**PROJECT TITLE: Impact of Climate Change on forest health in the southeast US: Constructing a hierarchical framework to integrate downscaled NASA's climate data and FIA/FHM plots to quantify and forecast the responses of health indicators to climate and environmental stresses at multiple levels.**

Location: the southeast US (11 States)
Duration: 3 (renewal) of 3 years    Funding source: Fire Plan EM

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PROJECT OBJECTIVES:

1. Develop a hierarchical modeling framework to quantify and forecast climate change impact on FHM health indicators (crown condition, tree mortality, tree regeneration, stand density, and down woody material) for the southeast US.
2. Assess fire risk of southern forest ecosystems under changing climate scenarios based on the monitoring of FHM health indicators in 1).

JUSTIFICATION: Over 215 million forested acres, nearly 30% of the total in the United States, are located in the South (Conner and Hartsell 2002). Southern forests are characterized by diverse and rich species and genetic resources as well as high productivity. As elsewhere in the country, southern forests are facing threats from climate change and associated environmental stresses such as widespread drought, increasingly warmer temperature, and other extreme climate/weather events. Climate change and environmental stresses can trigger interrelated health problems such as non-native species invasion, increased wildfire risk, southern pine beetle outbreak, oak wilt, forest decline and directly result in rapid and large-scale shift of ecosystem function and structure and productivity (e.g., Boisvenue and Running 2006). The FHM indicators collected on ground, coupled with remotely sensed vegetation and climate data, provide a platform to monitor forest heath condition under changing climate scenarios and disturbances and develop a climate-smart forest protection and planning system. This research will help the national FHM program to fill the technical and information gap in climate change and forest health study (2008 FHM Working Group Meeting Climate Change Focus Group Resolutions).

DESCRIPTION:

a. Background

Climate change and associated environmental stresses (e.g., drought, extreme temperatures) have dramatic effects on the southern forests. There is enormous potential that climate change impact can be monitored through health indicators collected annually (periodically in a cycle of every 5-8 years before 1999) on FIA/FHM plots. However, the great barrier to analyze climate change effects on forest health through FIA/FHM plots is the mismatch over both space and time between these two sets of data (Fan et al 2004, 2005). Climate change data observed through weather stations/satellites or projected by models are usually at very coarse resolutions (>100 km) and at more frequent time intervals compared to local/focal scale health condition represented by FHM/FIA plots and health indicators. Thus, climate change impact is often spatially and temporally confounded by land use patterns and site factors. Climate impact research often uses "the nearest station" and/or regionally averaged climate/weather data which neglect the variation of climate pattern and thus result in great uncertainty in modeling and response analyses (Leininger 2002, Wilson et al. 2004, Breshears et al. 2005, Kurz et al. 2008). Based on the fact that climate change, associated environmental stresses and site/stand factors interact at varied temporal and spatial scales we propose an ecological classification system (ECS)-based hierarchical framework to forecast climate change impact on forest health indicators for the southeast US. Based on our previous and ongoing work on multiple scale modeling and landscape simulation of forest vegetation dynamics and forest health indicators (e.g., down woody material, tree mortality) (Spetich and He 2008, Fan et al. 2006) we will focus on five fire risk and productivity-related FHM indicators: crown condition, tree mortality, tree regeneration, stand density, and down woody material in this study. To accomplish this we will use a hierarchical modeling framework that is unique in three major ways.

b. Methods:

1) Dynamic downscaling of IPCC projections – using WRF model

The fourth Assessment Report (AR4) from the Intergovernmental Panel on Climate Change (IPCC) provides a thorough report of past, current, and future climate change based on observations and numerical model projections. The Weather Research and Forecasting (WRF) model, which is developed at National Center for Atmospheric Research (NCAR) and the National Centers for Environment Predictions (NCEP), has been utilized in many aspects of operational and research activities and has been in full support from the development and research community.

