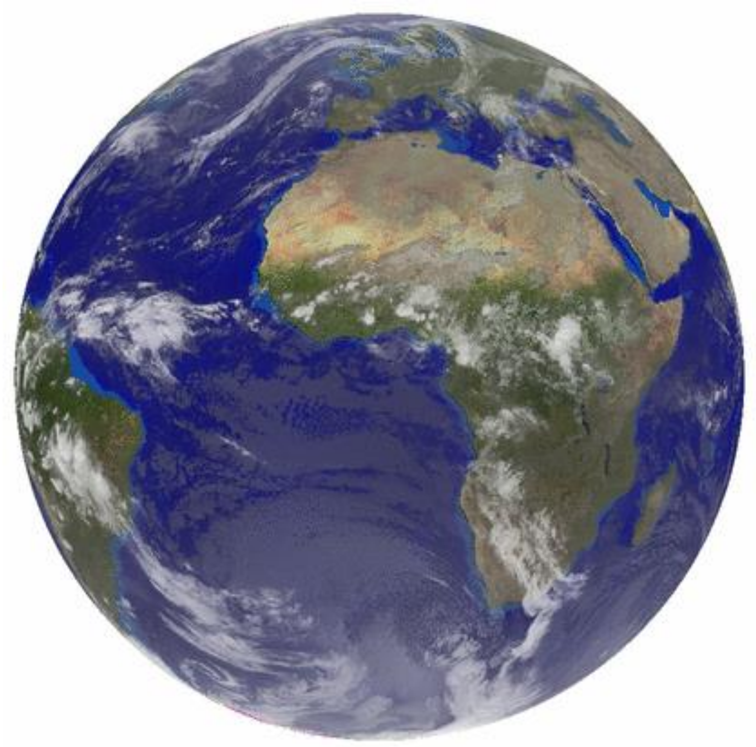


Earth Observations from Space

John Le Marshall[1], Norman, Robert[2], Howard, David[1], Ara Carte[2] , Michael Moore[3], Carl Wang[3], Salim Masouli[3],Tingwell, Chris[1], Jung, Jim[4], Daniels, Jamie[5] , Jan Kaplon[2] and Tim Morrow[1] …..

[1] Bureau of Meteorology, Melbourne, Australia

[2] RMIT University, Melbourne, Australia

[3] Geoscience Australia

[4] UW/CIMSS, Madison,USA

[5] NOAA/NESDIS/STAR, College Park, USA

ABSTRACT

Earth Observations from Space

Earth Observation from Space (EOS) currently have a considerable impact on the accuracy of numerical weather prediction (NWP) in the southern hemisphere.

Space based observations extend the length of a high quality 500HPa global numerical forecast by a factor of four when the forecast is verified using analyses incorporating both satellite and conventional (all) data.

A number of instruments have recently been placed in earth orbit for use in Numerical Weather Prediction (NWP) and others are soon to follow. These include the Advanced Himawari Imager (AHI) on Himawari-8, the Advanced Baseline Imager (ABI) and the Geostationary Lightning Mapper (GLM) on GOES-16, CrIS on JPSS, the wind lidar ADM Aeolus and the COSMIC-2 constellation of satellites.

The important contributions some of these new instruments have and will make, particularly over Australia and the southern hemisphere and in relation to extreme weather, are discussed in some detail (emphasis on AMVs, Adv.S, GPSRO, GNSS S2G)

Overview

- The Importance of EOS (in the SH)
- Current and Impending Benefits
  - The Advanced Sounders
  - Atmospheric Motion Vectors - Himawari – 8
  - Radio Occultation
  - GNSS S2G
- The Future

The Importance of EOS (in the SH)

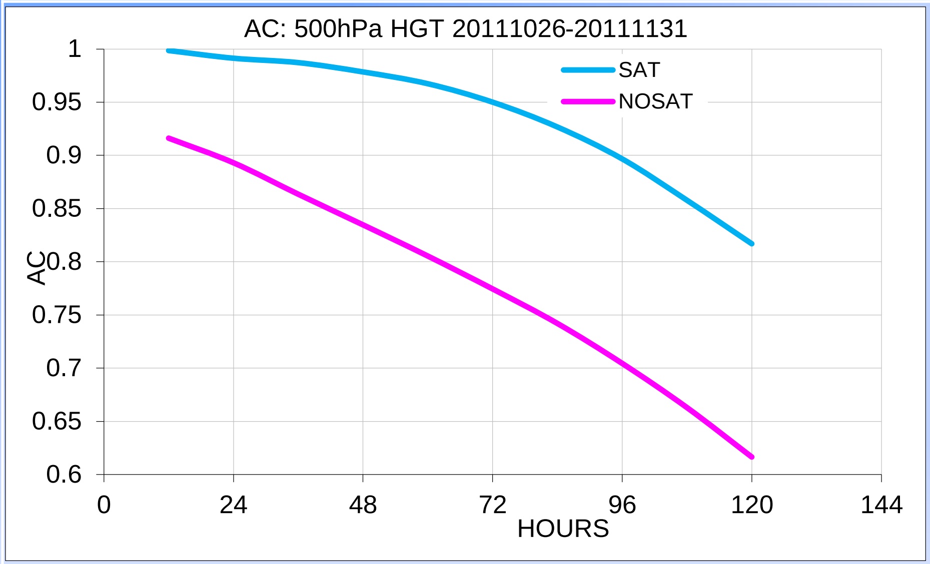
Observing System Experiments (OSEs)

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 (US Op. Sys)
  - 15 August to 30 September 2010

Earth observations From Space



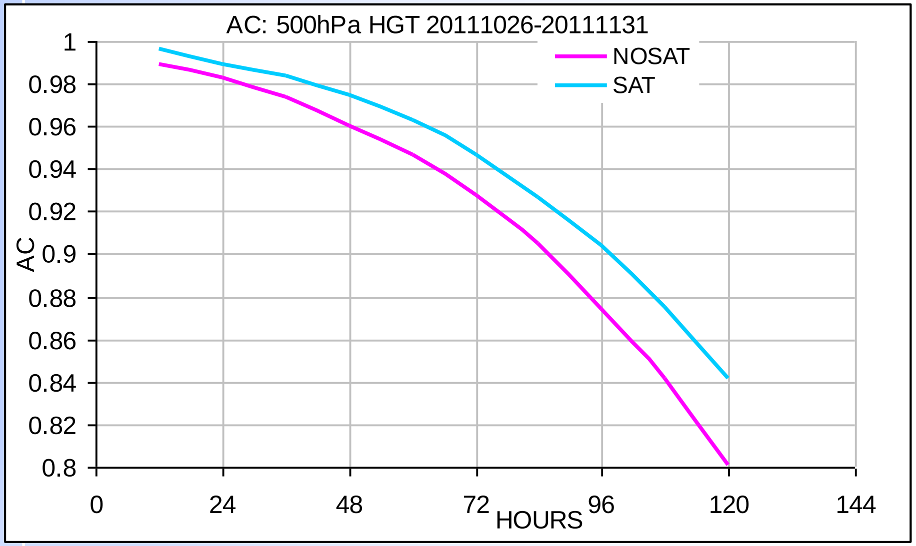
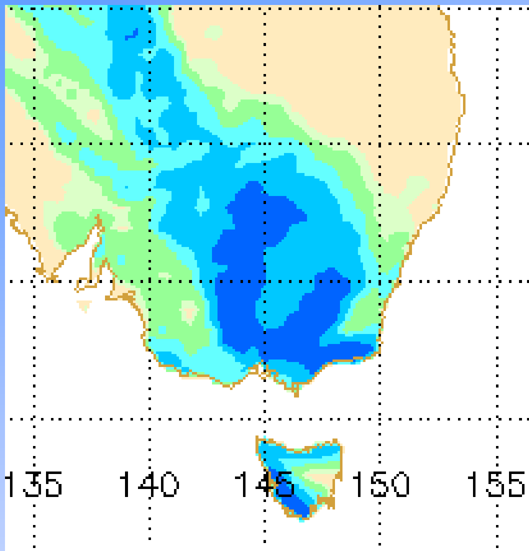


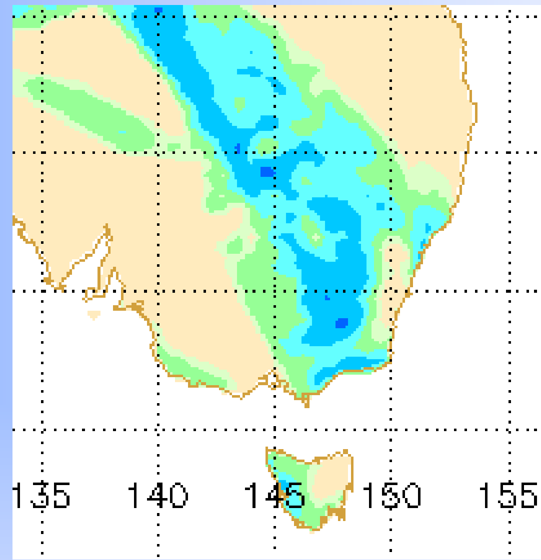
Fig. 8(c). SH 500hPa height anomaly correlation for the control (SAT) and no satellite (NOSAT), 28 October to 30 November 2011 using ACCESS and verifying against the control analysis

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

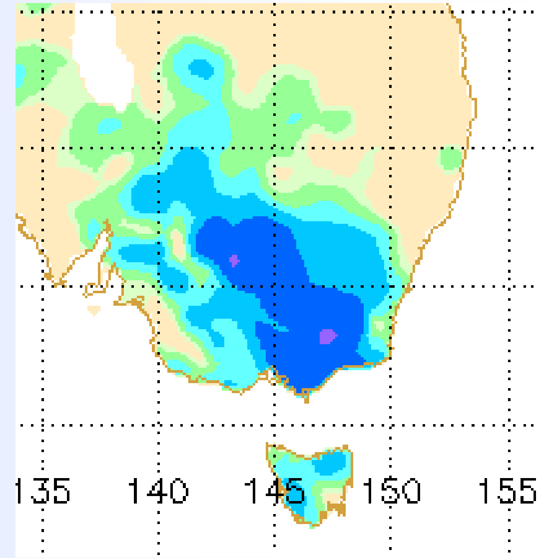
Hi Impact Weather



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

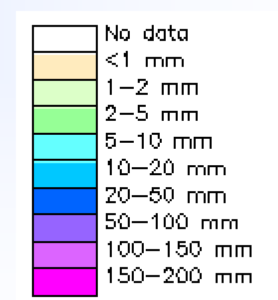


ACCESS-G 48 to 72 hour rainfall forecast for 9 November 2011 using no satellite data.



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



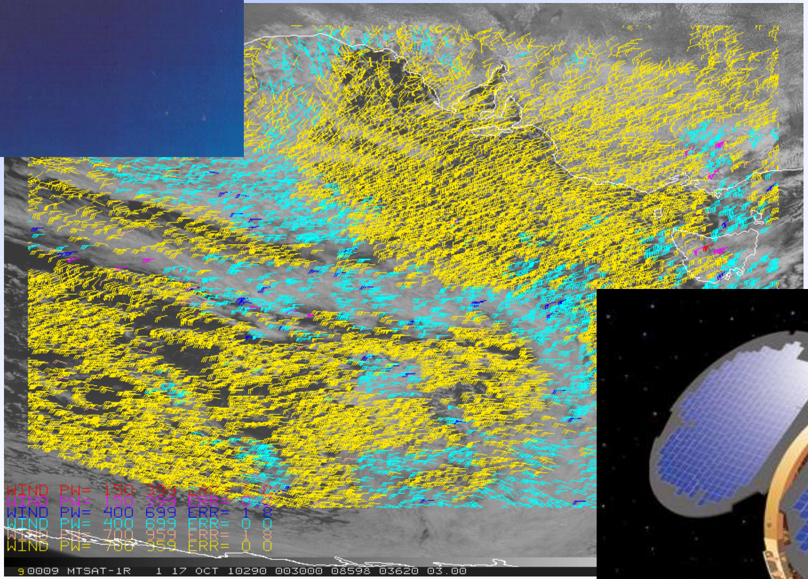
Daily rainfall values.

Recent and Impending Advances - Examples

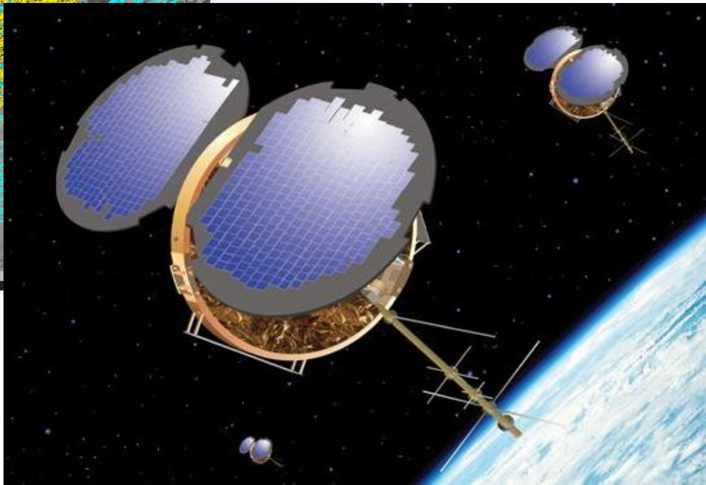
Ultraspectral Advanced Sounders

AIRS
IASI
CrIS

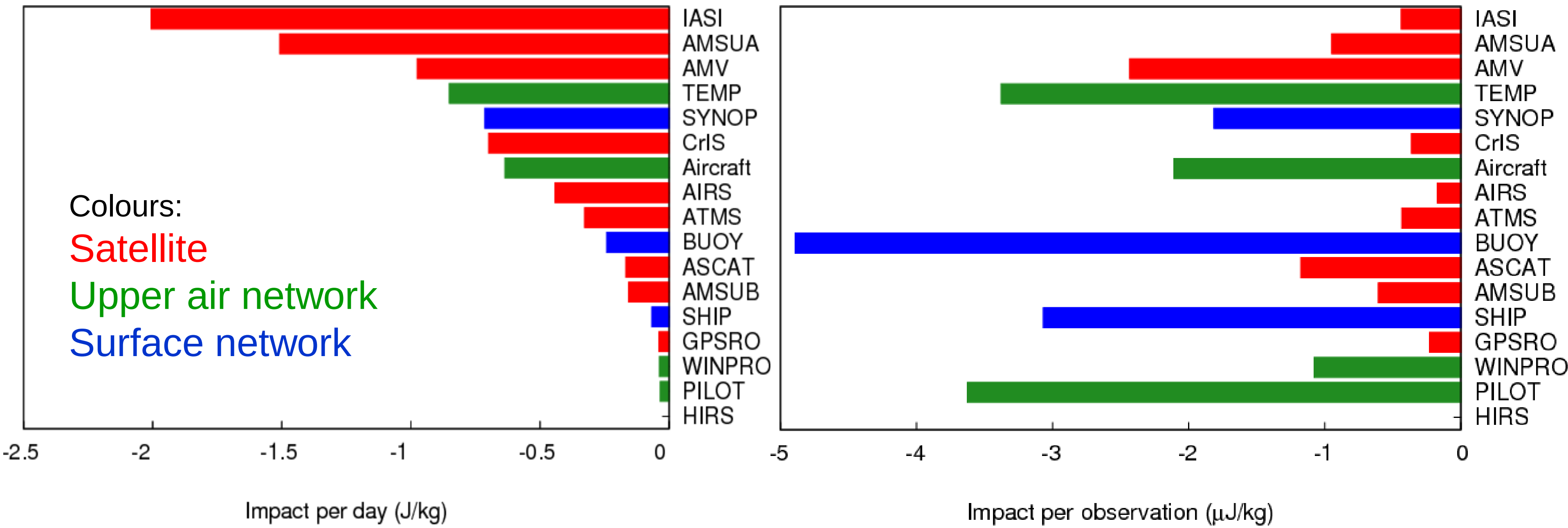
AMVs



GPS RO



ACCESS APS2: Forecast Sensitivity to Observations



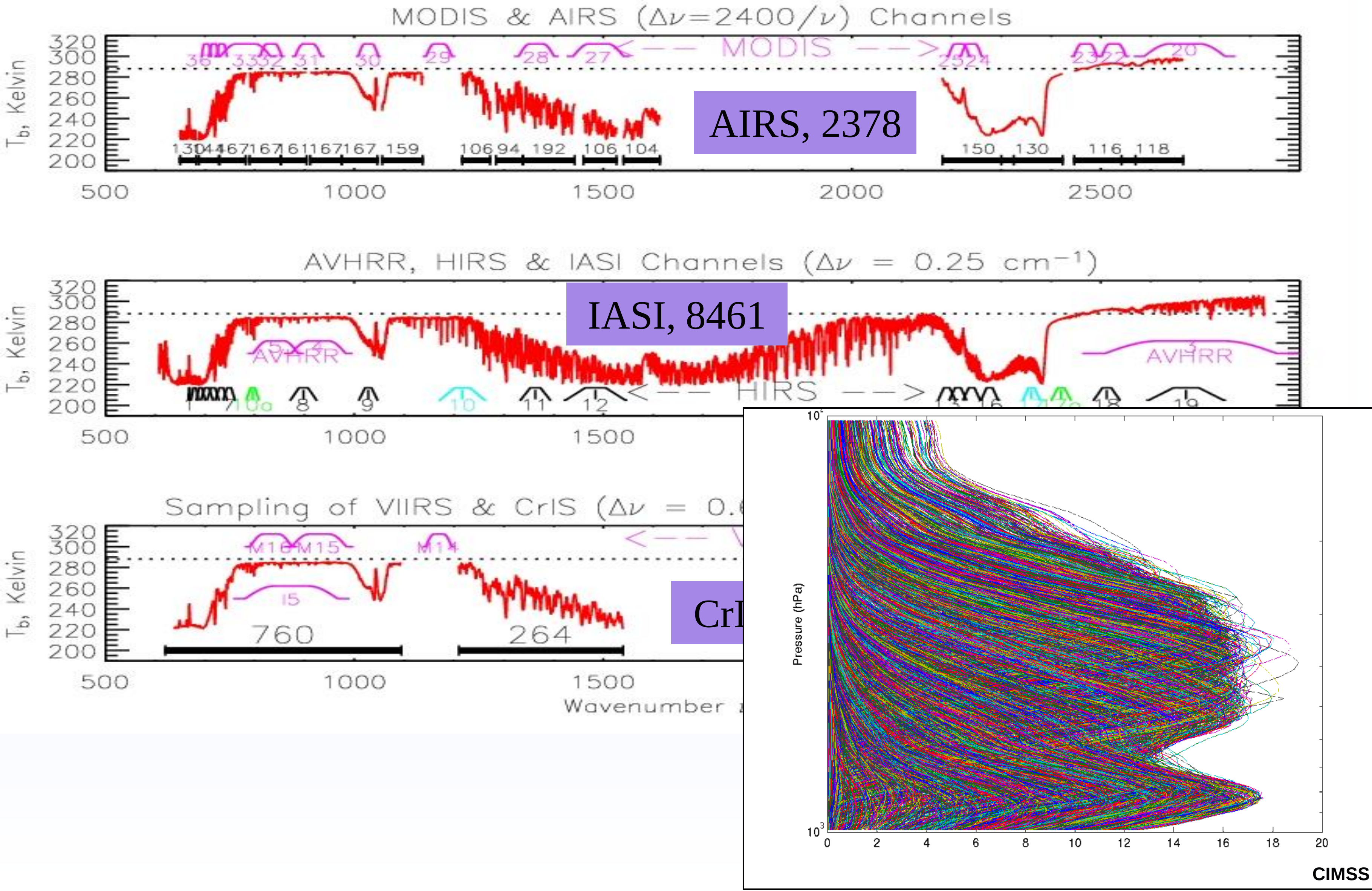
<u>Global 24-hour forecast error reduction from each of the observation types assimilated in ACCESS</u>

- Three months: April, May and June 2016. Himawari-8 AMVs included in full period.
- All types of observations are beneficial, i.e. reduce the forecast error.
- **Total impact (LH panel)** is dominated by satellite instruments (e.g. the **IASI**, **AMSU** and **CrIS** sounding instruments carried on polar orbiters and **AMV**s) - due to large numbers & global coverage.
- Greater **impact *per observation* (RH panel)** comes from balloon upper air measurements plus surface measurements from drifting and fixed buoys.

