

The relative contributions of various space observing systems to the ECMWF forecast system.

EUMETSAT contract

(SOW EUM.MET.SOW.04.0290)

Graeme Kelly (ECMWF)

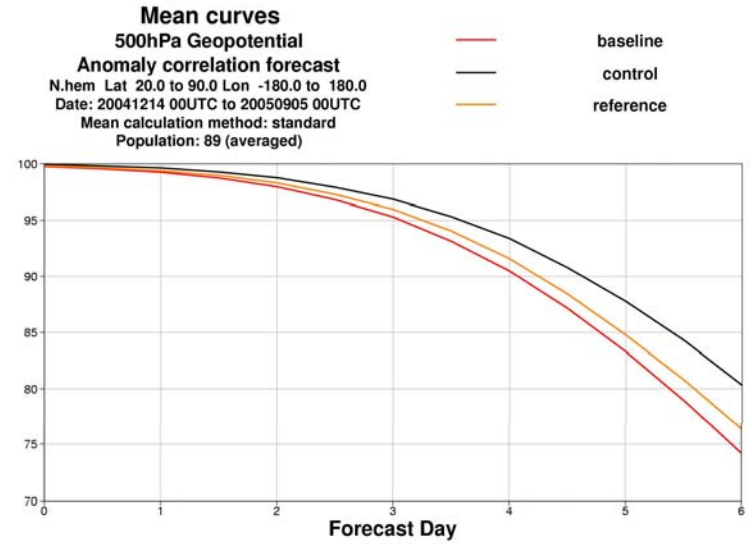
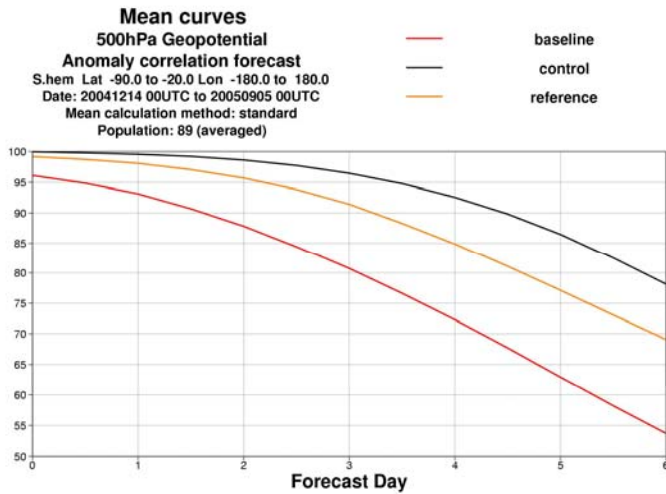
Experimental set-up

- The data assimilation framework used for all the OSEs presented in this report corresponds to the system operational until June 2005 (cycle 29r1). Winter period, from 20041204 until 20050125 and a Summer period from 20050715 until 20050915.
- The first 10 days are excluded from the verification to ensure a reasonable warm-up phase for each assimilation scenario. No real difference in the impact was found between summer and winter so the mean scores were combined to give a sample of 89 days for each experiment. In total more than 1000 days of data assimilation were run including the warm up period. All experiments are validated using the operational analysis.
- The main characteristics are listed below:
 - T511 L60 forecast model resolution
 - 4D-Var assimilation, 12 hour window
 - T95/T159 L60 analysis inner loop resolution
 - T511 L60 analysis outer loop resolution
- Conventional observations currently assimilated in the system include:
 - Radiosondes, Pilots and wind profilers
 - Synops, Ships, METARS and buoys (moored and drifters)
 - Aircrafts (AMDARS, AIREPS, ACARS) including ascent/descent reports

The observational scenarios tested

- (i) **BASELINE** all conventional observations used in NWP (radiosonde + aircraft + profiler network + surface land data + buoy observations + ship data)
- (ii) **REFERENCE= BASELINE** + Atmospheric Motion Vectors (AMVs) from GEO+MODIS
- (iii) **REFERENCE** + **HIRS** radiances
- (iv) **REFERENCE** + **AMSUA** radiances
- (v) **REFERENCE** + **AMSUB** radiances
- (vi) **REFERENCE** + **SSMI** radiances
- (vii) **REFERENCE** + GEO Clear Sky Radiances (**CSRs**)
- (viii) **REFERENCE** + **AIRS** radiances
- (ix) **REFERENCE** + **SCAT** winds
- (x) **BASELINE** + **GEO** AMVs (no MODIS)

Validation of the use of a REFERENCE assimilation for evaluation of various space components.



RESULTS (1)

- A series of seven different data assimilation (corresponding to different observation scenarios) have been run for a summer and winter period.
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- All these data assimilation experiments have a sensor type added to the **REFERENCE** assimilation from the operational data stream. Some sensors (e.g. AMSUA) are on various operational satellites whereas AIRS only flies on AQUA.
- An additional experiment has been run to evaluate the impact of the MODIS winds and this has been done by removing MODIS winds from the '**REFERENCE**'.

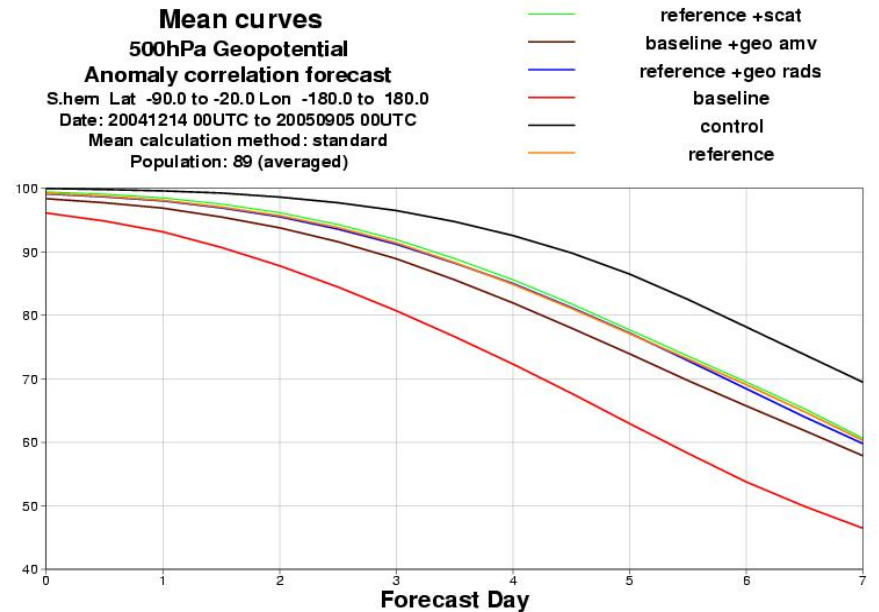
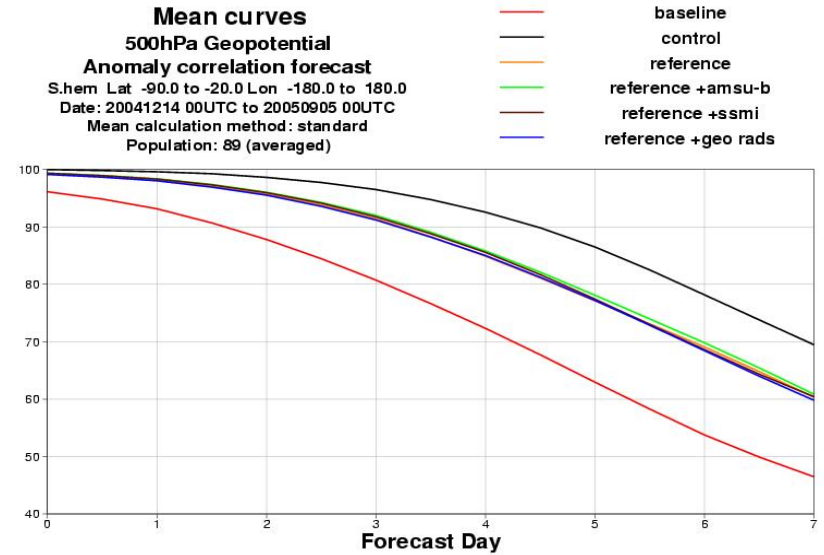
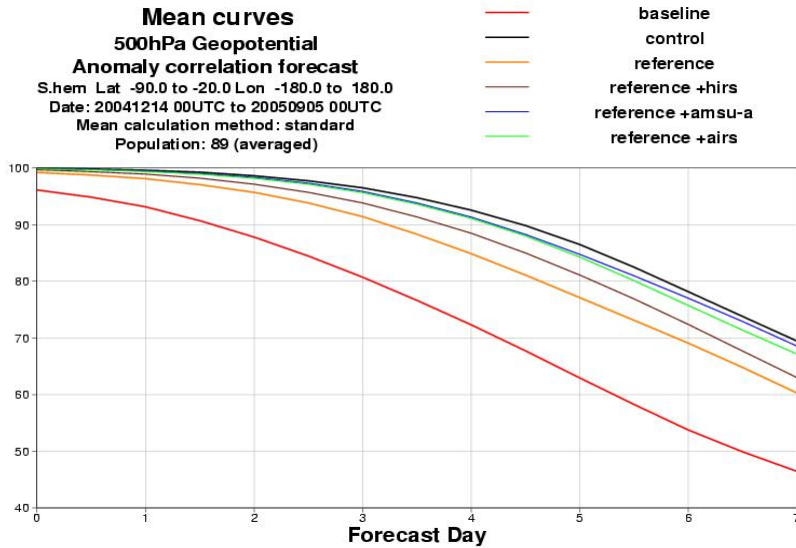
The evaluation of forecasts has also been done using three variables and at various levels

- Geopotential 500 hPa Height (anomaly correlation for mean scores and Normalised RMS error for geographical and scatter plots)
- Relative Humidity at 850,500 and 200 hPa (mean scores in percent and Normalised RMS error for geographical and scatter plots)
- Vector wind at 1000 and 200 hPa (mean scores in percent and Normalised RMS error for geographical and scatter plots)
- The mean plots are grouped into three selections of sensors in order to avoid too much congestion on a single plot:
 - AMSUA ,HIRS and AIRS
 - SSMI, AMSUB and GEO CSR
 - SCAT, GEO AMV and GEO CSR (repeated)

