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An End-to-End Hydrometeorological Forecasting System

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1. INTRODUCTION

Baron Advanced Meteorological Systems, in collaboration with Lockheed Martin Corporation, the Hydrologic Research Center, the US National Weather Service Office of Hydrology, and researchers at NASA and the National Institute of Hydrology and Water Management (NIHWM) in Bucharest, Romania, have developed an end-to-end hydrometeorological forecasting system. The system relies upon gauge-corrected hourly to sub-hourly Doppler-radar-based QPF estimates supplying inputs to advanced hydrological model forecast systems. Numerical weather prediction models comprise additional, longer-range elements of the forecast system.

For larger-scales, the NWSRFS (National Weather Service River Forecast System), using the Sacramento Soil Moisture Accounting Model (SAC/SMA) and appropriate river/stream routing, is used to detect and forecast river flood/stage. Nested within this, the contributions from upstream higher-order basins are estimated with the TOPLATS model running as a land-data-assimilation system (LDAS). Both mean-areal precipitation estimates (needed for the SAC/SMA model) and very high resolution estimates (needed for the fully distributed TOPLATS model) are derived from the networked-mosaic Doppler system.

The system also includes a flash-flood guidance component, in which soil-moisture deficits are estimated from either the SAC/SMA model or the TOPLATS model. The deficits are used together with up-to-date (1 hr, 3hr, 6hr, and 12hr) precipitation totals to estimate the amount of additional precipitation needed for streams to reach bankful. Our system is unique in that it is comprised not only of the modeling components including a fully distributed hydrological model, but of the radar-hardware and interpretation software needed to drive the models: that is, it is a complete end-to-end system that may be deployed anywhere in the world.

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2. SYSTEM OVERVIEW AND EXAMPLE: DESWAT

The **Des**tructive **Wat**er Abatement and Control of Water Disasters (DESWAT) program, recently authorized by the Romanian government, is the first example implementation of the end-to-end system as it becomes functional over the next three years. DESWAT was established as a follow-on to the SIMIN (National Integrated Meteorological System, Ioana, et al., 2003) project, which integrated weather radars, automated weather observations stations, lightning detection networks, satellite data acquisition, NWP models, buoys, and forecaster decision/display systems using various telecommunications platforms in Romania. DESWAT moves beyond this by accessing the SIMIN data as inputs to a river/stream and flash-flood forecast decision support system.

The main objectives of the DESWAT project are:

- Upgrade the hydrological monitoring system:
  - Upgrade hydrometric sensors and data collection - automatic stations:
    - about 600 stations – with water level, air and water temperature and precipitation sensor.
    - about 70 stations - with water quality sensors (dissolved oxygen, conductivity, pH, turbidity, etc).
  - Enhance the communication system between the upgraded hydrometric sensors and the NIHWM using two from the following systems:
    - radio data transceiver module supporting voice and data
    - GSM mobile telephone using SMS
    - satellite Data Collection Platform transmission

- Deploy hydrological data integration software capable of:
  - o Ingest and analysis of a massive volume of data from various sources: weather and hydrometric station sensors, radars, satellites.
  - o Interpret quickly all these data using improved river forecast models.
  - o Generate forecast products.
  - o Deliver the forecast products to the public and to the decision makers in flood defence.

Figure 1 shows a conceptual overview of the DESWAT system (without the sensor detail) as it was envisioned in June of 2003; only minor changes have been made at this time.

2.1 National Hydrologic Radar Processing System (NHRPS)

The SIMIN-based component, shown in the diagram as the National Hydrologic Radar Processing System (NHRPS), features the integratation of sparsely spaced surface hydro- and meteorological-type measurements with high-spatial resolution remotely sensed radar imagery. This includes integration of the products from five (5) WSR-98D S-Band weather radars provided by SIMIN, and four (4) legacy C-Band weather radars integrated by SIMIN. Thus all nine (9) radars in the Romanian National Radar Network are integrated into the Hydrological processing. The NHRPS performs this function in real-time using four separate but linked processing applications; C-Band Radar Product Generator, HydroFutureScan, Hydro COBRA, and Rain Gauge Bias.

