Lawrence Livermore National Laboratory

Toward Regional Fossil Fuel CO_2 Emissions Verification Using WRF-CHEM

Branko Kosović, Luca Delle Monache,

Philip Cameron-Smith, Dan Bergmann, Keith Grant, Tom Guilderson

9th WRF Users Workshop, Boulder, CO, June 26, 2008

Lawrence Livermore National Laboratory, P. O. Box 808, Livermore, CA 94551

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

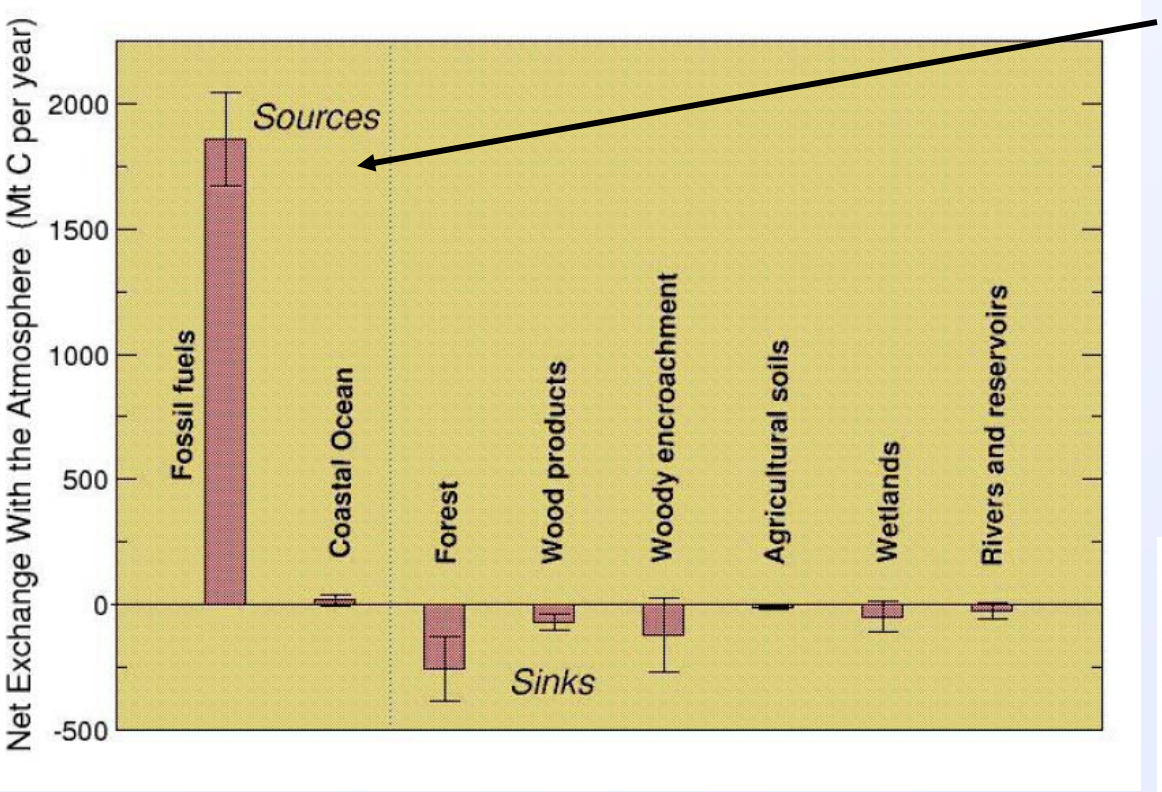
LLNL-PRES-404890

AB32 Calls for a 25% Reduction in GHG Emissions by 2020

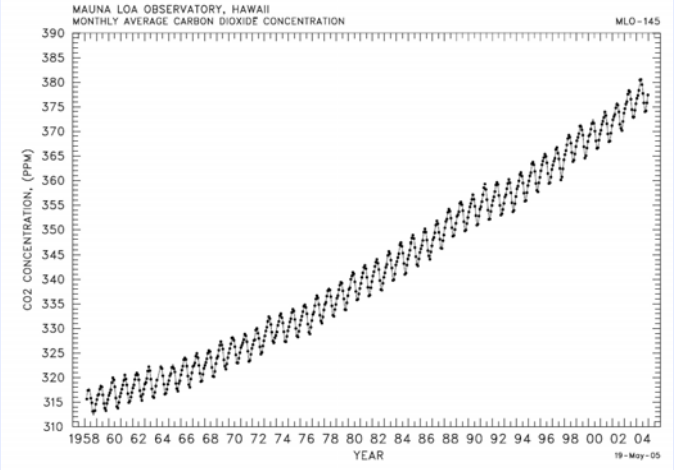
- **The California Air Resources Board (CARB) has the responsibility for monitoring greenhouse gas emissions on an annual basis and enforcing compliance**
- **Existing estimation methods are inadequate/insufficient for this task**
- **Scientifically defensible methods for verification of emissions at regional scales will require significant measurement expertise coupled with the development of inversion models to accurately constrain sources**

To address this problem it is essential to couple capability for ^{14}C analysis by accelerator mass spectrometry with atmospheric modeling

Fossil-fuel Emissions are Responsible for the Net Increase in Atmospheric CO_2



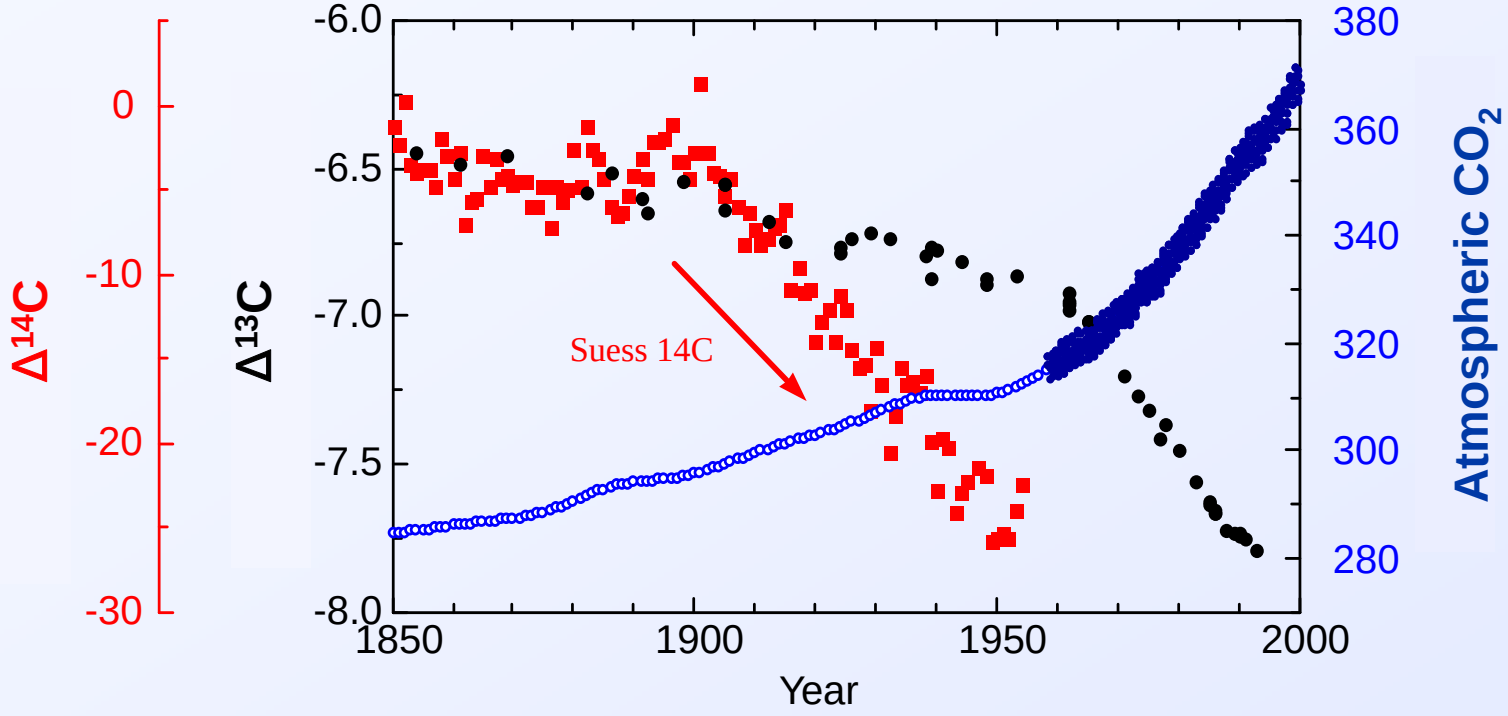
- **Due to uncertainties in fuel consumption and oxidation efficiencies, estimates of carbon emissions have initial uncertainties of at least ± 10%**
- **Because carbon trades at $4-30 ton, this uncertainty has significnat economic implications**



