Towards the Operational Implementation of the Canadian Land Data Assimilation System

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Initial conditions of soil moisture and surface temperature are known to have a strong impact on the forecast accuracy of surface and boundary layer variables. Several national meteorological prediction centres have implemented analysis schemes that generate increments of surface temperature and soil moisture that are correlated with errors in the forecast of screen-level air temperature and humidity. In the Canadian Land Data Assimilation System (CaLDAS), the method is further refined by making use of dynamic correlations generated by perturbing precipitation, radiation and temperature forcings in the context of an Ensemble Kalman Filter. Pre-implementation tests have been conducted in offline mode for the year 2008 on a global 33-km latitude-longitude grid. More recently, extensive tests have been run in coupled mode with the EnVar atmospheric data assimilation system, for the year 2011, on a global 25-km latitude-longitude grid. Final tests have been run again in coupled mode for the same year on a global 15-km Yin-Yang grid. Surface analyses have been generated for series of 120 cases in both summer and winter and their impact on numerical weather prediction will be shown using objective evaluation based on upper air and surface observations.
The Auto-tuned Land Data Assimilation System (ATLAS) for land data assimilation

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Two unique challenges of land data assimilation systems are: 1) uncertainty in the definition of observation operators due to large climatological differences between satellite-retrieved and model-forecasted surface states and 2) the complexity and diversity of modeling error sources. Off-line land surface prediction is not an initial value prediction problem and is instead impacted by dynamic errors in external forcings (principally precipitation and incoming radiation) which must be applied to the prognostic calculation of terrestrial water and energy balances. On the other hand, land models lack unstable modes and are notably less nonlinear than atmospheric and oceanic models. These issues are shaping recent efforts to develop data assimilation systems uniquely designed to handle the problem of assimilating satellite-based soil moisture retrievals from the upcoming NASA Soil Moisture Active/Passive mission into terrestrial water balance models driven by precipitation estimates derived from the Global Precipitation Mission constellation.

In response to challenge #1, it has become common practice to empirically define observation operators using long time series of open loop model predictions and assimilated observations. However, recent work has clarified the neither linear regression nor moment-matching techniques provide an optimal empirical solution [1]. Instead, either ancillary signal-to-noise information (for the open loop model and/or the assimilated observations) or a third, observation data set (with wholly independent errors) is required [2]. In addition, challenge #2 has motivated the application of adaptive filtering techniques to better constrain error models applied in land data assimilation systems [3]. However, the expected limitations of innovation-based adaptive filtering approaches in the presence of auto-correlated observation errors have been noted [4].

This presentation will detail development and application of the Auto-tuned Land Data Assimilation System (ATLAS) to the simultaneous assimilation of both active radar and passive radiometer-based SMAP soil moisture retrievals into a simple terrestrial water balance model. By coming aspects of triple collocation estimation with classical innovation analysis, ATLAS can simultaneously solve for: the full observation error covariance matrix (including cross-covariance information), the model forecast error covariance and the auto-correlation of observation errors. This error information can, in turn, be used to define optimal observation operators and provide the basis for an efficient Colored Kalman filter analysis. The theoretical basis of the approach will be established using a synthetic twin experiment, and real data results using existing ASCAT (active radar-based) and AMSR-E (passive radiometer-based) soil moisture products will presented.

References
Land surface processes and their initialization are of crucial importance for Numerical Weather Prediction (NWP). Current land data assimilation systems used to initialize NWP models include snow depth analysis, soil moisture analysis, soil temperature and snow temperature analysis. A range of approaches of various complexities, for example simple Cressman Interpolation, Optimal Interpolation or Extended Kalman Filters, are used by NWP centers for their surface analysis. This paper gives a review of the different approaches that are used in NWP to initialize land surface variables. It discusses the observations availability and quality, and it addresses the combined use of conventional observations and satellite data.

Based on results from the European Centre for Medium-Range Weather Forecasts (ECMWF), soil moisture and snow depth data assimilation impact on near surface weather parameters forecasts is shown [1]. For soil moisture, data assimilation of satellite observations from ASCAT (Advanced Scatterometer) and SMOS (Soil Moisture and Ocean Salinity) is addressed. Future satellites such as SMAP (Soil Moisture Active and Passive) will ensure a good continuity with the current SMOS satellite.

Both surface fields and low level atmospheric variables are highly sensitive to the soil moisture and snow initialization methods. This presentation shows that recent developments of ECMWF in soil moisture and snow data assimilation contributed to improve surface and atmospheric forecast performance [1,3].

References


Assimilation of Geostationary Satellite Land Surface Skin Temperature Observations into the GEOS-5 Global Atmospheric Modeling and Assimilation System

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The land surface skin temperature is central to the surface energy, water, and radiation balances. In an atmospheric model, improved skin temperature estimates are expected to yield improved temperature and humidity profiles, while in an atmospheric data assimilation system improved skin temperature states are ultimately expected to enhance the assimilation of atmospheric radiances from surface-sensitive channels. Near-instantaneous skin temperature estimates can be retrieved from geostationary Earth orbiting satellite observations with high temporal frequency (potentially sub-hourly) and extensive spatial coverage (all clear-sky low and mid-latitudes). Using a constellation of five geostationary satellites, NASA Langley are generating 3-hourly skin temperature observations at 0.3125x0.25 degrees, with an estimated error over land of less than 2K. These skin temperature observations are assimilated into the Goddard Earth Observing System Model, version 5 (GEOS-5) every 6 hours over North America, using an ensemble Kalman filter-based Land Data Assimilation System (LDAS). The LDAS has been coupled to GEOS-5 in that it receives atmospheric forcing from GEOS-5, and returns incremental land surface analysis updates to GEOS-5. A dynamic observation bias correction scheme has been implemented within the LDAS to remove the biases in the geostationary skin temperature observations. The impact of the assimilation is evaluated by examining the impact on forecasts of skin temperature, land surface fluxes, and low-level temperature and humidity.
Using SMOS Near-Real Time Brightness Temperatures in ECMWF’s Land Surface Analysis: An Overview of Recent Developments, Results and Future Challenges