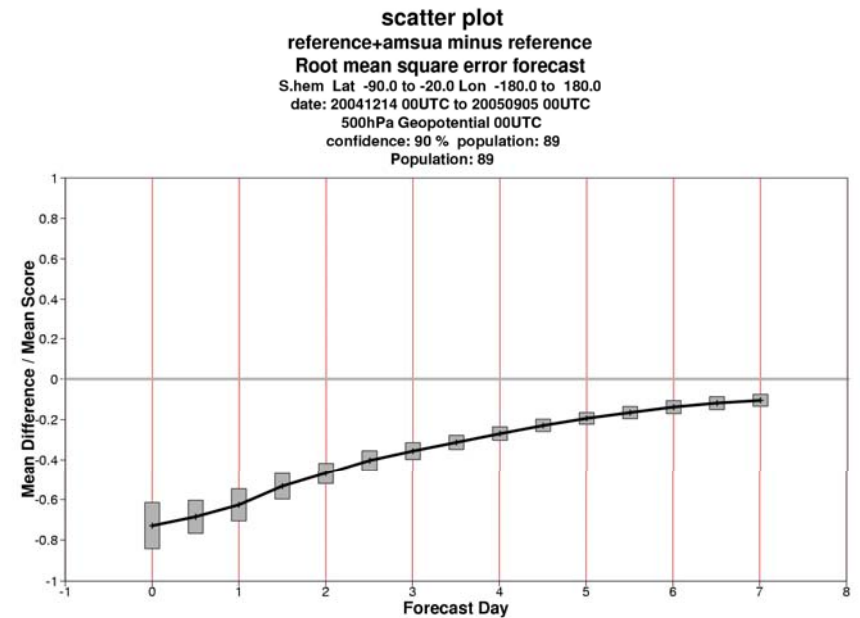
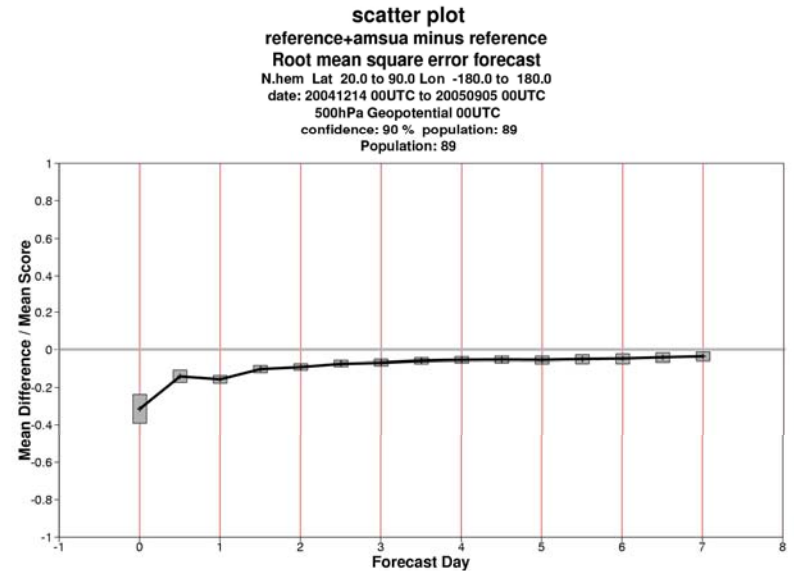
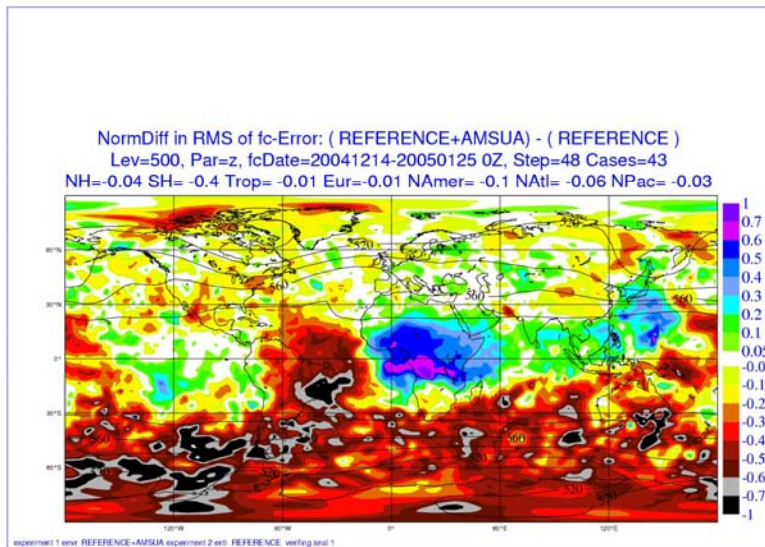
500 hPa Height

- The overall impact on geopotential height in the troposphere is similar at all levels, hence, plots are shown at 500 hPa.
-
- It is evident from the three sets of plots below that AMSUA, AIRS and HIRS are clearly the sensors with the strongest impact.
- In addition significant impact comes from the removal of the MODIS winds from the **REFERENCE** system

Anomaly correlation 500 hPa geopotential

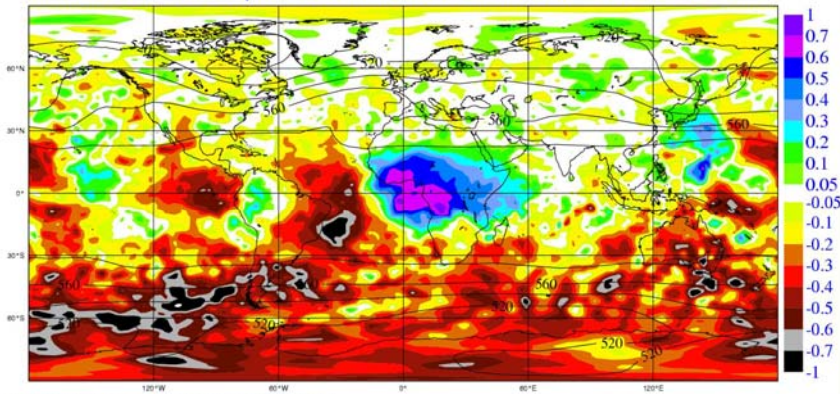


Impact of adding AMSUA to the REFERENCE

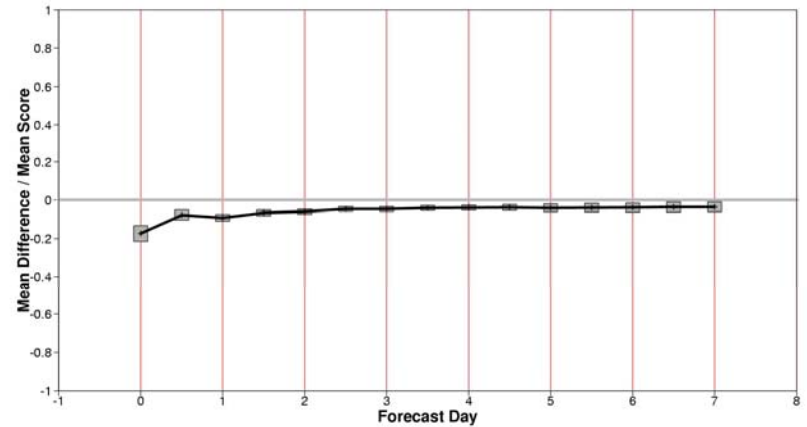


Impact of adding AIRS to the REFERENCE

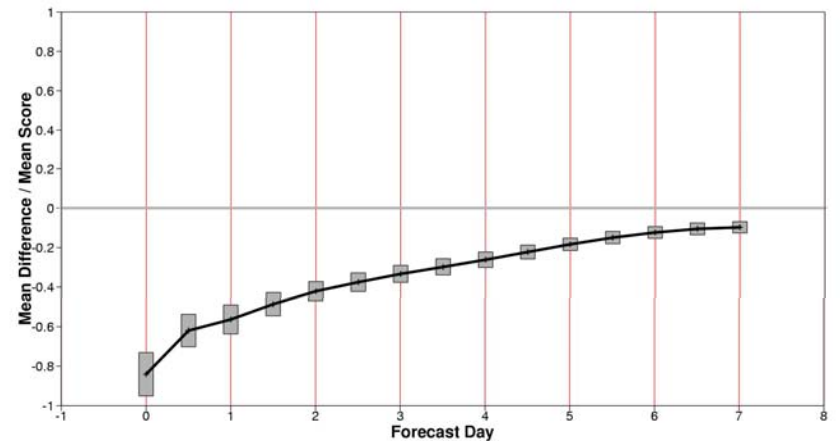
NormDiff in RMS of fc-Error: (REFERENCE+AIRS) - (REFERENCE)
 Lev=500, Par=z, fcDate=20041214-20050125 0Z, Step=48 Cases=43
 NH=-0.03 SH=-0.34 Trop=-0.05 Eur=-0.01 NAmer=-0.06 NATl=-0.03 NPac=-0.05



scatter plot
 reference+airs minus reference
 Root mean square error forecast
 N.hem Lat 20.0 to 90.0 Lon -180.0 to 180.0
 winter 43 cases summer 46 cases
 500hPa Geopotential 00UTC
 confidence: 90 population: 89



scatter plot
 reference+airs minus reference
 Root mean square error forecast
 S.hem Lat -90.0 to -20.0 Lon -180.0 to 180.0
 winter 43 cases summer 46 cases
 500hPa Geopotential 00UTC
 confidence: 90 population: 89



Humidity

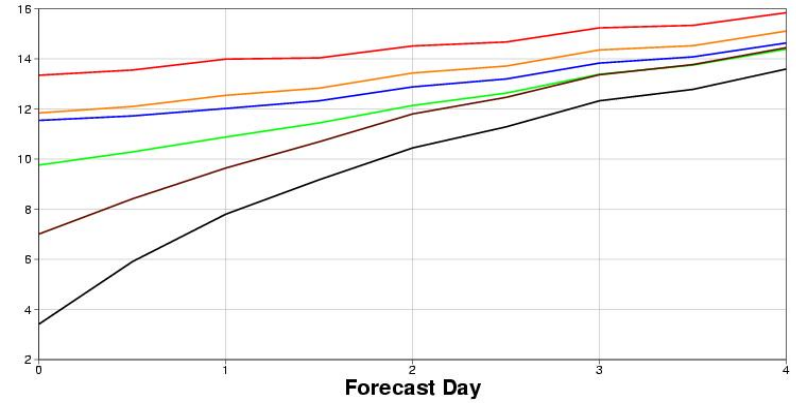
- The influence of the humidity observations on the forecast are mostly in the tropics and their influence on the forecast decays more quickly in time than geopotential.
- As a consequence humidity verification has been focused on the short range forecast (to day four).
- The results are also evaluated at three atmospheric levels as different satellite sensors sense different regions of the troposphere.

Relative humidity at 850 hPa

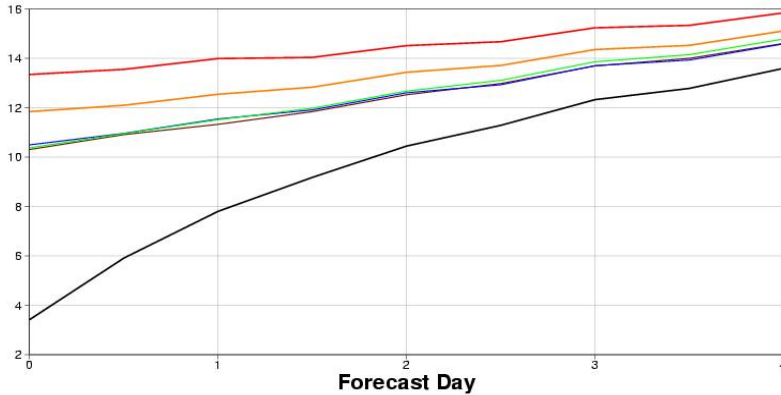
- With reference to the mean plots below, SSMI is the most important sensor affecting this level.
- Even after adding SSMI to the **REFERENCE** there is still relative large gap to the **CONTROL** suggesting the there is a small but additive contribution of many other sensors contributing to the moisture analysis.

