論文の内容の要旨
Abstract of Dissertation

Title of dissertation:
Improving precipitation predictability over land using multi-parameter passive microwave remote sensing and data assimilation strategies
(多パラメータマイクロ波放射計とデータ同化手法を用いた陸域降水量の予測可能性の向上)

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Both solid (snowfall) and liquid (rainfall) precipitation are critical components of the water and energy cycles. During precipitation formation huge amounts of heat are released into the atmosphere, becoming the driving force of weather systems. Rainfall provides fresh water, and especially for developing economies, it is very important in driving these economies as most of them are agriculture based, depending to a large extent on rain-fed farming. It is therefore necessary to have reliably accurate precipitation forecast

The potential of remote sensing to identify and inform on a wide variety of issues relating to the environment has been demonstrated over time. Remote sensing offers the opportunity to obtain information about systems, objects or things without necessarily being close to them. It thus is a powerful tool for informing decision makers and technocrats as they attempt to address issues relevant to their specialist fields or needs.

Within the microwave region of the electromagnetic spectrum, water exhibits interesting behavior depending on whether it exists in bound state (e.g. wet soil) or unbound state (free water). This behavior is captured in the form of the dielectric constant which defines the electrical properties of a material. To serve as an illustration, very dry soil has a dielectric constant of ~ 4, but the dielectric constant of free water is ~ 80 at L-band frequencies. This wide gap in the behavior the dielectric constant helps in understanding water quantities in substances using microwave frequencies.

Within the microwave region, there are two branches of remote sensing; namely active and passive microwave remote sensing. In the active part, a radar sensor emits radiation which interacts with the object. The sensor then receives backscattered signal and depending on its magnitude, various interpretations can be arrived at. On the other hand, a passive microwave radiometer does not emit radiation but rather senses radiation being emitted by the object under study. Although the theoretical basis of microwave remote sensing is clear, this field is relatively young (~ 40 years old) and many of its potentials have not yet been fully harnessed. This research effort aims at making use passive microwaves to improve predictability of precipitation over land, lending a hand to water resource management.

It is an accepted fact that it is difficult to have an adequate distribution of instrumentation to capture the water cycle. There are regions that are actually un-gauged due to their remoteness. On the other hand, many satellite sensor platforms have been launched in space and although their spatial resolutions may not be as would be desired, the trend is moving towards finer spatial resolution imagery. Microwave specific sensors already launched include but are not limited to, the Advanced Microwave Spectro-Radiometer on board the Earth Observing Satellite (AMSR-E), the Special Sensor Microwave Imager (SSM/I). In this research, AMSR-E imagery (brightness temperatures) is utilized.

Within passive microwave remote sensing, two distinct approaches have emerged, observation of atmosphere and observation of land surface. Due to response signature of microwaves, lower frequencies have been favored for observation of land surface condition, while higher frequencies are favored for atmosphere observation over ocean and sea surfaces. At lower frequencies (< 20GHz) the atmosphere is largely transparent and hence land surface condition can be inferred. Higher microwave frequencies are sensitive to atmospheric state and have therefore been typically exploited for its observation.

At all microwave frequencies, land surface exhibits heterogeneous emission due to its heterogeneous nature (soil moisture, roughness e.t.c.), and in an effort to overcome this, atmospheric research with microwaves has been devoted to observations over sea surfaces.

The sea surface exhibits largely homogeneous emission and is significantly darker (colder) than land surface emission, which means that atmospheric emissions can be easily detected and identified.

In the past empirical models have been developed and used to obtain estimates of soil moisture. These empirical models are region specific and lack strong physical basis.

They are simple and easy to implement and find application in grid based analyses.

Several physically based models have also been developed to address various parts of the challenge. The approach to incorporate surface roughness effects is by using statistical roughness parameters namely root mean square height and correlation length. In the past, the effects of correlation length were ignored in simulations yielding somewhat unreliable results.