***State of the Carbon Cycle Report, v 2.2 (2007)**

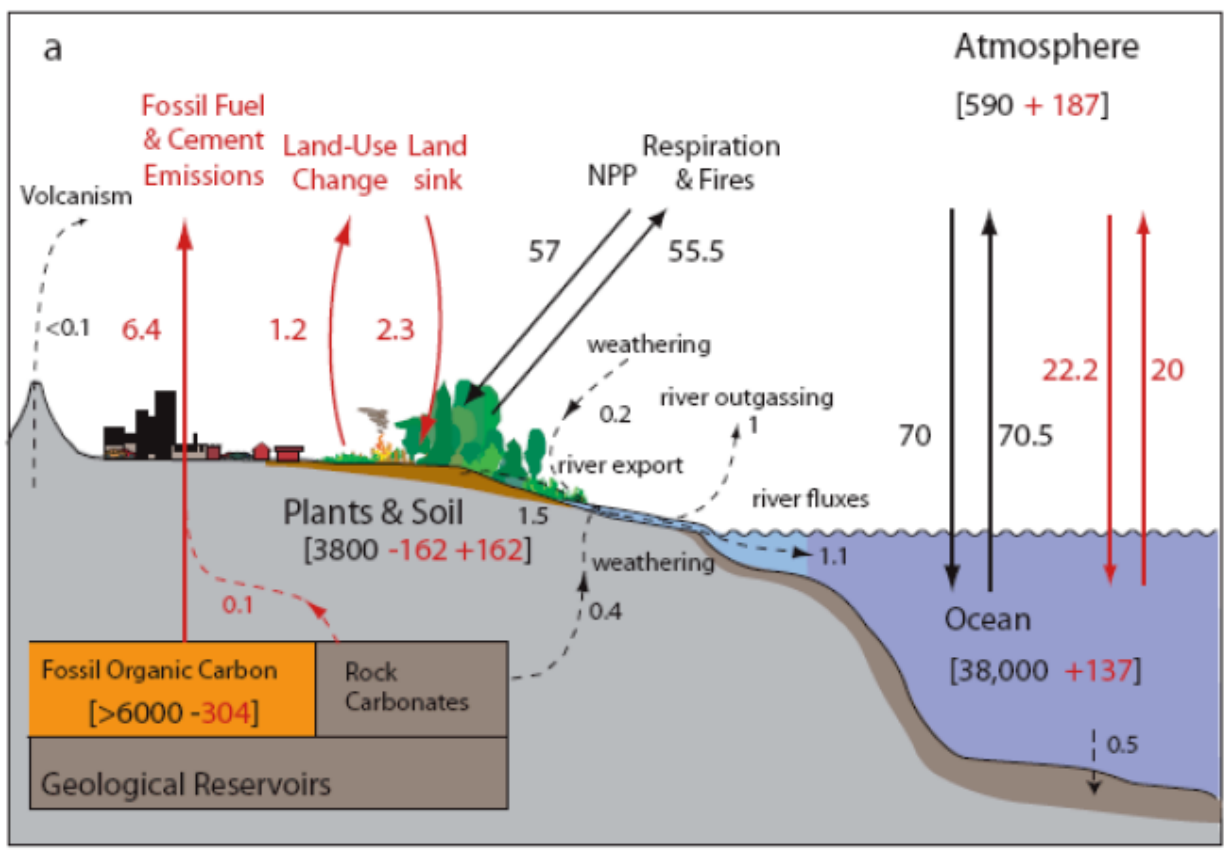
C.D. Keeling and T.P. Whorf

$^{14}CO_2$ Can Be Used As a Fossil Fuel CO_2 Tracer



- **Atmospheric CO_2, $\Delta^{13}C$, and $\Delta^{14}C$ as reconstructed in tree-rings and ice cores for the pre-atmospheric weapons testing. The decrease in $\Delta^{14}C$ and $\Delta^{13}C$ is caused by the burning of fossil fuels.**
- **Present day atmospheric $^{14}CO_2$ has returned to near "pre-bomb" levels.**

Fossil Fuel Emissions are Embedded in the Carbon Cycle



- **Fossil fuel CO_2 does not contain ^{14}C because this isotope has naturally decayed**
- **Measuring $^{14}CO_2$ to ≤2‰ will allow us to estimate fossil fuel CO_2 to 2ppm out of 380ppm**

From: "The First State of the Carbon Cycle Report" 2007.

