Met Office

Satellite Observations for Numerical Weather Prediction: Trends and Challenges

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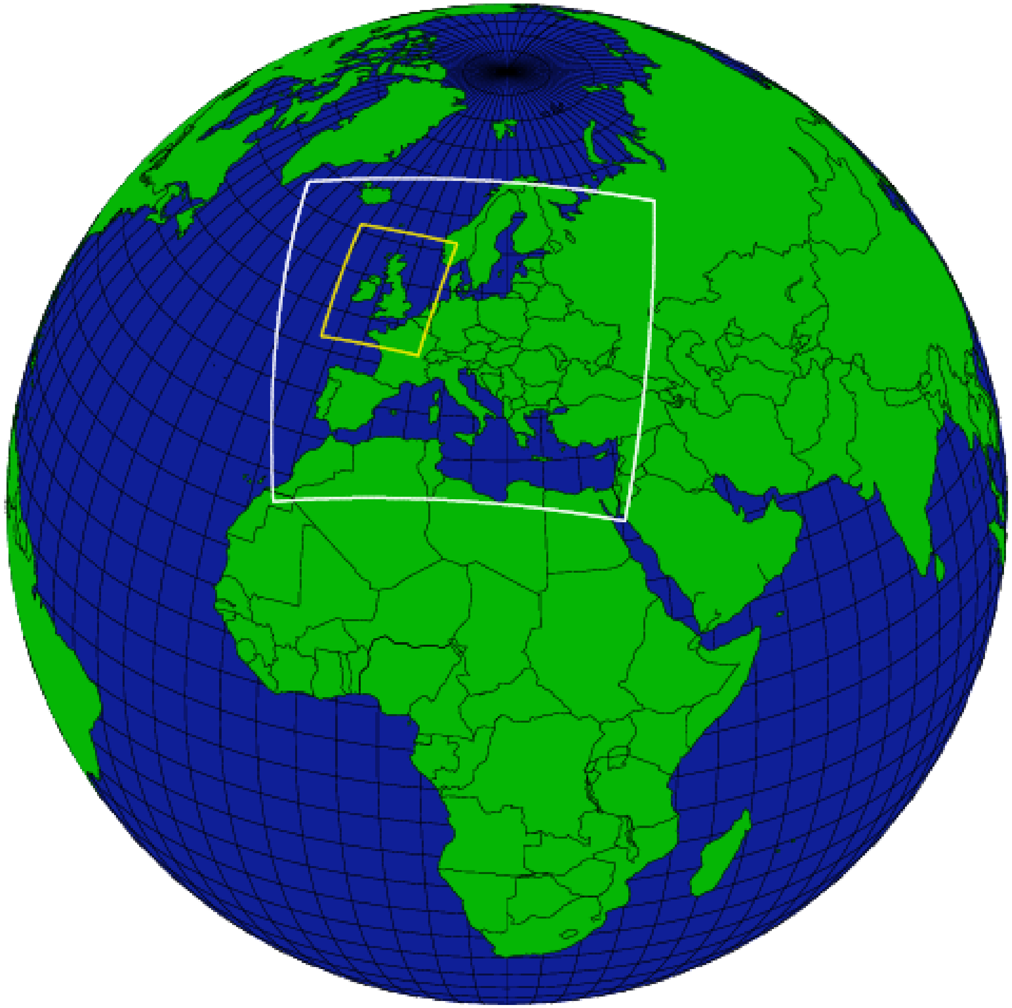
Outline

- Satellite observations in NWP – data assimilation
- What observations matter most ?
- How are the requirements evolving ?

Numerical Weather Prediction (NWP) Models



The Met Office currently run several NWP models, including:

• A **global model:**

- ➢ 25 km resolution (17 km, May 2014)
- ➢ Forecasts to T+6 days
- ➢ Data assimilation: 4D-Var
- ➢ ~40% of recent (2000→) skill improvements (1day.decade^{-1}) due to improved assimilation of satellite data – *esp.* MW & IR T-sounding obs
- ➢ Mature observing system → future development focussed on: (i) gaps (*eg* 3D-winds) & (ii) same, or better, capability at same/lower cost

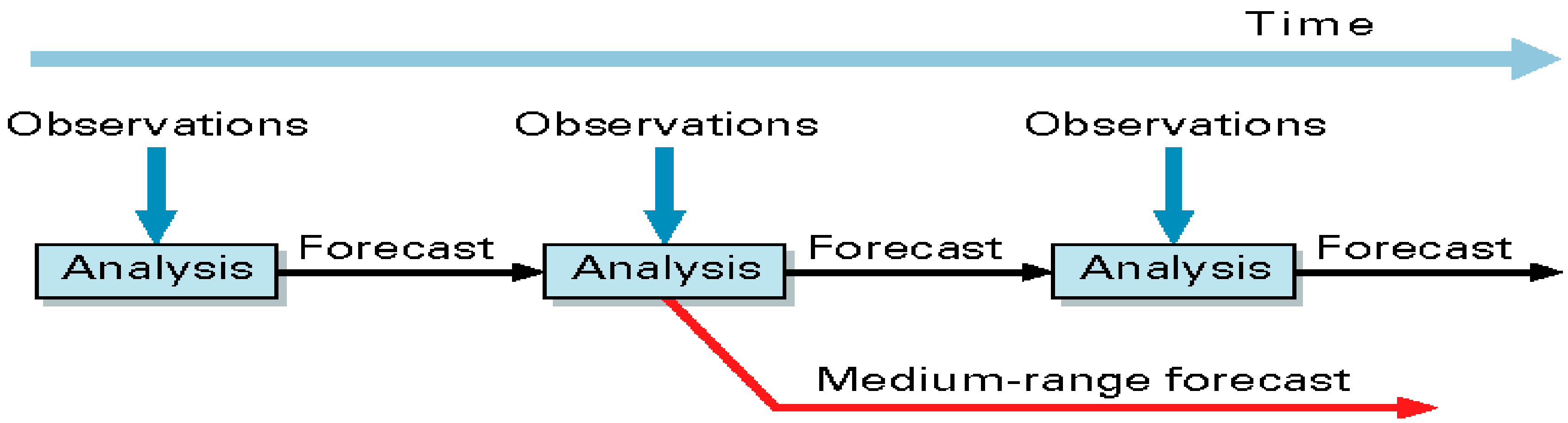
• A high resolution **UK model:**

- ➢ 1.5 - 4km resolution, L70 (0 - 40 km)
- ➢ Forecasts to T+ 36 hours
- ➢ Data assimilation: 3D-Var
- ➢ Use of satellite data less mature:
    - ➢ Emphasis on hydrological cycle variables
    - ➢ Higher spatial and temporal resolution

• **Ensemble variants** of global and UK models
- to quantify forecast uncertainty

