

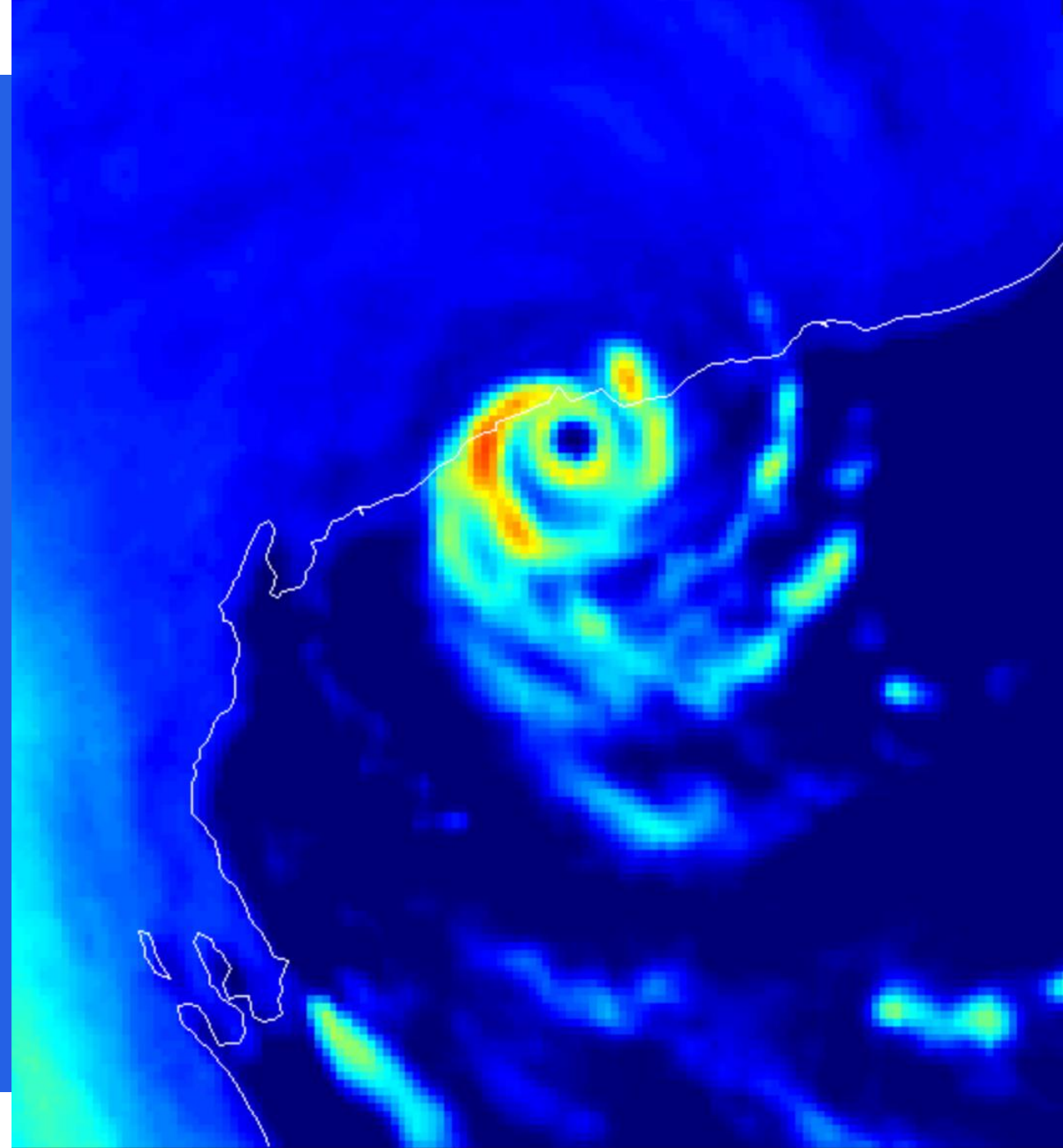


Review of satellite radiance observations in operational Numerical Weather Prediction

Fiona Smith

AMSR-2 microwave image of cyclone Damien off Western Australia, February 2020

Image courtesy of CIMSS



Thank you to the NWP Community

- Results in this presentation were taken from various publications but also from the information provided biennially by members of the International (A)TOVS Study Conference (ITSC) DA/NWP working group
- Thank you also to people who contributed directly to the content of this presentation:
 - Jin Lee (Bureau of Meteorology)
 - Hyoung-wook Chun (Korea Meteorological Administration)



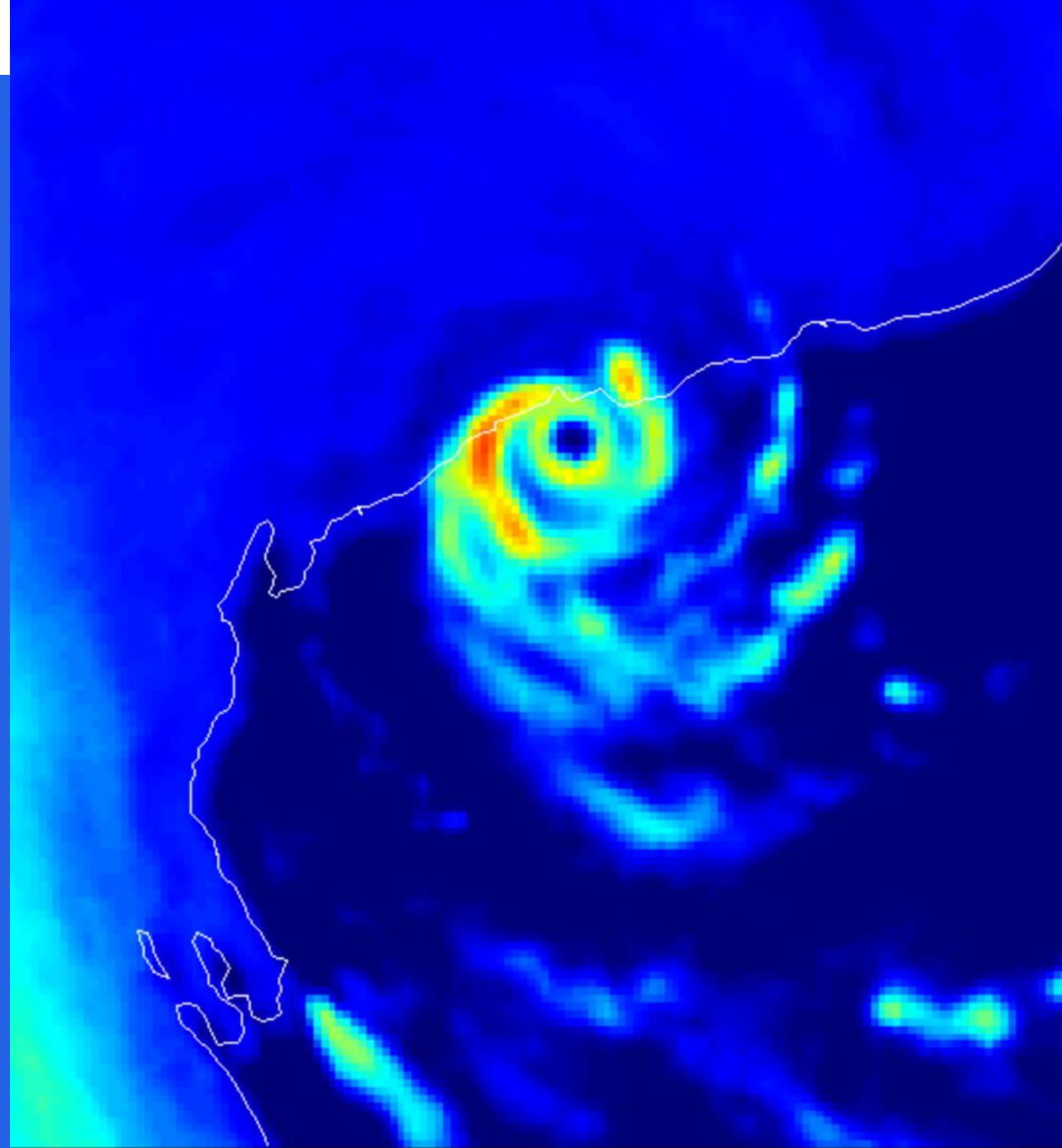
Outline

- Overview of the importance of satellite data for NWP
- How radiance data is used and its impact on forecast skill
- Use of radiances in high-resolution models
- Current scientific directions in radiance data assimilation