The proposers have utilized both the Mesoscale Meteorology (MM5) and WRF models in Arctic regional modeling and an Arctic regional reanalysis project (e.g., Fan et al. 2008; Fan et al. 2007). For this study, the scheme of Lo (2003)'s 3-D nudging scheme will be used, since there will not be any data assimilation involved for the purpose of this study. The model evolutions are nudged toward the driving data at 6-hourly intervals or other intervals related to different datasets.

The model domain is configured to have three nested domains, as shown in Figure 1, to downscale the NASA Goddard Institute for Space Study (GISS) AOM data, of which the horizontal resolution is 3°×4°. The outer coarse model domain (D1) has 95×69 grid points with 90-km grid spacing; the second domain (D2) has 151×103 grid points with 30-km resolution, which covers the conterminous US; and the third domain (D3) has 163×100 grid points with 10-km grid spacing, which covers the southeast US. For the downscaling of the North American Regional Climate Change Assessment Program (NARCCAP) data, of which the resolution is 50-km, only the inner two domains (D2 and D3) will be used. The domain D2 is within the NARCCAP WRF domain. The WRF model is configured to have 41 vertical levers.

Two sets of downscaling are proposed as illustrated in Figure 1. One is the downscaling of the NARCCAP 50-km resolution regional climate projections from GFDL-WRF models for two time slices of 1970-2000 and 2040-2070. It will be downscaled to 10-km resolution in domain D3 by nesting via the D2 domain. The D2 domain will be nudged to the NARCCAP fields and provide lateral boundary conditions to the D3 domain.

The other is the downscaling of NASA GISS AOM model projections under the A1B SRES scenario. The A1B scenario assumes that carbon dioxide increases from 380 to roughly 700 parts per million (ppm) over the 21$^{st}$ century. It is a 'middle-of-the-road' scenario, in which there is a balanced mix of fossil and non-fossil fuels. The GISS AOM model has a horizontal resolution of 3°×4° for atmosphere; and thus one coarser domain (D1) is used. The D1 domain will be nudged to the GISS model states, and provide lateral boundary conditions for D2, and then for D3.

The two downscaled data will enable the inter-comparisons of global and regional climate projections, as well as for their impacts on regional forest simulation and projection. All downscaled data and modeling data will be disseminated through Ecosystems Data Assembly Center (EDAC).

2) Land surface modeling using the NASA Land Information System (LIS)

The Noah land surface model and/or the community land model (CLM) in LIS will be configured to conduct land surface modeling at 10 km resolution. Model meteorological input will be derived from the downscaled climate dataset. The land cover and soil data will come from climatological data. The LIS model is able to simulate soil properties at various depths that are dependent on the available options of land surface model in the LIS package, including soil temperature, soil moisture, land surface fluxes of moisture and energy. Since we are focusing on forest modeling, properties at deep layers of soil play important roles in contributing to long-term forest growth/health. The CLM option of LIS is planned for the land surface simulation in this study.

