LITE OBSERVATIONS OF BIOMASS BURNING OVER SOUTH ATLANTIC BASIN

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ABSTRACT

Large-scale distributions of plumes from biomass burning regions in South America and Africa were observed from space by the LITE (Lidar In-space Technology Experiment) system during the STS-64 Shuttle mission in September 1994. Simultaneous three-wavelength aerosol backscatter measurements were made by LITE on many orbits over South America, Africa, and the tropical South Atlantic Ocean during the 11-day mission to study the distribution and long-range transport of biomass burning plumes and the impact of these plumes on the chemistry of the troposphere in the southern hemisphere. During this mission, plumes from extensive fires in South America and Africa were observed by LITE near their source and in outflow regions over the southern Atlantic and over the Pacific west of Peru. Advection of the plumes was observed primarily below 5 km, and long-range transport of these plumes over large regions of the tropical southern Atlantic was also observed. The spatial distribution and optical characteristics of the biomass burning plumes are discussed in this paper, and these observations are compared to airborne lidar measurements of biomass burning plumes made over this same region during 1992.

INTRODUCTION

Biomass burning can have a major impact on the chemistry of the troposphere by introducing gases that are precursors to ozone production and emitting aerosols that can play a role in heterogeneous chemistry and the redistribution of trace elements between ecosystems. In addition, biomass burning has an influence on the radiation budget of the Earth by contributing to the increase of greenhouse gases, such as carbon dioxide, methane, carbon monoxide, and ozone, and by the direct and indirect effects of aerosols. These aerosols can increase the Earth's albedo over land and water and decrease the albedo over clouds. Aerosols can also lower surface temperatures and modify the distribution, lifetimes, and precipitation of clouds in the same air mass.

The Lidar In-space Technology Experiment (LITE) [Couch et al., 1991; McCormick et al., 1993] was flown on the Space Shuttle Discovery (STS-64) between September 9 and September 20, 1994. LITE produced the first space-based lidar measurements of the atmosphere, and many orbits of lidar data were obtained over the South Atlantic Basin. Simultaneous lidar measurements of atmospheric backscatter were made at 1064, 532, and 355 nm. Early analysis of the aerosol data from these measurements has been limited to the 532 and 355 nm channels due to low signal-to-noise levels in the 1064-nm channel for non-cloud applications. The aerosol scattering ratio profiles were determined from the LITE measurements at 532 and 355 nm, and wavelength dependence of the aerosol backscattering was calculated for selected aerosol layers thought to be from biomass burning regions.

LITE measurements of biomass burning aerosols were compared to multiple-wavelength airborne lidar measurements [Browell, 1989; 1995] made during the NASA Global Tropospheric Experiment (GTE) - TRansport and Atmospheric Chemistry Experiment - Atlantic (TRACE-A) field experiment conducted in September-October 1992 [Browell et al., 1996]. The main objective of TRACE-A was the investigation of the impact of biomass burning on the chemistry across the South Atlantic Basin. Simultaneous measurements above and below the aircraft were made with the airborne lidar system at 1064 and 600 nm. The airborne lidar measurements of aerosols from biomass burning regions were made in the same region and in the same season as the LITE measurements. Comparisons between the LITE and airborne lidar aerosol data are discussed in the following section.

BIOMASS BURNING MEASUREMENTS

Plumes from many fires in Brazil and Africa were visually observed from Discovery during the LITE mission, and the enhanced aerosols in the plumes were easily seen in the LITE lidar returns obtained over the South Atlantic Basin. A sample of the LITE orbits over this region is shown in Figure 1. This sequence of six orbits (orbit numbers 145-150) provided a large-scale view of this region from eastern Africa and Madagascar to western South America. All of these atmospheric cross sections were obtained by LITE in less than 8 hours, and thus they serve to provide a nearly-instantaneous "snapshot" of biomass burning aerosols over the South Atlantic Basin during the late summer.

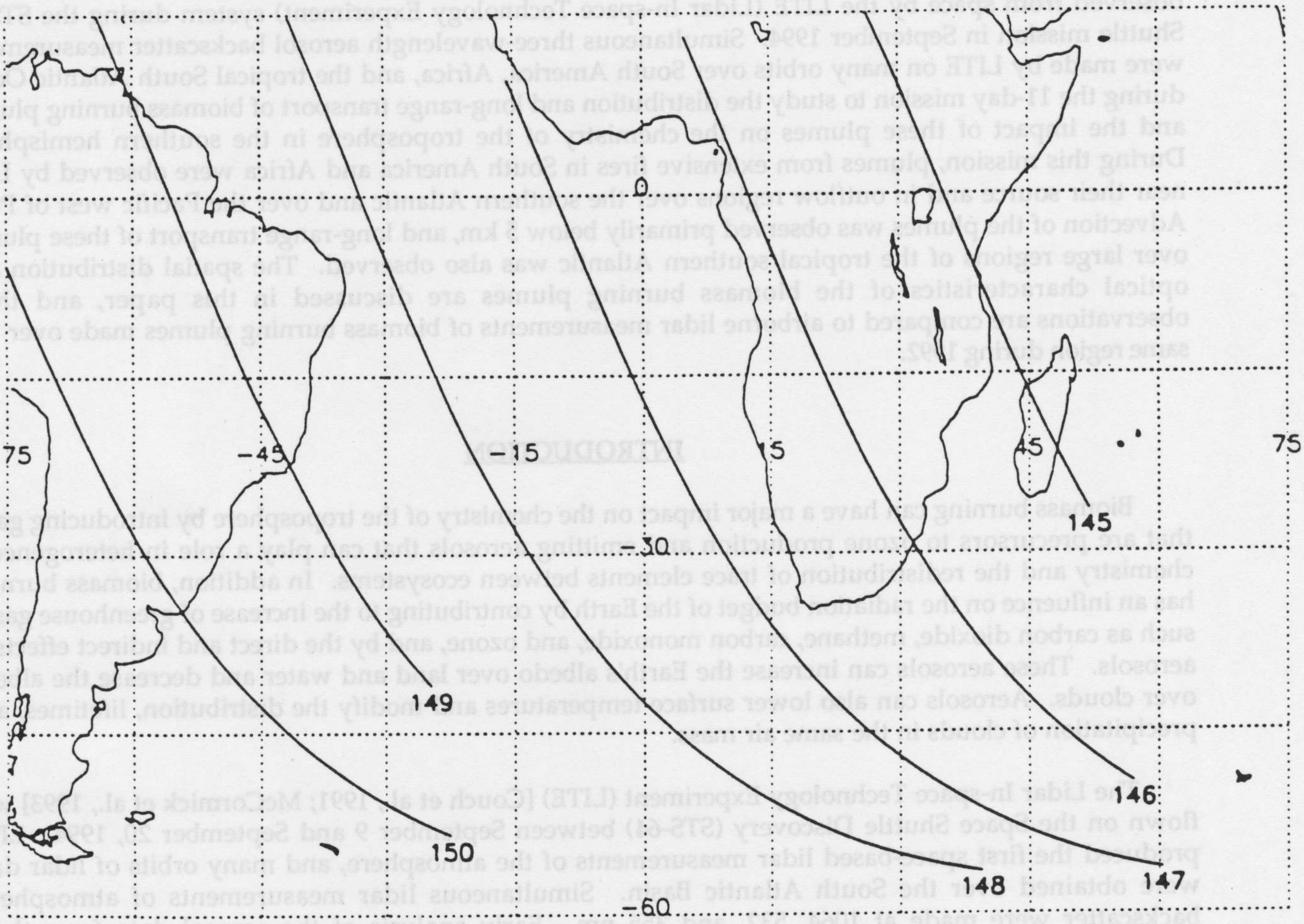

Figure 1. LITE orbits (145-150) across South Atlantic Basin on September 18-19, 1994.

An example of the distribution of aerosols measured by LITE is shown in Figure 2. The plumes from biomass burning over Africa was observed from 4-25°S latitude. A temperature inversion prevented the plumes from rising above 4.5-5.5 km. Dense clouds over central Africa prevented observations of the plumes north of ~4°S. The aerosol scattering ratio (aerosol backscattering, β, divided by molecular backscattering at the lidar wavelength, λ) near the top of the plume at 17°S was 1.13 at 532 nm and 0.30 at 355 nm. The wavelength dependence for aerosol backscattering (α), where it is assumed that $\beta \propto \lambda^{-\alpha}$, was estimated to be 0.6 for this case. Near the fires in central Africa (~3°S on orbit 145) and on the island of Madagascar, the scattering ratios exceeded 2.0 and 0.8 at 532 and 355 nm, respectively. At large distances from the fires, such as observed off the west coast of Africa on orbit 147, the aerosol scattering ratios in the diluted plumes generally decreased to less than 0.4 and 0.11 at 532 and 355 nm, respectively. The region of the advected biomass burning plumes observed on orbits 145-147 was generally below the primary inversion, which was in the altitude range of 4.5-6.0 km.

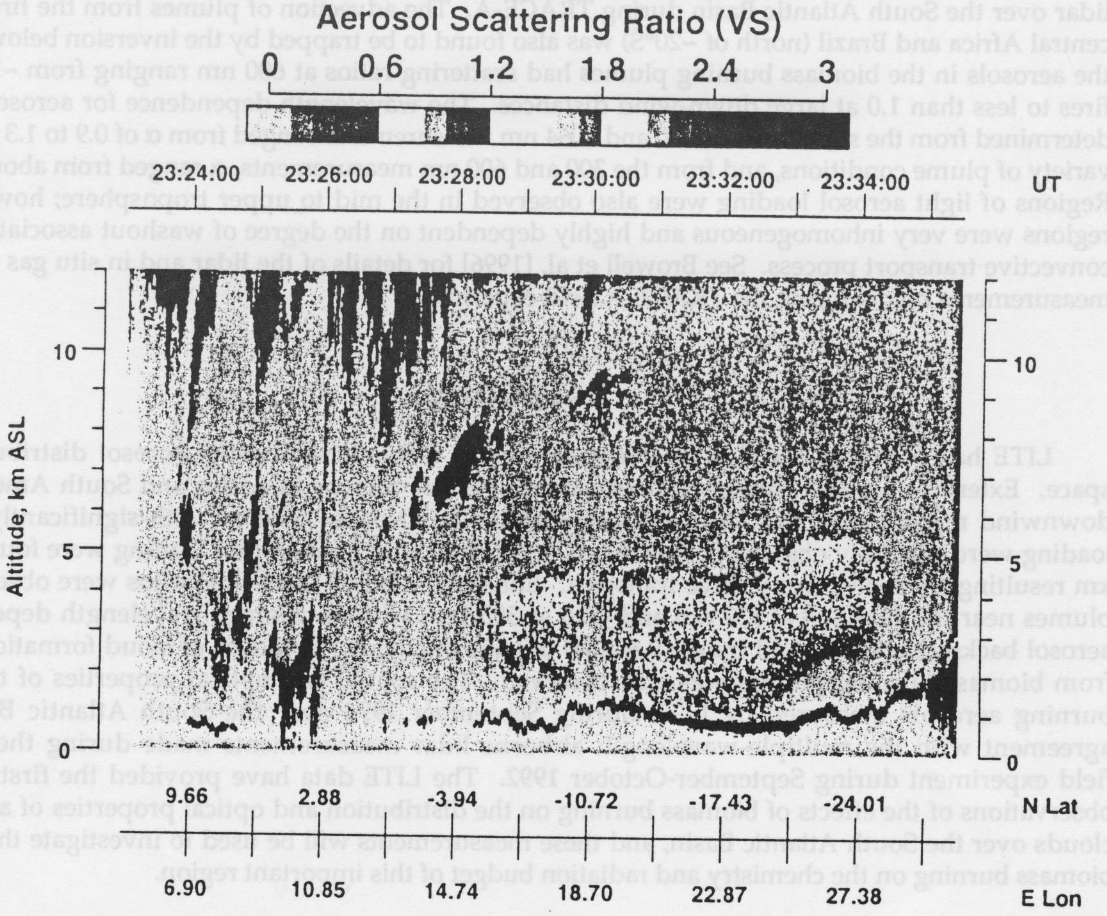

Figure 2. LITE aerosol scattering ratio cross section at 532 nm (VS) along orbit 146 on September 18, 1994.

