Very nice, but …
it works well ?

- Models include a large number of parametrization of complex processes
- We are often interested to problems that involve a large number of processes
- And results are sensitive to (a lot) of them
- How to improve them ?
    - Observations are the key
    - An example using a simple assimilation scheme

Mesoscale systems in West Africa

MSG

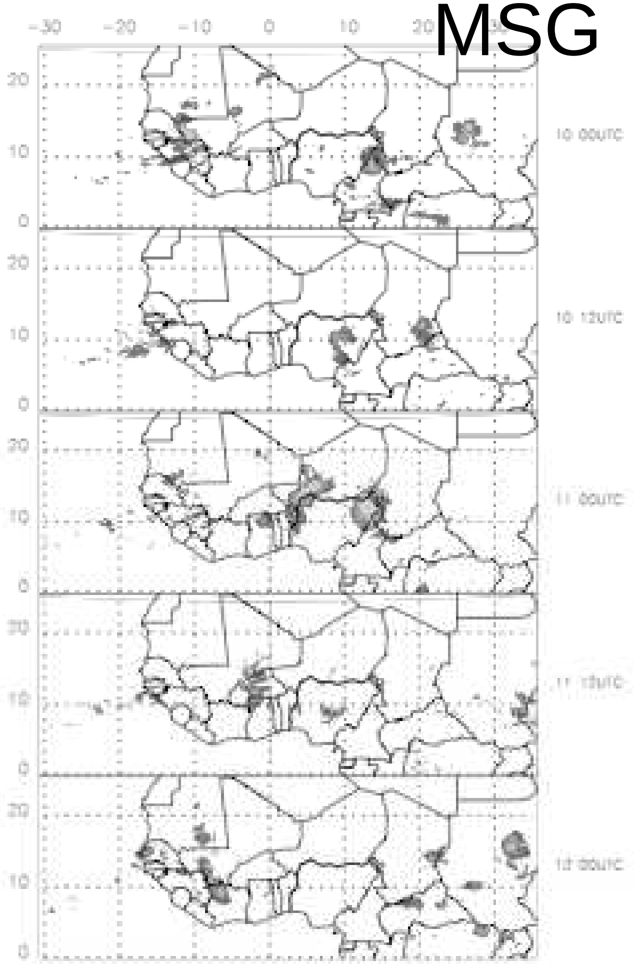
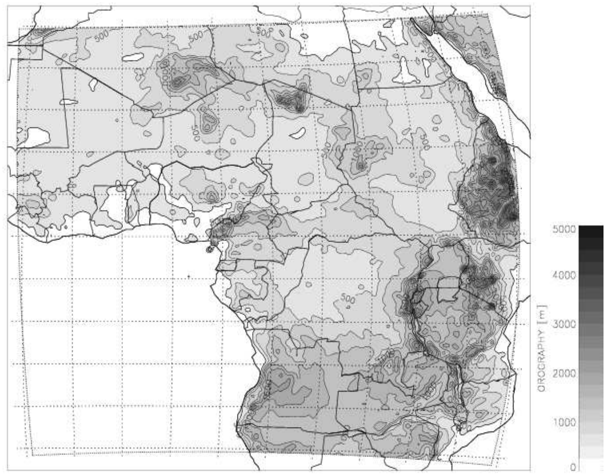
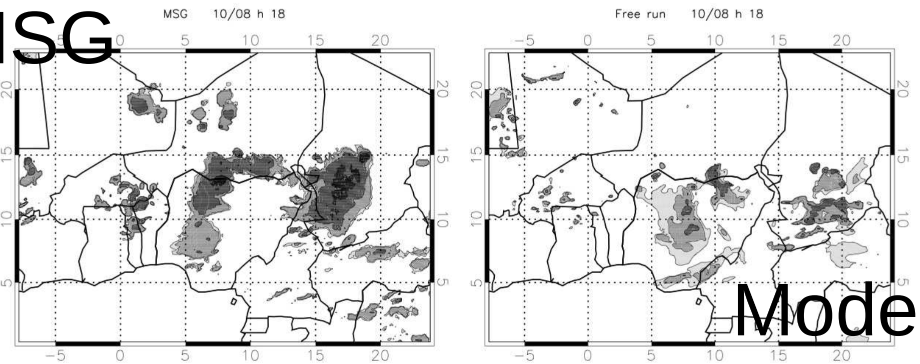


Figure 1. Meteosat cloud top temperature from 00 UTC 10 Aug. to 00 UTC 12 Aug. 2006, every 12 hours. Colour scale in K.



MSG



Model

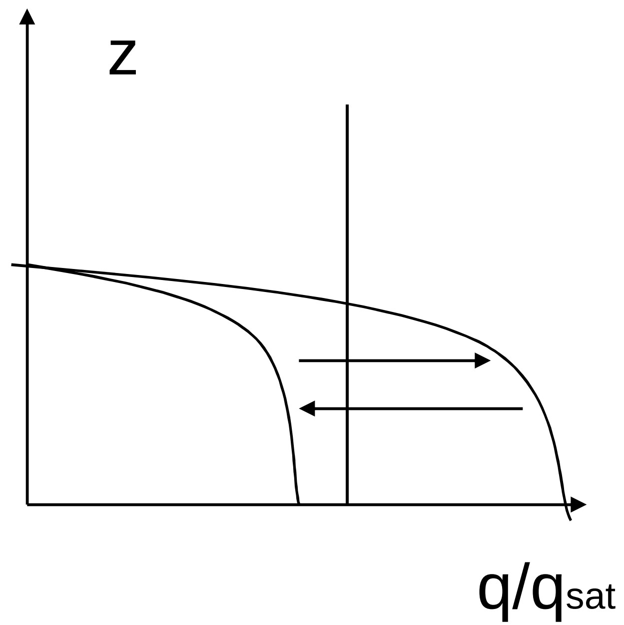
Orlandi et al., QJRMS (?), 2009

A simple scheme to force the model: nudging on water vapour

Nudging scheme

The variation due to the nudging procedure on model moisture profile is:

$$\delta q(k) = -\nu(k)\, .\tau^{-1}\ [\, q(k) - \varepsilon q^{sat}(k)]\, \delta t$$



where $\nu(k)$ is the vertical modulation profile

τ^{-1} is a constant relaxation time

$q^{sat}(k)$ is the saturation humidity profile

ε is the over/under saturation coefficient

Which observations ?

Should be dense enough to force the model in a “proper” way

Avoid instabilities

Have a non-negligible impact ---> satellite

Use precipitation (Kalnay et al, 1997)

Use radiance temperatures (less derived variable)

```
if Trad_obs < Tcloud then
        if Trad_model <  Trad_obs then dq > 0
else
        if Trad_model < Trad_obs then dq > 0
endelse
```

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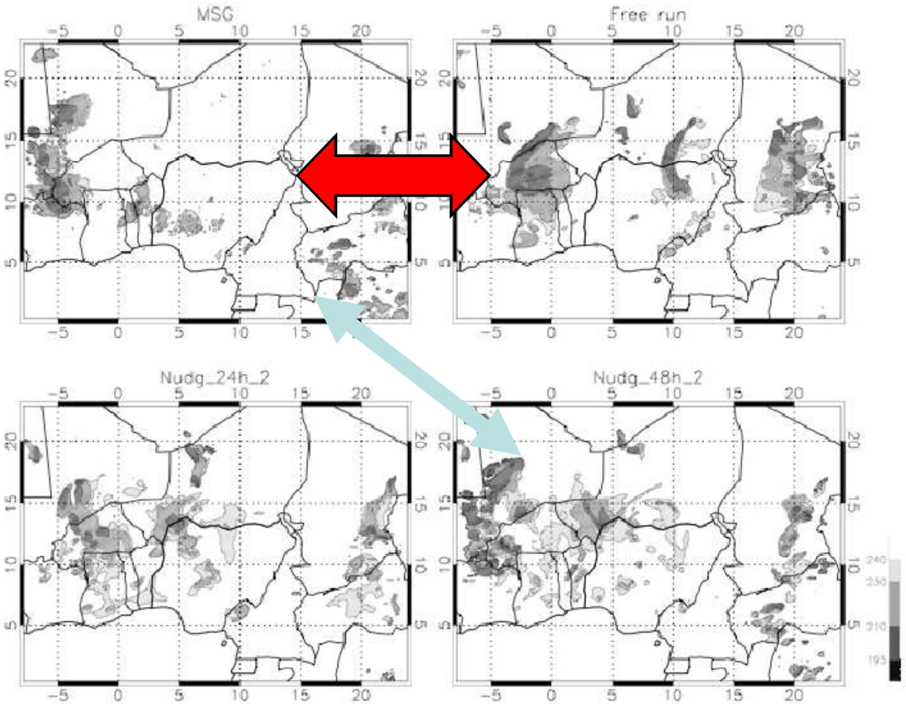
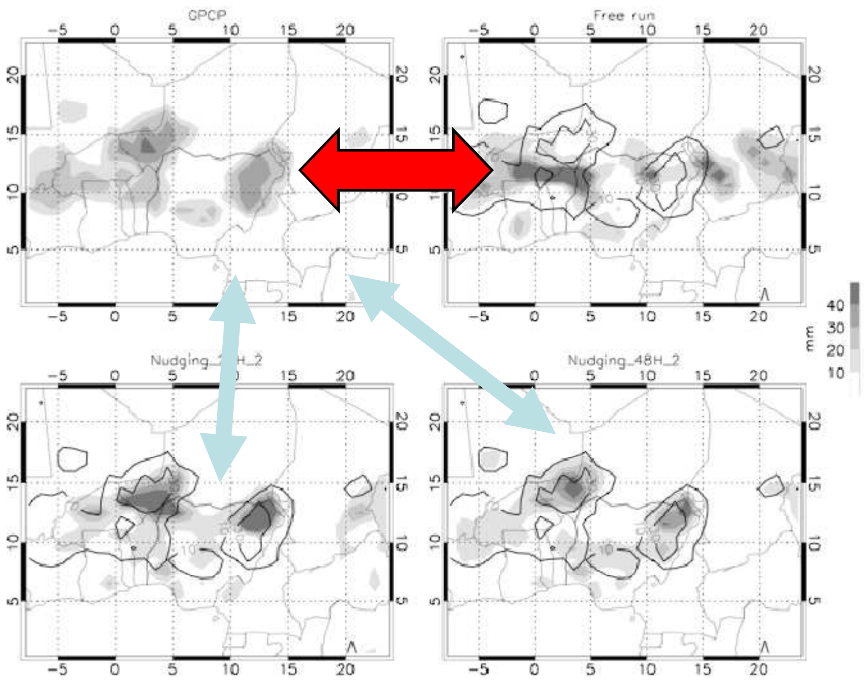
At each timestep … this is a sequential approach

