TERN Subcontract Landscape Assessment, ANU 2018-19

S-GRAFS: Satellite-Guided Root-zone Analysis and Forecasting System

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Summary

The overall project objective was to develop a method and explore key data sources required to produce Australia-wide estimates of top-layer (0-5 cm) and root-zone (0-1 m) soil wetness at 1-km in near real-time (< day latency). We adopted a 'data-heavy, model-lite' approach where greater emphasis is placed on observations to capture the dynamics of soil water than any particular land surface or hydrology model. To this end we employed a simple autoregressive time series model to represent soil wetness dynamics in the top-soil layer with satellite-derived rainfall as the forcing data. Assimilation of satellite soil moisture data was used to correct modelled estimates of top-layer moisture, which were then extended to the root-zone estimates via a temporal smoothing filter. Finally, we trialled a temporal regression between the coarse ~10-km model resolution and finer-scale satellite radar data as an approach to downscale the model product to 1-km. Given the focus on satellite data to drive and constrain estimation, we have named the production system *Satellite-Guided Root-zone Analysis and Forecasting Systems* (S-GRAFS).

Satellite data

Three sources of satellite observations are considered in this investigation. The first are the near real-time multi-satellite rainfall analyses from the Global Precipitation Mission (GPM) IMERG system; second are the near real-time passive microwave retrievals of top-layer (0-5 cm) soil moisture from the Level 2 Soil Moisture Active/Passive (SMAP) production systems; and finally the gamma-0 backscattered C-band microwave reflectivities from the radar aboard the Sentinel-1 satellite.

Daily composites are constructed of the satellite rainfall and soil moisture data at their nominal 10-km resolution. These data are the main inputs to S-GRAFS for Australia-wide top-layer and root-zone soil moisture estimation. Owing to computational resource limitations we were only able to trial a downscaling method to 1-km using Sentinel-1 radar data for a small part of the continent.

Modelling and Assimilation

A simple approach to modelling the temporal dynamic of soil moisture in the vertical soil profile is to represent the process as a lag-1 autoregressive (AR-1) time series. A popular implementation of the AR-1 approach is known the antecedent precipitation index (API). The API models the wetness in the top soil layer for today as a fraction (<1) of yesterday's soil wetness plus today's GPM rainfall forcing. The 'fraction' of previous day's wetness represents the total losses of water in the volume of soil that result from drainage, root water uptake, evaporation and lateral transport. For simplicity the implementation of API in S-GRAFS uses a time varying 'fraction' based on the variation of climatologically derived average daily air temperature for the given day of year from the 30-year mean air temperature. These temperature data were those from AWAP system.

Recognising that API model is an overly simplistic representation of top-soil wetness dynamics, we employ assimilate SMAP soil moisture to compensate for model deficiencies. A 3-day assimilation window is employed to ensure a temporal smoothness in the analysed (i.e. best guess) top-layer soil wetness and minimise the visibility of the satellite track in the resulting nation-wide gridded product.

The exponential filter was developed as a way of extending to satellite observations of moisture in the top few cm's of soil (0-2 cm or 0-5 cm) to deeper in the soil profile (Wagner et al, 1999). It basically acts as a temporal smoother to produce a soil water index (SWI) that mimics the comparatively slower moisture dynamics observable in deeper soil profile than that of the surface layer. We have used the exponential filter in S-GRAFS to propagate the constraint of the analysed top-layer soil wetness into the deeper soil profile. The smoothing parameter of the filter was judiciously chosen that the SWI estimates provided maximum temporal correlation with 0-1 m average moisture measured at OzFlux sites around Australia. As such, we suggest that S-GRAFS implementation of the exponential filter provide root-zone SWI in the 0-1 m. Example of the SMAP daily soil moisture and the S-GRAFS estimate of top-layer and root-zone soil wetness is given in Figure 1.

Both top-layer and root-zone soil wetness estimate are produced for Australia on daily time step at ~10-km resolution (Fig 1.). We explored a potential downscaling approach using 1-km composites of Sentinel-1 gamma-0 data. These gamma-0 values from individual passes are processed from the original Sentinel-1 backscatter reflectivities using the *SentieNt Application Platform* (SNAP). However due to the heavy demand of the software for computing resources, we were only able to trial the approach across the Murrumbidgee.

