"HIAPER Pole-to-Pole Observations (HIPPO) of Carbon Cycle and Greenhouse Gases"

- **Will measure cross sections from the surface to the tropopause, at 5 times of year in a 3-year period, for a comprehensive suite of tracers: CO_2, O_2:N_2 ratio, CH_4, CO, N_2O, $^{13}CO_2$:$^{12}CO_2$, H_2, SF_6, COS, CFCs, HFCs, HCFCs, and selected hydrocarbons.**
- **HIPPO will transect the mid-Pacific ocean and return over E. Pacific.**
- ***Pre-HIPPO will be based in Boulder and will coalesce with START-08 (April-June 2008). It is a preliminary mission to test the payload, aircraft, and sampling concepts.***

Science Questions

1. What are the rates for vertical exchange, mixing within a hemisphere, and inter-hemispheric transport, and how do these transport processes interact with source distributions to produce concentration gradients for key species (CO_2, CH_4, CO, O_2) in the carbon cycle and for tracers used to diagnose the carbon cycle (SF_6, HCFCs, COS)? .
2. How do vertically resolved tracer data provide new constraints on global inverse models for sources and sinks of CO_2 and related gases?

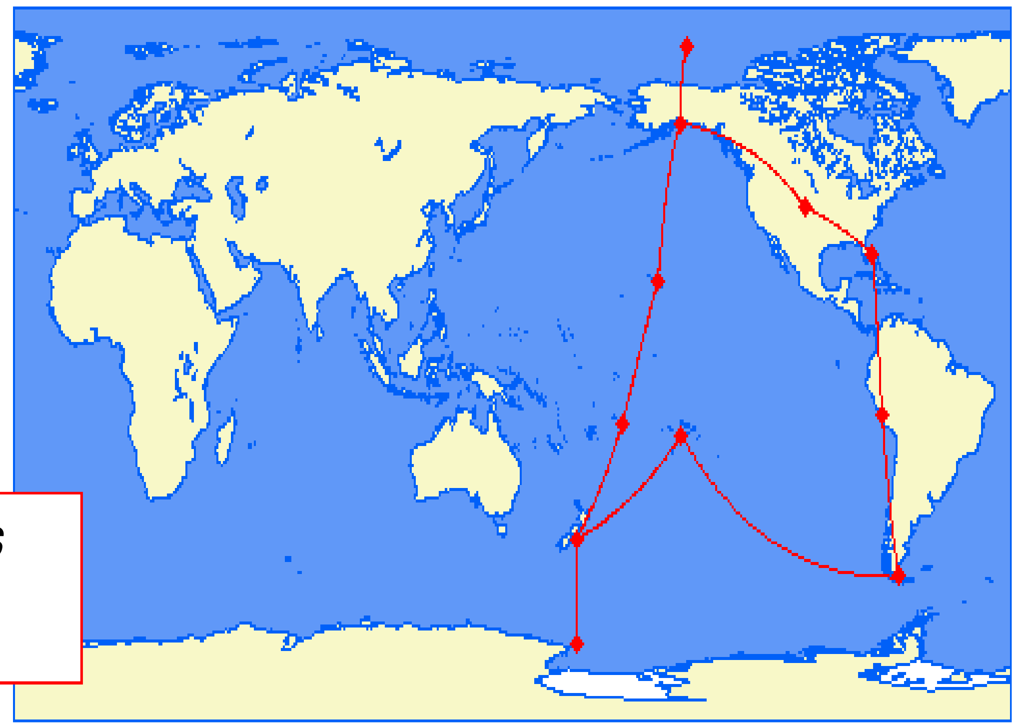
We will address these questions by *obtaining the first set of high-definition, seasonally resolved, global tracer data,* nearly pole-to-pole and surface-to-tropopause, and *interpreting the observed tracer distributions and fluxes* with the GEOS-CHEM global 3-D chemical transport model. We will *estimate global sources and sinks of* CO_2, CH_4, and CO.

