How can aircraft measurements tell us about the source/sink distribution of greenhouse gases?

Canadian Space Agency Workshop on Suborbital Platforms and Nanosatellites: April 14th~16th, 2010

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Unique Value of In-situ Aircraft Sampling

The ability to probe tracers both in the vertical and the horizontal at multiple scales, enabling:

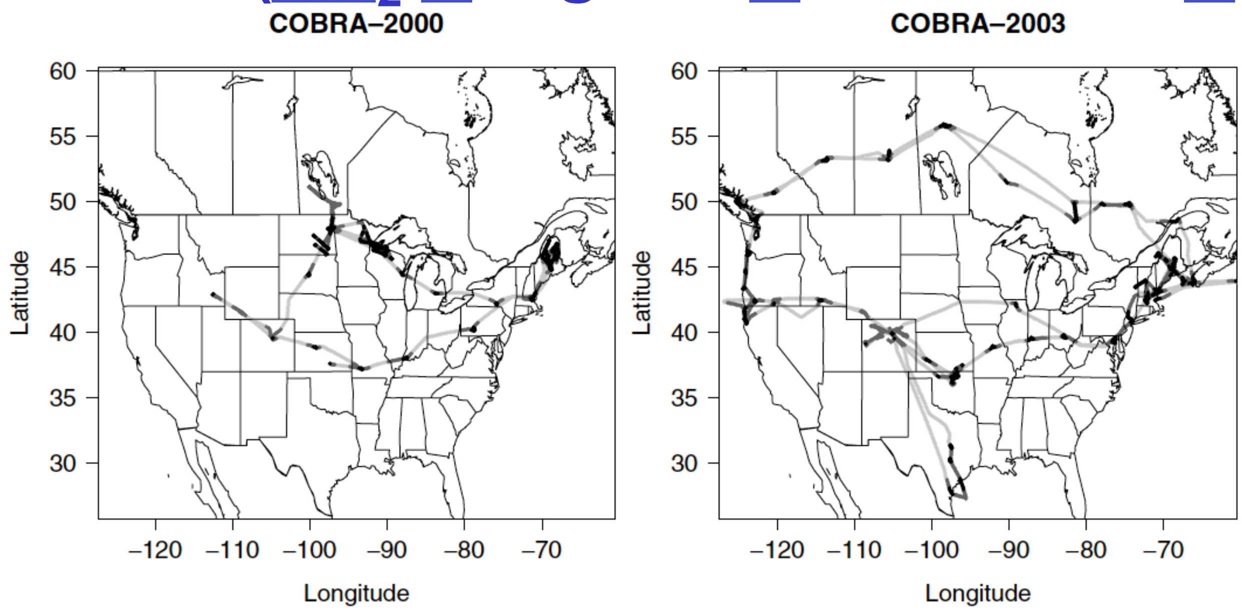
•Determination of spatial variability of tracers (CO_2 as example here)

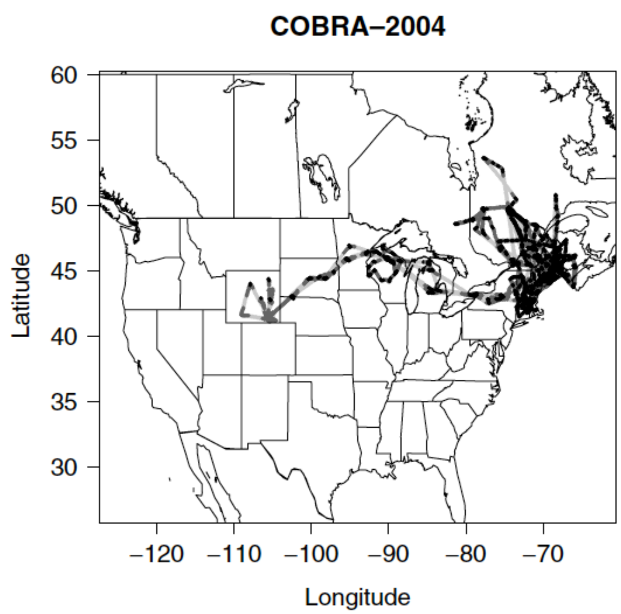
•Direct constraint of regional-scale fluxes from airmass-following experiments

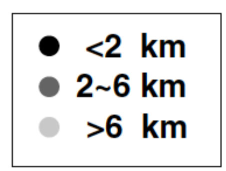
•Model testing: diagnosis of errors in atmospheric modelling (e.g., PBL ht, wind vectors, convection)

•Validation of space-borne sensors

COBRA (CO$_2$ Budget & Rectification Airborne Study)







What have we learned from intensive atmospheric sampling field programmes of CO$_2$?

By J. C. LIN[1]*, C. GERBIG[2], S. C. WOFSY[3], B. C. DAUBE[3], D. M. MATROSS[3], V. Y. CHOW[3], E. GOTTLIEB[3], A. E. ANDREWS[4], M. PATHMATHEVAN[3] and J. W. MUNGER[3]

Tellus (2006), 58B, 331–343

Fig. 1. Flight tracks from the CO$_2$ Budget and Rectification Airborne (COBRA) study from three different years: August 2000, May–June of 2003, and May–August of 2004. The aircraft altitude above sea-level is shown in grayscale.

Supported by: NASA, NSF, NOAA, and Dept. of Energy

COBRA (CO_2 Budget & Rectification Airborne Study)

University of North Dakota Citation
(COBRA-2000, 2003)

University of Wyoming King Air
(COBRA-2004)

COBRA (CO_2 Budget & Rectification Airborne Study)

COBRA Participants:

Steven C. Wofsy, Paul Moorcroft, Bruce Daube, Dan Matross, Bill Munger, V.Y. Chow, Elaine Gottlieb, Christoph Gerbig, John Lin: (***Harvard University***)

Tony Grainger, Jeffrey Stith: (***University of North Dakota***)

Ralph Keeling, Heather Graven: (***Scripps Institution of Oceanography***)

Britton Stephens: (***National Center for Atmospheric Research***)

Pieter Tans, Peter Bakwin, Arlyn Andrews, John Miller, Jim Elkins, Dale Hurst: (***Climate Monitoring & Diagnostic Laboratory***)

Dave Hollinger: (***University of New Hampshire***)

Ken Davis: (***Pennsylvania State University***)

Scott Denning, Marek Uliasz: (***Colorado State University***)

Larry Oolman, Glenn Gordon: (***University of Wyoming***)

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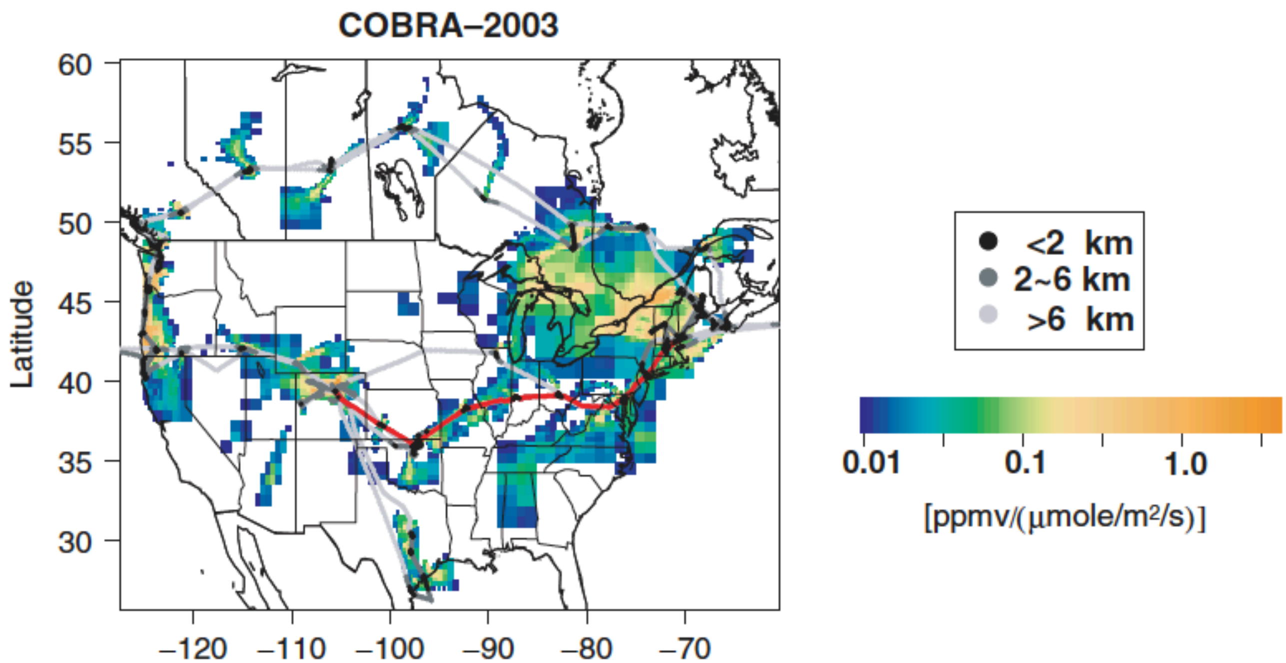

