

Pollution Plume Transport of Ozone

1,000 to 10,000 km

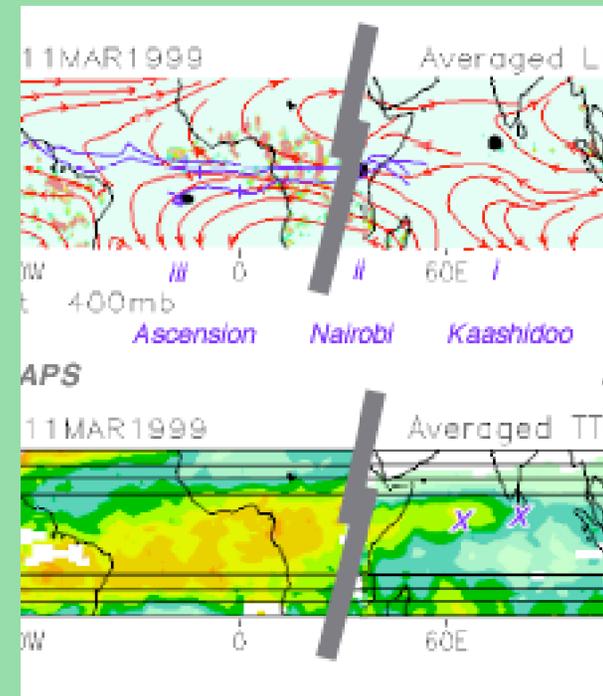
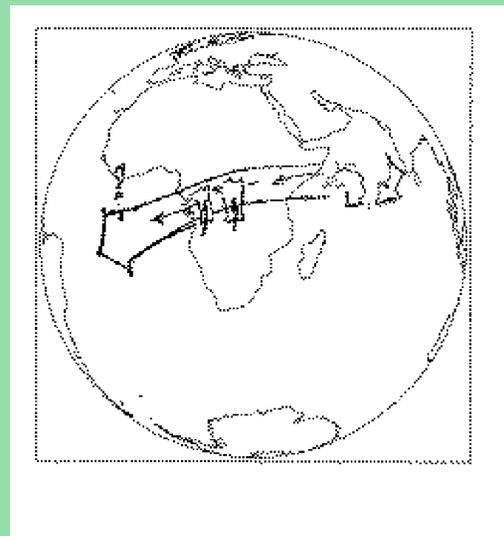
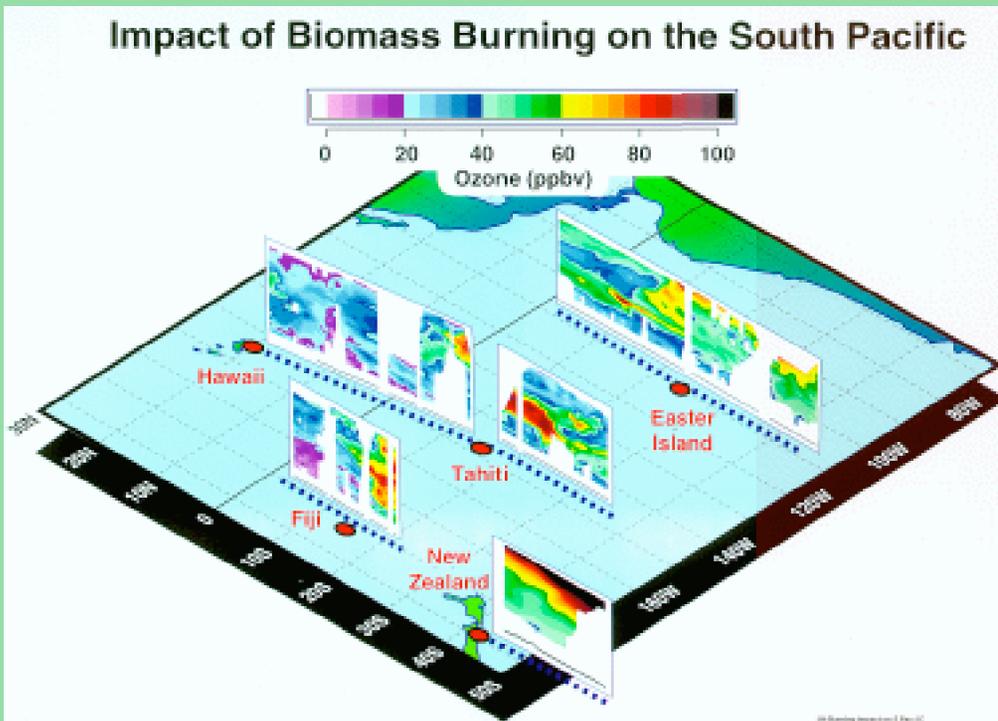
Robert Chatfield

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NASA

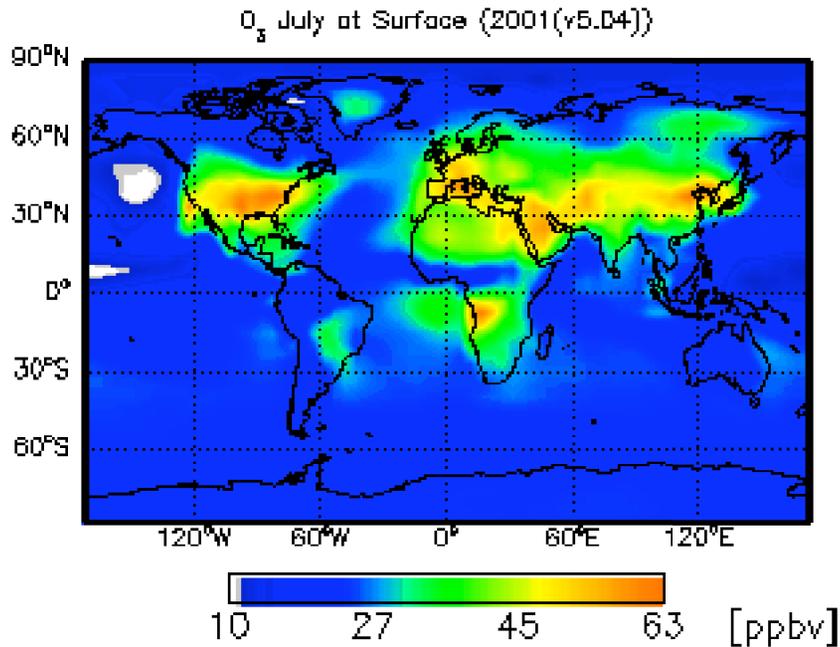
(Ames Res. Ctr, California, USA)

with Hong Guan, R. Esswein)



Original ideas of pollution plumes:

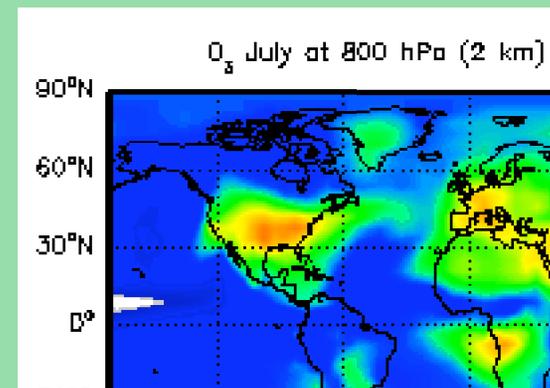
Continental plumes were extensions of urban plumes, which might merge and move out westward in the PBL. Mostly Northern Industrial-Urban Theory was an extension of industrial, urban



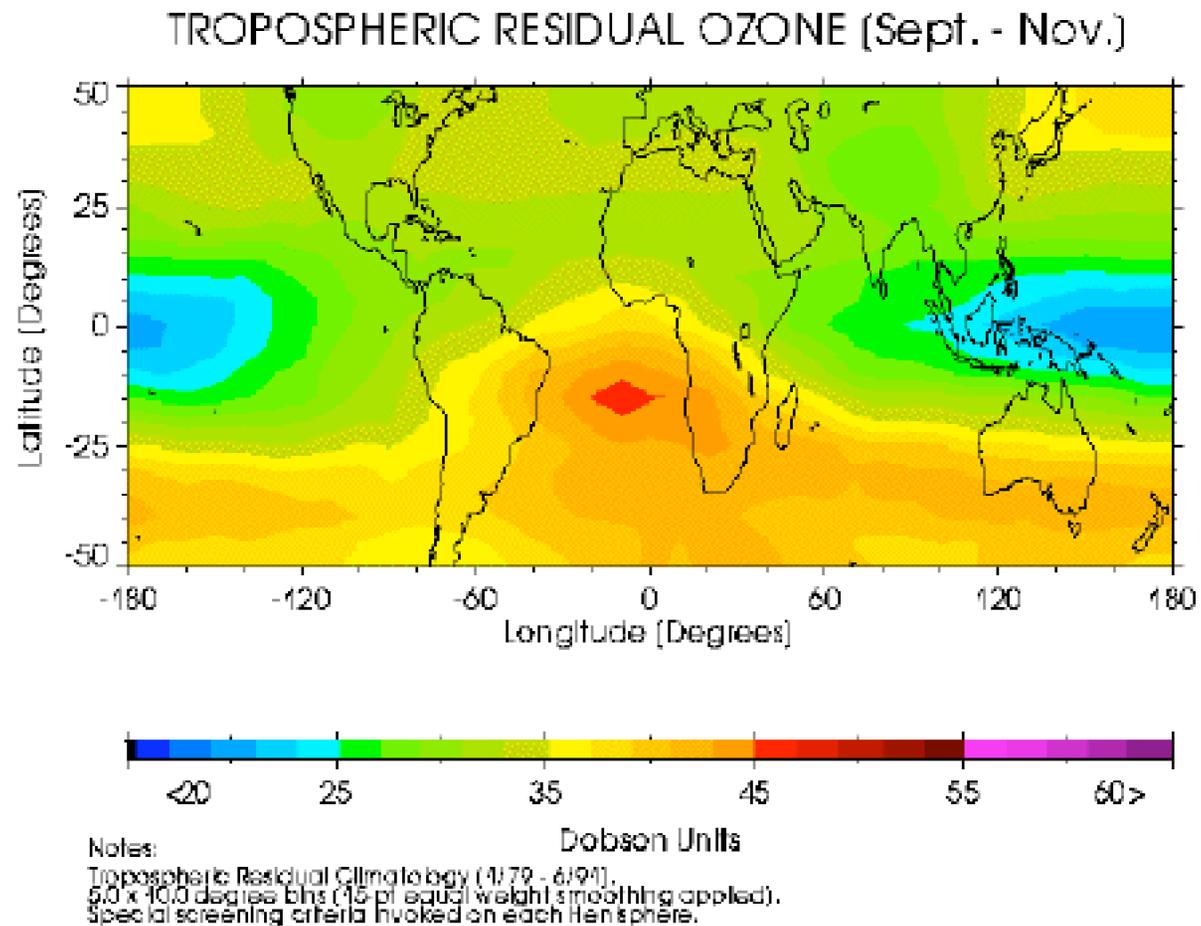
Harvard U.: GEOS-CHEM website

Fishman and Vukovich noted plumes could move forward by filling a deep continental PBL and then "override" a thin marine PBL, gaining velocity and isolated from some destruction.

(An early use of TOMS data for tropospheric interpretation.)