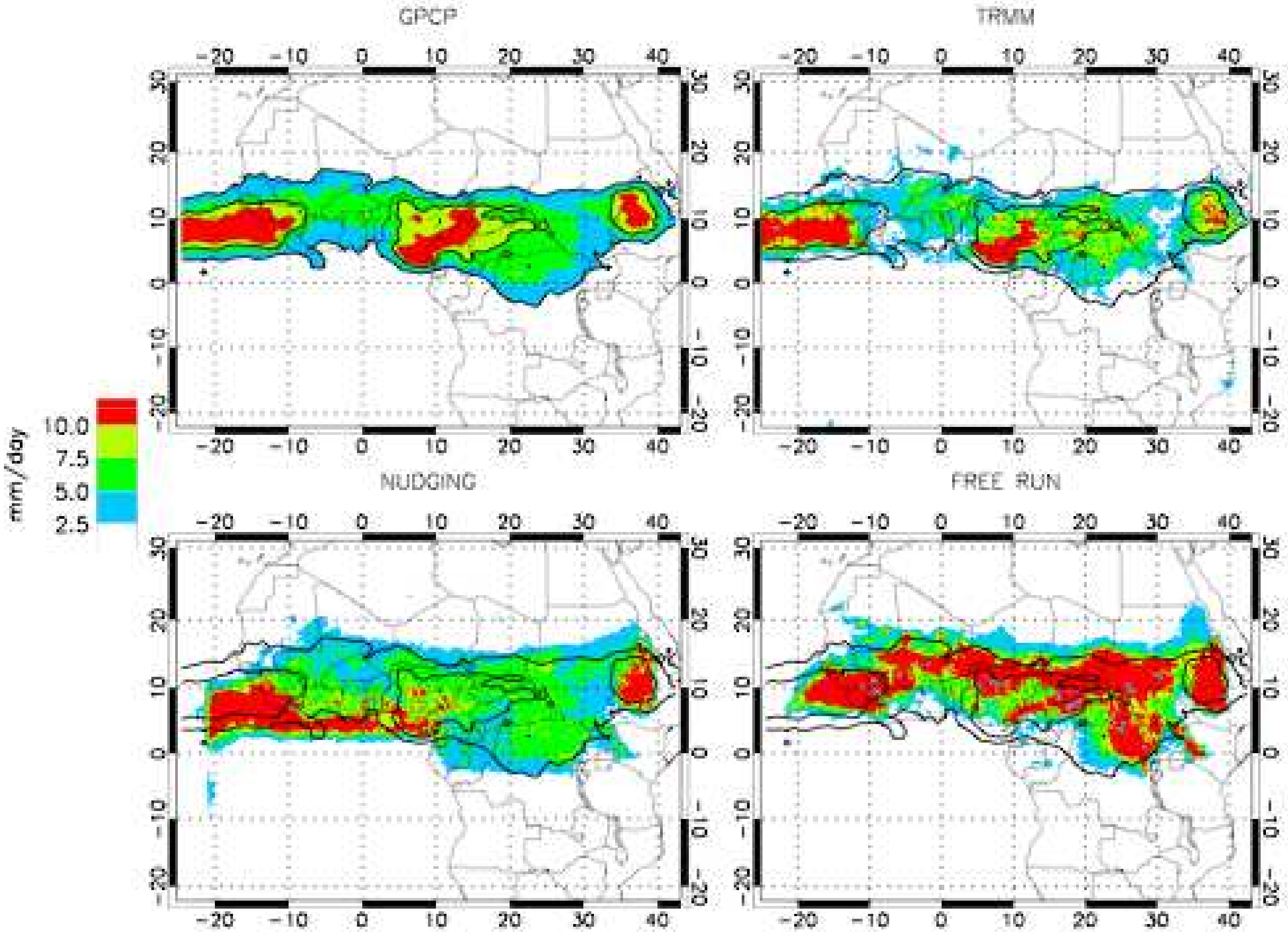


Improves radiance Temperature (seems straightforward but no obvious)



Improves precipitation (less straightforward)

Nudging improves precipitation over longer timescales
4-months simulation



More and more complex

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- P & L related to transport
  - Advection, Convective re-adjustment, Ground fluxes
- Address chemical processes …

Chemistry Transport models

Going towards interactive chemistry:

Aerosol and chemicals determines radiative budget

Aerosol influences microphysics

More and more complex… chemistry

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Concept of lifetime

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Transport lifetime

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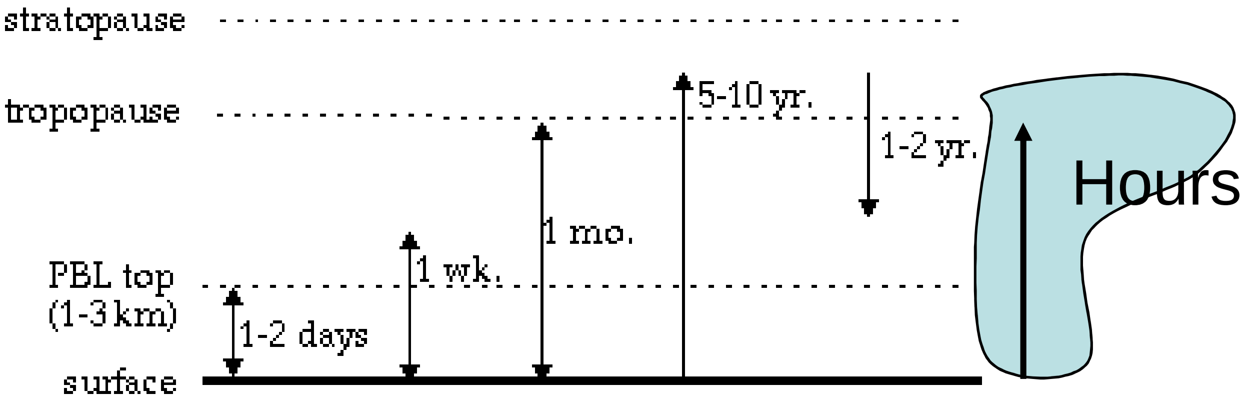
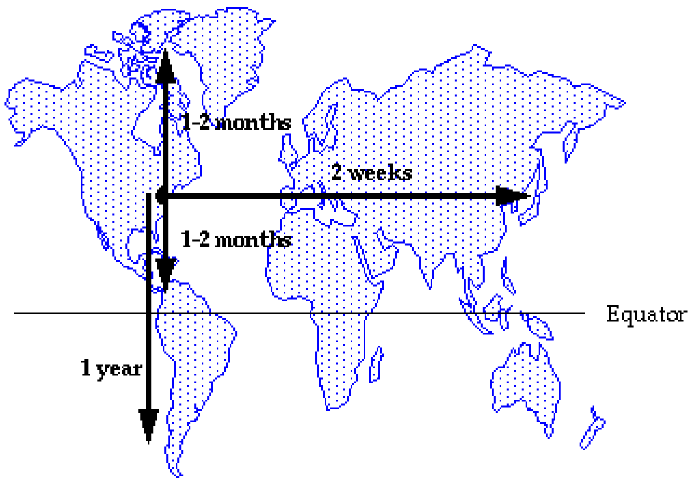
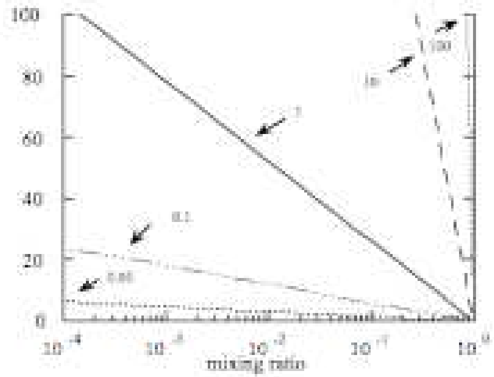




Chemical vs. transport lifetime



•When the chemical lifetime is 100 times larger than the dynamical lifetime, materials will have an almost con mixing ratio to nearly 1 altitude.

• However, when the ch lifetime is 1% of the dynamical lifetime the r ratio falls very rapidly i troposphere.

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Lifetimes of some interesting materials

Material	M, Abundance (Tg)	P, Source (Tg/yr)	t, Lifetime (yr)
H_2O	$1.3x10^7$	$5x10^8$	0.025
CH_4	$5x10^3$	515	10
COS	5.2	1.2	4.3
SO_2	0.6-0.9	200	.003-.005
N_2O	$2.5x10^3$	12-21	120
CFC-11	6.2	0.25	50
CFC-12	10.3	0.37	102
CH_3Cl	5	3.5	1.5
NaCl	3.8	1300	0.003

From Toon et al.

A+B --> C+D

dC/dt=k[A][B]

100 species / 200 reactions

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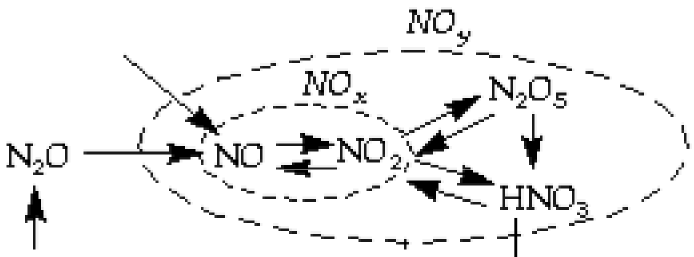

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NOx

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What a coupled model looks like ?

