



## CALIPSO Version 5 Aerosol Lidar Ratio Workshop

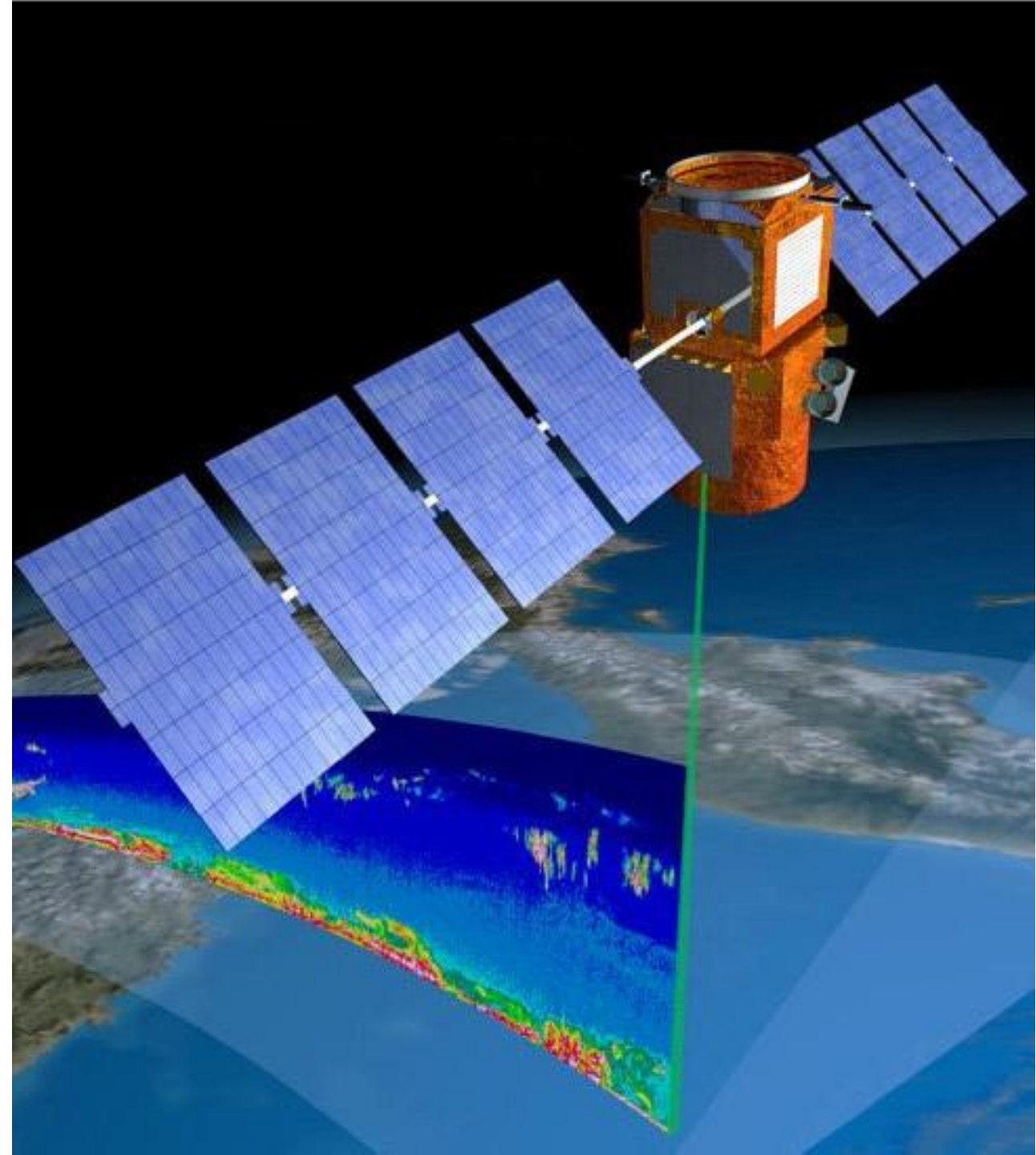
### CALIPSO Assisted Observations in South America

Eduardo Landulfo<sup>1</sup>, Fábio J. S. Lopes<sup>1,2</sup>, Alexandre Cacheffo<sup>3</sup>, Ester O. de Jesus<sup>2</sup>, Giovanni de Sousa<sup>1</sup>

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3 - Instituto de Ciências Exatas e Naturais do Pontal – Universidade Federal de Uberlândia (UFU), Brasil





# INTRODUCTION

## NETWORK SCIENTIFIC DRIVES



DUST TRANSPORT



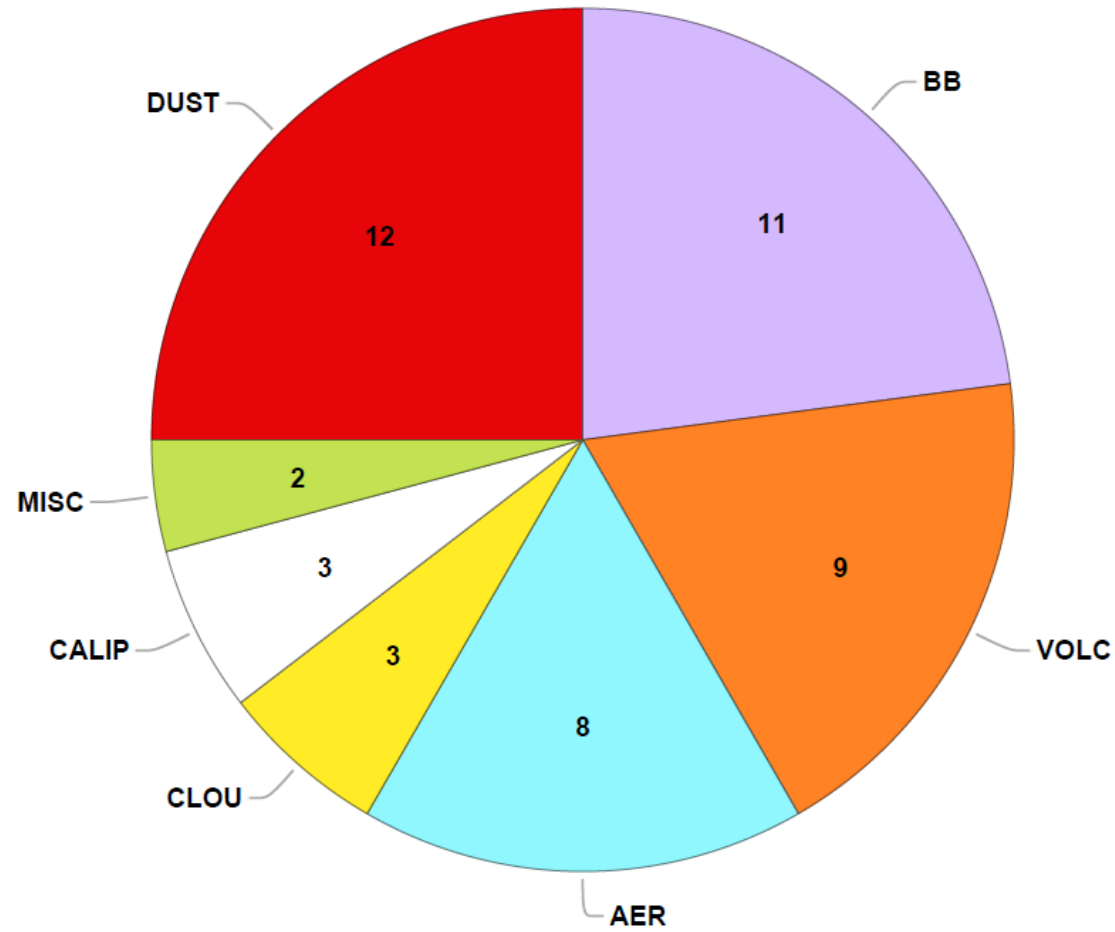
BIOMASS BURNING



VOLCANIC ASHES  
& PLUMES



# INTRODUCTION



Relevant Studies – South  
America Related

2008 - 2021

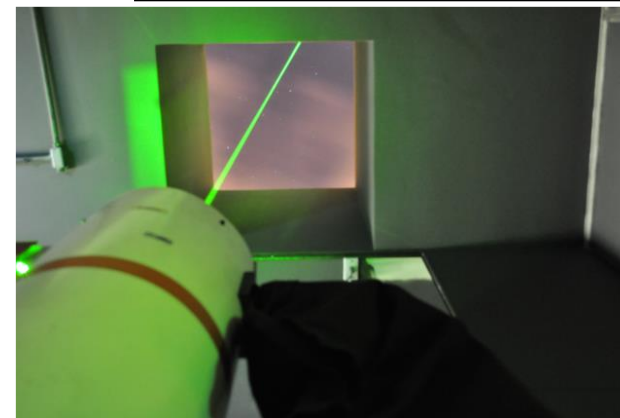
# SPU Lidar station

<http://gescon.ipen.br/leal/>

Laboratory of Environmental Applications Laser (LEAL) belongs to the Center for Lasers and Applications (CELAP) Focusing on the study of the optical properties of aerosols in the metropolitan region of São Paulo atmosphere.



Multiwavelength lidar system	
Nd:YAG laser – Brilliant B	400 mJ and 230 MJ @ 532 and 355 nm
Channels	1064 nm (FWHM 1.0 nm) 532 nm (FWHM 1.0 nm) 530 nm (FWHM 0.5 nm) 355 nm (FWHM 1.0 nm) 387 nm (FWHM 0.25 nm) 408 nm (FWHM 0.25 nm)
PMTs	Hamamatsu PM-HV-P03-R7400 / PM-R9880-20
Vertical Resolution	7.5 m



# SPU Lidar station

<http://gescon.ipen.br/leal/>

Laboratory of Environmental Applications Laser (LEAL) belongs to the Center for Lasers and Applications (CELAP)

Focusing on the study of the optical properties of aerosols in the metropolitan region of São Paulo atmosphere



## Research field and applications

- Atmospheric Aerosol and Cloud Optical Properties
- Aerosol Transportation (Biomass Burning and Dust)
- Satellite Validation
- Planetary Boundary Layer Dynamics
- Synergy Between Lidar, Satellites, remote sensing and air pollution monitoring instruments
- Cirrus Clouds
- Hygroscopicity of Urban Aerosols

# CALIPSO validation

Atmos. Meas. Tech., 6, 3281–3299, 2013  
www.atmos-meas-tech.net/6/3281/2013/  
doi:10.5194/amt-6-3281-2013  
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Atmospheric  
Measurement  
Techniques

Open Access



## Evaluating CALIPSO's 532 nm lidar ratio selection algorithm using AERONET sun photometers in Brazil

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Revised: 2 October 2013 – Accepted: 28 October 2013 – Published: 28 November 2013

<https://doi.org/10.5194/amt-6-3281-2013>

# CALIPSO validation

- Five operational AERONET locations: Rio Branco, Alta Floresta, Cuiabá, Campo Grande and São Paulo
- Measurement period of 2006 to 2009
- Correlative measurements with  $\Delta D \leq 100$  km and  $\Delta T \leq 6$  km centered at the closest approach by CALIPSO