"Jack's Max"



*When Jack Fishman applied an early technique of subtracting stratospheric ozone,
... northern plumes were visible but the unexpected story was
a prominent near-Equatorial ozone maximum, "Jack's Max"*

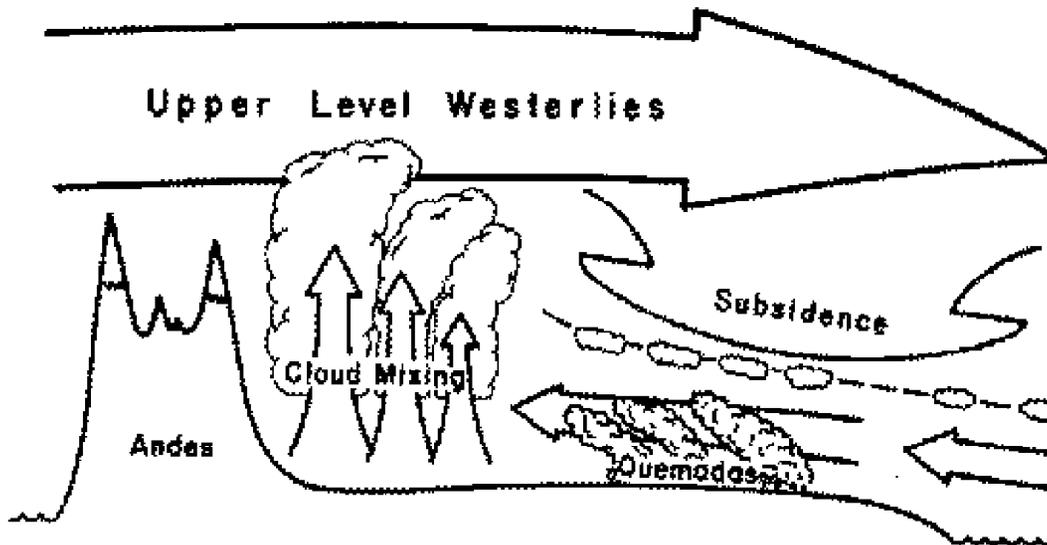
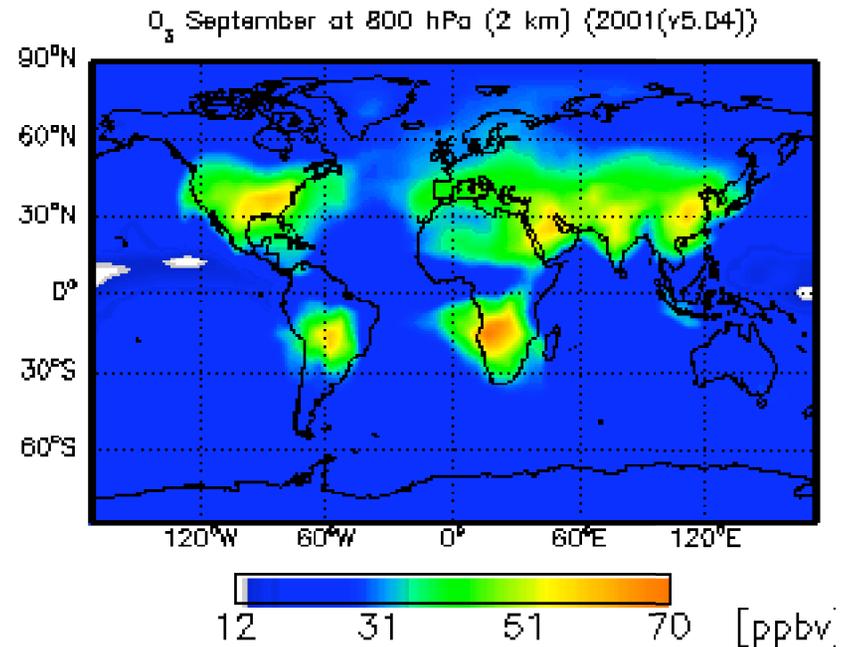


Fig. 1. Overview of the meteorology over the late-winter Cerrado when agricultural burning occurs, at the process by which it enters the free troposphere.

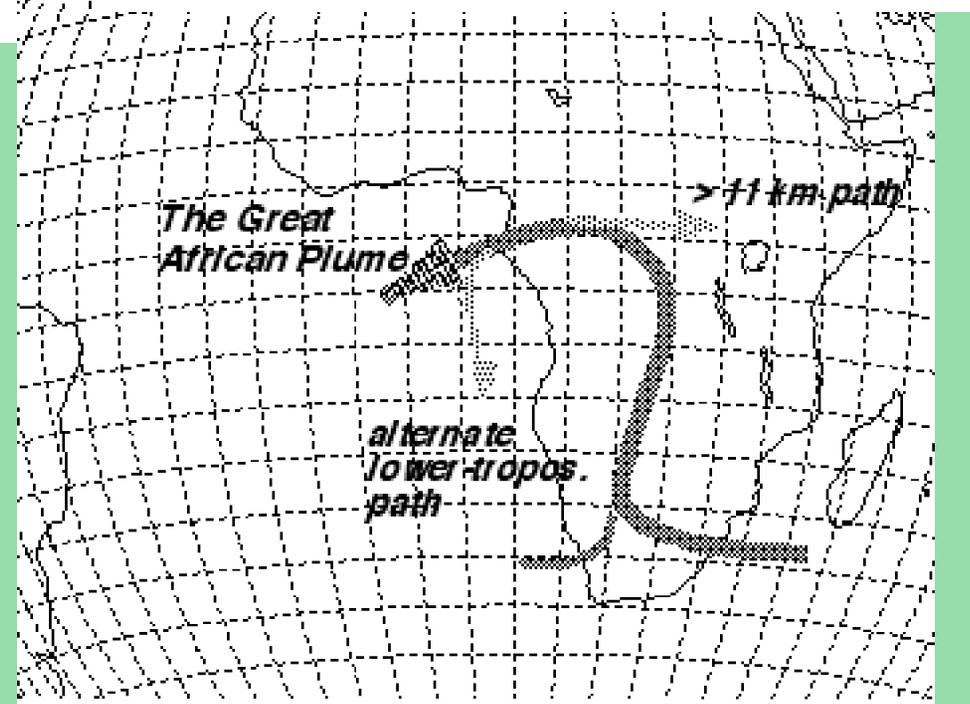


Chatfield and Delany, 1990
New theory was required to explain this: even current models at 4x5 degree resolution have difficulties.

Various explanations including stratospheric ozone came forth
I first favored an explanation involving lofted pollution

1) South America, cloud venting
... then

2) Africa, with cloud and PBL venting



Chatfield et al, 1996

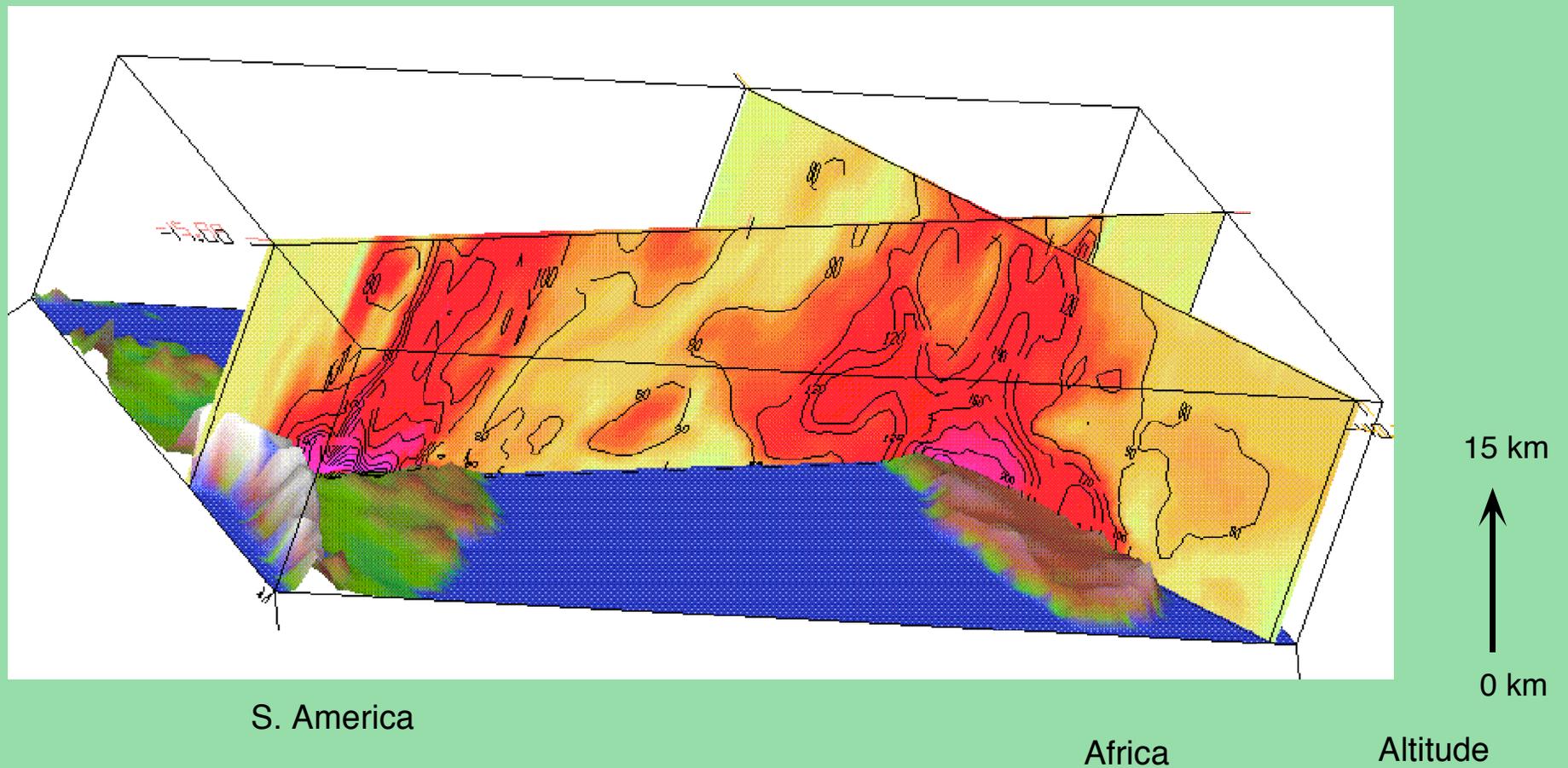
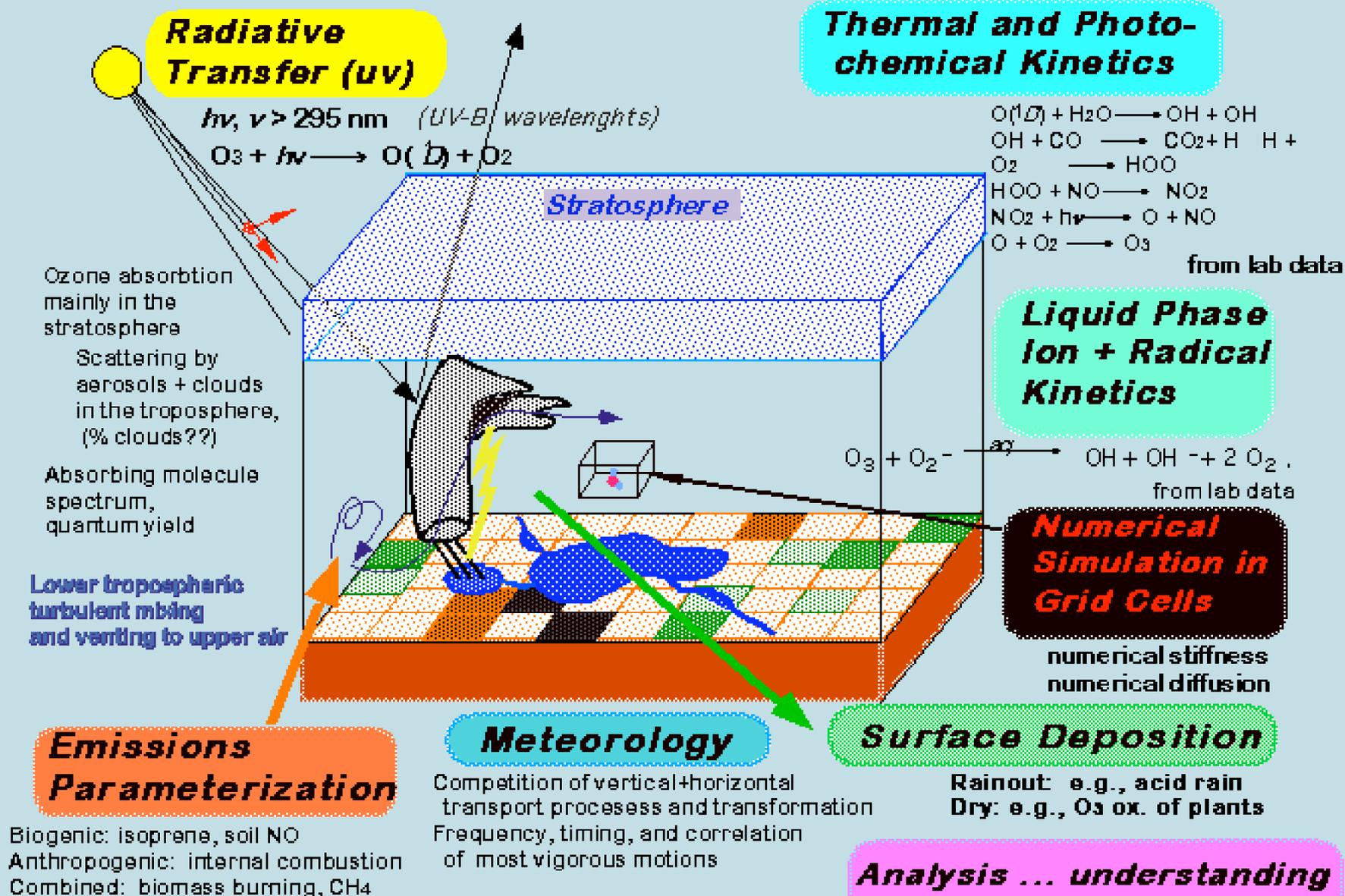


