Quantification of Regional and Continental Scale Surface Fluxes of Carbon Using Airborne Measurements in a Lagrangian Framework

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OVERVIEW

- Motivation
  - COBRA2000 campaign
  - Why Lagrangian approaches?

- Regional scale
  - Lagrangian "matches" and CO_2 fluxes
  - STILT model operational flight planning

- Large scale
  - STILT model: Lagrangian analysis, surface influences and first attempt to infer large scale fluxes

COBRA

(CO_2 Budget and Rectification Airborne Study)

"Measurements on the missing scale"

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

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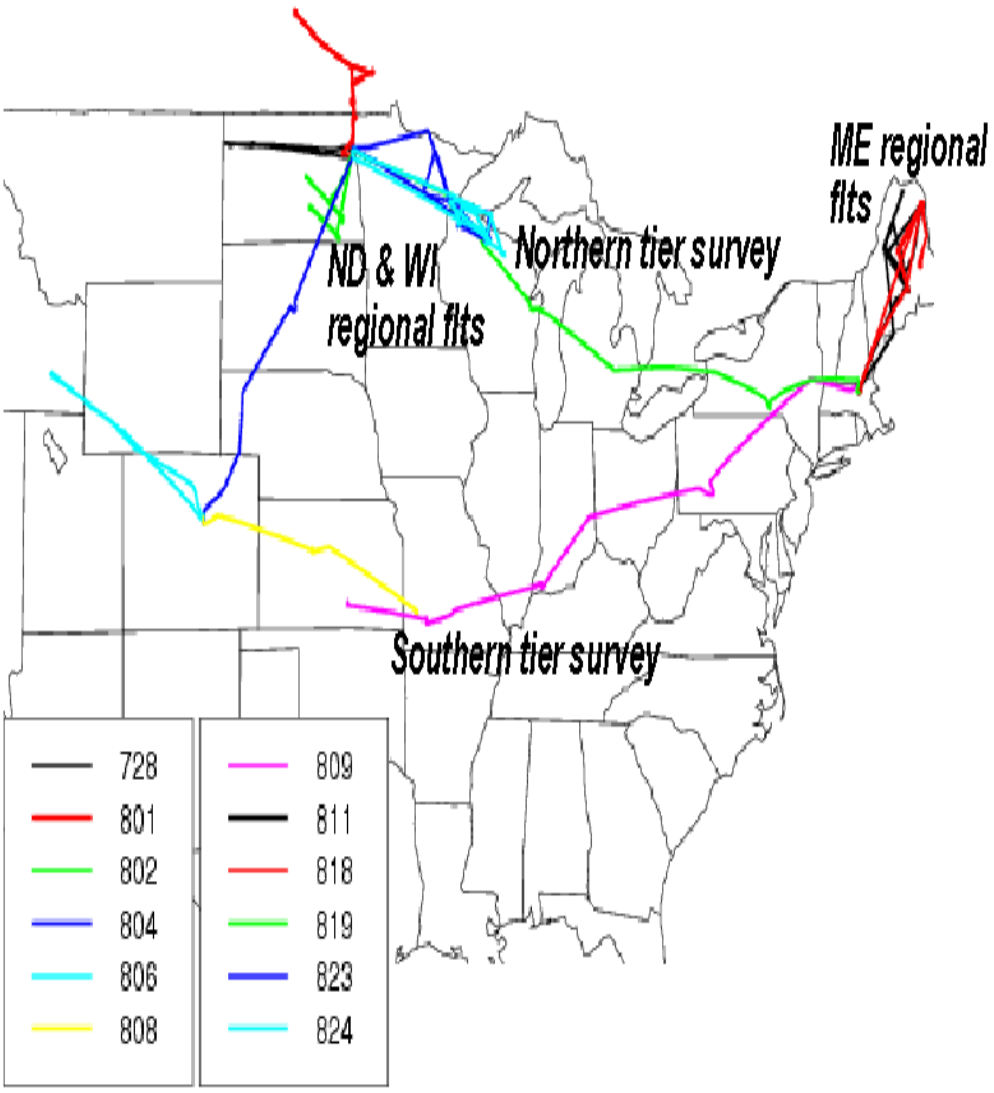
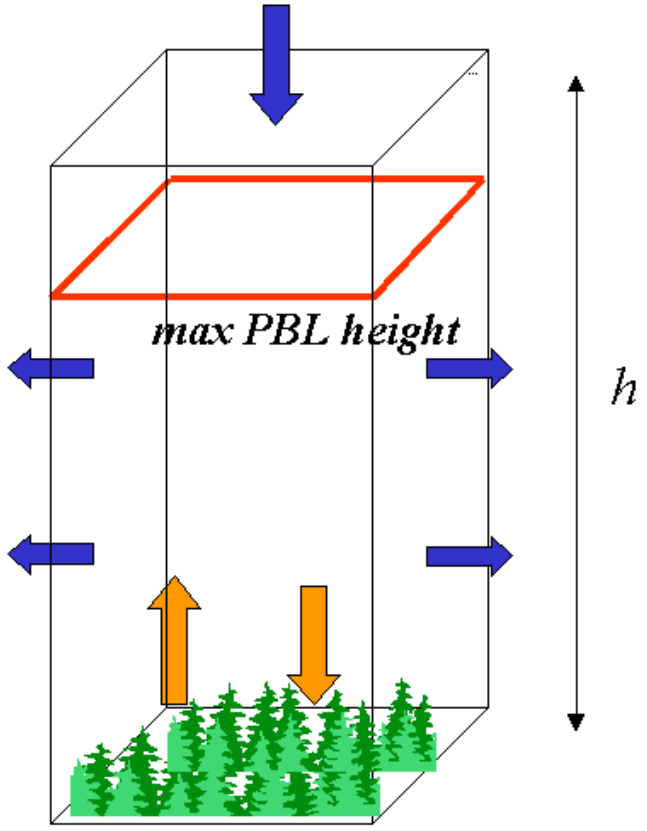
COBRA 2000 Flight Tracks



Why Lagrangian approaches?

COLUMN BUDGET METHOD

1-D = no advection



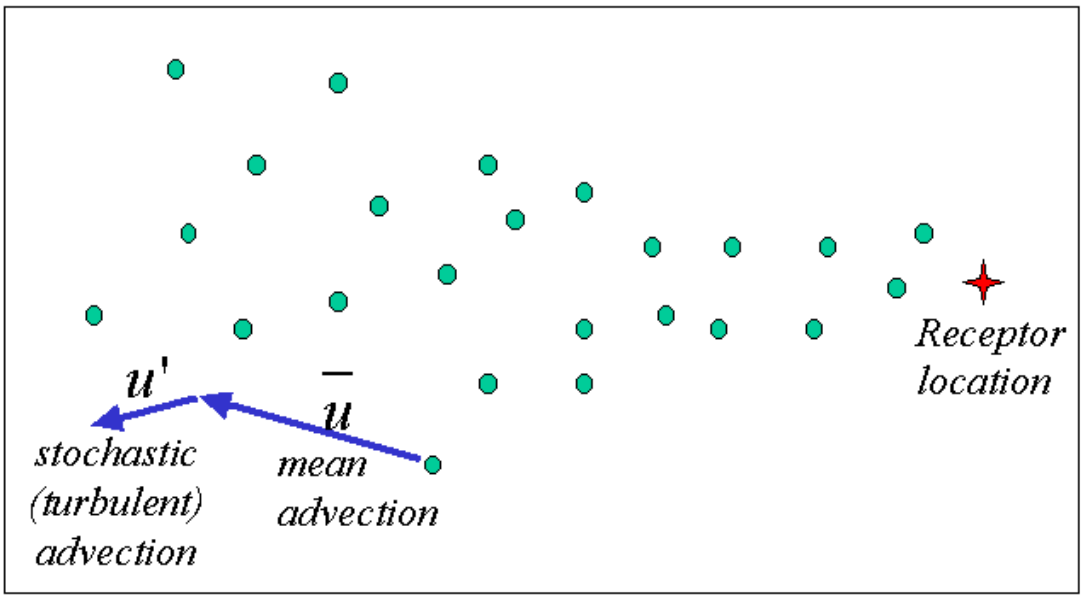
$$S_{bio} + S_{foss} = \frac{\partial}{\partial t}\left(\int_0^h nqdz\right) + \frac{h}{\tau} n_h \left(q_h - \overline{q}\right)$$

storage term + Flux from top

No advection:
Only true for columns moving with the wind!

