WMO Regional Office for Asia and the South-West Pacific, Singapore

Impact of RFI on Numerical Weather Prediction and Climate Reanalysis

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ECMWF

Deputy Director of Research

With special thanks to Markus Dreis (EUMETSAT), Yan Soldo, Flavio Jorge and Bruno Espinosa (ESA), Kirsty McBeath (Met Office), Tony McNally, Niels Bormann, Tracy Scanlon and Alan Geer (ECMWF) and the whole “ESSEO” team at ESA

Training Workshop on Use and Management of Radio Spectrum for Meteorology

ECMWF

Recent evolutions in NWP…resolution and complexity

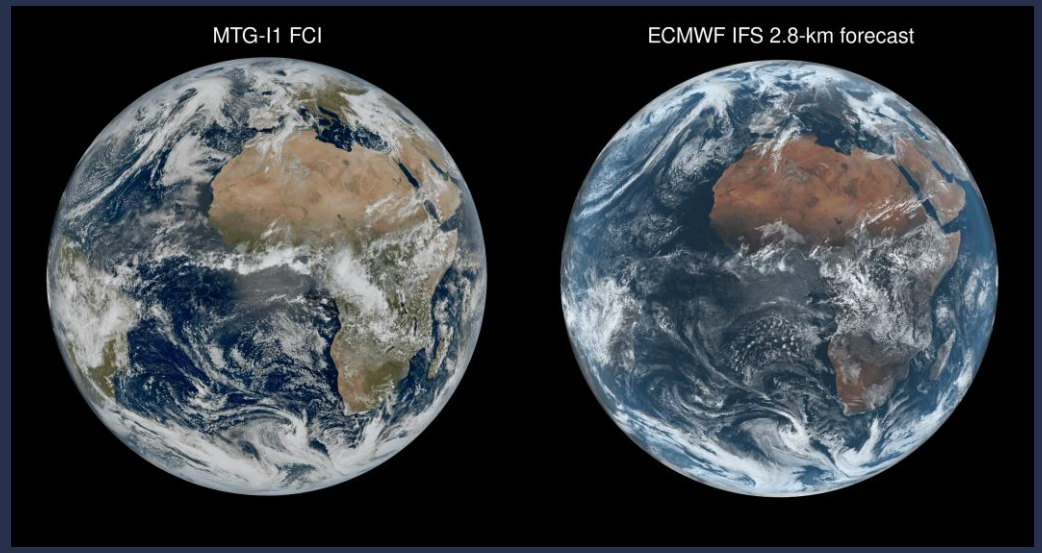
- Physics-based global NWP models have evolved to ever higher spatial resolution (km scale) and levels of complexity (i.e. full Earth system)

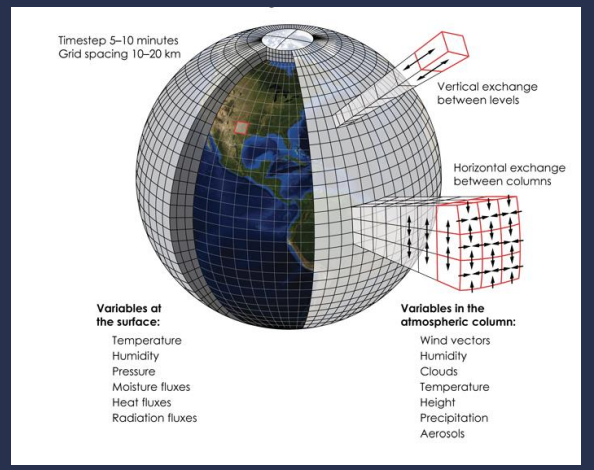
- Now Machine Learning is changing how NWP is done

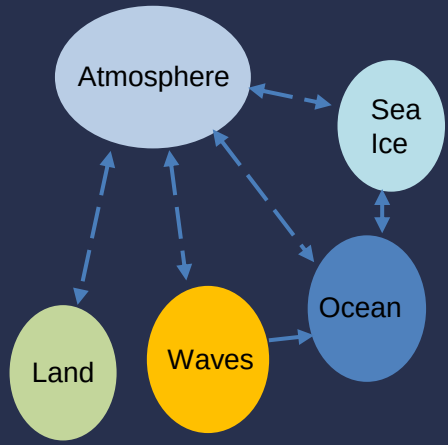
- The one constant in this fast changing world is the need for accurate and reliable observations

