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The Considerable Benefits of Earth Observations from Space in Meteorology

-Status and Future

John Le Marshall

Bureau of Meteorology

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Use of Satellite Data in the Bureau

Timeliness is key

Weather and Warning Services

- **Forecasters** repeatedly use VIS, IR, WV products for nowcasting
  - e.g. colour enhanced satellite images, volcanic ash products, fog detection products., satellite based/NWP applications…..

Numerical Weather Prediction:

- **Temperature and humidity sounding**
  - key sources - microwave and IR polar orbiting satellite radiance data
  - GPS/GNSS is an emerging data source (Radio Occultation and ground-based water vapour)
- **Wind**
  - Scatterometers , Radiometer, Doppler wind lidar
  - Satellite-derived Atmospheric Motion Vectors
- **Psurf.**
- **Other** (Soil Moisture, Emissivity, ….)
- Ideally ~80-100 sat. data streams for a high res global model

Earth-related applications:

- **Sea Surface Temperature, NDVI, Grassland Curing, Solar Radiation ……**

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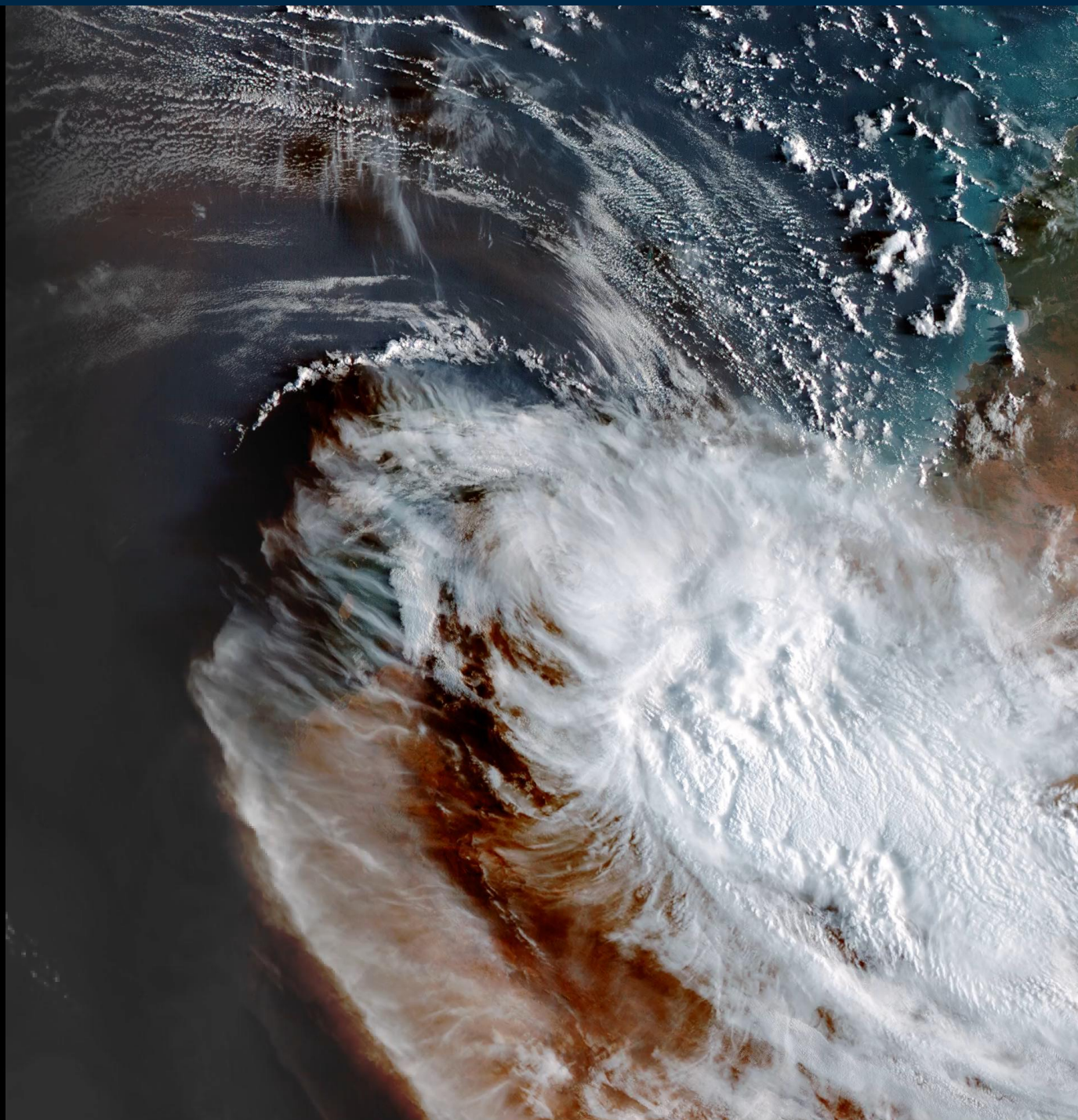

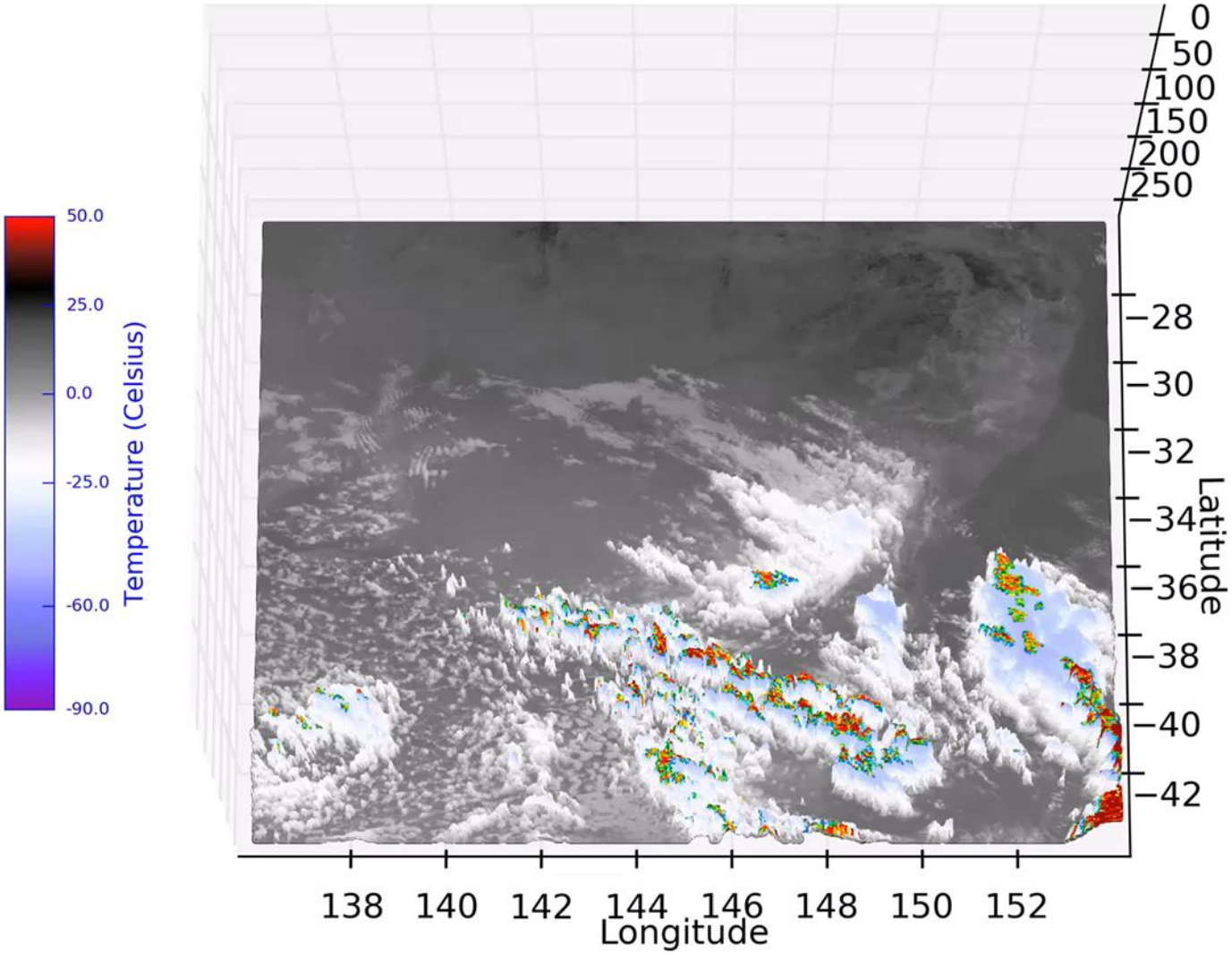

- Nowcasting SAF Convective Rainfall Rate (CRR) product for Himawari-8/9
- Data is from the 15th June 2018 over the South East corner of Australia

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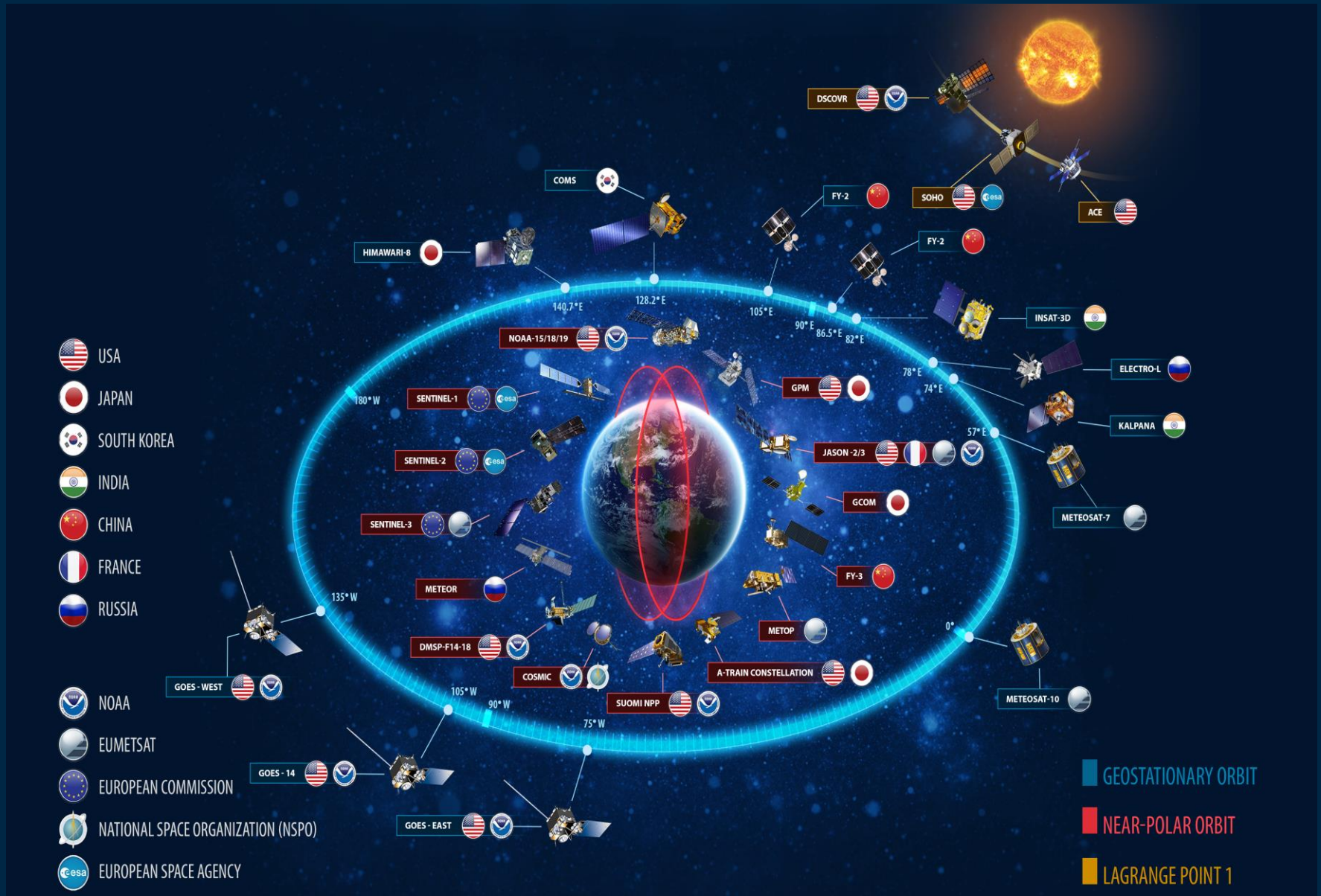

