An evaluation of remotely sensed soil moisture over Australia

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Introduction

Soil moisture is an important control over atmospheric evolution, since it controls the partition of incoming radiation into latent and sensible heating. To accurately model these land surface fluxes, atmospheric models must ultimately have accurate soil moisture fields. Yet soil moisture is typically initialised indirectly in Numerical Weather Prediction (NWP) models, frequently resulting in unrealistic model soil moisture. For example, both the soil moisture and land-surface fluxes in the Australian NWP system (LAPS) have been observed to be unrealistic (e.g., Draper and Mills, (2007)). The soil moisture in LAPS is initialised using a background field based on antecedent precipitation and climatological evaporation, which is then incremented (following the scheme developed by Viterbo and Beljaars (1995) at ECMWF) according to low-level forecast humidity errors.

Novel remote sensing technologies offer the potential to replace these indirect soil moisture initialisation schemes with techniques that utilise observed surface soil moisture. It has already been demonstrated that assimilating remotely sensed soil moisture into land surface models can be benefit modelled soil moisture (e.g., Reichle and Koster, 2005). Currently, the most advanced techniques for remote sensing soil moisture over Australia are based on data from the Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) instrument, on NASA's Aqua satellite. AMSR-E provides global coverage of passive microwave brightness temperatures in two days or less (except for regions of dense vegetation or frozen ground cover), with a nominal spatial resolution of 25 km. These observed brightness temperatures can be related to near-surface (~ 1cm at C-band and a few mm at X-band) soil moisture using a geophysical emissivity model.

This paper presents an evaluation of AMSR-E derived near-surface soil moisture over Australia, within the context of its potential for assimilation into Australian NWP systems. If the remotely sensed data is shown to be more accurate than existing initialized soil moisture fields, then its assimilation is expected to readily benefit modelled soil moisture. Surface (0 – 7 cm) soil moisture from the newly initialised LAPS model has then been adopted as the benchmark against which the AMSR-E derived soil moisture is assessed. Two different AMSR-E soil moisture retrieval models are considered here: one developed collaboratively by Vrije Universiteit Amsterdam (VUA) and NASA (VUA-NASA), following Owe et al (2007), and one developed at NASA, following Njoku and Chan (2003). The VUA-NASA retrieval algorithm has been separately applied to C-band (6.92 GHz) and X-band (10.65 GHz) AMSR-E brightness temperatures (referred to below as VUA-NASA-C and VUA-NASA-X). Due to radio frequency interference in C-band frequencies across North America, the NASA product (NASA-X) is based on the higher frequency X-band AMSR-E data only, which is considered to be less appropriate for soil moisture sensing.

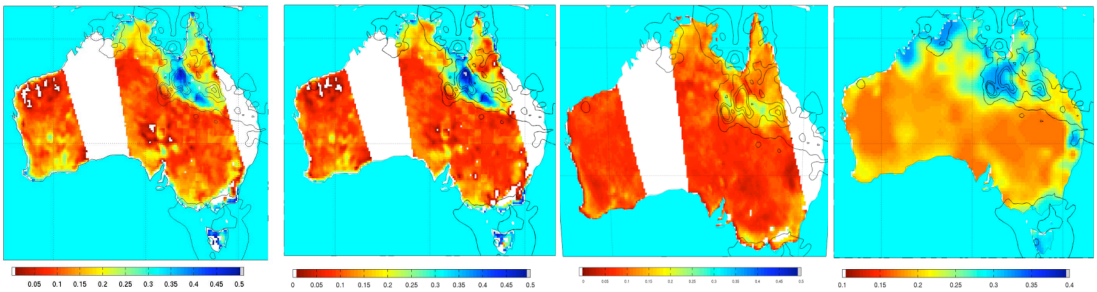

Figure 1: Maps of soil moisture on 6 January, 2005: (left to right) VUA-NASA-C, VUA-NASA-X, NASA-X, and LAPS. The black lines are 20 mm precipitation contours from the previous 24 hours. The soil moisture colour range in each panel describes the range of each product (0 – 0.5 vol/vol from AMSR-E, and 0.17 – 0.32 vol/vol for LAPS

