Ground Truth for Flux Measurements from Urban Areas

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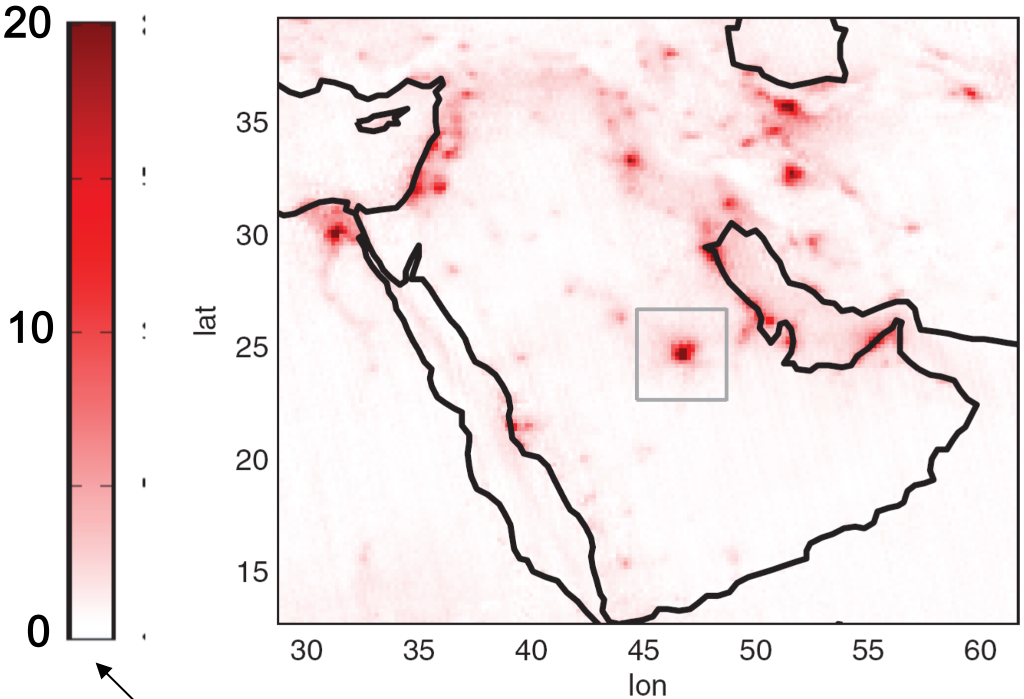
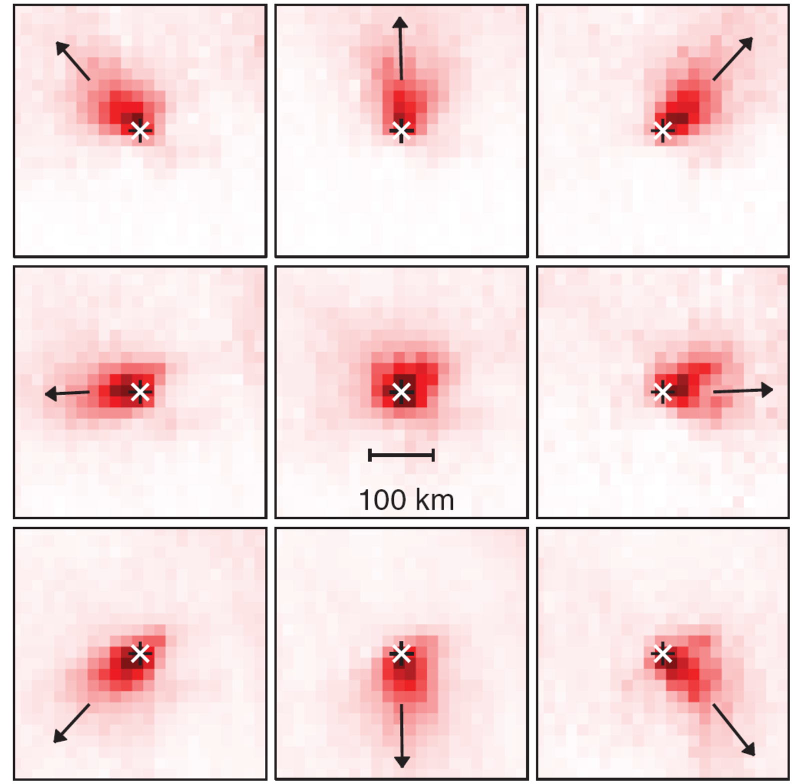
EU ACCENT PLUS and ICACGP Workshop on:
"Pollution studied by REmote Sensing of Conurbations/megacities and Retrieved from observations made by Instrumentation on space BasEd platforms - **PRESCRIBE**"
May 15-16, 2013

