Remote Sensing and Diagnostic Atmospheric Modeling for NACP

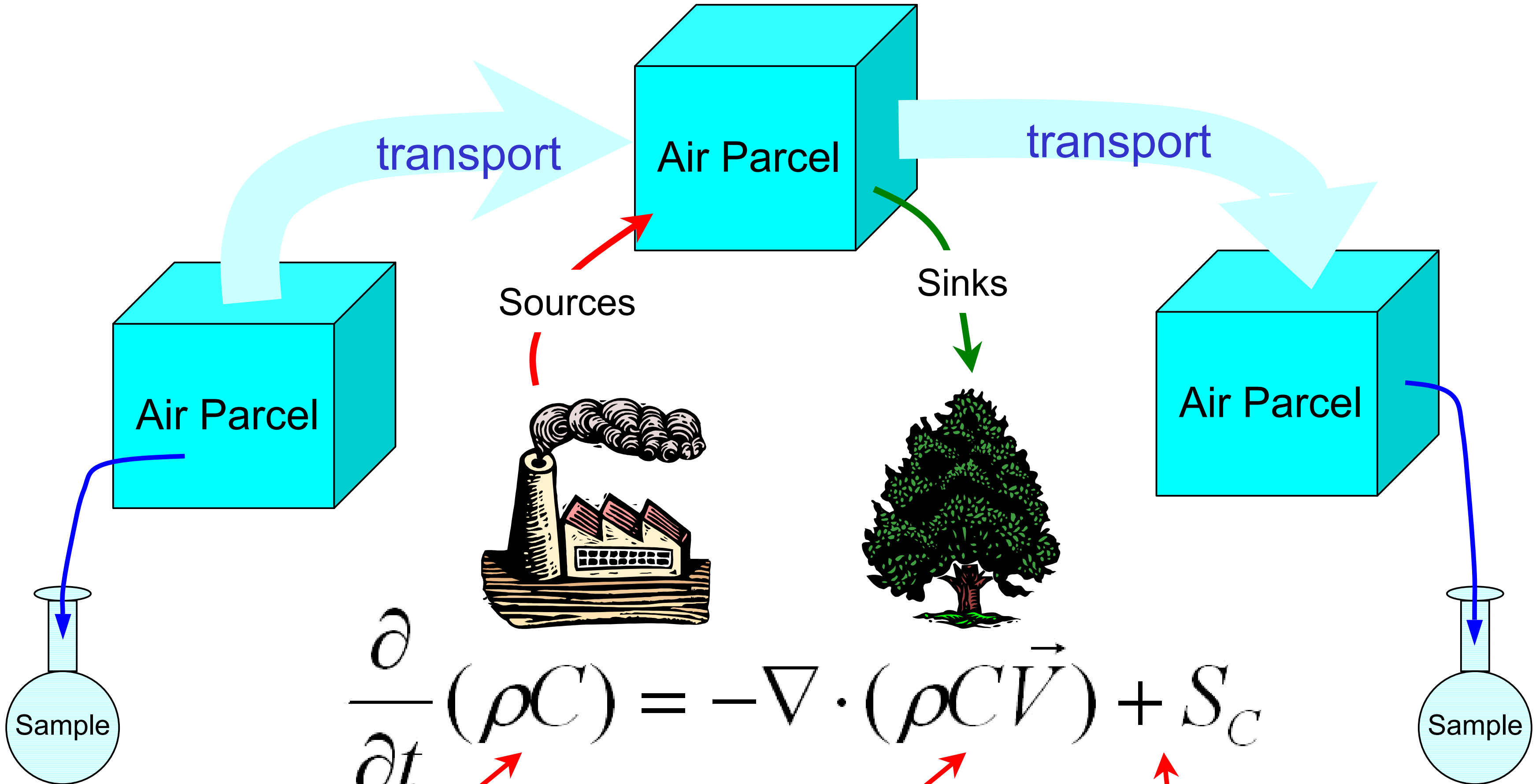
Scott Denning

Colorado State University

U.S. Global Change Research Program
Carbon Cycle Science Program
An Interagency Partnership

US Climate Change Science Program
www.climatescience.gov

Inverse Modeling



$$\frac{\partial}{\partial t}(\rho C) = -\nabla \cdot (\rho C \vec{V}) + S_C$$

concentration
(observe)

transport
(model)

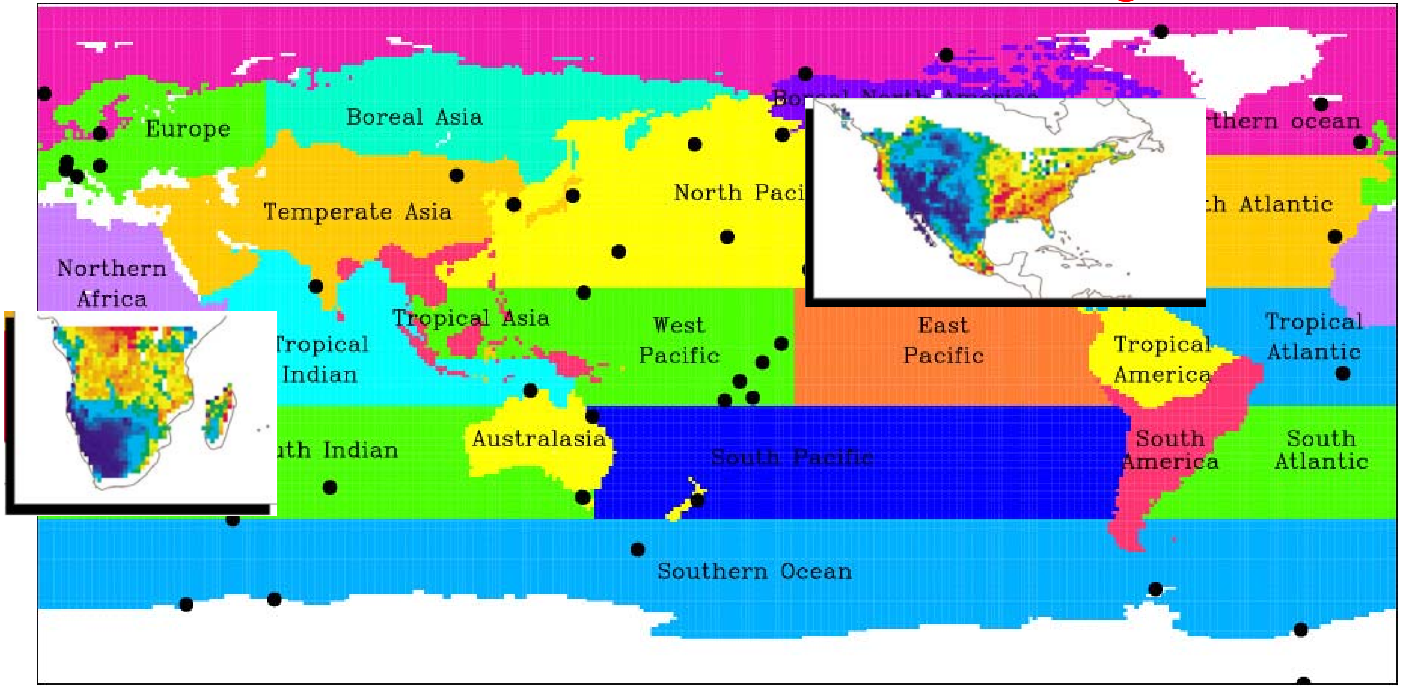
sources and sinks
(solve for)

