What can we learn from intensive in-situ airborne observations of CO2 over the continent?

John C. Lin, Christoph Gerbig, Bruce C. Daube, Arlyn E. Andrews and Steven C. Wofsy

OUTLINE

I. Observations and variability of CO_2 at various scales

-unique feature of **intensive aircraft** sampling: could probe CO_2 structure in the vertical and the horizontal at multiple scales

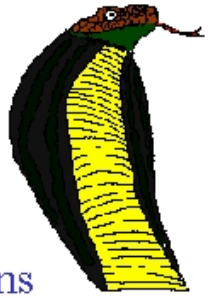
II. A tool to model atmospheric transport and reveal footprint of atmospheric observations

III. What airborne observations + transport tool can tell us

IV. Conclusions

COBRA

(CO_2 Budget and Rectification Airborne Study)



Regional intensives:
- Regional flux estimates in the vicinity of flux towers
- Lagrangian framework

Large scale surveys:
- Large scale tracer distributions (CO_2, CO, H_2O, isotopes)
- Lagrangian analysis

Participants:

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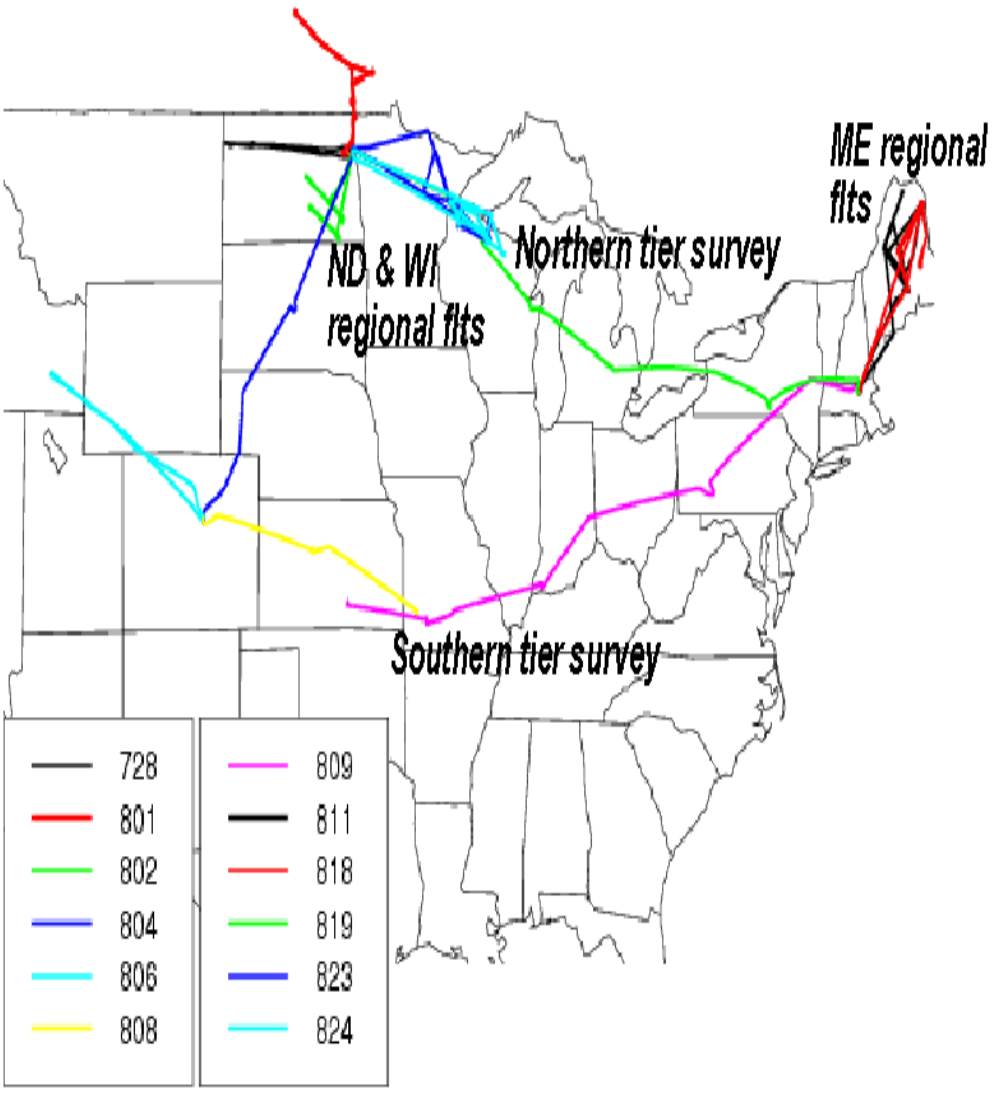
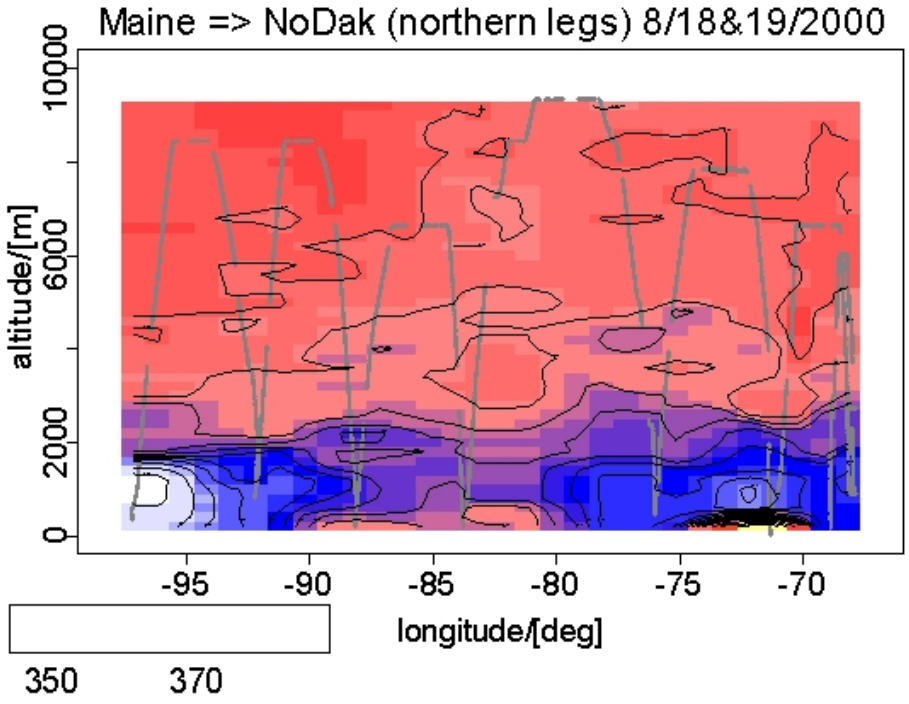
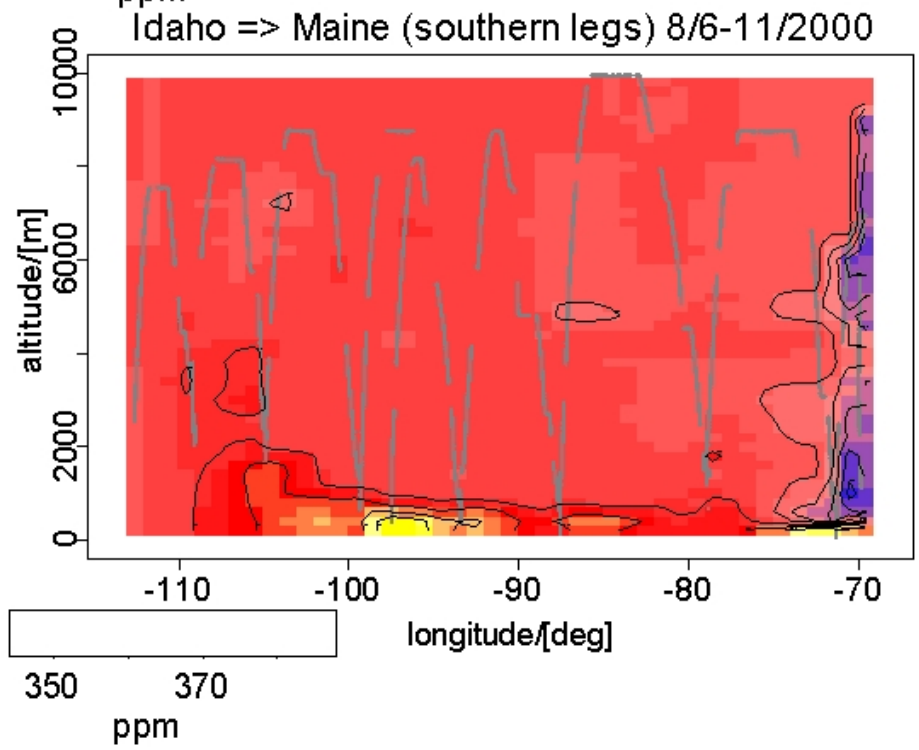
Supported by: NOAA, NASA, NSF, and DoE