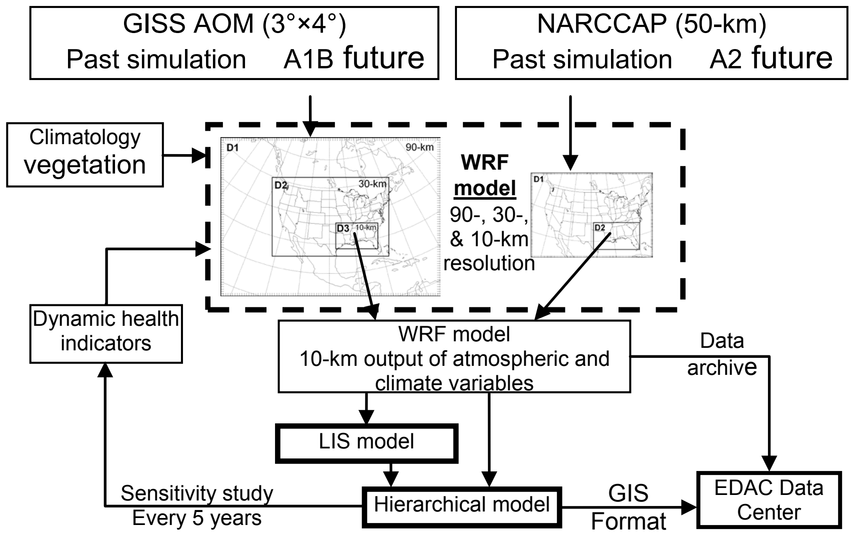


Figure 1. Flow chart of the climate data downscaling and application in the hierarchical modeling of forest health.

3) Development of the hierarchical modeling framework of forest health indicators

FIA/FHM plot data/health indicators will be transformed and aggregated at three levels: Ecoregion, forest type/group, and FIA/FHM plot cluster based on Bailey's ecological classification system hierarchy. Considering the non-stationary characteristics of a forest health indicator, we will first spatially classified the study domain (the southeast US) into a set of disjoint regions based on the spatial variation of a selected health indicator, say CWD, by using nonparametric kernel smoothing method. The disjoint regions will be further classified into a set of smaller of FIA/FHM clusters with a cluster only belonging to the same forest type and ecoregion.

A FIA/FHM cluster is a basic unit reflecting the interaction of ecoregion (climate) factors, forest type (bio-geographical) factors and local disturbance and site factors. Because of the weak correlation between plot data and climate and vegetation data, probability models instead of regression (mean-based) models will developed to predict the probabilistic distributions of a health indicator within a cluster.

Within a forest type, regression models will be developed based on a set of embedded FIA/FHM clusters and associated factors by using statistical resampling methods. The regression models are to predict the quantity/abundance of a health indicator.

Within an ecoregion, the distribution parameters (e.g., mean, variance) of a health indicator and its change with climate will be estimated by using stochastic spatial-temporal models. The three-level hierarchical modeling will be implemented in the Bayesian framework through the Markov chain Monte Carlo (MCMC) methods. Finally, fire risk for different forest types will be quantified based on fuel loading.

Compared to other studies, the hierarchical modeling framework is unique in the following three aspects. 1) It takes a bottom-up approach starting with FHM/FIA plots and uses downscaled fine resolution climate data as model input for other site/plot variables. The downscaled fine-resolution (10 km) climate data will overcome the scale mismatch problem in data analysis and modeling. Moreover, the downscaled climate data include observed or projected climate data for the past, current and future time. The data thus make possible model validation and comparison, which were poorly addressed in other studies. 2) We fully consider the uncertainty of forest health indicators and employ a stochastic aggregation process to quantify health indicators dynamics by ECS levels (e.g., ecoregion, forest type/group, land type association). The ESC hierarchy matches well at the resource planning and decision making level. 3) We use ground truth (FIA/FHM plots) to quantify climate change impact on FHM health indicators at multiple levels. Our funded NASA project "Forecasting the Change of Coastal Forest Ecosystems under a changing climate in the Northern Gulf of Mexico" will provide climate data support for this project should it be funded.

c. Products:

- A hierarchical modeling framework to evaluate climate change impact on FHM health indicators.
- A set of risk maps by health indicators.
- A set of fire risk maps for different forest type/groups and land type associations.

d. Schedule of Activities:

Year 1: Climate downscaling and MODIS' NDVI development

- (**Fan, X**., and **Postdoc**. supported by the GeoResources Institute, High Performance Computing Collaboratory (HPC2), Mississippi State University) and exploratory analyses of FHM indicators
- Construction of Biological hypotheses and conceptual models of health indicators (**Leininger, Spetich, Fan, Z**.)

