Vertical Profiles of CO_2 and the Latitudinal Partitioning of Carbon Fluxes

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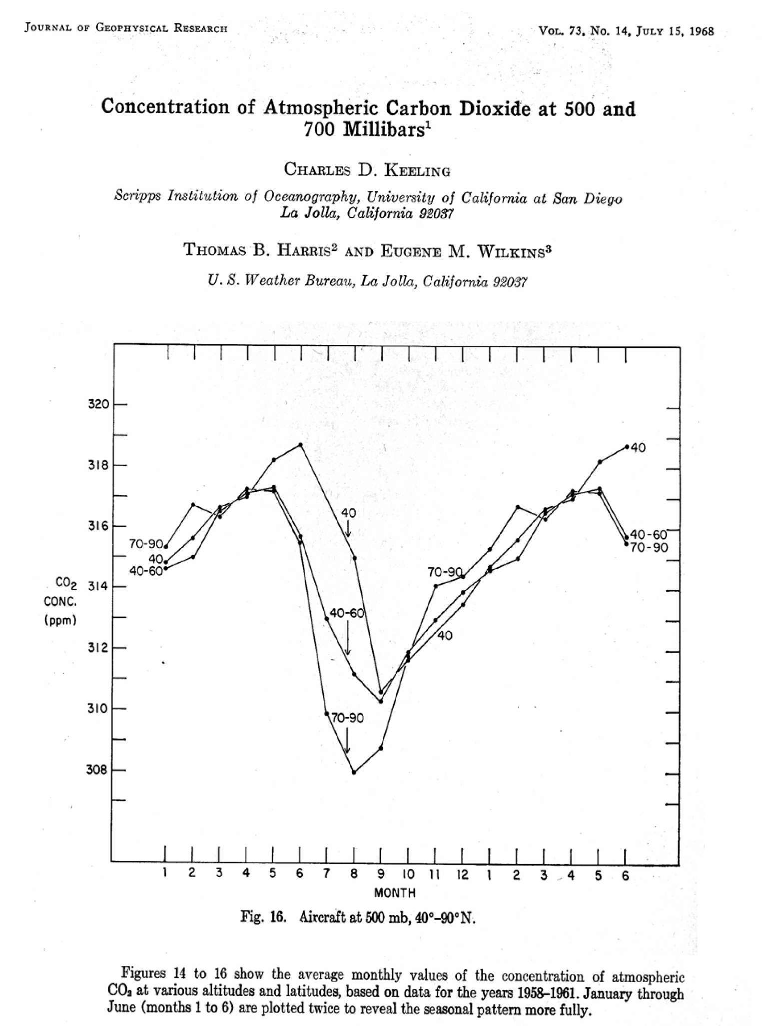
Overview: Measurements of midday vertical atmospheric CO_2 distributions reveal annual-mean vertical CO_2 gradients which are inconsistent with atmospheric models that estimate a large transfer of terrestrial carbon from tropical to northern latitudes. The 3 models that most closely reproduce the observed annual-mean vertical CO_2 gradients estimate weaker northern uptake of -1.5 $PgCyr^{-1}$ and weaker tropical emission of +0.1 $PgCyr^{-1}$ compared to previous consensus estimates of -2.4 and +1.8 $PgCyr^{-1}$ respectively. This suggests a smaller role for northern terrestrial uptake of industrial CO_2 emissions than previously thought and, after subtracting land use emissions, that tropical ecosystems may currently be strong sinks for CO_2. Adding airborne flask data to existing inverse models without first fixing their transport biases will not improve their flux estimates. Future inverse models must be validated against available metrics, including vertical profiles of CO_2, SF_6, and other tracers.

1. Airborne flask sampling for CO_2 was first conducted five decades ago by Dave Keeling. Although funding limitations ended the program, these early measurements revealed the attenuation of the seasonal CO_2 cycle with altitude and latitude.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Concentration of Atmospheric Carbon Dioxide at 500 and 700 Millibars

