Satellite data assimilation for NWP

Niels Bormann

Phil Browne, Chris Burrows, Giovanna de Chiara, David Duncan, Stephen English, David Fairbairn, Alan Geer, Sean Healy, Lars Isaksen, Bruce Ingleby, Katrin Lonitz, Cristina Lupu, Tony McNally, Mike Rennie, Patricia de Rosnay

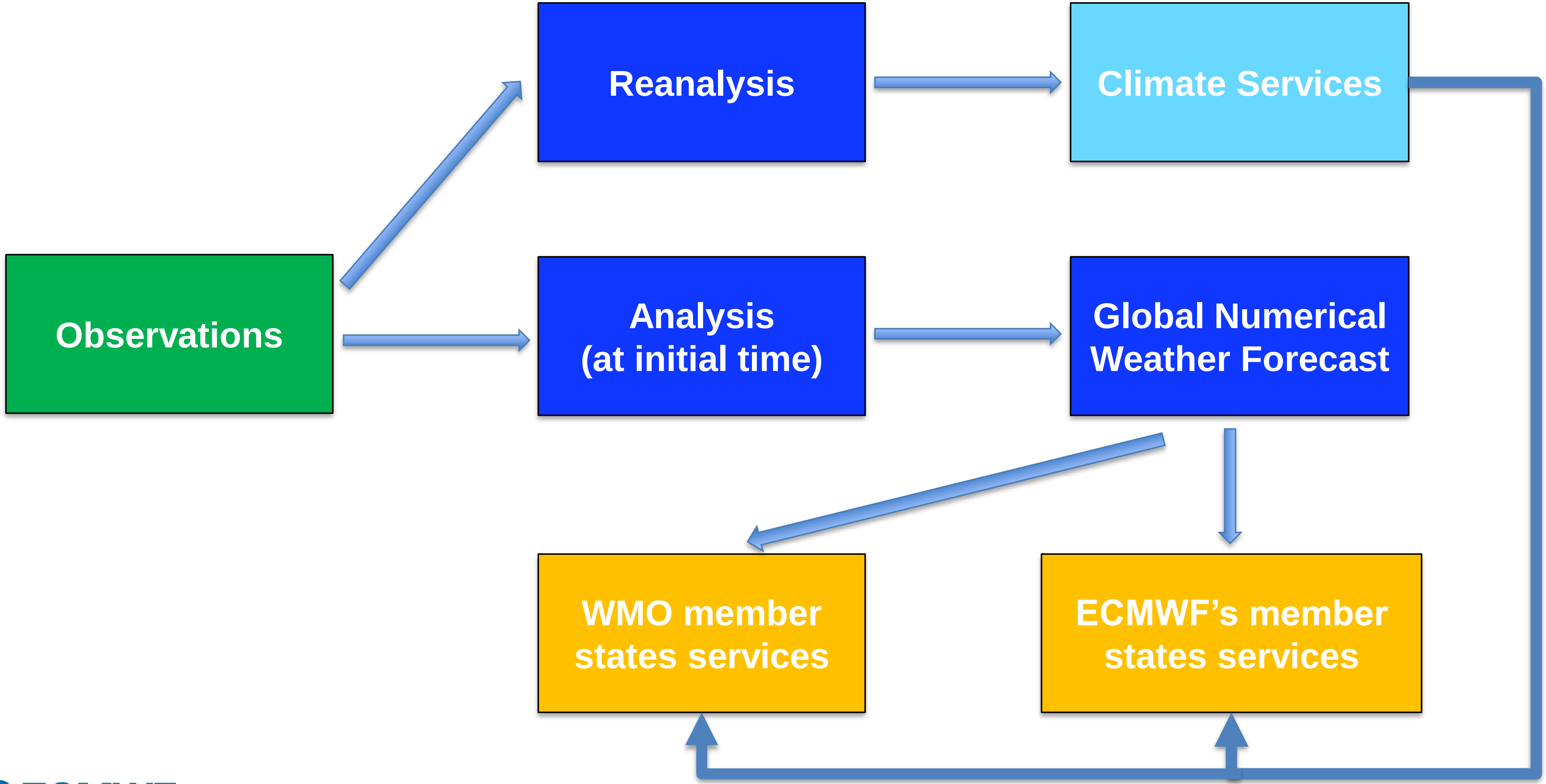
ECMWF

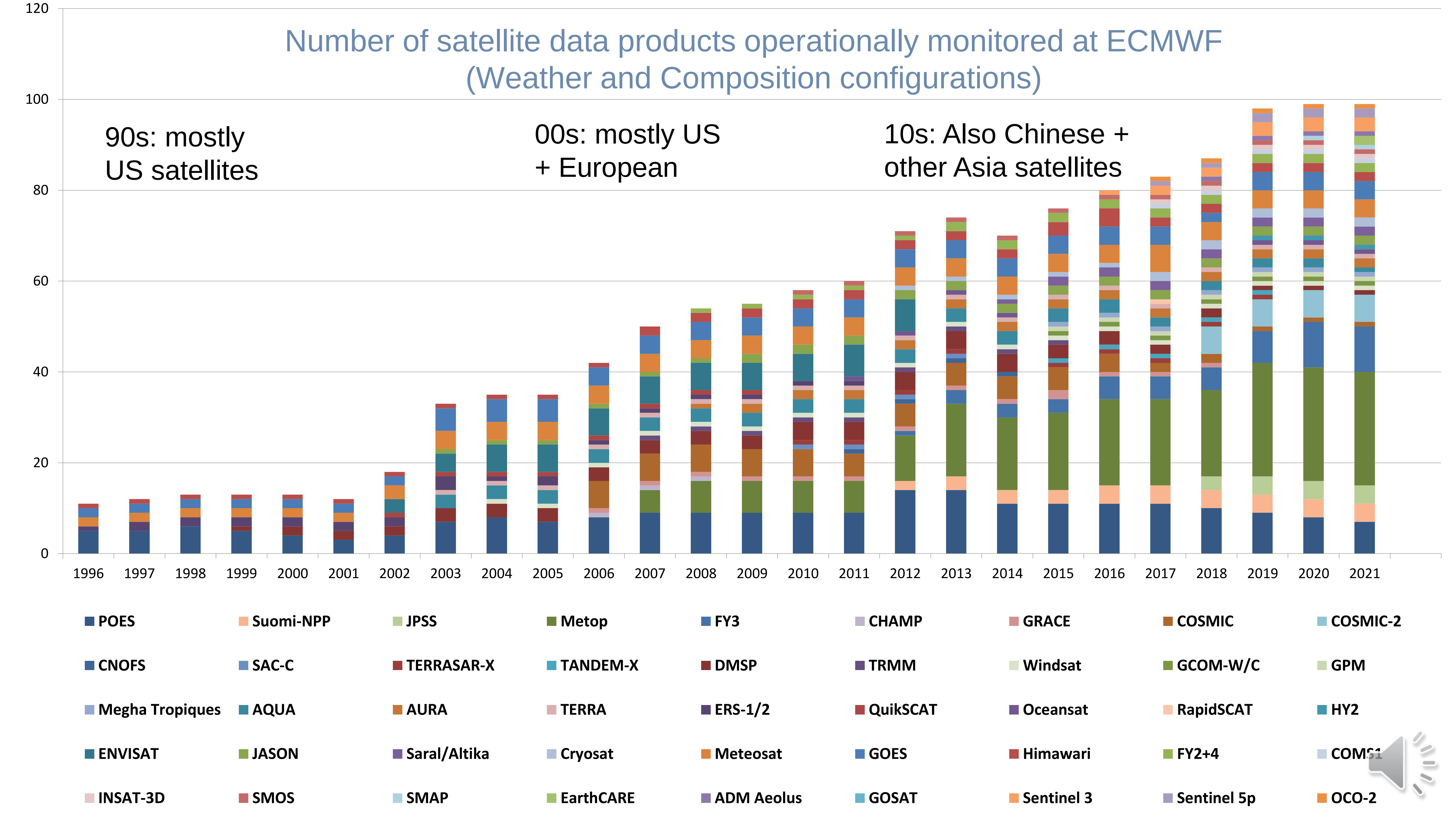
- 34 Member and Co-operating States
- 350 staff +, from 30 countries

Operational global NWP system:

- High-resolution model at T_{Co} 1279 (9 km)
- 4D-Var, 12-hour window, final incremental resolution T_L399 (50km)
- EDA, ENS, SEAS5, NEMO, …
- Reanalyses, Atmospheric Chemistry analyses

ECMWF: Global predictions for medium range (out to 15 days), extended range (out to 45 days), sub-seasonal and seasonal





Number of satellite data products operationally monitored at ECMWF
(Weather and Composition configurations)
90s: mostly US satellites
00s: mostly US + European
10s: Also Chinese + other Asia satellites
120
100
80
60
40
20
0
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
POES
Suomi-NPP
JPSS
Metop
FY3
CHAMP
GRACE
COSMIC
COSMIC-2
CNOFS
SAC-C
TERRASAR-X
TANDEM-X
DMSP
TRMM
Windsat
GCOM-W/C
GPM
Megha Tropiques
AQUA
AURA
TERRA
ERS-1/2
QuikSCAT
Oceansat
RapidSCAT
HY2
ENVISAT
JASON
Saral/Altika
Cryosat
Meteosat
GOES
Himawari
FY2+4
COMS1
INSAT-3D
SMOS
SMAP
EarthCARE
ADM Aeolus
GOSAT
Sentinel 3
Sentinel 5p
OCO-2

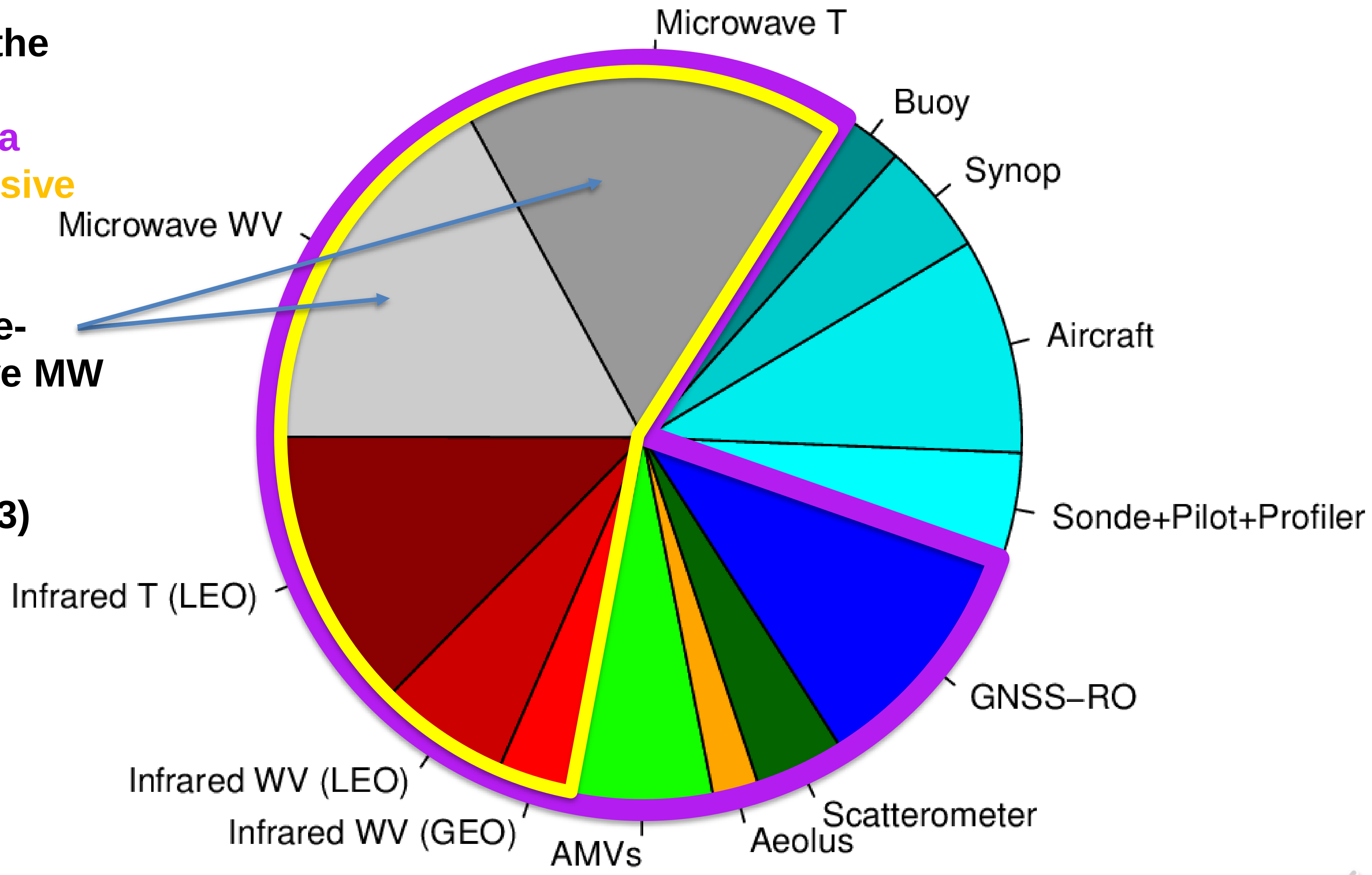
Weather observations: relative importance in the ECMWF system

