The Changing Earth Science Network -Projects and Results from the First Call

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Abstract

To better understand the different processes and interactions that govern the earth system and to determine whether recent human-induced changes could ultimately de-stabilise its dynamics, both natural system variability and the consequences of human activities have to be observed and quantified. In this context, the European Space Agency published in 2006 “The Changing Earth: New Scientific Challenges for ESA's living Planet Programme” as the main driver of ESA’s new EO science strategy. The document outlines 25 major scientific challenges covering all the different aspects of the Earth system, where EO technology and ESA missions may provide a key contribution. In this context, and responding to a request from ESAC (Earth Science Advisory Committee) to enhance the ESA scientific support towards the achievement of “The Challenges”, the Agency has launched the Changing Earth Science Network as an important programmatic component of the new Support To Science Element (STSE) of the Earth Observation Envelope Programme (EOEP). In this paper we summarize the objectives of this initive and provide a review of the first projects that were selected in 2009 and are now generating their first results.

Introduction

Since their advent, satellite missions have become central to monitoring and learning about how the Earth works, resulting in significant progress in a broad range of scientific areas. Although the Earth has undergone significant changes in the past, there is mounting evidence that the changes imposed, mostly by human activity, during the last 150 years cannot be compared with any previous change. In the mid-1990s, ESA set up its Living Planet Programme (LPP) and began working in close cooperation with the scientific community to define, develop and operate focused satellite missions.

Moreover, realising the importance of further understanding our planet and how it may react to these recent changes, ESA drafted a new science strategy for Earth Observation (EO) in 2006 titled 'The Changing Earth'. This strategy, drafted in collaboration with the scientific community, outlines the 25 major scientific challenges faced today in which EO may provide key contributions to better understand the interacting components of the Earth System – including water, atmosphere and land.

Based on the 25 major scientific challenges identified in 2006, ESA is now reinforcing this strategy. In 2008, the Support to Science Element (STSE) was launched to provide scientific support to both future and on-going missions by taking a proactive role in the formulation of novel mission concepts and their related scientific agenda and by fostering innovation in the scientific exploitation of ESA on-going and future missions. In this context, STSE main pillars include:

- Development of novel mission concepts in preparation for the next generation of European scientific missions;
- Development of advanced algorithms and innovative products that may exploit the increasing ESA multi-mission capacity;
- Reinforcing ESA collaboration with the major international scientific programmes and initiatives in Earth and natural sciences;
- Fostering the scientific return of ESA EO data by promoting their use by the Earth system science community with special attention to the new generations of young European scientists;
- Contributing to the evolution of the ESA EO science strategy.

As one of the main programmatic components of the STSE, ESA launched in 2008 a new initiative – the Changing Earth Science Network – to support young scientists to undertake leading-edge research activities contributing to achieve the 25 scientific challenges of the LPP by maximising the use of ESA data. The initiative is implemented through a number of research projects led by young scientists, starting their career in the area of Earth system science, for a period of two years. Projects should undertake innovative research activities furthering insight into the most pressing issues of the Earth system, while exploiting ESA missions data with special attention to the ESA data archives and the new Explorer missions.

By providing this opportunity, ESA aims at reinforcing the links with the next generation of Earth scientists, while contributing to enhance our knowledge of the Earth system and ensuring the scientific return of ESA EO data. The initiative will also help to consolidate a highly dynamic network of young scientists in Member States with a good knowledge of the Agency and its EO programmes. To this end, selected candidates have the option to carry out part of their research in an ESA centre as a visiting scientist.

Figure 1. Distribution of selected proposals in ESA Member States.

The first call for proposals issued in 2008 resulted in the selection of 11 postdoctoral scientists from the Agency's Member States (www.esa.int/stse). The preliminary results include several important advances in the use of ESA Earth Observation data to address some of the key open points today in Earth science. This paper gives a brief overview of these activities.
The second call for proposals was issued in early 2010 and will result in the selection of a new set of leading-edge research activities to be implemented with 2012.

