Investigation of the Interactions Between Climate Change, Biomass, Forest Fires and Air Quality with an Integrated Modeling Approach

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Acknowledgments

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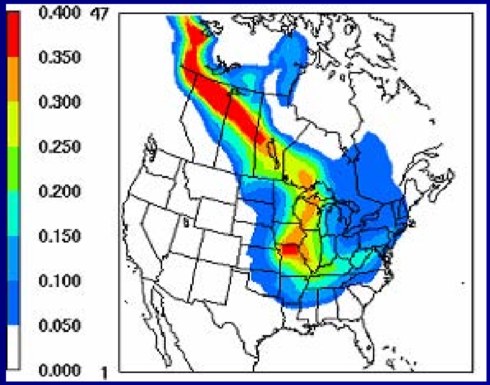
- Team members:
  - Craig Mattocks: PnET model and database implementation, linkages to BEIS3
  - Andy Holland: BlueSky-EM and Database implementation, PnET linkage, SMOKE runs
  - Frank Binkowski: Radiative transfer model development, testing and analysis
  - Adel Hanna: Analysis of climate impacts
  - Jennifer Moore Myers (SGCP) – PnET model consultation

Motivation

- Wild fire impacts seen at regional and global scales
- BC aerosol exerts strong positive forcing on climate; SO_2 from biomass burning contributes to negative forcing through secondary SO_4 formation
- Recently dioxins, GHGs also associated with fire plumes (FS 2005; Simmonds et al., *AE 39*, 2005)
- Short-term climate variability affects forest growth, and thus the biogenic emissions as well as fuel availability for potential fires



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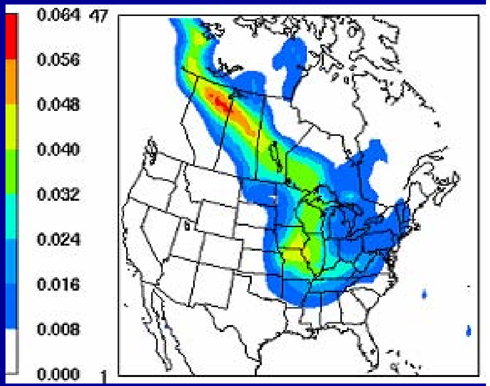

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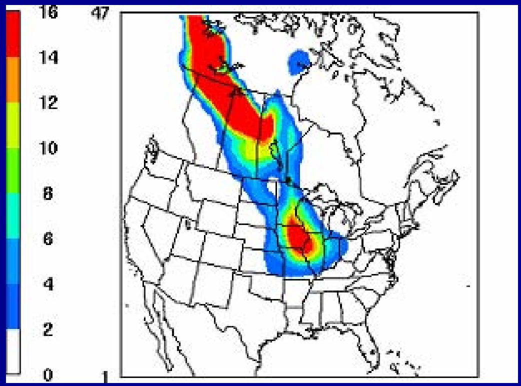


Carbonaceous PM

Modeling Issues

- Most climate models do not simulate feedback of short-term climate variability to forest growth
- Most AQ models do not include feedback to dynamics of scattering and absorbing aerosols or ozone
- Model enhancements needed to better assess the impact of managed vs. uncontrolled fires on forest land and the benefits of fire management plans