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Numerical Weather Prediction Data assimilation

Instruments Include

Platforms	Instruments
NOAA-18	AMSU-A/B
NOAA-19	AMSU-A/B
EOS: Aqua	AIRS (139 channels)
MetOp-A	AMSU-A/B + HIRS + IASI (138 channels) + ASCAT
MetOp-B	AMSU-A/B + HIRS + IASI (138 channels) + ASCAT
Suomi-NPP	CrIS (134 channels) + ATMS
NOAA-20	CrIS (134 channels) + ATMS + VIIRS
Himawari-8	AHI - Clear Sky Radiances

Platform	Product
Geostationary and Polar Orbiting satellites	Atmospheric Motion Vectors
Geostationary and Polar Orbiting satellites	Sea Surface Temperatures
Jason-2/3	Altimeter wave/winds, sea surface heights
SARAL	Altimeter wave/winds, sea surface heights
GNSS-Radio Occultation	Bending Angles
GNSS	Zenith Total Delay (IWV)

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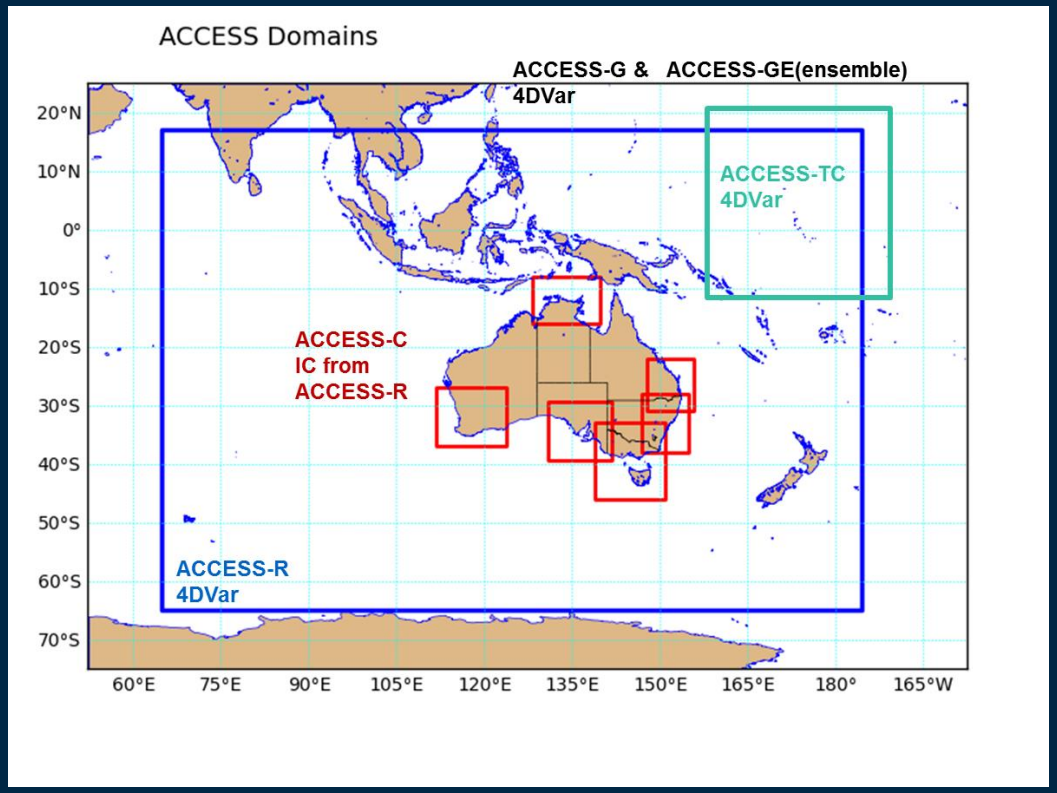
ACCESS NWP Systems

Australian Community Climate & Earth System Simulator



Grid size (km)

G	**12**
GE	**33**
R	**12**
TC	**1.5**
C	**1.5**

70 vertical levels

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The Importance of EOS (in the SH)

In the southern hemisphere space based observations extend the length of a high quality global numerical forecast by a factor of four when the forecast is verified using analyses incorporating satellite and conventional (all) data.

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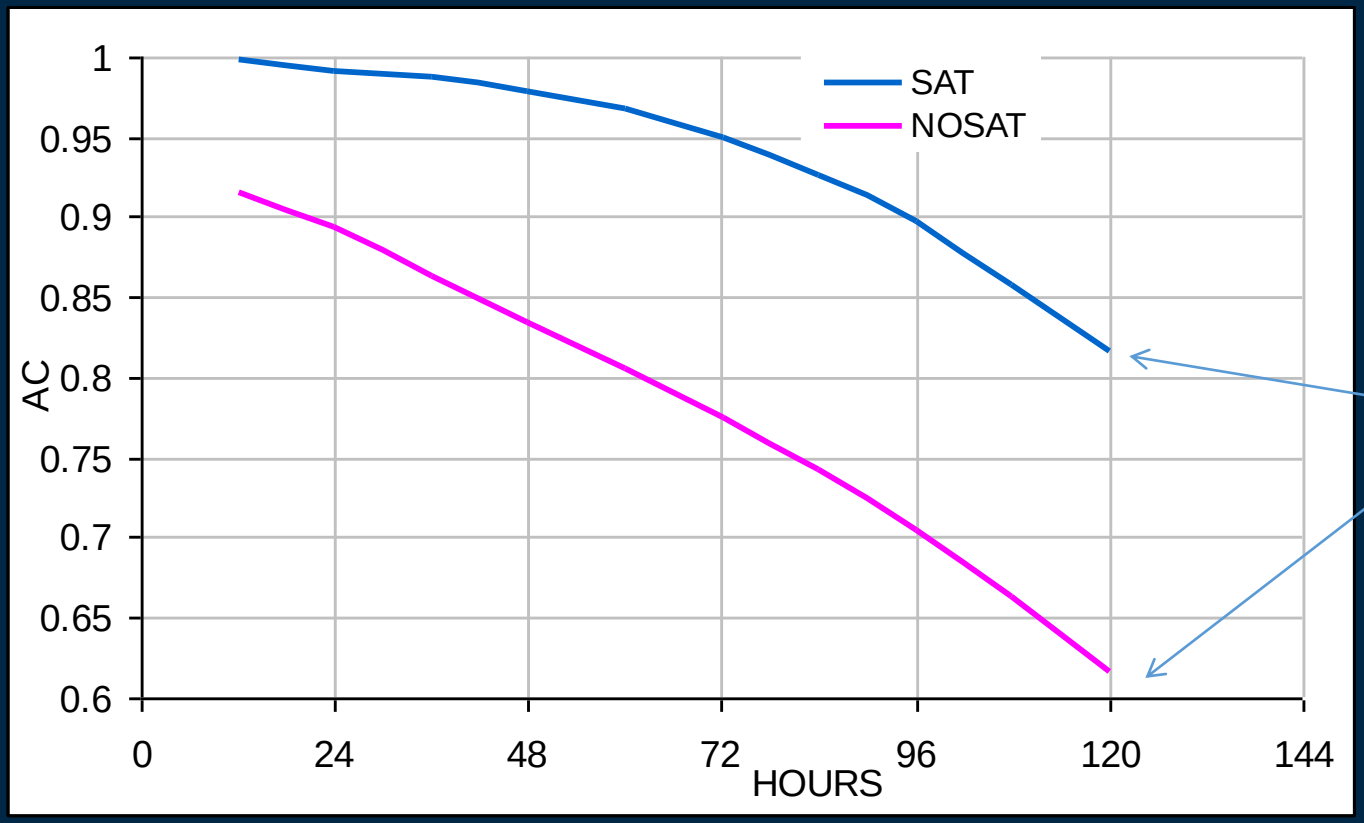
Importance of Satellite Data in the Bureau

Numerical Weather Prediction



FORECAST SKILL (AC) VERSUS TIME

These curves show how forecast accuracy degrades with time.

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.

John Le Marshall, Jin Lee, Jim Jung, Paul Gregory and Belinda Roux, 2013. The Considerable Impact of Earth Observations from Space on Numerical Weather Prediction, 2013. Aust. Meteor. and Ocean. Jnl., 63, 497-500.

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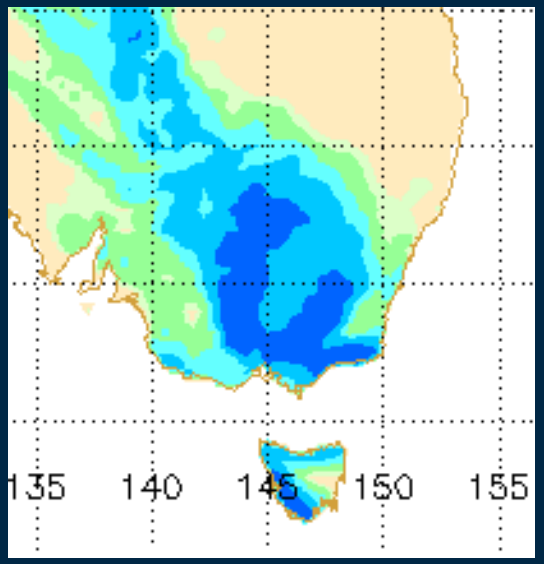
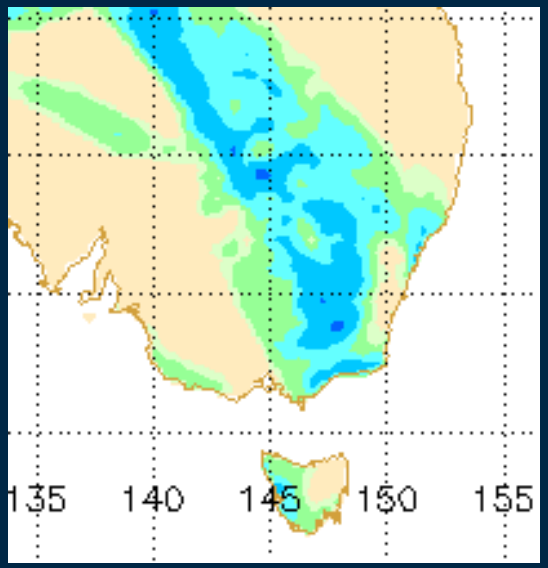
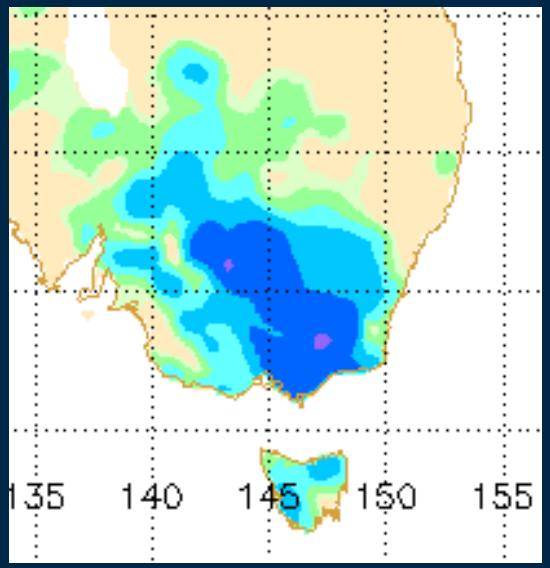


ACCESS-G 48 to 72 hour rainfall forecast for 9 November 2011 using satellite data.

