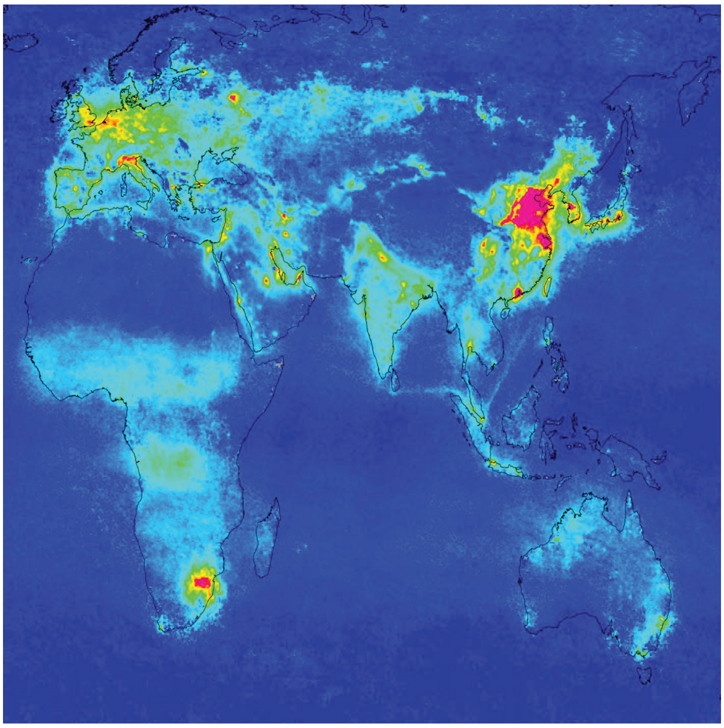
ECMWF Feature article

from Newsletter Number 138 – Winter 2013/14

METEOROLOGY

Ten years of ENVISAT data at ECMWF



NO2 pollution map courtesy of KNM/IASB/ESA

www.ecmwf.int/en/about/news-centre/media-resources

doi:10.21957/plfwhvuo

This article appeared in the Meteorology section of ECMWF Newsletter No. 138 – Winter 2013/14, pp. 13–17.

Ten years of ENVISAT data at ECMWF

Rossana Dragani, Saleh Abdalla, Richard Engelen, Antje Inness, Jean-Noël Thépaut

On 8 April 2012 the European Space Agency (ESA) suddenly lost communication with ENVISAT (ENVIronmental SATellite) after just over ten years in space. The satellite, launched in February 2002, carried ten instruments to provide continuous observation of the Earth's land, atmosphere, oceans and ice caps from a sun-synchronous orbit at about 800 km altitude (see Table 1 for a full list of the ENVISAT payload).

During its ten years of operations, ENVISAT continually delivered high-quality data to a large user community including ECMWF, where data from seven instruments (out of a payload of ten) was routinely received, monitored and validated. The data from ENVISAT has supported Earth-science research and monitoring of the evolution of environmental and climate changes, as well as development of operational and commercial applications.

This article provides an overview of the contribution of the ENVISAT observations to various components of the ECMWF assimilation and forecasting suite that form part of the Integrated Forecasting System (IFS) – see Box A. The aim is to highlight the way in which ECMWF has exploited data from a research satellite within a Numerical Weather Prediction (NWP) system, and discuss the lessons learnt from a fruitful collaboration with ESA. Furthermore, an outlook on future usage of these valuable data is also presented.

A thorough discussion of the activities and lessons learnt from ten years of ENVISAT observations at ECMWF can be found in *Dragani et al*. (2014).

Data usage and data monitoring

ENVISAT data usage

Contracted by ESA, ECMWF was involved in the daily monitoring and assimilation of a variety of products from several instruments on board ENVISAT during its ten-year lifetime. Annual summary reports of can be found at http://www.ecmwf.int/publications/library/do/references/list/18/.