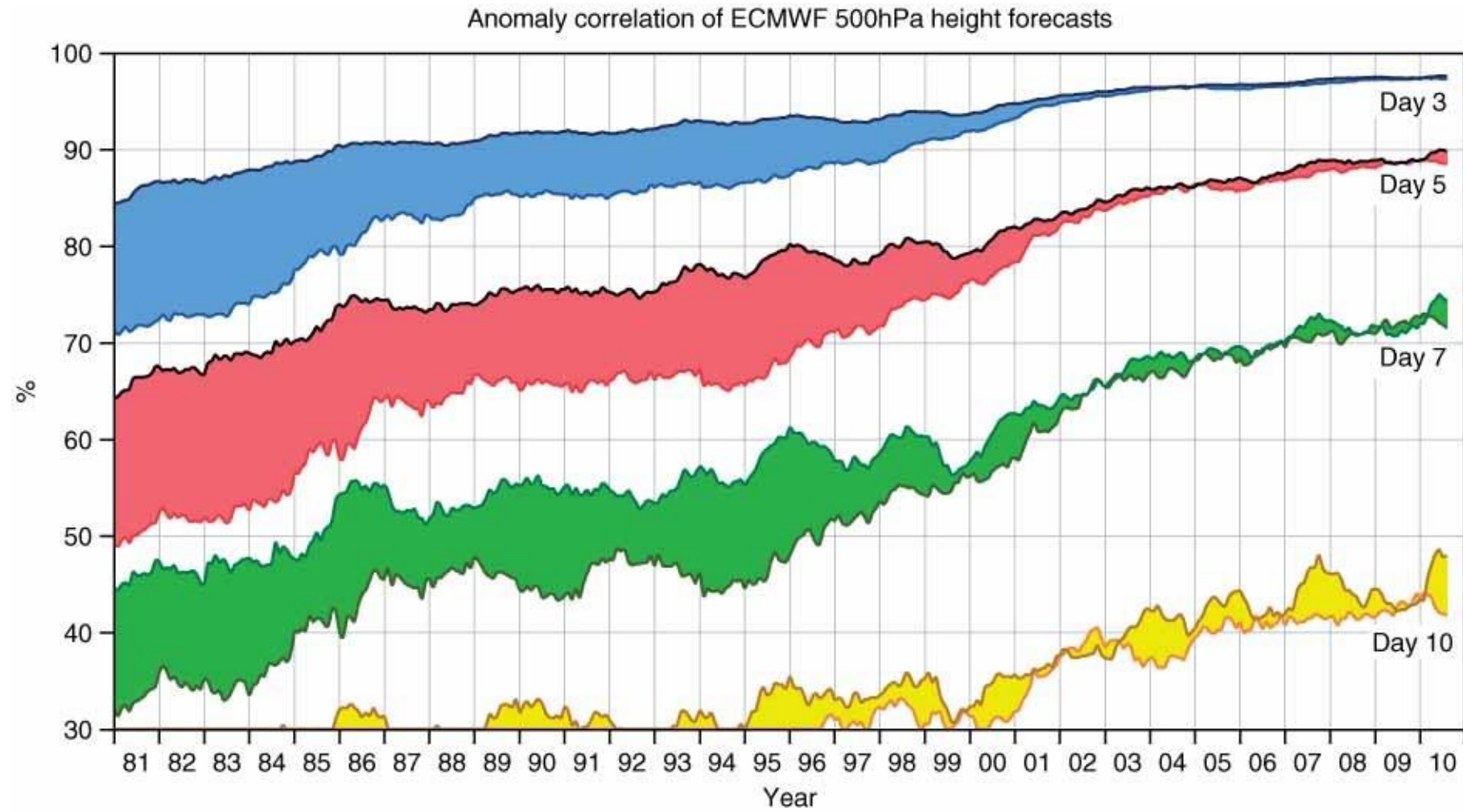




Overview of the importance of satellite data for NWP



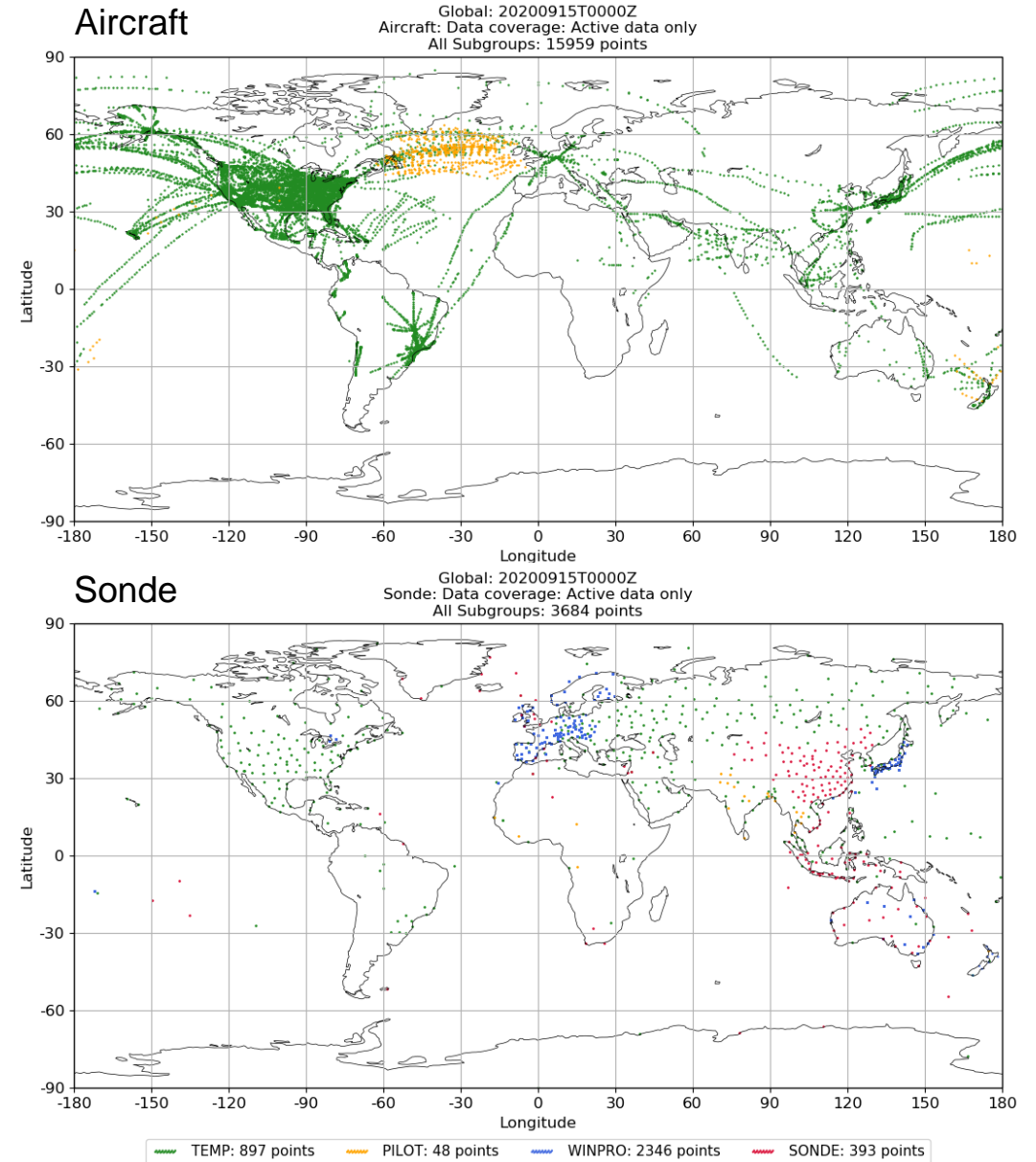
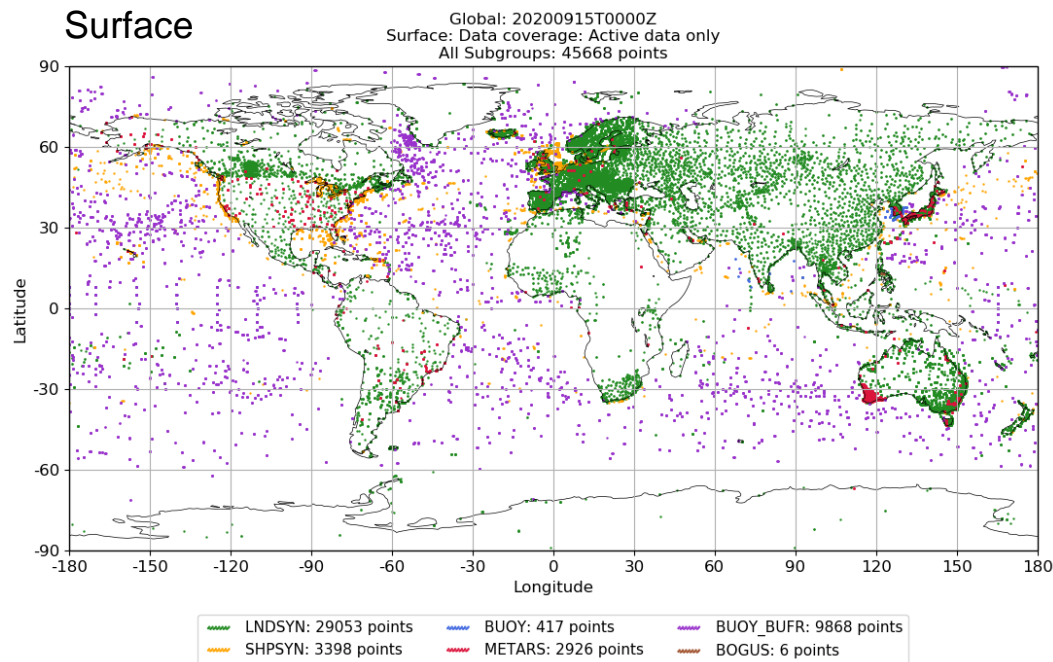
Importance of satellite data for the southern hemisphere



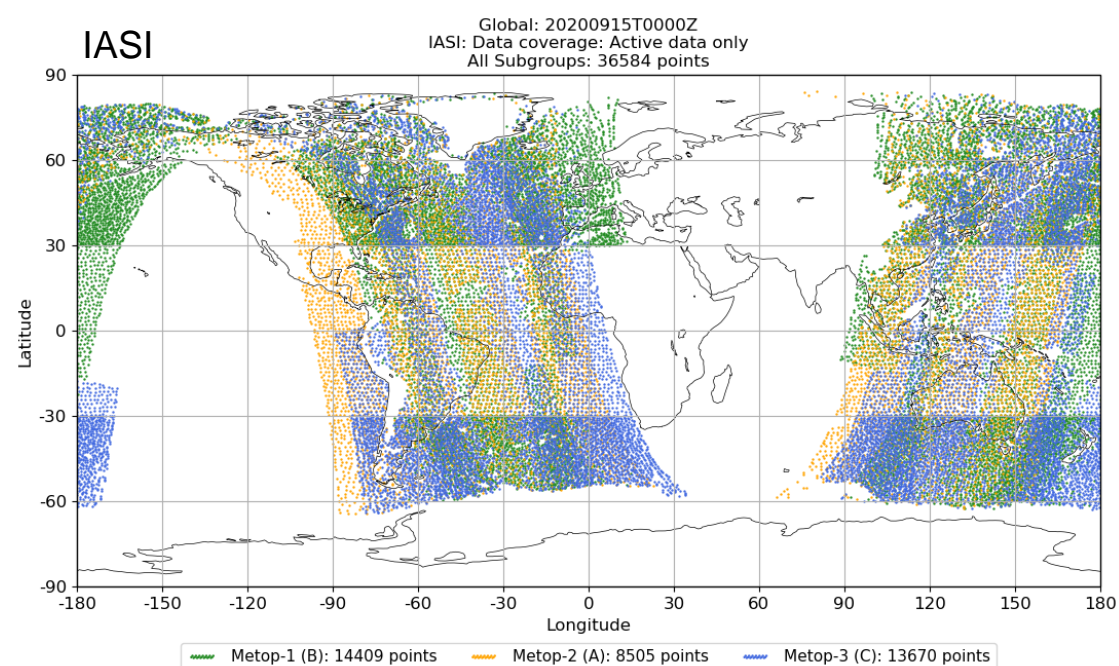
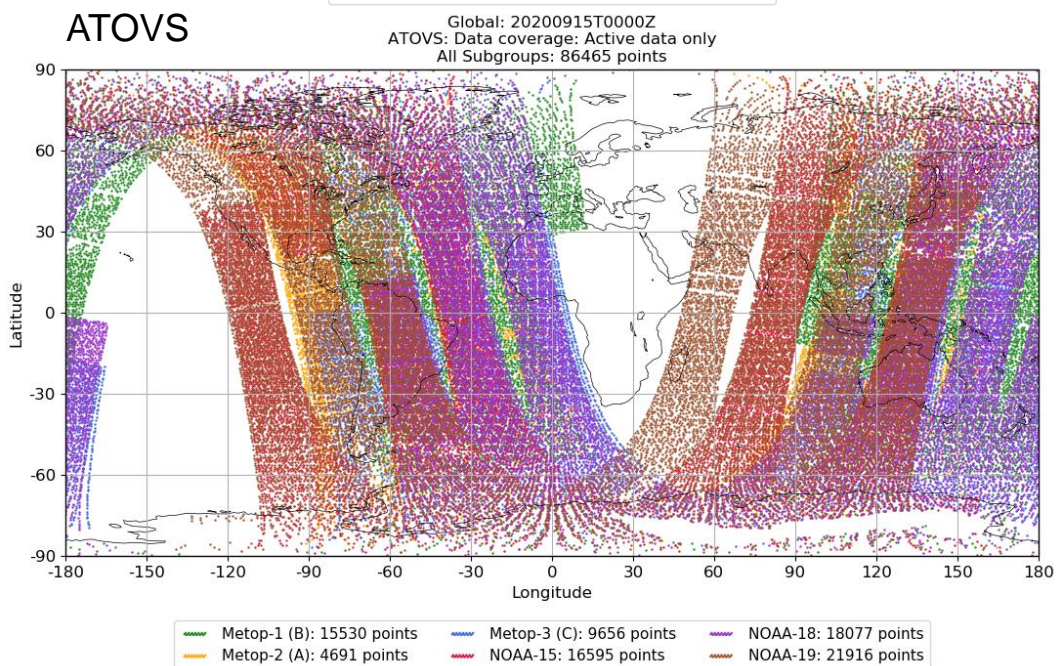
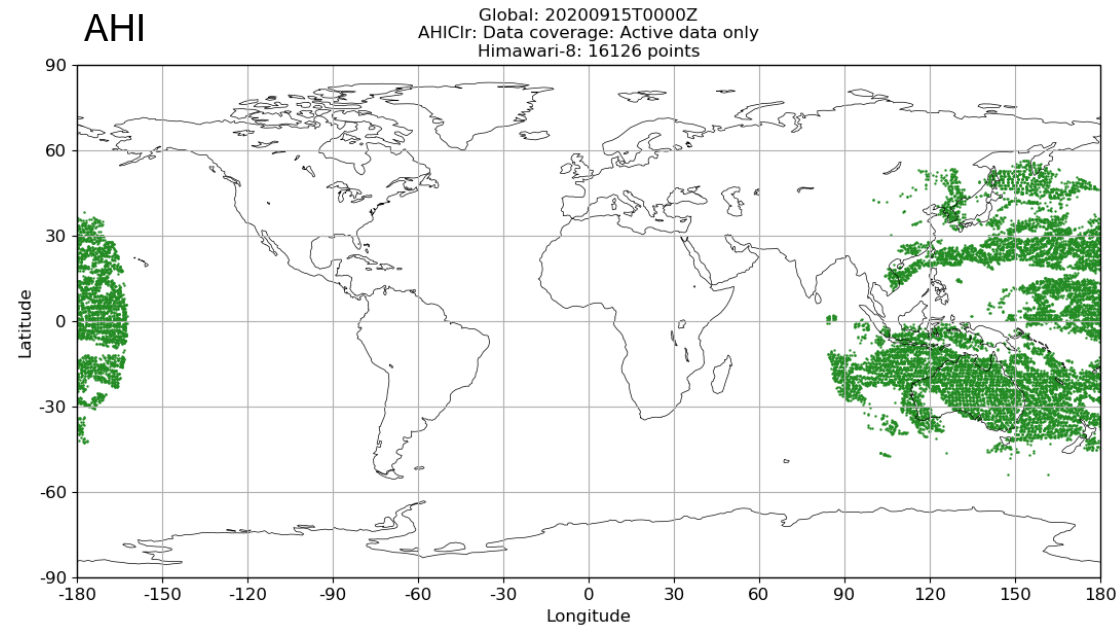
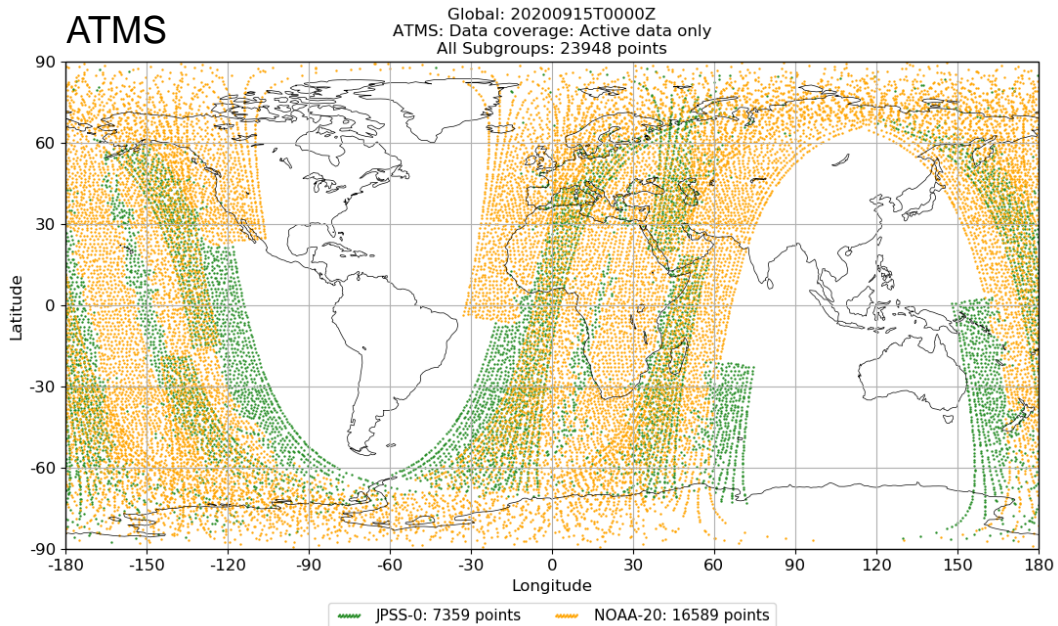
Courtesy of ECMWF. Adapted and extended from Simmons & Hollingsworth (2002)

Conventional obs: Aircraft, Surface and Sonde Coverage

- Coverage is poor particularly in the Southern Hemisphere
- Sondes only report 0Z and 12Z but Data assimilation cycles and forecasts are run every 6 hours at most centres

