B 1.3.2 Timing of work packages and their components:

Year	**YEAR 1**				**YEAR 2**				**YEAR 3**				**YEAR 4**
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1
WP1 Changes in terrestrial carbon and water fluxes													
WP 1.1													
WP 1.2													
WP 1.3													
WP 1.4													
WP 1.5													
WP2 Changes in sea level and ocean circulation													
WP 2.1													
WP 2.2													
WP 2.3													
WP 2.4													
WP 2.5													
WP 2.6													
WP3 Changes in marine carbon cycle													
WP 3.1													
WP 3.2													
WP 3.3													
WP4 Synthesis and Interaction with the Scientific Community													
WP 4.1:													
WP 4.2:													
WP 4.3:													
WP 4.4:													
WP5 Management													
WP 5.1-WP 5.4													

B 1.3.3 Work package list / overview:

Work package list

Work Package Number	Work Package Title	Type of activity	Lead beneficiary number	Person months	Start months	End months
1	Changes in terrestrial carbon and water fluxes	RTD	2	**132**	1	39
1.1	Decadal snow dynamics and their consequences for GHGs and climate	RTD	4	21	1	30
1.2	The decadal dynamics of high latitude lakes and their consequences for GHGs and climate	RTD	4	18	1	30
1.3	Long-term and Decadal Changes in Permafrost	RTD	5	55	1	30
1.4	Land cover and fire and their representation in models.	RTD	2	20	1	30
1.5	Reanalysis of the water and carbon balances of the major high-latitude catchments and their link to climate	RTD	2	18	24	39
2	Changes in sea level and ocean circulation	RTD	3	**139**	1	39
2.1	Improved use of historical data bases	RTD	4	29	1	16
2.2	Improved mean sea surface and mean dynamic topography	RTD	3	14	1	16
2.3	Change in mass balance of the Greenland ice sheet and its transfer to sea level rise	RTD	4	23	1	39
2.4	Assessing uncertainty of existing reanalyses and simulations over the Arcti	RTD	3	20	1	39
2.5	Improved estimate of the sea level and the ocean circulation of the Arctic	RTD	3	38	1	39
2.6	Improved estimate sea ice fluxes and the freshwater cycle in the Arctic Ocean	RTD	3	15	1	39
3	Changes in marine carbon cycle	RTD	4	**76**	1	39
3.1	In-situ and remotely sensed observations on the inorganic carbon cycle	RTD	6	18	1	39
3.2	In-situ and remotely sensed observations on marine ecosystems	RTD	5	32	4	39
3.3	Integration of observations with biogeochemical ocean model hindcast	RTD	6	26	18	39
4	Synthesis and Interaction with the Scientific Community	RTD	1	**35**	1	39
4.1	Synthesis of the state and variability	RTD	1	23	1	39
4.2	Maintain regular interaction across the science communities	RTD	1	4	12	39

4.3	Bring the integrated science and technology achievements to the attention of relevant groups	RTD	1	4	12	39
4.4	Upload of final data products to be accessible via web-portal	RTD	1	4	12	39
5	Management	MGT	1	**7**	1	39
5.1	Implement a management that maintain and capitalize on the work plan and budget	MGT	1	4		39
5.2	Setting and organizing the public website of the Project	MGT	1	1	1	39
5.3	Create Consortium Agreement	MGT	1	0.5	1	6
5.4	Monitor and control the project scheduling	MGT	1	1.5	1	39
	TOTAL			**389**		

B 1.3.4 Deliverables list:

List of Deliverables

Del. Number	Deliverable name	WP no.	Lead beneficiary	Estimated indicative person months	Nature	Dissem. level	Delivery date
D5.1.4	Report on service level agreement with the GMES core services and ESA CCI projects	5.4	NERSC	0.2	R	PU	6
D1.1.1	Monthly and 5-day fields of snow extent	1.1	CNRS	6	O	PU	9
D1.1.3	Start and end dates of snow cover	1.1	CNRS	4	O	PU	9
D1.2.2	Water level variations over the large Arctic rivers from satellite altimeters related to input into Arctic ocean	1.2	CNRS	3	O	PU	12
D1.2.3	Water level variations over the large Arctic lakes from satellite altimeters	1.2	CNRS	3	O	PU	12
D2.4.1	Assessment of existing descriptions of the Arctic Ocean circulation and its transport properties.	2.4	UHAM	7	R	PU	12
D2.4.2	Assessment of shortcomings and needs for new improved Arctic Reanalysis	2.4	UHAM	8	R	PU	12
D3.1.1:	Consistent data bases of inorganic marine carbon cycle data.	3.1	UiB	6	O	PU	12
D1.4.1	Analysis of available land cover and fire products and recommendations for use in climate models	1.4	USFD	8	R	PU	12
D1.4.2	Land cover maps transformed into forms suitable for climate modelling	1.4	USFD	4	O	PU	15
D2.1.1	Gridded time series of sea level data since 1992 from altimetry and since 1950 from reconstructions methods over 50 years.	2.1	CNRS	18	O	PU	16
D2.1.2	Time series of sea ice data to describe changes over 50 years.	2.1	NERSC	5	O	PU	16
D2.1.3	Gridded time series of ocean mass variations from GRACE	2.1	DTU	8	O	PU	16
D2.2.1	Improved mean sea surface covering 50 years for the Arctic Ocean.	2.2	DTU	6	O	PU	16
D2.2.2	Annual-decadal modifications of the mean sea surface data time series for the satellite period (1993-2008).	2.2	DTU	4	R,O	PU	16
D2.2.3	Improved dynamic topography field for the Arctic Ocean.	2.2	NERSC	4	R,O	PU	16
D1.1.2	Monthly and 5-day fields of snow	1.1	CNRS	6	O	PU	18
D1.1.4	Snow Water Equivalent fields	1.1	CNRS	2	O	PU	18
D1.2.1	Global summer monthly fields of surface water extent from SSMI	1.2	CNRS	3	O	PU	18
D1.2.4	Timing of freeze/thaw periods over large rivers and lakes from combination of SSMI and altimeters	1.2	CNRS	3	O	PU	18
D1.3.1	Reference permafrost map from historical sources	1.3	NIERSC	10	O	PU	18

D2.1.4	Gridded time series of steric sea level from in situ hydrography and from 'altimetry minus GRACE ocean mass'	2.1	CNRS	8	R,O	PU	18
D2.3.1	Time series of height changes of the Greenland ice sheet since 1992 as grids.	2.3	DTU	5	O	PU	18
D2.3.2	Grid of ICESat height change average trend	2.3	DTU	5	O	PU	18
D2.3.3	Timeseries of GRACE-based mass change of the Greenland ice sheet since 2002 .	2.3	CNRS	6	O	PU	18
D2.4.3	Assessment of quality of existing data base.	2.4	NERSC	5	R	PU	18
D2.6.1	Time series of grids of sea ice thickness, and improved SSH measurements.	2.6	DTU	4	O,R	PU	18
D2.6.2	Ice volume flux time series across the Fram Strait and other outlets based on satellite data.	2.6	NERSC	3	O,R	PU	18
D2.6.3	Freshwater flux time series grids for the Arctic Ocean.	2.6	NERSC	4	O,R	PU	38
D3.1.2	Co-located multi tracer data sets of biogeochemical and physical variables.	3.1	UiB	4	O	PU	18
D3.2.1	Primary productivity time series as gridded data sets	3.2	NIERSC	18	O,R	PU	18
D1.2.5	Yearly flood extent variations from assimilation of satellite altimeter water levels in hydrodynamic models for large Arctic rivers	1.2	CNRS	3	O	PU	24
D3.1.3	Monthly fields of sea-surface pCO_2, pH, carbonate saturation state and air-sea CO_2 fluxes.	3.1	UiB	8	O	PU	24
D3.2.2	$CaCO_3$ production time series as gridded data sets .	3.2	NIERSC	14	O	PU	24
D3.3.1	Spin-up of coupled physical biogeochemical ocean model run.	3.3	UiB	4	O	PU	24
D1.1.5	Statistical analysis of relations between ECVs and other water and carbon variables	1.1	USFD	1	R	PU	30
D1.1.6	Definition of methods to relate snow ECVs and brightness temperatures to models	1.1	USFD	2	R	PU	30
D1.3.3	Model for energy flows in permafrost/soil/snow/atmosphere layered media interfaced to the BCM climate model	1.3	USFD	30	R	PU	30
D1.4.3	Integrated fire products for carbon and climate modelling	1.4	USFD	8	O	PU	30
D1.5.1	Software modules interfacing variables derived in WP 1.1-1.4 to models.	1.5	USFD	6	R	PU	30
D2.5.3	Assessment of using high resolution satellite based wind field observations.	2.5	IFREMER	6	R	PU	30
D3.3.2	Modelled time series of surface ocean CO_2 partial pressure, air-sea CO_2 flux, biological export production, and further biogeochemical variables	3.3	UiB	4	O	PU	37
D3.3.3	Reanalyses of oceanic anthropogenic carbon uptake, transports in the Arctic and the GIN Sea as well as the carbon export into the North Atlantic.	3.3	UiB	12	O,R	PU	37
D1.5.2	Analysis of feedback mechanisms on	1.5	USFD	6	R	PU	39

