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Thinking ahead for Europe

Space Observation Systems
An underused asset in EU and global climate change policy

Monica Alessi and Christian Egenhofer

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The problem actually is not going to be verification in the sense that this international consultation and analysis mechanism will actually tell us a lot of what we need to know. And the truth is that we can actually monitor a lot of what takes place through satellite imagery and so forth. So I think we're going to have a pretty good sense of what countries are doing.

US President Obama in Copenhagen,
18 December 2009[1]

1. Executive summary

The European Union has long played a key role in global efforts to reduce GHG emissions and, where necessary, to adapt to its impacts. It has also been an advocate of a legally binding comprehensive global climate change agreement.

1. A major element – yet less documented within the EU – of this global effort is the importance of satellite-based remote sensing technologies, which are an integral part of the UNFCCC work, and unlike many other issues within global climate change negotiation, hardly contentious. All major negotiation partners agree that in order to implement efficient mitigation *and* adaptation policies, reliable data are needed. Satellite-based remote-sensing technologies are now an integral part of the UNFCCC work, through the Global Climate Observing System (GCOS), whose mandate is to determine what data are needed for the monitoring of climate impacts.
2. Operationally, the GCOS has identified 44 Essential Climate Variables (ECV) as being essential to understanding the climate change process and developing the appropriate mitigation and adaptation policies. They are needed to determine the prevailing climate of any given region and to measure rates of change of variables, such as temperature and rainfall (monitoring), to assess the future state of the climate system, years and decades ahead (prediction), supported by continued developments in the collection, archiving, analysis and application of climate data (research).

[1] The White House, Office of the Press Secretary, Remarks by the President during press availability in Copenhagen, Bella Center, Copenhagen, Denmark, 18 December 2009.

* Monica Alessi and Christian Egenhofer, CEPS.

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3. Climate monitoring, prediction and research thus become a core pillar of the global response to climate change mitigation and adaptation. Improved accuracy about the pace of change and better definition of uncertainty levels improves policy definition and may accelerate a global consensus. Better evaluation of mitigation and adaptation measures positively impacts funding allocation and prioritisation, as well as post-project audit to measure the success of given projects. This should also allow for more efficient policy responses and scenario building. MRV (Measurement, Reporting and Verification) on areas such as greenhouse gas emissions, carbon sinks, biodiversity protection, etc. can be improved and can complement national reporting. Finally, it improves the alarm function, such as for forest fires, flood and droughts etc., with implications for security of food supply, access to water and so on.
4. No fewer than 31 of the 44 ECVs can be obtained through or at least with significant input from space-based observations. All space-based observations, including ECVs, can be and are already used for a multiplicity of policy applications across policy areas such as climate change, biodiversity, disaster response or monitoring the impacts of EU and third countries' regulations.
5. To date, the European Space Agency (ESA), along with EUMETSAT, are global leaders in Earth observation and together they have the potential to provide up to 29 out of a total of 31 ECVs, which require input from space-based observations. To provide climate-related observations consistent with the format required by GCOS standards, the ESA started the six-year Climate Change Initiative (CCI) in 2009, paid out of its own funding (ESA, 2008), which aims at generating 11 ECVs, to be potentially expanded to 10 more ECVs.
6. Generating ECVs requires both the collection and more importantly, processing of data. Data collection is ongoing as an ESA core activity for the different current and potential policy applications. It is data processing that proves to be the bottleneck. Up to now, data that have been collected for three decades remain unprocessed because the ESA lacks the operational capacity. This is a result of climate change not having been among its responsibilities until the GCOS publication of its data requirement, which results in a shortfall of resources. The continuation of the CCI beyond the initial six years also looks highly uncertain.
7. The EU has been expanding its analytical capabilities with the Global Monitoring for Environment and Security (GMES).[2] The GMES gathers data, which can be a central information source for climate adaptation purposes at global level, as it is designed to identify vulnerabilities to nature and human-induced changes. With its objectives to protect terrestrial, marine and coastal ecosystems, GMES can easily be adapted to be an important provider of ECVs. However, GMES is at present not designed to provide data in a format suitable for the formation of ECVs. This could be easily rectified with a limited investment in its data processing capabilities however.

The way forward

Space-based observation systems will play an increasing role in EU and global climate change policy, as witnessed by the international consensus on GCOS. This allows the EU to inject additional momentum into global climate change negotiations by building on EU leadership in both global earth observation and climate change negotiations. This offers a number of advantages that EU and member state policy-makers could use to strengthen the case for an efficient global climate change agreement.

- Space-based observations are essential to provide reliable data on the climate change process, as well as data on emissions and impacts on the ground, and will continue to grow in importance; the socio-economic benefits of an appropriate ECV coverage are considerable;
- Data from space-based observation will become more important for European Union climate negotiations because without reliable

[2] This arises from a joint programme of ESA and the European Commission as part of the European Earth Observation Programme.

science-based data, its influence within the UNFCCC will eventually be weakened;

- The ESA is a leader in space-based observation and could provide many of the ECVs needed for science-based assessments;
- The ESA has the advantage of having the know-how and technology already in place to potentially provide the data for a majority of ECVs, but it lacks the operational budget to process the data and monitor the ECVs in the future.

