Solutions Network Formulation Report

Candidate Solution Project Title:

Enhancements for California-Nevada River Forecasting Center's (CNRFC) Streamflow Forecasting by High Resolution Data Assimilation, Atmospheric and Land Surface Models

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Abstract

Statement of the Problem

The National Oceanic and Atmospheric Administration (NOAA) CNRFC has the responsibility of issuing flood alerts, along with issuing seasonal water supply forecasts and snowmelt runoff forecasts. Washington State, Oregon, California, Utah, and Colorado have rugged topography where terrain exerts a major influence in determining the distribution of precipitation. This orographic precipitation on the windward slopes of mountain ranges has complex patterns that are difficult to measure and predict. Mountain air flows produce heavy windward precipitation patterns and "rain shadow" effects on the leeward slopes of mountain

ranges that are controlled by mountain valley circulations that are important to water supplies. The National Weather Service River Forecasting System (NWSRFS) Decision Support Tool (DST) employs a suite of forecasting tools that extrapolate precipitation over watersheds, create immediate runoff and delayed runoff from the imposed precipitation fields using the Sacramento Soil Moisture Accounting scheme (SAC-SMA), and route river and channel flow. This modeling system simulates and predicts water surface elevations and water levels with respect to bank full discharge and flood conditions. In these western states it is difficult to extrapolate freezing level which is a critical determinant of frozen precipitation accumulating as snow pack in the mountains from liquid precipitation, which runs off immediately. The zero degree isotherm and freezing level is dependent upon the unique synoptic conditions of the individual storm systems that require high resolution models to predict the temperature and precipitation patterns. The western RFCs use two numerical models: the "Parameter-elevation Regressions on Independent Slopes Model" (PRISM) and Mountain Mapper to extrapolate precipitation fields across the mountains from known station locations.

Recent NASA rese4arch results have great potential for improving the CNRFC decision support tools, and better meeting their decision needs. Satellite-based products from the NASA Land Information System, the NOAA's OHD's Hydrologic Modeling Branch, ESRL's Physical Sciences Division and NASA's SPoRT project show good potential to improve prediction of water supplies and stream flow in the major river basins serviced by the California-Nevada River Forecast Center (CNRFC).

NASA Research Result

The proposed candidate solution should use the WRF mesoscale forecasting model to forecast spatially varying precipitation fields in mountainous areas, thus providing better precipitation (frozen and liquid) estimates to the NWSRFS decision support tool. WRF has been successfully deployed by the Air Force Weather Agency to meet the terrain extremes found in Afghanistan , and is being actively advanced by NASA research and satellite information. Specifically, WRF is being complemented by the assimilation of high resolution MODIS data fields, as already developed by the NASA SPoRT program Weather Research and Forecasting (WRF) model and ARPS Data Assimilation System (ADAS), and the GSFC Land Information System (LIS) Land Surface Model coupling software and the community NOAH-LSM. Post-MODIS support will continue to be provided by use of VIIRS. WRF is also supported by the additional NASA product, the GSFC Tao et.al. 2003 convective parameterization.

Some steps have already been taken at other NOAA NWS RFS offices in the southeast, in areas of less extreme topography, by deploying MODIS within WRF, as developed within the NASA SPoRT program. These latter SPoRT cases entailed the use of high resolution MODIS SST (sea surface temperature fields) to improve coastal forecasts, particularly sea breeze regimes.

This particular candidate solution involves modeled freezing level for a higher resolution WRF grid, as an improvement of proportion of liquid rain to solid snow precipitation predicted, along with estimated respective snowfall and rainfall at the surface. This candidate solution supports NASA's water management national application area. The solution could potentially improve NWSRFS operational forecasts, thus reducing losses due to floods and increase revenues from hydropower plants and additional water supplies for potable water and irrigation, thus impacting municipal water supplies and agricultural production.

Introduction and Problem Description

Escalating development in the California central valley and coastal floodplains has increased the potential for flood damage to homes, businesses and communities. California's flood protection system is a deteriorating, including a 50 year old flood protection system that has been weakened by deferred maintenance and reduced state and local funding for flood management programs. As noted by the California Department of Water Quality, "The State will continue to pay out millions, and potentially billions, of dollars every time a levee break occurs in the flood control system. An aggressive investment in the flood management system and a new flood management philosophy is vitally important to public safety and our economic well being. (California Department of Water Quality 2005)"

The National Oceanic and Atmospheric Administration (NOAA) National Weather Service River Forecasting System (NWS RFS) has the statutory responsibility to issue flood warnings when appropriate and issue seasonal water supply forecasts and snowmelt runoff forecasts. Meetings were held at the CNRFC offices in Sacramento, California, in order to illustrate and delineate all the steps employed within the NWS RFS forecasting system and to identify areas that users (forecasters) felt warranted improvement and modernization. Identification of these problem areas was continued by follow-up discussions to identify possible NASA research assets that could be brought to bear to improve the decision process. The NASA Short-term Prediction Research and Transition Center (SPoRT) is producing research results that accelerate the transfer of NASA research results to the NOAA NWS. SPoRT has developed an interface to directly incorporate higher resolution MODIS data into the NOAA Advanced Weather Interactive Processing System (AWIPS). SPoRT has also improved forecasts by using the higher resolution coastal Gulf of Mexico and Atlantic SST fields of MODIS within the WRF model to improve the spatial resolution of the sea breeze regime forecasts, and initiation of convection and precipitation along sea breeze fronts.