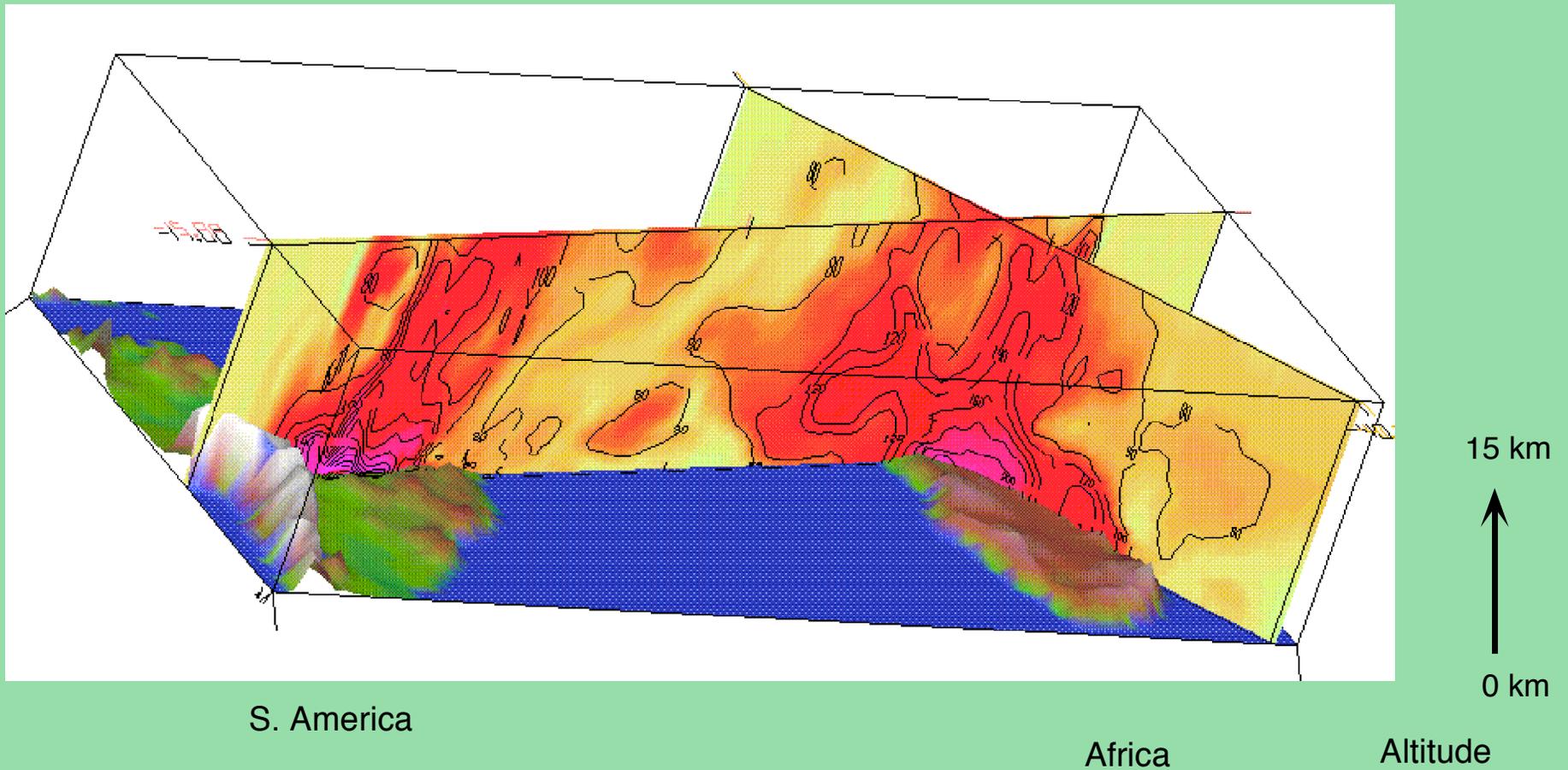
Figure 2

Chatfield et al., 1996
NASA program 579-24-13-10

Components of a Photochemical Simulation



Robert Chatfield NASA / Ames R.C. Earth Science



S. America

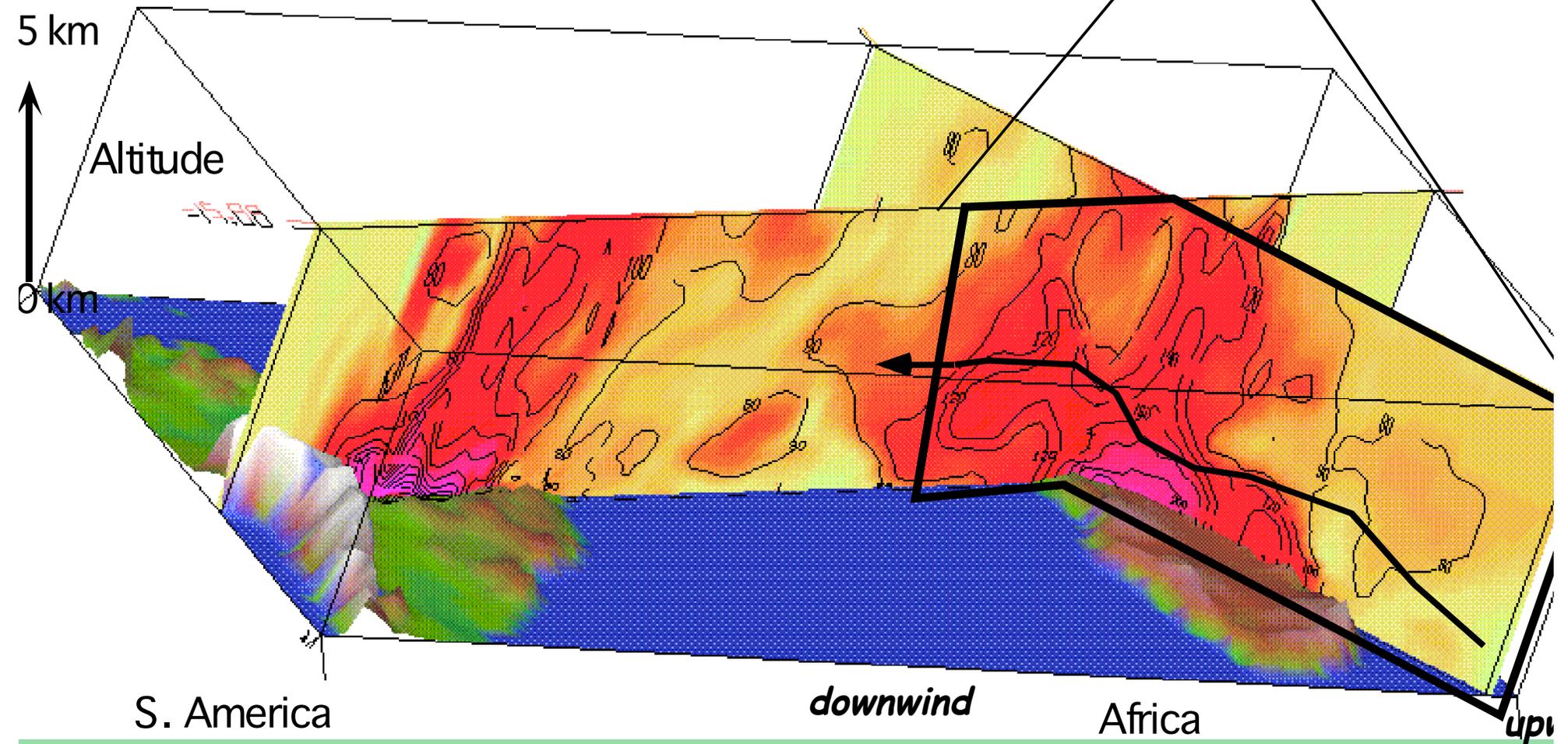
Africa

Altitude

Figure 2

Chatfield et al., 1996
NASA program 579-24-13-10

*Make an idealized model
of this flow in detail*

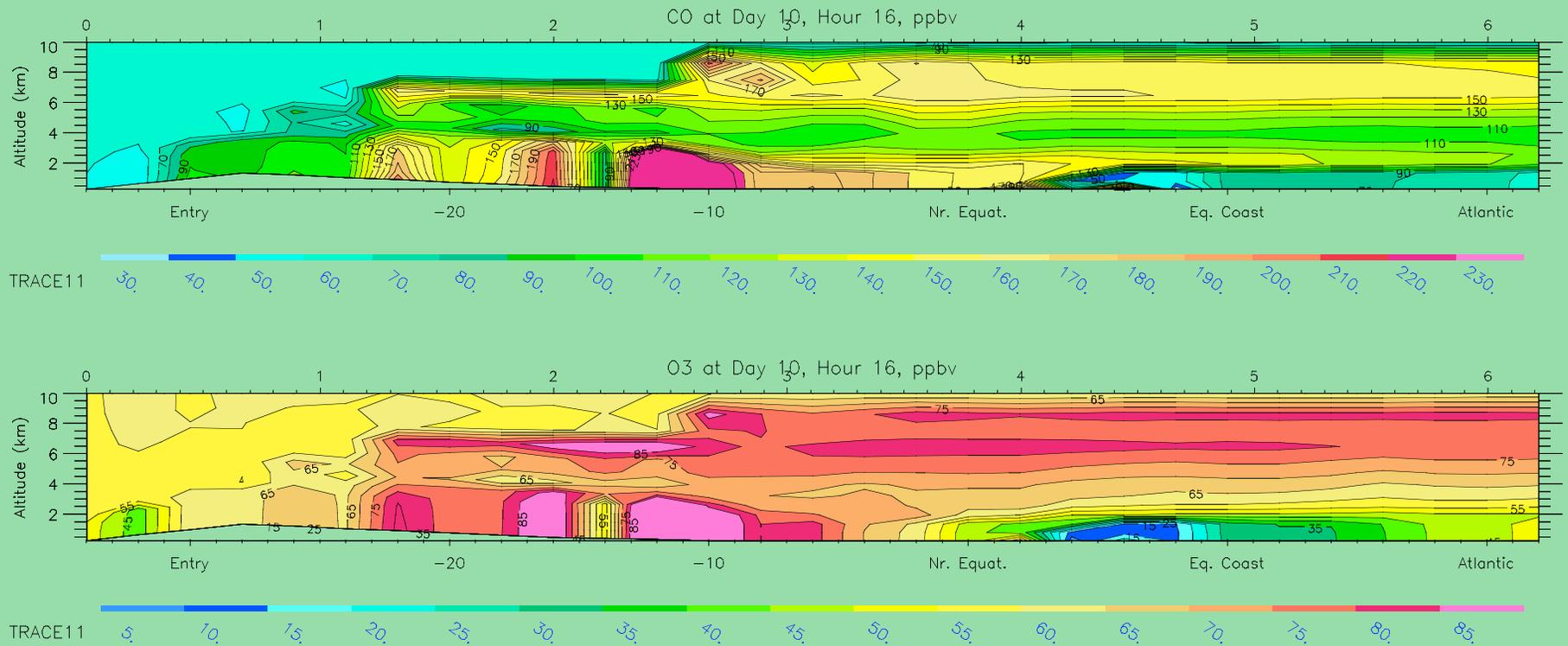


CO concentrations, 60 to 140 ppb

- A simplified conceptual model useful to explain vertical mixing and transport*

The vertical expression of the tropospheric plume depends on the compound described:

- *some compounds follow emission nearly molecule-for-molecule*
- *some compounds are removed by upward transport in raining clouds*
- *some compounds are preferentially produced or preserved in the upper troposphere*

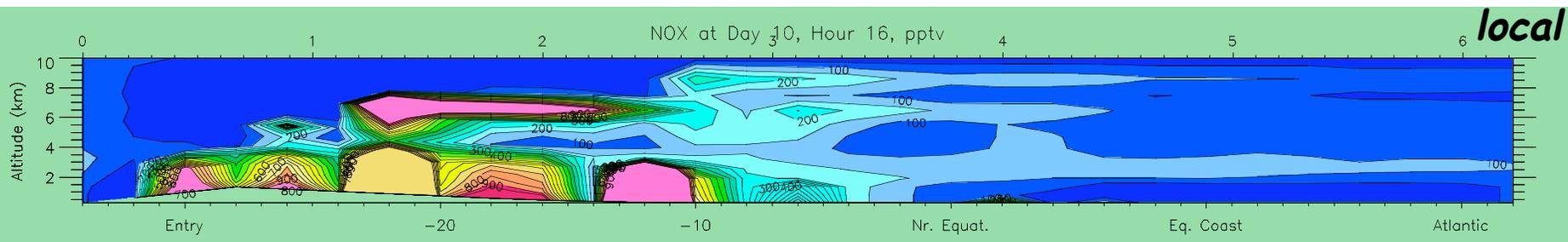


upwind

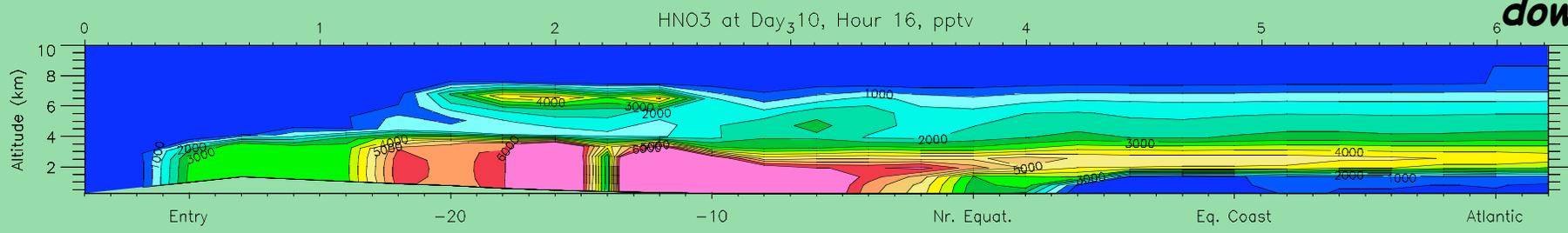
downwind

Figure 7

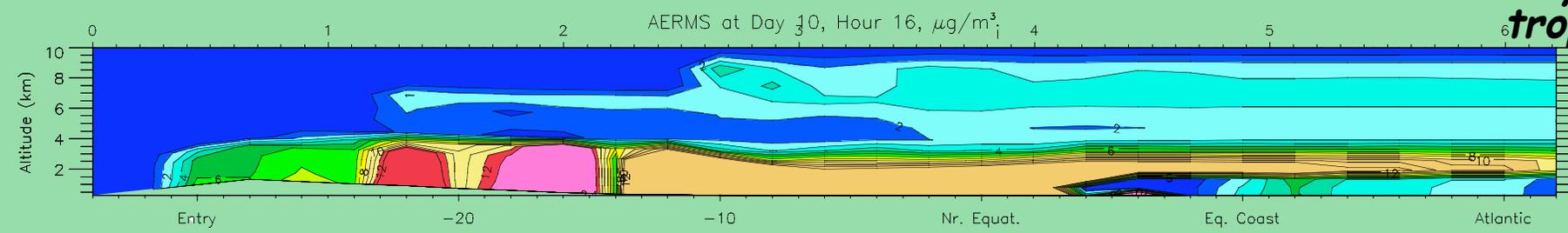
CO tracer follows each molecule emitted; O₃ emphasizes upper troposphere