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SMOS is ESA’s water mission observing key-elements of the Earth’s water cycle, i.e. soil moisture and ocean salinity. It features a novel instrument – MIRAS – that is the first synthetic aperture L-band radiometer ever operated on an EO space mission. High quality measurements representing the full Stokes vector have been made since 2009 and operationally delivered to a large user community. SMOS is also the first Earth Explorer mission with a dedicated Near-Real-Time (NRT) processing chain for its Level 1 observations in the operational ground segment [1]. Operational weather forecasting centers have been the prime customers for the NRT product as the brightness temperatures over land are very sensitive to soil moisture and therefore potentially useful for the corresponding analysis [2]. However, a number of challenges associated to introducing an entirely novel product in the land surface analysis have been addressed by ECMWF:

1) Until recently, the soil moisture analysis has been based on screen level parameters, namely two-meter temperature and relative humidity at synoptic observation times. The Optimal Interpolation analysis was replaced by an Extended Kalman Filter to accommodate the satellite observations [3].

2) A forward operator for the generation of model-based polarized brightness temperatures in the antenna reference frame has been implemented [4].

3) ECMWF’s Integrated Forecasting System has been revised optimizing task scheduling following the computational demands of the EKF and the large volume of SMOS brightness temperature observations [5].

Results from data assimilation experiments reflecting the operational set up show a positive impact on the soil moisture analysis and the forecast of low-level air temperatures and relative humidity up to day 5 for large parts of the Northern Hemisphere. Especially over North America the improvement of forecast skill has been highly significant. Densely vegetated areas and large parts of Asia with a strong contamination of the signal through Radio Frequency Interference pose problems. The presentation will provide an overview of the mission status, recent and ongoing developments for the land surface analysis, and the SMOS potential for operational applications related to soil frost, sea ice, and high wind speeds over the ocean.

References

Assimilating Biogeochemical and Biophysical Observations into a Land Surface Model Using the Data Assimilation Research Testbed

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Interactions between the climate system and vegetation exhibit a number of complex feedbacks. Climate dynamics control many aspects of ecological function, whilst changes in vegetation influence carbon, water and energy budgets directly affecting local and global climate. This role is recognized by the inclusion of complex land surface schemes in Earth System Models.

The National Ecological Observatory Network (NEON) is a National Science Foundation funded, continental-scale facility that will collect biogeochemical and biophysical data from 60 sites across the USA over 30 years. Data will include: (i) observations from eddy covariance flux towers which provide direct measurements of the ecosystem exchange of water, carbon and energy between the land surface and atmosphere; (ii) profiles of soil moisture and temperatures; and (iii) air-borne platform derived measurements of vegetation height, leaf area and biomass.

Such observations, along with comparable observations from space-borne satellites, can be used to inform land surface schemes in a variety of ways, but most directly through a data assimilation (DA) system. As with atmospheric or ocean DA systems, the goal with a land surface model is that it will update model states to make them more similar to the true state of the land surface, and this will then improve the model’s forecast ability.

Here we describe how we are using the recently developed support for the Community Land Model (CLM) provided by the Data Assimilation Research Testbed, a community tool for ensemble data assimilation developed and maintained at the National Center for Atmospheric Research, in the development of prototype continental-scale data products for NEON.

In the early stages of this project we have concentrated on investigating methodologies for assimilating Ameriflux network observations of carbon and water fluxes and assessing the impacts of this on modeled carbon and water state variables describing vegetation and soil. As a next step we have assimilated MODIS satellite measurements of leaf area index, which is linked to modeled leaf carbon through a simple relationship describing leaf area per unit of leaf carbon.

Using both real observations and observing system simulation experiments (OSSEs) we have developed tools to preprocess these observations for use with DART and have tested different update time steps and approaches to aggregate different observations that are available at contrasting time intervals (half hourly, weekly, annually).

These early results suggest that ensemble DA is potentially a powerful tool for informing many different state variables in a land surface model, constraining the water and carbon pools and their interaction with the atmosphere. Whilst land surface models are not as sensitive to initial conditions on the same timescales as the atmosphere, we demonstrate that the impact of DA is long lasting, effecting land surface model forecasts over a number of years.
Benchmarking a Soil Moisture Data Assimilation System for Agricultural Drought Monitoring

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Agricultural drought is defined as a shortage of moisture in the root zone of plants. Recently available satellite-based remote sensing data have accelerated development of drought early warning system by providing continuous soil moisture information in space and time. Nonetheless, the shallow sensing depth (top few cm) and uncertain accuracy of currently available satellite soil moisture retrievals necessitated the integrating hydrologic models and surface soil moisture observations through data assimilation techniques to obtain more accurate root zone soil moisture estimates. Although a number of previous studied have demonstrated the benefits of soil moisture data assimilation system, relatively little is known about the relative merits of particular retrieval, modeling and/or data assimilation strategies. In particular, it remains unclear what level of complexity and/or nonlinearity is appropriate for each of these components.

In this study, we attempt to assess individual components of a drought-monitoring soil moisture data assimilation system and benchmark the efficiency of these components relative to simpler retrieval, modeling and data integration strategies. In this way, we improve our understanding of skill contributed by various components of the system and, ultimately, pinpoint specific aspects of such systems to target for improvement. First, the efficiency of a retrieval algorithm, Land parameter Retrieval Model (LPRM) is evaluated using data from the Advanced Microwave Scanning Radiometer-EOS (AMSR-E). Second, the two-layer Palmer water balance model being in operational use by the USDA - Foreign Agricultural Service is tested. Lastly, a well-proven data assimilation technique, Ensemble Kalman filter (EnKF) is evaluated. The metric to measure the performance of each process is the lagged rank correlation between the output of each component and the normalized difference vegetation index (NDVI). A simple statistical model, the multiple linear regression model is used as benchmarks (minimal reference level) against which the performances of different components of assimilation system are evaluated.