C-Band Radar Product Generator. The C-Band Radar Product Generator (RPG) systems are used to generate fundamental radar parameters from the legacy C-Band radars to allow the integration of new SIMIN radar data with these existing systems.

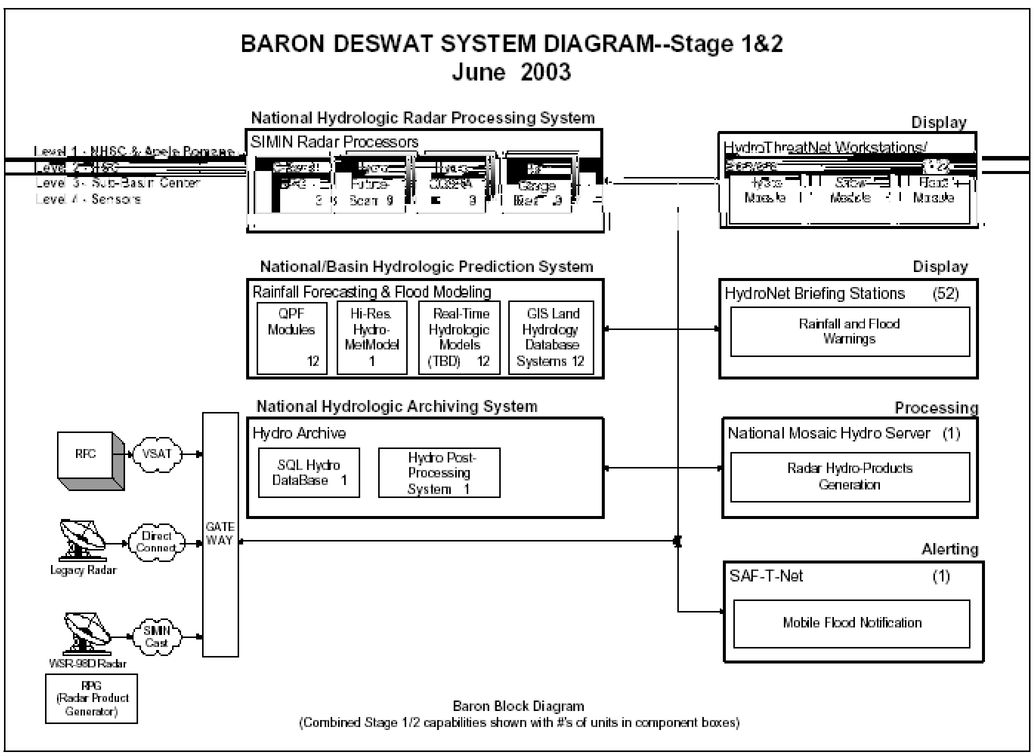

Figure 1. High-level conceptual diagram of the DESWAT end-to-end hydrometerological forecasting system

HydroFutureScan. HydroFutureScan systems are used to project individual radar imagery into the future taking into account advection, growth and decay, allowing for an accurate 0-2h quantitative precipitation forecast (QPF). Figure 2 shows an example of a single prediction of reflectivity for a convective storm moving southeastward through the Central US.

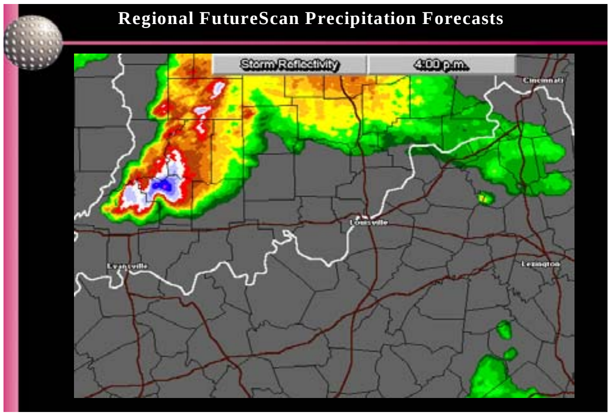

Figure 2. Example HydroFutureScan™ reflectivity for a storm moving southeastward across the Central US.