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$OH + CO \rightarrow H + CO_2$ (1)
$H + O_2 + M \rightarrow HO_2 + M$ (2)
$HO_2 + NO \rightarrow NO_2 + OH$ (3)
$NO_2 + \text{sunlight} \rightarrow NO + O$ (4)
$O + O_2 + M \rightarrow O_3 + M$ (5)
Net: $CO + 2\,O_2 \rightarrow CO_2 + O_3$

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Importance of sources
Emissions
There is a important uncertainty
See Geia database (global)
http://www.geiacenter.org
Emep http://www.ceip.at/

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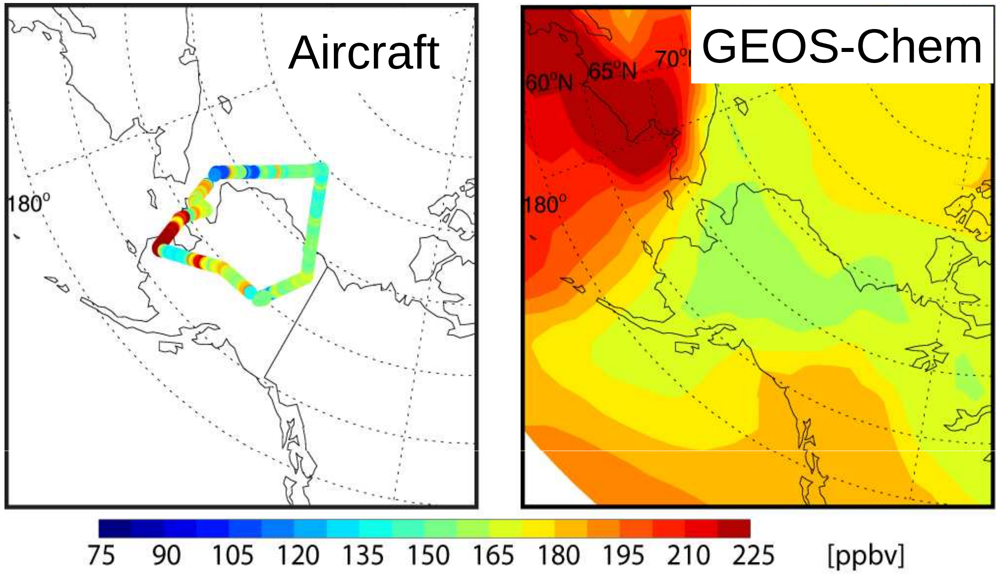
Geos-Chem model / D. Jacob Harvard

INTEGRATING SATELLITE, AIRCRAFT, AND MODEL INFORMATION TO BETTER UNDERSTAND SOURCES OF ARCTIC POLLUTION

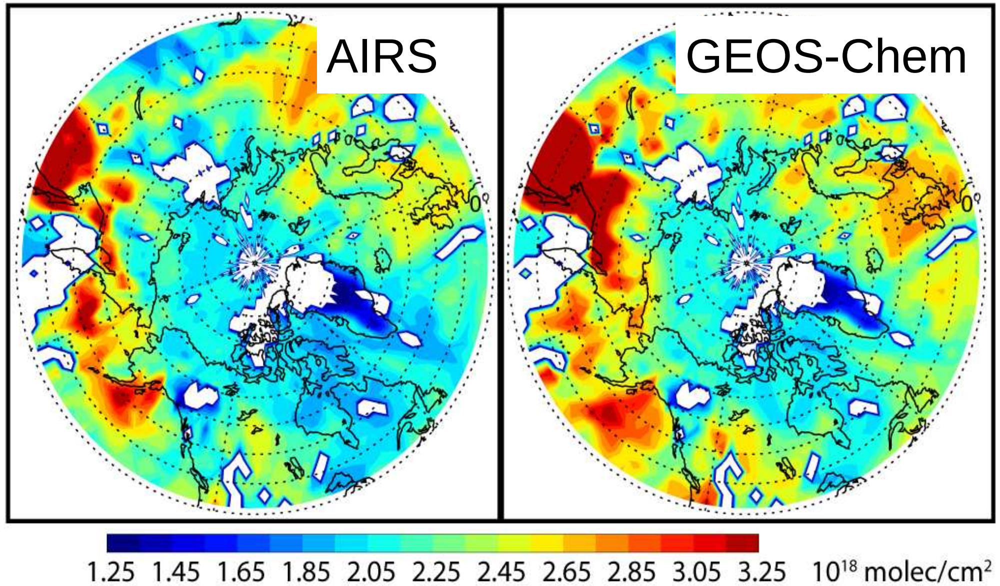
Asian plume transported to Arctic in warm conveyor belt on April 16, 2008

Aircraft CO data at 4-6 km (500 hPa) compared to GEOS-Chem chemical transport model



***Satellites** provide global continuous observations;*
***Aircraft** provide satellite validation, complementary species, local process information;*
***Models** provide link between aircraft and satellite, platform for understanding and prediction*

AIRS satellite data for CO at 500 hPa compared to GEOS-Chem with averaging kernels



J.A. Fisher [Harvard], G. Diskin [LaRC], J. Warner [UMBC], D Jacob [Harvard]

Transport: Lagrangian

Transition probability density

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Q is difficult to estimate ---> use wind field U

Assumptions about Trajectory Transport

Parcels have no inertia (m = 0)

Parcels have no size yet “represent” their surroundings

Parcels don’t know about each other except when some kind of explicit mixing is included

$$\frac{dX}{dt} = \dot{X}[X(t)] \qquad X^1(t_1) \approx X(t_0) + \frac{1}{2}(\Delta t)[X(t_0) + X(t_1)]$$

The “constant acceleration” solution

Neglects higher order terms in the Taylor series expansion of the first equation (source of truncation errors)

- time resolution of wind fields, interpolation errors, vertical wind issues, wind field errors, tropospheric process errors

Stohl A., Computation, Accuracy and Applications of Trajectories - A Review and Bibliography, *Atmospheric Environment*, *32*, 947-966, 1998.

A simple example of parametrization

Stohl

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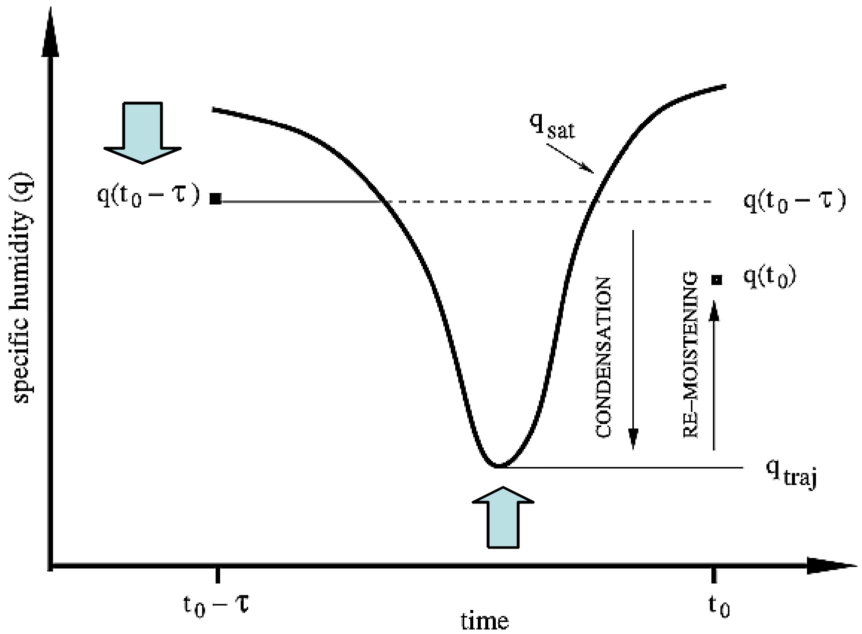


A simple approach:
Min(q_{sat}) trajectories

- **Assuming no mixing or condensation, q is conserved along the trajectory**

-**The value q(t0 − τ) of specific humidity analyzed at their origin is assigned to them**

- **If along the trajectory q(t0 − τ) > q_{sat}**
(min(q_{sat})) is assigned to it (q_{traj})

Estimate of water cycle using lagrangian approach

$$E - P \approx \frac{\sum_{k=1}^{K} (e - p)}{A} \qquad (2)$$

is equivalent to the Eulerian budget equation

$$E - P = \frac{\partial w}{\partial t} + \nabla \cdot \frac{1}{g} \int_0^{p_s} q\mathbf{v}\, dp, \qquad (3)$$

DECEMBER 2005 STOHL AND JAMES 965

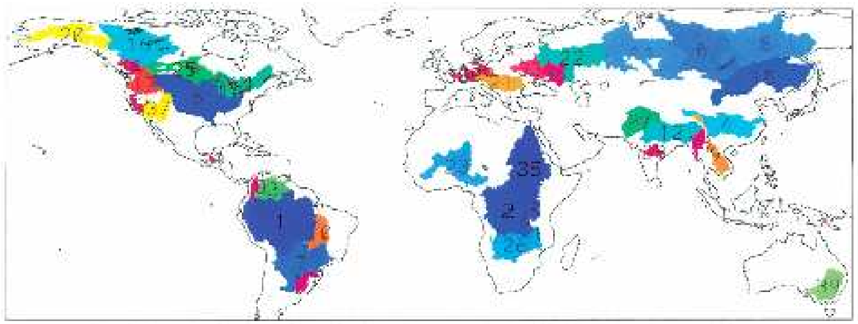


FIG. 2. Map of the river basins investigated. Basins are numbered as in Table 2; the colors are arbitrary.

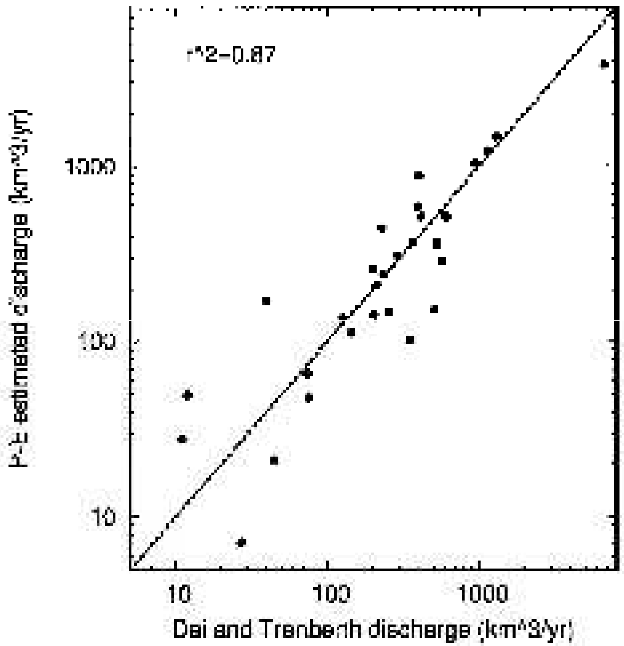
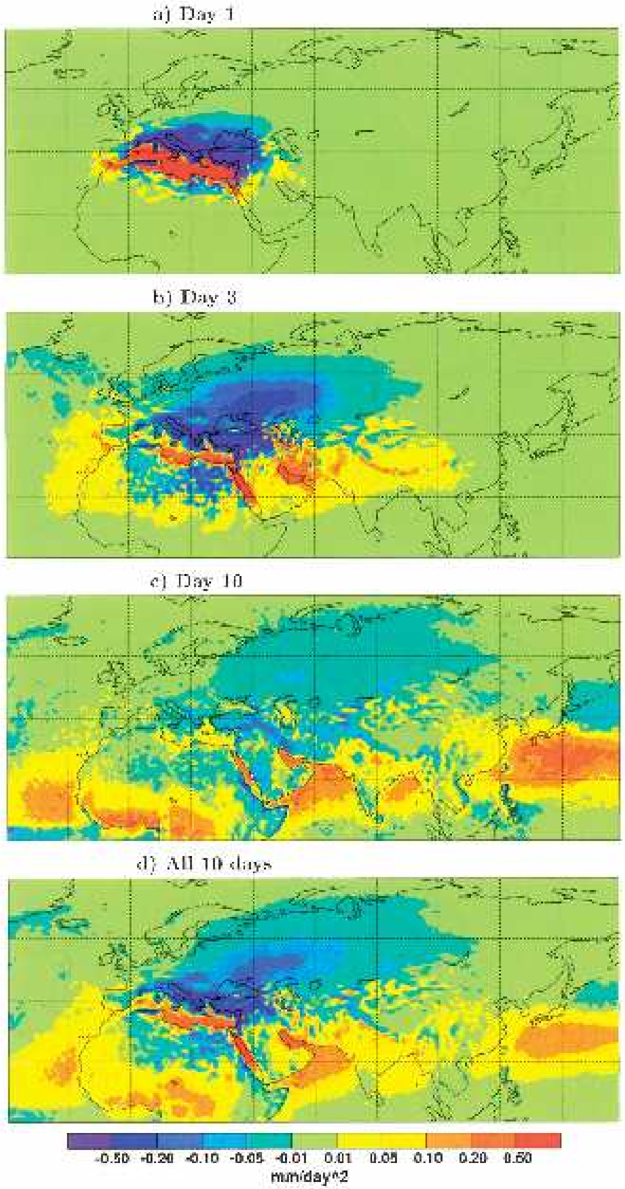