Regions of light aerosol loading were also observed in the mid to upper troposphere (generally in the altitude range of 6-12 km). On orbit 147, the aerosol scattering ratios were found to be 0.16 and 0.07 at 532 and 355 nm, respectively. The wavelength dependence was found to be about 1.9. This indicates that the size distribution of the aerosols has been shifted to smaller aerosols compared to the aerosols in the directly advected plumes. The presence of enhanced concentrations of gases from biomass burning products with low aerosol loading was investigated as part of the TRACE-A field experiment. Plumes from fires are transported into the mid to upper troposphere through deep convective events over Africa [Browell et al., 1996] (see clouds in Figure 2). The insoluble gases are readily transported in these events while the larger aerosols are washed out of the air leaving only a limited amount of smaller aerosols. This explanation is consistent with the shift in the wavelength dependence of the aerosols observed in the outflow regions in the mid to upper troposphere.

The pall of smoke from burning in Brazil was observed in the visible images from the GOES satellite over large regions of South America east of the Andes mountains. LITE measurements of aerosol distributions over this region confirmed the spatial extent of the plumes from the fires in Brazil. Most of the aerosols were observed to be mixed from near the surface to the main temperature inversion at 3.5-4.0 km. Evidence of plume-induced clouds was also observed in the LITE data on several orbits over South America. Layers with reduced aerosol loading were detected in the 7-12 km range. These layers are thought to be evidence of convective transport of the biomass burning plumes from near the surface to the mid to upper troposphere.

The aerosol characteristics observed by LITE are very similar to those observed with the airborne lidar over the South Atlantic Basin during TRACE-A. The advection of plumes from the fire regions in central Africa and Brazil (north of ~20°S) was also found to be trapped by the inversion below 6 km and the aerosols in the biomass burning plumes had scattering ratios at 600 nm ranging from ~2.8 near the fires to less than 1.0 at large down-wind distances. The wavelength dependence for aerosol scattering determined from the simultaneous 600 and 1064 nm measurements ranged from α of 0.9 to 1.3 over a wide variety of plume conditions, and from the 300 and 600 nm measurements, α ranged from about 0.5 to 1.1. Regions of light aerosol loading were also observed in the mid to upper troposphere; however, these regions were very inhomogeneous and highly dependent on the degree of washout associated with the convective transport process. See Browell et al. [1996] for details of the lidar and in situ gas and aerosol measurements made during the TRACE-A field experiment.

CONCLUSION

LITE has provided the first lidar measurements of biomass burning aerosol distributions from space. Extensive aerosol plumes were observed over fire regions in Africa and South America and in downwind regions over the South Atlantic and Indian Oceans. Plumes with significantly enhanced loading were generally observed below 6 km, and layers with light aerosol loading were found up to 12 km resulting from deep convective transport. Enhanced aerosol scattering ratios were observed in the plumes near the fires ($\leq$4 at 532 nm and $\leq$0.5 at 355 nm) with an average wavelength dependence for aerosol backscattering of 1.18 (range 0.6-1.84) outside of clouds. Evidence of cloud formation resulting from biomass burning plumes was also observed. The spatial and optical properties of the biomass burning aerosols measured by LITE during September 1994 over the South Atlantic Basin are in agreement with the multiple-wavelength airborne lidar measurements made during the TRACE-A field experiment during September-October 1992. The LITE data have provided the first large-scale observations of the effects of biomass burning on the distribution and optical properties of aerosols and clouds over the South Atlantic Basin, and these measurements will be used to investigate the impact of biomass burning on the chemistry and radiation budget of this important region.

REFERENCES

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LITE Observations of Biomass Burning Over South Atlantic Basin

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Importance of Biomass Burning to Atmospheric Studies

Chemistry

Generates greenhouse gases

Associated with tropospheric ozone production in the tropical South Atlantic Ocean

Contributes to redistribution of trace elements, carbon and nitrogen

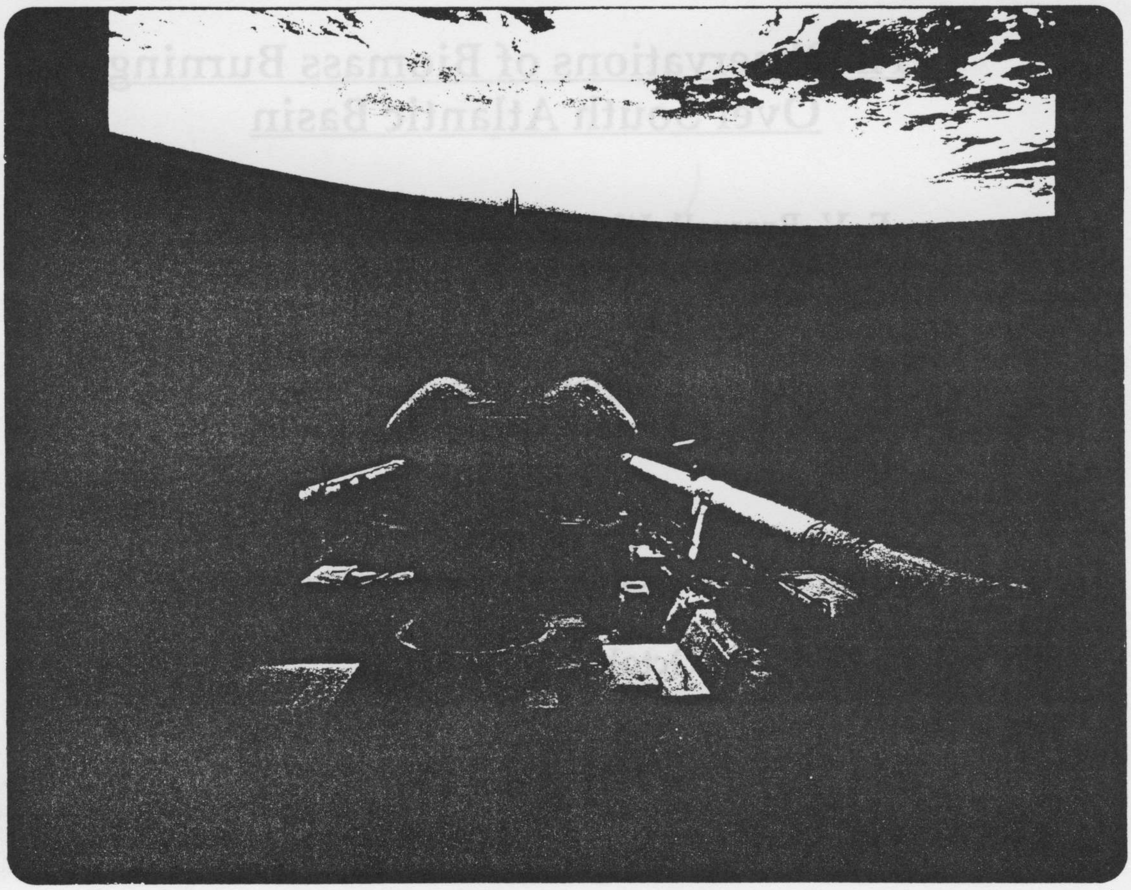
Radiation

Increases the Earth's albedo over land, water

Reduces the Earth's albedo over clouds

Can lower surface temperatures

Affects aerosol size distributions in clouds, thereby changing cloud lifetimes and precipitation rates



WAVELENGTH DEPENDENCE OF AEROSOL BACKSCATTERING

WAVELENGTH DEPENDENT LIDAR EQUATION:

$$P(\lambda,R) = \frac{\gamma(\lambda)\ [B_{AER}(\lambda,R) + B_{MOL}(\lambda,R)]}{R^2}\ \mathrm{EXP}[-2\int_{o}^{R}(\beta_{AER}(\lambda,r) + \beta_{MOL}(\lambda,r))dr]$$

SYSTEM CONSTANT, γ, DETERMINED IN CLEAN REGION WHERE $B_{AER} << B_{MOL}$

AEROSOL SCATTERING RATIO PROFILE:

$$S_{AER}(R) = \frac{B_{AER}(R)}{B_{MOL}(R)} = \frac{P(R)}{B_{MOL}(R)}\frac{B_{MOL}(R_o)}{P(R_o)}\ \frac{R^2}{R_o^2}\ \mathrm{EXP}[+2\int_{R_o}^{R}(\beta_{AER}(r) + \beta_{MOL}(r))dr]$$

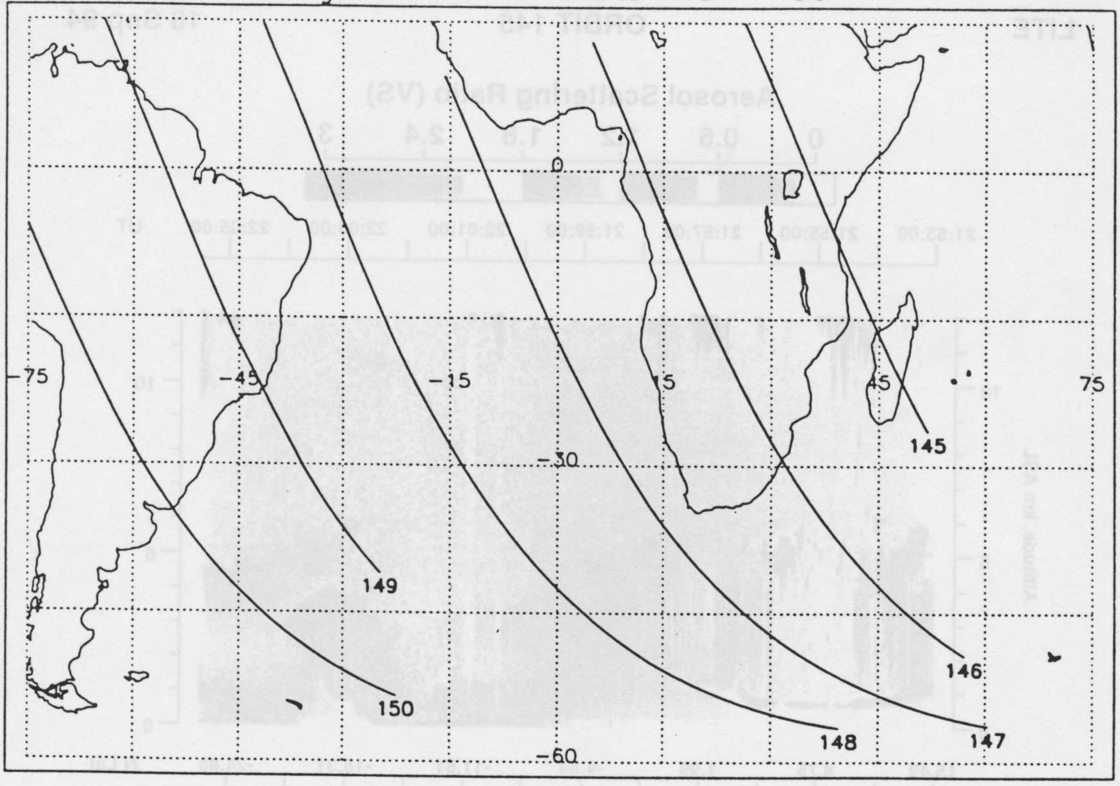
SINCE $B_{MOL}\ \alpha\ \lambda^{-4}$ AND ASSUMING $B_{AER}\ \alpha\ \lambda^{-\alpha}$, THEN $S_{AER}\ \alpha\ \lambda^{4-\alpha}$