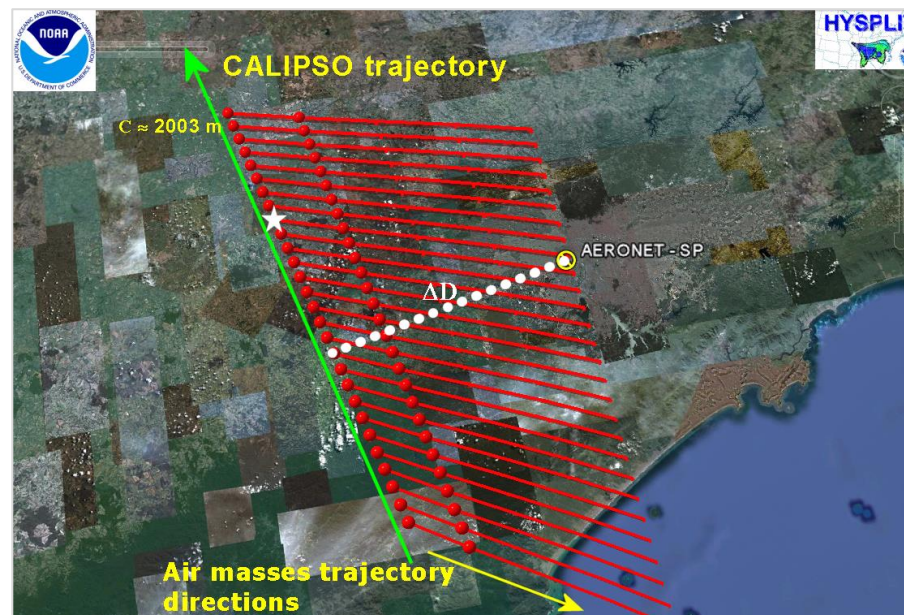
- CALIPSO level 2 – 5 km products
- Backscatter Center of Mass (BCM) for the aerosol layer detected
- $x_i$  is the layer total attenuated backscatter signal at 532 nm and  $Z_i$  the layer altitude

$$BCM = \frac{\sum_{i=1}^N x_i Z_i}{\sum_{i=1}^N x_i}$$

- Lidar ratio equation derived by Platt (1973)

$$S_{AC} = \frac{[1 - \exp(-2\eta\tau_{AERONET})]}{2\eta\gamma'_{CALIOP,532}}$$

Platt, C. M. R.: Lidar and radiometer observations of cirrus clouds, J. Atmos. Sci., 30, 1191–1204, doi:10.1175/1520-0469(1973)030<1191:LAROC>2.0.CO;2, 1973

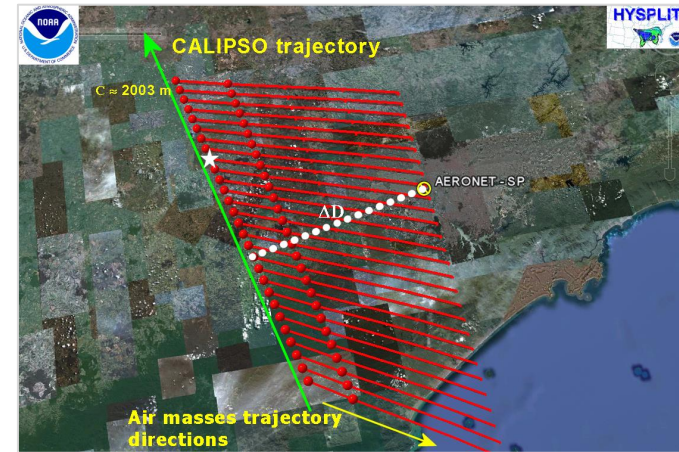


# CALIPSO validation

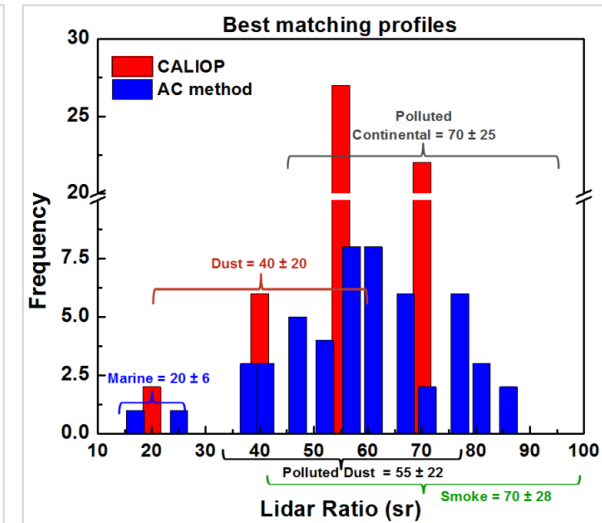
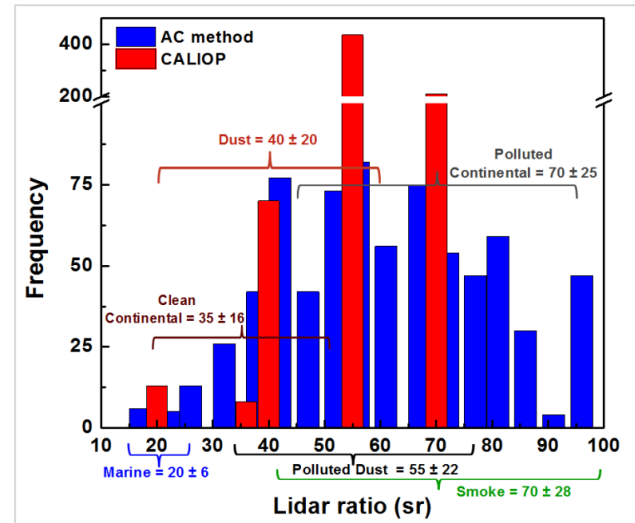
- Lidar ratio equation derived by Platt (1973)

$$S_{AC} = \frac{[1 - \exp(-2\eta\tau_{AERONET})]}{2\eta\gamma'_{CALIOP,532}}$$

$$MPD = \frac{S_{CALIOP,532} - S_{AC}}{S_{AC}} [\%]$$



Aerosol type	% difference $S_{AC}$ and $S_{CALIOP,532}$ total profiles	% difference $S_{AC}$ and $S_{CALIOP,532}$ best matching
Dust	-9.7% ± 13%	-5.4% ± 24%
Smoke	7.2% ± 40%	4.3% ± 27%
Polluted Continental	2.0% ± 35%	-1.7% ± 9%
Polluted Dust	-4.7% ± 39%	-2.5% ± 32%
Clean Marine	-6.3% ± 20%	-



# Volcanic eruption event





*remote sensing*



*Article*

## Synergetic Aerosol Layer Observation After the 2015 Calbuco Volcanic Eruption Event

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<sup>4</sup> Universities Space Research Association, Greenbelt, MD 20771, USA; ghassan.taha-1@nasa.gov

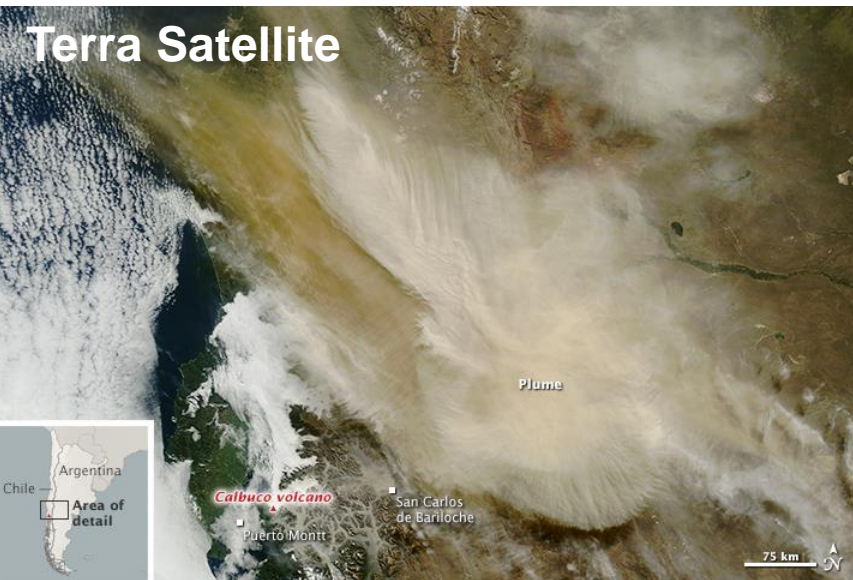
\* Correspondence: fabiolopes@usp.br; Tel.: +55-11-3133-9361

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<https://doi.org/10.3390/rs11020195>

# Volcanic eruption event

- Calbuco volcanic eruption in April 2015 in Chile-South America (VEI 4)
- First eruption on 22<sup>nd</sup> April - 9:04 PM (UTC)
- Second high-energy ashes pulse – 23<sup>rd</sup> April – 4:00 AM (UTC)



**Model Grid Resolution:** .5° x .5°

**Plume Top:** 18km  
*Based on CALIPSO Obs.*

**Plume Thickness:** down to 8km  
*Based on satellite obs.*

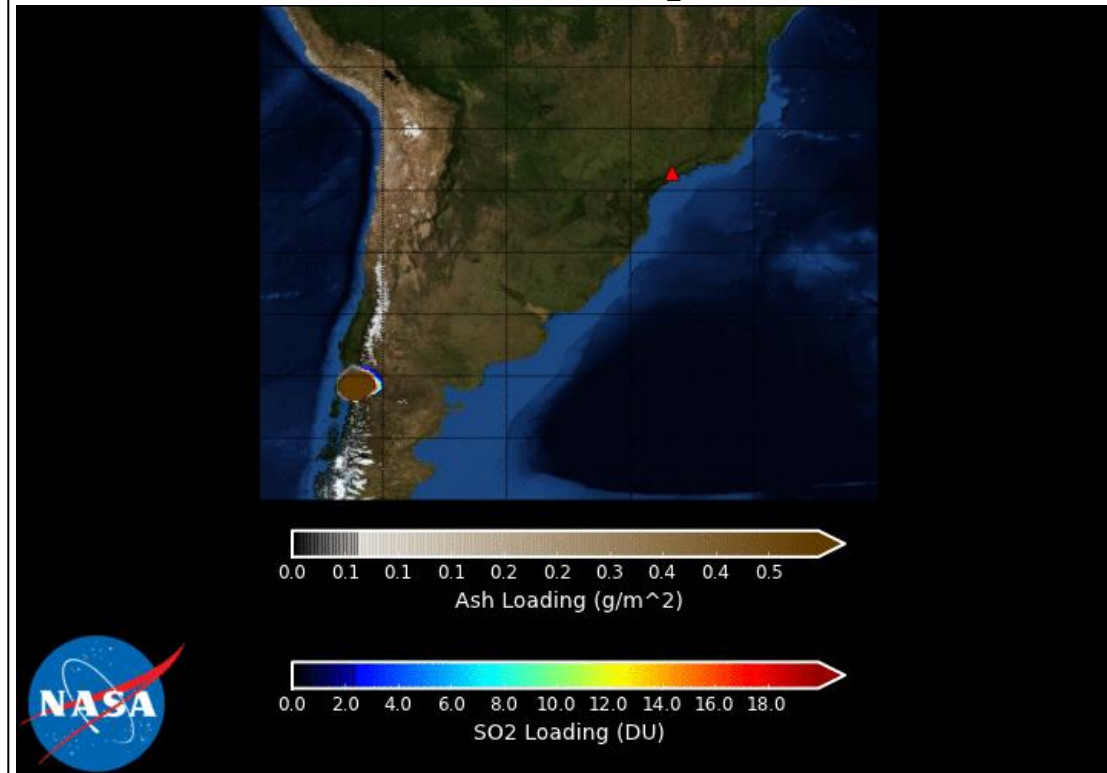
**Ash Emission Rate:**  $5 \times 10^4$  Kg/s

