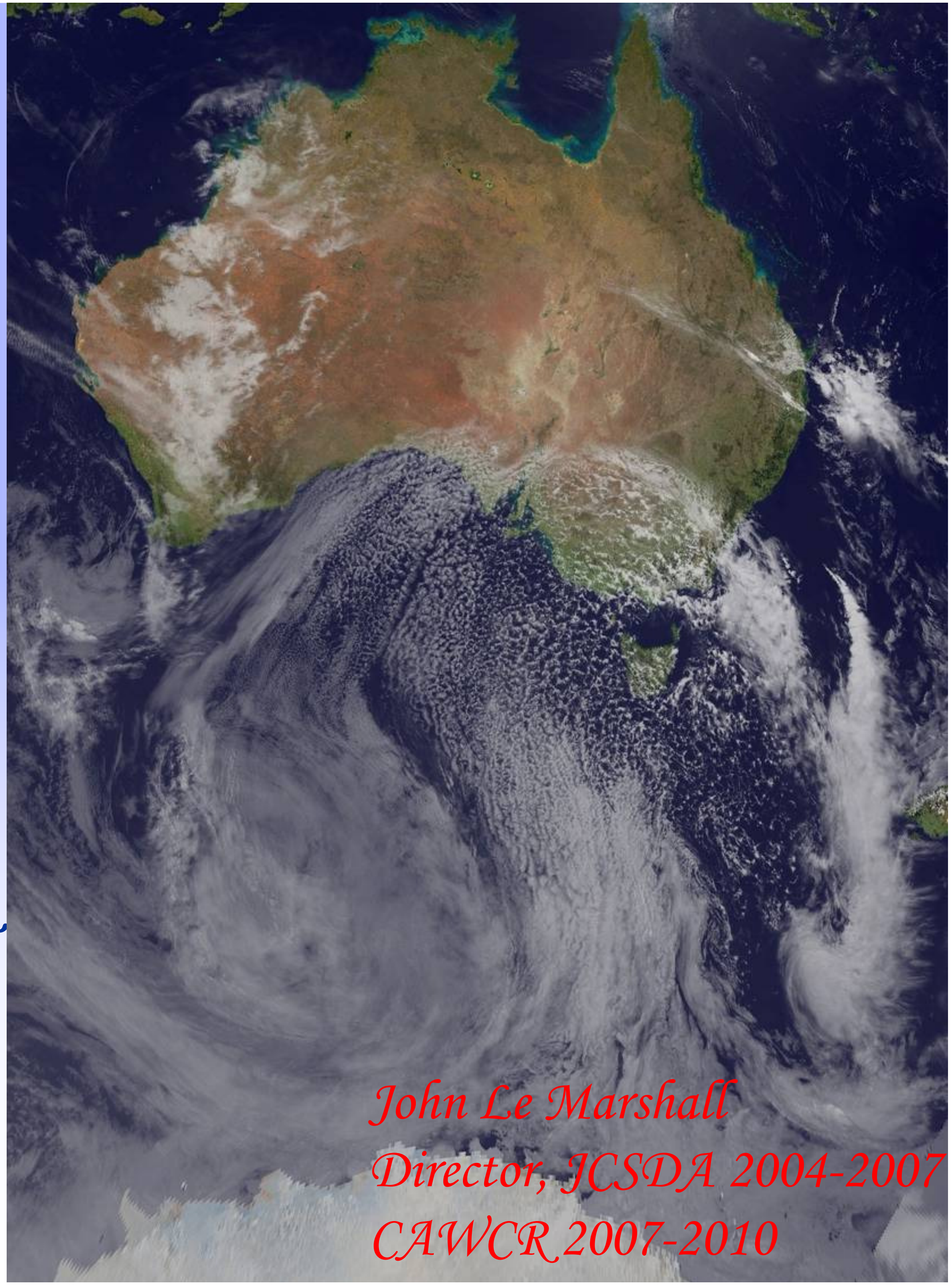
Australian Government
Bureau of Meteorology

HIGH SPATIAL AND TEMPORAL RESOLUTION ATMOSPHERIC MOTION VECTORS – GENERATION, ERROR CHARACTERIZATION AND ASSIMILATION



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

Australian Government
Bureau of Meteorology

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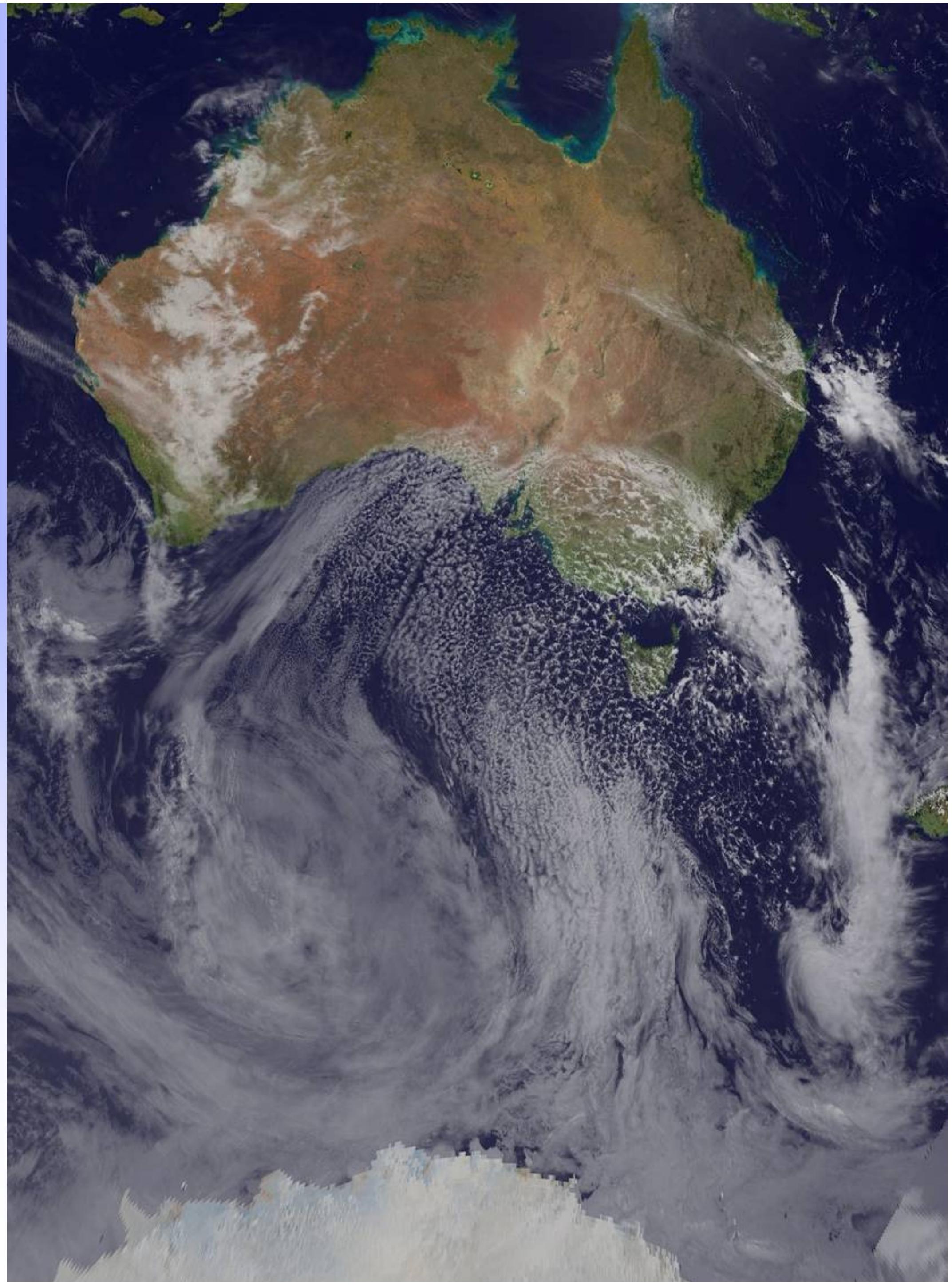
[2]Physics Dept., Latrobe University, Australia

[3] OEB, Bureau of Meteorology, Melbourne, Australia

[4] JCSDA, Camp Springs, USA

[5]NMOC, Bureau of Meteorology, Melbourne, Australia



Overview

- Introduction
- Operational MTSaT-1R AMV Generation at the BoM
- MTSaT-1R AMV Accuracy and Error Characterization
- MTSaT-1R Data Impact Studies
- Plans/Future Prospects
  - Verification
  - MTSaT-2
- Summary

MTSaT-1R 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) or Window Method.

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

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

No autoedit

Operational 15, 30 and 60 Minute MTSAT-1R 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.

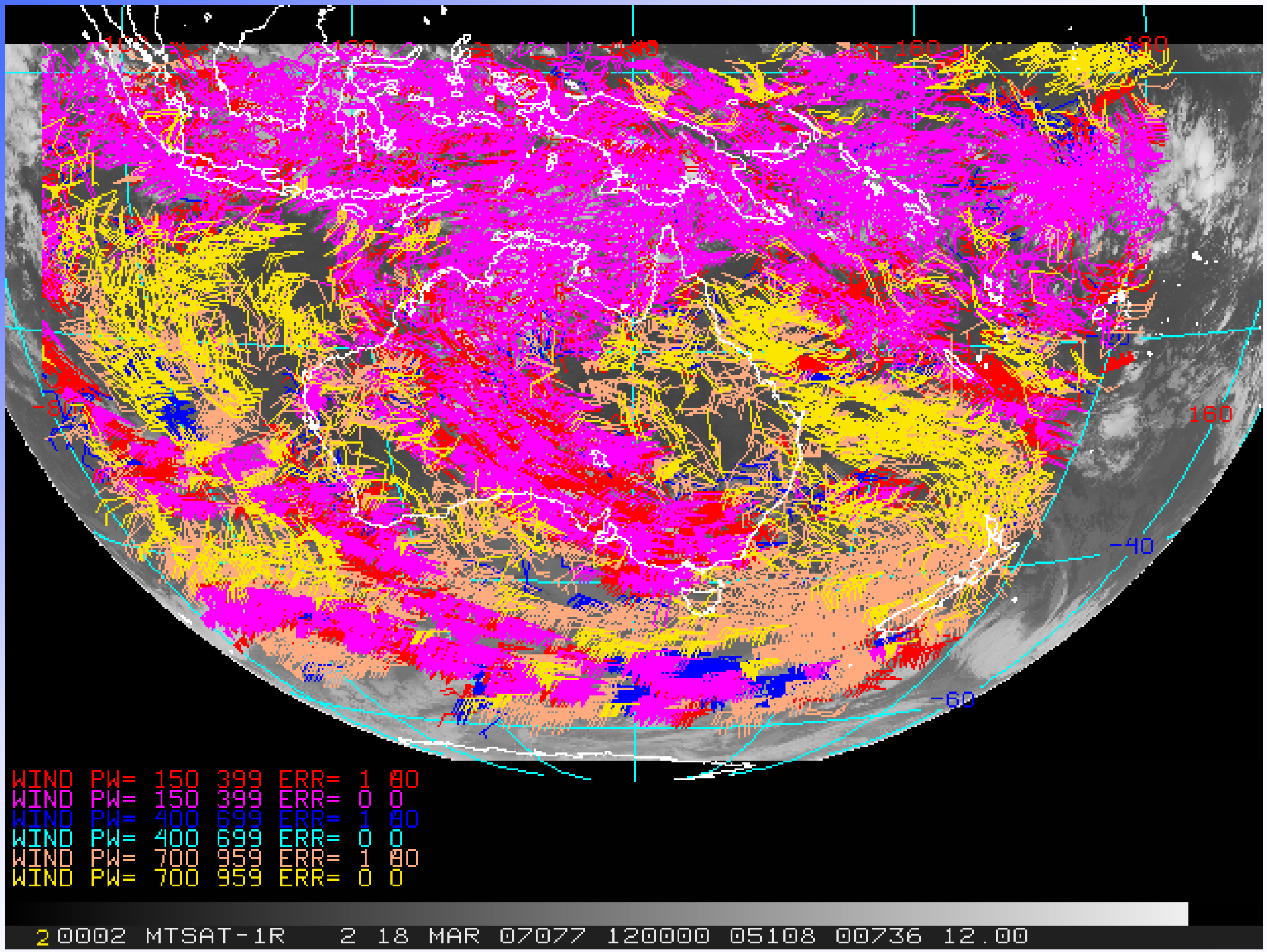
DATE	HHMM 1	HHMM 2	HHMM 3	IR1	HRV	WV
16 June 2008	2230	2330	0030			
16 June 2008	2330	2357	0013			
16 June 2008	2357	0013	0030			
17 June 2008	0030	0130	0230			
17 June 2008	0130	0230	0330			
17 June 2008	0230	0330	0430			
17 June 2008	0330	0430	0530			
17 June 2008	0430	0530	0630			
17 June 2008	0530	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

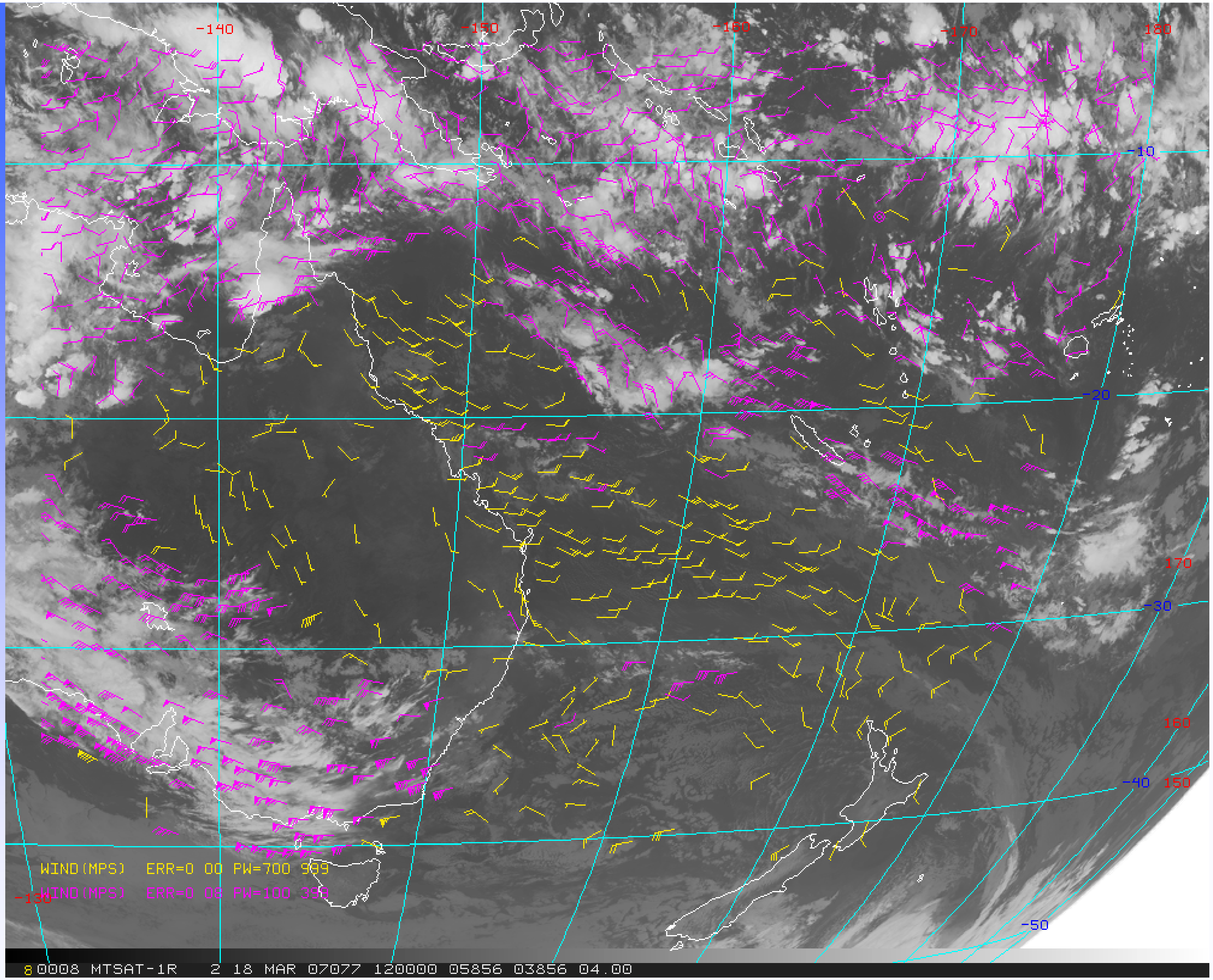
Part of the schedule for Northern Hemisphere wind generation from MTSAT-1R images. This part provides 24 Infrared Channel (IR1) based wind data sets, 22 High Resolution Visible (HRV) image and 4 Water Vapour (WV) image based data sets from the full disc and northern hemisphere images listed.

