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Satellite Sounding

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Outline

- Why do we want to use satellite observations in Numerical Weather Prediction (NWP)?
- What do satellite measurements tell us?
    - Example from satellite sounding
- Our current use of satellite data in NWP
- Future directions

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Why satellite data?

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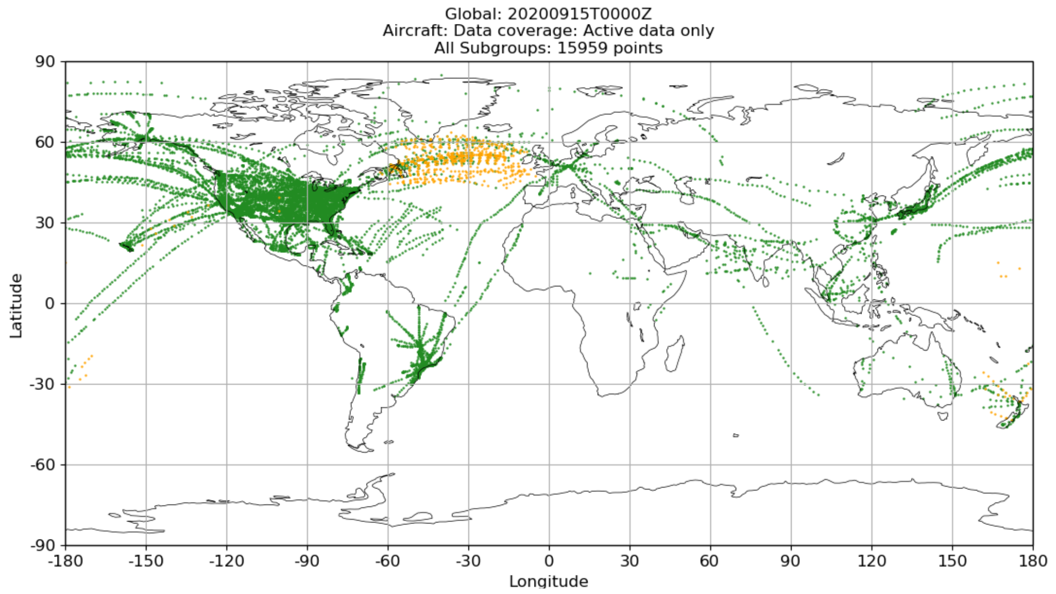
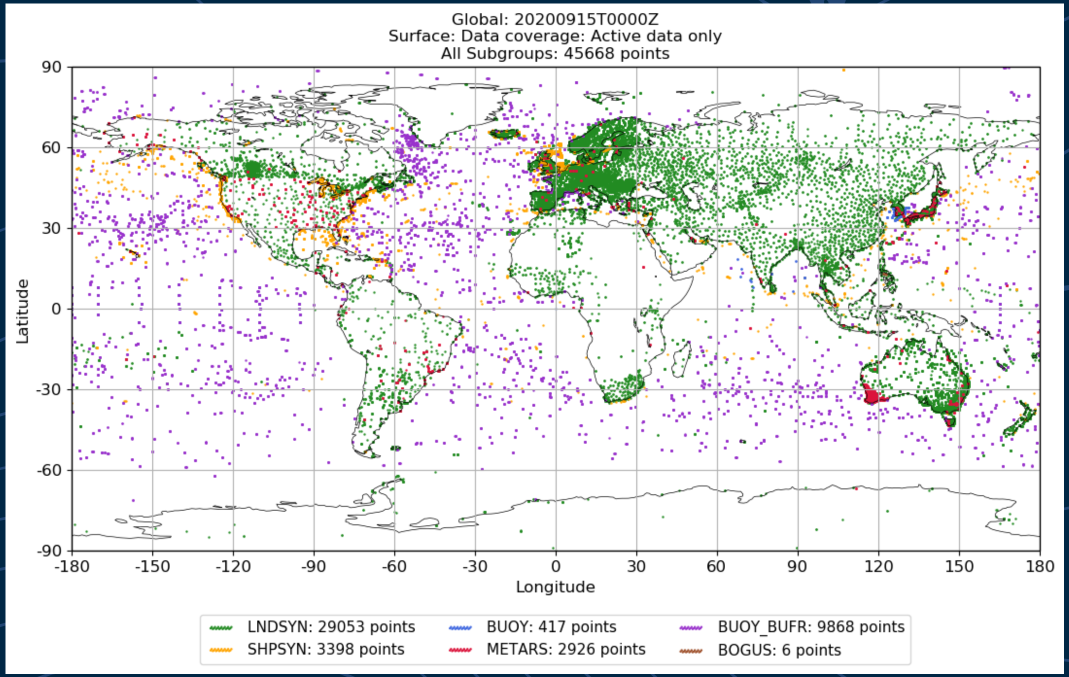
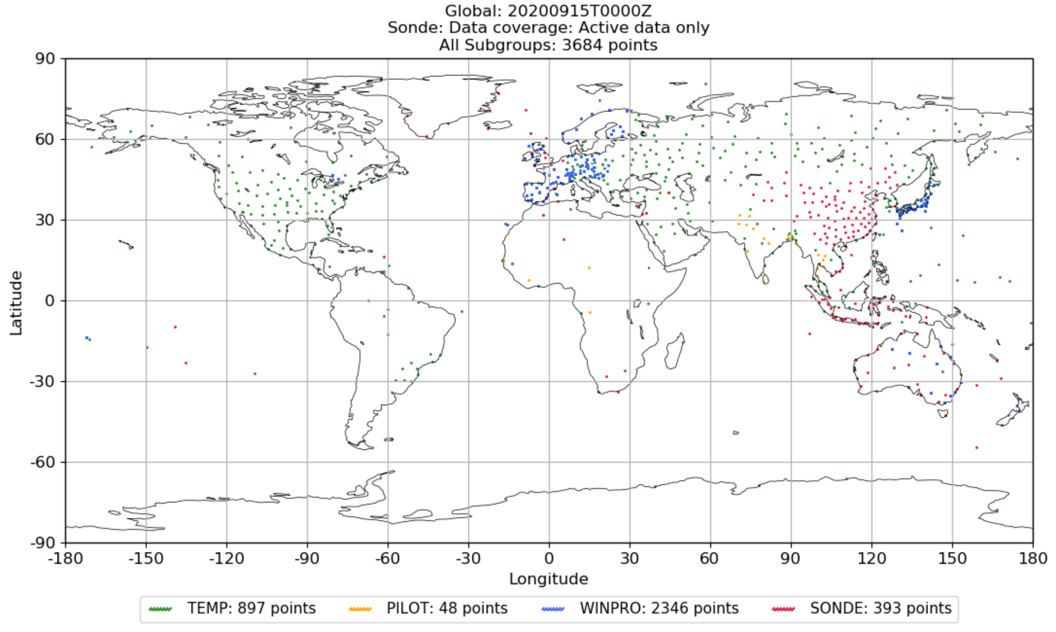
Conventional obs: Aircraft, Surface and Sonde Coverarge

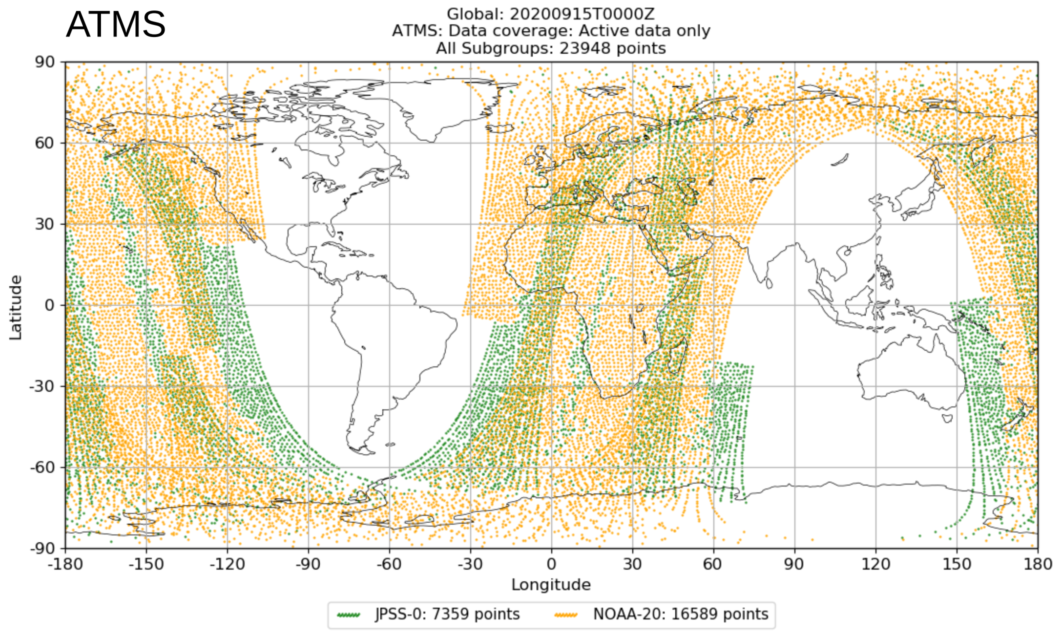
- Coverage is poor particularly in the Southern Hemisphere
- Sondes only report 0Z and 12Z but Data assimilation cycles and forecasts are run every 6 hours

