

# **Developing a hydrologic data assimilation scheme to integrate multiple satellite data sets in stream-flow forecasting**

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## **Introduction**

The aim of hydrologic forecasting is to predict at some future time state variables of rainfall, evapotranspiration, soil moisture content, runoff, drainage, stream flow and/or flood extent based on the evolution of those variables in time (determined by a 'forward' model and forcing data), and on the conditioning of those variables with observations. The conditioning involves selecting optimal values of state variables that take into account the relative errors introduced by both the model and observations to yield an analysis product that forms the basis of the forecast (McLaughlin 2002). This talk will present a prototype model-data assimilation scheme for forecasting profile soil moisture and stream inflows based on satellite data for the Murrumbidgee River catchment that is independent of stream gauge observations. The independence from flow observations allows direct assessment of the utility of this method for prediction of stream flow in ungauged basins.

## **Current limitations to improved stream flow forecasting**

As water resources become increasingly limited, information on the future hydrologic status of rivers and catchments at timescales ranging from hours through days, to seasons and decades is increasingly important for a range of management and policy purposes. On short timescales rapid updating of flows is required for flood warning and implementation of emergency plans. On day to week timescales, hydrologic forecasts are required for release scheduling and river operations, as well as anticipating water demand for irrigation off-takes, and management of environmental flows to ecological assets. On seasonal to annual timescales, hydrologic forecasts are required for developing water accounts and water availability scenarios and assessing soil water stores in rain-fed agricultural systems. And, finally, on decadal timescales scenarios of water availability are required for developing land use and water allocation policy. The benefits of an improved capability for hydrologic forecasting are many-fold and include improved efficiencies of water use leading to reductions in water loss and reduced shortfalls on water orders, improved targeting of flows to environmental assets through better anticipation of natural flow events, basin-wide consistency in management practices and enhanced responses to flood threat.

Currently, the primary limitations to improved forecasting of hydrologically relevant variables are:

- Uncertainties associated with rainfall distribution in space and time due to gaps in rainfall observation network and biases introduced through indirect methods of rainfall measurement;
- Spatial variation in soil and vegetation biophysical properties as parameters in hydrological models due to limited datasets on landscape properties; and,
- Inadequate knowledge of antecedent soil moisture as initial conditions for catchment models which determines the partitioning of rainfall between runoff and infiltration into soil water stores.

The inadequate characterization of spatial and temporal correlations between precipitation, surface physical properties and antecedent soil moisture is the primary source of uncertainty in flow prediction from catchment models. To address this problem, it is necessary to exploit new information sources; particularly, spatially extensive datasets of observations to constrain state variables in catchment models (eg Renzullo *et al.* 2007). This improvement in initializing catchment models coupled with improved precipitation forcing from NWP models is the basis for improved flow prediction on day to week timescales.

## Role of remote sensing in hydrologic forecasting

Satellite observations provide an important and rich source of spatially contiguous information on the radiometric properties of the earth's atmosphere and land surface at update frequencies from minutes to days. Routine products are now available from passive and active microwave, thermal, optical, infrared and gravity sensors that provide information on surface layer soil moisture, surface temperature, snow cover and depth, water storage and evapotranspiration. Hydrologic forecasting from satellite observations provides the opportunity for flow prediction in ungauged basins in remote areas and in internal, ungauged sub-catchments. This approach does not, however, preclude the integration of flow observations in the assimilation scheme where they are available.

The challenge to utilizing satellite observations in hydrologic forecasting is two-fold: Firstly, errors and artifacts that are introduced by the earth's atmosphere, sub-pixel variability, and sensor calibration and drift problems need to be identified and removed. Secondly, observed reflectance or radiance data need to be related directly to state variables and/or parameters in the hydrologic model. Currently, rainfall-runoff models do not represent well satellite observations due to differences in scale and interpretation between the observation and model state variables. For example, rainfall-runoff models do not directly represent the surface layer moisture observed by passive microwave sensors. This is a major research challenge and requires the development of suitable observations models to better relate satellite radiance and reflectance data to hydrologic variables.

