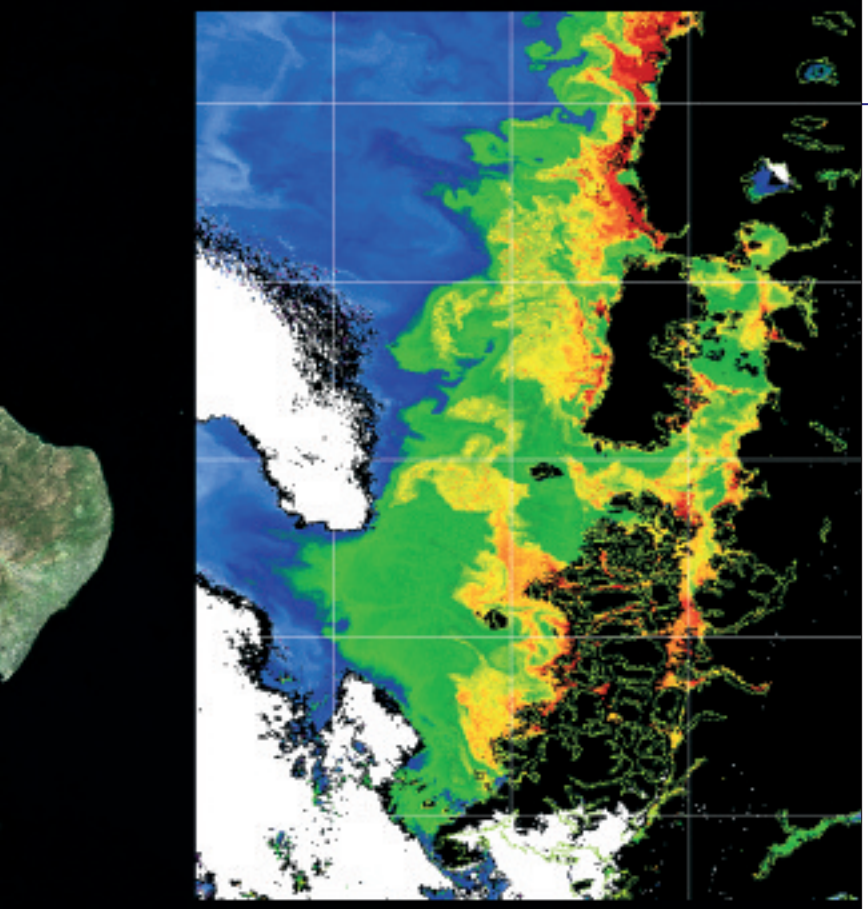
Monitoring Marine Life from Space

Envisat Experience in Chile



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The use of satellite data, primarily from instruments aboard ESA's Envisat, together with in situ sea measurements, provides a powerful tool for monitoring the environmental conditions of coastal waters and the health of southern oceans. Ocean monitoring by satellite remote sensing to protect public health and the fishing industry started in southern Chile in 2002. Last year, a major advance was achieved when Envisat data products were received in near-realtime, allowing early detection of marine conditions that favoured harmful algal blooms and the growth of dangerous bacteria.