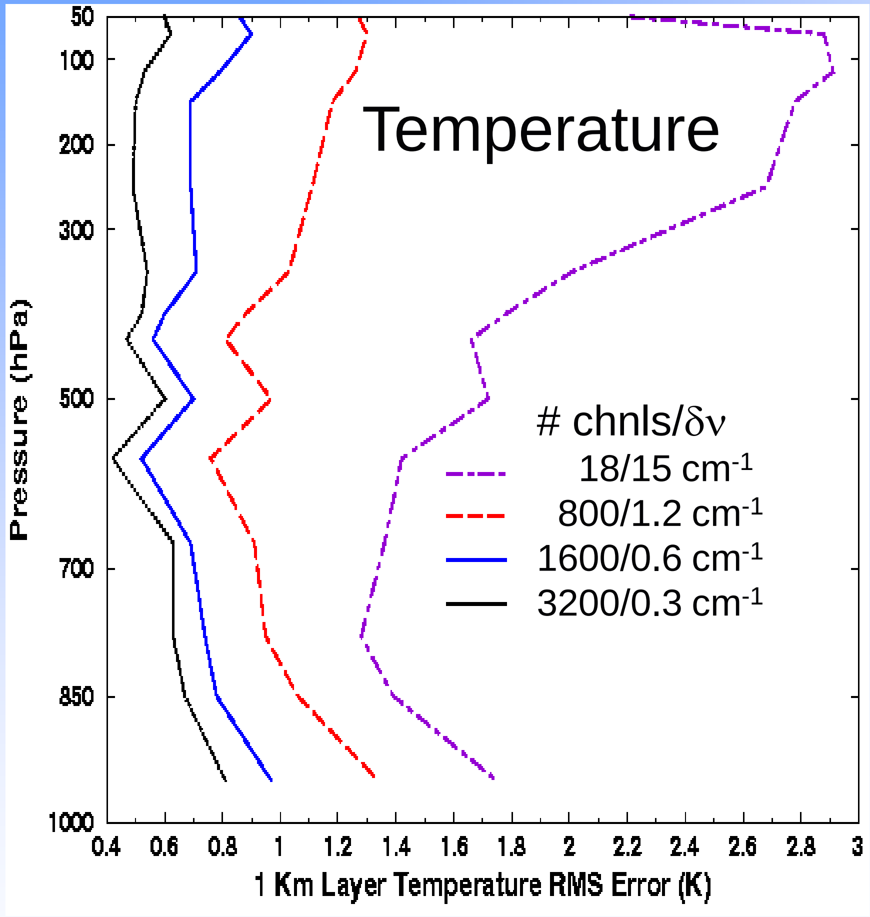
Ultraspectral Advanced Sounders

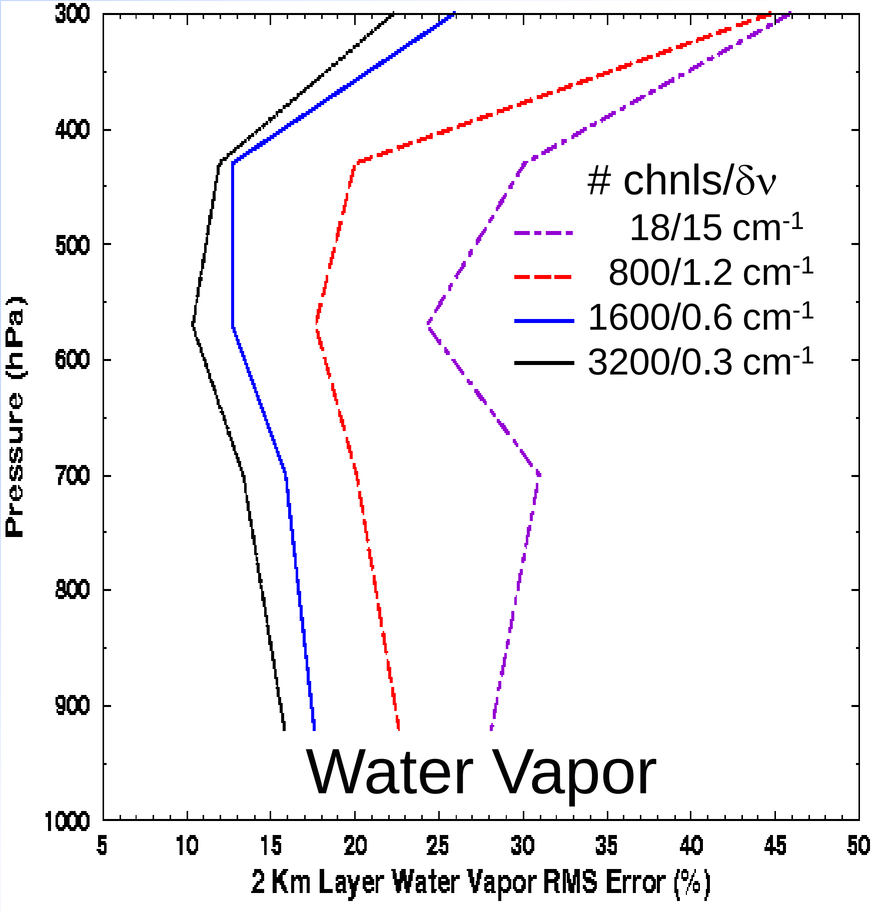
AIRS
IASI
CrIS

Spectral Coverage and Example Observations of AIRS, IASI, and CrIS

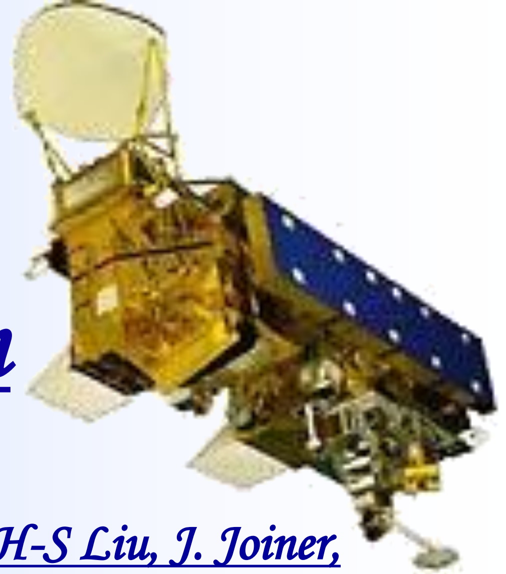


Retrieval Accuracy Vs Spectral Resolution
(i.e., number of spectral radiance observations)





The vertical resolution and accuracy increases greatly going from multi-spectral to ultra-spectral resolution. The improvement in ultra-spectral performance is proportional to the square root of the number of channels (i.e., S/N)



AIRS Data Assimilation

J. Le Marshall, J. Jung, J. Derber, R. Treadon,

S.J. Lord, M. Goldberg, C. Barnet, W. Wolf and H-S Liu, J. Joiner,

and J Woollen……

1 January 2004 – 31 January 2004

Used operational GFS system as Control

Used Operational GFS system Plus AIRS as Experimental System

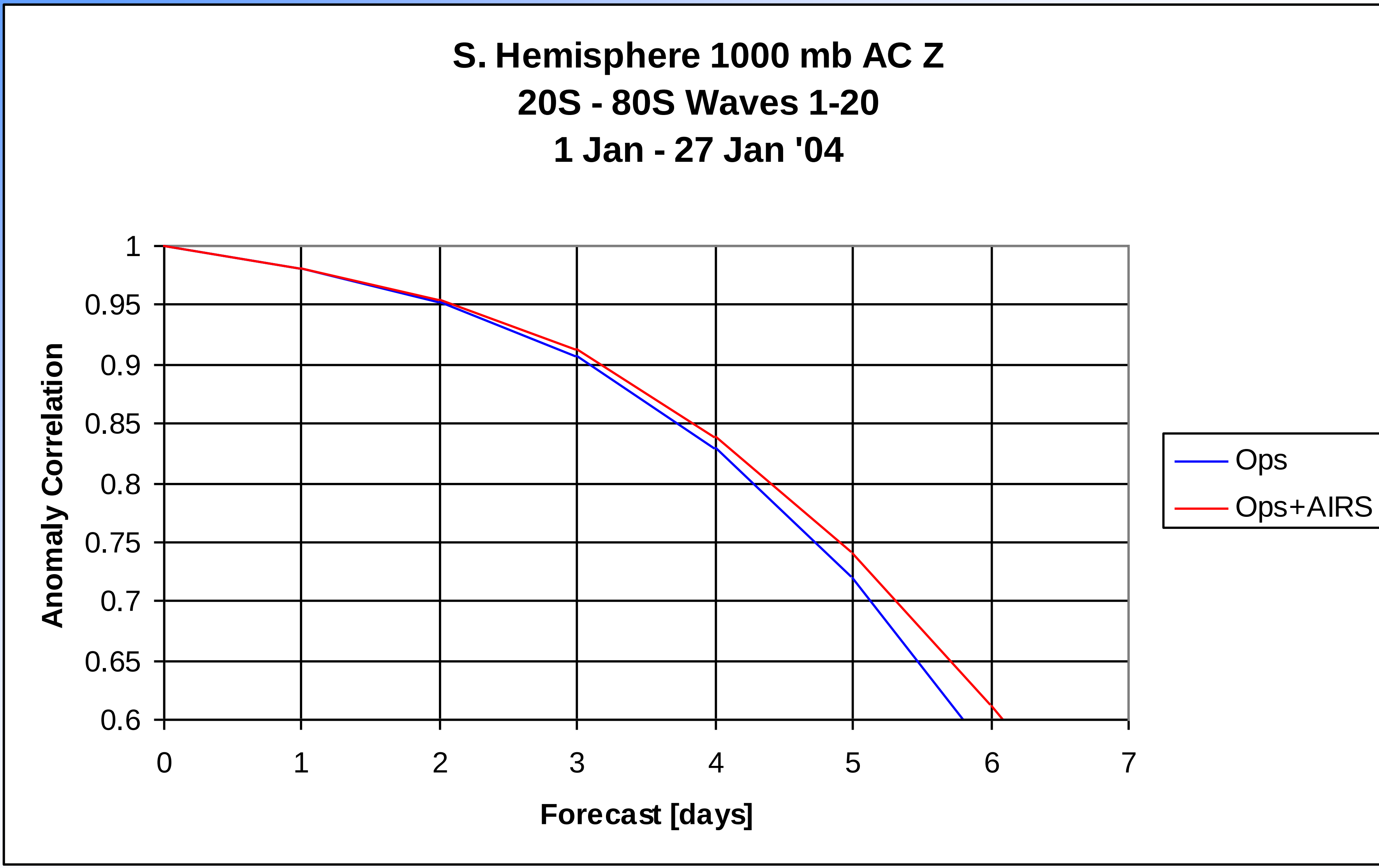
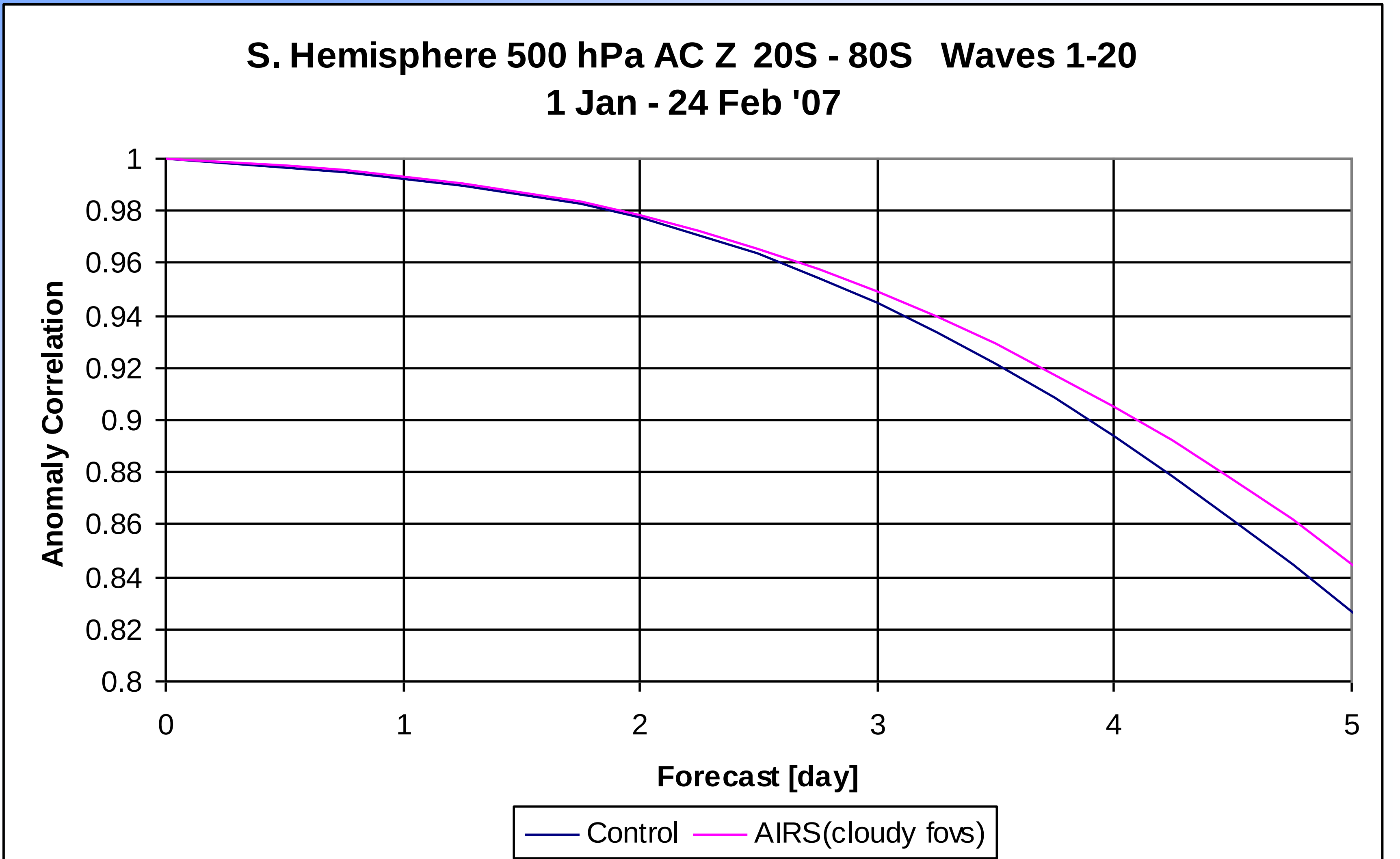


Figure1(a). 1000hPa Anomaly Correlations for the GFS with (Ops.+AIRS) and without (Ops.) AIRS data, Southern hemisphere, January 2004

AIRS Data Assimilation

Using Cloudy Fields of View

1 January – 24 February 2007


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)

AIRS /IASI Data Assimilation

Using Moisture Channels

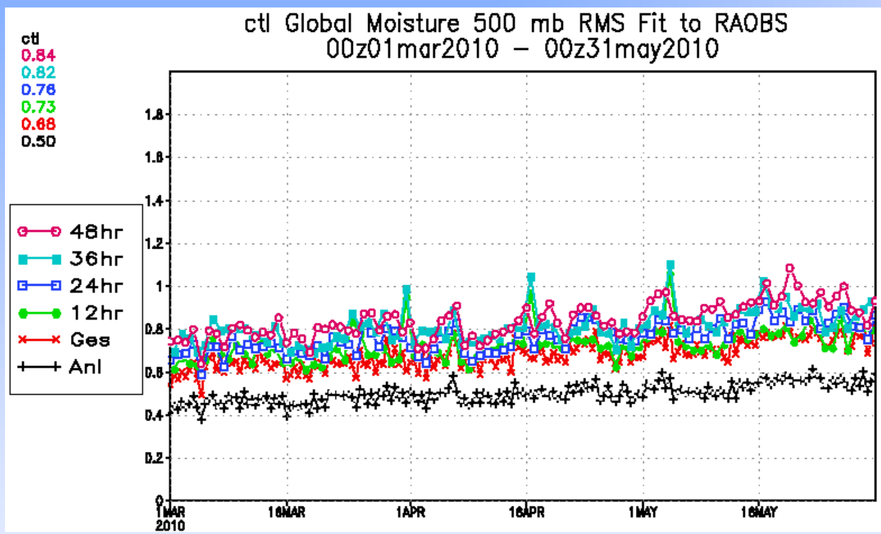
Adding 80 AIRS and IASI Tropospheric Water Vapour channels

Adding 40 AIRS and IASI Stratospheric Water Vapour channels

Analysing Tropospheric Moisture by Assimilating Hyperspectral Infrared Water Vapor Channels

control

experiment



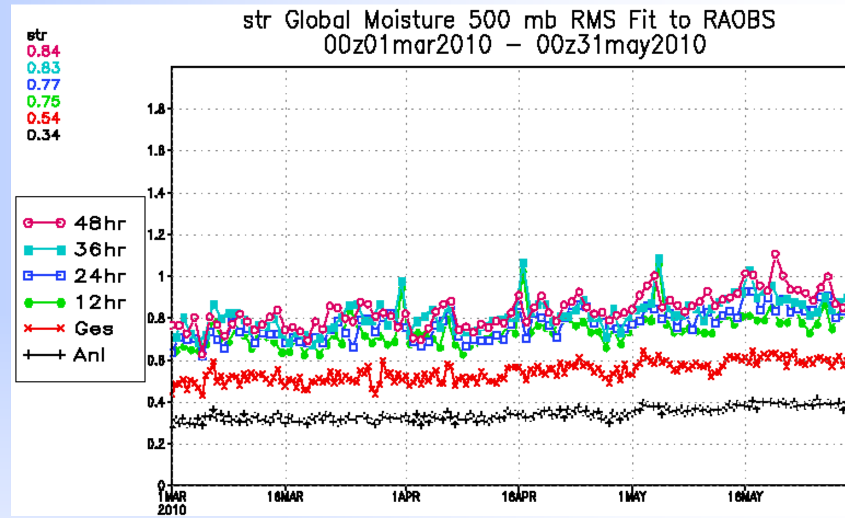


Figure 3: Specific humidity fits to rawinsondes humidity data during the time period March to May 2010 for the analysis, 6(Ges)- , 12- , 24- , 36- and 48-hour forecasts. Note the considerable improvement in the 6-hour and 12-hour forecasts.

