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Development of an integrated radar-radiometer estimation algorithm for retrieval of soil moisture for SMAP

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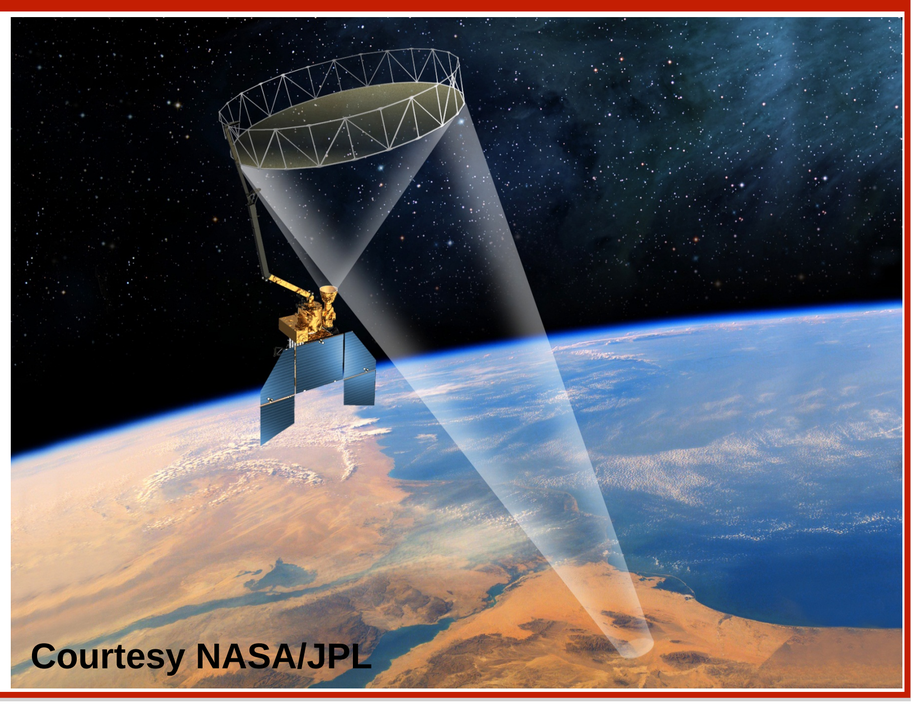
Motivation

As part of a coordinated effort to observe global surface water cycles, the NASA Soil Moisture Active and Passive (SMAP) mission will map global surface soil moisture by combining low-frequency radar and radiometer microwave measurements. SMAP's active (radar) and passive (radiometer) microwave instruments will provide a unique opportunity to develop an integrated soil moisture retrieval algorithm.

Radar's high spatial resolution and high sensitivity to vegetation is complimentary to radiometer's low spatial resolution but lower vegetation sensitivity. Proper understanding and utilization of the physical models contributing to this complimentary relationship between active and passive sensing will greatly improve soil moisture retrieval resolution and errors by allowing the formulation of a unified inversion methodology.



Objectives

The focus of this works is on the development of an Active/Passive inversion method for bare surfaces only. The difference in active and passive measurements' resolutions poses a challenge. For SMAP active measurements are at approximately 3km and passive are at 36km resolutions. Thus, a two step approach is taken first Single-scale optimization and then Multi-scale optimization.

Soil Moisture Retrieval Method

Soil Moisture is retrieved by minimizing a unified cost function $L(\bar{X}) = \left\| \bar{d} - \bar{\bar{F}} \right\|^2$ where $\bar{d}$ is the active and/or passive data. Optimum model parameters, $\bar{X}_{opt}$, which minimize $L(\bar{X})$ are record as retrieved soil moisture. Minimization of the cost function follows the method of Simulated Annealing, where small random perturbations are applied to model parameters. New states are accepted if the cost function value is reduced

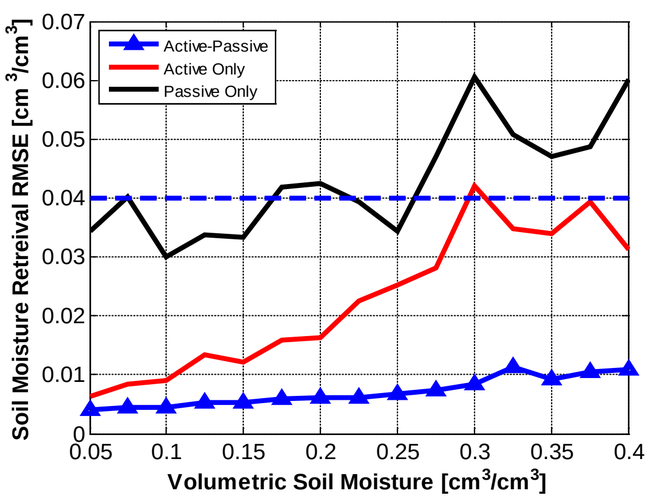
Optimization Exit Criteria

1. $L < \delta$: cost function becomes smaller than a threshold
2. The number of forward model evaluations passes a certain limit
3. For a certain number of iterations the algorithm converges to a local minimum

Optimization parameters such as δ and model evaluations are chosen empirically to reach best retrieval results.

