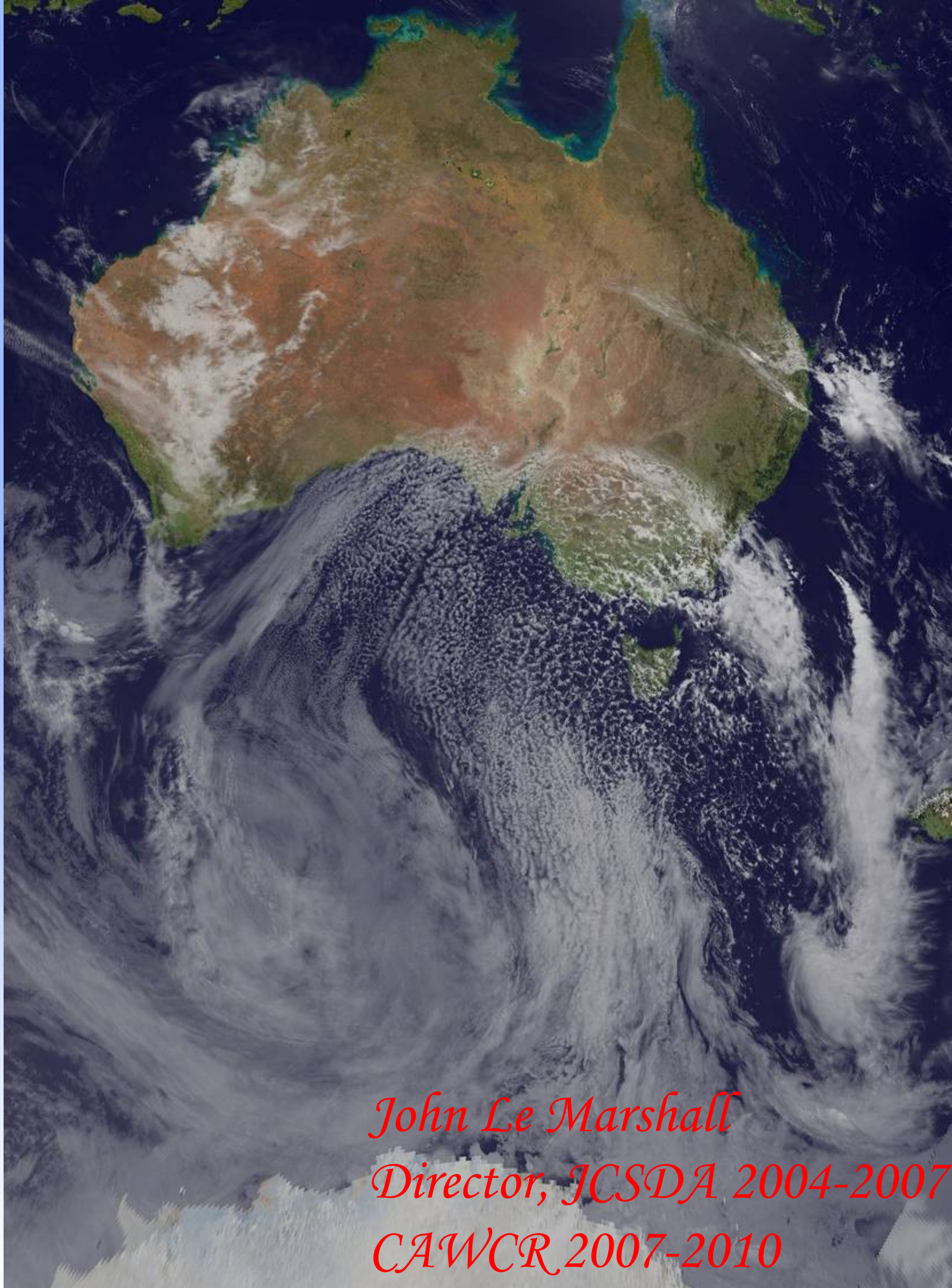
Australian Government
Bureau of Meteorology

OPRATIONAL GENERATION OF CONTINUOUS AMVS AND THEIR ASSIMILATION WITH 4DVAR



John Le Marshall
Director, JCSDA 2004-2007
CAWCR 2007-2010

Australian Government
Bureau of Meteorology

John Le Marshall[1,2], Rolf Seecamp[3], Yi Xiao[1], Jim Jung[4], Terry Skinner[5], Peter Steinle[1], Paul Gregory[1] , J. Lee[1] and Tan Le[1] ………..

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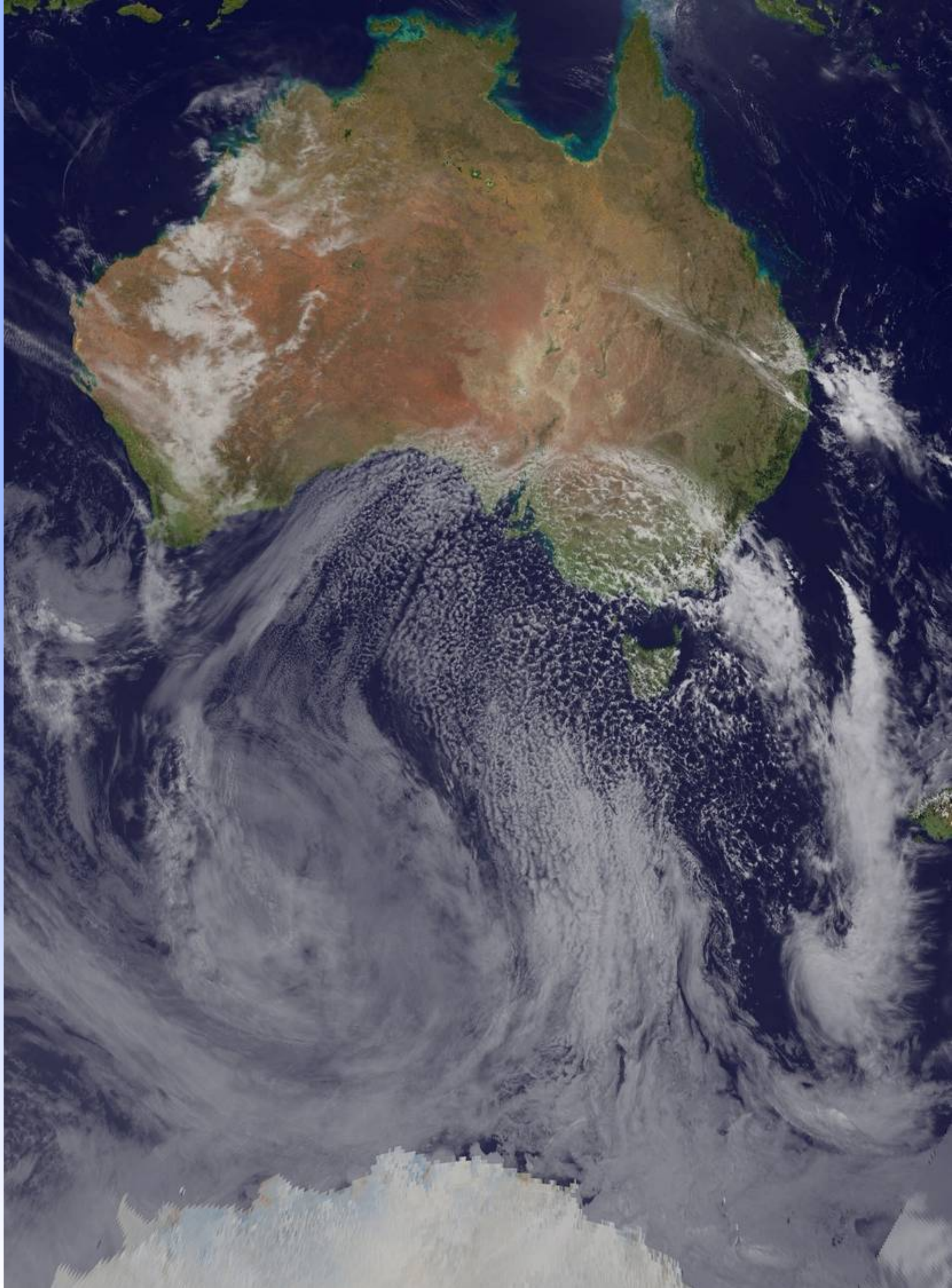


Overview

- Introduction
- The Importance of Satellite Data (in the SH)
- Operational MTSaT-1R & 2 AMV Generation at the BoM
- MTSaT-1R/2 AMV Accuracy and Error Characterization
- MTSaT-1R and 2 Data Impact Studies
- Plans/Future Prospects
- Summary

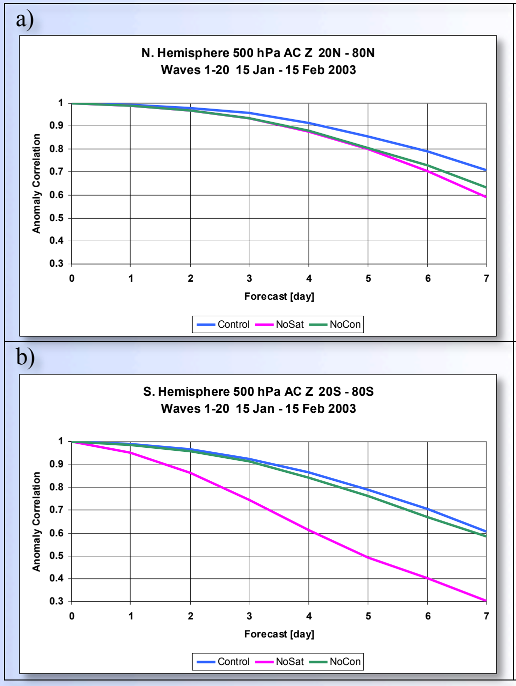
The Importance of of Earth Observations from Space

Earth Observations from Space double predictability in the SH

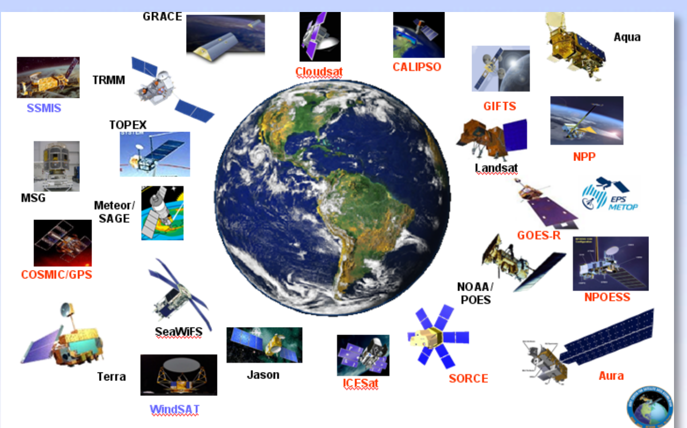
The incremental gain from introducing satellite data into an analysis in the SH is seven times that seen in the NH.

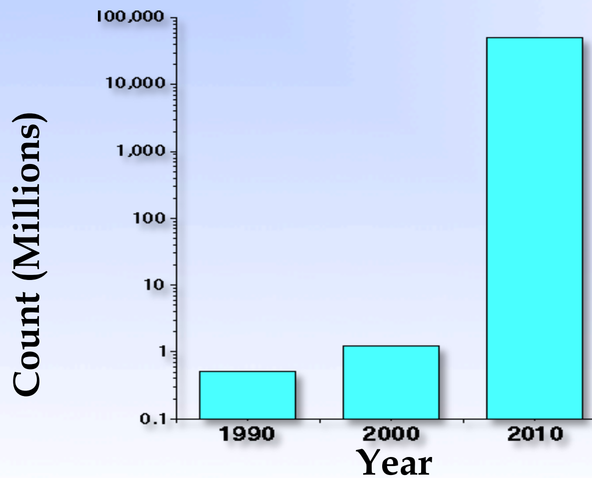
Earth Observations from Space are becoming increasingly important for monitoring climate

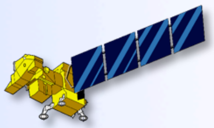
Anomaly correlation for 500 hPa Z for each Hemisphere. Control is blue, NoSat and NoCon are magenta and green, respectively.



The Challenge







Five order of Magnitude increase in satellite Date in 10 years

Data Assimilation/Observing System Experiments - Satellite and Conventional Data

- **Total Contribution**
  - All satellite data
  - All conventional observations
- **Sensor Contribution**
  - Advanced Microwave Sounding Unit (AMSU)
  - High Resolution Infrared Radometric Sounder (HIRS)
  - Geostationary Atmospheric Motion Vectors (AMVs)
  - QuikSCAT winds
  - Rawinsondes
- **Satellite Contribution**
  - NOAA-17
  - NOAA-16 and NOAA-17
  - NOAA-15, NOAA-16 and NOAA-17

OBSERVING SYSTEM EXPERIMENTS

OBSERVING SYSTEM EXPERIMENT
WITH
FOUR SATELLITE DATA TYPES
AND
RAWINSONDE DATA

T. Zapotocny, J. Jung. J. Le Marshall, R Treadon, ……

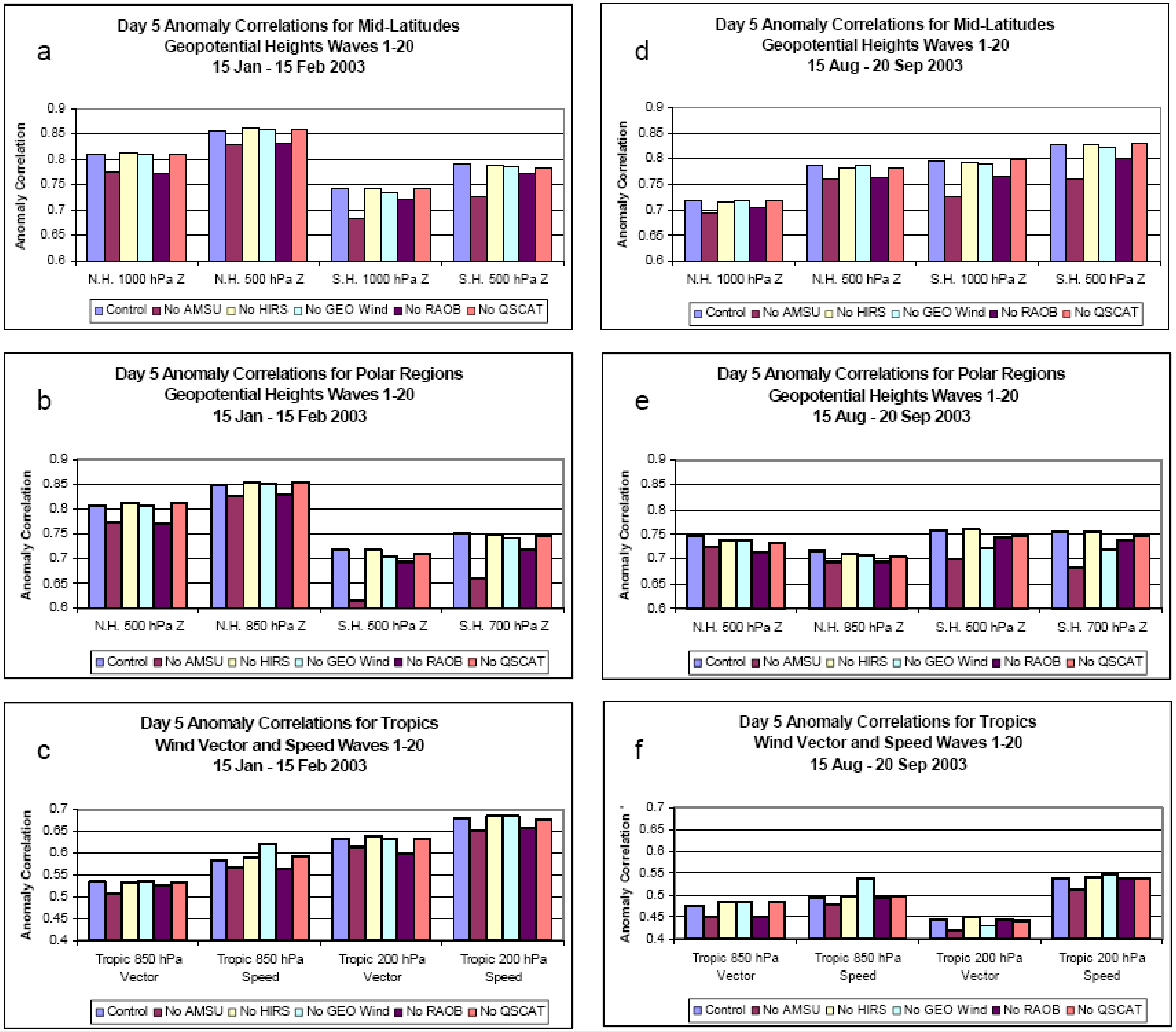


Fig. 8 The day 5 anomaly correlations for waves 1-20 for the (a and d) mid-latitudes, (b and e) polar regions and (c and f) tropics. Experiments shown for each term include, from left to right, the control simulation and denials of AMSU, HIRS, GEO winds, Rawinsondes and QuikSCAT. The 15 January to 15 February 2003 results are shown in the left column and the 15 August to 20 September results are shown in the right column. Note the different vertical scale in (c and f).

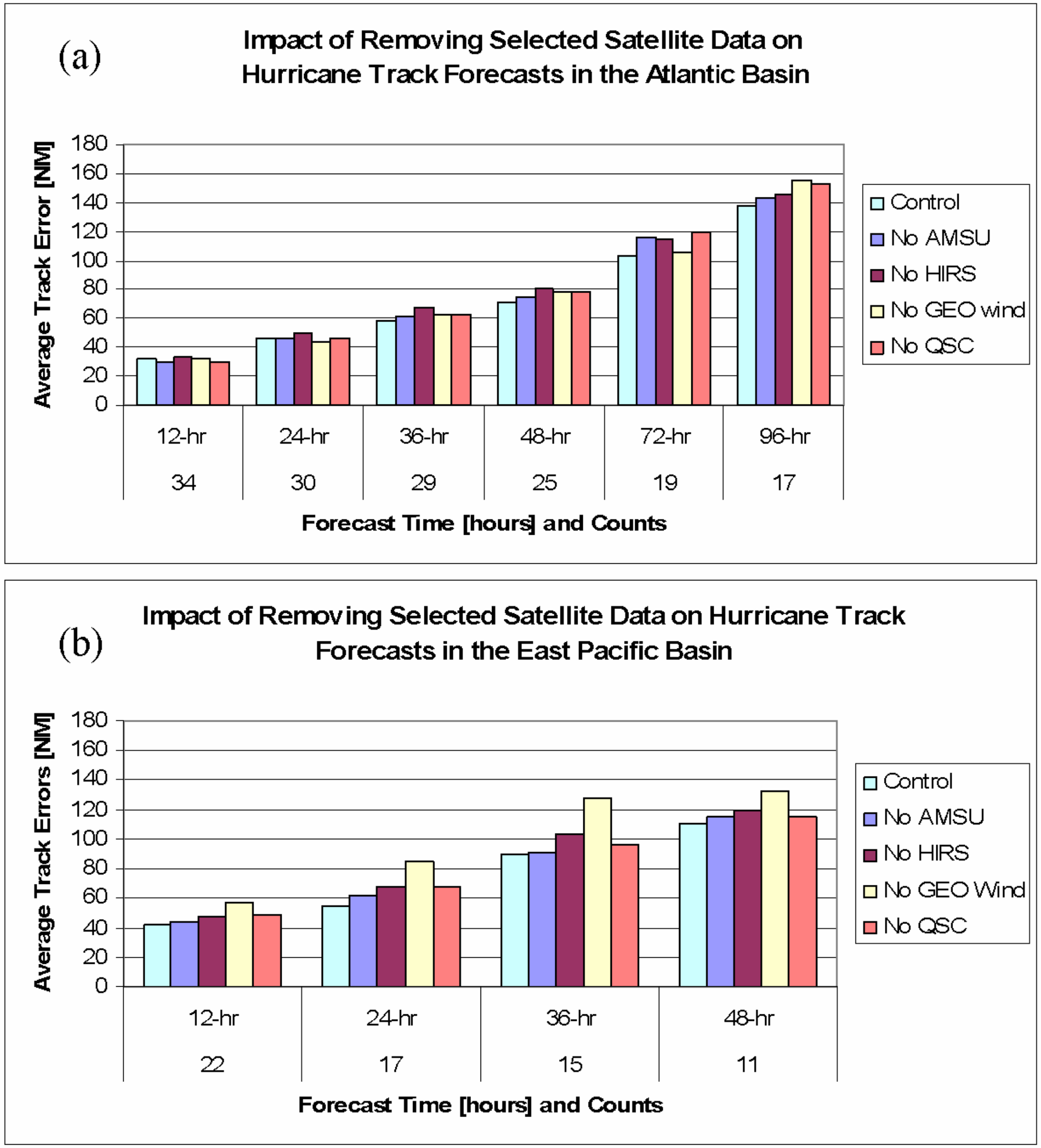
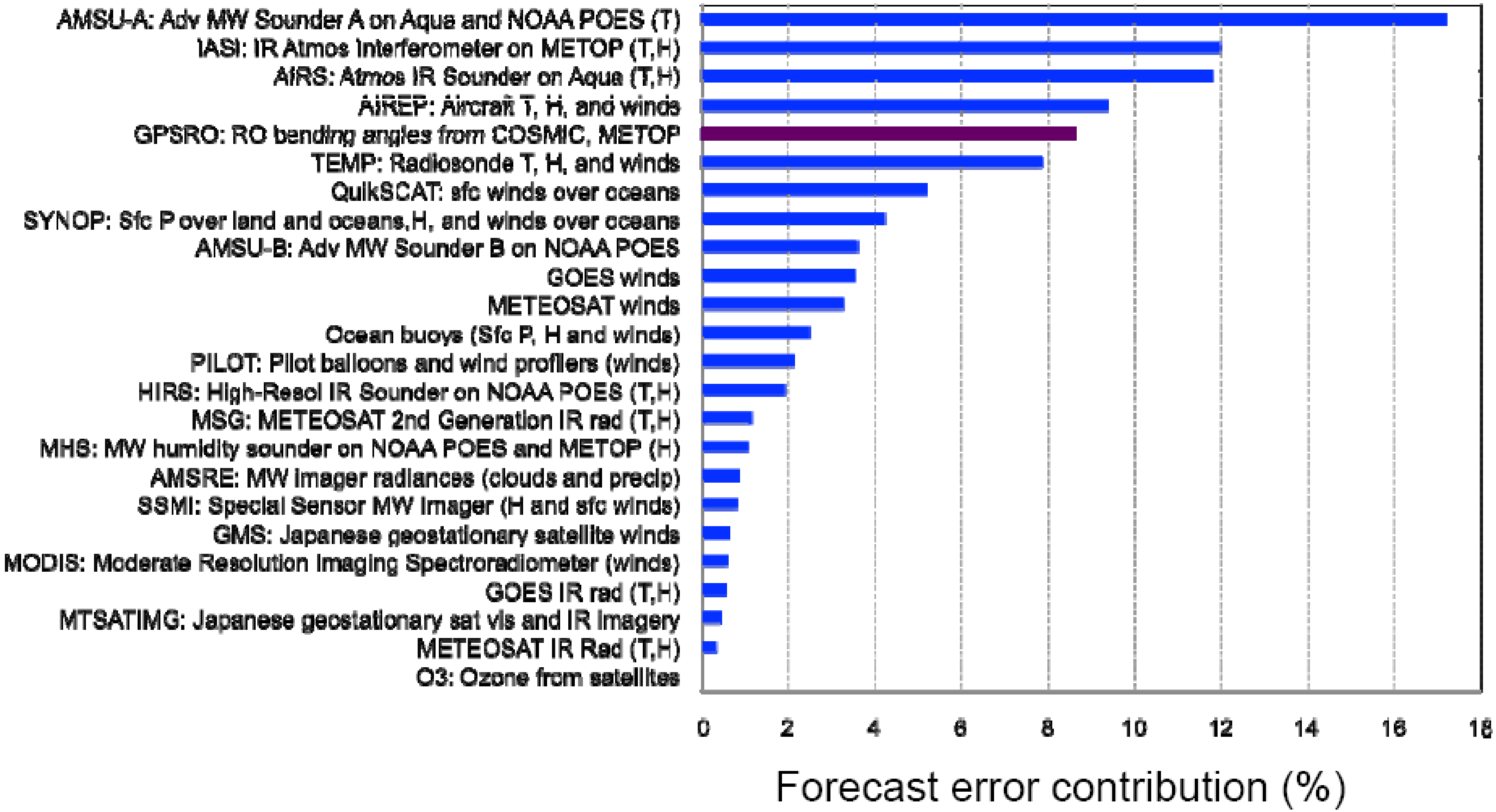


Fig. 10. Average track error (NM) by forecast hour for the control simulation and experiments where AMSU, HIRS, GEO winds and QuikSCAT were denied. The Atlantic Basin results are shown in (a), and the Eastern Pacific Basin results are shown in (b). A small sample size in the number of hurricanes precludes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

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

MTSaT-1R/2 Operational AMV Generation

Uses 3 images separated by 15, 30 or 60 min.