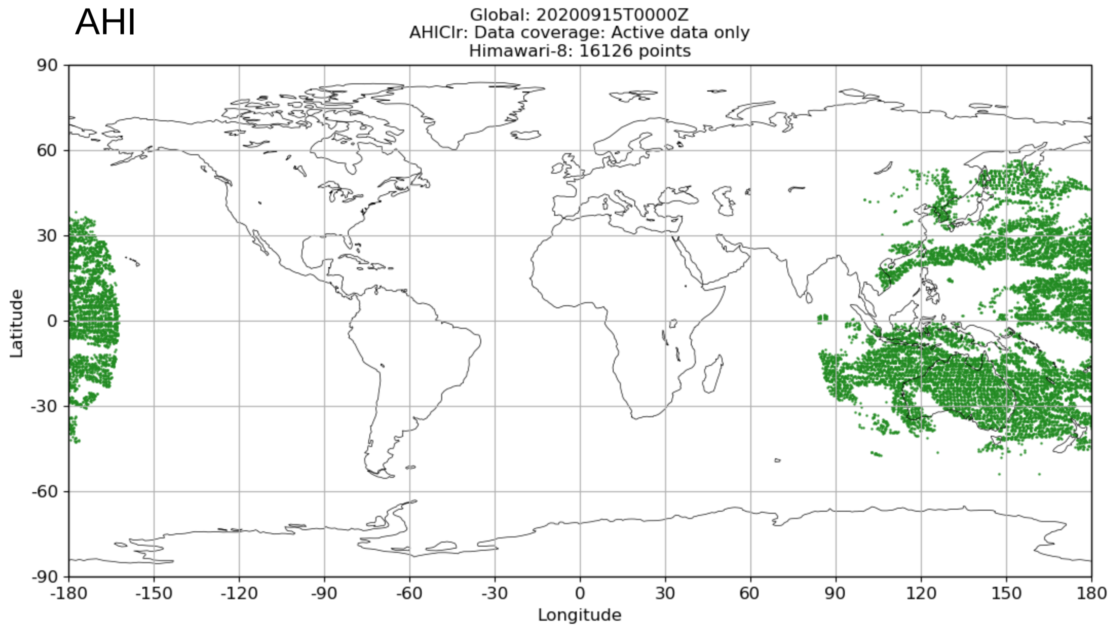


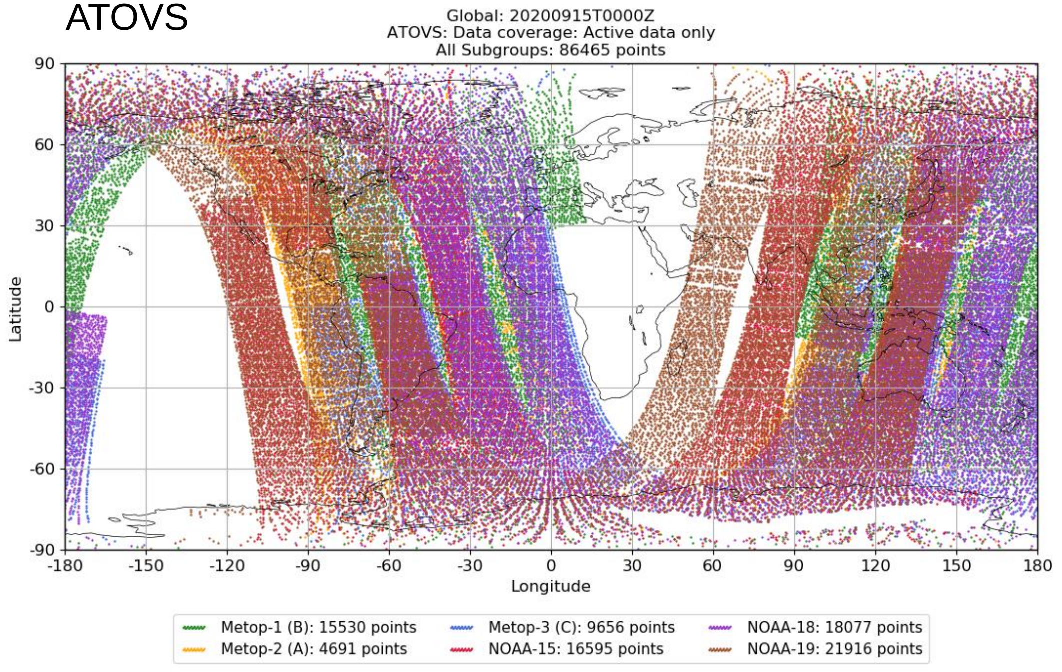


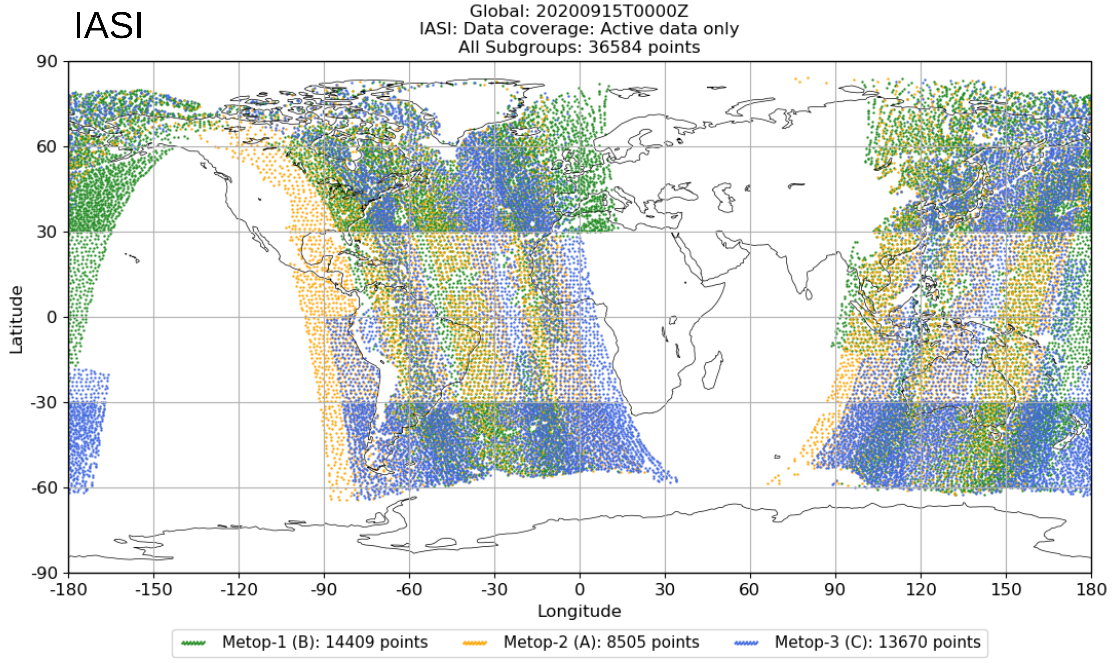


Sounder coverage

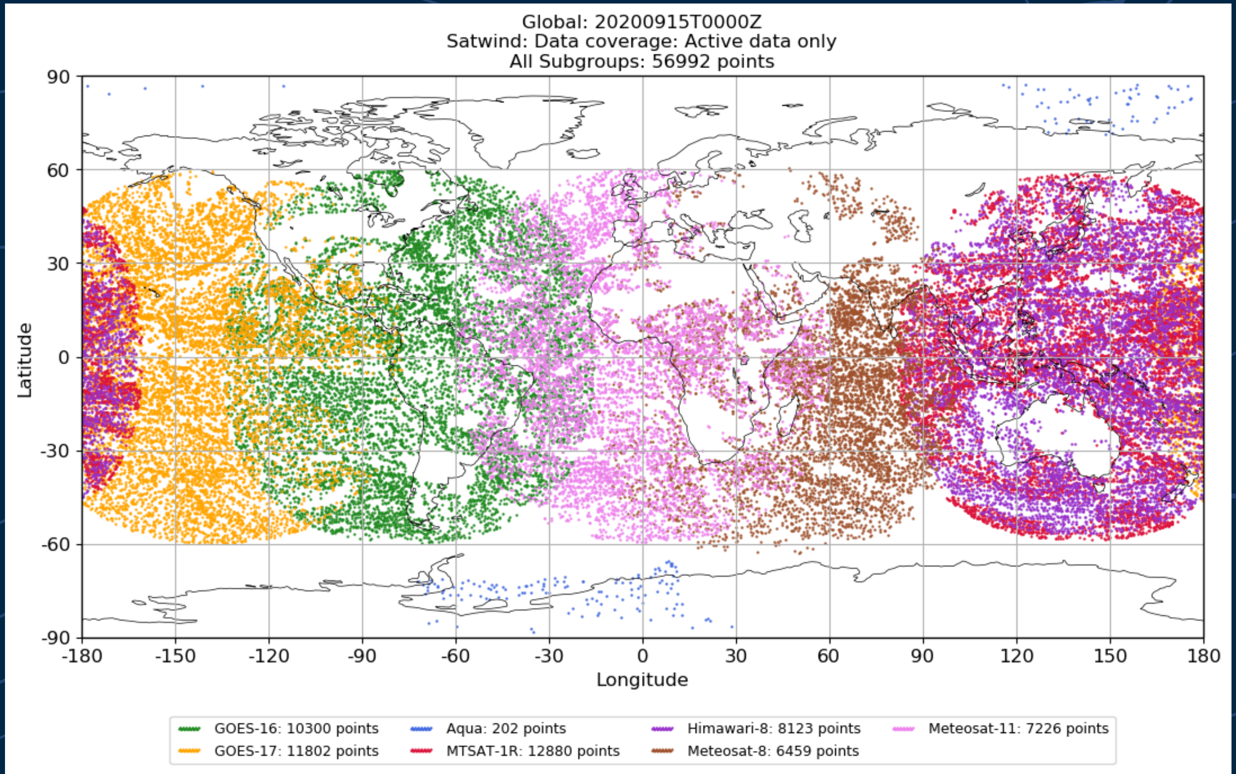


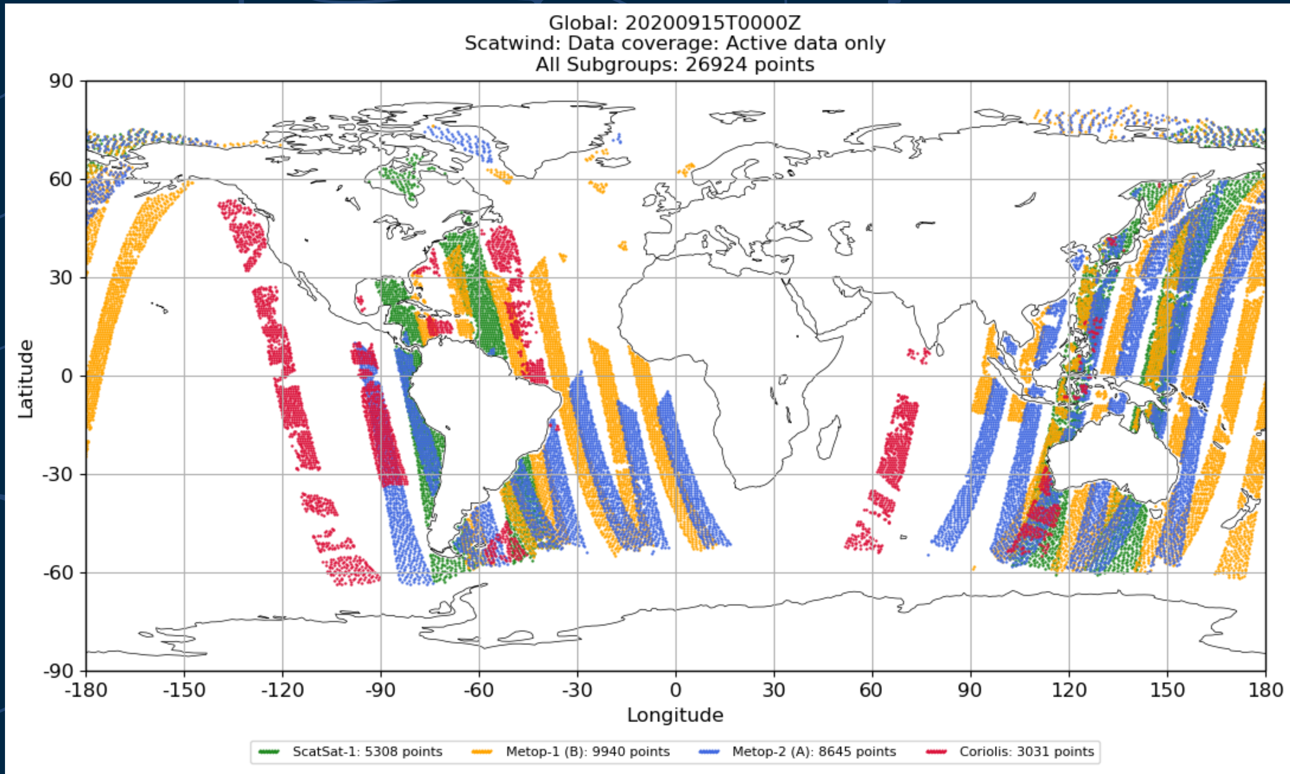






Wind coverage – AMV and Scatterometer





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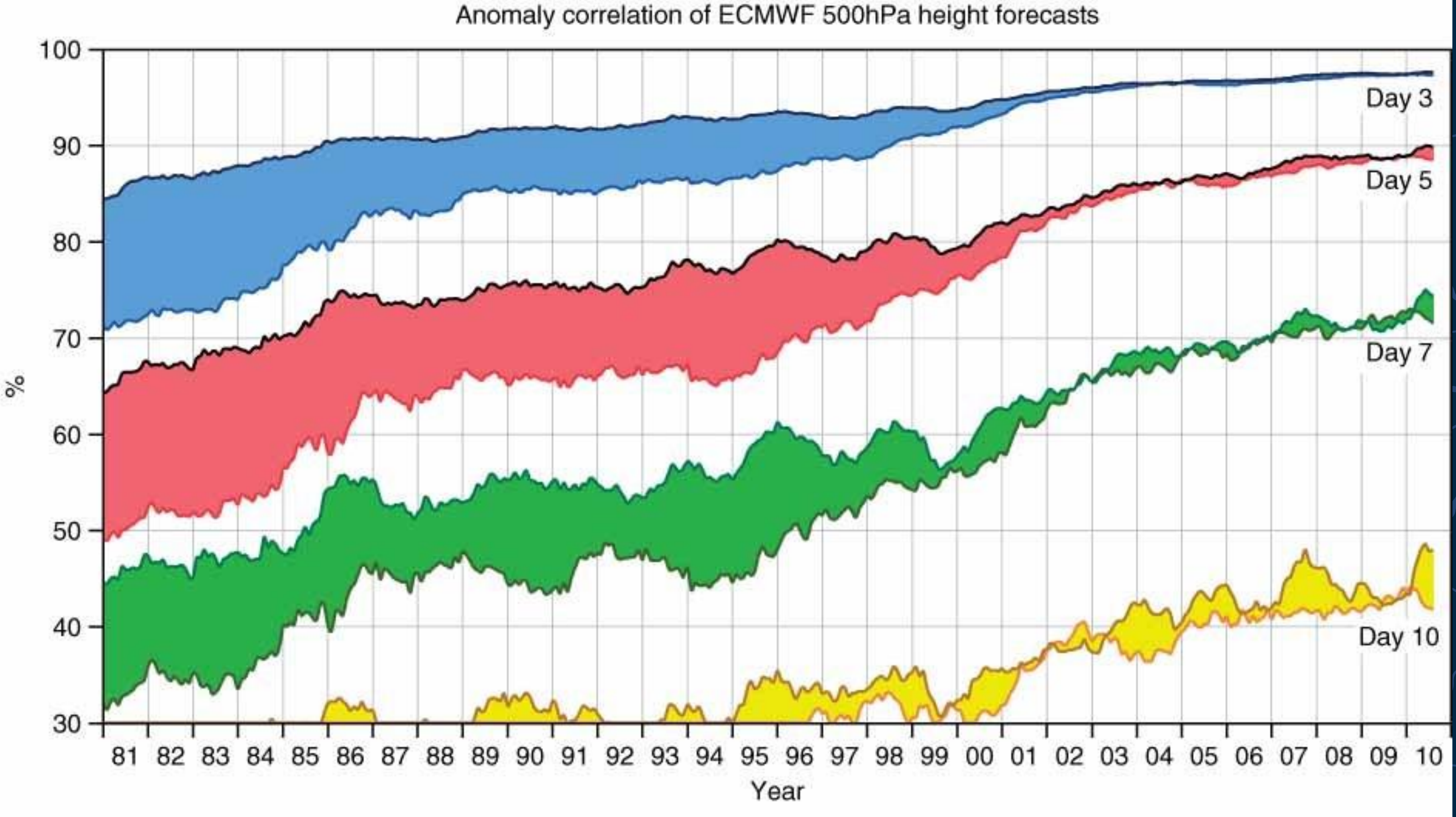
Importance of satellite data for the southern hemisphere



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

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What do satellite observations tell us?

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Satellite observations are indirect

Satellites are equipped with remote sensing instruments. They don't measure the temperature, humidity or windspeed directly

- Radiance measurements can be used to infer temperature and humidity content of partial columns of the atmosphere (Satellite Sounders)
- Successive images can be used to track features such as clouds to infer the wind speed and direction (Atmospheric Motion Vectors or Satellite Winds)
- Backscatter of microwave radar signals off the ocean surface can tell us about surface windspeed (Scatterometers)