STILT

Stochastic Time Inverted Lagrangian Transport Model



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

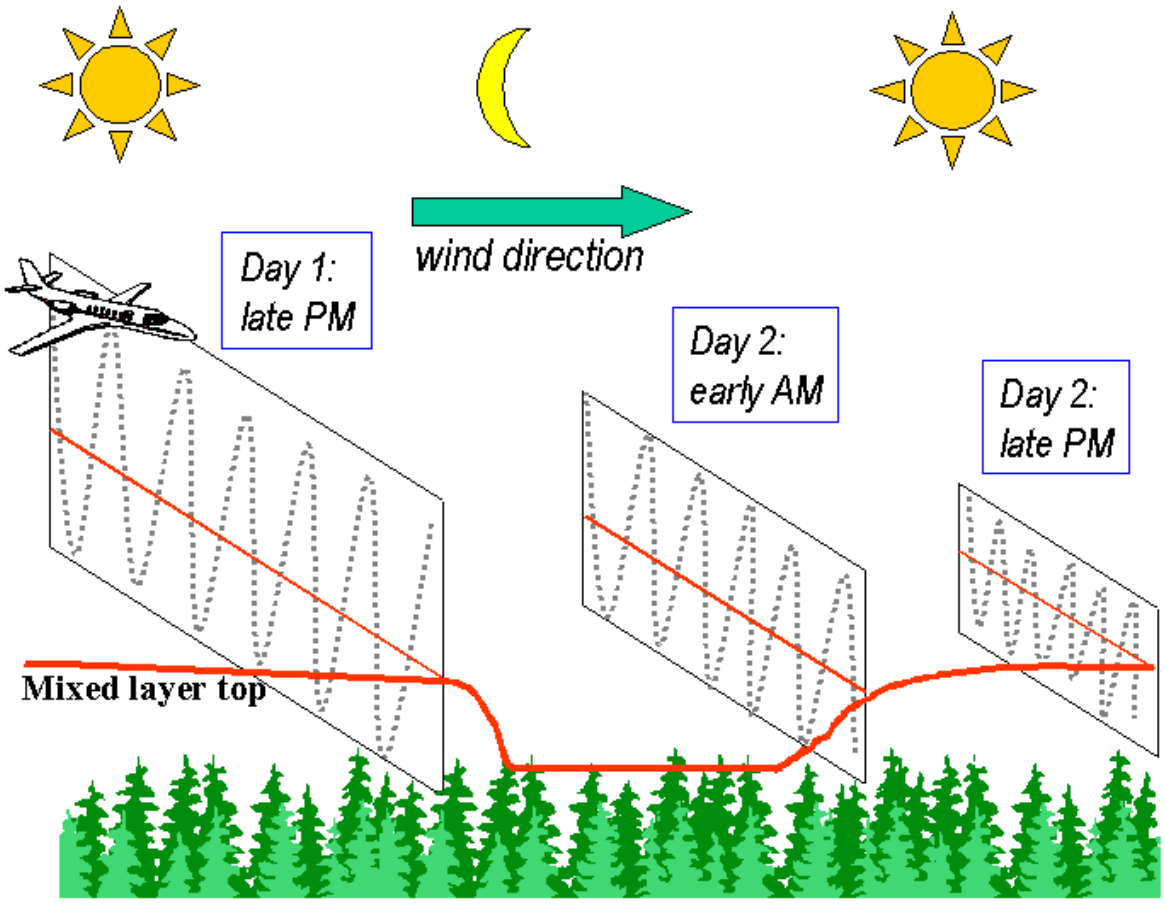
- Driven by ETA, AVN (forecasts) or EDAS, FNL (assimilations)

- 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 (where is a downstream measurement (receptor location) influenced by?)

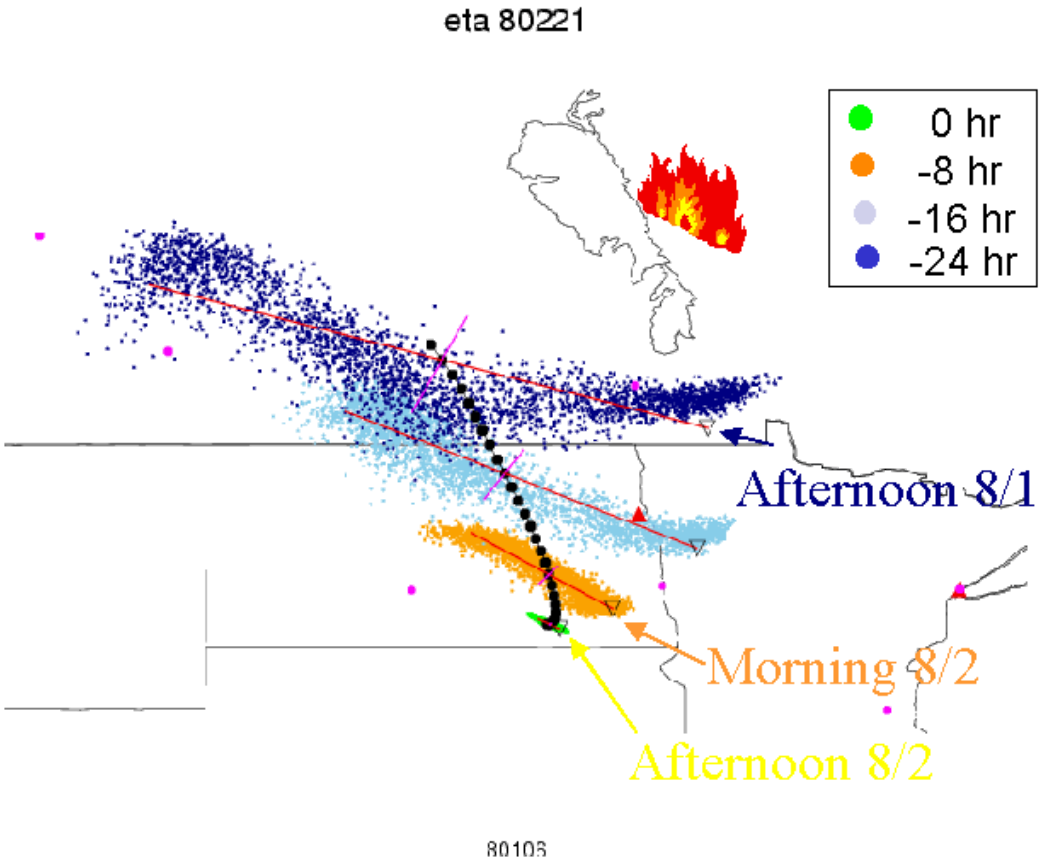
Regional Scale Experiment
"Moving columns"

Regional Lagrangian Experiment Concept



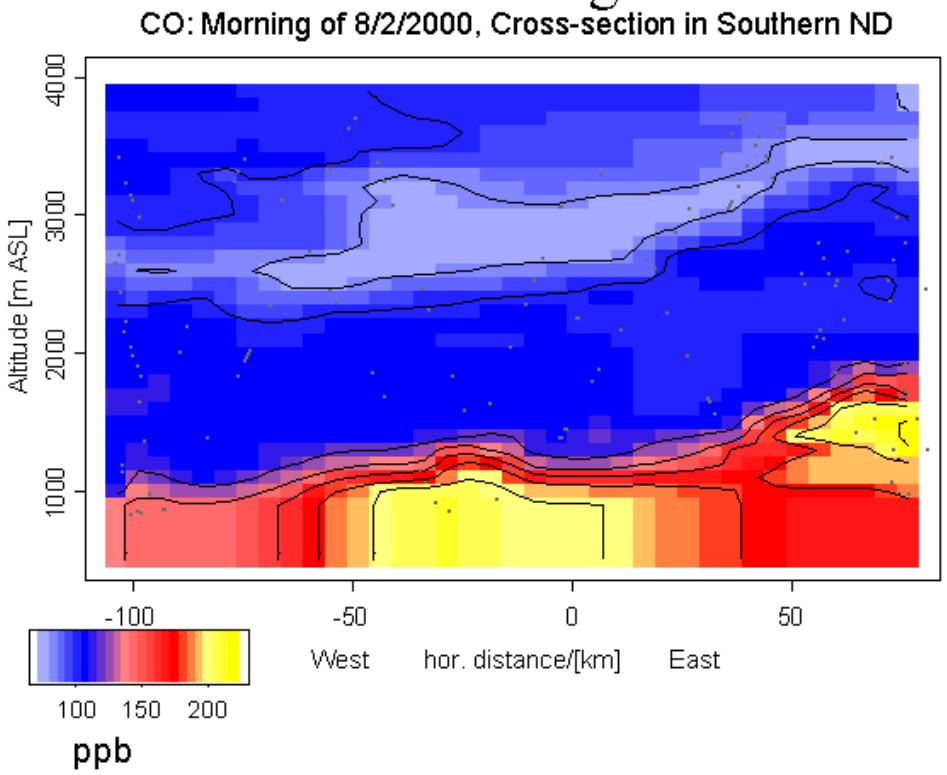
Regional Scale Experiment

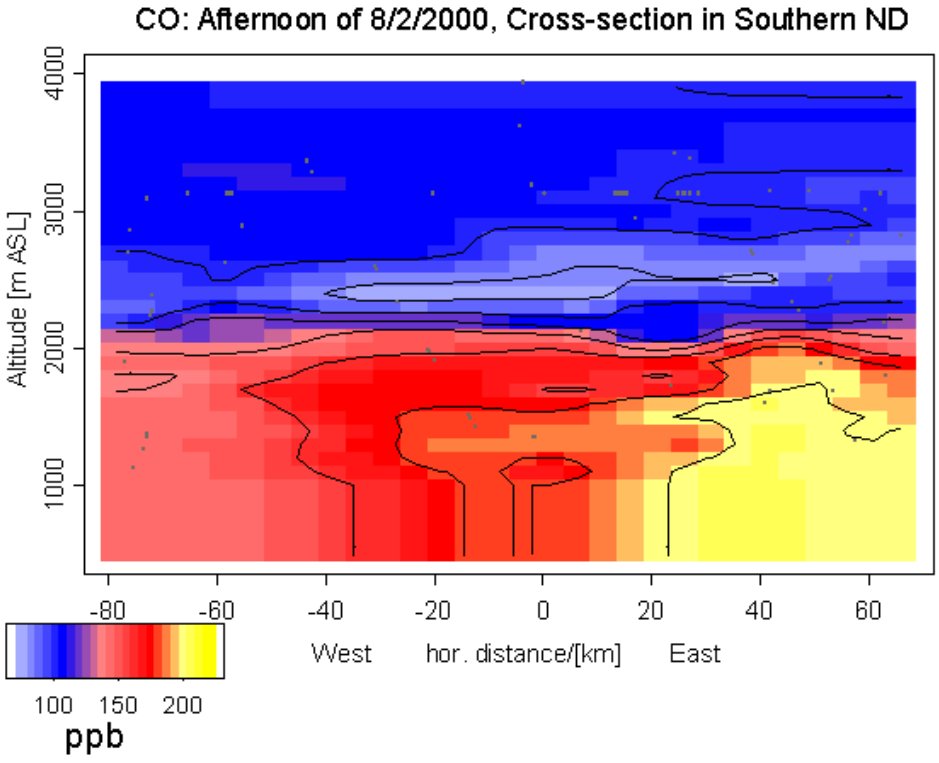
STILT: Operational forecasting tool for Lagrangian flight planning



