P2.3 ADVANCED HYDROMETEOROLOGICAL ANALYSIS AND FORECASTING FOR WATER MANAGEMENT DECISION-MAKERS IN SLOVENIA

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1. INTRODUCTION

This paper discusses the current procedures used by the Environmental Agency of the Republic of Slovenia (EARS) for forecasting streamflows and extreme events. It focuses on the decision-making process and how new emerging science and technology will be used to improve the quality of water resource management, and protection of life and property in floods and droughts. With Slovenia's entry into NATO and the European Union in 2004, it is seeking to enhance its ability to fully use new science and technology to improve hydrometeorological forecasts. Slovenia receives between 800 and 3000 mm of annual precipitation from the Pannonian basin to the Julian Alps respectively, which creates unique challenges for water managers and hydrometeorological forecasters especially under recent changing climatic conditions, when extremes of drought and floods appear to occur more frequently.

2. BACKGROUND

Examples of the extreme drought of 2003 and very wet 2004 water years show the dramatic range of variability, and how the hydrologic and atmospheric forecasters are able to provide information of immediate value to the water managers on the Sava, Soca, Drava, and other major river systems in Slovenia. EARS produces daily forecasts of discharges of all major Slovene rivers. One of its main purposes is flood early warnings. EARS decided to use the HBV model developed by SHMI. In 2003 and 2004 preliminary forecasts and calibration of the model were performed. There are still many imperfections, mainly in the data input side.

This paper will discuss how the Global Land Data Assimilation System (GLDAS) – Land information System (LIS) products may improve the streamflow forecasts. The limited area numerical model ALADIN has been used operationally in weather forecasting practice for eight years in EARS. The performance is generally good, excellent in some fields (e.g. wind forecasts), and quite poor in case of precipitation. Implementation of detailed microphysics and non-hydrostatic dynamics is planned in forthcoming years in The ALADIN/AROME community; it is expected that precipitation forecast scores will improve. Results from this model improvement will be evaluated using the RiverWare modeling framework.

2.1 Water Resources in Slovenia

For hydrological modelling and river basin water management the Slovenian territory is divided into 583 watersheds, figures 1 and 2. Area of these watersheds varies from 536 km^2 to 0.17 km^2. Smaller parts are on impervious areas and larger one in Karstic region, where watershed borders could not be established on orographical characteristics of region alone due to the important groundwater flows.

Differences between low medium and high waters are great, which is typical of the majority of Slovenian streams, thus emphasizing their torrential features. Only in the Karst streams, where the water is retained underground, these differences are smaller. For example some extreme ratios for the past 30 years range from 1:26:714 for low medium and high waters at Zamusani on the Pesnica river.

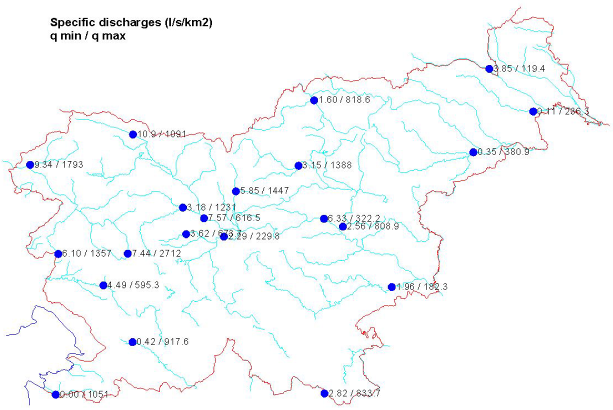

Figure 1. Slovenian maximum and minimum specific discharges showing a large range of extreme values.

Surface specific discharges have a large range shown in Fig. 1. from 9 to 1734 l s^1 km^2 in the Julian Alps to 0.0 to 1051 in the southwest Medeterranian region above Piran. The precipitation on the territory of Slovenia (20,320 km^2) annually totals 1567 mm on the average, or 1005 m^3/s (31 693 680.000 m^3) of water. Of which 417 m^3/s (650 mm)

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evaporate or 13 150 512.000 m^3 ~41 %. The total outflow from Slovenia is 588 m^3/s (917mm), (18 543 168.000 m^3).