• A range of local area models

Data assimilation



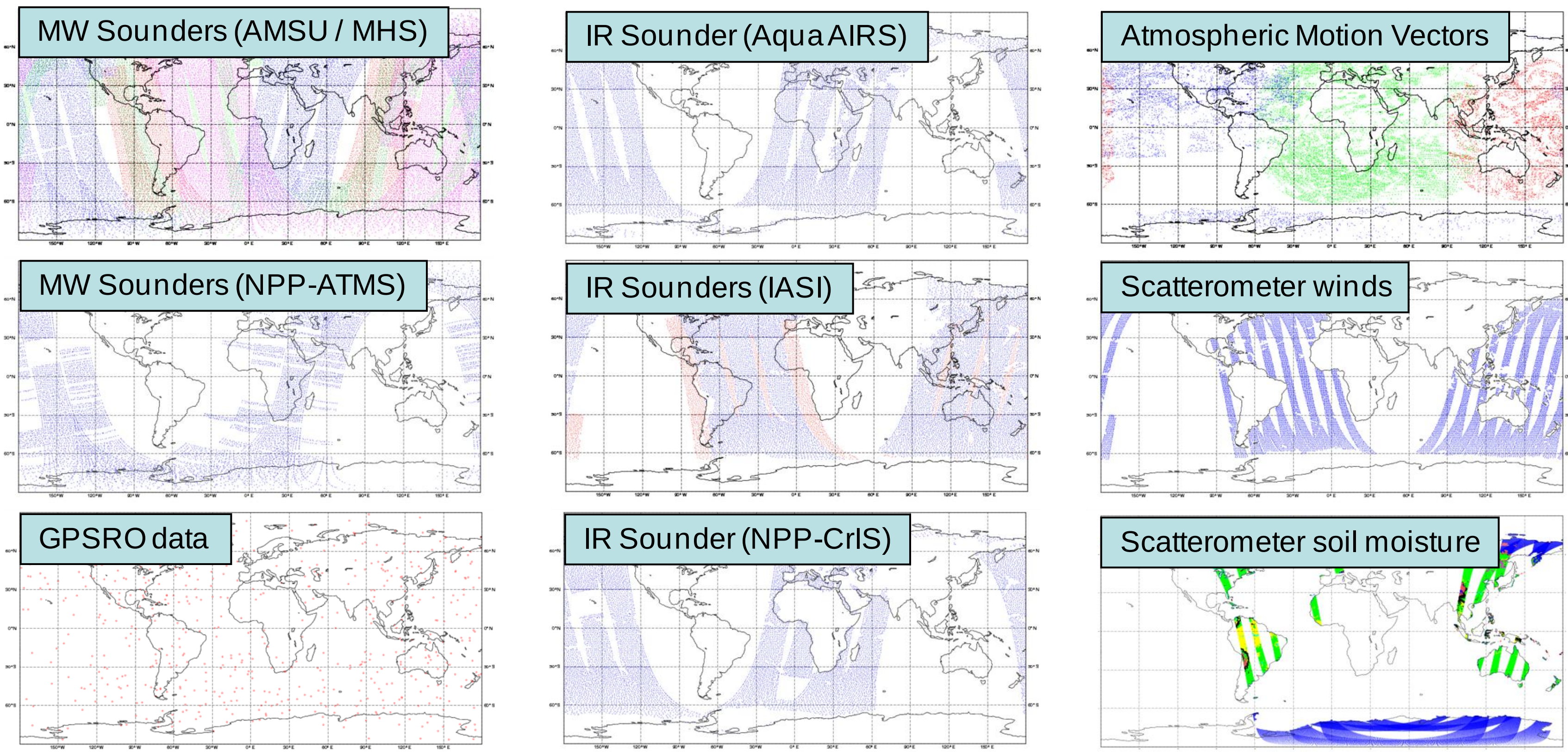
- The primary purpose of satellite observations in NWP is to provide the initial conditions (the *analysis*) for the forecast model.

- Every 6 hours ~5 million observations processed by assimilation system, to generate the atmospheric analysis. State vector ~10^9.

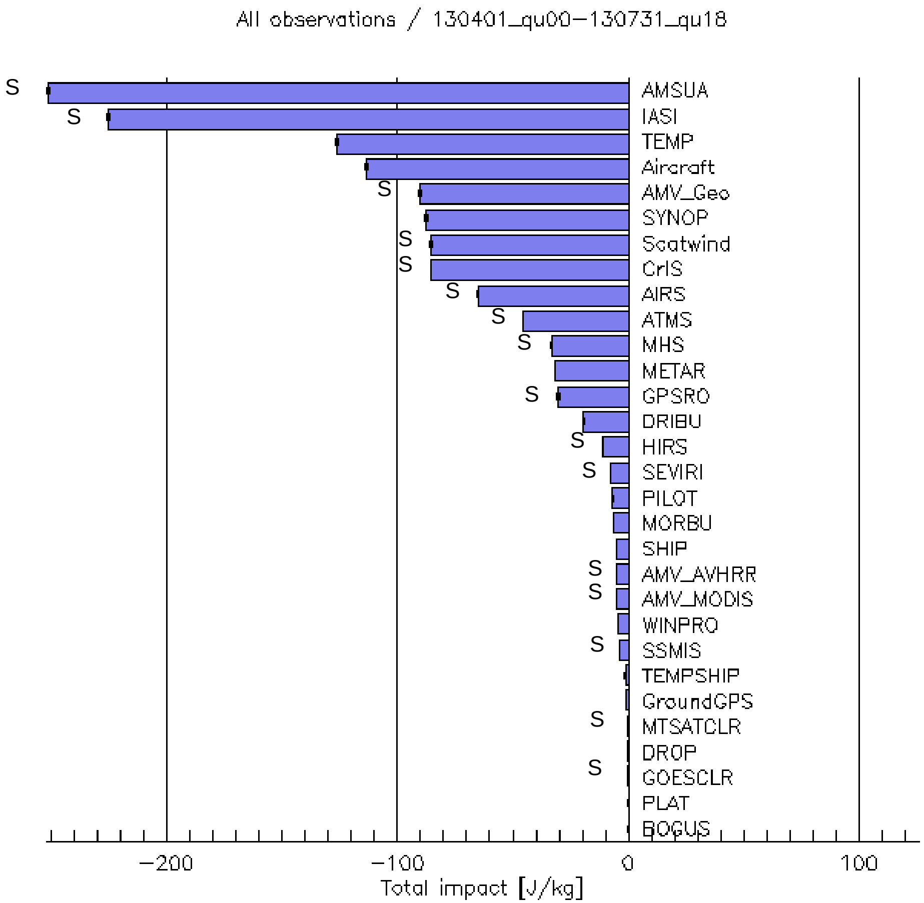
- **80%** of the information in the analysis is extracted from the previous forecast, **20%** from new observations.

- Analysis cost ~25 minutes: Forecast cost ~45 mins (96 nodes of IBM Power 7).

Satellite data coverage 00Z 28th April 2014



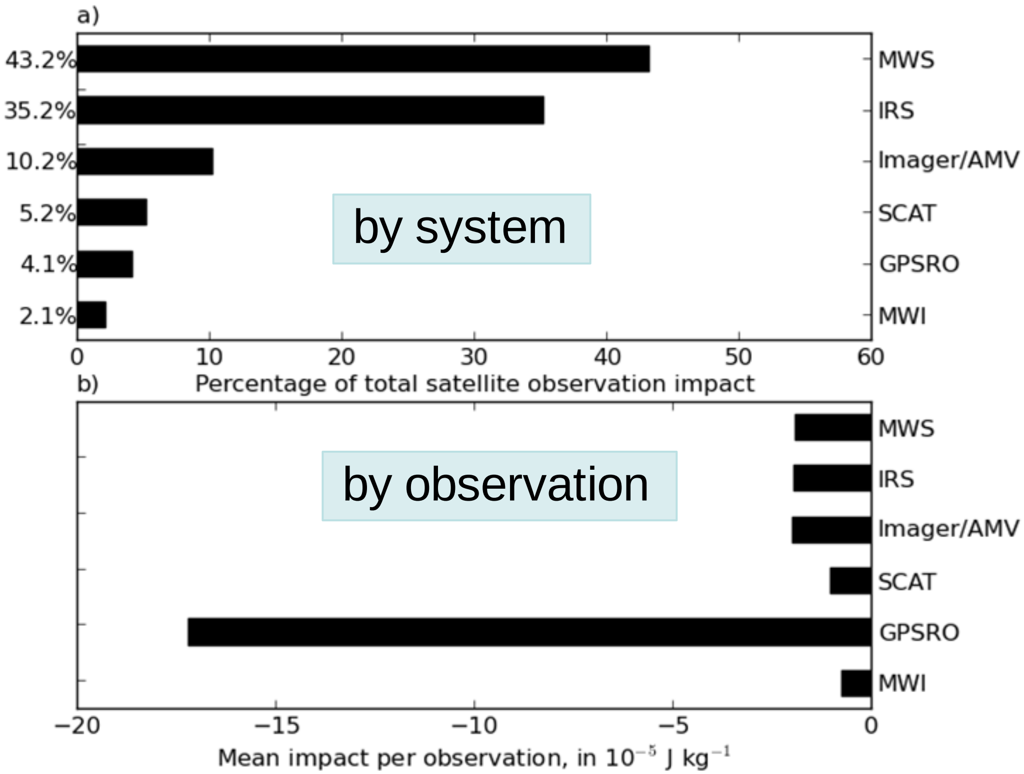
The relative benefit of observations



- Impacts diagnosed from the operational configuration, as of May 2013
- Satellite data ('S'), collectively, provides very significant benefit

Technique described in ***Joo, Eyre and Marriott*** (*Monthly Weather Review*, Oct. 2013) based on '*Forecast Sensitivity to Observations*' – an adjoint based technique for assessing the relative contribution of observing systems to forecast accuracy

Forecast impact per system & per observation



As a system, microwave sounding (MWS) data provides the largest benefit - followed by IR sounding data from hyperspectral sounders

