

NCEO Theme1: EO for climate system diagnosis and prediction

1.ABSTRACT

The challenge presented by climate change makes it imperative that optimal use is made of observations to quantify what is happening to the climate system as a whole, to understand the processes involved and to forecast how it will evolve in the future. The warming of the global oceans, increases in sea level, the melting of Arctic ice, and changes in weather and vegetation cover are all linked processes capable of being quantified by EO. The global nature of EO data, and the fact that they sample the surface-interface between the climate subsystems (atmosphere-ocean/land/ice), also makes them an ideal source of information for testing the performance for coupled climate models. This theme provides a focal point within NCEO; it will use EO data to analyse key variables pertaining to the atmosphere, oceans, cryosphere and land surface and their interaction in the energy, hydrological and carbon cycles. It will use process results from other themes and will integrate this information using data assimilation methods to create synthesized and reanalysed global products in which the uneven effects of data sampling and quality have been removed, allowing changes to the climate system to be quantified. This directly addresses Task 1 of the GEO program under climate, for “Sustained reprocessing and reanalysis”. These data sets will then be used to improve climate models and to test their performance on seasonal to multi-decadal timescales. Existing close links between NCEO and the Met Office and ECMWF will be strengthened. The Hadley Centre climate model is now the basis for climate research in the NERC NCAS community and will be a main focus for the climate work in this theme, building a strong partnership with the Met Office through the shared evaluation and exploitation of the model. The EO data and assimilated products will be used to assess the recent state of the climate system and its changes over the past few decades, to quantify changes in key processes over a wide range of timescales and use this information to improve the modelling, and to provide initial conditions for climate/environmental prediction experiments on the seasonal to decadal timescale. The theme will support 15 FTE researchers, among 12 institutes, for 5 years, involving leading scientists representing National Capability in EO from across the UK.

2.BACKGROUND AND MOTIVATION

Background and the science challenge: The Summary for Policymakers of the IPCC Fourth Assessment Report states that “the warmth of the last half century is unusual in at least the previous 1300 years” and that “most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations”. Climate change is widely regarded as the greatest challenge now facing mankind. However large uncertainties remain in predictions of changes in circulation patterns, temperatures, rainfall, sea-level rise, extreme events and in the implications of these changes for regional and local climate. There is an urgent need for more tightly-constrained climate projections on seasonal to multi-decadal timescales relevant to businesses and policymakers. Reducing the uncertainties in climate projections on these timescales is under-researched and requires much better use of data to improve coupled models and to provide initial conditions (e.g. through assimilation). The vast quantities of EO data represent a major opportunity in this respect.

The unique contribution of this theme will be to exploit EO data to diagnose the evolving state of the climate system as a whole and to confront and improve Met Office climate models and their components. Only EO data can provide the global coverage and high time resolution to do this effectively. The improvements to model formulations and initial conditions will feed through to produce improved climate change predictions on seasonal to decadal timescales. Such forecasts are dependent on EO and other data to initialise the models, unlike longer timescale predictions in which emission scenarios dominate. The approach builds on existing collaborations between NCEO groups, the Met Office and ECMWF. In collaboration with NCAS, the theme will use high resolution versions of the Hadley Centre climate model, linking the EO expertise in NCEO with the modelling activities in NCAS and the Met Office. New techniques for exploiting EO data will thus be included in future operational forecasting work at the earliest opportunity. This theme therefore provides a framework for greater Knowledge Transfer from NERC to operational climate and weather prediction agencies in the UK.

The work is organised under the **four Earth-system component sub-themes** of **Atmosphere, Oceans, Cryosphere and Land surface**. The shared aim will be to use EO directly or via expertise from other NCEO themes to diagnose global fluxes of heat, water and carbon both within and between the Earth-

system components, and to test whether climate models correctly represent these fluxes (Annex 1 illustrates links). The theme will thus build strong links within the EO community. Within sub-themes, the work is presented under **three subject** areas; **Global EO datasets and errors, Exploiting new sensors and modelling, and Confronting climate models with EO data**. The first two emphasise the technical challenges to using both existing and new EO sensor data to derive Earth system information.

The atmospheric sub-theme focuses on radiative fluxes and the atmospheric branch of the hydrological cycle. The absorption of solar radiation provides the energy source for the climate system, while the emission of thermal radiation to space provides the ultimate sink. These radiation streams are strongly influenced by water vapour and clouds, so the study of the coupling between the radiation balance and hydrological cycle is of fundamental importance for understanding how the climate system works. It is also a prerequisite for the prediction of climate change, because all of the known driving forces for change involve perturbations to the radiation budget and the strongest feedbacks involve the hydrological cycle. We therefore need to understand what factors control the radiation budget and its variability, how the various driving forces are leading to climate change, how feedbacks are modifying the climate response and how all of these processes can best be represented in climate models.

The oceans have the largest heat capacity of any component of the climate system and therefore strongly influence the rate of global warming, as well as being key to predicting much of the low frequency variability in climate through changes in circulation and transports. EO data play a key role in developing understanding of ocean circulation and change. Global sea level data from altimeters provide information about ocean heat content, sea level changes and ocean circulation, and satellite sea surface temperatures provide understanding of surface driving for atmospheric circulation over 70% of the globe. The oceans also absorb about 50% of the anthropogenically emitted CO₂ and modelling this uptake involves ocean biology which can be observed globally through ocean colour.

The land and sea ice cover that make up the cryosphere interact strongly with the Earth's radiation budget through albedo feedbacks, and with the ocean circulation through heat and freshwater exchanges. Recent changes in Arctic sea-ice cover and in ice shelves around Antarctica suggest that the cryosphere is evolving quickly. EO data provide the only means to globally monitor sea ice extent and thickness as well as changes in glacial ice streams around the edge of the Greenland and Antarctic ice sheets.

Over land, vegetation also affects the albedo and hence the net radiation at the land-atmosphere interface. The availability of soil water strongly influences the hydrological cycle through the partitioning of rainfall into runoff and evapotranspiration, and the land carbon cycle through its impact on plant growth. Modelling studies have shown that feedbacks between the land-surface and the atmosphere are vital for both climate prediction and weather forecasting. However, models differ markedly in the strength of the land-atmosphere coupling, leading to uncertainties in predictions. This subtheme will produce observationally-based constraints on the state of the land-surface with global coverage and high temporal and spatial resolution which will allow quantification of land-atmosphere interactions.

The use of climate models to forecast future change relies on compatible methods of data synthesis that allow models to be initialised across all Earth-system components. The synthesis of past EO data through reanalysis on decadal timescales is a prerequisite to prediction, because it provides both more complete information on recent climate change and a stringent test of compatibility of the different components of the coupled climate models and data synthesis systems. It is on the global scale that interactions and feedbacks between the components of the Earth system are most important, and global EO provides the most natural datasets with which to test understanding of these interactions. The formation of the NCEO is an ideal opportunity to sponsor such a cross cutting theme, bringing together experts from previously different fields of EO expertise.

Wider context and motivation for the theme: This theme contributes directly to NERC's Strategic Goals in its draft strategy "Next generation science for planet Earth", released in February 2007, particularly the Principal Science Goal "UK to lead the world in the prediction of the regional and local impacts of environmental change from months to decades". The work proposed contributes directly to this aspiration and to NERC's Climate system theme, bringing together NCEO expertise with the modelling expertise in NCAS and the Hadley Centre. The ability to forecast climate change on seasonal to decadal timescales is of vital importance to UK interests. This is challenging scientifically, requiring an integrated and multi-disciplinary approach. The theme also exploits efficiently the UK investment in satellite instrumentation

through membership of ESA and EUMETSAT, as well as satellites launched by other agencies.

Why should the theme be included in NCEO: Satellites provide the most important source of global observations of key variables for monitoring the climate system and for initialising, evaluating and improving models. This theme is at the heart of the NCEO mission to provide a focal point within NERC for EO data exploitation. The programme builds on the expertise of the previous EO collaborative NERC centres. This theme will provide a framework for enhanced collaboration within the UK EO community and a focus within NCEO for Knowledge Transfer to operational climate and NWP centres.

