TECHNICAL BRIEF

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The WRC operates in terms of the Water Research Act (Act 34 of 1971) and its mandate is to support water research and development as well as the building of a sustainable water research capacity in South Africa.

WATER RESEARCH COMMISSION

Validating the variables in hydrometeorological models for soil water measurement

A Water Research Commission (WRC) study has been completed on the validation of the variables (evaporation and soil water) in hydrometeorological models, particularly focusing on the application of cosmic ray probes for soil water measurement.

Background

For many field and modelling applications, accurate soil water estimates are required, but these are often lacking. Modelled estimates of soil water are often used without proper validation, and the verification of the results is questionable.

In addition, remotely sensed products are becoming more widely used in hydrological modelling. However, remotely sensed soil water measurement cannot "see" below the soil surface and penetrate the aerial plant canopy layer.

This still presents a major source of uncertainty in many hydrological applications where soil water forms the interface between the atmosphere and the vadose zone, and ultimately streamflow generation.

The vulnerability of South Africa to climate and environmental change is increasing as demands on resources continue to rise in conjunction with rapidly growing populations. Disaster management agencies have to adapt to the increasing number of natural disasters, which includes droughts and floods.

In addition, water resources management, crop modelling, and irrigation scheduling all require accurate and spatially distributed daily estimates of soil water and total evaporation from catchment level to national scale. This will only be feasible through remote sensing technologies.

It is therefore essential to further the development and integration of space-based technologies within already existing national disaster management plans.

Cosmic ray probe

Until the development of the cosmic ray probe (CRP), there has not been a suitable technology for measuring soil water at the appropriate scales to validate existing models. The CRP is new technology that has not been used by researchers in southern Africa before. A cosmic array network could provide a powerful new addition to the flood forecasting ability of the South African Weather Service.

The need to provide an independent validation of the Hydrologically Consistent Land Surface Model for Soil Moisture and Evapotranspiration (HylarsMet) model was recognised. As a result, a project (K5/2066) was initiated to provide a spatially explicit validation procedure for the 1 km grid of soil water and total evaporation produced by the Satellite Applications and Hydrology Group at the University of KwaZulu-Natal and other global climate models.

Measurements using the CRP at area scales of up to 34 ha have the potential to provide hydrometeorologists with an entirely new way of evaluating surface soil water at spatial scales never achieved with ground-based techniques. This new technology can be employed in water demand forecasting and promises to improve the utilisation of irrigation water, especially in water scarce regions like South Africa.

The probe can also be used for predictive weather and climate models by measuring soil water content (SWC). In addition to spatial estimates of total evaporation (micrometeorological and remote sensing techniques), spatially distributed field-based measurements of soil water were also used to verify the CRP estimates. The aim here was to assess how spatially determined soil water measurements compared with the point measurements of soil water, and soil water measured using the CRP.

This project was designed to build on the recent work in WRC projects, namely, K5/1683: *Soil water from satellites*, and K5/2066: *The validation of the variables (evaporation and soil moisture) in hydrometeorological models.*

The aims of this project were to:

- Provide data for the continued support of soil water modelling of South Africa using a hydrologically consistent land surface model (follow-on project proposed from K5/1683).
- Provide accurate field and satellite estimates of total evaporation and soil water to calibrate hydrometeorological models.
- Evaluate the spatial variability of soil water at catchment scale.
- Test the suitability of the CRP for providing spatial estimates of soil water at the same scale as the remote sensing products from HylarsMet.

Study sites

Three different sites with contrasting land uses were selected for this study:

- Agricultural crops at Baynesfield (soybean and maize) near Pietermaritzburg.
- Natural grassland vegetation at Cathedral Peak in the KwaZulu-Natal Drakensberg.
- Commercial forestry at the Two Streams catchment, afforested with *Acacia mearnsii* (black wattle) in the KwaZulu-Natal midlands.

First validation experiment

Validating the CRP soil water estimates

The CRP estimates were validated against in situ soil water datasets to test the suitability of the CRP to provide spatial estimates of soil water. A time series analysis was plotted to see how the CRP dataset compared with the in situ TDR soil water estimates. The volumetric SWC values at Baynesfield varied between 0.17 and 0.36 during the measurement period. Calibrated hourly CRP SWC calculated using the corrected neutron counts from two calibration periods showed that soil water values varied between 0.13 and 0.36 during the measurement period, which agreed with measured TDR values.