These activities were performed routinely using the Observation Monitoring Facility, a robust tool developed at ECMWF to provide statistics about how different observations available in the ECMWF system compare with their model equivalent (i.e. the modelled field that simulates the observed parameter). These statistics, updated twice a day, allow ECMWF to provide timely feedback to the data providers when there are events such as data anomalies and loss of performance.

Instrument	Extended name
ASAR	Advanced Synthetic Aperture Radar
GOMOS	Global Ozone Monitoring by Occultation of Stars
MERIS	Medium Resolution Imaging Spectrometer
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MWR	MicroWave Radiometer
RA-2	Radar Altimeter 2
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
AATSR	Advanced Along Track Scanning Radiometer
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
LRR	Laser Retro-Reflector

Table 1 List of the ENVISAT payload. The top seven ENVISAT instruments were received at and monitored by ECMWF.

doi:10.21957/plfwhvuo

The ECMWF system and its applications

A

The ECMWF Integrated Forecasting System (IFS) is a comprehensive system simulating the dynamics, thermodynamics and composition of the Earth's atmosphere and interacting parts of the Earth-system. It includes three forecasting components: a global spectral atmospheric model, an ocean wave model and an ocean model that simulates the ocean circulation and sea ice.

Several ECMWF applications are based on the IFS.

- The core high-resolution forecast (hereafter HRES).
- The environmental atmospheric monitoring and forecasting suite, initiated and recently developed under the FP-7 project Monitoring Atmospheric Composition and Climate, precursor of the future Copernicus Atmosphere service (hereafter MACC).
- The climate reanalysis activities, which are contributing to the development of a European climate monitoring infrastructure (hereafter ERA).

All these applications have heavily relied on and taken full advantage of high-quality information provided by the ENVISAT observations.

Whenever possible, observations of proven high quality that positively impacted on ECMWF's high-resolution forecast (HRES) were also assimilated in the parallel applications: ERA (reanalysis activities) and MACC (Monitoring Atmospheric Composition and Climate).

Figure 1 summarises the data usage timeline of all the ENVISAT observation types received at ECMWF across the HRES, ERA and MACC applications. In contrast to all the other retrieved parameters and owing to its unavailability in near-real time, the SCIAMACHY methane data was mainly used for monitoring purposes in a delayed-mode at ECMWF. It was also used for direct flux inversions in combination with surface flask observations by one of the MACC partners.

In addition to the data usage depicted in Figure 1, it is worth mentioning that:

- ENVISAT derived sea-level data has been assimilated in the ocean reanalysis that provides initial conditions for the operational monthly and seasonal forecasting systems.
- Although never operationally implemented, the assimilation of the MIPAS limb radiances was also tested using both the full spectral resolution radiances in 2004 and the reduced spectral resolution channels in 2009. Both attempts showed that the direct assimilation of limb radiances could be used to provide temperature, humidity and ozone information in the upper troposphere-lower mesosphere region, without significantly degrading the fit to other observations.

The ENVISAT observations have continuously been delivered by ESA in near-real time with a generally good timeliness to guarantee that between 85% and 95% of the data (depending on the instrument) arrived on time to be ingested in the assimilation for the HRES.

Ten years of data monitoring revealed that the ENVISAT data has been stable during the satellite's lifetime and with good long-term consistency. Some changes in the level of agreement between the ENVISAT data and the model equivalent were observed over the years, but in most cases they were the consequences of either upgrades to the IFS model or changes to the retrieval algorithm.