Global Context: "Pre-aggregation"

Twelve global transport models

Monthly estimation of regional flux and uncertainty

TransCom 3 Sites & Basis Regions



(e.g., TransCom, Gurney et al 2003)

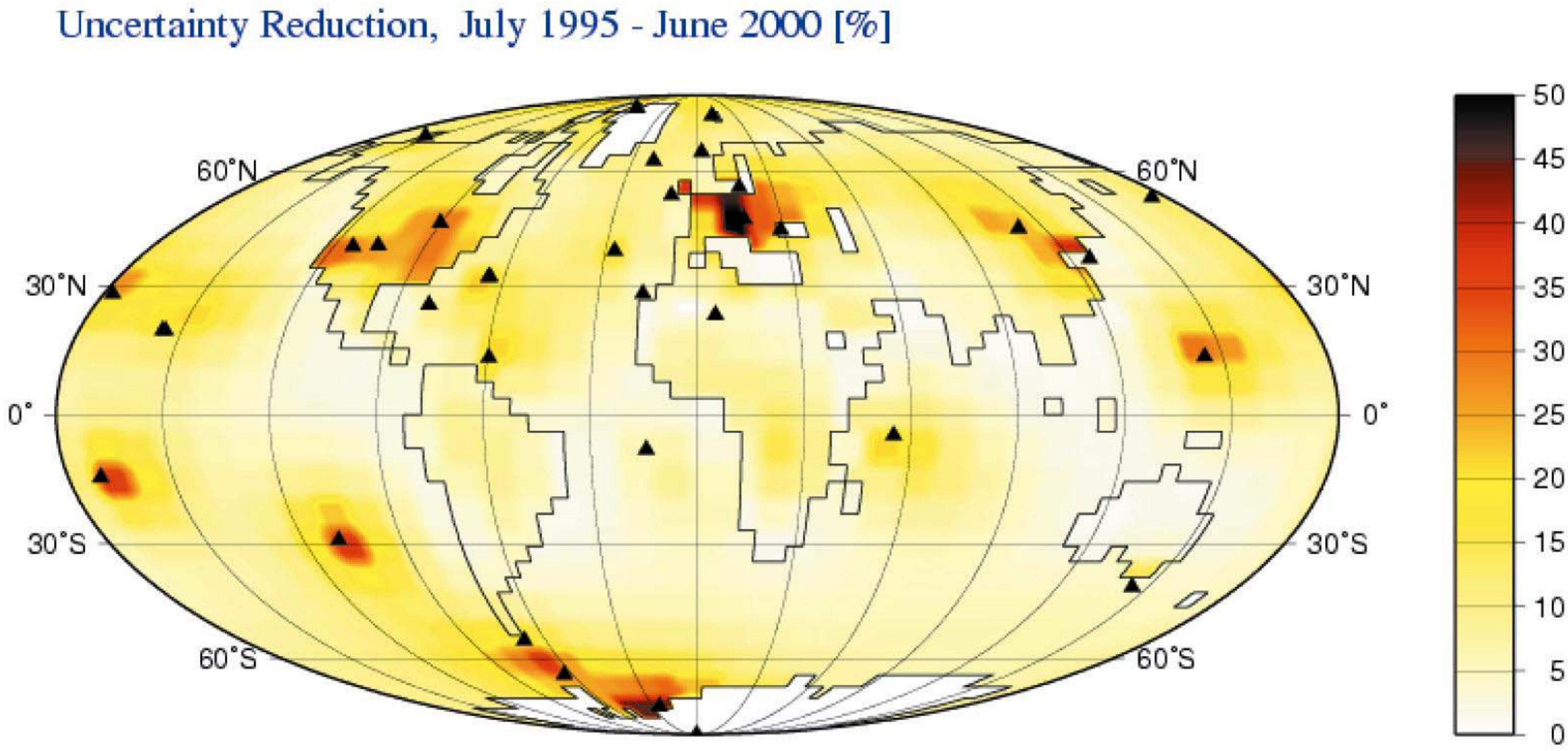
- Sparse data constrain only large regions
- Try to be "smart" about sub-regional distributions
- Monthly regional patterns must be based on vegetation cover and types, physiology, land mgmt, etc: remote sensing, eddy covariance, plot studies!

Adjoint Inversion

(e.g., Rodenbeck et al, 2003)

- Fill rows of transport Jacobian (as opposed to columns in older "synthesis" approach)
- Advantage: computationally feasible estimates of monthly fluxes on transport model grid!
- Sparsely sampled world … many equally "valid" flux patterns w.r.t. observations
- Without pre-defined regional patterns and temporal phasing, flux adjustment only occurs in proximity to stations on days samples are collected!
- Post-aggregation using covariance matrix
- Prescribed space/time flux correlations

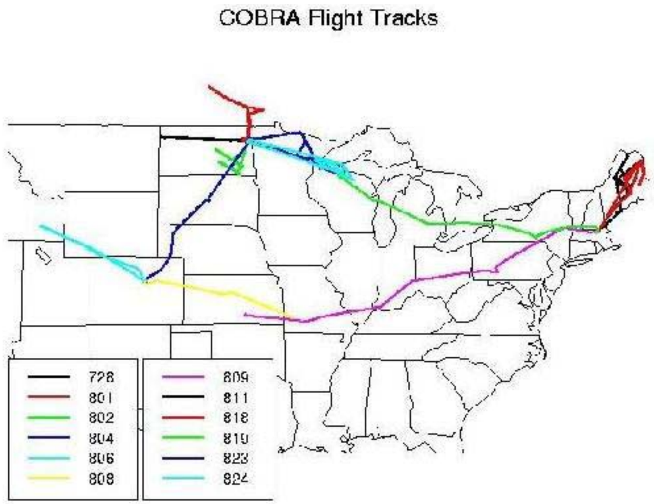
Monthly Mean "Measles"