Year 2: Hierarchical modeling framework development of FHM indicators (**Postdoc, Fan, Z.)**

Year 3: Fire risk estimation based on indicators and NDVI, application of models and risk maps, and final report revision and draft publication (**Spetich, Leininger, Fan, Z., and postdoc**).

e. Progress/Accomplishments:

Our analysis of the impacts of climate change on forest health began with an assessment of the impacts of drought on crown dieback. We analyzed the relationship between drought and crown dieback utilizing Palmer's Drought Severity Index (PDSI) as an indicator of drought (Figure 1). We performed this analysis for four species groups within both forest types and ecoregions that occur in the southeastern United States using as our study area those states that have existing Forest Health Monitoring data and PDSI data available (Figure 2). We have found that there exists a negative relationship between drought and crown dieback within four to five years of a drought occurrence. We provide our analysis of the correlation between drought and crown dieback by ecoregion as an example (Figure 3). The amount of dieback and correlation with PDSI vary between ecoregions and species groups (Table 1). We intend to utilize this information to guide subsequent analysis as few of the correlation coefficients were significant, indicating that while drought may be an important factor in overall forest health, additional, local-scale variables need to be considered to provide meaningful models.

The downscaling of climate data from the Weather Research and Forecasting (WRF) model has been completed and made available for the southeastern United States (Figure 4). The data are averaged monthly totals of approximately 50 meteorological/climatological variables ranging from temperature to water runoff to energy flux data. Currently data are monthly averages for the years 1970 to 2000. Some examples of variables to be utilized in conjunction with forest health data are provided (Figures 5-7). We will be able to combine these data as variables in model construction to discern if any, and to what extent, they may assist in the prediction of climate change on forest health.

Our on-going tasks are combining these data sources to develop multiple-scale, hierarchical models to evaluate the potential impacts of climate change on forest health in the southeastern US.

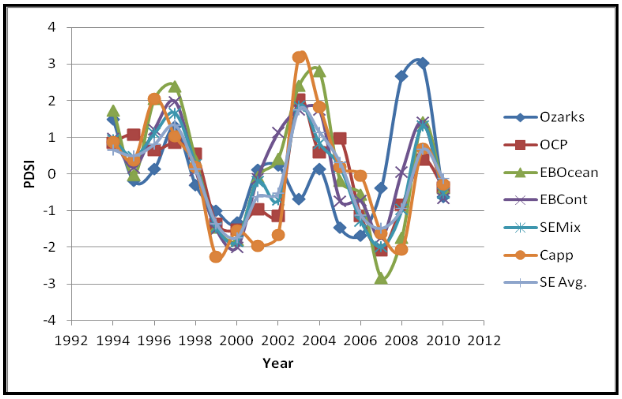


**Figure 1. PDSI values, averaged by ecoregion, for the southeastern US.**

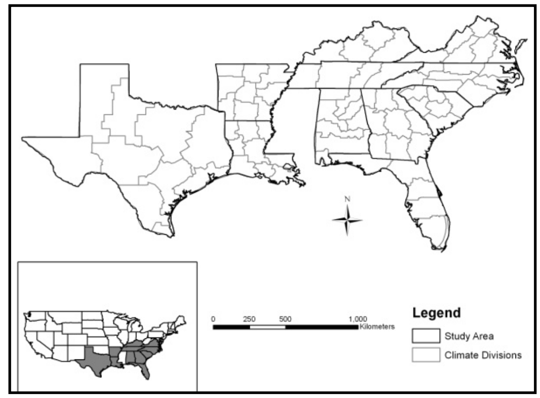


**Figure 2. Study area utilized for assessing the relationship between drought and crown dieback in the southeastern US**