This report recommends the EU to urgently consider ensuring that existing space-based observation capacities are fully exploited in line with the observations outlined above. To do so:

- The European Commission, in collaboration with ESA and EUMETSAT, should consider drafting a comprehensive list of requirements to fully utilise Europe's space-based observation potential to generate ECVs;
- Proposals to cover the financial and resource requirements should be put forward, including the possible sources, i.e. ESA member states, the EU budget or other funding sources.

1. Introduction

Satellite-based remote-sensing technologies are an integral part of the UNFCCC work, through the Global Climate Observing System (GCOS). GCOS, whose mandate is to determine what data are needed for the monitoring of climate impacts, has identified 44 so-called Essential Climate Variables (ECVs) (Mason, 2010; Mason and Bojinsky, 2009). Thirty-one of these ECVs use space-based remote sensing outputs (Wilson et al. 2010, pp. 14-15). According to GCOS, progress in producing the 44 ECVs has been sluggish to date. Nonetheless, the increasing importance of adaptation – in terms of both costs and needs – has heightened the interest in space-based operations.

Space-based observation is increasing in importance due to the need to appropriately understand and model climate impacts and to the rising demand for reliable emissions reductions monitoring systems. Where adaptation is concerned, information on climate change and vulnerability to those changes will drive policy making in general, and the negotiations on allocation of financial assistance in particular. Without appropriate data, the effectiveness of the international effort will be undermined. The EU will have a major role as a donor, and it is in its own interests to ensure that the effects of its contribution are adequately monitored.[3]

Furthermore, it is recognised that satellite-based tools can and will play an increasingly important role in the monitoring of greenhouse gas emissions. Especially but not only with the advent of the Copenhagen Accord and the Cancún Agreements about verification and transparency, space-based technologies generate interest in the US, the EU and beyond. Over time, the issue of monitoring will move up the political agenda.

The issue of verification appears in paragraphs 4 and 5 of the Copenhagen Accord, and was then integrated into paragraph 61 of the Cancún Agreements, in which it is stated that verification procedures apply to developed as well as developing countries. Verification procedures are thus expected to be a key issue in international and bilateral/multilateral negotiations for many years to come, irrespective of whether there is a comprehensive legally binding global agreement or a bottom-up pledge approach. In the US, for example, verification procedures are already attracting interest in domestic deliberations on US national climate change policy-making.

Just before and after the Copenhagen negotiations, the governments of the UK and France indicated their interest in space-based technologies to monitor greenhouse gas (GHG) emissions within the EU and in other parts of the world.[4] The European Commission, on behalf of the EU and the European Space Agency, has taken initial steps to enhance its capabilities in this regard.[5]

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[3] See also European Commission (2011, especially p. 5).

[4] Articles on 28 November 2010, and 20 December 2010, in *The Telegraph* (London) (http://www.telegraph.co.uk/earth/nvironment/climatechange/6673792/Satellites-to-monitor-countries-for-climate-change-under-Gordon-Brown-plan.html and http://www.telegraph.co.uk/earth/copenhagen-climate-change-confe/6851246/Copenhagen-climate-summit-plan-for-EU-to-police-countries-emissions.html).

[5] See http://sedac.ciesin.org/rs-treaties/initiatives.html.

Other industrialised countries, such as Japan, have already put in place space-based monitoring systems.[6] And such activities do not limit themselves to industrialised countries. The government of India, for example, intends to have its first such satellite in operation by 2012 and its second in 2013, with the objective to monitor GHG emissions "across the country and globe".[7] Finally, at a press conference during the Copenhagen negotiations, President Obama stated that "…[W]e can actually monitor a lot of what takes place [in greenhouse gas emissions] through satellite imagery and so forth. So I think we are going to have a pretty good sense of what countries are doing."[8] Space-based observations are also central for the UN programme REDD ('Reducing Emissions from Deforestation and Forest Degradation in Developing Countries')[9] and considerable attention is devoted internationally to the technical capabilities for monitoring emissions and removals by sinks in agriculture, forestry and other land uses.[10] The European Earth Observation Programme component of the GMES could therefore provide very valuable information on forest cover, deforestation processes and carbon sinks, as laid out in the recent Communication on a European space strategy (European Commission, 2011).

Because of the presence of satellite-based remote sensing technologies for monitoring on the international and domestic climate change agendas, questions about international cooperation, sharing and transfers of these technologies, especially data, is also on these agendas. For instance, there is interest in the possibility of creating a new international agency that would be responsible for the gathering and processing of data from different space agencies. This could be in addition to any other system the EU develops for its own regional purposes.

2. Essential space-based observation requirements

Space-based observation can provide vital data about the impacts of climate change, as well as provide essential tools for monitoring the progress of actions implemented to reduce greenhouse gas emissions. More concretely, space-based observation can reduce the present level of uncertainty in climate prediction linked to the lack of quality observations, as has been recognised by the UNFCCC Global Climate Observing System (GCOS). The GCOS was established in parallel to the UNFCCC and is itself made up of the national meteorological, hydrological, oceanographic, space, environmental, research and other Earth observing agencies of more than 190 member countries from the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC), the United Nations Environment Programme (UNEP), the International Council for Science (ICSU) and the Food and Agriculture Organization (FAO), with the support of other national, regional and international coordination and capacity building organisations and mechanisms, such as national meteorological organisations.

In 2004, the GCOS published the *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC*, which catalogues the needs for global monitoring of climate change, and in which space-based observations are presented as an important element of the monitoring process.[11] The space component has been led by ESA.

