EuroClim: A System for Enhanced Modelling of Climate Change in Europe by the use of Satellite Monitoring of the Cryosphere

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Abstract – **One of the potentially greatest threats to human beings is climate change. Climate scenario modelling indicates 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 it is not known whether we will experience regional cooling or warming in a future warmer world in general.**

The EuroClim system, currently being developed a European consortium, will be an advanced tool for climate monitoring and scenario modeling for the support of a sustainable development and protection of the environment in Europe. The European cryosphere will be the main indicator system. Snow and ice variables are extracted from satellite data and processed by advanced algorithms. The cryospheric information is applied in a regional climate model producing enhanced climate scenarios. Statistical tools extract the information needed by the users, like extreme weather, changes in the length of the growing season, etc.

I. INTRODUCTION

Although there will be warming on the global scale there will be large regional variations in the climate that will affect various parts of the world differently [1]. Most likely, global warming will change the living conditions in Europe significantly. The population distribution may change and the weather will show more extreme conditions, like flooding and hurricanes.

The Arctic ice cover and high-mountain seasonal snow cover will be monitored by EuroClim over decades in order to continuously assess the climatic health of Europe. Observations already indicate that the Arctic may be free of sea ice in the summer within 50-100 years. Therefore, it is of great importance to monitor the cryosphere in order to make updated climate scenarios and be able to take the necessary measures in time to limit the consequences to European citizens.

The main objective of the EuroClim project is to develop an advanced climate monitoring and prediction prototype system for Europe. The EuroClim system includes sub-systems for extraction of cryospheric variables from remote sensing data. Cryospheric variable products are stored in an advanced, distributed database system connecting all the storage and processing sites comprising the EuroClim network. Each database in the network is an innovative storage system for multi-dimensional raster data. Sub-systems for climate modelling and statistical analysis apply the cryospheric variables in order to do scenario analysis, trend estimation, uncertainty assessments, etc. A web-based system presents the results – from cryospheric products to high-level information showing possible climate changes and consequences thereof.

The project is establishing a 20-year historic database of selected cryospheric variables in order to have a baseline dataset for climate modelling and statistical analyses. The database will be updated continuously by the EuroClim system. About each year, a new climate-modelling scenario will be computed based on the updated cryospheric database. The cryospheric observations will be used to tune the climate modelling such that observations and modelling results match reasonably well for the time period covered by the database. Based on the tuned model, scenarios for 50-100 years will be computed. A regional coupled ocean-atmosphere model, covering Europe, with a global coupled model of coarser resolution making the boundary conditions, is applied.

EuroClim is a EU RTD project within the IST programme. Ten European research institutes and companies participate in the three-year project, which started in September 2001. The partners are: Norwegian Computing Center (project coordinator); HUSAT Research Institute, Loughborough University; Active Knowledge; Norwegian Meteorological Institute; Geological Survey of Denmark and Greenland; Max Planck Institute for Meteorology; NORUT Information Technology; Norwegian Polar Institute; Scott Polar Research Institute, University of Cambridge; and Kongsberg Spacetec.

II. CRYOSPHERIC VARIABLE RETRIEVAL

The EuroClim system will monitor the European cryosphere – the Arctic region and high-mountain areas with seasonal snow and glaciers, including Greenland. Examples of satellite data sources are ENVISAT's sensors MERIS, AATSR and ASAR, Terra's MODIS and Radarsat. Cryospheric products are currently being defined. Most of them will be monthly products with 1 km resolution.

A. Remote sensing of sea ice

The sea-ice variables to monitor include sea ice concentration and sea ice thickness.

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Sea ice concentration will be based on a multi-sensor algorithm using Bayes theory to combine SSM/I, scatterometer data and in the future AVHRR. The AVHRR algorithm outputs probability of sea ice. The SSM/I algorithm is a smooth combination of the NASA/TEAM algorithm and the Bootstrap (Comiso) frequency mode algorithm. This ensures an optimum performance over both marginal and consolidated ice.