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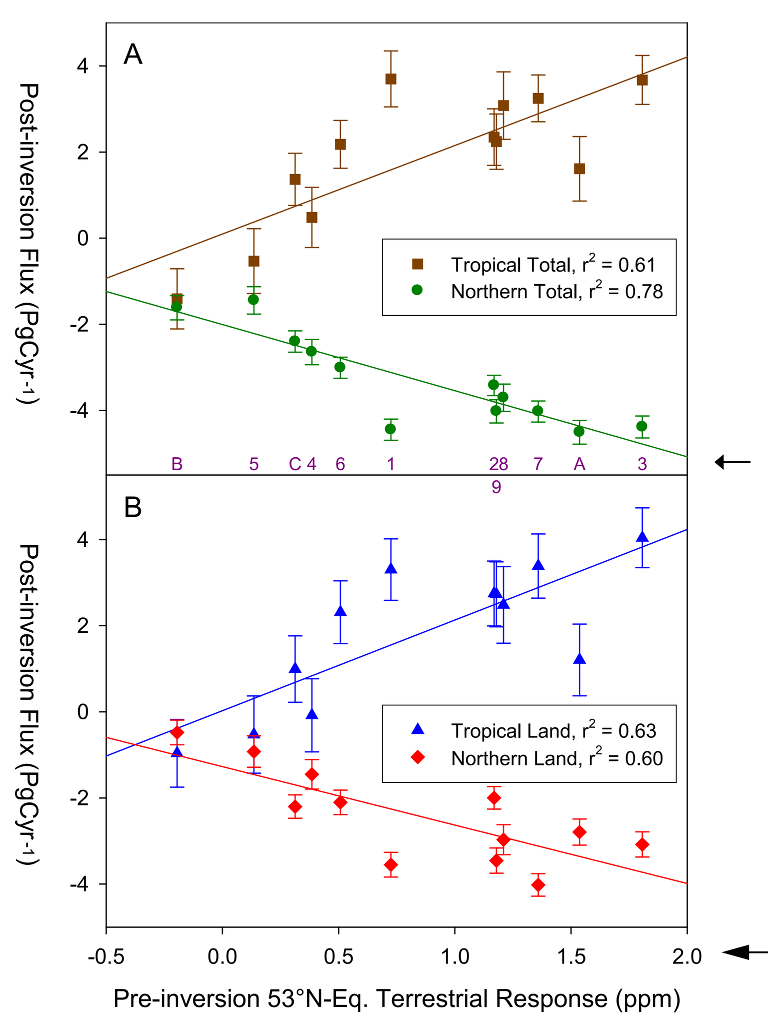
Fig. 16. Aircraft at 500 mb, 40°-90°N.

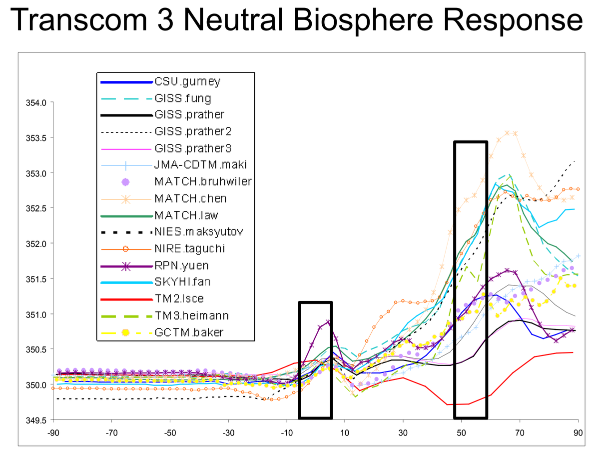
Figures 14 to 16 show the average monthly values of the concentration of atmospheric CO_2 at various altitudes and latitudes, based on data for the years 1958-1961. January through June (months 1 to 6) are plotted twice to reveal the seasonal pattern more fully.

2. TransCom 3 Level 2 estimated fluxes for northern and tropical aggregated regions vary across models by as much as 5 billion tons of carbon per year.



