DEVELOPMENT PLAN
FOR
THE AIR FORCE WEATHER AGENCY (AFWA)
LAND INFORMATION SYSTEM (LIS)

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1.0 Introduction: The LIS is a National Aeronautics Space Administration (NASA) developed Land Data Assimilation System (LDAS) targeted as the next generation operational software infrastructure at AFWA. The LIS provides surface layer characterization of soil temperature and moisture profiles, and energy fluxes at varying resolution both regionally and globally. The LIS software will replace the current AFWA LDAS package commonly known as the Agricultural Meteorology (AGRMET) Model, a software package developed at AFWA and used operationally for the past 20 years to supply surface moisture, temperature, and precipitation for United States Department of Agriculture (USDA) global crop production estimates, US Army tactical decision aid systems, other National Programs, the National Centers for Environmental Prediction (NCEP), the Air Force Technical Applications Center, US government, and other DoD organizations. Since LIS is a community package, AFWA will realize significant benefits from by being able to leverage partnership research and development support for continued LIS enhancements. Secondly, after further scientific and software development, AFWA A8TM believes the LIS package will be able to unify all surface characterization capabilities functionality provided by multiple software systems, including the infrared-based Geostationary Satellite-based Precipitation (GEOPRECIP) analysis model, Snow Depth (SNODEP) analysis model, and the Surface Temperature (SFCTMP) analysis model. Additionally, the LIS package provides the support AFWA requires to provide consistent, high resolution, domain-based soil profile moisture and temperature information necessary to initialize the coupled land-atmosphere components of the AFWA Weather Research and Forecasting (WRF) model forecasts. This document provides a near to medium term roadmap for development of the LIS package toward satisfying unification goals.

2.0 Purpose: This plan explains the operational requirements and background for the AFWA land surface characterization mission, and provides an outline for future application research conducted under the AFWA Weather and Forecasting Improvements program. These applications research efforts will further improve surface characterization capabilities at AFWA, using LIS as a framework to fully exploit the vast amount of satellite data coming in the National Polar-orbiting Operational Environmental Satellite System (NPOESS) era and the latest advancements available from the research community. The goal of this plan is to lay the groundwork for continued migration towards a mature Air Force Weather Weapon System (AFWWS) capable of providing surface characterization products optimally tuned to support battlefield scale requirements and various Tactical Decision Aids (TDAs). Existing TDAs currently use coarse resolution surface environment products to determine target detection range and weapon selection systems. US Army troop support and Air Force targeting TDAs require a robust Numerical Weather Prediction (NWP) system to produce battlefield scale analyses and predictions. This planning document addresses specific areas of interest to the DoD and Air Force Weather Community outlined in numerous Air Force (AF) requirements and planning documents:

- USAF Weather (AFW) Characterization: Weather Model Exploitation (WME) Implementation Plan (I-Plan) Version 0.7, September 2006
- Air Force Doctrine Document 2-9.1, 3-May 2006
- AFW Strategic Plan and Vision FY2008-2032 Transformation Vector #4
- AFW Characterize the Environment Enabling Concept, Version 3.0, April 2006
- Air Force Enabling Concept for Weather Support to Army Modular Forces, 16-September 2005
- AFW Centralized Aerospace Weather Capability Operational Requirements Document (CAWC-ORD) 12-March 2001
- Air Force Master Capabilities List (MCL) Version 5.4

- Air Force Weather Requirements Oversight Council Priorities (4, 5, 13, 14, 23, 25) 18-August 2004
- AFWA Strategic Plan (Goals 5, 6), 12-April 2006

The goal of this plan is to lay the groundwork for continued migration towards an AFWWS capable of producing surface characterization products to support battlefield scale requirements and TDAs currently using coarse resolution surface environment products to determine target detection range and missile selection systems. US Army troop support and Air Force targeting TDAs require a robust NWP system to produce battlefield scale analyses and predictions.

Further advancements in technology in the Intelligence, Surveillance, and Reconnaissance (ISR) community will ultimately rely upon high resolution and accurate analysis of surface information for remote platforms.

3.0 Background:

3.1 Established Requirements. AFWA is the primary DoD agency responsible for predictive battlespace awareness for US Air Force, Army, and Intelligence Community warfighter forces. A vital component of the global terrestrial, atmospheric, and space environment measurement and prediction system is an accurate representation of the land surface. AF, AFW, and AFWA documents identify the current shortfalls and the need to improve the surface characterization capabilities. These documents describe goals for providing improved DoD capabilities to simulate background weather and surface effects upon DoD decision systems at battlefield scales. National Programs and Army assets benefit from coupled earth-atmosphere capabilities (Air Force Doctrine Document 2-9.1; Air Force Enabling Concept for Weather Support to Army Modular Forces (2005)) including US Army mobility applications, USAF targeting systems, ISR programs, and other US Government agencies.

AFWA is solely responsible for providing surface and subsurface soil moisture and temperature profile data and precipitation estimates to the USDA Foreign Agriculture Service (FAS) and other National Programs customers. The soil data and precipitation estimates are created by the AFWA LDAS for global crop assessment and production estimate programs programs. The AFWA support for this program is outlined in an AFWA and USDA-FAS Memorandum of Understanding dated [Month Date Year]. The agreement, in place and continuously renewed since the early 1980's, now restricts public release of the AFWA LDAS output to reduce adverse effects upon US Commodities market trading prior to the release of USDA global crop production estimates.

Surface characterization requirements are rapidly expanding as tactical decision support tools become more advanced and numerical weather prediction systems are enhanced to include more complex surface interaction physics. Land surface temperature, a product derived by the AFWA LDAS, will soon be an input to the Target Acquisition Weapons Software/Infra-red Target Scene Simulator (TAWS/IRTSS) TDA (figure 3.1) system used to aid target detection algorithms which require information about the background surface temperature for infrared (IR) missile lock-on range assessment.

Pearcy (2005) described potential benefits to the TAWS capabilities through the addition of real time soil moisture information from the AGRMET based AFWA LDAS system with further improvements possible when using higher resolution surface characterization information. The AFWA LDAS is the primary software platform required to produce land surface profile

information as the initial conditions for the AFWA Weather Research and Forecasting (WRF) model coupled earth-atmosphere physics module. The AFWA SNODEP analysis model, another component of the AFWA LDAS system, is the only operational daily global snow depth analysis model. It is used by many internal AFWA processes and external DoD, U.S. Government, and other worldwide meteorological agencies to provide valuable snow depth and cover estimates for decision systems. NCEP uses the SNODEP in conjunction with their higher resolution satellite based snow coverage product as an input to the Global Forecast System (GFS). The GFS model is a component of NCEP's NWP system used by AFW forecasters and DoD TDAs in addition to its use in the global cloud analysis system.

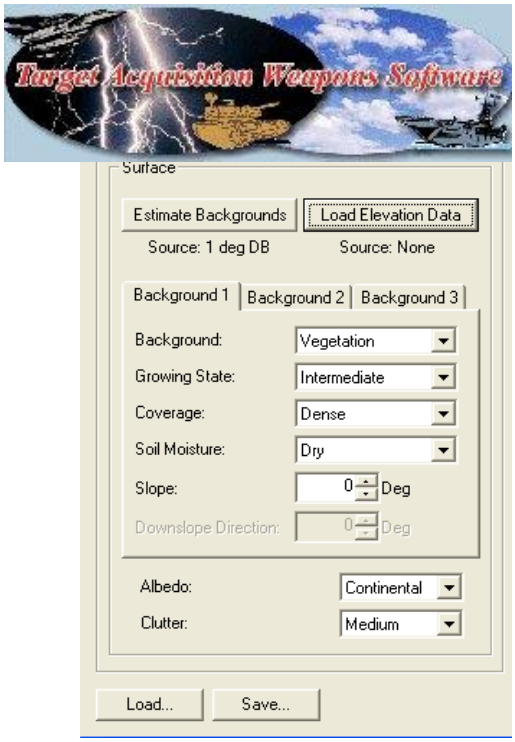

Figure 3.1 - TAWS background data graphical user interface. Background surface state variables, soil moisture, and other background terrain features require user input.

