SYNTHESIS

Water from space: soil moisture, groundwater and vegetation dynamics

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Abstract: Several remote sensing datasets monitoring soil moisture and landscape dynamics are to be implemented into the Australian Water Resources Assessment (AWRA) model. The current state of some of these products was presented during the *Water from space: soil moisture and landscape dynamics* session at the Water Information Research and Development Alliance (the Alliance) meeting in Melbourne, 2011. This synthesis paper summarises findings presented during this session in a broad disciplinary and international context. Further, it provides recommendations on steps to be undertaken by the Alliance to remain competitive in international research, or to potentially take over a leading role within the modelling community.

Keywords: Remote sensing, soil moisture, validation, groundwater, fPAR.

1 INTRODUCTION

Remote sensing datasets have been assimilated into numerical weather prediction models for more than 40 years, yet only recently became important in water resource monitoring systems (Van Dijk and Renzullo, 2011). The emergence of remote sensing data in hydrological models has been supported by increasing availability of long and continuous datasets, improved algorithms, and general advances in technology. The typical products implemented within water resource monitoring systems include soil moisture, leaf area index (LAI), fraction of photosynthetically active radiation (fPAR), albedo, seawater level, evaporation, precipitation and estimates of groundwater. The role of these datasets in hydrological models has been investigated with varying success and has been thoroughly elaborated elsewhere (Van Dijk and Renzullo, 2011).

Several remote sensing datasets monitoring soil moisture and vegetation dynamics are to be implemented into the Australian Water Resources Assessment (AWRA) model. The current state of these products was presented during the *Water from space: soil moisture and landscape dynamics* session at the Water Information Research and Development Alliance (the Alliance) meeting in Melbourne, 2011. This paper summarises findings presented during this session in a broad disciplinary and international context.

Given the variety of the topics presented, the paper is presented in four subsections: (i) microwave datasets of soil moisture in hydrological modelling, (ii) optical vegetation indices in hydrological modelling, (iii) gravity for total water stores in hydrological modelling, and (iv) validation activities across the three preceding topics. The diversity of the session mirrored the broad role of satellite observations in hydrological modelling.

The remainder of the paper is organised as follows. The second section sets out the four subtopics in a broad disciplinary and international context. In the third section, international leadership and collaboration opportunities for the Alliance are listed and potential impacts on international research are discussed. The concluding section summarises common findings about remote sensing data for hydrological modelling and highlights critical points from each section.

2 WATER INFORMATION RESEARCH AND DEVELOPMENT ALLIANCE'S WATER FROM SPACE ACTIVITIES IN A SCIENTIFIC AND INTERNATIONAL CONTEXT

In this section, the four subtopics are set out in a broad disciplinary context and the steps remaining to be undertaken at an international research level are discussed.

2.1 Microwave datasets of soil moisture in hydrological modelling

Soil moisture is an essential component of the hydrological cycle. Recently, significant progress has been achieved in the retrieval of top soil moisture from microwave remote sensing data. As a consequence, a vast amount of soil moisture datasets have become available from active and passive sensors at spatial resolutions ranging from 1 kilometre (Pathe et al., 2009) to 50 kilometres (Bartalis et al., 2007; Jeu et al., 2008; Kerr et al., 2010). The water content in the soil profile can be estimated from top soil moisture using a simplified two-layer water balance model (Wagner et al., 1999).

Recently, efforts were made to develop a consistent, long-term (30+ years) soil moisture dataset by combining acquisitions from several microwave sensors (Su et al., 2010). The resulting product is expected to be highly valuable for modelling activities and studies of climate variability. Apart from the generation of long term datasets, the abundance of soil moisture information provides an ideal basis for data cross-comparisons, validation and error assessment (Scipal et al., 2008).

The CSIRO team has a good understanding of the recent developments in soil moisture research, including error characterisation. This is supported by wide international collaborations. First efforts on data assimilation have been initiated (Frost, 2011) using both soil moisture and brightness temperature (Henderson, 2011; Renzullo, 2011) from coarse resolution sensors. Future implementation of these datasets within the AWRA system could be a great asset and may support monitoring of flood and drought situations.

