Scientific Programs

Earth & Environment

Contents

Chapter 1

Copernicus Programme

Copernicus is the world's largest single earth observation programme and directed by the European Commission in partnership with the European Space Agency (ESA).[1][2] It aims at achieving a global, continuous, autonomous, high quality, wide range Earth observation capacity. Providing accurate, timely and easily accessible information to, among other things, improve the management of the environment, understand and mitigate the effects of climate change, and ensure civil security.[3] It follows and greatly expands on the work of the previous 2.3 billion euros European Envisat program which operated from 2002 to 2012.

Its cost during 1998 to 2020 are estimated at 6.7 billion euros with around €4.3bn spend in the period 2014 to 2020 and shared between the EU (66%) and ESA (33%) with benefits of the data to the EU economy estimated at roughly 30 billion euros through 2030.[4] ESA as a main partner has performed much of the design and oversees and co-funds the development of Sentinel mission 1, 2, 3, 4, 5 and 6 with each sentinel mission consisting of at least 2 satellites and some like sentinel 1 consisting of 4 satellites.[5] They will also provide the instruments for MTG and MetOp-SG weather satellites of EUMETSAT where ESA and EUMETSAT will also coordinate the delivery of data from upwards of 30 satellites that form the contributing satellite missions to Copernicus.[6]

The objective is to use multi-source data to get timely and quality information, services and knowledge, and to provide autonomous and independent access to information in relation to the environment and security on a global level. In other words, it will pull together all the information obtained by the Copernicus environmental satellites, air and ground stations to provide a comprehensive picture of the "health" of Earth. The geo-spatial information services offered by Copernicus can be grouped into six main interacting themes: land, ocean, emergency response, atmosphere, security and climate change. The first three Copernicus services under the land, ocean and emergency response themes and two additional services addressing the atmosphere and security themes were unveiled at the Copernicus Forum held in Lille in September 2008.

Copernicus builds upon three components:

- the space component (observation satellites and associated ground segment with missions observing land, atmospheric and oceanographic parameters) This comprises two types of satellite missions, ESA's five families of dedicated Sentinel (space missions) and missions from other space agencies, called Contributing Missions.
- in-situ measurements (ground-based and airborne data gathering networks providing information on oceans, continental surface and atmosphere)
- services to users.

1.1 History

Over the last decades, European and national institutions have made substantial R&D efforts in the field of Earth observation. These efforts have resulted in tremendous achievements, but the services and products developed during this period had limitations that were inherent to R&D activities (e.g. lack of service continuity on the long-term). The idea for a global and continuous European earth observation system was developed named **Global Monitoring for Environment and Security** (**GMES**) which was later turned into Copernicus after the EU became involved in financing and development.

In 2014-2015 Copernicus is moving towards an operational phase. The key to providing operational Copernicus services is to have an appropriate governance and business model structure in place that supports provisioning of these services. Copernicus has been moving from R&D to operational services, following a phased approach:

- **2008 – 2010**: Copernicus pre-operational services (FTS and Pilot services)
- **2011 – 2013**: Copernicus initial operations
- **From 2014**: Copernicus fully operational services

19 May 1998: institutions involved in the development of space activities in Europe give birth to GMES through a declaration known as “The Baveno Manifesto”. At that time, GMES stands for “Global Monitoring for Environmental Security”

Year 1999: the name is changed to “Global Monitoring for Environment and Security”, thus illustrating that the management of the environment also has security implications.

Year 2001: at the occasion of the Gothenburg Summit, the Heads of State and Government request that "*the Community contribute to establishing by 2008 a European capacity for Global Monitoring for Environment and Security*".

October 2002: the nature and scope of the “Security” component of GMES are defined as addressing prevention of and response to crises related to natural and technological risk, humanitarian aid and international cooperation, monitoring of compliance with international treaties for conflict prevention, humanitarian and rescue tasks, peacekeeping tasks and surveillance of EU borders.

February 2004: the Commission Communication "*GMES: Establishing a GMES capacity by 2008*" introduces an Action Plan aimed at establishing a working GMES capacity by 2008. In 2004, a Framework Agreement is also signed between EC and ESA, thus providing the basis for a space component of GMES.

May 2005: the Commission Communication "*GMES: From Concept to Reality*" establishes priorities for the rollout of GMES services in 2008, the initial focus being on land monitoring, marine monitoring and emergency response services, also known as Fast Track Services (FTS). Later services, also known as Pilot Services, are expected to address atmosphere monitoring, security and climate change.

June 2006: the EC establishes the GMES Bureau, with the primary objective of ensuring the delivery of the priority services by 2008. Other objectives of the GMES Bureau are to address the issues of the GMES governance structure and the long-term financial sustainability of the system.

May 2007: adoption of the European Space Policy Communication, recognising GMES as a major flagship of the Space Policy.

September 2008: official launch of the three FTS services and two Pilot services in their pre-operational version at the occasion of the GMES Forum held in Lille, France.

November 2008: the Commission Communication "*GMES: We care for a Safer Planet*" establishes a basis for further discussions on the financing, operational infrastructure and effective management of GMES.

May 2009: the Commission Proposal for a Regulation on "*the European Earth Observation Programme (GMES) and its initial operations (2011-2013)*" proposes a legal basis for the GMES programme and EC funding of its initial operations.

November 2010: the regulation on "*the European Earth Observation Programme (GMES) and its initial operations (2011-2013)*" entered into force.

June 2011: the Commission presents its proposal for the next multiannual financial framework (MFF) corresponding to the period 2014-2020 (Communication “A Budget for Europe 2020”). In this document, the Commission proposes to foresee the funding of the GMES programme outside the multiannual financial framework after 2014.

November 2011: The Commission Communication on the “European Earth monitoring programme (GMES) and its operations (from 2014 onwards)" presents the Commission’s proposals for the future funding, governance and operations of the GMES programme for the period 2014 - 2020. In particular, the Commission proposes to opt for the creation of a specific GMES fund, similar to the model chosen for the European Development Fund, with financial contributions from all Member States, based on their Gross National Income (GNI).

December 2012: the Commission announces the name change to Copernicus.

