Fall Creek Falls Conference – 2007 Climate Modeling Schedule

- **David Erickson (ORNL) - Climate modeling overview: What is next?**
- **Auroop Ganguly (ORNL) - Climate extreme events: Models and Observational Methods**
- **BREAK**
- **Lawrence Buja (NCAR) - Climate Modeling in a Changed World: New Directions and Requirements following the breakthrough IPCC AR4**
- **Rich Loft (NCAR) – Computational aspects of climate modeling – unable to attend**
- **Panel Discussion**

Earth Systems Modeling Overview: What is next?

David Erickson

Computer Science and Mathematics Division
Oak Ridge National Laboratory

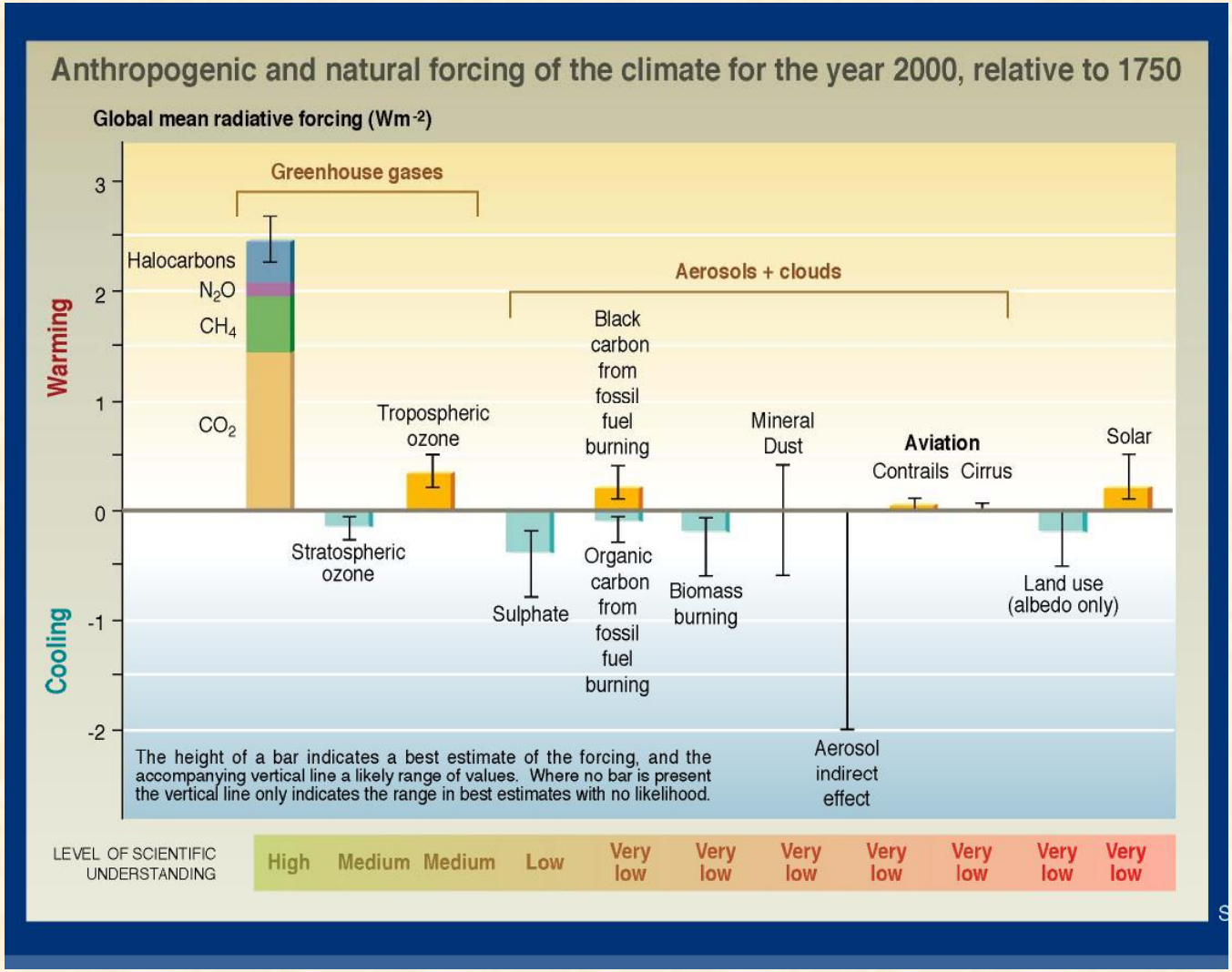
Fall Creek Falls Conference
Nashville, TN

Sep. 24, 2007

Outline

- Global Earth System Modeling
- Fully Coupled Climate-Carbon-Chemistry Models
- Geophysical Statistics and Ecosystem Niche Evolution (1870-2100)
- Global Satellite – Climate Model Merge
- Financial impacts from changing energy usage

