THE USE OF SATELLITE DERIVED SURFACE HEATING RATES TO RETRIEVE SOIL MOISTURE IN CLOUDY CONDITIONS

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OBJECTIVE

Several remote sensing approaches to the problem of soil moisture analysis are discussed, including single sensor microwave retrievals, and temporal analysis techniques based on the analysis of surface heating rates. This paper addresses on-going research related to augmenting the current surface infrared heating rate methods with passive microwave data for use in cloudy conditions. Several research steps are involved in this process and a rationale of the current approach is given. As a prerequisite, multisensor data fusion techniques are employed to achieve these objectives.

This work is relevant to both model simulations and operational arenas. In particular, initializations of atmospheric/hydrological models require better specification of the heterogeneous surface fields for accurate weather/runoff forecasts. The observational surface wetness product should also be useful as a data source for improved trafficability indices in data-denied regions. These data sets offer the potential of high temporal monitoring of surface wetness and vegetation conditions over areas of military interest.

RESEARCH ACCOMPLISHED

Two remote sensing approaches are discussed with results from previous studies used to propose a third hybrid approach that combines the strengths of the two single sensor methods into a combined multisensor algorithm. An outline of the essential formulation is presented in this paper. A demonstration of the multisensor data fusion capabilities that will allow for such a method to perform in near-real time will be presented during the poster session.

SINGLE SENSOR PASSIVE MICROWAVE RESULTS

The first method is a more traditional approach that is based on the strong dielectric behavior of water within the soil at microwave frequencies. A simple soil dielectric mixing model is used to simulate the behavior of a 6.9 GHz passive microwave response to soil moisture for bare soil conditions. The results (Figure 1) show that the soil moisture sensitivity is strongest for dry soil moisture conditions and begins to saturate as the soil moisture increases. This is in contrast to the heating rate method that will be discussed in following section.

Earlier work by the authors combined DMSP SSM/I and GOES IR data to retrieve microwave surface emissivity (Jones and Vonder Haar 1997) as a simple surrogate for soil moisture. The data in this method are quality controlled with the removal of cloud-contaminated data, and an atmospheric correction is applied to remove water vapor attenuation effects in both the microwave and infrared spectral regions. The emissivity product is thus a more refined view of the surface radiometric behavior than would be given by effective microwave brightness temperatures alone. The emissivity product is physically related to the soil dielectric properties and surface scattering effects (such as that due to vegetation scattering). This method was shown to be best for identifying surface flood events due to the lack of soil depth penetration of the higher frequencies on the DMSP SSM/I. The method shows promise, in that low emissivity regions were spatially correlated to Landsat-derived irrigation classifications in regions with known irrigation farming practices. A more detailed analysis indicates that the vegetation effects are dependent on several other complicating factors, including surface roughness, fractional vegetation, vegetation amount, vegetation type, etc. An example of the vegetation scattering (Figure 2) shows that vegetation can exhibit complex microwave emissivity behavior. This behavior typified all DMSP SSM/I frequencies and can be generalized to non-SSM/I microwave frequencies. However, at lower microwave frequencies, the effect is reduced due to the wavelength dependence of the surface/vegetation radiation interactions, but remains significant in areas with moderate to heavy vegetation to reduce the overall soil moisture retrieval performance. It is anticipated, that in regions of limited vegetation, the lower microwave frequencies (and in particular the 6.9 GHz) will be useful for soil moisture remote sensing purposes. 6.9 GHz channels are currently scheduled to launch with the NASA AQUA/AMSR, DOD WINDSAT, and the NASDA ADEOS-II/AMSR instruments.

SINGLE SENSOR INFRARED HEATING RATE RESULTS

A satellite data assimilation procedure has also been developed for incorporating GOES infrared heating rates into the CSU-regional atmospheric mesoscale modeling system (RAMS) (Jones et al. 1998a). The data assimilation procedure is a direct inversion of the RAMS surface parameterization and includes a prognostic soil model and simple "big leaf" vegetation parameterization. The method is an extension of the McNider et al. (1994) data assimilation method and includes the effect of the diurnal heating rate on the model vegetation. The bare soil data assimilation component has an iterative solution procedure, while the inverted vegetation parameterization is solved as an analytical function of the original model equations.

