Ocean measurements from space

Satellite Monitoring

By Kira Coley

Since the beginning of the Industrial Revolution, billions of metric tons of carbon dioxide (CO2) have been emitted into the Earth's atmosphere each year. The ocean absorbs about 25% of these global emissions annually, causing fundamental changes in seawater chemistry throughout the world's oceans. For more than 50 years, measurements from space have given scientists a worldwide prospective of the Earth's climate and more recently, ocean topography. The continued advancement of satellite technology is expanding the range of ocean parameters which can be measured. The recent addition of salinity, pioneering techniques and sustained funding are set to revolutionize the way that marine and climate scientists study the ocean, hailing the start of a new era of ocean monitoring.

Source: ESA/AOES Medialab

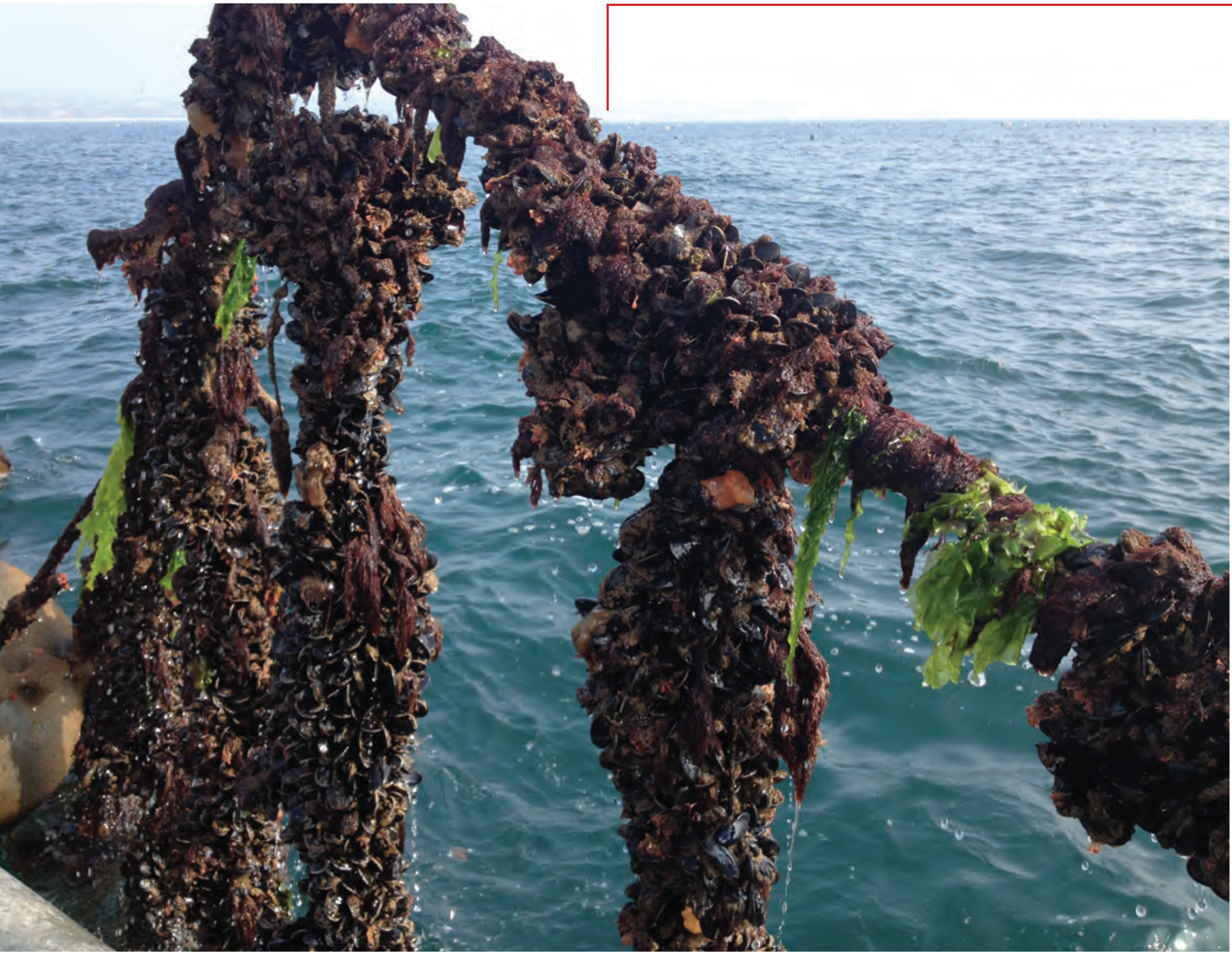
Artistic impression of the The Soil Moisture and Ocean Salinity (SMOS) satellite in orbit around the Earth. The SMOS satellite and its sensor have been monitoring the Earth's soil and oceans since late 2009 and the salinity data are now beginning to be used for supporting ocean carbonate research.