AFWA LDAS products are used by many other DoD applications and systems, including the Army Integrated Meteorological System (IMETS), Fleet Numerical Meteorological and Oceanographic Center (FNMOC) Naval Oceanographic Global Atmospheric Prediction System (NOGAPS) model, Defense Threat Reduction Agency (DTRA) Hazard Prediction and Assessment Capability (HPAC) model, and the AFWA Dust Transport Application (DTA). NCEP receives AFWA LDAS products to aid with comparisons to their global LDAS output and possible use within the Land Surface Model (LSM) component of the GFS as outlined in NCEP-AFWA Memorandum of Agreement (MOA) dated May 21, 2007. AFTAC, NCAR, the National Intelligence Agency, and NASA also receive LDAS products.

Specific requirements for AFWA LDAS products span multiple warfighter disciplines in the operational support AFWA provides to DoD decision systems. Internally, AFWA is responsible for providing global cloud analysis and forecast products, and serves as the primary center for cloud analysis and forecasting for all DoD operations to include providing cloud information to the intelligence community and mission planners. AFWA was one of the first operational centers to produce global estimates of terrestrial environment conditions in support of US crop intelligence programs. Additional requirements were added to the AFWA surface characterization program to aid USDA-FAS global crop production estimates.

During the last 10 years numerical weather prediction capability expanded to couple the atmosphere to a LSM aiding more accurate understanding of the surface-atmosphere energy exchange. The development of the coupled model enhances the requirements for off-line and coupled LDAS to initialize the coupled earth-atmosphere modeling system. Recent studies [Kumar et al. (2007); Chen et al. (2007); Trier, Chen, and Manning. (2004); Holt et al. (2006); Trier et al. (2007)] illustrate the need for a highly accurate and high resolution LDAS to provide surface characterization profiles consistent with the WRF domain structure to eliminate errors created by re-projecting coarser resolution AGRMET output to the higher resolution domain. The continued development of the coupled WRF system enhances the AFWWS capability to

provide background land surface temperature and moisture analysis and prediction fields decision systems use in target detection or weapon system selection.

3.2 Current Operational Capability. AFWA was the first United States operational weather organization to produce daily model-based estimates of global soil moisture and temperature conditions. The AFWA LDAS 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 USDA-FAS. The USDA-FAS has continued to use the output from the AFWA LDAS to facilitate crop yield assessments in major growing regions of the world. The AFWA LDAS blends temperature, humidity, and wind observations with the NCEP 0.5 degree GFS initial forecast output to produce the atmospheric forcing for the core hydrology scheme. The AFWA LDAS infrastructure gathers surface, satellite, or climatology based measurements of land state variables including vegetation characteristics, soil characteristics, precipitation estimates, longwave and shortwave radiation, and lower atmosphere meteorological data, and feeds the information to an LSM to compute the desired soil moisture and temperature profiles. The primary LSM physics package within the AFWA LDAS is the Noah Community LSM (Figure 3.2) described in Chen & Dudhia (2001), Chen et al. (1997), Ek et al. (2003) and Pan & Mahrt (1987). The Noah LSM was originally developed through collaboration by NCEP, Oregon State University, AFWA, and the National Oceanic and Atmospheric Administration (NOAA) Office of Hydrology, and AFWA continues to play a valued role in the development of the LSM.

Model	**Model Grid Projection**	**Product Output Interval**	**Product Resolution**
AGRMET	Lat/Lon (cylindrical)	3 hourly	½ degree (~50 km)
	Polar Stereographic	24 hourly	8th mesh (47 km)
SNODEP	Polar Stereographic	24 hourly	16th mesh (24 km)
GEOPRECIP	Polar Stereographic	3 hourly	8th mesh (47 km) 16th mesh (24 km) 64th mesh (6 km)
SFCTMP	Polar Stereographic	3 hourly	16th mesh (24 km)
LIS	Lambert	Variable, requirements driven (i.e. 15 min up to 24 hourly product generation)	Resolutions as high as 1 km regionally or globally. LIS IOC defined as ¼ degree global resolution Regional domain resolution dependant on WRF domain requirements (i.e. 15km, 12km, 5km)
	Mercator		
	Lat/Lon (cylindrical)		
	Polar Stereographic		
	Gaussian		

Table 3.1- Current AFWA land surface characterization models (AGRMET, SNODEP, GEOPRECIP, & SFCTMP) descriptions of grid projection, product output interval, and product resolution. The LIS description includes the additional grid projections not currently supported by current software. The LIS product resolution is variable (up to 1km globally or regionally), and dependant upon requirements.

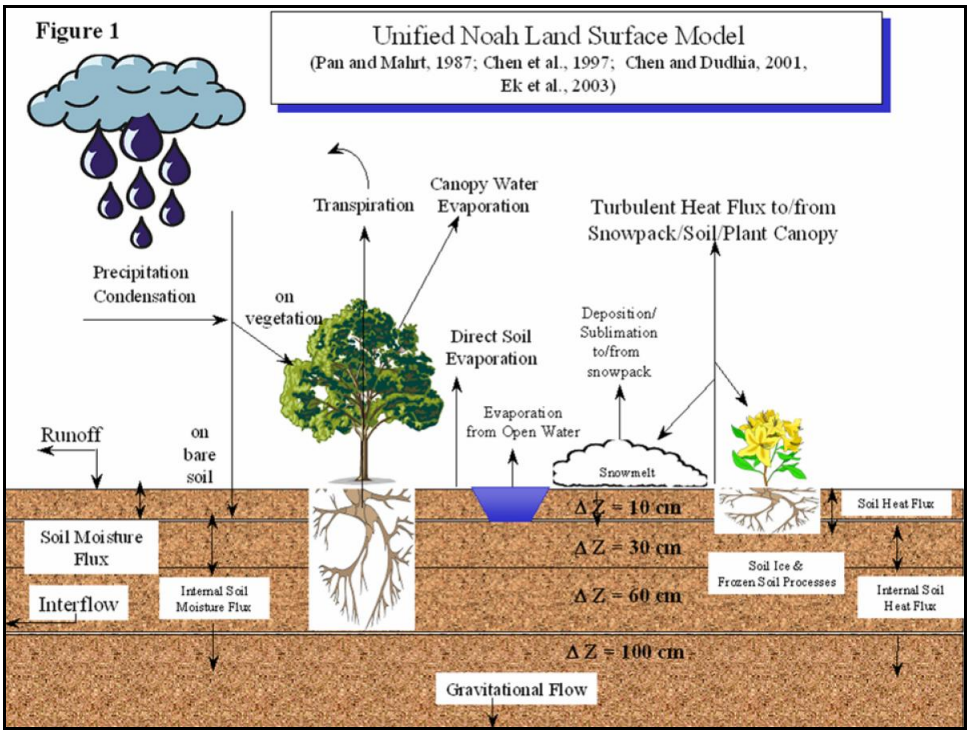

Figure 3.2 - Graphic illustration of the physics within the Unified Noah Land Surface Model (after Pan and Mahrt, 1987; Chen et al., 1997; Chen and Dudhia, 2001; and Ek et al., 2003)

In the AFWA LDAS, incoming solar radiation calculations are computed using a scheme described in Shapiro (1987) that exploits cloud properties provided by the hourly AFWA Cloud Depiction and Forecast System Version II (CDFSII) World Wide Merged Cloud Analysis (WWMCA). Longwave radiation estimates are generated using a combination of algorithms described by Idso (1981) and Wachtmann (1975), again with cloud conditions provided by the hourly AFWA 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 current AFWA LDAS package is limited in its ability to exploit the vast amount of remotely sensed data currently available from operational DoD and NOAA satellite sensors because of the lack of a more advanced data assimilation capability. With future NPOESS missions on the horizon offering significantly more capabilities to operationally measure earth's surface and atmosphere characteristics, and the need for DoD to capitalize on these measures to increase battlespace awareness, significant work is required to upgrade the AFWA LDAS system. Currently, the primary information driving surface vegetation influences and surface albedo are based on long term climatological assessments. Additionally, the surface and subsurface soil temperature and moisture profiles are not forced using remotely sensed or in-situ measurements due to the lack of scientific capability to use those measurements within the AFWA LDAS. The current AFWA LDAS system is identified as an operational deficiency due to the inability to support high resolution numerical prediction requirements and battlefield scale Army requirements supporting mobility/trafficability applications based on the current operational AFWA LDAS resolution of 0.5 degrees. Finally, severe limitations in AFWA's ability to further enhance the AFWA LDAS based on manpower shortfalls require the adoption of a community based infrastructure to ensure AFWA will continue to provide high level support to DoD decision systems.

