Evolution of observations usage in the ECMWF Operational atmospheric NWP system

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Evolution of data counts and availability

Observations play a crucial role in Numerical Weather Prediction (NWP). They are the primary input to the data assimilation, the process that combines observational data with the dynamical and physical information represented in numerical models. The resulting analysis is used to initialise weather forecasting models. Observations availability and usage evolved rapidly since the establishment of ECMWF. Over the years, the volume and diversity of data have increased significantly. Data assimilation techniques have also evolved from simple Optimal Interpolation algorithms to sophisticated variational methods that make extensive use of satellite observations. The evolution was marked by small incremental changes, and major upgrades implemented in between allowing substantial improvements in forecast skill.

Currently, ECMWF receives 800 million observations daily, and 60 million quality-controlled observations are available daily for use in the Integrated Forecasting System (IFS). The vast majority of these are satellite measurements, but ECMWF also benefits greatly from all available observations from non-satellite sources, including surface-based and aircraft reports. The evolution of in-situ observations is slow but has a steady upward trend. Satellite data availability varies with mission lifetime, outages/failures and the launch of new satellites. The exploitation of a new instruments is influenced by the scientific and technical readiness which are complex for novel data and relatively simple for data with known heritage technology.

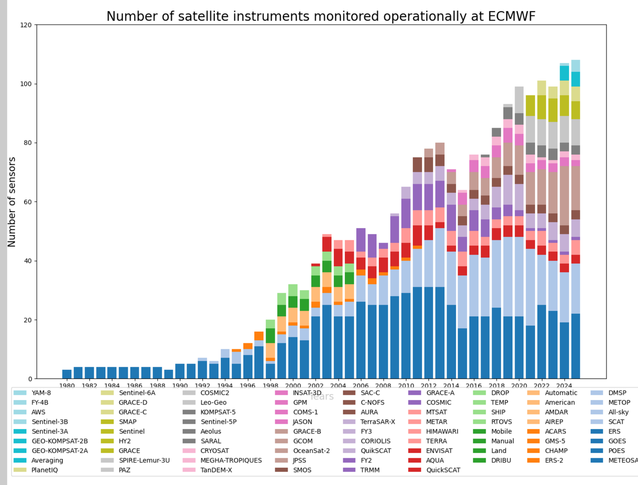


Fig 1: Evolution of data sources operationally monitored at ECMWF

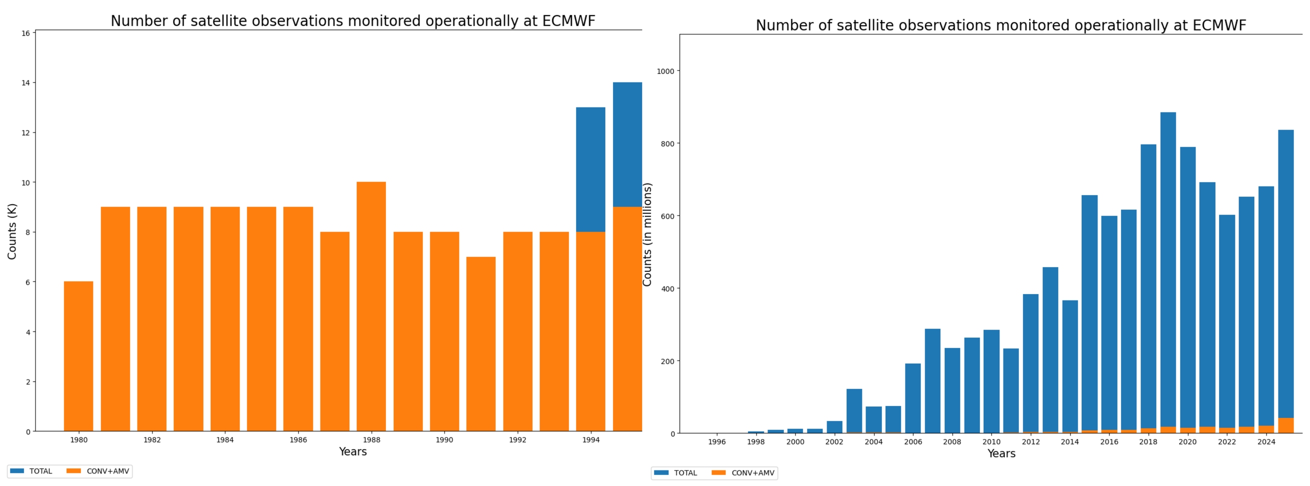


Fig 2: Evolution of data counts operationally monitored at ECMWF pre 1996 in thousands (left) and after 1996 in millions (right)