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			

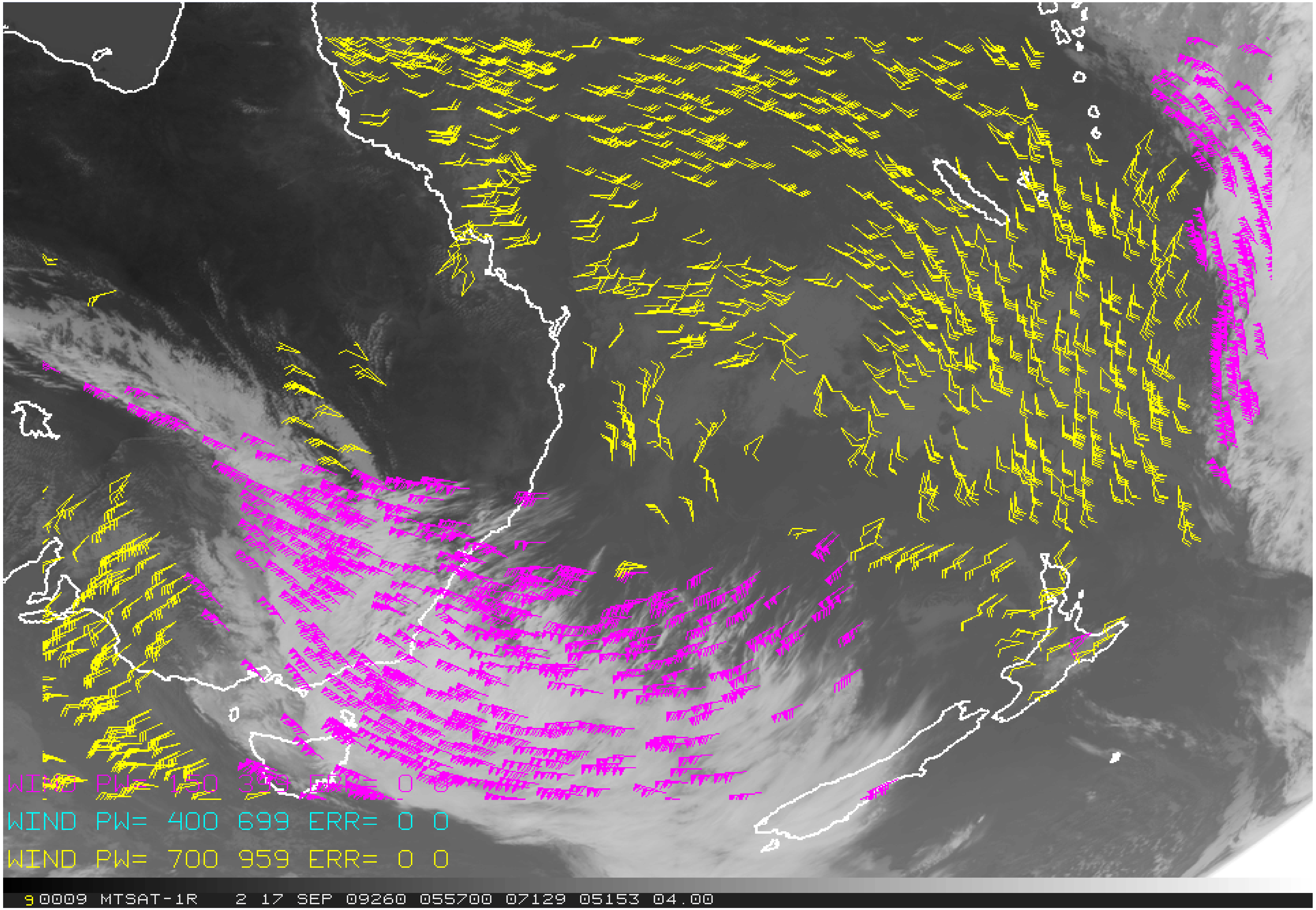
Full Disc Image
Northern Hemisphere Image



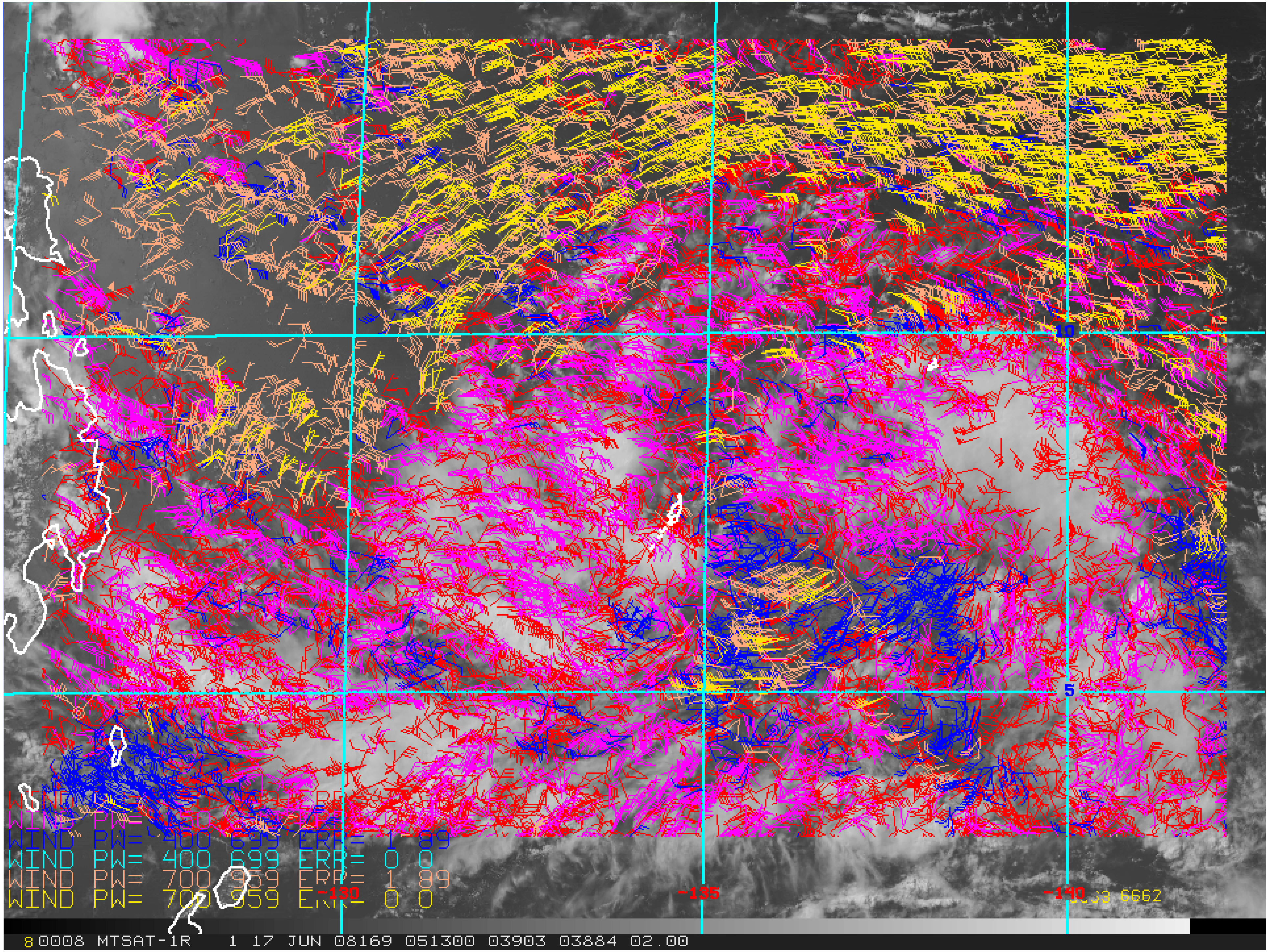
MTSat-1R AMVs generated around 12 UTC on 18 March 2007. Magenta denotes upper level tropospheric vectors, yellow, lower level tropospheric vectors

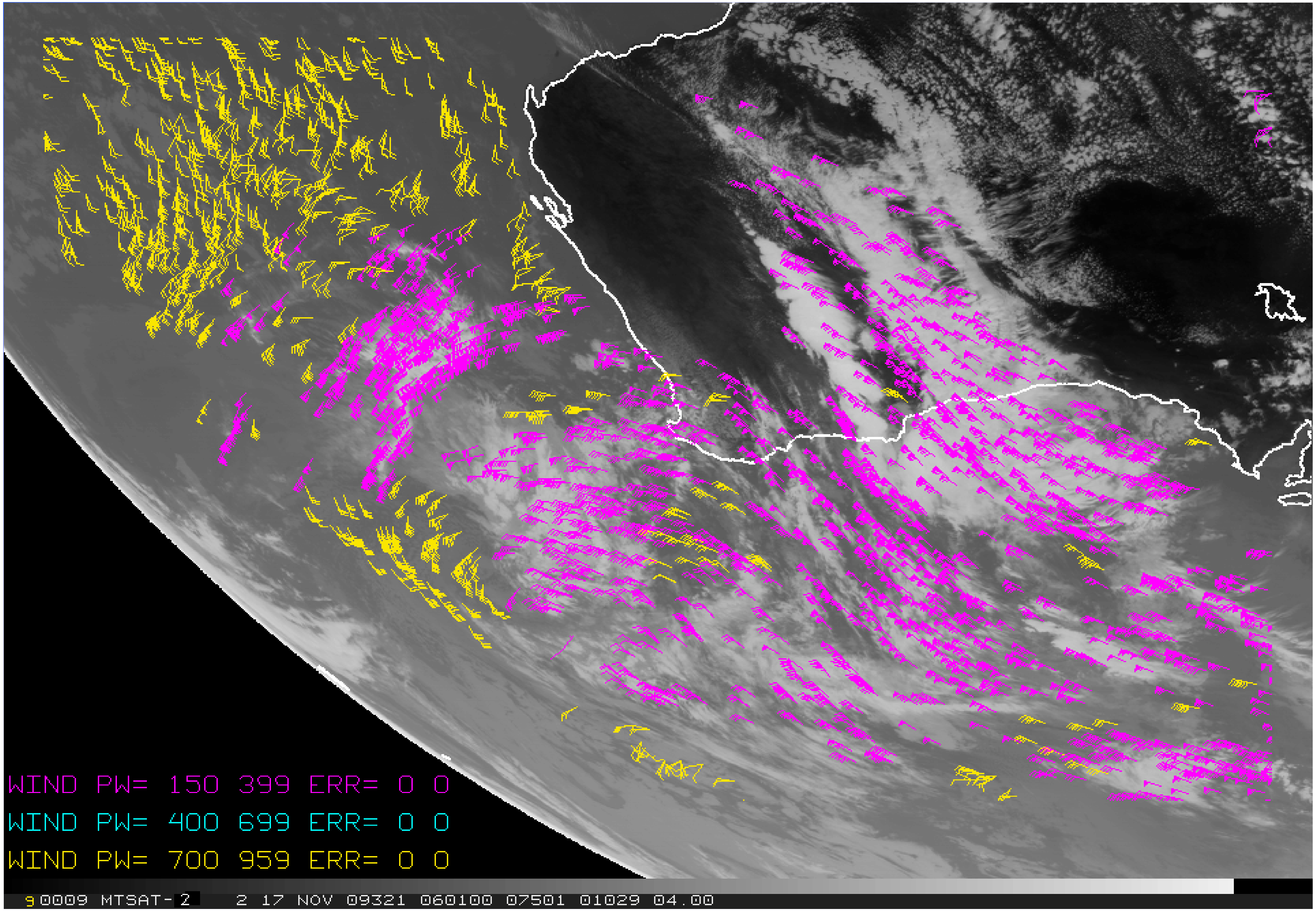


A selection of MTSat-1R AMVs generated around 12 UTC on 18 March 2007. Magenta denotes upper level tropospheric vectors (above 500 hPa), yellow, lower level tropospheric vectors (below 500 hPa)

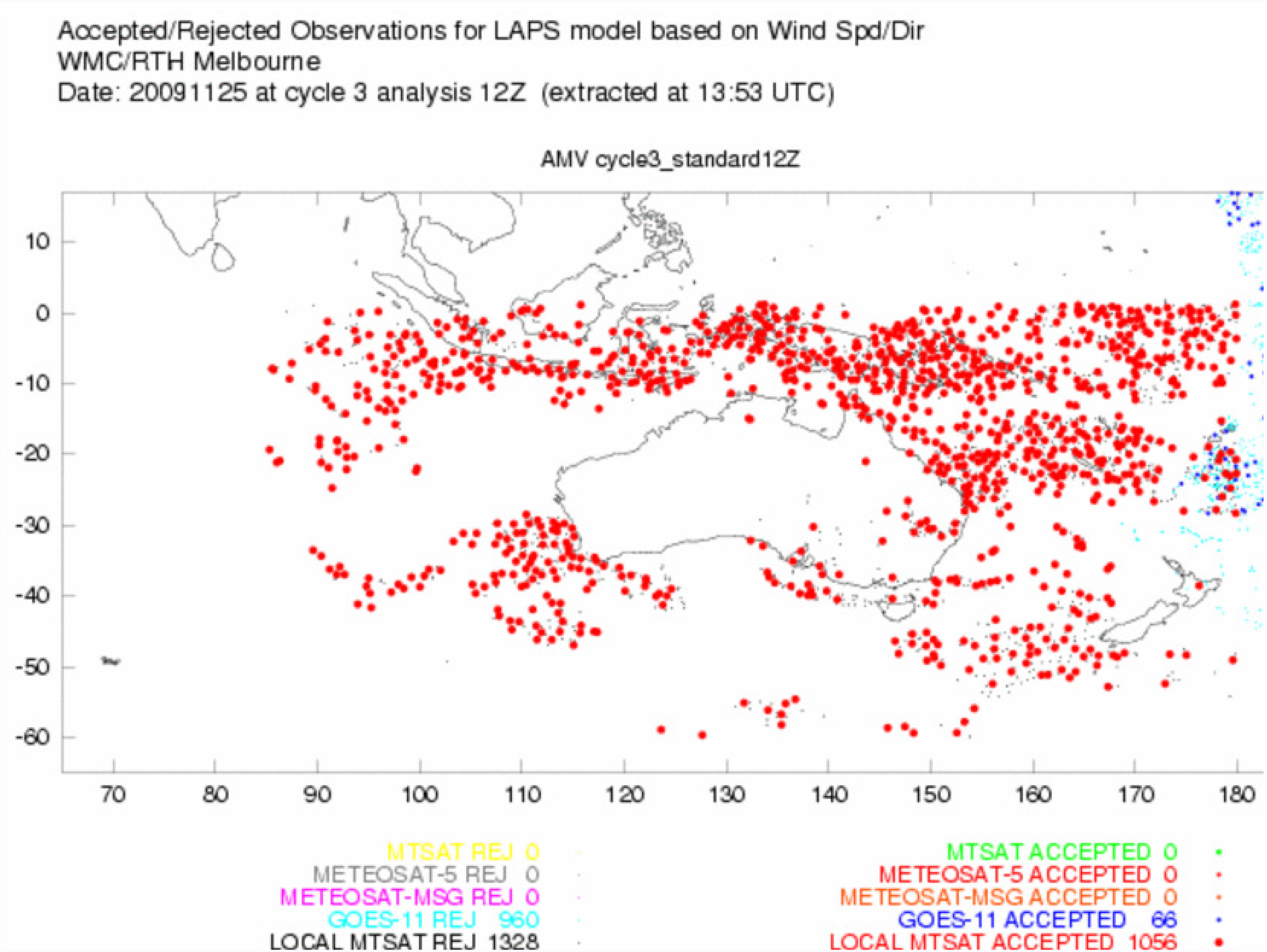


MTSat-1R IR-1 AMVs generated around 06 UTC on 17 September 2009. Magenta denotes upper level tropospheric vectors, yellow, lower level tropospheric vectors


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



MTSat-2 IR-1 AMVs generated around 06 UTC on 17 September 2009. Magenta denotes upper level tropospheric vectors, yellow, lower level tropospheric vectors



MTSat-2 IR-1 AMVs generated around 012 UTC on 25 November 2010. Red denotes AMVs used by the operational analysis.

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

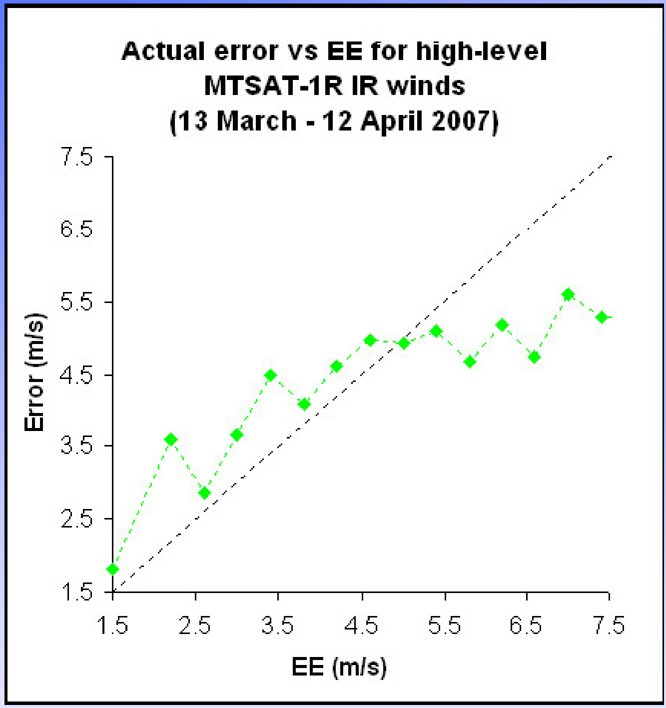


Fig. 2 (a) Measured error (m/s) versus EE for high-level MTSAT-1R IR winds (13 March - 12 April 2007

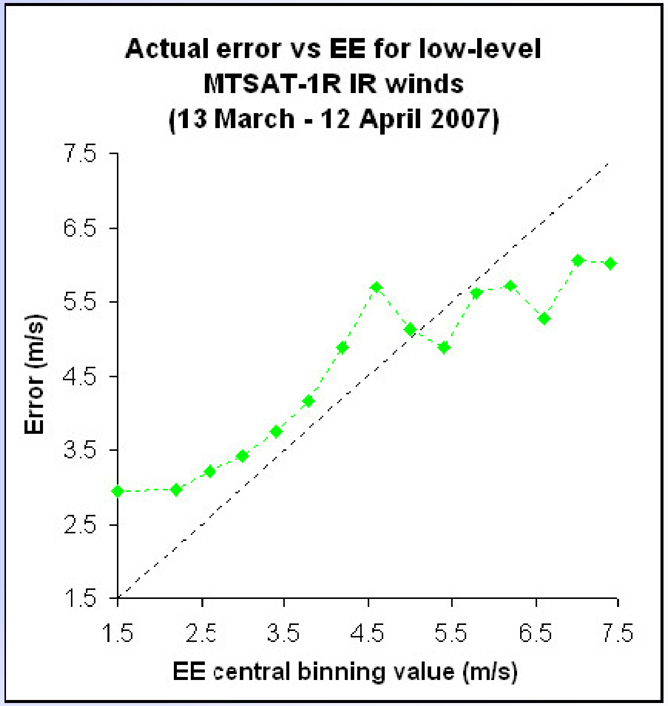
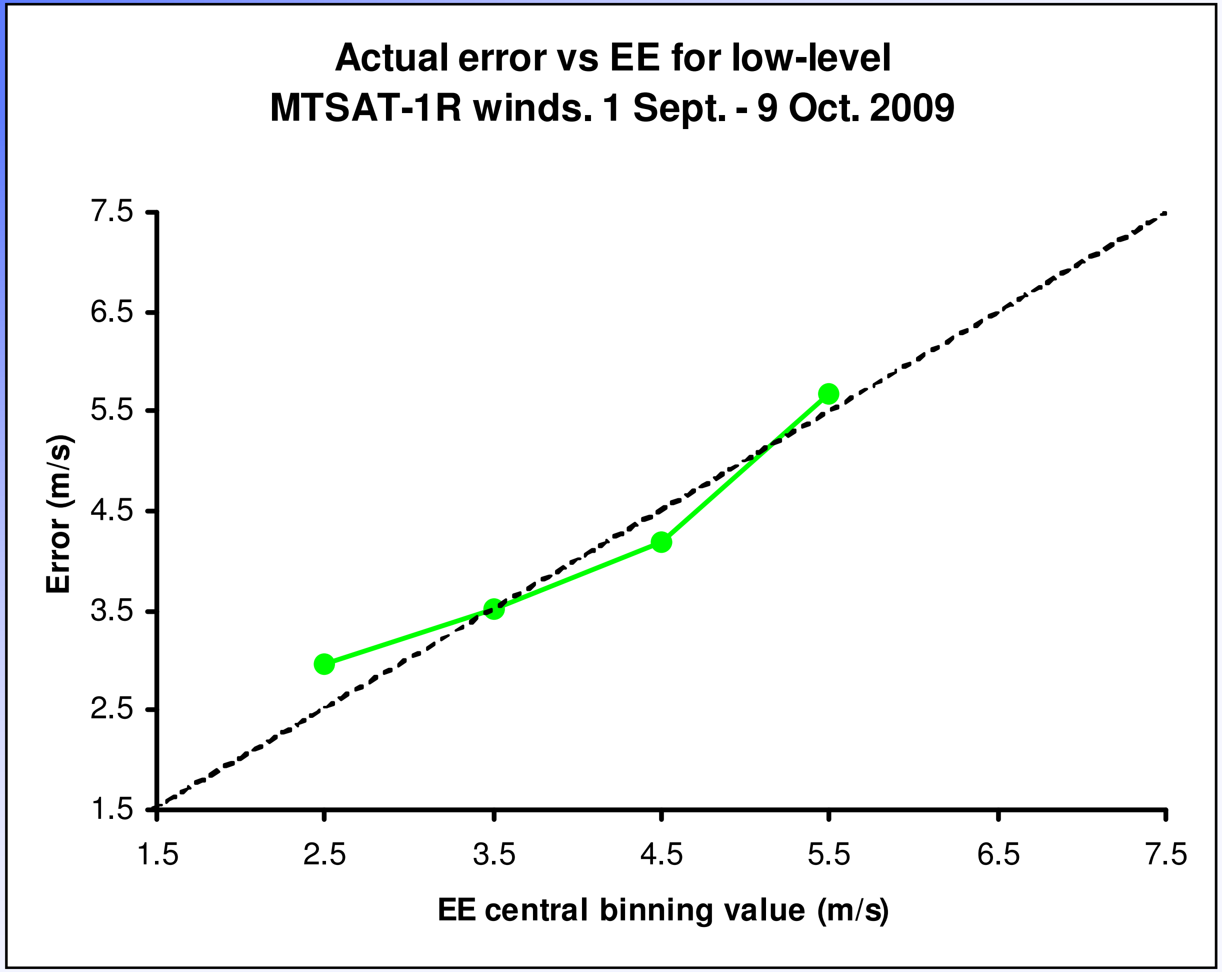


Fig. 2 (b) Measured error (m/s) versus EE for low-level MTSAT-1R IR winds (13 March - 12 April 2007)



Measured error(m/s) vs EE for low-level MTSAT-1R IR winds. (1 Sept. - 9 Oct. 2009)

Mean Magnitude of Vector Difference (MMVD) and Root Mean Square Difference (RMSD) between MTSat-1R AMVs, forecast model first guess winds and radiosonde winds for the period 18 August to 18 September 2007

Level	Data Source	Bias (ms^{-1})	No. of Obs	MMVD (ms^{-1})	RMSVD (ms^{-1})
High – up to 120 km separation between radiosondes and AMVs	**AMVs**	-1.09	500	4.85	5.71
	First Guess	-1.34	500	4.85	5.64
Low – up to 40 km separation between radiosondes and AMVs	**AMVs**	-0.34	79	2.48	2.91
	First Guess	-0.35	79	2.52	2.85

Correlated Error

Correlated error

The correlated error has been analysed for the Bureau produced MTSat-1R 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 **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.