COBRA 2000 Flight Tracks



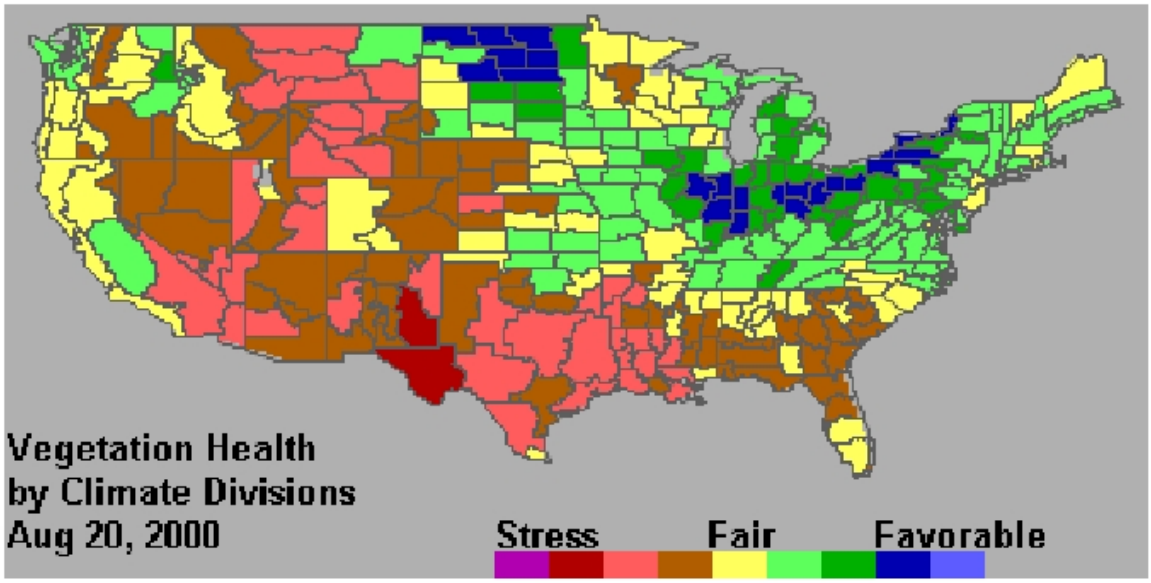
COBRA: Large scale CO_2 distribution





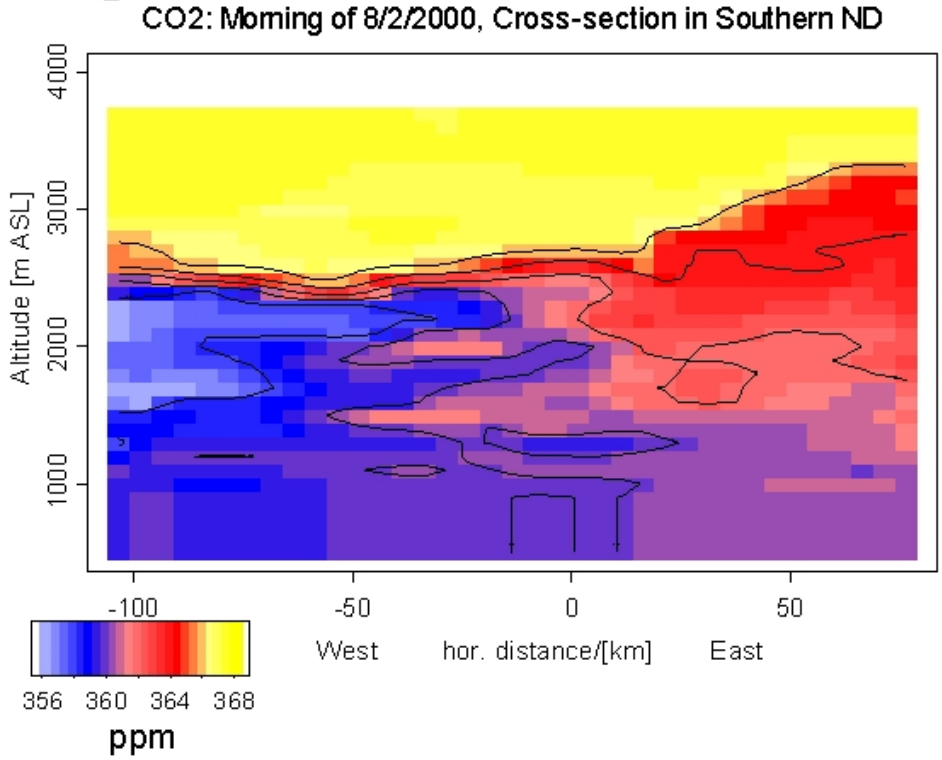
Vegetation Health Index

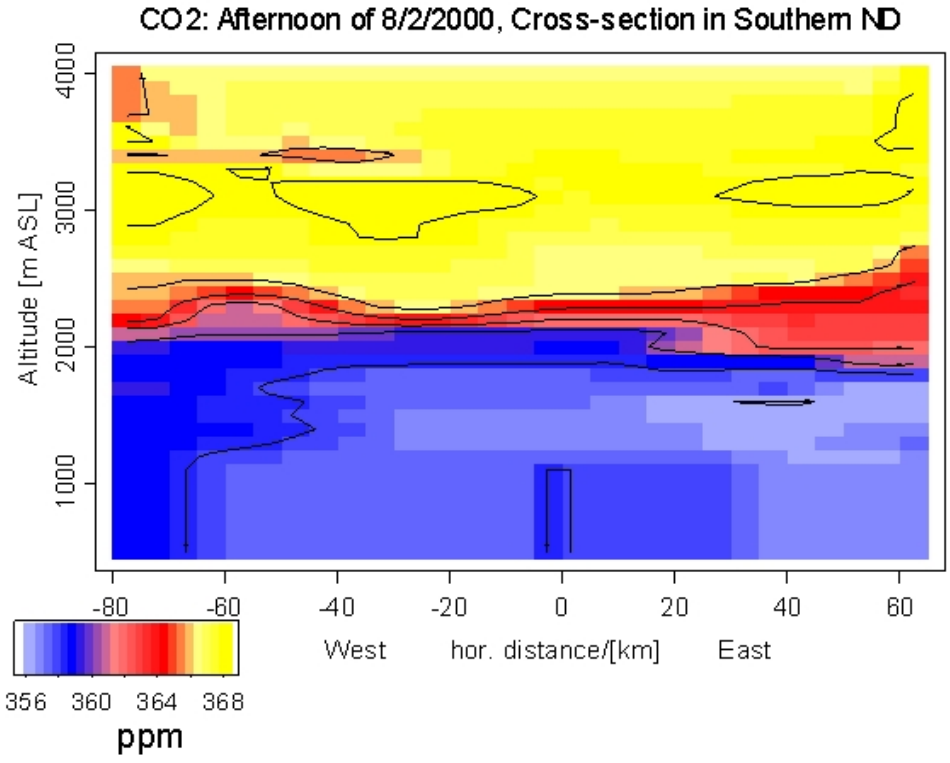
(NOAA National Environmental Satellite, Data, and Information Service)



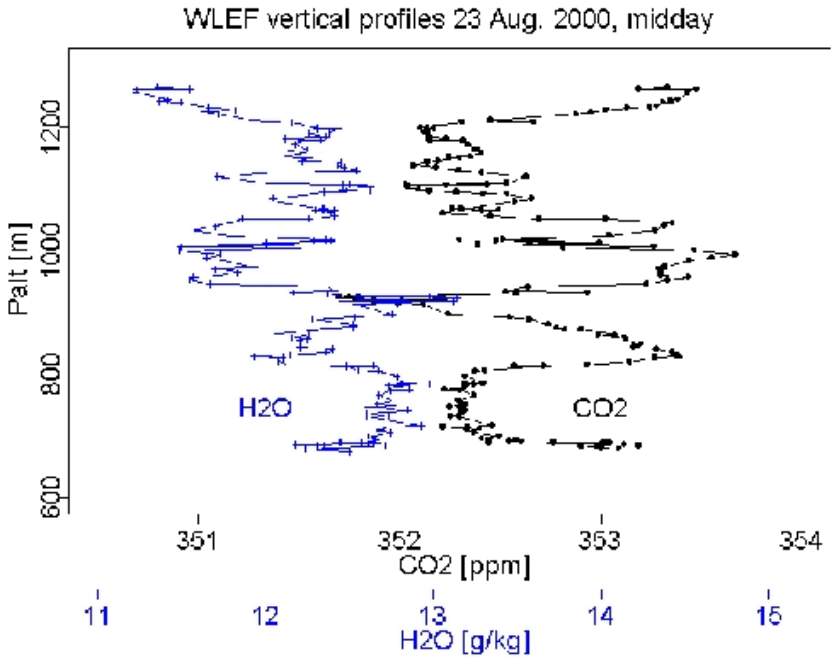
http://orbit-net.nesdis.noaa.gov/crad/sat/surf/vci/uscd/usacd.html