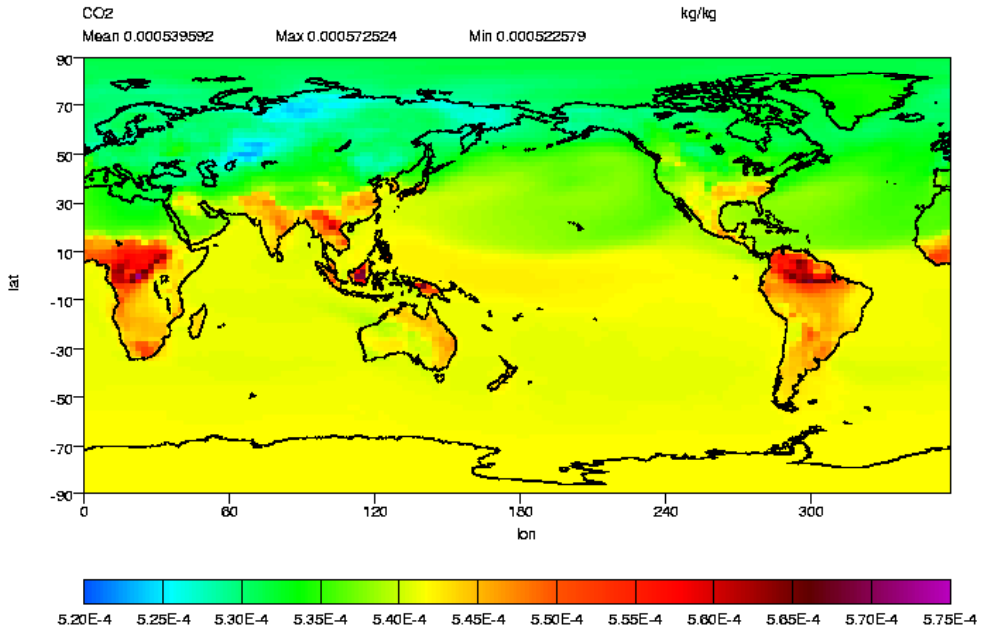
Biogeochemical Forcing on Climate



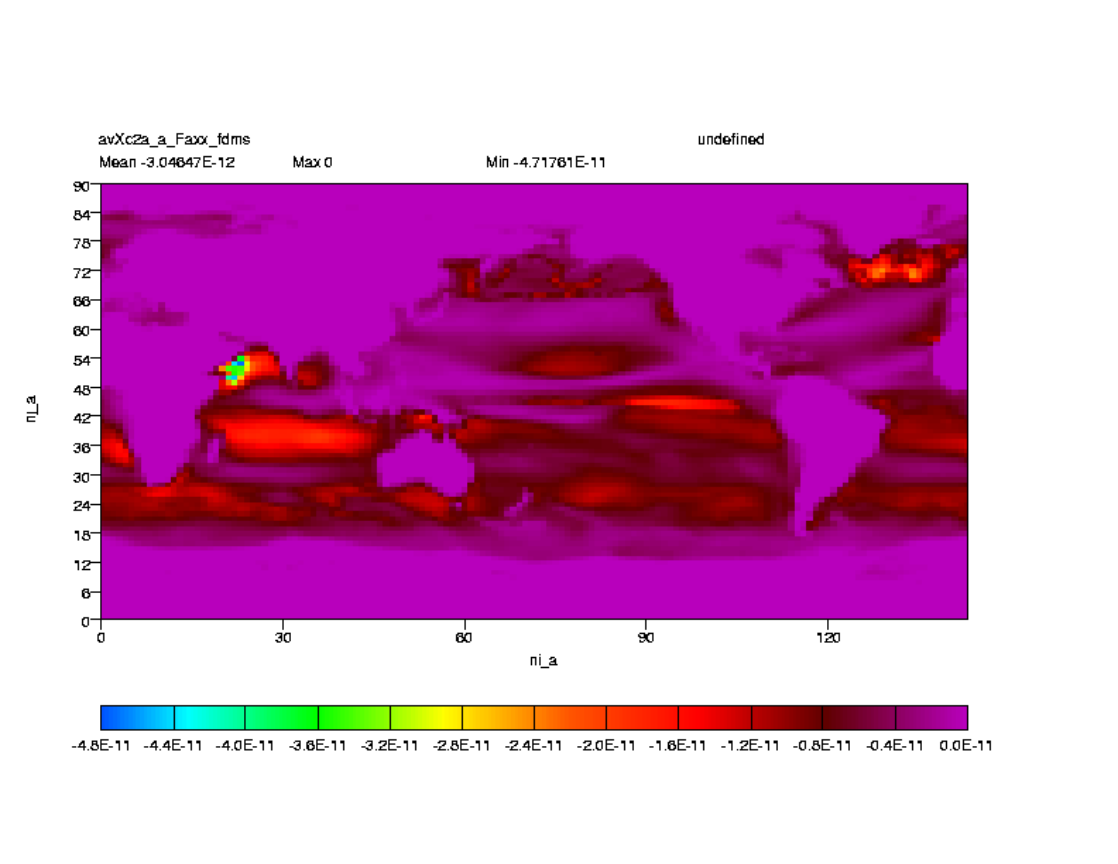
Fully coupled biogeochemistry-physical climate simulation

- **Infrastructure of CCSM3**
- **CAM3 atmosphere with MOZART chem**
- **POP2 with ecosystem-trace gas module**
- **CASA' land model in CLM**
- **Explicit coupler between land-ocean-atmosphere**
- **CO2 tracer**
- **DMS tracer**

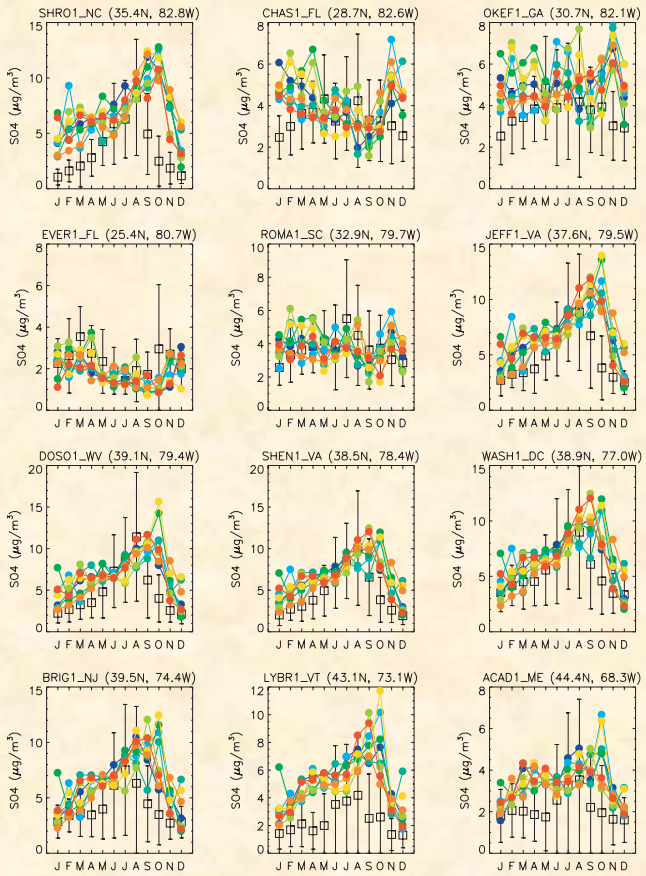
CO2 concentration in lowest atmospheric level