Fig. 3 Error correlation versus distance (100 km bins) for low-level MTSat-1R AMVs with EE < 6 and 8 m/s (March – July 2007)

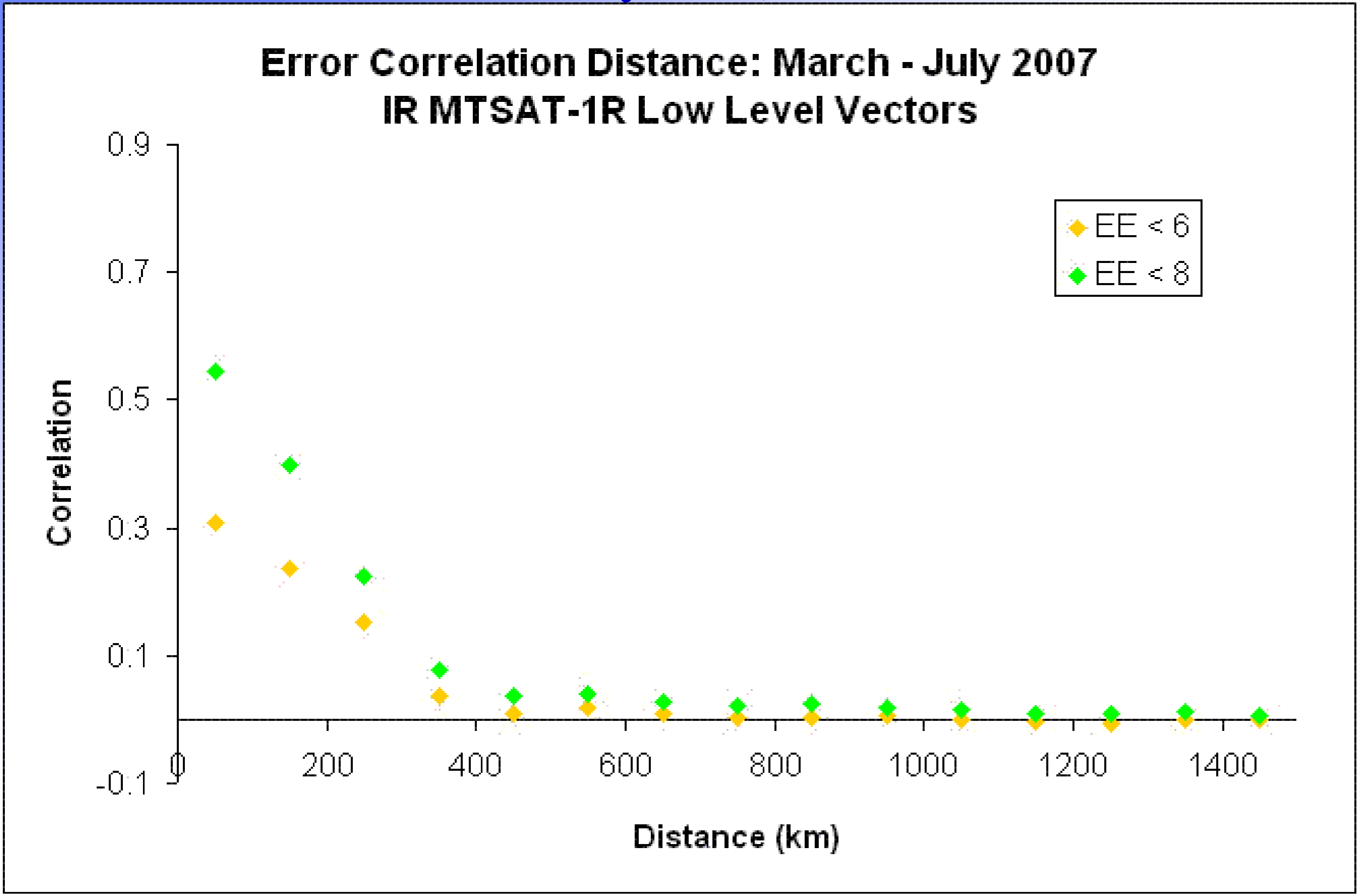


Table 3. Parameters of the SOAR function (Equation 2) which best model the measured error correlations for the MTSat-1R AMVs listed in the left column of the table. (February – April, 2007)

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-1R DIRECT READOUT AMV GENERATION AND RT ASSIMILATION

MTSaT-1R at 140^{o}E 0^{o}S from 2005

Ch2 (IR1) AMVs generated in RT

RT trial 1 Sept. - 8 Oct. 2007 – 72 cases
Trial used now operational RT LAPS 375 61 levels

Local AMVs subsequently accepted for operational use.

OPERATIONAL TRIAL

OLD OPERATIONAL SYSTEM

1 September – 8 October 2008

Used

* Real Time Local Satellite Winds

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

* Operational Regional Forecast Model (L61)and Data Base (Inc JMA AMVs)

* Operational Regional Verification Grid

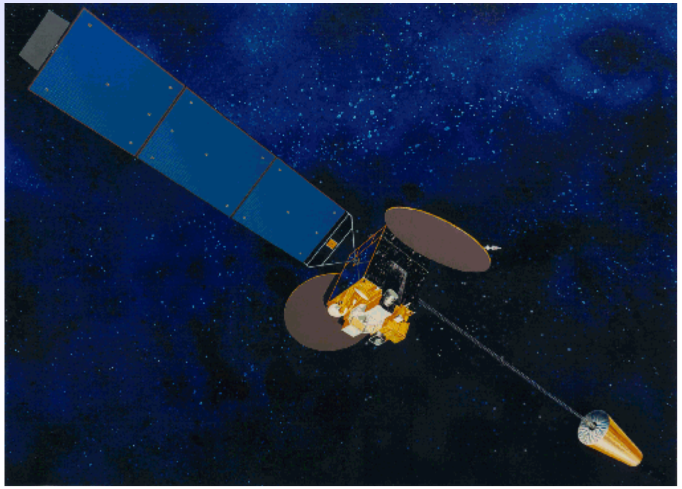
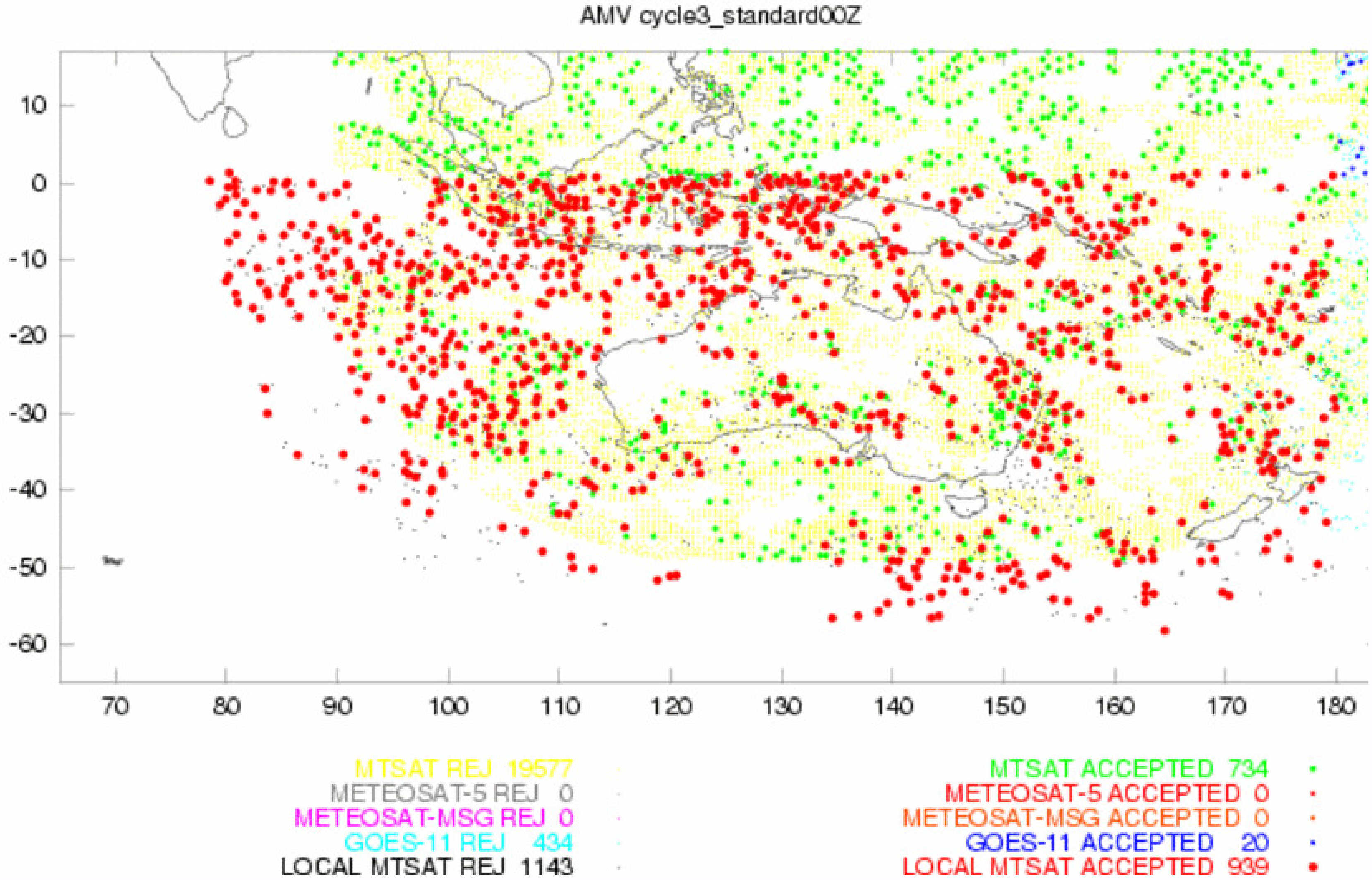


Table 5 (b) 24 hr forecast verification S1 Skill Scores for the next operational regional forecast system (L61 LAPS) and L61 LAPS with IR, 6-hourly image based AMVs for 1 September to 8 October 2007 (72 cases)

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

Accepted/Rejected Observations for LAPS model based on Wind Spd/Dir
WMC/RTH Melbourne
Date: 20071216 at cycle 3 analysis 00Z (extracted at 00:49 UTC)



AMV Data Impact Studies in the Australian Community Climate Earth System Simulator (ACCESS)

Initial Regional Data Impact Studies Using Then Operational AMV System, Continuous Wind Data (Hourly) with 4D-VAR in the Regional Model, ACCESS-R

Note: Beneficial impact of hourly winds on operational NWP demonstrated 1996. Winds first used operationally in BoM from 1996 (Le Marshall, 1996)

Australian Community Climate and Earth System Simulator (ACCESS)

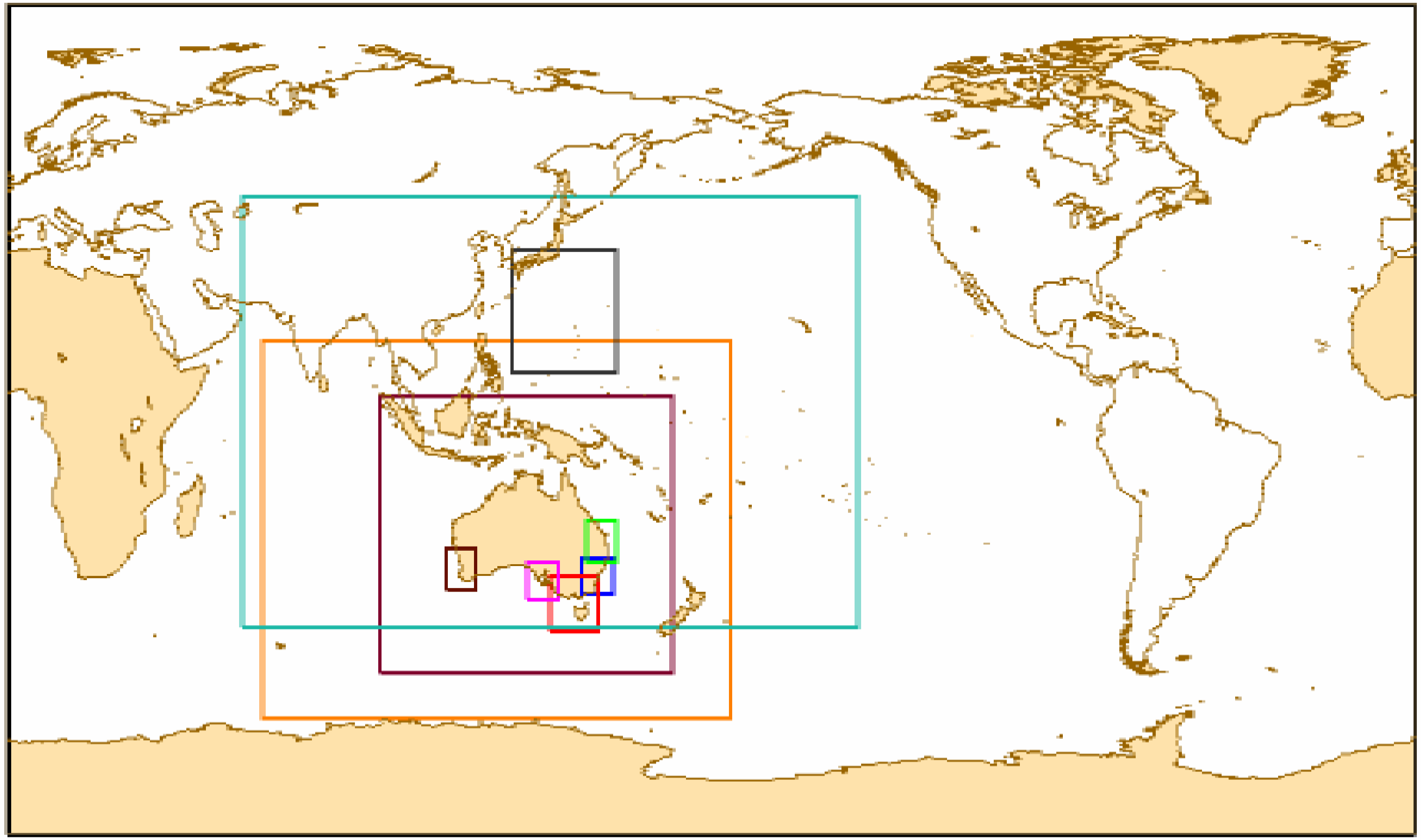
ACCESS - R uses

- The 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)

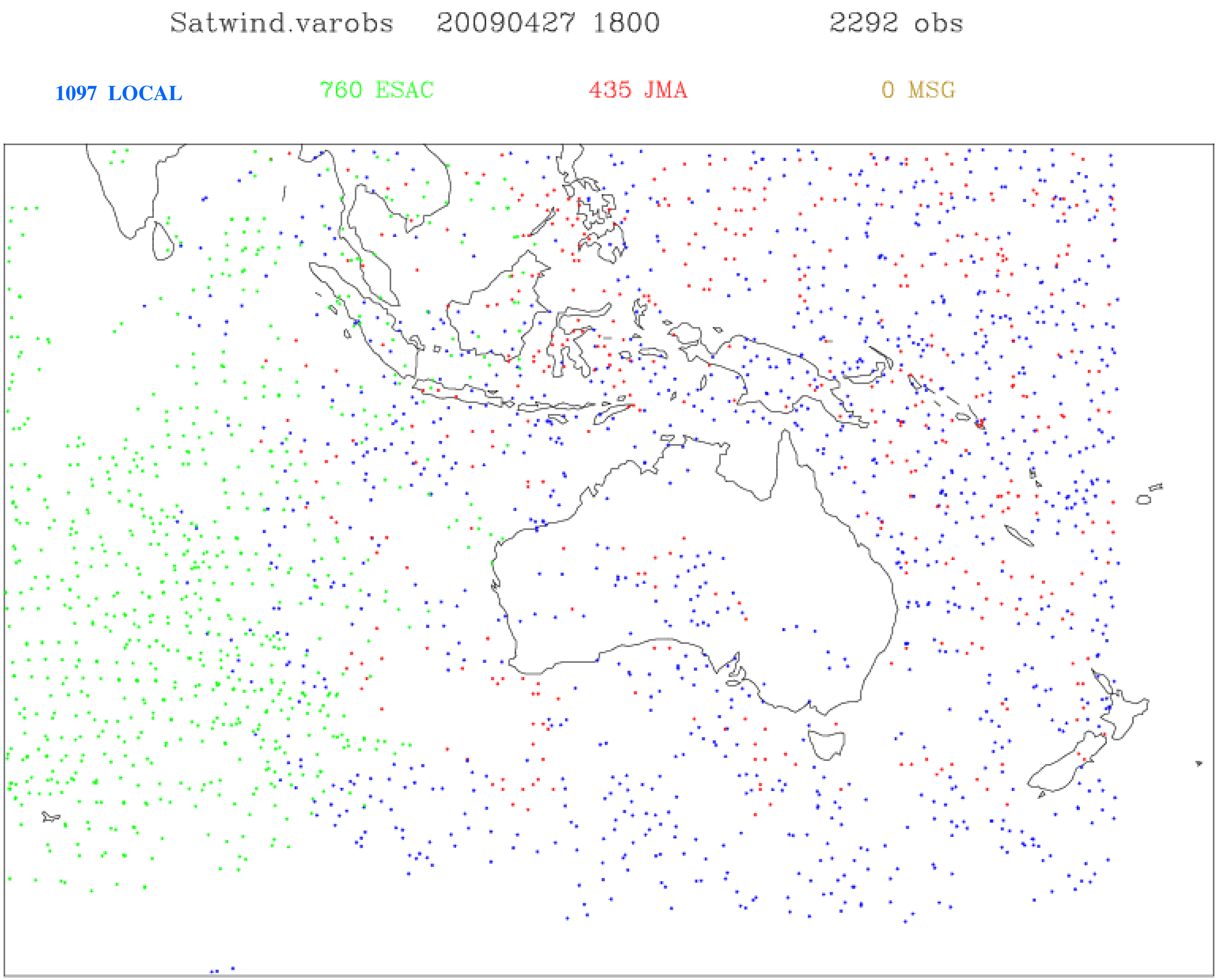
DOMAIN : AUSTRALIA REGION	65.0°S TO 17.125°N,65.0°E TO 184.625°E
UM Horizontal Resolution (lat x lon)	220x320 (0.375°)
Analysis Horizontal resolution (lat x lon)	110x160 (0.75°)
Vertical Resolution	L50
Observational Data Used (6h window)	AIRS, ATOVS, Scat, AMV, SYNOP, SHIP, BUOY,AMDARS, AIREPS, TEMP, PILOT
Sea Surface Temperature Analysis	Daily 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
Suite Definition	SCS vn18.2

