Lidar characterization of volcanic plumes

Luca Fiorani[1], Francesco Colao[1], Antonio Palucci[1], Davod Poreh[2]
[1]Diagnostics and Metrology Laboratory, ENEA
[2]ENEA guest with ICTP fellowship

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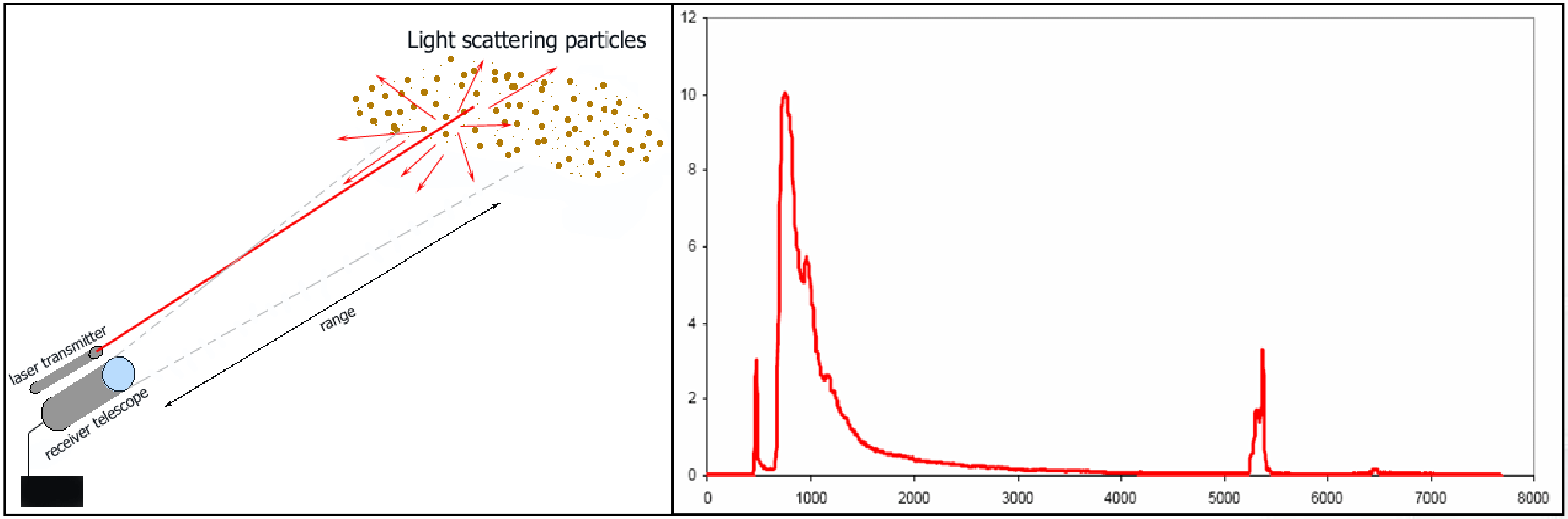
Plan

- Introduction to atmospheric lidar
- Principle of operation of backscattering lidar, differential absorption lidar and wind lidar
- Etna campaign (backscattering)
- Stromboli campaign (backscattering, water vapor, wind)
- Conclusions

Atmospheric lidar

- Lidar (light detection and ranging) = laser radar
- A laser sends a light pulse to the atmosphere
- The atmosphere interacts with the laser beam
- A telescope detects the backscattered light
- R=ct/2



Advantages of lidar

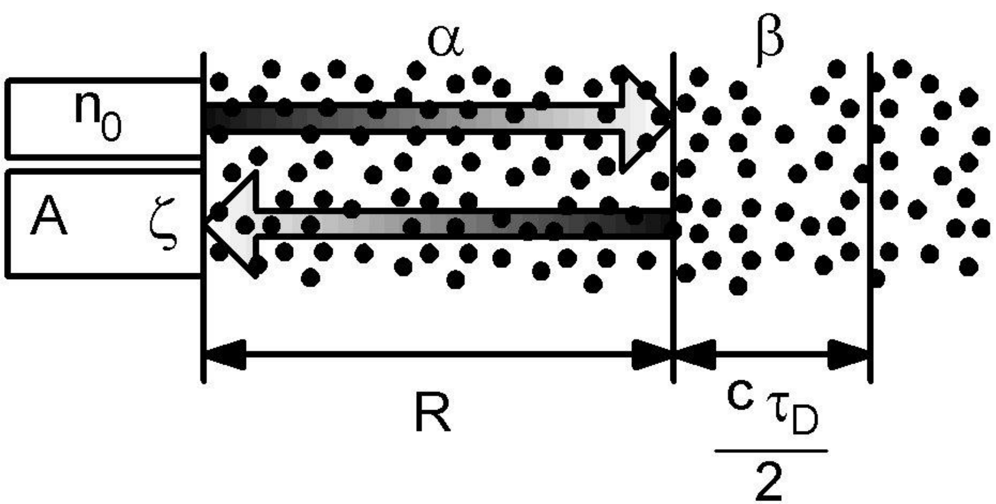
- Continuous retrieval of aerosol load, wind speed and gas concentration profile in a considerable range and with a good spatio-temporal resolution
- Probe-less measurement, thus eliminating the possibility of modifying the sample
- Integrated-path determination, less sensitive to local effects
- Capability of sweeping the complete hemisphere, thus allowing to follow the physico-chemical dynamics of the atmosphere

Backscattering lidar

- Lidar equation

$$n(R,\lambda)=n_0(\lambda)\,(A/R^2)\,\zeta(\lambda)\,\beta(R,\lambda)\,(c\tau_D/2)\,\exp[-2\int_0^R\alpha(R',\lambda)dR']$$

n (n_0) number of detected photons (transmitted), $R=ct/2$ is the range (c is the speed of light, t is the time between transmission and detection), λ is the wavelength, A (ζ) is the detection surface (efficiency), β (α) is the backscattering (extinction) coefficient, τ_D is the response time of the detector

