Scope of Work For

Project # 17-039
Use of satellite data to improve specifications of land surface parameters

Prepared for

Air Quality Research Program (AQRP)
The University of Texas at Austin

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Approvals

This Scope of Work was approved electronically on October 26, 2016 by Elena McDonald-Buller, The University of Texas at Austin

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1.0 Abstract

It is the purpose of this proposal to continue a process to evaluate and improve the performance of the land surface models used in 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. 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*. 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 Meteorology and Air Quality Modeling and Biogenic Emissions Priority. Biogenic emissions are highly sensitive to temperature. Improvement in temperature predictions in conjunction with improved radiation inputs into biogenic emission model (MEGAN or BEIS) should increase the quality of biogenic emissions. The proposal is responsive to three areas in the Meteorology and Air Quality Modeling Priority- (1) boundary layer performance can impact local circulations driven by thermal gradients and the strength of low level jets is controlled by nighttime surface cooling rates; (2) boundary layers can impact clouds both boundary layer topped cumulus and clouds in sea breeze convergence zones; (3) dry deposition of ozone and nitrogen species is often controlled by stomatal uptake which depends on soil moisture.

The proposal will continue and expand activities under a 2015 funded AQRP project using satellite observed skin temperatures. That project was a late selected reduced scope project. Despite some initial issues with a NOAA skin temperature data set, the project ended up showing improvement in model performance for skin temperatures and in wind performance. However, the improvements were not as large as in previous uses of skin temperature data. Part of this may be due to following the Pleim-Xiu air temperature approach in the project, in which absolute differences between model and observed skin temperatures were used rather than skin temperature tendencies. Differences between the model and satellite skin temperatures not related to the boundary layer parameters such as emissivity or atmospheric correction in the satellite product might be an issue. Under this proposed activity skin temperature tendencies will be tested instead which avoids such problems. The DISCOVER-AQ period of 2013 was an unusually cloudy and windy period over most of the Eastern U.S. and not characteristic of the conditions usually associated with ozone episodes in Texas. While significant effort went into QA for the skin temperature data set, cloud contamination in the skin temperatures may still be an issue. Also, in consultation with TCEQ additional periods such as TEXAQS 2006 or the 2012 SIP period will be examined. Finally, the work on the previous project included emphasis on the large 12-km domain. Under, this proposed activity a greater

emphasis will be given to fine scale model performance around Houston and Dallas. Particular attention will be given to wind changes due to changes in boundary layer parameters including changes in sea breezes and low level jets.

2.0 Background

This is a proposed continuation of AQRP 2014-022 using satellite data to improve land surface model in performance in the WRF meteorological model during the 2013 DISCOVER-AQ field campaign. The AQRP 2014 project was a late selected project only beginning in February 2015 and ending August 2015. While it succeeded in showing that the satellite data improved performance, there was little time during the six month project to refine the analyses or respond to new information found during the investigation. Thus, the following describes the work done on the previous project and plans for the 2016-2017 project.

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 process such as plant transpiration rates, leaf water interception, soil moisture and run-off and parameterizations which control thermal and water transfer through canopies and soils (Sellers et al. 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. 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). Figure 1 shows that indeed there are definite relations between land use classes and temperature. The key question is whether the physical parameters associated with land use classes can be specified well enough that the land surface model skin temperature can be made to agree with the satellite observed skin temperature.

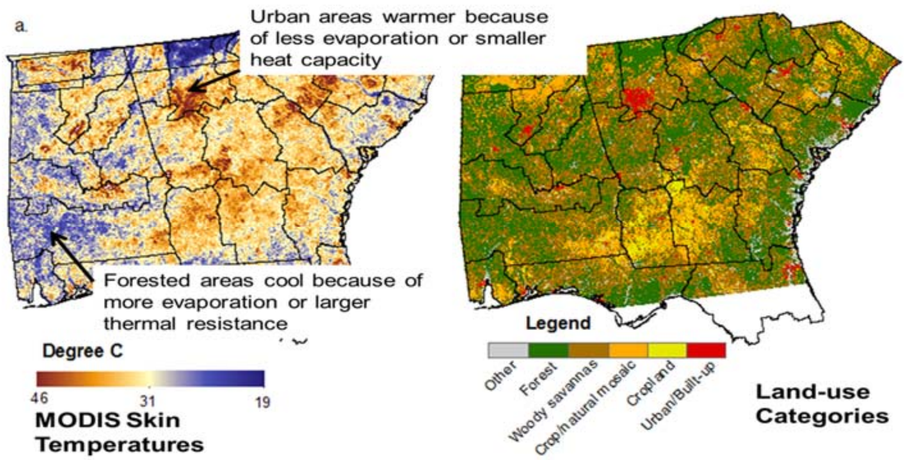


Figure 1 Illustration of relation of satellite skin temperature to land use. Left is the MODIS average afternoon temperature for July 2012. The question is can we ascribe the proper physical parameters in the land use classifications so that a model reproduces the observed skin temperature distribution. From Ellenburg et al. (2015).

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).

Satellite Skin Temperatures as a Model Performance Metric: While National Weather Service 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. Satellites have long used atmospheric window thermal IR temperatures to provide estimates of surface radiating temperatures. Unlike standard thermometer based temperatures the skin temperatures observed by satellites (approximately 4-10 km in GOES and 1 km in MODIS) provide a rich base for model inter-comparison (see figure 1 as an example of the resolution of the skin temperature).