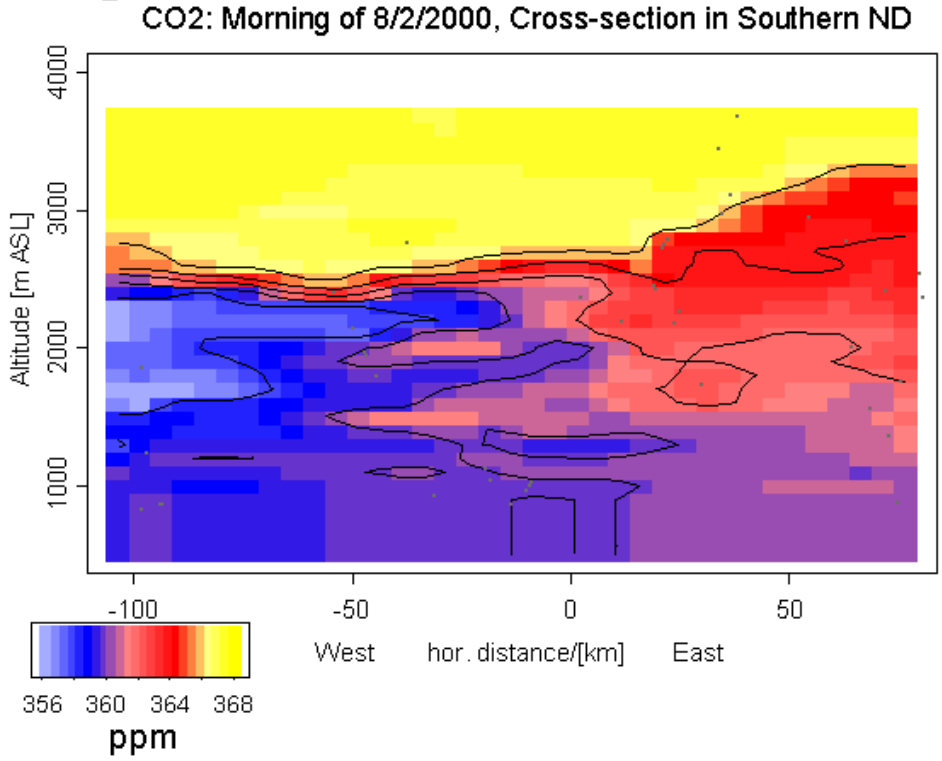
- uses ETA (40km) or AVN (191km) winds
- 2 or 3.5 day forecasts

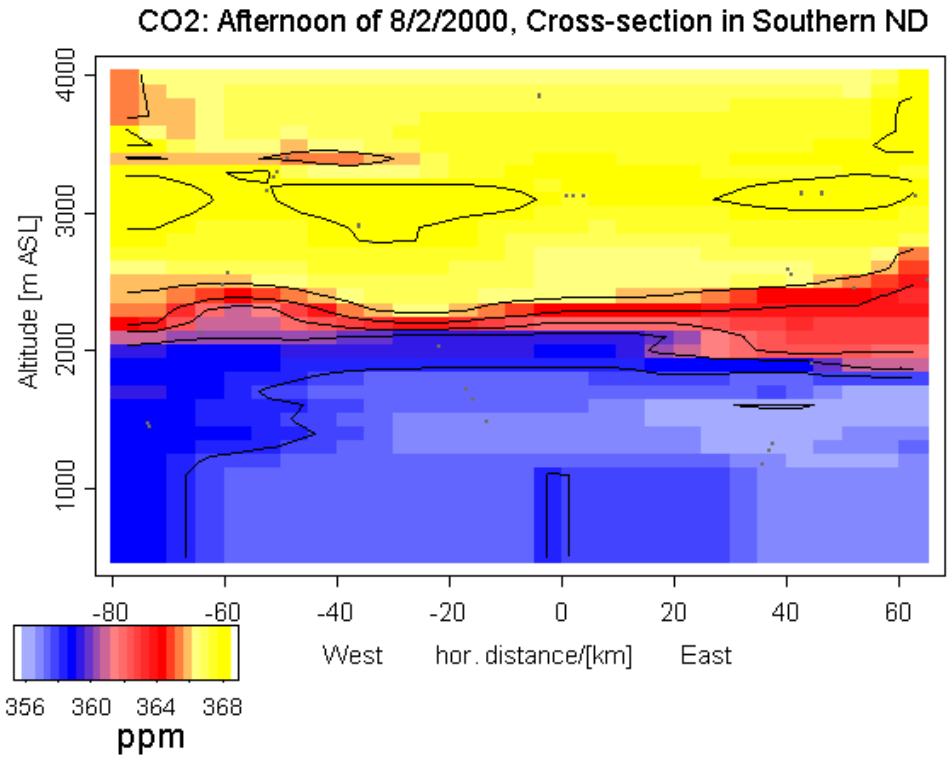
CO cross-sections through air mass



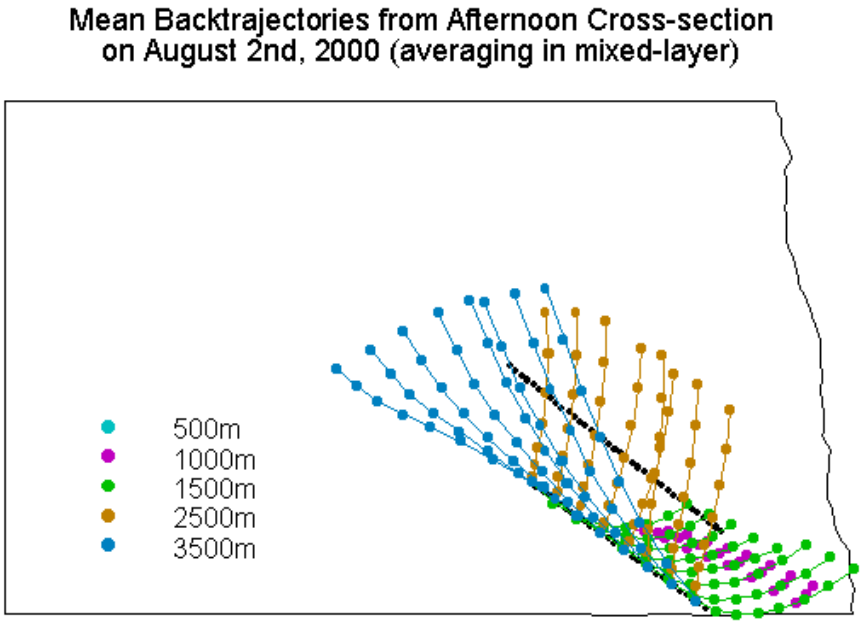


CO_2 cross-sections through air mass





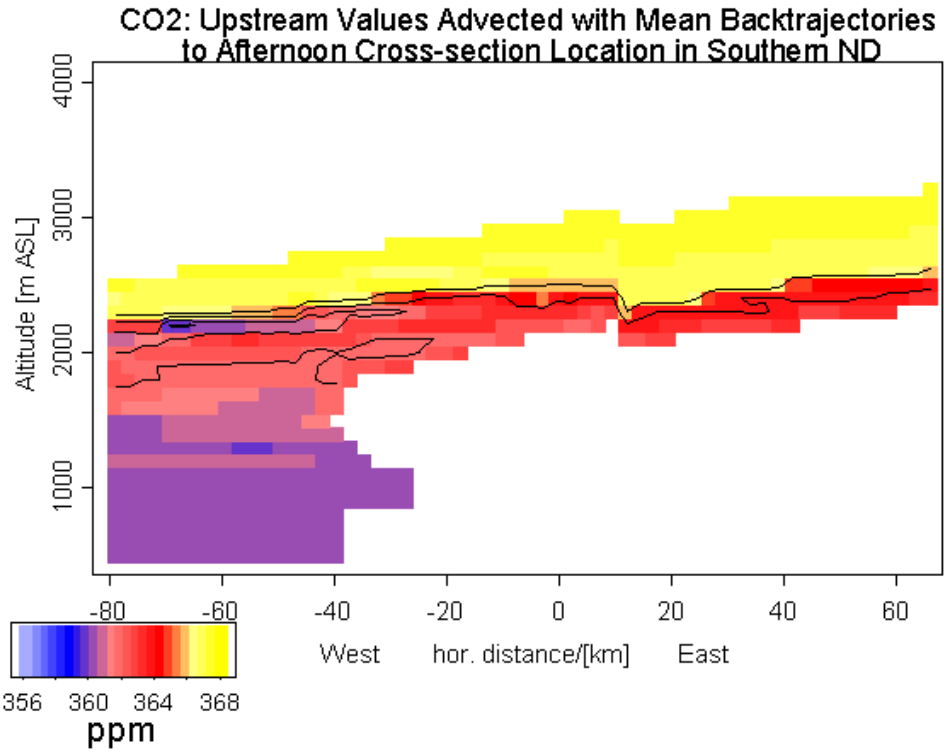
Regional Scale Experiment: Simple column advection model