- The bending of a GNSS signal through the atmosphere as the satellite disappears over the horizon can tell us about temperature and humidity across shallow layers of the atmosphere (GNSS Radio Occultation)

Example: radiance measurements from satellite sounders

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Satellite sounders (radiometers, spectrometers and interferometers) use emitted radiation to tell us about the atmosphere

A layer of atmosphere, like any other object, emits radiation over a range of frequencies that depend upon its temperature and chemical composition.

- The amount of radiation emitted is determined by the Planck function and the absorption/emission properties of the chemical species in the atmosphere, which depend on how much of it there is and what temperature it is at.

The inverse problem, for temperature sounding, is to infer the temperature of the atmosphere from the measurement of emitted radiation.

- You can use the absorption lines of a well-mixed gas in the atmosphere to do this
- You know the amount of the gas, so you can work out the temperature

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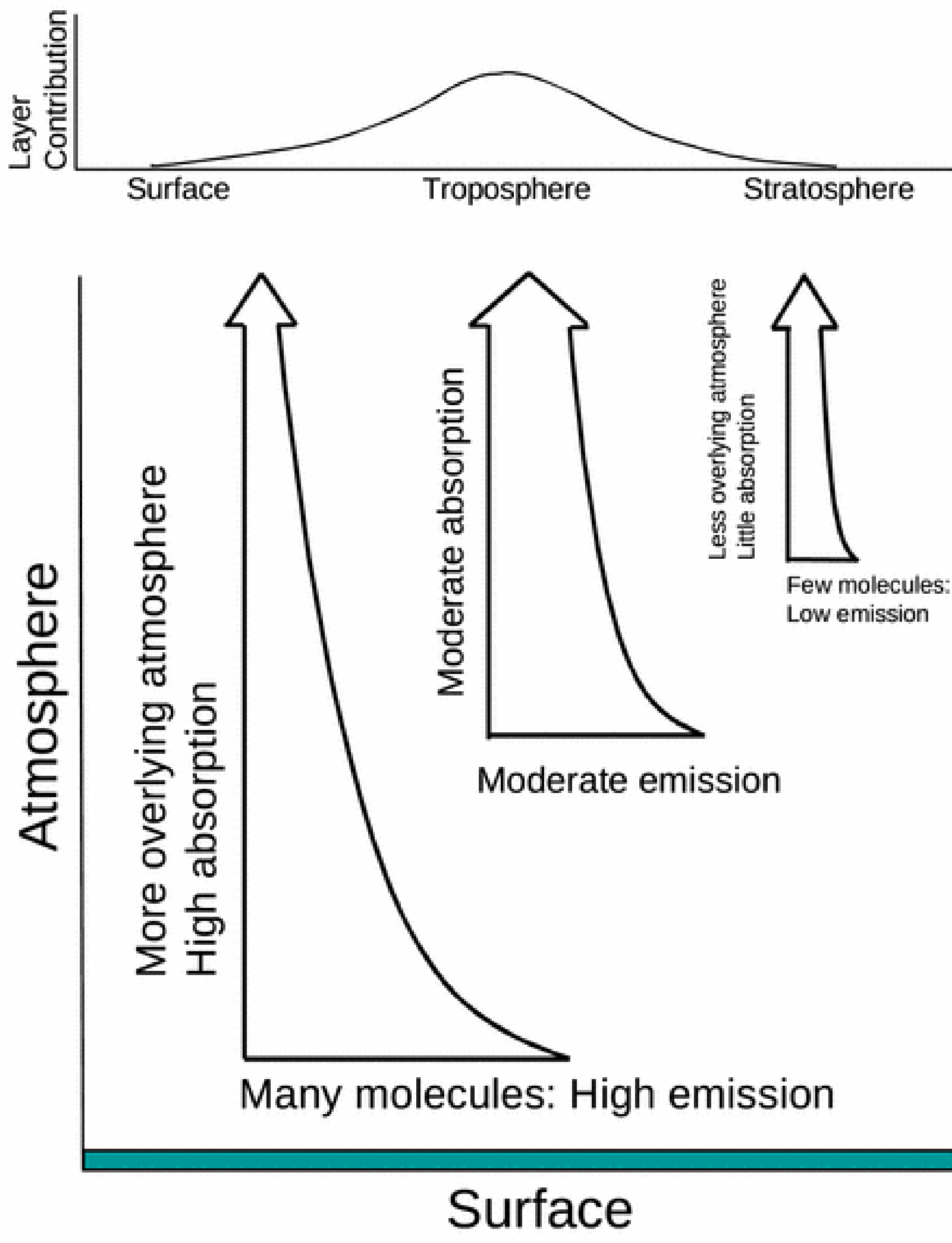
Emission and absorption