Real satellite observations

ECMWF 2.8km DestinE model

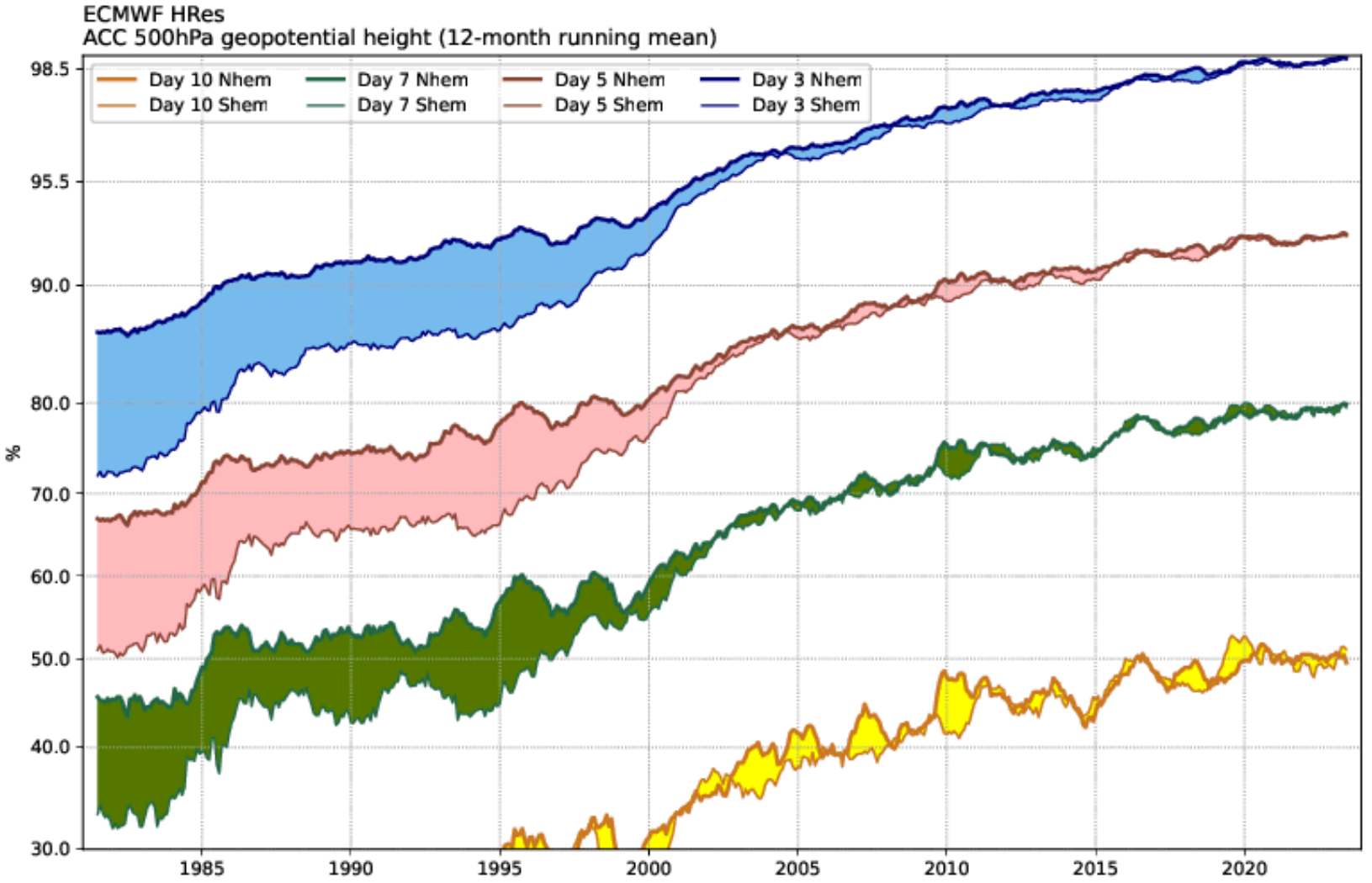






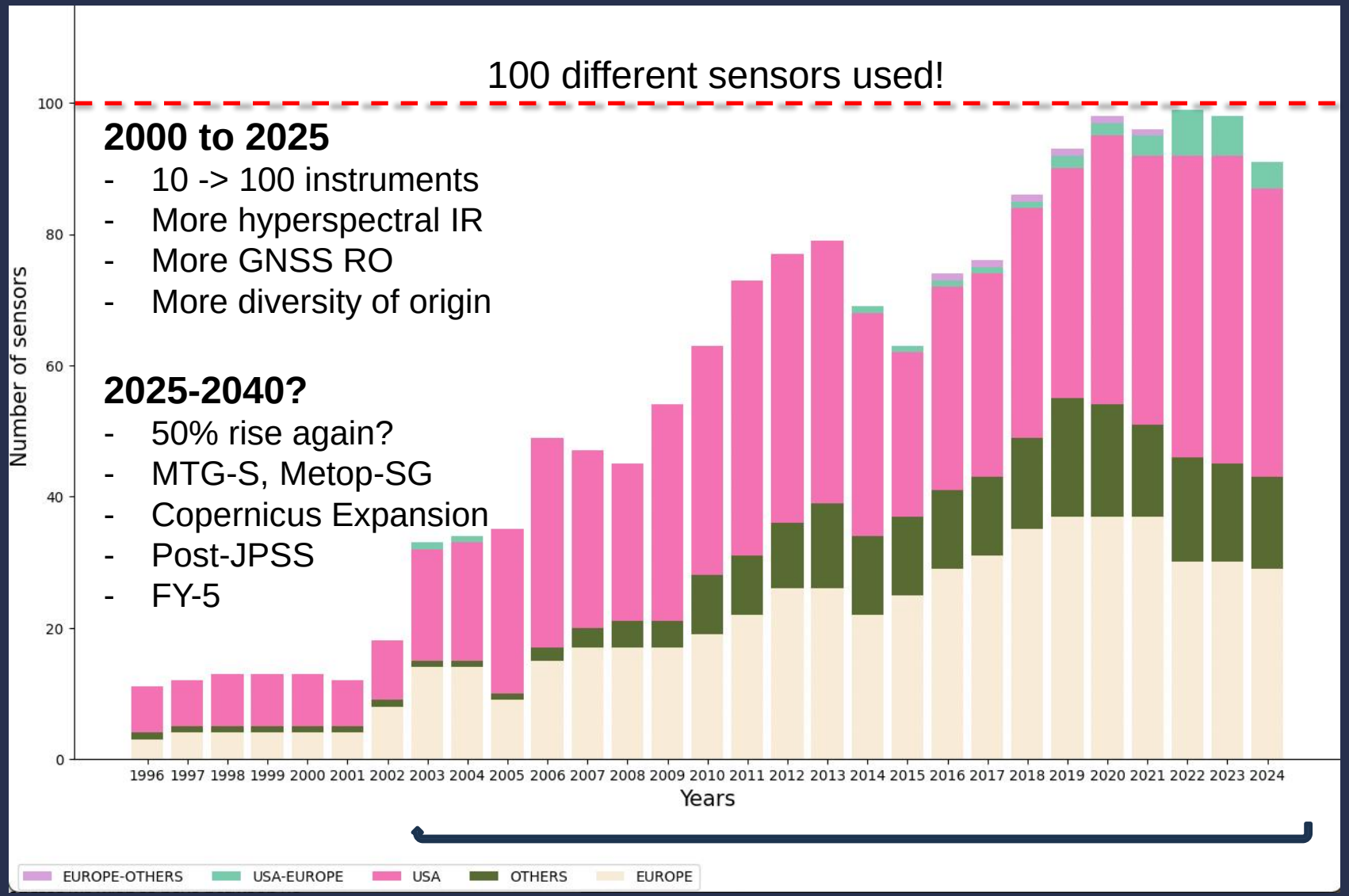
Thanks to Tony McNally and Patricia de Rosnay

WEATHER



Headline: 1 day per decade skill improvement

Origin of satellite used at ECMWF



USA
AQUA
AURA
C-NOFS
CORIOLIS
COSMIC2
COSMIC
DMSP
GOES
JPSS
PlanetIQ
POES
QuikSCAT
SAC-C
SMAP
TERRA

OTHERS
COMS-1
FY2
FY3
GCOM
GPM
HIMAWARI
HY2
INSAT-3D
KOMPSAT-5
MTSAT
OceanSat-2
SARAL
TRMM

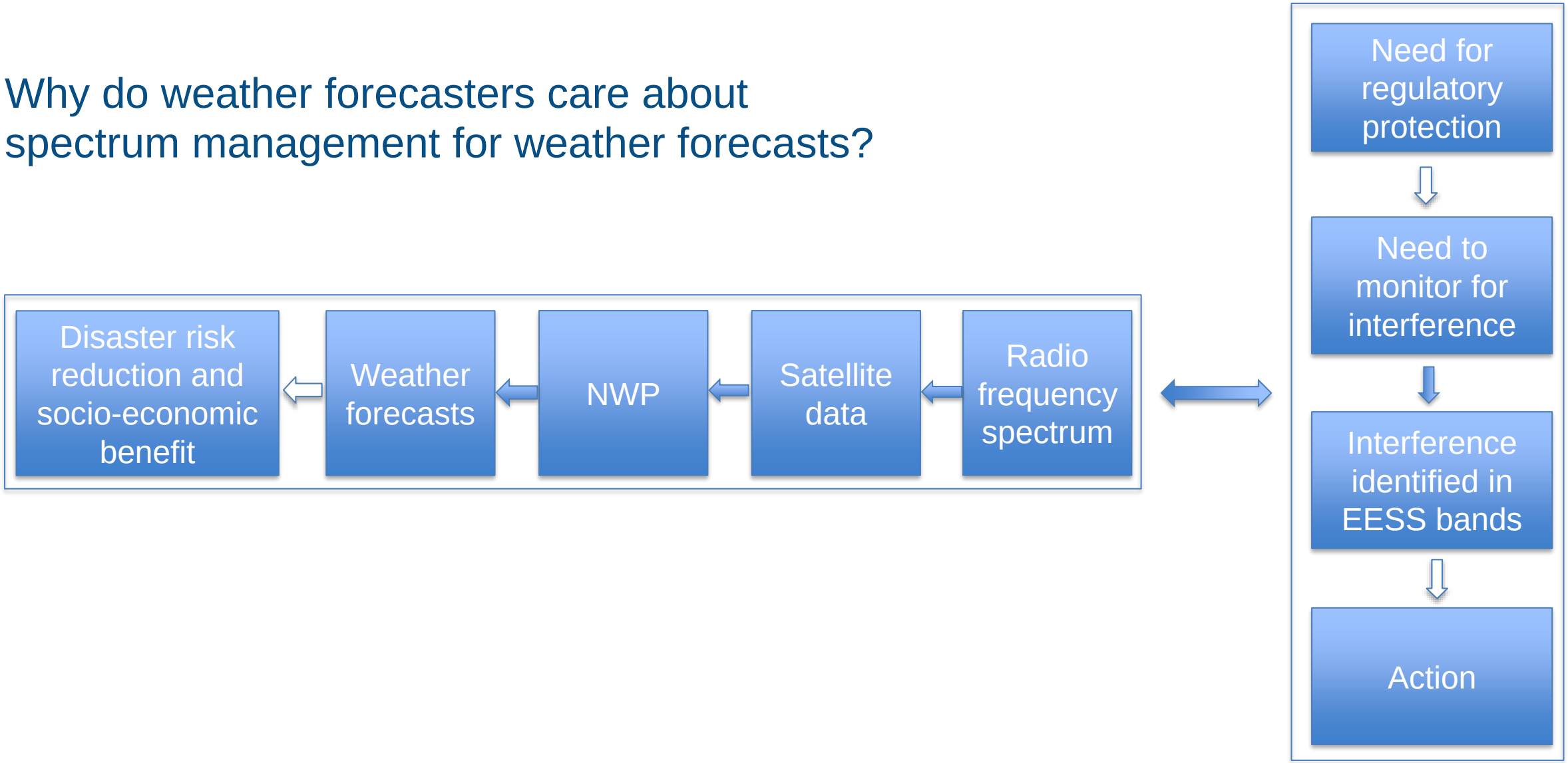
EUROPE
Aeolus
CHAMP
CRYOSAT
ENVISAT
ERS
JASON
METEOSAT
METOP
Sentinel
SMOS
TanDEM-X
TerraSAR-X

