Tropical observations in NWP: availability, impact and future evolution

John Eyre Met Office, UK

ECWMF Tropical Workshop, Nov 2016

Tropical observations in NWP: availability, impact and future evolution

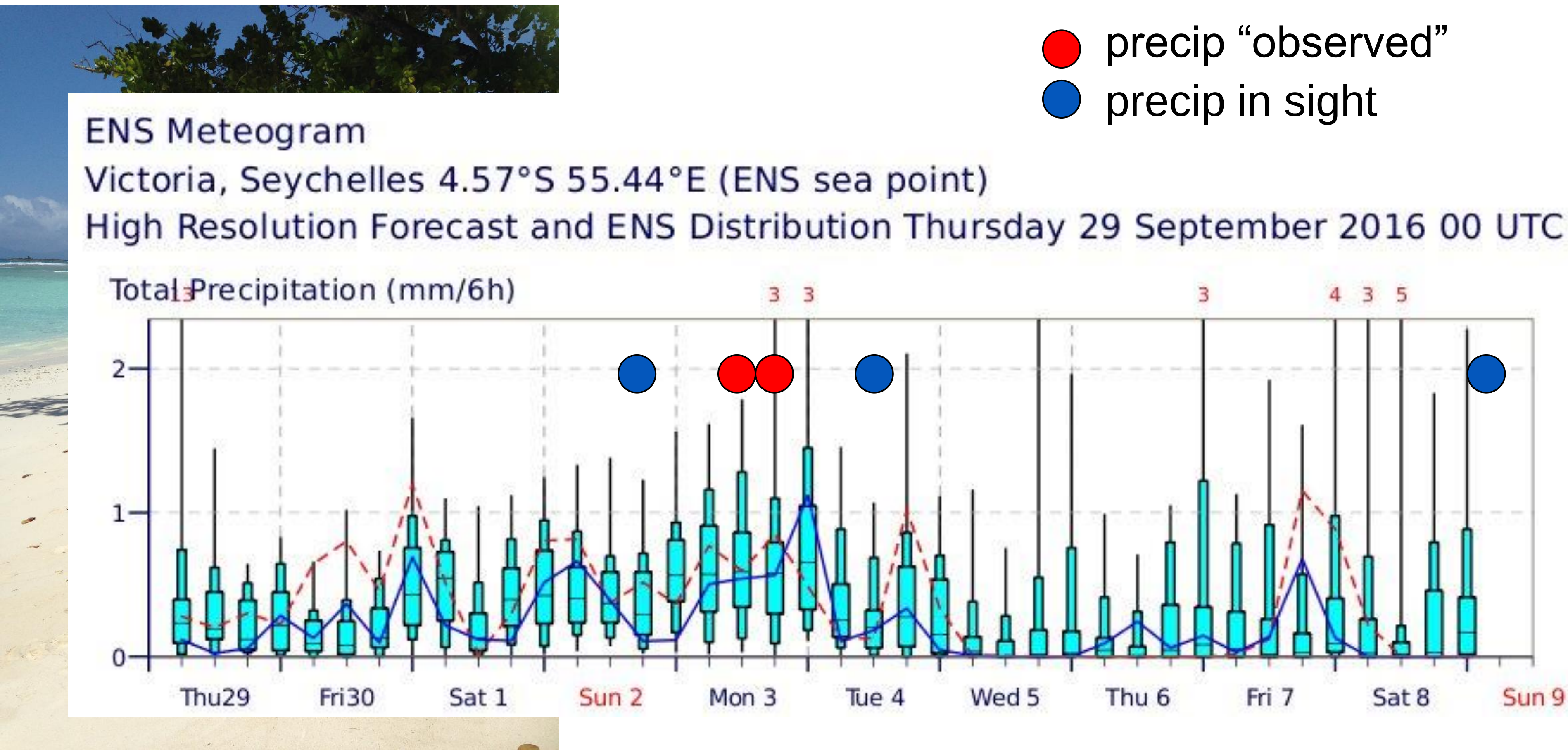
- Which observations are available?
- Which observations are most useful?
- How will the observing system evolve?

Acknowledgments

- Cristina Lupu
- Tony McNally
- Sean Healy
- James Cotton
- Mary Forsythe
- Bill Bell
- Indira Rani
- Amy Doherty
- Stuart Newman

VerFoRTIO

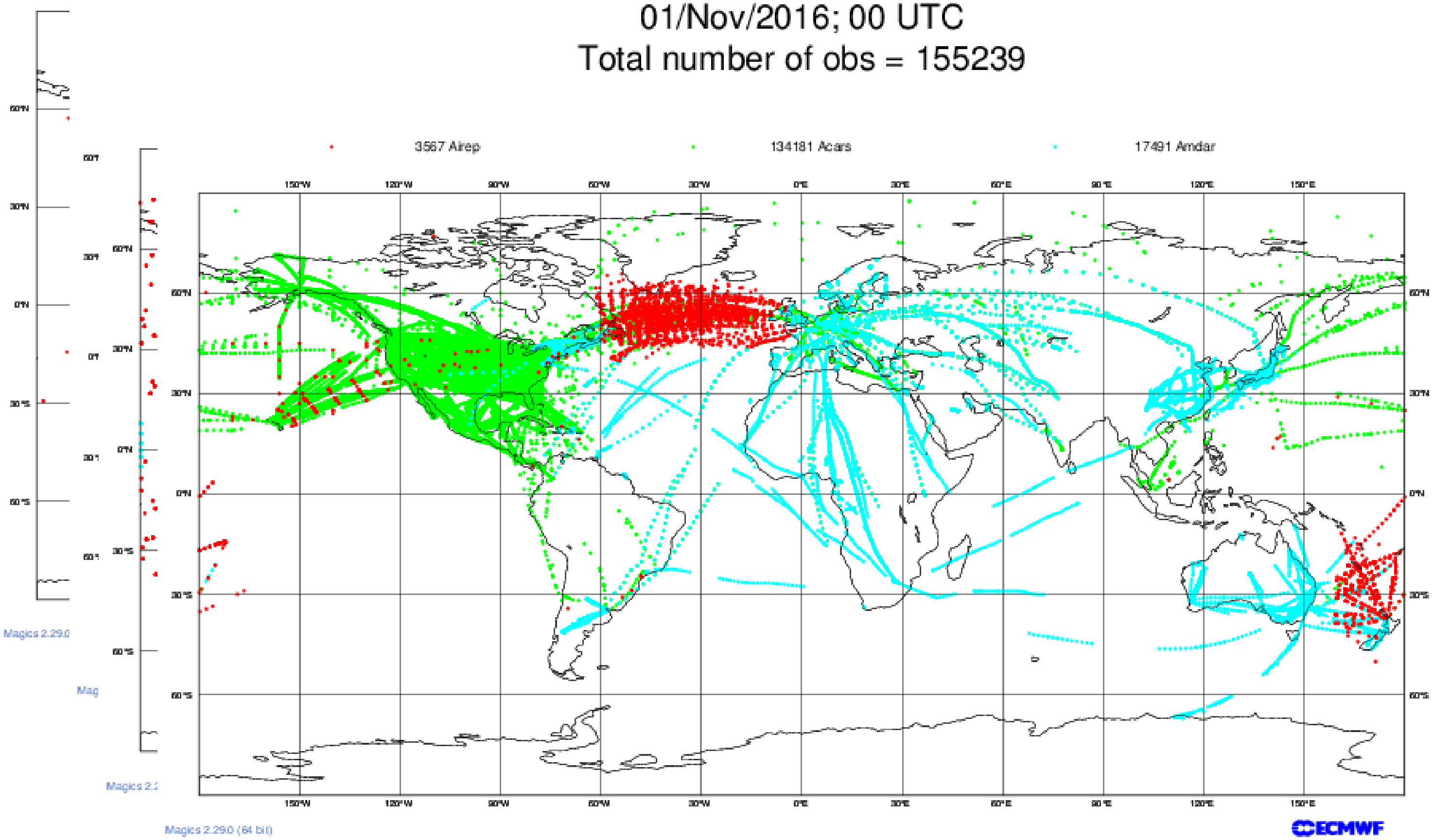
Verifying Forecasts of Rainfall in the Tropical Indian Ocean



Which observations are available?

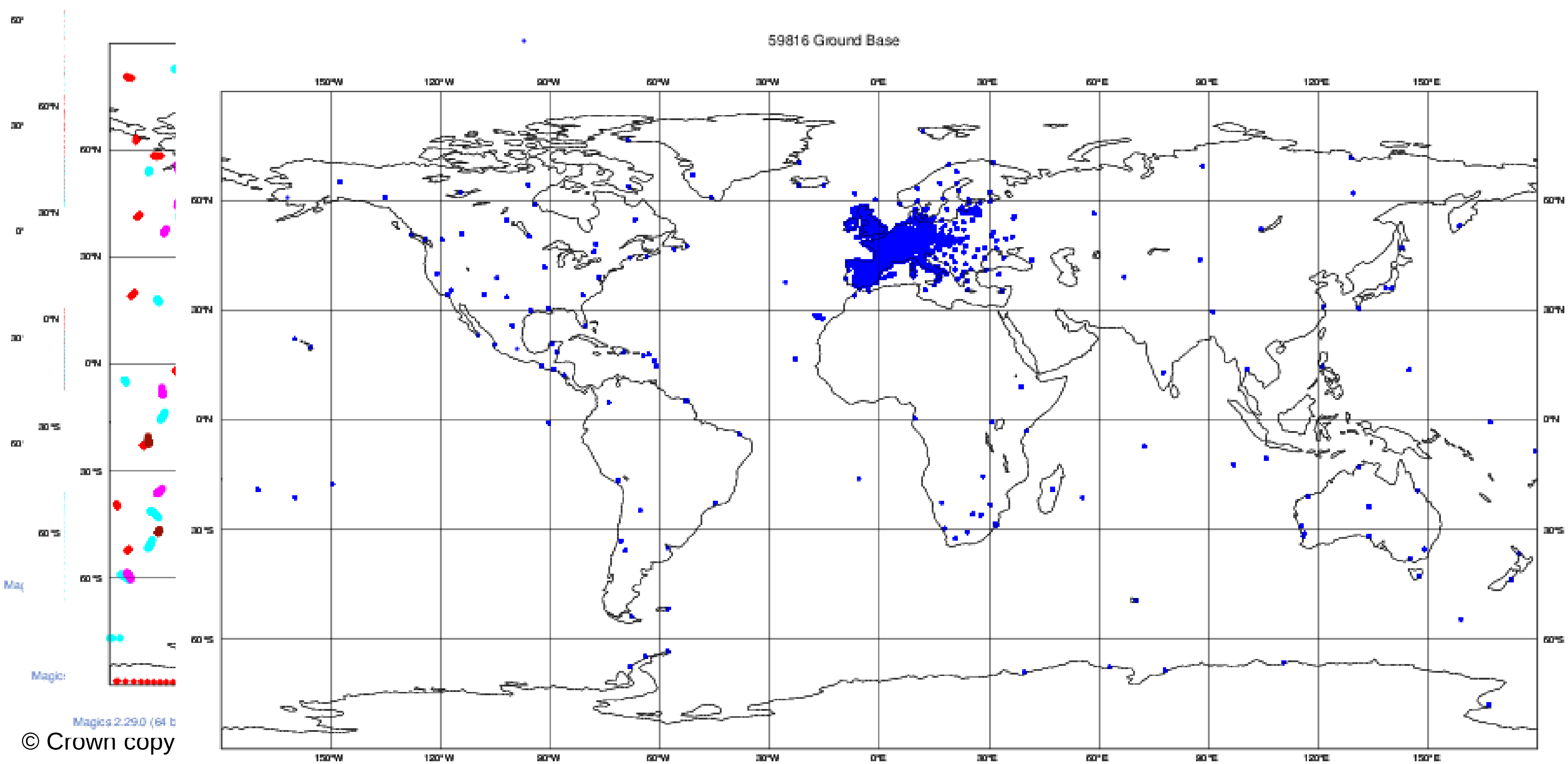
Observation coverage (1)

ECMWF Data Coverage (All obs DA) - Temp
ECMWF Data Coverage (All obs DA) - Pilot-Profiler
ECMWF Data Coverage (All obs DA) - Synop-Ship-Metar
ECMWF Data Coverage (All obs DA) - Buoy
ECMWF Data Coverage (All obs DA) - Aircraft
01/Nov/2016; 00 UTC
Total number of obs = 155239

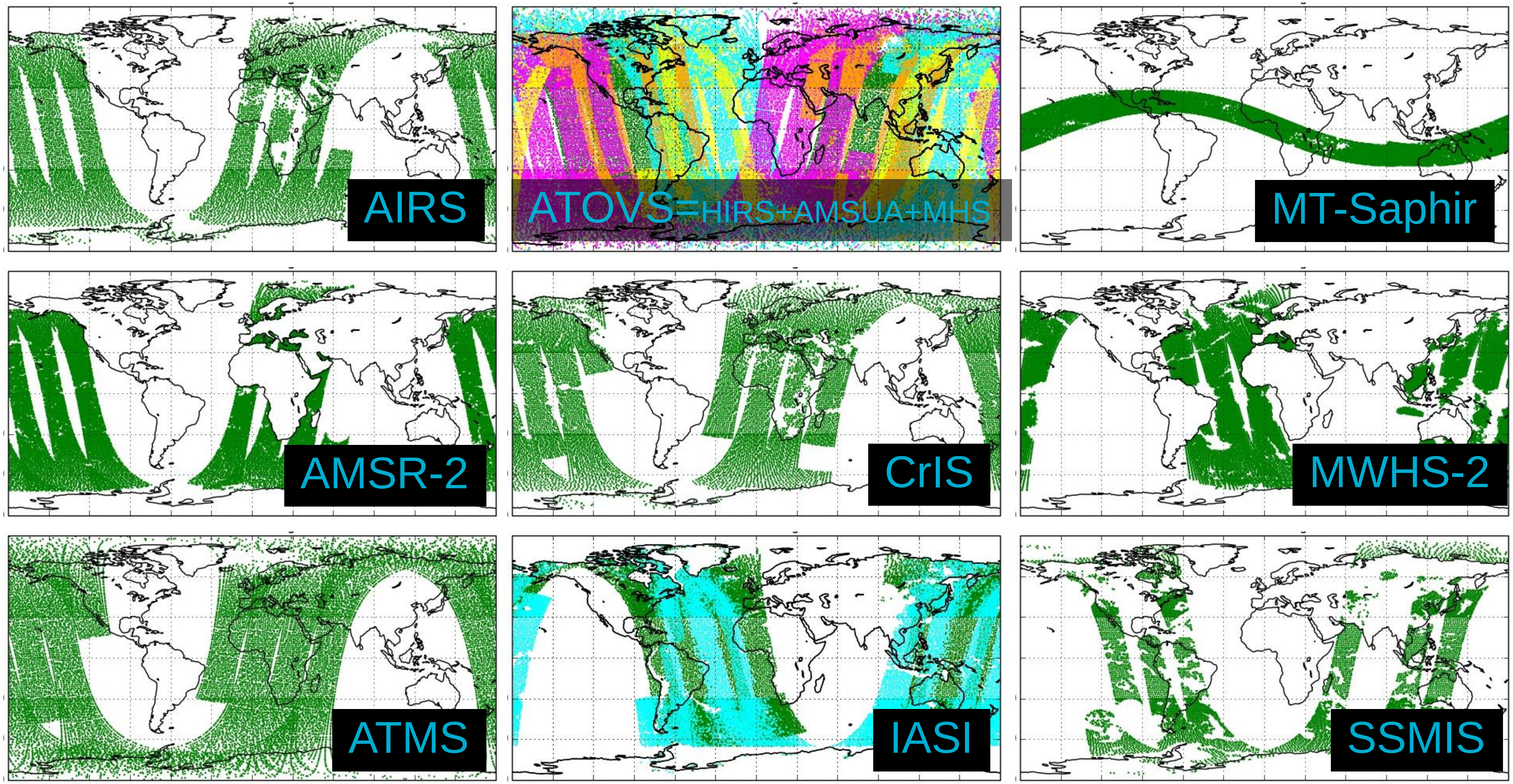


Observation coverage (2)

ECMWF Data Coverage (All obs DA) - AMV IR
ECMWF Data Coverage (All obs DA) - AMV POLAR IR
ECMWF Data Coverage (All obs DA) - SCAT
ECMWF Data Coverage (All obs DA) - GPSRO
ECMWF Data Coverage (All obs DA) - Ground Based GPS
01/Nov/2016; 00 UTC
Total number of obs = 59816



Radiance data coverage
Met Office global NWP system, Mar 2016



Satellite data used in Met Office NWP

May 2016

* G=global, UK=UK area

Observation type	Satellites	NWP models *
AMSU / ATMS / MHS radiances	3 NOAA + S-NPP + Metop-A+B	G, UK
HIRS clear radiances	Metop-A	G
IASI, CrIS and AIRS radiances	Metop-A+B + S-NPP + Aqua	G, UK
SSMIS radiances	1 DMSP (F-17)	G
AMSR-2 radiances	GCOM-W	G
MWHS-2 radiances	FY-3C	G
Saphir radiances	Megha-Tropiques	G
Geo imager clear IR radiances	MSG, MTSAT, GOES	G, UK
GPS RO bending angles	4 COSMIC, GRAS, TerraSAR-X	G
GPS ZTDs	~430 European + ~100 non-Europ.	G, UK

Satellite data used in Met Office NWP

May 2016

* G=global, UK=UK area

Observation type	Satellites	NWP models *
AMVs – geo	5 geo satellites	G, UK
AMVs – MODIS and AVHRR	Aqua, Terra, 3 NOAA, Metop-A+B	G
AMVs – GEO-LEO	Various	G
Scatt. sea-surface winds: ASCAT + RapidScat	Metop-A+B + ISS RapidScat	G, UK
MW imager sea-surface winds: Windsat	Coriolis	G
SEVIRI cloud height and amount	MSG	UK
SSTs: AVHRR, AATSR, AMSR-E…	3 NOAA, Metop-A+B, Aqua	G, UK
Soil moisture: ASCAT	Metop-B	G, UK
Sea ice: SSM/I, SSMIS	DMSP	G
Snow cover	various	G

Which observations are most useful?