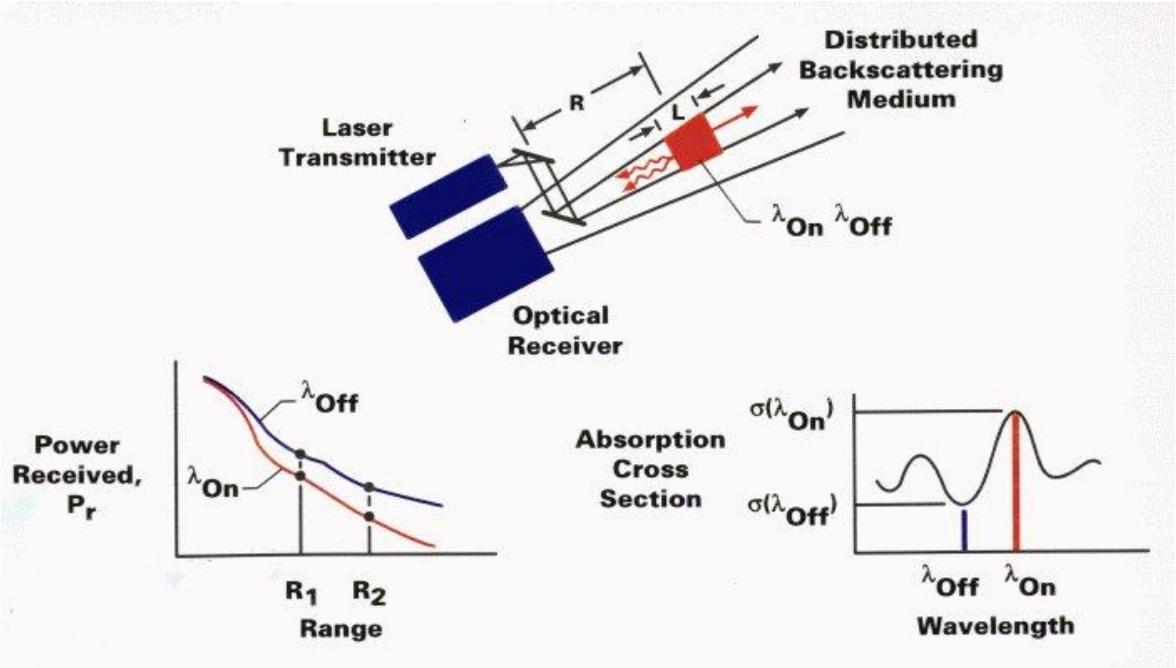


Differential absorption lidar

- DIAL (differential absorption lidar) equation

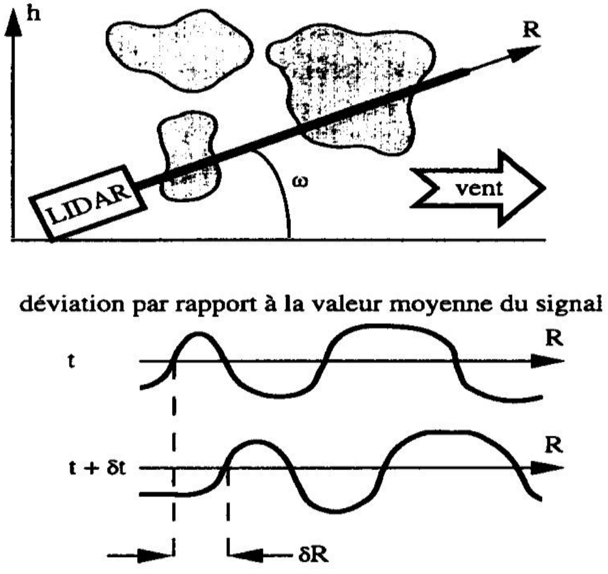
$$C(R)=\{1/[2(\sigma_{ON}-\sigma_{OFF})]\}(d/dR)\ln[n(R,\lambda_{OFF})/n(R,\lambda_{ON})]$$

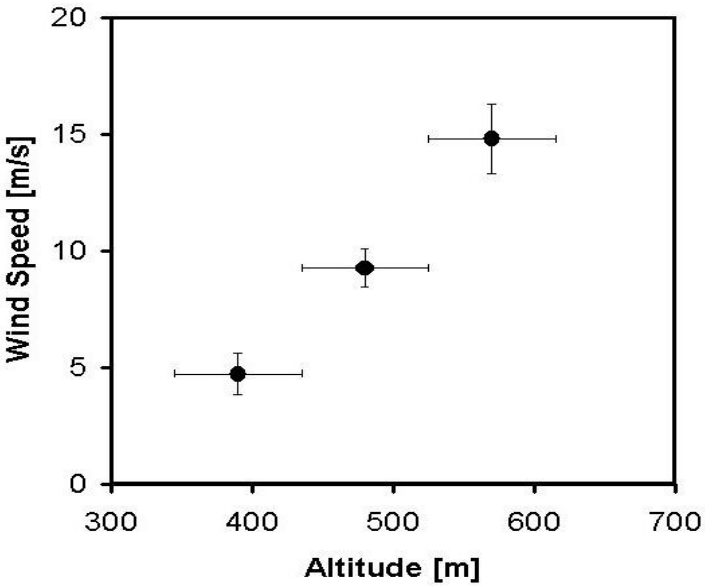
σ_{ON} (σ_{OFF}) is the cross section of the molecule at λ_{ON} (λ_{OFF}), λ_{ON} (λ_{OFF}) is the more (less) absorbed wavelength



Wind lidar

- Observation of the displacement in time of the aerosol load





Lidar at Frascati

- From the fixed lab… to the mobile lab

ENEA lidar ground station in the eighties.

ENVILAB (ENVIronmental LABoratory).

ATLAS

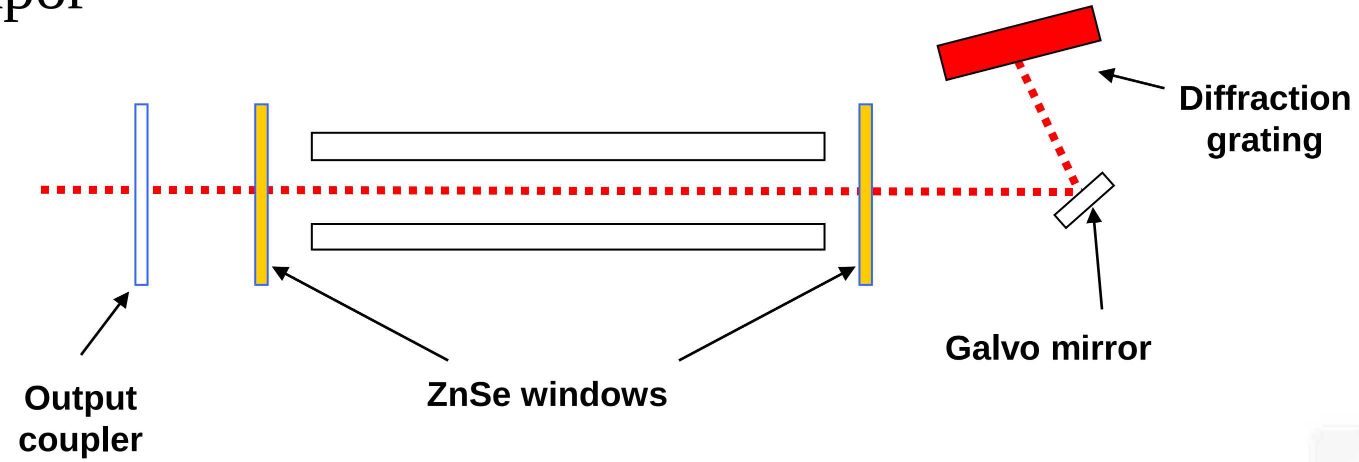
- ATLAS (agile tuner lidar for atmospheric sensing)

ATLAS (Agile Tuner Lidar for Atmospheric Sensing). Bottom-left: CO_2 laser. Right: Newton telescope. Top-left: control/acquisition computer.

ATLAS

- The agile tuner allows the tunability of the laser and, as a consequence, the detection of:
  - Ammonia
  - Ethylene
  - Ozone
  - Water vapor