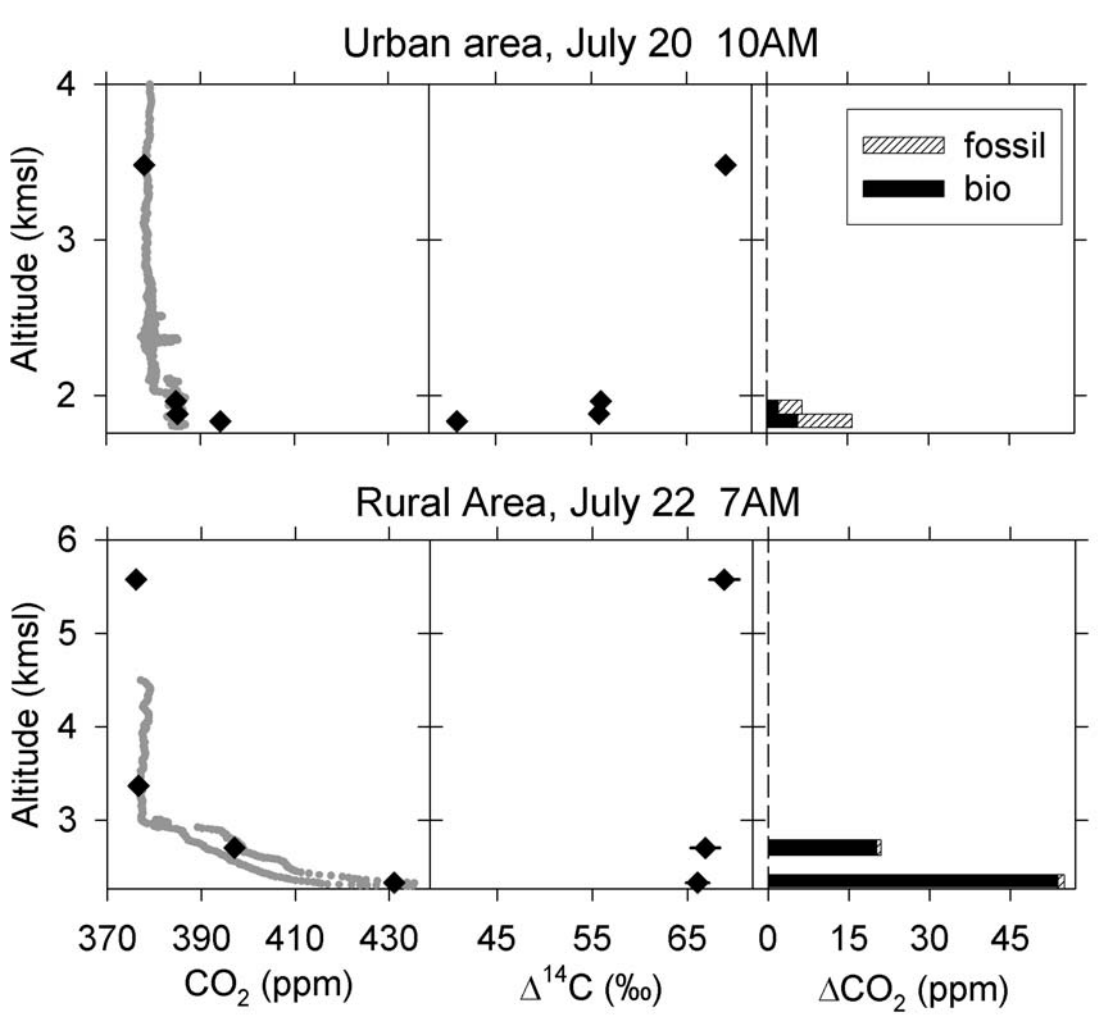
Black = pre-industrial carbon

Red = anthropogenic carbon

The Goals is to Develop End-to-end Prototype Fossil Fuel Emissions Verification Capability for Sources in California

- **First temporal evaluation of fossil fuel emissions (FFE) ($^{14}CO_2$) coupled with combustion tracers for a major metropolitan areas (San Diego and Sacramento)**
- **The goal is to develop and demonstrate a viable fossil fuel CO_2 emissions verification methodology based on integrating measurements and modeling**
- **Fossil fuel CO_2 emissions verification capability could have applications for carbon management strategies (e.g., carbon offsets)**

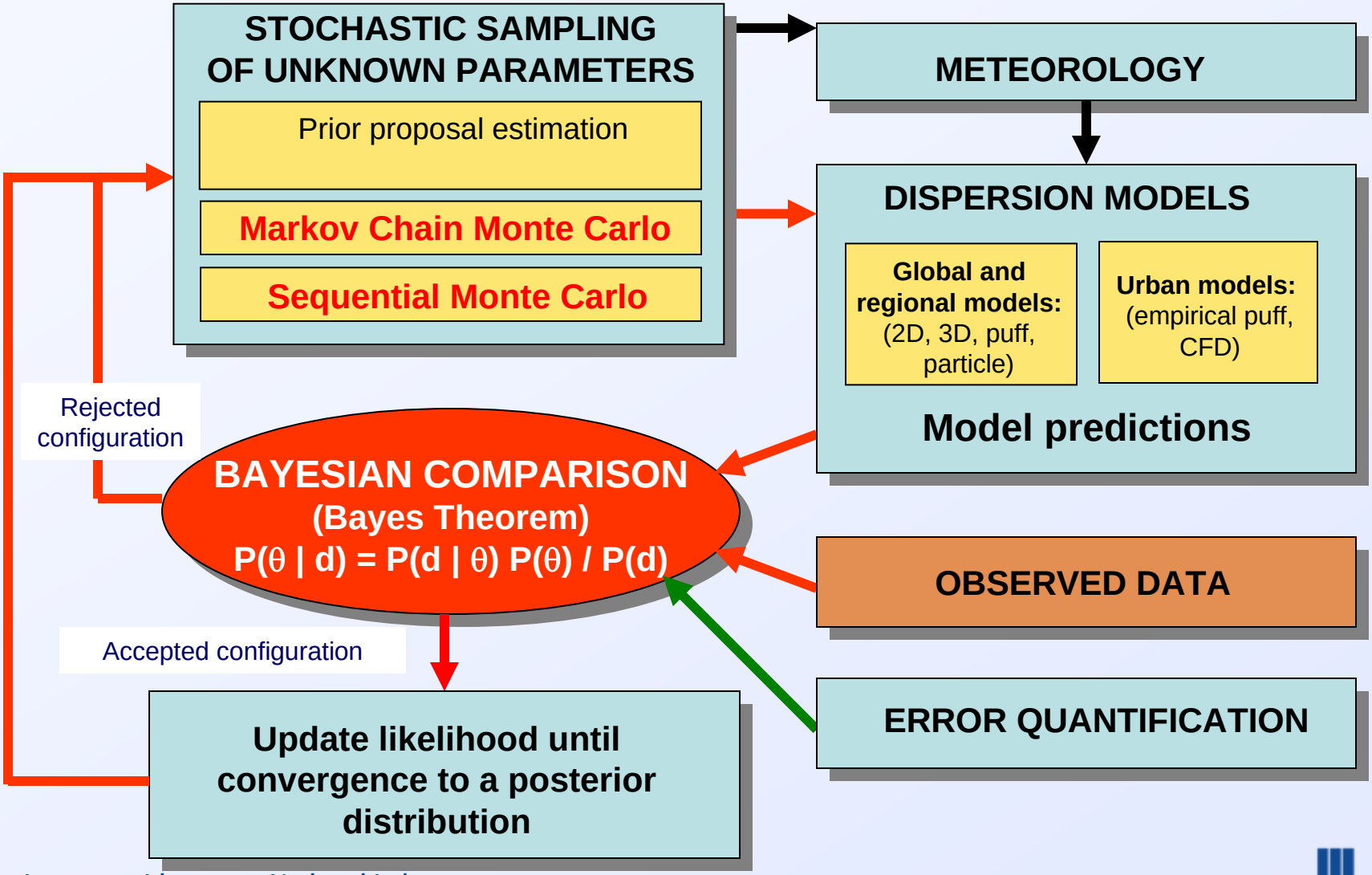
By Measuring Total CO_2 and ^{14}C We Can Distinguish Fossil Fuel Emissions from Bio Emissions



