Statement of Work

AQRP Project 14-022

Use of satellite data to improve specifications of land surface parameters

Prepared for:
Texas Air Quality Research Program (AQRP)

Prepared by:

Richard T. McNider
ESSC
University of Alabama – Huntsville
Pius Lee
NOAA Air Resources Laboratory

January 20, 2015

Listing of Key Personnel:

PI, Richard T. McNider , University of Alabama in Huntsville, mcnider@nsstc.uah.edu
Co-PI Pius Lee, NOAA Air Resources Laboratory, pius.lee@noaa.gov

Yuling Wu, Research Scientist, wuy@nsstc.uah.edu
Kevin Doty, Research Scientists, kevin.doty@nsstc.uah.edu

Vince Torres, AQRP Project Manager
Cyril Durrenberger, QAPP Officer

Bright Dornblaser, TCEQ Contact
Raj Nadkarni, TCEQ Contact

Abstract

It is the purpose of this proposal to evaluate and improve the performance of the land surface models used in the Weather Research and Forecast [model] WRF by the use of satellite skin temperatures to better specify physical parameters associated with land use classes. Improved temperature performance impacts biogenic emissions, thermal decomposition (chemical chain lengths and slopes of ozone/NOy curves) and thermally driven winds. 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 transport, 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 uses 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.

This proposal is directed toward the Biogenic Emissions Priority, Regional Transport Priority and Improving the Understanding of Ozone Priority. Biogenic emissions are highly sensitive to temperature. Improvement in temperature predictions in conjunction with improved radiation inputs into biogenic emission model (MEGAN [Model of Emissions of Gases and Aerosols from Nature] or BEIS [Biogenic Emissions Information System]) should increase the quality of biogenic emissions.

Boundary layer winds are intimately tied to the behavior of surface skin temperatures. Large variations in skin temperatures are related to mesoscale circulations such as sea breezes. Additionally, diurnal variations in skin temperatures are related to stabilization of the nighttime boundary which can lead to strong low level jets. The underestimation of low-level jets may under-predict the export and spread of urban emissions across the region. Additionally, dry deposition of ozone and nitrogen species is controlled by leaf stomatal uptake which is tied to land surface moisture. Thus, the long-range transport of ozone and precursors is dependent on these surface loss processes not being large.

The proposal will first develop skin temperature data sets from geostationary satellites and polar orbiting platforms and make direct comparisons to the skin temperatures from the WRF NOAH [N: NCEP; O: Oregon State University, Dept. of Atmospheric Sciences; A: Air Force (both AFWA and AFRL - formerly AFGL, PL); and H: Hydrologic Research Lab - NWS (now Office of Hydrologic Development - OHD)) land surface model. This will be done for past intensive field programs such TEXAQS 2000, TEXAQS 2006 and the more recent DISCOVER-AQ [Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality] and SEAC4RS [Studies of Emissions, Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys] campaigns. Second, techniques to use skin temperatures to adjust land surface parameters such as surface moisture and surface thermal resistance will tested to improve WRF skin temperature and air temperature.

Technical Work Plan
Background – Surface Land Use Parameters

The land surface is a critical component in local, regional and global modeling. Heat, momentum and scalar fluxes at the surface control temperature, turbulent mixing, winds and dry deposition of chemical species. Because of the importance of the characteristics of the land surface there has been tremendous investment by the climate, weather forecasting and air quality communities. Much of this investment has gone into developing complex land surface models which include many intricate parameterizations that attempt to capture processes such as plant transpiration rates, leaf water interception, soil moisture ,run-off and parameterizations which control thermal and water transfer through canopies and soils (Sellers 1997, Pitman 2003). Thus, these models require additional parameter specifications to close the model systems.

A second major area of investment has been the development of land-use classification data sets that attempt to define areas which are forested, croplands, urban areas etc. that can be used with the land surface models. The use of satellite data (with its observables such as greenness and albedo) have greatly improved the characterization of the surface into land use classes. However, land surface models such as WRF-NOAH don't use land use classifications directly, rather they use the physical parameters such as roughness, heat capacity, canopy thermal and water resistances, soil conductivity for water and heat etc. that are associated with the land use classes. Thus, in the models such as the WRF –NOAH land use schemes there are lookup tables that define these land-use associated parameters (Niu et al. 2011).

Difficulty in Specifying Land Use Parameters: Unfortunately, the specification of some of these physical parameters is difficult even in homogeneous land use classes (Rosero et al.2009). For example, the rate of temperature change in vegetation is controlled by plant transpiration and evaporation through water resistance parameters and by the canopy thermal resistance. Thermal resistance depends on the heat capacity of the canopy and the thermal conductivity through the canopy (Noilhan and Planton 1989). The water resistance depends on root zone moisture, the phenological state of the plant, leaf area, shaded leaf area etc. Field measurements using towers are usually conducted to try to establish these parameters. But, in effect, many of the parameters or processes have to be deduced as residuals in local canopy models which are tied to specific turbulence and radiative models (Yang and Friedl 2003, Pleim and Gilliam 2009). Thus, the parameters are often model heuristics as opposed to fundamental observables (Wegner and Gupta 2005) which is the reason a parameter such as canopy thermal resistance can vary by three orders of magnitude in different models (Pleim and Gilliam 2009). In inhomogeneous grid boxes which make up the real world the situation is even worse (McNider et al 2005). Here, dominant land-use classes are often used in models such as NOAH, but they may not represent well the actual mix of urban, crop and forest land uses.