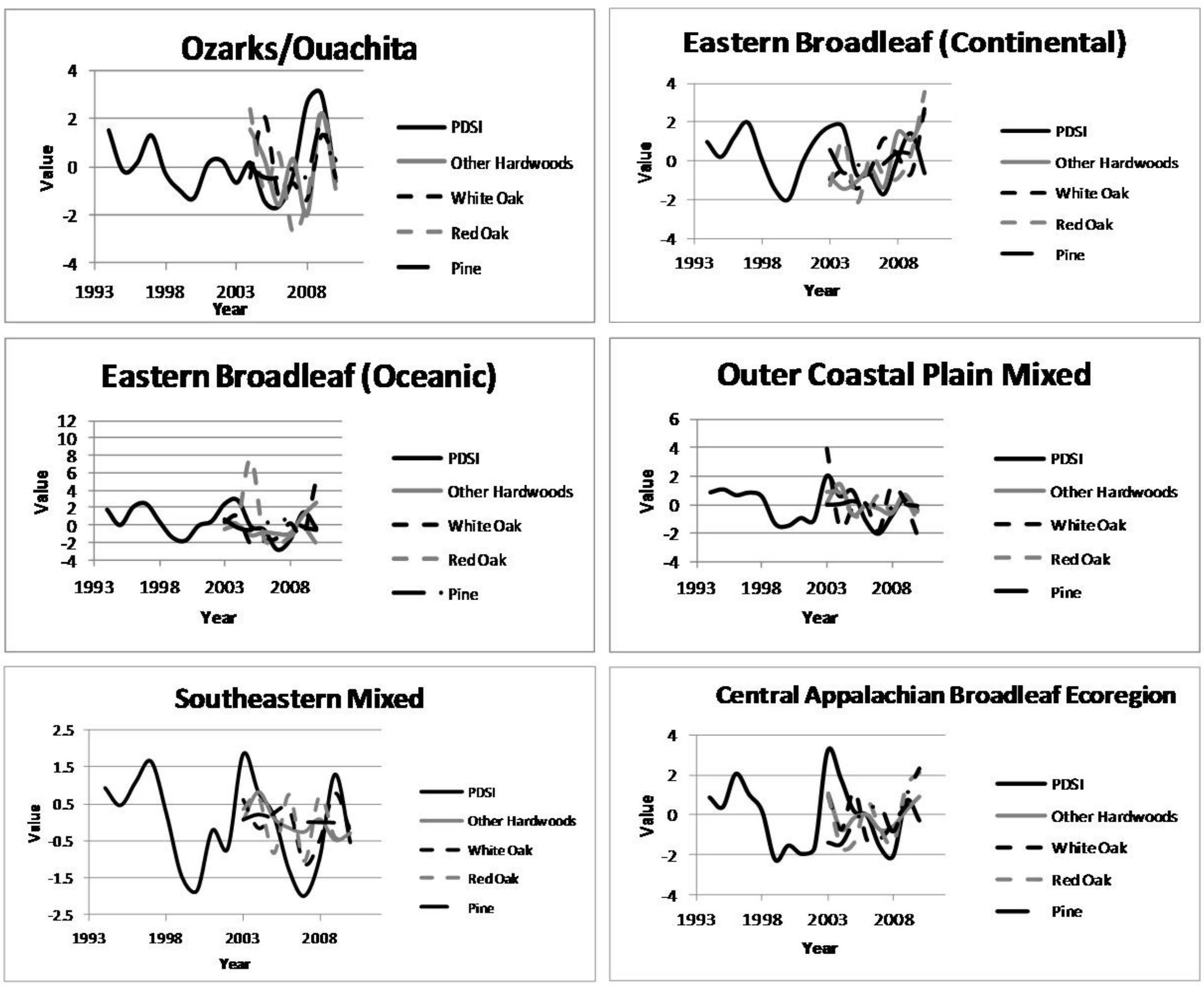


**Figure 3. Graphical representation of the relationships between drought and crown dieback, by ecoregion.**

**Table 1. Relationship between drought and crown dieback, by species group*, within each ecoregion. Relationships highlighted are significant at p = 0.1.**