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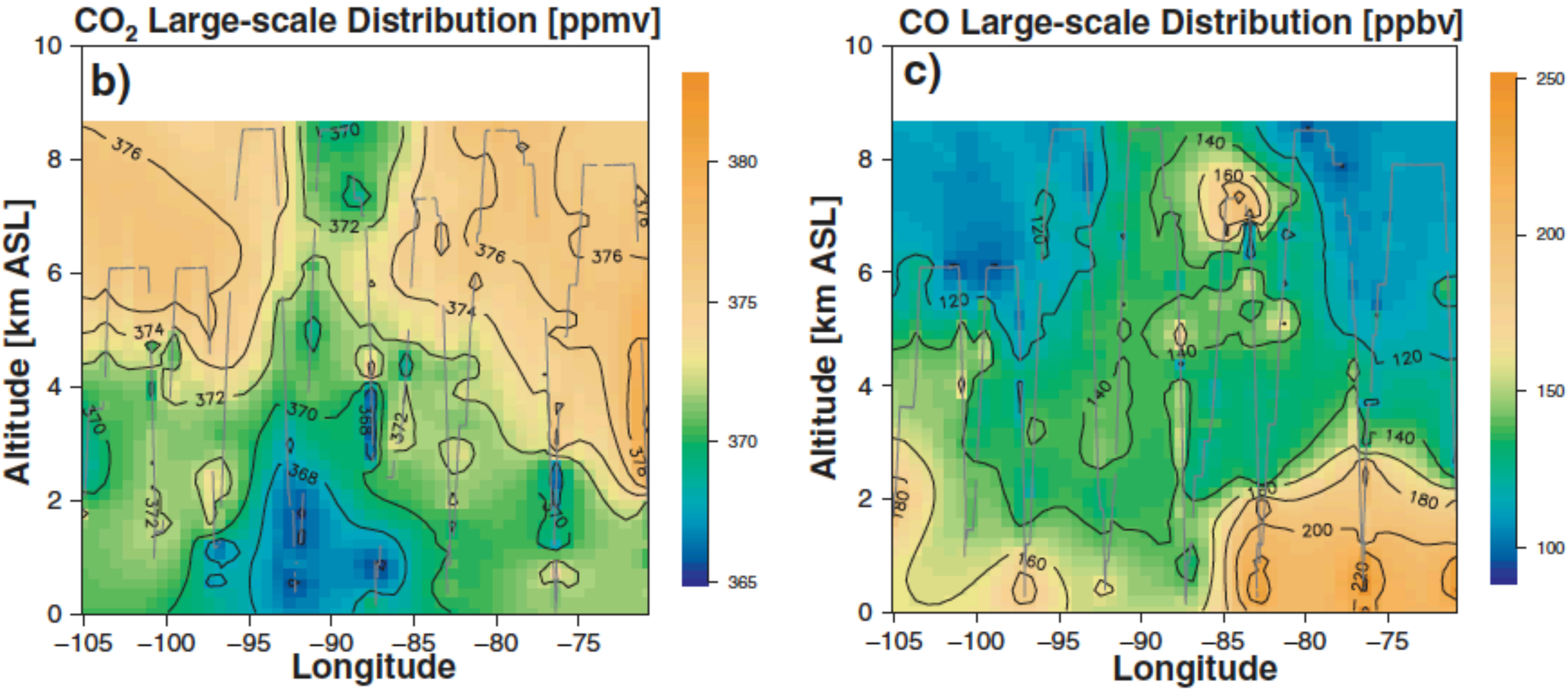
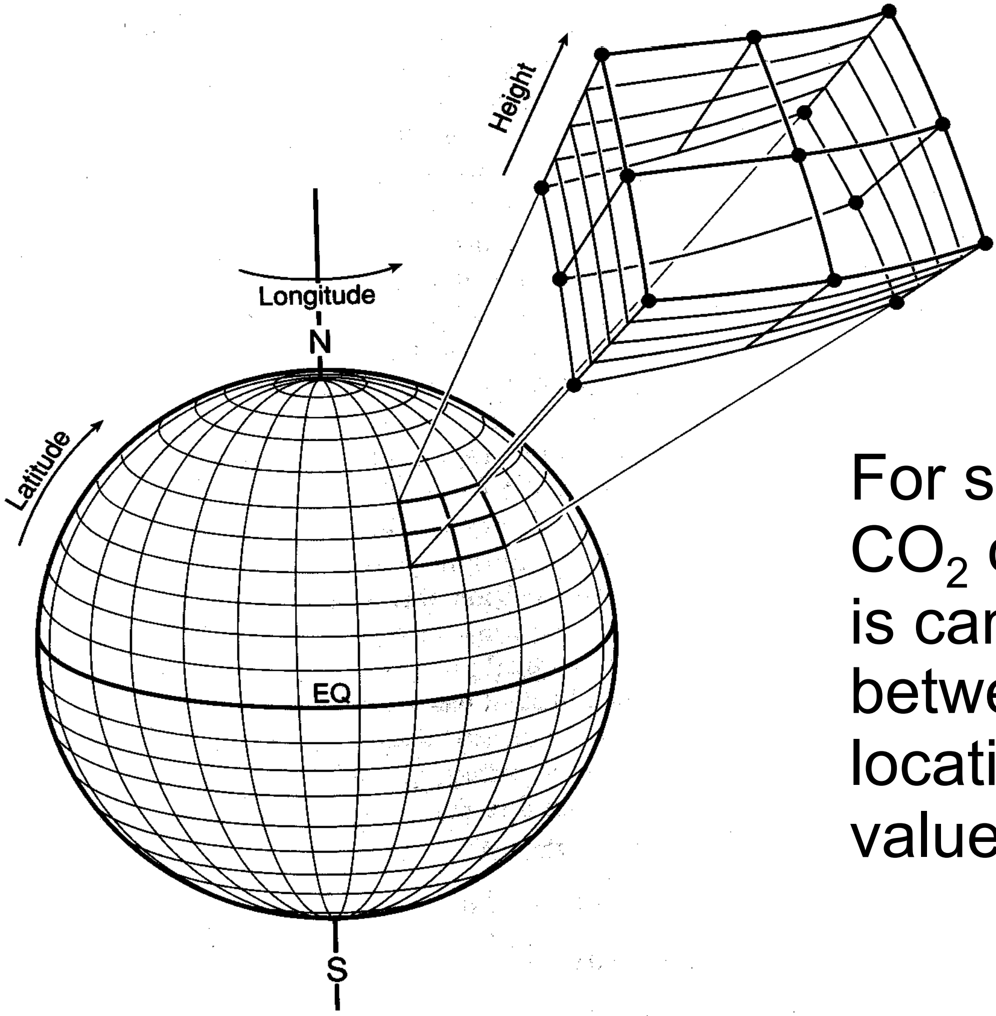


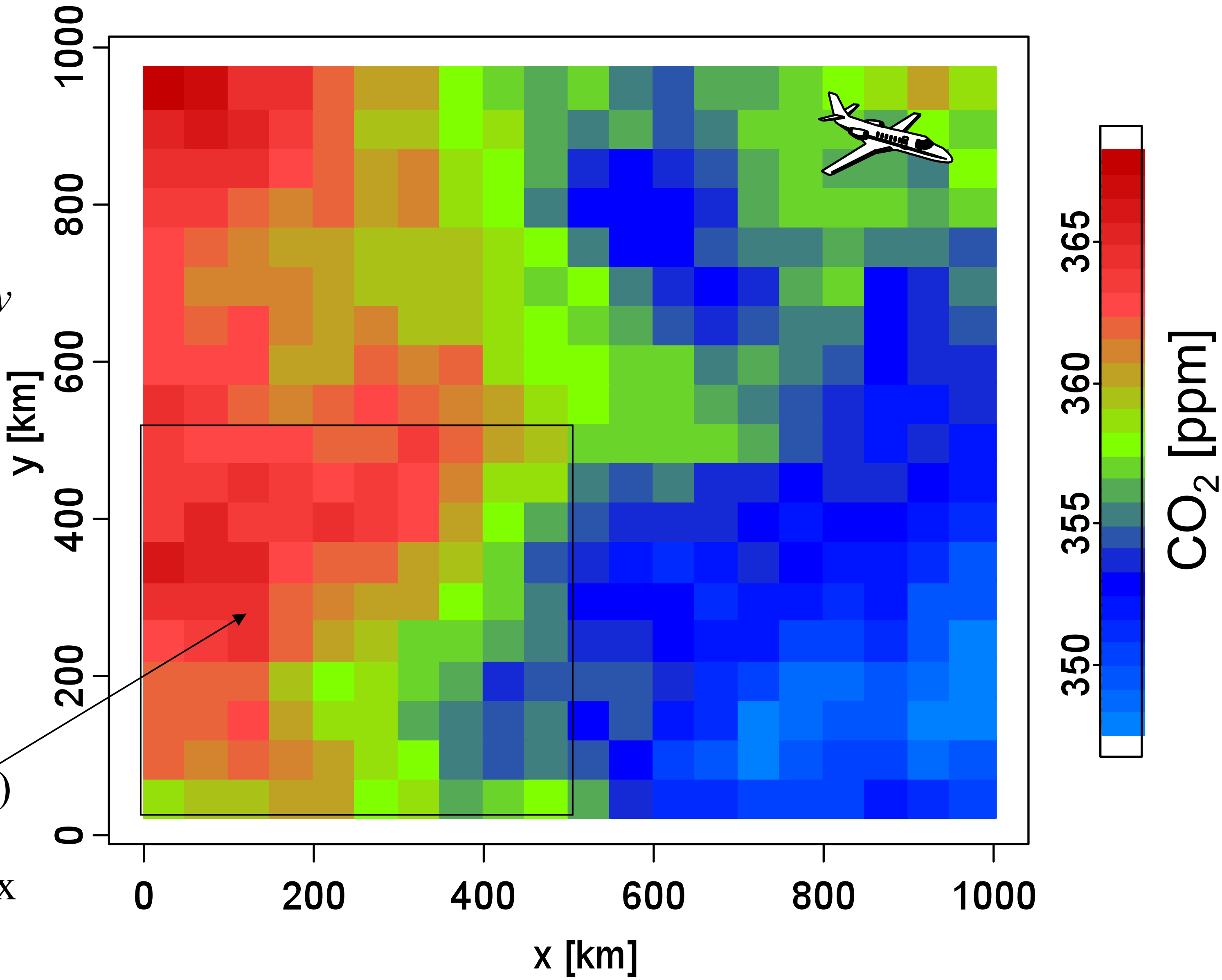
Models of the Atmosphere Divide it Up into Many Individual Boxes (gridcells)



For spatially heterogeneous field of CO_2 concentration over land, there is can be large differences between an observation at a point location and the gridcell-averaged value. ("representation error")

