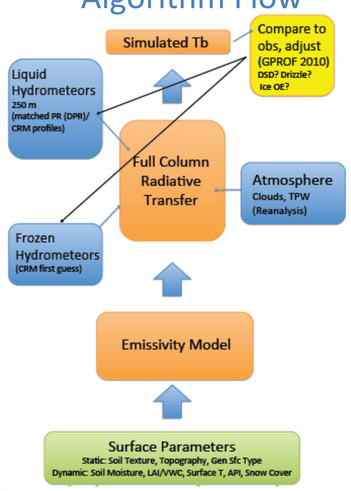
Constructing a Physically Consistent Database for Passive Microwave Precipitation Retrievals Over Land : US Southern Great Plains Prototype

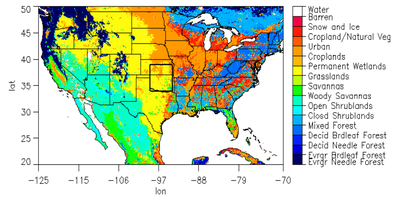
Sarah Ringerud*[2], Christian Kummerow[1], Christa D. Peters-Lidard[2]
(1) Colorado State University, Fort Collins CO USA (2) NASA Goddard Space Flight Center, Greenbelt, MD USA (*sarah.e.ringerud@nasa.gov)

Introduction

The recently launched NASA Global Precipitation Measurement Mission (GPM) offers the opportunity for greatly increased understanding of global rainfall and the hydrologic cycle. The GPM algorithm team has made improvement in passive microwave remote sensing of precipitation over land a priority for this mission, and developed a framework allowing for algorithm advancement for individual land surface types as new techniques are developed. In contrast to the radiometrically cold ocean surface, land emissivity in the microwave is large with highly dynamic variability. An accurate understanding of the instantaneous emissivity in terms of associated surface properties is necessary for a physically based retrieval scheme over land, along with realistic profiles of frozen and liquid hydrometeors. In an effort to better simulate land surface microwave emissivity, a combined modeling technique is developed and tested over the US Southern Great Plains (SGP) area. The resulting emissivities can then be implemented in calculation of upwelling microwave radiance, and combined with ancillary datasets to compute brightness temperatures (Tbs) at the top of the atmosphere (TOA). For calculation of the atmospheric contribution, reflectivity profiles from the Tropical Rainfall Measurement Mission Precipitation Radar (TRMM-PR) are utilized along with coincident Tbs from the TRMM radiometer, and cloud resolving model data from NASA-Goddard's MMF model for assigning hydrometeor profiles. Ice profiles are modified to be consistent with the higher frequency microwave Tbs. The synthesis of these models and datasets will lead to creation of a Tb database that includes both surface and atmospheric information physically consistent with the LSM, emissivity model, and atmospheric information, for use in a Bayesian-type precipitation retrieval scheme utilizing a technique that can easily be applied to GPM as data becomes available.

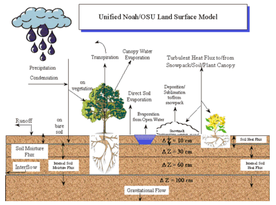
Algorithm Flow





As a proof-of-concept experiment, the modeling system is constructed over a 5-degree box in the US Southern Great Plains

The Physically Consistent Database



Land Surface Model

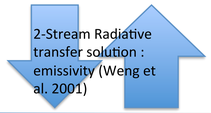
The NCEP Noah Model v3.2 is used for modeling the land surface. The model is run at 1 km resolution via the NASA Land Information System (LIS) framework and uses NLDAS-2 forcing along with MODIS 8-day LAI.

Atmosphere & Hydrometeors

Background atmospheric information is added using ERA-Interim reanalysis. Precipitation profiles are assigned based upon matched TRMM PR profiles. Ice profile first guess comes from GSFC GCE CRM profiles that match most closely in dBZ space.
Following radiative transfer, TOA Tbs are compared and the ice profiles iteratively adjusted toward a match at 85 GHz.

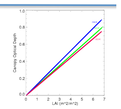
Physical Emissivity Model

A physical emissivity model, based largely upon the schemes utilized by NCEP and ECMWF for microwave emissivity, is used to compute land surface emissivity at at 10 GHz H-pol.