WAVELENGTH DEPENDENCE PARAMETER PROFILE DERIVED FROM $S_{AER}(\lambda,R)$ AT TWO λ's

ASSUMING $2\int_{o}^{R}\beta_{AER}(r)dr << 1$

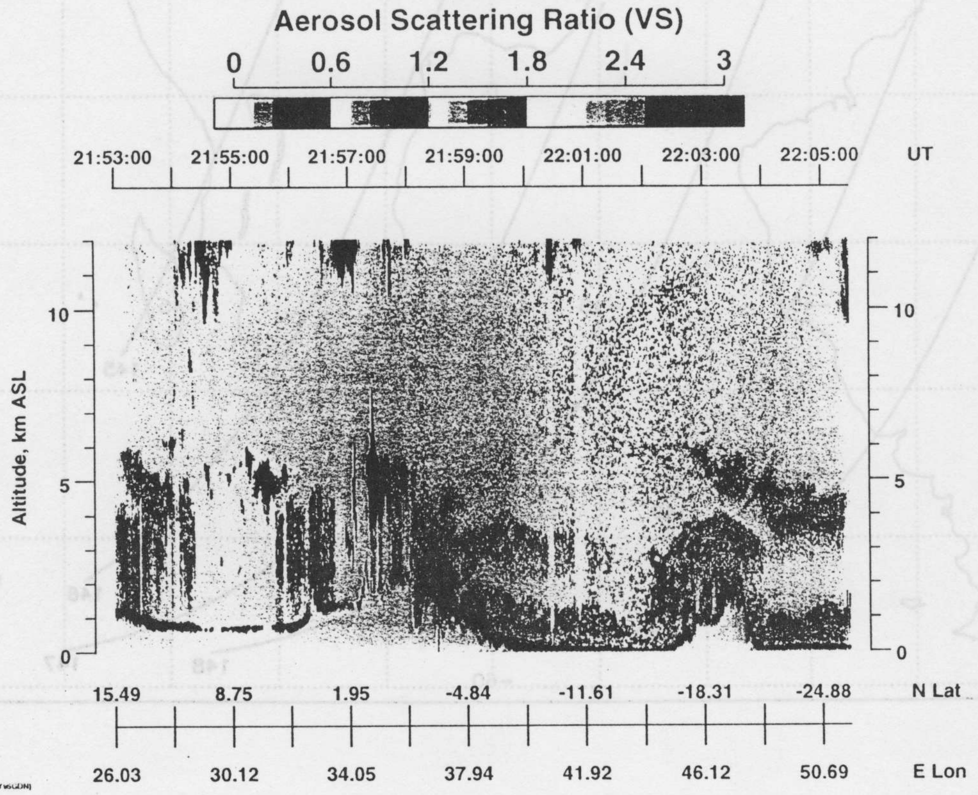
$$\alpha(R) = 4 - \frac{\ln[S_{AER}(\lambda_1,R)/\ S_{AER}(\lambda_2,R)]}{\ln[\lambda_1/\lambda_2]}$$

Flight Tracks For Orbits 145 – 150



High Rate Data

LITE ORBIT 145 18 Sep 94



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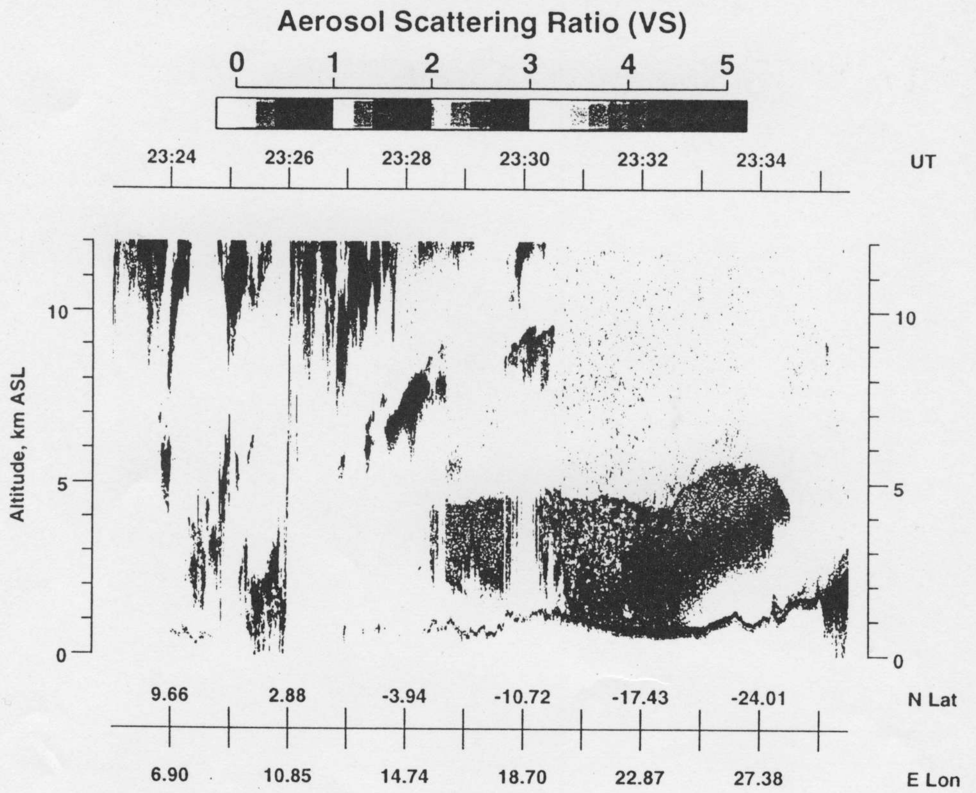
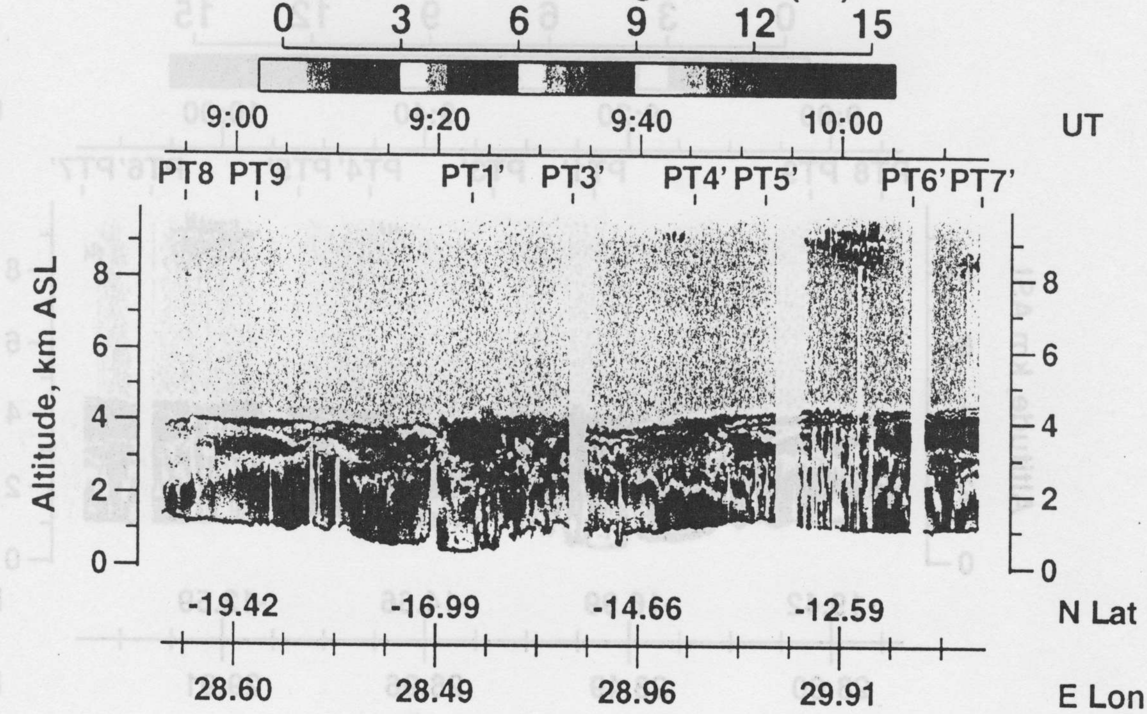


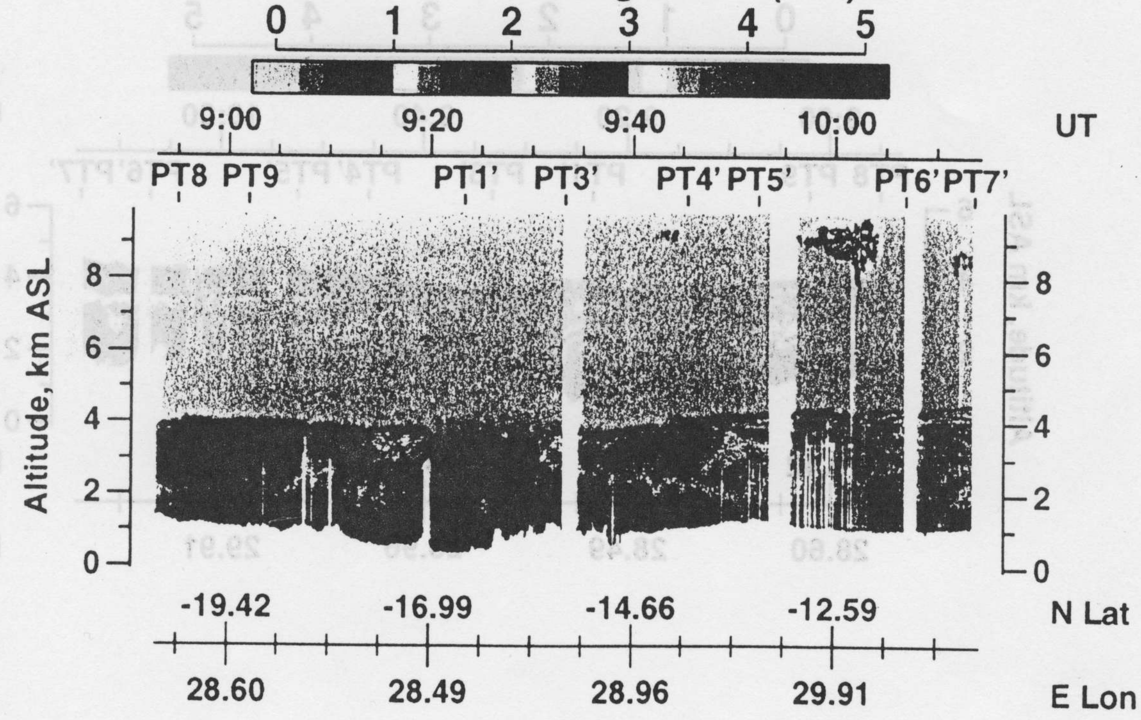
Source Characterization

TRACE-A **Flight 10** **6 Oct 92**

Aerosol Scattering Ratio (IR)