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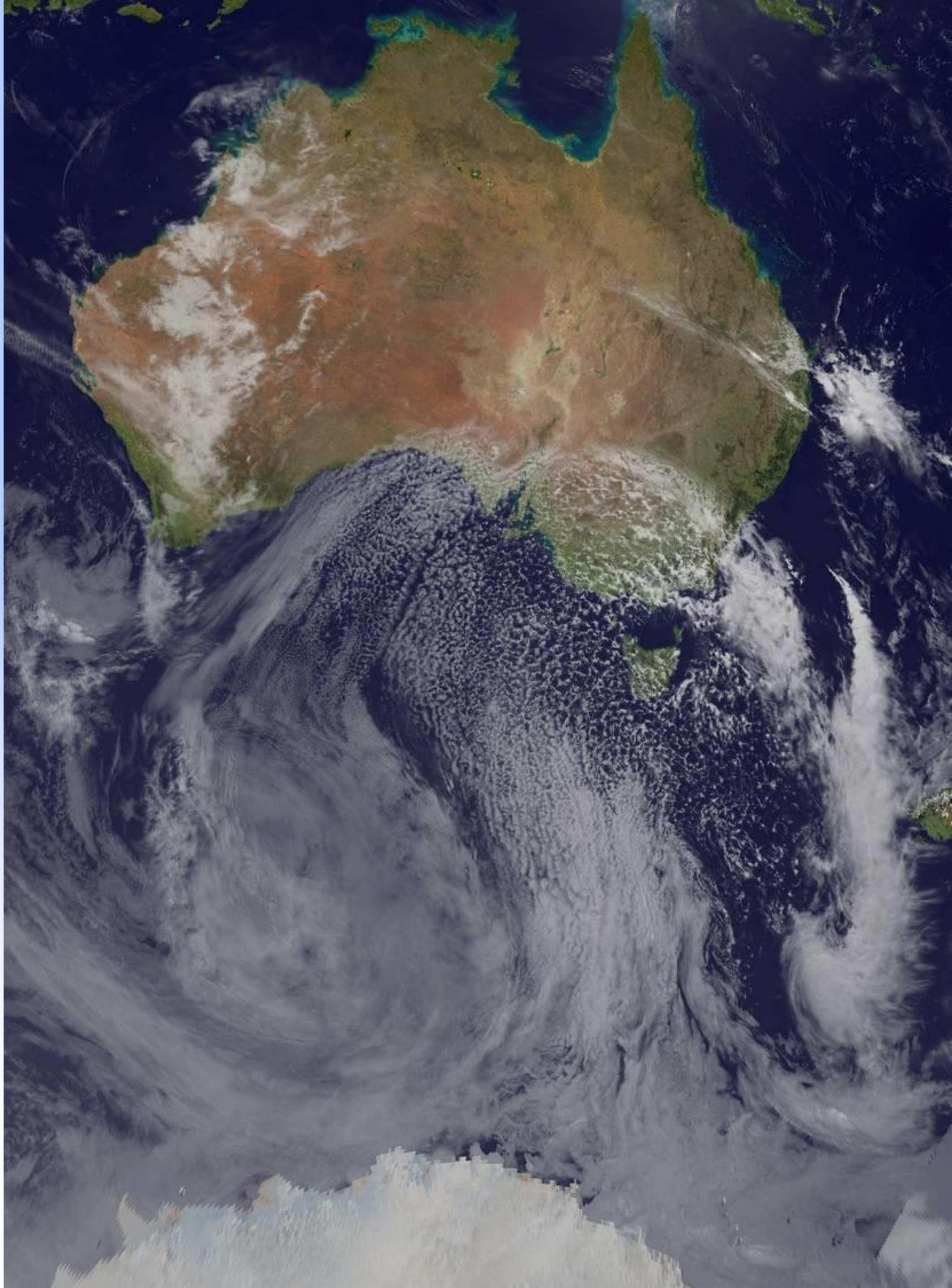
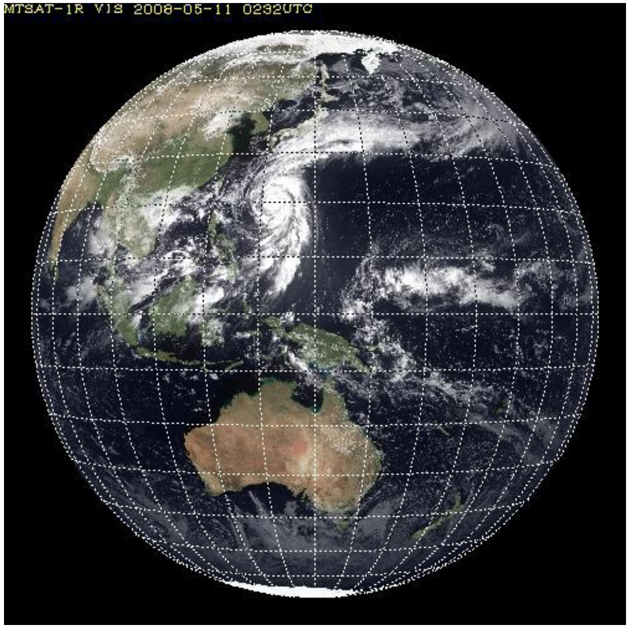
Himawari-6,7 and 8

THE GENERATION AND ASSIMILATION OF CONTINUOUS ATMOSPHERIC MOTION VECTORS WITH 4DVAR



Specification of "Himawari-8/9" Imager(AHI)

Full Disk Image
every 10 minutes



	Band	Central Wavelength [μm]	Spatial Resolution
	1	0.43 -0.48	1Km
	2	0.50 -0.52	1Km
X	3	0.63 -0.66	0.5Km
X	4	0.85 -0.87	1Km
X	5	1.60 -1.62	2Km
	6	2.25 -2.27	2Km
X	7	3.74 -3.96	2Km
X	8	6.06 -6.43	2Km
	9	6.89 -7.01	2Km
X	10	7.26 -7.43	2Km
X	11	8.44 -8.76	2Km
X	12	9.54 -9.72	2Km
X	13	10.3 -10.6	2Km
	14	11.1-11.3	2Km
X	15	12.2 -12.5	2Km
X	16	13.2 -13.4	2Km

RGB Composited True Color Image

1.3 μm for GOES-R

Water Vapour

SO_2

O_3

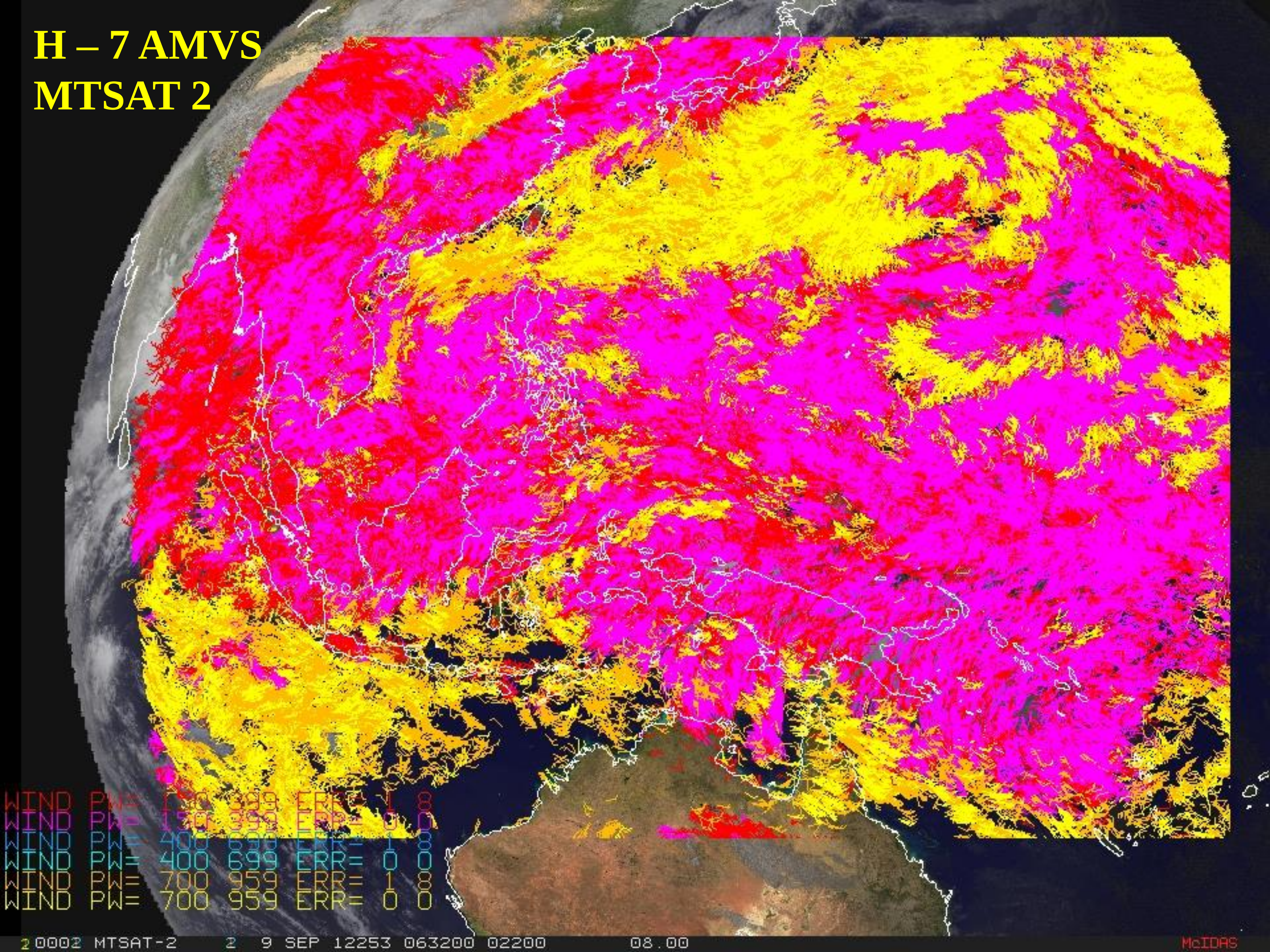
Atmospheric Windows

CO_2

MTSAT-1R/2

Band	Central Wavelength [μm]	Spatial Resolution
1	0.55 –0.90	1Km
2	3.50 –4.00	4Km
3	6.50-7.00	4Km
4	10.3 –11.3	4Km
5	11.5 –12.5	4Km

H – 7 AMVS
MTSAT 2



NEAR RT TRIAL

OPERATIONAL SYSTEM

27 January – 23 February 2011

Used

■ Real Time Local Satellite Winds MTSAT-2 (EE, hourly since 96, TB)

● 2 sets of quarter hourly motion vectors every six hours.

● Hourly motion Vectors

■ Operational Regional

Forecast Model (ACCESS-R) and

Data Base (Inc JMA AMVs)

HIMAWARI-7 NEAR RT TRIAL

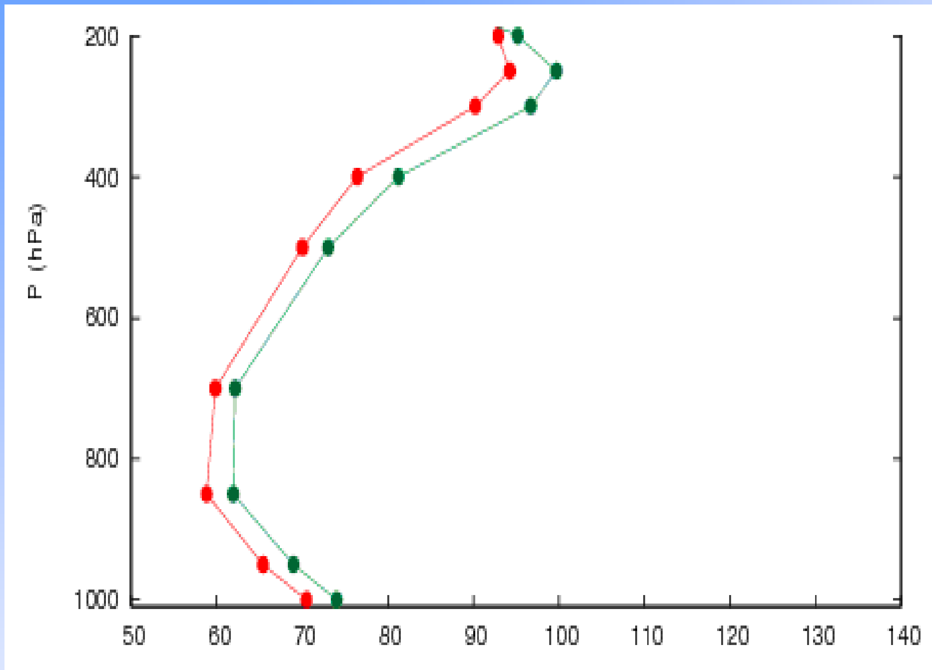


Fig.6(a). The RMS difference between forecast and verifying analysis geopotential height(m) at 24 hours for ACCESS-R (green) and ACCESS-R with hourly AMVs (red) for the period 27 January to 23 February 2011.

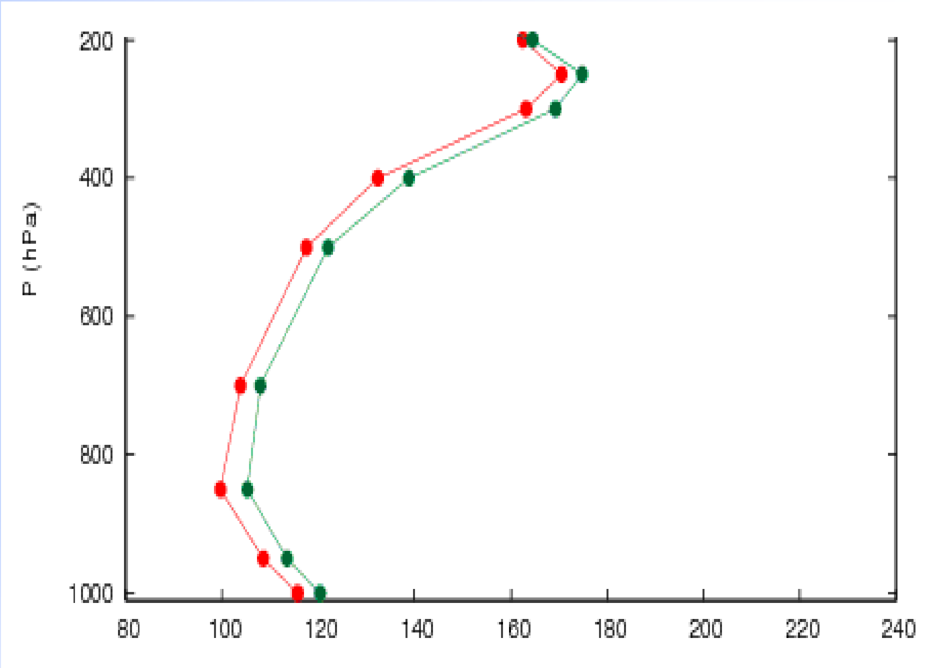


Fig.6(b). The RMS difference between forecast and verifying analysis geopotential height(m) at 48 hours for ACCESS-R (green) and ACCESS-R with hourly AMVs (red) for the period 27 January to 23 February 2011.