Uses H_20 intercept method for upper level AMVs (Schmetz et al., 1993/Le Marshall et al. 2011) or a Window Method.

Uses cloud base assignment for lower level AMVs (Le Marshall et al. 1997/Le Marshall et al. 2011) or a Window Method

Q.C. via EE, QI, ERR, RFF etc.

No autoedit Height assignment verification/ development uses Cloudsat/Calipso, RAOBS

Operational 15, 30 and 60 Minute MTSAT-1R/2 AMVs

Real time schedule for SH MTSat-1R Atmospheric Motion Vectors at the Bureau of Meteorology. Sub-satellite image resolution, frequency and time of wind extraction and separations of the image triplets used for wind generation (ΔT) are indicated.

Wind Type	Resolution	Frequency-Times (UTC)	Image Separation
Real Time IR/VIS*	4 km	6-hourly – 00, 06, 12, 18	15 minutes
Real Time IR/VIS* (hourly)	4 km	Hourly – 00, 01, 02, 03, 04, 05, . . . , 23	1 hour

*daytime

Part of the schedule for Southern Hemisphere wind generation from MTSAT-1R images. This part provides 26 Infrared Channel (IR1) based wind data sets, 24 High Resolution Visible (HRV) image and 4 Water Vapour (WV) image based data sets from the full disc and northern hemisphere images listed.

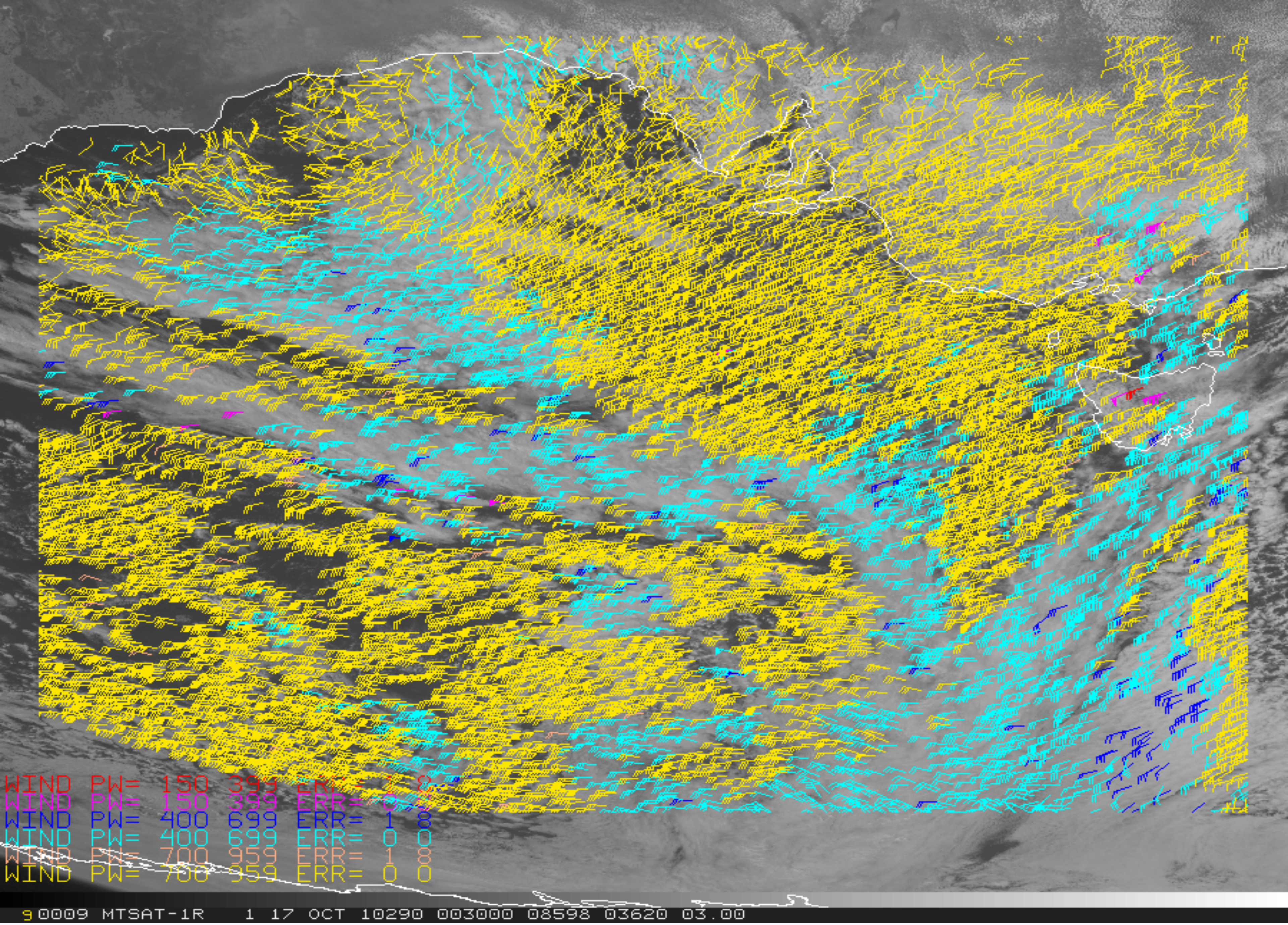
DATE	HHMM 1	HHMM 2	HHMM 3	IR1	HRV	WV
16 June 2008	2230	2330	0030			
16 June 2008	2330	2357	0013			
16 June 2008	2357	0013	0030			
17 June 2008	0030	0130	0230			
17 June 2008	0130	0230	0330			
17 June 2008	0230	0330	0430			
17 June 2008	0330	0430	0530			
17 June 2008	0430	0530	0630			
17 June 2008	0530	0557	0613			
17 June 2008	0557	0613	0630			
17 June 2008	0630	0730	0830			
17 June 2008	0730	0830	0930			
17 June 2008	0830	0930	1030			

Full Disc Image
Southern Hemisphere Image

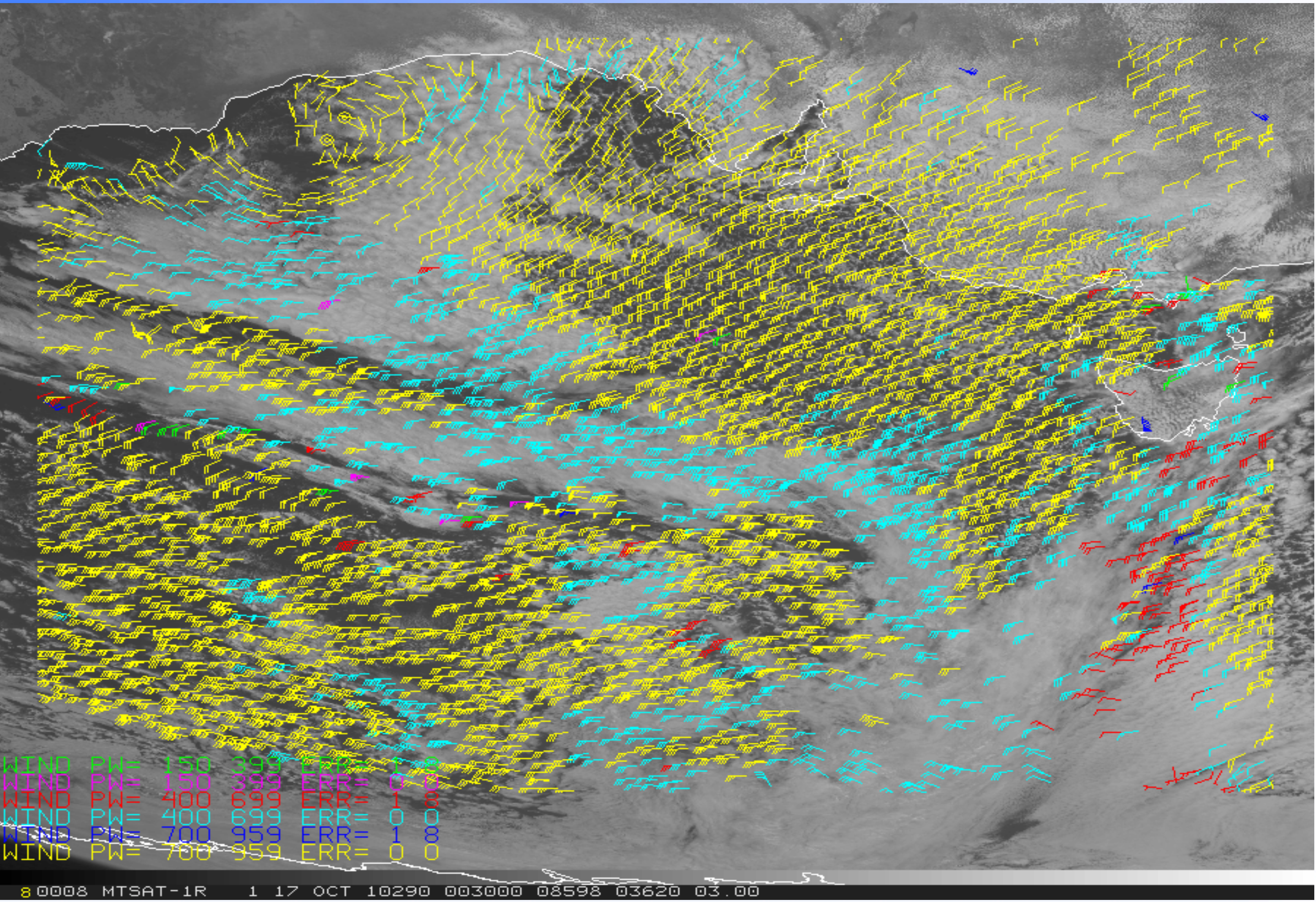
Part of the schedule for Northern Hemisphere wind generation from MTSAT-1R images. This part provides 24 Infrared Channel (IR1) based wind data sets, 22 High Resolution Visible (HRV) image and 4 Water Vapour (WV) image based data sets from the full disc and northern hemisphere images listed.

DATE	HHMM 1	HHMM 2	HHMM 3	IR1	HRV	WV
16 June 2008	2230	2330	0030			
16 June 2008	2257	2313	2330			
17 June 2008	0030	0057	0130			
17 June 2008	0130	0157	0230			
17 June 2008	0230	0257	0330			
17 June 2008	0330	0357	0430			
17 June 2008	0430	0457	0530			
17 June 2008	0430	0530	0630			
17 June 2008	0457	0513	0530			
17 June 2008	0630	0657	0730			
17 June 2008	0730	0757	0830			
17 June 2008	0830	0857	0930			

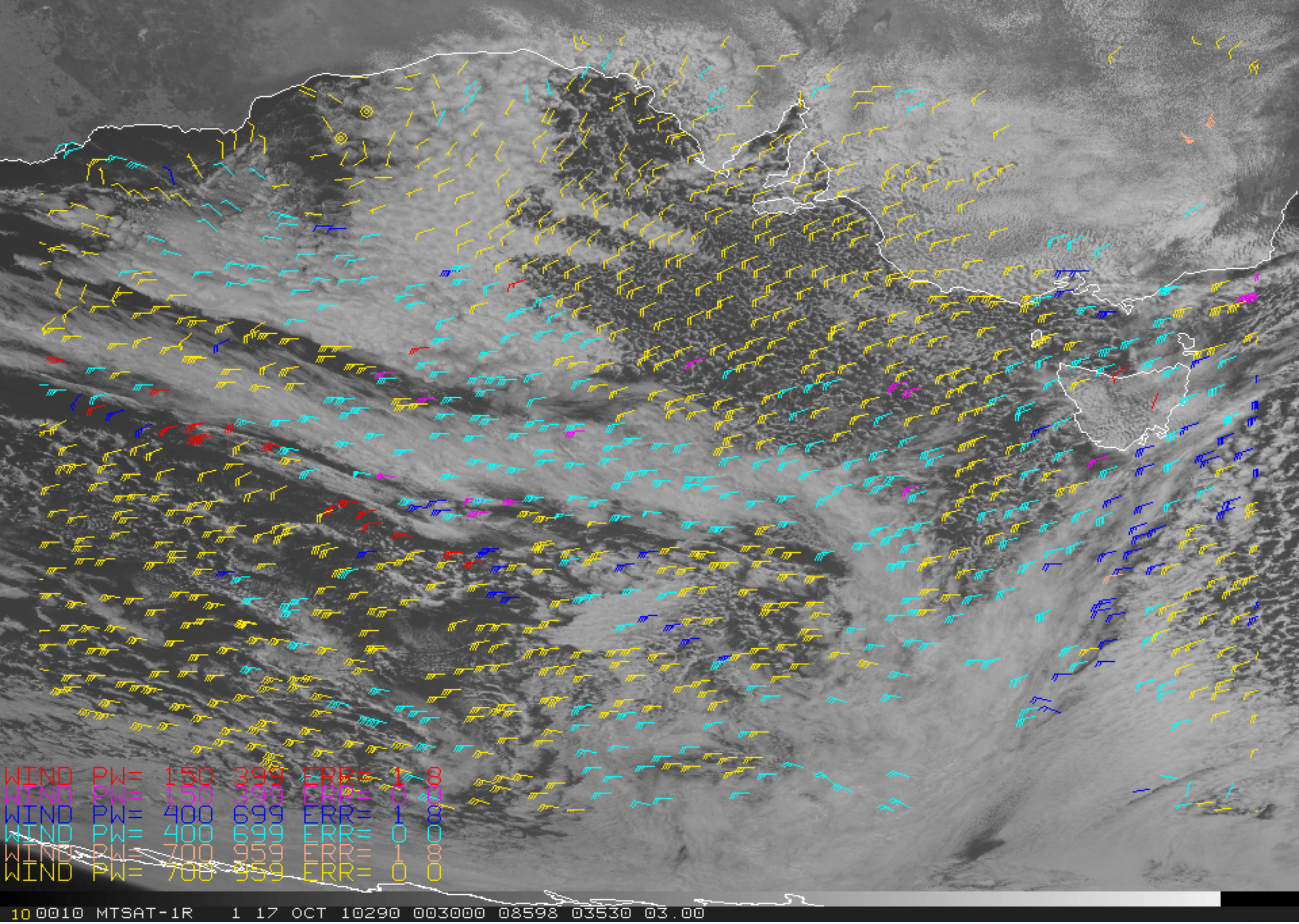
Full Disc Image
Northern Hemisphere Image



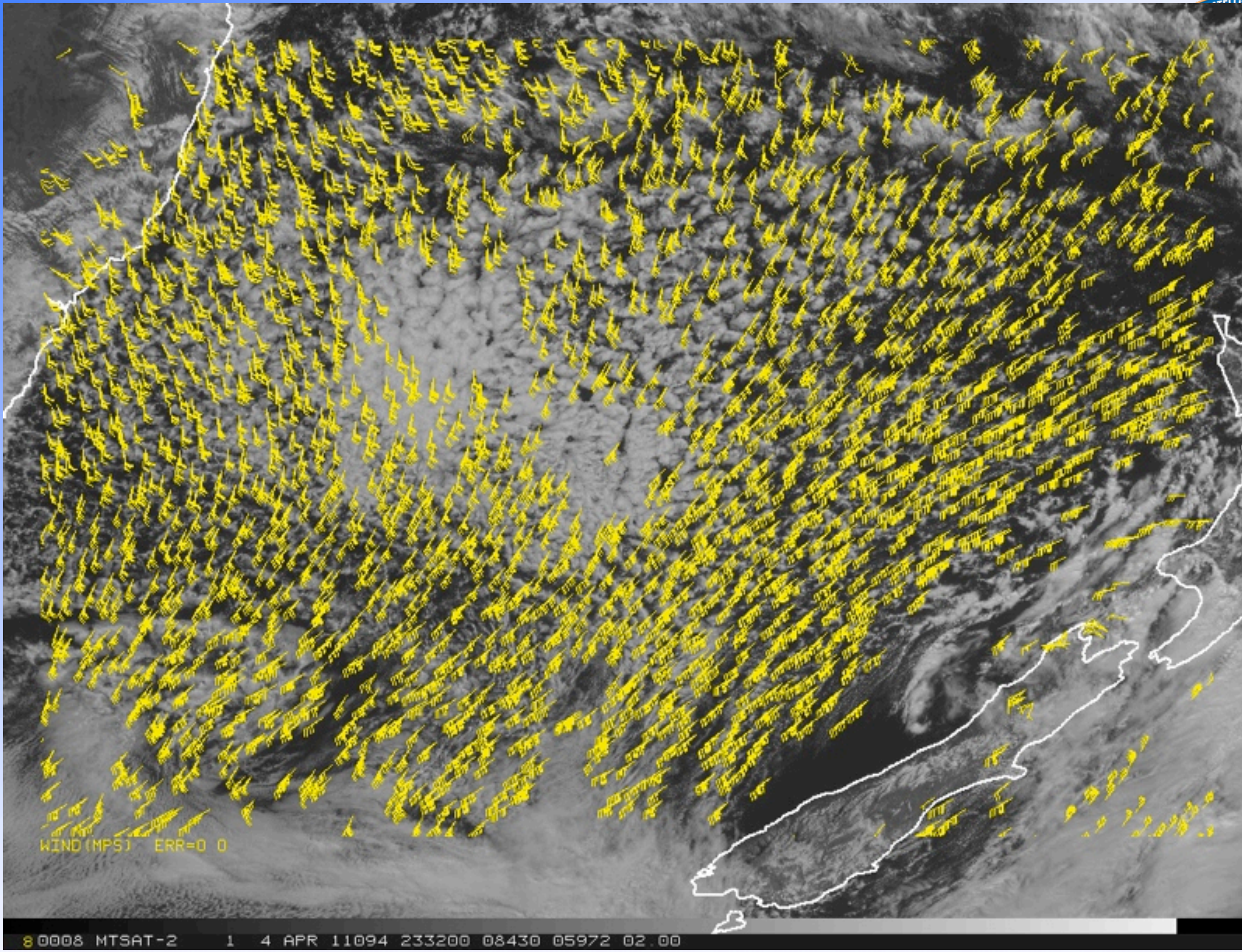
MTSat-1R VIS AMVs generated around 00 UTC on 17 October 2010.



