A New System for Climate Change Monitoring in the Cryosphere

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Abstract – The EuroClim project has developed an advanced monitoring and modeling system for climate variables. The system observes cryospheric variables using satellites and in situ measurement stations and produces a portfolio of products based on these observations. The system also provides climate model products, from both historical runs and a scenario run. The climate modeling results are provided as another product portfolio. All products are available through a web service developed by the project. The service is currently semi-operational, and will be further developed into a fully operational system in the next few years.

Keywords: Climate monitoring, climate change, cryosphere, remote sensing, climate modeling.

1. INTRODUCTION

One of the greatest threats to human beings and the nature as we know it today is global climate change. Predictions indicate that our environmental conditions will change with increasing speed in the coming years with one of the most significant changes being a warming of the global climate. Europe is maybe the most sensitive region of the world and, most likely, global warming will change the living conditions in this region significantly (IPCC, 2001).

In order to understand and better predict the development of the climate, continuous observations of climatic variables are crucial. The best natural indicators of global warming (or cooling) can be found in the cryosphere, i.e. masses of sea ice, snow, and glaciers. The Euro-Arctic sea ice, glaciers and seasonal snow cover should be monitored continuously in order to regularly assess the climatic status of Europe. Already, observations indicate that the Arctic may be free of sea ice during the summer within 50-100 years.

The EuroClim project, funded by the European Commission's FP5 IST program and the project partners, has developed an advanced monitoring and modeling system for climate variables. The system observes cryospheric variables using satellites and in situ measurement stations and produces a portfolio of products based on these observations. The system also provides climate model products, from both historical runs and a scenario run, where the observation products have been used for validation. The climate modeling results are provided as another product portfolio.

The system monitors sea ice for the whole Arctic Ocean, the Greenland ice sheet, glaciers in Svalbard and seasonal snow in Fennoscandia. A comprehensive set of sea ice, glacier and snow variables is retrieved, which is the basis for the product portfolio. The regional climate model covers Europe as well as the Arctic region. For all basic variables digital maps are available. There are also products for various types of climate change indicators. These are typically aggregated variables derived from time series of basic variables.

A significant amount of scientific research has been carried out by the EuroClim project in order to be able to establish the necessary algorithms and models required for a long-term operational service for time-consistent monitoring and modeling.

The service is provided free of charge through the web portal at http://www.euroclim.net. The service is currently semi-operational, and will be further developed into a fully operational system in the next few years. The intention is to let the EuroClim service be a part of the Global Monitoring for Environment and Security (GMES) system under development by Europe. GMES will be a Europe's contribution to the intergovernmental Group of Earth Observations' (GEO) system of systems.

2. THE MONITORING SYSTEM

The EuroClim system is built on the Java 2 Enterprise Edition Framework (J2EE), a framework for development of distributed systems. The EuroClim Information Portal provides the link between the user and EuroClim's distributed functionality and data (see Figure 1). The Information Portal's graphical user interface is implemented through a series of web pages. The Information Portal communicates with EuroClim Web Services to respond to the user actions. The Web Services is a web service running on, possibly, any machine in the EuroClim network. The Web Services receives request from the Information Portal, processes it, and returns a response. The communication of web service request/response consists in sending XML documents over HTTP channels. In EuroClim, the Web Services provides a known set of interface methods that are called by the Information Portal to set and retrieve the necessary information. The EuroClim Web

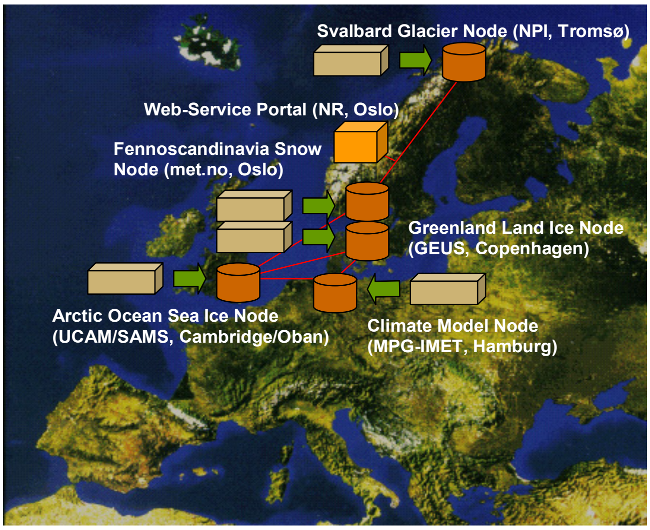

Figure 1. The network of product-production and storage systems

The work behind this paper has partly been funded by the European Commission's IST program