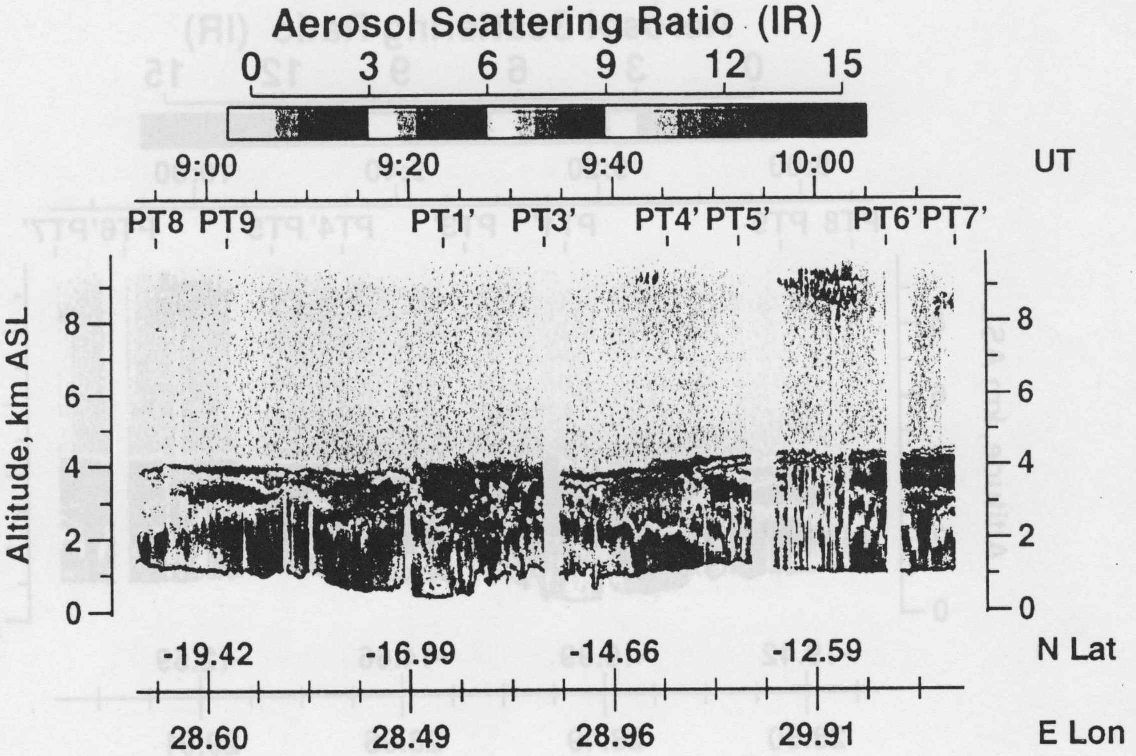


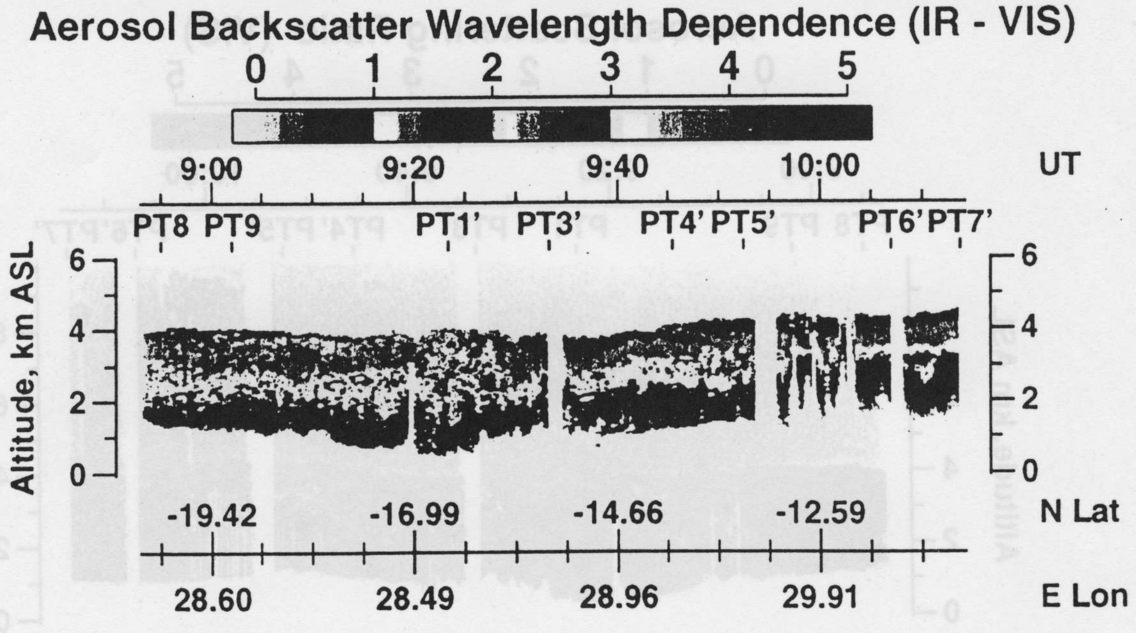
Aerosol Scattering Ratio (VIS)



Source Characterization

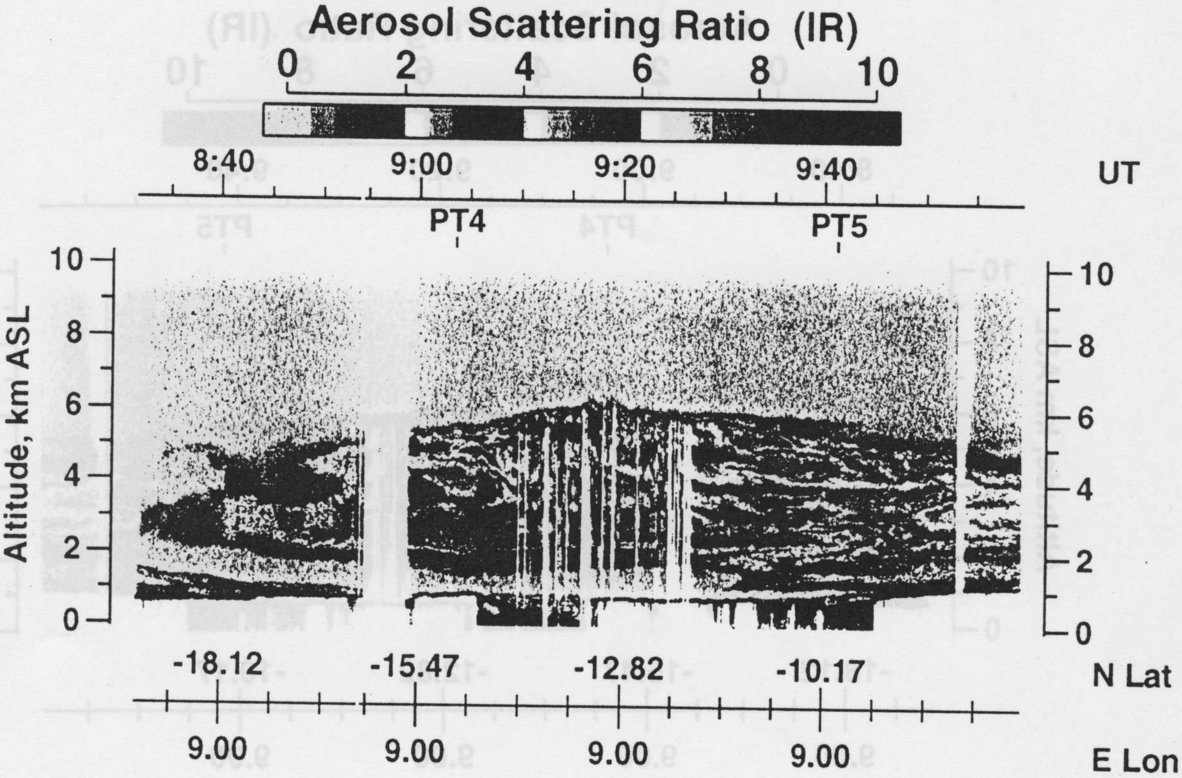
TRACE-A Flight 10 6 Oct 92

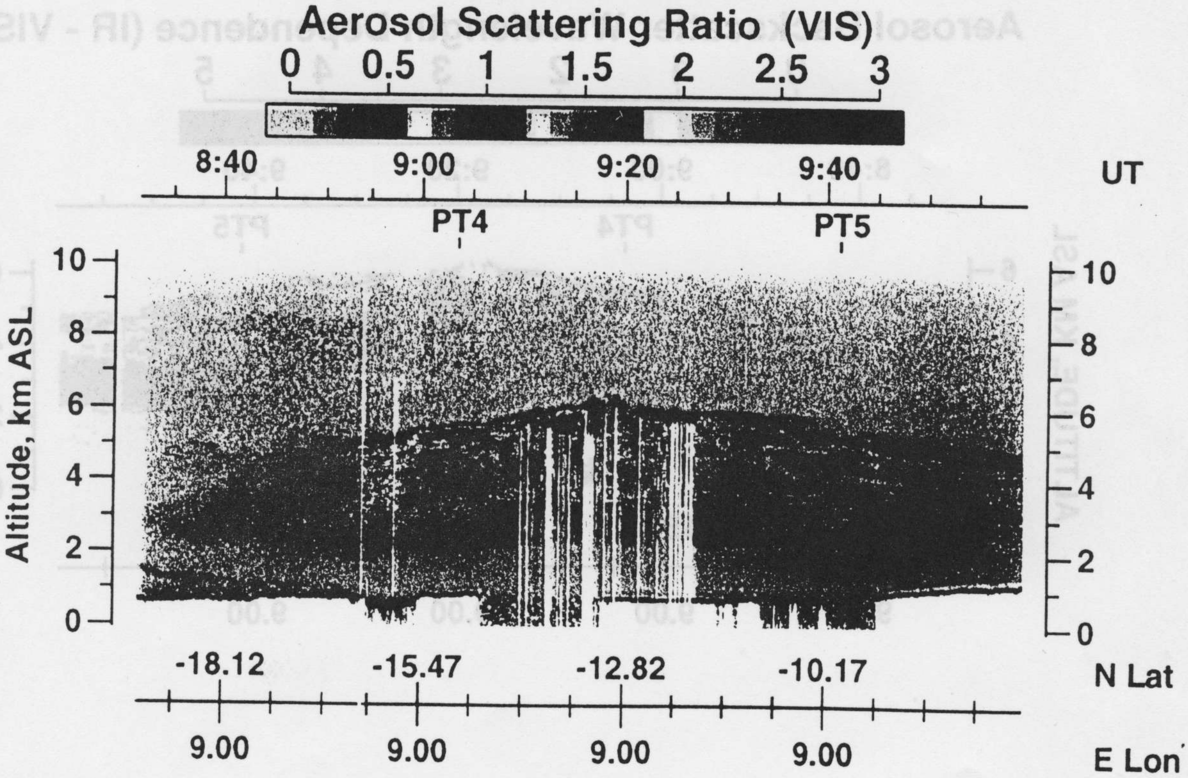




African Outflow - West (Day 1)