Impact of assimilating observations

Over the past decades, the skill of weather forecasts has continued to increase. A large part of this improvement is driven by the enhanced use of observations in both data assimilation and forecast verification. The impact of observations on analyses and forecasts depends on the availability of datasets, their intrinsic quality, and the data assimilation methods employed. The incremental inclusion of new datasets, together with continuous optimisation of the assimilation framework, has led to steady improvements in forecast quality across all time ranges. A striking example is the combined implementation of four-dimensional variational assimilation (4D-VAR) and the direct use of satellite radiances, which sharply reduced the forecast skill gap over the Southern Hemisphere (Fig. 3).

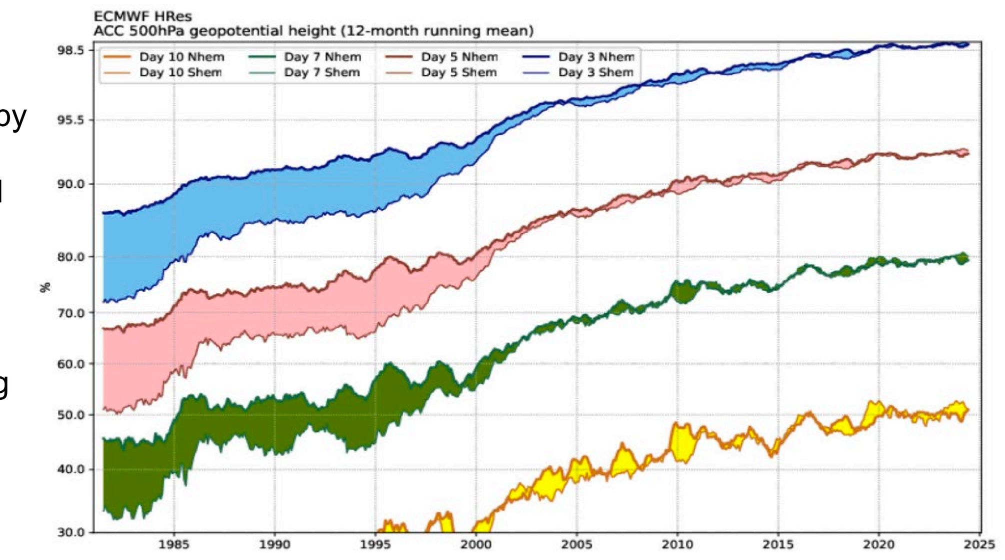


Fig 3: Evolution of ECMWF HRES Anomaly correlation scores for both Hemispheres

The contribution of each observation type primarily depends on the physical quantity being measured, its spatial and temporal coverage, and the associated measurement uncertainties. Despite their smaller numbers, in-situ observations make a significant contribution (around 30% according to FSOI studies), with their impact being particularly pronounced in data-sparse regions. The largest overall impact arises from satellite microwave and infrared radiances, followed by GPS radio-occultation measurements. The design of the current global observing system ensures robust redundancy across platforms, helping to mitigate the effects of data outages.