October 2014: ESA and European Commission have established a budget for Copernicus Programme covering years 2014-2020 within Multiannual Financial Framework. Budget provided a total of €4.3 billion, including €3.15 billion for ESA to cover operations of the satellite network and a construction of the remaining satellites.[7][8]

1.2 Earth Observation missions

1.2.1 Sentinel missions

ESA is currently developing seven missions under the Sentinel programme. The Sentinel missions include radar and super-spectral imaging for land, ocean and atmospheric monitoring. Each Sentinel mission is based on a constellation of two satellites to fulfill and revisit the coverage requirements for each mission, providing robust datasets for all Copernicus services. The Sentinel missions will have the following objectives:

- Sentinel-1 will provide all-weather, day and night radar imaging for land and ocean services. The first Sentinel-1A satellite was successfully launched on 3 April 2014, by an Arianespace Soyuz, from the Guyana Space Center;.[9] The second Sentinel-1B satellite was launched on 25 April 2016 from same spaceport.

- Sentinel-2 will provide high-resolution optical imaging for land services (e.g. imagery of vegetation, soil and water cover, inland waterways and coastal areas). Sentinel-2 will also provide information for emergency services. The first Sentinel-2 satellite has successfully launched on 23 June 2015.[10]

- Sentinel-3 will provide ocean and global land monitoring services. The first Sentinel-3A satellite was launched on 16 January 2016 by a Eurockot Rokot vehicle from the Plesetsk Cosmodrome in Russia;[11][12]
- Sentinel-4, embarked as a payload upon a Meteosat Third Generation Satellite, will provide data for atmospheric composition monitoring. It will be launched in 2021;[13]
- Sentinel-5 Precursor - subset of the Sentinel 5 sensor set planned for launch in early 2017.[14] The primary purpose of this is to reduce the data gap (especially SCIAMACHY atmospheric observations) between the loss of ENVISAT in 2012, and the launch of Sentinel-5 in 2021.[15] The measurements will be done by the Tropomi spectroscope.[16]
- Sentinel-5 will also provide data for atmospheric composition monitoring. It will be embarked on a post-EUMETSAT Polar System (EPS) spacecraft and launched in 2021;[13]
- Sentinel-6 is the intent to sustain high precision altimetry missions following the Jason-3 satellite.

1.2.2 Contributing missions

Before the Sentinel missions provide data to Copernicus, numerous existing or planned space missions provide or will provide data useful to the provision of Copernicus services. (These missions are often referred to as "*GMES Contributing Missions (GCMs)*".)

- **ERS**: The European Remote Sensing Satellite ERS-1 (1991-2000) was ESA's first Earth observation satellite. ERS-2, launched in 1995, provides data related to ocean surface temperature, winds at sea and atmospheric ozone.
- **Envisat**: Launched in 2002, Envisat is the largest Earth Observation spacecraft ever built. It carries sophisticated optical and radar instruments among which the Advanced Synthetic Aperture Radar (ASAR) and the Medium Resolution Imaging Spectrometer (MERIS). Envisat provides continuous observation and monitoring of the Earth's land, atmosphere, oceans and ice caps. After losing contact with the satellite on 8 April 2012, ESA formally announced the end of Envisat's mission on 9 May 2012.[17]
- **Earth Explorers**: Earth Explorers are smaller research missions dedicated to specific aspects of our Earth environment. Earth Explorer missions focus on the atmosphere, biosphere, hydrosphere, cryosphere and the Earth's interior with the overall emphasis on learning more about the interactions between these components and the impact that human activity is having on natural Earth processes. There are seven missions selected for implementation:
  - GOCE (Gravity Field and Steady-State Ocean Explorer), launched on 17 March 2009.
  - SMOS (Soil Moisture and Ocean Salinity), launched on 2 November 2009.
  - CryoSat-2 (measurement of the thickness of floating ice), launched on 8 April 2010.
  - Swarm (high-precision and high-resolution measurements of the strength and direction of the Earth's magnetic field), launched on 22 November 2013.
  - ADM-Aeolus (Atmospheric Dynamics Mission), scheduled for launch in 2017.[18]
  - EarthCARE (Earth Clouds, Aerosols and Radiation Explorer), scheduled for launch in 2018.[18]
  - BIOMASS, scheduled for launch in 2020.[19]
- **MSG**: the Meteosat Second Generation is a joint project between ESA and EUMETSAT.
- **MetOp**: MetOp is Europe's first polar-orbiting satellite dedicated to operational meteorology. MetOp is a series of three satellites to be launched sequentially over 14 years from October 2006. The series will provide data for both operational meteorology and climate studies.
- French **SPOT**: SPOT (Satellite Pour l'Observation de la Terre) consists of a series of earth observation satellites providing high resolution images of the Earth. SPOT-4 and SPOT-5 include sensors called VEGETATION able to monitor continental ecosystems.
- German **TerraSAR-X**: TerraSAR-X is an Earth observation satellite providing high quality topographic information. TerraSAR-X data has a wide range of applications (e.g. land use / land cover mapping, topographic mapping, forest monitoring, emergency response monitoring and environmental monitoring)
- Italian **COSMO-SkyMed**: the COnstellation of small Satellites for the Mediterranean basin Observation is an Earth observation satellite system that will include four satellites equipped with synthetic aperture radar (SAR) sensors. Applications include seismic hazard analysis, environmental disaster monitoring and agricultural mapping.

- UK and international **DMC**: The Disaster Monitoring Constellation (DMC) consists of five remote-sensing satellites. The constellation provides emergency Earth imaging for disaster relief under the International Charter for Space and Major Disasters.
- French-American **JASON-2**: The JASON-2 satellite provides precise measurements of ocean surface topography, surface wind speed and wave height; as this type of measurement is a crucial requirement for the Copernicus Marine Services the European Commission has included this type of mission in its latest communication on the future Copernicus Space Component as Sentinel 6
- French **PLEIADES**: The PLEIADES constellation consists of two satellites providing very high resolution images of the Earth

Data provided by non-European satellite missions (e.g. LANDSAT, GOSAT, RADARSAT-2) can also be used by Copernicus.

