GLOBAL CHANGE

MIT JOINT PROGRAM SCIENCE POLICY

NATIONAL EMISSIONS VERIFICATION

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39^{th} MIT GLOBAL CHANGE FORUM

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CLIMATE MITIGATION

Whether Emission Reductions are claimed through Cap & Trade, Taxes, or Mandates

Reliable Independent Estimates of Anthropogenic Emissions of Greenhouse Gases are arguably ESSENTIAL

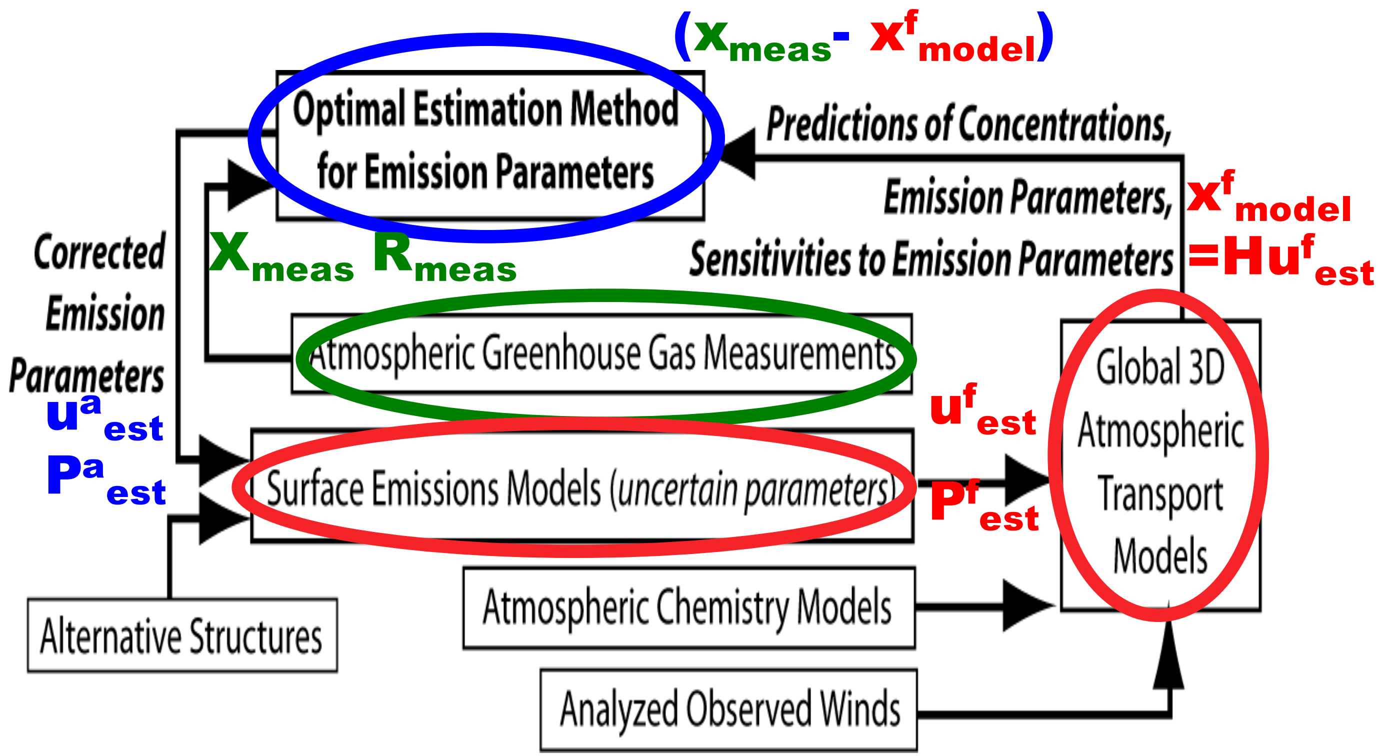
SUMMARY OF CURRENT "TOP-DOWN" APPROACH

INFER EMISSIONS

(in vector $u_{est}(t)$ with errors in matrix $P_{est}(t)$)

USING MEASUREMENTS

(in vector $x_{meas}(t)$ with errors in matrix $R_{meas}(t)$)