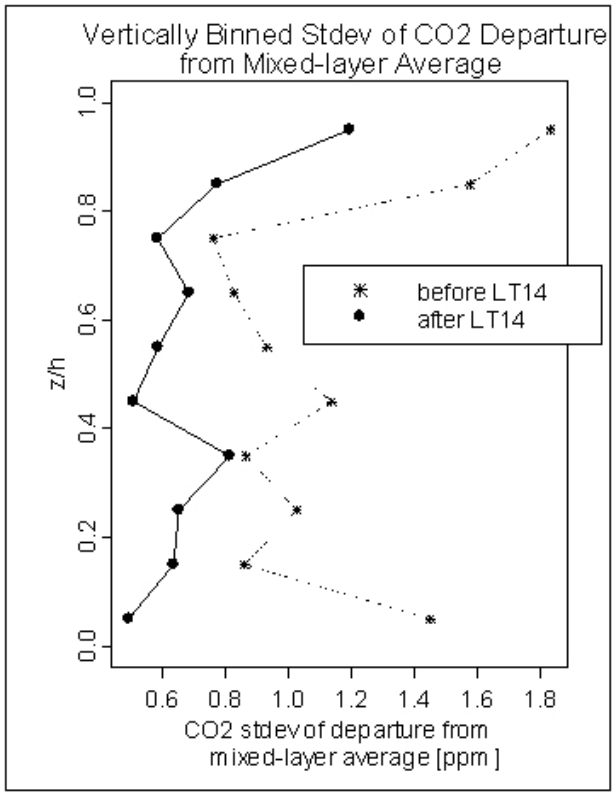
CO_2 cross-sections through air mass



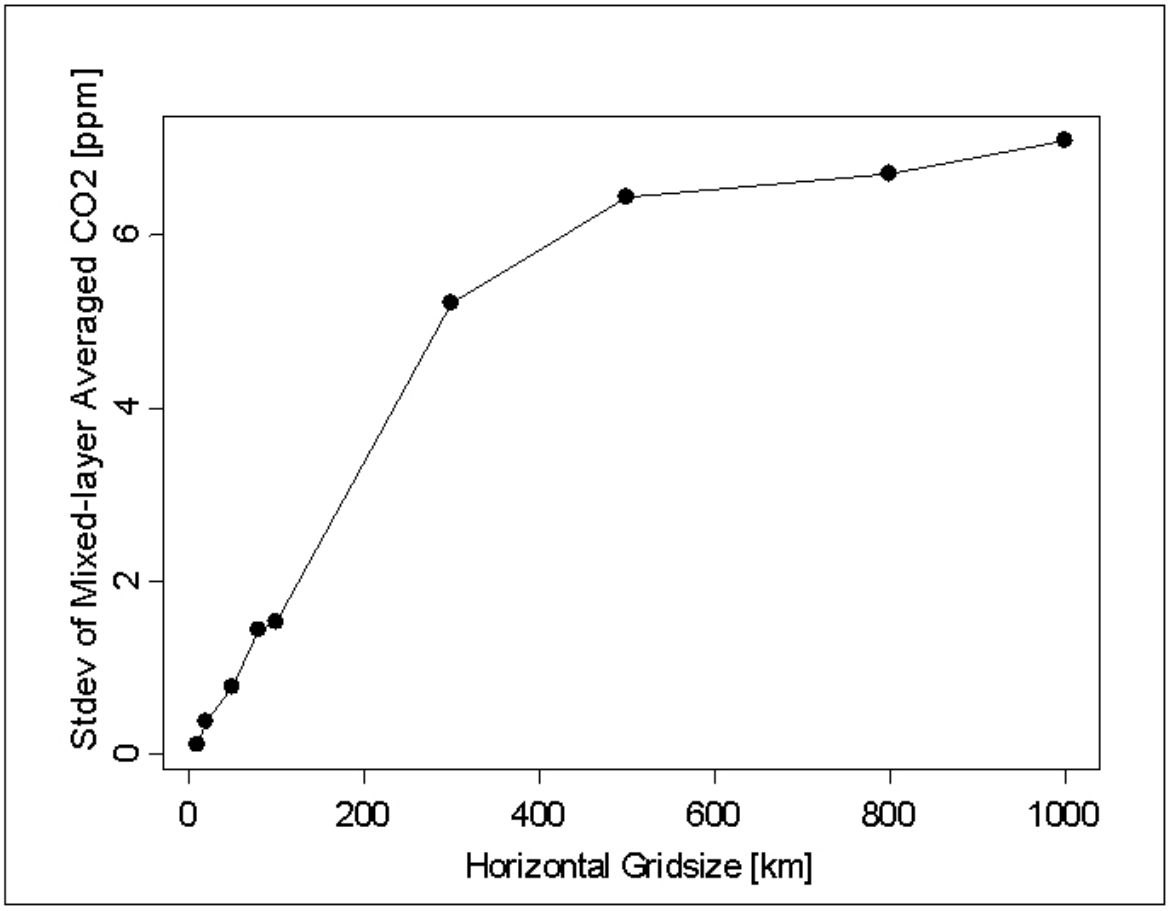


Fluctuations in Tracer Concentrations due to Turbulent Eddies



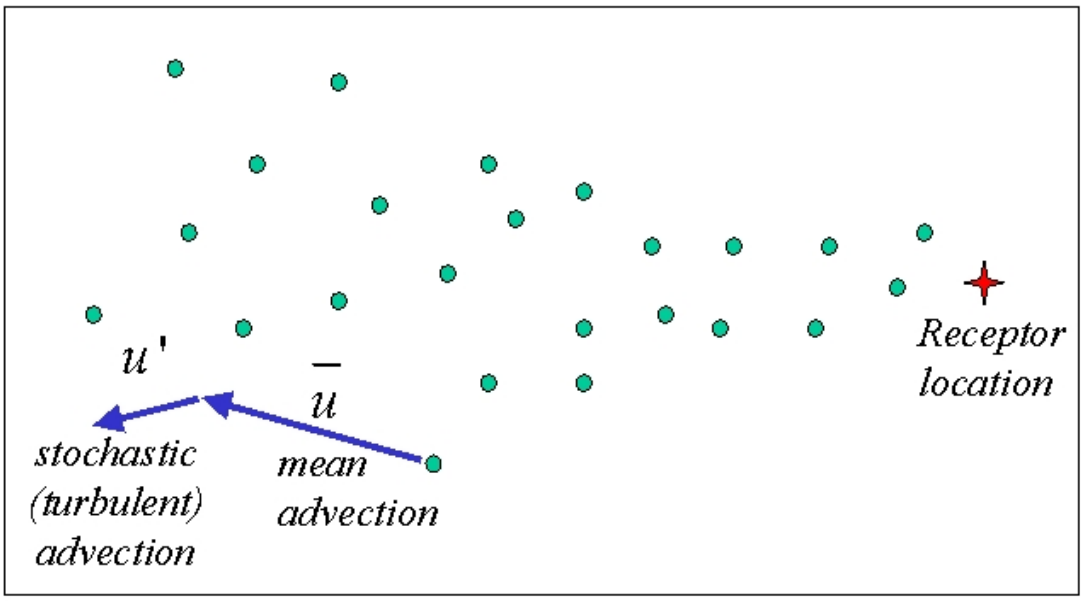


Subgrid-scale Variability of Mixed-layer Averaged CO_2



STILT

Stochastic Time Inverted Lagrangian Transport Model

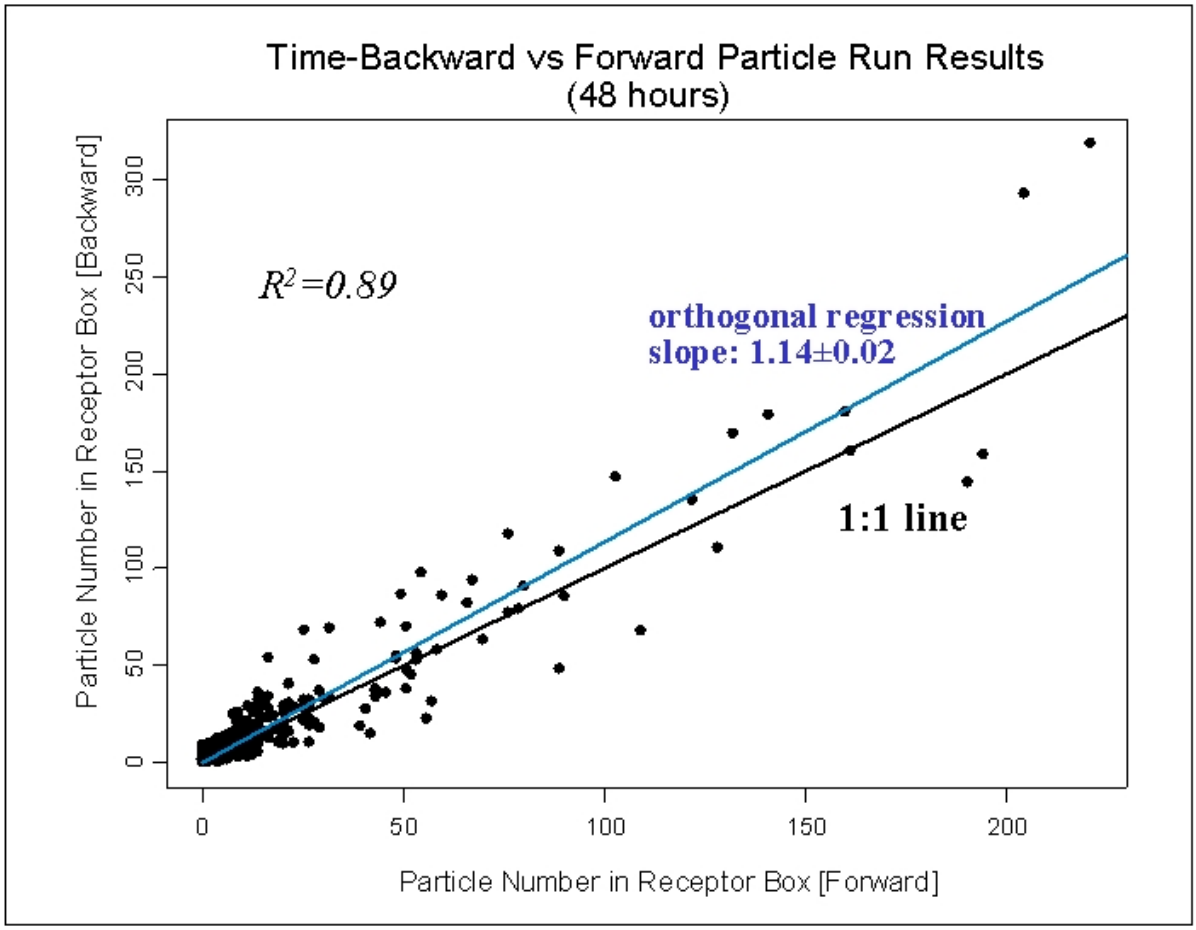


- Based on HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory) model code [*Draxler and Hess, 1998*]

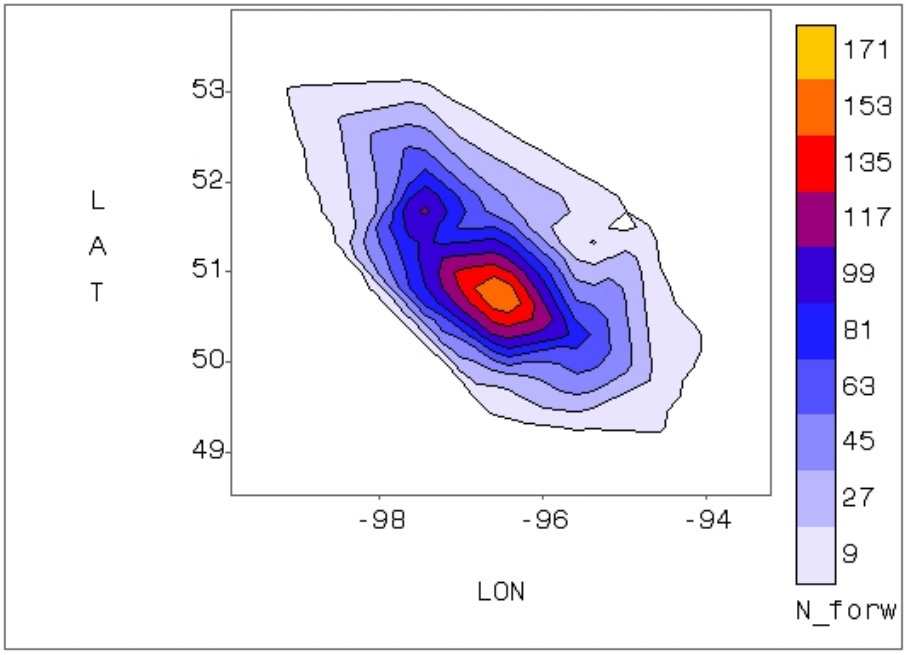
- Driven by ETA, AVN (forecasts) or EDAS, FNL (assimilations)

- Improved turbulence parameterization
  - T_{Lw} (vertical) and σ_w after *Hanna* [1982]
  - reflection/transmission scheme at interfaces between high and low turbulence after *Thomson* [1997]