**SO<sub>2</sub> Emission Total:** 300 Kt  
*Based on satellite observations*

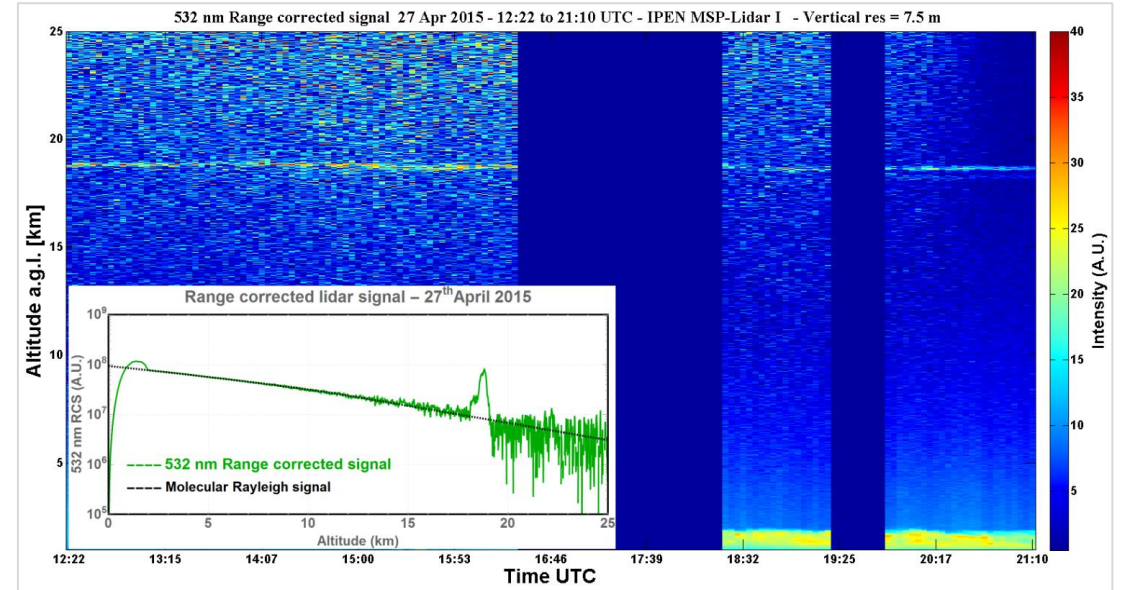
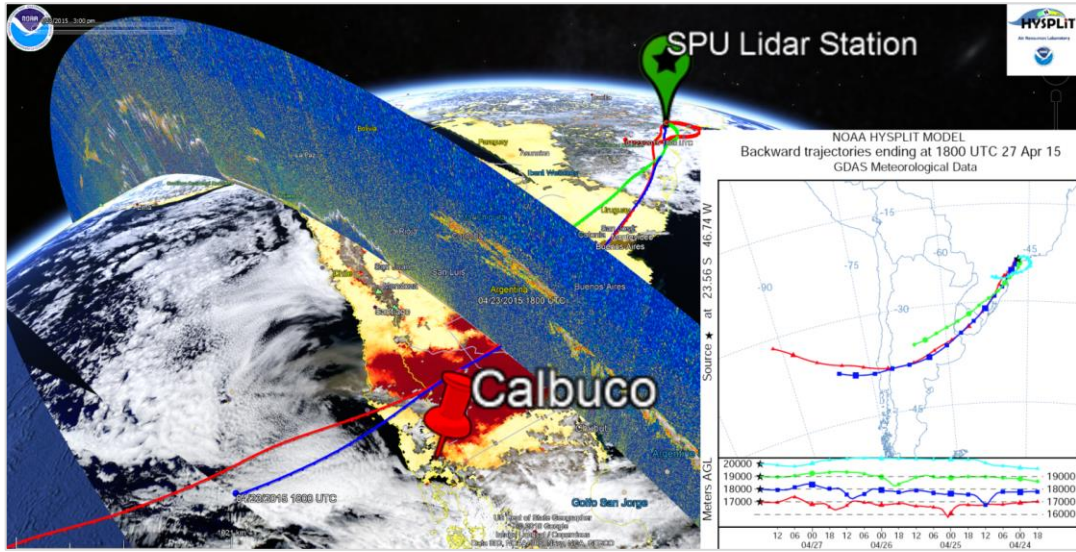
**Timing:** Two Eruption Pulses  
(1) 04/22 21:38Z – 23:38Z  
(2) 04/23 04:38Z – 10:08Z  
*Based on GOES IR and Reports*

Simulation run with GOES-5 Replay  
Meteorology (not forecast)

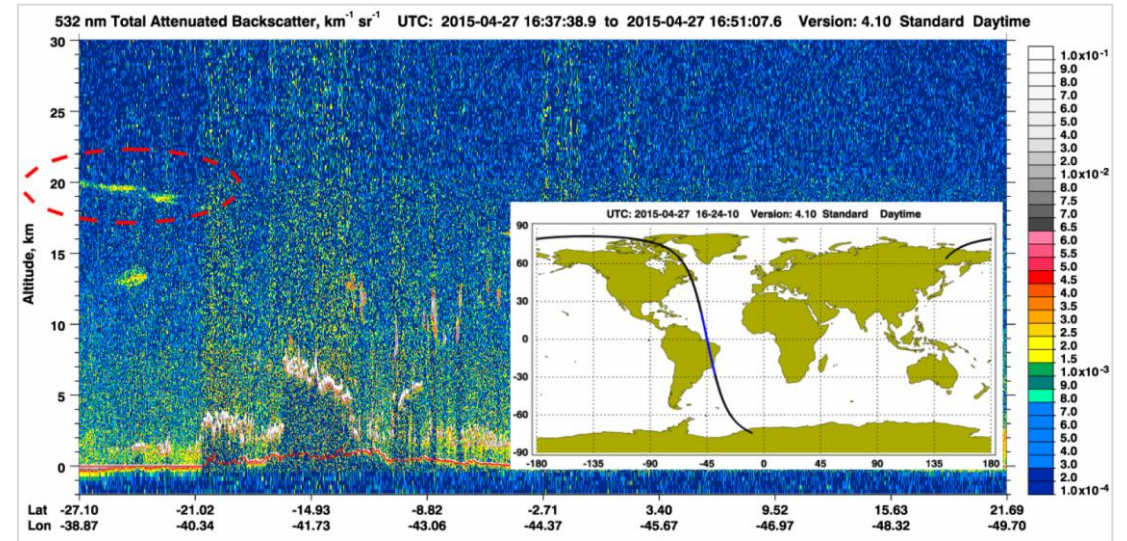
## GEOS-5 Ash plotted onto SO<sub>2</sub>



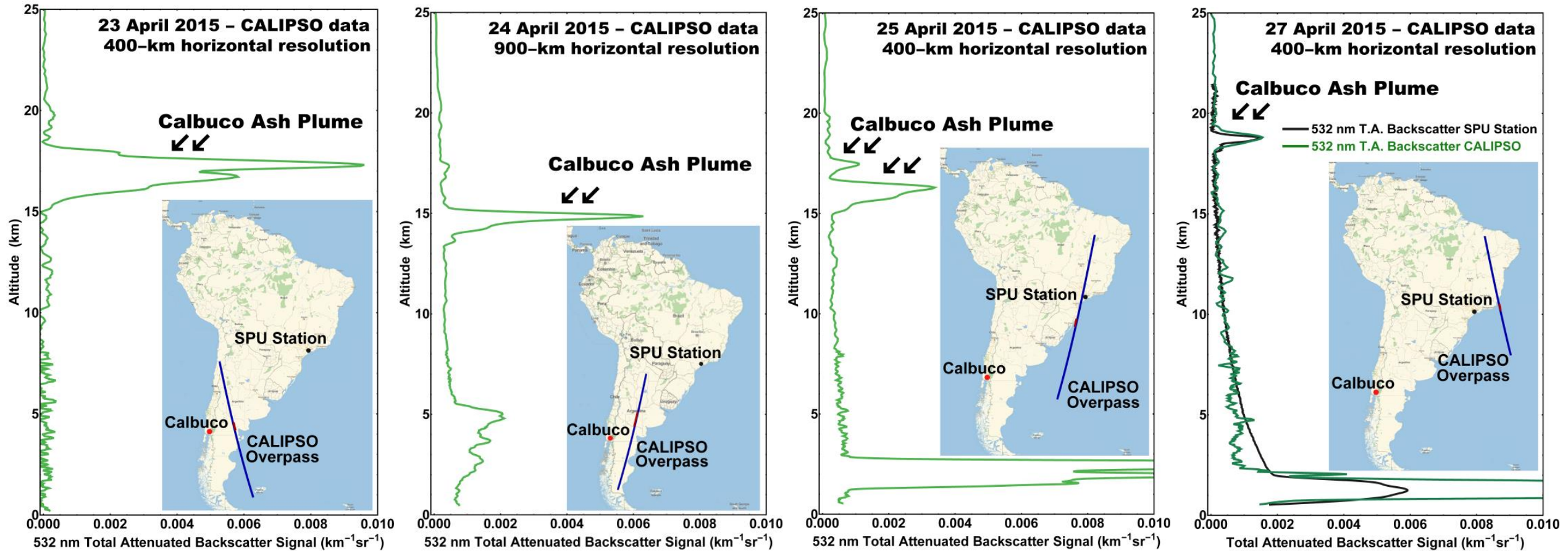
# Volcanic eruption event



- Calbuco eruption detected by TERRA/MODIS and CALIPSO satellites on 23 April 2015 and the air masses trajectories from HYSPLIT model pointing to the aerosol plumes travel forward to São Paulo region.
- Aerosol plume from Calbuco Volcano detected by the SPU Lidar station (Range corrected signal at 532 nm) and CALIPSO total attenuated backscatter profile at 532 nm