  …



ATLAS

- Specifications

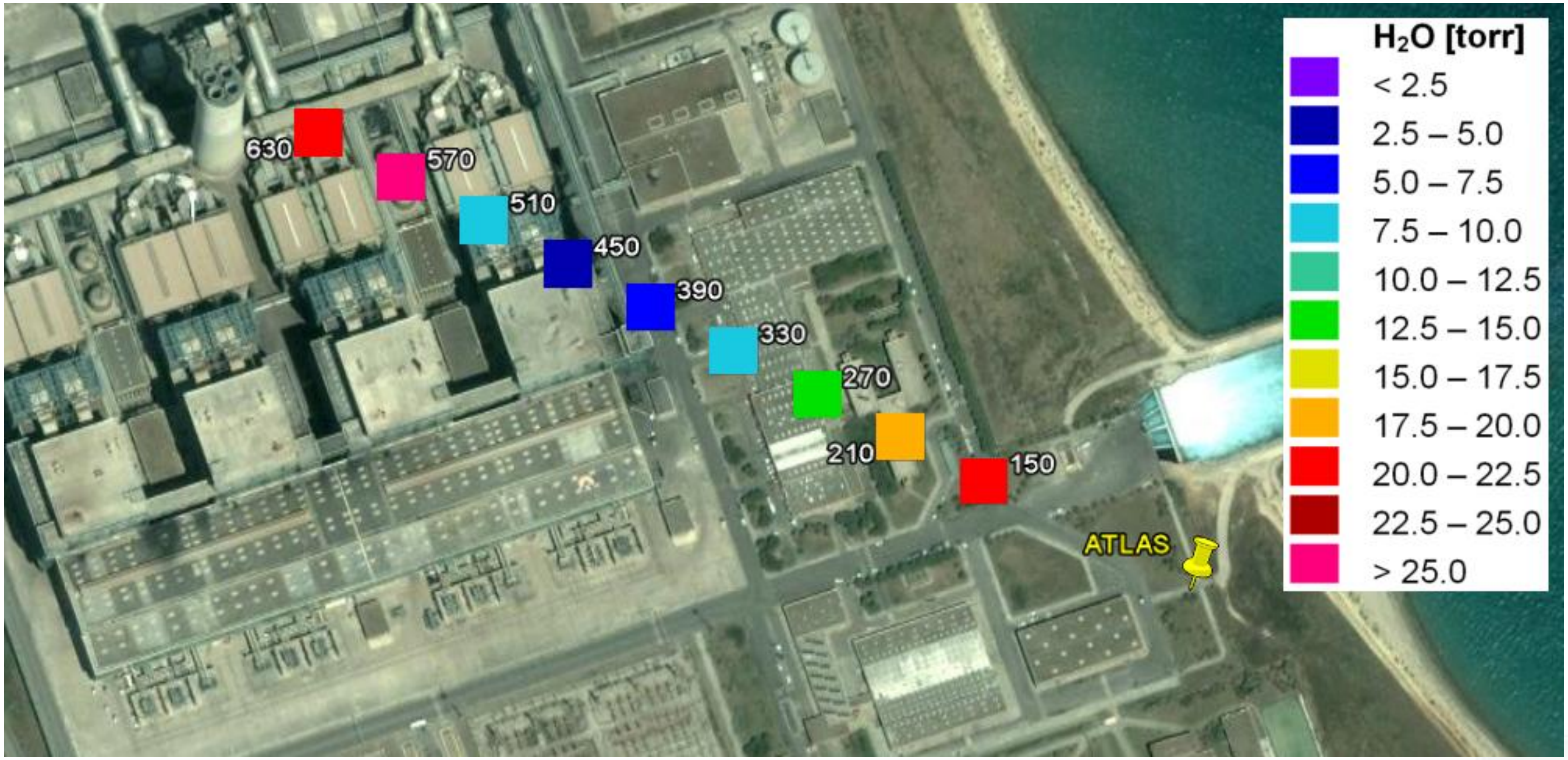
Transmitter	Pulse energy	850 mJ (at the 10P20 emission line)
	Pulse duration	60 ns (full width at half maximum)
	Repetition rate	1 ÷ 20 Hz
	Transmitted wavelength	9.2 ÷ 10.8 µm
	Beam divergence	0.7 mrad
Receiver	Mirror coating	Au
	Diameter	310 mm
	Focal length	1.2 m
Detector	Diameter	1 mm
	Specific detectivity	4×10^{10} cm $Hz^{1/2}$ W^{-1}
	Gain	200
	Linear dynamic range	0.1 ÷ 1000 mV
	Bandwidth	0 ÷ 10 MHz
Analog-to-digital converter	Dynamic range	8 bit
	Sampling rate	10 Ms s^{-1}

Monitoring application

- Power Plant of Cerano (Brindisi)