	climate and carbon from reanalysis calculations						
D2.3.4	Time series of Greenland ice sheet mass changes from 1992 (combining all remote sensing techniques) and improved “overall” freshwater input trend to the oceans surrounding Greenland	2.3	CNRS	7	O,R	PU	39
D2.5.1	Improved estimate of the ocean circulation and sea level with at least 1/6 ° spatial resolution.	2.5	UHAM	12	R	PU	39
D2.5.2	Improve ECVs over the Arctic Ocean, including sea ice cover, sea ice transports, sea level and ocean transports of heat and freshwater.	2.5	UHAM	10	R	PU	39
D2.5.4	Pilot system of fast track services with climate relevance over the Arctic.	2.5	DTU	7	R	PU	39
D2.6.4	Time series of GRACE signals of freshwater flux pulses.	2.6	DTU	4	O,R	PU	39
D4.1	Synthesis report of the state and variability of changes in high latitude and Arctic regions including dedicated feedbacks to the GMES core services	4	NERSC	14	R	PU	12, 24,39
D4.2	Interaction and feedback report from contacts with external scientific communities	4	UHAM	9	R	PU	12,24,39
D4.3	Support document to design and implementation of Arctic monitoring and decadal prediction system	4	UiB	9	R	PU	39
D4.4	Design, implement and maintain web portal.	4	NERSC	2	O,R	PU	12,24,39
D4.5	Upload and regular update of information and products to web portal	4	NERSC	1	O,R	PU	12,24,39
D5.1.1	Periodic management reporting	5.1	NERSC	1.5	R	PU	12,24,39
D5.1.2	Periodic cost reporting	5.2	NERSC	1.5	R	CO	12,24,39
D5.1.3	Periodic activity reporting	5.3	NERSC	1.3	R	PU	12,24,39
D5.1.5	Final report	5.5	NERSC	2.5	R	PU	39
TOTAL				366			

B 1.3.5 Work package descriptions:

Work package number	5	Start date or starting event:				Mo 1	Mo 39
Work package title	**Management**						
Activity Type	MGT						
Participant number	1						
Person-months per participant:	7						

Objectives

The goal of this WP is to implement appropriate management and organizational activities to monitor the short and long term development and deployment of MONARCH-A. It includes:

- day to day management of the project
- chairing the steering committee consisting of one representative per partner and/or the WP leaders.
- maintain efficient management procedures to meet milestones and reporting/deliverables deadlines.
- setting up of consortium agreement,
- follow contracts and payment procedures and rules in consistence and cooperation with the EU project financial officer.
- Establish and maintain contact with the GMES core services and the relevant ESA CCI projects.

Description of work

The management will be performed on a day-to-day basis and through regular meetings of the steering group via phone conferences and face-to-face meetings (~every 6 months) to address issues of relevance to the MONARCH-A progress. This includes:

Task 5.1 - Implement a management that maintain and capitalize on the work plan and budget in close collaboration with the partners and the project steering committee..

Task 5.2 - Create Consortium Agreement in cooperation with leaders from each project partners

Task 5.3 - Monitor and control the scheduling for deliverables, project meetings presentations, milestones etc and documents supporting dissemination activities and exploitation plan.

Task 5.4 – Service level agreements in which the user requirements from the MONARCH-A projects are mapped on to the service specification and product catalogues and or implementation of special agreements between the projects will be arranged. The goal is to have this completed and documented no later than six months after kick-off of MONARCH-A.

Deliverables

D5.1 - Periodic Management report
D5.2 - Periodic cost reporting
D5.3 – Periodic activity report
D5.4 – Report on service level agreement with the GMES core services and ESA CCI projects
D5.5 - Final Report

Work package number	1	Start date or starting event:				Mo 1	Mo 39
Work package title	**Changes in terrestrial carbon and water fluxes**						
Activity Type	RTD						
Participant number	1	2		4	5		
Person-months per beneficiary:	3	68		36	25		

Objectives

1. Analyze the decadal snow dynamics and their consequences for GHGs and climate.
2. Analyze the decadal dynamics of high latitude lakes and their consequences for GHGs and climate.
3. Analyze the long-term decadal changes in permafrost.
4. Assess the representation of land cover and fire in carbon, water and climate models.
5. Reanalysis of the water and carbon balances of the major high-latitude catchments and their link to climate

Description of work

Task 1.1 - This task will provide a long time-series of measurements of the properties of the snow-pack and investigate the most effective way to use these data to improve the performance of models.

Task 1.2 . This task will analyse and assess the consequences for the greenhouse gas budget, and for evapo-transpiration, runoff and groundwater during the summer, when snow and ice have disappeared, and the spatio-temporal variability of surface waters in rivers, lakes, wetlands and flooded regions changes rapidly.

Task 1.3 – This will analyze and assess how permafrost is a critical element of land surface processes at high latitudes, affecting land cover, hydrology and snow dynamics.

Task 1.4 - This task will assess the consistency of land cover and fire products in terms of how they will be used in models, assess their accuracy and evaluate how they may be combined to produce the best available product for carbon, water and climate modelling.

Task 1.5 - In this task, after analysing the structure of the SDGVM coupled carbon-water model and the NorESM coupled climate model, we will produce software modules to bring the variables defined in WPs 1.1-1.4 into model calculations.

Deliverables

See sub-workpackages 1.1, 1.2, 1.3, 1.4 and 1.5

Work package number	1.1	Start date or starting event:				Mo 1	Mo 30
Work package title	**Decadal snow dynamics and their consequences for GHGs and climate**						
Activity Type	RTD						
Participant number		2		4			
Person-months per beneficiary:		3		18			

Objectives
1. To analyze the spatio-temporal Arctic snow pack variability from the last 20 years of satellite measurements, including snow depth, extent and period.
2. To identify how these datasets can be use to affect calculations by carbon, water and climate models, and to carry out any necessary data transformations (e.g. conversion to Snow Water Equivalent).
3. To evaluate the merits of using the derived snow ECVs against the use of raw brightness temperature measurements to either parameterise coupled carbon, water and climate models or in a data assimilation process.

Description of work
The Arctic continental snow-pack and its variability interact with climate in a major feedback loop that affects the carbon and water cycles on a regional and global basis. This task will provide a long time-series of measurements of the properties of the snow-pack and investigate the most effective way to use these data to improve the performance of models.
Task 1.11. The existing satellite snow depth algorithm will be adapted to compute 5-day and monthly fields on a grid of snow extent and snow depth, and estimate dates for the start and end of the snow season using SSMI from 1987 to the present (CNRS). Transformations of these variables to other relevant variables (especially Snow Water Equivalent) will be developed and applied.
Task 1.1. 2. The yearly variability of the snow pack will be analyzed and related to variation in the carbon and water variables (CNRS, USFD).
Task 1.1.3. By examining the structure of the SDGVM carbon-water model and the BCM land surface model, methods to use the ECVs in model parameterisation will be derived and assessed, and compared with data assimilation methods using the ECVs or the raw brightness temperatures. (USFD).

Deliverables
D1.1.1 - 1.1.3 Over the period 1987-2009, global (north of 50°N latitude) monthly and 5-day fields of snow extent (month 9), snow depth (month 18) and dates of start and end of the snow season (month 9).
D1.1.4 - Snow Water Equivalent fields derived from Deliverable 1 (month 18).
D1.1.5 - Statistical analysis of relations between these ECVs and other water and carbon variables (month 30)
D1.1.6 - Definition of methods to relate both the ECVs and brightness temperatures to models (30).

