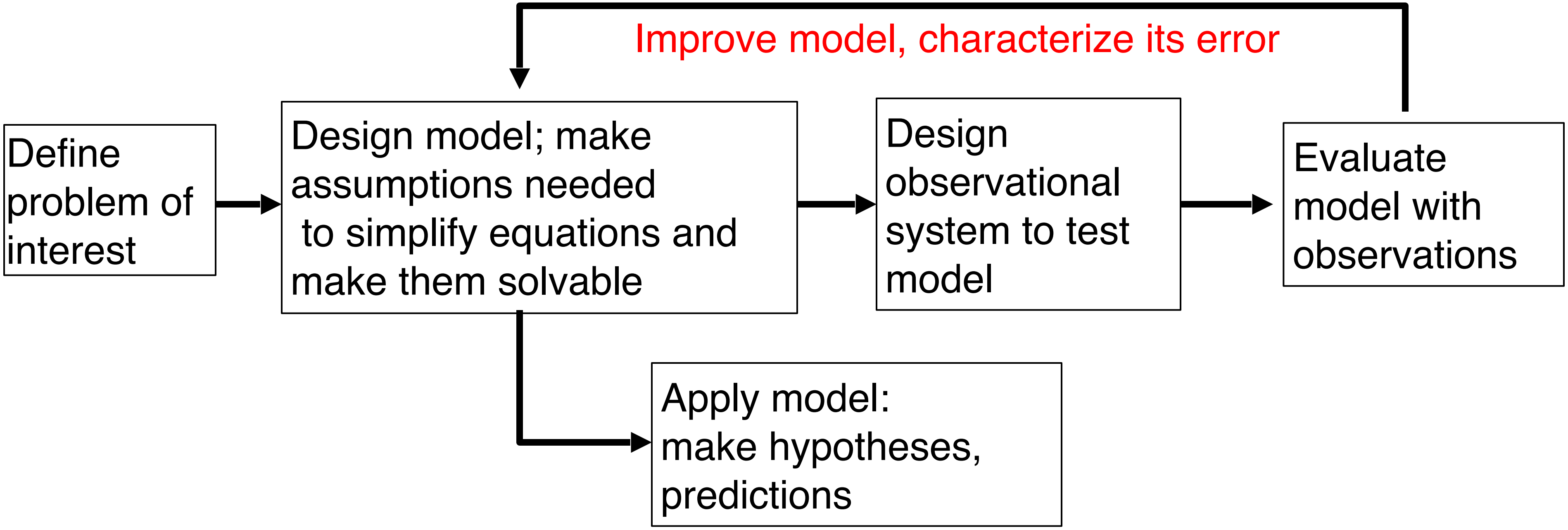
3. Simple models

A model is a simplified representation of a complex system enabling prediction of the system behavior within acceptable error



Improve model, characterize its error

Define problem of interest

Design model; make assumptions needed to simplify equations and make them solvable

Design observational system to test model

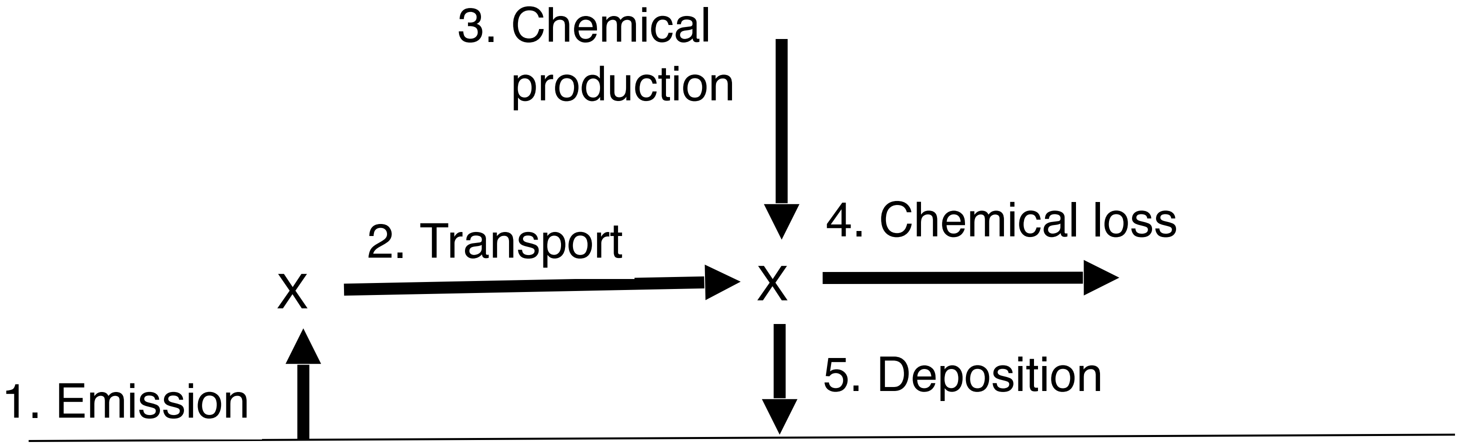
Evaluate model with observations

Apply model: make hypotheses, predictions

"All models are wrong, but some are useful"