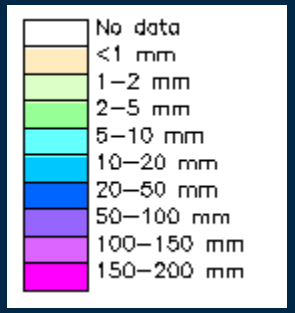


ACCESS-G 48 to 72 hour rainfall forecast for 9 November 2011 using no satellite data.



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.

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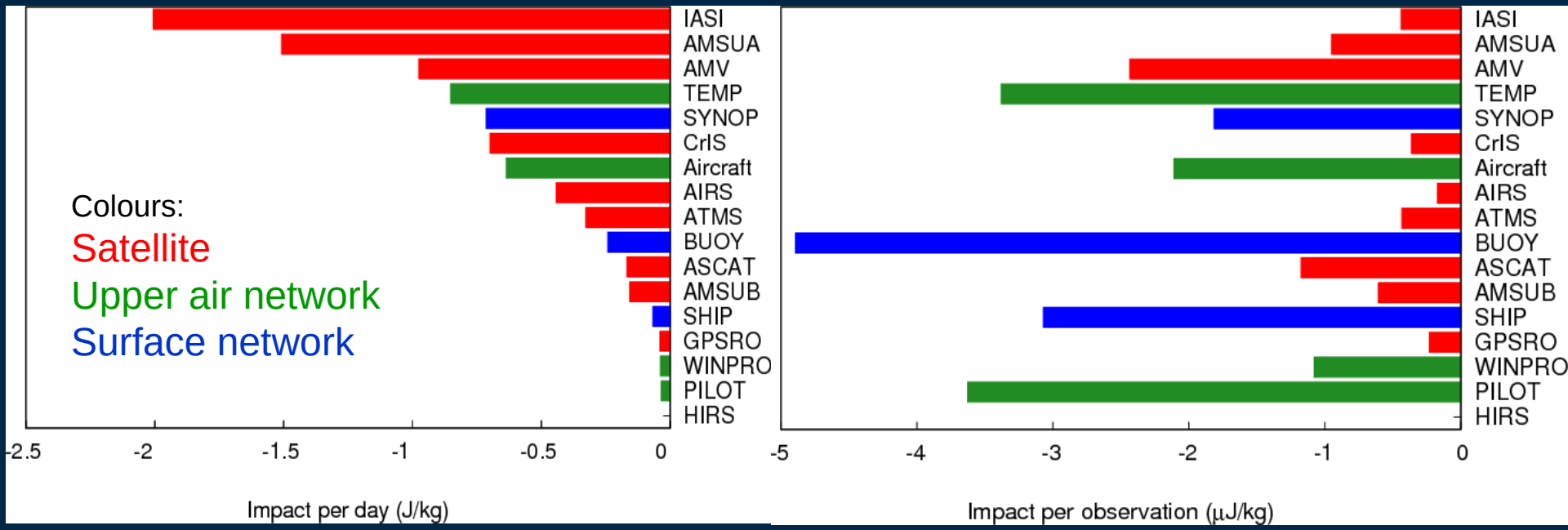
ACCESS APS2: Forecast Sensitivity to Observations



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

- 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.

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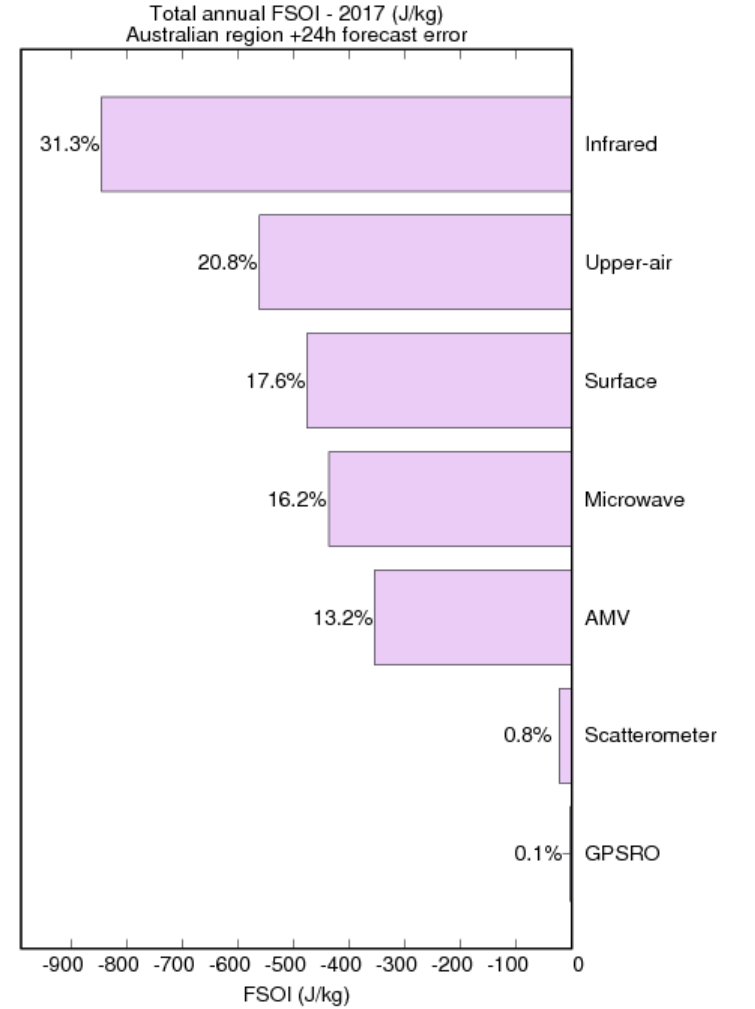

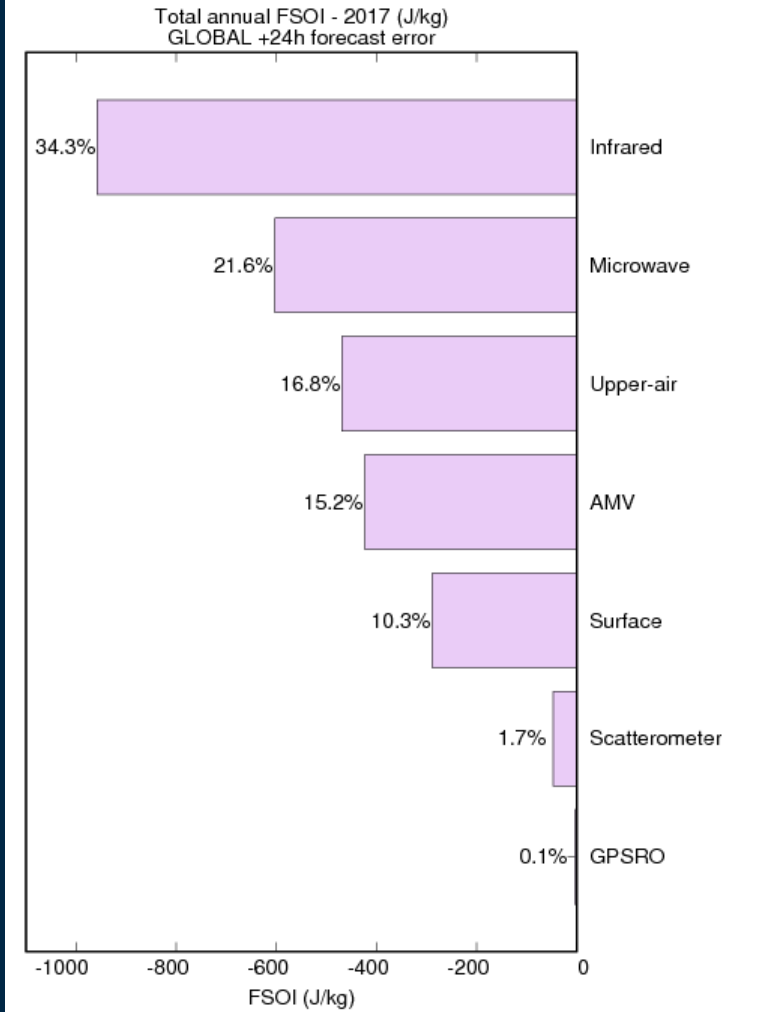

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Satellite observation products new/under development/test for NWP

- Products for high resolution City Model, low latency requirement
  - 10 minute Himawari Ch14 AMVs (operational)
  - 10 minute Himawari visible AMVs (under trial)
  - 10 minute water vapour AMVs (under trial)

- Polar winds
  - Using heritage methods/GEOCAT

- GPS ZTD - water vapour
  - RT Data stream from RMIT/Geoscience Australia received at the Bureau
  - Operational

- Himawari-8 clear sky radiances

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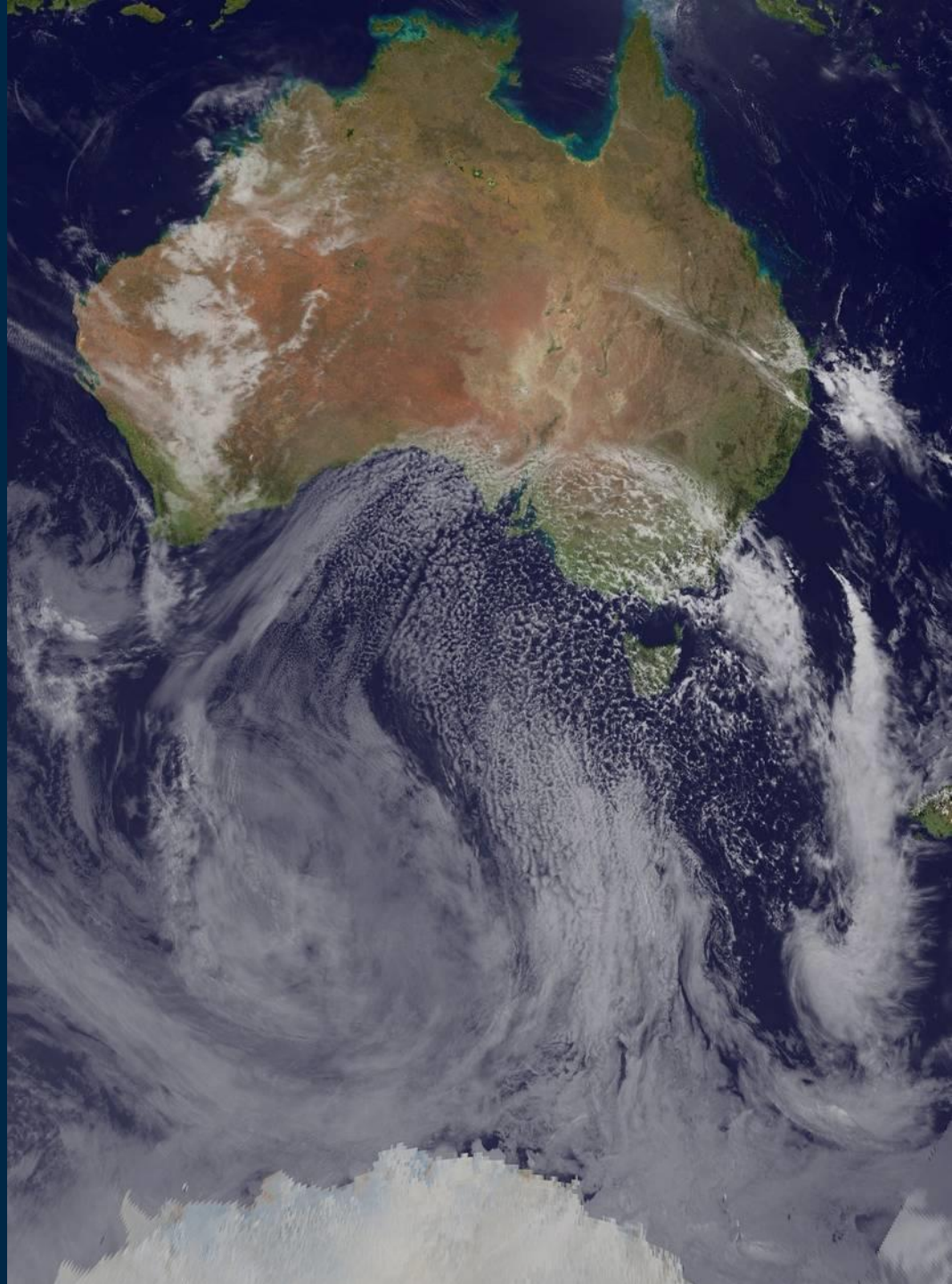
Himawari-6,7 and 8