Relative humidity 850hPa

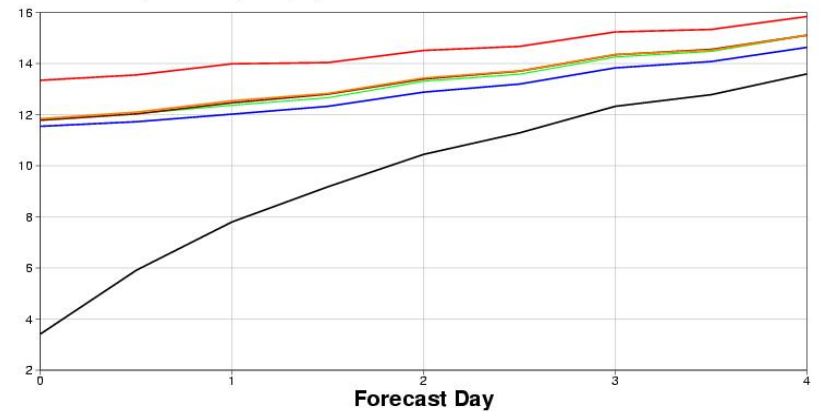
Mean curves
850hPa Relative humidity
Root mean square error forecast
 Tropics Lat -20.0 to 20.0 Lon -180.0 to 180.0
 Date: 20041214 00UTC to 20050905 00UTC
 Mean calculation method: standard
 Population: 89 (averaged)



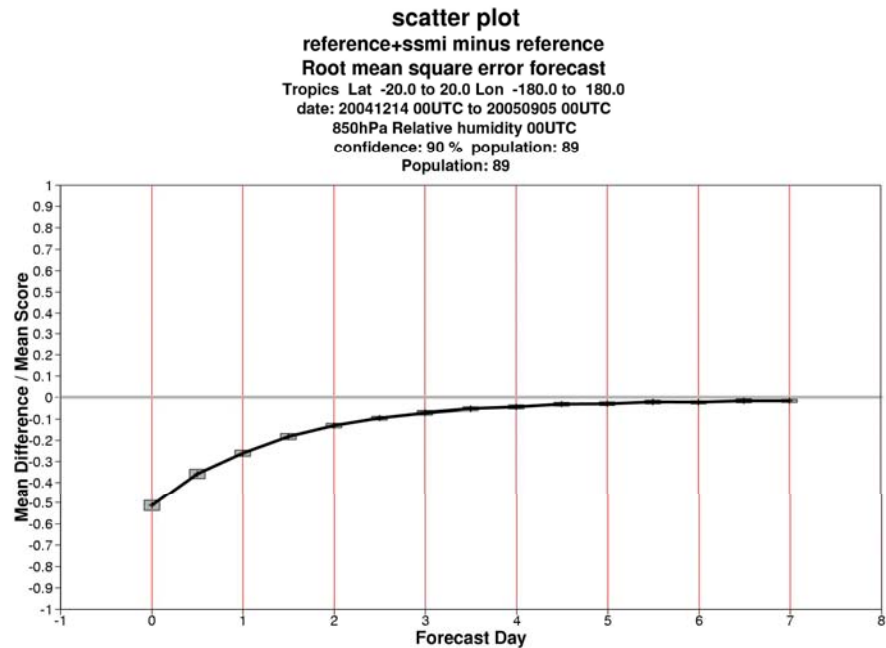
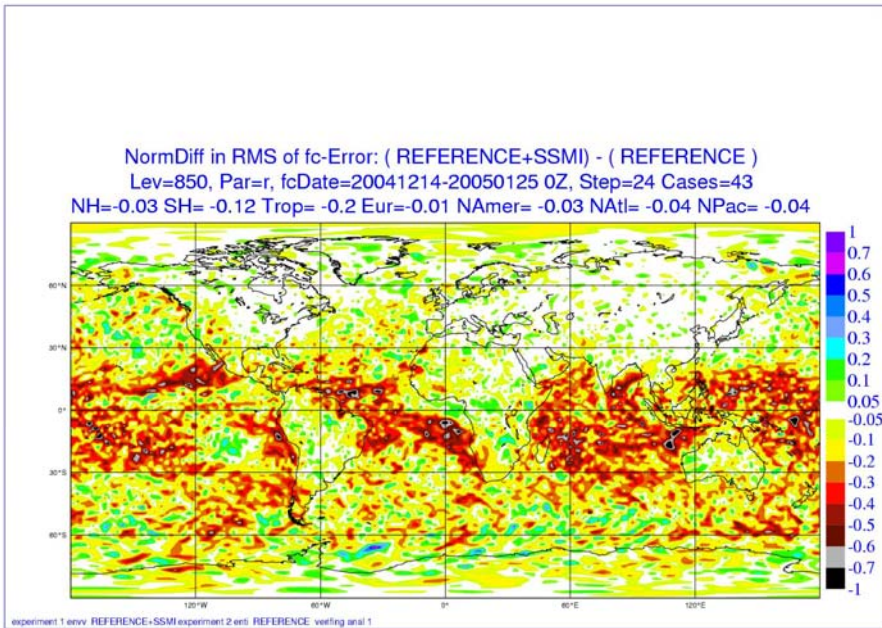
Mean curves
850hPa Relative humidity
Root mean square error forecast
 Tropics Lat -20.0 to 20.0 Lon -180.0 to 180.0
 Date: 20041214 00UTC to 20050905 00UTC
 Mean calculation method: standard
 Population: 89 (averaged)



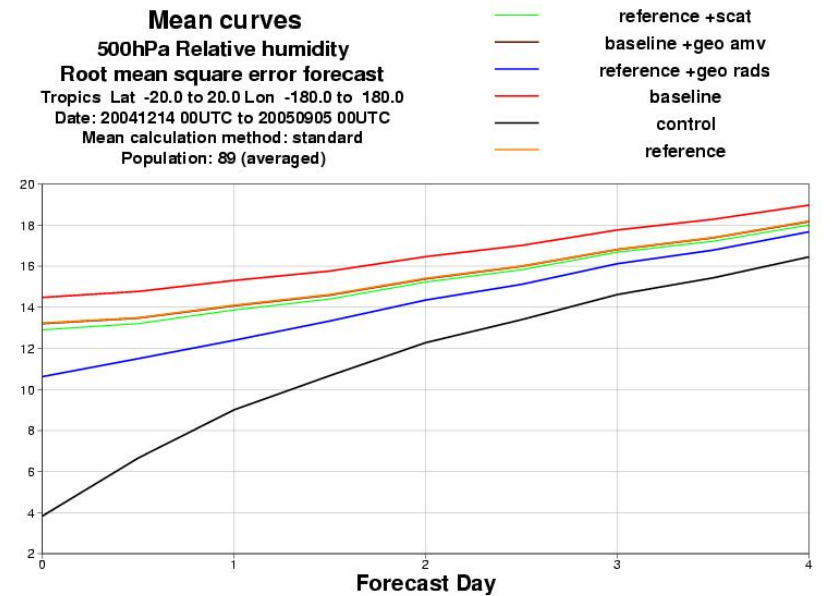
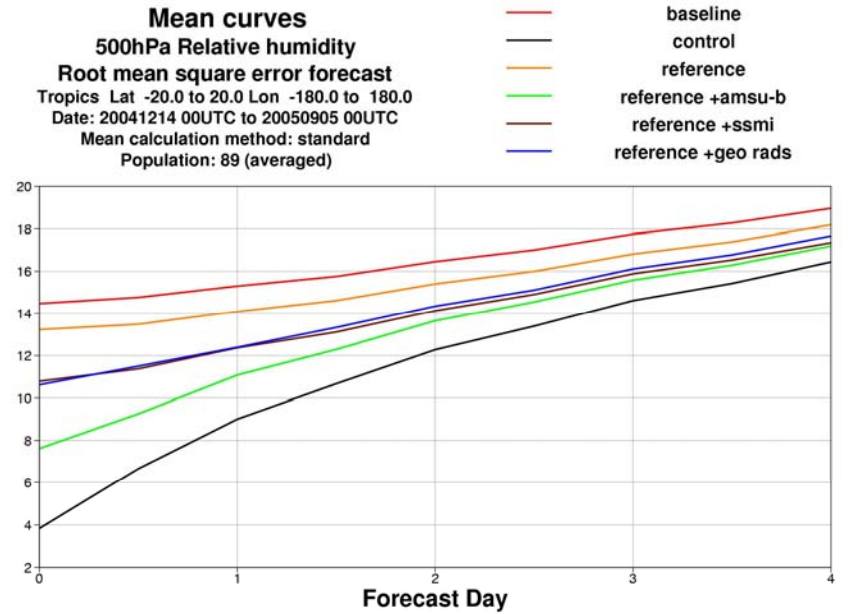
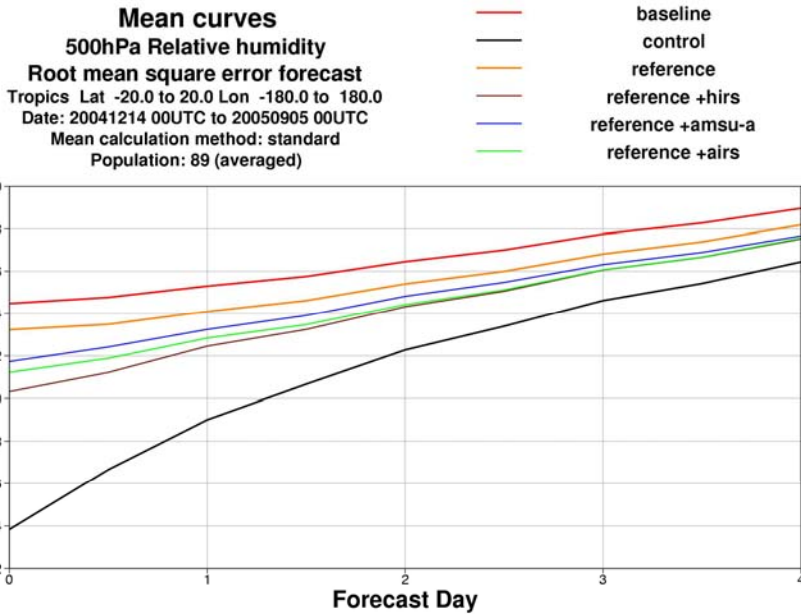
Mean curves
850hPa Relative humidity
Root mean square error forecast
 Tropics Lat -20.0 to 20.0 Lon -180.0 to 180.0
 Date: 20041214 00UTC to 20050905 00UTC
 Mean calculation method: standard
 Population: 89 (averaged)



Impact of adding SSMI to the REFERENCE

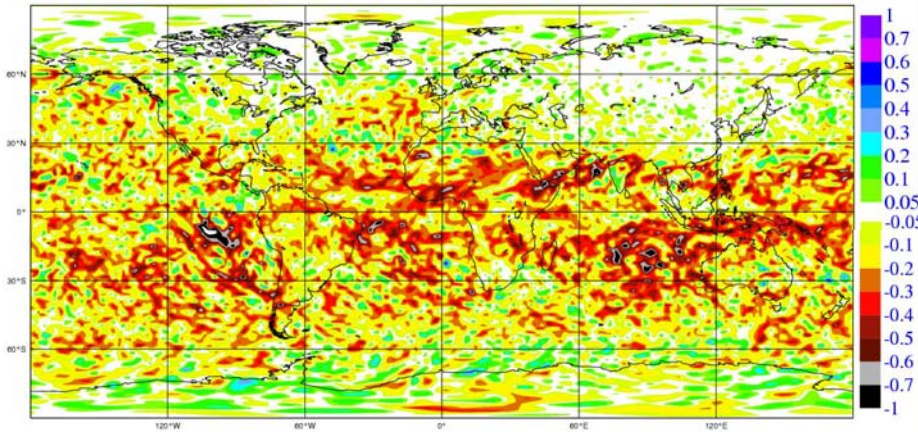


Relative humidity at 500 hPa

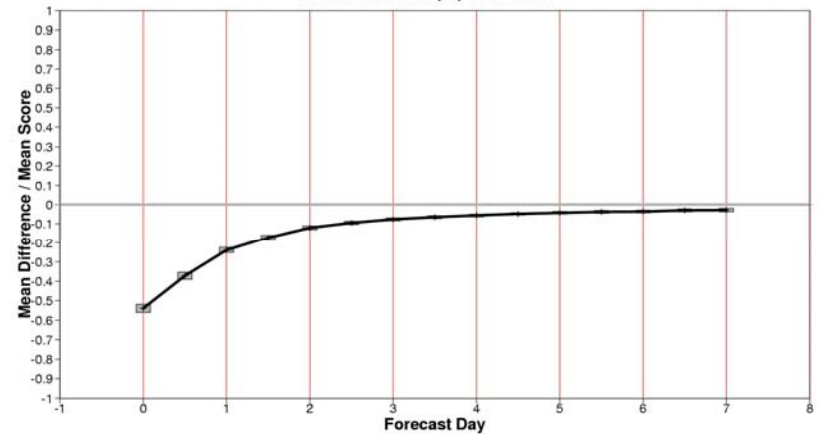


Impact of adding AMSUB to the REFERENCE

NormDiff in RMS of fc-Error: (REFERENCE+AMSUB) - (REFERENCE)
Lev=500, Par=r, fcDate=20041214-20050125 0Z, Step=24 Cases=43
NH=-0.06 SH= -0.13 Trop= -0.21 Eur=-0.03 NAmer= -0.06 NATl= -0.07 NPac= -0.08