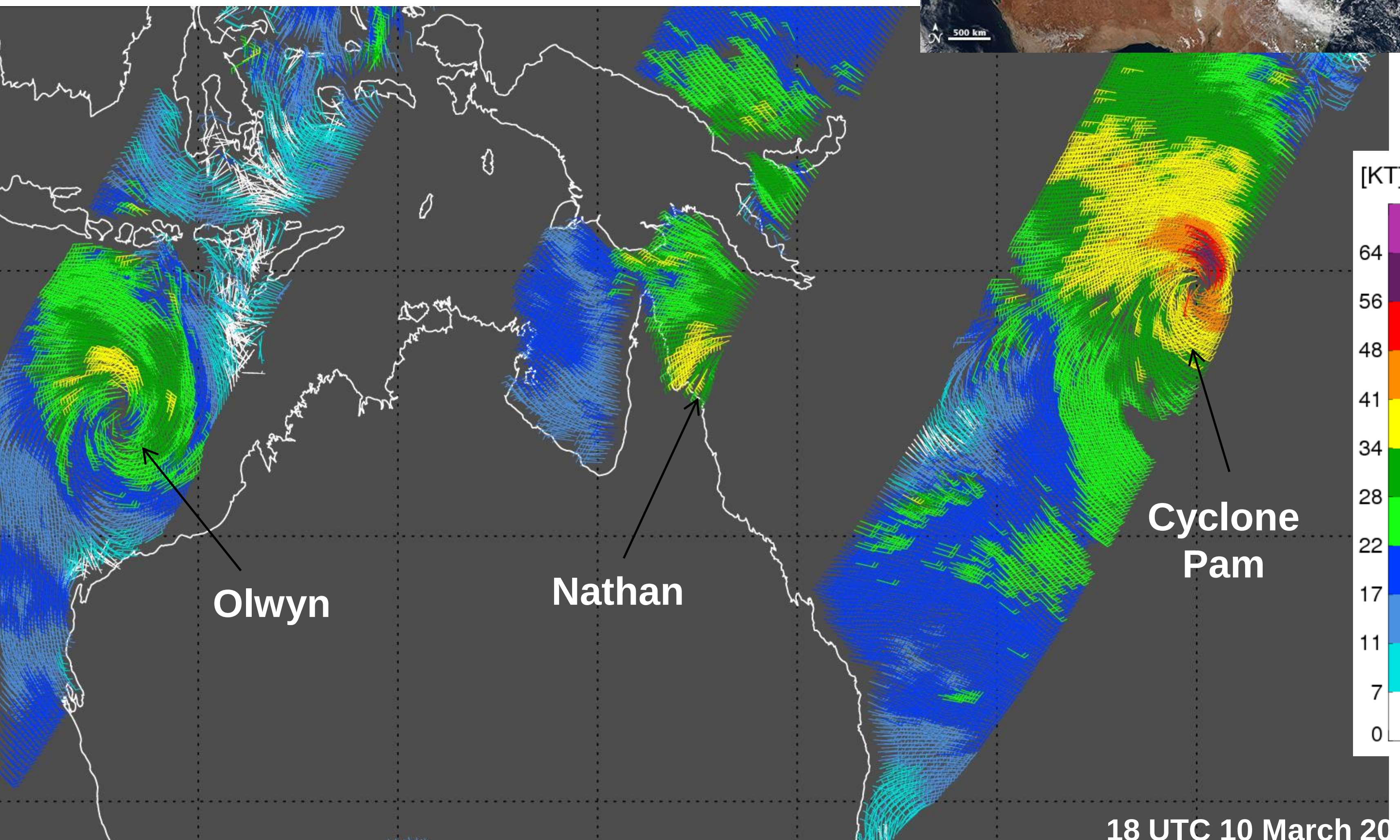
Impact of recently available satellite data

- ISS-RapidScat (James Cotton)
- AMSR-2/SAPHIR (Bill Bell, Indira Rani, Amy Doherty, Stuart Newman)

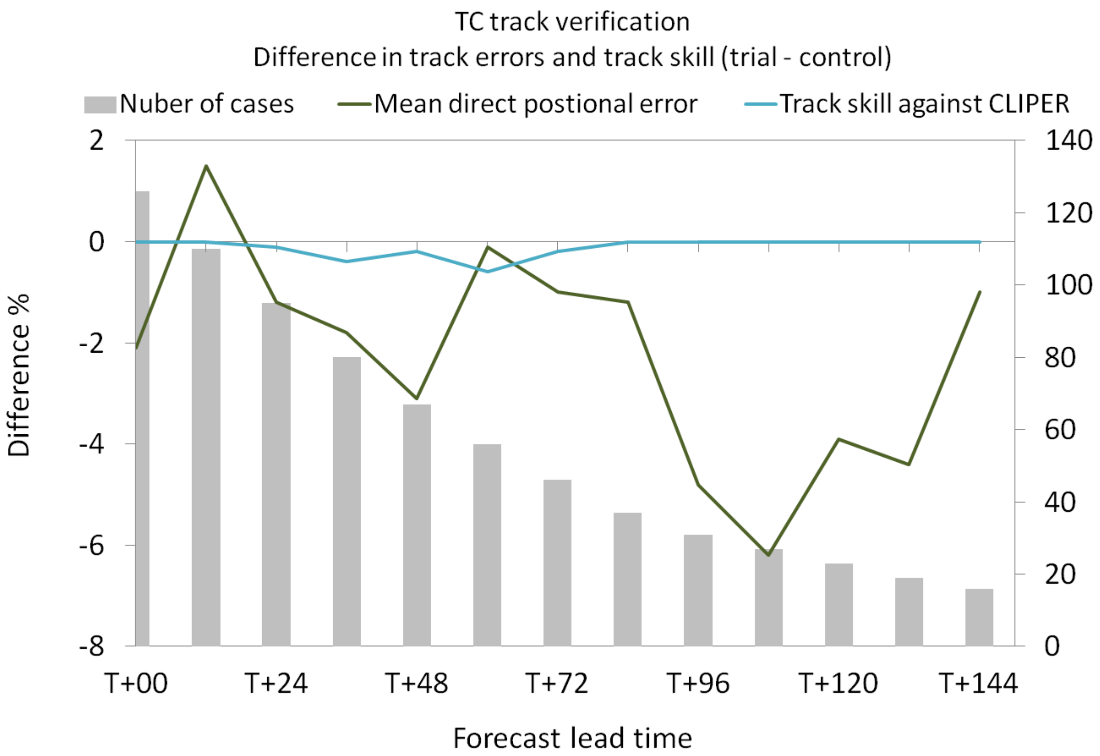
ISS-RapidScat

Met Office

Assimilated in Met Office operations from Sept 2015



RapidScat impact on TC track forecasts



Track errors reduced

RapidScat impact on tropical cyclone positional errors

- Analysis errors 2.1% lower over 126 analyses ✔
- Forecast errors 1.5% lower over 607 forecasts ✔
- Forecast skill neutral

Assimilation of imager data (AMSR-2 and SSMIS) and SAPHIR

Background fits to observations (O-B) used as key diagnostic of performance

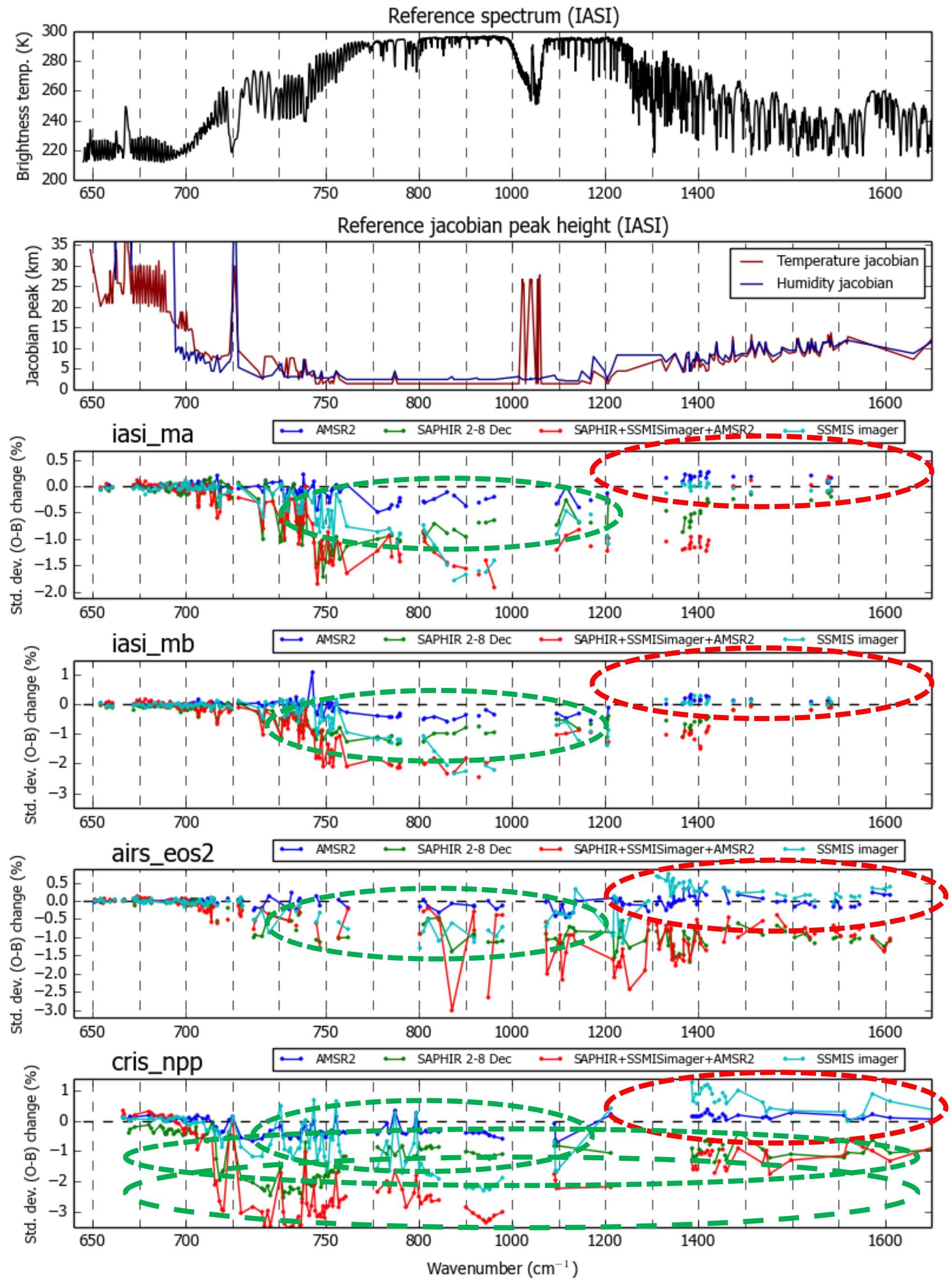
Imagers - in isolation - show:

- improved background fit to low level moisture, BUT...

- degraded fits to upper level moisture

SAPHIR - in isolation - shows:
- improvements to both lower and upper level humidity

SAPHIR + imagers show:
- enhanced improvements for lower and upper level humidity

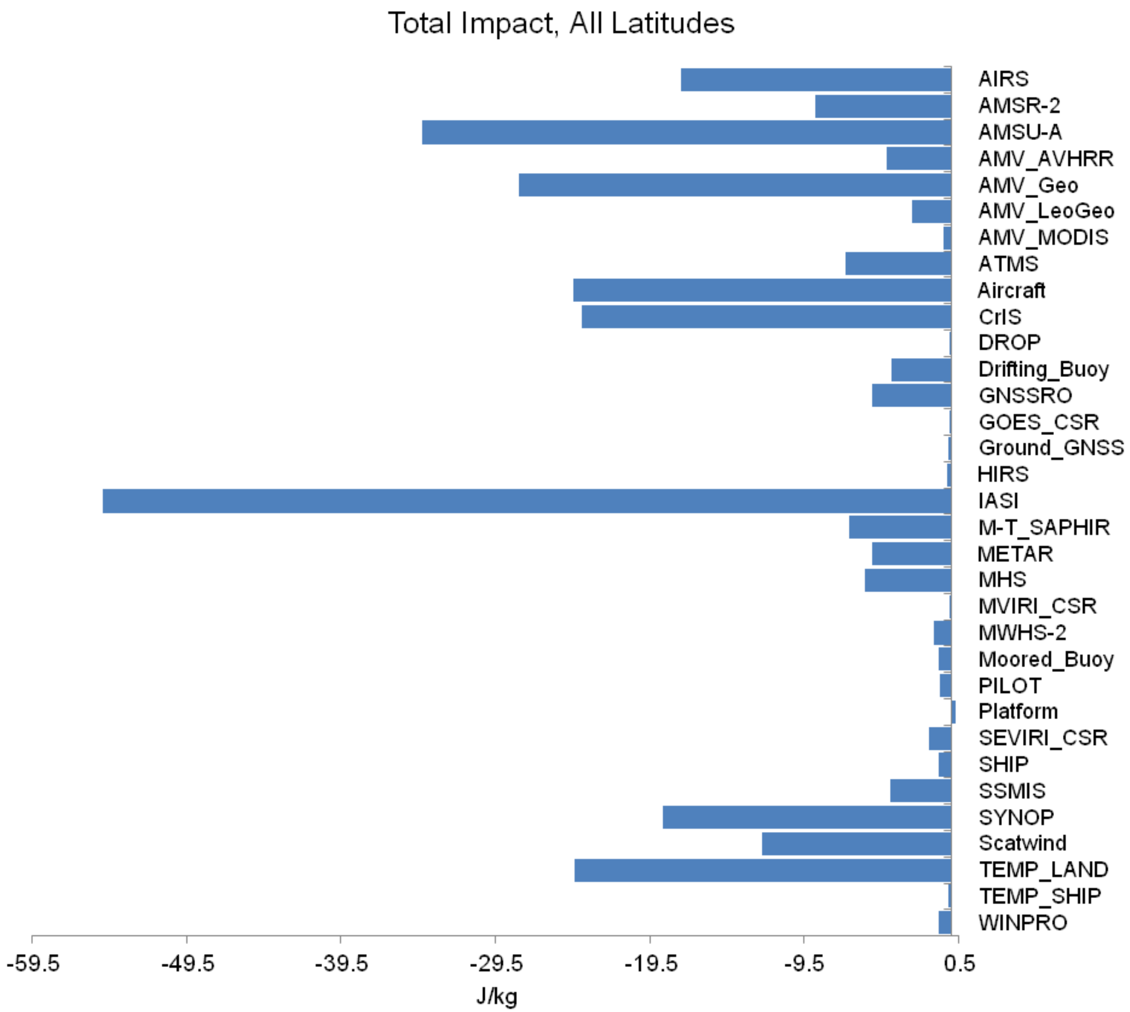


Forecast Sensitive to Observations Impact (FSOI)

Met Office
James Cotton

August 2016

Forecast Sensitivity to Observations Impact (FSOI)