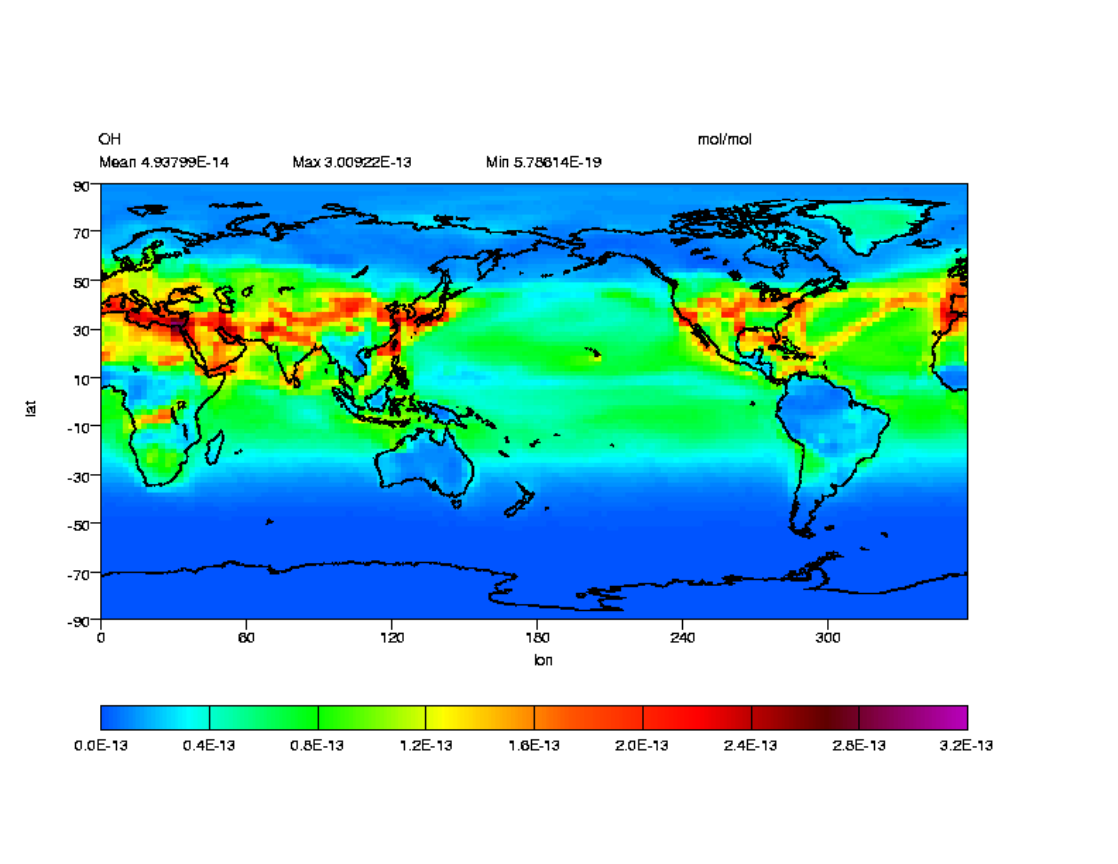
DMS flux IN COUPLER



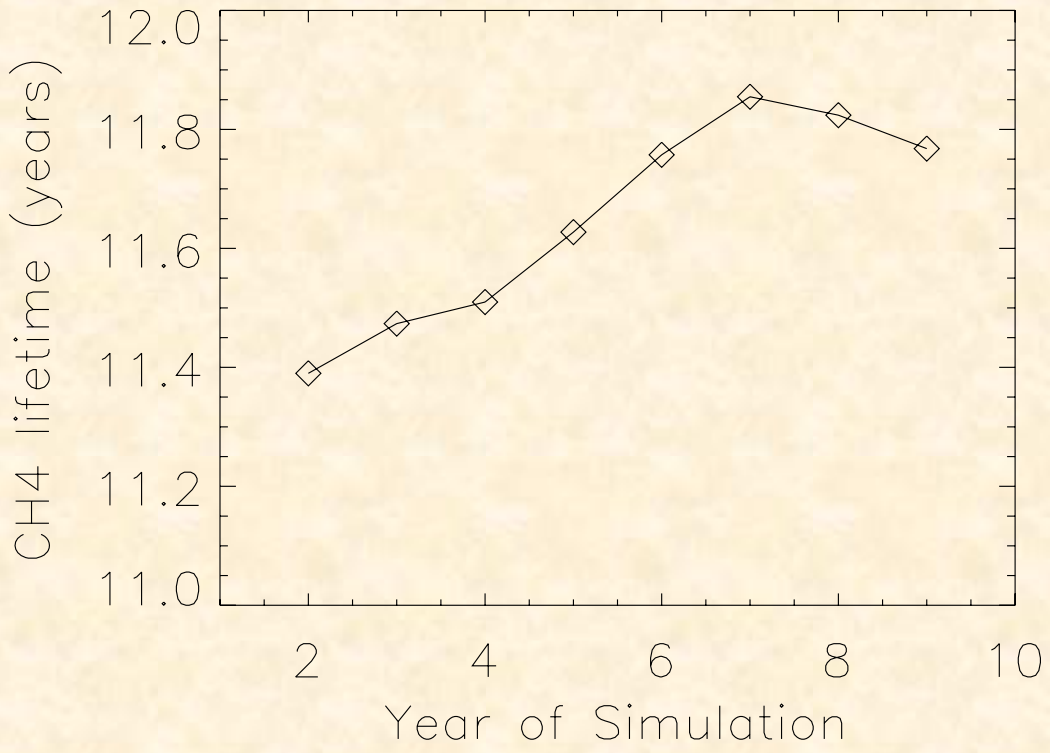
Model-observations for land stations



Atmospheric OH concentration for July



Residence time of atmospheric CH_4



Thompson et al. (2004) Coupled Climate-Carbon model (PCM-IBIS)

Climate Model:

NCAR-DOE Parallel Climate Model 2 (PCM2, *aka* PCTM)
- **CCM3 atmospheric GCM (T42, L18 resolution)**
- **POP oceanic GCM (2/3º, L40 resolution) with dynamic sea ice**

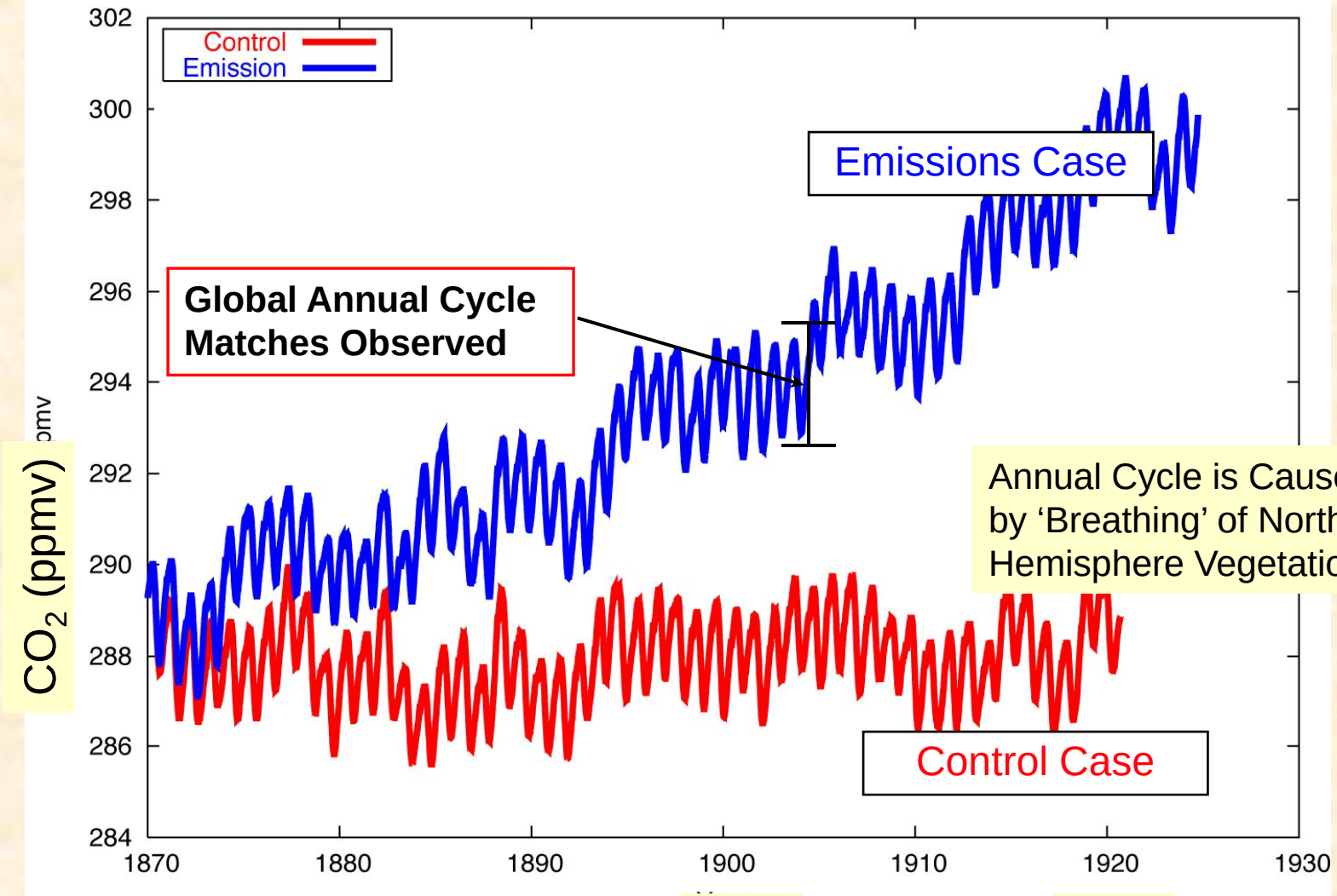
Terrestrial Biosphere Model:

University of Wisconsin Integrated Biosphere Simulator 2 (IBIS-2)
- **Vegetation biophysics, carbon cycling, and dynamics**
- **No nitrogen cycling or acclimation (yet)**
- **Dynamic potential natural vegetation (no land use change)**

Ocean Carbon Cycle Model:

LLNL Variant of OCMIP Biotic Protocols
- **Biological production: f(light, dissolved inorganic phosphate)**
- **No Fe limitation or zooplankton grazing**

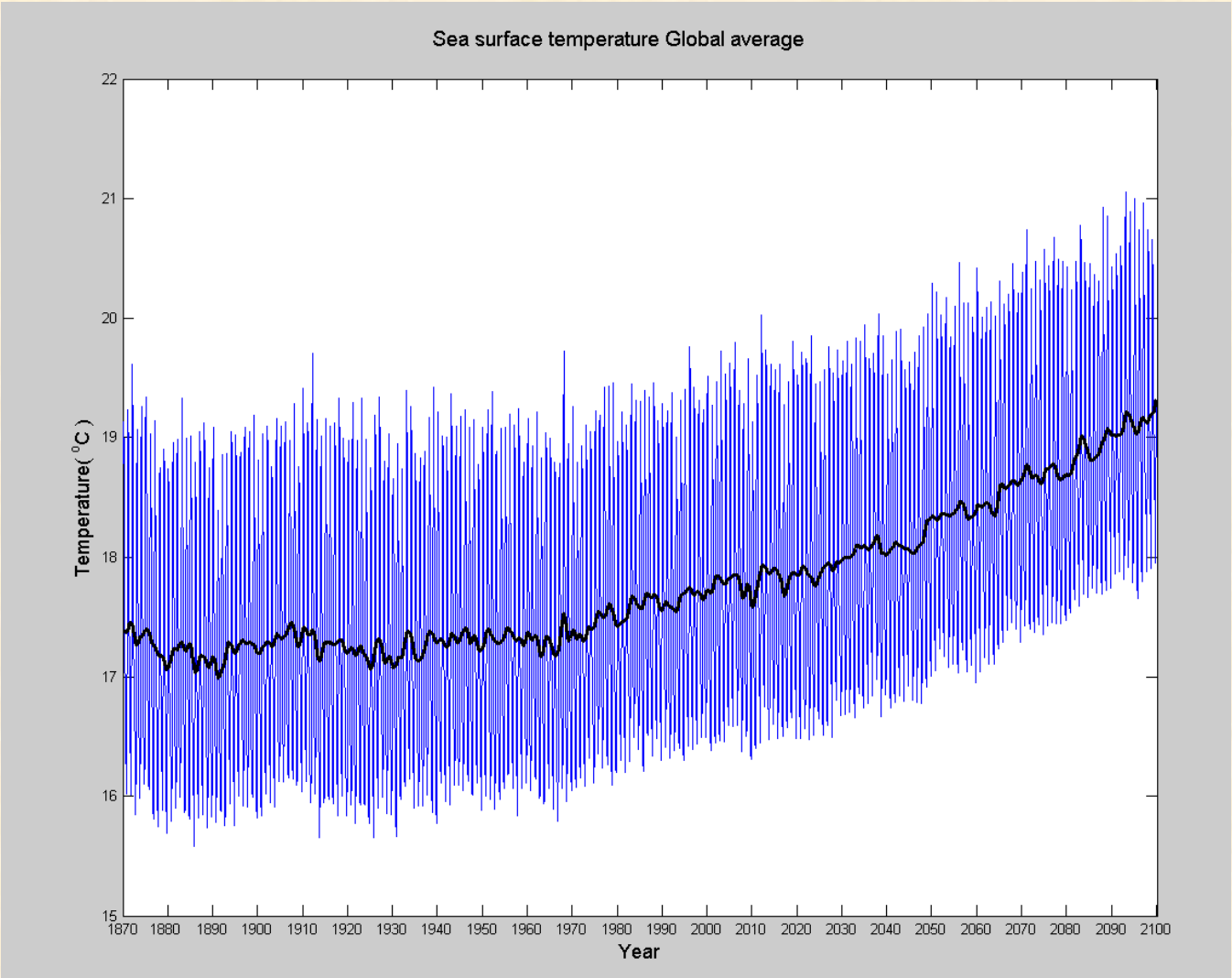
Simulated Atmospheric CO_2: 1870-1920



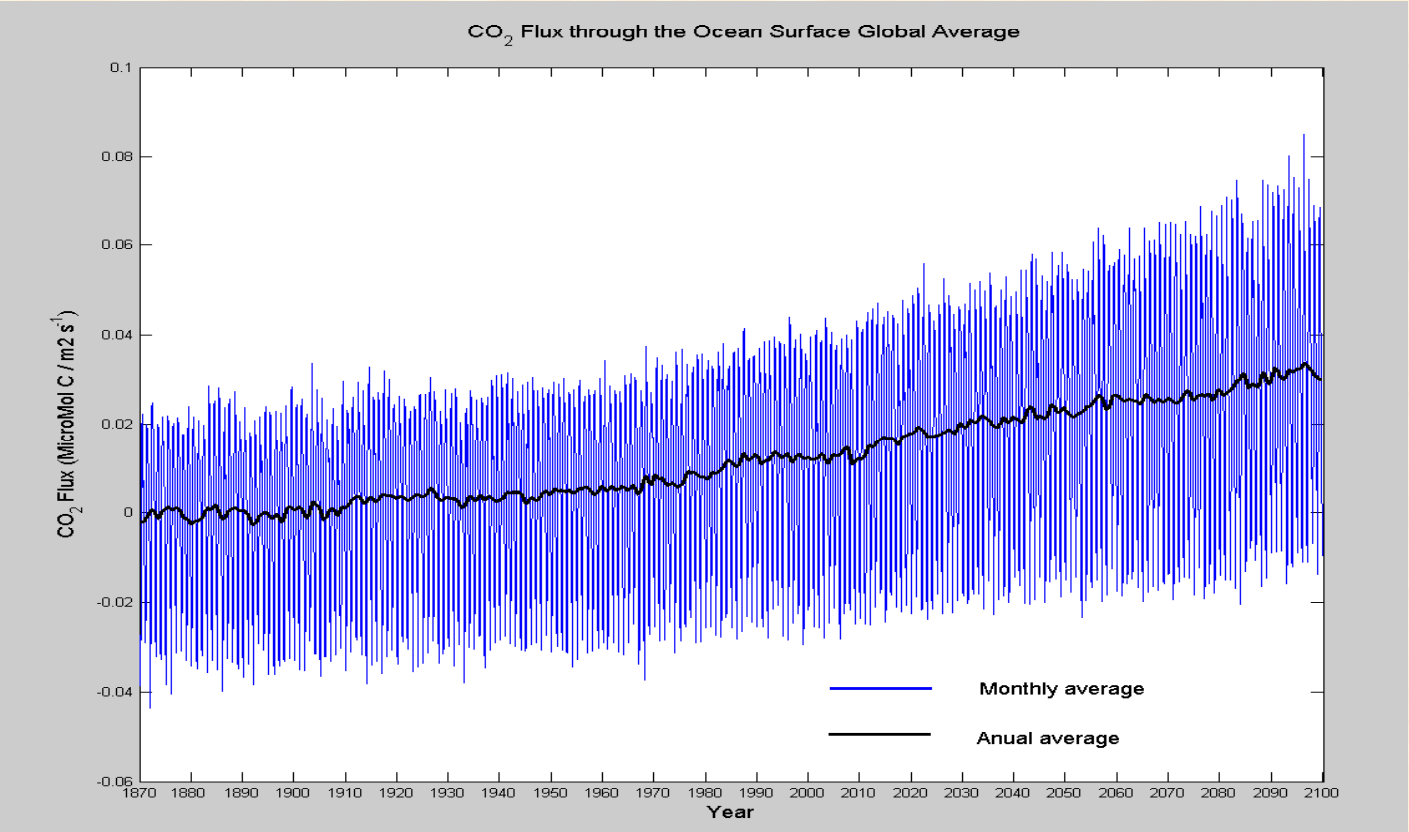
