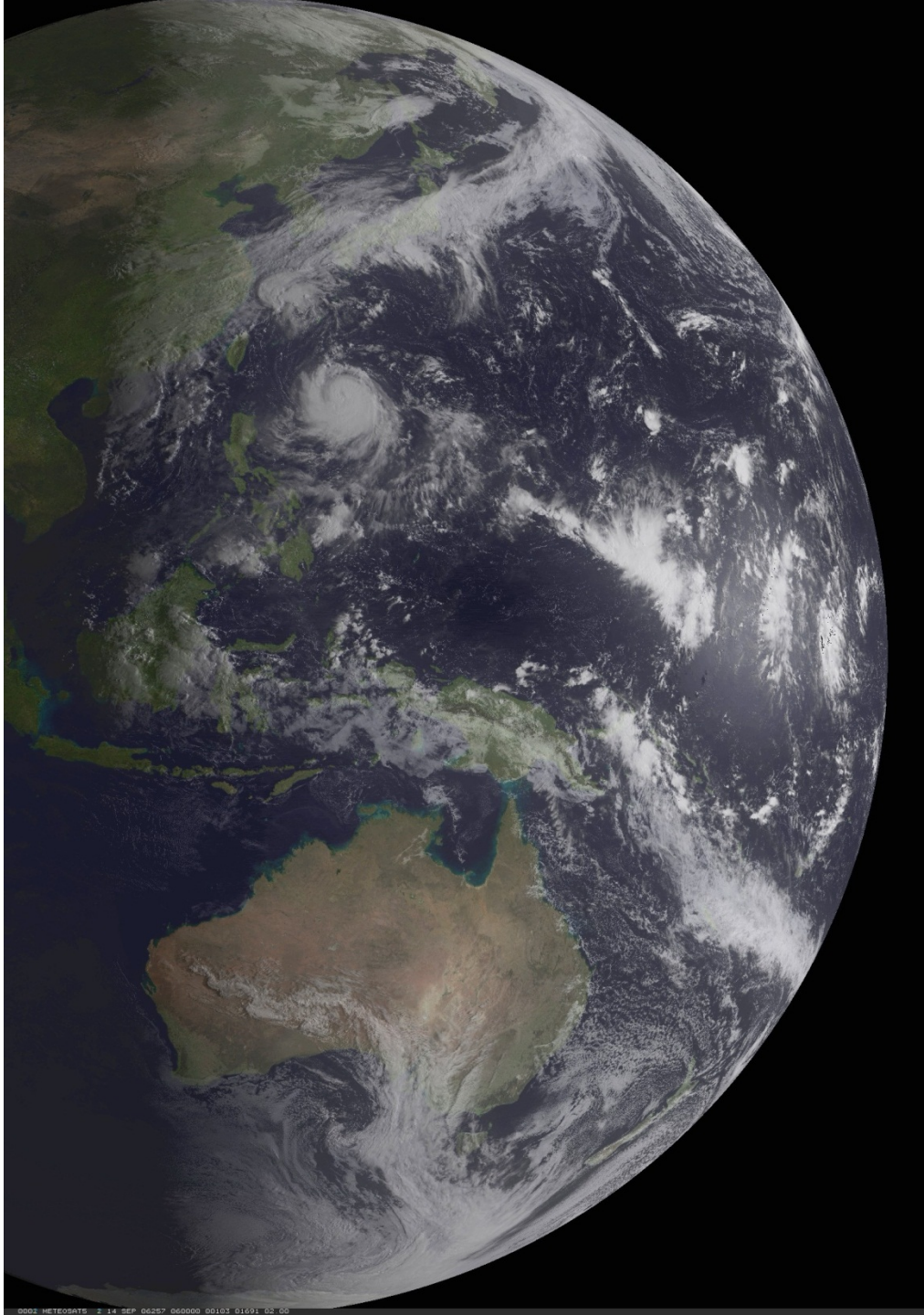
Australian Government
Bureau of Meteorology

The Use of Radio Occultation for Climate Monitoring and Numerical Weather Prediction in the Australian Region

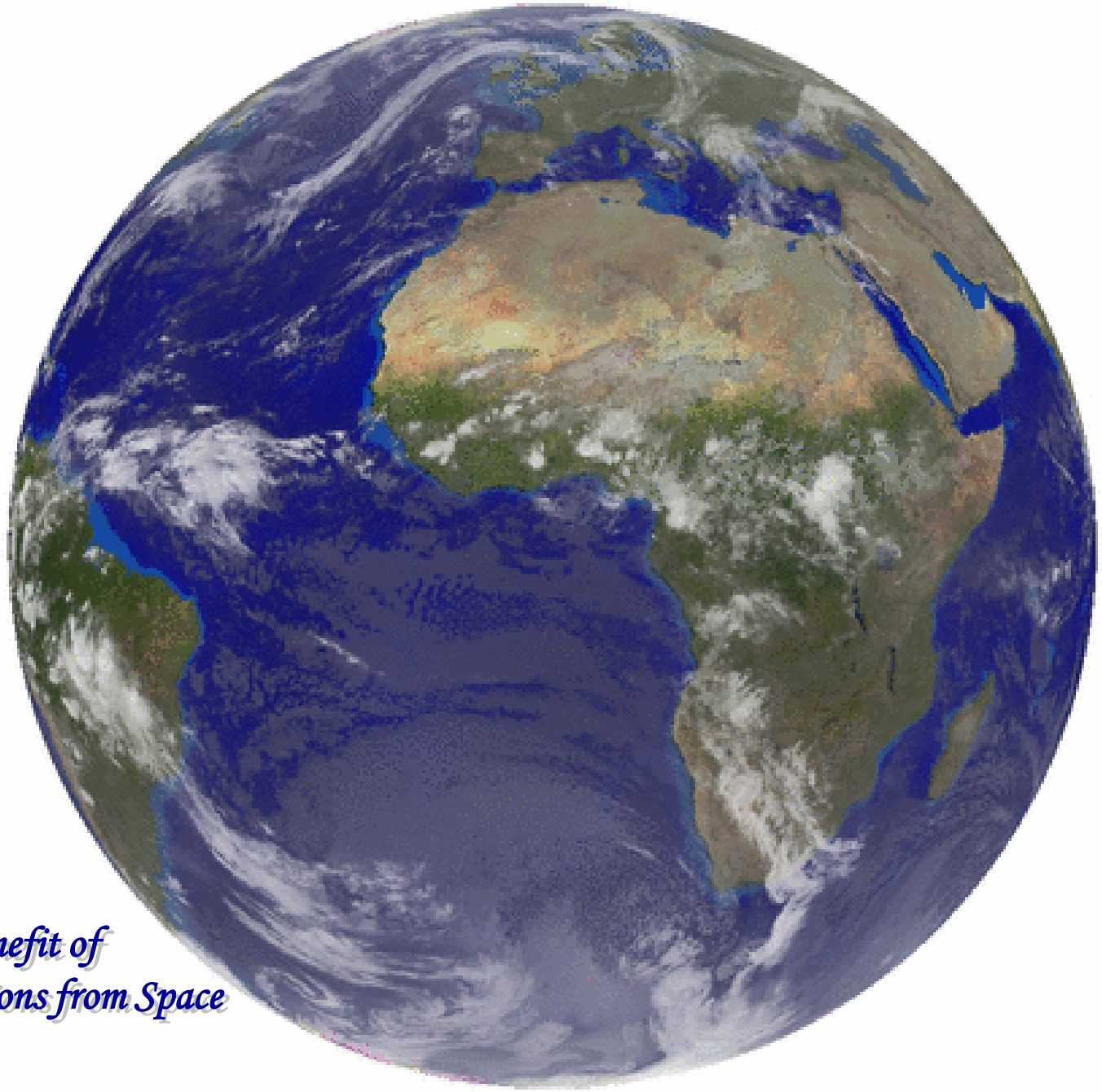
John Le Marshall 1,2, Yi Xiao1, R. Norman2, Jin Lee1, C Tingwell, 1, K. Zhang, P. Gregory1, Jim Jung4, P. Steinle, E. Fu …..



Overview

- Background/Introduction
- The Importance of Satellite Data (in the SH)
- The Challenge
- Advances/RO in Analysis and Prediction
- Monitoring the Climate
- Plans/Future Prospects
- Summary

EOS



Subtitle: The benefit of Earth Observations from Space On NWP

The Importance of Satellite Data (in the SH)

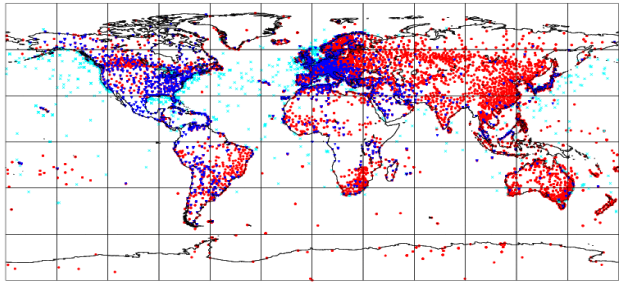
Observing System Experiments (OSEs)

With and Without Satellite Data

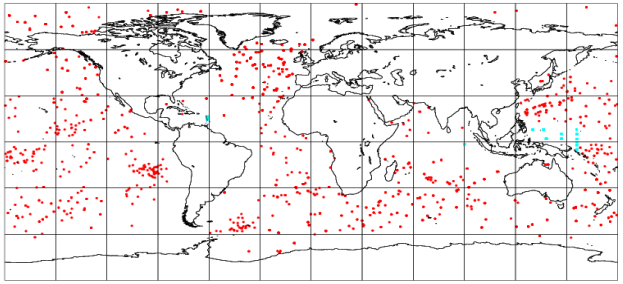
- **Systems Examined**
  - ACCESS (APS1) – Operational data base (Australian Op. Sys)
  - 28 October to 30 November 2011

  - GFS (2010) - Operational data base (NCEP Op. Sys)
  - 15 August to 30 September 2010

SYNOPS AND SHIPS



BUOYS



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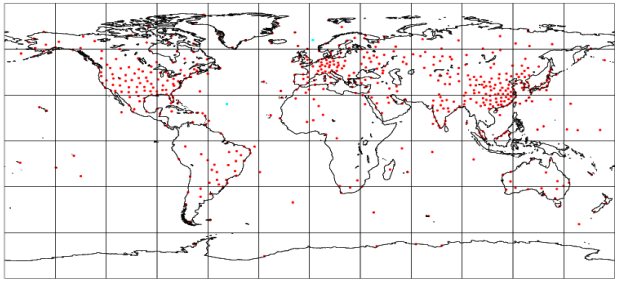
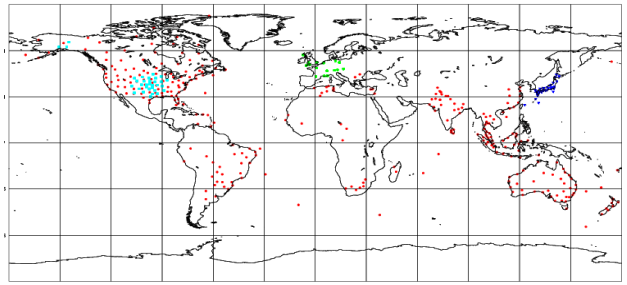
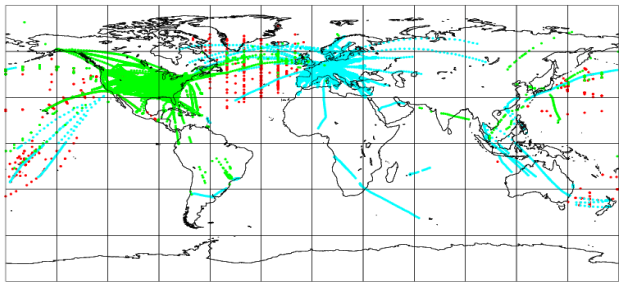


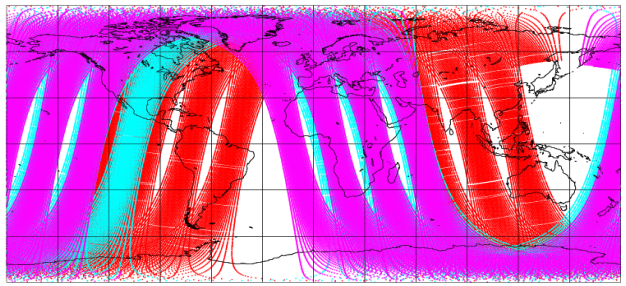
PILOTS AND PROFILERS



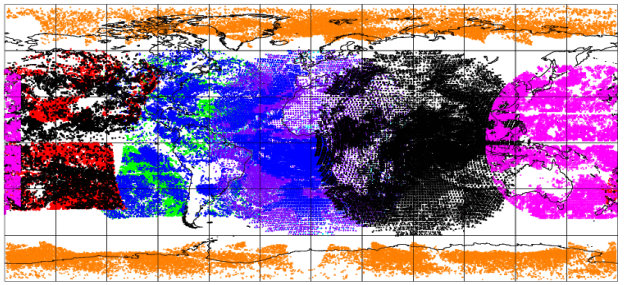
AIRCRAFT



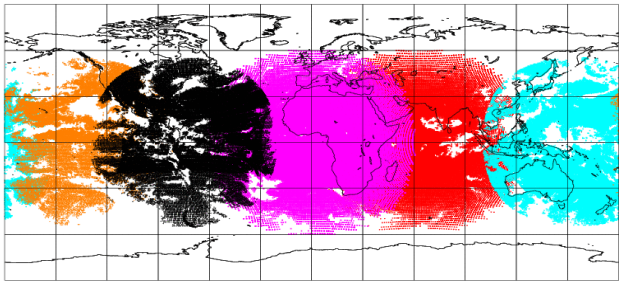
IR AND MW SOUNDERS



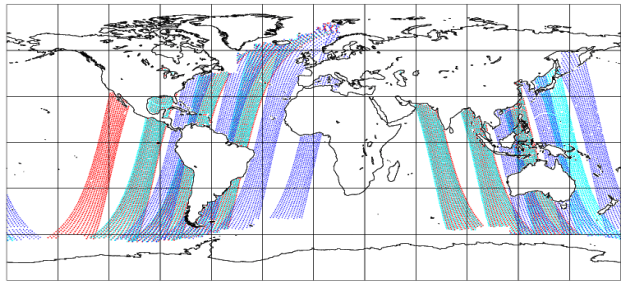
SATELLITE WINDS



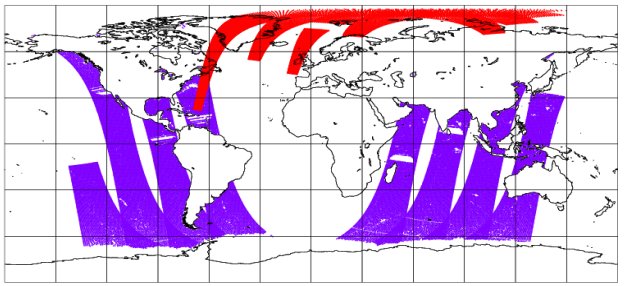
WATER-VAPOUR RADIANCES



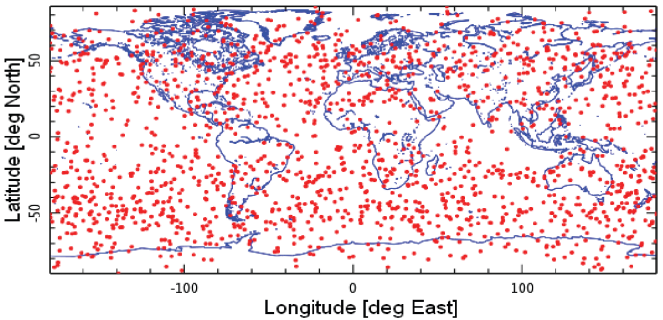
SSM/I



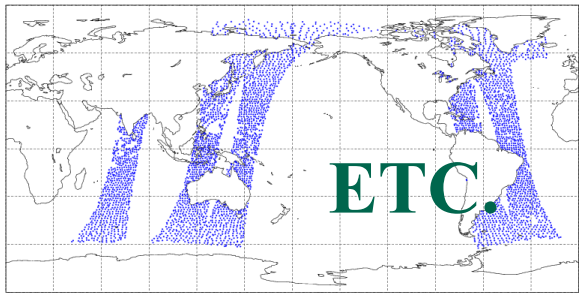
SCATTEROMETER



GPS RO



AIRS



Issue time 23UTC 20 Sep 2012

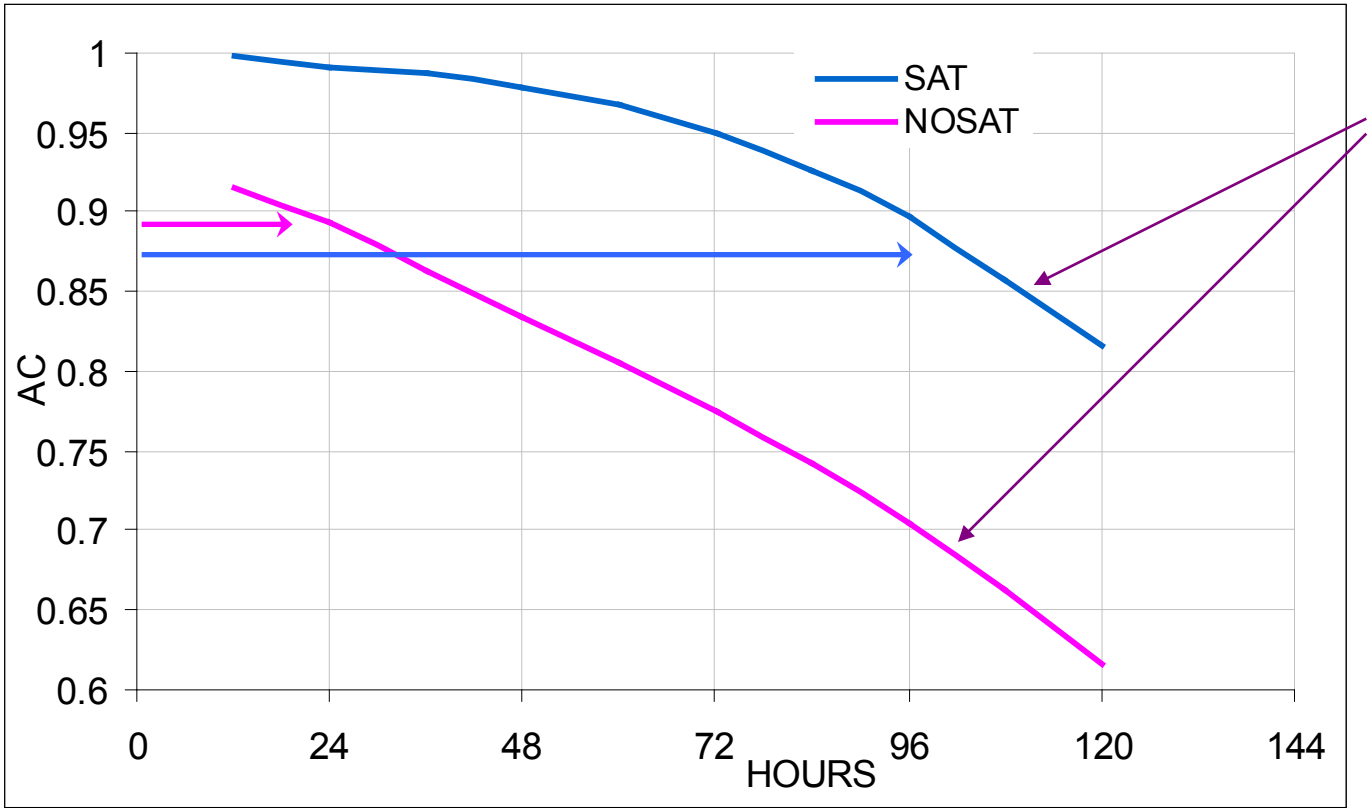
Australian Community Climate and Earth System Simulator (ACCESS) - G

The Characteristics of the ACCESS-G Forecast System

DOMAIN	GLOBAL
UM Horizontal Resolution (lat x lon)	640 X 481(`0.5625Deg X 0.375Deg) ~47km.
Analysis Horizontal resolution (lat x lon)	288 X 217 (1.250Deg X 0.833Deg) ~106km.
Vertical Resolution	L70
Observational Data Used (6h window)	AIRS, IASI, ATOVS, Scat, AMV, SYNOP, SHIP, BUOY,AMDARS, AIREPS, TEMP, PILOT, GPS-RO…
Sea Surface Temperature Analysis	Daily, global 1° sst analysis
Sea Ice analysis	Daily, global 1/12° sea ice analysis
Soil moisture Nudging	SURF once every 6 hours
Model Time Step	12 minutes (96 time steps per day)
Analysis Time Step	30 minutes
Suite Definition	SCS vn18.2

Table 1: N288L70 System Specification

ACCESS FORECAST SKILL (AC) VERSUS TIME
SH 500hPa HGT 26 October - 31 November 2011



A high quality (AC=0.9) 24 hour (1 day) forecast without using satellite data is of the same quality as a 96 hour (4 days) forecast using satellite data.

From Le Marshall et al. 2013 AMOJ.