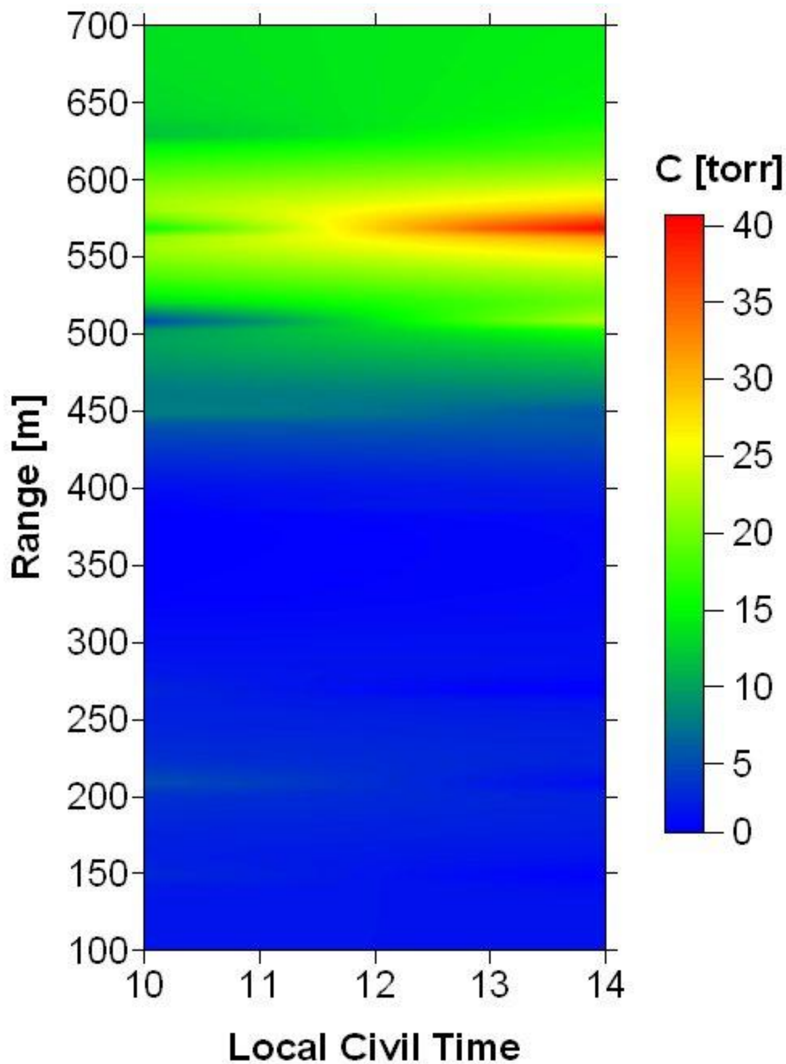
Monitoring application

- Concentration profiles in industrial zones



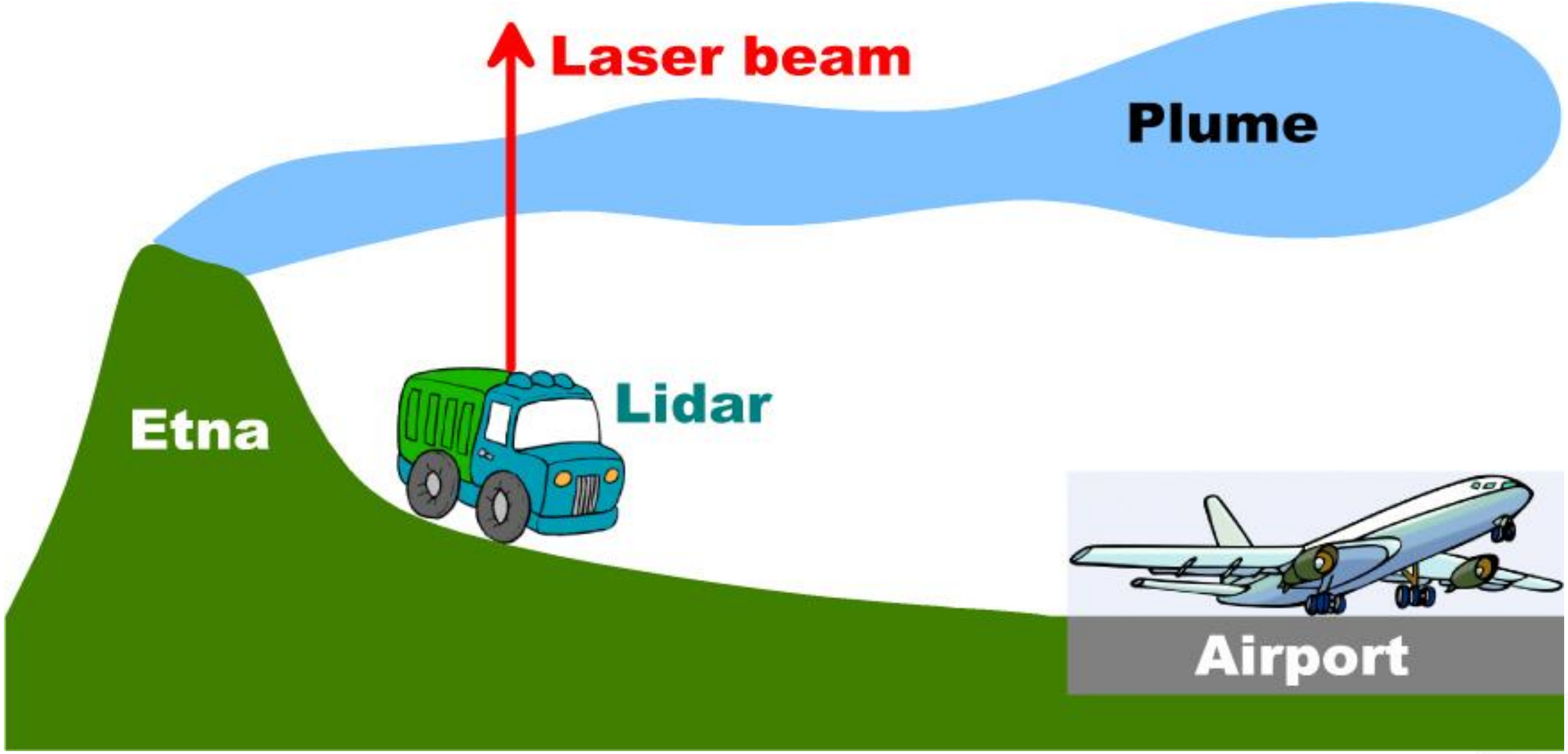
Monitoring application

- Spatiotemporal evolution



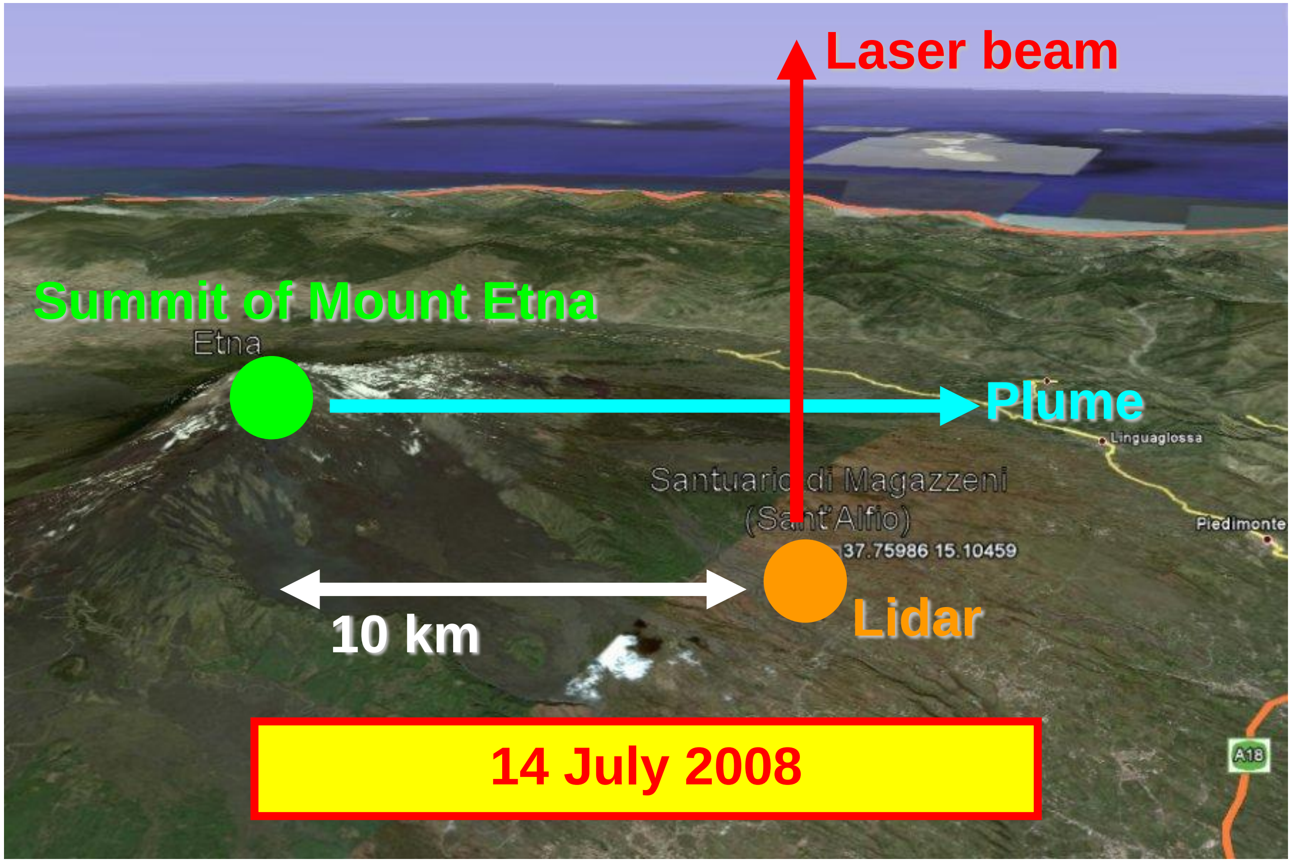