For precipitation measurements there is, beside rain gages, a source of information also the C-band radar situated in the central part of the country on Mt. Lisca. The rainfall Quantitative Precipitation Estimates (QPE), derived from radar have many errors due to ground clutter caused by mountain peaks, beam blocking, and radar beam curvature effects on the base heights of precipitation at long distances from radar, and differences in vertical reflectivity profiles, (Divjak 1992, Rakovec 1997). The key question is how to implement satisfactory QPE for rainfall under such conditions. Another question is the time-scale for useful radar data in a nowcasting tool (Zgonc and Rakovec 1999).

2.2 Water Use

Ten percent of the Slovene population uses surface water resources for water consumption, and those resources are located mainly in the Karst region and are sensitive to the rainfall distribution. Thirty percent of energy production, about 3,000 GWh, is derived from hydropower plants. Additional power production from thermal power plants is also closely related to the water regime and suffers in the period of low water flows. The hydrological forecast is essential for power production. Water use for irrigation, industrial consumption and fish farming is rather small, but consumers also suffer from droughts.

2.3 Water Management Decision Support Tools

The RiverWare modeling framework used for decision-making is being investigated to see how it may apply advanced scientific methods to improve water management within Slovenia. RiverWare, developed by the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES), University of Colorado in partnership with the US Bureau of Reclamation, Tennesee Valley Authority, and US Army Corps of Engineers, is a state-of-technology system that enables water managers to fully describe the hydrologic and hydraulic characteristics of a river system including dams, diversion structures, and hydropower plants, to better manage the distribution of water. It is driven by streamflow forecasts at key inflow points, thus it is an ideal test bed for evaluating impacts of scientific enhancements to hydrologic forecasts.

3. HYDROMETEOROLOGICAL DATA AND FORECASTING

Hydrological forecasting in Slovenia depends mainly on precipitation prediction. Both forecast offices – meteorologiocal and hydrological – are collocated in the EARS, so there are no problems concerning data flow and exchange of information and understanding of forecast model limitations and capabilities.

3.1 Networks

A network of hydrological monitoring is the foundation of the entire hydrological activity. The development of this network has been fostered, above all, to provide the protection of settlements against floods, the utilization of water for power production, technological purposes and water supply, and in the recent times, to satisfy the increasing needs for research investigations and environmental protection. The first water gaging stations began to operate as early as 1850. There are 160 operating gaging stations in Slovenia in 2004, of which 28 stations are on-line (Fig.2).

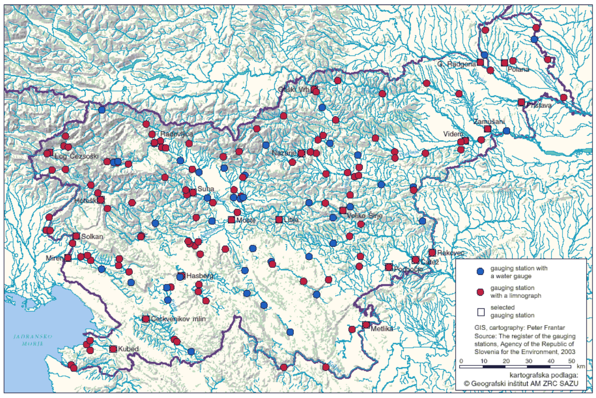

Figure 2. Network of 160 gauging stations with 28 on-line real-time stations.

3.2 Hydrologic Models

The Slovenian hydrological forecasting service operationally uses regression models for predicting the peaks of flood waves. In addition to regression models, the conceptual, physically based rainfall-runoff models are used for some basins. The WMS (Watershed Modeling System) software and HEC-1 model have been introduced in hydrological modelling (Kobold and Sušnik, 2000). HEC-1 model is limited to simulations of single storm events because the soil moisture recovery is not taken into account during periods of no precipitation. In the year 2003 the HBV model was tested on the Savinja river test basin as research contribution in EFFS (European Flood Forecasting System) project (EFFS, 2003).

3.3 Meteorological Models

ALADIN model (ALADIN stands for Aire Limitée Adaption Dynamique Développement International) has been proposed by Meteo-France and developed in collaboration with central-European meteorological services (later also partners from western Europe and north Africa have joined the project). A unique solution for model development has been chosen with aim to benefit as much as possible from existing French spectral global model ARPEGE. Therefore, the ALADIN model also uses spectral representation of fields for calculation of derivatives (it uses bi-Fourier transformation which requires bi-periodic field; that is achieved by adding a fictious "extension zone" along lateral boundaries). Computational domain of Slovene operational model configuration including extension zone is presented in Fig. 3. The Annual precipitation chart is added to figure 3 in order to show why running accurate high resolution Local Area Model (LAM) is important for meteorological and hydrological forecasting in Slovenia.