- The large mass of molecules in the lower troposphere emits a large amount of radiation which is partially absorbed as it travels upwards through the atmosphere.
- The molecules that absorb also emit.
- The higher in the atmosphere you go, the fewer emitting/absorbing molecules there are.
- This results in a peak in sensitivity to the single radiation measurement from some part of the atmosphere
- A family of measurements at different frequencies have different peaks and allow you to unravel the temperature profile
- Can be microwave or infrared



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Quality control

1. Instruments have biases that need to be removed
2. 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)
3. Infrared observations and strongly affected by cloud. Microwave observations are sensitive to rain in the field of view, and some cloud depending on frequency.

Screening is necessary in some cases, and pre-processing is often required

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Thinning

We can account for correlations between channels in the assimilation system, but not so much for correlations between nearby observations.

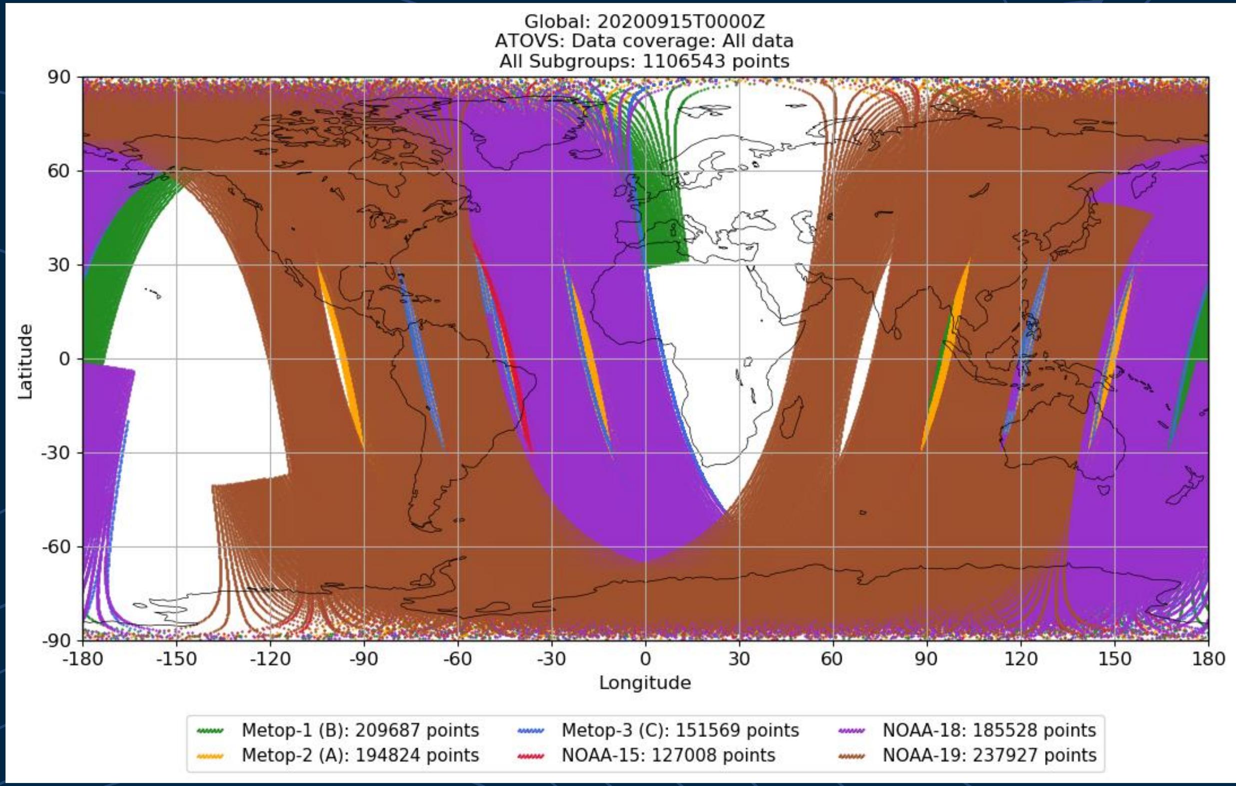
These correlations result from differences between what the model sees and what the instrument sees

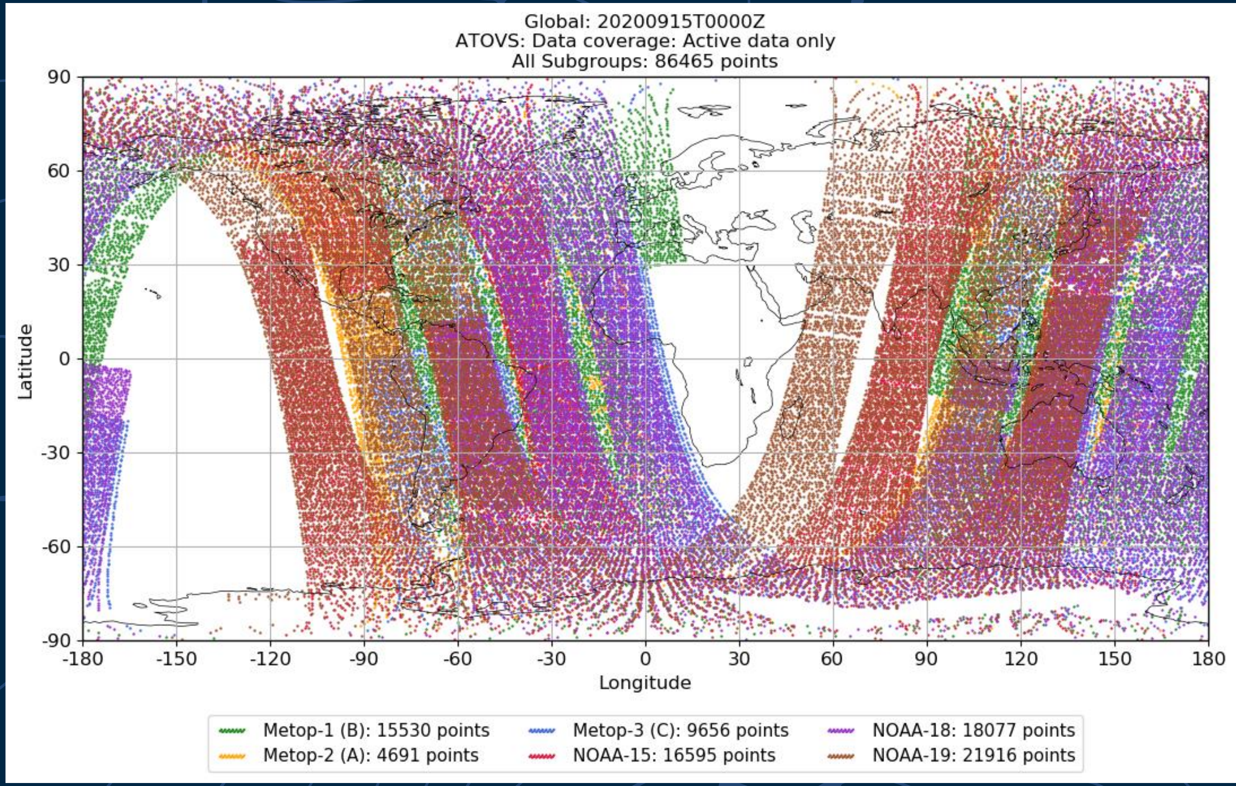
- E.g. 12 km grid vs 50 km footprint; sub-gridscale variability (like real vs model cloud)
- Successive observations from the same instrument do not have correlated measurement errors.

To deal with these correlations, we "thin" the observations to match the resolution of the assimilation system.