1880 **1900** **1920**

Year

PCM-IBIS surface ocean temps



PCM-IBIS Global air-sea CO2 flux time series



Fate of Anthropogenic Carbon Dioxide in the Standard Emissions Case

1871-1920

Land	**……**	**39%**
Ocean	**……**	**22%**
Atmosphere	***…..***	***39%***

1971-2000

Land	**……..**	**38%**
Ocean	**……..**	**21%**
Atmosphere	***……***	***41%***

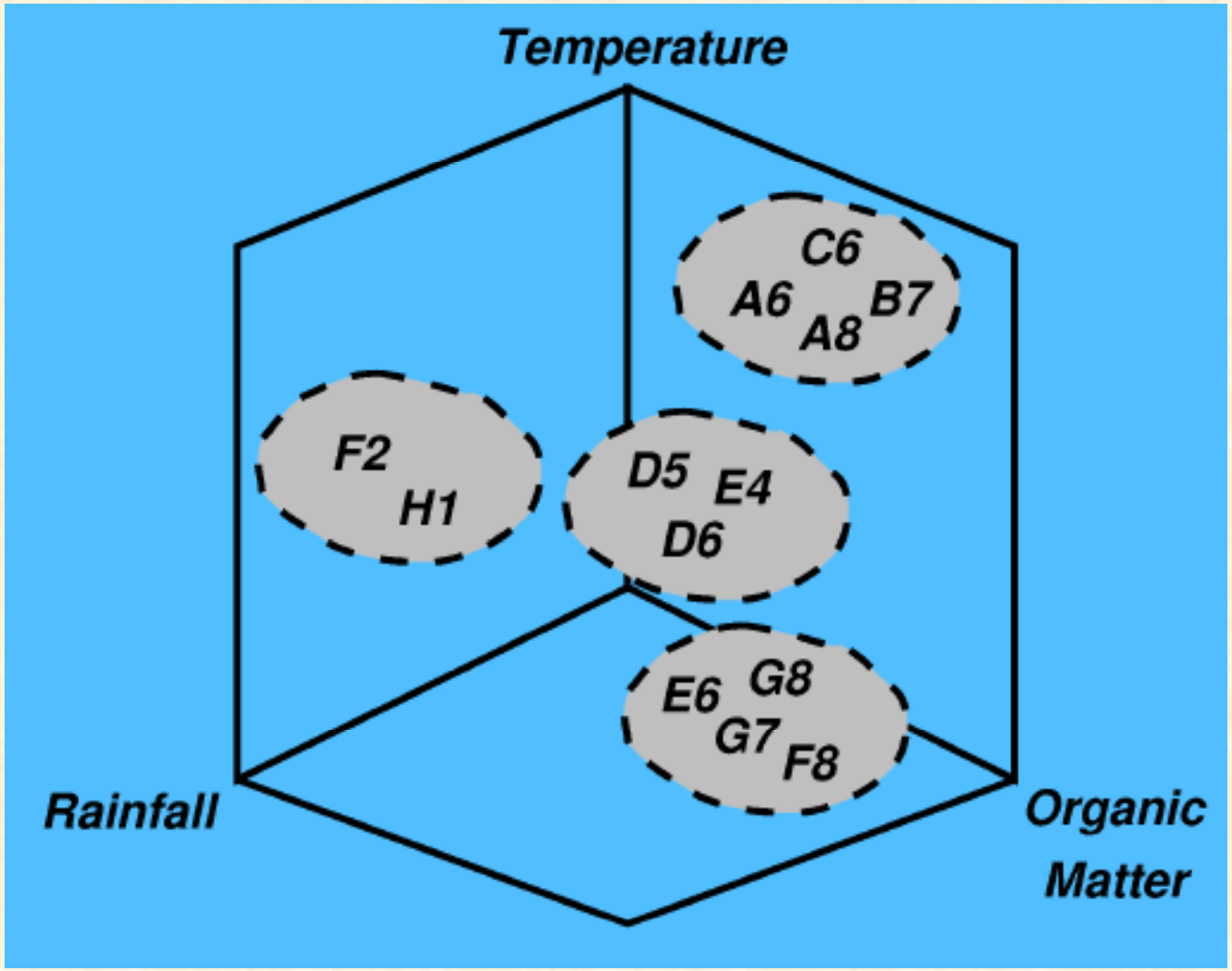
Atmospheric 'airborne fraction' increases over time from 39% to 47% as the earth system's ability to take up CO_2 declines.