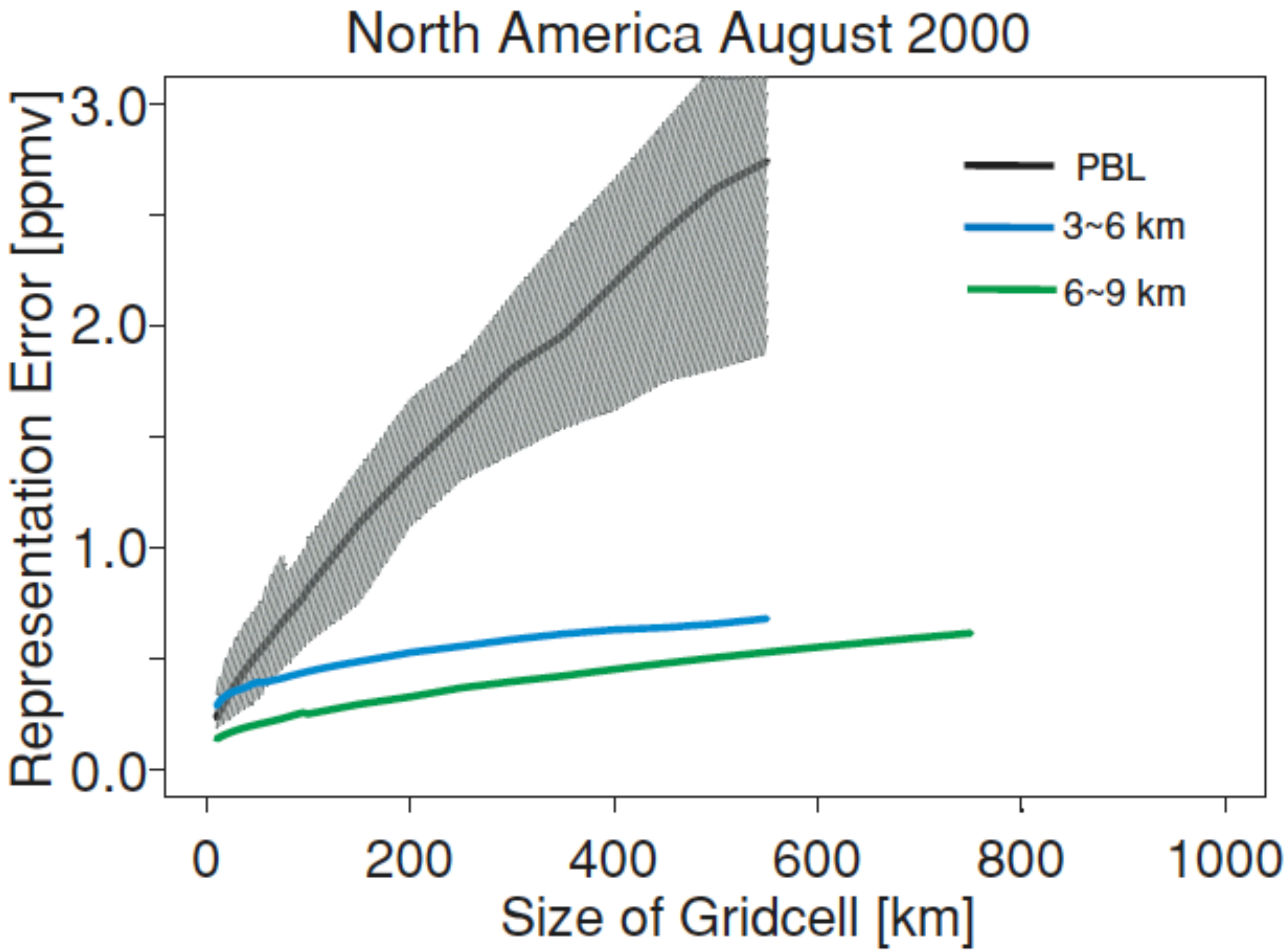
Representation Error derived from Spatial simulation for CO_2, based on Variogram

error dependent on *grid size* (hor. resolution) and *spatial variability* of tracer



Representation error: Stdev(CO_2) within each subgrid of size Δx Δy

Representation error: continent vs ocean



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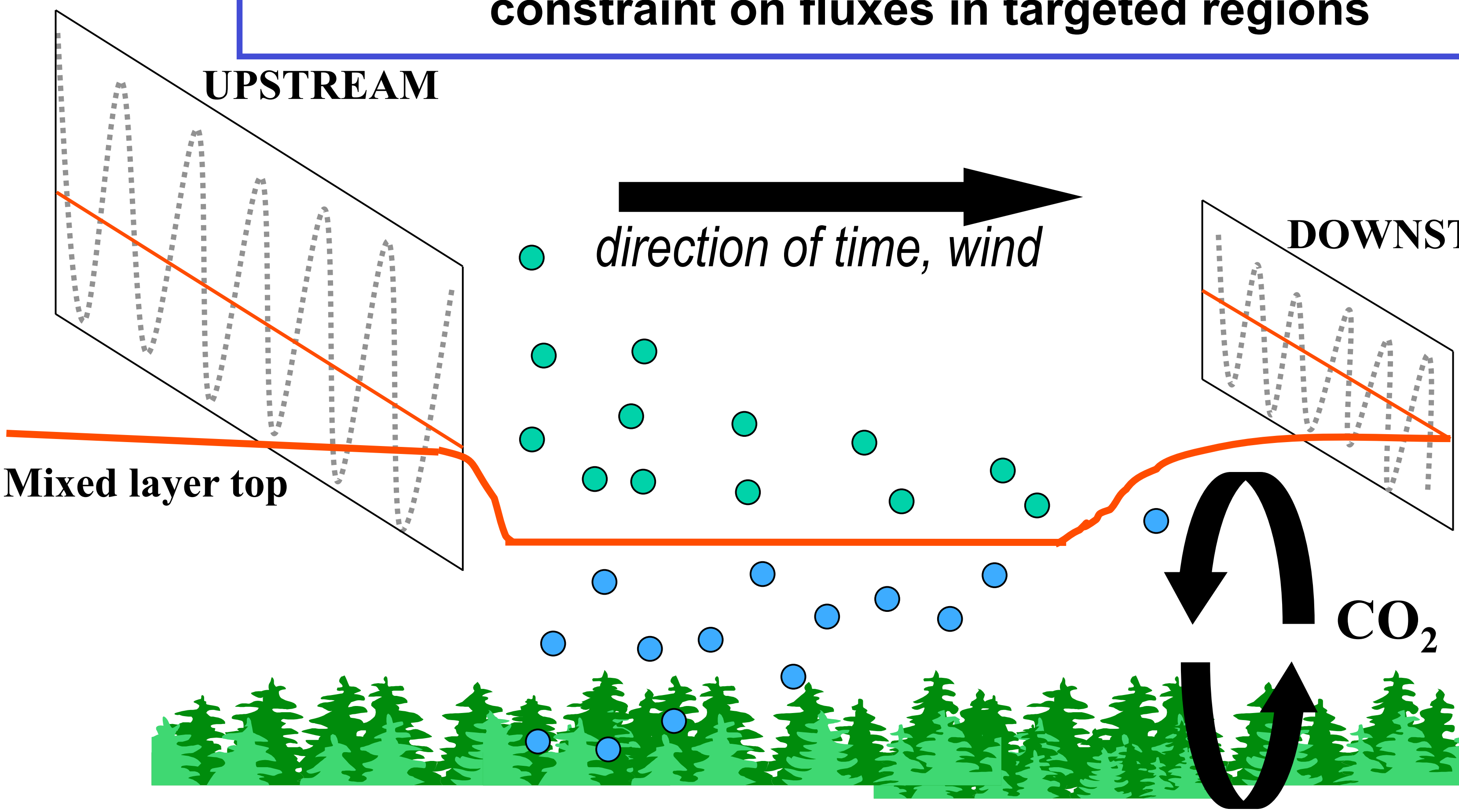
Lin, J.C., et al., *Designing Lagrangian experiments to measure regional-scale trace gas fluxes, J. Geophys. Res.,* 112(D13312, doi:10.1029/2006JD008077), 2007.

Planning and Analysis of “Air-Following” Experiments

Objective: test method for providing tight atmospheric constraint on fluxes in targeted regions