Simple Land Use Models Constrained by Observations: 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 constrained by 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 was the path pursued in last year's project with observational constraints provided by satellite skin temperature data. The relatively simple land use model employed was the Pleim-Xiu 2003 land surface model which has been one of the preferred models in air quality studies especially by EPA. In last year's project the assimilation scheme to adjust soil moisture was modified to use satellite skin temperature rather than NWS observed 2-m temperatures

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.

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

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). In the past project because observed NWS observations are coarse the NWS observed temperatures were replaced with satellite skin temperatures, i.e.

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

The final project report (McNider et al. 2015) - http://aqrp.ceer.utexas.edu/projectinfoFY14_15%5C14-022%5C14-022%20Final%20Report.pdf) provides details of the implementation of the satellite skin temperature assimilation including the recovery of a radiating skin temperature in the Pleim-Xiu scheme.

Summary of Results 2015 Project: The following provides a summary of the results of the project. In the proposed work, it was intended to use the NOAA GOES GSIP operational skin temperature product (the GSIP product (Heidinger et al 2013), see also data links NOAA GSIP Data). However, as part of initial QA activities it was found that this product had temperatures that were too high in the Western U.S. compared to other skin temperature and air temperature observations. So, a second GOES skin temperature product used by the NOAA/USDA ALEXI group (Anderson et al. 2007a, Anderson et al. 2007b) was employed The satellite adjustment of moisture (2) was employed for the DISCOVER-AQ period – September 1-30, 2013. Figure 2 shows difference between the WRF diagnosed skin temperature before implementation of the moisture adjustment technique and the satellite observed skin temperature field. As can be seen there are differences (bias) between the model and observed fields. WRF was next run using the moisture adjustment technique. Figure 3 shows the change in bias of due to the implementation of the moisture adjustment technique. It shows that in most of the domain the bias is reduced especially in Texas. Similarly, figure 4 shows the change in Root-Mean Square Error (RMSE). It also shows that over most of the domain that RMSE is decreased especially in Texas. Table 1 gives the total statistics for the entire domain relative to skin temperatures for various WRF simulations. Table 2 provides the statistics for a Texas only domain. As can be seen with the satellite moisture adjustments (WRF-TS) the bias and RMSE were all improved for the period by about 25%. In addition, to the skin temperature evaluations, comparative statistics were also made with standard NWS surface 2m observations. Most notably wind speed and wind direction showed improvement.

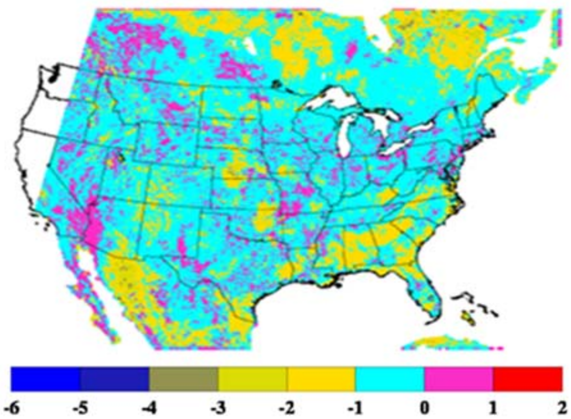


Figure 2 ***Average bias (units of degrees K) (soil moisture nudging (WRF-TS) run minus observed) of skin temperatures for the period 0000 UTC 1 September 2013 through 2300 UTC 30 September 2013 for daytime conditions.***

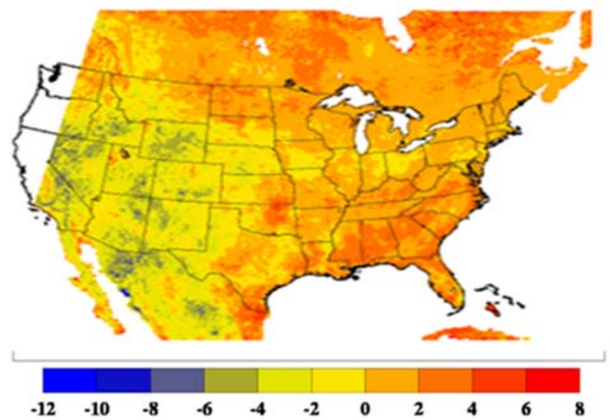


Figure 3 ***Difference in bias values (units of degrees K) soil moisture nudging run (WRF-TS with moisture adjustment) minus WRF-CONTR) of skin temperatures for the month of September for daytime conditions. Negative values indicate an improvement in model performance.***

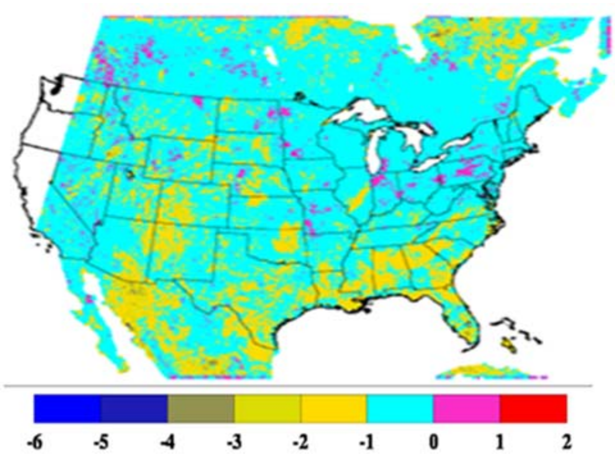


Figure 4 Difference in the respective RMSE values (units of degrees K) (WRF-TS with skin temperature adjustment) minus (WRF-CONTR) of skin temperatures for the month of September 2013 for daytime conditions. Negative values indicate a decrease in the RMSE or improvement in model performance.