Dramatic Events Detected from Space

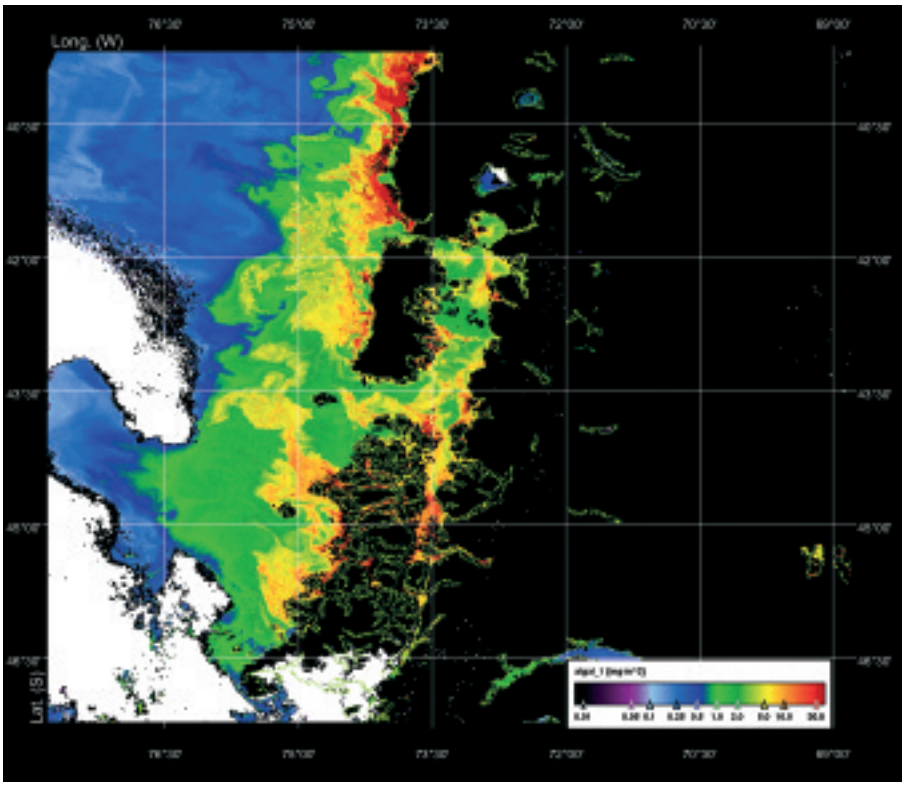
South of Chiloe Island, where the Pacific Ocean meets one of the most beautiful areas of Chilean Patagonia, some micro-algal cells grew and proliferated in the Gulfs of Ancud and Corcovado. Measurements in the sea could not reveal the extent but, from space, satellite instruments detected how this population of micro-organisms evolved. These organisms are lethal to human beings in doses of only 80 micrograms per gram of shellfish. After two people died and a hundred were poisoned in 2002, the harvesting of shellfish was forbidden in the whole area and the President declared a national disaster.

This type of event tends to occur most years. It is normally well documented by the press, particularly because the people of the region depend on natural marine resources and agriculture. Nowadays, the SeaSTAR, Terra, Aqua, ERS-2 and Envisat satellites can study the whole southern Chilean region, where the

Puerto Montt has the highest growth rate in Latin America. For the first time since 2002, this region is being observed from space.

Having established the usefulness of satellite data in monitoring ocean surface conditions, significant progress is now being made in relating satellite observations to the bulk characteristics of sea water when they are properly integrated with underwater measurements, particularly in ocean models.

This is very important because, as with humans, the health of marine life depends largely on environmental conditions. Very often, this dependency is critical and even a minor change in the value of a physical or chemical parameter, such as temperature or oxygen content, can lead to dramatic consequences. That is why satellite coastal monitoring is indispensable, particularly in regions with exponential economic growth in tourism or industrial activity, and where systematic environmental monitoring is very difficult owing to complex regional geography.



Phytoplankton concentration derived from Envisat MERIS measurements of 9 February 2005. Red is equivalent to about 30 mg per cubic metre of seawater. Strong gradients in the fronts around Chiloé Island match the sightings of blue whales and other cetaceans

Characteristics of the Project Area

The western Patagonian coast offers ideal conditions for salmon farming, to the point where the country became the world's top producer by the end of 2004. In addition, shellfish and algae farming is growing further south, in Region XI of Chile, where the economic prospects indicate explosive development in the next few years.

The area of investigation is in the south-eastern part of the Pacific Ocean. Here, the coast of the South American continent is broken up into thousands of islands, which create a special environment of bays, fjords and channels with a complex geomorphology. The ocean dynamics produce great environmental variability, enhanced by the strong influence of fresh water from heavy rainfalls and continental glaciers. The region has hydrographical and ecological peculiarities that are not well understood, but which determine the biological variability of its marine communities.

