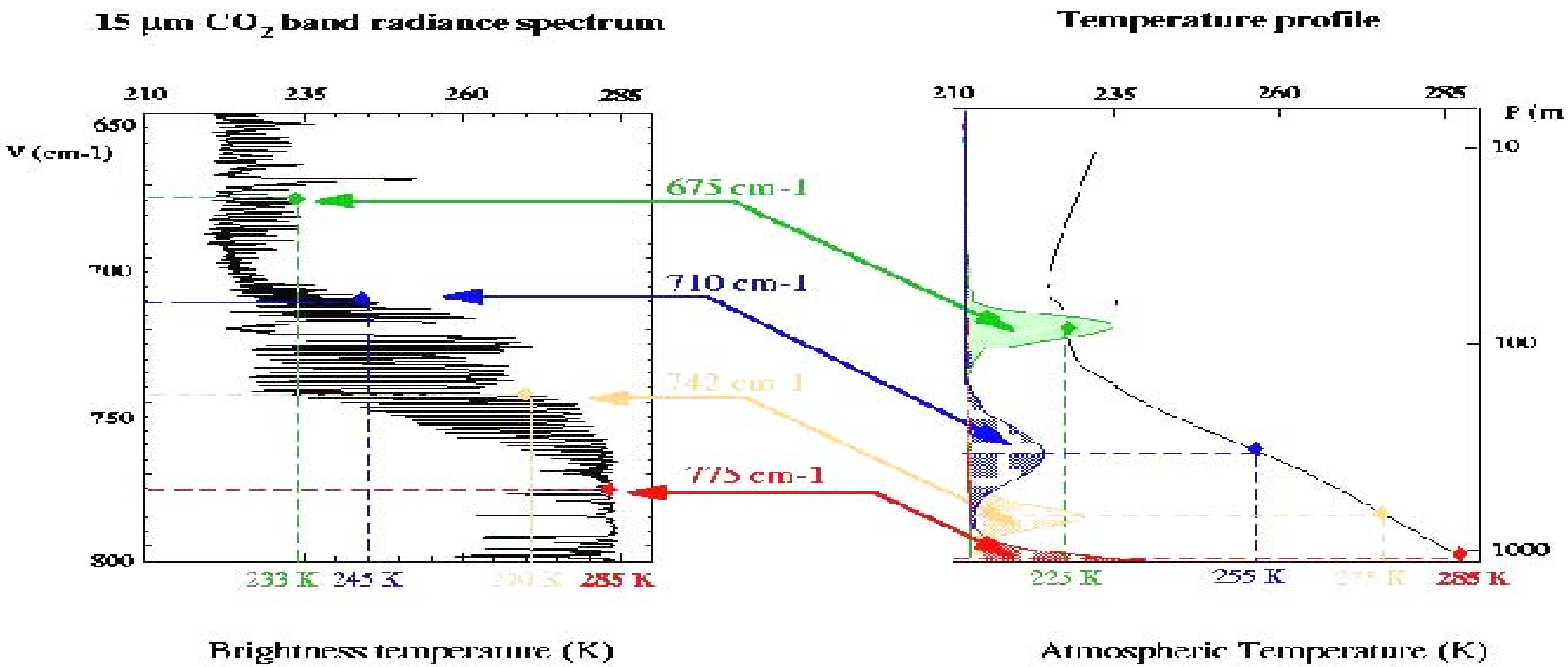






3. Direct use of Radiances

- Atmospheric/Oceanic models need initial conditions in terms of geophysical parameters
- Radiance Data assimilation solves this inverse problem
- Firstly a 1DVAR was developed using the forecast as first guess
- Now 3D/4Dvar uses radiances directly in the analysis



Important issues for the assimilation of satellite radiances

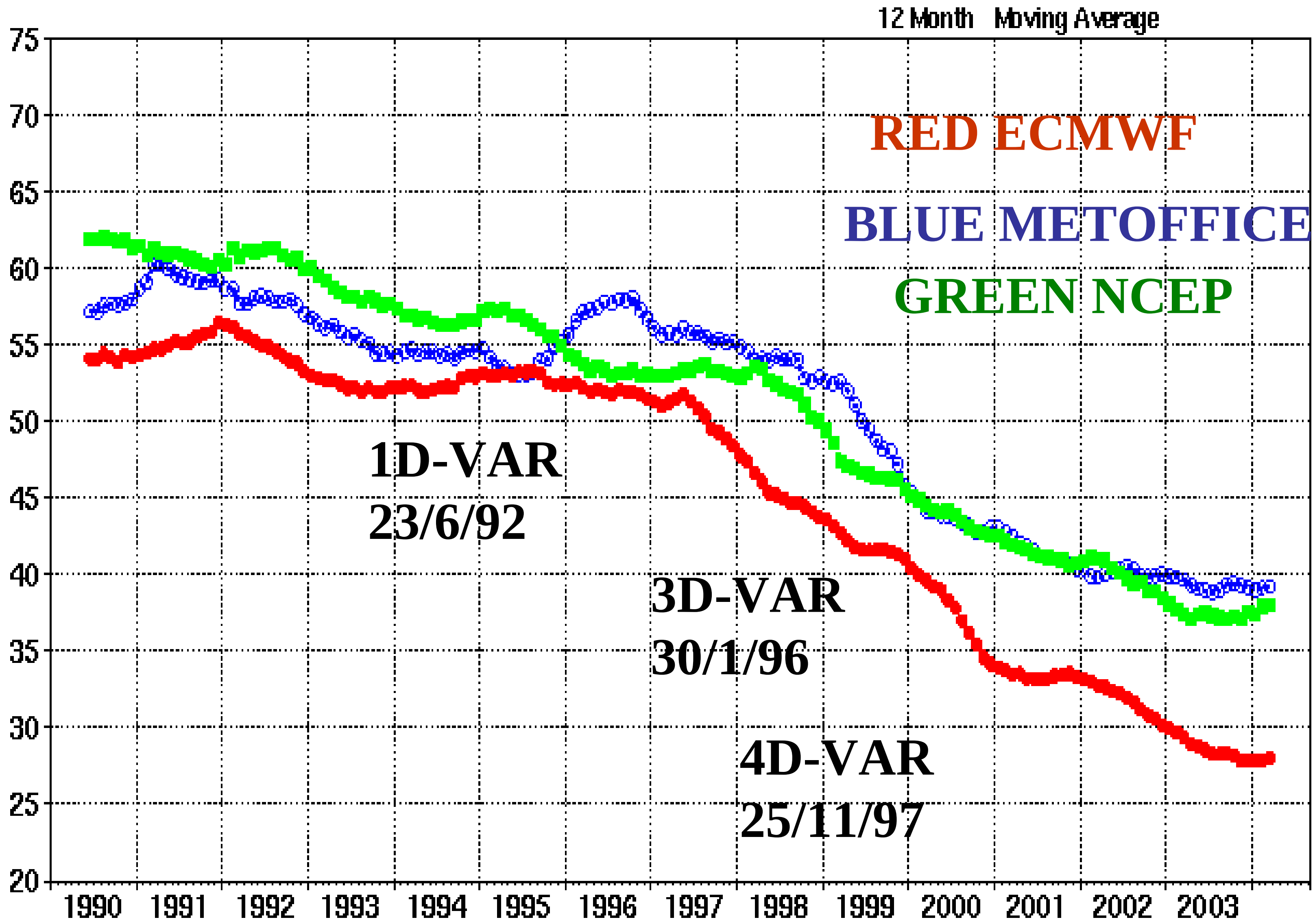
- Various sources of systematic errors:
  - Instrument error (calibration)
  - Radiative transfer error
  - Cloud/rain detection error
  - Background model error

- Difficult to disentangle between various sources

- Systematic errors must be removed before the assimilation (bias correction using four forecast predictors) (Harris and Kelly 2001)

- Importance of MONITORING departures between model background (and analysis) and various observations to detect any instruments or pre-processing problems

Southern Hemispheric 500 hPa RMS error (m) for Day 3



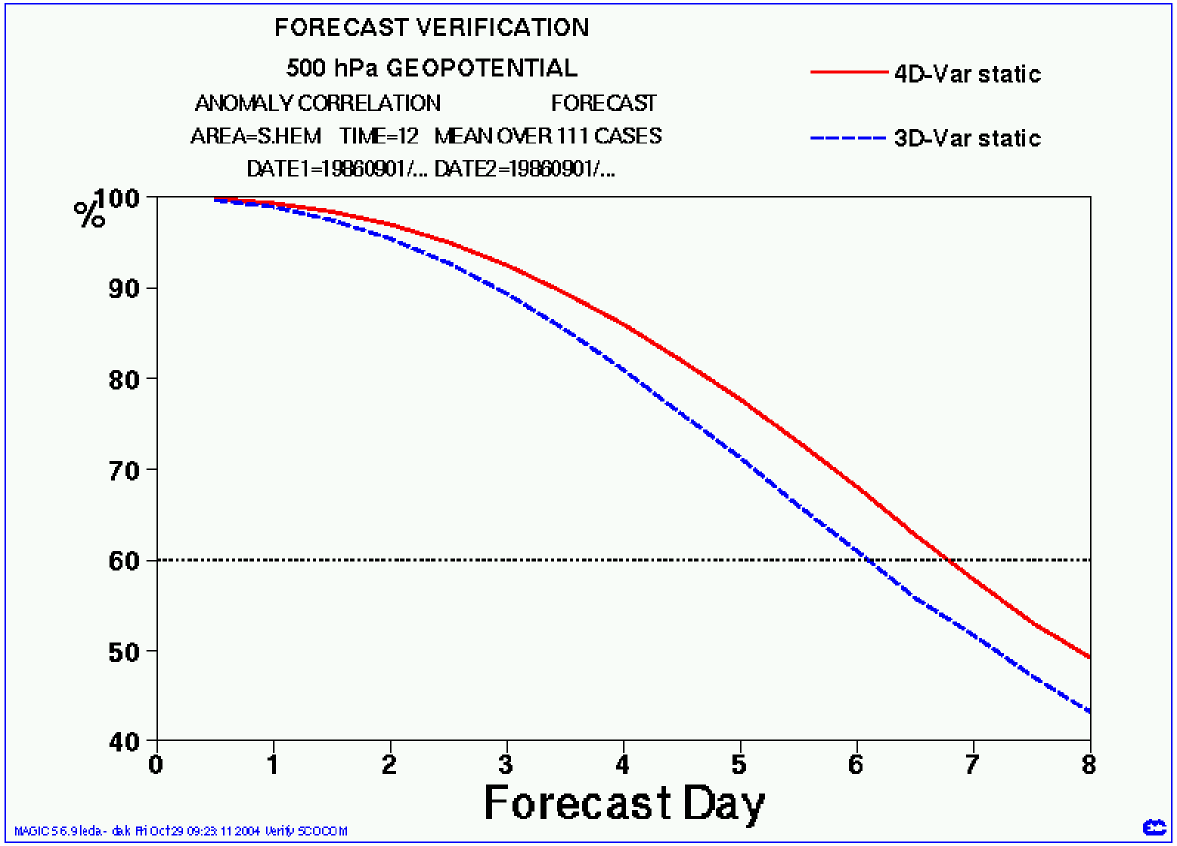
4. Impact experiments with ERA reanalysis system

After ERA40 four experiments were run to test 3D/4D VAR and effect of using an adaptive bias correction.

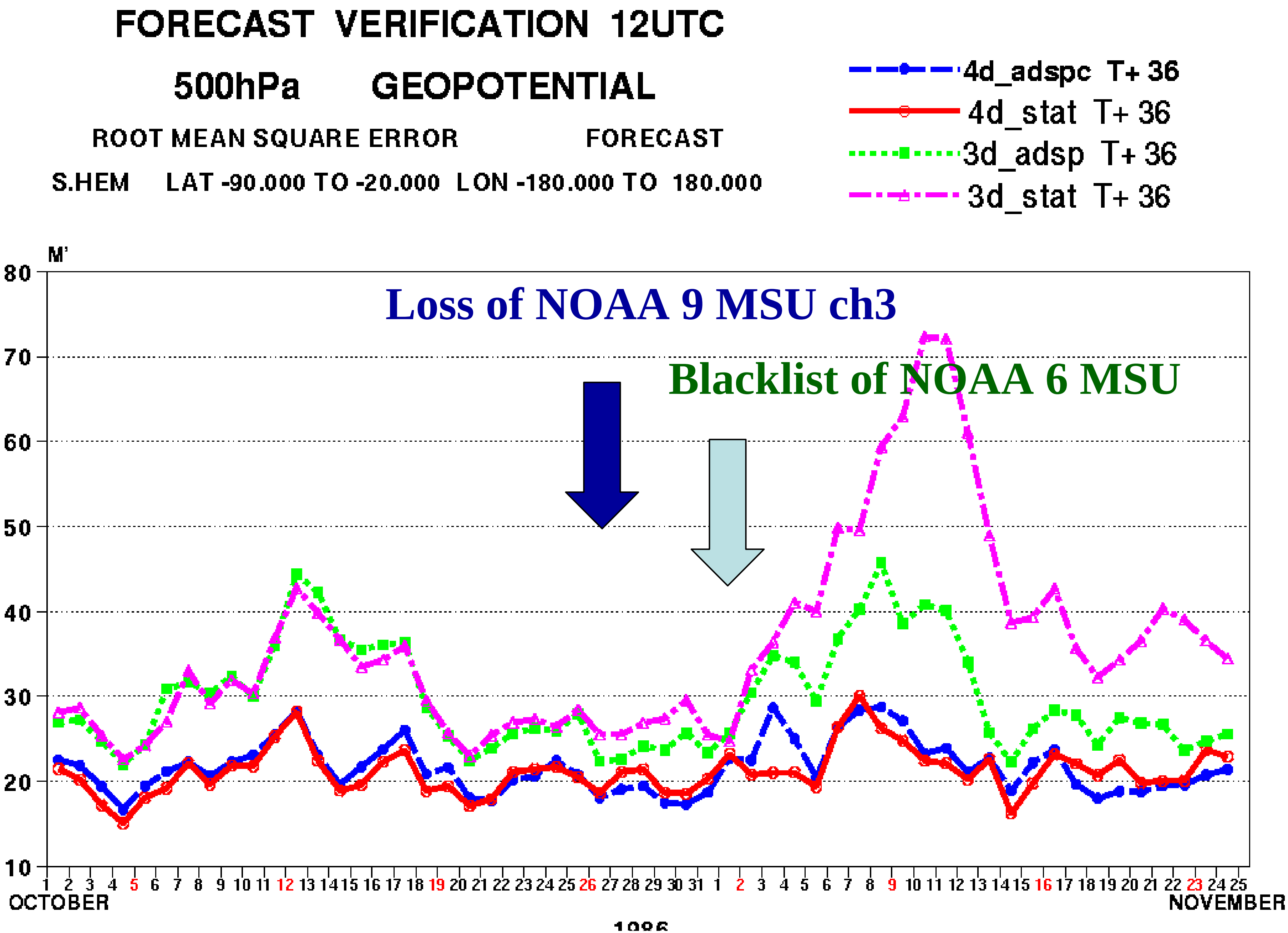
Resolution TL159/159
2 satellites max 5 sensors

1. **3dvar control stat**
2. **3dvar adaptive**
3. **4dvar control**
4. **4dvar adaptive**

Comparsion of 3/4DVAR (4 months)
500 hPa rms error



Time series


FORECAST VERIFICATION 12UTC
500hPa GEOPOTENTIAL
ROOT MEAN SQUARE ERROR FORECAST
S.HEM LAT -90.000 TO -20.000 LON -180.000 TO 180.000
4d_adspc T+ 36
4d_stat T+ 36
3d_adsp T+ 36
3d_stat T+ 36
M'
Loss of NOAA 9 MSU ch3
Blacklist of NOAA 6 MSU
OCTOBER
NOVEMBER

5. Past OSE (1996,2000 and 2003) studies with satellite data

Three sets of OSEs were run at ECMWF soon after the introduction of 3D-Var in 1996,

In 2000 after the operational implementation of 4D-Var,

in 2003 (extra satellites many improvements to the operational system)

***CONTROL*: For each set of OSEs the model cycle closest to the operational system at that time was used.**

***NOAIREP*: All aircraft measurements (wind and temperature) removed.**

***NOUPPER*: All TEMP, PILOT and PROFILER reports removed.**

***NOSAT*: All satellite data removed (the terrestrial network used in operations).**

OSEs (1996, 2000 and 2003)

The 2003 OSE used
(4dvar (TL511 40km L60) forecast model
and
(TL159/511 120km L60) 4dvar analysis).

The number of cases:
1996 OSE 34 days *(Kelly 1997)*
2000 OSE 43 days *(Bouttier and Kelly 2001)*
2003 OSE 120 days *(Kelly 2004)*

DATA used in 2003 OSE

As well as conventional observations (TEMP, PILOT, PROFILER, AIREPS, SYNOP, PAOBS and BUOY reports), the 2003 OSEs included data from:

Three AMSU-A/B and two HIRS instruments from the NOAA satellites.

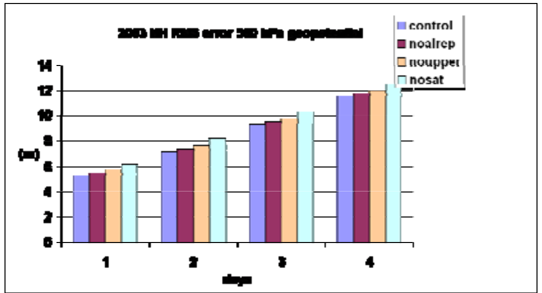
Five geostationary satellites and one polar orbiter (TERRA) providing Atmospheric Motion Vectors.

Three geostationary satellites providing Clear Sky water-vapour Radiances (CSRs).

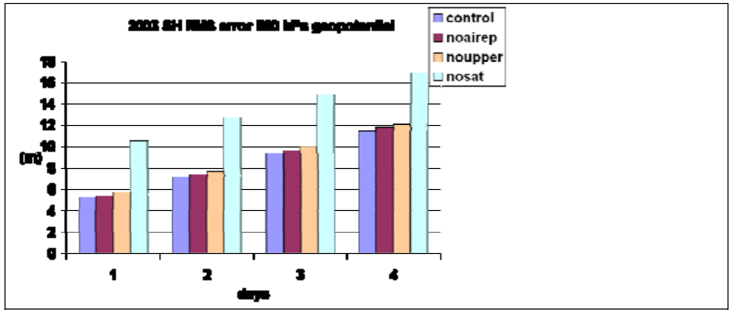
Three SSMI instruments from the DMSP platforms.

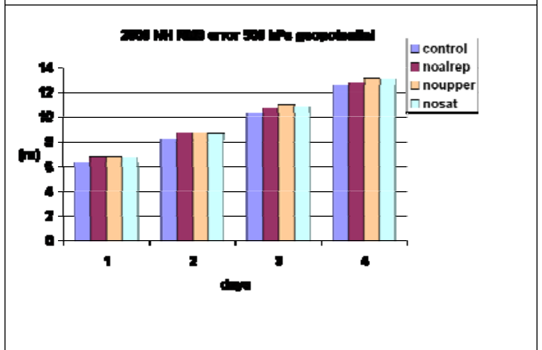
Quickscat.

Comparison of three OSEs for 500 hPa rms error geopotential height.