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



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HIMAWARI-7 NEAR RT TRIAL

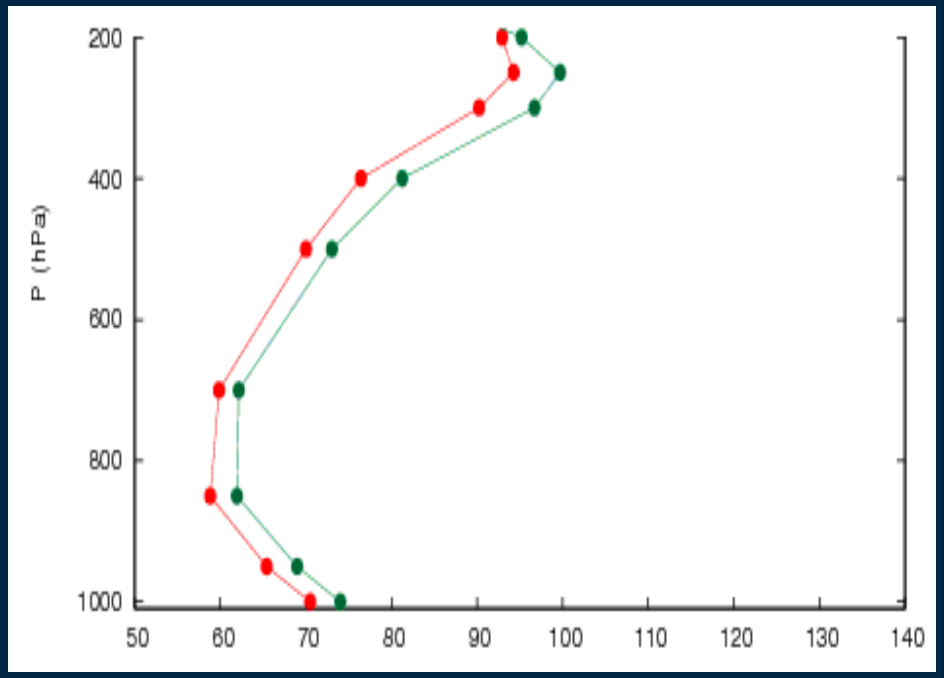

Fig.6(a). The RMS difference between forecast and verifying analysis geopotential height(m) at 24 hours for ACCESS-R (green) and ACCESS-R with hourly AMVs (red) for the period 27 January to 23 February 2011.

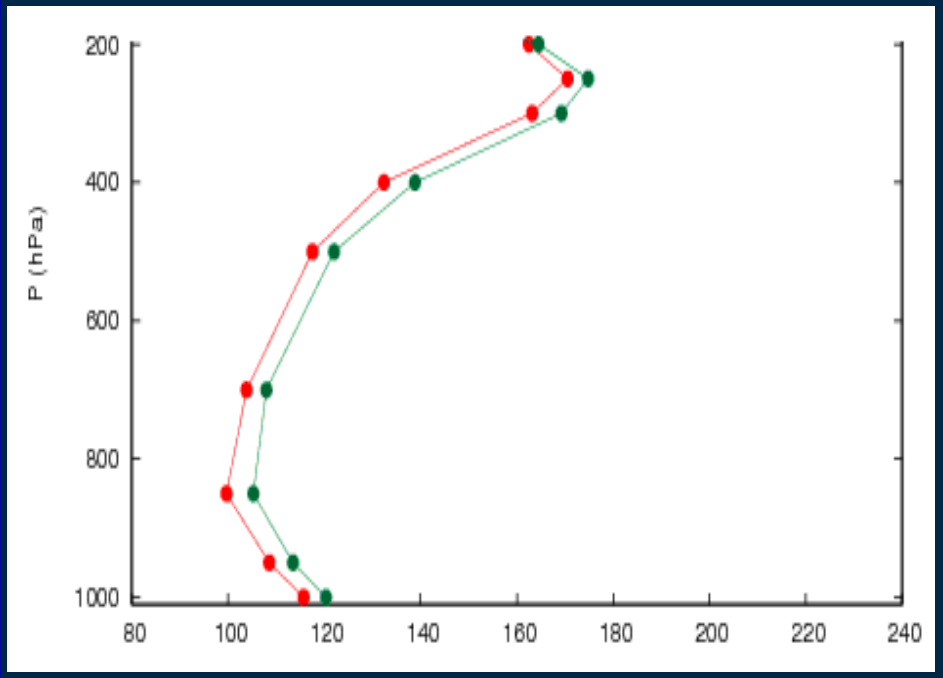

Fig.6(b). The RMS difference between forecast and verifying analysis geopotential height(m) at 48 hours for ACCESS-R (green) and ACCESS-R with hourly AMVs (red) for the period 27 January to 23 February 2011.

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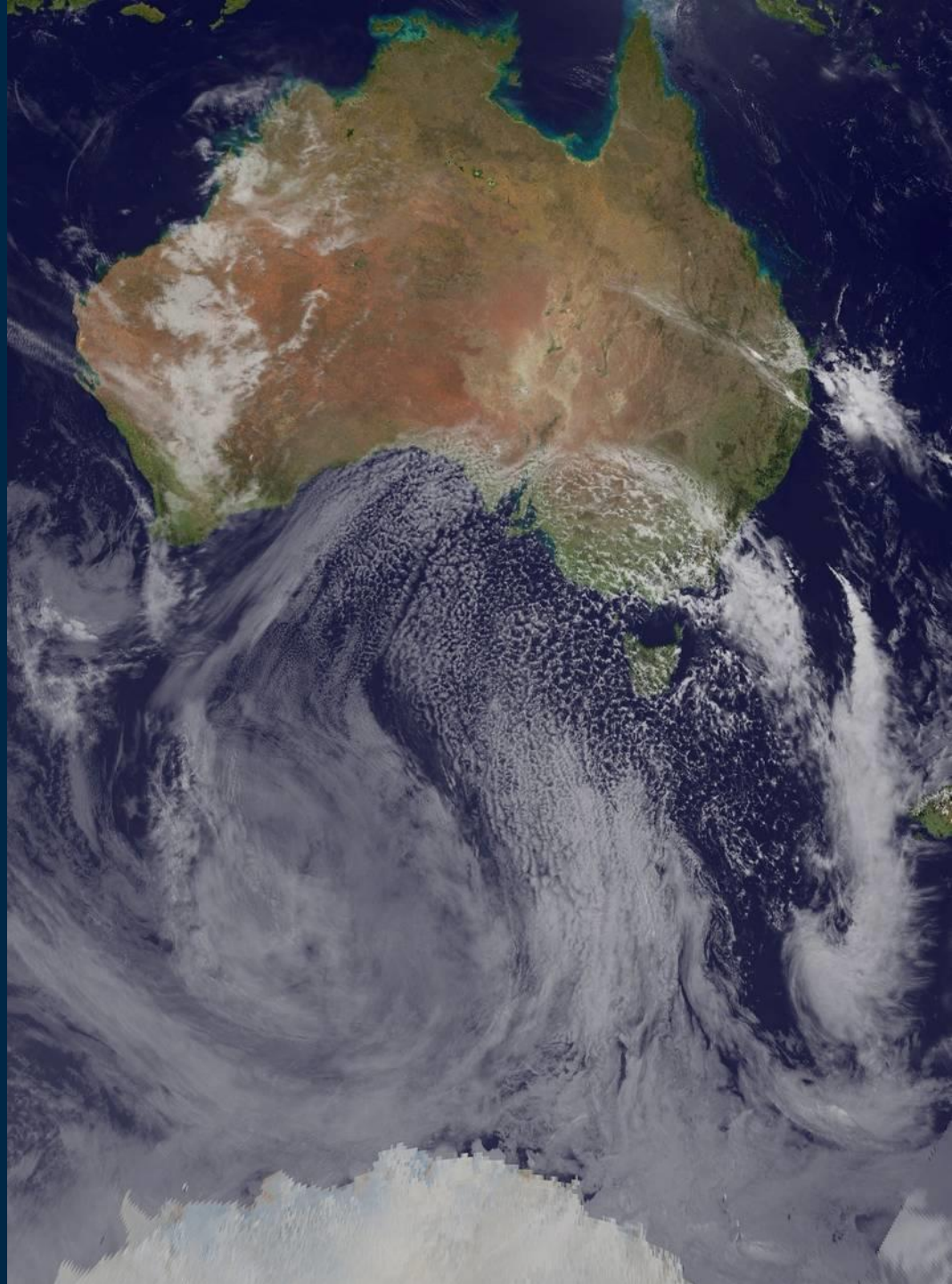
GENERATION AND ASSIMILATION OF CONTINUOUS (10 Minute) H-8 ATMOSPHERIC MOTION VECTORS , USING GEOCAT AND 4DVAR



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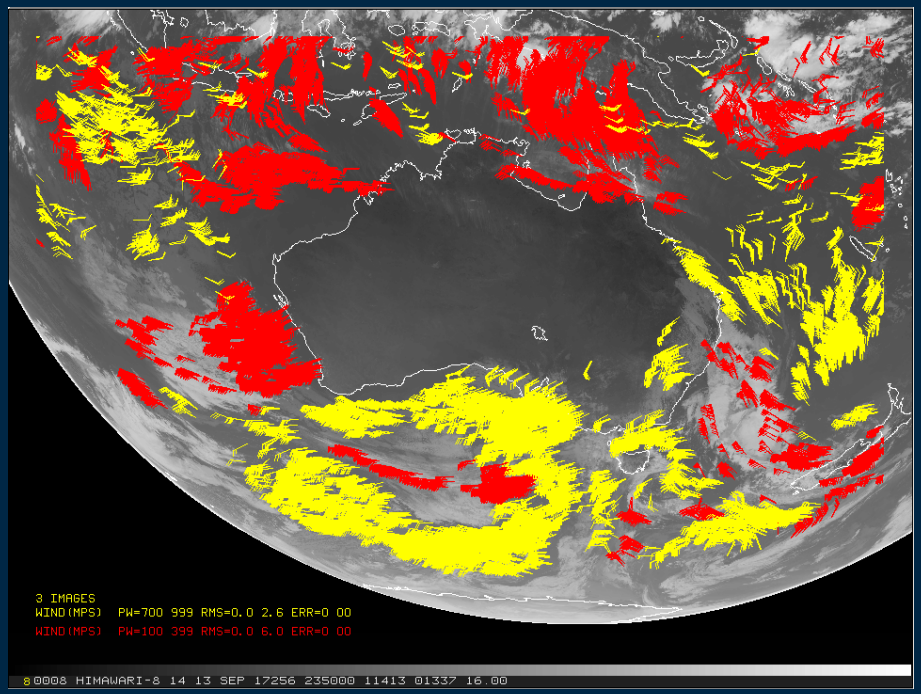


Figure 10(a) shows Channel 14 (IR) low level AMVs (yellow) with expected errors less than 2.6m/s and upper level AMVs (red) with expected errors less than 6.0m/s generated by one image triplet.