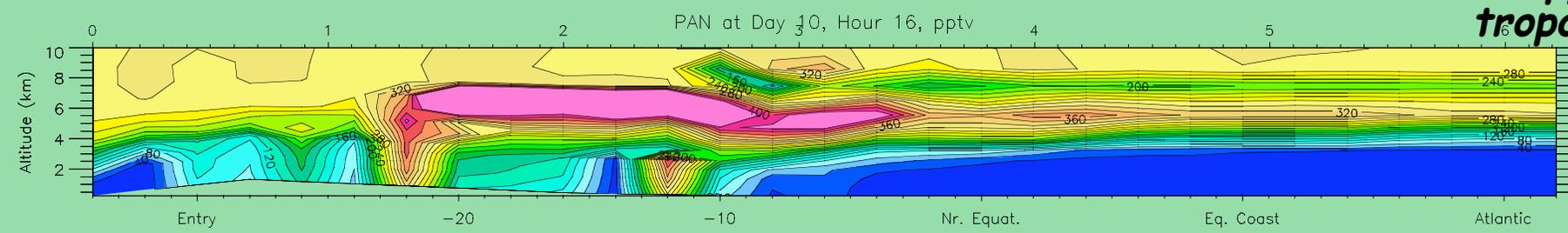
local



*local;
downwind*



*only low
troposp*



*responds
in upper
troposph*

upwind

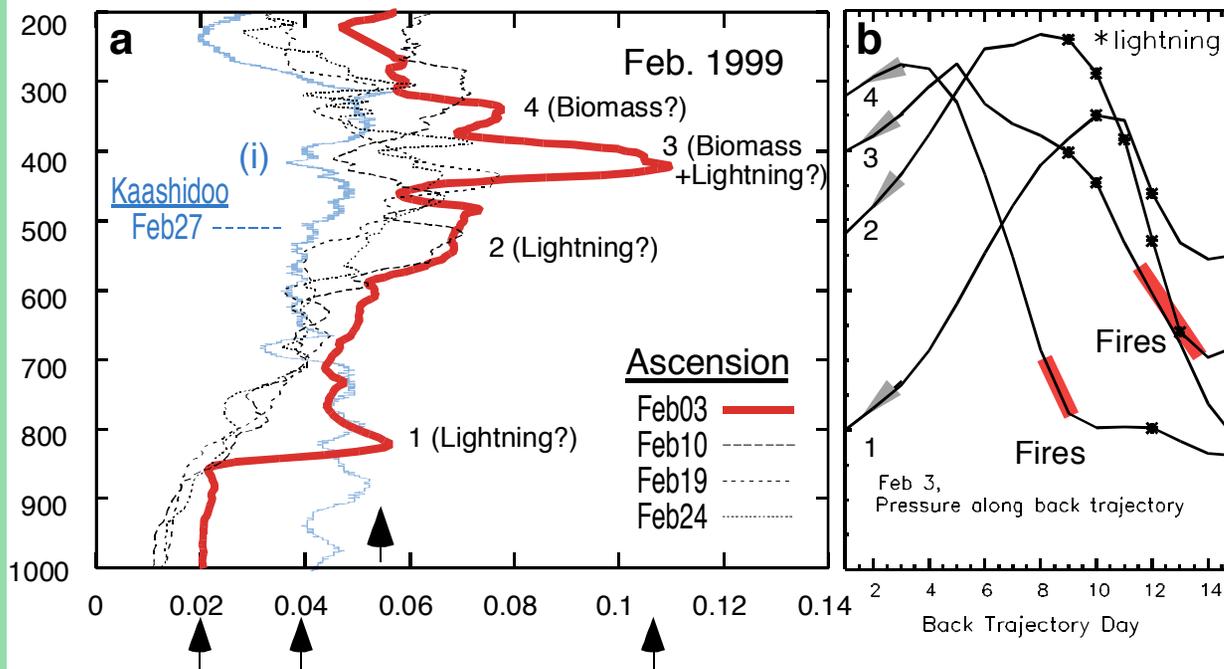
downwind



Origins of plumes in the Equatorial Atlantic west of Africa

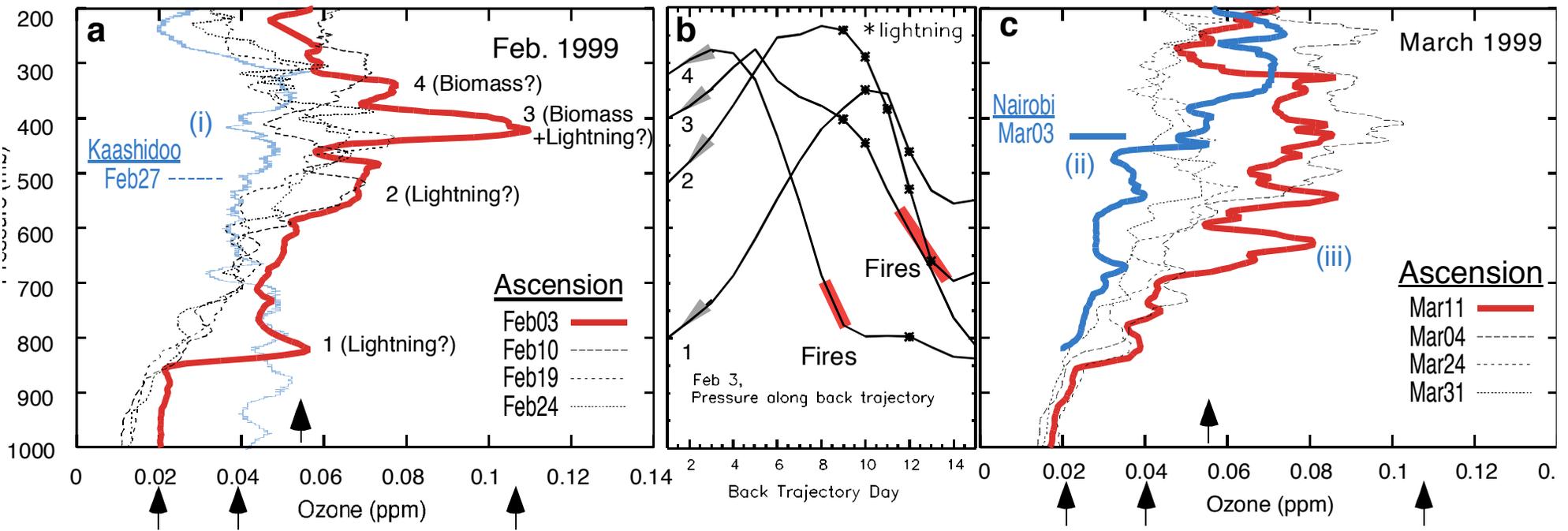
Each weekly sonde has individual peaks, but there is a suggestion of an Atlantic "background" which also varies.

Tracking of peaks suggests lightning of biomass burning sources, ... or both (much in accordance with photochemical theory)!



Background ozone also deserves explanation. Why is there an enhanced background? The two blue peaks (i) and (ii) and the red peak (iii) suggest an unexpected answer ...