Project Descriptions

ASSOCO: Assimilation of Ocean Colour Satellite Data to Monitor the biogeochemical State of oceans and estimate its variability
PI: Maeva Doron, Laboratoire des Ecoulements Géophysiques et Industriels (LEGI/CNRS**)**

The oceans account for around 50% of the primary production and play a major role in the carbon cycle, through capture of atmospheric CO_2 and sequestration of carbon in sediments. However, ocean's physical and biogeochemical properties are largely under-sampled and modelling activities are necessary to improve the quantification of the processes. Coupled physical-biogeochemical models are now comparable to satellite observations and data assimilation is a powerful approach to do such systematic comparisons and assessments. Robust assimilation techniques have been developed, principally for physical oceanography and this project will extend these capabilities to primary production models coupled to ocean circulation models [1]. It has been proven that simple biogeochemical models can be efficient if they are properly calibrated, and a major objective is to use data assimilation of ocean colour MERIS data to perform this calibration, in parallel to harvesting ocean colour products such as light penetration [2]. Sensitivity experiments of a 3D model over the North Atlantic with parameter perturbations have been performed for the spring bloom period. The model response is very inhomogeneous spatially in terms of phytoplankton, as illustrated in Fig. 2 (standard deviation of 200 simulations). In addition, the response is nonlinear, thus requiring new methodological development for the calibration step.

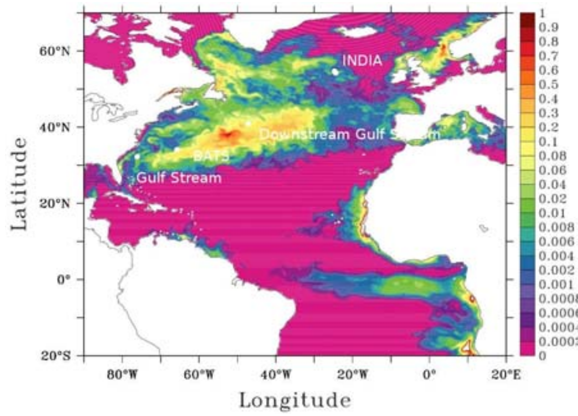

Figure 2: Standard Deviation ensemble for surface phytoplankton concentration after 1 day calculated with a 200-member ensemble with regionally perturbed parameters of the biogeochemical model.

DECPHy: Global ocean analysis of decadal covariability in phytoplankton and physical forcings through satellite remote sensing, in-situ measurements and Upper Ocean modelling
PI: Elodie Martinez, Laboratoire d'Océanographie de Villefranche, France

The main aim of this project is to provide new elements to understand the global response of phytoplankton to climate change through its physical forcing to better understand and forecast phytoplankton evolution in future. A first objective is to extend the recent analysis (1979-2002) till 2009, and confirm (or not) the role played by the natural basin scale decadal oscillations over the last three decades. Secondly, the Envisat time series extension over the last ten years will allow comparisons with other relevant remote sensing and in situ physical parameters which may be physical forcing to Chl variability (satellite derived wind, sea level anomaly, surface current, SST and in situ mixed layer depth). Finally, to go further in the comprehension of the dynamics which rule the upper ocean mixed layer (ML) and which is therefore responsible, through its depth variability, for the amount of nutrient inputs and so productivity, a 1-dimensionnal model of the ML will be run locally according to the results obtained above, and its outputs will be investigated

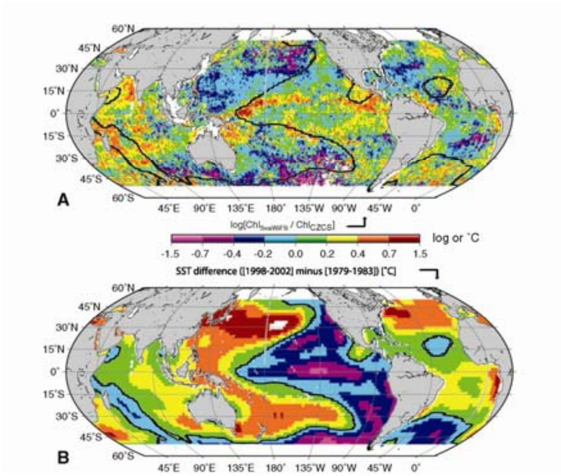

Figure 3 (adapted from [3]): (A) Chl change from the CZCS (1979–1983) to the SeaWiFS (1998–2002) era, expressed as the logarithm of the ratio of the average values over the two time periods [changes by a factor of 2 correspond to values of –0.7 (halving) or 0.7 (doubling)]. (B) SST difference over the same period.