Science Questions

3. **What is the role of the Southern Ocean in global budgets of CO_2 and O_2?** ***HIPPO data for CO_2, the O_2:N_2 ratio, and the Ar:N_2 ratio, will be assessed and inverted*** **using GEOS-CHEM.**
4. **How can we establish tracer "clocks", and determine age spectra, for air in the Tropical Tropopause Layer and global remote troposphere? We will use our seasonally varying tracers in the tropics above 14 km (= 46 kft) in a Green's-function analysis of this question.**

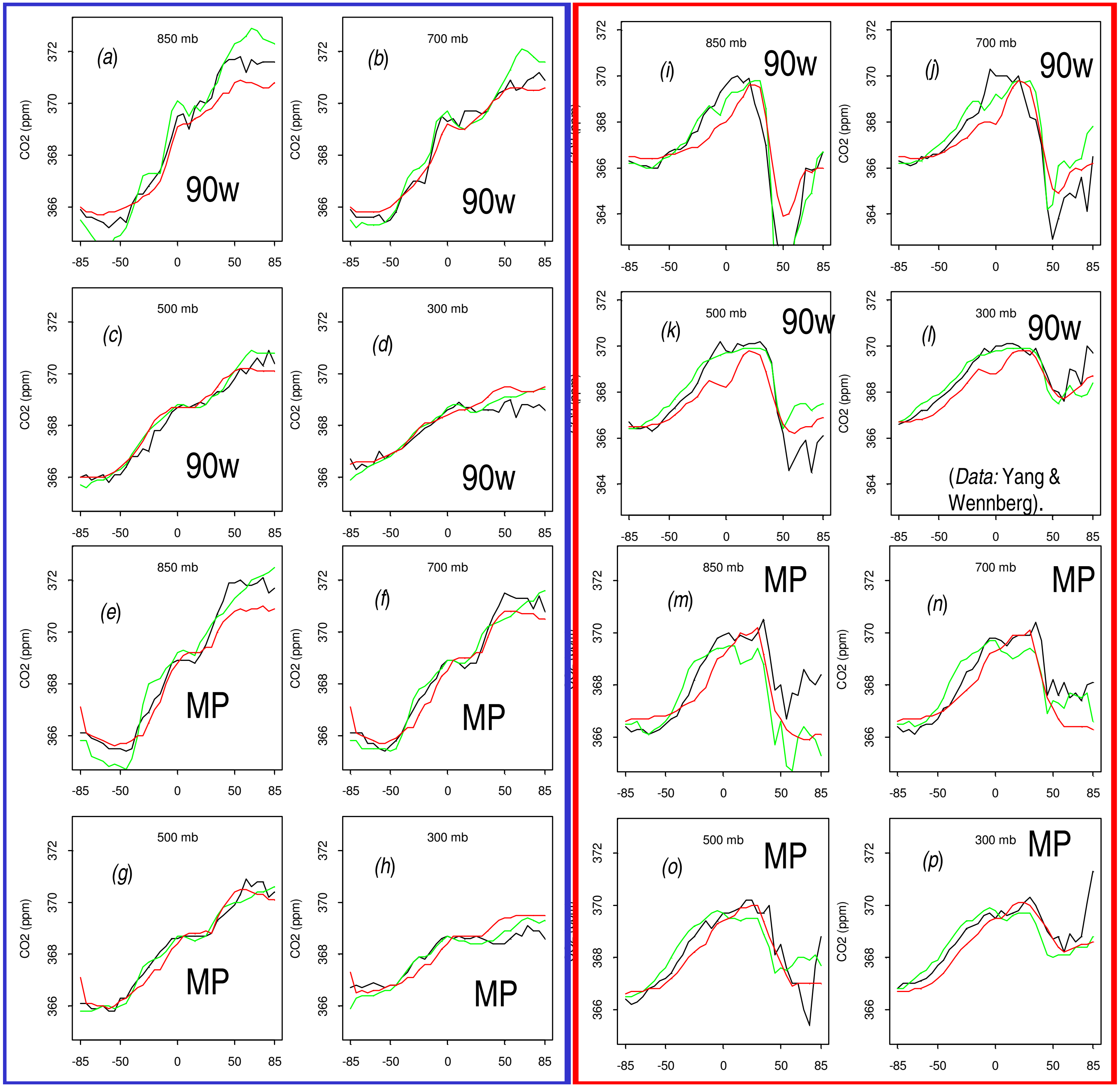
- *Deliverables*: **(1) Publicly available global data sets for CO_2, O_2:N_2 ratio, $^{13}CO_2$:$^{12}CO_2$, CH_4, CO, N_2O, CFCs, HCFCs, COS, O_3, PAN, and other tracers. Six missions in 2 years will span the seasonal cycle, covering pole-to-pole and the full depth of the troposphere. (2) Assessment of the validity of inverse studies of CO_2 sources and sinks used in the IPCC and TransCom by comparison between HIPPO data and associated global models. (3) Analysis of the seasonal exchange of O_2 with the oceans, and (4) assessment of CO_2 and O_2 exchange in the Southern Ocean, major oceanographic puzzles. (5) Analysis of transport and mixing rates in the TTL and (6) development of Green's functions for the vertical propagation of the seasonal cycle through the troposphere, major issues for climate. (7) New analyses of the global sources and sinks for CH_4 and (8) of <u>pollution in remote areas</u> of the atmosphere.**