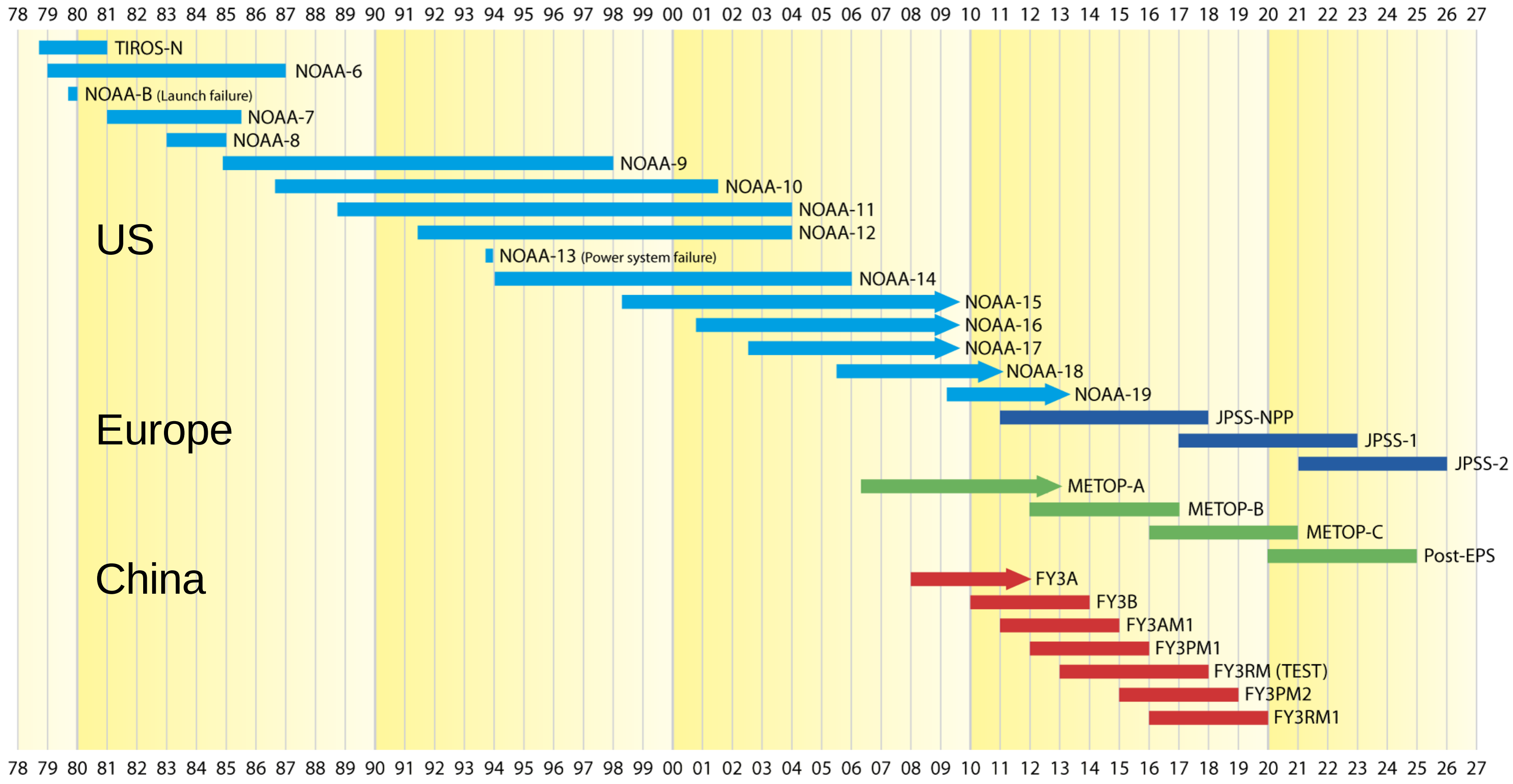
Challenge: maintain – same or better performance – for same cost.

per observation
GPSRO (v. high vertical resolution) provides most benefit.

Challenge: to maintain, and expand, the constellation of GPSRO receivers.

Results from Joo, Eyre and Marriott (Monthly Weather Review, 2013) based on '*Forecast Sensitivity to Observations*' – an adjoint based technique for assessing the relative contribution of observing systems to forecast accuracy

Background
Operational Sounding Satellites: 1978 - 2020



- MW & IR sounding data also used in climate and atmospheric reanalysis
- Missions specified, designed & launched in the next decade will serve NWP to 2030 and beyond
- China will play an increasing role in the global observing system
- Future for MW & IR sounding instruments is assured beyond 2020.

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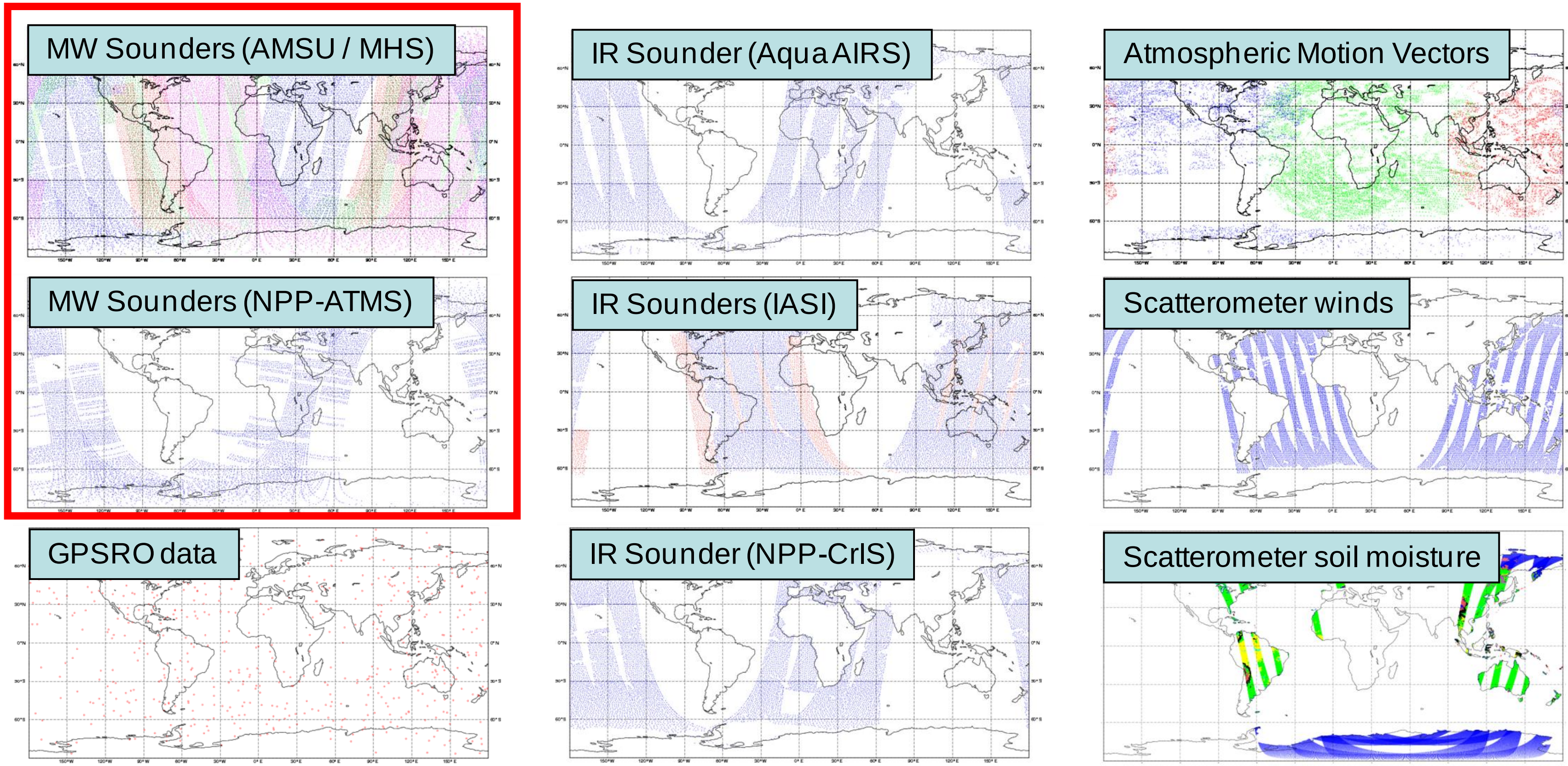
Temperature, humidity and clouds