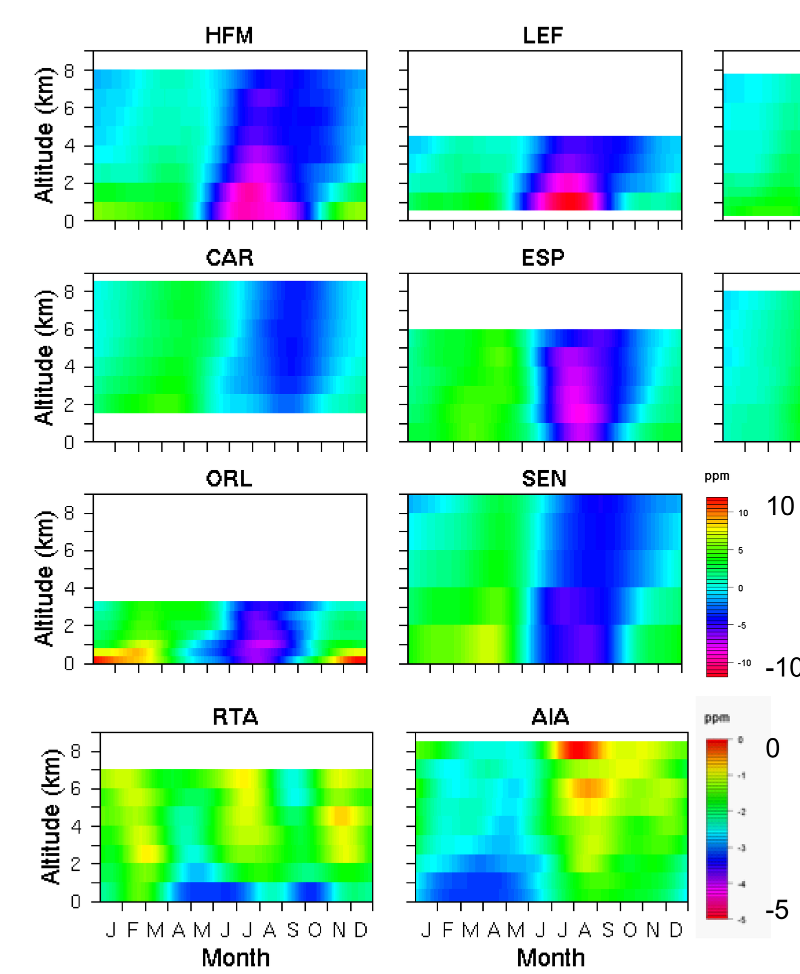
Model	Model Name
1	CSU
2	GCTM
3	UCB
4	UCI
5	JMA
6	MATCH.CCM3
7	MATCH.NCEP
8	MATCH.MACCM2
9	NIES
A	NIRE
B	TM2
C	TM3

Transcom 3 Neutral Biosphere Response

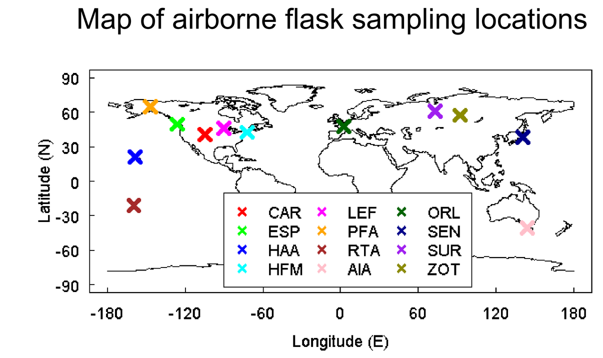


These variations are systematically related to how the models transport CO_2 in and out of the northern-hemisphere lower troposphere. Without validation, the across-model mean is no more robust than any individual estimate.

Altitude-time CO_2 contour plots for all sampling locations



Map of airborne flask sampling locations

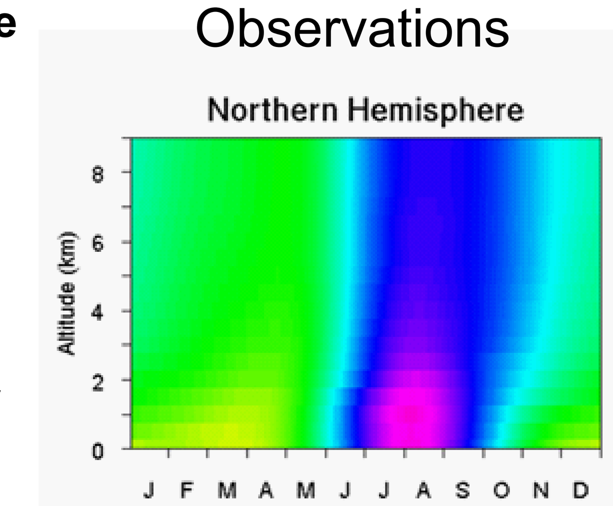


Northern Hemisphere sites include Briggsdale, Colorado, USA (CAR); Estevan Point, British Columbia, Canada (ESP); Molokai Island, Hawaii, USA (HAA); Harvard Forest, Massachusetts, USA (HFM); Park Falls, Wisconsin, USA (LEF); Poker Flat, Alaska, USA (PFA); Orleans, France (ORL); Sendai/Fukuoka, Japan (SEN); Surgut, Russia (SUR); and Zotino, Russia (ZOT). Southern Hemisphere sites include Rarotonga, Cook Islands (RTA) and Bass Strait/Cape Grim, Australia (AIA).