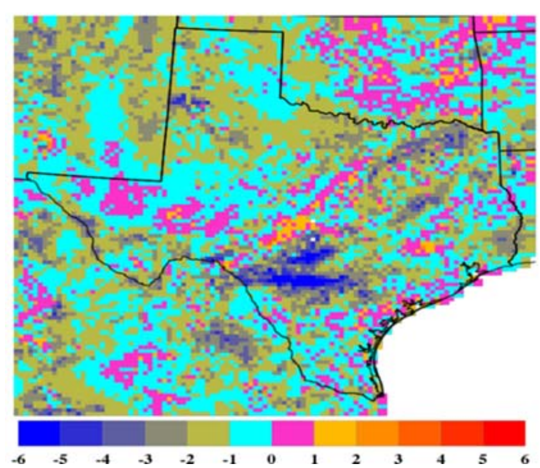


Figure 5 Difference in the magnitudes of the daytime average bias between WRF with satellite assimilation (moisture adjustment, heat capacity adjustment, cloud albedo) minus WRF with no satellite products for the first 5.5 days of September 2013. Units are in K. Negative values indicate a decrease in bias (improvement in model performance)

Table 1 Total Domain Statistics

SIMULATION	BIAS ALL	BIAS WEST	BIAS EAST	RMSE ALL	RMSE WEST	RMSE EAST
WRF-BASE	0.06	-1.08	1.31	3.68	4.11	3.21
WRF-PLEIM	0.08	-1.08	1.35	3.64	4.05	3.18
WRF-CONTR	0.09	-1.13	1.42	3.70	4.17	3.18
WRF-TS	-0.13	-0.95	0.78	3.00	3.43	2.53

With satellite adjustment → WRF-TS

Table 2 Texas Domain

SIMULATION	BIAS	RMSE
WRF-BASE	-0.34	4.10
WRF-PLEIM	-0.50	3.98
WRF-CONTR	-0.13	4.02
WRF-TS	-0.26	3.13

Table 1. (left) Overall bias and RMSE statistics for the 1-30 September, 2013 for total domain. Table 2 (right) for Texas only. WRF-BASE is the simulation with no Pleim NWS nudging, no satellite insolation, and no skin temperature moisture nudging. WRF-PLEIM is the same as WRF-BASE except the Pleim NWS temperature nudging is activated. WRF-CONTR is the simulation with no Pleim nudging, with satellite insolation, and no skin temperature moisture nudging. WRF-TS is the simulation with no Pleim NWS nudging, with satellite insolation, and with skin temperature moisture nudging. East West domains are determined by the 105^0 longitude line.

3.0 Objectives

Under this proposed project we intend to build on the results of last year's investigation and carry out additional analyses on the impact of the improved land surface model on other model attributes such as wind performance and boundary layer heights. We will carry out additional comparisons with special aircraft observations under the DISCOVER-AQ Period. Also, we will continue to refine the techniques for assimilating the satellite data including testing the use of skin temperature tendencies and by adjusting the surface heat capacity. An additional satellite product MODIS Greenness (Case et al. 2014) will be employed. A new calibrated satellite insolation and satellite albedo product will be tested.

The following are listings of sub-objectives for the project. Task descriptions associated with these objectives are given in section 4.0 below.

1. In the present project there will be a focus on small scale performance around Houston and Dallas and other metrics besides temperature such as wind performance.
2. Explore the use of skin temperature tendencies rather than absolute value of skin temperature to improve model performance.
3. Adjustments in heat capacity will also be tested for improving model performance
4. Impact of new satellite derived vegetative fraction to replace the USGS values in WRF will be tested.
5. A new tool for investigating sensitivity of land surface model components will be employed
6. Impact of new satellite derived insolation and albedo will be tested
7. An additional model evaluation period will be selected and satellite techniques will be tested.

4.0 Task Descriptions

The following list describes the tasks to be carried out under this proposal. Section 4.8 provides an overview of model evaluation performance statistics. The basic model set up is provided in table 3 below. As explained in the QAPP there are two types of model runs. The first are parameter selection runs where many different runs are made (usually using a short test period) to best determine parameters such as assimilation time scale or methods for using data. The second is where these are applied to assess model performance in a longer or independent test period. This procedure will be followed for Tasks 2-6 below. That is for each new product or procedure the test statistics bias and RMSE (see below) will be evaluated in terms of improvement. In the end we will examine the significance of the improvements in terms of whether the bias or RSME is changed significantly both separately for each task variable and for all variables. The significant tests will follow standard protocols (Mann and Whitney 1947).