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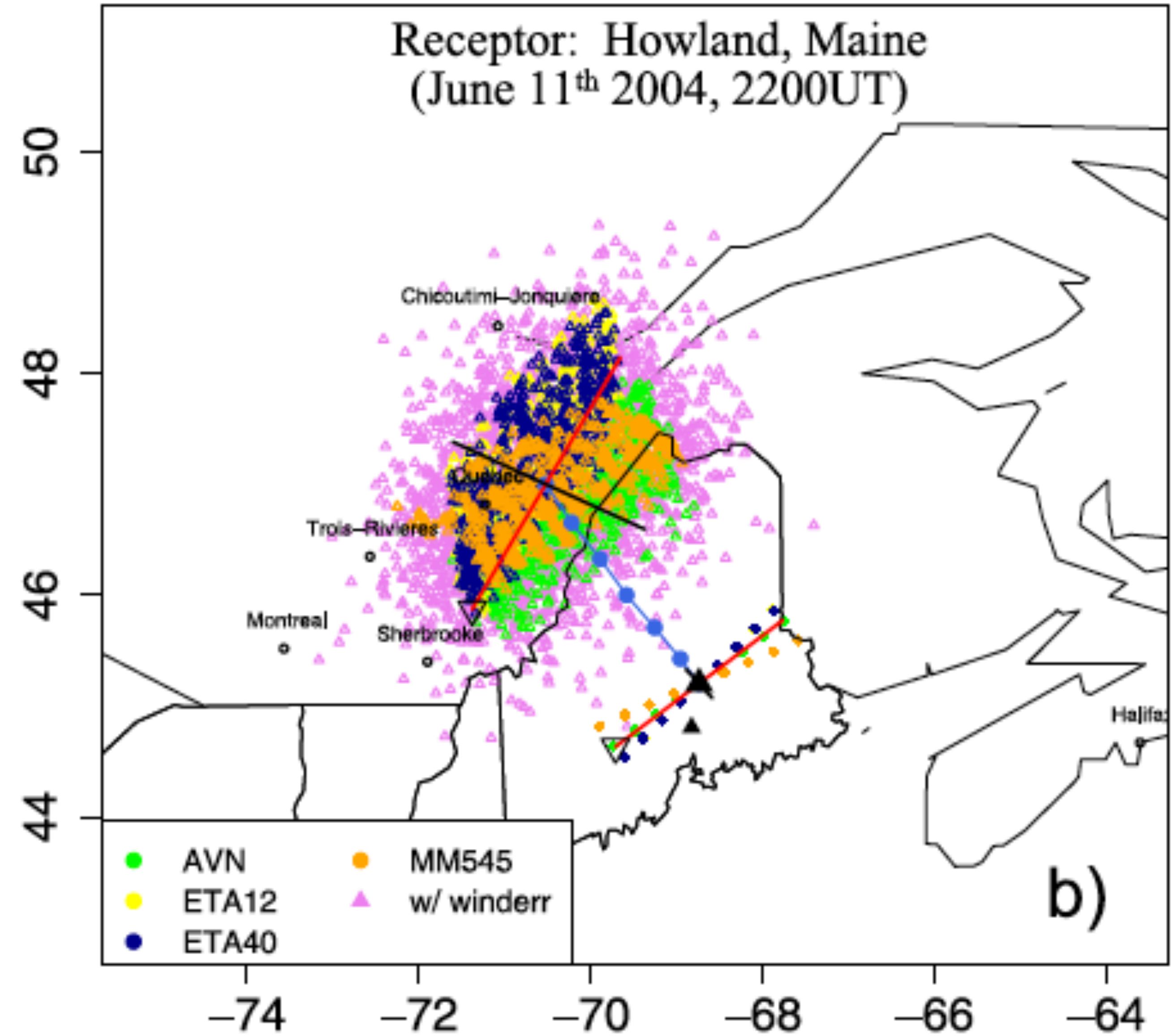

Citation: Lin, J. C., C. Gerbig, S. C. Wofsy, V. Y. Chow, E. Gottlieb, B. C. Daube, and D. M. Matross (2007), ''Designing Lagrangian experiments to measure regional-scale trace gas fluxes'', *J. Geophys. Res.*, *112*, D13312, doi:10.1029/2006JD008077.

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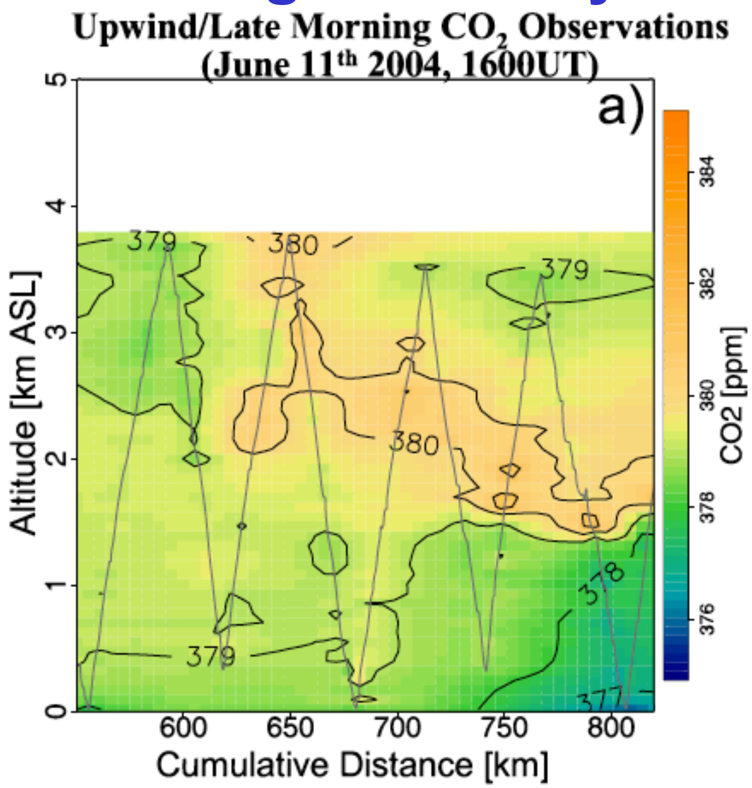

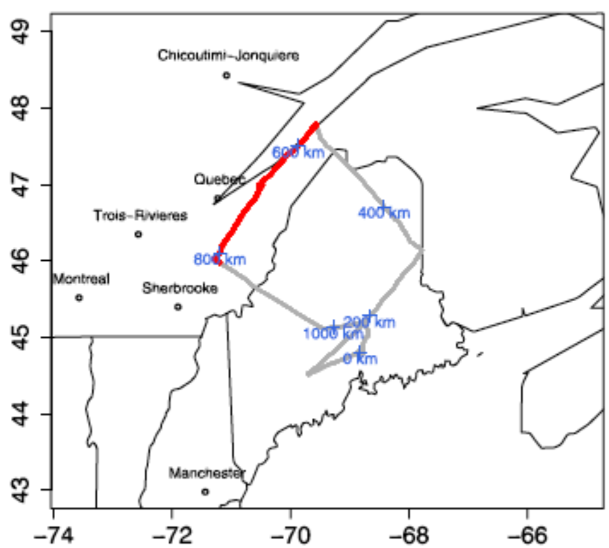

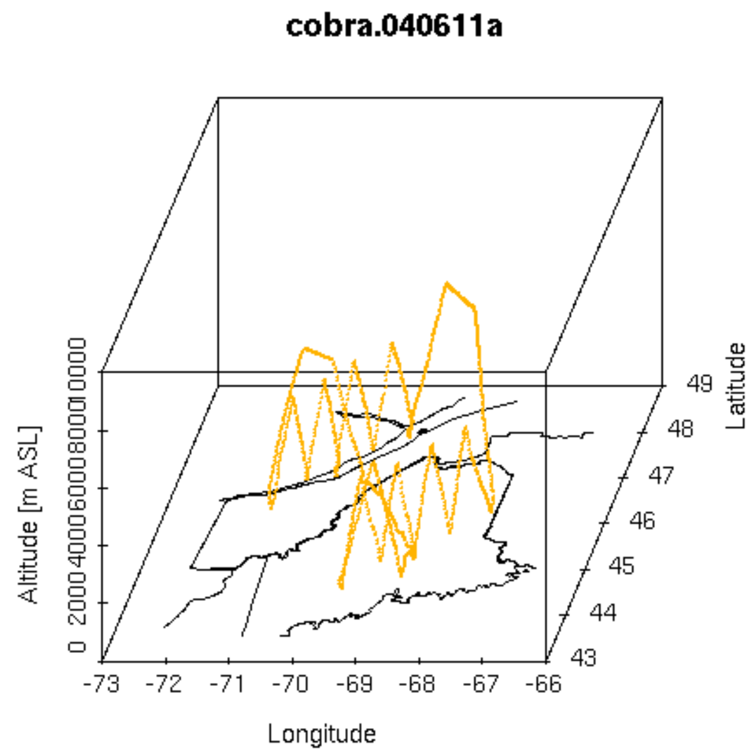

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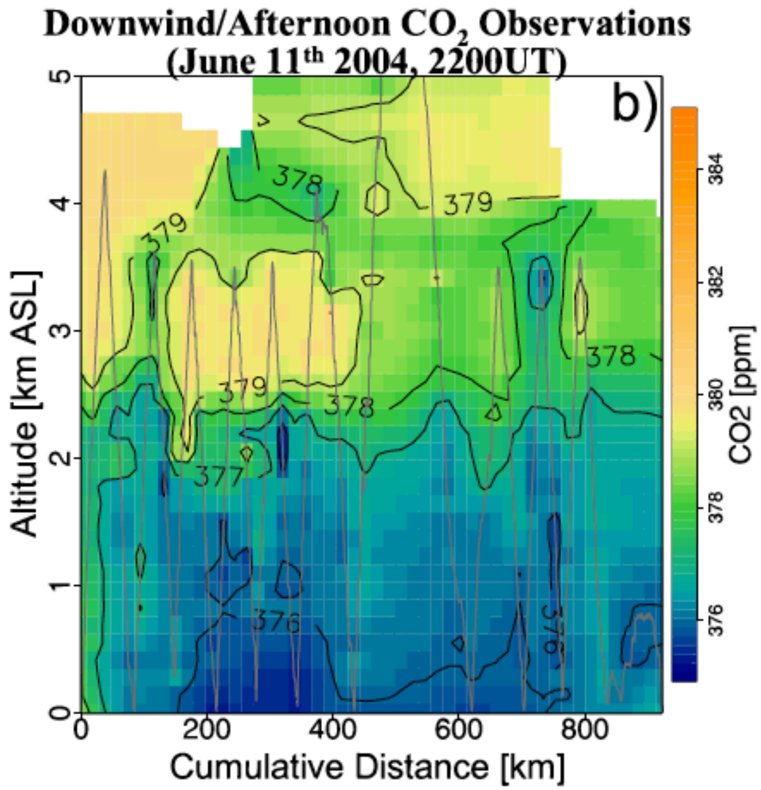