[6] See: http://sedac.ciesin.org/rs-treaties/initiatives.html, with reference to: http://www.eorc.jaxa.jp/ALOS/en/kyoto/kyoto_index.htm.

[7] Statement by Minister for Environment and Forests, reported in *The Times of India*, 13 March 2010 (http://timesofindia.indiatimes.com/home/environment/global-warming/India-to-have-satellite-to-monitor-green-house-emission-/articleshow/5680536.cms).

[8] Op. cit., The White House, US.

[9] See FAO, UNDP, UNEP (2008) and http://www.un-redd.org

[10] US National Research Council of the National Academies, Verifying Greenhouse Gas Emissions, "Methods to Support International Climate Agreements, Prepublication Version" [2010]; especially section 3, pp. 41-52 (http://www.nap.edu/catalog/12883.html). The technologies are briefly described in US Climate Change Technology Program, "Enhancing Capabilities to Measure and Monitor GHG Emissions" (http://www.climatetechnology.gov/library/2003/currentactivities/measure-monitor.htm). More generally, see the references at the site of the Socio-Economic Data and Applications Center (SEDAC) at Columbia University (http://sedac.ciesin.org/rs-treaties/initiatives.html).

[11] The document has been updated in 2006 and 2010.

According to the Implementation Plan, there are 44 Essential Climate Variables (ECVs) required to support the work of the UNFCCC and the IPCC (Table 1). ECVs are a set of atmospheric, oceanic and terrestrial variables needed to understand the physics of climate change (including the measurements of greenhouse gas emissions and their sources), formatted to specific standards to make them available internationally. They are the essential variables that need to be monitored by parties to the UNFCCC in order to meet their commitments under Articles 4 and 5 of the Convention. (These articles specify the obligations of the parties to provide the necessary information on emission inventories, national programmes for mitigation, research, and physical data on climate impacts). According to the JRC (Wilson et al., 2010) 31 out of these 44 ECVs are at least partly to be provided by satellite-based observation (in *italics* in Table 1).

Table 1. GCOS Essential Climate Variables

Domain	Essential Climate Variables
Atmospheric (over land, sea and ice)	**Surface:**[1] *air temperature, wind speed and direction, water vapour, pressure, precipitation, surface radiation budget* **Upper-air:**[2] *temperature, wind speed and direction, water vapour, cloud properties, earth radiation budget (including solar irradiance)* **Composition:** *carbon dioxide, methane, and other long-lived greenhouse gases,*[3] *ozone and aerosol, supported by their precursors.*[4]
Oceanic	**Surface:**[5] *sea-surface temperature, sea-surface salinity, sea level, sea state, sea ice,* surface current, *ocean colour,* carbon dioxide partial pressure, ocean acidity, phytoplankton. **Sub-surface:** temperature, salinity, current, nutrients, carbon dioxide partial pressure, ocean acidity, oxygen, tracers.
Terrestrial	River discharge, water use, groundwater, *lakes, snow cover, glaciers and ice caps, ice sheets,* permafrost, *albedo, land cover (including vegetation type), fraction of absorbed photosynthetically active radiation (FAPAR), leaf area index (LAI), above-ground biomass, soil carbon, fire disturbance, soil moisture.*

1. Including measurements at standardised, but globally varying heights in close proximity to the surface .
2. Up to the stratopause.
3. Including N20, CFCs, HCFCs, HFCs, SF6 and PFCs.
4. In particular NO2, SO2, HCHO and CO.
5. Including measurements within the surface mixed layer, usually within the upper 15 m.

Source: GCOS (2010), p. 19.

According to Wilson et al. (2010), the ECVs data can assist in the following:

- *climate monitoring* to determine the prevailing climate of any given region and to measure rates of change of variables such as temperature and rainfall;
- *climate prediction* to determine the future state of the climate system years and decades ahead; supported by
- *climate research* to ensure continued developments in the collection, archiving, analysis and application of climate data.

From the perspective of policy formation, climate information is needed in the policy cycle at four key points (Wilson et al., 2010):

- *policy definition*: improved accuracy about the pace of change and better definition of uncertainty levels;
- *management and scenario building*: improved accuracy of assessments, with implications on funding allocation and prioritisation, as well as on post-project audit to measure the success of given projects;
- *reporting requirements, i.e. MRV (Measurement, Reporting and Verification)*: improved verification of data provided by countries on elements such as greenhouse gas emissions, carbon sinks, biodiversity protection, etc.;
- *alarm function*: forest fires, flood and droughts etc., with implications for security of food supply, access to water, etc.

In its latest progress report on the Implementation Plan, published in April 2009, GCOS expresses concern about the lack of progress in the systematic analysis of ECVs and calls on all members to undertake efforts in this respect, including on weaknesses in data processing from satellite observations (despite the availability of such data), and on the lack of

operational structures to do so. A full analysis of the present capabilities and needs can be found in the CEOS/ESA Earth Observation Handbook online.[12]

The GCOS ECV requirements can only be fulfilled through the collection of observations from several sources (i.e. atmospheric, oceanic, and terrestrial variables collected through combined observation from different satellites and *in situ* measurements): "Since no single technology or source can provide all the needed observations, the ECVs will be provided by a composite system of *in situ* instruments on the ground and on ships, buoys, floats, ocean profilers, balloons, samplers, and aircraft, as well as from all forms of remote sensing, including satellites" (CGOS, 2010, p. 6). The data obtained requires subsequent processing to supply the finished ECV products, through analysis and integration in both time and space. In 2006, the CGOS published a document on the satellite-based component of the implementation plan, detailing with more precision the requirements for space observation, and specifying the data sets that need to be produced. A detailed list of the present global capability to cover the 31 space-based ECVs can be found in "Profile and main needs of the climate modelling Community" by the Climate Modelling User Group (CMUG) of ESA, August 2010.