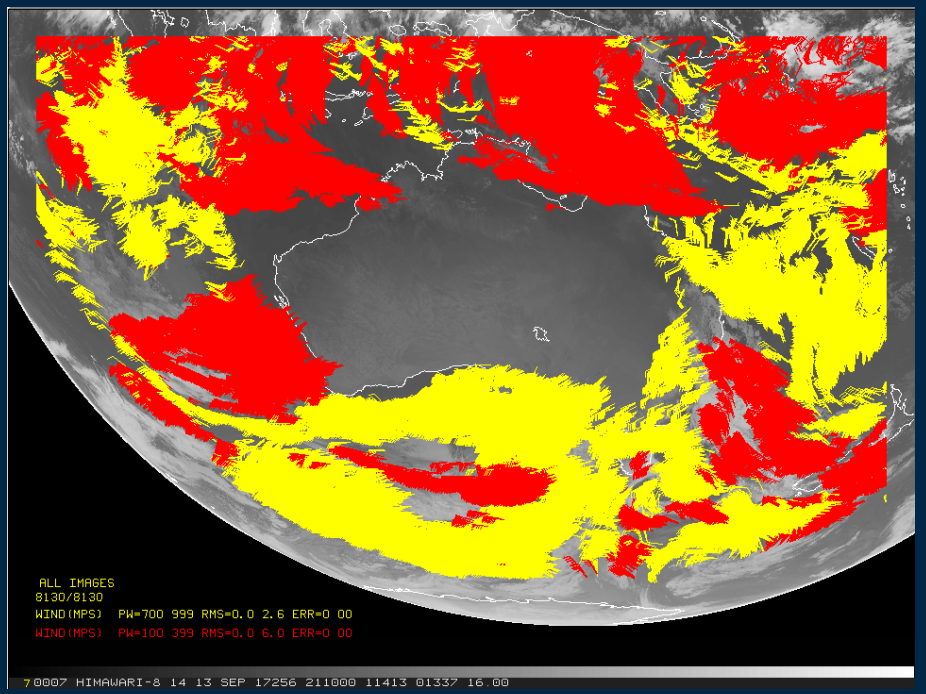
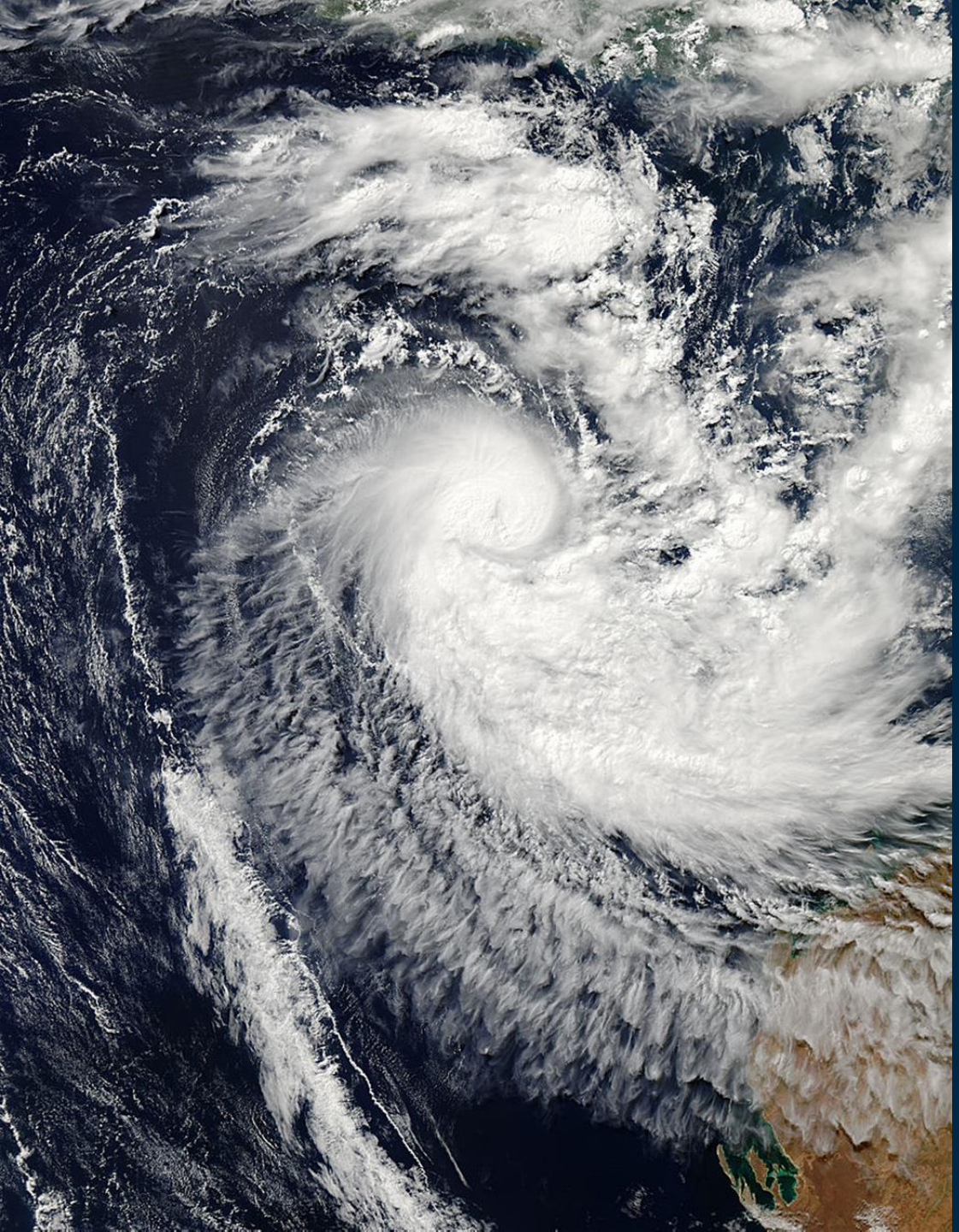


Figure 10(b) shows Channel 14 (IR) low level AMVs (yellow) with expected errors less than 2.6m/s and upper level AMVs (red) with expected errors less than 6.0m/s generated by six image triplets.



Using 10 Min AMVs with 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

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TC Quang Himawari-8 AMV Assimilation

Used operational TCX system over Timor Sea.

Used all Vis/IR image triplets (separated by 10 min/HSF format). (2km IR, 1km VIS) plus full operational data base.

TCX is a nested TC model (nested in APS-2 ACCESS-G) of 4km resolution and has 70 levels .

Forecast start time 00UTS 29 April 2015

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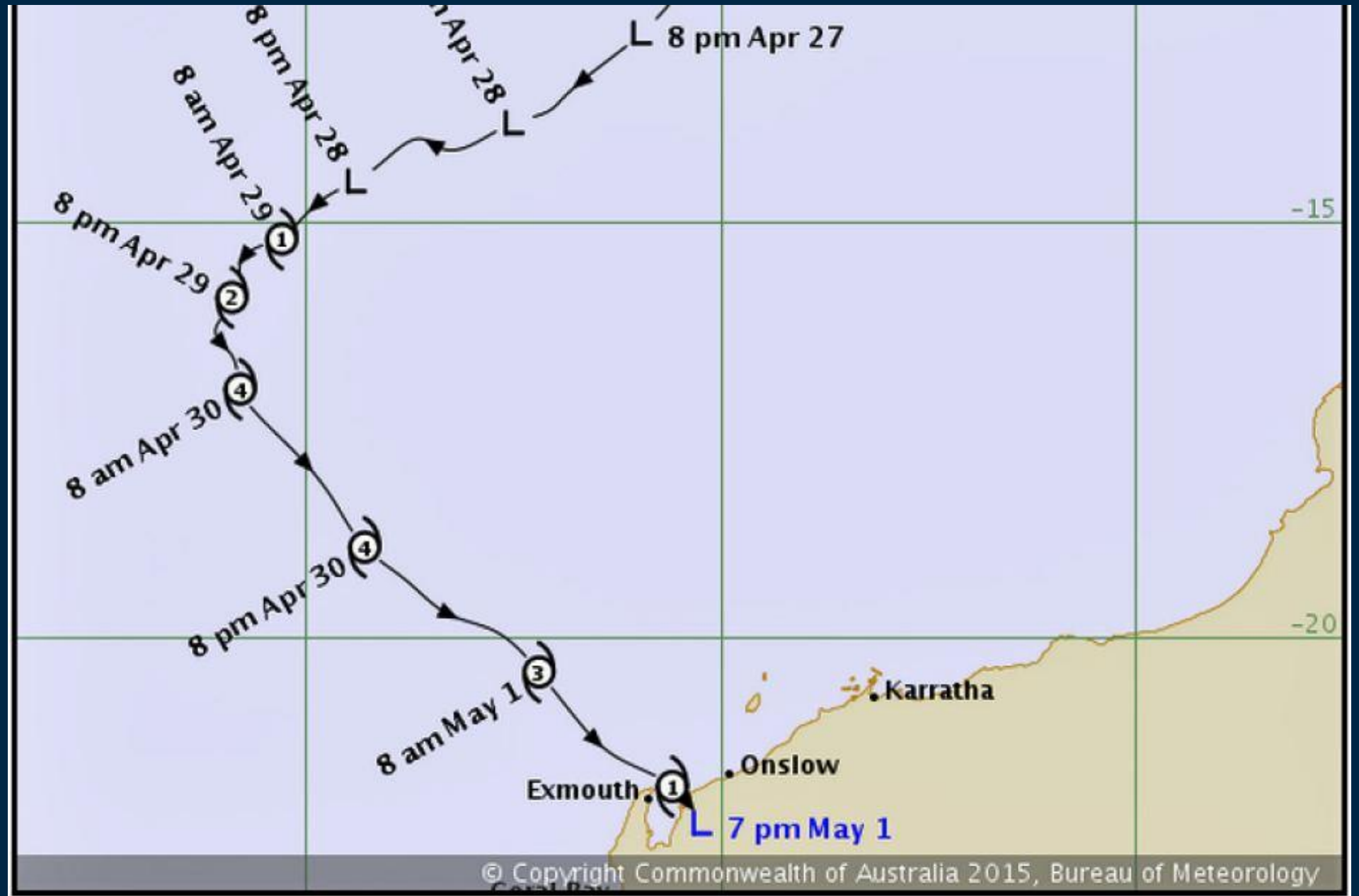