Critical partnerships: The Met Office and ECMWF are major partners. The strong interaction with these operational agencies expands the capabilities of each partner, so the benefits of such an interdependence are far reaching. The recently established National Centre for Ocean Forecasting (NCOF) provides such a marine science partnership which can be built upon by the NCEO. Collaboration will be extensive within NERC, particularly with Oceans2025, NCAS and QUEST. The interaction between NCEO, NCAS and the Hadley Centre create a joined-up programme of model development and evaluation. For ocean modelling, NEMO and the assimilation development for it is shared between NCEO, ECMWF and Hadley Centre, providing a core partnership for seasonal to decadal predictions. NCEO and NCAS will collaborate to ensure that NERC supercomputer resources are used efficiently, e.g. by sharing integrations, diagnostics and analysis, especially for high resolution modelling. This will avoid duplication of the current Hadley Centre programme, and provide opportunities for jointly defining the next generation of high resolution climate models.

3.THEME OBJECTIVES

- Improve understanding of the coupled climate processes that control the Earth's radiation budget, the hydrological cycle, ocean circulation and transports, cryosphere and the properties of the land surface, through better exploitation of existing and new EO data.
- Improve the representation of these processes in the Unified Model, by working with partners within NERC and the Met Office.
- Improve techniques for assimilating existing and new EO data into models, in order to initialise seasonal to decadal predictions of climate anomalies.
- Perform retrospective analyses (“re-analyses”) of EO and other data to produce long-term, internally consistent global data sets for the atmosphere, ocean and land.
- Provide a national focal point for the exploitation of EO data for the improvement of seasonal to decadal climate prediction, and to communicate this knowledge to decisions makers.

3.1 ATMOSPHERIC SCIENCE (Leader: Slingo, Reading)

Summary: The focus of this work is the radiation budget and the variables that control it, in particular water vapour, clouds, other greenhouse gases and aerosols. This sub-theme will analyse global EO datasets and their variability in space and time. Several datasets show significant natural variability, for example during ENSO events, as well as the forced response to volcanic eruptions. This variability provides opportunities for identifying physical interactions and the feedbacks associated with water vapour and clouds. Some datasets are also beginning to show evidence for longer period trends that may be associated with global warming. The timeliness of the work is illustrated by the fact that well-calibrated satellite datasets are beginning to encompass decadal variability, so that, with the warming trend becoming more robust each year, there are new opportunities to disentangle the signals relating to climate feedbacks. In addition, several satellite instruments have recently been launched that provide new information on the radiation budget, water vapour, clouds and aerosols. These include GERB and SEVIRI on Meteosat-8 and 9, IASI on Metop and the CloudSat cloud radar and Calipso lidar, which complement the NASA “A-train” instruments already in orbit (e.g. the AIRS and TES spectrometers).

In conjunction with surface sites, the new EO data provide an unprecedented opportunity to develop novel observation-based metrics for evaluating and improving the representation of radiative heating and the hydrological cycle in models. Comparison of the data with the Unified Model is an integral element of the programme. Some model diagnostics, such as radiative fluxes, can be compared directly with high level EO products and surface measurements. More direct comparisons between the model and EO data will be developed in collaboration with Met Office groups, employing forward simulations from the model of the satellite data, whether from passive infrared or active (e.g. CloudSat) instruments.

In each subject area, NCEO will provide a core capability, to be enhanced by existing co-funding for specific projects and by future grant applications. Coordination work will bring together the results and to interact with key national and international partners. Outreach will take place with external groups, e.g. to the model intercomparison projects sponsored by GEWEX and IPCC. This will enable strategic decisions to be made regarding the balance and direction of the work in the different areas.

Work description and Methodology:

3.1.1 Global EO datasets and errors

Task 3.1.1a Use EO and other data to quantify global variability and trends in the radiation budget and hydrological cycle, and to identify climate feedbacks (Reading, initially through co-funding).

The inexorable warming trend emerging in recent decades is now monitored continuously by increasingly long-term, well-calibrated EO datasets, providing valuable information on global variability and climate feedbacks. Satellite observations of the Earth's radiation budget from ERBE and CERES, together with cloud data from ISCCP, show evidence for reductions in tropical cloudiness from the 1980s to the 1990s (Wong et al. 2006). Observations of solar radiation at the surface also show decadal variations, probably due to changes in aerosols and clouds (Wild et al. 2005). Other datasets, including column-integrated water vapour and upper tropospheric humidity from microwave (SMMR and SSM/I) and infrared (HIRS) radiances, show further evidence for trends in the hydrological cycle. In collaboration with NASA Langley and other partners, we will combine these and other data (including the new aerosol and cloud products from (A)ATSR produced by the Atmospheric Composition theme) to produce a consistent description of the radiation budget and hydrological cycle. This will be used to quantify natural variability, to identify trends and to establish relationships between the radiation budget, water vapour, clouds and aerosols, with the ultimate goal of isolating the feedbacks taking place during global warming. Metrics will be developed that encapsulate hydrological and other feedback processes crucial for climate change. These will be applied to integrations of the Unified Model performed under Task 3.1.3a and to the models included in IPCC. Work at Reading has shown that the representation of the hydrological cycle is improving steadily in reanalyses and the new ERA-Interim reanalysis (ECMWF Newsletter No. 110) will be included in this work. Dynamical fields from reanalyses will be employed to investigate cloud feedbacks from marine stratocumulus, processes which are proving crucial for determining climate sensitivity in current models.

Task 3.1.1b Analysis of surface radiation budget data from satellites and surface sites (Reading).

Satellite data have been employed extensively in studies of the Earth's radiation budget and in evaluating models, but less use has been made of direct radiation measurements at the surface. One reason is the uneven distribution of such measurements, with virtually none over the oceans. The measurements will be combined with flux estimates from the Ocean sub-theme (Task 3.2.1b) and there will be interaction with the Land sub-theme on land surface temperatures (Task 3.4.1b). The goal is to combine the surface data with top of atmosphere fluxes provided under 3.1.1a, to quantify the partitioning of radiative heating between the atmosphere and surface. Data from the Baseline Surface Radiation Network and the Global Energy Balance Archive will be included, in collaboration with ETH Zurich, as well as from deployments of the ARM Mobile Facility and permanent ARM sites (see also Task 3.1.3b). In collaboration with the Hadley Centre, the data will be compared with new versions of the climate model under Task 3.1.3a.

Global retrievals of the surface radiation budget are available from several satellite projects, notably ISCCP and GEWEX, although with quite low spatial and temporal resolution. Since model resolutions are expected to improve beyond that of these retrieved products, there is a need to explore methodologies for producing higher resolution without the considerable task of re-processing the raw data, for example by using disaggregation techniques. The potential of geostationary data, e.g. from GERB and SEVIRI, for increasing the spatial and temporal resolution will be investigated.

3.1.2 Exploiting new sensors and modelling

Task 3.1.2a EO measurements with high spectral resolution (Imperial, Edinburgh, Reading).

The signatures of climate feedback processes can be detected more readily in observations with high spectral resolution than in the broad-band observations mentioned above. Indeed, satellite observations from 1970 and 1997 have already allowed the identification of changes in the radiative forcing due to greenhouse gas changes (Harries et al. 2001). Decadal scale variability in observations and in the Met

Office climate model will continue to be studied (Brindley and Allan, 2003). A joint project between Oxford University and Imperial College will exploit the multiple climate simulations from the climateprediction.net project in studies of the variability of the outgoing spectrum. An exciting opportunity now exists to extend this work much further, since we are enjoying an era of new, high quality resolved spectral measurements, some of which (IASI) will extend for more than a decade in an operational series. These new data are becoming available from several instruments, including IASI, AIRS and TES, and will be analysed to explore the information content of the radiances to represent the spectral signatures of changes in atmospheric temperatures, humidities, clouds and aerosols. In an important new project (HadIR) the Met Office will exploit the high spectral resolution measurements from IASI to produce a climate-quality dataset for both clear and cloudy skies which will be available in near-real time. The Met Office will use these to improve the characterisation of HIRS data and then re-process all data to create a homogeneous record of global infrared observations from 1979, for clear-sky and all-sky conditions. We will work closely with the Met Office to analyse this new record.

Task 3.1.2b Exploitation of data from CloudSat and Calipso (Reading).