Earth observations From Space

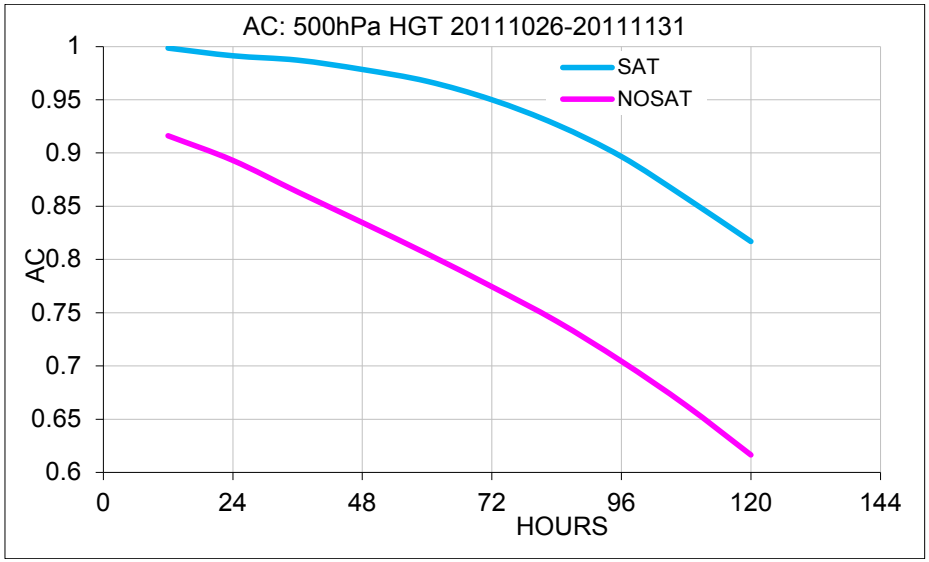


Fig. 8(c). SH 500hPa height anomaly correlation for the control (SAT) and no satellite (NOSAT), 28 October to 30 November 2011 using ACCESS and verifying against the control analysis

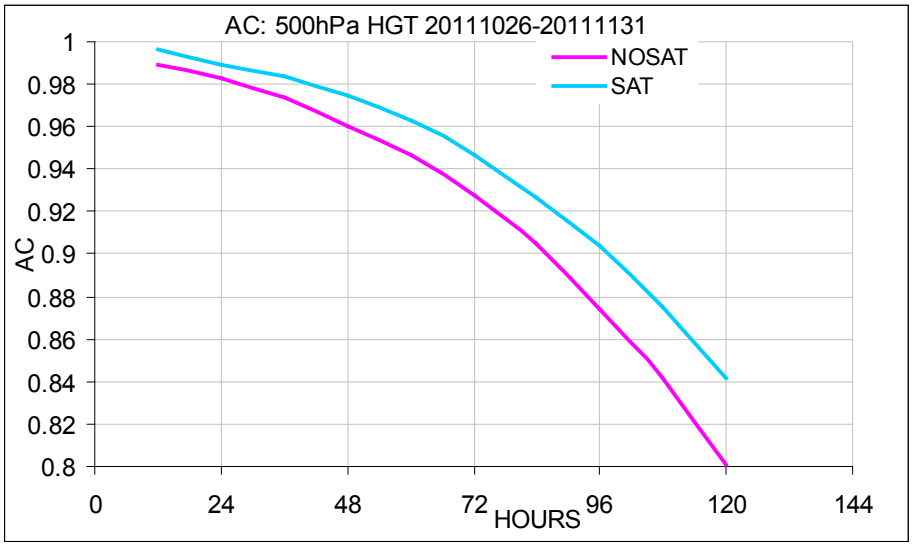


Fig. 8(f). NH 500hPa height anomaly correlation for the control (SAT) and no satellite (NOSAT), 28 October to 30 November 2011 using ACCESS and verifying against the control analysis

Earth observations From Space

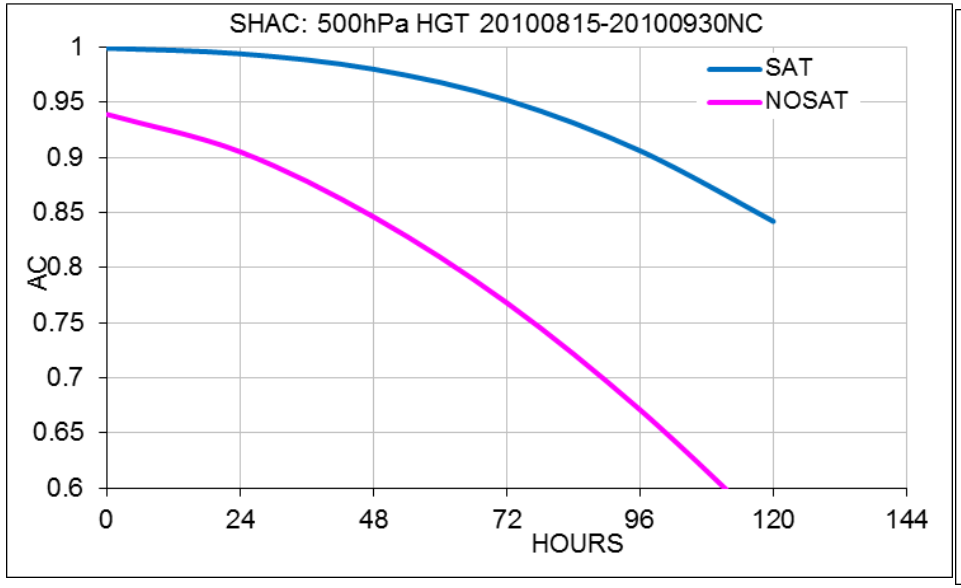


Fig. 8(g). SH 500hPa height anomaly correlation for the control (SAT) and no satellite (NOSAT), 15 August to 30 September 2010 using GFS and verifying against the control analysis

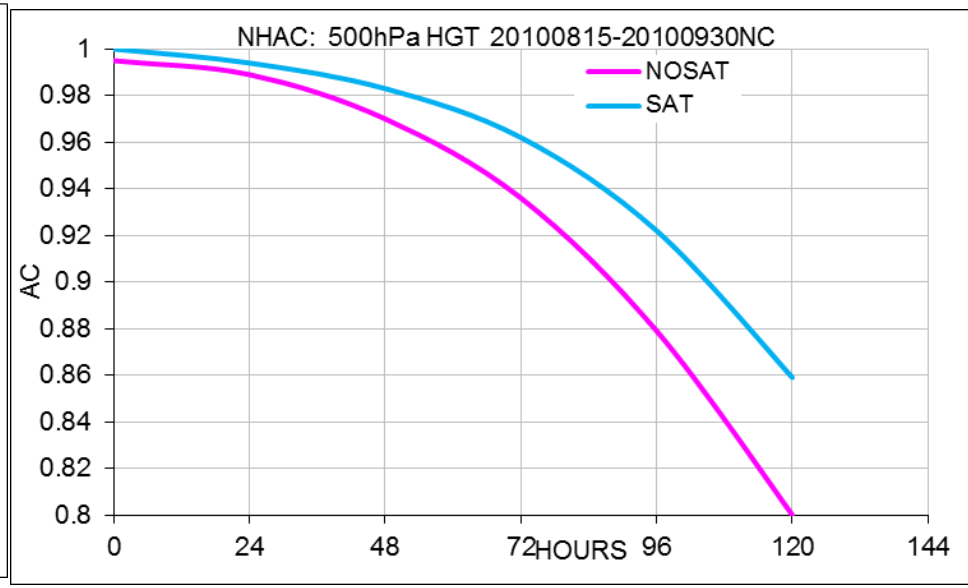


Fig. 8(hNH 500hPa height anomaly correlation for the control (SAT) and no satellite (NOSAT), 15 August to 30 September 2010 using the GFS and verifying against the control analysis

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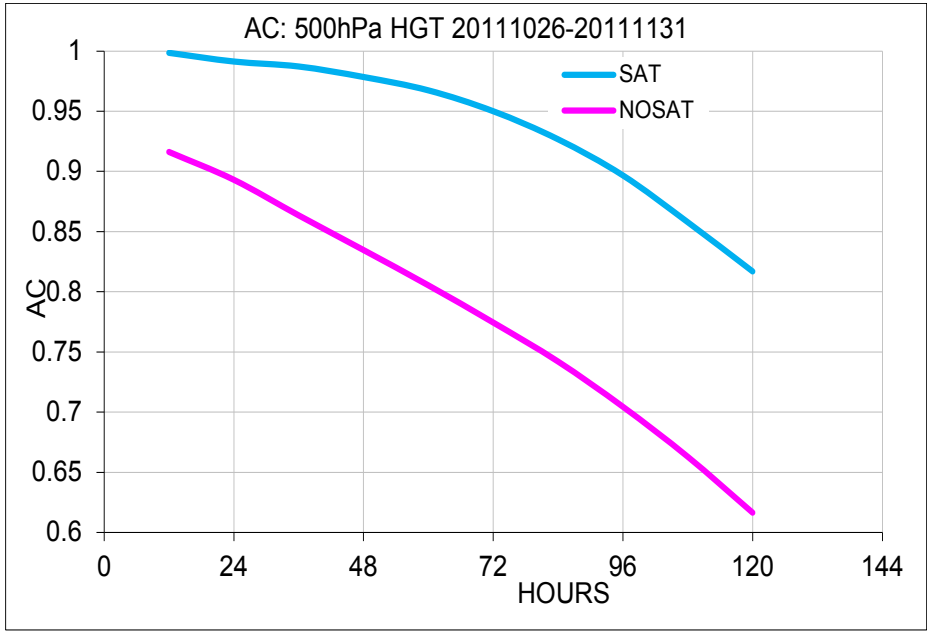
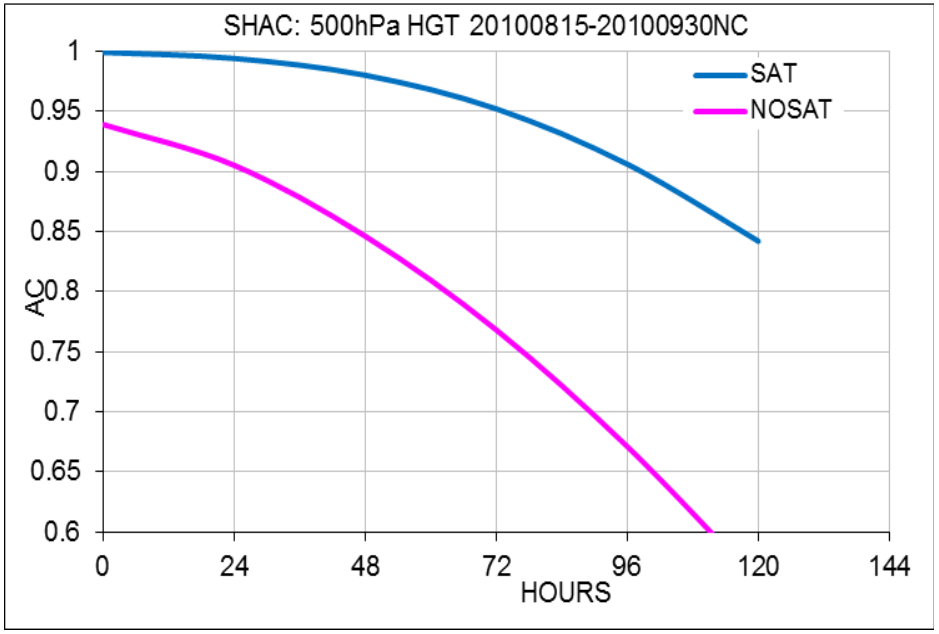
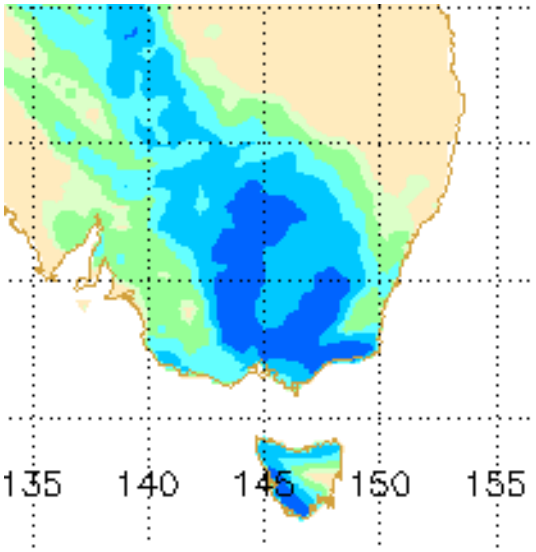
Earth observations From Space



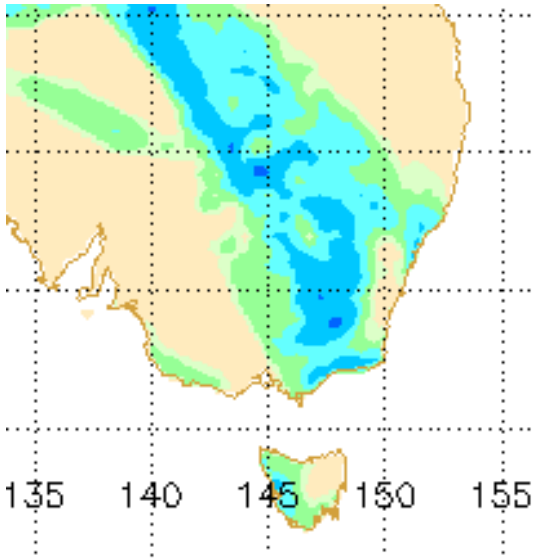
SH 500hPa height anomaly correlation for the control (SAT) and no satellite (NOSAT), 28 October to 30 November 2011 using ACCESS-G and verifying against the control analysis



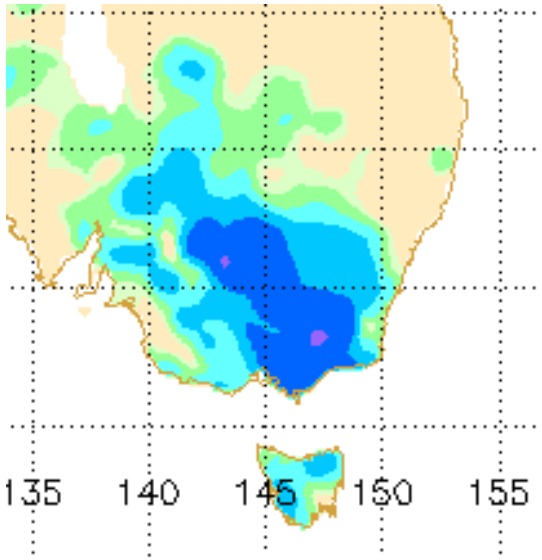
SH 500hPa height anomaly correlation for the control (SAT) and no satellite (NOSAT), 15 August to 30 September 2010 using GFS and verifying against the control analysis.



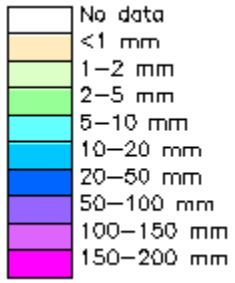
ACCESS-G 48 to 72 hour rainfall forecast for 9 November 2011 using satellite data.



ACCESS-G 48 to 72 hour rainfall forecast for 9 November 2011 using no satellite data.

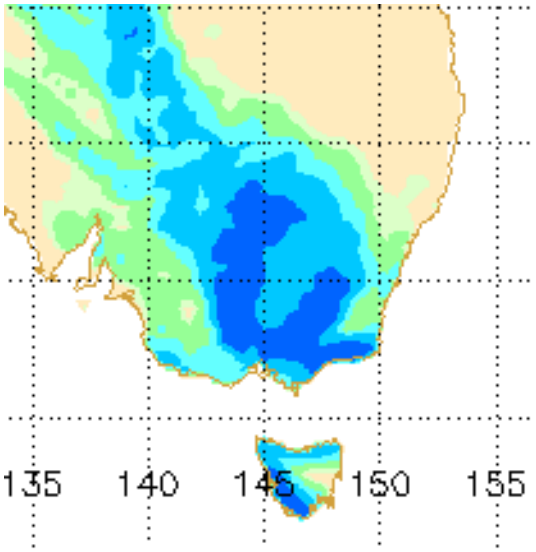


Daily rain gauge analysis for 9 November 2011.

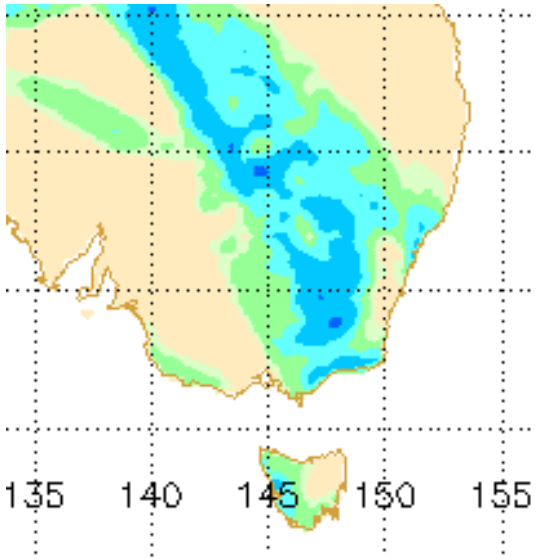


Daily rainfall values.

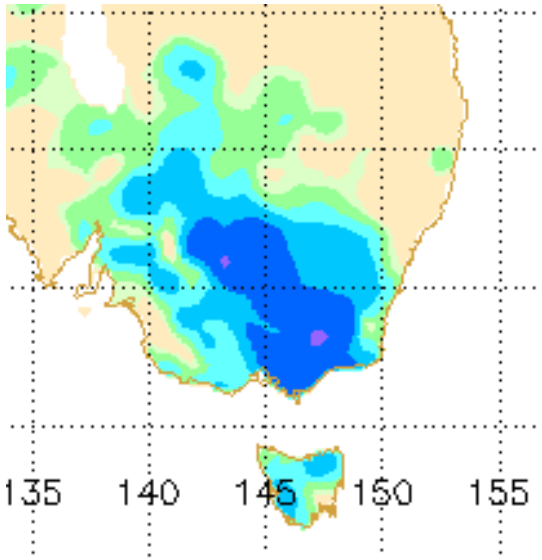
Extreme Weather



ACCESS-G 48 to 72 hour rainfall forecast for 9 November 2011 using satellite data.

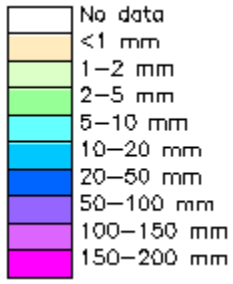


ACCESS-G 48 to 72 hour rainfall forecast for 9 November 2011 using no satellite data.



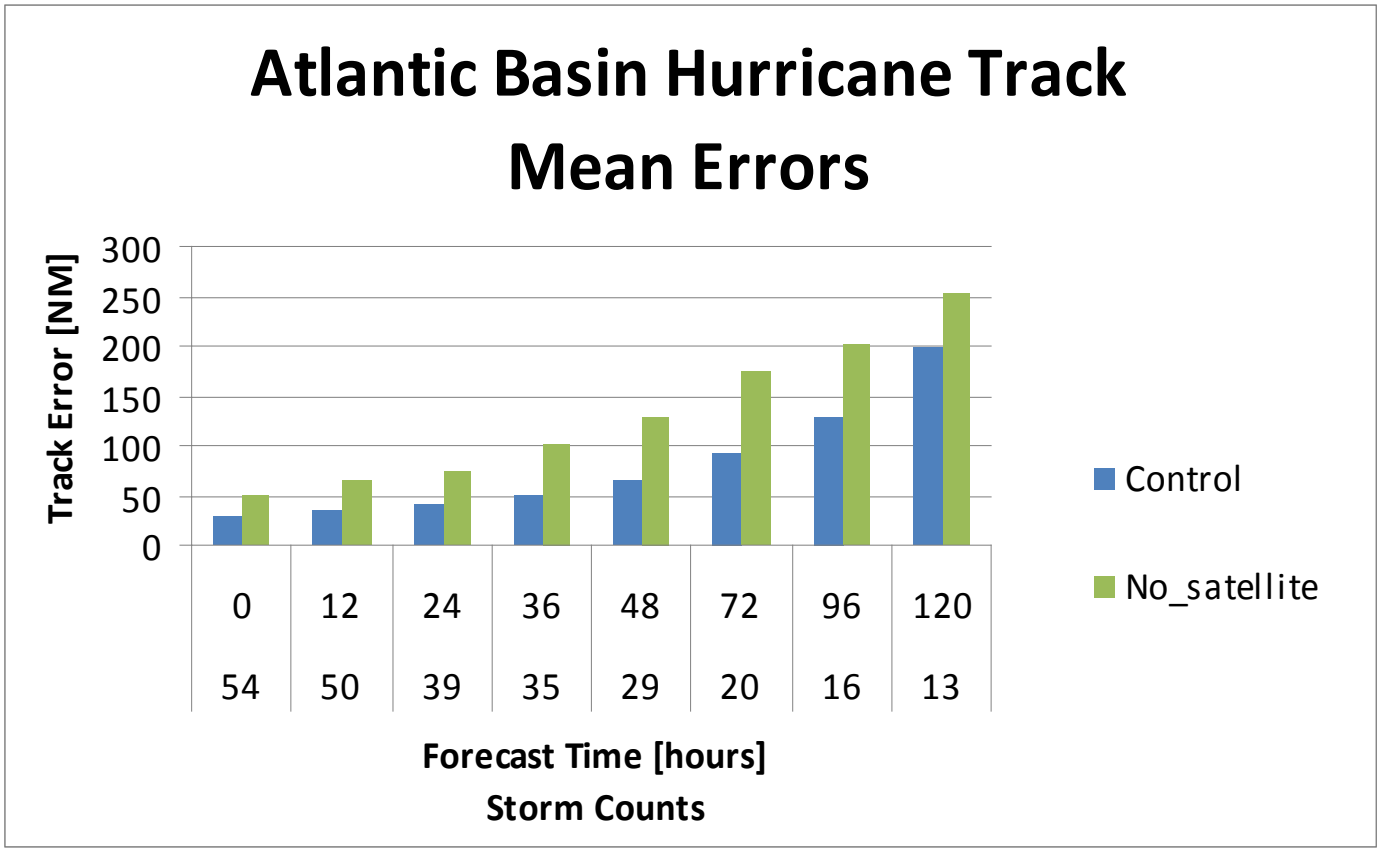
Daily rain gauge analysis for 9 November 2011.

9 November 2011	NOSAT	SAT
Correlation between observed and forecast rainfall (Aust. Region)	0.282	0.699
Hanssen and Kuipers (Aust. Region)	0.360	0.596

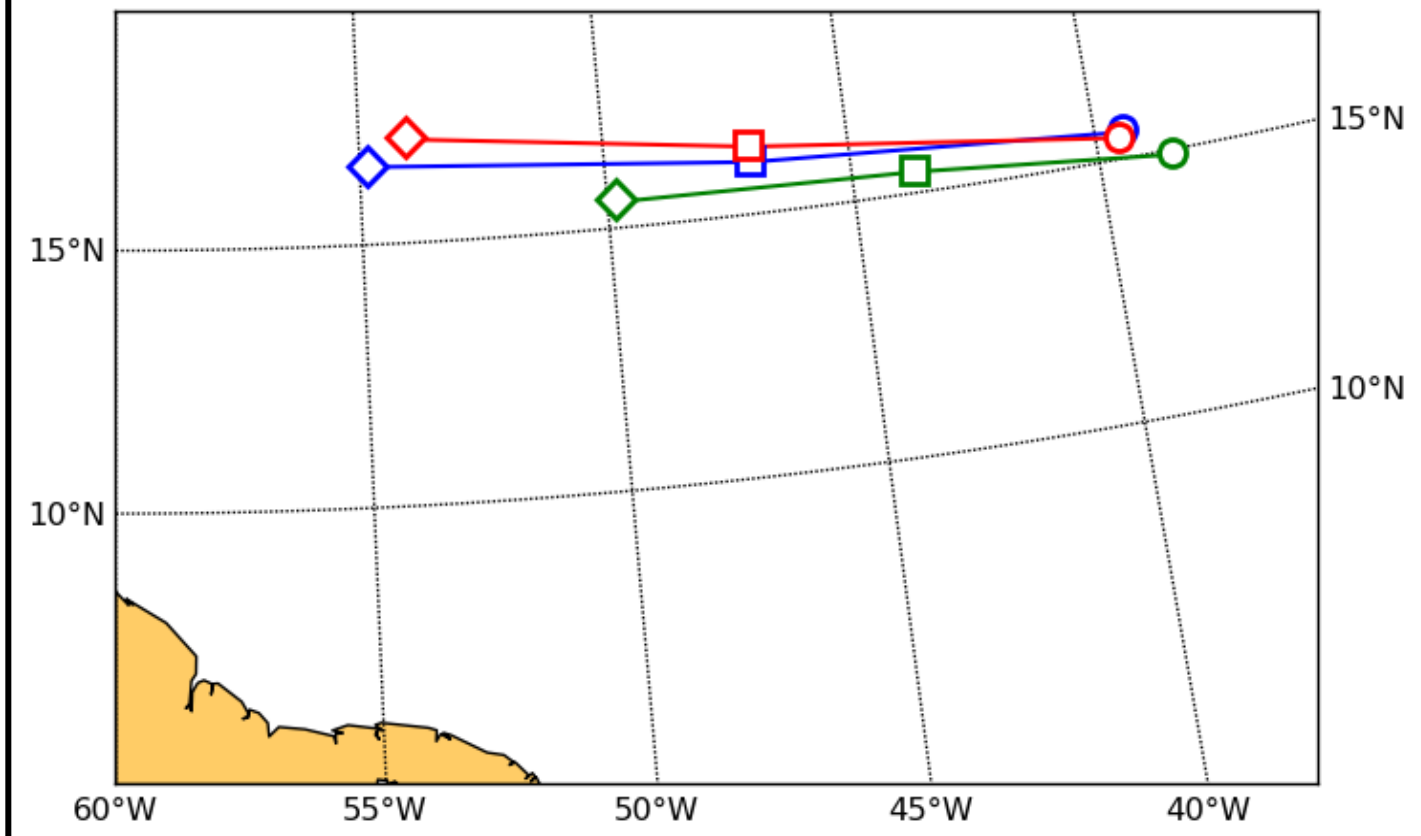


Daily rainfall values.

Table 1. ACCESS-G verification statistics for all of Australia for the month of November 2011 for forecasts produced with (SAT) and without (NOSAT) satellite data		
1 – 30 November 2011 (72-96 hrs)	**NOSAT**	**SAT**
Correlation between observed and forecast rainfall (Full Aust. Region)	0.25	0.41
Hanssen and Kuipers (Full Aust. Region)	0.36	0.51



Atlantic basin mean hurricane track errors for the control (all data) and no satellite data case, 15 August to 30 September 2010 using GFS and verifying against the control (all data) analysis.