- DigitalGlobe, an American commercial vendor of space imagery and geospatial content, provides imagery from satellites with a true maximum resolution of up to 25 cm. The DigitalGlobe tasking constellation currently includes GeoEye-1, WorldView-1, WorldView-2 and WorldView-3. Archive data is also available from IKONOS and QuickBird.
- LANDSAT
- GOSAT
- RADARSAT-2

1.3 *In-Situ* Coordination

GMES In-Situ Coordination (GISC). GISC is a FP7 funded initiative, will last for three years (January 2010 – December 2012) and is coordinated by the European Environment Agency (EEA).

In-situ data are all data from sources other than Earth observation satellites. Consequently, all ground-based, air-borne, and ship/buoy-based observations and measurements that are needed to implement and operate the Copernicus services are part of the in-situ component. In-situ data are indispensable; they are assimilated into forecasting models, provide calibration and validation of space-based information, and contribute to analysis or filling gaps not available from space sources.

GISC objectives will be achieved by:

- documenting the in-situ data needs and data requirements
- cooperating with the users, stakeholders, and service providers
- exploring and determining methods to enable networks to provide the required in-situ data for Copernicus
- exploring approaches to the integration of in-situ assets and networks into long-term sustainable frameworks for Copernicus services
- providing 'quick-wins'

GISC is undertaken with reference to other initiatives, such as INSPIRE (Infrastructure for Spatial Information in Europe) and SEIS (Shared Environmental Information System) as well as existing coordination and data exchange networks. The coordinated access to data will retain the capacity to link directly data providers and the service providers because it is based on the principles of SEIS and INSPIRE. The implementation of INSPIRE is embedded in the synergies and meta-data standards that are used in GISC. Data and information will aim to be managed as close as possible to its source in order to achieve a distributed system, by involving countries and existing capacities that maintain and operate the required observation infrastructure.

1.4 Services component

Copernicus services are dedicated to the monitoring and forecasting of the Earth's subsystems. They contribute directly to the monitoring of climate change. Copernicus services also address emergency management (e.g. in case of natural disaster, technological accidents or humanitarian crises) and security-related issues (e.g. maritime surveillance, border control).

Today, Copernicus services address six main thematic areas:

- Land Monitoring (see video available on the Copernicus.eu website: Copernicus Land Monitoring Service). The service was declared operational on 1 April 2012.
- Marine Environment Monitoring (see video available on the Copernicus.eu website: Copernicus Marine Environment Monitoring Service). The service was declared operational on 1 May 2015.
- Atmosphere Monitoring (see video available on the Copernicus.eu website: Copernicus Atmosphere Monitoring Service). The service will be declared operational in 2015.
- Emergency Management (see video available on the Copernicus.eu website: Copernicus Emergency Management Service). The service was declared operational on 1 April 2012.

- Security (See Copernicus Service for Security Applications)
- Climate Change (see video available on the Copernicus.eu website: Copernicus Climate Change Monitoring Service)

The development of the pre-operational version of the services has been realised by a series of projects launched by the European Commission and partly funded through the EU's 7th Framework Programme (FP7). These projects were geoland2 (land), MyOcean (marine), SAFER (emergency response), MACC and its successor MACC II (atmosphere) and G-MOSAIC (security). Most of these projects also contributed to the monitoring of Climate Change.

- **geoland2** started on 1 September 2008. The project covered a wide range of domains such as land use, land cover change, soil sealing, water quality and availability, spatial planning, forest management, carbon storage and global food security.
- **MyOcean** started on 1 January 2009. It covered themes such as maritime security, oil spill prevention, marine resource management, climate change, seasonal forecast, coastal activities, ice survey and water pollution.
- **SAFER** started on 1 January 2009. The project addressed three main domains: civil protection, humanitarian aid and Security crises management.
- **MACC** started on 1 June 2009. The project continued and refined the products developed in the projects GEMS and PROMOTE. A second phase of funding for the pre-operational Copernicus atmospheric monitoring and forecasting service provided by MACC (MACC II) had been secured until July 2014.
- **G-MOSAIC** started on 1 January 2009. Together with the LIMES project (co-funded by the European Commission under FP6), G-MOSAIC specifically dealt with the Security domain of Copernicus addressing topics such as Support to Intelligence & Early Warning and Support to Crisis Management Operations.

1.5 Interaction

1.5.1 Users

The system focuses on needs of the European Commission and its agencies. Main users of Copernicus will be for example farmers, rescue workers and scientists. Copernicus should allow policy-makers to prepare national, European and international legislation on environmental matters (including climate change) and to monitor the implementation of this legislation.

Copernicus is the European Union contribution to the Global Earth Observation System of Systems (GEOSS) thus delivering geospatial information globally.

1.5.2 Dependencies

Copernicus uses OpenStreetMap data in their maps production.[20]

1.6 Other relevant initiatives

Other initiatives will also facilitate the development and functioning of Copernicus services:

- INSPIRE: this initiative aims at building a European spatial data infrastructure beyond national boundaries.
- Urban Atlas: Compiled from thousands of satellite photographs, the Urban Atlas provides detailed and cost-effective digital mapping, ensuring that city planners have the most up-to-date and accurate data available on land use and land cover. The Urban Atlas will enable urban planners to better assess risks and opportunities, ranging from threat of flooding and impact of climate change, to identifying new infrastructure and public transport needs. All cities in the EU will be covered by the Urban Atlas by 2011.
- SEIS: The Shared Environmental Information System (SEIS) is a collaborative initiative of the European Commission and the European Environment Agency (EEA) to establish together with the Member States an integrated and shared EU-wide environmental information system.
- Heterogeneous Missions Accessibility, the European Space Agency initiative for interoperability of Earth observation satellite payload data ground segments.