- **Measured CO_2 (in situ shown in gray), $D^{14}C$ and calculated FF-CO_2, and Bio-CO_2 for profiles sampled in the morning in an urban area (top) and a rural area (bottom) in Colorado**
- **Urban CO_2 is dominated by FF**
- **Rural CO_2 is dominated by biogenic sources**

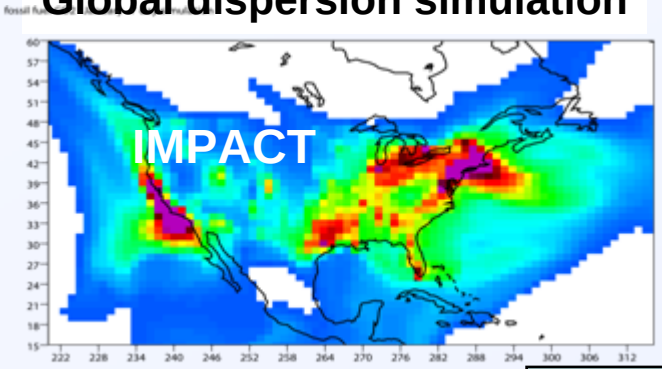
Graven et al., submitted to Geophys. Res. Letts.

Predictive Models and Data are Coupled With Bayesian Inference and Stochastic Sampling



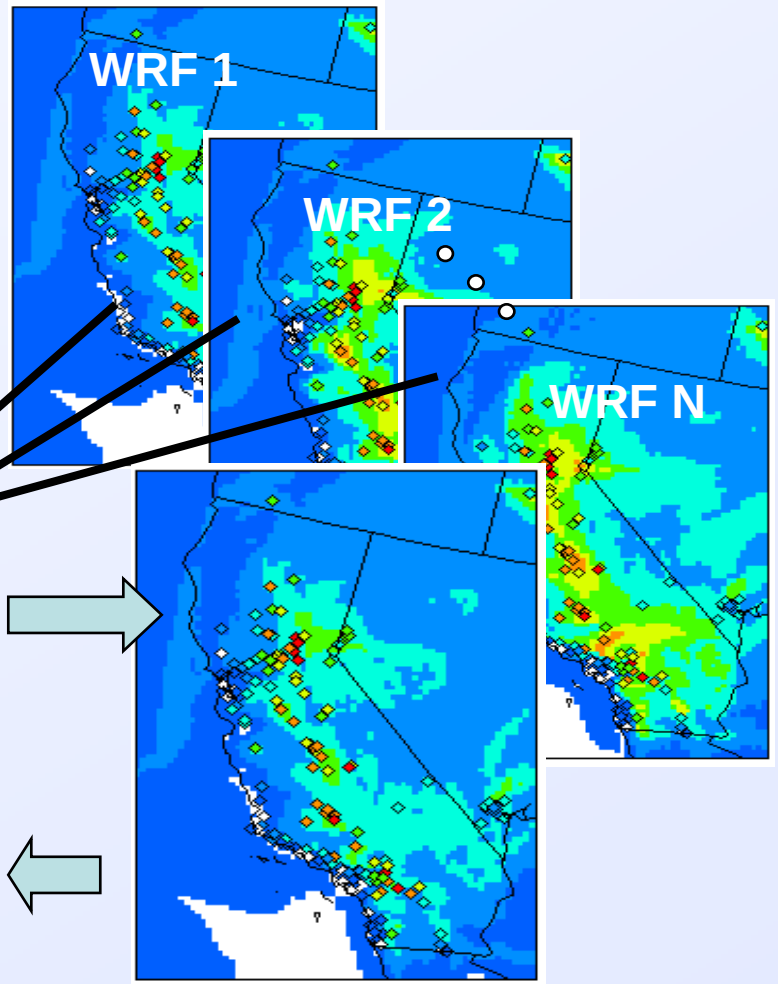
Predictive Models and Data are Coupled With Bayesian Inference

Global dispersion simulation



Boundary Conditions

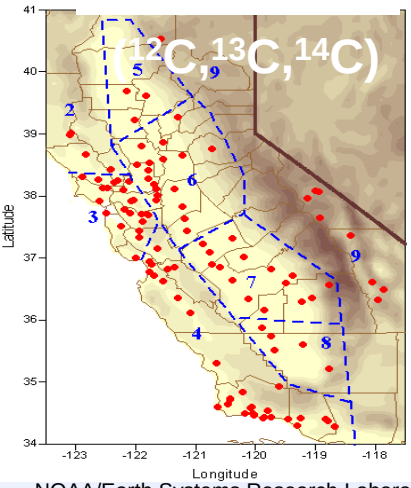
Library of regional dispersion simulations



Update likelihood
(until convergence to posterior distribution)

