Evaluating Model-Observation CO_2 Sampling Strategies: Implications for the Strength of the Latitudinal CO_2 Gradient

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Introduction

Differences between model-simulated and observed atmospheric CO_2 concentrations have been used to infer the location and magnitude of regional CO_2 sources and sinks. These analyses suggest that the Northern Hemisphere terrestrial biosphere is sequestering approximately 2 PgC/yr. However, in these studies the model simulated data is generally averaged over all times of day and meteorological conditions whereas most of the observations were made during daylight hours and subject to meteorological restrictions, e.g., wind speed and direction criteria. We investigated the effect of several different sampling strategies on modeled CO_2 distributions in two different global chemical transport models driven with different meteorological inputs. In our analysis we used diurnally varying CO_2 fluxes from the terrestrial biosphere and focused on the stations used in the Transcom 3 model intercomparison study. We found that annual mean CO_2 concentrations simulated in the models were sensitive to the time of day sampling and wind speed and direction. Failing to account for the diurnal cycle of CO_2 when sampling atmospheric models leads to an overestimate of CO_2 levels at a number of continental and coastal stations. In atmospheric inversions, this bias could lead to an overestimation of the size of the Northern Hemisphere carbon sink. As more observations in non-remote locations are incorporated into model-observation comparisons, extra care will be necessary to sample model simulations in the same manner that the observations were sampled.

We specifically addressed the question of:

How does the modeled annual average CO_2 mixing ratio at stations used in Transcom 3 depend on sampling criteria, e.g., time of day and wind speed?

Chemistry Transport Models

We evaluated sampling scenarios in two chemistry transport models.

1) UCI CTM
- T42 Resolution ($\sim 2.8^o$ lat x 2.8^o lon)
- 40 vertical levels from the surface up to 2mb ($\sim$34 km)
- ECMWF forecast fields (3-hr)

2) **M**odel of **A**tmospheric **T**ransport and **Ch**emistry (MATCH)
- T21 Resolution ($\sim 5.5^o$ lat x 5.5^o lon)
- 26 vertical levels, surface to 0.2 hPa ($\sim$60 km)
- CCM3 meteorological input (3-hr)

Model CO_2 Sources

Fossil Fuel Source:
Annual 1995 (5.8 Gt C y^{-1}) [Andres et al., 1996]

Ocean Sink:
Monthly (-2.2 Gt C y^{-1}) [Takahashi et al., 1999]

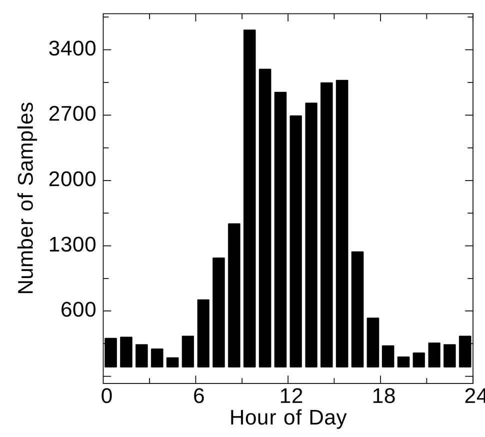
NEP Biosphere Source:
Diurnal CASA 3-hr [Olsen and Randerson, 2004]

CMDL Sampling

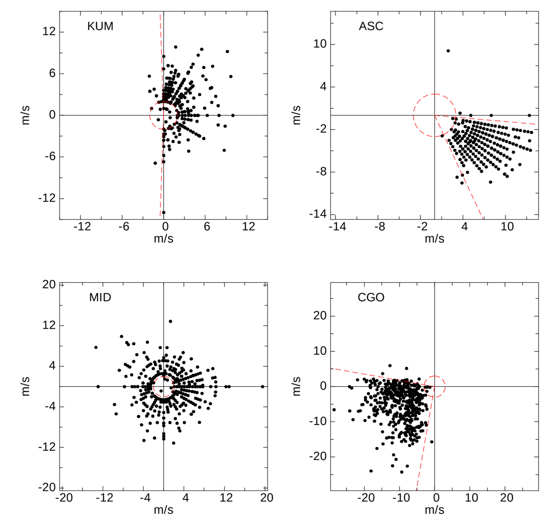
The Climate Monitoring and Diagnostics Laboratory (CMDL) provide CO_2 observations frequently used for model comparisons. CMDL flask data are largely taken during the daytime and predominantly during certain meteorological conditions which may vary from station to station and are designed to sample "background" conditions. We analysed available meteorological data over the period from 1992 to 2004. The quantity and quality of meteorological data varies greatly between stations. We have used only meteorological data where the corresponding CO_2 concentration data passed the CMDL quality control for background samples. This includes data from the following stations ALT, ASC, ASK, AZR, BAL, BME, BMW, BRW, BSC, CBA, CGO, CHR, CMO, CRZ, EIC, GMI, GOZ, HBA, HUN, ICE, IZO, KCO, KEY, KUM, KZD, KZM, LEF, MBC, MHD, MID, MLO, NMB, NWR, PSA, PTA, RPB, SEY, SGI, SHM, SMO, SPO, STM, SUM, SYO, TAP, TDF, UTA, UUM, WIS, ZEP