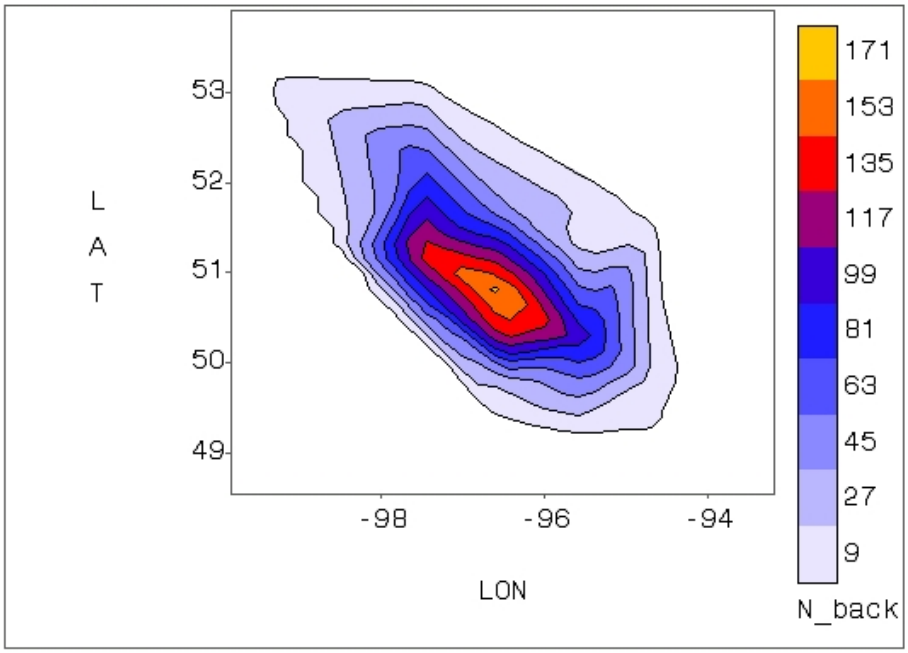
- Time Inverted/Receptor oriented (what is the footprint of a measurement at the aircraft (receptor location)?)


Time-Backward vs Forward Particle Run Results
(48 hours)
Particle Number in Receptor Box [Backward]
Particle Number in Receptor Box [Forward]
R^2=0.89
orthogonal regression
slope: 1.14±0.02
1:1 line
0
50
100
150
200
250
300

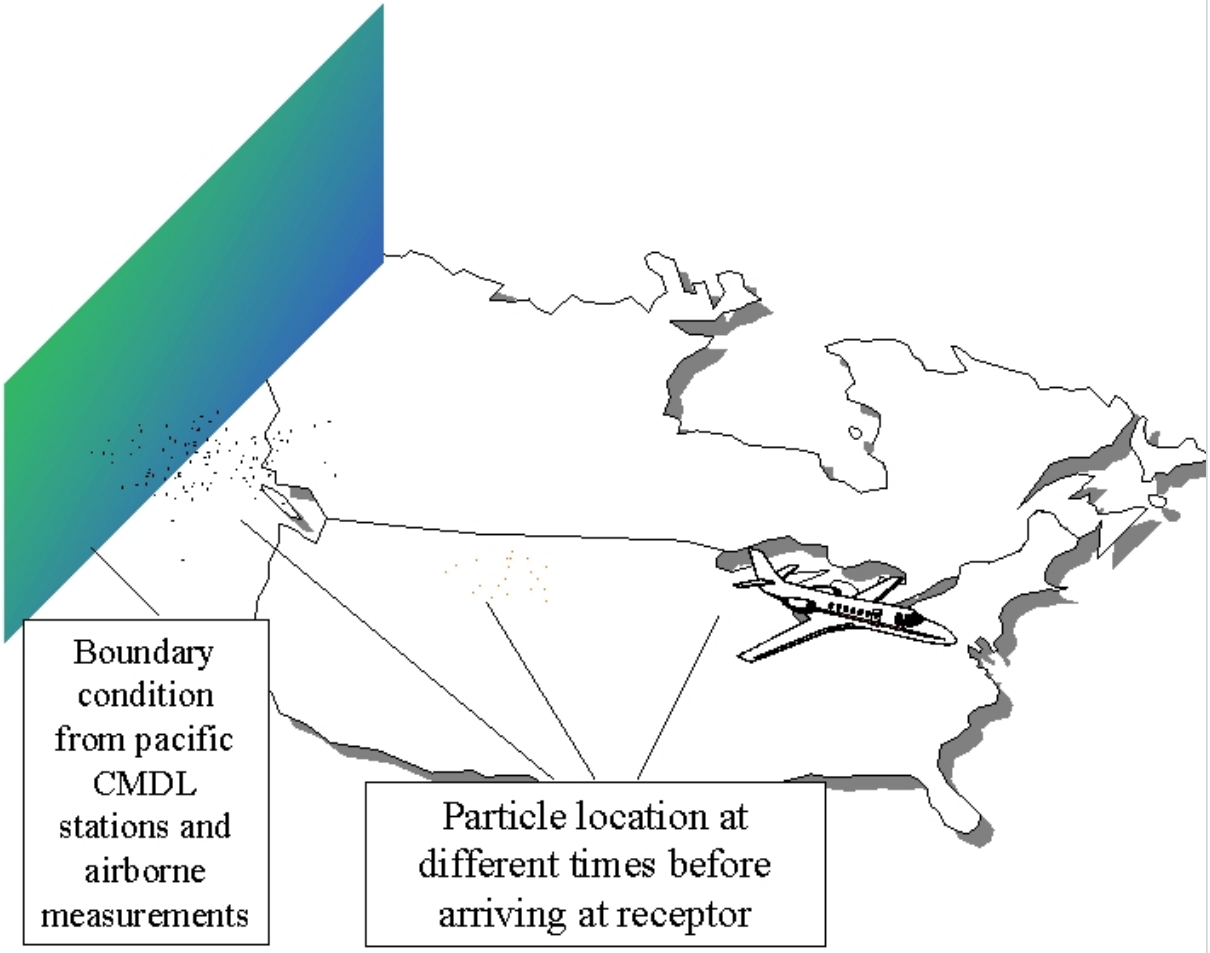
Footprint at –48 h, forward STILT run



Footprint at –48 h, backward STILT run

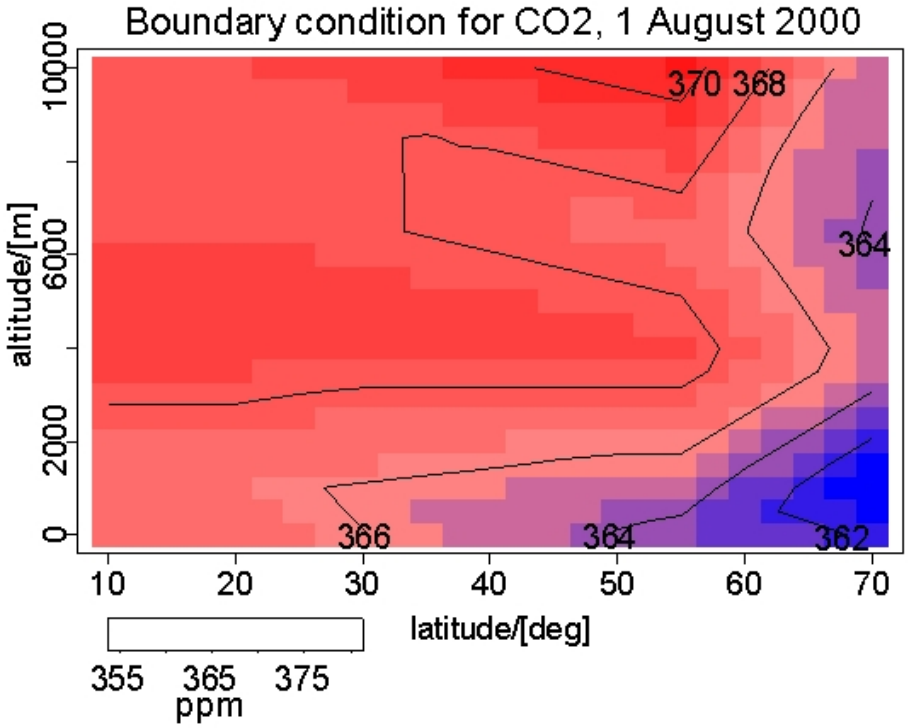


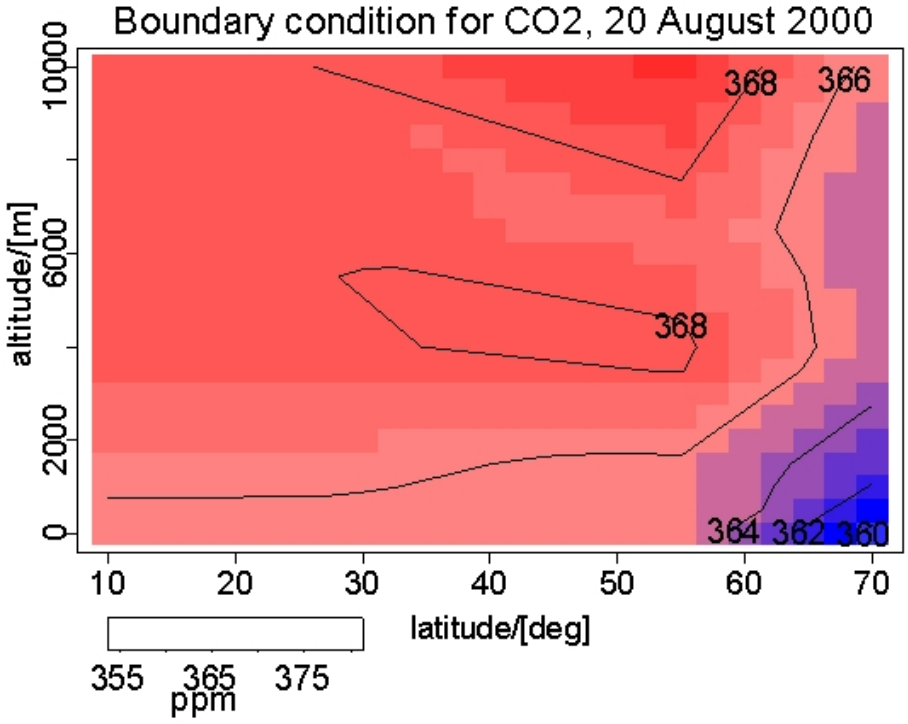
STILT-model analysis of large scale tracer distribution