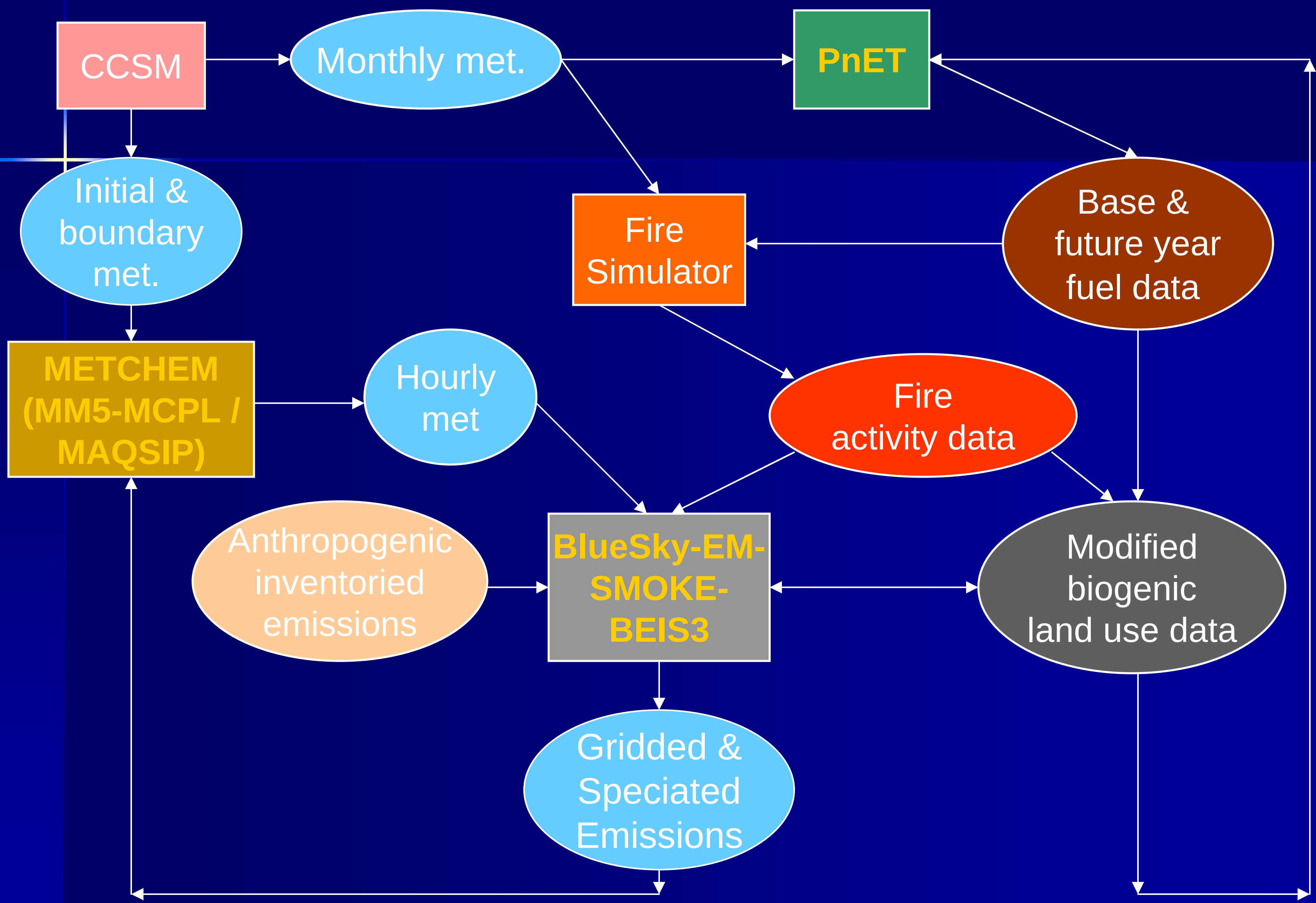
Project Objectives

- To examine the impacts of climate variability on vegetative cover and fuel characteristics, their impact on fire emissions, and feedbacks to biomass load and biogenic emissions
- To investigate the changes in air quality due to evolution of emissions in response to fires in successive years under various fire scenarios
- To study the feedbacks of these air quality changes to climate variability
- In the process, to build a modeling system that can be further refined for such applications

System Overview

- Four main components
  - Photosynthetic Evapotranspiration Model (PnET)
  - BlueSky-EM Smoke Emissions Model
  - Sparse Matrix Operator Kernel Emissions Modeling System (SMOKE)
  - Coupled meteorology-chemistry model (METCHEM)