Figure 2. The geographical regions currently monitored

Services is the gateway between the EuroClim Information Portal client and Product Store, and between the Information Portal and EuroClim Interactive Processing, where the processing of the products is executed. The main function of the EuroClim Web Services is to generate an XML request that Product Store or Interactive Processing can understand. The purpose of the Product Store is to give the other EuroClim components access to products stored in any database in the system.

The EuroClim network includes the portal and a set of data processing and storage nodes (Figure 1). The observation nodes handle automatic processing of remote sensing and in situ datasets for the extraction of the cryospheric variables for a set of geographical regions (Figure 2) and the generation and storage of the final products. For the climate model node, a climate model post-processor transfers the model output data from its original structure to EuroClim raster products.

3. CRYOSPHERIC RETRIEVAL ALGORITHMS

The project has improved existing and developed new cryospherical variable retrieval algorithms. The algorithms are adapted to and applied in the geographical regions indicated in Figure 2.

3.1 Arctic Ocean Sea Ice

There are two types of sea ice products for climate monitoring. Sea Ice Concentration (SIC) provides the percentage ice concentration within an area. Sea Ice Multiyear (SIM) is the percentage of ice that is multi-year, i.e. sea ice that has survived one or more summer seasons. Both products are derived from an algorithm processing SSM/I data and whose input parameters are adjusted to the time of year and are determined by statistical analysis of a historical archive. Data are also processed to provide products in a numerical form. The Sea Ice Area (SIA) product provides histograms of SIC for the entire Arctic Ocean and for the regions used by the National Ice Center for ice forecasts.

3.2 Fennoscandia Seasonal Snow

There are three types of snow products for climate monitoring covering the variables Snow Cover Area (SCA), Snow Temperature for the Surface (STS) and Snow Surface Wetness (SSW). SCA is a snow/no-snow product based on an algorithm utilizing AVHRR satellite data as well as a network of meteorological ground stations (Eastwood and Thyness 2003). STS is based on the measured brightness temperature of the snow using MODIS data (Amlien and Solberg 2004). The product only covers areas completely snow covered. The same is true for the SSW product, which is based on a combination of the STS product as well as measured temporal changes of the observed grain size (both retrieved from MODIS data). It shows areas where snowmelt is likely to be ongoing and the overall magnitude of the melting (Solberg et al. 2004).

3.3 Greenland Ice Sheet

The Greenland ice sheet product is created from a sequence of single MODIS scene products processed through spatial and temporal transformations to a one month re-projected product (Mayer et al. 2003). The Glacier Surface Type (GST) product describes the surface classes (see an example in Figure 3). The sensor detects the reflected light from the sun and different threshold values are used for the four surface classes depending on the grain size. A normalized index is then used to obtain comparable results for the final products. The Glacier Melt Area (GMA) is derived from GST. It is the combined area of wet snow, superimposed ice and glacier ice.

3.4 Svalbard Glaciers

Two glacier product types are available for Svalbard, both based on SAR data (ERS and ENVISAT – alternatively also Radarsat). The Glacier Surface Type (GST) shows different surface types on the glacier: firn, superimposed ice and glacier ice. A product is produced for each year for selected glaciers, allowing one to analyze changes in the extent of these areas. The Glacier Balance Area (GBA) product looks similar to the GST except that the balance area is shown, which in size follows annual mass balance. The algorithm is building on König et al. (2004) where it was discovered that applying a k-means classification into three