3.3 LIS Description. Scientists with the NASA Goddard Space Flight Center (GSFC) Hydrological Sciences Branch (HSB) developed the LIS (figure 3.3) to provide both regional and global LDAS products and demonstrate a capability to use NASA Earth Observing System (EOS) satellite data from such sensors as the Tropical Rainfall Measuring Mission (TRMM) and Moderate Resolution Imaging Spectroradiometer (MODIS) (Peters-Lidard et. al, 2004). The result was a highly efficient and configurable LIS software package (figure 3.4) able to provide surface profile analyses at varying resolution and on multiple projections based on user requirements (Kumar et. al, 2006).

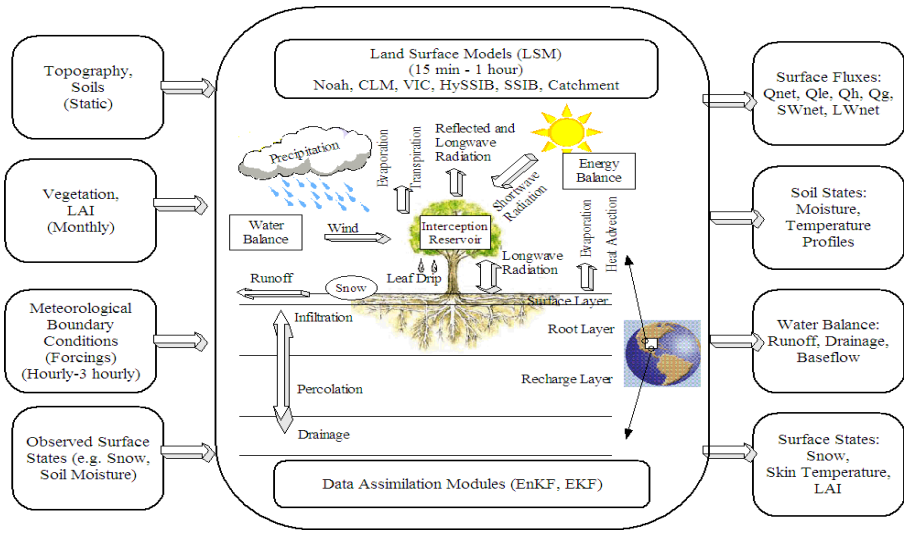

Figure 3.3 – [After Kumar et al. (2006)]. Inputs to the LIS are described in the left hand column (topography, vegetation, meteorological information, etc). The core of the LIS system, the data assimilation tools and land surface model physics modules, is described in the center. The output characteristics (surface fluxes, soil state and surface variables) are listed in the right hand column.

In 2004 AFWA Air and Space Models Integration Branch (A8TM, formerly DNXM) personnel evaluated the LIS and identified the software package as potentially providing strong benefits to improve AFWWS capabilities of increased accuracy and precision of global terrestrial environmental characterization, and provide a software infrastructure already capable of using some NPOESS type satellite data. Replacing the AGRMET-based AFWA LDAS with LIS will enhance AFWA's ability to provide surface characterization products at much higher resolution and accuracy, potentially down to 1km globally, than current operational capabilities. The high resolution information should enhance AFWA's ability to support decision systems that require precise and accurate surface information including those that support troop mobility/trafficability decisions, coupled numerical weather prediction systems supporting target detection, and missile selection systems. Additionally, current agriculture intelligence systems and USDA agriculture economic policy decision makers will be able to exploit enhancements in the global precipitation and soil temperature analysis fields that are used in global crop stress/production decision systems. While NASA HSB personnel are responsible for the software design and maintenance of the LIS software baseline, there has been significant community involvement in the development and improvements to the LIS science. University and government research scientists from Princeton University Civil and Environmental Engineering Department, NCEP Environmental Modeling Center, NASA Hydrospheric Sciences Branch, and the Center for Ocean-Land-Atmosphere Studies (COLA) at George Mason University collaborated on the initial NASA funded Computational Technologies Round-3 Grand Challenge Investigation LIS

development project. Additionally, various other research groups, government agencies, and private industry have adopted the LIS infrastructure in their land surface research programs, including the NASA-NCEP-DoD Joint Centers for Satellite Data Assimilation (JCSDA), George Mason University, NASA Marshall Space Flight Center, and Atmospheric and Environmental Research, Inc. (AER), NASA Global Modeling and Assimilation Office, Colorado State University, NOAA Office of Hydrology, Mississippi State University, and Baron Meteorological Services. NCEP is targeting LIS to become the operational LDAS supporting coupled GFS and North American Mesoscale (NAM) models. Finally, AFWA A8TM personnel are integrating the LIS software into operations to replace the current operational AGRMET model using in-house dedicated A8TM personnel, aiming for an initial operational configuration (IOC) by late FY 2008.

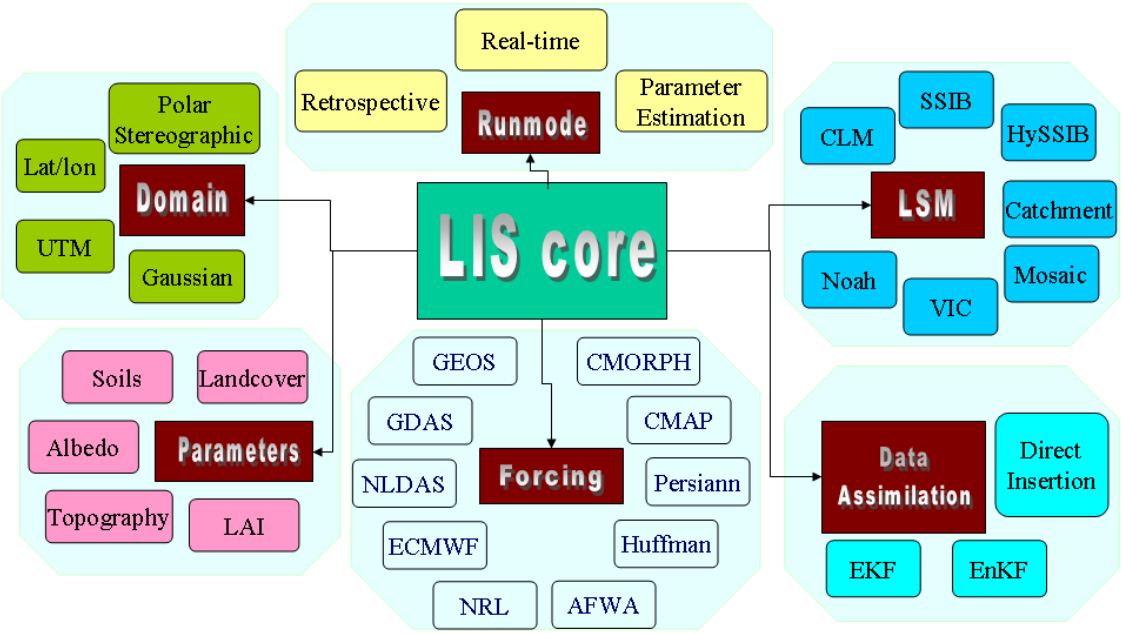

Figure 3.4 - Illustration of LIS modular design. System consists of module based interfaces allowing multiple configurations or "plug-ins". The LSM module options include many different physical LSM packages. The Domain module includes the four different grid projections used at NCEP, AFWA, and NASA. The Forcing module allows the user to configure the model to use many difference sources of meteorology and precipitation, the Runmode module accounts for the execution method (i.e. operational or "Real-Time" mode; historical or "retrospective" testing mode; and research or "Parameter Estimation" mode). Additional configuration options are available in the parameter and data assimilation methods.