Interestingly, it is found that most of the benefits from the assimilation system to predict root zone soil moisture are attributed to the initial remote sensing observations (i.e., brightness temperature). The nonlinearities in the retrieval algorithm (LPRM) and hydrologic model (Palmer model) and the complexities in the EnKF marginally contribute to the predictive skills of the system. This suggests that there are considerable rooms for improvement in those nonlinear processes for effective agricultural drought monitoring. Specifically, for the hydrologic model, it appears there is no utility in enforcing a nonlinear saturation limit on soil moisture dynamics for coarse-scale agricultural drought monitoring. In addition, issues related to inappropriate implementation of the EnKF are discussed.
Ensemble Data Assimilation for Soil-Vegetation-Atmosphere Systems

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There are many open research questions in the relatively new field of data assimilation for land surface models. We know that all models are imperfect and are probably biased. We also know that our knowledge of the initial conditions and forcing for those models is imperfect. The observations of interest may not be represented explicitly in the model and both the models and the observations have uncertainties and differences in representativeness. An effective data assimilation system must address all of these while producing a model state that contains the information that may be derived from those observations.

The main focus of an ensemble data assimilation system is to produce a collection of model states – the ensemble – that are indistinguishable from the modeled system. Land surface processes are challenging in this regard given the tremendous heterogeneity of the land surface and the range of scales of interest; from individual plants to watersheds to continental-scale responses. Furthermore, the equations governing ecological processes are not nearly as well-defined as those for atmospheric modeling, for example. Our goal is to produce an ensemble of land surface states that can be used to produce a forecast. The accuracy of this forecast is our measure of the success of our ensemble system. A good forecast is believed to depend on a good initial state and accurate model dynamics and so is a challenging measure of success.

This talk will focus only on a method that directly informs and updates the model state with the information content of the observations. The Data Assimilation Research Testbed (DART) is a community facility for ensemble data assimilation developed and maintained at the National Center for Atmospheric Research (NCAR). DART\textsuperscript{[1]} is a software environment that makes it easy to explore a variety of data assimilation methods and observations with different numerical models and is designed to facilitate the combination of assimilation algorithms, models, and real (as well as synthetic) observations to allow increased understanding of all three. Land surface models supported by DART are the Community Land Model (CLM) and the uncoupled mode of the Noah Land Surface Model (Noah LSM). This talk will present an overview of three very different experiments and summarize the challenges and future direction of research. CLM is used to assimilate MODIS snow cover fraction observations to improve daily estimates of snow water equivalent. Noah LSM is used at a single site to assimilate hourly soil moisture estimates from a neutron probe and verified against (withheld) in-situ soil moisture estimates. CLM is also used at a single site to assimilate flux tower observations and is compared to open-loop simulations.

References

Assimilation of Soil moisture Retrievals from FY-3B Microwave Radiometer Imager into Community Land Model using Ensemble Kalman Filtering

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It is widely known that soil moisture plays an important role in meteorological, agricultural and hydrological fields. Both soil moisture retrieved from remotely sensed microwave measurements and predicted from numerical models have advantages and disadvantages. An effective way to achieve soil moisture estimates with high accuracy and large coverage is to assimilate information from satellites to models.

In this study, two-year surface soil moisture product over China derived from the microwave radio imager (MWRI) sensor onboard of the Fengyun 3B satellite (FY-3B) is assimilated into the Community Land Model (CLM). The FY-3B soil moisture retrievals are firstly compared to the soil moisture product generated by CLM forced by China Land Assimilation System version 1.0 (CLDAS v1.0) forcing data. To reduce satellite-model bias, cumulative distribution function (CDF) matching is used to scale the FY-3B soil moisture retrievals to the CLM modeled soil moisture. Then the scaled satellite retrievals are assimilated into CLM by using Ensemble Kalman Filtering (EnKF) technique. To evaluate the impacts of FY-3B soil moisture product assimilation, CLM with FY-3B soil moisture product assimilation and CLM without any change are run separately over China forced by the CLDAS v1.0 forcing data from Jan. 2011 to Jan. 2013 with a spatial resolution of 0.0625°.

In situ observations from more than one thousand automatic observation stations are used to evaluate the impacts of the assimilation of satellite retrievals. Validation against in situ data shows that the assimilation of FY-3B soil moisture products improves the soil moisture simulation accuracy over many regions in China. Especially, the top 10 cm simulation with assimilation of FY-3B soil moisture retrievals has a reduced bias and higher correlation compared to the simulation without assimilation of satellite information.

References
Assimilation of remotely sensed hydrological datasets in the North American Land Data Assimilation System (NLDAS)

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The North American Land Data Assimilation System (NLDAS) has produced over 34 years (Jan 1979 to present) of hourly land-surface meteorology and surface states, including soil moistures and temperatures, snow cover, runoff, and evapotranspiration. NLDAS uses the best-available observations and reanalyses to create near-surface forcing for land-surface models (LSMs) in “off-line” mode, but to-date has not included the ability to assimilate relevant hydrological remote sensing datasets. Several recent works have independently demonstrated the value of assimilating AMSR-E based soil moisture, AMSR-E based estimates of snow depth; MODIS-based estimates of Snow Covered Area (SCA); GRACE-based terrestrial water storage (TWS) and MODIS-based estimates of irrigation intensity. In this presentation, we will present results of assimilating these datasets in the NLDAS configuration using the NASA Land Information System (LIS), as part of the new phase of the NLDAS project. The results from the individual assimilation of AMSR-E based soil moisture and snow depth into the Noah LSM indicate that systematic improvements are obtained not only in soil moisture and snow states, but also on evapotranspiration and streamflow estimates. We will also present results from the combined assimilation of the above-mentioned multi-sensor datasets in NLDAS and an evaluation of the resulting improvements and trends in soil moisture, snowpack, evapotranspiration and streamflow.
Land Data Assimilation over Norway: A stringent test of EnKF capabilities