Modeling System Showing Yr 1 Task Areas



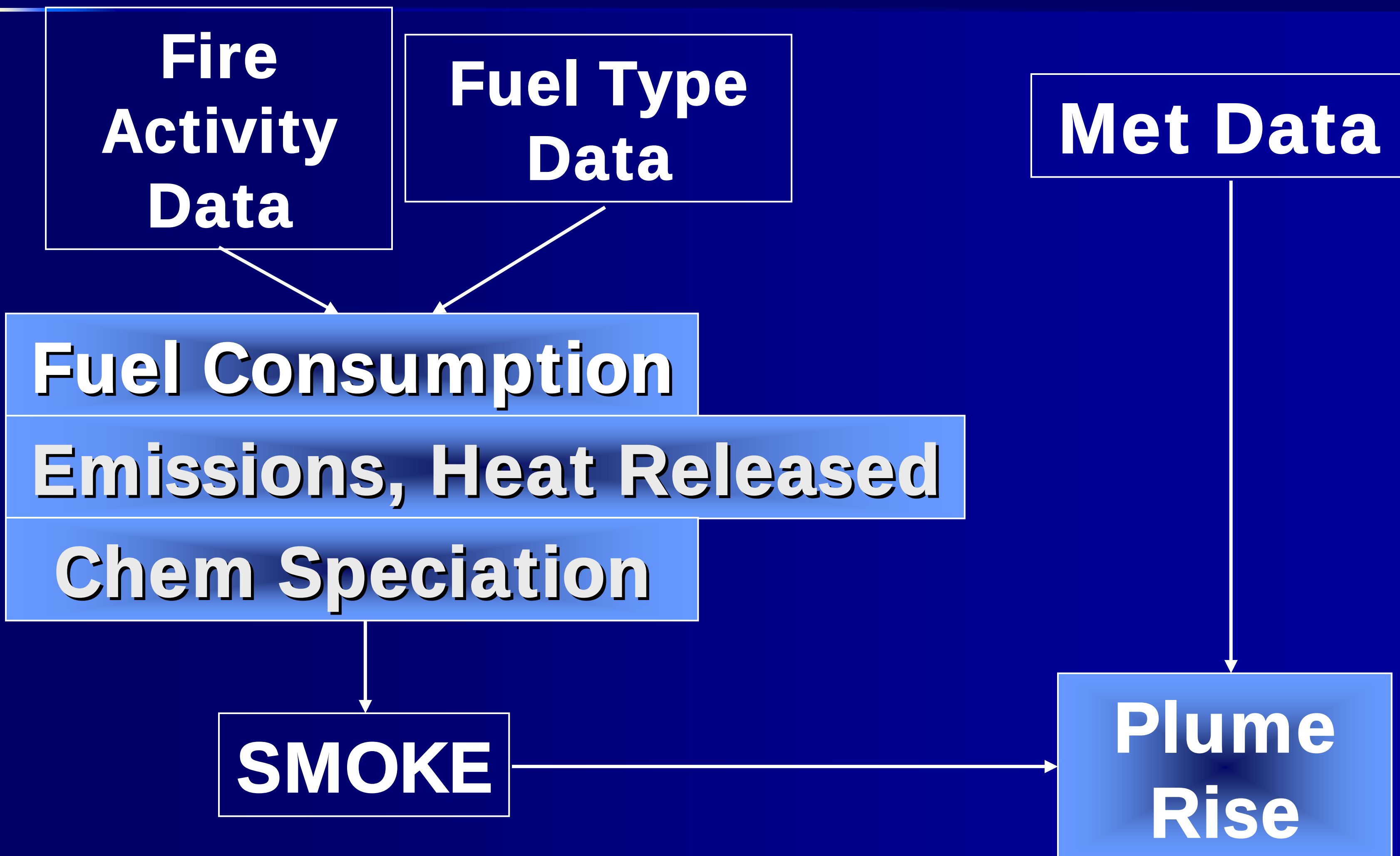
PnET Model Features

- Highly customized version currently used by SGCP
  - predicts forest productivity, hydrology, carbon storage for a range of climate and site conditions
  - Uses soil moisture + monthly means for 4 climate parameters (max and min air temp, precip, solar radiation) and forest-specific attribute coefficients
  - Linked to a regional GIS for vegetative cover and timber species data
- Can input disturbances: N deposition, changes in O_3, CO_2, insects, wildfires, climate change
- Various versions extensively validated against C, N and water balance measurements from the Harvard Forest and other ecosystems