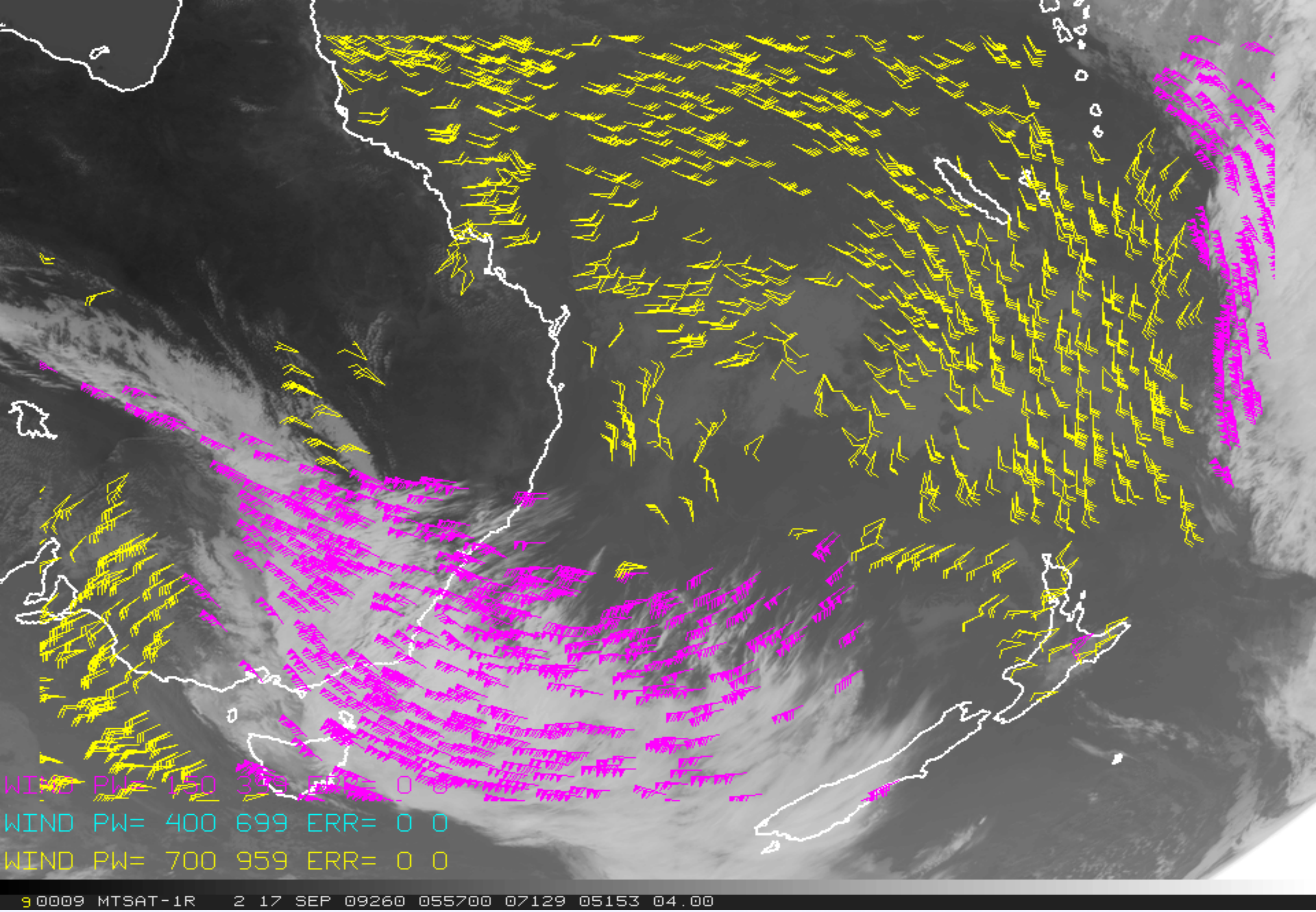
MTSat-1R VIS AMVs generated around 00 UTC on 17 October 2010.



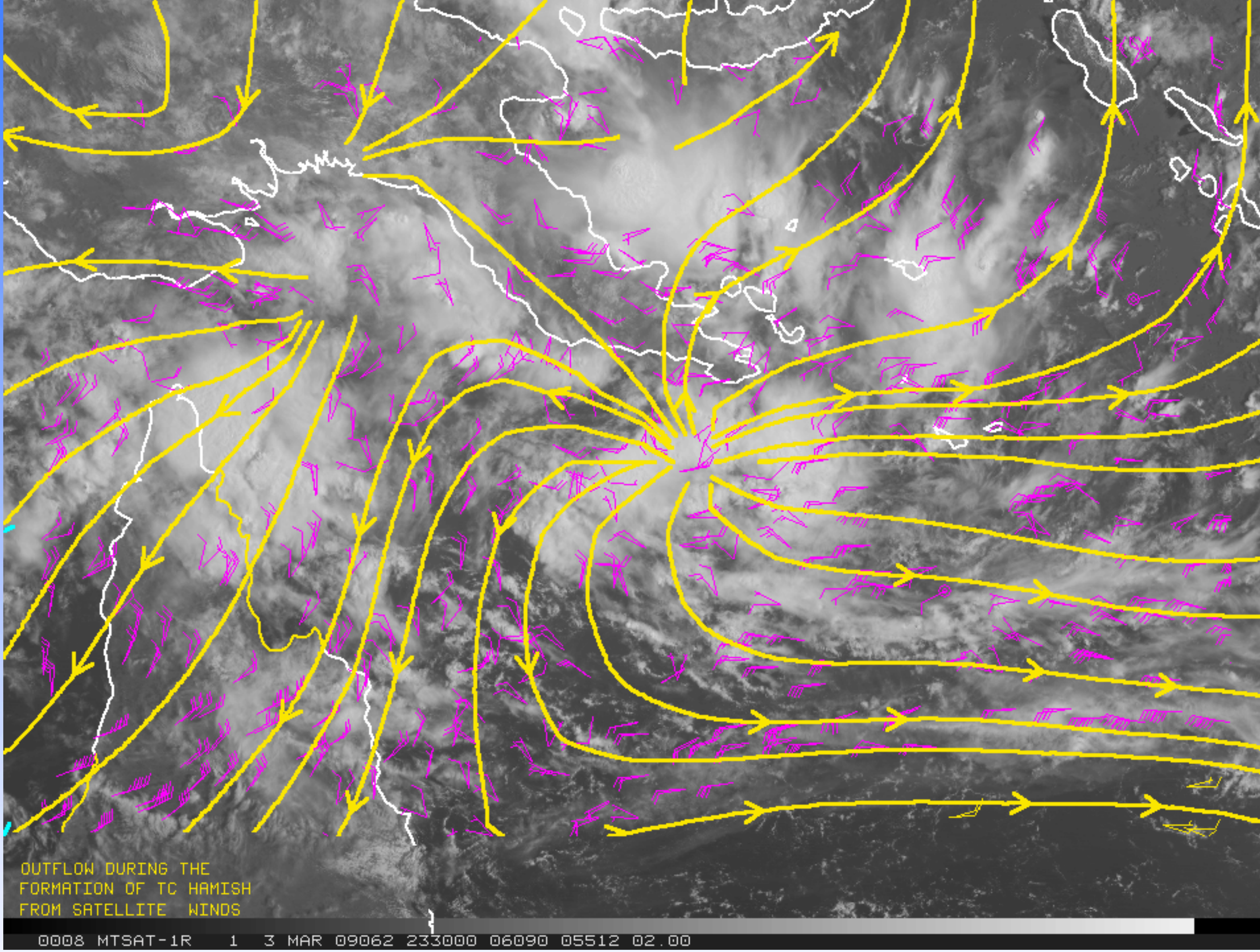
MTSat-1R VIS AMVs generated around 00 UTC on 17 October 2010.



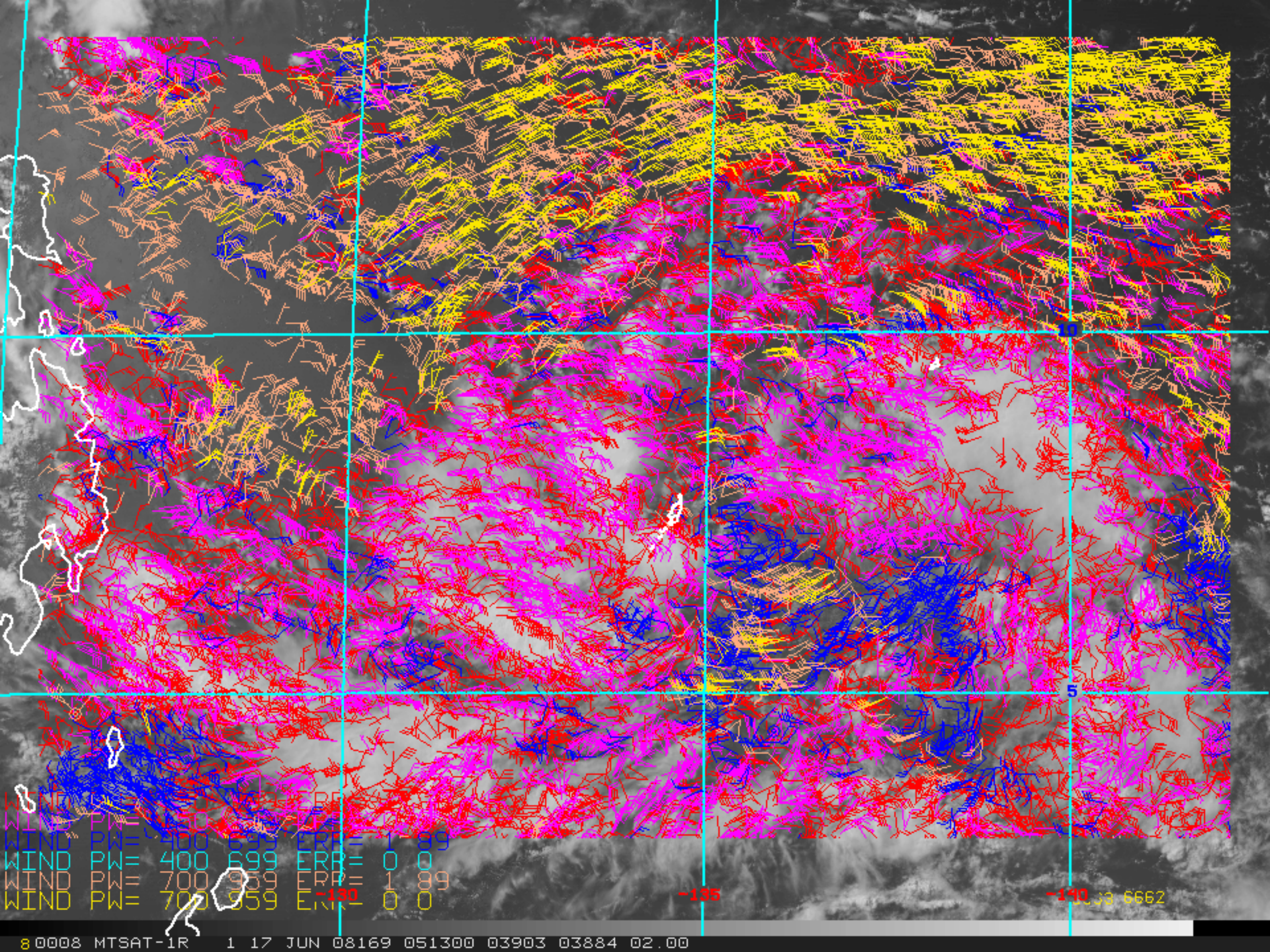
MTSAT-2 IR and VIS AMVs generated over the Tasman Sea around 00 UTC on 5April 2011



MTSat-1R IR-1 AMVs generated around 06 UTC on 17 September 2009. Magenta denotes upper level tropospheric vectors, yellow, lower level tropospheric vectors



Upper level streamline analysis (100-300hPa) from local MTSAT-1R AMVs showing upper level divergence during the formation of TC Hamish at 2330UTC on 3 March 2009



WIND PW= 400 699 ERR= 1 89
WIND PW= 400 699 ERR= 0 0
WIND PW= 700 959 ERR= 1 89
WIND PW= 700 959 ERR= 0 0
10
5
-130
-135
-140
8 0008 MTSAT-1R 1 17 JUN 08169 051300 03903 03884 02.00

ACCURACY and ERROR CHARACTERIZATION

OF

ATMOSPHERIC MOTION VECTORS

QUALITY CONTROL

Quality Control

(ERR)

Considers

- Correlation between images
  - U acceleration
  - V acceleration
  - U deviation from first guess
  - V deviation from first guess
  - ………

Quality Indicator (QI)

Considers

- Direction consistency (pair)
- Speed consistency (pair)
- Vector consistency (pair)
- Spatial Consistency
- Forecast Consistency

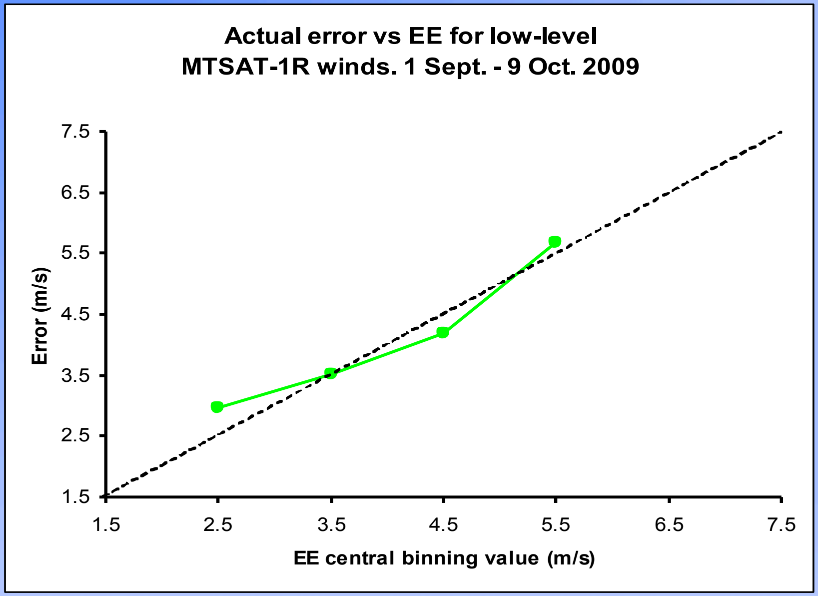
$QI = \sum w_i . QV_i / \sum w_i$

EE - provides RMS Error (RMS)

– In ops. currently estimated from:

the five QI components, wind speed
vertical wind shear, temperature shear, pressure level
which are used as predictands for root mean square error

Other statistical and physical calculation methods have been tested



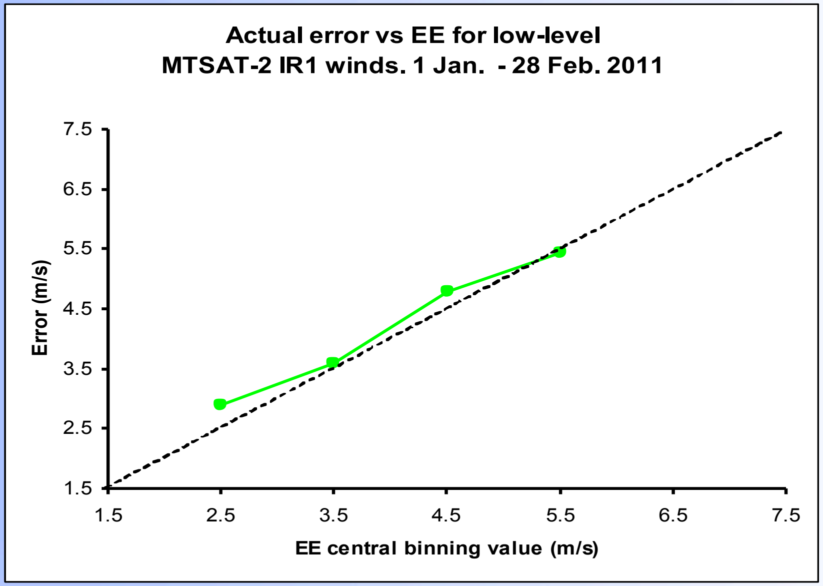
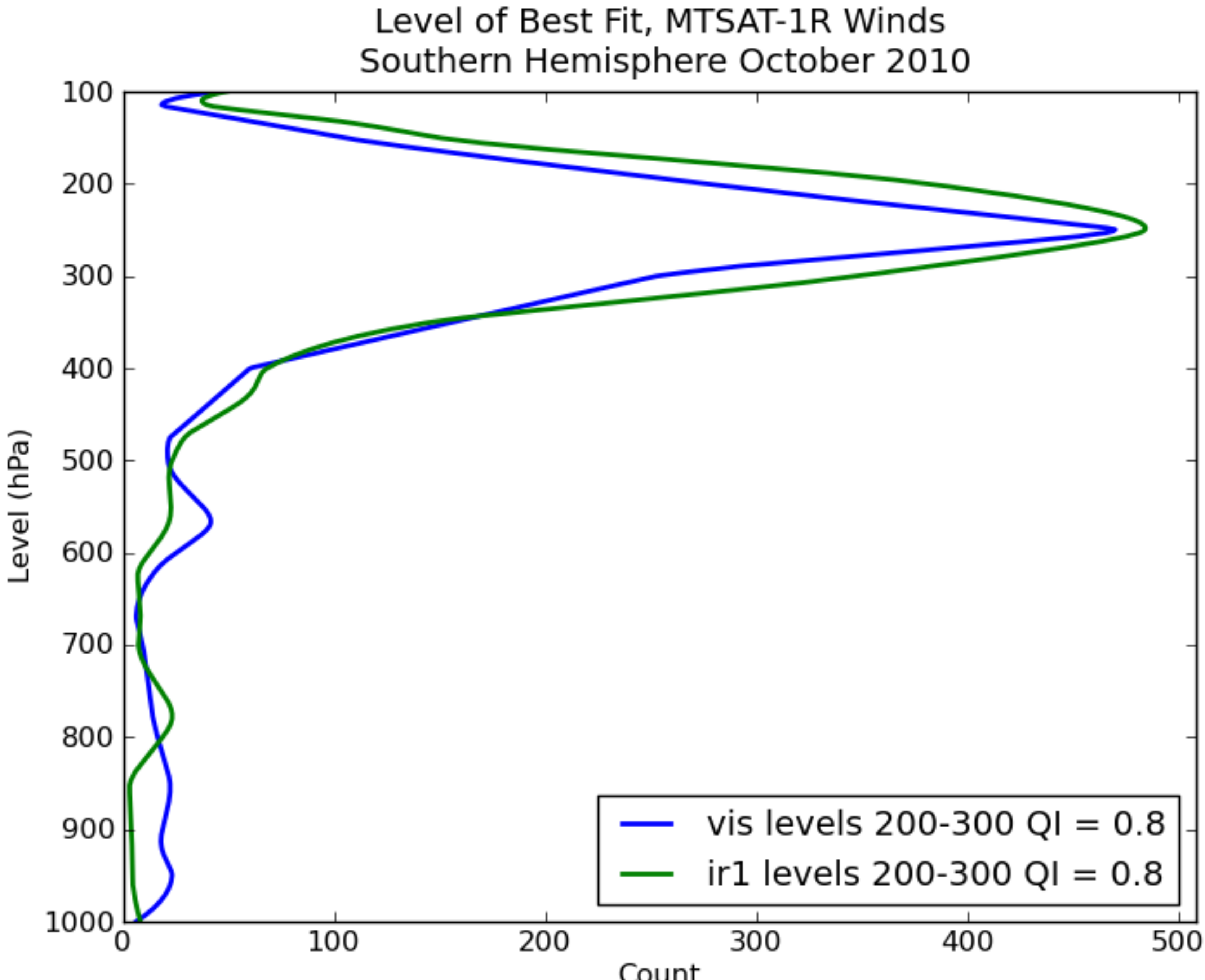


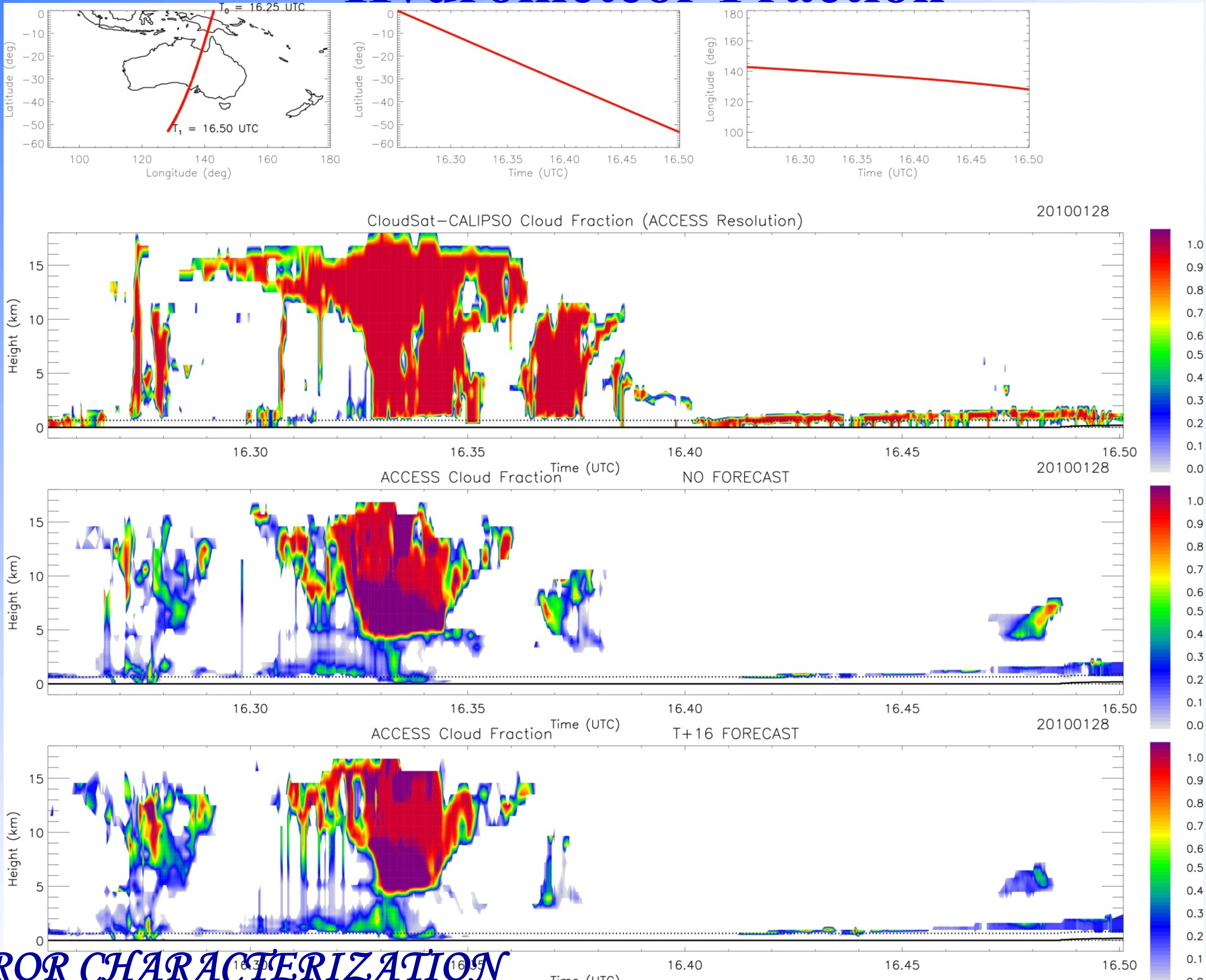
Fig. 2 (a) Measured error (m/s) versus Expected Error (EE) for low-level MTSAT-1R IR winds. (1 September – 9 October 2009)