Copernicus is one of three related initiatives that are the subject of the GIGAS (*GEOSS, INSPIRE and GMES an Action in Support*) harmonization and analysis project [21] under the auspices of the EU 7th Framework Programme.[22]

1.7 See also

- CNES

- French space program
- BOSS4GMES, a project that coordinates GMES research effort
- European Space Technology Platform
- Mission Science Division

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1.9 External links

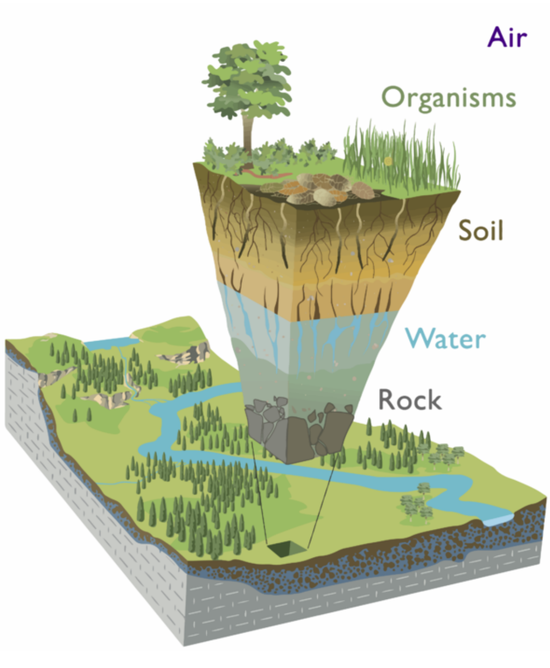
- EC Copernicus web site
- Copernicus R&D website, operated by FDC under a EU-funded service contract (89/PP/ENT/2011 - Lot 1), with participation of SpaceTec Partners for the "Copernicus Observer" e-magazine
- ESA Copernicus web site
- Copernicus reference documents
- GNU (GMES Network of Users)
- GEO (Group on Earth Observation)
- SEIS (Shared Environmental Information System)
- Article upon the 1st GMES Masters
- GISC Website
- A video presenting the Copernicus programme is available on the Copernicus.eu website (Video presenting the Copernicus Programme)

Chapter 2

Critical Zone Observatories

Critical Zone Observatories (CZO) is an interdisciplinary collaborative research project across nine institutions with the purpose of understanding the chemical, physical, geological, and biological processes that both shape the surface of Earth and support terrestrial life.[1] Active CZO sites include locations in Boulder Creek, Calhoun, Eel River, Intensively Managed Landscapes (IML), Jemez River Basin & Santa Catalina Mountains, Luquillo, Reynolds Creek, Susquehanna Shale Hills, and Southern Sierra.

Funded by the National Science Foundation,[2] CZO has been working since its 2007 inception to critically engage the scientific community and increase understanding of the importance of Critical Zone science.[3][4]



Earth's Critical Zone. Illustration by Critical Zone Observatories (CZO) based on a figure in Chorover et. al. 2007.

2.1 Mission

To use its institutions together to create a unique network that fosters scientific inquiry and discovery with regards to Earth's Critical Zone.[3] Much like the interconnectedness of Earth's critical zone systems, CZO relies upon a range of disciplines, including geosciences, hydrology, microbiology, ecology, soil science, and engineering, to develop a theoretical spatial-temporal framework for critical zone evolution for both quantifiable and conceptualized data analyses.

2.2 Education and Outreach

Through research and education opportunities associated with each CZO, cross-CZO scientific endeavors, and annual meetings, CZO uses a variety of interfaces to communicate Critical Zone science to students and teachers.

2.3 NSF-funded Critical Zone Observatories

2.3.1 Boulder Creek Critical Zone Observatory

The Boulder Creek CZO is managed by researchers at the University of Colorado at Boulder and comprises four highly variable research sites at Colorado Creek, Rocky Mountains, and Colorado Front Range. [5] Primary research interests focus on rates of erosion and controlling weathering, dynamics between climate, ecosystem, and rock properties, as well as establishing Critical Zone architecture and evolution.[5] The highest site is at the Continental Divide is located at 4120 m and the lowest elevation site is on the eastern plans at 1480 m elevation.

2.3.2 Calhoun Critical Zone Observatory

The Calhoun CZO was originally established as the Calhoun Experimental Forest within the Southeastern Forest Experiment Station in South Carolina by the United States Forest Service in 1947.[6] The Calhoun Experimental Forest became a CZO in 2014.[2] The Calhoun CZO is managed by the scientists from the Nicholas School of the Environment at Duke University. The book "Understanding Soil Change: Soil Sustainability over Millennia, Centuries, and Decades" by Daniel D. Richter, Jr and Daniel Markewitz covers the history and science conducted at the Calhoun Experimental Forest.

2.3.3 Eel River Critical Zone Observatory

The Eel River CZO is managed by researchers from the University of California, Berkeley to study how the critical zone will mediate watershed currencies and ecosystem response in a changing environment. The Eel River CZO considers four different scales: 1) the hillslope, 2) the stream reach, 3) the whole Eel River watershed scale (nearly 10,000 km^2), and 4) the regional scale (>13,000 km^2). In 2014, the Eel River CZO received a $4.9 million grant from the NSF over the next five years to study how vegetation, geology and topography affect water flow all the way to the Pacific Ocean.[7] The Eel River CZO works closely with the Eel River Recovery Project and the University of California Angelo Reserve.[8]

2.3.4 Intensively Managed Landscape (IML) Critical Zone Observatory

Intensively Managed Landscapes (IML) CZO consists of three main sites: the Upper Sangamon River Basin in Illinois, the Clear Creek Watershed in Iowa, and the Minnesota River Basin in Minnesota and are representative of the glaciated Midwest. IML CZO aims to study the geologic evolution and anthropogenic influence on CZ structure and function, the co-evolution of biota, and fluxes of water, carbon, nutrients, and sediment.[9] IML CZO uses historical data, existing observational networks, remote sensing, sampling and laboratory analyses to address these goals.[9] IML is studied by researchers from the University of Illinois, Purdue University, University of Minnesota, University of Tennessee, and University of Iowa.