Short-range forecast impact in the ECMWF system (FSOI, 2020/21)

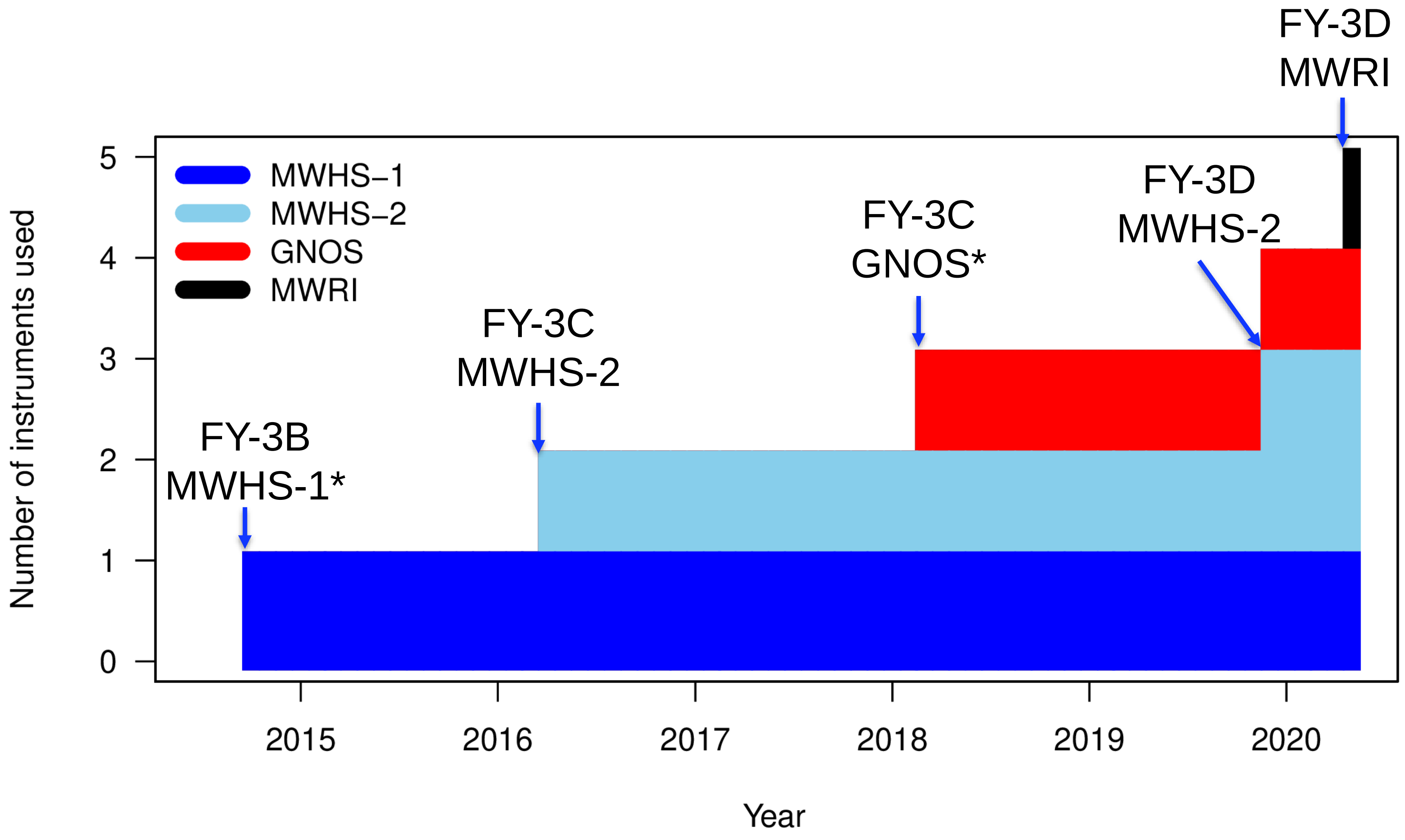
- **78% comes from satellite data**
- **56% from assimilation of passive IR or MW radiances**

Similar impact from temperature-sounding and humidity-sensitive MW radiances

- **All-sky use**
- **Many sensors (incl. from FY-3)**



Increasing number of FY-3 instruments used at ECMWF in operations



* = data unavailable since June 2020

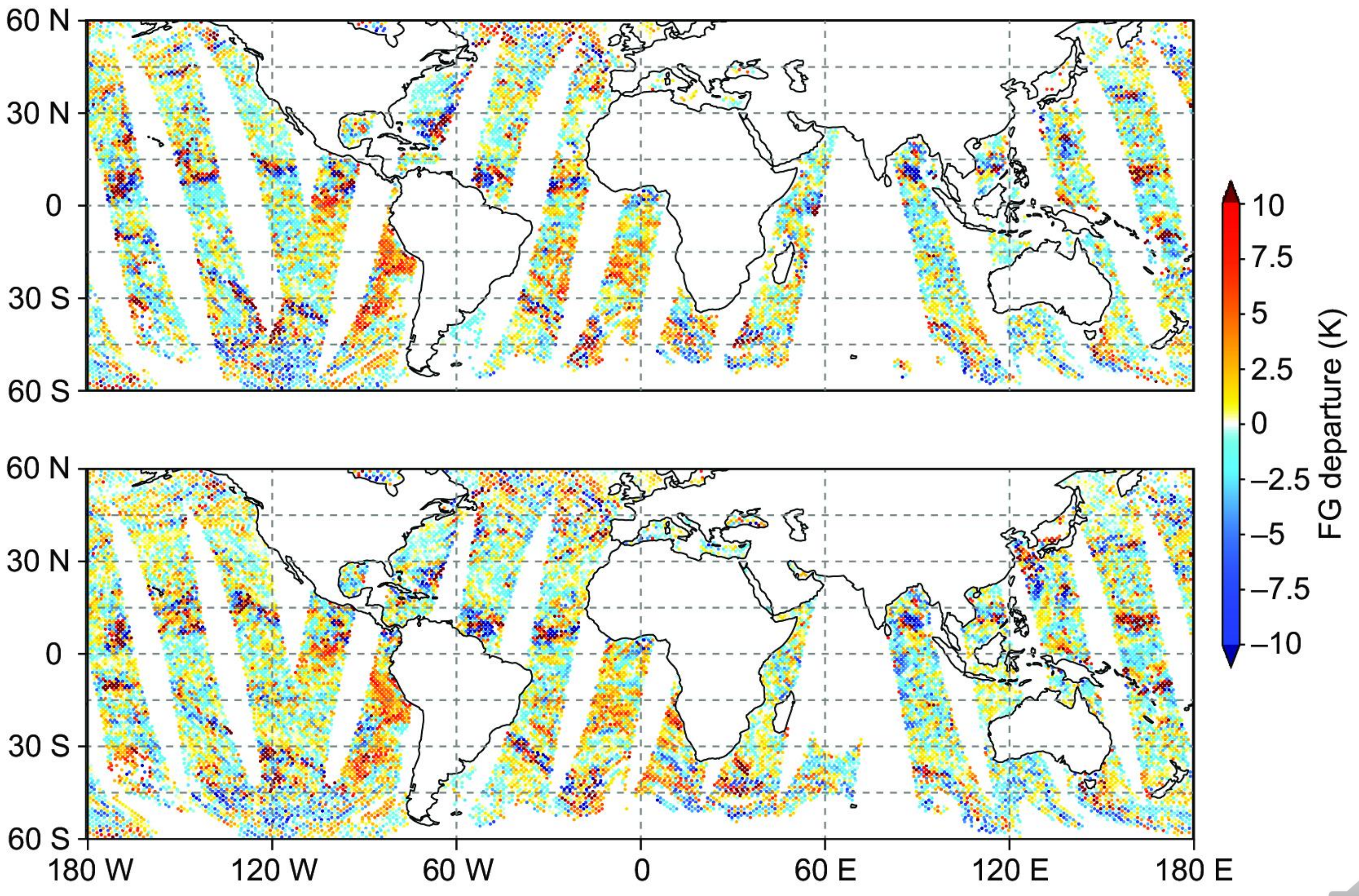
(Katrin Lonitz, David Duncan)

Latest addition from the FY-3 series: MWRI from FY-3D

Operationally assimilated since 13 May 2020

MWRI, 37 GHz V, o-b (after bias correction)

AMSR2, 37 GHz V, o-b (after bias correction)



FY-3 data have a significant impact in the ECMWF system

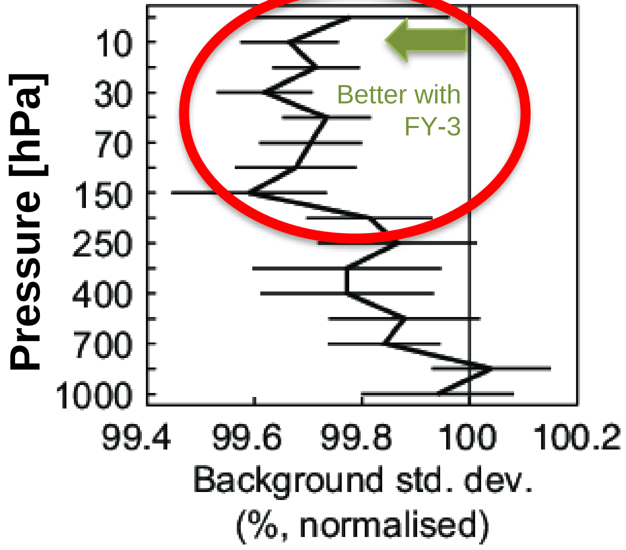
Combined impact of 5 FY-3 instruments, Sept 2019 – Feb 2020

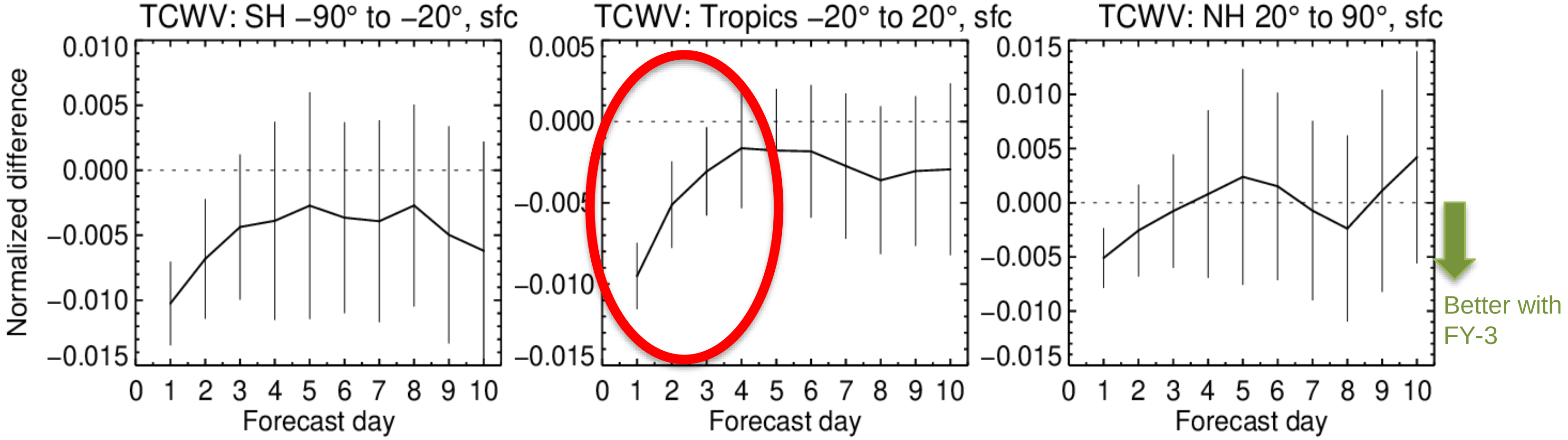
- 1 MWHS; 2 MWHS-2; 1 MWRI; 1 GNOS

Forecast benefits especially for humidity, and in the upper troposphere/stratosphere