To determine the heat capacity (or bulk thermal resistance) of a single entity such as a brick in a laboratory setting, one would measure the amount of energy added and measure the corresponding change in the brick's temperature. The ratio of temperature change to heat added defines the heat capacity and/or thermal resistance of the brick. Now, look out your window and try to think how you might define the heat capacity or thermal resistance of the landscape you see. It seems a difficult task, if not an impossible task, to imagine how you could *a priori* amalgamate all the different features – trees, buildings, roads to arrive at a grid scale heat capacity.

Satellite Skin Temperatures as a Model Performance Metric: While National Weather Service (NWS) and other observations of air temperature have been used to examine the performance of meteorological models in air quality settings, the spacing of these thermometers and their siting criteria means they cannot capture the variation in temperatures across all the different land uses. Almost all modern land surface models used in climate or weather forecast or air quality settings have a grid average radiating temperature or skin temperature. The NOAH land surface model (Niu et al. 2011) has a diagnosed skin temperature as one of its fundamental outputs. Satellites have long used atmospheric window thermal IR [Infrared Radiation]temperatures to provide estimates of surface radiating temperatures. Unlike standard thermometer based temperatures the skin temperatures observed by satellites (approximately 8-10 km in GOES [Geostationary Operational Environmental Satelite] and 1 km in MODIS [Moderate Resolution Imaging Spectroradiometer]) provide a rich base for model inter-comparison. Figure 1 shows a comparison between the (version # 3.5.1) WRF-NOAH model day time temperatures for a 12km domain over Texas for the period 20-27 August 2006 with the GOES satellite skin temperatures. There is a warm bias but also a large scatter in results and there are patterns which may relate to inaccurate specification of land surfaces. For example, the model appears too warm for this period especially over the pine forests in East Texas and along the southern Texas Gulf Coast . Such errors may impact biogenic emissions and boundary layer development. Figure 2 shows a similar plot for nighttime temperatures. The plots here for the night indicate less bias but very large scatter.

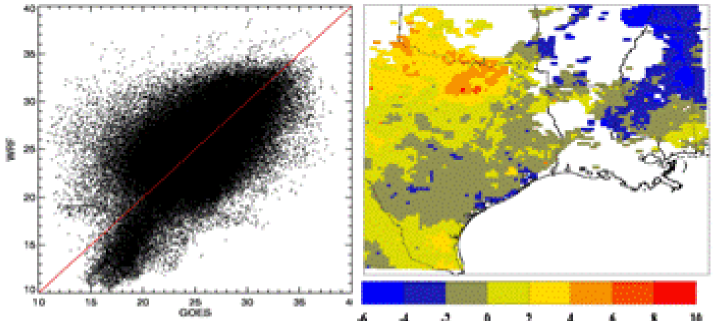

Figure1. Left scatter plot of afternoon WRF skin temperatures versus GOES satellite skin temperatures.Right difference map of average of WRF skin temperature compared to GOES skin temperatures .

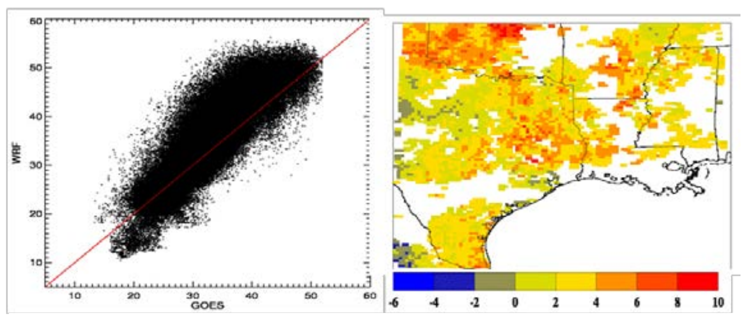

Figure2. Left scatter plot of nighttime WRF skin temperatures versus GOES satellite skin temperatures. Right difference map average of WRF-GOES skin temperatures. Note one purpose of this investigation to reduce the scatter.

Simple Land Use Models: The development of complex land surface models mentioned above was consistent with the need in the climate modeling community for surface models that could be run for years without being constrainedby data. Thus, they needed vegetative surface interaction, water balance models, etc. However, Diak 1990, McNider et al 1994 ,Anderson et al. 1997 and others argued that for short-term weather forecasting and for retrospective air quality simulations (McNider et al. 1998, Pleim and Xiu 2003) simpler models that could be constrained by observations might be preferred. The simple models avoid setting many uncertain parameters in the complex models. This is the path to be pursued here with observational constraints provided by satellite skin temperature data. We will employ two techniques – (1) the Pleim-Xiu assimilation scheme modified to use satellite skin temperature rather than NWS observed 2m temperatures and if time allows (2) an updated form of the combined McNider et al 1994 (here after McN94) and McNider et al 2005 (here after McN05) surface energy budget technique.