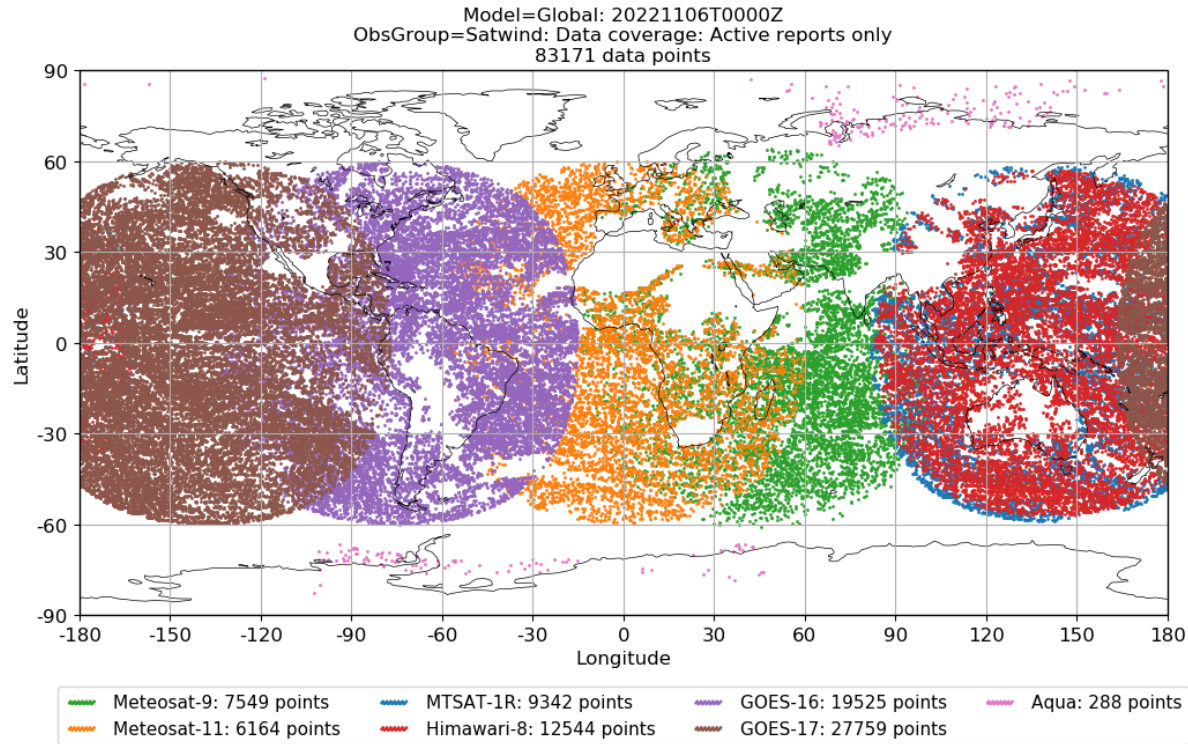


Selected Sounder coverage

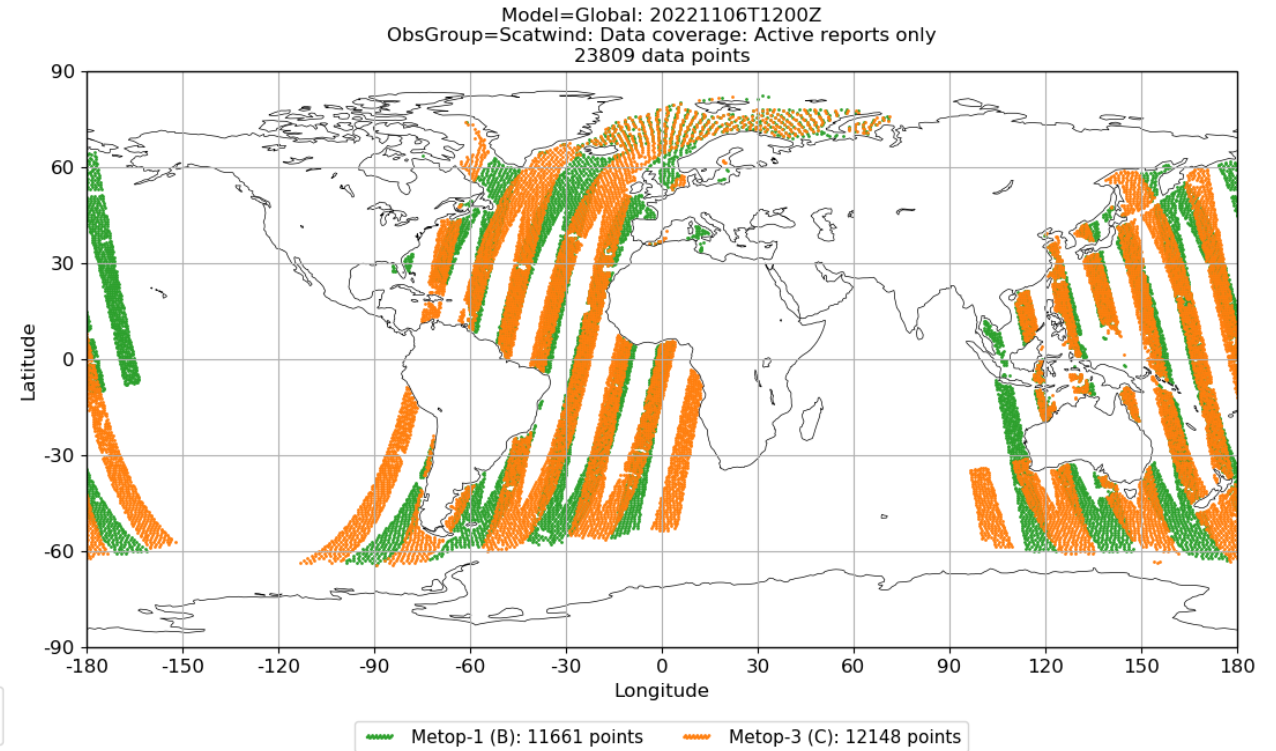


Wind coverage – AMV and Scatterometer

AMV

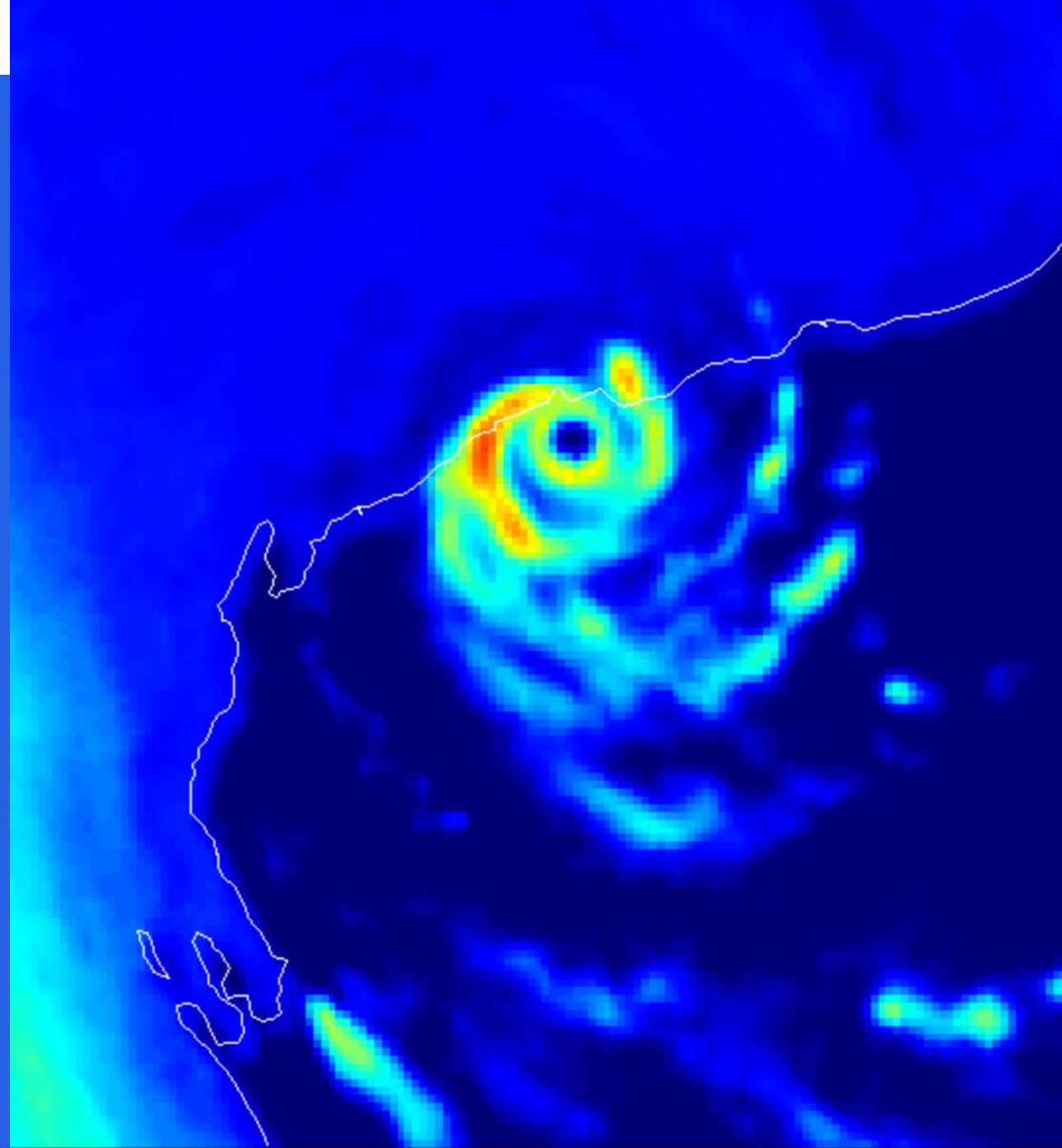


Scatterometer



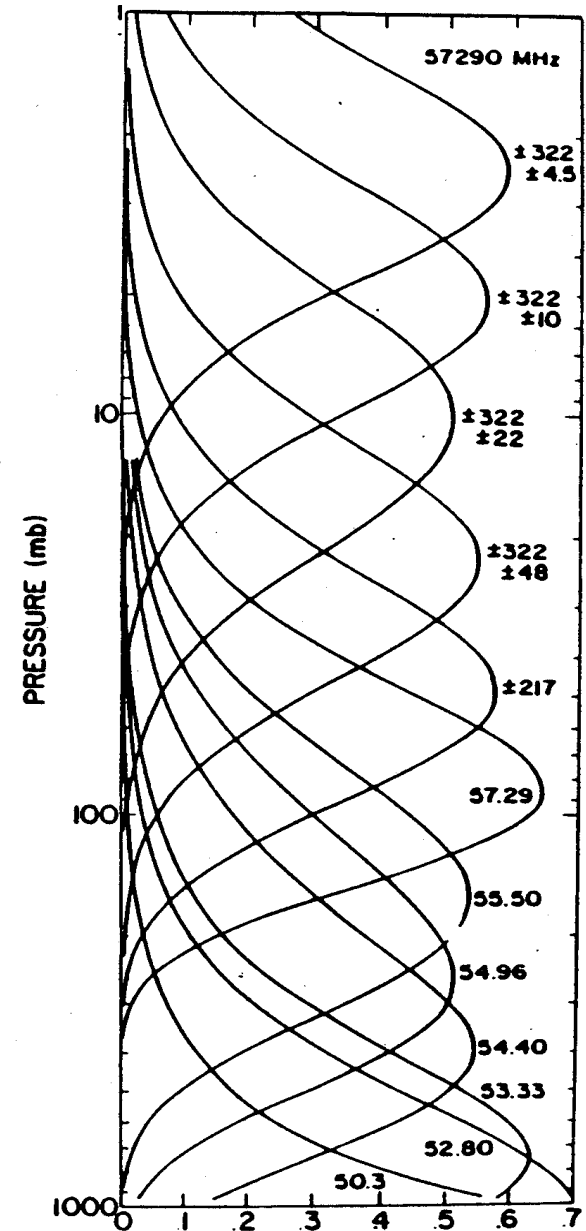


How radiance data is used and its impact on global forecast skill

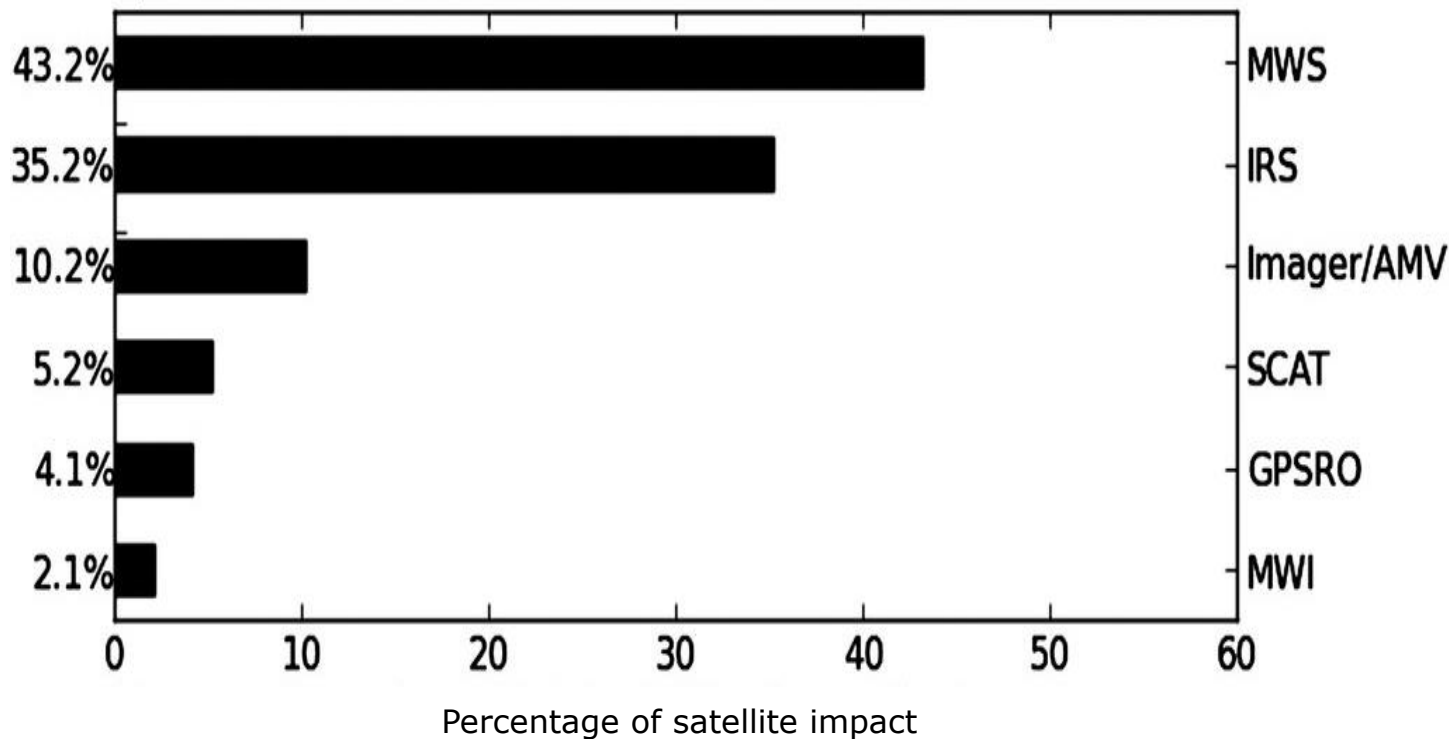


Satellite Sounding

- Satellite sounders are passive radiometers.
- The measurements are due to emission of gases in the atmosphere.
- By changing the frequency of radiation detected, you can take a measurement that is sensitive to a different layer in the atmosphere.
 - The sensitivity to the different parts of the atmosphere is known as the weighting function
- A family of measurements can be made to give a collection of overlapping weighting functions that give information on the temperature or humidity profile
- When we assimilate them, we use a radiative transfer model to provide a model-equivalent observation using a temperature and humidity profile as inputs.
- Measurements can be infrared or microwave – each technology has advantages and disadvantages.
- To the right are the weighting functions of AMSU-A, the microwave sounder with the longest heritage in NWP.



