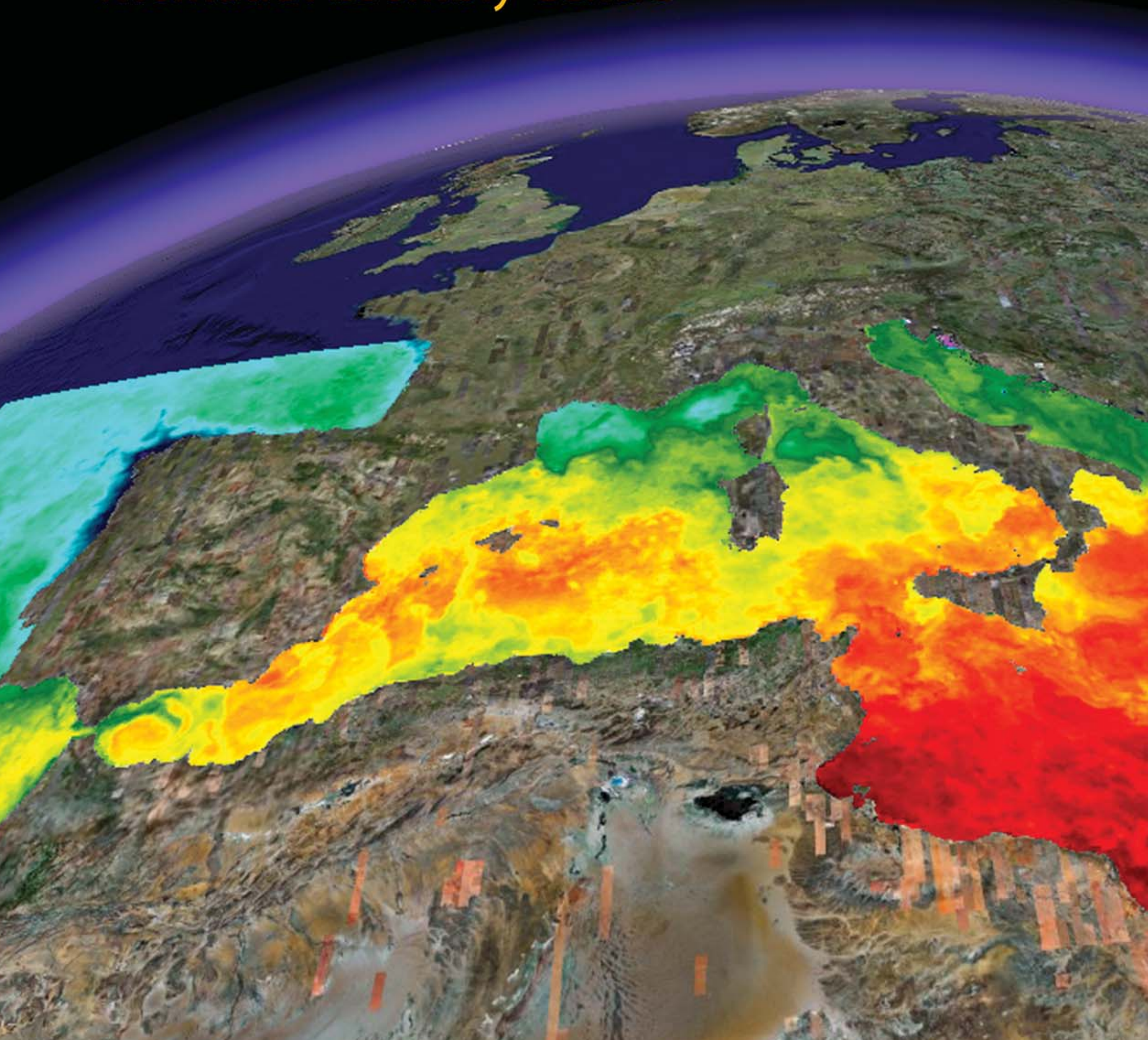