Pleim-Xiu technique: Pleim and Xiu 2003 noted that since surface moisture is not a direct observable that use of auxiliary information is needed. They have used observed NWS surface temperatures to nudge moisture. Here they adjust surface layer moisture w_G using the difference between model daytime temperatures (T^F) and analyses of observed temperatures (T^A) and model and observed relative humidity.

$$\Delta w_G = \alpha_1 \left(T^A - T^F \right) + \alpha_2 \left(RH^A - RH^F \right)_{\text{Daytime}} \qquad (1)$$

where α_1 and α_2 are nudging coeficients. The Pleim-Xiu approach has been widely used and in recent California inter-comparisons performed better than the NOAH complex land surface scheme (Fovell 2013). Because observed NWS observations are coarse we propose to replace the observed temperatures with satellite skin temperatures (T_S), i.e.

$$\Delta w_G = \beta_1 (T_s^{Sat} - T_s^{Mod})_{Morning} \qquad (2)$$

where Sat and Mod are satellite and modeled. We also plan to use the Pleim and Gilliam 2009 technique to nudge deep soil temperature using evening t satellite skin temperatures. Here we will test a technique to recover a true skin temperature which is consistent with the Pleim-Xiu scheme. The current Pleim-Xiu scheme has a prognostic equation for the ground temperature, T_g

$$\frac{1}{c_t}\frac{\partial T_g}{\partial t} = R_s + L_{dn} - \varepsilon\sigma T_g^4 - H - E - G \qquad (3)$$

where T_g is the ground temperature, c_t is a surface resistance, R_s is the net shortwave radiation at the surface, L_{dn} is the longwave down radiation, $\varepsilon\sigma T^4$ is the outgoing long wave radiation, H is the sensible heat flux, E is the evaporative heat flux and G is the ground heat flux. However, this ground temperature is associated with a finite heat capacity/resistance (the inverse of c_t in the prognostic equation) so that T_g does not have the dynamic range of a true skin temperature. Here we recover a true skin temperature by taking the limit when the heat capacity/resistance goes to zero (see Mackaro et al. 2011).

$$0 = R_s + L_{dn} - \varepsilon\sigma T_s^4 - H - E - S \qquad (4)$$

The skin temperature is found by rootfinding techniques in this algebraic equation.

Here S is the flux to the skin from both the canopy and bare soil

$$S = [(1 - V)C_s + VC_v](T_s - T_g)$$

With V being the vegetative fraction.

Although it may be difficult under the time constraints of the project we will also compare the performance of McNider et al: 1994 and McNider et al 1995 technique previously applied to Texas (see below), the McN94/McN05 retrieval of moisture and surface resistance carries out a laboratory type experiment in the real world. Carlson 1986 proposed that the two most uncertain parameters in the surface energy budget in terms of their impact and specification are the surface moisture and thermal resistance. We use two observational constraints to recover these two parameters – the morning rise in satellite skin temperature to recover moisture and the evening decline to recover the thermal resistance. Mathematically,

$$E_S = C_b \left[\left(\frac{dT_G}{dt} \right)_m - \left(\alpha \frac{dT_R}{dt} \right)_S \right]_{Morning} + E_m \quad \text{and} \quad C_{bs} = C_{bm} \left[\left(\frac{dT_G}{dt} \right)_m \Big/ \alpha \left(\frac{dT_R}{dt} \right)_s \right]_{Evening}$$

where E_s is the satellite derived evaporative flux as an adjustment to the original model evaporative flux, E_m , $\left(\frac{dT_G}{dt} \right)_m$ and $\left(\frac{dT_R}{dt} \right)_s$ are the ground temperature tendency in the model and satellite radiating skin temperature, respectively. Following Mackaro et al 2011 $\alpha = \frac{dT_G}{dt} / \frac{dT_R}{dt}$ is the internal fractional relationship in the model between the ground and skin temperature to avoid mixing the use of model ground temperatures and skin temperatures . The surface moisture is analytically recovered from the surface similarity relations. Here C_{bs} represents the satellite adjusted surface bulk heat capacity or thermal resistance to the model default C_{bm} . Note that the use of tendencies avoids issues with errors in absolute temperatures (see discussion below on potential errors in satellite derived temperatures).

In the original McN94/05 implementation and the Texas runs below a single stream (composite soil and vegetation surface) was used. Under this proposal we will adapt the form similar to the (Jones et al. 1998) modification made to McN94 and employ a three stream surface – ground, vegetation and water. Because of space we cannot provide the complete equations (see Jones et al. 1998)

Land Surface Model Performance in Texas: The McN94 technique for recovering moisture was applied to the TEXAQS2000 data period in the MM5[mesoscale modeling system version 5] model framework. TEXAQS2000 occurred during an extraordinary hot and dry period which was especially true during the last two weeks of August. Normal specification of moisture in the MM5 model produced maximum temperatures that were too cool and boundary layer heights that were low (see the red line in figure 3). Application of the McN94 to retrieve surface moisture (equation (1) in the MM5 model dried the surface and produced much warmer temperatures and deeper boundary layer heights (see the green line in figure 4). However, as can be seen the technique actually over corrected and produced daytime temperatures that were too hot and also humidity values that were too low.

After publication of McN05 we then revisited the TEXAQS2000 (McNider et al. 2011) where we now included retrieving the thermal resistance at the same time as retrieving surface moisture. The blue line in figure 3 shows the results of this experiment. The improvement is quite remarkable. At the start of the run not all the grid boxes have been touched by the retrieval due to cloud covered satellite pixels, however, by 28 Aug the blue line shows almost perfect agreement. Later there is degradation in the results but this is likely due to other model issues besides surface parameter specification. The retrieved surface moisture values and humidity comparison with NWS observations (not shown) were also much better. At approximately the same time that these results were produced, we found an inconsistency in our retrieval procedure as implemented in the MM5 in that ground temperature tendencies were being mixed with skin temperatures. This correction is described in Mackaro et al. 2011 and included above.

