The critical role of fine-grained atmospheric data in determining the rates of transport, sources, and sinks of greenhouse gases across the globe.

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Pasadena, CA 03 March 2010
HIAPER Pole-to-Pole Observations 2009 ("HIPPO")

Brooks Range, AK
Part I: Global Science Objectives:
Use observed distributions of major greenhouse gases to help determine the continental-scale sources and sinks of major greenhouse gases.

Motivation:

Computer models are the basic tool for this application. Models obtain the global distributions of surface fluxes for GHGs by optimizing \textit{a priori} emission rates to match time series observations at surface stations.

Approach:
Challenge models with fine-grained data of global scale: HIAPER Pole-to-Pole Observation program (HIPPO).
"HIPPO" is designed to confront models with a new type of data.

We wish to uncover and eliminate sources of bias and error that limit the application of models to assessment of source trends and distributions: to distinguish to model-data differences that tell us about sources and sinks from those arising due to deficiencies of transport, model aggregation, etc.

Fine-grained data for multiple species of different source/sink distributions, at the surface and in profile should provide critical tests of models.
Part II: Verification Science

Objectives:
Use observed time series of CO$_2$ and other greenhouse gases in major source locales to help track trends in emission sources.

Motivation:
The largest emissions sources reveal the largest signals of human-caused emissions. Compliance with treaty provisions will translate into measurable changes in emission rates from major emitting regions.

Approach:
Modeling of highly resolved concentration data from a highly resolved inventory and fine-resolution model. Use of multiple tracers ($^{222}$Rn, $^{14}$CO$_2$, CO, ...).
- ~400 vertical profiles in 3 of 6 missions.
- 3 missions yet to go; nearly 1000 at HIPPO's conclusion.
Shadow of the Earth visualized by ice crystals over the Alaska range.

Pago Pago, Samoa
# HIPPO Aircraft Instrumentation

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Measured Species</th>
</tr>
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<tbody>
<tr>
<td>Harvard/Aerodyne—HAIS QCLS</td>
<td>$\text{CO}_2$, $\text{CH}_4$, $\text{CO}$, $\text{N}_2\text{O}$ ($1 \text{ Hz}$)</td>
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<tr>
<td>NCAR AO2</td>
<td>$\text{O}_2$:$\text{N}_2$, $\text{CO}_2$ ($1 \text{ Hz}$)</td>
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<td>Harvard OMS $\text{CO}_2$</td>
<td>$\text{CO}_2$ ($1 \text{ Hz}$)</td>
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<td>NOAA CSD $\text{O}_3$</td>
<td>$\text{O}_3$ ($1 \text{ Hz}$)</td>
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<td>$\text{O}_3$ ($1 \text{ Hz}$)</td>
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<td>NCAR RAF $\text{CO}$</td>
<td>$\text{CO}$ ($1 \text{ Hz}$)</td>
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<tr>
<td>NOAA-UCATS, PANTHER GCs</td>
<td>$\text{CO}$, $\text{CH}_4$, $\text{N}_2\text{O}$, CFCs, HCFCs, $\text{SF}_6$, $\text{CH}_3\text{Br}$, $\text{CH}_3\text{Cl}$, $\text{H}_2$, $\text{H}_2\text{O}$</td>
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<td>Whole air sampling: NWAS</td>
<td>$\text{O}_2$:$\text{N}_2$, $\text{CO}_2$, $\text{CH}_4$, $\text{CO}$, $\text{N}_2\text{O}$, other GHGs, $\text{COS}$, halocarbons, solvent gases, marine emission species, many more</td>
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<td>(NOAA), AWAS (Miami),</td>
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<td>MEDUSA (NCAR/Scripps)</td>
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<td>Princeton/SWS VCSEL</td>
<td>$\text{H}_2\text{O}$ ($1 \text{ Hz}$)</td>
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<td>NOAA SP2</td>
<td>Black Carbon ($1 \text{ Hz}$)</td>
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<tr>
<td>MTP, wing stores, etc</td>
<td>$\text{T}$, $\text{P}$, winds, aerosols, cloud water</td>
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</table>
Global distribution of potential temperature – January 2009
HIPPO_1