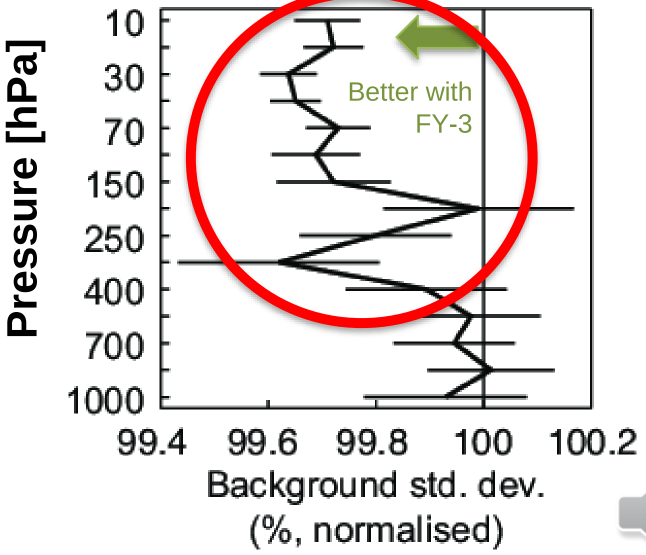
(see also Bormann et al 2021, AAS)

Short-range forecast vs radiosondes, temperature

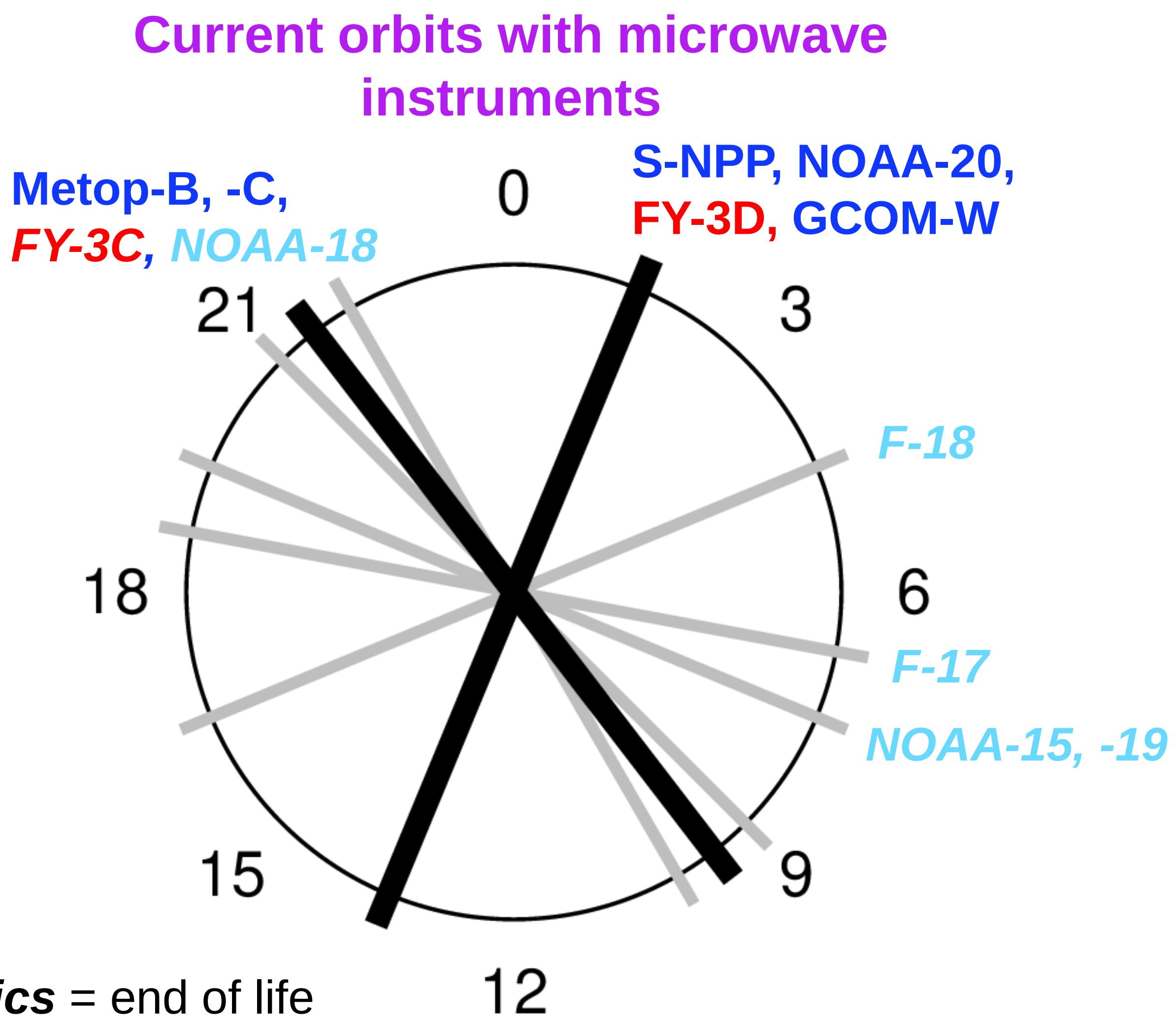




Short-range forecast vs wind observations



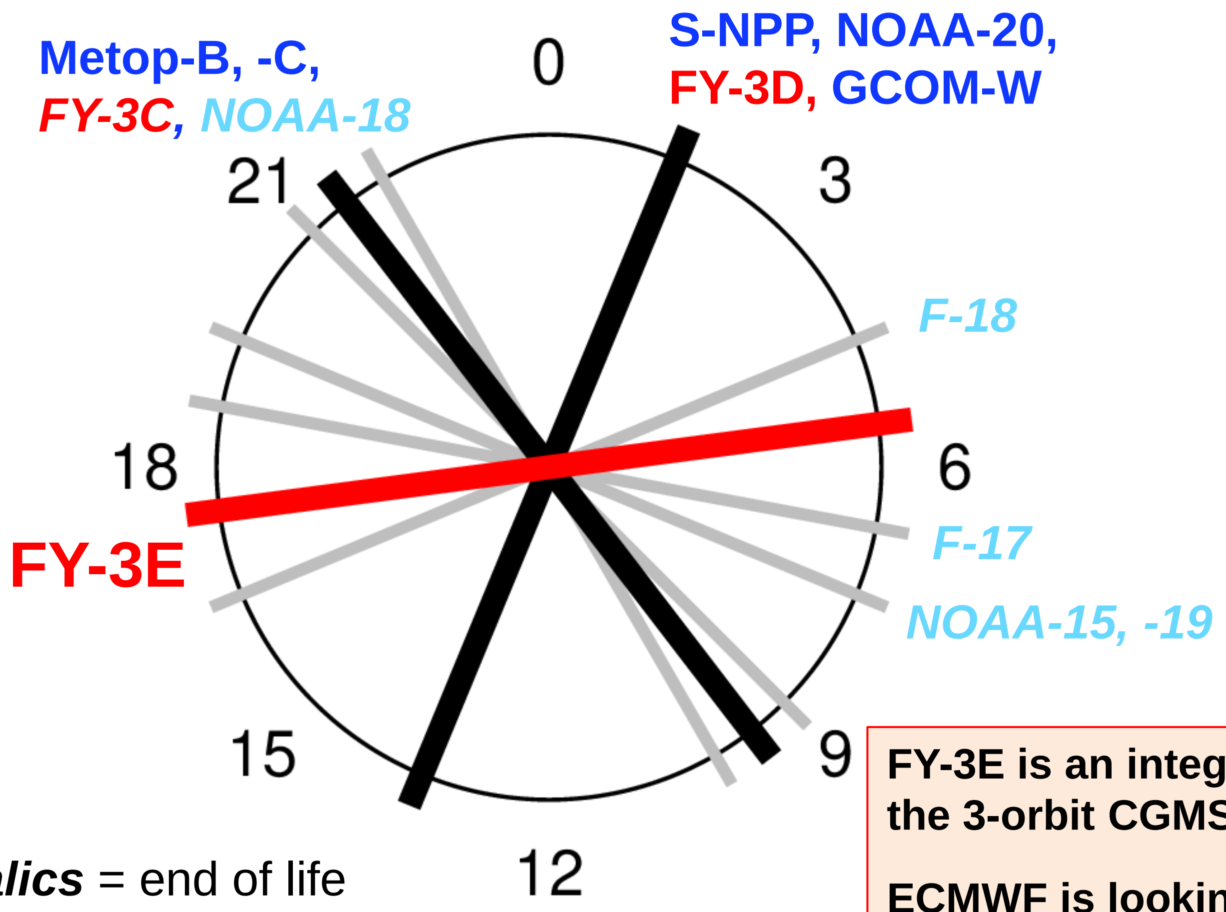
FY-3C/D in the context of other polar satellites



Italics = end of life expected soon

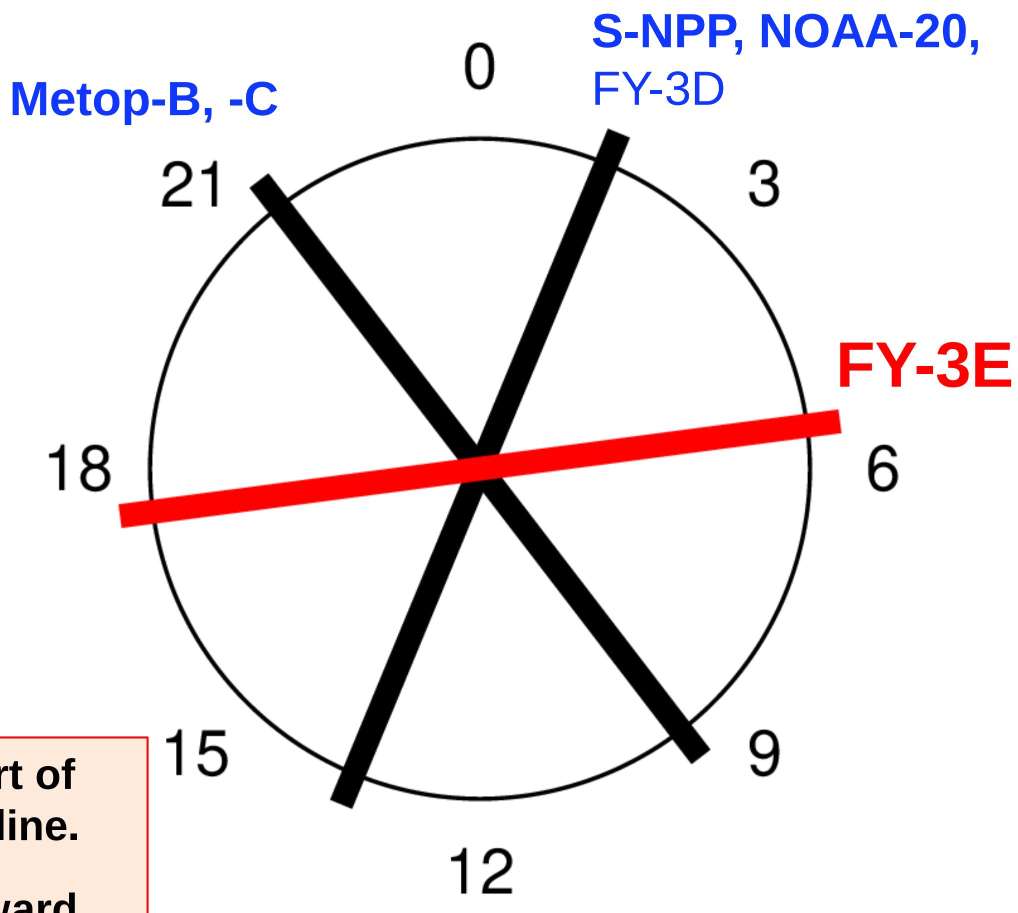
FY-3E in the early morning orbit: important coverage in a unique orbit