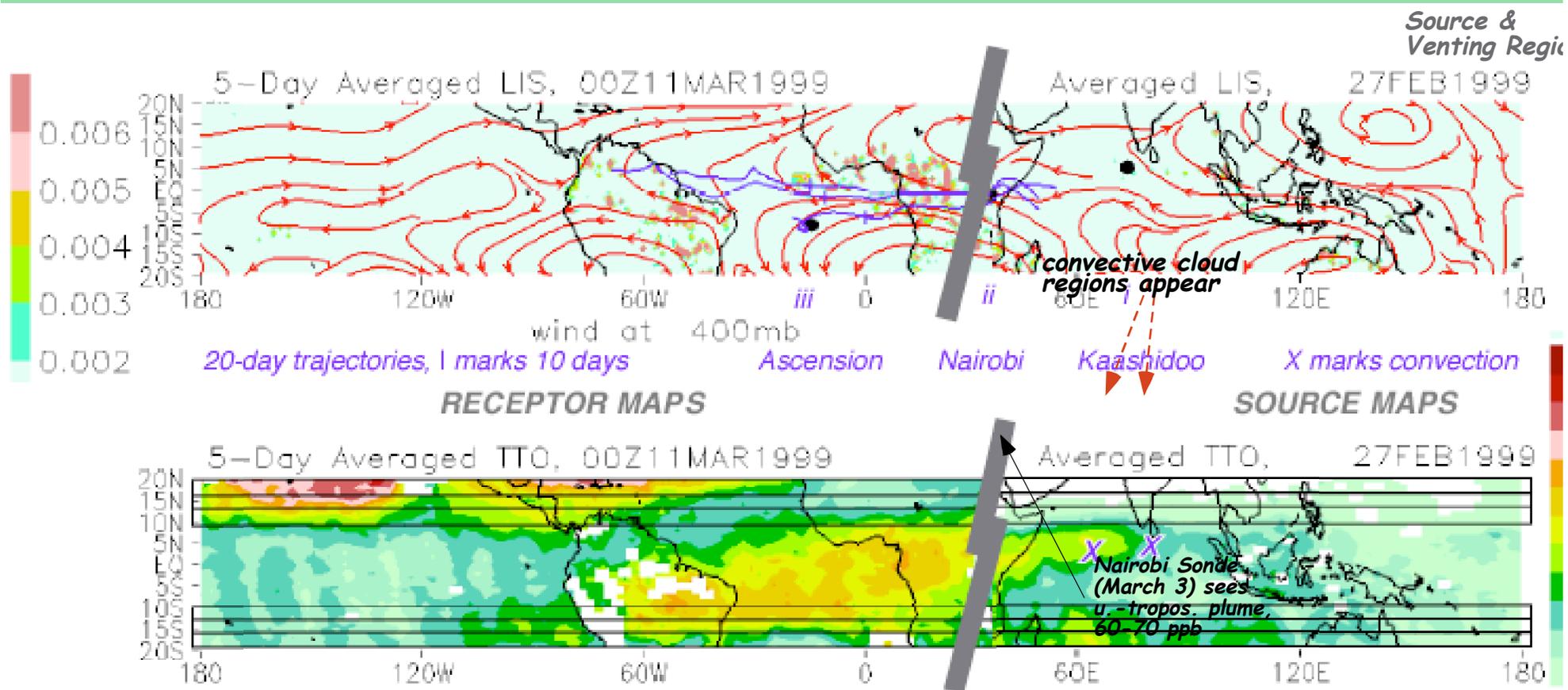
... Asian pollution!

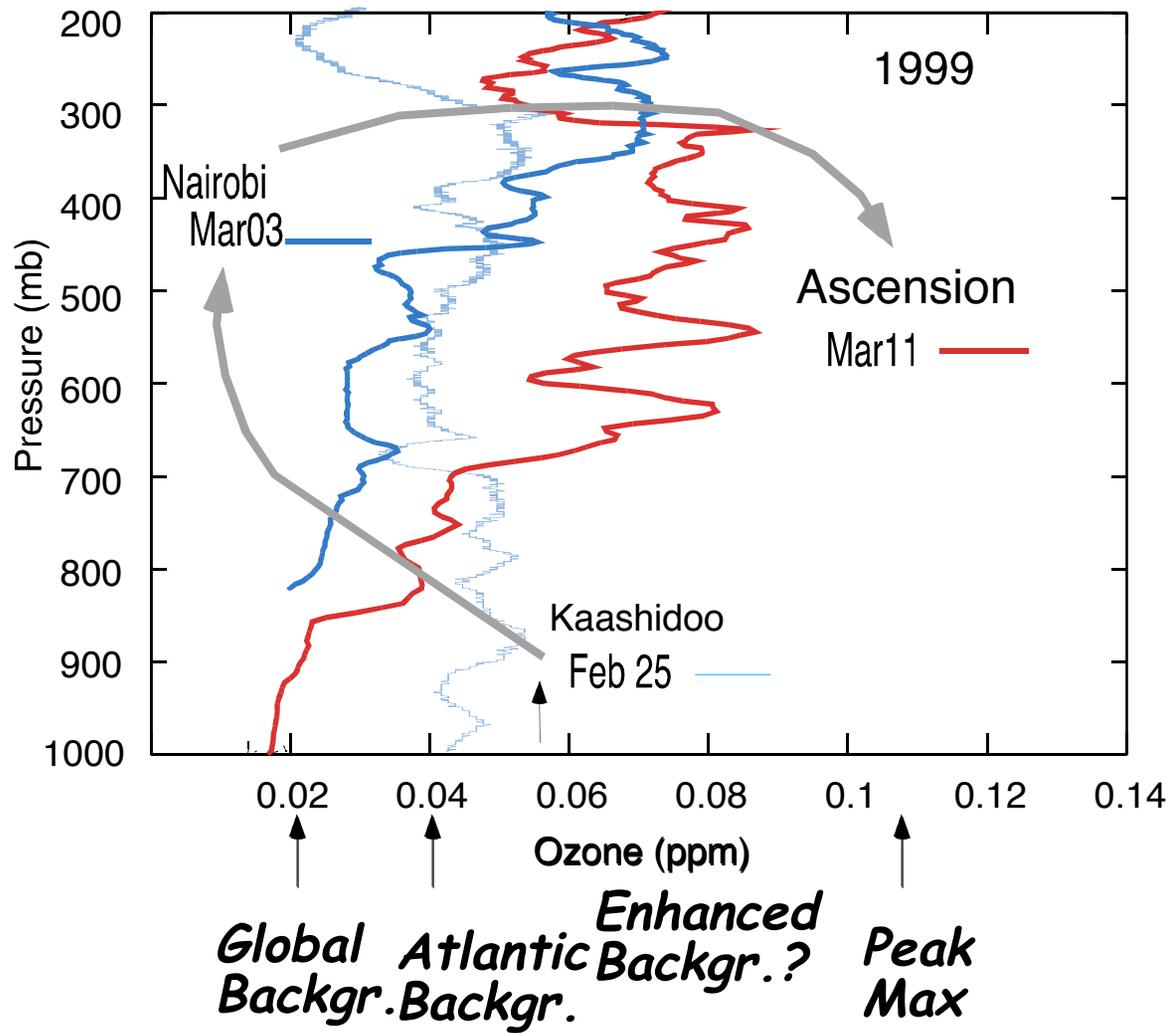


Global Backgr. Backgr. Atlantic Backgr. Enhanced Backgr.? Peak Max

Global Backgr. Backgr. Atlantic Backgr. Enhanced Backgr.? Peak Max

An analysis of the TTO ozone product along with the Lightning Imaging Sensor product could help explain suggested a W to E transport pattern could explain the highest ozone levels seen in the Ascension Sondes



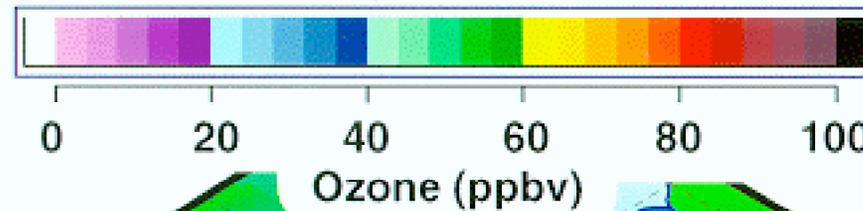


By a great stroke of fortune (or planning), there are 3 ozonesondes which illustrate the transport pattern. The sondes are not exactly along the trajectory, but are linked by common T patterns.