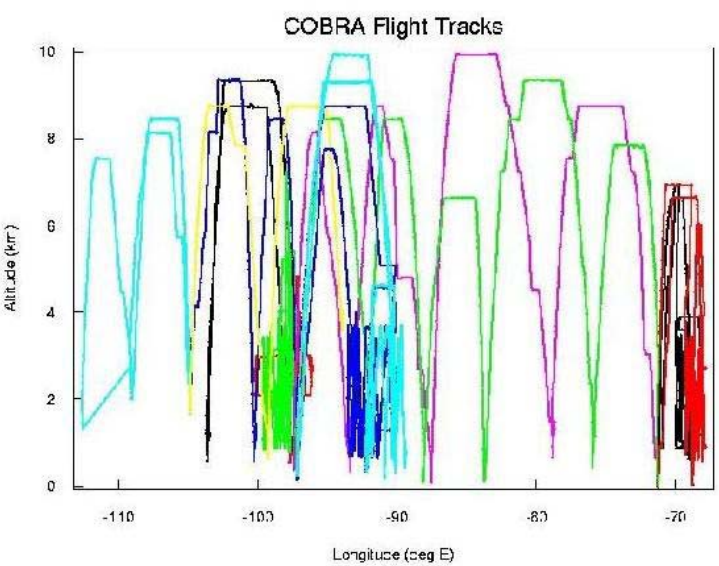


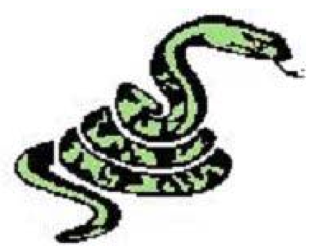
Rodenbeck et al (2003)

Interpretation requires post-aggregation to larger regions, assumptions about autocorrelation in space and time

COBRA 2000







- 14 flights during August 2000
- Large-scale surveys
- Lots of lower tropospheric data
- Some up to 10 km
- Multiple trace gases