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Providing information on the land surface hydrological cycle over Norway is problematic owing to the difficulties of making remote sensing observations. Norway is one the most difficult and challenging areas in the globe for measuring soil moisture remotely. Measurements are difficult or not possible owing to the presence of snow, ice, water bodies, orography, rocks, and a very high coastline-to-area ratio. One way to improve this information is to use land data assimilation to combine observational and model information in an objective manner [1]. We provide first results of efforts to assimilate soil moisture from satellite platforms (AMSR-E, ASCAT and SMOS) into the NILU (Norwegian Institute for Air Research) Ensemble Kalman filter (EnKF) system [2]. We explore the range of parameters (number of ensemble members; parameters to be perturbed; observational quality control; specification of model errors) affecting the EnKF analyses. By focusing on these challenging conditions in Norway, the work described in this study provides a stringent test of the capabilities of land data assimilation to provide information on the land surface hydrological cycle. This information is useful for various applications, including land surface monitoring, weather forecasting, hydrological modelling and climate modelling.

References


Mesonet Data Assimilation and Quality Control Challenges for the Real-Time Mesoscale Analysis (RTMA) System

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The Real Time Mesoscale Analysis (RTMA) system at NCEP[1] is a 2DVar assimilation system that includes surface observations from a wide variety of sources. Of particular interest are mesonet stations, which require special attention with respect to quality control. Many mesonet stations are sited in less than ideal environments, but often their observations still add value to the analysis. In addition, a lack of available metadata for mesonet stations can hinder the ability to make real time quality control decisions necessary for the RTMA.

Currently, static lists of usable (or non usable) mesonet stations are used for quality control. This is an attempt to expand upon these lists; creating dynamic uselists (or reject lists) which are based on stratified statistics. The hope is to find stations that are usable only in certain situations, and use those stations only in situations where it is appropriate to do so. Quality control lists will be presented based on observed wind direction (to identify stations where winds are partially obstructed) and local sun angle (to identify under or over exposed stations). These lists are based on the methods developed by Benjamin et. al[2] and Levine et. al[3], but are expanded to include different weather situations.

The lists are also used to infer metadata about specific mesonet sites where none is available. The quality control lists and metadata are used to identify which mesonet stations should be used in the analysis. The full quality control methodology, impact of the lists on the analysis, and potential new methods of using mesonet metadata will be presented.

References


Assessment of a New Dense Media Radiative Transfer Model Based on the Quasicrystalline Approximation (QCA/DMRT) in Assimilation of Passive Microwave Satellite Observations

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Satellite observations of snow properties have been available for more than 40 years from both passive microwave sensors and active microwave radiometers. We developed a model for both active and passive microwave remote sensing of layered dry snowpack based on dense media radiative transfer (DMRT) theory with the quasicrystalline approximation (QCA). In the new model snow layer with ice fractional volume less than 50\% is modeled as ice particles imbedded in air background. Snow layer with ice fractional volume larger than 50\% is modeled as air bubbles imbedded in ice background. This provides more accurate results compared to the current multilayer QCA/DMRT model when highly packed snow layers or thick ice layers exist.

The multilayer Dense Media Radiative Transfer Theory Based on the Quasicrystalline Approximation (multilayer QCA/DMRT) model has been developed to simulate both passive and active microwave remote sensing signatures from layered snowpacks [1], [2]. In former model, all snow layers were modeled as ice particles imbedded in air regardless of ice fractional volume. When forced with snow ground measurements, this multilayer QCA/DMRT model simulations are in good agreement with Ground Based Passive Microwave Radiometer (GBMR-7) measurements, ground-based and airborne Ku band polarimetric scatterometer (POLSCAT) observations. Andreadis et al. [3] showed that coupled multilayer snow hydrology model and this multilayer QCA/DMRT model resulted in improved snow depth estimates in assimilation of Special Sensor Microwave Imager (SSM/I) observations.

Ice particles in snow adhere to each other and form large clusters. Scattering from a single ice particle follows Rayleigh or Mie scattering depending on the particle size comparison to wavelength. If ice particles are clustered, electromagnetic field interacts among the particles need to be considered when calculating total scattering. By taking into account these field interactions, the QCA/DMRT theory calculate collective scattering effects of the ice particles and predicts different scattering properties of snow from classical theory. However, QCA/DMRT simulations of extinction coefficient deviate from numerical simulations when scatterers fractional volume is large. Taking this into consideration, in this new model, we apply air bubbles instead of ice particles as scatterers for snow layer with large density.

We assess this new multilayer QCA/DMRT model by forcing it with ground snow truth measurement and compare with both ground based and space based brightness temperature observations.

References


Assimilating Satellite-Based Snow Depth and Snow Cover Products for Improving Snow Predictions in Alaska

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Several satellite-based snow products are assimilated, both separately and jointly, into the Noah land surface model for improving snow prediction in Alaska. These include the standard and interpreted versions of snow cover fraction (SCF) data from the Moderate-Resolution Imaging Spectroradiometer (MODIS) and the snow depth (SD) estimates from the Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E). The satellite-based SD estimates are adjusted against in situ observations via statistical interpolation to reduce the potentially large biases, prior to being assimilated using an ensemble Kalman filter. A customized, rule-based direct insertion approach is developed to assimilate the two SCF datasets. Our results indicate that considerable overall improvement on snow prediction can be achieved via assimilating the bias-adjusted satellite SD estimates; however, the improvement does not always translate into improvements in streamflow prediction. Assimilating the standard MODIS SCF is found to have little impact on snow and streamflow predictions, while assimilating the interpreted SCF estimates, which have reduced cloud coverage and improved snow mapping accuracy, has resulted in the most consistent improvements on snow and streamflow predictions across the study domain. When the SCF and SD products are jointly assimilated, the impact of SD assimilation is found to be dominant on the results of snow and streamflow predictions.