There is considerable interest in the exploitation of CloudSat and Calipso data both for clouds and aerosol. A variational retrieval scheme has been developed at Reading that combines the CloudSat radar, Calipso lidar and MODIS infrared window channels to retrieve ice cloud profiles. Its applicability spans the thin cirrus detected only by Calipso and MODIS to stratiform precipitating ice cloud penetrated by CloudSat, but through which Calipso is rapidly extinguished. The microphysical properties retrieved from the three instruments together are expected to be significantly more accurate than the standard products derived from single instruments. This unique approach will be extended to include liquid clouds and deep tropical convection, within which multiple scattering (Hogan 2006) and attenuation by precipitation become important. Attenuation by precipitation will be accounted for by incorporating microwave radiances from AMSR-E into the scheme, thereby constraining the information from the radar and allowing the precipitation profile to be estimated. The data will be used to estimate the vertical profile of radiative heating, which is of immense interest for model evaluation. Working closely with the Cloudsat PI and Science Team, we will test the retrieved profiles through comparisons with aircraft measurements during several CloudSat validation campaigns worldwide, then by their ability to predict the top-of-atmosphere radiative fluxes measured by the CERES instrument. The approach will be embodied in the CloudSat/Calipso simulator to be used in Task 3.1.3a. This work will be extended in preparation for the launch in 2013 of the ESA/JAXA EarthCARE satellite, in which the UK has strong interests.

3.1.3 Confronting climate models with EO data

Task 3.1.3a Evaluation of high resolution versions of the Hadley Centre climate model (Reading).

Comparisons between climate models and EO data have always been hampered by the much lower horizontal resolution of the models. Building on the existing collaborations with NCAS-Climate and the Hadley Centre on the HiGEM and UK Japan Climate Collaboration (UJCC) modelling projects, this problem will be addressed by running the Hadley Centre model at high resolution on HECToR and comparing results with the datasets analysed or created in the previous tasks. Time on HECToR will be applied for in collaboration with NCAS-Climate. Our membership of the CSRMTA consortium will also provide access to large-domain cloud-system resolving UM simulations with a target resolution of 1-2km. The model integrations will include forward simulations to continue the “model-to-satellite” approach used in earlier work, consistent with the goal in the other sub-themes of assimilating such data in future re-analyses. A fast radiance code will be used to simulate the HIRS and IASI radiances prepared under Task 3.1.2a and a CloudSat/Calipso simulator being developed at the Hadley Centre will enable direct comparisons with the results from Task 3.1.2b. Evaluation will include the statistical comparison of cloud properties and by compositing results to determine the radiative errors associated with particular cloud types. Cloud systems will be followed using the feature tracking software developed in Theme 4 (Weather/Flooding). Using high resolution minimises differences between the model and the EO data, provides regional detail both in the forcing and model simulations and will accelerate the development of new versions of the model for future implementation in the Hadley Centre climate prediction programme.

Task 3.1.3b Regional validation and process studies (Reading, Imperial College).

The GERB instrument on Meteosat-8 has provided high quality broadband fluxes since it was launched in 2002 (Harries et al. 2005) and has already been used to study the radiative forcing by clouds, the

diurnal cycle of convection and Saharan dust storms. The second GERB instrument, funded by EUMETSAT, was launched on Meteosat-9 in 2006 and two more instruments will follow. In this task, the data will be exploited to study the radiative effects of clouds, water vapour, the surface and aerosols, exploiting the high time resolution (15 minutes). The successful evaluations of the simulation of the radiation budget, clouds and the surface by the Met Office NWP model, started under the SINERGEE project (Allan et al. 2005), will also be continued.

Observations by well-instrumented surface sites are an essential complement to satellite observations: they allow the radiation budget to be constrained at the top and bottom of the atmosphere, they can be used to evaluate models in more detail than is possible by satellite, and they provide a testbed for retrieval algorithms that are intended for use from space. Work in this task will build on two existing projects, which use data in near-real time to evaluate NWP models. Cloudnet established a system for objectively evaluating the representation of clouds in 7 forecast models over 3 European sites equipped with radar, lidar, microwave radiometers and many other instruments (Illingworth et al. 2007). RADAGAST is combining data from GERB with detailed surface observations from the US ARM program's Mobile Facility in Niamey, Niger, during 2006 (Slingo et al. 2006). In collaboration with partners within ARM and at ETH Zurich, the methodologies developed in these projects to compare models with the data will be extended to other sites, with the goal of deriving the vertical structure of the atmosphere and of the associated radiative heating profiles. These sites will also provide testbeds for retrievals to be applied globally to Cloudsat and Calipso data under Task 3.1.2b.

Deliverables:

1. Improved understanding of decadal variability and trends in the radiation budget, water vapour, clouds and aerosols, and of the representation of these processes in models
2. Exploitation of satellite measurements with high spectral resolution to investigate climate feedback processes and to evaluate models.
3. Global retrievals of the vertical structure of clouds, aerosols and radiative heating from CloudSat and Calipso, for process studies and model evaluation.
4. Evaluation and development of surface radiation budget datasets.
5. Datasets describing the vertical structure of the atmosphere using well-instrumented surface sites and geostationary data, for process studies, model evaluation and algorithm development.

Collaborations:

- Met Office, ECMWF, US ARM program, NASA Langley Research Center, Colorado State University, ETH Zurich (letters of support are attached to this proposal).
- NCAS-Climate and NERC APPRAISE directed programme.
- Links within theme: To Ocean and Land surface on surface temperatures and radiation budgets.
- Links to other themes: Atmospheric composition theme; trace gases, clouds and aerosols. Weather/Flooding: feature tracking and regional surface radiation budget.

3.2 OCEAN SCIENCE (Leader: Haines, Reading)

Summary: The oceans play a key role in the climate system, in particular storing and transporting vast amounts of heat and freshwater. These can have huge impacts on regional climate. The oceans also have naturally long thermodynamic timescales, exerting a moderating influence on changes induced by perturbations in other parts of the climate system, eg. to the radiation budget. The capacity to detect subtle changes in the ocean as it responds to global warming will enhance our preparedness to mitigate the impacts of climate change. Earth observation methods from satellites provide the spatially detailed, regularly repeated global coverage needed for identifying climatically important ocean variability. NCEO will direct its research in this sub-theme towards (i) characterising the accuracy and errors of crucial satellite measurements needed to quantify ocean climate variability and change (tasks 3.2.1a,b), (ii) developing the capacity to interpret new EO data through modelling (tasks 3.2.2) and (iii) refining the ways in which such observations are used to confront climate models (tasks 3.2.3a-d). In particular ocean observations are known to be crucial for constraining climate models used for seasonal forecasting and thus they hold the key to interannual to decadal predictions which are an important element for policy makers. This Oceans EO programme will be tightly integrated within the NCEO climate theme; working to improve data products and modelling tools that enhance the UK's climate prediction capability.

The programme will strengthen and focus the satellite EO expertise spread through NERC's marine science community and will complement the UK Marine Institutes programme, Oceans 2025, which has relatively little EO focussed content. It will strengthen the interaction between scientists working with Earth observing satellites, making observations in the ocean and modelling the climate. It will directly support KT projects with the Met Office, Hadley Centre and with the ECMWF, who have operational interests in synthesis of marine data and initialisation of seasonal to interannual prediction systems.

This integrated programme of research covers the key applications of EO in ocean science, including SST and air-sea interaction, sea level and circulation, and ocean colour and carbon fluxes, with a focus on reanalysis and initialisation of climate models. Coordination will ensure the work contributes internationally to the GEO and GCOS agendas on climate change fingerprinting, and to space agency plans for new and continuing instrument programs. The KT elements with the Met Office and ECMWF will be used to put the NCEO at the heart of the UKs program for climate prediction. All ocean modelling and assimilation work will use versions of the NEMO model which has been adopted as the community model by O2025 and QUEST and will become part of the Met Office Unified model and the ECMWF seasonal forecasting framework within the next few years.

Work description and methodology:

3.2.1 Global EO datasets and errors:

Task 3.2.1a Development of long climate-quality SST records using ATSR series data, extending the ARC program up to Sentinel 3 (Edinburgh, NOCS, Leicester, Hadley Centre).

Sea surface temperature (SST) is a key Earth system parameter providing a strong constraint on the atmosphere, ocean and climate models, and supporting more accurate inference of circulation, air-sea fluxes (of heat, water and CO₂) and heat budgets. The satellite era is a period of historically high SST trends (~0.2 K per decade), and of problematic changes in the in situ observational network. Climate-quality EO-based SST is thus a priority for quantifying contemporary rates of change. The UK has addressed this via its investment in the (A)ATSR sensors (the (Advanced) Along Track Scanning Radiometers) and the ongoing project, the (A)ATSR Re-analysis for Climate, ARC. The main ARC targets are: global and regional biases <0.1 K; stability of the observing system of <0.05 K per decade; and a comprehensive error model. ARC SSTs are integral to the Hadley Centre plans for improving the marine climate data record. Additionally, simultaneous retrieval of top-of-atmosphere clear-sky irradiance and SST will create a dataset of window-region atmospheric absorption which will be exploited within the HadIR project in the atmospheric sub-theme.