Fig. 2 (b) Measured error (m/s) versus Expected Error (EE) for low-level MTSAT-2 IR winds . (1 January – 23 February 2011)



ERROR CHARACTERIZATION

Hydrometeor Fraction



ERROR CHARACTERIZATION

Correlated error

The correlated error has been analysed for the Bureau produced MTSat-1R/2 winds. The methodology was similar to that followed previously (Le Marshall et al., 2004). The correlated error and its spatial variation (length scale) were determined using the Second Order Auto Regressive (SOAR) function :

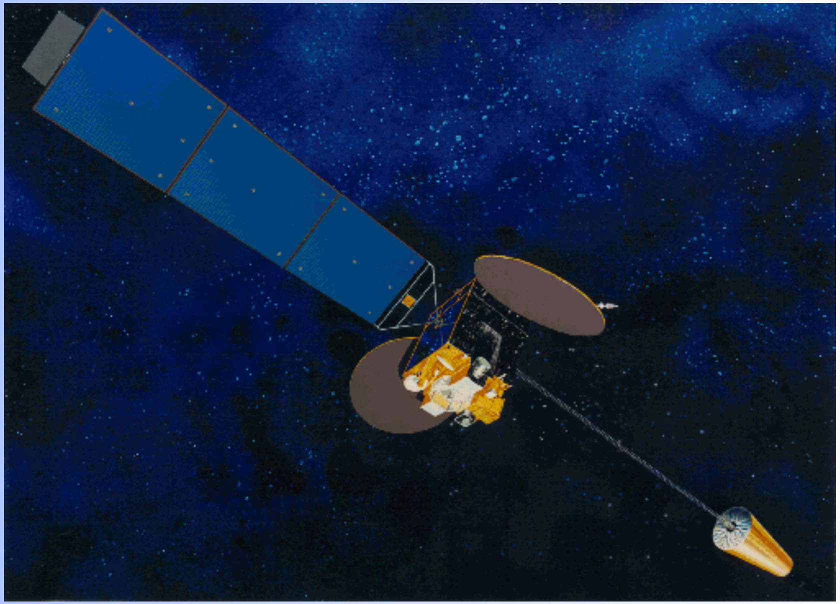
$$\mathbf{R(r) = R_{00} + R_0(1 + r/L)\ exp\ (-r/L)} \qquad (2)$$

Where $\mathbf{R(r)}$ is the error correlation, $\mathbf{R_0}$ and $\mathbf{R_{00}}$ are the fitting parameters (greater than 0), L is the length scale and r is the separation of the correlates. The difference between AMV and radiosonde winds (error) has been separated into correlated and non-correlated parts. A typical variation of error correlation with distance for MTSat-1R IR1 AMVs is seen in Figure 3, while the parameters of the SOAR function which best fits the observations are contained in Table 3.

Table 3. Parameters of the SOAR function (Equation 2) which best model the measured error correlations for the MTSat-1R AMVs listed in the left column of the table. (February – April, 2007)

MTSat-1R IR1 AMVS	R_{00}		R_0		L (km)	
	Low	High	Low	High	Low	High
EE < 6	0.006	0.370	0.460	0.460	86.000	99.900
EE < 8	0.066	0.052	0.640	0.440	122.700	110.900

MTSaT AMV Generation and Application – Operational Trial



GeostationaryMTSaT – 1R

1 September – 8 October 2008

Used

* Real Time Local Satellite Winds

~ 2 sets of IR1 quarter hourly motion vectors every six hours.

* Operational 2008 Regional Forecast Model (L61)and Data Base. Intermittent Assimilation

(Inc JMA AMVs)

* Operational Regional Verification Grid

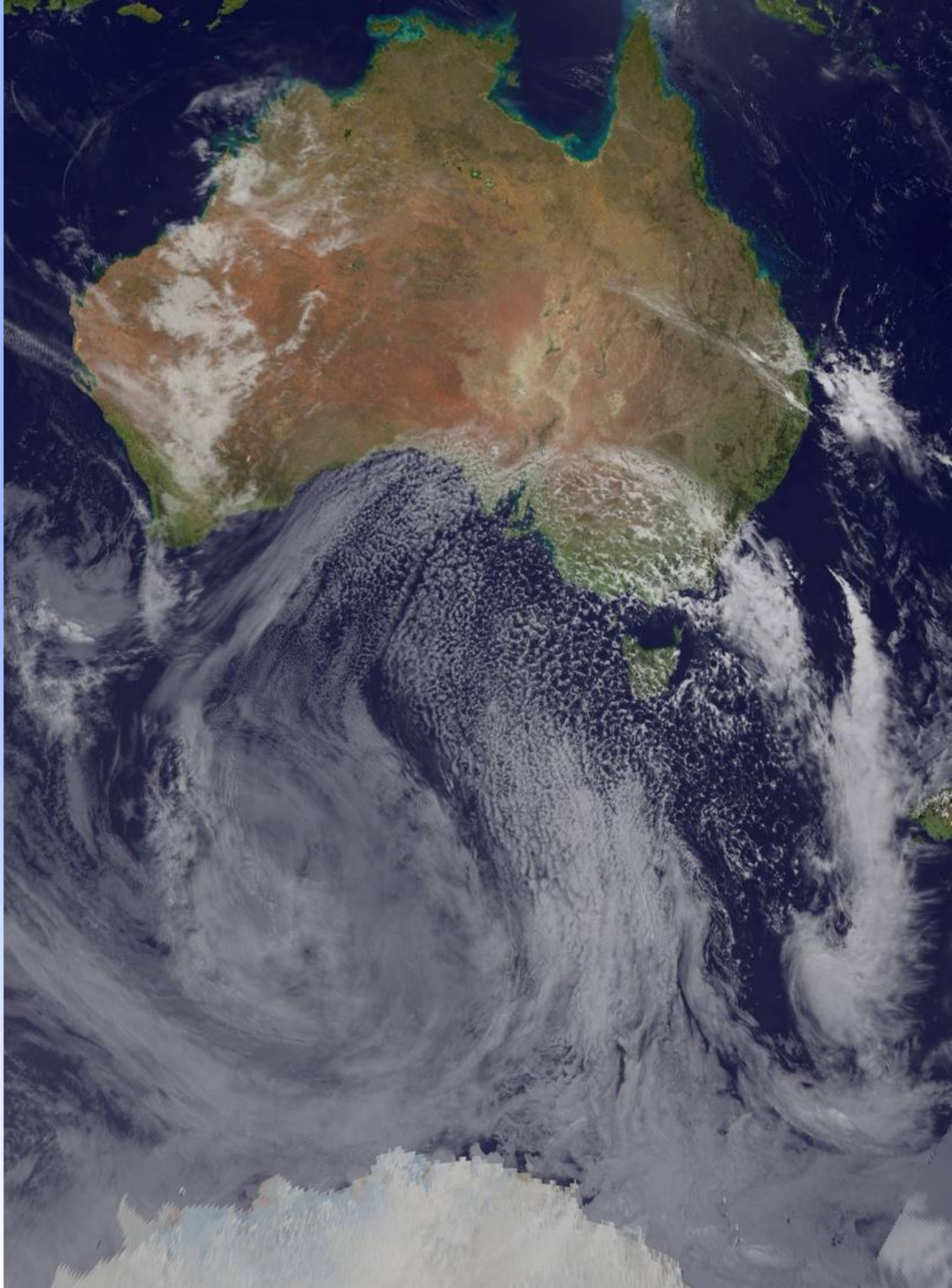
Table 5 (b) 24 hr forecast verification S1 Skill Scores for the next operational regional forecast system (L61 LAPS) and L61 LAPS with IR, 6-hourly image based AMVs for 1 September to 8 October 2007 (72 cases)

LEVEL	(LAPS) S1	(LAPS + MTSAT-1R AMVS) S1
MSLP	20.24	19.15
1000 hPa	20.06	19.13
900 hPa	18.65	17.75
850 hPa	17.41	16.69
500 hPa	12.41	11.73
300 hPa	10.49	9.76
250 hPa	12.41	11.90

Australian Government

Bureau of Meteorology

OPERATIONAL GENERATION AND ASSIMILATION OF CONTINUOUS (HOURLY) ATMOSPHERIC MOTION VECTORS WITH 4DVAR



Australian Community Climate and Earth System Simulator (ACCESS)

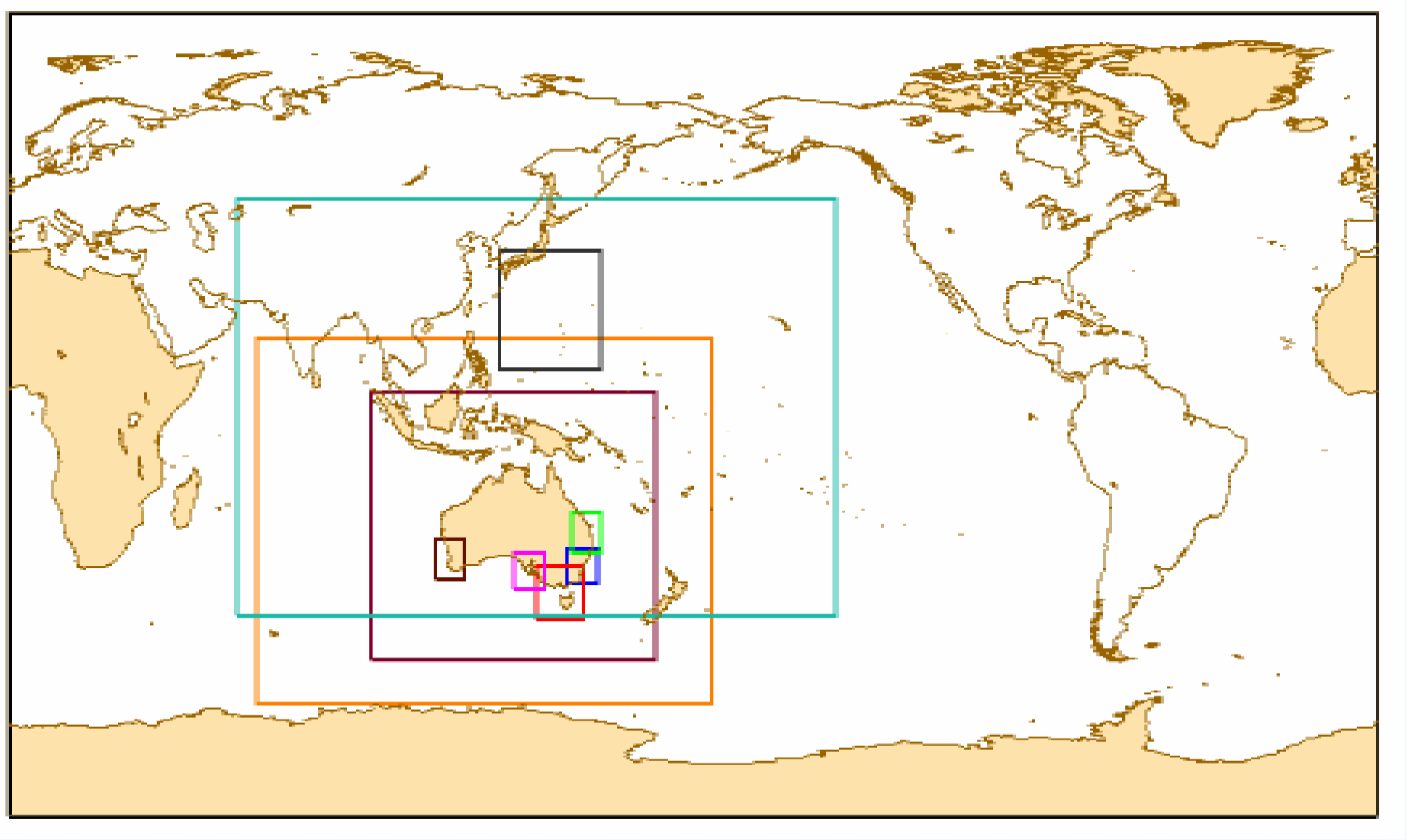
ACCESS - R uses

- The Met. Office Unified Model (UKUM)
- 4DVAR Analysis System (VAR)
- Observation Processing System (OPS)
- The Surface Fields Processing system (SURF)

Australian Community Climate and Earth System Simulator (ACCESS)

Table 5: The Characteristics of the ACCESS-R Forecast System.

DOMAIN : AUSTRALIA REGION	65.0°S TO 17.125°N, 65.0°E TO 184.625°E
UM Horizontal Resolution (lat x lon)	220x320 (0.375°)
Analysis Horizontal resolution (lat. x long.)	110x160 (0.75°)
Vertical Resolution	L50
Observational Data Used (6h window)	AIRS, ATOVS, Scat, AMV, SYNOP, SHIP, BUOY,AMDARS, AIREPS, TEMP, PILOT
Sea Surface Temperature Analysis	Daily, spatial resolution 1/12° SST analysis
Soil moisture analysis	N144L50 soil moisture field - SURF once every 6 hours
Model Time Step	15 minutes (96 time steps per day)
Analysis Time Step	15 minutes
Nesting	Lateral Boundary Condition derived from N144L50, ACCESS-G



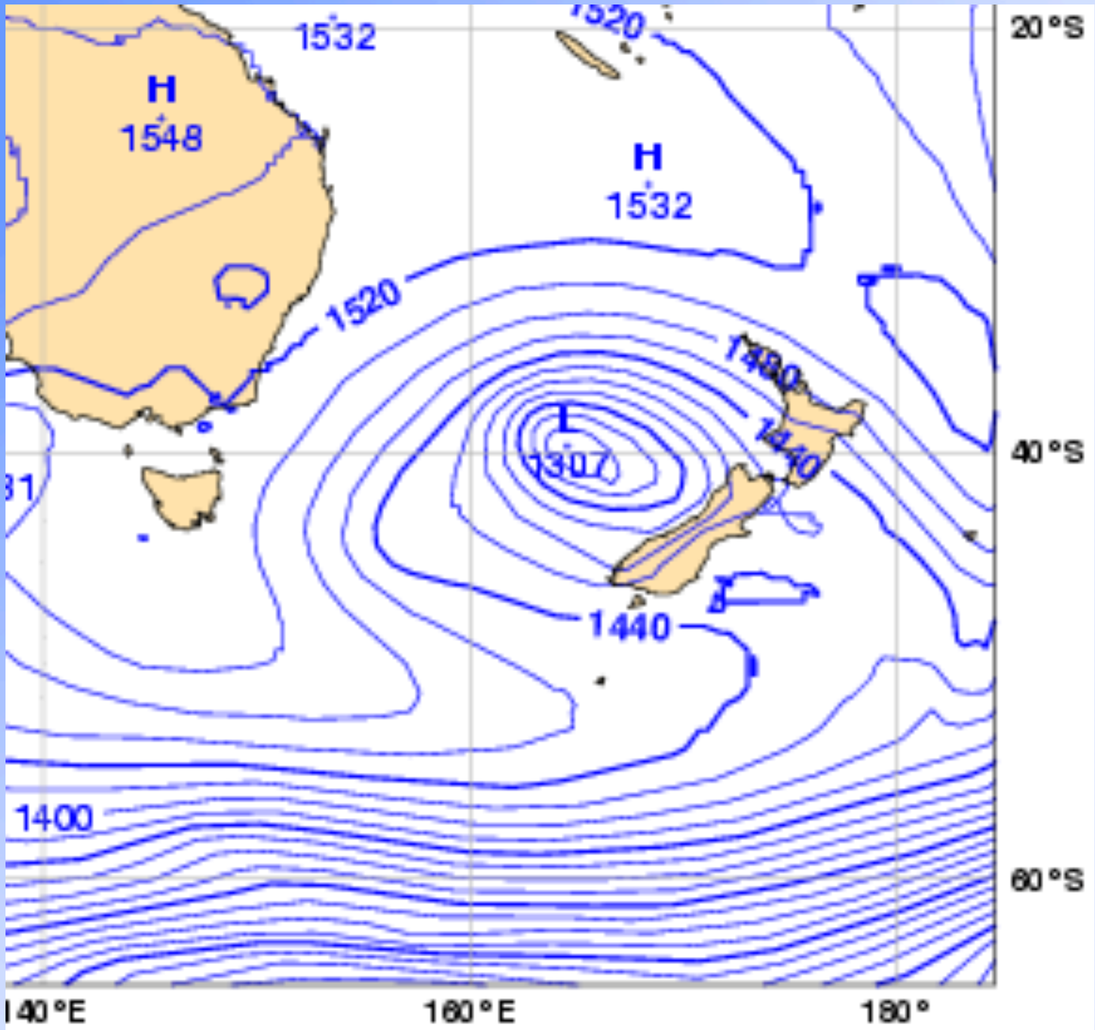


Fig.4(a) Control 48 hour forecast of 850 hPa geopotential height valid 00UTC on 24 April 2011.

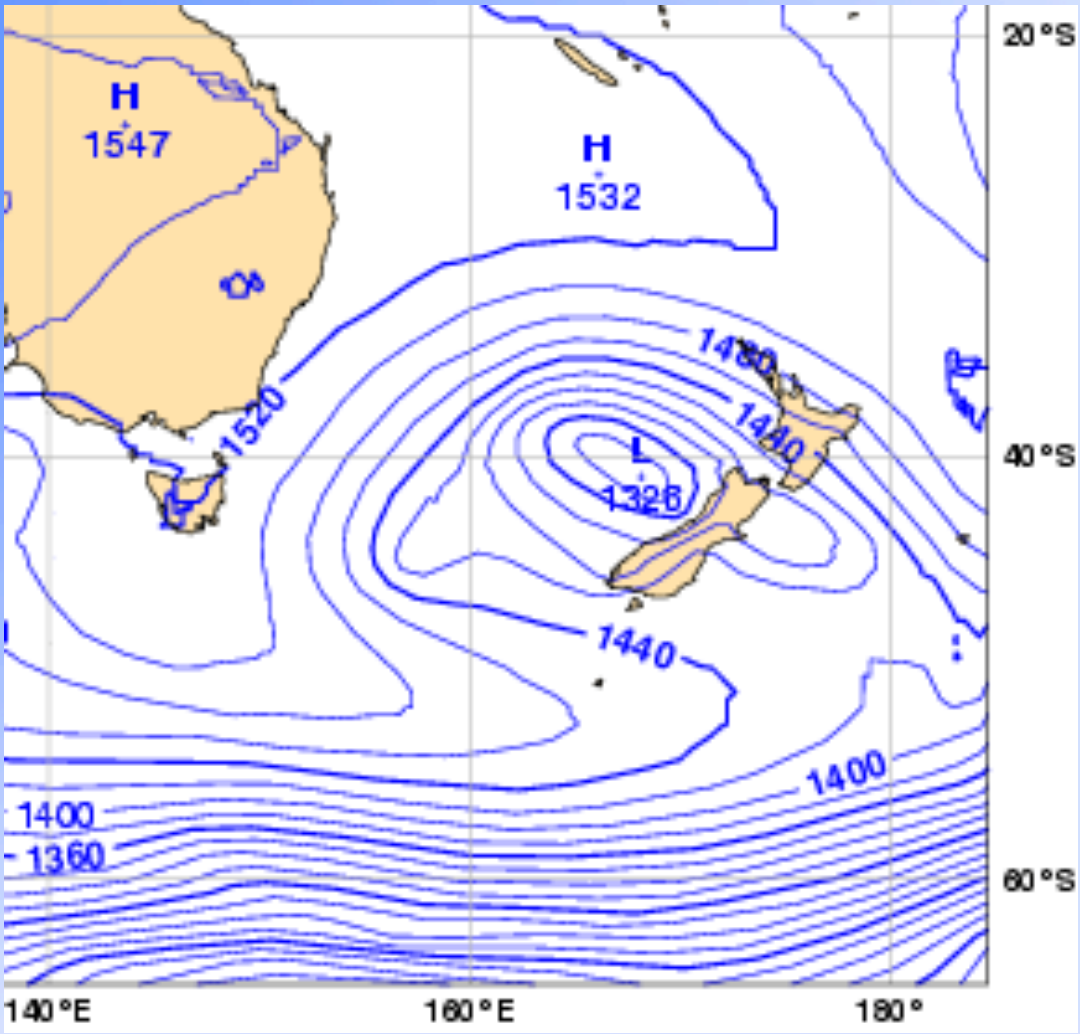


Fig.4(b) Experimental 48 hour forecast of 850 hPa geopotential height (using continuous AMVs) valid 00UTC on 24 April 2011.