Plume profiling

- Experimental scheme



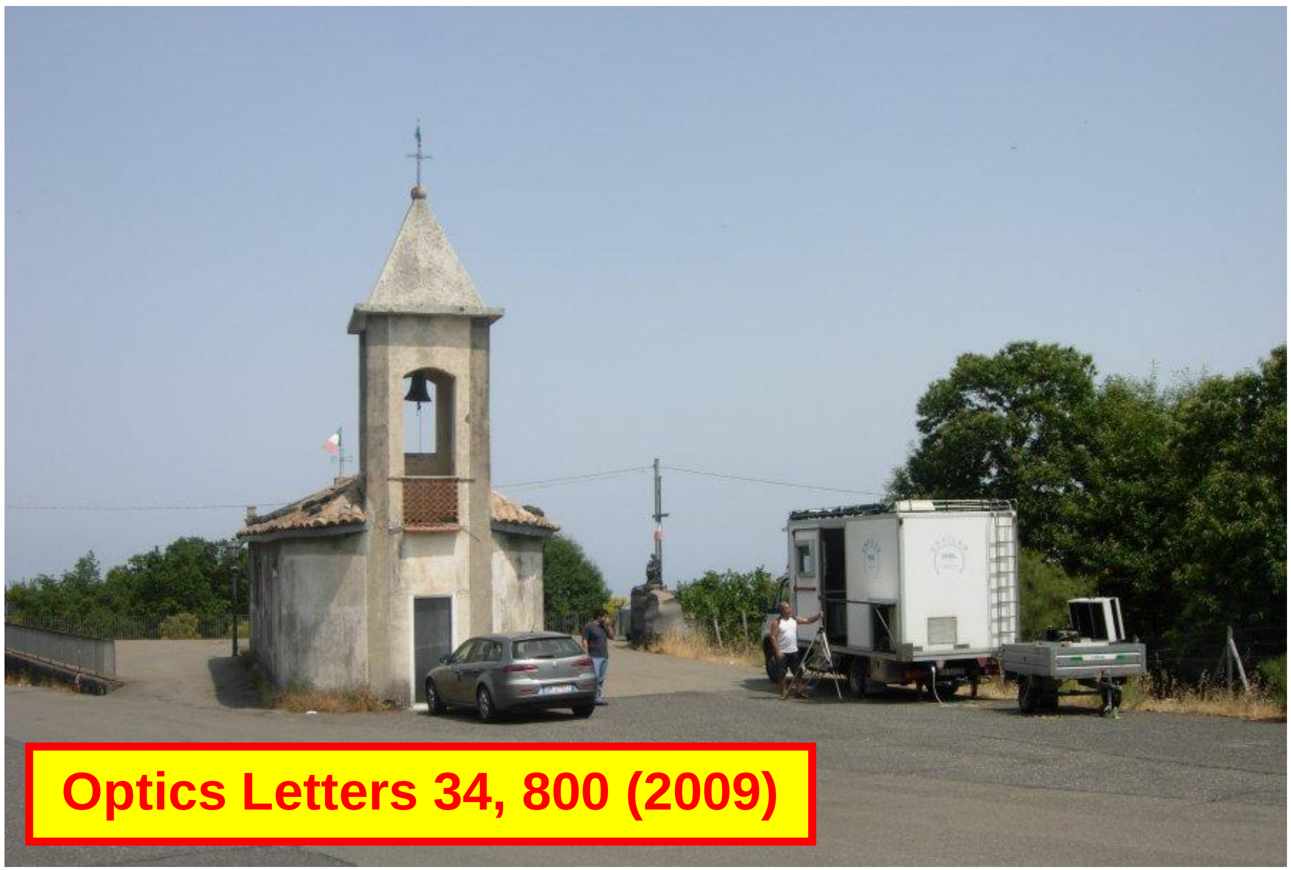
Plume profiling

- Geographical situation



Plume profiling

- Sant'Alfio (Catania) – Santuario Magazzeni

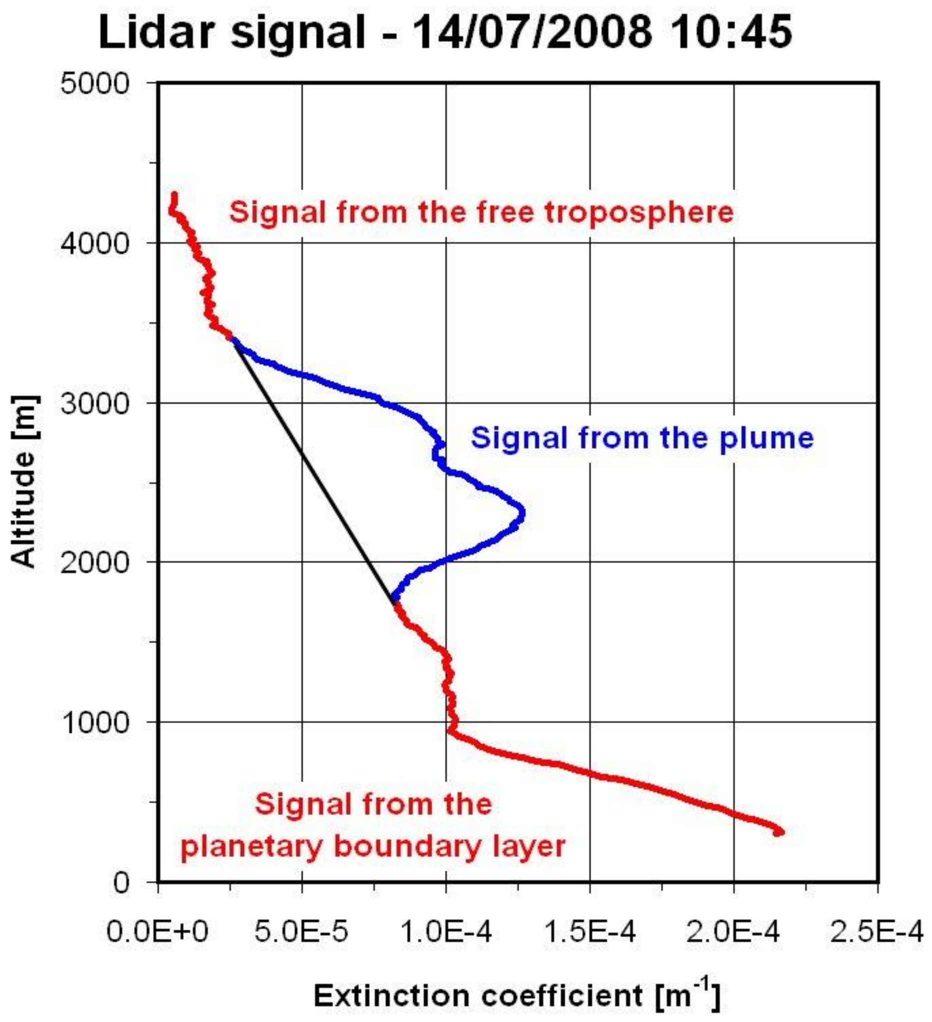


Optics Letters 34, 800 (2009)