The Pacific Northwest terrain completely differs from the flat topography found in the Southeast USA: rugged, sharply marked by the Sierra Nevada and Cascade mountains. This rugged western topography is an environment dominated by small-scale internal circulations, such as mountain valley circulations, and orographic precipitation, arid conditions on the lee sides of the mountain ranges, and coastal sea breeze regimes along the coast. These landscapecreated circulations impact surface fluxes (latent heat and sensible heat), sites of initiation of cloud and storms, and modulate the delivery of precipitation to the ground surface. Most land surface models are based on homogeneous tracts of vegetation types and are not designed to deal with the spatial assortment of different landscape units that give rise to mesoscale circulations, affecting the way synoptic meteorology interacts with the region. The California-Nevada River Forecasting Center (CNRFC) approached this problem using a different starting point. CNRFC prepares maps of precipitation, temperature, and freezing altitude (0 degree isotherm) which they use to determine where precipitation falls as rain or snow and estimate snowpack melting. Station data and NEXRAD radar data exist for the lower elevation coastal region and western central valley. However, NEXRAD radar does not work in the mountains, given the physical obstruction of radar. How does one extrapolate precipitation and temperature fields to the mountains?

The technique developed by the far western states, Utah, and Colorado was to utilize two software packages called "PRISM" and "Mountain Mapper." "Parameter-elevation Regressions on Independent Slopes Model" and Mountain Mapper introduce landscape heterogeneity into streamflow forecasting. Christopher Daly at the Oregon State University Spatial Climate Analysis Service developed PRISM to predict orographic precipitation. PRISM attempts to mimic orographic precipitation by setting up localized regressions of station precipitation and elevation over areas with the same facing slope. It also attempts to mimic rain shadow, applying differing regression weights to forward facing and leeward facing slopes. **Both of these PRISM and Mountain Mapper regressions are constructed using climatological station data and are thereby limited to mean, static precipitation patterns accumulated over past conditions. RFS forecasters have expressed an interest in an alternative "smart" PRISM that uses the actual, dynamic synoptic conditions found within given current storm systems during the forecasting period. This candidate solution seeks deliver such a "smarter" version of PRISM.**

PRISM estimates the orographic elevation of each station within a digital elevation model (DEM), assigns a topographic "facet" to each DEM grid cell by assigning a slope orientation (Figure 2), and then estimates precipitation at each DEM grid cell by using a window technique to develop a linear precipitation-elevation regression function from nearby stations on the cell's facets (same facing slopes).

If an air mass has a weak flow (low wind speed) or has strong static stability (strong thermal stratification with a temperature inversion), then the kinetic energy of the air may not be large enough to exceed the gravitational restoring force, forcing air flow down a mountain by gravitational acceleration. In this situation, the air flow does not have the kinetic energy to flow over the summit of the mountain range, but forms a "blocking" air mass on the windward side of the range. If the mountain topography has passes, then the air may flow parallel to the range, followed by flow around the sides of the mountain range through the passes. These are complex flow regimes, beyond most of the capabilities of PRISM. PRISM attempts to represent "effective" terrain by comparing the height of a DEM pixel to that of the same pixel on a smoothed representation of the terrain. Features rising only slightly above the background are considered to have little effect on the precipitation.

Coastal orographic uplift of a shallow boundary layer may result in a mid-slope precipitation maximum. A mid-elevation temperature maximum may also occur in areas where inversions persist or in areas of frequent temperature inversions during winter. PRISM divides the atmosphere above the cell into a lower "layer 1" which represents the planetary boundary layer and an upper "layer 2" which represents the free atmosphere above. Stations in the same layer as the target grid cell receive the full weight in the regression. Stations falling in different cells do not. This approach fails to account for the naturally complex eddy airflows over mountain barriers and local thermodynamic changes induced by synoptic and mesoscale storm systems.

Selection of Proposed Candidate Solution

Meetings with the CNRFC staff, including Robert Hartman, Hydrologist-in-Charge (HIC) suggested that the development of a "smart" PRISM would be desirable. This Smart PRISM would not weigh processes based solely on climatology, as a function of past time periods, but would produce spatially varying precipitation fields based on the current synoptic situation of the forecast period. The Weather Research and Forecasting model (WRF) - a high resolution forecasting model, predicts spatially varying temperature and precipitation fields among others.

The WRF is a next-generation mesoscale forecast model and assimilation system that will be used to advance the understanding and the prediction of mesoscale precipitation systems. It consists of four primary subsystems, (1) WRF Standard Initialization (WRFSI), (2) WRF Variational Data assimilation system (WRF-Var), (3) Advanced Research WRF (ARW) dynamic solver, (4) Numerous physics packages contributed by research community. The WRF model is used for a wide range of applications, from idealized research to operational forecasting, with an emphasis on horizontal grid sizes in the range of 1-10 km. WRF can resolve the small-scale weather features such as front, localized convection, hurricane core, and topographic effect much better than a global model.