The reprocessing of the ocean colour remote sensing product from MERIS is ongoing. These data are reprocessed in terms of calibration (vicarious) and algorithms to make them compatible with the initially reconstructed field combining CZCS and SeaWiFS missions. The aim is to provide a reconstructed product over 3 decades, extending the initially reconstructed field from 2002 to 2008 using MERIS data.

OCCUR Study of the chemistry-climate coupling in the UTLS region with satellite measurements

PI: Enzo Papandrea, University of Bologna, Italy

This project investigates how the dynamic variability of the UTLS regions can be studied using measurements acquired with remote sensing techniques and a Chemical Transport Model (CTM). Satellite missions, having global and multi year coverage, give the possibility to study the physical and chemical quantities of the atmosphere whereas the CTM can complement measurements for the understanding of the chemistry-dynamics coupling of the stratospheric and upper tropospheric circulations. Among the considered instruments, an infrared (Michelson Interferometer for Passive Atmospheric Sounding, MIPAS) and a UV/VIS instrument (Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY, SCIAMACHY) both on ENVISAT, limb sound the atmosphere since March 2003.

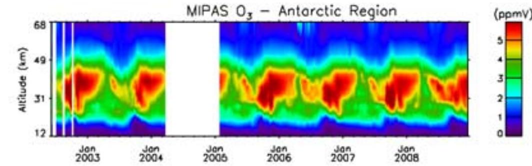

Figure 4: MIPAS ozone time series from GMTR Level 2 analysis (MIPAS2D)

The first results of this project confirm that high quality data is needed in order to understand more in detail the atmosphere in its multiple aspects. It has indeed recently seen that non-physical day-night differences are present in 1-D retrieval fields from MIPAS spectra, mostly at locations where the temperature gradient of the atmosphere is strong. These differences almost disappear using a tomographic approach, suggesting that a 2-D retrieval describes a more realistic picture of the atmosphere [4]. In this direction, the tomographic capability of MIPAS measurements in its three observation modes that sound the UTLS region through the information-load analysis [5] and of SCIAMACHY limb viewing observations through the altitude-latitude Box-airmass factors has been studied. In both cases, a bi-dimensional retrieval approach has been set up. Tomographic fields of pressure, temperature and volume mixing ratio of species related to ozone chemistry has been retrieved through the GMTR analysis code [6] for the whole MIPAS full resolution mission [7]. Besides, the freely available MIPAS2D database [8] has been updated and now covers the period from the beginning of its mission up to December 2009.

ISMER: InSAR Survey of the Magmatic Effects on Rift development

PI: Juliet Biggs, University of Oxford, United Kingdom

The aims of this project are to perform a systematic observation of ground deformation along the East African Rift using both archived and new data satellite data. This project will produce the first high-resolution geodetic surveys of the Main Ethiopian Rift, the Western Branch of the East African Rift and the Malawian Rift. Together with previous observations from the Kenyan Rift [9] these will form the first map of the temporal and spatial distribution of magmatic activity in a developing rift system. This comparison between rift segments at different stages of maturity is the key to understanding the development of rift systems both in East Africa and elsewhere and will act as the basis to test future models of continental rifting. This project will demonstrate the use of ESA InSAR data for hazard monitoring and geothermal exploration in East Africa.

This project is also designed to provide a rapid response to seismic events in the region. InSAR has been used to show that magmatic intrusions were responsible for previous seismic swarms, such as 2005 Afar [10] and 2007 Lake Natron [11].