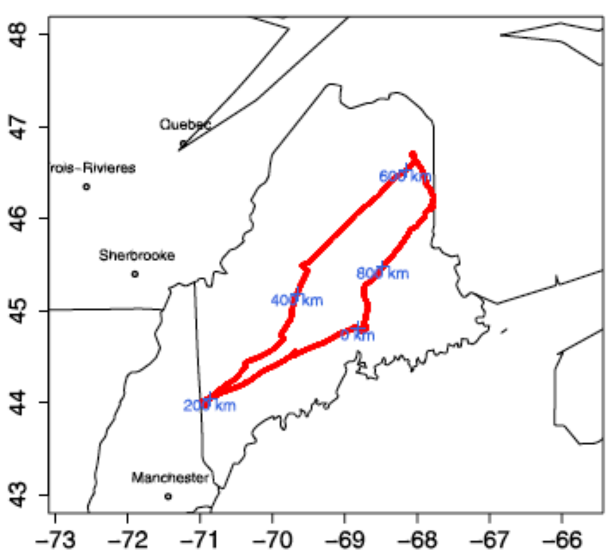

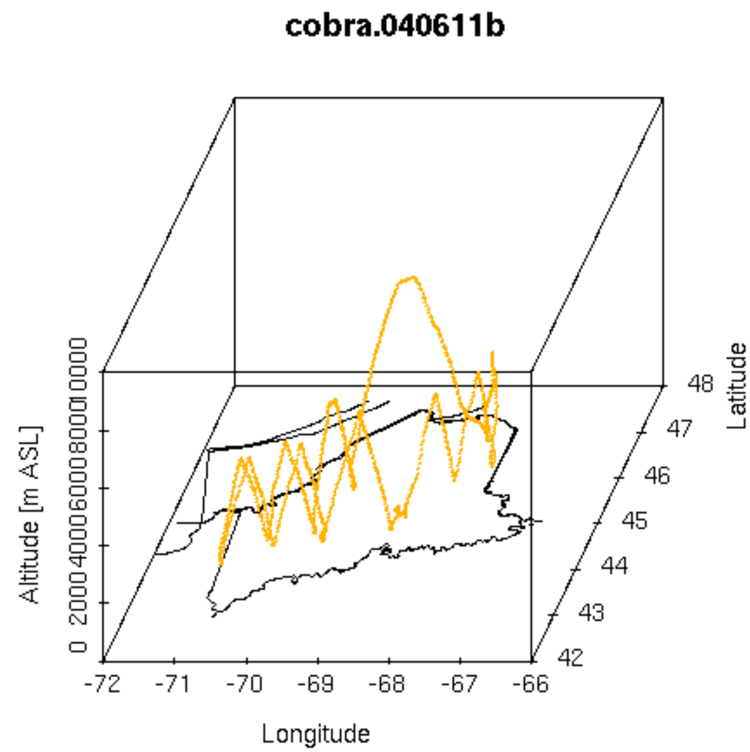

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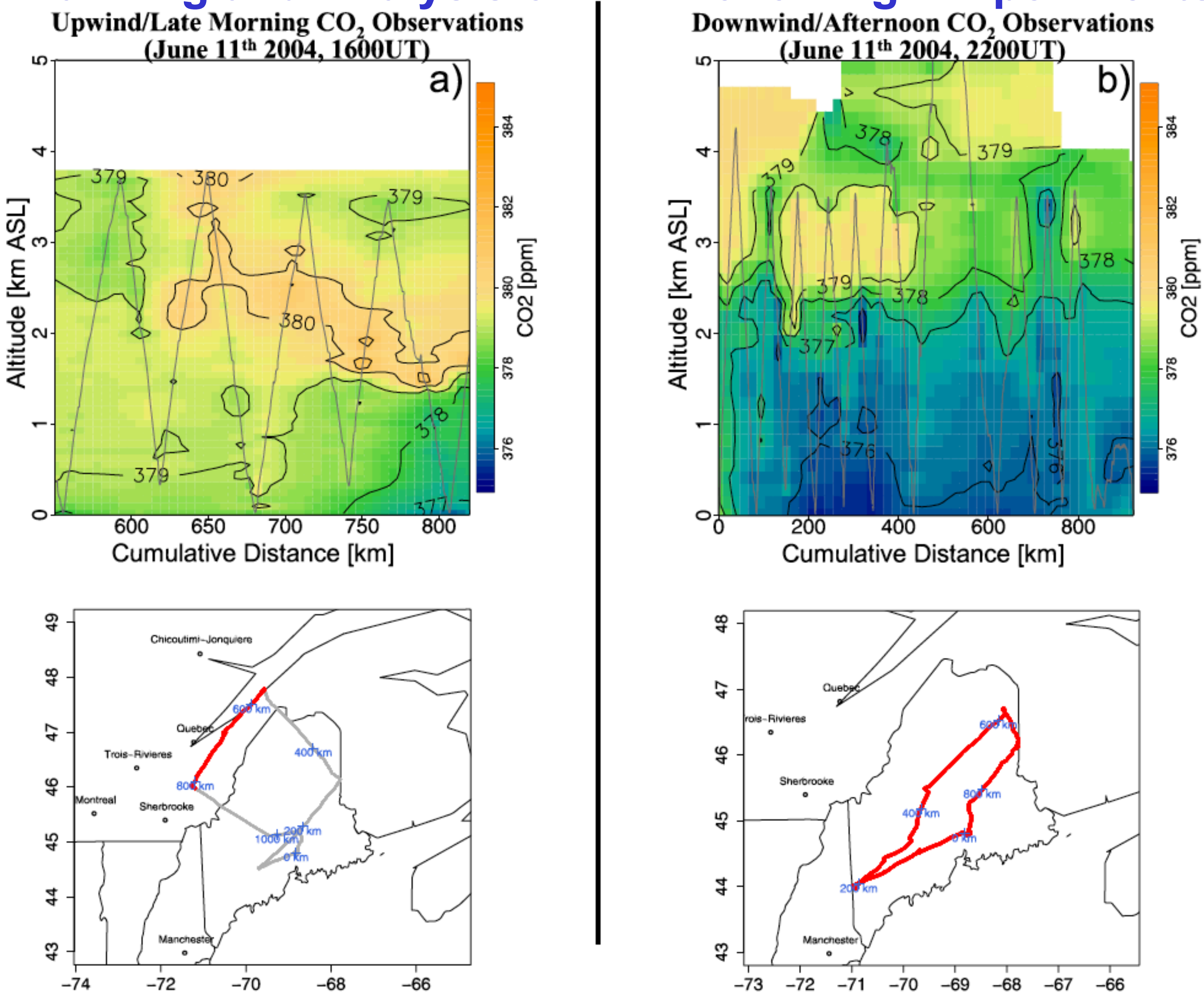

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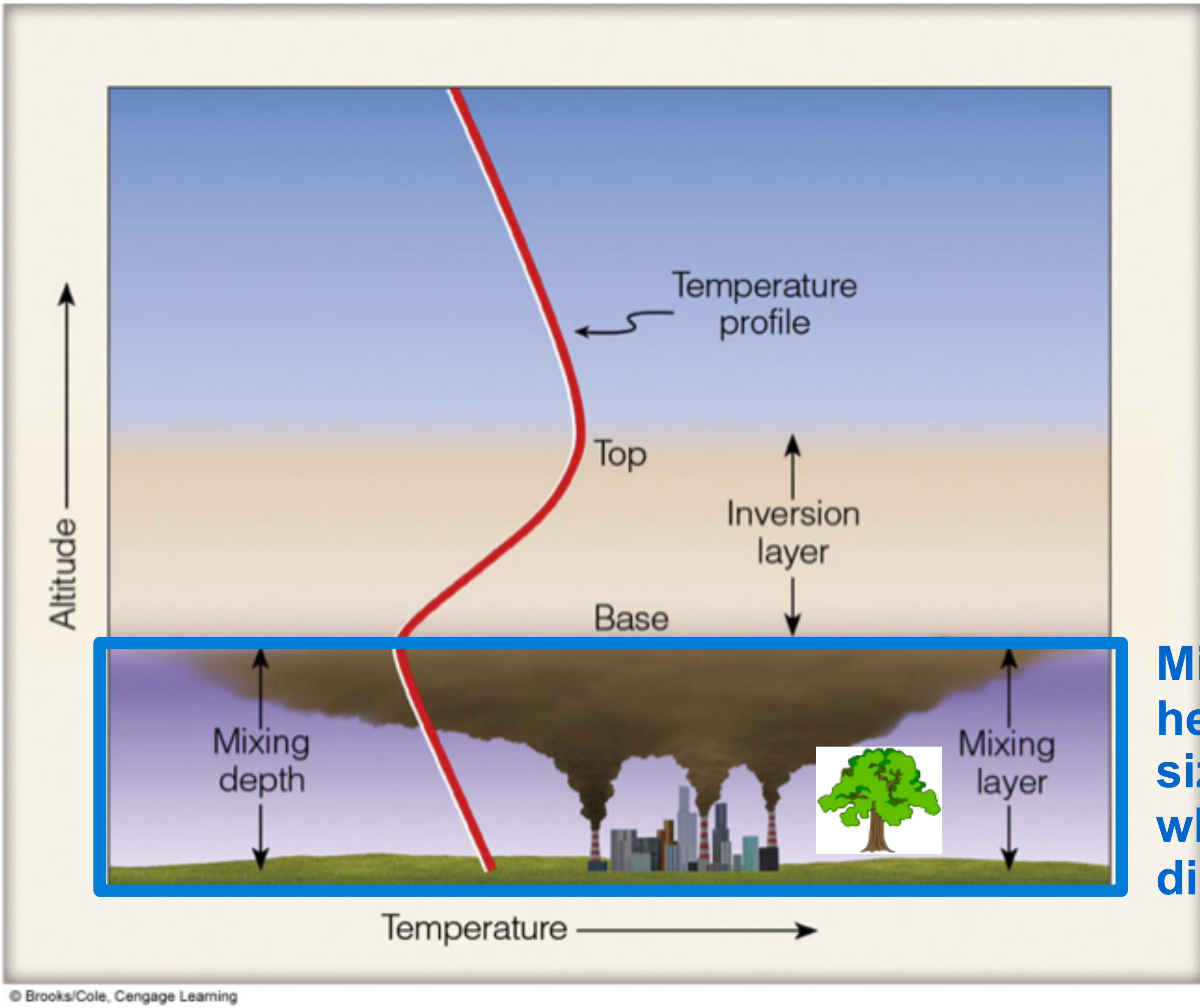
Atmosphere Serving as an Integrator. But need to know how big box is! (mixed-layer height)