Table 3 Summary of Principal WRF Model Namelist Parameters

Category	Namelist Variable	Namelist Value	Description
Microphysics	MP_PHYSICS	8	New Thompson scheme
Longwave Radiation	RA_LW_PHYSICS	4	RRTMG scheme
Shortwave Radiation	RA_SW_PHYSICS	4	RRTMG scheme
Surface Layer	SF_SFCLAY_PHYSICS	7	Pleim-Xiu surface layer
Land Surface	SF_SURFACE_PHYSICS	7	Pleim-Xiu Land Surface Model
Planetary Boundary Layer	BL_PBL_PHYSICS	7	ACM2 PBL:
Cumulus Parameterization	CU_PHYSICS	1	Kain-Fritsch scheme
3D Analysis Nudging	GRID_FDDA	1	turned “on”
Wind Nudging	GUV	3.0×10^{-4} s^{-1}	time scale of about 55 min
Temperature Nudging	GT	3.0×10^{-4} s^{-1}	time scale of about 55 min
Water Vapor Nudging	GQ	1.0×10^{-5} s^{-1}	time scale of about 28 h
Pleim-Xiu Soil Nudging	PXLSM_SOIL_NUDGE	1	

4.1 Task 1 - Focus on Small Scale Performance Around Houston and Dallas and Other Metrics Such as Wind Performance

Under the prior project, in concentrating on implementing the skin temperature assimilation, attention was given to performance statistics over the entire domain. Because of limited time only cursory examination was given to fine scale performance, although the work did show that statistical improvements were even greater in the Texas domain than in the national domain (see table 1 and 2 in Prior AQRP Results Section). Under the 2016-17 activities we will focus on wind performance and fine scale temperature performance in the Texas domain especially around Dallas and Houston where SIP development may be a priority. This will be done for the new evaluation period. Data sources for the 2013 case will include satellite skin temperature and standard NWS surface data as well as where appropriate special data such as aircraft skin temperature and PBL heights from the DISCOVER-AQ program. (See the DISCOVER-AQ web site for links to data http://www-air.larc.nasa.gov/missions/discover-aq/discover-aq.html. Also, there are some AQRP projects which have analysed special DISCOVER-AQ data http://aqrp.ceer.utexas.edu/aprojectsFY14-15.cfm?Category=Discover%20AQ, e.g. project 14-006 led by Sonoma Technology that analyzed boundary layer data.) Data sources for model evaluation for the new test period may not have the special aircraft observations such as were available during DISCOVER-AQ, but will include satellite skin temperatures and standard NWS observations. In conjunction with AQRP and TCEQ any relevant special observations will be obtained Figure 4 above provides a graphic of improved model performance for the Texas domain using the moisture adjustment, heat capacity adjustment and satellite albedo run. Note these were run after the formal end of the last AQRP project.

The focus on smaller areas such as the Texas domain in figure 5 for model evaluation may be separate from the model domain and grid. For example, the depiction in figure 5 shows the domain over which statistics were calculated in table 2 while figure 6 top panel shows the 12 km WRF domain modeling domain. Figure 6 bottom panel shows the proposed new 4-km domain. Even smaller sub-domains in the 4 km domain may be used for model evaluation – e.g example around Dallas or Houston.