Stochastic sampling of emission rates

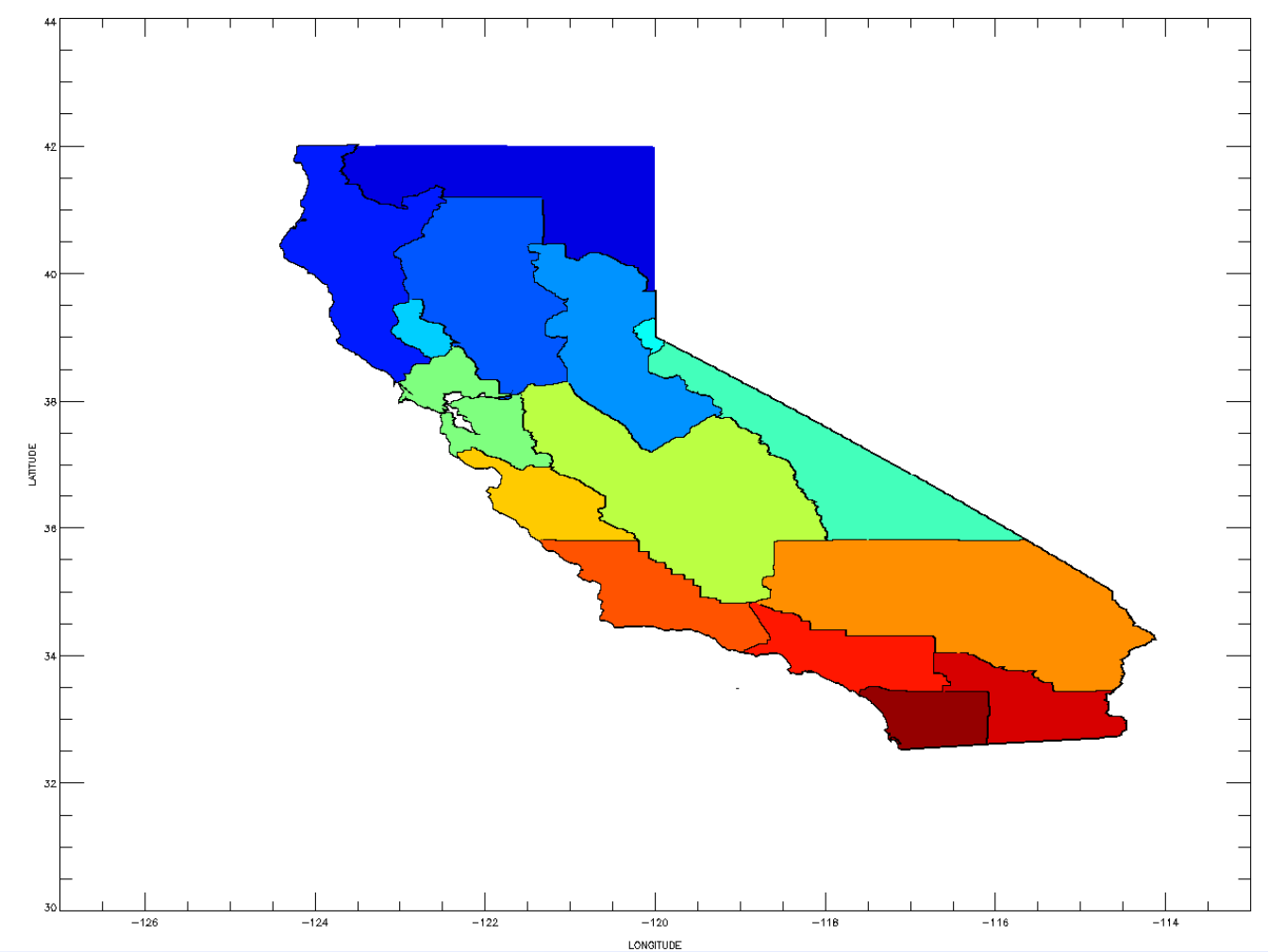
Observations



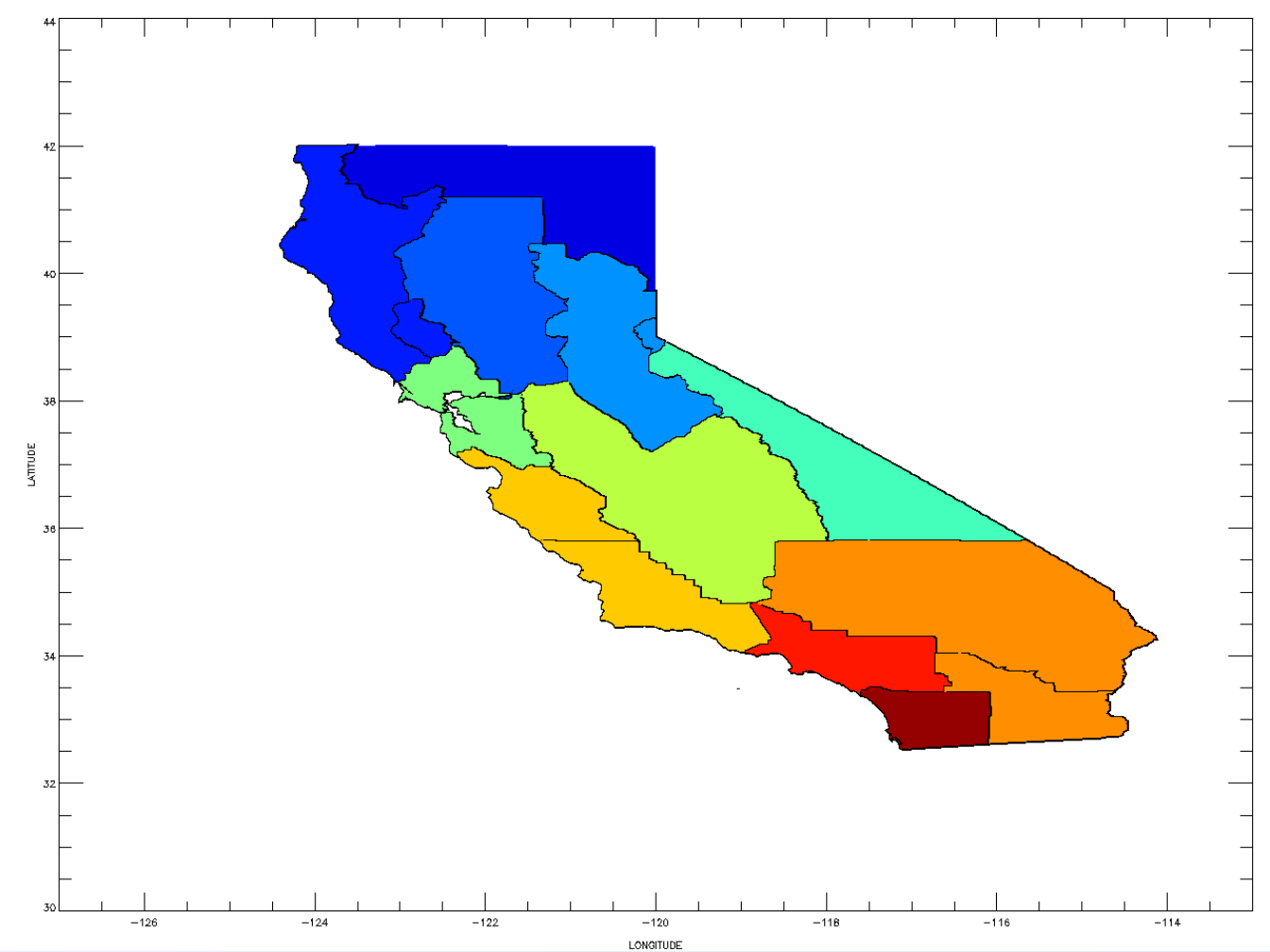
NOAA/Earth Systems Research Laboratory

Bayesian Inference
$P(e|d)=P(d|e)P(e)/P(d)$

California Air Basins and Distributed Emission Sources



California Air Basins and Distributed Emission Sources