TRACE-A Flight 13 14 Oct 92

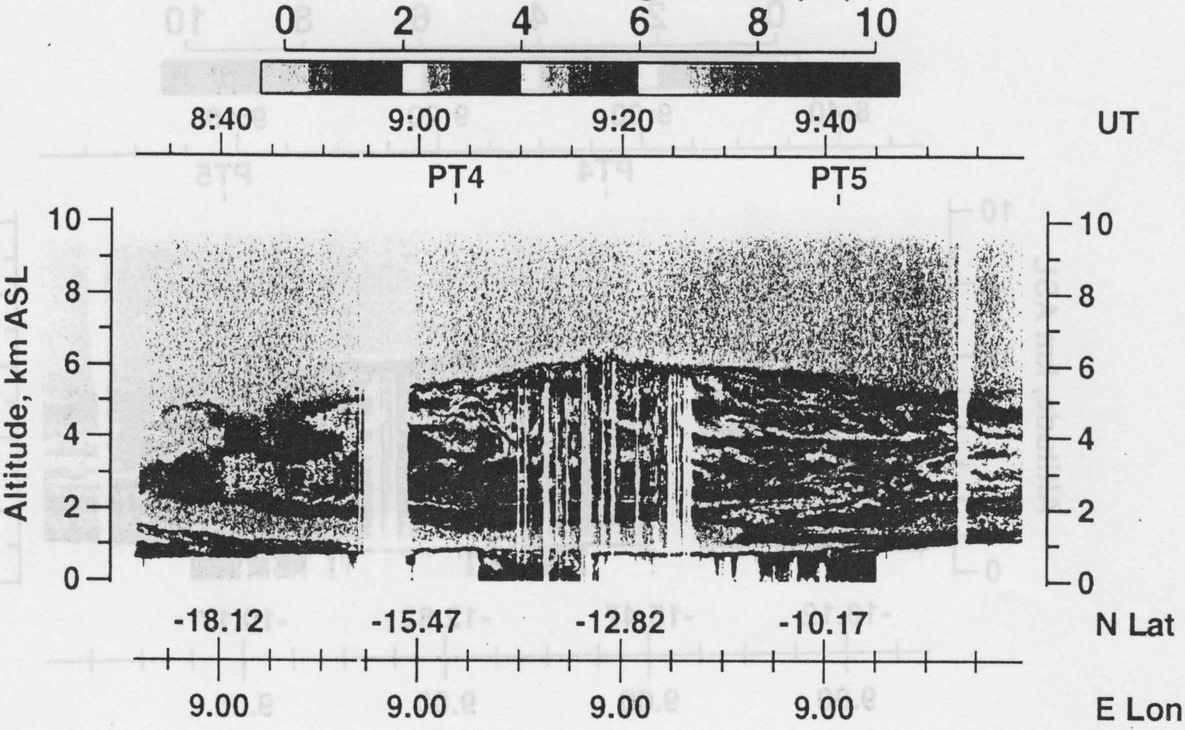




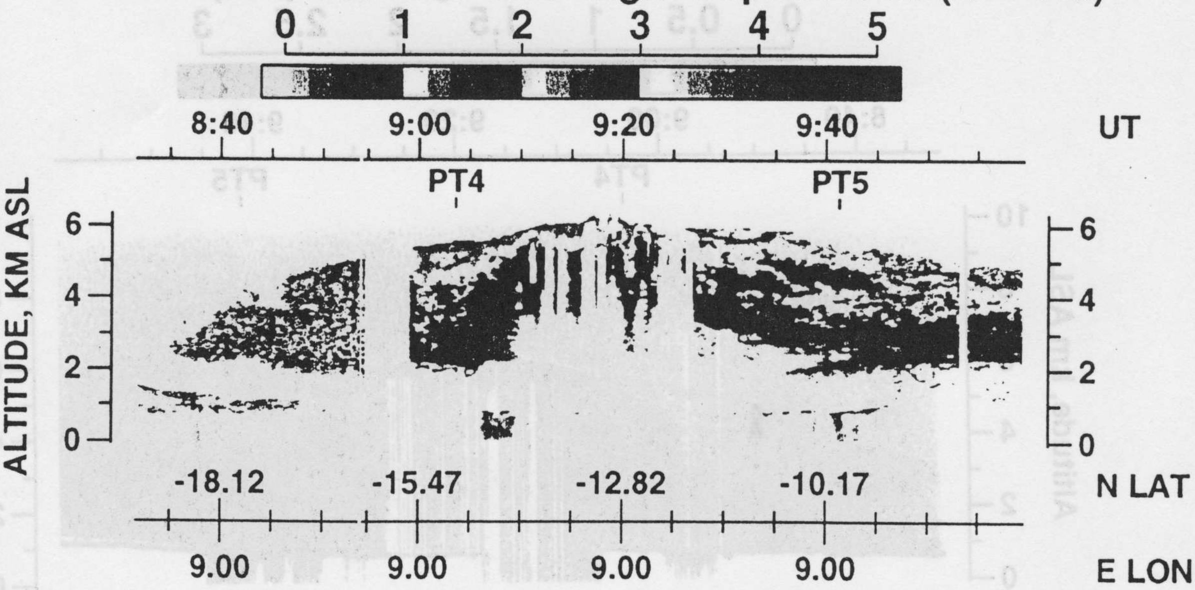
African Outflow - West (Day 1)

TRACE-A **Flight 13** **14 Oct 92**

Aerosol Scattering Ratio (IR)

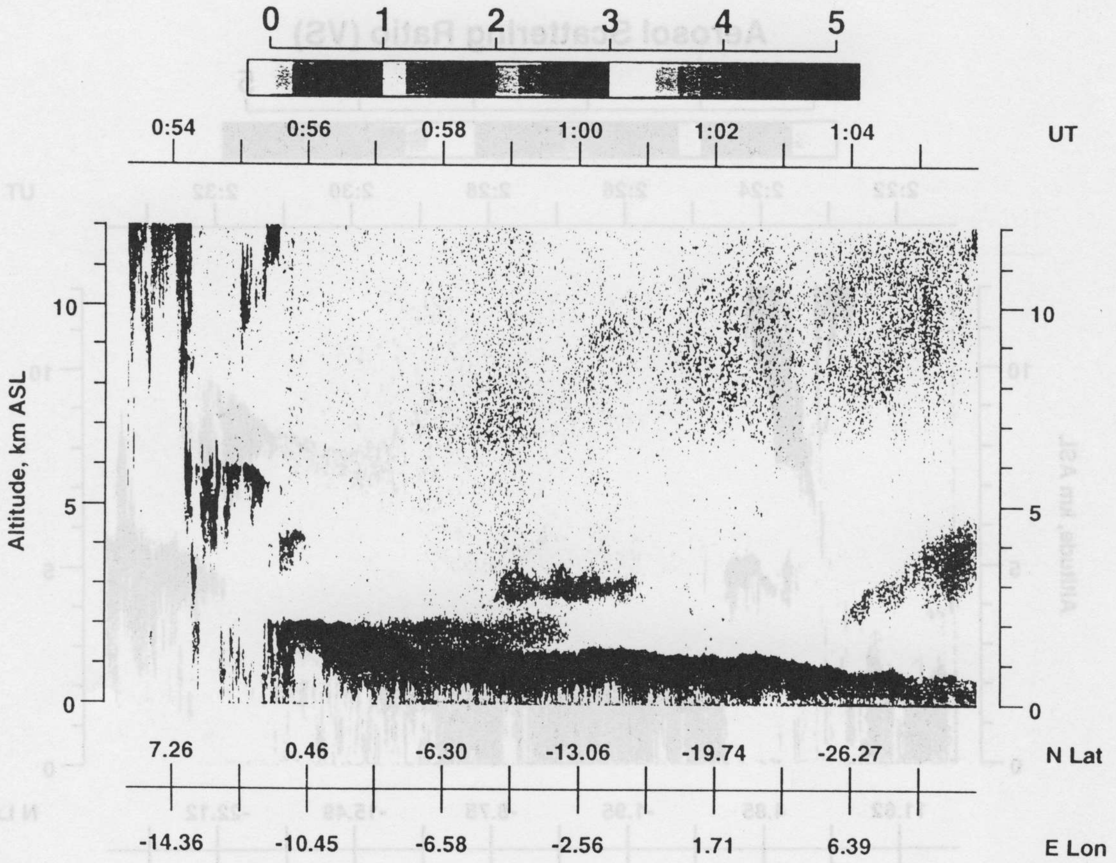


Aerosol Backscatter Wavelength Dependence (IR - VIS)



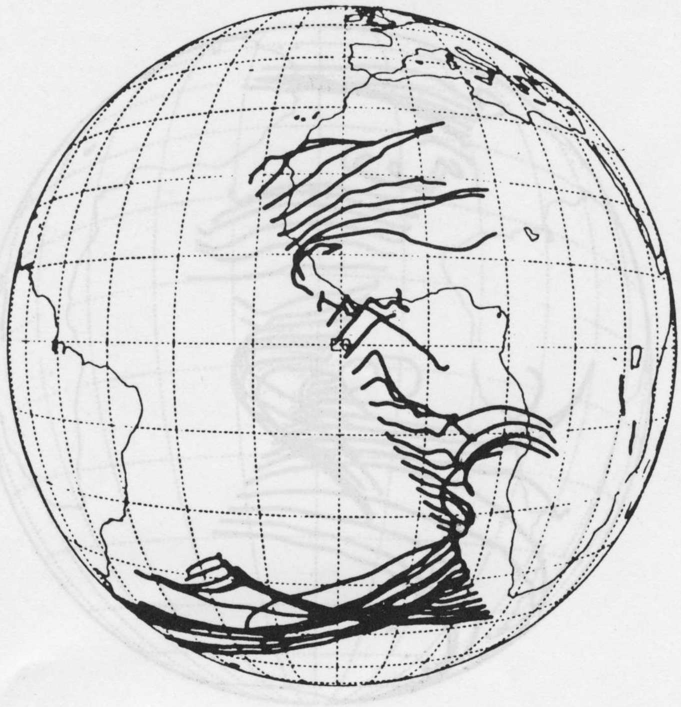
LITE ORBIT 147 19 SEP 94

Aerosol Scattering Ratio (VS)