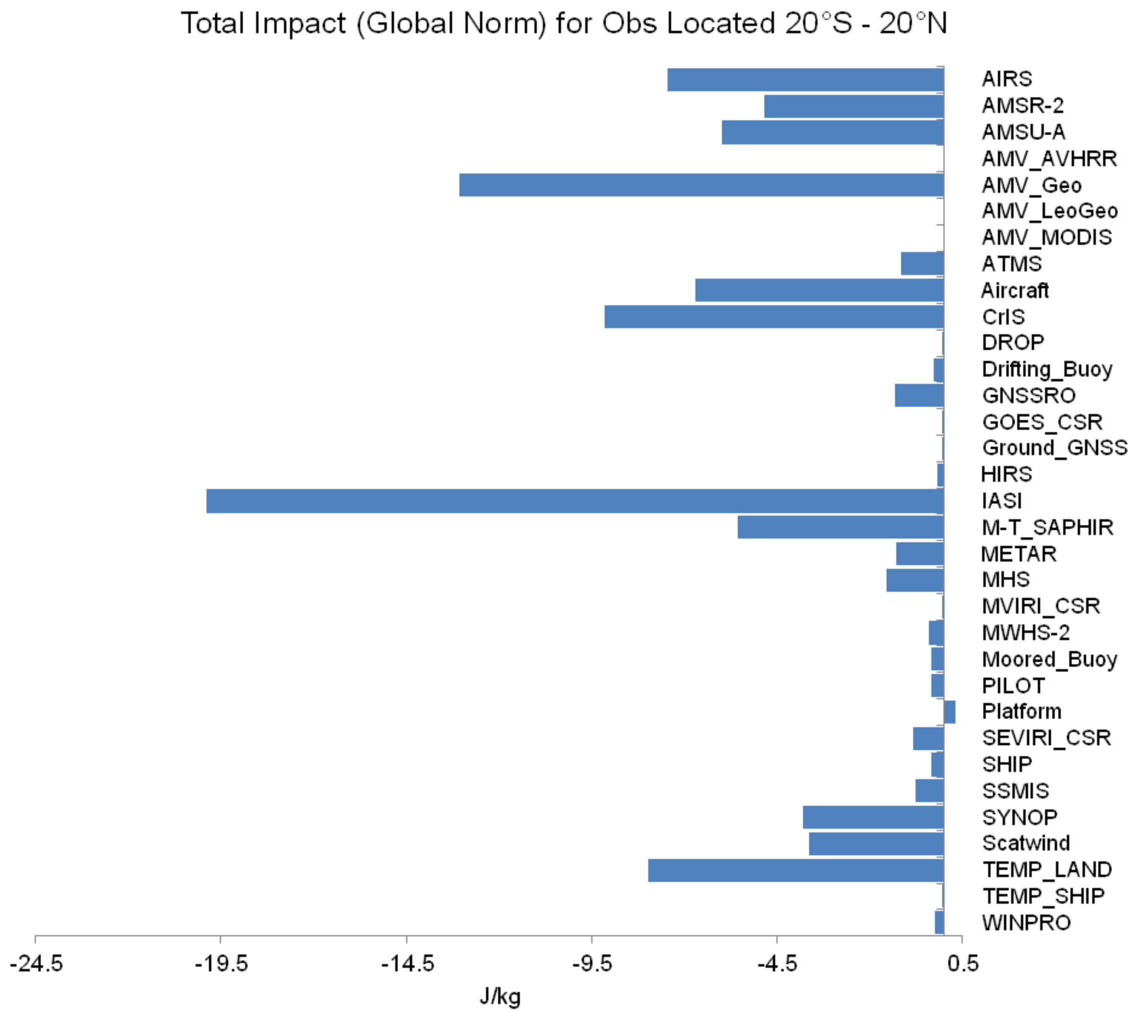


Impact of **global** observations on reducing 24-hr forecast errors

Measured using a **global**, moist energy norm, surface to 150 hPa

- IASI 18%
- AMSU-A 12%
- Geo AMVs 9%
- Sondes 8%
- Aircraft 8%
- CrIS 8%

Forecast Sensitivity to Observations Impact (FSOI)

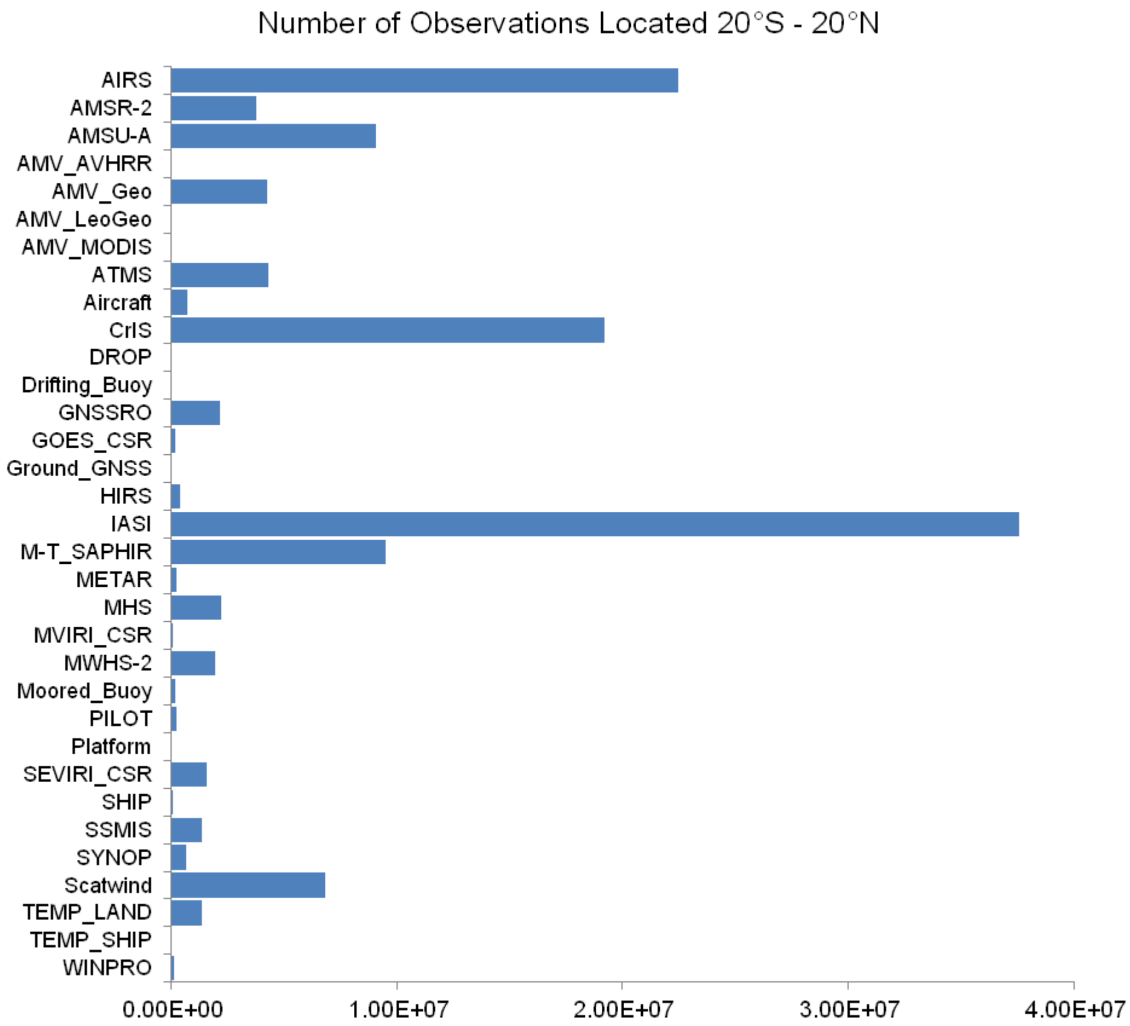


Impact of **tropical** observations on reducing 24-hr forecast errors

Measured using a **global**, moist energy norm, surface to 150 hPa

- IASI 21%
- Geo AMVs 13%
- CrIS 9%
- Sondes 8%
- AIRS 8%
- Aircraft 7%

Forecast Sensitivity to Observations Impact (FSOI)

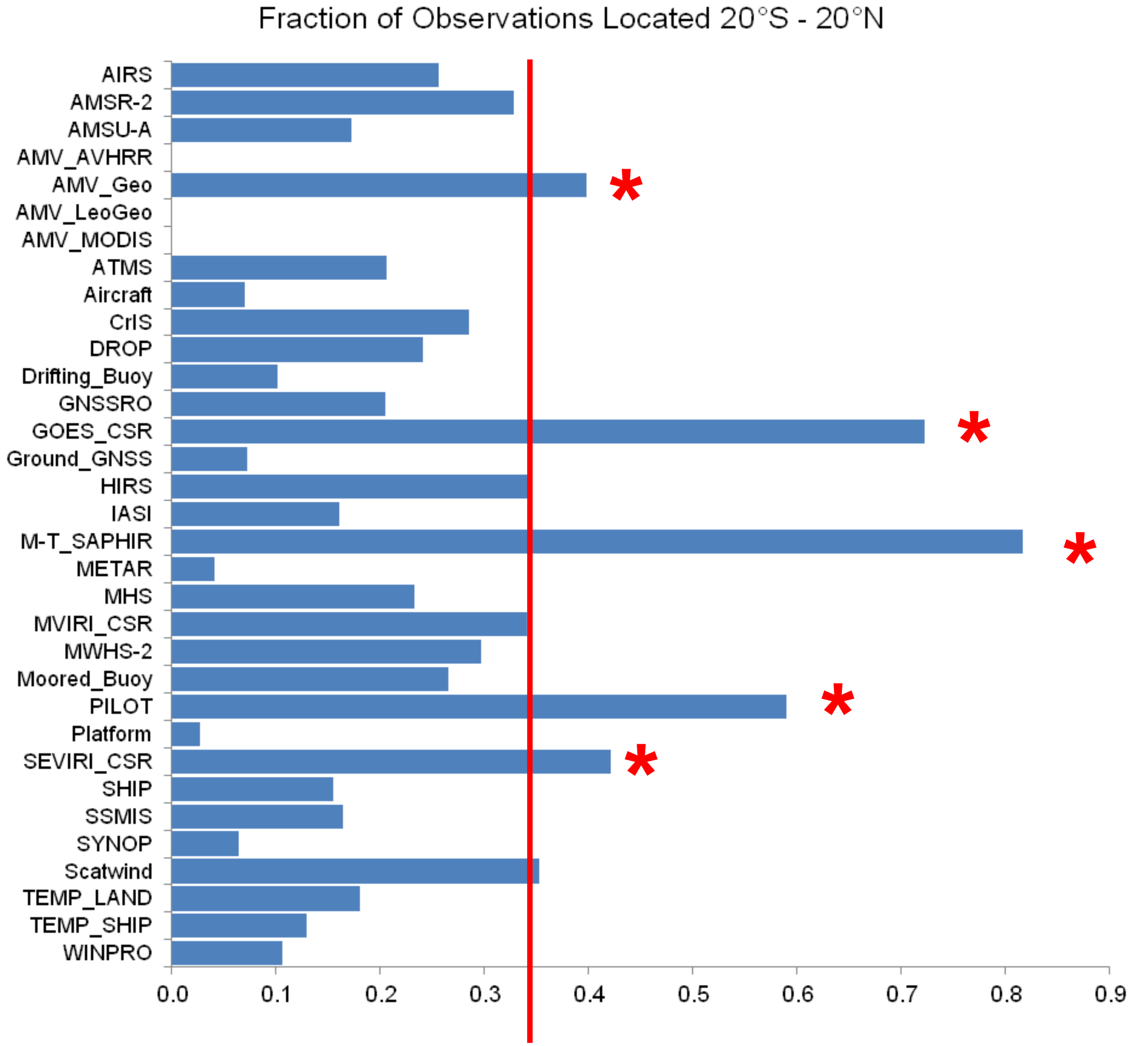


22% of observations are located in tropics

They contribute **33%** towards the total, global impact as measured by FSOI

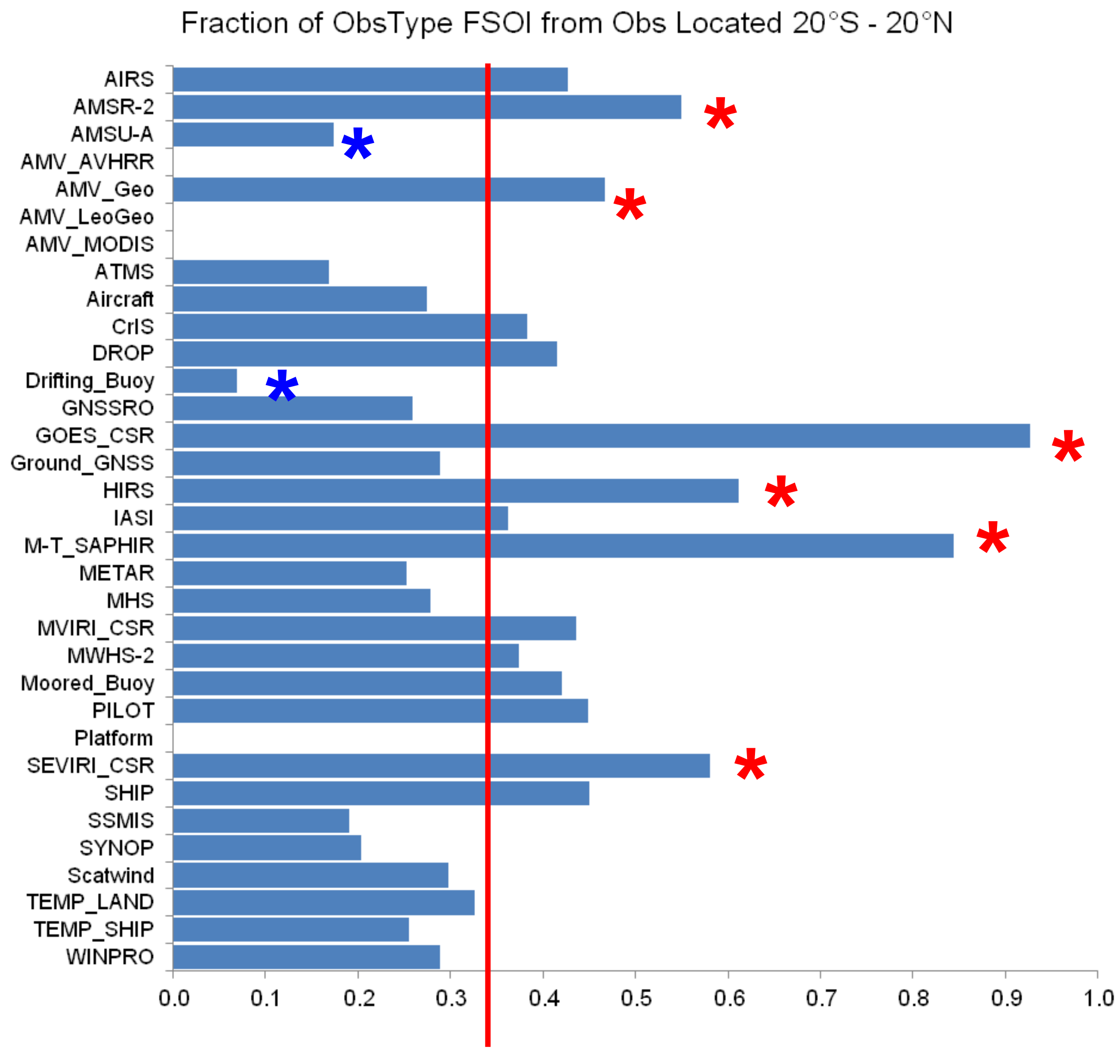
20˚N-20˚S is **34%** of the global area

Forecast Sensitivity to Observations Impact (FSOI)



82% of M-T Saphir observations are located in the tropics

Forecast Sensitivity to Observations Impact (FSOI)