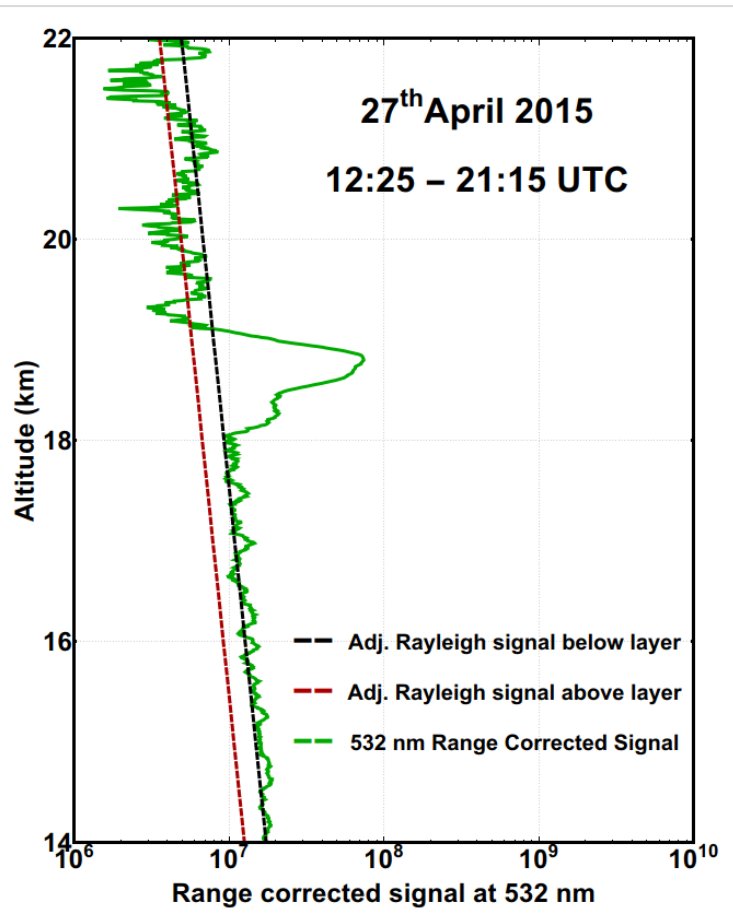
# Volcanic eruption event



CALIPSO overpasses and the Total attenuated backscatter profile at 532 nm retrieved using Level 1B V3 data for consecutive days of Calbuco eruption: (right) the attenuated backscatter profiles at 532 nm retrieved by CALIPSO and SPU station, respectively. Total agreement in intensity and physical properties such as top and bottom volcanic layer altitude.

# Volcanic eruption event

The transmission method (1,2) was applied to calculate optical transmission of the volcanic plume, and therefore, estimate AOD and Lidar Ratio value



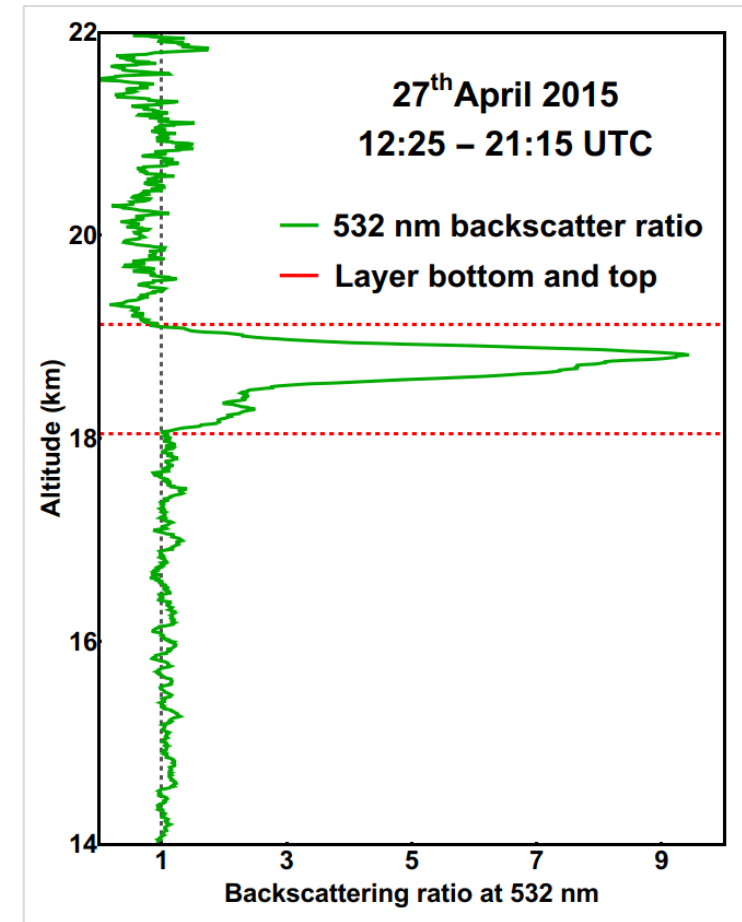
$$T^2(\lambda, z) = \exp \left[ -2 \int_{z_{base}}^{z_{top}} \alpha(\lambda, z') dz' \right] = \exp \left[ -2\tau(\lambda, z) \right]$$

$$T_{fit} = \left[ \frac{P_{top}(z) z^2}{P_{base}(z) z^2} \right]^{\frac{1}{2}}$$

$$S(\lambda, z) = \frac{1 - \exp \left[ -2 \eta \tau(\lambda, z) \right]}{2 \eta \gamma(\lambda, z)}$$

$$\gamma = \int_{z_{base}}^{z_{top}} \beta(\lambda, z') dz' \quad \eta = \frac{\tau(\lambda, z)}{\exp \left[ \tau(\lambda, z) \right] - 1}$$

- 1 - Young, S.A. Analysis of lidar backscatter profiles in optically thin clouds. *Appl. Opt.* 1995, 34, 7019–7031.
- 2 - Young, S.A.; Vaughan, M.A. The Retrieval of Profiles of Particulate Extinction from Cloud-Aerosol Lidar Infrared Pathfinder Satellite Observations (CALIPSO) Data: Algorithm Description. *J. Atmos. Ocean. Technol.* 2009, 26, 1105–1119.



# Volcanic eruption event

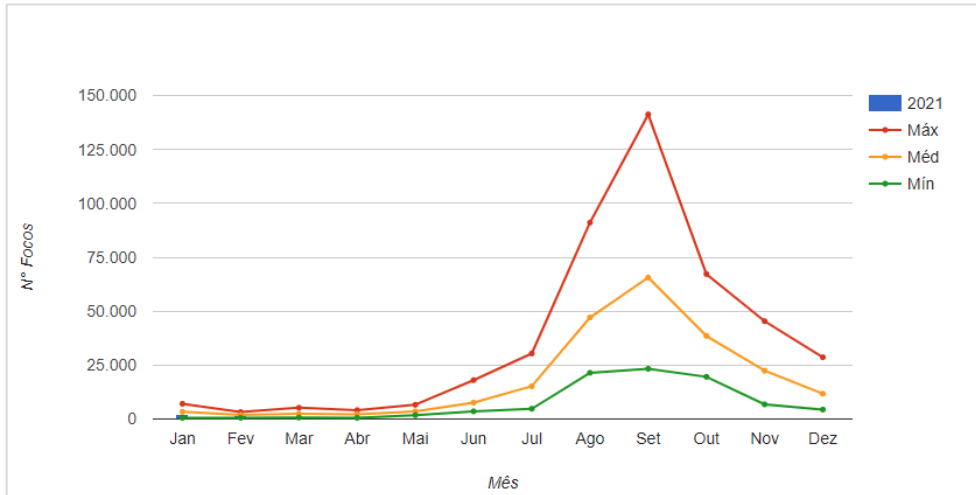
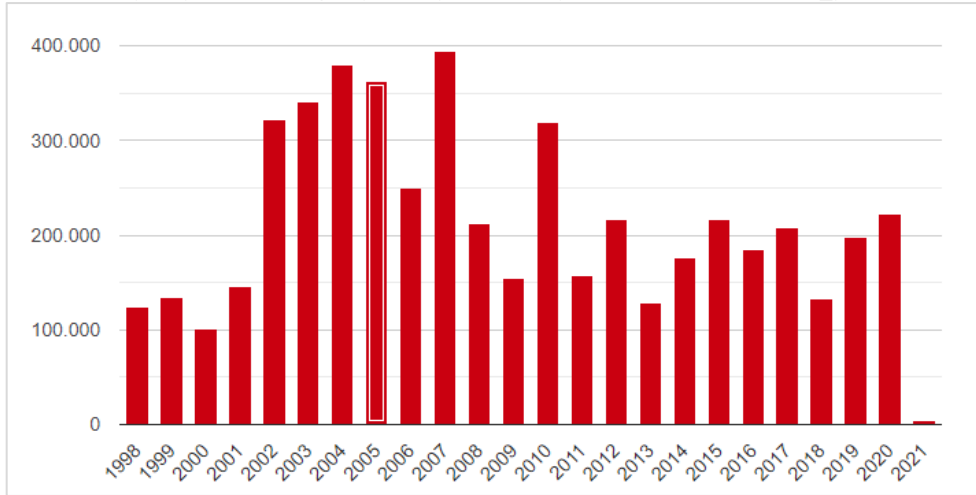
Location	Layer Height (km)	AOD at 532 nm	LR (532nm)	LR (355nm)	Ångström 355/532	Type
Leipzig	2.6–4.3	0.35	60 ± 5	60 ± 5	0.03 ± 0.40	Ash
Munich	2.6–3.5	-	50–60	50 ± 5	-0.11 ± 0.18	Pure dry ash
Potenza	2.0–3.0	-	42 ± 2	50 ± 3	1.4 ± 0.2	Sulfates with some ash
Evora	2.7–3.7	0.07	39 ± 2	32 ± 4	0.68 ± 0.63	Fresh volcanic particles
Granada	2.6–2.9	-	47 ± 7	48 ± 16	0.066 ± 0.005	
Cabauw	2.7–6.0	0.53	42 ± 1	44 ± 24	0.30 ± 0.03	Sulfate-ash mixture
Athens	3.0–4.8	0.05	67 ± 13	89 ± 3	0.57 ± 0.26	Aged ash/sulfates
Athens	2.5–3.0	0.04	76 ± 5	78 ± 3	1.72 ± 0.06	Sulfates
Brazil	18–19.3	0.16	76 ± 27	63 ± 21	0.61 ± 0.58	Sulfates with some ash

- 1 - Ansmann, A.; et al. The 16 April 2010 major volcanic ash plume over central Europe: EARLINET lidar and AERONET photometer observations at Leipzig and Munich, Germany. *Geophys. Res. Lett.* 2010, 37, L13810.
- 2 - Ansmann, A.; et al. Ash and fine-mode particle mass profiles from EARLINET-AERONET observations over central Europe after the eruptions of the Eyjafjallajökull volcano in 2010. *J. Geophys. Res. Atmos.* 2011, 116, D00U02.
- 3 - Groß, S.; et al. Dual-wavelength linear depolarization ratio of volcanic aerosols: Lidar measurements of the Eyjafjallajökull plume over Maisach, Germany. *Atmos. Environ.* 2012, 48, 85–96.
- 4 - Mona, L.; et al. Multi-wavelength Raman lidar observations of the Eyjafjallajökull volcanic cloud over Potenza, southern Italy. *Atmos. Chem. Phys.* 2012, 12, 2229–2244.
- 5 - Sicard, M.; et al. Monitoring of the Eyjafjallajökull volcanic aerosol plume over the Iberian Peninsula by means of four EARLINET lidar stations. *Atmos. Chem. Phys.* 2012, 12, 3115–3130.
- 6 - Navas-Guzmán, F.; et al. Eruption of the Eyjafjallajökull Volcano in spring 2010: Multiwavelength Raman lidar measurements of sulphate particles in the lower troposphere. *J. Geophys. Res. Atmos.* 2013, 118, 1804–1813.
- 7 - Kokkalis, P.; et al. Optical, microphysical, mass and geometrical properties of aged volcanic particles observed over Athens, Greece, during the Eyjafjallajökull eruption in April 2010 through synergy of Raman lidar and sunphotometer measurements. *Atmos. Chem. Phys.* 2013, 13, 9303–9320.