3. EU climate change policy and space observation

In the EU, climate change policy has long been a priority. As early as 1996, the EU adopted a long-term target to limit the temperature increase to a maximum of 2°C above pre-industrial levels. This was recently reiterated by the European Council of March 2010 and lays the foundations for domestic policies and measures aimed at the mitigation of, and adaptation to climate change. The EU has been the most vocal 'developed country' advocate of a comprehensive and legally binding global agreement capable of reducing global GHG emissions up to 80% or more by 2050. Consequently, EU climate change policy has become an integral part of the EU flagship 2020 Strategy, the "Commission's vision of a social market economy for the 21st century", broadly endorsed by the European Council.

Internationally, the EU has been – and still is – promoting a legally binding global agreement with national ceilings covering all sources of GHG gas emissions. This could also include emissions from aviation and maritime shipping, for which the EU is pushing an international agreement. But even in the absence of a binding agreement, the present pledge-and-control system will also require monitoring.

Since the beginning of the century, adaptation to climate change impacts has been steadily climbing up the agenda, both internationally and within the EU. This comes in acknowledgement that, even if the world as a whole succeeds in achieving the most ambitious mitigation targets, the Earth will take time to recover from the greenhouse gases already in the atmosphere and will be faced with the impacts of climate change for at least 50 years, and possibly much longer. Increase of the knowledge base, financing and international cooperation are among the core elements of the emerging EU adaptation strategy, and better data on adaptation costs and needs will therefore be a major priority. As noted in the White Paper on Adaptation by the European Commission (2009, p. 7), space observation will play an important role in this.

The potential for space-based observation lies in particular in reducing uncertainty, and more generally in improving the knowledge base of climate science. Any future political ambition of the EU will be affected by the commitments of other parties to the UNFCCC. It is in the interests of the EU that strong, sufficient and enforceable commitments at international level are introduced. This will only be possible if uncertainty in climate research is reduced by best possible data and underlying research and if the reduction commitments can be monitored and enforced.

While developing the capacity to produce the datasets to GCOS standards is a basic requirement to fulfil the obligations of the Parties to the UNFCCC, there could be added benefits towards other EU policy interests, such as environmental and security related issues, as well as informing policy on international assistance for adaptation. As for MRV, space observation could provide point source estimations of emissions,

[12] See: http://www.eohandbook.com/.

e.g. from maritime transport and aviation, which could address some of the concerns linked to their integration in the EU ETS. In the context of REDD, current European satellites, as well as two new satellites to be launched from 2012 onwards in the framework of the GMES programme, will provide reliable and routine observation of land cover, land use and land use change.

Europe's potential to provide space-based climate data

Europe's space-based capabilities will be vital to the provision of data on climate change, as they count amongst the world most advanced Earth observation systems. They offer the prospect of supporting a solid science-backed role in international negotiations – provided the system is fully developed. In this way our understanding of domestic and international climate impacts, adaptive responses and the capacity to control emissions could be enhanced. There is some acknowledgment of this in European policy circles. The Space Council Resolution of 26 September 2008, in its chapter on "Space and Climate Change", "invites the Commission to conduct a study to assess the needs for full access to standardised data and for increased computing power, and the means to fulfil them, taking into account existing capacities and networking in Europe". It also "calls for the scientific community, in conjunction with the EC, ESA and EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites), to define how the range of GMES (Global Monitoring for Environment and Security) services and European space observation archives can contribute most effectively to the provision of data including Essential Climate Variables (ECVs) for scientific research".

ESA and EUMETSAT in Europe and NASA and NOAA in the US are leading space data providers for climate variables, with other countries, in particular China, Russia, Japan and Korea covering regional areas. However, the provision of data in the appropriate format is insufficient. Only the ESA and NASA have the potential to cover a large part of the ECVs with global coverage. The ESA's Earth Observation Programme is the most advanced. NASA is now also increasing its Earth observation capabilities for climate change research as the Obama administration has increased the funding for this programme.

ESA together with EUMETSAT can potentially deliver the necessary Fundamental Climate Data Records (FCDRs) [13] needed to produce 29 out of the 31 space based ECVs. Today, the data are only partly used and little is available in a processed format. Annex 1 lists the ECVs that can be monitored through the existing ESA and EUMETSAT[14] capabilities.

ESA and EUMETSAT

The European Space Agency (ESA), established in 1975, is an intergovernmental organisation comprising 18 member states, including 16 EU[15] and 2 non-EU countries (Norway and Switzerland). Hungary, Romania, Poland, Estonia and Slovenia are 'European Cooperating States', and several other countries[16] have signed cooperation agreements with the ESA. The objective is to include all EU member states in the near future and thereby become the space agency for the European Union.[17]

Broadly, its mission is to promote the development of Europe's space capability for exclusively peaceful purposes, and coordinate the financial and intellectual resources of its members, to reach beyond the scope of any single European country and thus enhance Europe's competitiveness in this area. The ESA's

[13] Fundamental Climate Data Record (FCDR): "a long-term data record, involving a series of instruments, with potentially changing measurement approaches, but with overlaps and calibrations sufficient to allow the generation of homogeneous products providing a measure of the intended variable that is accurate and stable enough for climate monitoring. FCDRs include the ancillary data used to calibrate them." ECVs or ECV products are "geophysical variables derived from FCDRs, often generated by blending satellite observations and in-situ data, and using physical model frameworks" (GCOS, 2006, p. 5).