84% of M-T Saphir impact is from tropical observations

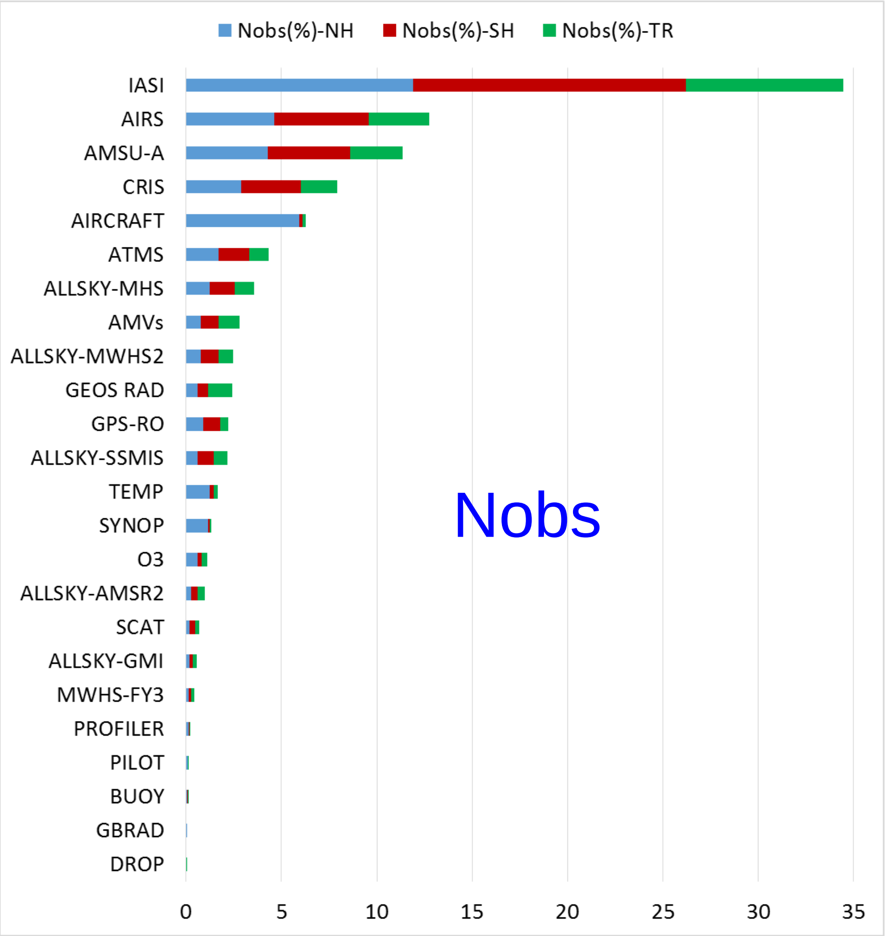
N.B. GOES CSR impact is very small

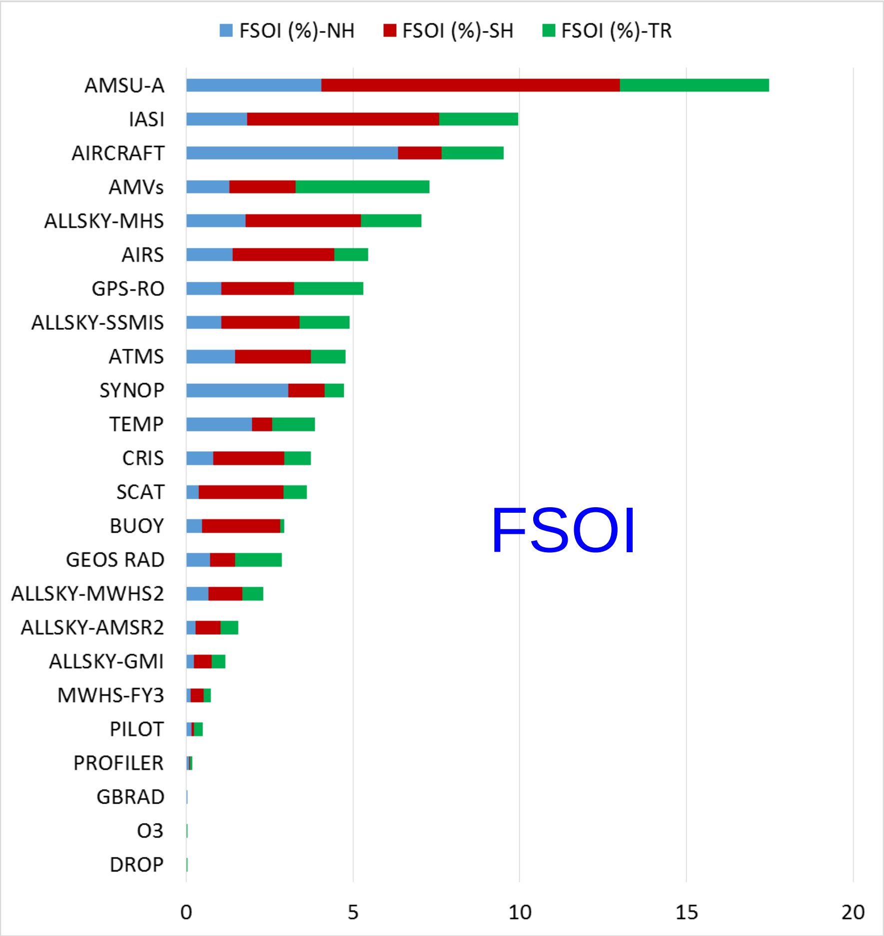
Forecast Sensitivity to Observation Impact (FSOI)

ECMWF

Cristina Lupu

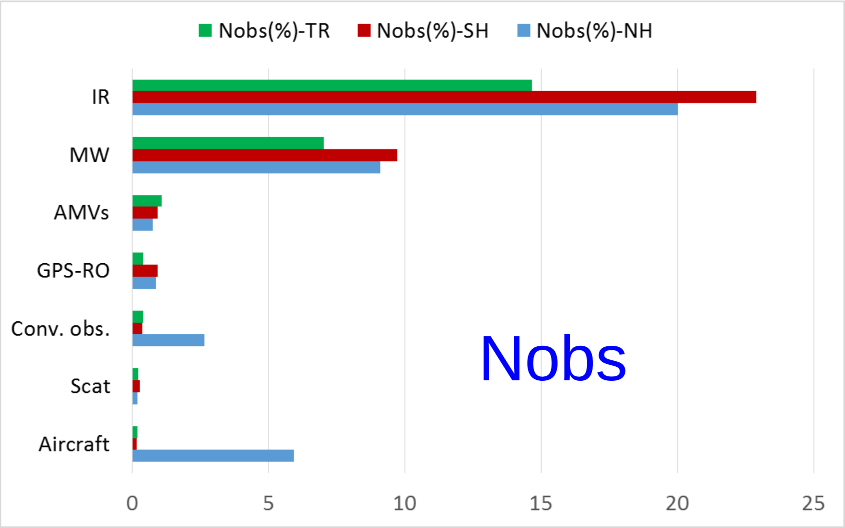
Nobs and total FSOI by instrument: NH, SH, TR

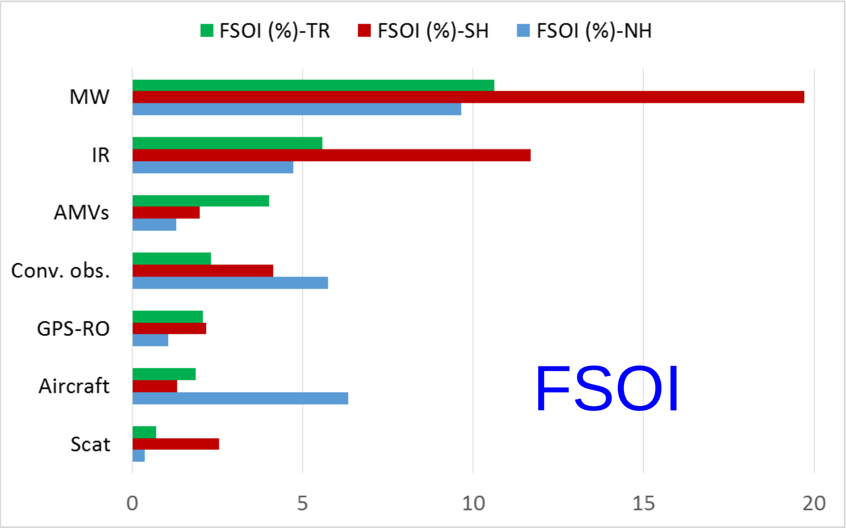




May – August 2016

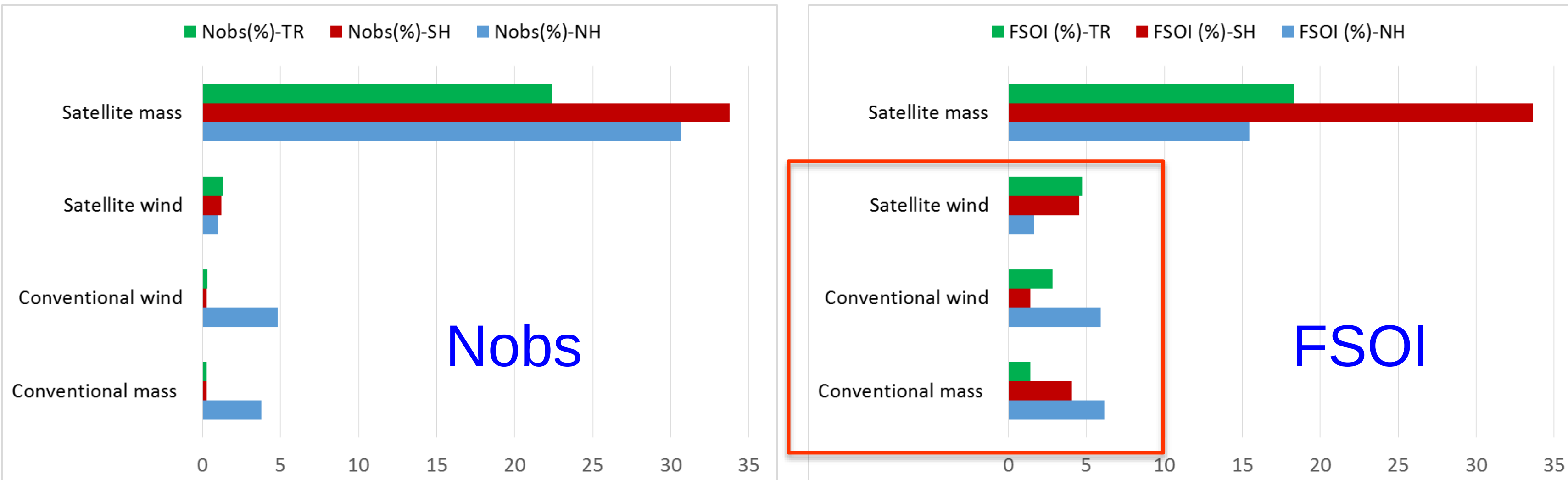
Nobs and total FSOI by observation type: NH, SH, TR