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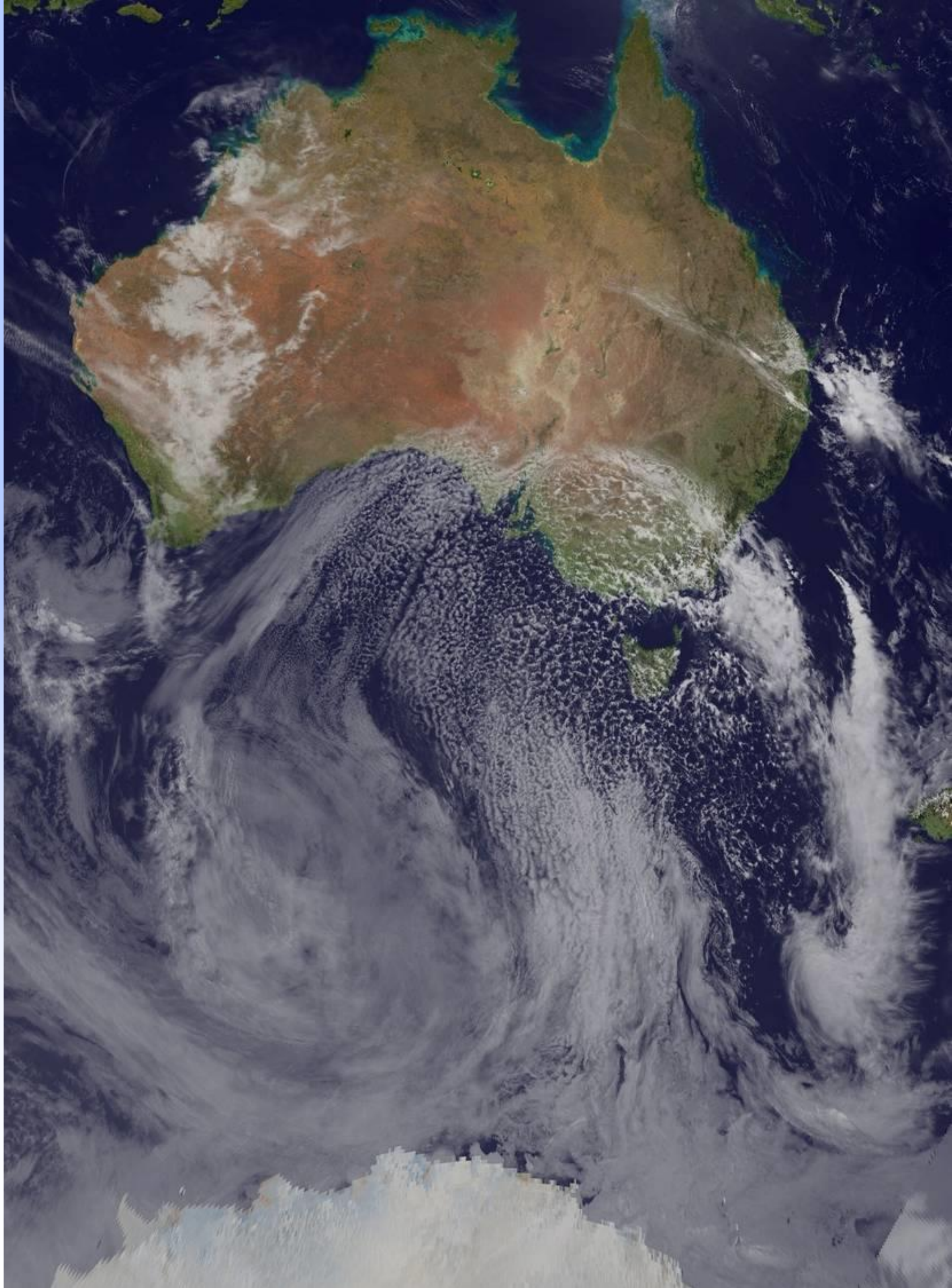
GENERATION AND ASSIMILATION OF CONTINUOUS (10 Minute) ATMOSPHERIC MOTION VECTORS FROM MTSAT-1R (HIMAWARI-6) USING 4DVAR



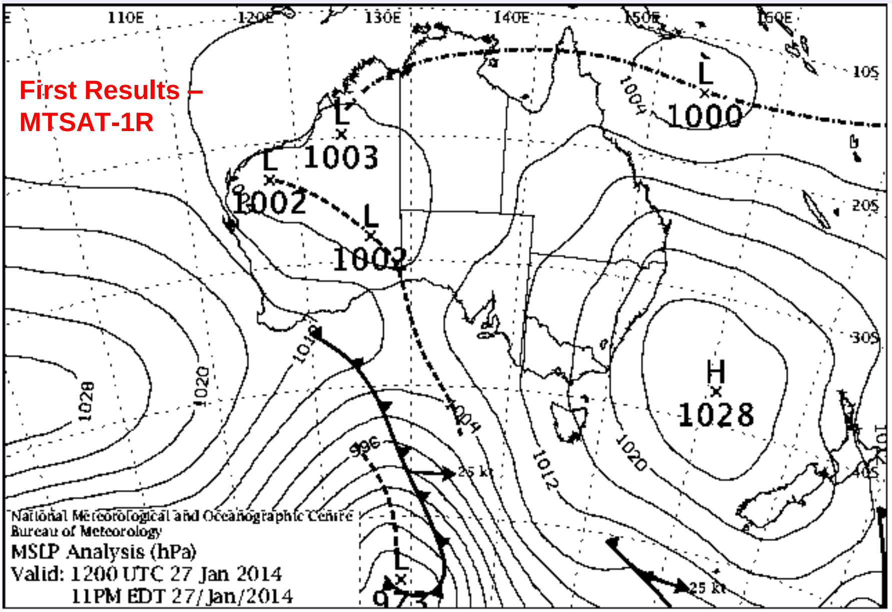


Fig. 13 Bureau of Meteorology Analysis for 12 UTC on 27 January 2014.

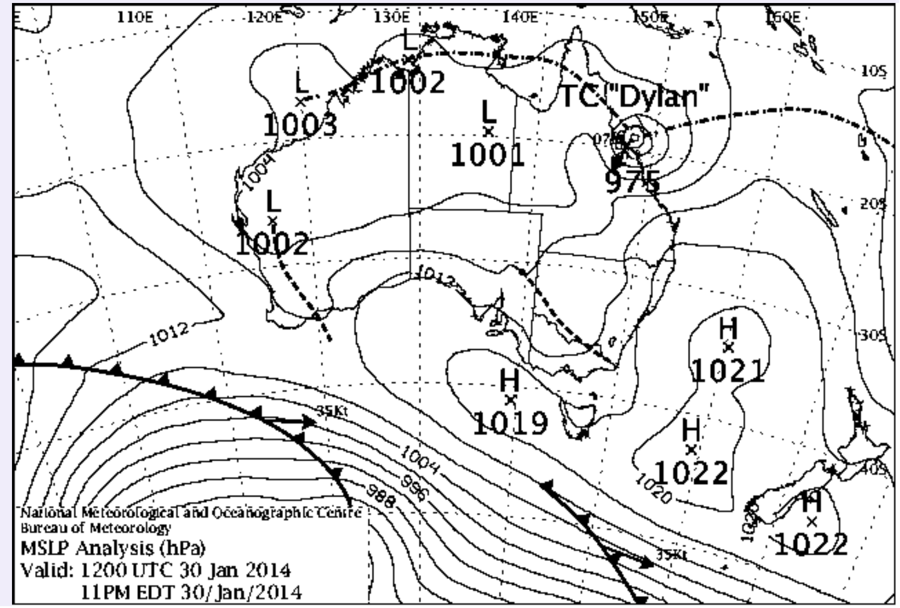


Fig. 14. Bureau of Meteorology Analysis for 12 UTC on 30 January 2014

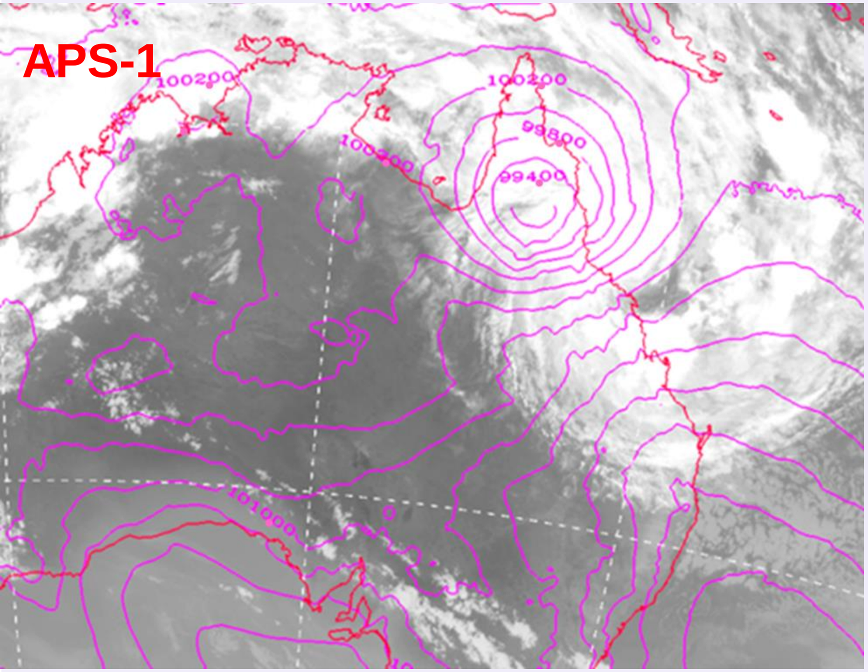


Fig.15 The Bureau of Meteorology operational three-day MSLP (hPa) forecast valid 1200 UTC 30 January 2014, shown remapped over an MTSat infrared image, valid at the same time.

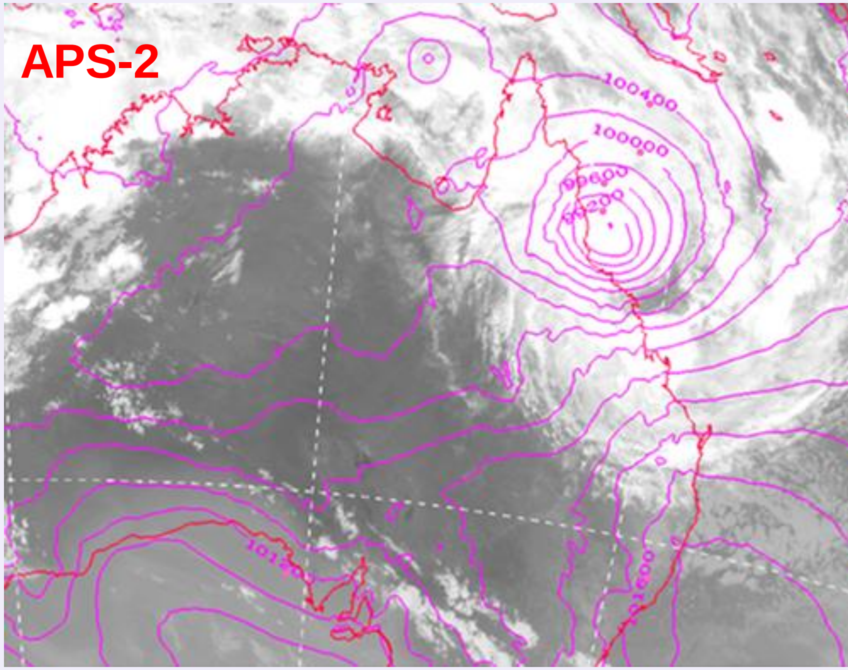
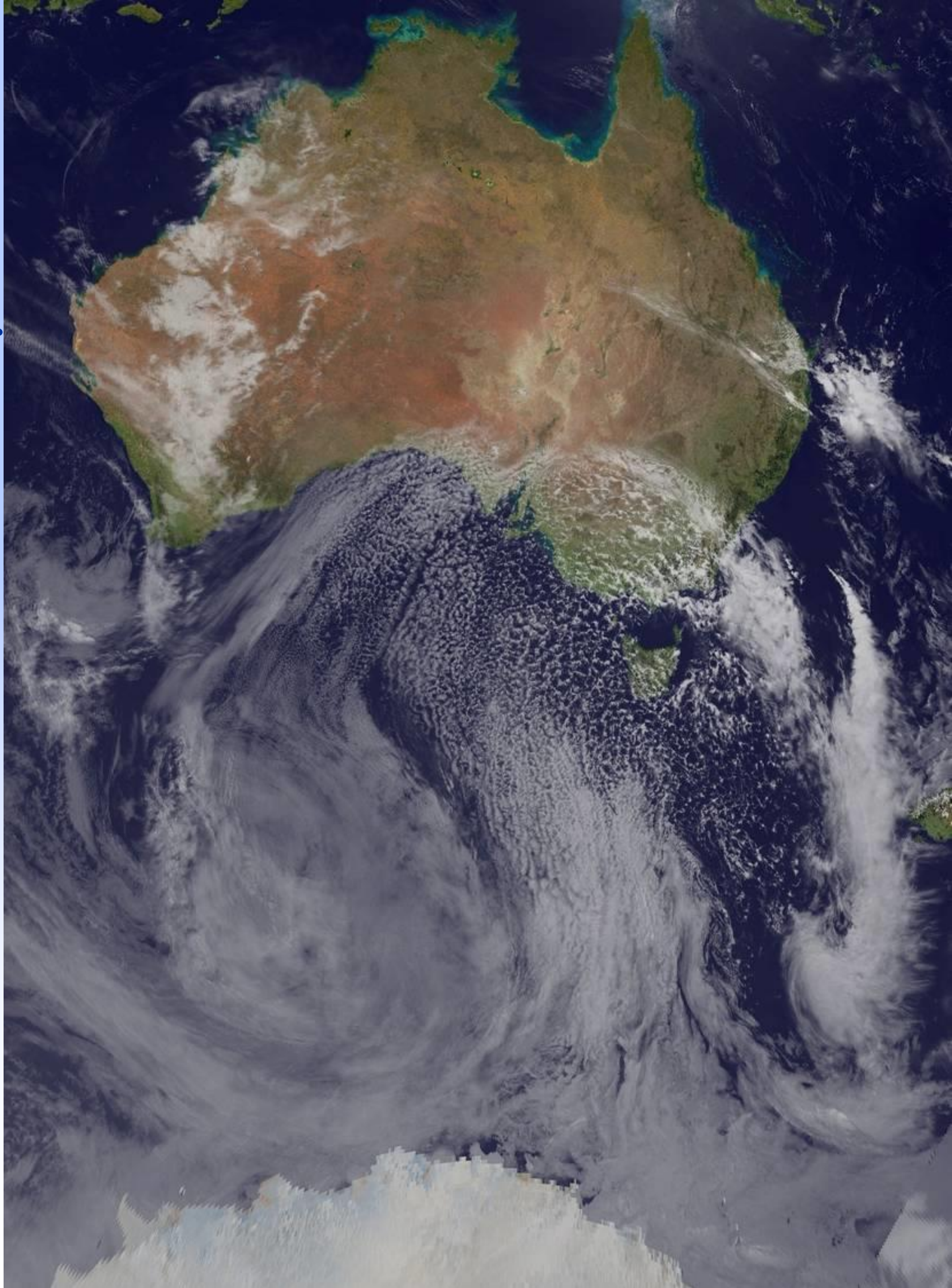


Fig.16 The Bureau of Meteorology three-day MSLP (hPa) forecast valid, 1200 UTC 30 January 2014 using the next generation operational regional forecasting system with ten, fifteen and sixty minute AMV data from MTSat-1R and MTSat-2. The forecast remapped over the 1200 UTC MTSat image.

Australian Government

Bureau of Meteorology

RECENT GENERATION AND ASSIMILATION OF CONTINUOUS (10 Minute) H-8 ATMOSPHERIC MOTION VECTORS , GEOCAT AND 4DVAR



Himawari-8 Operational AMV Generation

Uses 3 images separated by 10 min in HSF format.

Employs modified GEOCAT (Geostationary Cloud Algorithm Testbed) software in initial processing.

Height assignment methods similar to GOES-R ABI ATBD For Cloud Height (Heidinger, A. 2010)

AMV estimation is similar to GOES-R ABI ATBD for Derived Motion Winds (Daniels, 2010) / BoM system

Error characterization, data selection, QC via EE, QI, ERR etc. (Le Marshall et al., 2004, 2015)

Height assignment verification Cloudsat/Calipso, RAOBS

(System also used for H-7)

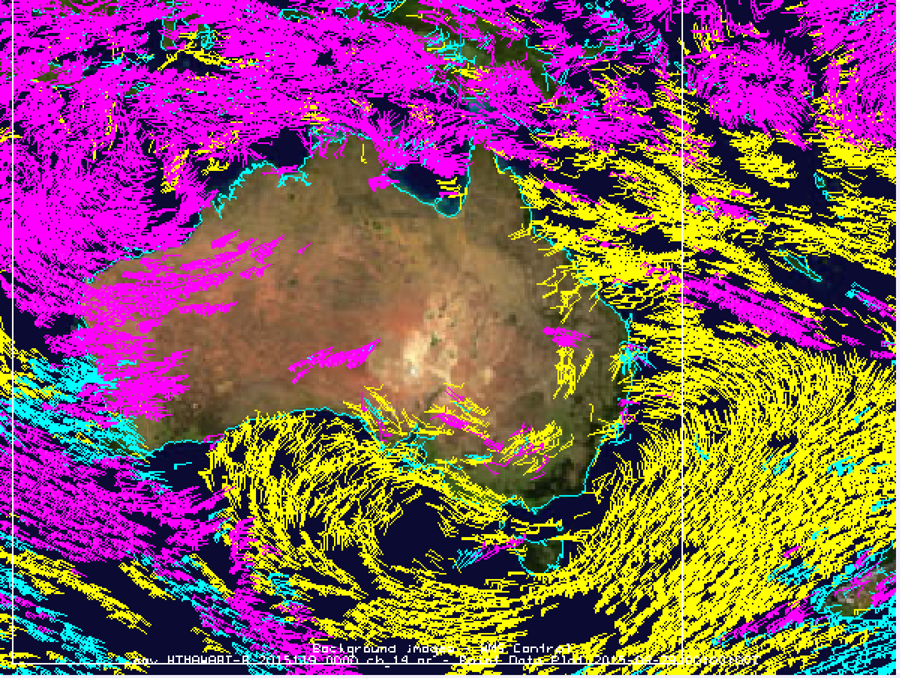


Fig.7 AMVs generated around Australia 0000UTC 29 April 2015 – Note box around Australia.

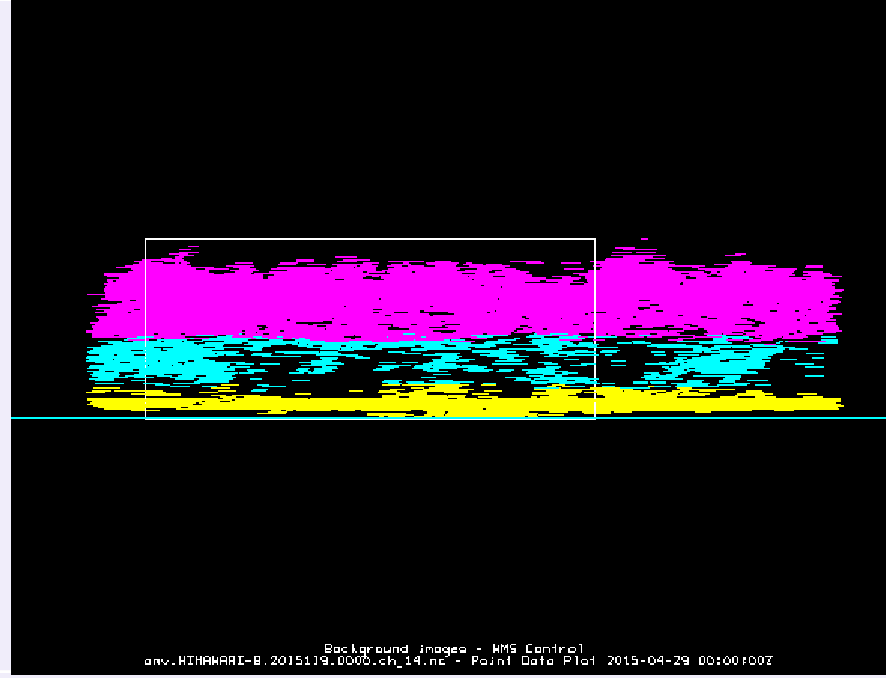


Fig.8 AMVs generated around Australia 0000UTC 29 April 2015 – View from the south.