Work package number	1.2	Start date or starting event:				Mo 1	Mo 30
Work package title	**The decadal dynamics of high latitude lakes and their consequences for GHGs and climate**						
Activity Type	RTD						
Participant number		2		4			
Person-months per beneficiary:		3		15			

Objectives

1. To produce and analyze estimates of the spatio-temporal variability of high-latitude surface water extent (permanent and seasonal lakes) over the last 20 years using satellite passive and active microwave measurements complemented by observations in the visible and infra-red range.
2. To analyze the spatio-temporal variability of lake and river water levels for the last 15 years from satellite radar altimeters.
3. To devise methods to assimilate water levels in hydrodynamic models and improve the physics of the models to estimate the variability of flooded regions.
4. Estimate freshwater input to the Arctic Ocean from major Russian and Canadian rivers.

Description of work

The Arctic continental H2O cycle is affected by climate warming. During the summer, when snow and ice have disappeared, the spatio-temporal variability of surface waters in rivers, lakes, wetlands and flooded regions changes rapidly. This has large consequences for the greenhouse gas budget, and for evapo-transpiration, runoff and groundwater.

T1.2.1 Adapt the existing satellite surface water extent algorithm to compute global monthly fields of surface water extent on a 25x25 km grid, using SSMI from 1987 to now (CNRS).

T1.2.2 Compute surface water levels variability for large rivers and lakes using available altimeter data (Topex/Poseidon, ERS, ENVISAT, Jason1/2) (CNRS).

T1.2.3 Compute the timing of freeze/thaw periods over large rivers and lakes (CNRS).

T1.2.4 Analyze the monthly and yearly variability of the surface water extent and water levels, the timing of freeze/thaw periods and the feedback mechanisms with the snow-pack and the C cycles (CNRS, USFD)

T1.2.5 Develop methods to assimilate satellite altimeter water levels and runoff data into hydrodynamic models (CNRS).

Deliverables

D1.2.1 - Global (North of 50°N latitude) summer monthly fields of surface water extent from SSMI (month 18);

D1.2.2 - Water level variations over the large Arctic rivers from satellite altimeters related to input into Arctic ocean, including use of data from GRDC (month 12);

D1.2.3 - Water level variations over the large Arctic lakes from satellite altimeters (month 12)

D1.2.4 - Timing of freeze/thaw periods over large rivers and lakes from combination of SSMI and altimeters (month 18);

D1.2.5 - Yearly flood extent variations from assimilation of satellite altimeter water levels in hydrodynamic models for large Arctic rivers (month 24)

Work package number	1.3	Start date or starting event:			Mo 1	Mo 30
Work package title	Long-term and Decadal Changes in Permafrost					
Activity Type	RTD					
Participant number		2			5		
Person-months per beneficiary:		30			25		

Objectives
1. To synthesise historical and recent permafrost measurements for the pan-Arctic regions in order to measure trends in permafrost dynamics.
2. To provide an interface between permafrost data and both land surface models and the climate models in which they embedded.

Description of work

Permafrost is a critical element of land surface processes at high latitudes, affecting land cover, hydrology and snow dynamics. Permafrost melting under climate warming will cause potentially dangerous releases of greenhouse gases, as well as changing high-latitude hydrology and affecting human activities. Current maps of permafrost and its changes are inadequate. In addition, most current models (including the SDGVM and BCM) are unable to exploit permafrost information as they have no software interfaces to these data. This will lead to serious under-exploitation of the potential of permafrost data to improve surface fluxes unless this deficiency is corrected.

Task 1.3.1: A reference permafrost map will be developed based on historical data and a map of permafrost evolution since the first observations (Russia, Yakutsk, 1828) up to the period of contemporary warming (the 1980s). A time series of permafrost parameters and an up-to-date digital multi-layer permafrost map for the period extending from the 1980s to the present will then be developed, using data from the following programmes: Circumpolar Active Layer Monitoring Network-CALM II, Global Terrestrial Network for Permafrost, Frozen Ground Data Centre, and Thermal State of Permafrost (TSP), as well as data from permanent geo-cryological and meteorological stations and new results from the IPY (the IPA-IPY TSP project). We will revisit previously measured boreholes and in some cases drill new ones. Satellite passive microwave data available continuously since 1979 will be used for permafrost dynamics analysis. Based on the established time series, major trends in permafrost location and depth will be identified (NIERSC).

Task 1.3.2: A permafrost-soil-snow-atmosphere thermal module will be developed that can be interfaced to the BCM/NorESM coupled model. It will be linked to the data to be provided in WP 1.1 and WP 1.3 Task 1 as well as climate variables provide by the BCM/NorESM (USFD).

D1.3.1 - Reference permafrost map from historical sources (18).
D1.3.2 - Up-to-date permafrost map taking into account new results from the IPY, identifying major trends in permafrost location and depth (28)
D1.3.3 - A model for energy flows in permafrost/soil/snow/atmosphere layered media interfaced to the BCM coupled climate model (30).

Work package number	1.4	Start date or starting event:			Mo 1	Mo 30
Work package title	**Land cover and fire and their representation in models.**					
Activity Type	RTD					
Participant number		2				
Person-months per beneficiary:		20				

Objectives

1. To amalgamate high latitude land cover maps derived from remote sensing, assess their consistency and uncertainty, and transform them into forms suitable for carbon, water and climate models.

2. To amalgamate the different sources of information about fire at high latitudes derived from remote sensing, assess their consistency and whether they reveal any trends, and define methods to interface these data with carbon and climate models.

Description of work

Task 1.4.1: Land cover is a critical control on the water and carbon cycles and land-atmosphere interactions. Particularly important medium resolution (around 300 m – 1 km) sources of satellite-derived land cover data include Global Land Cover 2000 (derived from SPOT-VGT), various products derived from MODIS (including the Vegetation Continuous Fraction [VCF] product), and the new ESA GLOBCOVER dataset. Different land cover products lead to very different estimates of carbon and water fluxes, and using the VCF product also has large effects compared to direct use of land cover. Uncertainties arise from differences between products and their conversion into the form typically used for modelling, i.e. proportional occupancy per grid-cell by a small number of Plant Functional Types. This task will assess the consistency of the products in terms of how they will be used in models, assess their accuracy and evaluate how they may be combined to produce the best available product for carbon, water and climate modelling.

Task 1.4.2: There have been major advances in satellite-based databases of fire activity and the associated emissions over recent years, with development of Fire Radiative Power and the new MODIS Collection-5 Burnt Area product being very recent highlights. This task will synthesise the information on active fires, burnt area and Fire Radiative Power at high latitudes, and assess the existing data record for evidence of trends. A second major element of this task will be the definition of how these data will be used by climate and carbon models. This is necessary since emissions from fire are internally generated in current models; the lack of constraints by data raises serious questions of well the models represent this important climate and carbon process.

For both tasks, USFD will carry out the data analysis, but the analysis of data interactions with a coupled climate model will be joint with NERSC.

Deliverables

D1.4.1 - Analysis of available land cover and fire products, their trends and uncertainties, preferred products, and recommendations for combining different products for best use in climate models (month 15).

D1.4.2 - Land cover maps transformed into forms suitable for carbon, water and climate modelling (month 15).

D1.4.3 - Integrated fire products for carbon and climate modelling (month 30).

Work package number	1.5	Start date or starting event:			Mo 24	Mo 39
Work package title	**Reanalysis of the water and carbon balances of the major high-latitude catchments and their link to climate**					
Activity Type	RTD					
Participant number	1	2		4			
Person-months per beneficiary:	3	12		3			

Objectives

1. To develop interfaces between the variables derived in WPs 1.1 – 1.4 and coupled carbon, water and climate models, including data assimilation methods where time-series are available.
2. Use of these variables to modify the calculations from coupled carbon, water and climate models and assessment of the consequences.

Description of work

Task 1.5.1: The ECVs defined by GCOS include both indicators of climate change and are also in several cases intended to be used to modify climate calculations. However, over the land, methods to interface many of the ECVs to the models are poorly developed, so that the power of the data to constrain the models is exploited only as a diagnostic. In this task, after analysing the structure of the SDGVM coupled carbon-water model and the NorESM coupled climate model, we will produce software modules to bring the variables defined in WPs 1.1-1.4 into model calculations. This will include data assimilation methods for those variables where long time-series are available (particularly the snow and water records). Model analysis will be a joint effort between NERSC, CNRS and USFD, but most of the software development will be carried out by CNRS and USFD.

Task 1.5.2: The methods developed in Task 1 will be used in reanalysis to assess the consequences for carbon, water and climate calculations of constraining the models with the datasets developed in WPs 1.1-1.4. Particular stress will be placed on assessing the reduction in uncertainty in model calculations by exploiting the new data in a well-founded way (USFD and NERSC).