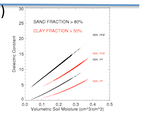


INTERCEPTED WATER (Empirical)

Vegetation Optical Depth: Tau-Omega approach (CMEM, based on Wegmiller et al. 1995, formulated for 1-100 GHz using geometric optics)
LAI: MODIS



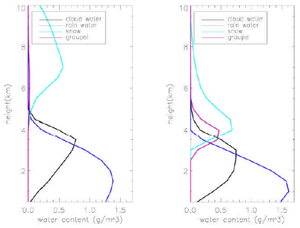
Smooth surface Reflectivity: Fresnel law
Rough reflectance: Wegmuller and Matzler 1999 (1-100 GHz)



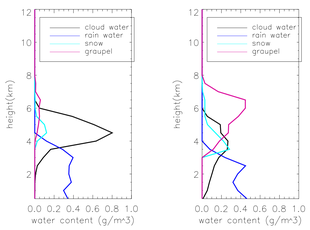
Soil Dielectric Model: Dobson et al. 1985 (1-18 GHz) (SMOS, LandEM)
Texture and Moisture: Noah LSM + STATSGO + NLDAS2

The 10 GHz frequency is chosen as the "reference frequency" due to good agreement in this channel between the physical model and emissivities retrieved in clear-sky conditions. (Ringerud et al. 2014)

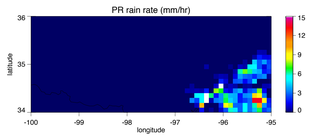
The two sets of hydrometeor profiles shown here demonstrate the information content available by combining active and passive microwave observations for retrieval.

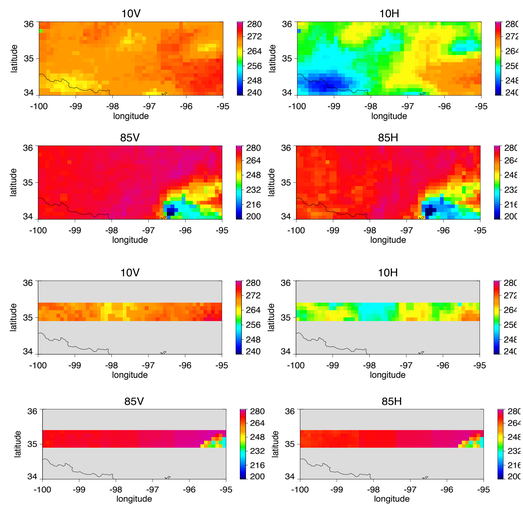


Profiles have nearly identical Tbs, but surface rain rates differ by 6 mm/hr.

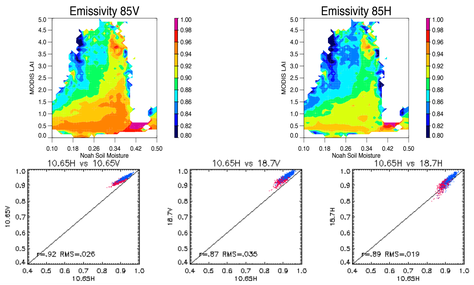


Profiles have identical surface rain rates and 10 GHz Tbs, but 85 GHz Tbs differ by nearly 100K.





A snapshot example of the database generation procedure for an overpass of south SGP area. Only the center 11 near-nadir PR pixels are used.



Empirical Emissivity Model

Five years of retrieved CLEAR SKY TRMM TMI emissivities over the 5°x5° box encompassing the Southern Great Plains area are employed for the construction of emissivity covariances. Cloud clearing is strict and requires the MODIS confident-clear flag. Retrievals use ERA-Interim atmospheric information coupled with the LSM skin temperature. The approach is based on Bytheway and Kummerow (2010). Covariance relationships are binned by soil moisture and LAI, optimizing the correlations with 10.65H values.

Results

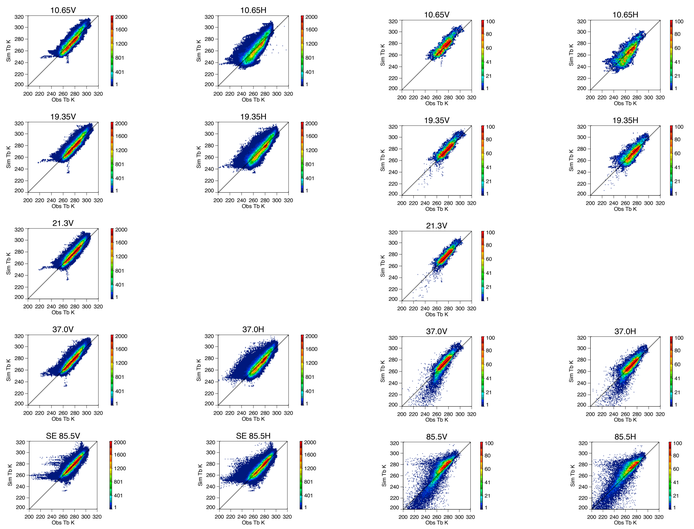
Simulated Tbs are compared to observed TMI values for a 5-year period. Statistics are given in the table below.