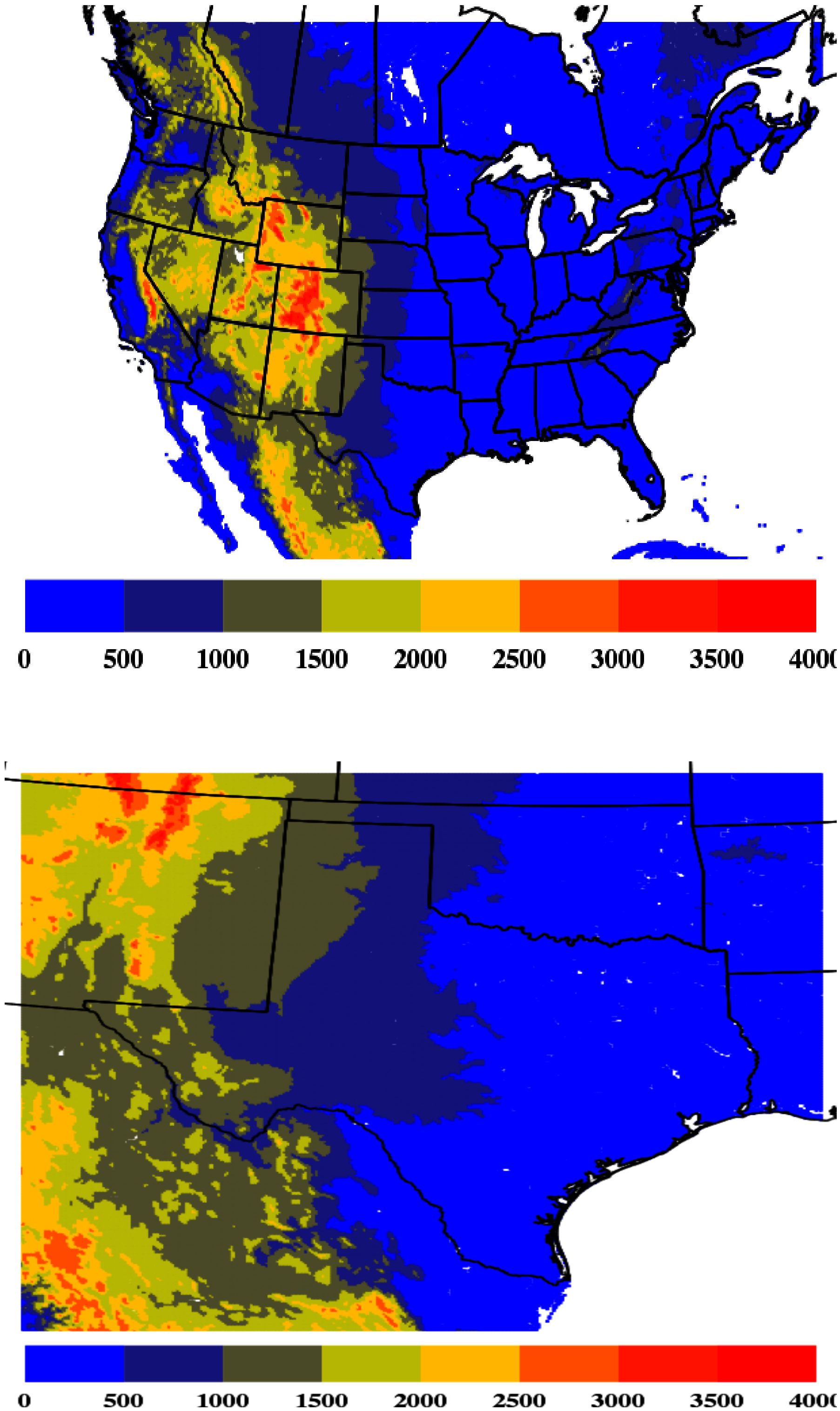


Figure 6 Top panel shows original 12 km domain and the bottom panel shows the proposed new 4 km domain. The underlying image is topography in meters.

Schedule: This task will encompass most all model runs for this project. Thus different runs will include a special Texas domain for graphics and statistics and where appropriate a domain for Houston/Dallas. There will also be a higher resolution 4-km domain for some of the final experiments (see figure 6).

Deliverables: Comprehensive descriptions of all model simulations and their results will be included in final report.

4.2 Task 2 - Use of Skin Temperature Tendencies

In previous applications of adjustments in surface parameters using satellite skin temperatures (McNider et a. 1994, McNider et al. 2011) greater improvement in model performance was found especially compared to NWS observations than in the previous AQRP project. Part of the differences in application was that in these earlier investigations differences in skin temperature tendencies were used to adjust surface moisture. As mentioned above in the Pleim-Xiu scheme absolute differences between skin temperatures are used. However, satellite skin temperatures can sometimes have absolute errors due to atmospheric corrections or emissivity assumptions. Use of skin temperature tendencies avoids issues with such absolute offsets. As an example in the prior AQRP moisture was adjusted based on the difference in model skin temperatures in the morning time frame. Here we will investigate whether differences in tendencies perform better. That is the difference in rate of change in the model over a three – five hour period (the temperature tendency) will be compared to the temperature change in the satellite data used to adjust moisture. Under this proposed project we will test using morning skin temperature tendency in (2) rather than absolute the values. We will use observed anomalies for evaluation rather than absolute values.

Schedule: Early in the project a test will be made for at least part of the DISCOVER-AQ period. If performance statistics are significantly improved than the tendency technique will be implemented for remaining model runs.

Deliverables: A technical report will be included as part of our monthly report for January, and results will also be included in the final project report.

4.3 Task 3 - Heat Capacity Assimilation

Under last year's project we proposed as an optional task (if there was time) to test whether skin temperature adjustments to surface bulk heat capacity using evening skin temperature might also improve model performance. Because of the initial unexpected issues with the NOAA Operational GSIP skin temperature product and the short six month time we did not complete this optional task. However, since the end of last year's project we continued to work on the Texas project and have implemented the heat capacity adjustment and have made initial tests for the September 1-6, 2013 period. As shown by Carlson (1986) the afternoon and evening drop in temperatures is most sensitive to thermal resistance/heat capacity. We use the technique proposed by McNider et al. (2005) within the Pleim-Xiu model to nudge thermal resistance, C_T, using afternoon/evening skin temperatures (as opposed to the Pleim and Gilliam 2009 of using afternoon/evening temperatures to nudge deep soil temperature) as illustrated by equation (3). Here T_S^{SAT} is the satellite observed skin temperature and T_S^{MOD} is the WRF modeled skin temperature.

$$C_T^{NEW} = C_T^{OLD} \frac{\frac{\partial T_S^{SAT}}{\partial t}}{\frac{\partial T_S^{MOD}}{\partial t}} \qquad (3)$$

See Mackaro et al. (2011) and McNider et al. (2005) for further details. Initial results show model improvement (figure 5). Under this project we will carry out a complete analysis of this parameter.

Schedule: An initial test for this task will be carried out by December 31, 2016 for the DISCOVER-AQ period. If successful it will be implemented for the new test period (see below).

Deliverable: A report on the impact of heat capacity adjustment will be provided for the DISCOVER-AQ period by February 28, 2017 and included in the February monthly report as well as in the final project report.