Table 1: ACCESS-R System Specification

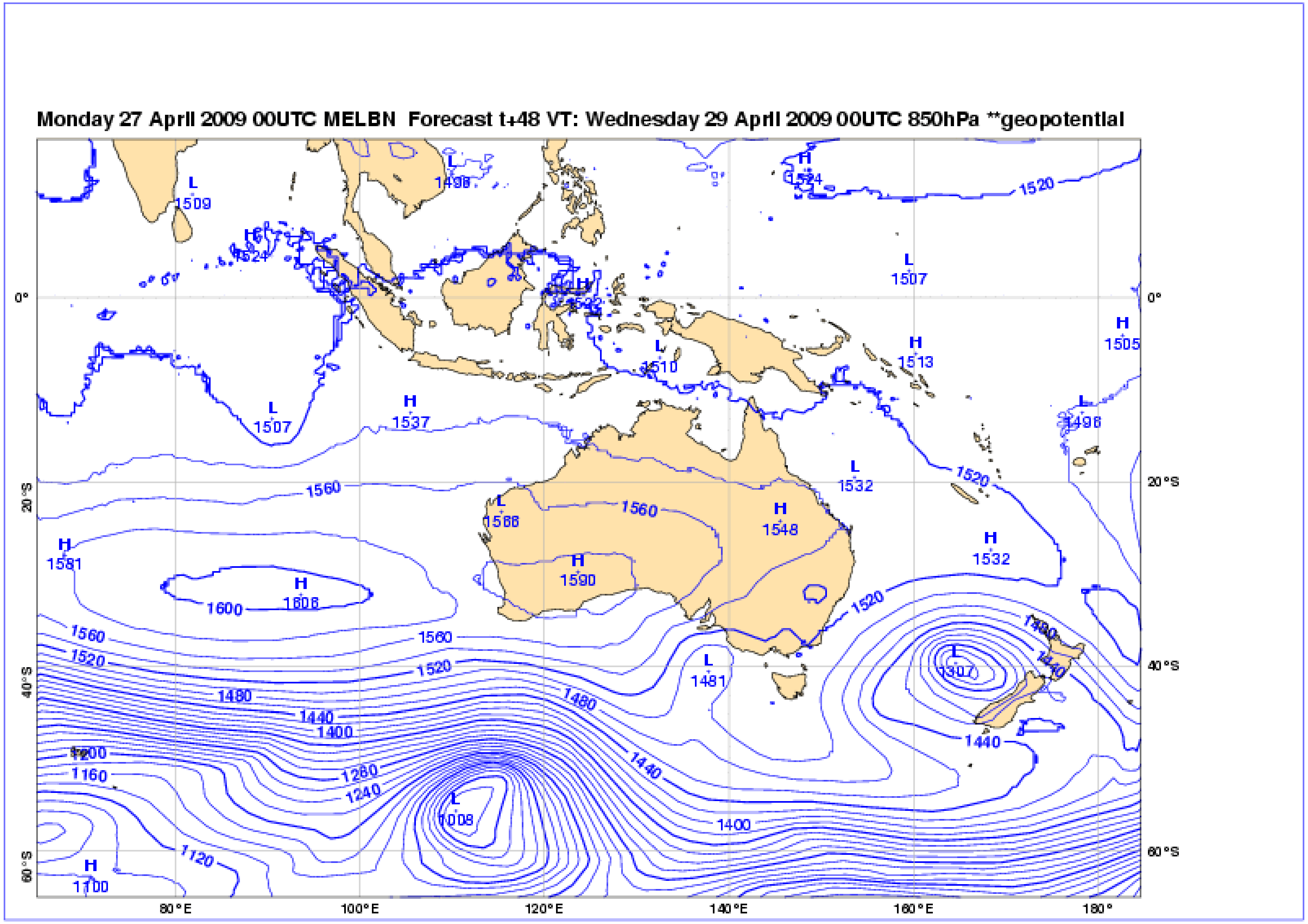


Coverage

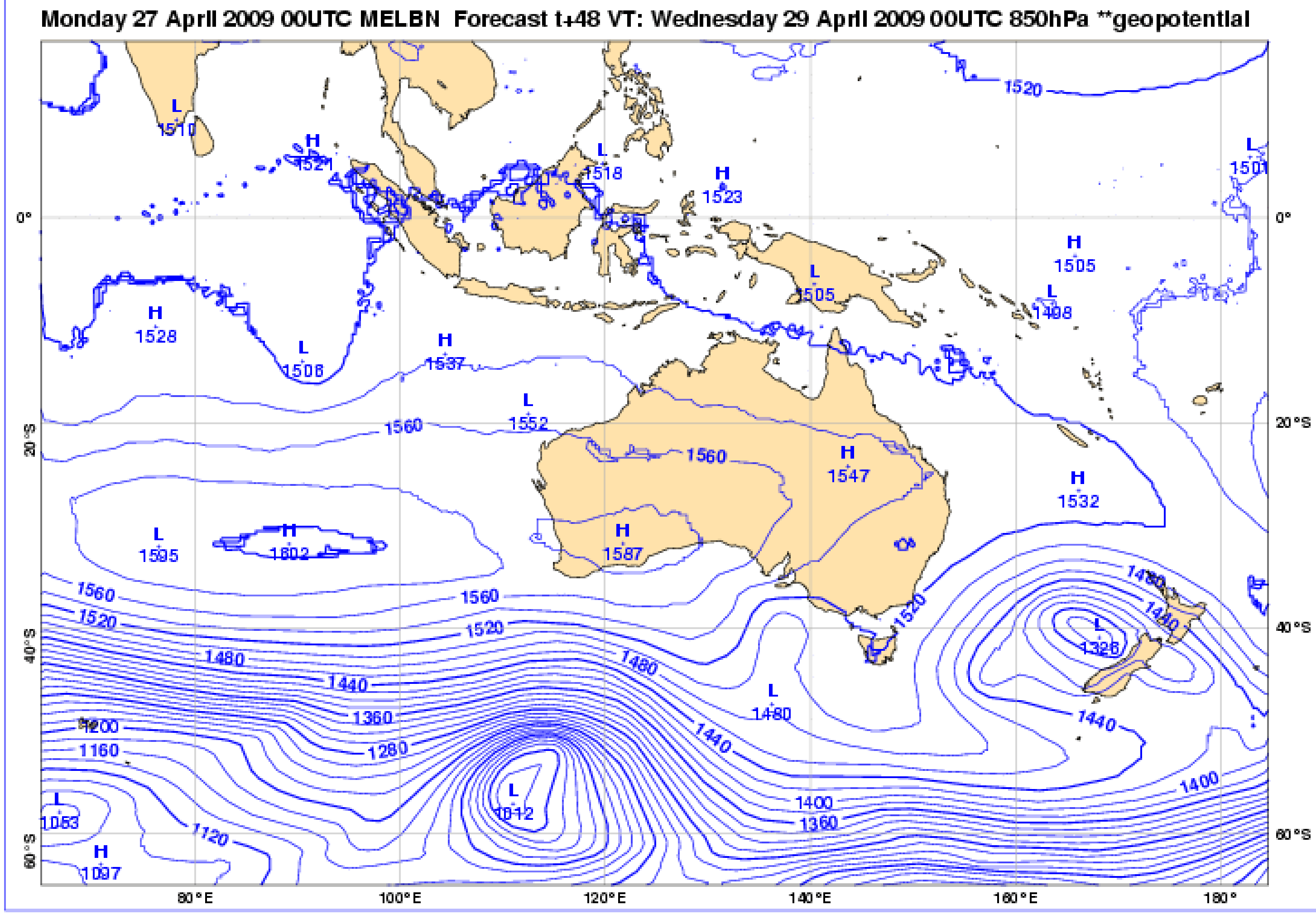
LOCAL MTSat-1R AMVs



CNTL

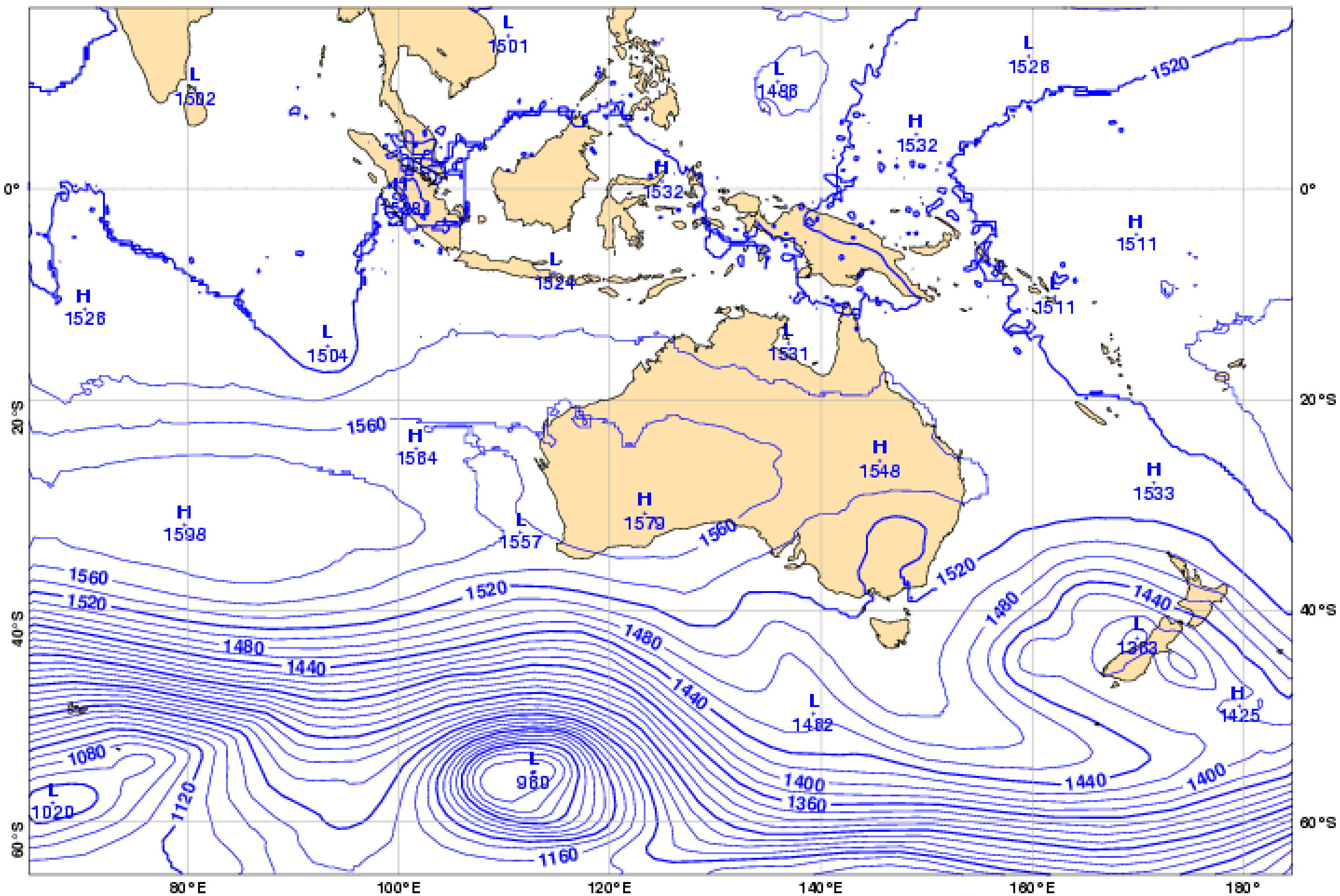

Monday 27 April 2009 00UTC MELBN Forecast t+48 VT: Wednesday 29 April 2009 00UTC 850hPa **geopotential
80°E
100°E
120°E
140°E
160°E
180°
0°
20°S
40°S
60°S
1520
1560
1600
1480
1440
1400
1200
1160
1280
1240
1120
H 1606
H 1590
L 1307
L 1008
L 1481

Hourly AMVs

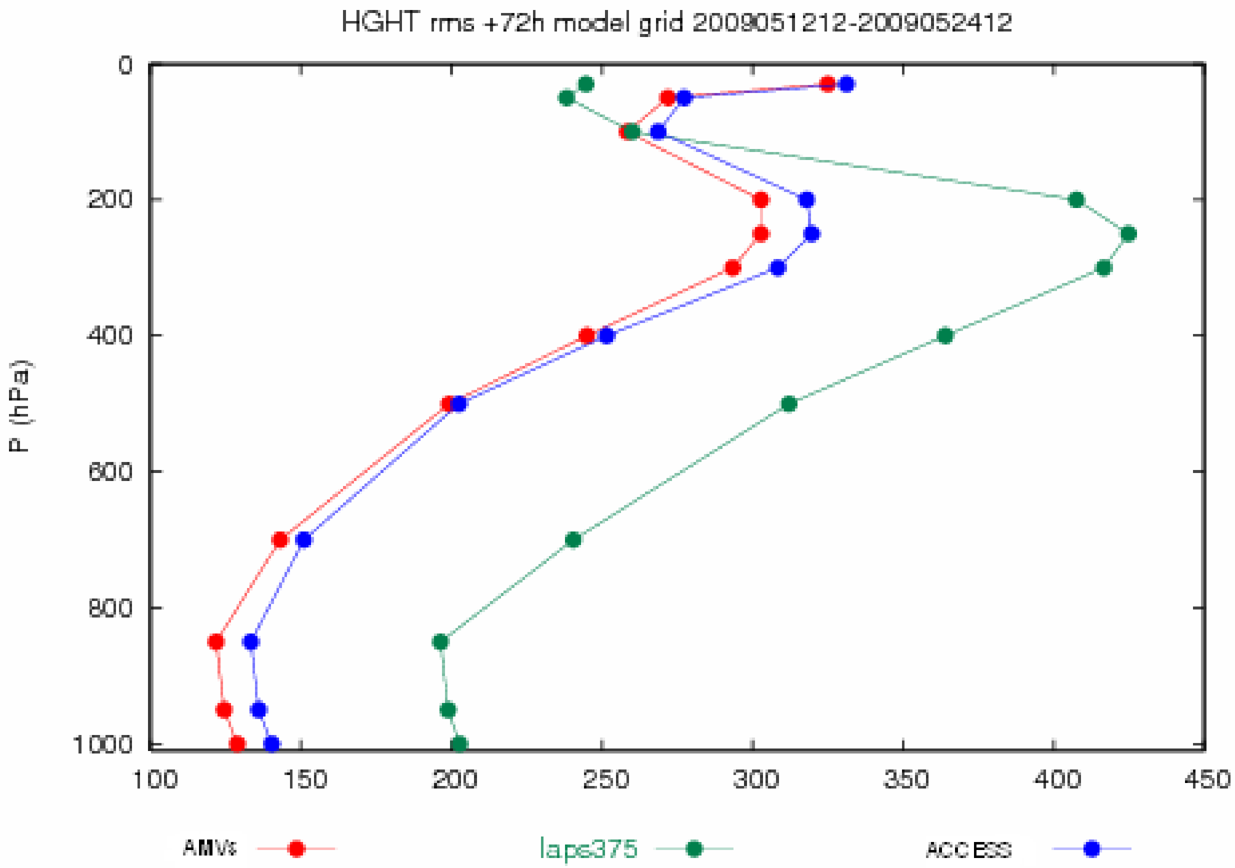


Monday 27 April 2009 00UTC MELBN Forecast t+48 VT: Wednesday 29 April 2009 00UTC 850hPa **geopotential

MELBN Analysis VT:Wednesday 29 April 2009 00UTC 850hPa **geopotential



4D-VAR with Hourly AMVs – Australian Region



AMV Data Impact Studies in the Australian Community Climate Earth System Simulator (ACCESS)

Initial regional data impact studies using then operational AMV System and quarter hourly and one hourly data in the Regional Model, ACCESS-R consistent with earlier tests. (ie Beneficial Impact)

This data impact has been subsequently repeated with next generation ACCESS related AMV system.

(ACCESS used for QC, height assignment, data thinning etc.)