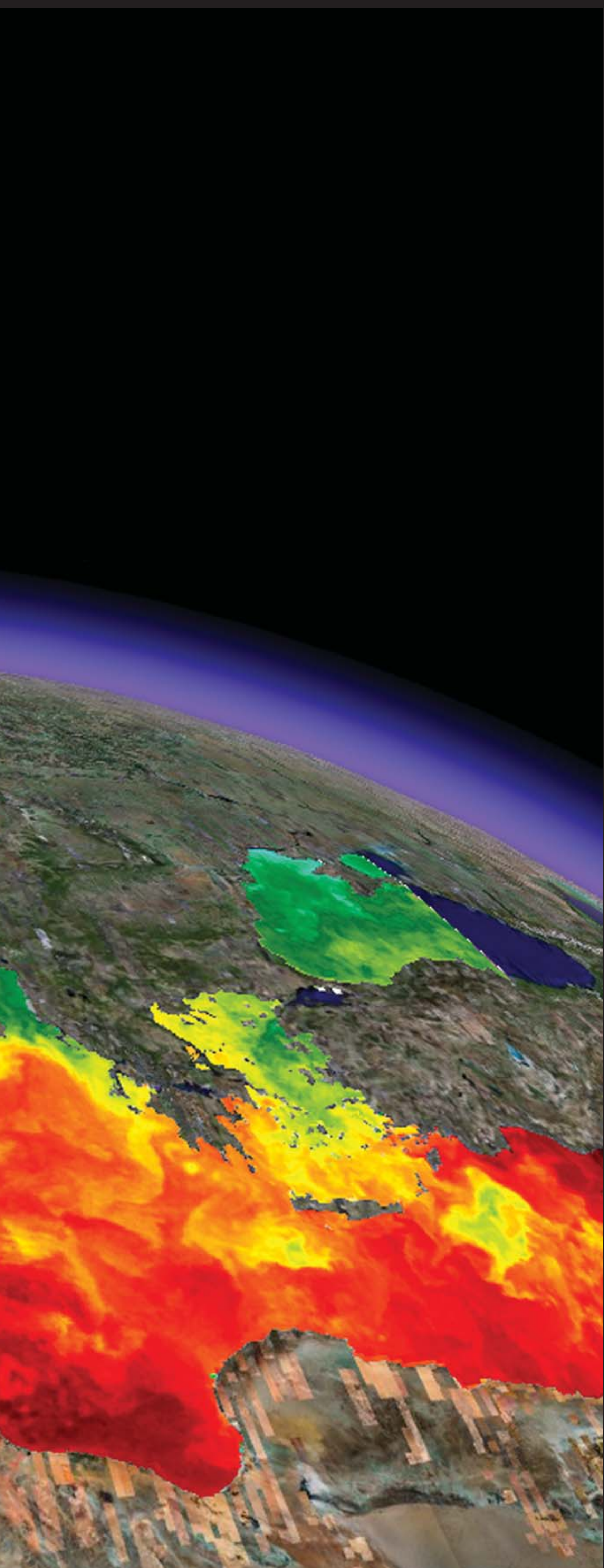
Medspiration

