The AFWA Next Generation Land Data Assimilation System

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Background
The Air Force Weather Agency (AFWA) is migrating to a new land data assimilation system (LDAS; e.g., Mitchell et al., 2004; Rodell et al., 2005, see also http://ldas.gsfc.nasa.gov) to replace the Agriculture Meteorology (AGRMET, Moore et al., 1990) model currently providing global soil moisture and temperature analysis to the Department of Defense and partner agencies. AFWA has partnered with NASA to aid further development of the Land Information System (LIS; Peters-Lidard et al., 2004; Kumar et al., 2005, see also http://lis.gsfc.nasa.gov) which integrates the latest NASA remote sensing products (e.g., Moderate Resolution Imaging Spectroradiometer (MODIS), and the Tropical Rainfall Measuring Mission (TRMM)) and several existing modeling and data components, including the Noah land surface model, into a computationally efficient, end-user oriented, performance enhanced system. NASA is currently benchmarking the LIS against AGRMET using the AFWA precipitation and radiation forcing schemes and will deliver the initial capability in early 2005. The LIS package will provide AFWA the capability to compute high resolution global and regional lower boundary conditions. The output from the LIS package will provide the analyzed surface conditions necessary to initialize the operational Weather Research and Forecasting (WRF) land states while continuing to provide global analysis for our current customers and applications. A higher resolution soil moisture and temperature analysis would benefit DoD Decision Support Systems including Army mobility software and the Target Acquisition Weapons Software (TAWS) – Night Vision Goggle Operational Weather Software (NOWS). The NASA/AFWA partnership will also help speed delivery of the latest research into operations through a common environment.

The AGRMET system
The AFWA was the first United States operational weather organization to produce daily model generated global analyses of soil moisture and temperature conditions. The AGRMET model traces its heritage back to 1974 when the Air Force Global Weather Central (AFGWC, reorganized into AFWA) provided global analyses of soil temperature and moisture to the United States Department of Agriculture’s (USDA) Foreign
Agriculture Service (FAS). The FAS used and continues to use the output from the AGRMET model to facilitate crop yield assessments in major growing regions of the world. The AGRMET model blends temperature, humidity, and wind observations with National Centers for Environmental Prediction (NCEP) ½ degree Global Forecast System (GFS) initial forecast output to produce the atmospheric forcing for the core hydrology scheme. The Shapiro (1987) solar radiation scheme calculates the incoming solar radiation data using hourly global cloud analyses from the AFWA Cloud Depiction and Forecast System II (CDFSII) World Wide Merged Cloud Analysis (WWMCA). Analysis of longwave radiation are computed using a combination of Idso (1981) and Wachtmann (1975) using cloud analysis data from the WWMCA. Both the solar radiation and longwave radiation schemes were chosen for their accurate results in grain-growing regions of the mid-latitudes (Moore Et al., 1990).

The precipitation forcing within AGRMET is generated by combining surface rain gauge observations with output from the AFWA Geostationary satellite infra-red channel Precipitation (GEOPRECIP) analysis model, WWMCA precipitation analysis algorithm output, Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSMI) rain rate environmental data record (EDR), and climatology. The core Noah Land Surface Model (Ek et al. 2003) uses the atmospheric, radiation, and precipitation data, with output from the AFWA Snow Depth (SNODEP) analysis model to generate the soil moisture and temperature analysis fields.

The current operational AGRMET system produces 3 hourly increment output on a global ½ degree grid. During the next year, AGRMET will be upgraded to use the latest Noah Land Surface Model (version 2.7.1). AFWA plans to implement a higher resolution version of the model in late 2006 increasing the resolution to ¼ degree globally. Once the WRF is operational at AFWA, AGRMET will be used to initialize the lower boundary conditions at the beginning of model initialization.

The resolution and projection are limitations to the AGRMET model since the software was not designed with flexibility to be reconfigured for higher resolutions or multiple projections. The system lacks the ability to assimilate real time satellite observations of vegetation stress conditions, surface skin temperature, and soil moisture. Integration of an updated modeling infrastructure at AFWA is necessary to take advantage of the vast amount of new satellite observations and assimilation capabilities that exist within the research community.