4.4 Task 4 - Vegetative Fraction

In last year's project we found that the seasonally adjusted USGS vegetation used in the Pleim-Xiu scheme was producing erroneous values especially in the Western U.S. We communicated directly with Jon Pleim and he agreed and said that a new paper by Ran et al. (2015) found similar results. Because of the importance of vegetative fraction and in view of Ran et al. (2015) we will employ a MODIS derived vegetative fraction in the land surface model. Case et al. (2014) has developed a MODIS-derived 1-km CONUS Green Vegetation Fraction (GVF) dataset which extends back to June 2011. We plan to use this dataset to replace the USGS values in the WRF model to assess its impact on the September 2013 simulation. As noted in the previous project we found considerable deficiencies in the seasonal adjustments to the USGS data employed by the Pleim-Xiu scheme. Since that time we have found (personal communication Jon Pleim) that EPA will likely drop this seasonal adjustment and go to a satellite derived greenness fraction. Thus, we believe that our approach is consistent and perhaps ahead of EPA. We inherently believe that not only are seasonal adjustments needed but that these can depend on specific years. For example the Texas greenness is likely much different for the drought years 2010 and 2011 from 2013. We will make a control case using USGS data and the satellite greenness values and use the standard performance statistics to assess the impact/validity of the new data set.

Schedule: Initial tests of a new vegetative product will be made by March 31, 2017

Deliverable Results will be included in the March monthly report as well as in the final project report

4.5 Task 5 - Tool for Investigating Sensitivity of Land Surface Model Components

The 2016-17 AQRP call suggested that model analysis tools be developed to help understand over or under-prediction of ozone. In the meteorological model we have the same need to understand why 2-m air temperatures (or skin temperatures) are over or under-predicted. We have developed a model analysis tool based on forward stepwise regression (Efroymson 1960) to develop a linear regression equation for a selected dependent variable. At each step the variable with the highest correlation with the dependent variable is the candidate for inclusion if certain statistical measures are met. We envision using this method as one tool to determine what variables may be correlated with various surface energy budget errors. Table 1 provides a preliminary example of the results for the warm bias for the WRF BASE simulation. It shows that the top two correlated variables were vegetation fraction and the observed GOES insolation.

Schedule: This will be implemented as part of our model evaluation protocols at the beginning of the project and applied to both DISCOVER-AQ and new evaluation period.

Deliverables: A short technical report on this tool will be provided by November 30, 2016 and included in the November monthly report as well as in the final project report.

Variable	**Coefficient**	**R-Squared**
Vegetation Frac	-0.75232E-02	4.173
GOES insolation	-0.29416E-02	8.384
Heat Flux	0.37096E-02	16.006
Humidity Bias	-0.92568E-01	17.884
Moisture Flux	0.13826E-02	19.210
Ground Flux	0.69043E-02	20.019

Table 1. Example of stepwise regression for the case where the dependent variable is the 2-m temperature bias (model minus observed) for the CNTRL simulation. This subset is for daytime warm bias values only and for locations east of -105^{o} W

4.6 Task 6 - Satellite Derived Insolation and Albedo

Net shortwave radiation is one of the largest terms in the daytime boundary layer and is dependent on insolation and surface albedo. Models can have clouds at the wrong place and wrong time. In figure 5 above the major improvement in model performance (areas in blue) are due to the improved net radiation. In the prior project we used GOES satellite derived insolation (McNider et al. 1995) but used the USGS land use albedo rather than a satellite derived insolation. We have made preliminary runs using a satellite derived albedo and will compare the results of these two different albedos on model performance. While the prior project showed GOES insolation to be much better than WRF insolation when compared to surface pyranometer observations, we did find some east-west bias issues. Based on the pyranometer comparisons we will develop a calibrated GOES insolation product and test it in model performance evaluations using the test statistics described below and in the QAPP.

Schedule: This will activity will begin immediately (October 1, 2016) and will continue through the project period as new data periods are considered in that satellite derived insolation will be used for all runs. Updates will be provided in each of the monthly and quarterly reports and throughout the project as appropriate.

Deliverables: A summary of results will be provided in the final technical report.

4.7 Task 7 - Additional Model Evaluation Period

Under last year's project, the model evaluation period was the DISCOVER-AQ Period flight period September 1-30, 2013. However, this period was selected in the AQRP RFP because of the aircraft data available - not because it was representative of extreme ozone events in the past. The synoptic situation for the month was especially active with multiple fronts producing excess cloudiness and higher winds in Texas and the Southeast (see Alrick et al. 2015). They showed that the DISCOVER-AQ Period was not as conducive to high levels of ozone as TEXAQS II. While last year's project showed that the satellite technique provided substantial improvement in land surface performance, the cloudiness reduced the number of times that the skin temperature data could be used. Examination of MODIS skin temperatures for the month of September 2013 shows virtually no thermal signal for Dallas (compared to Atlanta in figure 1) indicating high winds may be reducing thermal gradients.   Thus, the skin temperature technique may have even greater positive impact under other episodes where clear skies and light wind conditions most associated with high ozone events dominate. In consultation with TCEQ we will select another episode such as TEXAQS II 2006 or 2011.