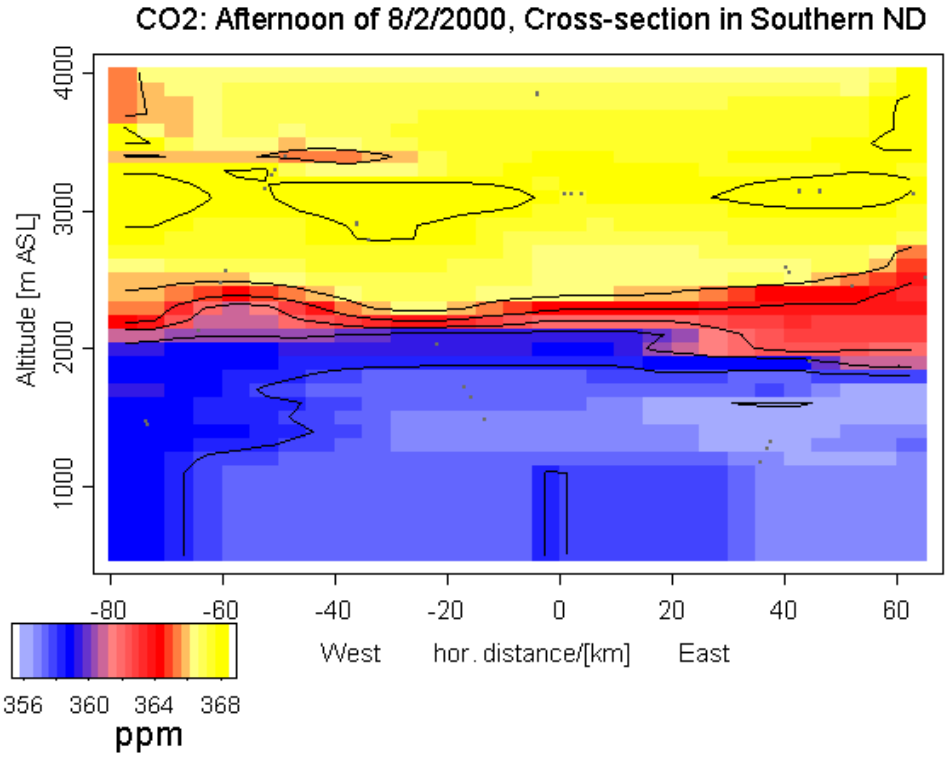


- Back trajectories use mixed layer averaged wind for mixed layer air

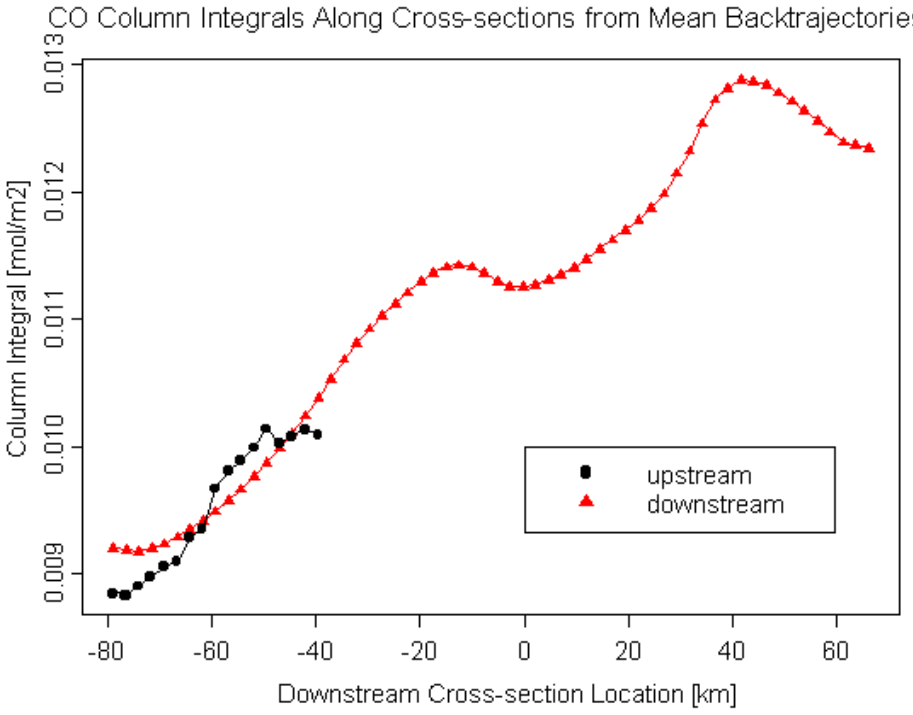
- Mixed layer height $z_i(t)$ constrained by tracer measurements