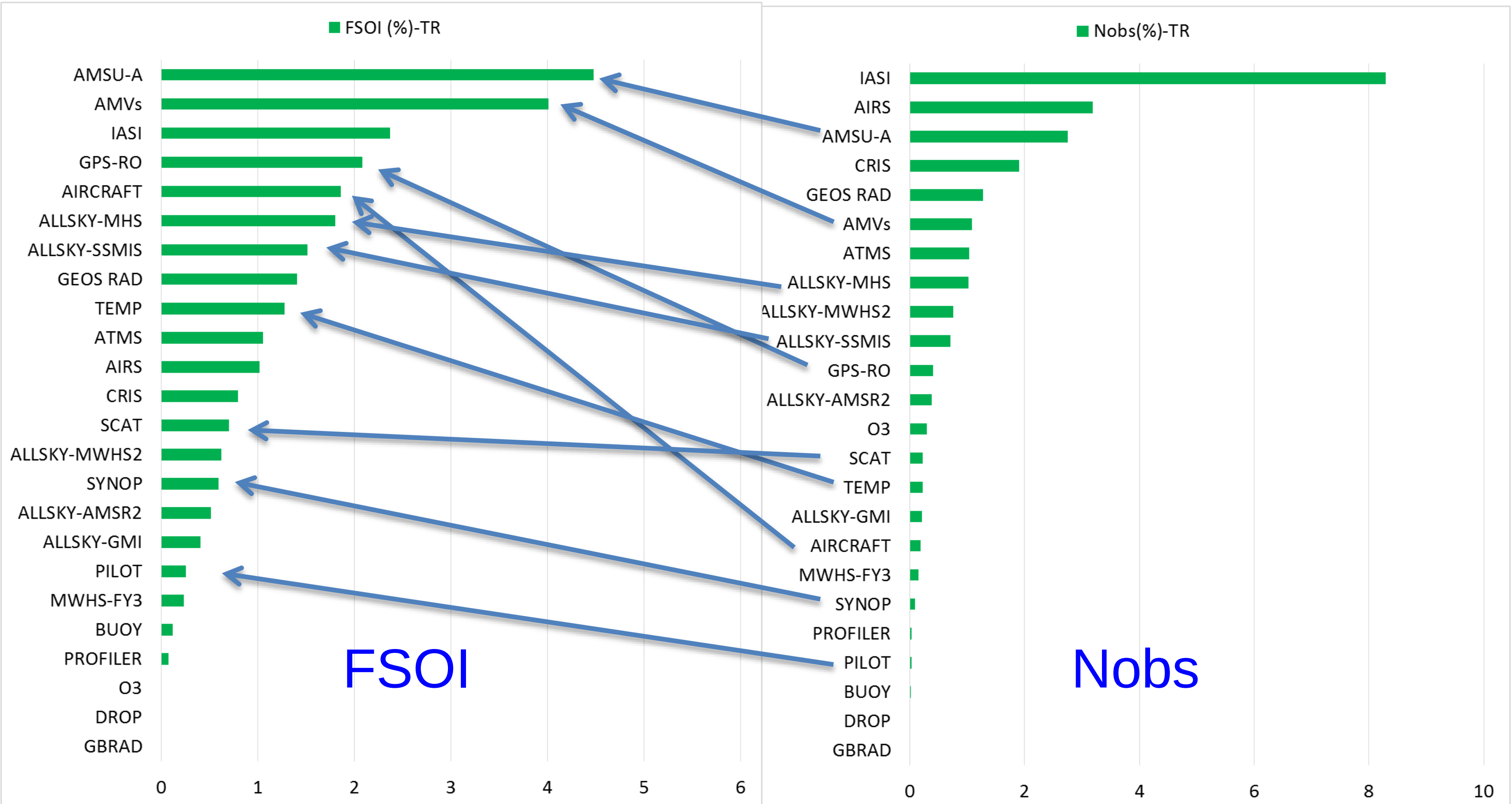
May – August 2016

Nobs and total FSOI: mass and wind observations



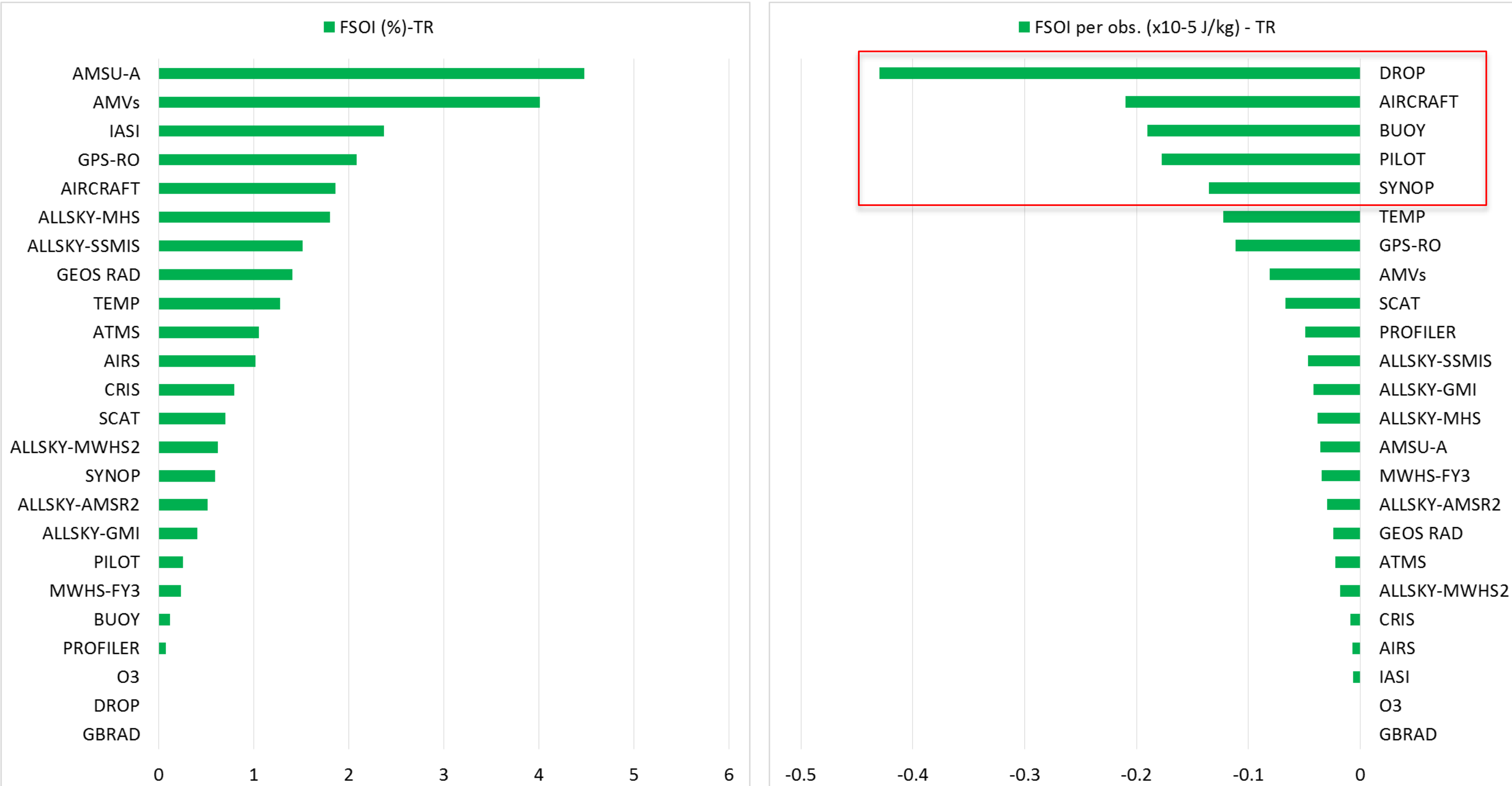
May – August 2016

Nobs and total FSOI by instrument: tropics



May – August 2016

Total FSOI and FSOI-per-observation: tropics



May – August 2016

Data Denial Experiments

ECMWF
Tony McNally

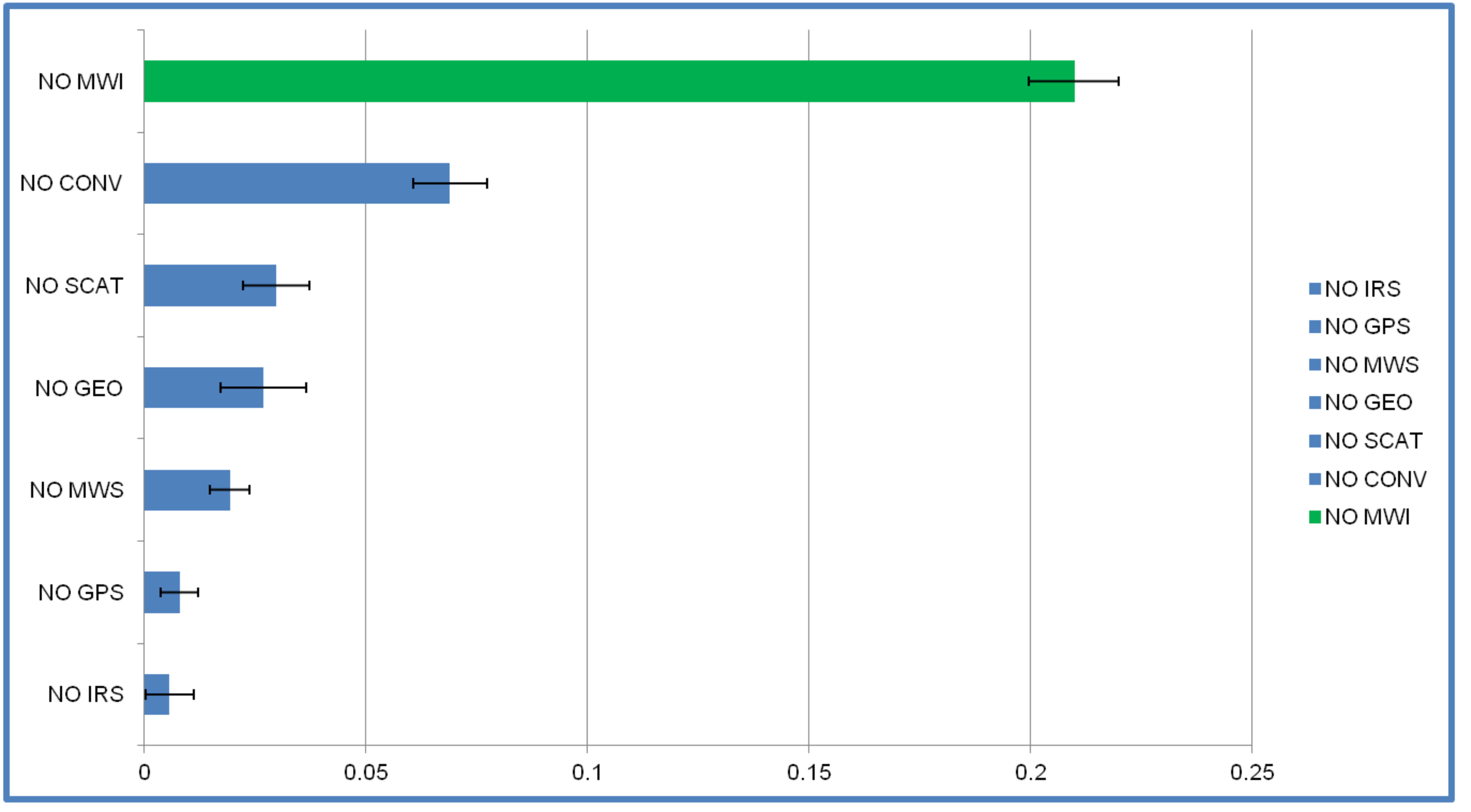
March-June 2014

Data denial experiments – observation sets

All conventional (in situ) data	CONV	TEMP/AIRCRAFT/SYNOP/SHIP
All Satellite Data	SAT	
Microwave sounding radiances	MWS	7 x AMSUA, 1 x ATMS, 4 x MHS
Infrared sounding radiances	IRS	2 x IASI, 1 x AIRS, 1 x HIRS
All GEO data (AMVs and radiances)	GEO	2 x GOES, 2 x METEOSAT, 1 x MTSAT, polar AMVs
GPS-RO bending angle data	GPS	COSMIC, 2 x METOP-GRAS
Microwave imager radiances	MWI	1 x TMI, 1 x SSM/IS
Scatterometer surface wind data	SCAT	2 x ASCAT