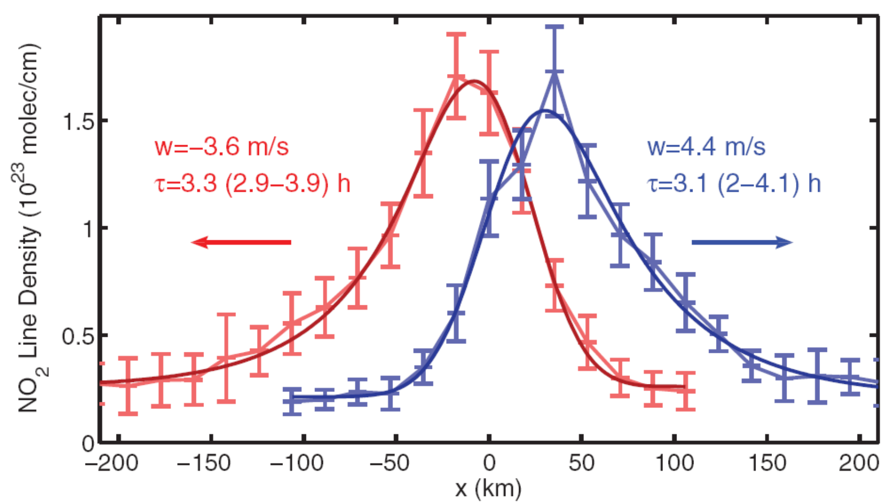
ACCENT *Plus*
ATMOSPHERIC COMPOSITION CHANGE
THE EUROPEAN NETWORK

Satellite Measurement of Urban NO_2 - Source Strengths (Example: Rhyad)



NO_2-Column
(10^{15} molec/cm^2)

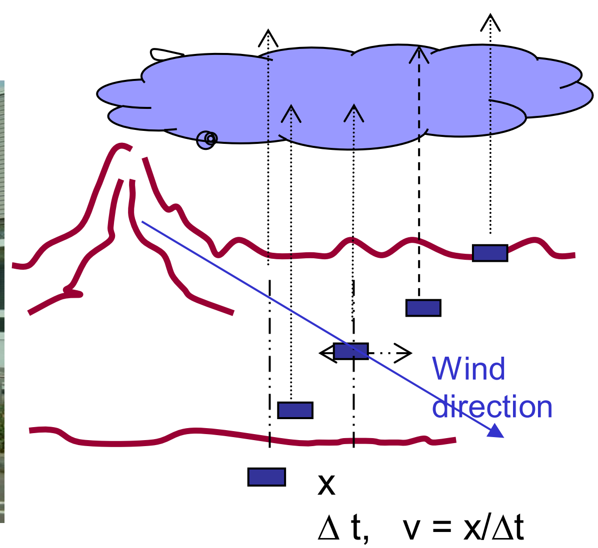


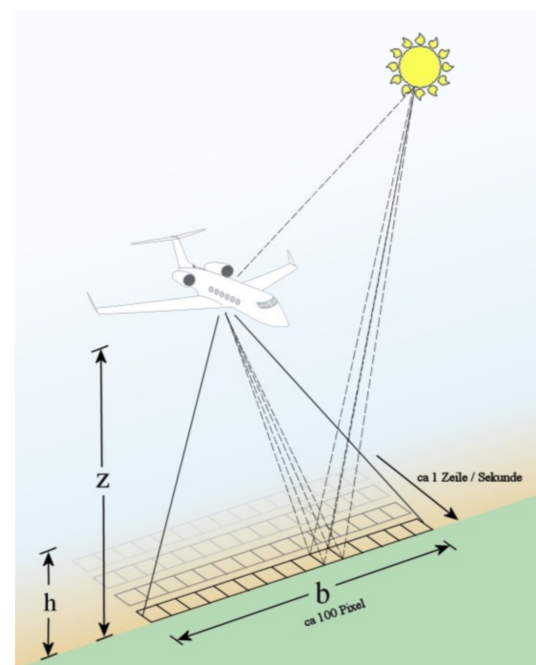


Beirle S., Boersma K.F., Platt U., Lawrence M.G., and Wagner T. (2011), Megacity emissions and lifetimes of nitrogen oxides probed from space, Science 333, 1737-1739.