Current orbits with microwave instruments



Italics = end of life expected soon

Orbits with hyperspectral infrared instruments



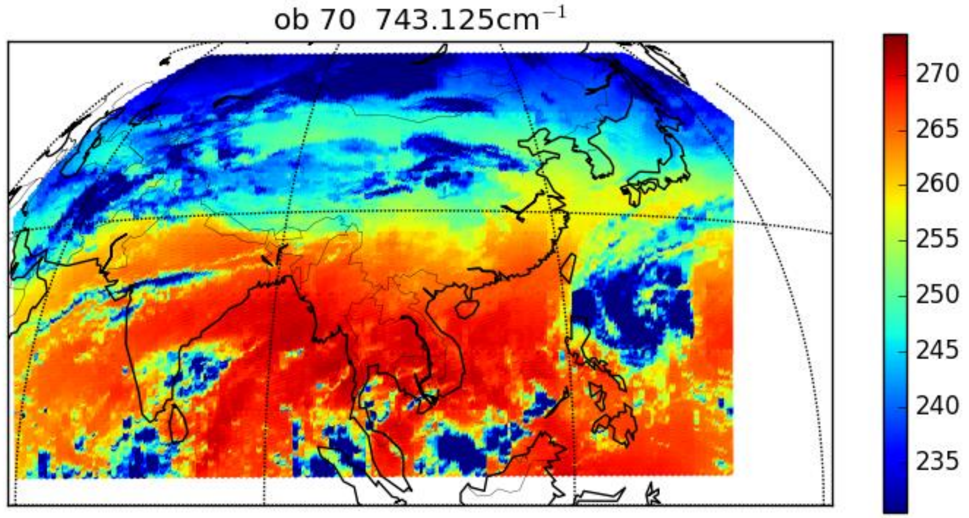
FY-3E is an integral part of the 3-orbit CGMS baseline.

ECMWF is looking forward to using FY-3E data.

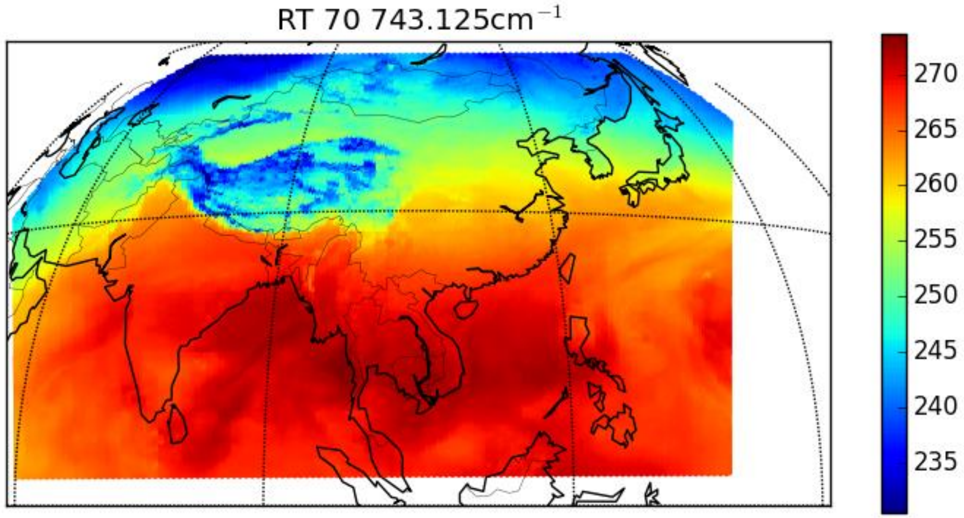
GIIRS on FY-4A: first hyper-spectral IR from geo-orbit

(Chris Burrows)

Obs (BT) from one scan



Clear sky simulations (ECMWF analysis + RTTOV)



- Comparisons against ECMWF model fields have allowed issues with the data to be identified, in collaboration with CMA and SSEC.
- They also informed data selection choices for subsequent assimilation.

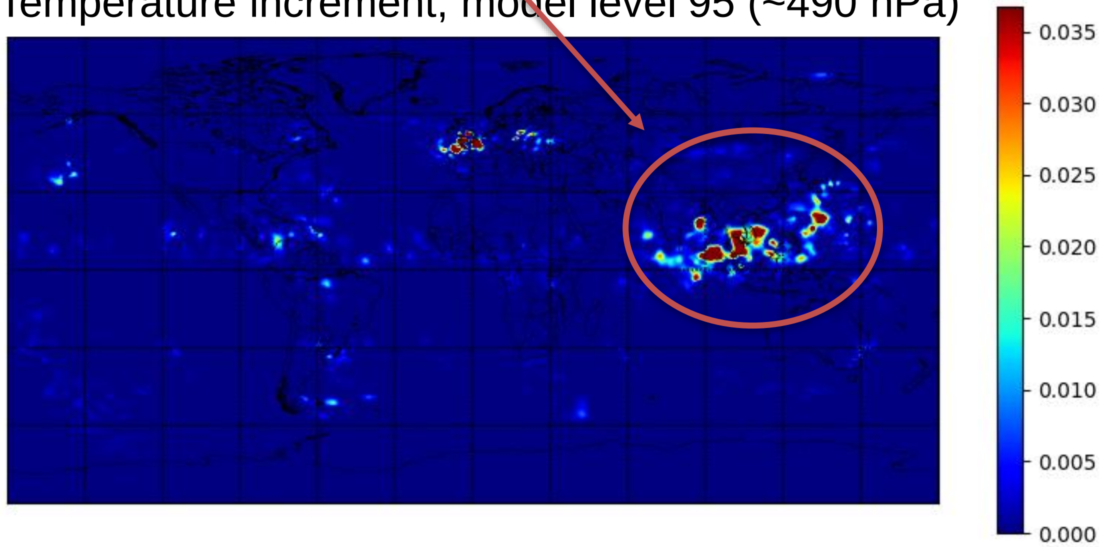
ECMWF

Experimental assimilation of GIIRS data from FY-4A

(Chris Burrows)

GIIRS produces temperature increments with sensible magnitudes over the scanning domain.

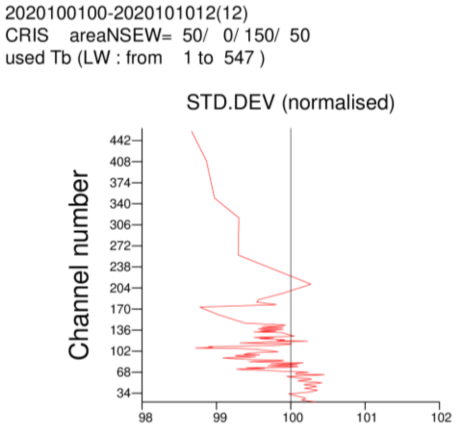
Temperature increment, model level 95 (~490 hPa)



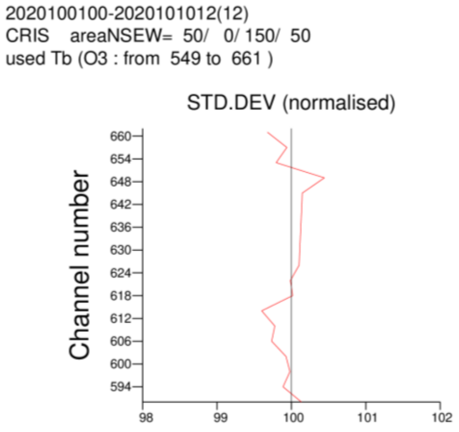
ECMWF is looking forward to evaluating data from the recently launched FY-4B satellite.

Short range forecast fits to CrIS observations are improved over GIIRS domain

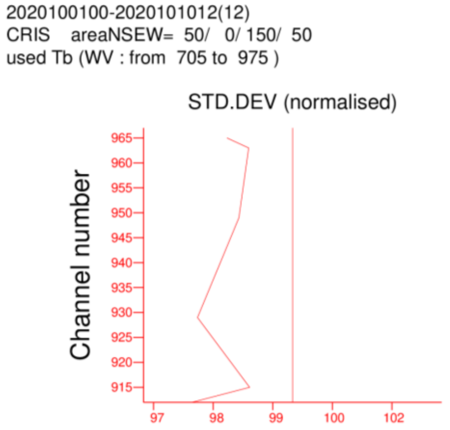
Temperature+window



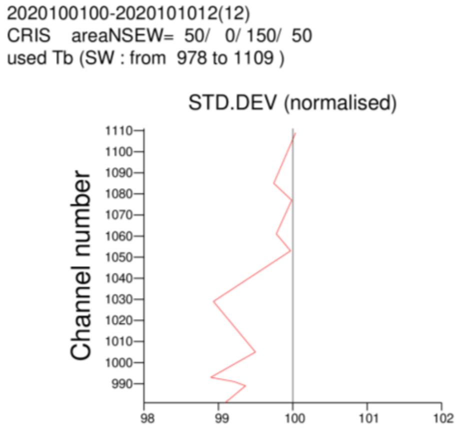
Ozone



Lower WV



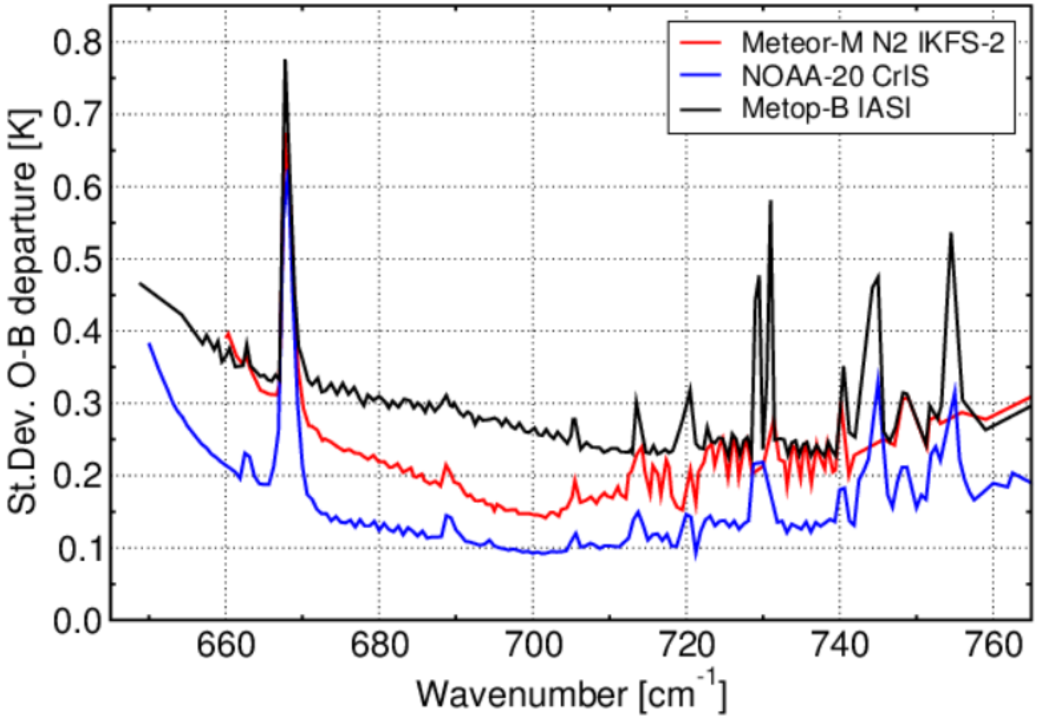
Upper WV



(Reima Eresmaa, Cristina Lupu)