Building an atmospheric chemistry model

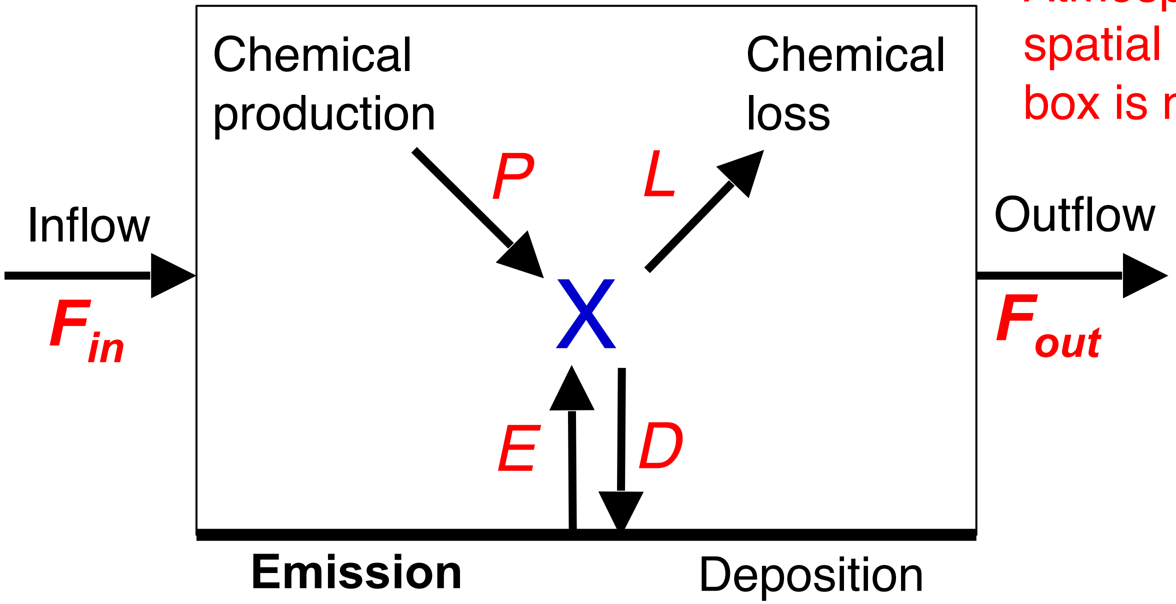
What processes control atmospheric concentrations?



"*What goes up must come down*"…but transport and chemistry can happen in between

One-box model

Atmospheric “box”;
spatial distribution of X within
box is not resolved



Chemical production

Chemical loss

P

L

Inflow

F_{in}

X

Outflow

F_{out}

E

D

Emission

Deposition

Mass balance equation: $$\frac{dm}{dt} = \sum \text{sources} - \sum \text{sinks} = F_{in} + E + P - F_{out} - L - D$$

Atmospheric lifetime: $$\tau = \frac{m}{F_{\text{out}} + L + D}$$

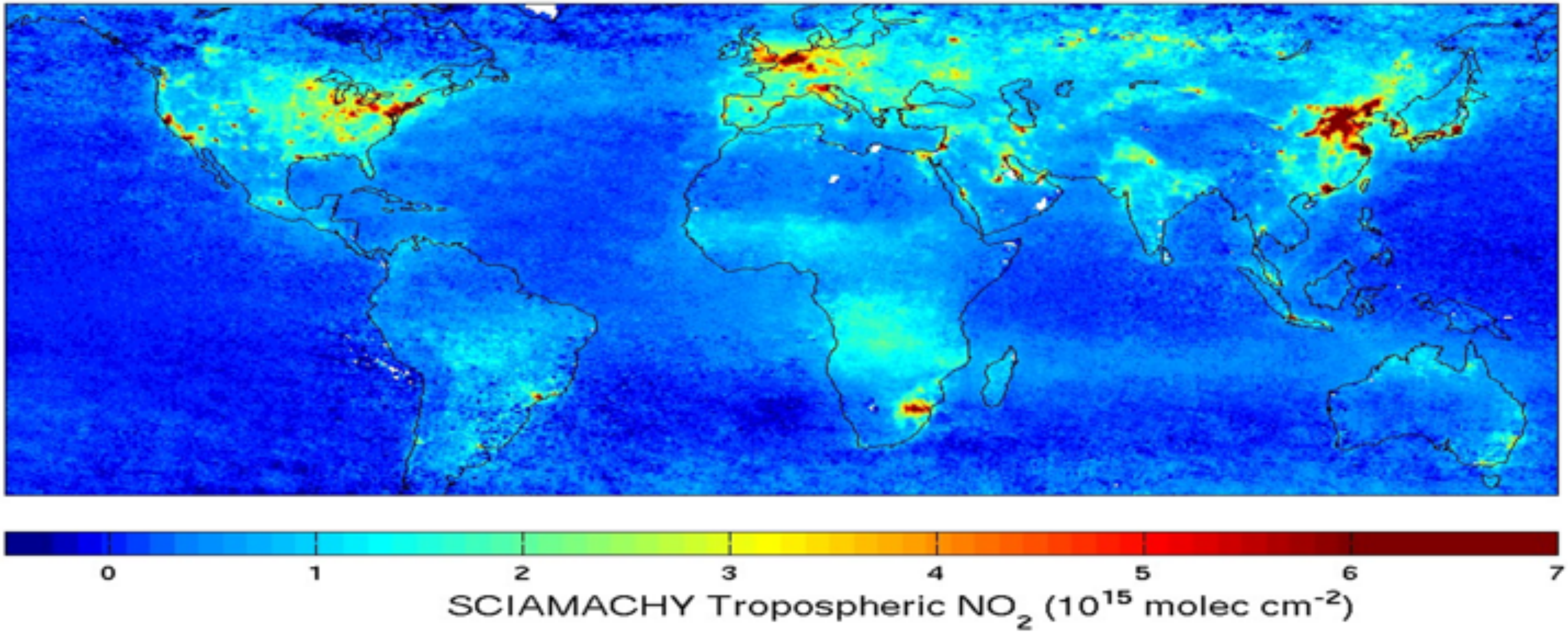
Loss rate constant: $$k = \frac{1}{\tau} = \frac{F_{out} + L + D}{m}$$