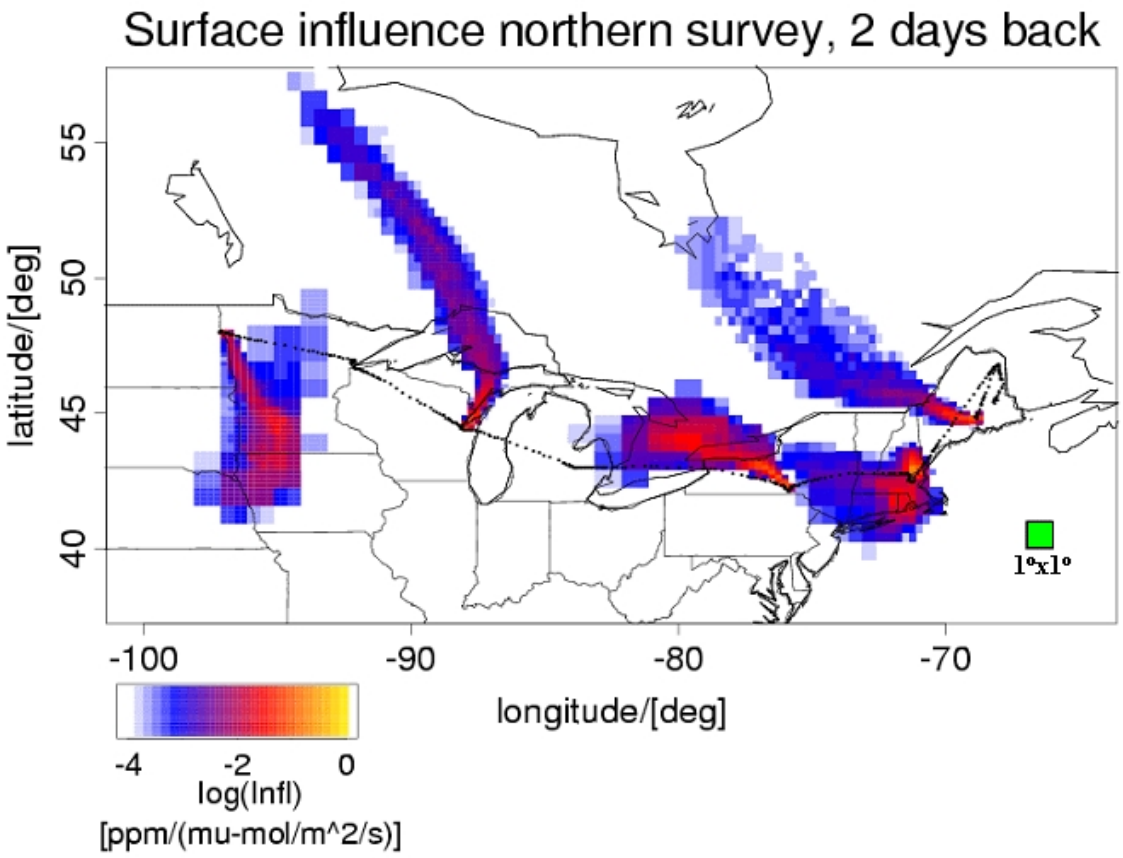


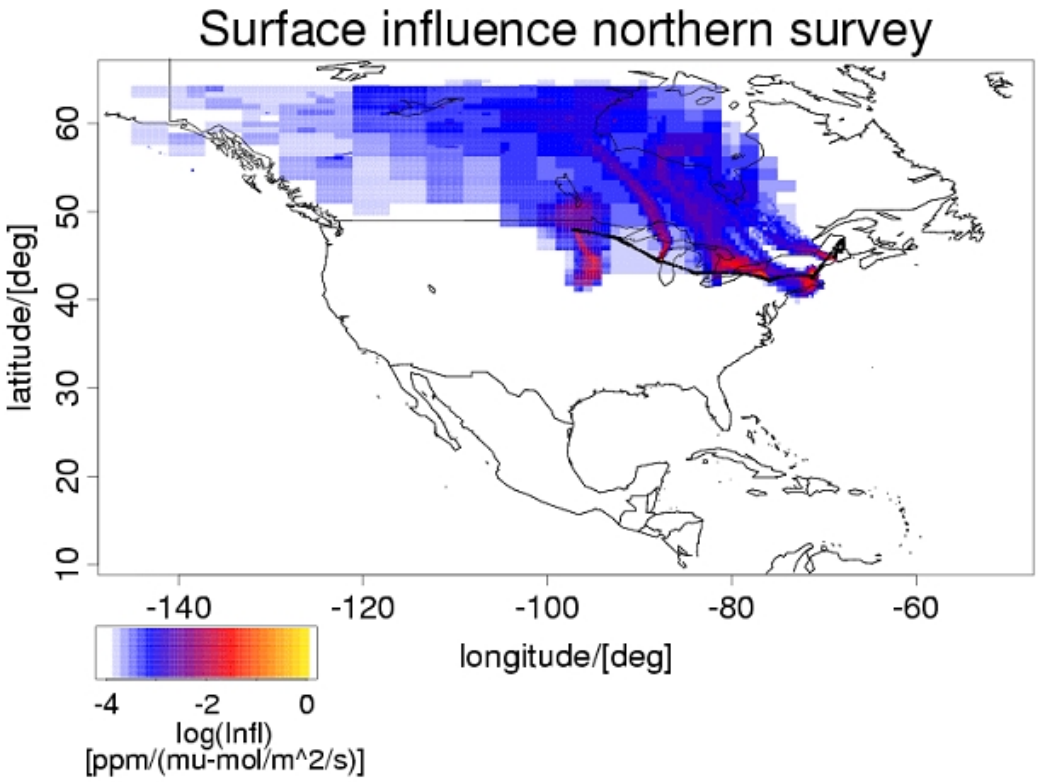
- 100 particles per receptor point (aircraft position along the survey) followed for 15 days back
- particles represent “little air masses” with equal mass
- particles “sample” surface fluxes below 0.5 * mixed layer height
- particles get initial concentration at boundary

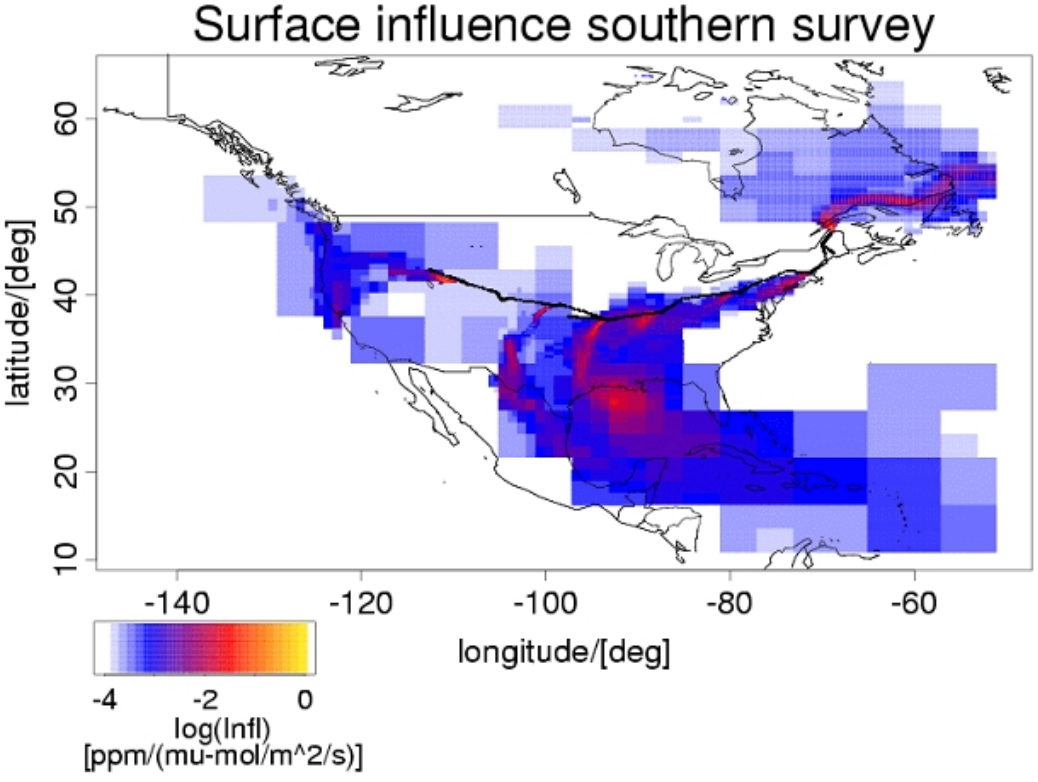
STILT boundary condition:
climatology of pacific ground based and airborne data