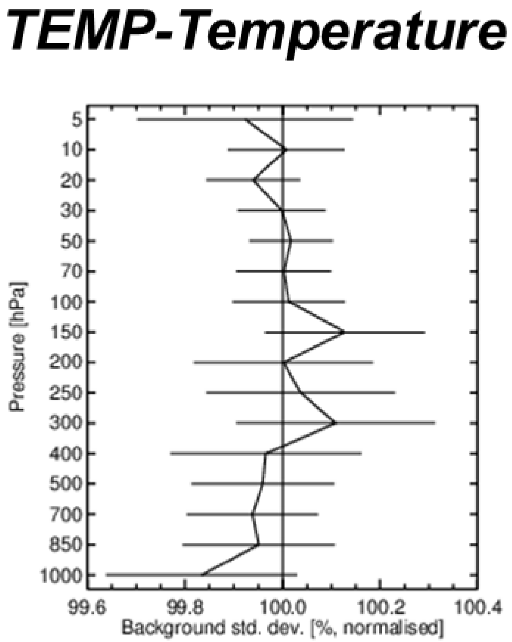
ECMWF also evaluates new observations from Russia

E.g.: hyperspectral IR instrument IKFS-2 on Meteor-M N2

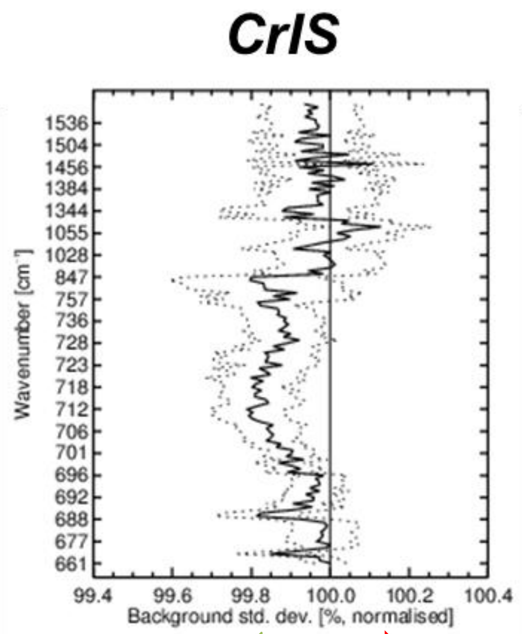


(note: different spectral and spatial resolution)

Encouraging short-range forecast impact from assimilating 258 IKFS-2 channels:
(1 March -14 July 2021)

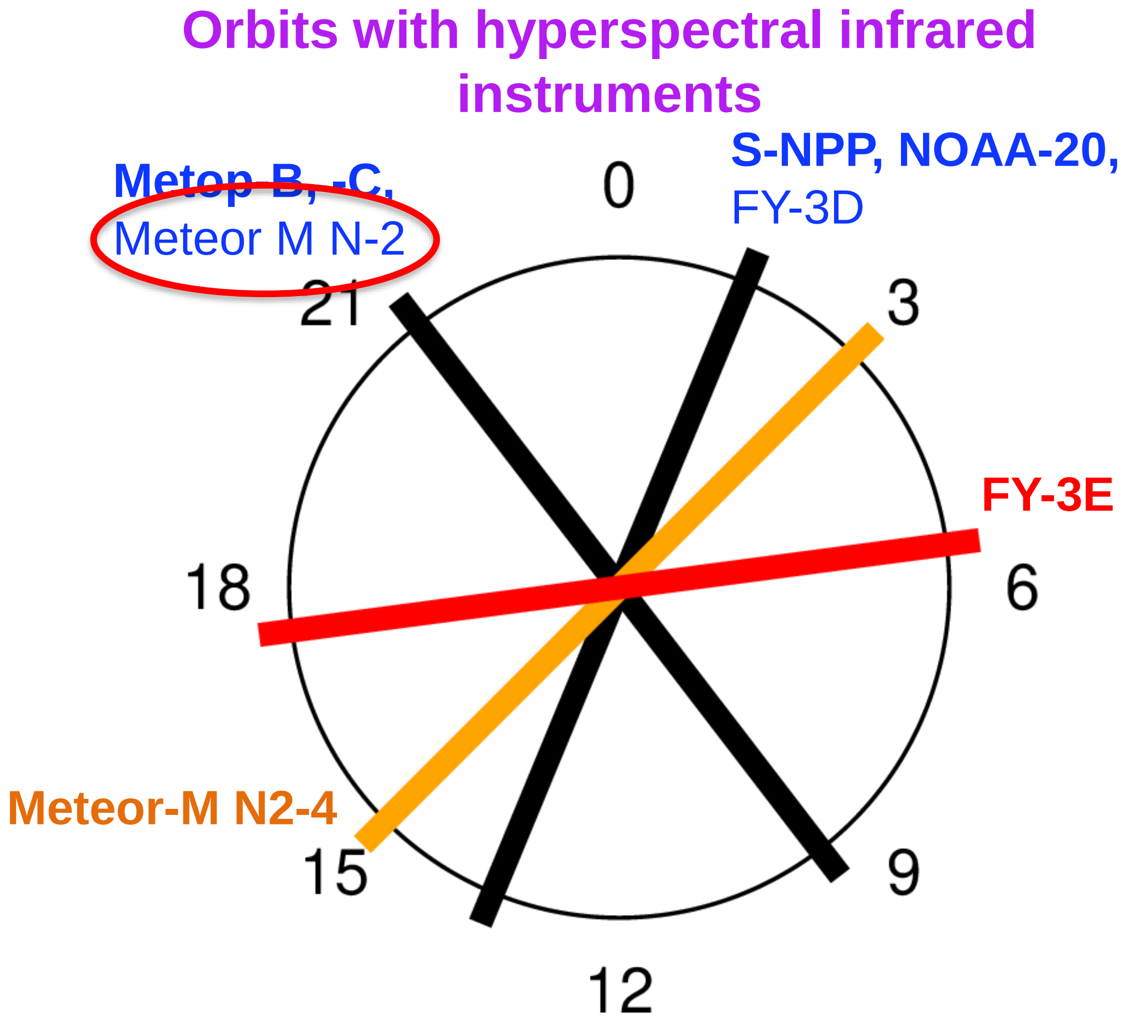


Better with IKFS-2
Better without



Better with IKFS-2
Better without

Future Meteor-M N2-4 satellite very attractive to further complement the LEO IR constellation

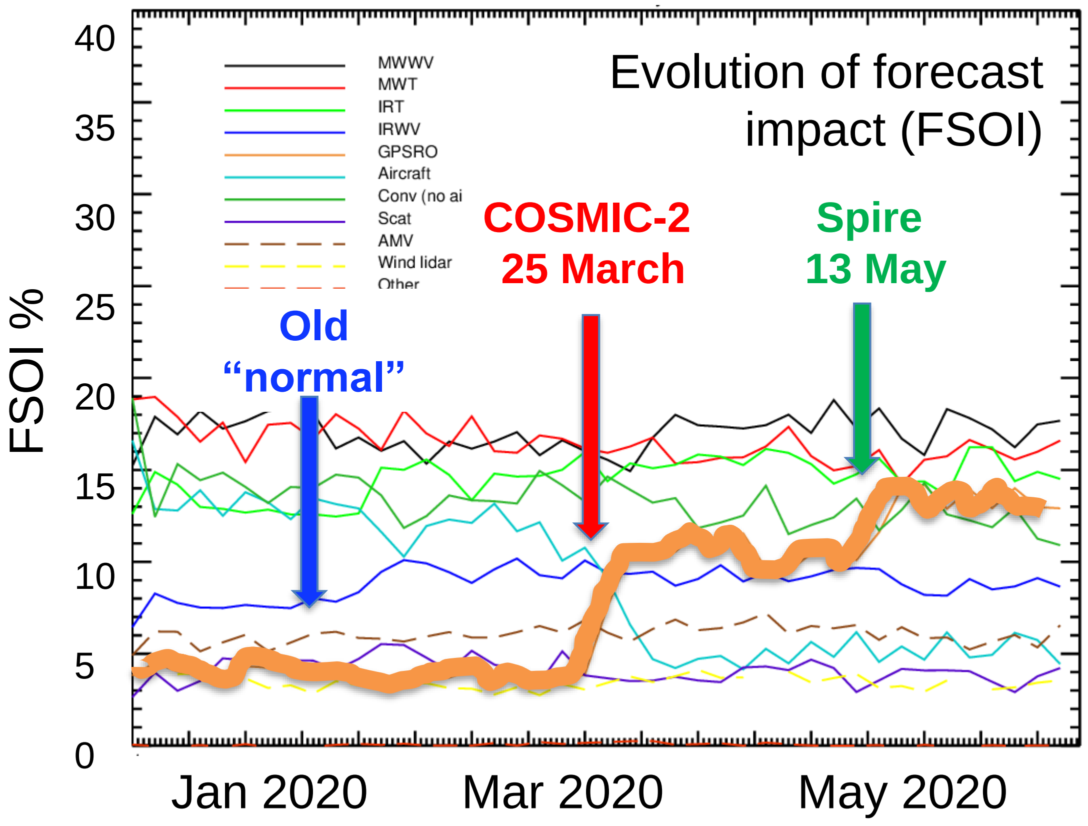


Other new observations used in operations

- **GNSS/RO data from COSMIC-2 and Spire**
- **Aeolus Doppler Wind Lidar**

Strong increase in the impact of radio occultation data

(Chris Burrows, Katrin Lonitz, Sean Healy)