Lifetimes add in parallel: $$\frac{1}{\tau} = \frac{F_{out}}{m} + \frac{L}{m} + \frac{D}{m} = \frac{1}{\tau_{\text{out}}} + \frac{1}{\tau_{\text{chem}}} + \frac{1}{\tau_{\text{dep}}}$$

Loss rate constants add in series: $$k = \frac{1}{\tau} = k_{\text{out}} + k_{\text{chem}} + k_{\text{dep}}$$

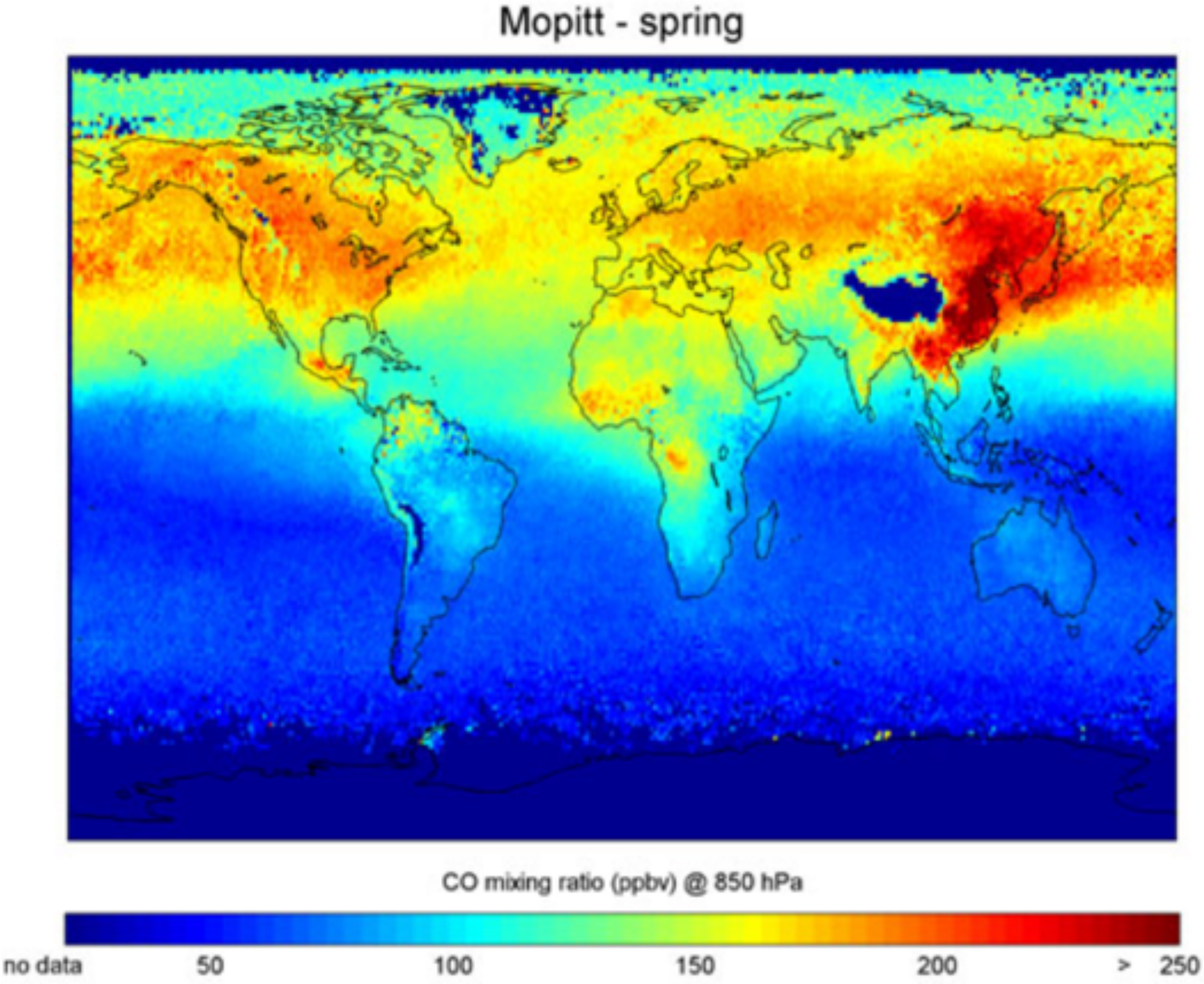
Nitrogen dioxide (NO_2) has atmospheric lifetime ~ 1 day: strong gradients away from combustion source regions