FIG. 3. Scatterplot of 4-yr-average river-basin-integrated annual $P - E$ obtained with the Lagrangian method vs the climatological annual river-mouth streamflow data taken from Dai and Trenberth (2002). Values are for the 39 river basins listed in Table 1. Eight river basins are not shown because of too small or negative $P - E$. The dashed line represents a 1:1 relationship.

Stohl and James, Journ. Hydromet, 2005



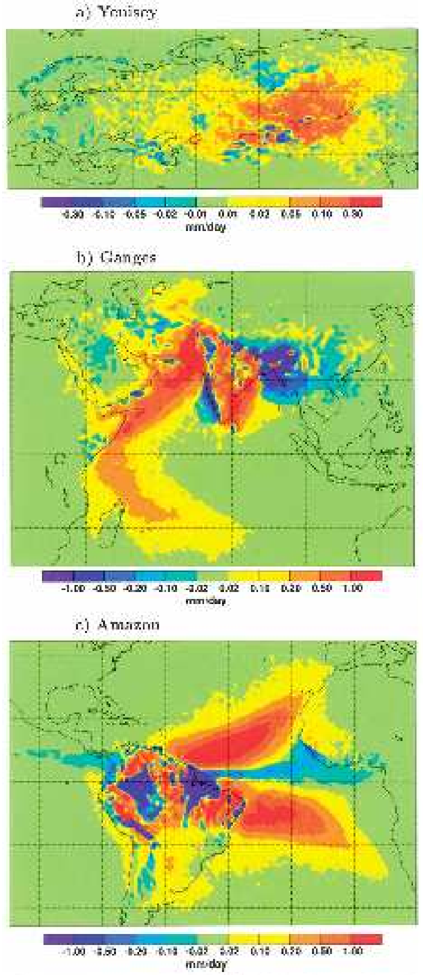


FIG. 11. Annual mean $(E - P)_c^{-10,i}$ fields from backward tracking for (a) the Yenisey, (b) the Ganges, and (c) the Amazon River.

increase from $(E - P)_c^{-2,i} = -21\%$ to $(E - P)_c^{-10,i} = -3\%$, indicating that significant recycling may indeed take place, which is masked in the 10-day-integrated value by precipitation occurring shortly before an iden-

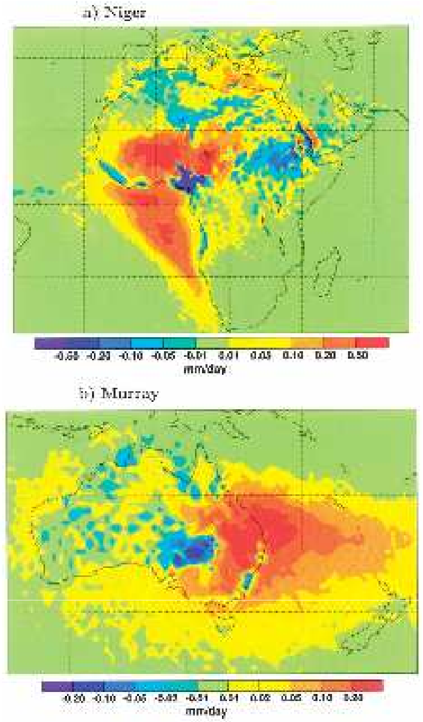


FIG. 12. Annual mean $(E - P)_c^{-10,i}$ fields from backward tracking for (a) the Niger and (b) the Murray River.

tified precipitation event. Eltahir and Bras (1996) reported recycling ratios of 25% and 35%, depending on the dataset used, and Trenberth (1999) reported various values from 5% to 34% for the Amazon basin, depending on how the recycling ratio was defined. Both studies also noted the large heterogeneity in the recycling ratio over the Amazon basin, a feature that is reflected also in our $(E - P)_c^{-10,i}$ field.

For the Murray River in Australia, the Pacific Ocean is the dominant moisture source (Table 4; Fig. 12b), but recycling over the basin and other parts of Australia also makes a significant contribution.

6. Discussion

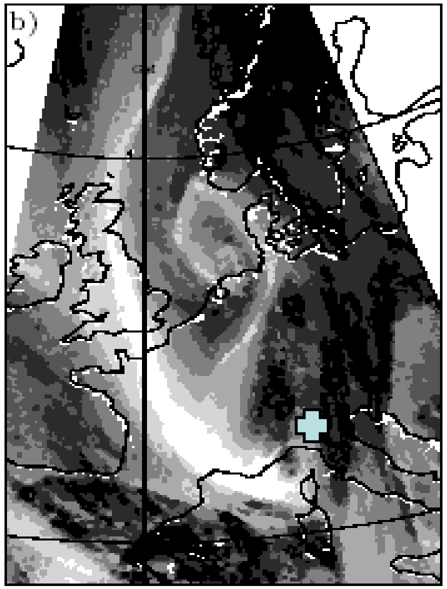
In this paper and in Part I we have developed a Lagrangian method to track water vapor in the atmo-

2 posters …

Fine-scale structure of strat-intrusions

How is the fine-scale structure ?
How deep intrusions are ?
How dry ?

Meteosat IR image



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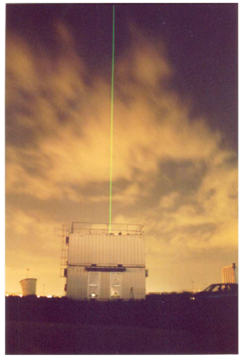
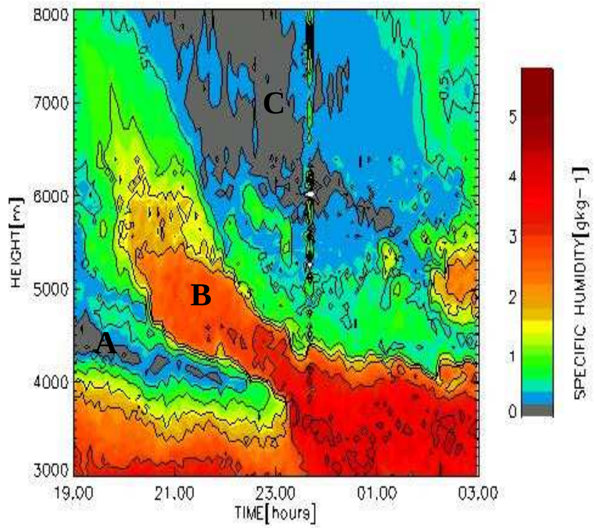
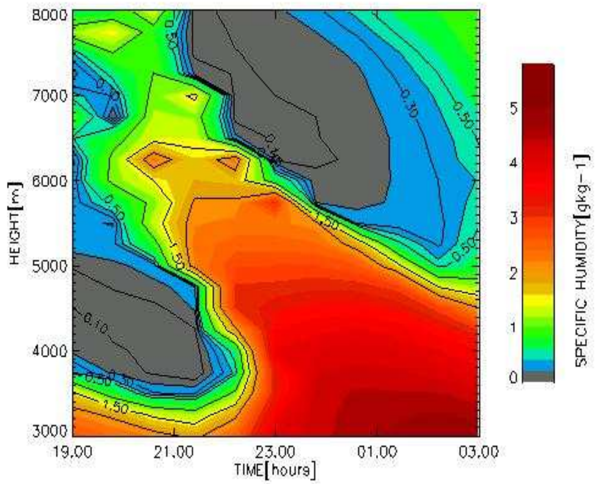
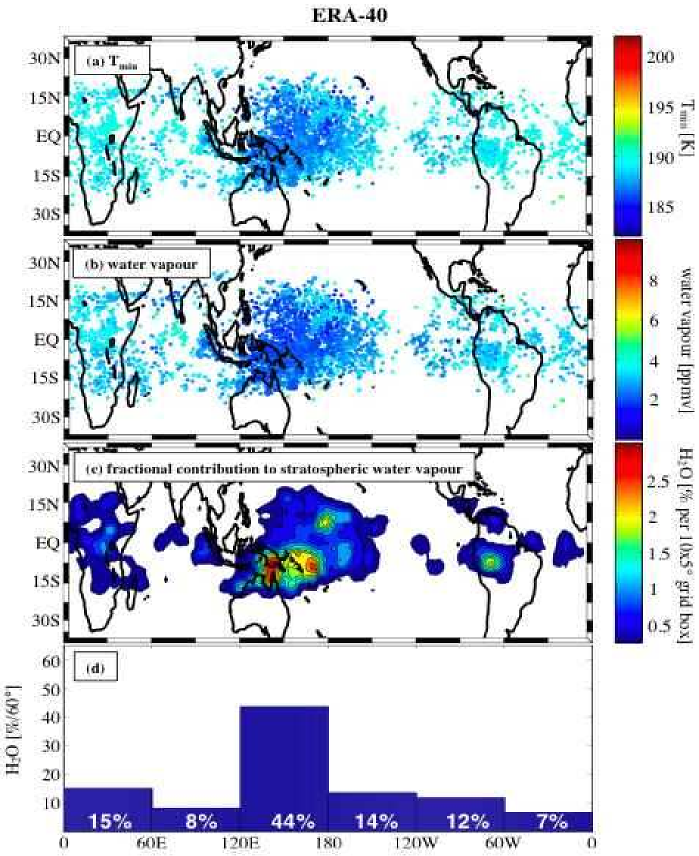