Deliverables

D1.5.1 - Software modules interfacing variables derived in WP 1.1-1.4 to selected coupled carbon, water and climate models; these will include methods of assimilating time-series of data for those variables where long time-series are available (month 30).
D1.5.2 - Reanalysis of climate and carbon calculations exploiting these variables (month 39).

Work package number	**2**	**Start date or starting event:**					**Mo 1**	**Mo 39**
Work package title	**Changes in Sea Level and Ocean Circulation**							
Activity Type	RTD							
Participant number	1		**3**	4		6	7	8
Person-months per beneficiary:	22		41	30		6	35	5

Objectives

The objective is to compile a climate-data base of the Arctic ocean and to enhance its use in support of fast track services.

1) Improve our understanding of the role the Arctic plays in water mass formation, in influencing the global circulation and in changing sea level on regional and global scale.
2) Provide a reanalysis of the Arctic Ocean over the last 50 years, connecting especially also the IPY era to long-term Arctic variability. By doing so, WP 2 will interact intensely with other work packages.
3) Improve climate-quality data base for the Arctic Ocean
4) Estimate sea ice motion.
5) Improve ECVs for the high-latitude Atlantic and the Arctic.

Description of work

Task 2.1 Improved use of the historical marine data base (space and in situ): Compile a climate-data base of the Arctic ocean in support of the Arctic Ocean synthesis.

Task 2.2 Improved mean sea surface and mean dynamic topography: Improve the mean sea surface model for the Arctic Ocean using newly developed models combined with sea level time series data.

Task 2.3 Improve use of the available data bases describing the changes in the mass balance of the Greenland ice sheet and its transfer to sea level rise

Task 2.4 Assessing uncertainties of existing reanalyses over the Arctic: Evaluate existing ocean reanalyses and simulations, assessing their quality through an intercomparison against observations and thereby identifying the reasons for discrepancies among currently available analyses.

Task 2.5 Improved sea level and the ocean circulation of the Arctic: Produce an improved Arctic reanalysis, using dynamically consistency as a criterion for assessing the quality.

Task 2.6 Improved sea ice fluxes and the freshwater cycle in the Arctic: Assess the changes in sea ice motion and transport, especially in and out of the Arctic straits, using satellite data, together with gridded fields of ice thickness and mean sea level anomalies.

Deliverables

See sub-workpackages 2.1, 2.2, 2.3, 2.4, 2.5 and 2.6

Work package number	**2.1**	**Start date or starting event:**				**Mo 1**	**Mo 16**
Work package title	**Improved use of historical data bases**						
Activity Type	RTD						
Participant number			3	**4**			7
Person-months per beneficiary:			3	18			8

Objectives

The objective is to compile a climate-data base of the Arctic ocean in support of the Arctic Ocean synthesis. This includes the improvement of the use of

1. Sea level and ocean circulation data to describe changes over 50 years based on compilation of historical in situ and satellite data, including MyOcean, GLOSS, PSMSL and tide gauge data not yet in global data bases and reconstruction methods.
2. Sea ice data to describe changes over 50 years based on a combination of data from a variety of sources, including synoptic ice observations from operational ice services and passive microwave time series satellite data from 1979.
3. Ocean mass change time series using GRACE data
4. Steric sea level time series from in situ data and 'altimetry minus GRACE-based ocean mass'

Description of work

Task 2.1.1: Regional sea level data based on Topex, Jason and Envisat altimetry will be delivered by MyOcean for the recent period (1992-2008). Monitoring sea level variations in the Arctic region (regional mean and its contribution to the global mean, as well as the regional variability) and understanding its causes (estimates of the steric and ocean mass contributions, as well as other non climatic factors –e.g. GIA-)) is a challenge for climate research .With the much longer period of 50+ years that is considered in this project, there is a need for including other data than altimetry, e.g. tide gauge data from the Global Sea Level Observing System (GLOSS) and the Permanent Service for Mean Sea Level (PSMSL), as well as from other non global data bases. The tide gauges data will be corrected for crustal motions using GNSS data (when available) and GIA modeling . Most of the data will be incomplete in both spatial and temporal coverage, so it will be important to use ocean circulation models as well. Such models are derived from previous analyses of the ocean circulation, e.g., those from ECCO, GECCO, MICOM and BCM. The compilation of those data into 30-50 years time series will be carried out in this task. In addition, past sea level reconstruction methods that combine altimetry, tide gauges and ocean circulation model outputs will be adapted to the Arctic Ocean region to provide past 50+ years regional sea level variations. (month 16)

Task 2.1.2: For sea ice data MyOcean and the EUMETSAT OSI SAF will be the important sources. The observed sea ice parameters from satellites are primarily ice area, ice concentration and ice drift. Ice buoys also provide drift data at scattered locations across the Arctic, while moorings provide ice drift and thickness data in a few locations such as the Fram Strait. Ice thickness data for the Arctic Basin are obtained primarily from submarine cruises and scientific expeditions. Of particular relevance are the Russian expeditions, including the North Pole Drifting stations, which provide thickness and drift data over six decades starting in the 1930s. Additional data will be obtained from GLOBEICE and national archives, including those available in Canada and the US. Also in this case the challenging compilation of data incomplete data coverage into 30-50 years time series will be carried out using sea ice models to bridge those gaps. (month 16)

Task 2.1.3: In order to characterise the steric and ocean mass variations of the observed sea level variability, the regional contributions for steric variations and land ice and continental fresh water input will be estimated using different data sets, in particular in-situ hydrographic profiles and space gravimetry data from GRACE. Steric sea level regional variability will also be estimated from the difference between altimetry and GRACE ocean mass. (month 16)

Deliverables

D2.1.1 – Gridded time series of sea level data over the altimetry period and last 50+ years

D2.1.2 - Time series of sea ice data to describe changes over 50 years.

D2.1.3 – Gridded time series of ocean mass variations since 2002

D2.1.4 Gridded time series of steric sea level from in situ hydrography and 'altimetry minus GRACE ocean mass'

Work package number	2.2	Start date or starting event:				Mo 1	Mo 16
Work package title	**Improved mean sea surface and mean dynamic topography**						
Activity Type	RTD						
Participant number	1		3			6	**7**
Person-months per beneficiary:	4		2			2	6

Objectives

- To improve the mean sea surface model for the Arctic Ocean using newly developed models combined with sea level time series data from WP2.1 and the improved sea-ice thickness corrections of WP2.5.
- To derive a reference sea surface model using available satellite data for the period of 1993-2008 with a special emphasis on annual to decadal variability.
- To improve the mean dynamic topography model for the Arctic Ocean using the improved mean sea surface data, recent geoid models and ocean circulation models.

Description of work

The mean sea surface is an important reference surface for the pre-processing of sea level data – especially for combining in situ and satellite data. For the assimilation of sea level data into the models the mean dynamic topography model becomes important. Existing models are not of a sufficient quality due to the problems related to poor coverage, effects of sea ice, and lack of sufficiently long time series, as described above. (month 16)

Task 2.2.1: Existing models of the mean sea surface covering the Arctic ocean are assessed and combined with the sea level time series derived in WP2.1. Hereby, a mean sea surface covering the time period of 50 years will be derived. (month 16)

Task 2.2.2. The annual-decadal modifications to the mean sea surface data time series will be based on ERS, ENVISAT and ICESat data for the satellite period (1993-2008). (month 16)

Task 2.2.3: Based on the mean sea surface derived in Task 2.2.1 a mean dynamic topography model will derived using the new Earth gravity model EGM08 and later improvements. This model will be assessed using the output of the ocean circulation models. Subsequently, the mean dynamic topography model will be revised using a combination of the different models. (month 16)

Deliverables

D2.2.1 - Improved mean sea surface model covering 50 years for the Arctic Ocean
D2.2.2 - The annual-decadal modifications of the mean sea surface data time series for the satellite period (1993-2008),
D2.2.3 - Improved dynamic topography model for the Arctic Ocean

Work package number	2.3	Start date or starting event:			Mo 1	Mo 39
Work package title	**Change in mass balance of the Greenland ice sheet and its transfer to sea level rise**					
Activity Type	RTD					
Participant number	1			4			**7**
Person-months per beneficiary:	4			12			7

Objectives:

Task 2.3 will assess results of overall Greenland mass balance by comparison and synthesis of different satellite-based data and estimation methods. This will provide improved estimates of current estimates of total freshwater input into the ocean from the ice sheet melt, as well as the contribution of Greenland ice mass loss to sea level rise.