The eastern boundary of the Pacific Ocean's general circulation is strongly influenced by the atmosphere's dynamics. These meteorological conditions cause great variability in the surface wind structure. Offshore, the winter circulation from the east subdivides into two branches: the Humboldt Current off Peru and Chile, and the current off Cape Horn. The first is responsible for probably the most important upwelling region on Earth; the high inorganic nutrient influx from deeper levels creates the conditions for a major fishing area.

The Humboldt Current flows from below 40ºS, up to the equatorial region in two branches: oceanic and coastal. Under the coastal branch at depths of 100 m to 400 m there is the equatorial current, characterised by low oxygen concentration (anoxia, or severe hypoxia). The distribution of these water masses has been measured from the north of Peru down to the latitudes of Chiloé Island.

Some researchers have found anoxic conditions in the area damaging to aquaculture, relating the conditions to these water masses that occasionally arrive during parts of the year. These are new areas for future oceanographic investigation.

Envisat Helps to Monitor Ocean Conditions

Combining data in the visible and infrared spectral bands from Envisat's MERIS (Medium Resolution Imaging Spectrometer) and AATSR (Advanced Along-Track Scanning Radiometer) instruments, respectively, has made it possible to describe dynamic aspects of both the open ocean and the Gulf of Corcovado in Chile's Region X. Some of the most important observations identified areas where thermal fronts in the ocean originate, with strong temperature and probably salinity gradients. These zones retain nutrients and provide phytoplankton with optimal conditions for development.

These areas, as well as other locations, are risk areas for the development of marine algae blooms. Depending on the composition of the phytoplankton

population, these blooms can be harmful to humans, and they are generally harmful to fish farming. It has also been possible to develop risk maps for other marine agents, as detected during the outbreak of *Vibrio parahaemolyticus* in the southern summers of 2004 and 2005.

Harmful Algal Blooms

Micro-algal blooms are natural phenomena known since ancient times. However, they have increased in frequency and now appear more widely around the planet. Furthermore, the growth in human population and coastal settlements means that the socio-economic impact of these phenomena has become more dramatic in recent decades. In Chile, a major example is the paralytic poisoning of marine shellfish, first seen in Punta Arenas in 1972.

During 2002, an outbreak of *Alexandrium catenella* was detected in the research area and was responsible for 73 poisonings and two deaths. The outbreak affected an area where 60% of the shellfish are destined for export. As a result, the zone to the south of 43ºS was closed for shellfish extraction during 2002 and 2004. An intense control programme is now under way for marine products, and a permanent sanitary area has been established that prohibits the export of shellfish products without certification to national and international destinations.

There is a clear need for a deeper understanding of the toxic micro-algal outbreaks in the area.

MERIS and AATSR

The MERIS instrument on Envisat has several mission goals, one of which is to generate data for the analysis of the spatial and temporal distributions of marine biological activity in the surface layers of the ocean. AATSR's key task is to provide data in the thermal-IR band, to generate sea-surface temperature maps.

The results from this project confirm that both instruments have achieved those objectives. In the south of Chile, the combined use of MERIS and AATSR data provides early alerts of local and regional algal blooms, as well as of other marine phenomena. However, this is not an easy or automated task, because it requires a detailed knowledge and experience of interpreting satellite data, integrated with other information from different sources.

Envisat data were acquired as part of an ESA Category 1 project. During the pilot phase, data were received with a time delay of several weeks. After the implementation of new ground segment procedures by ESA, images were received from the servers at ESRIN (I) and Kiruna (S) in near-realtime, within 3 hours of acquisition by Envisat. Thanks to those improvements, it was possible to monitor large coastal areas in one of the remotest parts of Patagonia, where rapid social and economic development can be affected by natural phenomena.