Trajectories
With q_{sat}



D'Aulerio et al, ACP 2005



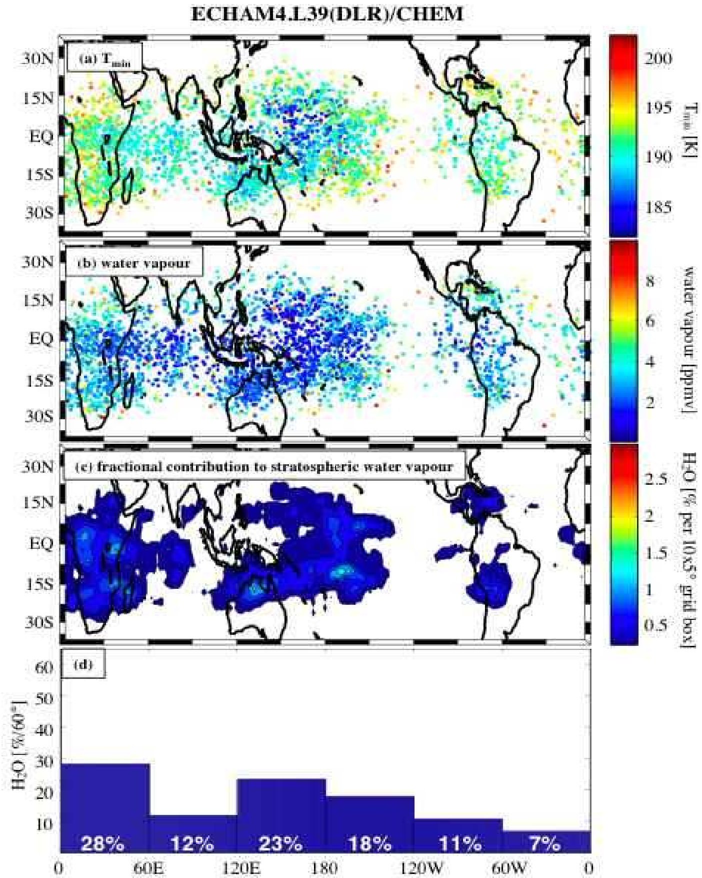
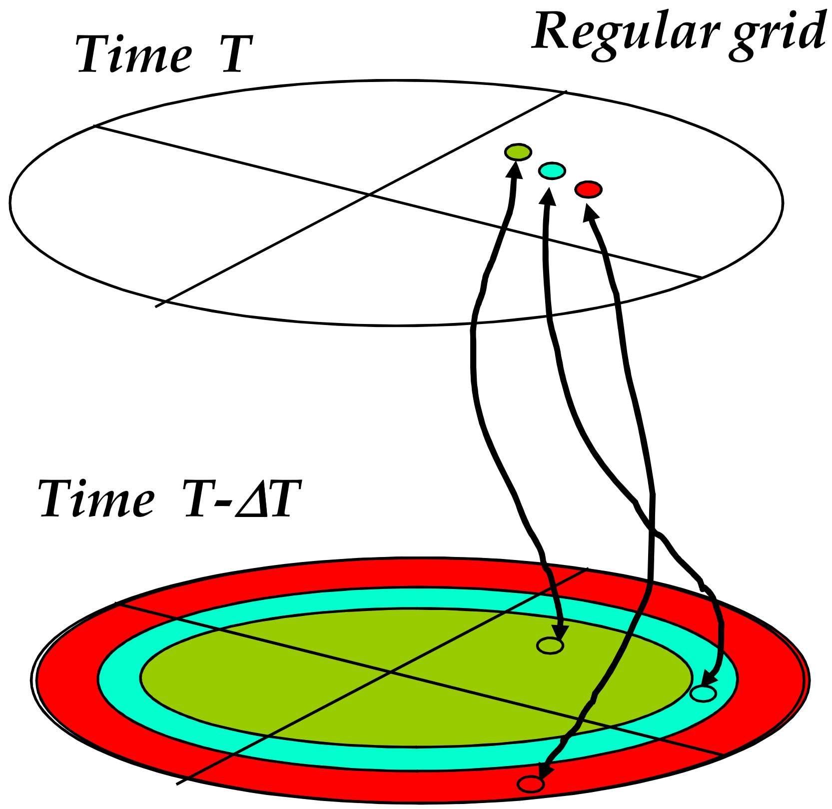


Fig. 2. NH winter 1995–1996. The scatter plots (panel **a** and **b**) show the geographical distribution of the dehydration points for ERA-40. Color code in (a) shows the minimum temperatures experienced by the TS trajectories and in (b) the corresponding equilibrium water vapour mixing ratios. Panel **(c)** illustrates the fractional contribution to stratospheric water vapour from different geographical areas, expressed by percentage contribution per individual 10°×5° grid boxes. Panel **(d)** shows longitudinal distribution of the water vapour entry, i.e. the value from (c) integrated over latitude (30° N–30° S) per 60° longitude. The results from kinematic calculations, based on ERA-40 reanalysis data, are very similar.

1 poster …

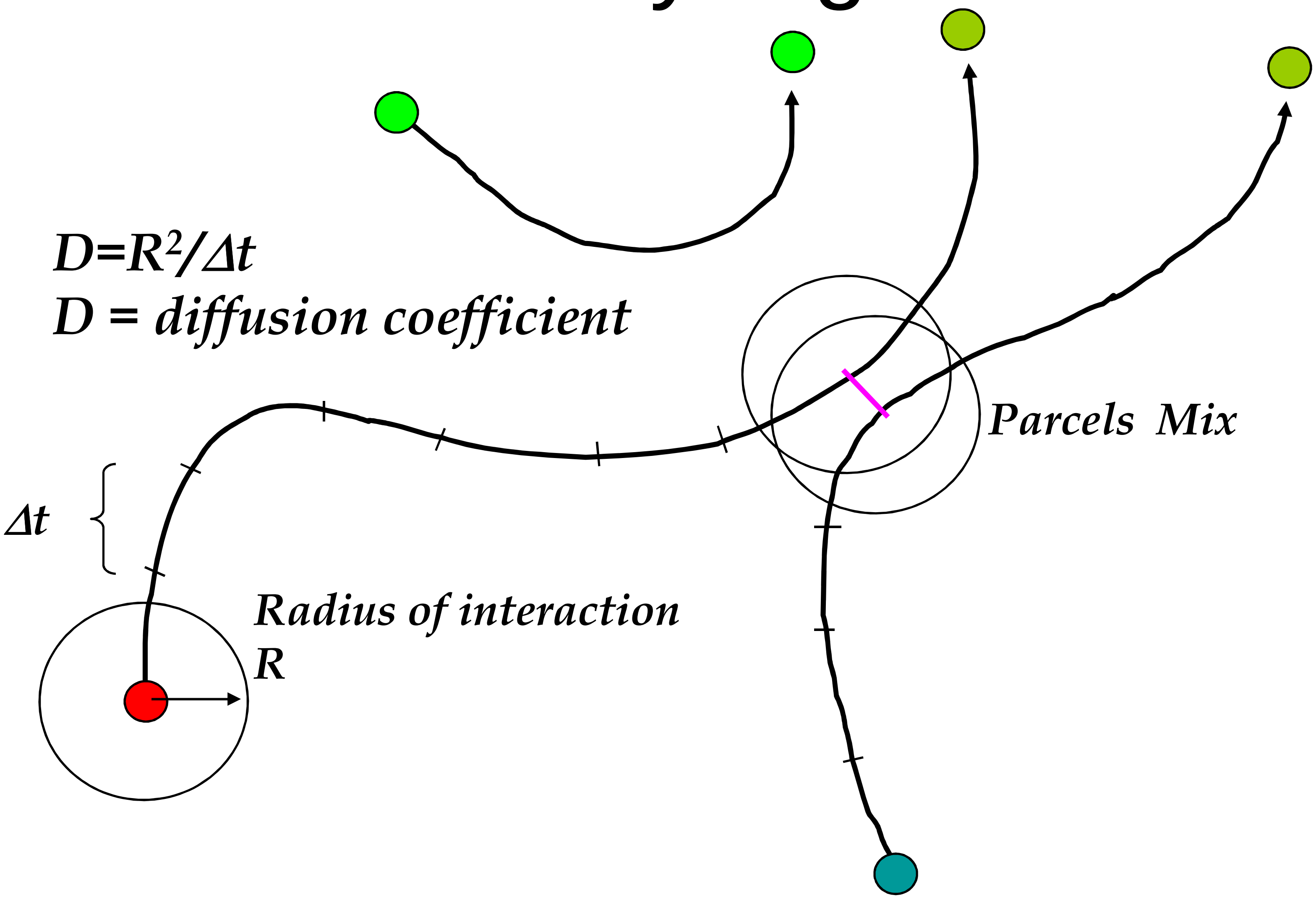
Reverse Domain Filling (RDF)

- ***Step 1***
  Run a back trajectories starting with a regular gridded array
- ***Step 2***
  Interpolate observations to back trajectory points
- ***Step 3***
  Copy values forward to regular grid



Anne Douglass, NASA GCFC

Proximity Algorithm



The trajectory approach is an important tool in transport process study
can provide insight into transport and mixing processes
can reveal large scale characteristics of atmospheric flow

The trajectory approach has some issues/limitations:

- position errors
- mixing issues

Moreover, most trajectories calculation rely on winds, pressure, water vapour from met analysis …

- Tropospheric processes (convection, clouds, boundary layer)

Three scalar fields x_0, y_0, z_0, hereafter referred as the *initial coordinates*, are used to calculate this vector field. They are initialized with the Cartesian coordinates:

$$x_0(\mathbf{x}, t=0) = x, \quad (1)$$

$$y_0(\mathbf{x}, t=0) = y, \quad (2)$$

$$z_0(\mathbf{x}, t=0) = z. \quad (3)$$

These fields are considered as passive scalars driven by the flow, i.e. their evolution is governed by the equation

$$\frac{\partial \mathbf{x}_0}{\partial t} + \mathbf{u} \cdot \vec{\nabla}\, \mathbf{x}_0 = 0, \quad (4)$$