Impact on forecast skill using the data assimilation system adjoint to determine which observations had the most impact on forecast skill (FSOI)



Met Office, from Joo, Eyre and Marriott (2013)

FSOI results are subject to change as observing networks change and satellites are launched and deorbited, but MWS and IRS have topped the impact tables for at least the last 15 years.

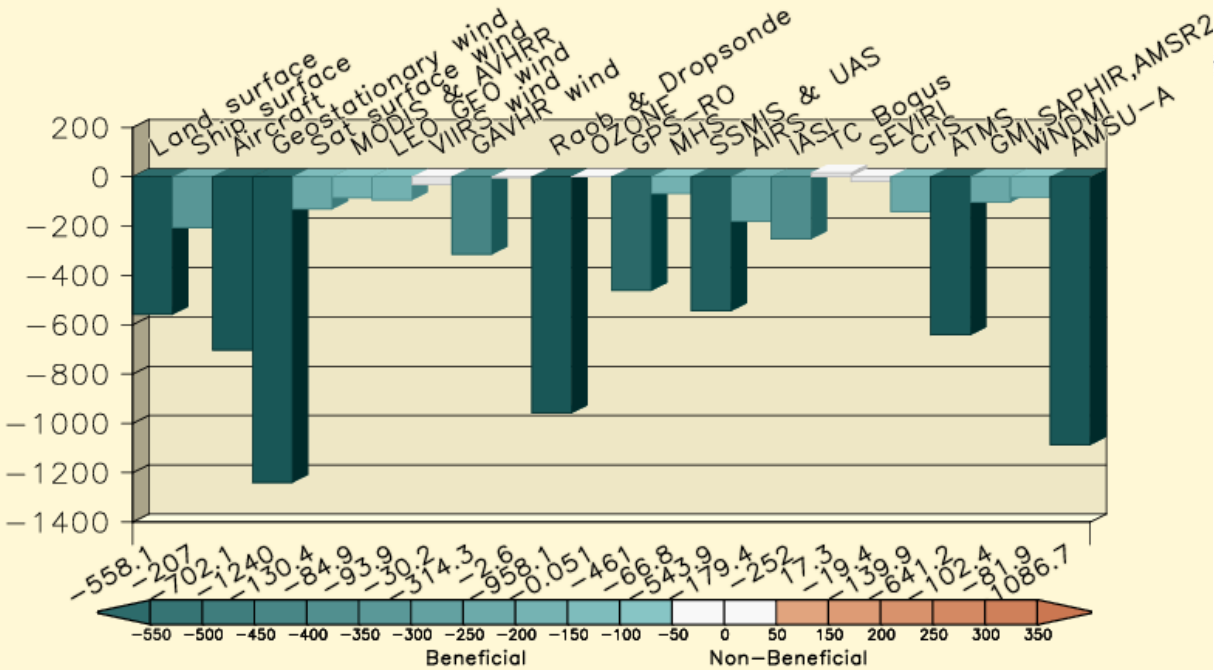


Impact of Satellite Data on NWP – consistent across centres (Forecast Sensitivity to Observations Impact - FSOI)

NAVGEN [OPS] NAVDAS-AR All Zs Impact Sum by Instrument Type

Impact of 00UTC observations on 24h global forecast error – moist total energy norm (J kg⁻¹)

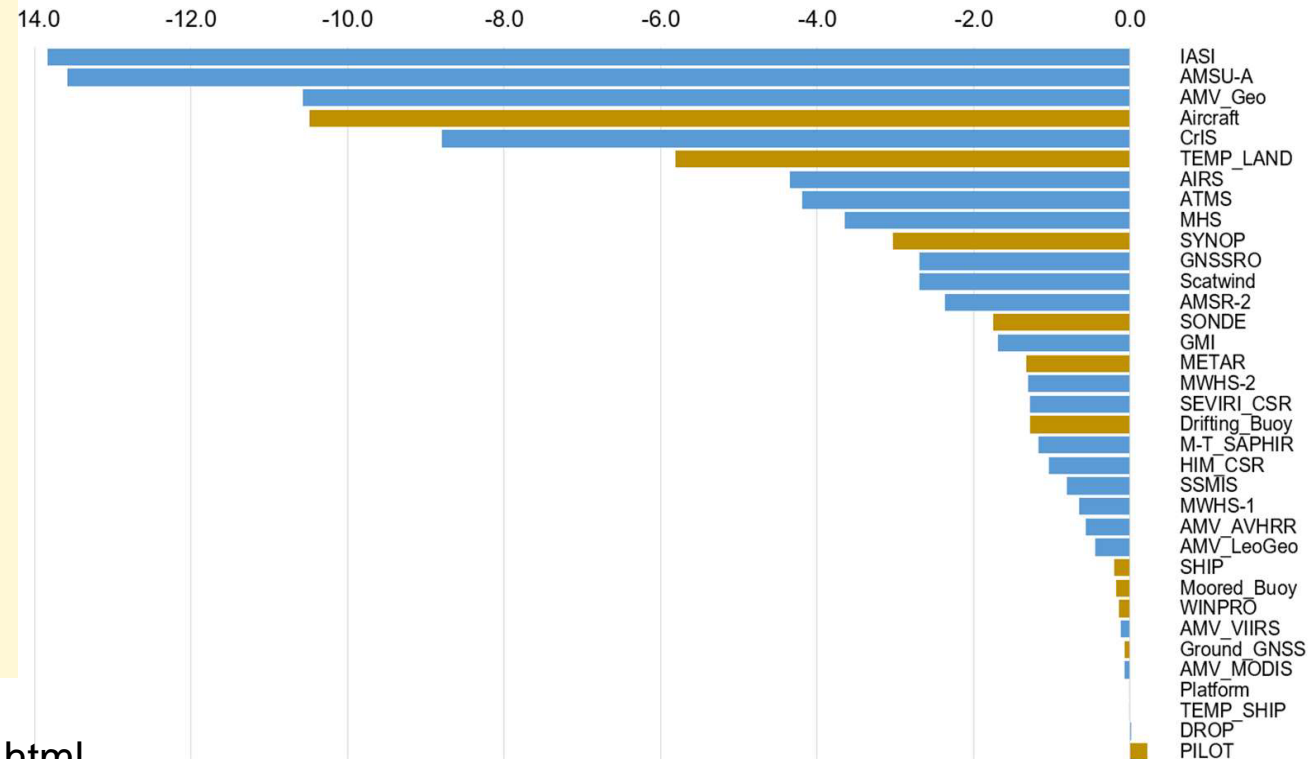
Sum = -7880 for 349 days of 1 year ending 10 Apr 2020



Met Office (Sep 2018-Jan 2019)

Cotton & Eyre, Met Office FRTR 636

All observations / 20180926T0600Z - 20190112T0600Z
Relative total impact (%)

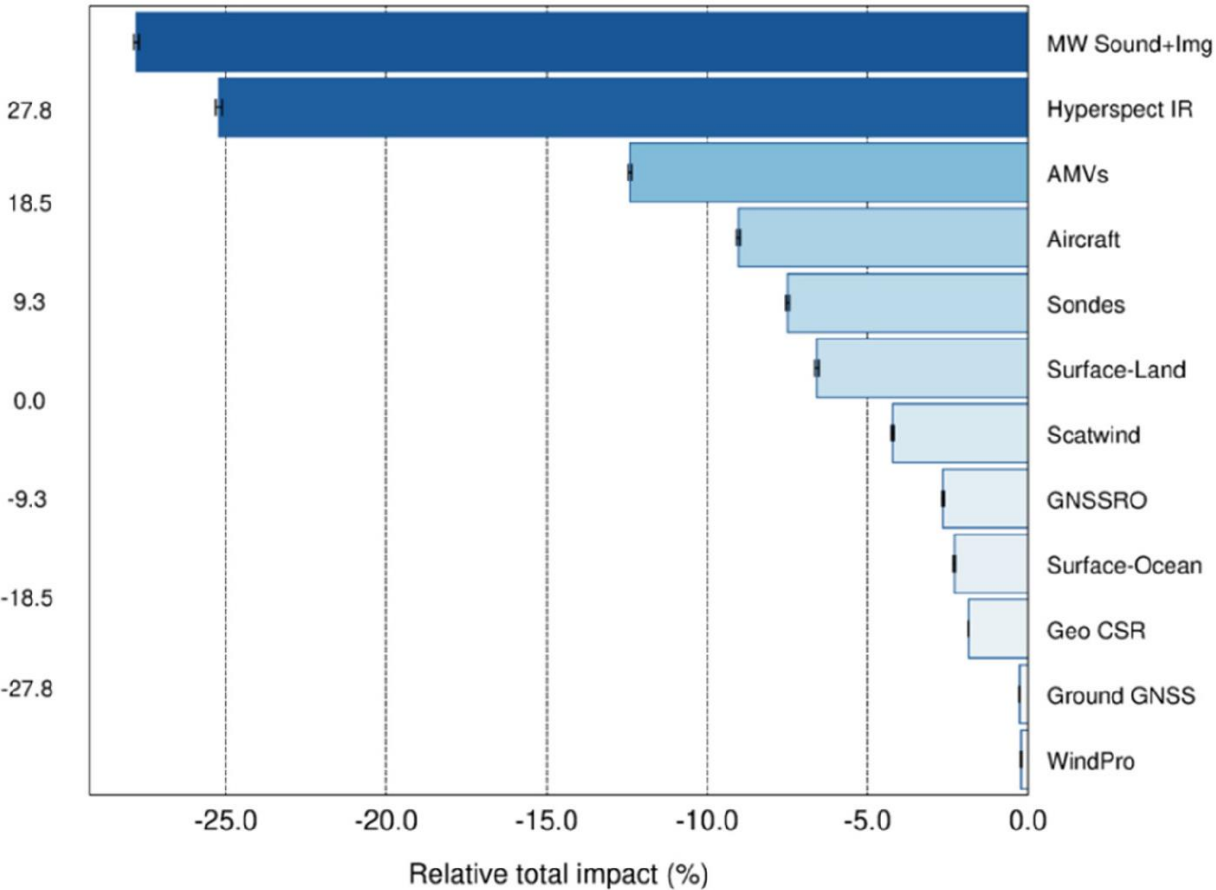


NRL (2020)

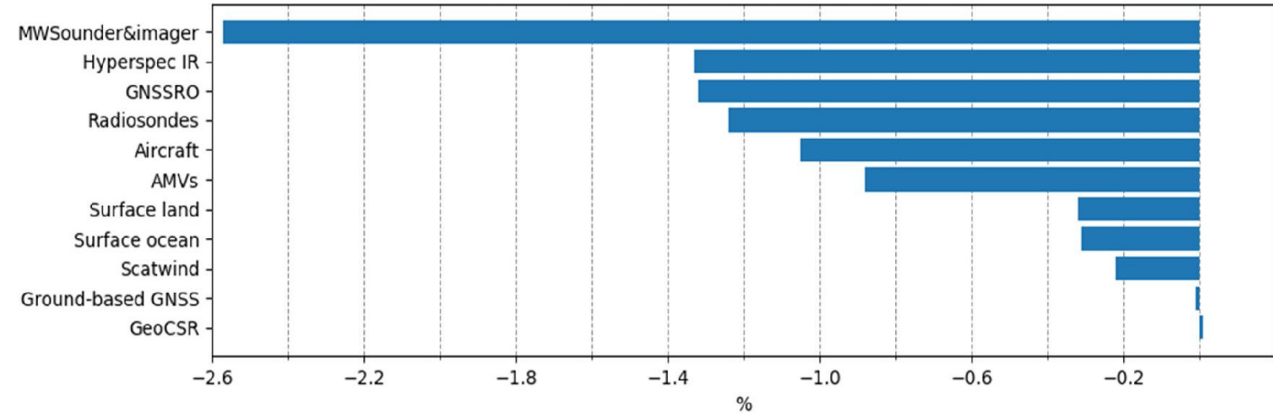
https://www.nrlmry.navy.mil/obsens/navgem/obsens_main_od.html

Impact is consistently good across different ways of assessing skill FSOI (left) and data denial experiments (right)

All categories / 20190815T1800Z-20191016T0600Z
Relative total impact (%)



Mean change in scorecard versus ECMWF analysis



From Eyre et al., 2021
Impact is also fairly consistent year-to-year
(plots in this talk span 2016 to 2020)



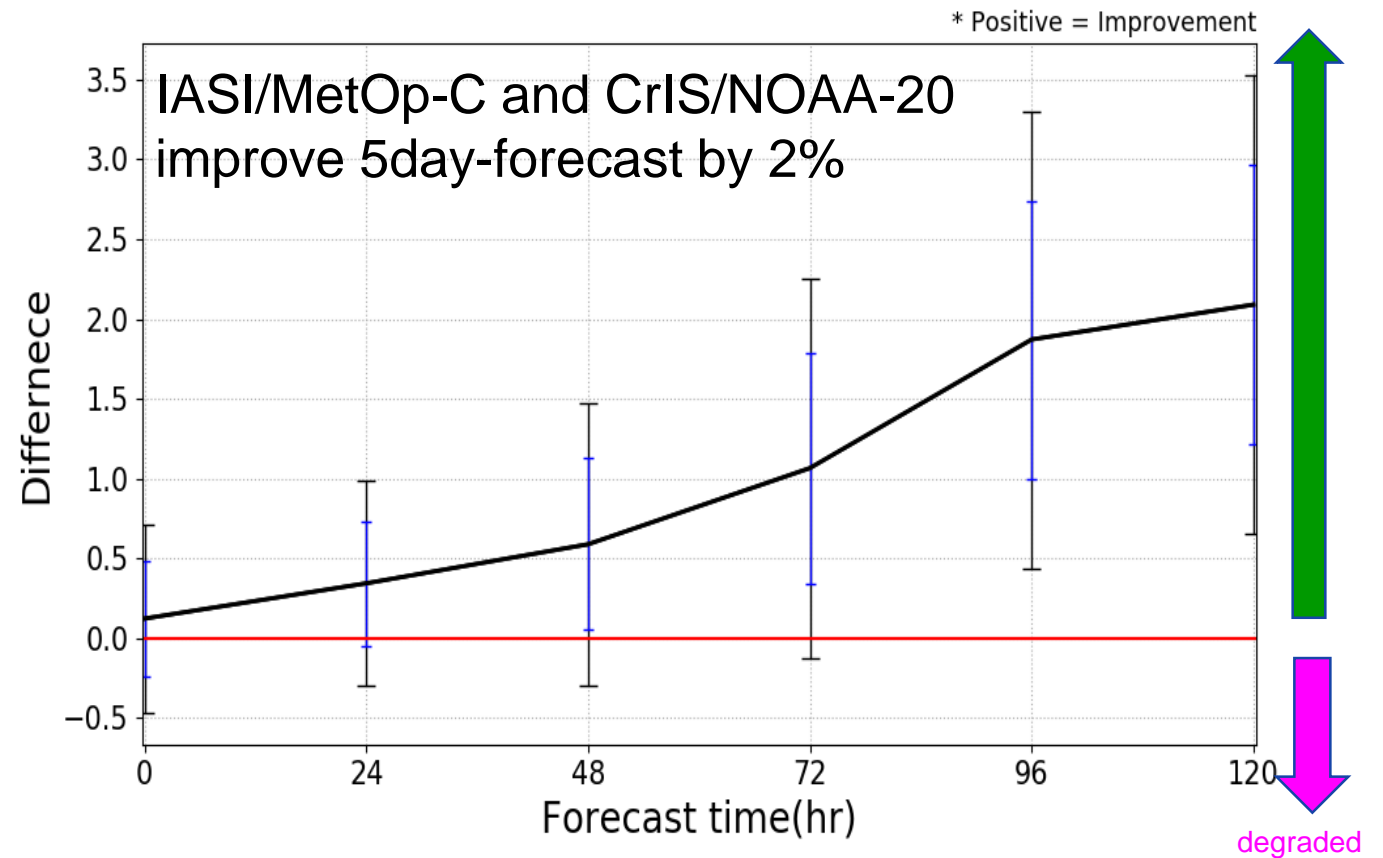
Impact from adding new sensors

Despite a comprehensive global observing system, we still see impact from adding new satellite observations.