S. Wofsy, PI *see Gerbig et al (2003)*

influence function for concentration measurements C^*

concentration sample

$$\Phi(C) =$$

influence function for concentration measurements C^*

concentration sample

surface fluxes

$$\Phi(C) =$$

$$\int_0^T \int_0^{L_x} \int_0^{L_y} C^* \Big|_{z=0} q\,dx\,dy\,dt +$$

influence function for concentration measurements C^*

concentration sample

surface fluxes

initial concentration

$$\Phi(C) =$$

$$\int_0^T \int_0^{L_x} \int_0^{L_y} C^*\Big|_{z=0} q\,dx\,dy\,dt +$$

$$\int_0^{L_x} \int_0^{L_y} \int_0^{H} C^*\Big|_{t=0} C_0\,dx\,dy\,dz +$$

influence function for concentration measurements C^*

concentration sample

surface fluxes

initial concentration

inflow fluxes

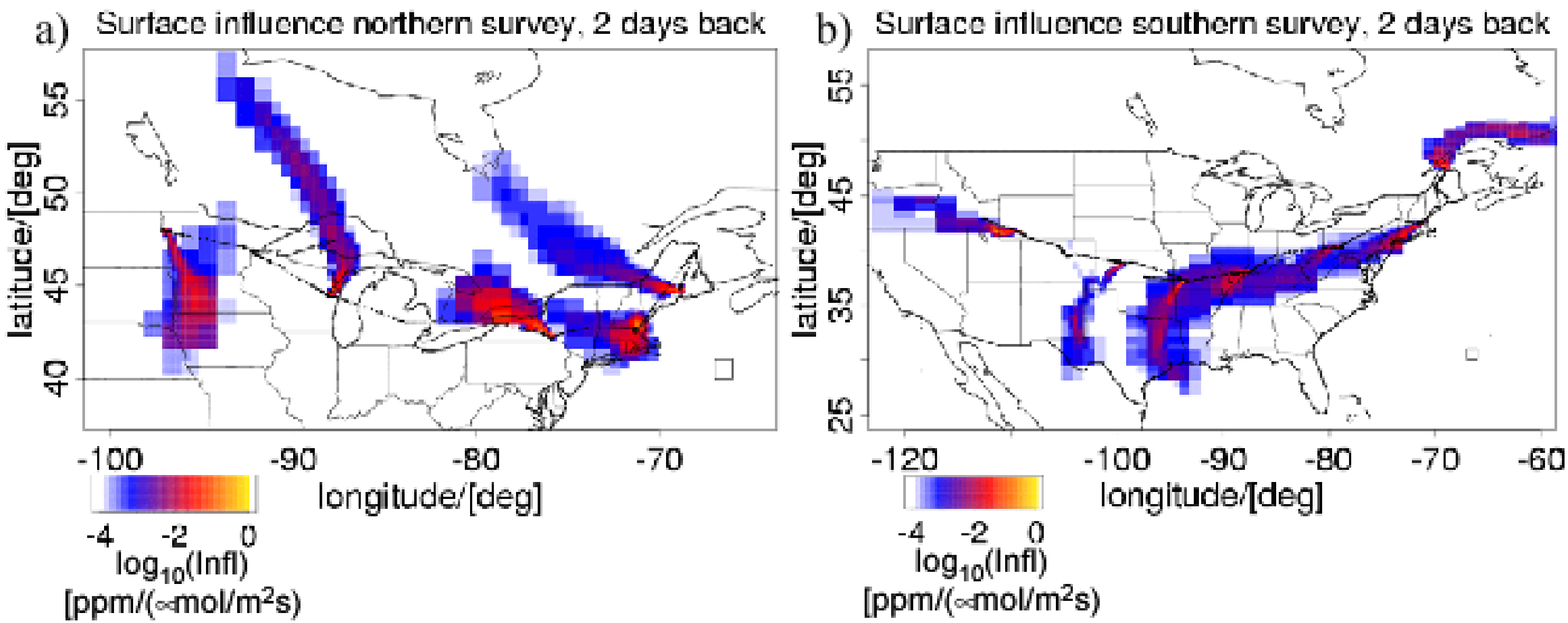
$$\Phi(C) =$$

$$\int_0^T \int_0^{L_x} \int_0^{L_y} C^*\Big|_{z=0} q \, dx\, dy\, dt +$$

$$\int_0^{L_x} \int_0^{L_y} \int_0^{H} C^*\Big|_{t=0} C_0 \, dx\, dy\, dz +$$

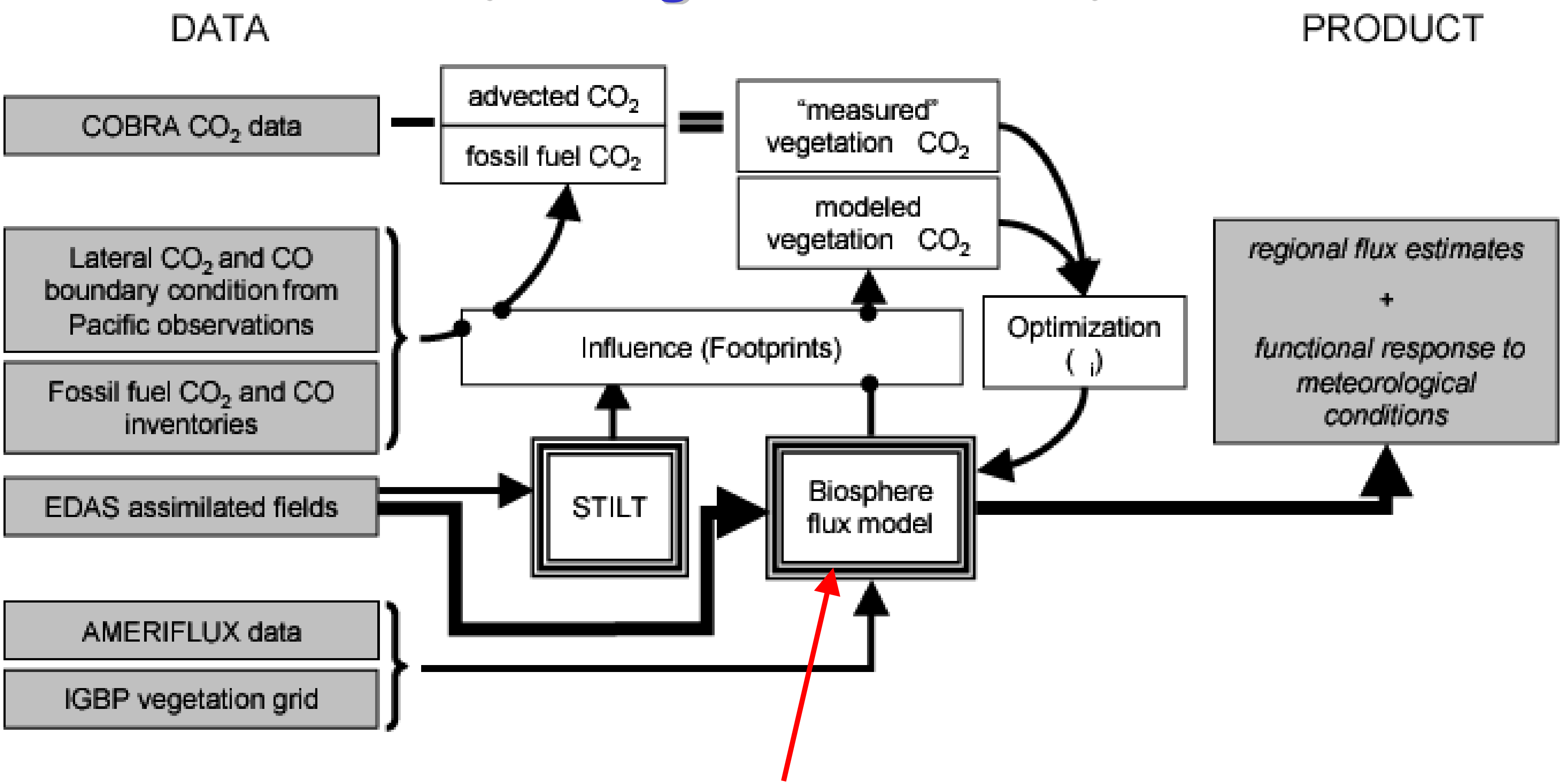
$$\int_0^T \int_0^{L_y} \int_0^{H} (\hat{u} C^*\Big|_{x=0} C_W + \hat{u}\, C^*\Big|_{x=L_x} C_E)\, dy\, dz\, dt + \int_0^T \int_0^{L_x} \int_0^{H} (\hat{v} C^*\Big|_{y=0} C_S + \hat{v}\, C^*\Big|_{y=L_y} C_N)\, dx\, dz\, dt$$