The climate-quality satellite SST record will be extended beyond the operations of the last (A)ATSR (on Envisat, operations expected until 2009) to ensure continuity through to the next ATSR-class sensors (on Sentinel3, operations from 2011). The approach is to exploit the operational METOP platforms using synergy of the Advanced Very High Resolution Radiometer (AVHRR) and Infrared Atmospheric Sounding Interferometer (IASI). The task extends the ARC project's infrastructure and collaborations, ensuring efficient use of resources and pull-through to the marine climate data community. Careful analysis of the Envisat/METOP overlap period and comparisons with selected in situ data will be undertaken. As with ARC SSTs, the Hadley Centre will assess this extended climate-quality satellite SST record for prescribing SSTs, climate model validation, and assimilation for decadal forecasting.

Task 3.2.1b EO data for air-sea flux assessment, and validation against model / in situ data (NOC).

Surface fluxes of heat and freshwater connect the atmosphere and ocean and are poorly quantified, despite being vital forcing fields for models and essential to understand the ocean in a changing climate. In situ flux data cover less than 50% of the ocean and EO cannot presently measure all of the components of the heat and freshwater budgets with usable accuracy. For example, remotely sensed sensible and latent (evaporative) fluxes contain large uncertainties, mainly due to their poor retrieval of surface air temperature and humidity. Building on previous NERC Core Strategic and Met Office investment Oceans2025 has funded the development of new higher spatial and temporal resolution in situ flux and surface marine meteorological datasets which are ideally suited to confront the EO data. This work package will use existing user accuracy requirements for fluxes (sensible, latent, short- and long-wave radiation and stress) and flux-related variables (including SST, winds, humidity, air temperature, clouds and salinity) to identify the major sources of uncertainty in the EO heat and freshwater budgets. Exploitation of the new in situ datasets from Oceans2025 and new satellite observations will allow us to

target particular areas, or causes, of poor performance in the EO data and thus significantly reduce the uncertainty in the EO heat and freshwater budgets. The need for different flux parameterisations will be investigated. New salinity datasets from, e.g. Aquarius, SMOS, will allow us to explore the potential for diagnosing the freshwater fluxes from surface salinity changes. An important element of the work package will be intercomparison of fluxes from multiple NWP models (including Met Office, NCEP and ECMWF), EO, and in situ data, and contributing to WCRP SURFA flux.

3.2.2 Exploiting new sensors and modelling:

Task 3.2.2 Combining altimetric sea level with gravity from GRACE and GOCE. Assimilation into ocean models to quantify circulation and heat/freshwater transports (Reading, MetO)

The major signal in the height of the sea surface measured by altimeters comes from gravity, i.e. geoid variations. To get at the sea level variations driving ocean dynamics we need to remove this signal. Using altimeter data alone this is done by subtracting a mean sea surface and working with anomalies, however in consequence we lose any information on climatically important mean ocean currents. By measuring gravity directly, GOCE will produce a new geoid at smaller scales than ever before. Combining this independent estimate of the geoid with altimeter data will produce the full ocean dynamic topography. These calculations are not easy and require new techniques for combining the GOCE geoid with an altimetric mean sea surface, focusing on careful treatment of omission and commission errors because the dynamic topography is a small residual. The UK has contributed strongly (eg. Bingham et al. 2007) to the EU (GOCINA) and ESA (GOCE User Toolbox) programmes tackling these issues using data from the US/German satellite GRACE. We will also develop new algorithms to assimilate the resulting dynamic topography from GOCE into models in order to better determine mean ocean currents and transports, by, for example, treating GOCE errors as contributing observational bias, (Drecourt et al. 2006). An NCEO KT science post seconded to the Met Office and the NCOF, will support this work reflecting the strong interest and impact on operational oceanography and seasonal forecasting. Complementary work is supported in task 3.2.3a where altimetry and GOCE will be used with models to improve quantification and fingerprinting the patterns of sea level change.

Some SMOS comparisons come under 3.2.1b but resources for properly exploiting SMOS are being sought through proposals in preparation at NOCS. NCEO will monitor further exploitation opportunities.

3.2.3 Confronting climate models with EO data:

The UK has a world-leading climate modelling program through the work of both the Hadley Centre and the closely coordinated research in NCAS. However, such coupled earth system climate models still contain many uncertainties. The NCEO can make unique contributions to this program by providing the data to (i) constrain and improve model processes, (ii) develop model-EO synthesised/reanalysed data sets, and (iii) provide initialised data sets for climate model predictions. Conversely climate models can provide new methods for analysing EO data sets using “regional fingerprinting” studies based on the magnitude of spatial-temporal patterns reproduced in climate change models.

Task 3.2.3a Fingerprinting the spatial distribution of sea level change from EO data against mass source scenarios using modelling (POL, Reading, ECMWF).

There is still great uncertainty about the rate of sea-level change, and the likely future rate, due to uncertainty in ocean thermal expansion, the amount of mass being added to the ocean from glaciers and icecaps and changes in water storage on land, both natural and anthropogenic. Impacts on sea-level are not expected to be spatially-uniform, eg. melting of the Greenland icecap should actually result in a reduction of sea-level within about 20° of Greenland, due to reduced gravitational attraction towards the icecap. This, in principle, makes it possible to use the regional pattern of sea-level change measured by satellite altimetry and tide gauges, to “fingerprint” the mass sources contributing to present-day sea-level change. At the same time GRACE data are now making it possible to measure directly the mass redistribution around the earth, placing strong constraints on the current rates of change.

We will use altimetry, tide gauges and GRACE (and GOCE) data, paying particular attention to the error sources, and correlate or fingerprint sea-level distributions against ocean and earth-climate model estimates of sea-level change, based on variously controlled scenarios of mass sources. Collaboration with Task 3.2.3c on ocean reanalyses and implied sea-level change estimates due to steric effects will be developed. This will make it possible to quantify the various sources of ocean mass change, together with error bounds. Quantification will, for the first time, take account of both sea level change fingerprints

resulting from gravitational changes, and those resulting from ocean dynamics, together with their correlations. The work will be a present-day EO complement to sea level fingerprint research on longer timescales using tide-gauges, archaeological and geological records.

Task 3.2.3b Assimilation of ocean colour data to constrain Hadley Centre physics-biology models, and quantification of the impact on primary production and carbon cycling (NOC, MetO).

Observations from satellite ocean colour sensors have the potential to improve the representation of biogeochemical processes in climate models. This requires the enhancement of a new sequential assimilation system for EO derived chlorophyll, which has been developed within CASIX by NOCS and Met Office, and its incorporation into NEMO-based models to be used at Met Office in the new UM (Hemmings et al; 2007). While benefiting from the ecosystem model parameter estimation work in the Carbon theme 3.8 the emphasis here is to improve the capacity of short-term climate models to represent the biogeochemical response of the ocean, in order to study the impacts on the global distribution of biomass and primary production. The nitrogen balancing scheme will be improved to distribute nitrogen optimally between different plankton functional types present in an extended version of the HadOCC model, with attention to conserving budgets over interannual time scales. Using hindcasts of the last decade (linked to 3.2.3c) we will evaluate how satellite ocean colour data constrain the model behaviour. These results will inform the interpretation of short and mid-term climate forecasts of biogeochemical components. We will also determine the accuracy and sampling capacity required by ocean colour sensors for detecting the ocean response to global warming.

Task 3.2.3c Reanalysis of EO and in situ data with climate models to produce climate quality data sets, with a special focus for the IPY (Reading, MetO, UCL).

An ocean reanalysis effort is currently supported by the Rapid programme, with a focus on in situ data exploitation through an extended period (1950-present) using pioneering isopycnal and isothermal analysis of water properties, Haines et al. 2006. This includes a generalised observation operator developed in collaboration with ECMWF to represent model-data differences in new ways. This will provide flexibility for handling near surface data and high latitude data, to be analysed for the IPY in projects EU-DAMOCLES and NERC-ASBO. Results will be used to infer changes in ocean circulation, including the thermohaline circulation, transports and budgets of heat and freshwater and water mass volumes and properties.