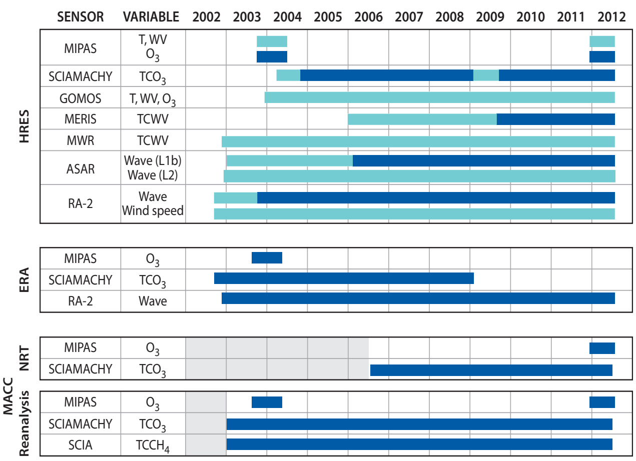


Figure 1 Data usage across three applications of the ECMWF model, namely the HRES, the ERA-Interim reanalysis, and the MACC near-real-time (NRT) products and reanalysis. The blue bars indicate periods during which their corresponding variables were actively assimilated; the green bars indicate periods during which their corresponding variables were monitored. The MACC system was available in near-real time only from July 2006; whilst the MACC reanalysis was run from January 2003 onwards. Periods during the ENVISAT lifetime for which the MACC applications are not available are shaded in grey.

doi:10.21957/plfwhvuo

Feedback to data producers

The collaboration between ESA (the data producer) and ECMWF (the operational data user) has produced substantial benefits to both. On one hand, the operational data user contributes to the calibration and validation activities by:

- Monitoring the performance of all the data received in near-real time.
- Detecting anomalies in the data.
- Providing timely feedbacks to the data producer (e.g. in case of anomalies).
- Assessing the impact of changes in the data processing chains.
- Providing support to new instrument assessments.

On the other hand, the availability of long data records allows the operational data users to (a) monitor their own model performance and changes, and (b) take full advantage of observations with sufficiently high quality to positively impact the corresponding forecasts and analyses through data assimilation.

Figure 2 presents an example of time series of the standard deviation of the difference in significant wave height between the radar altimeter data (RA-2) and the model equivalent. This observation–model comparison clearly shows that the introduction of a new version of the RA-2 processing chain (February 2010) resulted in a slight degradation of the wave data quality – this information was fed back to ESA. At the same time, the model improvements affecting the HRES produced the steady and continuous reduction of the standard deviation as shown in the figure.

In some cases, the collaboration between data producer and data user can also lead to improvements in the retrieval algorithms, as in the case of the RA-2 wind speed retrieval algorithm. Such an algorithm was fine-tuned by ECMWF using collocations between RA-2 and model data over two months, and then extensively verified for a numbers of altimeters against ECMWF model and buoy observations. Verifications after the implementation showed a better performance in terms of wind speed retrieval and a 5% reduction in the scatter index (*Abdalla*, 2012).

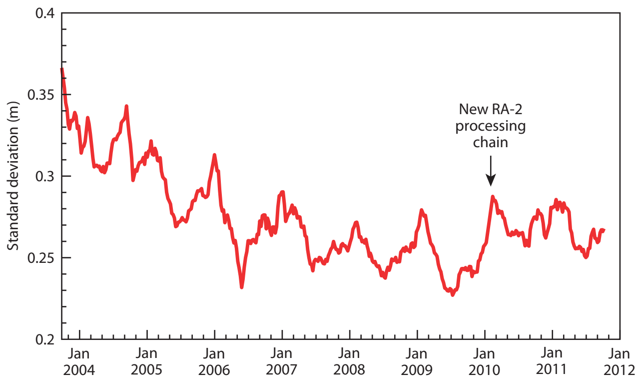


Figure 2 Time series of the standard deviation of the difference between RA-2 and the model departures of significant wave height.

Impact of ENVISAT data on NWP

During the satellite lifetime, ECMWF regularly assessed the impact of the assimilated ENVISAT data on the quality of its analyses and forecasts. The assimilation of the MERIS total column water vapour, discussed in detail by *Bauer* (2009), showed a small impact on the corresponding analyses and forecasts (still visible in the day-3 forecasts) in regions where the total amount was below 30 kg/m2.

Two selected examples are discussed here, one for wave data and one for ozone. Both studies were run for the period December 2011 to March 2012, although only the period January to March is discussed here so that the results are not affected by spin-up issues.

Impact of wave data

To assess the value of the RA-2 and ASAR wave observations, the impact of adding ENVISAT wave information to a baseline configuration was assessed for one instrument at a time. The following experiments were run.