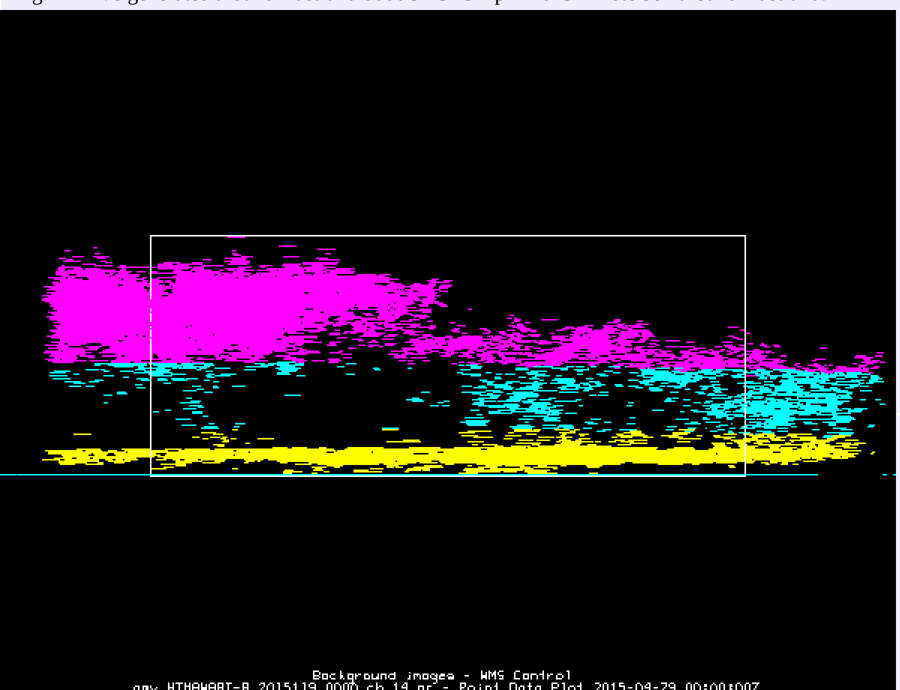


Fig.9AMVs generated around Australia 0000UTC 29 April 2015 – View from the west.

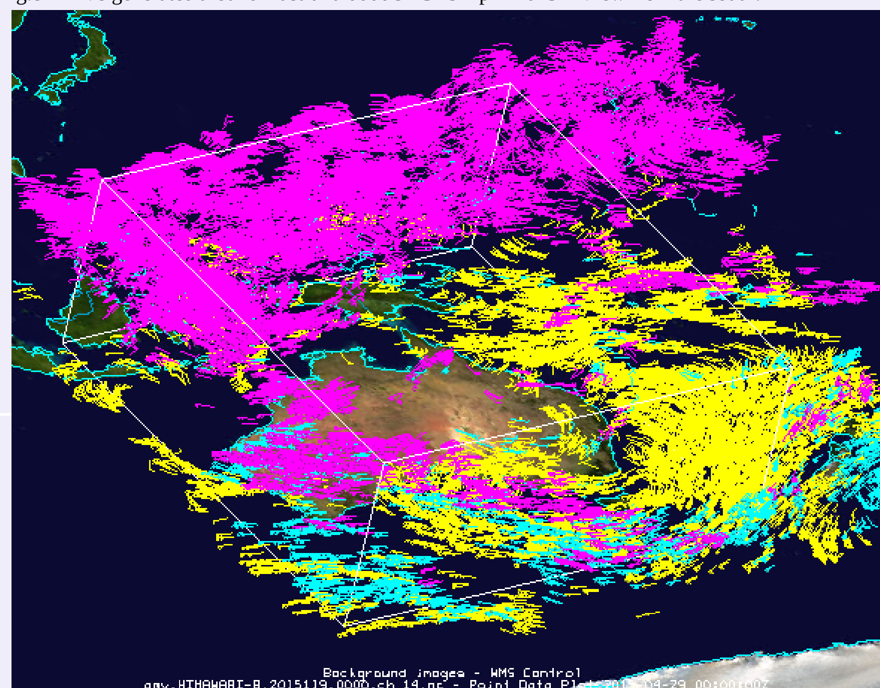


Fig.10AMVs generated around Australia 0000UTC 29 April 2015 – Slant view from southwest.

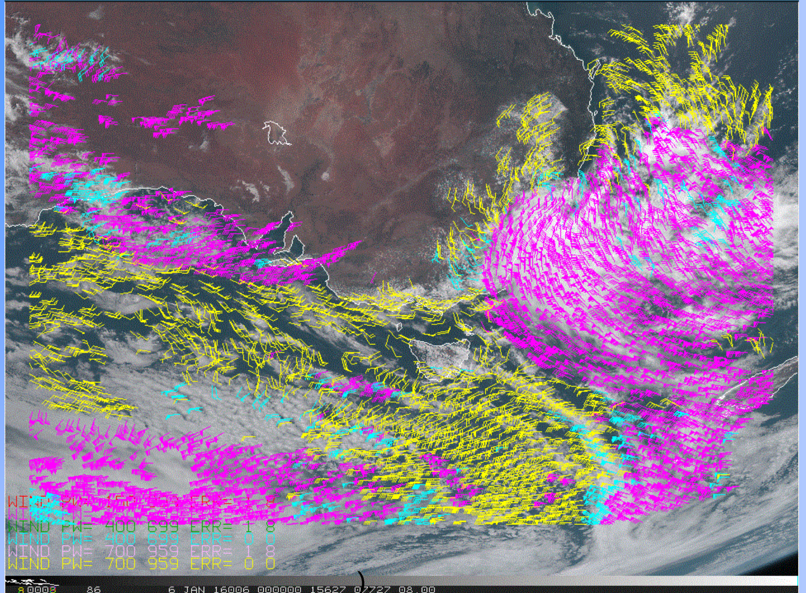


Fig.3 Himawari-8 AMVs tracked using IR (11 µm) channel 14 tracers at 00 UTC 16 January 2016 using the next generation operational system

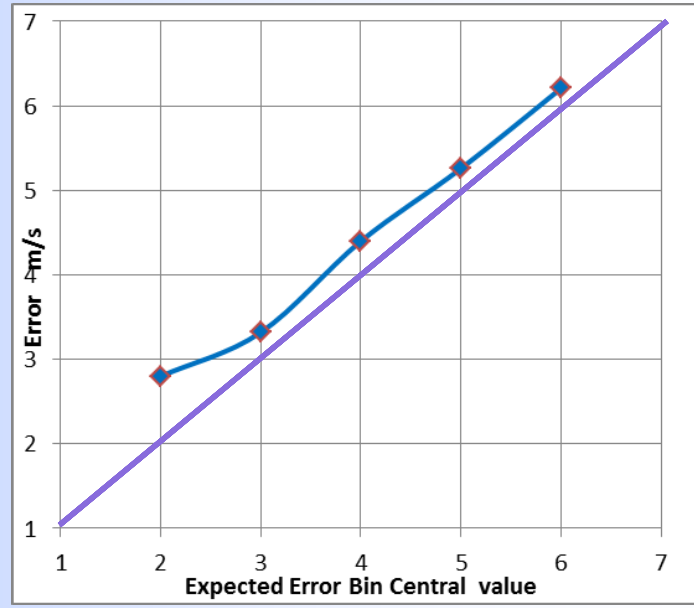


Fig. 4. Measured error (m/ s) vs Expected Error (m/s) for low-level Himawari-8 IR winds (1 31 August –29 2016).

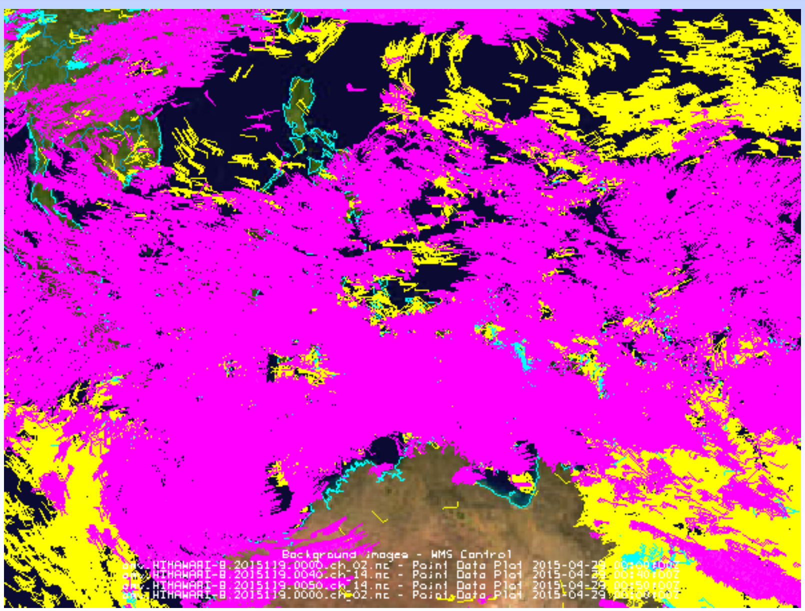


Fig. 5 Coverage of AMVs from Himawari-8 in the tropics to the north of Australia around 0000 UTC 29 April 2015

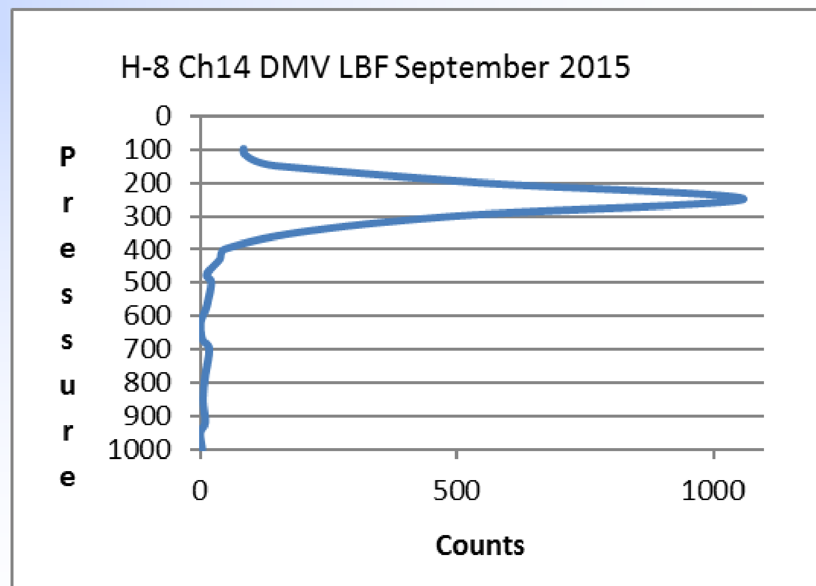


Fig. 6 Himawari-8 level of best fit height assignment statistics for CH.14 AMVs for September 2015 (see text)

Verification for real time vectors from Himawari-8

Verification Table for Himawari-8 IR (channel 14) AMVs compared to radiosondes 1 March – 31 March 2016

AMV Type	Category	m/s	NOBS
Low Sep. <50 km	MMVD	2.4	358
	RMSVD	2.8	
	BIAS	0.3	
High Sep. <50 km	MMVD	3.3	1460
	RMSVD	3.9	
	BIAS	-0.6	

Processing every 10 minutes

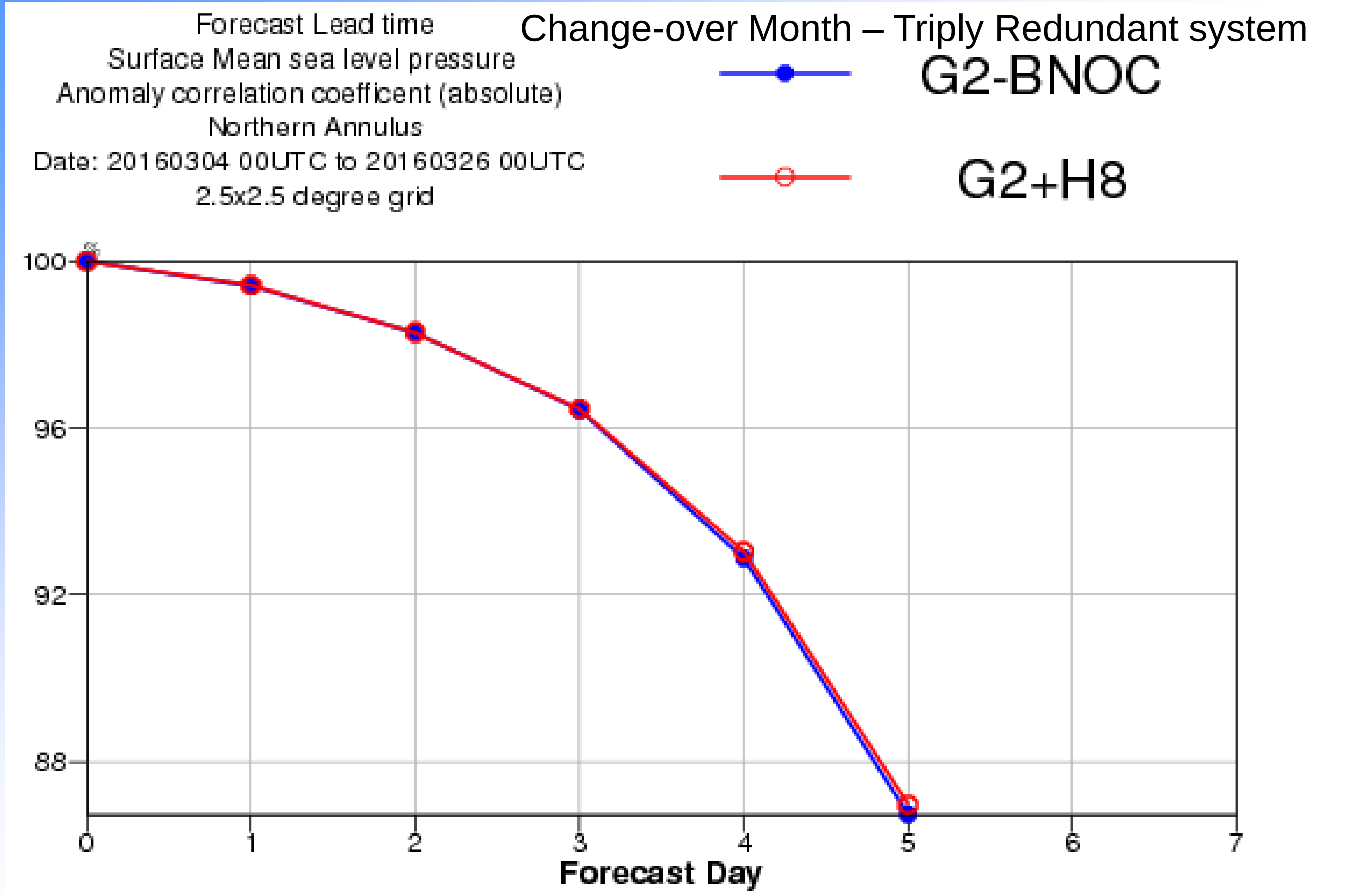
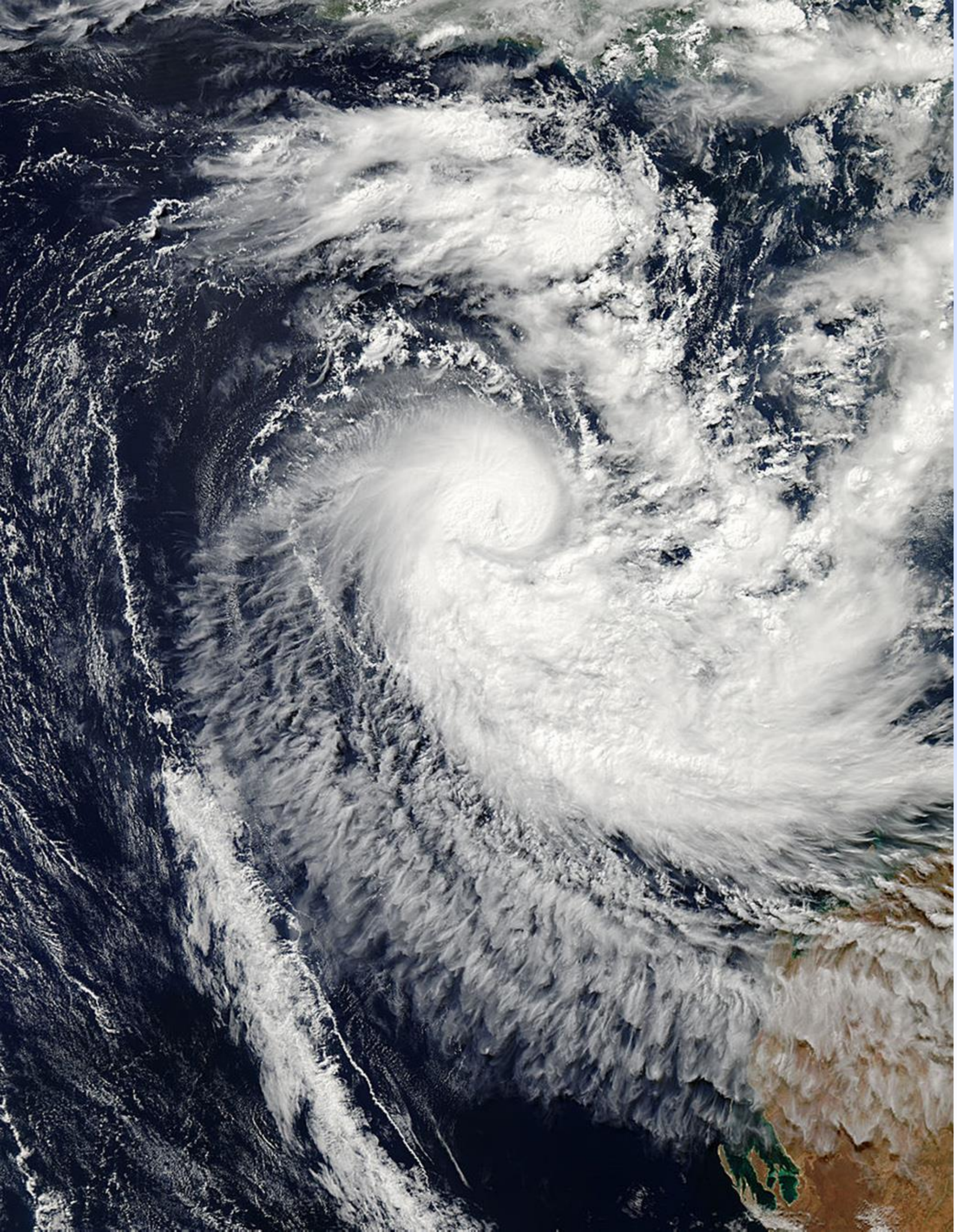