In December 2009, a sequence of 4 earthquakes ranging in magnitude from 5.3 to 5.9 occurred on the western shore of Lake Malawi. The close ties with ESA enabled a rapid response and radar images were collected during the swarm and in several beam modes dramatically improving the quality of the data and models. Despite the swarm-like seismic activity which is more usually associated with magmatic intrusion, the satellite observations showed no magmatic involvement - the ground deformation patterns can be explained by a sequence of earthquake progressing along an immature fault [12].

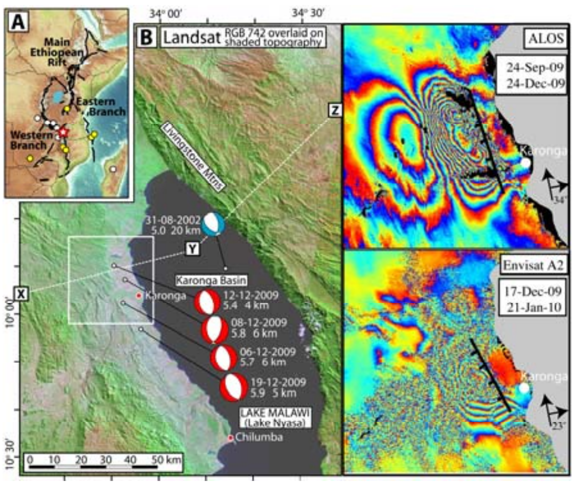

Figure 5: Location of the 4 largest earthquakes in the December 2009 Karonga Malawi earthquake sequence from teleseismic records. The earthquakes were located on the western shore of the Lake, 50 km from the major rift-bounding Livingstone Fault. White box: location of the interferograms (right) which show deformation patterns from the satellites ALOS and Envisat displayed such that each fringe (red to blue) represents 2.8 cm of motion away from the satellite. Top panel: deformation from the complete earthquake sequences; lower panel last earthquake of the sequence only. The patterns are consistent with the rupture of a shallow, west-dipping fault represented by the black line.

OC-Flux Open Ocean and Coastal CO_2 fluxes from Envisat and Sentinel-3 in support of global carbon cycle monitoring

PI: Jamie Shutler, Plymouth Marine Laboratory, United Kingdom

The rate at which CO_2 exchanges between the ocean and the atmosphere (termed air-sea fluxes) is related to wind speed, wave height and sea state. Understanding these exchanges is clearly of importance for understanding the global carbon cycle and for climate modelling. Earth Observation (EO) is well placed to study and monitor air-sea fluxes. However, there remain large uncertainties in the current parameterisations of EO derived air-sea gas interactions, which can have profound effects on the resulting predictions from global carbon-cycle models. OC-flux exploits the synergy of the sensors on board Envisat to investigate the uncertainties in current EO retrievals of air-seafluxes, studying both Open Ocean and coastal regions. The knowledge gained will then be used to extend the current methods to the proposed Sentinel-3 suite of sensors, potentially enabling future missions to monitor CO_2 fluxes in near-real time. Figure 6 shows some initial results illustrating the global distribution of sea to air CO2 flux for 2004 derived from one years worth of coincident Envisat data.

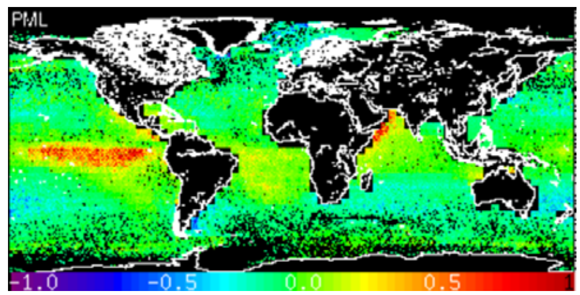

Figure 6: Mean daily CO2 fluxes for the year 2004 determined using coincident Envisat RA2 and AATSR data (units g -C m^-2 day^-1).