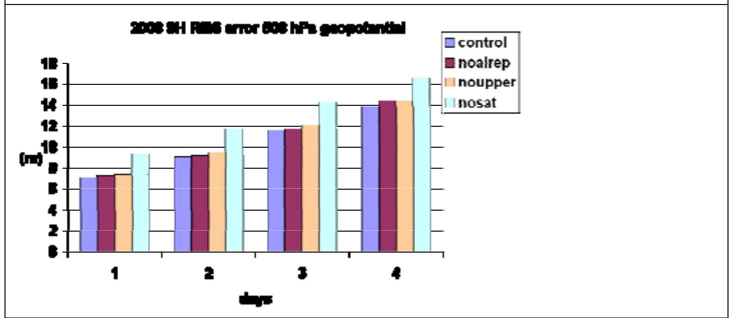


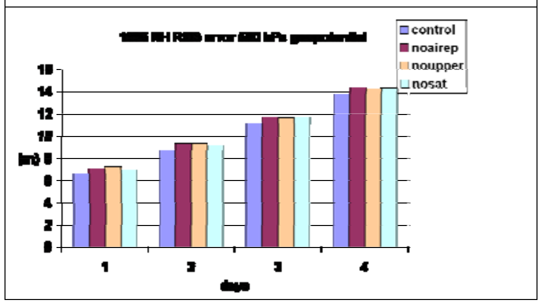
2003



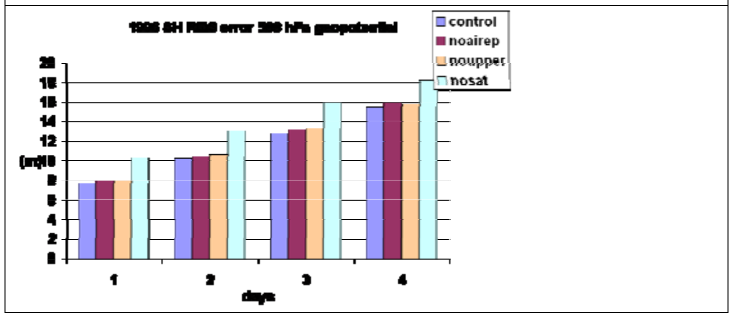


2000



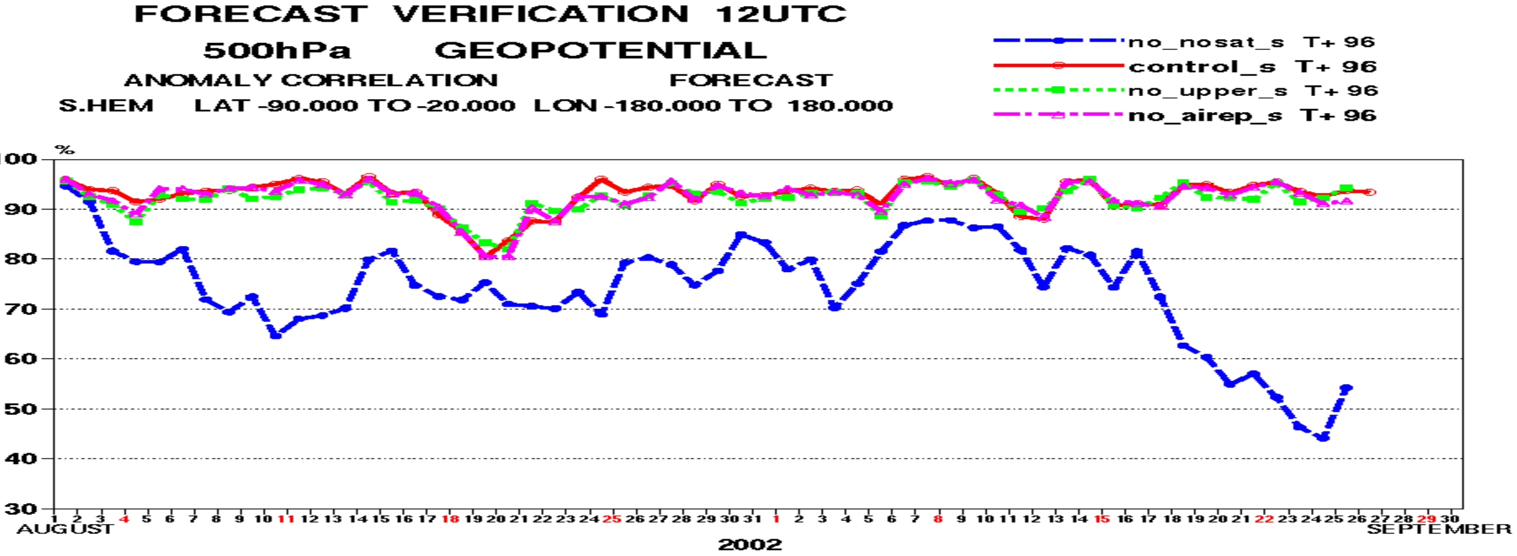


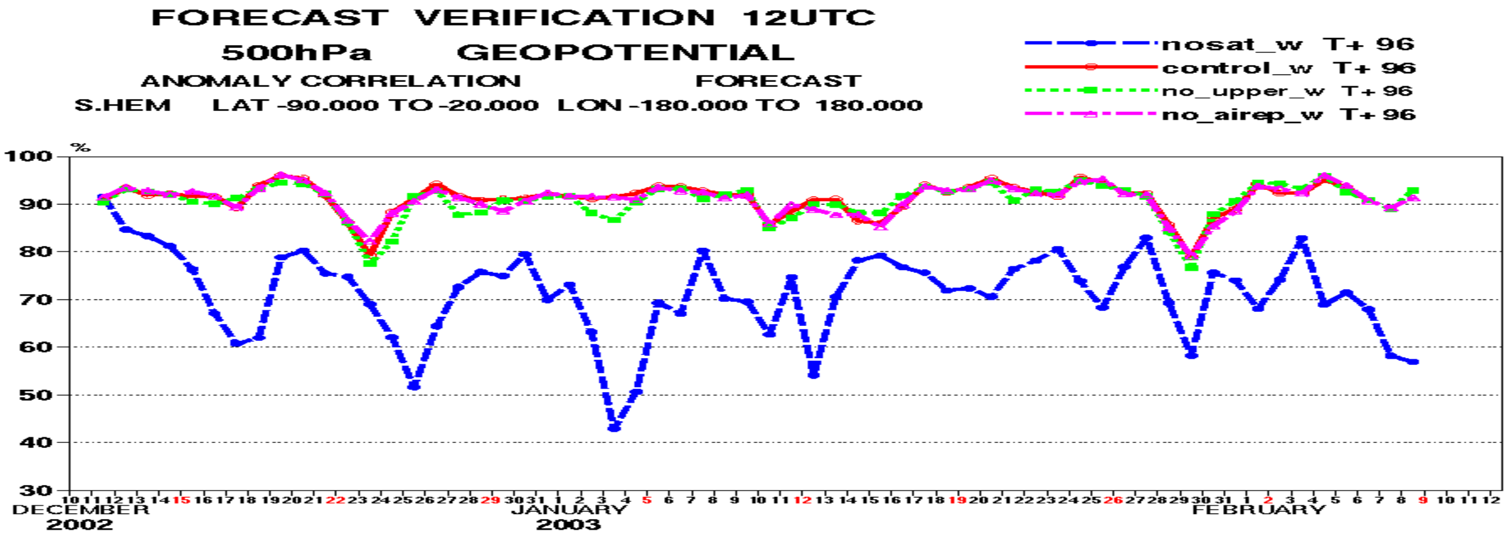
1996



Northern Hemisphere **Southern Hemisphere**

Time series Southern Hemispheric 500hPa geopotential height day 4 forecasts





Discussion of OSEs

Some important findings for the 2003 OSEs are:

The satellite data has more impact in the Northern Hemisphere than in previous OSE's even more than radiosondes and profilers combined.

In the four months of assimilation there are very few busts as defined by the anomaly correlation dropping less than 0.6 at day 4.

The Southern Hemispheric forecasts are almost as good as the Northern Hemispheric forecasts.

The short range RMS wind and temperature forecasts are of excellent quality and show the importance of satellite data.

6. Reference plus OSEs

Requirement for Observing System Studies

- Since 1998 several NWP centres have demonstrated substantial benefit from the assimilation of improved microwave sensors. (AMSUA, AMSUB ect.)

- In 2003 data became available from first of the second generation radiometers (AIRS). These instruments provide significantly enhanced temperature and humidity sounding capabilities. Now IASA is also operational METOP and soon CRIS on NPOESS.

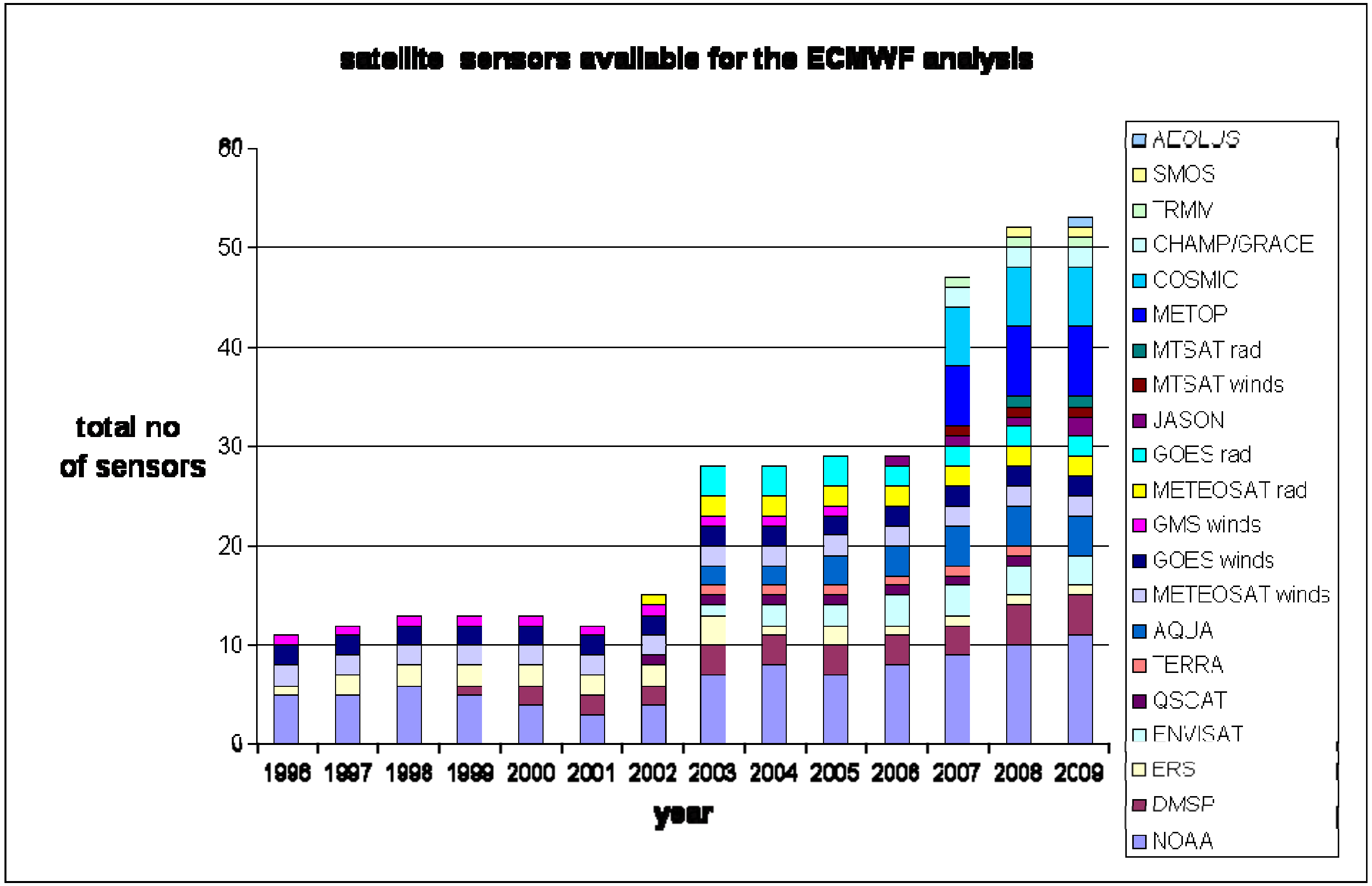
Requirement for terrestrial Observing System study

- **It was agreed that, as far as EUCOS is concerned, the primary issues were:**
- **What are the relative contributions of various components of the terrestrial observing system within the current overall composite observing system?**
- **How should the terrestrial systems evolve over the next five to ten years and beyond to complement the projected evolution of the space-based observing systems?**
- **This led to a proposal from *Andersson et al*. (2004) to carry out a set of OSEs specifically designed to evaluate the role of the terrestrial component of the Global Observing System.**

Requirement for space Observing System study

- A second proposal from *Andersson et al*. (2004) was to carry out a set of OSEs specifically designed to evaluate the role of the space component of the Global Observing System.
- A study, sponsored by EUMETSAT, has been carried out to evaluate the impact of the space component of the Global Observing System through Observing System Experiments.
- In this study the relative contributions of the various space observing systems have been assessed within the context of the ECMWF data assimilation system. It is found that all the space based sensors contribute in a positive way to the overall improvement of the ECMWF forecast system.

Number of satellite sensors that are or will be soon assimilated in the ECMWF operational data assimilation.



Main characteristics of the data assimilation system

T511L60 forecast model resolution

4D-Var assimilation, 12 hour window

T95/T159 L60 inner loop resolution

T511L60 outer loop resolution

Data currently assimilated

Conventional observations currently assimilated in the system include:

TEMP, PILOT and PROFILER reports
SYNOP, SHIP, METAR and BUOY (moored and drifters) reports
Aircrafts (AMDARS, AIREPS, ACARS) including ascent/descent reports

Satellite observations assimilated in the system for the atmospheric analysis were at that time for the winter run:

Atmospheric Motion Vectors from GEO (Met-5/7,
Goes-9/10/12 and LEO (MODIS Terra and Aqua) platforms
Clear-sky water vapour radiances from GEO (Met-5/8, Goes-9/10/12)
Level 1c IR radiances from NOAA-14/17 (HIRS) and AQUA (AIRS)
Level 1c µw radiances from NOAA-15 (AMSU-A),
NOAA-16 (AMSU-A and AMSU-B),
NOAA-17 (AMSU-B), AQUA (AMSU-A) and DMSP 13/14/15 (SSM/I)
Sea surface winds from scatterometers QuikScat and ERS-2
Ozone products from NOAA-16 (SBUV) and ENVISAT (SCIAMACHY).

Observation data count for one 12 hour 4D-Var cycle for 0900–2100 UTC on 24 April 2007.

	Screening		Used in Analysis	
SYNOP	421,000	0.43%	64,000	1.94%
Aircraft reports	519,000	0.53%	247,000	7.53%
DRIBU	24,000	0.02%	6,000	0.18%
TEMP	152,000	0.16%	75,000	2.28%
PILOT	119,000	0.12%	57,000	1.75%
AMVs	4,272,000	4.37%	131,000	3.99%
Radiance data	91,786,000	93.91%	2,508,000	76.46%
Scatterometer winds	274,000	0.28%	118,000	3.61%
GPS radio occultation	167,000	0.17%	73,000	2.24%
TOTAL	97,734,000	100.00%	3,280,000	100.00%

‘Screening’ refers to the actual amount of data presented to 4D-Var

‘Used in Analysis’ indicates the amount of data used during the analysis minimization.

Use of reference assimilations for evaluation of various space components

In the southern hemisphere and tropics the *BASELINE* assimilation (terrestrial observations only) is poor and not suitable as a reference.

The addition to the *BASELINE* of either AMVs (geostationary and polar) or data from one AMSU-A instrument considerably improves the quality of the assimilation with the southern hemispheric forecast skill increasing by about two days at day four.

Observational scenarios tested with *AMV(REF)* (*BASELINE* plus AMVs from GEO and MODIS)

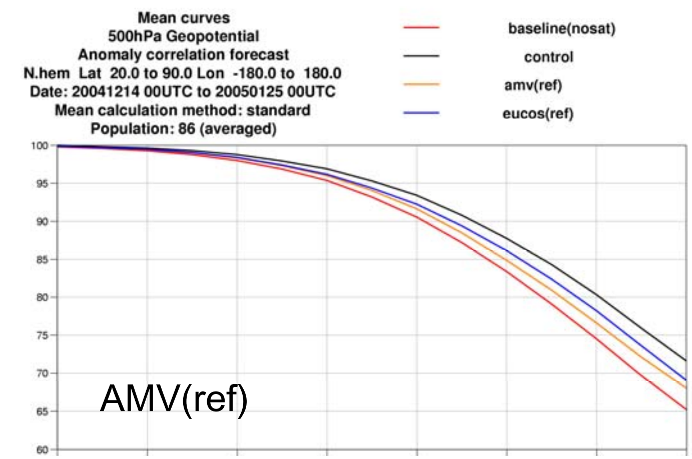
Experiment	Datasets
BASELINE	All conventional observations used in NWP (radiosonde + aircraft + profiler network + surface land data + buoy observations + ship data)
AMV(REF)	BASELINE + AMVs from GEO and MODIS
HIRS	AMV(REF) + HIRS radiances
AMSU-A	AMV(REF) + AMSU-A radiances
AMSU-B	AMV(REF) + AMSU-B radiances
SSMI	AMV(REF) + SSMI radiances
CSRs	AMV(REF) + CSRs (Clear Sky Radiances) from GEO
AIRS	AMV(REF) + AIRS radiances
SCATT	AMV(REF) + SCATT winds
AMVs	AMV(REF) + AMVs from GEO (not MODIS)
CONTROL	Full operational system (all the observations)

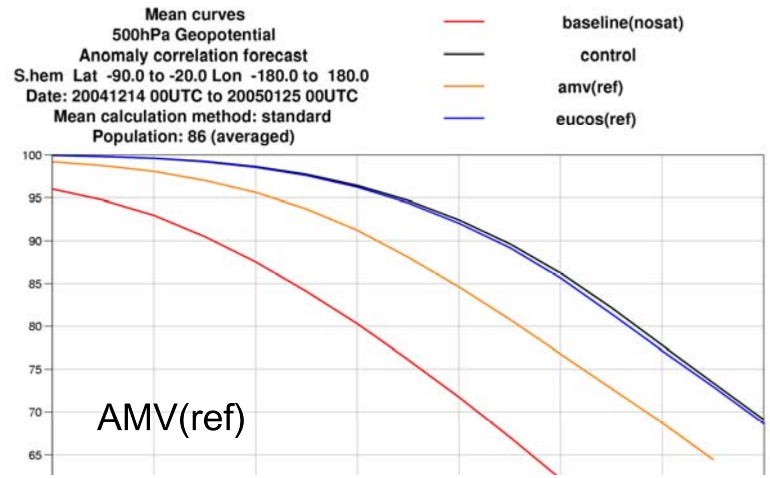
Observational scenarios tested with *AMSUA(REF)* (*BASELINE* plus AMSU-A from NOAA 16)

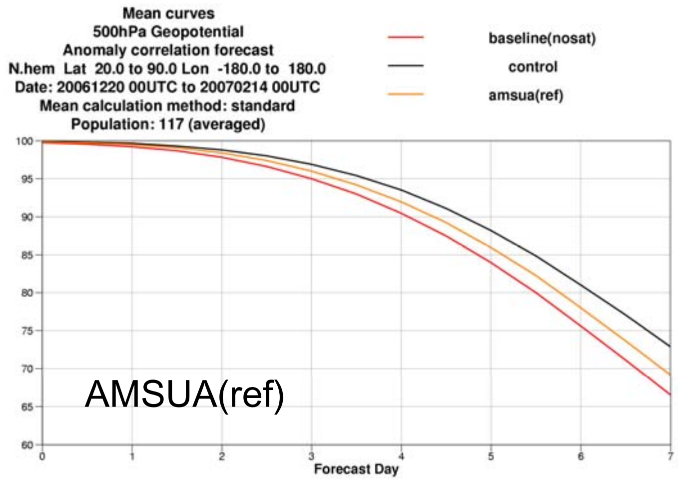
Experiment	Datasets
BASELINE	All conventional observations used in NWP (radiosonde + aircraft + profiler network + surface land data + buoy observations + ship data)
AMSUA(REF)	BASELINE + AMSU-A radiances from NOAA 16
HIRS	AMSUA(REF) + AMVs from GEO and MODIS
AMSU-A	AMSUA(REF) + AMSU-A radiances
AMSU-B	AMSUA(REF) + AMSU-B radiances
CSRs	AMSUA(REF) + CSRs (Clear Sky Radiances) from GEO
AIRS	AMSUA(REF) + AIRS radiances
SCATT	AMSUA(REF) + SCATT winds
CONTROL	Full operational system (all the observations)

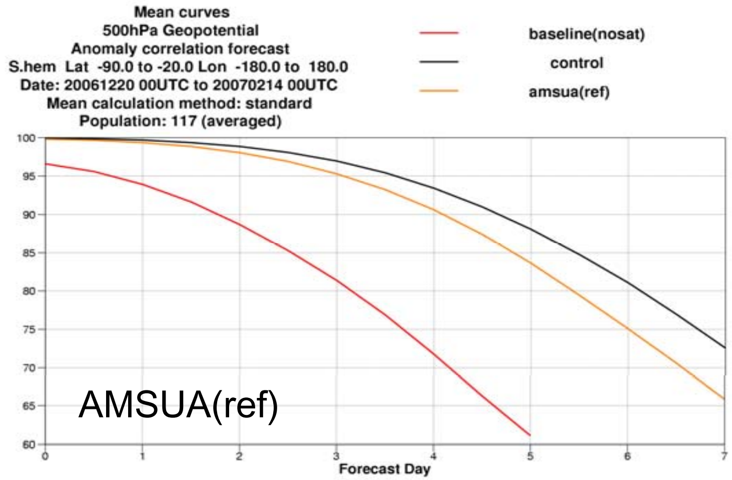
Comparison of *Reference* with *BASELINE* (*NOSAT*) and *CONTROL*

Northern hemisphere (20°–90°N) Southern hemisphere (20°–90°S).