Optimization Method and Retrieval Results

Same-scale active-passive retrieval



Soil moisture retrieval is preformed when both radar and radiometer measurements are at the same spatial scale (i.e. resolution). Note the improvement of retrieval RMS errors when optimization both measurements at the same time.

Active cost function:

$$L_{act} = \sum \left(\frac{\sigma_{pp} - \sigma_{pp}^{d}}{\sigma_{pp}^{d}} \right)^2$$

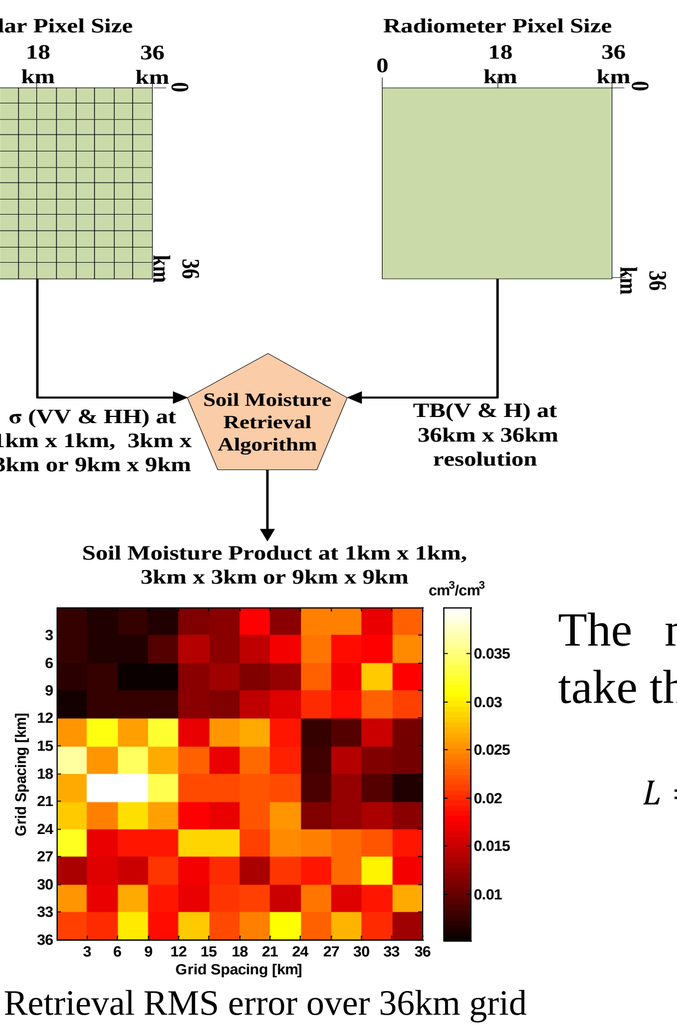
Passive cost function:

$$L_{pass} = \sum \left(\frac{TB_p - TB_p^{d}}{TB_p^{d}} \right)^2$$

The Active-Passive cost function unifies both measurements at the same spatial resolution : $L_{ap} = L_{act} + L_{pass}$

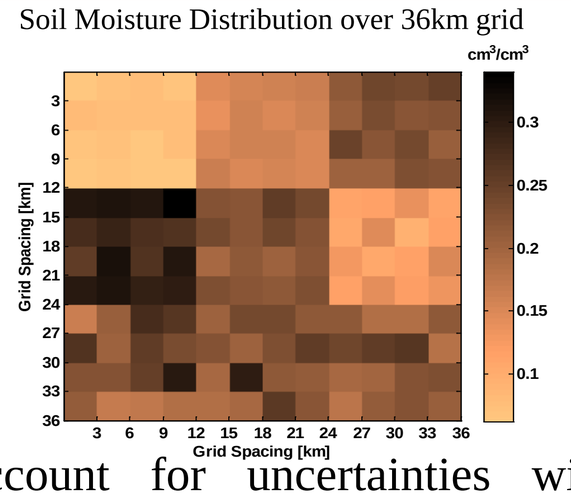
Multi-scale active-passive retrieval

The Active-Passive cost function definition is the similar to the same-scale scenario. However, the measurement data vector, $\bar{d} = [d_1, d_2, \ldots, d_n]$, consists of active and passive measurements at different spatial resolutions.



Retrieval RMS error over 36km grid

Soil Moisture Distribution over 36km grid



To account for uncertainties within measurements and further physically constrain active and passive measurements within the optimization process, a simple thresholding scheme is used to find equivalent brightness temperature TB_e using radar backscatter. This step will further reduce retrieval errors.

The multi-scale Active-Passive cost function take the following from:

$$L = \sum_{pp=vv\,\&\,hh} \left(\frac{\sigma^0_{pp_i}(vsm) - \sigma^0_{pp_{d(i)}}}{\sigma^0_{p(i)}} \right)^2 + \sum_{p=V\&H} \left(\frac{2 \cdot TB_p(\langle vsm \rangle) - TB_{p_e} - TB_{p_d}}{TB_{p_d}} \right)^2$$

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