Pre-HIPPO/START08: Aircraft and payload testing, 1st science/exploratory flights



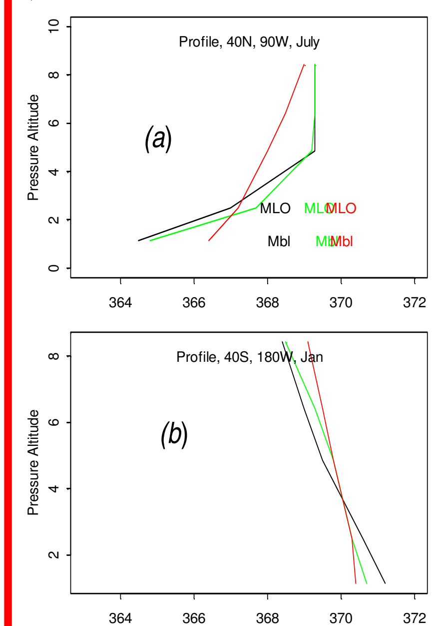
HIPPO Global: 5 missions over 3-4 years

Duration each 17—25 days



←**Fig. 1. Meridional gradients for modeled CO_2.** Jan. (*left, blue border*), and July (*red border*) for mid-Pacific ("MP") and "90w", for 3 TRANSCOM models: GCTM (**black**), SKYHI (**grn**), and TM2 (**red**). Fluxes were fixed at the TRANSCOM mean inverse. TM2, with small meridional gradients in the PBL (eg. Fig 1i), has a small vertical gradient (Fig. 2a) , both due to more rapid vertical mixing than in GCTM or SKYHI. Model differ by > 2 ppm

Fig. 2. Vertical profiles of CO_2 in summer [models as Fig. 1: *upper, mid-continent N. America, 40^{O}N ; lower, mid-Pacific 40^{o}S]*. Models with the steep vertical gradients have strong horizontal gradients, especially in the PBL (Fig. 1). Model CO_2 at Mauna Loa (MLO (3 km) and 40N (surface, mid-Pacific) are noted in *(a)*. ↓