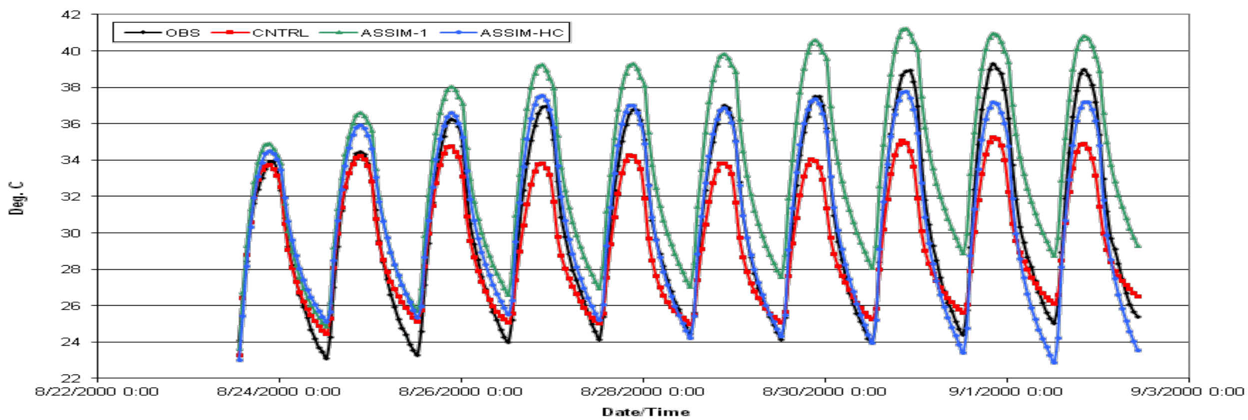

Figure 3. MM5 evaluation of surface air temperature against all observations NWS observations in the domain. Black are observations. Red is the control run. Green is the run with moisture assimilation alone. Blue includes both moisture and thermal resistance assimilation(from McNider et al. 2011)

Research Plan, Deliverables and Schedules

The final modeling period for this activity will be the Discovery AQ period September 2-September 29. However, some modeling early in the project where techniques are still being testing may include smaller time periods for efficiency. Figure 4 shows the 12 km modeling domain of the project.

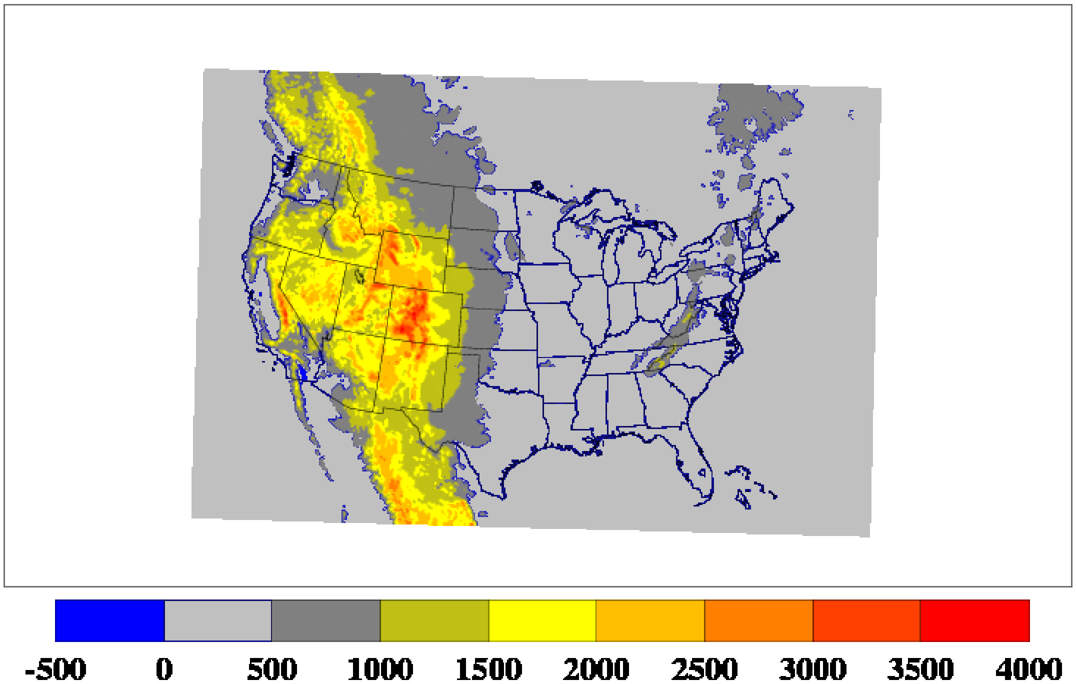

Figure 4 *Illustration of 12 km domain to be used in the project. As time permits a smaller 4 km grid will be used consistent with recomendations of TCEQ on the domain extent. The colored contours are terrain heights.*

The tasks and task deliverables under this proposal are:

Task -1 Satellite derived insolation: One of the key factors in land surface temperatures is the correct specification of incoming solar radiation into the land surface. Models often have clouds at the wrong place a wrong time. Under this task we will use satellite derived insolation in the WRF model in place of the modeled insolation.

Deliverable – A report on the impact of specifying insolation on surface air temperatures and ground temperatures in the WRF model for a 12 km domain (see figure 4) for at least one week in September 2013 aspart of the Discovery AQ Period**. Delivery Date- March 1, 2015**

Task 2- Diagnosed Skin temperature in Pleim-Xiu Scheme: Under this task we will diagnose a true skin temperature from the Pleim-Xiu scheme using the approach in equation (4) above within the WRF framework.