The downscaling idea is the within each 10-km S-GRAFS cell is 100 1-km Sentinet-1 gamma-0 values. The time series of gamma-0 from April 2015 to December 2018 is used to derive the well-established linear relationship between soil wetness and gamma-0. In our case, the soil wetness values are the oversampled 10-km grid values. The fitted linear equations are then used to downscale the 10-km gridded top-layer moisture to 1-km. Figure 2 shows an example of output from the downscaling using Sentinet-1 gamma-0 for 29 Feb 2016.

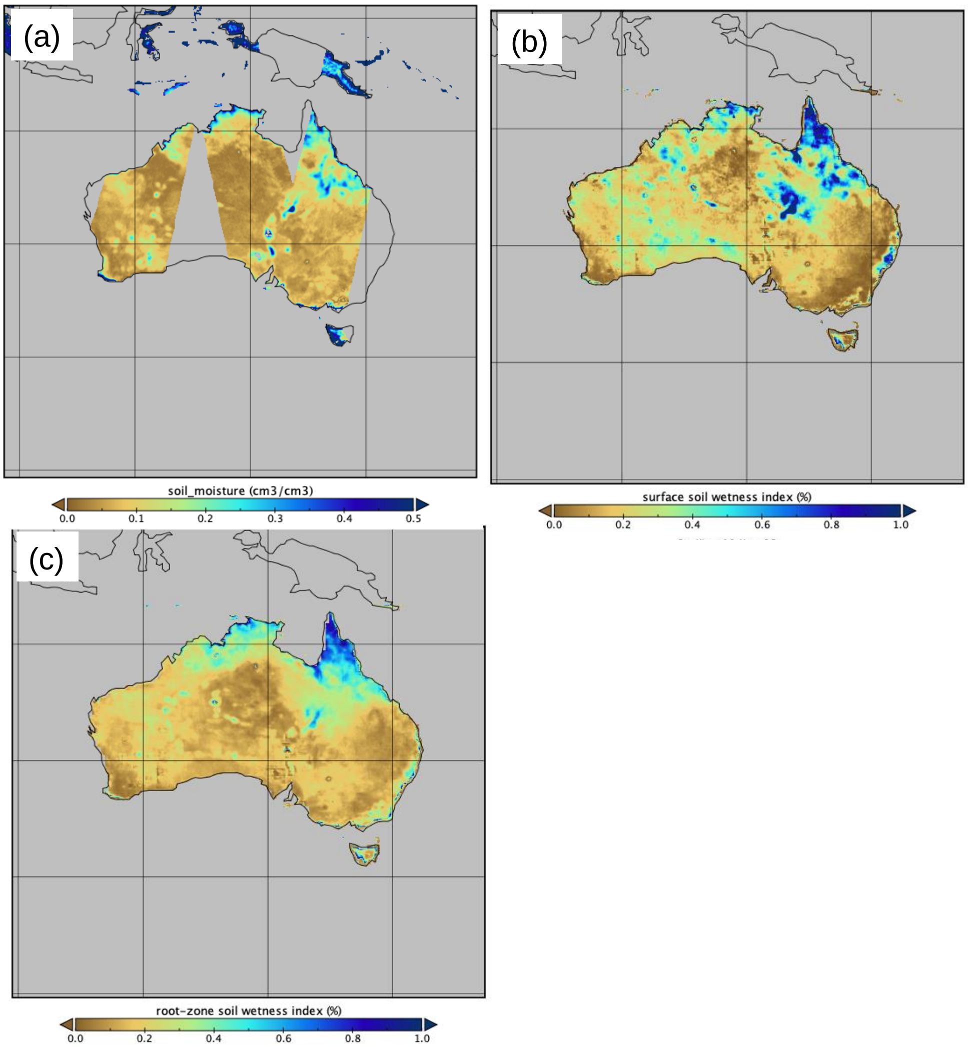

Figure 1. Example of S-GRAFS products for 25 Feb 2019: (a) daily composite of SMAP soil moisture retrieval (m3 m^{-3}); analysed top-layer (0-5 cm) soil wetness index; and (c) root-zone (0-1 m) soil wetness index.