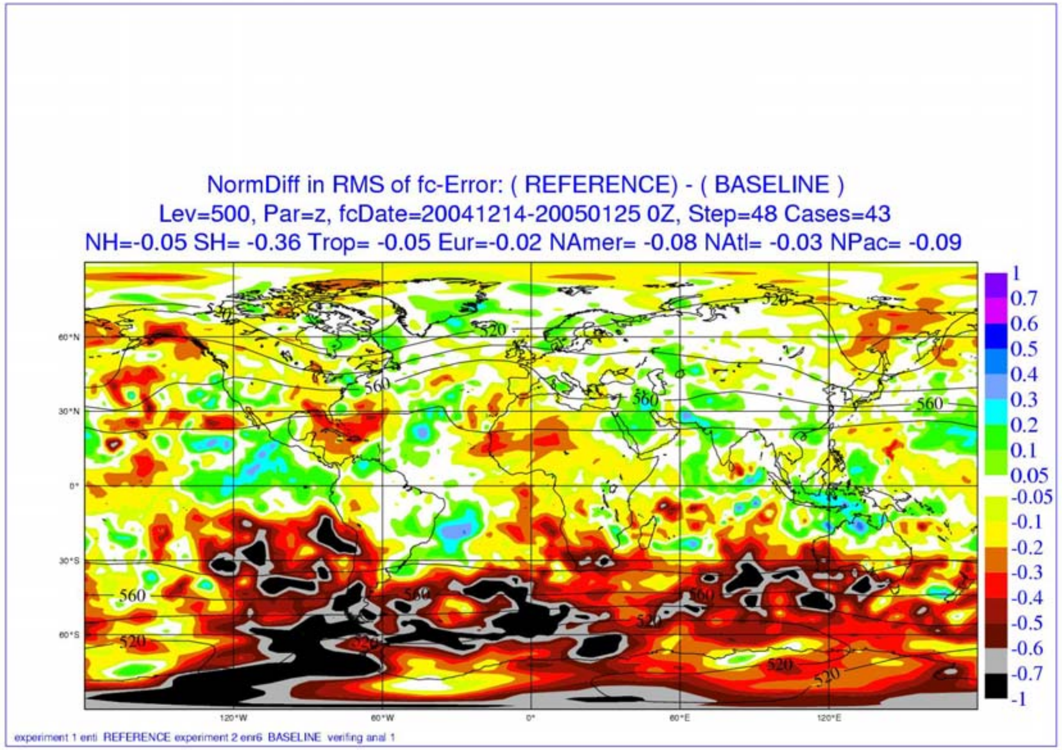






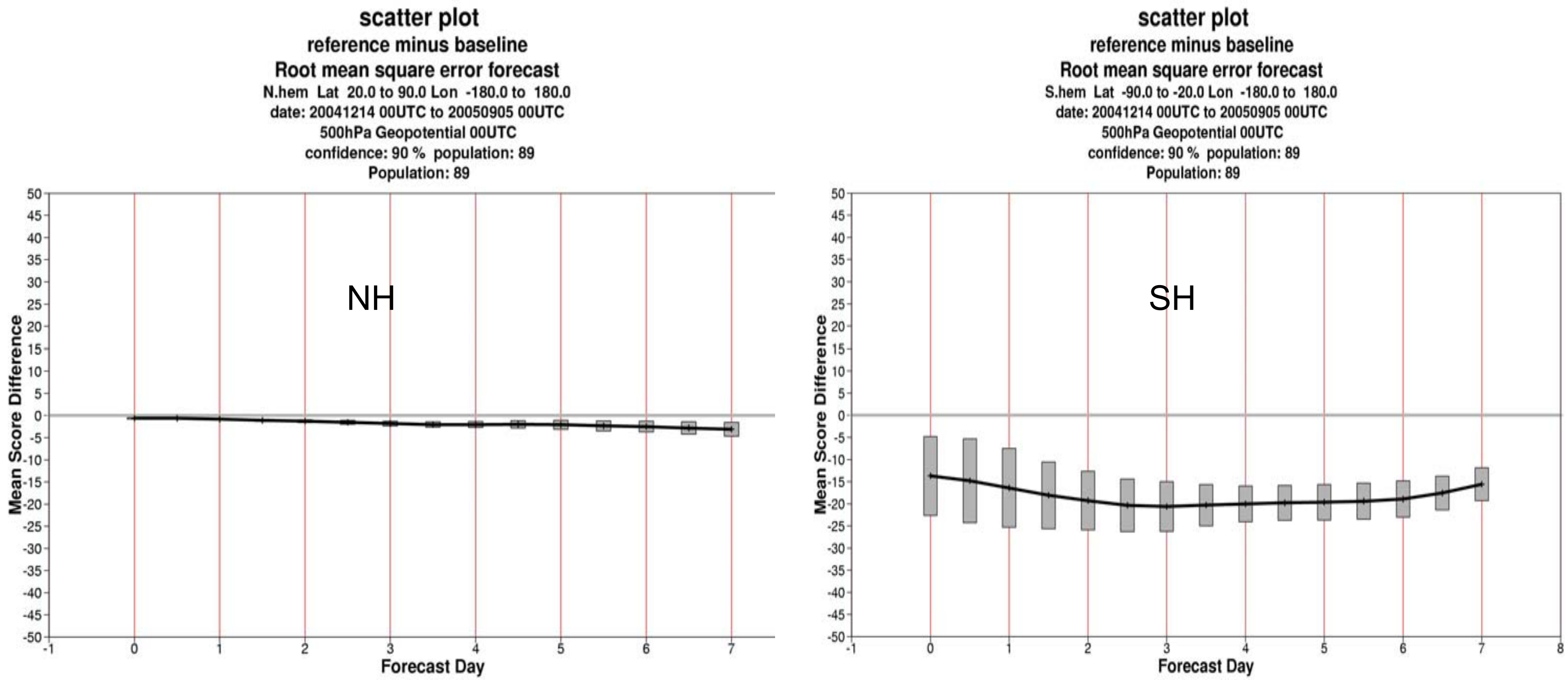


AMV(REF) minus BASELINE



Mean normalized 48-hour forecast error difference between AMV(REF) and BASELINE(NOSAT) for the 500 hPa geopotential height.

AMV(REF) minus BASELINE



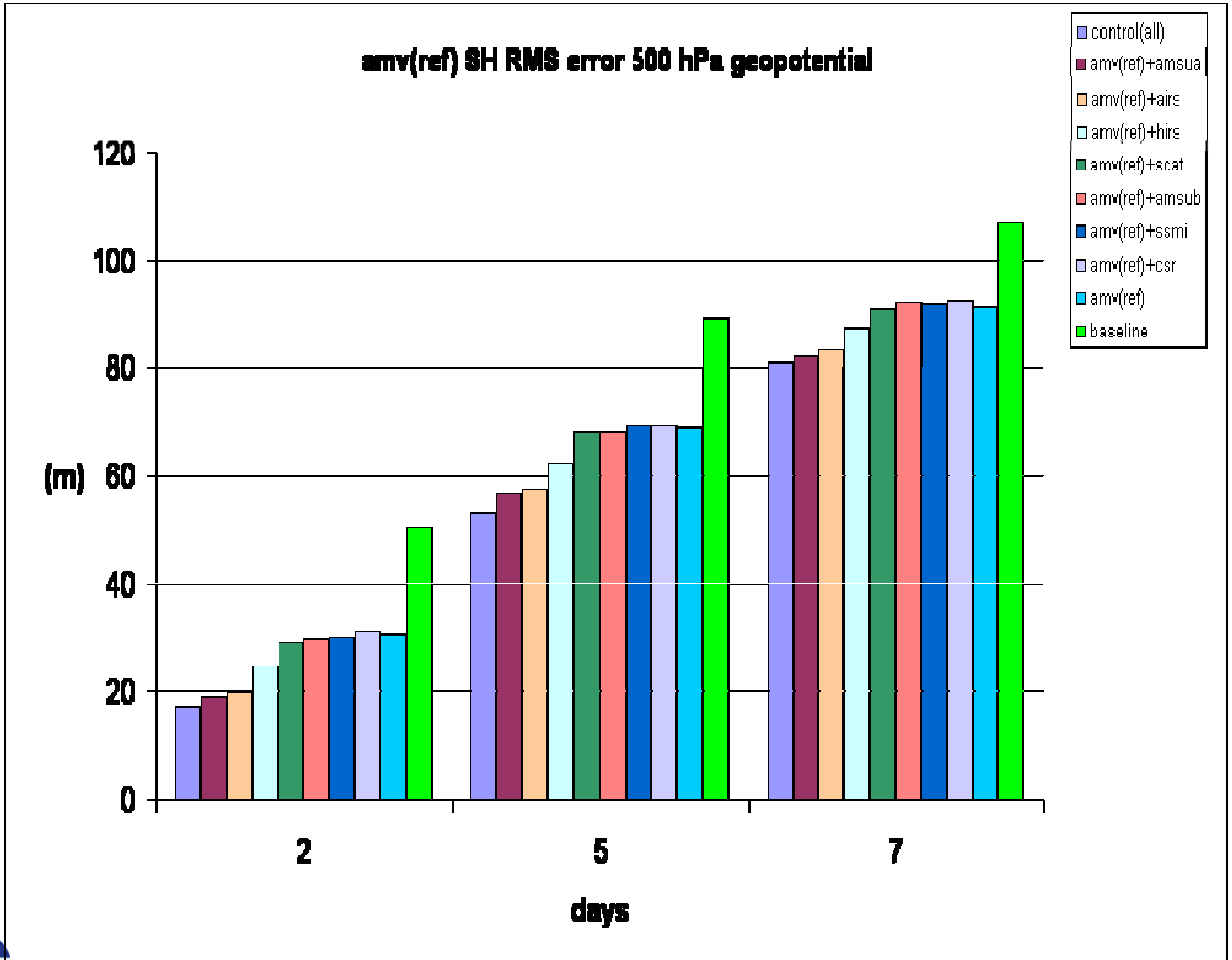
Time series of normalized 500 hPa height *rmse* differences between *AMV(REF)* and BASELINE for forecast errors up to day 7. Negative values indicate positive impact for the AMV(REF)

Impact of sensors

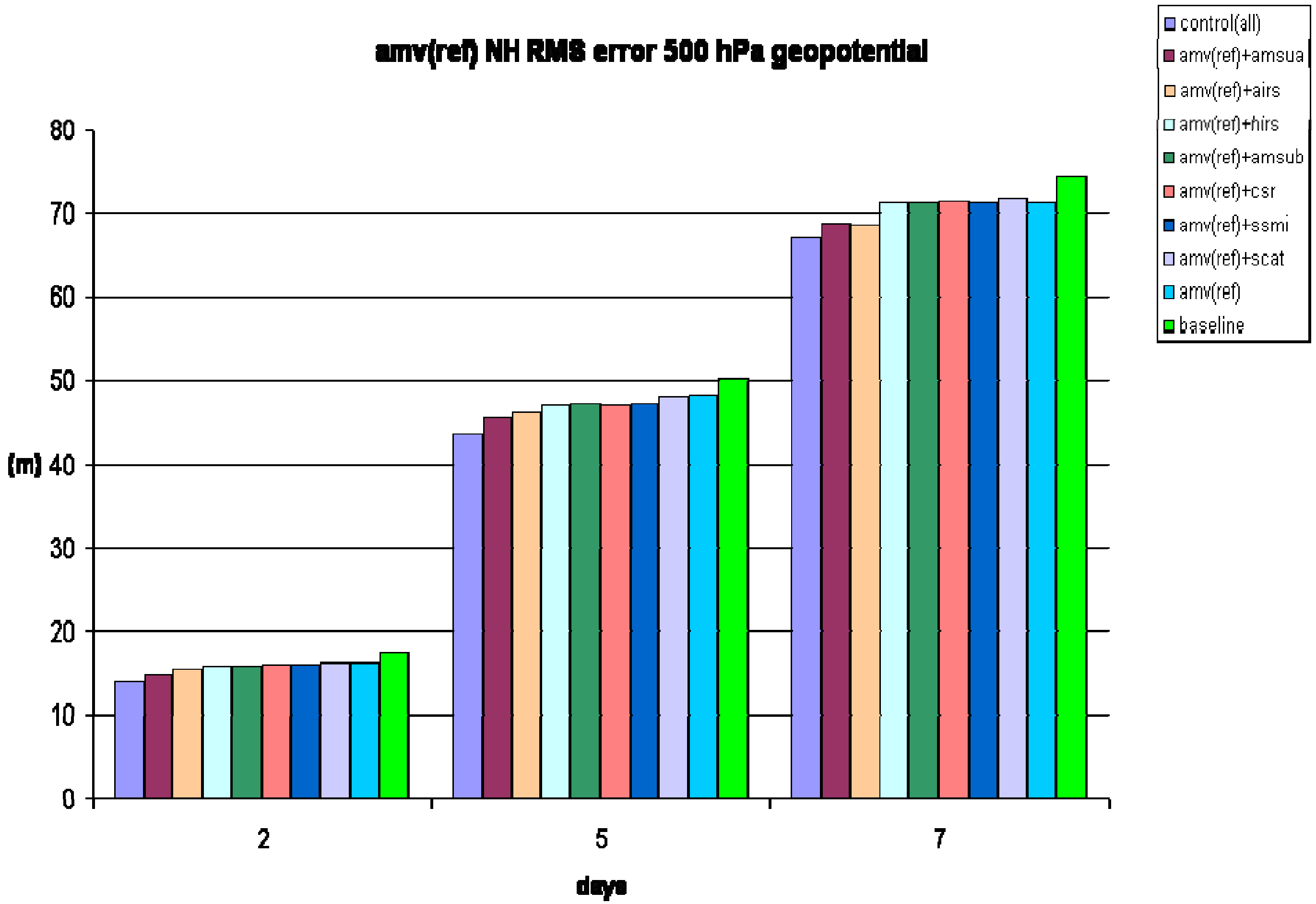
Generally the sensors are ranked in order of increasing rms error for the first verified forecast range. Usually this ranking is maintained throughout the forecast, however there are some exceptions.
Generally all sensors contribute in a positive way on some Parameters but some sensors have a neutral or slightly negative Impact on other parameters.

The small negative impact, mostly noticed on the 500 hPa geopotential height parameter and when using *AMV(REF)* as a reference, may be due to the fact that the accuracy of the *AMV(REF)* temperature field is still not quite good enough to assimilate radiances that are mostly sensitive to moisture. This negative impact of some sensors is not generally found when *AMSUA(REF)* is used as a reference instead

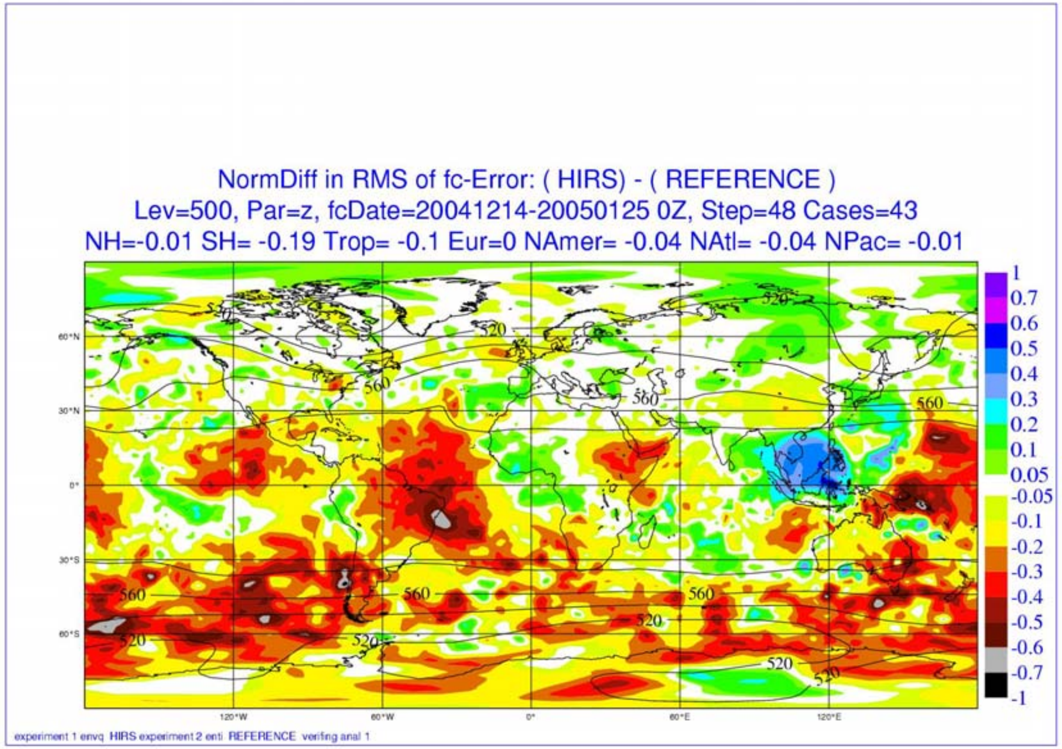
Impact of all sensors on 500 hPa geopotential for *AMV(REF)* for (a) southern hemisphere (20°–90°S)



Impact of all sensors on 500 hPa geopotential for *AMV(REF)* for northern hemisphere (20°–90°N)



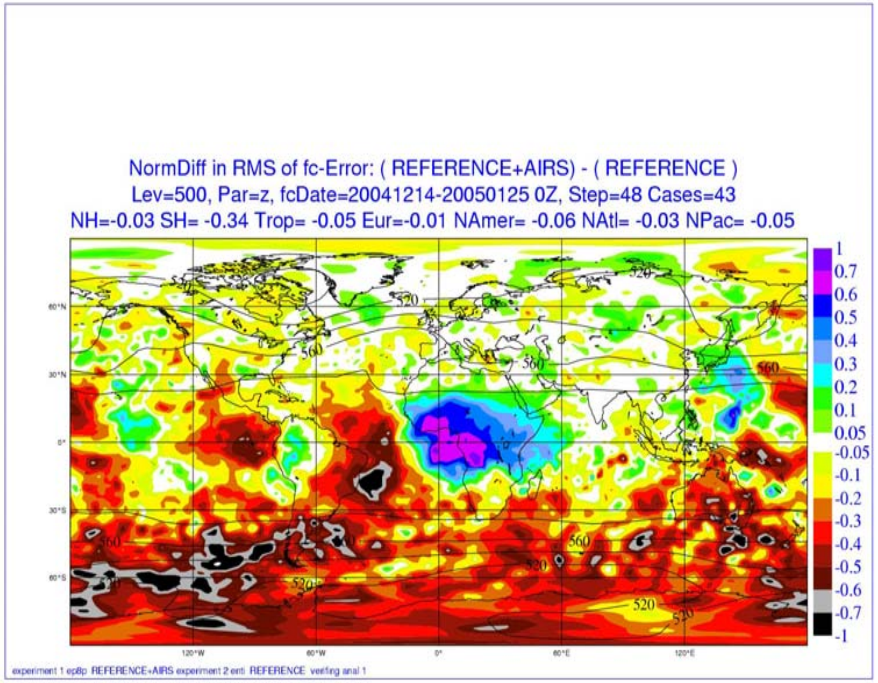
Impact of adding HIRS to the *AMV(REF)*



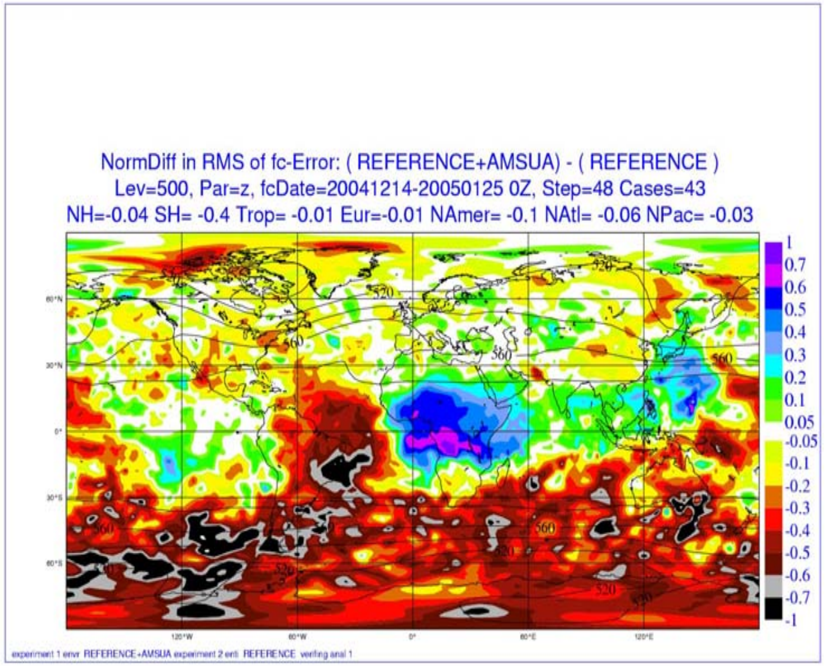
- **Mean normalized 48-hour forecast error difference between and AMV(REF)+AIRS and AMV(REF) for the 500 hPa geopotential height.**