COBRA 2000 Influence Functions



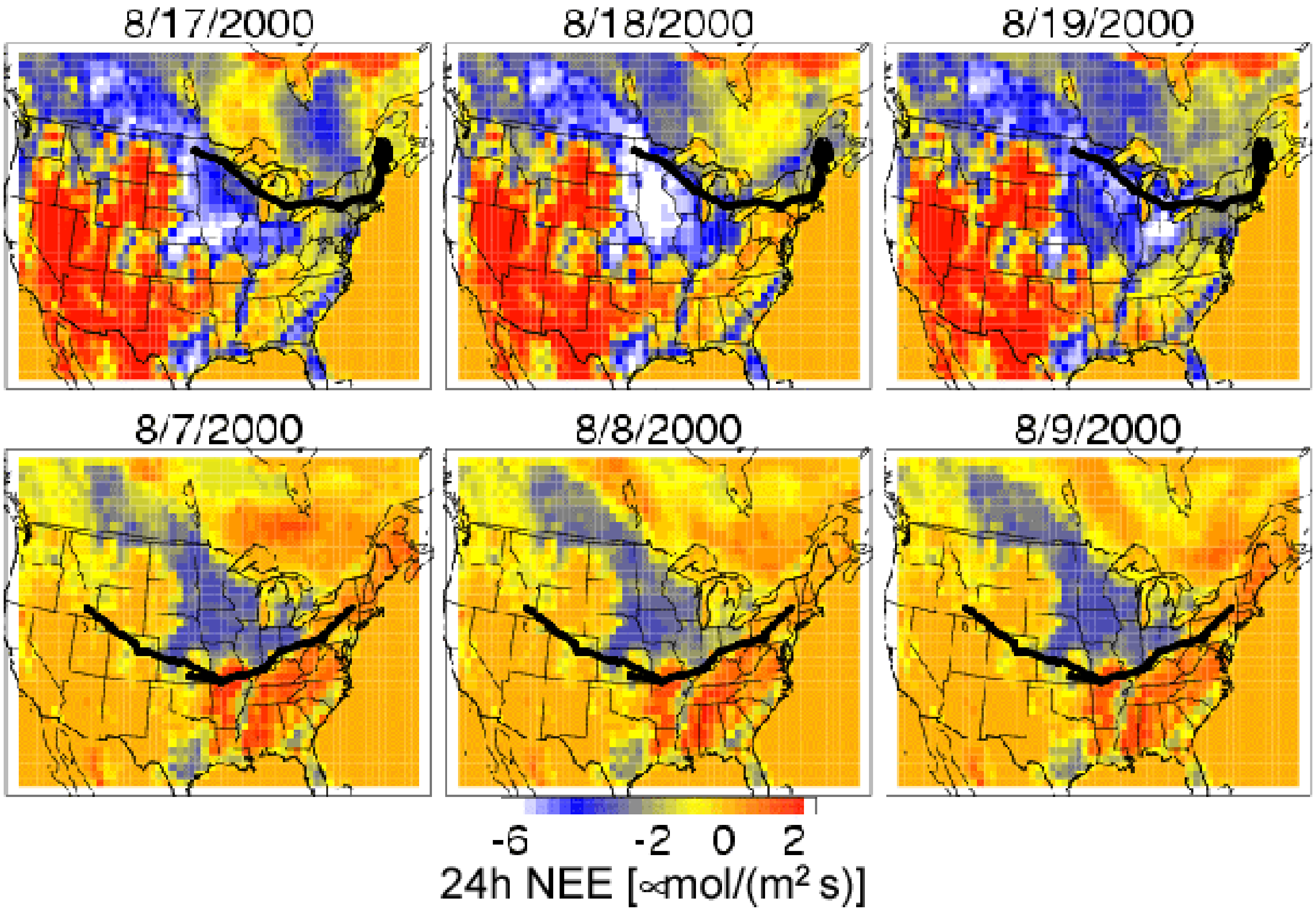
- Nearly all the information about surface fluxes in COBRA campaigns was collected in (rare) "missed-approach" sampling within PBL
- Model parameters determined by optimization of these data
- Model was then be integrated to produce "spatialized" fluxes

Regional Inversion Framework
(Gerbig et al, 2003)



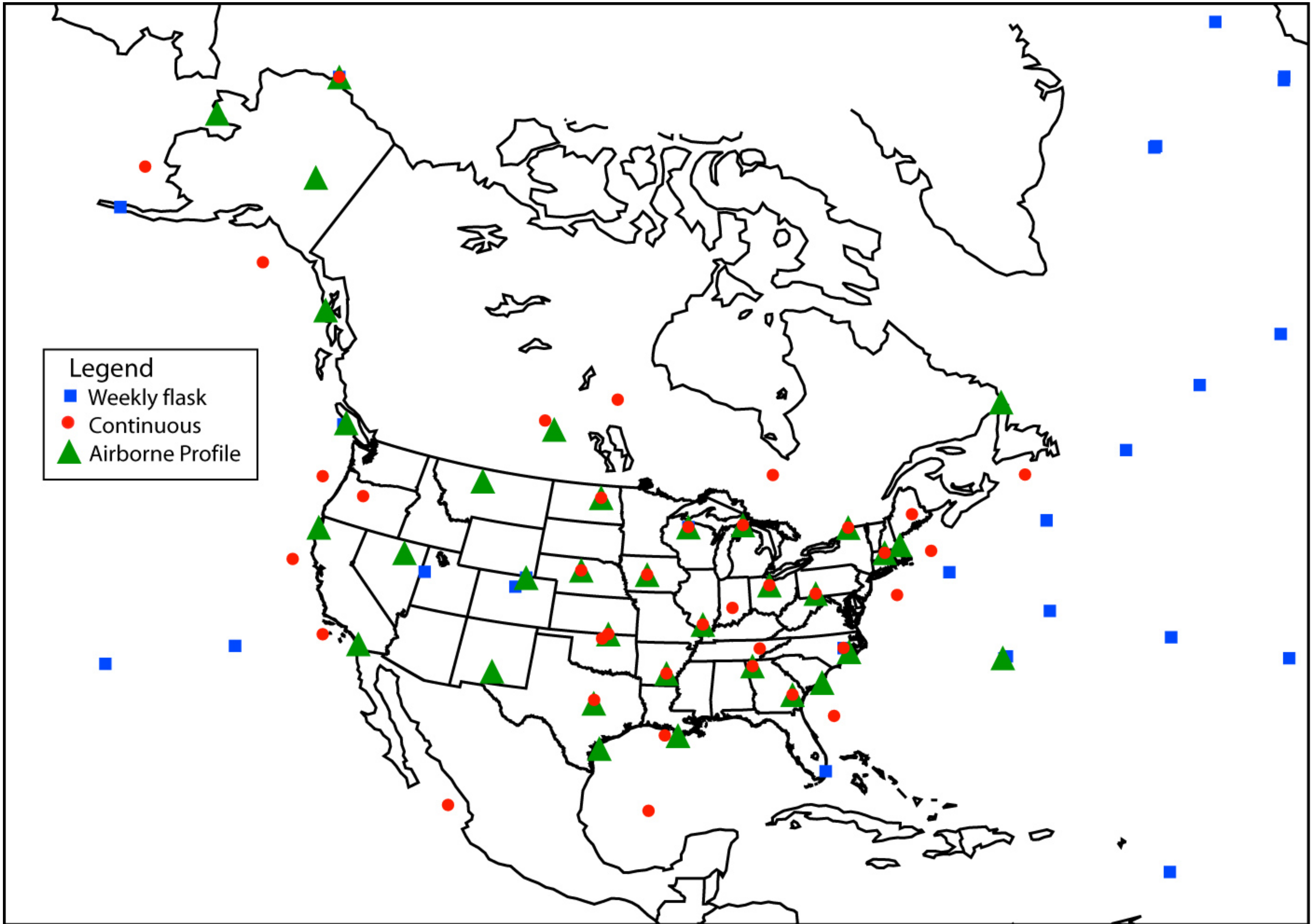
- Light response curve and Q_{10} for ecosystem respiration
- Scaling factors for A and R by biome