Ground Truth for Satellite Measurements of Fluxes

1. Encircle Source Area with MAX-DOAS instrument (e.g. Auto-MAX-DOAS, Tram, Train, …
2. Fence in Source Area with many MAX-DOAS instruments
3. Map out area with Airborne Imaging DOAS measurements
4. Active instruments (LP-DOAS, DOAS-LIDAR)





Measurement of the Trace Gas Source Strength Inside an Encircled Area

Source strength Φ = net flux leaving the area:

$$\Phi = \int_{Vol.} \vec{\nabla} \vec{J}\, dV = \square \quad \vec{} \quad \vec{} \quad \square$$

J

Integration over z (by DOAS) yields:

$$\Phi = \square \quad \square \quad \alpha$$

$\vec{J}$ = Trace Gas Flux Density (*e.g. molec cm*$^{-2}$ *s*$^{-1}$)

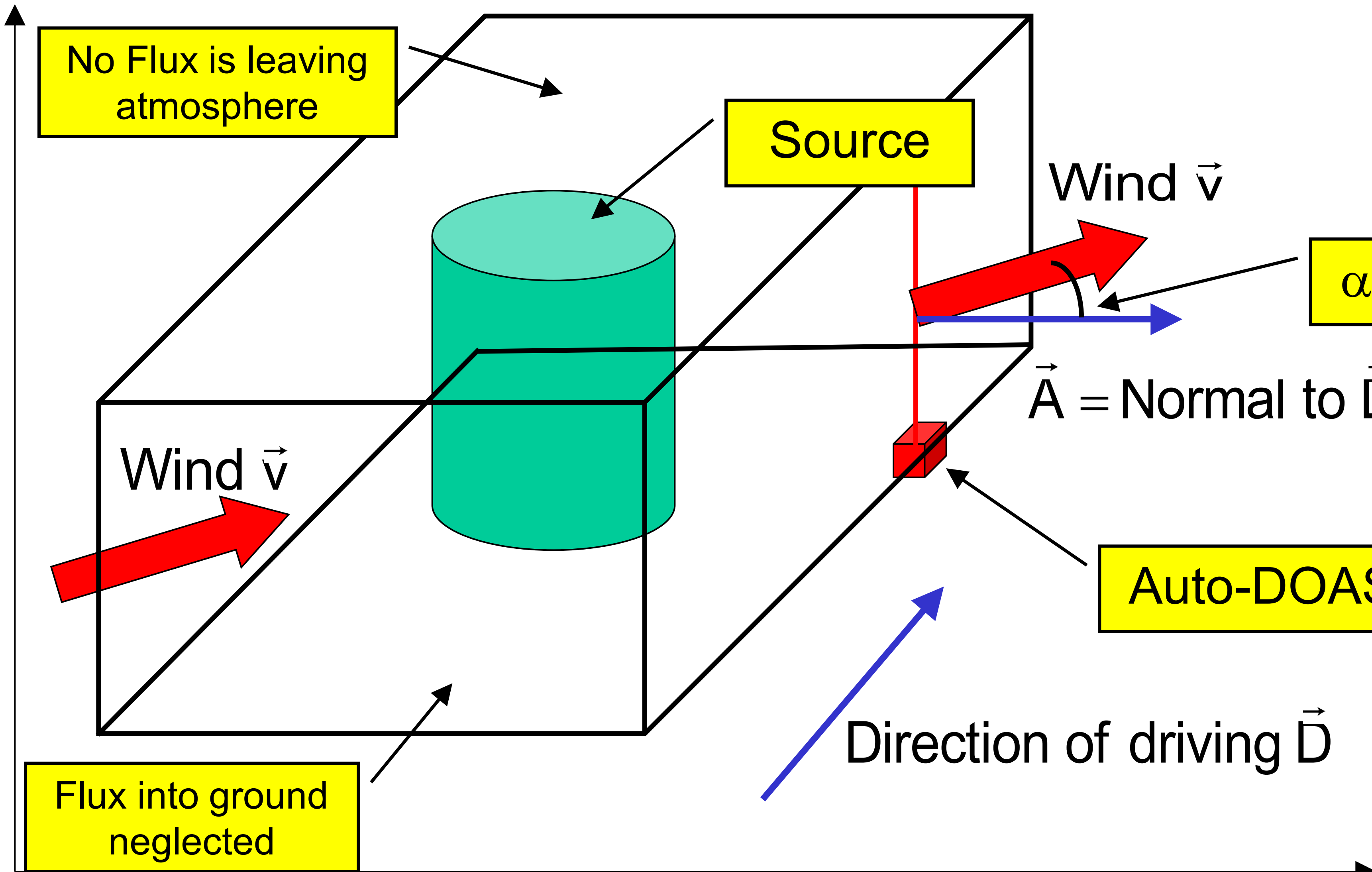
$\vec{v}$ = Wind Speed

c = Trace Gas Concentration

$V = \int_0^\infty c(z)\,dz$ = Vert. Column Density

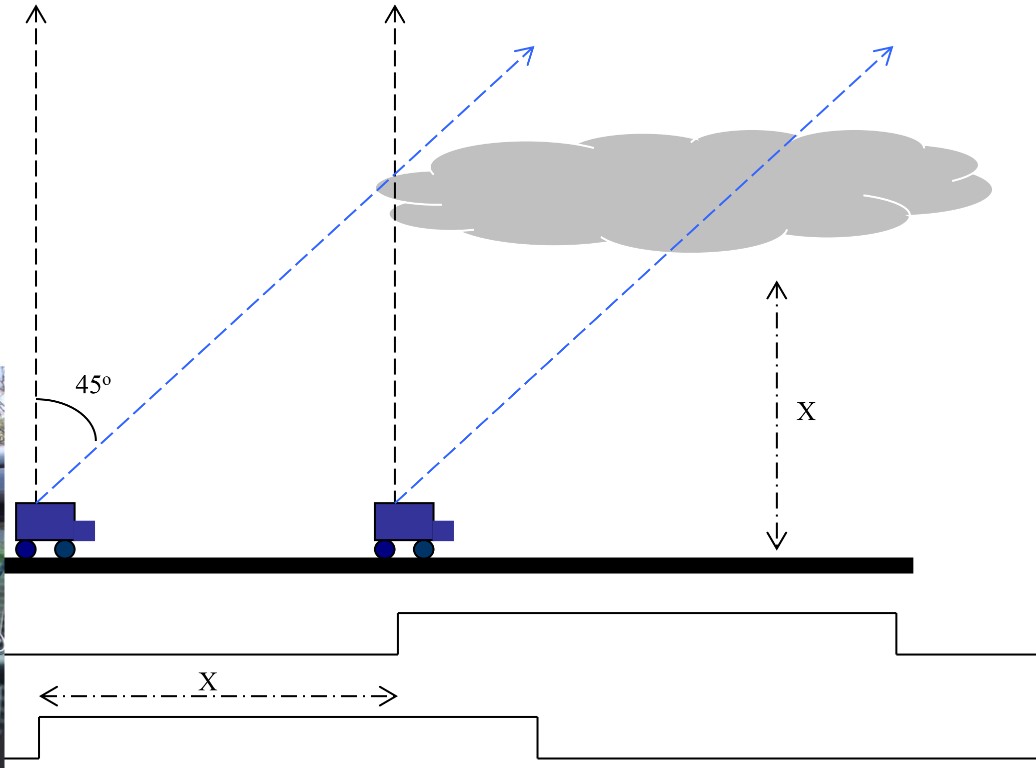
α = Angle between Surface-Normal and $\vec{v}$

Measurement of the Trace Gas Source Strength Inside an Encircled Area (2)