| | Sp. Group | Year to Year | Lag1 | Lag2 | Lag3 | Lag4 | Lag5 | Lag6 | Lag7 | Lag8 | Lag9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ozarks | oh | 0.24 | 0.31 | 0.25 | 0.30 | 0.19 | 0.24 | 0.19 | 0.31 | 0.41 | 0.34 |
| | wo | -0.05 | 0.31 | 0.33 | 0.40 | 0.42 | 0.35 | 0.25 | 0.26 | 0.48 | 0.48 |
| | ro | 0.26 | 0.38 | 0.46 | 0.45 | 0.40 | 0.44 | 0.31 | 0.48 | 0.56 | 0.61 |
| | pine | 0.67 | 0.69 | 0.54 | 0.47 | 0.42 | 0.60 | 0.53 | 0.56 | 0.54 | 0.42 |
| Outer Coastal | oh | 0.30 | 0.49 | 0.11 | 0.00 | -0.12 | -0.46 | 0.30 | 0.23 | 0.32 | 0.32 |
| | wo | 0.57 | 0.03 | -0.11 | -0.10 | -0.23 | 0.04 | 0.31 | 0.06 | 0.26 | 0.20 |
| | ro | 0.28 | 0.10 | -0.09 | -0.17 | -0.07 | -0.34 | 0.24 | -0.07 | 0.08 | 0.21 |
| | pine | 0.44 | 0.65 | 0.89 | 0.69 | 0.59 | 0.17 | 0.12 | 0.40 | 0.65 | 0.73 |
| EB Ocean | oh | 0.38 | 0.30 | -0.08 | -0.42 | -0.69 | -0.85 | -0.65 | 0.08 | 0.09 | -0.07 |
| | wo | 0.16 | 0.21 | -0.06 | -0.38 | -0.57 | -0.80 | -0.77 | 0.02 | 0.02 | -0.10 |
| | ro | 0.20 | 0.47 | 0.59 | 0.56 | 0.52 | 0.40 | 0.29 | 0.34 | 0.56 | 0.58 |
| | pine | -0.25 | -0.54 | -0.43 | -0.27 | -0.10 | 0.13 | 0.24 | -0.17 | -0.47 | -0.36 |
| EB Continent | oh | -0.04 | -0.16 | -0.34 | -0.64 | -0.70 | -0.65 | -0.31 | 0.14 | -0.01 | -0.31 |
| | wo | -0.48 | -0.38 | -0.45 | -0.55 | -0.50 | -0.55 | -0.52 | -0.28 | -0.32 | -0.41 |
| | ro | 0.03 | 0.16 | 0.09 | -0.11 | -0.33 | -0.55 | -0.52 | 0.18 | 0.27 | 0.13 |
| | pine | 0.25 | 0.10 | -0.27 | -0.68 | -0.86 | -0.76 | 0.06 | 0.37 | 0.06 | -0.25 |
| SE Mixed | oh | 0.26 | 0.47 | 0.49 | 0.54 | 0.34 | 0.12 | -0.13 | 0.43 | 0.51 | 0.53 |
| | wo | 0.75 | 0.58 | 0.48 | 0.28 | 0.01 | 0.07 | 0.65 | 0.54 | 0.64 | 0.53 |
| | ro | 0.17 | 0.15 | 0.00 | 0.13 | -0.16 | 0.07 | -0.06 | 0.22 | 0.15 | 0.15 |
| | pine | 0.56 | 0.52 | 0.43 | 0.26 | 0.15 | -0.15 | 0.21 | 0.60 | 0.60 | 0.46 |
| Cent. App. | oh | 0.51 | 0.08 | -0.17 | -0.34 | -0.66 | -0.69 | -0.21 | 0.61 | 0.45 | 0.25 |
| | wo | 0.40 | 0.17 | 0.05 | -0.38 | -0.67 | -0.64 | -0.33 | 0.51 | 0.49 | 0.32 |
| | ro | 0.25 | -0.14 | -0.41 | -0.36 | -0.48 | -0.46 | 0.25 | 0.76 | 0.26 | -0.02 |
| | pine | -0.40 | -0.34 | -0.35 | -0.23 | -0.04 | 0.03 | 0.49 | 0.70 | -0.01 | -0.29 |

*Species groups utilized for grouping are **oh** = other hardwoods (i.e. those not belonging to red oak or white oak species groups); **wo** = white oak species; **ro** = red oak species; **pine** = all pine species.