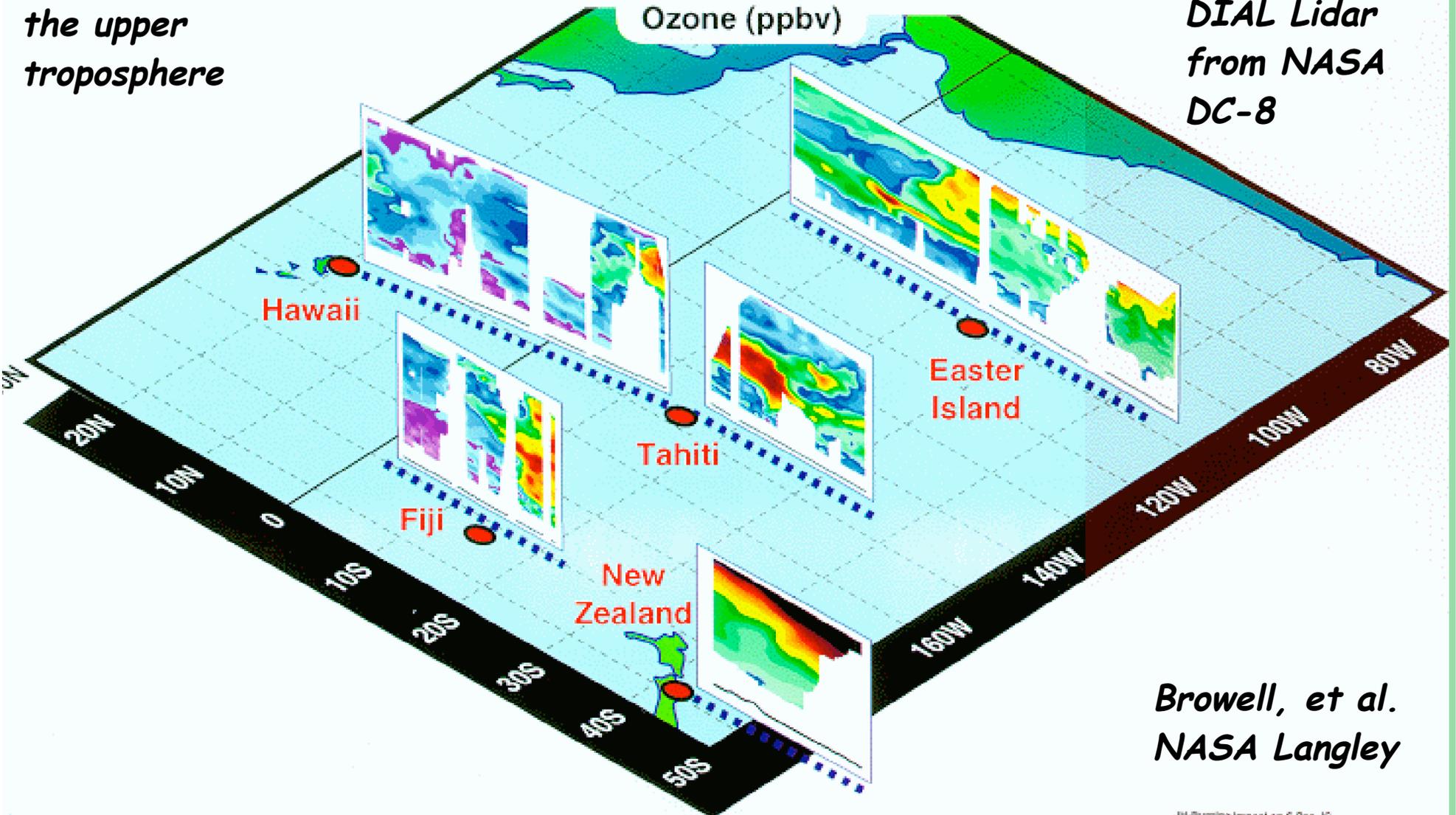
Unexpected Biomass Burning Plumes at ~10000 km; discovered in 1996

Impact of Biomass Burning on the South Pacific

*Ozone pollution
expressed in
the upper
troposphere*



*DIAL Lidar
from NASA
DC-8*



*Browell, et al.
NASA Langley*

Other studies concur ... but it's hard to distinguish stratosphere (high O₃, low CO) from burning influence (high O₃ and CO)

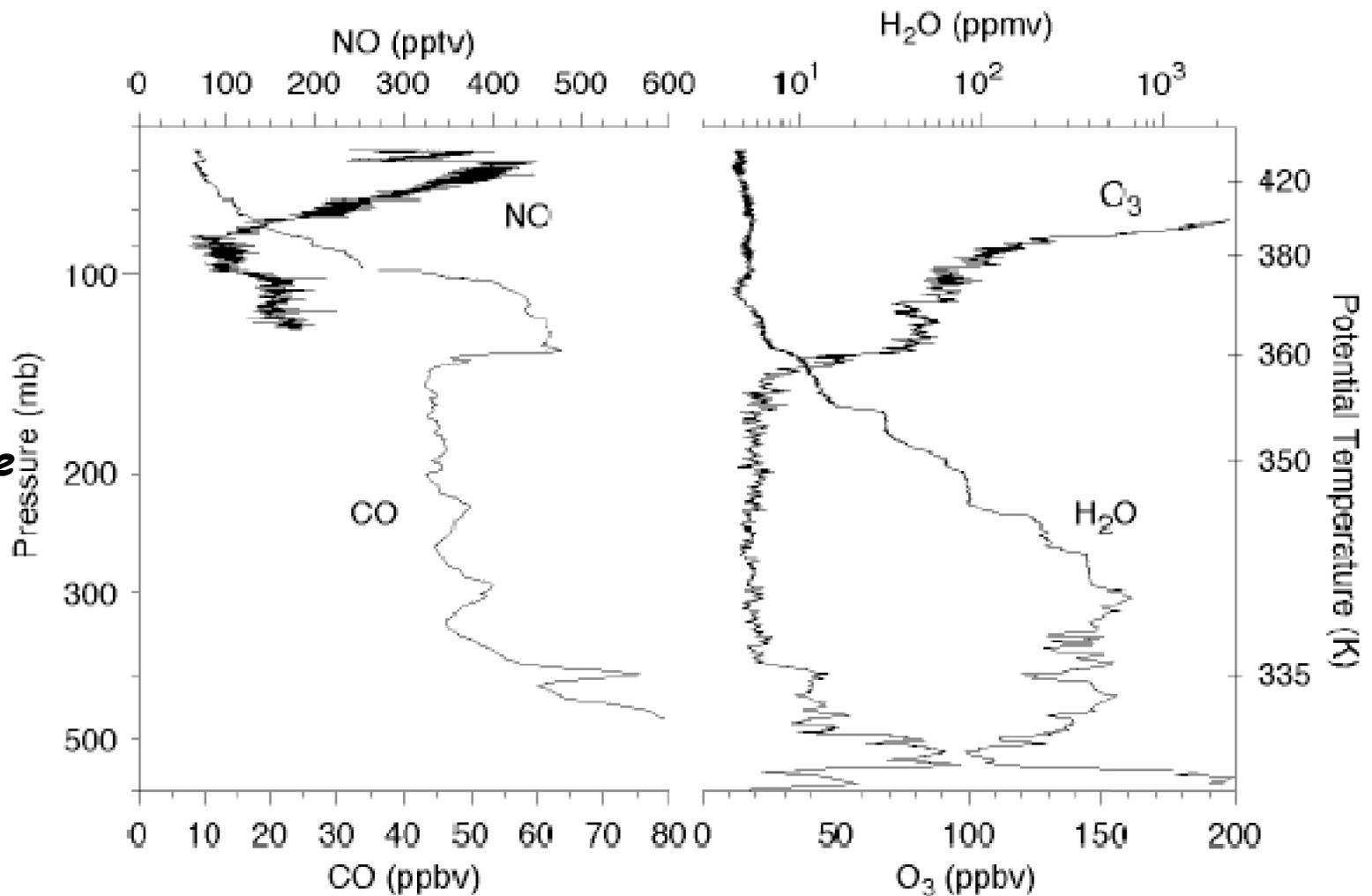
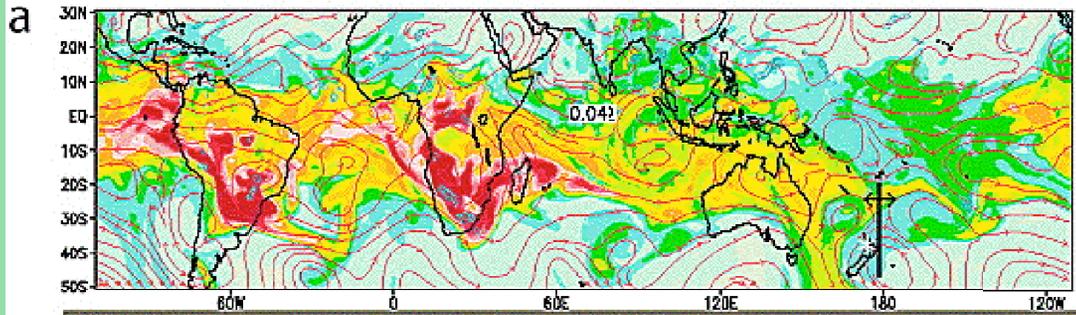
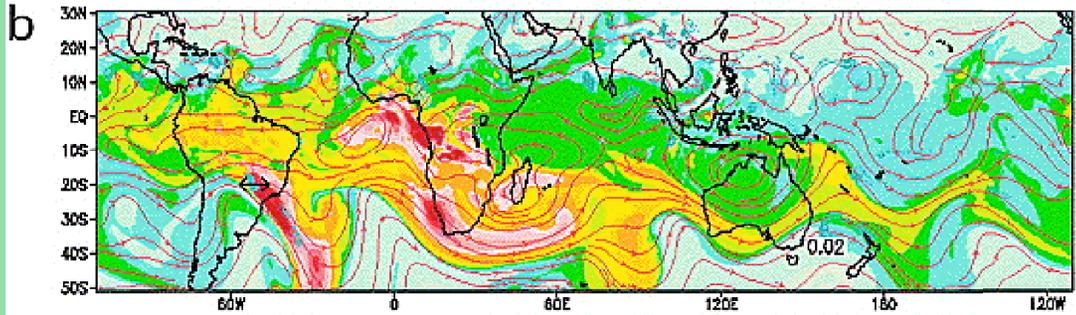


Fig. 3. Analysis of CO, O₃, and H₂O for ER-2 profiles observed during ASHOE-MESA [Folkins et al., 1997]. While the O₃ vertical trend is similar to climatology, CO peaks indicate some upper tropospheric O₃ is clearly determined by vertical venting of burning emissions.