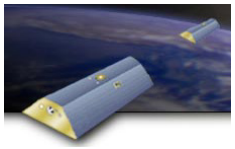


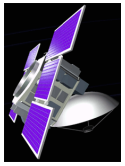
Atlantic basin tracks for hurricane Earl commencing 00UTC 27 August 2010. The control (all data) forecast is red and the no satellite data forecast case is green. The blue line is the best track. Circles represent 00 UTC on 27 August, squares 00 UTC on 28 August and diamonds 00 UTC on 29 August 2010.

Observing the Atmosphere
Satellite systems

THE CHALLENGE

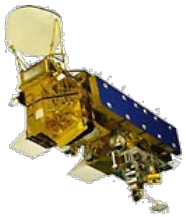
GRACE





Cloudsat

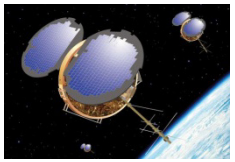
CALIPSO



Aqua

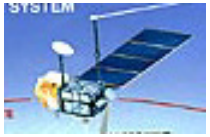
SSMIS

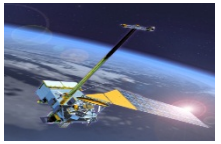
TRMM



COSMIC

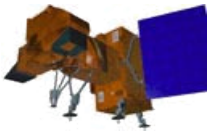
TOPEX





NPP

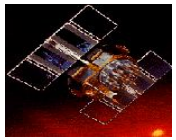
MSG



Landsat

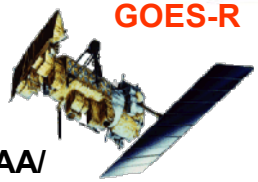
Meteor/
SAGE

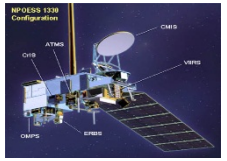
EPS
METOP



COSMIC/GPS

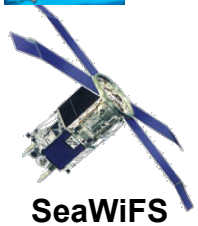
GOES-R





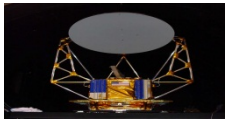
NOAA/
POES

NPOESS



SeaWiFS

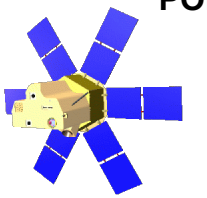
Terra



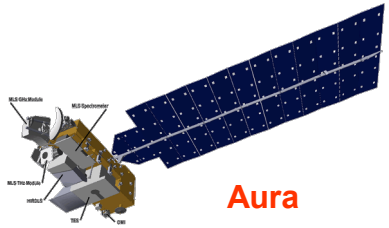
WindSAT

Jason

ICESat

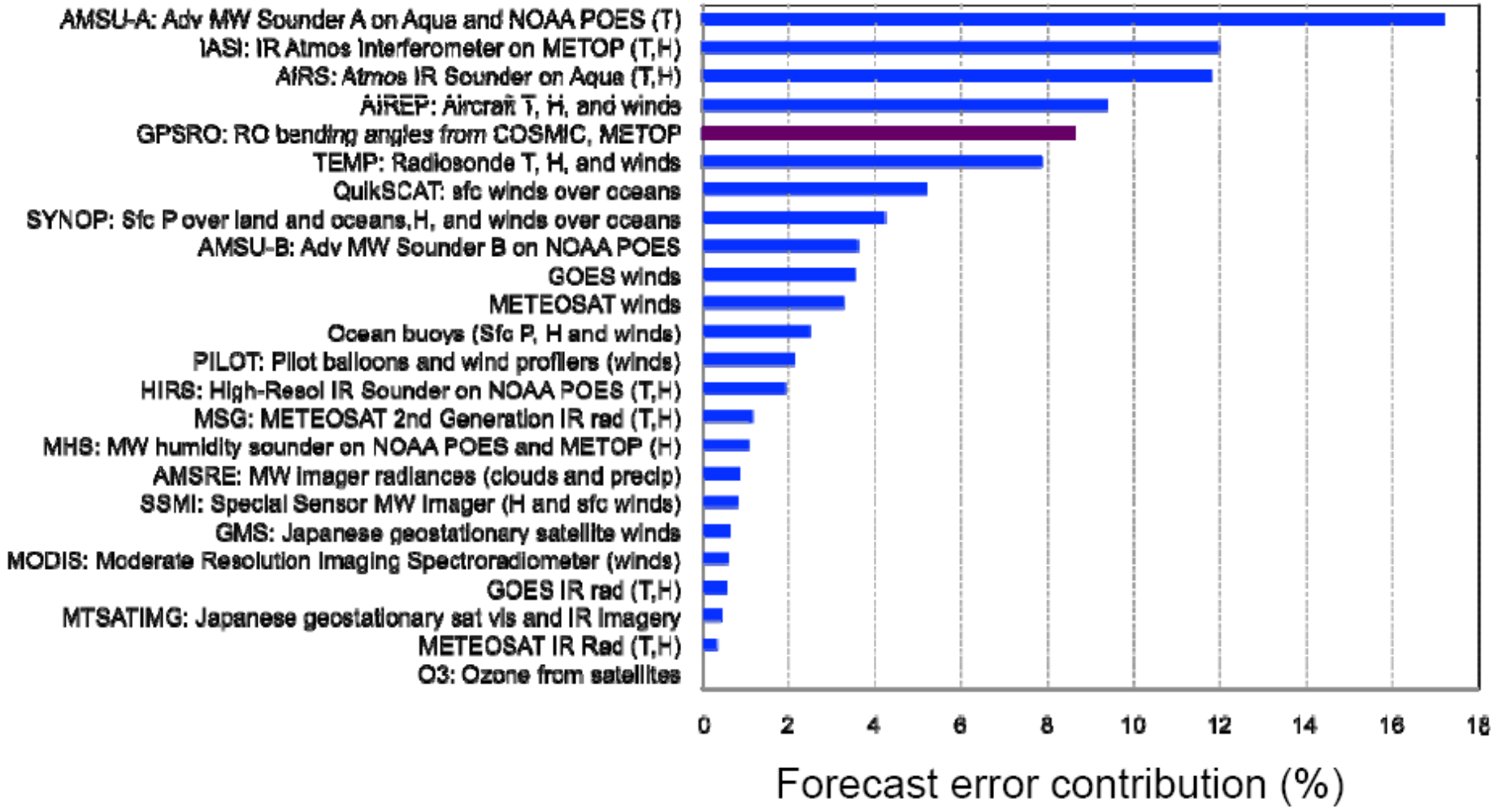


SORCE



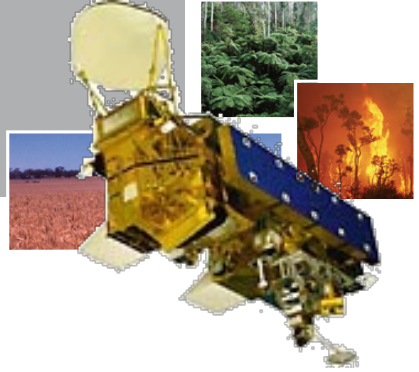
Aura

Operational ECMWF system September to December 2008. Averaged over all model layers and entire global atmosphere. % contribution of different observations to reduction in forecast error.



Advanced Sounders have largest single instrument impact in reducing forecast errors.

Courtesy: Carla Cardinali and Sean Healy, ECMWF 22 Oct. 2009



AIRS Data Assimilation Using Cloudy Fields of View

Initial Experiments: 1 January – 24 February 2007

Assume :

$$R_j = (1 - \alpha_j) R_{clr} + \alpha_j R_{cld}$$

Only variability in AIRS fov is cloud amount α_j

9 AIRS fovs on each AMSU-A footprint used to estimate R_{clr}

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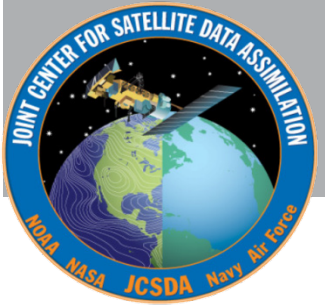
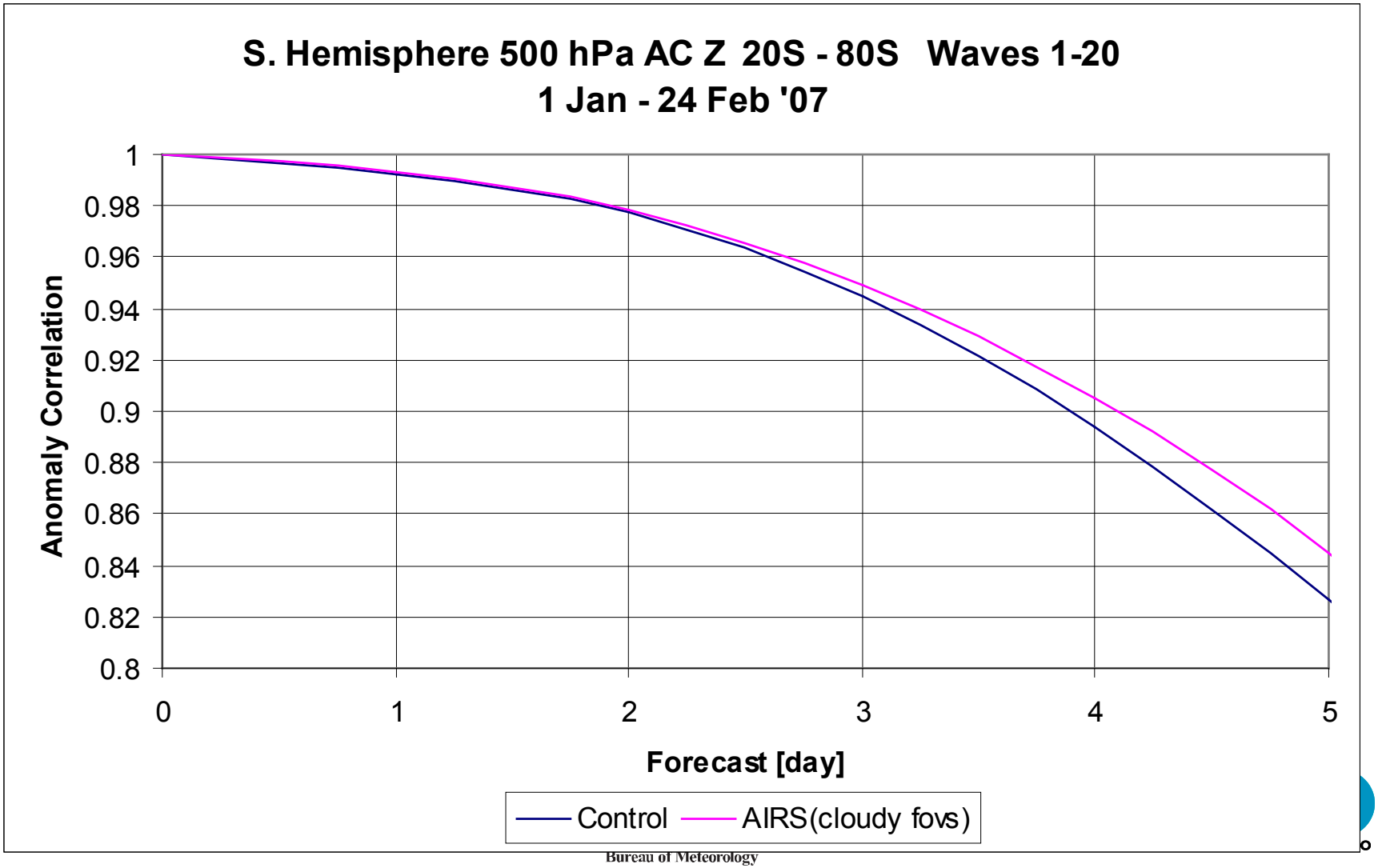
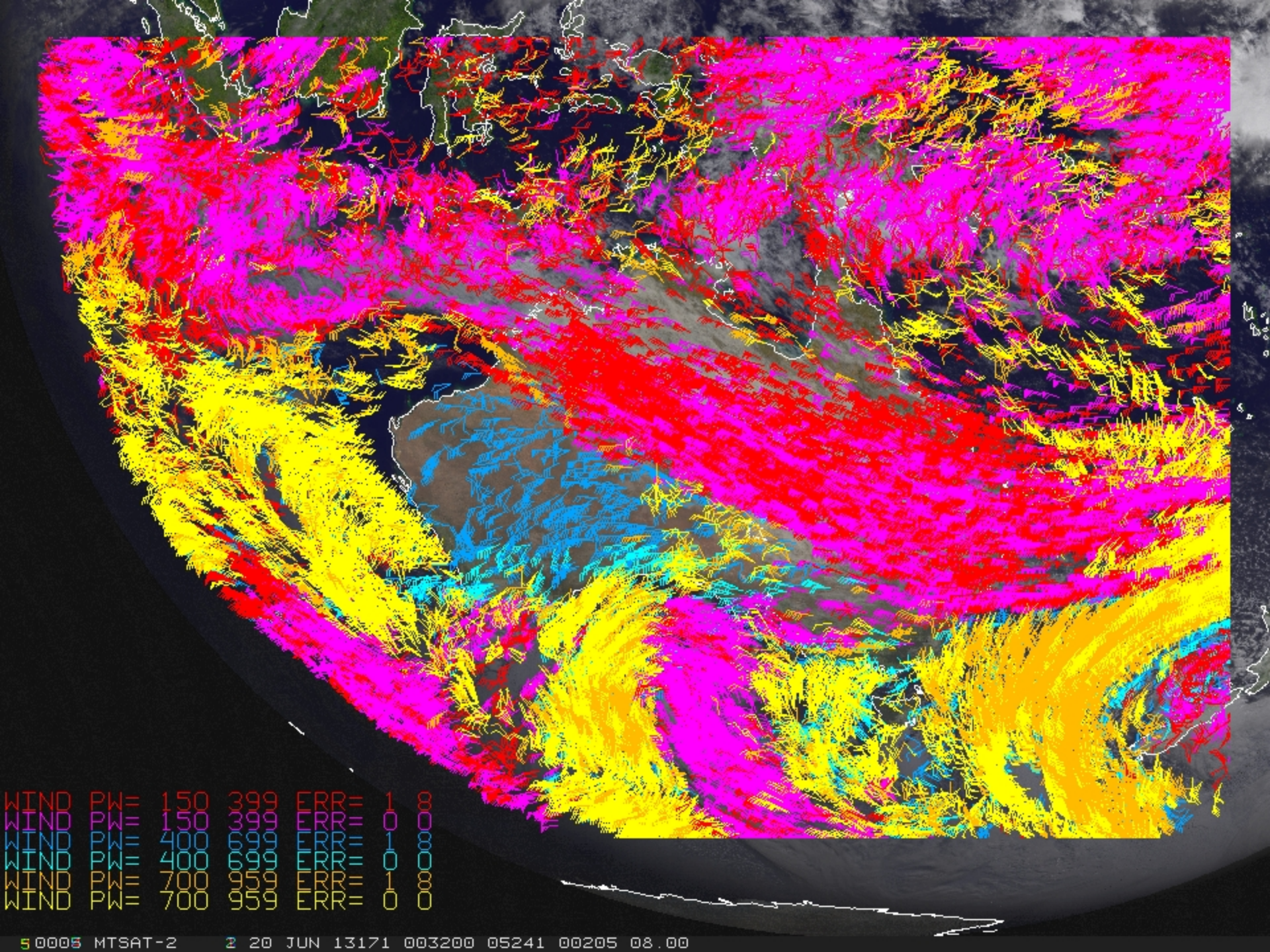

JOINT CENTER FOR SATELLITE DATA ASSIMILATION
NOAA
NASA
JCSDA
Navy
Air Force


S. Hemisphere 500 hPa AC Z 20S - 80S Waves 1-20
1 Jan - 24 Feb '07
Anomaly Correlation
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0
1
2
3
4
5
Forecast [day]
Control
AIRS(cloudy fovs)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5 0000S MTSAT-2 2 20 JUN 13171 003200 05241 00205 08.00

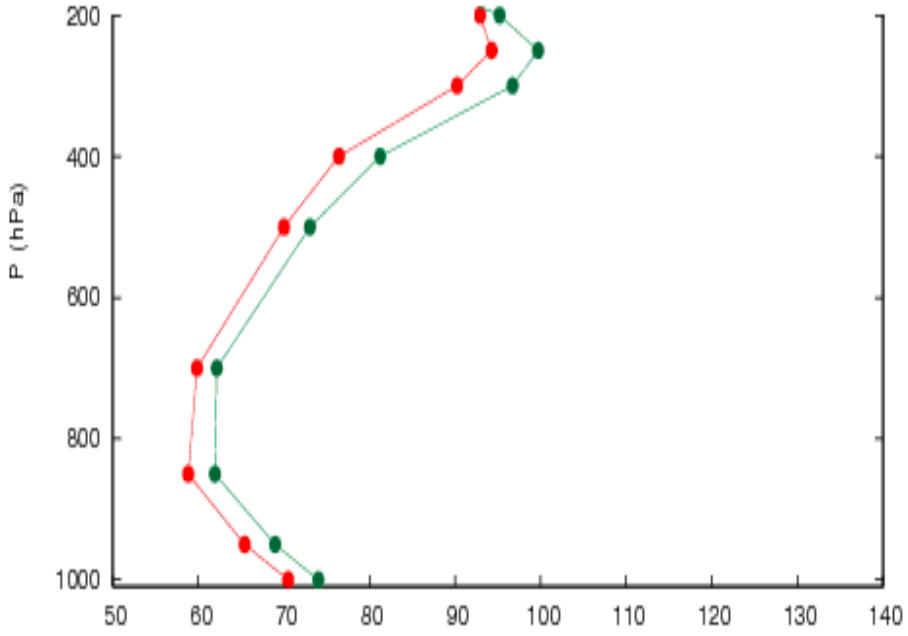


Fig.6(a). The RMS difference between forecast and verifying analysis geopotential height(m) at 24 hours for ACCESS-R (green) and ACCESS-R with AMVs (red) for the period 27 January to 23 February 2011.

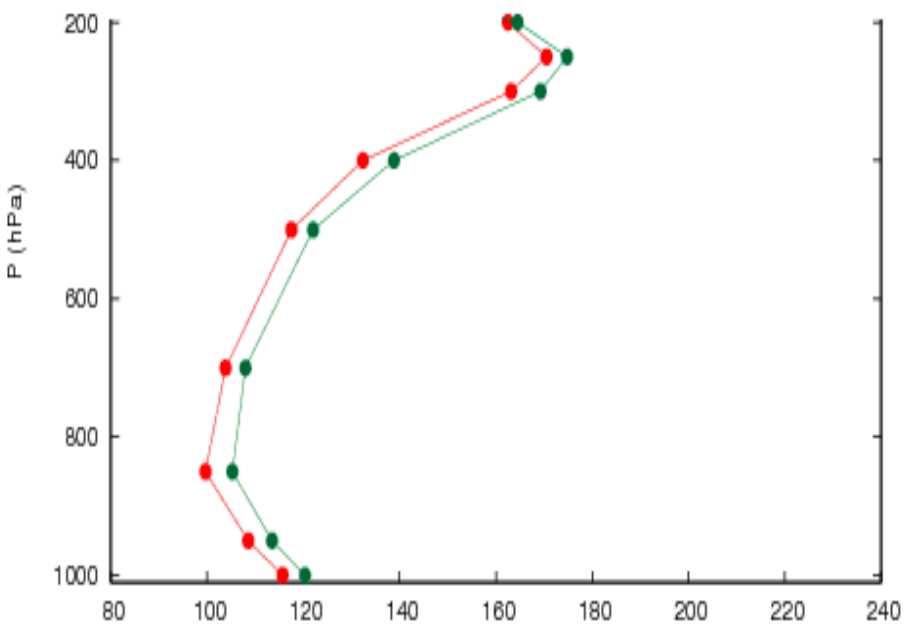
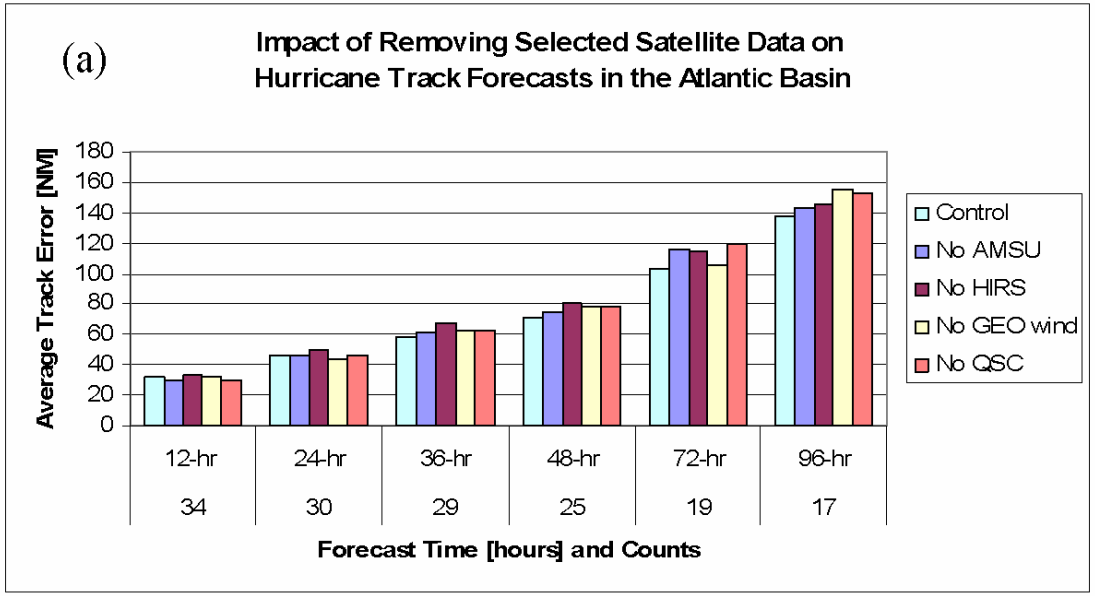


Fig.6(b). The RMS difference between forecast and verifying analysis geopotential height(m) at 48 hours for ACCESS-R (green) and ACCESS-R with AMVs (red) for the period 27 January to 23 February 2011.



