4-D Variational Data Assimilation for Soil Moisture using WindSat Data

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Motivation and Goal

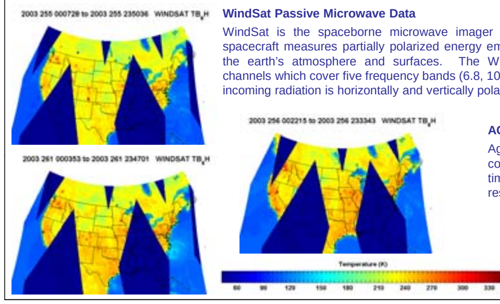
Motivation

- Surface soil moisture information improves weather and climate prediction; specifically in temperature and precipitation forecasting.
- Initialization of the Soil Moisture State in Numerical Models Extends the Predictability of Processes Influenced by Surface Fluxes.
- WindSat is sensitive to surface soil moisture variations. By matching those variations to the atmospheric/land surface model system, the soil moisture information can be inferred through its impact on the diurnal land / atmospheric physics.

Goal

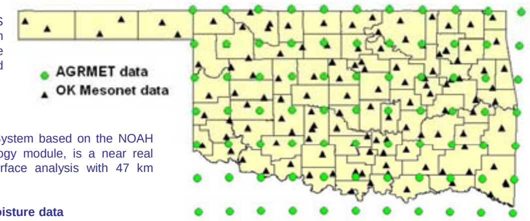
- To Implement 4D Data variational assimilation System to assimilate soil moisture from CORIOLIS WindSat passive microwave sensor by inserting soil moisture operator in to the RAMDAS system.

Remote Sensing and Soil Moisture Data Sets



WindSat Passive Microwave Data

WindSat is the spaceborne microwave imager mounted onboard the CORIOLIS spacecraft measures partially polarized energy emitted, scattered and reflected form the earth's atmosphere and surfaces. The WindSat operates with 22 discrete channels which cover five frequency bands (6.8, 10.7, 18.7, 23.8, 37.0 GHz) measured incoming radiation is horizontally and vertically polarized.



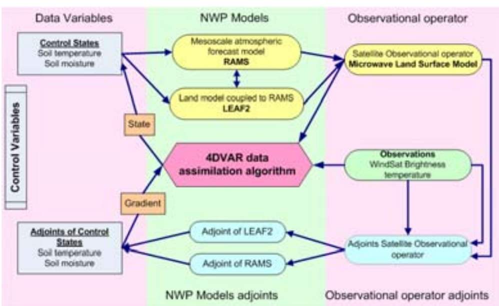
AGRMET Soil Moisture data

Agricultural Meteorology Modeling System based on the NOAH community land-surface soil hydrology module, is a near real time globally operated for land surface analysis with 47 km resolution by the U.S. Air Force.

OK Mesonet (in-situ) Soil Moisture data

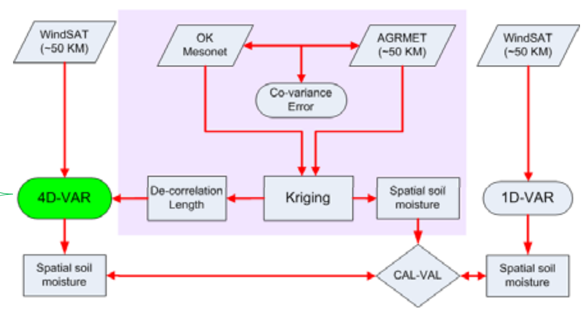
The Oklahoma Mesonet is a surface network of 100+ weather stations measures surface weather variables such as wind speed, wind direction, temperature, relative humidity, precipitation and soil moisture. The soil moisture sensors were installed at 4 depths: 5cm, 25 cm, 60 cm, and 75 cm below the surface to collect the data at every 30 minute interval. The soil moisture maps generated from in-situ data using Kriging technique was used for validation of 4D-VAR soil moisture output.

RAMDAS for Soil Moisture Retrieval



The Regional Atmospheric Modeling and Data Assimilation System (RAMDAS) is a 4 dimensional variational analysis (4D-VAR) data assimilation algorithm (Zupanski et al., 2005) developed at the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University (CSU). The current version of RAMDAS assimilates satellite observations from the Geostationary Operational Environmental Satellite (GOES) and assimilation of other satellite observations are in progress using the same generalized 4DVAR framework.

Flow Chart of Overall Goal



The analysis of the variogram of AGRMET and Mesonet data indicates that the de-correlation length is higher for AGRMET compared to Mesonet data. The soil moisture maps of AGRMET and Mesonet were generated by Kriging using experimental variogram. Kriging performance was evaluated in estimating soil moisture value by jack-knifing 11 Mesonet stations. The average RMSE value of estimated soil moisture at 11 sampling locations not used in kriging analysis is found as 3.8% of soil moisture.