Schedule: In conjunction with AQRP and TCEQ a test period will be selected. Both a short (1 week) test period and longer period (1 to 2 months) will be identified. The short-term period allows for testing of model assimilation strategies without having to wait inordinately for model wall clock times. These selected test periods will be used as tasks 2-6 are carried out.

Deliverable: A short technical report identifying the period and rationalization for selection will be provided by November 1, 2016:

4.8 Model Performance Statistics

The model performance will also be discussed in the QAPP document

The evaluations will be based on standard statistical metrics such as error statistics and regression analysis with a focus on east/southeast Texas. As an example, 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 variables to be compared and the sums are over all i,j grids.

The primary initial model comparisons will be made against satellite observed skin temperatures and NWS observed surface data.

In addition to the overall statistics, the spatial and temporal variability of error statistics will be examined using visual graphical imagery (and subsetting of statistics if visual inspection warrants) to determine geographical variations in performance.

Final parameter selection will be based on sensitivity studies that show the best model performance.

4.9 Task 8 - Project Reporting and Presentation

As specified in Section 7.0 “Deliverables” of this Scope of Work, AQRP requires the regular and timely submission of monthly technical, monthly financial status and quarterly reports as well as an abstract at project initiation and, near the end of the project, submission of the draft final and final reports. Additionally, at least one member of the project team will attend and present at the AQRP data workshop. For each reporting deliverable, one report per project will be submitted (collaborators will not submit separate reports), with the exception of the Financial Status Reports (FSRs). The lead PI (or their designee) will electronically submit each report to both the AQRP and TCEQ liaisons and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources. The report templates and accessibility guidelines found on the AQRP website at http://aqrp.ceer.utexas.edu/ will be followed. ****Draft copies of any planned presentations (such as at technical conferences) or manuscripts to be submitted for publication resulting from this project will be provided to both the AQRP and TCEQ liaisons per the Publication/Publicity Guidelines included in Attachment G of the subaward.**** Finally, our team will prepare and submit our final project data and associated metadata to the AQRP archive.

Deliverables: Abstract, monthly technical reports, monthly financial status reports, quarterly reports, draft final report, final report, attendance and presentation at AQRP data workshop, submissions of presentations and manuscripts, project data and associated metadata

Schedule: The schedule for Tasks and Deliverables is shown in Section 7.

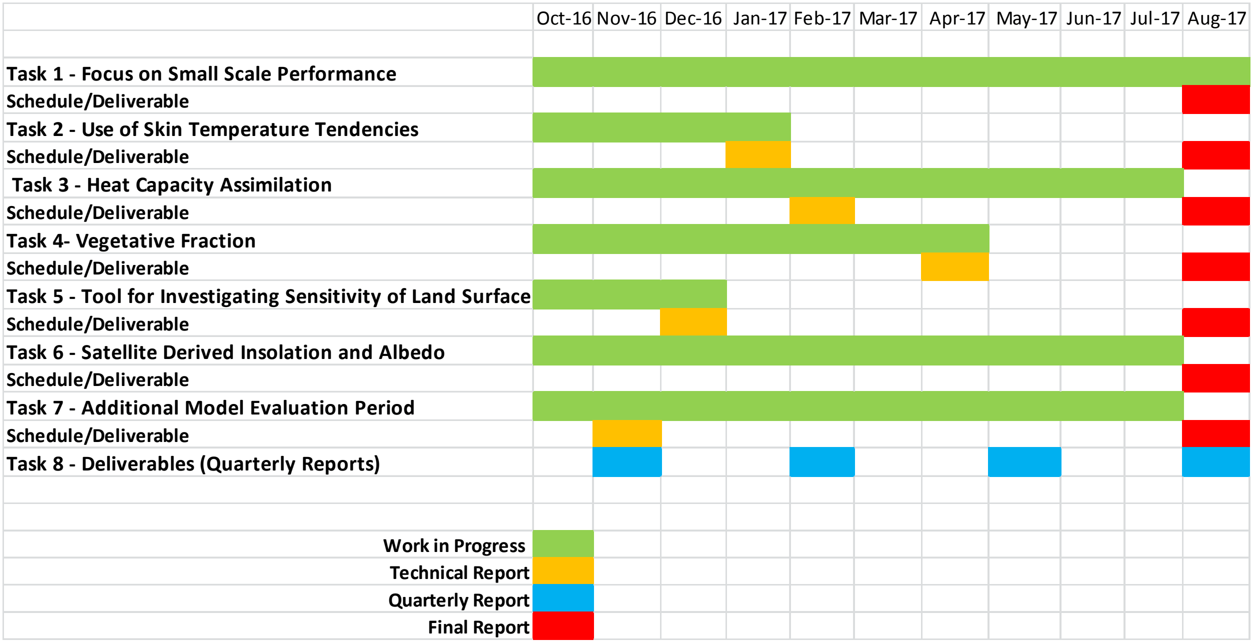
5.0 Project Participants and Responsibilities

The following are the key participants in the project and their major responsibilities.