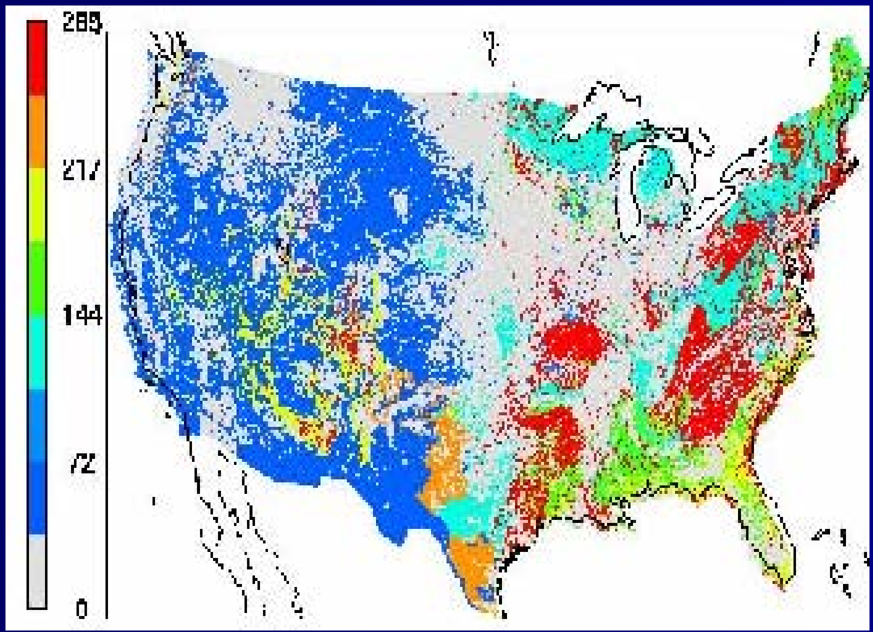
BlueSky-EM Overview

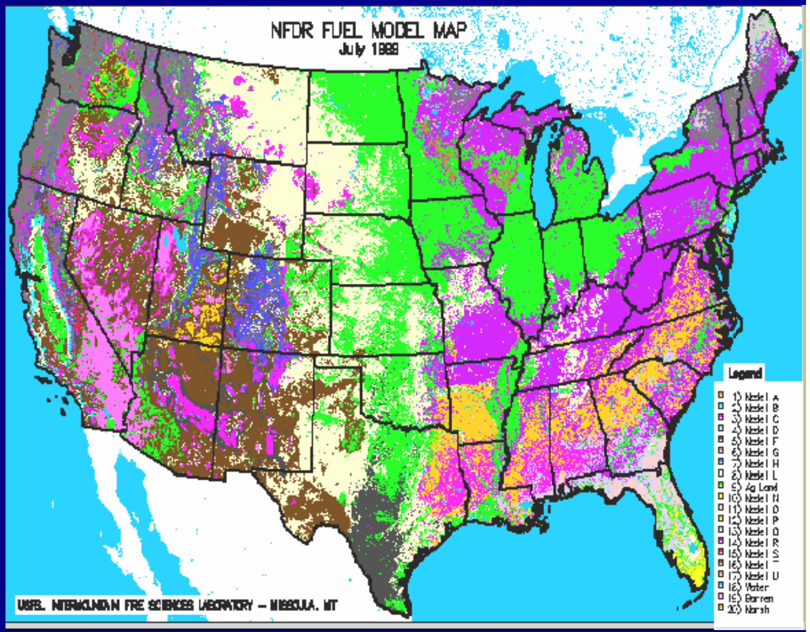
- Fire emissions:
  - regional to national scale; 1 - 36 km spatial resolution
  - temporal resolution: hourly to multi-year
  - chemical species include CO, CO_2, PM_{10}, $PM_{2.5}$, CH_4, EC, OC, NO_x, NH_4 and VOC
  - accuracy equivalent to other emissions estimates
- Aggregation of existing models and datasets:
  - FCCS (default), NFDRS or Hardy fuel databases
  - Consume (fuel consumption), Emission Processing Model (EPM)
- Has been linked to the SMOKE model in a recent development for EPA

Flow Diagram of BlueSky-EM and SMOKE

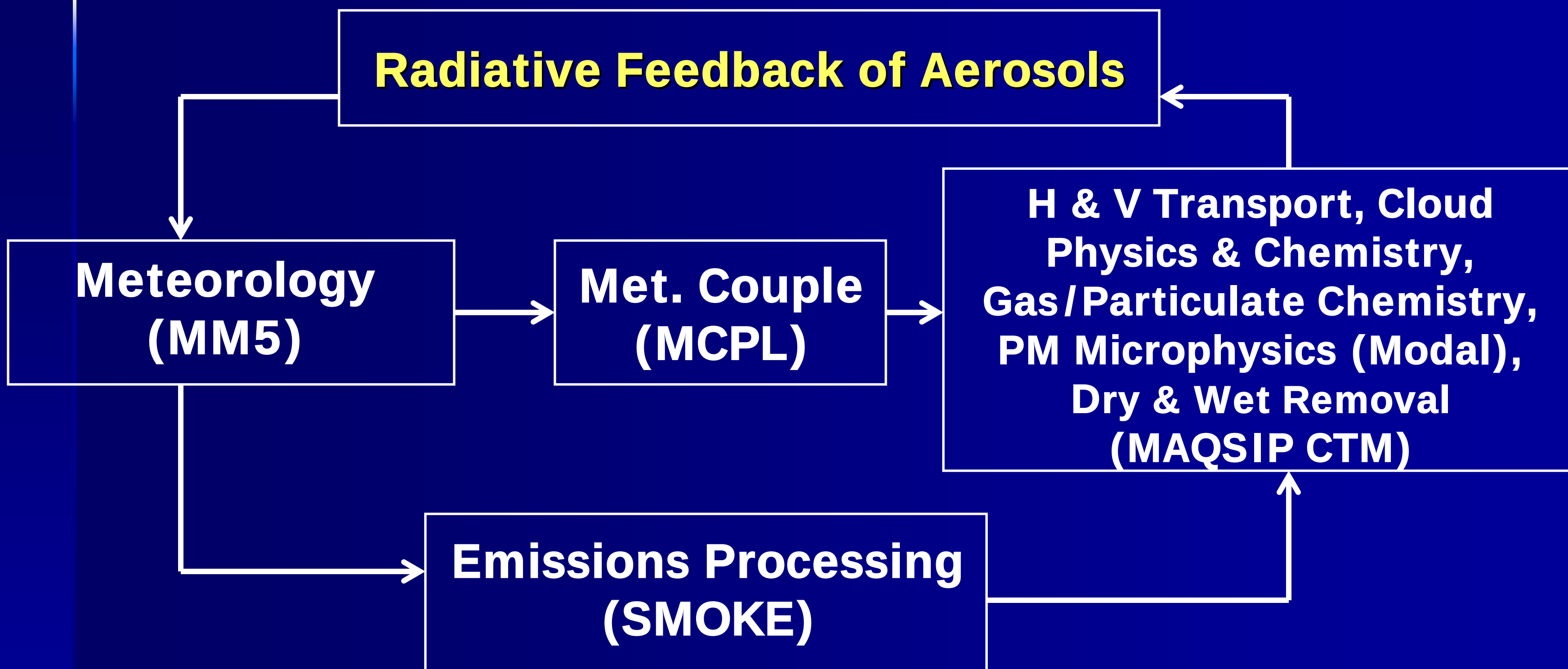


FCCS and NFDRS Fuel Maps





Integrated Meteorology-Chemistry Model (METCHEM)



Radiation Scheme

- CCM2 radiation scheme in MM5
- δ-Eddington approximation to calculate solar absorption with the solar spectrum divided into 18 discrete intervals
- Absorption of O_3, CO_2, O_2, and H_2O
- Scattering and absorption of cloud droplets
- Aerosol optical properties were calculated by Mie scattering algorithm of Toon et al. (*J. Atmos. Sci., 45*, 1988) with refractive indices based on Stelson (*Env. Sci. Technol., 24*, 1990); this module has been updated in the past year