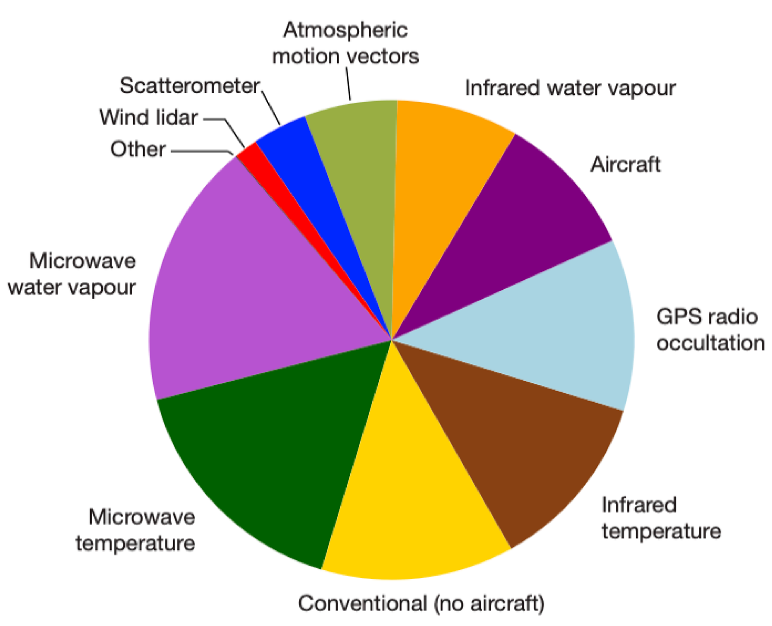
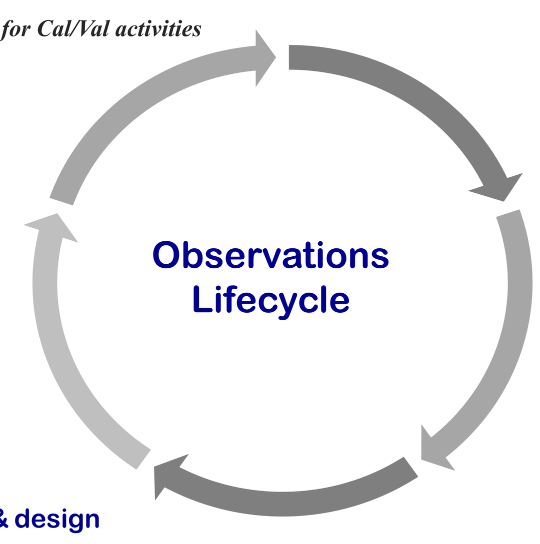


Fig 4: Relative FSOI contribution from observation types assimilated at ECMWF

Monitoring of observations

Deployment

Feedback for Cal/Val activities



Discovery & evaluation

- *Assessment of quality*
- *Estimation of observation errors*
- *Assessment of impact*
- *Decision to use the data*

Planning & design

Monitoring statistics from similar or heritage data

End of life

Use & Re-use

- *Continuous monitoring of quality and availability*
- *Blacklist/Re-activation when necessary*
- *Assessment of drifts*
- *Monitor data impact (FSOI)*
- *Improve the way the data are used*

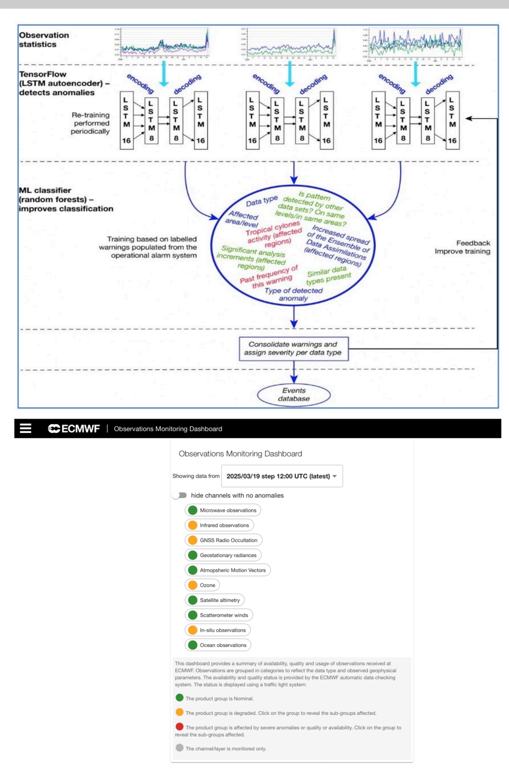


Fig 5: Snapshot of the ML anomaly detection and the observing system dashboard

Future evolution of observations and their handling

The global observing system is expected to expand significantly over the coming years, driven by a large set of already-committed operational and research satellite missions from major space agencies. The geostationary ring (apart from the Indian Ocean region) is expected to be fully populated with hyperspectral infrared sounders, offering high spectral, spatial, and temporal coverage. The first MTG and EPS-SG satellites are already in orbit, and testing and evaluation activities are well under way. The Sterna constellation will boost the microwave coverage and provide access to more orbital planes. China will continue to develop its successful FY-3 and HY polar-orbiting series alongside the FY-4 geostationary program. From NOAA, we anticipate continued JPSS missions and the introduction of a new geostationary system that includes a hyperspectral IR sounder. Japan is also preparing the next generation of Himawari satellites, which will feature both an advanced imager and a hyperspectral sounder. The involvement of the private sector is increasing, both for in-situ observations (e.g. Windborne, Saildrone) and for space-based missions such as GNSS-RO constellations and small microwave satellites. Interest is also growing in IoT-based observations, with parallel work underway on governance, data sourcing, and the technical infrastructure required for pre-processing and quality control.