2.3.5 Jemez River Basin and Santa Catalina Mountains Critical Zone Observatory

This observatory is managed by researchers from the University of Arizona. Focused on the Santa Catalina Mountains near Tucson and the Jemez Mountains north of Albuquerque, this CZO is tasked with researching sites along elevation gradients in the semi-arid Southwest. Since the mountains of Arizona and New Mexico host a range of rock types and climates, temperatures and the amount of precipitation vary dramatically with elevation. This project includes a $4.35 million grant from the NSF for five years starting in 2009. The team is setting up sensor networks in low, intermediate and high elevation watersheds in the two mountain ranges to measure water flow flows through vegetation, soils, groundwater and streams. Collecting data on precipitation, soil moisture, plant uptake, aquifer recharge and stream flow during and between both rainfall and snowmelt is a central task.[10]

2.3.6 Luquillo Critical Zone Observatory

Research in the Luquillo Experimental Forest of northeastern Puerto Rico started 1989, as part of a Long Term Ecological Research Program.[11] Two watersheds of the Luquillo National Forest were subsequently established as the Luquillo CZO in 2009.[12] Luquillo CZO has been important for studying organismal influences on weathering because of the contrasting bedrock material and long term data collection.[13][14]

2.3.7 Reynolds Creek Critical Zone Observatory

Reynolds Creek CZO is located in the 239 km^2 Reynolds Creek Experimental Watershed (RCEW) in the Owyhee Range in southwest Idaho. Instrumentation includes numerous stations for collecting climate, precipitation, stream flow and snow and soil data and data collection network dates back to the 1960s.[15] Research conducted at Reynolds Creek CZO is primarily conducted by the Idaho State University, Boise State University and USDA ARS.[15]

2.3.8 Susquehanna-Shale Hills Critical Zone Observatory

The Susquehanna-Shale Hills CZO (SSHCZO) is a 0.08 km^2 watershed located in central Pennsylvania principally managed and studied by Penn State researchers. The CZO comprises two watersheds, the main SSHCZO is developed on Rose Hill shale and while the second watershed, Garner Run, is developed on Sandstone. SSHCZO is part of the Shale transect, which includes 7 other locations, ranging from the most northern site in Wales, United Kingdom, five sites along the Appalachian Mountains, to the most southern site of Mayaguez, Puerto Rico. SSHCZO has been studied to understand potential impacts from natural gas developments on terrestrial ecosystems of Pennsylvania.[16][17]

2.3.9 Southern Sierra Critical Zone Observatory

The Southern Sierra CZO is located on and near the Providence Creek watershed in the Sierra National Forest, California. Southern Sierra CZO comprises three watersheds in the Providence Creek and four eddy co-variance towers. Southern Sierra CZO also conducts research as part of the Kings River Experimental Watershed, Sierra

Nevada Adaptive Management Project, and the American River Observatory. Southern Sierra CZO is principally studied by researchers at the University of California, Merced.[18]

2.3.10 National Office

In 2014 a National Office branch was formalized to facilitate communication and collaboration among researchers and students, support education and outreach initiatives, coordinate data protocols and common measurements, and to provide a single point of contact for the Critical Zone Observatories.

2.4 Critical Zone Observatories Worldwide

According to SoilTrEC, there are 46 Critical Zone Observatories globally, with the majority in North America and Europe.[19] There are 17 CZOs in Europe, 5 in Southeast Asia, 3 near Australia, 2 CZOs in Africa, and 2 in South America.[20]

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2.6 External links

- http://www.criticalzone.org
- http://czo.colorado.edu/html/research.shtml
- http://www.udel.edu/czo/research.html
- http://www.czo.arizona.edu/research.html
- http://www.sas.upenn.edu/lczo/research.html
- http://www.czo.psu.edu/
- http://www.czen.org/
- http://czo.colorado.edu/

Chapter 3

Orbiting Carbon Observatory 2

Orbiting Carbon Observatory 2 (**OCO-2**) is an American environmental science satellite which launched on 2 July 2014. A NASA mission, it is a replacement for the Orbiting Carbon Observatory which was lost in a launch failure in 2009. It is the second successful high-precision (better than 0.3%) CO_2 observing satellite, after GOSAT.

3.1 Mission overview

The OCO-2 satellite was built by Orbital Sciences Corporation, based around the LEOStar-2 bus.[4] The spacecraft is being used to study carbon dioxide concentrations and distributions in the atmosphere.[5]

OCO-2 was ordered after the original OCO spacecraft failed to achieve orbit. During the first satellite's launch atop a Taurus-XL in February 2009, the payload fairing failed to separate from around the spacecraft and the rocket did not have sufficient power to enter orbit with its additional mass. Although a Taurus launch was initially contracted for the reflight, the launch contract was cancelled after the same malfunction occurred on the launch of the Glory satellite two years later.[6]

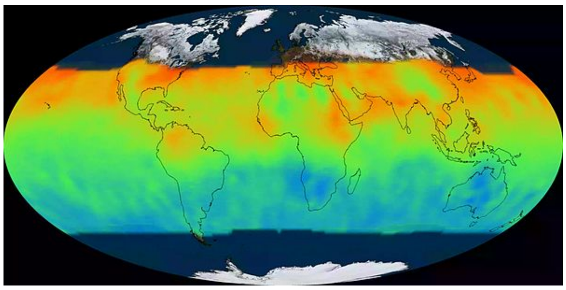
Launch of OCO-2 on a Delta II rocket

United Launch Alliance launched OCO-2 using a Delta II rocket at the beginning of a 30-second launch window at 09:56 UTC (2:56 PDT) on 2 July 2014. Flying in the 7320-10C configuration, the rocket launched from Space Launch Complex 2W at Vandenberg Air Force Base.[7] The initial launch attempt on 1 July at 09:56:44 UTC was scrubbed at 46 seconds on the countdown clock due to a faulty valve on the water suppression system, used to flow water on the launch pad to dampen the acoustic energy during launch.[8]

OCO-2 joined the A-train satellite constellation, becoming the sixth satellite in the group. Members of the A-train fly very close together in sun-synchronous orbit, to make nearly simultaneous measurements of Earth. A particularly short launch window of 30 seconds was necessary to achieve a proper position in the train.[9] As of 19 September 2016 it was in an orbit with a perigee of 701.1 km (435.6 mi), an apogee of 703.8 km (437.3 mi) and a 98.2 degree inclination.[2]

The mission is expected to cost US$467.7 million, including design, development, launch and operations.[1]

3.2 Column CO_2 measurements



Mollweide projected animation of CO2 data from the OCO-2 mission

OCO-2 makes measurements in three different spectral bands over four to eight different footprints of approximately 1.29 km × 2.25 km (0.80 mi × 1.40 mi) each.[10][11] About 24 soundings are collected per second while in sunlight and over 10% of these are sufficiently cloud free for further analysis. One spectral band is used for column measurements of oxygen (A-band 0.765 microns), and two are used for column measurements of carbon dioxide (weak band 1.61 microns, strong band 2.06

microns).[3]