Methods and Data

Timeseries of AMSR-E and LAPS soil moisture have been evaluated against in-situ soil moisture data from ten sites within the Murrumbidgee Soil Moisture Monitoring Network (MSMMN; see http://www.oznet.unimelb.edu.au for details), in southeast Australia. Two of these sites multiple monitoring stations (five at Kyeamba Creek and four at Adelong Creek), and a simple average has been used at each of these. There are differences between the spatial scale of soil moisture obtained from models, remote sensing, and ground-based monitoring stations (or calculated from the average of a modest number of stations in the case of Kyeamba and Adelong). While these differences will lead to differences in the behaviour of soil moisture from each source, their temporal behaviour should still be similar. Consequently, inter-comparison of soil moisture from LAPS, AMSR-E, and the MSMMN has focussed on comparison of their temporal dynamics. To better enable this comparison, the LAPS and AMSR-E soil moisture timeseries have been re-scaled so that their range over 2005 matches that of the MSMMN data range at each location (the range is defined here as difference between the 5^{th} and 95^{th} percentile).

Prior to the timeseries comparison, the LAPS and AMSR-E soil moisture have been visually compared to maps of (24-hour) antecedent precipitation across Australia, to check that the broad spatial patterns described by each are realistic. This comparison is based on the Bureau's daily 0.25° rain gauge analysis (Weymouth et al, 1999).

Results

Figure 1 shows maps of the AMSR-E and LAPS soil moisture, together with the previous day's precipitation for 6 January, 2005. All of the soil moisture panels show the expected climatological distribution of soil moisture across Australia, with a superimposed region of wetter soil associated with a rain-band south of the Gulf of Carpentaria. The VUA-NASA C- and X- band retrievals are similar, while NASA-X shows comparatively dry soils, with little variability. This is typical of the NASA-X soil moisture, which has a strong tendency to remain low. All three AMSR-E panels in Figure 1 show several small in-land moist regions which are not associated with recent rainfall. These false moist regions are persistent through time and are caused by high surface salinity. For example, the yellow and green region to the north of Spencer Gulf in South Australia is the Lake Torrens salt pan. In contrast to AMSR-E, the LAPS soil moisture shows a broader region of wet soil, which is associated with rain several days previously (indicating a longer memory in the

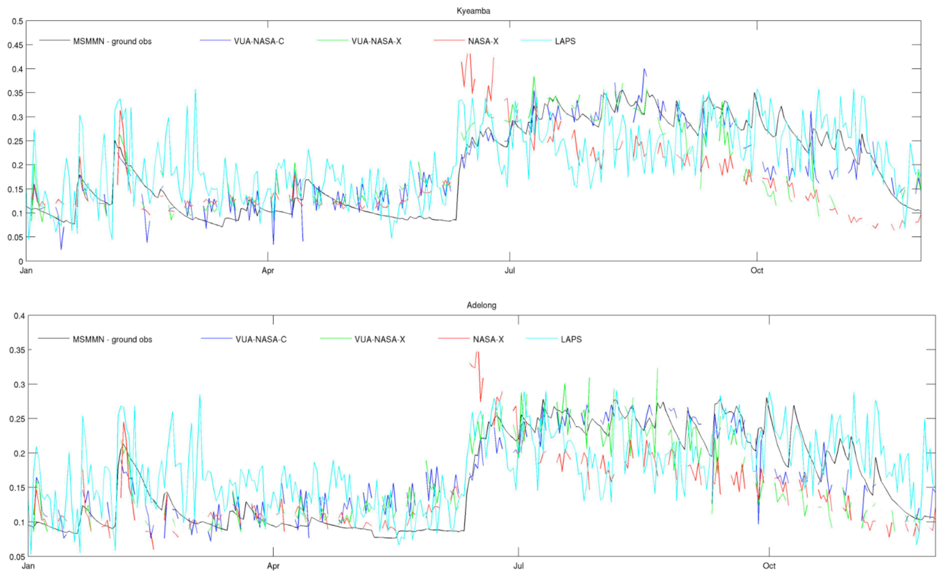

Figure 2: Comparison of LAPS and AMSR-E derived soil moisture to MSMMN observations for 2005, at Adelong (upper) and Kyeamba (lower) Creek catchments.