The value of α at $t=0$ for the parcel located at $\mathbf{x}$ at time t is given by

$$\alpha_0(\mathbf{x}, t) = \alpha(\mathbf{x}_0(\mathbf{x}, t), t=0), \quad (5)$$

and hence the net change of α experienced by this parcel between $t=0$ and t is

$$\Delta\alpha = \alpha(\mathbf{x}, t) - \alpha_0(\mathbf{x}, t). \quad (6)$$

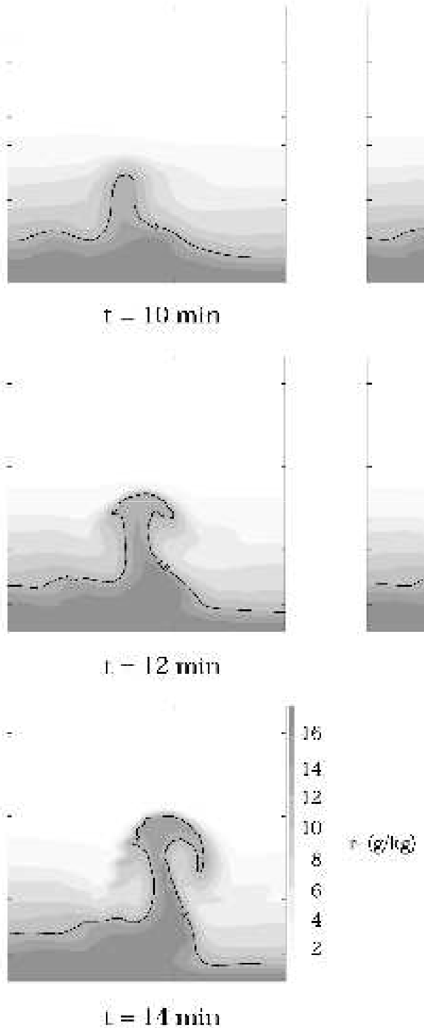
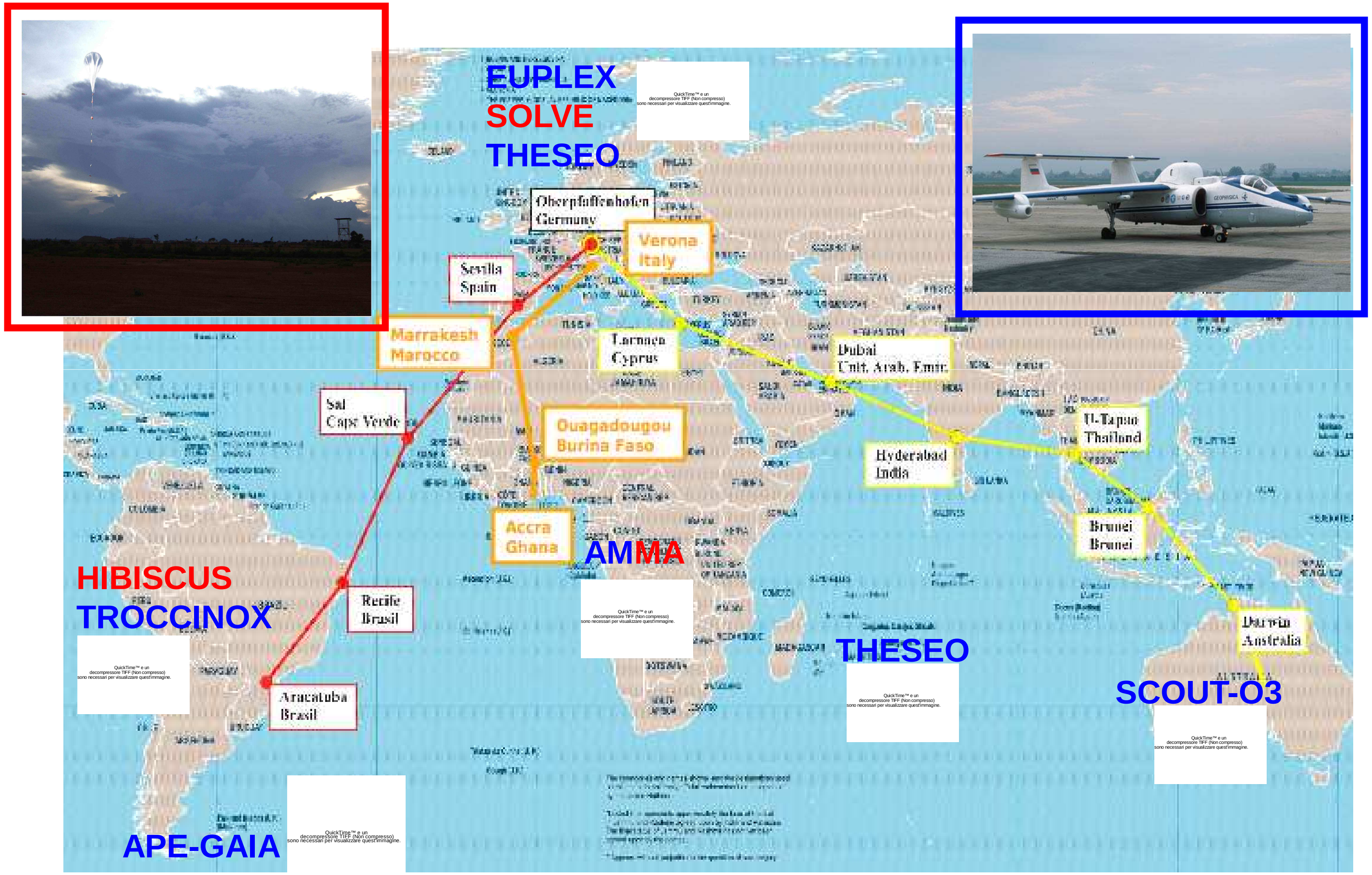


Figure 4. Simulation SQLINE (see Table 2), time-evolution of the first convective plume. Greyscale: total water content, $r_t = r_v + r_c$ (g kg^{-1}). Solid contour: initial altitude $z_0 = 1500$ m. See text for further details.

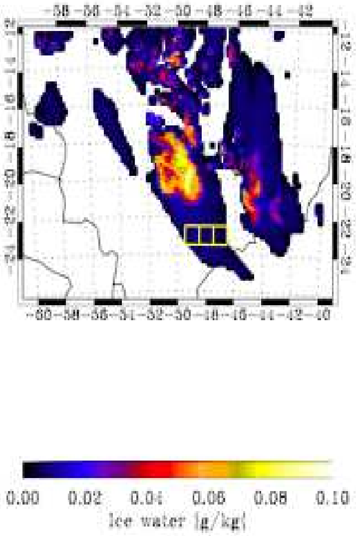
Gheusi and Stein QJRMS 2002

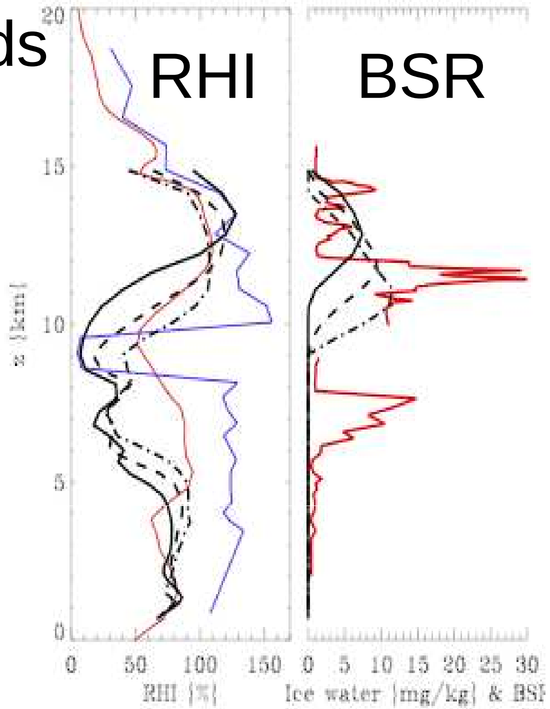
In-situ observations 2003-2007



Age of convective outflow

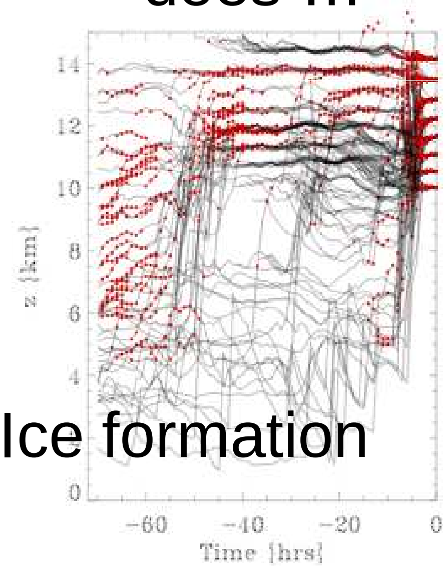
Model ice clouds



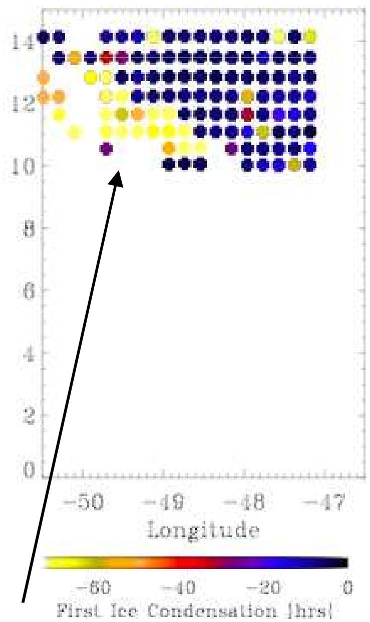


Mesoscale simulation
Outflow over Brasil

But on-line trajectories does …



Ice formation



Time since ice formation

Optical measurements shows
Two layers with different
backscatter and RHI
---> different particle size / number
Model hardly discern between
Different cirrus layers