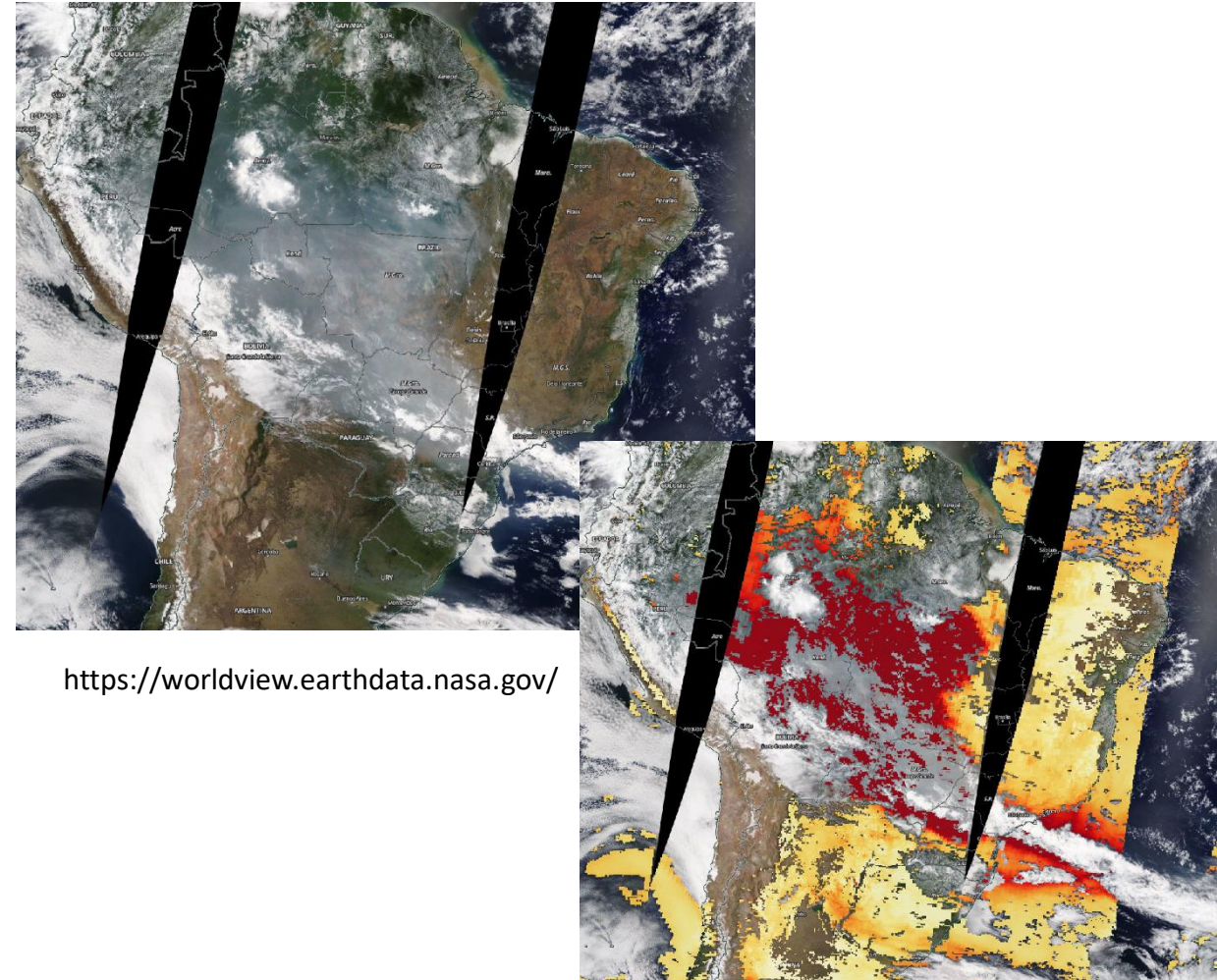
# Biomass burning events

## Number of focus fire cases in Brazilian territory

[http://queimadas.dgi.inpe.br/queimadas/porta-static/estatisticas\\_paises/](http://queimadas.dgi.inpe.br/queimadas/porta-static/estatisticas_paises/)



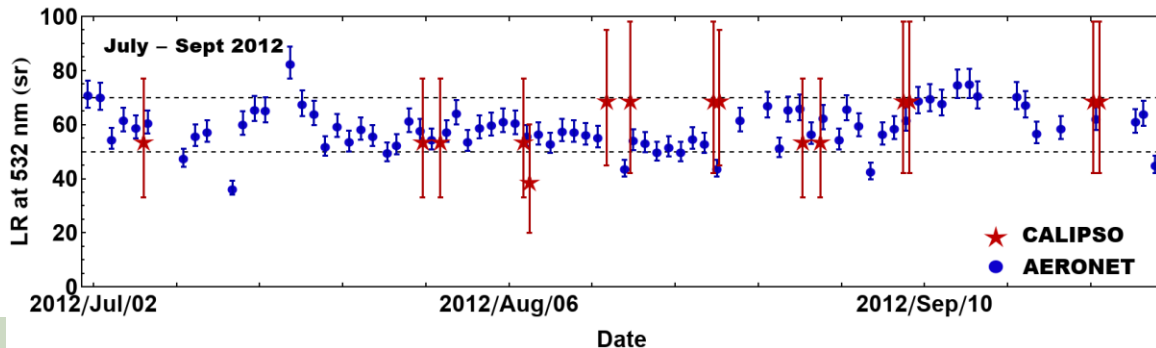
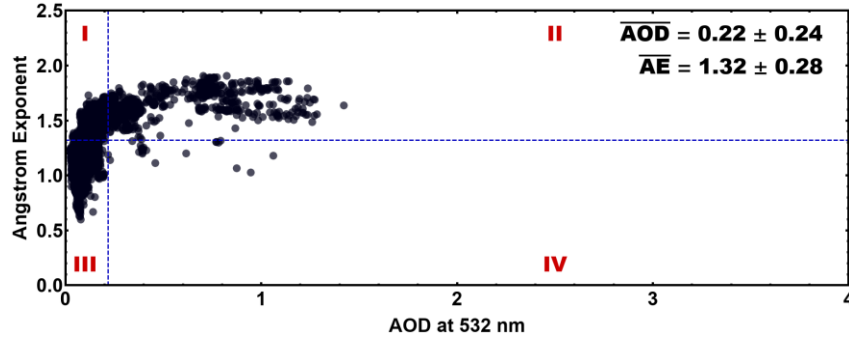
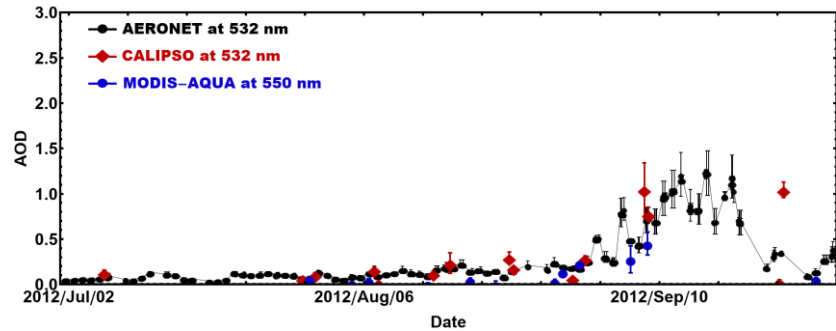
## Biomass burning scenario 2020



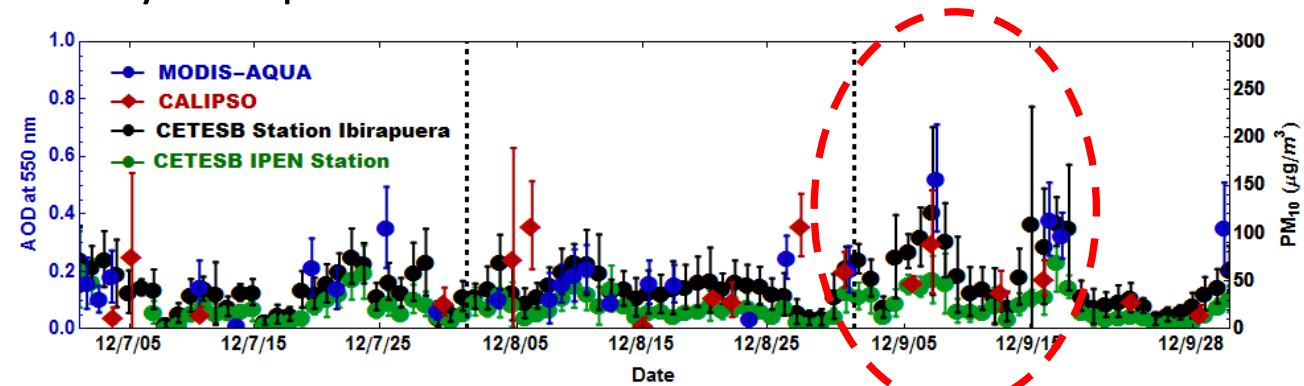
# Biomass burning events

Biomass burning scenario at Central Brazil  
July to September 2012

Cuiaba-Miranda Station – July–September–2012

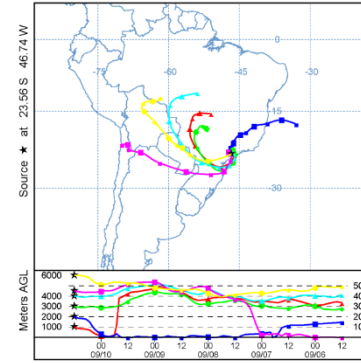


AOD and particulate matter concentration at São Paulo  
July to September of 2012

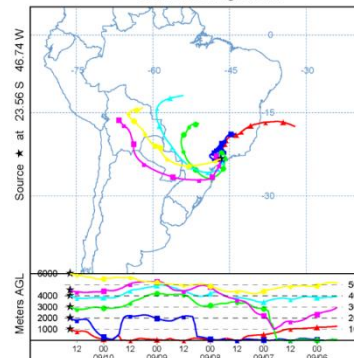


Aerosol transportation to Metropolitan region of São Paulo

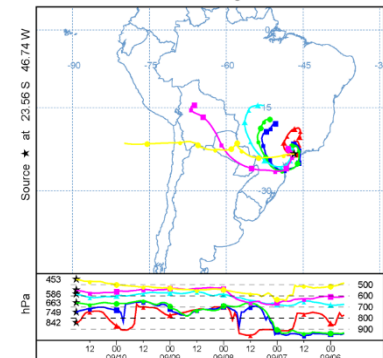
NOAA HYSPLIT MODEL  
Backward trajectories ending at 12 UTC 10 Sep 12  
GDAS Meteorological Data