Total Database	10.65V	10.65H	19.35V	19.35H	21.3V	37.0V	37.0H	85.5V	85.5H
Correlation	0.91	0.84	0.92	0.87	0.92	0.91	0.86	0.91	0.89
Mean bias (K)	0.52	-0.63	0.53	0.03	0.54	0.69	0.51	0.76	1.08
RMS	0.009	0.020	0.009	0.017	0.011	0.010	0.017	0.015	0.021

Non-Raining	10.65V	10.65H	19.35V	19.35H	21.3V	37.0V	37.0H	85.5V	85.5H
Correlation	0.91	0.85	0.92	0.87	0.93	0.92	0.86	0.91	0.89
Mean bias (K)	0.43	-0.61	0.50	0.00	0.48	0.74	0.53	0.80	0.99
RMS	0.009	0.021	0.010	0.017	0.011	0.011	0.018	0.016	0.021

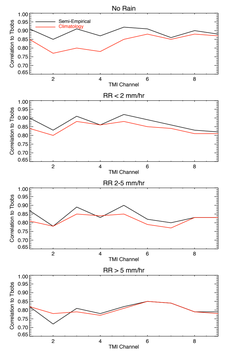
Raining	10.65V	10.65H	19.35V	19.35H	21.3V	37.0V	37.0H	85.5V	85.5H
Correlation	0.87	0.78	0.88	0.81	0.90	0.89	0.85	0.89	0.88
Mean bias (K)	2.0	-0.99	1.55	0.50	1.7	0.22	0.23	0.24	2.64
RMS	0.013	0.059	0.021	0.051	0.029	0.0017	0.027	0.003	0.017

2004-2008 SGP Non-Raining



2004-2008 SGP Raining

Correlations to observations are computed using databases created with the semi-empirical emissivity model and a climatology. Results demonstrate surface representation most important at lower frequencies and lighter rain rates.



Conclusions

In developing a physical database for Bayesian-type precipitation retrieval schemes over land, accurate representation of the surface emission is an important and difficult problem. In the work presented here, a simple physical database is constructed in order to assess sensitivity of such a database to surface emissivity characterization. A semi-empirical emissivity model is implemented for this purpose, and is used to compute emission from the surface in a forward model for database radiative transfer simulations. The atmosphere is modeled using background environment information from the ERA-Interim reanalysis along with hydrometeor profiles derived from constrained matching of CRM profiles with profiles from the active measurements of the TRMM PR. Ice profiles are adjusted in an iterative scheme aimed at increasing agreement in the higher frequency channels. For non-raining pixels, resulting agreement between simulated and measured TMI Tbs is good, with correlations around 0.9 and multispectral biases less than 1K. In raining areas the agreement is somewhat degraded, but still shows correlation with measured Tbs of 0.8-0.9. Comparison of the database to an identical one constructed using climatological emissivity values provides information regarding the importance of dynamic representation of emissivity in such a scheme. Correlations to observed Tb values are increased when simulated using the dynamic surface, particularly at the lowest TMI frequencies. This improvement is largest for pixels with no rain, and decreases with rain rate. At a rain rate of 5 mm/hr averaged over the 19 GHz TMI footprint area, the difference in correlation becomes insignificant. This comparison suggests that dynamic representation of surface emissivity in simulations for precipitation database construction will have the most significant impact in areas of light or no rain, with emissivity accuracy becoming less important in areas of heavier rain and at higher frequencies that have less sensitivity to the surface.
It appears clear that with optimization, it is possible to develop a database with precipitation signals that can be accurately distinguished from surface emission over land, and that such a database could be implemented in to a Bayesian retrieval framework. While the present study demonstrates the feasibility of physical retrieval, clear biases are present along with other problem areas, which could be targeted in future work.