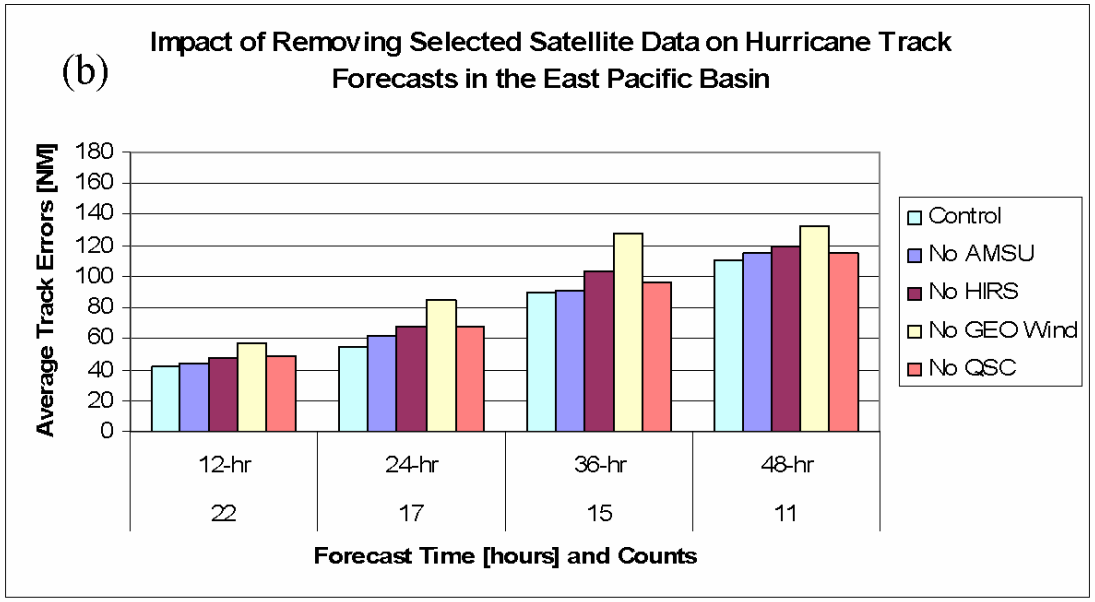
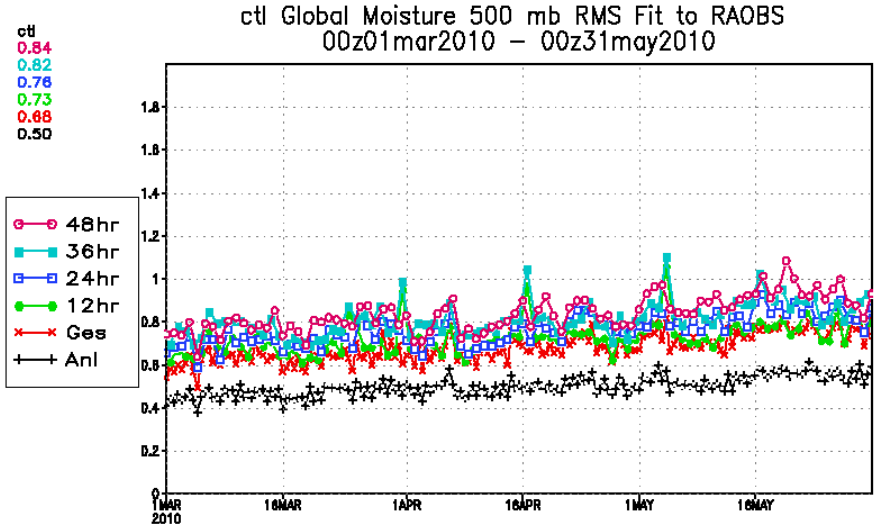


Fig. 10. Average track error (NM) by forecast hour for the control simulation and experiments where AMSU, HIRS, GEO winds and QuikSCAT were denied. The Atlantic Basin results are shown in (a), and the Eastern Pacific Basin results are shown in (b). A small sample size in the number of hurricanes precludes presenting the 96 hour results in the Eastern Pacific Ocean.

Analysing Tropospheric Moisture by Assimilating Hyperspectral Infrared Water Vapor Channels

control

experiment



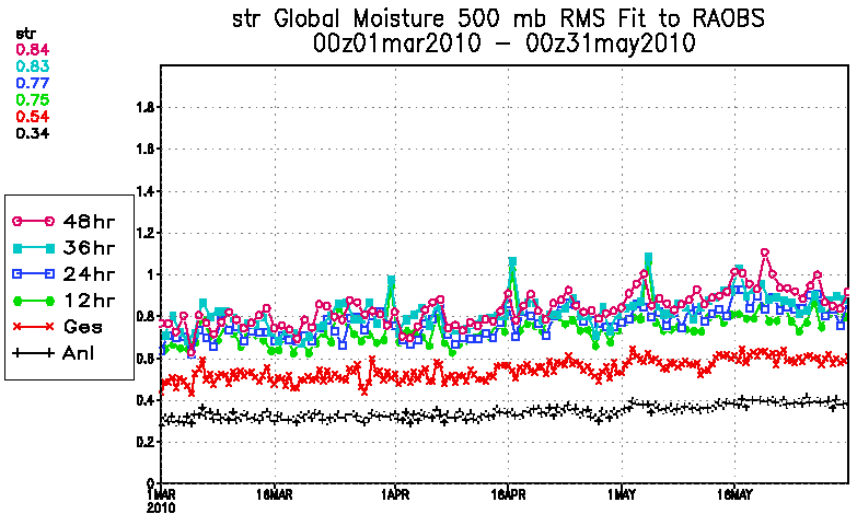
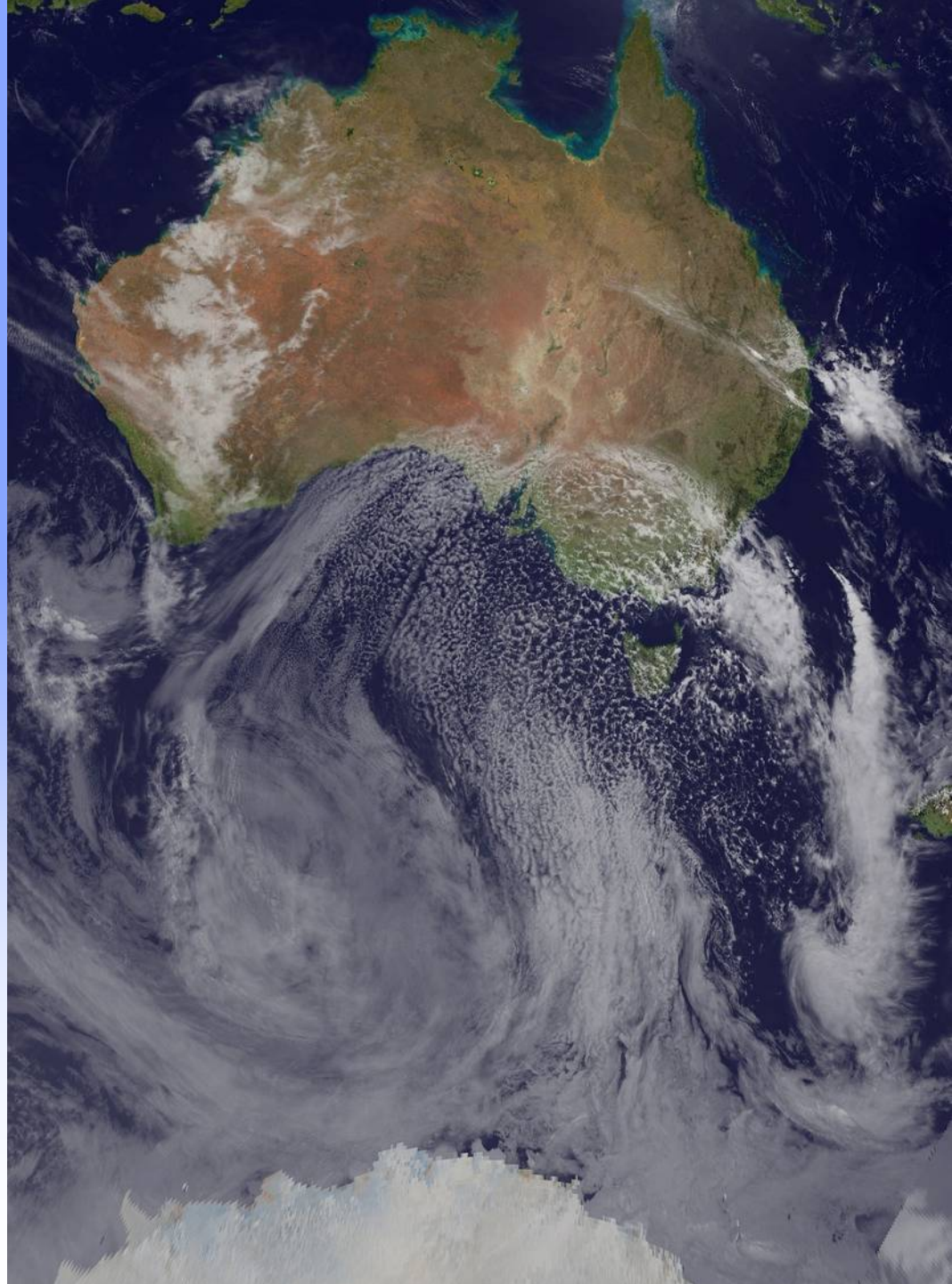


Figure 3: Specific humidity fits to rawinsondes humidity data during the time period March to May 2010 for the analysis, 6(Ges)- , 12- , 24- , 36- and 48-hour forecasts. Note the considerable improvement in the 6-hour and 12-hour forecasts.

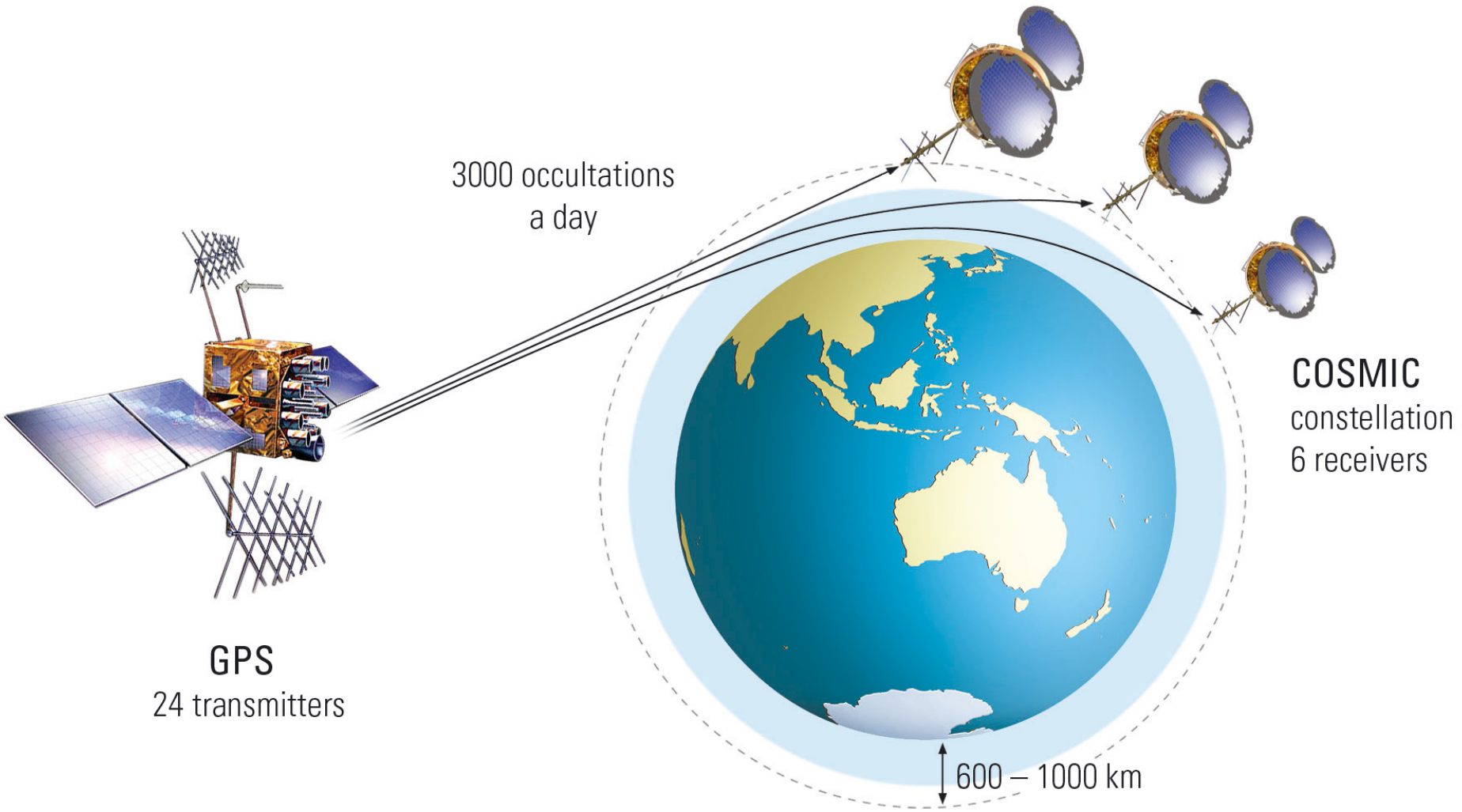
Australian Government
Bureau of Meteorology

Use of COSMIC Data for Weather Forecasting and Climate Monitoring in Australia

John Le Marshall 1,2, Robert Norman, Yi Xiao1, P. Gregory1, Jin Lee1, Peter Steinle1, Kefei Zhang, …..



GPS/COSMIC, METOP…RADIO OCCULTATION
(Operational in BoM)



OPERATIONAL TRIAL

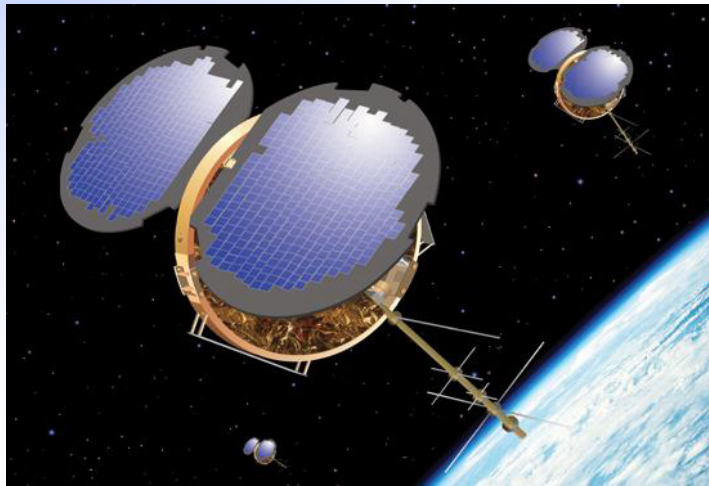
OPERATIONAL SYSTEM ACCESS-G

26 February – 26 March 2009

Used

- Refractivity Data from
  - the COSMIC Constellation
  - GRACE and METOP

- Operational Global Forecast Model (ACCESS-G N144 L50) and Operational Data Base



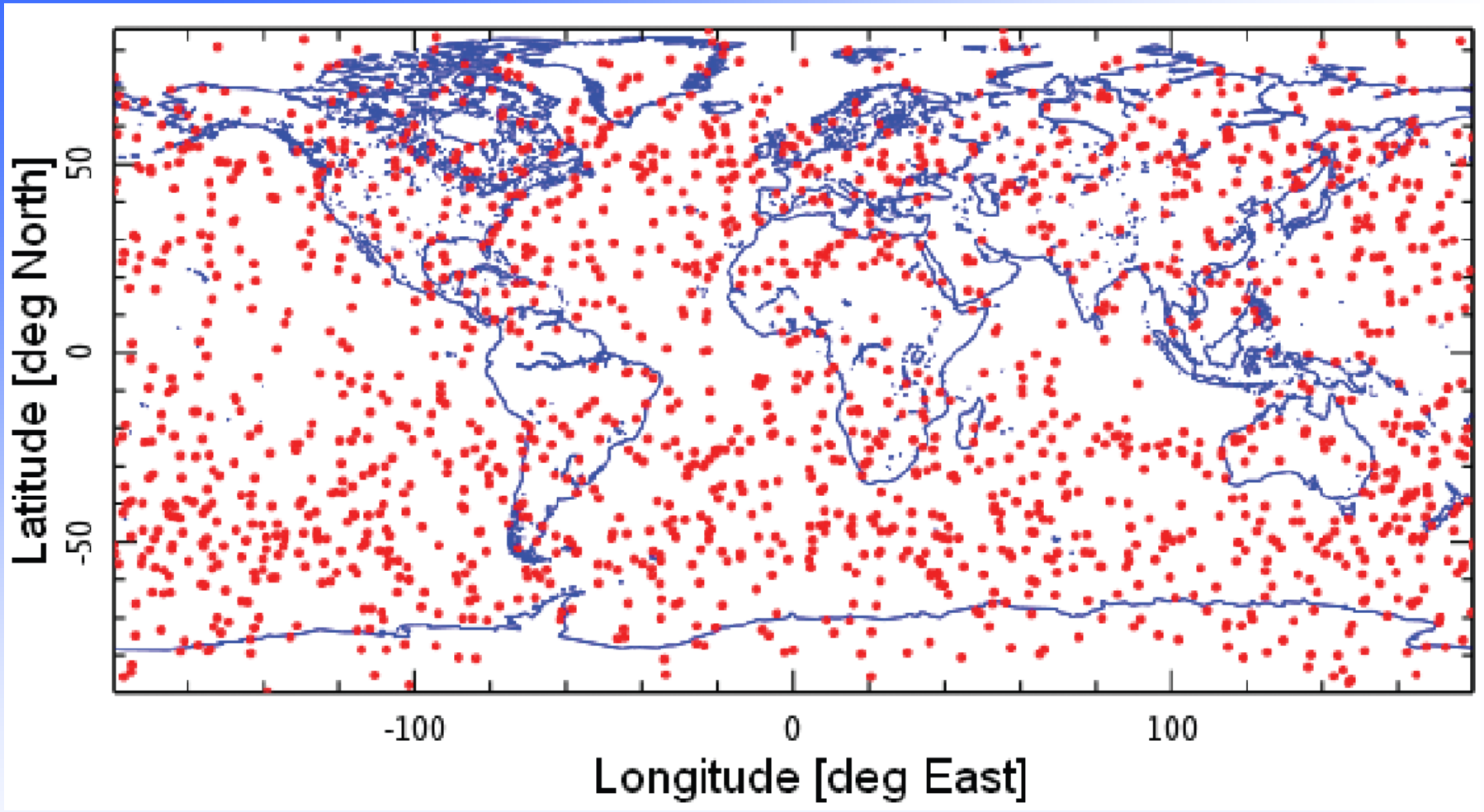
Australian Community Climate and Earth System Simulator (ACCESS) - G

The Characteristics of the ACCESS-G Forecast System

DOMAIN	GLOBAL
UM Horizontal Resolution (lat x lon)	217x288 (~ 125km x 83 km)
Analysis Horizontal resolution (lat x lon)	163x216 (~166km x 111km)
Vertical Resolution	L50
Observational Data Used (6h window)	AIRS, ATOVS, Scat, AMV, SYNOP, SHIP, BUOY,AMDARS, AIREPS, TEMP, PILOT, GPS-RO…
Sea Surface Temperature Analysis	Weekly, global 1° sst analysis
Sea Ice analysis	Daily, global 1/12° sea ice analysis
Soil moisture Nudging	SURF once every 6 hours
Model Time Step	15 minutes (96 time steps per day)
Analysis Time Step	40 minutes
Suite Definition	SCS vn18.2

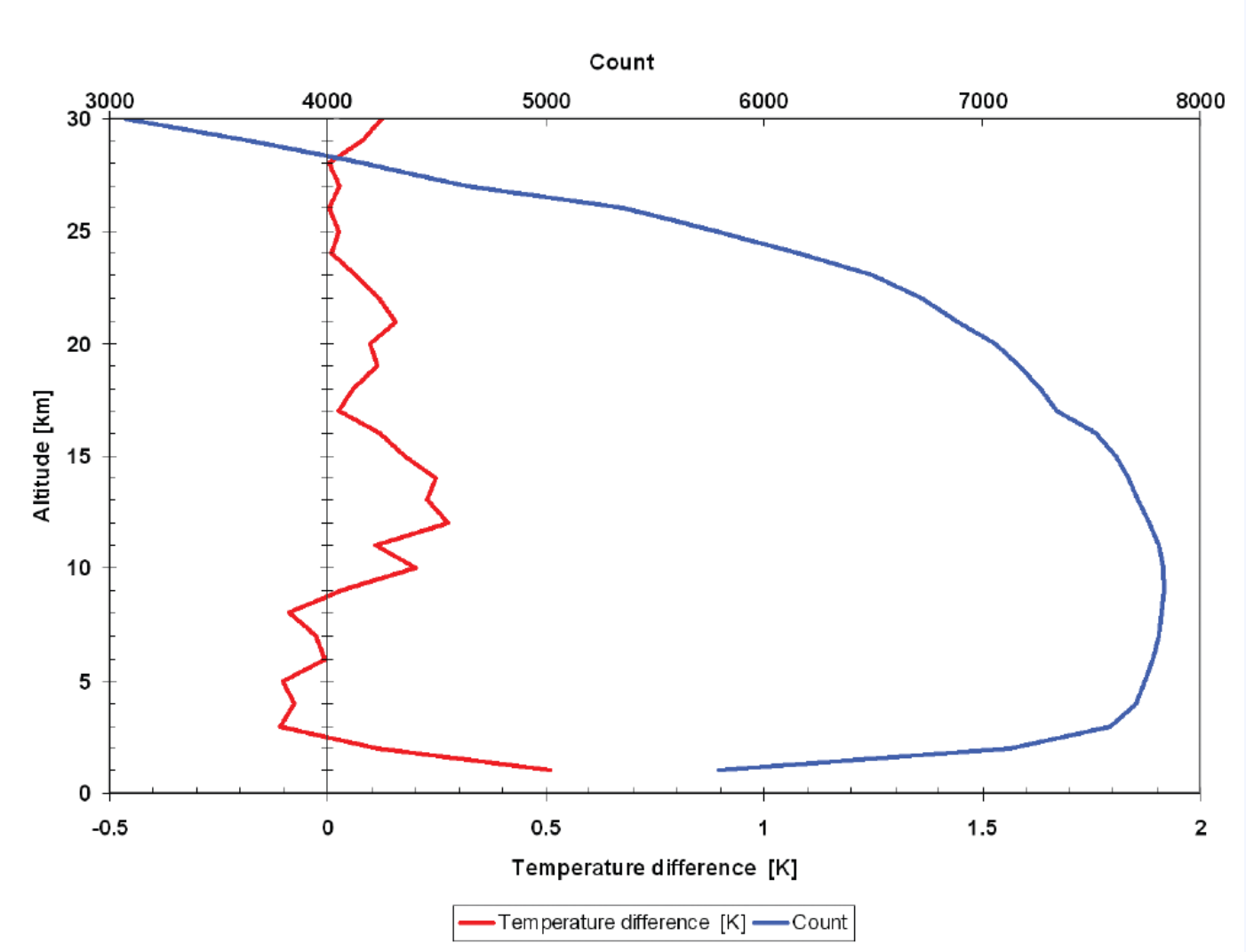
Table 1: N144L50 System Specification

GPS/COSMIC



GPS radio occultation sounding positions for 15 March 2009.
(Image courtesy of UCAR.)

GPS/COSMIC



A plot of the mean temperature difference (red) between COSMIC and radiosonde observations for the period, 5 March to 20 March 2009. The number of samples (blue) is also shown. (Data courtesy of UCAR.)

OPERATIONAL TRIAL - 26 February to 26 March, 2009

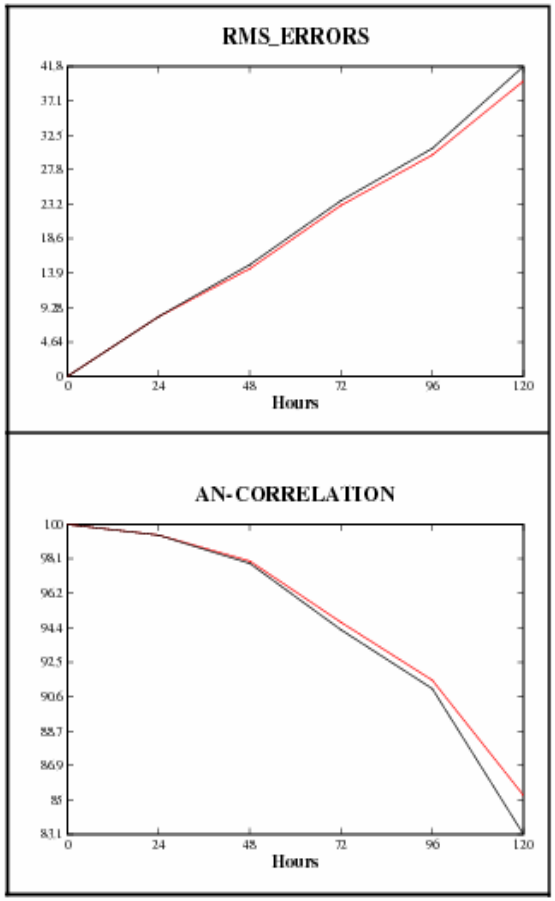


Figure 8(a). RMS Errors and anomaly correlations for ACCESS-G MSLP forecasts to five days, for the Australian region. Control (black), and with GPS RO data (red) for the period 26 February to 26 March, 2009.