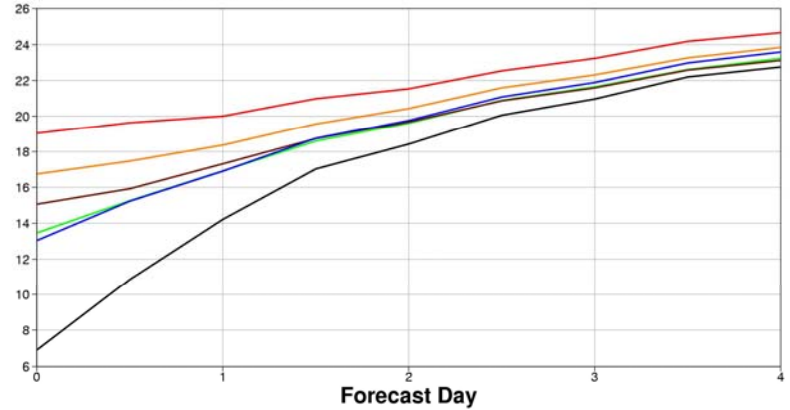
scatter plot
reference+amsub minus reference
Root mean square error forecast
Tropics Lat -20.0 to 20.0 Lon -180.0 to 180.0
date: 20041214 00UTC to 20050905 00UTC
500hPa Relative humidity 00UTC
confidence: 90 % population: 89



Relative humidity at 200 hPa

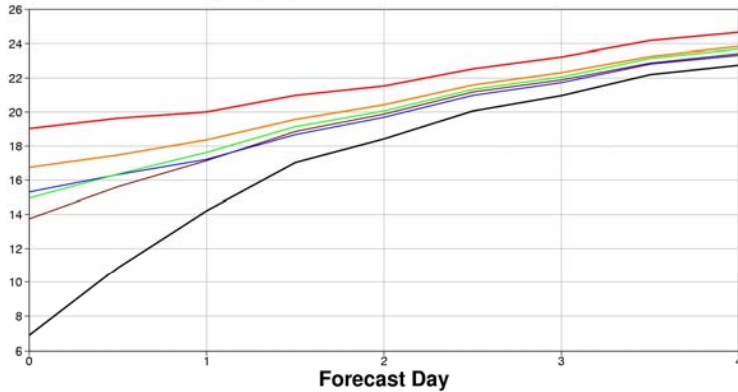
Mean curves
 200hPa Relative humidity
 Root mean square error forecast
 Tropics Lat -20.0 to 20.0 Lon -180.0 to 180.0
 Date: 20041214 00UTC to 20050905 00UTC
 Mean calculation method: standard
 Population: 89 (averaged)

- baseline
- control
- reference
- reference +amsu-b
- reference +ssmi
- reference +geo rads



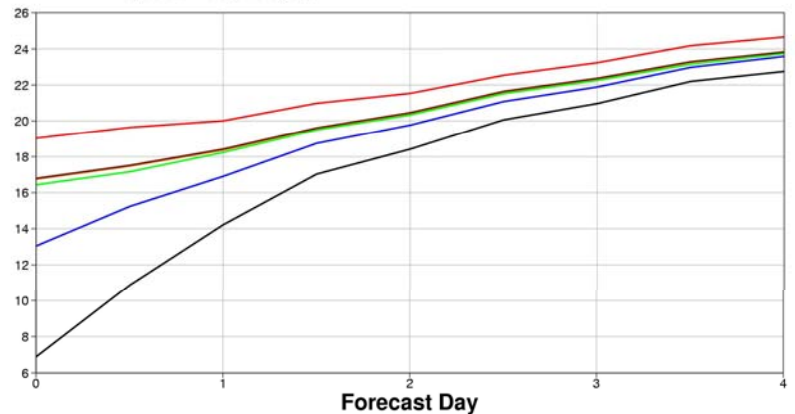
Mean curves
 200hPa Relative humidity
 Root mean square error forecast
 Tropics Lat -20.0 to 20.0 Lon -180.0 to 180.0
 Date: 20041214 00UTC to 20050905 00UTC
 Mean calculation method: standard
 Population: 89 (averaged)

- baseline
- control
- reference
- reference +hirs
- reference +amsu-a
- reference +airs



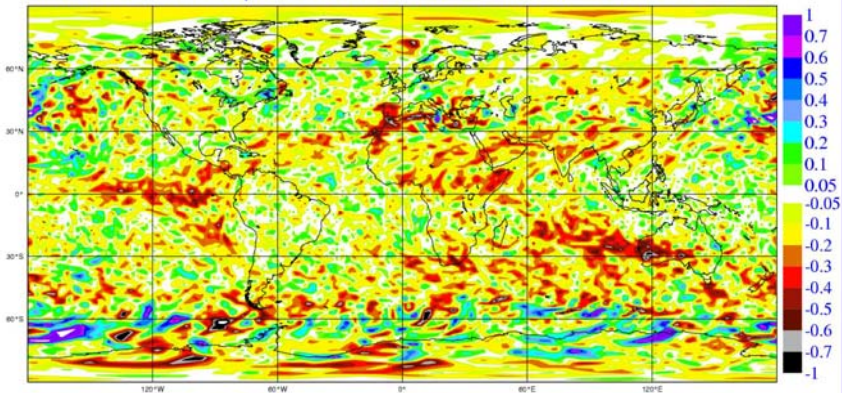
Mean curves
 200hPa Relative humidity
 Root mean square error forecast
 Tropics Lat -20.0 to 20.0 Lon -180.0 to 180.0
 Date: 20041214 00UTC to 20050905 00UTC
 Mean calculation method: standard
 Population: 89 (averaged)

- baseline
- control
- reference
- reference +scat
- reference +geo amv
- reference +geo rads



Impact of adding CSRs to the REFERENCE

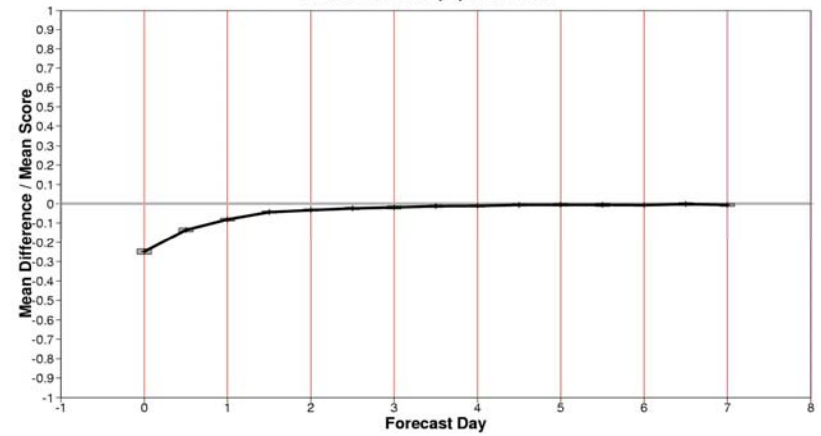
NormDiff in RMS of fc-Error: (REFERENCE+CSR) - (REFERENCE)
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NH=-0.05 SH= -0.08 Trop= -0.07 Eur=-0.08 NAmer= -0.03 NATl= -0.04 NPac= -0.02



experiment 1 enwv REFERENCE-CSR experiment 2 enri REFERENCE voefing anal 1

scatter plot

reference+csr minus reference
Root mean square error forecast
Tropics Lat -20.0 to 20.0 Lon -180.0 to 180.0
date: 20041214 00UTC to 20050905 00UTC
200hPa Relative humidity 00UTC
confidence: 90 % population: 89



Vector Wind

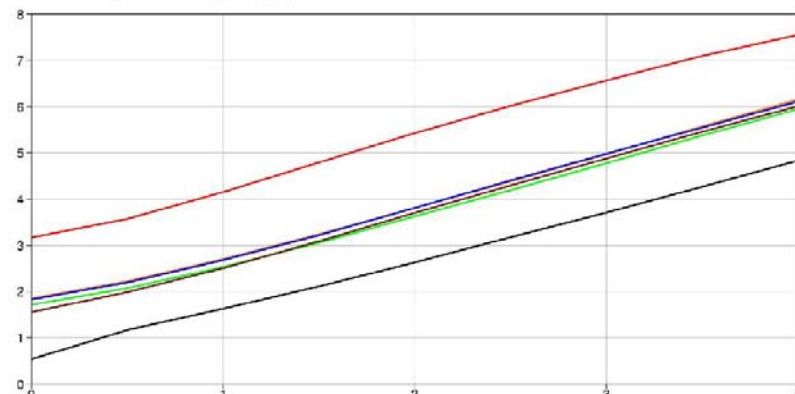
The influence of the satellite sensors on the vector wind is strongest in Tropics and Southern Hemisphere.

Analysis of the impact is done for lower and upper levels as different satellite sensors sense different regions of the troposphere.

Surface wind (1000 hPa)

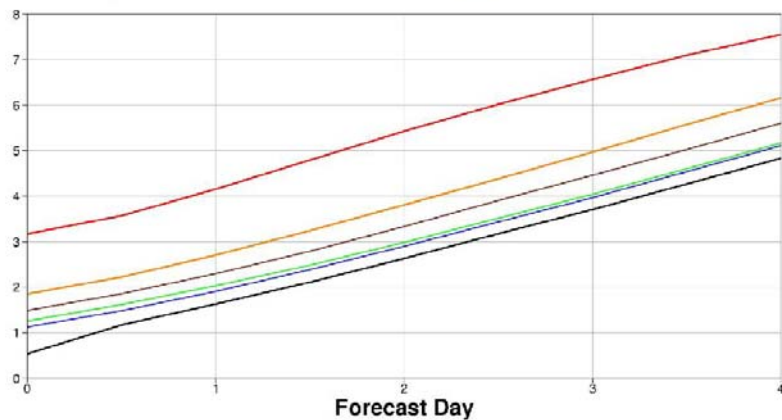
Mean curves
1000hPa Vector Wind
Root mean square error forecast
 S.hem Lat -90.0 to -20.0 Lon -180.0 to 180.0
 Date: 20041214 00UTC to 20050905 00UTC
 Mean calculation method: standard
 Population: 89 (averaged)

— baseline
 — control
 — reference
 — reference +amsu-b
 — reference +ssmi
 — reference +geo rads



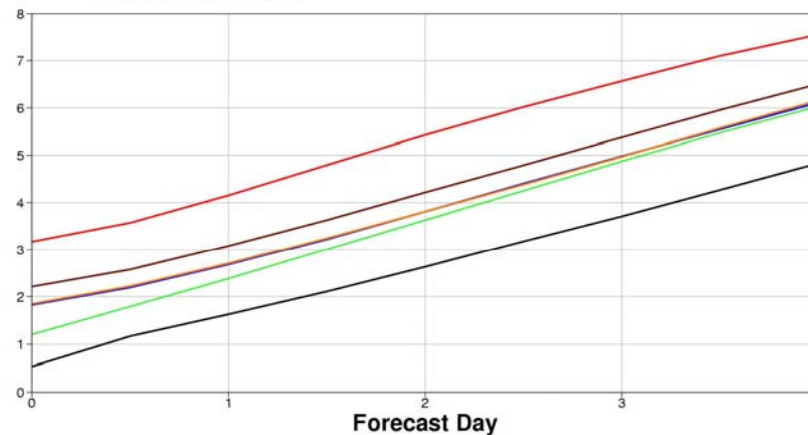
Mean curves
1000hPa Vector Wind
Root mean square error forecast
 S.hem Lat -90.0 to -20.0 Lon -180.0 to 180.0
 Date: 20041214 00UTC to 20050905 00UTC
 Mean calculation method: standard
 Population: 89 (averaged)

— baseline
 — control
 — reference
 — reference +hirs
 — reference +amsu-a
 — reference +airs