Deliverable – Report describing the recovery of the skin temperature and tests of the recovery against FIFE data. The report will also include images of the recovered skin temperature in WRF for the Discovery AQ Period for the 12 km domain. **Delivery Date – April 1, 2015**

Task 3 – Satellite Skin Temperature: Under this task we will provide GOES and MODIS skin temperature data sets to evaluate the spatial and temporal performance of the WRF model (and other models) in Texas. These data will be provided for the DISCOVER-AQ and SEAC4RS 2013 intensive data collection periods. While satellite data can infer a land surface temperature (LST) it is not always a direct clean observable in that cloud contamination and atmospheric intereference may alter the direct radiometric. Adjustments to remove contamination in the surface radiation from the intervening atmosphere and also emissivity assumptions have to be made. To examine the observed error in skin temperatures we will compare three skin temperature products for the 12 km WRF domain. These will be the GOES standard LST product, a physical split window technique (Jedlovec 1987, Guillory et al. 1993) and the MODIS operational LST product (see Wan and Dozier 1996 and updates). While we expect some differences in the actual values of the different satellite LST we expect anomalies across land uses to be more invariant. Thus, we will compute anomalies and base the anomalies on the domain average LST for each satellite product. In the same way we can also compute anomalies in the WRF model so that the scatter plots and other spatial comparisons will be plotted versus the anomalies. Thus, any errors in satellite absolute values will be minimized. Also, for consistency we will use the same emissivity (correct for) in the model as used in the satellite skin temperature retrieval. One caveat which may cause a delay in providing the quality of data needed for model verification in task 4 and task 5 are cloud contamination in the skin temperatures. If so we may have to create our own cloud mask based on temporal changes in surface reflectance. This may impact being able to complete task 5 (see below). We don't expect a significant problem but we will be using a new skin temperature product from NOAA and this needs verification.

Deliverable – A report that includes images of the anomalies of satellite skin temperature products for the 12 km domain with parallel images of the land surface category. Similar images will be provided of the skin temperature from the WRF 12 km domain. It will also include differences between the satellite and WRF anomalies. Scatter plots of model versus satellite skin temperatures for the 12 km domain will be provided. **Delivery Date May 15, 2015**

Task 4 – Implement Pleim-Xiu assimilation technique using satellite skin temperature in WRF: The current Pleim-Xiu scheme uses NWS observations to adjust soil moisture. Under this task we will use the difference in skin temperatures in the model to adjust surface moisture as described in equation (2) above for the 12km domain in WRF for the Discovery

AQ period. Comparison of model performance with and without the satellite assimilation will be provided both in terms of satellite skin temperatures and standard NWS observations.

Deliverable – A report describing the technique and implementation of Pleim-Xiu satellite assimilation in WRF. The report will include images of skin temperature for the control and assimilation case and difference images. Also, bias and standard error statistics for the runs will be provided. That is the bias is defined as difference of the means

$$Bias = 1/N \sum (T1\ (i,j) - T2(i,j))$$

and mean standard error is

$$MSE = sqrt\ \left(\frac{1}{n}\right) sqrt\ ((\sum \left(\left(T1\ (i,j) - T2(i,j)\right) ** 2 \right))$$

where T1 and T2 are two skin temperature variables to be compared and the sums are over all i,j grids.

Similar statistics will be provided for standard NWS observations. **Delivery Date – July 15, 2015**

Task 5 – Implement Three Stream MCN94/MCN05 Technique: Because of the short-time table on this project this is a tentative task and depends somewhat on the pace of progress on task 3 concerning cloud contamination. Under this task we will implement the three stream MCN94/MCN05 technique within the Pleim-Xiu scheme. We will determinedsurface moisture and surface thermal resistance. The results of this model experiment will be compared to the WRF Pleim-Xiu model and possibly a WRF NOAH control run for the Discovery AQ period if time is available for this task.

Deliverable – A report describing the implementation of the three Stream MCN94/MCN05 technique. The report will also include images of skin temperature with and without the technique. Scatter plots of (see examples figure 1 and 2) for theDiscovery AQ period against the satellite LST will be provided as well as bias and standard error statistics (see above). . We will also compare to standard NWS observations (see figure 3). The expectation is that scatter and bias will be reduced when compared to the satellite and NWS observations. Maps of surface moisture and surface thermal resistance will be provided. **Delivery Date August 15 , 2015**

Task 6 - Deliver temperatures/WRF model set up for use in biogenic models. We will provide WRF runs to other AQRP investigations and TCEQ to examine the impact on biogenic emissions from the above Discovery AQ period. **Delivery date September 15, 2015.**

Deliverables

In addition to the task based reports described above the project will provide AQRP required reports as enumerated below.

The lead PI will submit the reports, unless that responsibility is otherwise delegated with the approval of the Project Manager. All reports will be written in third person and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources. Report templates and accessibility guidelines found on the AQRP website at http://aqrp.ceer.utexas.edu/ will be followed.

Executive Summary

At the beginning of the project, an Executive Summary will be submitted to the Project Manager for use on the AQRP website. The Executive Summary will provide a brief description of the planned project activities, and will be written for a non-technical audience.

Due Date: Friday, January 9, 2015

Quarterly Reports

The Quarterly Report will provide a summary of the project status for each reporting period. It will be submitted to the Project Manager as a Word doc file. It will not exceed 2 pages and will be text only. No cover page is required. This document will be inserted into an AQRP compiled report to the TCEQ.