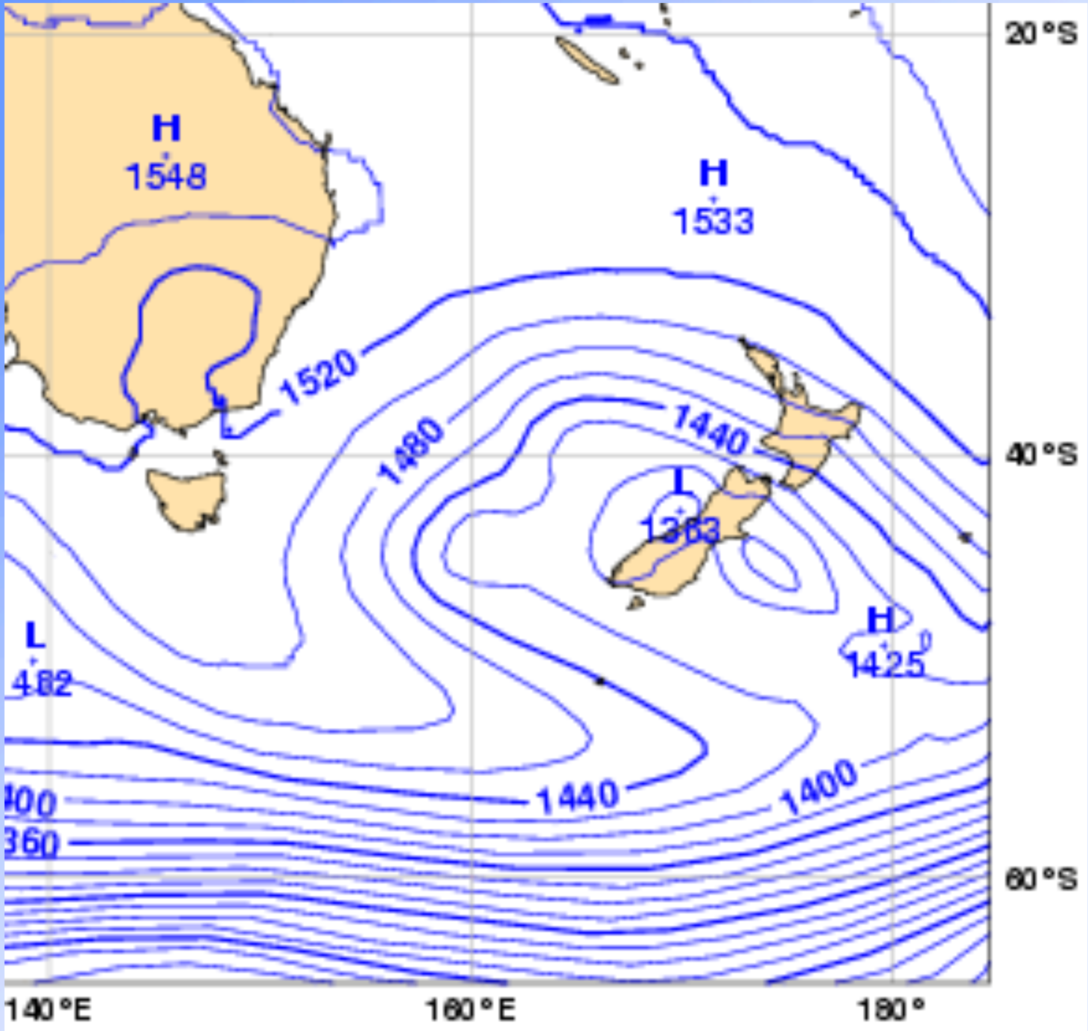


Fig.4(c) Verifying analysis of 850 hPa geopotential height valid 00UTC on 24 April 2011.

NEAR RT TRIAL

NEW OPERATIONAL SYSTEM

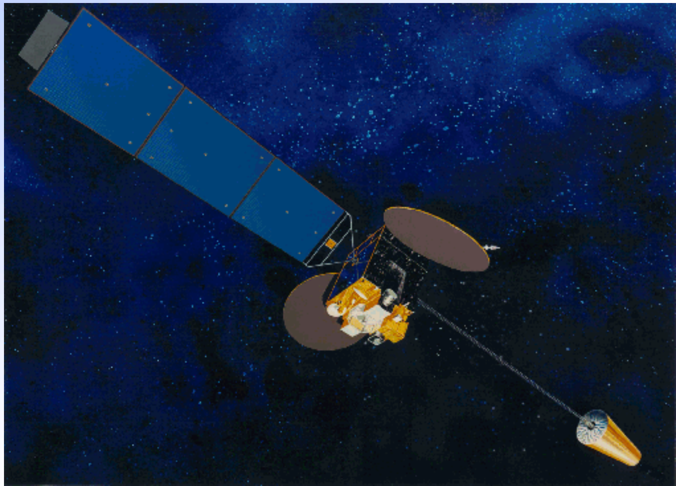
1 September – 10 October 2009

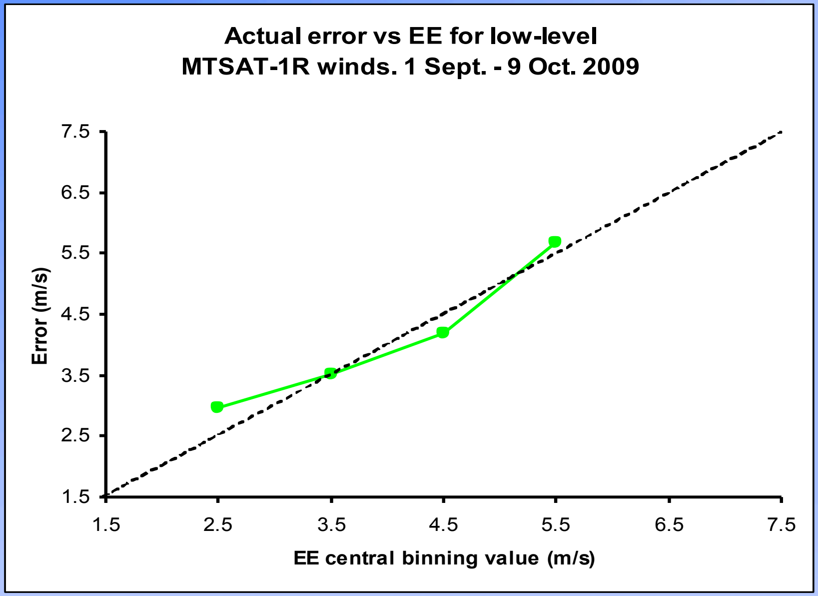
Used

■ Real Time Local Satellite Winds MTSAT-1R

- 2 sets of quarter hourly motion vectors every six hours.
- Hourly motion Vectors

■ New Operational Regional Forecast Model (ACCESS-R) and Data Base (Inc JMA AMVs)





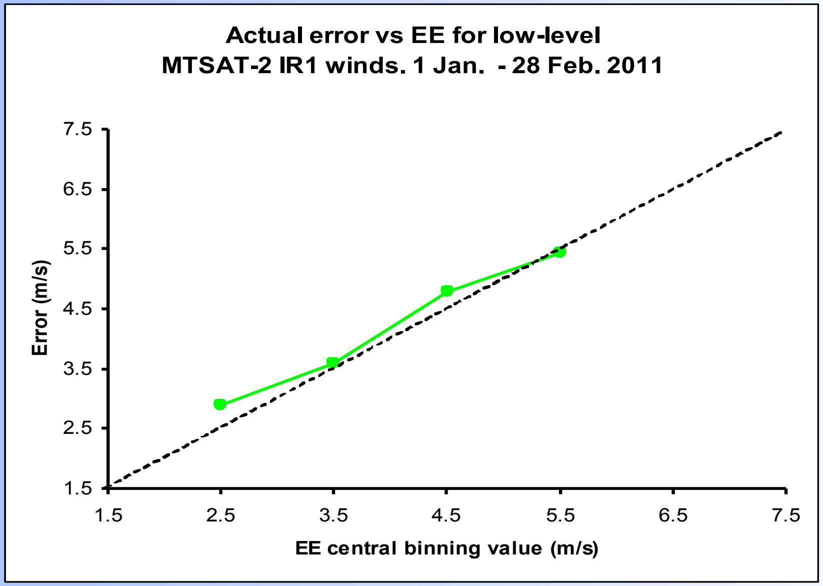


Fig. 2 (a) Measured error (m/s) versus Expected Error (EE) for low-level MTSAT-1R IR winds. (1 September – 9 October 2009)

Fig. 2 (b) Measured error (m/s) versus Expected Error (EE) for low-level MTSAT-2 IR winds . (1 January – 23 February 2011)

Error Characteristics for Current Local AMV System In ACCESS (UKMO) environment

Table 2 (a) Mean Magnitude of Vector Difference (MMVD) and Root Mean Square Difference (RMSD) between MTSAT-1R IR1 AMVs, forecast model first guess winds and radiosonde winds for the period 1 September to 9 October 2009

Level	Data Source	Bias (m/s)	MMVD (m/s)	RMSVD (m/s)
High – up to 80 km separation between radiosondes and AMVs	AMVs	-0.6	3.3	4.0
	First Guess	-0.3	3.5	4.1
Low - up to 150 km separation between radiosondes and AMVs	AMVs	0.2	2.9	3.4
	First Guess	0.2	2.7	3.1
Low – up to 30 km separation between radiosondes and AMVs	AMVs	0.2	2.3	2.5
	First Guess	-0.2	2.3	2.6

4D-VAR with Hourly AMVs – Australian Region

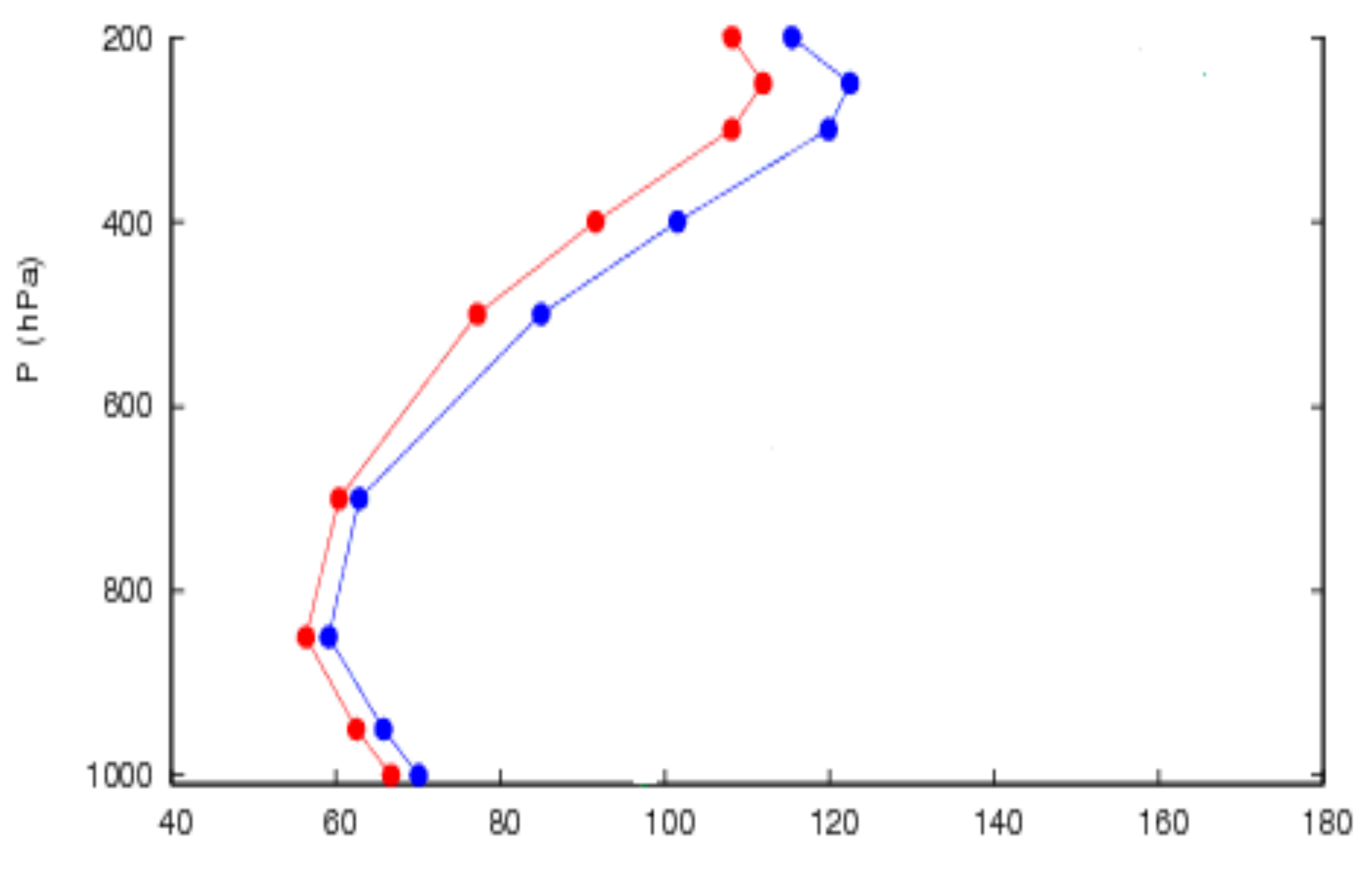


Fig.5 (a). The RMS difference between forecast and verifying analysis geopotential height(m) at 24 hours for ACCESS-R (blue) and ACCESS-R with AMVs (red) for the period 1 September to 10 October 2009

4D-VAR with Hourly AMVs – Australian Region

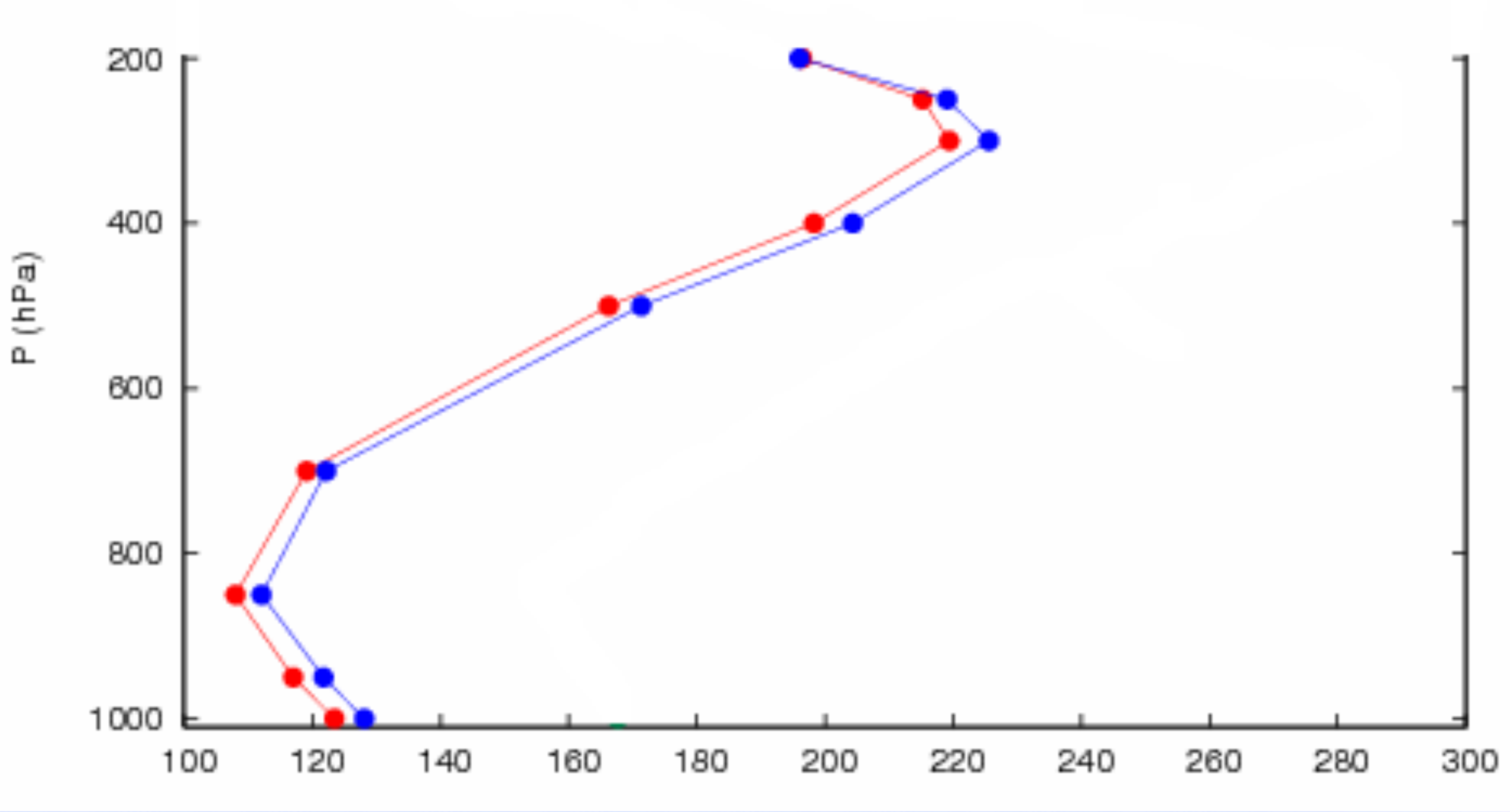
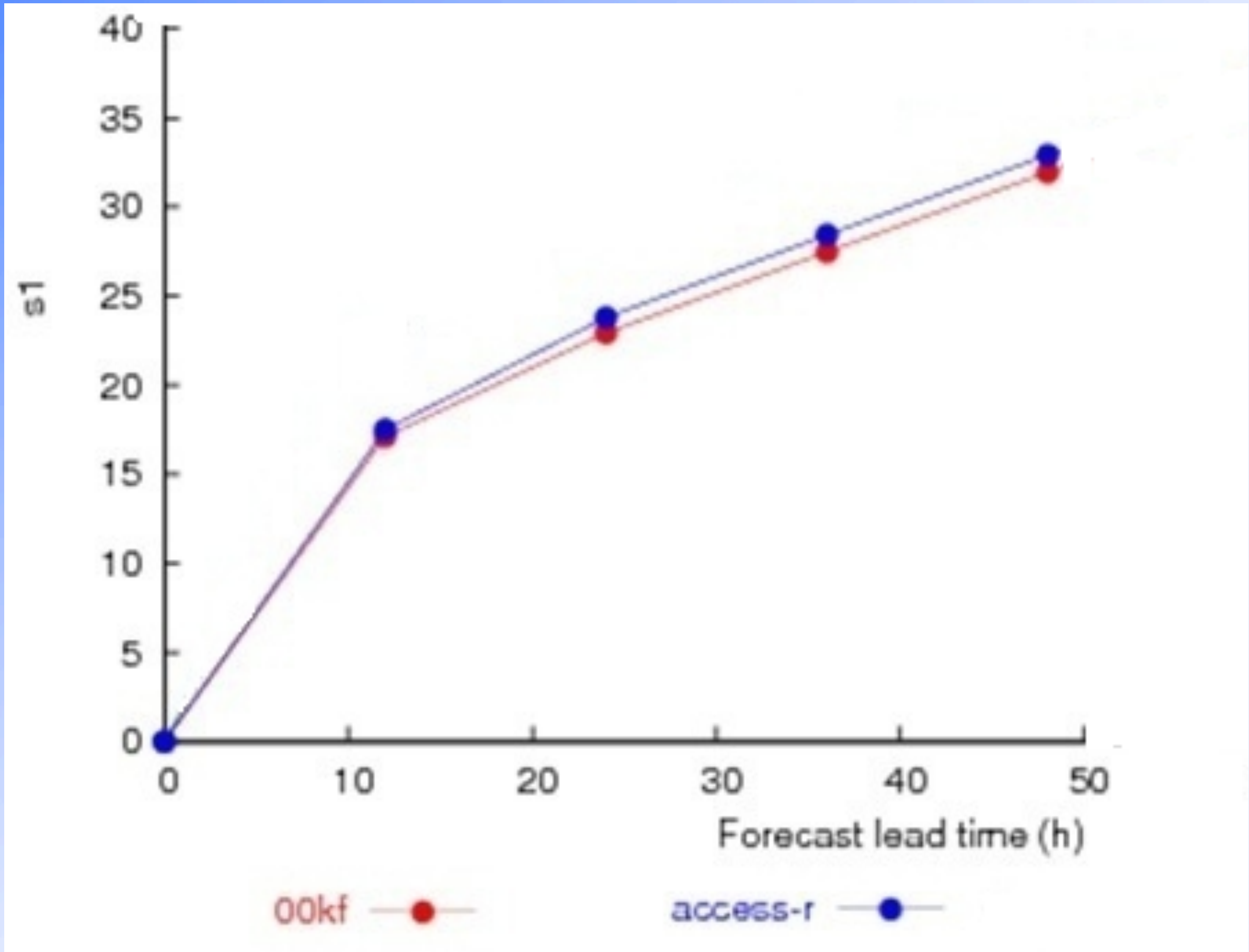


Fig.5(b). The RMS difference between forecast and verifying analysis geopotential height(m) at 48 hours for ACCESS-R (blue) and ACCESS-R with AMVs (red) for the period 1 September to 10 October 2009

4D-VAR with Hourly AMVs – Australian Region



The S1 Skill Score difference between forecast and verifying analysis at MSLP up to 48 hours for ACCESS-R (blue) and ACCESS-R with hourly AMVs (red) for the period 1 September to 10 October 2009

NEAR RT TRIAL

NEW OPERATIONAL SYSTEM

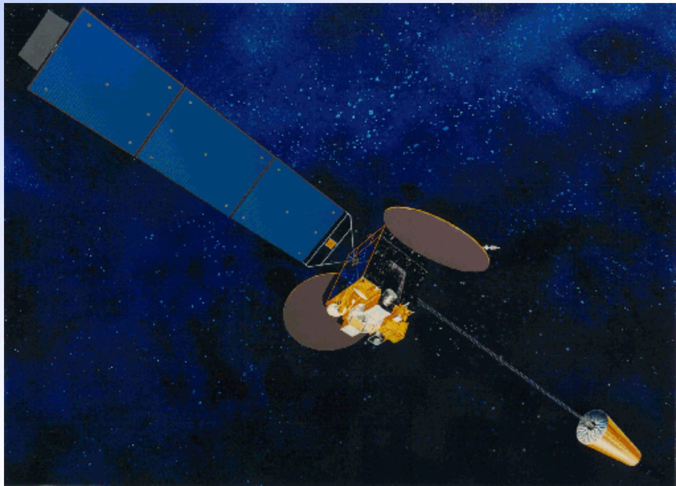
27 January – 23 February 2011

Used

■ Real Time Local Satellite Winds MTSAT-2

- 2 sets of quarter hourly motion vectors every six hours.
- Hourly motion Vectors