While the LIS software does have community involvement, AFWA has been providing significant funding for applications research to the NASA LIS team since 2005 to add AFWA unique data requirements and enable future satellite data assimilation with Ensemble Kalman Filtering (EnKF) capability. After initial projects were completed in 2005, later projects in 2006 and 2007 were funded for application research and to transition proven science from the Research and Development (R&D) community into the LIS baseline for use at AFWA. In September 2006, NASA delivered an updated version of LIS containing an ensemble Kalman filter package for data assimilation. This updated package represents the first of a kind operational data assimilation system able to assimilate real time satellite observations of snow cover, ground

temperature, and soil moisture. This enhancement to the LIS infrastructure will enable significant advancements to land data assimilation over the next several years.

3.4 Computational Resources. Since the inception of the LIS integration effort, the DoD High Performance Computing Modernization Program (HPCMP) Naval Oceanographic Office (NAVO) Major Shared Resource Center (MSRC) computing resources at Stennis Space Center have been used for integration testing due to similarity in computational platforms between NAVO and AFWA. Continued use of NAVO MSRC resources is required for successful completion of the AFWA LIS integration. Additionally, the NAVO MSRC is available for use by AFWA, NASA, and other DoD research partners as long as they have an ability to provide security clearance information and log in remotely to the MSRC system through the Kerberos port. AFWA has already established a long term data archive on the MSRC to assist R&D efforts and advocates for additional accounts when R&D partners request use of AFWA data benefiting AFWA modeling. AFWA will continue to seek computational hours on the NAVO MSRC as long as those resources are available. The NAVO MSRC provides great benefit to AFWA modeling development and AFWA greatly appreciates the ability to use those resources. Additional resources at other HPC MSRC sites will be requested if required for continued R&D support to the LIS development program.

4.0 Scientific Motivation

AFWA and NASA are collaborating to further enhance the LIS software with new capabilities to enable use of the extensive amount of operational satellite data planned under the NPOESS era. Additionally, AFWA and NASA are collaborating with many other scientific and application research organizations to improve the science for surface characterization through the LIS community framework. After operational integration, LIS will enable AFWA to fulfill surface characterization requirements for the AFWA WRF model, Ensemble Prediction System (EPS) land surface model initialization, and Joint Forces requirements including Army mobility/trafficability modeling and hydrological assessments.

Two specific vectors are explored in this planning document. The first vector includes enhancements to the LIS software used in the stand alone data assimilation or "off-line" mode. The second vector includes improvements aimed at specific elements of a coupled NWP system.

4.1 Offline LIS Improvements. While the AGRMET-based AFWA LDAS provides significant benefit to the operational community, there are many capability shortfalls that are easily addressed with the LIS software. The LIS software was developed under a NASA funded program to enable a highly configurable and efficient computational software system capable of using data from the MODIS sensors. Therefore, LIS in its earliest form already provided a more efficient and capable platform to meet NPOESS era requirements due to the ability to use MODIS sensor data as a proxy for NPOESS Visible/Infrared Imager/Radiometer Suite (VIIRS) sensor data above the capabilities of the AGRMET model. To be "fully compliant" with NPOESS era capabilities, the LIS system requires further enhancements to incorporate applied research from the R&D community. Additional AFWA funded projects were conducted to install an advanced EnKF capability to assimilate skin temperature, snow information, and soil moisture measurements from space, and improvements to the precipitation analysis are needed to enhance accuracy and improve resolution. Development is further needed to better characterize global land surface estimates. Additional software and scientific development is needed to integrate a Radiative Transfer Model (RTM) into the LIS. Remote measurements of precipitation and land surface fields from space are greatly influenced by variability in surface emissivity which can be

corrected using a RTM. The JCSDA has developed a Community-based Radiative Transfer Model (CRTM) software framework to help fulfill radiance based assimilation needs.

The combination of the EnKF and the JCSDA-CRTM additions to the LIS baseline should provide an advanced capability to assimilate significant amounts of remotely sensed surface observations, including such fields as skin temperature from infrared and microwave sensors, soil moisture measurements from microwave sensors, and surface vegetation information from multiple sensors. Additionally, the CRTM will enable improved precipitation estimates used to force added wetness to the soil fields.

Further improvements are also to begin merging the multiple software baselines currently operational at AFWA into a unified LIS software baseline responsible for all land surface analysis. AFWA maintains four surface environmental models including the AGRMET analysis model, the SNODEP analysis model, the GEOPRECIP analysis model, and the Cloud Depiction and Forecast System Version II (CDFS II) SFCTMP analysis model. LIS will replace AGRMET, and A8TM believes the SNODEP and GEOPRECIP model capabilities can be added and/or replaced by enhancements to the LIS. A8TM also believes that LIS can be enhanced to create short term forecasts of surface and shelter temperature, using GFS meteorology and precipitation forecasts to provide the needed input data to LIS, potentially providing a more accurate replacement for the SFCTMP function required by CDFS II cloud detection algorithms. Merging multiple software baselines currently maintained by A8TM personnel into one LIS baseline would reduce the operational software maintenance costs while improving R&D support.

4.2 Coupled LIS-WRF data assimilation systems. The WRF model utilizes a land surface model to simulate the Earth-atmosphere latent and sensible energy exchange primarily responsible for heating the lower portions of the atmosphere. Proper execution of the WRF model requires a set of initial state variables of surface moisture and temperature for the land surface component of WRF. However, fully coupling the LIS to the WRF software infrastructures would provide more options and capabilities than simply using the LIS as the initialization for WRF. The modular infrastructure of LIS and its capability to use multiple LSM options add additional coupling configuration options for users of the WRF system. In addition, full coupling of LIS to WRF would enable consistency between land surface parameters, model configurations, and model physics allowing LIS to control the LSM interface and configuration with its software baseline. This would eliminate the need for two separate versions of the LSM (one version in LIS and one version in WRF) within the forecasting system. Additionally, this would ensure the LSM used in the creation the initialization surface fields is the same as the LSM used in the prediction system. Currently, the AFWA AGRMET model uses a slightly older version of the Noah LSM then the version installed in the WRF prediction system due to previously existing software limitations in AGRMET. This planning document accounts for a path towards a more accurate and consistent, fully coupled NWP system using the WRF and LIS software infrastructures.
Warfighter decision support systems and personnel, and other fielded systems will benefit from the operational LIS systems once coupled to the AFWA WRF mesoscale prediction system. Unlike previous AFWA mesoscale models, the WRF system utilizes a dynamic physics-based LSM. The purpose of the land surface model is to describe the energy exchange between the earth and atmosphere. Since the atmosphere is chiefly heated by an exchange of longwave radiation between the earth and planetary boundary layer, further improvements to NWP accuracy and resolution capability will require sophisticated physical interfaces to accurately assess the earth-atmosphere energy balance. Currently, the operational WRF-LSM is initialized by the coarse resolution (~47km) AFWA AGRMET model data. Using AGRMET output to initialize the WRF-LSM is not consistent due to differences in the surface terrain, vegetation, soil

textures, land-use, and other climatology information between coarse resolution AGRMET and much higher resolution WRF. The highly configurable and efficient LIS software provides AFWA the ability to compute high resolution surface characterization information using identical resolution and grid structure as the operational WRF model, providing a significantly improved consistency in the WRF-LSM initialization. Studies are being conducted to explore a more direct coupling of the LIS software to WRF. NASA and National Center for Atmospheric Research (NCAR) personnel are currently exploring a method to fully couple LIS and WRF using the Earth System Modeling Framework (ESMF), a software infrastructure which would act as an interface between the WRF model and the LIS software (figure 4.1). Using ESMF, the WRF model can use the LIS software at each time step where land surface information is required. This enables a much more consistent handling of the land surface scheme and reduces the need for having multiple copies of the land surface model in both WRF and LIS. This will provide a level of consistency not currently available in the coupled earth-atmosphere modeling environment. WRF would also be able to include a much more robust assortment of land surface models available through the LIS infrastructure, potentially enabling many more ensemble members as part of the ensemble prediction system. The enhanced lower atmosphere energy balance calculations feed back into the global atmospheric circulation system further improving forecasting skills of variables not limited to relative humidity, wind speed and direction, temperature, cloud information, and precipitation.