Mixed-layer height controls size of box over which fluxes are diluted

Fig. 18.15 of *Meteorology Today*, by C. Donald Ahrens

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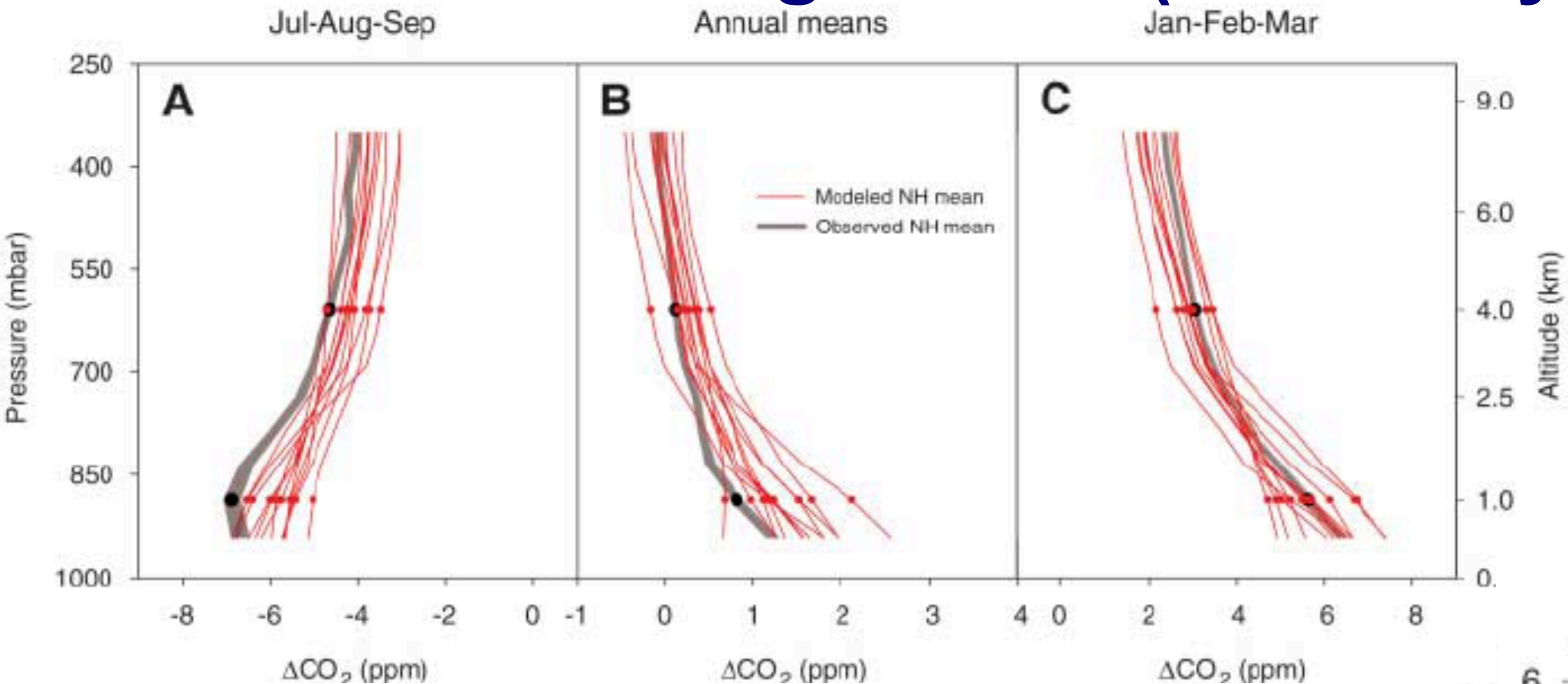
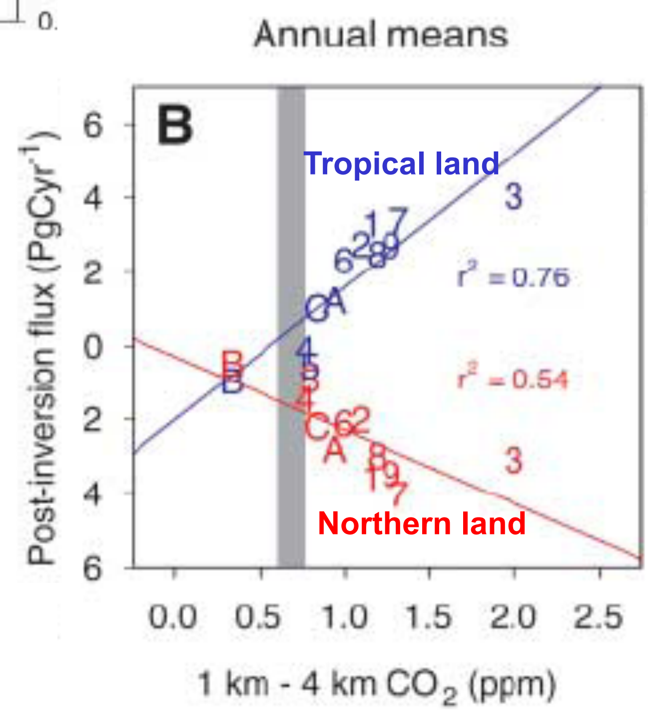


Fig. 2. (**A** to **C**) Observed Northern Hemisphere average profiles compared with predictions of the 12 T3L2 models over the same seasonal intervals as in Fig. 1. Gray lines indicate the observed average vertical CO_2 gradients (center) and uncertainties (width) from Fig. 1 (*25*). The model output was processed in the same way as the observations at each site before averaging (*25*). Symbols indicate 1- and 4-km values used for calculating the vertical gradients shown in Fig. 3. The horizontal axis in (B) is zoomed by a factor of 2 relative to those in (A) and (C).

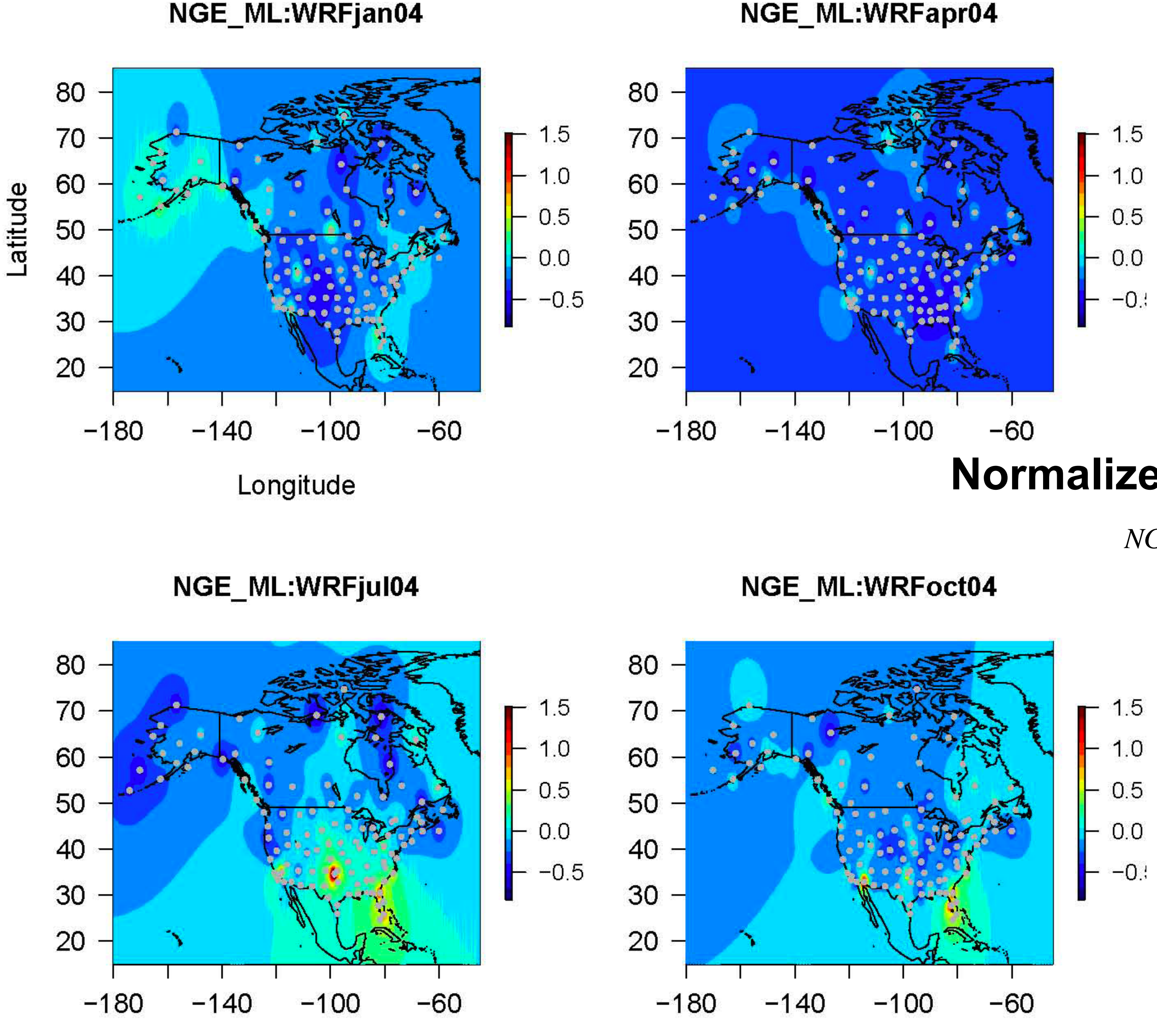


Weak Northern and Strong Tropical Land Carbon Uptake from Vertical Profiles of Atmospheric CO_2