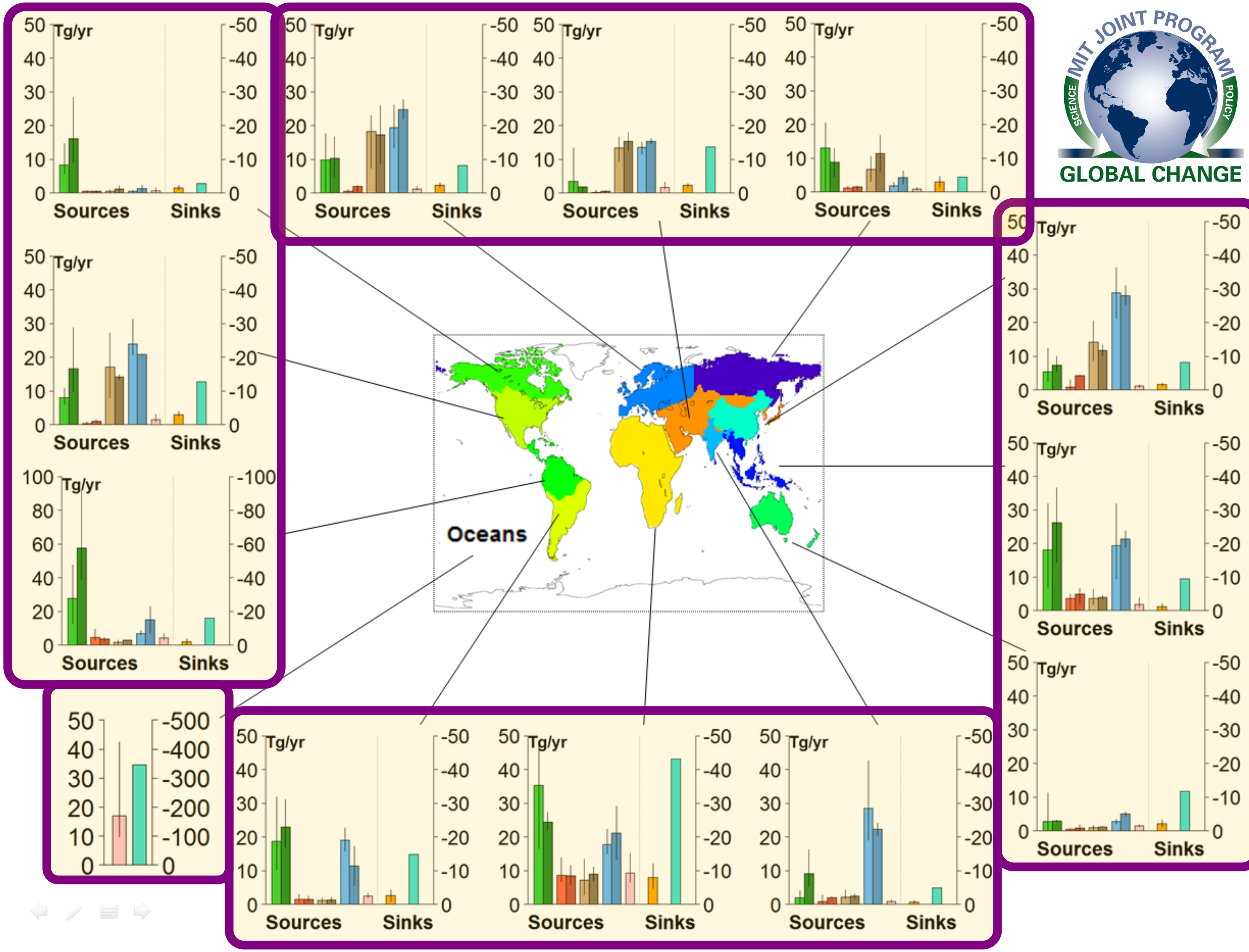


MULTI-MODEL, MULTI-NETWORK, MULTI-METHOD ESTIMATIONS FOR METHANE

Both TOP-DOWN (T-D) and BOTTOM-UP (B-U) approaches are used to calculate decadal budgets for the different categories.

Error bars indicate the spread between the minimum and the maximum values.

Ref: Kirschke et al, Nature-Geoscience, 2013.



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BUDGETS FOR 13 REGIONS CALCULATED FOR THE 2000s (2000-2009) (12 LAND regions and ALL oceans, and for the various source and sink categories. Ocean (bar chart at bottom left), with ocean emissions (pink, left scale) and OH loss over the ocean (turquoise, right scale).