With ICESat laser altimetry and recent airborne campaigns, the coastal ice mass loss has been detected with spectacular details, especially in the regions of the major outlet glaciers and the margins of south-eastern and western Greenland. With the gravity change mission GRACE a direct estimate of yearly mass loss from the ice sheet is available since 2002. For the computation and interpretation of GRACE results there is, however, yet no scientific consensus on the value of the overall mass balance of the ice sheet, with numbers in the range 150-300 GT/year obtained, depending on time span of analysis, processing centres and methods, including the uncertainty of the glacial isostatic adjustment (GIA). Moreover recent unpredicted evidence of accelerating ice flow in coastal regions of Greenland shows that dynamical response to climate forcing (in addition to changes in melting and accumulation) may influence ice-sheet mass balance on short time scales, and thus make prospects for rapid changes in freshwater output larger.

To assess ice thickness/volume change, altimeter measurements of surface elevation change will be combined with modelled data on vertical motion of underlying ground associated with GIA and changes of snow densification. The joint analysis will be extended back in time to 1992, the start of the GRACE and ICESat epochs. New high-resolution interferometric radar altimetry data will be used to supplement the ICESat time series for the duration of the project (the future of ICESat laser mission beyond 2008 is currently very uncertain). Improved estimates of GRACE-based Greenland mass balance will also be provided since 2002 and compared with estimates from other techniques.

The work with the Greenland mass balance will to a large degree build on research funded nationally and in other COST and EU cooperative projects addressing GIA and ice sheet changes.

Description of work

Different satellite observations will be combined to analyse Greenland ice sheet mass balance over the last two decades. Measurements of radar altimeters from a series of satellites provide the basis to investigate surface-elevation changes from 1992 onward. ICESat satellite laser altimeter measurements since 2003 will provide data on elevation change closer to the ice-sheet margins, where the quantity and quality of radar altimeter data are limited. Gravity Recovery and Climate Experiment (GRACE) satellite mission provide gravity-change data that will improve the estimates of the mass balance. A compilation of those data and US airborne data (PARCA) will improve the assessment of mass balance of Greenland ice sheet, its contribution to see-level change and impact of freshwater discharge on ocean circulation.

Task 2.3.1: Measurements of radar altimeters from a series of satellites (ERS1, ERS-2 and Envisat) will be investigated for surface-elevation changes from 1992 onward. Surface-elevation time series based of crossover analysis will be used to investigate of inter-satellite biases. Correlation between elevation and backscattered power will be taken into account. (month 18)

Task 2.3.2: ICESat satellite laser altimeter measurements since 2003 will provide data on

elevation change free of radar penetration effects, and especially provide coverage closer to the ice-sheet margins. The ICESat data will be analysed by repeat-track analysis methods. (month 18)
Task 2.3.3: GRACE satellite data will be investigated from mass-con inversion and filtering solutions, based on monthly or 10-day solutions from different Level-4 processing centres (CSR, GFZ, JPL, LEGOS), and combined into an estimated "joint" GRACE series of monthly mass balance and long-term trends. The GRACE data will be corrected for GIA effects (using different GIA models), to give a best total estimate in GT/year of current freshwater input to the Arctic Ocean, Norwegian-Greenland Seas, and the Baffin Bay/Davis Strait, respectively (and associated contribution to global mean sea level) (month 18)
Task 2.3.4: To jointly assess ice volume and mass changes from altimeter and GRACE missions, altimeter measurements of surface elevation change will be combined with modelled data on vertical motion of underlying ground associated with GIA as well. Differences of volume of mass changes will be investigated under the assumptions of temporal firn compaction and density changes, leading to an improved, unified understanding of total mass balance changes. Focus will be on long-term trends, and not the (larger) yearly mass balance. (month 39)

Deliverables

D2.3.1 - Time series of satellite altimetry height changes of the Greenland ice sheet, year since 1992 expressed as height change grids. Month 18.

D2.3.2 - Grid of ICESat height changes, average trend 2003-2008. Month 18.

D2.3.3 – Gridded time series of GRACE-based Greenland mass changes. Month 18.

D2.3.4 - Time series of Greenland ice sheet mass balance from 1992 to present (combining all techniques) and improved "overall" freshwater input trend to the oceans surrounding Greenland and sea level contribution.

Work package number	**2.4**	**Start date or starting event:**				**Mo 1**	**Mo 39**
Work package title	**Assessing uncertainty of existing reanalyses and simulations over the Arctic**						
Activity Type	RTD						
Participant number	1		**3**			6	7
Person-months per beneficiary:	4		9			4	3

Objectives

- Evaluate existing ocean reanalyses and simulations, assessing their quality through an intercomparison against observations and thereby identifying the reasons for discrepancies among currently available analyses.

- Identify key processes that drive interannual to decadal variability in key components of the high latitude and the Arctic Ocean

Description of work

Task 2.4.1: Exploit existing ocean analyses, simulations and reanalyses which have been produced recently by our project partners to evaluate the quality of products provided by different methods. The evaluation will use independent observations (i.e. not assimilated into the models) and estimates of Atlantic inflow and overflow fluxes. The evaluation will go beyond simply comparing the different state estimates. (month 12)

Task 2.4.2: Through a set of focused sensitivity experiments with analysis systems it will establish what are the key factors required to estimate the current Arctic state (month 18)

- resolution of eddy and boundary current processes;
- choice of covariances in assimilating observations;
- critical levels of data density (e.g. Argo);
- relative value of different data sources in constraining the ocean circulation estimates.

Deliverables

D2.4.1 - Assessment of existing descriptions of the Arctic Ocean circulation and its transport properties.

D2.4.2 - Assessment of shortcomings that need to be improved through an Arctic Reanalysis

D2.4.3 - Assessment of existing data base.

Work package number	**2.5**	**Start date or starting event:**					**Mo 1**	**Mo 39**
Work package title	**Improved estimate of the sea level and the ocean circulation of the Arctic**							
Activity Type	RTD							
Participant number	1		**3**				7	8
Person-months per beneficiary:	5		23				5	5

Objectives

Produce an improved Arctic reanalysis, using the time series derived in WP2.1 as constrains and using dynamically consistency as a criterion for assessing the quality. The estimate will be dynamically consistent and will provide a best possible description of the circulation of the Arctic, of sea level, of ocean and ice transports and of surface forcing fields over the last 60 years, as well as run-off required to bring the model into consistency with all available data sets. The optimization will be performed in close collaboration with WP 4.

Description of work

Task 2.5.1: Produce a best possible reanalysis of the Arctic Ocean and its sea ice covering the period since 1948. To obtain the estimate, the GECCO model will be nested into global GECCO results to provide boundary conditions from the Atlantic and the Pacific. The estimation will cover up to 50 years, but will especially include the 1990th up to date to provide a best possible Arctic Reanalysis covering the IPY period. The model domain will be the entire northern hemisphere north of 40° latitude and will be provided using a coupled ocean/ice model. The reanalysis will use all available observations provided in WP 2.1, information about run off and surface fluxes provided from WP1 and WP 2 and with use anthropogenic carbon as a tracer to diagnose online not only freshwater transports, but also carbon transports in the Arctic. The coupled model will have an active sea ice module and will use sea ice information as constraints during the optimization procedure. (month 39)

Task 2.5.2: Resulting sea ice motions will be input for the diagnostics performed in WP 2.5. The model will have compute anthropogenic carbon uptake over the model domain. Results will also serve as the basis to provide or expand fast track services, such as ocean transports and information about sea level change in the Arctic. (month 39)

Task 2.5.3: Beside a dynamically consistent reanalysis, the Nansen Center version (Hatun et al. 2005, Lohman et al. 2008, Sandø and Furevik, 2008) of the Miami Isopycnic Coordinate Ocean Model (MICOM; Bleck et al., 1992) will be used in forward mode in two grid configurations: An intermediate horizontal resolution of about 15 km and a conventional resolution of about 60 km in the Atlantic-Arctic. The two model versions will be run in tandem, using identical atmospheric forcing fields. In this way, the added value of (a) increased horizontal resolution, (b) different forcing fields, and (c) a combination thereof will be assessed. This exercise will highlight the ocean response to improved atmospheric forcing, as well as the importance of horizontal grid resolution, in simulating the ocean climate. Therefore, the overlying aim of this work is to continue to provide reliable scientific input to the climate research community, and especially to the models used in the major assessment reports of the Intergovernmental Panel on Climate Change, IPCC. (month 24)

Task 2.5.4: One set of forcing fields will be the continuously updated (and commonly used) NCAR/NCEP reanalysis product (Kalnay et al. 1996). A second set of forcing fields will consist of the wind data from CERSAT/IFREMER, which is intended for the oceanographic community. The CERSAT wind field is monitored using scatterometers from different satellites that have been in operation since 1991. The resolution of these fields varies from 15 to 50 km. Compared to the 2.5-degree resolution of the NCAR/NCEP forcing, this is a considerable improvement, although the observational period of the CERSAT wind is limited to the last two decades. Both the seasonal cyclone variability, storm track pathways and frequencies of extremes will be assessed w.r.t to the location of sea ice edge, sea ice drift patterns and ocean circulation. Its consequence for C02 partial pressure will be examined in WP3. (month 39)

Deliverables

D2.5.1 - Improved estimate of the ocean circulation and sea level with at least 1/6 ° spatial resolution.