From this we define our "best estimate" sampling criteria as the daytime (10:00 to 16:00) with wind speed $>$ 2m/s and using wind direction data at the stations where it is available.

CMDL Sampling cont.

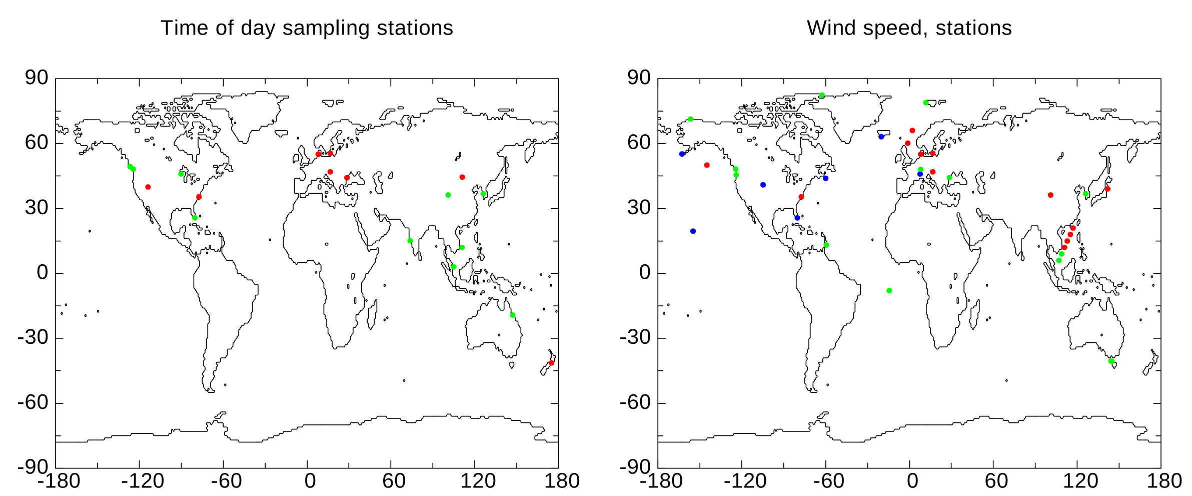


Time of day sampling distribution for CMDL samples.