## A hydrologic model-data assimilation scheme

The hydrologic forecasting prototype scheme for the Murrumbidgee River catchment comprises the following components (Barrett *et al.* 2007):

- A 'forward' model, **M**, comprising a six-layer soil water balance scheme, Penman-Monteith actual evapotranspiration function and infiltration/runoff module;
- Model state variables of surface soil moisture (to 2.5cm depth;  $q_{s1}$ ) and soil profile average soil moisture content ( $\bar{q}_z$ );
- Model parameters of soil physical properties, leaf area index, and canopy micrometeorology;
- Forcing data comprising climate inputs of rainfall, daily maximum and minimum temperatures, vapour pressure, and shortwave downward radiation;
- Satellite observations of reflectance in red and near infra-red (MODIS *Terra* bands 1 & 2 at ~10:30am overpass), thermal (AVHRR NOAA-18 bands 4 & 5 at ~1:30pm overpass) and microwave wavelengths (AMSR-E Aqua 6.9 GHz at ~1:30pm overpass);
- 'Observation' models of (1) the surface energy balance relating soil profile average moisture content and land surface temperature,  $T_s$ , via the dependency of canopy

- conductance on moisture content; and, (2) a microwave radiative transfer model relating surface brightness temperature,  $T_B$ , to soil dielectric constant *via* the dependency of the dielectric constant on surface soil moisture content; and,
- a '3-D' variational assimilation scheme that generates optimal estimates of state variables ( $\mathbf{q}_{s1}$  and  $\bar{\mathbf{q}}_z$ ) based on satellite observations and their modeled counterparts and the relative errors from the model and observations.

Observation errors were derived from published specifications for each satellite sensor while model errors were obtained from the spatial covariance of  $\langle T_k^f - T_k^a \rangle$ ; where subscript  $k$  refers to observations type (land surface temperature or brightness temperature) and the super-script refers to forecast at 1-day lead time ( $f$ ) or analysis ( $a$ ). The scheme utilizes satellite observations when they are available (cloud-free conditions and within the image swath) or modeled values only when observations are absent (subject to covariances imparted by the model errors). Initial verification work has examined the relationship between predicted inflows from storm events, calculated as integrated surface runoff across sub-catchments, and peak flow/base flow separation based on gauge observations.

Figure 1 shows an example of the modeled and observed land surface temperatures and the subsequent 'innovation' by the assimilation scheme expressed as the difference in modeled and analysis soil profile average moisture contents. In a band extending from the lower left hand to upper right hand corners across the Murrumbidgee catchment, modeled land surface temperatures are hotter than observed by satellite whereas in the upper left hand corner (in the hottest part of the scene) land surface temperatures are close to observed. The cooler observations indicate that actual profile average soil moisture content (due to a rainfall event 3 days prior) is greater than suggested by the model as shown by the innovations ( $\bar{\mathbf{q}}_z^m - \bar{\mathbf{q}}_z^a$ ). This discrepancy could result from errors in the rainfall forcing, from lateral flows not represented by the soil moisture model or from surface-groundwater linkages leading to increase in water table height in the affected areas.

While this prototype assimilation scheme demonstrates the utility of these methods in hydrologic forecasting of short term stream flow, further work is required to elucidate the mechanisms associated with lateral flows, understand the error covariances of observations and model (particularly bias removal), examine the errors associated with forcing data (particularly rainfall), and improve the efficiency of the system for potential operational applications.

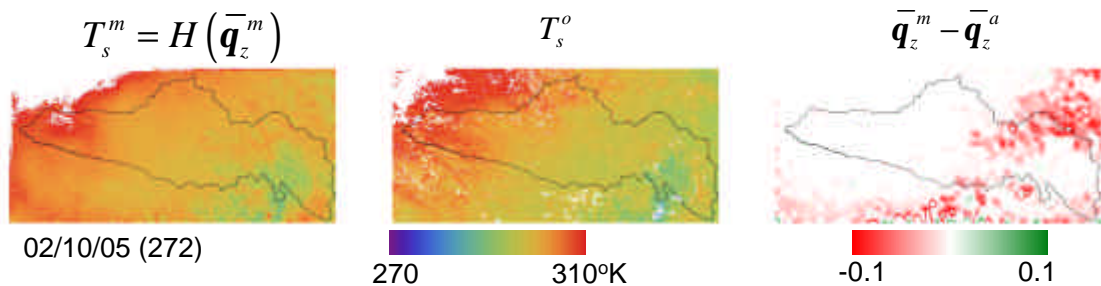


Figure 1: Modeled ( $m$ ) and observed ( $o$ ) land surface temperature ( $T_s$  K) and modeled less analysis ( $a$ ) deviations of soil profile average volumetric water content ( $\bar{\mathbf{q}}_z$ ) for the Murrumbidgee River catchment (outlined).

## References

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