A Precursor to the GMES Marine Core Service Sea-Surface Thematic Assembly Centre





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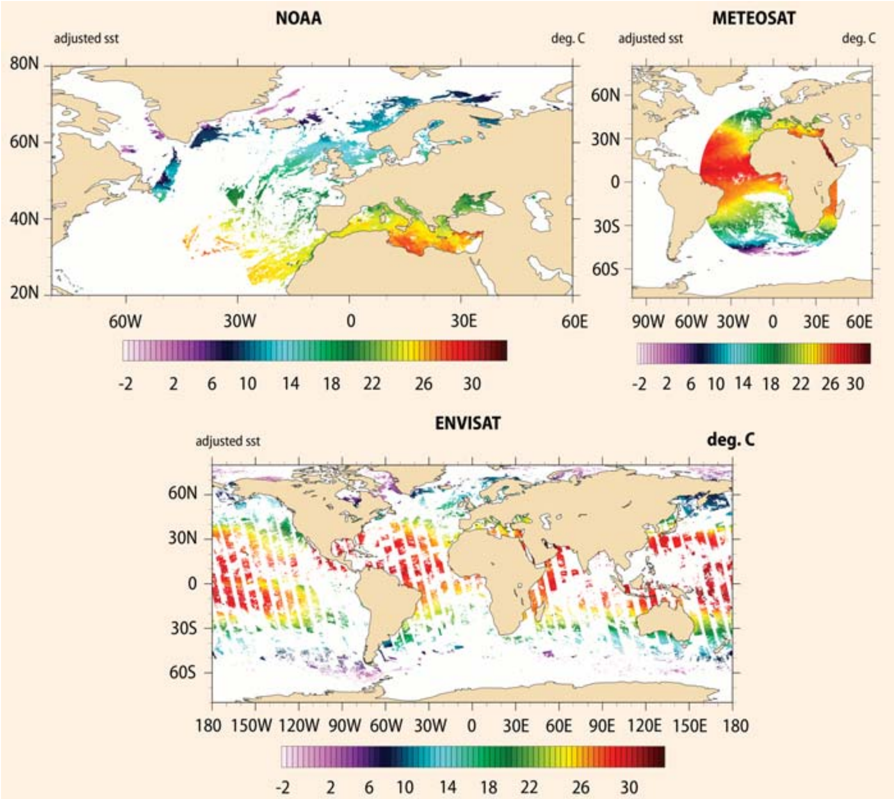
The Global Monitoring for the Environment and Security (GMES) initiative lead by the European Commission and ESA recently opened the call to set up the 'Marine Core Service' for oceanography users. Two of the six planned 'Thematic Assembly Centres' will build on ESA's Medspiration and GlobColour projects, which covered, respectively, sea-surface temperature and ocean colour. Both are described in companion articles in this issue. The services will make full use of instruments aboard ESA's Envisat. Their successors on the Sentinel-3 satellite series will ensure operational space oceanography services for the two decades starting in 2012.

Introduction

Accurate knowledge of sea-surface temperatures (SSTs) and how they changes with time is essential for many applications: monitoring climate variability, seasonal forecasting, operational weather and ocean forecasting, military operations, validating ocean and atmosphere models, ecosystem assessment, tourism and fisheries research. In particular, SSTs are required to feed the numerical models used by operational



Observations from several space sensors are combined to obtain Medspiration products: NOAA AVHRR17 & AVHRR18 (2 km resolution, two passes/day, top left); Meteosat/SEVIRI (10 km resolution, 3-hourly snapshots, top right) and Envisat/AATSR (1 km resolution, 14-15 orbits/day, bottom)

weather and ocean forecasting centres in near-real time. The minimum specifications for SST observations were defined by the Global Ocean Data Assimilation Experiment (GODAE): global coverage each day, 10 km resolution and an accuracy of 0.3ºC, updated every 6 hours. In 2002, recognising that none of the existing satellite measurements could meet these requirements, the GODAE High-Resolution SST Pilot Project (GHRSST-PP; see *http://www.ghrsst-pp.org*) was started. As the European contribution and to develop demonstration services in collaboration with European users, ESA began the Medspiration project in January 2004.

The Measurement Challenge

Different *in situ* and satellite sensors provide different results because the thermal structure of the top few centimetres of the sea is complex. For instance, infrared sensors operating in the 3.7–12 micron band are seeing the the 'conductive diffusion-dominated sublayer' at a depth of 0.01–0.02 mm, whereas microwave radiometers operating at 6–11 GHz sense the temperature at a depth of about 1.2 mm. Beneath the ocean surface, *in situ* buoys record temperatures at depths ranging from 20 cm to hundreds of metres.

Comparison between all these measurements is complicated by their different spreads in time and space, daily and seasonal changes in ocean thermal structure and the different local conditions such as winds, surface heating by the Sun and the time of day.

Many operational centres require estimates of the accuracy of each satellite observation so that they can make full use of the data. As the accuracy of satellite SST observations has increased to the point where they are equal to, if not better than, the operational *in situ* observing systems, ancillary information is required to understand how complementary observations differ. GHRSST-PP established through international consensus a data product that includes ancillary information necessary to interpret the SST data derived from satellite instruments. This 'L2P product' includes wind speed, solar irradiance at the surface, atmospheric aerosol optical depth, sea-ice cover and deviation from reference climatology for each satellite pixel. In addition, uncertainty estimates are computed, in order to deliver information to the users for them to develop their own quality control when merging complementary datasets. Medspiration spearheaded the development of the GHRST-PP L2P specification that is now used by centres around the world.