ATOVS thinning

ATOVS is thinned to one observation every 100 km





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Detailed steps of satellite radiance pre-processing

1. Convert to Brightness Temperatures
2. Extrapolate temperature profile to Top of Atmosphere if model top is too low
3. Determine the surface type and set a default/first guess emissivity
4. Filter observations on the basis of pre-processing flags (e.g. bad scan lines, spike in interferogram, checks on data quality)
5. THINNING STEP 1
6. Call RTTOV with background profile to put model profile in BT space
7. Perform bias correction
8. O-B check: throw away obs where background is too far away
9. THINNING STEP 2
10. Cloud Detection
11. Choose channels for assimilation (select dynamically depending on cloud conditions)
12. Perform 1D-Var retrieval
13. Perform QC after 1D-Var (not converged, RT errors, retrieval doesn't fit obs)
14. Final channel selection for IR to choose channels above cloud
15. FINAL THINNING

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Current use of satellite data in NWP

Recent changes in observation usage – ACCESS-G3

	ACCESS-G2	ACCESS-G3 (from July 2019)	ACCESS-G3.1 (from June 2020)
Hyperspectral IR sounder (LEO)	AIRS CrIS – S-NPP IASI – Metop-A, Metop-B	AIRS CrIS – S-NPP IASI – Metop-A, Metop-B	AIRS CrIS – S-NPP, NOAA-20 IASI – Metop-A, Metop-B, Metop-C
IR sounder (GEO)		Himawari AHI CSR	Himawari AHI CSR
Microwave sounders (LEO)	ATMS – S-NPP ATOVS – N18, N19, Metop-A, Metop-B	AMSR-2 ATMS – S-NPP ATOVS – N15, N18, N19, Metop-A, Metop-B SSMIS	AMSR-2 ATMS – S-NPP, NOAA-20 ATOVS – N15, N18, N19, Metop-A, Metop-B, Metop-C SSMIS
GNSS measurements	GPSRO – COSMIC, TerraSar-X, TanDem-X, Metop-A, B	GPSRO – TerraSar-X, TanDem-X, Metop-A, Metop-B, FY-3C GPS WV	GPSRO – TerraSar-X, TanDem-X, Metop-A, Metop-B, Metop-C, FY-3C, GPS WV
AMV (mostly GEO)	Himawari, GOES-16, GOES-15, Meteosat-8, Meteosat-11, MODIS (Aqua)	Himawari, GOES-16, GOES-15, Meteosat-8, Meteosat-11, MODIS (Aqua)	Himawari, GOES-16, GOES-17, Meteosat-8, Meteosat-11, MODIS (Aqua)
Scatterometer	ASCAT – Metop-A, B, Windsat	ASCAT – Metop-A, B, Windsat	ASCAT – Metop-A, B, ScatSat-1

Impact of observations in Global NWP

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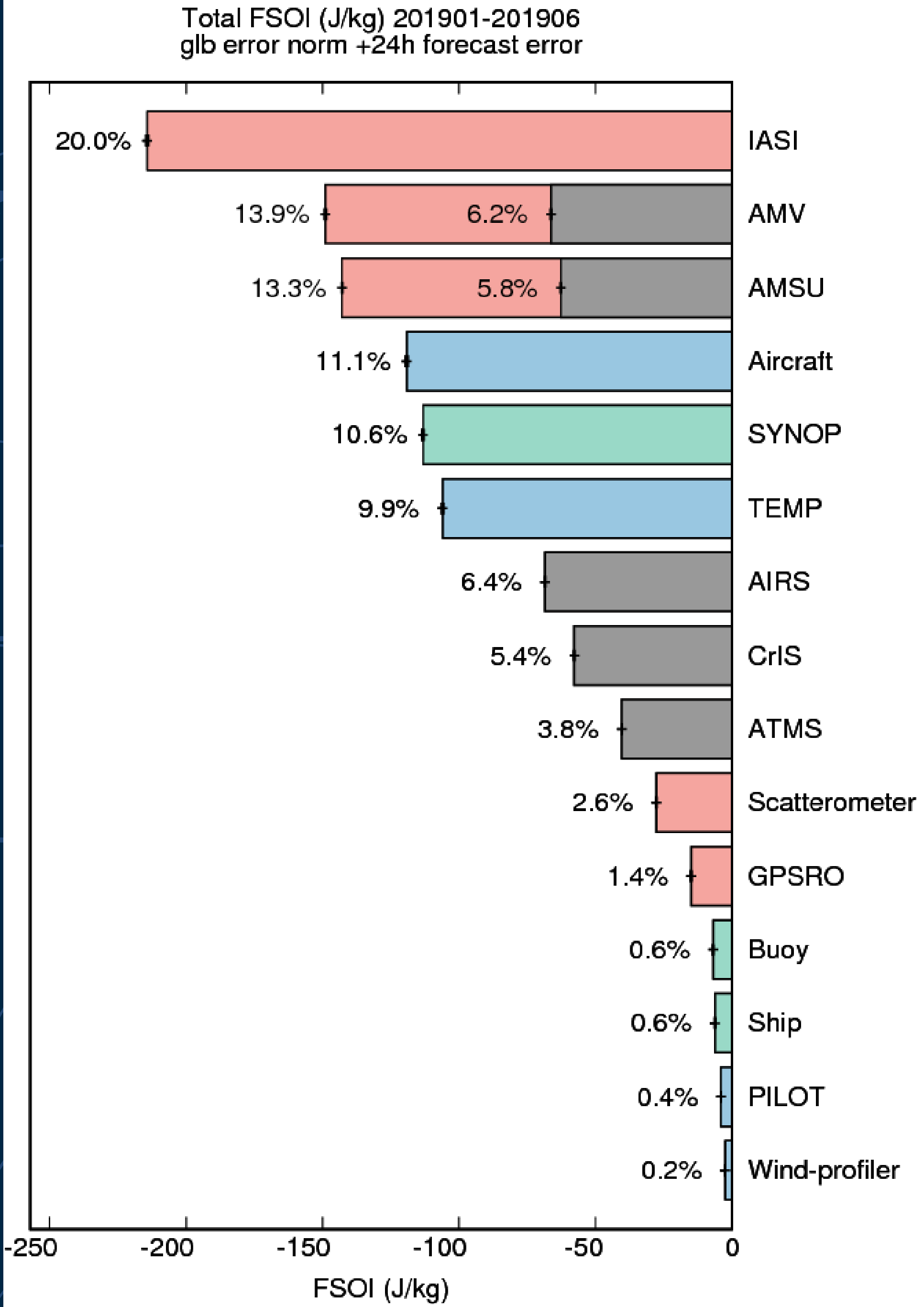
Total Forecast Sensitivity to Observations Impacts (FSOI) in ACCESS-G2 January – June 2019

Reduction in 24 hour forecast error measured by global moist energy norm.

Red: space-based observations
Blue: upper air network
Green: surface observations

contributions from NOAA/NASA satellite platforms



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G3.1 trial Scorecard

Australia

Anomaly Correlation and S1 Skill Score on left

Bias and RMSE on right

Statistically significant values in colour:
+ve Blue
-ve Red

Australia

Parameter	Level (hPa)	24	48	72	96	120	144	168
Geopotential Height	100	A S	A S	A S	A S	A S	A S	A S
	250	A S	A S	A S	A S	A S	A S	A S
	500	A S	A S	A S	A S	A S	A S	A S
	850	A S	A S	A S	A S	A S	A S	A S
Mean Sea-Level Pressure	0	A S	A S	A S	A S	A S	A S	A S
Temperature	100	A S	A S	A S	A S	A S	A S	A S
	250	A S	A S	A S	A S	A S	A S	A S
	500	A S	A S	A S	A S	A S	A S	A S
	850	A S	A S	A S	A S	A S	A S	A S
Wind U-Component	100	A S	A S	A S	A S	A S	A S	A S
	250	A S	A S	A S	A S	A S	A S	A S
	500	A S	A S	A S	A S	A S	A S	A S
	850	A S	A S	A S	A S	A S	A S	A S
Wind V-Component	100	A S	A S	A S	A S	A S	A S	A S
	250	A S	A S	A S	A S	A S	A S	A S
	500	A S	A S	A S	A S	A S	A S	A S
	850	A S	A S	A S	A S	A S	A S	A S

Australia

Parameter	Level (hPa)	24	48	72	96	120	144	168
Geopotential Height	100	B R	B R	B R	B R	B R	B R	B R
	250	B R	B R	B R	B R	B R	B R	B R
	500	B R	B R	B R	B R	B R	B R	B R
	850	B R	B R	B R	B R	B R	B R	B R
Mean Sea-Level Pressure	0	B R	B R	B R	B R	B R	B R	B R
Temperature	100	B R	B R	B R	B R	B R	B R	B R
	250	B R	B R	B R	B R	B R	B R	B R
	500	B R	B R	B R	B R	B R	B R	B R
	850	B R	B R	B R	B R	B R	B R	B R
Wind U-Component	100	B R	B R	B R	B R	B R	B R	B R
	250	B R	B R	B R	B R	B R	B R	B R
	500	B R	B R	B R	B R	B R	B R	B R
	850	B R	B R	B R	B R	B R	B R	B R
Wind V-Component	100	B R	B R	B R	B R	B R	B R	B R
	250	B R	B R	B R	B R	B R	B R	B R
	500	B R	B R	B R	B R	B R	B R	B R
	850	B R	B R	B R	B R	B R	B R	B R