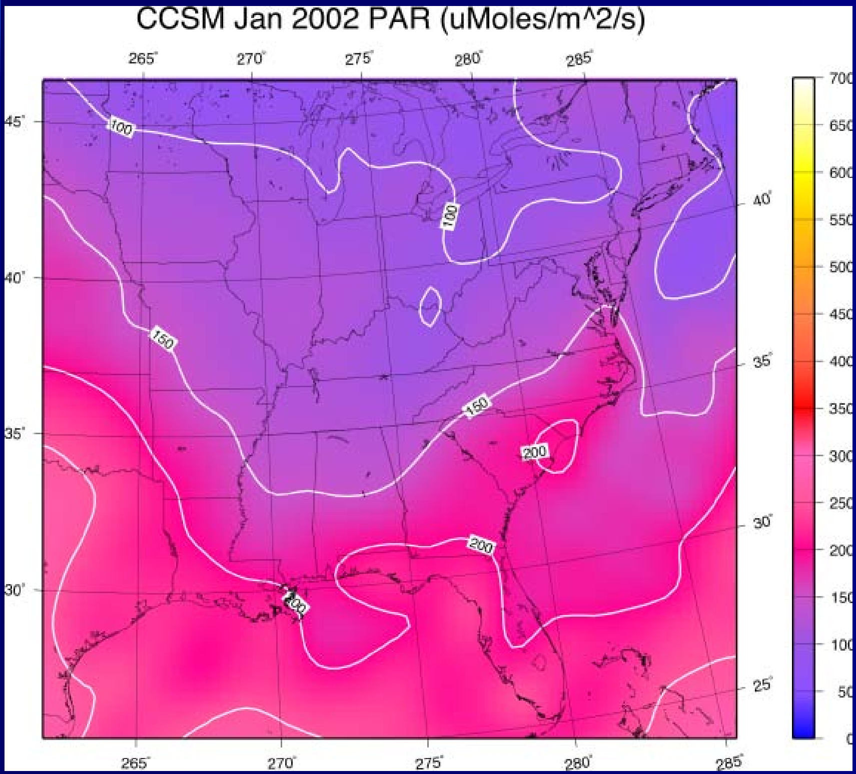
PnET Progress

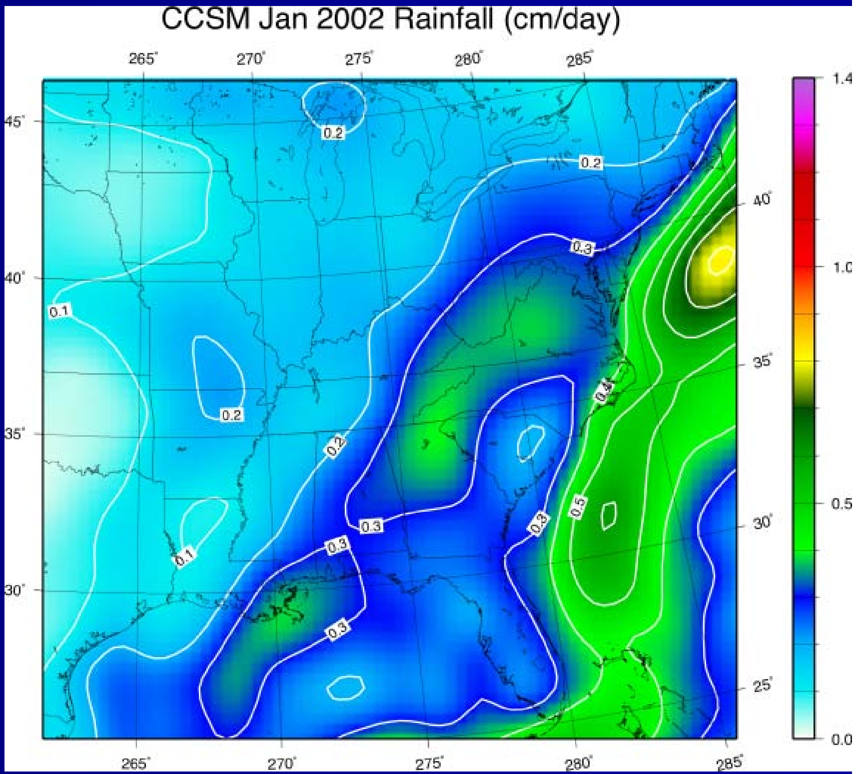
- Implemented 4 versions of the model on CEP platforms after extensive consult w/ SGCP
  - Visual Basic (June '05 version) + MS SQL server from Southern Global Change Program, USFS-Raleigh
  - C v4.1 (UNH)
  - C++ 'daily' version w/ CN (live biomass, litter and soil, nitrogen soil cycling) (UMN)
  - Java (port from C++) (CEP)
- Java version reproduced 10-year C++ simulation results for 1991-2001 using daily climatology from Harvard Forest (benchmark case)