The basis of the satellite data assimilation is the satellite-derived heating rate derived from GOES data (however, in principle, any accurate heating rate product could be used). The satellite data are navigated and aligned for temporal analysis of the satellite surface skin temperature heating rates using a multisensor-multispectral data fusion analysis package (Jones et al. 1995). The model surface parameterization is replaced with the satellite data assimilation model equation set that directly couples the satellite-derived heating rates to the model surface parameterization variables, thus forcing the surface of the model with the satellite-derived heating rate observations. Since the method is limited to clear-sky conditions, the data assimilation period was only 1 hour for the case to be shown, due to cloud conditions that interfered with a consistently clear view of the morning heating. As an example, the satellite data assimilation method was performed for 8 September 1991 over the central U.S. (Jones et al. 1998b) (see Figure 3). The main feature is the dry region in the western portion of the domain of the satellite-assimilated results, and a contrasting wet region over the eastern portion of the domain. Thus, the method is able to correctly capture the dry/wet contrast of this case study day. However, large regions that were cloudy during the case study could not be adjusted since the infrared data is only sensitive to the surface during clear-sky conditions. Additional research into similar methods is on going due to the promise of high spatial and temporal resolution, but the clear-sky restriction remains for all such infrared heating rate methods (van den Hurk, 2000).

The sensitivity of this method to soil moisture is greater in wet conditions than for dry conditions as shown by a simulation using a constant $1\ K\ h^{-1}$ forcing (Figure 4). This is the opposite behavior as compared to the single sensor microwave methods (recall results previously shown in Figure 1). This is due to the physical energy balance at the surface being highly sensitive to very wet conditions. Therefore, the infrared heating rate methods are using a temporal signal that is otherwise not used in traditional single sensor microwave methods.

A PROPOSED MULTISENSOR MICROWAVE AND INRARED HEATING RATE METHOD

This leads to a proposed hybrid approach that combines the strengths of the previous two methods. Since the heating rate data assimilation method has many beneficial characteristics such as being tightly coupled to the research forecast model and its surface parameterization, it seems very feasible to focus on improvements to the surface heating calculation itself to remove the detrimental cloud effects. This does not imply that soil moisture estimates from single sensor instruments are not a worthwhile pursuit, but that the direct connection to the model physics is such an obvious benefit it seems most likely that improvements to numerical weather prediction (NWP) applications could be made via this route. This hypothesis of course will have to be evaluated during the course of our on going research. In any event, the future work is currently planned to proceed through the various stages presented in Figure 5, where red denotes the new research areas being undertaken. While still in its early stages, the emphasis of the new work focuses on the calculation of a combined infrared/microwave heating rate product that can be used to force a cloud tolerant heating rate data assimilation method. Much of the data fusion capabilities to perform such a task have already been implemented and will be demonstrated during the poster session. Preliminary studies are underway to produce single sensor LST products, and then to combine these into a combined multisensor product using the information gleaned from that stage of the research.

CONCLUSIONS AND RECOMMENDATIONS

In course of this work, two general methods to remotely sense soil moisture have been explored in various levels of detail, with the primary weaknesses and strengths being identified for each. The proposed hybrid approach will minimize detrimental cloud effects in the heating rate data assimilation approach, and allow the complex vegetation influences to be modeled via the NWP vegetation parameterization (and thus be self consistent with the NWP forecast model). The new hybrid approach should also have complimentary soil moisture sensitivity to the single sensor passive microwave approach. It is very likely that a combined product utilizing both may be the most optimal approach.