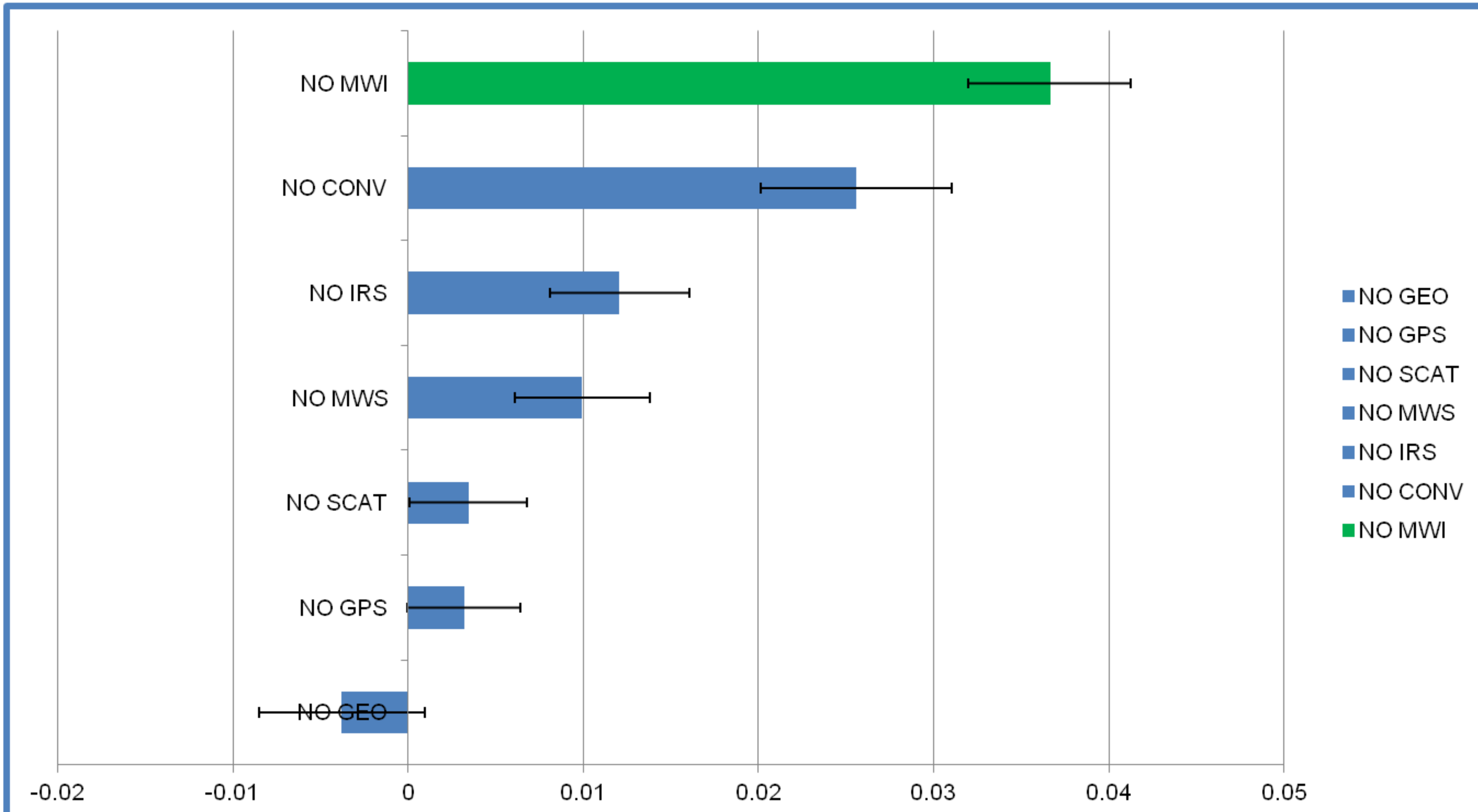
Low level humidity in the tropics

24h 850hPa RH tropics

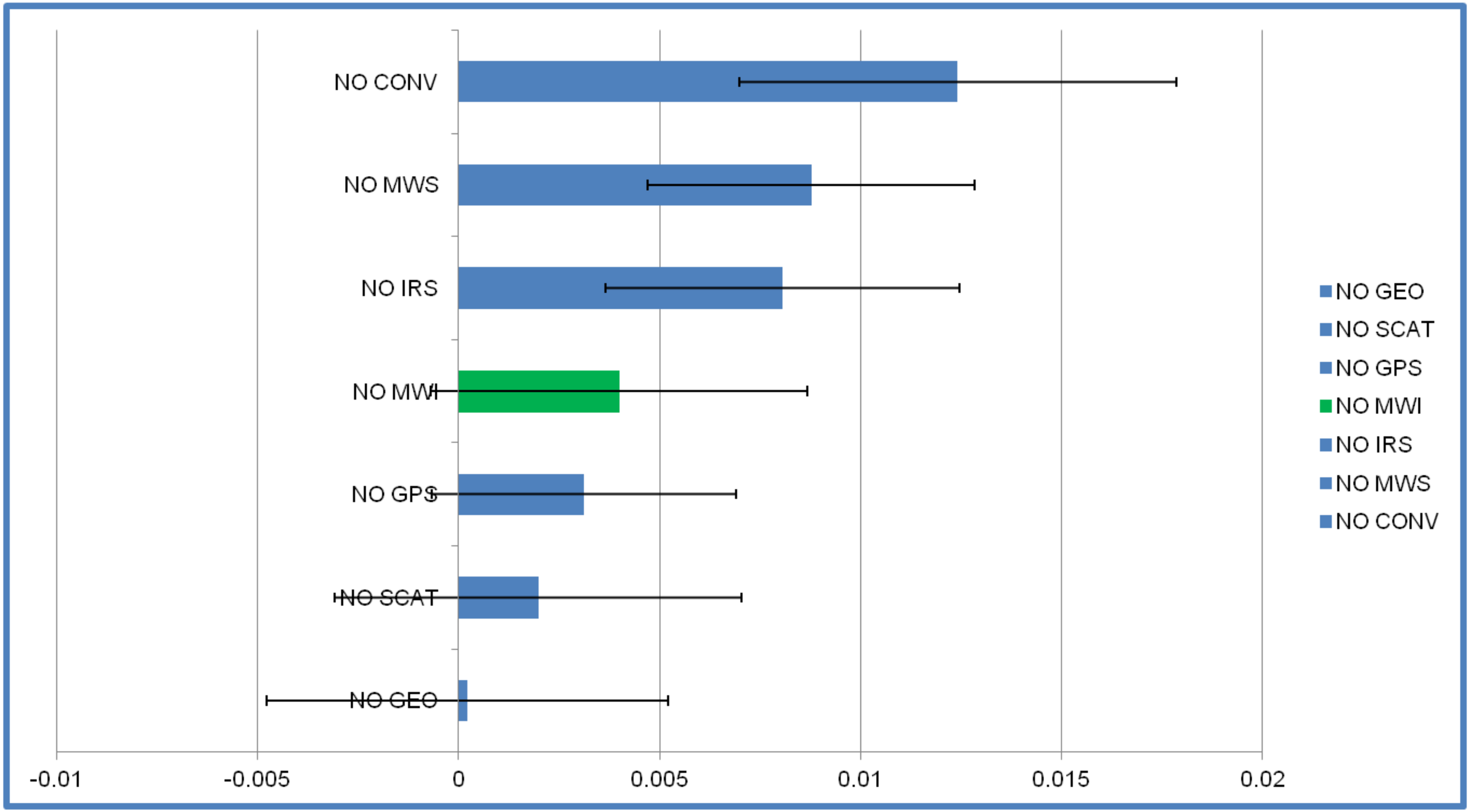


ECMWF EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

72h 850hPa RH tropics

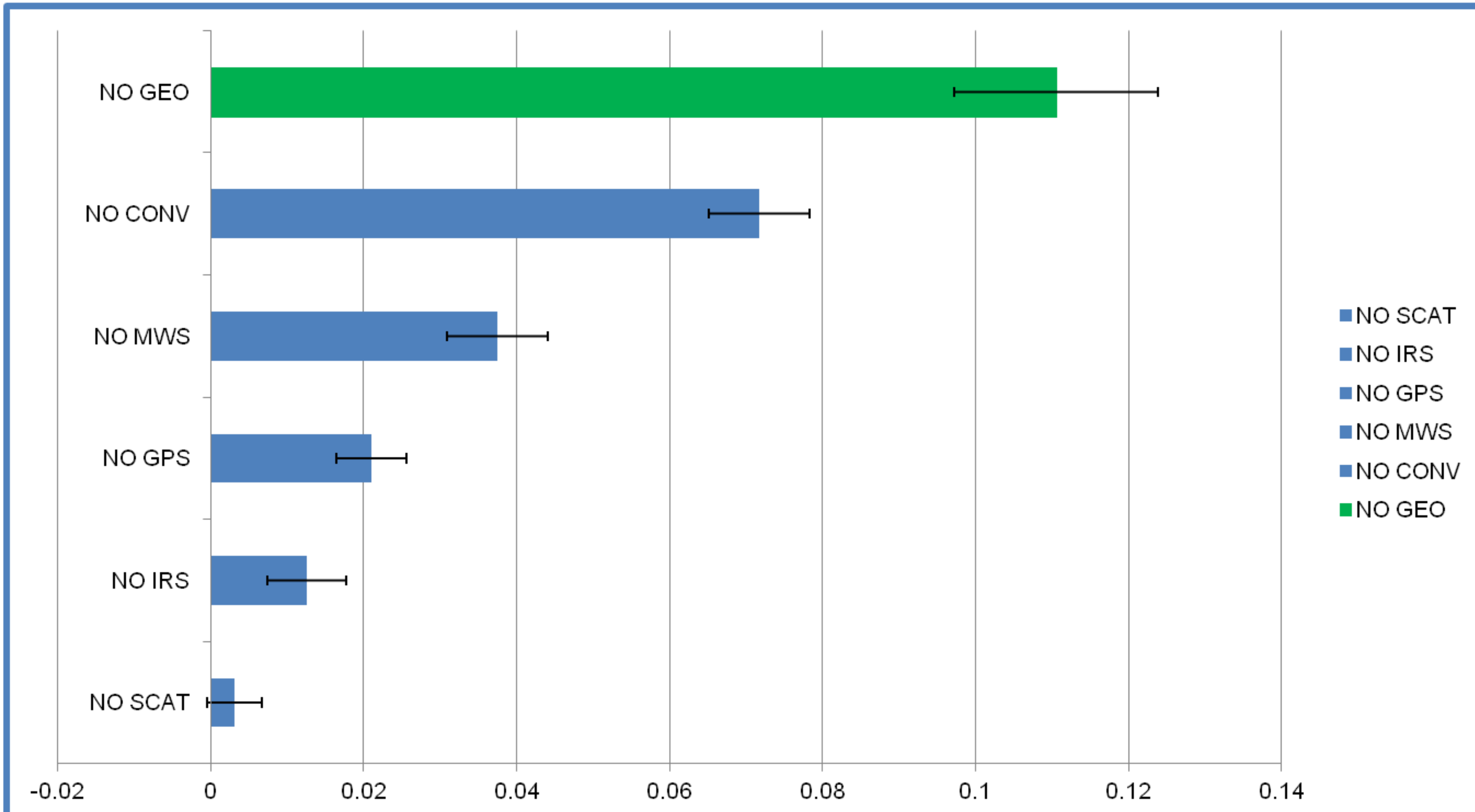


144h 850hPa RH tropics

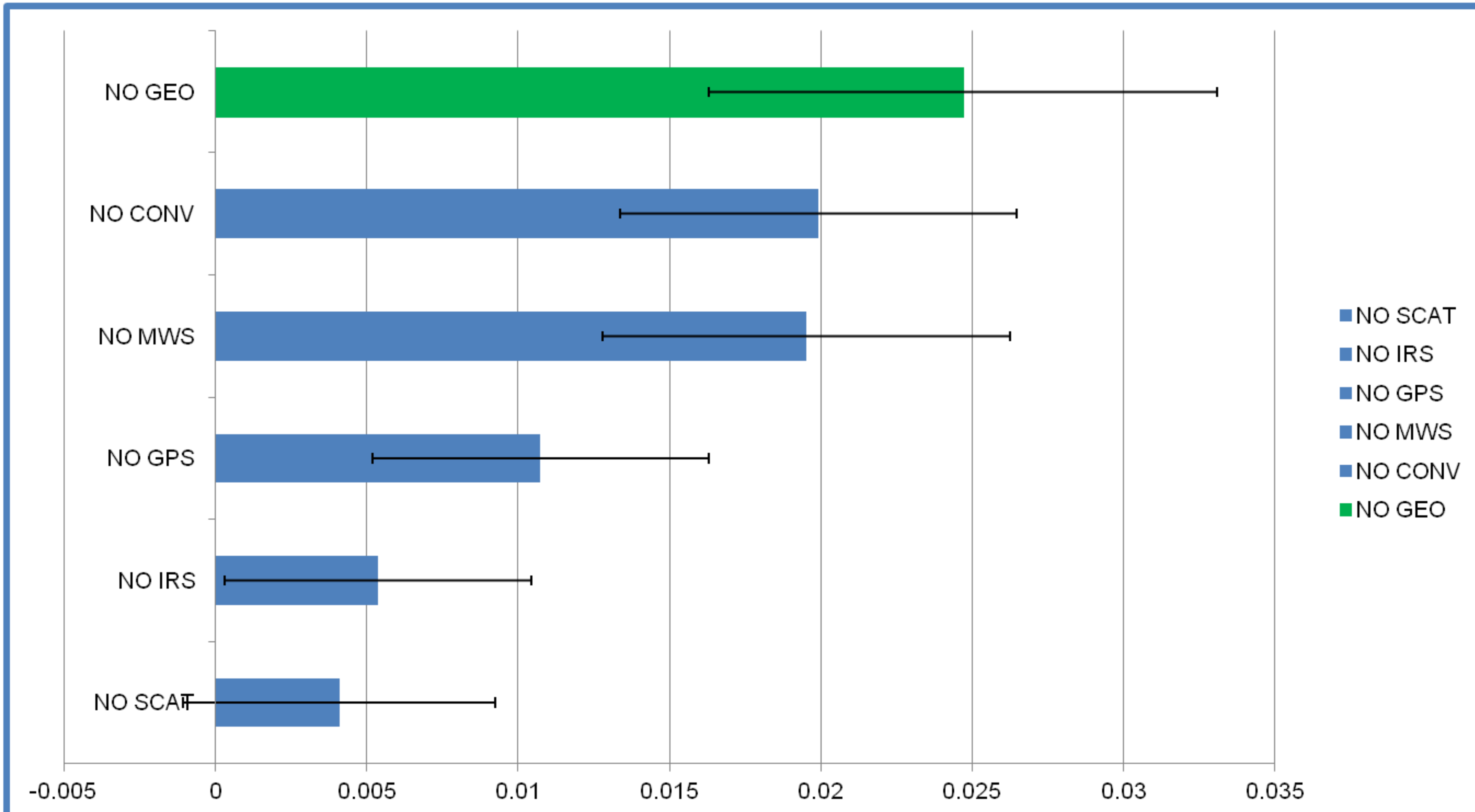


Upper level winds in the tropics

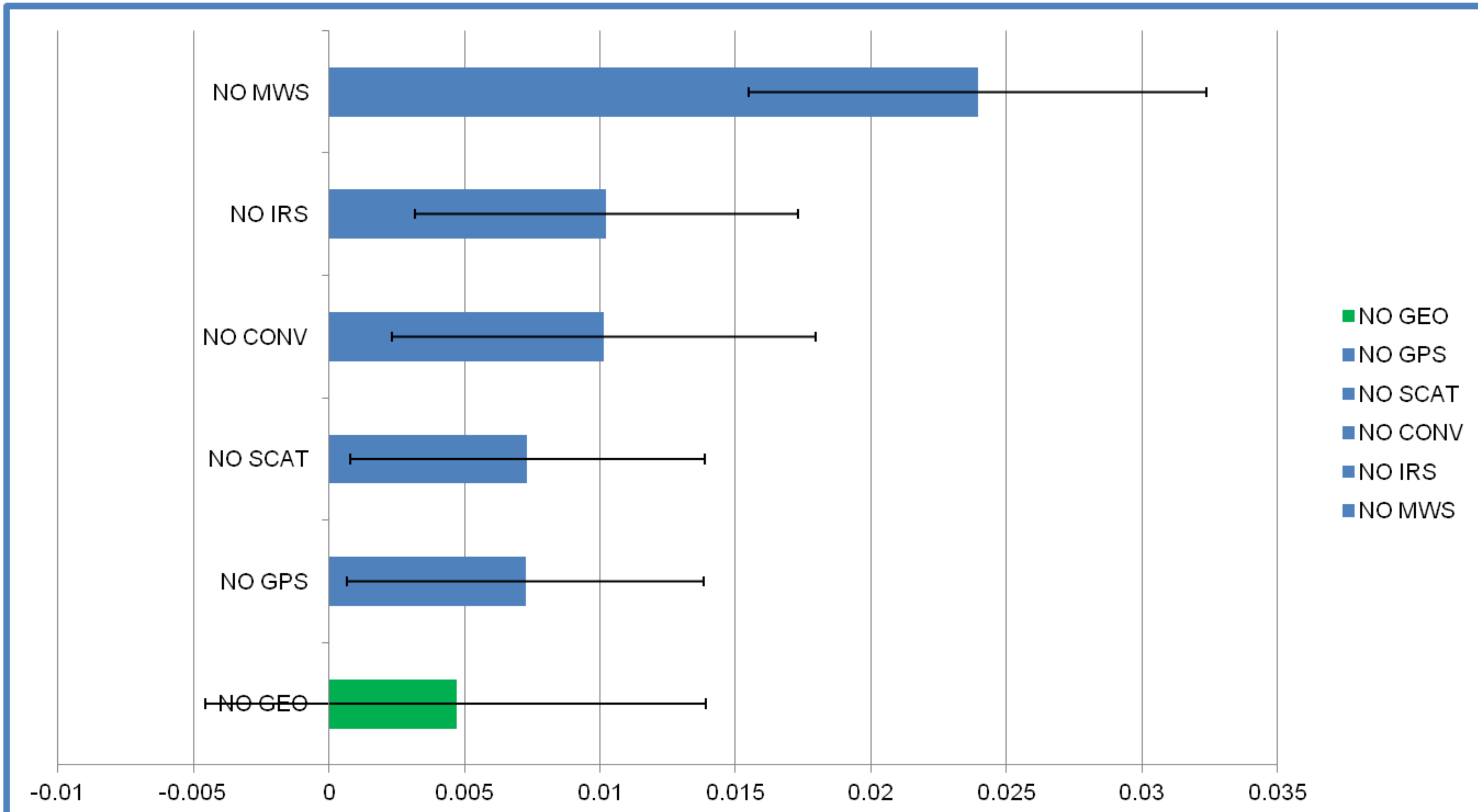
24h 200hPa VW tropics



72h 200hPa VW tropics



144h 200hPa VW tropics



GPS-RO data denial experiments

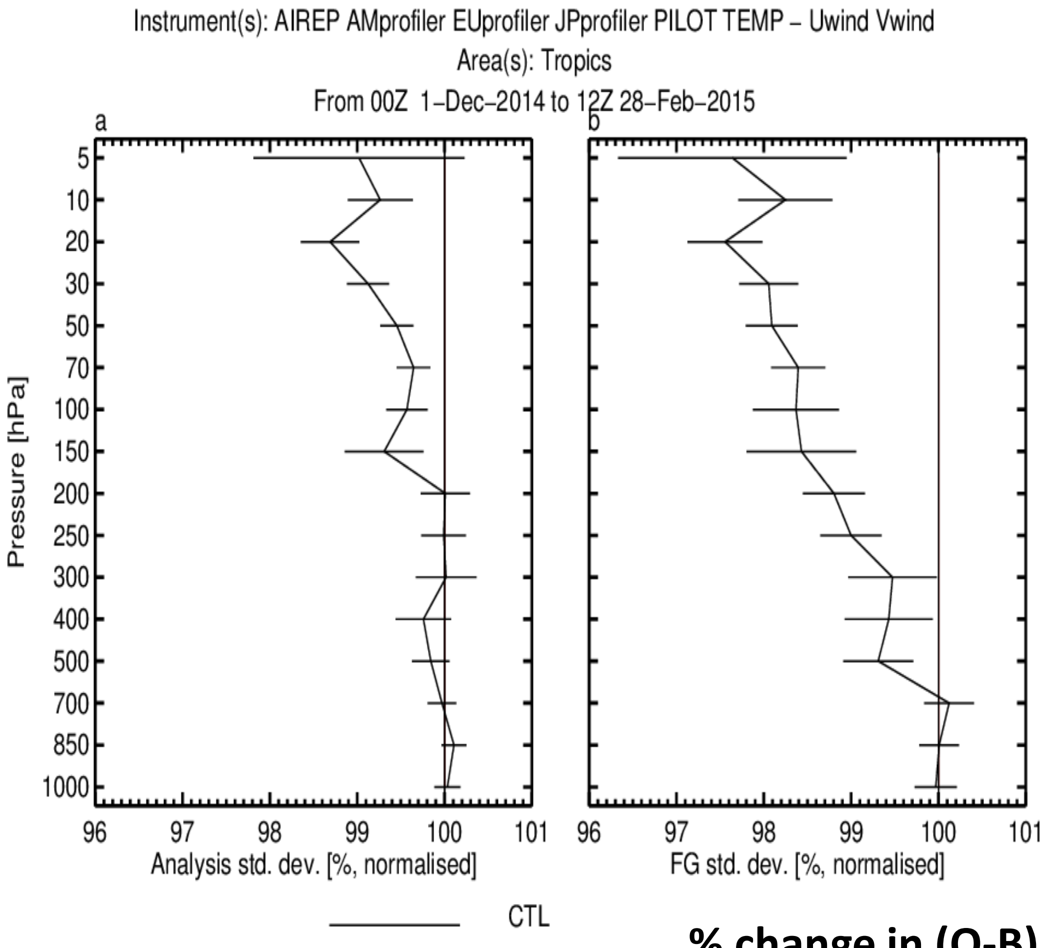
Sean Healy

- Dec 2014 – Feb 2015

- CONTROL: full observing system
- EXPERIMENT: all GPS-RO removed.

- Fractional change in fit of analysis and short-range forecast to other observations in the tropics

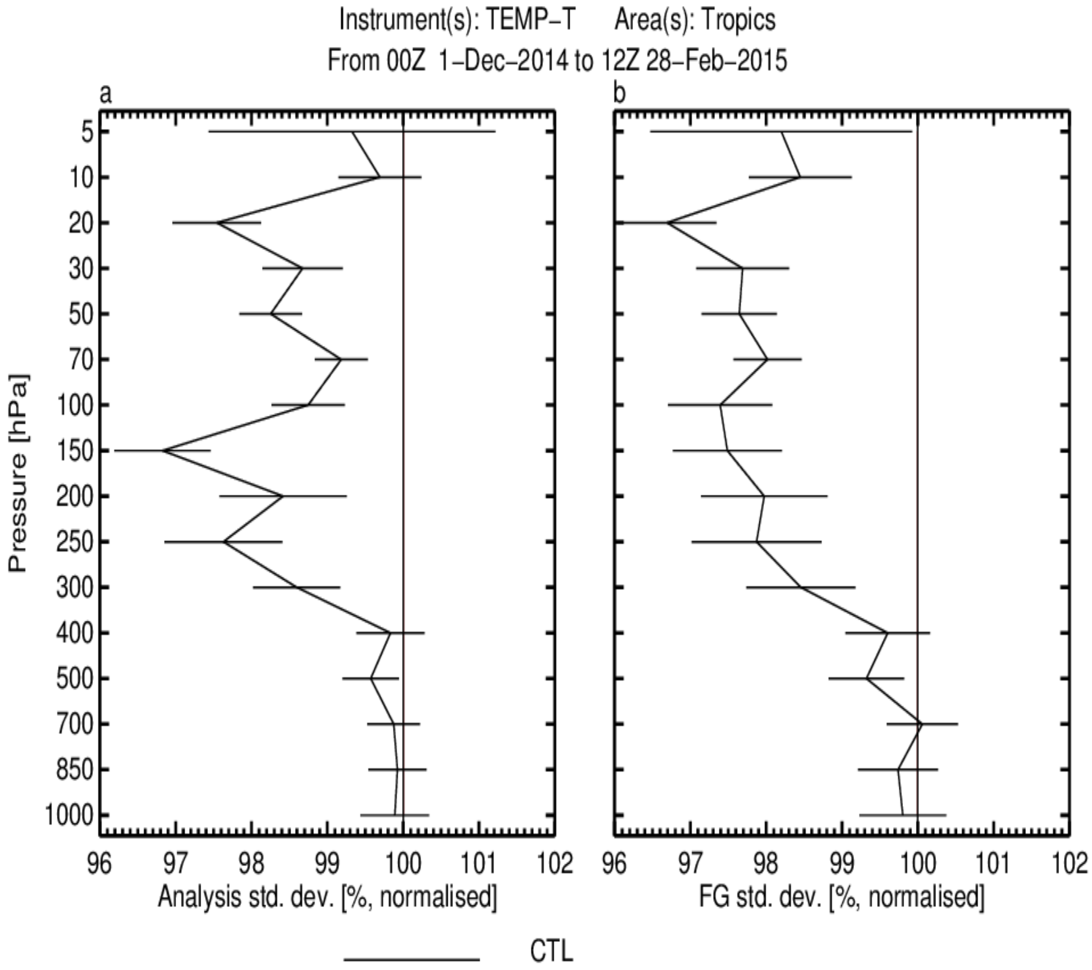
Vector wind improvement in Tropics - v. aircraft and PILOT winds



% change in (O-B)

-ve indicates GPS-RO improves fit.

Vector wind improvement in Tropics - v. sonde winds



How will the observing system evolve? (with focus on the tropics)

Space-based

See Proc. ECWMF Seminar 2014:

“The WMO Vision for global observing systems in 2025: to what extent will it be met by space agencies’ plans”

J. Eyre

Surface-based

Observing system evolution to 2025 (1)

SPACE-BASED OBSERVING SYSTEM

- Operational GEOs
  - Vis/IR imagery – continuity assured
  - AMVs – work still needed on quality
  - New opportunities - hyperspectral IR (humidity and wind), lightning imagery (precip, latent heating)

- Operational LEOs – hyperspectral IR and MW sounding, and Vis/IR imagery
  - Continuity assured in at least 2 orbits
  - … and probably in 3 orbits, with some back-up
  - Impact from all-sky radiances – more to come

Observing system evolution to 2025 (2)

SPACE-BASED OBSERVING SYSTEM

- MW imagery – clouds, precip, TCWV, surface wind
  - Prospects for continuity are good
  - Low-inclination orbit is useful but not assured
- Scatterometry – surface wind vector, soil moisture
  - Continuity assured in at least 2 orbits
- Radio occultation
  - Many initiatives – prospects of greatly increased coverage
  - Better use of information on humidity profile and PBL top
  - COSMIC-2 part 1 will be in low-inclination orbits

Observing system evolution to 2025 (3)

SPACE-BASED OBSERVING SYSTEM

- Doppler wind lidar
  - Prospects for continuity are not good
- Low-frequency MW – soil moisture, SSS, sea surface wind
  - Prospects for continuity are not good
- Cloud and precip radar
  - Two missions planned for 2025 (FY-3RM-1, -2)
  - Good for model validation and climate. Impact on NWP?