[14] European Organisation for the Exploitation of Meteorological Satellites.

[15] Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the UK (see http://www.esa.int/SPECIALS/About_ESA/SEMW16ARR1F_0.html).

[16] Argentina, Brazil, Canada, China, Russia and India.

[17] See: http://www.esa.int/SPECIALS/About_ESA/SEMONSEVL2F_0.html

programmes are designed to expand knowledge about Earth and space, as well as to develop satellite-based technologies and services, and to promote European industries. The ESA also works closely with space organisations outside Europe.

With its headquarters in Paris, the ESA has a number of specialised sites in other countries.[18] The ESA's governing body is the Council, which provides the basic policy guidelines of ESA's work. The Council also appoints the ESA Director General every four years. Each member state is represented on the Council and has one vote, regardless of its size or financial contribution.

Each work division has its own Directorate and reports directly to the Director General. Around 2000 staff originating from all the participating states work for the ESA, and include scientists, engineers, and information technology specialists.

EUMETSAT was established in 1986 and has its origins in the ESA, but their responsibilities are different, as the ESA focuses on space technology development as a research and development agency, while EUMETSAT is an 'operational' organisation providing weather forecasts. For example, the ESA develops the systems used by EUMETSAT, such as the sixth METEOSAT Third Generation (MTG) of geostationary satellites, which should be ready for launch in 2017.[19]

The ESA and EUMETSAT are independent organisations without a formal organic link to the European Commission. The two organisations not only have different memberships but are also governed by different rules and procedures. The relationship between the European Commission and the ESA is based on a Framework Agreement providing the legal basis for cooperation between the two institutions, which entered into force in May 2004.[20] Nevertheless, space programmes are mentioned in Article 189 of the EU Treaty. The Treaty of Lisbon also establishes a role for the European Commission in space policy. As a result of these links, the European Commission runs joint programmes with the ESA, such as the Global Monitoring for Environment and Security (GMES). More recently, the European Commission (2011) in its Communication on a European space strategy identified the role of space observation as a central part of the EU space policy, and stated that space observation is a "powerful tool […] in the fight against climate change"(p. 5).

GMES

The GMES is designed to provide information to decision-makers on how the planet's environment and climate are changing due to natural events or human activity. As such, GMES can also provide important FCDRs to generate ECVs, but its objectives go beyond providing climate data for forecasting. The programme is designed to give insights into the wider socio-economic implications of environmental degradation. It will offer key insights for spatial planners, which can positively influence policy decisions on settlements, transport, ecosystem management, natural disaster protection and thus mitigation and adaptation to climate change. Despite the difficulties to estimate precisely the value of GMES in socio-economic terms, an analysis by PriceWaterhouseCoopers (2006) shows the potential of applications in the areas of climate change adaptation and mitigation, biodiversity protection, food security, crisis prevention and conflict management. In the area of adaptation to climate change alone, an efficient use of the GMES Earth observations could reduce the global costs of adaptation by €5 to €25 bn a year as from 2025. In comparison, the 2007-2013 budget for GMES has been €1.2 bn (€670 M for FP7 and €710 M for ESA activities (Moutalier, 2008)).

As stated above, space monitoring has a crucial role to play in adaptation, as space research provides important information on the

[18] EAC (the European Astronauts Centre) in Cologne, Germany; ESAC (the European Space Astronomy Centre) in Madrid, Spain; ESOC (the European Space Operations Centre) in Darmstadt, Germany; ESRIN (the ESA centre for Earth Observation) in Frascati, Italy; and ESTEC (the European Space Research and Technology Centre) in Noordwijk, the Netherlands. A new ESA centre has opened in the United Kingdom, at Harwell, Oxfordshire. ESA also has liaison offices in Belgium, USA and Russia; a launch base in French Guiana and ground/tracking stations in various parts of the world (see http://www.esa.int/SPECIALS/About_ESA/SEMY8TEVL2F_0.html).

[19] Information by ESA (http://www.eumetsat.int/Home/Main/Satellites/MeteosatThirdGeneration/index.htm).

[20] ESA (2008), ESA and the EU (http://www.esa.int/SPECIALS/About_ESA/SEMFEPYV1SD_0.html).

vulnerabilities of different regions to climate change, as well as important variables necessary to develop the regional predictions on temperature and precipitation changes in the future. The information provided by space-based monitoring can raise the quality of decision-making on adaptation policies and thus considerably reduce the global social and economic impacts of climate change. It is in the interests of the European Union, being a key global provider of development and adaptation aid, to reduce unnecessary costs and the misallocation of resources due to a lack of detailed impact information (PriceWaterhouseCoopers, 2006). The European Commission's White Paper on adaptation also points at evidence-based analysis as a key policy element (European Commission, 2009). It specifically refers to GMES (Ibid., p. 7) as an input to the Shared Environmental Information System of the future Clearing House Mechanism; a tool to provide information to citizens and policy-makers.