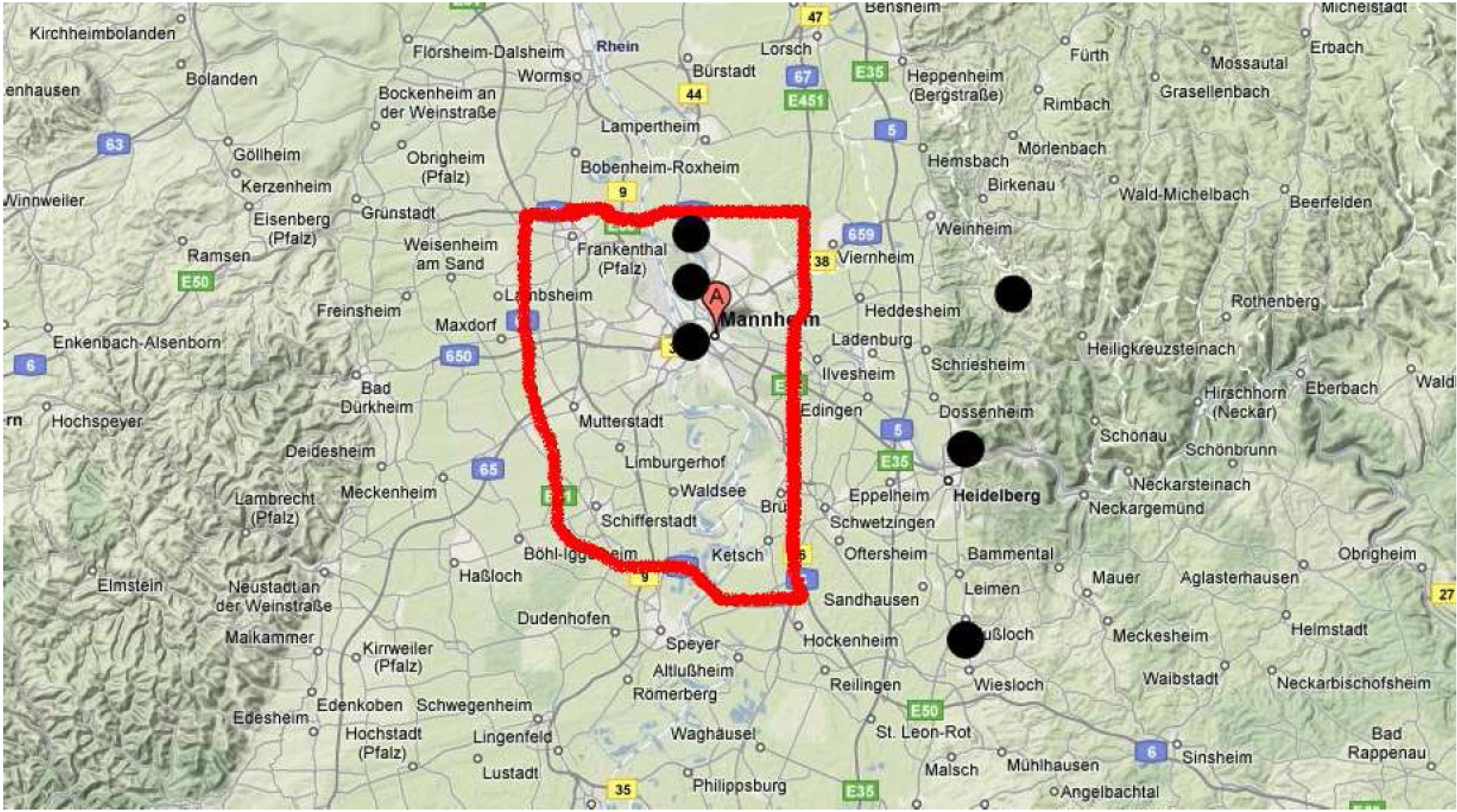


Plume Monitoring from Mobile Instruments