Britton B. Stephens,[1*] Kevin R. Gurney,[2] Pieter P. Tans,[3] Colm Sweeney,[3] Wouter Peters,[3] Lori Bruhwiler,[3] Philippe Ciais,[4] Michel Ramonet,[4] Philippe Bousquet,[4] Takakiyo Nakazawa,[5] Shuji Aoki,[5] Toshinobu Machida,[6] Gen Inoue,[7] Nikolay Vinnichenko,[8]† Jon Lloyd,[9] Armin Jordan,[10] Martin Heimann,[10] Olga Shibistova,[11] Ray L. Langenfelds,[12] L. Paul Steele,[12] Roger J. Francey,[12] A. Scott Denning[13]

22 JUNE 2007 VOL 316 SCIENCE

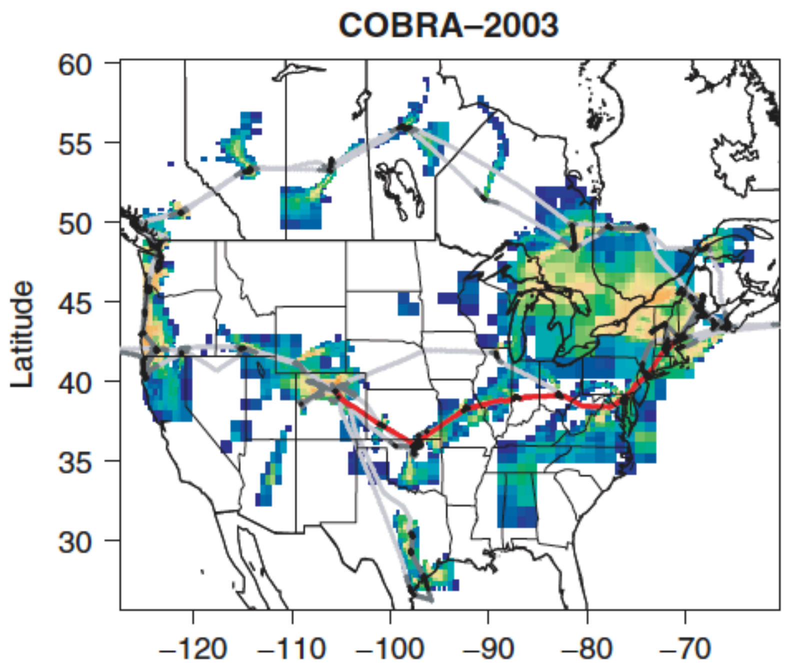
Mixed-Layer Biases



WRF mesoscale model fields compared against radiosonde data

Normalized Gross Error (NGE)

$$NGE = \frac{mean(model) - mean(obs)}{mean(obs)}$$



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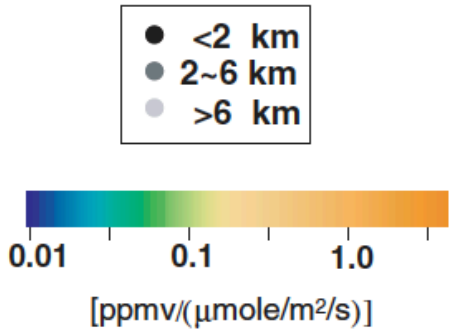
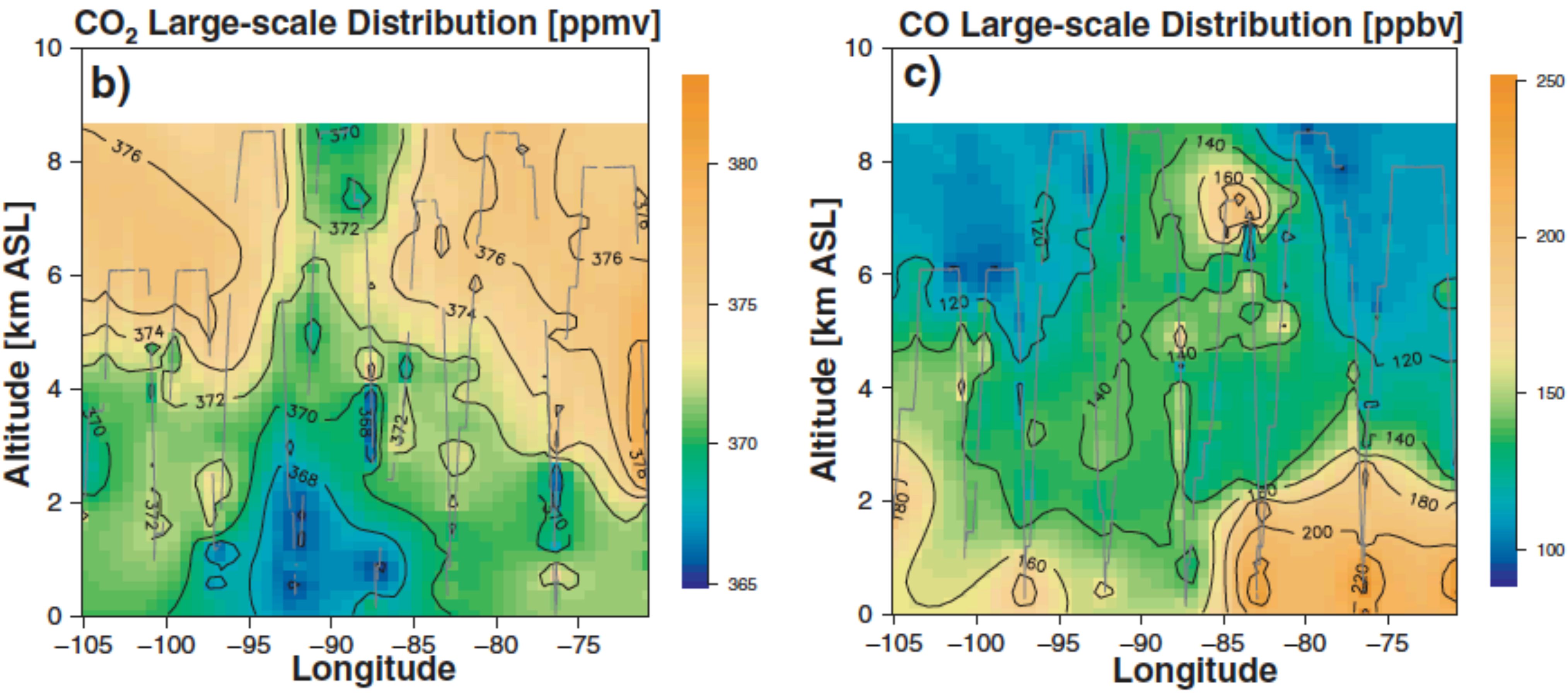


Aircrafts yield rich datasets with which to test models



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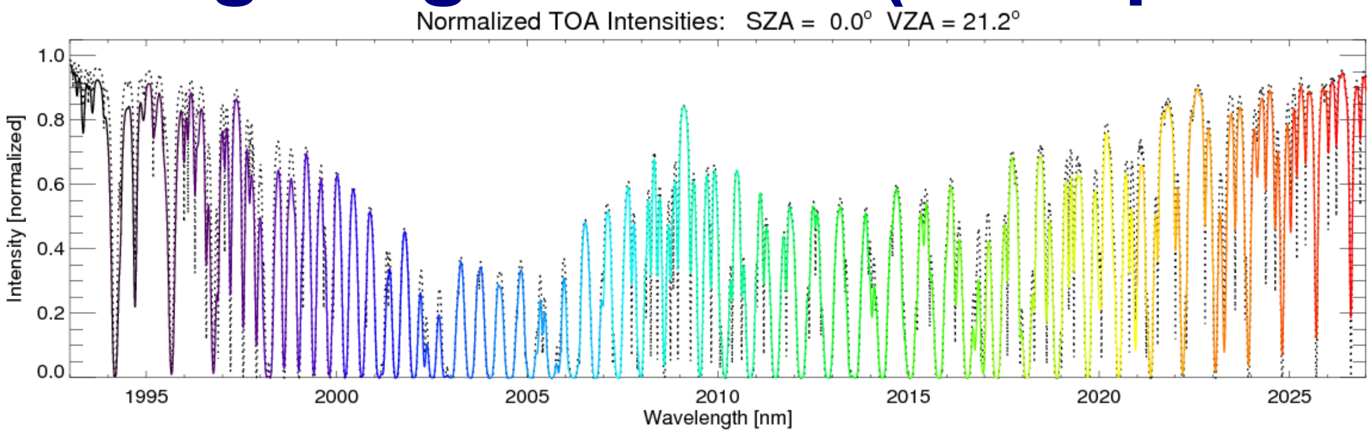
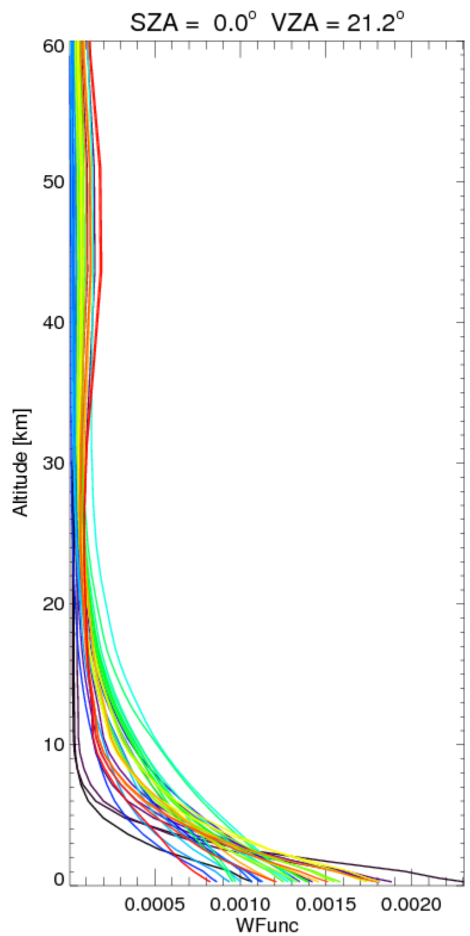
Satellite Weighting Function (example from MEOS)