Ocean acidification (OA) is a relatively new field of research. While this area has gained considerable attention over the last decade, there are many challenges in acquiring high quality datasets which can be used to better predict the implications of decreasing pH in the oceans. As the ocean covers approximately 360 million sq. km. of the Earth's surface, difficulties surveying this enormous range confines studies to individual sites.

In 2012, the Global Ocean Acidification Observing Network (GOA-ON) was formed with the aims to improve global observations and expertise. Monitoring efforts are currently dominated by in situ measurements taken from research vessels, moorings and other platforms. While these methods are vital for OA research, challenging and remote regions can be difficult to access, causing low spatial and temporal resolution in global datasets.

The resulting accumulation of in situ data over the last decade allows for the advancement and testing of satellite-derived products for ocean monitoring. In a paper published in Environmental Science & Technology, researchers suggest that the relatively new ability to observe salinity using satellites was the missing piece to monitoring OA parameters.

"In situ data is key to OA research, but in situ measurements will always be sparse in time and space. This is because they are point data and so it's expensive, time consuming and often difficult and dangerous to monitor spatially large areas using in situ methods. The combination of in situ models and satellite Earth observation, provides us with a good combination of spatial and temporal coverage. It is only by using all three of these methods that we will be able to efficiently monitor our Earth," said Dr. Jamie Shutler, an oceanographer and former



European Space Agency (ESA) fellow, now specializing in atmosphere-ocean gas exchange at the University of Exeter.

Dr. Shutler is part of an international team of researchers based at the University of Exeter, Plymouth Marine Laboratory, Institut français de recherche pour l'exploitation de la mer (Ifremer), the European Space Agency and other collaborators, highlighting the potential role of satellites in OA research.

Measuring a Complex Carbonate System

Many ocean variables can now be observed using satellite Earth observations. These include sea surface temperature, sea state (waves, wind speed and direction), optical color (called ocean color) and more recently, salinity. These variables are derived from observations of different parts of the electromagnetic spectrum, from ultra-violet visible wavelengths through to near-infra and microwaves.

The carbonate system can be studied using four parameters: dissolved inorganic carbon (DIC), total alkalinity (TA), partial pressure of CO2 (pCO2) and pH. None of which can currently be directly observed using satellites.

The solubility of CO2 in Water is mostly controlled by temperature, so seasonal changes in sea temperature can be important for driving changes in pCO2 and consequently, DIC and pH. Salinity a ects the coe cients of the carbonate system equations. Therefore, in order to characterize the carbonate system, two of these four parameters are required, together with temperature and salinity. The recent addition of salinity to the parameters measurable from space unlocks the potential to measuring the other carbonate variables used in OA observations.

Dr. Shutler explains, "While we can make salinity observations from space, the technology and methods are continually being improved and enhanced. The precision and accuracy of the salinity measurements are continuing to improve as our knowledge develops. The Arctic regions are particularly dif-

Mussels being grown on ropes in waters off the coast of Cornwall, UK. Mussels are a popular source of food enjoyed by millions of people around the world. Ocean acidification, caused by the oceanic uptake of carbon dioxide, is thought to reduce the ability of mussels to attach to their host surface. Suggesting that in the future, as carbon dioxide levels continue to rise, it may become more difficult to cultivate them.

ficult as the sensitivity of the salinity measurements reduces in lower temperature waters."

Biological activity is also an important factor for the removal or addition of CO_2. Plankton photosynthesis or respiration can be a significant component of seasonal variation. Additional factors, such as nutrients and light conditions, can also drive regional changes in biological activity. The ability to measure chlorophyll, a proxy for biomass, as well as oxygen concentration, can be valuable for interpreting the biological part of the carbonate system.