D2.5.2 - Improve ECVs over the Arctic Ocean, including sea ice cover, sea ice transports, sea level and ocean transports of heat and freshwater.

D2.5.3 – Assessment of using high resolution satellite based wind field observations.

D2.5.4 - The resulting system will be a pilot system of fast track services with climate relevance over the Arctic.

Work package number	2.6	Start date or starting event:				Mo 1	Mo 39
Work package title	**Improved estimate of sea ice fluxes and the freshwater cycle in the Arctic Ocean**						
Activity Type	RTD						
Participant number	1		3				**7**
Person-months per beneficiary:	5		4				6

Objectives

Sea ice thickness is a major limitation in the measurement of mean sea surface heights, and thus the derivation of realistic mean dynamic topography, and thus providing independent remote sensing constraints on Arctic Ocean circulation models. The changes in sea ice motion and transport, especially in and out of the Arctic straits, can be assessed using satellite data, together with gridded fields of ice thickness and mean sea level anomalies.

The total volume of sea ice, its seasonal melting and freezing, the regional variability and the fluxes through the straits can be estimated from a combination of satellite observations, model simulations and in-situ data (upward looking sonar). This assessment will build on observations provided in WP 2.1, independent in-situ data, and on the estimates provided in WP 2. 4.

Description of work

Task 2.6.1: Development of ice thickness time series from ICESat and CryoSat (when available). An updated ArcGP/EGM08 geoid model will be used together with ICESat 40 Hz data to recover freeboard data. Algorithms for thickness retrieval will be improved based on in-situ data collected during especially ESA CryoSat campaigns 2003-2010 and the EU Damocles project 2007-8. The ice thickness will be computed in grids corresponding to the grids used in WP2.4, and correlated with other modelled and observed climate parameters. (month 18)

Task 2.6.2: The time series of sea ice thickness will be used in combination with model results and assimilation results to obtain improved estimates of sea ice volume fluxes. These fluxes represent a component of the freshwater cycle in the Arctic, where freshwater increase and decrease due to melting/freezing of sea ice and freshwater import/export to/from certain regions of the Arctic. (month 18)

Task 2.6.3: The fresh water fluxes will be compared to the Arctic Ocean part of the Greenland ice sheet melt, the river discharges, and merged into a freshwater flow grid, using the input of WP 2.4 and compared to the sea level time series of WP 2.2. The direct measurements of the freshwater pulse by satellite gravity (GRACE) will be exploited as part of this comparison. (month 18 and 39)

Deliverables

D2.6.1 - Time series of grids of sea ice thickness, and improved SSH measurements, 2003-2008 (for the 3-yearly laser periods), with comparisons to selected ocean models and field-calibrated satellite data.

D2.6.2 - Ice volume flux time series across the Fram Strait and other outlets (Bering Strait, Nares Strait) based on satellite data (2003-).

D2.6.3 - Freshwater flux time series grids for the Arctic Ocean based on modelled Greenland freshwater output, river discharge and sea ice flux and melt.

D2.6.4 - Computed time series of GRACE signals from freshwater flux pulses and comparison to satellite data

Work package number	**3**	**Start date or starting event:**				**Mo 1**	**Mo 39**
Work package title	**Changes in Marine Carbon Cycle**						
Activity Type	RTD						
Participant number	1		3		5	6	
Person-months per beneficiary:	6		8		26	36	

Objectives

Exploiting and (re-) processing of the relevant EO-data sets (EO=Earth Observations) including ***surface ocean CO_2 partial pressure*** and ocean ***colour/primary productivity*** based on up-to-date algorithms and cal/val corrections.

Integrating and merging of the individual calibrated data sets for each ECV to constitute comprehensive and well-characterized long term records for the high latitude and Arctic regions for the last 30-50 years that in turn can be assessed in the context of changes in marine carbon cycle.

Description of work

WP3 is structured into three sub-workpackages:

3.1 In-situ and remotely sensed observations on the inorganic carbon cycle:

Focus on surface ocean pCO_2 as ECV and derived quantities, in particular pH value and carbonate saturation. Compilation of data products based on in-situ and remotely sensed observations.

3.2 In-situ and remotely sensed observations on marine ecosystems:

Focus on ocean colour as ECV plus derived quantities, in particular biological primary production (POC and PIC). Compilation of data products based on in-situ and remotely sensed observations.

3.3 Integration of observations with biogeochemical model hindcast:

Synoptically forced couple physical-biogeochemical ocean model run over the past 50 years. Production of gridded time series data including air-sea CO_2 fluxes and biological export production.

Deliverables

See sub-workpackages 3.1, 3.2, and 3.3.

Sub-Work package number	3.1	Start date or starting event:			Mo 1	Mo 39
Sub-Work package title	**In-situ and remotely sensed observations on the inorganic carbon cycle**					
Activity Type	RTD					
Participant number					6	
Person-months per beneficiary:					18	

Objectives
Integrating and merging of the individual calibrated data sets for ECV surface ocean CO_2 partial pressure to long term records the northern high latitude and Arctic regions for the last 30-50 years.
Build up database of existing inorganic carbon and relevant data from the Arctic and Nordic Seas, and merge and employ these for the production of monthly basin-wide fields of (1) partial pressure of CO_2 (pCO_2)and air-sea CO_2 flux which are validated by measurements from research ships on standard sections and random locations (ii) pH and carbonate saturation values
The results will be used to validate model output from WP 3.3. and to evaluate the influence of changes in primary production on pCO_2(from WP 3.2).

Description of work
Task 3.1.1: Collate existing observational data sets:
Best possible observational data sets on carbon cycle relevant biogeochemical variables will be collated from existing data bases for the Arctic Ocean and the Nordic Seas, notably from CARINA (Olsen et al., 2008) and SOCAT (Pfeil et al., 2008). In-situ data include surface seawater pCO_2, dissolved inorganic carbon, alkalinity, dissolved nutrients (N, P, Si).We will also have access to the pCO_2 and SST measurements from aboard RV Johan Hjort and GO Sars, which are collected by UiB. Remotely sensed data from scatterometer as well as active and passive microwave measurements and respective data from existing re-analysis on wind speed, sea surface temperature, mixed layer depth and ice cover will be made available from data archives and/or the other WPs (In particular WP2).
Tracer variables (in situ): depth, T, S, surface pCO_2, DIC, Alk, NO_3^-, PO_4^{3-}, $Si(OH)_4$, O_2
Data sets (in situ): CARINA, SOCAT, GLODAP, Station M.
Tracer variables (satellite/reanalyses): SST, wind speed, ice cover, salinity, chl a, mld.
Data sets (satellite/reanalyses): MYOCEAN, GHRSST, OSI-SAF, CM-SAF, CERSAT, ECMWF, NCAR/NCEP, SeaWiFS, Aqua MODIS.
Partners involved (person months): UiB (6 pm).
Task 3.1.2: Integrated comprehensive records of ECVs:
The in-situ, satellite and reanalyses data will be collocated and secondary QC-ed to form integrated comprehensive and well-characterized records of ECVs for the high latitude and Arctic regions.
The result is essential for WP 3.1.3 and for validating time dependent hindcast model results (WP 3.3)
Partners involved (person months): UiB (6 pm).
Task 3.1.3: Produce monthly fields of pCO_2 and pH:
Monthly, basin-wide fields of pCO_2 estimates will be produced, using pCO_2– proxy techniques and datasets from WP 3.1.2. In this respect, there are a number of possible techniques to choose between e.g. multi linear regression (Olsen et al., 2004), neural networks (Lefevre et al., 2005) as well as artificial intelligence search techniques (Wickramaratna et al., 2008). The algorithms will be validated using ship measurements from aboard RV Johan Hjort and G.O. Sars from selected regions. The fields of pH and carbonate saturation state will be computed using AT –proxy techniques (Nondal et al., 2008) and the pCO_2 fields. The pCO_2 fields will be combined with transfer velocities (WP 3.2) to compute air-sea CO_2 fluxes. Additionally, the fields can be used to infer the annual pCO_2 changes, due to anthropogenic and/or climatic forcing (Omar et al., 2003).