To address precipitation estimation and prediction over land, it is necessary to unify the gains made in land surface condition remote sensing and atmosphere condition remote sensing. In this research, the first target is to improve surface emission modeling to address land surface heterogeneity, which would enable research of atmosphere over land. With surface emission modeling clarified, there is need to unify it with radiative transfer modeling in atmosphere.

The models developed in this quest though significantly improved still contain modeling assumptions and are thus not suited for direct retrieval of land and atmosphere conditions, it can best be used in forward modeling.

Data assimilation strategies are used to combine imperfect models and observations that include errors for forecast simulations. Data assimilation enables imperfect models and inadequate observations that contain observation errors give better predictions than if only either the models or the observations were used to obtain the same prediction.

Field experiments seeking to understand the effects of surface roughness on land surface emission were undertaken. The results of these experiments demonstrated that in addition to surface roughness, it is important to consider the effects of shadowing introduced by the roughness of the surface. By incorporating effects of shadowing on a rough surface, it was possible to obtain remarkably good agreement between observations and simulations. This research verified that the Advanced Integral Equation Model (AIEM) can be used to model emission from a rough, bare and wet soil surface if shadowing effects are considered.

A land data assimilation scheme (LDAS) developed using empirical QH model as its observation operator was modified to assess the capability of improved understanding of surface emission. Using this improved surface emission model as its observation operator,

LDAS was found to give reliable near surface soil moisture estimates. Near surface soil temperature was also found to improve significantly in comparison to no-assimilation cases.

After the verification of AIEM as being a reliable model for representing surface emission, it was coupled with Dense Media Radiative Transfer model (DMRT) coupled with 4 stream approximation for soil that

accounts for volume scattering in dry soil, to address radiative transfer from soil. To address the effects from the atmosphere, 4-stream approximate model for atmosphere was used. To address radiative transfer in vegetation, the w - t model was used. The performance of the coupled Radiative Transfer Model referred to hereafter as the Land Atmosphere Radiative Transfer Model (LA-RTM) was tested using data from Tibet and Mongolia sites in the Coordinated Enhanced Observing Period (CEOP) reference sites.
For bare wet surfaces, LA-RTM and the improved surface emission model simulations agree perfectly at low frequencies, and hence it can be used for modeling radiative transfer at all microwave frequencies with an increased level of confidence.

An ice microphysics data assimilation scheme (IMDAS) had been developed previously for estimation of cloud properties over sea surfaces. To use it over land, it is necessary to have reliable estimation of land surface condition. By using LDAS, improved land surface condition estimate is obtained, which is then used as lower boundary condition in IMDAS. IMDAS as originally developed did not consider precipitation for direct retrieval as assimilation variables, since it was developed for non precipitating cloudy atmosphere. In this research it was extended to allow consideration of snow and rain for direct retrieval, since in Tibet, the target site, presence of precipitating clouds is reported as being significant.

Using this coupled data assimilation approach, improved prediction of surface conditions (mainly soil moisture and surface temperature) and integrated atmospheric variables (water vapor, cloud water content, cloud ice content, rain water and snow water) was realized.
By feeding back these improved land surface and atmosphere conditions to the mesoscale model, there was significant improvement in precipitation forecast skill. Comparisons of daily cumulative precipitation forecast by the model using assimilation results gives better agreement with reported daily cumulative precipitation. Time series prediction skill showed promise, though it has not been validated in this research as in-situ data was missing. To compensate for this, Infra-Red imagery is used to compare against forecast, giving an indication of the distribution pattern. 1-hour forecast (after assimilation) showed good agreement with observed cloud pattern. For subsequent 6 - hour, 12-hour forecasts, there was general agreement but the distribution did not match well. However, in the case of 24-hour forecast, though the distribution is somewhat different, there is agreement about the quantities simulated. It is suspected that wind fields are not modeled correctly, thereby interfering with precipitation and cloud transport.
This is attributed to the fact of the mesoscale model reading boundary conditions from Global Circulation Model (GCM) output. Thus if GCM output has incorrect wind fields, these are introduced in the mesoscale model upsetting the improved states.