Due Dates:

Report	Period Covered	Due Date
Quarterly Report #1	February 2015	Friday, February 27, 2015
Quarterly Report #2	March, April, May 2015	Friday, May 29, 2015
Quarterly Report #3	June, July, August 2015	Monday, August 31, 2015
Quarterly Report #4	September, October, November 2015	Monday, November 30, 2015

Technical Reports

Technical Reports will be submitted monthly to the Project Manager and TCEQ Liaison as a Word doc using the AQRP FY14-15 MTR Template found on the AQRP website.

Due Dates:

Report	Period Covered	Due Date
Technical Report #1	Project Start – February 28, 2015	Monday, March 9, 2015
Technical Report #2	March 1 - 31, 2015	Wednesday, April 8, 2015
Technical Report #3	April 1 - 28, 2015	Friday, May 8, 2015
Technical Report #4	May 1 - 31, 2015	Monday, June 8, 2015
Technical Report #5	June 1 - 30, 2015	Wednesday, July 8, 2015
Technical Report #6	July 1 - 31, 2015	Monday, August 10, 2015
Technical Report #7	August 1 - 31, 2015	Tuesday, September 8, 2015

Financial Status Reports

Financial Status Reports will be submitted monthly to the AQRP Grant Manager (Maria Stanzione) by each institution on the project using the AQRP FY14-15 FSR Template found on the AQRP website.

Due Dates:

Report	Period Covered	Due Date
FSR #1	Project Start – February 28, 2015	Monday, March 16, 2015
FSR #2	March 1 - 31, 2015	Wednesday, April 15, 2015
FSR #3	April 1 - 28, 2015	Friday, May 15, 2015
FSR #4	May 1 - 31, 2015	Monday, June 15, 2015
FSR #5	June 1 - 30, 2015	Wednesday, July 15, 2015
FSR #6	July 1 - 31, 2015	Monday, August 17, 2015
FSR #7	August 1 - 31, 2015	Tuesday, September 15, 2015
FSR #8	September 1 - 30, 2015	Thursday, October 15, 2015
FSR #9	Final FSR	Monday, November 16, 2015

Project Data

All project data including but not limited to QA/QC measurement data, databases, modeling inputs and outputs, etc., will be submitted to the AQRP Project Manager within 30 days of project completion. The data will be submitted in a format that will allow AQRP or TCEQ or other outside parties to utilize the information.

AQRP Workshop

A representative from the project will present at the AQRP Workshop in June 2015.

Reports

1. **Monthly tech reports and quarterly reports will be provided per the AQRP web site.** These reports will document components of the deliverables above.

2. **Draft Final Report** A Draft Final Report will be submitted to the Project Manager and the TCEQ Liaison. It will include an Executive Summary. It will be written in third person and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources. **Due Date: Tuesday, August 18, 2015**

3. **Final Report** A Final Report incorporating comments from the AQRP and TCEQ review of the Draft Final Report will be submitted to the Project Manager and the TCEQ Liaison. It will be written in third person and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources. **Due Date: Wednesday, September 30, 2015**

Implications and Importance to TEXAS AQRP 2013 Priority Areas

Biogenic Emissions Priority: Biogenic emissions of hydrocarbon species are highly dependent on the physical atmosphere (Sharkey et al. 1999) through insolation (related to photosynthetic active radiation PAR), leaf temperature and humidity, yet models often do not capture the timing and location of these variables. Another AQRP proposal by Pour Biazar and Cohan are examining the impact of insolation and PAR on biogenic emissions. In this activity we are concentrating on the role of temperature driven by land surface variations. Emissions of isoprene and monoterpenes are strongly related to leaf/air temperature (Guenther et al. 1993, Monson et al. 1994). There is also dependence of emissions on relative humidity but these are complex since water availability also controls transpiration and hence leaf temperature (Fuentes 2000). Models such as BEIS and MEGAN use air temperature in their emission parameterizations. Byun et al., 2003 found that that meteorological simulation results for the Houston Galveston Area were very sensitive to the land surface characterization (e.g., land use and soil moisture) data . These variations in temperature due to land surface variations can then greatly impact the isoprene and monoterpene emissions. Soil NOx is also highly related to soil temperature and soil moisture. Thus, it is critical that temperatures associated with vegetation and crop areas be correctly specified so that isoprene and NOx emissions can be correctly computed in models such as BEIS or MEGAN. As discussed above, the correct prediction of temperature is difficult due to uncertainty in the o specification of land parameters. Improved specification of land parameters through the use of satellite observational constraints has promise to improve temperature predictions and biogenic emissions.

Global and Regional Transport Priority*:* Mesoscale circulations such as sea and land breezes are dependent on surface energetics. Surface dry deposition of ozone and some nitrogen species is strongly related to stomatal uptake (Pleim et al. 2001) which in turn is a function of root-zone moisture. In times of drought reduced dry deposition can increase the efficacy of long-range transport, thus accurate land surface estimates of plant transpiration is important. This may be especially important for Discovery AQ /SEACRS4 since many parts of the south were anomalously wet.

Improving the Understanding of Ozone Priority: In addition to the direct transport and surface losses related to land surface, temperature impacts chemical chain links through thermal decomposition of nitrogen species (e.g . Sillman and Samsom 1995) thus, impacting slopes of ozone NOy curves which is directly applicable to the efficacy of NO versus hydrocarbon control strategies.