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G3.1 trial Scorecard

Tropics

Anomaly Correlation and S1 Skill Score on left

Bias and RMSE on right

Statistically significant values in colour:
+ve Blue
-ve Red

Tropics

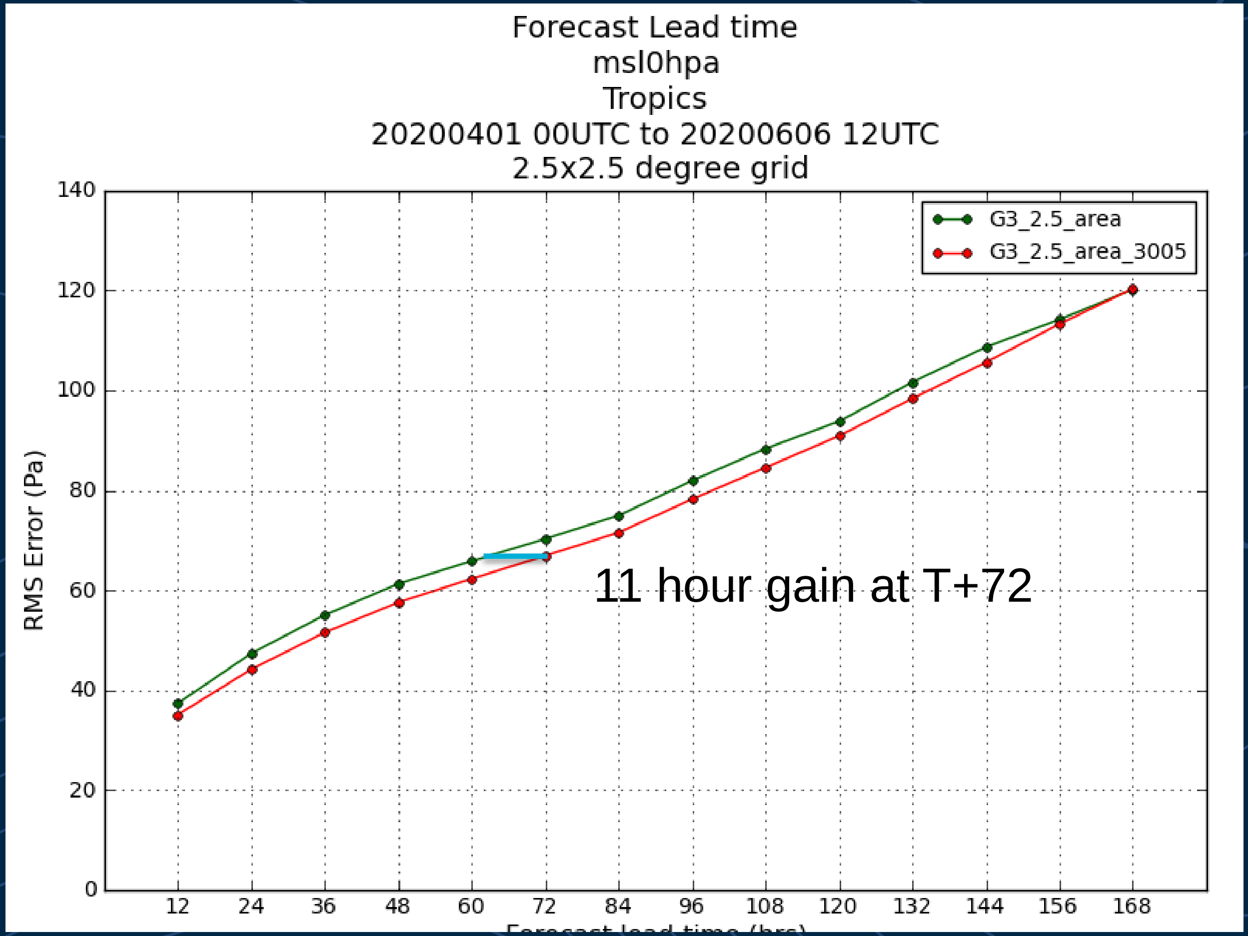
Parameter	Level (hPa)	24	48	72	96	120	144	168
Geopotential Height	100	A S	A S	A S	A S	A S	A S	A S
	250	A S	A S	A S	A S	A S	A S	A S
	500	A S	A S	A S	A S	A S	A S	A S
	850	A S	A S	A S	A S	A S	A S	A S
Mean Sea-Level Pressure	0	A S	A S	A S	A S	A S	A S	A S
Temperature	100	A S	A S	A S	A S	A S	A S	A S
	250	A S	A S	A S	A S	A S	A S	A S
	500	A S	A S	A S	A S	A S	A S	A S
	850	A S	A S	A S	A S	A S	A S	A S
Wind U-Component	100	A S	A S	A S	A S	A S	A S	A S
	250	A S	A S	A S	A S	A S	A S	A S
	500	A S	A S	A S	A S	A S	A S	A S
	850	A S	A S	A S	A S	A S	A S	A S
Wind V-Component	100	A S	A S	A S	A S	A S	A S	A S
	250	A S	A S	A S	A S	A S	A S	A S
	500	A S	A S	A S	A S	A S	A S	A S
	850	A S	A S	A S	A S	A S	A S	A S

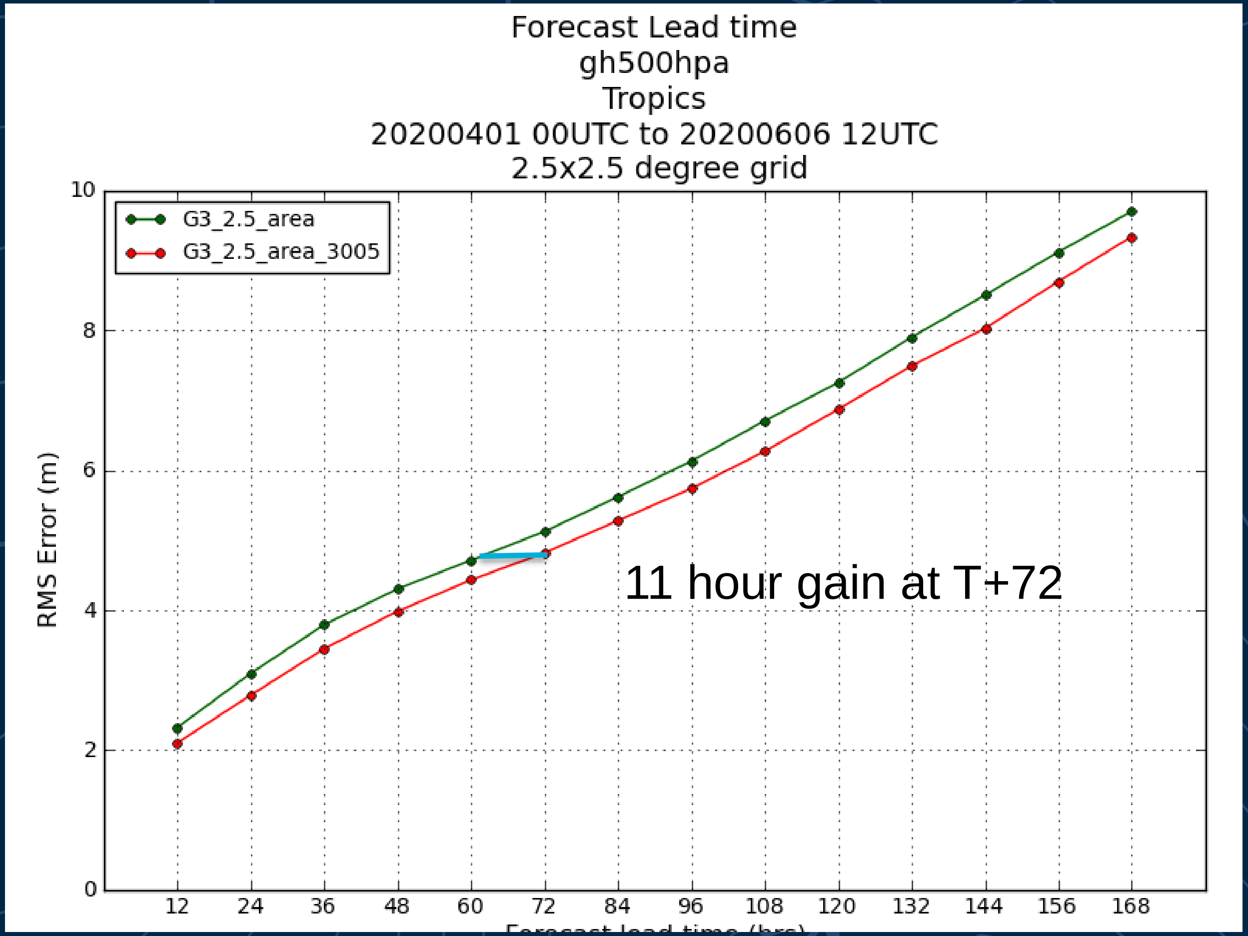
Tropics

Parameter	Level (hPa)	24	48	72	96	120	144	168
Geopotential Height	100	B R	B R	B R	B R	B R	B R	B R
	250	B R	B R	B R	B R	B R	B R	B R
	500	B R	B R	B R	B R	B R	B R	B R
	850	B R	B R	B R	B R	B R	B R	B R
Mean Sea-Level Pressure	0	B R	B R	B R	B R	B R	B R	B R
Temperature	100	B R	B R	B R	B R	B R	B R	B R
	250	B R	B R	B R	B R	B R	B R	B R
	500	B R	B R	B R	B R	B R	B R	B R
	850	B R	B R	B R	B R	B R	B R	B R
Wind U-Component	100	B R	B R	B R	B R	B R	B R	B R
	250	B R	B R	B R	B R	B R	B R	B R
	500	B R	B R	B R	B R	B R	B R	B R
	850	B R	B R	B R	B R	B R	B R	B R
Wind V-Component	100	B R	B R	B R	B R	B R	B R	B R
	250	B R	B R	B R	B R	B R	B R	B R
	500	B R	B R	B R	B R	B R	B R	B R
	850	B R	B R	B R	B R	B R	B R	B R