Xsects along the Dateline

Jan 2009
HIPPO_1
Xsects along the Dateline
Jan 2009
HIPPO_2

Xsects along the Dateline

Nov 2009

$N_2O$ is upside down
Models with detailed simulations of HIPPO_1 or Pre-HIPPO Data

- **Earth Simulator – ACTM** CCSR/NIES/FRCGC AGCM
- **GEOS-CHEM** (NASA DAO) Harvard
- **MACC-GEMS** ECMWF Air Quality and Air Chemistry model

<table>
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<tr>
<th></th>
<th>CO2</th>
<th>SF6</th>
<th>C2H6</th>
<th>CO</th>
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*16
sources and vertical and horizontal transport
Jan 2009  Observed

ACTM (GEIA)
Using multiple tracers to help solve the model-measurement conundrum

- The stratosphere has a major influence on the concentrations of tracers distributed through the troposphere. How well is this feature captured by models?
- What do we learn about sources, versus transport, from latitude and altitude profiles?
CO₂ and other gases in S. Polar regions

lat -60 to -70
CO$_2$ and other gases in Southern Ocean area
Northern Hemisphere Tropospheric Tracers of Strat/Trop Exchange

Normalized Concentration

\[ \frac{(X - X_{\text{min}})}{(X_{\text{max}} - X_{\text{min}})} \]

Latitude

\( \text{SF}_6 \)
\( \text{O}_3 \)

\( \text{N}_2\text{O} \)
HIPPO_2: High-altitude pollution phenomena in the Arctic

CH$_4$

CO

$Z$ (m)

$N_2O$

$HIPPO_2$

70 -80N

6 profiles
78N latitude, 160W (north of Barrow) 04 Nov 2009
moonrise, haze, black carbon
Urban plumes (Dallas, Houston): 500-600 ng/kg
Texas non-urban: 50-100 (USA) (Schwartz et al., 2008)
HIPPO_2:

Pollution from Asia covered a vast area of the Arctic on 02 Nov 2009
H2 Profile 19

How do anomalies arise? How is a profile composed?

Arctic, very dense high-altitude pollution juxtaposed with "a pure CH$_4$ play"
H1 Profile 24

How do anomalies arise? How is a profile composed?

Arctic low altitude pollution
H1 Profile 51

How do anomalies arise? How is a profile composed?

Central Pacific
**Summary/ conclusions: Part 1 – Global fine-grained data**

• HIPPO provides a new type of data for CO₂ and GHG studies: global, extremely fine grained, many tracers. Data of this type should be part of a global observing strategy for GHG treaties.

• Major transport processes are elucidated: Stratosphere [sets the stage; Pre-HIPPO connection]; warm conveyor belt (intense, persistent, ensemble of small scale processes)—mixes the whole atmosphere [CO₂, CH₄, CO: QCLS, RAF; all models]; Arctic Cold Dome—brings strong pollution to high altitudes in pivotal season [BC, CH₄, N₂O: QCLS, SP2; GEMS, ACTM and GEOS] and Antarctic marine PBL—distortion of surface observations used in models [CO₂, CH₄, O₂, SF₆: QCLS, UCATS; all models].