2071-2100

Land	**……**	**36%**
Ocean	**……..……**	**17%**
Atmosphere	***……***	***47%***

Ecosystem Niche Evolution Computed from A Fully Coupled Climate Model (PCM) for the time period 1870-2100

Ecosystem Niche Clustering



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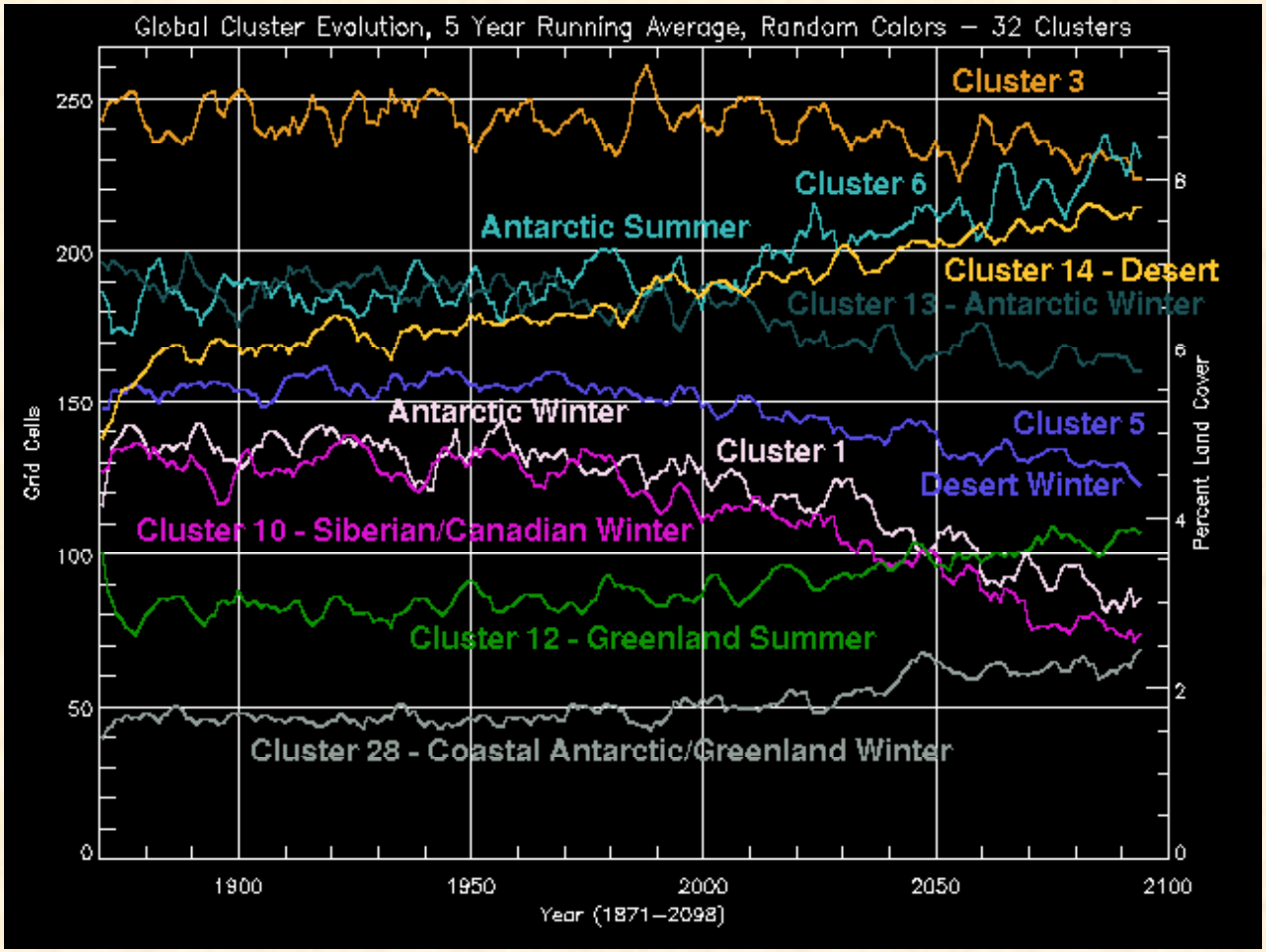
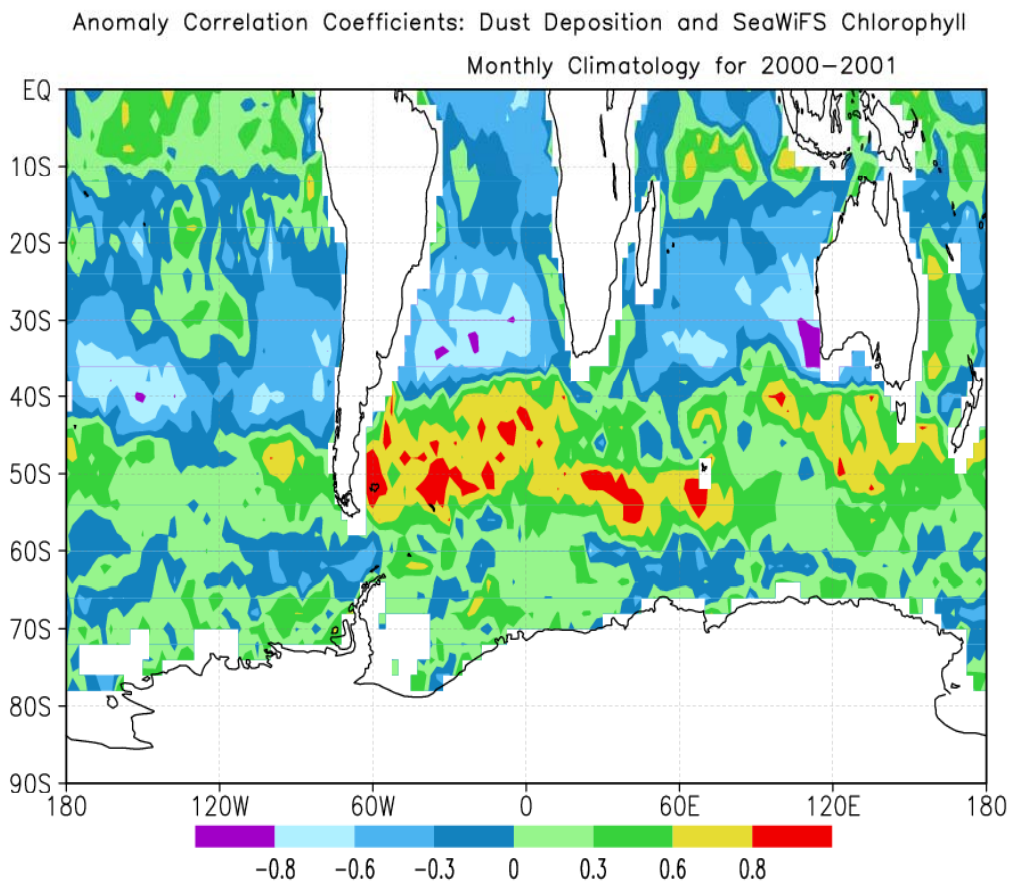
Time Trend of Cluster Changes (1870-2100)