COBRA 2000 Flux Estimates



- Big differences from day to day almost entirely related to clouds through light-response curve

NACP Atmospheric [CO_2] Network

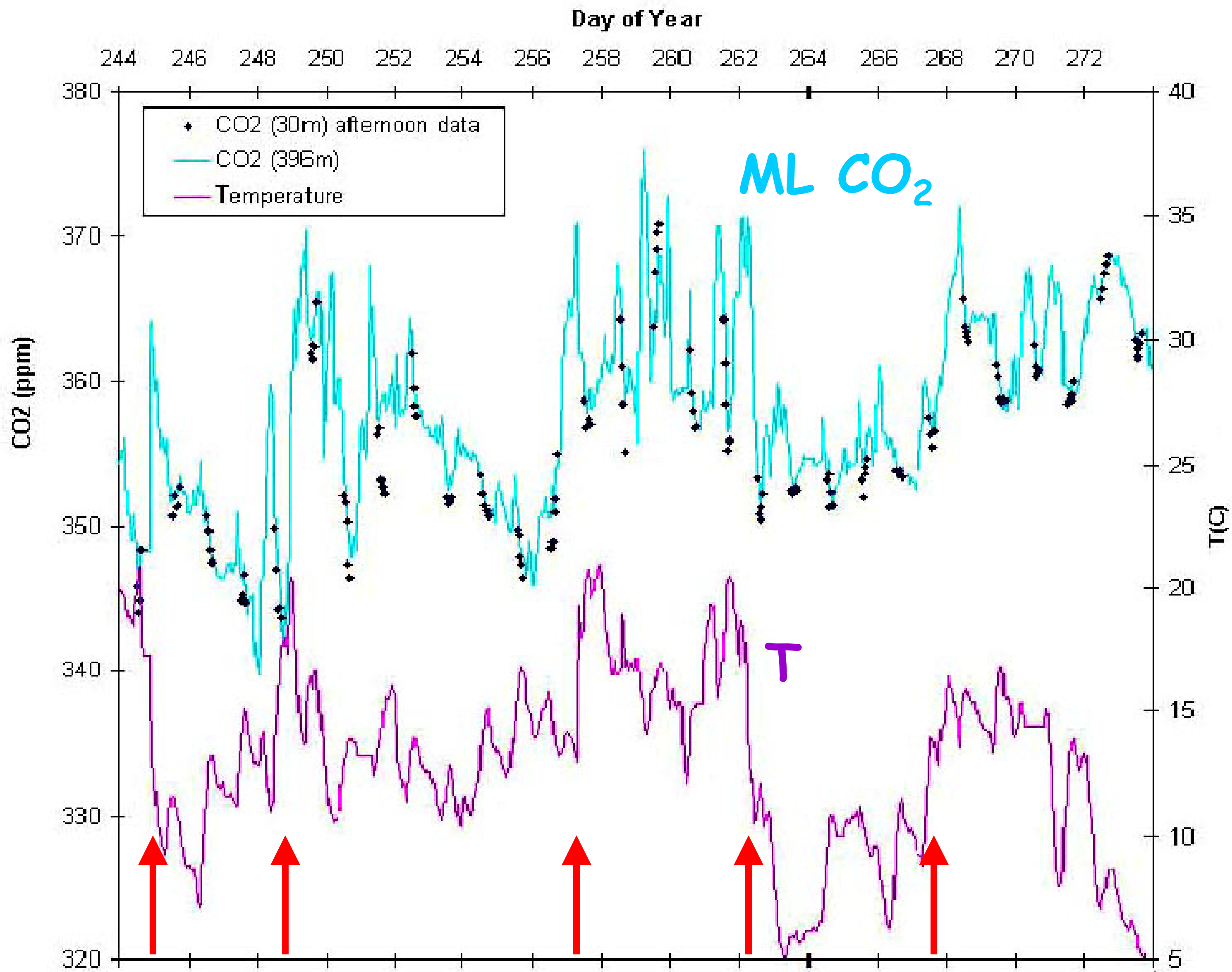


influence function animation:

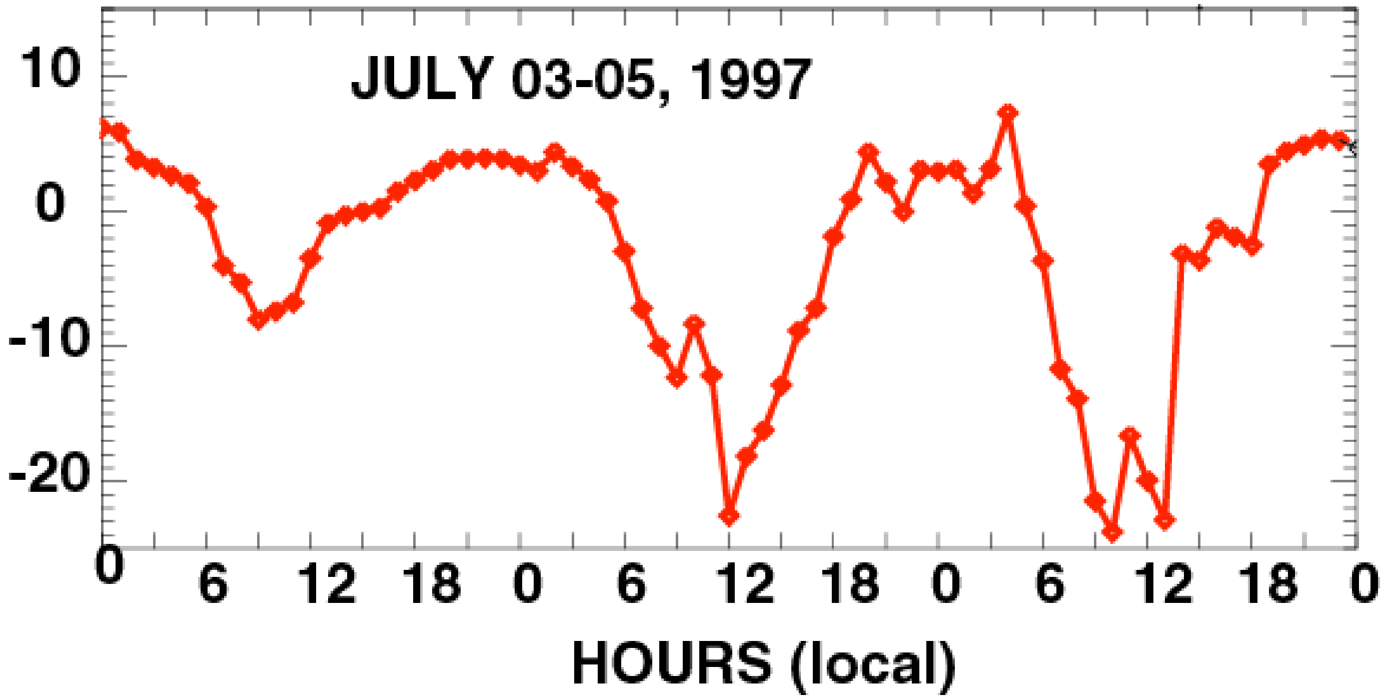
Influence functions for individual samples are tiny!