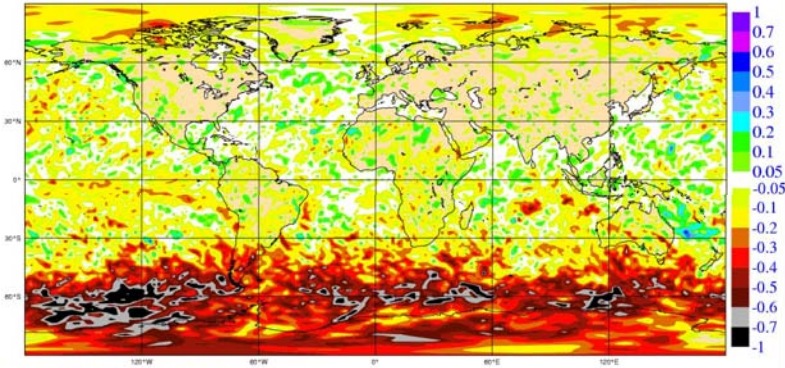
Mean curves
1000hPa Vector Wind
Root mean square error forecast
 S.hem Lat -90.0 to -20.0 Lon -180.0 to 180.0
 Date: 20041214 00UTC to 20050905 00UTC
 Mean calculation method: standard
 Population: 89 (averaged)

— reference +scat
 — baseline +geo amv
 — reference +geo rads
 — baseline
 — control
 — reference



Impact of adding AMSUA to the REFERENCE

NormDiff in RMS of fc-Error: (REFERENCE+AMSUA) - (REFERENCE)
Lev=1000, Par=vwind, fcDate=20041214-20050125 0Z, Step=24 Cases=43
NH=-0.02 SH= -0.26 Trop= -0.04 Eur=0 NAm= 0 NATl= 0 NPac= -0.05



experiment 1 env REFERENCE+AMSUA experiment 2 env REFERENCE_writing anal 1

scatter plot

reference+amsua minus reference

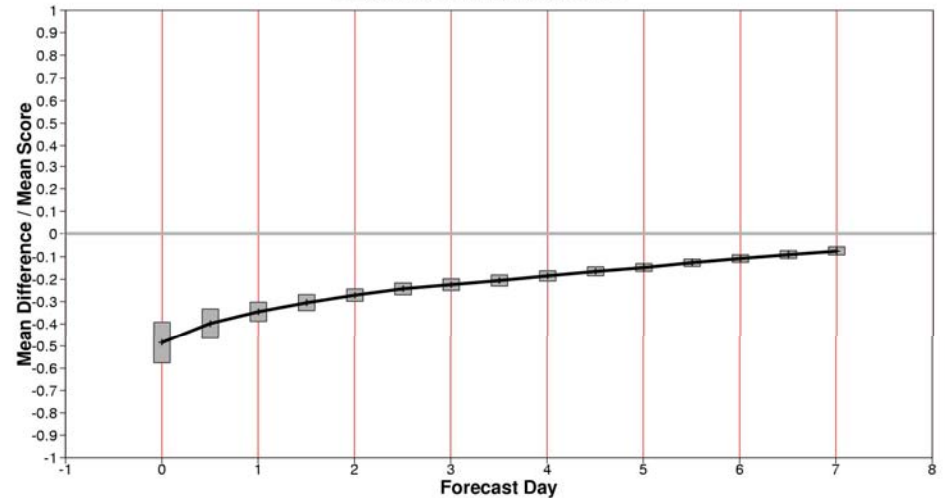
Root mean square error forecast

S.hem Lat -90.0 to -20.0 Lon -180.0 to 180.0

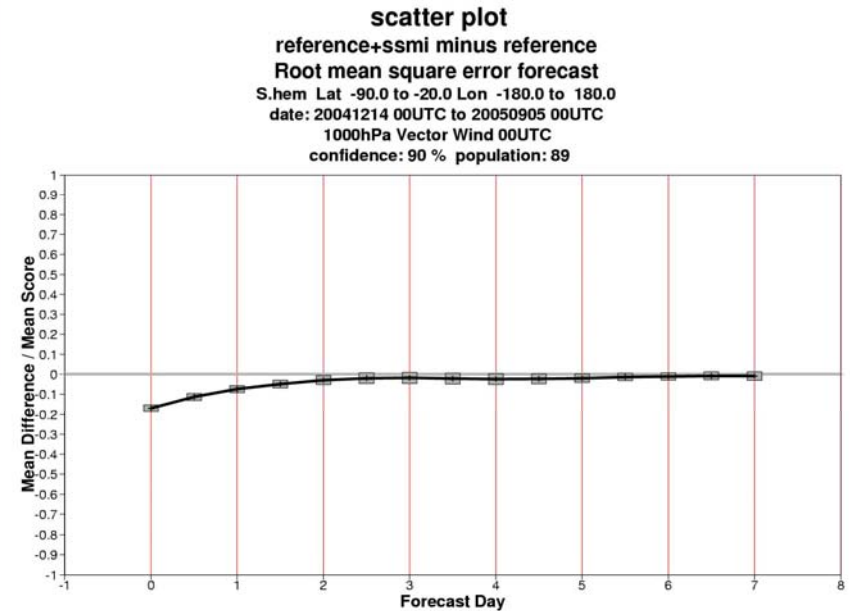
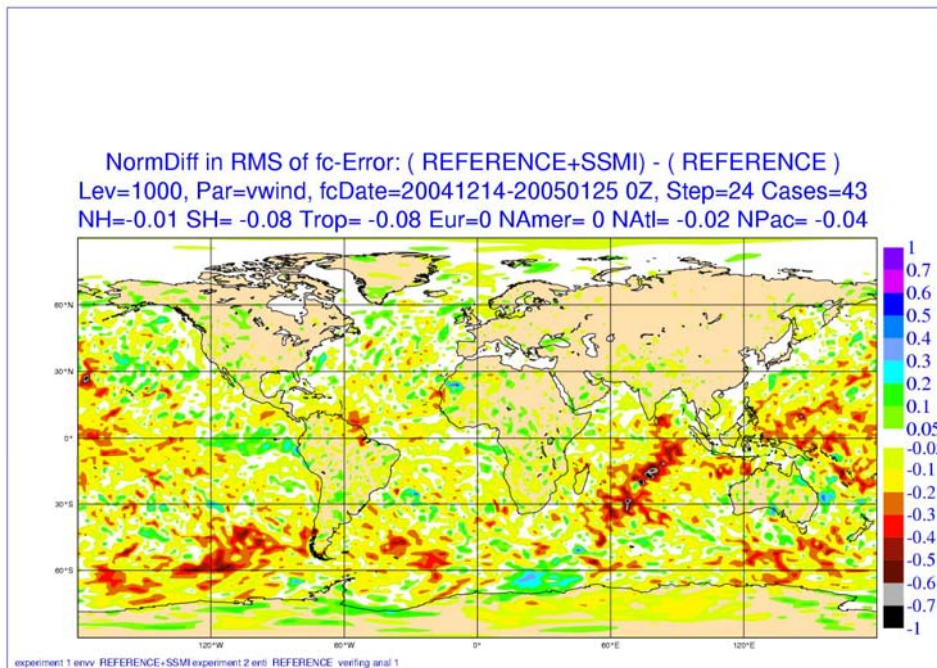
date: 20041214 00UTC to 20050905 00UTC

1000hPa Vector Wind 00UTC

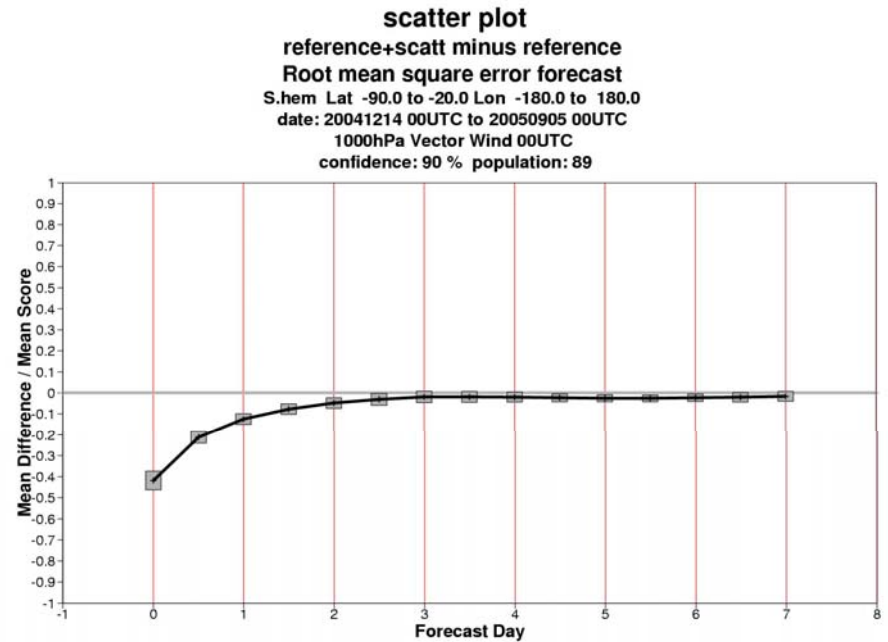
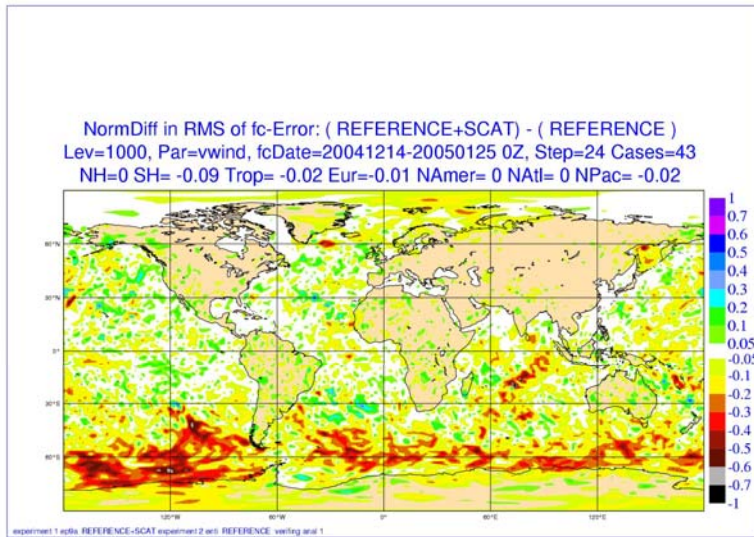
confidence: 90 % population: 89