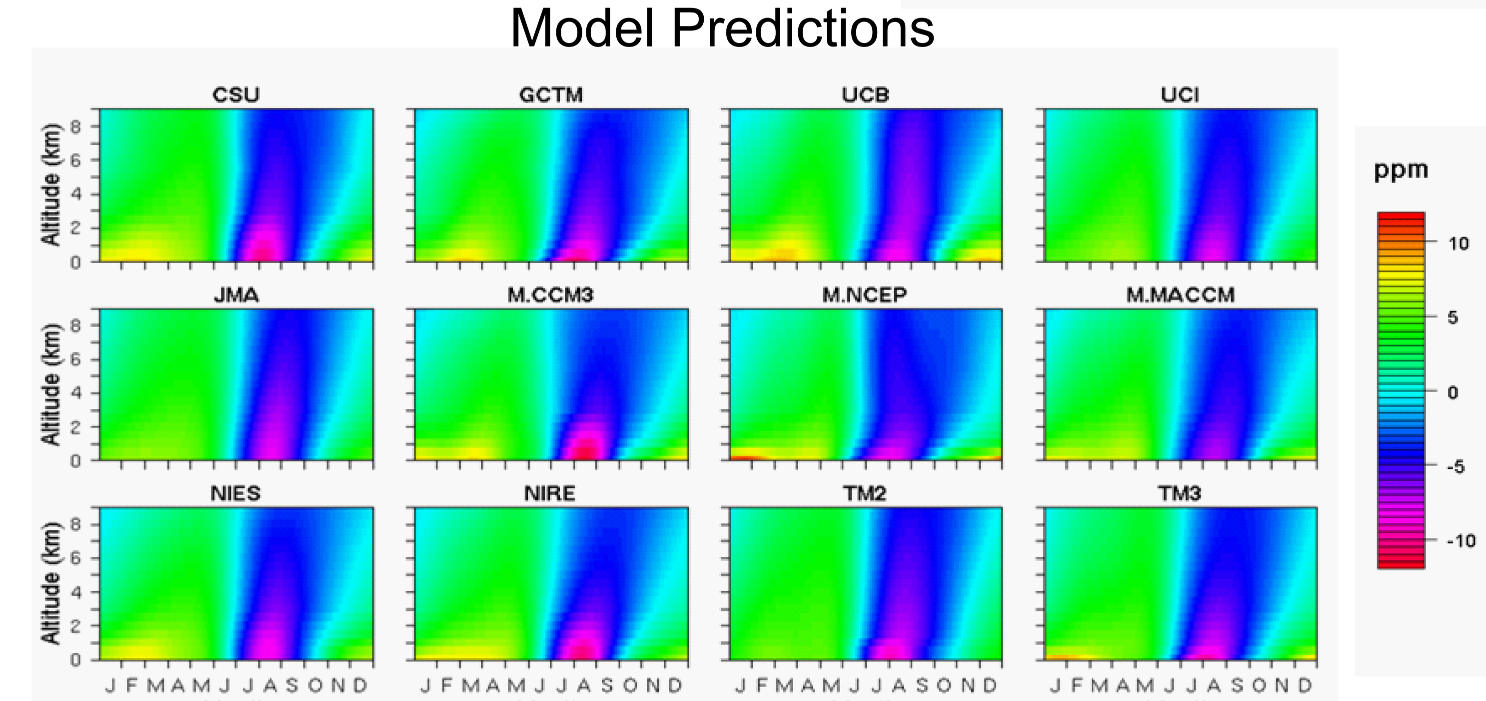
3. Existing airborne sampling includes these 12 sites with records over 5 years long and several with records over 20 years long, with reasonable global and continental coverage. However, the use of these data in global inverse models has been limited.

4. Observed **northern-hemisphere average profiles** reveal stronger vertical mixing in summer than winter. We extracted and averaged model-predicted profiles to match the observations. After optimization to marine-boundary-layer surface data, these models show large variations with generally overestimated summer mixing and both over and underestimated winter mixing.