Reference:
Surface Temperature Downscaling based on Genetic Particle Smoother

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Thermal infrared (TIR) data are efficiently used for surface fluxes estimation giving the possibility to assess energy budgets through surface temperature. However, an accurate knowledge of such data at high spatial/temporal resolution is not possible considering the present instruments on board satellites. In fact, available instruments allow either the high spatial resolution with a low temporal one (e.g. ASTER: repeat cycle of 15 days/spatial resolution of 15m to 90m) or the high temporal resolution with a coarse spatial one (e.g. SEVIRI: repeat cycle of 15min/spatial resolution of 3km). Then, it is necessary to develop methodologies to combine these multi-scale and multi-temporal data to better monitor fluxes at appropriate scales. Our approach consists in the development of a new downscaling method based on the Genetic Particle Filter (GPF) or more precisely Particle Smoother (PS) to extract sub-pixel variables from large scale data measurements. This methodology consists in constraining surface temperatures trajectories simulated by a dynamic model and aggregated at the scale of the observations. The SETHYS land surface model [1] was used for that purpose. The first step was to develop and test our approach on a synthetic database based on the French "Crau-Camargue" region landscape and climate. A heterogeneous pixel containing 4 different land cover types equally distributed (bare soil, prairie, wheat and rice) was considered. The results of PS LST downscaling approach [2] applied on the synthetic database showed good performances. It has also been shown that PS performances decrease with observation error amplitude and rise with observation frequency. The second step was to apply the PS downscaling approach on real data and at larger scale (a whole image and not only a pixel) and compare its performances to other approaches [3, 4]. Some assumptions were considered on the spatial correlation between pixels in a first time (no correlation). The comparison based on the assimilation of METEOSAT-SEVIRI Coarse Spatial Resolution (CSR) observations and the efficiency of the downscaling method compared to ASTER High Spatial Resolution (HSR) images will be presented.

References


A soil moisture data assimilation system for SMOS and SMAP

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The Soil Moisture Ocean Salinity (SMOS) mission launched in 2009 and the Soil Moisture Active Passive (SMAP) mission scheduled for launch in 2014 are specifically designed to provide global estimates of near-surface soil moisture (in the top 5 cm of the soil column).

In this paper, we use observations of L-band (1.4 GHz) microwave brightness temperature from SMOS in a land-only data assimilation system to generate a prototype of the Level 4 Surface and Root Zone Soil Moisture (L4_SM) product under development for SMAP.

The assimilation system consists of an ensemble Kalman filter (EnKF) and the NASA Catchment land surface model. The Catchment model is driven with surface meteorological forcing data from the NASA GEOS-5 atmospheric analysis system, with precipitation corrected towards gauge-based observations. The system provides global surface and root zone soil moisture estimates at a horizontal resolution of 9 km every three hours.

We assess the performance of the assimilation system by validating the SMOS-based soil moisture assimilation results against independent in situ measurements. Our results indicate that the SMAP L4_SM root zone soil moisture data product will meet its accuracy requirement (RMSE < 0.04 $\text{m}^3/\text{m}^3$ after removal of the long-term mean bias).

We further assess the system performance by analyzing data assimilation diagnostics, including the observations-minus-forecast residuals and the soil moisture and temperature increments. These diagnostics are critical for the calibration of the model and observation error parameters that are needed in the assimilation system.
Satellite Soil Moisture Data Assimilation into the Australian Water Resources Assessment modeling system

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Many researchers over the last decade have demonstrated how the assimilation of satellite soil moisture data can improve the accuracy of soil water representation in land surface models, and result in improved estimates of evaporative flux, drainage and runoff [1,2,3]. In this study we investigated whether similar benefits are achievable for the Australian Water Resources Assessment Landscape (AWRA-L) model through the assimilation of the soil moisture products derived respectively from the Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) on NASA’s Aqua satellite and the Advanced Scatterometer (ASCAT) on EUMETSAT’s Metop-A satellite.

The AWRA-L model was co-developed by Australia’s CSIRO and Bureau of Meteorology researchers as the landscape component of the larger AWRA system (that includes river and groundwater modeling components), which supports the Bureau's mandated reporting requirements on national water accounts and water resource assessments. AWRA-L represents the soil column as three conceptual storage layers: a top-layer (equivalent to the emitting soil layer for C- or L-band microwave radiometry); and separate layers for shallow- and deep-rooted vegetation respectively. Field capacity values are ascribed to each soil layer \textit{a priori} through independent calibration activities. The model is run cell-wise (i.e. no lateral flows) across the continent at 0.05-degree steps providing estimates of daily fluxes and stores of landscape water.

We used perturbed meteorological forcing (specifically rainfall, shortwave radiation and air temperature) and the ensemble Kalman filter (EnKF) to assimilate AMSR-E and ASCAT soil moisture products into AWRA-L. Evaluations to-date have focused on the Murrumbidgee area of southeastern Australia because of the OzNet network of \textit{in situ} moisture sensors, but will be extended to other parts of the continent via the cosmic ray probes and (indirectly) through evaluation against independent satellite soil moisture retrievals (e.g. SMOS). Currently results in the Murrumbidgee clearly show an improvement in AWRA-L top-layer soil moisture estimation compared to open-loop simulations, as well as improved runoff estimation in some catchments. The results of assimilation on root-zone soil moisture estimation are mixed, but appear to be linked to a combination of satellite product error specification or the strength of vertical coupling of the soil layers. Further investigations will identify where and when the assimilation of satellite soil moisture benefits AWRA-L estimation in terms of soil water status and runoff estimation.