In the retrieval algorithm measurements from the three bands are combined to yield column-averaged dry-air mole fractions of carbon dioxide. Because these are dry-air mole fractions, these measurements do not change with water content or surface pressure. Because the molecular oxygen content of the atmosphere (i.e. excluding the oxygen in water vapour) is well known to be 20.95%, oxygen is used as a measure of the total dry air column. To ensure these measurements are traceable to the World Meteorological Organization, OCO-2 measurements are carefully compared with measurements by the Total Carbon Column Observing Network (TCCON).[3]

3.3 References

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3.4 External links

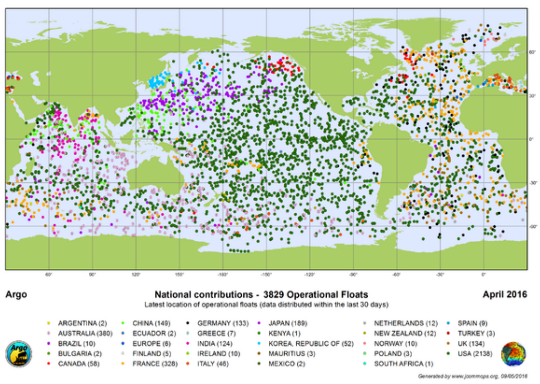
Media related to Orbiting Carbon Observatory-2 at Wikimedia Commons

- Orbiting Carbon Observatory at NASA.gov
- Orbiting Carbon Observatory by the Jet Propulsion Laboratory
- Orbiting Carbon Observatory by the JPL Science Division

Chapter 4

Argo (oceanography)

Argo is a system for observing temperature, salinity, and currents in the Earth's oceans which has been operational since the early 2000s. The real-time data it provides is used in climate and oceanographic research.[1][2] A special research interest is to quantify the ocean heat content (OHC).



The distribution of active floats in the Argo array, colour coded by country that owns the float, as of the end of April 2016.

Argo consists of a fleet of almost 4000 drifting profiling floats deployed worldwide. Each Argo float weighs 20–30 kg. Profiling floats are commonly used in oceanography and become "Argo floats" only when they are deployed in conformity with the Argo data policy. In most cases probes drift at a depth of 1000 metres (the so-called parking depth) and, every 10 days, by changing their buoyancy, dive to a depth of 2000 metres and then move to the sea-surface, measuring conductivity and temperature profiles as well as pressure. From these, salinity and density can be calculated. Seawater density is important in determining large-scale motions in the ocean. Average current velocities at 1000 metres are directly measured by the distance and direction a float drifts while parked at that depth, which is determined by GPS or Argos system positions at the surface. The data are transmitted to shore via satellite, and are freely available to everyone, without restrictions.

The Argo program is named after the Greek mythical ship *Argo* to emphasize the complementary relationship of Argo with the Jason satellite altimeters.

4.1 International collaboration

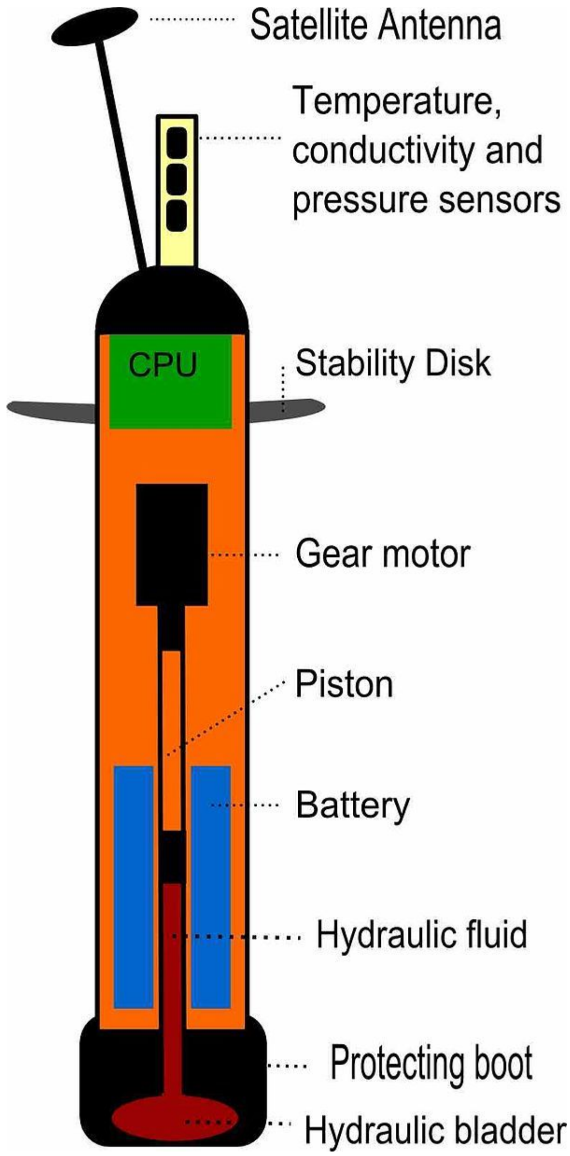
The Argo program is a collaborative partnership of more than 30 nations from all continents (most shown on the graphic map in this article) to provide a seamless global array allowing any country to explore the ocean environment. Argo is a component of the Global Ocean Observing System (GOOS).[3] Argo is coordinated by the Argo Steering Team – an international body of scientists and technical experts that meets once per year. The Argo data stream is managed by the Argo Data Management Team. Overall coordination is provided through the Argo Information Centre, an office belonging to the Intergovernmental Oceanographic Commission which also coordinates GOOS, and the World Meteorological Organization. Argo is also supported by GEO (the Group on Earth Observations), and has been endorsed since its early beginnings by the World Climate Research Programme's CLIVAR Project (Variability and predictability of the ocean-atmosphere system), and by the Global Ocean Data Assimilation Experiment (GODAE OceanView).