Coupling Climate Models with NASA Satellite Data

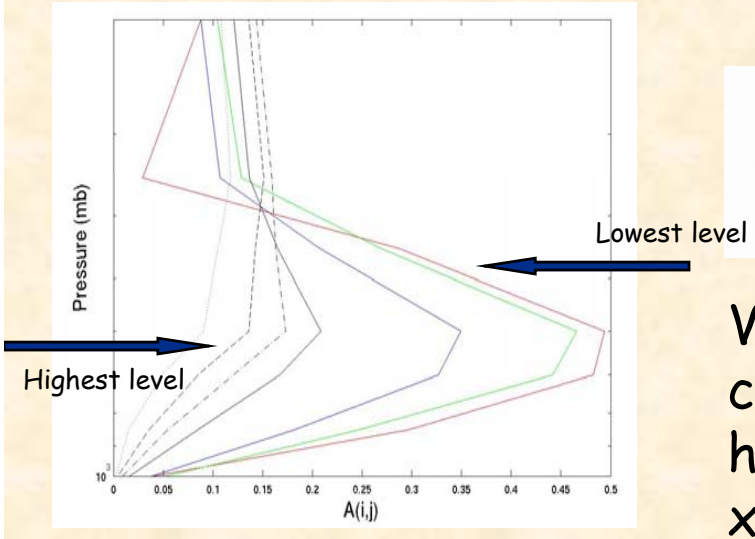
- Global Atmospheric Dust Simulation Based on NASA DAS (Ginoux et al., 2001)
- Coupled for statistical analysis with SeaWifs ocean color

Erickson et al., Geophys. Res. Lett., 2003

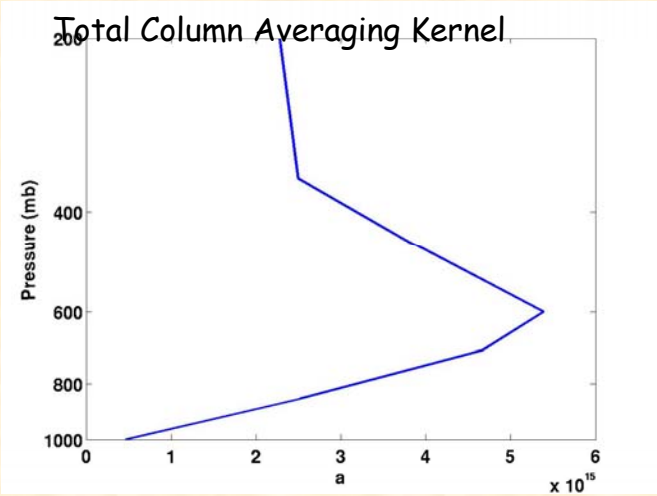


MOPITT total column operator

Averaging Kernel: Sensitivity of each retrieval level



$$c^f = h(x^f) = c^{ap} + \sum_{j=1}^{nlevels} a_j (x_j^f - x_j^{ap})$$



Where:

c^f=total column CO forecast (molecules/cm^2)