The Land Information System

NASA personnel developed LIS to demonstrate the capability of using NASA Earth Observing Satellites (EOS) program data to analyze surface water states and calculate surface energy fluxes at 1 km resolution. LIS is capable of using 1 km MODIS vegetation and surface temperature analyses. As described in Kumar et al., 2005, LIS was developed as an efficient and modular software system able to be expanded or adapted to use new data assimilation techniques and contains many soil hydrology modules. Subsequent work with Departments of Commerce and Defense and other Research and
Development organizations is helping to improve the model before the transition to NCEP and AFWA. AFWA will benefit from the efficient design of LIS by gaining the capability to quickly generate a high resolution global analysis covering a span of many months. The LIS can be easily configured to also generate regional analyses to initialize the lower boundary of the AFWA WRF model, computing the soil moisture and temperature analysis at the resolution of each WRF theater. AFWA will also benefit from the preparatory MODIS work already accomplished with LIS as a future ability to ingest real time observations from the planned National Polar orbiting Operational Environmental Satellite System (NPOESS) Visible and Infrar-red Imager Radiometer Suite (VIIRS). The NASA MODIS sensor onboard Aqua and Terra is providing risk reduction for the planned NPOESS VIIRS mission; therefore, many of the capabilities developed to use MODIS data are potentially available for use with VIIRS data once operational status is achieved. Finally, the strategic partnership between the research and development community and the operational modeling centers using the LIS as a common infrastructure will provide a conduit to help advance land modeling and speed delivery of new scientific methods quickly into the operations.

AFWA/LIS Benchmarking Project

NASA is currently porting some of the AGRMET assimilation capabilities to work in the LIS system, including the precipitation and radiation schemes. The project is currently on track for an initial LIS delivery to AFWA in spring 2006. Initial LIS retrospective tests using the AGRMET radiation scheme were conducted using AFWA supplied data. The tests were initialized from May 6, 2005 AGRMET output, and continuously cycled for nearly 4 months until August 29, 2005. Background surface information came from a combination of sources, including the United States Geological Survey (USGS) 24-type vegetation classification, United Nations Food and Agriculture Organization (FAO) soils texture, MODIS 4 km maximum snow albedo provided by the University of Arizona under a Joint Center for Satellite Data Assimilation (JCSDA) funded project, and USGS 0.144 degree greenness vegetation fraction climatology background surface states. The NCEP Global Forecast System ½ degree resolution initial forecast of temperature, relative humidity, and winds were used as the atmospheric forcing, and precipitation was retrieved from the AGRMET merged precipitation analysis. The test involved executing the LIS software 3 times, each run at different grid resolutions (15km, 5km and 1km) using the latitude/longitude boundaries of the AFWA southwest Asia WRF domain for the 15km case, and the Afghanistan WRF theater boundaries for the 5km and 1km cases. The results from each LIS case were compared with AGRMET data valid August 29, 2005 at 18Z covering the same geographic region.

Figure 1 contains 1 km LIS output with matching AGRMET volume soil moisture output images covering the Afghanistan southwest Asia domain. The most readily apparent differences between the two models is that LIS is capable of generating a much higher resolution analysis then AGRMET is able to produce. The 1 km and 5 km output from LIS used much higher resolution background land and vegetation data that include geographic locations of small lakes, rivers, and fine terrain characteristics. The 1 km
analysis is fine enough to analyze the effect larger rivers have on adjacent soil moisture along the river boundaries as evidenced by the slightly higher moisture content along the northern border of Turkmenistan along the Amy Darya river (upper left in figure 1).

Figure 1 LIS 1km (left) and AGRMET (right) volume soil moisture output valid 29-August-2005 at 1800 UTC covering Afghanistan and portions of Pakistan. The black lines represent geographic political boundaries. The blue lines represent geographic locations of streams and rivers.