PnET Progress Details

- I/O Improvements
  - More robust, flexible format for IC files (site, veg)
  - netCDF replaces MS SQL – important for common format of model I/O
  - Java version has been tooled to read CCSM output
    - Interpolated 2002 output to 36-km model grid
    - Conversion factor for FSDS (downwelling solar flux) to PAR
    - Conversion of large-scale and convective precip to rainfall rate for PnET
- Other milestones
  - Created a CVS archive for the model
  - build.xml file automatically compiles, builds and runs model with a single command

CCSM Output for 36-km Grid





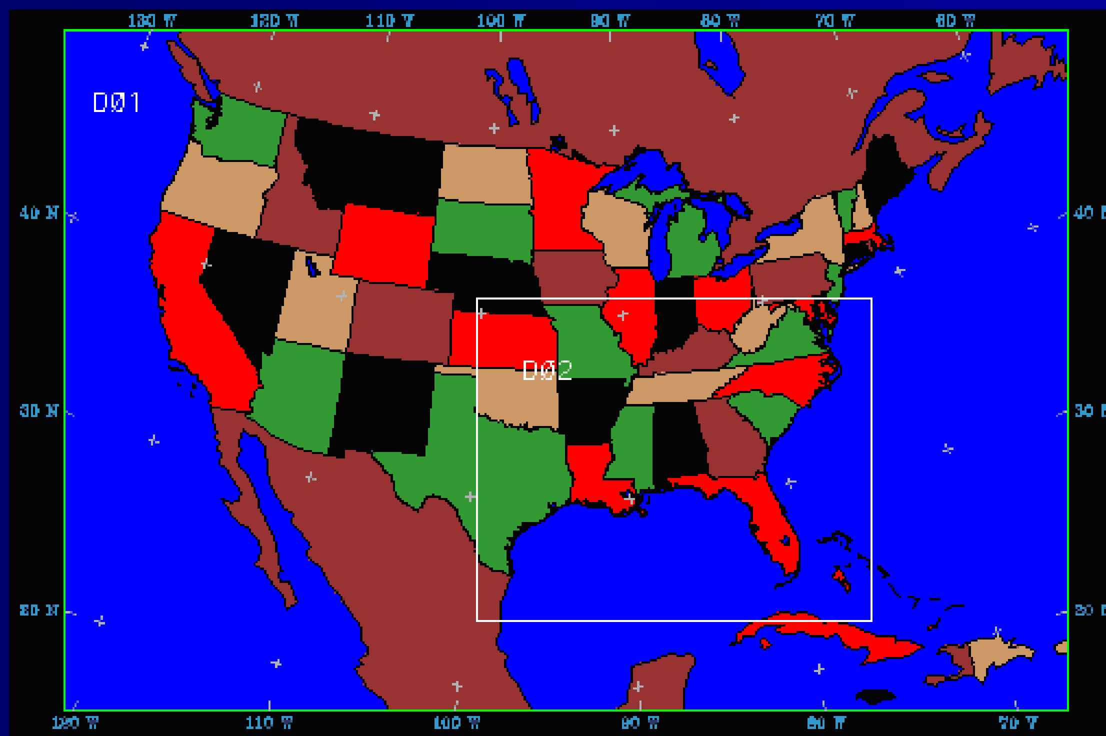
BlueSky-EM Progress

- Investigated pros and cons of Community Smoke Emissions Model and BlueSky-EM; selected latter because of integration with SMOKE
- Downloaded the model and examined fuel databases (FCCS, NFDRS, Hardy)
- Have run examples provided for August 2002 western U.S. simulation
- May 2002 run to generate emissions for Florida wild fires in progress

Modeling Domains and Periods

- Outer domain – ConUS at 108-km to provide boundary conditions, especially on the western boundary to:
- a nested SE US domain at 36-km resolution to use the full suite of models for the simulation of the interactions of forest biomass, fire emissions, AQ and climate
- Base year: 2002; 3 future years: 2015, 2030 and 2050

Modeling Domains



Initial and Boundary Conditions

- Initial conditions assumed to be uniform, background values for each species
- Lateral boundary conditions for coarse grid derived from ConUS simulations for the base year (2002) from GEOSCHEM
  - 9 gas-phase species: PAN, CO, isoprene, HNO_3, HCHO, N_2O_5, HNO_4, O_3, and SO_2
  - 5 aerosol species: SO_4, NH_4, NO_3, EC, and OM
  - Will refine these with observational data and evaluated inputs from prior simulations for this period as appropriate

METCHEM Progress: Radiative Transfer Model

- CCM2 calculates direct radiative forcing of aerosols using new module for aerosol optical properties
  - Mie approximation for scattering and extinction efficiencies (Evans and Fournier, *Appl. Optics, 28*, 1990) uses accumulation mode mean diameter and species concentrations from MAQSIP
    - composite aerosol refractive index based on data from OPAC software package (Hess et al., *BAMS, 79,* 1998).
    - absorption algorithm based upon approach of Bohren and Nevitt (*Appl. Optics, 22*, 1983) for absorption efficiency
    - asymmetry factor based upon empirical fit to Mie calculation (Hanna and Mathur)
  - Fast optics uses analytical approach [Heintzenberg and Baker (*Appl. Optics, 15*, 1976), and Willeke and Brockmann (*AE 11*, 1977)]