Regional Data Impact Studies Using New ACCESS based Operational AMV System, Continuous Wind Data (Hourly) with 4D-VAR in the Regional Model, ACCESS-R

NEAR RT TRIAL

NEW OPERATIONAL SYSTEM

1 September – 10 October 2009

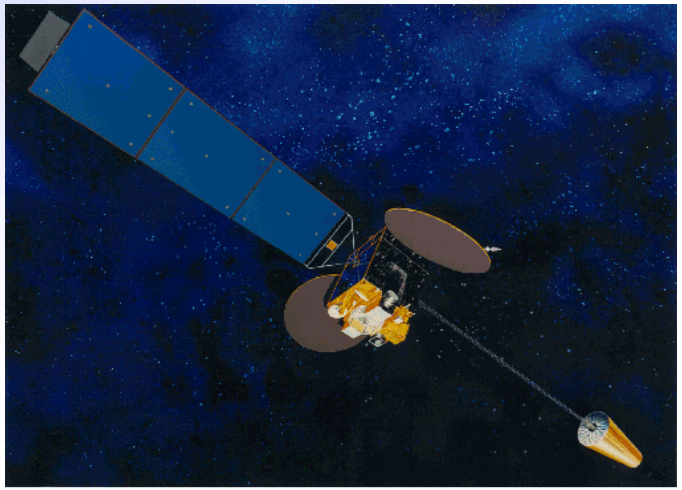
Used

* Real Time Local Satellite Winds

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

~Hourly motion Vectors

* New Operational Regional Forecast Model (ACCESS)and Data Base (Inc JMA AMVs)



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

Table 1. 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

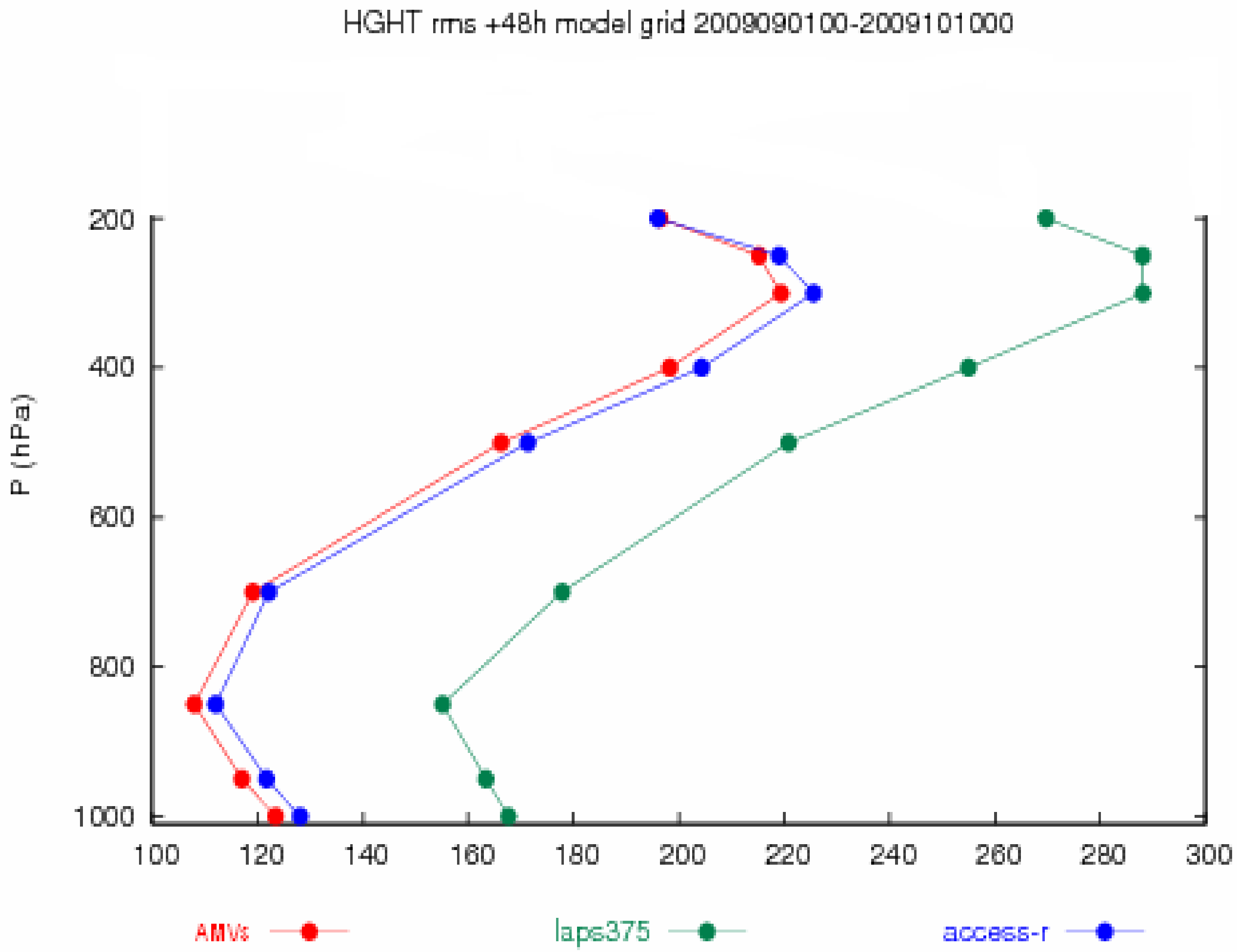
Level	Data Source	Bias (ms^{-1})	MMVD (ms^{-1})	RMSVD (ms^{-1})
High – up to 80 km separation between radiosondes and AMVs	**AMVs**	-0.65	3.31	3.92
	Background	-0.30	3.48	4.09
Low - up to 150 km separation between radiosondes and AMVs	**AMVs**	0.17	2.86	3.36
	First Guess	0.18	2.67	3.14
Low – up to 30 km separation between radiosondes and AMVs	**AMVs**	0.22	2.26	2.51
	First Guess	-0.24	2.30	2.57

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

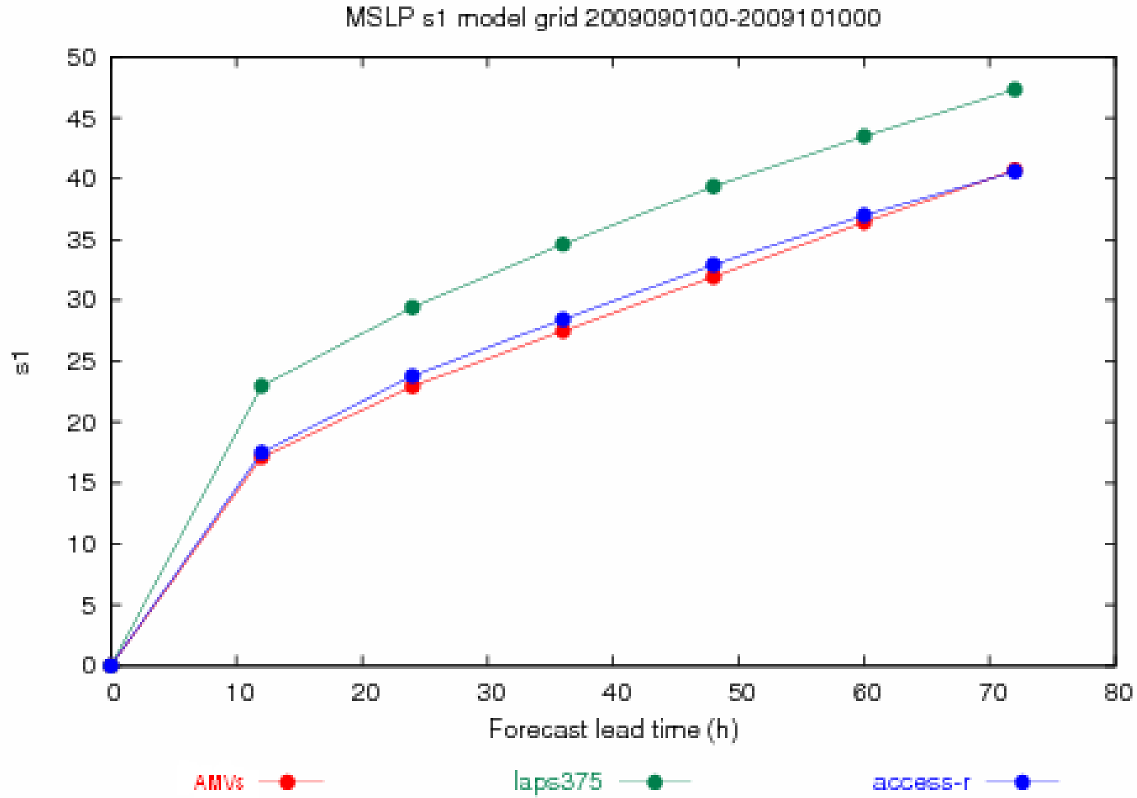
Table 2. EE Range (ms^{-1}), Root Mean Square Difference (RMSD) between MTSAT-1R IR1 AMVs and radiosonde winds and number of matches for the period 1 September to 9 October 2009

Level	EE Range	Mean RMSVD (ms^{-1})	NOBS
Low (700 – 1000 hPa)- up to 80 km separation between radiosondes and AMVs	**2 - 3 (2.5)**	2.96	116
	3 – 4 (3.5)	3.51	84
	4 – 5 (4.5)	4.18	50
	5 – 6 (5.5)	5.67	32

4D-VAR with Hourly AMVs – Australian Region



4D-VAR with Hourly AMVs – Australian Region



Australian Community Climate and Earth System Simulator (ACCESS)

Initial regional data impact studies using new operational AMV System and hourly data in the Regional Model, ACCESS-R consistent with earlier tests. (ie. Beneficial Impact)

(In the new ACCESS related AMV system. ACCESS used for QC, height assignment, data thinning etc.)

TC Forecasting Using High Res. Local Winds in the Operational ACCESS 4D-VAR environment- Some examples

.

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

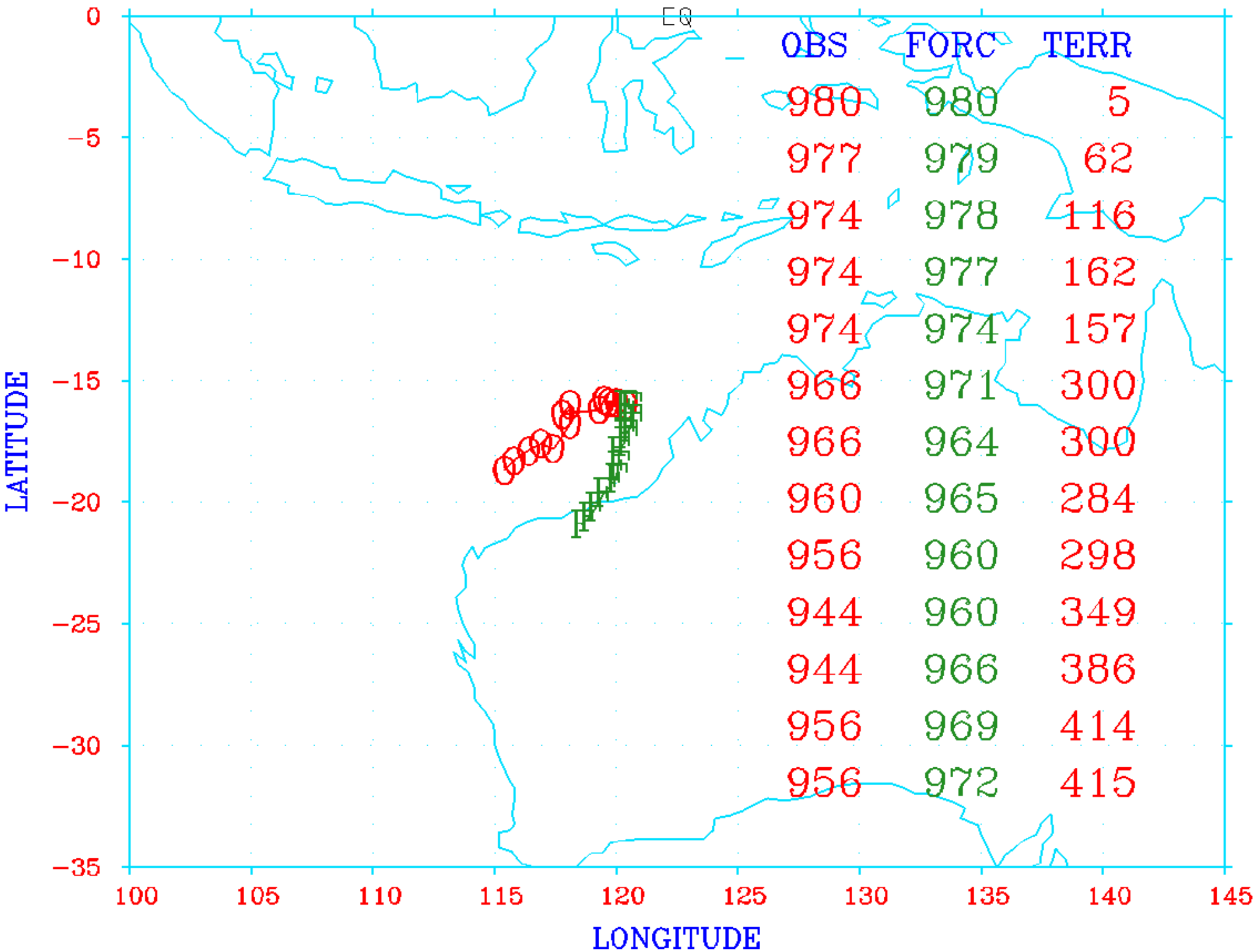
Error Characteristics for Current Local AMV System In ACCESS (UKMO) environment

Table 1. Mean Magnitude of Vector Difference (MMVD) and Root Mean Square Difference (RMSD) between MTSAT-1R AMVs, forecast model first guess winds and radiosonde winds for the period 26 January to 2 February 2009

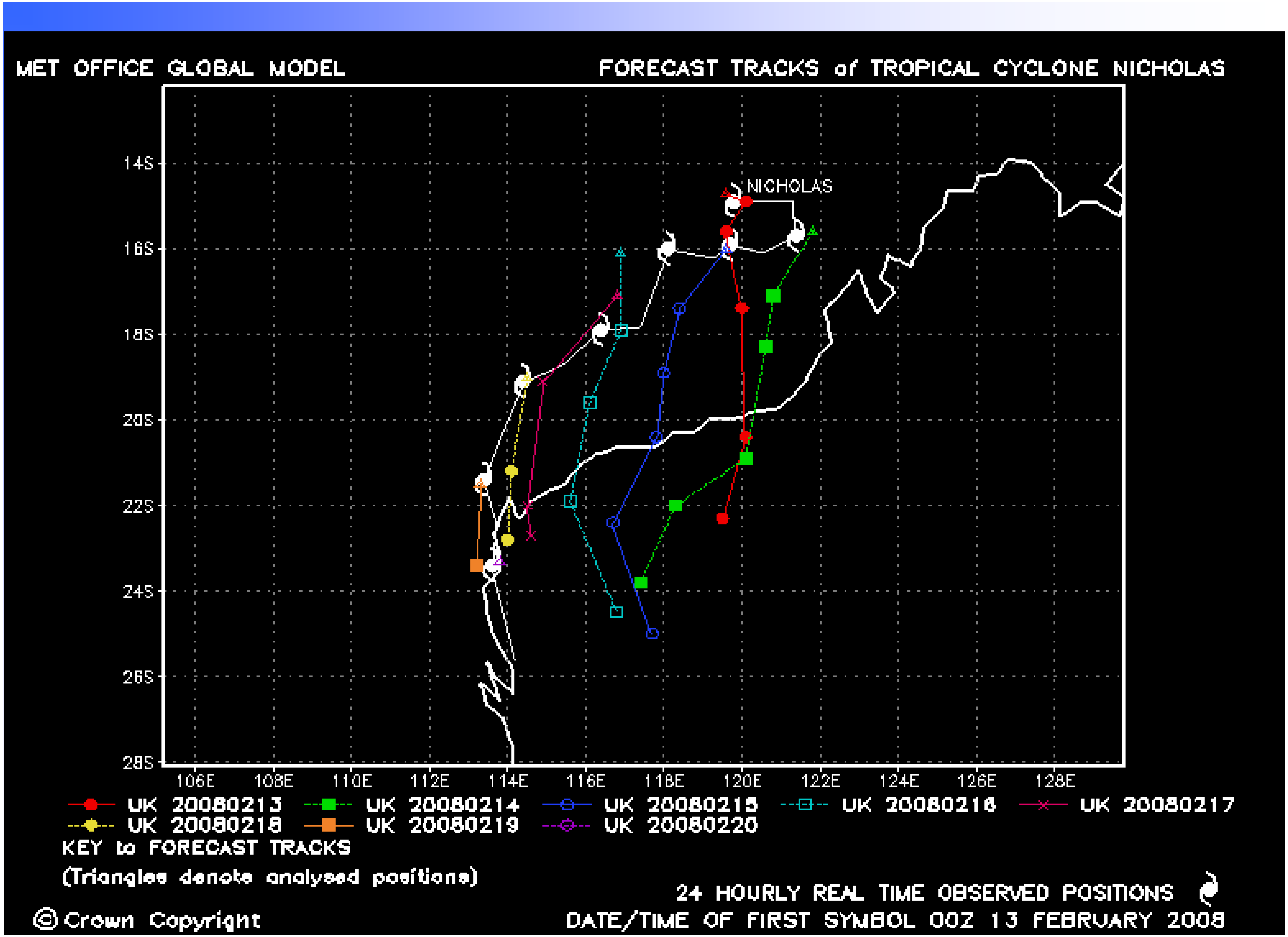
Level	Data Source	Bias (ms^{-1})	MMVD (ms^{-1})	RMSVD (ms^{-1})
High – up to 150 km separation between radiosondes and AMVs	**AMVs**	-0.81	4.18	4.72
	Background	-0.65	4.34	4.94
Low - up to 150 km separation between radiosondes and AMVs	**AMVs**	-0.13	2.43	2.79
	First Guess	-0.55	2.55	2.8
Low – up to 30 km separation between radiosondes and AMVs	**AMVs**	-0.28	2.05	2.27
	First Guess	-0.56	2.46	2.76

OBSVD, FCAST CPS and TRK ERRS (km)