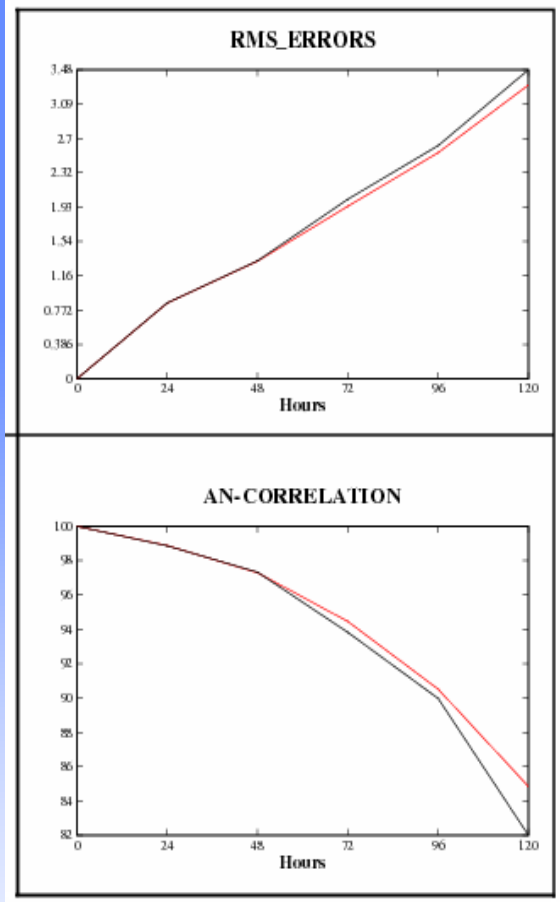


Figure 8(b). RMS errors and anomaly correlations for ACCESS-G 500hPa forecasts to five days, for the Australian region. Control (black) and with GPS RO data (red) for the period 26 February to 26 March, 2009.

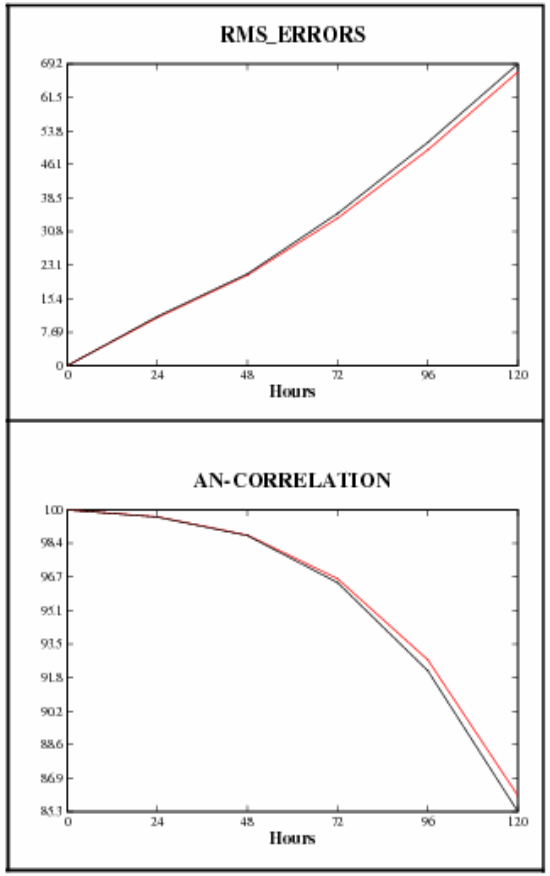
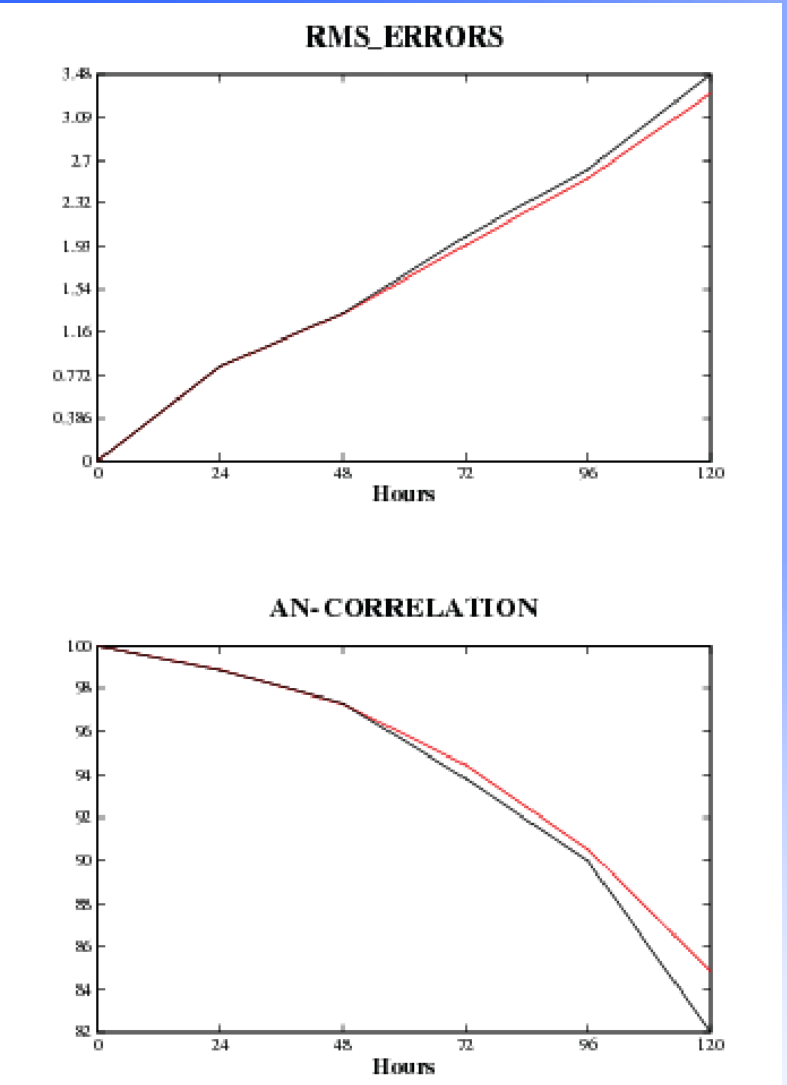
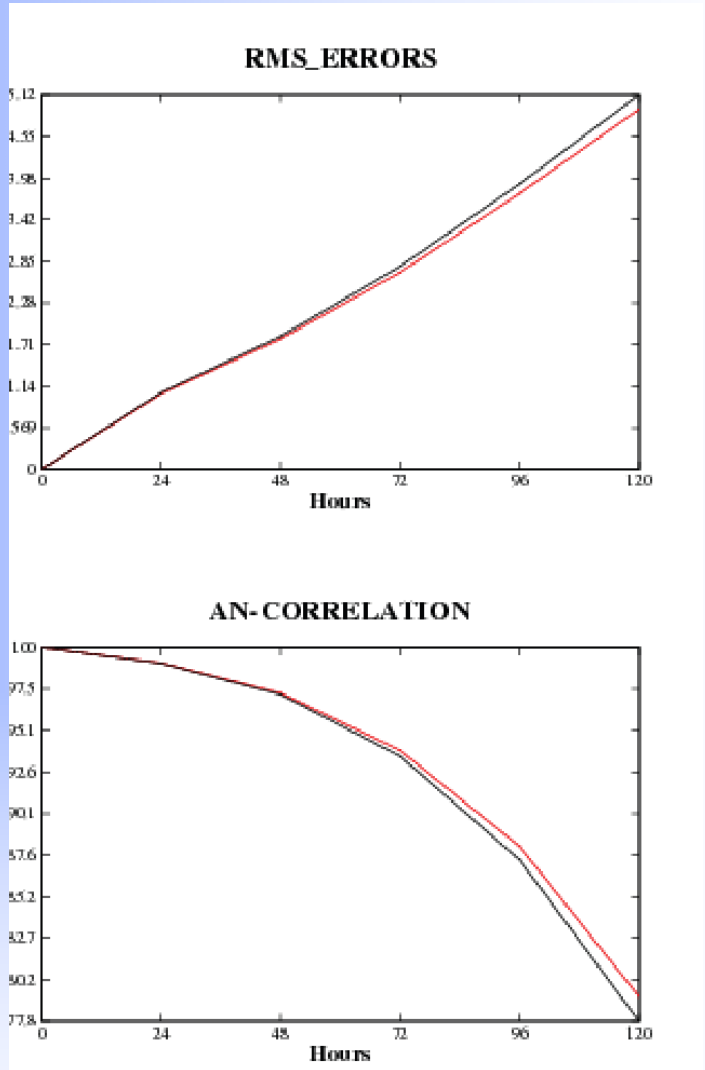


Figure 8(c). RMS errors and anomaly correlations for ACCESS-G 200hPa forecasts to five days, for the Australian region. Control (black) and with GPS RO data (red) for the period 26 February to 26 March, 2009.

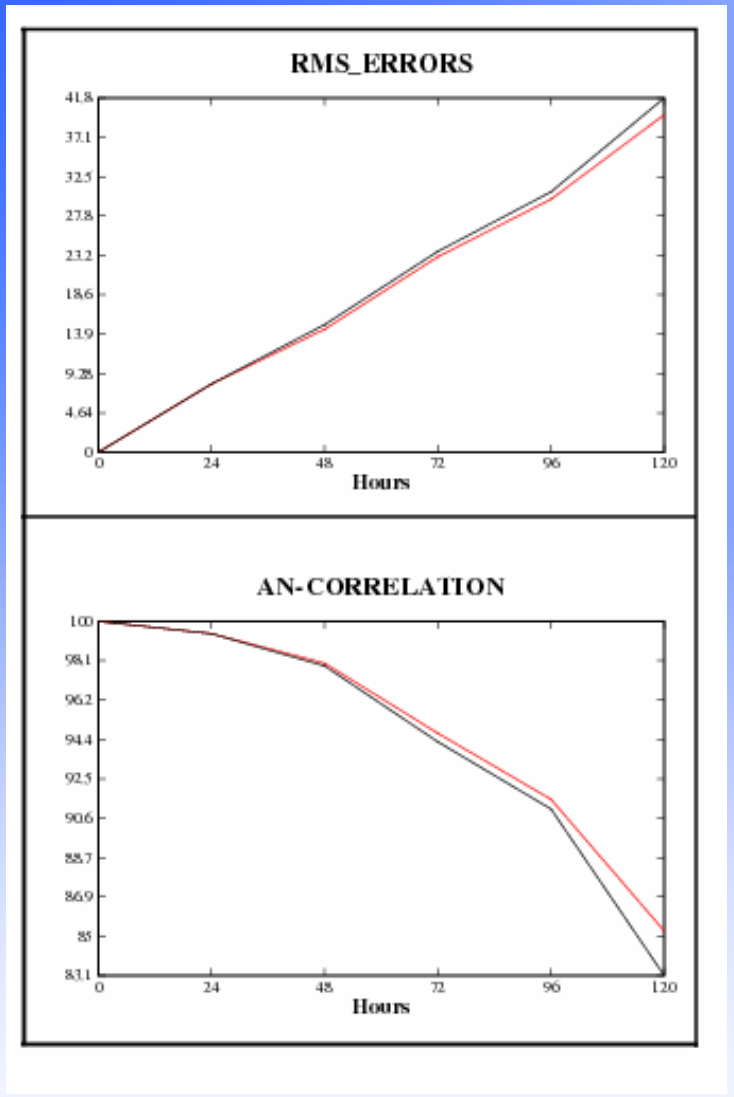
GPS/COSMIC

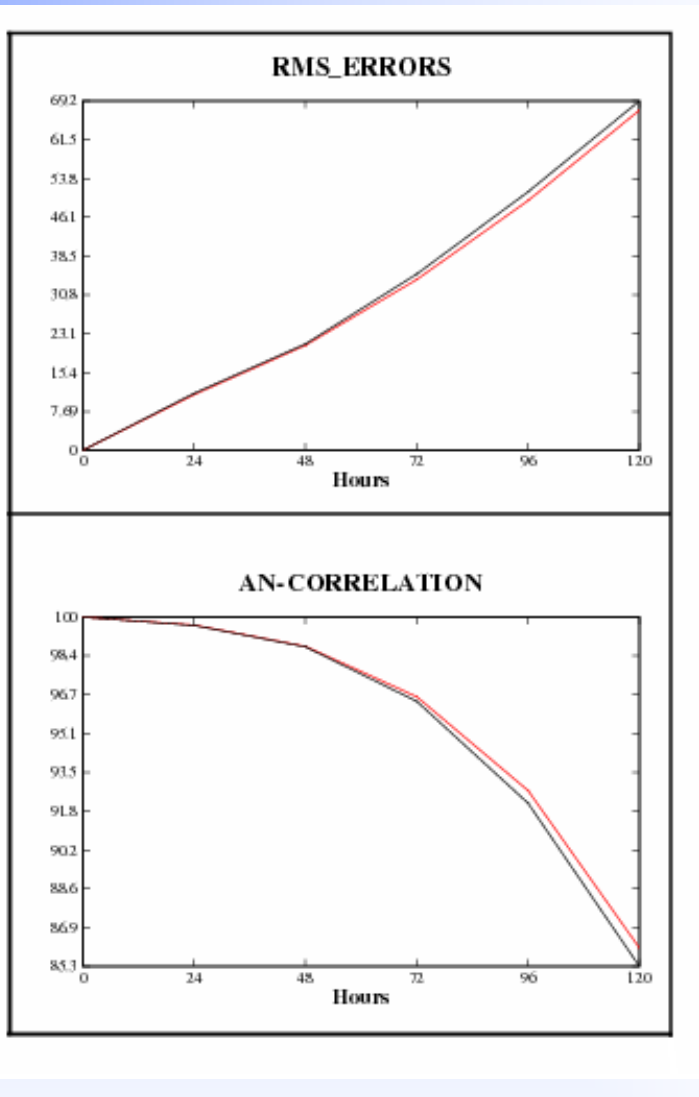




RMS errors and anomaly correlations for ACCESS-G MSLP forecasts to five days, for the Australian region (left) and the southern hemisphere annulus: 60°S-20°S, 0°E-360°E (right). Shown are results for Control (black), and with GPS RO data (red).

GPS/COSMIC





RMS errors and anomaly correlations for ACCESS-G 500hPa geopotential height forecasts to five days, for the Australian region (left) and a similar plot for 200hPa geopotential height forecasts (right). Shown are results for Control (black), and with GPS RO data (red).

OPERATIONAL TRIAL

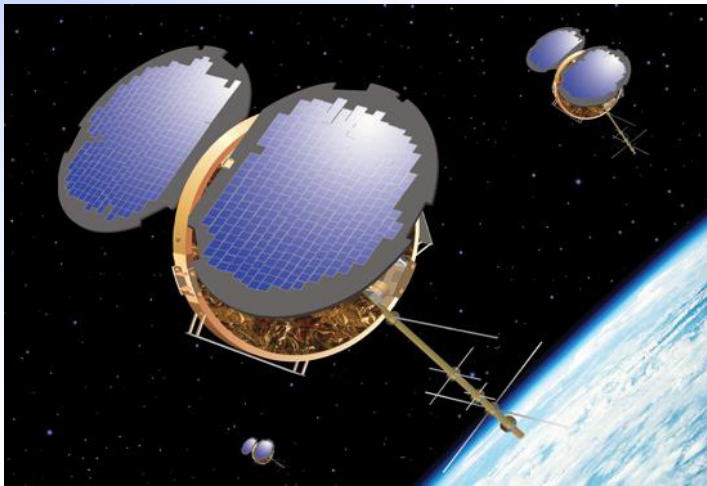
OPERATIONAL SYSTEM ACCESS-G

13 October – 12 November 2010

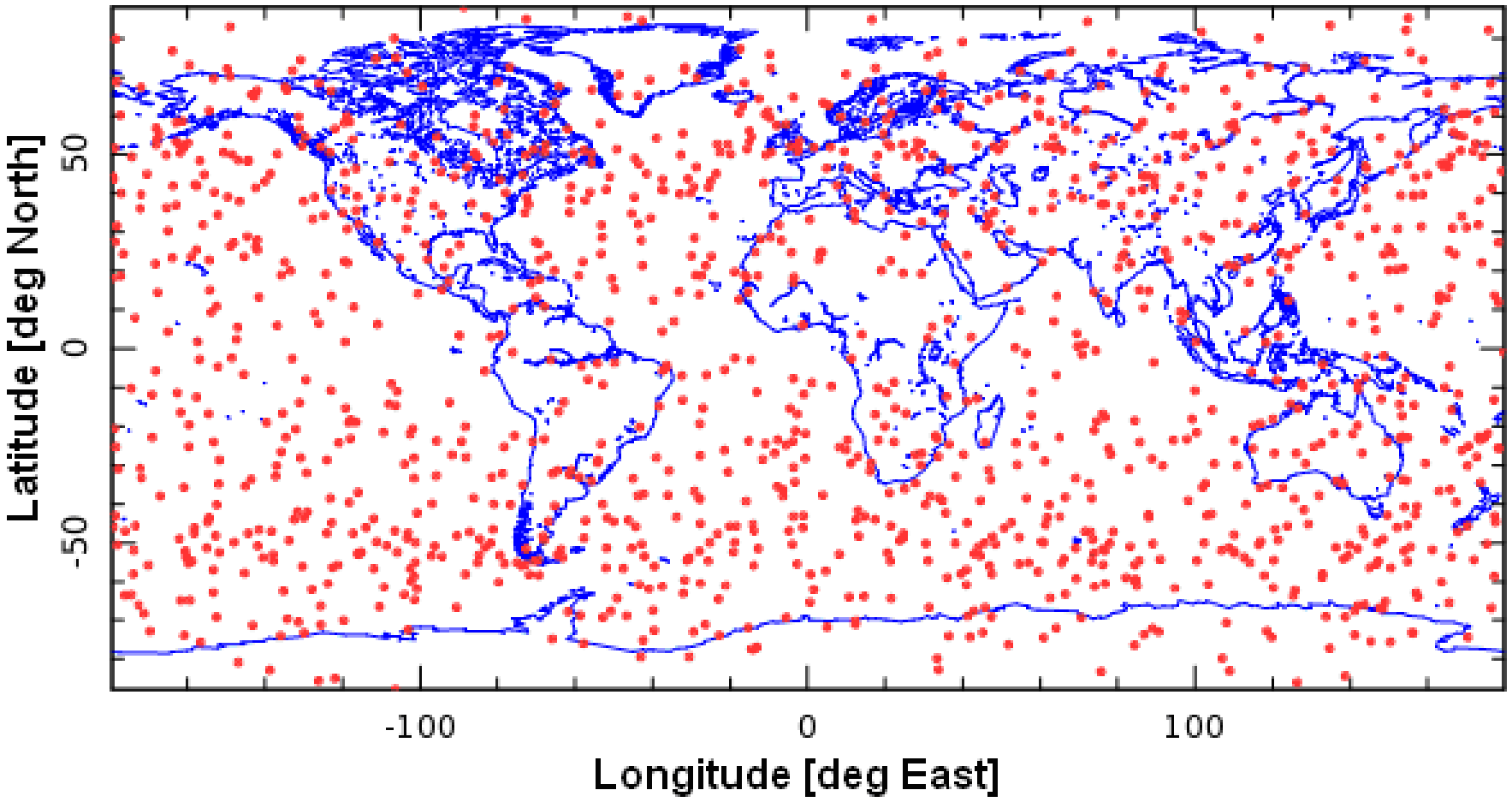
Used

- Refractivity Data from
  - the COSMIC Constellation
  - GRACE and METOP

- New Operational Global Forecast Model (ACCESS-G N144 L50) and Operational Data Base



GPS/COSMIC



GPS radio occultation sounding positions for 13 October 2010.
(Image courtesy of UCAR.)

OPERATIONAL TRIAL - 13 October – 12 November 2010

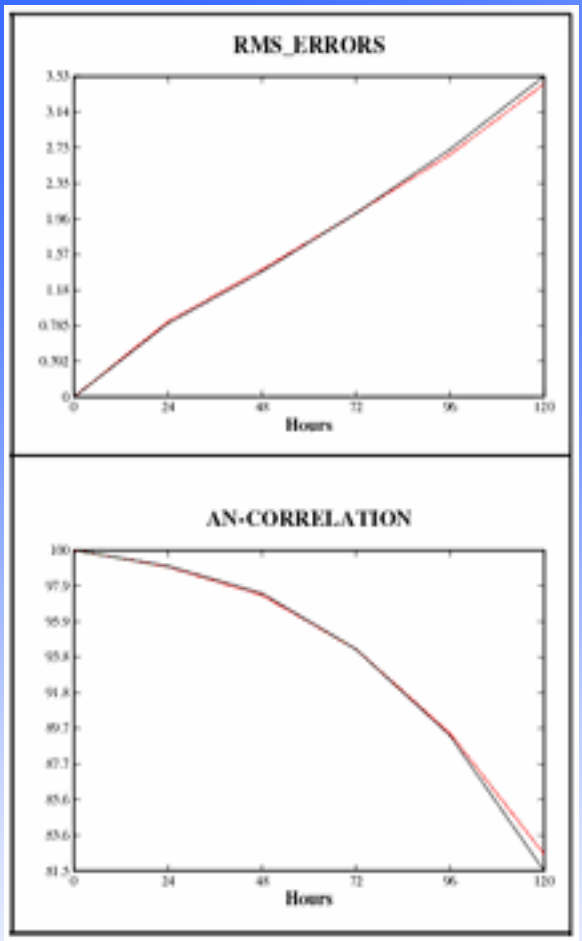


Figure 5(a). RMS Errors and anomaly correlations for ACCESS-G MSLP forecasts to five days, for the Australian region. Control (black), and with GPS RO data (red) for the period 13 October to 12 November 2010.

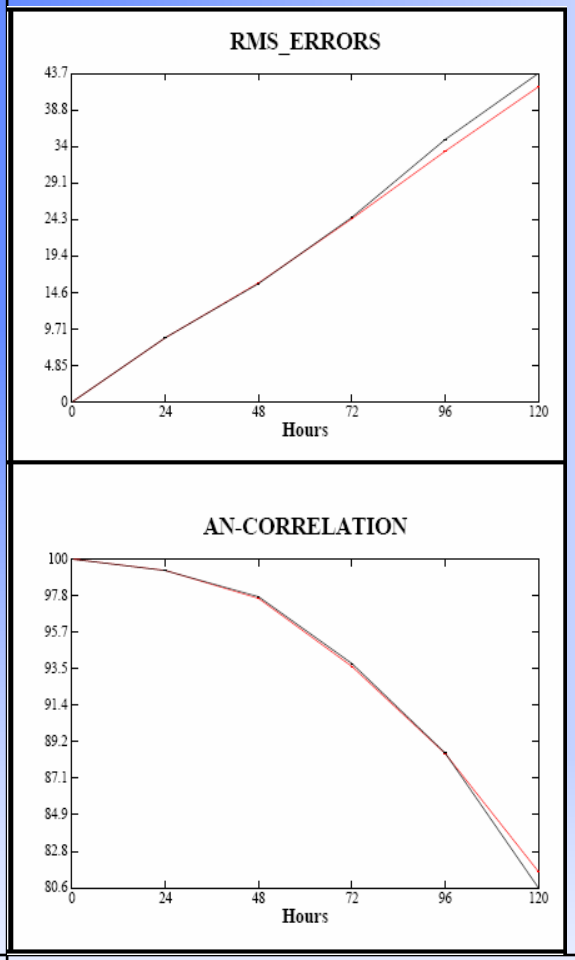


Figure 5(b). RMS errors and anomaly correlations for ACCESS-G 500hPa forecasts to five days, for the Australian region. Control (black) and with GPS RO data (red) for the period 13 October to 12 November 2010.