Observing system evolution to 2025 (4)

SURFACE-BASED OBSERVING SYSTEM

MOST IMPORTANT

- Aircraft – AMDAR – ascent/descent profiles into more airports, and more flight-level data
- Remote stations and small islands – continuing pressure
- Land-based surface and sonde stations – WIGOS?
- Ocean sub-surface – temp., salinity, current – ARGO, …
- Moored buoys – TPOS2020 – surface fluxes for validation

TPOS2020 Report (2016): "… a paucity of studies on the impact the Tropical Moored-buoy Array on NWP and associated reanalysis products and in coupled models."

Observing system evolution to 2025 (5)

SURFACE-BASED OBSERVING SYSTEM

LESS IMPORTANT (in the tropics)??

- Remotely-sensed upper air observations
- GNSS receivers on ships and buoys (and land)
- Weather radars – precipitation and wind
- ASAPs – more routes?
- Drifting buoys – surface pressure (impact mainly extra-tropics?); surface currents

Summary and Conclusions

Summary and conclusions

- Despite relative difficulties of modelling and assimilation in tropics, current observations have strong impacts on forecast scores:
  - Short-range: MWI(humidity?), AMVs, clear-sky radiances, surface-based observations
  - Medium-range: MWS, IRS (from extra-tropics?)

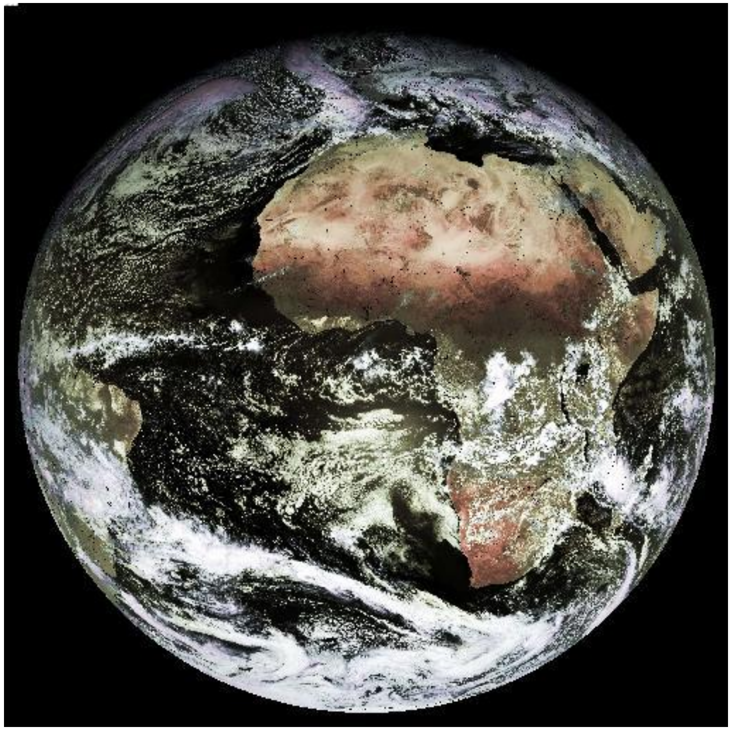
- … and don't forget TCs

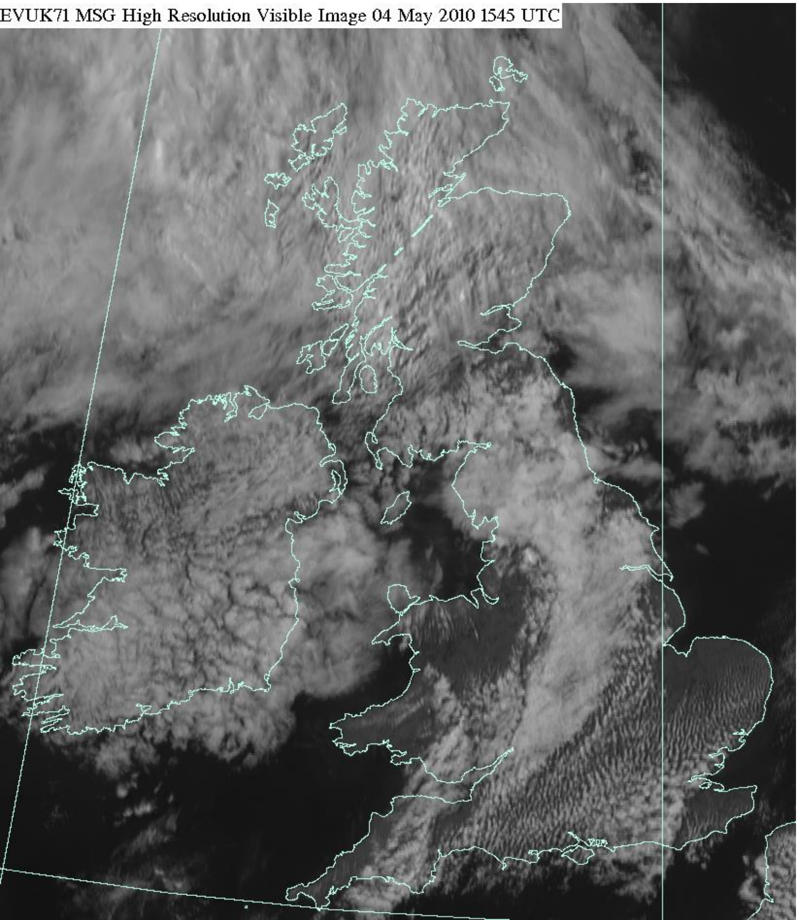
- In future:
  - New instruments on geos
  - More impact from current satellite obs types, e.g. all-sky radiances
  - DWL – and its continuity?
  - More aircraft observations, particularly important for wind
  - Maintain NWP community efforts to support surface-based observations

Thank you! Questions?

Met Office

Operational geostationary satellites





Objectives

- weather in motion - nowcasting
- cloud cover and cloud height
- winds (from moving clouds)
- other cloud properties
- aerosols
- vegetation, snow, fire
- sea/land surface temperature

Operational geostationary satellites

	2015	→ 2025
E.Pacific		
	GOES-13,-14,-15	GOES-R,-S,-T,-U
W.Atlantic		
		Electro-M?
E.Atlantic	MSG: M-8,-9,-10,-11	MTG/I+S
Indian	M-7 INSAT-3C, Kalpana-1	MSG? INSAT-3DS
Ocean	Electro-L N1 INSAT-3D	Electro-M N1-1,-2
	FY-2D,-2E INSAT-3A	FY-4B,-4C,4D
W.Pacific	FY-2F,-2G COMS-1	GEO-KOMSAT-2A,-2B
	Himawari-6,-7 (MTSAT-1R,-2)	Himawari-8,-9
	Himawari-8	Electro-L N4

Operational geostationary satellites in 2025 (1)

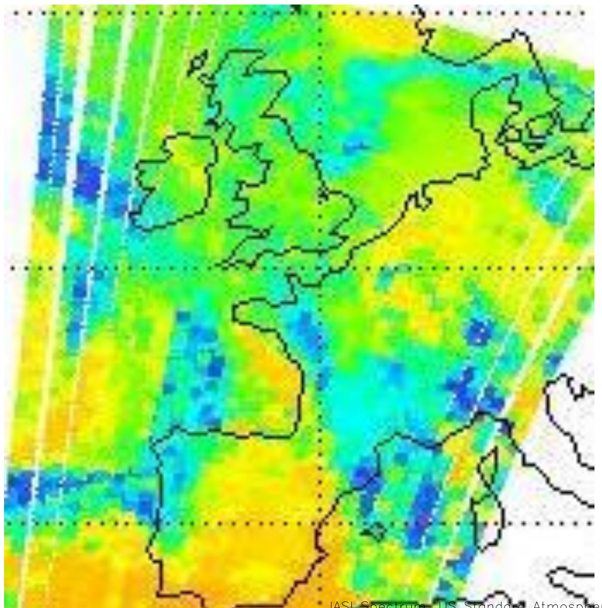
satellite series	Vis/IR imager	Hyperspectral IR sounder	Lighting imager
MSG	**SEVIRI (12 ch)**	**no**	**no**
MTG	**FCI (16 ch)**	**IRS**	**LI**
GOES-R	**ABI (16 ch)**	**no**	**GLM**
Himawari	**AHI (16 ch)**	**no**	**no**
FY-4	**AGRI (14 ch)**	**GIIRS**	**LMI**
INSAT-3DS	**IMAGER (6 ch)**	**no (low-res SOUNDER)**	**no**
GEO-KOMSAT-2	**AMI (16 ch)**	**no**	**no**
Electro-M	**MSU-GSM (20 ch)**	**IRFS-GS**	**LM**

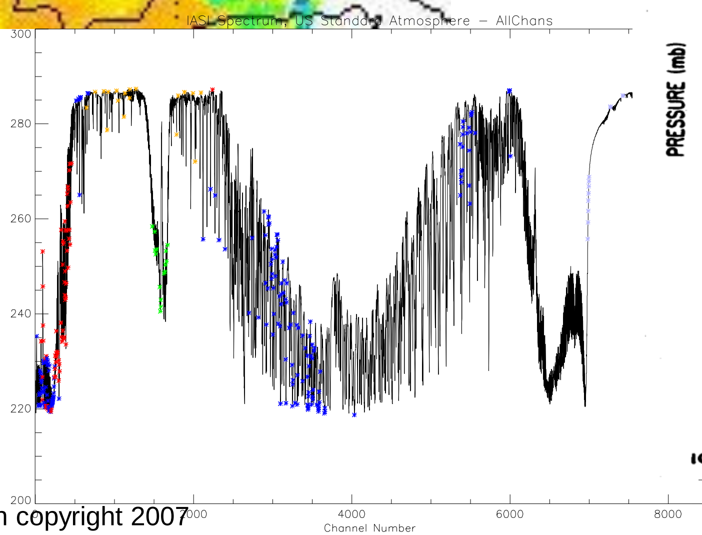
Operational geostationary satellites in 2025 (2)

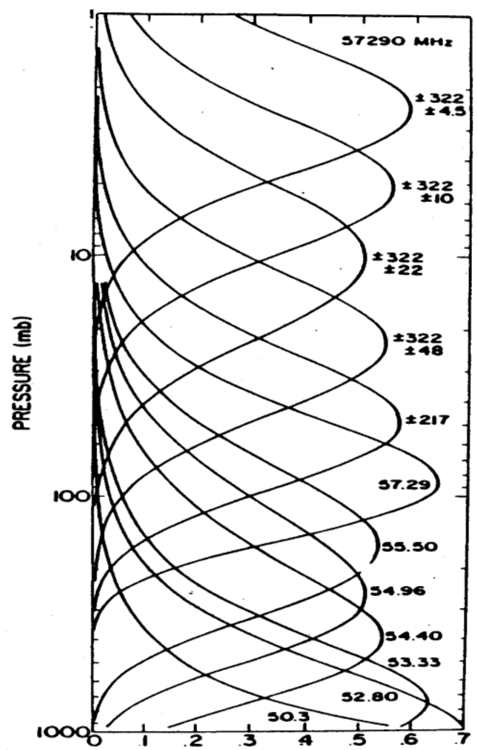
	Vis/IR imager	Hyperspectral IR sounder	Lighting imager
E.Pacific	YES	?	YES
W.Atlantic	YES	?	YES
E.Atlantic	YES	YES	YES
Indian Ocean	YES	YES	YES
W.Pacific	YES	?	?

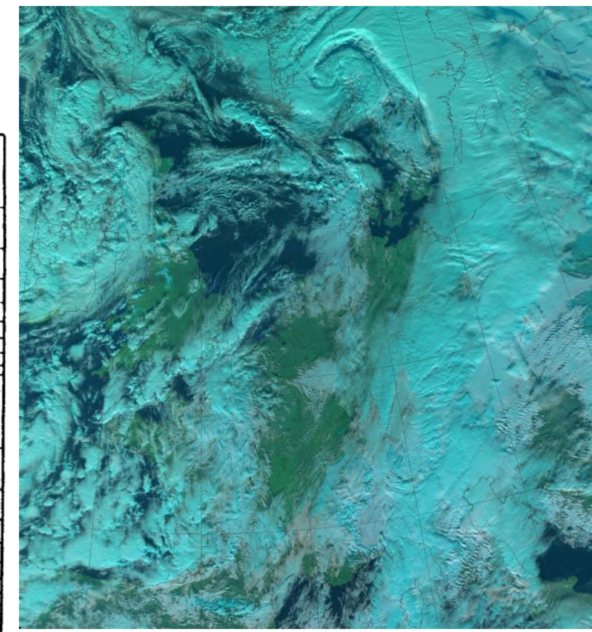
Operational polar-orbiting sun-synchronous satellites

- hyperspectral IR sounding
- MW sounding
- vis/IR imagery









Observation info? Tropics?

Operational polar-orbiting sun-synchronous satellites

	2015	→ 2025
Early morning (LECT ~1730)	**DMSP F-16,-17,-18,-19**	**DMSP F20** **FY-3E(?),-3G(?)**
Morning (LECT ~0930)	**Metop-A,-B** **DMSP-18 FY-3C** **Meteor-M N2**	**Metop-C Metop-SG** **Meteor-M N2-4, -MP N2**
Afternoon (LECT ~1330)	**NOAA-15,-18,-19** **Suomi-NPP** **FY-3B**	**JPSS-1,-2** **FY-3F**
(LECT ~1530)		**Meteor-M N2-5, -MP N1**

Operational polar-orbiting sun-synchronous satellites in 2025 (1)

satellite series	Hyperspectral IR sounder	MW sounder	Vis/IR imager
Metop-SG	**IASI-NG**	**MWS**	**METimage**
Metop	**IASI**	**AMSU-A, MHS**	**AVHRR**
JPSS	**CrIS**	**ATMS**	**VIIRS**
FY-3,-3RM	**HIRAS**	**MWTS-2, MWHS-2**	**MERSI-2**
Meteor-3M	**IKFS-2**	**MTVZA-GY**	**MSU-MR**
Meteor-3MP	**IKFS-3**	**MTVZA-GY-MP**	**MSU-MR-MP**
DMSP	**no**	**SSMIS**	**OLS**

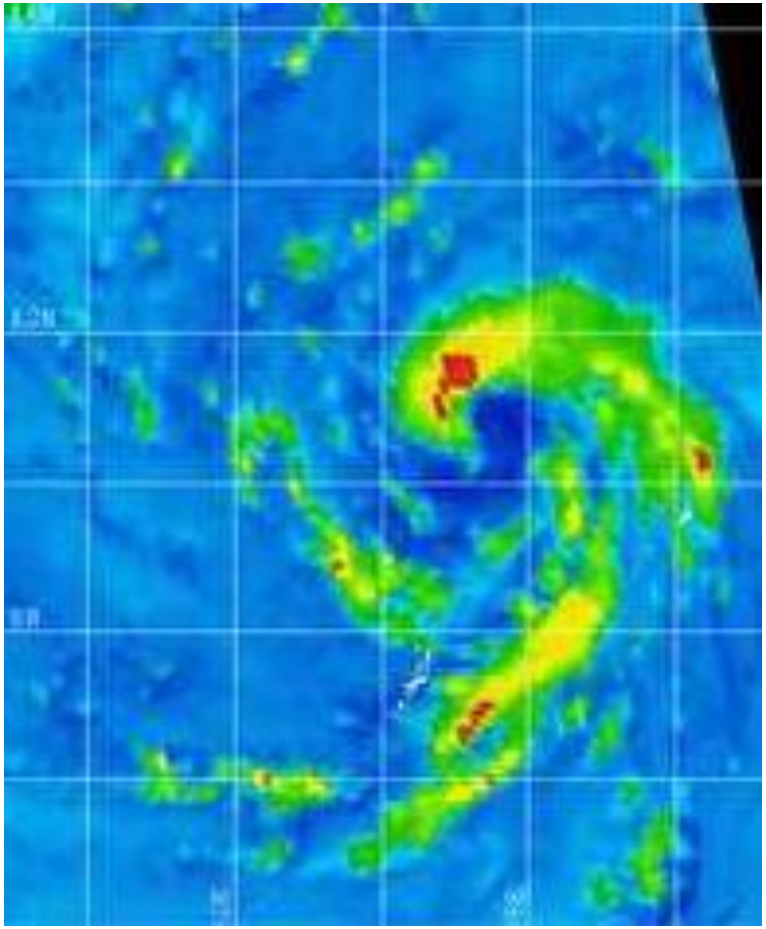
Operational polar-orbiting sun-synchronous satellites in 2025 (2)