Impact of adding *AMV(REF)*

AIRS

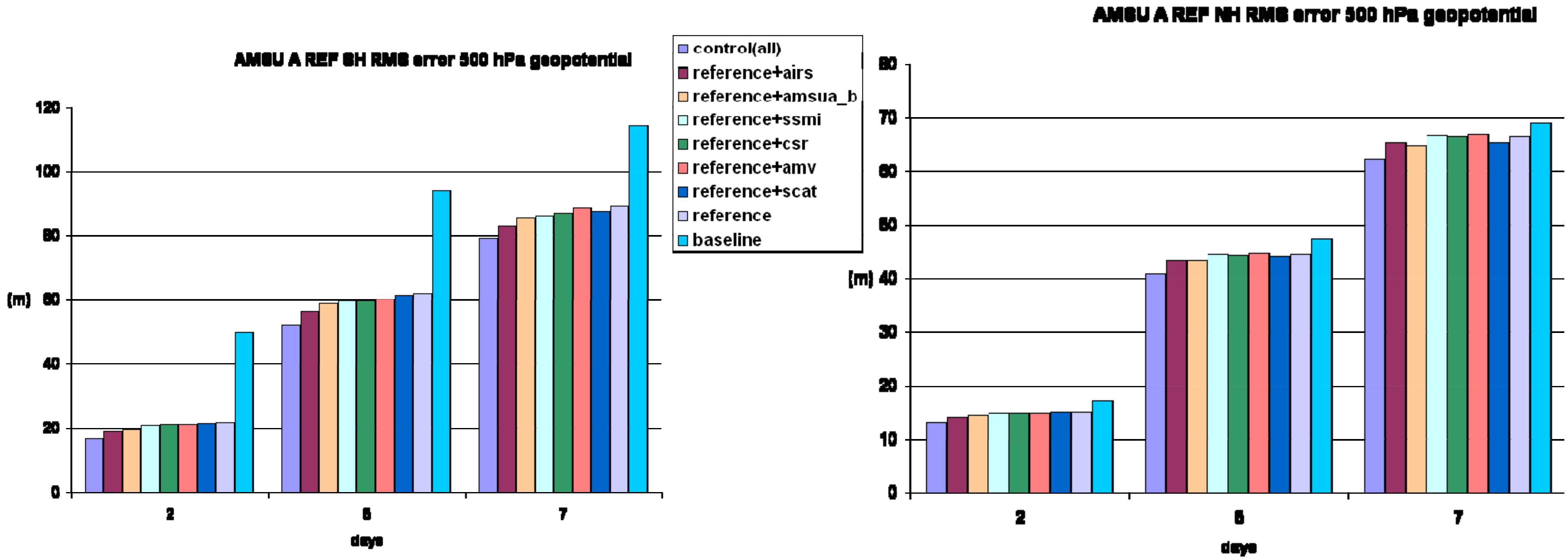


AMSUA

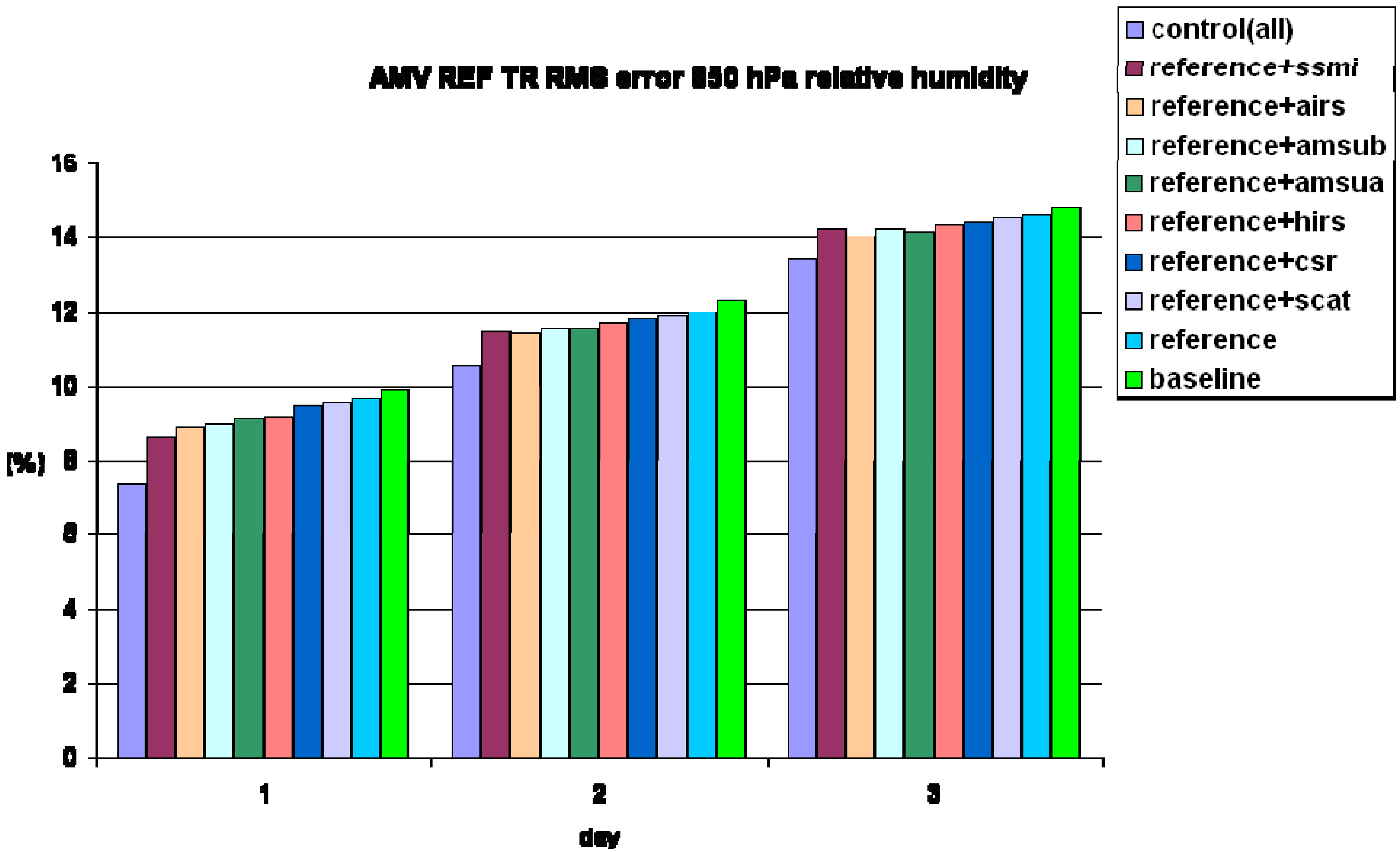


- Mean normalized 48-hour forecast error difference for the 500 hPa geopotential height.

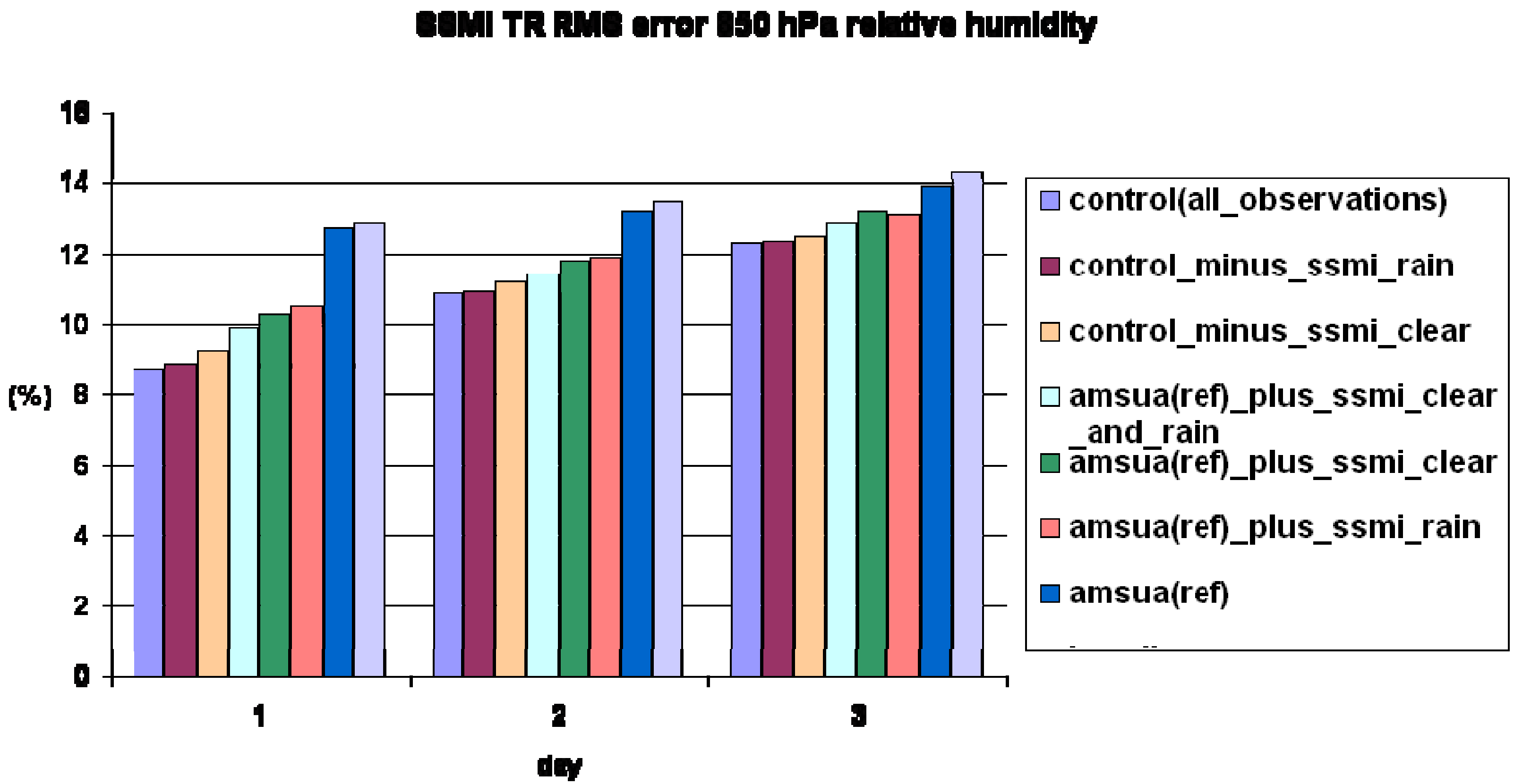
Impact of all sensors on 500 hPa geopotential for *AMSUA(REF)* for (a) southern hemisphere (20°–90°S) and (b) northern hemisphere (20°–90°N).



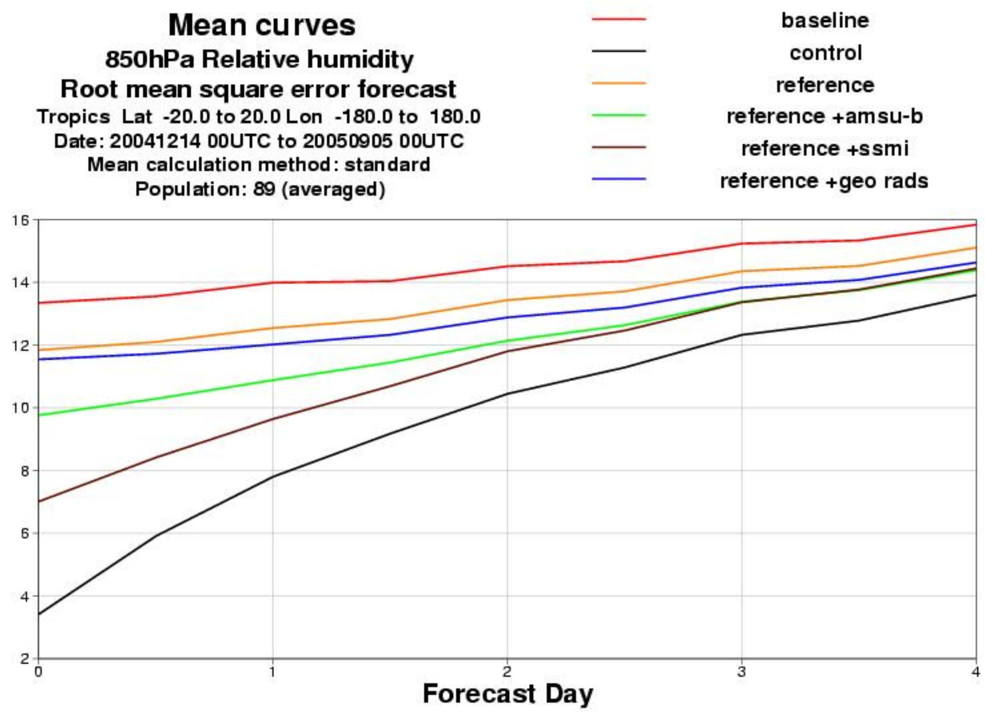
Impact of all sensors on 850 hPa relative humidity for the tropic for *AMV(REF)*



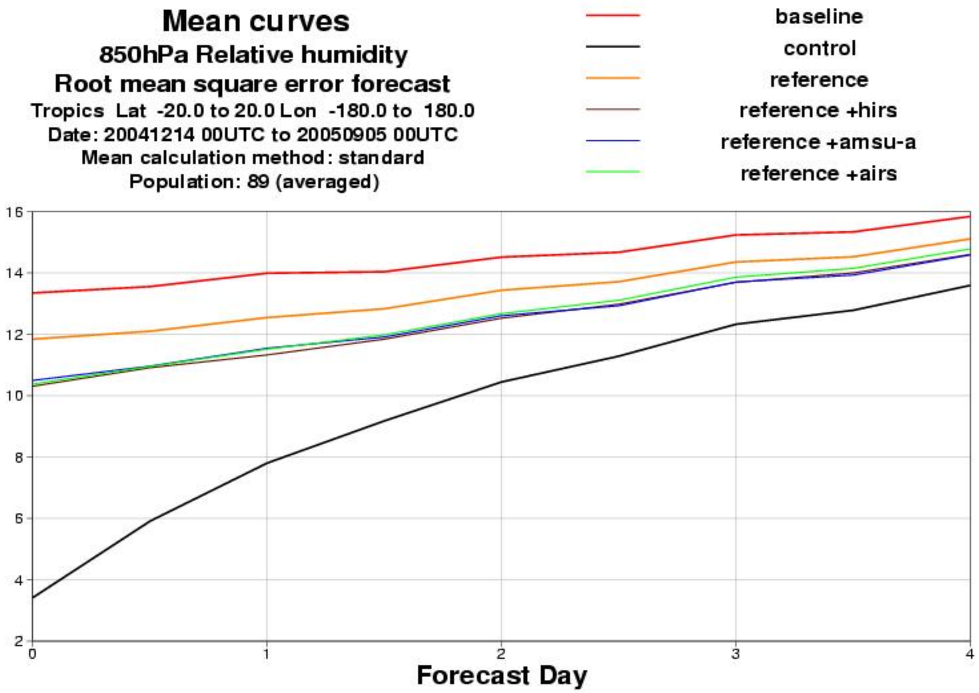
Impact of all sensors on 850 hPa relative humidity for the tropic for *AMSUA(REF)*.



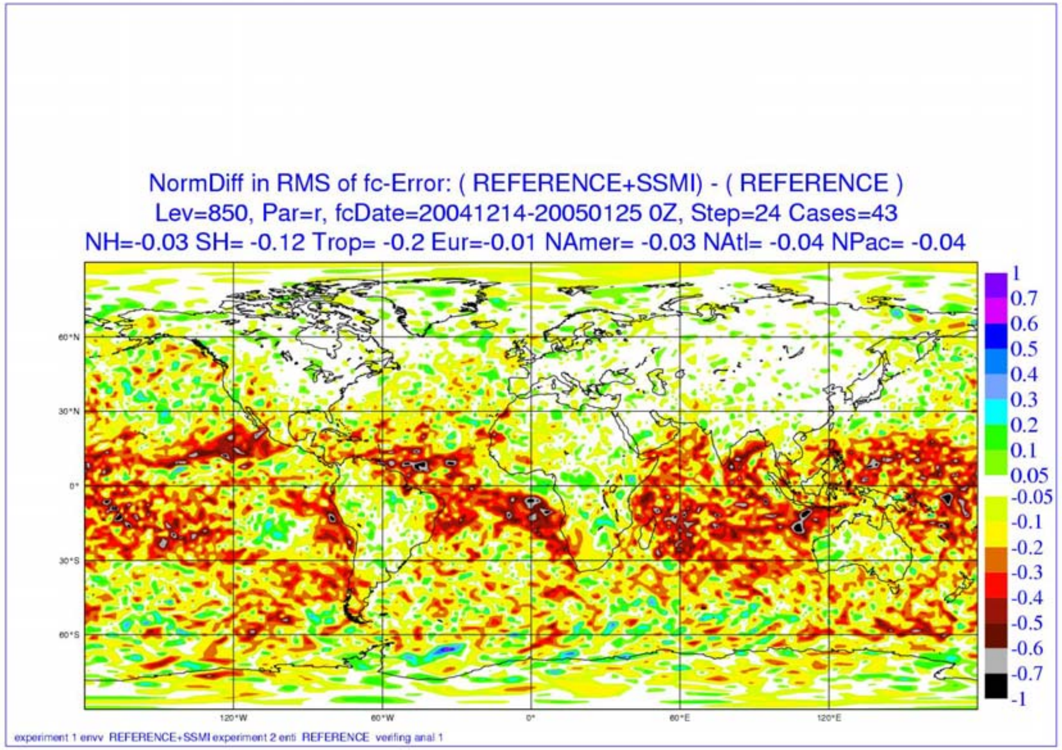
Relative humidity at 850 hPa



Relative humidity at 850 hPa

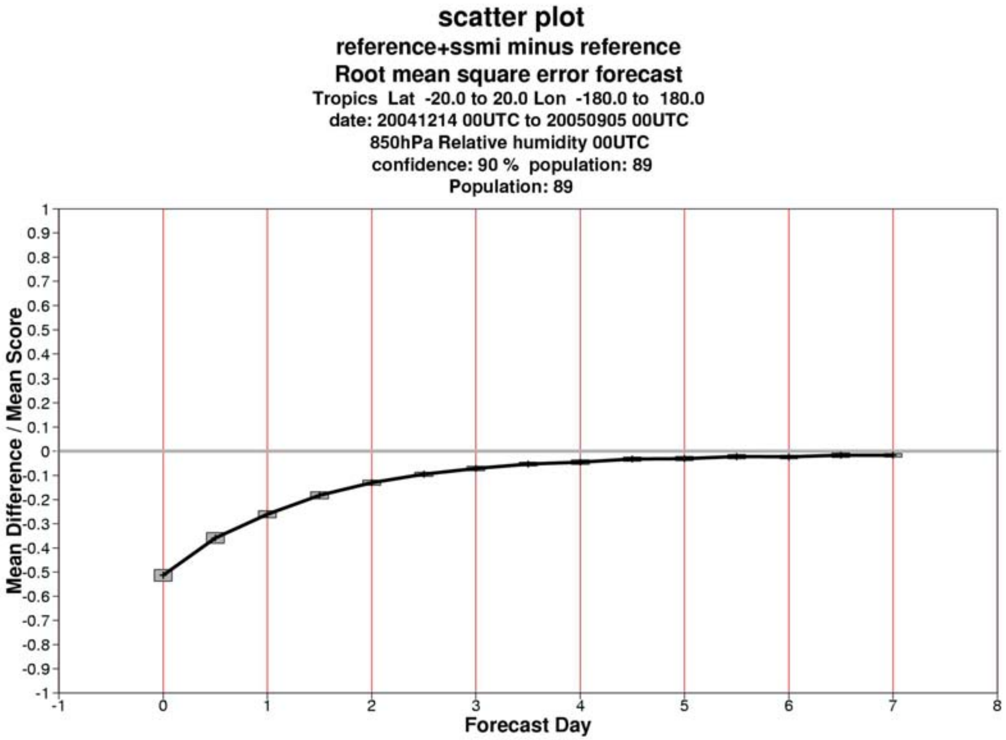


Impact of adding SSMI to the AMV(REF)



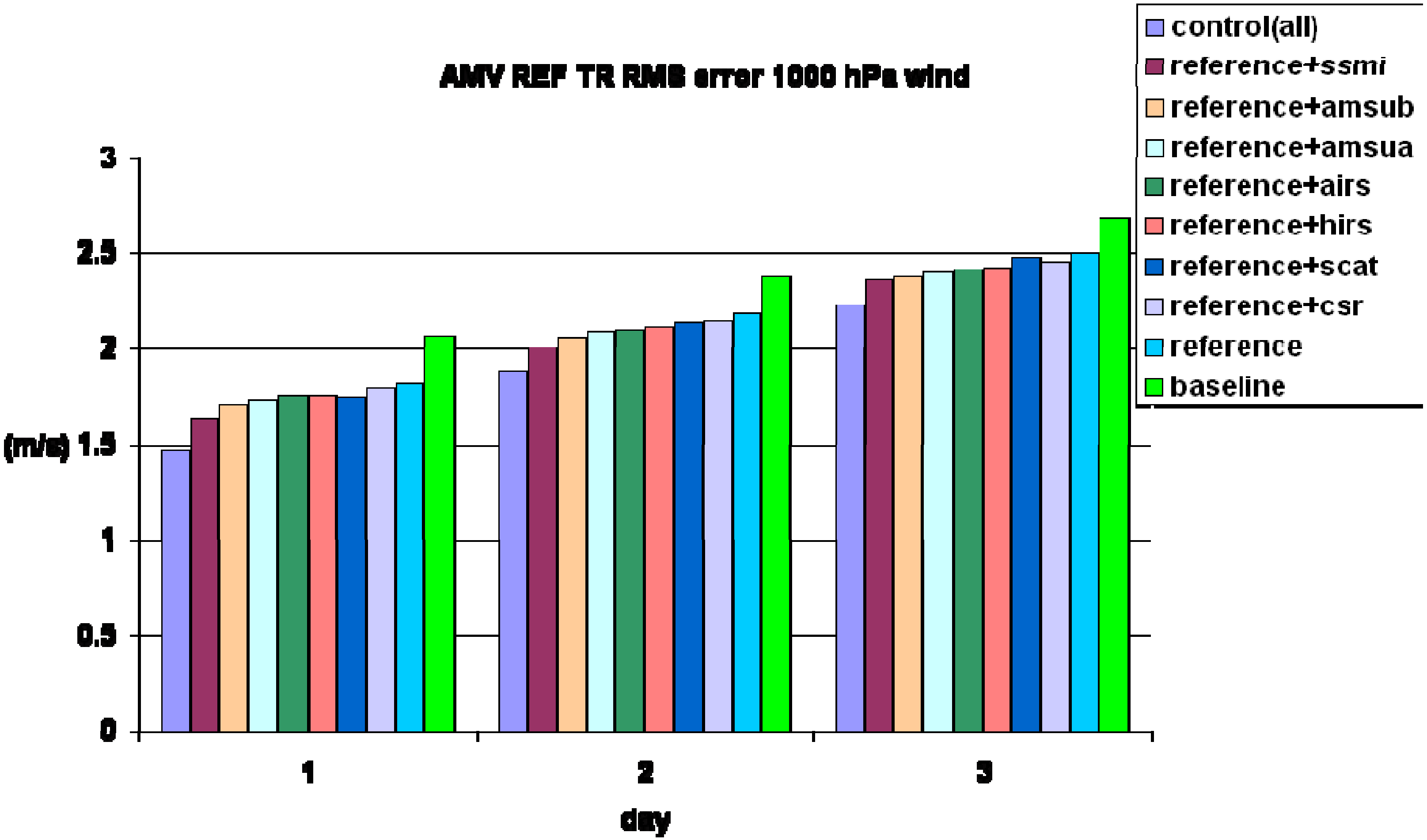
Mean normalized 48-hour forecast error difference between and AMV(REF)+SSMI and AMV(REF) for the 850 hPa relative humidity.