USA-EUROPE
GRACE
JASON
Sentinel-6A
SPIRE-Lemur-3U
SPIRE

EUROPE-OTHERS
MEGHA-TROPIQUES

Thanks to Tony McNally

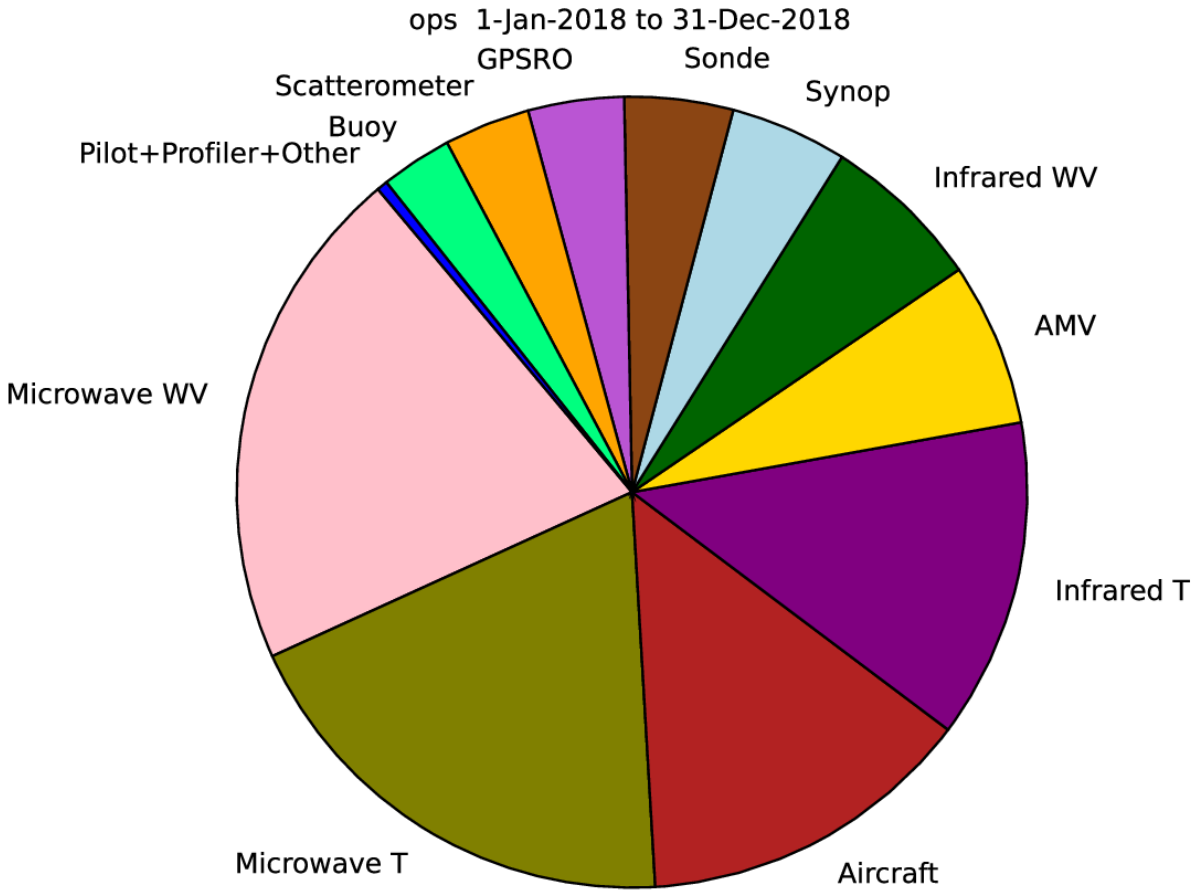
Why do weather forecasters care about spectrum management for weather forecasts?



Microwave (radio frequency spectrum) observations are critical to NWP

Passive microwave observations contribute around 40% of the overall improvement of short-range forecast skill, plus a further 10% from active microwave.

- 50-60 GHz and 176-190 GHz remain the two most critical spectral bands (176-190 much more than 10y ago).
- 18.7, 23.8, 31.4, 37, 89, 166 essential for direct measurements as well as indispensable in combination with the bands listed above (50-60 GHz and 176-190 GHz)
- 1.4, 6.8, 10.7, 209, 229 important for emerging applications

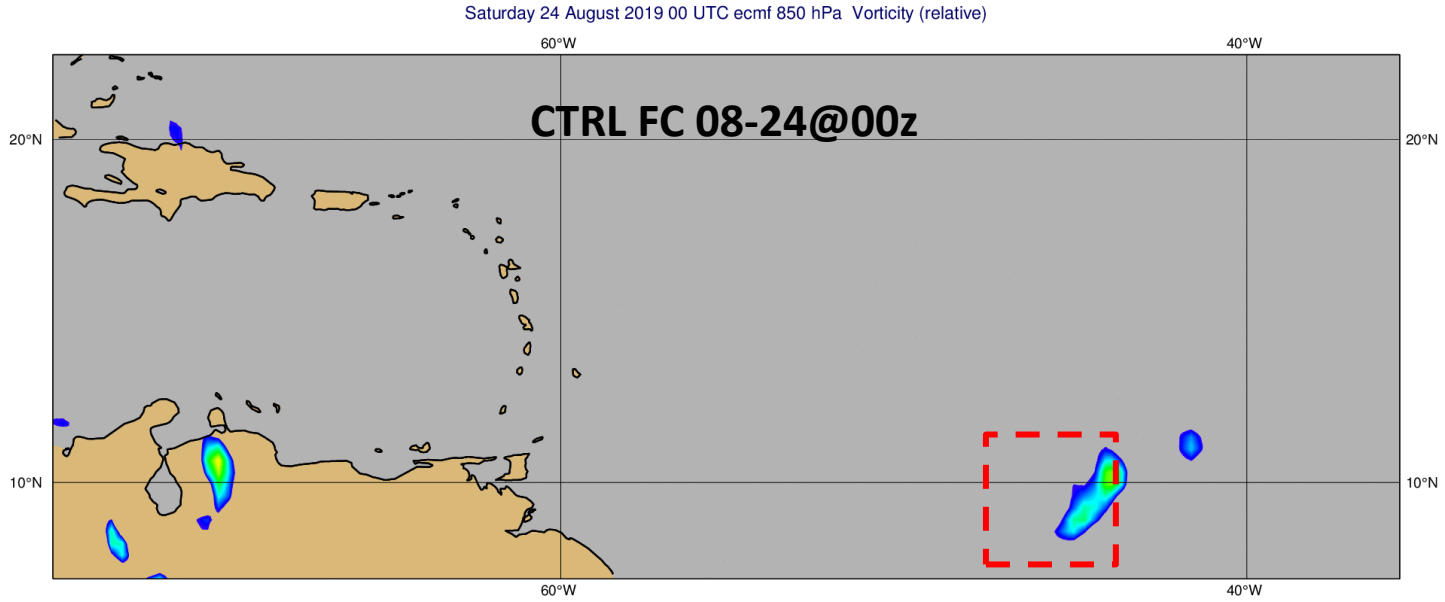


- Many countries have detailed financial assessments of the value of their weather and environment services
  - e.g. UK $2.0B per year, USA $11.4B per year, France $1.5-2.5B (see ECMWF RFI 2019 workshop report)

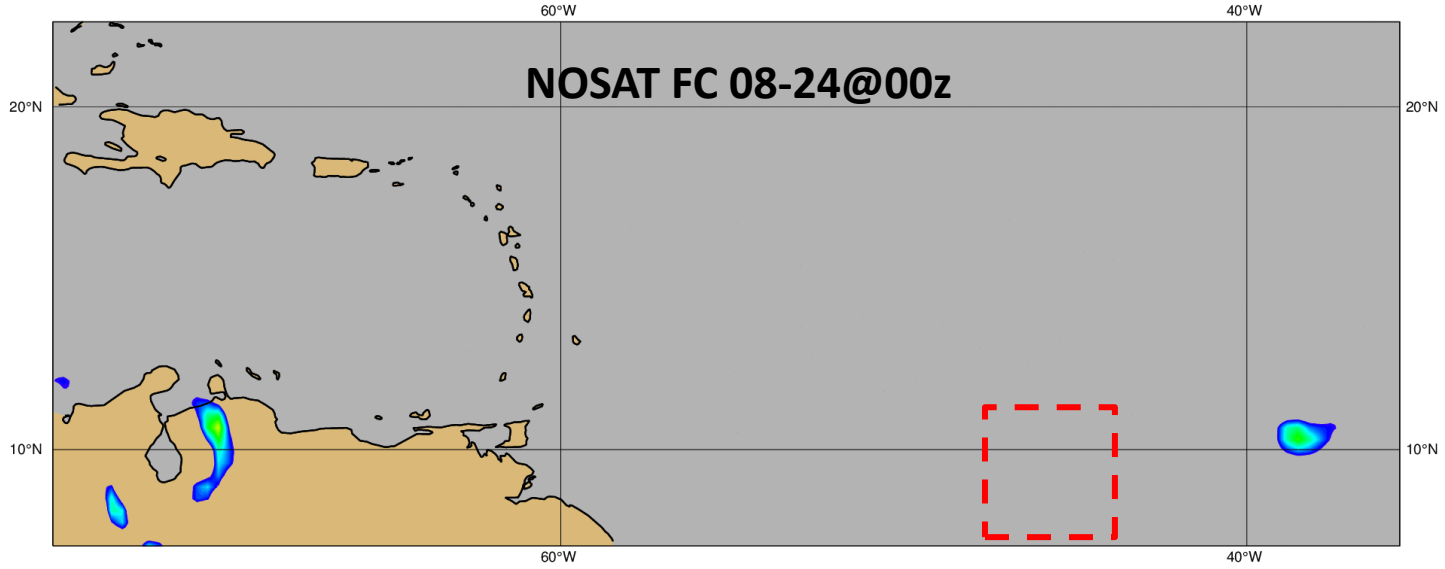
ECMWF

Figure from Alan Geer, ECMWF

Another way to think of satellite data impact…
Dorian genesis to landfall on Windward Islands