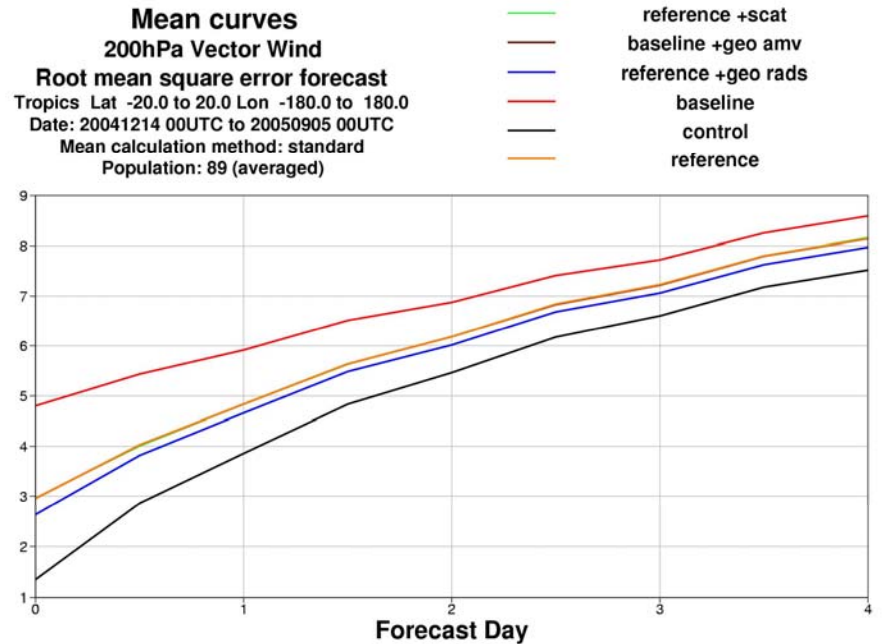
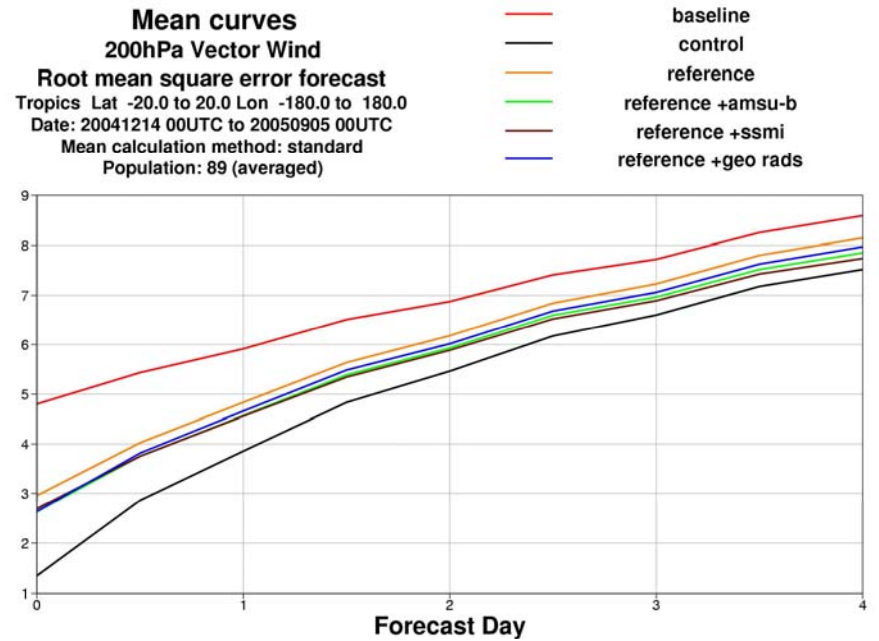
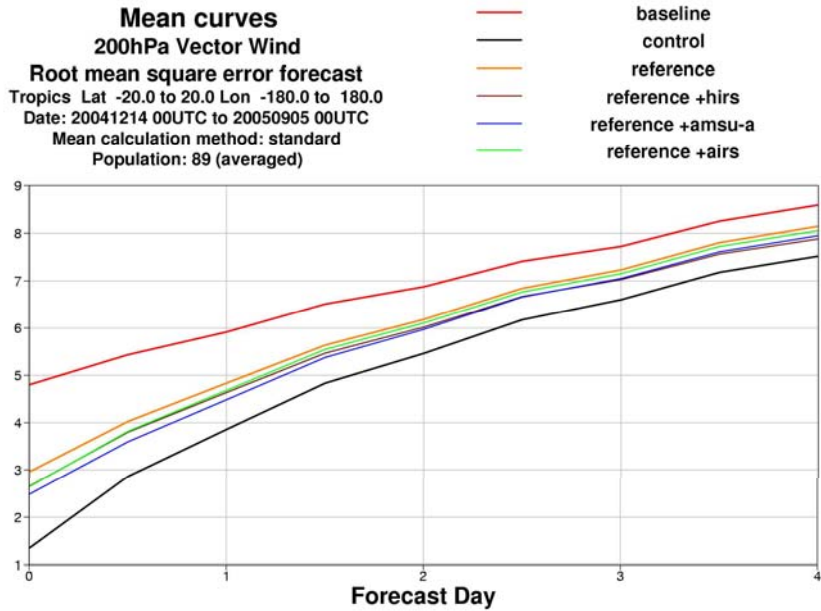
Impact of adding SSMI to the REFERENCE



Impact of adding SCAT to the REFERENCE

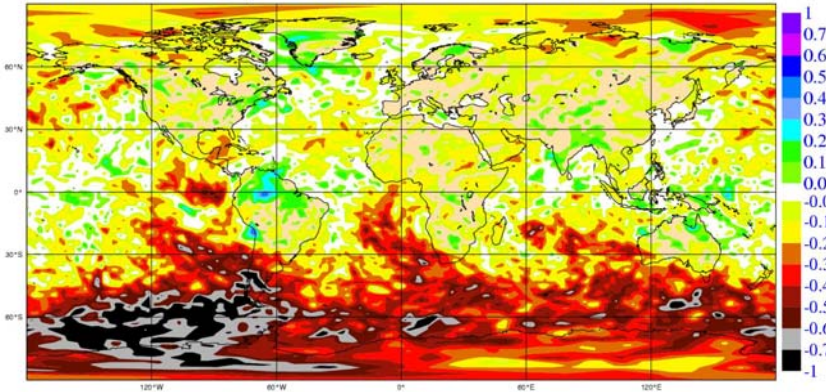


Upper level wind (200hPa)



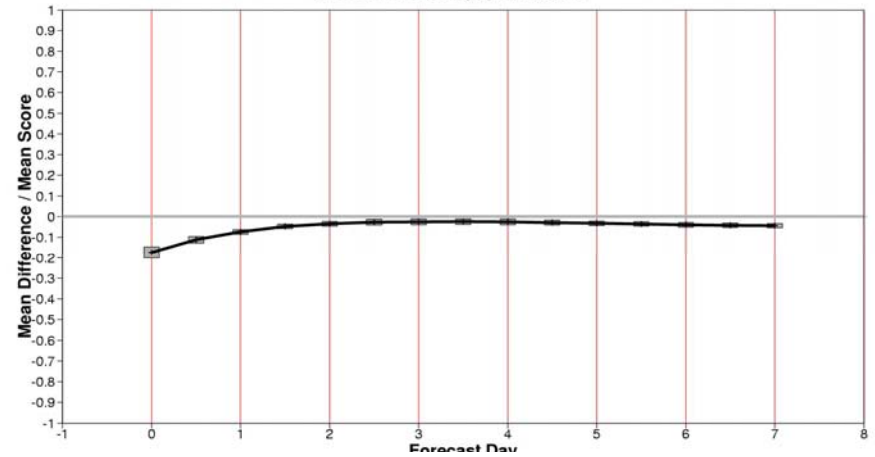
Impact of adding AMSUA to the REFERENCE

NormDiff in RMS of fc-Error: (REFERENCE+AMSUA) - (REFERENCE)
 Lev=200, Par=vwind, fcDate=20041214-20050125 0Z, Step=24 Cases=43
 NH=-0.06 SH= -0.32 Trop= -0.06 Eur=-0.02 NAmer= -0.03 NATl= -0.03 NPac= -0.1

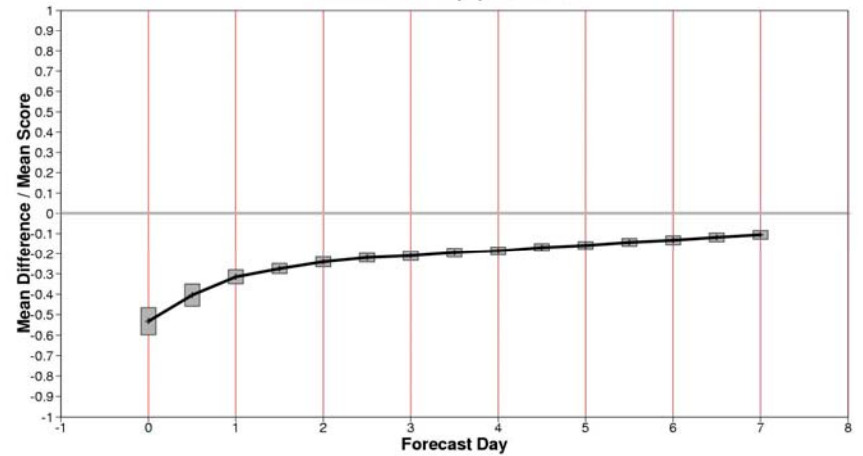


experiment 1 envr REFERENCE+AMSUA experiment 2 envr REFERENCE_wrfing anal 1

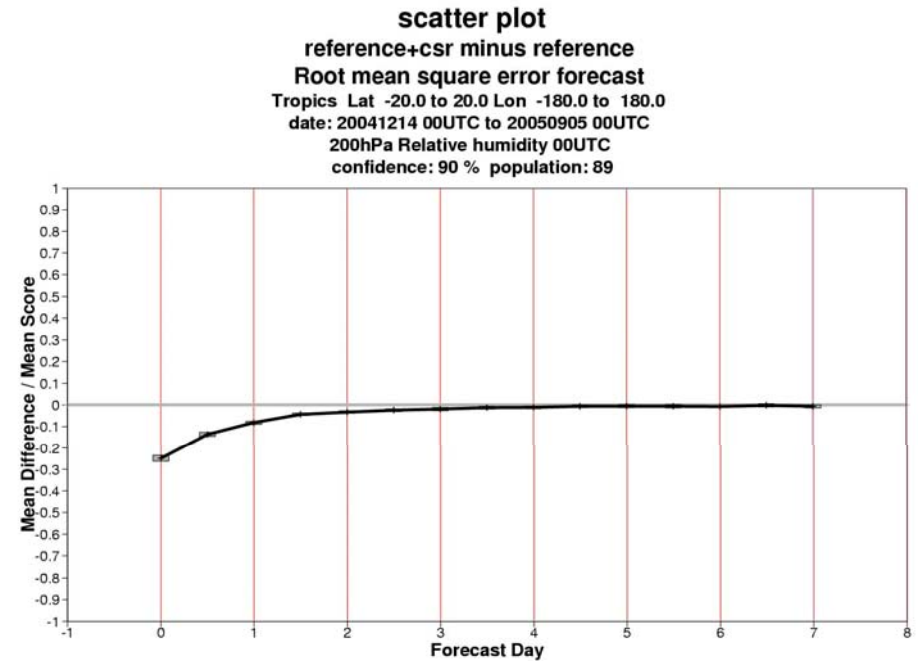
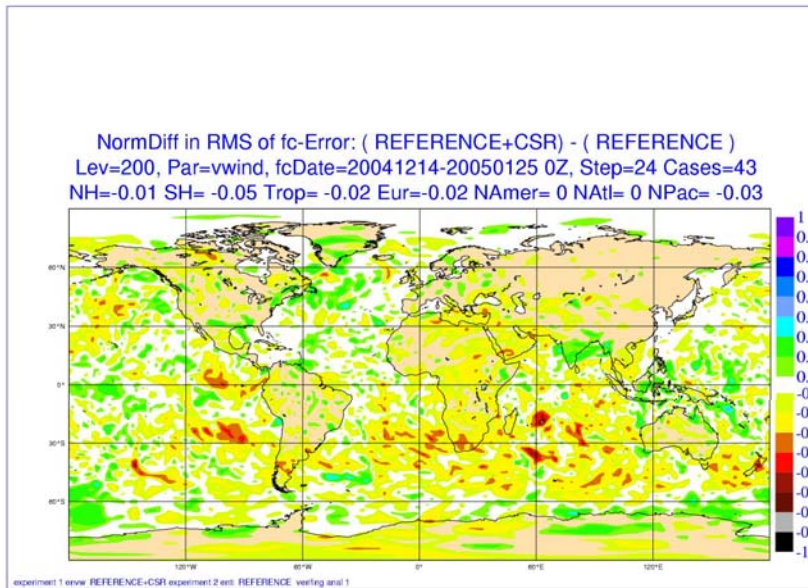
scatter plot
 reference+amsua minus reference
 Root mean square error forecast
 Tropics Lat -20.0 to 20.0 Lon -180.0 to 180.0
 date: 20041214 00UTC to 20050905 00UTC
 200hPa Vector Wind 00UTC
 confidence: 90 % population: 89



scatter plot
 reference+amsua minus reference
 Root mean square error forecast
 S.hem Lat -90.0 to -20.0 Lon -180.0 to 180.0
 date: 20041214 00UTC to 20050905 00UTC
 200hPa Vector Wind 00UTC
 confidence: 90 % population: 89



Impact of adding CSRs to the REFERENCE



Summary of analysis of results

To present the results of eleven sets of data assimilation experiment in a concise way is a somewhat daunting task.

There are over 1000 days of assimilation days and the evaluation period consists of 43 days in winter and 46 days in summer.

The variables used for evaluation are geopotential height, relative humidity and wind.

A final summary of results has been condensed to six bar graphs containing all eleven experiments (see below). It is reassuring to see that all the space base sensors contribute in a positive way to the overall improvement of the ECMWF forecast system

Conclusions (geopotential impact)

Sensors like AMSUA, AIRS and HIRS are clearly very important. These sensors have a large impact initially on the temperature and humidity but during assimilation process the wind adjusts very quickly. In all the verification of all variables these sensors have the largest effect on the data assimilation.