Figure 4.1 - Graphic illustration of a fully coupled mud-to-sun Numerical Weather Prediction system. Each "section" of the modeling system (i.e. space, atmosphere, and ground) are represented by separate models (i.e. GAIM, WRF, or LIS) coupled together by ESMF

The ultimate goal of the data assimilation system is to provide an accurate analysis of the state of the environment in a manner consistent with model physics states so the information can be forecast. Previous attempts at AFWA to couple coarse resolution AGRMET data with the AFWA Mesoscale Model Version 5.0 (MM5) revealed the many disconnects possible when

systems are not coupled in a consistent manner. Evaluating lessons learned from previous experiments and using information available in the research community has led toward a new project aimed at discerning the best possible method for coupling the LIS to WRF. In order to fully provide the information necessary for WRF to be effective at forecasting environmental conditions for long lead forecasts, there needs to be consistency within the initialization of WRF surface fields. To do this effectively, WRF needs to have the option of being fully coupled to LIS via an interface (i.e. an ESMF interface) where all surface environmental information is provided to WRF via LIS. When WRF arrives at a point where it requires surface albedo, temperature, snow cover and depth, vegetation information, terrain height, and other surface or subsurface characterization data, LIS will provide the information. LIS, in turn, would receive meteorological information (i.e. precipitation, wind, temperature, and humidity) and radiation forecasts from WRF to enable characterization of future states of the surface. This not only ensures consistency between the initialization and forecast modes of LIS and the WRF-LSM, but also ensures that both are operating on a common LSM without differences. Additionally, WRF will be able to use the numerous additional land surface model options within LIS, including those not yet available such as the US Army Fast All-Season Soil Strength (FASST) surface model, and other options.

5.0 Work Completed

LIS-AGRMET initial benchmarking study: The NASA LIS development team completed a pilot study in April 2006 expanding the LIS capabilities to include those that use AGRMET forcing data and enabling integration into the AFWA operational framework. The primary goal of this project was to adapt the AGRMET atmospheric, radiation, and precipitation forcing software to the LIS framework. The new packages enable a stand alone LIS system capable of producing a blended gauge-satellite based precipitation forcing analysis and a radiation forcing analysis to fully replace AGRMET in an operational framework. Additionally, this initial project acted as a pathfinder project for developing an efficient “research to operations” partnership between AFWA and NASA. This pathfinder mission will ultimately lead to better relationships between the research and operations communities to help bridge the gap between those communities, resulting in shorter transition periods required to integrate the latest proven science into a common LIS framework benefiting the mission weather forecasters and decision makers.

LIS precipitation enhancements*:* A strength of the AGRMET-based AFWA LDAS system is the accuracy of precipitation due to the use of surface-based precipitation gauge estimates combined with satellite data sources. However, in areas where gauge estimates are not available, the accuracy of the precipitation estimates decline due to the primary use of uncorrected or

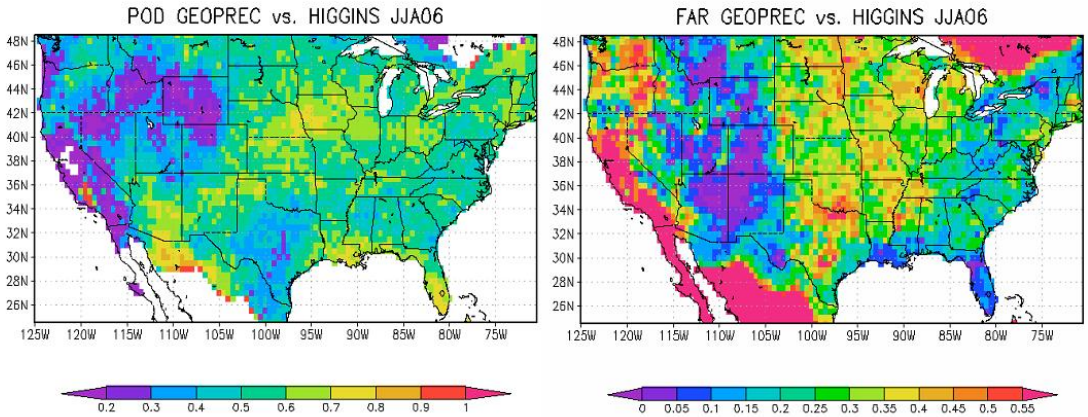

Figure 5.1 - Comparisons between the AFWA GEOPRECIP model and the NASA Higgins precipitation analysis product. Higgins is used as a "truth" dataset. Left image is probability of detection (POD). Right image is False Alarm Rate (FAR).

uncorrelated measurements from IR sources and Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I) Microwave (MW) data (figure 5.1). Additionally, the MW data is limited to tropical regions because previous implementations of the MW based rain rate Environmental Data Record (EDR) were highly inaccurate for mid-latitude regions. NASA analyzed four years of AGRMET precipitation data against other leading precipitation datasets available, including the Higgins analysis, NOAA Climate Prediction Center (CPC) Morphed precipitation analysis (CMORPH), TRMM 3B42V6 precipitation analysis, and the NCEP Stage IV merged radar and gauge precipitation analysis product. Recommendations included: expanding the use of satellite based microwave precipitation estimates to include more global coverage from existing sources; adding new sources of microwave precipitation estimates; and reducing the priority of GEOPRECIP in the AGRMET blended algorithm.

Evaluation of High Resolution Scaled Climatology*:* The Oregon State University Spatial Climate Analysis Division Parameter-elevation Regressions on Independent Slopes Model (PRISM) project uses digital elevation model datasets, long term precipitation, temperature, and humidity records, and a terrain "weighting" model to produce terrain-scaled high resolution climatology products of temperature and precipitation (figure 5.2). These model-

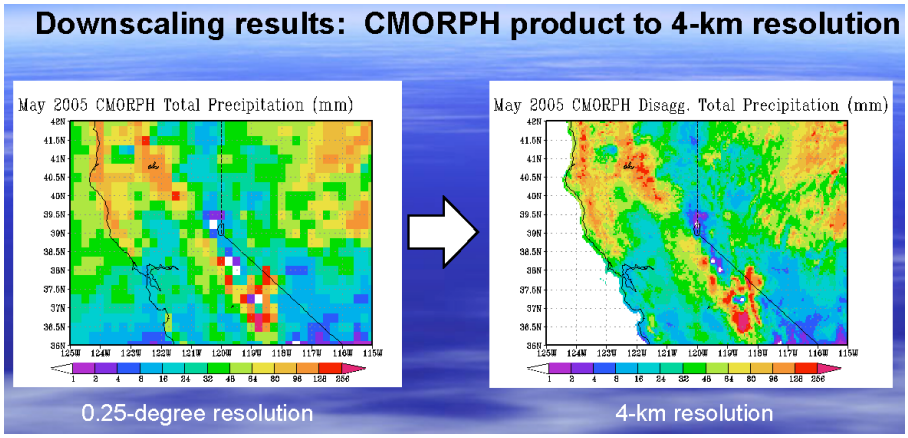

Figure 5.2 - Example of using highly resolution precipitation climatology from PRISM to downscale CMORPH from 0.25 deg to 4 km (Garcia et al., 2007)

based climatological estimates are being evaluated to help correlate remotely sensed precipitation estimates in regions of high terrain variability. Based on the results of the study, further projects may be conducted or advocated to derive additional climatological datasets for regions of the globe not currently studied. The high resolution climatology was demonstrated in LIS to aid accurate precipitation representations of low resolution measurements to a high resolution domain using high resolution terrain information over the western U.S., providing physically-based spatial distributions of precipitation where topographic influence plays a significant role in the occurrence of rainfall. Potential areas of future application include eastern Africa, Middle East and Asia.