TC NICHOLAS

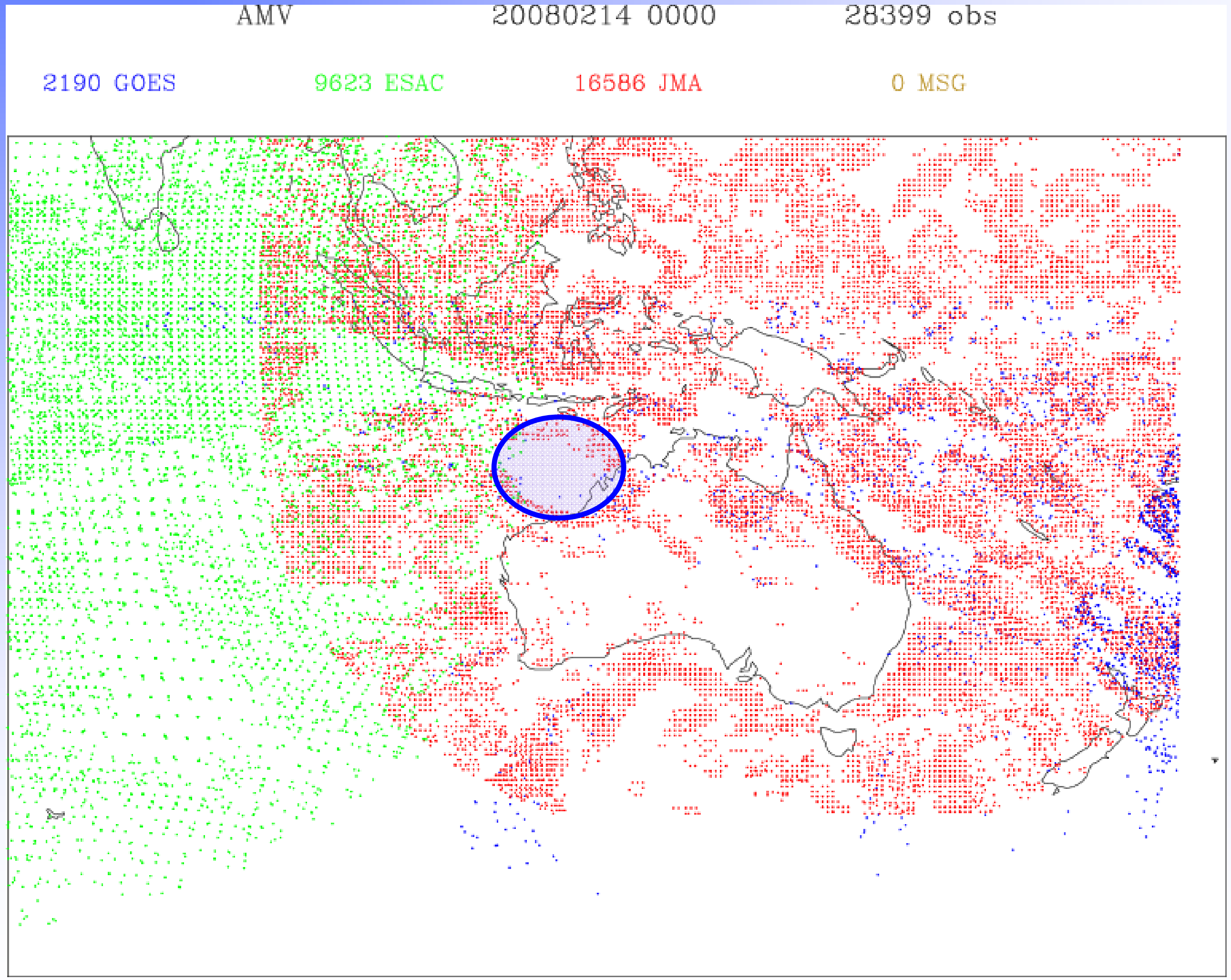


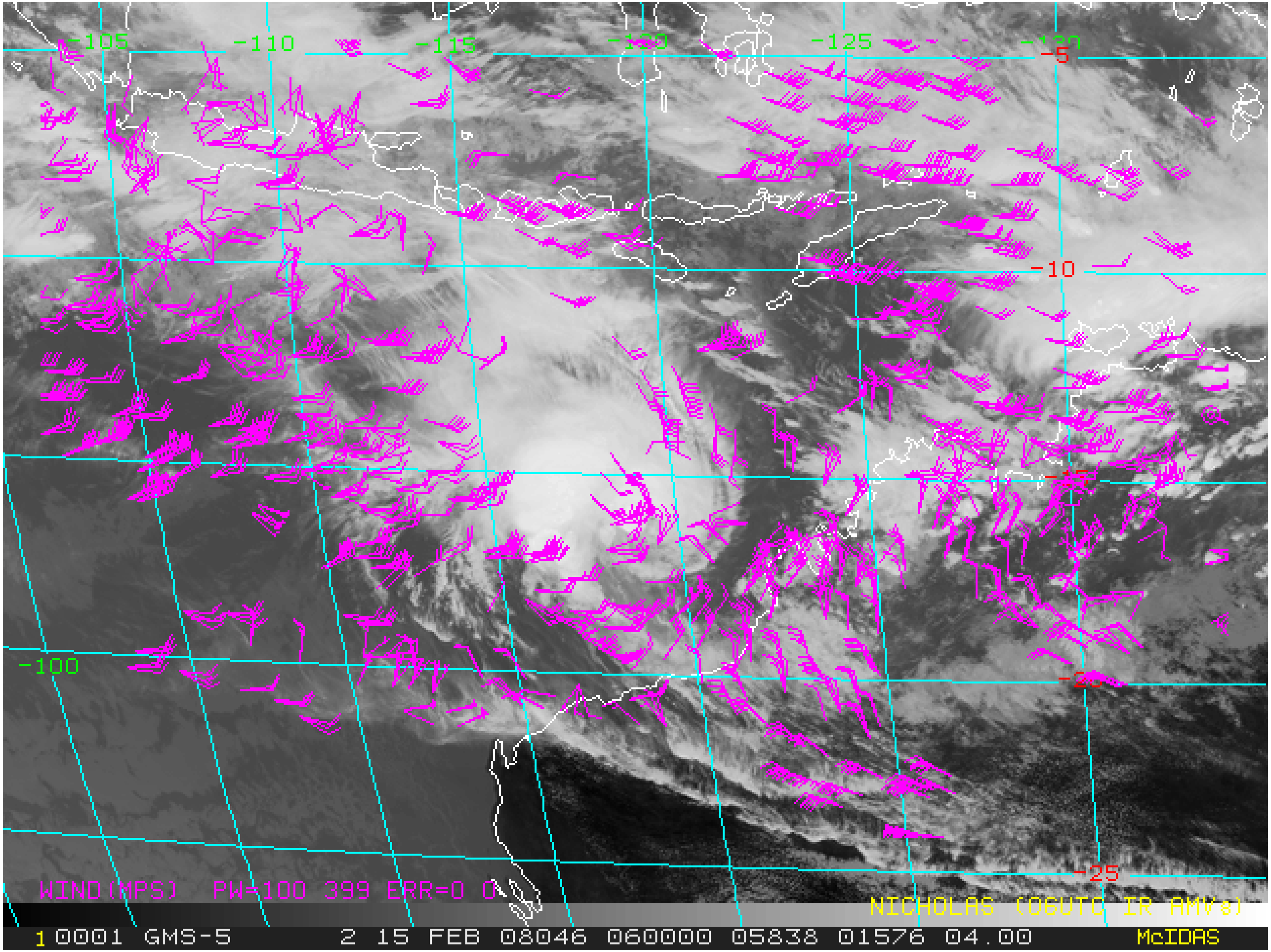
06 HOUR INTERVALS FROM 8021412



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
-100
-25
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NICHOLAS (06UTC IR AMVs)
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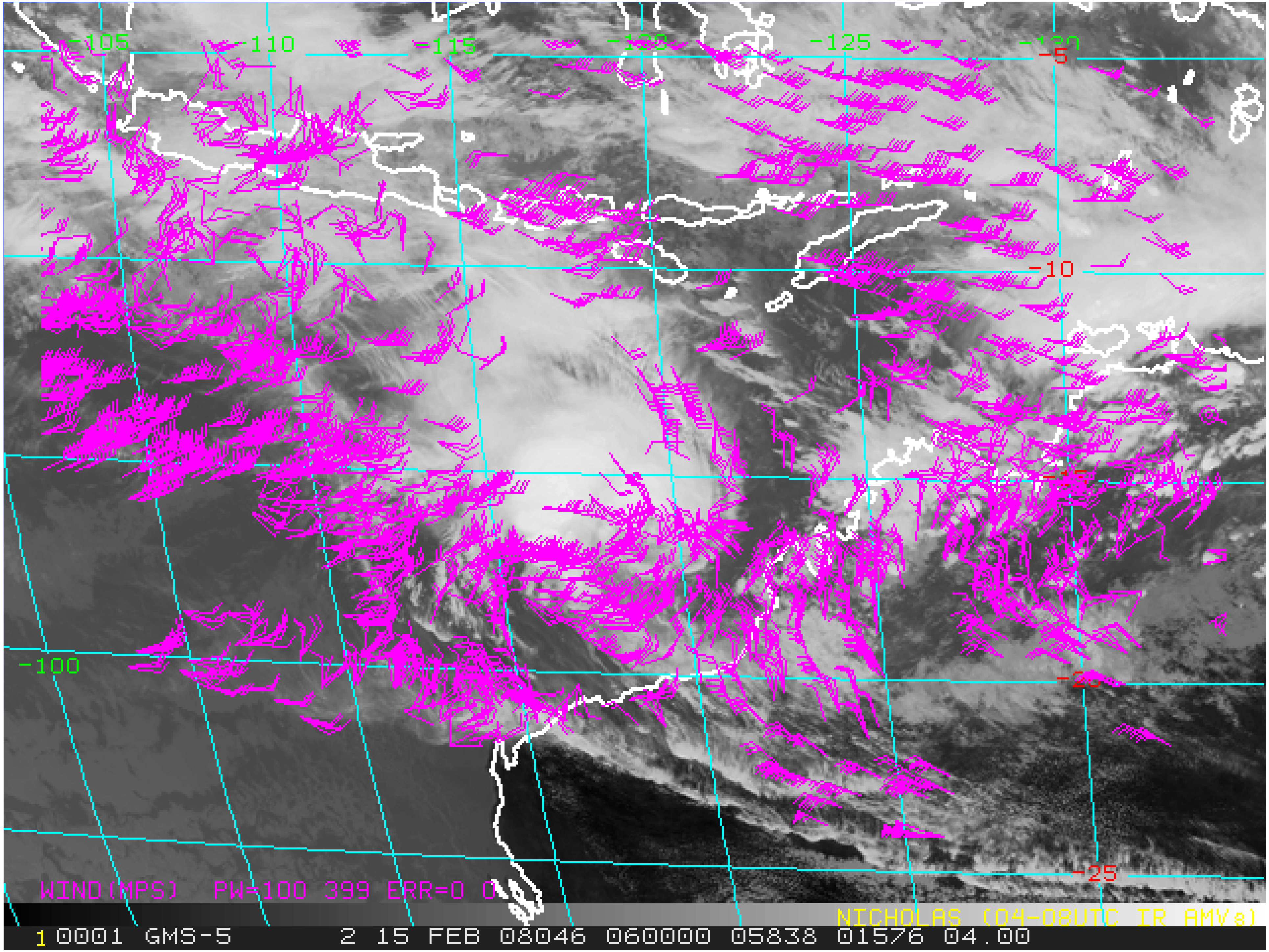
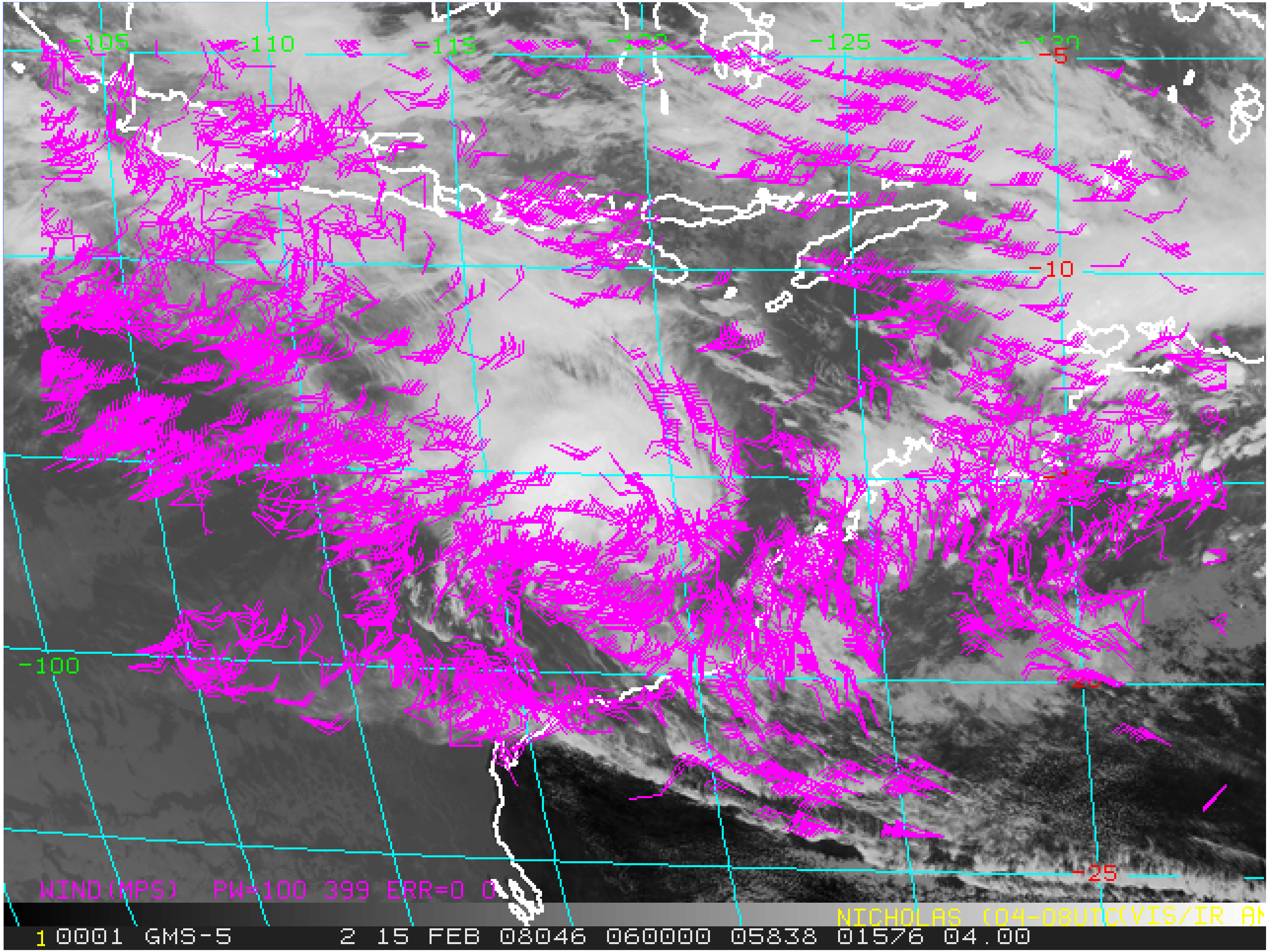
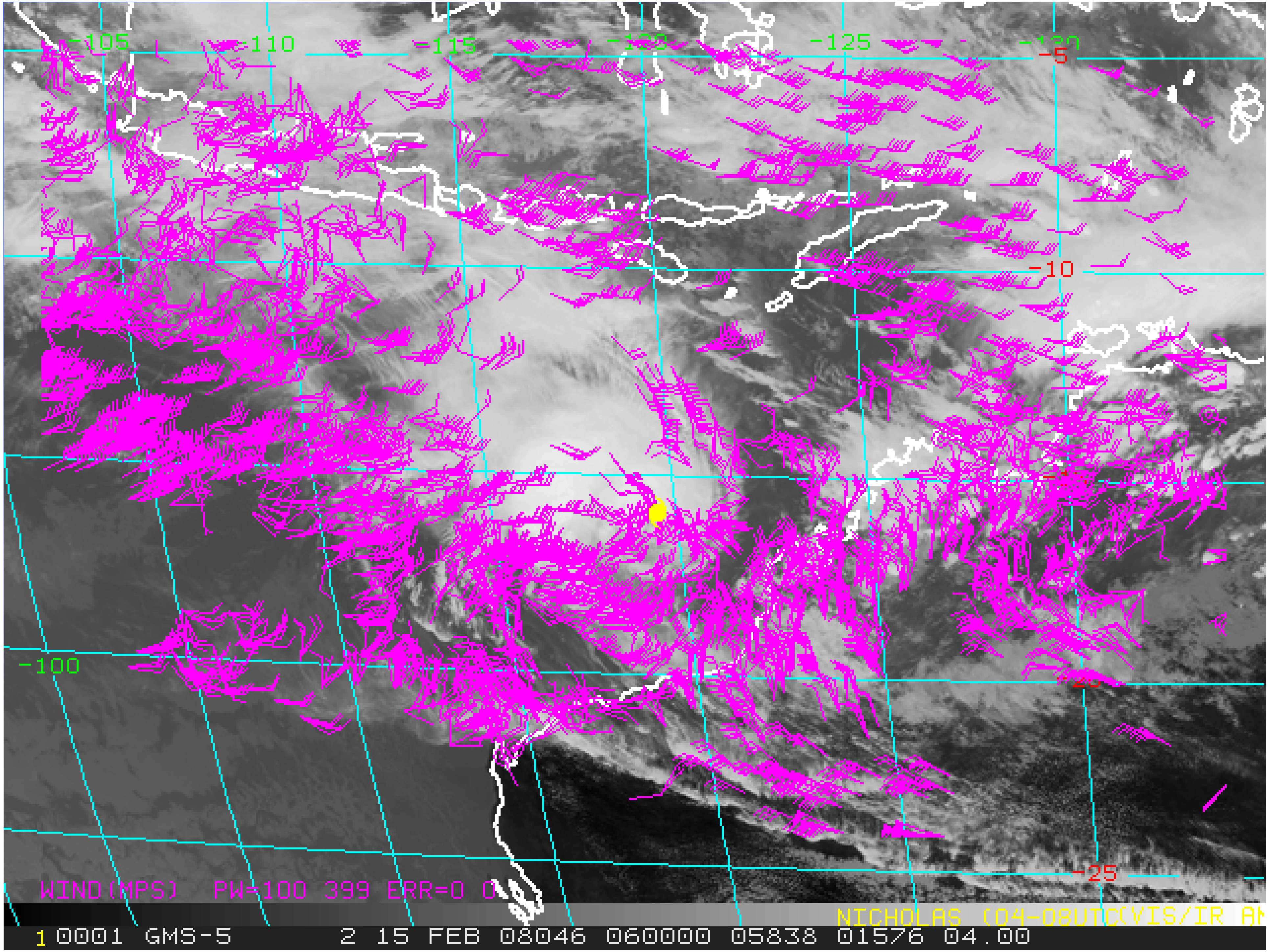
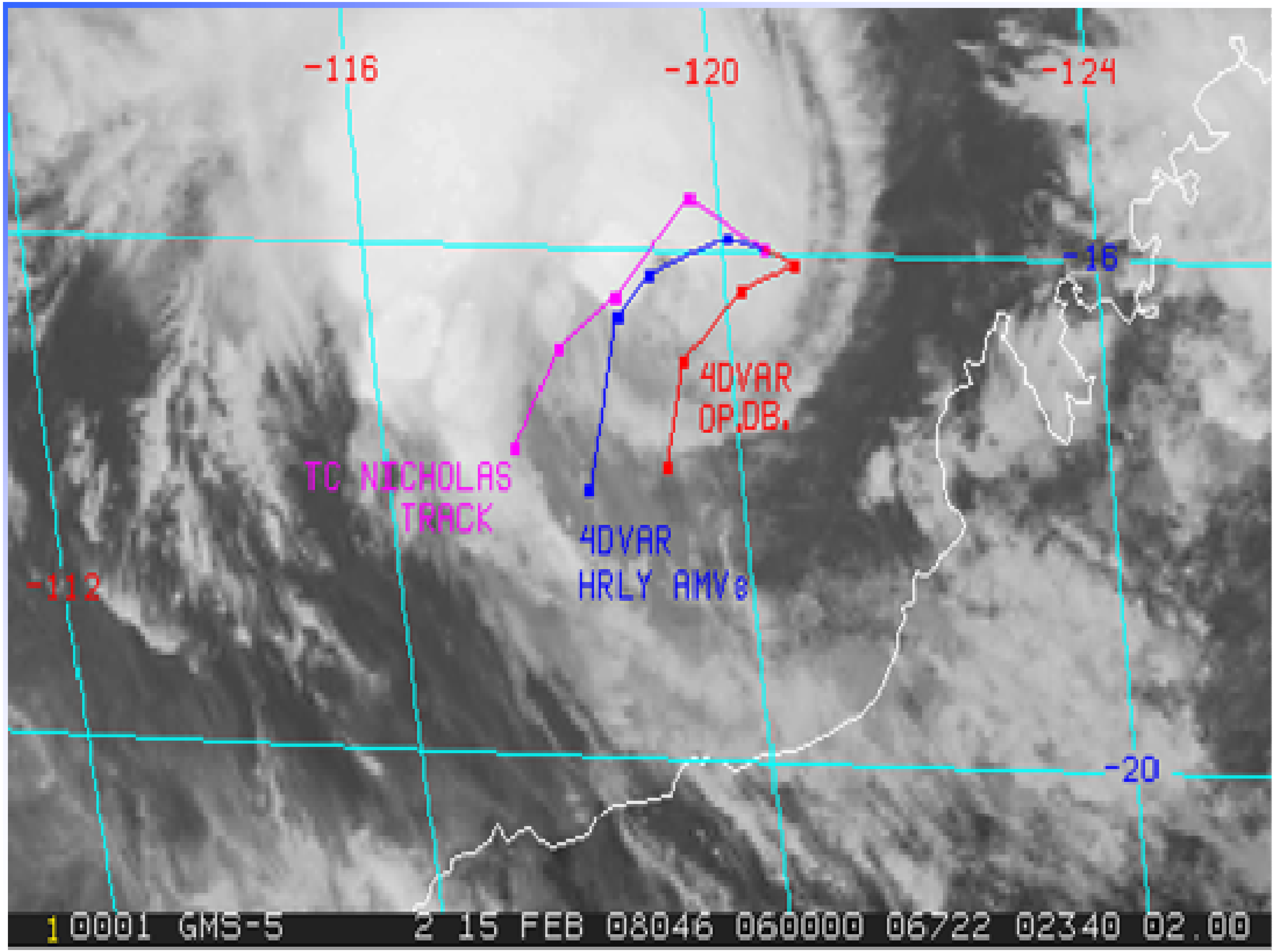