Additional sensors (AMSUB (including MHS), GEO CSRs, SSMI and SCAT) clearly have their part to play as there is still a gap between AMSUA sensor impact (the largest) and the full system (**CONTROL**).

Conclusions (humidity impact)

The impact of SSM/I low level humidity (850hPa) in the Tropics clearly shown in the detailed plots.

The impact on the mid level moisture (500hPa) of sensors AMSUB and SERVIRI CSRs is clearly positive and is confirmed using the detailed RMS plots for these instruments.

At upper levels (200hPa)
the impact of AMSUB, HIRS and all the CSRs is clear
for the experiments

Conclusions (vector wind impact)

The impact of SSMI and SCAT on the surface wind (1000 hPa) in the Southern Hemisphere is small but clearly shown in the detailed plots.

The sensors that have most impact on the upper level wind (200 hpa) are again AMSUA, AIRS, and HIRS but it is gratifying to see there is some indirect effect on the wind fields from the SEVIRI CSRs.

Finally the impact of AMVs and MODIS winds is clearly demonstrated.

RESULTS (2)

An additional data assimilation have been run for a summer and winter period.

Compare of AIRS (which includes humidity and temperature channels) with of two microwave instruments AMSUA and AMSUB.

AMSUA is sensitive to temperature and AMSUB humidity.

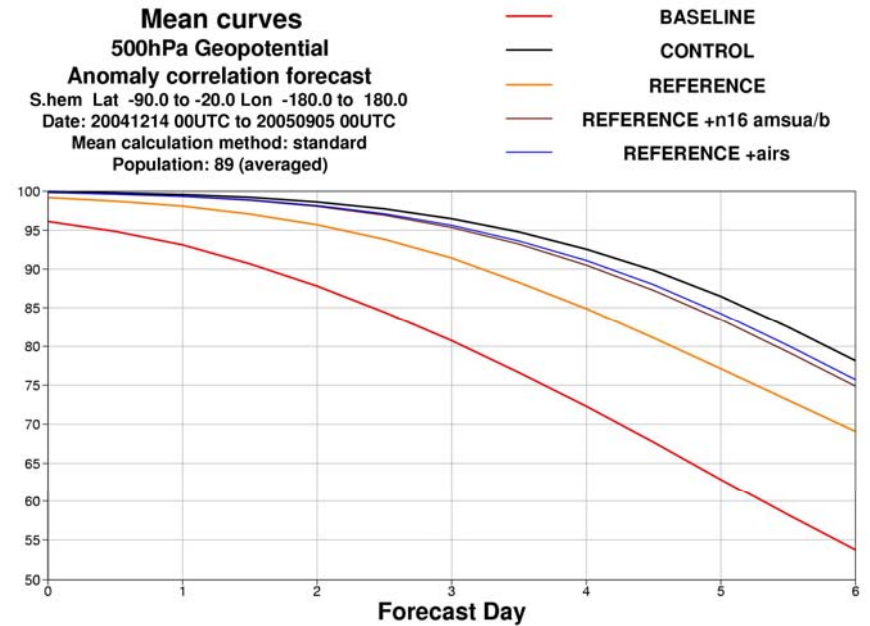
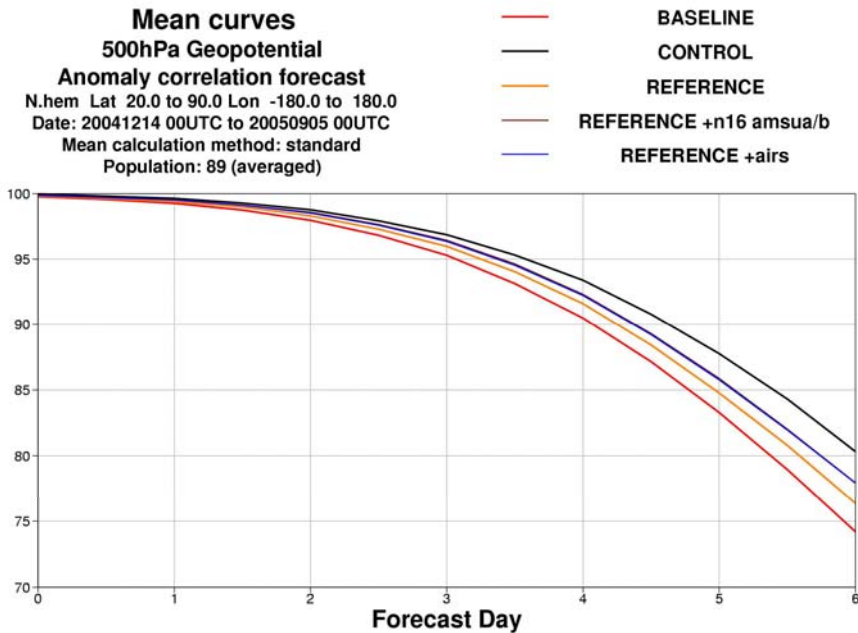
This data assimilation experiment only used NOAA 16 AMSU which was added to the **REFERENCE** assimilation.

The evaluation of forecasts has also been done using two variables and at various levels

Geopotential 500 hPa Height (anomaly correlation for mean scores and Normalised RMS error for geographical and scatter plots)

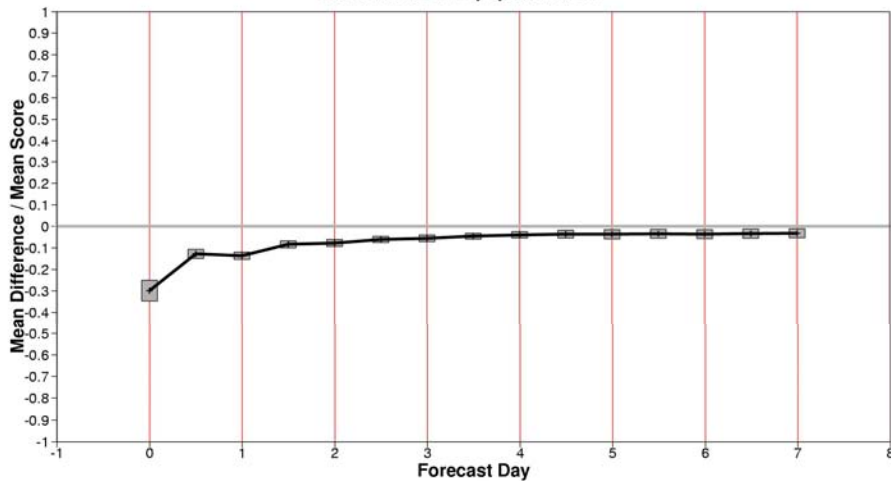
Relative Humidity at 500 and 200 hPa (mean scores in percent and Normalised RMS error for geographical plot)

500 hPa Geopotential impact of adding AMSUA/B and AIRS to the REFERENCE in the Northern Hemisphere

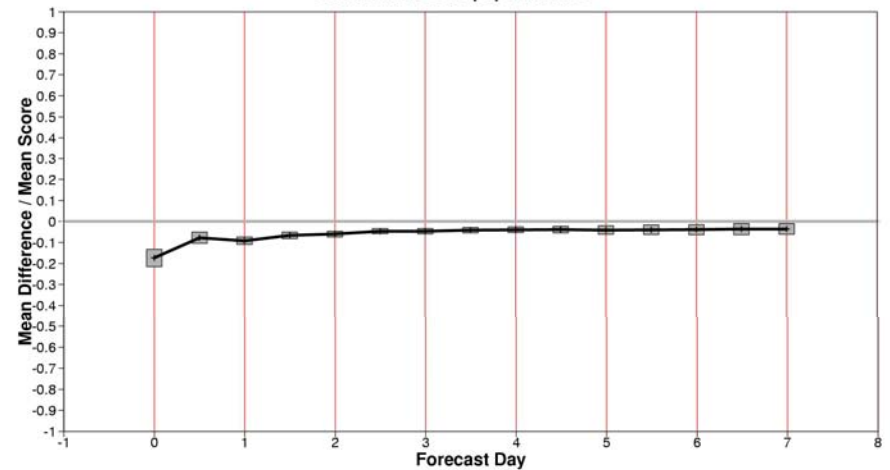


500 hPa Geopotential impact of adding AMSUA/B and AIRS to the REFERENCE in the Northern Hemisphere

scatter plot
reference+n16_amsua/b minus reference
Root mean square error forecast
N.hem Lat 20.0 to 90.0 Lon -180.0 to 180.0
date: 20041214 00UTC to 20050905 00UTC
500hPa Geopotential 00UTC
confidence: 90 % population: 89

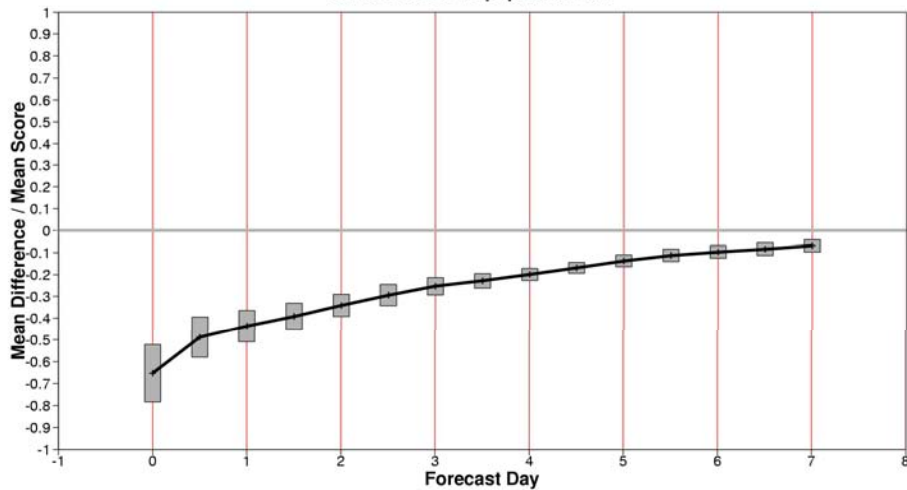


scatter plot
reference+airs minus reference
Root mean square error forecast
N.hem Lat 20.0 to 90.0 Lon -180.0 to 180.0
date: 20041214 00UTC to 20050905 00UTC
500hPa Geopotential 00UTC
confidence: 90 % population: 89

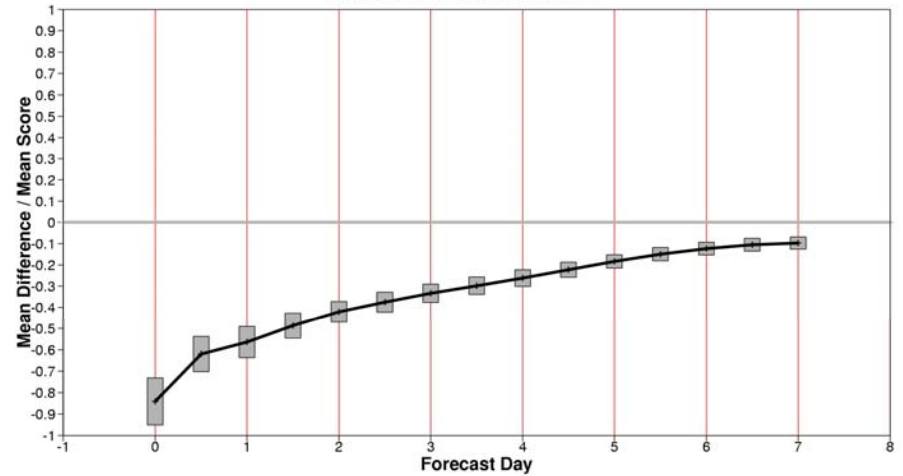


500 hPa Geopotential impact of adding AMSUA/B and AIRS to the REFERENCE in the Southern Hemisphere