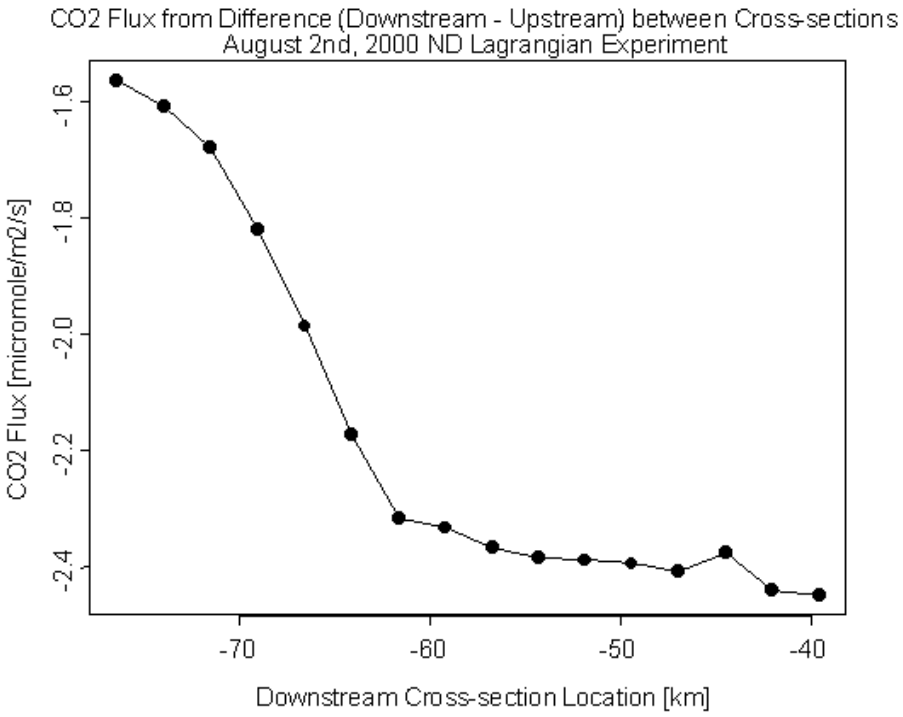
Regional Scale Experiment



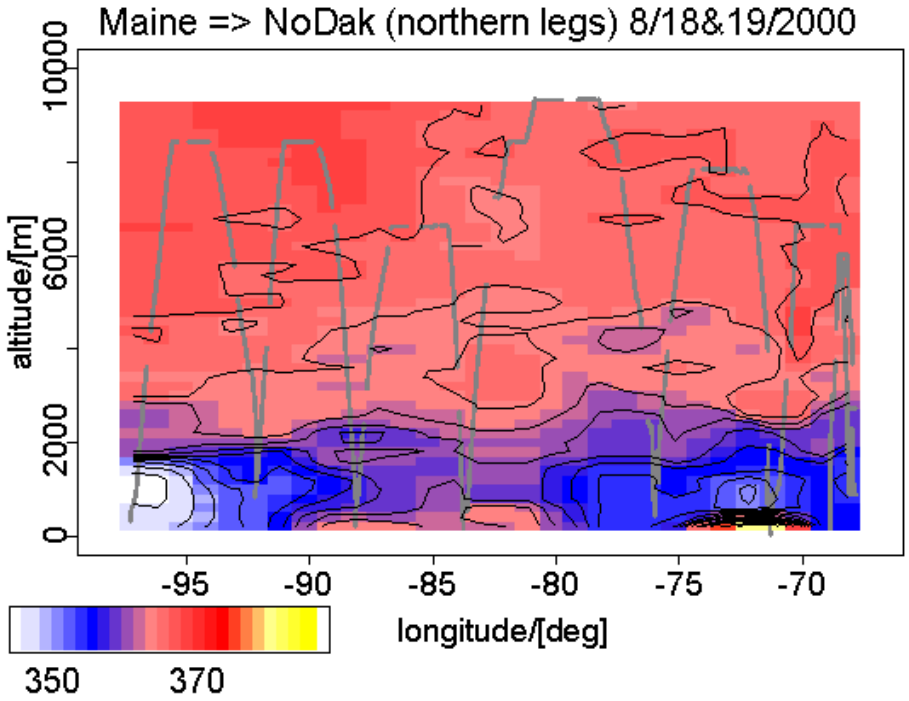


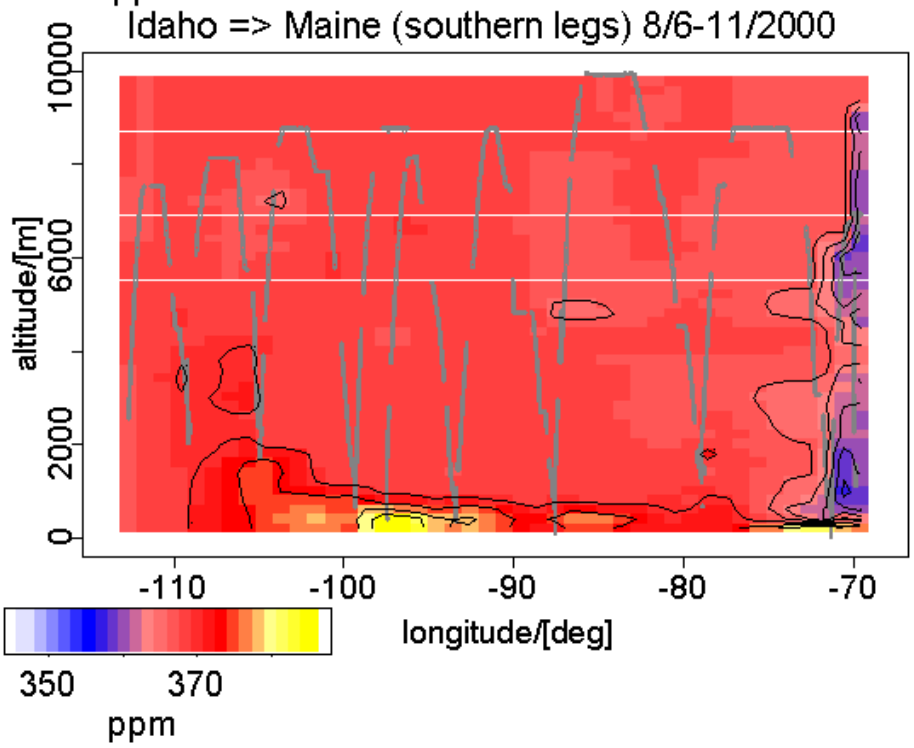
Regional Scale Experiment



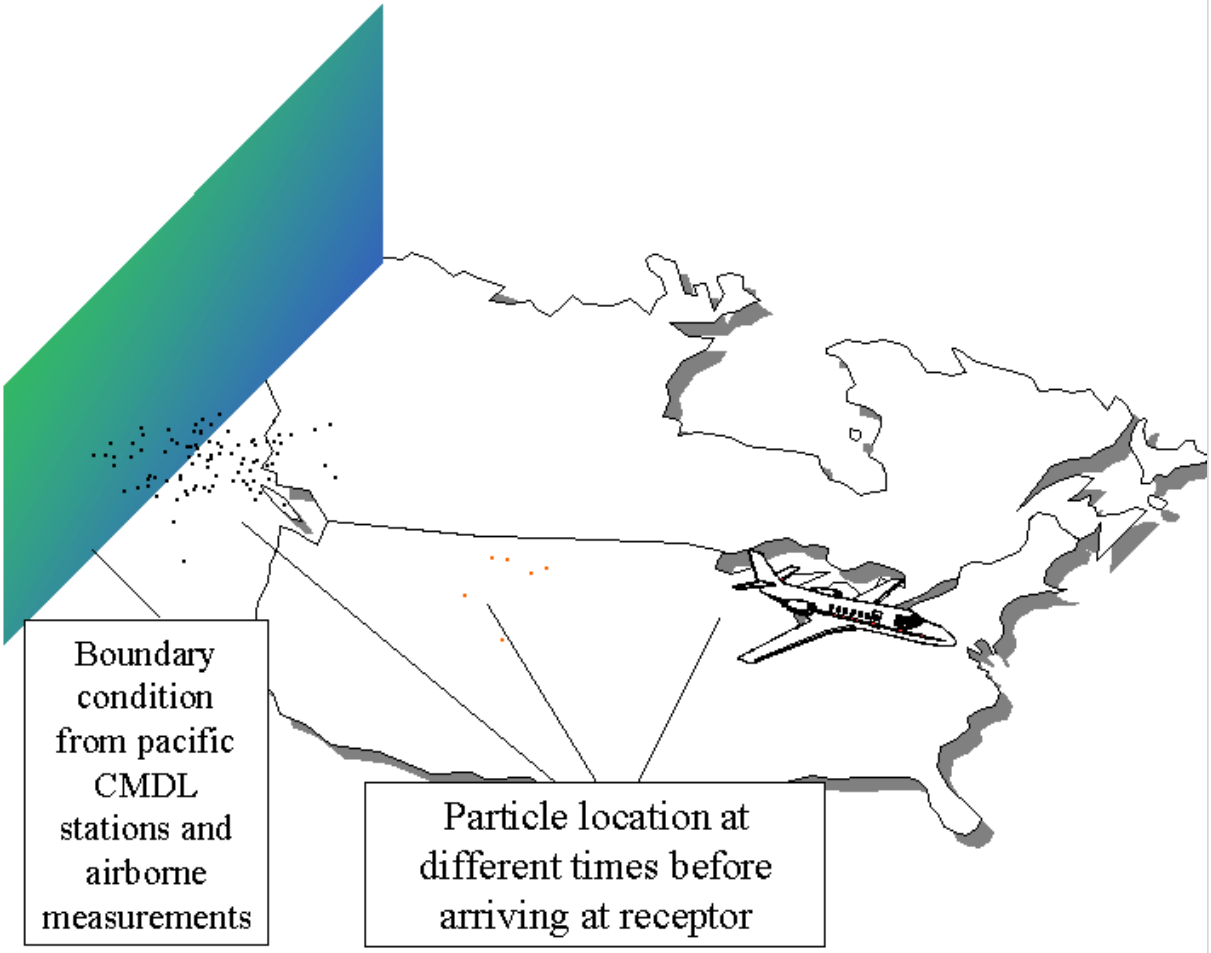


COBRA: Large scale CO_2 distribution



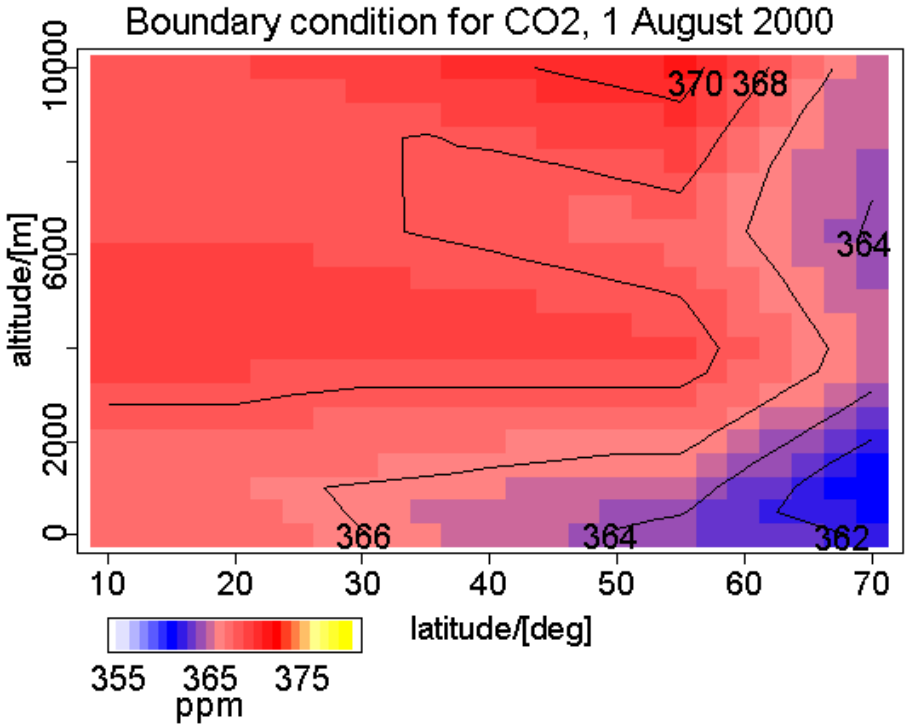


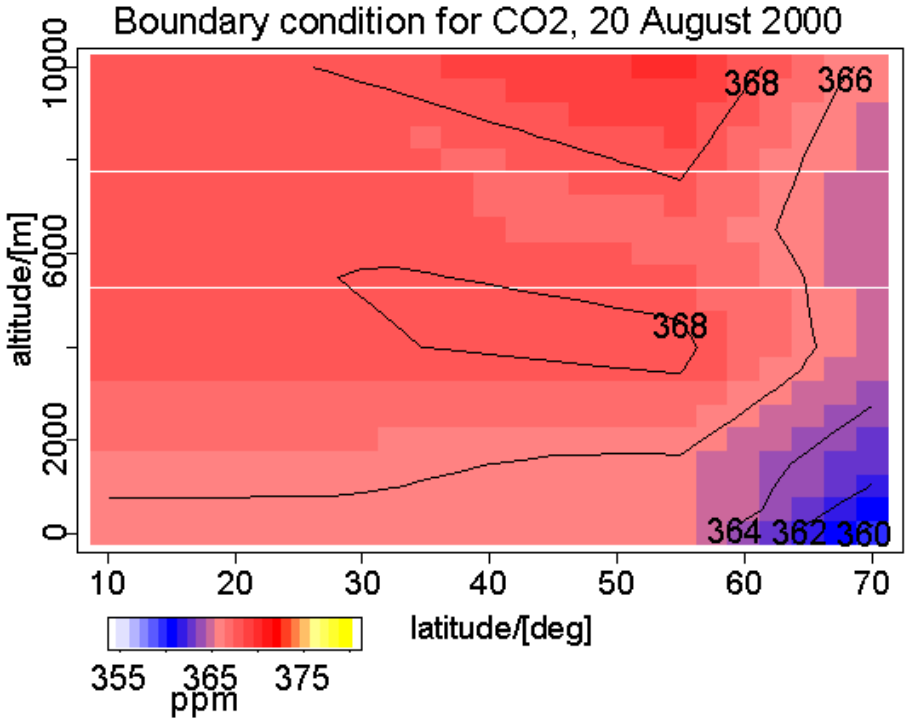
STILT-model analysis of large scale tracer distribution