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HydroCobra and Rain Gauge Bias. The HydroCobra component is used to derive hydrologic products from the individual radar base data. These products include, but are not limited to, 1h, 3h, 6h, and 12h storm total precipitation estimates updated every 5 minutes, quantities required for inputs to the operational hydrological models (Figure 3 below) Further, DESWAT will fully implement a rain gauge bias correction system, which will be used to correct the radar estimates of precipitation rate and accumulations based upon real-time surface rain gauge measurements. Figure 4 shows an example of rain gauge measurements made over a county region that are obtained in real-time to adjust the radar estimates to a higher accuracy. Figure 5 shows the results of apply these measurements to a multi-radar coverage pattern producing highly accurate quantitative totals and spatial coverage.

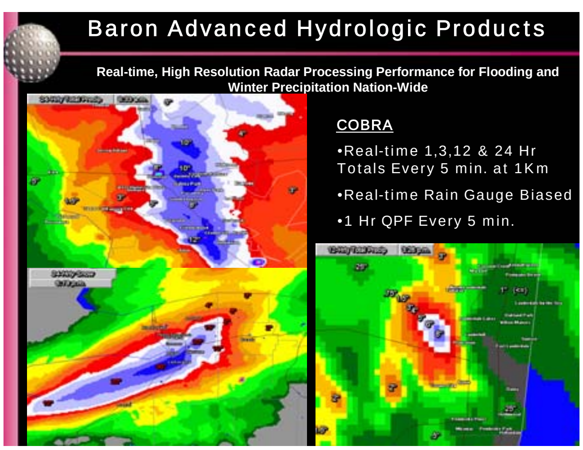

Figure 3. Example incremented storm total precipitation QPE products.

Figure 4. Example rain-gauge network used to bias-correct radar-derived QPEs.

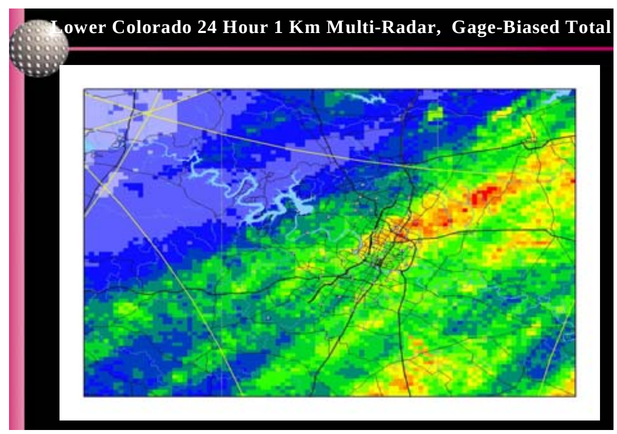

Figure 5. Example rain-gauge adjusted radar rainfall estimate over the Lower Colorado River in SE Texas.

2.2 Baron Hydrological Forecast and Modeling System (BHFMS).

The major components of the Baron Hydrological Forecast and Modeling System were mentioned in the Introduction. A high-level diagram depicting its configuration for DESWAT is shown in Figure 6.

In this diagram, elements of the BHFMS are broken into functional components. The left-hand side of Figure 6 depicts the River-Stream Forecast Component (RSFC), while the right-hand side depicts the Flash Flood Forecast Component (FFFC). Within the RSFC, the traditional "lumped modeling approach (RSFC-L)," driven by mean-areal precipitation and represented by the NWSRFS and all of its component models, is shown on the left-hand side. On the right-hand side of the RSFC are the distributed models (Baron Land Surface

Hydrology Models (BLSHM), represented by versions of the TOPLATS (Peters-Lidard, et al., 1997) and NOAH (Sridhar et al., 2002) land-surface hydrology models. In addition, the emerging NWS Distributed Modeling System (NWSDMS 2.0) is shown as an option.