-105
-110
-115
-125
-5
-10
-100
-25
WIND(MPS) PW=100 399 ERR=0 0
NICHOLAS (04-08UTC IR AMVs)
1 0001 GMS-5 2 15 FEB 08046 060000 05838 01576 04.00


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


-105
-110
-115
-125
-5
-10
-100
-25
WIND(MPS) PW=100 399 ERR=0 0
NICHOLAS (04-08UTC(VIS/IR
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

TC Forecasting Using High Res. Local Winds in the Operational ACCESS 4D-VAR environment- Some examples

- Typhoon Fengshen Western Pacific June 2008
- Used enhanced NH AMV generation schedule (eg.24 data sets in 10 hours)
- UKUM 37.5km resolution
- 6-hour time window used
- No bogus data used

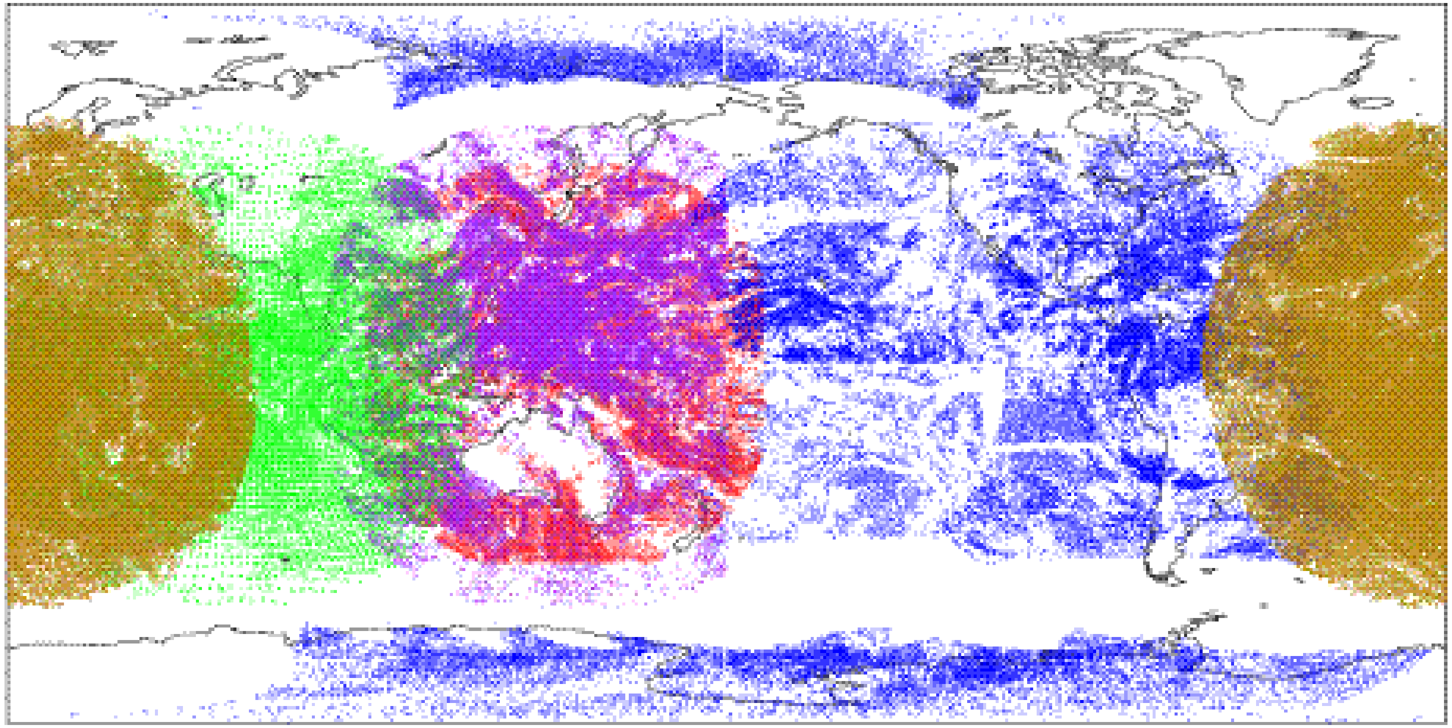
Part of the schedule for Northern Hemisphere wind generation from MTSAT-1R mages. This part provides 24 Infrared Channel (IR1) based wind data sets, 22 High Resolution Visible (HRV) image and 4 Water Vapour (WV) image based data sets from the full disc and northern hemisphere images listed.

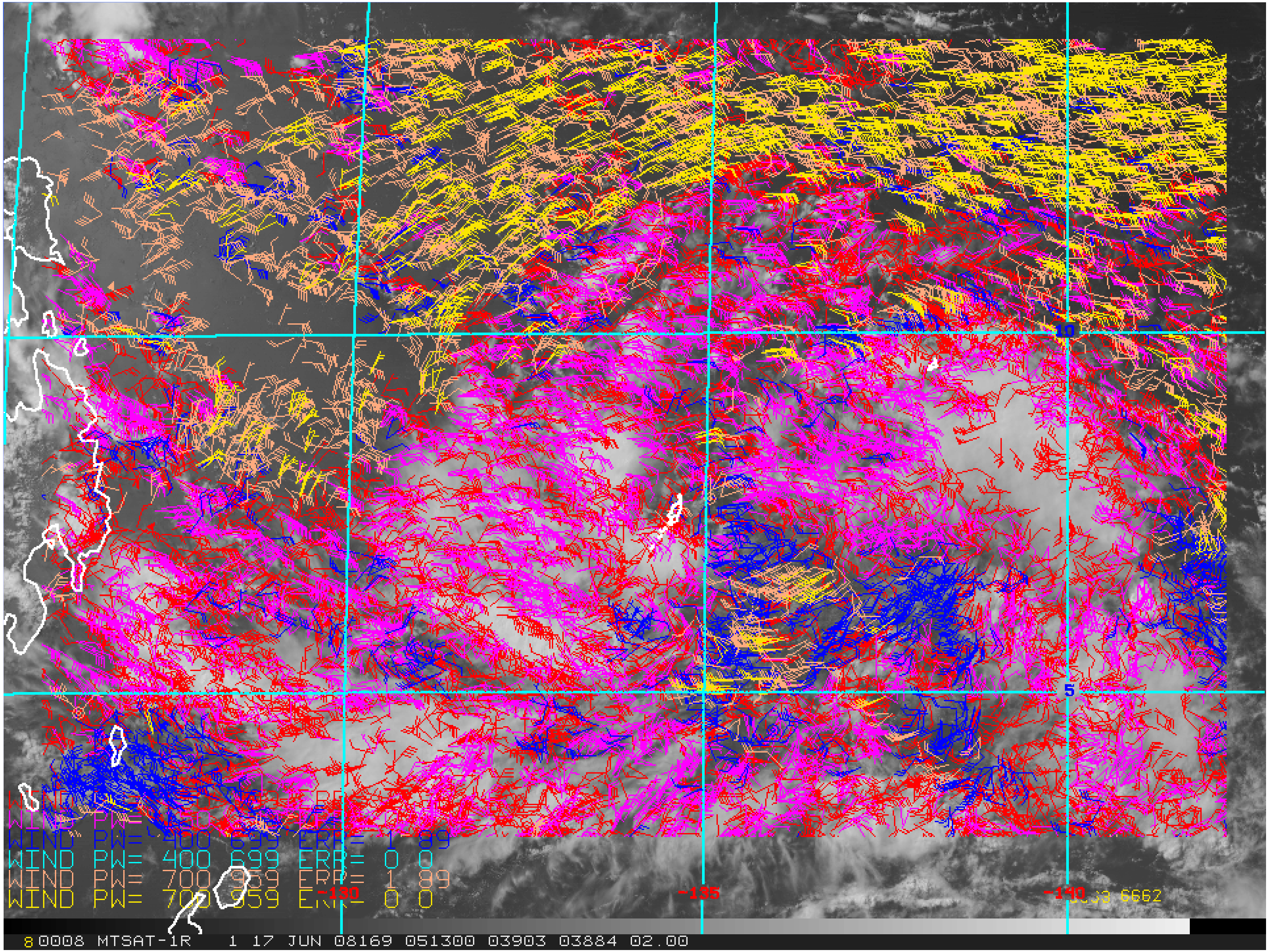
DATE	HHMM 1	HHMM 2	HHMM 3	IR1	HRV	WV
16 June 2008	2230	2330	0030			
16 June 2008	2257	2313	2330			
17 June 2008	0030	0057	0130			
17 June 2008	0130	0157	0230			
17 June 2008	0230	0257	0330			
17 June 2008	0330	0357	0430			
17 June 2008	0430	0457	0530			
17 June 2008	0430	0530	0630			
17 June 2008	0457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

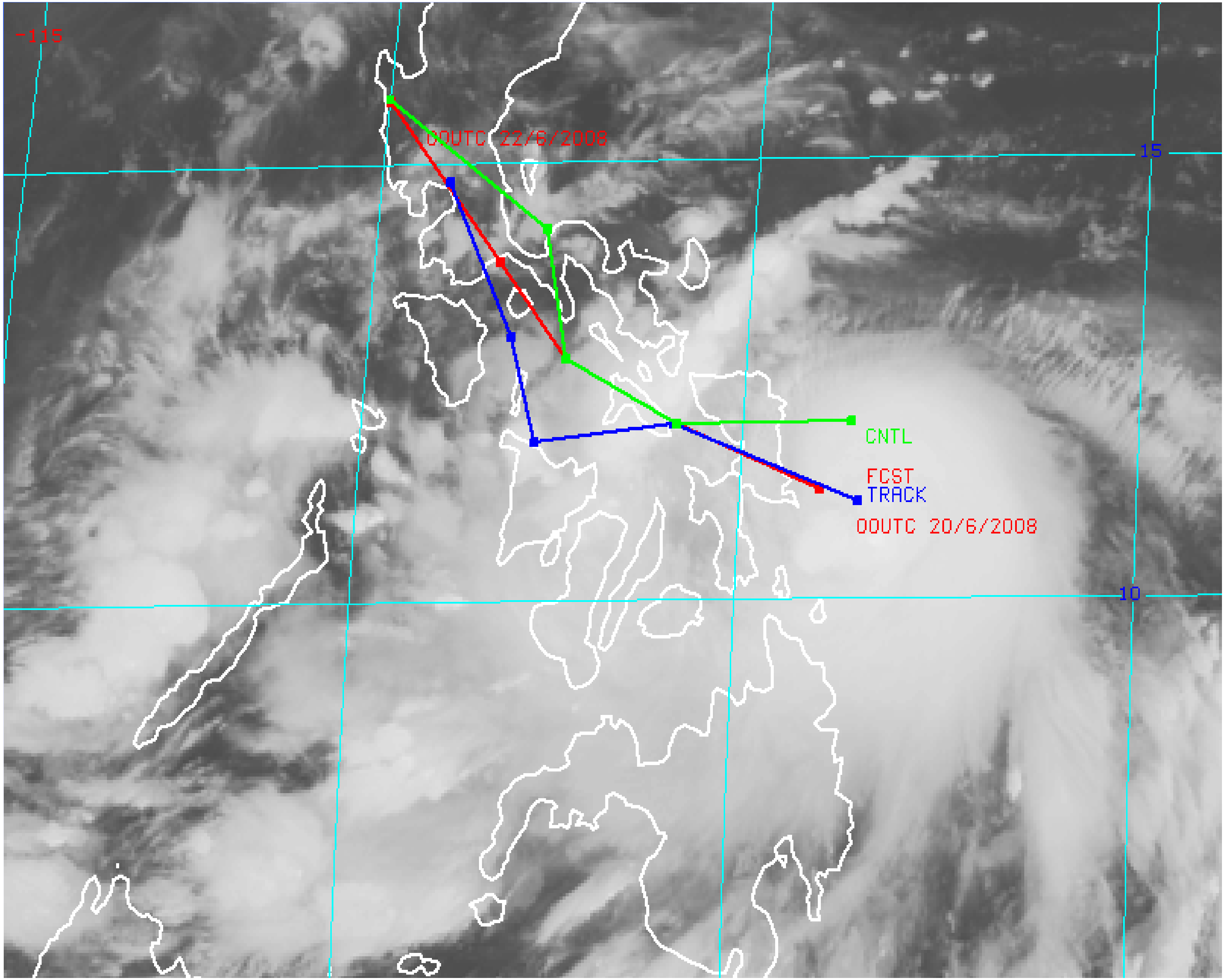
AMV 20080617 0600 420871 obs

67387 GOES 40625 ESAC 69465 AUS 29191 JMA 214203 MSG





10
5
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
-130
-135
-140
8 0008 MTSAT-1R 1 17 JUN 08169 051300 03903 03884 02.00

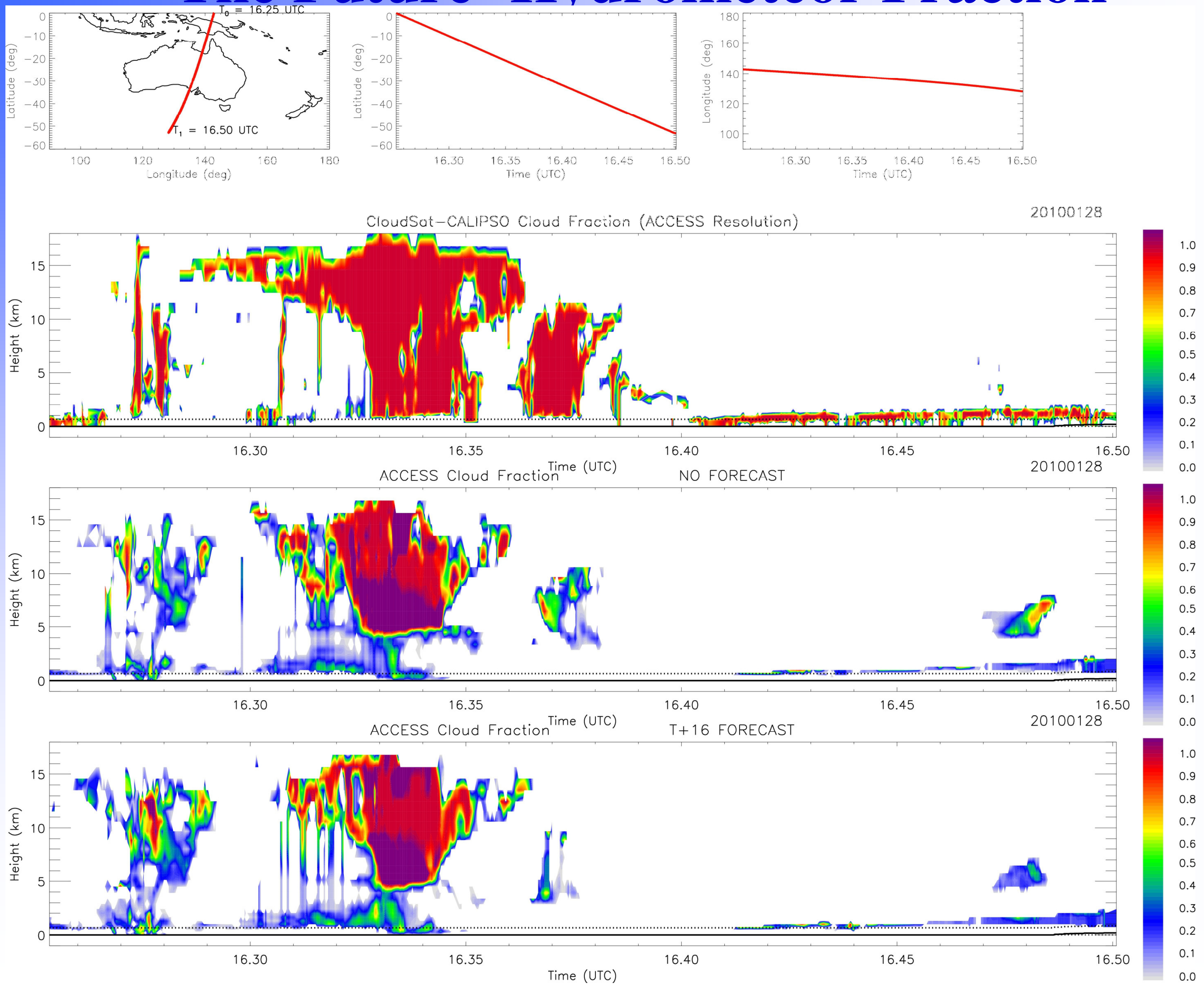


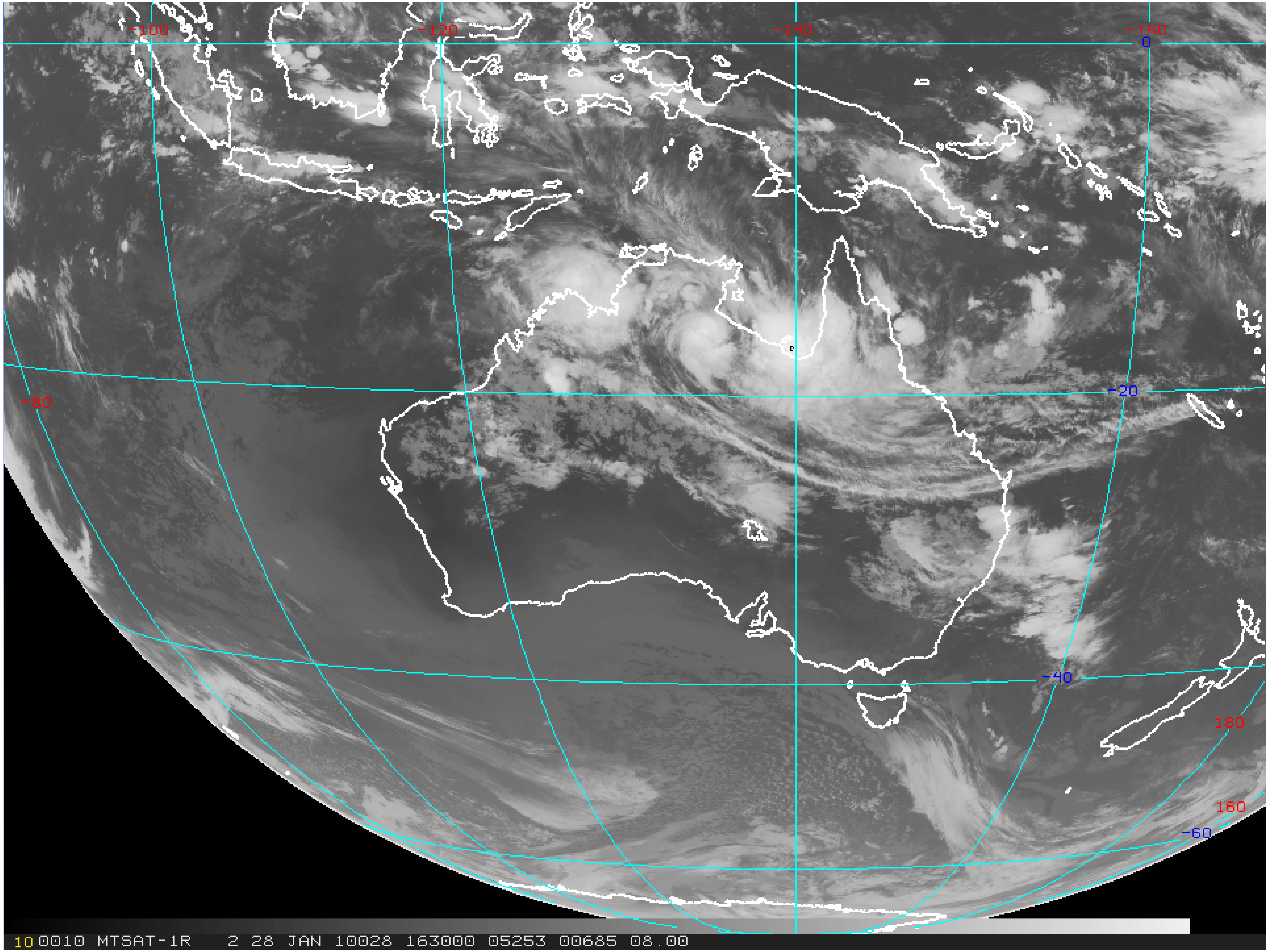
-115
00UTC 22/6/2008
15
CNTL
FCST
TRACK
00UTC 20/6/2008
10