References


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China Land Data Assimilation System (CLDAS) Research and Operation

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In recent years, frequent drought events have caused enormous losses. High quality space-time soil moisture products are urgent to support CMA in China drought monitoring services. Soil moisture retrieved from satellite observation or simulated from land surface models or from in-situ observations has different advantages and defects. Merging all the soil moisture information together may have the ability to obtain high quality soil moisture continuously. Therefore, China Land Data Assimilation System (CLDAS) is proposed to meet the demand of drought monitoring and other meteorological, agricultural and hydrological requirements over China.

CLDAS consists of three stages. The first stage aims to realize STMAS operation for producing forcing data; to realize operational running of CLM; to evaluate forcing and CLM output; and to publish the operational products for users. The second stage aims to build retrospective forcing data set since 1995 over China; to develop multi-LSMs operational system; and to develop multi-satellite merged soil moisture product. The third stage aims to assimilate multi-satellite merged soil moisture; to assimilate satellite radiance or brightness temperature.

The first stage of CLDAS (V1.0) will be operated in national meteorological information center of CMA by the end of Jun 2013. The product coverage is 70-150E, 0-60N and the spatial resolution is 1/16 (0.0625) degree. Hourly gridded forcing data, including air temperature, pressure, humidity, wind speed, downward shortwave radiation and precipitation, are used to drive CLM in CLDAS. STMAS (Space-Time Multi-scale Analysis System) (Xie, Y., 2011) are used to combining NCEP/GFS data with regional automatic surface observation temperature (more than 30000) over China, and the result are validated using national automatic observation (more than 2400). The result shows that the combined temperature product is closer to surface observations than GFS product. Air pressure, relative humidity and wind speed are processed similar as temperature. The Downward shortwave radiation (DSR) is retrieved from FY-2(C-F) series geostationary meteorological satellites, operated by CMA. The DISORT method for radiation transfer calculations with the climatic data sets from the ISCCP C2 is used in the retrieval. The DSR is evaluated against ground-based observations (OBS) from 94 stations over mainland China (Jia, B., 2013). Grid precipitation is produced by merging more than 30000 rain gauge data and CMORPH product.

CMA began to establish automatic soil moisture observation network since 2009. More than 2000 stations are put into operation till now. The automatic observation network will gradually replace the human observation network which has more than 700 stations since 1981. After quality control, soil moisture observations are used to evaluate CLDAS soil moisture product.

References
Data Assimilation for Fuel Moisture in WRF-SFIRE: Method and Implementation

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Fuel moisture is a major influence on the behavior of wildland fires and an important underlying factor in fire risk. In this presentation, we report on experiences with a recently developed method [1] which assimilates ground station fuel moisture observations into the fuel moisture model of WRF-SFIRE [2,3].

The method uses a weather model (WRF) forecast together with additional covariates in a trend surface model approach to model the spatial structure of the fuel moisture field. These predictions are then combined with the moisture model forecast using a nonlinear Kalman filter to obtain the analysis. We report on two applications of the method: spin-up of the fuel moisture content for a wildland fire simulation and continuous dead fuel moisture mapping.

In the first application, this method was used to generate a realistic spatial distribution of the fuel moisture required for fire spread modeling. The available fuel moisture observations prior to the 2007 San Diego fires have been fed into the system in order to prepare the best estimate of the fuel moisture at the time ignition of Witch fire [4]. In order to assess the effects of the fuel moisture assimilation on the simulated fire spread two numerical experiments have been performed, one with the assimilated fuel moisture and one without it. We report on the improvements in the simulation following assimilation of ground station observations as the result of the applied data assimilation method.

The second application is the mapping of dead fuel moisture on a domain enclosing Colorado, which has been embodied in a server-side system for continuous operation. We report on our experiences with long-term operation of the model and its monitoring.

References

North American Land Data Assimilation System Phase 2 (NLDAS-2):
Evaluation and Applications

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Abstract

Currently, NLDAS is a quasi-operational system that supports U.S. operational drought monitoring and seasonal hydrological prediction, in particular for the National Integrated Information System including U.S. Drought Monitor (USDM) and NCEP Climate Prediction Center Monthly Drought Briefing [1]. Detailed information about NLDAS can be found at NOAA (http://www.emc.ncep.noaa.gov/mmb/nldas) and NASA (http://ldas.gsfc.nasa.gov/nldas/) websites. NLDAS consists of four stages. The first stage is to establish NLDAS infrastructure (2000-2005) and test performance of the models, the second stage is to upgrade models and surface forcing to generate long-term NLDAS products (2006-2009), the third stage is to evaluate quality and reliability of these long-term products using as many as available in situ observations and satellite-retrieved data (2009-2011), and the fourth stage is to transition this system to NCEP operations and apply these products to U.S drought analysis and monitor (2012-beyond).

This presentation gives an overview of our overall evaluation results performed during the last three years including evaluation tools, in-situ observations and satellite-retrieved data used in NLDAS-2, and the performance of the different land models [2]. The evaluated products include streamflow/total runoff, evapotranspiration, sensible and latent heat flux, ground heat flux, soil moisture, soil temperature, and land surface skin temperature. These evaluations cover different spatial scales, varying from basin to continental scale, and time scales varying from hourly to annually. After we summarize our evaluation results, we also show some preliminary results from recent efforts to further improve individual models and suggest some possible directions to improve different NLDAS-2 land surface models in future. Finally, we will also show how to use our NLDAS products to support U.S. operational drought monitoring and prediction activities.

We recognize that the current NLDAS is not an “actual” land data assimilation system because remotely-sensed estimates of land-surface states such as soil moisture and snowpack, and in-situ observations such as streamflow and soil moisture, are not yet assimilated into the current version of NLDAS. The NCEP/EMC NLDAS team is collaborating with the NASA Goddard Hydrological Sciences Laboratory to add their Land Information System to the current NLDAS system which would allow assimilation of remotely-sensed data and in-situ observations, e.g. via an ensemble Kalman filter approach.