Impact of adding SSMI to the AMV(REF)

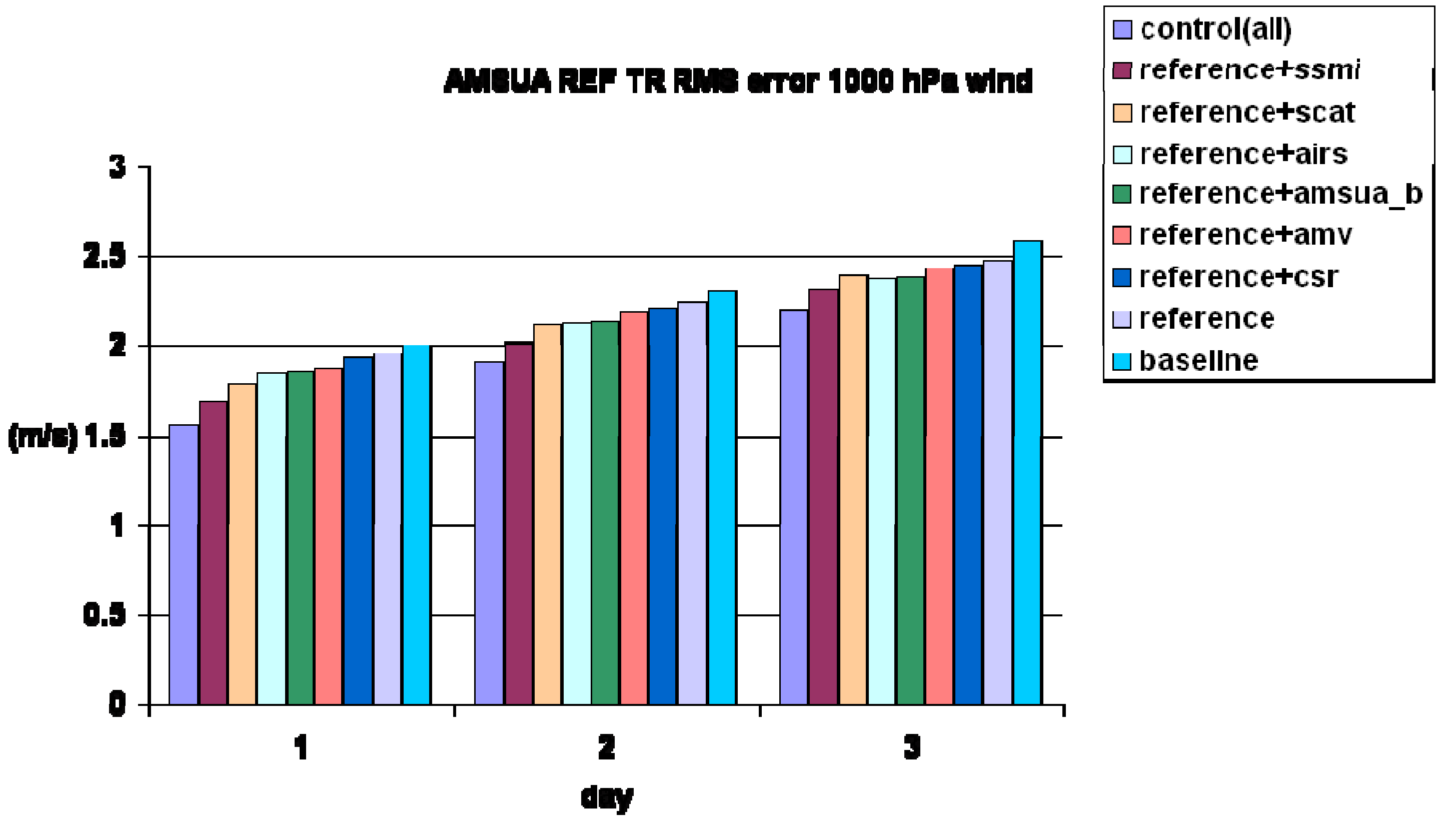


Time series of normalized 500 hPa height *rmse* differences between *AMV(REF)+SSMI* and AMV(REF) for forecast errors up to day 7 in the Tropics Negative values indicate positive impact for the AMV(REF).

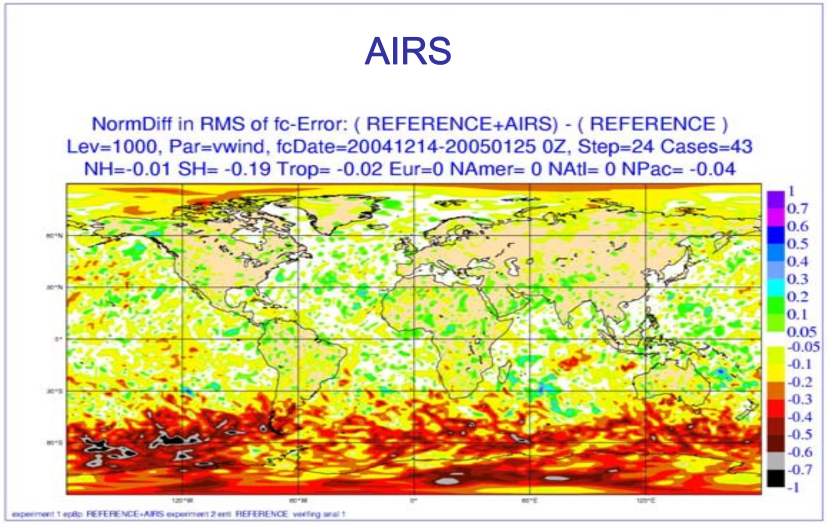
Impact of all sensors on 1000 hPa vector wind for the tropics for *AMV(REF)*

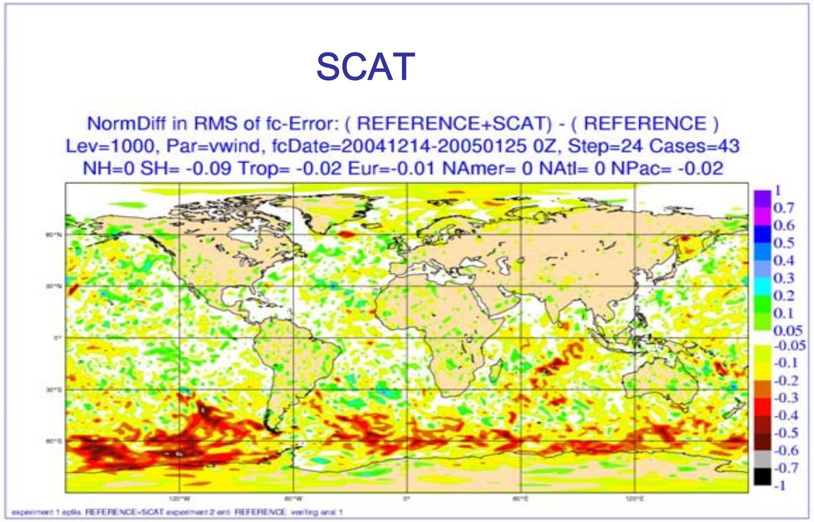


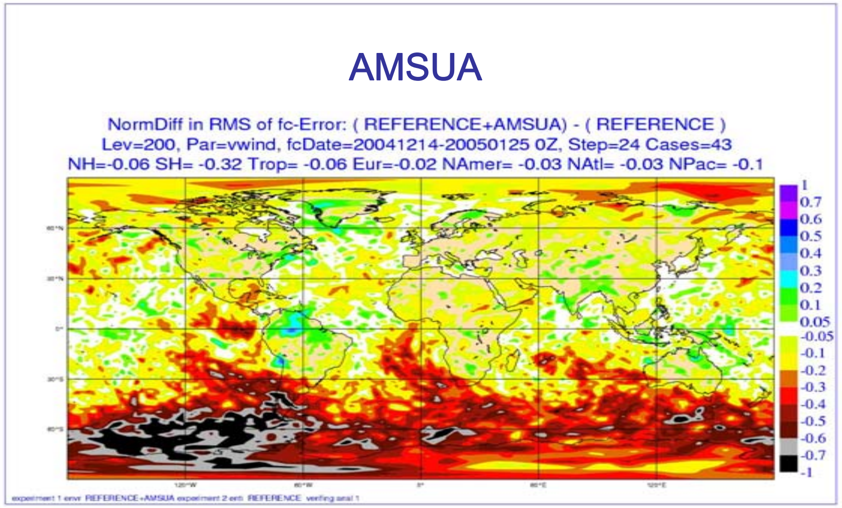
Impact of all sensors on 1000 hPa vector wind for the tropics for *AMSUA(REF)*

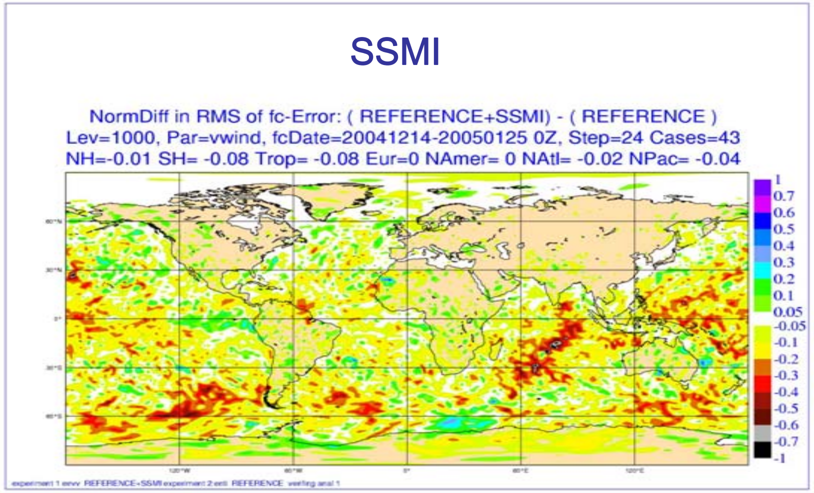


Impact of adding AMSUA,HIRS,SCAT and SSMI to the *AMV(REF) for 1000 hPa Wind*

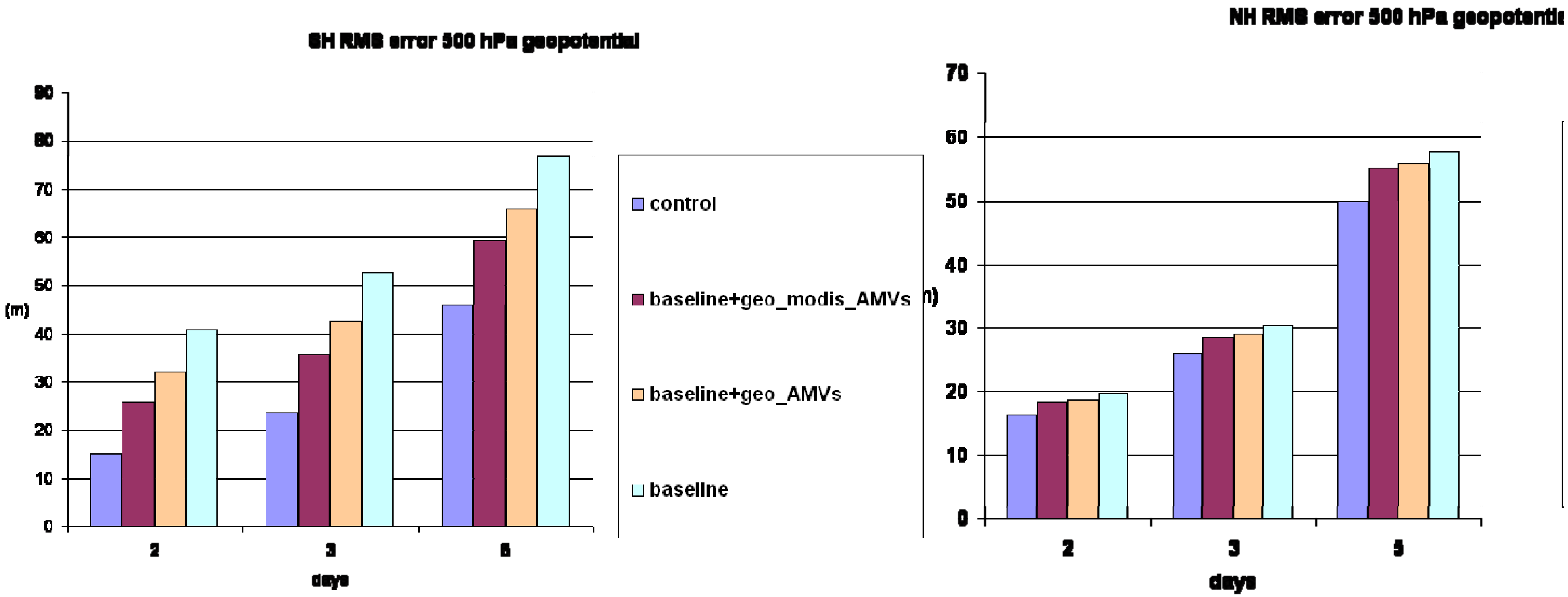




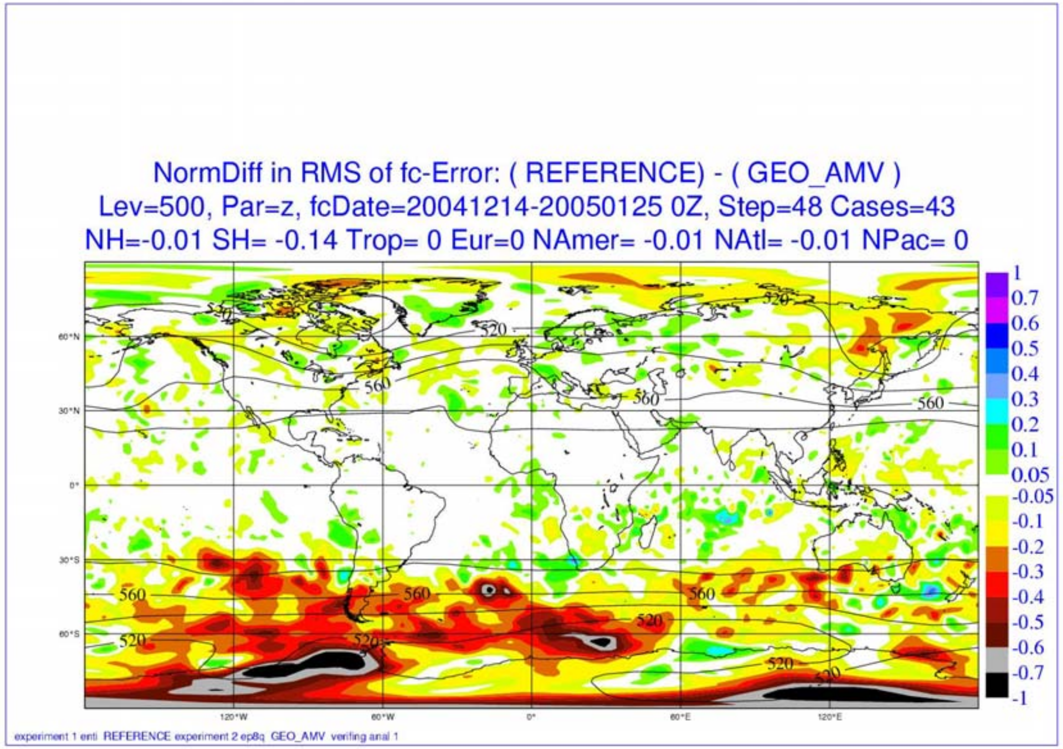




Impact of MODIS AMVs on 500 hPa geopotential for (a) southern hemisphere (20°–90°S) and (b) northern hemisphere (20°–90°N).



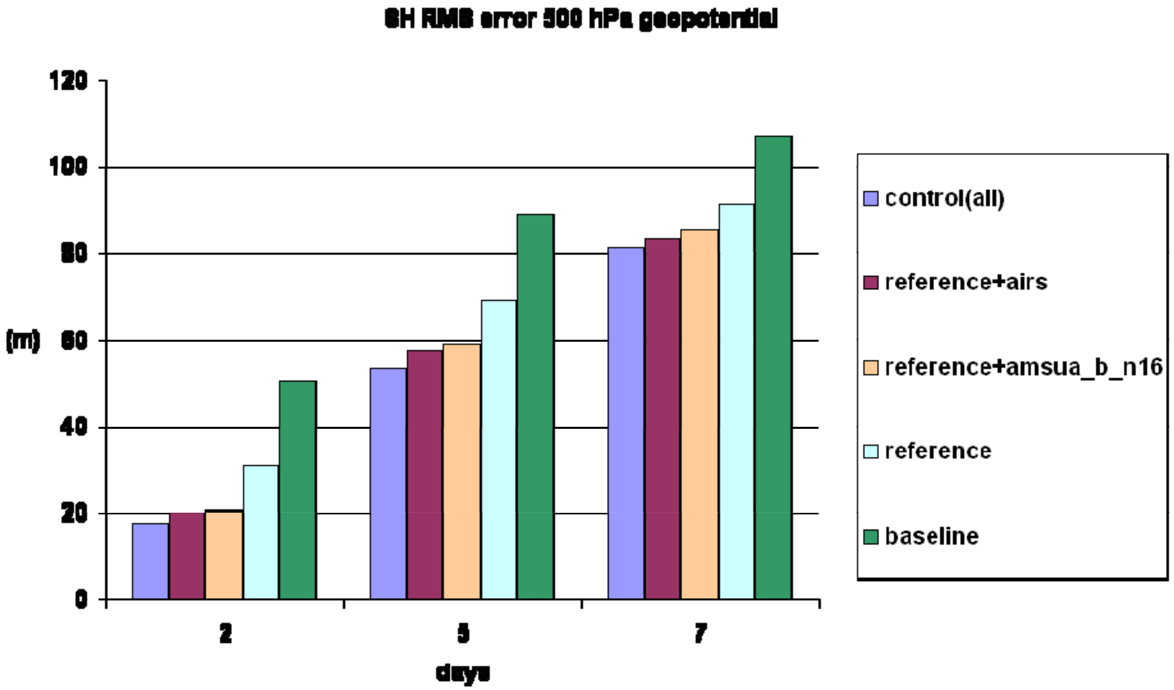
Impact of removing MODIS from the *AMV(REF)*



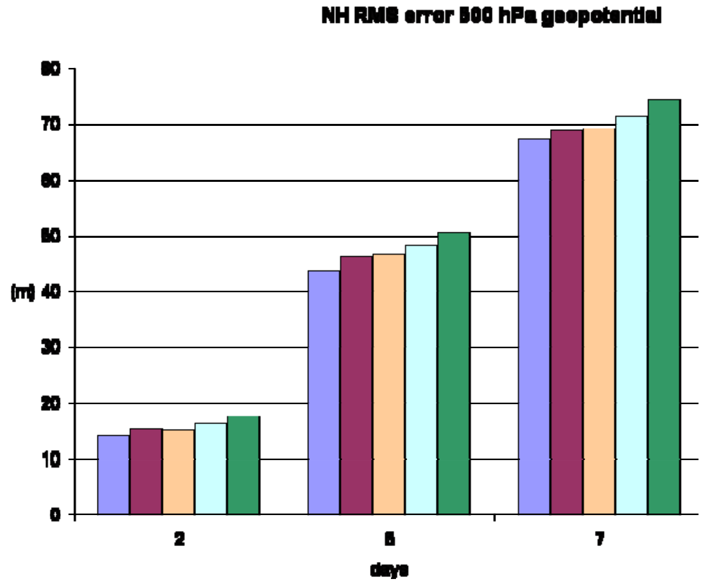
Mean normalized 48-hour forecast error difference between and AMV(REF) and AMV(REF)-GEO(AMV) for the 500 hPa geopotential height.

Comparison of AIRS and with the two microwave instruments (AMSU-A and AMSU-B) on NOAA 16

500 hPa geopotential

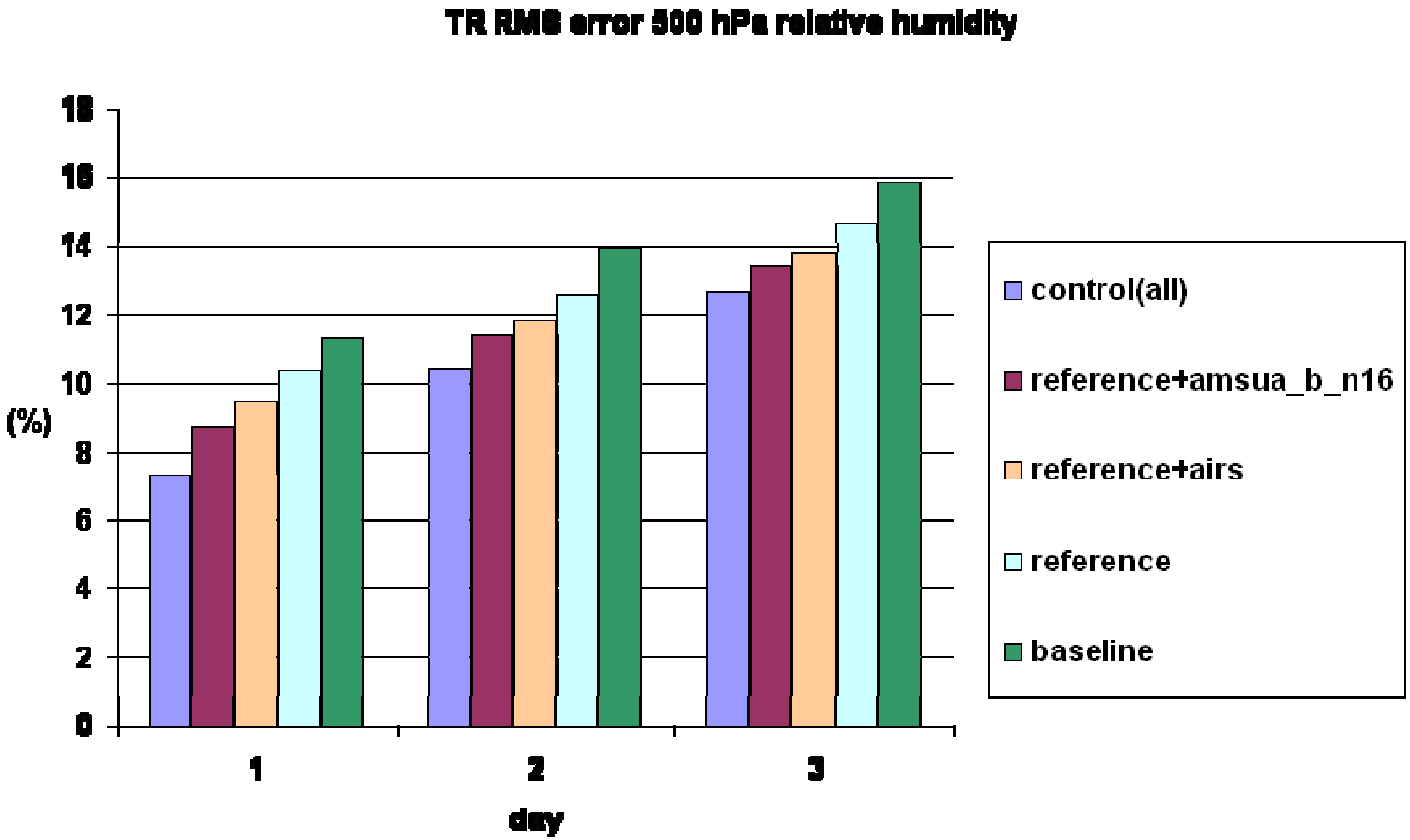


Southern Hemisphere



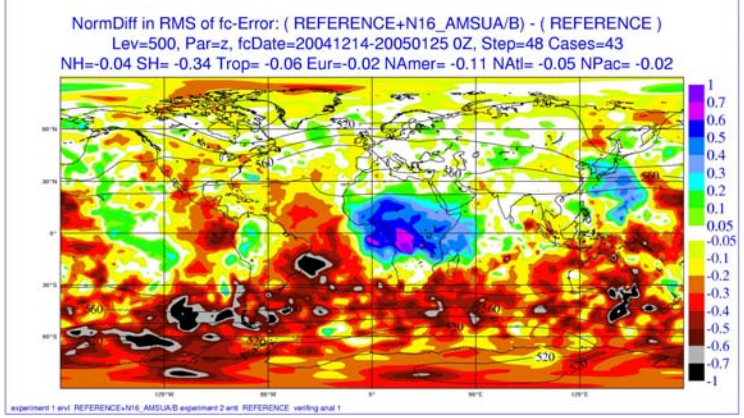
Northern Hemisphere

Comparison of AIRS and with the two microwave instruments (AMSU-A and AMSU-B) on NOAA 16 for 500 hPa relative humidity in the tropics.