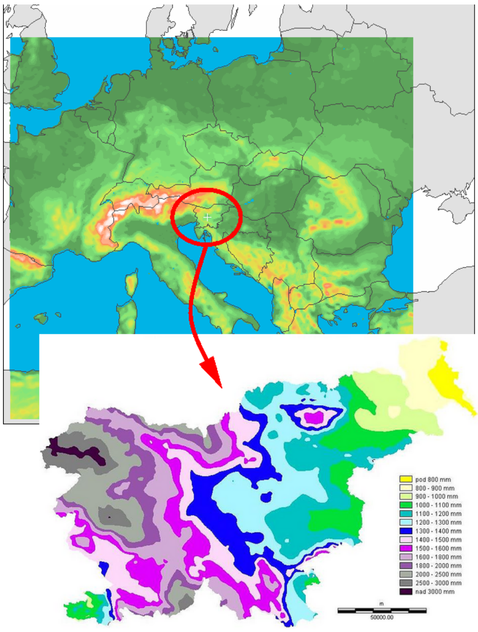

Figure 3. Computational domain of Slovene operational ALADIN configuration (color scale presents orography inside computational domain, LBC coupling and extension zone is in grey). Position of Slovenia is encircled in red, yearly precipitation map is added in the bottom.

The ALADIN model has a non-hydrostatic option (Bubnova et. al., 1995) and uses a 3DVAR assimilation system. It is planned that in 2008 the next-generation numerical model (called AROME – Applications for Research and Operations at Mesoscale) will become operational at least in some of the partners' services. AROME will be suitable to run in very high (convection-resolving) resolution which will hopefully improve quality of precipitation forecasts. http://www.cnrm.meteo.fr/aladin/

Recently a lot of attention was devoted to assimilation of conventional and non-convetional, remote sensing data into ALADIN and Meso-NH model (the latter being a French research non-hydrostatic mesoscale model which will – together with ALADIN – converge into AROME). An example of successful application of two-step initialization technique which uses both optimal interpolation of conventional data and humidity adjustment based on radar and satellite data (Ducrocq et al, 2000; Ducrocq et al, 2003) is presented in Fig. 4. We may expect improvement of high resolution precipitation forecast in near future.

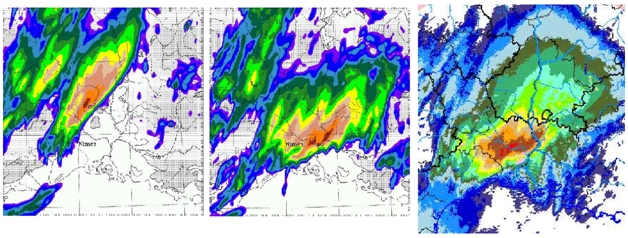

Figure 4. 12-hour precipitation accumulation (8th September 2002 12 UTC – 9th September 2002 00 UTC). Meso-NH control run (left), Meso-NH run using two-step mesoscale initialization technique (Ducrocq et al, 2000 – middle) and radar product over approximately same domain (southern France). Courtesy of Veronique Ducrocq.

3.4 Radar

A C-band radar has been operated by Slovene meteorological service since 1984. The radar is located on Lisca mountain in eastern part of Slovenia (Fig. 5). Most of the country is within 100km range from radar, whole Slovenia and parts of neighboring countries are within 200km range. Radar coverage is reasonably good (except mountain valleys in north-west which are shadowed by relief) and (after suitable processing of raw radar data) allows good precipitation amount estimation.

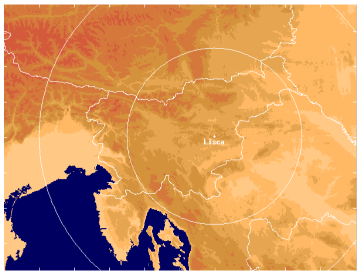

Figure 5. Map of Slovenia with indicated position of radar and both (100km and 200km) range circles.
On-line radar images:
http://www.arso.gov.si/podro~cja/vreme_in_podnebje/napovedi_in_podatki/radar.html

4. CHALLENGES TO BE SOLVED

Challenges in Slovenia are connected to large climatic variability over small area (Fig. 3 bottom). In such an environment, where small scale phenomena (small scale precipitation systems and torrential nature of rivers and flash floods) prevail, it is challenging to provide accurate hydrological prediction and warning systems.