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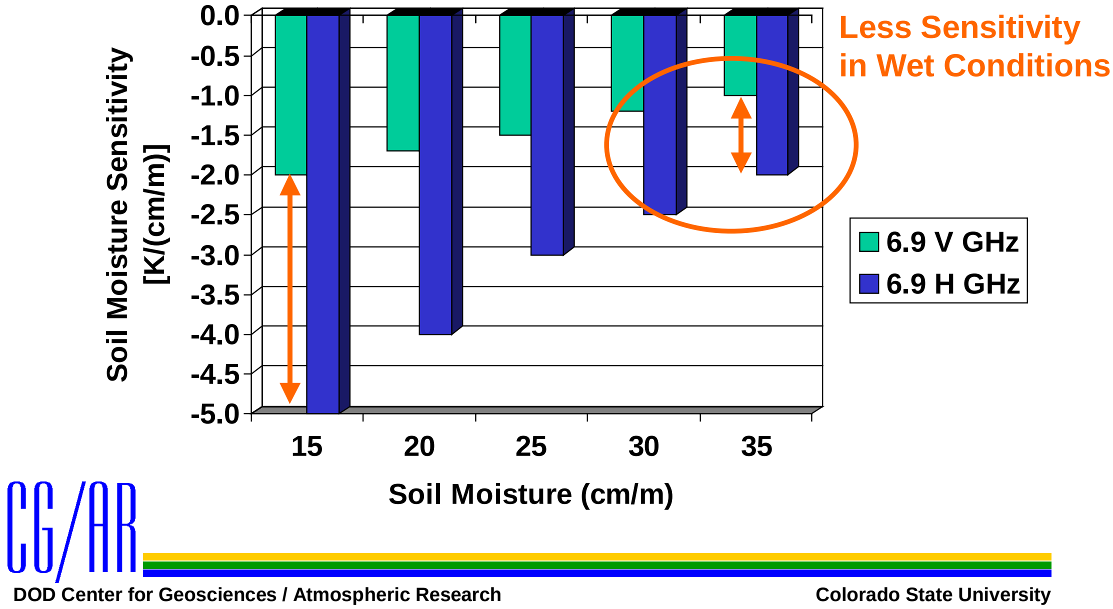

Figure 1. Microwave single sensor sensitivities to soil moisture at 6.9 GHz.