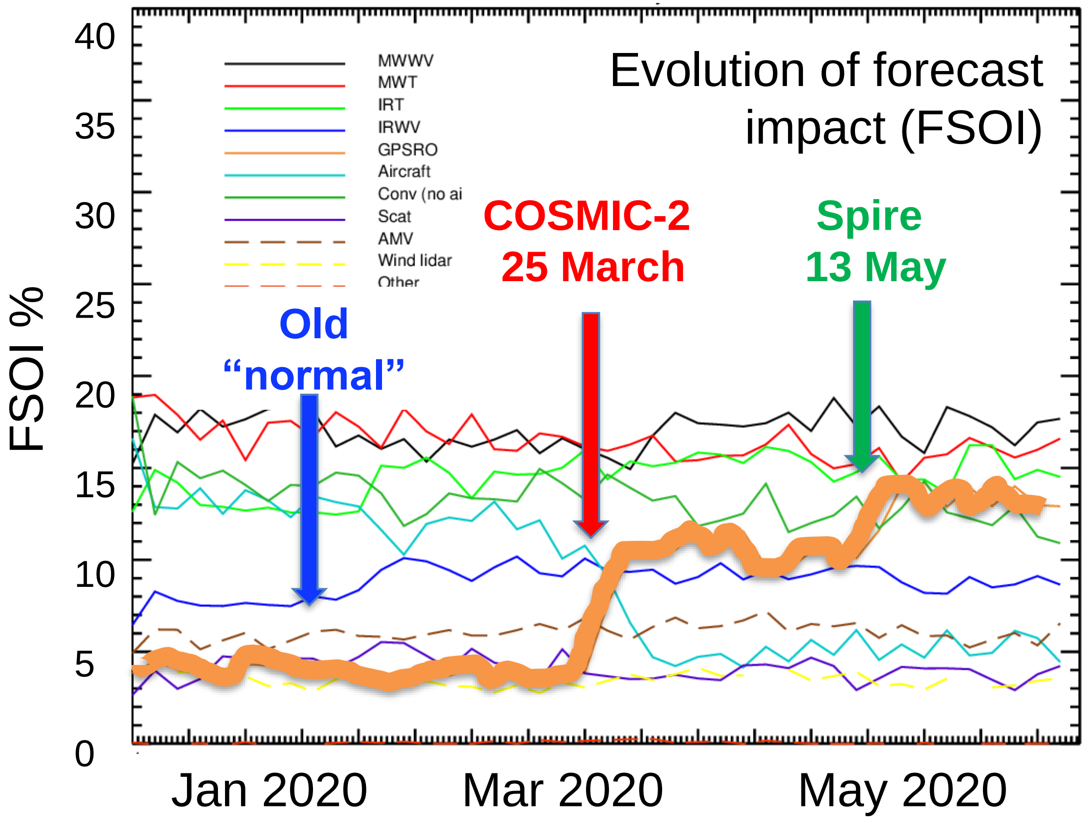


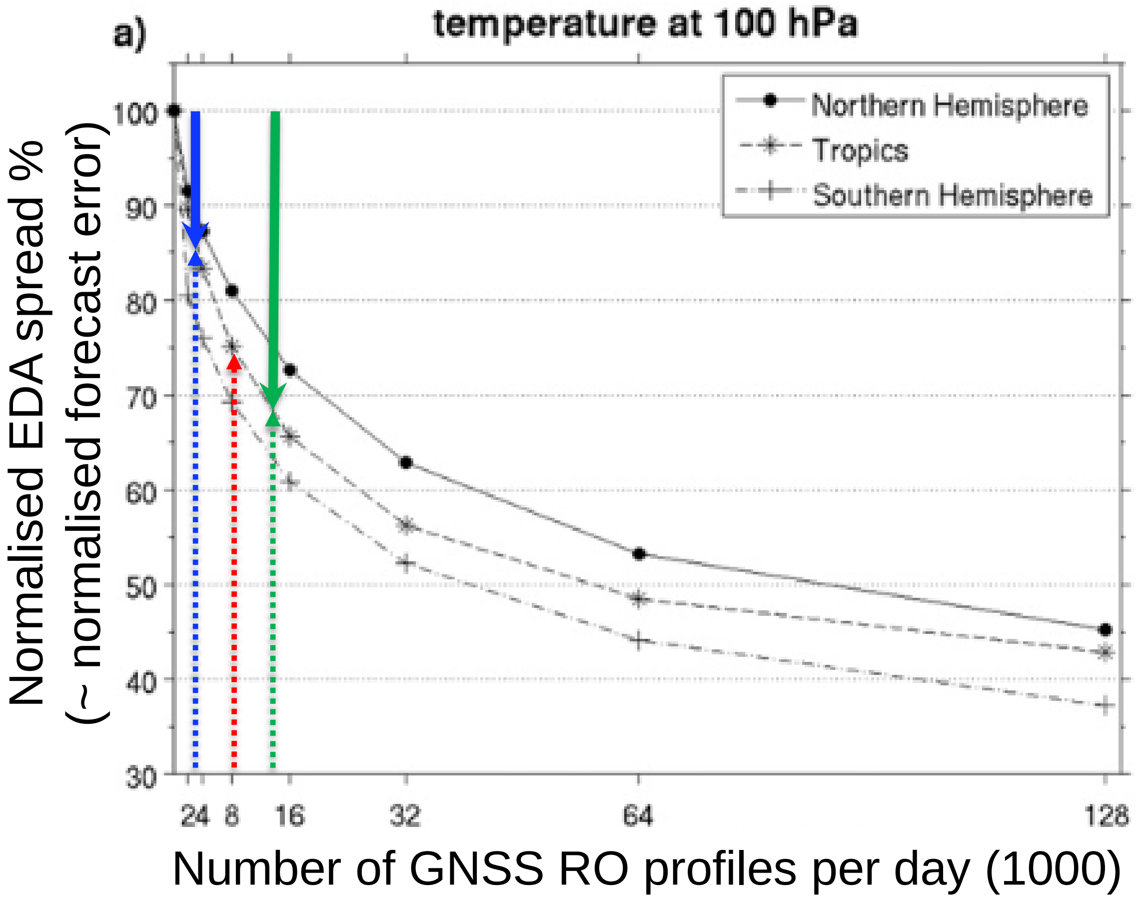
More GNSS RO profiles assimilated:

- Start of 2020: ~ 3000 profiles per day
- March: + ~5000 profiles per day from COSMIC-2
- May: + ~5000 profiles per day from Spire
  (until 30 Sept 2020)

Strong increase in the impact of radio occultation data

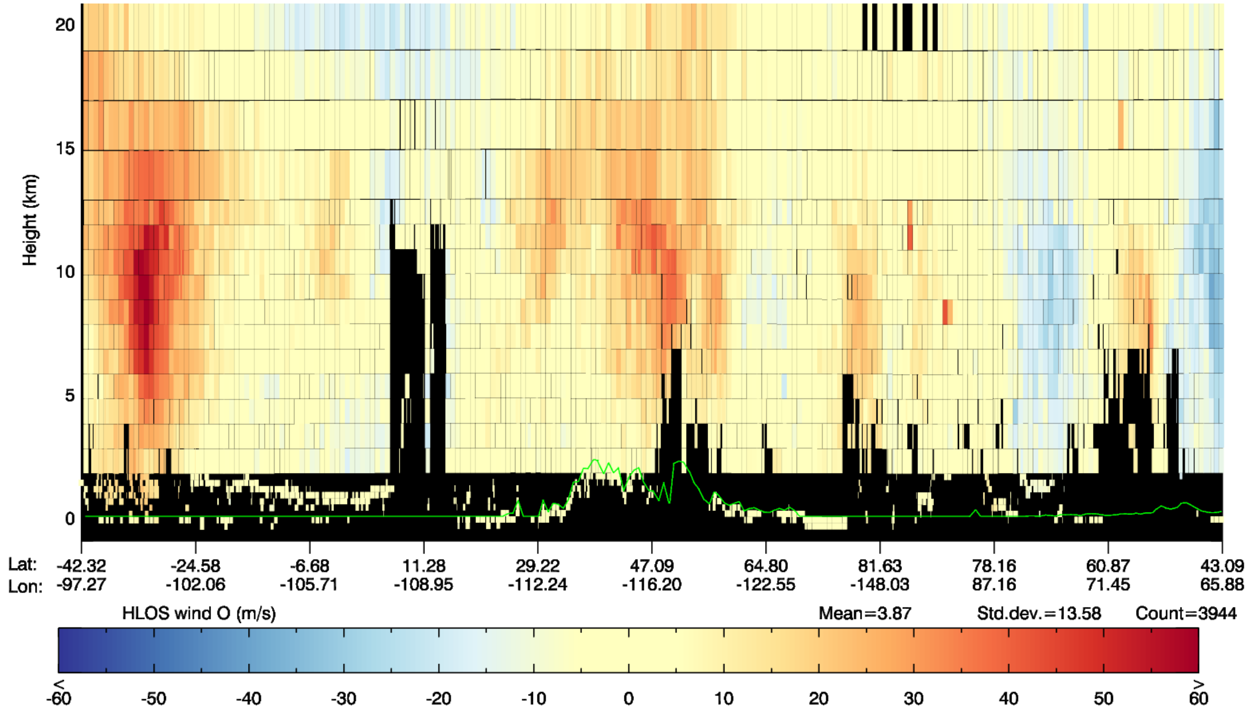
(Chris Burrows, Katrin Lonitz, Sean Healy)





Impact broadly consistent with predictions from simulations conducted in 2013 (Harnisch et al 2013)

Aeolus: first doppler wind lidar in space



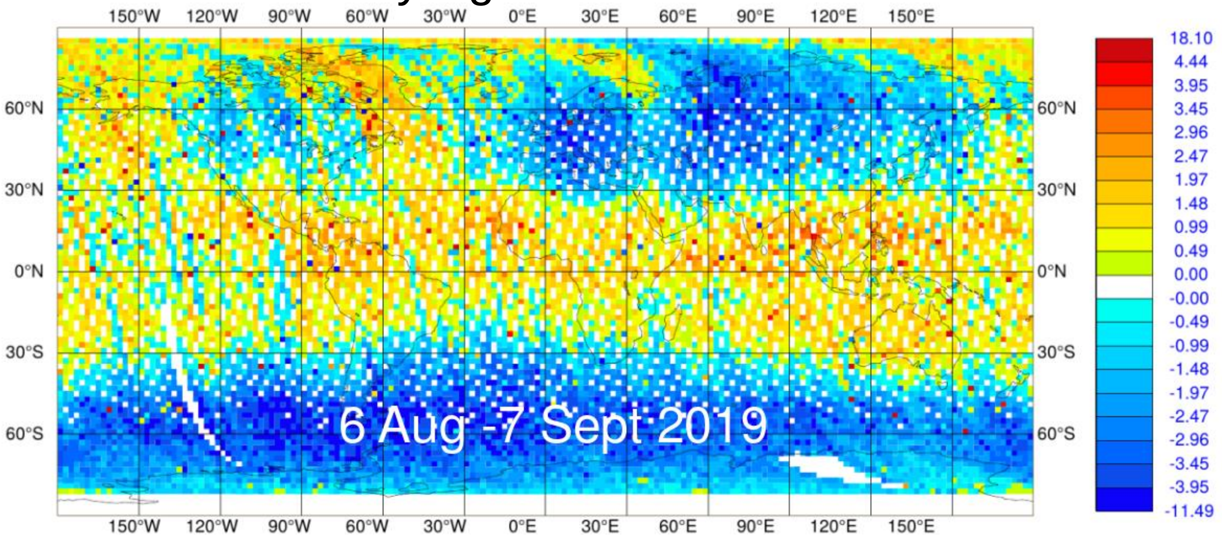
Wind profiles generated at ECMWF less than two weeks after launch.

(Mike Rennie, Lars Isaksen)

Initial Aeolus wind biases understood, aided by monitoring in NWP

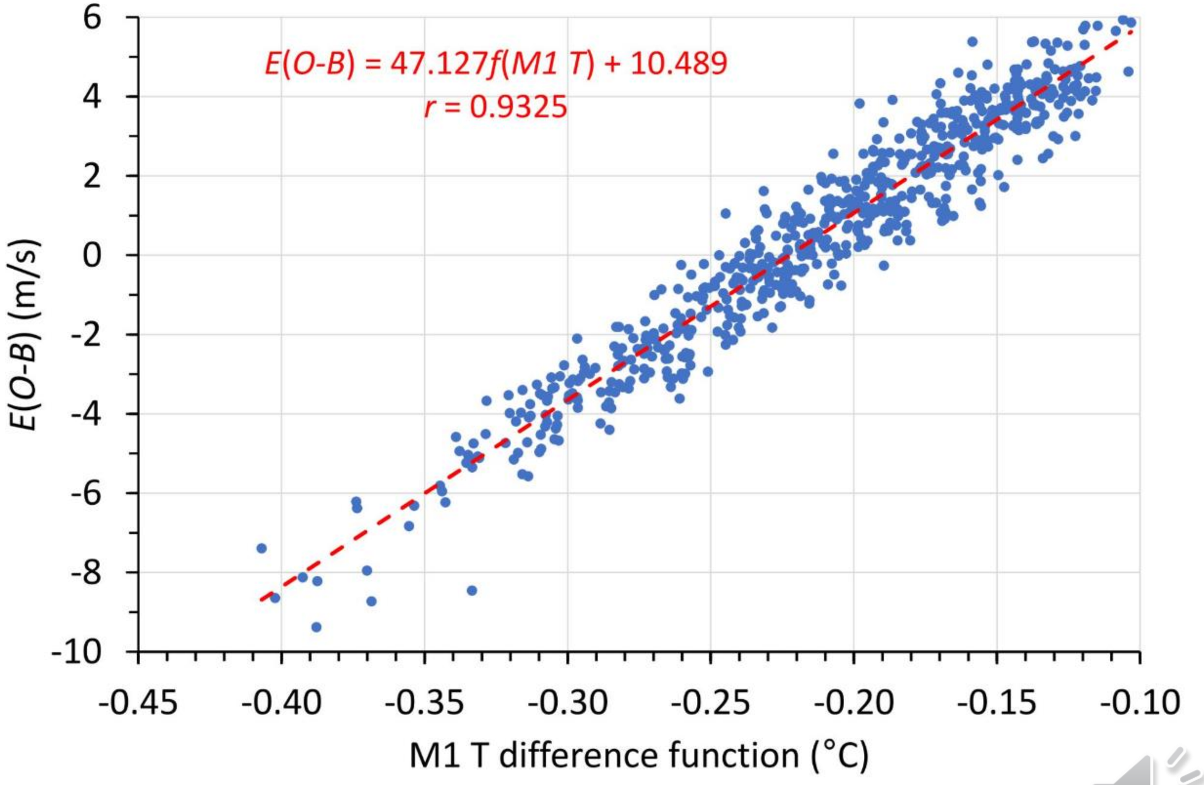
(Mike Rennie, Lars Isaksen)

Bias (o-b) m/s, ascending phase, Rayleigh-clear winds



Linked to temperature gradients on M1 mirror, affecting mirror shape and focus.