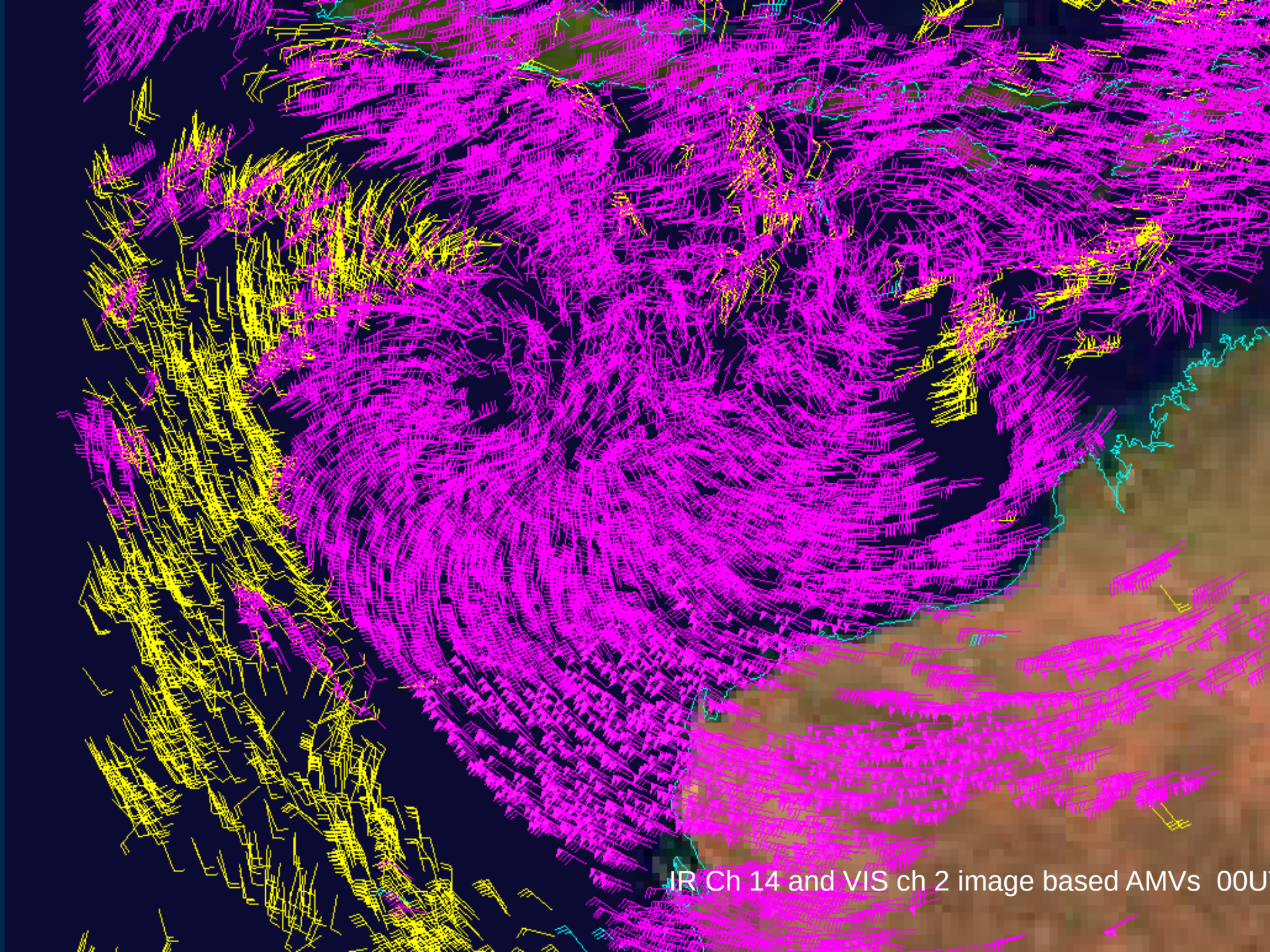
IR Ch 14 and VIS ch 2 image based AMVs 00U

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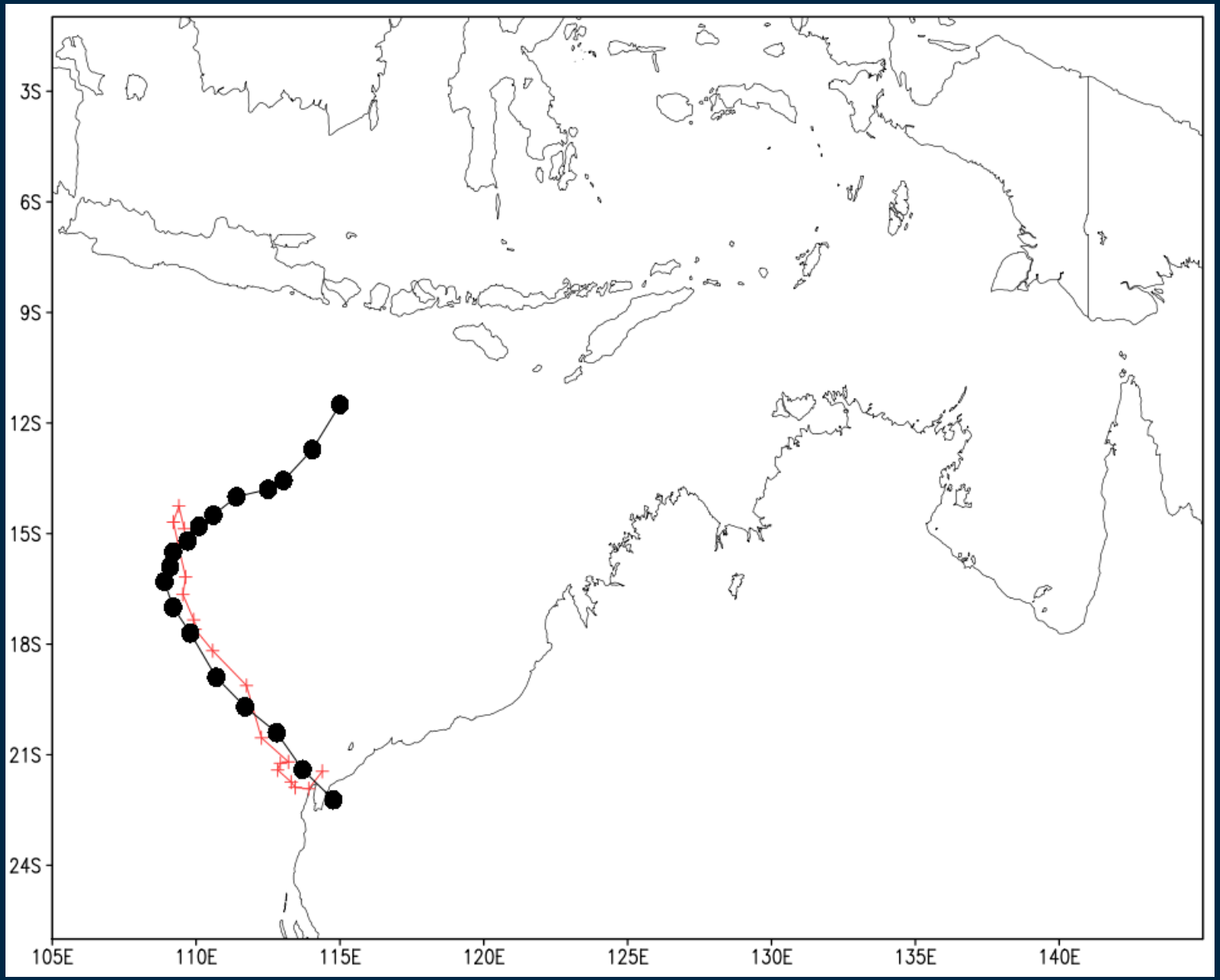

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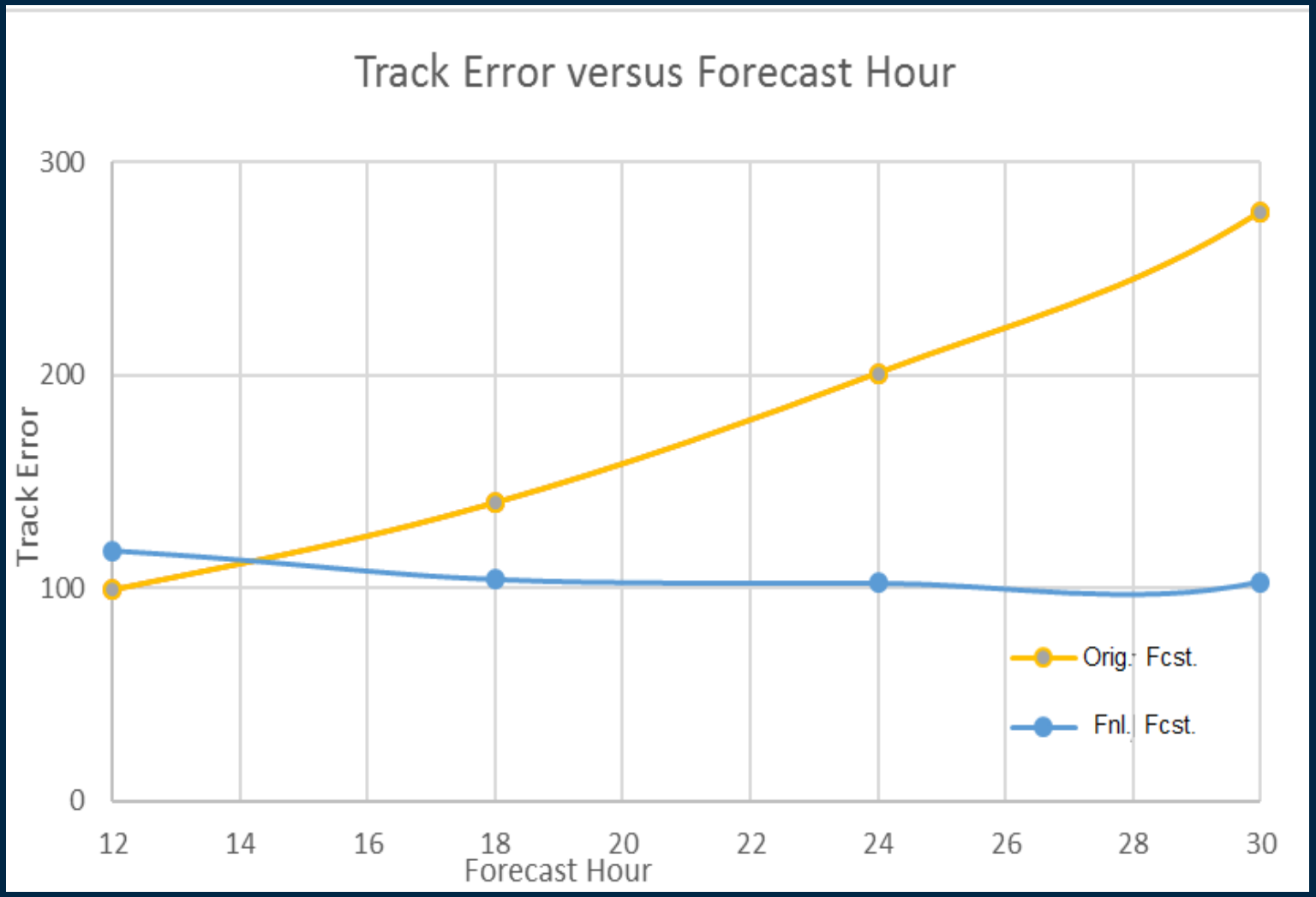

Fig. 15 The original forecast track error of tropical cyclone Quang from 00 UTC 29 April 2015 (yellow) and the final track error (Blue), both in six hour intervals (see text).

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ADM (Atmospheric Dynamics Mission) - Aeolus

Satellite built by the ESA launched 2018.