Plume profiling

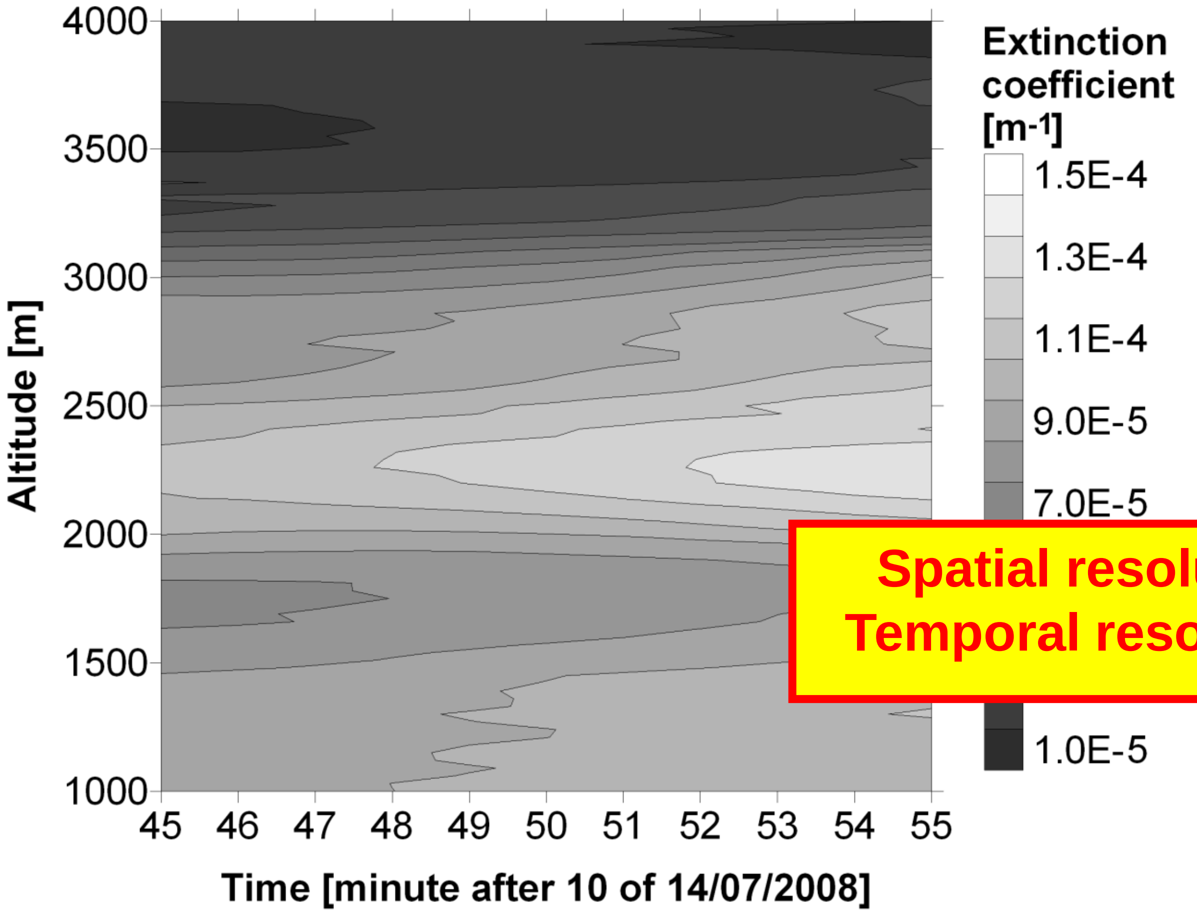
- Extinction coefficient calculated at 10.6 μm with an algorithm similar to those by JD Klett, Applied Optics 20 (1981) 211 and FG Fernald, Applied Optics 23 (1984) 652

Maximum range > 5 km



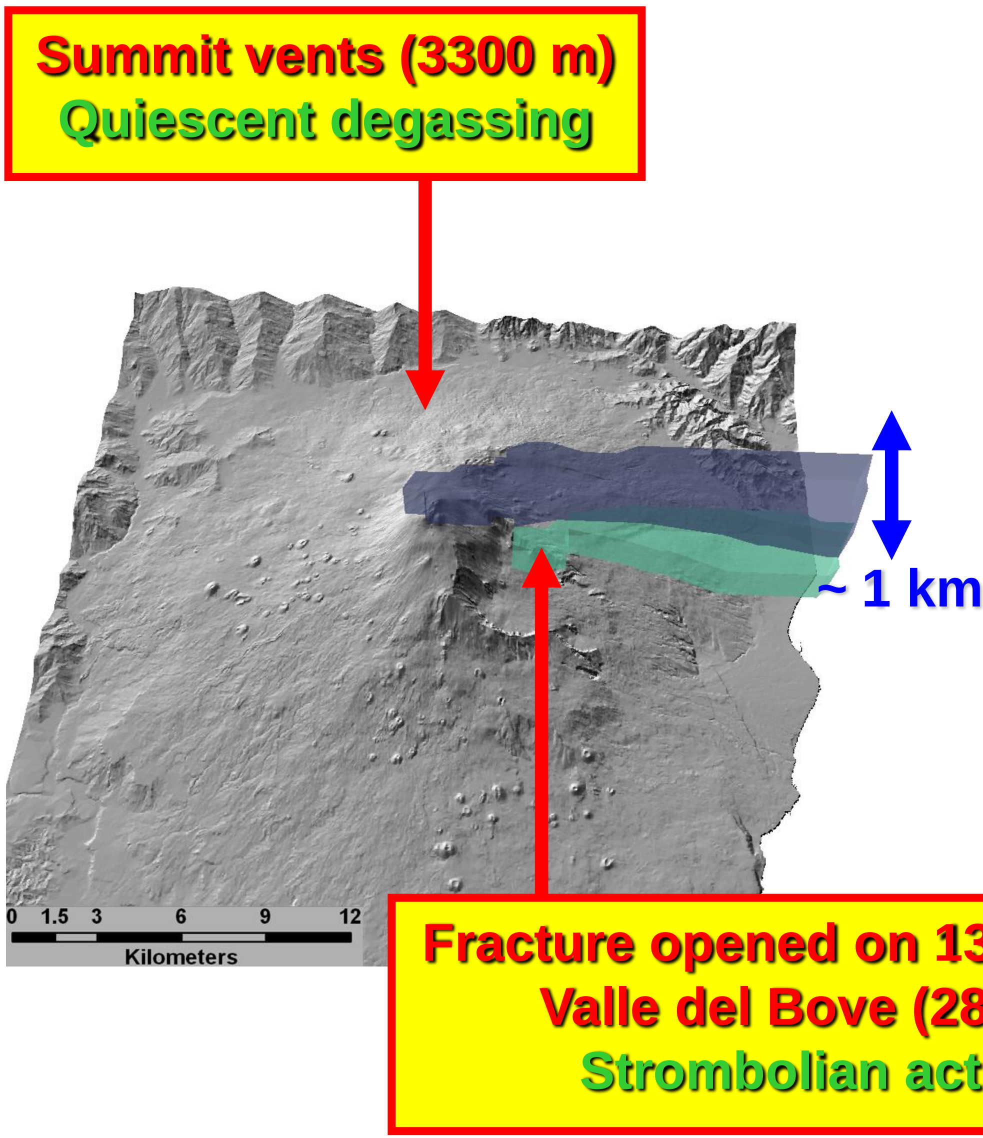
Plume profiling

- Spatiotemporal evolution



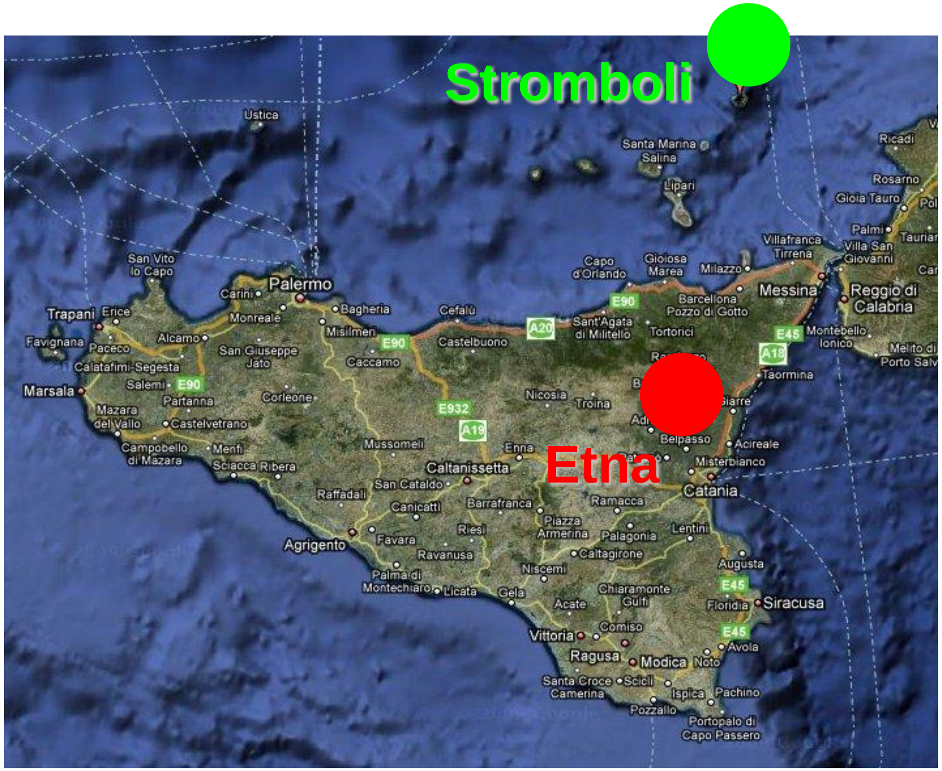
Spatial resolution: 15 m, Temporal resolution: 1 min