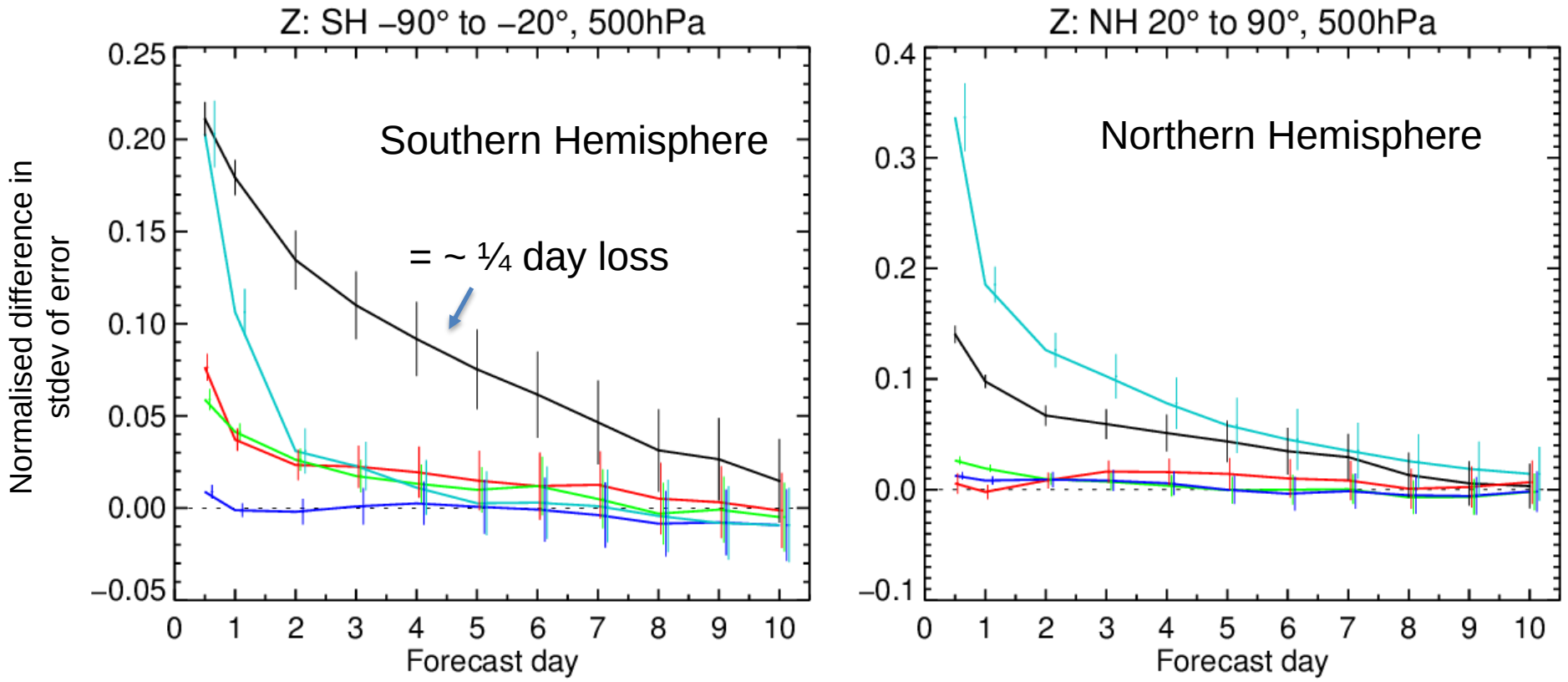
Control system with satellites identifies storm genesis on 24th August and provides 4 days warning of direct strike on Windward Islands



System with satellites denied (for 36hrs prior to forecast) misses the storm genesis and provides no warning of strike on Windward Islands

Figure from Tony McNally, ECMWF

Current impact of various observing systems: Z 500 hPa

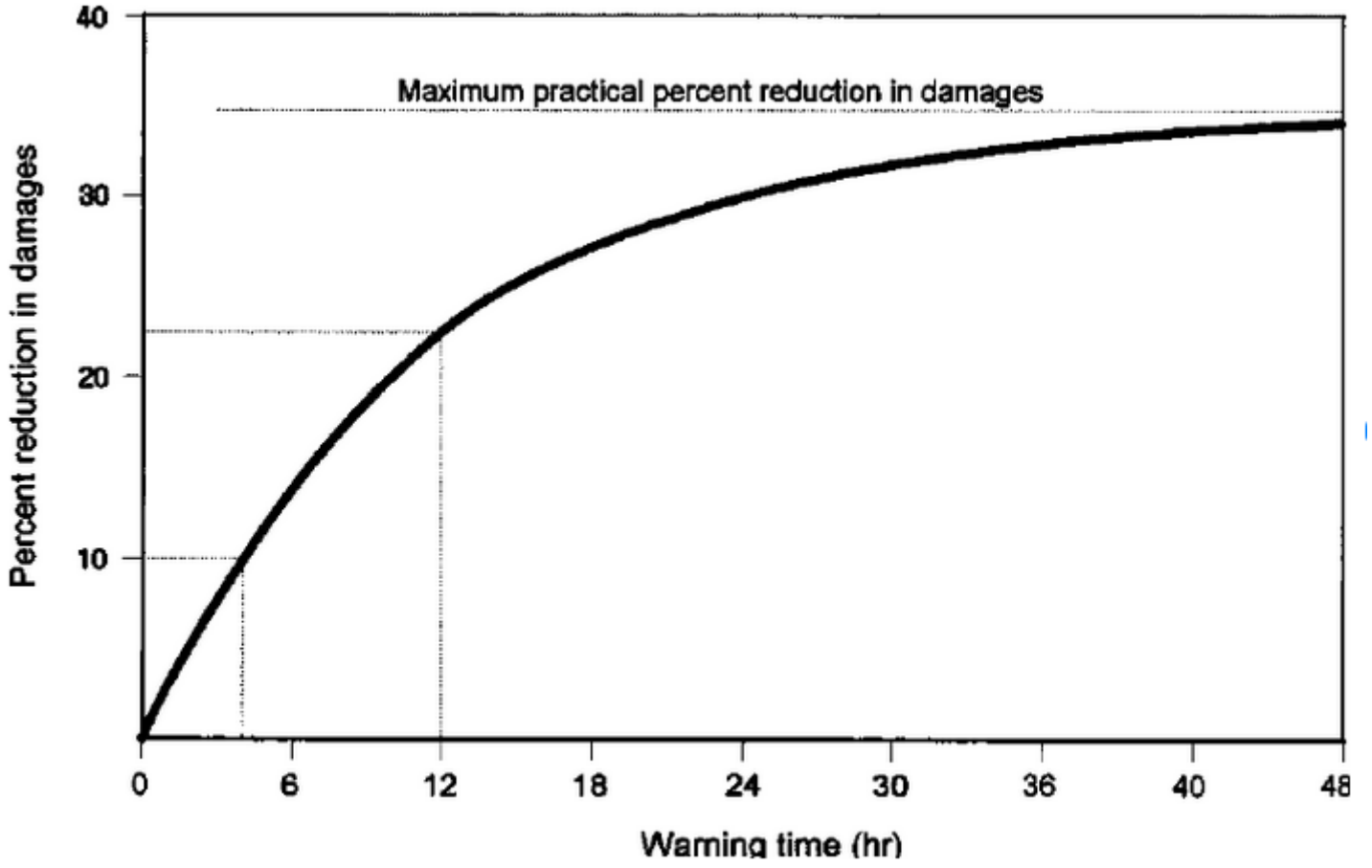


MW radiances are the leading satellite observing system.

(verified against operational analyses, both seasons combined)

Figure from Niels Bormann, ECMWF

Day's curve helps us understand impact of early warnings…..



Day's curve for damage mitigation as a function of the forecast lead times. Source: Day et al., 1970.

e.g. Day's curve: A 6-h warning time can reduce damage by 12% whereas a 12-h warning time can lead to a 24% reduction.