Tropics – change in RMSE for G3.1 vs G3

PMSL   G3 G3.1   Z500





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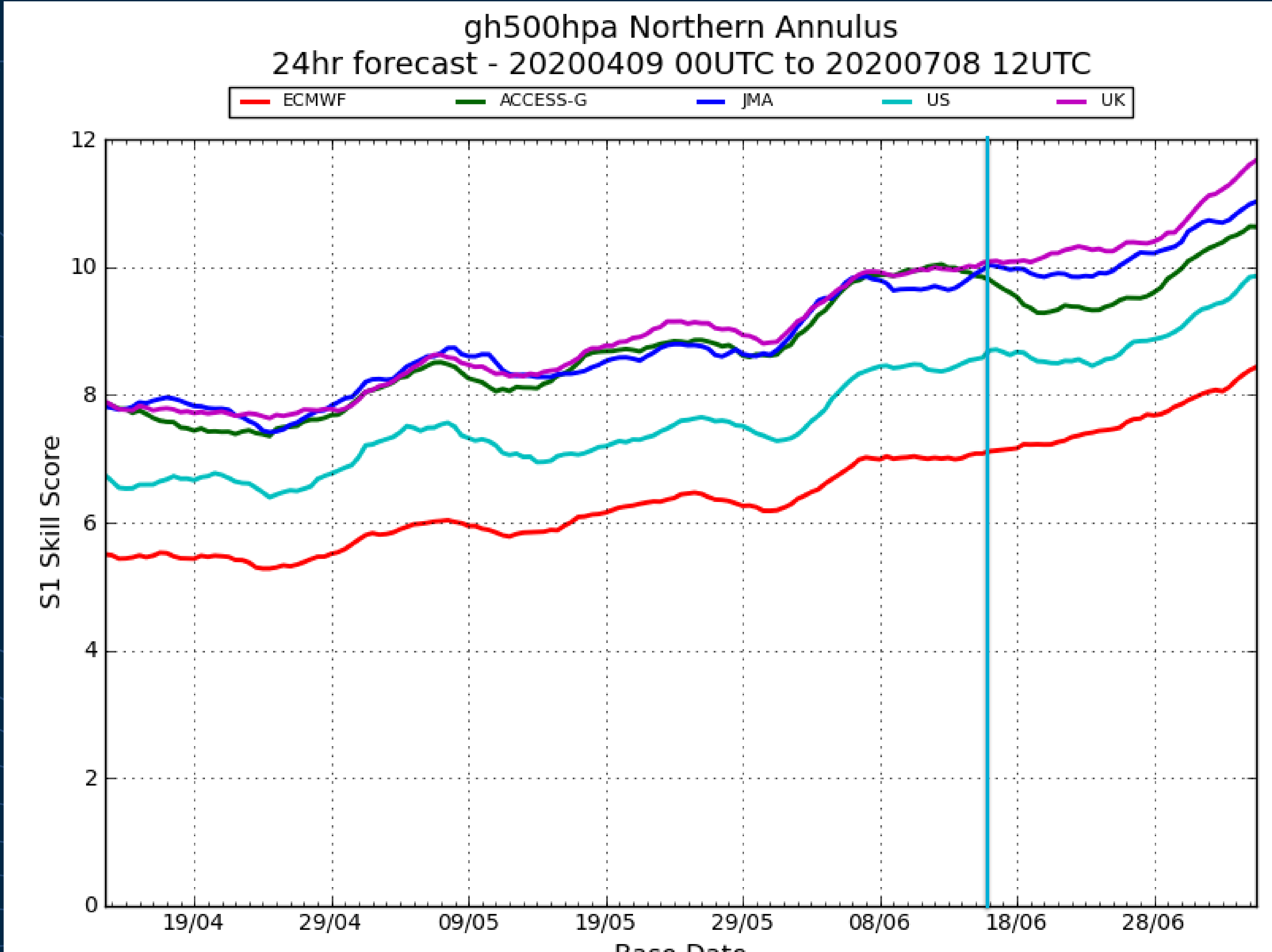

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Observation usage across all models (satellites in red)

	Global (ACCESS-G3)	City (ACCESS-C3)	Tropical Cyclone (ACCESS-TC3)
Hyperspectral IR sounder (LEO)	AIRS, CrIS, IASI	AIRS, CrIS, IASI	AIRS, CrIS, IASI
IR sounder (GEO)	Himawari AHI CSR		
Microwave sounders (LEO)	AMSR-2, ATMS, ATOVS, SSMIS	ATMS, ATOVS	ATMS, ATOVS
GNSS measurements	GPSRO, GPS WV	GPS WV	GPS WV (if in domain)
AMV (mostly GEO)	Himawari, GOES-16, GOES-17, Meteosat-8, Meteosat-11, MODIS	Himawari	Himawari (Meteosat-8, GOES-17 if in domain)
Scatterometer	ASCAT, ScatSat-1	ASCAT	ASCAT, ScatSat-1
Conventional observations	AIREPS, AMDAR, BUOY, METAR, PILOT, SHIP, SYNOP, TEMP, WINPRO	AIREPS, AMDAR, BUOY, METAR, PILOT, SHIP, SYNOP, TEMP, WINPRO	AIREPS, AMDAR, BUOY, METAR, PILOT, SHIP, SYNOP, TEMP, WINPRO
Radar		Doppler Winds	
Other	TC BOGUS		TC BOGUS

Bureau Direct Reception of LEO sounders for ACCESS-C3

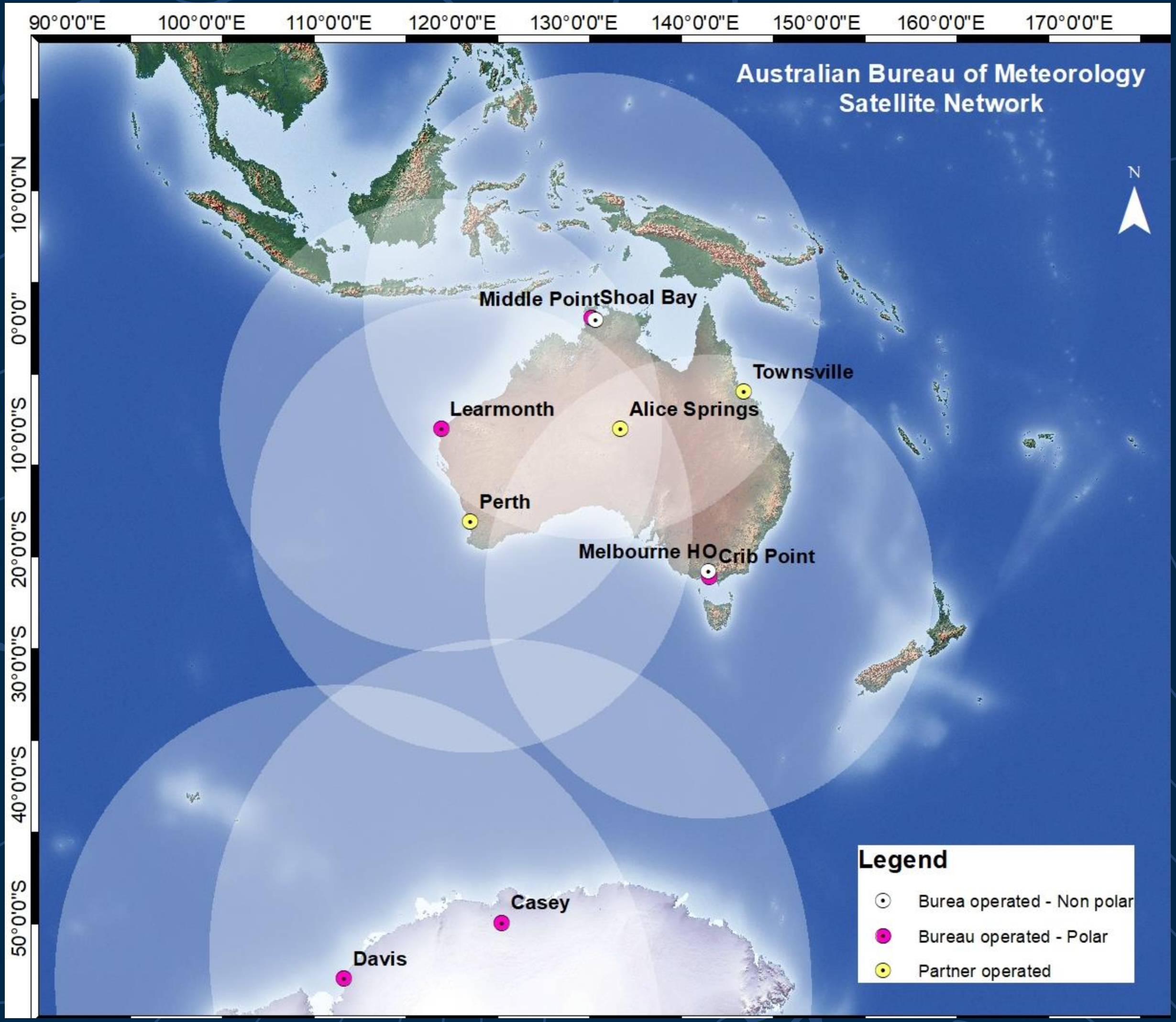
The Bureau operates three mainland receiving stations and two in Antarctica

- Shoal Bay, Learmonth, Crib Point
- Casey, Davis

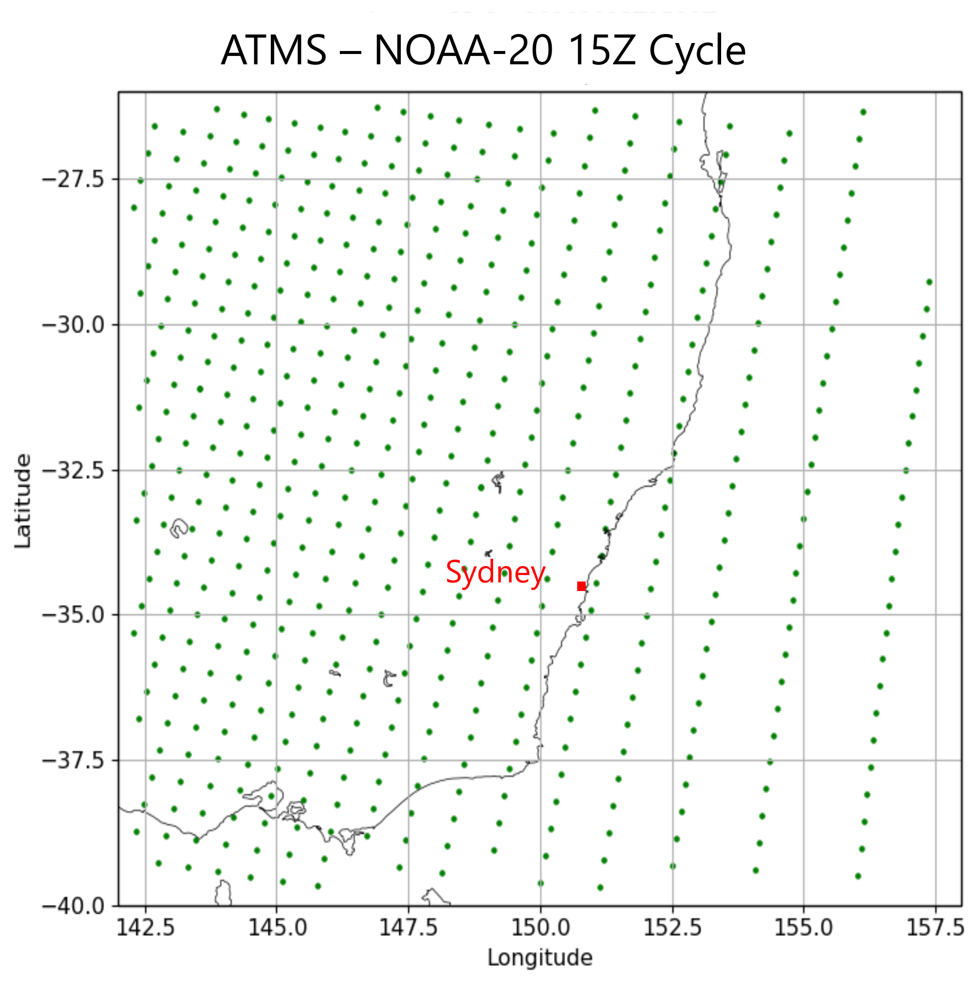
Three additional reception sites are operated by partner agencies