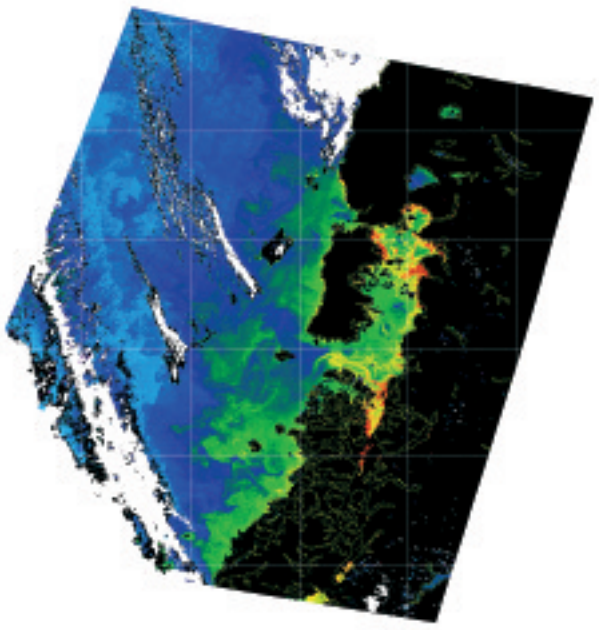
The support provided by satellite information for daily activities in the sea also led to the parallel development of small pilot applications. These were aimed at evaluating and then demonstrating the usefulness of remote sensing for the aquaculture industry, insurance companies and governmental organisations in monitoring potential toxic outbreaks through the consumption of tainted seafood.

Benefits from New Technologies

Research into phytoplankton monitoring using remote sensing began in 2002 with the use of SeaWiFS and then MERIS and MODIS (Moderate Resolution Imaging Spectroradiometer on Terra and Aqua) satellite products, with the purpose of applying sea-surface temperature and ocean-colour information. Initial results indicated that it was possible to focus research funding on selected specific areas.

Later, the use of Envisat satellite data demonstrated that it is possible to predict the occurrence of critical algal bloom periods, in order to mitigate the damage to aquaculture. Advance warnings of only 4 days allow enough response to reduce the effects of an algal bloom. Experimental early warnings sent to selected companies enabled them to make key decisions in time. For example, 'smolts' (young salmon) were not introduced into areas affected by the algal bloom: a small delay at this stage of the production process avoided the loss of several million dollars later on.

In addition, Envisat observations detected areas of maximum phytoplankton activity in a zone where marine mammals such as the blue whale had been recently seen. This zone was thus proposed as a new protected marine ecosystem. MERIS images have shown high phytoplankton concentrations connected with thermal fronts detected by AATSR. These observations fit well with the positions of the whale sightings.



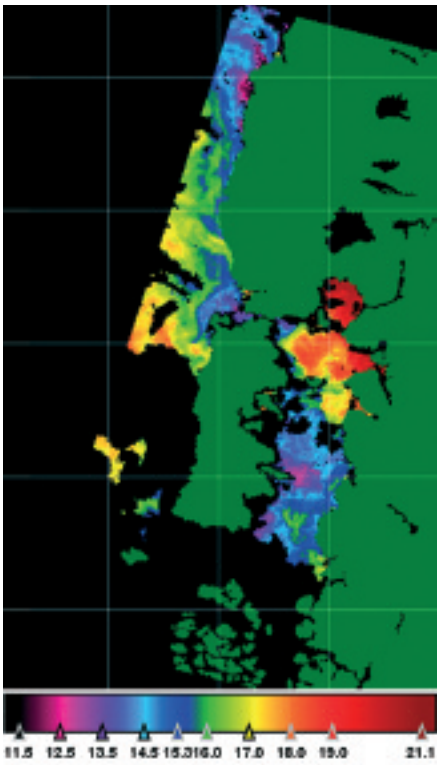
Algal bloom of Gymnodinium chlorophorum, *occurring every year since 2003 and detected by MERIS on 26 April 2005*

Threats to Aquaculture

Aquaculture in southern Chile mainly concerns the production of salmon and shellfish. Algal blooms of different spatial and temporal characteristics have been observed. In some cases, these explosive growths of micro-algae lasted for several weeks, as with the bloom of a new species, *Gymnodinium chlorophorum*, during southern autumn 2005. Whether toxic or not, these micro-algae are solely responsible for changes in the feeding behaviour of fish, slowing their growth.