An animation for children was created recently by IMOS (Integrated Marine Observing Strategy, Australia) showing how Argo works.[4]

4.2 History

A program called Argo was first proposed at OceanObs 1999 which was a conference organised by international agencies with the aim of creating a coordinated approach to ocean observations. The original Argo prospectus was created by a small group of scientists, chaired by Dean Roemmich, who described a program that would have a global array of about 3000 floats in place by sometime in 2007.[5] The 3000-float array was achieved in November 2007 and was global. The Argo Steering Team met for the first time in 1999 in Maryland (USA) and outlined the principles of global data sharing. The Argo Steering Team made a 10-year report to OceanObs-2009[6] and received suggestions on how the array might be improved. These suggestions included enhancing the array at high latitudes, in marginal seas (such as the Gulf of Mexico and the Mediterranean) and along the equator, improved observation of strong boundary currents (such as the Gulf Stream and Kuroshio), extension of observations into deep water and the addition of sensors for monitoring biological and chemical changes in the oceans. In November 2012 an Indian float in the Argo array gathered the one-millionth profile (twice the number collected by research vessels during all of the 20th century) an event that was reported in several press releases.[7][8] In 2014 the Bio-Argo program was expanding rapidly.[9]

4.3 Float design and operation



A schematic diagram showing the general structure of a profiling float as used in Argo

The critical capability of an Argo float is its ability to rise and descend in the ocean on a programmed schedule. The floats do this by changing their effective density. The density of any object is given by its mass divided by its volume. The Argo float keeps its mass constant, but by altering its volume, it changes its density. To do this, mineral oil is forced out of the float's pressure case and expands a rubber bladder at the bottom end of the float. As the bladder expands, the float becomes less dense than seawater and rises to the surface. Upon finishing its tasks at the surface, the float withdraws the oil and descends again.[10]

A handful of companies and organizations manufacture profiling floats used in the Argo program. APEX floats, made by Teledyne Webb Research, are the most common element of the current array. SOLO and SOLO-II floats (the latter use a reciprocating pump for buoyancy changes, unlike screw-driven pistons in other floats) were developed at Scripps Institution of Oceanography. Other types include the NINJA float, made by the Tsurumi Seiki Co. of Japan, and the PROVOR float developed by IFREMER in France. Most floats use sensors made by Sea-Bird Electronics, which also makes a profiling float called Navis. A typical Argo float is a cylinder just over 1 metre long and 14 cm across with a hemispherical cap. Thus it has a minimum volume of about 16,600 cubic centimetres (cm^3). At Ocean Station Papa in the Gulf of Alaska the temperature and salinity at the surface might be about 6 °C and 32.55 parts per thousand giving a density of sea-water of 1.0256 g/cm^3. At a depth of 2000 metres (pressure of 2000 decibars) the temperature might be 2 °C and the salinity 34.58 parts per thousand. Thus, including the effect of pressure (water is slightly compressible) the density of sea-water is about 1.0369 g/cm^3. The change in density divided by the deep density is 0.0109.

The float has to match these densities if it is to reach 2000 metres depth and then rise to the surface. Since the density of the float is its mass divided by volume, it needs to change its volume by $0.0109 \times 16{,}600 = 181\ \text{cm}^3$ to drive that excursion; a small amount of that volume change is provided by the compressibility of the float itself, and excess buoyancy is required at the surface in order to keep the antenna above water. All Argo floats carry sensors to measure the temperature and salinity of the ocean as they vary with depth, but an increasing number of floats also carry other sensors, such as for measuring dissolved oxygen and ultimately other variables of biological and chemical interest such as chlorophyll, nutrients and pH. An extension to the Argo project called BioArgo is being developed and, when implemented, will add a biological and chemical component to this method of sampling the oceans.[11]

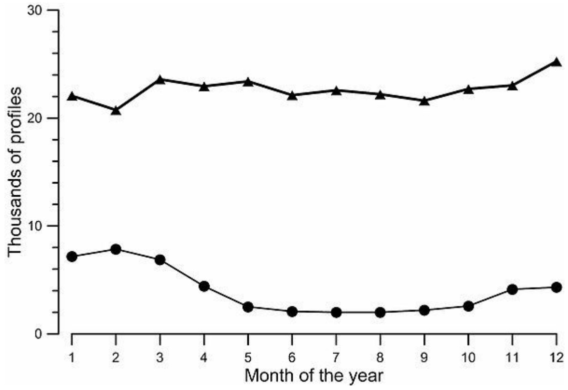
The antenna for satellite communications is mounted at the top of the float which extends clear of the sea surface after it completes its ascent. The ocean is saline, hence an electrical conductor, so that radio communications from under the sea surface are not possible. Early in the program Argo floats exclusively used slow mono-directional satellite communications but the majority of floats being deployed in mid-2013 use rapid bi-directional communications. The result of this is that Argo floats now transmit much more data than was previously possible and they spend only about 20 minutes on the sea surface rather than 8–12 hours, greatly reducing problems such as grounding and bio-fouling.

The average life span of Argo floats has increased greatly since the program began, first exceeding 4-year mean lifetime for floats deployed in 2005. Ongoing improvements should result in further extensions to 6 years and longer.

As of March 2016, new types of floats were being tested to collect measurements much deeper than can be reached by standard Argo floats. These "Deep Argo" floats are designed to reach depths of 6000 metres, versus 2000 metres for standard floats. This will allow a much greater volume of the ocean to be sampled. Such measurements are important for developing a comprehensive understanding of the ocean, such as trends in heat content.[12]

4.4 Array design

The original plan advertised in the Argo prospectus called for a nearest-neighbour distance between floats, on average, of 3° latitude by 3° longitude.[5] This allowed for higher resolution (in kilometres) at high latitudes, both north and south, and was considered necessary because of the decrease in the Rossby radius of deformation which governs the scale of oceanographic features, such as eddies. By 2007 this was largely achieved, but the target resolution has never yet been completely achieved in the deep southern ocean.[6]



The number of profiles gathered by Argo floats south of 30°S (upper curve) compared with profiles gathered by other means (lower). This shows the near elimination of the seasonal bias.

Efforts are being made to complete the original plan in all parts of the world oceans but this is difficult in the deep Southern Ocean as deployment opportunities occur only very rarely.