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

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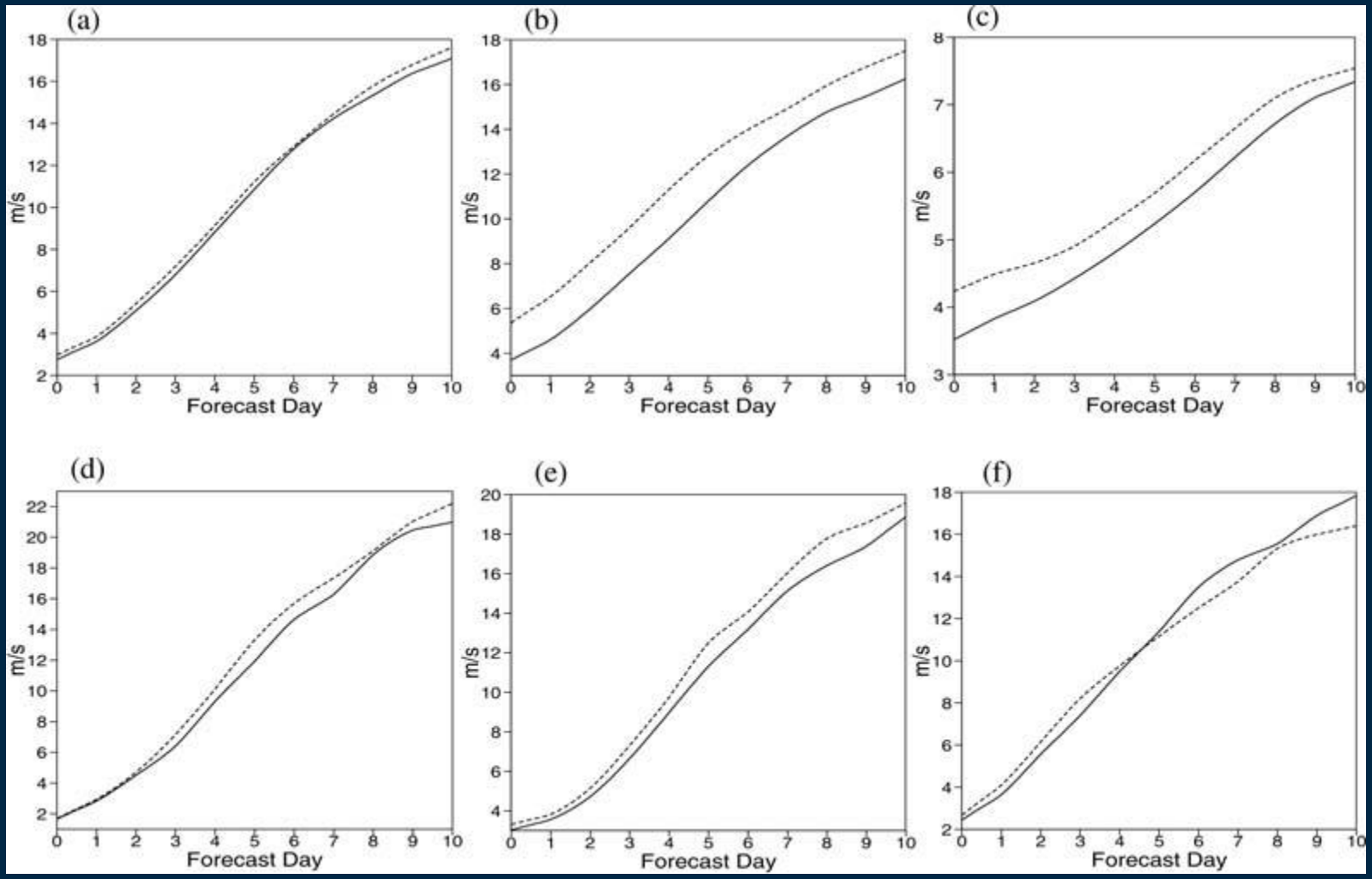
DOPPLER WIND LIDAR OSSE



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.

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GROUND GPS/ZTD IN NWP

The GNSS/ZTD Application project

- Partnership of Bureau of Meteorology, RMIT University and Geoscience Australia

- Aims
  - Improve moisture analysis and forecasting by developing a GPS-based ZTD/IWV estimation system across Australian Region.
  - Effective assimilation of ZTD data into the ACCESS model.
  - Improve moisture analysis and forecasting

- Currently we assimilate into next generation Capital City, Regional, and Global ACCESS Models, including the operational G-3 model.

ZTD - Zenith Tropospheric Delay

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Background

The measured ZTD is the delay in reception of a signal from a GPS satellite which is directly overhead as a result of the presence of the neutral atmosphere and is expressed in terms of excess path length (Bevis et al. 1992). Slant path delays are mapped to the zenith using a mapping function, for example Neill 1996. ZTD is related to the refractivity along the signal path by

$$\mathrm{ZTD} = 10^{-6} \int_{z_a}^{\infty} N \, dz$$

where z_a is antenna height (m) and N is the neutral atmosphere refractivity. Expanding N provides

$$\mathrm{ZTD} = 10^{-6} \int_{Z_a}^{\infty} k_1 \rho R_d \, dz + 10^{-6} \int_{Z_a}^{\infty} \frac{R_d}{\epsilon} \left(k_2 - \epsilon k_1 + k_3/T \right) q\rho \, dz$$

where R_d = 287.05 J kg^{-1} K^{-1} is the gas constant of dry air, ρ is the water vapour density (kg m^{-3}) and Є= 0.62 is the ratio of molar weights. The empirical constants are k1 = 77.6 K hPa^{-1}, k2 = 70.4 K hPa^{-1} and k3 = 373900 K^2 hPa^{-1} (Thayer, 1974). ZTD has two components, the delay due to hydrostatic pressure and the delay due to the water vapour along the path (Bengsston et al., 2003)

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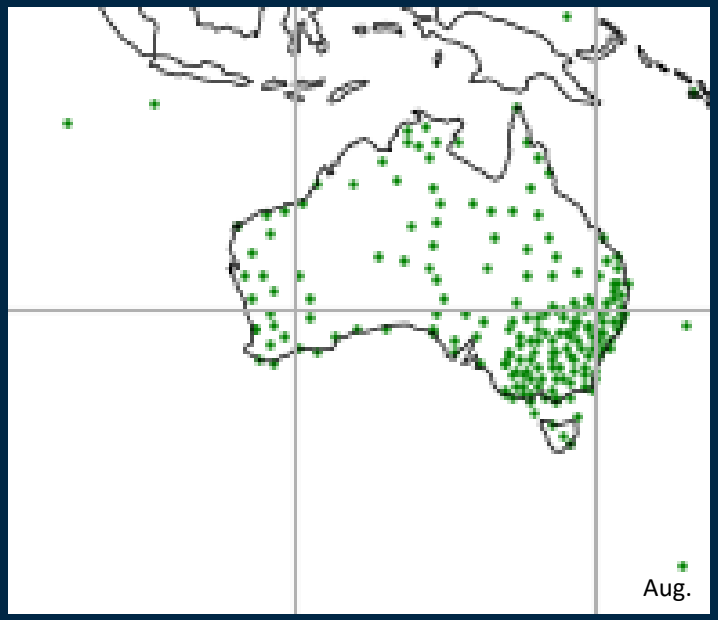
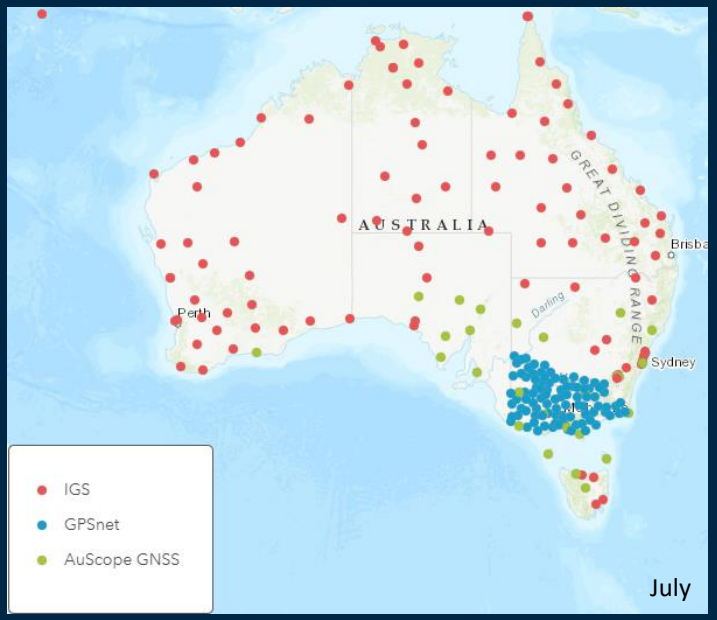
USING GROUND GPS/ZTD DATA IN NWP





Map of stations around Victoria/Australia used as sources of GNSS data and used in (near) real time processing for NWP.

ZTD - Zenith Tropospheric Delay

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Surface synoptic observations	Atmospheric Motion Vectors	CrIS radiances
Radiosonde observations	Scatterometer Winds	IASI radiances
Aircraft observations	ATOVS radiances	GPSRO bending angles
Doppler radar radial winds	AIRS radiances	ATMS and AMSU radiances

Some of the conventional observations and Earth Observations from Space included in the next generation observational data base for the ACCESS-C3 suite.

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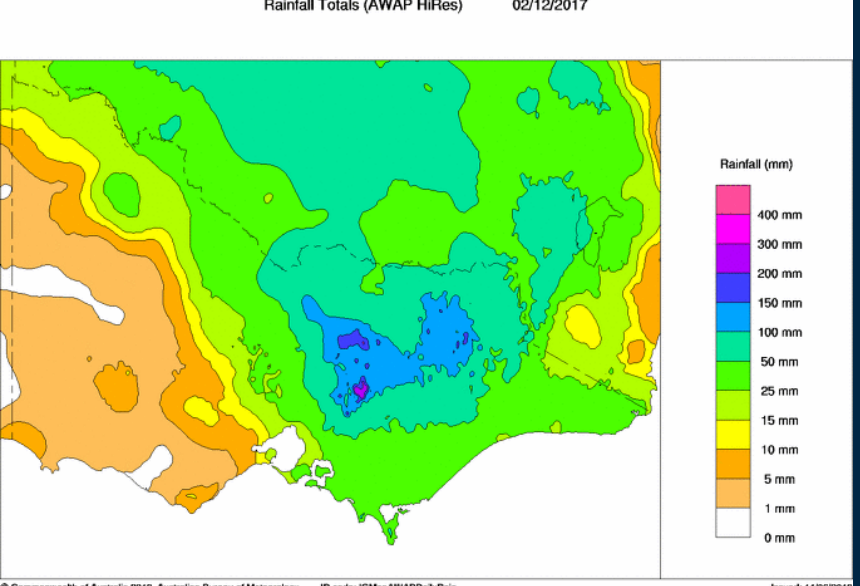
GROUND GPS/ZTD in NWP