The fine resolution of background data available to LIS accounts for some of the differences in the output, while other differences relating to differences between LIS and AGRMET in the radiation calculations and snow depth over terrain need to be addressed during the pilot study. The accuracy of either system has not been analyzed at this point in the development effort. The rigidity of the AGRMET model is evident in figure 1 as the output appears blocky because of the low model resolution. Some output differences can be traced to the individual background data used within the models. The higher resolution surface type data used within LIS (figure 2) is different from that used within AGRMET. LIS uses combination of the 5 minutes FAO fractional sand/silt/clay content and soil color coverage maps to identify surface types, while AGRMET uses the 47 km combined soil texture data.

Figure 2 - LIS 5-min FAO clay coverage field (left) and AGRMET soil texture data (right). The LIS uses fine resolution soil type content while AGRMET uses a 47 km soil texture field. The numbers in the AGRMET soil classification represent table values of sand, sandy loam, sandy clay loam, etc.
The differences between the background soils data can lead to slightly different estimations of the soil water holding capacity between the models. The affect of the higher resolution fractional soil type is visible over the central portion of Pakistan in figure 1. The region east of the Indus river is low on clay content, and higher on sand content. The LIS output indicates lower soil moisture over the region with a higher sand content while AGRMET has a more uniform soil moisture content across the area.

Additional differences between LIS and AGRMET output are attributed to the 1 km terrain database used in LIS (figure 3). The AGRMET terrain height again is a very coarse 47 km field which looses much of the terrain variability within the theater. The terrain within LIS captures in fine detail the highly variable terrain of the region, and the resultant soil moisture and temperature fields capture these differences. Comparing the soil moisture and terrain height reveals patterns in the soil moisture that are closely tied to terrain features including mountain valleys and river basins, while the connection is much more difficult to identify in the AGRMET data due to coarseness of the output.

One issue discovered during the initial LIS testing will need to be addressed before LIS is inserted into AFWA operations. Initially, LIS will rely upon the WWMCA to provide the global cloud analysis data needed for the solar and longwave radiation calculations. The WWMCA is produced on a 24 km polar stereographic projection (true at 60 degrees latitude) grid and is relatively coarse compared to the LIS capabilities and AFWA WRF theaters. In the short term, NASA and AFWA will have to determine the best approach to using interpolated WWMCA data within LIS to produce a better estimation of radiation then exhibited by initial testing. Long term solutions might include producing a higher resolution WWMCA, developing a system at AFWA to store pixel level cloud information which could be used by downstream models (including LIS) to generate radiation analyses at higher resolution, or working with NASA to develop a LIS capable of handling directly inserted satellite resolution radiances to perform the radiation calculations. AFWA and NASA are also seeking higher resolution background soil type data (currently 5-minute) and vegetation greenness fraction climatology data (currently .144 degree). Newer vegetation climatology data may be available soon through JCSDA funded projects while a source for higher resolution soil type needs to be determined.
Potential Applicability to DoD operations

Army Mobility/Trafficability Analysis

Developed by the U.S. Army Corps of Engineers, Engineering Research and Development Center (USACE/ERDC), the Army Remote Moisture System (ARMS) is designed to provide fine-resolution (10-100m) estimates of soil states (i.e., soil moisture) that are critical for tactical applications such as mobility/trafficability analysis. ARMS incorporates the Noah LSM, and uses COTS Parameter ESTimation software (PEST) to simultaneously and optimally estimate soil properties and states by combining modeled and remotely sensed surface soil moisture estimates. The LIS infrastructure undergoing benchmarking at AFWA is fully compatible with ARMS, and could be applied at global or regional (i.e., WRF theater) resolutions for strategic applications. Output from LIS could be linked with ARMS and be deployed at tactical scales to support route planning and/or other battlespace terrain applications that require soil states, such as countermine operations and landing strip analysis. By combining remotely-sensed surface soil moisture estimates with continuous, modeled simulations of profile soil moisture, ARMS produces maps of root zone (depth to 1 m) soil moisture over regions of interest.