Data assimilation techniques are expected to continue advancing, with more focus on extracting more information in challenging regions and conditions. Progress will likely come from hybrid methods that combine machine-learning components with established legacy schemes, as well as from more fully end-to-end machine-learning approaches such as GRAPH-DOP.

Timeline of key observation changes

- 1979 > 3D Optimal Interpolation (OI) and non-linear normal mode initialisation
- 1980 > SYNOP, SHIP, Radiosondes, AIREP, PILOT
- 1981 > SATEM (Satellite derived profiles of temperature and humidity) from 1980s
- 1982 >
- 1983 > Satellite derived winds (geostationary satellites)
- 1984 >
- 1985 >
- 1986 >
- 1987 >
- 1988 >
- 1989 >
- 1990 >
- 1991 > Scatterometer (ERS)
- 1992 >
- 1993 >
- 1994 >
- 1995 > 3D-VAR assimilation
- 1996 > 4D-VAR assimilation
- 1997 > Multiple Aircraft data sources
- 1998 > Cloud cleared TOVS radiances
- 1999 > METEOSAT-7 (AMVs); Direct assimilation of raw satellite radiances (TOVS/ATOVS)
- 2000 >
- 2001 >
- 2002 > Geostationary radiances
- 2003 >
- 2004 > 1st Hyperspectral IR (AIRS)
- 2005 > SSMIS, AMSR-1, MET-8
- 2006 > Assimilation of GNSS-RO
- 2007 > Metop-A (AMSUA, MHS, ASCAT, HIRS, GRAS); TMI
- 2008 > Metop-A/IASI; Jason-1, Jason-2
- 2009 > METEOSAT-9
- 2010 > MW in all-sky; MTSAT-2, GOES-13, GOES-15
- 2011 > EDA implementation
- 2012 > METEOSAT-10
- 2013 > NPP/ATMS, Metop-B (IASI,AMSUA,MHS,ASCAT,GRAS)
- 2014 > AMSR2, FY-3B/MWHS
- 2015 > NPP/CrIS, GPM
- 2016 > FY-3CMWHS-2, HIMAWARI-8, GOES-16, Jason-3, MEGHA-TROPIQUE/SAPHIR
- 2017 > BUFR migration started for SYNOP and radiosondes
- 2018 > MET-11, NOAA-20 (ATMS, CrIS, VIIRS AMVs)
- 2019 > Metop-C (AMSUA, MHS, ASCAT, GRAS, IASI), GOES-17
- 2020 > Aeolus, MODE-S, Commercial GNSS-RO, FY-3D/MWHS2
- 2021 > HY-2B
- 2022 > HIMAWARI-9
- 2023 > GOES-18; NOAA-21 (ATMS, CrIS)
- 2024 >
- 2025 > AWS, MTG/FCI, Global MODE-S, GOES-19
- 2026 > EarthCare, MTG-S1, METOP-SG-A1; Visible reflectances
- 2027 >
- 2028 >