INCUSAR: Inverting consistent CUrrent fields from SAR

PI: Knut-Frode Dagestad, Nansen Environmental and Remote Sensing Center, Norway

This first part of this study will focus on a method to improve the accuracy of wind retrieval from Synthetic Aperture Radar (SAR), which will benefit the second part which is a consistent inversion of wind, waves and the surface current. Novel wind retrieval techniques will be used to improve upon traditional wind retrieval from SAR. The subsequent inversion of consistent wind, waves and surface current will combine both SAR Doppler and roughness measurements, and will utilise a complex radar imaging model [13] to simulate the radar signatures for given wind, wave and current fields. An iterative approach will be attempted to converge to a consistent solution.

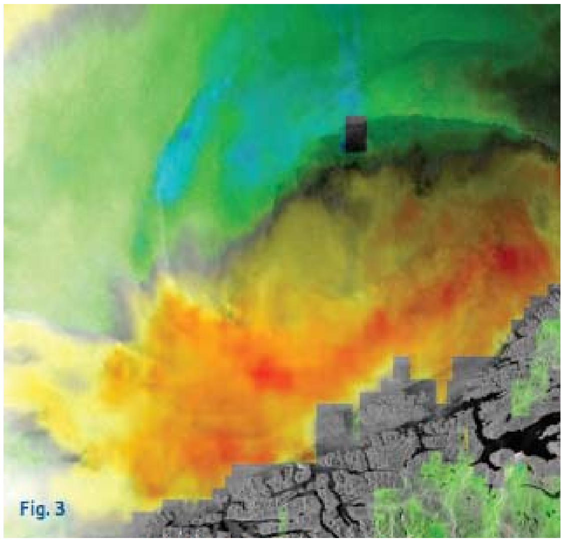

Figure 7: Doppler velocity from an Envisat ASAR scene showing a low pressure system off the coast of Norway. Yellow/orange colours indicate ocean velocity (wind/waves motion in this case) away from sensor (towards right), and green/blue colours indicate ocean velocity towards left. The Doppler velocity is an additional resource to the radar cross section for retrieval of wind speed and direction.

The first results of this project [14] demonstrate that the Doppler information may improve the SAR wind retrieval, in particular in vicinity of complex dynamical situations such as wind fronts and cyclones. The Doppler Centroid from Envisat ASAR, which is utilised in this study, was however at time of satellite design not intended to be used as a geophysical product, and thus the accuracy of this quantity is a limiting factor. A lot of efforts have therefore been spent on calibration of this parameter, by application of several empirical corrections. Early results of retrieval of ocean currents [15], after empirical correction for wind contribution, show accuracy of about 20-30 cm/s, which is sufficient to map the main features of typical coastal current systems such as the Gulf Stream, Kuroshio and Agulhas currents.

DIMITRI: DIagnostics of MIxing and TRansport in atmospheric Interfaces

PI: Elisa Palazzi, Istituto di Scienze dell'Atmosfera e del Clima (ISAC-CNR)

This project aims to improve the understanding of transport and mixing processes in the global Upper Troposphere-Lower Stratosphere (UT-LS) and in the so-called "dynamical edge" regions, collocated in the stratosphere at the boundary between tropical and extratropical air and at the polar vortex periphery [16,17]. Much has been learned about stratospheric transport and mixing across dynamical edges through the use of long-lived tracer observations. Strong latitudinal gradients of long-lived tracers, for instance, are collocated with dynamical barriers, suggesting an inhibition to horizontal mixing (see Fig. 7). Transport across such barriers is among the most important processes that must be understood for prediction of global change. These aspects of the atmospheric circulations are addressed within DIMITRI, through the use of MIPAS and GOMOS data and the application of diagnostic tools to chemical tracer distributions.

Within DIMITRI, probability distribution functions (PDFs) of satellite measurements of long-lived tracers have been used to identify the air in the subtropical edge region. When possible, a single characteristic latitude for the edge region has been identified, and its variability through the seasons and years analyzed. The analysis of the interannual variability takes advantage of the long satellite database available (from 1991 up to the present), which is obtained merging the data from different satellite instruments.