Plume profiling



- Combining the AOT (Aerosol Optical Thickness) map (satellite) and the altitude information (lidar), two different plumes can be distinguished (thanks to MF Buongiorno, L Guerrieri, C Spinetti)

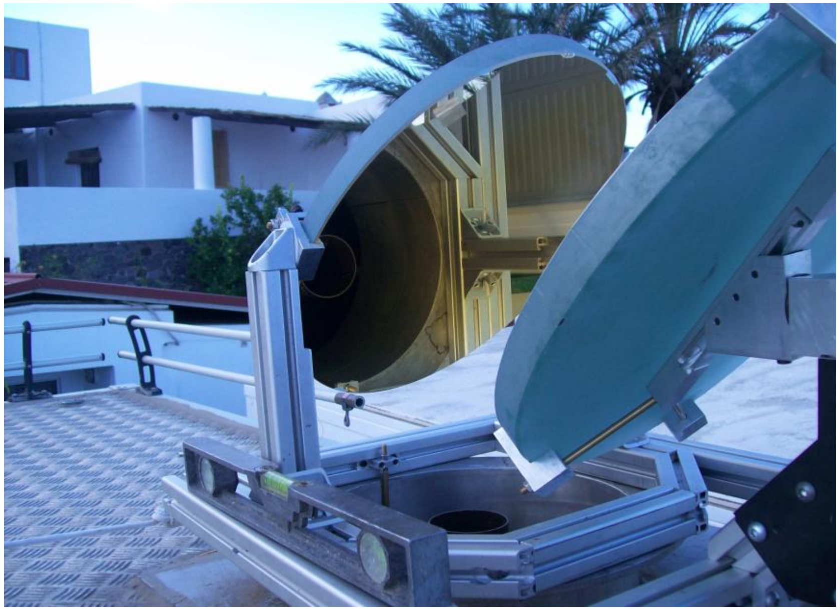
From Etna to Stromboli…



12-17 September 2009

From Etna to Stromboli…

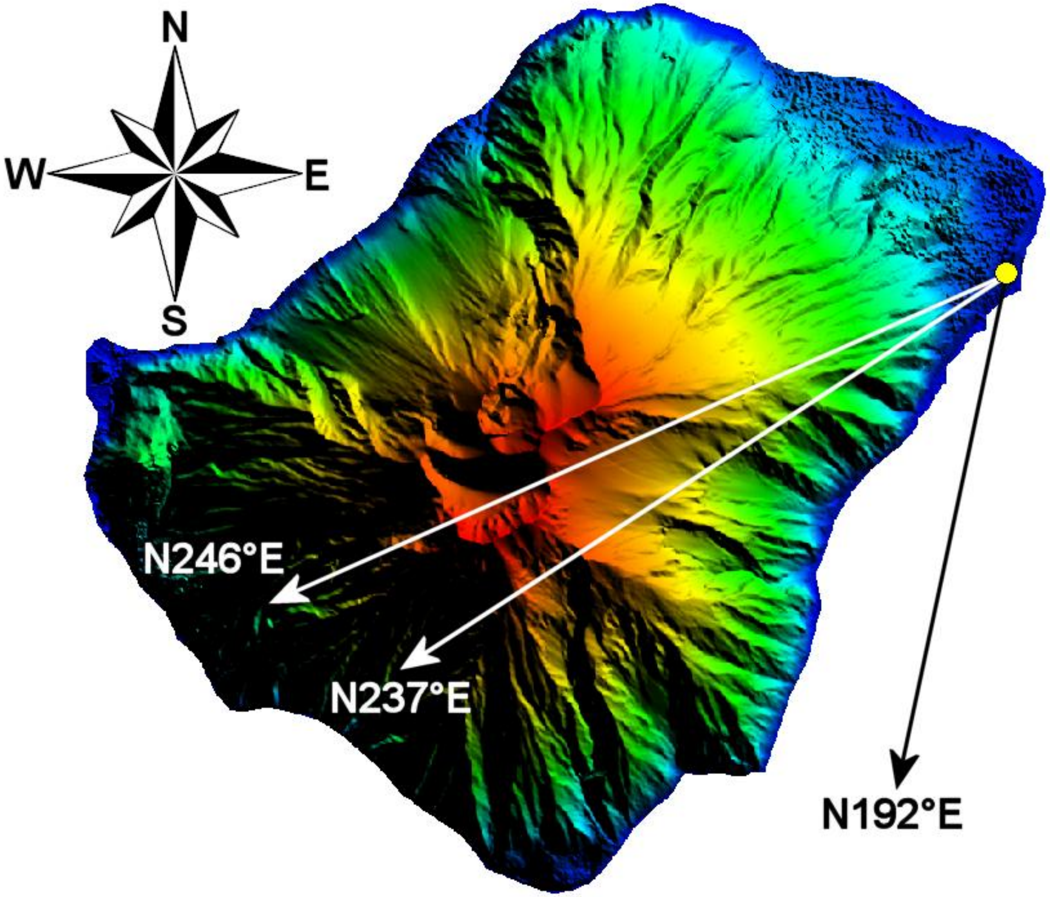
- The lidar is directed to the plume with a coelostat



Optics Communications (in press)