- ***Exp/Base.*** A baseline experiment that used neither the RA-2 significant wave height data nor the ASAR level 1b radiances.
- ***Exp/RA2.*** Exp/Base plus the assimilation of the RA-2 wave data.
- ***Exp/ASAR.*** Exp/Base plus the assimilation of ASAR radiances.

For both instruments, the results suggest a statistically significant positive impact on the ECMWF analyses and forecasts.

 doi:10.21957/plfwhvuo

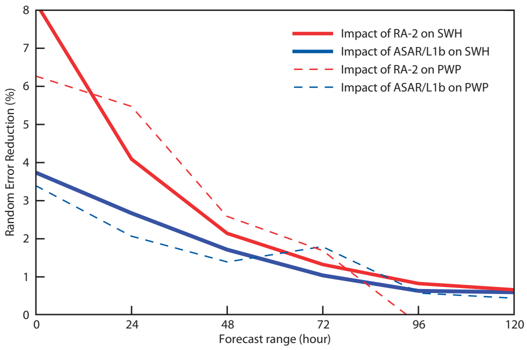


Figure 3 Random error reduction (%) in the tropics against buoys as function of the forecast day and computed for either Exp/ASAR or Exp/RA2 with respect to Exp/Base during the period 1 January to 31 March 2012. The impact is shown for significant wave height (SWH) and the peak wave period (PWP).

Figure 3 shows the reduction in tropical random error against in-situ data as function of the forecast day. This random error reduction is computed as the relative difference between the standard deviation of the residual between the model and in-situ wave values for Exp/Base and that of either Exp/RA2 or Exp/ASAR, both of which benefitted from the assimilation of the ENVISAT data. Positive values mean that Exp/Base exhibits larger model random error than either Exp/RA2 or Exp/ASAR. Results are presented for the significant wave height (SWH) and the peak wave period (PWP).

Figure 3 shows that both observing system leads to a reduction of the model random error in the tropics of the significant wave height. This reduction is largest at the analysis time (8% in the case of RA-2 and 4% for ASAR) and shows a persistence of up to day 5 of the forecast for both sets of data. A similar but somewhat less persistent impact was found in the extra-tropics, where the assimilation of the ENVISAT wave data could lead to a reduction of the model random error visible up to day 2.

Additionally, the assimilation of wave information has a positive impact on the characterisation of other wave parameters. Figure 3 shows that the peak wave period error is reduced with a change at analysis time that can be as high as 6%.

Impact of ozone data

To assess the impact of the ENVISAT ozone products, two denial experiments were run at reduced horizontal resolution of T511 with 91 levels referred to as follows.

- ***Exp/Ctrl.*** Control experiment that used all observations assimilated for the HRES, including the ENVISAT ozone data.
- ***Exp/NoO3.*** Like Exp/Ctrl after withdrawing the SCIAMACHY and MIPAS ozone observations.

The results from the assessment of withdrawing the ENVISAT ozone information from the HRES showed a statistically significant negative impact on the ECMWF ozone field, and only a limited impact on the main meteorological variables (e.g. temperature and wind). This is because the ozone-radiation coupling and the coupling through the 4DVAR data assimilation scheme are not currently exploited in the IFS, although ozone is included in the radiative transfer model used to assimilate the radiances.

Figure 4 shows the comparisons of the ozone analyses from Exp/Ctrl (top panel) and Exp/NoO3 (bottom panel) with the reprocessed Aura Microwave Limb Sounder (MLS) ozone retrievals given in terms of their zonally-averaged temporal mean difference. These results indicate that the loss of ENVISAT ozone data substantially degraded the mean ozone state, particularly in the stratosphere between 10 and 100 hPa. This degradation is also confirmed by comparisons of the ozone analyses with the ozone sonde profiles from the World Ozone and Ultraviolet Radiation Data Centre.