Partners involved (person months): UiB (6 pm)

Deliverables

D3.1.1: Consistent data bases of inorganic marine carbon cycle data including derived quantities, including meta-information on data quality and statistics (coverage in space and time). (Month 12)

D3.1.2: Co-located multi tracer data sets of biogeochemical (from task 3.1) and physical variables (from tasks in other WPs) including error estimates. (Month 18)

D3.1.3: Monthly fields of sea-surface pCO_2, pH, carbonate saturation state and air-sea CO_2 fluxes. (Month 24)

Sub-Work package number	3.2	Start date or starting event:			Mo 4	Mo 39
Sub-Work package title	**In-situ and remotely sensed observations on marine ecosystems**					
Activity Type	RTD					
Participant number	1				5		
Person-months per beneficiary:	6				26		

Objectives

Exploiting and (re-) processing of the relevant EO-data sets (EO=Earth Observations) on carbon cycle related changes in surface ocean ecosystems in particular surface ocean primary production. Integrating and merging of the individual calibrated data sets for ECV ocean colour to long term records of marine primary production for the northern high latitude and Arctic regions for the last 30-50 years.

Description of work

Task 3.2.1. Collection of archival data on the parameters relevant to primary production: a) water column vertical stratification, b) water surface temperature, c) parameters of the photosynthetic curve, d) phytoplankton chlorophyll concentration.

Partners involved (person months): NERSC (3pm), NIERSC (5 pm)

Task 3.2.2. Quantification of the distribution of phytoplankton, with respect to pigment biomass. By using ground-truthing and from a combination of factors such as the light environment, nutrient regime, water temperature, degree of vertical mixing etc. the distribution of phytoplankton, will be related with available biomass (Bricaud *et al*., 2004).

Partners involved (person months): NIERSC (5 pm)

Task 3.2.3. Quantitative assessment of primary productivity in the Arctic including pelagic and coastal regions from satellite measurements: Ocean colour data from different archives (MERIS, MODIS sensors; MyOcean) will be downloaded. Pigment biomass, chlorophyll concentration, and biological primary production (phytoplankton production) will be determined from the ocean colour data using suitable algorithms following Behrenfeld et al. (2005) with as high as possible temporal resolution, including use of the NASA and ESA standard algorithms for open ocean waters and area-specific algorithms for coastal zones (see e.g. Pozdnyakov *et al*. (2005). The necessary input on mixed layer depth to these retrieval algorithms will be derived from MICOM, GECCO and BCM/NorESM.

Partners involved (person months): NERSC (3 pm), NIERSC (8 pm)

Task 3.2.4. Quantitative assessment from satellite measurements of suspended inorganic carbon release into the ocean due to coccolithophore blooming.

The method of (Korosov et al., 2008) will be applied to automatically identify and numerically assess the concentration of coccolithophores and coccoliths from satellite data. Given that on average 32-38 coccoliths are normally attached to each coccolithophore cell, and the concentration of C in the coccolith is also known (about 0.2·10-12 g of inorganic carbon), the total amount of suspended inorganic carbon will be quantified. The seasonal dynamics of the areas occupied by coccolithophores and coccoliths will be determined.

Partners involved (person months): NIERSC (6 pm)

Task 3.2.5. Assessment of trends in the past/in situ measured and remotely sensed ECVs relevant to marine carbon cycle for the available time periods. The time periods are assumed to be 30-50 and 10 years long for, respectively historic in situ and remotely sensed data.

Partners involved (person months): NIERSC (2 pm)

Deliverables

D3.2.1: Primary productivity time series (biological organic carbon production by phytoplankton) as gridded data sets for the time of available high quality remotely sensed data for the Arctic

Ocean. (Month 18)
D3.2.2: $CaCO_3$ production time series as gridded data sets for the time of available high quality remotely sensed data for the Arctic Ocean. (Month 24)

Sub-Work package number	**3.3**	**Start date or starting event:**				**Mo 18**	**Mo 39**
Sub-Work package title	**Integration of observations with biogeochemical ocean model hindcast**						
Activity Type	RTD						
Participant number			3			6	
Person-months per beneficiary:			8			18	

Objectives

Integrating and merging of the individual calibrated data sets of marine carbon cycle relevant ECVs to provide comprehensive and well-characterized long term records for the northern high latitude and Arctic regions for the last 30-50 through a synoptically forced coupled physical-biogeochemical ocean general circulation model (MICOM-HAMOCC), which is validated through the multi-variable data set of observations

Description of work

Task 3.3.1: Spin-up for synoptically forced coupled physical biological ocean model MICOM-HAMOCC (globally, with sufficient resolution at northern high latitudes and the Arctic ocean; we opt here for the same resolution as used in the NorESM Earth system model to be used in IPCC assessment report no. 5) until quasi-equilibrium for pre-industrial state and subsequent ramp up until start of "observed" synoptic forcing at 1948 (NCAR-NCEP, Kalnay et al., 1996). The model will be run in two modes: (a) With free floating atmospheric CO_2 starting from equilibrium pre-anthropogenic ocean at 280 ppm atmospheric CO_2 mixing ratio until modern using CO_2 emission data from Marland et al. (2008). (b) With prescribed atmospheric CO_2 partial pressure from ice core (pre-1958) and direct atmospheric measurements.
Partners involved (person months): UiB (4 pm).
Task 3.3.2: First order validation of the spun-up model against physical and biogeochemical variables and model improvement through sensitivity experiments through comparison against climatological data (GLODAP, Key et al., 2004; Takahashi et al., 2002, 2008).
Partners involved (person months): UiB (1 pm)
Task 3.3.3: Synoptically forced coupled physical biological ocean model run using MICOM-HAMOCC (including slab atmosphere) using spin-up of Task 3.3. Validation of modelled distributions with respect to variations in time and space. The model will be compared against the data sets compiled in WPs 3.1 and 3.2 for the following variables: T, S, surface pCO_2, DIC, Alk, NO_3^-, PO_4^{3-}, $Si(OH)_4$, O_2, primary production (organic carbon), $CaCO_3$ production, gas transfer velocity (computed from model versus derived from remote sensing). First order mismatches will be removed trough dedicated sensitivity experiments and parameter adjustments.
Partners involved (person months): UiB (7 pm)
Task 3.3.3a: Comparison of the anthropogenic carbon air-sea carbon fluxes of the GECCO Re-analysis (optimised physical model with abiotic carbon cycle model using constant alkalinity and background DIC) for prescribed atmospheric CO_2 partial pressure with the respective fluxes from the full biogeochemical hindcast model.
Partners involved (person months): UoH/IFM (8 pm)
Task 3.3.4: Production of gridded time series (last 50 years) for surface ocean pCO_2, biogenic particle production (primary and export), marine carbon, nutrient, and oxygen budgets, including changes in pH value and carbonate saturation in relation to climate change and rising atmospheric CO_2 concentration. Vulnerability analysis on largest - potentially observable – gradients.
Partners involved (person months): UiB (6 pm)

Deliverables

D3.3.1: Spin-up of coupled physical biogeochemical ocean model run suited for subsequent time dependent data production in relation to climate change and rising atmospheric CO_2 including validation (a. with free atmospheric CO_2, b. with prescribed atmospheric CO_2). (Month 24)

D3.3.2: Modelled time series of surface ocean CO_2 partial pressure, air-sea CO_2 flux (total, natural, anthropogenic), biological export production, and further biogeochemical variables in relation to climate change and rising atmospheric CO_2 for the northern high latitudes and the Arctic and respective changes in marine Arctic carbon budget over the past 50 years (a. with free atmospheric CO_2, b. with prescribed atmospheric CO_2). (Month 37)
D3.3.3: Reanalyses of oceanic anthropogenic carbon uptake, transports in the Arctic and the GIN Sea as well as the carbon export into the North Atlantic over the past 50 years (a. with free atmospheric CO_2, b. with prescribed atmospheric CO_2). (Month 37)

Work package number	4	Start date or starting event:				Mo 1	Mo 39
Work package title	**Synthesis and Interaction with the Scientific Community**						
Activity Type	RTD						
Participant number	**1**	**2**	**3**	**4**		6	7
Person-months per beneficiary:	9	4	6	4		8	4

Objectives

- Assess and synthesize the trends and consistency of the ECVs generated in WP 1- 3 during the last 30-50 years in the context of mutual forcing and feedback mechanisms arising due to changes in: (i) terrestrial carbon and water interaction; (ii) sea level and ocean circulation; and (iii) marine carbon cycle.
- Establish and execute regular contacts and interactions with the scientific community.
- Feed knowledge into overall assessment of priorities for design and implementation of Arctic monitoring and prediction system for climate.
- Set-up a web site for visualization and dissemination of project data and results**.**

Description of work

T4.1 - Synthesis of the state and variability of river discharge, snow cover and snow water equivalent, permafrost extent and seasonal variability of frozen ground; sea ice drift and volume transport, sea level and mean dynamic topography, ocean current, mass and heat transport, CO2 partial pressure, and near surface wind field. A special feedback report to the GMES core services will also be provided.