San Francisco and LA Air Basin Emissions

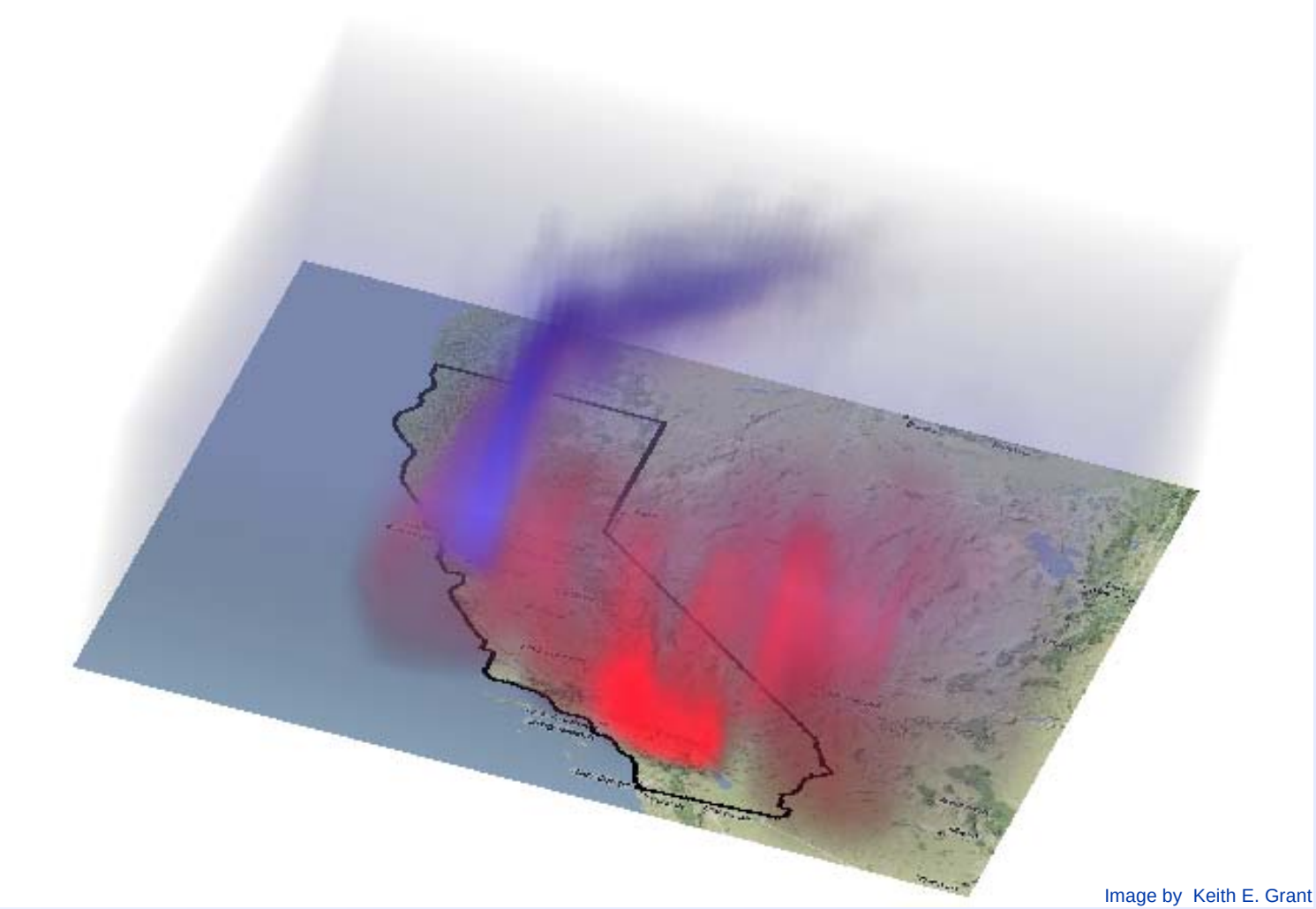
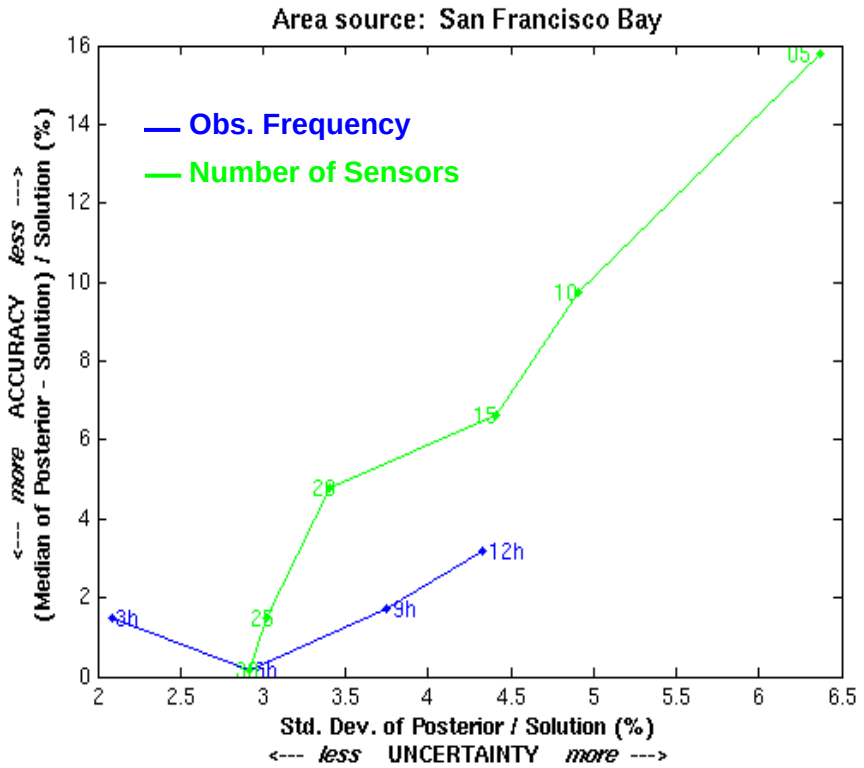
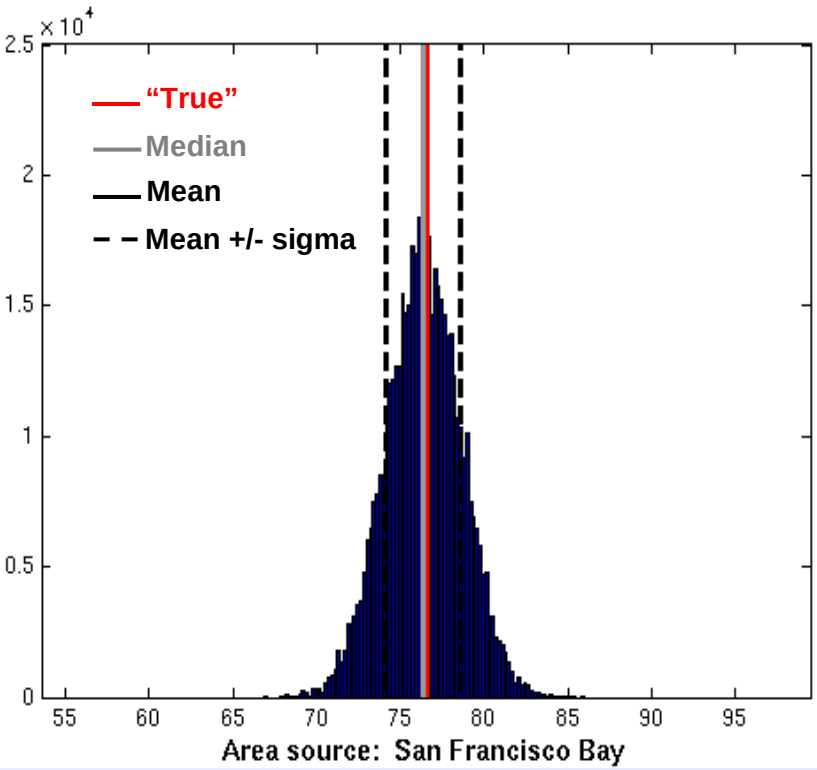


Image by Keith E. Grant

Area source “San Francisco Bay” - Posterior Distribution and Sensitivity Analysis of Reconstruction Accuracy and Uncertainty