Role of Principals in the Proposal

Richard McNider, PI, has a long history in mesoscale modeling and air quality. He served as an air pollution meteorologist with the State of Alabama. He was one of the five principals in the Southern Oxidant Study (SOS) and continued work in TEXAQS2000, TEXAQS2006 (nighttime transport and stationary fronts). He has also been a leader in the use of satellite data in mesoscale models and air quality models including developing techniques for using satellites to provide photolysis and surface energy budgets. He is currently a member of NASA's Applied Science Air Quality Team. Under the present proposal he will lead the implementation of the Pleim-Xiu and McN94/McN05 satellite retrievals of moisture and thermal resistance.

Pius Lee, Co-PI, has worked on both air quality models and weather forecasting models and currently leads NOAA's air quality forecasting system. He has recently been involved in the evaluation of model wind performance and his team was supported by the Texas AQRP. The paper by Ngan et al. 2013 was supported by this activity. He will take the lead on model wind evaluation.

References:

Anderson, M.C., Norman, J.M., Diak, G.R., Kustas, W.P., and Mecikalski, J.R., 1997. "A two-source time-integrated model for estimating surface fluxes using thermal infrared remote sensing", Remote Sensing Environ., 60, 195-216.

Angevine et al: 2012: Meteorological Model Evaluation for CalNex 2010. *MWR*, 140,3885-3906 DOI: 10.1175/MWR-D-12-00042.1

Bao, J-W., S. A. Michelson, P. O. G. Persson, I. V. Djalalova, J. M. Wilczak, 2008: Observed and wrf-simulated low-level winds in a high-ozone episode during the central california ozone study. *J. Appl. Meteor. Climatol.*, **47**, 2372–2394.

Beljaars, A.:The stable boundary l;ayer in the ECMWF model. Workshop on Diurnal cycles and the stable boundary layer, 7-10 November 2011

Byun, D.W., Kim, S.-T., Cheng, F.-Y., Kim, S.-B., Cuclis, A. and Moon, N.-K., 2003: Information infrastructure for air quality modeling and analysis: Application to the Houston-Galveston ozone nonattainment area., *J. of Env. Informatics 2 (2)*, 38-57.

Canty et al. 2013: Improving Air Quality Models through the Useof Satellite Retrievals and Aircraft Observations. AQAST. Air Quality Applied Sciences Team Meeting 4–6 June 2013. http://acmg.seas.harvard.edu/presentations/aqast/jun2013/day2_pm/5_canty_aqast_5june_final.pdf

Carlson, T. N., 1986: Regional scale estimates of surface moisture availability and thermal inertia using remote thermal measurements. *Remote Sensing Rev*., **1,** 197-246

Diak, G. R. ,1990: Evaluation of heat flux, moisture flux and aerodynamic roughness at the land surface from knowledge of the PBL height and satellite-derived skin temperatures, J. Agric. For. Meteorol. 52:181-198.

Fovell, R. 2013: WRF Performance Issues in the San Joaquin Valley and Southern California. Traversing New Terrain in Meteorological Modeling for Air Quality and Dispersion. U.California Davis. Sept 9-11,2013

Fuentes, J. D., Lerdau, M., Atkinson, R., Baldocchi, D., Bottenheim, J. W., Ciccioli, P., Lamb, B., Geron, C., Gu, L., Guenther, A., Sharkey, T. D., and Stockwell, W.: (2000) Biogenic hydrocarbons in the atmospheric boundary layer: a review, *Bull. Am. Meteorol. Soc.,* 81, 7, 1537–1575, 2000.

Guillory, A. R., G. J. Jedlovec, and H. E. Fuelberg, 1993: A technique for deriving column-integrated water content using VAS split window data. J. Appl. Meteor.,32,1226–1241

Guenther, A., P. Zimmerman, P. Harley, R. Monson, and R. Fall, 1993: Isoprene and monoterpene emission rate variability: Model evaluation and sensitivity analysis. *J. Geophys. Res.*, 98, 12 609–12 617.

Holtslag et al. 2013: Stable Atmospheric Boundary Layers and Diurnal Cycles Challenges for Weather and Climate Models. BAMS, March, DOI: 10.1175/BAMS-D-11-00187.

Holtslag, 2008a: Evaluation of limited area models for the representation of the diurnal cycle and

Jones, A. S., I. C. Guch, and T. H. Vonder Haar. 1998b. Data Assimilation of Satellite-Derived Heating Rates as Proxy Surface Wetness Data into a Regional Atmospheric Mesoscale Model. Part I: Methodology. Monthly Weather Review 126:634-645.

Mackaro, S., R.T. McNider and A. Pour-Biazar, 2011: Some physical and computational issues in land surface data assimilation of satellite skin temperatures. *Pure Appl. Geophys*. Springer Basel AG DOI 10.1007/s00024-011-0377-0