- MW sounders: 50-60 GHz for T-sounding, 183 GHz for humidity sounding (+ 23.8, 31.0, 89.0, 150.0)
- footprint ~ 40 km at Nadir
- swath width ~ 2000 km

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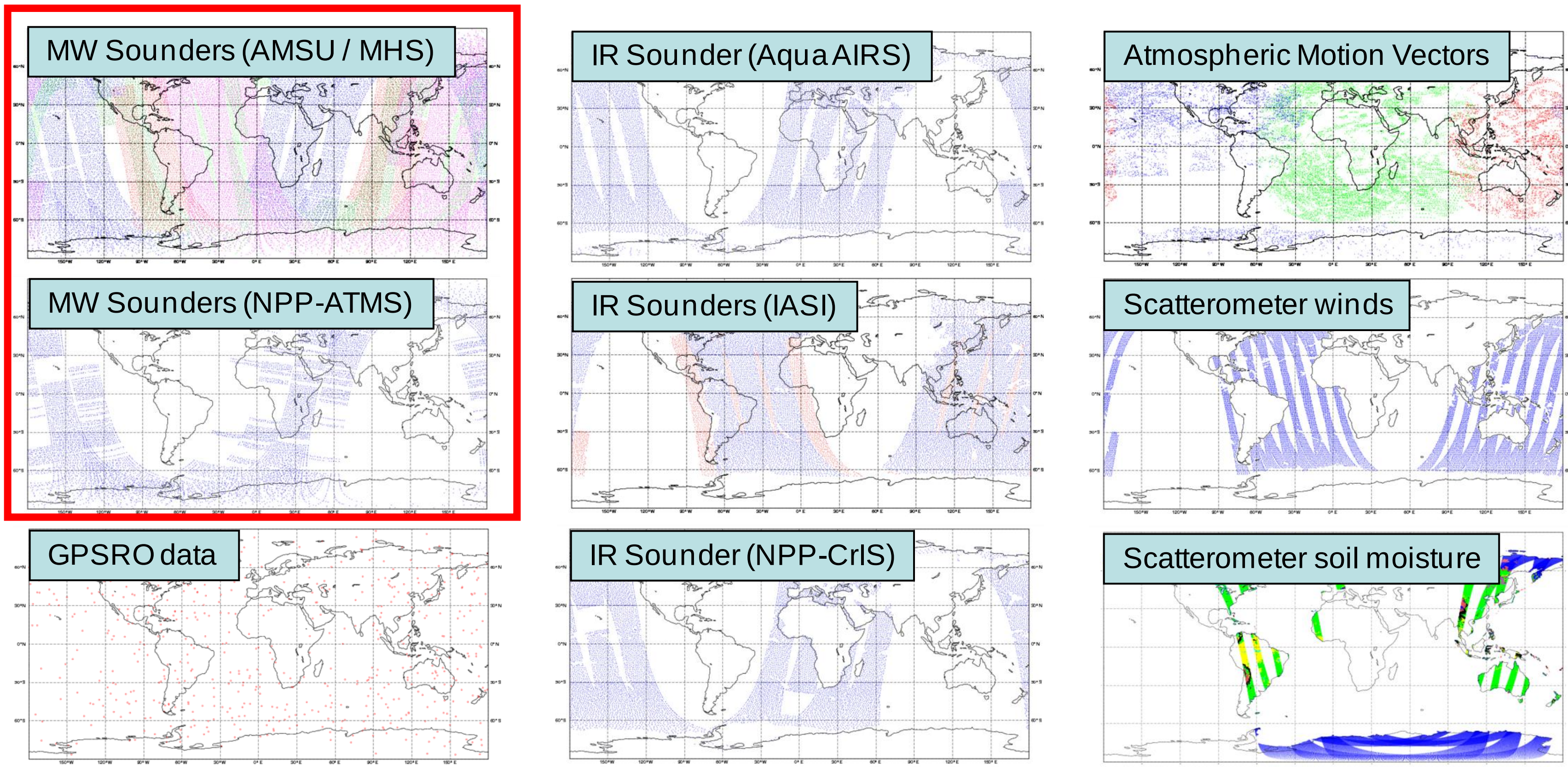
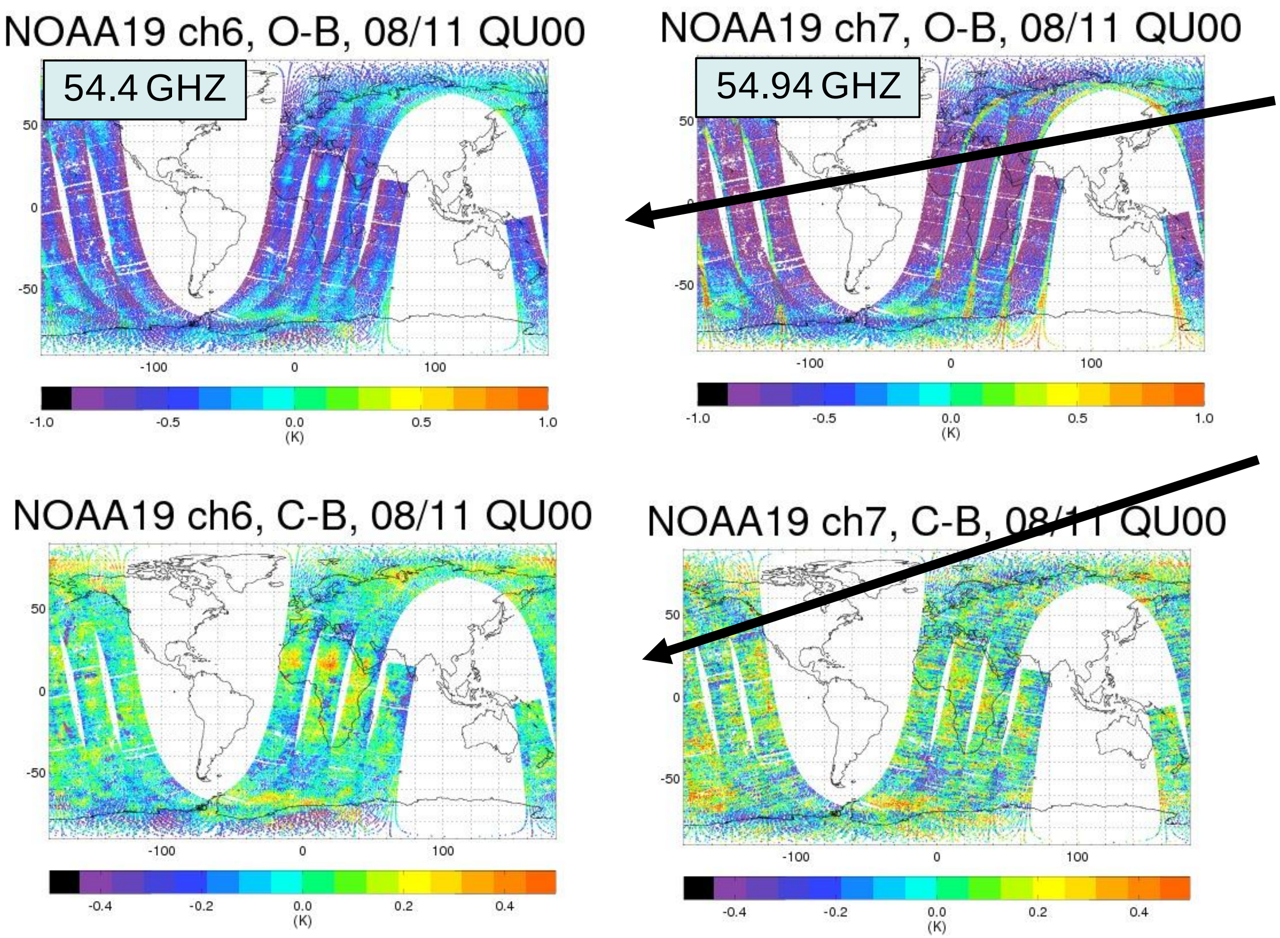
Temperature, humidity and clouds



- **Trends / challenges:**
  - **MetOp-SG MWS** – to be built in the UK **!**
  - lessons learned from SSMIS, MSU, AMSU-A & ATMS → improved pre-launch characterisation & cal.
  - Co-operation with China to assess / improve FY-3.
  - Novel approaches: hyperspectral (mesospheric sounding); 118 GHz (FY-3, cubesats – μmas); Geo-MW