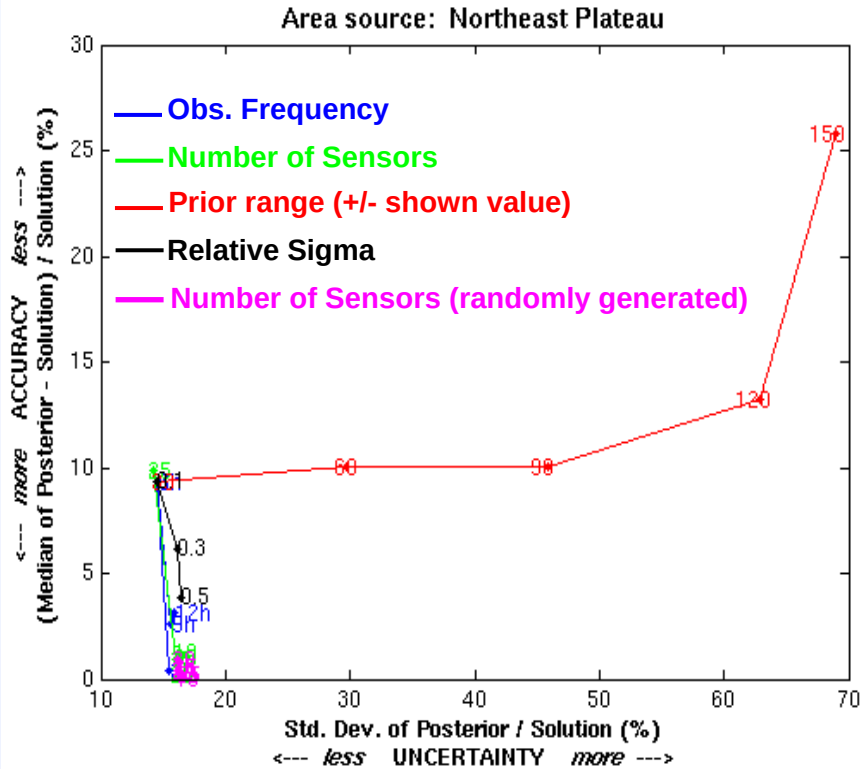


Uncertainty vs Accuracy

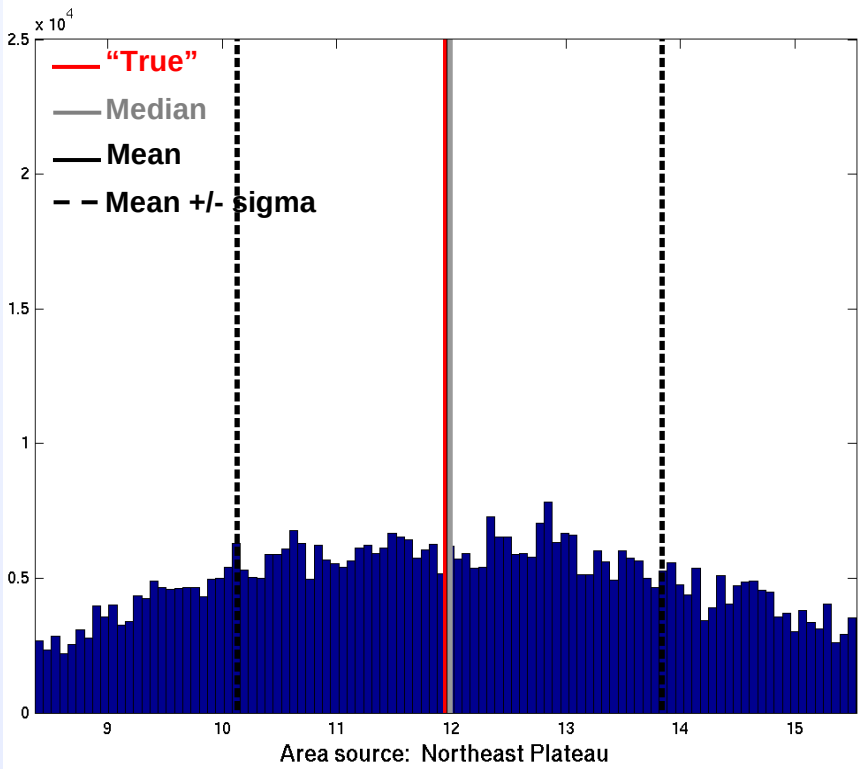


Posterior Distribution

Area Source “Northeast Plateau” -- Posterior Distribution and Sensitivity Analysis of Reconstruction Accuracy and Uncertainty