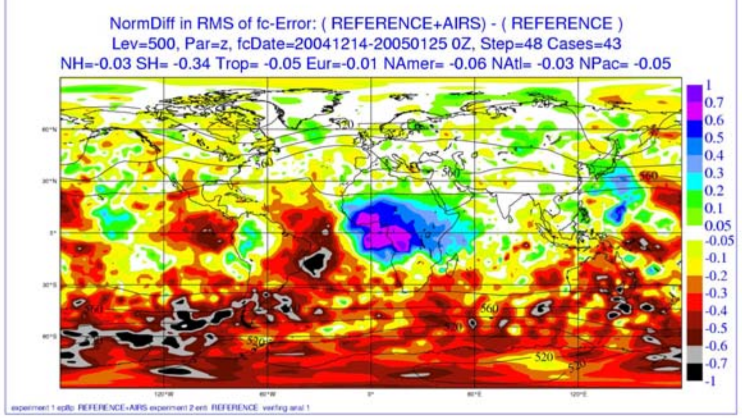


500 hPa Geopotential impact of adding a single AMSUA/B and AIRS to the *AMV(REF)*

AMSUA/B

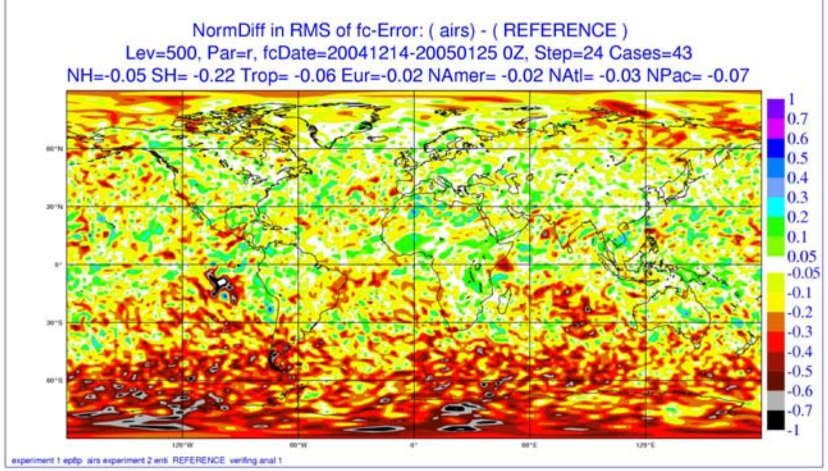


AIRS

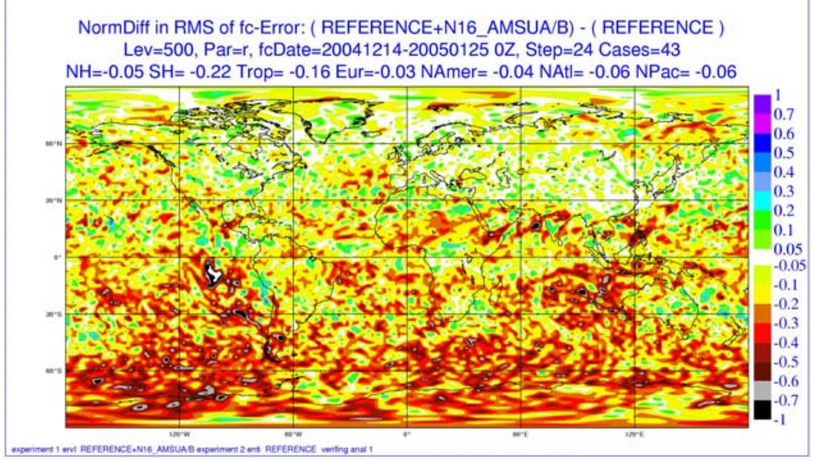


500 hPa Humidity impact of adding AMSUA/B and AIRS to the *AMV(REF)*

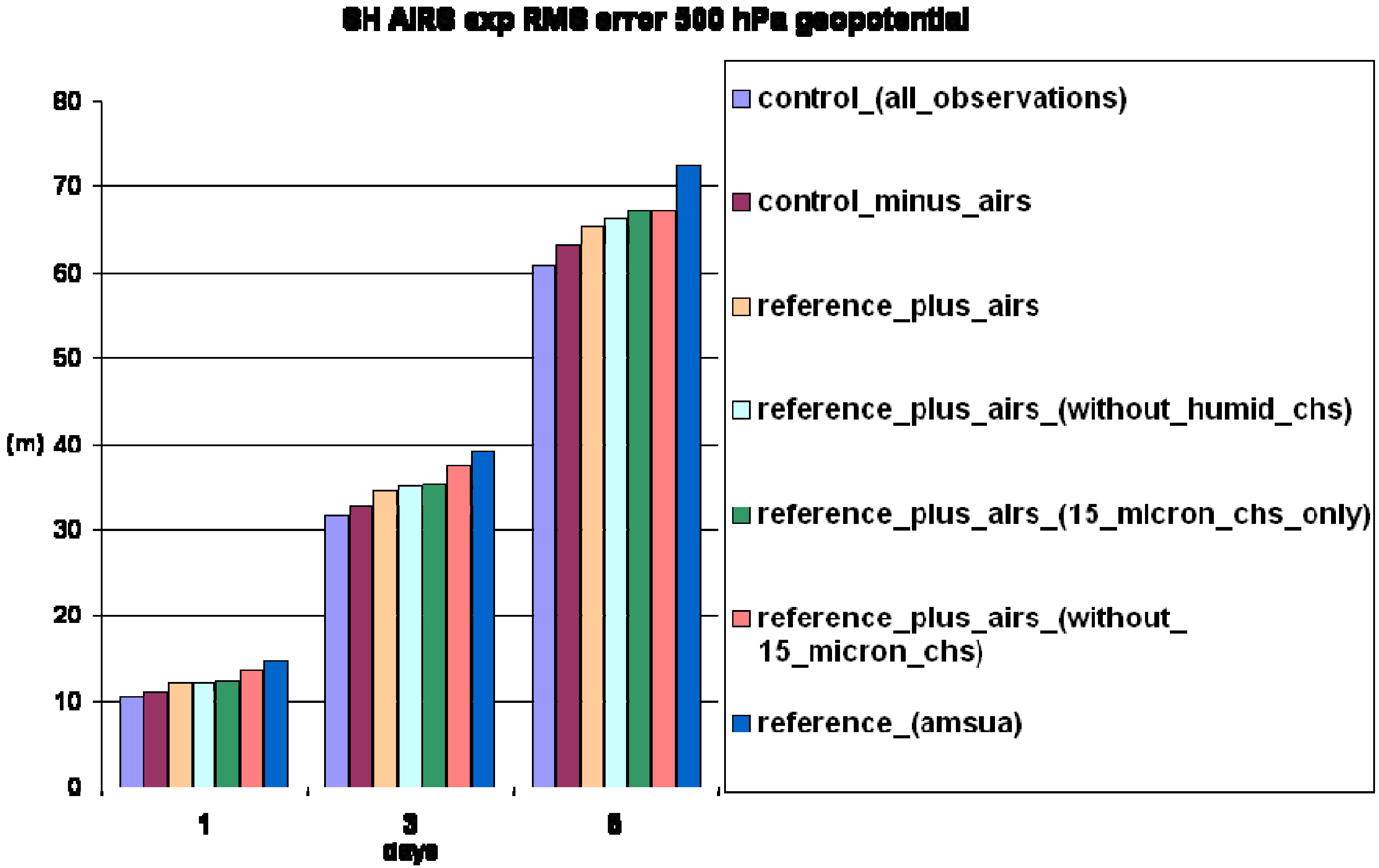
AIRS



AMSUA/B

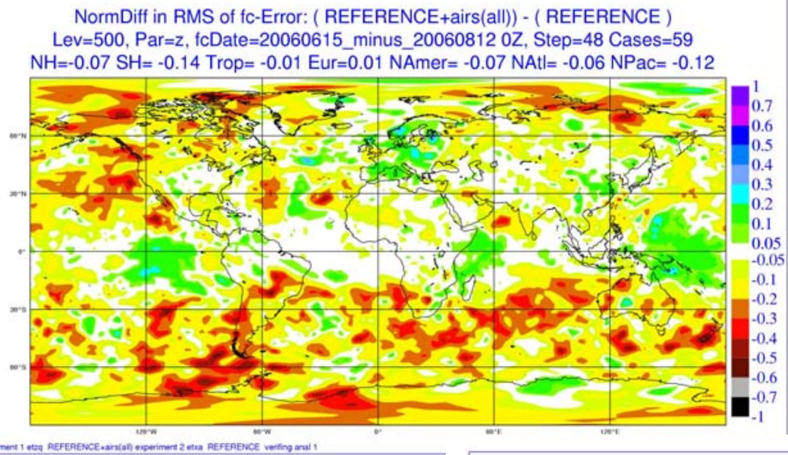


Comparison of the impact of various AIRS channel combinations on 500 hPa geopotential using *AMSUA(REF)*.

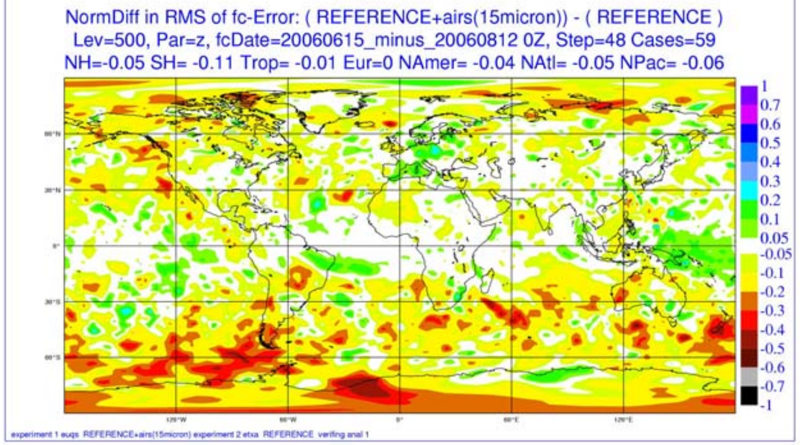


AIRS channels combinations

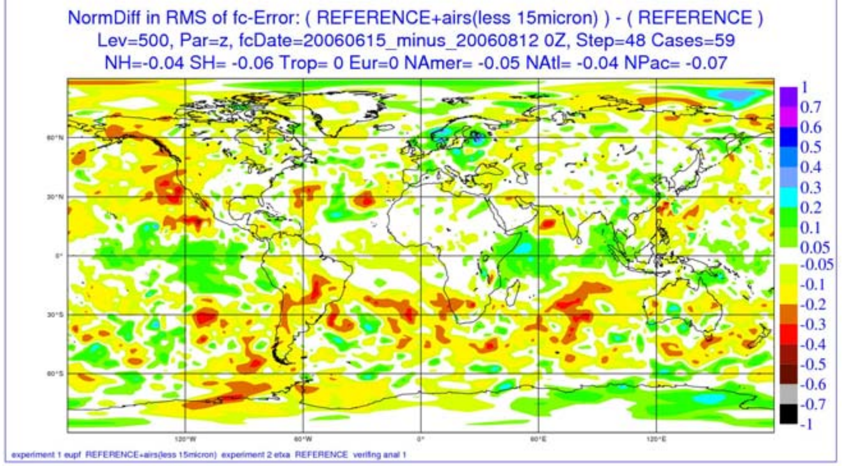
ALL AIRS



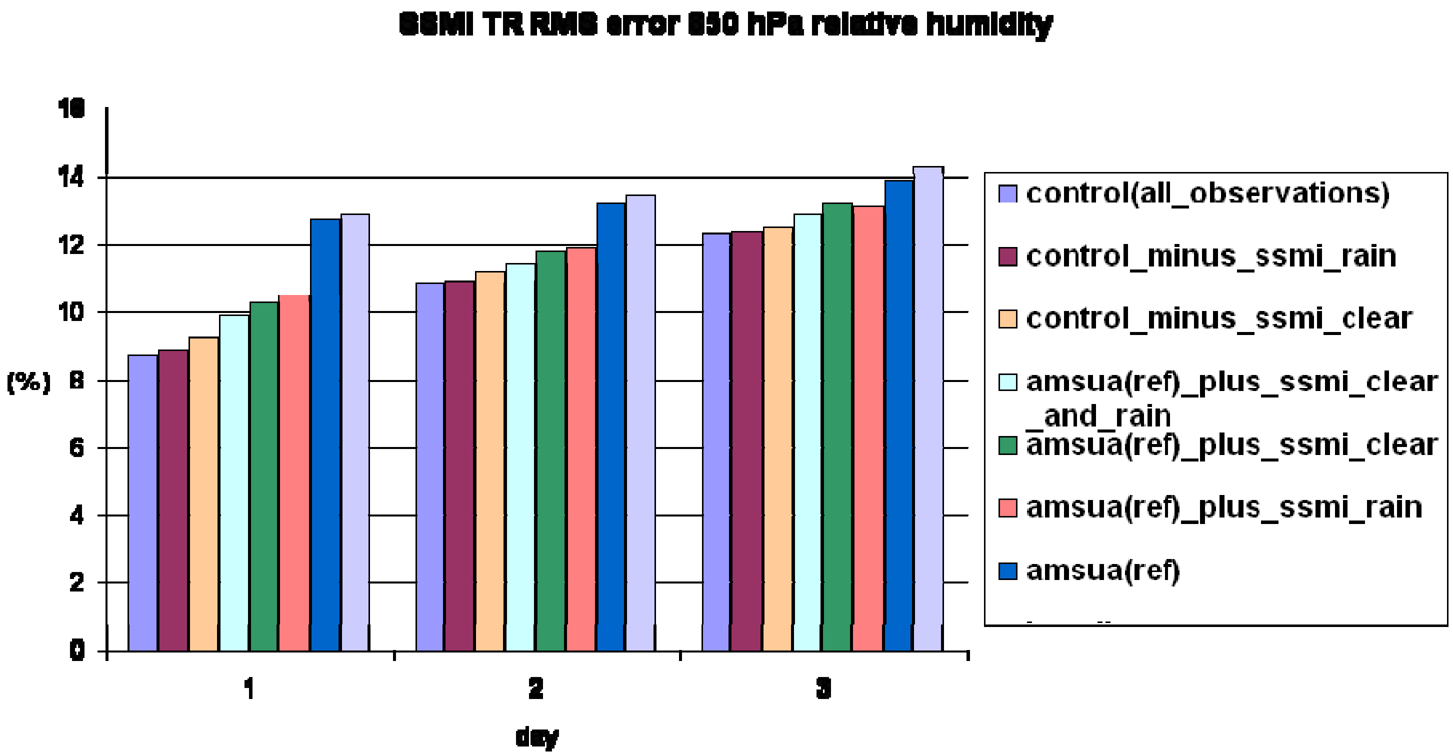
15 MICRON AIRS



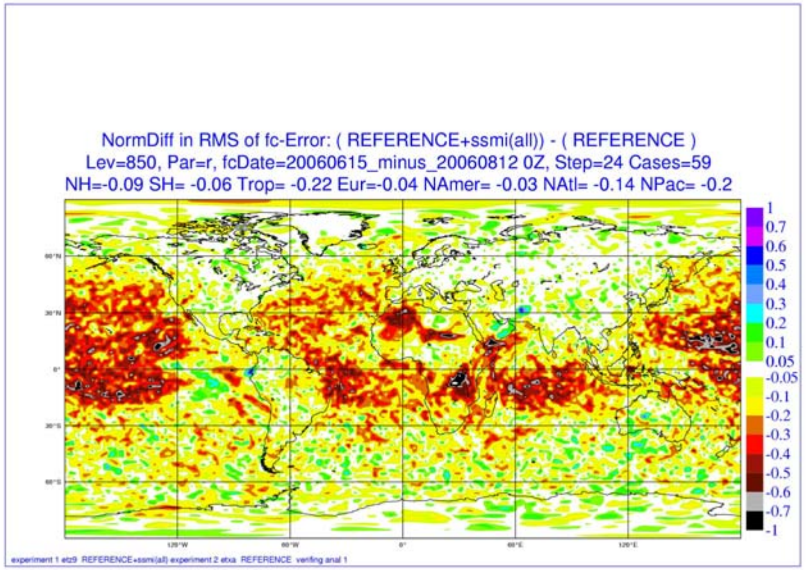
AIRS LESS 15 MICRON

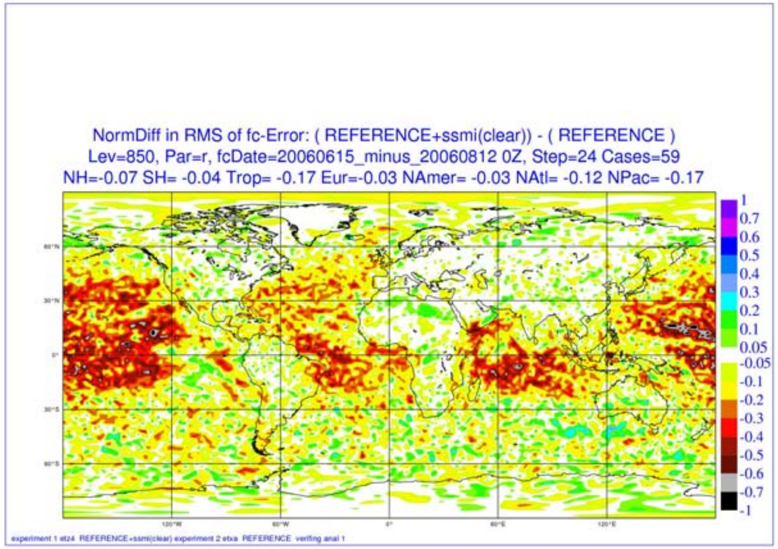


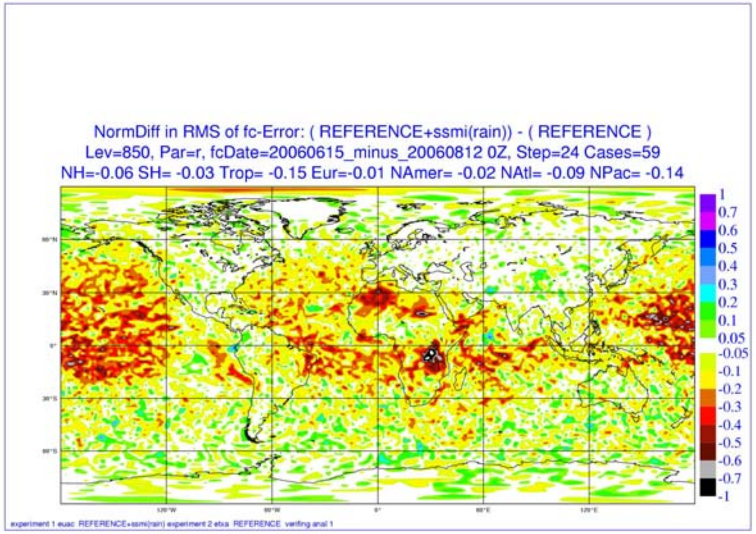
Comparison of the impact of various SSMI usage configurations using *AMSUA(REF)* for 850 hPa relative humidity



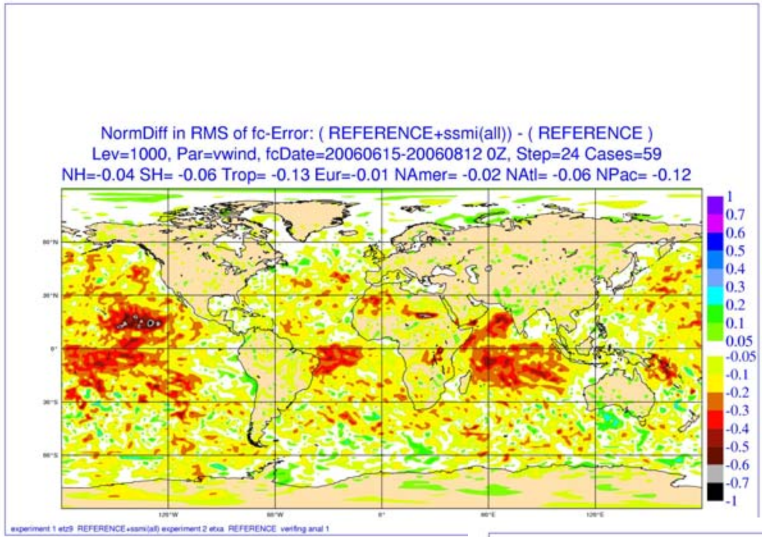
SSMI clear and rainy impact
AMSUA(REF) 850 hPa relative humidity