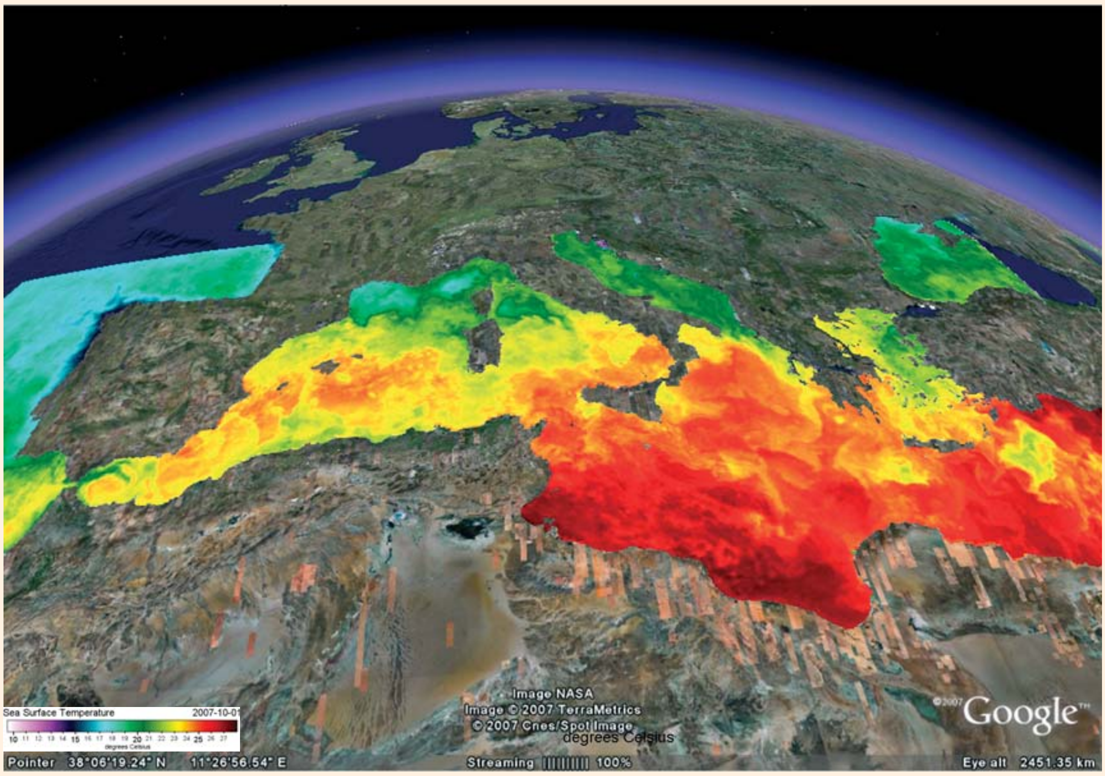
The Medspiration Project

Medspiration developed and operates a new processing system to generate near-real time L2P SST products for the Europe and Atlantic areas. These use information from Envisat's Advanced Along-Track Scanning Radiometer (AATSR), NOAA's Advanced Very High Resolution Radiometer (AVHRR), Meteosat's Spinning Enhanced Visible & InfraRed Imager (SEVIRI), Aqua's Advanced Microwave Scanning Radiometer (AMSRE) and the Tropical Rainfall Measuring Mission's TRMM Microwave Imager (TMI), following the GHRSST-PP specifications.