$h(x^f)$=observation operator

x^f_j=layer mean CO mixing ratio

x^{ap}_j= a priori layer mean CO mixing ratio

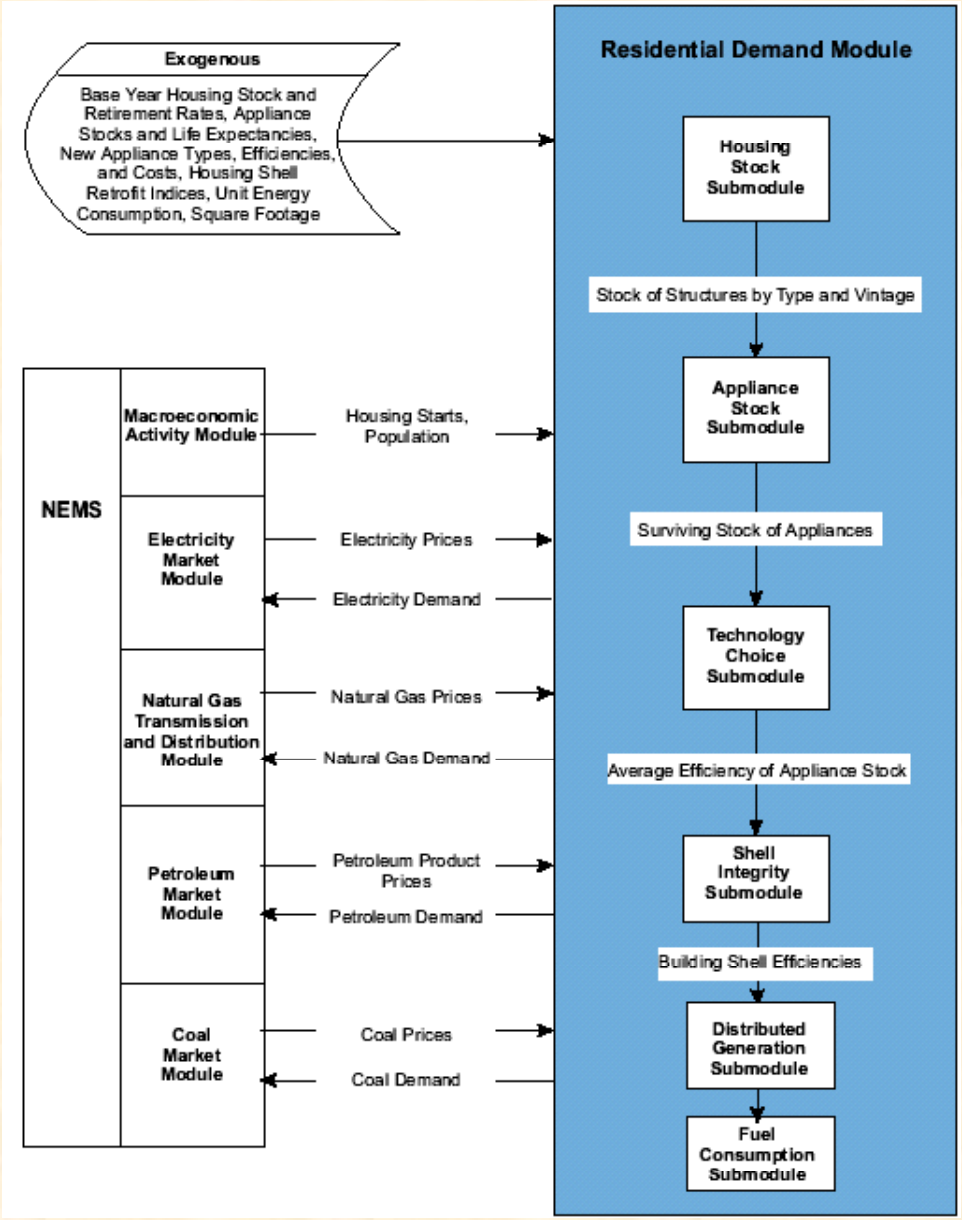
c^{ap}=a priori total column

a_j= Total column averaging kernel

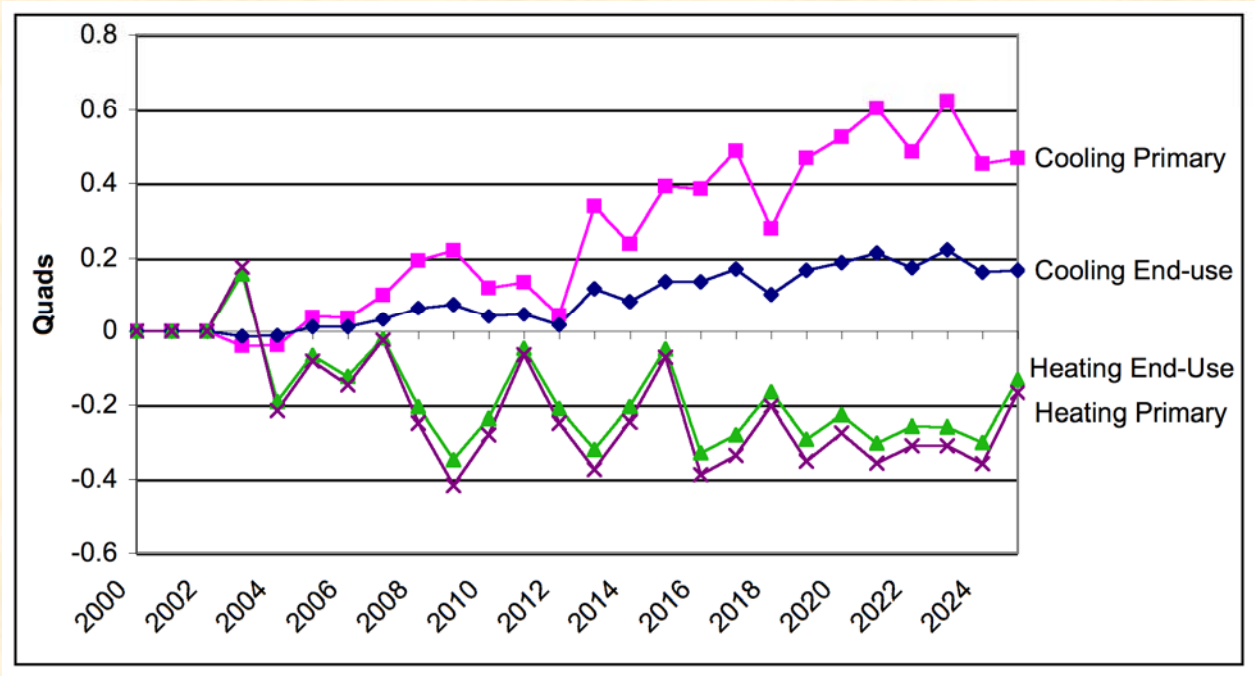
= (averaging kernel)x (Δp_j)x(2.12×10^{13})

Financial impact of temperature change

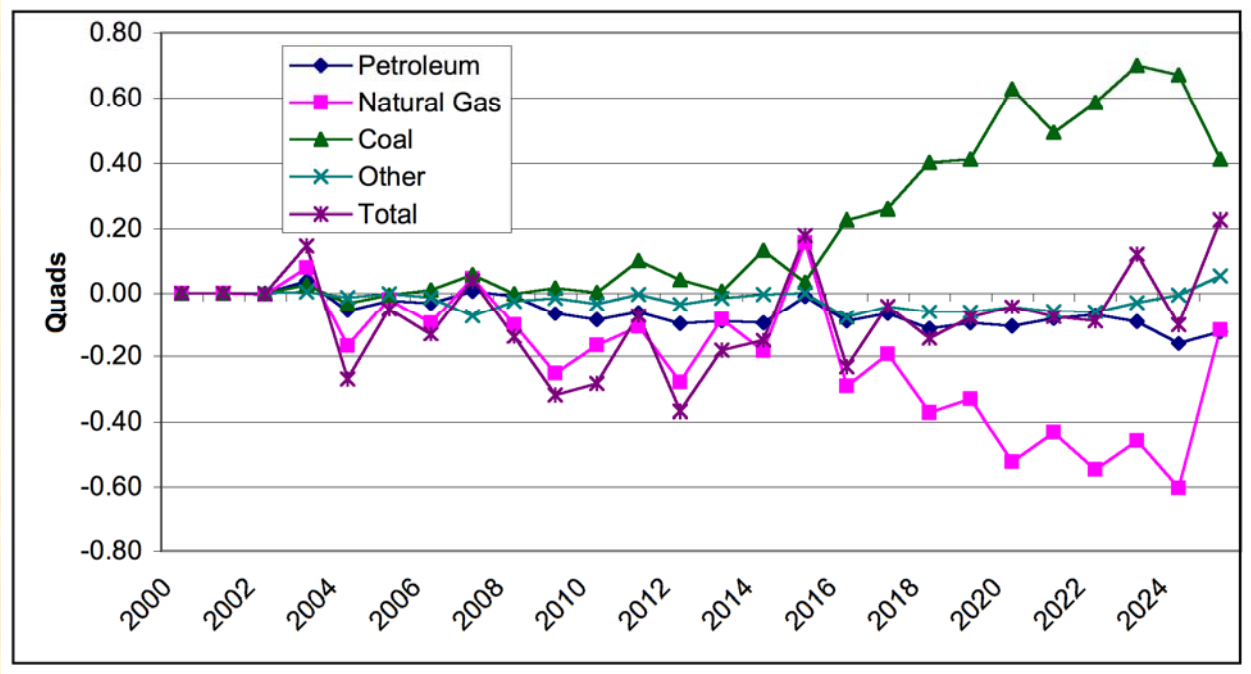
- **Creation of a unique, algorithmic, quantitative modeling structure that uses global GCM output to drive a state-of-the-art energy usage model**
- **Extreme events**


Exogenous
Base Year Housing Stock and Retirement Rates, Appliance Stocks and Life Expectancies, New Appliance Types, Efficiencies, and Costs, Housing Shell Retrofit Indices, Unit Energy Consumption, Square Footage
Residential Demand Module
Housing Stock Submodule
Stock of Structures by Type and Vintage
Appliance Stock Submodule
Surviving Stock of Appliances
Technology Choice Submodule
Average Efficiency of Appliance Stock
Shell Integrity Submodule
Building Shell Efficiencies
Distributed Generation Submodule
Fuel Consumption Submodule
NEMS
Macroeconomic Activity Module
Housing Starts, Population
Electricity Market Module
Electricity Prices
Electricity Demand
Natural Gas Transmission and Distribution Module
Natural Gas Prices
Natural Gas Demand
Petroleum Market Module
Petroleum Product Prices
Petroleum Demand
Coal Market Module
Coal Prices
Coal Demand

Change in heating and cooling end-use and primary energy



Change in national energy demand by fuel type



Climate Model Challenge Areas

- **High Resolution in Space and Time**
- **Fully coupled carbon-chemistry (Biogeochemistry) – Time Scales of Nano-seconds to Hundreds of Years (15 orders of magnitude)**
- **High end statistical methods inserted into climate models**
- **Massive Peta-Scale satellite data streams ingested in free running climate models (OCO NASA Mission)**
- **Policy/economic modeling**
- **Fully coupled Earth System Models (ESM) – Definition is evolving…..**