Bias and radiometric sensitivity performance for temperature sounders



prior to bias correction:
large scale biases of ~0.5K (peak-peak)

after bias correction:
geophysical signals : ~ 50-100 mK (stdev)

NEΔT ~ 100 - 200 mK

- Radiometric performance specifications (noise and bias) are demanding - for temperature sounders
- Errors in forecast fields for humidity are larger (1-2K in T_B) – therefore specifications are less demanding

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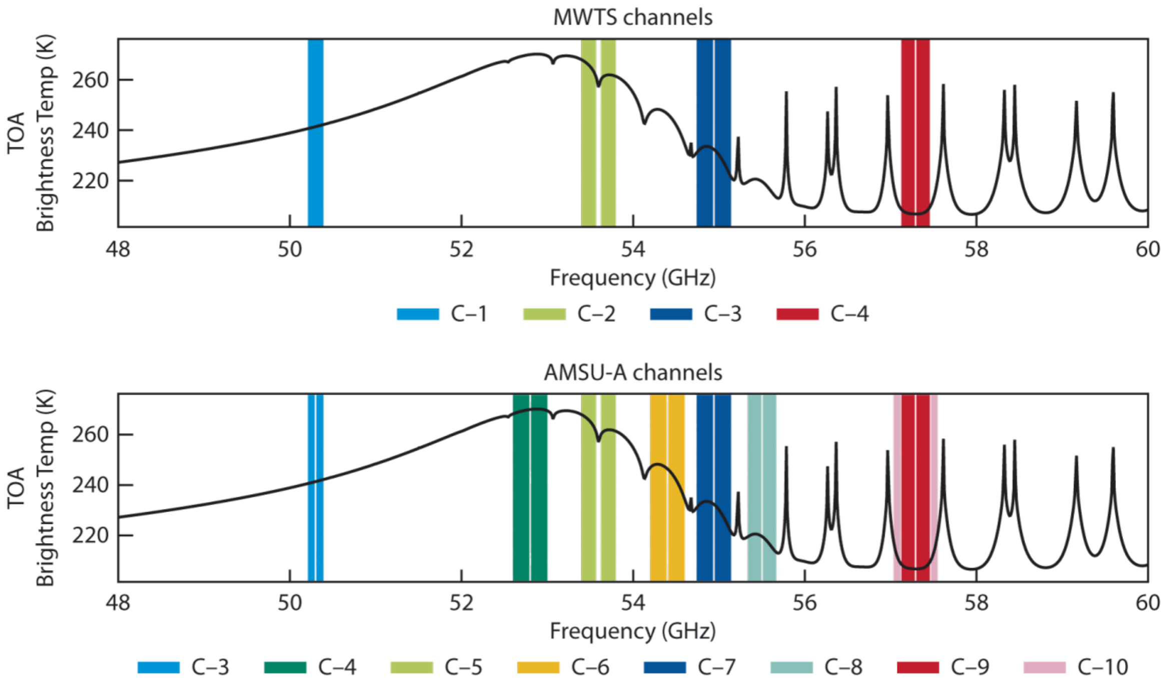
Temperature Sounding 50 - 60 GHz



- Hyper-spectral MW (ESA study):
  - ➢ Make full use of 50-60 GHz band.
  - ➢ RFI mitigation;
  - ➢ Zeeman split lines for mesospheric sounding

- Frequency stability of LOs important (MSU / AMSU / FY-3 MWTS)

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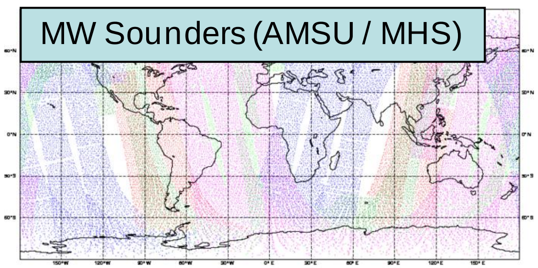
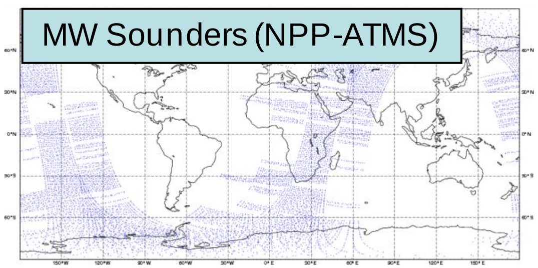
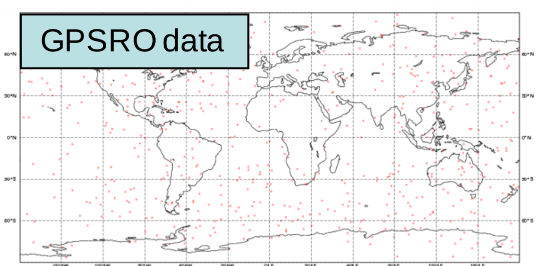
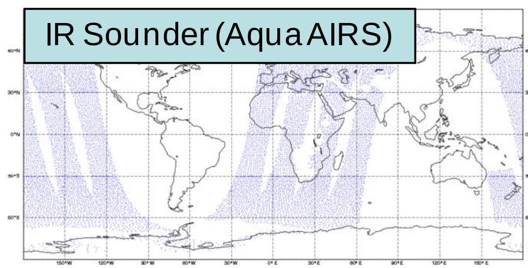
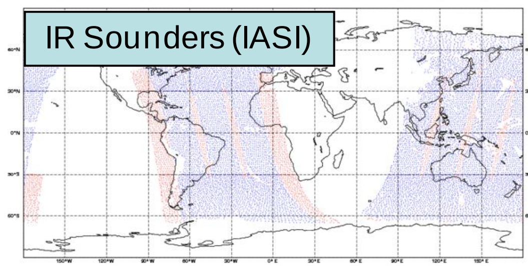


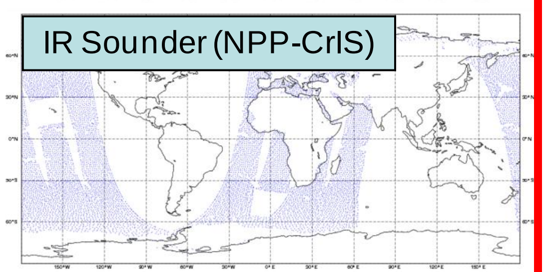


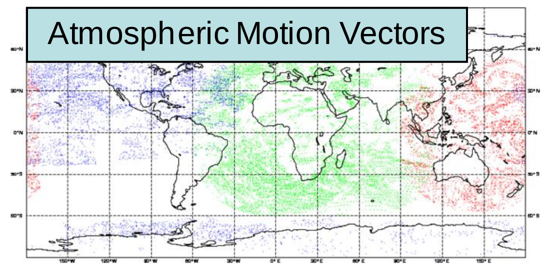


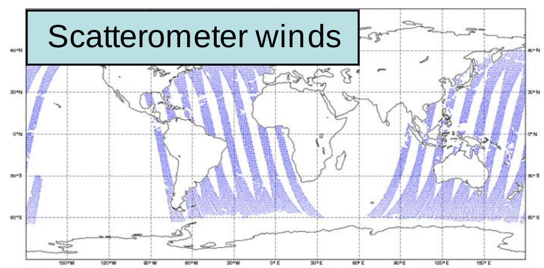
Temperature, humidity and clouds

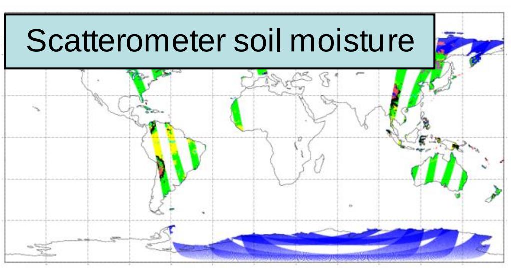












- IR sounders: 15.5 -3.6 μm, resolution 0.25 - 0.62 cm^{-1}
- footprint ~ 10 km at Nadir
- swath width ~ 2000 km