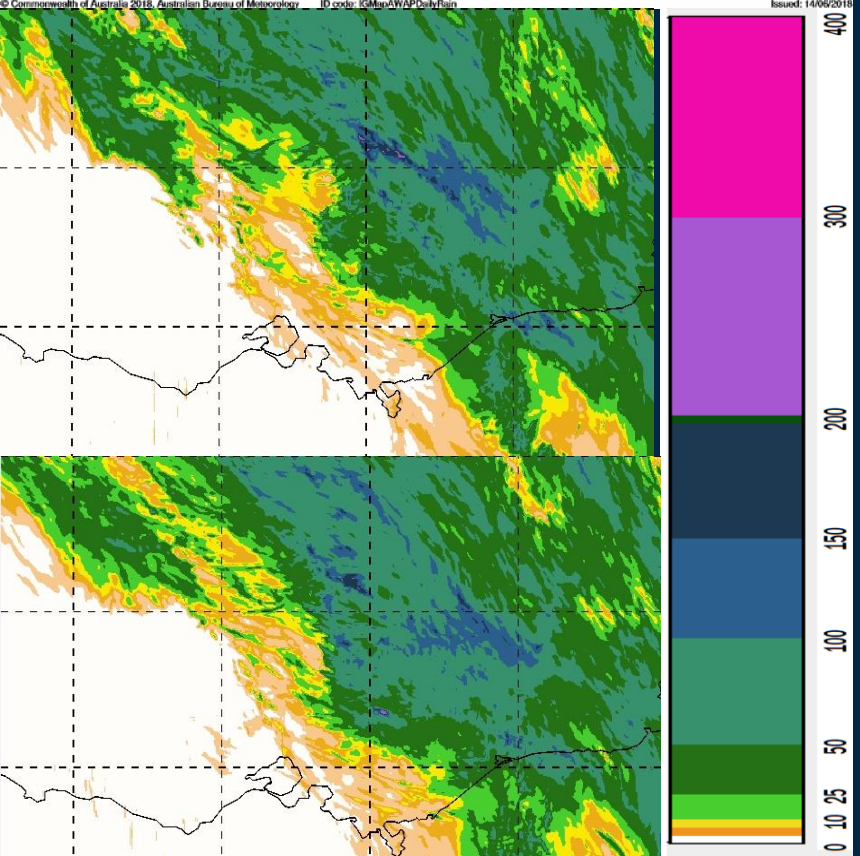
GNSS/ZTD Assimilation

- Sources of GNSS Observation data: RMIT University, Geoscience Australia
- Processing methodology: Double Difference(DD) solution (RMIT), Precise Point Positioning (PPP) method (GA). [Le Marshall et al., JSHESS,2019]

- Example
  - Assimilation of GNSS-based ZTD observations in ACCESS-C3 over Victoria, 29 Nov. – 4 Dec. 2017.
  - The ACCESS-C3 4DVAR system has a domain covering Victoria and Tasmania. Horizontal resolution near 1.5 km stretching to 4km at its border
  - ZTD data used with full operational data base
  - Nested in ACCESS-R

24 Hour Rainfall to 2/12/2017 00UTC





Operational AWIPS system

No GNSS ZTD data

With GNSS ZTD data

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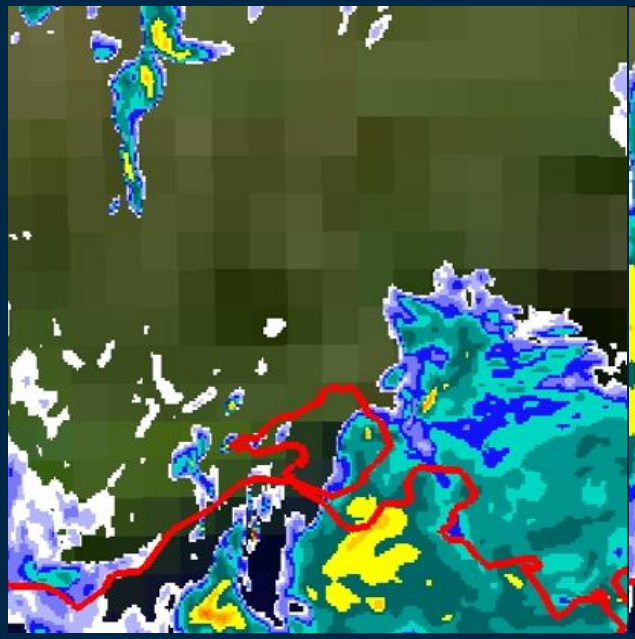
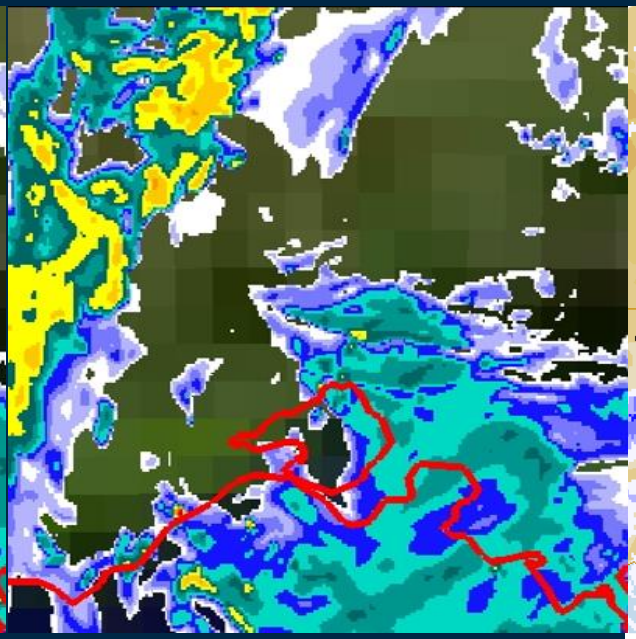
BoM Melbourne Radar Loop - Rain Rate

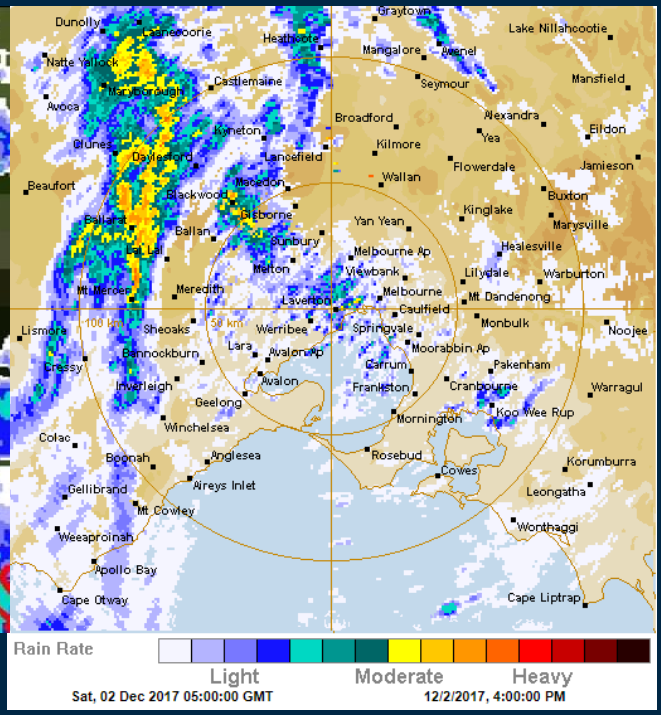
Radar reflectivity 1km agl(No GPS)



Radar reflectivity 1km agl (With GPS)



BoM Melbourne Radar Loo[p – Rain Rate



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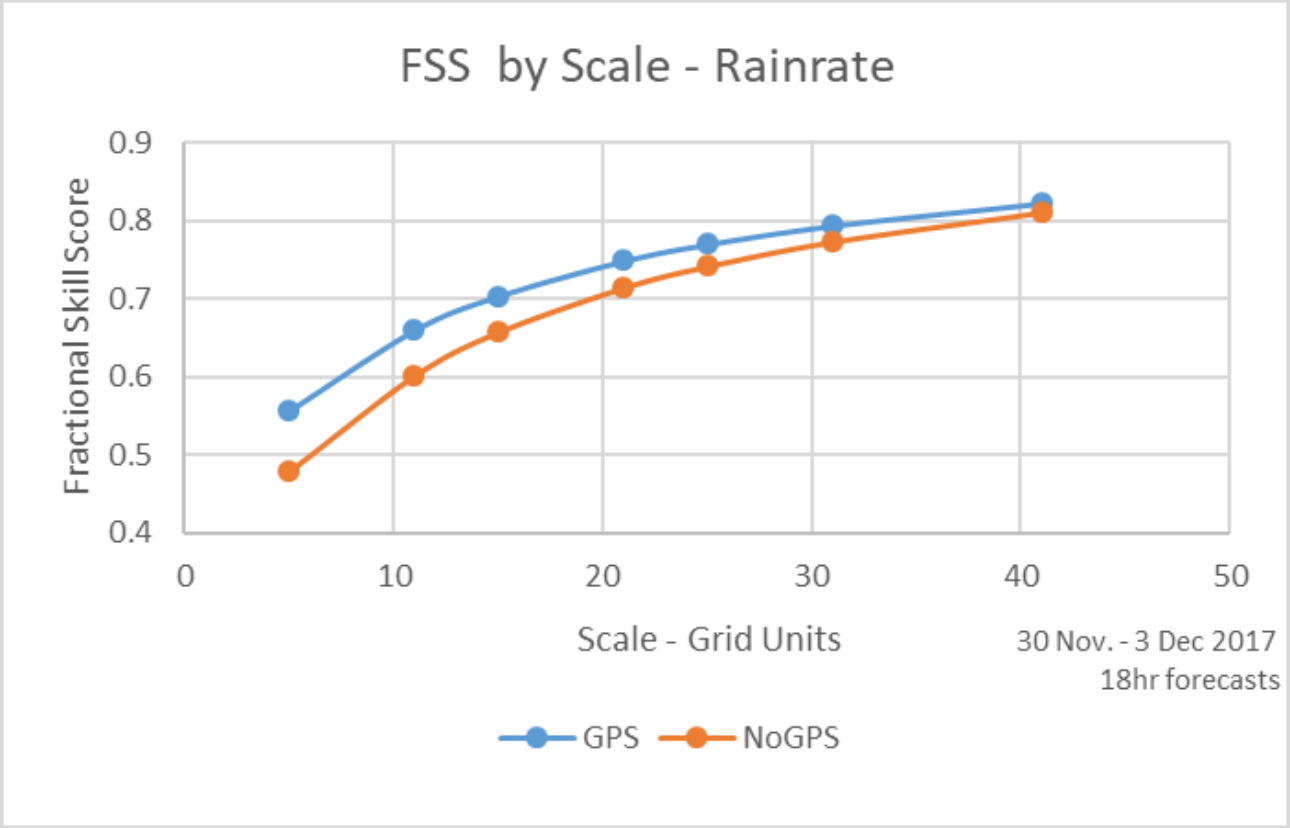

Fractions Skill Score versus Scale for 18 hour forecasts during the same period for forecasts where GPS data was and was not included in the forecast data base

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Summary

Results indicate reasonableness of the forecasts and demonstrate potential for improving rainfall forecasts over Australia by inclusion of ZTD data in moisture analysis field

The Future

Australia has already a very dense coverage of GPS receiving stations and this number will increase in coming years

This is expected to enable improved moisture analysis and is expected to improve the quality of numerical prediction across the continent

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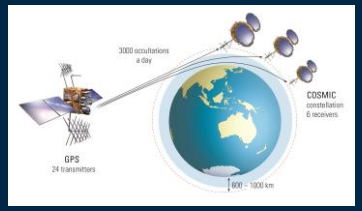
Future Opportunities for Australia. (Background)

Radio Occultation Related Opportunity

Orbit a Number of Satellites with RO Capability
Capability already demonstrated with Fedsat
Provides Improved Global Forecast Capabilty



Geostationary Advanced IR Sounder

A Geo Hyperspectral Sounder will Fly in our Region
2km Footprint at SSP, operational CC models now 1.5km
This Sounder Data will Significantly Improve Analysis and Forecasts

Looking Down

Is

Looking Up

TC LAURENCE

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Thank you

john.lemarshall@bom.gov.au