Need time integration to obtain meaningful constraint

WLEF: September, 1997



Measured NEE of CO_2 (WLEF)



- Coherent diurnal cycles, but …
- Day-to-day variability of ~ factor of 2 due to passing weather disturbances
- How to specify temporal autocorrelation in inversions?

Temporal Decomposition of Fluxes

$$F_C(x,t) = \tilde{R}_e(T_z, w, C_{soil}, \pi_R) - \tilde{A}(PAR, T_c, q, w, \pi_A) + \bar{F}(x)$$

ecosystem respiration (balanced)

net carbon assimilation (balanced)

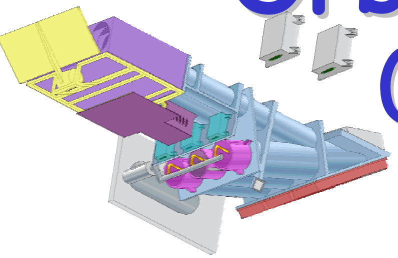
time-mean residual flux

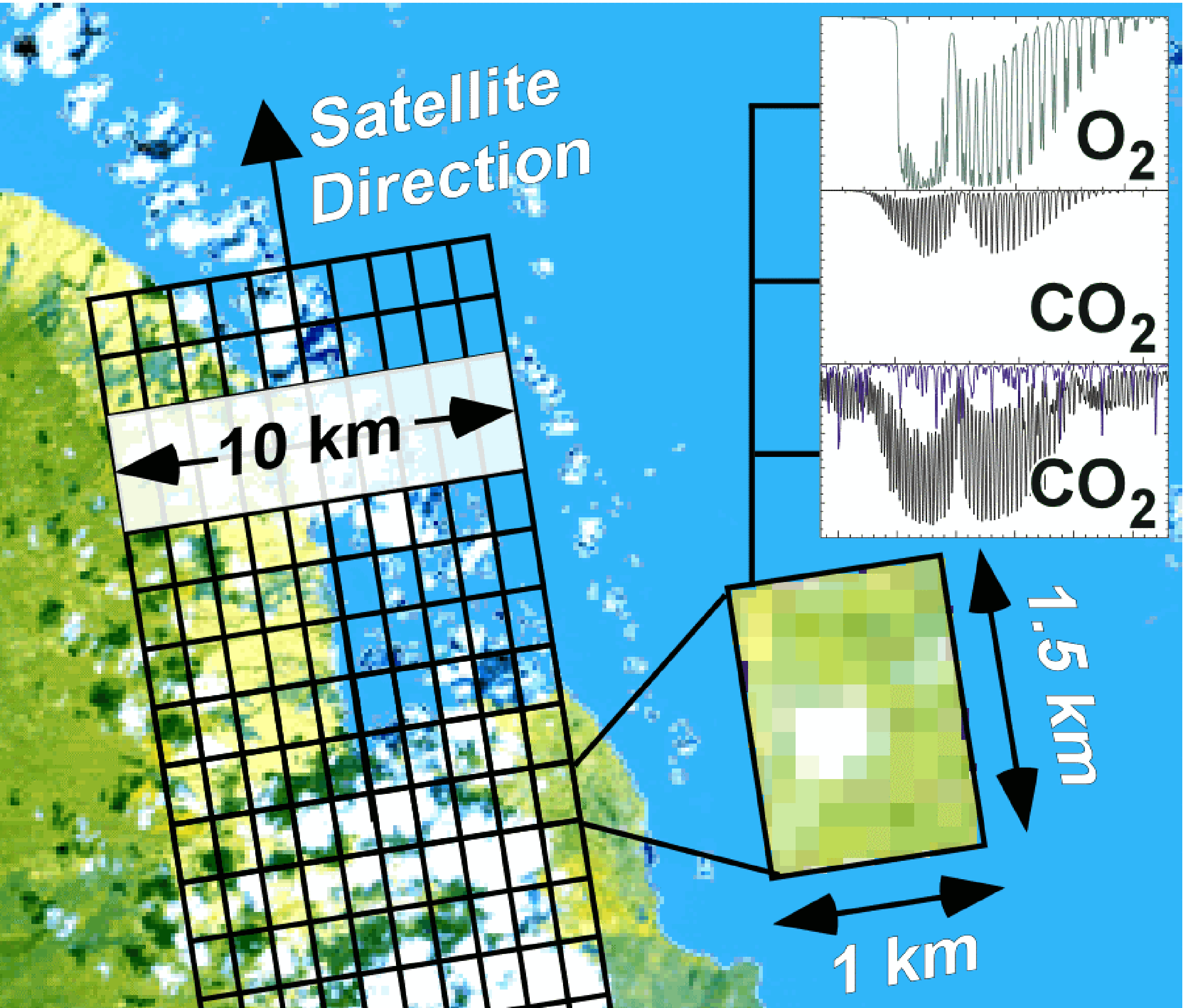
- Impose time-mean balance *("~")* on ***R*** and ***A***
- Determine parameters π_R and π_A from flux towers, remote sensing, etc
- Time-mean flux is due to processes not represented in forward model (people)

Temporal Autocorrelation

- Autocorrelation time scale of NEE is of order hours, not days or weeks (e.g., strongly impacted by diurnal cycle)
- Influence functions ("retroplumes") integrated over these time scales are too small to offer much constraint (i.e., they cover too little area)!
- Approach recommended is to model high frequency variations (diurnal, synoptic) that are reasonably well-understood, after optimizing parameters
- Relevant time scale becomes autocorrelation of $(\tilde{R} - \tilde{A}) - NEE_{obs}$
- Reflects systematic errors in forward flux model, may have autocorrelation time scales of weeks (if we're lucky), allowing influence function to be integrated long enough to provide constraint