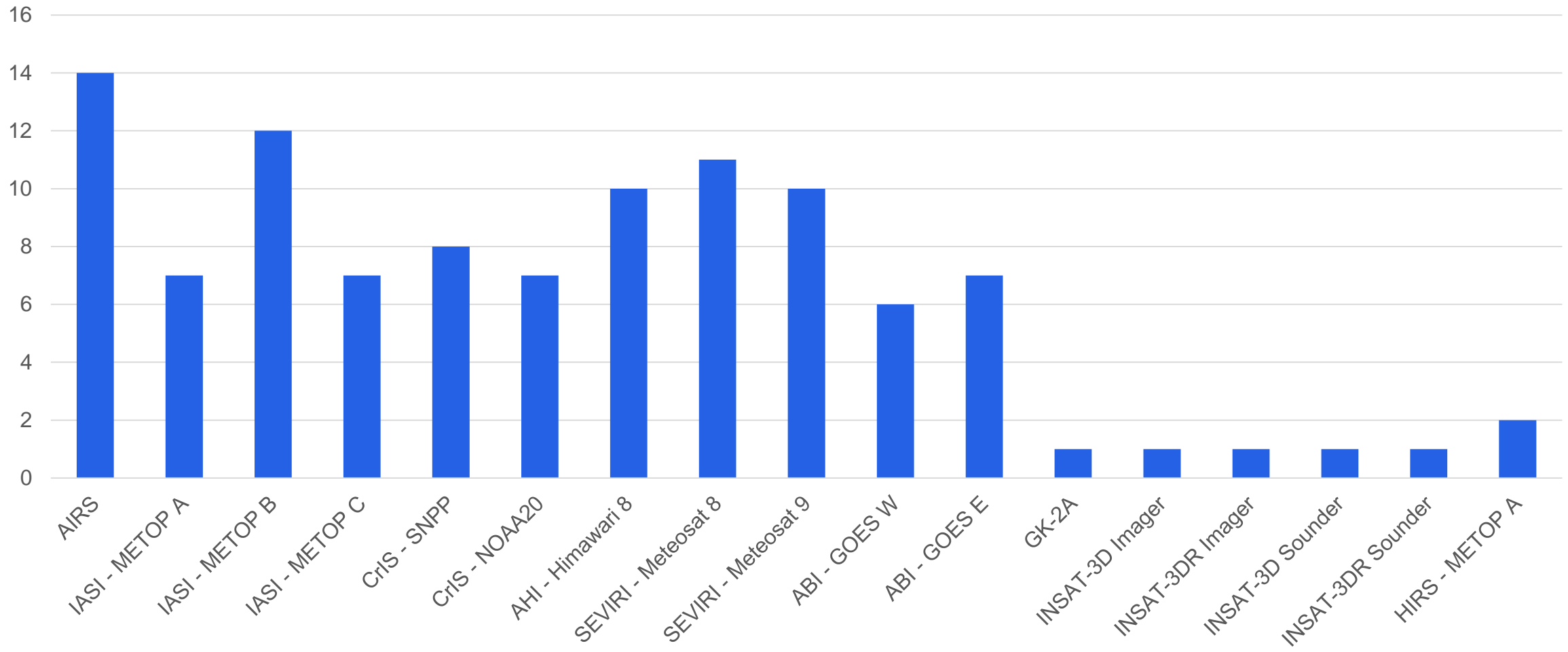
This plot shows the positive impact at medium-range from adding two new hyperspectral IR sounders into the KIM model.

Results from Hyoung-Wook Chun (KMA)

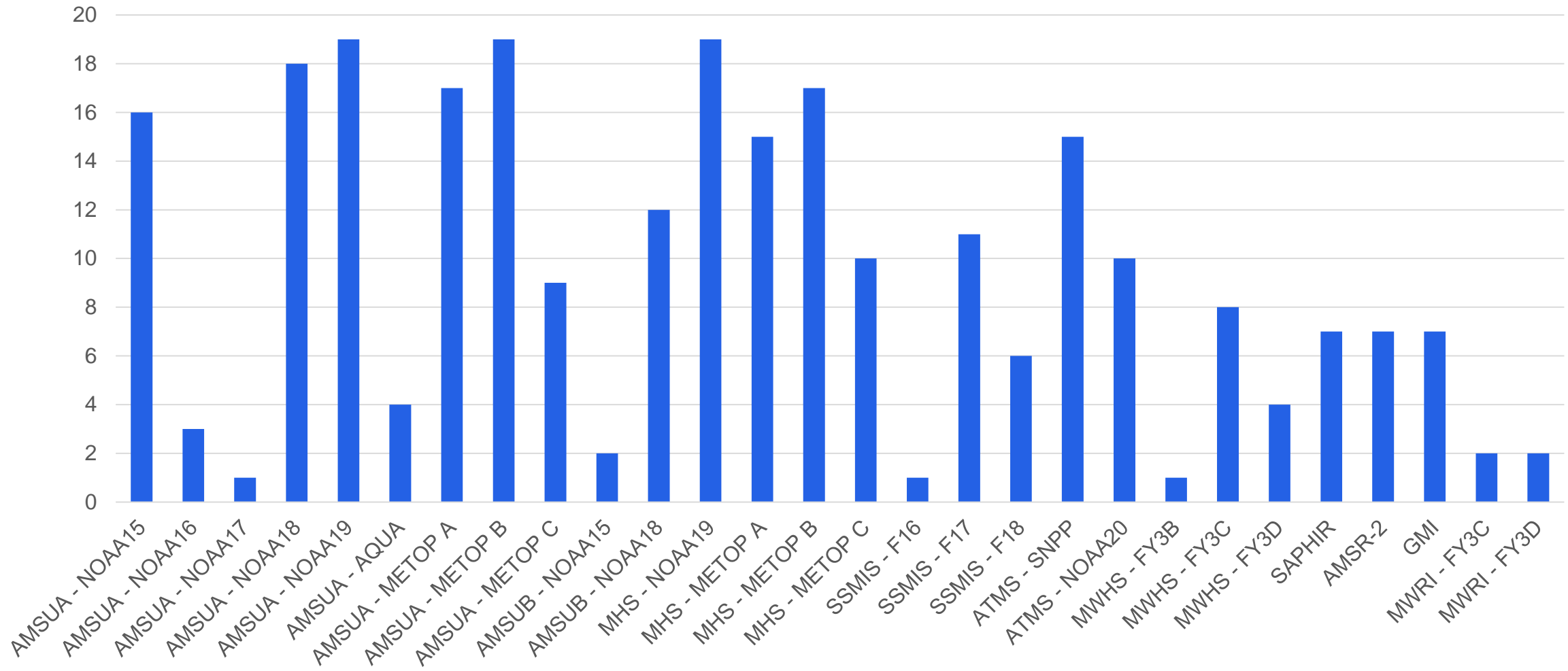
Normalized Difference at NH 12UTC 500GPH, Confidence: 90%