- Wetlands (T-D)
- Wetlands (B-U)
- Biomass Burning (T-D)
- Biomass Burning (B-U)
- Fossil Fuels (T-D)
- Fossil Fuels (B-U)
- Agriwaste (T-D)
- Agriwaste (B-U)
- Other Emissions (T-D)
- Other Emissions (B-U)
- Soil Sink (T-D)
- Soil Sink (B-U)
- Chemical Loss (T-D)
- Chemical Loss (B-U)

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LOOKING TO THE FUTURE,
Verifying Emission Reductions requires very Important improvements in Current Capabilities

Significant advances in Global Observing Systems and Economic Data Collection Systems with close attention to Precision & Accuracy

Significant measurement-driven improvements in Models of Natural Processes, Anthropogenic Emissions, and Atmospheric & Oceanic Circulation

Use all relevant data and observations (not just greenhouse gases but also many other variables)

Examples of RELEVANT DATA AND OBSERVATIONS

ATMOSPHERIC GREENHOUSE GAS OBSERVATIONS

Earth System Research Laboratory (NOAA-ESRL)
Advanced Global Atmospheric Gases Experiment (AGAGE-NASA)
Network for Detection of Atmospheric Composition Change (NDACC)
Scanning Imaging Absorption Spectrometer (SCIAMACHY-ESA)
Greenhouse Gases Observing Satellite (GOSAT-Japan)
Orbiting Carbon Observatory (OCO-NASA)
Atmospheric Infrared Sounder (AIRS-NASA)
Civil and Research aircraft (CARIBIC, HIPPO, ESRL flasks)

NATURAL AND MANAGED LAND ECOSYSTEMS

Net Fluxes of carbon from Towers (FLUXNET)
International Long Term Ecological Research biomass network (ILTER)
Advanced Very High Resolution Radiometer (AVHRR)
Moderate Resolution Imaging Spectro-radiometer (MODIS)

OCEANS

In situ measurements of CO_2, nutrients, pH, chlorophyll, particles (GLODAP, CLIVAR, JGOFS, WOCE, BATS, HOT)
Satellite derived products (SeaWifs, MODIS-Aqua, OCTS, chlorophyll)