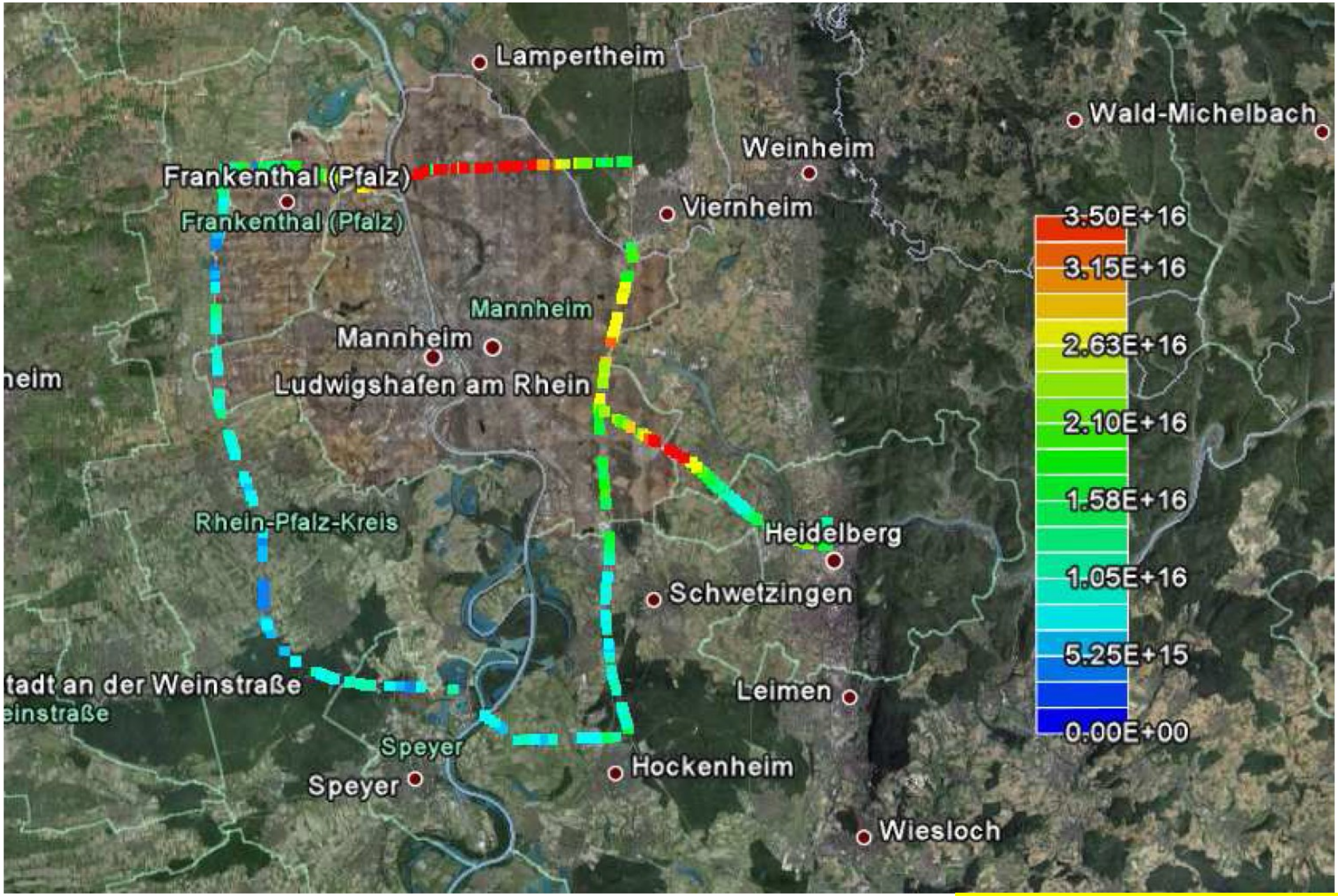
Determine plume height with dual spectrometer system:



Example: Auto-DOAS Measurements, Mannheim-Area, August 2006 (Ibrahim 2009)



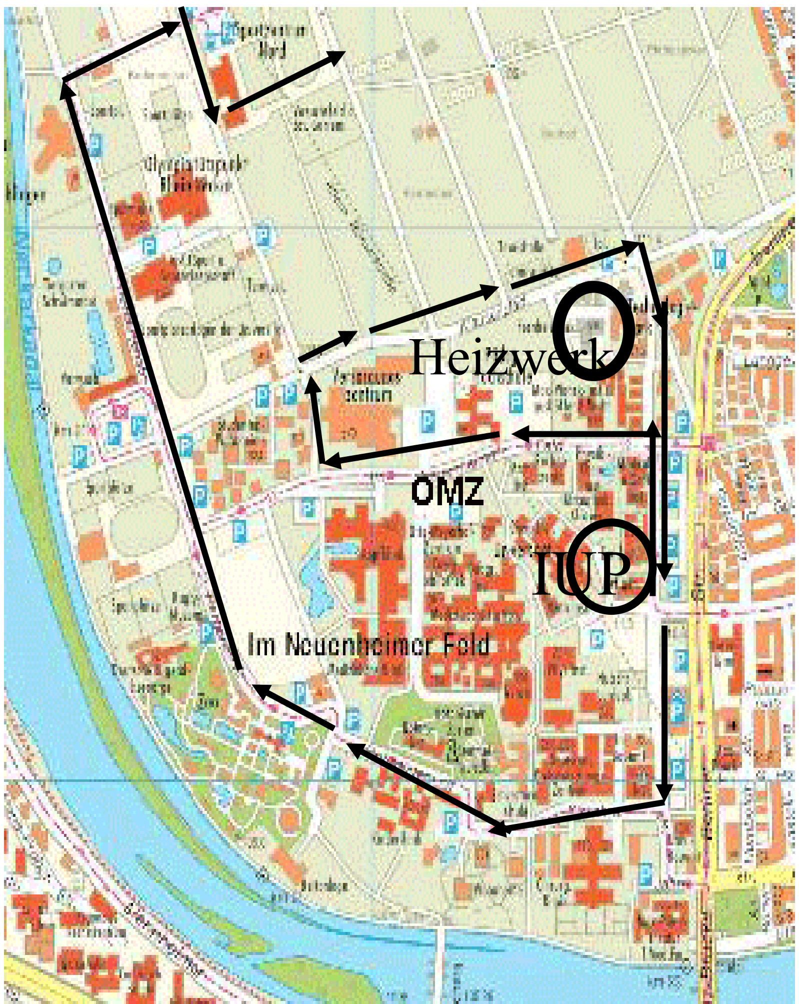
Auto-DOAS NO_2 - Measurements, Mannheim-Area, August 23, 2006