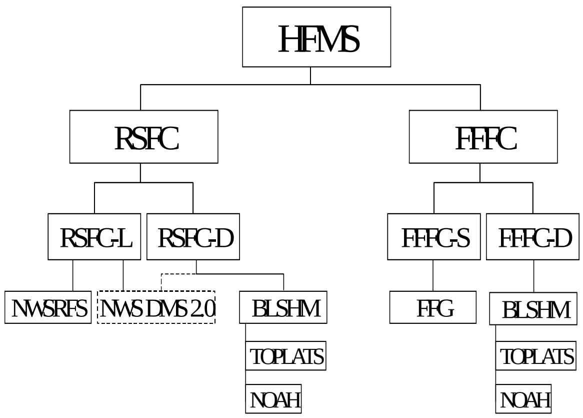

Figure 6. Baron Hydrological Forecast Modeling System

On the right-hand side of the overall system, the FFFC is shown, also with two branches. On the left-hand side of the FFFC branch, the semi-distributed (FFFC-S) flash-flood forecast system (Georgakakos, 1997, 2004) is shown, with a box noting that the primary output is the flash-flood guidance (FFG) number. On the right-hand side of the FFFC, a fully distributed (FFFC-D) augmentation is shown in which the BLSHM distributed hydrology models are used to calculate soil-moisture deficits needed to produce higher-resolution FFGs. The BLSHM implementations on both sides of the diagram will be implemented as Land-Data Assimilation Systems (LDAS's) using the SIMIN-derived QPE. Forecast QPF from one of the Romanian NWP models, probably the ALADIN model, will be used to predict evolution of the soil moisture fields 2-60 hours into the future.

2.3 National Hydrologic Archiving System

The National Hydrologic Archiving System (NHAS), shown in the lower-left hand of Figure 1, will allow event reconstruction and analysis. Data from the National Hydrologic Radar Processing System and the Baron Hydrological Forecast and Modeling System are archived for post storm analysis to continually improve the existing and newly provided advanced surface hydrologic and atmospheric models.

2.4 Interactive Display Systems for Decision Support

Interactive display systems for use in decision-support are shown on the right-hand side of Figure 1. *HydroThreatNet*™ workstations and supporting servers allow users to view all the products from the NHRPS and NHPS elements interactively in real-time down to the street level and for the entire country. *HydroNet*™ Briefing Stations allow remote user access to the real-time quick-look analyses of the key hydrometeorological parameters over any portion of the country, down to the street level. These are primarily focused on real-time water management and emergency flood/severe weather warnings. National Flash Flood alerts are produced and transmitted automatically by the *SAF-T-Net*™ alerting system via cell phones, pagers and e-mail. Finally, the National Mosaic Hydro Server (NMHS) combines all the meteorological and hydrological information from multiple radars and surface data into countrywide digital image products for analysis and display as well as transmission to regional hydrologic service centers.

3. CONCLUSIONS

During the next three years a new hydrological forecast and warning system will be implemented at the national level in the framework of DESWAT project (Destructive Water Abatement and Control of Water Disasters).

As part of DESWAT, the Baron Hydrological Forecasting and Modeling System relies upon gauge-corrected hourly to sub-hourly radar-based QPF estimates supplying inputs to advanced hydrological model forecast systems. Numerical weather prediction models comprise additional, longer-range elements of the forecast system. For larger-scales, the NWSRFS (National Weather Service River Forecast System), using the Sacramento Soil Moisture Accounting Model (SAC/SMA) and appropriate river/stream routing, is used to detect and forecast river flood/stage. Nested within this, the contributions from upstream higher-order basins are estimated with the TOPLATS amd NOAH models running as a land-data-assimilation system (LDAS). Both mean-areal precipitation estimates (needed for the SAC/SMA model) and very high resolution estimates (needed for the fully distributed TOPLATS model) are derived from the networked-mosaic radar system. The system also includes a flash-flood guidance component, in which soil-moisture deficits are estimated from either the SAC/SMA model or the TOPLATS model. The deficits are used together with up-to-date (1 hr, 3hr, 6hr, and 12hr) precipitation totals to estimate the amount of additional precipitation needed for streams to reach bankful.

The system represents a state-of-the art river stage, flood, and flash-flood forecasting system whose first implementation will be within the Romanian DESWAT program. The developers anticipate that the new system will allow the Romanian NIHWM to produce significantly more accurate hydrological forecasts under improved notification and alert capability.

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