Uncertainty vs Accuracy

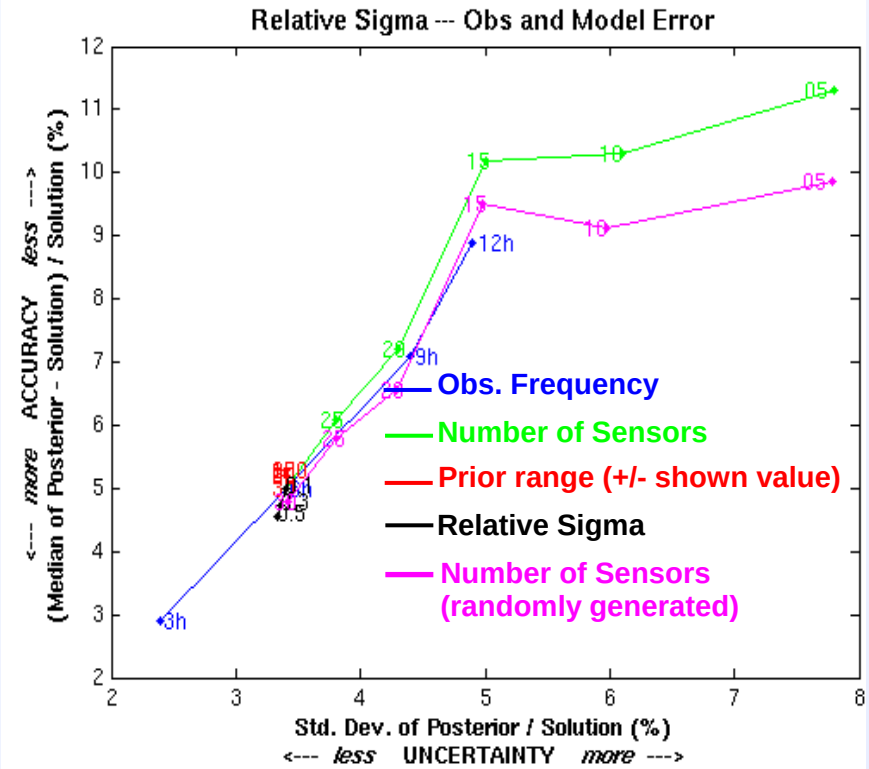


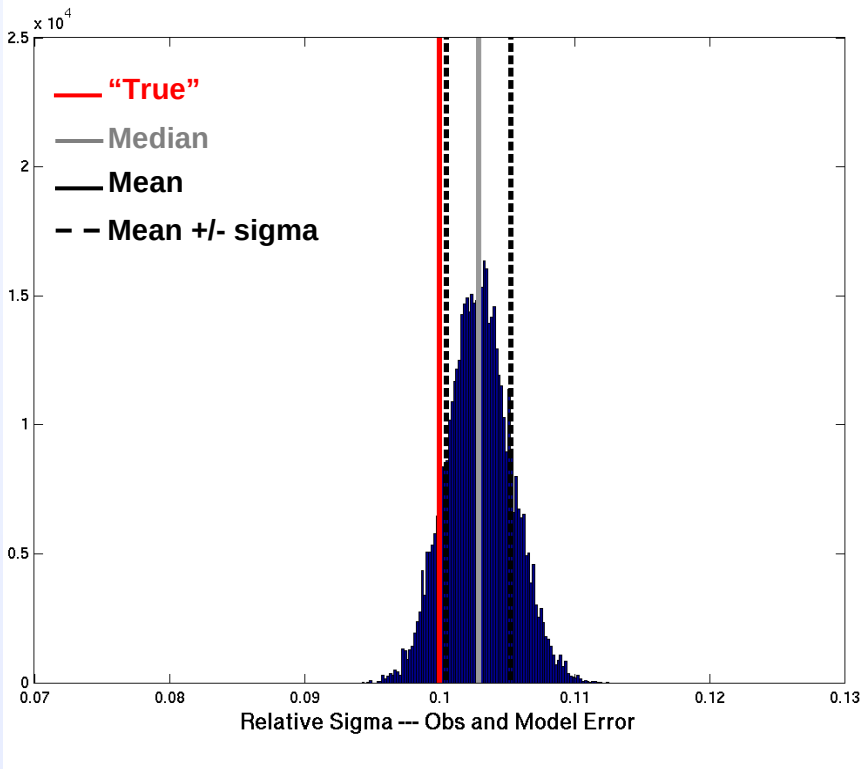
Posterior Distribution

Summary and Future Work

- **Verification of fossil fuel CO_2 emissions will be an essential component of any greenhouse gas control policy**
- **We demonstrated use of WRF-CHEM in a framework with Bayesian inference with stochastic sampling and observations of ^{14}C to quantify fossil fuel CO_2 emissions in California**
- **Future work will include:**
  - **Quantify model error by carrying out ensemble simulations**
  - **Examine diurnal and seasonal variations in emissions**
  - **Include inventories of fossil fuel CO_2 emissions in California when they become available**
- **This general methodology can be applied to other greenhouse gases**

Combined Relative Error (Sigma) - Posterior Distribution and Sensitivity Analysis of Reconstruction Accuracy and Uncertainty

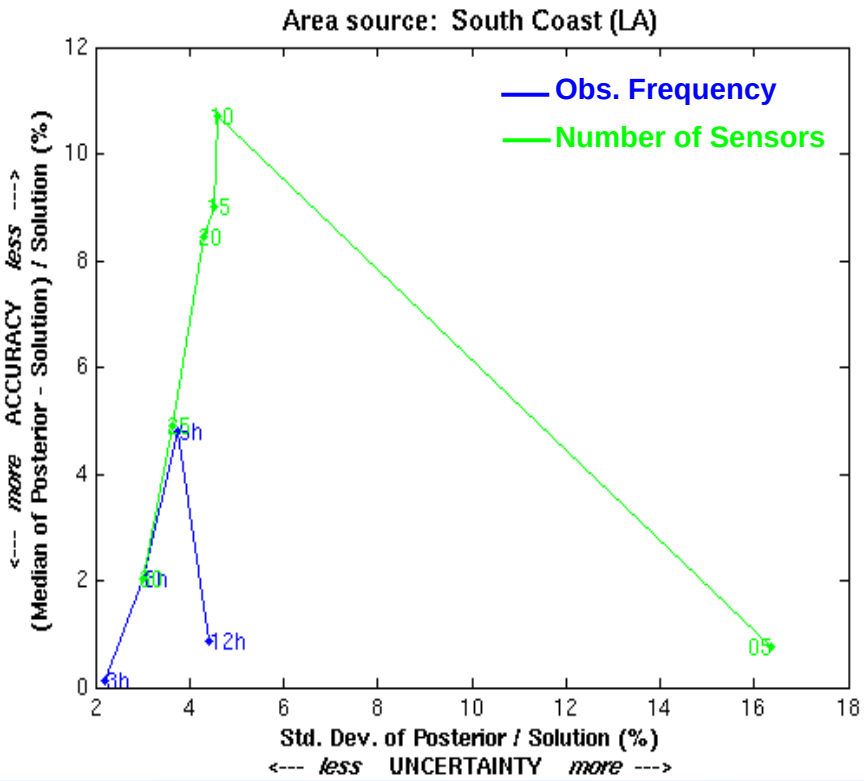




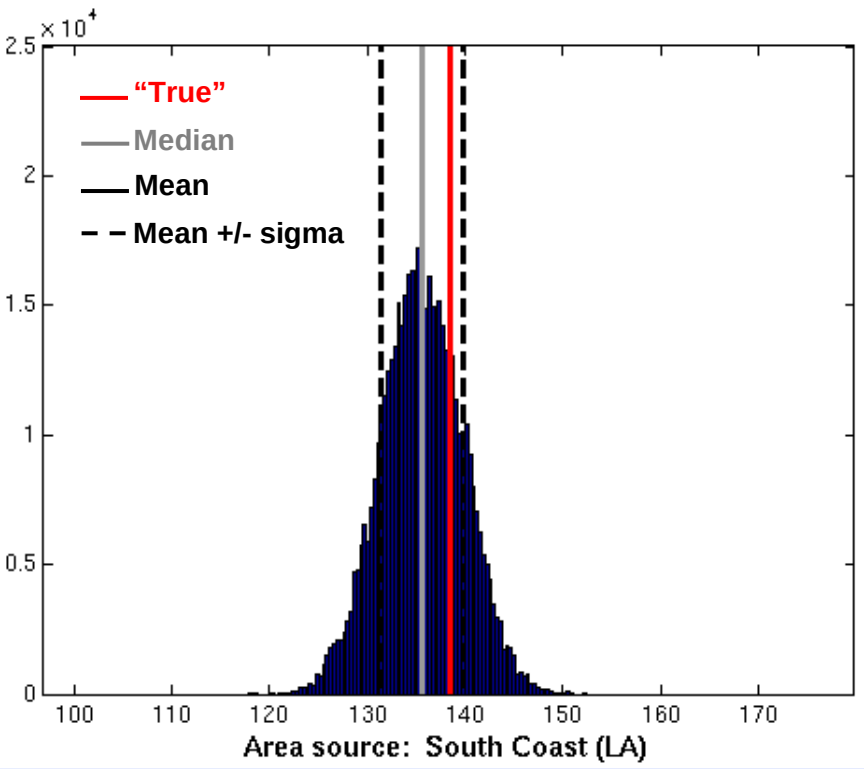
Uncertainty vs Accuracy

Posterior Distribution

Area source “South Coast (LA)” - Posterior Distribution and Sensitivity Analysis of Reconstruction Accuracy and Uncertainty



Uncertainty vs Accuracy



Posterior Distribution