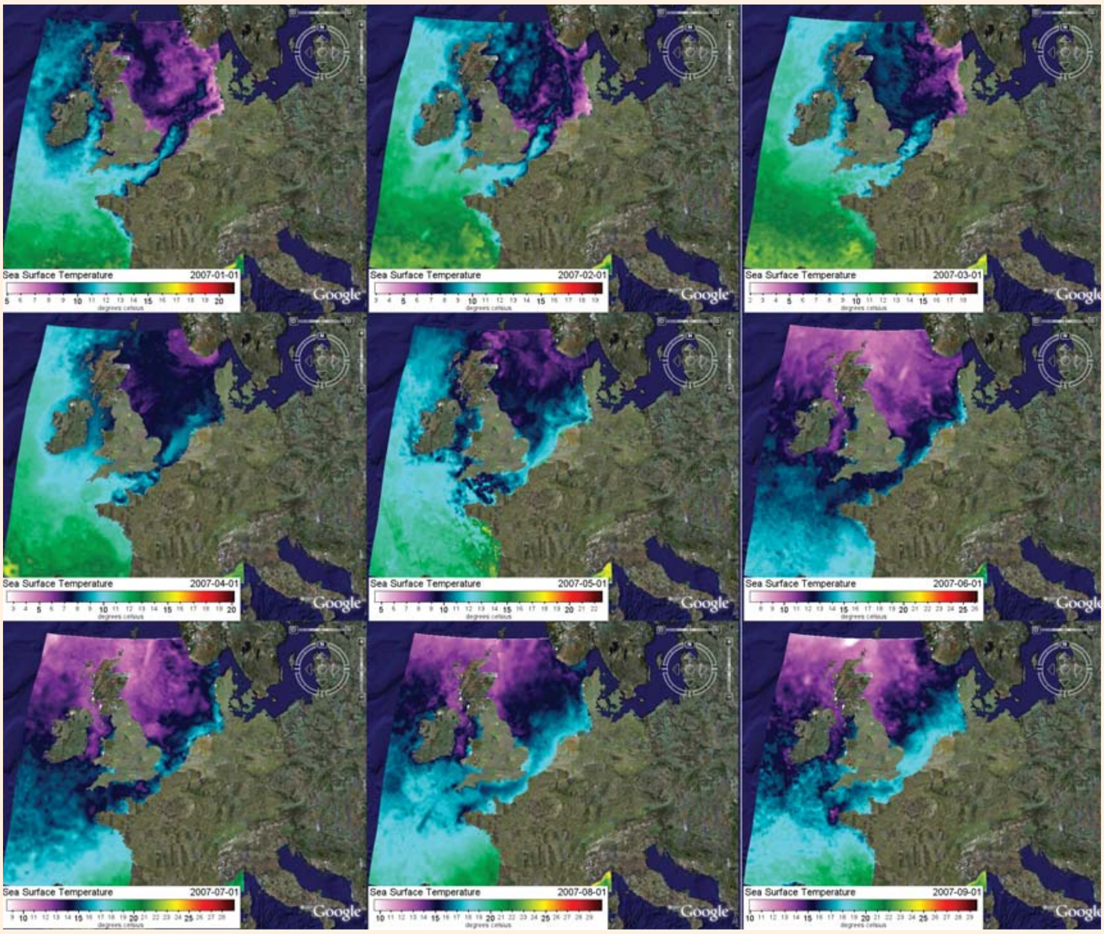
The Medspiration consortium is led by the National Oceanography Centre, Southampton (NOCS, UK), partnered with the Institut Francais de Recherce et d'Exploitation de la Mer (IFREMER, F), Météo-France, Collecte Localisation Satellites (F), Avel Mor (F), Consiglio Nazionale delle Richerche (I), Meteorogisk institutt (N) and Vega (UK).

Providing SST products since June 2005 in a uniform format has made it much easier for major users to work with data from several complementary sources and to blend them into single products.

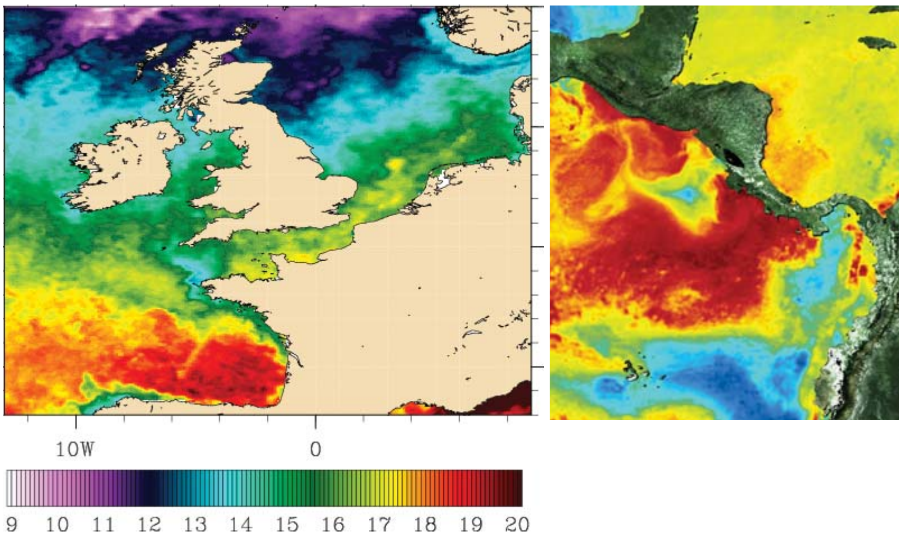
Uncertainty estimates for each SST observation is a key user requirement