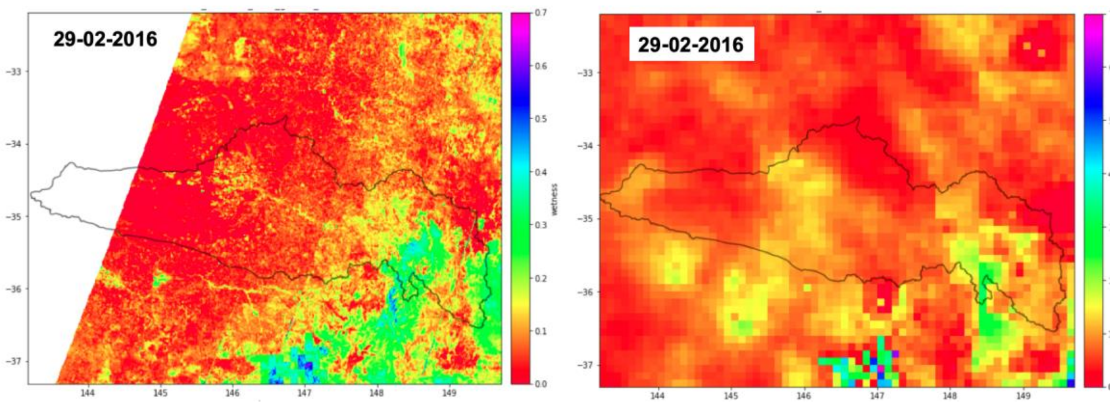

Figure 2. Top-layer soil wetness index across the Murrumbidgee from S-GRAFS for 29 Feb 2016: (a) 1-km resolution estimates from the time series downscaling approach using Sentinel-1 radar backscatter data; and (b) 10-km estimates for the same date.

S-GRAFS Outputs

S-GRAFS runs operationally on National Computational Infrastructure (NCI) to produce daily Australia-wide estimates in near real-time (~20 hour latency). The generated ouputs are available through THREDDS:

http://dapds00.nci.org.au/thredds/catalog/ub8/au/S-GRAFS/catalog.html

Examples of the levels of product are given below.

Top-layer soil wetness forecast (i.e. initial guess before SMAP soil moisture assimilation):

S-GRAFS/Surface_Wetness_from_API_forecast_window_Australia_2019.nc

Top-layer soil wetness analysis (i.e. estimate after SMAP soil moisture assimilation):

S-GRAFS/Surface_Wetness_from_API_analysis_window_Australia_2019.nc

Root-zone soil water index:

S-GRAFS/SWI_1m_forecast_window_Australia_2019.nc

Murrumbidgee sample of 1-km downscaled soil wetness:

S-GRAFS/downscaled_1km_surface_wetness_2018.nc

Next steps

The focus of on going work will be the **extension and further testing of the downscaling approach using the Sentinel-1 gamma-0 data**.

However, it is estimated from the this study to generate an Australia-wide gamma-0 time series at 1-km will consume 300 KSU on NCI raijin if SNAP is used. Exploration of alternative methods is recommended, e.g. CSIRO Sentinel-1 radar processing software from Dr Catherine Ticehurst which may be a computationally cheaper. Furthermore, there may be plans to generate Australia-wide gamma-0 as an analysis ready product via Geoscience Australia, in which case we would be the very happy recipients of the undertaking (to be investigated).

After having applied the downscaling to S-GRAFS top-layer soil wetness estimates continentally, the next step would be to **apply the exponential filter to the downscaled data to generate estimates of 1-km root-zone soil wetness index.**

Finally, and most importantly, an **extensive evaluation of S-GRAFS against the OzNet, OzFlux and CosmOz networks** alongside peer models (e.g. AWRA, JASMIN) is highly recommended to gain user acceptance.