METCHEM Progress: Aerosol Chemistry

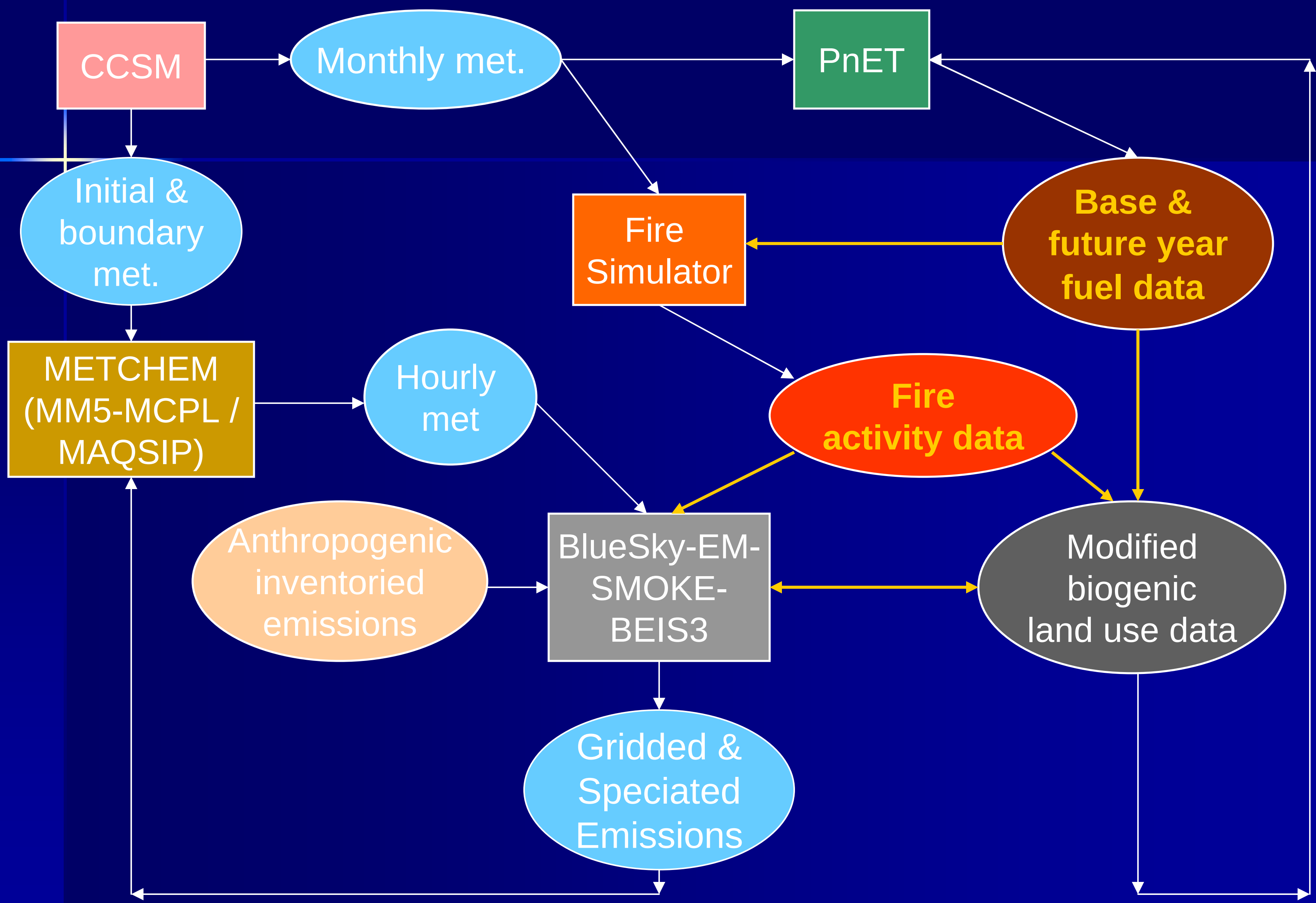
- A supporting project for CMAS has enabled improvements in aerosol composition representation and interaction w/ sea salt species (Shankar et al., 2005*)
  - Corrected a bug in the mass transfer scheme for volatile species partitioning to the aerosol modes during CMAQ v4.5 AERO4 module development
  - Currently modifying the aerosol speciation in the fine modes to port this correction to MAQSIP
  - Coarse mode chemistry improvements on the way

*http://www.cmascenter.org/conference/2005/blank.cfm?CONF_PRES_ID=129

Next Steps: Data Linkages

- PnET-BELD3
  - create x-reference file to map FCCS fuel beds to BELD3 landuse data
  - use "fire" version of Subregion Timber Supply (SRTS) Model to remove burned area veg; link to BELD3
- PnET-BlueSky
  - disaggregate FIA county-level plot data to FCCS 1-km res to augment/replace FCCS data for future years
- BlueSky-BELD3:
  - represent burned land types in BELD3 ("shrubland" for VOC and "misc cropland" for NO; others?)
  - identify fire activity data sources for SE U.S.