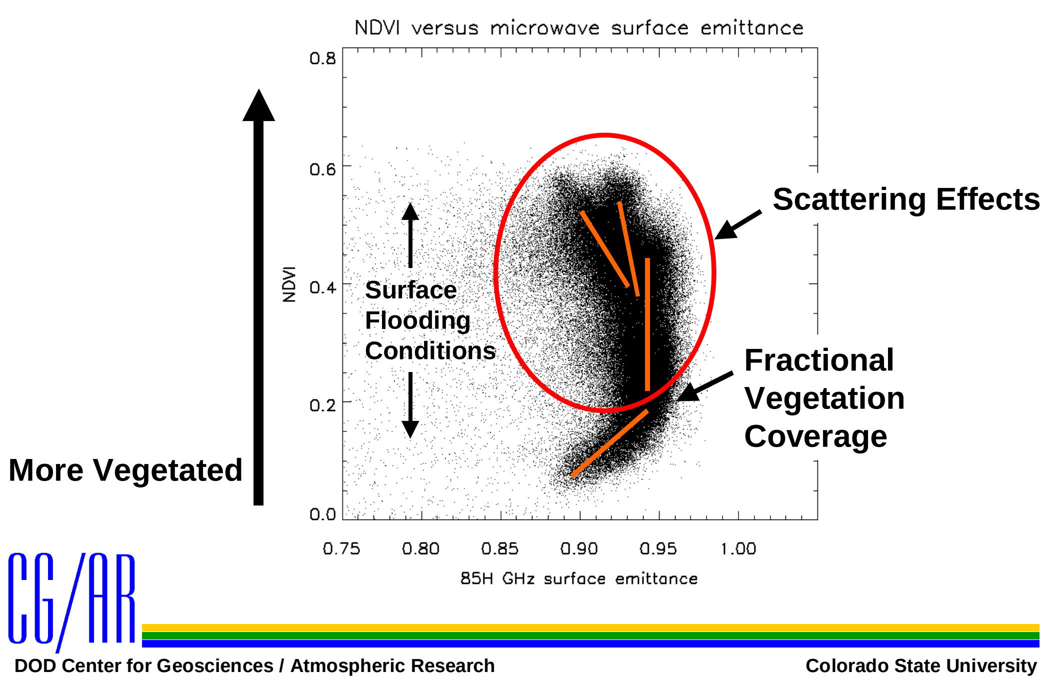

Figure 2. Microwave vegetation-masking effects at 85.5 GHz from the DMSP SSM/I from an intercomparison of AVHRR Normalized Difference Vegetation Index (NDVI) data.

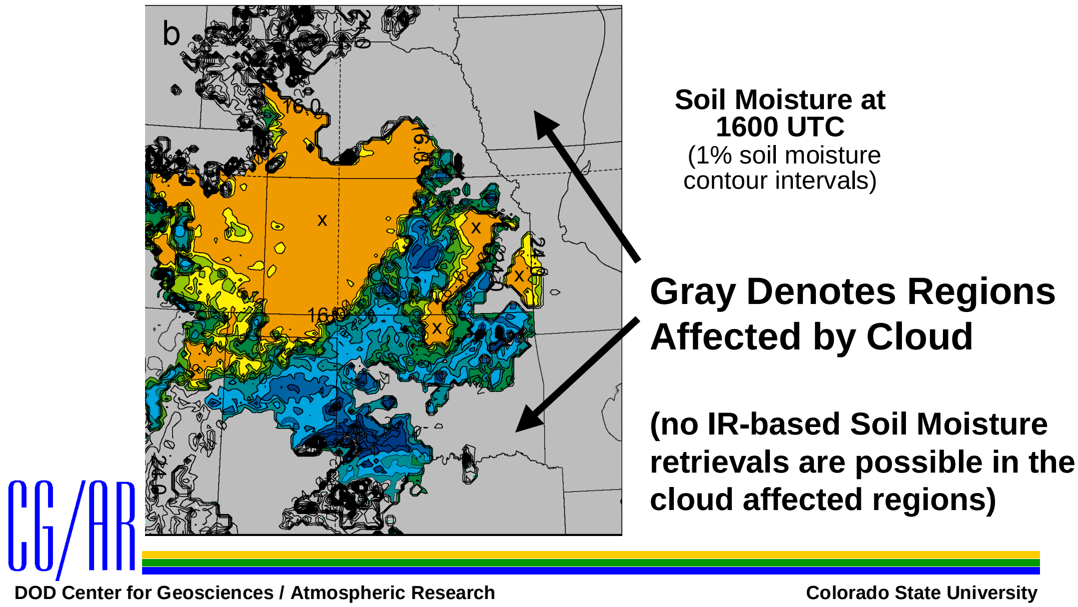

Figure 3. An example of retrieved bare-soil surface soil moisture using infrared satellite data (dry areas are orange, and wet areas are blue).