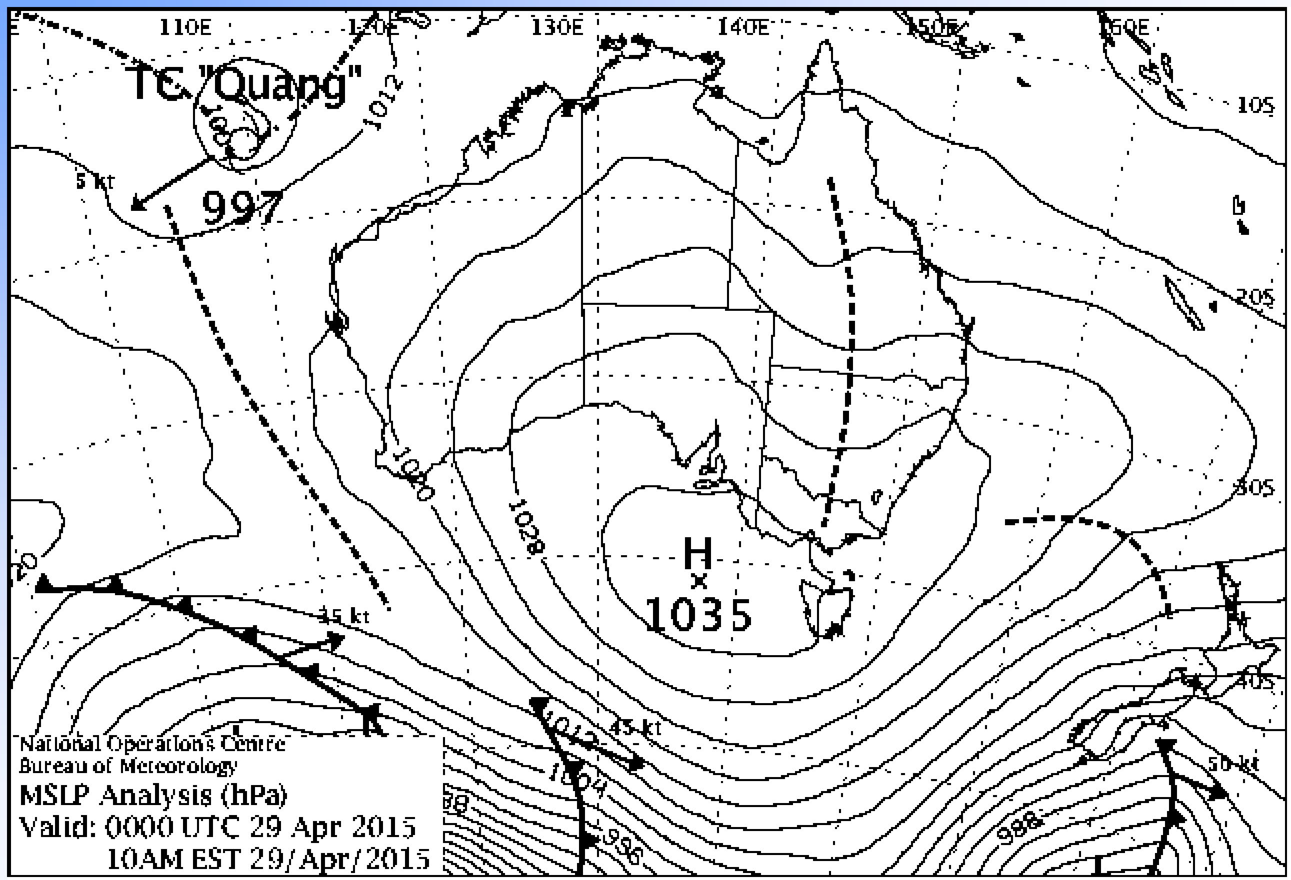
Fig.13 MSLP anomaly correlation coefficients for the Northern Hemisphere Annulus for the operational system (blue) and for the operational test system for 4 – 26 March 2016.



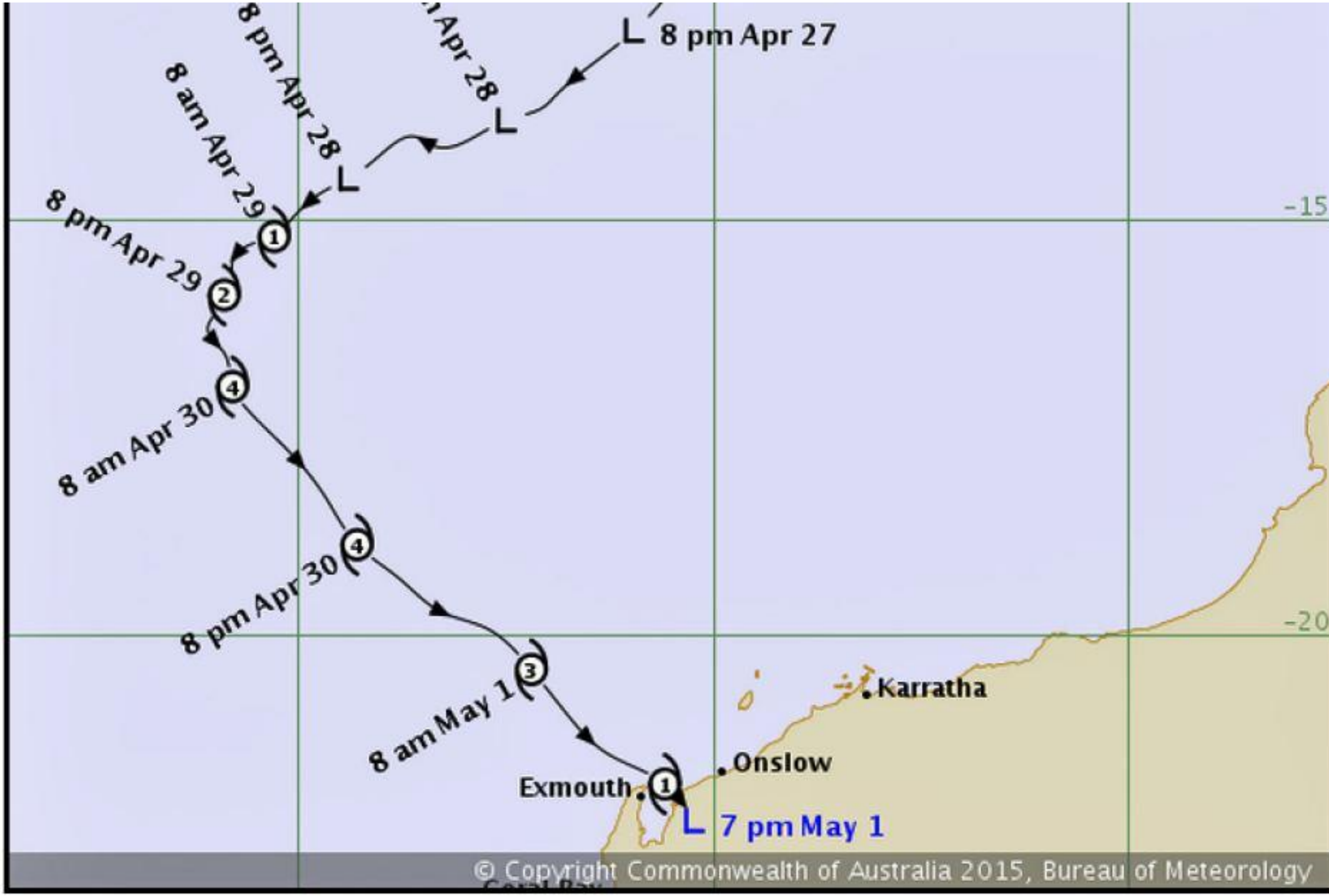
Tropical Cyclone Quang

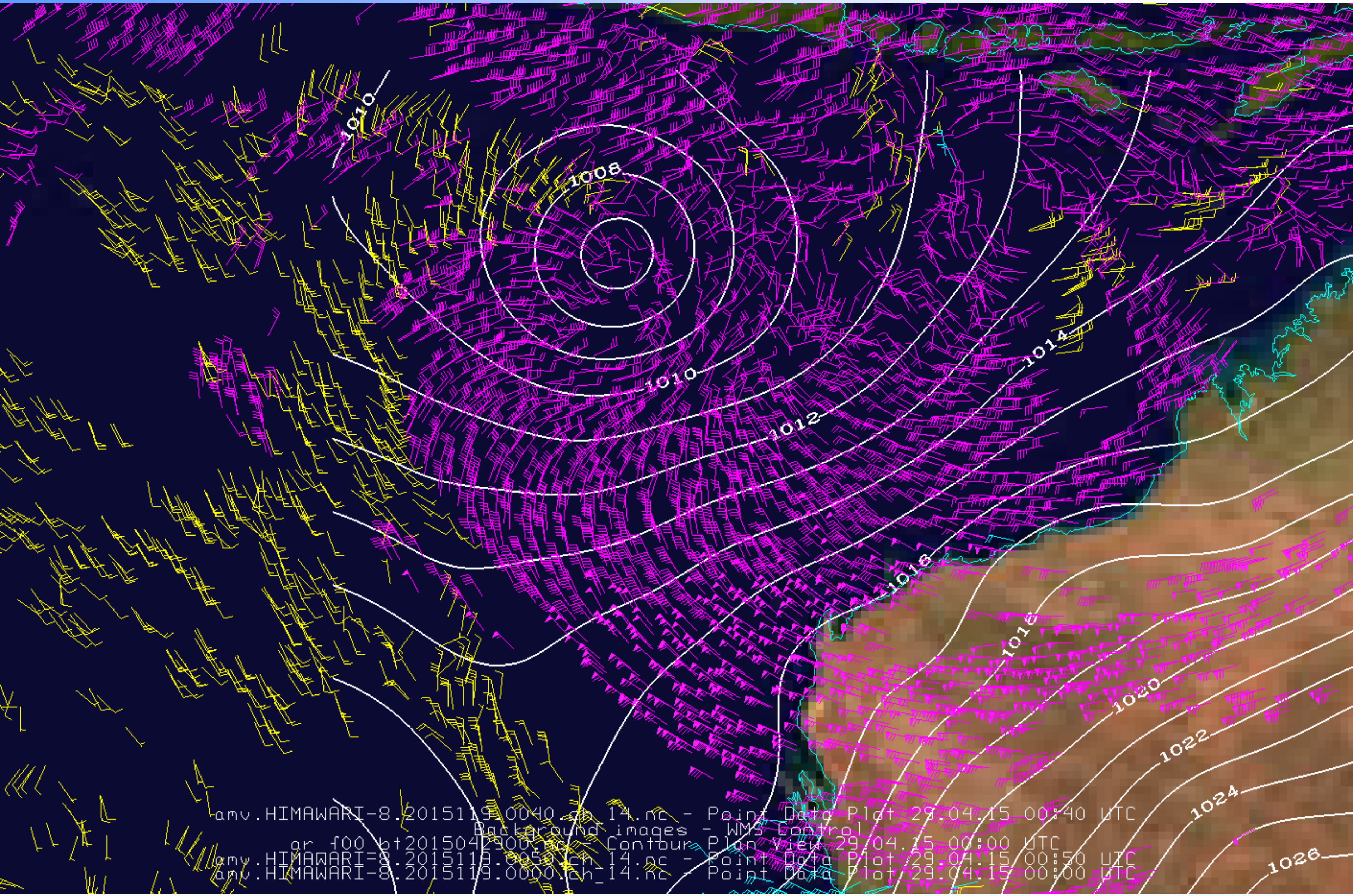
Visible image on April 29 at 06:35 UTC (2:35 a.m. EDT) from the MODIS instrument on NASA's Aqua satellite of Tropical Cyclone Quang in the Southern Indian Ocean.

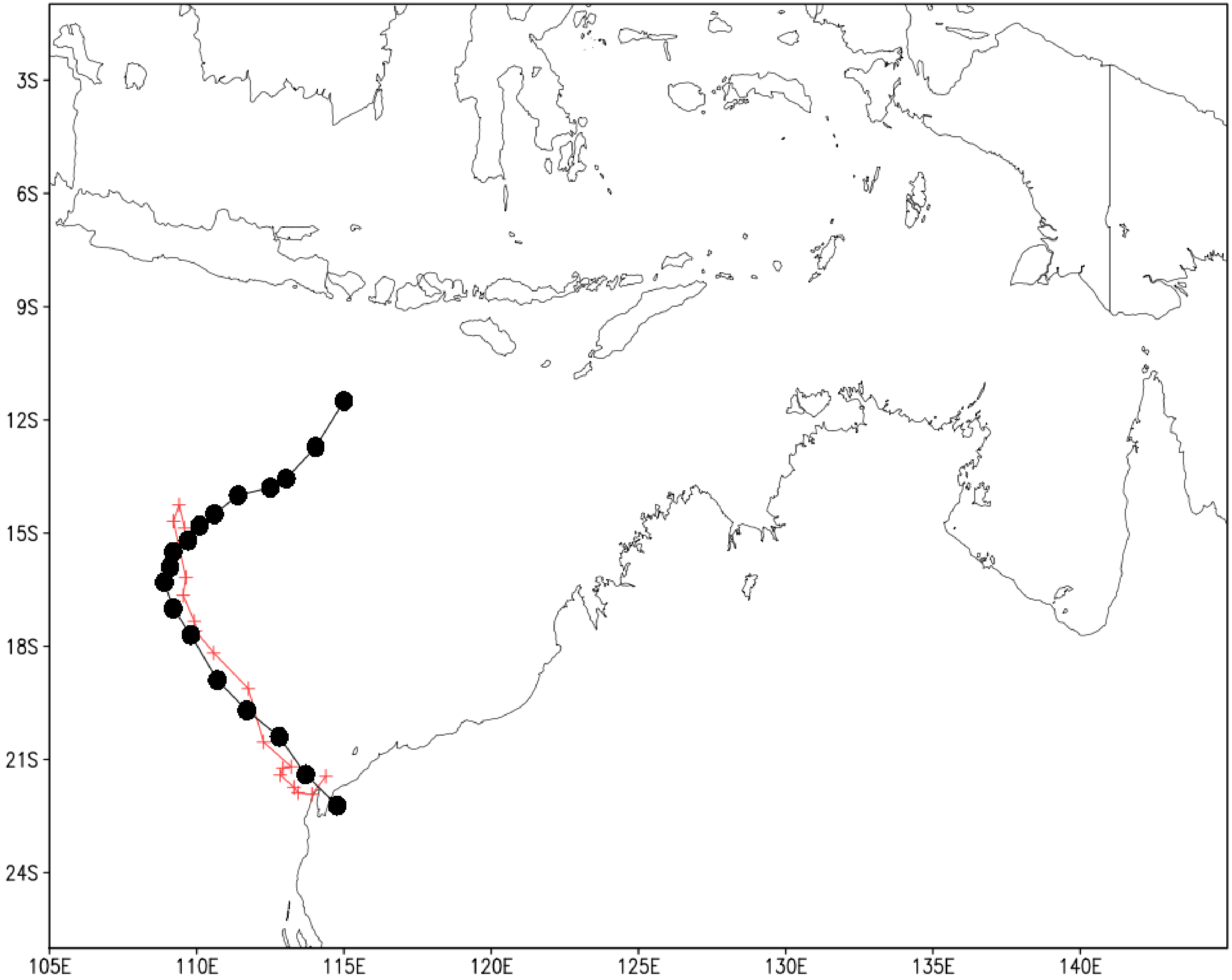
Credit: NASA Goddard MODIS



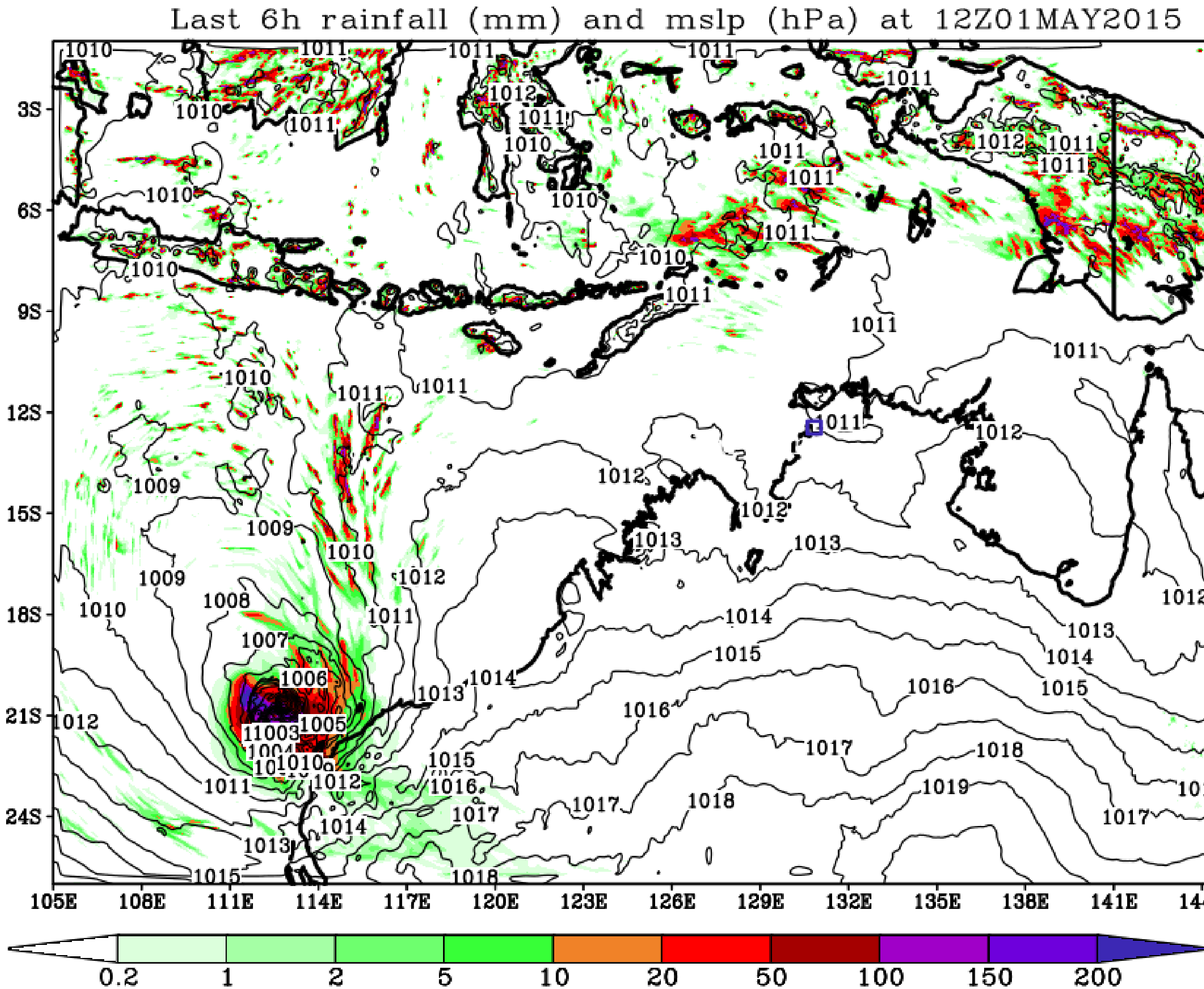
110E
120E
130E
140E
150E
160E
10S
20S
30S
40S
TC "Quang"
997
5 kt
1012
1020
1028
H
1035
35 kt
45 kt
1012
1004
996
988
50 kt
National Operations Centre
Bureau of Meteorology
MSLP Analysis (hPa)
Valid: 0000 UTC 29 Apr 2015
10AM EST 29/Apr/2015


8 pm Apr 27
Apr 28
8 pm Apr 28
8 am Apr 29
8 pm Apr 29
8 am Apr 30
8 pm Apr 30
8 am May 1
7 pm May 1
-15
-20
Karratha
Onslow
Exmouth
© Copyright Commonwealth of Australia 2015, Bureau of Meteorology


1010
1008
1010
1012
1014
1016
1018
1020
1022
1024
1026
amv.HIMAWARI-8.2015119.0040.ch_14.nc - Point Data Plot 29.04.15 00:40 UTC
Background images - WMS Control
gr f00 bt2015042900.nc - Contour Plan View 29.04.15 00:00 UTC
amv.HIMAWARI-8.2015119.0050.ch_14.nc - Point Data Plot 29.04.15 00:50 UTC
amv.HIMAWARI-8.2015119.0000.ch_14.nc - Point Data Plot 29.04.15 00:00 UTC



3S
6S
9S
12S
15S
18S
21S
24S
105E
110E
115E
120E
125E
130E
135E
140E


Last 6h rainfall (mm) and mslp (hPa) at 12Z01MAY2015

Summary and Conclusions

10-minute winds are being continuously generated and assimilated operationally in the Australian region with 4D Var – First country to do so.