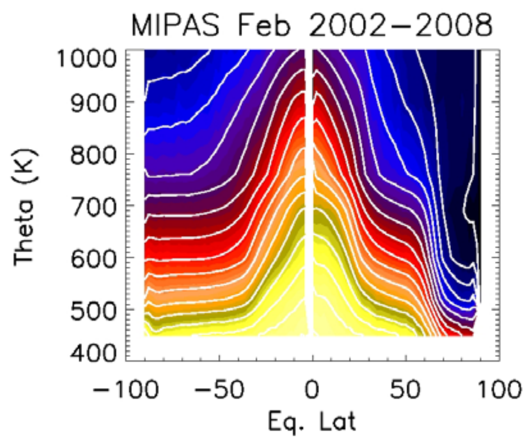

Figure 8: Equivalent latitude-potential temperature cross section of MIPAS N_2O concentrations for February. Closely-spaced contours are found in the subtropics and at the vortex edge, collocated with transport barriers.

Chocolate: CH_4, H_2O and CO from limb middle-Atmosphere Emissions

PI: Maya Garcia-Comas, Instituto de Astrofisica de Andalucia – CSIC, Spain

Water vapour is a key constituent in the middle atmosphere since it is involved in the ozone chemistry, it is the source of polar stratospheric and mesospheric clouds, and it is an important infrared cooler in the stratosphere. Its precursor in the stratosphere is methane, which is oxidized producing water vapour and carbon monoxide and which concentration has increased due to human- activity. H_2O and CH_4 are vertically transported up to the mesosphere where their photolysis occurs. CO is there locally produced by photolysis of CO_2. Their long lifetime make these three species excellent middle-atmosphere tracers. Few simultaneous global measurements of H_2O, CH_4 and CO are currently available in the middle atmosphere for an extended period of time. This project aims at deriving H_2O, CH_4 and CO concentrations in the stratosphere and mesosphere from MIPAS spectra around 6.3, 7.6 and 4.7 µm, respectively, measured in its Middle Atmosphere and Upper Atmosphere modes using the IMK-IAA processor, able to cope with the non-LTE nature of those emissions. One of the main error source in abundances retrieved from IR measurements in the middle atmosphere is due to the non-LTE models [18]. An additional objective is the characterization of the non-LTE processes affecting those emissions.

First MIPAS Middle Atmosphere water vapour results show a decrease around 85km towards the summer pole, where it condenses to form the polar mesospheric clouds, and an increase around 80km, where the ice forming the clouds sublimates (see figure). Around the stratopause, the typically large polar summer water vapour concentrations are anti-correlated with small methane abundance, showing a clear evidence of the larger local oxidation of the latter under prolonged illuminated conditions. MIPAS results also show that, during the 2006 and 2009 sudden stratospheric warmings of the northern hemisphere winter pole, the typical water vapour vertical descent in the mesosphere was interrupted. That was followed by a very strong descent a few days later.

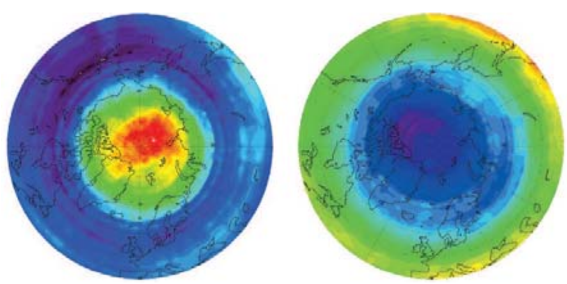

Figure 9: MIPAS Summer solstice water vapour distribution around the north pole at 80km (left) and 85km (right). Dehydration at the mesopause and water vapor increase at 80 km are very well correlated to MIPAS simultaneous water ice measurements [19].