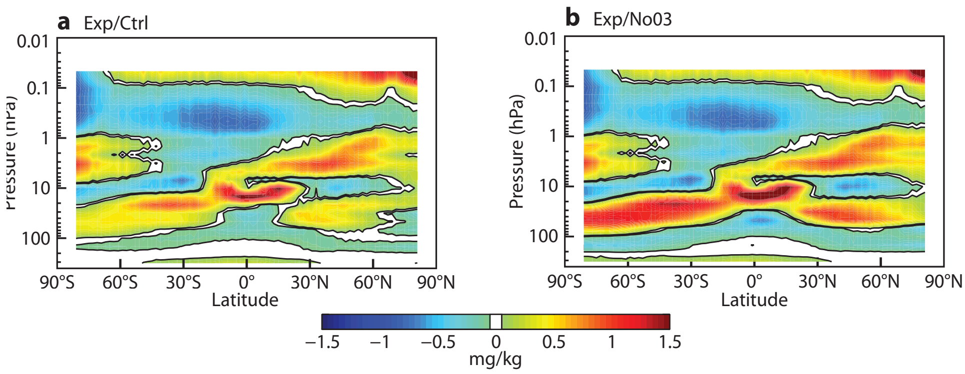


Figure 4 Mean difference between the MLS ozone profiles (v2.2) and the co-located ozone analyses computed for (a) Exp/Ctrl and (b) Exp/NoO3 averaged over January to March 2012.

Ozone impact across different applications

The loss of the ENVISAT products has led to degraded analyses and forecasts across the various ECMWF applications, but – as one would expect – the actual impact strongly depended on the particular observing system used. For instance, a pair of experiments equivalent to Exp/Ctrl and Exp/NoO3 was also run using the MACC system. As the MACC ozone analyses benefitted from the assimilation of MLS ozone profiles, the results of the study only showed a marginal impact from the loss of ENVISAT ozone products.

It is, however, interesting to assess the impact of several data sources, including those from ENVISAT, on the skill that the ozone analyses have in fitting independent observations (e.g. in-situ measurements, across different IFS applications). An example is presented in Figure 5 for the Neumayer station in Antarctica where the Common Area Fraction (CAF) score – an indicator of how well the analysis profile fits the observation profile – is computed for the HRES and MACC ozone analyses for the period 2010–2012. A CAF value of one means a perfect fit.

Three periods can be identified in Figure 5.

- ***January 2010 to November 2011.*** The MACC system performed better than the HRES. That is because the MACC assimilated the height-resolved MLS ozone profiles on top of ozone products retrieved from ultra-violet sensors that were also used for the HRES.
- ***November 2011 to April 2012.*** The two ozone analyses show similar skill. The combination of the assimilation of ozone-sensitive radiances in the infrared (introduced in HRES in November 2011) and the MIPAS ozone profiles (introduced in both systems on 8 December) produced a substantial improvement in the high-resolution ozone analyses.
- ***April 2012 onwards.*** After the loss of MIPAS, both systems show a slightly degraded agreement with the ozone sondes. This reduced performance is more visible in the high-resolution analyses than in those from MACC. This is particularly evident from June onwards with the start of the southern hemisphere winter period where limited constraint is provided by ozone observations retrieved from ultra-violet sensors due to the lack of sunlight.

Two conclusions can be drawn from these results. The first one concerns the obvious reduction in performance of the HRES with respect to MACC following the loss of ENVISAT data: in terms of the CAF score, this is approximately 5%. The second concerns the impact of the ozone-sensitive radiances in the infrared: it is argued that, although this data improved the high-resolution ozone analyses and their corresponding CAF score (of about 10% compared with the same period of 2011), having their vertical sensitivity limited to the upper troposphere–lower stratosphere (*Dragani & McNally*, 2013) means this radiance data cannot provide a constraint as strong as that of MLS.