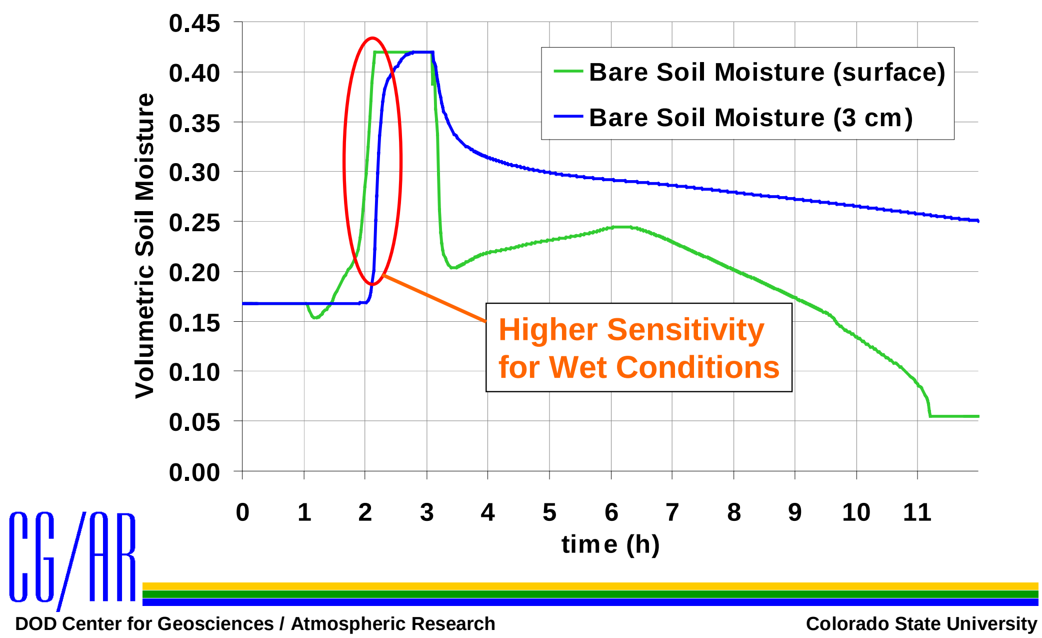

Figure 4. Model soil moisture with simulated 1 K h^{-1} satellite forcing using an infrared heating rate data assimilation method.

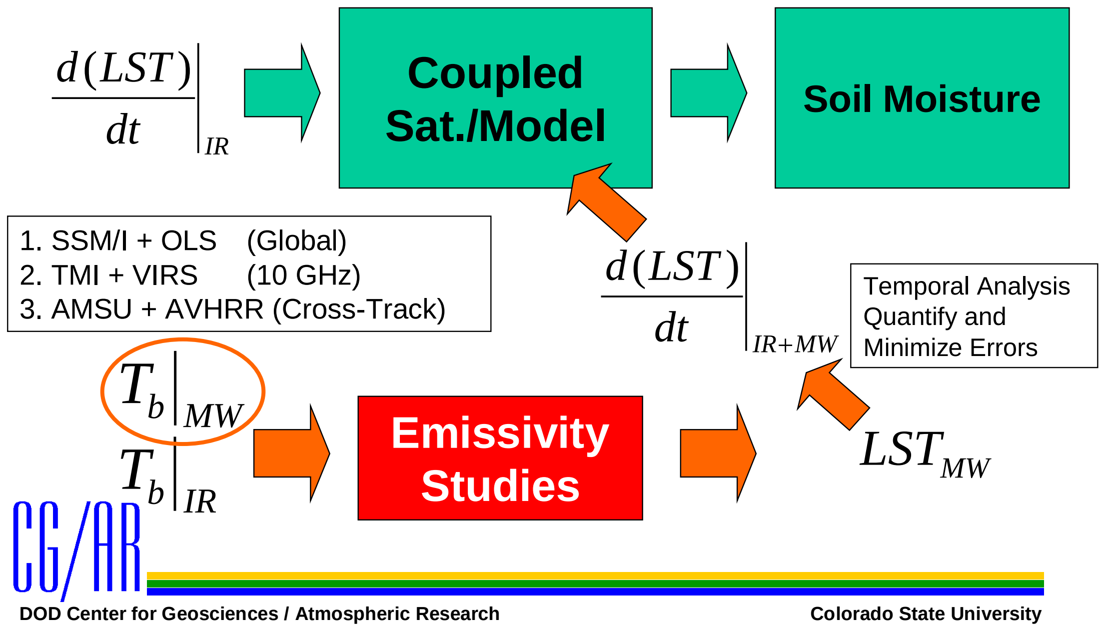

Figure 5. Items highlighted in red denote the current line of research work necessary to expand the heating rate algorithm approach beyond the current IR only limitations (i.e., clear sky conditions).