Satellite observations of NO_2 columns



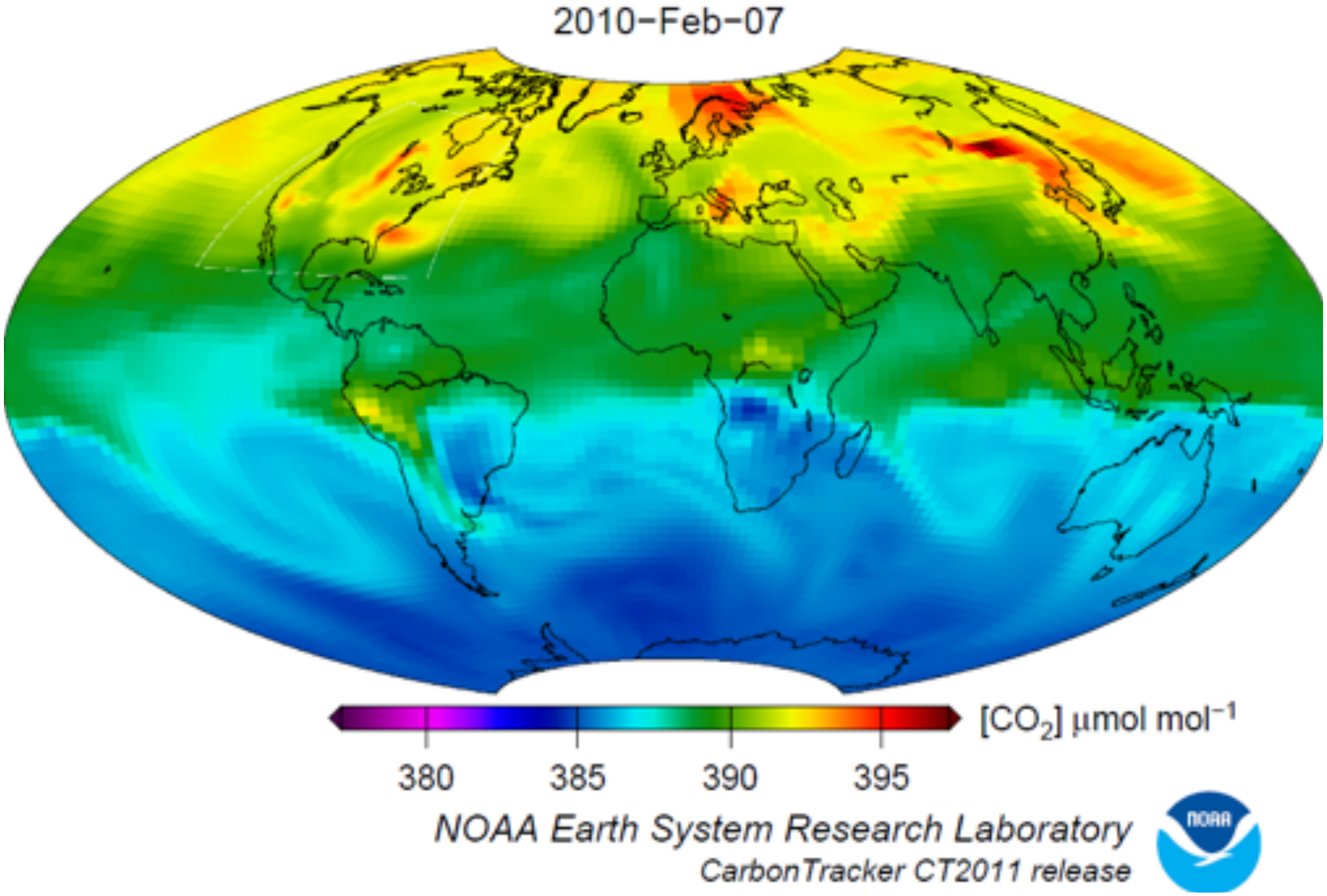
Carbon monoxide (CO) has atmospheric lifetime ~ 2 months: mixing around latitude bands