Tactical Decision Aid System support

The TAWS combines environmental data with target and surrounding background characteristics, celestial information, angle of attack, and other parameters to calculate the effective performance ranges for a weapons system, under the specific conditions of the proposed attack, thermal loading, reflectivity, albedo and atmospheric extinction for the target, background and weapon to target path. The information helps military mission planners choose the right type of weapons system for operational missions. Meteorological forecasting models supply TAWS with the future environmental conditions for a target. Standard background information including soil moisture, soil temperature, and foliage status are not discerned from real time analysis or climatological datasets, rather they are based upon coarse resolution 1° by 1° latitude/longitude static lookup table. Pearcy (2005) looked at the uncertainty in the background error contributed by the use of the standard datasets and calculated an uncertainty of roughly 20% in range calculation. Pearcy discovered the uncertainty lead to an underestimate of urban lock-on range and suggested TAWS be equipped to account for real time soil moisture analyses as a background variable to reduced range uncertainty. The low resolution of the default background error also contributes the range uncertainty, and upgrading the software to use high resolution soil moisture, soil temperature, and vegetation greenness fraction generated by the LIS could provide pilots an earlier lock-on range.

Dispersion Modeling

The Hazard Prediction and Assessment Capability (HPAC) automated software system provides the means to accurately predict the effects of hazardous material releases into the atmosphere and its impact on civilian and military populations. The system uses integrated source terms, high resolution weather forecasts (e.g., those from the WRF/LIS system being benchmarked) and particulate transport analyses to model hazard areas produced by military or terrorist incidents and industrial accidents. It models nuclear,
biological, chemical, radiological and high explosive collateral effects resulting from conventional weapon strikes against enemy weapons of mass destruction production and storage facilities. The HPAC system also predicts downwind hazard areas resulting from a nuclear weapon strike or reactor accident and has the capability to model nuclear, chemical and biological weapon strikes or accidental releases.

**Future Development Plan**

AFWA and NASA have developed a long term plan to continue development of the LIS. The initial NASA delivery of the LIS will occur in spring 2006; afterwards, additional work will commence to improve the precipitation assimilation, begin assimilating real time satellite data, and improve background climatology fields. In 2006 NASA personnel will begin to improve the precipitation assimilation and explore new sources of remotely sensed precipitation data to aid the global analysis especially in remote locations. Another project will examine the use of terrain scaled climatology to help improve the background. The LIS project will also soon benefit from a Kalman Filter assimilation technique. The addition of the Kalman filter is the first step forward in assimilating real surface states including remotely sensed skin temperature analysis, vegetation conditions, and soil moisture data. Longer term plans include further development of the ensemble modeling capability. NASA, AFWA, NCEP, NCAR, and NRL have also teamed up to seek funding to fully couple the LIS into WRF.

**Conclusion**

The LIS is the next generation land data assimilation system which will dramatically enhance the capability to more accurately and precisely analyze surface conditions. LIS will generate both the global and high resolution regional soil moisture and temperature analyses need to satisfy current AGRMET customers, and to initialize the AFWA WRF model. The addition of a high resolution capability could benefit numerous DoD applications, including the TAWS, Army mobility/trafficability applications, and dispersion modeling applications.

The LIS capability to utilize MODIS will benefit AFWA in the future NPOESS era. Many of the MODIS capabilities written into LIS will be available to use with VIIRS data once NPOESS satellites are launched and the data becomes available operationally.

Finally, the strategic partnership between AFWA and NASA will benefit the operational community through the use of a common architecture to help speed new research and development into operations. AFWA and NASA plan to continue working together to improve the LIS over the next several years by improving precipitation assimilation, adding a capability to assimilate real time satellite derived land surface temperature and soil moisture analyses, and improve that background climatology data. The continued improvements will ultimately lead to a more accurate assessment of land surface conditions used within the WRF model and other DoD applications.
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