CLARIFI: Clouds and Aerosol Radiative Interaction and Forcing Investigation: the semi-direct effect

PI: Martin de Graaf, Royal Netherlands Meteorological Institute (KNMI), Netherlands

Satellite observations are ideally suited to monitor the heterogeneous distribution of aerosols globally. However, most aerosol retrieval techniques rely on cloud masks, hampering aerosol-cloud interaction studies. This project focuses on identifying UV-absorbing aerosols in the cloud scenes using direct space-based SCIAMACHY radiance measurements. The spectra of absorbing aerosol contaminated clouds are skewed in the UV [20], which can be used to quantify the absorption of solar radiation. The identification and quantification of the absorption of solar radiation by aerosol in clouds can help to understand the radiative feedback mechanisms between clouds and aerosols, and improve our understanding of this important climate effect.

Using space-borne passive and active instruments, the most important areas in the world where cloud scenes are affected by aerosol absorption are identified. These areas, where cloud cover is persistent and biomass burning aerosols, often from anthropogenic origin, overlay the clouds, are most prominent south-west of Africa [21] and in Asia. The detailed structure of the cloud and the aerosol layers and their radiative interaction are shown in a comprehensive case study.

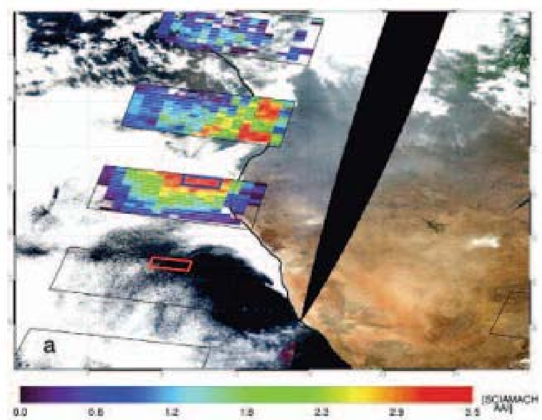

Figure 10: MODIS RGB image of biomass burning on 9 September 2004 over the eastern South Atlantic Ocean overlaid with SCIAMACHY AAI (Absorbing Aerosol Index), [22]

CARBONGASES: Retrieval and analysis of CARBON dioxide and methane greenhouse GAses from SCIAMACHY on EnviSat

PI: Oliver Schneising, Institute of Environmental Physics (IUP), University of Bremen, Germany

The main objective of CARBONGASES is to make a contribution to fill the significant gaps in our understanding of the global carbon cycle by improving our knowledge about the regional sources and sinks of greenhouse gases by generating the required global multi-year satellite datasets, namely column-averaged dry air mole fractions of carbon dioxide and methane retrieved from SCIAMACHY on Envisat. The focus of CARBONGASES is on four years of data (2006-2009) which have not been analysed before. The existing SCIAMACHY dataset [23,24] will be further improved

and extended up to 2009 during the CARBONGASES project.
An initial analysis of the newly processed data shows that the CARBONGASES retrieval results based on improved Level 1 calibration are consistent with the afore existing data set for the overlapping time period and that stability can be achieved until the end of 2009 when using an appropriate detector pixel mask approach. The steady increase of atmospheric carbon dioxide can be clearly observed with SCIAMACHY for the whole time period analysed (2003-2009). The methane results show that after years of near-zero growth, atmospheric methane has started to increase again in recent years which is consistent with surface measurements.

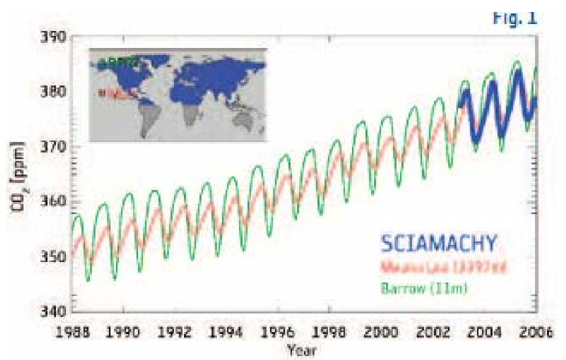

Figure 11: Comparison of northern hemispheric atmospheric carbon dioxide column-averaged mole fractions retrieved from SCIAMACHY with two NOAA surface stations demonstrating the seasonal cycle and the increase with time of CO_2.