As mentioned in the history section, enhancements are now planned in the equatorial regions of the oceans, in boundary currents and in marginal seas. This requires that the total number of floats be increased from the original plan of 3000 floats to a 4000-float array.

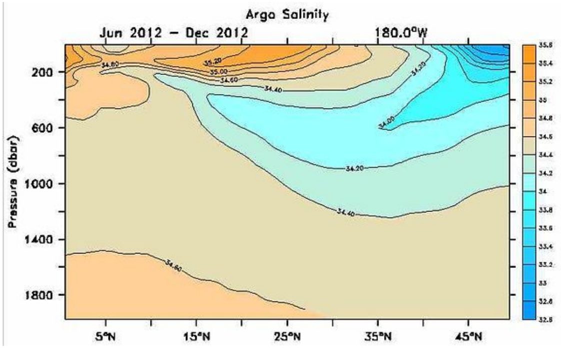
One consequence of the use of profiling floats to sample the ocean is that seasonal bias can be removed. The diagram opposite shows the count of all float profiles acquired each month by Argo south of 30°S (upper curve) from the start of the program to November 2012 compared with the same diagram for all other data available. The lower curve shows a strong annual bias with four times as many profiles being collected in austral summer than in austral winter. For the upper (Argo) plot, there is no bias apparent.

4.5 Data access

One of the critical features of the Argo model is that of global and unrestricted access to data in near real-time. When a float transmits a profile it is quickly converted to a format that can be inserted on the GTS (Global Telecommunications System). The GTS is operated by the World Meteorological Organisation, or WMO, specifically for the purpose of sharing data needed for weather forecasting. Thus all nations who are members of the WMO receive all Argo profiles within a few hours of the acquisition of the profile. Data are also made available through ftp and WWW access via two Argo Global Data Centres (or GDACs), one in France and one in the US.

About 90% of all profiles acquired are made available to global access within 24 hours, with the remaining profiles becoming available soon thereafter.

For a researcher to use data acquired via the GTS or from



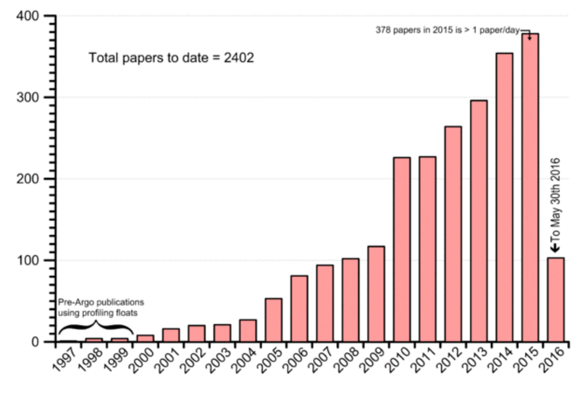
An actual section of salinity along the date line computed from Argo data using the Global Marine Atlas.

the Argo Global Data Centres (GDACs) does require programming skills. The GDACs supply multi-profile files that are a native file format for Ocean DataView. For any day there are files with names like 20121106_prof.nc that are called multi-profile files. This example is a file specific to 6 November 2012 and contains all profiles in a single NetCDF file for one ocean basin. The GDACs identify three ocean basins, Atlantic, Indian and Pacific. Thus three multi-profile files will carry every Argo profile acquired on that specific day.

A user who wants to explore Argo data but lacks programming skills might like to download the Argo Global Marine Atlas [13] which is an easy-to-use utility that allows the creation of products based on Argo data such as the salinity section shown above, but also horizontal maps of ocean properties, time series at any location etc. This Atlas also carries an “update” button that allows data to be updated periodically. The Argo Global Marine Atlas is maintained at the Scripps Institution of Oceanography in La Jolla, California.

Argo data can also be displayed in Google Earth with a layer developed by the Argo Technical Coordinator.

4.6 Data results



The number of papers, by year, published in refereed journals and that are extensively or totally dependent on the availability of Argo data as of 30th May 2016.

Argo is now the dominant source of information about the climatic state of the oceans and is being widely used in many publications as seen in the diagram opposite. Topics addressed include air-sea interaction, ocean currents, interannual variability, El Niño, mesoscale eddies, water mass properties and transformation. Argo is also now permitting direct computations of the global ocean heat content.

A notable recent paper was published by Durack and Wijffels and analyses global changes in surface salinity patterns.[14]

They determine that areas of the world with high surface salinity are getting saltier and areas of the world with relatively low surface salinity are getting fresher. This has been described as 'the rich get richer and the poor get poorer'. Scientifically speaking, the distributions of salt are governed by the difference between precipitation and evaporation. Areas, such as the northern North Pacific Ocean, where precipitation dominates evaporation are fresher than average. The implication of their result is that the Earth is seeing an intensification of the global hydrological cycle. Argo data are also being used to drive computer models of the climate system leading to improvements in the ability of nations to forecast seasonal climate variations.[15]

Argo data were critical in the drafting of Chapter 3 (Working Group 1) of the IPCC Fifth Assessment Report (released September 2013) and an appendix was added to that chapter to emphasize the profound change that had taken place in the quality and volume of ocean data since the IPCC Fourth Assessment Report and the resulting improvement in confidence in the description of surface salinity changes and upper-ocean heat content.

4.7 See also

- Ocean acoustic tomography
- Underwater gliders
- Integrated Ocean Observing System

4.8 References

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[15] "GODAE OceanView". Retrieved 8 October 2014.

4.9 External links

- The Argo Portal
- International Argo Information Centre
- Argo at the Scripps Institution of Oceanography, San Diego
- Realtime Interactive Map
- Realtime Google Earth File
- Coriolis Global Argo Data Server - EU Mirror
- FNMOC Global Argo Data server - US Mirror
- NOAA/Pacific Marine Environmental Laboratory profiling float project deploys floats as part of the Argo program, provides data on-line, and is active in delayed-mode salinity calibration and quality control for US Argo floats.
- Changing conditions in the Gulf of Alaska as seen by Argo
- Government of Canada, Department of Fisheries and Oceans, Argo Project
- A New World View Argo explorations article by Scripps Institution of Oceanography
- JCOMMOPS
- Argo on NOSA

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4.10.1 Text

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4.10.2 Images

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