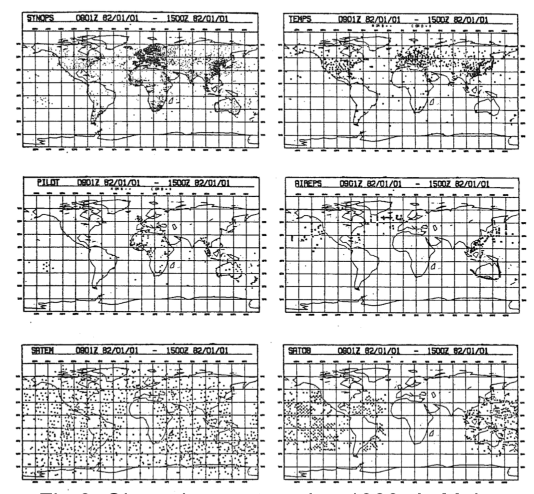


Fig 6: Observing system Jan 1980. A. Mohr ECMWF Annual Seminar Sep 1984

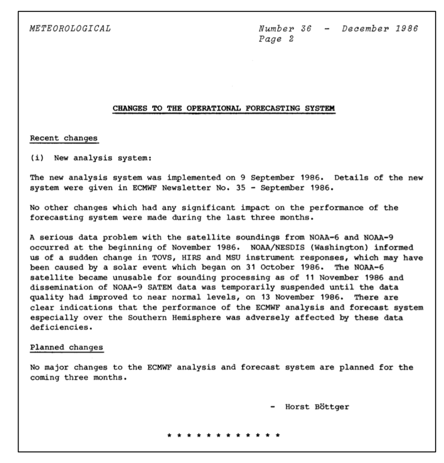


Fig 8: Extract of operational changes in 1986

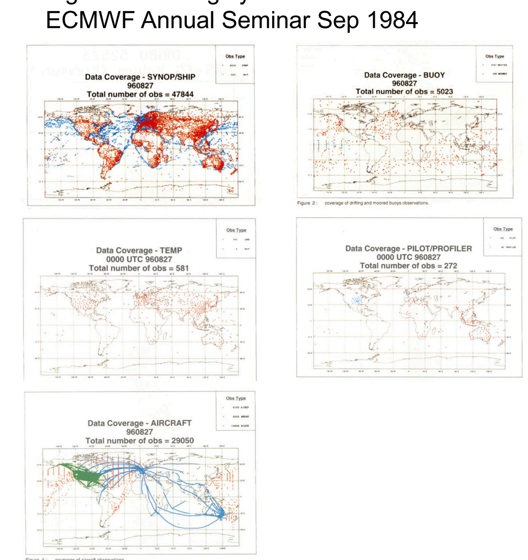


Fig 7: Observing system Aug 1996. B Strauss ECMWF Annual Seminar Sep 1996

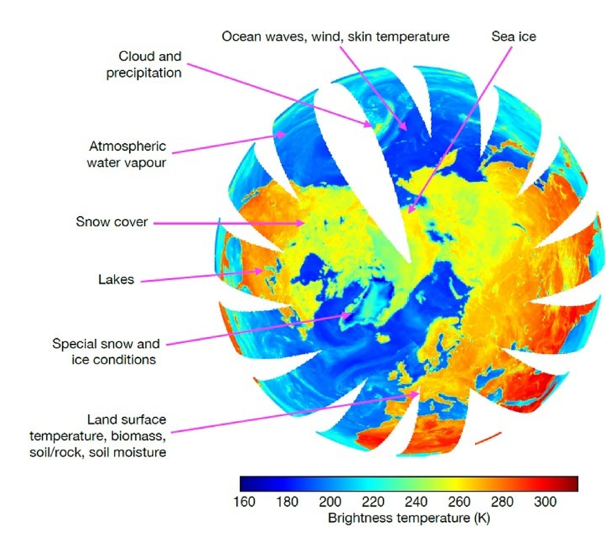


Fig 9: Assimilating MW in All-sky enabled access to new information especially in the surface

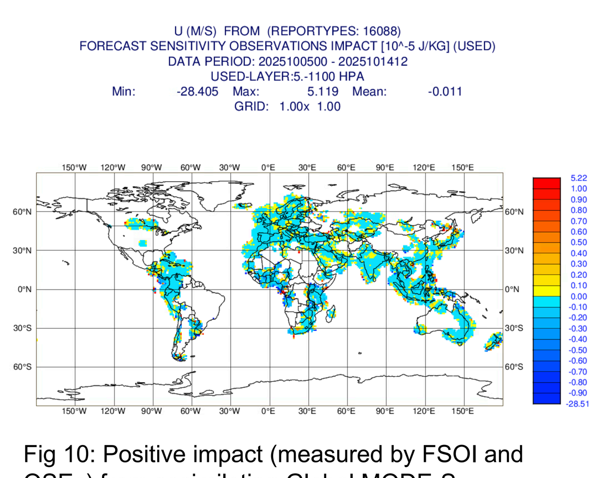


Fig 10: Positive impact (measured by FSOI and OSEs) from assimilating Global MODE-S

https://confluence.ecmwf.int/display/FCST/Observations+data+events

Acknowledgments

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