	Vis/IR imager	Hyperspectral IR sounder	MW sounder
Early morning	**YES?**	**YES?**	**YES?**
Morning	**YES**	**YES**	**YES**
Afternoon	**YES**	**YES**	**YES**

Microwave Imagery

Objectives

- cloud and precipitation
- total column water vapour
- sea-ice, snow, sea surface wind
- SST, soil moisture



Microwave imagers - 2015

satellites	instrument	channels (GHz)
DMSP F15	**SSM/I**	19-85
DMSP F16,F17,F18,F19	**SSMIS**	19-183, incl.50-60
TRMM	**TMI**	10-85
Coriolis	**Windsat**	6.8-37
GCOM-W1	**AMSR-2**	6.9-89
FY-3B,-3C	**MWRI**	10-89
Megha-Tropiques	**MADRAS**	18-157
GPM Core	**GMI**	10-183
Meteor-M N2	**MTVZA-GY**	10-183, incl.50-60
HY-2A	**MWI**	6.6-37

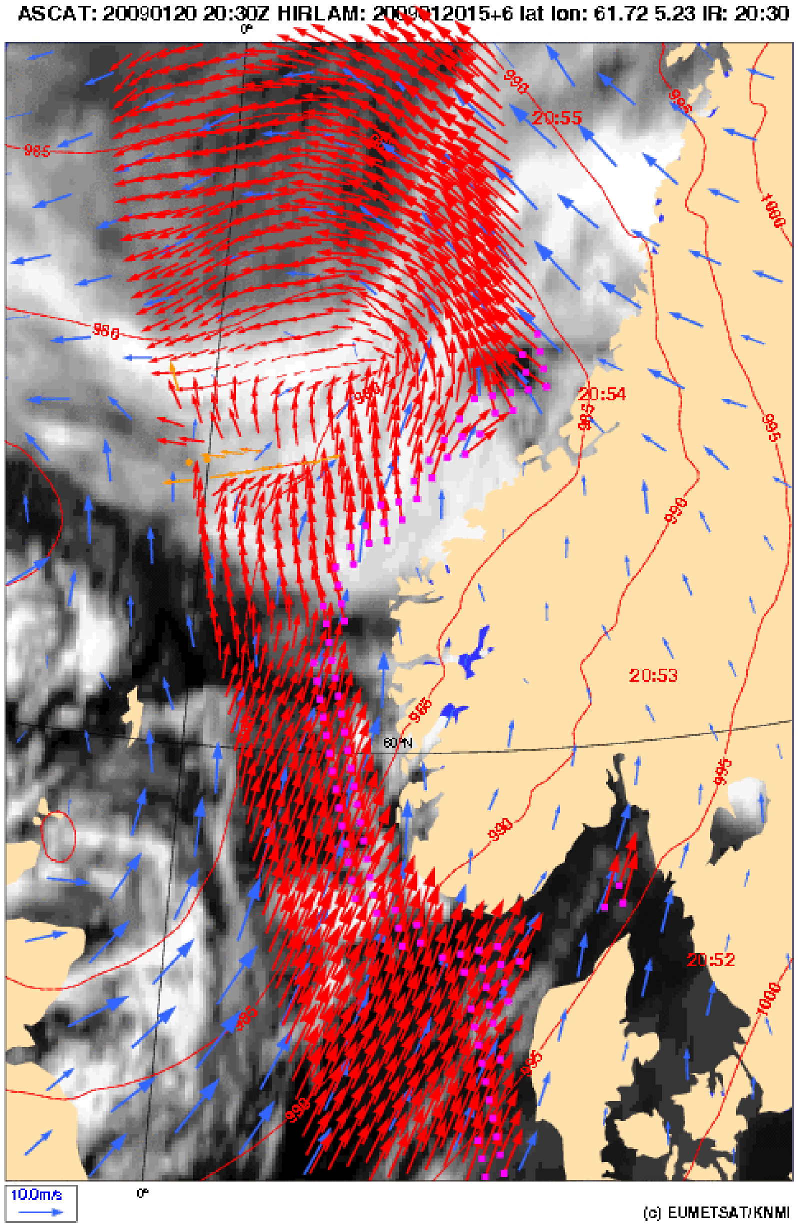
Microwave imagers - 2025

satellite series	instrument	channels (GHz)	
DMSP	**SSMIS**	19-183, incl.50-60	→ 2025
GCOM-W	**AMSR-2**	6.9-89	→ 2025
GPM-Core, -Braz	**GMI**	10-183	→2021+
HY-2	**MWI**	6.6-37	→ 2025
FY-3, FY-3RM	**MWRI**	10-89	→ 2028
Metop-SG	**MWI**	18-183, incl.50-54,118	2022→
Metop-SG	**ICI**	183-664	2022→
DWSS	**MIS**	6.3-183, incl.50-60	??
Meteor-M	**MTVZA-GY**	10-183, incl.50-60	→2025
Meteor-MP	**MTVZA-GY-MP**	6.9-183, incl.50-60	2021-2030

Scatterometry

Objectives

- ocean surface wind speed and direction
- soil moisture
- snow equivalent water
- sea-ice type



Met Office

Scatterometers - 2015

satellites	instrument	
Metop-A,-B	**ASCAT**	C-band
Oceansat-2	**OSCAT**	Ku-band
ISS RapidScat	**RapidScat**	Ku-band
HY-2A	**SCAT**	Ku-band

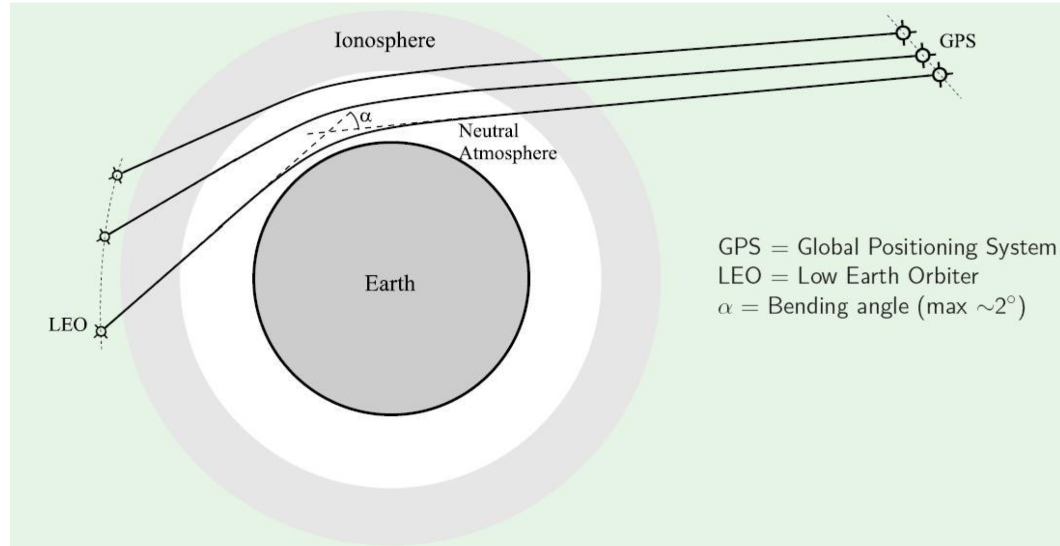
Scatterometers - 2025

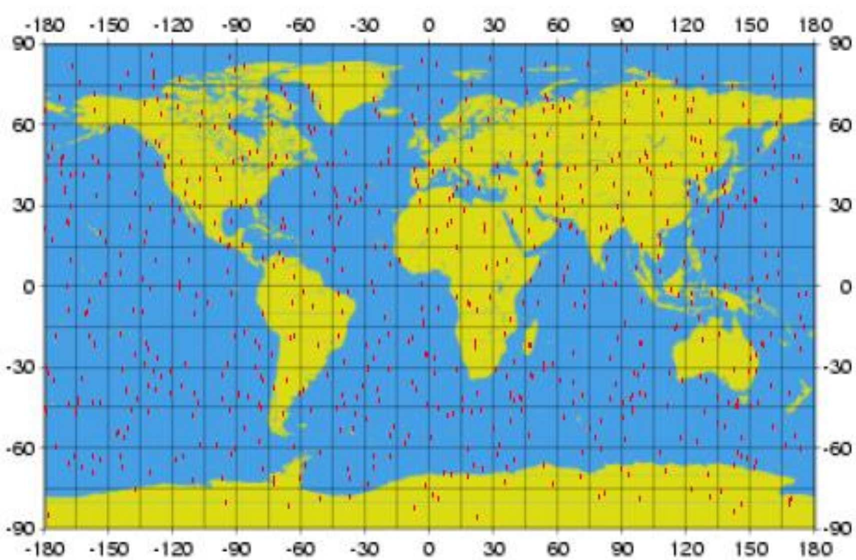
satellite series	instrument		
Metop	**ASCAT**	C-band	→ 2024+?
Metop-SG	**SCA**	C-band	2022 →
FY-3	**WindRad**	C+Ku-band	2021+
HY-2	**SCAT**	Ku-band	→ 2025
Meteor-M	**SCAT**	Ku-band	2020-25
ScatSat-1	**OSCAT**	Ku-band	2016-21
CFOSAT	**SCAT**	Ku-band	2018-21
OceanSat-3	**OSCAT**	Ku-band	2018-23

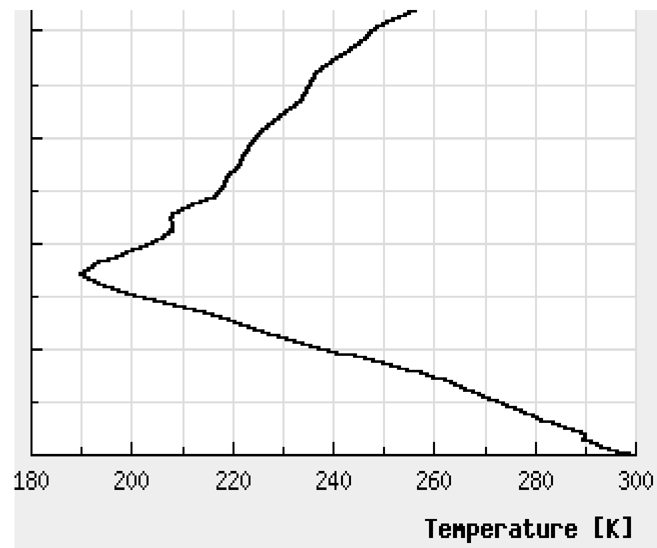
Radio occultation

Objectives

- refractivity profiles at high vertical resolution
  - temperature / humidity profiles
- ionospheric electron content







Radio occultation – 2015

Total:

9 receivers

~2300 occultations per day

(Nov 2015)

satellites	instrument	
COSMIC	**IGOR**	~4 satellites
Metop-A and -B	**GRAS**	
GRACE-A or -B	**Blackjack**	
TerraSAR-X	**IGOR**	
Tandem-X	**IGOR**	
FY-3C	**GNOS**	
Oceansat-2	**ROSA**	
Megha-tropiques	**ROSA**	
KOMPSAT-5	**AOPOD**	

Radio occultation - 2025

WMO EGOS-IP says:

“ at least 10000 occultations per day”

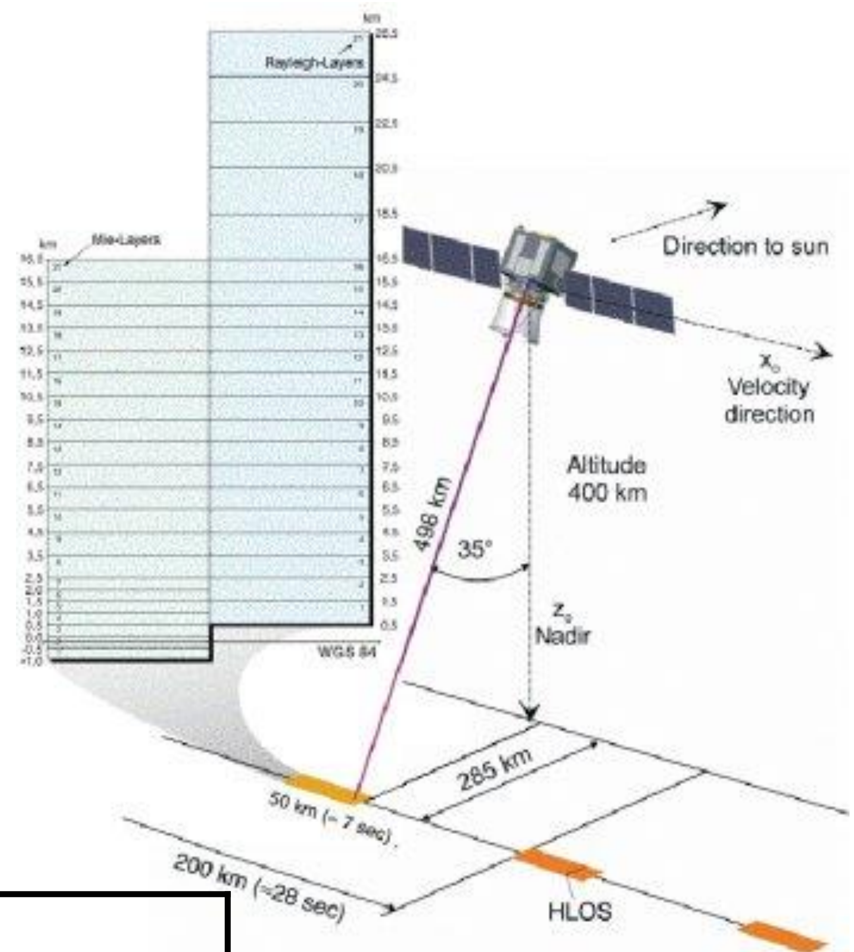
satellite series	instrument		
COSMIC-2A,-2B	**Tri-G**	12 sats	2016-25
Metop-C	**GRAS**		→ 2024+?
Metop-SG	**RO**	2 sats	2021→
FY-3	**GNOS**		→ 2026
Meteor-M N3	**Radiomet**		2020-25
Meteor-MP	**ARMA-MP**		2021-30
JASON-CS	**Tri-G**		2020-33
SEOSAR/Paz	**ROHPP**		2015-20
GRACE-FO	**Tri-G**	2 sats	2017-22

Doppler wind lidar

Met Office

Objectives

- wind profiles (line-of-sight)
- profiles of cloud and aerosol
- aerosol properties
- boundary layer height



satellites	instrument	
ADM-Aeolus	ALADIN	2017-20
3D-Winds	3D-Winds lidar	2023-26

Low frequency microwave – ~1.4 GHz

Objectives

- soil moisture
- sea surface salinity
- sea surface wind (high wind speed)
- sea ice thickness (thin ice)

satellites	instrument	
SMOS	**MIRAS**	2009-17+
SAC-D	**Aquarius**	2011-15
SMAP	**SMAP**	2015-18+

Cloud and precipitation radar

satellites	instrument	frequency (GHz)	
TRMM	**PR**	13.8	1997-2015
Cloudsat	**CPR**	94	2006-15+
GPM-Core	**DR**	13.6 + 35.6	2014-17
EarthCARE	**CPR**	94	2018-21
FY-3RM-1, -2	**Ku/Ka-PR**	? 12-18 + 26-40 ?	2020-28

Met Office data denial experiments: Summary for the tropics (Mary Forsythe)

- T+24 forecast rms % error reductions
- Experiment v Control, verified against ECMWF analysis
- Many levels and variables:
  - PMSL, H500, W250, W850, W700, W500, W100, W50, H850, H700, H250, H100, H50, T850, T700, T500, T250, T100, T50, RH850, RH700, RH500

- % of the global %-rms error reduction in band 20˚N-20˚S:
  - IR sounders 56%
  - AMVs 39%
  - MW sounders + imagers 34%
  - Sondes 30%
  - GNSS-RO 23%

Tropics = 34% of global area

Met Office data denial experiments: Summary for the tropics (Mary Forsythe)

- **A set of OSEs designed to show impacts of observations operational at the Met Office from March 2016**
- **Period: 15 Nov 2015 to 15 Jan 2016**
- **Data denial experiments included:**
  - **No IR data: IASI, CrISS, AIRS, HIRS, SEVIRI**
  - **No MW data: AMSU/MHS, ATMS, SSMIS, Aphis, FY-3C**
  - **No AMVs**
  - **No sondes**
  - **No aircraft**
- **For each region (NH, TR, SH), calculated mean % RMS difference between control and experiment, verifying against ECMWF operational analyses of 7 variables (PMSL, H500, W250, W850, T850, T500, RH850)**

Data denial trials – change in %rmse vs EC analyses