LIS-WRF coupling evaluation: One of the initial goals for integrating LIS into AFWA operations was the demonstrated capability for LIS to readily support providing surface characterization data on the same grid-space as the WRF, thereby providing more direct support for WRF-LSM initialization. This project advances the capability to couple the two systems together providing more consistent characterization of the surface during both the assimilation and forecast cycles. Without full coupling, the LIS and WRF models are at risk to remain inconsistent with the implementation of the Unified Noah LSM. Additionally, the LIS coupling provides many more resources to the WRF system, including full ensemble based data assimilation and different land surface physics package options. The results from this study illustrated positive benefits for coupling using LIS to initialize high resolution WRF grids, with improved WRF performance both in the lower and upper regions of the atmosphere. Based on the initial task results, NCAR and NASA produced a report on the software engineering tasks needed to fully couple the WRF-LIS system. The software engineering design uses ESMF as a driver for the fully coupled WRF-LIS system enabling all surface features required by WRF in both the assimilation and forecast cycles to be fully described through the LIS infrastructure.

SNODEP Enhancement Task*:* This initial project is aimed at drastically improving the surface characterization capability in SNODEP. Currently, SNODEP only uses microwave imagery data from DMSP SSM/I and newer generation Special Sensor Microwave Imagery/Sounder (SSMI/S) sensors as a first guess "mask" of where snow is/isn't using an algorithm adapted from Grody, et al. (1991), and then applies snow depth observations from Aviation Routine Weather Reports (METAR) and synoptic observations (SYNOP) to derive the global snow depth reports. The improvements outlined in this task drive SNODEP towards using more remotely sensed snow observations from MODIS and Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) platforms to include high resolution snow mask and microwave estimates of snow depth (figure 5.3). The blending

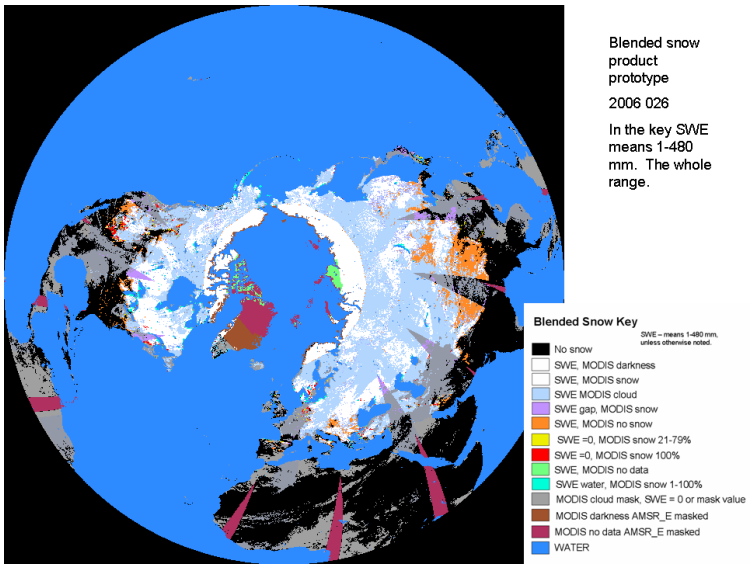

Figure 5.3 - Prototype of the new AFWA-NASA blended snow depth/cover capability. Colored regions represent snow water equivalent (SWE) greater then 0 mm. The key (lower right corner) illustrates how the snow cover was determined (by MODIS, AMSR-E, or combination of the two) (Foster et al. 2007)

of these observations together with snow depth observations from METAR and SYNOP reports will drastically improve the characterization of the snow surface for AFWA NWP and warfighter support system.

6.0 Ongoing Work.

Satellite-based skin temperature and snow data assimilation: The primary focus with 2007 projects is to add functionality using the EnKF to assimilate remotely sensed estimates of surface skin temperature from the MODIS sensors flying on the Terra and Aqua satellites. Current estimates of soil temperature and moisture are derived only from a physically integrated combined interaction of near surface meteorology, precipitation, snowfall, and energy balance data. The addition of remotely sensed surface skin temperature estimates from the high resolution MODIS sensor should provide a more accurate assessment for surface skin temperature estimates and result in more accurate energy balance calculations and corresponding weather predictions from the coupled LIS-WRF system. An additional project is to investigate use of a high resolution snow mask dataset to augment the current snow depth analysis in LIS and to enhance accuracy of high resolution snow fields. Accurate representation of surface snow information represents a significant deficiency in land surface characterization yet it represents a problem not easily solved. The amount of water locked up in snow on Earth's surface is not easy to measure remotely, yet direct measurements do not represent the large spatial variability of real distributions. The number of snow depth observations from global synoptic sites has decreased and the quality of the data is being questioned. The addition of remotely sensed snow depth observations is critical to DoD ability to effectively characterize the surface environment.

Investigate integration of JCSDA CRTM into LIS: The ability to move toward directly assimilating satellite radiance information is a primary interest in both the near and the long term. Currently, satellite EDRs are provided by centers and satellite processing systems containing atmospheric temperature and humidity profiles and surface condition information (i.e. temperature, soil moisture, vegetation health). These EDRs typically use atmospheric information provided by numerical weather prediction models to aid in the derivation of the desired quantity. Assimilating EDRs which use model data provides additional sources of error and inconsistency. Newer techniques have been developed to move toward using the satellite radiances within the assimilation scheme to prevent the use of inconsistent model data, thus reducing assimilation error. Recent work at the JCSDA resulted in a completed software framework for radiance assimilation. The CRTM framework binds together RTMs developed by many organizations into a joint selectable framework. The goal is to provide a common R&D solution for assimilating satellite radiances into NWP models. Near term goals for LIS improvement include using the CRTM software baseline to aid radiance assimilation in LIS. The goal is to use significantly more real time satellite measurements of Earth's surface by assimilating surface temperature, moisture, vegetation, and snow information via radiance-based processes through the CRTM.

Enhance SNODEP using additional remotely sensed observations and parameters from NASA's Quick Scatterometer (QuikSCAT), SSMI/S, and AMSR-E measurements: NASA GSFC personnel are already working to improve the SNODEP model with additional algorithms aimed at remotely measuring surface snow characteristics from visible and microwave sensors available on NASA EOS satellites. These previously discussed enhancements will add tens of thousands of additional observations to the SNODEP model, providing the first significant upgrade to the science in the SNODEP model in decades. Additionally, this task will aim to add observations of the onset of snow melt using satellite scatterometer observations (e.g. QuikSCAT) and day/night differences in microwave frequencies to help better understand the

surface water budget in regions where snow is in the active melting phase. Current measurements from passive microwave sensors are limited to detecting snow in regions where the snowpack is completely frozen.

Improve computational scalability of the LIS-AGRMET implementation: The first effort to add AGRMET software modules to the LIS software created some software inefficiencies due to the legacy software characteristics in the AGRMET processing software. While this enabled direct correlation between LIS and AGRMET it also created processing inefficiencies in the LIS. This effort will improve the scalability and clean up the software to remove dependence on the old AFWA polar stereographic grid.

