



Deep Soil Moisture (10-100 cm) Satellite Data Assimilation Research



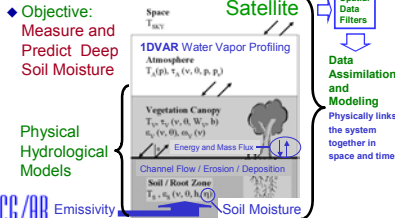
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Introduction

Objectives

- Develop "deep" soil moisture remote sensing capabilities (no direct measurements from space, therefore must include spatial and temporal soil moisture data assimilation (i.e., 4D) capabilities to infer deep soil moisture conditions)
- Remove undesirable satellite spatial characteristics (i.e., the false sensor-dependent signatures)
- Improve understanding of existing Microwave Emissivity Models (MEMs)

The Deep Soil Moisture Problem



Soil Moisture Operator

MWLSM Observational Operator

- The passive microwave observational operator (including the adjoint) is complete
 - Microwave Land Surface Model (MWLSM)
 - Based on 6 and 10 GHz passive microwave data
 - After Njoku (1999) (AMSR land algorithms)
- Applicable to a new generation of passive microwave imagers:
 - AQUA's AMSR-E (launched May 4, 2002)
 - ADEOS-II's AMSR (launched Dec. 14, 2002)
 - WindSat (launched Jan. 6, 2003)
 - NPOESS "C1" CMIS (~ 2009)

MWLSM Observational Operator

- The MWLSM observational operator is the link that connects the microwave remote sensing land surface physics to the atmospheric/land surface prognostic model during the data assimilation minimization process
- A much simpler IR land surface observational operator has also been constructed
- Porting of RAMDAS to NCAR SC is in progress
- Related sensitivity studies are underway using the recently completed RAMDAS
- WRF data interfaces in RAMDAS are used to bring in conventional data
- Several experiments are in progress

Selection of Control Variables

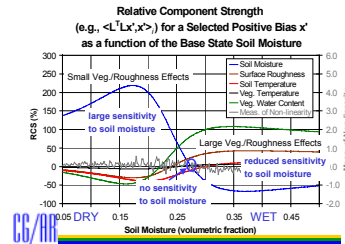
- For nominal conditions at 6 and 10 GHz
 - Greatest sensitivity is to soil moisture
 - Next is vegetation water content
 - Microwave roughness parameter (h)
 - Effective soil temperature
 - Veg. canopy temperature (ranked 10 out of 14 – included for completeness and model state availability)
- Vegetation water content and microwave roughness are slowly varying variables
- Opportunity to optimize these "parameters" within the 4DDA system given assumptions about their temporal constraints.

Operator Results

Relative Component Strength

- The adjoint can transform the analysis space from radiometric space to model vector space
- $RCS = \langle L^T L x', x' \rangle / \langle L^T L x', x' \rangle_{total}$
 - L is the model perturbation operator
 - x' is the model state perturbation vector
 - L' is the adjoint
- The RCS is a directional-magnitude indicator for the OO (i.e., which component-variable information is "able to" push or pull the solution given a specified model state perturbation, x')
- Full sensitivities require the cost-function analysis in conjunction with the full NWP-4DDA system, these are planned future experiments

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What We Learned

- Satellite observational operator sensitivities can be a strong function of their base states
- This work creates an improved analysis of the multivariate physical interactions
- Cross-sensor data sets should improve results in particularly difficult base state environments (i.e., sensitivity transitions and/or sensitivity inflection points)
- It required derivation of the adjoint in complex number space (submitted manuscript)
 - Complex numbers are not handled by current automated adjoint compiler technologies
 - Has practical implications for all future satellite observational operators involving radiative scattering processes

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Observational Operator Derivation within Complex Number Space

- Complex numbers are common within the RTM codes
- Automated adjoint compilers fail on this code, e.g.,
 - Real number adjoint representation:

$$d^2 x = d^2 x + d^2 x \frac{\partial^2}{\partial x^2}$$

$$d^2 y = d^2 y \frac{\partial^2}{\partial y^2}$$
 - Real -> Complex transforms:

$$d^2 r = d^2 r + (Re z + \tan \theta \text{Im} z) (\tan \theta \cos \theta + \cos \theta)$$

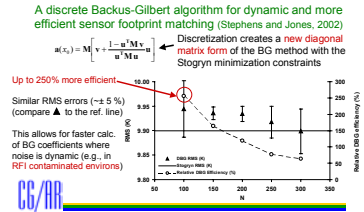
$$d^2 \theta = d^2 \theta + \cos \theta (k^2 \cos \theta - Re z)$$
 - Complex -> Real transforms:

$$d^2 z = d^2 z + \frac{\partial^2}{\partial z \partial z^*} (\cos \theta - \sin \theta) + d^2 r (\cos \theta + \sin \theta)$$
- for more details see (Jones et al., 2003)

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Spatial Filter Advances

Adaptive Spatial Filter Work for Satellite Data Assimilation Use and RFI Avoidance



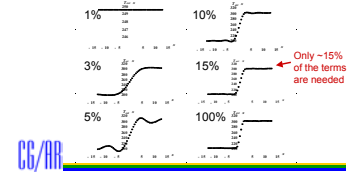
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Backus-Gilbert method: Pros and Cons

- Advantages of Backus-Gilbert methods
 - Mathematically-consistent error propagation behaviors
 - Antenna gain patterns are explicitly used
 - Analysis function is highly tunable
 - Heritage within the remote sensing community
- Disadvantages of Backus-Gilbert methods that are mitigated by the Discrete BG method
 - Computationally expensive and rigid (not dynamic)
 - Difficult to use in RFI-contaminated environments

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An example of how the DBG Singular Value Decomposition (SVD) approximation works on a coastline cross-section



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Improved computational method to integrate data with models

- A 1D version of the method is available and is 4X faster than existing Backus-Gilbert methods
- Computationally flexible and efficient
- Handles the spatial analysis and data uncertainties
- Suitable for multi-source data
- Conducive to additional optimizations
- With additional work, the performance of the method could be dynamically adjustable
 - e.g., requests like "I'd like 0.2 K precision in my temperature data for my NWP data assimilation grid" are now possible.

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