Subsequently corrected for in data processing.

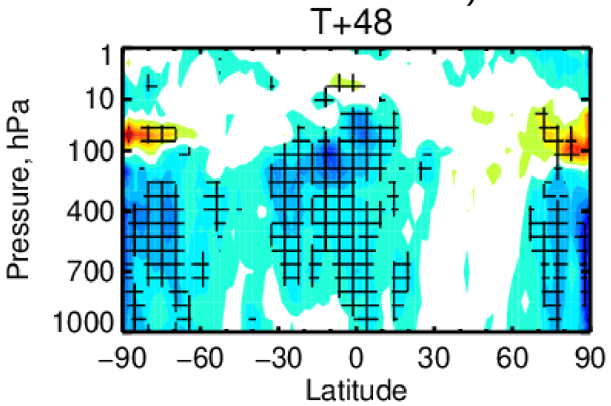


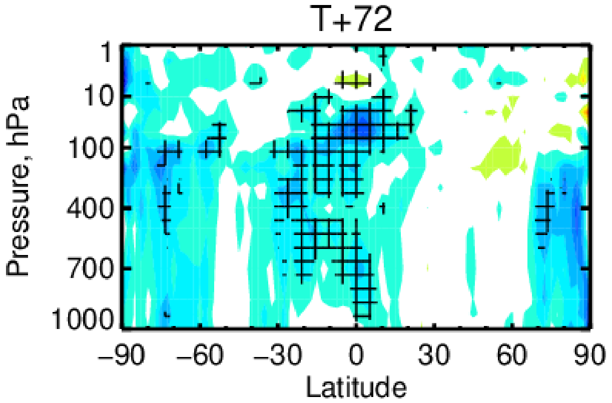
Impressive NWP impact achieved with Aeolus wind observations

(Mike Rennie, Lars Isaksen)

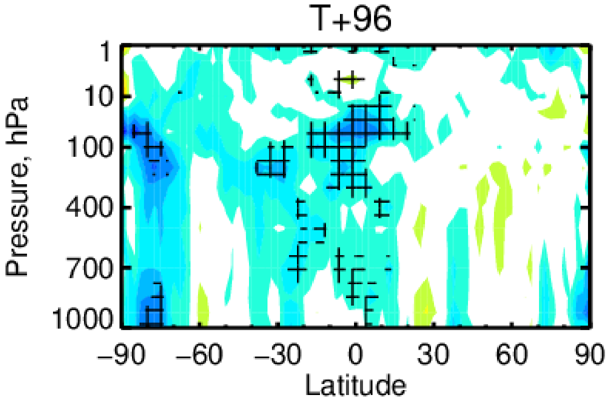
- **Assimilated operationally since 9 January 2020**

Forecast impact in OSEs from adding reprocessed Aeolus data:
(29 June – 31 December 2019)

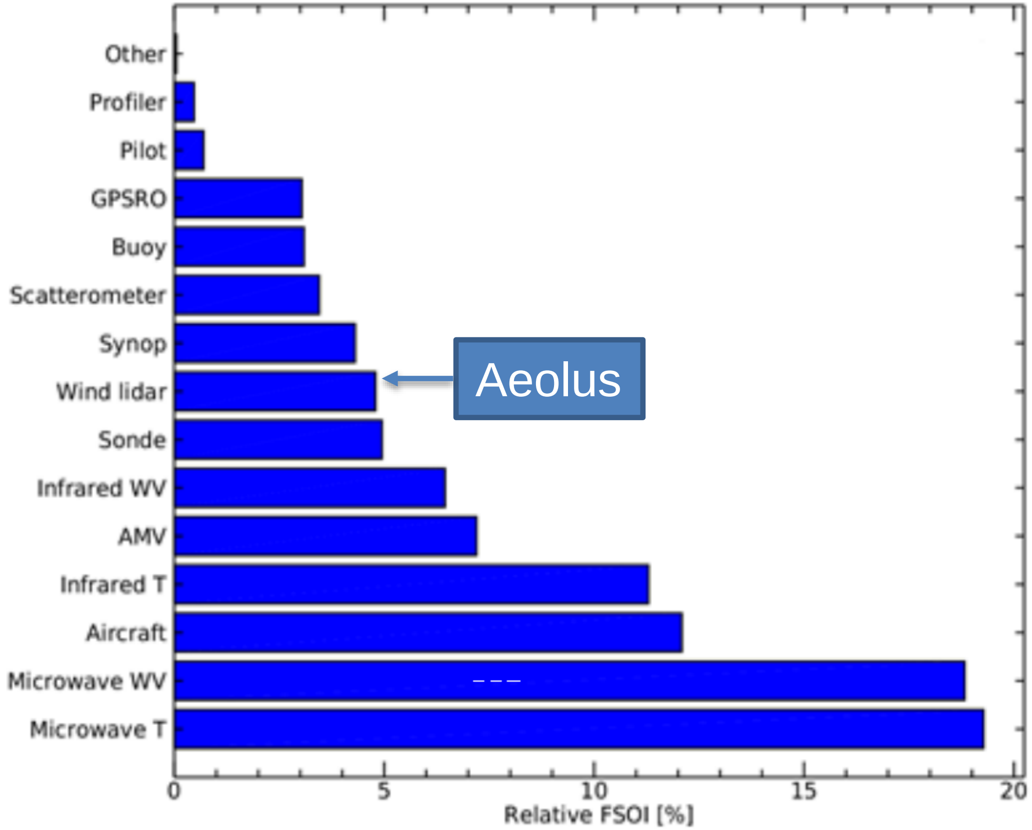




Difference in vector wind RMSE: ±4% scale



Forecast impact in terms of FSOI:
Aeolus compares well with other data types despite being a single instrument.

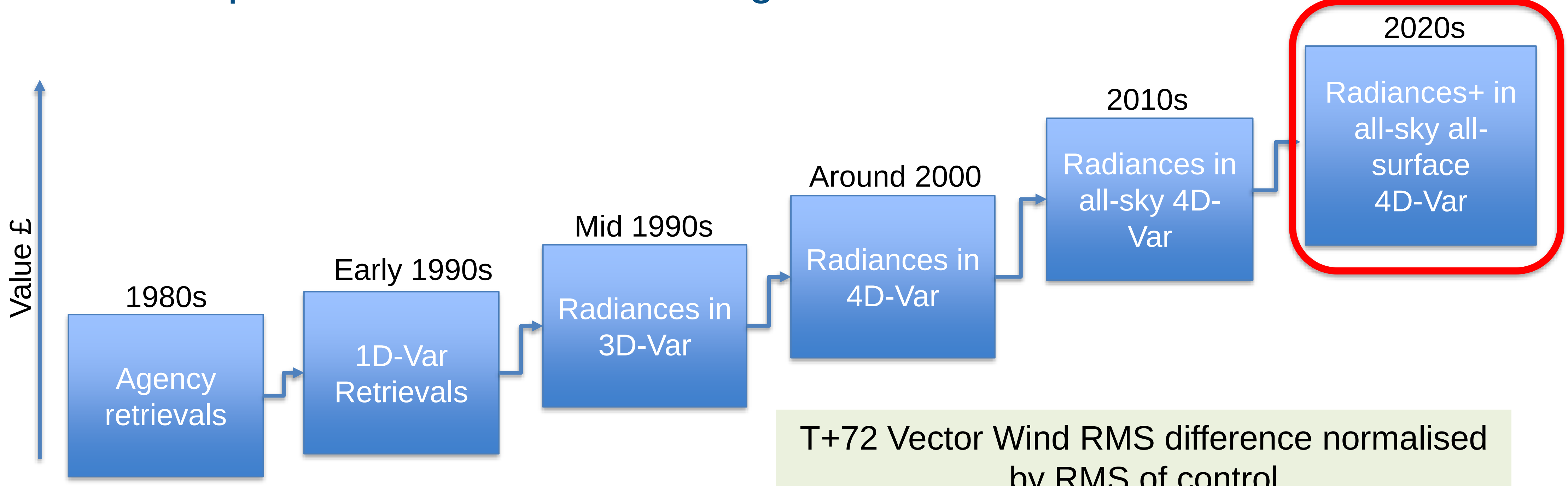


(Note: later periods affected by gradual signal loss, under investigation.)

Strategies towards fuller exploitation of observations

- **All-sky/all-surface**
- **Coupled Earth System**

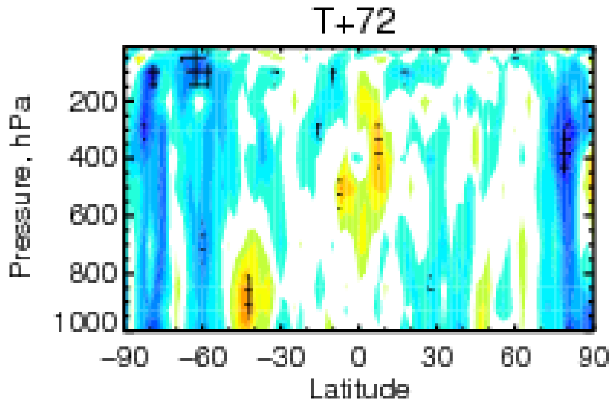
Increased impact of observations through better data assimilation



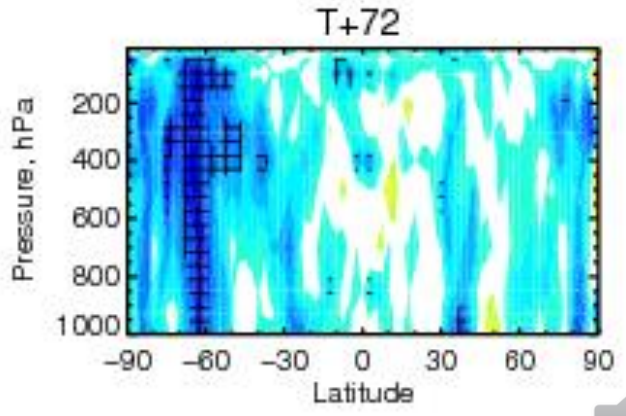
E.g., impact of humidity-sensitive MW observations: Increased from minor to major through move to **all-sky** assimilation