NWP centres regularly conduct socioeconomic benefit studies which demonstrate value of services e.g. ECMWF has recently conducted such surveys for NWP and also for the Copernicus Climate Change Service (C3S).

Weather summary

So weather forecasts **save lives, property and livelihoods.**

Weather forecasts **rely on NWP**, especially several days in advance.

NWP **relies on satellite data**, especially several days in advance.

The most critical satellite data for medium range weather forecast are microwave observations that **need 'clean" radio frequency spectrum**.

So meteorological spectrum allocation (EESS) saves lives, property and livelihoods.

CLIMATE

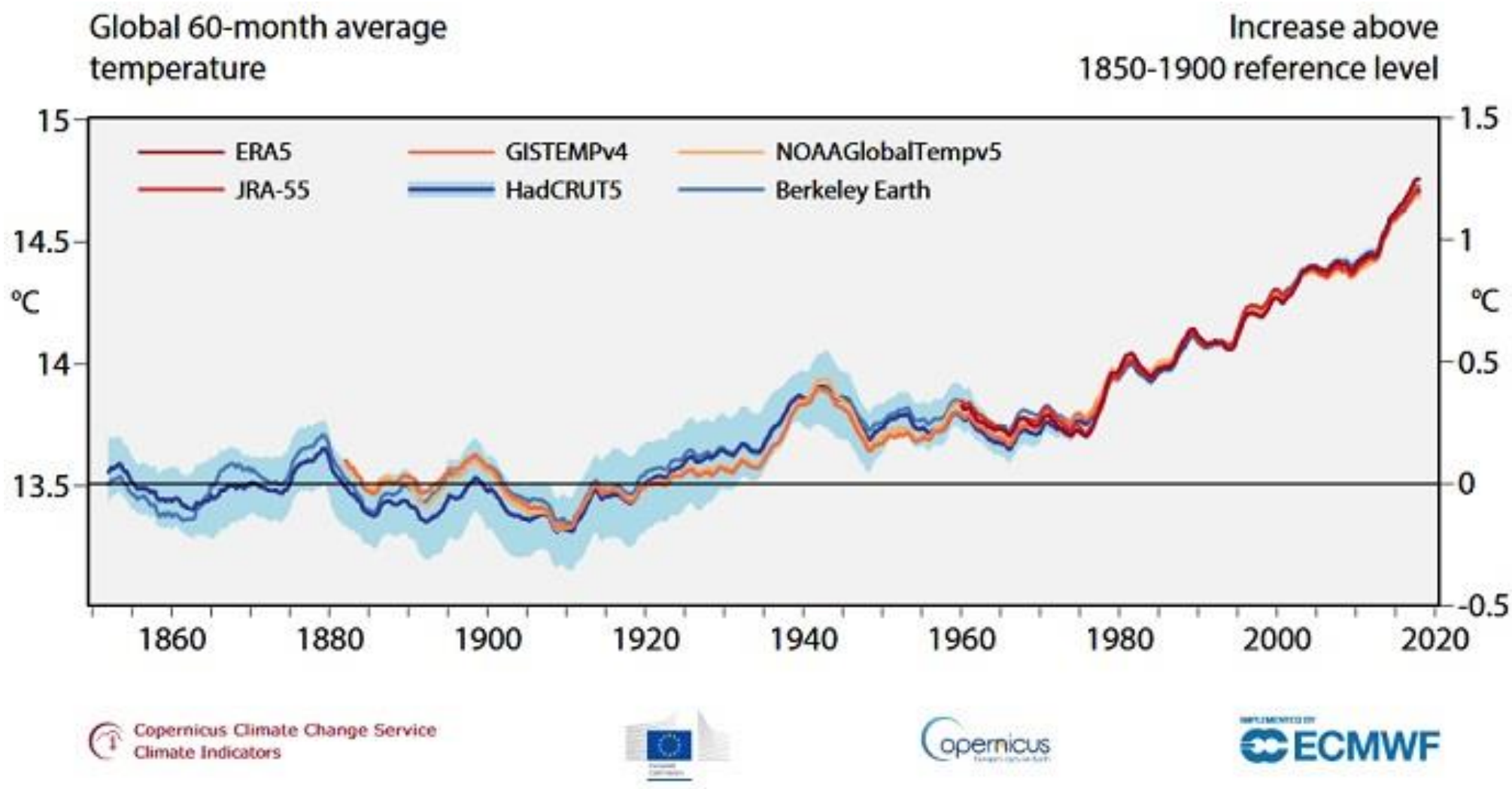
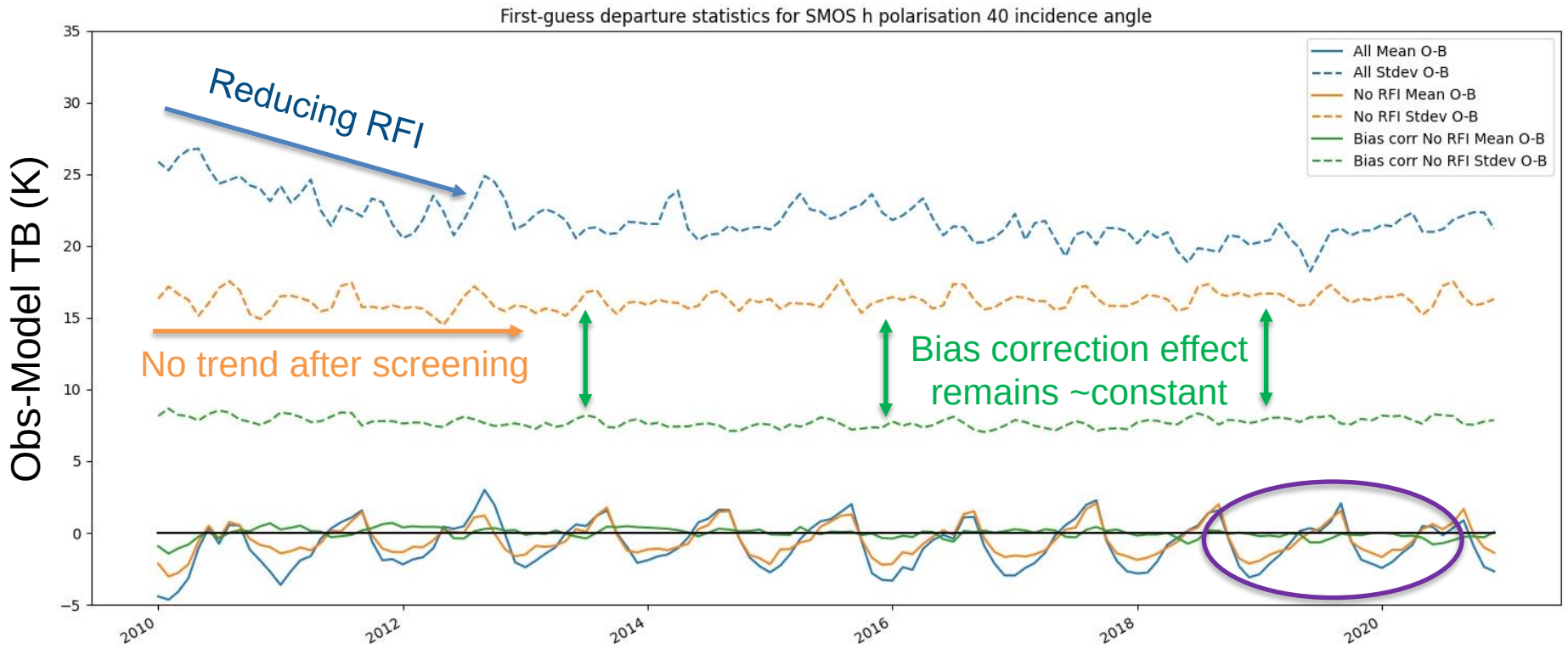


Figure from C3S European State of the Climate report 2020

SMOS multi-year monitoring

- Monitor latest re-processed v724 SMOS L1C Tbs against stable ERA5 reference from 2010 to 2021