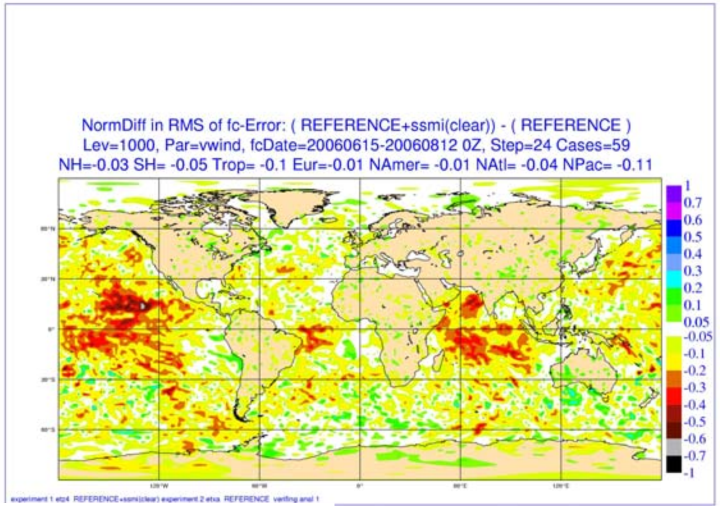


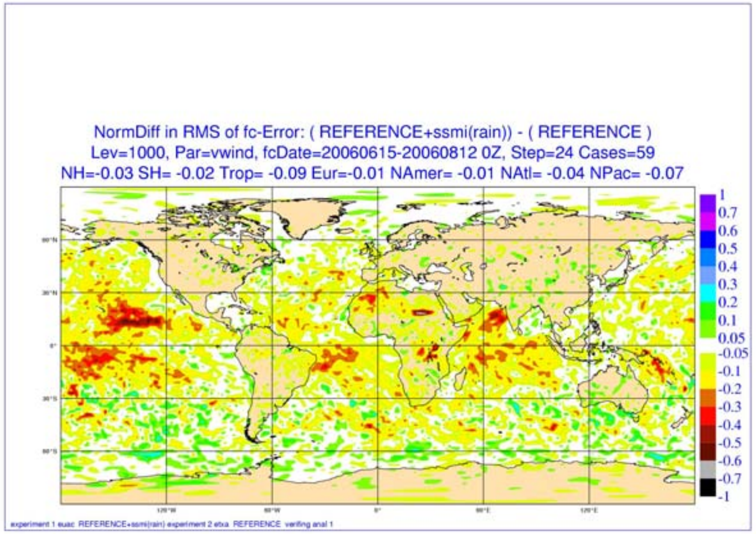




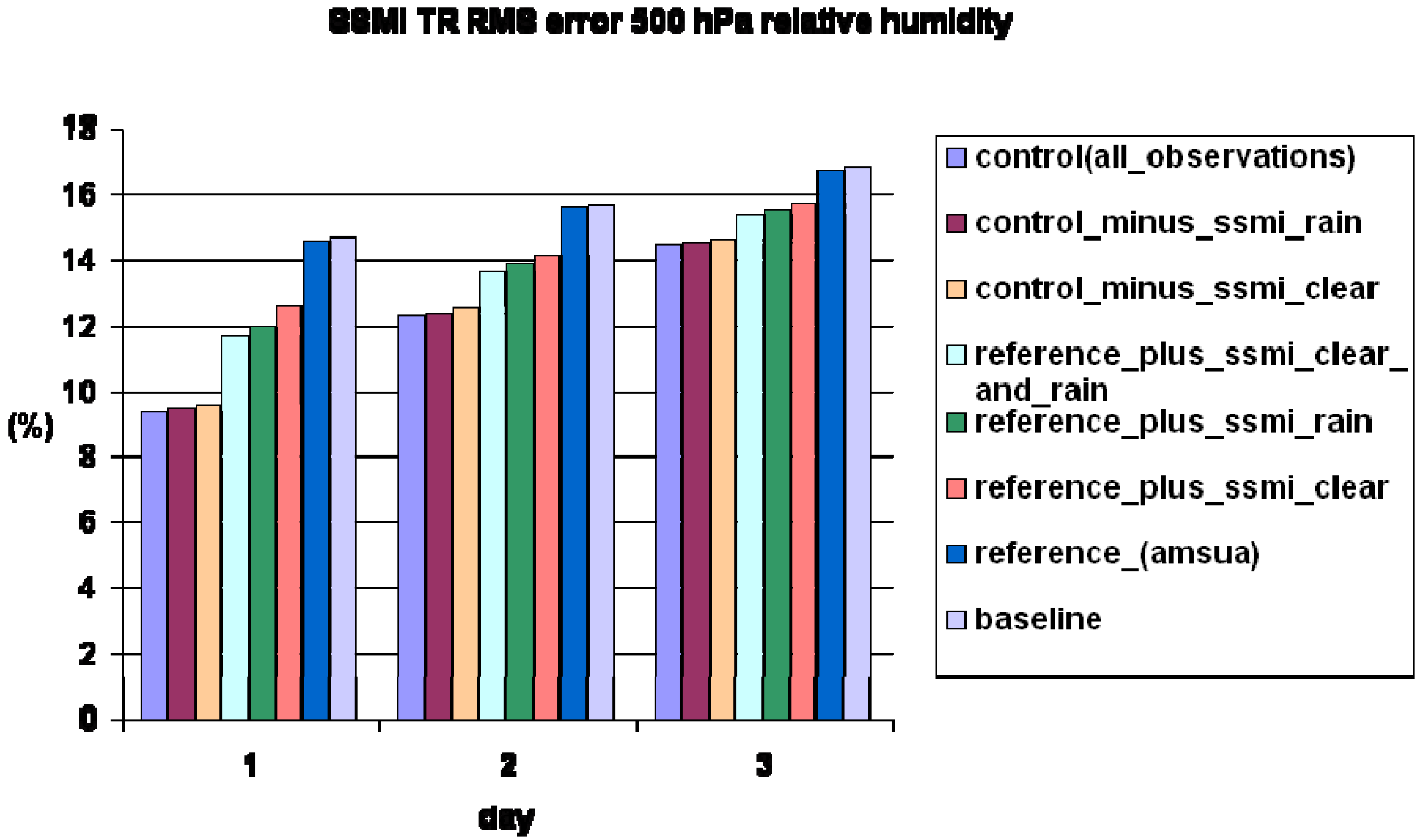
SSMI clear and rainy impact AMSUA(REF) 1000 hPa wind



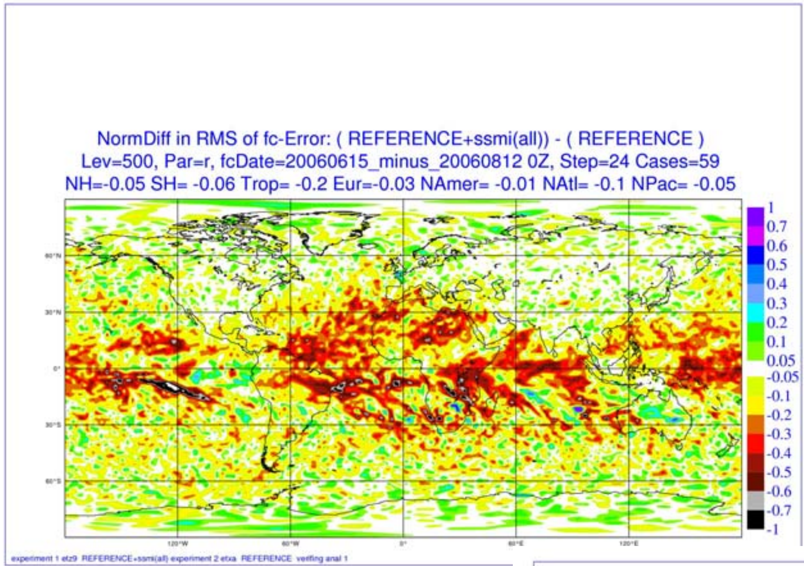


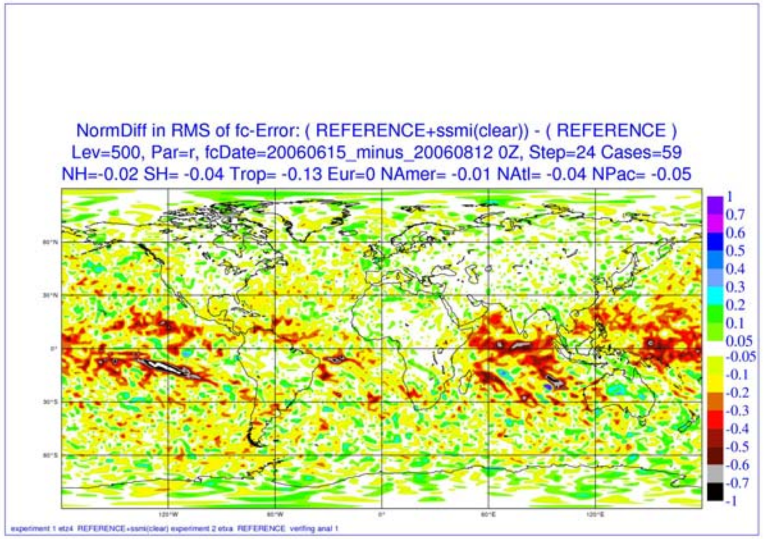


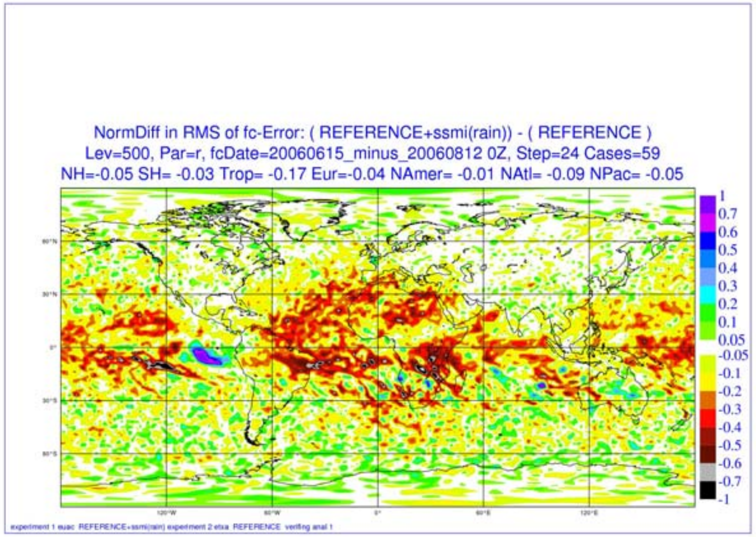
Comparison of the impact of various SSMI usage configurations using *AMSUA(REF)* for 500 hPa relative humidity.



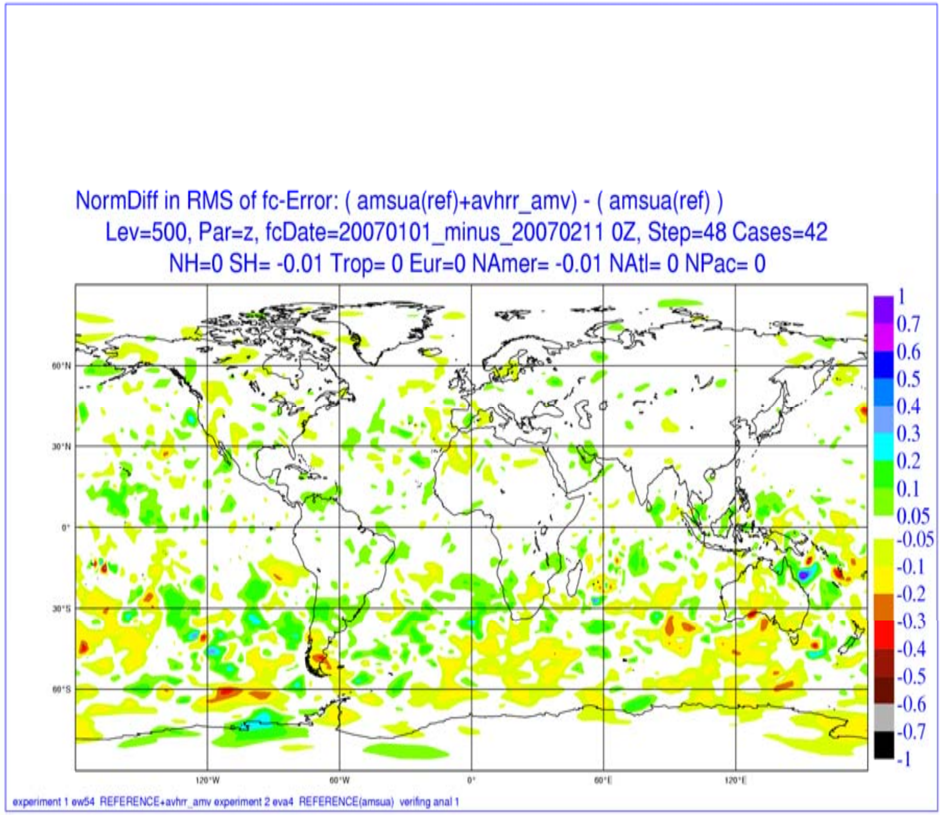
SSMI clear and rainy impact AMSUA(REF) 500 hPa geopotential

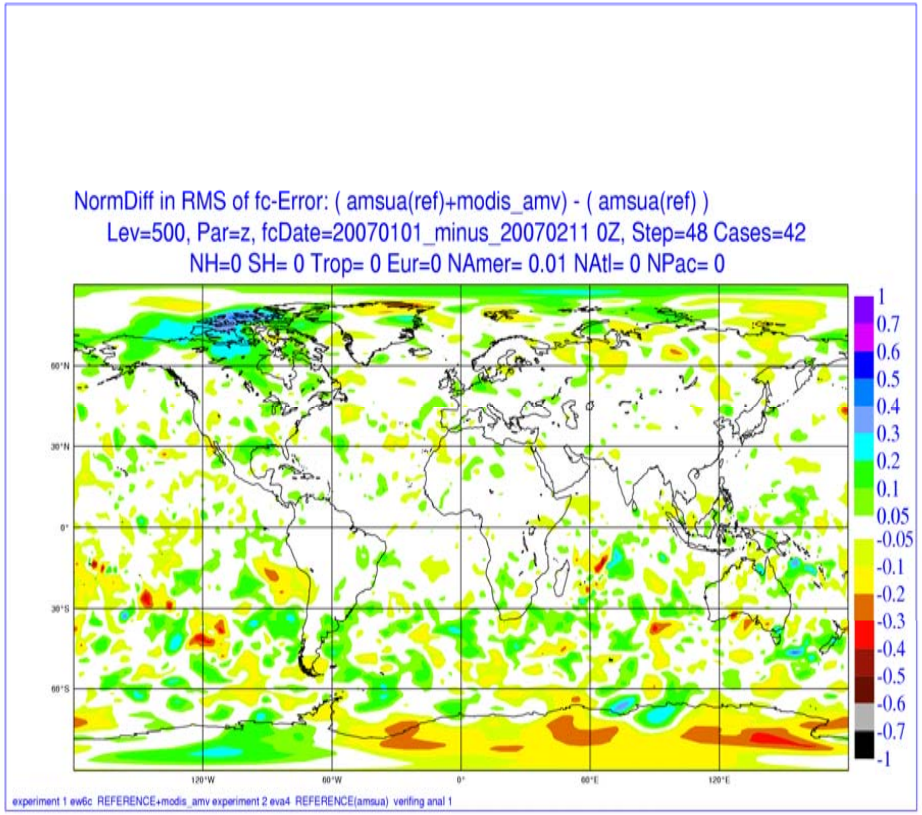






Normalized 48-hour forecast error for 500 hPa geopotential for (a) AVHRR AMVs and (b) MODIS AMVs.

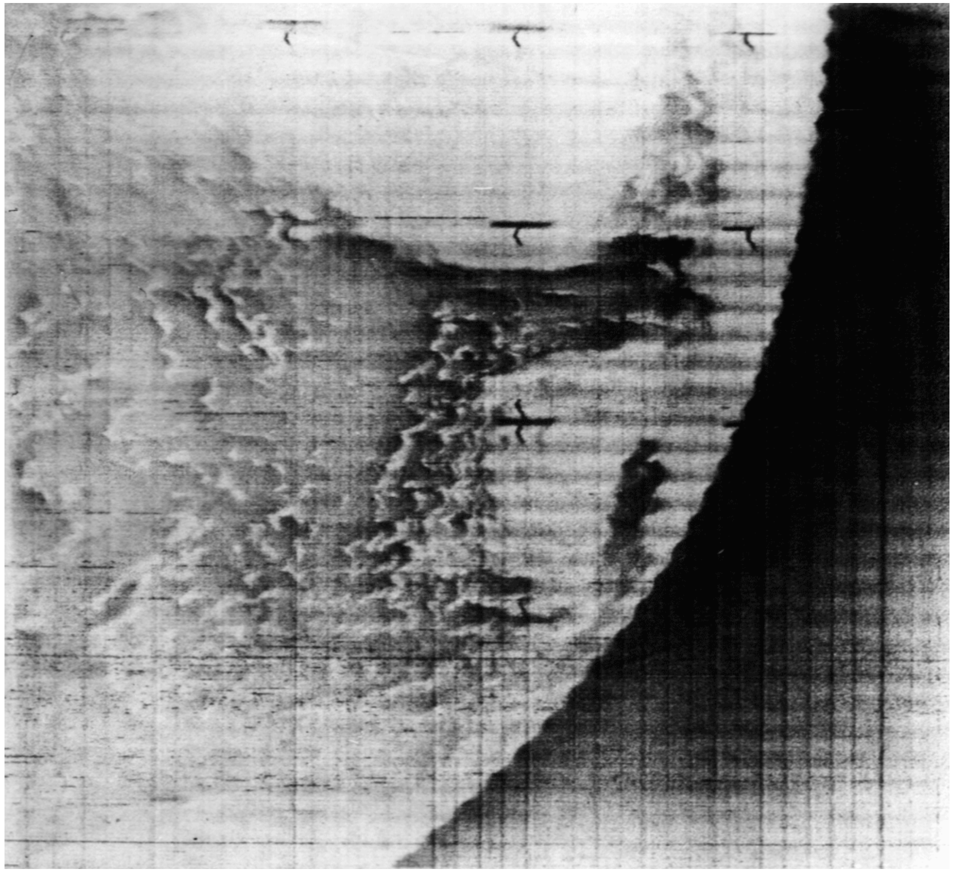




7. Concluding remarks

- Satellite data have been very successfully exploited by new data
- Data Assimilation schemes are such that introducing additional well characterised satellite data improves the system.
- The combined availability of new accurate satellite observations and improvement of models will allow an improved extraction of information content from these new data.(use of cloudy radiances & surface channels)
- The proliferation of new satellite instruments makes it hard for end-users to keep up (choices will have to be done)
- Massive investment in data handling and monitoring is required
- Short-loop dialogue between users and space agencies is vital (timeliness remains an issue)!

TIROS 8 APT



The first satellite TV cloud picture

An extract from
'FEDERATION and METEOROLOGY, 2000'

Australian Government Publication

recalls:
"Keith (Henderson) can recall numerous career highlights, but particularly remembers the first satellite picture to be transmitted to the Bureau. TIROS-8, the first US meteorological satellite to carry an APT camera, was launched on 21 December 1963 and the first picture was received four days later. Keith was there, with Graeme Kelly, to operate the manual system—at about 1.00 pm on Christmas Day."