NCEO will take this work further, extending the scope to include altimeter and GOCE assimilation algorithms from 3.2.2, and better constrained air-sea fluxes from 3.2.1b, producing a combined EO and in situ reanalysis within the satellite era (1990-present). Global and regional signals and metrics of climate variability and change will be sought within these reanalyses. Collaborative work with NCEO Cryosphere (NERC-ASBO) will study high latitude EO data and reanalyses and infer the impact of changing Arctic ocean heat transports on sea ice. The KT science post at the Met Office will work on combined EO and in situ assimilation in the NEMO model framework developing satellite era reanalyses.

Task 3.2.3d Use of EO for initialising climate model predictions on seasonal to decadal timescales (Reading, ECMWF, MetO).

We will investigate the use of ocean reanalyses based on EO, Task 3.2.3c, for initialising seasonal to interannual climate predictions, through collaboration with ECMWF and the Hadley Centre. We will test whether the global coverage of EO, combined with the very recent increase in situ data coverage from Argo, will allow for improved coupled model predictions of regional climate. This will be pursued through a KT NCEO fellow seconded to ECMWF within the seasonal forecasting team. S/he will also provide an NCEO link to examine the potential impact of EO over land and ice on coupled predictions, (and fundamentals of initialising coupled systems in the Data Assimilation theme 7). ECMWF, the Hadley centre and Reading have collaborated for many years on seasonal forecasting, supported by EU projects (eg. for advancing ocean assimilation and multi-model forecasting). All work will use the NEMO model and assimilation algorithms (Task 3.2.3c) which are already fully shared developments, with current special project status at ECMWF. The new NCEO fellow will have access to ECMWF computing as part of the seasonal forecasting groups resources. NCEO research will here reap the benefits of a joint development strategy, performing EO research directly within the operational framework, to deliver an impact of EO on seasonal to interannual predictions of great benefit to government and policy makers.

Deliverables:

1. Climate-quality SST consistent with (A)ATSR sensors through to Sentinel3.
2. Reduced uncertainty estimates for EO fluxes, and in heat and freshwater budgets.
3. Intercomparison of model, EO and in situ fluxes as contribution to WCRP SURFA.
4. New algorithms and assimilation methods for altimeter and space gravity (GOCE, GRACE) data, and subsequent quantification of mean ocean currents and transports
5. Improved estimates of sea-level change and identification of mass sources by spatial fingerprinting.
6. Improved assimilation methods for estimating bio-geochemical parameters using ocean colour and a coupled ocean/ecological model
7. Quality controlled ocean reanalysis data sets suitable for assessing climate variability and change

Collaborations:

- Oceans2025 work at NOC, Met O, ECMWF and Reading in developing the NEMO ocean model as the strategic ocean modelling tool for UK science; at NOC on establishing in situ flux dataset; and at POL on sea and land level changes based on tide gauge, altimeter and geological information
- NCOF consortium work on NEMO and assimilation methods for operational oceanography
- ECMWF work of seasonal forecasting group on NEMO and assimilation algorithms for NEMO
- Development of GOCE applications is linked with ESA GUTS project and EU GOCINO Network
- Reanalysis links to NERC Rapid project
- Work focussed on the IPY related to EU DAMOCLES and NERC ASBO
- QUEST work on ocean biogeochemical modelling and assimilation
- NERC e-Science program for making ocean reanalysis data sets readily available and easily explored by the wider community. Follow up in NCEO Informatics

3.3 CRYOSPHERE (Leader: Laxon UCL)

Summary: The Cryosphere has a separate NCEO theme and thus the purpose of this sub-theme is to integrate cryosphere processes into the wider climate program of the NCEO, and to facilitate direct Knowledge Exchange to climate modelling and, specifically the Hadley Centre models (e.g. HADGEM, FAMOUS). This will involve the transfer of advances in model physics developed under the Cryosphere and Polar Oceans theme, followed by rigorous testing using calibrated EO data, sourced both from the NCEO and from external parties. The NCEO will generate model physics and climate system metrics specifically designed to interface directly to the requirements of climate modelers, based on a full understanding of the limitations and uncertainties in EO retrievals. These uncertainties are critical in distinguishing model deficiencies from observational errors. The work will involve the provision of new data and models in support of climate research and the wider community.

Work description and methodology:

3.3.1 Global EO datasets and errors:

Task 3.3.1 Specify and facilitate the generation of long-term climate metrics related to the evolution of the cryosphere from EO data (UCL, Bristol).

The NCEO cryosphere theme will as part of its activities generate time-series of EO derived climate metrics, primarily related to the evolution of the cryosphere. These metrics will be employed within the NCEO climate theme to rigorously test the UM estimates of the same metrics over the periods for which reliable and validated data exists. Examples of metrics which may be included are the arctic sea ice mass balance, fresh-water fluxes through primary gateways, the mass balances of the Greenland and Antarctic ice sheets and of small ice caps and the fresh-water input from ice caps.

A potential new application to be explored under this heading is the combination of EO data with model estimates to identify changes and long-term trends which are directly attributable to different A1 forcing scenarios (in collaboration). This will become possible for the first time under the NCEO period due to the length of time-series (~2 decades) now derivable, in particular from high latitude satellite altimetry.

3.3.2 Exploiting new sensors and modelling:

Task 3.3.2 Snow depth and lead fraction over sea ice from passive microwaves, and relation to sea ice deformation from SAR will be assessed. Over land, regional mass balance of small glaciers using gravity and new data from CryoSat will be investigated (UCL, Bristol, MetO).

The primary role of the Climate theme under this heading will be to facilitate knowledge exchange between the Hadley Centre and the NCEO Climate theme with regard to the exploitation of new sensors

and development of new metrics and constraints on UM model validation. Over sea ice two good examples of this are snow depth and lead fraction. Estimates of these parameters are currently available from passive microwave data but their accuracy is limited and not well determined. More precise estimates of such parameters and their errors could be determined using sea ice deformation estimates (from SAR) and laser/radar estimates of sea ice elevation. The regional mass balance of small glaciers can be derived using gravity and new data from CryoSat. Investigation of algorithms to extract relevant parameters will take place through the NCEO *Climate* theme (including PhD studentships) and will rely heavily on in-situ studies for validation.

3.3.3 Confronting climate models with EO data:

Task 3.3.3 Hadley model validation against EO data for sea-ice extent, concentration and motion, and glacial ice-stream flows from altimetry and lidar, and the importance of small scale processes for ice sheet mass balance (UCL, Bristol, MetO).

This component will focus on the implementation and validation of new model components developed under the NCEO *Cryosphere* theme. At a general level this work will involve implementing the coupled components, in particular the CICE-NEMO coupled ocean-ice model and the GLIMMER land ice model. A preliminary list of new model physics which will be implemented and tested includes the representation of melt ponds on sea ice, new sea ice rheology schemes, controls on ice flow at grounding lines and mechanisms of grounding line retreat.

Following the implementation of this new model physics a key part of the UM model testing is the use of errors in the state of each metric. For the cryosphere the determination of these errors is a central component of the NCEO *Cryosphere* theme. Here they will be employed to determine whether model-EO differences are significant in terms of the errors in those elements. In this way the metrics which are most poorly reproduced will indicate the processes within the UM which require attention and which should be subject to further scrutiny using the specialist regional models developed within the *Cryosphere* theme. UCL requires two Xserve processors, and a RAID system for storage of model output, to support the development and integration of model components into the Hadley climate model.

Deliverables:

1. Long-term time-series of calibrated and validated cryospheric metrics
2. Improved predictions of Arctic sea ice evolution during the 21st Century
3. A assessment of Antarctic and Greenland ice sheet evolution over the next millennium
4. Estimate of the contribution of ice caps to sea-level change over the next millennium.