The CRP followed the same seasonal trend as the in situ soil water estimates at the Cathedral Peak Catchment VI site. The CRP correlated better with the in situ soil water dataset in wetter periods when the soil water values were higher (above 30%) than the drier periods. Overall, the CRP data correlated well with the in situ soil water dataset.

Validating the SEBS soil water estimates

In the first validation experiment, 15 relative evaporation maps were generated using the SEBS model in ILWIS 3.8.3. These maps were exported, opened and analysed in ArcGIS 9.3, where the relative evaporation of the area within Catchment VI was determined.

The relative evaporation followed seasonal trends with the values being high in summer (wet period) and very low in winter (dry period). To estimate the actual soil water from the relative soil water, the saturated SWC was required. This was inferred from the porosity, which in turn was estimated using the bulk density.

The back-calculation of soil water from relative evaporation estimates the soil water in the root zone as this is where the evaporated water (soil evaporation and transpiration) is sourced from. The Su et al. (2003b) and Scott et al. (2003) methods were used for estimating soil water using the SEBS model relative evaporation values. The relative evaporation values were substituted in the equations, and the soil water at field capacity was 0.74. The estimated soil water was plotted against the corresponding CRP measurements.

The methods proposed by Su et al**.** (2003b) and Scott et al. (2003) followed the same trend, but overestimated soil water in the wet periods and underestimated soil water in the dry periods. Both methods followed the expected seasonal trend. The Scott et al. (2003) method performed relatively better than the method proposed by Su et al. (2003b). The poor agreement with these methods and the CRP methods was mainly ascribed to vertical and horizontal scaling issues.

Validating the PyTOPKAPI (SAHG) soil water estimates

The SAHG soil water product is on a 12 × 12 km grid, which results in a pixel area of 144 km^2. To obtain a year-long dataset, 2920 images were downloaded and used to create 365 daily images. The SAHG dataset is continuous and has no gaps.

The SAHG soil water was obtained in soil saturation index (SSI) and converted to soil water by using a representative porosity value. The SAHG soil water estimates followed the same seasonal trend as the CRP estimates with a close correlation between the two datasets in terms of general increases and decreases in SWC.

The CRP had more day-to-day variation in soil water. The SAHG product had gradual changes in soil water and did not exhibit the same degree of temporal fluctuations observed in the CRP estimates. In general, the SAHG soil water product provided good estimates of soil water, which correlated well with the CRP measurements.

Validating AMSR-2 and soil moisture and ocean salinity soil water products

The AMSR-2 Level 3 soil water product is on a 10 km grid. Although this grid is relatively small in comparison to other remote sensing soil water products, it is still very large in comparison to the Catchment VI area of 0.68 km^2, whereas the pixel area is 100 km^2.

Therefore, the pixel is 147 times larger than the study area. However, this is an improvement from validating remote sensing soil water products with in situ point measurements. The AMSR-2 soil water product underestimated soil water throughout the study period. The AMSR-2 soil water product followed the seasonal trend of the CRP estimates but fluctuated more in the wet periods with less fluctuation in the dry periods. Although, the AMSR-2 dataset underestimated the soil water at the site, it followed a similar trend in daily soil water fluctuations.

The soil moisture and ocean salinity (SMOS) Level 3 soil water product is on a 25 km grid. Although this grid is smaller than the Level 2 product (40 km), it is still very large in comparison to the catchment area. The pixel size was 920 times larger than the study area. The SMOS soil water estimates followed the same general trend as the CRP estimates. The SMOS dataset generally underestimated soil water for most of the study period. However, the SMOS product partly overestimated soil water during the wet period. The SMOS soil water estimates fluctuated most during the wet season. This fluctuation is less in the dry periods. This was due to greater fluxes in soil water in summer than winter.

Second Validation Experiment

The project team focused on the Baynesfield site for this experiment as the CRP, EC150 and large aperture scintillometry at Cathedral Peak was vandalised by thieves and the equipment was not available for this experiment.