After the exponential growth of algae, bacterial development follows through decomposition of the algae. Metabolic reactions reduce the concentration of dissolved oxygen (hypoxia) in the seawater, killing the fish. In the case of the shellfish industry, the threat comes from species carrying toxins that then accumulate in the shellfish. Paralytic, diarrhoeic and amnesic toxins have also been found between Regions III and XII in Chile, with some isolated cases in the central zones of the country.

In 1993, the amount of exported blue mussels (*Mytilus chilensis*) was 3000 t, increasing to 60 000 t in 2003, and an estimate of 100 000 t for 2008. Careful management of the exploited areas is required for sustainable development.



Sea-surface temperature derived from Envisat AATSR data of 21 February 2004. The thermal situation favoured the exponential growth of V. parahaemolyticus. *The highest temperature (°C) is shown in red*

For this, it is necessary to integrate all the methods available for monitoring coastal zones, in particular multi-disciplinary programmes involving satellite data.

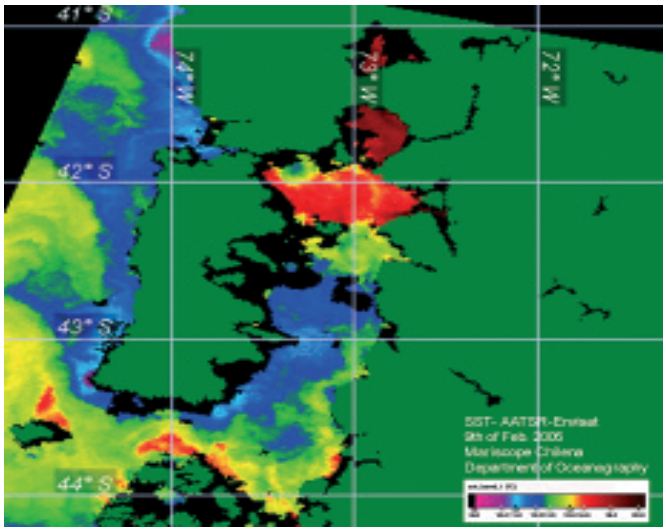
Earth Observation and Epidemiology

In 2003, some bacterial species were detected for the first time in the area. One was identified as *V. parahaemolyticus*, responsible for more than 1500 poisonings during the southern summer of 2004 and more than 10 000 cases in 2005, including one death. The origin of these bacteria in the region was probably ballast water spilling from other countries. This hypothesis is supported by the results of the genetic analysis of the bacteria strains found in Chile, which corresponds to the pandemic complex seen in some Asian countries after 1996.

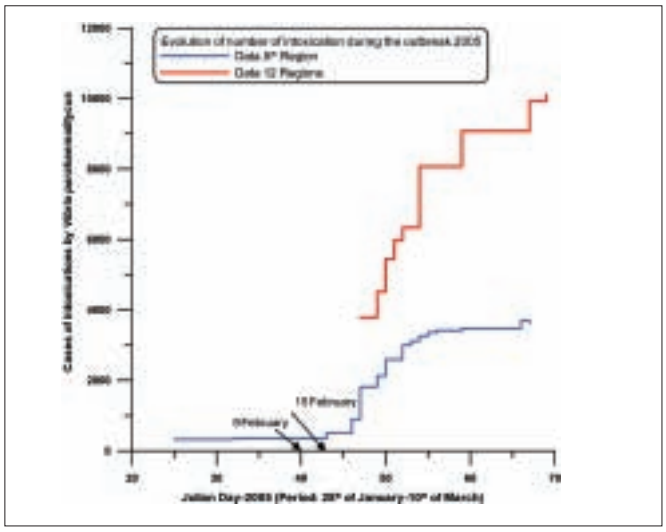
V. parahaemolyticus is a bacterium of the same genus as *V. cholera*, which lives in marine environments. Several parameters influence its life cycle; water temperature has been demonstrated to be one of the most important factors that accelerate its growth. Envisat AATSR data showed the rise of sea-surface temperature during January 2004 in that area. The seafood areas at most risk of being infected with this bacterium were determined through the analysis of AATSR and ancillary data. Eventually, remote-sensing data helped local health authorities to establish a well-defined region of increased risk, and to avoid closing low-risk areas.