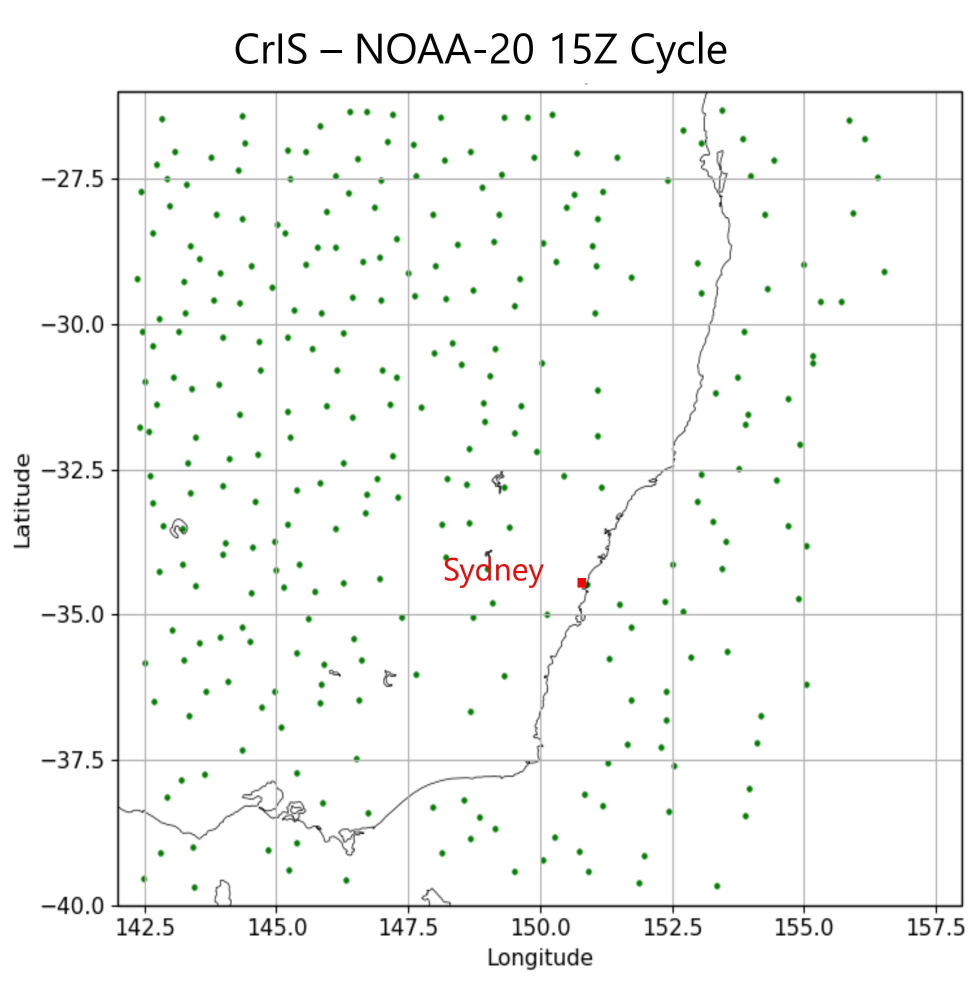
- Perth, Alice Springs, Townsville

Observations from these sites come in much more quickly, allowing us to use sounder data in ACCESS-C3



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





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Future Directions

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New Science and new instruments

- Addition of many new instruments already in space
  - Extra winds: Polar orbiting AMVs, more scatterometers, Aeolus Lidar horizontal line of sight winds
  - Extra GNSS-RO from COSMIC-2
  - Extra ground-based GNSS-RO
  - (Extra GEO radiances)
  - (Radiances from Chinese and Korean satellites)
- More use of observations over land, and higher resolution sounder obs in C3
- Use GEO sounder obs in C3
- Use of observations in cloudy conditions
  - Meteorologically active: Use the observations where the weather is
  - Should improve cloud analysis
  - Difficult because depends on formulation of the DA system and cloud errors are non-Gaussian

Hyperspectral GEO Sounders

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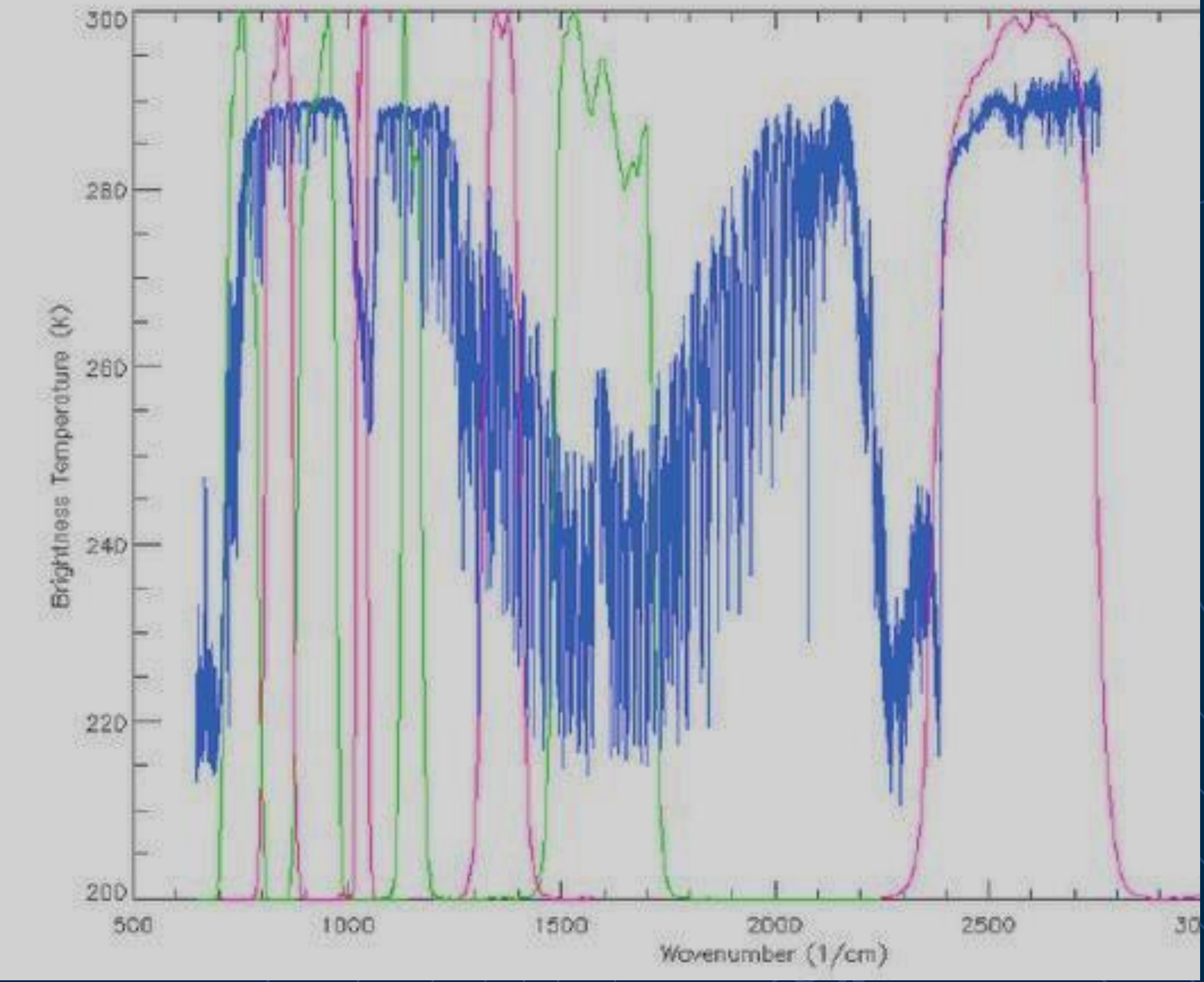
A portion of an infrared measured hyperspectral spectrum in blue (IASI) with the spectral response functions of a broadband radiometer (SEVIRI on MSG)

Future Himawari satellites may carry a hyperspectral sounder

- Big challenges but big opportunities

From Hewison, T., and M. König, 2008



The satellite landscape is changing

- Smaller satellites, shorter-lived instruments
- Commercial providers

- We need to be faster and more agile
- We need to make good use of our partnerships

- Australian Space Agency – Earth Observation Roadmap
- Potential partnership with JMA for future Himawari missions

- Also the advent of coupled modelling (Atmos/Ocean; Atmos/Hydrology) provides its own opportunities and challenges

- The future is exciting, but there's a lot to do!

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Thank You

Any questions?

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