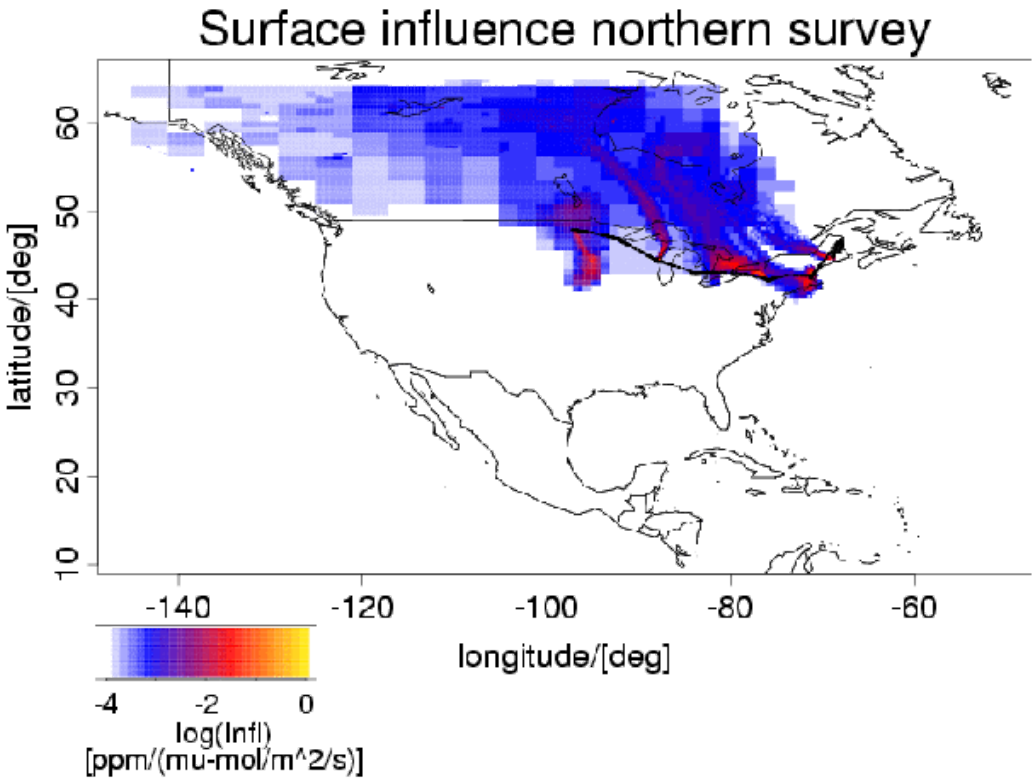


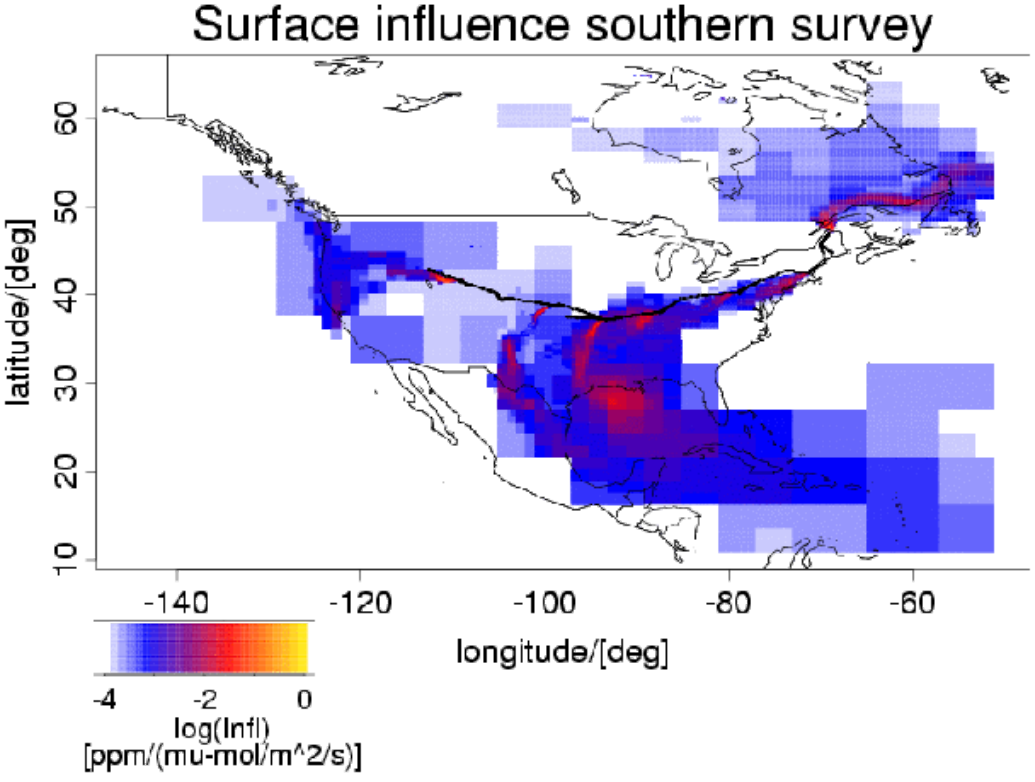
- 100 particles per receptor point (aircraft position along the survey) followed for 15 days back
- particles represent “little air masses” with equal mass
- particles “sample” surface fluxes below 0.5 * mixed layer height
- particles get initial concentration at boundary

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



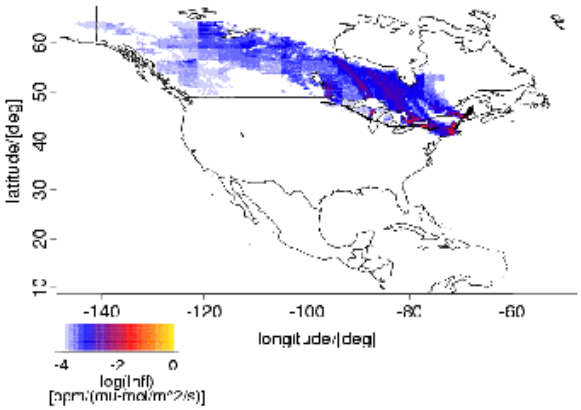



Surface influence northern survey
latitude/[deg]
10
20
30
40
50
60
-140
-120
-100
-80
-60
longitude/[deg]
-4
-2
0
log(Infl)
[ppm/(mu-mol/m^2/s)]

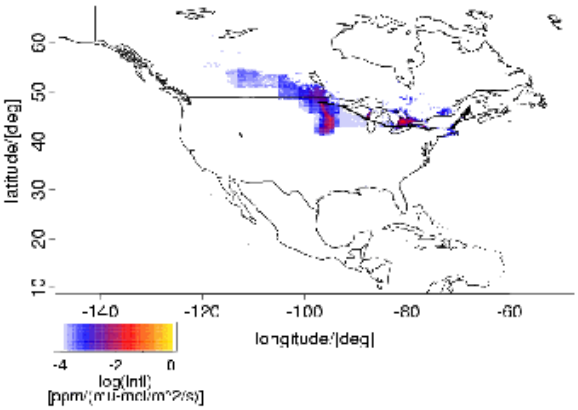

Surface influence southern survey
latitude/[deg]
10
20
30
40
50
60
-140
-120
-100
-80
-60
longitude/[deg]
-4
-2
0
log(Infl)
[ppm/(mu-mol/m^2/s)]

Influence from different vegetation types (derived from 1-km IGBP vegetation classification)