McNider, R. T., M. Moran and R. Pielke: Influence of Diurnal and Inertial Boundary Layer Oscillations on Long-Range Dispersion. Atmospheric Environment, Vol. 22, pp. 2445-2462, 1988.
McNider, R. T., W.M. Lapenta, A. Biazar, G. Jedlovec, R. Suggs, and J. Pleim, 2005: Retrieval of grid scale heat capacity using geostationary satellite products: Part I: Case-study application, *J. Appl. Meteor., 88*, 1346-1360
McNider, R., A. Pour-Biazar, W.Crosson, J. Pleim, A. Xiu, G. Jedlovec, 2011: Use of Satellite Data to Improve the Physical Atmosphere in SIP Decision Making Models http://appliedsciences.nasa.gov/pdf/AQ-SIPDecision_MakingModels.pdf
McNider, R.T., A.J. Song, D.M. Casey, P.J. Wetzel, W.L. Crosson, and R.M. Rabin, 1994: Toward a dynamic-thermodynamic assimilation of satellite surface temperature in numerical atmospheric models. *Mon. Wea. Rev.*, **122,** 2784-2803.
McNider, R. T., M.P. Singh and J. T.Lin: Diurnal Wind-Structure Variations and Dispersion of Pollutants in the Boundary Layer. *Atmos. Environ., Vol***. 27A**, pp. 2199-2214, 1993.
McNider, R. T., W. B. Norris, D. M. Casey, J. E. Pleim, S. J. Roselle, and W. M. Lapenta: Assimilation of satellite data in regional air quality models XII. Edited by Gryning, Chaumerliac, and Plenum Press, pp. 25-35. 1998.
McNider, R. T., G. J. Steeneveld, A. A. M. Holtslag, R. A. Pielke Sr., S. Mackaro, A. Pour-Biazar, J. Walters, U. Nair, and J. Christy (2012), Response and sensitivity of the nocturnal boundary layer over land to added longwave radiative forcing, J. Geophys. Res., 117, D14106
Ngan Fong, Hyuncheol Kim, Pius Lee, Khalid Al-Wali, Bright Dornblaser, 2013: A study on nocturnal surface wind speed over-prediction by the WRF-ARW model in Southeastern Texas Journal of Applied Meteorology and Climatology (in press) doi : "10.1175/JAMC-D-13-060.
Niu, G.-Y., et al. (2011), The community Noah land surface model with multiparameterization options (Noah-MP): 1. Model description and evaluation with local-scale measurements, J. Geophys. Res., 116, D12109
Noilhan, J., S. Planton, 1989: A Simple Parameterization of Land Surface Processes for Meteorological Models. Mon. Wea. Rev., 117, 536–549
Peters-Lidard, C. D., E. Blackburn, X. Liang, and E. F. Wood (1998), The effect of soil thermal conductivity parameterization on surface energy fluxes and temperatures, J. Atmos. Sci., 55(7), 1209–1224
Pitman, A. J. (2003), The evolution of, and revolution in, land surface schemes designed for climate models, Int. J. Climatol., 23, 479–510
Pleim, J., and A.Xiu, 2003: Development of a land surface model. Part II: Data assimilation. J. Appl. Meteor., 42, 1811–1822.
Pleim, J. A. Xiu, P. Finklestein and T Otte, 2001: A coupled land-surface and dry deposition model and comparison to field measurements of surface heat, moisture, and ozone fluxes *Water, Air and Soil Pollution: Focus,* Volume 1, Issue 5-6, pp 243-252
Pleim, Jonathan E., Robert Gilliam, 2009: An Indirect Data Assimilation Scheme for Deep Soil Temperature in the Pleim–Xiu Land Surface Model. J. Appl. Meteor. Climatol., 48, 1362–1376
Rosero, E., Z.-L. Yang, L. E. Gulden, G.-Y. Niu, and D. J. Gochis (2009), Evaluating enhanced hydrological representations in Noah-LSM over transition zones: Implications for model development, J. Hydrometeorol., 10, 600–62

Sharkey, T. D., E. L. Singsaas, M. T. Lerdau, and C. Geron, 1999: Weather effects on isoprene emission capacity and applications in emissions algorithms. Ecol. Appl., 9, 1132–1137.

Sellers, P. J., et al. (1997), Modeling the exchanges of energy, water, and carbon between continents and the atmosphere, Science, 275(5299), 502–509

Shi, X., R. T. McNider, D. E. England, M. J. Friedman, W. Lapenta, and W. B. Norris (2005), On the behavior of the stable boundary layer and role of initial conditions, *Pure Appl. Geophys.*, ***162***, 1811-1829.

Sillman, S., and P. J. Samson (1995), Impact of temperature on oxidant photochemistry in urban, polluted rural and remote environments, J. Geophys. Res., 100(D6), 11497–11508, doi:10.1029/94JD02146

Steeneveld, G.J., A.A.M. Holtslag, C.J. Nappo and L. Mahrt, 2008a: Exploring the role of small -scale gravity wave drag on stable boundary layers over land, J. Appl. Meteor. Clim.,47, 2518–2530

Steeneveld, G.J., T. Mauritsen, E.I.F. de Bruijn, J. Vilà-Guerau de Arellano, G. Svensson and A.A.M. Holtslag, 2008b: Evaluation of limited area models for the representation of the diurnal cycle and contrasting nights in CASES99. *J. Appl. Meteor. Climatol.*, **47**, 869-887.

Storm, B., Dudhia, J., Basu, S., Swift, A. and Giammanco, I. (2009), Evaluation of the Weather Research and Forecasting model on forecasting low-level jets: implications for wind energy. Wind Energ., 12: 81–90. doi: 10.1002/we.288

Wagener, T., and H. V. Gupta (2005), Model identification for hydrological forecasting under uncertainty, Stochastic Environ. Res. Risk Assess., 19, 378–387.

Wan, Z., and J. Dozier, 1996: A generalized split-window algo-rithm for retrieving land-surface temperature from space.IEEE Trans. Geosci. Remote Sens.,34,892–905.

Yang, R., and M. A. Friedl (2003), Modeling the effects of three-dimensional vegetation structure on surface radiation and energy balance in boreal forests, J. Geophys. Res., 108, 8615