Snow cover is another challenge to be dealt with in Slovene mountainous terrain; snow pack evolution has large impact on avalanches, floods and water use. Use of new techniques emerging from fields of remote sensing, and newly developed modeling and assimilation systems is the way to tackle these difficult challenges.

Integration of hydrometeorological forecasts into the water resources decision-making process using advanced automated decision support systems is a proposed solution. Hence, the purpose of this paper is to describe the capabilities and needs of the Slovenian hydro-meteorological service in an attempt to initiate interagency, interdisciplinary, and inter-governmental cooperation to meet the challenges.

5. RECENT PROJECTS

Slovenia has been involved in a number of regional European Commission projects that are related to improved hydro-meteorological analysis and prediction of: streamflows, quantitative precipitation estimation (QPE) and forecasts (QPF), and extreme events, including floods and droughts. This section describes key EU projects which will enhance the proposed plan, and may benefit from the results of the proposed work.

5.1 HBV

The HBV model (Bergström, 1995) is a semi-distributed conceptual rainfall-runoff model for continuous calculation of runoff, developed by Swedish Meteorological and Hydrological Institute. The model consists of subroutines for snow accumulation and melt, a soil moisture accounting procedure, routines for runoff generation, and a routing procedure. Input data are precipitation, air temperature and potential evapotranspiration. Normally, monthly standard values of potential evapotranspiration are sufficient. The principal output is discharge; however, the other output variables relating to water balance components (precipitation, evapotranspiration, soil moisture, water storage) are available from the model. The model has a number of parameters, values of which are estimated by calibration. There are also parameters describing the geographical characteristics of the basin. The basin can be separated into a number of sub-basins and for each one of these, a subdivision into elevation zones can be made. Each elevation zone can further be divided into different vegetation zones (forested and non-forested area…). The calibrated model can be used for hydrological forecasting in two ways: short-range forecast and long-range forecast.

During the European Flood Forecasting System (EFFS) project, the HBV model was set up for the Savinja River test basin. This basin with a drainage area of 1848 km^2 is very often affected by exceptional precipitation amounts and intensities leading to relatively frequent high water events, more frequently in autumn. The length of the main watercourse is 101 km, and is the largest tributary of the Sava River, main Slovenian river system. The upper part of the basin extends over the high mountainous area of the eastern Karavanke and the Savinja Alps with peaks higher than 2000 meters. The altitudes of the plain area, in the middle reach of the Savinja, are between 200 and 400 meters. The basin is mainly forested, especially in the mountainous and hilly areas. Forests cover nearly 60% of the basin. The bottom of the river valleys are densely populated and used mainly for agriculture. These areas are the most affected in floods. Flood events are short time duration events of one or two days. Due to its runoff characteristics the Savinja River has the important influence both on developing flood waves, and the forecast for the lower Sava River in Slovenia. Its drainage area can contribute up to 40% of the Sava River's discharge in extreme meteorological events.

In the 2003, the HBV model version HBV-96 (Lindström et al., 1997) was tested on the Savinja river test basin in a research contribution to the EFFS project (EFFS, 2003). Two HBV models were set up for the Savinja River basin - a model with daily data and a model with hourly data. The time step in the HBV model is usually one day. However, in Slovenia, flash floods caused by intense precipitation, especially in mountainous regions are very frequent. Hence short travel times of the flood wave require a shorter time step of one hour. These more extreme hydrologic characteristics will challenge any hydrologic models that are developed and tested in this mountainous country.

5.2 AWARE

AWARE is the European Union project for development of tools for monitoring and forecasting **A**vailable **WA**ter **RE**sources in the mountain environment. The aim of AWARE is to provide innovative tools for monitoring and predicting water availability and distribution in those drainage basins where snowmelt is a major component of the annual water balance, a common condition in Alpine catchments. Recent droughts observed in these basins call for the need of an efficient technology to predict medium and long-term flows for sustainable water resources management.

The project will develop appropriate mathematical models to represent snow-pack dynamics, and snowmelt runoff. These models will be expressly designed to integrate Earth Observation data, and in-situ hydrological and meteorological measurements, thus introducing a novel approach to the representation of the pertinent physical processes at the most appropriate time and space scales.