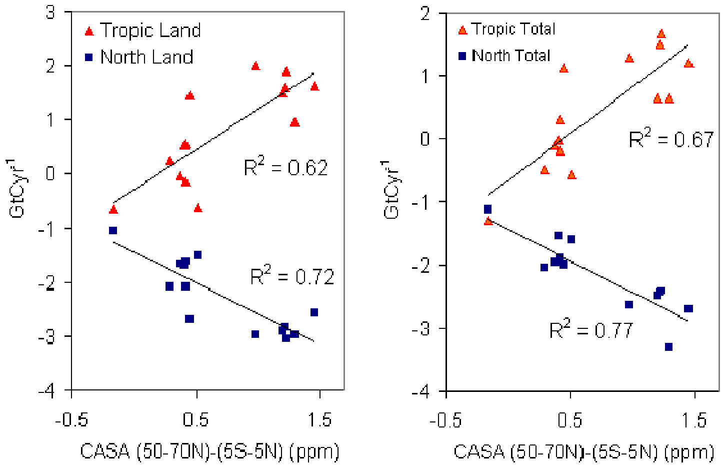


Figure. 3. Relationship between model gradients and inferred regional sinks in TRANSCOM3. Large-scale fluxes for tropical and northern (mid- to high-latitudes) land (*left*) and land+ocean (*right*) derived in the TRANSCOM3 inverse modeling, are shown on the [*y-axis*]. The x-axis shows the annual mean horizontal gradient in the marine PBL in the same models, given a prescribed, balanced (CASA) biosphere. Models with the largest gradients (largest *x*) for the balanced-biosphere have the strongest seasonal rectification; hence these same models put larger sinks (■) at northern latitudes to match observations, and they must put large sources (▲)in the tropics to maintain global mass balance (y-axis).

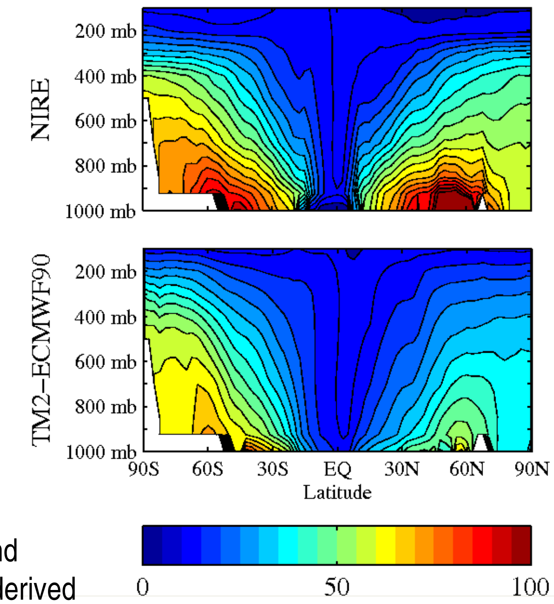


Figure. 4. Seasonal amplitude in APO in per meg units from two representative models from the TRANSCOM 3 suite. The seasonal cycle in APO arises predominately from air-sea exchanges of O_2 and N_2. Simulations used surface O_2 sources from (Garcia and Keeling, 2001) and N_2 based on ECMWF heat flux data (Blaine, 2005). Differences in rates of vertical and horizontal transport in the models lead to large differences the horizontal and vertical structure (amplitude, phase) of seasonal cycles of APO.

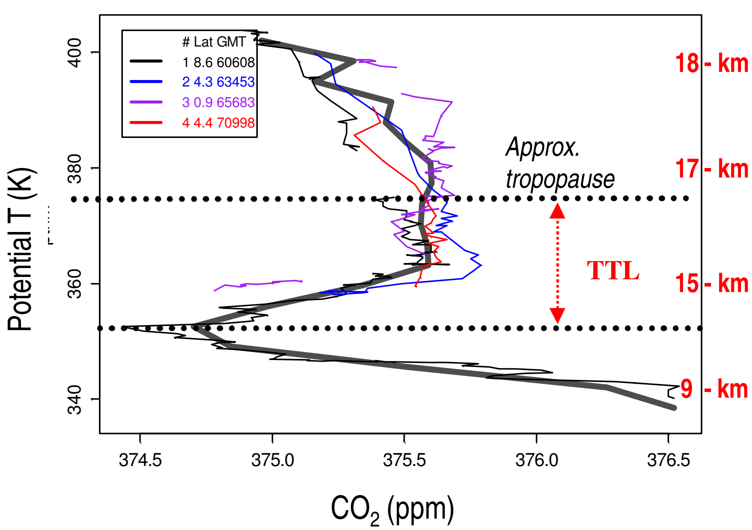
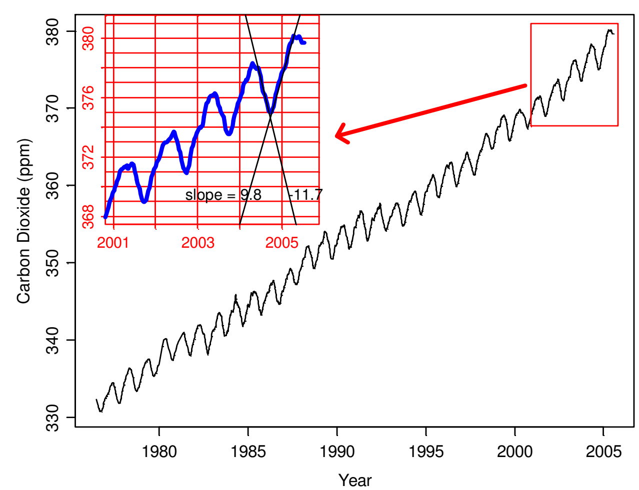