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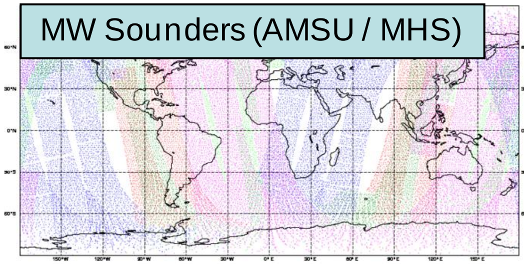
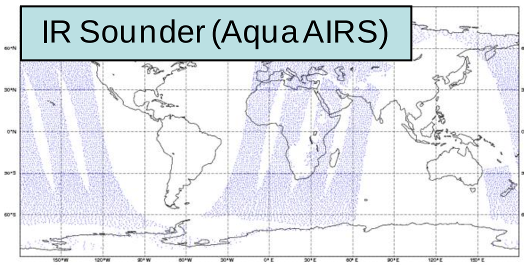
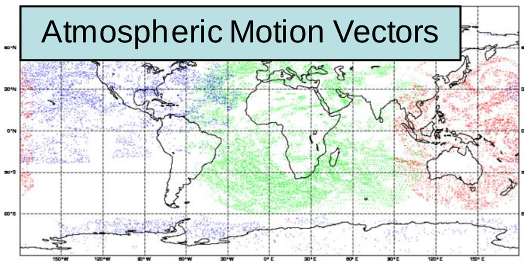
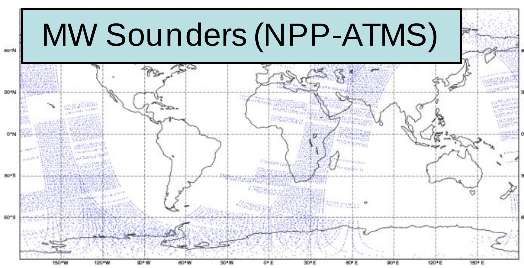
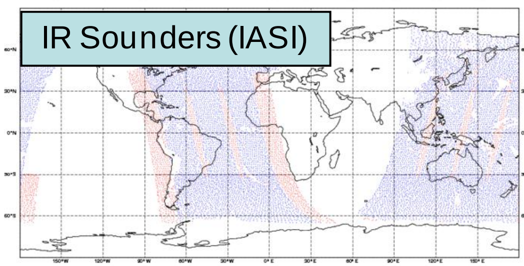
Temperature, humidity and clouds

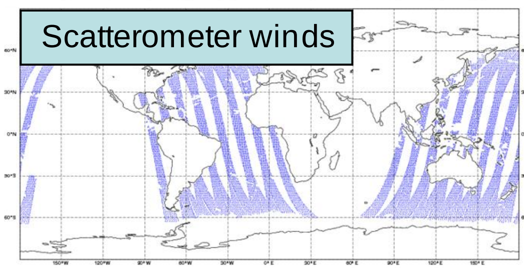


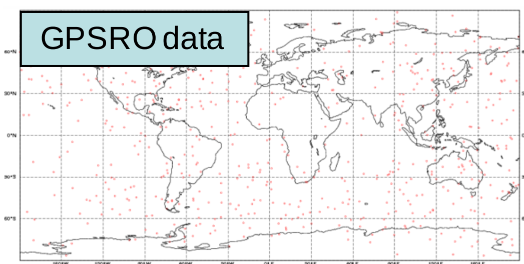


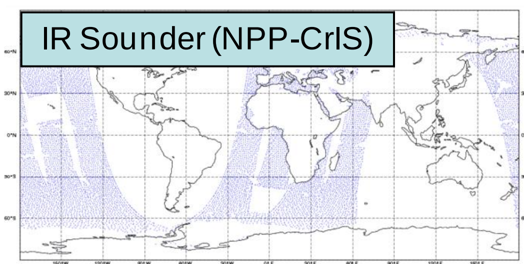


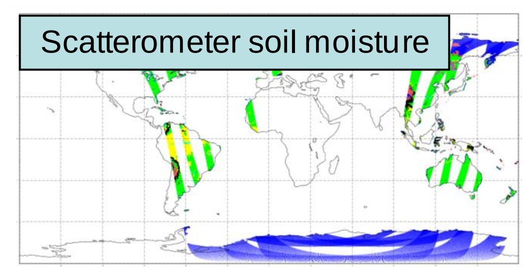








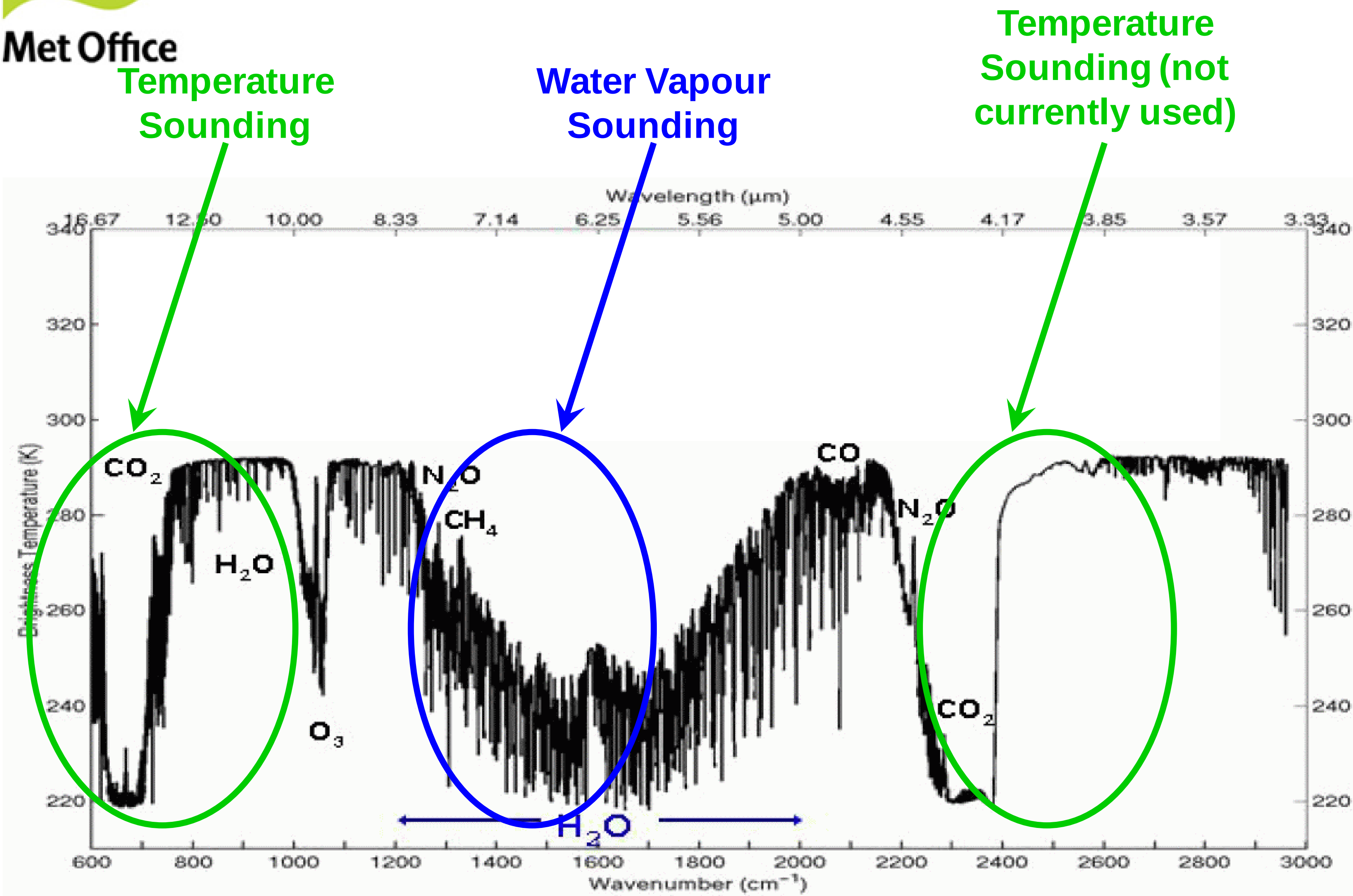




• **Trends /challenges:**

- MetOp-SG IASI-NG (2020, improved resolution & noise performance); FY-3D
- MTG-IRS : GEO hyper-spectral (2020)
- Challenges: very large data volumes; humidity feature tracking for MTG-IRS; cloud affected radiances