Microwave Land Surface Model (MWLSM)

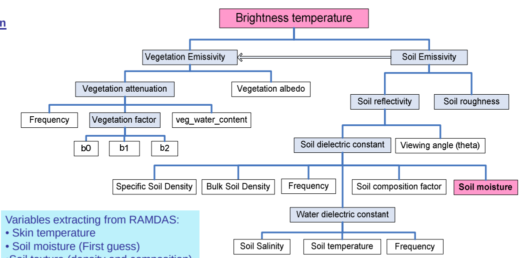
The MWLSM defines physical relationship between soil moisture and brightness temperature (Tb). However, the horizontal and vertical polarization behaviors at a given frequency can be quite different due to the polarization-dependent Fresnel reflectivities being used in the MWLSM Tb calculation (Jones et al., 2004). The MWLSM calculates the surface Tb at a particular polarization, p, by:

$$T_{bp} = T_{se}(1-r_{sp})e^{-\tau_c} + T_{ce}(1-\omega_p)\left(1-e^{-\tau_c}\right)\left(1+r_{sp}e^{-\tau_c}\right)$$

where Tse is the effective soil temperature, rsp is the Fresnel soil reflectivity at polarization p, τc is the optical depth of the vegetation canopy, Tce is the vegetation canopy effective temperature, and ωp is the single scatter albedo of the canopy. Note that the above equation considers radiative surface effects and does not include atmospheric effects.

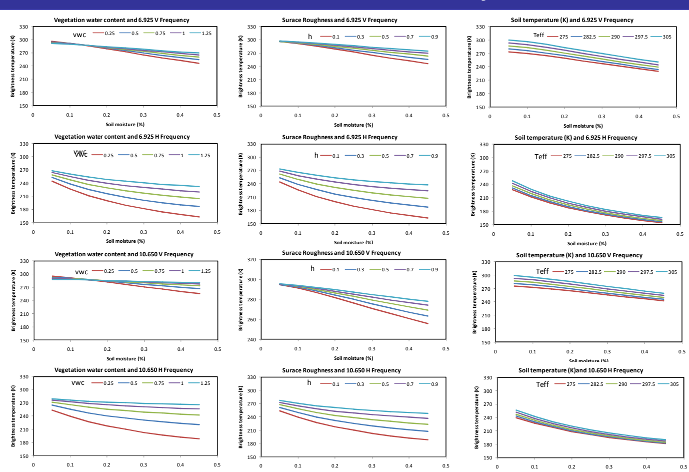
Variables rank in the order by perterbation response to BT: (Base values and Range)

Vol. soil moisture = 0.15 (0.05 - 0.45)
Veg. water content = 0.25 (0.00 - 1.50)
Soil roughness = 0.1 (0.00 - 1.00)
Veg. canopy factor b2 = 1.6 (1.20 - 2.00)
Soil temperature = 300 (273 - 320)
Veg. canopy factor b0 = 0.0 (-0.02 - 0.02)
Vegetation albedo = 0.06 (0.03 - 0.13)
Veg. canopy factor b1 = 2.5 (1.00 - 6.00)
Soil density bulk = 1.2 (1.00 - 1.70)
Veg. temperature = 300 (273 - 320)
Viewing angle (theta) = 55.0 (54.7 - 55.3)
Soil texture (% clay) = 0.15 (0.02 - 0.66)
Soil texture (% sand) = 0.20 (0.02 - 0.82)
Soil density specific = 2.59 (2.50 - 2.75)
Soil salinity = 0.0 (0.00 - 0.70)

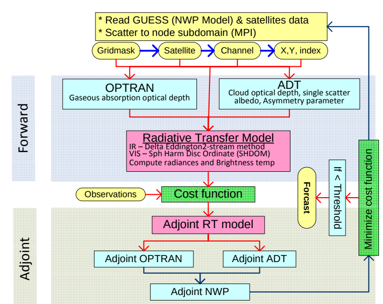


Variables extracting from RAMDAS:
- Skin temperature
- Soil moisture (First guess)
- Soil texture (density and composition)

MWLSM Parameter Sensitivity



RAMDAS Observational Operator



The gradient of cost function:

$$\frac{\partial J}{\partial \mathbf{x}(t_0)} = \mathbf{B}^{-1}\left[\mathbf{x}(t_0) - \mathbf{x}_b(t_0)\right] + \sum_{i=0}^{N} \mathbf{L}(t_i, t_0)^T \mathbf{H}_i^T \mathbf{R}_i^{-1}\left[H(\mathbf{x}_i) - \mathbf{y}_i\right]$$

"x" = model state vector at the initial time t_0 (control variable, and the object of the minimization process)
"x_b" = model background state vector
"B" = background error covariance of the forecast and model errors
"y" = satellite observational vector i.e., the satellite input data (typically radiances)
"H" = observational operator, also known as the "forward radiative transfer model"
"R" = observational error covariance matrix that specifies the instrumental noise and data representation errors

Summary and Future Work

- The framework for soil moisture (MWLSM) operator has been finalized.
- The sensitivity of soil moisture operator tested using all control variables.
- The MWLSM model were tested to all variables at their ranges given in box above.
- The MWLSM model shows higher sensitivity for vegetation water content, surface roughness compared to other variables. The horizontal polarization signals are more sensitive to vegetation water content and surface roughness.
- The RTMOD (Radiative transfer code) in RAMDAS was studied. The microwave operator will be inserted in RTMOD in series with VIS-IR operator.
- The insertion of soil moisture operator is in progress due to large code of RTMOD operator.
- The variables such as skin temperature, soil texture will be extracted from RAMS system.

Future Work

- Implementing and testing of soil moisture operator using first guess from AGRMET soil moisture data.
- Validation of soil moisture output with in-situ soil moisture data from OK Mesonet.
- Validation of soil moisture output with kriged soil moisture maps of OK Mesonet.

References:

- Jones, A. S., T. Vukicevic, and T. H. Vonder Haar, 2004: A microwave satellite observational operator for variational data assimilation of soil moisture. Journal of Hydrometeorology., 5, 213-229.
- http://ramdaswiki.cira.colostate.edu/ramdas_wiki/index.php/Main_Page

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