Fig. 5 Profiles of CO_2 on 29 Jan 2004 at latitudes **8.6**, **4.3**, and **0.9** deg N. Note the uniform appearance of the CO_2 maximum just below the tropopause, indicating that air in this layer is youngest in the UTLS. The **CO_2 seasonal clock** indicates ~30 days for the tropical tropopause layer to descend from 380K to 350K, about the same as the turnover time for the whole troposphere. Approx. GPS altitudes are given in **red. HIAPER** can reach 15 km, covering the critical gradient region of the TLL. Youngest air was at ~13 km in Jan., 2006.

Fig. 6. The global **CO_2 clock**, from the index, (CO_2-MLO + CO_2-SMO)/2 [*Boering et al., 1994*] using CMDL data [*Conway et al., 1994, updated*]. The Harvard CO_2 instrument has long-term precision better than 0.07 ppm [*Andrews et al., 2003*], equivalent to resolution of 2.6 days in winter (slope +9.8 ppm/yr) and 2.2 days in summer (slope -11.7 ppm/yr).



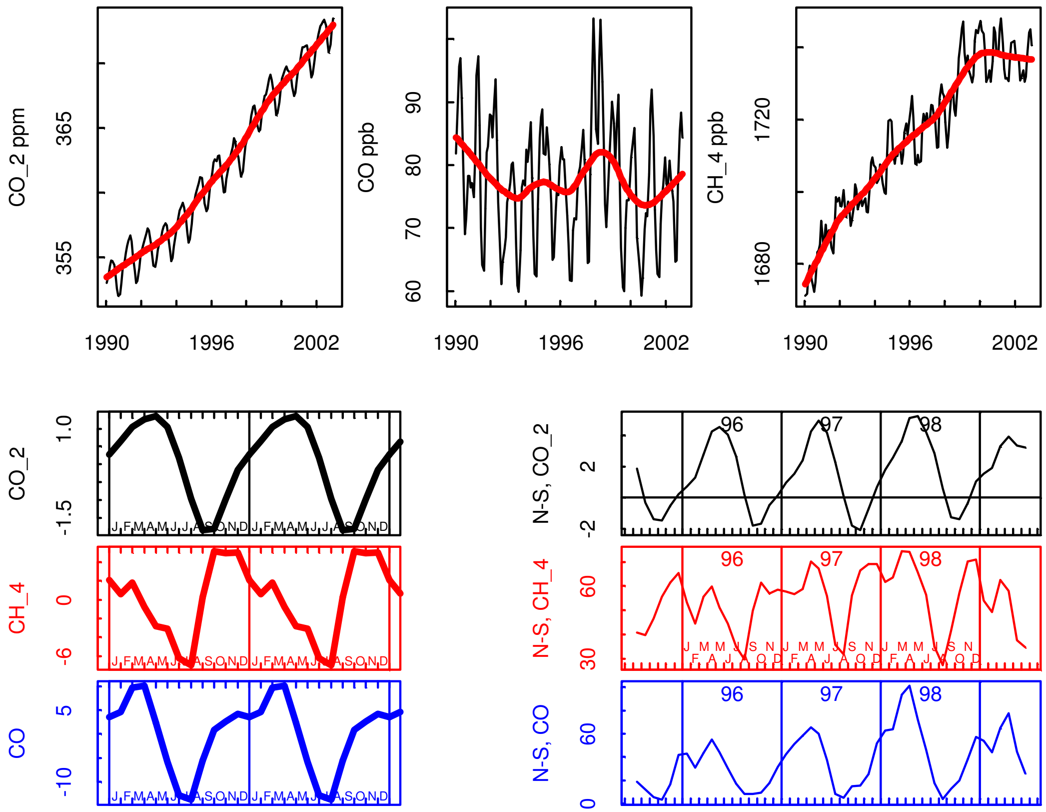