■ New Operational Regional Forecast Model (ACCESS-R) and Data Base (Inc JMA AMVs)



Error Characteristics for Current Local AMV System In ACCESS (UKMO) environment

Table 2 (b) Mean Magnitude of Vector Difference (MMVD) and Root Mean Square Difference (RMSD) between MTSAT-2 IR1 AMVs, forecast model first guess winds and radiosonde winds for the period 27 January to 23 February 2011

Level	Data Source	Bias (m/s)	MMVD (m/s)	RMSVD (m/s)
High – up to 80 km separation between radiosondes and AMVs	AMVs	-1.2	3.5	4.2
	First Guess	-1.5	3.7	4.3
Low - up to 150 km separation between radiosondes and AMVs	AMVs	-0.2	2.7	3.1
	First Guess	-0.1	2.4	2.8
Low – up to 30 km separation between radiosondes and AMVs	AMVs	-0.6	1.9	2.2
	First Guess	-0.4	2.0	2.2

4D-VAR with Hourly AMVs – Australian Region

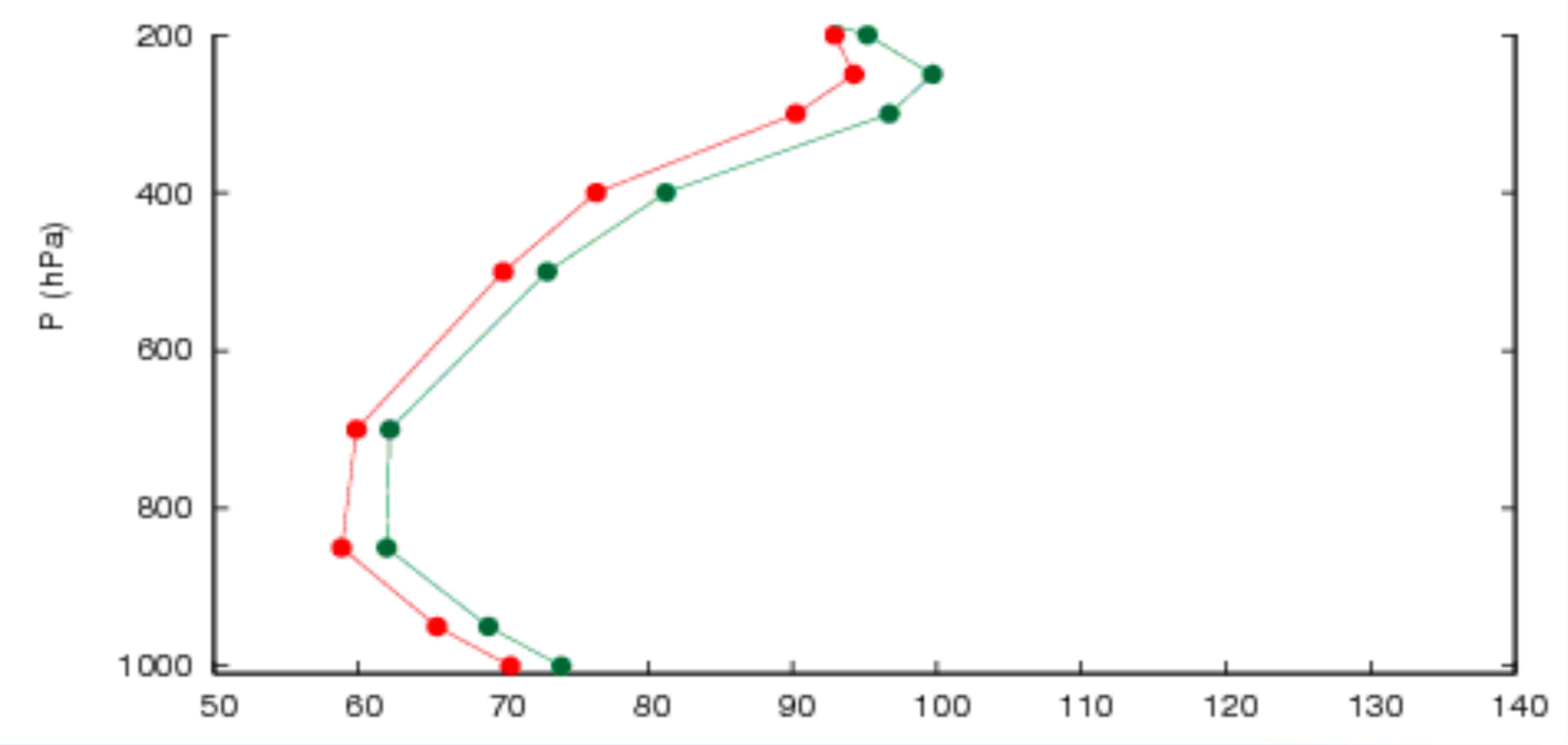


Fig.6(a). The RMS difference between forecast and verifying analysis geopotential height(m) at 24 hours for ACCESS-R (green) and ACCESS-R with AMVs (red) for the period 27 January to 23 February 2011

4D-VAR with Hourly AMVs – Australian Region

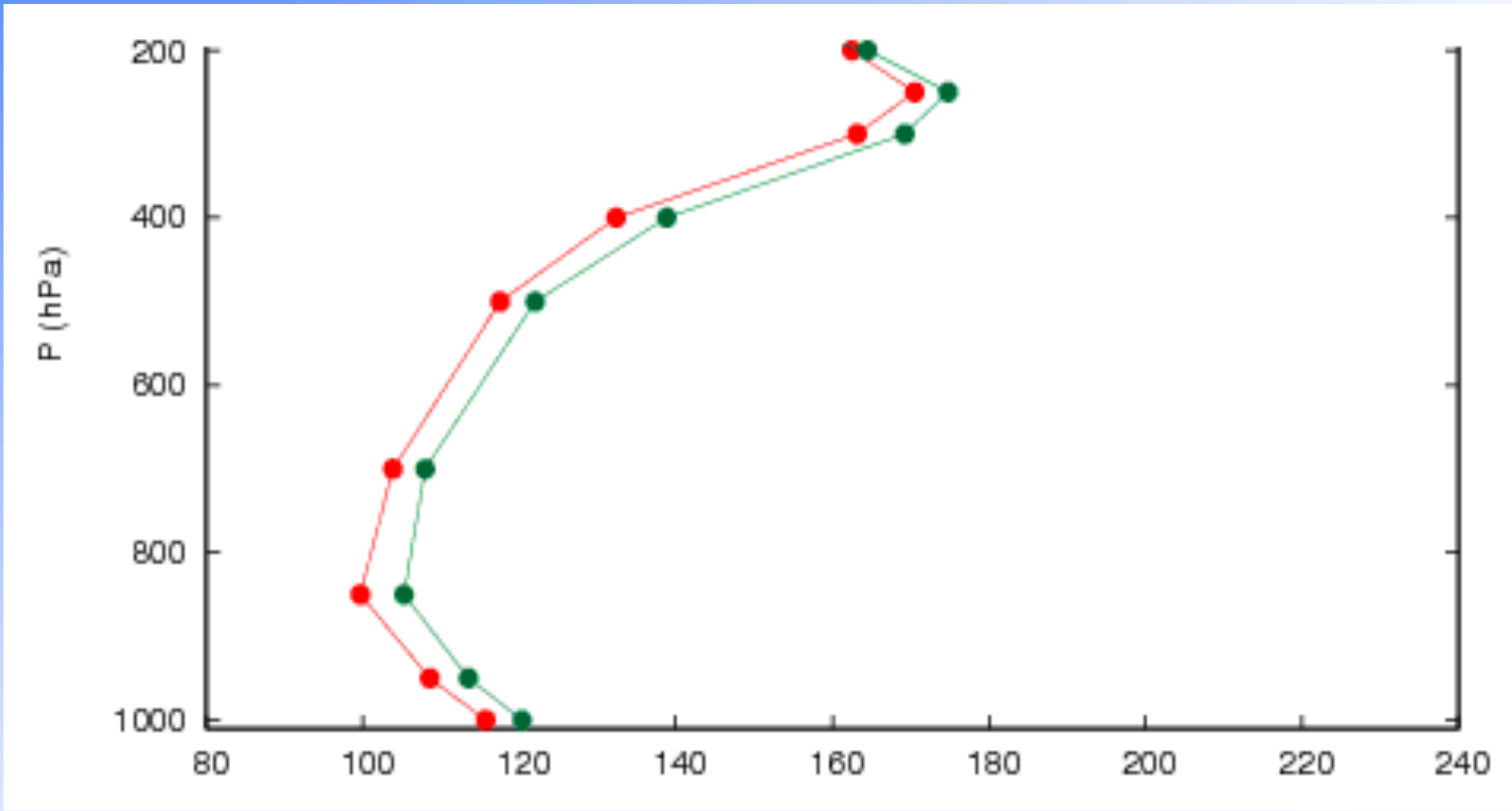


Fig.6(b). The RMS difference between forecast and verifying analysis geopotential height(m) at 48 hours for ACCESS-R (green) and ACCESS-R with AMVs (red) for the period 27 January to 23 February 2011.

4D-VAR with Hourly AMVs – Australian Region

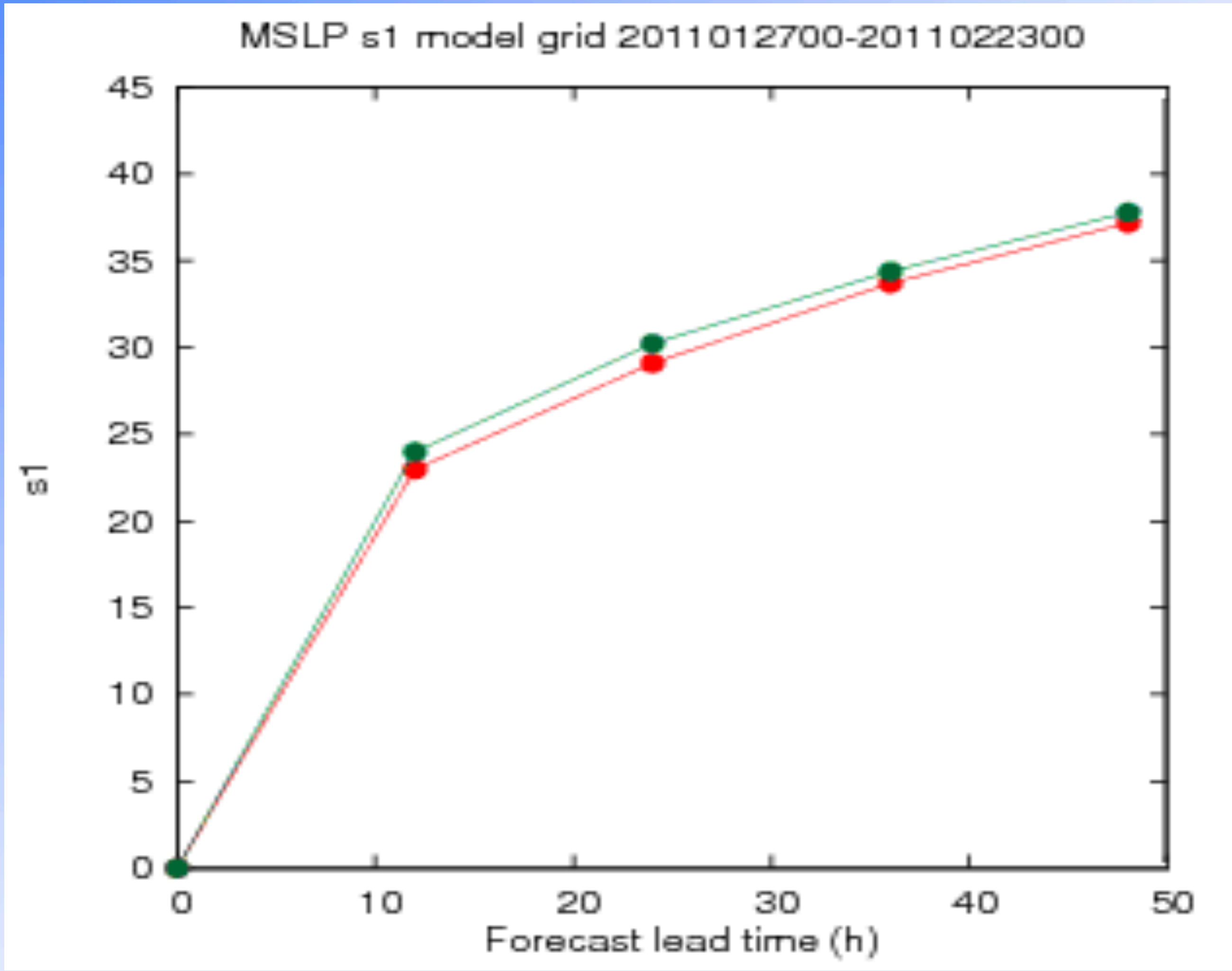


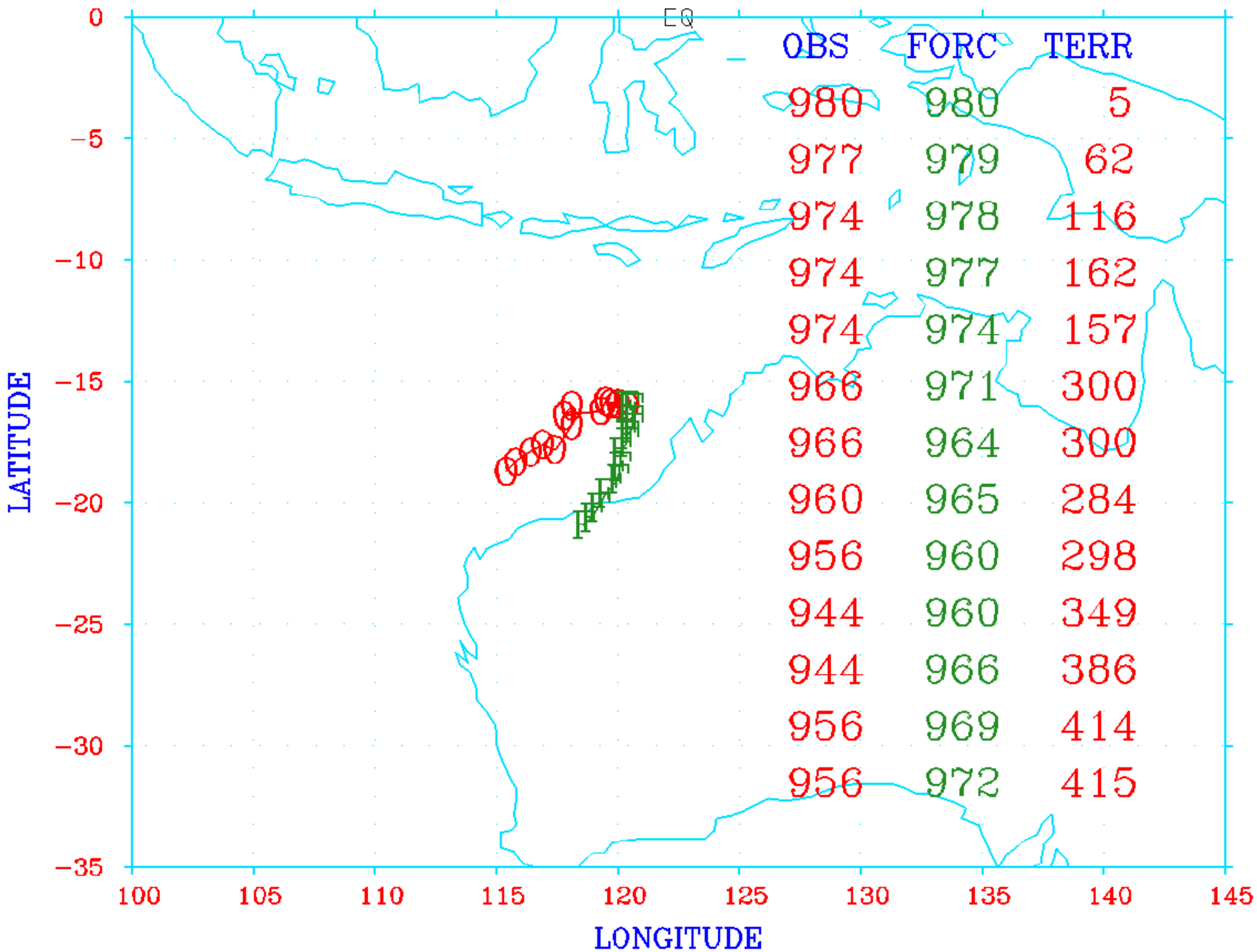
Fig.6(d). The S1 difference between forecast and verifying analysis MSLP out to 48 hours for ACCESS-R (green) and ACCESS-R with AMVs (red) for the period 27 January to 23 February 2011

Use of high res local AMVs in ACCESS 4D-VAR environment for TC forecasting.

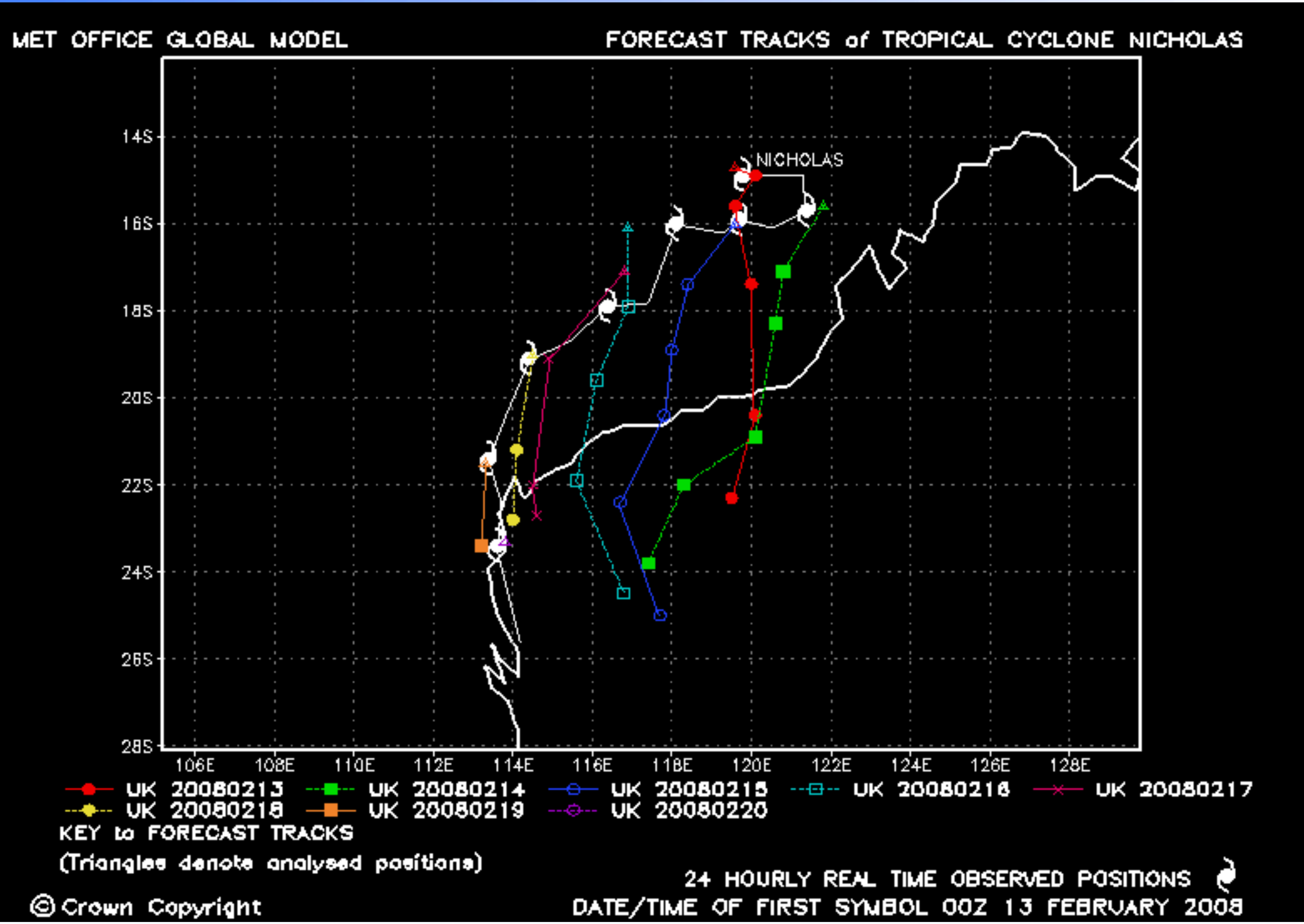
- Example:
- TC Nicholas Western Australian Region February 2008
- UKUM 37.5km resolution
- 6-hour time window used
- No bogus data used

OBSVD, FCAST CPS and TRK ERRS (km)