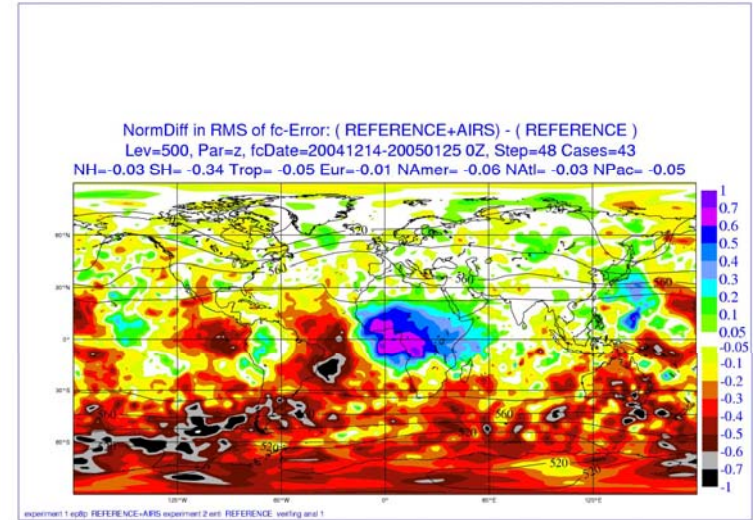
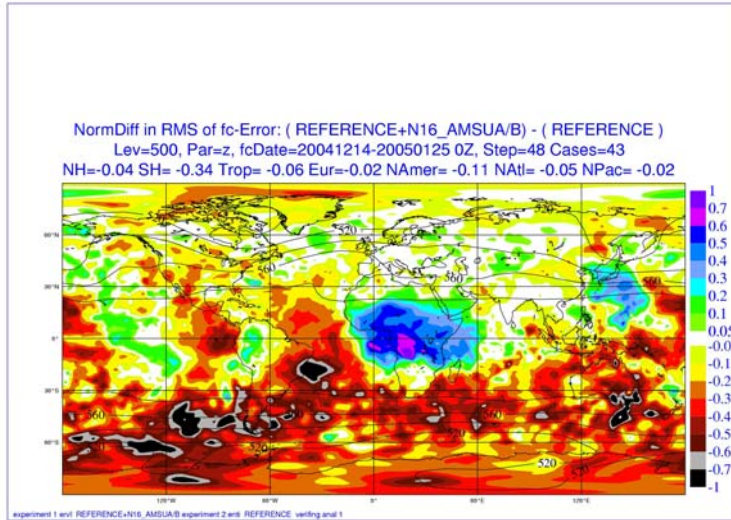
scatter plot
reference+n16_amsua/b minus reference
Root mean square error forecast
S.hem Lat -90.0 to -20.0 Lon -180.0 to 180.0
date: 20041214 00UTC to 20050905 00UTC
850hPa Geopotential 00UTC
confidence: 90 % population: 89



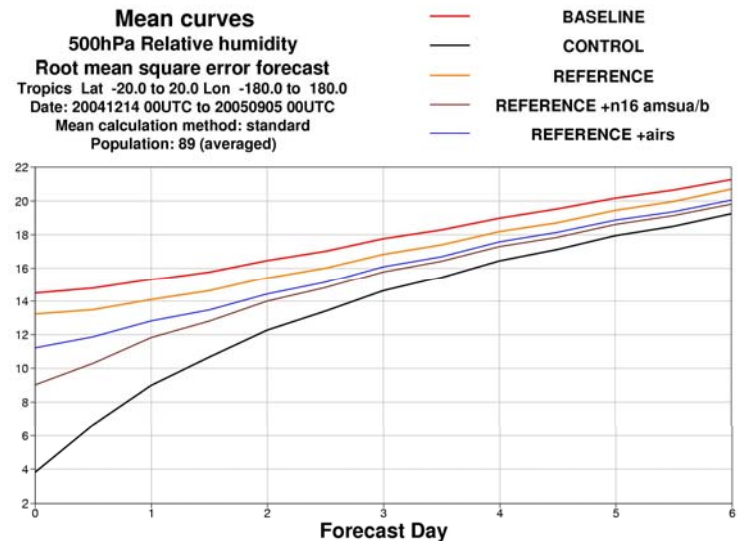
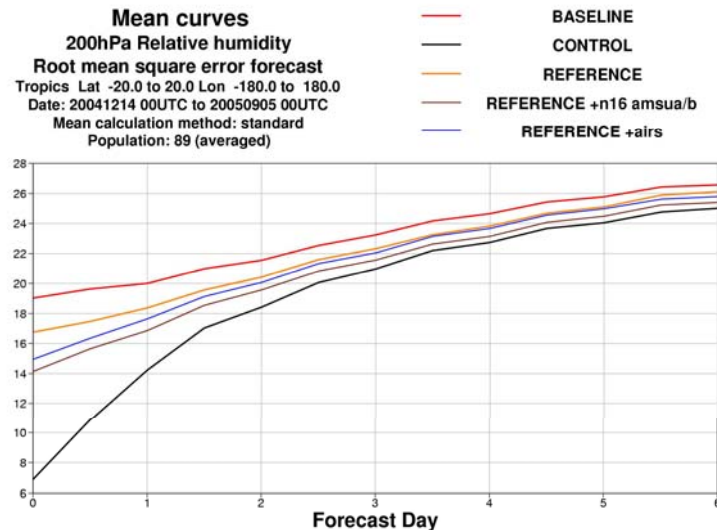
scatter plot
reference+airs minus reference
Root mean square error forecast
S.hem Lat -90.0 to -20.0 Lon -180.0 to 180.0
date: 20041214 00UTC to 20050905 00UTC
500hPa Geopotential 00UTC
confidence: 90 % population: 89



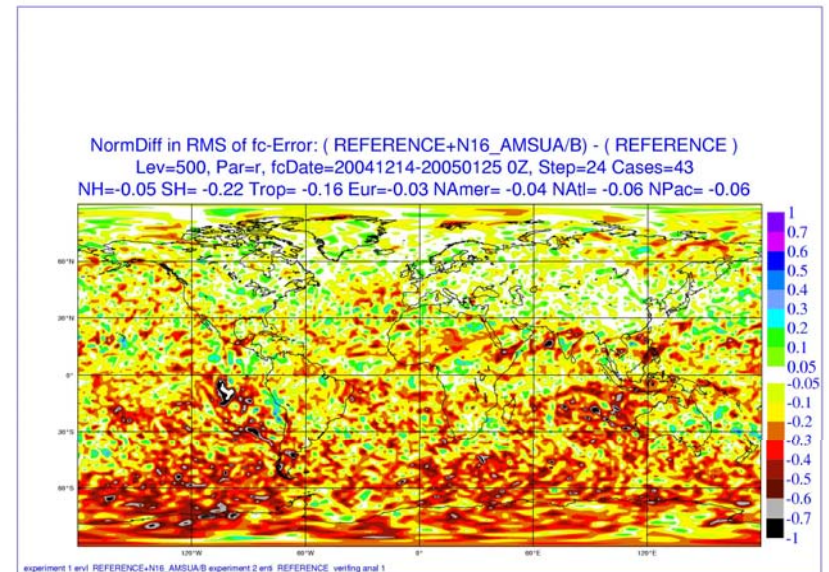
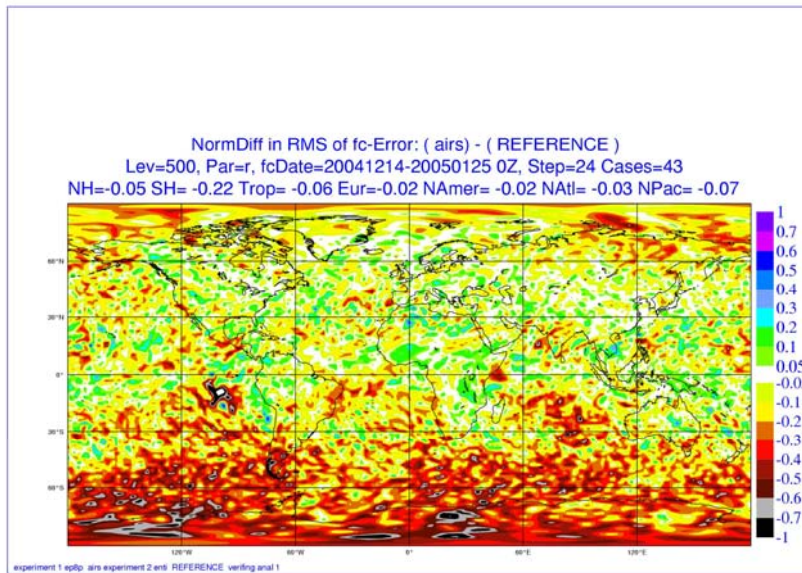
500 hPa Geopotential impact of adding AMSUA/B and AIRS to the REFERENCE



Humidity impact of adding AMSUA/B and AIRS to the REFERENCE



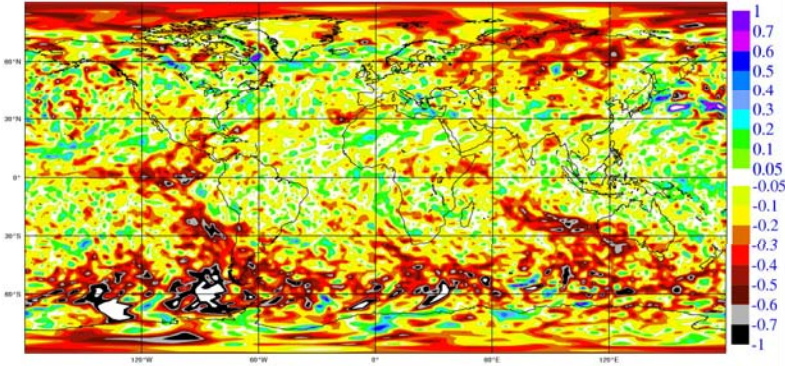
500 hPa Humidity impact of adding AMSUA/B and AIRS to the REFERENCE



200 hPa humidity impact of adding AMSUA/B and AIRS to the REFERENCE

NormDiff in RMS of fc-Error: (REFERENCE+N16_AMSUA/B) - (REFERENCE)
Lev=200, Par=r, fcDate=20041214-20050125 OZ, Step=24 Cases=43

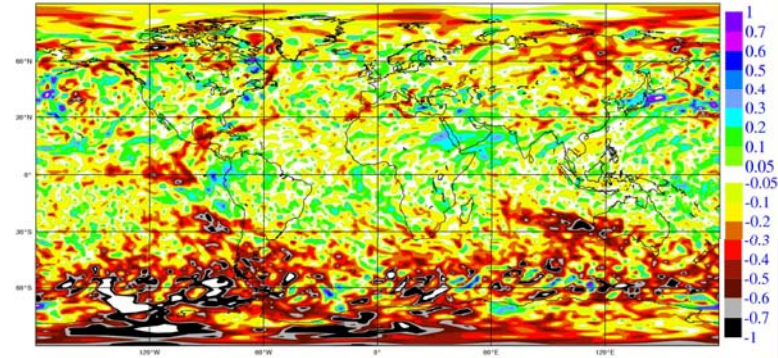
NH=-0.08 SH=-0.23 Trop=-0.06 Eur=-0.07 NAmer=-0.06 Natl=-0.05 NPac=-0.05



experiment 1 envl REFERENCE+N16_AMSUA/B experiment 2 envl REFERENCE_verifing anal 1

NormDiff in RMS of fc-Error: (REFERENCE+AIRS) - (REFERENCE)
Lev=200, Par=r, fcDate=20041214-20050125 OZ, Step=24 Cases=43

NH=-0.05 SH=-0.26 Trop=-0.01 Eur=-0.04 NAmer=-0.01 Natl=-0.03 NPac=-0.02



experiment 1 envl REFERENCE+AIRS experiment 2 envl REFERENCE_verifing anal 1

Conclusion (comparision of AIRS and AMSUA+AMSUB)

- The impact on geopotential height is a slightly more for AIRS in the Southern Hemisphere compared to the AMSUA/B but neutral in the Northern Hemisphere.
- The impact on humidity is greater for the AMSU instrument pair than for AIRS in particular in the Tropics.