At Goddard, the modeling and dynamic group has implemented several ice schemes (Tao et al. 2003), and Goddard Land Information System (LIS) (including the CLM and NOAH land surface models) into WRF V2.1. The Goddard radiation (including explicitly calculated cloud optical properties and other aerosols that are important for direct effect) will be implemented into WRF by Spring 2006. WRF can also be initialized with the Goddard Earth Observing System (GEOS) global analyses. This link between the GEOS global analyses and the WRF models could allow for many useful regional modeling applications as demonstrated by the Earth System Modeling Framework - ESMF. The ESMF provides a comprehensive means of integrating various models to provide a comprehensive high-performance flexible modeling system. For example, a series of WRF simulations will be conducted to test the sensitivity of the initial and boundary conditions derived from NCEP, ECMWF, and GEOS on precipitation over different geographic locations (GSFC Mesoscale Modeling and Dynamics Group at: atmospheres.gsfc.nasa.gov/cloud_modeling/models_coupledWRF-GCE-LIS.html)

The trade off in the use of WRF over PRISM would be a poor one, if WRF cannot improve upon the orographic precipitation predicted by PRISM. It would also be a poor exchange if the convective parameterization used to generate convective precipitation within WRF is inferior to the past precipitation fields predicted by PRISM. Metrics can be developed for both cases. WRF-predicted (frozen and liquid) precipitation fields can be compared with PRISM-predicted values, with both compared with measured values, particularly given the extensively instrumented sites, located as part of the Hydrometeorological TestBed HMT-West-2006 within the American River Basin located in the Sierra Nevada of California (www.esrl.noaa.gov/psd/programs/2006/hmt).

The NASA sponsored program Short-term Prediction Research and Transition center (SPoRT) has already demonstrated that use of higher resolution MODIS coastal ocean sea surface temperature (SST) fields increases the spatial resolution and improves the forecast fields generated within WRF. Indeed, William Lapenta of SPoRT is already working with the GSFC HSB to develop the coupled LIS-WRF (Case, Lacasse, Santanello, Lapenta, and Peters-Lidard 2007). Motivated by the positive results found using MODIS data to initialize sea-surface temperatures (SSTs) in numerical weather prediction (NWP) models [LaCasse et al. (2007)], this project attempts to improve the specification of the lower boundary in ERA-40 re-analysis data and regional NWP models over land areas. The Goddard Land Information System (LIS) software is being configured to optimize land and soil-state variables for initializing high-resolution regional simulations of the Weather Research and Forecasting (WRF) model for a case study period from May 2004.

The hypothesis for this project asks whether short-term mesoscale numerical forecasts of sensible weather elements can be improved by using optimally-tuned, high-resolution atmospheric models and land surface and soil fields. Therefore, the primary goal is to investigate and evaluate the potential benefits of high-resolution land surface and soil data derived from NASA systems and models for regional short-term numerical guidance (0-24 hours). Using the LIS software coupled to the Advanced Research WRF model for improving land/soil states, SPoRT is examining a one-month period of relatively benign weather to quantify possible increased skill of WRF numerical simulations due to optimized land/soil properties.

The methodology involves running the Noah LSM within LIS in an offline mode (i.e. not coupled to WRF) to provide land/soil initialization data on the WRF grid. Twenty-four hour simulations of the standard WRF are then compared to coupled LIS/WRF experiments during May 2004 over Florida and southern Georgia. All simulations are run on a high-resolution domain with 3-km horizontal grid spacing. The impacts are then examined on predicted atmospheric variables, focusing on low levels. Finally, verification statistics are compiled at surface observation locations to quantify any improvements in forecast skill.

The benefits of using LIS and coupling the system to WRF are several-fold. First, the soil initialization fields provided by LIS are at a resolution consistent with that of the regional WRF grid. Second, using LIS allows the user to optimize the surface and soil initialization variables. In addition, users have the ability to run additional land surface models (LSMs) within LIS that are not available in the standard WRF model. Finally, the LIS software provides a framework for incorporating unique NASA-derived land datasets.

Follow-on work includes examining the impacts of the LIS/WRF system on convective initiation (in conjunction with the NSSL/SPoRT collaboration), merging the LIS capability with the MODIS-derived SSTs to improve the overall lower-boundary specification for regional modeling in coastal and mountain regions, and possibly running LIS with additional LSMs.

These SPoRT and LIS related research results have the potential to contribute to a "smart" PRISM for the western United States. Further, SPoRT plans to incorporate its results into the NWS – EMC prediction system used by weather forecast will be examined to determine how they may be used in a "smart" PRISM for the western United States. If SPoRT is successful, these results will become part of the NWS – EMC prediction system used by weather forecast offices and river forecast centers. This will enable the CNRFC to readily integrate the WRF-LSM information into its NWSRFS using the methodologies developed and tested in the Hydromet Testbed (HMT) field programs in 2007-2009.

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