Richard McNider: PI, responsible for overall project direction and reporting
Arastoo Pour-Biazar: Co-PI**,** responsible for project direction and schedule including selecting test periods and strategies for model testing and improvement.
Kevin Doty: Research Scientist, responsible for overall model development and testing activities. Including the code changes for the Pleim-Xiu scheme and for overall evaluation of the model against NWS data.
Yu Ling Wu: Research Scientist, responsible for satellite data evaluation and some modeling tasks such as calculating model performance statistics against satellite data.She will also be responsible for the skin temperature data sets and quality assurance.

6.0 Timeline

Below is a schematic time line of project activities and deliverables. Note in the time line the technical reports are summations of the topic and different from the Monthly Technical Report required under the contract.



7.0 Deliverables

AQRP requires certain reports to be submitted on a timely basis and at regular intervals. A description of the specific reports to be submitted and their due dates are outlined below. One report per project will be submitted (collaborators will not submit separate reports), with the exception of the Financial Status Reports (FSRs). 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.

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

Abstract Due Date: Wednesday, August 31, 2016

Quarterly Reports: Each Quarterly Report will provide a summary of the project status for each reporting period. It will be submitted to the Project Manager as a Microsoft Word 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.

Quarterly Report Due Dates:

Report	Period Covered	Due Date
Aug2016	June, July, August 2016	Wednesday, August 31, 2016

Quarterly Report		
Nov2016 Quarterly Report	September, October, November 2016	Wednesday, November 30, 2016
Feb2017 Quarterly Report	December 2016, January & February 2017	Tuesday, February 28, 2017
May2017 Quarterly Report	March, April, May 2017	Friday, May 31, 2017
Aug2017 Quarterly Report	June, July, August 2017	Thursday, August 31, 2017
Nov2017 Quarterly Report	September, October, November 2017	Thursday, November 30, 2017

Monthly Technical Reports (MTRs): Technical Reports will be submitted monthly to the Project Manager and TCEQ Liaison in Microsoft Word format using the AQRP FY16-17 MTR Template found on the AQRP website.

MTR Due Dates:

Report	Period Covered	Due Date
Aug2016 MTR	Project Start - August 31, 2016	Thursday, September 8, 2016
Sep2016 MTR	September 1 - 30, 2016	Monday, October 10, 2016
Oct2016 MTR	October 1 - 31, 2016	Tuesday, November 8, 2016
Nov2016 MTR	November 1 - 30 2016	Thursday, December 8, 2016
Dec2016 MTR	December 1 - 31, 2016	Monday, January 9, 2017
Jan2017 MTR	January 1 - 31, 2017	Wednesday, February 8, 2017
Feb2017 MTR	February 1 - 28, 2017	Wednesday, March 8, 2017
Mar2017 MTR	March 1 - 31, 2017	Monday, April 10, 2017
Apr2017 MTR	April 1 - 28, 2017	Monday, May 8, 2017
May2017 MTR	May 1 - 31, 2017	Thursday, June 8, 2017
Jun2017 MTR	June 1 - 30, 2017	Monday, July 10, 2017
Jul2017 MTR	July 1 - 31, 2017	Tuesday, August 8, 2017

Financial Status Reports (FSRs): Financial Status Reports will be submitted monthly to the AQRP Grant Manager (Maria Stanzione) by each institution on the project using the AQRP FY16-17 FSR Template found on the AQRP website.

FSR Due Dates:

Report	Period Covered	Due Date
Aug2016 FSR	Project Start - August 31	Thursday, September 15, 2016
Sep2016 FSR	September 1 - 30, 2016	Monday, October 17, 2016
Oct2016 FSR	October 1 - 31, 2016	Tuesday, November 15, 2016

Nov2016 FSR	November 1 - 30 2016	Thursday, December 15, 2016
Dec2016 FSR	December 1 - 31, 2016	Tuesday, January 17, 2017
Jan2017 FSR	January 1 - 31, 2017	Wednesday, February 15, 2017
Feb2017 FSR	February 1 - 28, 2017	Wednesday, March 15, 2017
Mar2017 FSR	March 1 - 31, 2017	Monday, April 17, 2017
Apr2017 FSR	April 1 - 28, 2017	Monday, May 15, 2017
May2017 FSR	May 1 - 31, 2017	Thursday, June 15, 2017
Jun2017 FSR	June 1 - 30, 2017	Monday, July 17, 2017
Jul2017 FSR	July 1 - 31, 2017	Tuesday, August 15, 2017
Aug2017 FSR	August 1 - 31, 2017	Friday, September 15, 2017
FINAL FSR	Final FSR	Monday, October 16, 2017

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. It will also include a report of the QA findings.

Draft Final Report Due Date: Tuesday, August 1, 2017

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.

Final Report Due Date: Thursday, August 31, 2017

Project Data: All project data including but not limited to QA/QC measurement data, metadata, databases, modeling inputs and outputs, etc., will be submitted to the AQRP Project Manager within 30 days of project completion (September 29, 2017). The data will be submitted in a format that will allow AQRP or TCEQ or other outside parties to utilize the information. It will also include a report of the QA findings.

AQRP Workshop: A representative from the project will present at the AQRP Workshop in the first half of August 2017.

Presentations and Publications/Posters: All data and other information developed under this project which is included in **published papers, symposia, presentations, press releases, websites and/or other publications** shall be submitted to the AQRP Project Manager and the TCEQ Liaison per the Publication/Publicity Guidelines included in Attachment G of the Subaward.

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