Article 189 of the consolidated version of the Treaty of Lisbon states that:

1. To promote scientific and technical progress, industrial competitiveness and the implementation of its policies, the Union shall draw up a European space policy. To this end, it may promote joint initiatives, support research and technological development and coordinate the efforts needed for the exploration and exploitation of space.

2. To contribute to attaining the objectives referred to in paragraph 1, the European Parliament and the Council, acting in accordance with the ordinary legislative procedure, shall establish the necessary measures, which may take the form of a European space programme, excluding any harmonisation of the laws and regulations of the Member States.

3. The Union shall establish any appropriate relations with the European Space Agency.

Present shortcomings in Europe for the adequate provision of ECVs

The GCOS calls for the creation of international data centres (IDC) which actively collect data and organise it for international use. ESA and EUMETSAT have the potential to supply satellite data (FCDR) to develop a number of ECVs. ESA is running Earth Observation programmes through its satellites (The Earth Observation Envelope Programme) for the meteorological offices, the Living Planet Programme[21] and the GMES[22] programmes. Two recent reports by ESA (2008) and the JRC (Wilson et al., 2010) have dealt with the question of ESA's contribution to ECVs. The reports highlight the vast potential of the EU to collect the space-based FCDRs needed to generate the ECVs, which remains largely untapped to this day.

For ESA, the potential for the generation of FCDRs is considerable, but much of the data is not processed (the ESA possesses an archive of 30 years of unprocessed data that could help in establishing trends in climate change). Moreover, the long-term collection of these data is not guaranteed by its present programmes.

EUMETSAT is also capable of collecting various FCDRs as a result of its operations, although at present these are only partially developed on the fringe of its routine activities.

The reports identified a number of inherent weaknesses that hinder the space agency in the provision of ECVs in the format required to make it suitable for the UNFCCC:

1. The ESA works mainly on the technological development and research for space-based systems and the operation of satellites, but does not cover the handling of much of the data it collects nor does it guarantee the coverage of the ECVs' data collected through the appropriate maintenance and replacement of satellites.
2. Due to a shortage of project finance for the handling of ECV-related data, it is impossible for ESA to compile data into a format that can be used by the IPCC or other research centres investigating climate change or monitoring GHG emissions. Since 2009, the ESA has

[21] Programme established in the mid-1990s to provide space observations to the scientific community. A detailed description of the Programme can be found at ESA (2006).

[22] Initiated in 2008, Global Monitoring for Environmental Security is a service provided for the European Commission. It is similar to the Living Planet Programme, but concentrated on information for policy-makers to allow them to formulate responses to climate change impacts and other security responses, such as humanitarian aid in catastrophic events.

started a six-year climate change initiative (CCI) (ESA, 2008), aiming at generating 11 ECVs (less than half of Europe's potential), but the continuation of this effort beyond the six years is not guaranteed, and depends on funding. The ESA will also process the 30 years of data records for these ECVs – crucial to define trends and projections – which have not been stored in a suitable format.

3. The ESA presently focuses resources on the development of the satellite systems for weather centres and the EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites); the Galileo programme; on the running the satellites for the Earth Observation programme; and on the GMES (Global Monitoring for Environment and Security). The meteorological data and the GMES contain many elements needed to produce the ECVs, but, as in the case of EUMETSAT, the FCDRs that form the backbone of the ECVs are collected only on the margin of the programmes. As these programmes were not set up with climate change ECVs as their primary objective, the present limited funding does not allow a concentration on the processing of the data, either in terms of financial resources or specialised dedicated personnel.
4. Specific research on climate change that makes use of the data from ESA does exist, but finance is only for ad hoc studies and there is no guarantee of continuity. According to the two reports, there is a need to create "standardised – operational activities", i.e. constant and consistently formatted data.

The JRC (Wilson et al., 2010) identifies satellite operators as the most appropriate point at which data is formatted and stored in line with GCOS standards, and points to the advantages of organising the data from the ESA archives with an integrated end-to-end approach, so that compatibility and re-use can be applied across all stages of the process. This data can then be acquired by the institutions that will develop the ECVs, but would require additional financial and human resources. In 2008, the French Presidency proposed a European Centre for Climate Research, but EU member states stated their preference for the use of existing institutions, combined with better networking and coordination. It would also facilitate the climate research work of European research institutions, by having ESA and EUMETSAT provide consistent and accessible datasets to GCOS standards.

4. Steps to develop Europe's capabilities

According to the JRC (Wilson et al. 2010), the recommendations to develop Europe's space-based capabilities to produce the necessary FCDRs to GCOS standards are the following:

1. Provide to the existing satellite operators, i.e. ESA and EUMETSAT, the necessary resources to process the data.
2. Ensure that ESA's Earth observation programme is adapted to develop the FCDRs to support climate research and other EU programmes. This will require an expansion of human and material resources to guarantee the necessary level of operational capacity on a long-term basis, including the maintenance of the satellite infrastructure.