References


Advances in the GRACE Data Assimilation System

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The twin satellites of the NASA/German Gravity Recovery and Climate Experiment (GRACE) mission were launched just over a decade ago, in March 2002. Since that time, they have flown in Low Earth Orbit, 220 kilometers apart from one another, recording continuous, highly precise measurements of their location and the distance between them using GPS and a microwave ranging system. These measurements can be used to derive geodetic maps of Earth’s gravitational field, since accelerations of the satellites relative to each other are influenced by the presence of gravitational anomalies. Changes in the gravitational field over time are associated with the movement of mass near Earth’s surface, and over GRACE observed timescales—weeks to years—the movement of water constitutes a significant and quantifiable portion of this signal [1]. In this way, GRACE provides hydrogeodetic information by relating the temporal variations of the Earth's gravitational field to changes in the hydrologic cycle. Careful analysis of the GRACE signal over land yields estimates of terrestrial water storage (TWS) anomalies, a quantity that includes changes in surface water, snow and ice, vegetation water, soil moisture, and groundwater.

While the GRACE TWS estimate is an unprecedented observation that is of great value for basin scale hydrologic monitoring, many hydrology and water resources applications require water storage estimates at higher spatial resolution, greater temporal frequency, and with greater physical specificity (e.g., groundwater versus soil moisture versus snow) than GRACE can offer. The GRACE Data Assimilation System [2] was developed to skillfully merge GRACE information on large scale TWS anomalies with the physically-based hydrological simulation tools of advanced Land Surface Models in order to improve model simulation of water storage while disaggregating and downscaling the raw GRACE TWS estimate. The primary assimilation algorithm is a variant of the ensemble Kalman Smoother. In recent years the system has been applied to studies of water resources and drought monitoring in diverse climate conditions over four different continents. These experiences have led to refinements in the assimilation system that include modifications to land surface model parameters and the treatment of irrigation withdrawals, adjustments in the assimilation algorithm for snow updates, and, most recently, the implementation of a gridded observation assimilation capability that allows for a more flexible application of the system. This presentation will provide an overview of current GRACE-DAS capabilities, report on recent innovations in the modeling system, and describe future directions in GRACE data assimilation research and applications.

References
Soil moisture has long been recognized as one of the critical land surface initial conditions for numerical weather, climate, and hydrological predictions and agricultural and societal water resources management. Satellite soil moisture data products have been generated since more than a decade ago. However, none of these satellite soil moisture data products has been used operationally in the prediction models and management practice because of their accuracy or reliability issues. A climatologically consistent and qualitatively reliable global soil moisture product, is thus in urgent need for these applications. A group of scientists from NOAA-NESDIS and China Meteorological Administration (CMA) are collaborating in generating soil moisture data products from various optical and microwave remote sensing satellites. This presentation will focus on the algorithm development and validation of the soil moisture Environmental Data Record (EDR) from AMSR2 after a general introduction of the soil moisture operational production system (SMOPS) developed at NOAA-NESDIS and the atmosphere-land exchange inversion model (ALEXI) implemented with USDA-ARS collaborators. Examples of applications of these data products in numerical weather prediction and agricultural drought monitoring will be discussed. A multi-sensor soil moisture data merging system developed at CMA-NMIC will also be presented.
Dual Assimilation of Microwave and Thermal-Infrared Satellite Observations of Soil Moisture into NLDAS for Improved Drought Monitoring

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The utility and reliability of standard meteorological drought indices based on measurements of precipitation is limited by the spatial distribution and quality of currently available rainfall data. Furthermore, precipitation-based indices only reflect one component of the surface hydrologic cycle, and cannot readily capture non-precipitation based moisture inputs to the land-surface system (e.g., irrigation, shallow groundwater tables) that may temper drought impacts or variable rates of water consumption across a landscape. The Evaporative Stress Index (ESI), used here as a proxy for soil moisture, quantifies anomalies in the ratio of actual to potential ET (PET) mapped using signals of diurnal land-surface temperature (LST) change obtained from geostationary satellites. Because LST is a fast-response variable, and ESI quantifies anomalous water-use, the ESI has value in monitoring “flash drought” signals that may be missed or delayed in other drought indices based on precipitation or vegetation index.

The presentation will address the development of an operational system for optimal assimilation of thermal infrared (TIR) and microwave (MV) soil moisture (SM) and insertion of near real-time vegetation fraction (GVF) into the NLDAS Noah LSM towards the improvement of LSM-based drought monitoring. It has been demonstrated that diagnostic information about SM and evapotranspiration (ET) from MW and TIR remote sensing can reduce SM drifts in LSMs such as Noah. The two retrievals have been shown to be quite complementary: TIR provides relatively high spatial (down to 100 m) and low temporal resolution (due to cloud cover) retrievals over a wide range of GVF, while MW provides relatively low spatial (25-60 km) and high temporal resolution (can retrieve through cloud cover), but only over areas with low GVF. Furthermore, MW retrievals are sensitive to SM only in the first few centimeters of the soil profile, while TIR provides information about SM conditions integrated over the full root-zone, reflected in the observed canopy temperature. Outputs from the operational DA system will include near real-time (updated each night) maps of surface and root-zone SM, ET and runoff. Finally, an evaluation of SM moisture anomalies from the DA simulations will be compared to ALEXI ESI and standard drought metrics, including operational NLDAS output.
Gravity Recovery and Climate Experiment (GRACE) twin satellites, launched in 2002, were designed to map the earth’s gravity field and its temporal variations. Over the land, temporal changes in the gravity field is usually associated with changes in the atmosphere and terrestrial water storage (TWS) which includes snow, soil moisture, groundwater and surface water. By removing the temporal mean of the GRACE observed gravity field and atmospheric influences, anomalies of TWS, in equivalent water heights (cm), can be obtained. One major advantage of GRACE is its ability to detect water storage changes in the deeper subsurface including groundwater which cannot be sensed by other earth-orbiting satellites. Studies have linked long-term decreasing trends observed by GRACE to depletion of groundwater in several regions where groundwater withdrawal exceeded its natural replenishing rate.