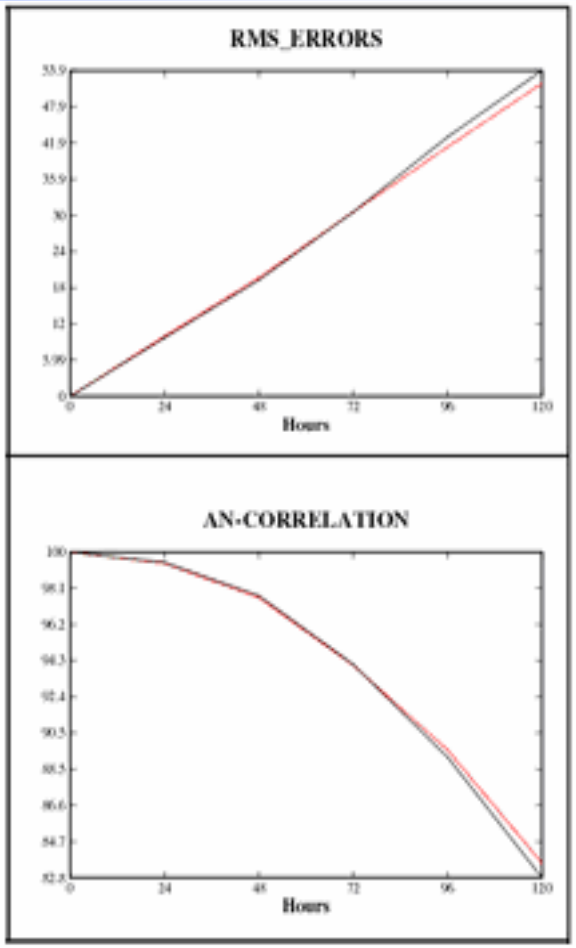


Figure 5(c). RMS errors and anomaly correlations for ACCESS-G 200hPa forecasts to five days, for the Australian region. Control (black) and with GPS RO data (red) for the period 13 October to 12 November 2010

OPERATIONAL TRIAL

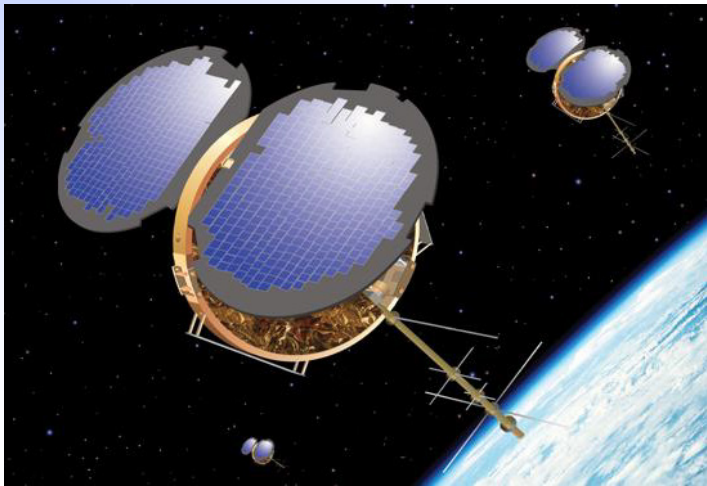
NEW OPERATIONAL SYSTEM ACCESS-G

1 November – 30 November 2010

Used

- Bending Angle data from
  - the COSMIC Constellation
  - GRACE and METOP

- New Operational Global Forecast Model (ACCESS-G N144 L50) and Operational Data Base



OPERATIONAL TRIAL - 1 November to 30 November, 2010

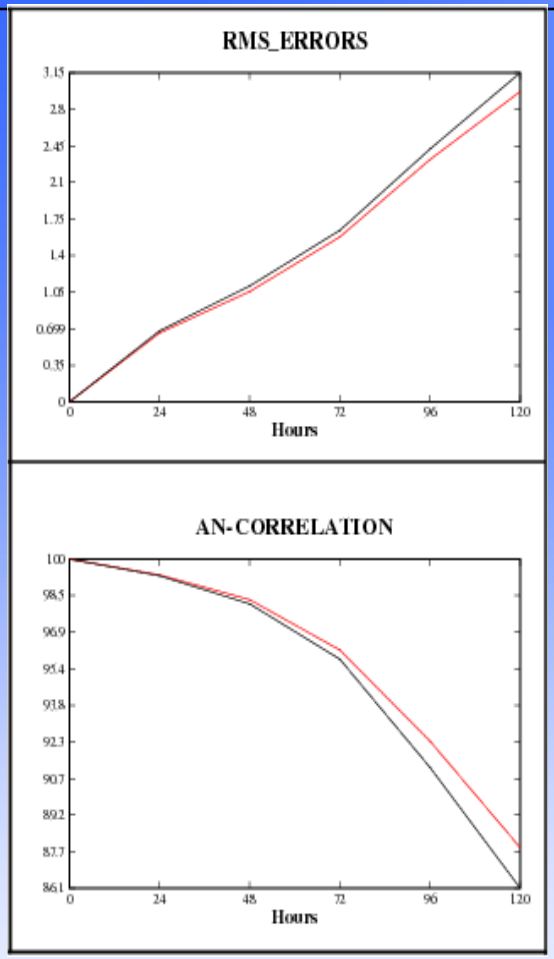


Figure 10(a). RMS Errors and anomaly correlations for ACCESS-G MSLP forecasts to five days, for the Australian region. Shown are results for Control (black), and with GPS RO data (red) for the period 1 November to 30 November 2010.

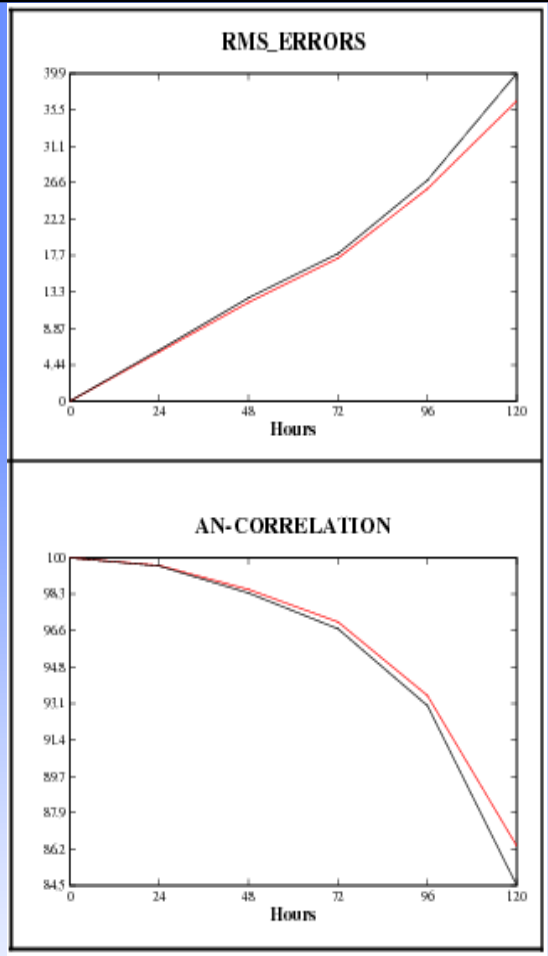


Figure 10(b). RMS errors and anomaly correlations for ACCESS-G 500hPa forecasts to five days, for the Australian region. Shown are results for Control (black) and with GPS RO data (red) for the period 1 November to 30 November 2010.

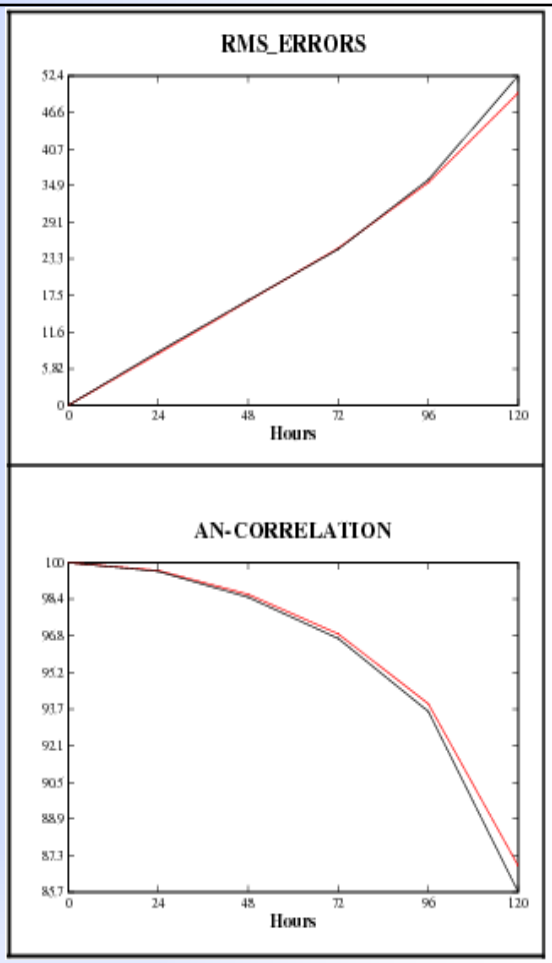


Figure 10(c). RMS errors and anomaly correlations for ACCESS-G 200hPa forecasts to five days, for the Australian region. Shown are results for Control (black) and with GPS RO data (red) for the period 1 November to 30 November 2010.

OPERATIONAL TRIAL - 1 November to 30 November, 2010

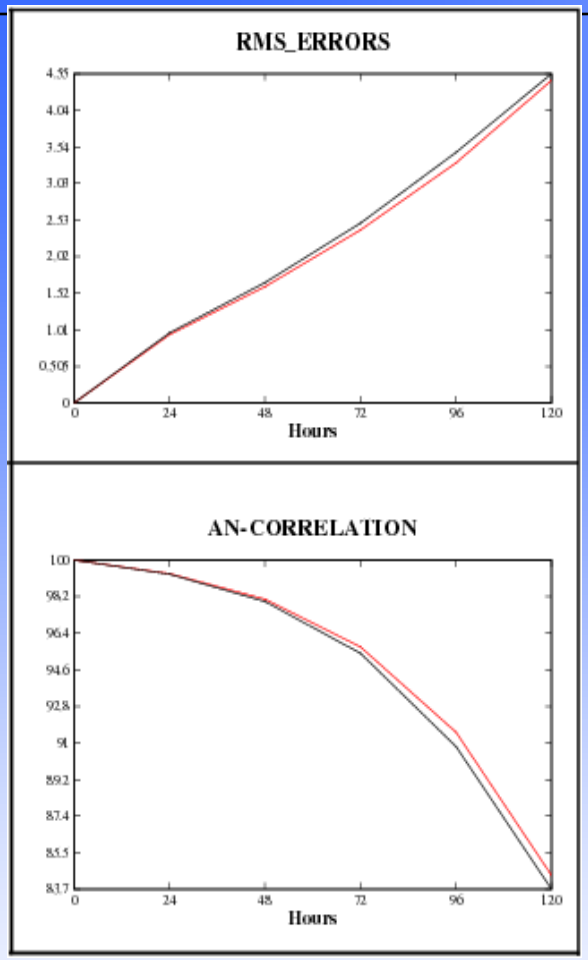


Figure 11(a). RMS Errors and anomaly correlations for ACCESS-G MSLP forecasts to five days, for Southern Hemisphere. Control (black), and with GPS RO data (red) for the period 1 November to 30 November 2010.

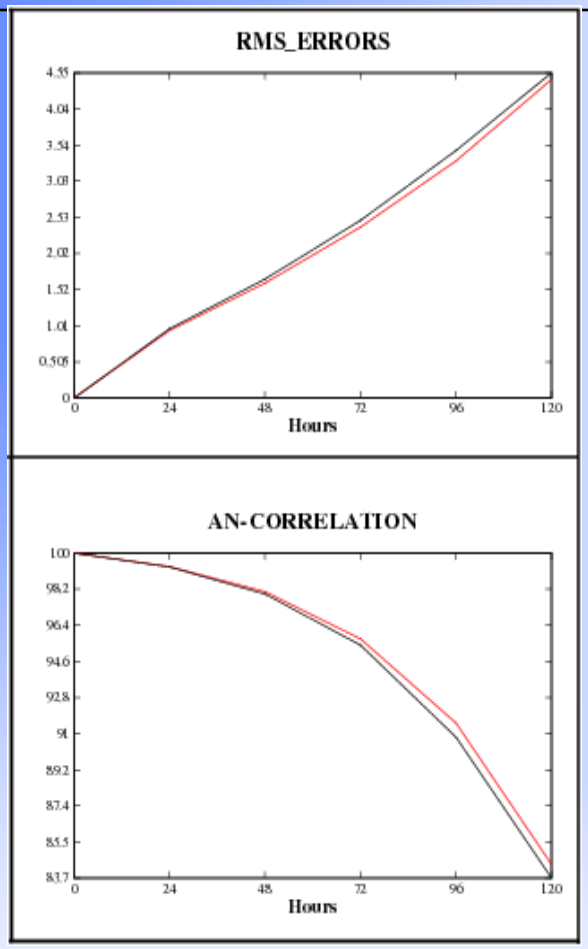


Figure 11(b). RMS errors and anomaly correlations for ACCESS-G 500hPa forecasts to five days, for Southern Hemisphere. Control (black) and with GPS RO data (red) for the period 1 November to 30 November 2010.

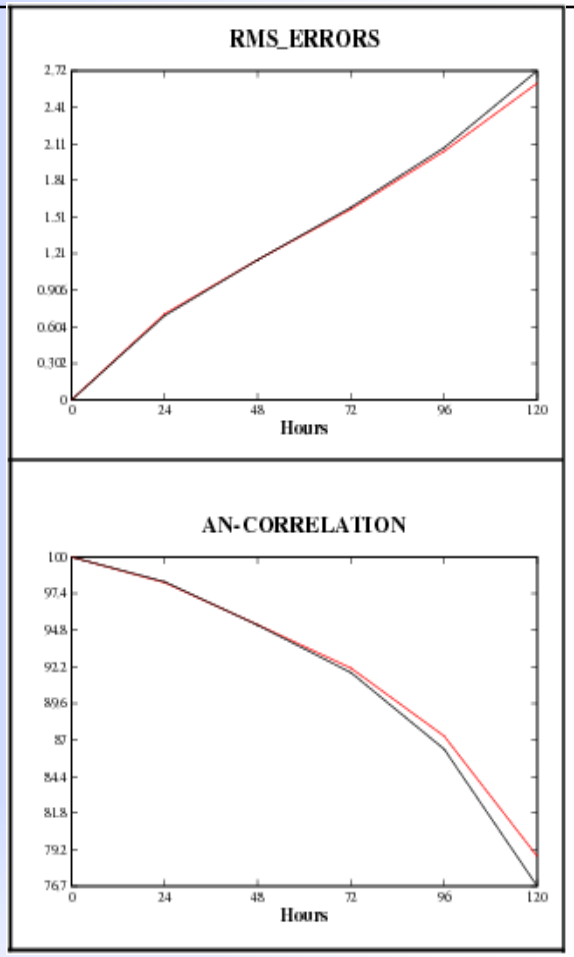


Figure 11(c). RMS errors and anomaly correlations for ACCESS-G 200hPa temperature forecasts to five days, for the Australian region. Control (black) and with GPS RO data (red) for the period 1 November to 30 November 2010.

Australian Community Climate and Earth System Simulator (ACCESS) - G

The Characteristics of the ACCESS-G Forecast System

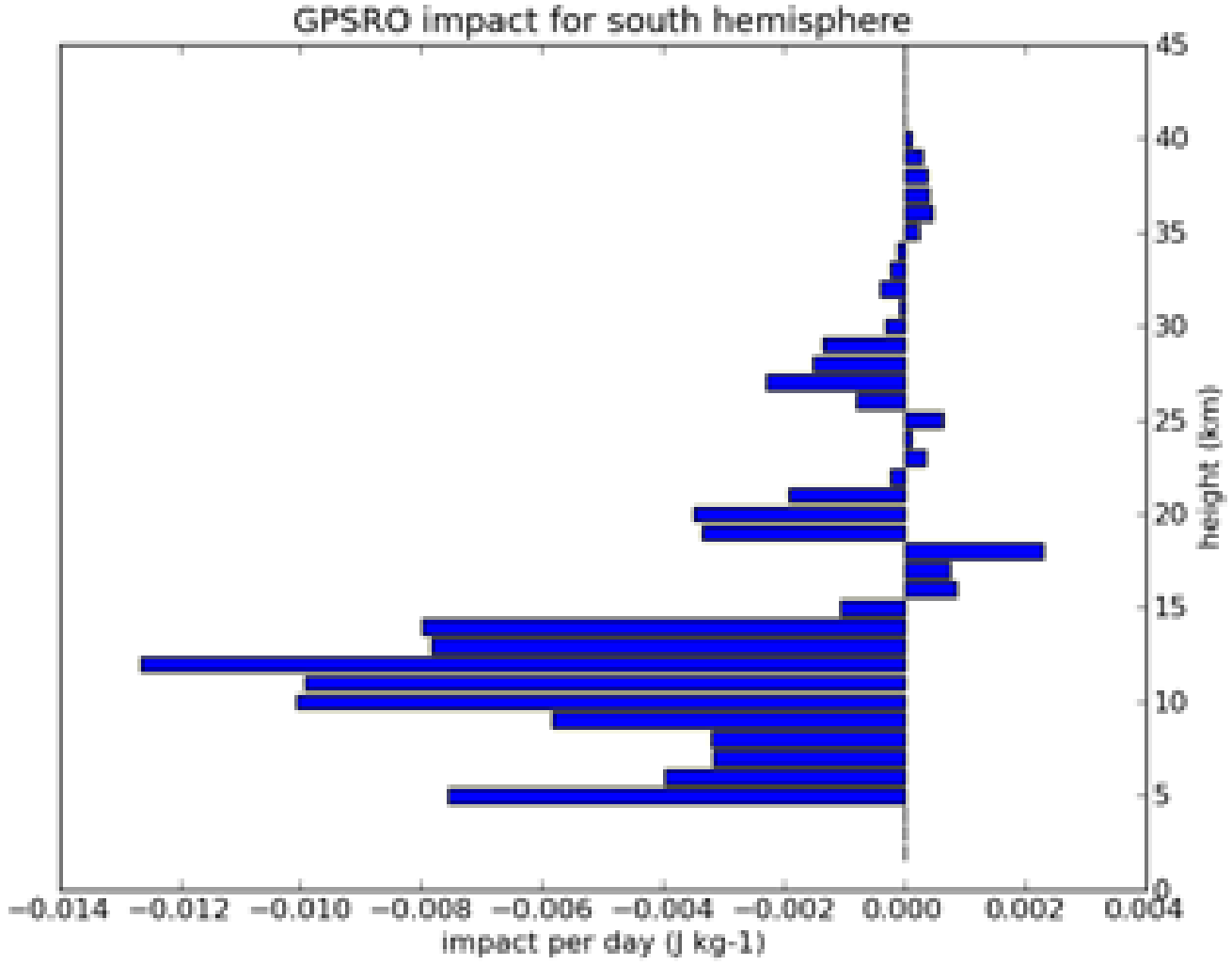
DOMAIN	GLOBAL
UM Horizontal Resolution (lat x lon)	640 X 481(`0.5625Deg X 0.375Deg) ~47km.
Analysis Horizontal resolution (lat x lon)	288 X 217 (1.250Deg X 0.833Deg) ~106km.
Vertical Resolution	L70
Observational Data Used (6h window)	AIRS, IASI, ATOVS, Scat, AMV, SYNOP, SHIP, BUOY,AMDARS, AIREPS, TEMP, PILOT, GPS-RO…
Sea Surface Temperature Analysis	Daily, global 1° sst analysis
Sea Ice analysis	Daily, global 1/12° sea ice analysis
Soil moisture Nudging	SURF once every 6 hours
Model Time Step	12 minutes (96 time steps per day)
Analysis Time Step	30 minutes
Suite Definition	SCS vn18.2

Table 1: N288L70 System SpecificationAP1

Australian Government
Bureau of Meteorology

CSIRO

GPSRO IMPACT BY HEIGHT



THE FUTURE

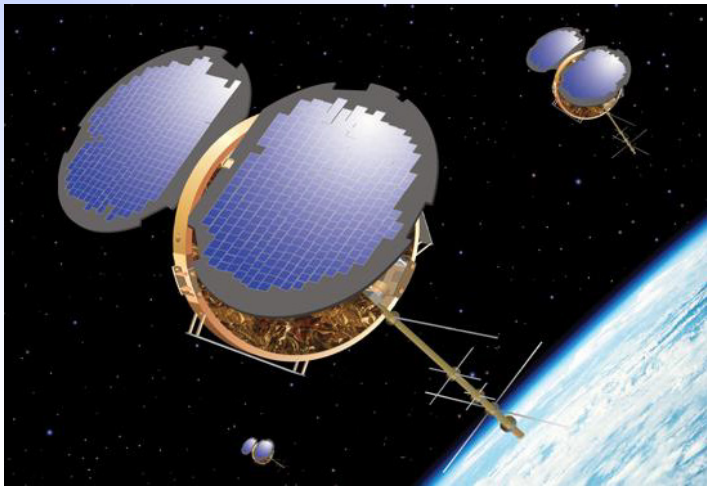
MOVING TO NEW OPERATIONAL SYSTEM ACCESS- G

Enhanced Model (N512, L70)

Enhanced Operational Data Base*

Significant Improvement in Operational Trials

- Bending Angle data from the COSMIC Constellation GRACE, METOP,
- New Operational Global Forecast System Uses Updated Operational Data Base (CrIS, ATMS, 10 Min DMVs….)