Collaborations:

- Key dependency on input from the NCEO *Cryosphere* theme
- Support for Cryosat 2 and Sentinel-3 calibration and validation activities
- Support for climate model evolution with in the Hadley centre

3.4 LAND SURFACE (Leader: Cox, Exeter)

Summary: Interactions between the land and the atmosphere (through water, energy and carbon fluxes) represent a key uncertainty in climate predictions. This sub-theme will utilise EO data to monitor the changing state of the land-surface, and to validate and improve JULES – the land-surface component of the HadGEM/HiGEM generation of climate models.. The central effort will be devoted to the development of a “Land Data Assimilation System (LDAS)” which will provide best estimates of land-atmosphere fluxes of energy, water and carbon from 1979 onwards. The LDAS will apply observation operators (developed in collaboration with the NCEO carbon cycle and Weather/Flooding themes) to relate JULES state variables and parameters to EO observations. This will allow validation of JULES through confrontation with EO data on land-atmosphere coupling strength, the diurnal cycle of land-surface variables and atmospheric convection, and snow-climate interactions. This sub-theme therefore bridges these gaps between EO-constraints on land hydrological and carbon cycles, and between monitoring and predicting the changing state of the land-surface. The pull-through to weather forecasting and climate modelling is assured through the active involvement of the Met Office and the focus on JULES, which provides a strong link to modelling activities in NCAS and QUEST.

Work description and methodology:

3.4.1 Global EO datasets and errors:

As a first stage, before LDAS becomes fully operational, the theme will build on existing work to develop important long-term datasets of key land-surface properties and state variables, specifically:

Task 3.4.1a Surface reflectance and aerosol optical depth from ATSR series instruments (Swansea).

The ATSR instrument series provides multi-angular observations of the land surface enabling quantitative separation of the surface reflectance and the aerosol optical depth (Grey et al. 2006). This allows for a greater accuracy of surface reflectance measurements, as well as a quantification of the aerosol load in the atmosphere. New satellite instrumentation, e.g. the A-TRAIN constellation, will provide further constraints on aerosol distributions through estimates of vertical profiles and of aerosol chemistry. This activity will link closely to the NCEO Atmospheric Composition theme. This task links in with, and is in part supported by, the ESA-GPOD activity.

Task 3.4.1b Land surface temperatures combining AATSR and SEVIRI to attain regional and diurnal accuracy, and dependency on surface vegetation (Leicester).

Land-surface temperature algorithms will be developed and applied to both AATSR and SEVIRI. This will allow us to take advantage of the radiometric sensitivity, calibration and global coverage of AATSR combined with the regional and diurnal coverage of SEVIRI. In particular, the retrieval work would build dynamic emissivity maps (based on fractional vegetation, geological and soil maps, and potentially soil moisture) to improve satellite LST estimates. The work would also seek to understand the problem of angular effects on effective emissivity (small) and temperature (large). Use of geometric projection models (e.g. Pineheiro et al. 2006) and synergistic studies of surface albedo will allow the latter to be studied and furthermore will provide a quantifiable link between kinetic (true) and satellite-observed LSTs. The potential for the combined data sets is high since we have already shown that AATSR and SEVIRI retrievals typically agree to within 1-2 K, which is small compared to the potential diurnal and seasonal range of temperatures. This work will link to work on the radiative nature of surfaces and aerosols in Task 3.4.1a/NCAS-atmosphere and also to the work on water vapour in Task 3.2.1.

3.4.2 Exploiting new sensors and modelling:

Task 3.4.2a Developing a Multi-Spectral Simulator for JULES (SSJ) to allow simultaneous exploitation of new surface information from different parts of the electromagnetic spectrum (Swansea, CEH).

This task will utilise observation operators (developed in collaboration with the NCEO Carbon Cycle and Weather/Flooding themes) to model the response of the land surface in different parts of the electromagnetic spectrum (reflected radiation in the visible and near-infrared wavelengths, emitted radiation in thermal infrared and microwave). The spectral simulations will be linked to relevant modules of JULES; in particular the reflectance in visible and near infrared simulations will be linked to vegetation phenology, soil background reflectance and albedo changes in response to soil wetness; the thermal simulations will be linked to the calculations of canopy temperature and land surface temperature; and the microwave simulations to the amount of water in and on the vegetation canopy and the upper parts of the soil. This task will require significant developments to the JULES land-surface model to make efficient use of satellite measurements, involving issues of spatial scaling from the satellite pixel to the GCM gridbox. However, it builds on good progress in these areas within the existing EO Centres (Barton and North 2001), and promises a major payoff in terms of the use of satellite data to constrain predictions of land-climate feedbacks on seasonal-to-century timescales.

Task 3.4.2b Development of a Land Data Assimilation System for JULES, using the SSJ for direct confrontation of JULES simulations with EO data (Exeter, Reading, MetO).

This task involves development of an LDAS to enable simultaneous use of EO data on the land hydrological and carbon cycles, which are closely connected through the behaviour of plants, and therefore provide invaluable constraints on one another (Gedney et al. 2006). The LDAS will also provide EO-constrained estimates of JULES land-surface parameters for use in climate simulations. International LDAS efforts are typically focused on either the land hydrological cycle (Pan and Wood 2006) or the land carbon cycle (Rayner et al. 2005), but not both; and tend to be concerned with diagnosing the changed state of the land-surface rather than improving climate predictions.

As a first stage, the JULES model will be implemented with an existing land data assimilation system ("CCDAS", Rayner et al. 2005), as part of an independently-funded Great Western Research fellowship. The JULES-CCDAS will assimilate EO-derived vegetation greenness in the form of FAPAR, as well as

flask measurements of CO₂ (Fig. 1, left). Incorporating the SSJ will allow a much broader range of satellite data to be assimilated, along with estimates of column integral CO₂ and biomass burning from the NCEO Carbon Cycle theme (Fig. 1, right).

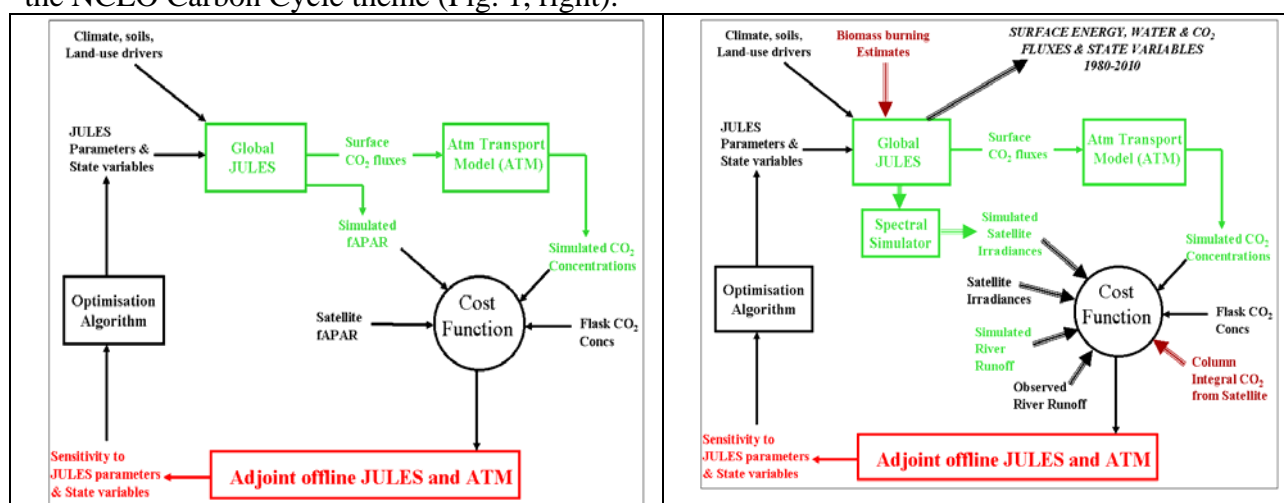


Figure 1: Schematic representations of the Land Data Assimilation System (LDAS). *Left Panel* – prototype based on JULES and the Carbon Cycle Data Assimilation System of Rayner et al. (2005). *Right Panel* – proposed NCEO LDAS using a much broader range of satellite irradiance data, as well as inputs from other NCEO themes (column integral CO₂ retrievals from satellite, and EO-derived biomass burning estimates; both in brown). Double thickness arrows denote new inputs and outputs and LDAS modules that the NCEO will focus on.

There is also a close link here to the Weather/Flooding NCEO theme, where work using JULES will be undertaken to improve estimation of the land surface hydrological cycle by careful comparisons with SMOS for estimating near-surface soil moisture, and with SSM/I and AMSR for estimating snow mass. Both snow and soil moisture are extremely poorly estimated in weather and climate models at present compared with observations, yet both are critical for climate prediction. The results of the work on snow and soil moisture will improve the representation of both in JULES, and so improve climate projections.