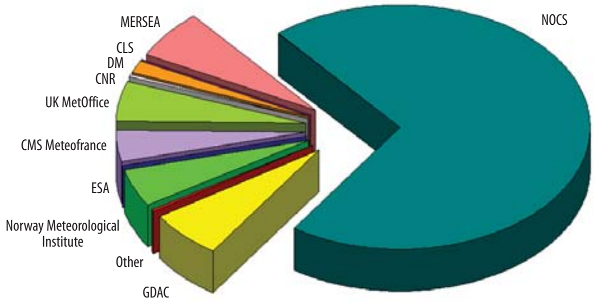
Sea-surface temperatures computed over the Mediterranean on 10 September 2007, visualised using Google Earth. Daily maps, ready for 3-D visualisation are available at http://www.medspiration.org/data_access/kml/



Time series of sea-surface temperatures (°C) computed over Europe on the first day of the January to September 2007. Daily plots of SST over selected areas are available on http://www.medspiration.org/



Sea-surface temperatures (°C) computed over north-western Europe (left) and the Galapagos (right). Daily plots of SST over selected areas are available at http://www.medspiration.org/



Left: more than 170 GB of data are disseminated monthly to Medspiration users worldwide (shown is August 2007). Right: newspapers in Germany, Spain and Portugal have been using the information provided by the project

for these products. They allow users to select the accuracy level suitable for their application and to make optimum use of the SST observations. However, estimating the uncertainties in a particular satellite observation is a challenging task. The vast amount of observations, the highly variable characteristics of the atmosphere and the stability of the satellite instruments themselves over time are all important factors to consider.

A 'Level4 blended product' is also produced at ultra-high resolution on a 2x2 km grid for the Mediterranean Sea, Atlantic shelves and Galapagos region in the tropical Eastern Pacific Ocean. This provides the 'foundation SST' (the temperature at the highest point in the water column each day that is not affected by diurnal warming or the 'thermal skin effect' (the top 1 mm or so of oceans is cooler) as derived from all the available L2P outputs and *in situ* data, weighted and interpolated according to the characteristics and quality of each input value. The product also contains an estimate of the skin temperature and its daily variation.

In the first quarter of 2007, an average of more than 1700 L2P products were generated every month by Medspiration, with more than 460 Gb disseminated to a wide range of users, including the UK Met Office, Mercator and Meteofrance.

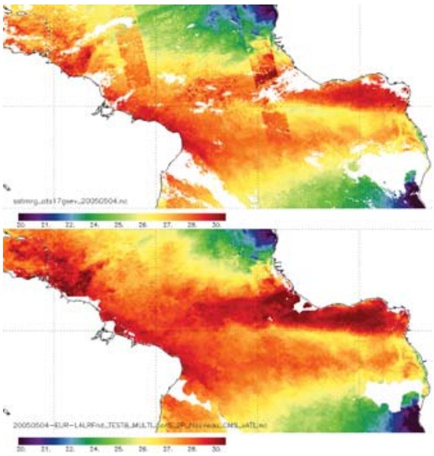
The ATSR Contribution

One of Medspiration's tasks is to convert the highly accurate Envisat/AATSR SST data into the GHRSST format and provide a near-real time demonstration service for operational users. While limited in daily global coverage because of its narrow 512 km swath, AATSR is now considered as an internationally recognised reference SST dataset thanks to Medspiration. AATSR SSTs are combined with other sources to generate daily global maps for a wide variety of ocean science applications that will ultimately lead to better weather forecasting, improved seasonal weather prediction, and stable climatologies for monitoring global change.