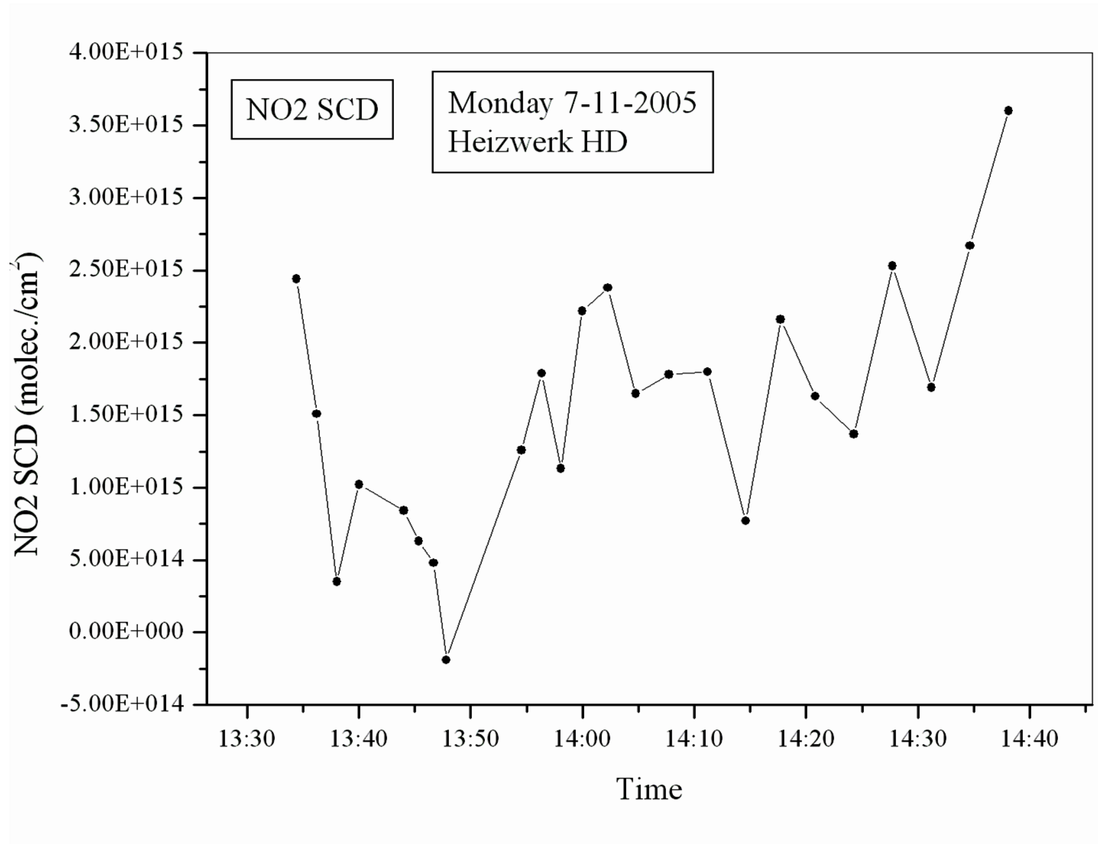


Wind Speed: 1-2 m/s,
Direction: SW

O. Ibrahim, Doktoral Thesis, 2009

Encircling the Central Heating Plant (Heizwerk) in Neuenheimer Feld, Heidelberg



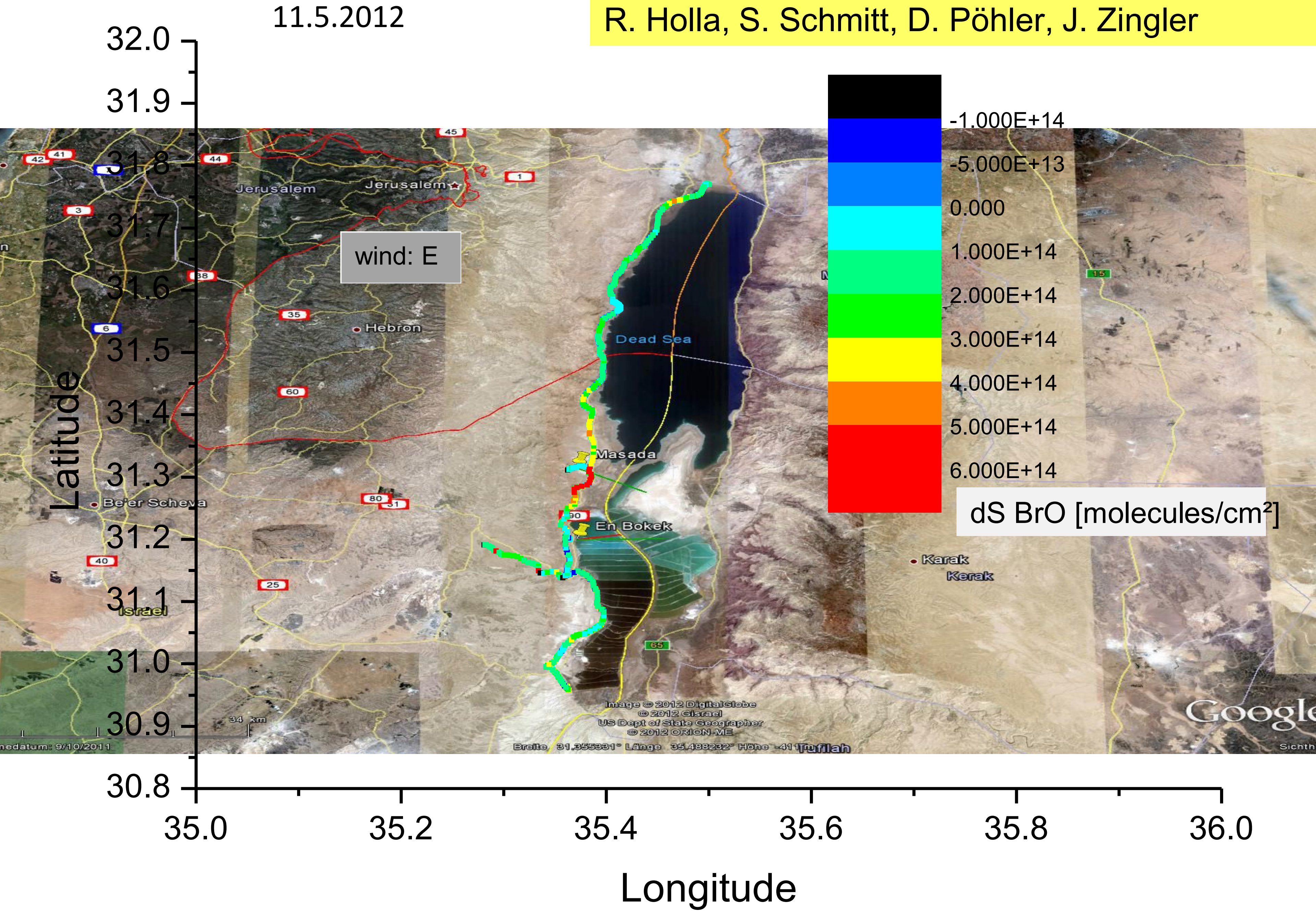