See: http://effs.wldelft.nl/index.htm

Comparisons with GLDAS and LSMs – LIS products with detailed observations and models developed in AWARE would prove most interesting and beneficial to the international hydrometeorological community.

5.3 VOLTAIRE

In the Mediterranean area, the climatic effects of the distribution of precipitation are complicated by the effects of mountain chains, which act as physical barriers to atmospheric circulation, and often introduce large precipitation gradients within small regions. Given such geographical complexity, an improvement in observational techniques is a prerequisite for precipitation estimates related to climate problems: associated on the one hand, to **droughts** and, on the other hand to the frequency of **extreme rainfall events**.

One of the specific aspects of Mediterranean climate is such that the absence (or presence) of few precipitation events may switch the climate characteristic from semi-arid to arid (or viceversa). The evaluation of climatic trends depends on the accurate estimate of intrinsically complex (both in time and space) precipitation fields, especially during extreme events, whose statistic could represent a fingerprint of such trends.

Measuring and monitoring precipitation over the Mediterranean Sea has not yielded satisfactory results so far (apart from some coastal and insular regions covered by land-radar), but it will be thanks to the precipitation radar onboard the future Global Precipitation Measurement (GPM) satellite mission (able to extend the recent TRMM observations to higher latitudes than the present limiting one at 35 N).

Voltaire's scientific goals are to: 1) to compare data quality insurance schemes for ground and space radar; to use radar-adjusted and gauge-adjusted precipitation fields as ground validation for TRMM radar (in order to assure its data validity in areas not covered by ground radar); to gain in experience and prepare European participation in GPM; 2) to improve the accuracy of surface-radar-derived precipitation fields in Mediterranean test sites using in situ measurements and adjustment techniques tailored to mountainous and hilly regions; 3) to quantitatively compare precipitation fields as represented by numerical models, by adjusted ground-radar and satellite radar (where available, i.e. in Cyprus).

The accuracy of land-radar estimates at ground will be improved by addressing the various sources of error in mountainous terrain in a painstaking manner and by focusing on the variability (continuity) of precipitation fields. The improvement in the accuracy will be reached through the following milestones: clutter elimination, correction for visibility and/or vertical profile correction, gage-adjustment. **See: http://voltaire.polito.it/**

5.4 EFFS

The EFFS project aims at developing a prototype of a European Flood Forecasting System for 4-10 days in advance. This system provides daily information on potential floods for large rivers as well as flash floods in small basins. This flood forecasting system can be used as a pre-warning system to water-authorities that already have a 0-3 day forecasting system. The system takes advantage of currently available Medium-Range Weather Forecasts (4 - 10 days) to produce reliable flood warnings beyond the current flood warning period of approximately 3 days. http://effs.wldelft.nl/index.htm

6.0 INTEGRATED MULTI-SENSOR AND LAND SURFACE MODELING PLANS

Our plan is to integrate a series of multi-sensor and land surface models and validate, test, and apply results from these projects to meet the challenging analysis and forecasting needs of Slovenia. This section describes the key components of our plan.

6.1 Global Land Data Assimilation System – Land Information System

The GLDAS system developed by a team of remote sensing, land surface modelling experts, and data assimilation experts at NASA, NOAA, and a team of universities is designed to integrate interdisciplinary efforts to provide a comprehensive high-resolution land surface model. More information about LIS may be found at

http://lis.gsfc.nasa.gov and http://ldas.gsfc.nasa.gov

The modeling system simulates physical processes including precipitation, snow accumulation and ablation, development of soil moisture, and the surface and groundwater hydrologic flows. It is operational today at a12 km grid spacing, and is planned to resolve 1 km information soon. Our goal is to evaluate and test this land surface modeling system in Slovenia's extreme precipitation regimes and in very steep mountainous regions of the Julian Alps, and the Karavanke and Savinja Alps in the headwaters of the Sava and Soca rivers and the Savinja River which contributes to 17% of the Sava drainage and plays a major role in floods, where ~200 to 400 mm / 24 hours may occur.