ECMWF Trajectories 3.0 K

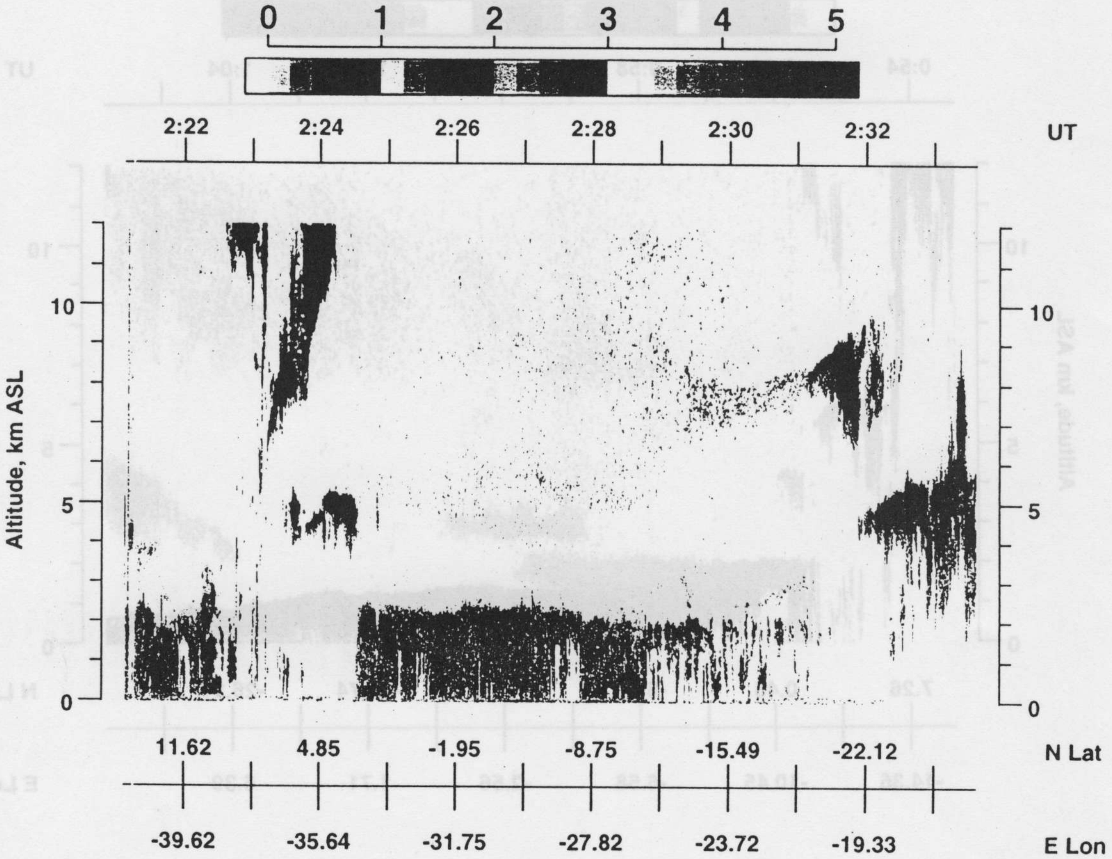
14 Sep 1994
19 Sep 1994



High Rate Data

LITE | **ORBIT 148** | **19 SEP 94**

Aerosol Scattering Ratio (VS)



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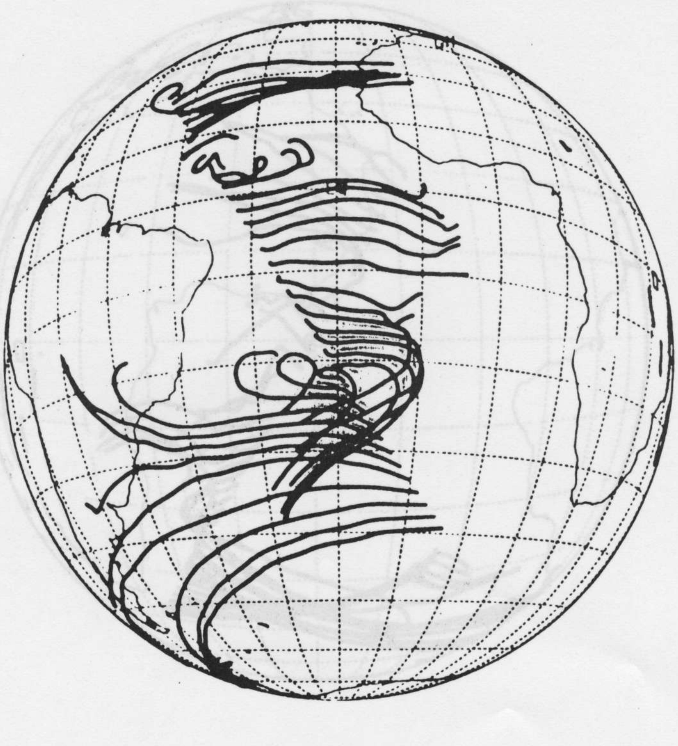


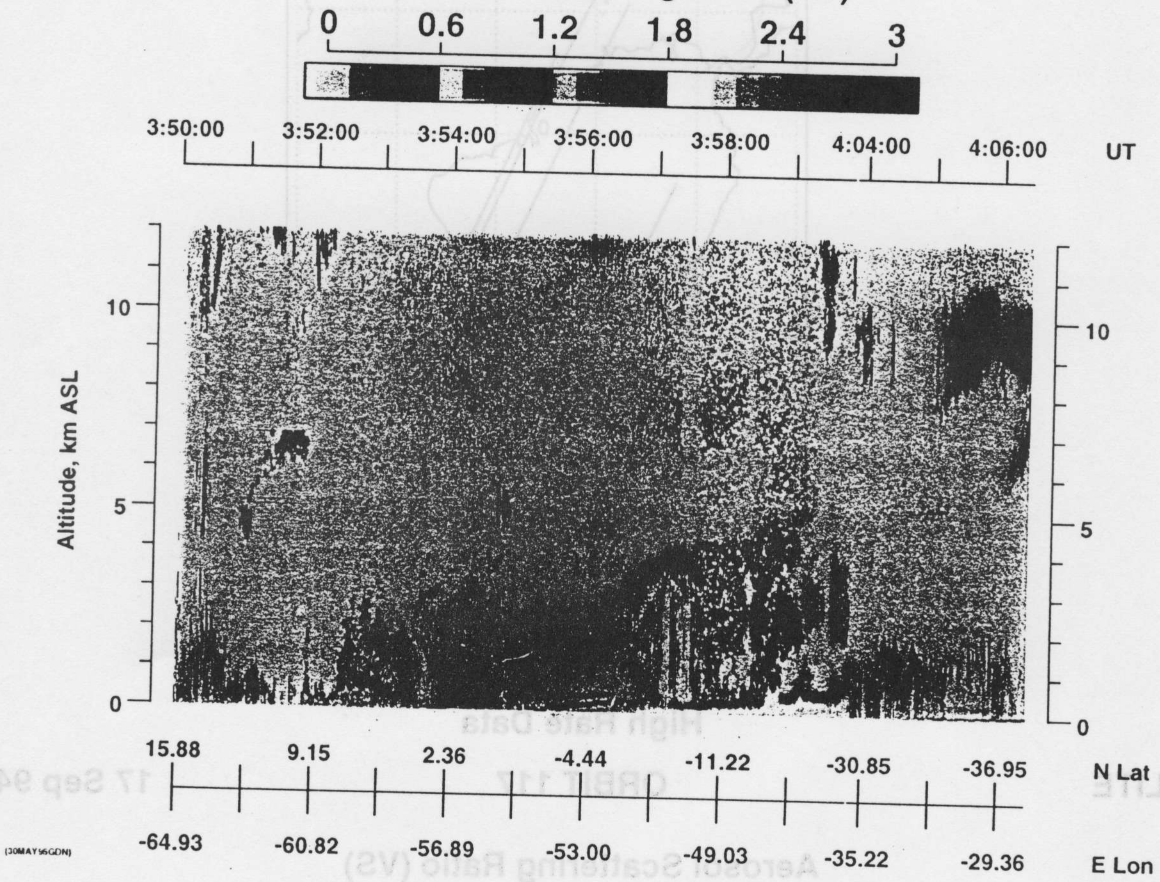
LITE

High Rate Data

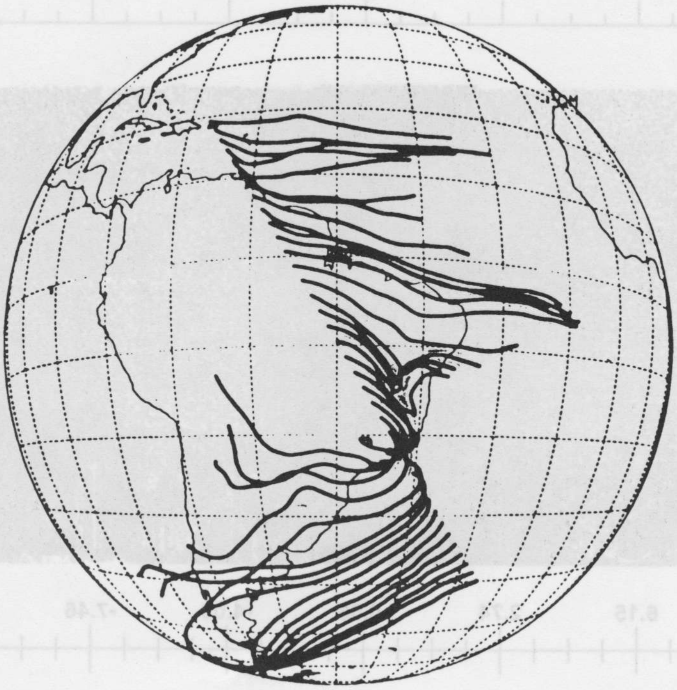
ORBIT 149

19 Sep 94

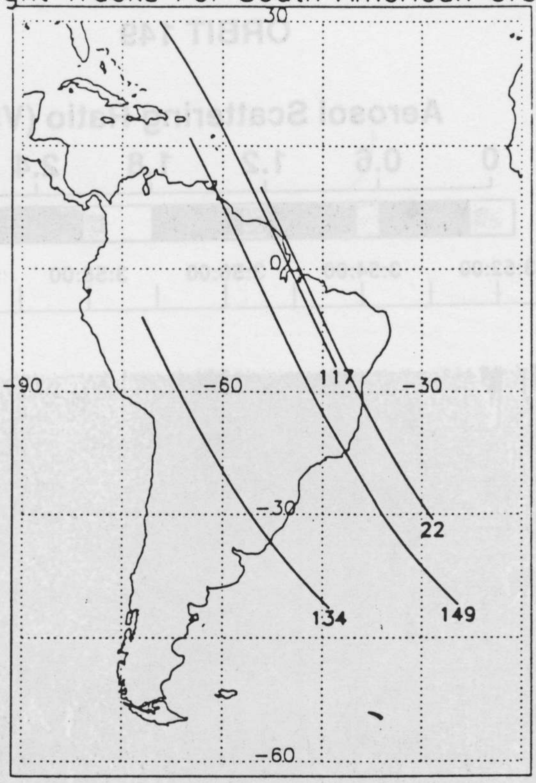
Aerosol Scattering Ratio (VS)