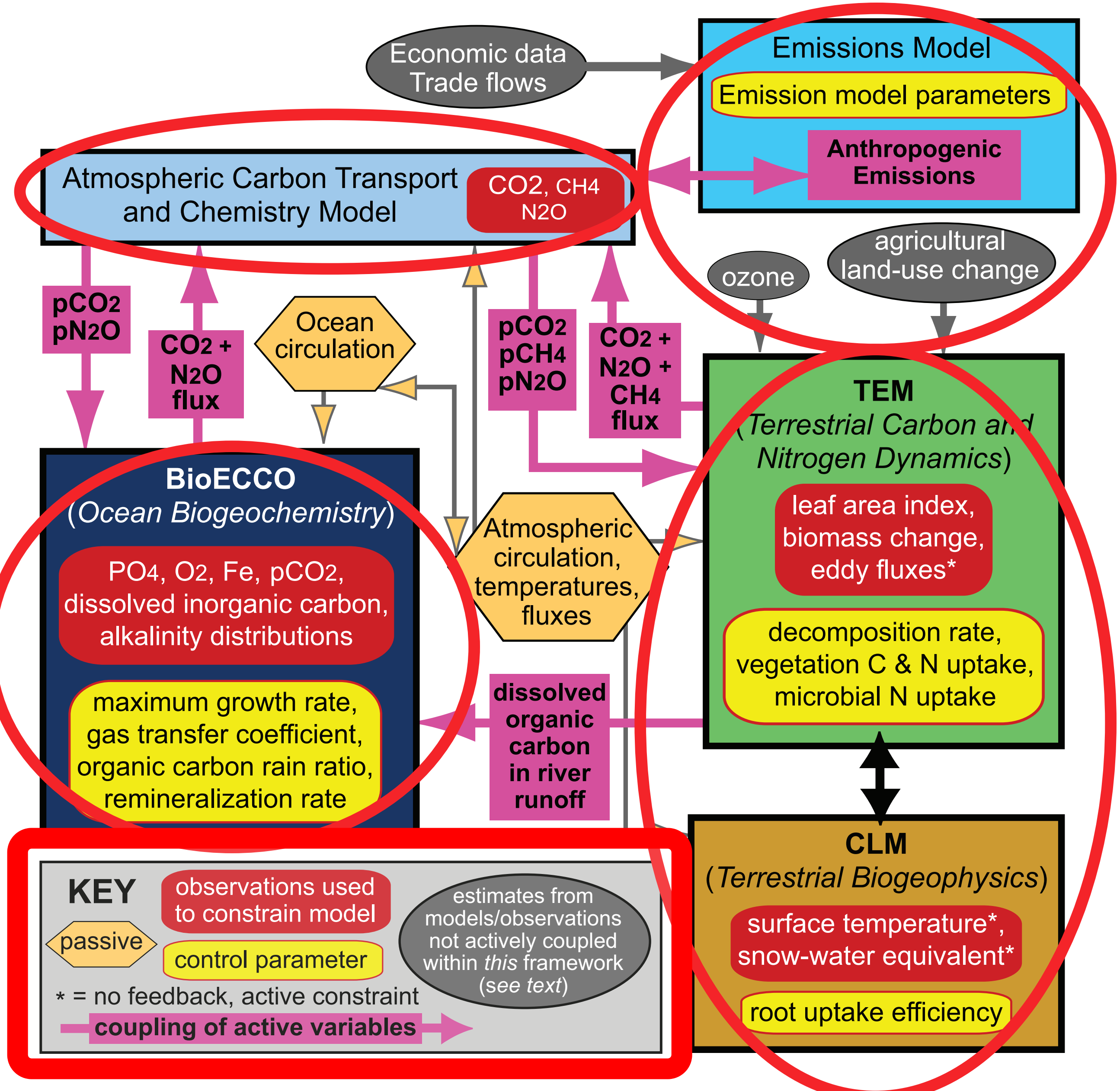
ECONOMICS DATASETS

Economic Activity & Emission Factors (IEA, FAO, CDIAC, USGS, IRRI, IFA, CRF, UNFCC)
Input/Output Data (EXIOPOL, WIOD, IDE, OECD)

A STRATEGY FOR A GLOBAL OBSERVING SYSTEM FOR VERIFICATION OF NATIONAL GREENHOUSE GAS EMISSIONS

R. Prinn, P. Heimbach, M. Rigby, S. Dutkiewicz, J. Melillo, J.Reilly, D. Kicklighter & C. Waugh

Report 200, Joint Program on the Science & Policy of Global Change [http://globalchange.mit.edu/research/publications/reports]



e.g. FOR GASES SUCH AS CO_2, CH_4 & N_2O THAT HAVE SIGNIFICANT NATURAL SOURCES & SINKS

SOLUTION METHOD: MINIMIZE COST FUNCTION J BY VARYING THE EMISSION-RELATED "CONTROLS" $U_C(t)$ & INITIAL CONDITIONS OF THE OBSERVATION-RELATED "STATES" $X_C(t = 0)$

THE COST FUNCTION J IS THE SUM OF 4 TERMS EXPRESSING:

(1) deviation of initial state $X_C(0)$ from a weighted first guess X_{C0}

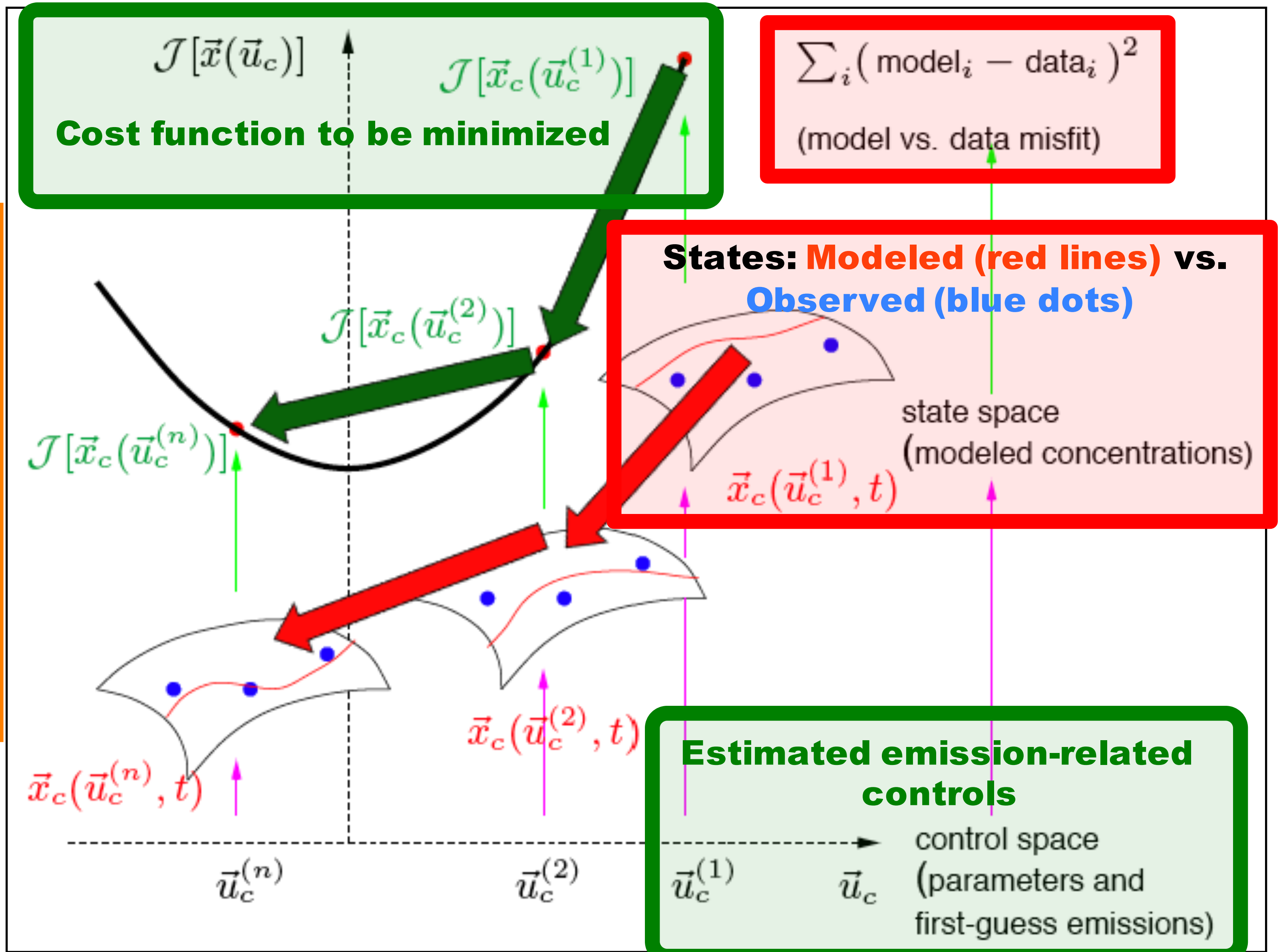
(2) deviation of the modeled observations $X_C(t)$ from the weighted actual observations $X_c^{obs}(t)$

(3) deviation of the estimated emission-related controls $U_E(t)$ from a weighted first guess U_{E0}

(4) deviations of the estimated state $X_C(t)$ from the model values, and deviations involving the coupling functions that link outputs of one model to inputs of another, with all weights expressed by Lagrange multipliers.

Iterative minimization of $\mathcal{J}$ by varying controls u_c. Solution achieved for controls (parameters and emissions) $u_c = u_c^{(n)}$, which give values of states $x_c = x_c^{(n)}$ that best fit observations (concentrations, etc.).

Vary u_c such as to minimize $\mathcal{J}$ ($d\mathcal{J}/du_c = 0$) using optimizing algorithms (steepest descent, conjugate gradient, Newton method).



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HOW ACCURATE SHOULD EMISSION ESTIMATES BE FOR POLICY, AND WHAT NEEDS TO BE DONE TO ACHIEVE THAT ACCURACY?

TO ANSWER, USE THE MODELING SYSTEM TO EXPLORE LOWERING UNCERTAINTY BY ADDING NEW MEASUREMENTS, and IMPROVING THEIR PRECISION, ACCURACY, and SPATIAL and TEMPORAL RESOLUTION.

WHAT WILL IT COST TO IMPLEMENT & WHO WILL PAY?

WHO WILL GOVERN & OPERATE IT?

MORE INFORMATION AT
http://web.mit.edu/global change

MIT Joint Program on the
Science and Policy of Global Change

A Strategy for a Global Observing System for Verification of National Greenhouse Gas Emissions

R. Prinn, P. Heimbach, M. Rigby, S. Dutkiewicz, J.M. Melillo, J.M. Reilly, D.W. Kicklighter and C. Waugh

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