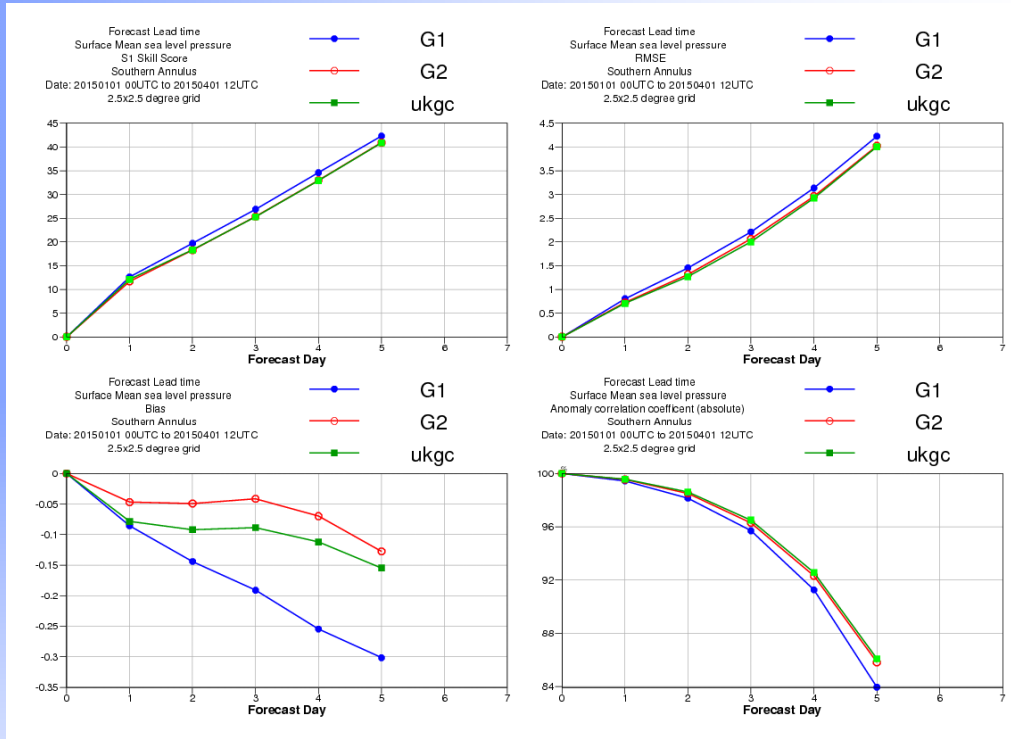
THE FUTURE

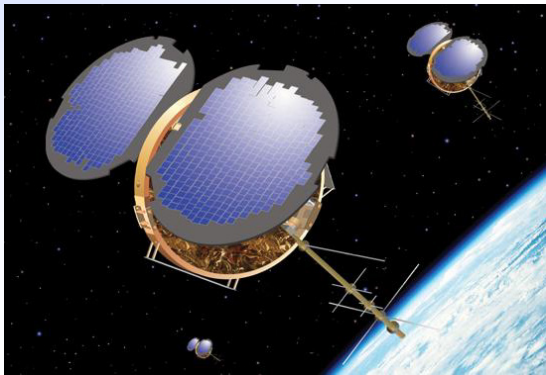
NEW OPERATIONAL SYSTEM ACCESS- G

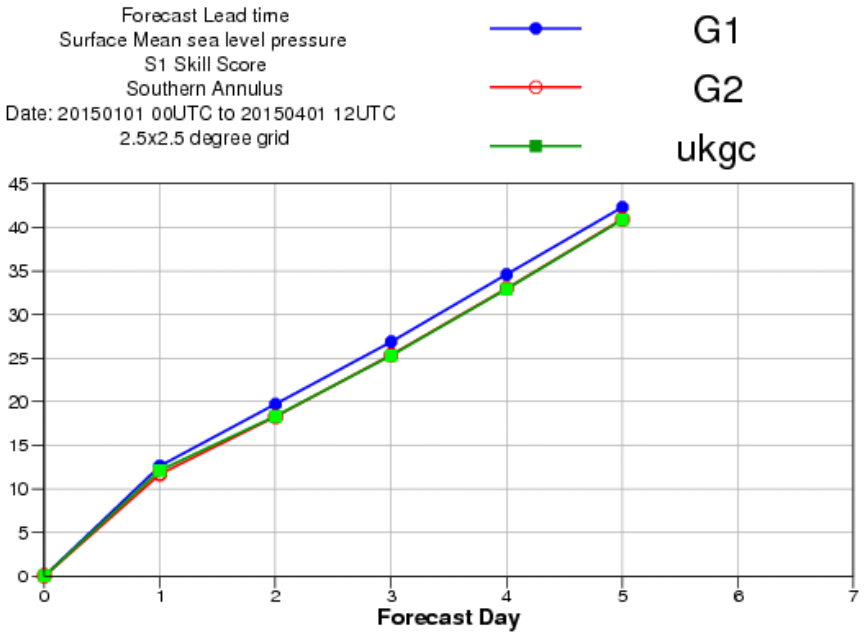
Trial Impact New Model/All Data

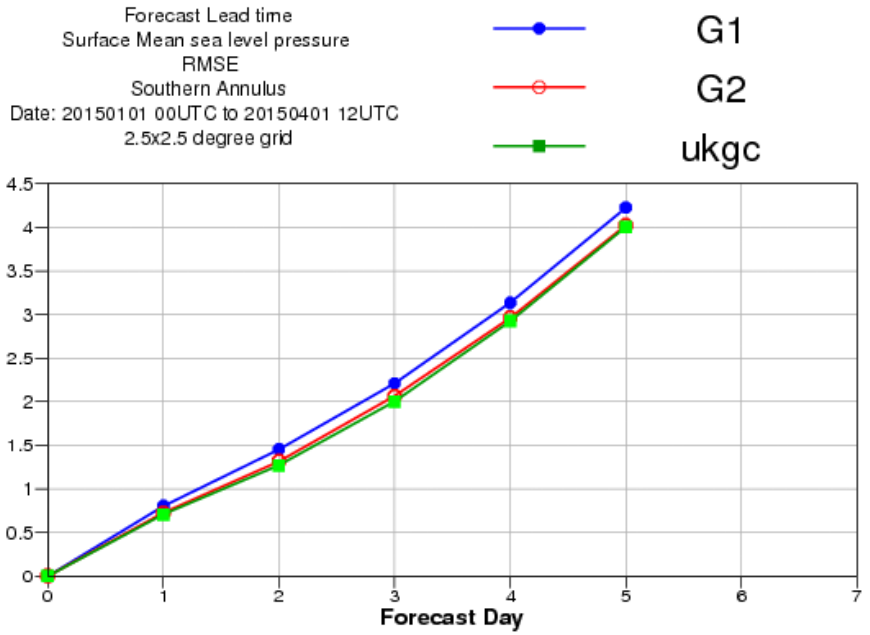
New elements still to be added to data base (10 minute AMVs etc.)

Impact of RO in new system now being determined. (June 2014)






Forecast Lead time
Surface Mean sea level pressure
S1 Skill Score
Southern Annulus
Date: 20150101 00UTC to 20150401 12UTC
2.5x2.5 degree grid
G1
G2
ukgc
45
40
35
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
Forecast Day


Forecast Lead time
Surface Mean sea level pressure
RMSE
Southern Annulus
Date: 20150101 00UTC to 20150401 12UTC
2.5x2.5 degree grid
G1
G2
ukgc
4.5
4
3.5
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2
1.5
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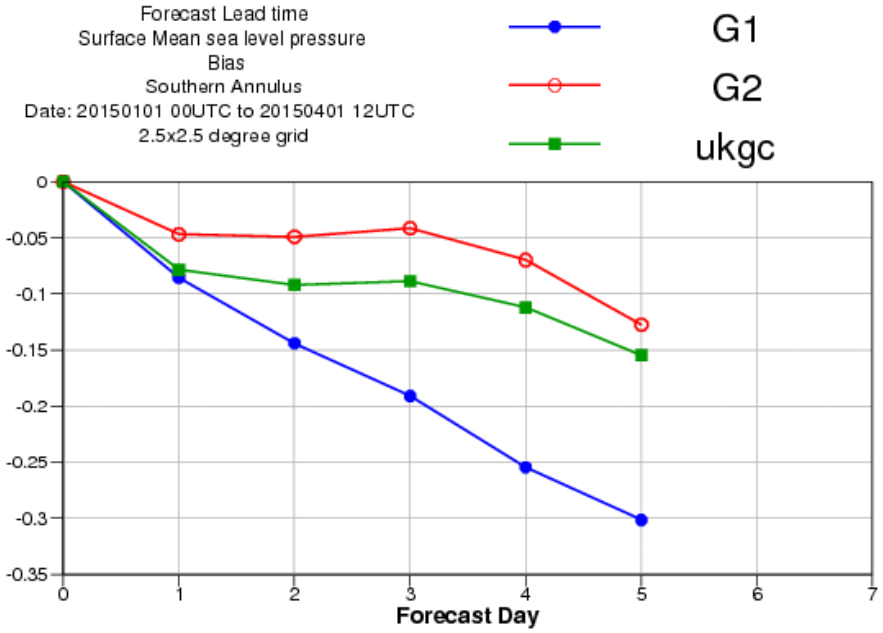
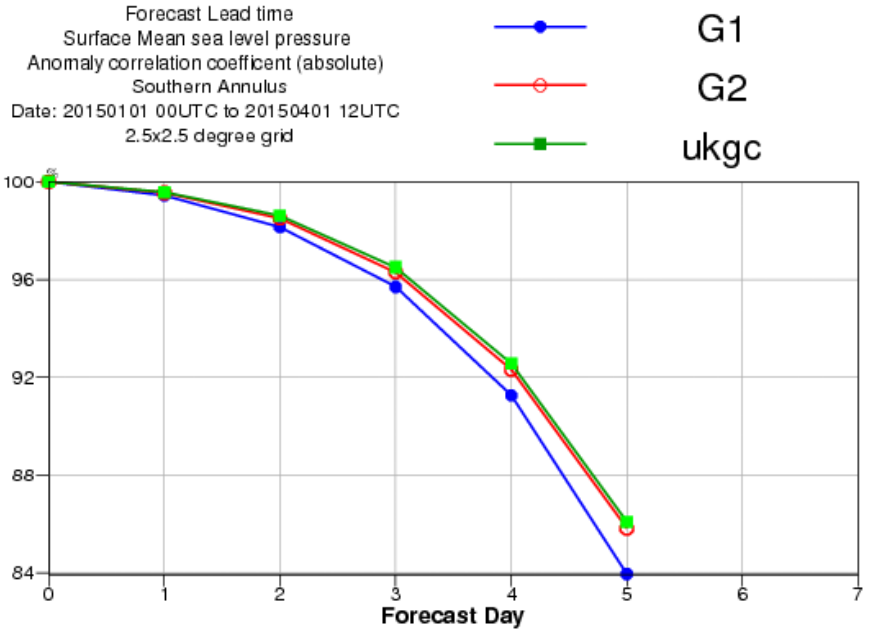
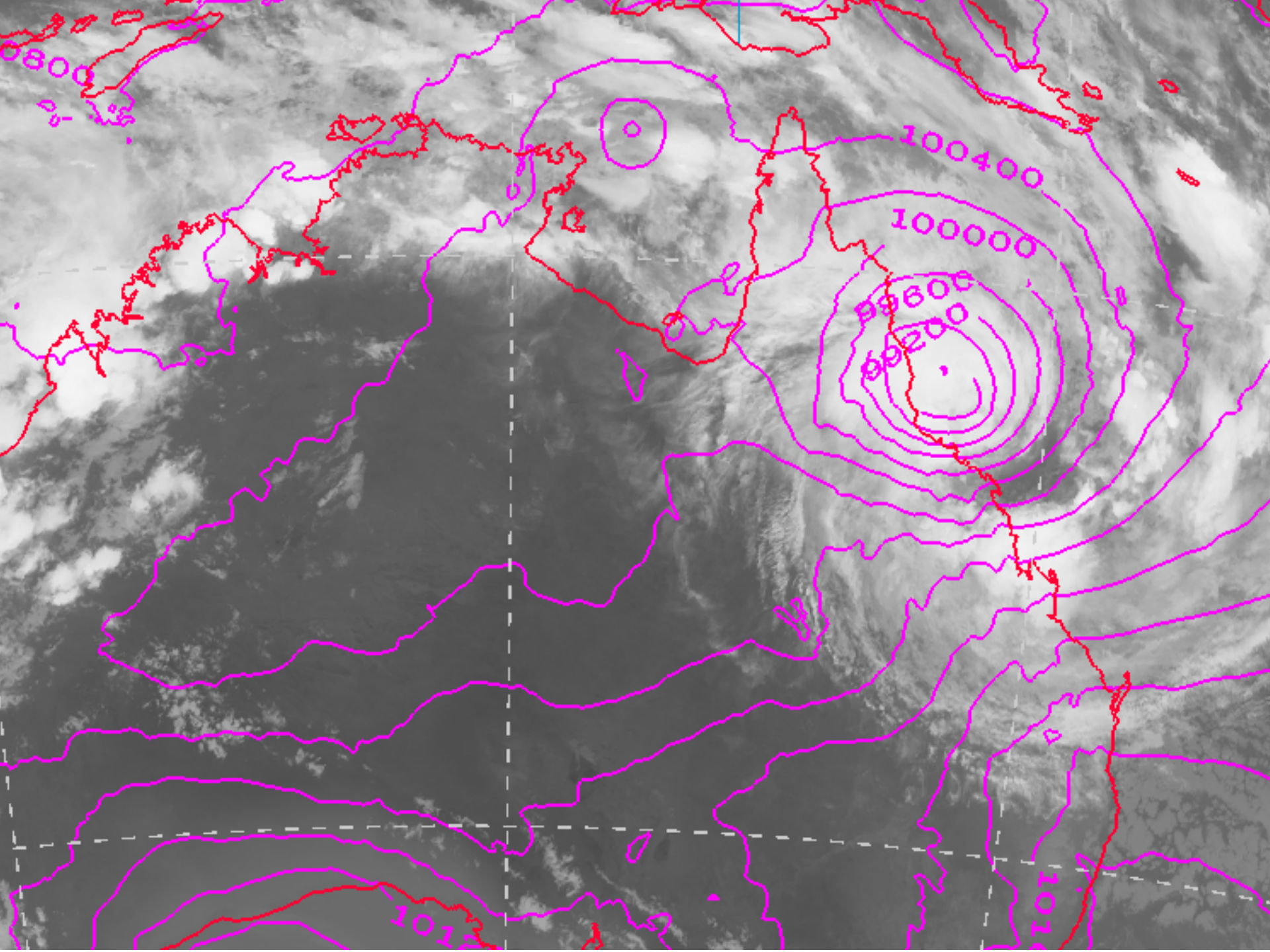
0
1
2
3
4
5
6
7
Forecast Day


Forecast Lead time
Surface Mean sea level pressure
Bias
Southern Annulus
Date: 20150101 00UTC to 20150401 12UTC
2.5x2.5 degree grid
G1
G2
ukgc
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
0
1
2
3
4
5
6
7
Forecast Day

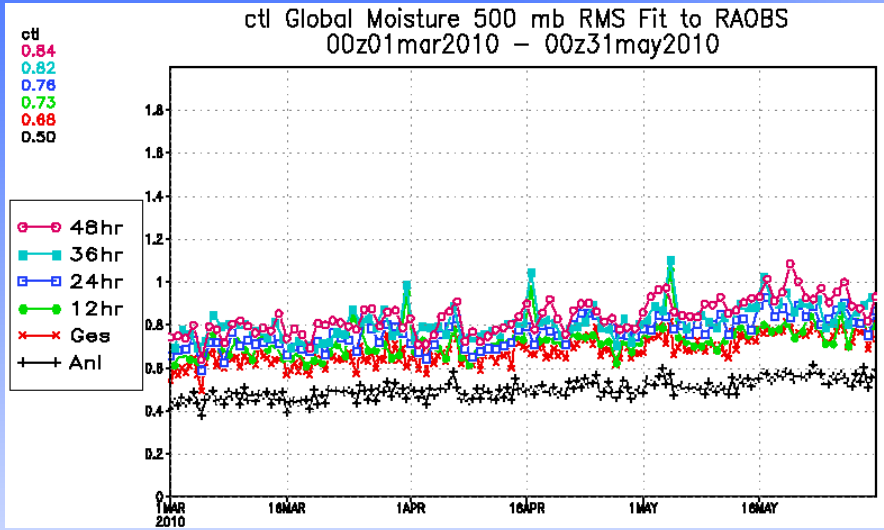

Forecast Lead time
Surface Mean sea level pressure
Anomaly correlation coefficent (absolute)
Southern Annulus
Date: 20150101 00UTC to 20150401 12UTC
2.5x2.5 degree grid
G1
G2
ukgc
100
96
92
88
84
0
1
2
3
4
5
6
7
Forecast Day


100400
100000
99600
99200

FUTURE – IR RO GNSS to Gnd MWave
Analysing Tropospheric Moisture by Assimilating Hyperspectral Infrared Water Vapor Channels

control

experiment



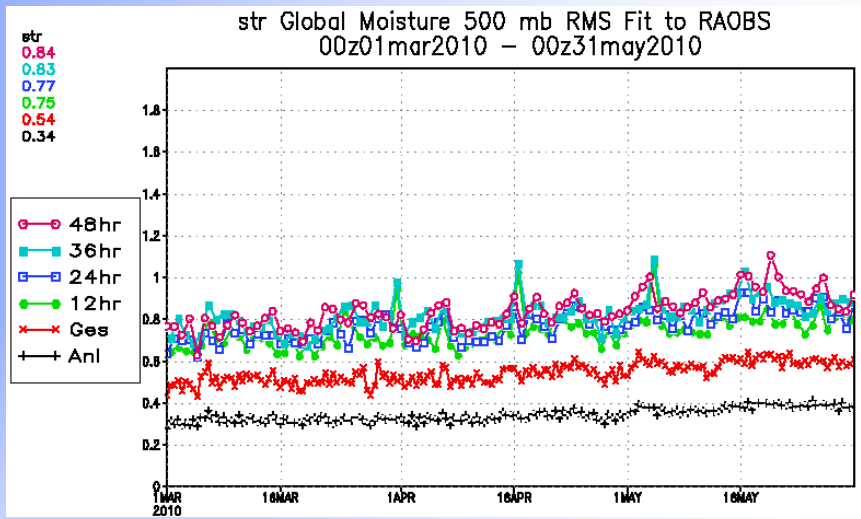
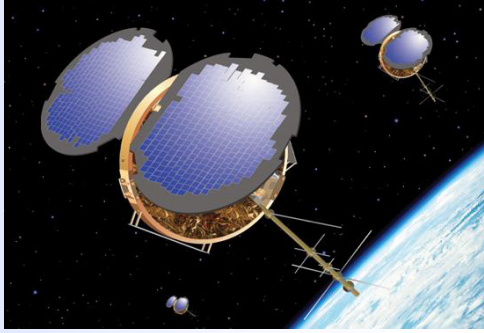


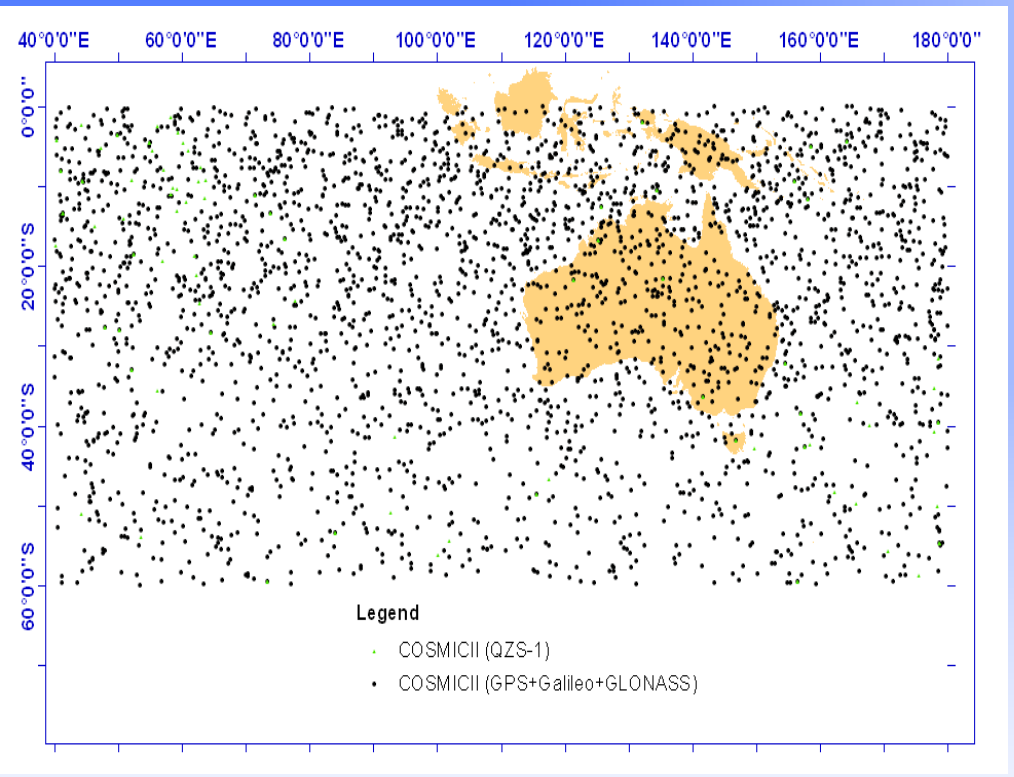
Figure 3: Specific humidity fits to rawinsondes humidity data during the time period March to May 2010 for the analysis, 6(Ges)- , 12- , 24- , 36- and 48-hour forecasts. Note the considerable improvement in the 6-hour and 12-hour forecasts.

THE FUTURE

Increased coverage with COSMIC II

Local processing of space weahter data





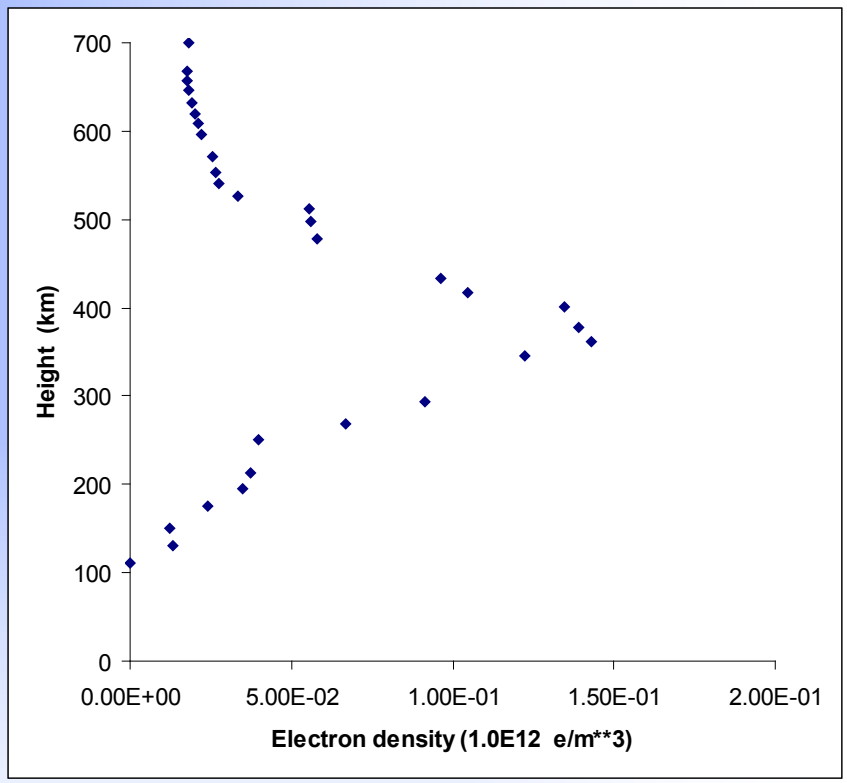
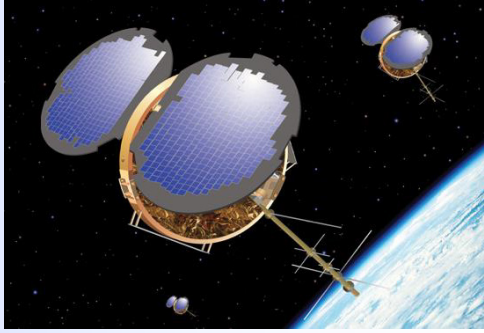


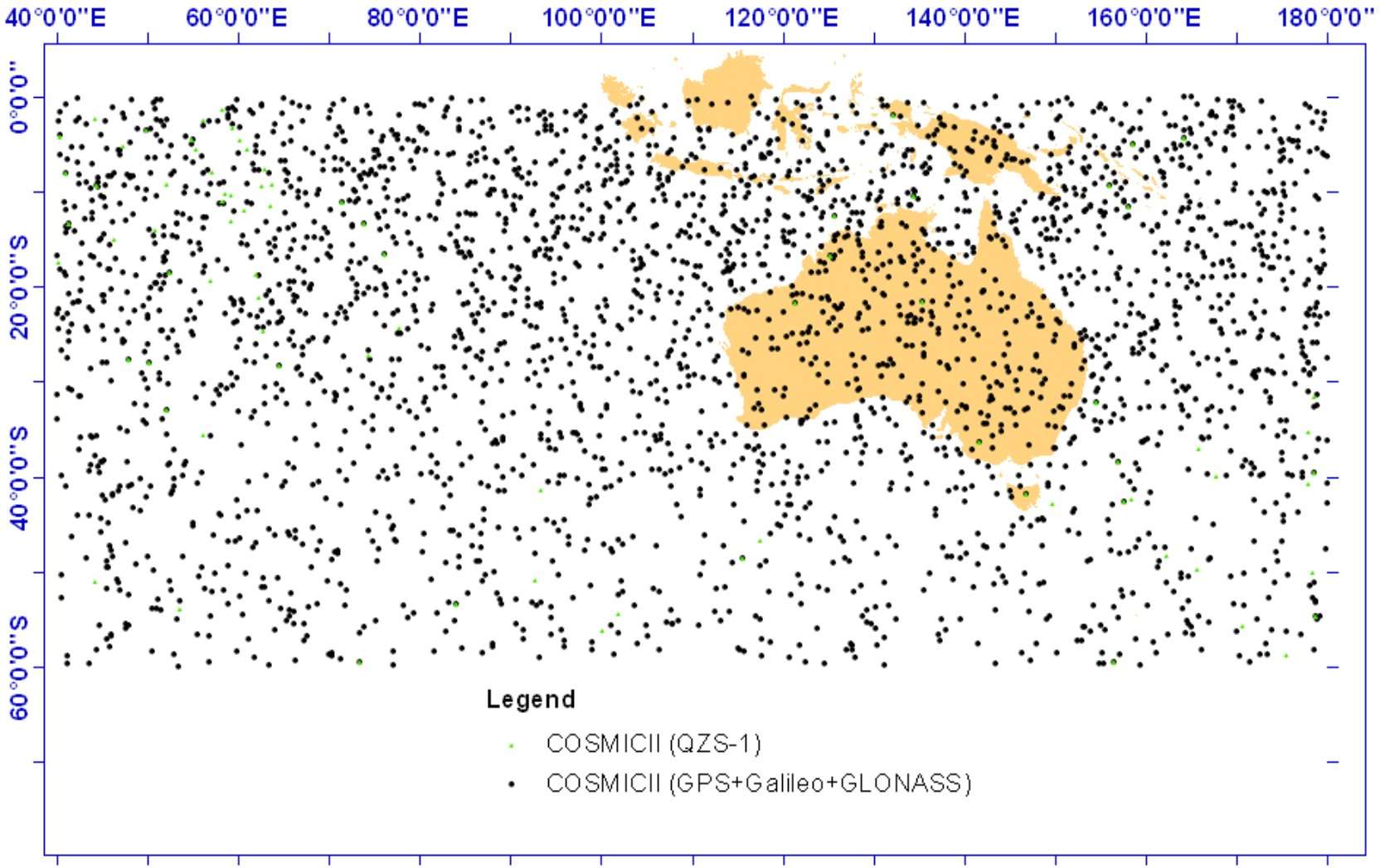
Fig. 12 Distribution of simulated daily COSMIC II RO events in the Australasian region with GPS, Galileo, Glonass and QZS-1

Fig.13. Ionospheric profile obtained from Fedsat radio wave occultation measurements on day 170, 2003 at 15.3N 170E.