H-8 10 minute DMVs provide an improved spatial and temporal resolution database for analysis and forecasting.

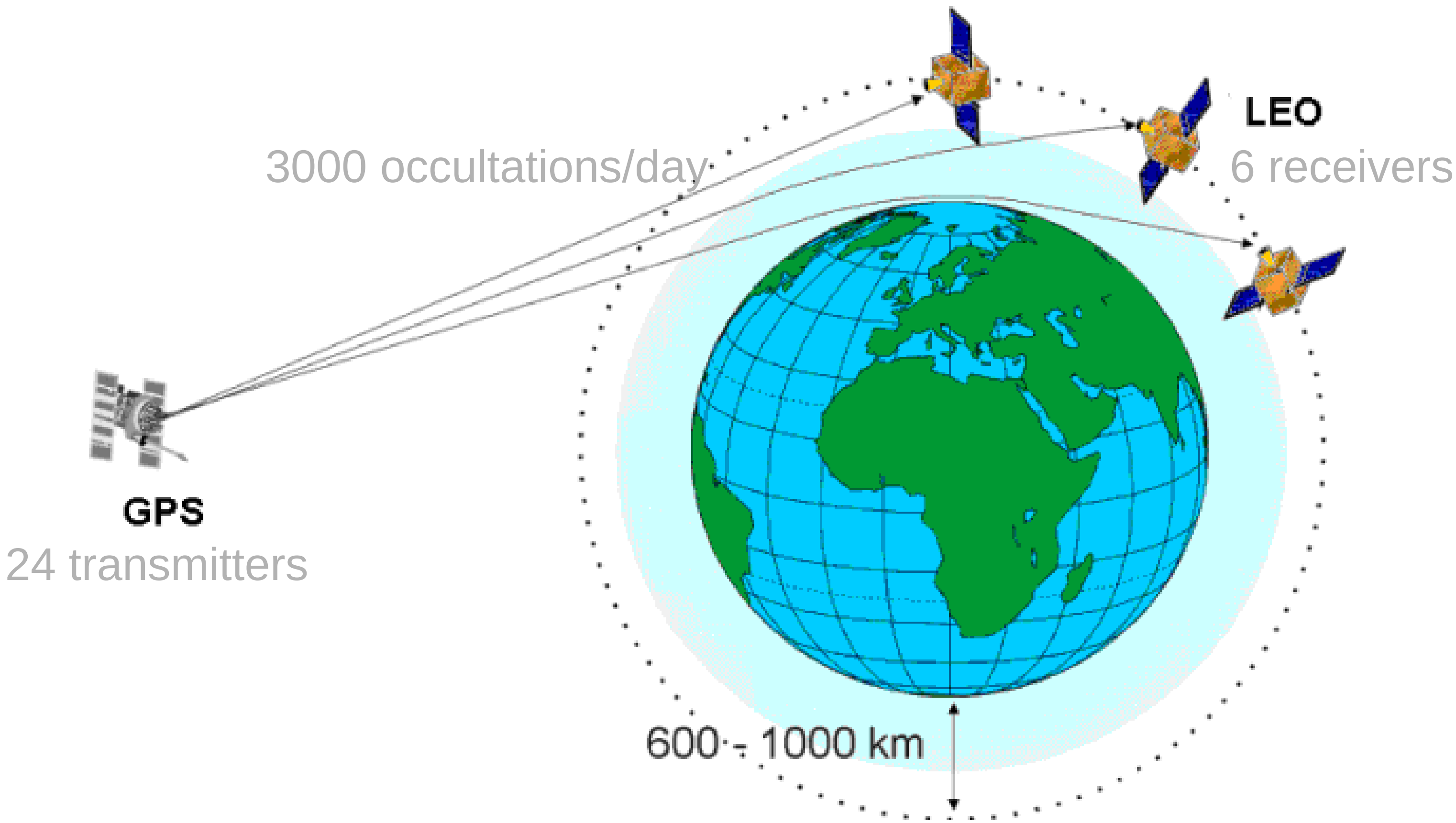
The quality of these higher spatial, temporal and spectral density data is of a level which renders them beneficial for NWP.

If the data is thinned to equal spatial density, *the quality of the H-8 data exceeds that of the operational H7 data*.

Data assimilation tests showed successful transfer of data into operations and successful use of the data by the NWP system.

Further quantification of the impact of these data in our current operational prediction system is underway. This involves use of all 10 minute data in the prediction of TC activity and severe weather.

GPS/COSMIC RADIO OCCULTATION



OPERATIONAL TRIAL

OPERATIONAL FORECAST SYSTEM ACCESS-G

1 November – 30 November 2010

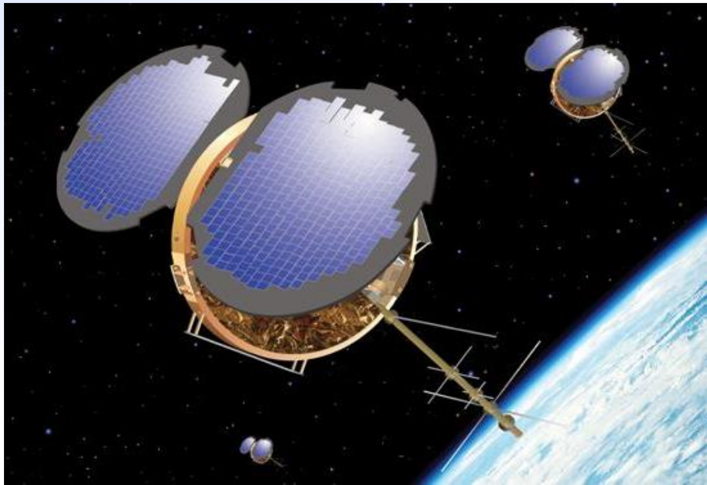
Used

■ Bending Angle data from

● the COSMIC Constellation

● GRACE and METOP

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



OPERATIONAL TRIAL - AUSTRALIAN REGION

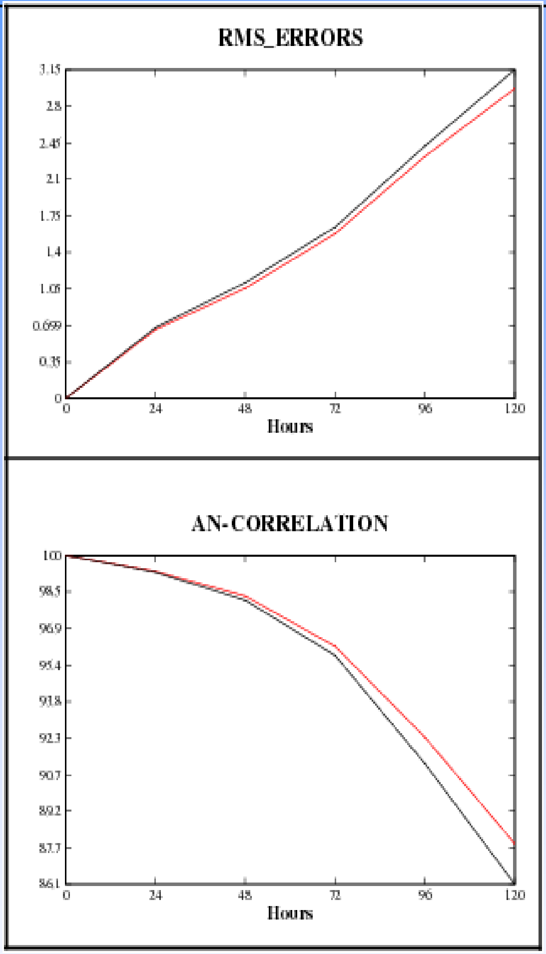


Figure 10(a). RMS Errors and anomaly correlations for ACCESS-G MSLP forecasts to five days, for the Australian region. Shown are results for Control (black), and with GPS RO data (red) for the period 1 November to 30 November 2010.

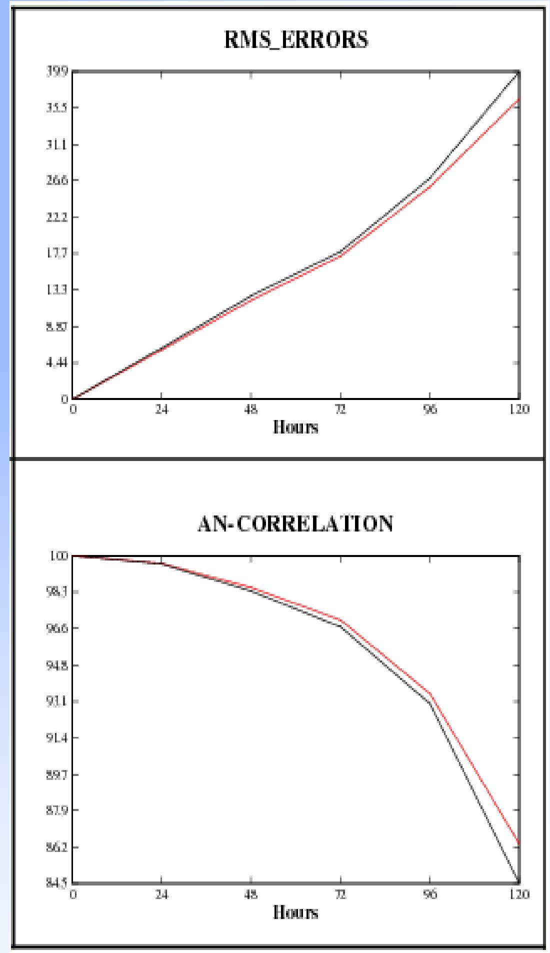


Figure 10(b). RMS errors and anomaly correlations for ACCESS-G 500hPa forecasts to five days, for the Australian region. Shown are results for Control (black) and with GPS RO data (red) for the period 1 November to 30 November 2010.

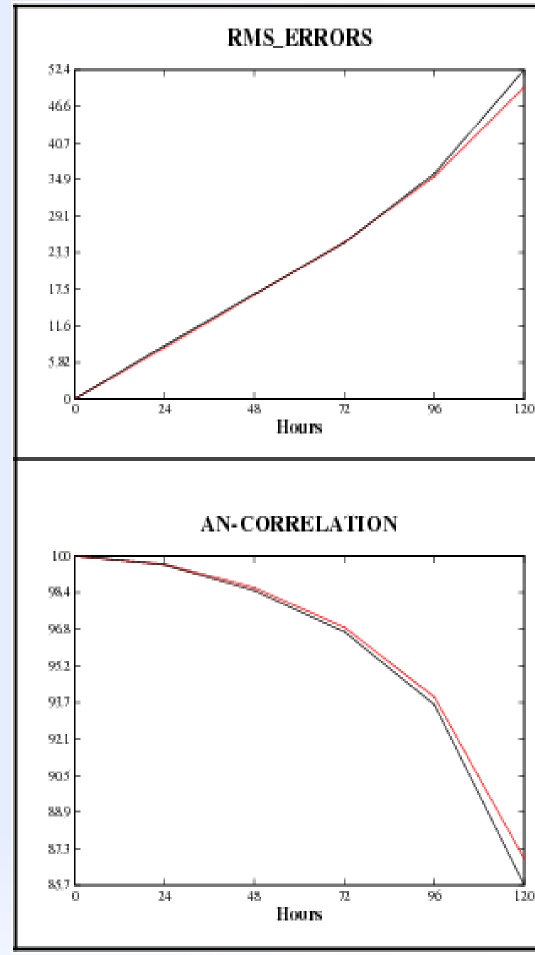


Figure 10(c). RMS errors and anomaly correlations for ACCESS-G 200hPa forecasts to five days, for the Australian region. Shown are results for Control (black) and with GPS RO data (red) for the period 1 November to 30 November 2010.