TC NICHOLAS

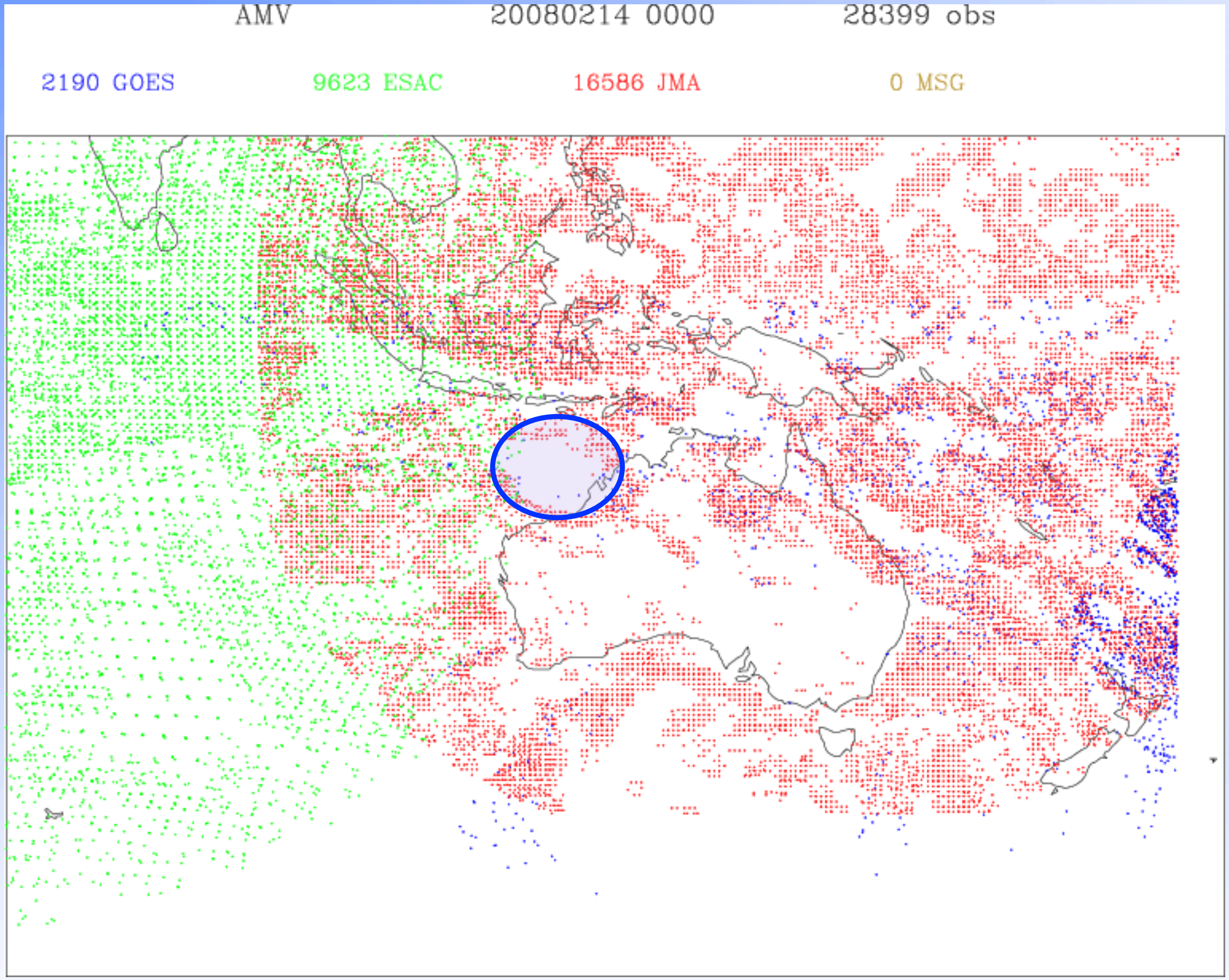


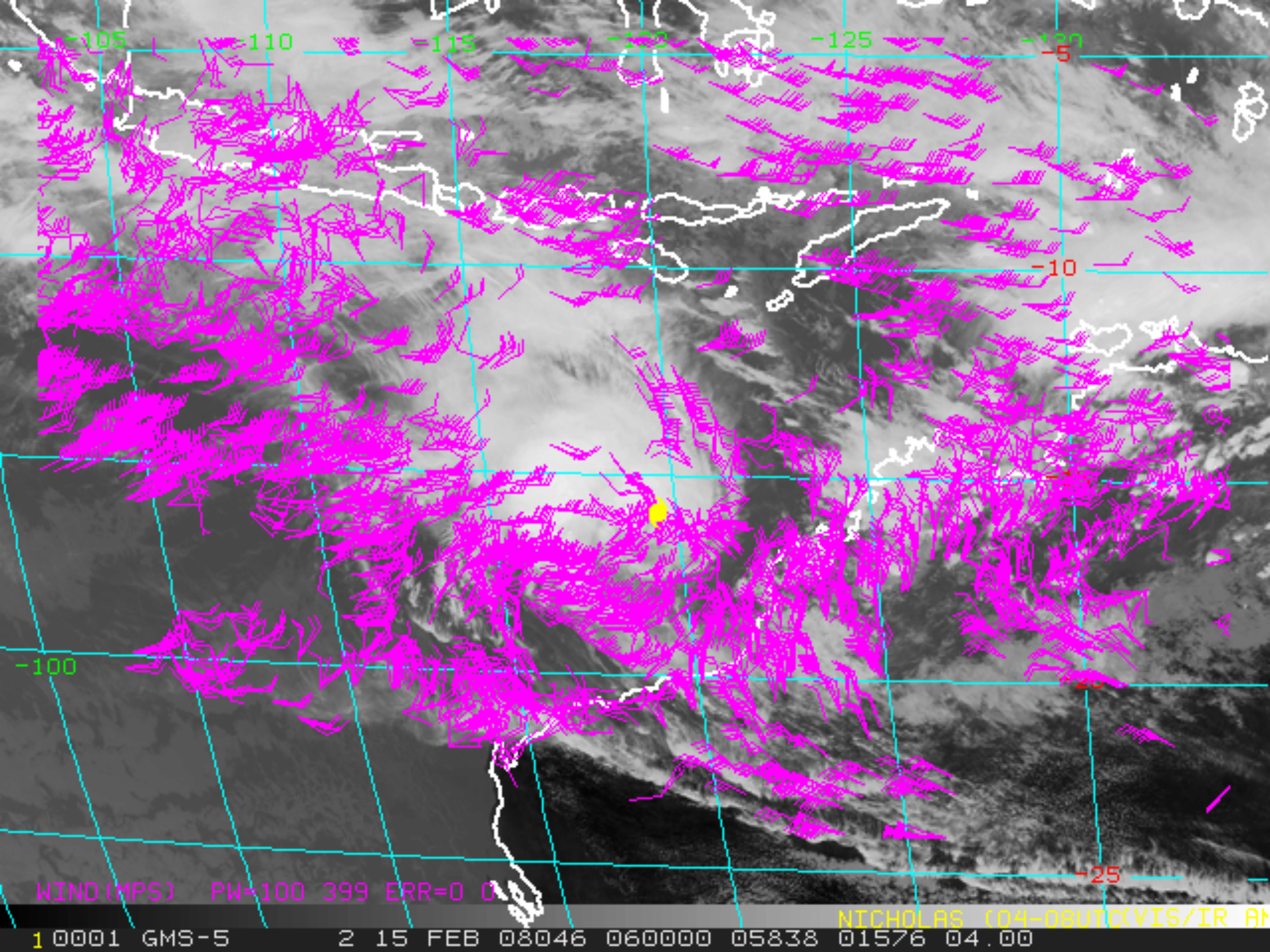
06 HOUR INTERVALS FROM 8021412

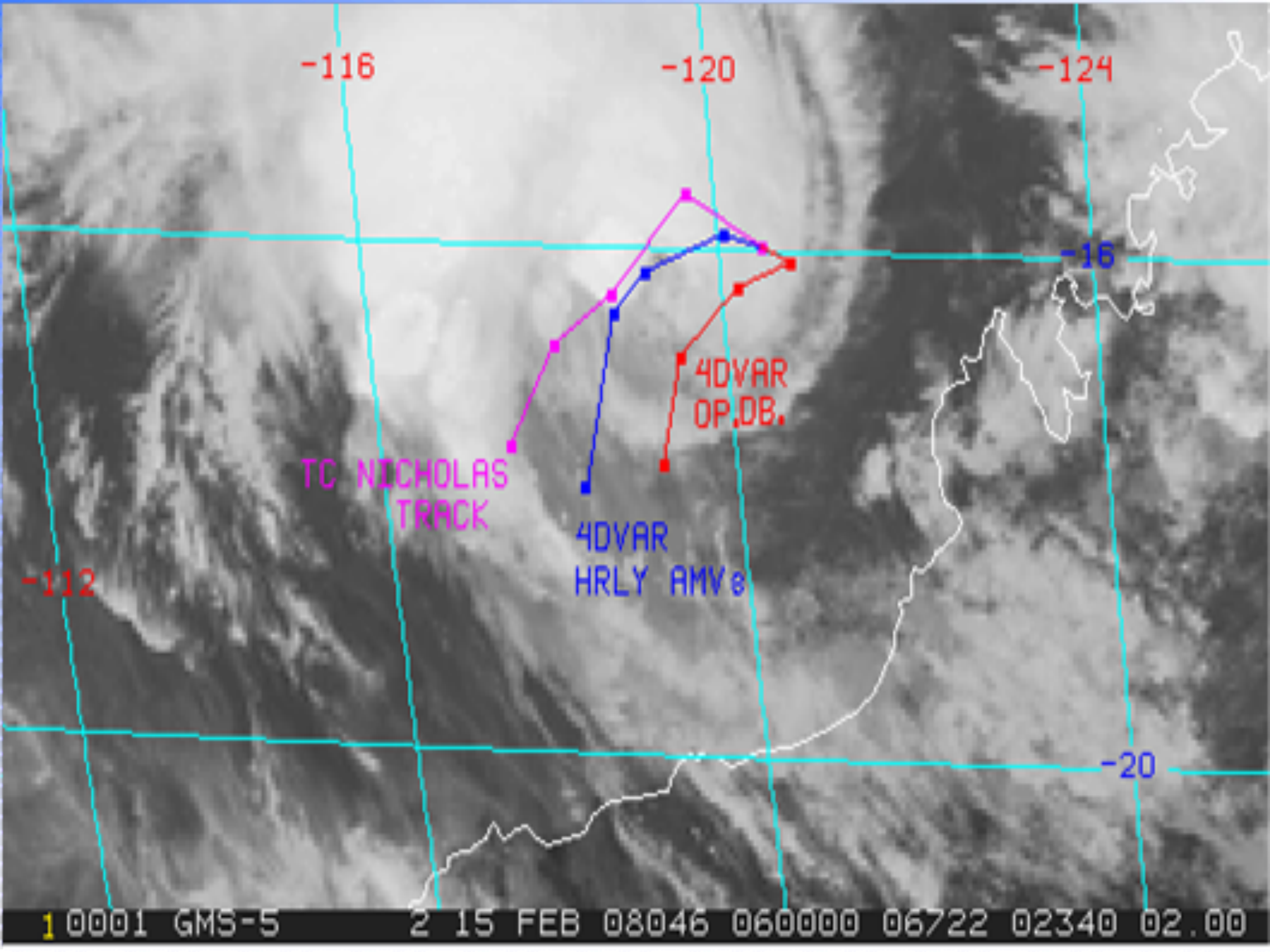


MET OFFICE GLOBAL MODEL
FORECAST TRACKS of TROPICAL CYCLONE NICHOLAS
NICHOLAS
14S
16S
18S
20S
22S
24S
26S
28S
106E
108E
110E
112E
114E
116E
118E
120E
122E
124E
126E
128E
UK 20080213
UK 20080214
UK 20080215
UK 20080216
UK 20080217
UK 20080218
UK 20080219
UK 20080220
KEY to FORECAST TRACKS
(Triangles denote analysed positions)
24 HOURLY REAL TIME OBSERVED POSITIONS
© Crown Copyright
DATE/TIME OF FIRST SYMBOL 00Z 13 FEBRUARY 2008

Local processing – MTSAT Atmospheric Motion Vectors

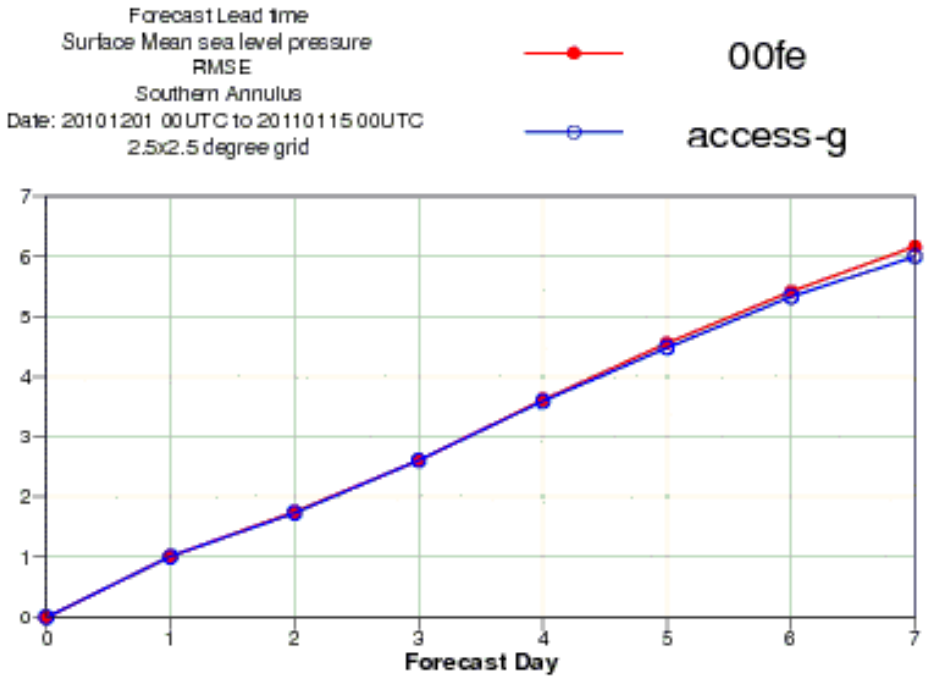



-105
-110
-115
-125
-5
-10
-25
-100
WIND(MPS) PW=100 399 ERR=0 0
NICHOLAS (04-08UTC(VIS/IR AN
1 0001 GMS-5 2 15 FEB 08046 060000 05838 01576 04.00


-116
-120
-124
-16
4DVAR
OP.DB.
TC NICHOLAS
TRACK
4DVAR
HRLY AMVs
-112
-20
1 0001 GMS-5 2 15 FEB 08046 060000 06722 02340 02.00

Intercomparison
1 Dec. 2010 - 15 Jan. 2011
ACCESS-G

Domain	Global
Unified Model horizontal resolution	(217 x 288) ~125km x 83km
Analysis horizontal resolution	(163 x 216) ~166km x 111km
Vertical resolution	L50
Observational Data Used (6h window)	AIRS, ATOVS, SCAT, AMV, SYNOP, SHIP, BUOY, AMDAR, AIREP, TEMP, PILOT
Sea surface temperature (SST) analysis	Weekly global 1° SST analysis
Model time step	15 minutes
Analysis time step	40 minutes


Forecast Lead time
Surface Mean sea level pressure
RMSE
Southern Annulus
Date: 20101201 00UTC to 20110115 00UTC
2.5x2.5 degree grid
00fe
access-g
0
1
2
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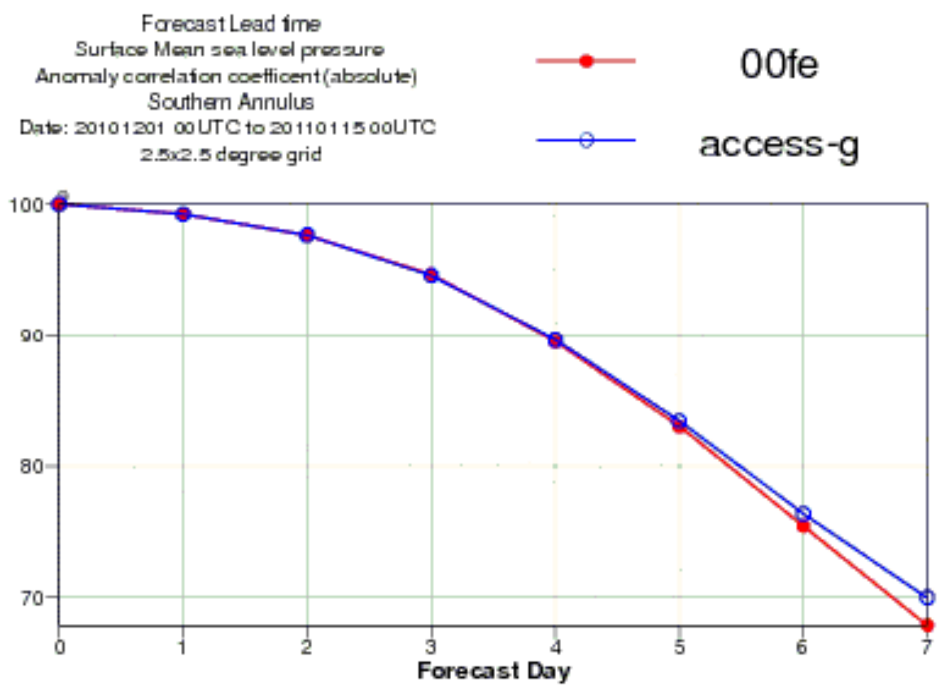
5
6
7
Forecast Day


Forecast Lead time
Surface Mean sea level pressure
Anomaly correlation coefficent (absolute)
Southern Annulus
Date: 20101201 00UTC to 20110115 00UTC
2.5x2.5 degree grid
00fe
access-g
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70
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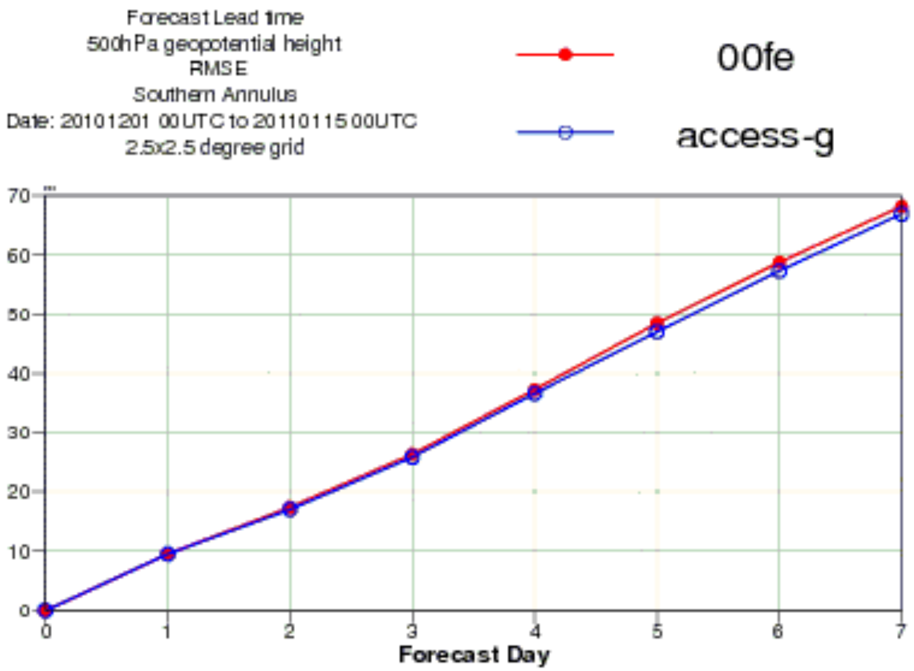
Forecast Day


Forecast Lead time
500hPa geopotential height
RMSE
Southern Annulus
Date: 20101201 00UTC to 20110115 00UTC
2.5x2.5 degree grid
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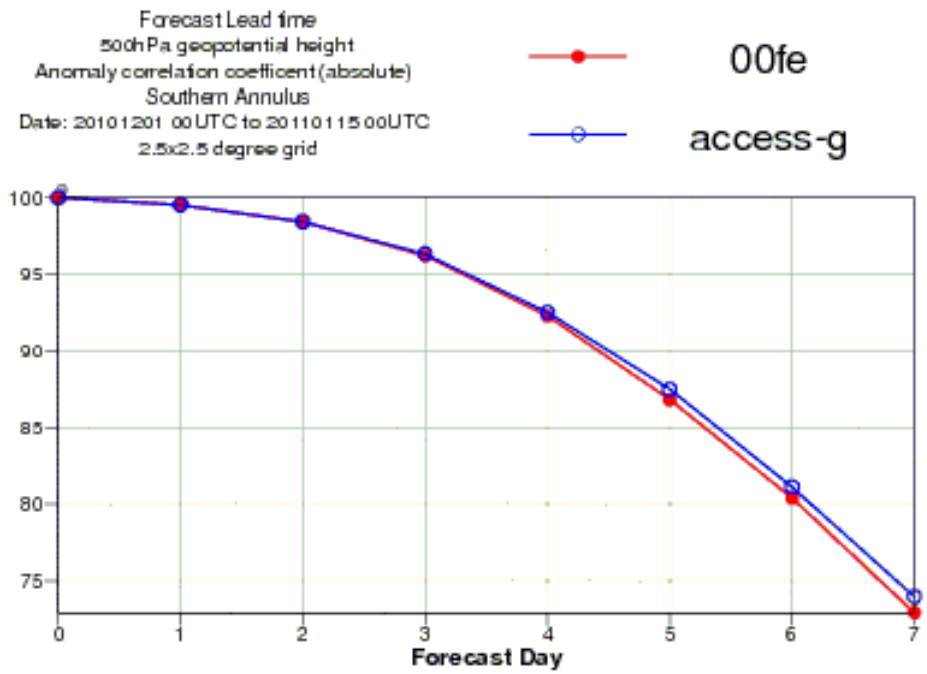
Forecast Day