NOAA HYSPLIT MODEL  
Backward trajectories ending at 15 UTC 10 Sep 12  
GDAS Meteorological Data

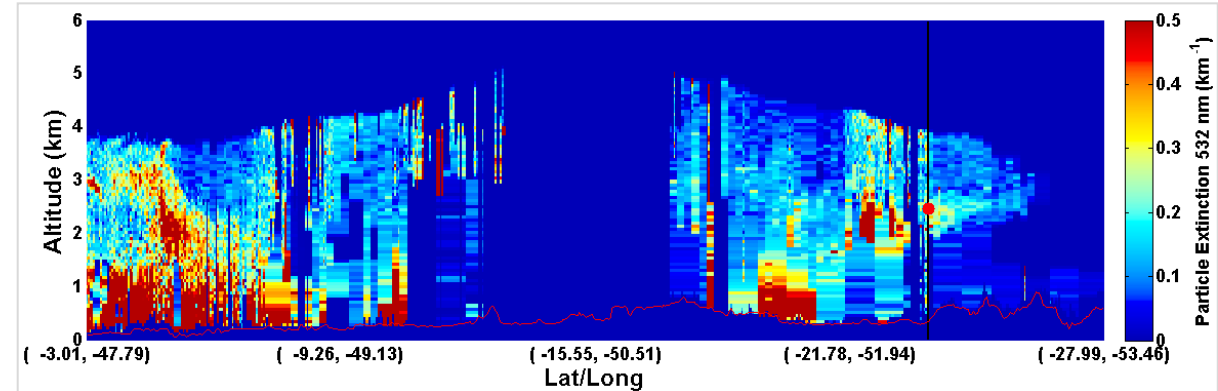
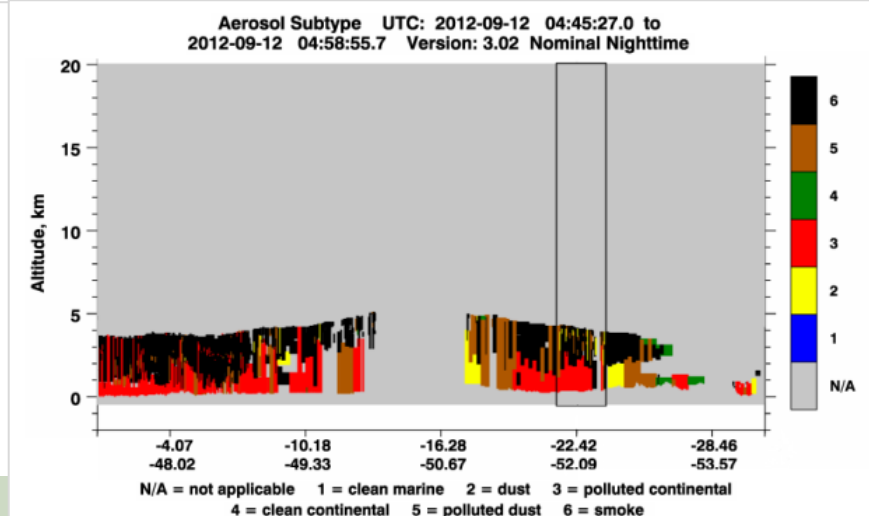
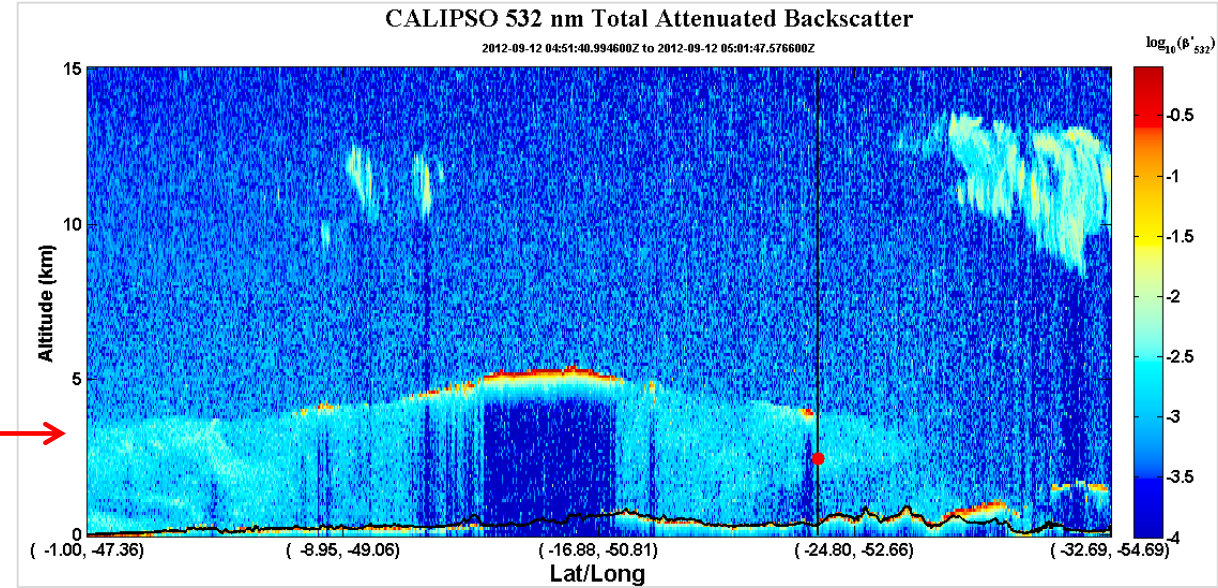
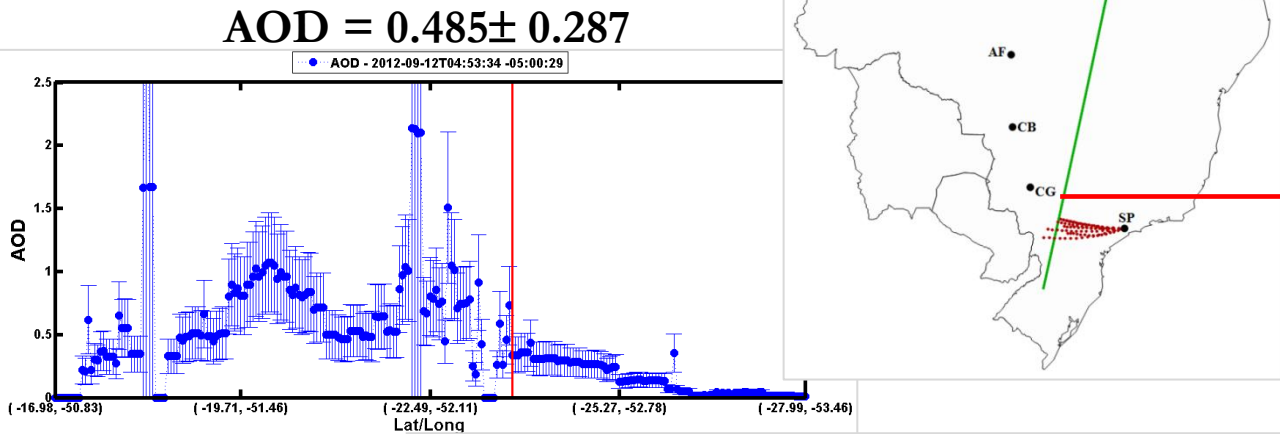


NOAA HYSPLIT MODEL  
Backward trajectories ending at 18 UTC 10 Sep 12  
GDAS Meteorological Data



# Biomass burning events

Biomass burning scenario at near Metropolitan region of São Paulo - September 2012



CALIOP Layers:

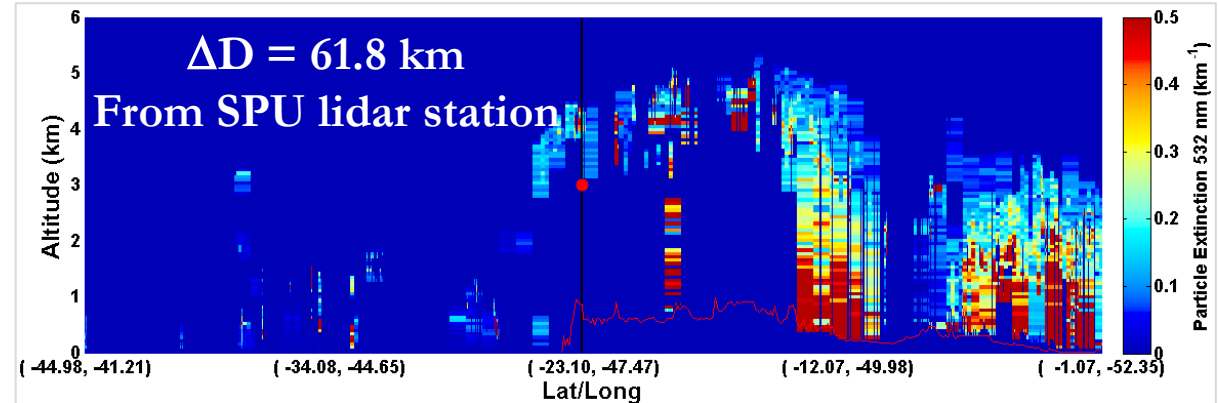
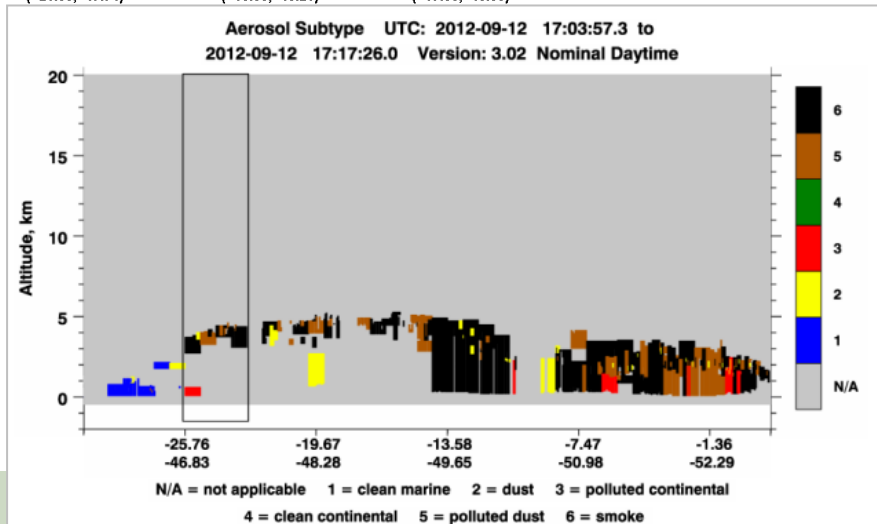
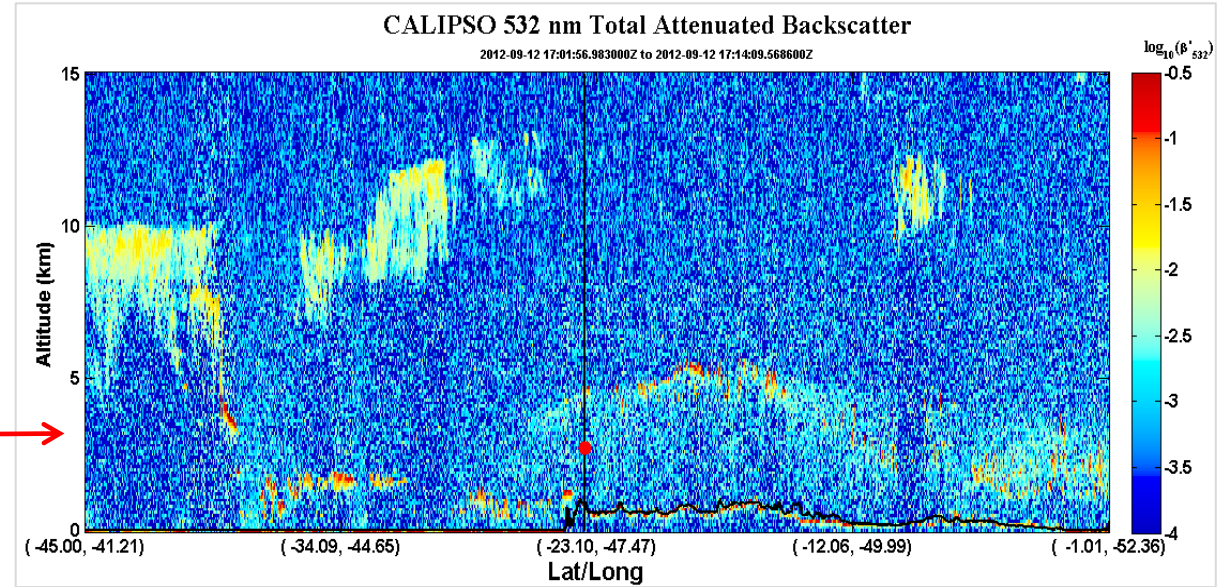
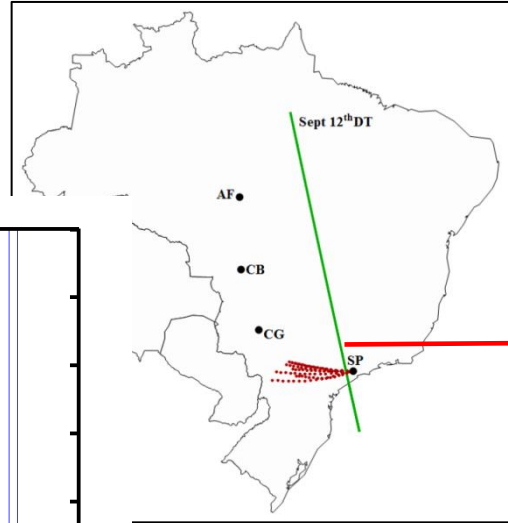
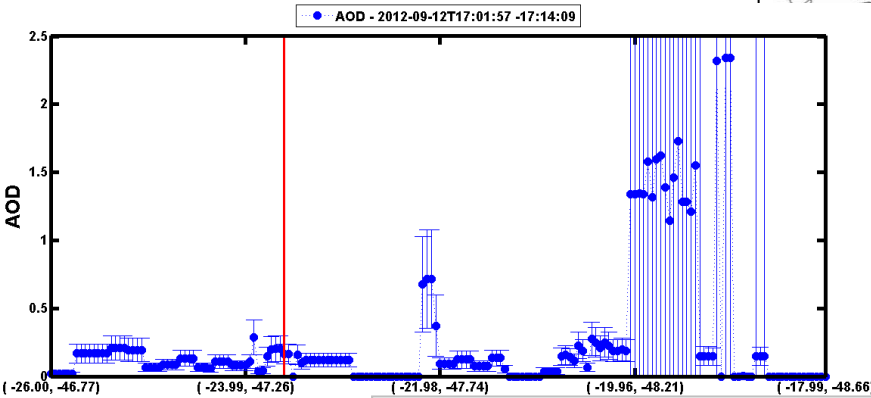
1<sup>st</sup> Layer  $\Rightarrow$  1.88 – 3.90 km 2<sup>nd</sup> Layer  $\Rightarrow$  2.14 – 2.95 km

3<sup>rd</sup> Layer  $\Rightarrow$  0.62 – 2.02 km

# Biomass burning events

Biomass burning scenario at near Metropolitan region of São Paulo - September 2012

AOD =  $0.164 \pm 0.075$



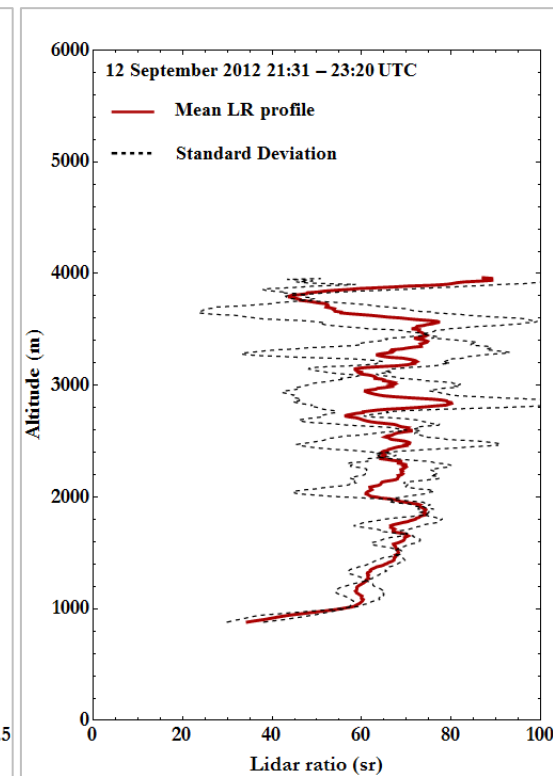
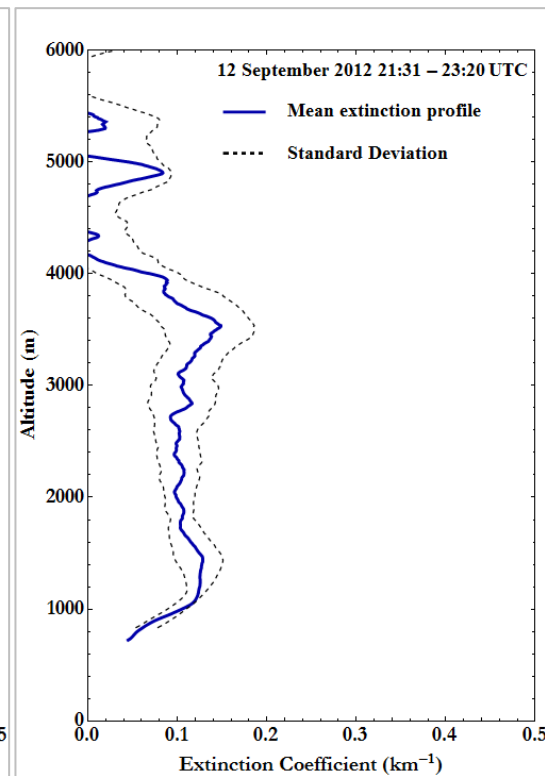
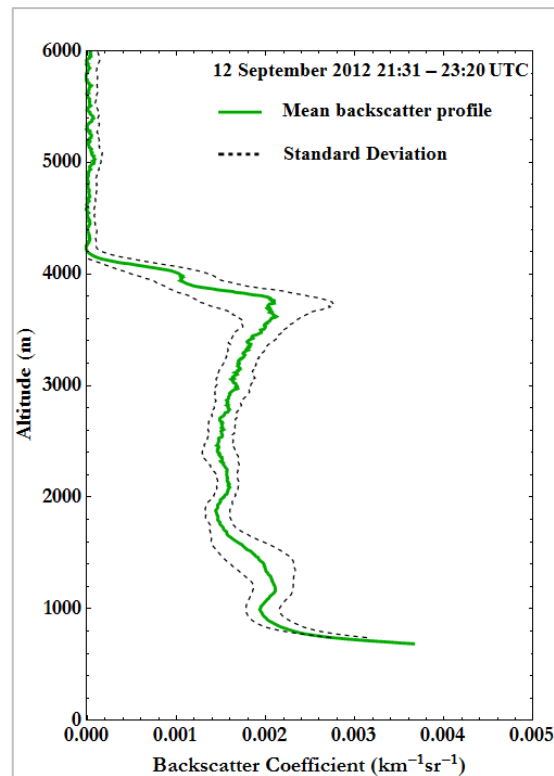
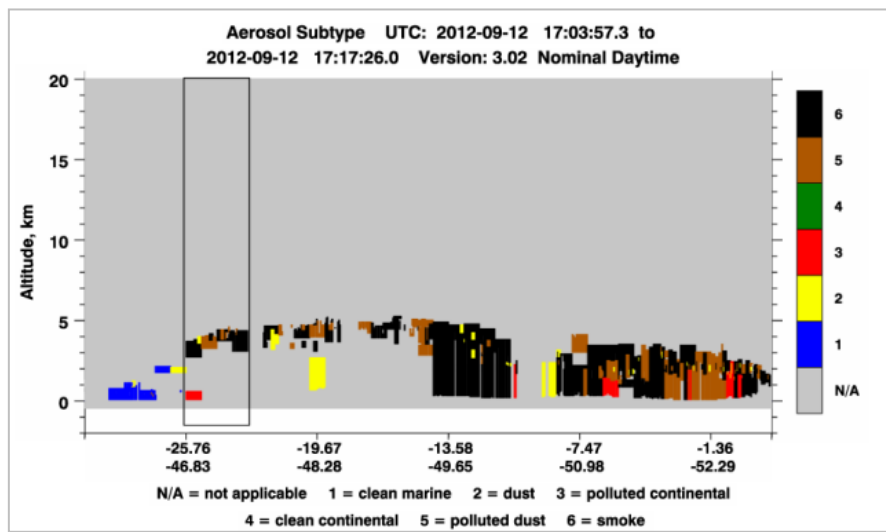
CALIOP Layers:

1st Layer  $\Rightarrow$  3.79 – 4.45 km

2nd Layer  $\Rightarrow$  3.97 – 4.40 km

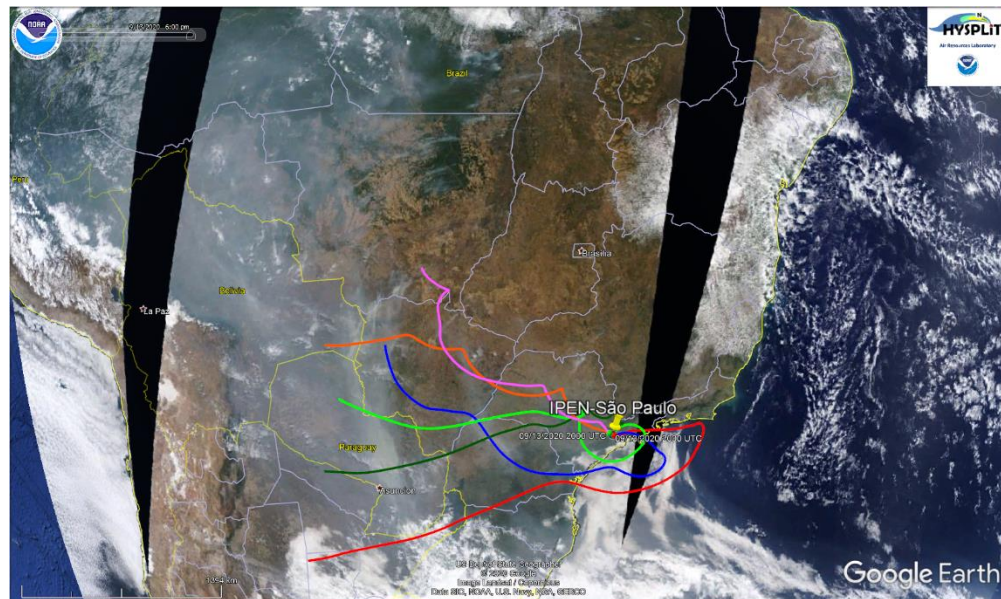
# Biomass burning events

Biomass burning scenario at near Metropolitan region of São Paulo - September 2012