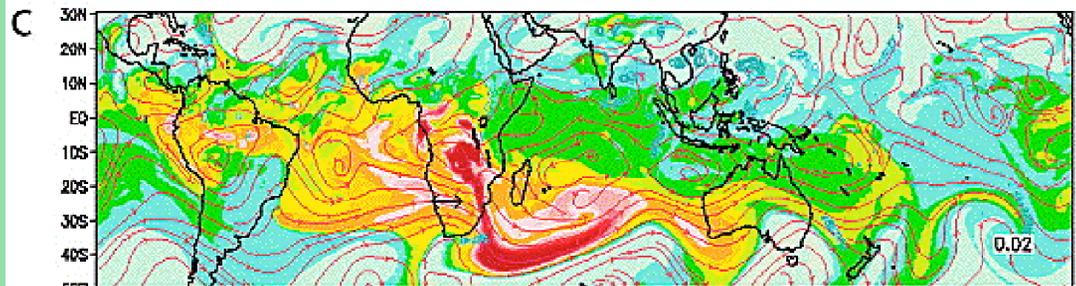
CO from surface emission, 3.26681 km, 00Z24SEP1996



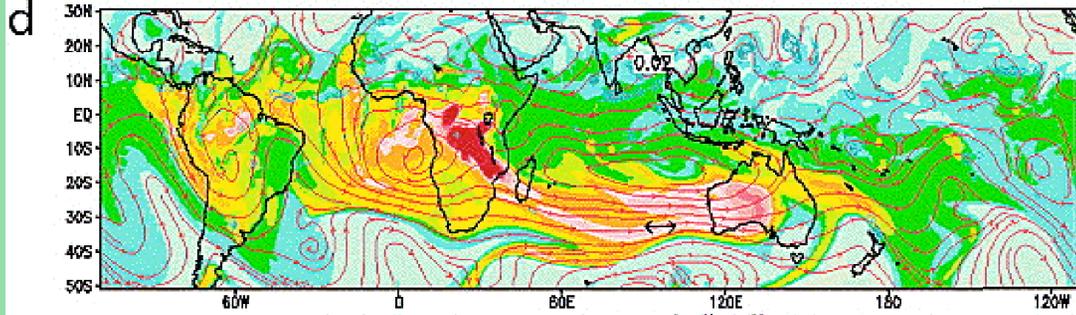
CO from surface emission, 8.39953 km, 00Z10SEP1996



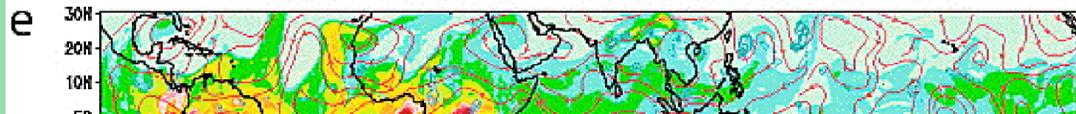
CO from surface emission, 8.39953 km, 00Z13SEP1996



CO from surface emission, 8.39953 km, 00Z15SEP1996



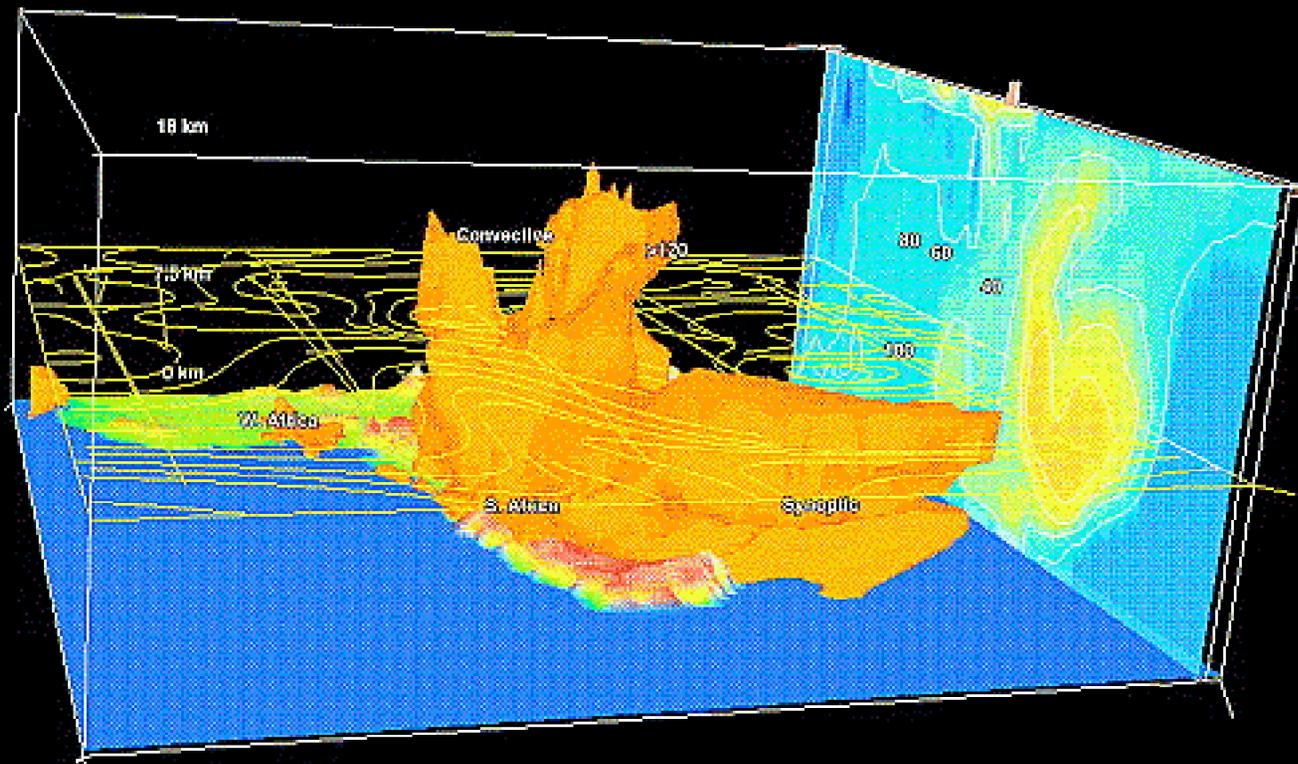
CO from surface emission, 8.39953 km, 00Z17SEP1996



A simulation of CO indicated origins of the Southern Pacific plumes in large-scale lofting from Africa and South America.

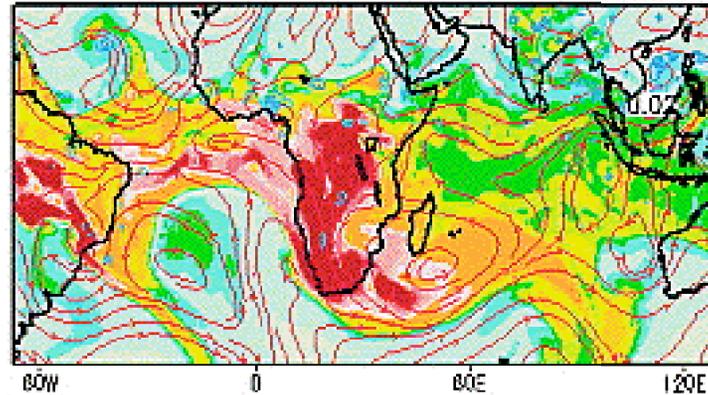
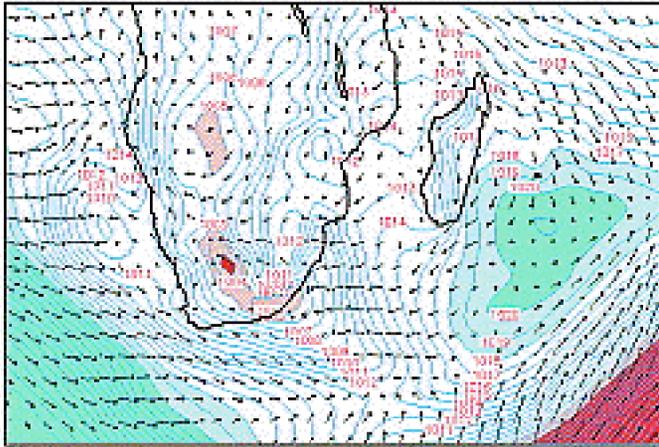
Chatfield et al., 2002

A 3-d image of CO pollution being exported from Africa via mid-latitude convection and a subtropical warm front over S. Africa and the Indian Ocean.

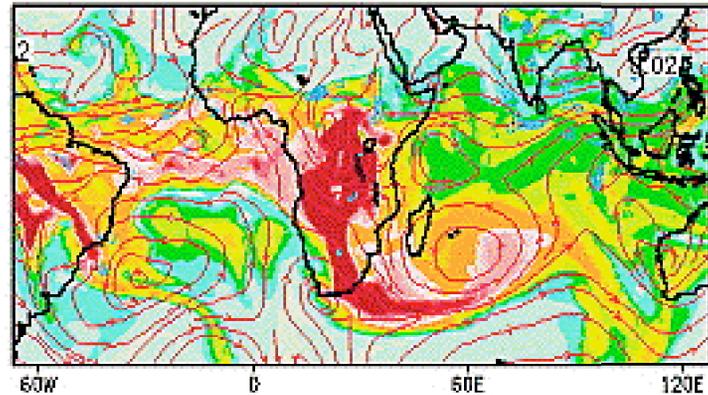
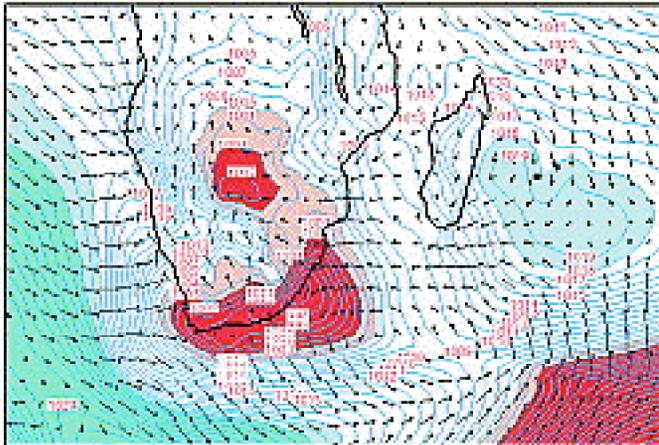


Origins of this megaplume were from a large synoptic front over South Africa and the Westernmost Indian Ocean