FEMM: Fire Effects Modelling and Mapping

PI: Patricia Oliva Pavon, University of Alcala

Accurate estimations of burn severity and its distribution in post-fire scenarios are critical for short-term mitigation and rehabilitation treatments. The use of remote sensing techniques, coupled with radiative transfer models (RTMs) can improve the accuracy, precision (in terms of number of classes) and cost-effectiveness of burn severity assessment and ensure the generalization power of the methodology [25]. In this project, an improved simulation model that combines PROSPECT and GeoSail to estimate burn severity from MERIS data was tested in European Mediterranean forest fires. The determination of burn severity was based on a new version of the CBI index (named GeoCBI), that takes into account the vegetation fraction cover (FCOV) to compute the burn severity of the total plot [26].
The methodology developed using Landsat-TM images was applied on MERIS data to estimate the burn severity of two large fires occurred in Spain in 2009. In order to validate the results a cross validation was performed using burn severity estimations from Landsat-TM as reference data. The regression analysis offered R^2 values over 0.90 in both study sites.

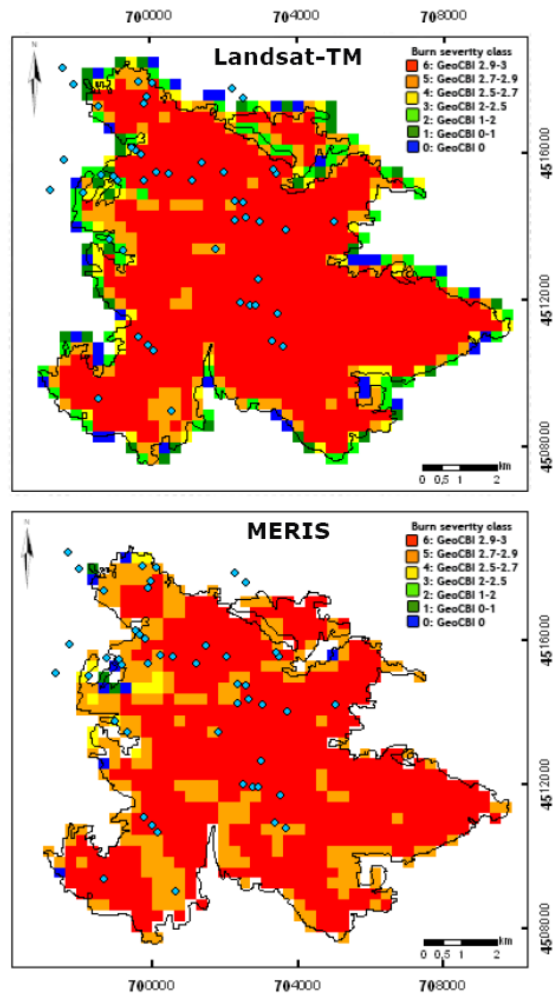

Figure 12: Burn severity estimation from Landsat-TM and MERIS data of a fire occurred in Teruel (Spain) 2009.

Conclusions

The Changing Erath Science Network responds to the need to establish close links between the Agency and the new generation of young scientists. In particular the initive supports young scientist (at post-doctoral level) in ESA Member States to undertake leading-edge research activities specifically dedicated to the challenges of the Living Planet Program by exploiting and maximizing the use of ESA EO data. The main two elements of the initiative are:

- Contribute to advance towards the achievement of the new 25 challenges of the Living Planet Program.
- Foster the use of ESA EO data by the Earth science community maximising the scientific return of ESA EO missions;

In addition, this initive will also contribute to 1) consolidate a critical mass of young scientist in Europe with a good knowledge of ESA EO assets and programs and 2) to enhance the interactions between ESA and leading edge Earth science labs, research centres and universities in member countries.
This paper has summarised the preliminary results of the first set of projects that have been selected as part of the first call for proposals. A new call has been opened early in 2010 in order to select a maximum of ten new projects to be completed before 2012.

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