ESA's Climate Change Initiative (CCI)

In order to ensure that its existing capabilities are used, in 2008 ESA presented its Climate Change Initiative (ESA, 2008). The aim of the CCI is to develop the necessary capacity to produce the FCDR for 11 ECVs, excluding those data sets that EUMETSAT can produce itself (e.g. surface wind speed and direction, upper-air temperature, water vapour, precipitation, earth radiation budget). The programme objectives include five main activities:

1. Gathering, collating and preserving the long-term time series in ESA's distributed and shared archives, ensuring and facilitating its access and exploitation.
2. (Re-)processing periodically the basic Earth Observation (EO)-data sets from each individual mission and applying the most up-to-date algorithms and cal / val corrections.
3. Integrating the calibrated data sets derived from individual contributing EO mission and sensors to constitute the most comprehensive and well-characterised global long-term records possible for each ECV.

4. Assessing the trends and consistency of the ECV records in the context of climate models and assimilation schemes.
5. Developing improved models and algorithms for production of the required variables from emerging data sources, consistent with the long-term record.

The initiative consists of integrating the basic data processing for climate observation into its routine operations, in order to provide accessible data sets of all information collected, as well as those already archived. In turn, these can be easily retrieved by the relevant organisations to generate ECVs. The main needs of ESA are network capacity, processing and storage capacity, and dedicated specialised personnel to operate those resources.

The Climate Change Initiative, which began operation in 2009, falls under the ESA's commitments to the IPCC. The groundwork is financed by an allocation agreed by the ESA Council of €75 million a year for six years.

The plan has three implementation phases. Phase 1 establishes the necessary procedures and determines the algorithms that will provide the necessary data. The data requirements for the following 11 ECVs will be addressed first:

- Sea-level
- Sea surface temperature
- Sea ice
- Ocean colour
- Land cover
- Fire disturbance
- Glaciers and ice caps
- Cloud properties
- Aerosol properties
- Ozone
- Greenhouse gases (CO2, CH4).

Phase 2 will associate the ESA to other research institutes to verify the quality of the work undertaken, while in Phase 3 the data will be assimilated with other large-scale data to produce the 11 ECVs. An additional 10 ECVs could be processed in the future if the programme is expanded.

The main concern of ESA is the need to 'operationalise' its work on ECVs, i.e. it should be guaranteed beyond the end of the present time-limited programme.

The ESA's budget is currently covering the efforts for the first 11 ECVs of the Climate Change Initiative. Nevertheless, funding is not sufficient to develop the full potential of Europe's space-based capacities for the development of ECVs and continuation is not guaranteed as the current processing work is project-based rather than operational. There will also be a need to determine which budget pays for which activities, as the EU, the ESA and EUMETSAT are independently funded. A roadmap on how to best develop the European space capacities cost-effectively, taking into account the existing structures, could advance this discussion.

5. Conclusions

The GCOS has established global guidelines on ECV data requirements. The guidelines on space-based observation requirements were drafted under the leadership of ESA, which is a world leading space and Earth observation agency. Of the 44 ECVs required to fulfil the needs of the UNFCCC, 31 consist mainly of space-based data. The European Space Agency, through its Earth observation programmes, could potentially deliver the data for 24 of those ECVs, with EUMETSAT covering another five.

Space-based observation and the development of the ECVs identified by the GCOS are important elements for a number of EU policies, and essential in the promotion of the EU's interests in international climate negotiations. ESA's space-based capabilities can enhance our understanding of climate change and significantly contribute to Europe's ability to influence international negotiations on climate change, as well as assisting in developing more targeted adaptation actions in Europe and globally. The global welfare benefits of space-based observation could be considerable. For example, PriceWaterhouseCoopers' study (2006) on the socio-economic benefits of adaptation policies shows that the costs of global adaptation could be reduced by a further to €25 bn from 2025 onwards if policy-makers made use of the data generated by GMES.

Through Europe's Earth Observation (EO) and GMES programmes, the EU can assist and support policies for domestic adaptation and for international aid, as well as use the information for a number of other policies. The present work,

coupled with additional resources and some targeted reorganisation, can add to the number of fundamental data records for the creation of ECVs.

Satellite observations could also be developed to monitor emissions at source. At present, this is used only in the context of REDD, whose data on forests and carbon sinks is essentially collected by ESA. This could not only help the EU's emission reduction policies, but may assist in reaching agreements on emission reductions with other countries, as MRV is an essential condition of negotiations.

The ESA Climate Change Initiative, which started in 2009, will process 30 years worth of archived information and develop the necessary data analysis tools to provide the fundamental data for 11 ECVs. The expansion of the programme to 10 additional ECVs and the guarantee of future monitoring should be addressed. The JRC has also provided a full assessment of how to produce the data that could be provided by the EU's existing space observation structures.

Given the importance of space-based research for the UNFCCC negotiations and to support the EU's policy on climate change, both domestically and internationally, Europe should ensure that it has the necessary capacity in place to produce the data. The infrastructure already exists for the most part, and considerable quantities of data are being collected but not used. We recommend that the European Union and the ESA member countries consider expanding the operational capabilities of the ESA, and ensure that EUMETSTAT data is formatted according to GCOS specifications.