Satellite observations

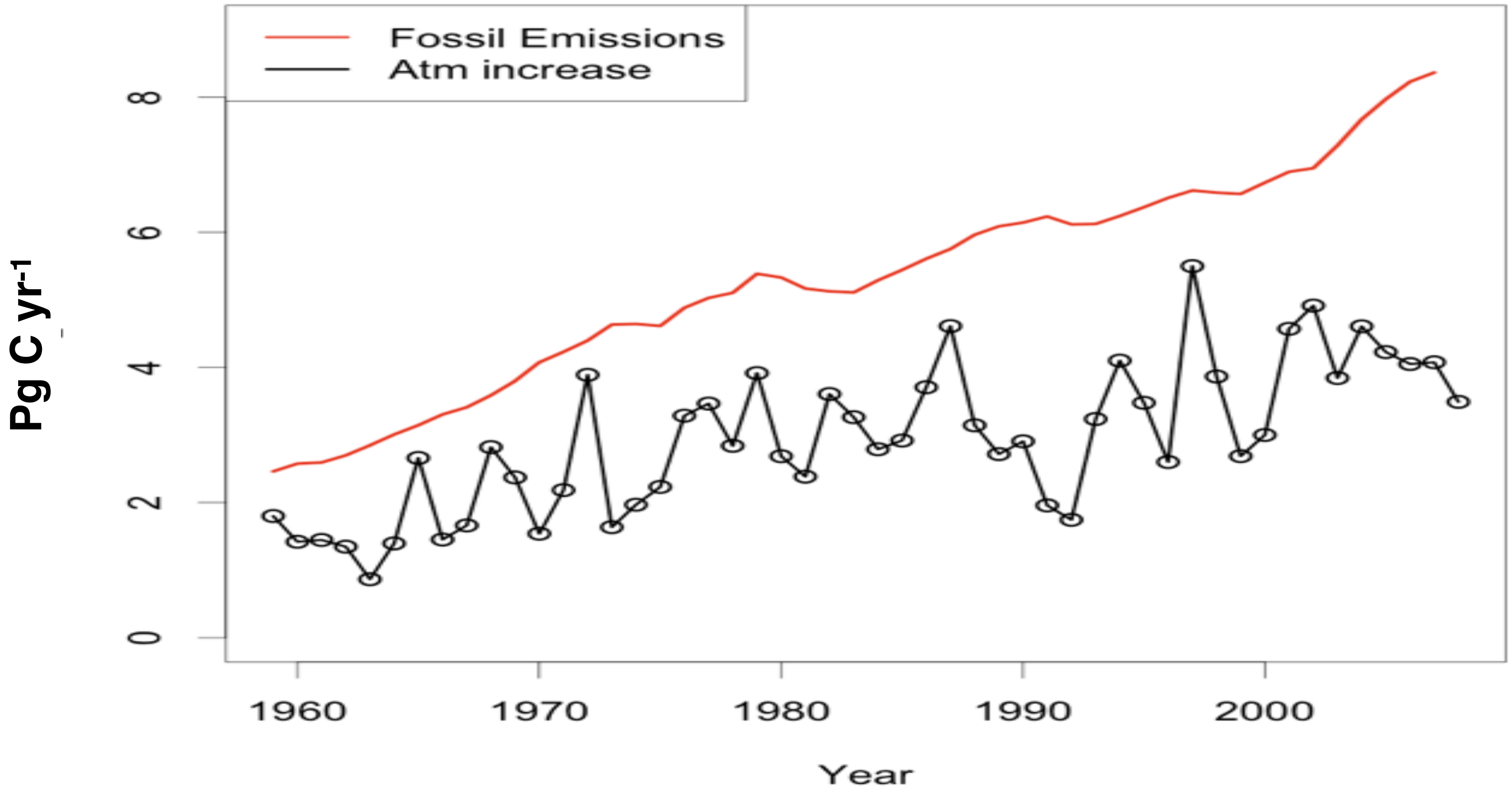


CO_2 has atmospheric lifetime ~ 100 years: global mixing

Assimilated observations



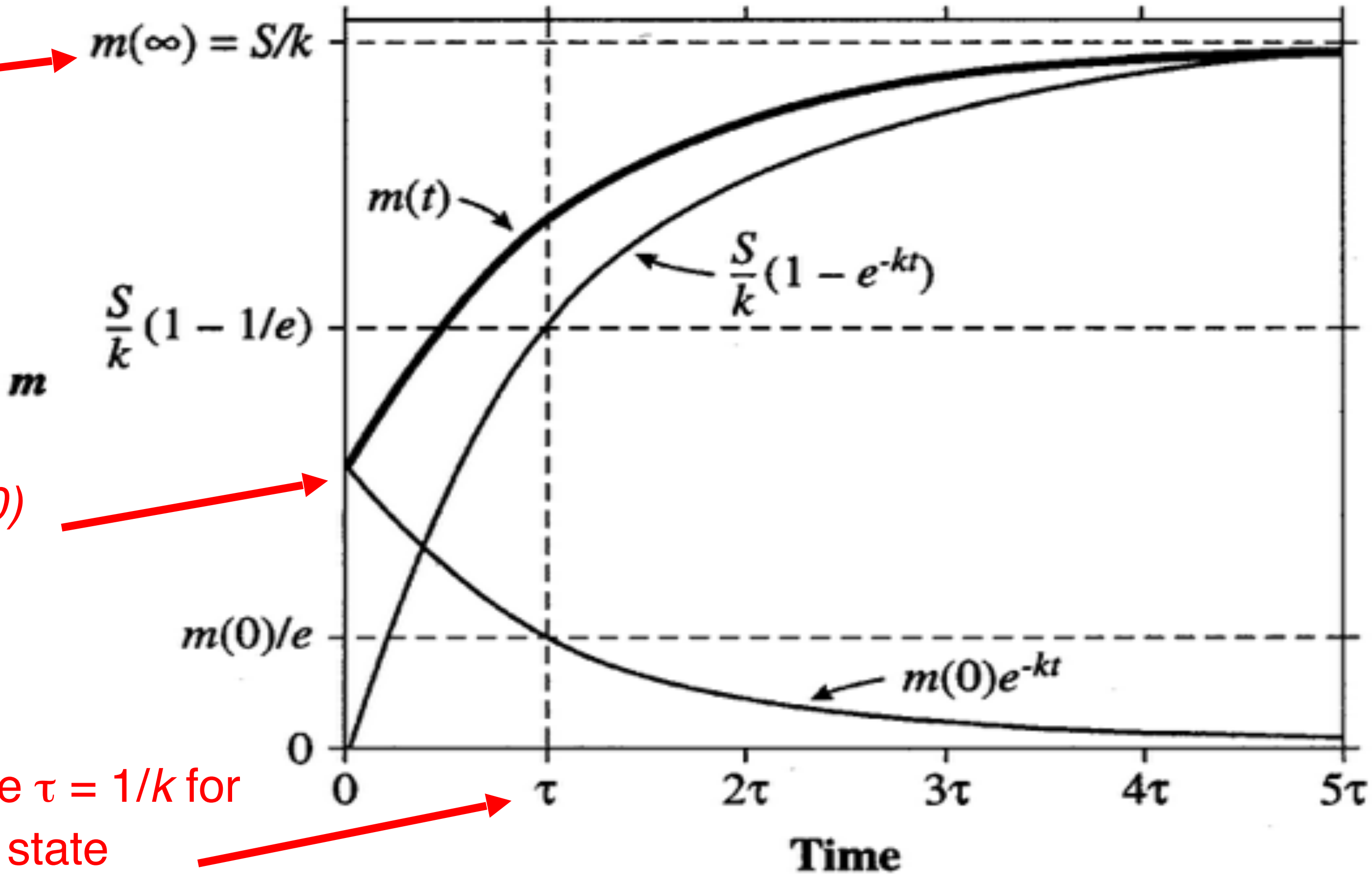
Using a box model to quantify CO_2 sinks