The Future

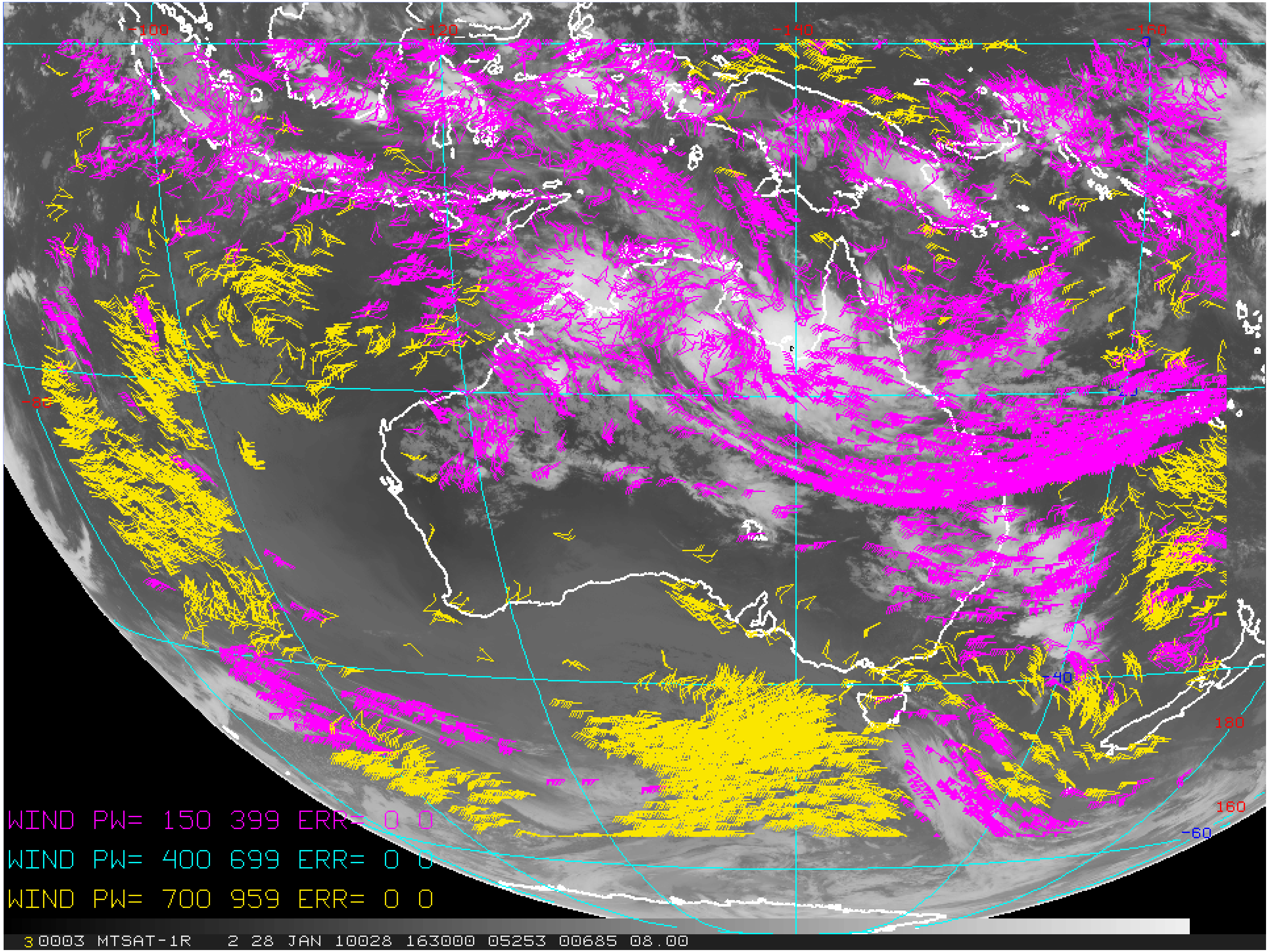
- Cloud Height Assignment and Verification – LBF, A-Train using Cloudsat and Calipso
- MTSAT - 2
- AMV Error Characterization
- AMV derivation for Model Clouds
- Continuous data/4D-VAR Assimilation
- Moisture tracking / 4D-VAR radiance assimilation
- ………..

The Future- Hydrometeor Fraction

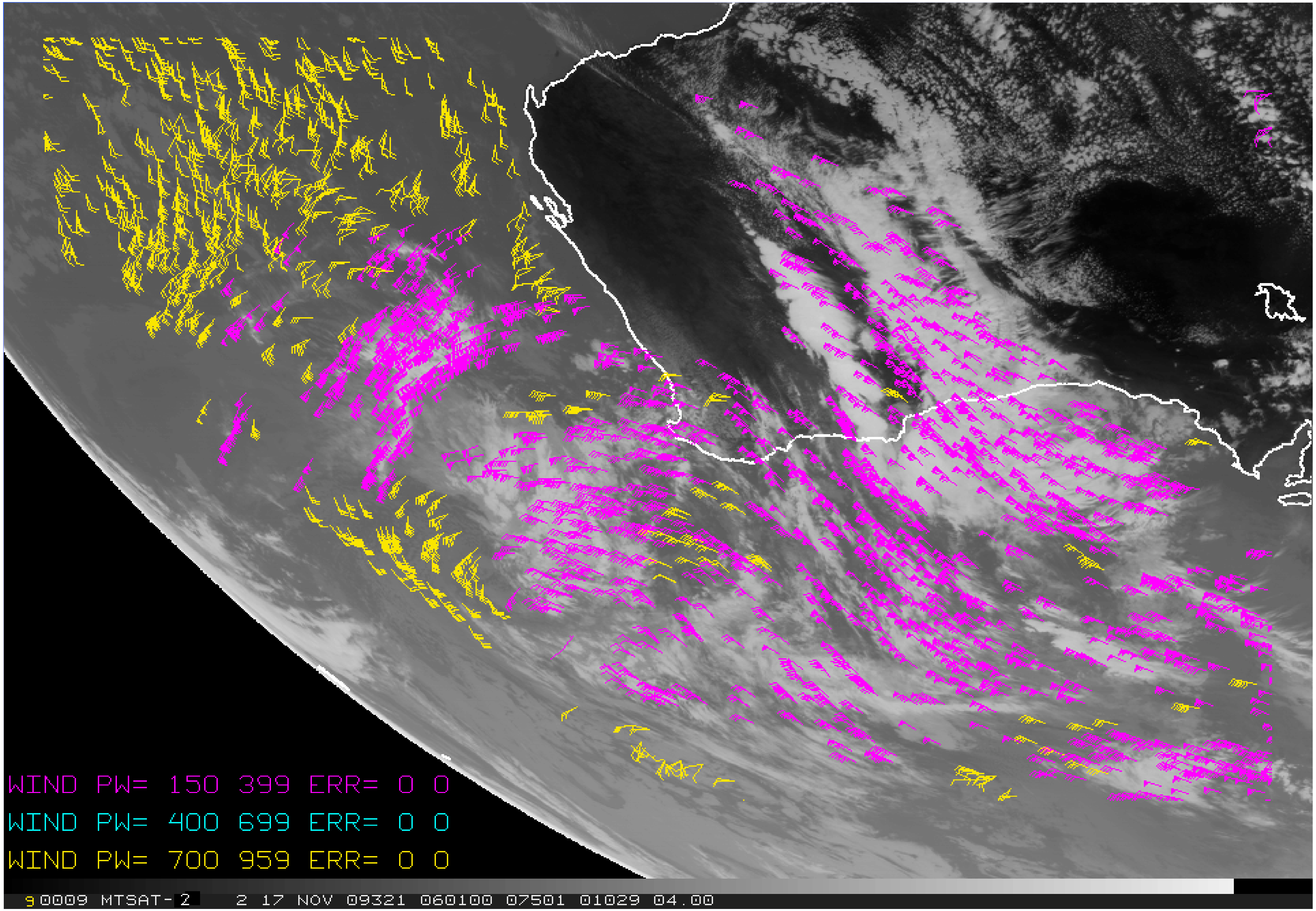




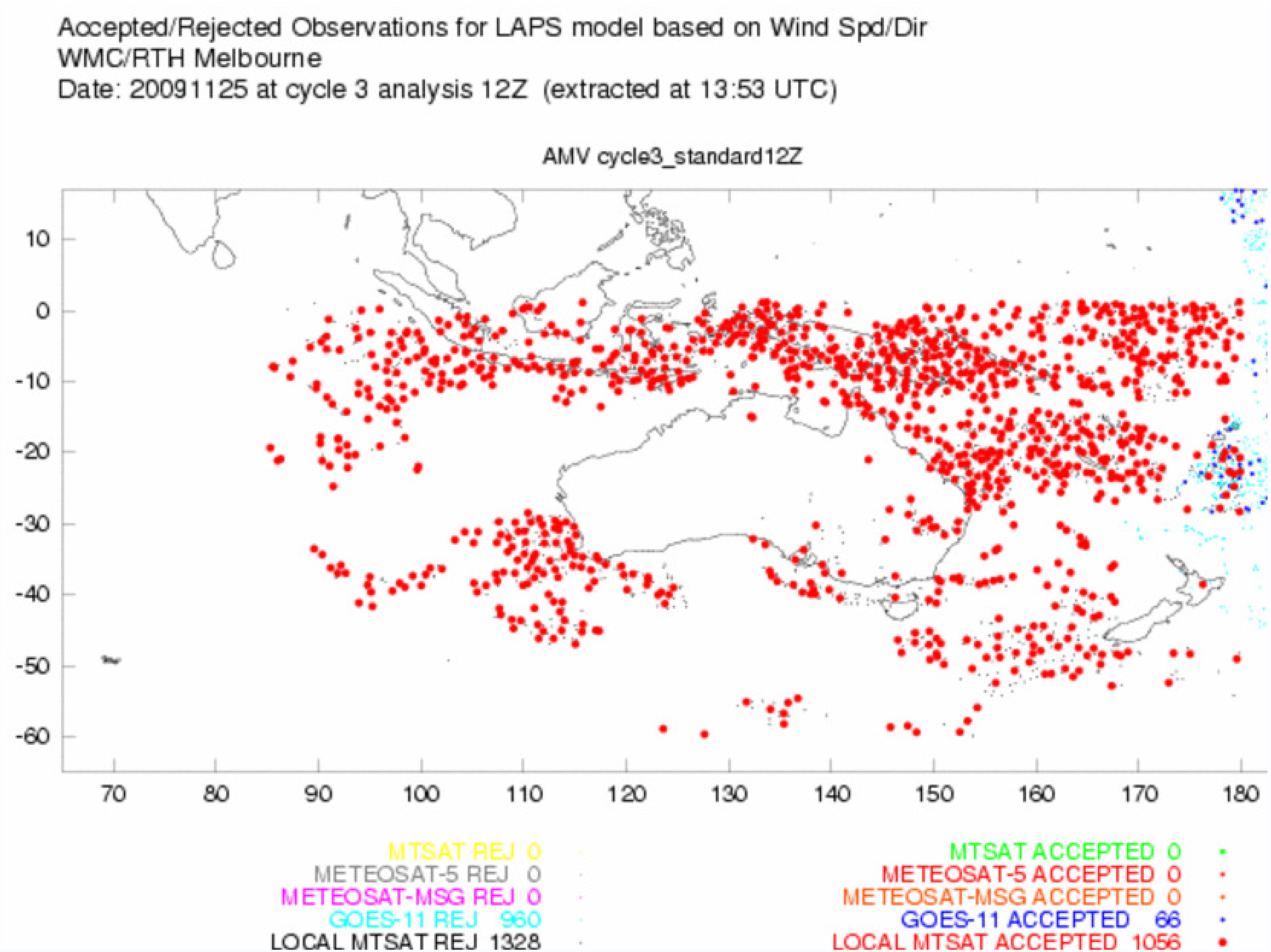
-100
-120
-140
-160
0
-80
-20
-40
180
160
-60
10 0010 MTSAT-1R 2 28 JAN 10028 163000 05253 00685 08.00



-100
-120
-140
-160
-80
-40
180
160
-60
WIND PW= 150 399 ERR= 0 0
WIND PW= 400 699 ERR= 0 0
WIND PW= 700 959 ERR= 0 0
3 0003 MTSAT-1R 2 28 JAN 10028 163000 05253 00685 08.00



MTSat-2 IR-1 AMVs generated around 06 UTC on 17 September 2009. Magenta denotes upper level tropospheric vectors, yellow, lower level tropospheric vectors



MTSat-2 IR-1 AMVs generated around 012 UTC on 25 November 2010. Red denotes AMVs used by the operational analysis.

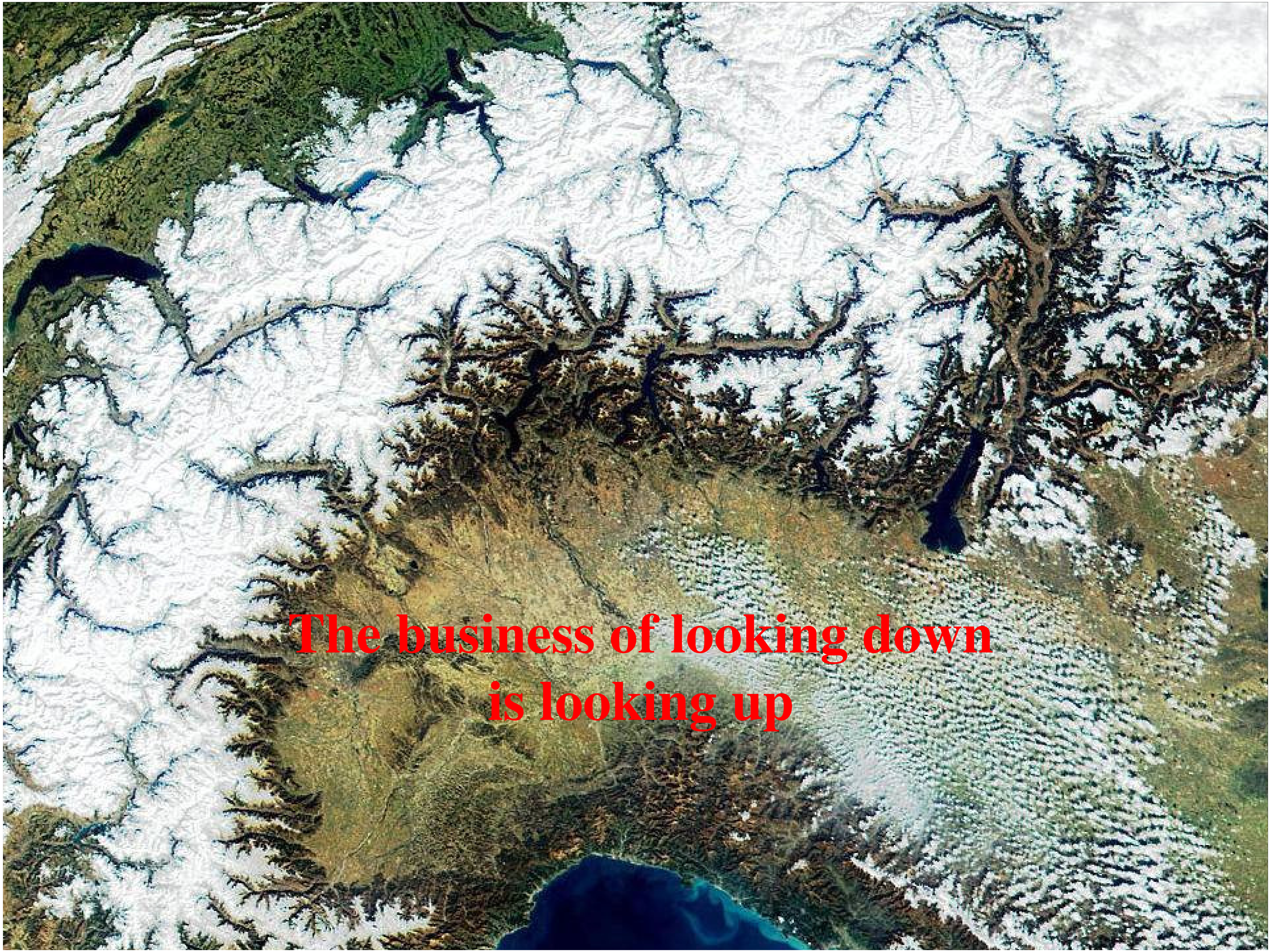
Summary

- Geo-stationery (and polar orbiting) satellite-based AMVs have been shown to make a significant contribution to operational Australian region and global analysis and forecasting.

- High spatial and temporal resolution (GMS, GOES-9, MTSaT-1R) AMVs have been generated operationally at the Australian BoM since the mid 1990's 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 local high temporal resolution (15, 30 and 60 minute) winds with 4DVAR have shown improved forecast skill.


The business of looking down
is looking up