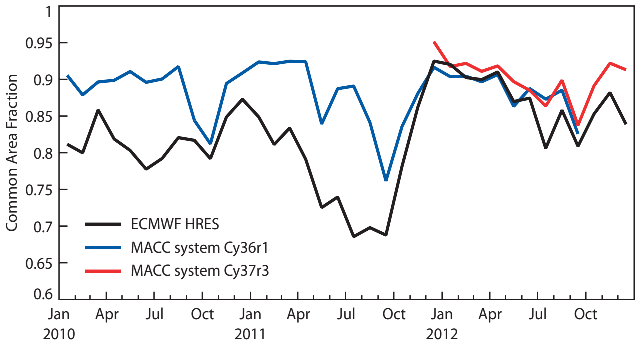


Figure 5 Time series of the common area fraction (CAF) score for ozone analyses computed for the Neumayer station (8.25°W, 70.65°S) in the Antarctic for three streams: high-resolution ozone analysis and two versions of the MACC ozone analysis (Cy36r1 and Cy37r3). A CAF value of one means a perfect fit.

doi:10.21957/plfwhvuo

The second life of ENVISAT

Although the ENVISAT mission officially ended in 2012, its observations are expected to continue and contribute to our understanding of the Earth system and its evolution for many years to come thanks to the on-going reprocessing activity. Such an activity will deliver more consistent data than has been available so far in near-real time.

The need for reprocessing satellite data arises from the main requirements to:

- Improve the quality of the satellite products by implementing the up-to-date algorithms and format over the whole life of the product.
- Produce a long, consistent data record suitable for climate studies.

The long-term consistency and homogeneity is a constant preoccupation in the production of any data record. Operational near-real-time products cannot fulfil this requirement due to the frequent algorithm updates implemented to either improve their products or solve problems. For example, Figure 6 shows the time series of difference in significant wave height between two RA-2 products (the operational near-real-time product and the newly reprocessed dataset) and the reanalysis equivalent using ERA-Interim. The processor that was used for the reprocessing was also used operationally since 1 February 2010 when the difference between the two timeseries became marginal. On one hand, it is clear that the implementation of the new algorithm in the near-real-time stream produced an improved data set, but on the other hand it also led to an artificial jump in the its data record.

Motivated by this, ESA has embarked upon a substantial reprocessing activity of all its observations using the latest available algorithms to produce long records of consistent data products. This activity started before the end of the ENVISAT mission, and has been successfully concluded for most instruments at the time of writing. Different applications and studies can benefit from these reprocessed datasets.

On their own, thanks to its ten-year lifetime, the ENVISAT data records provide a unique opportunity to perform short-term and decadal variability analysis studies. Furthermore, they will also provide an invaluable contribution to forthcoming reanalysis productions (e.g. the one that will replace ERA-Interim planned to start in 2014). In preparation for this future reanalysis, an initial pre-assessment of the value of these reprocessed data records has already been performed at ECMWF using the ERA-Interim reanalyses (Figure 7). The results of this assessment show that the MIPAS ozone profiles are in very good agreement with the ERA-Interim co-located reanalyses. Moreover, the ERA-Interim residuals from MIPAS also exhibit a very good long-term agreement with those from several other instruments. This result, together with those from the denial assimilation presented above, pave the way for the assimilation of the MIPAS reprocessed ozone profiles in future reanalyses.

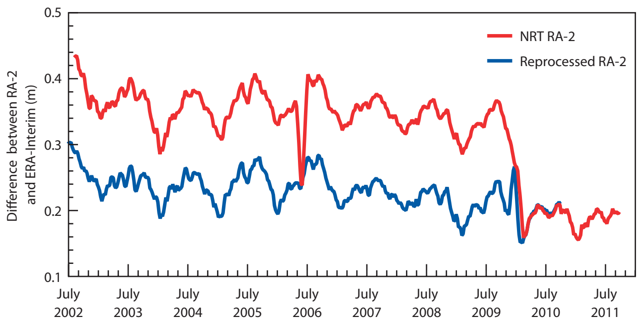


Figure 6 Time series of the difference between RA-2 and ERA-Interim for significant wave height computed for two sets of RA-2 data: the operational near-real-time (NRT) RA-2 data and version 2.1 reprocessed RA-2 data.