LAPS soil moisture). Additionally, the LAPS soil moisture has less fine detail than the AMSR-E fields (more so than can be attributed simply to their different resolutions).

Figure 2 compares the soil moisture timeseries from AMSR-E and LAPS to MSMMN data for the Adelong and Kyeamba Creek catchments (these are the two MSMMN sites with multiple monitoring stations). As with the spatial comparison above, the greatest differences between the AMSR-E soil moisture retrievals are the result of using different retrieval algorithms, rather than different observation frequencies. Again, the VUA-NASA products appear more realistic. All three AMSR-E soil moisture timeseries show the rapid soil moisture increase brought on by heavy rains in June, while the subsequent dry-down (and intermittent precipitation-induced increases) are well represented by only VUA-NASA-C, and to a slightly lesser extent by VUA-NASA-X. There is an artificial drift upwards in the three AMSR-E soil moisture products during the dry autumn months, when the MSMMN data is steady. Possible reasons for this drift are currently being investigated. In comparison to the AMSR-E fields, the LAPS soil moisture is extremely noisy, with the noise having a similar amplitude to the seasonal signal.

The relative performance of the LAPS and AMSR-E soil moisture fields was consistent across the ten MSMMN sites (only Kyeamba and Adelong are shown here). In summary, VUA-NASA-C has the best fit to the MSMMN data, with an average correlation coefficient across the ten MSSMN sites of 0.79, with VUA-NASA-X performing nearly as well, with an average of 0.77. In contrast, NASA-X and LAPS showed much poorer predictive skill, with average correlation coefficients of 0.54 of 0.58, respectively. The RMSE statistics (assuming the MSMMN data to be the truth) indicate a similar result, with low average RMSE for VUA-NASA-C and VUA-NASA-X (0.031 and 0.034 vol/vol), and a substantially higher value for NASA-X and LAPS (0.048 and 0.043 vol/vol).

Discussion and Conclusions

The VUA-NASA soil moisture derived from either C- or X- band AMSR-E brightness temperatures appear to be realistic, and both offer substantial improvement over the current LAPS soil moisture initialisation scheme. Both show a strong correlation with the

MSMMN soil moisture timeseries, and a good spatial agreement with precipitation data. The agreement between the VUA-NASA soil moisture products and the MSMMN is remarkably good, given the spatial differences between remotely sensed and ground-based (point) measurements. While the difference is minimal, VUA-NASA-C performed slightly better than VUA-NASA-X with better overall statistics. The C-band product is also theoretically superior, and it is recommended that this product be used in Australian applications. In contrast to the VUA-NASA products, the soil moisture produced by NASA from the AMSR-E X-band is less realistic. Since the VUA-NASA X-band product has compared favourably, the poor performance of the NASA product should not be contributed to its use of a sub-optimal microwave frequency.

While the broad spatial behaviour of AMSR-E and LAPS soil moisture has been checked for realism by comparison to precipitation, quantitative assessment here has been limited to a handful of locations, and these results do not necessarily extrapolate to other regions. However, the main findings regarding the relative performance of the different soil moisture products was consistent across all of the MSMMN sites, and was also supported by comparison to precipitation data. The superior performance of both VUA-NASA products over the NASA-X product also concurs with the findings of Wagner et al (2007), based on soil moisture data from Spain.

An experimental EnKF system is being developed to assimilate the VUA-NASA C-band soil moisture into the Bureau of Meteorology's NWP model. While assimilating soil moisture data into the model is expected to improve the modelled soil moisture, improved atmospheric forecasts may not automatically follow. Hurdles to achieving this improvement include inconsistencies between the definition of soil moisture in the observations and in the model, and inaccuracies in the land surface model physics (specifically, the parametrisations describing the dependencies between soil moisture and the land surface fluxes). However, assimilating realistic soil moisture data into an NWP model will enable better identification, and hence treatment, of these inaccurate model physics. The assimilation is (at the least) a first step towards improved land surface flux forecasts, and hence improved low-level atmospheric forecasts.

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