On average, only 60% of emitted CO_2 remains in the atmosphere – but there is large interannual variability in this fraction

Special case: constant source, first-order sink

$$\frac{dm}{dt} = S - km \quad \Rightarrow \quad m(t) = m(0)e^{-kt} + \frac{S}{k}(1 - e^{-kt})$$



Steady state solution (*dm/dt = 0)*

Initial condition *m(0)*

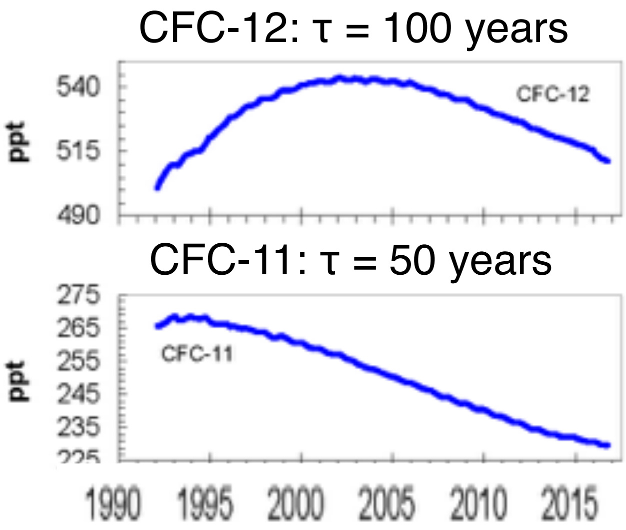
Characteristic time τ = 1/*k* for

- reaching steady state
- decay of initial condition

If *S, k* are constant over *t* >> τ, then *dm/dt* → 0 and *m*→ *S/k:* quasi steady state

Questions

1. The Montreal Protocol to protect the ozone layer banned worldwide production of the chlorofluorocarbon CFC-12 in 1996. CFC-12 is removed from the atmosphere by photolysis with a lifetime of 100 years. How long will it take for CFC-12 concentrations to drop to half of present-day values?



CFC-12: τ = 100 years

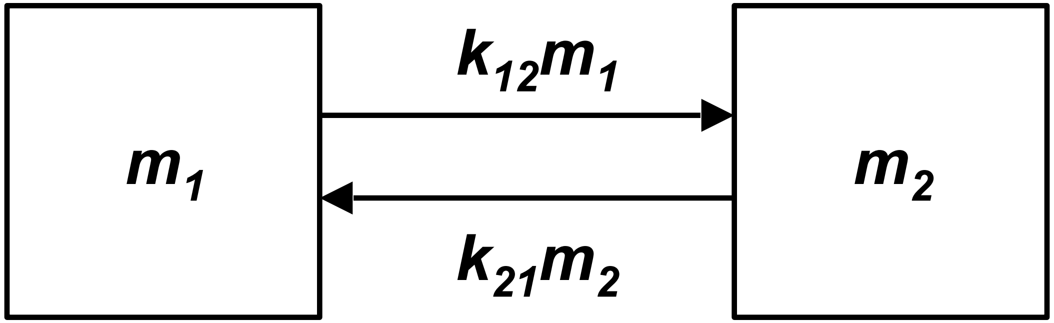
CFC-11: τ = 50 years

Global mean atmospheric CFC concentrations (NOAA ESRL data)

2. Consider a pollutant emitted in an urban airshed of 100 km dimension. The pollutant can be removed from the airshed by oxidation, precipitation scavenging, or export. The lifetime against oxidation is 1 day. It rains once a week. The wind is 20 km/h. Which is the dominant pathway for removal?

TWO-BOX MODEL

defines spatial variation between two domains



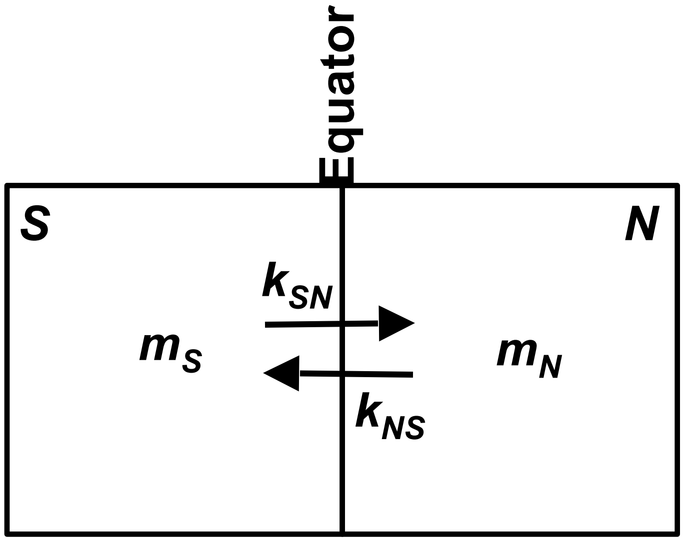
Mass balance equation:

$$\frac{dm_1}{dt} = E_1 + P_1 - L_1 - D_1 - k_{12}m_1 + k_{21}m_2$$

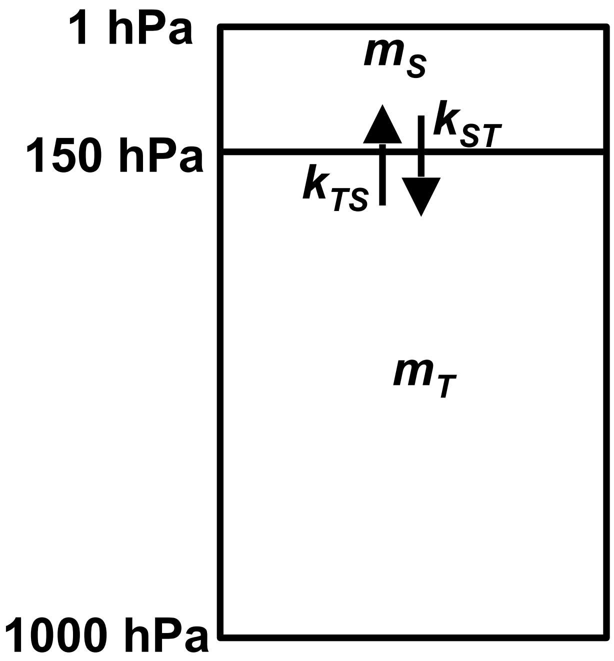
(similar equation for *dm_2/dt*)

⇨ system of two coupled ordinary differential equations
(or algebraic equations if system is assumed to be at steady state)

Applications of 2-box model

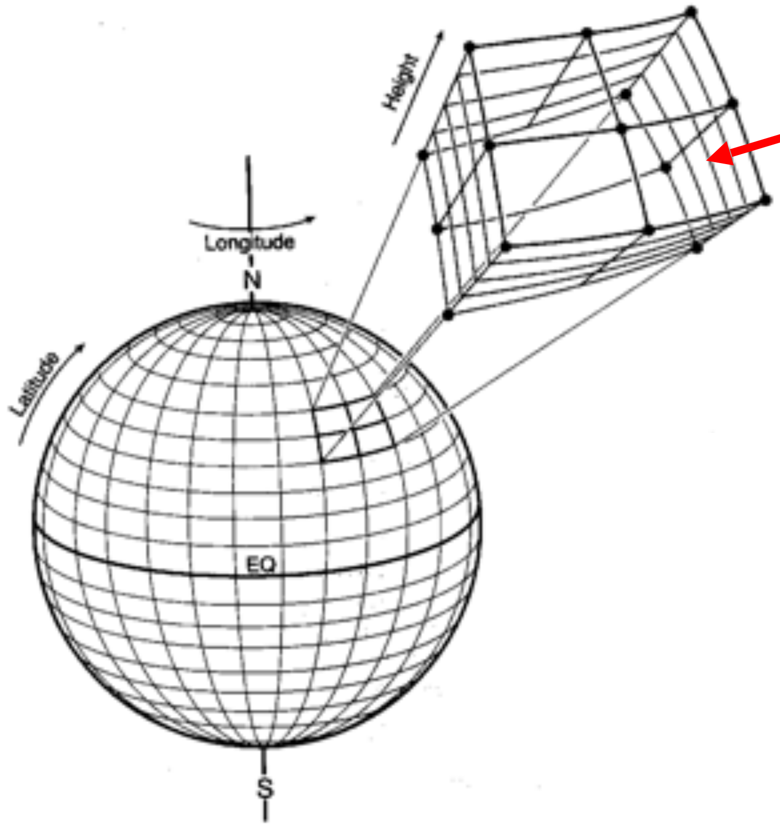


Interhemispheric exchange



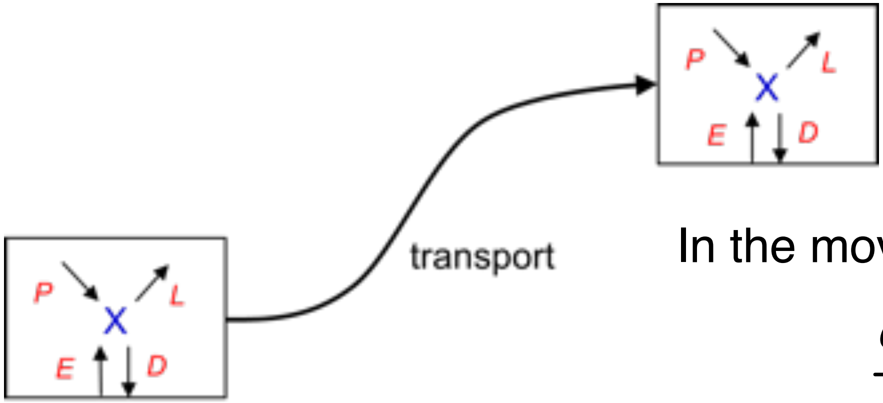
Stratosphere-troposphere exchange

Research models solve mass balance equation in 3-D assemblage of gridboxes



Solve mass balance equation for individual gridboxes

A different approach: follow air parcel moving with the wind (puff model)