Next Steps – Data Linkages and Databases

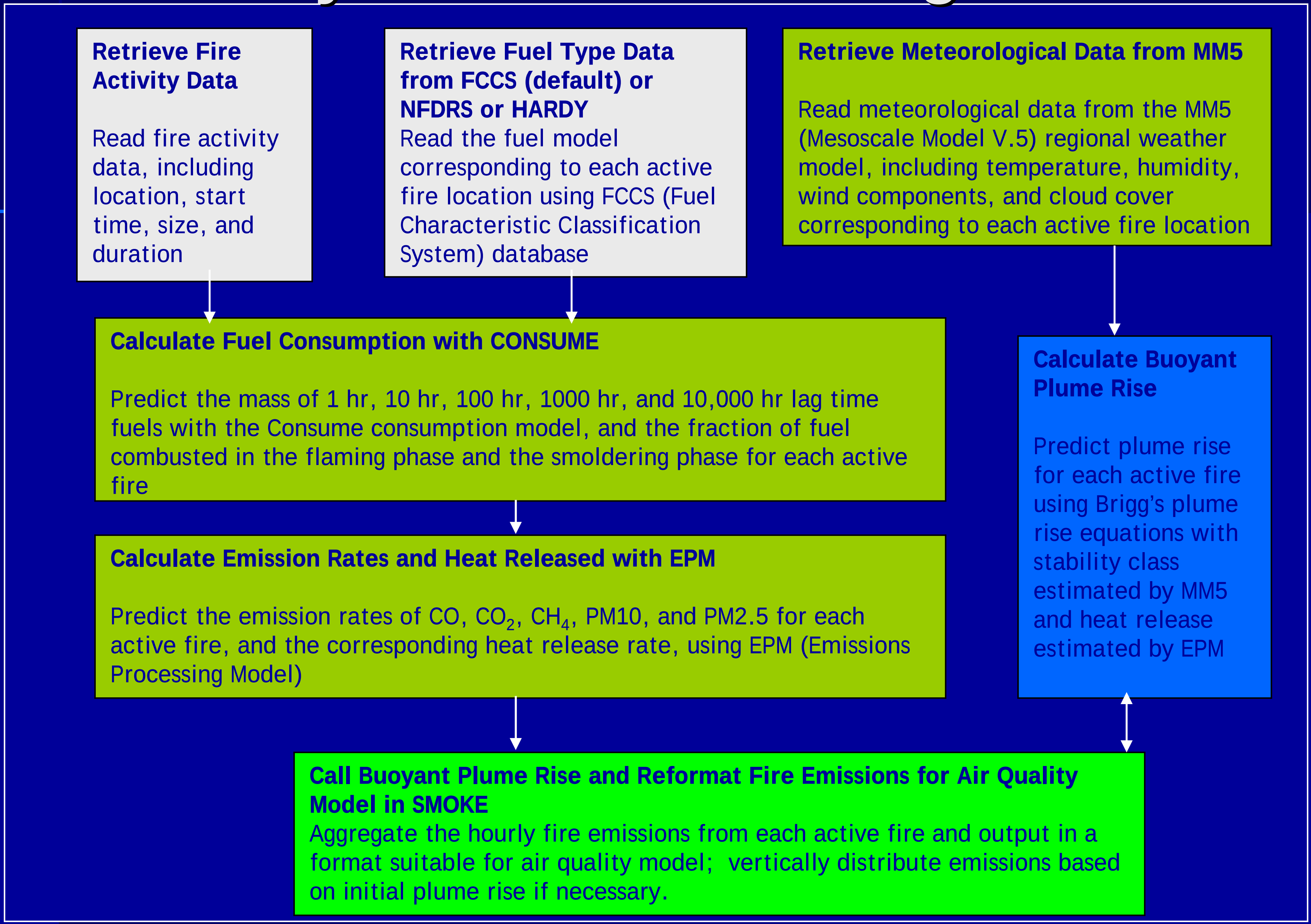


Next Steps: Models

- Evaluate sea salt model in METCHEM
- Finish evaluation of the radiative transfer model
- Develop coupling between CCSM and METCHEM for the future-year simulations
- Test system for base year
- Look into adapting the USFS Fire Scenario Builder [McKenzie et al. (in press), 2006] for wild fires to simulate future year wild and prescribed fires

The End

BlueSky/SMOKE Flow Diagram



Combustion Emission Scaling Factors

CO2	1833*CE
CO	961 - (984*CE)
CH4	42.7 – (43.2*CE)
PM2.5	67.4 – (66.8*CE)
PM10	1.18*PM2.5
EC	0.072*PM2.5
OC	0.54*PM2.5
NOx	16.8*MCE-13.1
NH4	0.012*CE
VOC	0.085*CO

Emissions in g/kg

$$CE = DCO_2 \ / \ \{DCO+DCO_2 + DCH_4+D_{other}\}$$

$$MCE = 0.15+.86*CE$$

$$D= [\cdot]_{plume} - [\cdot]$$