Second validation of the SAHG soil water product

The CRP was used to validate the SAHG soil water product between 1 December 2015 and 16 January 2016. The CRP was plotted on a time series against the SAHG product. The CRP and the SAHG soil water estimates followed similar trends. The CRP daily estimates were more variable than the SAHG estimates, which did not fluctuate as much. Overall, the SAHG product estimated higher values of soil water throughout the period. A scatter graph of the CRP soil water estimates against the SAHG soil water estimates had an R^2 of 0.1371 and showed that the SAHG product overestimated soil water throughout the period, compared to the CRP estimates. The difference in soil water estimates were attributed to both the large vertical and horizontal scaling differences (the spatial scales were two orders of magnitude different, as the CRP has a measurement area of 0.34 km^2, while the SAHG product was 156 km^2).

To extend the validation period, a previous one-year period from March 2014 to March 2015 was selected. The first nine months (March 2014 to November 2014) of the time series analysis showed a close correlation between the CRP and SAHG soil water estimates. The last three months (December 2014 to February 2015) showed a poorer relationship in the fluctuations of the CRP soil water estimates. Discussions with the SAHG team indicated that this may have been due to an error in the PyTOPKAPI model, such as an error in input data. Considering these vertical and horizontal scaling differences, it was clear that the SAHG product still provided good estimates of the relative soil water conditions and confirmed its suitability for both flood forecasting and drought prediction.

Soil water back-calculated from SEBS

Landsat 8 images were used to estimate relative evaporation and evaporative fraction using the SEBS model. The SEBS model was run to obtain the evaporative fraction and relative evaporation fraction. The relative evaporation and the evaporative fraction values were then used in the equations developed by Su (2002) and Scott et al. (2003) to obtain estimates of soil water.

The daily evaporation estimates from the SEBS model during this period ranged from 2.5 $mm{\cdot}day^{-1}$ to 8 $mm{\cdot}day^{-1}$. When these estimates were compared to the daily evaporation values estimated by the eddy covariance system, the SEBS daily soil water estimates were noticeably higher.

From 01 March 2014 to 01 March 2015, the relative evaporation and evaporative fractions were estimated using the SEBS model, which were used in the two equations to obtain soil water. These soil water estimates were then plotted against the CRP estimates from the same period.

The relative evaporation and evaporative fraction values followed a similar seasonal trend as the values were higher in the wetter periods and lower in the dry periods. The back-calculated soil water using both the Su and Scott methods resulted in the estimates following the general season trend. The back-calculation method of Scott et al. (2003) provided slightly better estimates of soil water than the method proposed by Su et al. (2003), when compared to the CRP soil water estimates.

Conclusion

Understanding the spatial and temporal variability of total evaporation and soil water at different scales is of great importance in many land surface disciplines such as hydrology. Soil water is a key hydrological variable as it impacts the water and energy balance at the land surface-atmosphere interface and is the main water source for natural vegetation and agriculture.

The CRP is a new and innovative in situ instrument capable of measuring soil water at an intermediate scale. The CRP, once properly calibrated, is suitable for providing spatial estimates of soil water.

The CRP estimates were used to validate modelled soil water estimates. These included the SAHG soil water product and the back-calculation of soil water from relative evaporation estimates from the SEBS model.

There was good correlation between the SAHG and CRP datasets. Although the SAHG product performed well, there was still the presence of vertical and horizontal scaling issues due to differences in the measurement depth and the footprints of the two datasets. There was also the issue of the conversion of SSI to VWC, which required a representative porosity of the study area to be determined.

The back-calculation of soil water from relative evaporation and evaporative fraction, estimated using the SEBS model, looked like a promising technique. The spatial resolution was less than the catchment area and the measurement depth was representative of the root zone of the vegetation (0.50 m).

Therefore, this product would have the least horizontal and vertical scaling issues when validated against the CRP. Although the back-calculation method results in soil water estimates on a 30 m spatial grid, the temporal resolution of the imagery used is 16 days, which is very impractical for continuous soil water measurements.

The SEBS model performed poorly against the CRP validation data. It is recommended that further research is required into the measurement of soil water using remote sensing products.

Related project:
The validation of the variables (evaporation and soil water) in hydrometeorological models: Phase II, Application of cosmic ray probes for soil water measurement (**Report No. 2323/1/17**). Contact Publications at Tel: (012) 761 9300; Email: orders@wrc.org.za or Visit: www.wrc.org.za