Biomass burning in mediterranean area

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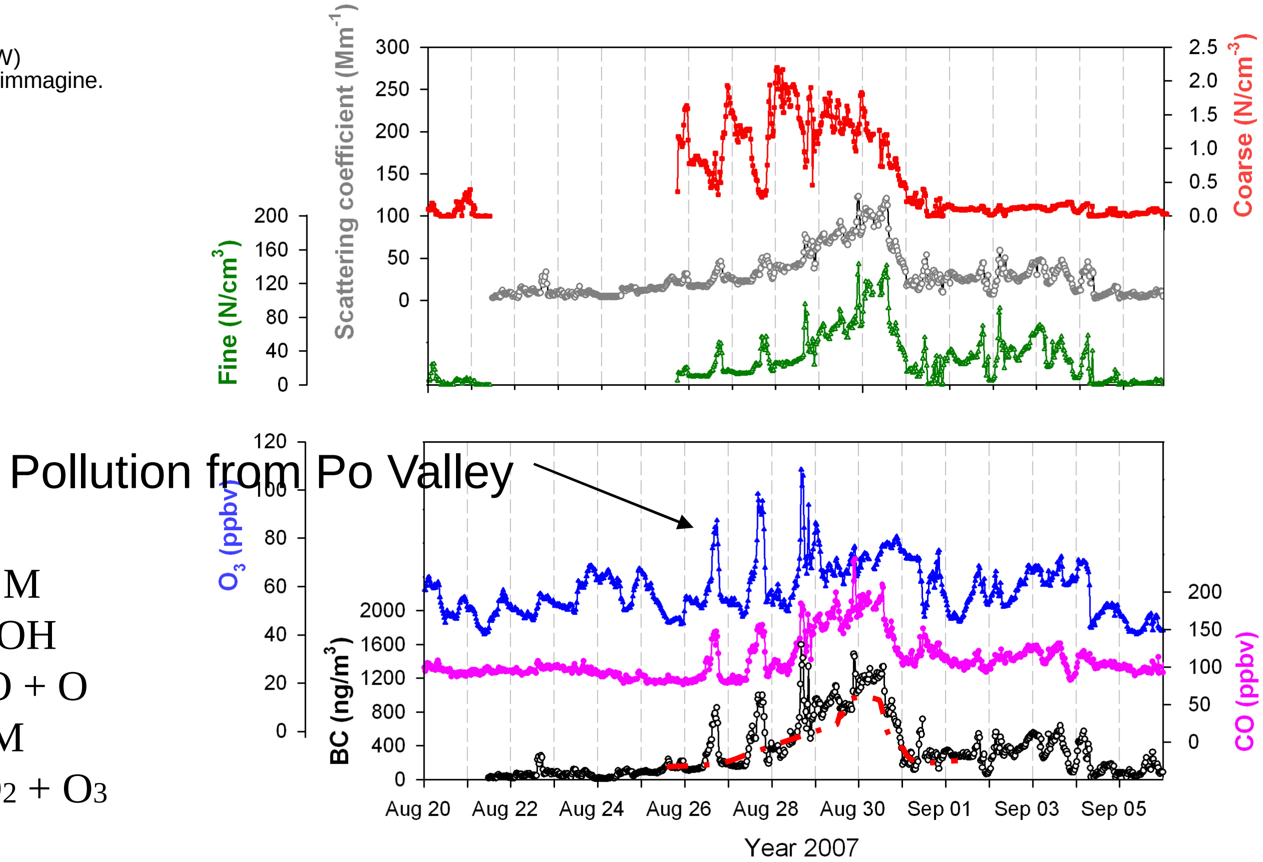
Mt. Cimone



$OH + CO \rightarrow H + CO_2$

$H + O_2 + M \rightarrow HO_2 + M$

$HO_2 + NO \rightarrow NO_2 + OH$

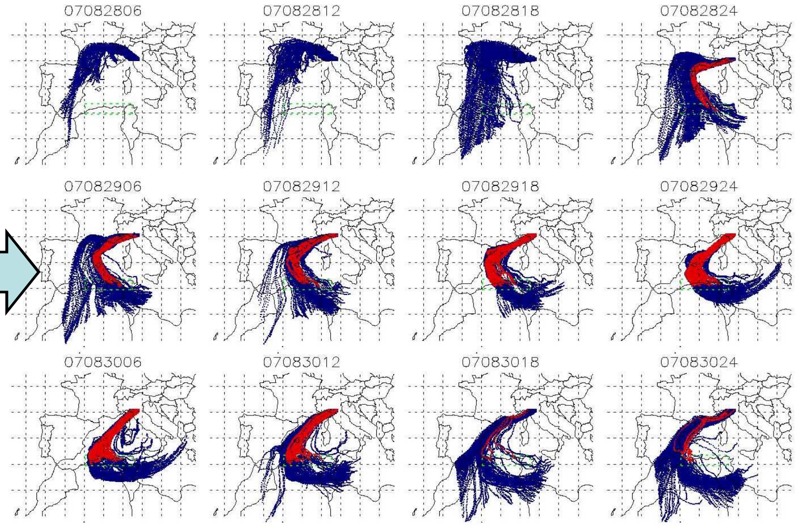
$NO_2 + \text{sunlight} \rightarrow NO + O$

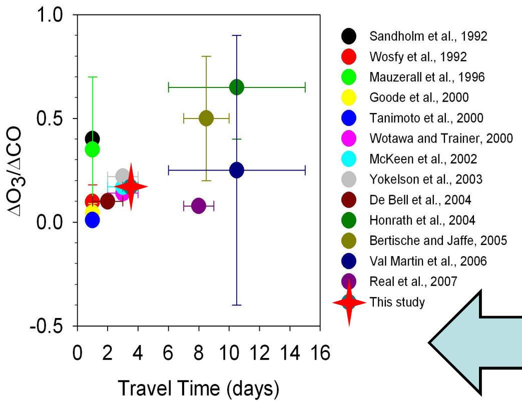
$O + O_2 + M \rightarrow O_3 + M$

Net: $CO + 2\,O_2 \rightarrow CO_2 + O_3$

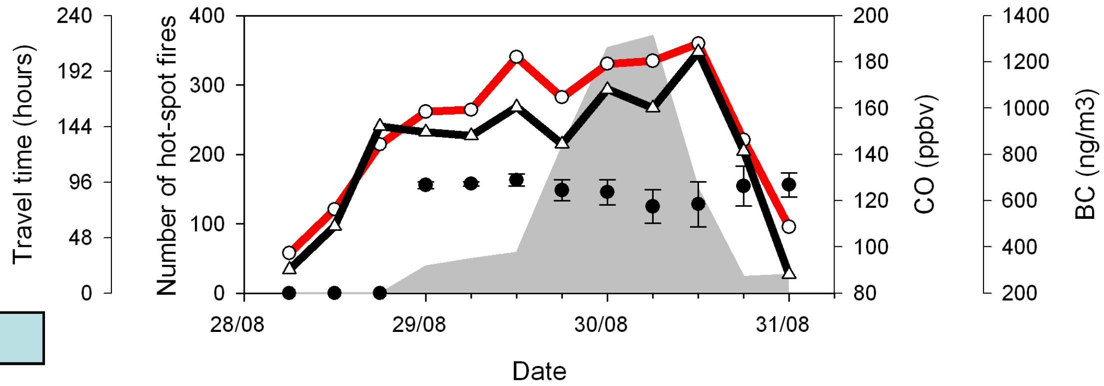
MODIS fires

On-line trajectories





O3 production rate



CO vs. BB passive tracer

Conclusions

Modelling and observations are key elements for understanding

--->Model allows to extrapolate …
Test hypothesis

Simplified models can work very well, depending on purposes

Think about the degree of complexity

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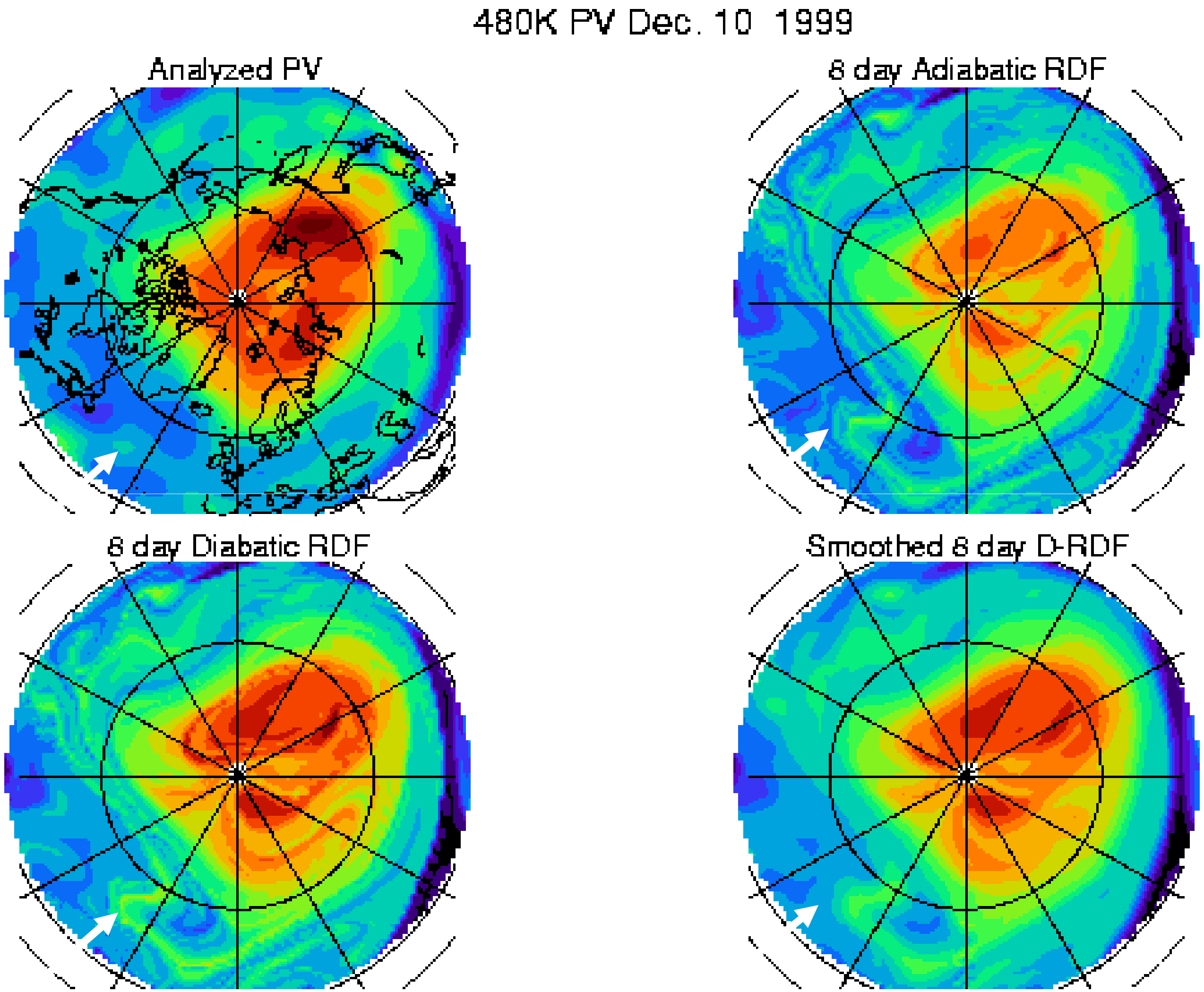
RDF Calculations