7.0 The Plan

This portion of the document outlines the development plan for LIS for the next 5 years. The overall development plan should evolve as new science becomes available. However, the main goals of improving precipitation forcing, assimilating actual soil moisture measurements, and the addition of remotely sensed data to the model versus using climatological datasets remain the top goals over the next several years. The plan is broken down by year, with the main priorities listed in each year. The current Program Objectives Memorandum (POM) for Research, Development, Test and Evaluation (RDT&E) for LIS development under the AFWA 3600 Weather Forecasting Improvements funding line are shown in the table below.

	FY08	FY09	FY10	FY11	FY12	FY13
LIS RDT&E Funding ($M)	0.63	2.300	1.000	0.950	1.900	1.550

Table 7.1- Summary of AFWA 3600 projected Weather and Forecasting improvements program funding for the LIS enhancement program

Currently, there are several ongoing LIS projects aimed at both enhancing LIS system analysis capabilities, enhancing coupled earth-atmosphere prediction capabilities, and preparing for future enhancements to better meet warfighter requirements. Two related projects funded by AFWA in FY2006 aim to improve the AGRMET LDAS precipitation blending capabilities.

7.1 FY2008 Planned Projects. The following projects are slated for completion in FY08:

Integrate the JCSDA CRTM into the LIS to enable radiance assimilation: The use of remotely-sensed surface information is influenced heavily by variability in surface emissivity in infrared and microwave frequencies caused by variances in surface soil wetness, temperature, and vegetation conditions. These variances in emissivity need to be accounted for when attempting to measure those characteristics from remotely sensed data. Additionally, microwave- and infrared-based surface temperature and moisture measurements, while attempting to diagnose the same characteristic, are measured from different regions of the surface layer. Microwave sensors measure temperature from a “penetrated” layer of the soil of varying depth, depending upon the emissivity, whereas the infrared surface temperature is measured from a very thin “screening” layer on the actual soil or vegetation surface. An RTM is needed to assimilate the different measurements. Additionally, a CRTM interface to LIS, by way of a new multi-band land surface emission modeling component, will enable further research in later years of this project plan toward assimilation of remotely sensed soil moisture measurements, vegetation conditions, and improved precipitation retrievals over land regions.

Investigate replacement of CDFS II WWMCA with CDFSII-generated cloud optical properties at high resolution: In 2007, AER completed the first in a series of tasks to upgrade CDFS II with algorithms to calculate cloud optical properties (COP) at high spatial resolution (~9 km). These high-resolution satellite cloud measurements would enable high-resolution LIS surface energy budget estimates. Integrating CRTM into LIS (previous paragraph) will enable the LIS development team to begin testing the use of COP data in collaboration with AER; however, until the cloud optical properties software is integrated into the CDFSII operational environment, full production capabilities with LIS is not possible. During the development period, NASA and AER will collaborate in order to further develop CRTM functionality and enable LIS to use the COP products. This effort will include planning and development of software to use the higher resolution cloud optical quantities provided in future CDFS II operations. AER has already provided development software enabling AFWA A8TM personnel to generate example cases of cloud optical properties datasets on the CDFS II development system. This software will enable limited testing of the new capability in LIS. The full realization of using high resolution cloud information from CDFS II will require a multi-year effort once the full physical retrieval algorithms are available in CRTM and LIS, and will require CDFS II to fully integrate the COP algorithms into production.

Begin work to couple LIS and WRF models using the Earth System Modeling Framework (ESMF): A coupled LIS-WRF system (via ESMF) will result in a fully coupled land and atmospheric weather data assimilation and prediction system which fully accounts for the surface energy exchange in a consistent manner through the initialization and forecast process. Additionally, the full coupling will enable WRF to take full advantage of the numerous land data assimilation capabilities being developed with LIS, and enables WRF to use many more LSM options available within the LIS software. This project is planned as a two-year effort (see below for project continuation).

7.2 FY2009 Planned Projects. The following projects are slated for completion in FY09:

Develop integrated and improved AFWA LIS precipitation estimates: Currently, the AFWA LDAS system combines precipitation information from global surface gauge observations, polar-orbiter microwave-based precipitation estimates, and geostationary IR estimates to create the global precipitation analysis. The IR-based estimates, while timely and providing a significant quantity of observations, are plagued with large errors due to the nature of the technique. The MW estimates are more accurate, though errors occur due to variances in surface emissivity, and the timeliness of the observation update is poor due to polar-orbit revisit times. A project was conducted in FY2006/2007 to determine what could be done to improve the precipitation analysis in a way that error measures for the surface gauge observations and satellite estimates could be used to "blend" these data for a complete precipitation analysis in regions where gauge observations remain sparse. This year's effort will build upon the outcome of the previous project, combining the spatial downscaling and interpolation of observations with advanced temporal interpolation methods to drive higher spatiotemporal resolution and accuracy in the global precipitation analysis. In addition, this effort would include an evaluation on the use of CRTM to correct MW-based radiances for background (surface) emission (based on FY2008 projects), thereby improving the precipitation estimates available to the blending and analysis method. This project is planned as a two-year effort. The first year will focus on development, the second on validation (reference description under FY2010 Planned Projects).

Benchmark coupled LIS-WRF development: The coupled LIS-WRF system will be developed during the first-year effort (2008), and benchmark testing on the Development and Testbed Center (DTC) hardware will be performed during this project period.

7.3 FY2010 Planned Projects. The following projects are slated for completion in FY10:

Investigate assimilation of microwave-based soil moisture measurements: Recent and ongoing research sponsored by the JCSDA has investigated assimilating soil moisture measurements from passive microwave sensors (e.g. AMSR-E). Until recently, the sensitivity and dynamic range of AMSR-E soil moisture assessments has limited the ability to use the data as input to land surface models. Recent projects have demonstrated a capability to scale the soil moisture measurements using 4-dimensional data assimilation (4DDA) techniques and assimilation through the AFWA-sponsored EnKF module in LIS. While current (2007) R&D is still progressing, integration efforts could begin during this project time frame with the goal of providing an operational capability to assimilate microwave-based soil moisture estimates as a pathfinder project for the NPOESS Microwave Imager/Sounder (MIS) sensor, planned for operation in 2013.

Validate integrated and improved AFWA LIS precipitation estimates: The integrated and improved precipitation analysis system will be developed during the first-year effort (FY2009), and benchmark testing will be performed during this project period. Specifically, the performance of MW-based precipitation retrievals over land areas will be assessed, and the continued utility of GEOPRECIP precipitation estimates in the blending algorithm will be determined. Work on the optimal handling and combination of surface gauge observations with remotely-sensed estimates will be performed, and validation of component and blended analyses with independent surface observations will be documented.

7.4 FY2011 Planned Projects. The following projects are slated for completion in FY2011.

Enable vegetation condition variable assimilation: NCEP and NCAR partners are collaborating with several research institutions (Purdue University, Univ. of Arizona, University of Texas) through the JCSDA to add dynamic vegetation models to the Unified Noah LSM. The result of adding dynamic vegetation capabilities to the LSM is enabling a more physics based approach toward modeling vegetation health within the LSM based on soil and boundary layer moisture and temperature variables. Additionally, the dynamic vegetation models will enable real time assimilation of satellite based measurements of vegetative health conditions (i.e. Leaf Area Index, Vegetation Greenness Fraction). The vegetative health conditions are important to understanding the amount of moisture plants transpire and directly affect lower atmosphere temperature, humidity, and precipitation.

7.5 FY2012 Planned Projects. The following project is slated for completion in FY2012.

Snow reporting improvements: NCEP and NCAR partners are collaborating with the University of Texas to include a multilayer snow pack physics module into the Unified Noah LSM. The inclusion of the multi-layer snow pack model will enable more explicit understanding of the surface water storage. The current global snow analysis generated by AFWA has very limited connection to real global surface water storage. Furthermore, the conversion of the snow depth information into a snow water equivalent, a physical state determined by the land surface model, is a single parameterized calculation which may differ significantly from reality leading to large sources of error. Additionally, certain mobility applications or landing zone determinations would benefit from snow analysis enhancements to determine strength of the snow cover for

mobility or troop deployment applications. Incorporation of the snow physics package should support an integrated snow analysis model enabling the replacement of SNODEP with a LIS solution.