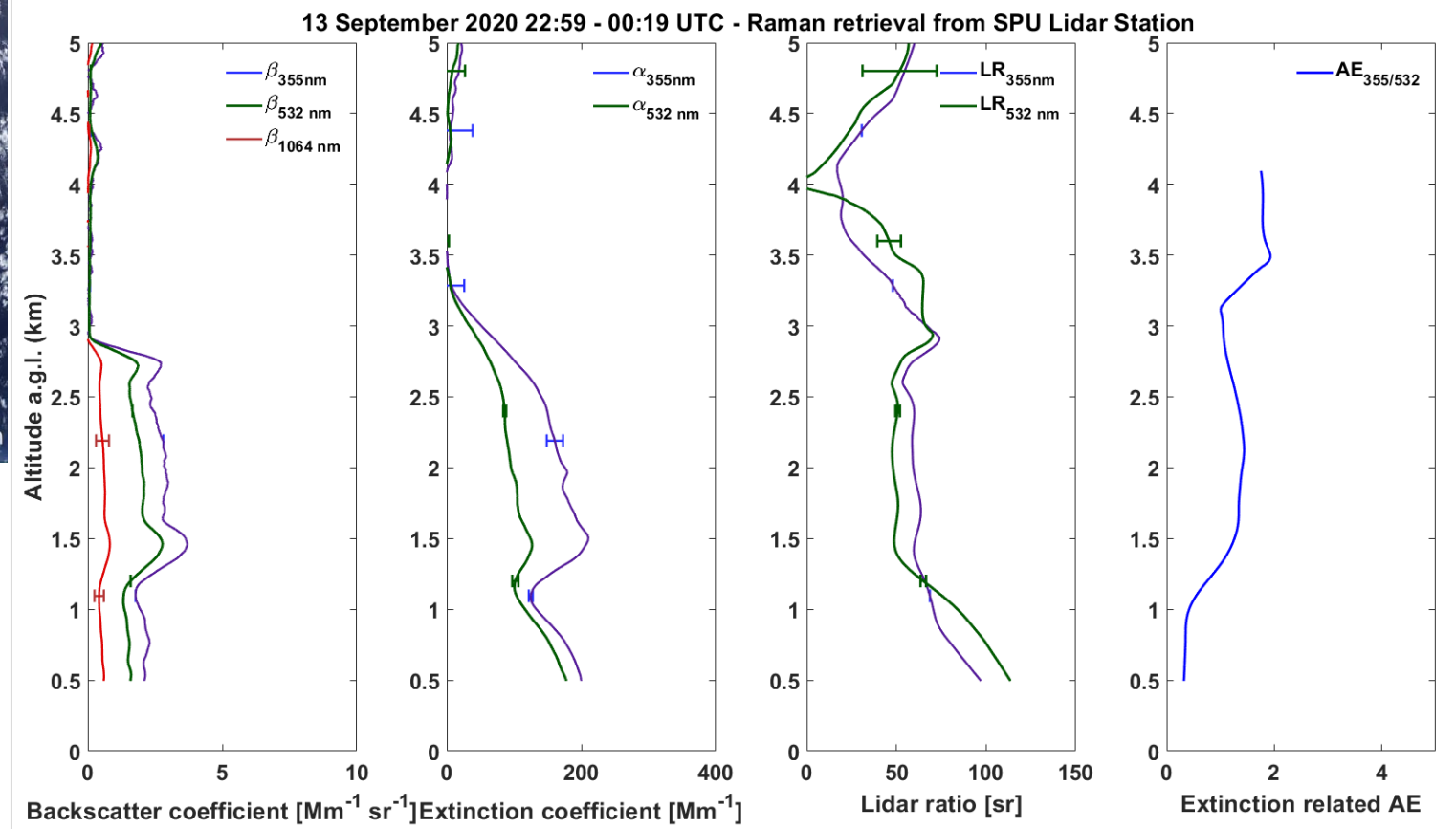
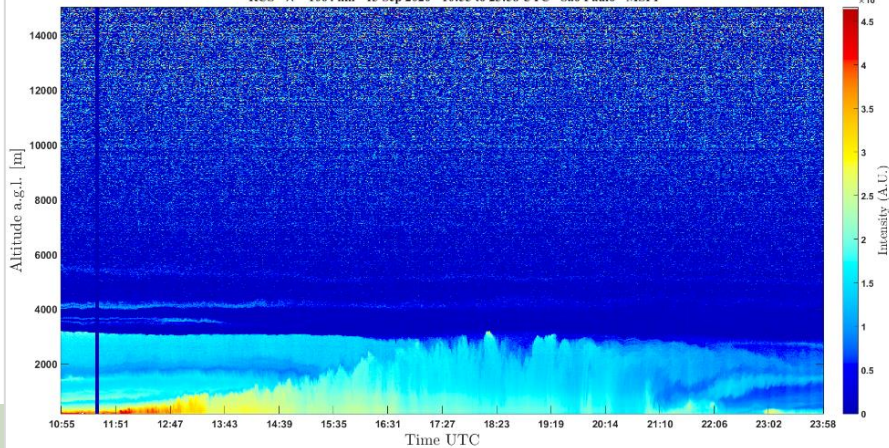


# Biomass burning events and LR studies

- Biomass burning + Lidar ratio scenario at São Paulo to be investigated
- Single Calculus Chain applications to retrieve Lidar ratio profiles

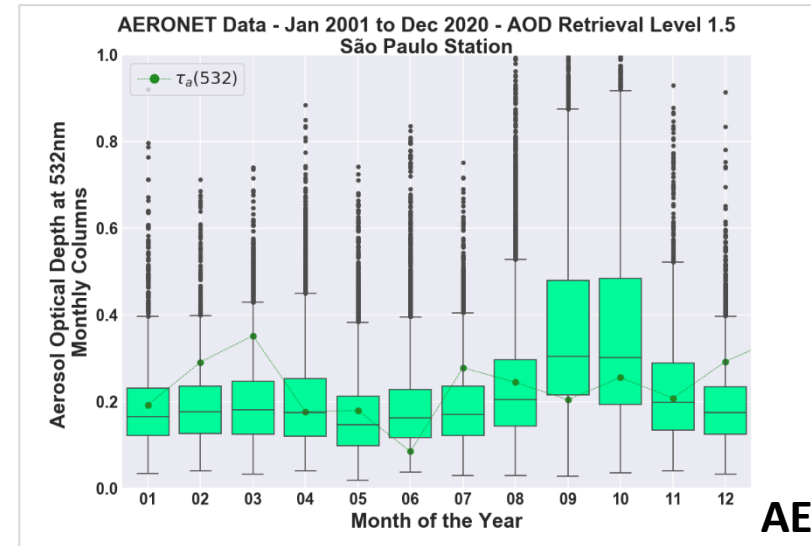
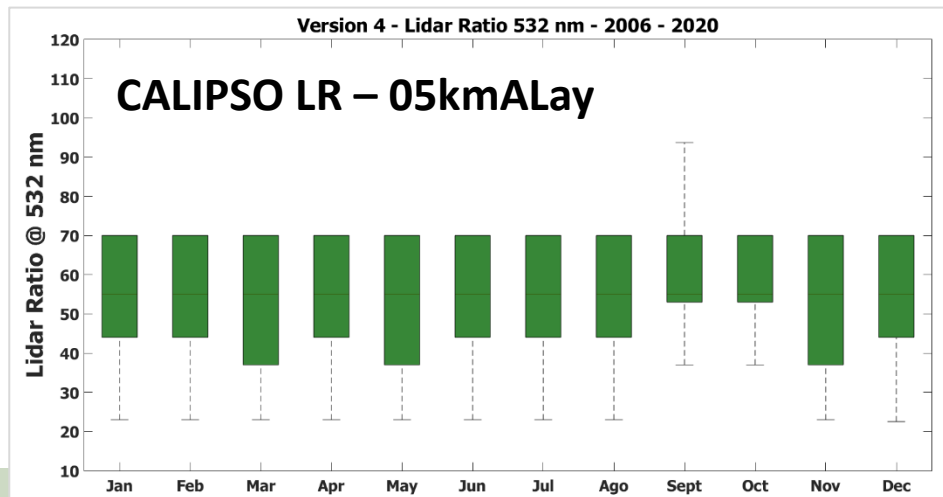
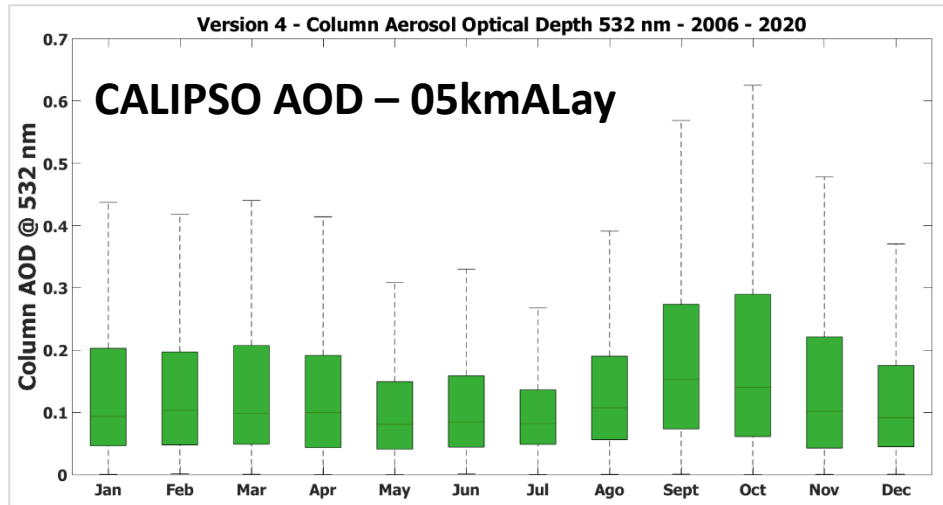


RCS -  $\lambda = 1064 \text{ nm}$  - 13 Sep 2020 - 10:55 to 23:58 UTC - São Paulo - MSP1



# Biomass burning events and LR studies

- Biomass burning + Lidar ratio scenario at São Paulo to be investigated
- CALIPSO data will help to improve LR scenario



AERONET São Paulo Site

