Executive Summary

It is the purpose of this project to evaluate and improve the performance of the land surface models used in the Weather Research and Forecasting model (WRF) by the use of satellite skin temperatures to better specify physical parameters associated with land use classes. Skin temperature, T_S, is the radiating temperature of the surface and thus represents the temperature of an infinitely thin surface that is controlling the outgoing longwave radiation (σT_S^4). Improved temperature performance impacts biogenic emissions, thermal decomposition (chemical chain lengths and slopes of ozone/NOy curves) and thermally driven winds such as sea breezes. Also, land surface parameters control surface deposition which impacts the efficacy of long-range transport.

While considerable work has been done by the national community and especially in Texas to develop improved land use classifications, land use classes themselves are not directly used in models. Rather, physical parameters such as heat capacity, thermal resistance, roughness, surface moisture availability, albedo, etc. associated with a land use class are actually used in the land surface model. Many of the land use class associated parameters such as surface moisture availability are dynamic and ill-observed depending on antecedent precipitation and evaporation, soil moisture diffusion, the phenological state of the vegetation, irrigation applications, etc. Other parameters such as heat capacity, thermal resistance or deep soil temperature are not only difficult to observe they are often unknowable *a priori*. In some sense they are model heuristics with different land surface models having several orders of magnitude difference in parameters such as vegetative thermal resistance. The specification of these physical parameters across grids having mixed land use types is even more problematic. Despite the difficulty in specifying these parameters they are incredibly important to model predictions of turbulence, temperature, boundary layer heights and winds.

The evaluation and use of skin temperature as a model evaluation metric is provided for the period 1-30 September 2015 which was part of the Houston campaign of Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ) project. Aircraft measurements of skin temperature and air temperature are also used in this evaluation. The National Oceanic and Atmospheric Administration (NOAA) Comprehensive Large Array Data Stewardship System (CLASS, www.class.ncdc.noaa.gov) was the source of the first skin temperature data we tested. This data was derived from the Geostationary Operational Environmental Satellite (GOES) and is under the CLASS category of GOES Surface and Insolation Products (GSIP). The evaluation of NOAA-GSIP skin temperature product revealed unphysical air temperatures over the western U.S. including parts of Texas when compared to the Moderate Resolution Imaging Spectroradiometer (MODIS) observation. An alternative NOAA skin temperature product used by the Atmosphere-Land Exchange Inverse (ALEXI) group was acquired, evaluated and employed to compare against model skin temperatures. In addition to the cloud clearing used by the ALEXI group, we also carried out additional screening of skin temperatures, which are described in the quality assurance chapter.

Insolation is one of the largest components in the daytime surface energy budget. Insolation largely depends on average solar zenith angle. However, clouds can dramatically alter the solar

energy received at the surface. This produces a potential source of error in air quality simulations since model clouds may be in the wrong place at the wrong time. Thus, on certain days when clouds are present in the model but not in reality the energy difference at the surface can be large. The Weather Research Forecast (WRF) model is run using both the default model insolation and satellite insolation. There are large differences found between model and satellite insolation at the surface largely due the placement of clouds. This in turn leads to large grid point differences in temperatures during the simulations. Because air quality standards such as ozone are based on events rather than long term averages, these large variations on specific times and at specific places can be very important in developing realistic recreations of the physical atmosphere in State Implementation Plan (SIP) modeling. Initial WRF simulations using the GSIP insolation actually had increased bias relative to the WRF control simulation with the National Weather Service (NWS) 2-m temperature as the comparison metric. Because of this, the final set of simulations used the National Aeronautics and Space Administration (NASA) Short-term Prediction Research and Transition Center (SPoRT) Geostationary Operational Environmental Satellite (GOES)-derived insolation product. While the SPoRT satellite derived insolation had better performance statistics against pyranometer data, the model case with satellite insolation showed slightly poorer performance than the run with WRF modeled insolation. This is an area for further investigation. In initial examination it appears that differences between the satellite insolation and modeled insolation cases have a pattern that appears to be related to surface albedo. In past uses of satellite insolation (McNider et al. 1994) the satellite derived insolation cases also used a satellite derived albedo. In the present case the regular WRF landuse albedo was used. This may be the cause of the slightly degraded performance.

The Pleim-Xiu land use model in WRF has used a surface moisture and deep soil nudging technique based on differences between model 2-m air temperatures at NWS observational sites. However, land use, vegetation coverage and convective precipitation can all have variations on spatial scales much smaller than the spatial scale of NWS observations. The major activity under this project was to determine whether satellite observed skin temperature, which has much finer resolution (10 km) than NWS observations (~40 km), can be used to nudge soil moisture and thermal resistance and provide improved model performance.

Using skin temperatures as the performance metric, the results showed that over most of the domain that the bias was improved but there was a slight negative bias increase in the overall bias. This means that the few areas that had an increase in bias were larger causing a slight increase in absolute bias for the domain. An examination of time series from the nudging runs compared to the control showed that the adjustments in moisture appeared to be working as formulated. In some places part of the error may have been due to bad skin temperature data.

Again, using skin temperatures as the performance metric, the root mean square error (RMSE) was calculated for the control run and for the skin temperature moisture nudging case. Here the moisture nudging provided significant improvement over the entire domain. The RMSE was improved by about .7 degrees K over the domain or approximately 20%. For the Texas only domain the decrease in RMSE was even greater with RMSE improving by nearly a full degree.

Comparisons with NWS observations were more mixed in regards to bias for humidity and 2-m temperature. RMSE was unchanged for humidity and decreased slightly for 2-m temperature. For 10-m wind speed and wind direction there was a slight decrease in bias and RMSE for all regions.

The largest areas in RMSE and bias remain in the Western U.S. where even drying the soil using moisture nudging did not give the diurnal range found in skin temperature observations. Here adjustments in other parts of the surface energy budget may be needed. It is felt that implementation of the heat capacity adjustment which was an optional task under this project for which there was not enough time may provide further significant improvement.

In conclusion a comparison of model performance in the WRF model was carried out with and without satellite data. The moisture nudging using satellite skin temperatures within the Pleim-Xiu model was a positive step in improving the model performanceOur findings were that RMSE was reduced by about 20% when satellite observed temperatures were used as a metric. For a special Texas only domain the improvements in performance were even greater for the moisture nudging in that RMSE was decreased by nearly one degree K. In comparison to NWS observations of wind direction and wind speed there was a slight decrease in bias and RMSE across the domain. Similar results were found for the Texas domain in comparison with NWS sites. Thus, it is felt that this supports the overall hypothesis in this research activity that simple land surface models constrained by observations may be path for improved meteorology in air quality simulations.