For sea ice thickness, a correlation has been demonstrated between backscatter gradients in a SAR image and the sea ice thickness distribution [2]. This offers enormous potential for inferring ice thickness and hence (from correlations between successive images) ice fluxes in the Arctic. New multi-sensor satellites (e.g. Envisat), and the data processing techniques developed in this project, aim to make operational measurements possible before the launch of ESA's Cryosat. Cryosat will measure sea ice thickness precisely by using altimeter data but will operate for 3 years only.

B. Remote sensing of snow

A large range of methods has been developed for snow-cover mapping. Spectral unmixing is currently one of the most accurate algorithms [3]. However, it is supervised and very time consuming. A new approach to spectral unmixing has been proposed by [4]. The method measures certain features in the observed spectrum which are compared to potential endmember spectra in order to predict the actual endmembers and the amount of them (e.g., snow cover area). The method has so far been tested on field spectrometer data only. The project intends to improve it into an operational algorithm.

SAR data has demonstrated the capabilities of detecting the extent of wet snow cover in mountainous areas. In order to achieve all-weather snow-cover mapping capabilities, the project will develop a multi-sensor algorithm using optical data as the basic source and include SAR data in the image time series under cloudy and wet conditions in order to obtain frequent observations.

The spectral albedo of the snow is another important cryospheric variable. Dry, weakly metamorphosed snow reflects most of the incoming shortwave radiation back into space. During snowmelt the albedo decreases rapidly and may drop from about 80% to about 10% within few weeks, completely changing the surface energy-balance. Snow spectral albedo cannot be measured accurately through the whole optical part of the spectrum due to strong atmospheric interference in parts of the spectrum and the anisotropic behaviour of the reflectance. The standard way to model the spectral reflectance is by means of the model of Warren and Wiscombe [5]. The model is calibrated by giving grain size and the content of impurities. However, the strong anisotropic effects of strongly metamorphosed snow must be taken into account to determine the actual spectral reflectance, which is not done by this model. The project aims at developing a complete empirical model for the bi-directional spectral reflectance covering the wavelengths from 400 nm to about 10 µm. Currently, any model is far from doing that.

Other snow-related variables that will be included in the system are snow wetness, snow temperature and snow grain size.

C. Remote sensing of glaciers

Small glaciers are responding to changes in climate, e.g., on air temperature and precipitation, on a decadal scale. Therefore, such glaciers are important climate change indicators. Glacier mass-balance measurements are used to monitor whether glaciers are retreating or advancing. The traditional method for mass-balance measurements is by direct in situ stake measurements at the end of the accumulation and ablation seasons, respectively. In the late 1980ies and early 1990ies attempts were made to use optical satellite remote sensing as a tool for locating the ELA on these glaciers [6]. However, the presence of superimposed ice, which is common on many Svalbard glaciers, made it impossible to locate the ELA with required accuracy. Radar satellite data in combination with ground penetrating radar have shown promising results. Reference [7] showed that the use of SAR data improved the localisation of the ELA because of the penetrating capabilities into the snow/ice of radar signals compared to optical signals.

III. CLIMATE DATA ANALYSIS AND MODELLING

Numerous global climate simulations have been carried out during recent years, but still with rather course resolution (about 300 km) due to limited computer resources. Regional climate models have during the last decade been utilized with success to improve the regional quantitative estimates of, e.g., climate change. Regional models are capable to reproduce the large-scale behaviour of the driving global models, and are been run with resolution of about 30 to 70 km for periods of up to 30 years.

The project will apply the regional model REMO with boundary conditions from ECHAM [8]. Both are coupled atmosphere-ocean models. An approach is currently being developed for improving the model parameterisation using satellite-measured cryospheric variables. The model output and cryospehric observations will be compared and the model parameterisation modified accordingly in an iterative manner until model results and observations show reasonable agreement.