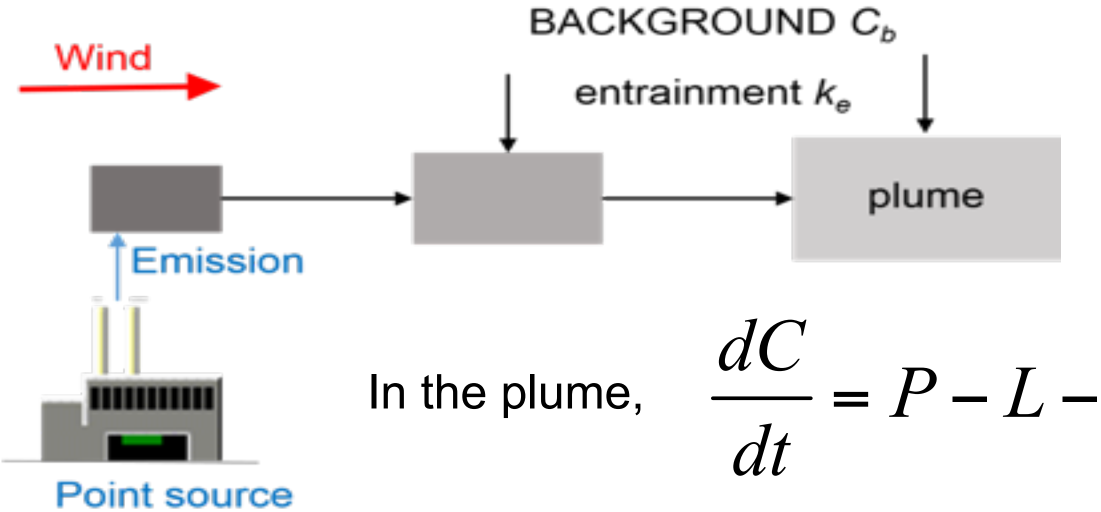


In the moving puff,

$$\frac{dC_X}{dt} = E + P - L - D$$

…no transport terms! (they're implicit in the trajectory)

Application to a diluting pollution plume:

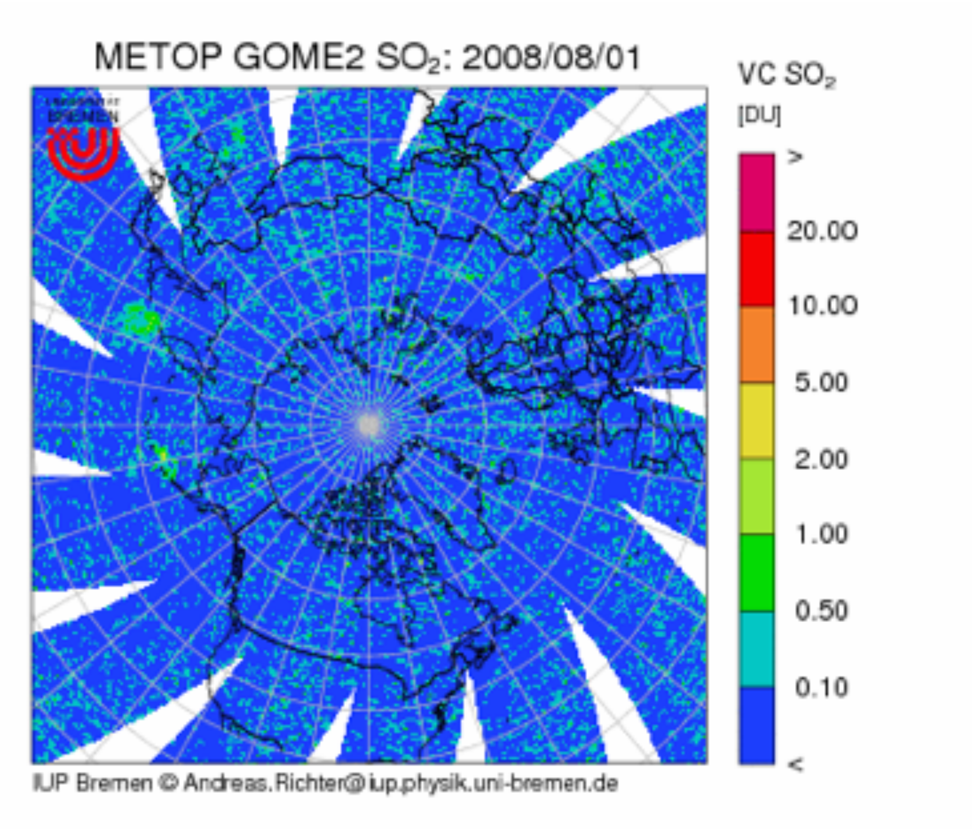


In the plume, $$\frac{dC}{dt} = P - L - k_e(C - C_b)$$

Application: transport and evolution of fire plumes

Fire plumes over southern California

Sulfur dioxide (SO_2) from Aleutian volcano eruption (8/8/2008)


METOP GOME2 SO_2: 2008/08/01

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http://www.avo.alaska.edu/

Kasatochi volcano

Altitude: 314 m
Latitude: 52.16°N
Longitude: 175.51° W