IASI spectrum



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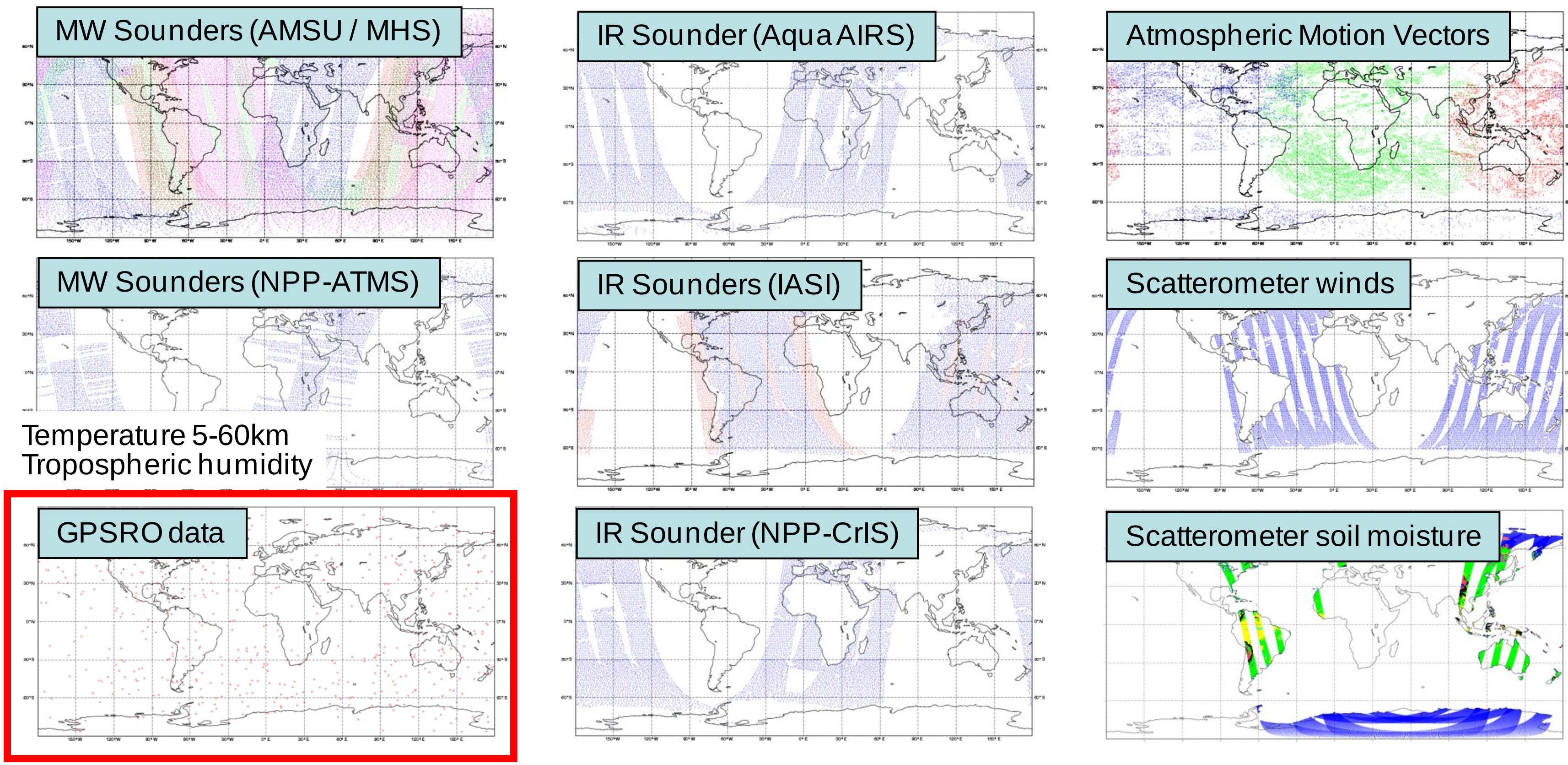

- GPS-RO: 'anchoring' observations. SI-traceable. Assimilated without bias correction.
- ~ 500 occultations per cycle (from 9 satellites)
- Poor horizontal resolution, excellent vertical.

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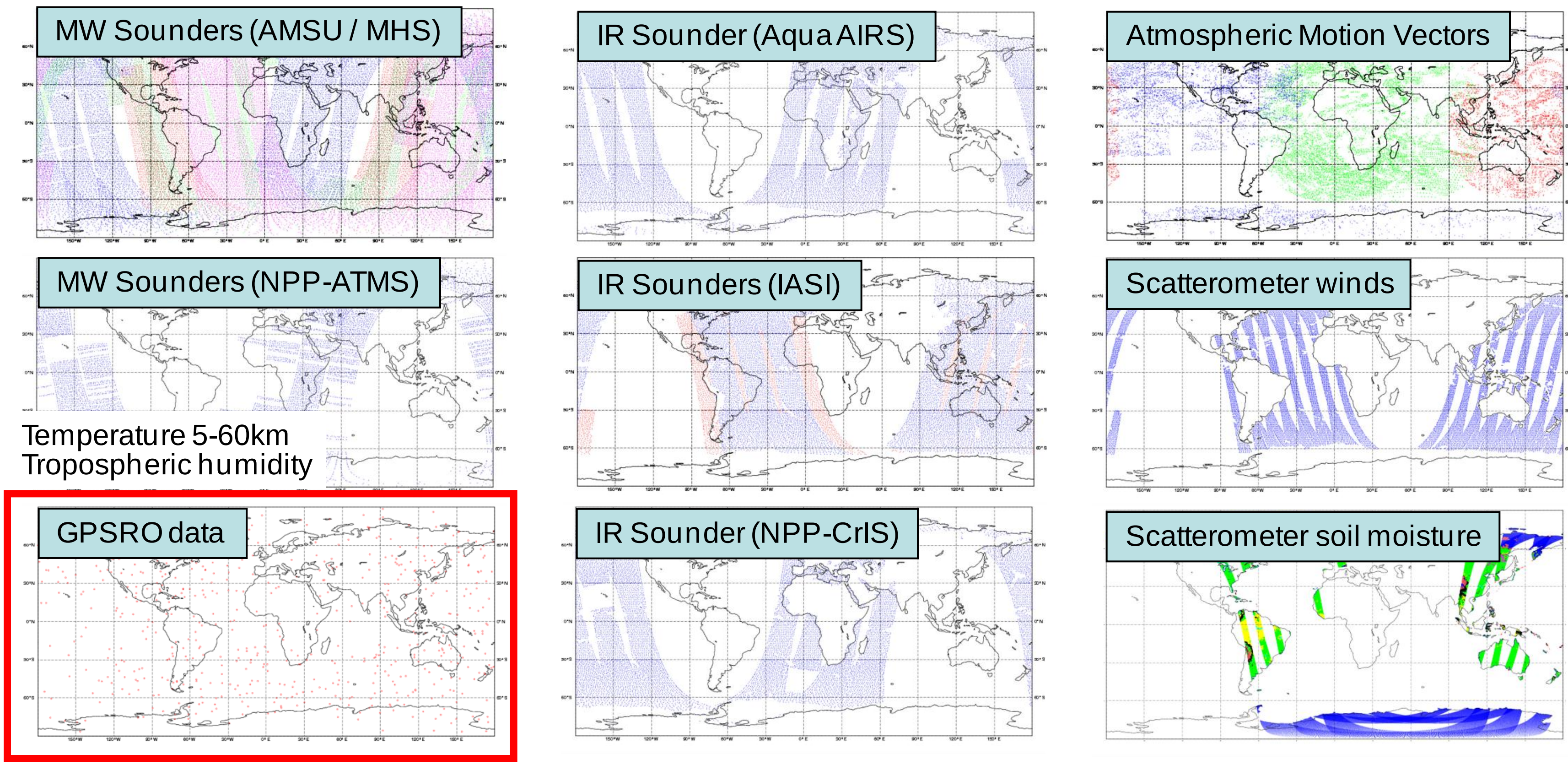

- **Trends / challenges**
  - ➢ Maintaining and enlarging the constellation (COSMIC ?). Significant benefits from more data;
  - ➢ Role for cubesats ?