Forecast Lead time
500hPa geopotential height
Anomaly correlation coefficent (absolute)
Southern Annulus
Date: 20101201 00UTC to 20110115 00UTC
2.5x2.5 degree grid
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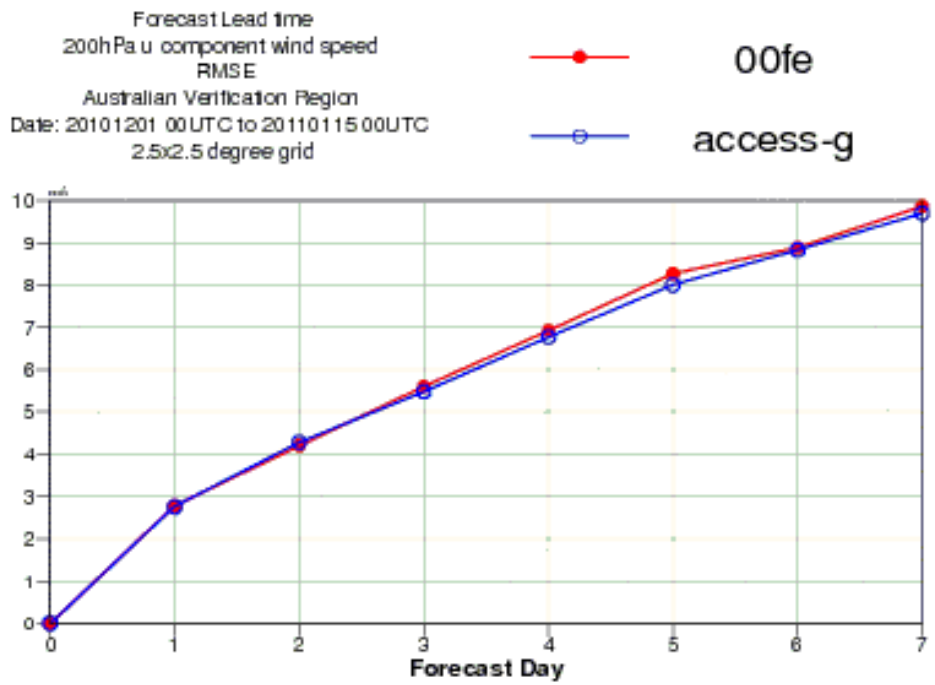
Forecast Day


Forecast Lead time
200hPa u component wind speed
RMSE
Australian Verification Region
Date: 20101201 00UTC to 20110115 00UTC
2.5x2.5 degree grid
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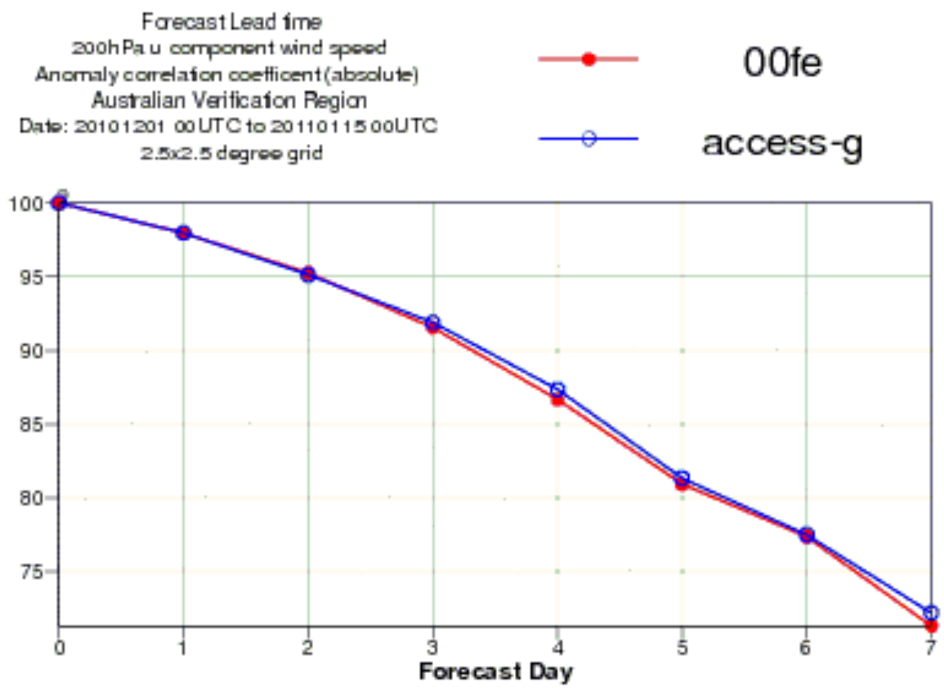
Forecast Day


Forecast Lead time
200hPa u component wind speed
Anomaly correlation coefficent (absolute)
Australian Verification Region
Date: 20101201 00UTC to 20110115 00UTC
2.5x2.5 degree grid
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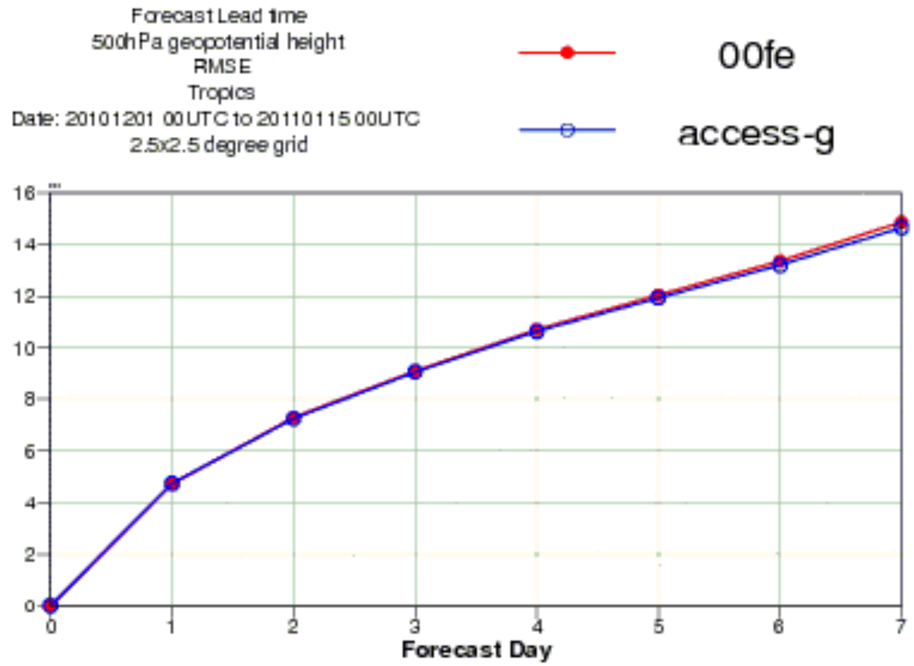
Forecast Day



Forecast Lead time
500hPa geopotential height
RMSE
Tropics
Date: 20101201 00UTC to 20110115 00UTC
2.5x2.5 degree grid
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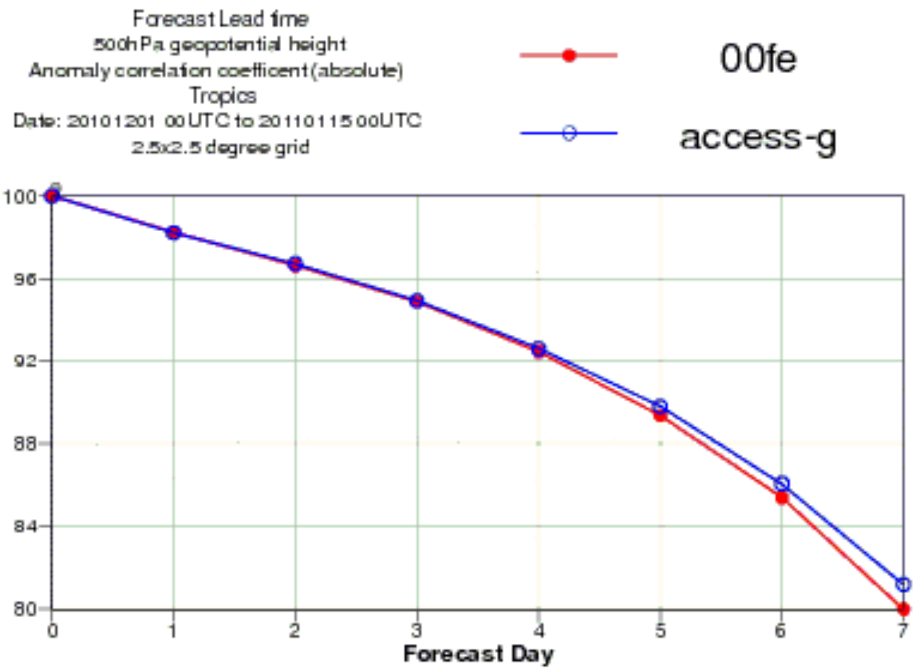
Forecast Day



Forecast Lead time
500hPa geopotential height
Anomaly correlation coefficient (absolute)
Tropics
Date: 20101201 00UTC to 20110115 00UTC
2.5x2.5 degree grid
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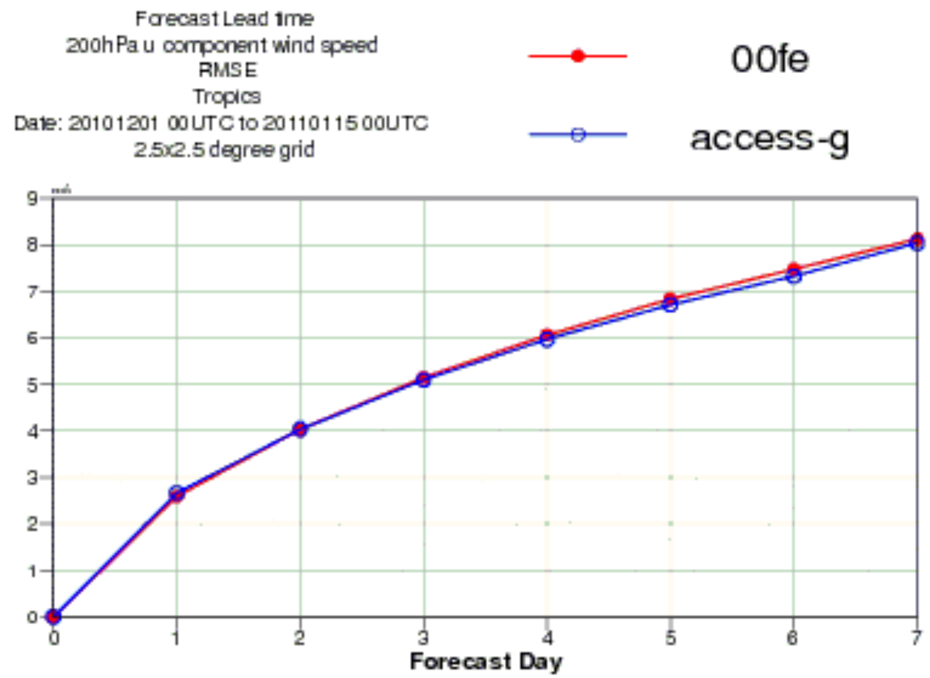
Forecast Day


Forecast Lead time
200hPa u component wind speed
RMSE
Tropics
Date: 20101201 00UTC to 20110115 00UTC
2.5x2.5 degree grid
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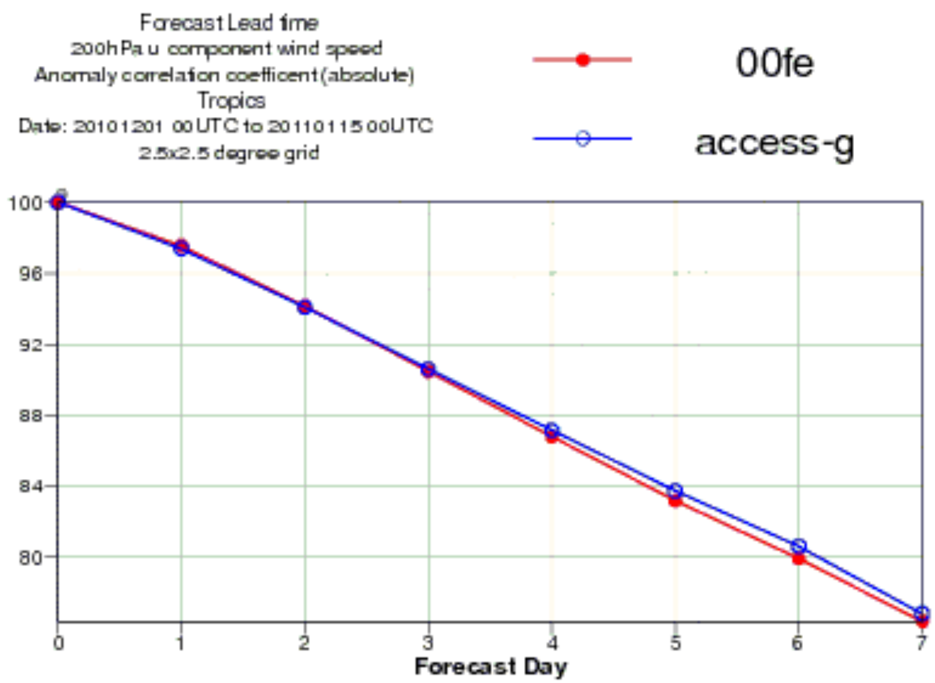
Forecast Day


Forecast Lead time
200hPa u component wind speed
Anomaly correlation coefficient (absolute)
Tropics
Date: 20101201 00UTC to 20110115 00UTC
2.5x2.5 degree grid
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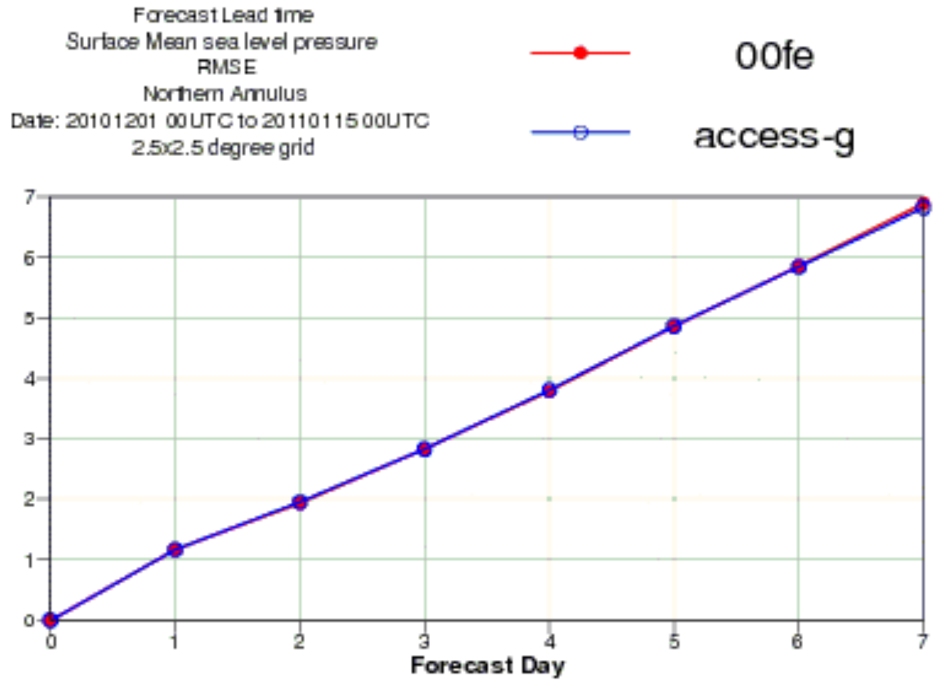
Forecast Day


Forecast Lead time
Surface Mean sea level pressure
RMSE
Northern Annulus
Date: 20101201 00UTC to 20110115 00UTC
2.5x2.5 degree grid
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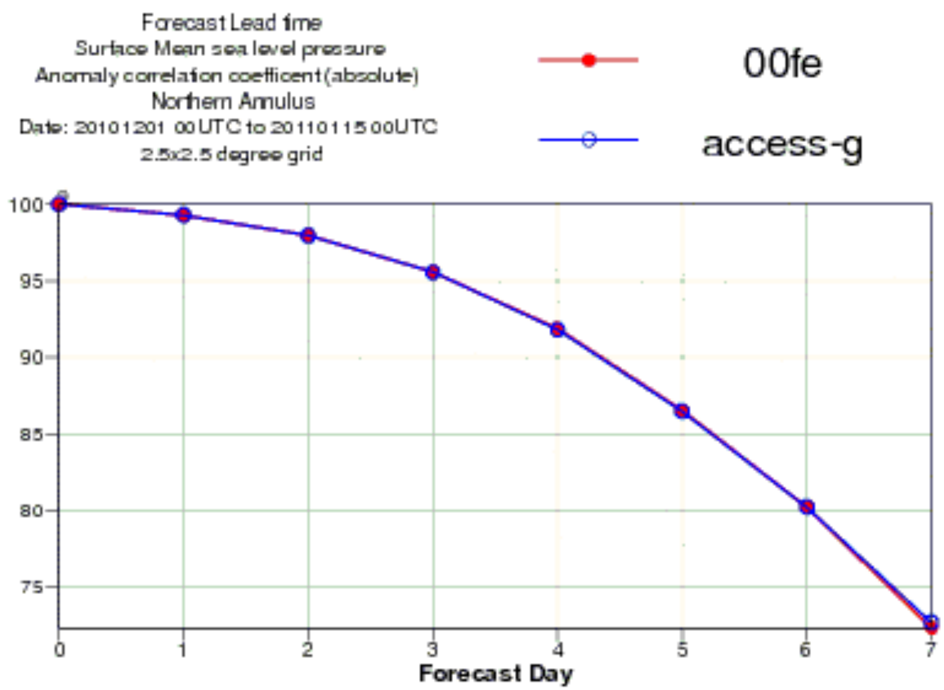
access-g
Forecast Day


Forecast Lead time
Surface Mean sea level pressure
Anomaly correlation coefficent (absolute)
Northern Annulus
Date: 20101201 00UTC to 20110115 00UTC
2.5x2.5 degree grid
00fe
access-g
Forecast Day

The Future

- Cloud Height Assignment and Verification – LBF, A-Train using Cloudsat and Calipso
- Polar Wind Height Assignment
- AMV Error Characterization
- AMV derivation for Model Clouds
- Continuous data/4D-VAR Assimilation
- Extreme Weather Events, TCs,…
- Algorithm Update

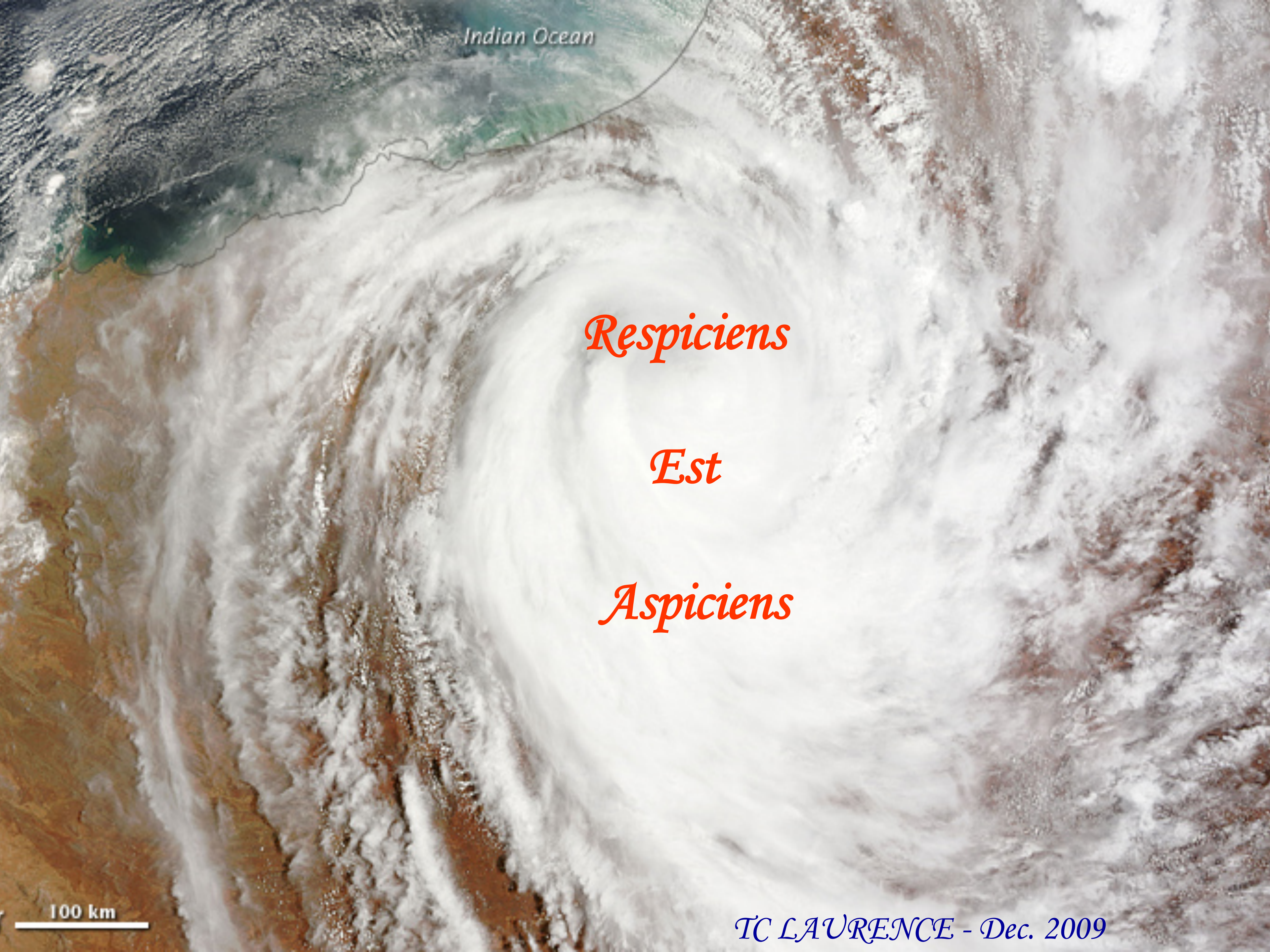
Summary

- Geo-stationery AMVs have been shown to make a significant contribution globally to operational analysis and forecasting.

- High spatial and temporal resolution MTSaT-1R/2 AMVs have been generated at the Australian BoM and have been shown to provide significant benefits in the Australian region.

- The successful application of high resolution MTSaT-1R AMVs has been facilitated by the careful use of quality-control parameters such as the ERR, EE and QI.

- Assimilation studies with UKUM based ACCESS model using 4DVAR show improved forecast skill.


Indian Ocean
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Aspiciens
100 km
TC LAURENCE - Dec. 2009


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