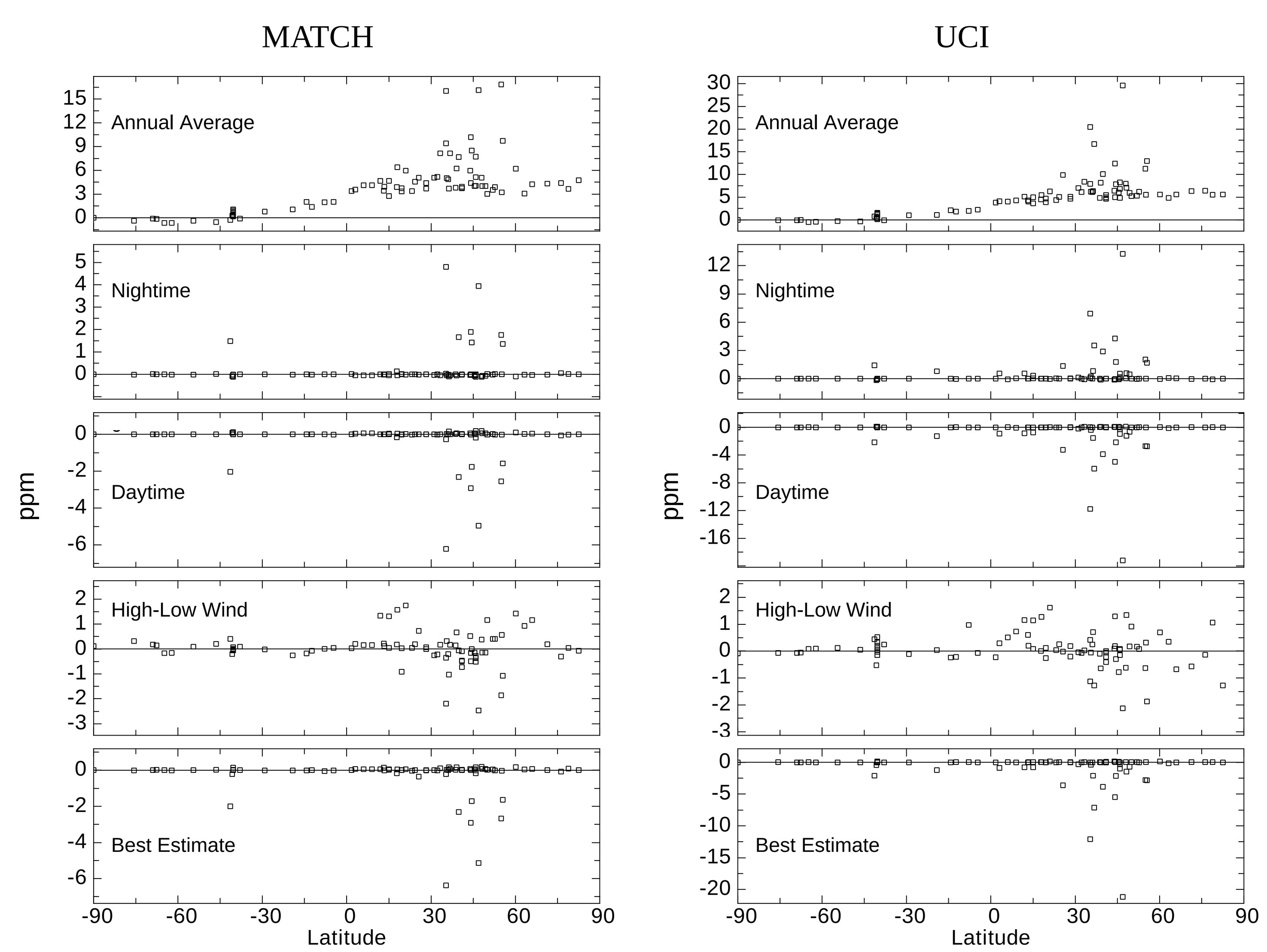
Wind direction and speed for selected CMDL stations. Red dashed lines indicate part of our best estimate sampling criteria.