Unfortunately, during the southern summer of 2005, preventive action was limited to advising people to avoid raw shellfish during the critical period. No sanitary barriers were established, and no restrictions were imposed on the shellfish extraction by area; such a difficult decision would have strongly affected local families dependent on the industry. This led to more than 10 000 cases of poisoning all over the country, and one death. The region is a key zone for extracting and exporting shellfish. This could explain how the outbreak rapidly turned into a national epidemic.

Envisat data helped local authorities to define the region of high risk of poisonings and to avoid closing low-risk areas



Sea-surface temperatures derived from AATSR data of 9 February 2005, some days before the exponential growth in poisonings from raw shellfish consumption



Evolution of the number of poisonings during the 2005 outbreak of V. parahaemolitycus

Through remote sensing, it was possible to demonstrate that the water temperature was above 18ºC on 9 February 2005 around the coastal zone with the highest population density, which is also the principal area of shellfish extraction. The temperature could have been one of the main reasons for the exponential growth of the bacteria. The Health and Consumer Protection Directorate General of the European Commission recommends avoiding the extraction of marine resources during the critical period in summer. This recommendation should be considered in equivalent regions beyond Europe.

By using satellite data, it is possible to forecast the most critical periods of contamination up to a week in advance. That certainly allows time to create at least temporary sanitary barriers, minimising the effects on the workers in the seafood industry, and on the regional and national population. This technology adds value to the exported products, in that it provides a sort of quality certification to the monitoring conducted during the extraction period.

Routine work of divers in the salmon industry. Remote sensing data help to plan their daily work and prevent decompression sickness

Novel Application to Human Health

Another recent application of satellite data with a positive effect on public health is the prevention of decompression sickness in working divers of the region. The link between divers and satellites may appear surprising, but it confirms the value of space data in multi-disciplinary applications.

One of the routine tasks of divers in the salmon industry is the daily clearing of dead salmon from nets to prevent disease in the remaining fish. An average of 10 salmon are taken out of each cage every day. A single diver normally does the job in up to 30 cages per farm. This level of effort already affects the diver's health owing to the repetitive diving and the accumulation of nitrogen bubbles in the body.

During and after algal bloom events, these divers have to cope with massive fish starvation in the cages. The amount of dead salmon is often so high that the load on the bottom of the net is too great for the installation to remain afloat. When the nets collapse and sink, they damage the surrounding nets. During these events, divers work for hours in the cages, often not following the necessary decompression procedures afterwards. Serious decompression accidents sometimes kill the divers. The insufficient number of divers to cope with these emergencies in the more remote regions of southern Chile means that the situation is not improving.

The use of satellite information to warn of an algal bloom can help to reduce accidents and losses, as demonstrated in 2005 through the use of Envisat MERIS and AATSR data. This is an important example of the many ways in which satellite information is of real daily benefit to people around the world.

Conclusion

The integrated use of satellite and *in situ* sea measurements is an important aid to decision-making for public and industry administrators. However, data integration and interpretation by skilled professionals is a fundamental prerequisite given the major socio-economic and public health impacts of their decisions. esa