Number of NWP centres assimilating infrared sounders

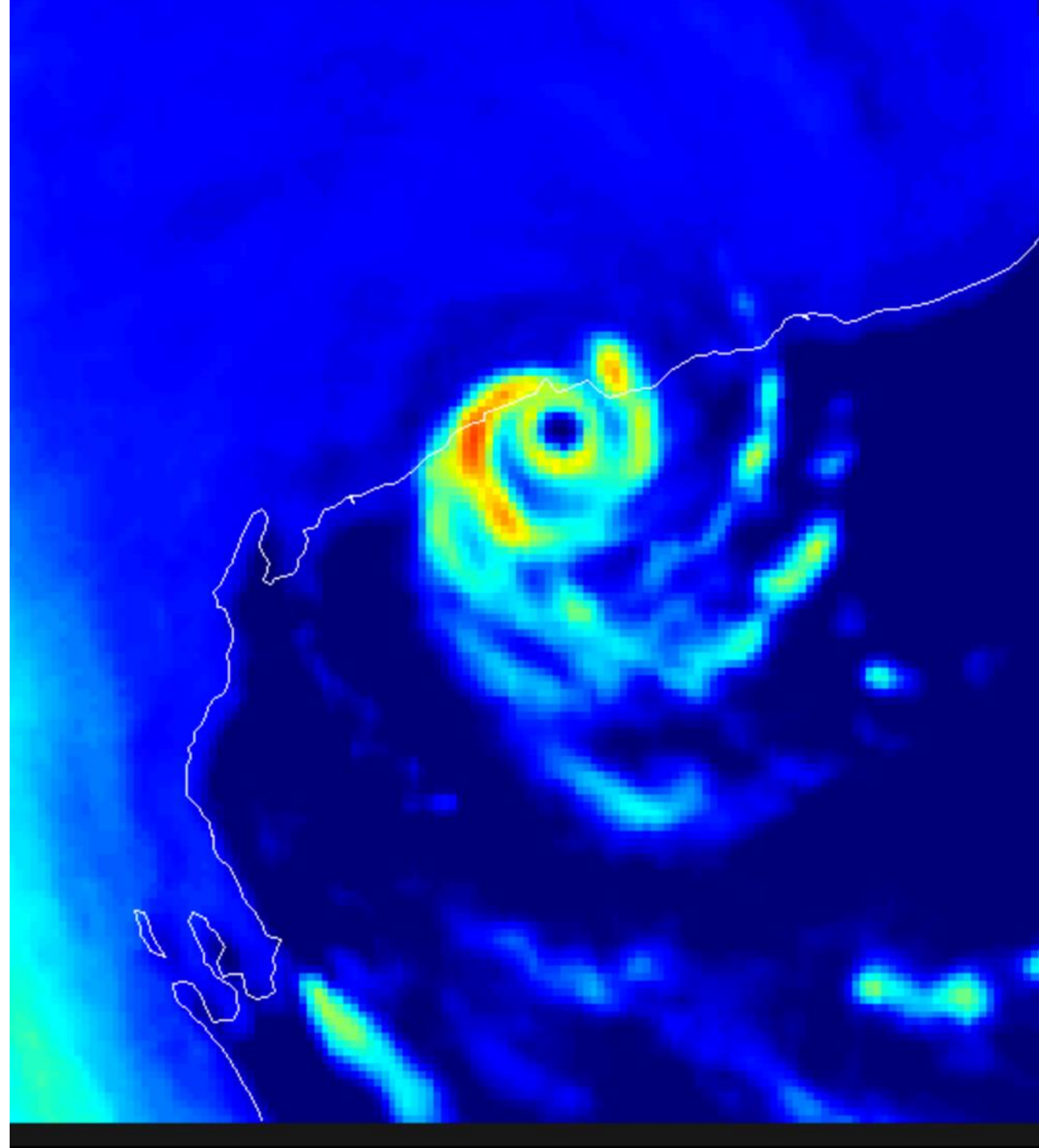


Number of NWP centres assimilating microwave sounders



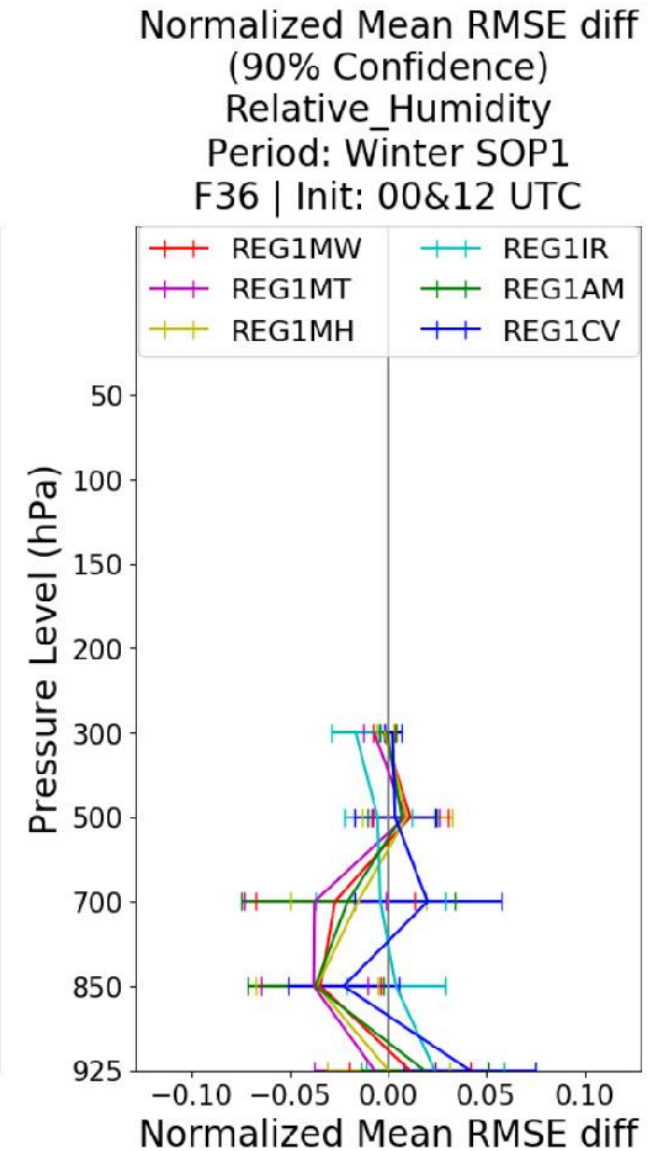
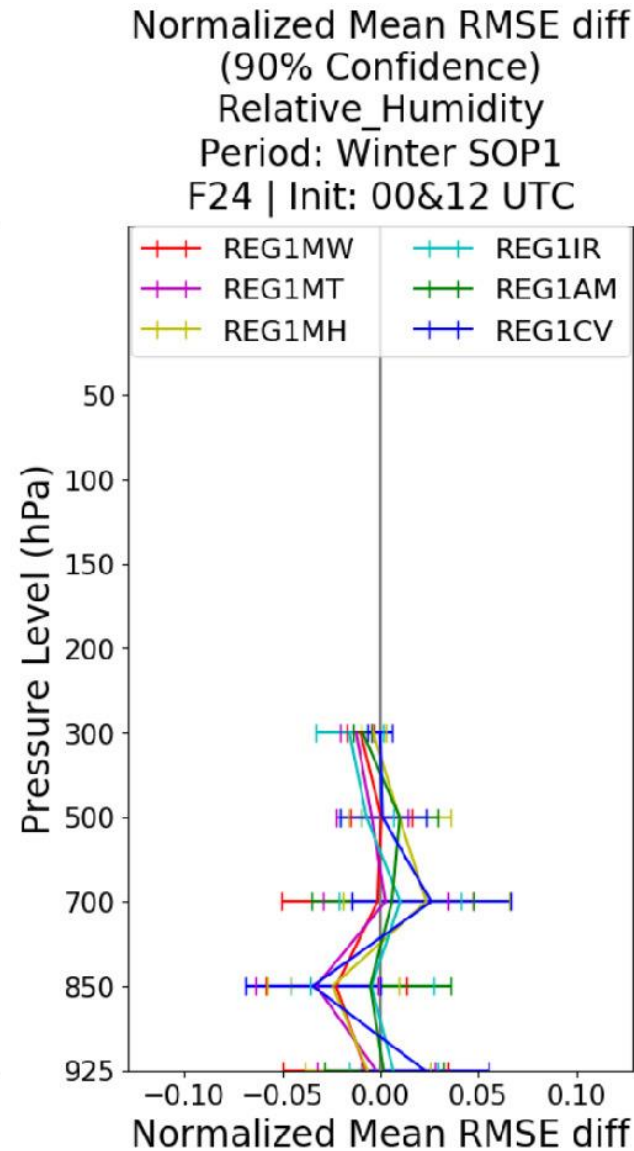
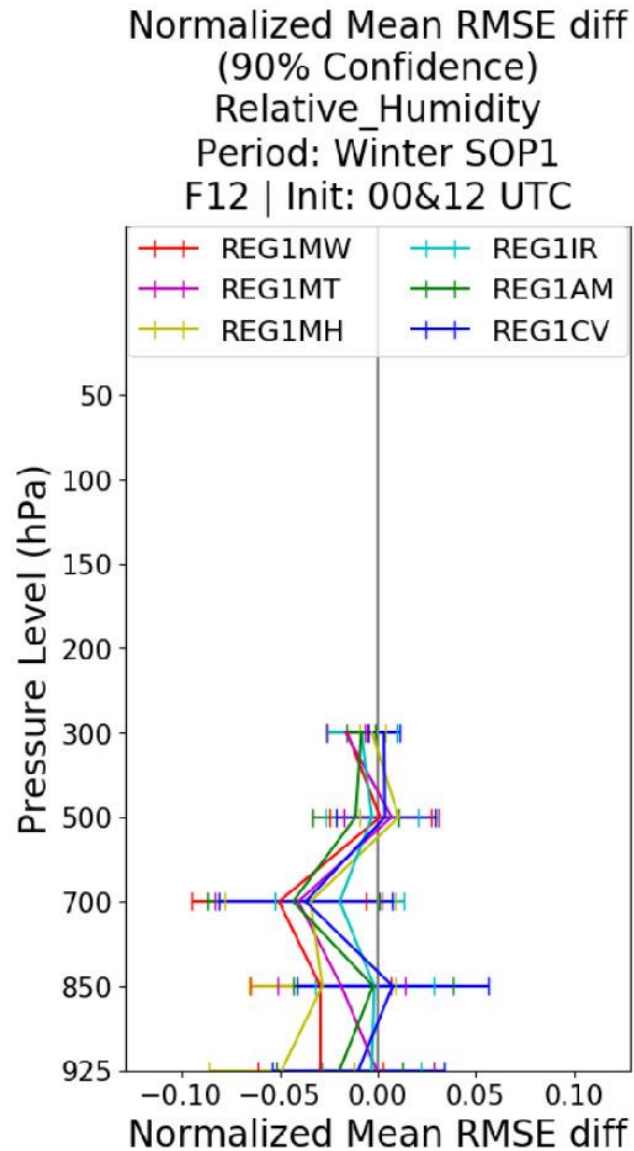


Use of radiances in high-resolution NWP models



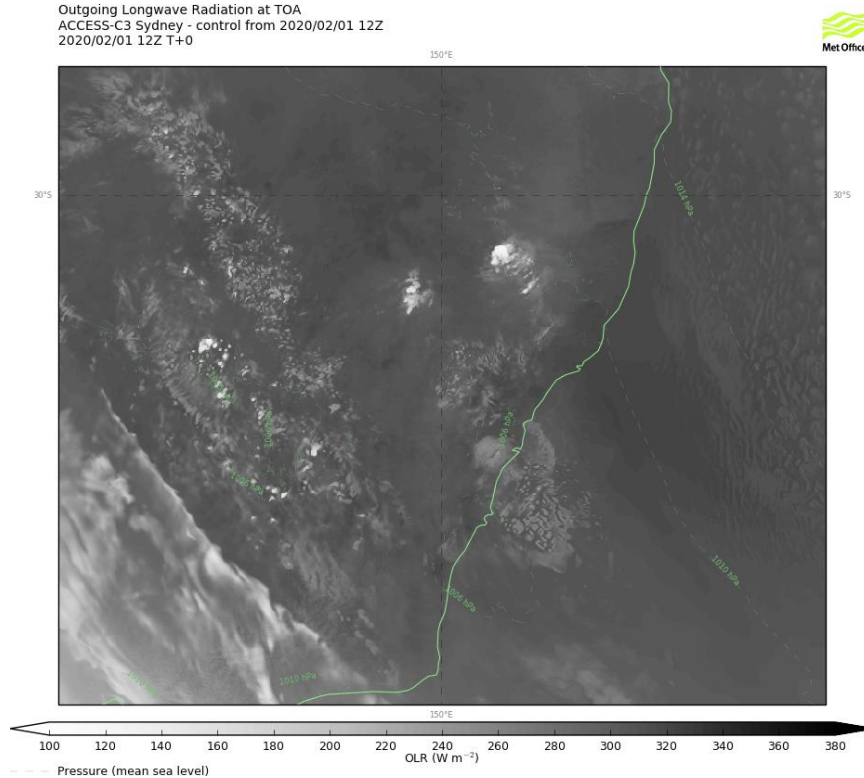
Impact of satellite data in high-resolution models

- It can be hard to prove impact of satellite data in small domain models.
- Some recent studies have shown good impact, like the results shown here from Met.no that demonstrate direct positive impact from satellite obs in a regional model in Winter.
- From Randriamampianina et al., 2021

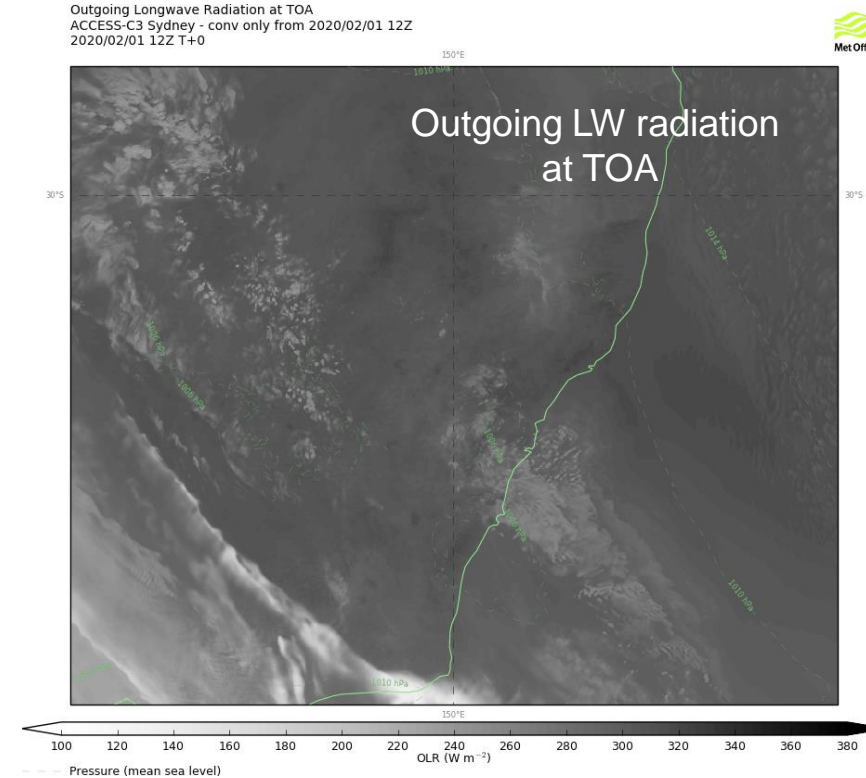


Impact of satellite observations in ACCESS-C3 (1)

	Observation types assimilated
Control ("control")	"aircraftsondesurface", "airs", "atovs", "atms", "cris", "dopplerradialwinds", "groundgps", "iasi", "satwind", "scat"
Sat Denial Expt ("conv")	"aircraftsondesurface" only



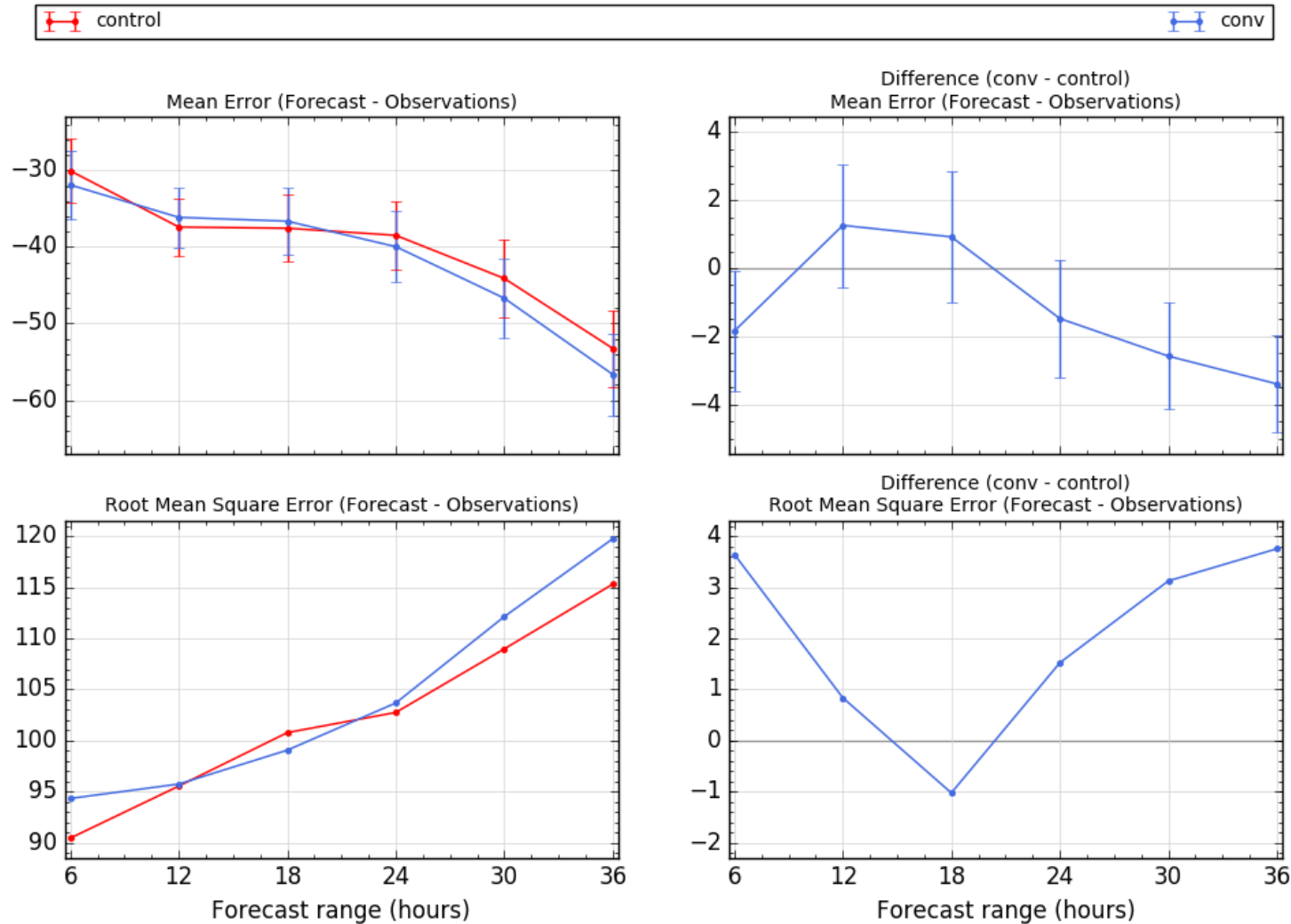
All observations



Conventional only

Impact of satellite observations in ACCESS-C3 (2)

Mean Sea Level Pressure (Pa), Area 999,
Equalized and Meaned between 20200201 00:00 and 20200302 18:00, Surface Obs