The Advanced Scatterometer (ASCAT), Soil Moisture and Ocean Salinity (SMOS) and Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E) soil moisture datasets recently became available in near real time with a latency of about 2 hours, and are expected to be a great asset for the AWRA operational system.

2.2 Land cover and surface biophysical properties in hydrological models

Recent studies demonstrate that vegetation information improves the accuracy of long-term annual stream flow predictions as spatial scale decreases (Donohue et al., 2010). Several datasets estimate physical properties of the vegetation (fPAR from remote sensing sensors), LAI, and to some extent, albedo). Some of these were assessed over Australia by Van Dijk and Warren (2010). Nevertheless, a consistent long-term dataset mapping fPAR over Australia was only developed recently (Donohue et al., 2008) and provides a great opportunity for hydrological modelling and assessments of climatic influence on vegetation (Donohue et al., 2009).

The estimation of water and energy fluxes in the AWRA model is performed independently for tall, deep-rooted and low, shallow-rooted vegetation. These two classes are mapped using different classification schemes, which are currently being assessed. While classifying vegetation into these two classes may seem a simplified approach, it probably serves the continental scale (7.6 million kilometres^2) of the study well.

Each dataset or classification scheme includes a level of uncertainty. Studies analysing the sensitivity of the AWRA stream flow outputs to different vegetation classification schemes could shed more light on the overall importance of the classification scheme in the assimilation step.

2.3 Groundwater measurements

There is a clear evidence that the Gravity Recovery and Climate Experiment (GRACE) can detect hydrological changes over Australia (Leblanc et al., 2009). The GRACE mission provides estimates of mass change at very coarse scale (>300 kilometres). In Australia, the mass change can generally be considered as total water storage (TWS) change, which includes contribution from surface waters, soil moisture and groundwater aquifers. The critical role of the analyst using GRACE data is to assign the mass change to the correct geophysical phenomenon.

Groundwater estimates can be derived by subtracting soil and surface water components from the GRACE TWS values. Correctly identifying errors in model estimates of soil moisture and the GRACE TWS values themselves is the key to understanding how accurately regional groundwater measurements can be made in Australia. The error of satellite soil moisture datasets has been recently estimated using triple collocation methods (Scipal et al., 2008). Similar techniques may be transformed to provide error of surface water estimates. Given the complexity of the retrieval algorithm, special attention should be paid to development of the error propagation model.

2.4 Validation activities

Several validation campaigns (i.e. NAFE’02, NAFE’05, SMOS, Tarrawarra project) over Australia provide data to validate soil moisture (Peischl et al., 2011), and biophysical parameters such as LAI, fPAR and albedo. These provide vital datasets for the international space agencies. However, they usually comprise only a few years’ worth of data and represent selected geographical regions.

Australia’s climate is highly variable, as it reflects the sea surface temperature variations in the Indian and Pacific Oceans. Given the long duration of these variations, the availability of long-term data for validation studies is critical. Tree ring analyses (De Jeu et al., 2011) are a cutting-edge example of such validation activities to be used in synergy with traditional validation techniques.

Australia is a land of extremes and serves thus as a perfect testing ground for algorithm quality. The modelling and remote sensing communities would greatly benefit from the establishment of more highly instrumented in situ stations and networks in Australia. These should be distributed over several land cover types and latitudes, and the retrieved data should be available online free of charge.

3 OPPORTUNITIES FOR LEADERSHIP, LINKAGES AND COLLABORATIONS

The following section briefly reviews opportunities for potential international impact and for uptake of the Alliance’s activities by other operational or research communities.

3.1 Soil moisture datasets

The newly developed soil moisture dataset from microwave sensors (Su et al., 2010) matches the needs for operational hydrological modelling, given the dataset’s consistency and 30-year time span. The long time span is particularly important for analysing phenomena such as El Niño/La Niña-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) that shape the Australian climate. By analysing ENSO and IOD phenomena, the Alliance may further elaborate on early studies demonstrating a strong link between ENSO and soil moisture (Liu et al., 2009).