• Source/sink regions are revealed and impacts quantified: N₂O in the tropics and Antarctic—a major finding [N₂O: QCLS; ACTM]; marine reactive species—obvious implications for source regions [COS, CS2, DMS; ALLWAS]; O₂ and CO₂ Antarctic and S. Ocean.—source strength, relate to PBL [CO₂, O₂: QCLS, AO2; GEOS-CHEM].
* HIPPO and Pre-HIPPO Teams *


NCAR and NCAR-RAF: B. Stephens, P. Romanshkin, T. Campos, Laura Pan, J. Haggerty, S. Schertz, GV Crew (Henry Boynton, Ed Ringleman, pilots)


Princeton: M. Zondlo  JPL: M. J. Mahoney

UCSD/Scripps: R. Keeling, J. Bent

U. Miami: E. A. Atlas, R. Lueb

Cooperating modeling groups: ACTM (Prabir Patra, Kentaro Ishijima), GEMS-MACC (Richard Engelen), …others soon.
Modelling CO$_2$ in Salt Lake City

March 3, 2010

Steve Wofsy, Kathryn McKain, Harvard University
Atmospheric and Environmental Research, Inc (AER)
Objective

- Develop and test a method for using ground-based CO₂ concentration measurements for estimating the emissions of a city

  - Quantify the relationship between CO₂ measurements and emissions via a modeling framework

\[ CO_{2\text{emissions}} = a \times \Delta CO_{2\text{observation}} \]

- Determine the statistical requirement for detecting a change in emissions from an observed change in CO₂ concentration

\[ \delta(CO_{2\text{emissions}}) = \varepsilon a \times \delta(\Delta CO_{2\text{observation}}) \]
Methods

• Emissions
  • **Vulcan Inventory** (by Gurney @ Purdue)
    • Hourly
    • 0.1° x 0.1° (~8.5 x 11 km)
    • 8 categories
    • 2002

• Observations
  • **Salt Lake City** (by Ehleringer & Pataki @ U of Utah)
    • 5 sites
    • 2001-present
    • 5-minute collection interval

-Model (LPDM)

-Stochastic Time Inverted Lagrangian Transport (STILT)
  -Driven by Weather Research and Forecasting (**WRF/ 3 km**)
  -Generates a footprint (ppm/(μmol/m²/s)) for each measurement point, which represents the sensitivity of the observed concentration to surface emissions
2006 – entire year – Cum PDFs variations by day of the week, 1000 – 1700h local.
2006, 1000—1700, Cum PDFs: Summer (June – Aug) Winter (Dec – Feb)
October, Hourly means
October, Daily means by hour

Downtown 2006

mean hourly modeled CO2 (ppm)

mean hourly observed CO2 (ppm)

weekday

Mon Tue Wed Thu Fri Sat Sun

380 400 420 440 460 480
Model – Data Fits – one month (Oct. 2006 or 2009)

<table>
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<tr>
<th>site</th>
<th>year</th>
<th>fit</th>
<th>%</th>
<th>slope</th>
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<td>0.02</td>
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</table>
Summary and conclusions for Part 2:

High-resolution data at even a single point contain clear signatures of emissions that respond to emission rates.

High resolution modeling appears potentially able of providing the metric for determining changes in emission rates for major emitting regions.

Goal of quantifying 5% change over 5 years appears feasible. Shorter times, small changes may not be feasible.

Long time series with unchanging tracers ($^{222}\text{Rn}$) and addition of key covariates ($^{14}\text{CO}_2$, CO, …) provide strong validation and high accuracy for change detection (Levine).
Reactive species in the atmosphere:

A movie… (not in 3-D)
Whole-Air Sampling  NWAS / AWAS (E. Atlas, S. Montzka)

Mid-Pacific Sample coverage
Dichloromethane

![Dichloromethane Graph]

- Values range from 0 to 12500.
- The x-axis represents GGLATavg.
- The y-axis represents CH2Cl2_md.

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Carbonyl Sulfide

![Image of Carbonyl Sulfide graph]

- **GGALTavg**
- **GGLATavg**

- **OCS_md**

Values:
- Carbonyl Sulfide concentration ranges from 0 to 12500.
- The graph shows variations in concentration across different GGLATavg and GGALTavg values.

Legend:
- Colors from blue to red indicate lower to higher concentrations of Carbonyl Sulfide.