Fig. 7. Seasonal variations of tracers in tropical regions. (*upper panels*, l to r) 1990-2003 data for the mean concentration, (MLO+SMO)/2, for CO_2, CO and CH_4 , the *TTL Index* as inferred from stratospheric CO_2 data. Long-term trends are shown as **red lines**. (*Lower panels*)(*left*) Mean seasonal variations for CO, CH_4, and CO_2, showing the phase differences for different tracers. (*right*) N – S concentration differences (MLO – SMO), showing another type of phase differences for the N—S.

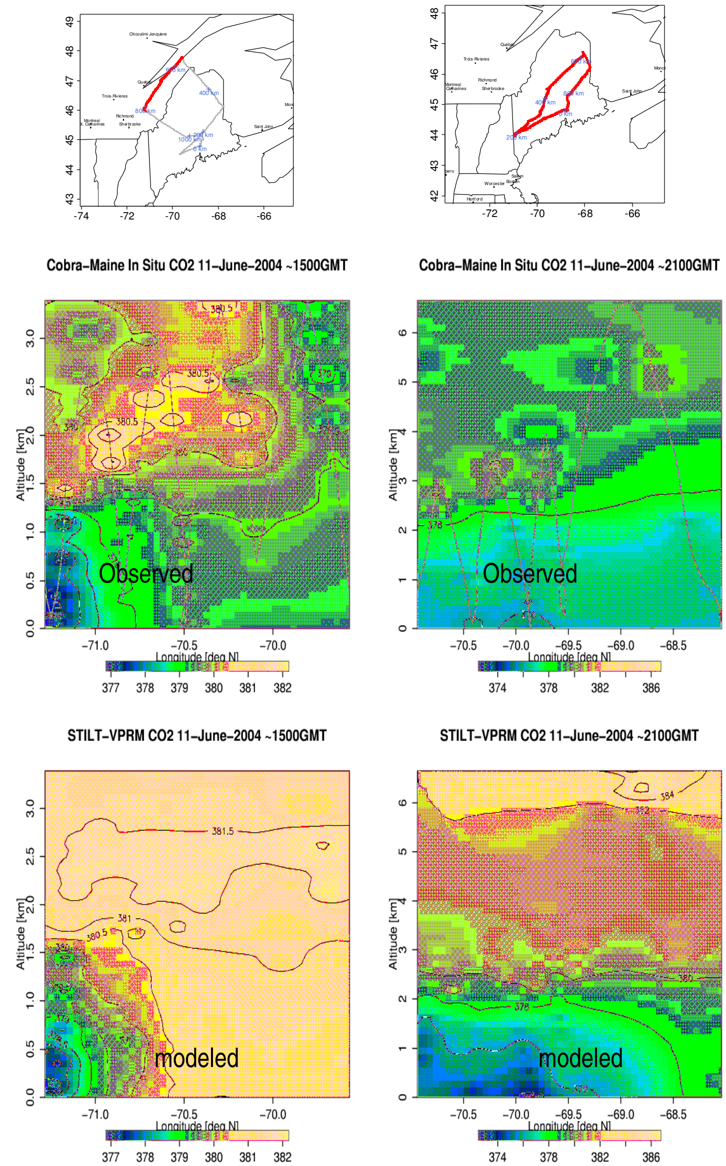


Fig. 8 COBRA Model-Data Fusion. Large-scale CO_2 concentrations predicted by *a priori* fluxes from VPRM: **Case study 11 Jun 2004:** (*upper*): Morning (*left*) and afternoon (*right*) tracks of the Wyoming King Air; (*lower left*) **measured** and **modeled** concentrations at 100m at Argyle, ME (red box indicates 11 June); CO_2 cross sections morning (*left*, 1500 GMT) and afternoon (*right*, 2100 GMT), 11 June: modeled using *a priori* surface fluxes (lower) and observed (upper) (source: *Matross et al., 2006*).