Seasonal biases successfully removed

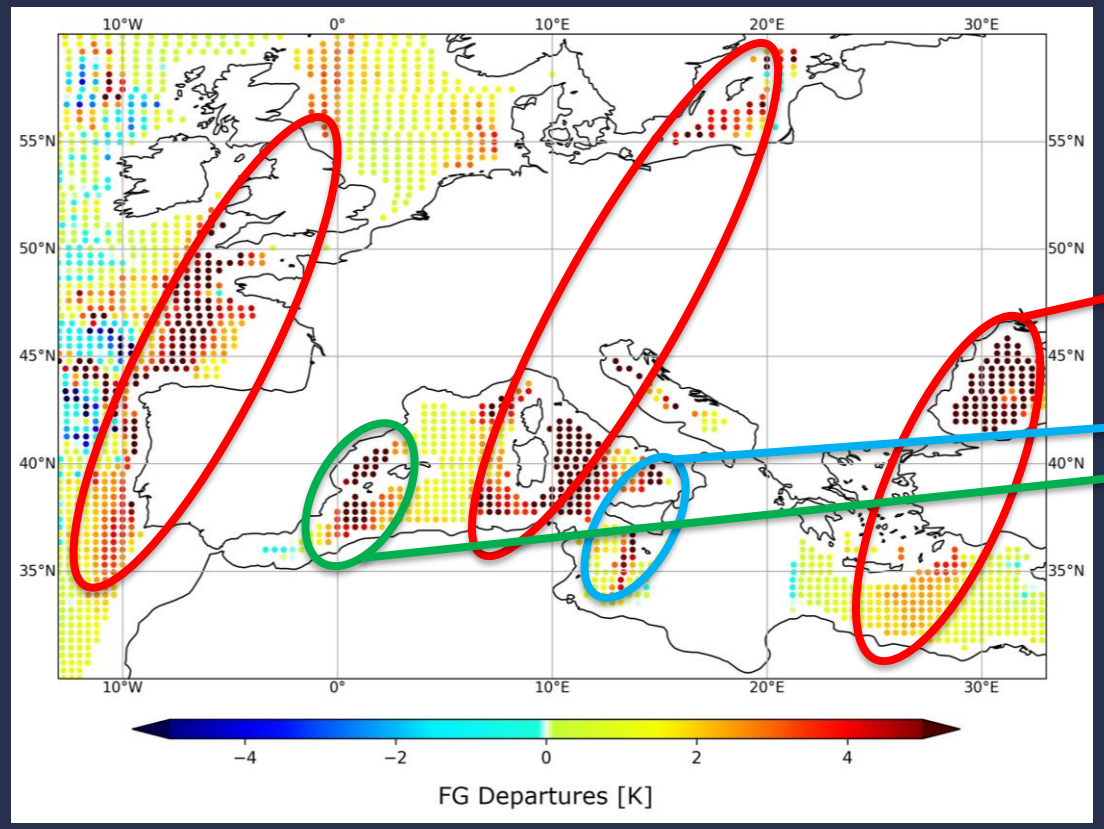
- Key take aways:
  - Improved RFI screening (orange v blue)
  - Newly developed bias correction performs consistently (green v orange)
  - Data quality is consistent over entire lifetime (after screening) – potential assimilation into future reanalyses

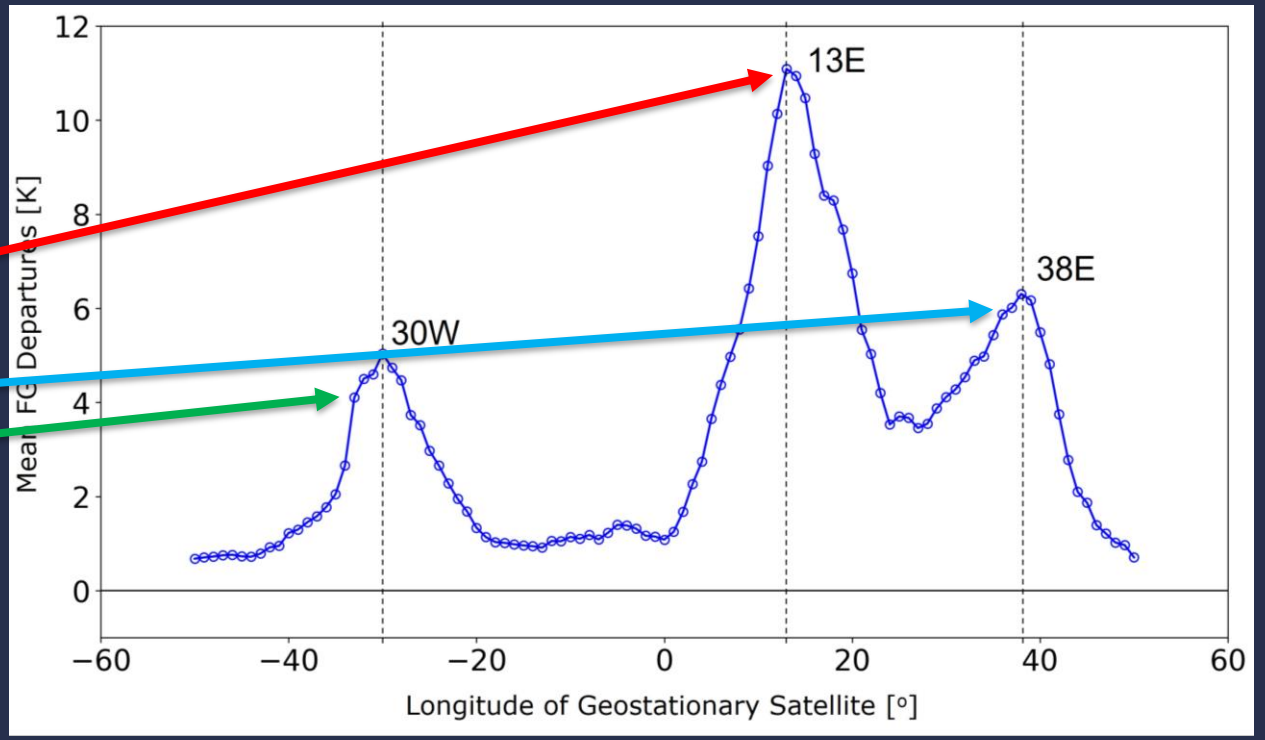
ECMWF

Slide courtesy of Patricia de Rosnay and Pete Weston, ECMWF

RFI detection and mitigation

- RFI caused by reflections of signals from direct broadcast satellites in geostationary orbit – clearly visible in background departures at 10 GHz.
- We can identify where the relevant satellites are by calculating the glint for a given satellite position and analysing the background departures.