T+72 Vector Wind RMS difference normalised by RMS of control

Clear-sky MHS impact



All-sky MHS impact



-4% -2% 0% 2% 4%

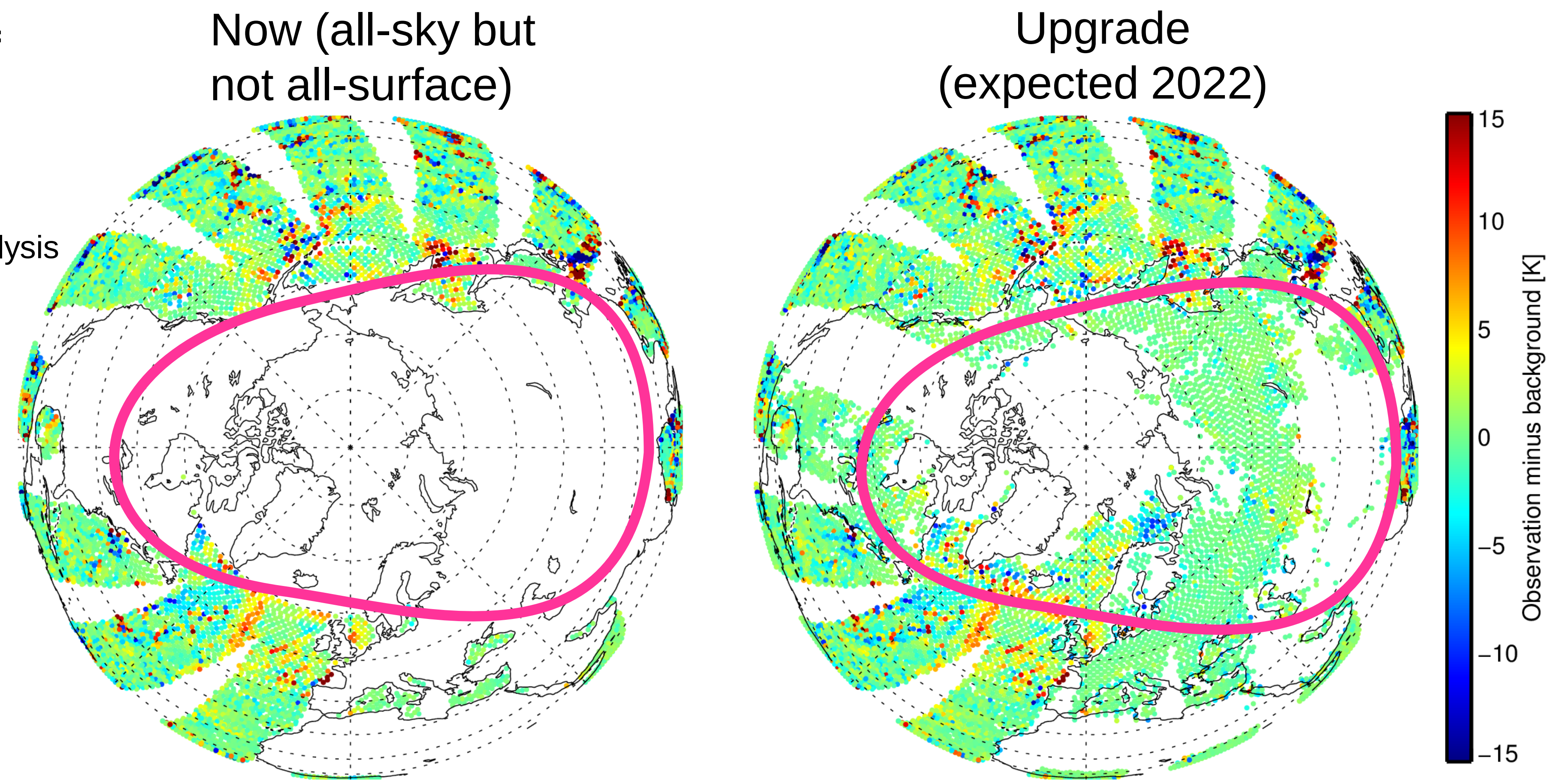
ECMWF

Extending the use of surface-sensitive MW imager radiances

(Alan Geer)

E.g., assimilation of AMSR2 radiances:

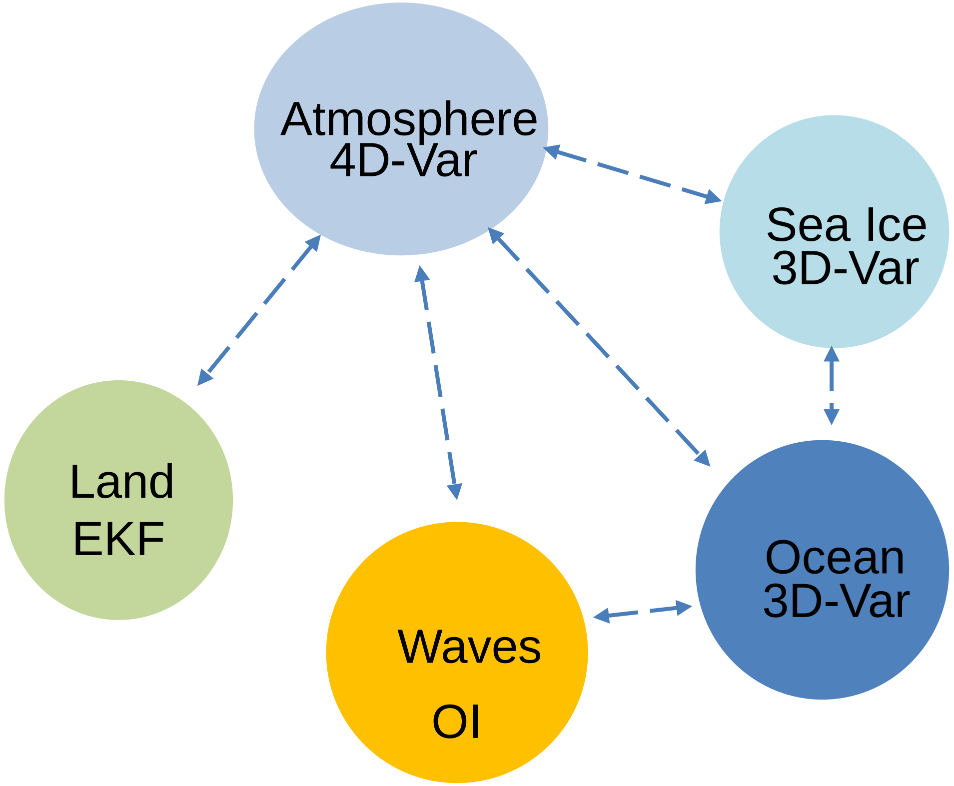
36.5 GHz, v-polarised, o-b
26 June 2019, 00 UTC analysis cycle



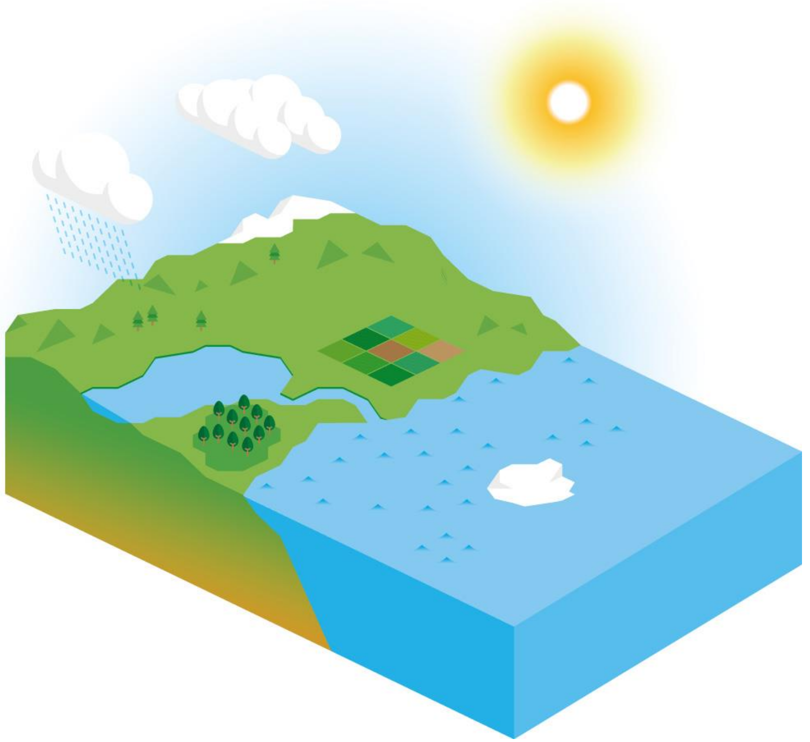
Adding higher latitudes, land surfaces, mixed scenes (land – water)

(but excluding sea-ice, snow, high altitudes, desert soils)

Coupled assimilation strategy: changes the role of observations



Coupled assimilation to initialise coupled forecasts in our operational systems



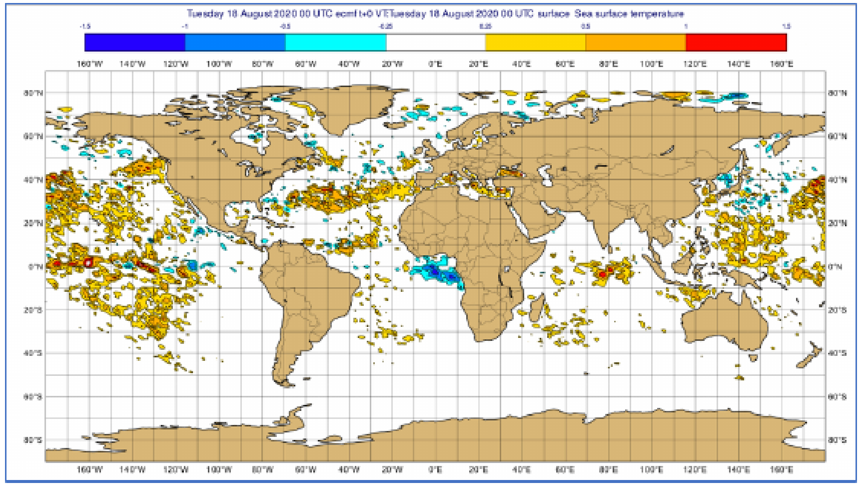
ECMWF

(Patricia de Rosnay and Phil Browne)

Exploiting opportunities in a coupled assimilation system: IR sounders affecting ocean temperatures

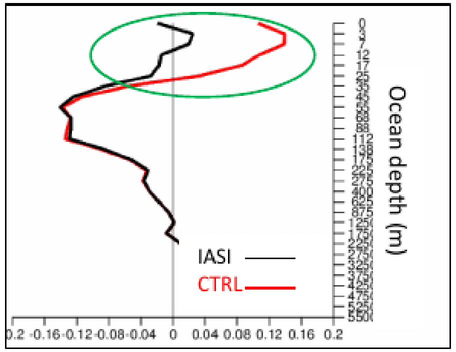
(Tony McNally, Phil Browne, David Fairbairn)

Mean SST change IASI minus CTRL (20200820-20200920)



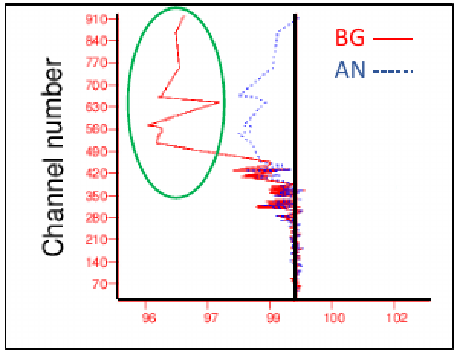
Skin-temperature is retrieved from three IASI instruments inside the atmospheric system and then ingested in the coupled ocean assimilation system.

Ocean analysis bias with respect to ARGO observed potential temperature(20200820-20200920)



Changes to ocean temperatures supported by surface and sub-surface in-situ observations in the ocean.

Normalized reduction (%) in random misfit to IASI radiances (20200820-20200920)



Improvements in the ocean feed back positively to the radiance assimilation for the atmosphere.

Conclusions

- **Growing use of FY-3 observations in the operational ECMWF system and reanalyses with beneficial impact (MWHS-1/2, MWRI, GNOS).**
  - Evaluations of MWTS-2 and hyperspectral IR from HIRAS and GIIRS on-going
  - FY-3E in the early-morning orbit is very important for adding unique orbit coverage
  - ECMWF is looking forward to receiving data from FY-3E and FY-4B
- **Strong benefits from recent additions of actively-sensed observations:**
  - GNSS/RO: COSMIC-2, SPIRE more than doubled the impact of GNSS/RO
  - Aeolus – strong impact of wind profiles from the first Doppler Wind Lidar in space
- **Exciting opportunities to exploit existing observations more fully in coupled Earth System Assimilation**
  - E.g., “interface observations” influencing atmosphere and ocean systems consistently
- **Global NWP centres like ECMWF combine the strengths of a wide range of observations in a physically consistent and optimal way, optimizing the return on investments in satellite programmes around the world.**
  - International collaboration on data provision and exploitation is more important than ever.

Thank you for listening