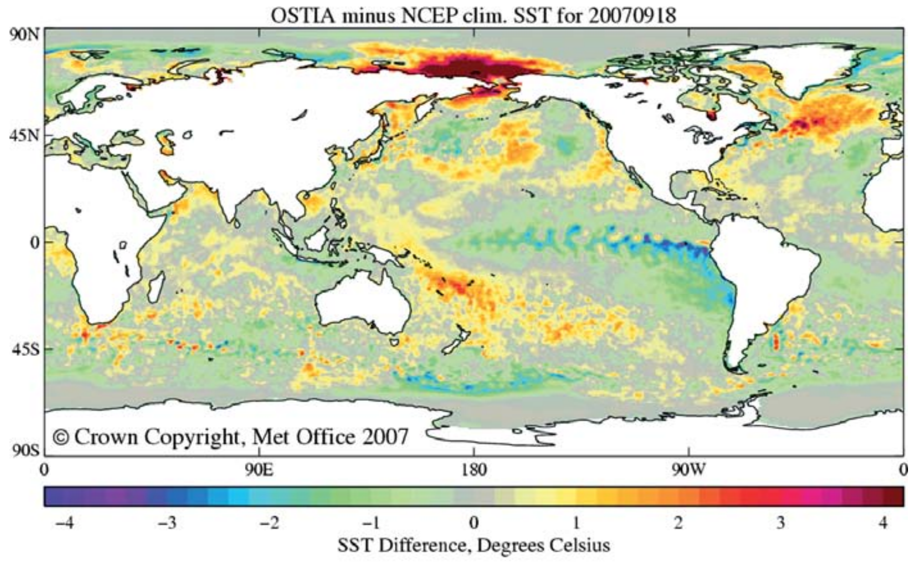
Infrared sensors at present offer the finest spectral resolution for derivation of SST. However, the SST calibration approach used over 20 years for NOAA AVHRR data is compromised by dependence on *in situ* buoy measurements that cannot eliminate the uncertainties from the unmeasured changing near-surface thermal structure of the water. AATSR's ability to look in two directions at once (as will Sentinel-3's Sea and Land Surface Temperature Radiometer) avoids this, providing a robust method for removing atmospheric effects. This allows the apparent cooling effect of Saharan dust in other IR sensors to be removed. Routine comparisons between SEVIRI and AATSR data have helped to develop a new retrieval algorithm that reduces the negative effect of Saharan dust on SEVIRI SST products.

Medspiration demonstrated that, even if AATSR coverage is less extensive than other polar-orbiting sensors for SST, its high absolute accuracy can be used as a benchmark against which bias adjustments can be made to other SST products, before being applied operationally.

By simply collating different sources of data without applying this bias correction, discontinuities appear along the boundaries between the sources. Such sharp edges are bound to corrupt the final analysis. When the bias



Exploitation of multiple assets allows bias correction and error removal. Top: Results of an SST analysis using SEVIRI, AVHRR and AATSR, when no bias correction is applied. Bottom: bias correction using AATSR as a reference standard is applied over a 5-day window



The difference between OSTIA SST and reference climatology (1985–2001) for 18 September 2007. The large SST anomaly in the Arctic Ocean is obvious: it is up to 8.5ºC warmer. Other features include the current La Nina condition in the eastern tropical Pacific Ocean, differences in the North American Great Lakes and upwelling off the north-west African coast. OSTIA data are available at http://ghrsst-pp.metoffice.com/pages/latest_analysis/ostia.html

adjustment to AATSR is applied, the sharp edges disappear and the temperature is raised significantly in those regions where the data were too cold. This is a far more satisfactory outcome than simply smoothing away the sharp edges. Research is continuing to optimise the choice of the time window and the averaging length scale when calculating the bias.

In Australia, the Bureau of Meteorology's BlueLink project uses AATSR instead of buoy SST data to tune the parameters in empirical algorithms for local atmospheric correction of AVHRR data. The outcome is regional maps of SST that are already bias-corrected to AATSR and which should enjoy the same improved stability as AATSR.