Validation will involve using data assimilation ideas which are well-established in Numerical Weather Prediction. We will study Observation minus Analyses (OmA) and Observation minus Forecast (OmF) differences, and their evolution in space and time. To assess biases in the model and assimilated observations, the observations in the OmA and OmF differences will be independent, i.e., not assimilated, and will generally consist in well-characterized in situ data. Finally, the analyses will be used as a “transfer standard” to evaluate biases in the assimilated observations by comparison against independent data. The LDAS will also produce significant benefits by improving existing EO products (e.g., by filling gaps in EO data in an objective way and by providing better estimates of uncertainty), and by improving the consistency of similar products derived from different sensors. This work will link closely to Met Office activities in land-data assimilation in the EU-GEMS and CarboEurope projects.

3.4.3 Confronting climate models with EO data:

This activity will use EO-derived data (particularly from 3.4.1 and 3.4.2) to validate and improve the representation of land surface processes in the Unified Model/JULES. Model-data comparison will be undertaken for: the diurnal cycle at flux sites, and globally / regionally (continental scale) for the seasonal cycle and for selected climate extremes, e.g., dry and wet years, and El Nino / La Nina years. Specific attention will be paid to two of the major uncertainties in the modelling of land-atmosphere coupling:

Task 3.4.3a Quantification of feedbacks between the land surface and precipitation in climate models using EO temperature and hydrological data from SMOS (CEH, Met O).

Realistic simulations of the hydrological cycle require an accurate description of the coupling between the land-surface state and precipitation (Koster et al., 2004). A critical issue is the effect that soil moisture has on the partition of surface fluxes between sensible and latent heat. This affects the development of convection on diurnal time scales (Taylor and Ellis 2006), and at seasonal scales can introduce significant regional variations in climate and climate change predictions (Seneviratne et al., 2006). The simulation of soil water control on evaporation within global models is not well constrained by earth observation data. The models are typically developed and calibrated at the point scale against local flux data, and then applied globally using off-the-shelf maps for parameters such as root depth and soil texture. The focus in this task will be the application of EO datasets of land surface temperature, soil water (from SMOS via

the Weather/Flooding theme) and spectral albedo, to better constrain parameters in the soil water component of JULES (tasks 3.4.1 and 3.4.2) and quantify the impact of soil moisture on precipitation using global simulations of the Met Office model. The work will be carried-out in close collaboration with the Met Office through the “Joint Centre for Hydrometeorological Research” in Wallingford.

Task 3.4.3b Quantification of snow feedbacks in climate models, using visible, IR and microwave data on snow. Coupling mechanisms will be tested in the Hadley Centre GCM (Durham, Met O).

Simulation of snow and frozen soil processes in JULES has been identified at the Met Office as an area of weakness. EO data from the visible, thermal and microwave bands, as well as from active radar instruments, will be used to obtain high latitude topography and a range of snow and frozen ground quantities. The former will be used in the development of the sub-grid tiling scheme of JULES, whereas the latter will be assimilated into the LDAS to improve model initial conditions and parameter estimates. Ground-truth validation will utilise landscapes for which excellent field data already exist (e.g. from the STEPPS project and the ongoing ABACUS project).

Deliverables:

1. EO-constrained estimates of the changing state of the land-surface, including: global datasets of land-surface temperature (1997 onwards); land-surface albedo (1997 onwards); and land-surface energy, water and carbon fluxes and stores (1979 onwards).
2. An interface between the JULES land-surface model and EO data, including: a multi-spectral simulator, allowing direct confrontation of JULES with observations; and a land-surface data assimilation system (LDAS) developed around JULES.
3. EO-constrained probability density functions of internal land-surface parameters, for use in probabilistic climate-carbon cycle projections
4. Improved predictive capability of the JULES model to inform policy makers of impacts of global change for the next 30 years
5. Estimates of the coupling strength between land surface, soil moisture, snow cover and vegetation

Collaborations:

- UK Met Office / Hadley Centre; close collaboration on JULES development, and use of EO derived products in numerical weather prediction
- UK Met Office, Reading on data assimilation, development of the land surface model, improve representation of C assimilation
- Free University implementation of microwave model in JULES; use of global soil moisture fields.

4.OBSERVATIONAL REQUIREMENTS FOR THE CLIMATE THEME

Satellite Data Requirements: The broad range of the climate theme means that a very wide range of EO instruments will be used. For Atmospheric radiation, *GERB*, *SEVIRI*, *CERES*, *ISCCP*, *SMMR*, *SSM/I*, *HIRS*, *IASI*, *AIRS*, *TES*, *CloudSat*, *Calipso* are all used. For SST and air-sea fluxes, and Land surface properties, *IASI*, *AVHRR*, *(A)ATSR*, *Sentinel3* are used. For ocean sea level and circulation Altimeter data from *TOPEX/P*, *ENVISAT*, *ERS1/2*, *JASON1/2*, *Cryosat2*, *Sentinel3*, and *GRACE* and *GOCE* gravity data are used. For marine biology and land vegetation *SeaWifs*, *MODIS*, *MISR*, *MERIS*, *ISLSCP*, *SPOT*, *GLAS*, (and *VIIRS*) are used. Other data will be used indirectly via the Cryosphere theme.

Auxiliary Data Requirements: Surface radiation and other data from ARM program and ETHZ archives; ECMWF and NCEP atmospheric reanalyses and ECMWF operational data sets; historical ocean in situ and current Argo floats and new program-specific IPY data; Global river runoff data.

5.KNOWLEDGE TRANSFER

The climate theme will promote strong knowledge transfer to the operational centres for weather and climate modelling at the Met Office and ECMWF, across all subthemes. Climate quality data sets are used in the Hadley Centre for climate change assessments and model testing and improvement. Algorithms for assimilating new EO data sets find immediate use in operational programs, where they are known to improve prediction performance and provide the tools to develop climate system reanalyses. NCEO personnel will be seconded to these operational centres to increase the use and value of EO data to operational programs. The global high quality data sets generated within the climate theme will be made widely accessible both within and outside the program, via NCEO’s Informatics theme, and there will be a major outreach effort to ensure that these data are visible and useable by policy makers.

6.RISK ASSESSMENT

- There is a risk of failure of Cloudsat and Calipso (although these have already delivered almost a year of data). Several years of GERB and other satellite data are available. IASI is an operational instrument, with a well-developed backup plan. Delays to the launch of EarthCARE in 2013 would not impact the programme, as only preparatory work is planned during the current 5-year period.

- Failure of GOCE is a medium risk given the technical challenges of the accuracy requirements. Mitigation will involve use of GRACE data for improved geoids (these data are still improving with a recent new release). The great improvements from airborne gravimetry will also provide useful regional geoid data for oceanography eg. in the Arctic.

- Failure of Cryosat2 mission. This is a low risk given the lessons learned after Cryostat 1 and the mostly standard altimetric technology.

- Reduced Met Office provision of model and computing resources for work with EO data due to budget shortfalls. This is a low risk given the considerable benefit gained by the Met Office and the large number of ongoing collaborative projects, eg through NCOF

7.THEME MANAGEMENT

Climate is a major new theme in the UK's EO program and it will be managed so as to integrate the diverse EO expertise in order achieve a more strategic program. This theme is complex and involves interactions between a large number of partners. The 4 Earth system subthemes will be headed by acknowledged leaders in the respected fields, Slingo (Atmosphere), Haines (Ocean), Laxon (Cryosphere) and Cox (Land). As joint PIs, Haines and Slingo are co-located in Reading and will devote a significant amount of time to top-level coordination and interaction with the other themes across the NCEO, to ensure that strategic objectives are met, in addition to their roles as leaders of subthemes. The four sub-theme CoIs will work closely together to ensure coordination within the climate program, and they, along with the EO Director and 2 external experts (selected from the NCEO Advisory committee) will meet initially, and regularly thereafter, to review strategic research and identify further funding opportunities. An annual all-hands Climate theme meeting will be held, starting at the beginning of the program, part of which will be a wider research forum as outlined in the coordinating NCEO proposal. Meetings will be held jointly with other themes wherever appropriate, for efficiency, and to help integrate NCEO work. We will use Wiki technology to encourage exchanges and discussion of latest results. We will use internet and video conferencing technology to encourage joint working across the 12 institutes in the theme, taking advantage of expertise in the Reading e-science Centre to solve technical issues. We will require support from the EO Informatics theme to establish 2 collaboration-building programs for: (1) integrated display of EO and model climate results in Geobrowsers, eg for reanalyses, providing visual stimulation for new ideas, and (2) the use of shared computer resources for climate data synthesis and reanalysis. The theme will be a major conduit for outreach within the NCEO and CoIs and Research fellows will fully support other activities outlined in the coordination NCEO proposal.