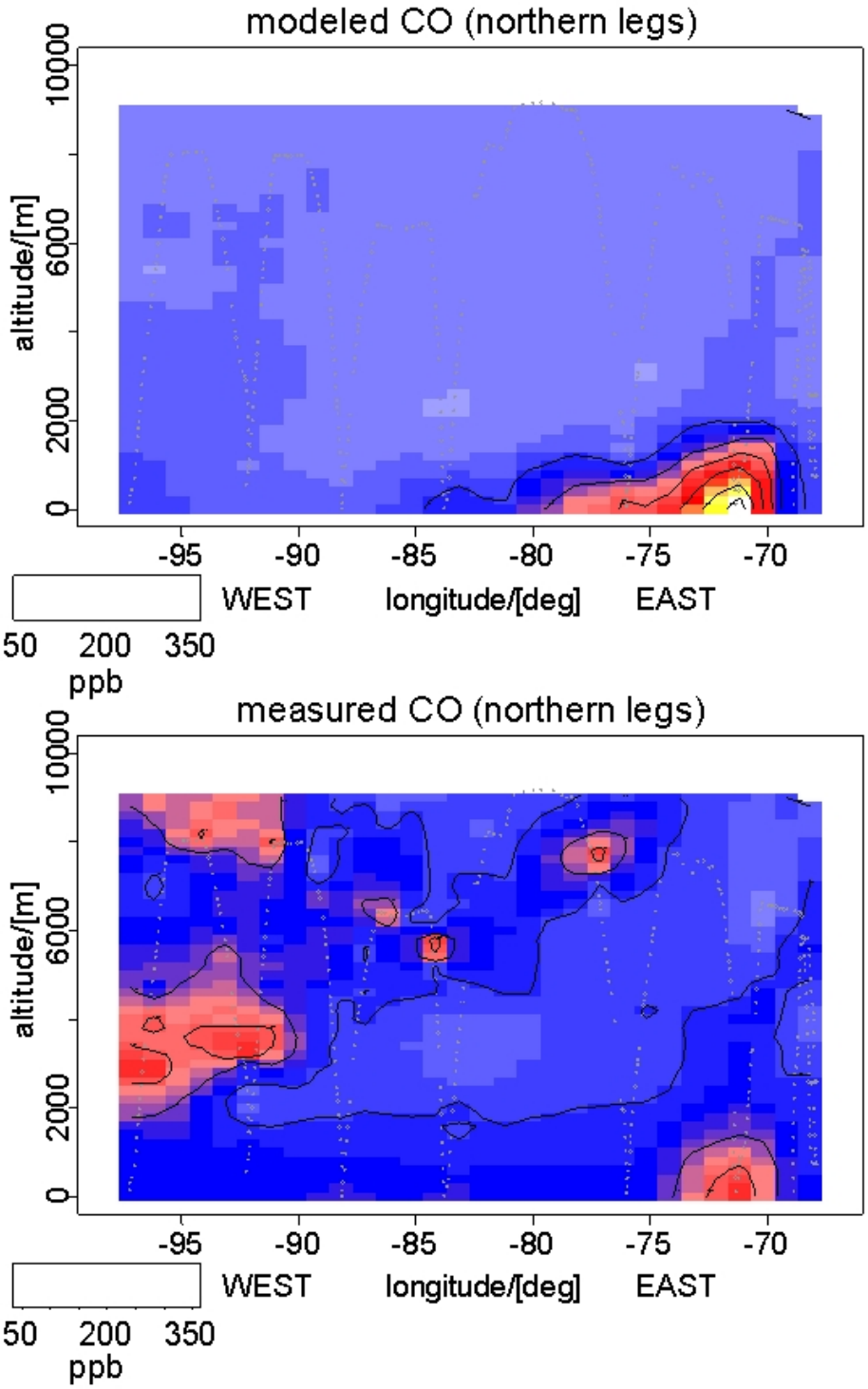



Surface influence northern survey, 2 days back
latitude/[deg]
55
50
45
40
-100
-90
-80
-70
longitude/[deg]
1°x1°
-4
-2
0
log(Infl)
[ppm/(mu-mol/m^2/s)]

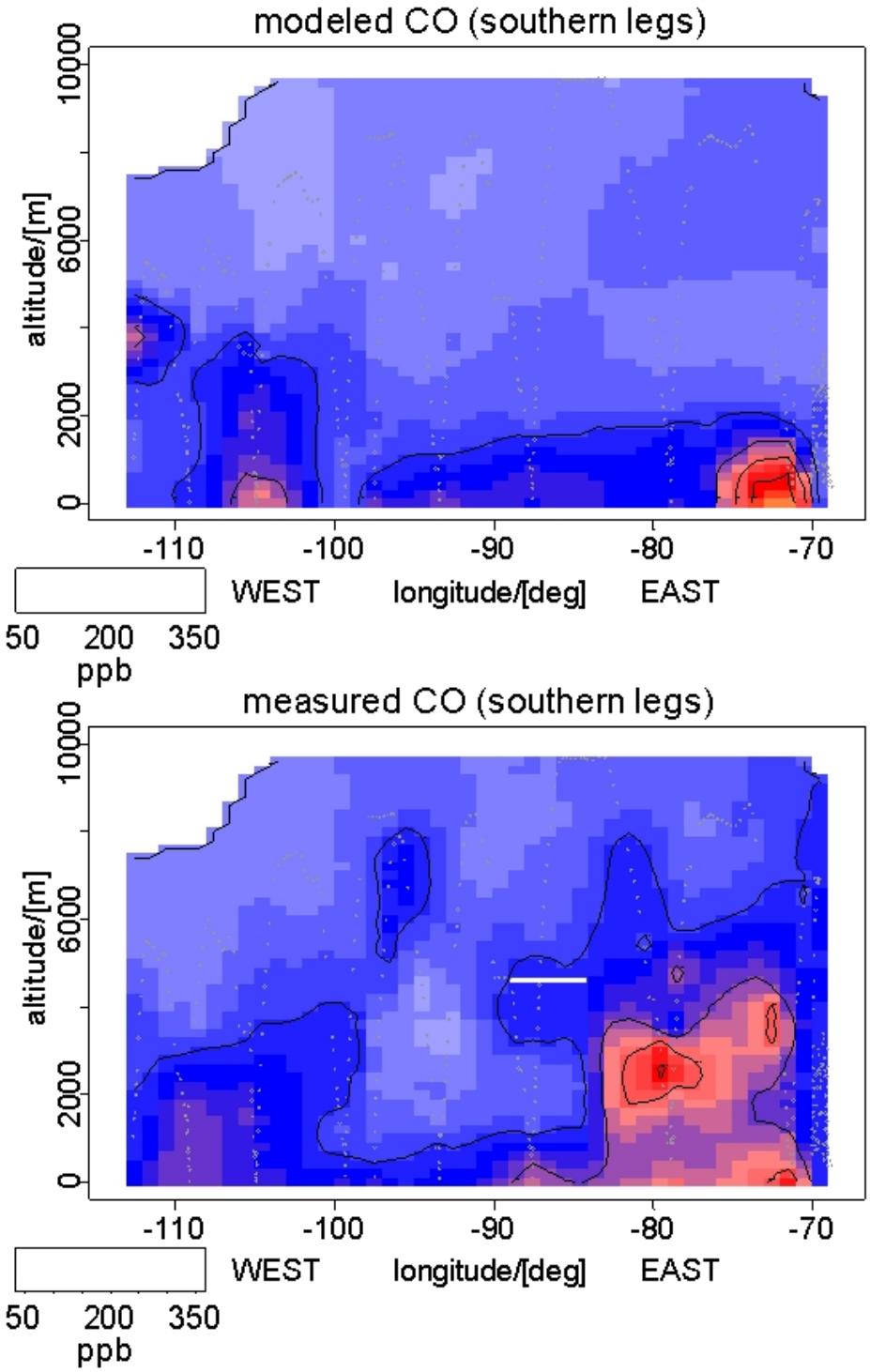

Surface influence northern survey
latitude/[deg]
10
20
30
40
50
60
-140
-120
-100
-80
-60
longitude/[deg]
-4
-2
0
log(Infl)
[ppm/(mu-mol/m^2/s)]


Surface influence southern survey
latitude/[deg]
10
20
30
40
50
60
-140
-120
-100
-80
-60
longitude/[deg]
-4
-2
0
log(Infl)
[ppm/(mu-mol/m^2/s)]