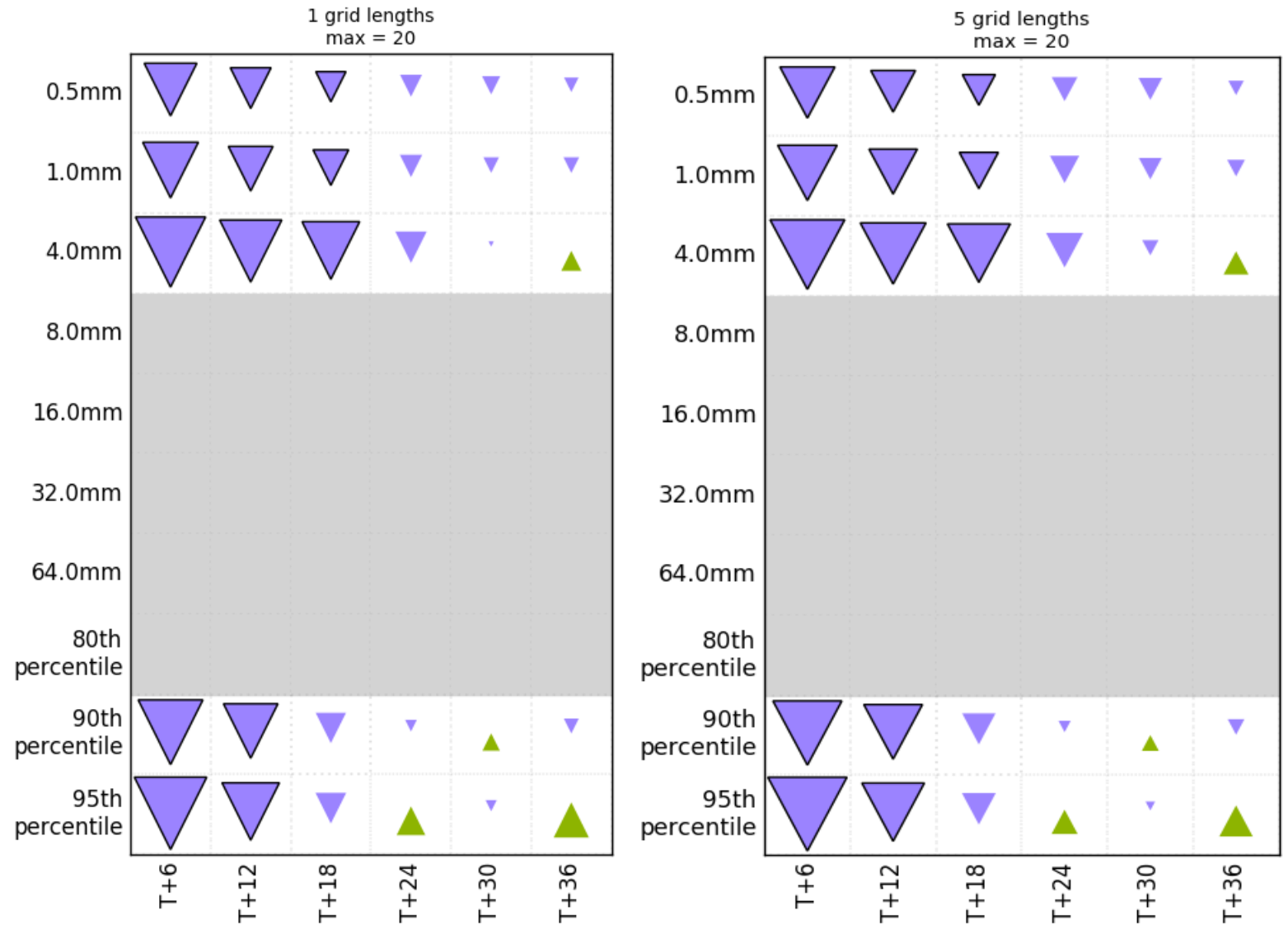


± 1 standard error bars calculated assuming independent observations

Impact of satellite observations in ACCESS-C3 (3)

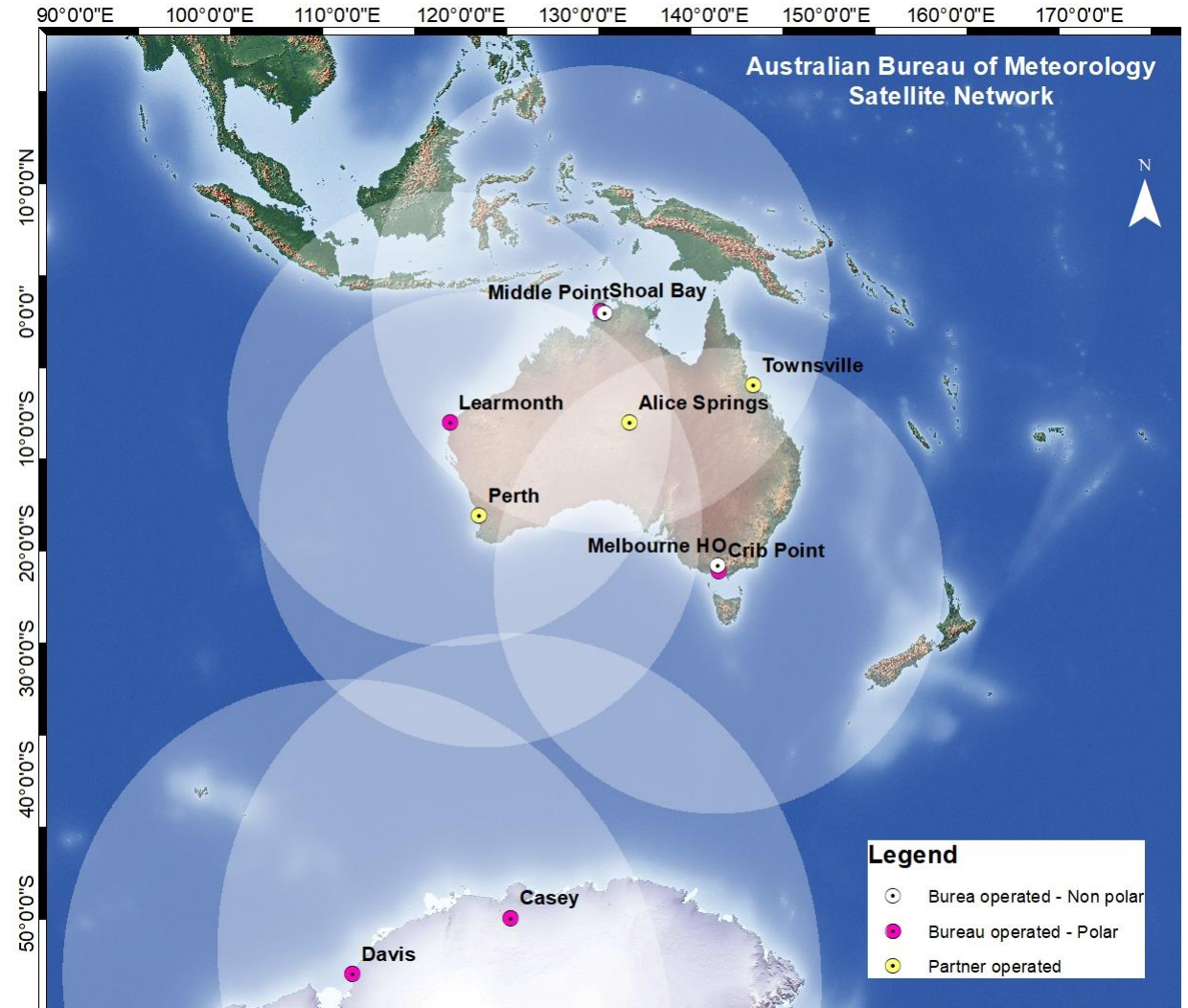
Conclude: significant positive impact on ACCESS-C3 forecast skill from satellite observations as measured by a number of skill metrics.

% diff FSS
6h accum. precip.
Sat denial vs control



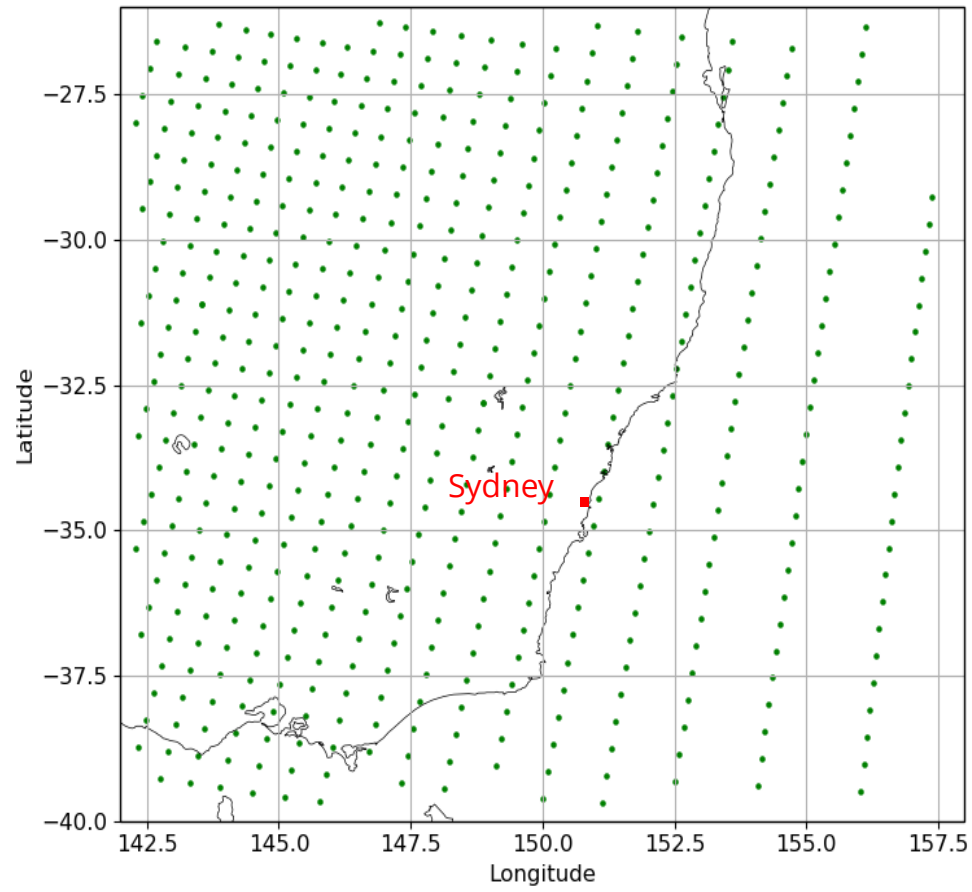
The importance of Direct Reception and DB-Net for assimilation of LEO sounders in high-resolution models

- Convective scale models typically have small domains and run with rapid update DA (e.g. once per hour)
- "Global" sounder observations don't make it on time.
- Applications are very reliant on local receiving stations and may also receive observations from the Direct Broadcast Network (DBNet)
- Observations from these sites come in much more quickly, allowing us to use sounders
- The Bureau operates three mainland receiving stations and two in Antarctica
 - Shoal Bay, Learmonth, Crib Point
 - Casey, Davis