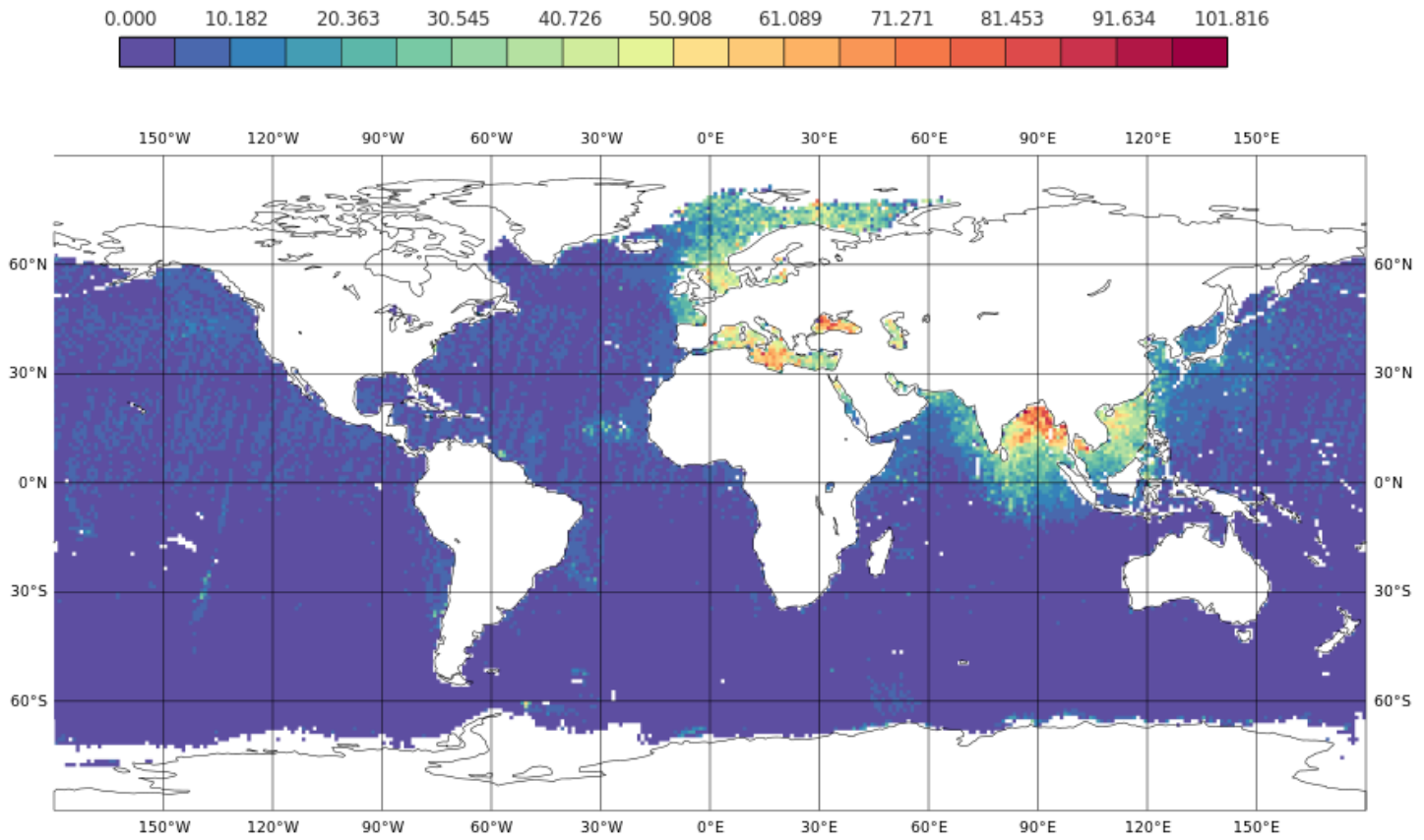


Thanks to Tracy Scanlon and Alan Geer

Recent issues

- 1.4 GHz
  - Protected band but severe interference found; some success in closing down sources: the process can work!
- 6.9 GHz
  - Significant RFI especially over land. No protection yet used since 1970s.
- 10 and 18 GHz
  - Reflected geostationary satellite emissions (See Tracy Scanlon talk).
- 24 GHz
  - Nothing yet. Around 2003-4 car collision avoidance radars. In 2019 5G – main rollout coming soon…..

L-band usually shown over land – where severe – here shown over ocean for a change!



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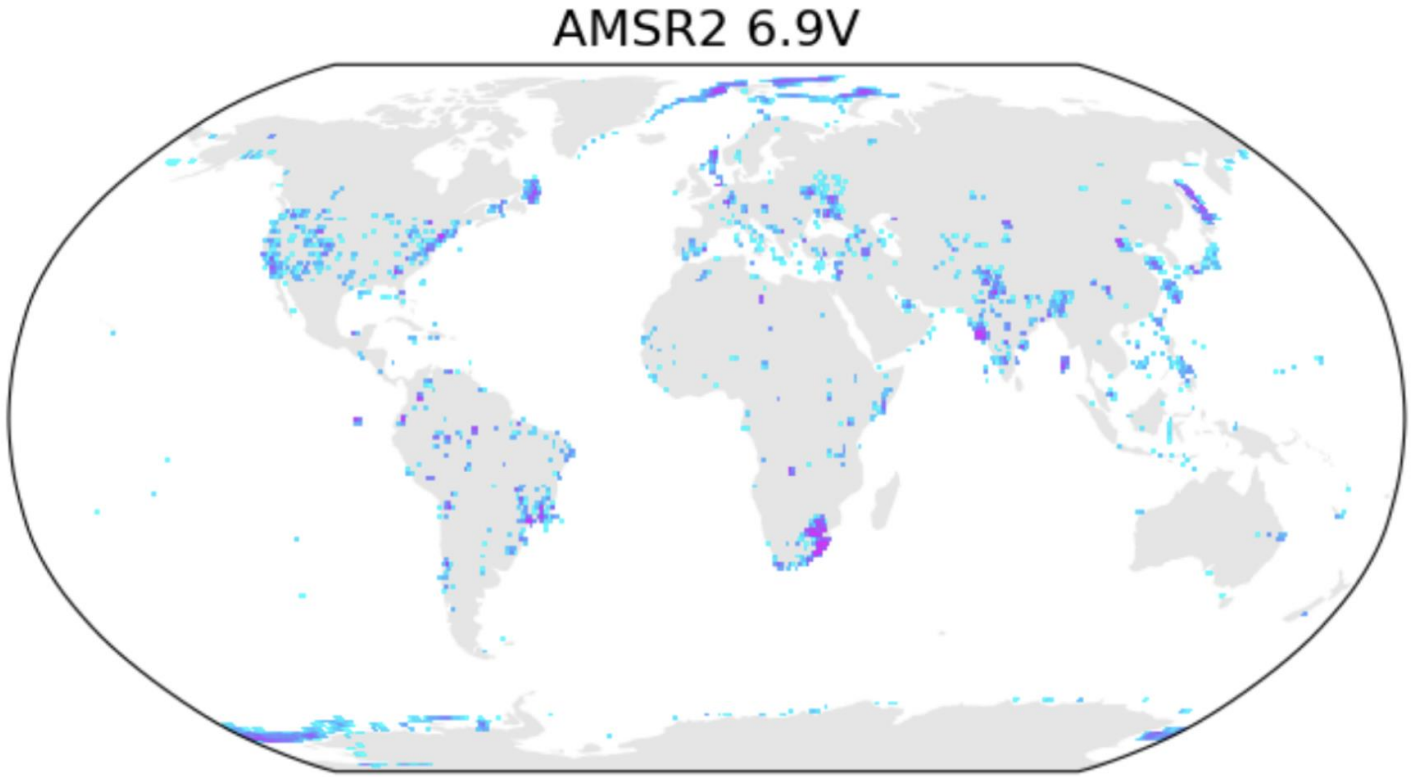

From Duncan, D. and N. Bormann "Assessing RFI flags at passive microwave bands with an NWP model", EORFIScan contract ESA AO/1-11605/22/NL/SD.

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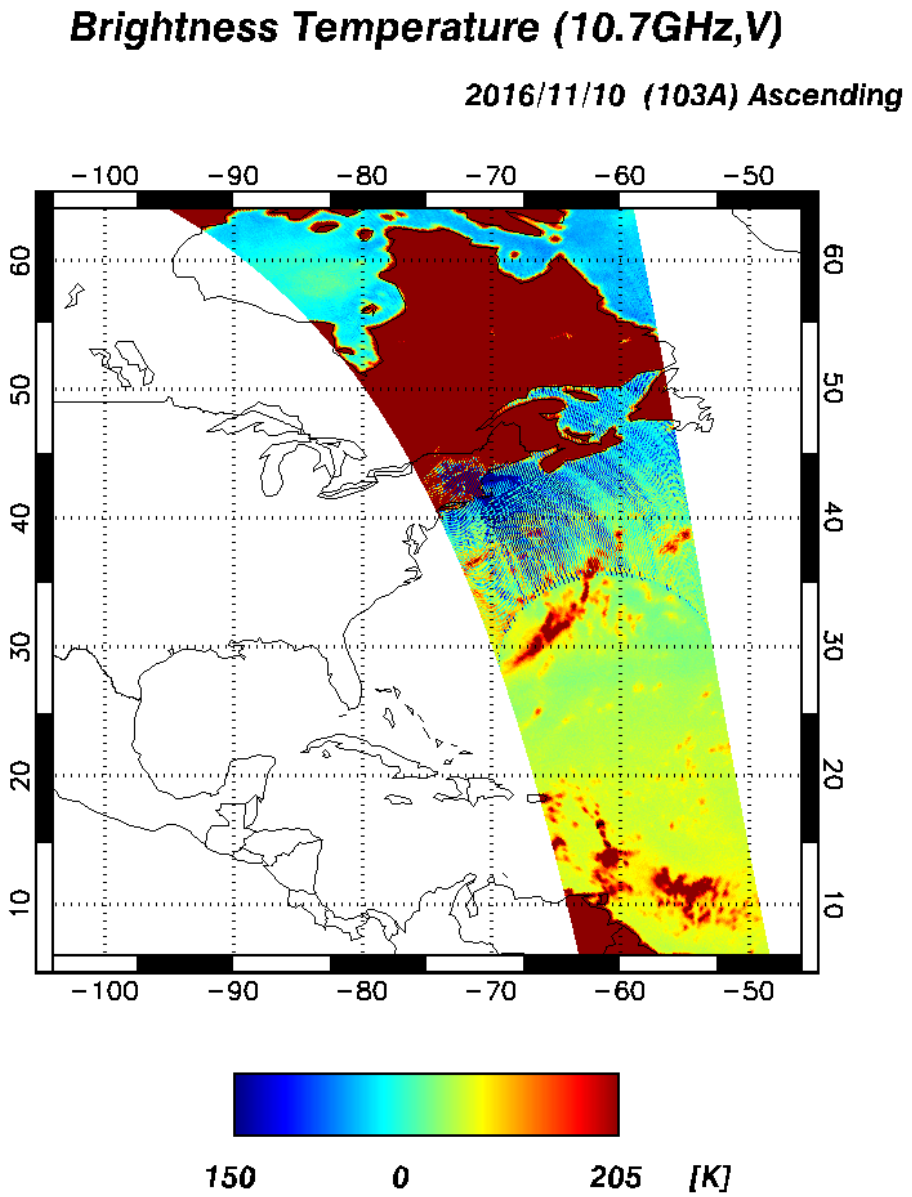

RFI in AMSR-2 data. From A. Shibata, JAXA.