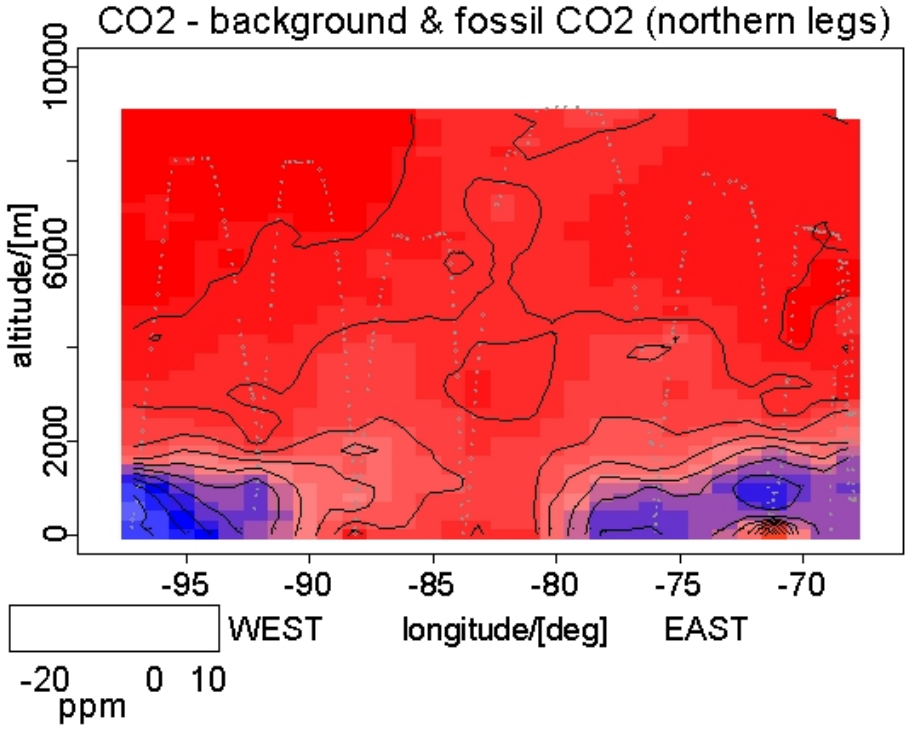
STILT results, COBRA northern survey



STILT results, COBRA southern survey



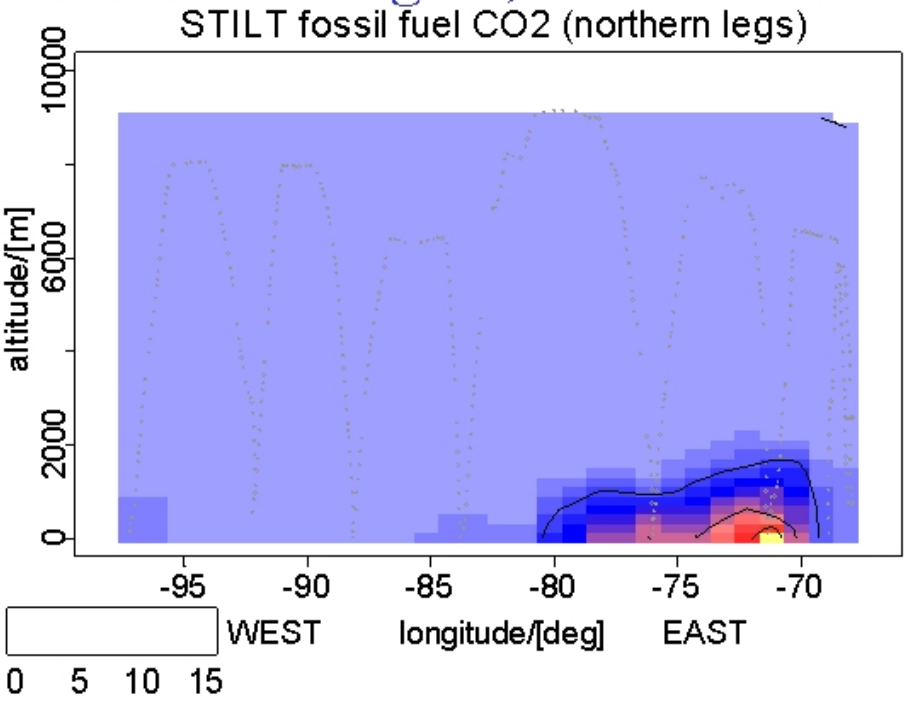
CO2 vegetation signal, northern survey

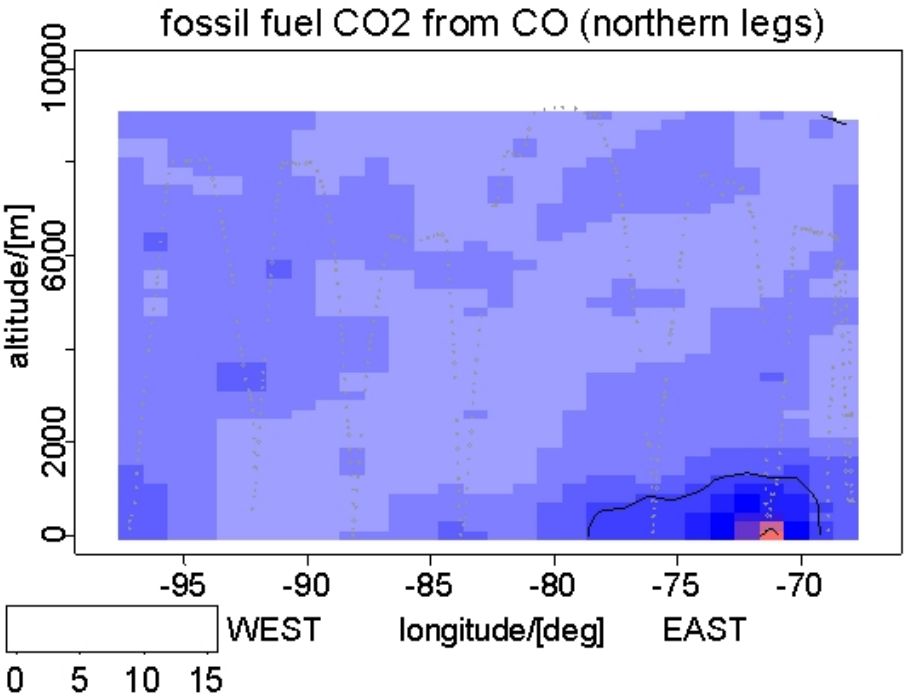


$$CO_{2,veg}(\text{meas.}) = CO_2(\text{meas.}) - CO_2(\text{foss.}) - CO_2(\text{ini.})$$

$$CO_2(\text{foss.}) = \left[CO(\text{meas.}) - CO(\text{ini.})\right] \cdot \frac{CO_2(\text{emission})}{CO(\text{emission})}$$

CO2 fossil fuel signal, northern survey





STILT inversion

Net ecosystem exchange for vegetation *i*:

First guess from Fluxnet:

$$NEE_i = \frac{\partial R_i}{\partial T} \cdot T + \frac{a_i \cdot PAR}{b_i + PAR}$$

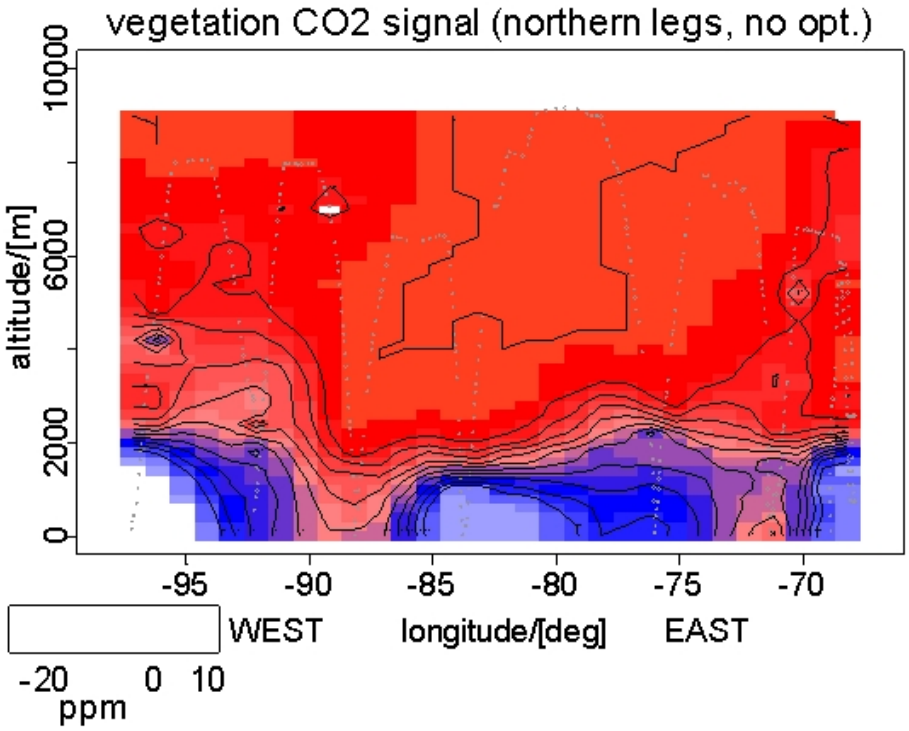
$$= \text{Respiration} + \text{GEE}$$

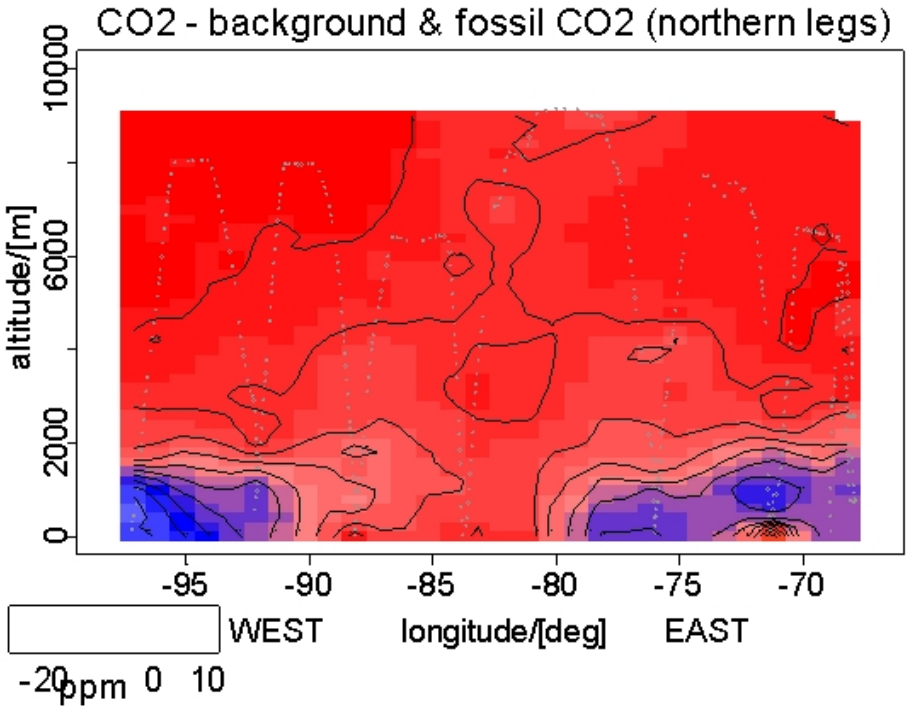
PAR: photosynthetically active radiation

a_i/b_i: quantum efficiency

b_i: max. GEE

STILT results using NEE from Fluxnet: North





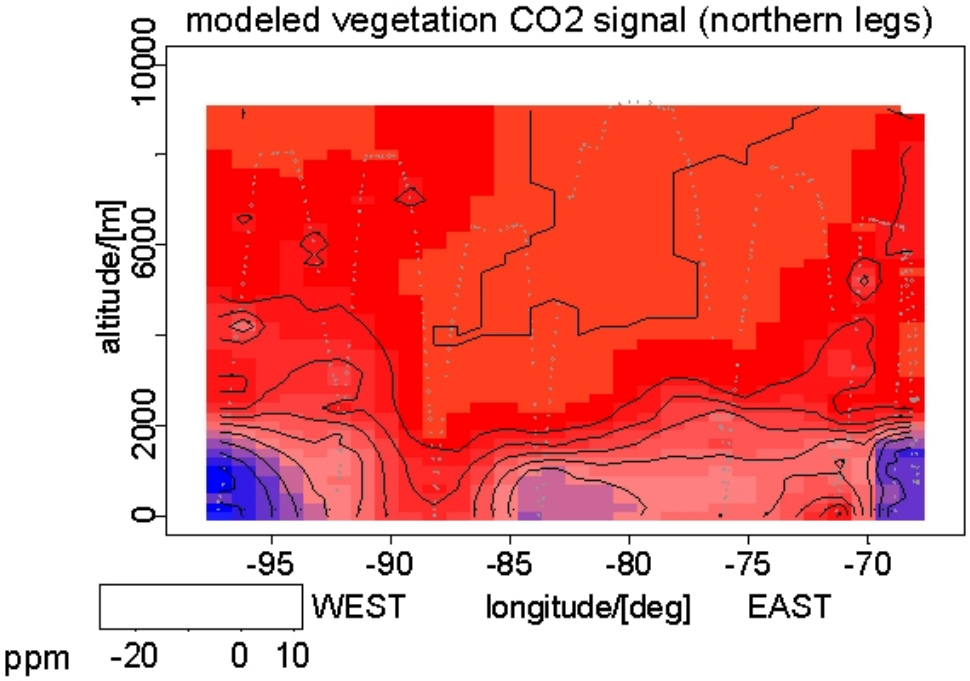
Inversion:

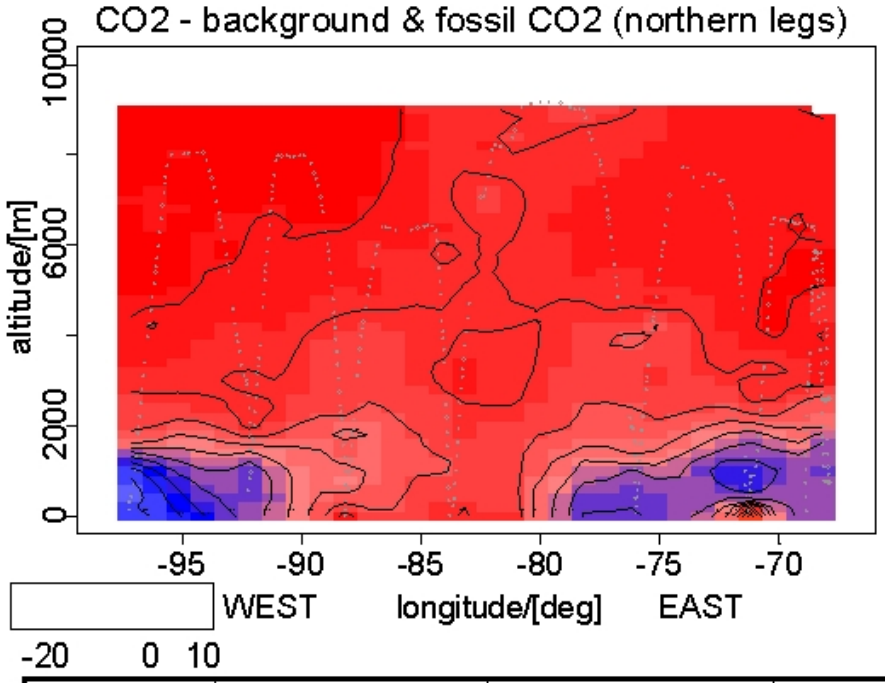
$$NEE_i = \lambda_i \cdot \left(R_i + \frac{a_i \cdot PAR}{b_i + PAR} \right)$$