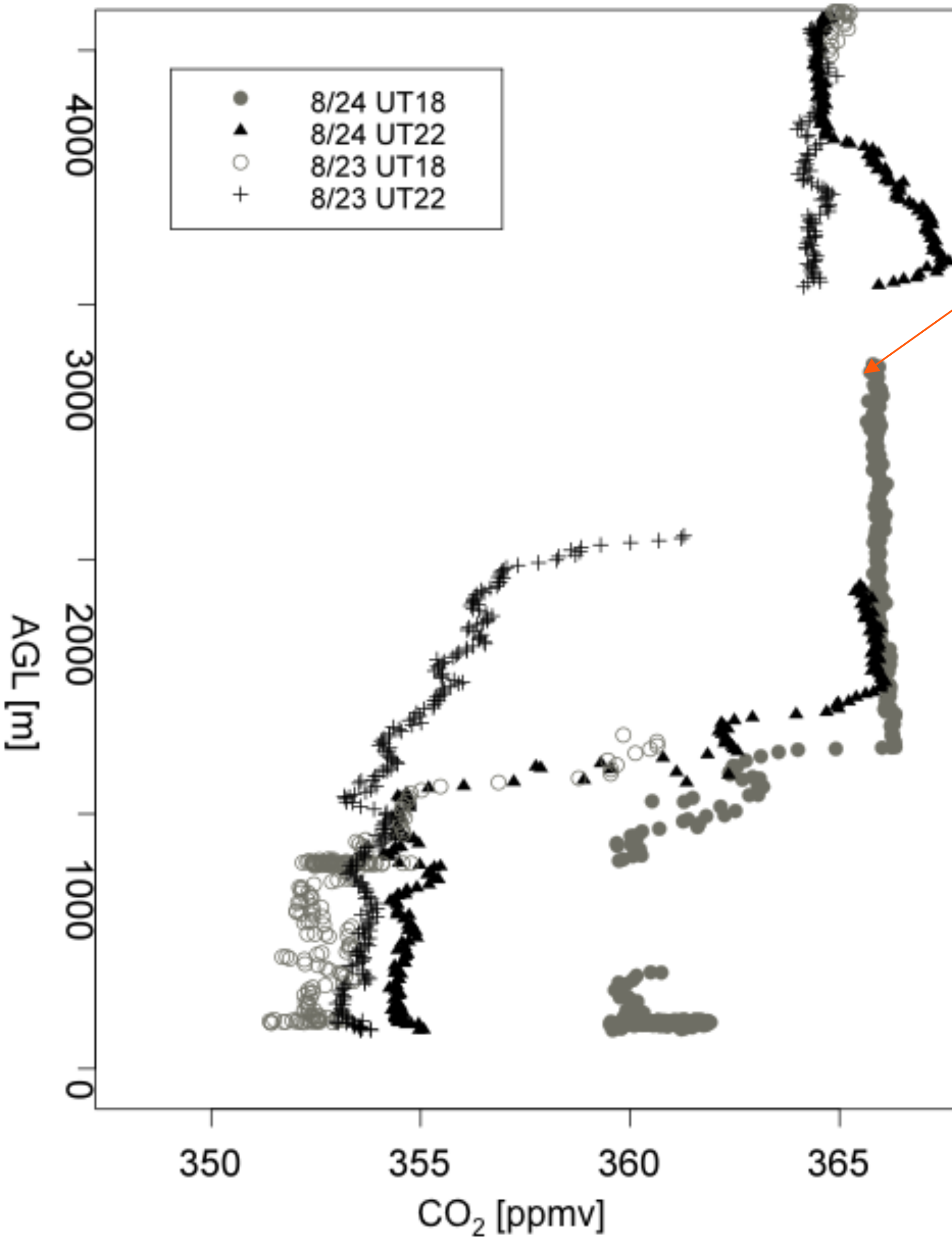




Aircraft measurements can help probe troposphere and contribute to validation efforts

(results from Thomas Kurosu, Harvard-Smithsonian Center for Astrophysics)

Column CO_2 Measurements from Satellites?



CO_2 vertical profiles measured by aircraft (COBRA field campaign)

Column amount would be insensitive to mixed-layer height

Even better: if we could separate out column into at least two pieces of information
1) within mixed-layer
2) free troposphere

Citation: Lin, J. C., C. Gerbig, S. C. Wofsy, A. E. Andrews, B. C. Daube, C. A. Grainger, B. B. Stephens, P. S. Bakwin, and D. Y. Hollinger (2004), Measuring fluxes of trace gases at regional scales by Lagrangian observations: Application to the CO_2 Budget and Rectification Airborne (COBRA) study, *J. Geophys. Res.*, *109*, D15304, doi:10.1029/2004JD004754.

Comparisons to Column CO_2

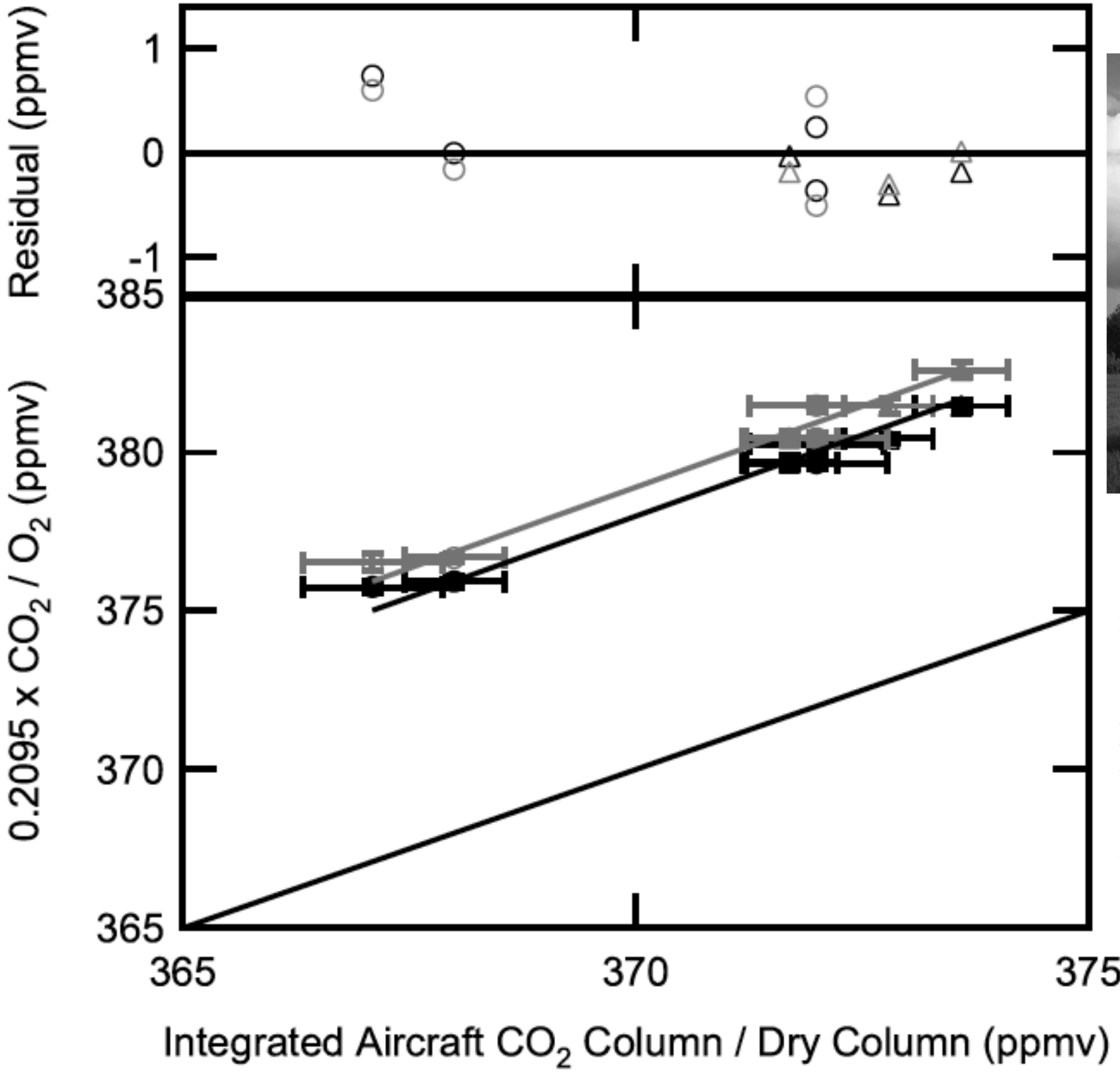


Figure 6. Integrated profiles by the DC-8 (triangles) and King Air (circles) compared to FTS retrievals from the two CO_2 bands. CO_2 6228 cm^{-1} band retrievals are solid; CO_2 6348 cm^{-1} band retrievals are shaded. Each integrated aircraft profile has been divided by the dry surface pressure, yielding the familiar units of ppmv. The relationship between integrated profile and FTS column-average CO_2 VMR is linear for each band. A linear fit with intercept 0 gives slopes of 1.0216 for the CO_2 6228 cm^{-1} band and 1.0240 for the CO_2 6348 cm^{-1} band. The top plot shows the difference between the FTS measurements and the fitted line.

Citation: Washenfelder, R. A., G. C. Toon, J.-F. Blavier, Z. Yang, N. T. Allen, P. O. Wennberg, S. A. Vay, D. M. Matross, and B. C. Daube (2006), Carbon dioxide column abundances at the Wisconsin Tall Tower site, *J. Geophys. Res.*, *111*, D22305, doi:10.1029/2006JD007154.

Conclusions and Future Steps

- Aircraft observations provide unique information on the spatial variability of tracers

- Airmass-following experiments yield constraints on regional fluxes for targetted areas: e.g., boreal forest fires, carbon loss in pine beetle-infested forests, methane release in Arctic

- The high-resolution atmospheric observations are valuable for improving models

- Aircraft data help in satellite validation efforts

=> Aircraft sampling is an important complement and addition to satellite observations!