Affected Stations



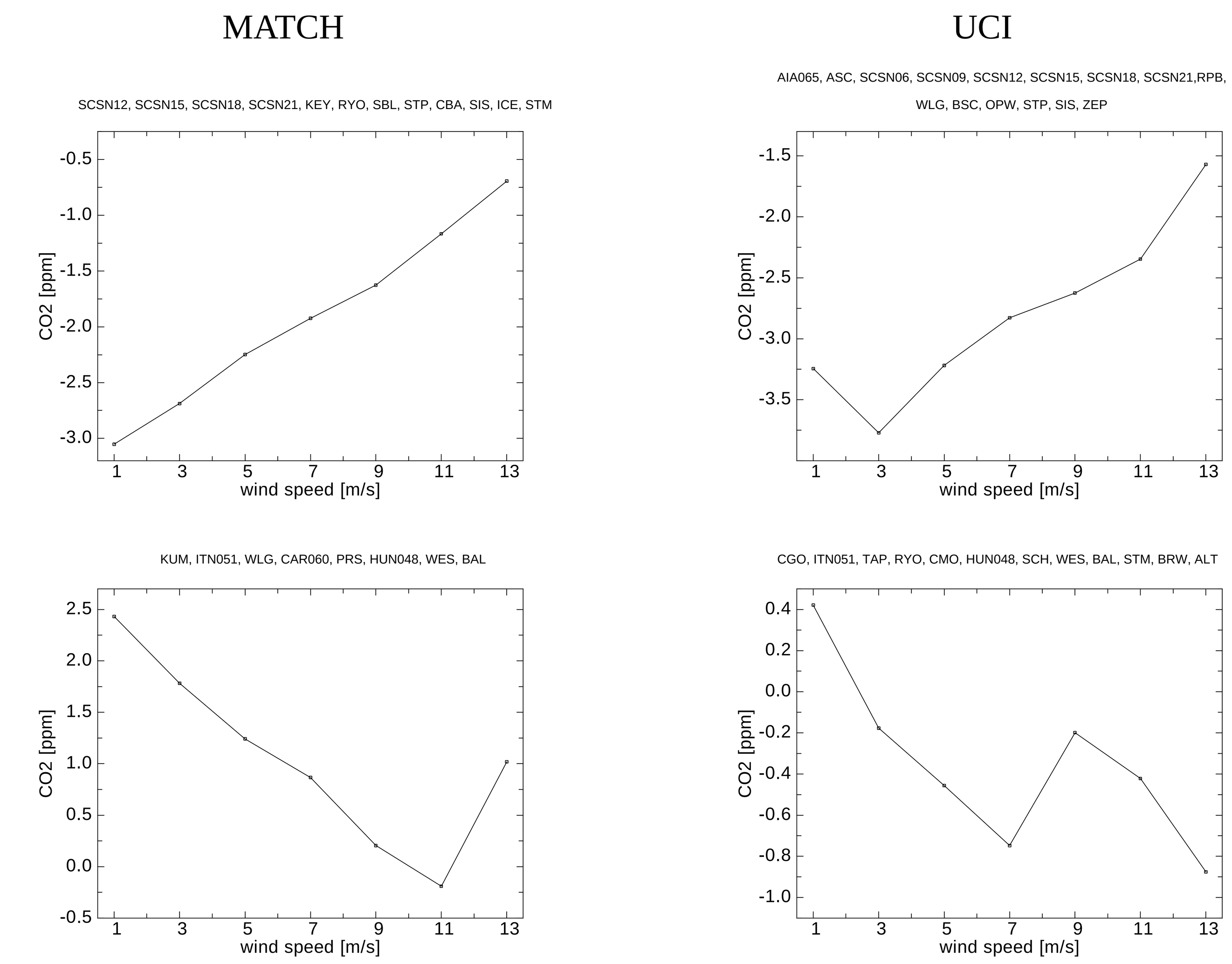
Stations with annual average effect $>$ 0.5 ppm for time of day sampling (left) and wind speed sampling (right). Both models red , MATCH blue, UCI green.

Impact of Sampling Strategies on Modeled CO_2 Concentrations



Annual average modeled mixing ratios from the MATCH model (left) and the UCI model (right), the differences when sampled at night (22:00 to 4:00) and day (10:00 to 16:00), the differences between sampling during high wind conditions (speed $>$ 5 m/s) and low wind conditions (speed $<$ 5 m/s), and finally the differences when sampled using our "best estimate" sampling criteria.

Impact of Sampling Strategies on Modeled CO_2 Concentrations cont.



Modeled mixing ratio versus wind speed at stations with a high sensitivity to wind speed for MATCH (left) and the UCI model (right). Upper plot is for stations where the mixing ratio is higher at higher wind speed and the lower plots are for stations where concentrations are lower at higher wind speeds. Mixing ratios are relative to all high wind sensitivity stations. High sensitivity is taken to be 0.5 ppm difference between high ($>$ 5m/s) and low ($<$ 5m/s) wind speed sampling regimes. Models were sampled during the daytime.

Conclusions

- $\sim$35% of stations are sensitive to sampling strategy at the 0.5 ppm level in the CTMs.
- The bias exceeds +0.5 ppm for the "best estimate" sampling strategy at the following stations.
  UCI: BHD, CFA, SCSN03, SCSN12, CRI, KEY, ITN051, WLG, TAP, UTA, BSC, UUM, LEF030, HUN048, OPW, ESP, WES, BAL
  MATCH: BHD, ITN051, UTA, BSC, UUM, HUN048, WES, BAL
- Time of day bias is most prominent near land regions with an active terrestrial biosphere.
- Wind speed bias is not localized to land or ocean regions.
- The lack of meteorological data at some sampling stations can complicate the comparison of model simulations with the observed data.
- However, there are likely covariances that need to be studied, e.g., wind direction covariance with wind speed.

Acknowledgements

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References

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