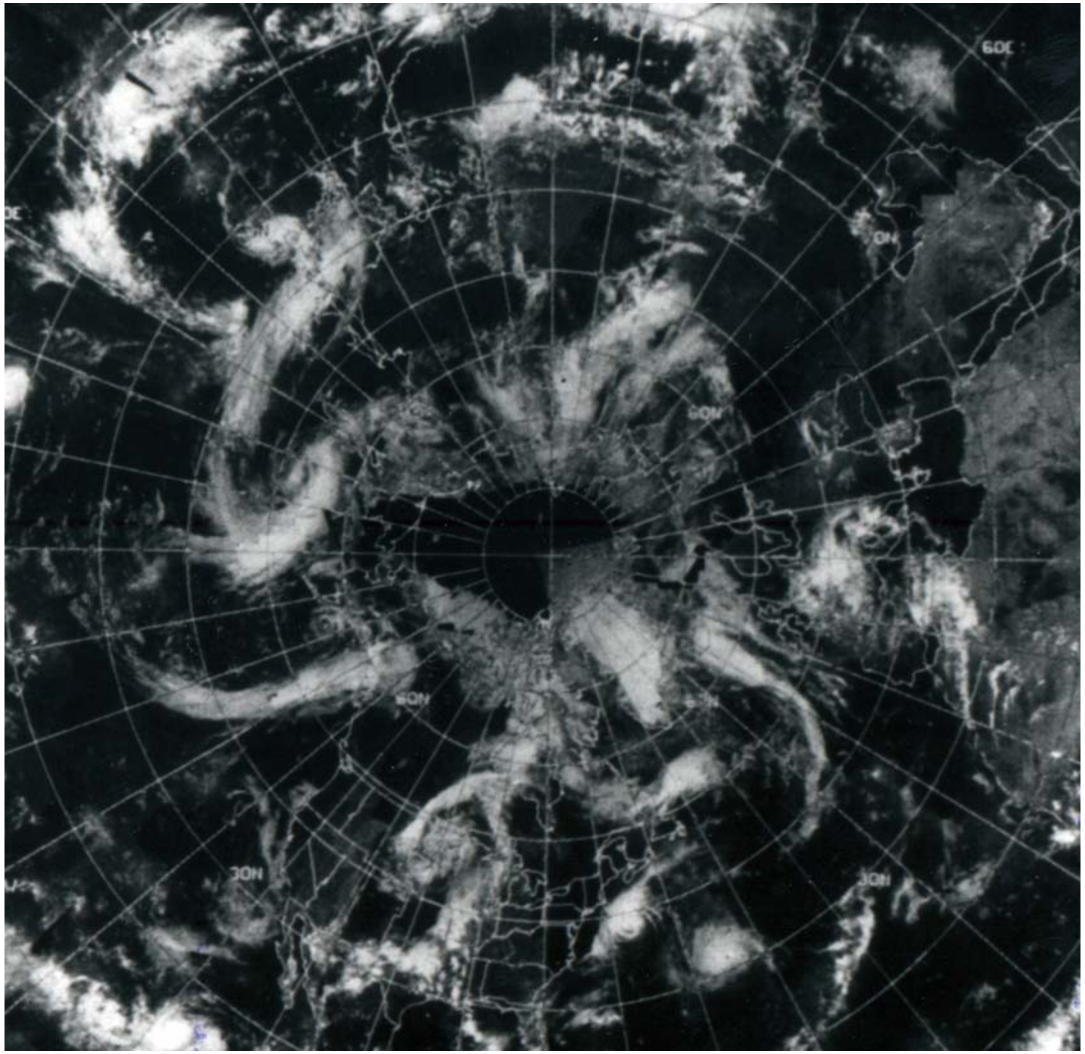
NIMBUS 2 NASA

NIMBUS II

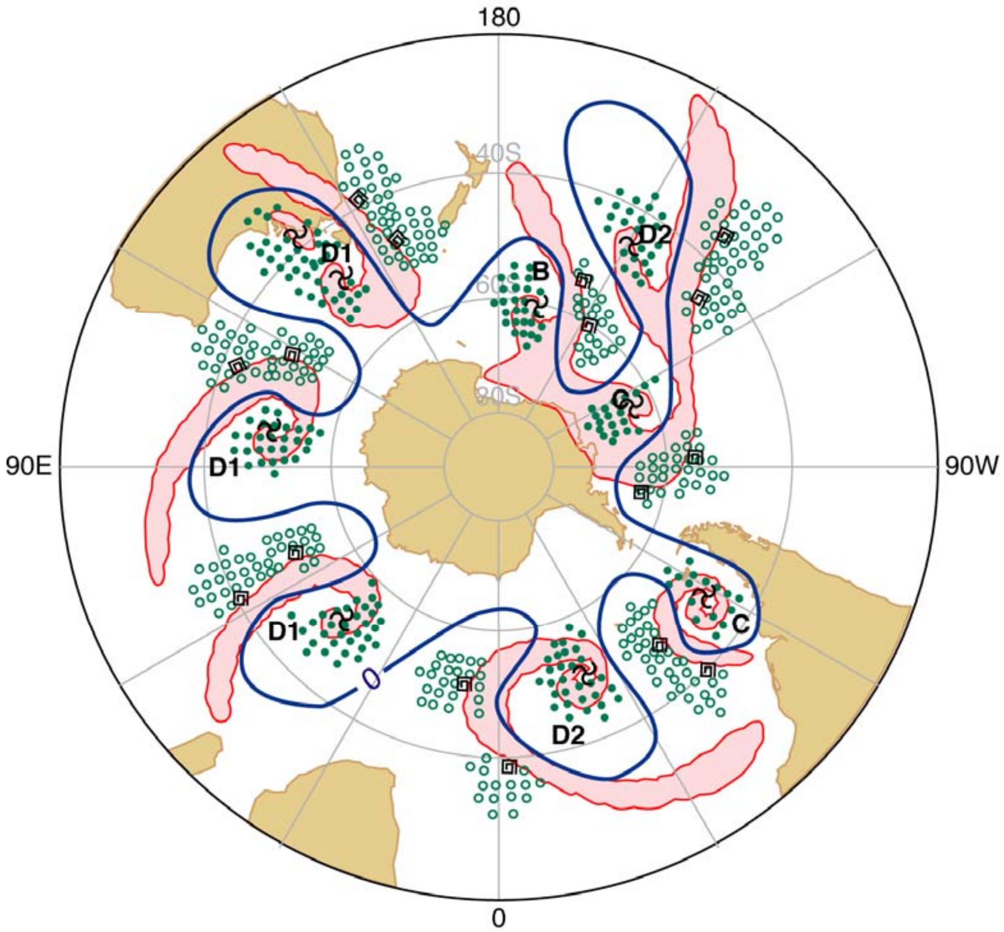
11µ image
HRIR on NIMBUS 2
allowed full day night
cloud surveillance for
forecasters and
measurements of
surface properties.

Hurricane inez
7 October 1966

Global re-mapped 11μ imagery from ESSA 5 satellite on September 14, 1967



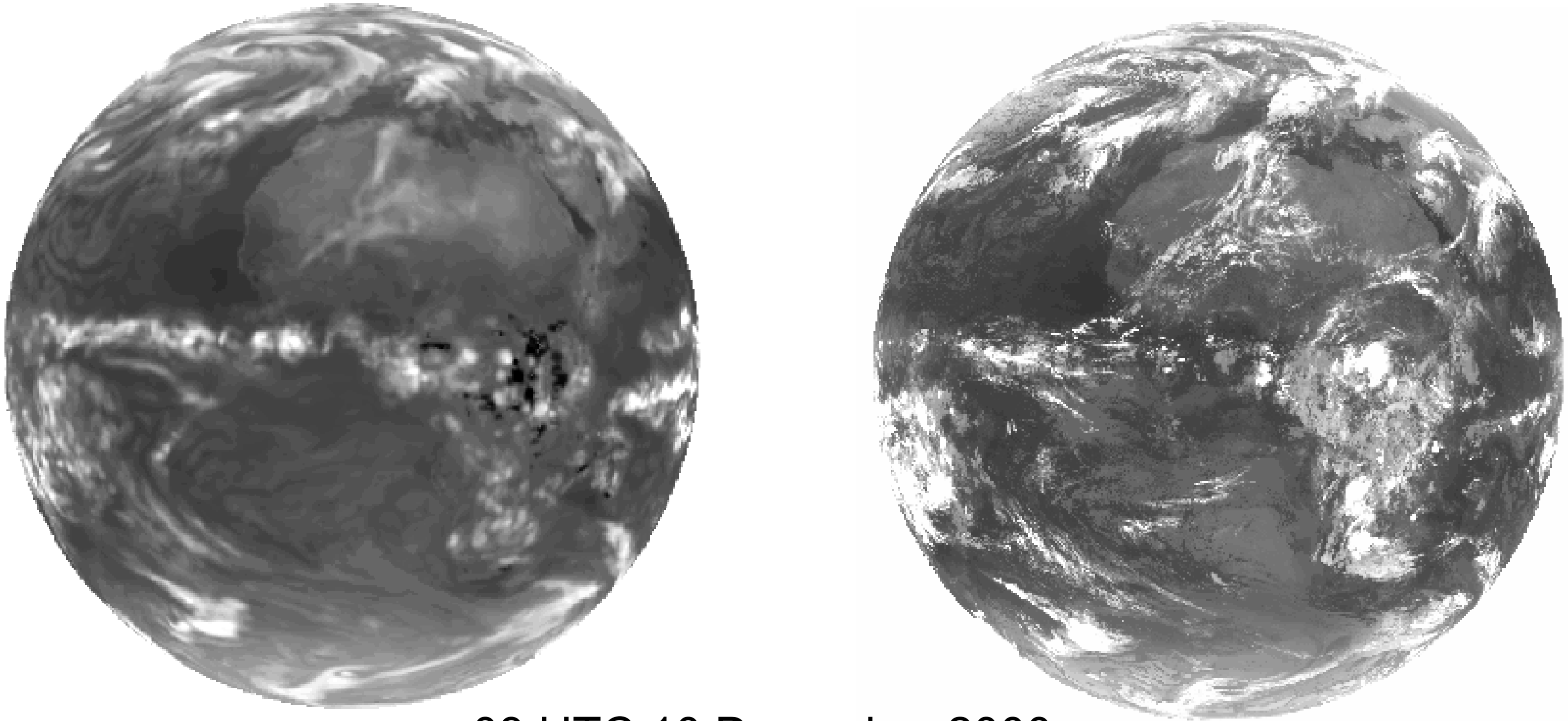
Use of cloud imagery in NWP



A semi-objective procedure to modify mean sea level pressure and 1000-500 hPa thickness using cloud vortex patterns obtained from satellite imagery.

The method combines the previous work of Nagle and Hayden (1971) and Troup and Streten (1973), and is designed for operational use, particularly in the Southern Hemisphere. The method is capable of reproducing synoptic-scale structure that can be deduced from cloud data and incorporated into a numerical analysis system using PAOBs. (Kelly,1978)

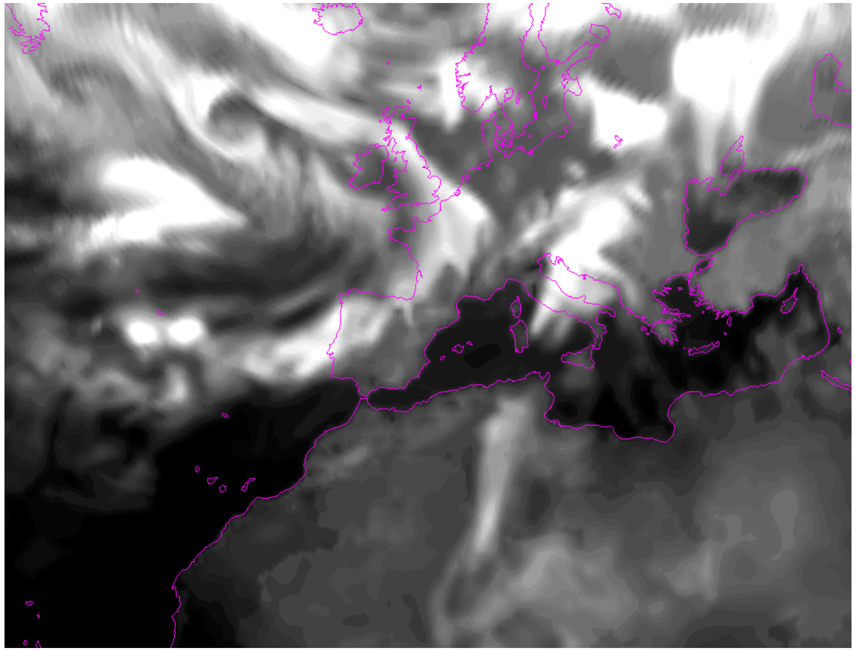
Model Clouds as Seen from Space: Comparison with Geostationary Imagery in the 11µ Window Channel

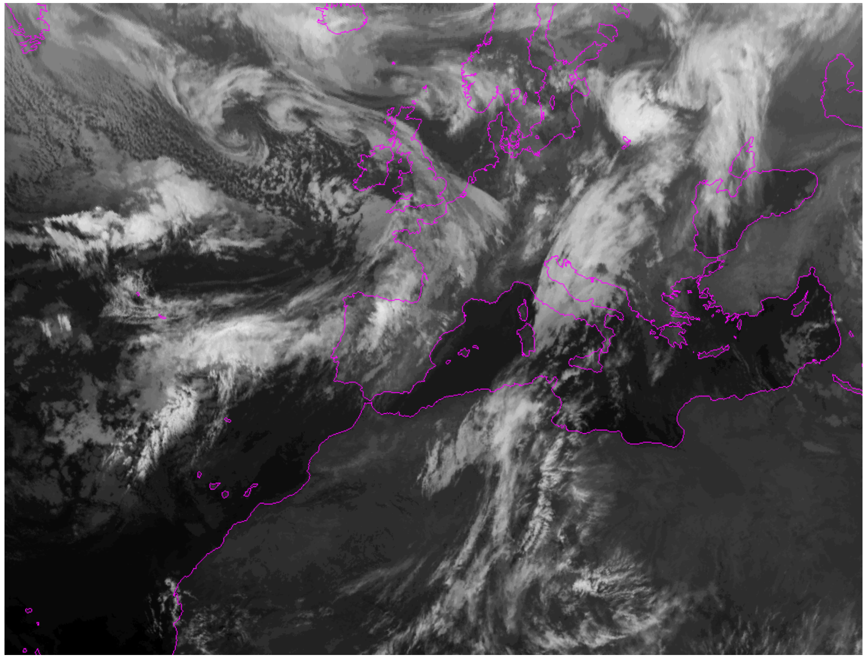


03 UTC 10 December 2000

F. Chevallier and G. Kelly Monthly Weather Review
Volume 130, Issue 3 (March 2002) pp. 712722

Model Clouds as Seen from Space: Comparison with Geostationary Imagery in the 11µ Window Channel

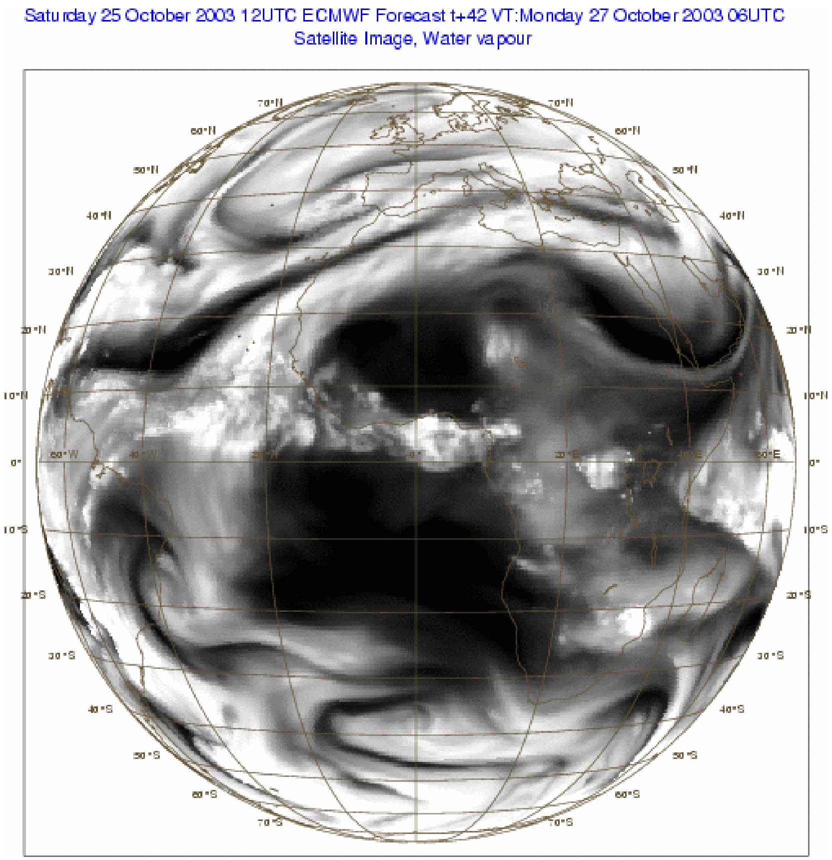


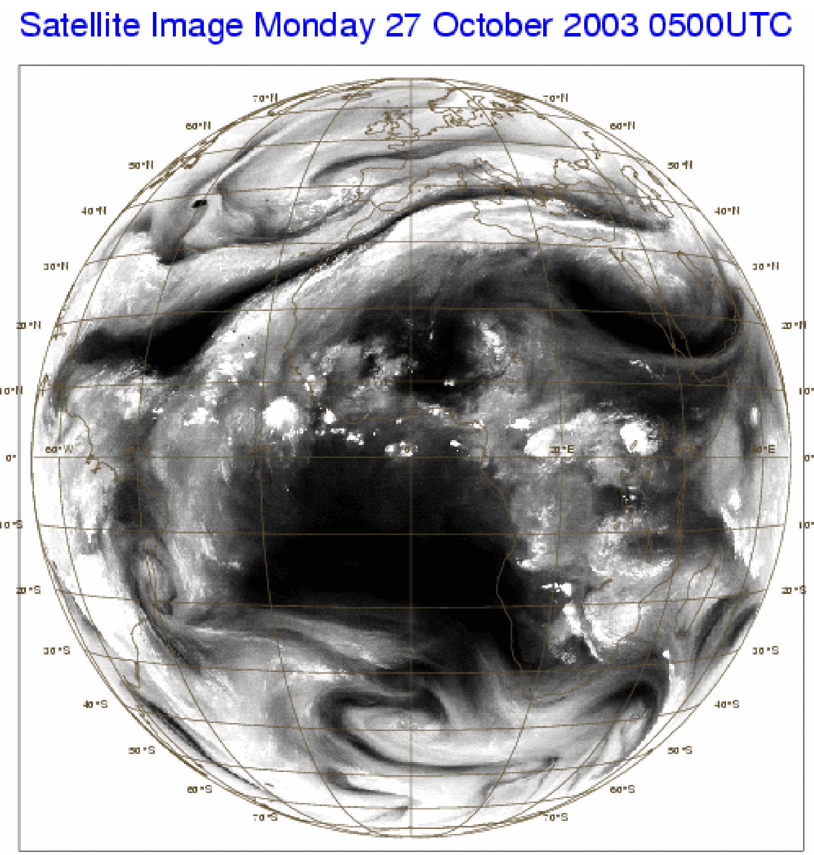


03 UTC 10 December 2000

Forecasted imagery: WV

- 42-hour forecast vs. observed

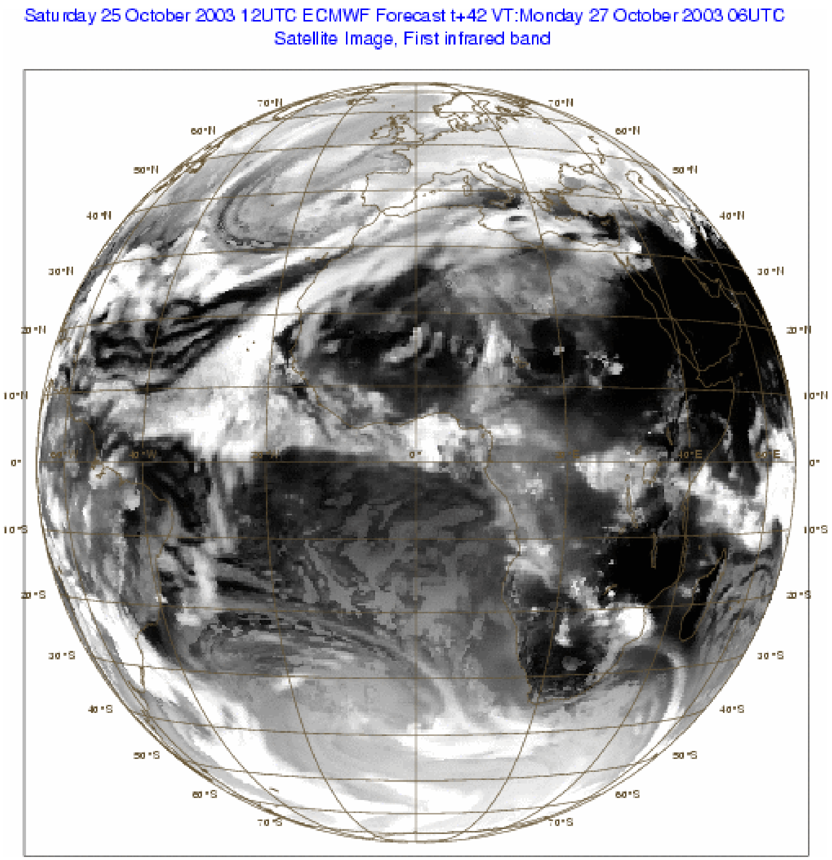


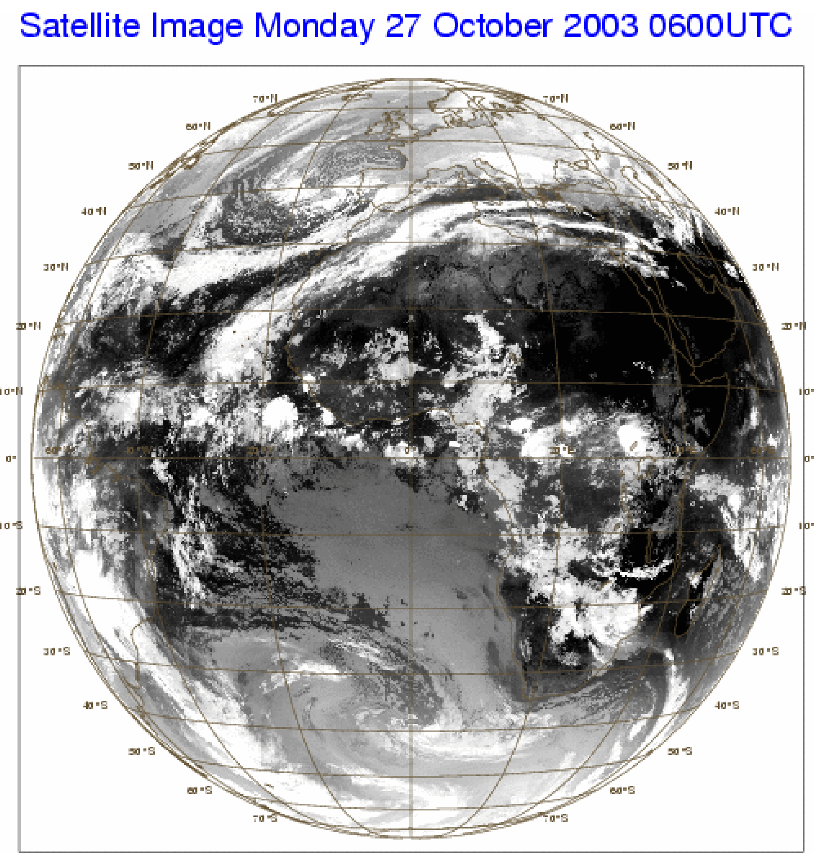


Different grey scales

Forecasted imagery: IR

- 42-hour forecast vs. observed





Different grey scales