Table 7.2 – Summary outline of development and integration efforts from fiscal year 2007 through 2014. The development efforts in the middle column are anticipated projects to be completed by the LIS development team at NASA Goddard Space Flight Center provided funding is available. The integration efforts in the right hand column are to be competed by AFWA personnel to integrate completed R&D into operations.

Fiscal Year	R&D efforts	Integration efforts
2007	- MODIS Skin Temperature and Snow coverage using EnKF	LIS RDT&E
2008	- JCSDA CRTM evaluation/integration - Cloud Optical Properties in LIS - LIS-WRF Full Coupling	LIS IOC (September)
2009	- Finish CRTM integration - Precipitation retrieval enhancements - LIS-WRF Full Coupling	LIS FOC
2010	- AMSR-E Soil Moisture Assimilation	Coupled LIS-WRF integration
2011	- MODIS/VIIRS Vegetation Condition Assimilation	CDFS II SFCTMP model replaced with LIS-GFS solution
2012	- Snow pack physics model integration into LIS - AMSR-E/SSMIS Snow Depth Measurements using EnKF/Snow pack physics model	GEOPRECIP capability integrated into LIS
2013	- Enhanced Precip Measurements from GPM - Distributed Watershed Modeling	
2014		SNODEP capability replaced with LIS-Snow physics

8.0 Work Needed but not yet in Plan.

Follow on projects based on the FY06 funded high resolution scaled climatology project with Oregon State University are not accounted for in this planning document. The method of using high resolution linearly scaled digital elevation model precipitation data has proven to be a highly useful capability in accurately analyzing precipitation; however, the cost of producing the datasets for additional countries is beyond the scope of this software development plan. Additional funding will be sought from other organizations to help fund development of PRISM datasets covering regions of the globe not currently accounted for, including Africa, southwest Asia, and many others.

9.0 Summary and Conclusions.

The requirements outlined in this document fully describe the need for AFWA to engage in active collaboration with NASA and other community surface characterization R&D groups to continue developing the LIS software to help provide support to AF, Army, and National Intelligence Agencies warfighter needs. Numerous DoD, National Programs, and other U.S. Government agencies rely upon AFWA to provide the surface characterization data to aid mission planners and other TDA systems. The current operational AGRMET model does not accurately or precisely describe the surface and subsurface soil conditions necessary to meet battlefield scale surface characterization requirements or to properly initialize the AFWA WRF model. Additionally, the AGRMET model is not suited to use the vast amount of satellite-based surface observation data soon be available in the NPOESS era.

The two main LIS development goals are to improve both the off-line or uncoupled LIS capabilities and to fully couple LIS to the WRF. Off-line LIS surface characterization improvements are necessary to provide the global land surface analyses required for the global cloud analysis and forecasting mission, meet surface characterization needs of the global mission planning and ISR community, and support intergovernmental support to the global weather prediction system. The coupled LIS and WRF software infrastructure will enable more accurate initialization and a more consistent land-atmosphere coupling scheme by reducing the need for multiple copies of the LSM software within the WRF atmospheric data assimilation and prediction system. The elements outline within the two focus areas of planning describe incremental improvements and deliveries which will enable use of a significant portion of the vast amount of satellite data currently available and planned with future DoD and national satellite program missions. Improvements to better characterize surface vegetation conditions, use remotely sensed soil moisture measurements from satellite sensors, and assimilate satellite estimated surface temperatures will improve our ability to assess the battlespace environment with more accuracy and precision than currently possible. The improvements discussed in this plan should enable a robust LDAS capable of unifying the entire AFWA surface characterization system from under one software umbrella.

Additional direct benefits will be realized from the increasing amount of community support associated with the LIS. Increasing numbers of community R&D groups have started to use LIS to support land surface modeling and land data assimilation research. AFWA will be able to capitalize and leverage a significant amount of research work being funded by other government and corporate sponsor groups to improve surface characterization capabilities. The result will be an increase in AFWA's ability to transition new science into the operational production environment through the use of a common software infrastructure.

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12.0 Table of Acronyms

Acronym	Description
4DDA	4-dimensional data assimilation
A8TM	AFWA Air & Space Models Integration Branch
AER	Atmospheric and Environmental Research, Inc.
AF	Air Force
AFGWC	Air Force Global Weather Central
AFW	Air Force Weather
AFWA	Air Force Weather Agency
AFWWS	Air Force Weather Weapon System
AGRMET	AFWA Agricultural Meteorology Model
AMSR-E	Advanced Microwave Scanning Radiometer for the Earth Observing System
CAWD-ORD	Centralized Aerospace Weather Capability Operational Requirements Document
CDFS II	Cloud Depiction and Forecast System Version II
CMORPH	Climate Prediction Center Morphing Technique
COLA	Center for Ocean-Land-Atmosphere Studies
COP	Cloud Optical Properties
CPC	Climate Prediction Center
CRTM	Community Radiative Transfer Model
DoD	Department of Defense
DTA	Dust Transport Algorithm
DTC	Development and Testbed Center
DMSP	Defense Meteorological Satellite Program
DTRA	Defense Threat Reduction Agency
EDR	Environmental Data Record
EnKF	Ensemble Kalman Filter
EOS	Earth Observing System
EPS	Ensemble Prediction System
ESMF	Earth System Modeling Framework
FAS	Foreign Agricultural Service
FASST	Fast All-season Soil Strength surface model
FNMOC	Fleet Numerical Meteorology and Oceanography Center
FY	Fiscal Year
GEOPRECIP	IR-based Geostationary Satellite-based Precipitation Analysis Model
GFS	Global Forecast System
GSFC	Goddard Space Flight Center
HPC	High Performance Computing
HPCMP	High Performance Computing Modernization Program
HSB	Hydrological Sciences Branch
IOC	Initial Operational Configuration
ISR	Intelligence, Surveillance, and Reconnaissance
IRTSS	Infra-Red Target Scene Simulator
IMETS	Integrated Meteorological System
JCSDA	Joint Centers for Satellite Data Assimilation
LDAS	Land Data Assimilation System
LIS	Land Information System
LSM	Land Surface Model
MCL	Master Capabilities List
METAR	Aviation Routine Weather Report (Meteorological Aviation Report)
MIS	Microwave Imager/Sounder
MM5	National Centers for Atmospheric Research & Penn State University Mesoscale Model

Acronym	Description
	Version 5
MOA	Memorandum of Agreement
MODIS	Moderate Resolution Imaging Spectroradiometer
MSRC	Major Shared Resource Center
MW	Microwave
NAM	North American Mesoscale Model
NASA	National Aeronautics and Space Administration
NAVO	Naval Oceanographic Office
NCAR	National Centers for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NOGAPS	U.S. Navy Operational Global Atmospheric Prediction System
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NWP	Numerical Weather Prediction
POM	Program Objectives Memorandum
PRISM	Parameter-elevation Regressions on Independent Slopes Model
QuikSCAT	NASA's Quick Scatterometer
R&D	Research and Development
RDT&E	Research, Development, Test, and Evaluation (RDT&E)
RTM	Radiative Transfer Model
SFCTMP	AFWA Surface Temperature Model
SNODEP	AFWA Snow Depth Analysis Model
SSM/I	Special Sensor Microwave/Imager
SSMI/S	Special Sensor Microwave Imager/Sounder
SWE	Snow Water Equivalent
SYNOP	Surface Synoptic Observations
TAWS	Target Acquisition Weapons Software
TDA	Tactical Decision Aid
TRMM	Tropical Rainfall Measuring Mission
USDA	United States Department of Agriculture
VIIRS	Visible/Infrared Imager/Radiometer Suite
WME	Weather Model Exploitation
WRF	Weather Research and Forecasting Model
WWMCA	World Wide Merged Cloud Analysis