IV. STATISTICAL SPACE-TIME ANALYSIS

Reliable trend estimation is one of the statistical problems the project will focus on. The analysis of environmental time series data at a fixed point in time has received generous attention in the statistics literature. To draw objective scientific conclusions about a trend, both the trend estimate and a measure of its uncertainty must be given. This often leads to adjustments for temporal correlation in the data. Formal methods for trend assessment rely heavily on the assumed parametric form for the trend. Often, there may be little scientific support for assuming that the parametric form is, say, linear. Alternatively, we may estimate a non-parametric trend through a local regression approach [9].

V. THE EUROCLIM SYSTEM CONCEPT

The principal system components and the major data flow between them are sketched in Fig. 1.

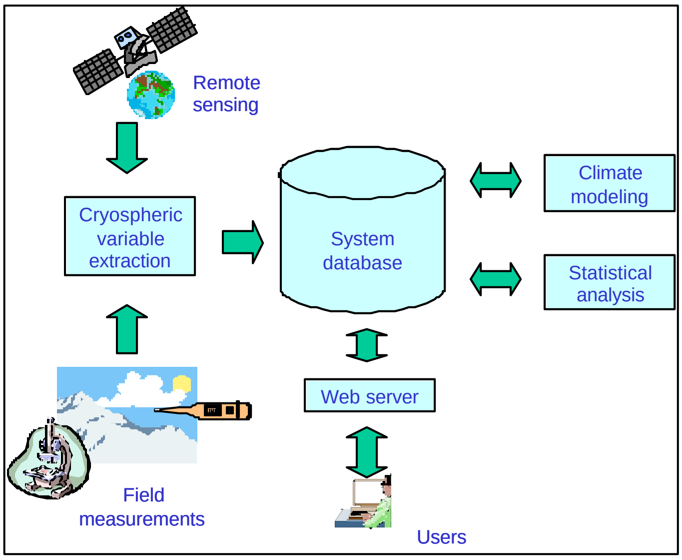

Fig. 1. Principal EuroClim system components and the dataflow between them

Input to *Cryospheric Variable Extraction* is remote sensing data, in situ data and ancillary data. Cryospheric variables are extracted and stored into the *System database*. Space-time data sets are retrieved from the database and analysed by the *Climate Modelling* and *Statistical Analysis* giving the climatic information required. The *Web Server* provides user access to the EuroClim system.

The system will in practice be implemented using a distributed approach with several systems for cryospheric variable extraction, including several databases. The various parts of the system will be at different geographic locations linked together over the Internet. The distributed approach gives the freedom to arrange for suitable pipelines for extracting the cryospheric variables from the different sets of raw data. The distributed EuroClim approach is not to assume new unrealistic international structures of responsibility, but adapt to the current organisational situation. Each pipeline is likely to be operated within one organisation.

The cryospheric variables will be stored in a common map projection in raster format in RasDaMan databases [10]. The 4-dimensional (space-time) functionality of the database makes it possible to extract time series of data for a selected area in a simple manner. The database also has a multi-spatial functionality, which makes it possible to combine data from various sources of different spatial resolution, including point sources.

VI. CONCLUSIONS

Through identification and monitoring of key climate parameters, the EuroClim project will provide an early-warning system for climate change, helping politicians to take necessary measures in time to limit the negative consequences on safety, health and life quality. The establishment of a system for long-term monitoring of data and continuous updating of climate change indicator parameters is crucial to ensure the necessary continuity.

Two groups of potential users for the results of the EuroClim system concept have been identified. The first of these are the *operational users* or organisations that would want to have raw variable data and have their own means of analysing and interpreting it. These include national scientific research institutions with responsibilities to their national government. The second group is the general *public* who just require a summarised presentation of the data produced by the EuroClim system.

Project partners with national operational responsibilities have committed themselves, with assistance from the industrial partners in the consortium, to make EuroClim an operational long-term monitoring system if the prototype system is a technical and cost-effective success.

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