All the datasets produced by Medspiration are used at the Met Office in the Operational SST and Sea Ice Analysis (OSTIA; (*http://ghrsst-pp.metoffice.com/pages/latest_analysis/ostia.html*). OSTIA produces global SST fields at a grid resolution of 6.5 km on a daily basis taking input from SEVIRI, AATSR, AVHRR, AMSRE and TMI. In the near future, AVHRR data from the MetOp satellite will be brought on-line. In this system, Envisat AATSR SST is used as a reference dataset to which all other satellite SST datasets are adjusted. Owing to the exceptional stability and accuracy of the AATSR SSTs, there is significant impact on the analysis in areas where no *in situ* observations are available, as in the Southern Ocean. This approach proved particularly important for determining the spatial structure of the AMSRE biases in the Southern and Arctic Oceans.

OSTIA is used to track temperatures in the Arctic area, showing them to have been exceptionally high in the summer of 2007. The unprecedented retreat of sea ice in the Arctic region since June 2007 and the large open water area in the Chuckchi and Beaufort Seas have resulted in unprecedented SST values in this region: more than 10ºC above the 1985–2001 computed values.

Higher SSTs are a consequence of thermal stratification in the surface ocean enhanced by predominant high-atmospheric pressure (typically low winds and clear skies) and more buoyant freshwater from melting ice and rivers. Warm southerly winds from the Gulf of Alaska increased the ice melt and freshwater input, while also pushing the sea ice polewards.

Sentinel-3 and the Marine Core Service

Medspiration has been instrumental in providing advanced integrated SST data products in a mature service that allows operational systems to develop new products, such as OSTIA, with confidence. At the outset, a primary goal for both GHRSST-PP and Medspiration was to establish a mechanism to sustain the systems, products and services developed by them. As the user community has developed in Europe, a need for a European GHRSST-PP Global Data Assembly Centre (GDAC) and SST services has emerged based on the rapidly developing operational ocean forecasting capability of several centres. The GMES initiative has recognised the importance of ocean forecasting in Europe and called for a federated Marine Core Service (MCS) with a sustained core operation delivering fundamental analyses and forecasts of the ocean state to a wide variety of users, ranging from operational forecasting centres to local government, businesses and individual citizens.

As part of the MCS system, an SST Thematic Assembly Centre (SST-TAC) has been defined that will deliver and operate a European core service providing comprehensive SST products derived from satellite and *in situ* observations. It offers economies of scale by integration and consolidation of SST activities within Europe. The European-GDAC will work in partnership with a US GDAC to specify, monitor and deliver accurate error uncertainties for individual satellite data streams and to integrate these data in the most appropriate manner using the next generation of analysis systems. Operational solutions will ensure the timely availability of complete and accurate SST products by proper integration of Medspiration (L2P production, L4 analysis, uncertainties) capabilities, and comprehensive interaction with operational forecast systems and users.

The evolution of Medspiration and GHRSST-PP within the MCS SST-TAC system includes a significant shift in the way that European SST data-providers generate and serve SST data to the applications community. L2P datasets will, ideally, be generated by each agency at source (similar to the US and Japanese GHRSST-PP systems): ESA will continue to generate and deliver operatioal near-real time L2P data from Envisat's AATSR, and plan to follow on with Sentinel-3 from 2012 for the next 20 years; Eumetsat will continue to generate and provide L2P for Meteosat's SEVERI and MetOp's AVHRR. In this way, there is a mature shift from the demonstration spearheaded by Medspiration in Europe into an integrated and sustained operational system making optimal use of all available assets and governance systems to benefit user communities with the best SST datasets for their applications.

GHRSST-PP developed a data standardisation strategy to maximise existing data sources, facilitating their exploitation for SST and use of their peculiar characteristics. The approach has been shown to be scientifically sound and technically feasible. Through Medspiration, a much wider range of users is benefiting from AATSR data in the GHRSST-L2P format. AATSR, thanks to its excellent accuracy, is becoming a SST reference standard for operational ocean and weather forecasting agencies. The heritage of the ATSR-class of sensors will be secured by the GMES Sentinel-3 mission, providing global SST to within 0.3ºC and 1 km.