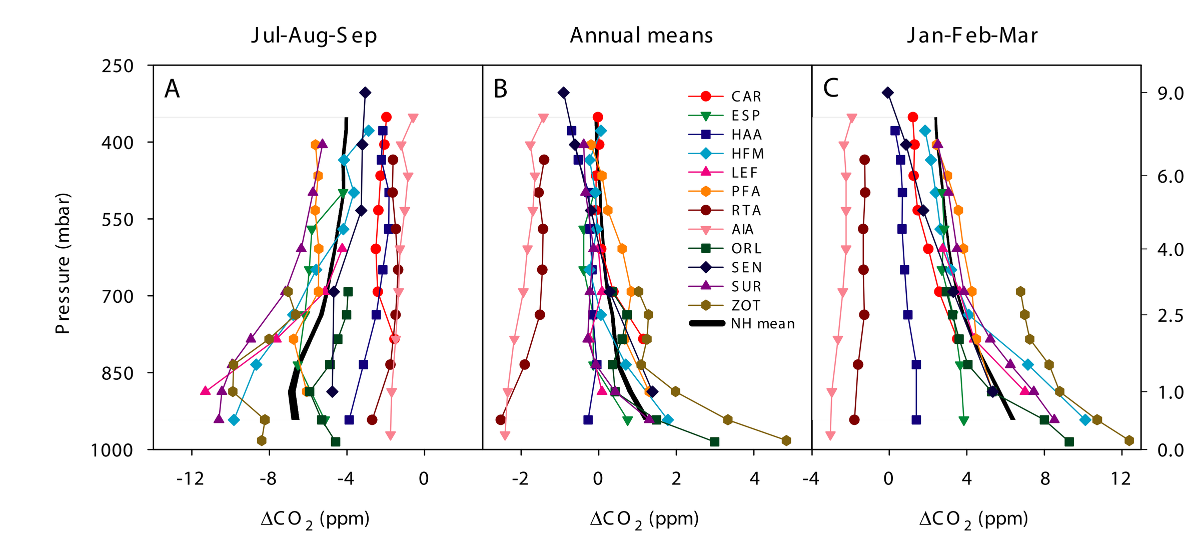
Observations



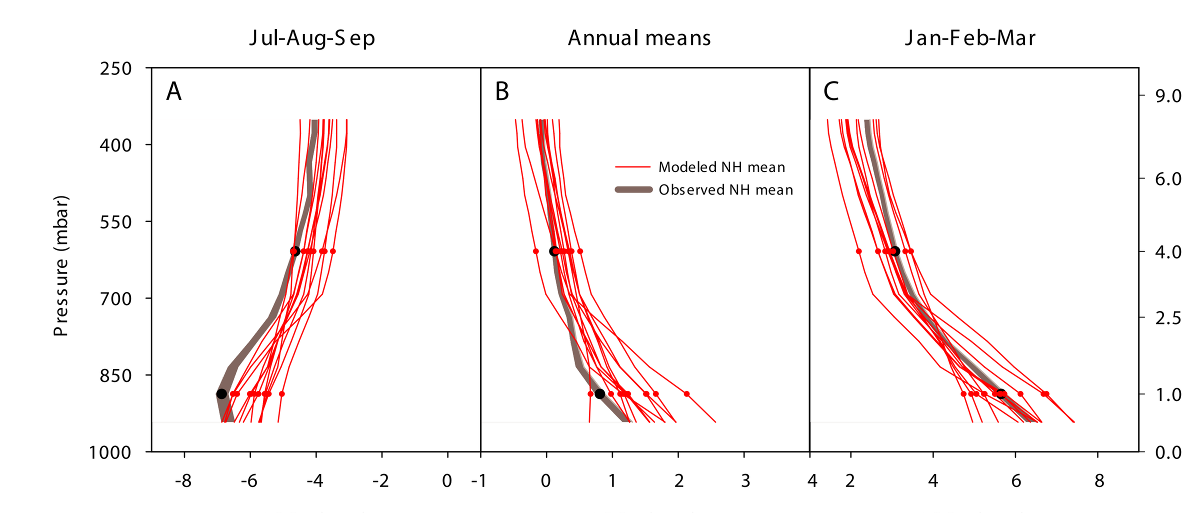
Model Predictions



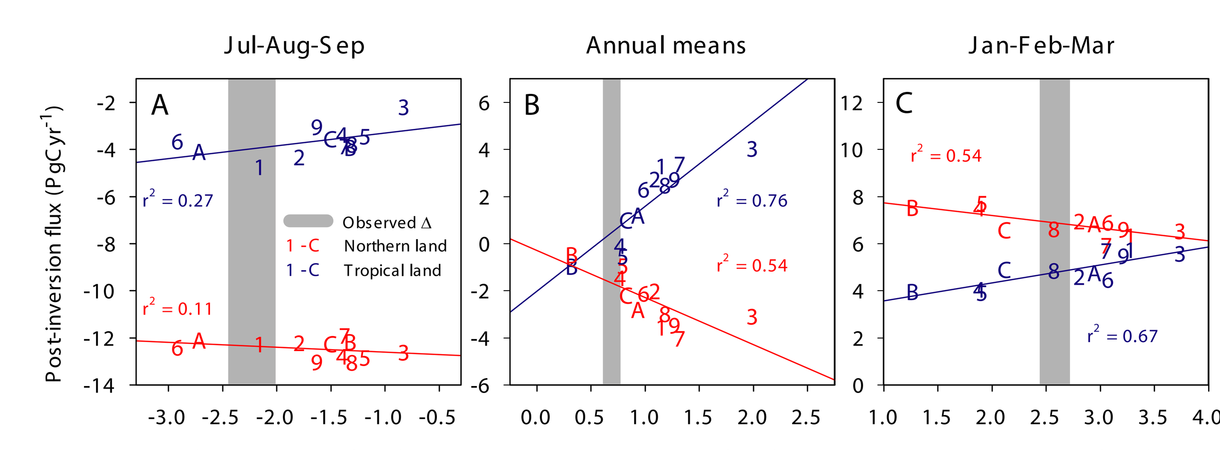
5. Seasonal and annual-mean comparisons show that no model accurately reproduces the observations at all times of year. We use the annual-mean 1 - 4 km gradient as a metric to select three models, which we then average to produce the new flux estimates.



Observed profiles at all sites (colors) and averaged across northern hemisphere sites (black).

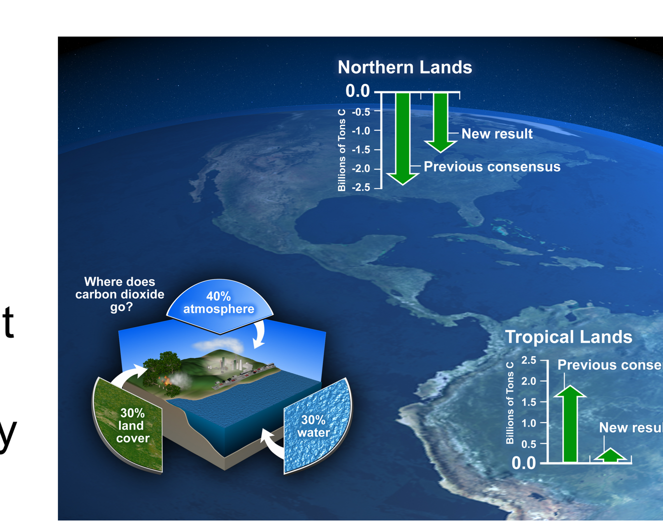


Northern-hemisphere average modeled (red) and observed profiles (gray).



Model estimated fluxes plotted versus predicted vertical profiles. The observed vertical profiles and uncertainties are indicated by gray bars.

Although considerable uncertainty remains, this result implies that northern countries may not be able to rely on their forests to offset their industrial emissions as much as hoped, but also that tropical countries can help to mitigate CO_2 increases by preserving their forests.



6. Reference: Stephens, B.B., K.R. Gurney, P.P. Tans, C. Sweeney, W. Peters, L. Bruhwiler, P. Ciais, M. Ramonet, P. Bousquet, T. Nakazawa, S. Aoki, T. Machida, G. Inoue, N. Vinnichenko, J. Lloyd, A. Jordan, M. Heimann, O. Shibistova, R.L. Langenfelds, L.P. Steele, R.J. Francey, A.S. Denning, Weak northern and strong tropical land carbon uptake from vertical profiles of atmospheric CO_2, Science, 316, 1732-1735, 2007.