The MONARCH-A project has together with some other EU and ESA funded projects generated new and highly valuable complementary fields (e.g. sea level, sea surface temperature, glaciers retreat, and ice sheet mass changes) for the accurate estimation and explanation of the ongoing sea level change associated with global warming. Month 36 to 39 will be used to gain more benefit of this complementary work. The final results are expected to lead to new accurate determination of the freshwater contribution to the sea level change in the high latitude and Arctic Ocean. During the final 3 months of the project, the MONARCH-A project will also establish the necessary collaboration and exchange of key findings and results with the CORE-CLIMAX and CHARMe projects that are supposed to start in early 2013. Finally, the most accurate GOCE derived geoid and mean dynamic topography (MDT) are expected to be released towards the end of 2012. This will have the best resolution and data length (2 years of data instead of current 1 year of data) and give a significant opportunity to assess, inter-compare and test the quality and reliability of other independent data and model based MDTs and ocean circulation in the high latitude and Arctic Ocean.

T4.2 – Maintain regular interaction with these communities and ensure adequate and efficient promotion and transfer of the results. Invite feedback and incorporation of new ideas from the external scientific community. This include also contacts to GEO/GEOSS, GMES, OOPC, CLIC, CLIVAR, etc…)

T4.3 – Bring the integrated science and technology achievements to the attention of those involved with consideration of priorities, design and implementation of high latitude and Arctic monitoring system for climate change. This will also include the evolution of long term vision of ECVs as a European public good supporting climate issues but also EU autonomy and EU competitiveness

T4.4: Design, implement and operate a suitable web-portal (or else) for disseminating the data products of the projects. This website will provide the front window for the project external communication. It will first present the general purpose and aims of the project, news and events, main technical aspects, partners, sponsoring, GMES context, Press materials and public deliverables. Upload of final data products to be accessible via web-portal. Test the accessibility of the web-portal and forward information about data access to important end-users

Deliverables
D4.1 – Synthesis report of the state and variability of changes in high latitude and Arctic regions including dedicated feedbacks to the GMES core services (month 24 and 39)
D4.2 – Interaction and feedback report from contacts with external scientific communities (month 12,24,39)
D4.3 – Support document to design and implementation of Arctic monitoring and decadal prediction system (month 39)
D4.4 – Create the web-portal
D4.5 - Upload and regular update of information and products to web portal (month 12, 24 and 39)

B 1.3.6 <u>Efforts for the full duration of the project</u>:

Project number (acronym): MONARCH - A

Indicative efforts per beneficiary per WP

Participant number/short name	WP1	WP2	WP3	WP4	WP5	Total Person months
1. NERSC	**3**	**22**	**6**	**9**	**7**	**47**
2. USFD	**68**			**4**		**72**
3. UHH		**41**	**8**	**6**		**55**
4. CNRS	**36**	**30**		**4**		**70**
5. NIERSC	**25**		**26**			**51**
6. UiB		**6**	**36**	**8**		**50**
7. DTU		**35**		**4**		**39**
8. IFREMER		**5**				**5**
Total	**132**	**139**	**76**	**35**	**7**	**389**

Project number (acronym): MONARCH - A

Indicative efforts per activity type beneficiary

Activity Type	1	2	3	4	5	6	7	8	Total
RTD/Innovation activities									
WP 1	3	68		36	25				**132**
WP 2	22		41	30		6	35	5	**139**
WP 3	6		8		26	36			**76**
WP 4	9	4	6	4		8	4		**35**
Total 'research'	40	72	55	70	51	50	39	5	**381**
Demonstration activities									
WP									
WP name									
Etc									

Total 'demonstration'									

Consortium management activities									
WP 5	7								
Total ' management'	7								

Other activities									
WP name									
Etc									
Total 'other'									

TOTAL BENEFICIARIES	**47**	**72**	**55**	**70**	**51**	**50**	**39**	**5**	**389**

B 1.3.7 List of milestones and planning of reviews:

List of schedule and milestones

Milestone number	Milestone name	WP number	Lead beneficiary	Delivery date from Annex 1	Comments
M1.1	Snow Database	1.1	CNRS	Month 18	Data products available on data server including meta-information
M1.2	Surface Water and Runoff Database	1.2	CNRS	Month 18	Data products available on data server including meta-information
M1.3	Permafrost Database	1.3	NIERSC	Month 28	Data products available on data server including meta-information
M1.4	Permafrost-model Interface	1.3	USFD	Month 30	Software available with documentation
M1.5	Land Cover Database	1.4	USFD	Month 15	Data products available on data server including meta-information
M1.6	Fire Database	1.4	USFD	Month 30	Data products available on data server including meta-information
M2.1	Arctic Climate Data Base	2.1	UHAM	Month 24	Data products available on data server including meta-information
M2.2	Arctic Mean Sea Level	2.2	DTU	Month 24	Data products available on data server including meta-information
M2.3	Arctic Climate Greenland ice sheet mass Data Base	2.3	CNRS	Month 24	Data products available on data server including meta-information
M2.4	Arctic Ocean and Ice Synthesis	2.5	UHAM	Month 39	Arctic Synthesis in form of gridded model output available on data server.
M2.5	Sea Ice Motion Data Base	2.4	NERSC	Month 39	Arctic Sea Ice Motion Atlas in form of gridded

					fields available on data server.
M2.5	Maps of sea ice thickness, volume and improved SSH measurements	2.5	DTU	Month 30	Time series of grids of sea ice thickness and Ice volume flux across Fram Strait and other outlets
M2.6	Provision of an improved "overall" freshwater input trend to the oceans surrounding Greenland.	2.6	CNRS	Month 30	Combined gridded fields of altimetry and GRACE data (incorporating if available early CryoSat data).
M3.1	Marine carbon cycle observational data sets available for model comparison and as input to reanalyses	3 (3.1, 3.2)	UiB	Month 24	Data products available on data server including meta-information
M3.2	Marine carbon cycle data hindcast for the past 50 years is available	3 (3.3)	UiB	Month 39	Gridded model data files are available as time series maps on data server
M3.3	Reanalyses of anthro-pogenic carbon up-take and transports in the Arctic for the past 50 years is available	3 (3.3)	UiB	Month 39	Gridded model data files are available as time series maps on data server
M4.1a	Preliminary synthesis report of the state and variability of changes in high latitude and Arctic regions	4.1	NERSC	Month 24	First version of consistent long time series of 11 ECVs produced from data merging and reanalyses.
M4.1b	Final synthesis report of the state and variability of changes in high latitude and Arctic regions	4.1	NERSC	Month 39	Final version of consistent long time series of 11 ECVs produced from data merging and reanalyses.
M4.2	Support to design and implementation of Arctic monitoring and decadal prediction system (month 36)	4.2	UIB	Month 39	Knowledge gaps will be specified for design of climate change observing system.
M5.1	Kick-off meeting	5.1	NERSC	Month 1	Minutes
M5.2	Annual Review Meetings	5.2	NERSC	Month 12, 24	Annual Review Reports
M5.3	Final Meeting	5.3	NERSC	Month 39	Final Report

Tentative schedule of project reviews

Review no.	**Tentative timing, i.e. after month X = end of a reporting period**	***planned venue of review***	***Comments , if any***

1	After project month: 12	USFD	Back-to-back with 1st Annual meeting
2	After project month: 18	tbd	Midterm status review
3	After project month: 24	DTU	Back-to-back with 2nd Annual Meeting
4	After project month 37	Bergen	Back-to-back with Final meeting