6.2 MODIS Satellite

A flagship satellite sensor on board EOS Terra and Aqua satellites is the MODerate resolution Imaging Spectroradiometer (MODIS). MODIS data provides global land, water and atmospheric data at a 1-km resolution (2 bands at 250 m for land products) and up to four times per day. In addition, MODIS data are archived and processed as specific products for the user community. For snowpack monitoring, algorithms for the instruments, MODIS and AMSR-e, have been developed to assess changes in snowpack growth and melt. During the spring and early summer months, snowmelt and sublimation processes become critical variables to monitor as snow translates into the needed water source for lower lying populated and agricultural productive areas. The remote sensing aspects of snow-monitoring can measure some of these changes, but current physically based snow models contribute to the enhanced knowledge of these changes and predictability of water inputs into the river systems. More information is available at: http://modis.gsfc.nasa.gov/

6.3 QPE-SUMS

Radar data from Sloveina's 5-cm radar will be used with satellite data in QPE-SUMS to better estimate the QPE for snow and rain. The Quantitative Precipitation Estimation and Segregation Using Multiple Sensors-2 (QPE-SUMS) system (Gourley et al., 2001) has been running in real time for nearly six years in several areas of the U.S. and abroad (Taiwan, Thailand, and Hungary). QPE-SUMS adaptively calibrates GOES infrared satellite data from radar-estimated precipitation rates below the melting layer during the cool season. Stratiform and convective precipitation is segregated, allowing application of different reflectivity-rain rate (Z-R) relationships to each. A 3-D objective analysis mosaicking scheme enables use of data from the radar with optimal sampling of a given volume. Eta model temperatures and a bright band detection algorithms are used to distinguish rain from snow. Plans are to incorporate an adjustment based on surface gauge measurements. Reclamation has been collaborating with National Severe Storms Laboratory's Worldwide Integrated Sensor Hydrometeorology (NSSL/WISH) group, the developer of QPE-SUMS, to refine the system, particularly for snowfall measurement.

Data and forecasts from the GLDAS land surface models, and observations from the MODIS satellite and the QPE-SUMS (Hunter, Vashaloff, Howard) will be used in hydrologic runoff models to predict streamflow, avalanche, and debris flow conditions. Streamflow will be used to initialize the RiverWare decision support system, which water managers on the Sava River use to assist in the regulation of hydropower and flood waves. RiverWare is an advanced decision support system used by the US Bureau of Reclamation in major river systems in the Western United States including the Colorado, Upper Rio Grande, Columbia, and Truckee Basins (Matthews and Frevert 2003, Fulp et al 2000, Arsenault et al, 2003). It has been recently applied in Slovenia at the University of Ljubljana and the Sava River Hydropower Project (Brilly), and the Environmental Agency of the Republic of Slovenia (Gregoric, Polajnar). The headwaters of the Sava River are in the Julian Alps, and it runs to the eastern end of Slovenia into Croatia and down the Balkan Pensulia through Bosnia and Serbia to the Danube at Belgrade. The Sava is part of the Black Sea catchment basin. This project will enhance the Danube Flood Management Project, an ongoing EU cooperative international flood management project in South Eastern Europe.

6.4 CAS2D GSSHA - Hydrologic Runoff Model

Plans include the development and testing of the Gridded Surface Subsurface Hydrologic Analysis (GSSHA) which is the reformulation & enhancement of Cascade of Planes, 2-Dimensional (CASC2D) model that solves transport equations using finite difference and finite volume techniques. It includes 2-D diffusive-wave overland flow routing and 1-D diffusive-wave channel routing. CASC2D has been used in the Sava to predict streamflows in the past and it shall be updated for current applications in partnership with the US Army Corps of Engineers, Engineer Research and Development Center, if funding and resources permit. This will provide an ideal test-bed to evaluate inputs from the GLDAS and QPE-SUMS for improved streamflow analysis and prediction in Slovenia.

6. CONCLUSIONS

Plans to improve hydrometeorological analysis and forecasts using new products from the multi-agency Land Data Assimilation System (LDAS) and Land Information Systems (LIS) developed at NASA, NOAA, and with the academic community were presented. Demonstrations of these emerging technologies will be conducted in 2004-2005 to evaluate the accuracy of snow water equivalent estimates from satellite and radar systems, and land surface models of the snowpack evolution using high resolution (1 km) grids and surface observations at key sites including on Mount Triglav – Kredarica observatory (2514 m msl), Slovenia's highest mountain where a meteorological observatory is manned throughout the year. Future presentations will provide documentation of the success of this newly emerging technology in managing Slovenia's water resources and improving flood and drought forecasts and responses.

7. ACKNOWLEDGEMENTS

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9. Major Web Links:

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http://nfp-si.eionet.eu.int/eionet-en/
http://www.meteo-drustvo.si
http://www.usbr.gov/pmts/rivers