ECMWF Trajectories 3.0 K 14 Sep 1994
19 Sep 1994



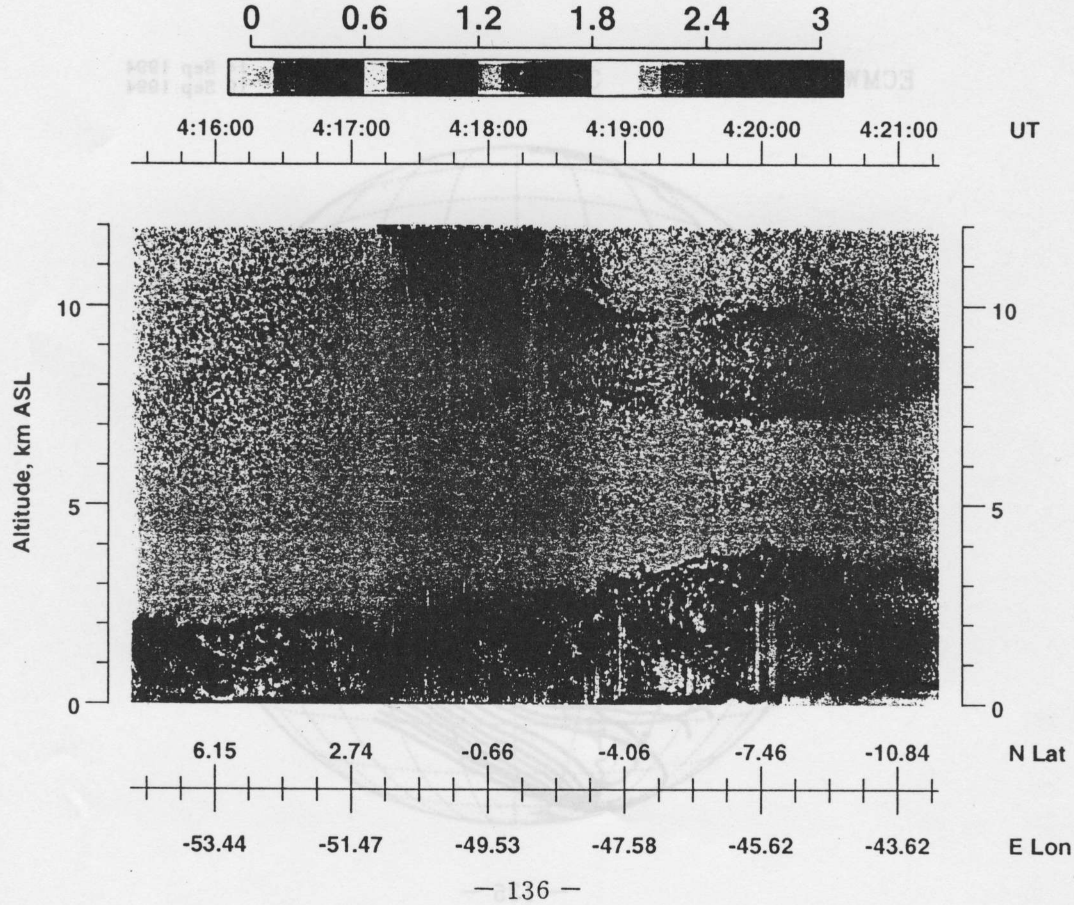
Flight Tracks For South American Orbits



High Rate Data

LITE **ORBIT 117** **17 Sep 94**

Aerosol Scattering Ratio (VS)