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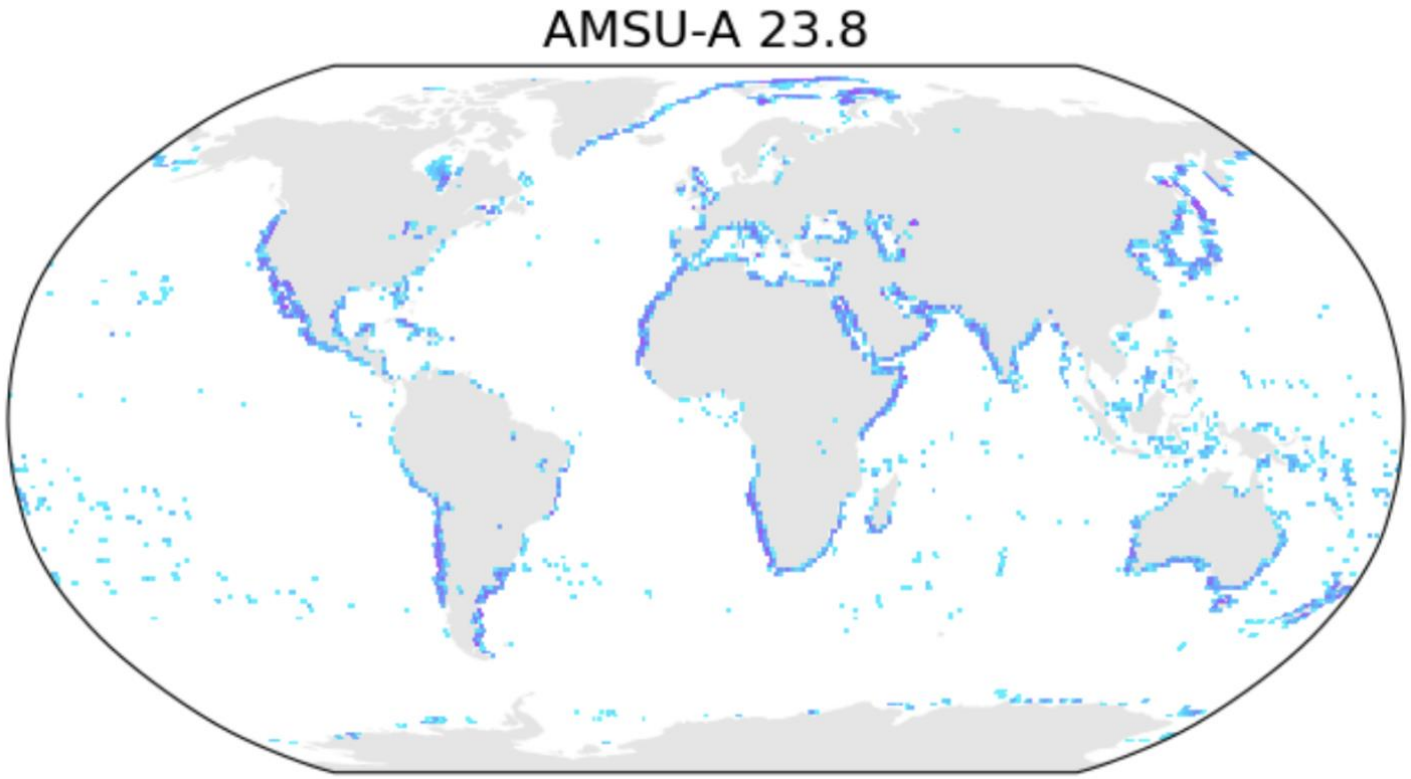

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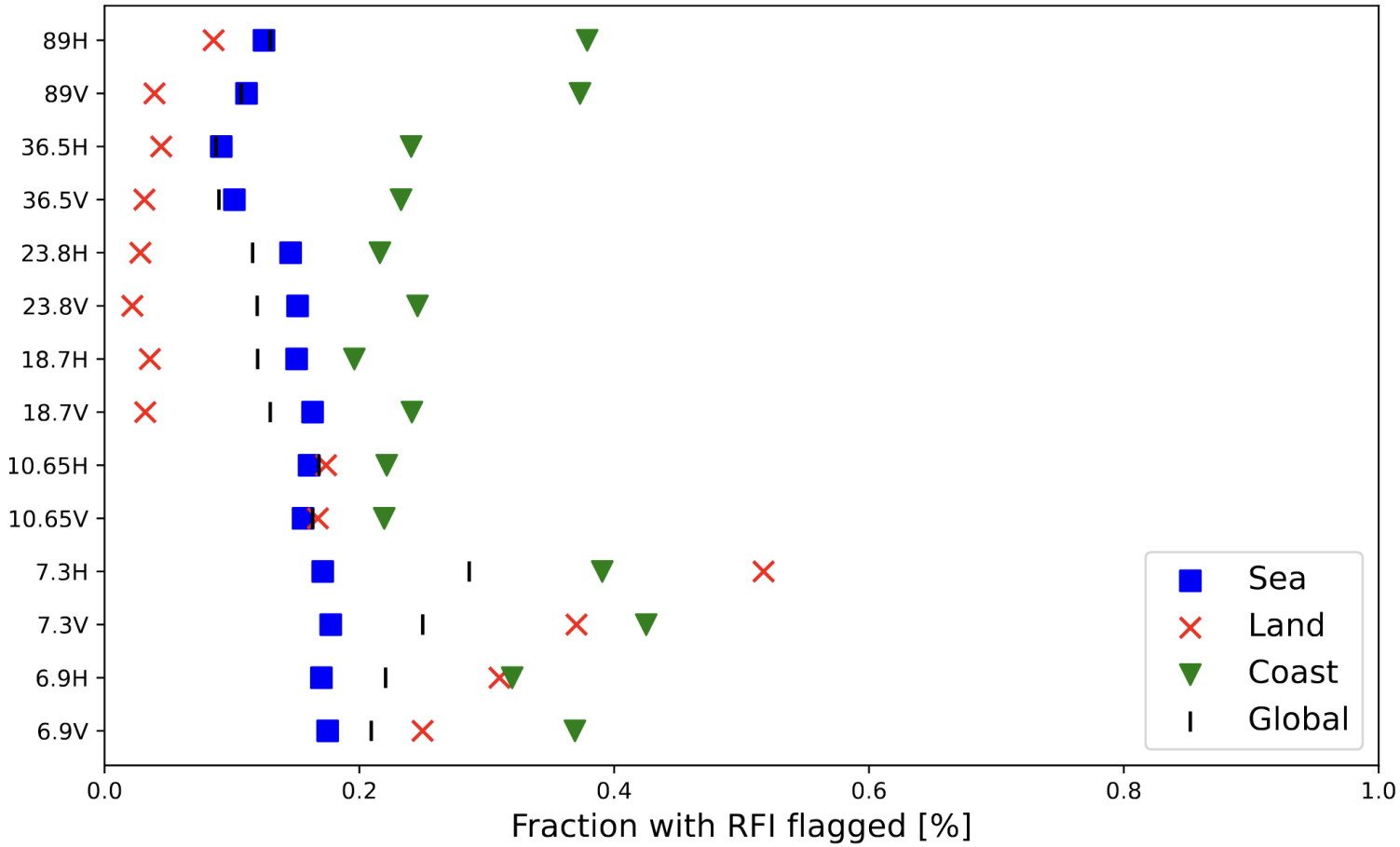
Summary of status

- 10 GHz and below correct rejections over land, false over sea?
- 18 GHz and above more false rejection over sea than land
- Be wary of overall statistics, points with mixed surfaces look similar to RFI



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SUMMARY

WEATHER

- Forecasts of high impact weather rely on numerical weather forecasts
- Numerical weather forecasts rely on observations
- The most impactful observations are radio spectrum (microwave) satellite observations
- Microwave satellite observations rely on spectrum bands where non-natural emissions are prohibited

CLIMATE

- The same radio spectrum observations are critical for monitoring our changing climate
- We rely on microwave spectrum for many Essential Climate Variables (ECVs): sea ice, snow, water vapour, cloud water and ice, precipitation, temperature, wind vectors, soil moisture
- Monitoring of trends is critical – RFI could introduce spurious trends
- SMOS has shown success in filtering our spurious trends – so it is not hopeless

IMPACT OF RFI

- Seen in all bands below 20 GHz
- Concern for critical 24, 31, 50-60 GHz, 89, 165, 175-191 GHz bands