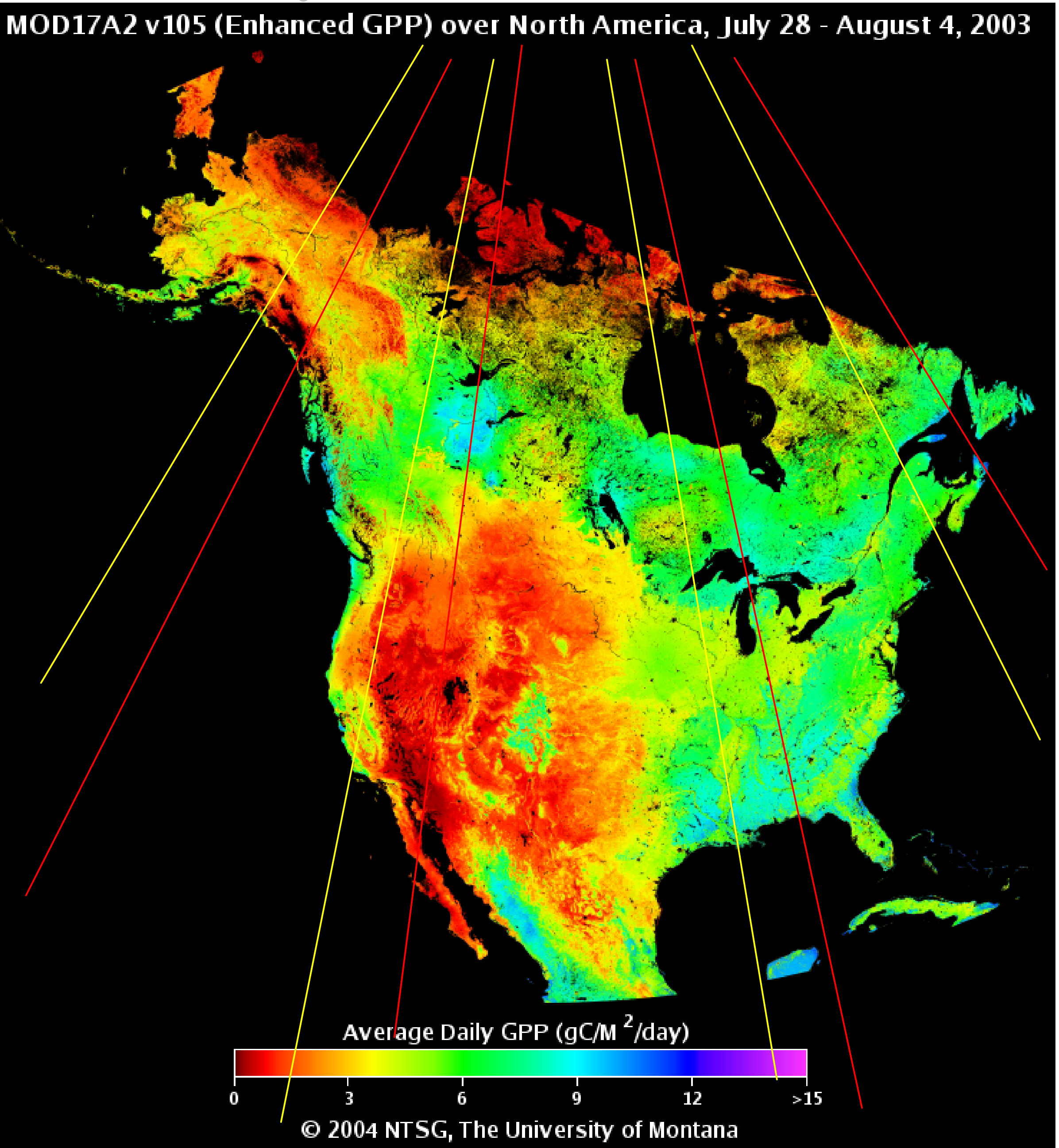
Orbiting Carbon Observatory
(Planned August 2007 launch)





- Estimated accuracy for single column ~1.6 ppmv
- 1 x 1.5 km IFOV
- 10 pixel wide swath
- 105 minute polar orbit
- 26° spacing in longitude between swaths
- 16-day return time

1 Day of North American OCO Data



- Three very narrow (10 km) swaths over N. America per day
- Most of domain will be outside of strongest influence of observations
- Spatial autocorrelation length scale?
- Are tomorrow's fluxes the same?
- How to handle temporal covariance?

Problems w/Meteorological Reanalysis for Transport and Inversion

- NCEP analyses currently ~2.5° at 6 hr intervals
- ERA40 ~1 ° at 6 hr intervals, w/conv mass flux
- Eta analyses higher resolution but limited area
- Lateral boundaries?
- No mass conservation
- Near-surface processes (e.g., PBL turbulence)
- Cloud transports

Needed for inversion of synoptic variations of hourly concentrations

- Heavily data-constrained periodic retrospective mesoscale reanalysis
- High-fidelity surface weather to drive surface source/sink/storage models
- High-fidelity atmospheric transport fields to drive atmospheric trace gas inversions
- High resolution in Δx, Δz, Δt
  (fronts, sea- and lake breezes, topographic flows, convective events, PBL entrainment, SBL)

Custom Met Reanalysis for Transport?

- Once or twice yearly mesoscale assimilation (can't do and do not want real-time)
- High-resolution (Δx~10 km; ~50 levels, many near sfc)
- Strong observational constraint
  - Radiosondes, sfc obs, radars
  - Wind profilers
  - Satellite radiances
  - Surface fluxes to inform surface module (H, LE, u*, NEE) -> light response, Q10, direct/diffuse
- Optimization of transport properties using multiple observational streams
  - Winds, convective mass fluxes, PBL entrainment, SBL
- Hourly archival of sfc wx, resolved and subgrid mass transport
- Cloud-resolving nest in support of IFCs?

Conclusions

- Enhanced observations of atmospheric trace gas mixing ratio under NACP will help to quantitatively constrain area average sources and sinks by regional inversion
  - Continuous tower data, satellite retrievals(?), episodic airborne samping
- Assumptions about temporal and spatial autocorrelations will be crucial for successful inversion, and must be reconciled with data
- Decomposition of total flux into "physiological" and "ecological" time scales may allow longer time average fluxes to be estimated
- Remotely sensed and other spatial data used in terrestrial ecosystem and air-sea flux models will be a central component of this effort
- Dedicated high-resolution meteorological reanalysis for transport diagnostics will likely be required too