λ_i optimized so that

$$\sum_{r=receptors} \left(CO_{2,veg,r}(\text{model}) - CO_{2,veg,r}(\text{meas.}) \right)^2 = \min$$

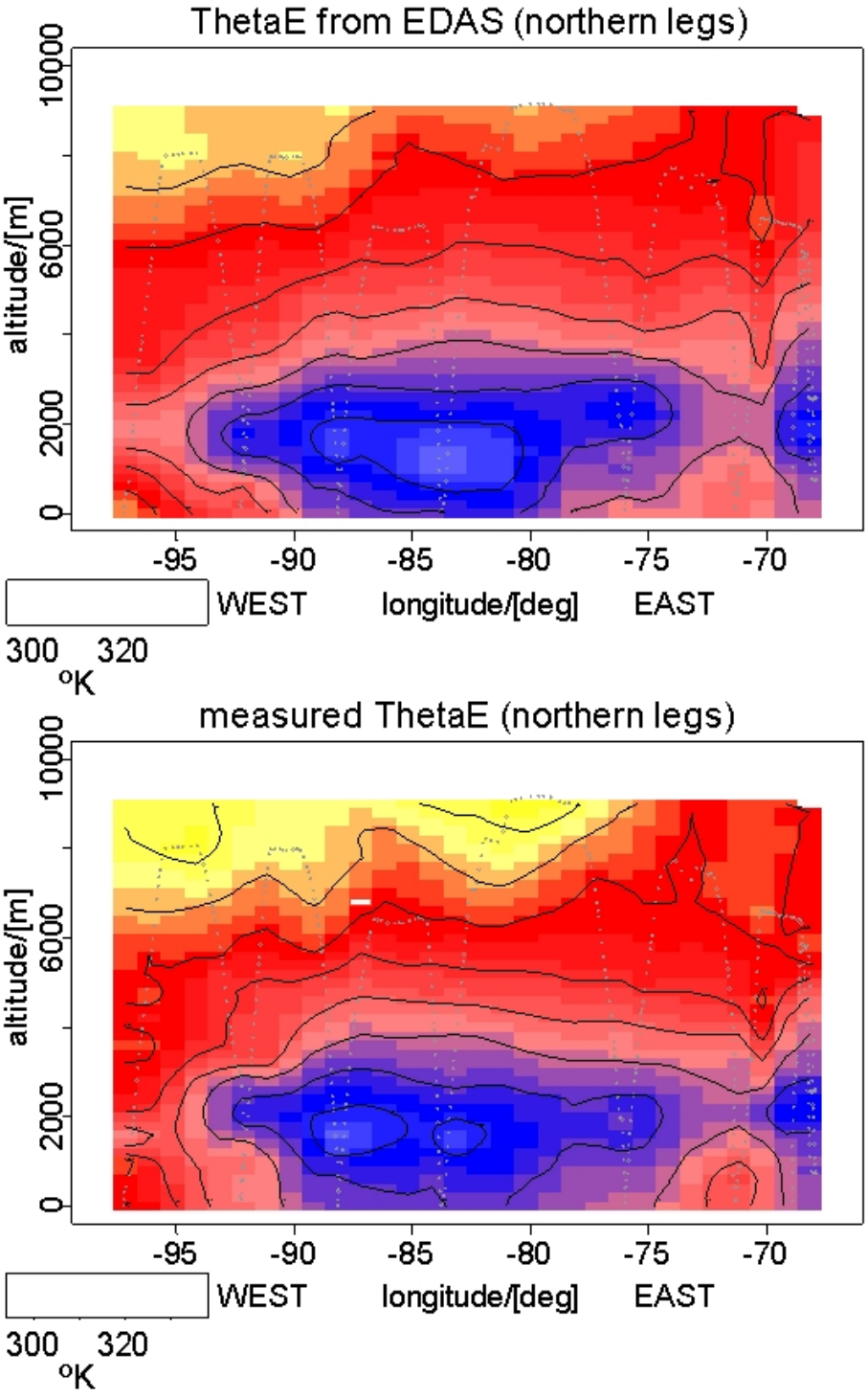
STILT results using optimized NEE: North

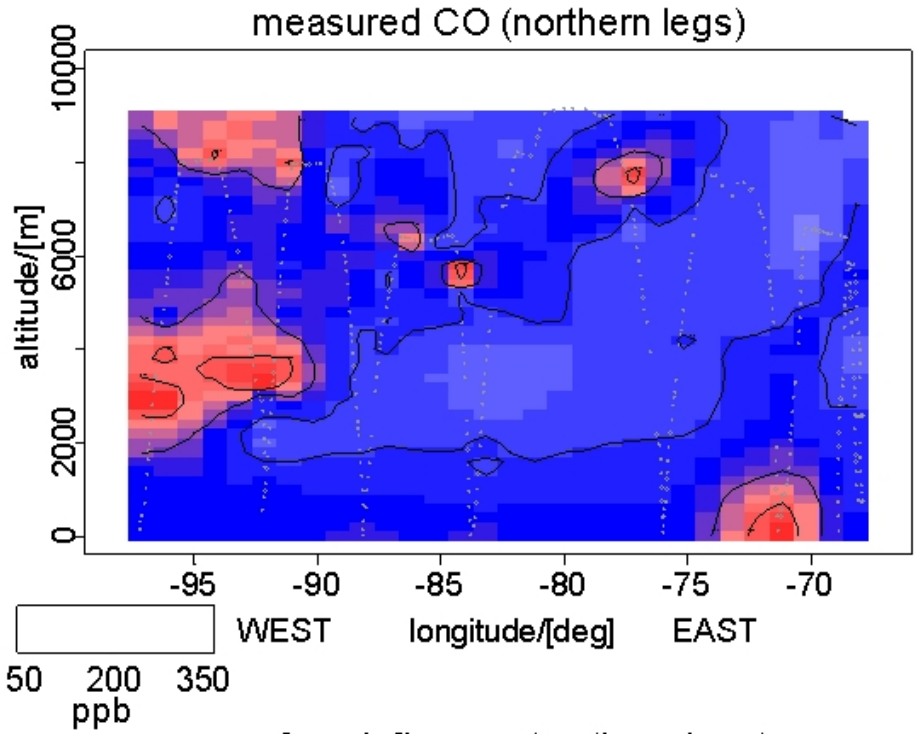


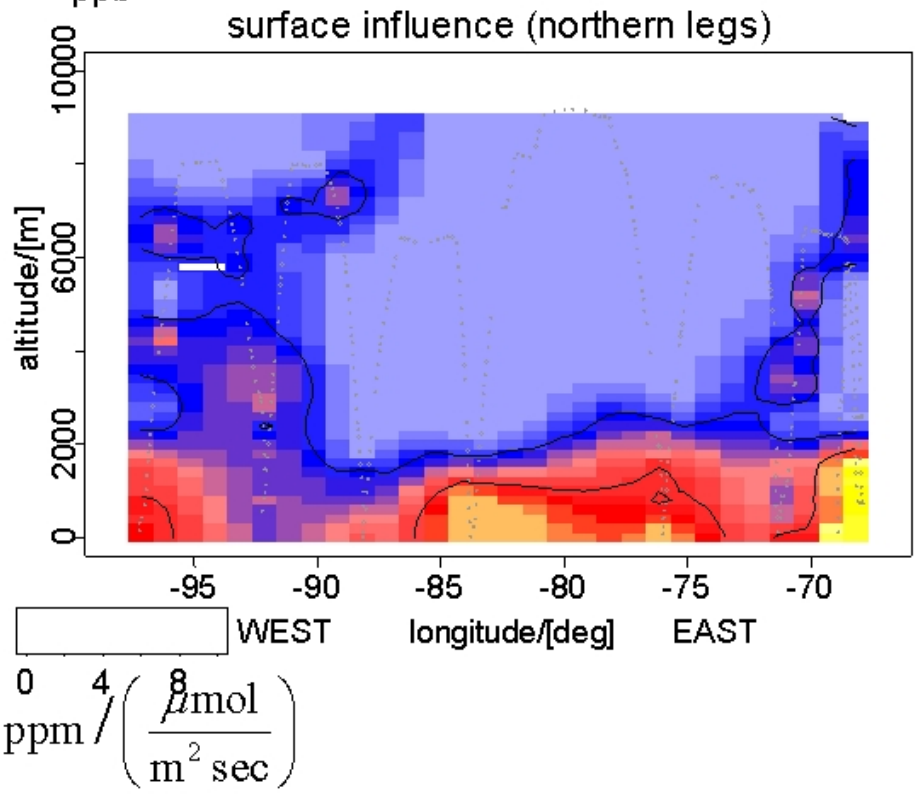


	NEE factor λ_i	Statistical error	r^2
Forests	**1.1**	**0.06**	**0.57**
Cropland	**0.75**	**0.08**	

Θ_e measured versus EDAS (Northern legs)




measured CO (northern legs)
altitude/[m]
0
2000
6000
10000
-95
-90
-85
-80
-75
-70
WEST
longitude/[deg]
EAST
50
200
350
ppb


surface influence (northern legs)
altitude/[m]
0
2000
6000
10000
-95
-90
-85
-80
-75
-70
WEST
longitude/[deg]
EAST
0
4
8
ppm / (μmol / m² sec)

CONCLUSIONS

- ***value of intense atmospheric sampling efforts***

-examine variability of CO_2

  -understand variability when assimilating observations into models

  -assess representativity of obs at long-term monitoring stations

-intense airborne data provides good test of model results

- ***aircraft observations, combined with a tool like STILT, have potential to constrain terrestrial C fluxes***

-errors in atmospheric transport need to be quantified and understood

- ***future: value of combining airborne obs with other models***

-synergy with global models: use STILT as near-field tool close to obs, but have global models simulate boundary-conditions over the ocean