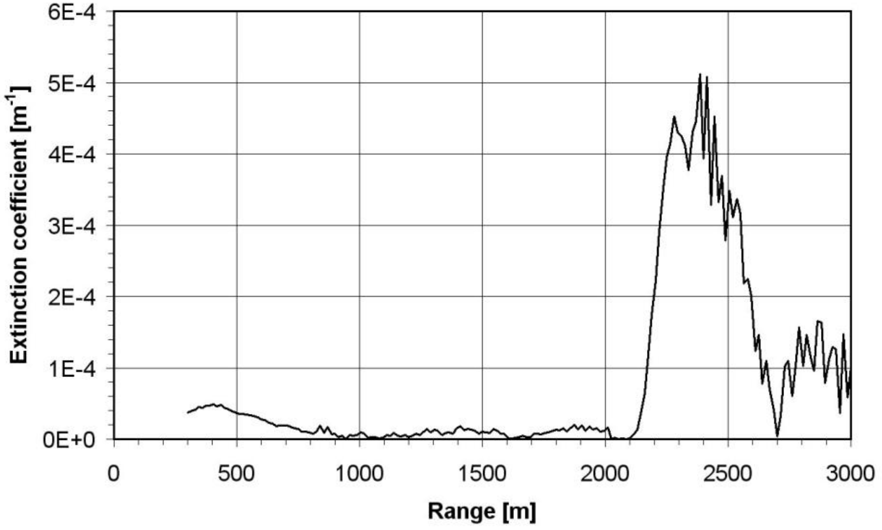
From Etna to Stromboli…

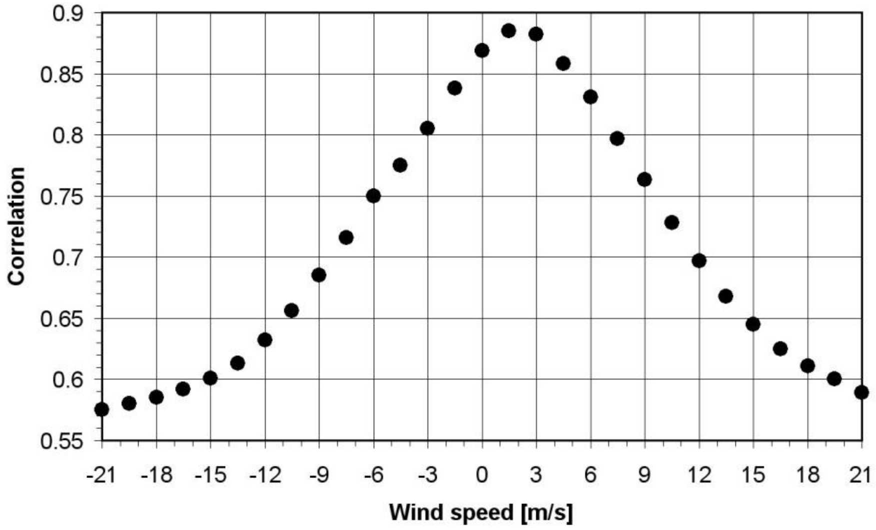
- We will consider three scans



From Etna to Stromboli…

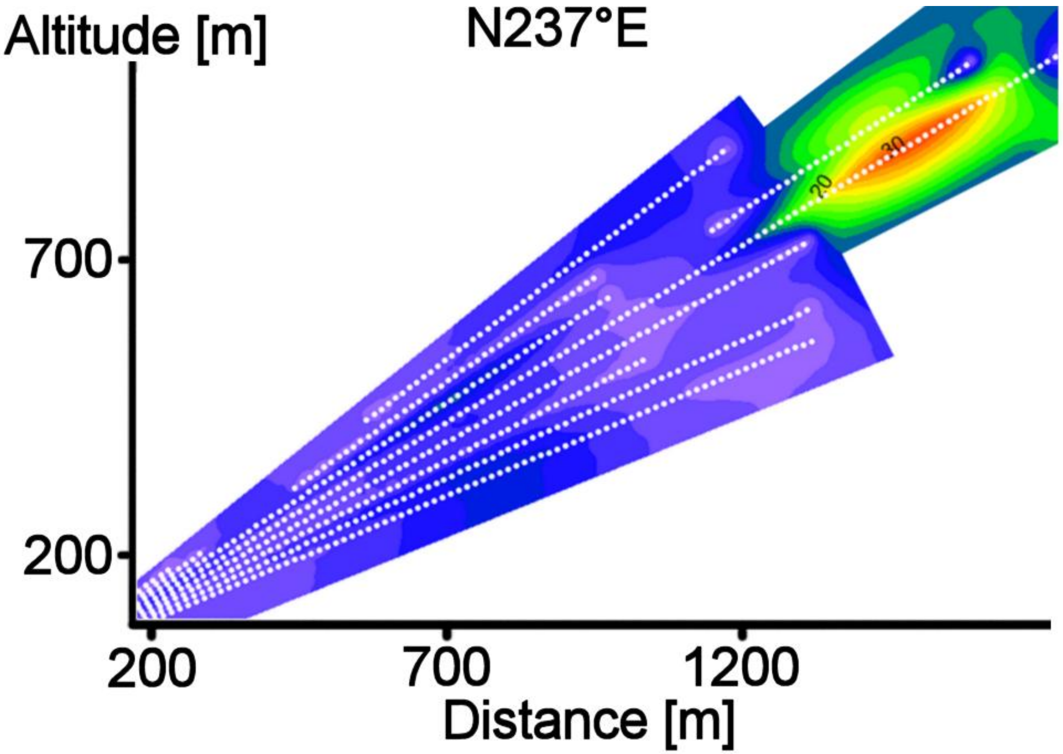
- Scan N246E (crater): backscattering and wind speed

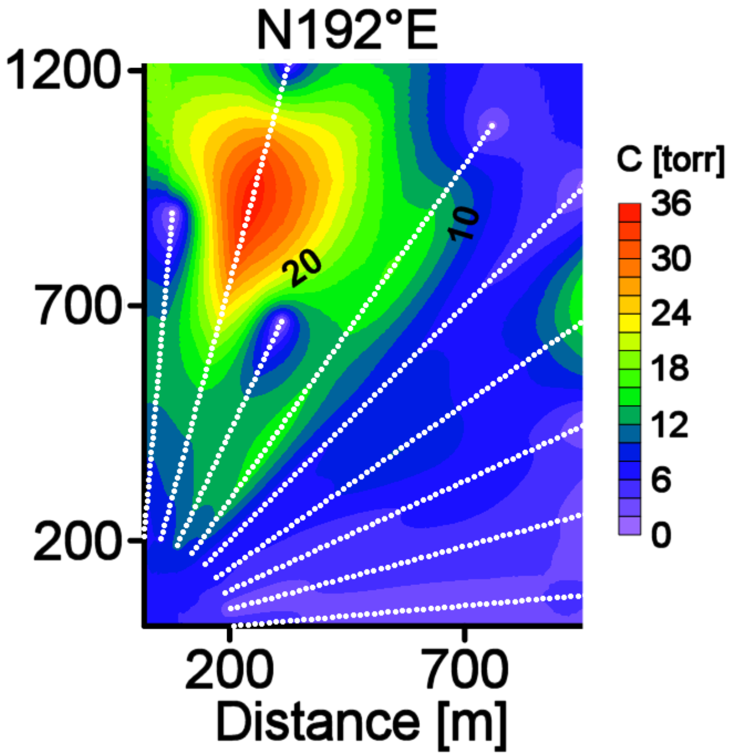




From Etna to Stromboli…

- Scans N237E and N192E (across the wind): water vapor and wind direction





From Etna to Stromboli…

- Results
  - wind direction: $\mathbf{u}_w$=(0.901253, 0.430714, 0.047201)
  - wind speed: $w=3.8\pm1.5$ m s^{-1}
  - water vapor concentration: $C=1.81\times10^{-2}\pm0.23\times10^{-2}$ kg m^{-3}
  - water vapor flux: $\Phi=C\times w=0.069\pm0.029$ kg m^{-2} s^{-1}

From Etna to Stromboli…

- Results
  Contribution to the flux from the volcanic plume
  (subtracting the natural background):
  $\Phi_P=0.032\pm0.015$ kg m^{-2} s^{-1},
  Daily emission rate:
  $R=\Phi_P\times A=10{,}200\pm4{,}800$ t day^{-1}
  (A is the cross-sectional area of the volcanic plume)
  Conventional measurement of daily emission rate:
  $5{,}600\pm1{,}100$ t day^{-1}
  (thanks to A Aiuppa G Giudice)

Conclusions

- The CO_2 laser-based lidar ATLAS has been used to profile the volcanic plumes of Etna and Stromboli.
- Extinction coefficient profiles have been retrieved up to an altitude above ground level of 5000 m.
- Also water vapor concentration and wind speed vector were measured.
- Eventually, the water vapor flux was retrieved from these two values.

Conclusions

- It is the first time that the water vapor flux in a volcanic plume is retrieved by lidar, representing the first direct measurement of this kind ever performed on an active volcano and showing the high potential of laser remote sensing in geophysical research.

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- A new book on atmospheric lidar will be published by INOE Publishing House:
- **RECENT ADVANCES IN ATMOSPHERIC LIDAR**
- Editors: *L. Fiorani and V. Mitev*
- Contributors: **D. Nicolae, T. Trickl, V. Rizi, A. Comeron, I. Serikov, J. Pelon et al.**

Thanks for your attention!

luca.fiorani@enea.it