Glossary of Abbreviations

CCI	Climate Change Initiative
ECV	Essential Climate Variable
EO	Earth Observation
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAPAR	Fraction of absorbed photosynthetically active radiation
FCDR	Fundamental Climate Development Records
GCOS	Global Climate Observing System
GMES	Global Monitoring for Environment and Security
IES	Institute for Environment and Sustainability
JRC	Joint Research Centre of the European Commission
ECMWF	European Centre for Medium Range Weather Forecasting
EEA	European Environment Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUMETNET	Network of European Meteorological Services
FAO	Food and Agriculture Organization (of the United Nations)
ICSU	International Council for Science
IDC	International Data Centres
IOC	International Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
MRV	Measuring Reporting and Verification
NOAA	National Oceanic and Atmospheric Administration
LAI	Leaf area index
REDD	Reducing Emissions from Deforestation and Forest Degradation
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention for Climate Change
UNEP	United Nations Environmental Programme
WIGOS	WMO Integrated Global Observing System
WMO	World Meteorological Organisation

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Annex 1. Essential Climate Variables and ESA's role

	Essential Climate Variable	Fundamental Climate Data Record	Lead EU Institutions	Contributing EU Institutions	Main areas of policy relevance
1	Precipitation	Passive microwave radiances, high frequency geostationary IR, Active radar (for calibration)	EUMETSAT (not addressed)	ECMWF	White Paper / European adaptation framework
2	Earth Radiation Budget	Broadband radiances, spectrally resolved solar irradiances, geostationary multi-spectral imagery	EUMETSAT (not addressed)	ECMWF	-
3	Upper-air temperature	Passive microwave radiances, GPS radio occultation, high spectral resolution IR radiances for re-analyses	EUMETSAT (not addressed)	ECMWF	-
4	Upper-air wind	VIS / IR imagery, Doppler wind lidar	EUMETSAT **ESA**	ECMWF	-
5	Surface wind speed and direction	Passive microwave radiances and scatterometry	EUMETSAT (not addressed)	KNMI, ECMWF	White Paper / European adaptation framework
6	Water vapour	Passive microwave radiances, UV / VIS Radiances, IR imagery / soundings in 6.7um band, microwave soundings in 183 GHz band	EUMETSAT (not addressed)	ECMWF	-
7	Cloud properties	VIS / IR imagery, IR and microwave soundings	EUMETSAT / **ESA**	ECMWF	-
8	Carbon dioxide	NIR / IR radiances	**ESA**, EUMETSAT	ESRON, U BREMEN, LMD / CNRS, ECMWF	UNFCCC
9	Methane	NIR / IR radiances	**ESA**, EUMETSAT	ESRON, BREMEN, LMD / CNRS, ECMWF	UNFCCC
10	Other GHGs	NIR / IR radiances	**ESA**, EUMETSAT	ECMWF	-
11	Ozone tropospheric	UV / VIS radiances, IR / Microwave radiances	**ESA** / NIVR / EUMETSAT	ECMWF	UNFCCC, Air Quality
12	Ozone stratospheric	UV / VIS radiances, IR / Microwave radiances	ESA / EUMETSAT	ECMWF	UNFCCC, Montreal Protocol
13	Aerosol properties	VIS / NIR / SWIR radiances	**ESA**, CNES	ECMWF	UNFCCC, Air Quality
	Oceanic				
14	Sea-surface temperature	Single & multi-view IR and microwave imagery	**ESA,** EUMETSAT	EEA,IFREMER, Met Office Hadley Centre	UNFCCC, Seasonal and decadal forecasting, operational meterology and oceanography

15	Sea level	Altimetry	**ESA** / CNES, EUMETSAT, EC	CLS	UNFCCC, White Paper / European adaptation framework
16	Sea ice	Passive Microwave imagery (DMSP, AMSRE), SAR, TIR & VIS imagery	ESA, (2ndary role) EUMETSAT	EUMETSAT / Met.no, ECMWF	UNFCCC, Seasonal and decadal forecasting, operational meterologyand oceanography
17	Sea state	Altimetry, scatterometer, SAR	**ESA** / EUMETSAT, EC	EUMETSAT	UNFCCC, GMDSS in Arctic and Antarctic
18	Ocean salinity	Microwave radiances	**ESA**	IFREMER, ECMWF	UNFCCC
19	Ocean colour (IOP + Chl_a)	Multispectral VIS imagery	**ESA**, EC	JRC, PML, CNR, DLR	UNFCCC
	Terrestrial				
20	Snow cover (extent, snow water equivalent)	VIS / NIR / IR and passive microwave optical	ESA (secondary role)	EUMETSAT	-
21	Glaciers and ice caps	VIS / NIR / SWIR optical imagery, Altimetry	**ESA**	-	-
22	Permafrost and seasonally-frozen ground -		-	-	-
23	River discharge	Altimetry	-	-	-
24	Lake level / properties	VIS / NIR imagery radar imagery, Altimetry, IR imagery	**ESA**	-	-
25	Albedo	Multispectral and broadband imagery	ESA, (secondary role) EUMETSAT	-	-
26	Land cover	multispectral VIS / NIR imagery	**ESA**, CNES	-	-
27	FAPAR	VIS / NIR imagery	**ESA**	JRC, EUMETSAT, VITO	UNFCCC, EEA
28	Leaf Area Index	VIS / NIR imagery	**ESA** / EUMETSAT	-	-
29	Biomass	L Band / P Band SAR, Laser altimetry	**ESA**	-	-
30	Fire disturbance	VIS / NIR / SWIR / TIR multispectral imagery	**ESA,** EUMETSAT	-	-
31	Soil moisture (surface and root zone)	Active and passive microwave (Scatterometer and SMOS)	**ESA,** EUMETSAT	EUMETSAT / ECMWF, ECMWF, H-SAF, Univ Vienna	-

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