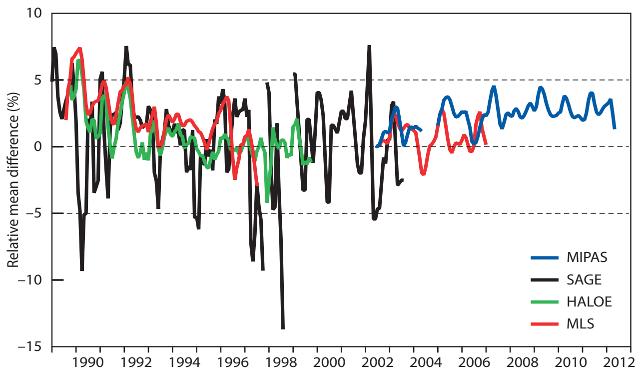


Figure 7 Relative mean difference at 10 hPa in the tropics between the ERA-Interim ozone analyses and reprocessed ozone data from the MIPAS, SAGE, HALOE and MLS instruments (computed as 100×(Observations-Analysis)/Observations). The period runs from January 1989 to December 2012. The two dotted lines indicate where the relative differences are within ±5%. The plot is an adaptation of Figure 5 (panel d) presented by *Dragani* (2011).

Moreover, the ERA-Interim residuals from MIPAS also exhibit a very good long-term agreement with those from several other instruments. This result, together with those from the denial assimilation presented above, pave the way for the assimilation of the MIPAS reprocessed ozone profiles in future reanalyses.

Although the reprocessed satellite data record from a given instrument is not long enough to perform climate analysis, there is an on-going effort in both Europe and the USA to merge observations of the same variable derived from different instruments in one consistent and homogeneous dataset. Although this is not possible for all variables, in some cases data records spanning most of the satellite era can be achieved.

These activities are important as such homogeneous and consistent data records can be used to study climate variability and perform trend analysis. Furthermore, the merging procedure can provide useful information about the offsets between different instruments (inter-instrumental biases), which can also be valuable in undertakings such as a reanalysis when the original, unmerged records are assimilated. Moreover, these activities also feed into a number of climate research projects: they help improve our current understanding of how, how much and possibly why the climate system has evolved to its current state. This understanding, in particular identifying the cause(s) of these changes, gives a scientific underpinning for predicting future climate. It is recognised that satellite data play a major role in all these activities.

In this context, ESA has launched the Climate Change Initiative that aims at providing satellite-based climate data records of essential climate variables that fulfil the requirements – set by the Global Climate Observing System (GCOS) – for satellite data to be useful in climate studies. These satellite-based climate data records will strongly rely on ENVISAT observations. ECMWF's involvement in the assessment of these essential climate variables ensures the continuation of the collaboration with ESA.

Alongside ESA, reprocessing work is also carried out by EUMETSAT through its various Satellite Application Facilities. In addition, in the USA, NOAA has initiated a Climate Data Record Program aimed at long-term data preservation.

Further reading

Abdalla, S., 2012: Ku-band radar altimeter surface wind speed algorithm. *Mar. Geod.*, **35,** 276–298.

Bauer, P., 2009: 4D-Var Assimilation of MERIS Total Column Water Vapour retrievals over land. *Q. J. R. Meteorol.* Soc., **135,** 1852–1862.

Dragani, R., 2011: On the quality of the ERA-Interim ozone reanalyses: Comparisons with satellite ozone data. *Q. J. R. Meteorol. Soc.*, **137,** 1312–1326.

Dragani, R., S. Abdalla, R.J. Engelen, A. Inness & **J.-N. Thépaut,** 2014: Ten years of ENVISAT observations at ECMWF: a review of activities and lessons learnt. *Q. J. R. Meteorol. Soc.*, under review.

Dragani, R & **A.P. McNally,** 2013: Operational assimilation of ozone-sensitive infrared radiances at ECMWF. *Q. J. R. Meteorol. Soc.*, DOI 10.1002/qj.2106.

 doi:10.21957/plfwhvuo