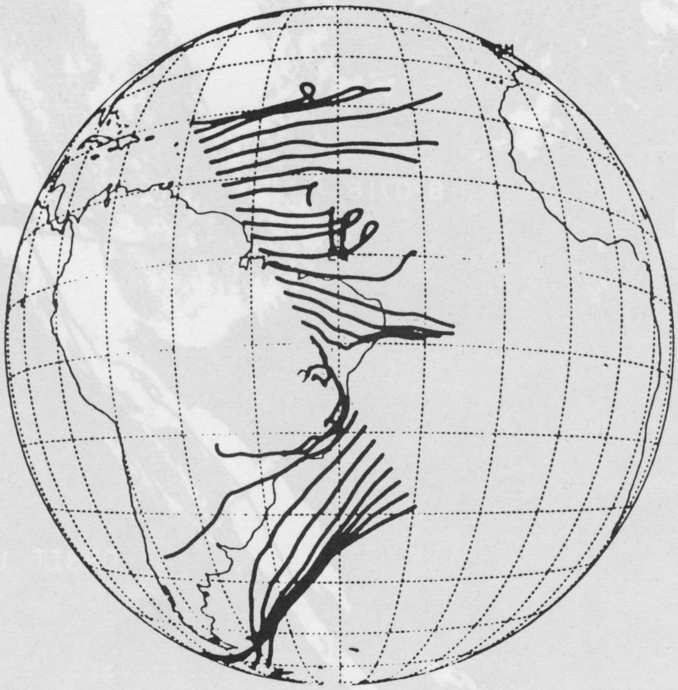


ECMWF Trajectories 1.0 K

12 Sep 1994
17 Sep 1994

ECMWF Trajectories 3.0 K

7 Sep 1994
12 Sep 1994



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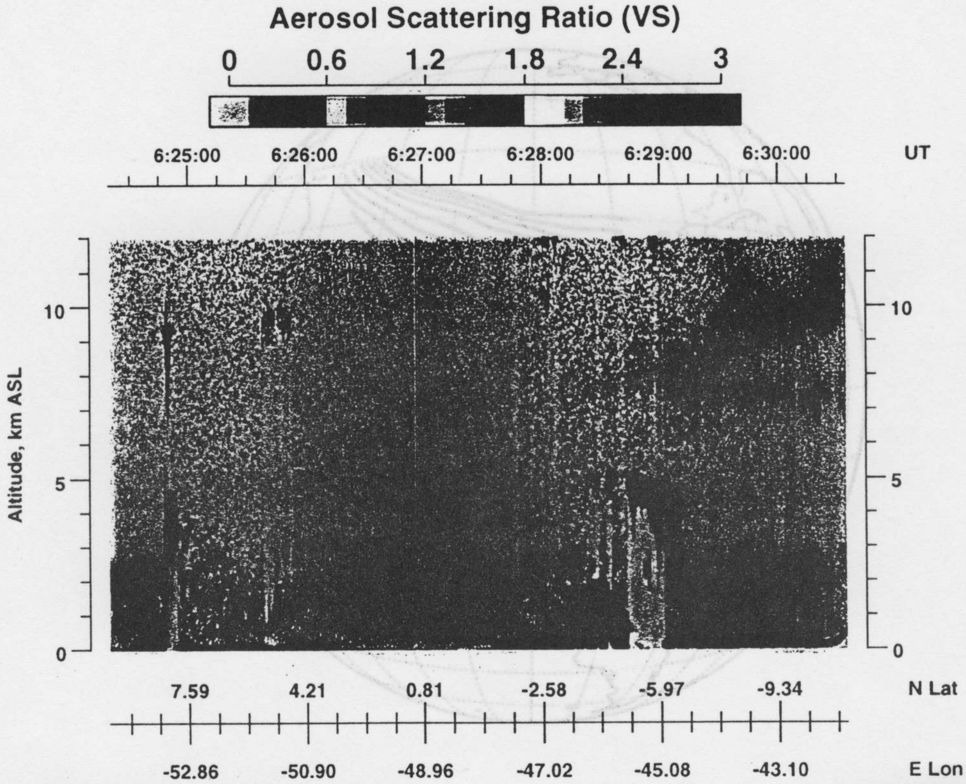
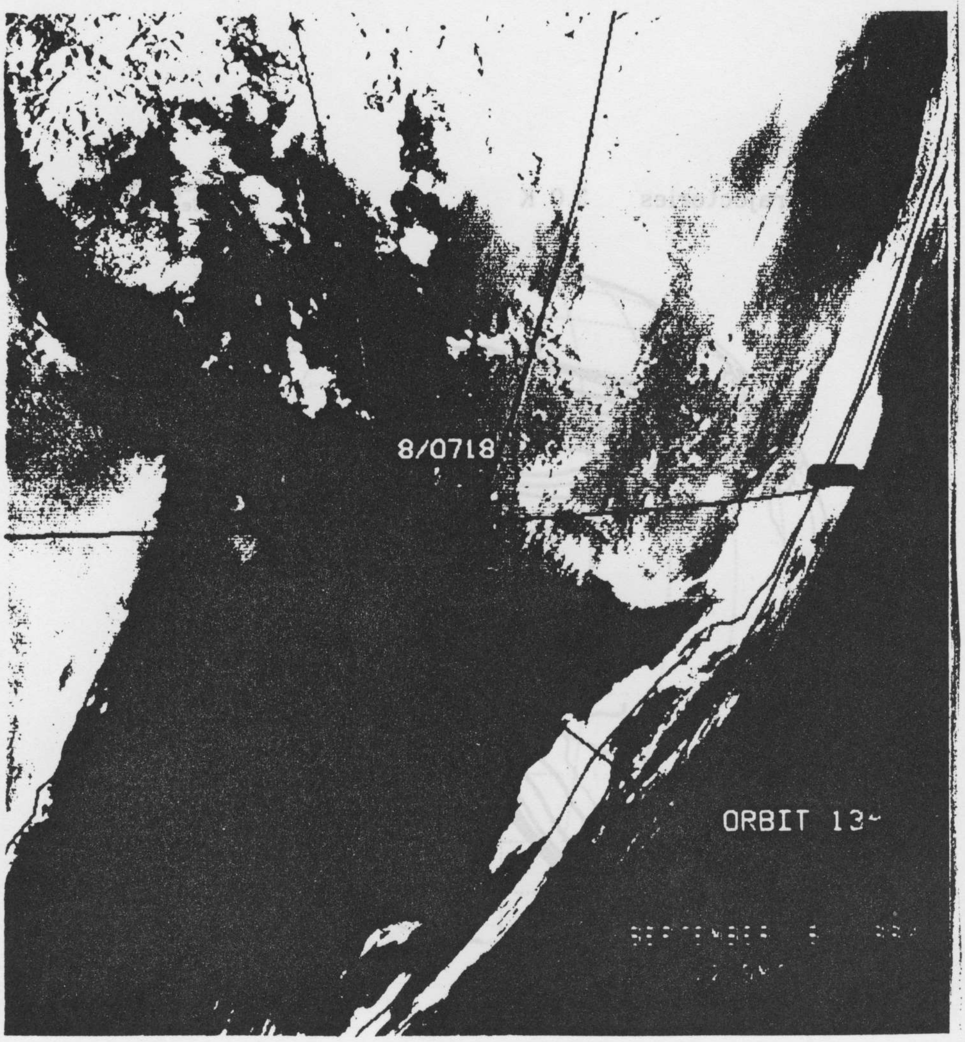
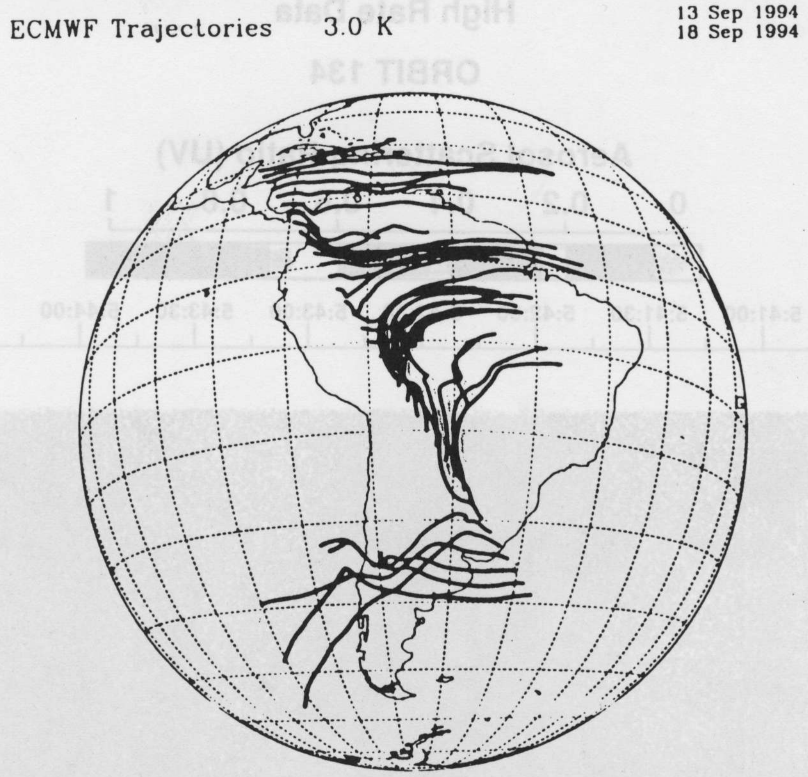
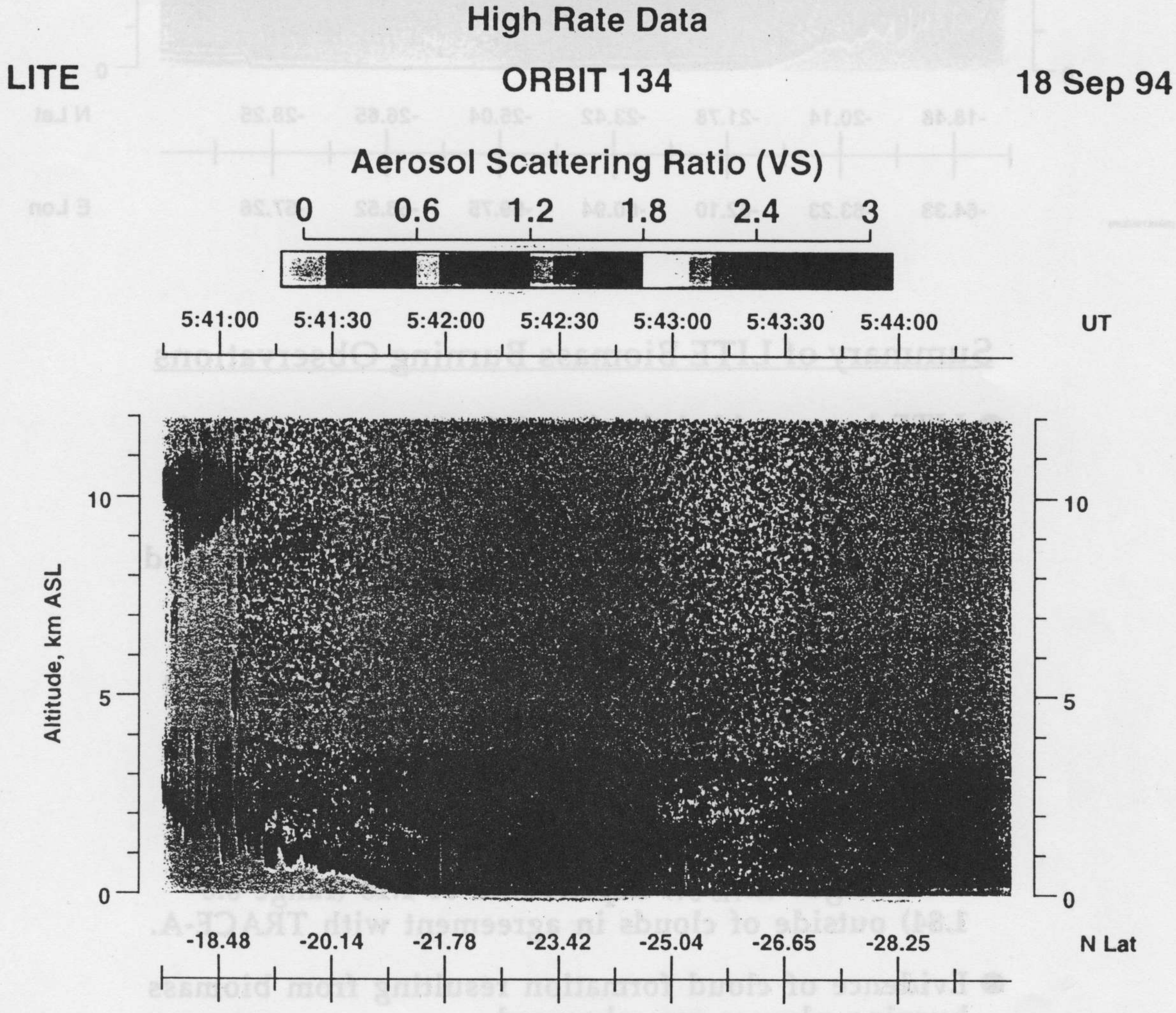





ECMWF Trajectories
3.0 K
13 Sep 1994
18 Sep 1994


High Rate Data
LITE
ORBIT 134
18 Sep 94
Aerosol Scattering Ratio (VS)
0
0.6
1.2
1.8
2.4
3
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5:41:30
5:42:00
5:42:30
5:43:00
5:43:30
5:44:00
UT
Altitude, km ASL
10
5
0
-18.48
-20.14
-21.78
-23.42
-25.04
-26.65
-28.25
N Lat
-64.33
-63.23
-62.10
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E Lon

High Rate Data

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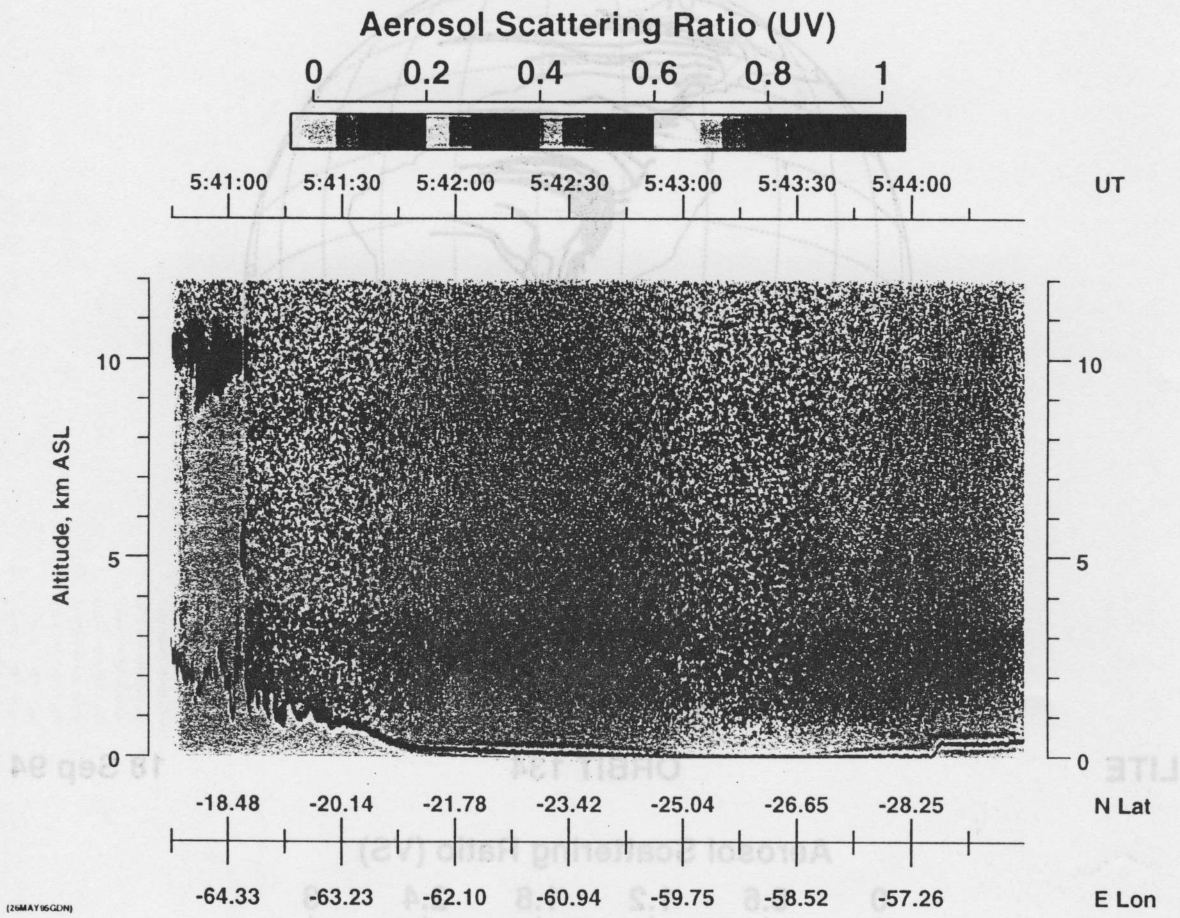

Summary of LITE Biomass Burning Observations

- LITE has provided the first lidar measurements of biomass burning plume distributions from space.
- Extensive aerosol plumes were observed over fire regions in South America & Africa and in downwind regions over the South Atlantic & Indian Oceans.
- Plumes with significantly enhanced loading were generally observed below 6 km and regions of light aerosol loading were found up to 12 km resulting from deep convection.
- Enhanced aerosol scattering ratios were observed in fire plumes ($VIS \leq 4$; $UV \leq 0.5$) with an average wavelength (α_{VIS-UV}) dependence of 1.18 (range 0.6-1.84) outside of clouds in agreement with TRACE-A.
- Evidence of cloud formation resulting from biomass burning plumes was observed.