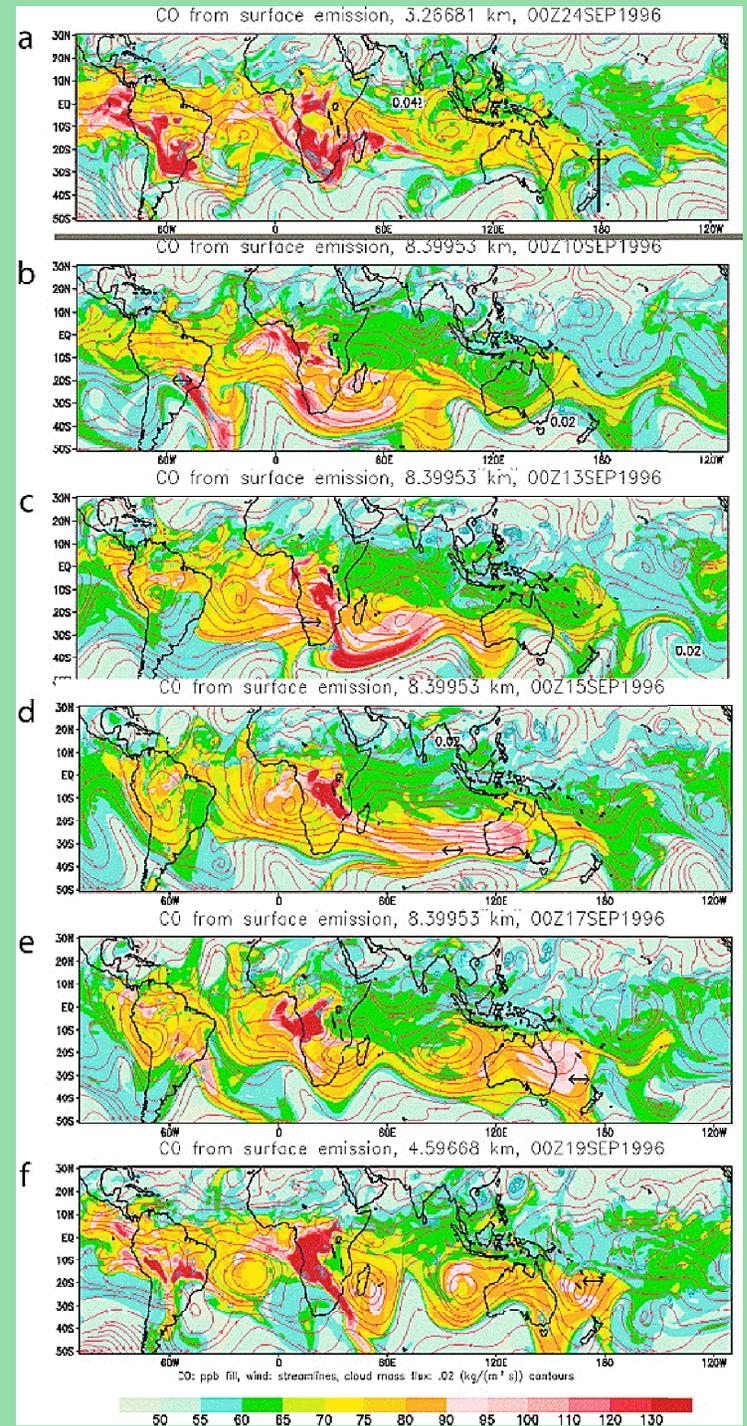
Surface Wind & SLP , 12Z11SEP1996



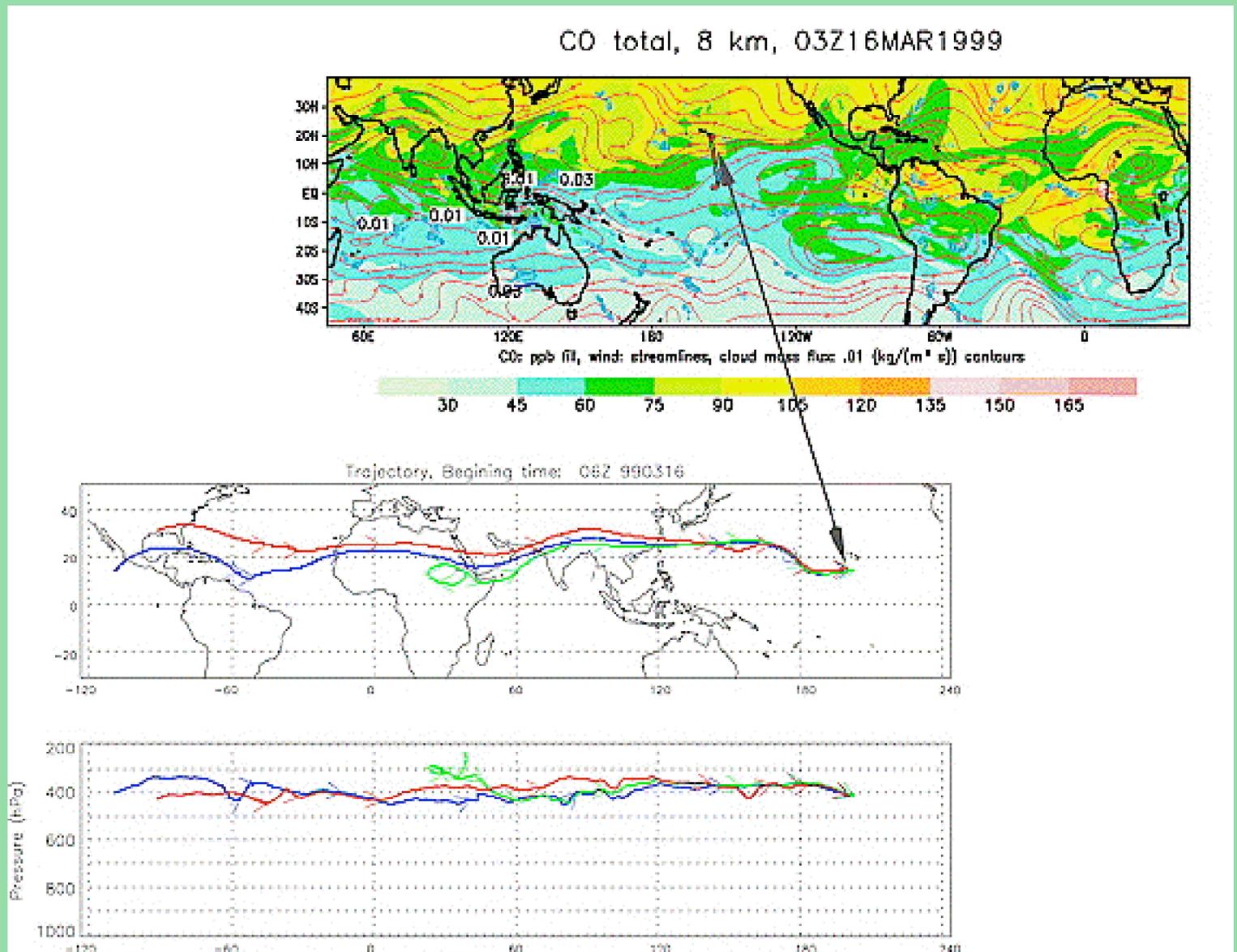
Surface Wind & SLP , 12Z12SEP1996



Show Movie Here



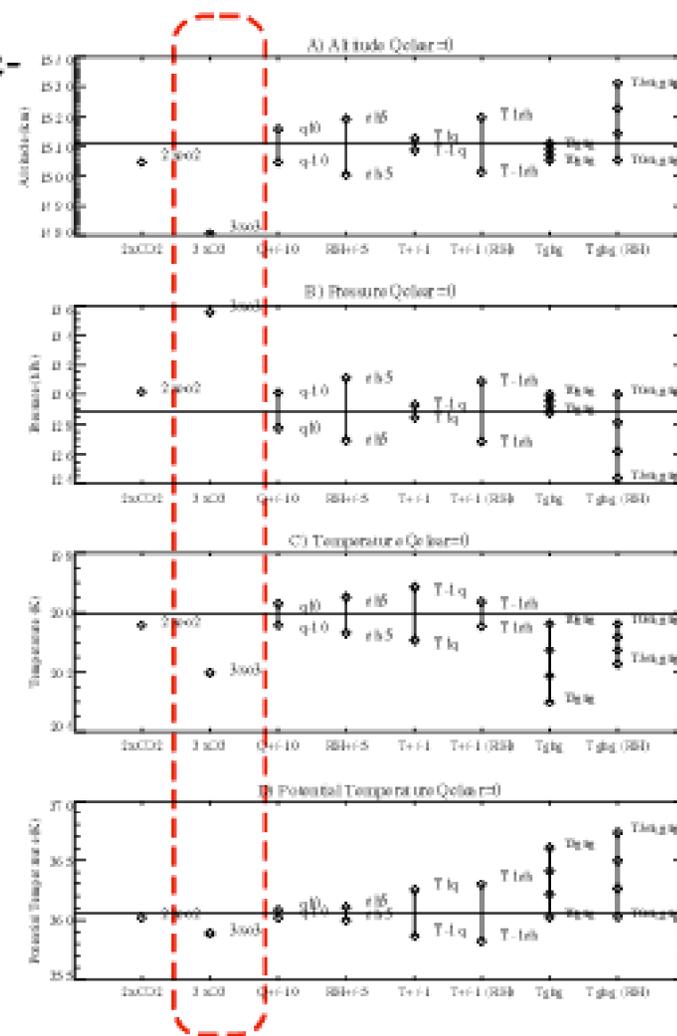
Subtropical Global Plumes also occur in the Northern Hemisphere
PEM-Tropics B



Movie

What are the reasons for variability in
 • the free-tropospheric ozone column, especially UT ozone?
 ... where ozone is an extremely variable, radiatively important trace species

**Upper Tropospheric
 Ozone is
 climatically
 important!**



Gettleman et al., 2003 (submitted)
 The radiation balance of the tropopause transition layer

O₃ variation has strong effects on Upper-Troposphere and Tropopause-Transition Layer structure ... compared to other greenhouse gases and "standard" H₂O effects

**See also Mickley et al.,
 JGR, 2001**

Pollution Plume Transport of Ozone

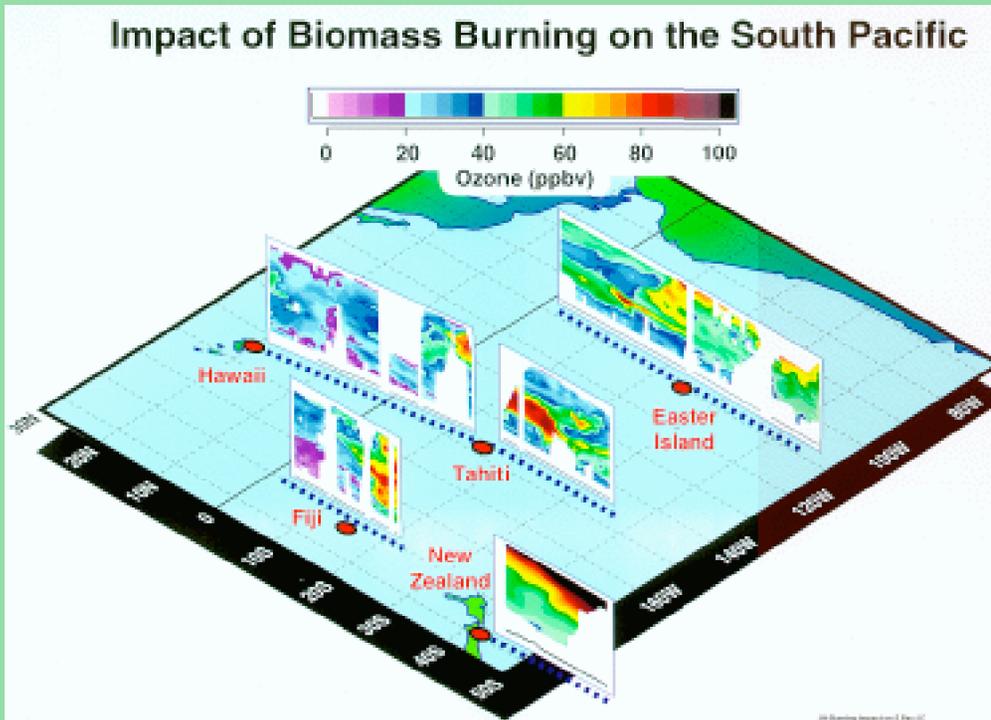
1,000 to 10,000 km

Robert Chatfield

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Chatfield et al., *Geophys. Res. Lett.* 2004.



Summary:

Evolution of plume ideas.

- *Boundary layer lofting*
- *Convective lofting*
- *Warm frontal lofting*

Different species have different plumes, upper or lower troposphere.

Importance to global climate