Figure 4. Study area in southeastern United States for which downscaling of WRF data were completed.

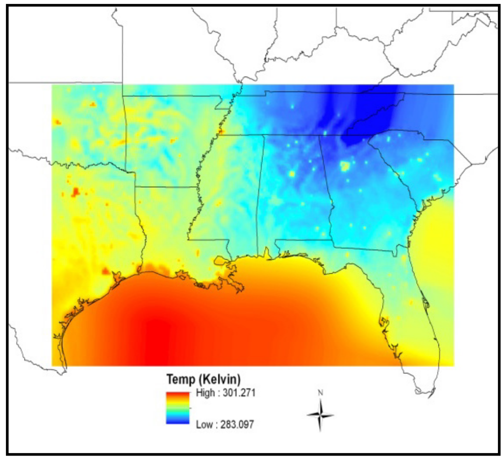


Figure 5. Downscaled temperature data for August 1975.

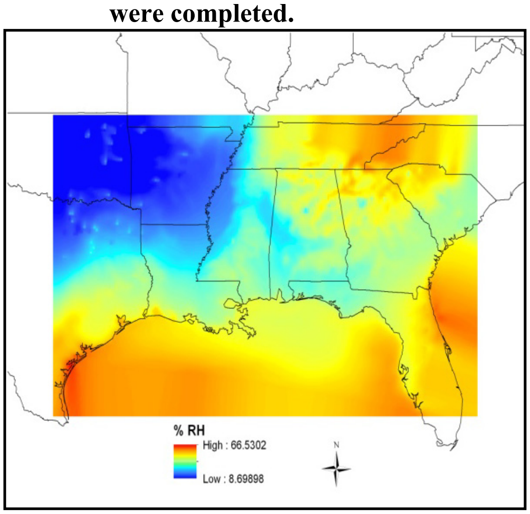


Figure 6. Downscaled relative humidity data for August 1975.

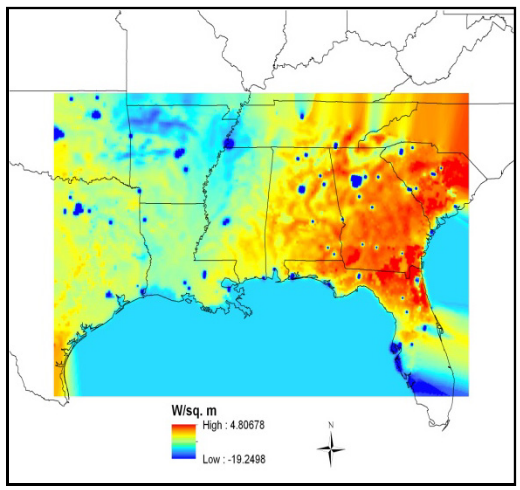


Figure 7. Downscaled data for radiation flux for August 1975.

COSTS for 2012:

| | **Item** | **Requested FHM EM Funding** | Other-Source Funding |
|---|---|---|---|
| **Year 2012** | | | |
| **Administration** | Postdoctoral Associate (10 months)<br>Salary<br>Fringe benefits (32.85%)<br>Dr. Fan (1 month)<br>Salary<br>Fringe benefits (32.85%) | <br>$36,054<br>$11,833<br><br>$7,210<br>$2,366 | Contributed salary<br>Dr. Roberts (1%) $960<br>(Spetich) $1,000<br>(Leininger) $1,000<br>MSU F&A cost share<br>(43%) $ 25,876 |
| **Procurements** | Travel (postdoc +Fan=2,000) | $2,000 | |
| | Contract services (stamps, LD calls, etc,) | $176 | |
| | Supplies | $537 | |
| **Year 2012 TOTAL** | | **$60,176** | **$28,836** |

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