Wave breaking features are better resolved

PV is higher

Smoothed RDF not the same as analyzed PV

5º box car smoothed

Lagrangian Mixing Algorithms

- RDF's can produce infinitely fine structure - such fine structure is not observed => must mix parcels at some point
- Mixing algorithm types
  - Proximity algorithms
    - Parcels which move within a certain distance mix with neighbors
  - Conditional Algorithms
    - Nearby parcels mix under certain flow conditions (most useful when small number of parcels used)

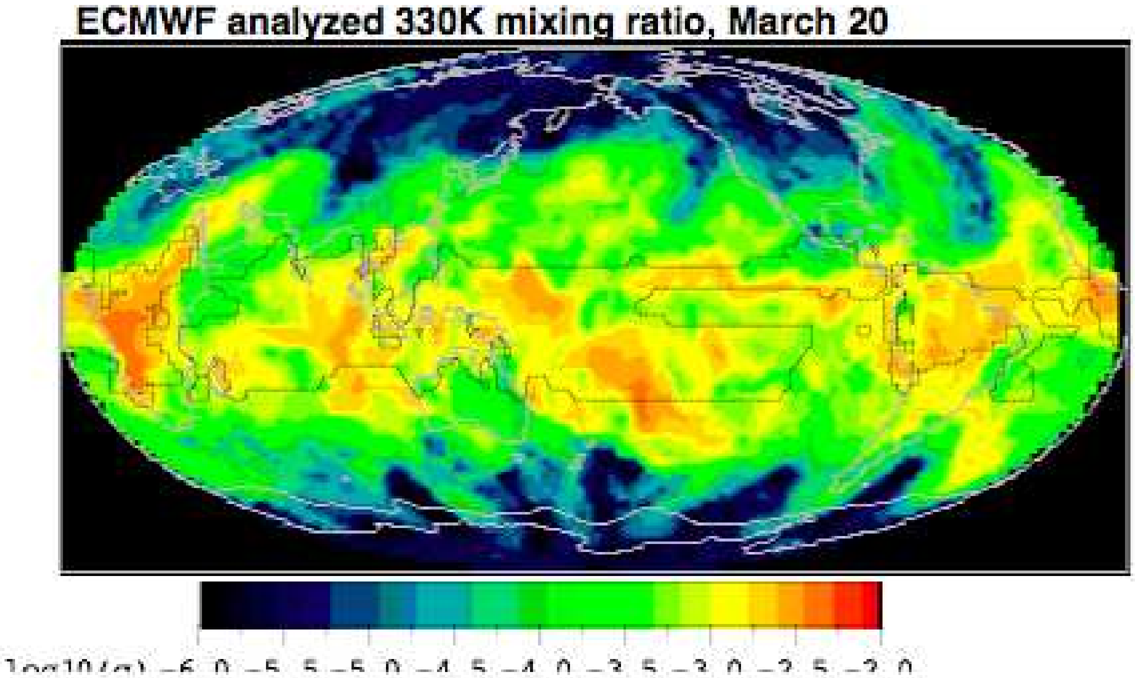
APPLICATION 2 - REVERSE DOMAIN FILL

If you start forward trajectories from a regular grid (no matter how dense), the result (no matter how long the calculations) is an irregular distribution of endpoints.

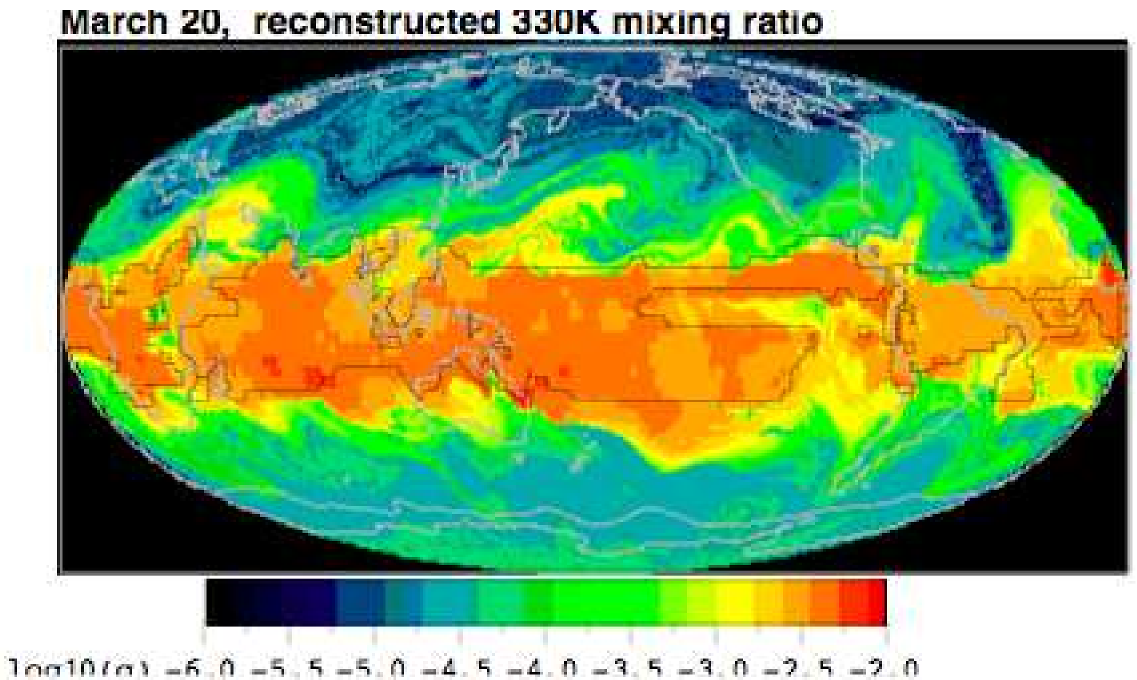
If you start from a regular grid and go backwards, the endpoints are similarly irregular.

The application called Reverse Domain Fill (RDF) starts backward trajectories from a dense regular grid, and produces a distribution of endpoints.

Take observations that you have and interpolate to this distribution.

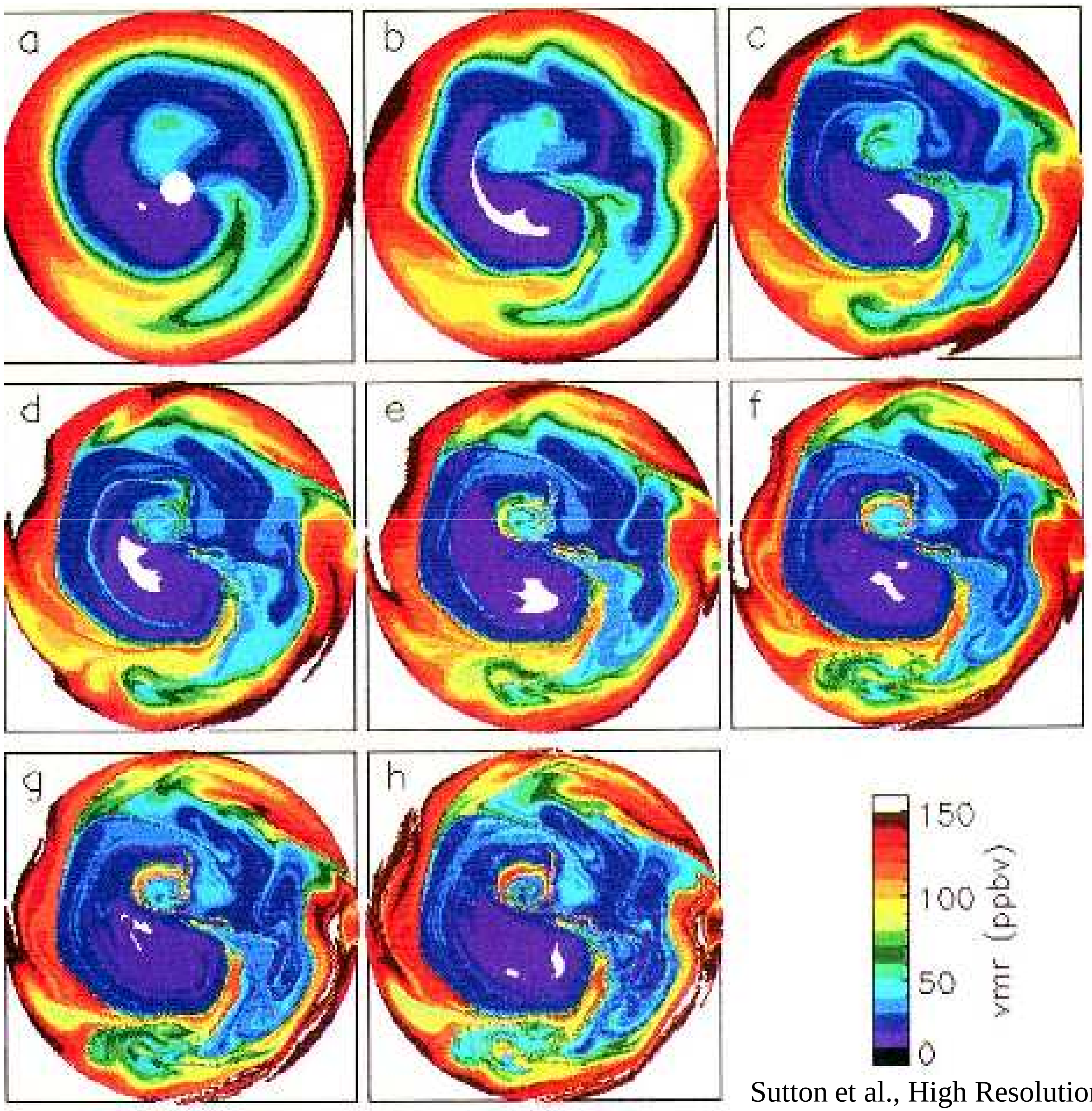


Pierrehumbert, GRL, 1997



N_2O 1150 K Jan 11, 1992

Gridded ISAMS **RDF from Jan 10** **RDF from Jan 9**



RDF from Jan 5 **RDF from Jan 4**

RDFs for Jan 11 are calculated using back trajectories from an equal area grid. Back trajectories are 1 to 7 days duration. Each day's data from the terminus of the back trajectory is projected to the equal area grid. Filamentary structures appear as the back trajectory duration lengthens.

Sutton et al., High Resolution Stratospheric Tracer Fields Estimated from Satellite Observations Using Lagrangian Trajectory Calculations, JAS 1994.