8.RESOURCE JUSTIFICATION

Coordinating PIs Haines and Slingo are both at Reading, which is the pre-eminent NERC location for climate simulation within the UK. With majority funding from the NCEO program they will build this theme, bring substantial co-funding from other programs, and provide core expertise to the NCEO director. With the other subtheme CoI's, Cox (Land) and Laxon (Cryosphere), they will initiate new collaborations to fully exploit and cross-validate EO products in areas such as global heat budgets and freshwater exchanges between atmosphere, land, ocean and ice.

The Atmospheric subtheme will support 4.2 FTEs between Reading, Imperial College and Edinburgh, focussed on radiation and hydrological cycle budgets. The Ocean subtheme will support 4.4 FTEs between Reading, NOC, POL and Edinburgh, focussed on ocean circulation and sea level studies, SST and surface fluxes, ocean colour, and reanalysis and climate prediction research. The Cryosphere subtheme will support 1 FTE between UCL and Bristol (2 joint posts with the main NCEO Cryosphere program) aimed at EO constraints on land and sea ice components of Hadley climate models, and two Xserve processors and a RAID system are needed to support the large model outputs. The Land subtheme will support 4.6 FTEs between Exeter, Swansea, CEH, Leicester and Durham, focused on use of EO to

improve land surface models and land-atmosphere coupling, and quantifying the hydrological and carbon cycles. (1 FTE = 1 Researcher for 5 years)

Several institutes have named PDRAs employed at a higher salary level including Reading, UCL, Bristol, Edinburgh, Swansea and NOC, reflecting experienced researchers already involved in the EO program who are part of the UK's National Capability and whose skills are needed to drive the theme.

The theme will need large data and computational resources with its focus on global and reanalysis data, and climate modelling, including high resolution modelling. The theme will heavily utilise data-focussed storage and computational resources requested for Reading and the NEDC within the EO Informatics theme for the preparation and dissemination of global data sets, and thus Reading has not requested these in the climate budget. It will require modelling resources on HECToR for the high resolution simulations with the Hadley Centre climate model, which will be closely coordinated with NCAS. The theme will use Met Office and ECMWF computational resources for the staff seconded within the operational centres.

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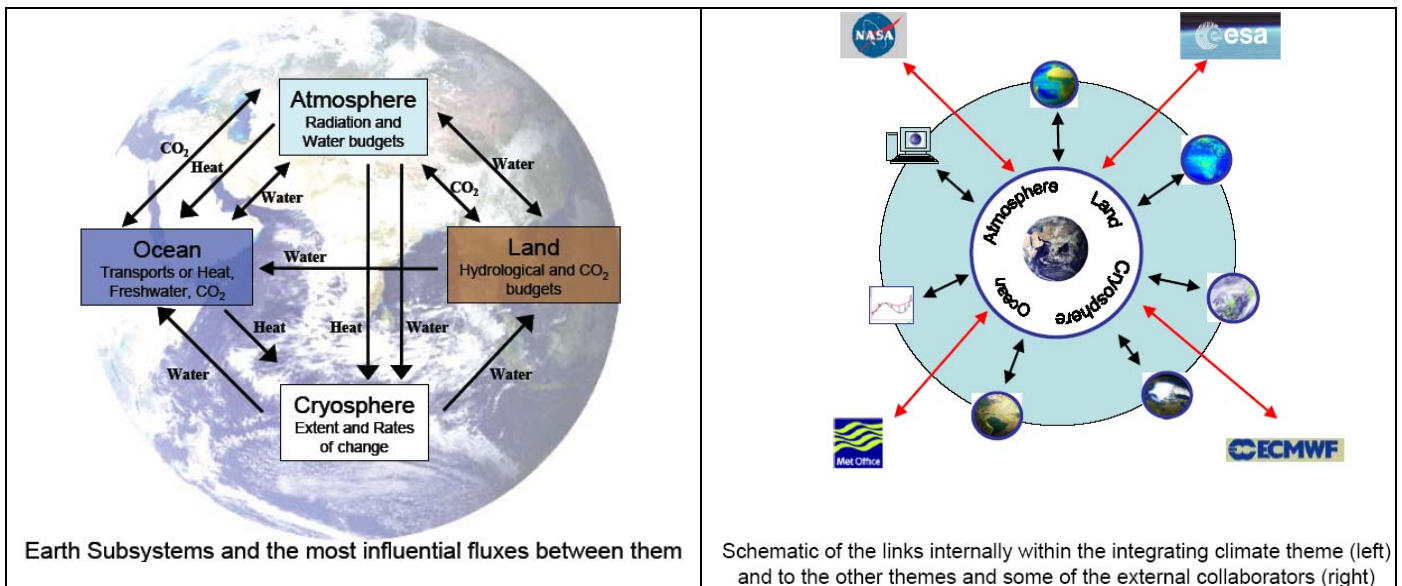
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Annexes

1. CONNECTIONS



Earth Subsystems and the most influential fluxes between them

Schematic of the links internally within the integrating climate theme (left) and to the other themes and some of the external collaborators (right)

This Integrating theme will work closely with all of the other themes within NCEO. In most cases the links will be extremely strong, bringing in data that have been produced by the other themes and combining them with the work carried out in the climate theme itself to provide an integrated picture of the Earth system. In the case of Theme 6 (Dynamic Earth), such direct links will probably not take place, but even here there is expected to be significant cross-fertilisation of ideas because of the synergy between observational platforms, for example on the use of gravity data from GOCE which will be used within Dynamic Earth provided the resolution and accuracy are sufficient.

The work in this theme on the assimilation of ocean colour data to constrain the physics-biology components of the Hadley Centre models builds directly on work in Theme 2 (Global Carbon cycle). We will also import estimates from Theme 2 of column integral CO₂ and biomass burning into the carbon cycle data assimilation System (CCDAS).

From Theme 3 (Atmospheric composition), retrievals of the new aerosol and cloud products from (A)ATSR will be added to the datasets used in our Atmospheric sub-theme to monitor the natural variability and trends in the energy budget and hydrological cycles, as well as to evaluate the high resolution simulations of the Unified Model.

Theme 4 (Weather/Flooding) will provide the feature tracking software that will be used to evaluate the simulation of storms in the model integrations. The potential of the SMOS satellite to monitor soil moisture will be evaluated in that theme and retrievals will be incorporated into our analysis when they have reached sufficient maturity.

The cryosphere sub-theme is specifically designed to provide a direct link from the process work carried out in Theme 5 (Cryosphere) to the wider climate programme and to integrate the results into a complete description of the climate system produced here. This is consistent with the role of the climate theme as providing a natural point of contact with the Hadley Centre global modelling, integrating work in all four components (atmosphere, oceans, cryosphere and land surface) and facilitating Knowledge Exchange to this major partner.

Data assimilation techniques underpin much of the analysis of EO data to be carried out in this theme, so Theme 7 (Data assimilation) will provide an important source of reference and of new ideas for improving the utilisation of the EO data, in areas such as the initialization of coupled climate systems.

Finally, this theme will analyse and produce very large quantities of EO data and model output, the processing, manipulation and storage of which will be undertaken in close collaboration with the underpinning EO Informatics theme and the globally synthesized products will be available to all other themes for further analysis of global scale processes and budgets.

2. RESOURCE TABLE FOR THE CLIMATE THEME

Sub-Themes	Atmospheric	Marine	Cryosphere	Land Surface
Reading	CoI + 2.6 FTE	CoI + 1.6 FTE		
UCL			CoI + 0.5 FTE	
Bristol			0.5 FTE	
IC	1.0 FTE			
Exeter				CoI + 1FTE
NOC		1.6 FTE		
POL		0.6 FTE		
Edinburgh	0.6 FTE	0.6 FTE		
Swansea				1.5 FTE
Leicester				0.6 FTE
CEH				1 FTE
Durham				0.5 FTE

Above FTE division is presently based on a standard costs assumption across Institutes
 Total Theme budget = 6.9m over 5 years.