The Future

Distribution of simulated daily COSMIC II RO events in the Australasian region with GPS, Galileo, Glonass and QZS-1





The Future

COSMIC II Groundstation
Northern Australia

Monitoring the Climate

2006 - 2012

Used

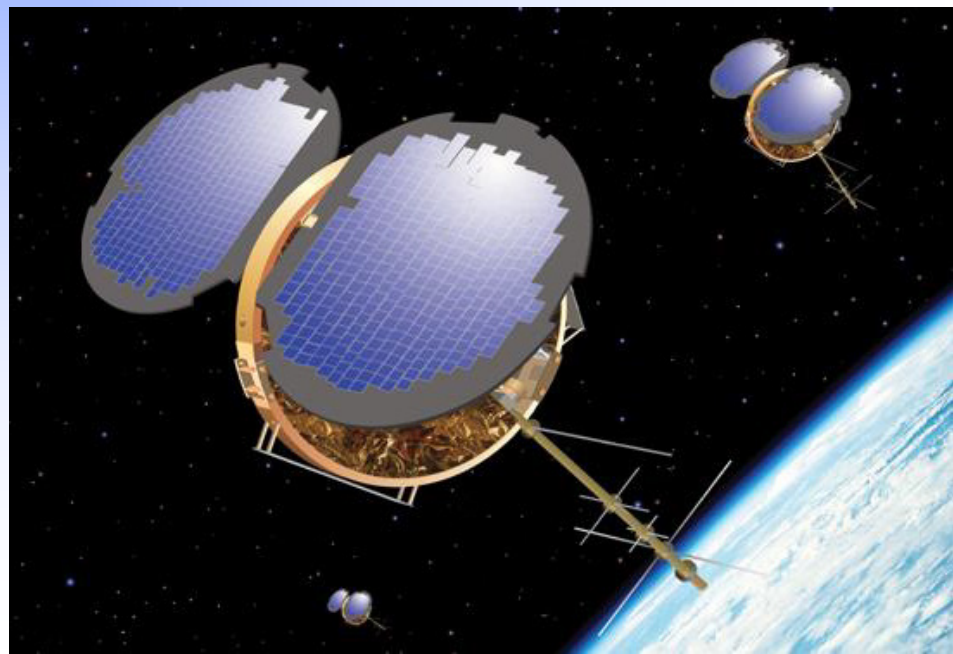
- Sounding Data from UCAR
- the COSMIC Constellation

- Examined

Aust. Region

SH/Globe

Antarctica



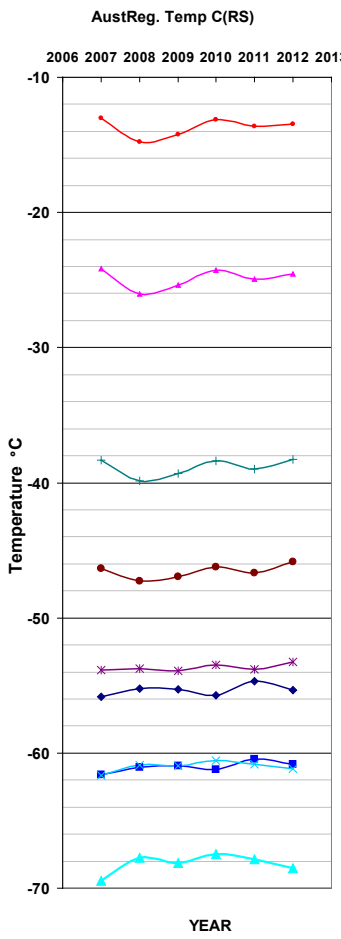


Figure 2(a). Mean Annual Atmospheric Temperatures (°C) 2007 to 2012 in the Australian region measured by radiosondes.

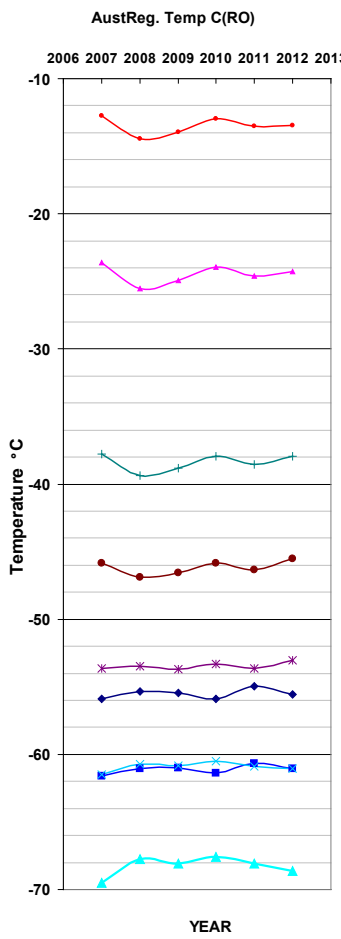


Figure 2(b). Mean Annual Atmospheric Temperatures (°C) 2007 to 2012 in the Australian region measured by radio occultation at a radiosonde sites.

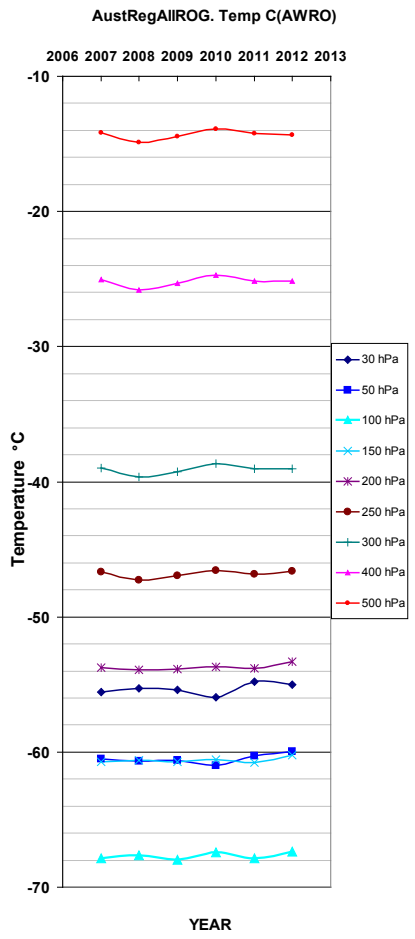


Figure 2(c). Mean Annual Atmospheric Temperatures (°C) 2007 to 2012 in the Australian region measured by area weighting all radio occultation observations in the Australian region.

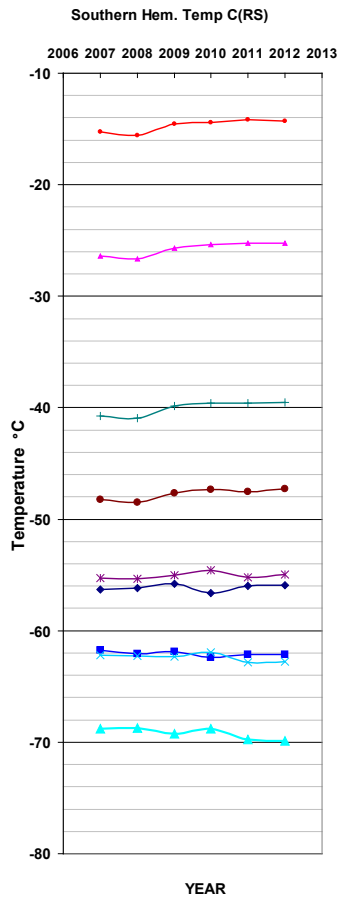


Figure 3(a). Mean Annual Atmospheric Temperatures (°C) 2007 to 2012 over the Southern Hemisphere measured by radiosondes.

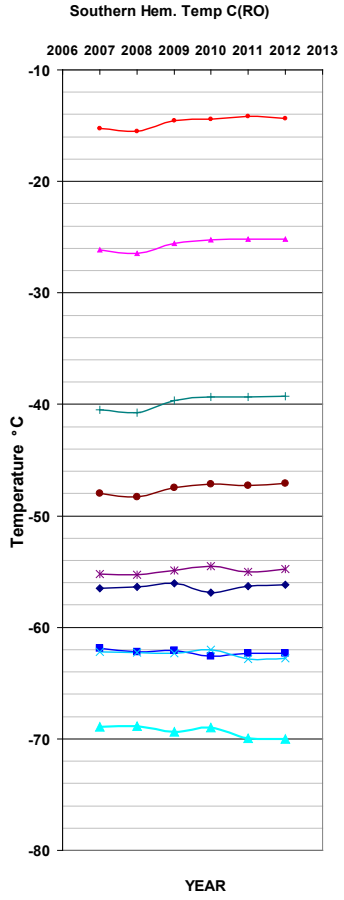


Figure 3(b). Mean Annual Atmospheric Temperatures (°C) 2007 to 2012 over the Southern Hemisphere measured by radio occultation at a radiosonde sites.

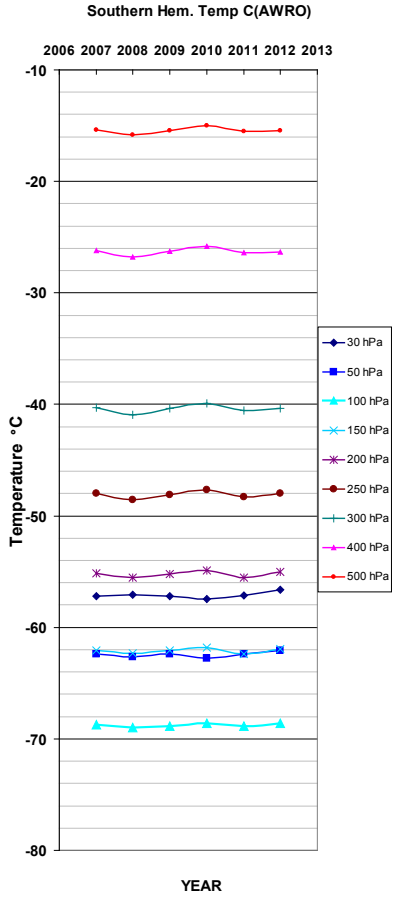


Figure 3(c). Mean Annual Atmospheric Temperatures (°C) 2007 to 2012 over the Southern Hemisphere measured by area weighting all radio occultation observations over the Southern Hemisphere.

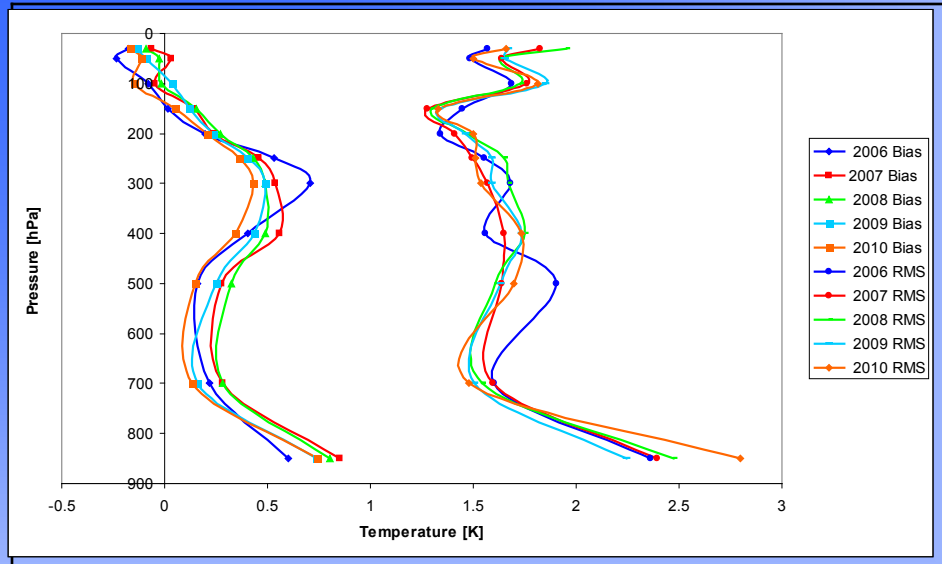


Figure 4(a).Annual average mean and R.M.S. temperature differences in the Australian region between co-located and contemporaneous radiosonde and radio occultation observations. (2006 is an incomplete year-see text)

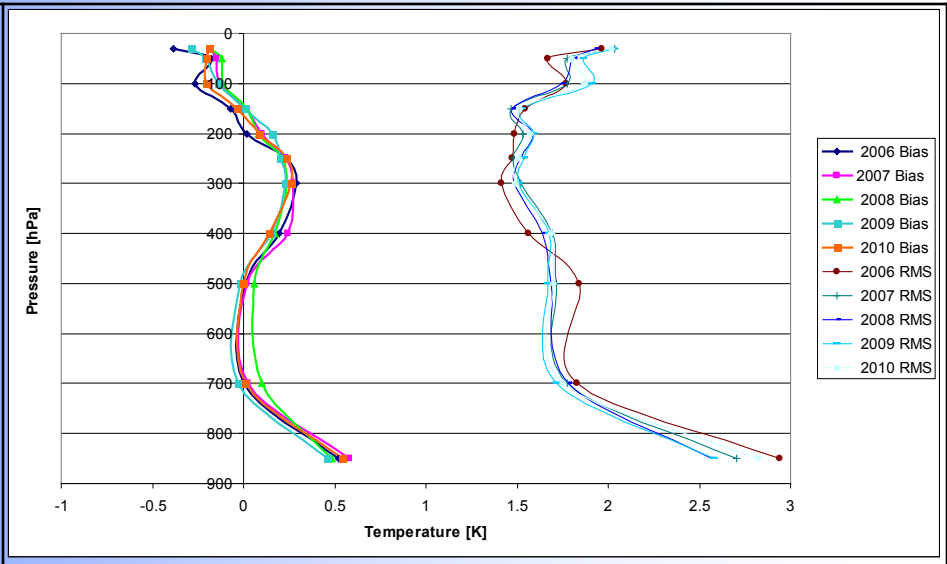


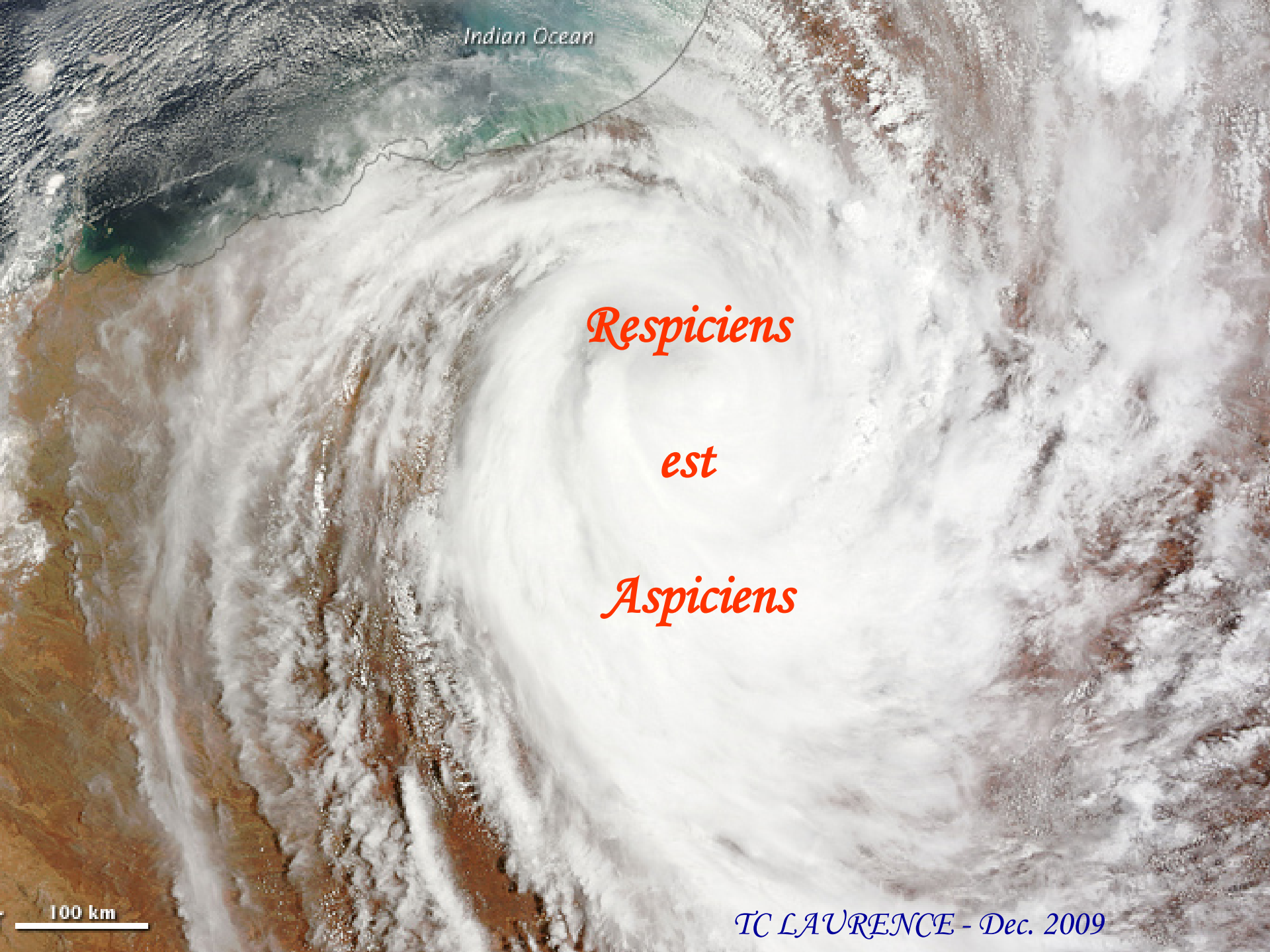
Figure 4(b) Annual average mean and R.M.S. temperature differences over the Southern Hemisphere between co-located and contemporaneous radiosonde and radio occultation observations. (2006 is an incomplete year-see text)

Conclusions

- The great benefit of current RO data in the Australian Region and Southern Hemisphere have been recorded using data impact studies
- COSMIC, GRACE and METOP data have been successfully assimilated into the current ACCESS system and the data are being used in the BoMs new operational forecast system
- The data are important for climate quality analyses helping particularly with calibration and sounding.
- The data are important for climate monitoring
- COSMIC – 2 will be an important data source for Australia

The Future

COSMIC II Groundstation
Northern Australia



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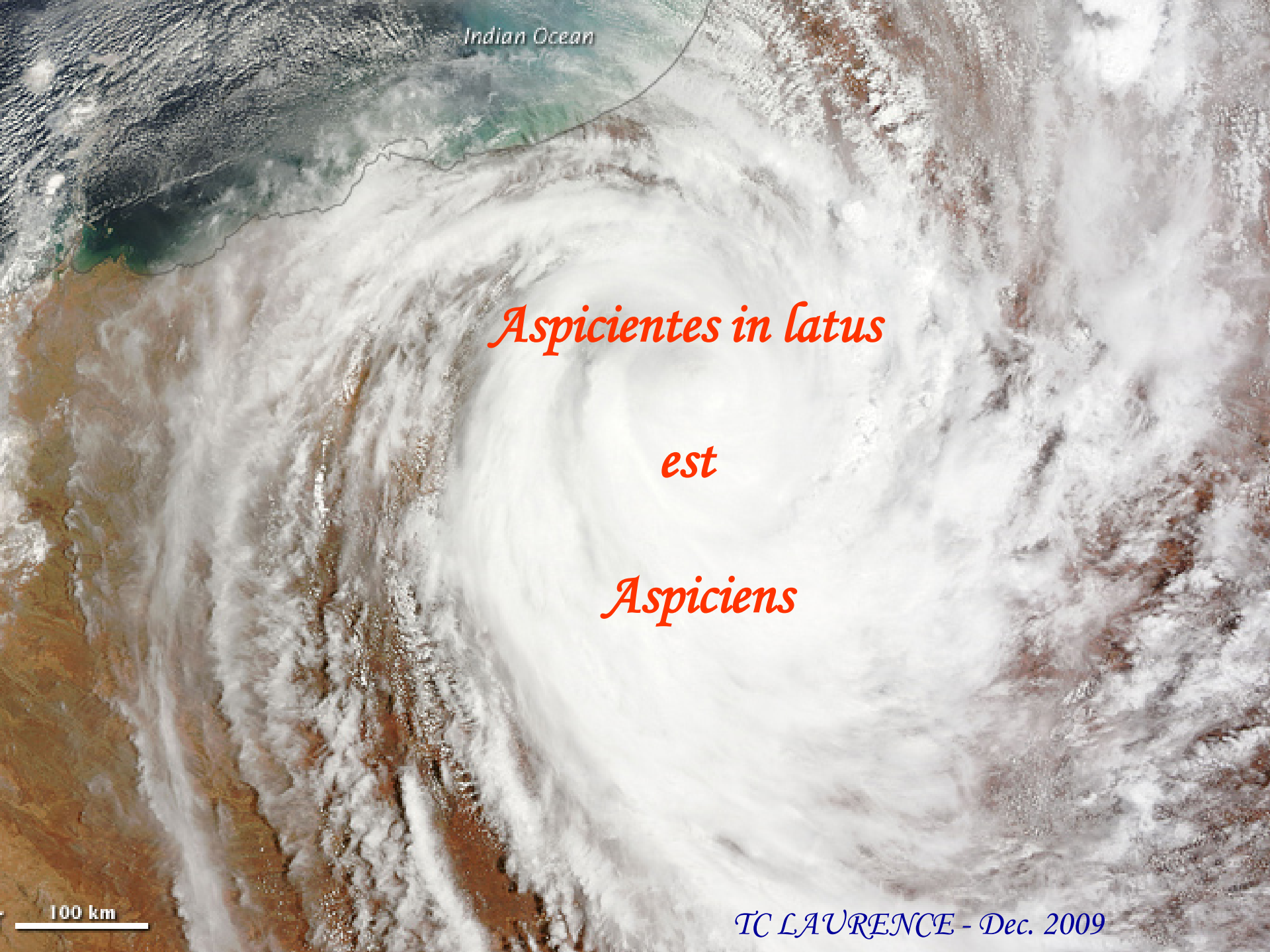
TC LAURENCE - Dec. 2009



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