Due to the smoothing techniques used in retrieving TWS, GRACE derived TWS is provided at about 150,000 km² spatial resolution and monthly temporal resolution, which often do not provide enough details for hydrological applications. In addition, since GRACE TWS values represent integrated changes in snow, soil moisture and groundwater (surface water is often negligible due to their small areal coverage), skillful disaggregation into individual states which are more relevant to hydrological purposes is needed. Data assimilation techniques in conjunction with a high resolution land surface model can be used to dynamically downscale (in space and time) and disaggregate GRACE TWS along the profile of the land surface. In this presentation we will present GRACE data assimilation results using an ensemble Kalman smoother (EnKS) and the NASA Catchment model in Western and Central Europe. Although significant improvements were obtained in runoff estimates through GRACE data assimilation, issues such as mass imbalances were also discovered. GRACE assimilated soil moisture and groundwater fields have also been applied for drought monitoring in the US and some of those results will be presented as well.
Assimilating Remotely Sensed Observations into the CABLE Land Surface Model with the EnKF

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Haverd et al. [1] used a modified version of the CABLE land surface model [2] to quantify key terms in the Australian continental carbon and water balance over the period 1990-2011. They used multiple observation types to calibrate model parameters, taking advantage of the links between the carbon and water cycles. However, uncertainty in rainfall, particularly in the sparsely-observed interior of the Australian continent, leads to significant uncertainty in both the water and carbon cycles. Here we extend the modelling to include assimilation with the Ensemble Kalman filter of remotely sensed soil moisture (starting with AMSR-E and ASCAT) and vegetation index (EVI) observations, and assess the impact of assimilation on estimates of carbon and water fluxes and their uncertainties.

References

Estimating Deep-Layer Soil Moisture with Consideration of Temporally Correlated Errors
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As demonstrated in the past, soil moisture in the top layers (e.g., within the top 1-m depth) can be retrieved based on the assimilation of near-surface soil moisture once a day using the ensemble-based Kalman filter (or other assimilation methods). However, no studies have been reported on retrieving soil moisture at depths below 1 m. The relatively low error correlation between the surface and the deep layer, the limited range of soil moisture with the high skewness toward the wet or dry end, and the temporally correlated soil moisture error between the surface and bottom layers all make it difficult to estimate the deep-layer soil moisture. To reduce these negative impacts, a revised ensemble-based Kalman filter error covariance method is proposed by a) explicitly using the error covariance at the previous time step and b) limiting the increase of the soil moisture error correlation with the increase of the vertical distance between the two layers. This method is then tested with an Observing System Simulation Experiment (OSSE) at three separate point locations with the different total precipitation of 568 mm (37.0°N, 86.2°W), 104 mm (31.4°N, 105.0°W) and 404 mm (45.5°N, 96.5°W), respectively, from 1 May - 30 September 1998 (hereafter referred to as wet, dry, and medium wetness locations, respectively). It is found that the proposed method can effectively control the abrupt changes of error covariance estimates between the surface layer and two deep layers and meanwhile, significantly improve the estimates of soil moisture in the two deep layers with daily updating. For example, relative to the initial background error, after 150 daily updates, the error in the deepest layer reduces to 11.4%, 32.3% and 27.1% respectively at the wet, dry and medium wetness locations while only reducing to 62.3%, 80.8% and 47.5% with the original method.

However, the new method is sensitive to the updating frequency. For example, when the updating frequency is reduced to once every three days, the improvement of deep-layer soil moisture retrieval from the new method is minimal at the medium wetness and wet locations compared with the ensemble square root filter (EnSRF) (Whitaker and Hamill 2002). Therefore, alternative methods still need to be developed to improve the soil moisture retrieval with an updating frequency of once every three days. It is also worth noting that the results here are based on a particular OSSE setup using the Community Land Model (CLM3.0) so the new method needs further tests using different land surface models and different observational data.

References
Assimilating landscape freeze/thaw information in the NCEP Global Forecast System: Exploring the potential of the SMAP Freeze-Thaw product for weather and climate forecasting

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The goal of this study is to facilitate the assimilation of landscape freeze-thaw (F/T) state data into the National Centers for Environmental Prediction (NCEP) global forecast system (GFS). We focus on northern latitudes where landscape surface state transitions between predominantly frozen and thawed conditions during the spring and autumn are critical to hydrological, meteorological and ecological processes. The ability to characterize these transitions using of satellite active and passive microwave data sets has been well-established. NASA’s Soil Moisture active/Passive (SMAP) mission, scheduled for launch in October 2014, will provide a global 3km-resolution F/T state product covering the high latitudes (>40 deg N) with 1-2 day temporal fidelity. The advent of new missions like SMAP will allow for better monitoring of the surface freeze/thaw and associated soil moisture phase (liquid or frozen), offering the potential to improve the performance of weather and climate models through direct assimilation of the F/T state variable. In this study, information on F/T state and the extent of frozen ground will be assimilated using a simplified EnKF in the GFS through a coupling with the Noah land surface model. This ensemble Kalman filter method is developed and currently installed in the GFS to test the assimilation of future SMAP soil moisture data [1]. The impact of the proposed improvements will be assessed using the F/T data record currently derived from SSM/I microwave observations and available from the NSIDC website. It is expected that the assimilation of F/T complements the improvement that soil moisture assimilation has achieved especially in northern regions.

References