Le Marshall et al 2012

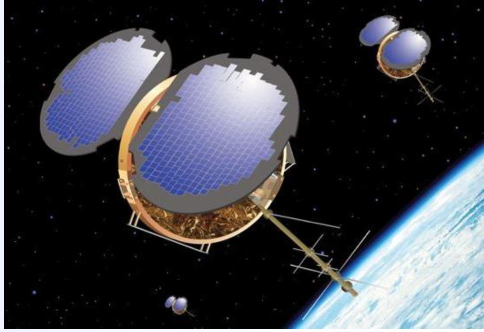
Currently

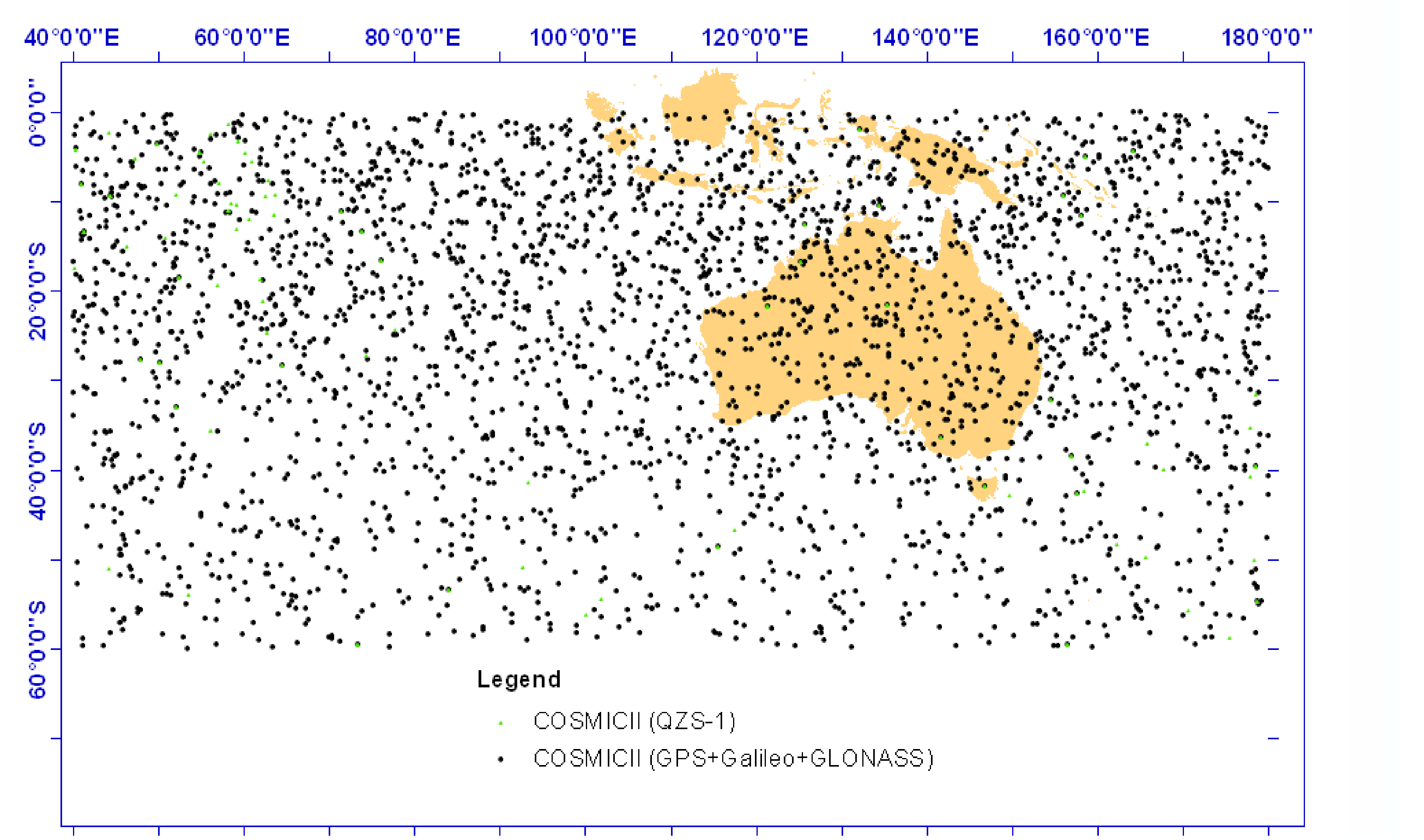
COSMIC 2 Ground Station

Command and acquisition groundstation for the new COSMIC-2 Constellation

The Future

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

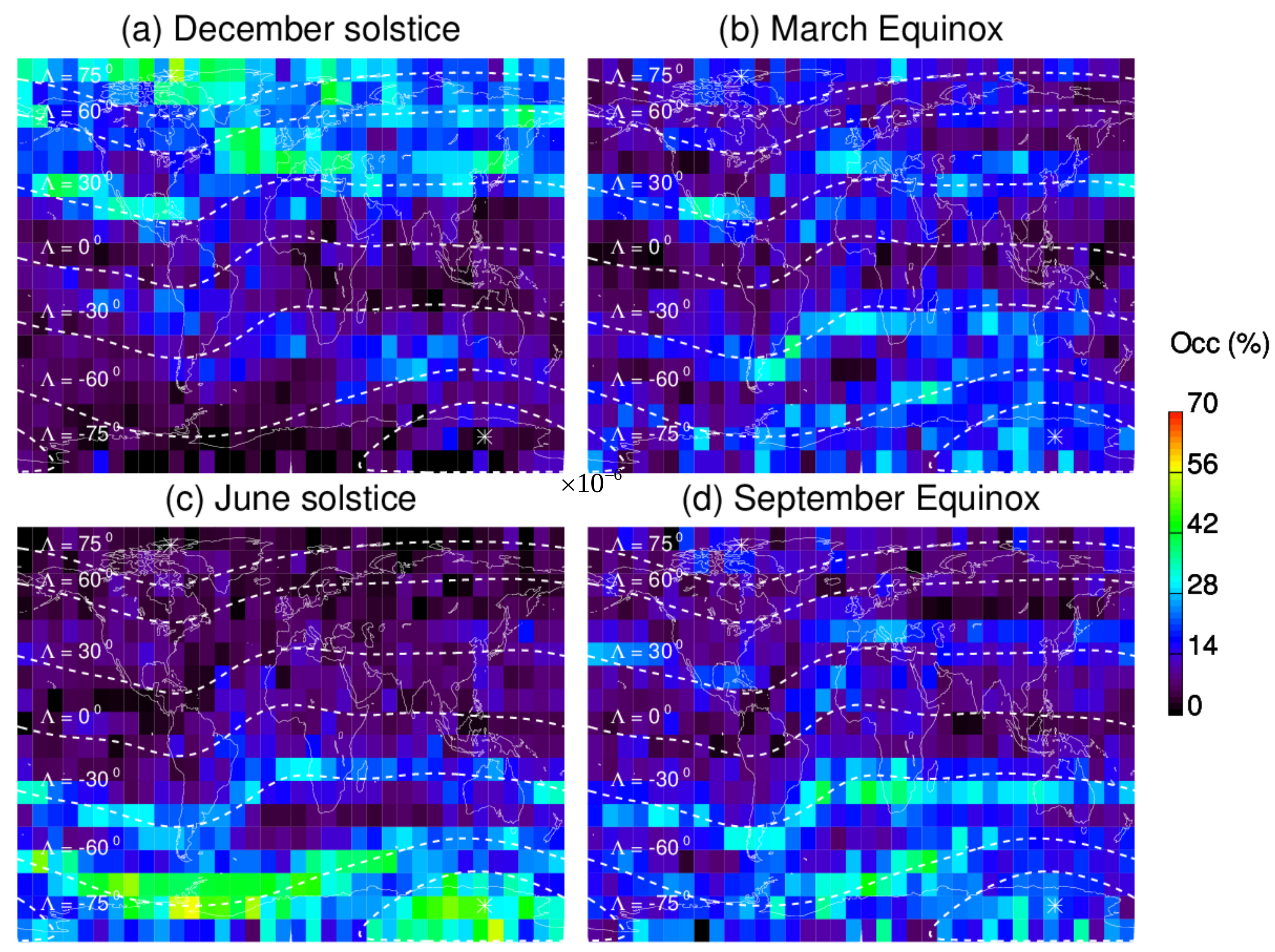




Anomalous GNSS Radio Occultation data

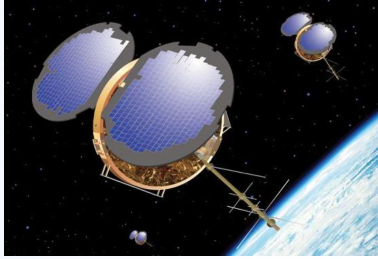
R. Norman, B. Carter, S. Healy, I.D. Culverwell, A. von Engeln, J, Le Marshall,J.P. Younger, A. Cate, K. Zhang………*

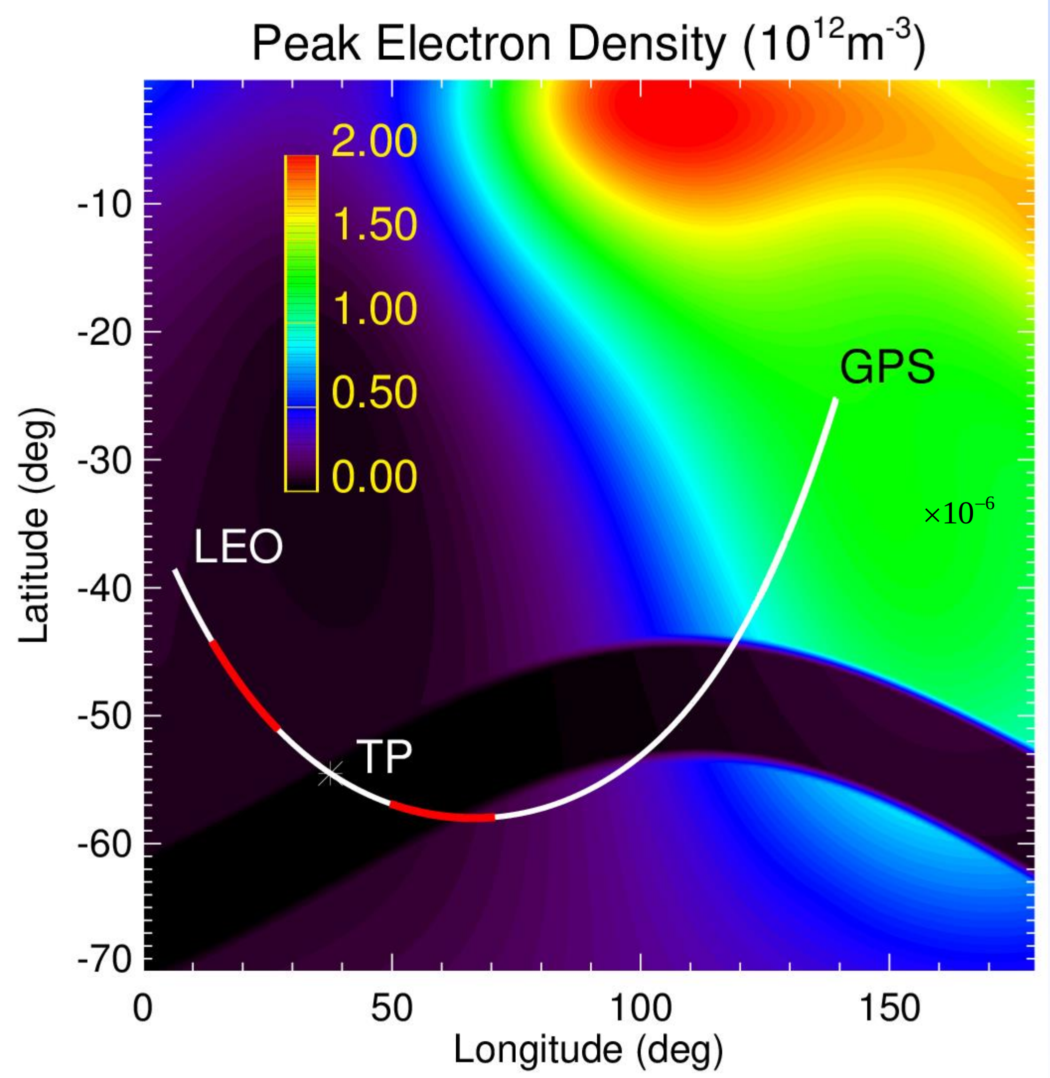
Anomalous RO results



The Occurances of Anomalous GPSRO events [α(L1) > α(L2)] in 2011

NmF2 from the IRI model





GPS satellite is located at:
25.26º S, 139.27º E, 20200 km

LEO satellite is located at:
38.58º S, 6.30º E, 800 km

Distance from the GPS to LEO satellite is 28975.2684 km.

For day 180, 2011. The local time at the GPS location is 11:00 am.

Anomalous BA

Table 1:
Azimuth angle of Straight-line path is 3.65 radians

	Elevation angle [deg]	Azimuth angle [deg]	Perigee height [km]
Straight-line	-76.017478	209.129595	50.000119
L1	-76.017365	209.129423	50.062996
L2	-76.017398	209.129312	50.056712

.

	Difference in Transmitted angle [rad]	Difference in Received angle [rad]	Bending angle [rad]
L1	2.11×10^{-6}	2.08×10^{-5}	2.286×10^{-5}
L2	1.83×10^{-6}	1.95×10^{-5}	2.113×10^{-5}

Table 2: $\alpha(L1) > \alpha(L2)$

$\alpha(L1) - \alpha(L2) = 1.72 \times 10^{-6}$ rad

$\alpha(\text{neutral}) = 2.6 \times 10^{-5}$ rad

$\alpha(\text{neutral}) > \alpha(L1) > \alpha(L2)$

Table 3:
Location and perigee height of the ray paths

	Latitude North [deg]	Longitude East [deg]	Perigee height [km]
Straight-line	-54.51794	37.64328	50.000119
L1	-54.51803	37.64322	50.062996
L2	-54.51809	37.64319	50.056712

For the extraordinary mode: $\alpha(L1) - \alpha(L2) = 1.2 \times 10^{-6}$ rad

Summary

Identified:

- Ionospheric features producing the increased anomalous RO occurrences

- The mechanisms causing the anomalous RO occurrences

Provided a RT simulation showing the anomalous results.

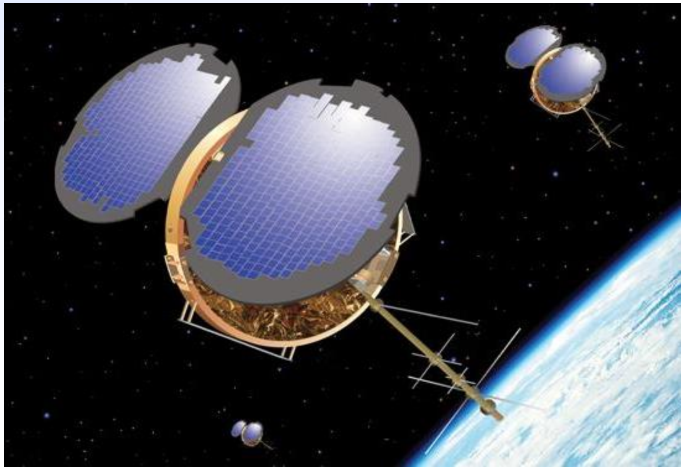
Tropospheric Moisture

Improve Tropospheric Moisture through

Assimilating satellite to ground GNSS/ZTD data

Assimilating Hyperspectral Infrared Water Vapor Channels

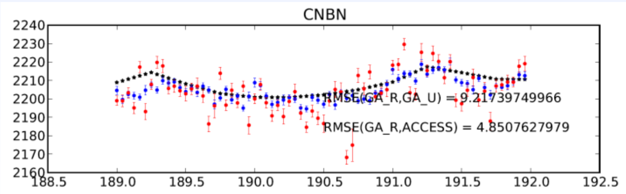
Improved surface characterization

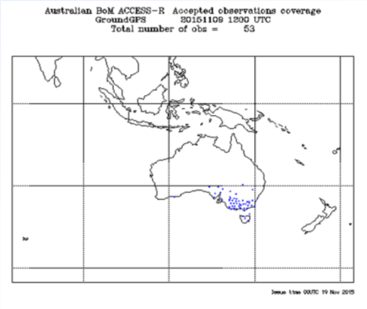


GNSS/ZTD Application

- ## The GNSS/ZTD Application project
- Partnerships Bureau of Meteorology, RMIT University, Geoscience Australia,
  - Commonwealth Attorney-General's Department Department of Environment and Primary Industries (DEPI), Univ of Melbourne, CRC-SI, UKMO

- Aims/objectives
  - Develop a GPS-based WV estimation <u>system to improve moisture measurement</u> and to reduce the risks/impact of natural weather disaster events
  - Assimilation of ZTD data in the Australian Community Climate and Earth-System Simulator (ACCESS) model.
  - Assimilation Studies Underway





Summary

- 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 now being used in the BoMs operational forecast system
- The data are important for climate quality analysis/monitoring
- The BoM is providing a command and acquisition Ground-station for the new COSMIC-2 Constellation
- Use of GNSS data by the BoM through a partnership with RMIT, Geoscience Australia, …. is providing important moisture observations for use by the ACCESS forecast suite.
- Opportunity – Development of small satellites with GPS reception capability may represent an opportunity to contribute to education and training locally and to the international observing system

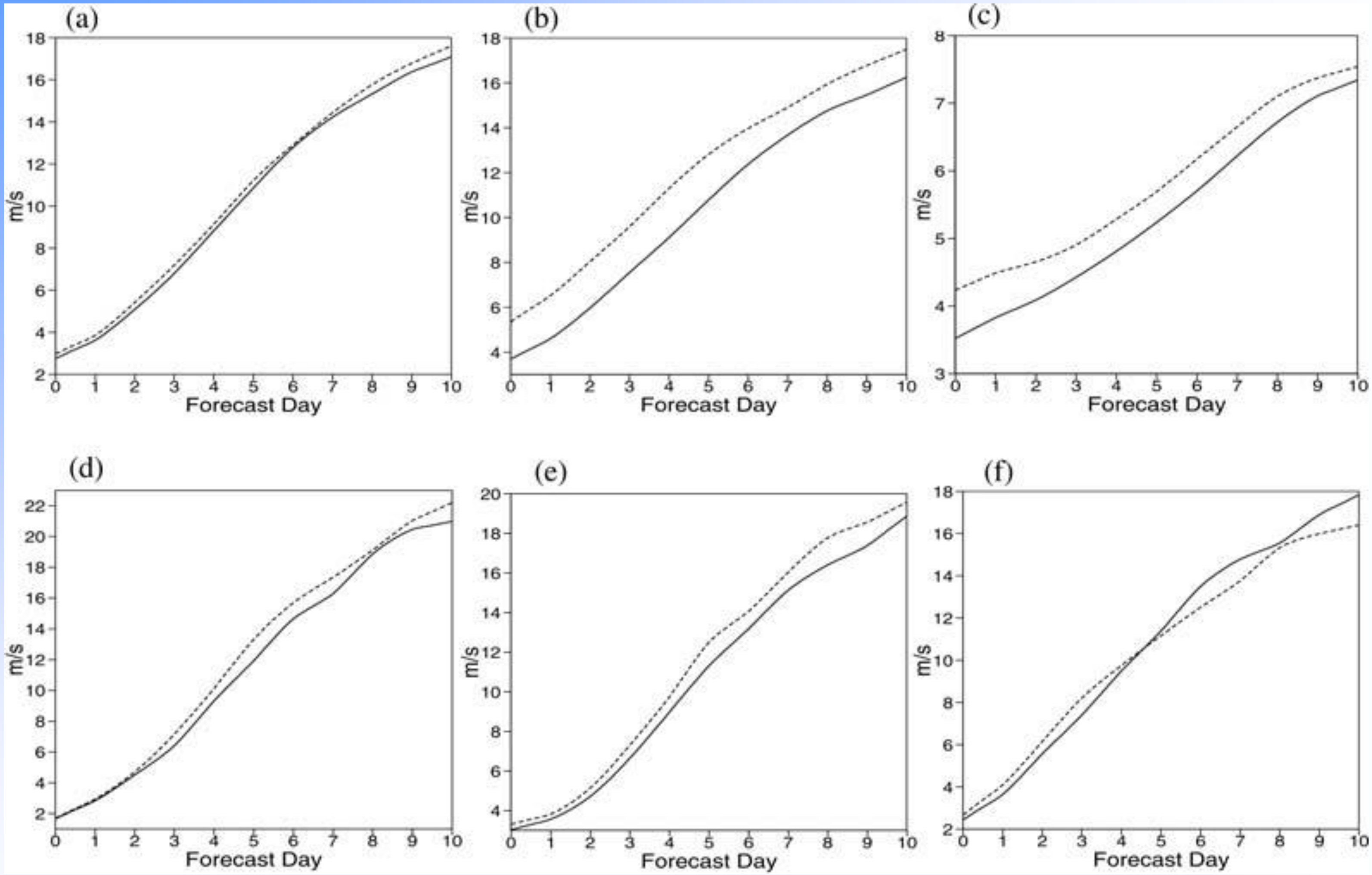
ADM (Atmospheric Dynamics Mission) - Aeolus

Satellite built by the ESA that is due for launch in 2017.

ADM-Aeolus Doppler wind lidar Observing System Simulation Experiment
By A. STOFFELEN1∗, G. J. MARSEILLE1, F. BOUTTIER2, D. VASILJEVIC3, S. de HAAN1 and C. CARDINALI3

Q. J. R. Meteorol. Soc. (2006), **132**, pp. 1927–1947

DOPPLER WIND LIDAR OSSE



Forecast skill, as represented by the wind vector RMSE (m s−1) at 500 hPa of the forecast fields for the NoDWL (dashed) and DWL (solid) experiments (both with respect to the nature run), as a function of forecast range and for six regions: (a) the northern hemisphere, (b) the southern hemisphere, (c) the tropics, (d) Europe, (e) the North Atlantic and (f) North America. Forecasts are initialized with analyses at 12 UTC each day in the period 6 to 20 February 1993. The mean is taken over all 15 cases.

Future Prospects

Environmental analysis /prediction using current and future satellite systems have been examined.

The great benefits from recent advances using current Earth Observations from Space have been documented.

The potential for greatly increased benefit from current and future satellite and assimilation systems has been noted and some of the planning related to gaining these benefits summarised.

Increasing benefits will continue to accrue from current and next generation advanced instruments, which represent an investment of billions of dollars by the international community. (eg.CrIS, ATMS, VIIRS,ABI,AHI, ADM, …ASCENDS….). This will need some local co-investment in infrastructure, research and trained staff.

Opportunity – Development of small satellites with GPS reception capability may represent an opportunity to contribute to education and training locally and vitally to the international observing system


Indian Ocean
Looking Down
Is
Looking Up
N
100 km
TC LAURENCE - Dec. 2009