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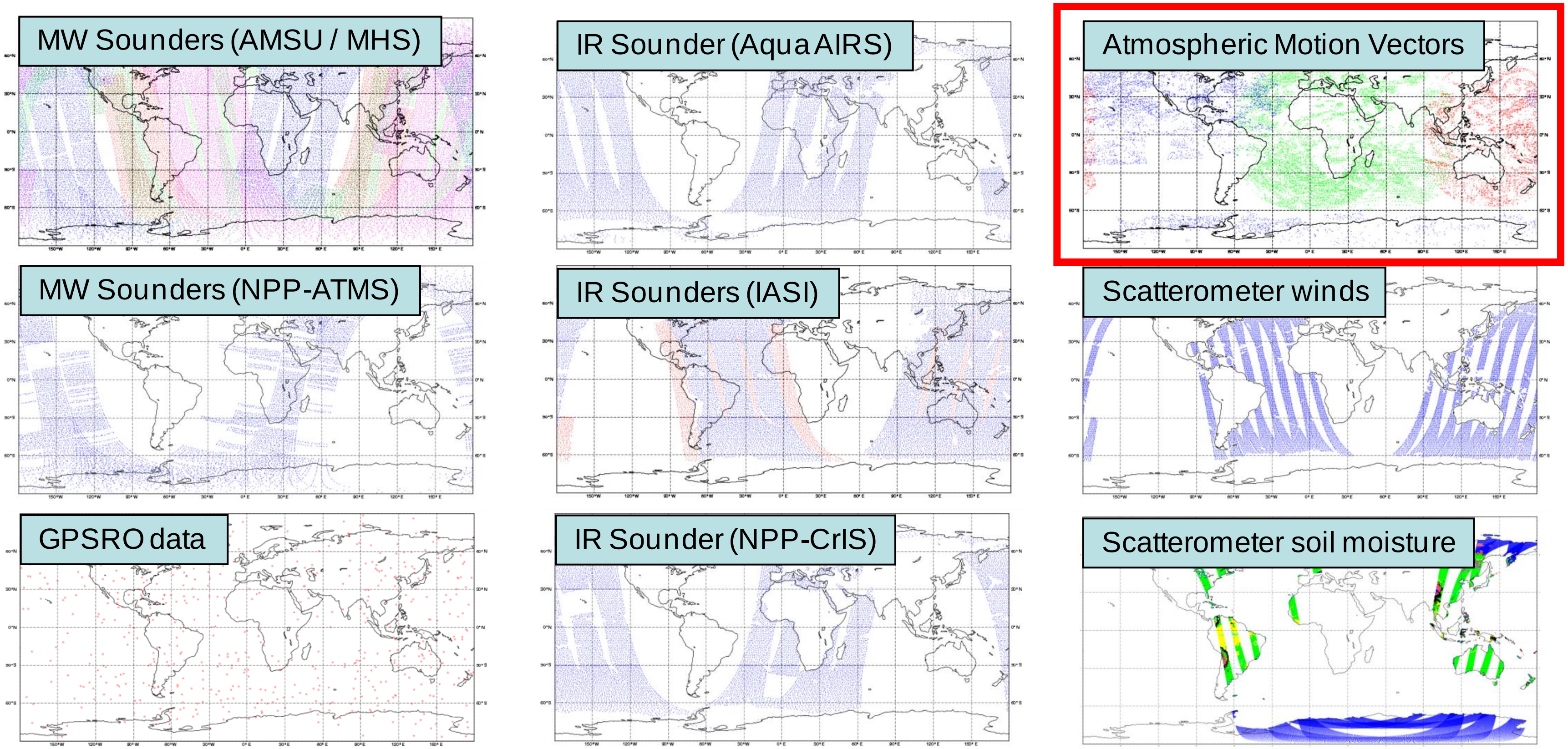
Tropospheric upper level winds



- Atmospheric motion vectors (AMVs). – derived from sequences of GEO (and LEO) cloud images
- **Trends / challenges:**

➢ future GEO missions assured (US, Europe, FY-4, ...);
➢ extension to humidity feature tracking with MTG-IRS
➢evaluation of ADM – doppler wind lidar 2016? (*esp*. tropical winds)

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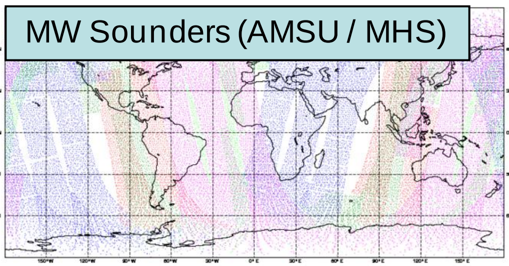

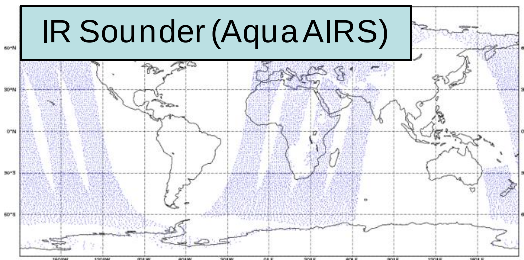

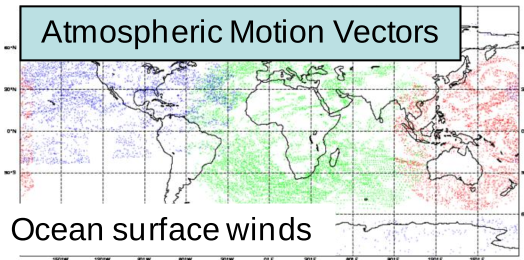

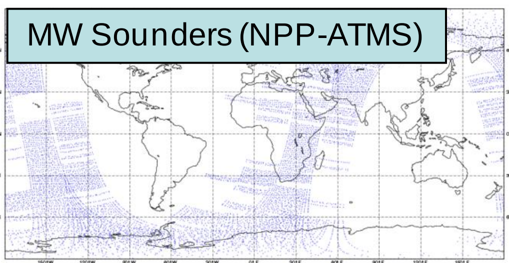

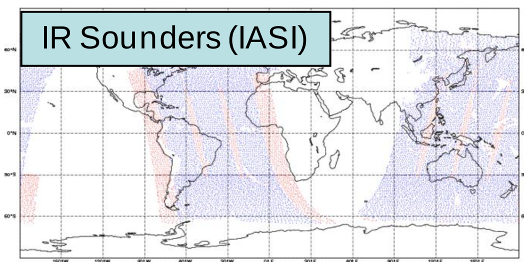

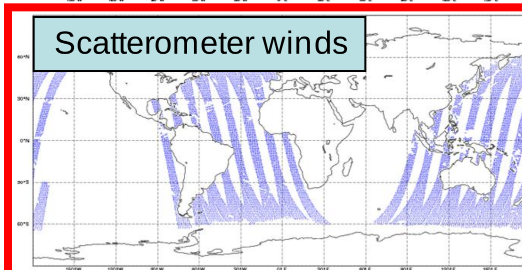

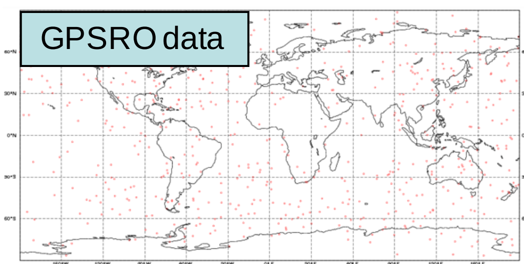

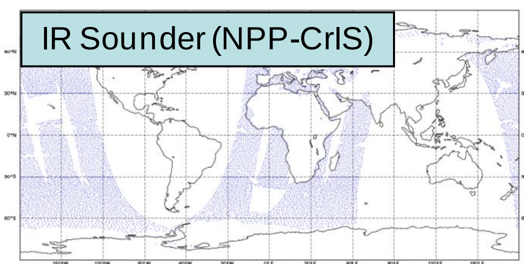

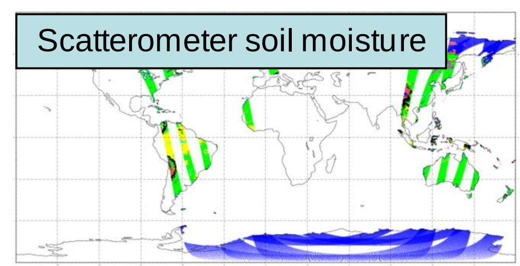

- Scatterometers: winds over ocean & soil moisture

- **Trends / challenges:**

➢ MetOp-SG scatterometer planned.

➢ Can SAR provide soil moisture information at higher resolution ?

Summary

- Satellite data has played a key role in improving global NWP forecast skill

- Temperature sounding radiances (MW & IR) are, and will continue to be, important . Scope for innovation to improve data quality (radiometric performance) further, lower costs.

- Continuity, and extension of, GPS-RO constellation a priority.

- 3D winds remain a gap. ADM DWL will quantify benefit .

- High resolution NWP demands a shift in focus to humidity, cloud and rain at high spatial and temporal resolution.