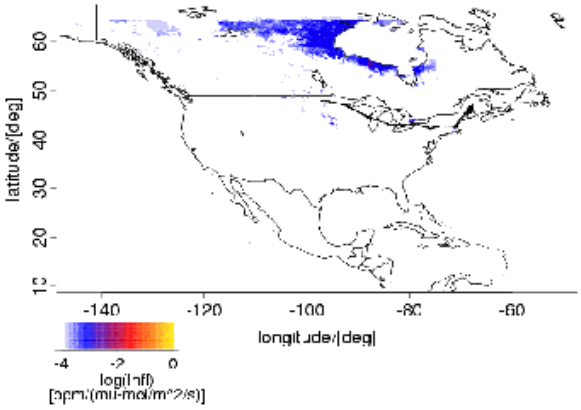
Forests



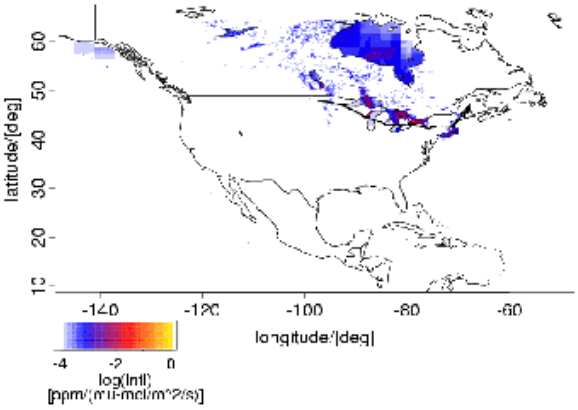
Crop

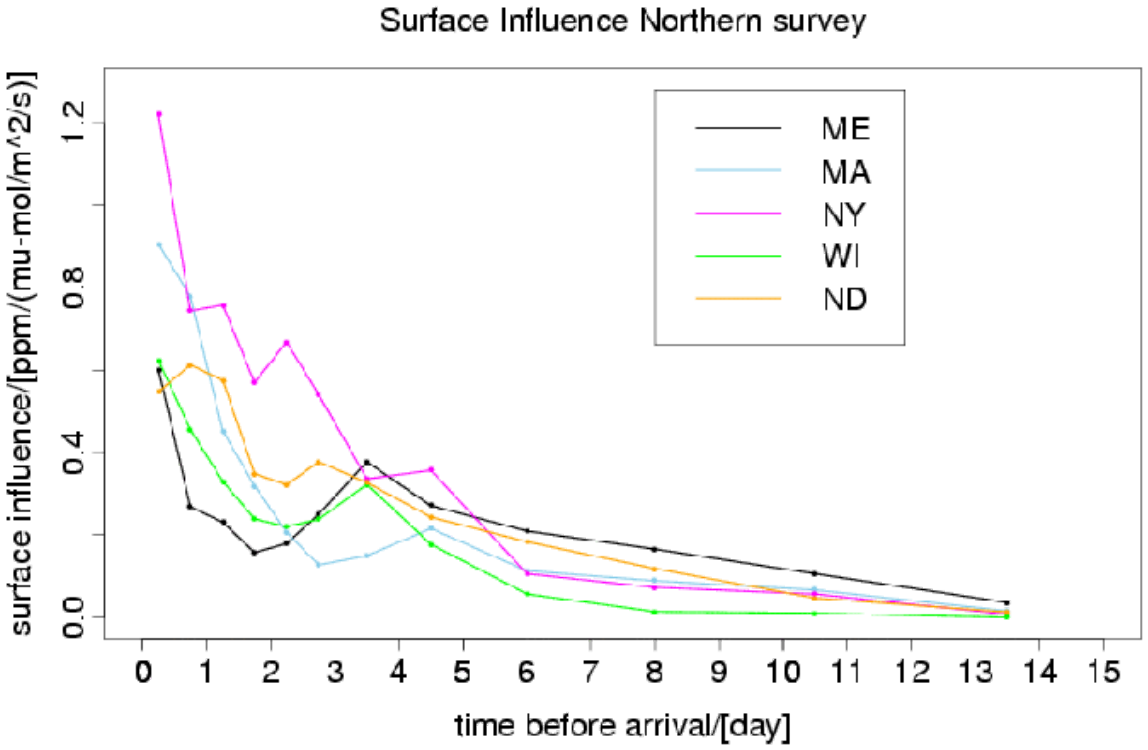


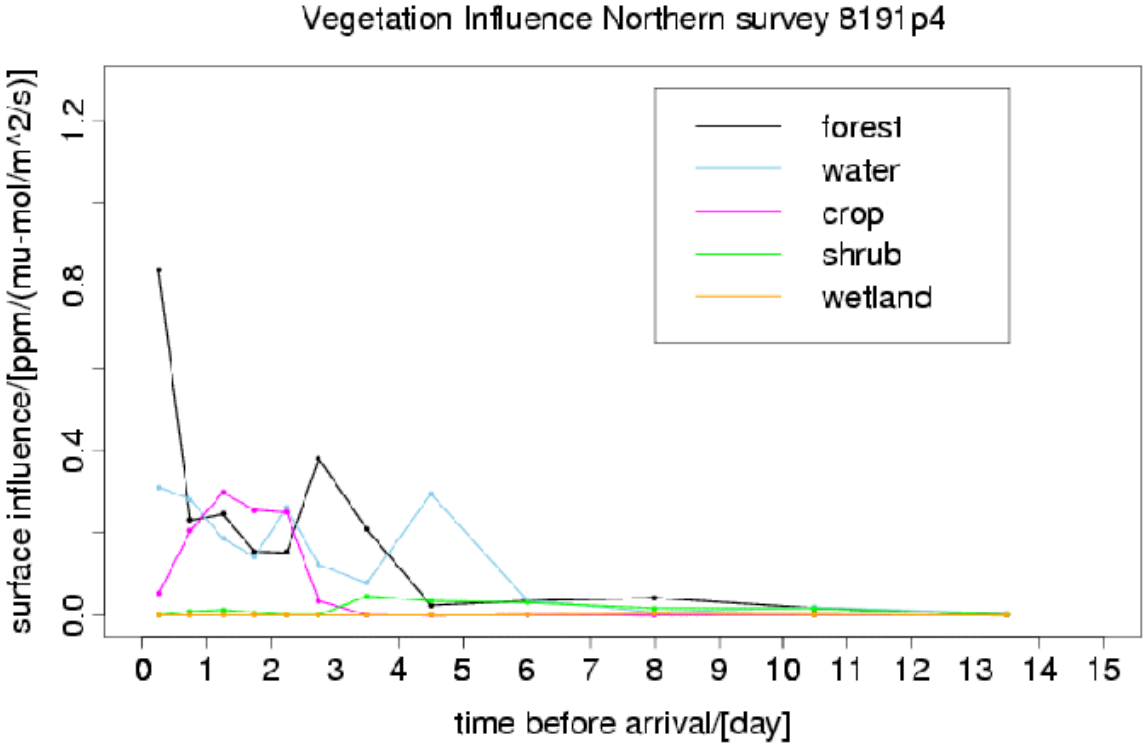
Grassland, shrubland



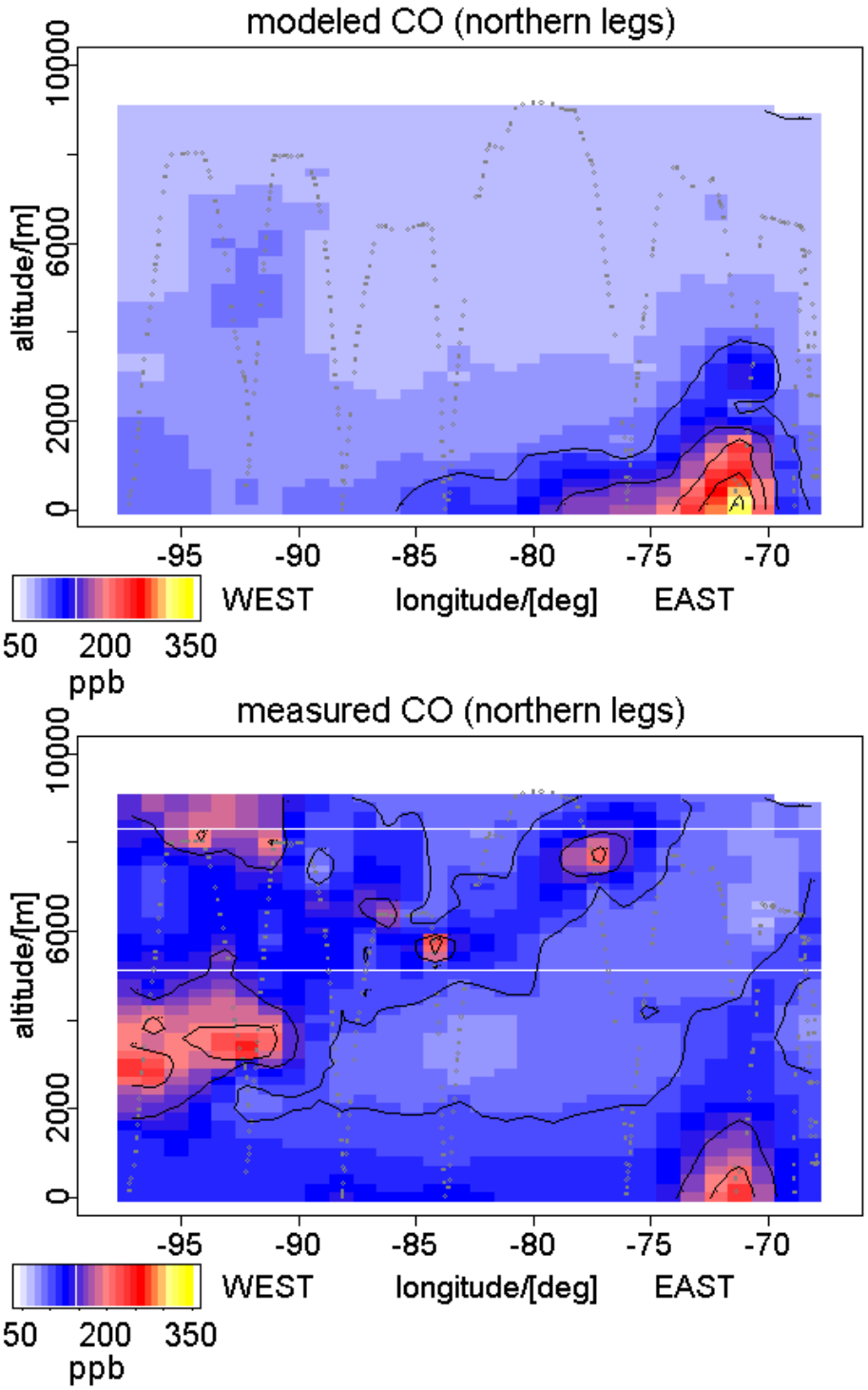
Water



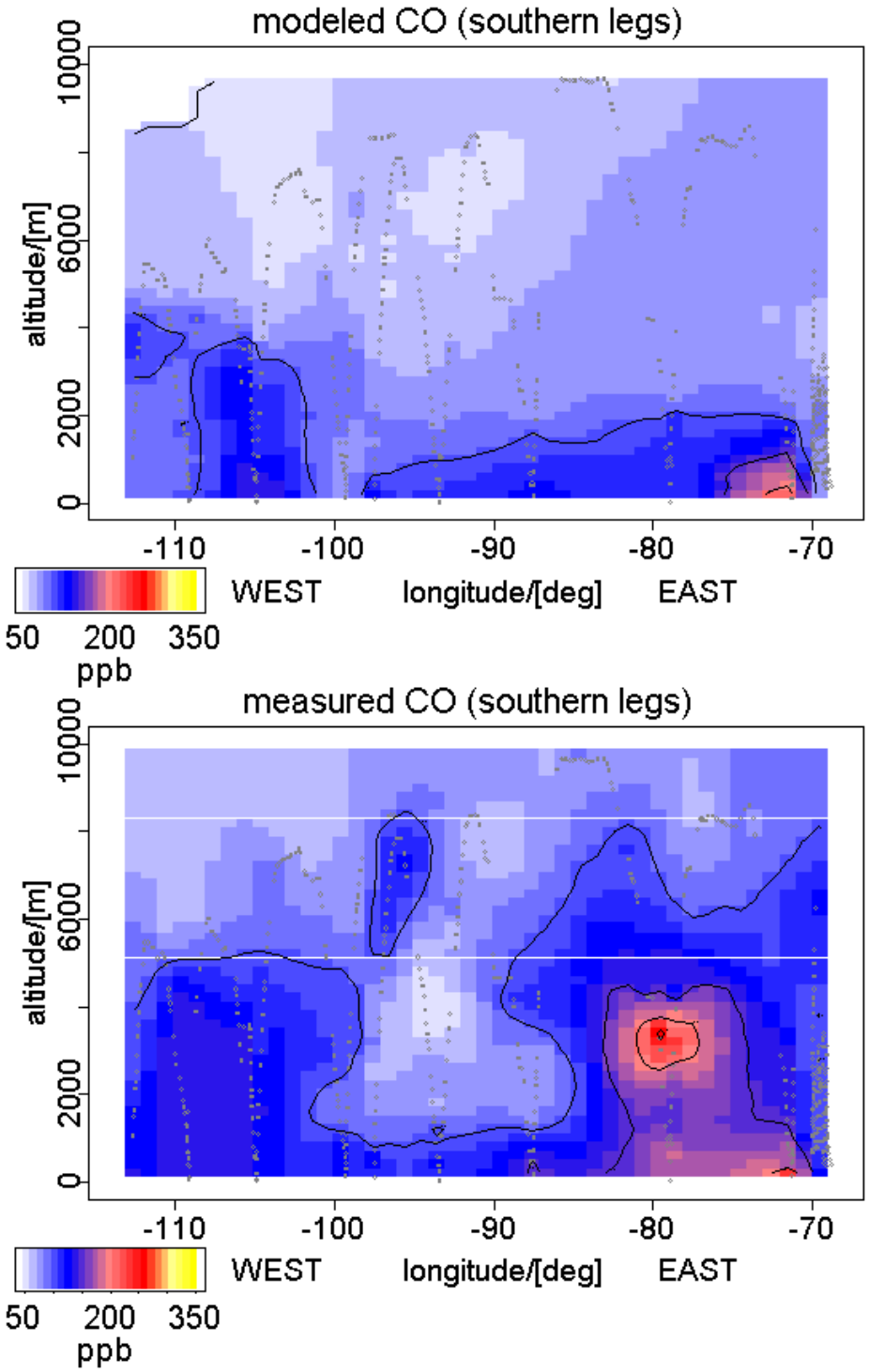

Surface Influence Northern survey
surface influence/[ppm/(mu-mol/m^2/s)]
0.0
0.4
0.8
1.2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
time before arrival/[day]
ME
MA
NY
WI
ND