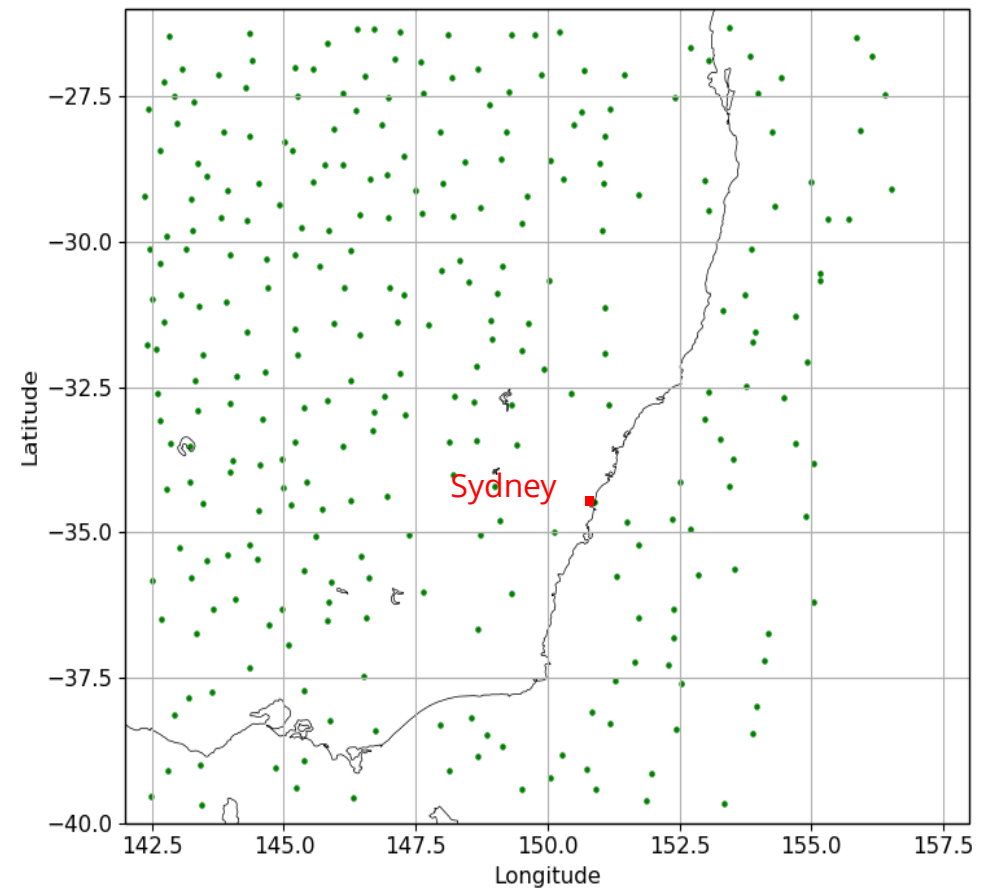


S-NPP and NOAA-20 data in C3 Sydney model

ATMS – NOAA-20 15Z Cycle

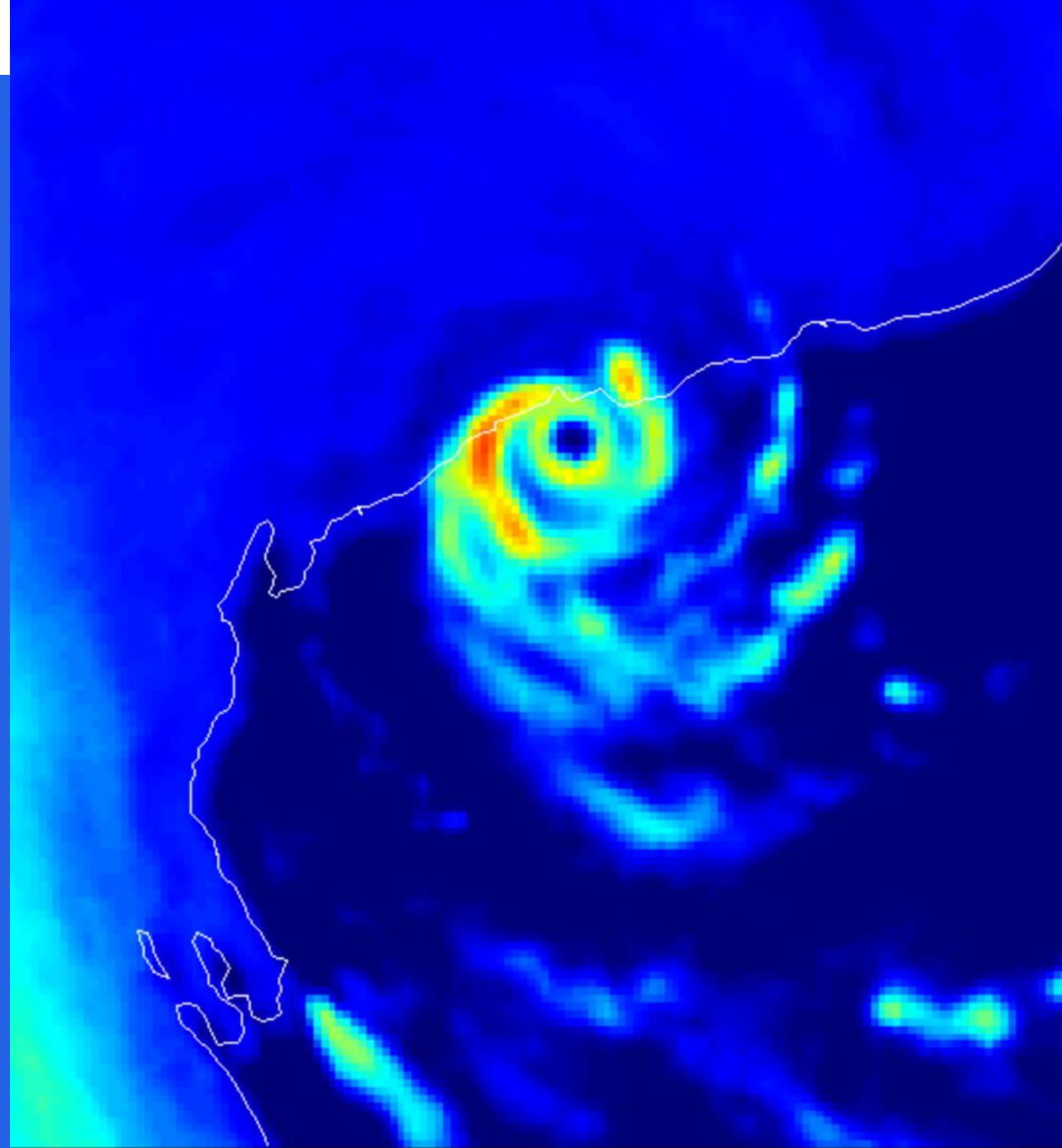


CrIS – NOAA-20 15Z Cycle





Current scientific directions in radiance data assimilation



Challenges - Quality control

- Instruments have biases that need to be removed
- Both microwave and infrared observations may be sensitive to geophysical features that are not well represented by the model. Prime examples are:
 - Skin temperature
 - Surface emissivity
 - Stratospheric temperature profile (particularly an issue where the model top is 40km)
- Infrared observations are strongly affected by cloud. Microwave observations are sensitive to rain in the field of view, and some cloud depending on frequency.
- Assignment of observation errors is required
 - Can be scene dependent
 - Can be correlated
- For limited area models, bias correction and thinning are major areas of research

Challenges – moving away from quality control

- We need to get better at using radiance observations in all weather conditions
 - All-sky assimilation schemes are limited by the ability of models to handle hydrometeors
 - And also the data assimilation schemes need to include the hydrometeors
 - Non-gaussian behaviour (cloud/no cloud; rain/no rain) is very hard for data assimilation schemes
- We need to get better at using radiance observations over land
 - Particularly important for regional models supporting population centres
 - Difficulties because we need to know the surface properties; at some frequencies it can be hard to distinguish whether observations are affected by the surface or cloud/rain.



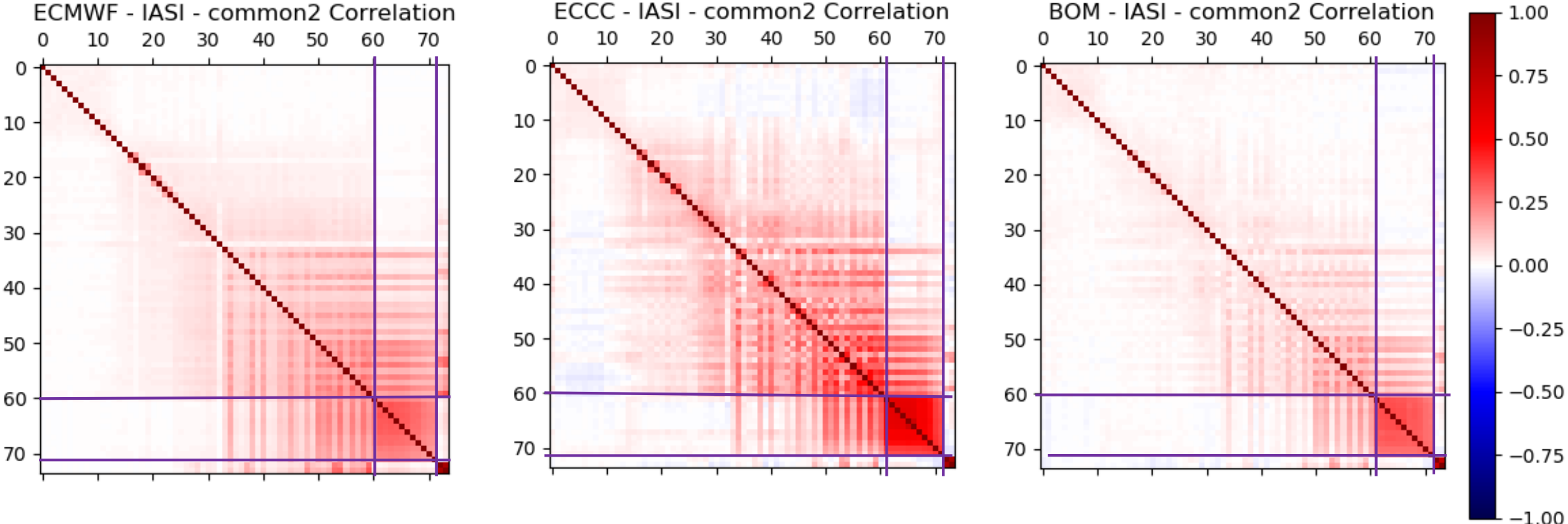
Challenges – observation errors

- Centres estimate observation error correlations using the DA system itself ("Desroziers method")
 - Centres report some dissatisfaction with the lack of confidence that their system for error estimation meets the underlying requirements for Desroziers
- Everyone wants to know what the best method is....
 - Using Desroziers is heavily dependent on the DA system and B-matrix
 - Need to progress work to understand the way the observation error covariances map into vertical structures in model space
 - Physical methods for error covariance estimation – work begun many years ago but not progressed.



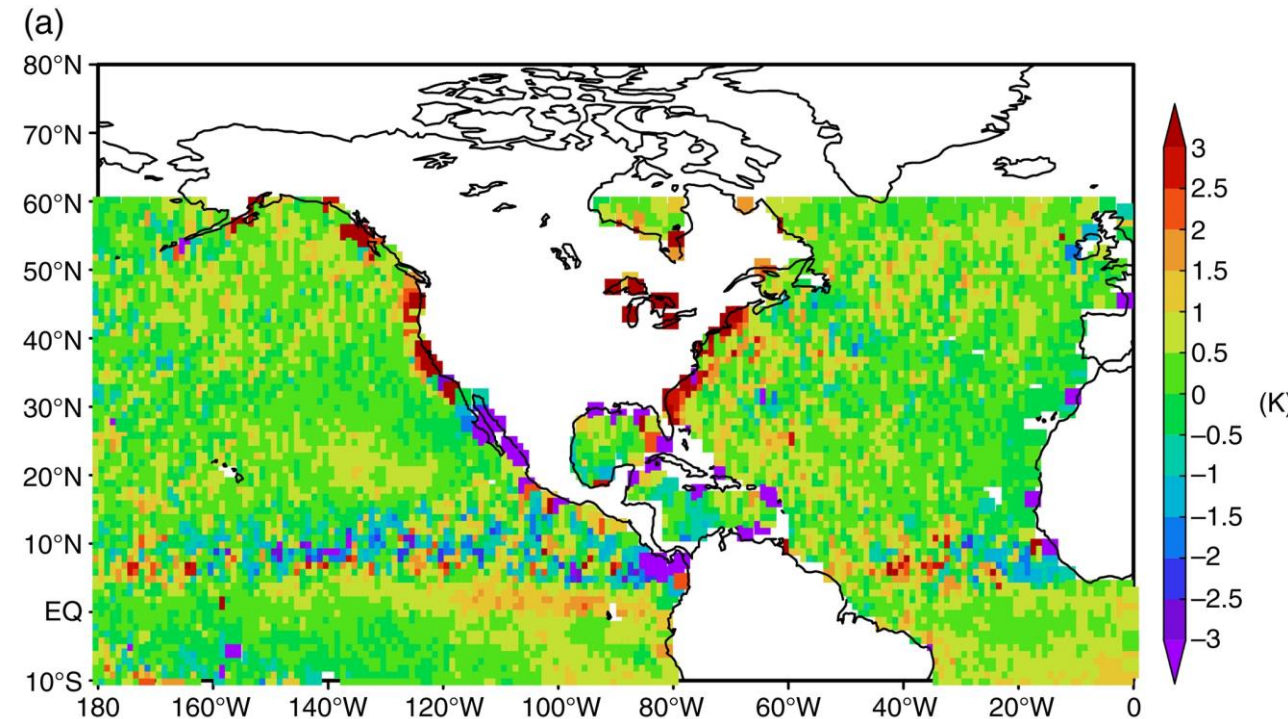
IASI correlations – common channels between three centres.

ECCC matrix shows higher correlations in tropospheric temperature sounding channels and window channels.



Challenges - Radio Frequency Interference

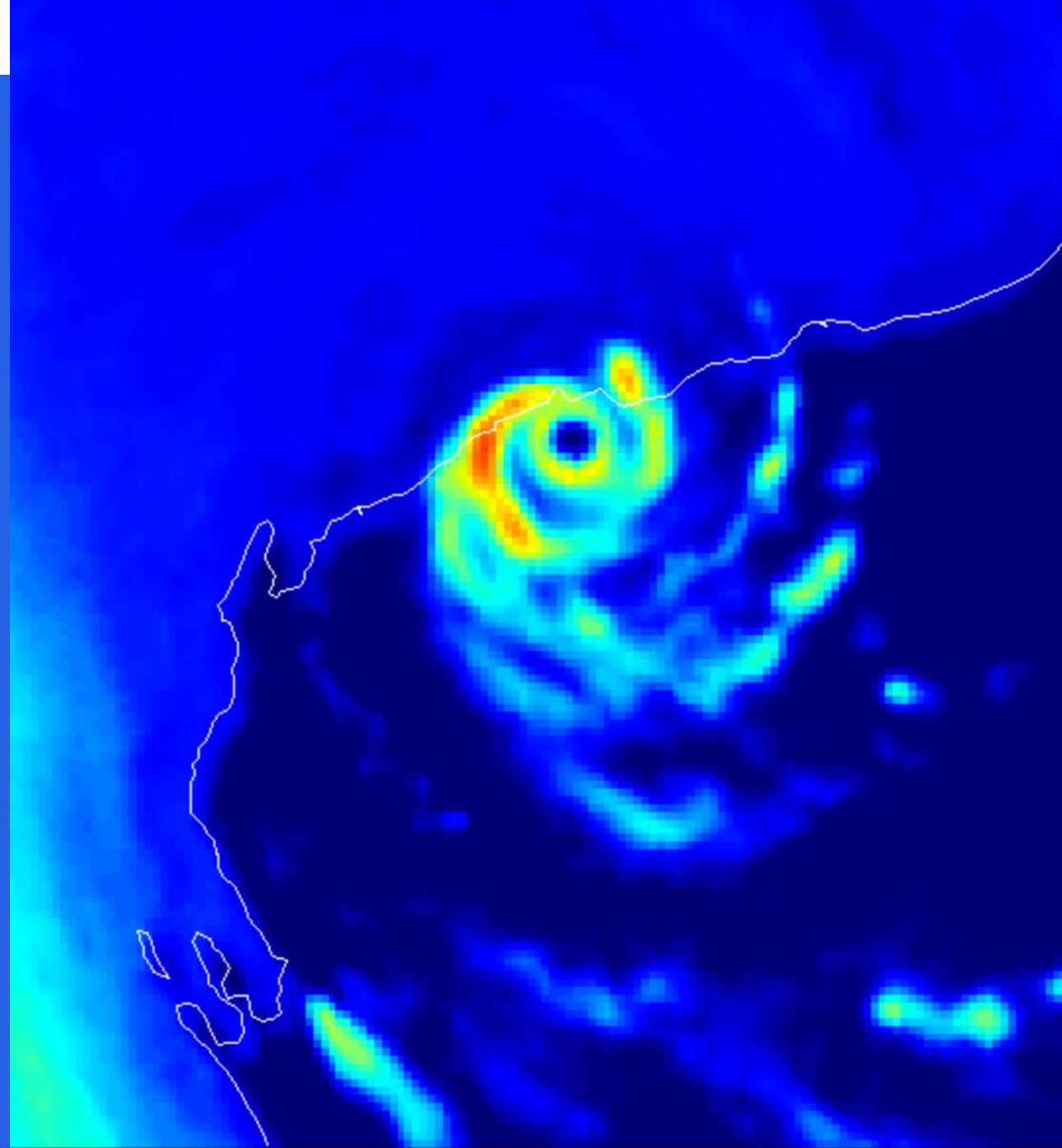
- Passive microwave instrumentation is affected by use of radio frequencies by active services such as telecoms.
- Our passive sounders are increasingly at risk because 5G and proposals for 6G are beginning to encroach on our passive frequencies.
- All meteorological agencies are advised to keep up to date with work by WMO to support us to argue for increased and continued protection for Earth Observation.



Example of RFI in AMSR-2 19GHz V channel
From Kazumori et al., 2015



Conclusions



Conclusions

- Satellite data comprise well over 90% of observations used in NWP
- Satellite radiances usually deliver the most impact in assimilation systems
- Satellite radiances also deliver forecast improvements in high-resolution limited area models
- We continue to get benefit from new instruments despite many scientific challenges remaining to get the best out of the instruments in all-weather and all-surface conditions.





The Bureau
of Meteorology

Thank you

Fiona Smith

fiona.smith@bom.gov.au