Potential of Space-based Measurements

While the use of remote technology to detect changes in ocean pH directly has proven difficult, satellites can measure sea surface temperature and salinity (SST and SSS), as well as surface chlorophyll-a. These measurements, used in combination with empirical relationships derived from in situ data, allows the estimation of carbonate system parameters.

Satellite Earth observations will usually be limited to the top few meters of the ocean. In the case of salinity, measurements are derived from the top few centimeters of the water, so are truly 'surface' measurements. In some regions where there is an upwelling of water, surface measurements will actually represent the conditions at depth.

"Questions asking if these surface measurements are enough to monitor OA, could also be asked of in situ data. In situ data are collected at one depth and a single location – so, are these in situ data points any use for determining the carbonate system conditions 1-5 meters, or further, away from the sampling position? In some cases they might be, and in others they won't. All methods of observation have limitations. The important thing is to fully understand the limitations," said Dr. Shutler.

As air-sea interactions and changes in carbonate chemistry

occur at the ocean surface first, these observations are particularly important for OA. This means that although satellites are mostly limited to surface observations, they have great potential as a tool for assessing changes in carbonate chemistry. Of the four parameters, only pCO2 and pH are routinely monitored in situ. DIC and TA measurements are usually made in laboratories, both at sea and on land. The accuracy obtained in laboratory conditions will far outcompete that which can be achieved from satellites and in situ methods. However, as research vessels are expensive and limited in coverage, autonomous in situ instruments are also deployed. Although autonomous vehicles can generally provide greater spatial coverage than research ships, shallow or enclosed seas remain unobserved due to difficulties accessing these areas.

While important for advancing ocean monitoring capabilities, satellite Earth observation will by no means replace in situ observations as they are needed to evaluate satellite data. Equally, satellite Earth observation often exploits advancements and knowledge gained through in situ data studies, therefore the two methods of observations complement each other.

"Satellite Earth observation is key to monitoring the health of our oceans. The global oceans cover about 71% of the Earth's surface. So arguably, the only way to efficiently and economically monitor this vast amount of water is to use satellite Earth observation. No other efficient method to monitor the vast oceans exists. Their size and often inhospitable nature means that we cannot solely rely on in situ observations," said Dr. Shutler. "However, satellite Earth observation is not the 'golden solution' for monitoring OA, it is just one piece of the puzzle. The combination of satellite observations along with in situ measurements and models will, together, provide an excellent capability for monitoring OA."

Future Developments

It is an important time for satellite ocean monitoring. The Copernicus program, a European flagship initiative worth more than $7 billion, launched the Sentinel-1A in 2014. This long term (15-20 year) program aims to provide an operational satellite monitoring capability and related services for the environment and security. These satellites will provide unmatched spatial and temporal coverage for both chlorophyll-a and SST observations.

Another satellite mission launched in 2014 was the NASA Orbiting Carbon Observatory (OCO-2). While its primary objective is to observe atmospheric CO2 concentrations, its potential for marine carbon cycle and OA is likely to be a focus of future research. The data from all of these satellites and their sensors will give scientists new insights into how OA may be influencing our oceans and marine life. However, these programs are still in their infancy and further developments are required to improve the accuracy and quality of satellite derived observations.

The advancement of the satellite-based technology and the ability to monitor ocean salinity will shape the development of future satellite sensors. These satellite observations, used in conjunction with in situ measurements and models, will become a key element in understanding and assessing OA.

"We are entering an exciting time for satellite Earth observation. The start of the EU Copernicus program heralds a new era in satellite monitoring. This large long term program will provide environmental monitoring via a fleet of satellites for the next 15 or more years at unprecedented temporal and spatial scales," said Dr. Shutler.

Acknowledgement

Dr. Jamie Shutler, Centre for Geography, Environment and Society, University of Exeter.

Land, P.E., Shutler J.D., Findlay H.S., et. al. (2015) Salinity from Space Unlocks Satellite-Based Assessment of Ocean Acidification. Environ. Sci. Technol., 49 (4), pp 1987–1994 DOI: 10.1021/es504849s.