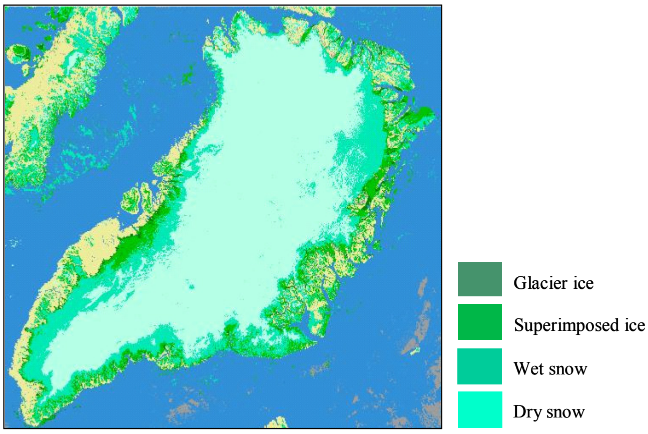

Figure 3. Average Glacier Surface Type (GST) for Greenland for June 2004. The indicator product Glacier Melt Area (GMA), which is based on GST, is the combined area of wet snow, superimposed ice and glacier ice. GMA is here 103.064 km^2

classes on the glacier surface in a SAR image reveals an area, whose variations in extent over the years are correlated amazingly well with the glacier's mass balance.

4. CLIMATE MODELING AND TREND ANALYSIS

The project has given scientific contributions to climate model configuration, parameterization and validation. It has also developed a statistical method for automatic trend analysis.

4.1 Climate modeling

For the climate model products ice, ocean and land surface variables are based on a regional high-resolution coupled atmosphere-ocean-sea-ice model for a future climate change scenario as well as for historical simulations (Haak et al. 2003).

A regional high-resolution climate model was developed for the Arctic and European region. The Ocean/Sea Ice component used in this climate model is the Max-Planck-Institute ocean model (MPI-OM). The regional atmospheric component is REMO developed at the German Weather Service and MPG-IMET. The horizontal resolution of the ocean model gradually varies between a minimum of 15 km in the Arctic and a maximum of 300 km in the Antarctic. Average resolution in the coupled domain is approximately 50 km.

The coupled model was used in "historical" simulations for the period from 1948 to 2001 using the available data from the NCEP reanalysis project as atmospheric boundary values. The "historical" dataset is also used for model validation. The scenario modeling (2000-2070) represents a transient climate response experiment with a 1% CO_2-increase as atmospheric boundary condition. Monthly map products have been produced for both the historical and the future climate change simulations.

Parameterization or modeling of cryospheric components has traditionally been a weak point in climate modeling. The project has improved cryospheric parameterization for albedo and sea ice. In an initial study, we made use of estimated albedo and surface temperature from AVHRR for snow albedo estimation, and data from the Surface Heat Budget of the Ocean (SHEBA) project for sea ice albedo. The conclusion for these tests was that for snow albedo in non-forested areas the original snow albedo scheme in the EuroClim climate model could be replaced with a polynomial temperature dependent scheme to give a more realistic snow albedo. For the sea ice albedo the test results showed that none of the existing schemes that we tested gave a good reproduction of the annual cycle. It was recognized that important improvements could be obtained if the sea ice albedo scheme was split between snow-covered, melt pond covered and melting/non-melting bare sea ice. Three new schemes were developed to improve on the major deficiencies (Køltzow et al., 2003).

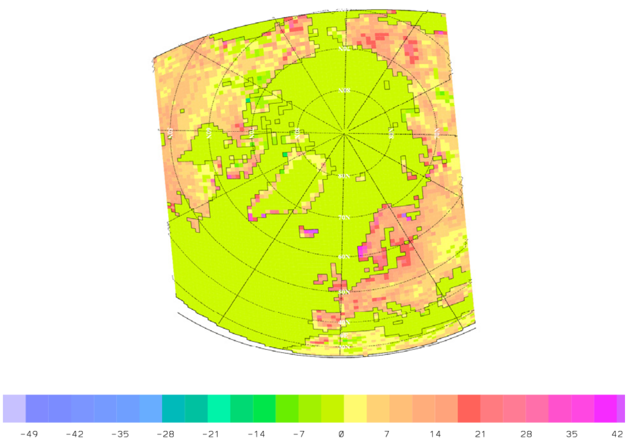

Figure 4. Growing season length change. The map shows the difference between Transient Climate Response (TCR) with 1% CO_2 increase and control run for the third decade. Units are days ice and glacier ice. GMA is here 103,064 km^2

4.2 Trend analysis

The overall goal was to establish an automatic framework for statistical analysis of climate variables. Time series of data are often noisy and detecting possible climate change by just looking at them could be difficult. Traditionally climatologists model the observations directly and assume the observed values to be proportional to the process of interest. In our approach we make no restrictions on linearity in changes of long-term variability and seasonal changes, but rather assume that changes are smooth. The model is described as a dynamic state space model. The process error represents the natural variability in the dynamics of the climate change indicators, while the observational error reflects the data collection process. We make inference by using a well-known Kalman filtering technique to estimate model parameters and to extract the long-term variability and seasonal variations from the temporal series of indicators. The statistical trend analysis is implemented as a software toolbox.