Vegetation Influence Northern survey 8191p4
surface influence/[ppm/(mu-mol/m^2/s)]
0.0
0.4
0.8
1.2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
time before arrival/[day]
forest
water
crop
shrub
wetland

STILT results, COBRA northern survey



STILT results, COBRA southern survey



STILT inversion

Net ecosystem exchange for vegetation i (i=forest, cropland):

$$NEE_i = \text{Respiration} + g_i \cdot \text{GEE (Ameriflux)}$$

$$= R_i + g_i \cdot \frac{a_i \cdot PAR}{b_i + PAR}$$

PAR: photosynthetically active radiation (EDAS)

a_i/b_i: quantum efficiency (Ameriflux)

b_i: max. GEE (Ameriflux)

Inversion:

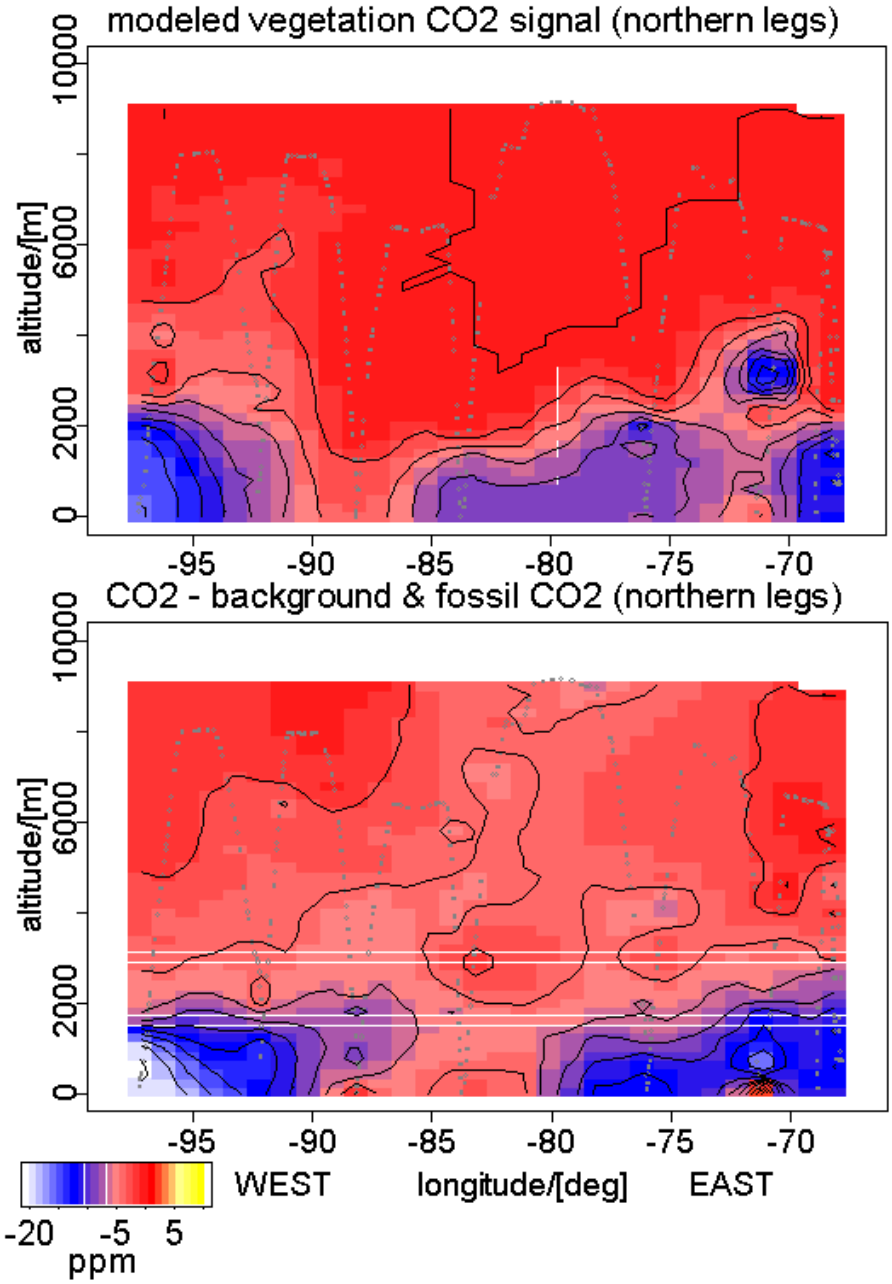
R_i and G_i optimized so that

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

with

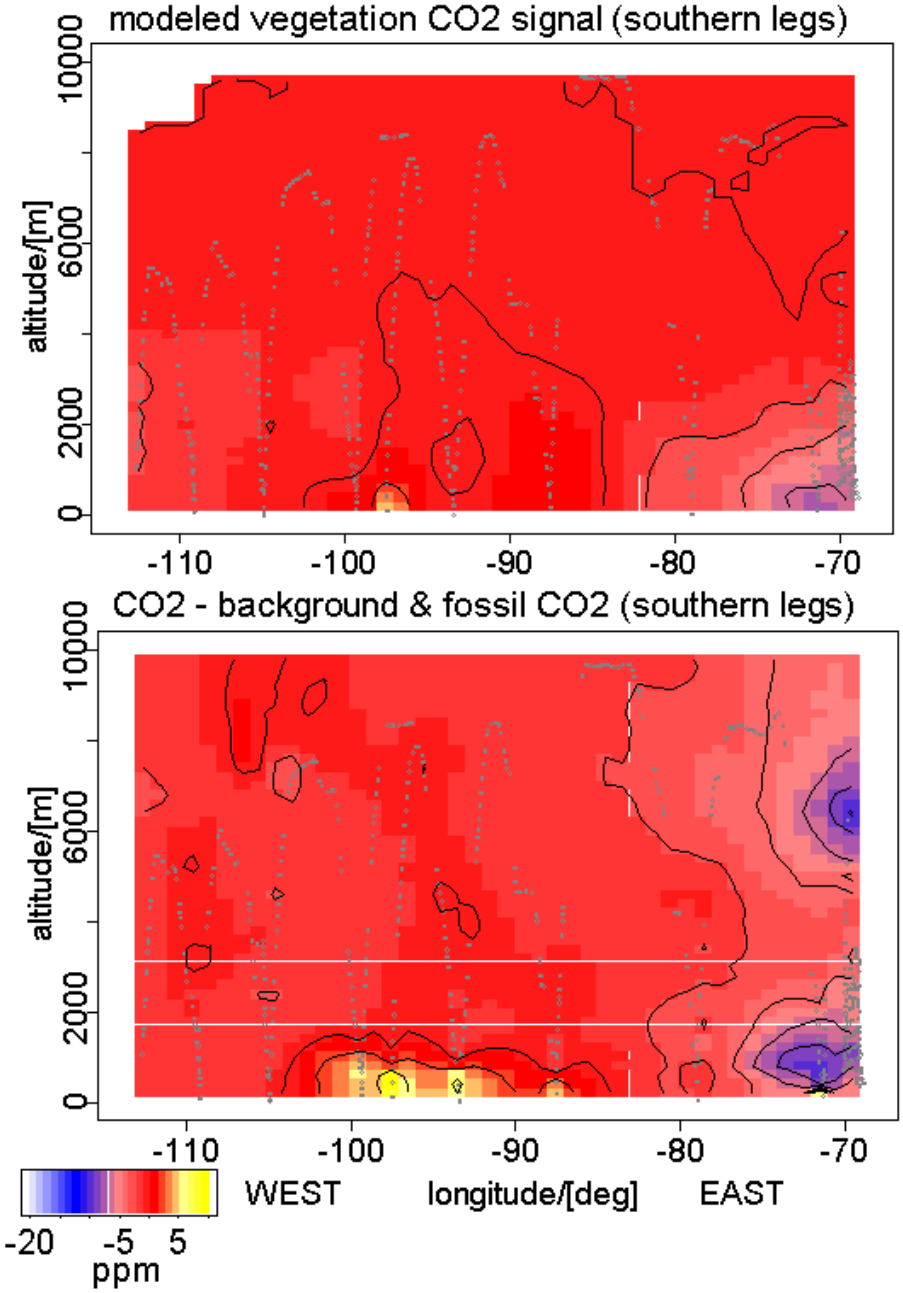
$$CO_{2,veg,r}(\text{meas.}) = CO_2(\text{meas.}) - CO_2(\text{foss.}) - CO_2(\text{ini.})$$

STILT results using optimized NEE: North



	GEE factor	Respiration
Forests	**0.96**	**5.4** $\mu mol/(m^2 s)$
Cropland	**0.44**	**0.9** $\mu mol/(m^2 s)$

STILT results using optimized NEE: South



	GEE factor	Respiration
Forests	**0.55**	**2.4** $\mu mol/(m^2 s)$
Cropland	**0.11**	**2.9** $\mu mol/(m^2 s)$

Summary and Outlook

• We have constrained regional and continental scale carbon fluxes by airborne observations using a receptor based approach

• Large scale differences in cross-sections can be linked to differences in biospheric activity in the footprint regions

Future:

• Closer link between fluxes and vegetation/environmental drivers

• Improvements of transport model: mixed layer height, vertical transport (convection), horizontal and vertical resolution

• Thorough analysis of statistical and systematic errors for the inversion

• Large scale flight planning to reduce uncertainty of upstream tracer distribution