Satellite data assimilation for NWP

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

Current orbits with microwave instruments

Metop-B, -C, FY-3C, NOAA-18
S-NPP, NOAA-20, FY-3D, GCOM-W

Italics = end of life expected soon
FY-3E in the early morning orbit: important coverage in a unique orbit

Current orbits with microwave instruments

Metop-B, -C, *FY-3C, NOAA-18*

S-NPP, NOAA-20, FY-3D, GCOM-W

Orbits with hyperspectral infrared instruments

Metop-B, -C

S-NPP, NOAA-20, FY-3D

* Italics = end of life expected soon *

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

ECMWF is looking forward to using FY-3E data.
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.
Experimental assimilation of GIIRS data from FY-4A

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.

2020100100-20201012(12)
CrIS areaNSEW= 50° 0° 150° 50 used Tb (LW : from 1 to 547)

2020100100-20201012(12)
CrIS areaNSEW= 50° 0° 150° 50 used Tb (SW : from 978 to 1109)

Temperature+window
Ozone

Lower WV
Upper WV

Temperature increment, model level 95 (~490 hPa)
ECMWF also evaluates new observations from Russia

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

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

(note: different spectral and spatial resolution)
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

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

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.

\[ E(O-B) = 47.127f(M1 \ T) + 10.489 \]

\( r = 0.9325 \)

6 Aug - 7 Sept 2019
Impressive NWP impact achieved with Aeolus wind observations

- 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**
Extending the use of surface-sensitive MW imager radiances

E.g., assimilation of AMSR2 radiances:

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

Now (all-sky but not all-surface)

Upgrade (expected 2022)

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

(Patricia de Rosnay and Phil Browne)
Exploiting opportunities in a coupled assimilation system: IR sounders affecting ocean temperatures

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

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

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