5. THE SERVICE PROVIDED

The EuroClim system has been tailored to provide services to three rather broad user groups: the citizen, the operational user and the scientist. The citizen represents here all non-specialists on climate change. The operational user is here meant to be organizations that collect information on climate change in order to assess the status of the climate in general. The scientist represents those who need data related to climate change for their own studies.

The EuroClim service certainly cannot provide all the services these broad user groups need concerning climate change in the cryosphere in general. For the citizen, we have focused on improving the general awareness (as recommended by the UN) on climate changes taking place in the cryosphere and how changes there may affect people in general, in particular people in Europe. Some of the material should also be suitable for educational purposes. The operational user typically performs overall assessments and provides information to decision makers as well as people in general – like EEA, UNEP, WWF, Greenpeace as well as national institutes providing information to national ministries. The operational user would typically focus on the climate-change indicator variables and trend analysis of those. The scientist typically needs rather basic data for own investigation. The scientist is able to use the service to download products of interesting geophysical variables that can be used to, e.g., study regional climate changes.

All the products are based on aggregation of a number of observations within a time period. The aggregation periods provided are month, season (Season 1 = December-January-February (winter season), etc) and year. Most map products provided are composed of a set of layers for the aggregation period: Average, maximum, minimum, and standard deviation of the observed variable, as well as number of observations and confidence per pixel.

All products are available through a web portal at http://www.euroclim.net (see the main portal structure in Figure 5). The products can be downloaded in Hierarchical Data Format (HDF). All map products are in polar stereographic projection. A 1 km grid is defined for all map products. Most observational map products are provided in 1 km resolution (20 m for Svalbard glaciers), while the climate model products are provided in 50 km resolution. Satellite and in situ data are currently being back-processed as long as possible in order to obtain as many years of observations as practically possible.

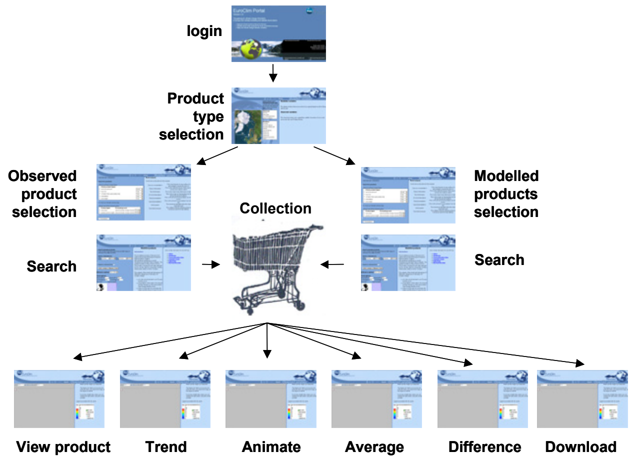

Figure 5. Structure of the part of the portal for product searching and

6. CONCLUSIONS

Changes seen in the Arctic are the early signs of climate changes that are likely to affect much of the world over the next decades. The Arctic temperature has increased at almost twice the rate compared to that of the rest of the world over the past few decades, in particular during winter. The EuroClim project has developed an advanced monitoring and modeling system for climate variables. The system observes cryospheric variables using satellites and in situ measurement stations and produces a portfolio of products based on these observations. The system also provides climate model products, from both historical runs and a scenario, where the observation products have been used for validation. The climate modeling results are provided as another product portfolio. The products are available through a web service developed by the project.

The EuroClim network includes the portal and a set of data processing and storage nodes. The observation nodes handle automatic processing of remote sensing and in situ datasets for the extraction of cryospheric variables and generation and storage of the actual observation products. The climate model node transfers the model output data from its original structure to EuroClim raster products.

The service is provided free of charge through the web portal at http://www.euroclim.net. The service is currently semi-operational, and will be further developed into a fully operational system in the next few years. EuroClim is intended to be a key service for cryospheric climate variable products in the Global Monitoring for Environment and Security (GMES) system being developed by Europe.

7. ACKNOWLEDGEMENTS

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