As mentioned in Section 2, the implementation of the operationally available ASCAT, SMOS and AMSR-E top soil moisture datasets could be a great asset to the AWRA system and may demonstrate capabilities to monitor drought and flood situations on an international level.

3.2 Land cover and surface biophysical properties

Incorporating vegetation indices from remote sensing into catchment-scale hydrological models has a long history (Pierce, 1993). The simplified methodology implemented in AWRA separates two contrasting vegetation types and serves the continental scale of the model well. Such an approach may be recommended for other continental models.

Linking in situ estimates of root depths with remote sensing information on vegetation types and LAI may improve the 'shallow/deep vegetation' method, which is equated to recurrent and persistent vegetation by suggesting broad-scale plant functional types.

3.3 Groundwater measurements

GRACE data is playing in increasingly critical role in assessing severity of long-term hydrological droughts and sustainable groundwater use assessment worldwide by providing broad-scale constraints on total water storage changes. An accurate, remotely sensed groundwater estimate requires a good understanding of the errors in GRACE TWS, surface water, soil moisture and tidal error estimate. This therefore requires close collaboration between the geodetic and hydrological modelling communities.

3.4 Validation activities

Australia does not have an existing satellite mission. As compensation, a 'validator' role for Australia has been suggested, which would follow up on past and current validation efforts (i.e. NAFE'02, NAFE'05, SMOS, or the Tarrawarra project). Extended validation networks with well-equipped stations would be of great value to international modelling and satellite communities, who would use these as a test bed for validation of algorithms in extreme conditions. Undoubtedly, international collaboration would result from this activity.

Application of tree ring analyses is expected to improve understanding of land–atmospheric circulation over southern Australia. Early studies have demonstrated a strong link between soil moisture and ENSO (Liu et al., 2009), but the total hydrological impact of ocean oscillation systems over Australia requires further investigation.

4 FINAL REMARKS

Problems faced by regional hydrologists in previous decades – which included limited availability of remote sensing datasets – were, in the last decade, replaced with dataset abundance, enormous computational processing power, and consequently, an often deficient physical understanding. Thorough reviews, sensitivity and error analyses must be performed to select an appropriate dataset for model parameterisation and/or assimilation. Operational challenges include consistency and continuity of the data; the latter applies especially over the variable climates of Australia.

The Alliance is aware of these issues and stays updated about the most recent datasets via international collaborations. The Alliance also has close links with several algorithm developers and provides them with feedback about data usage and accuracy (i.e. SHARE project) (Doubkova et al., 2009). These collaborations are of great benefit to both sides.

The following recommendations summarise steps the Alliance should undertake to remain at an international research level in the future, or to potentially assume a leading role within the modelling community.

- Given the semi-operational character of the Alliance, it seems appropriate to implement the approach of 'adopt, adapt, invent' (Van Dijk et al., 2011) when implementing remote sensing data in modelling.
- The ASCAT, SMOS and AMSR-E soil moisture datasets and the consistent Earth observation Water Cycle Multi-Mission Observation Strategy (WACMOS) soil moisture (30+ years) dataset should be implemented in the AWRA model. Improvements achieved in the modelled soil moisture and runoff should be assessed.
- The relationship between in situ root depth datasets and remote sensing should be established, as this may help understanding functional plant types and improve the suggested method for assimilation of biophysical parameters.
- To derive an estimate of ground water from the GRACE measurements, a good understanding of soil moisture, surface water and GRACE analysis error estimates is necessary. To gain this understanding, a close collaboration of the relevant research communities is necessary.
- The Alliance should consider establishing a 'validator' role for Australia by setting up highly instrumented, widely distributed, in situ networks for validation purposes of international modelling and remote sensing communities.
- Application of tree ring analyses is expected to improve understanding of long-term land–atmospheric circulation over Australia and should thus be further investigated.
- Participation in international meetings should be highlighted, as this raises awareness about the Alliance's activities.
- Presenting AWRA modelling activities in a broader geographical context (i.e. assessing its potential application over semi-arid regions of Africa) may cause uptake of the Alliance's activities by other communities.

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