Rainer Volk, Diploma Thesis, 2008

Debora Döringer, Bachelor thesis 2010

Auto-DOAS Measurements of BrO, Dead Sea, May 11, 2012

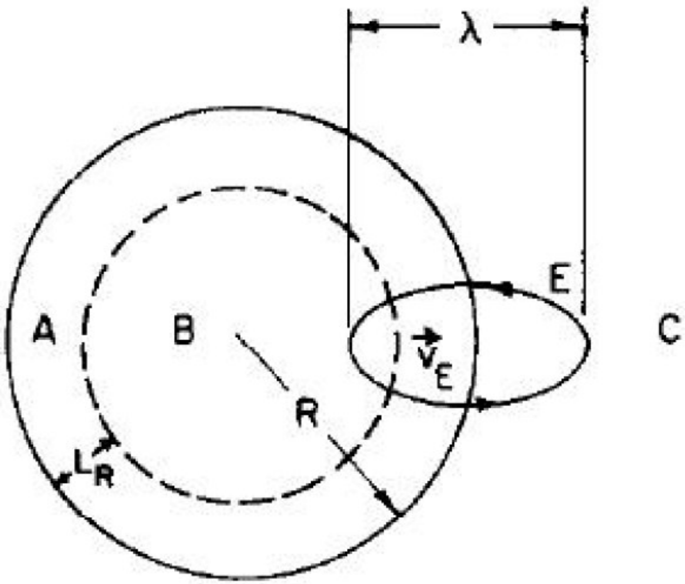
R. Holla, S. Schmitt, D. Pöhler, J. Zingler



Problems - Uncertainties

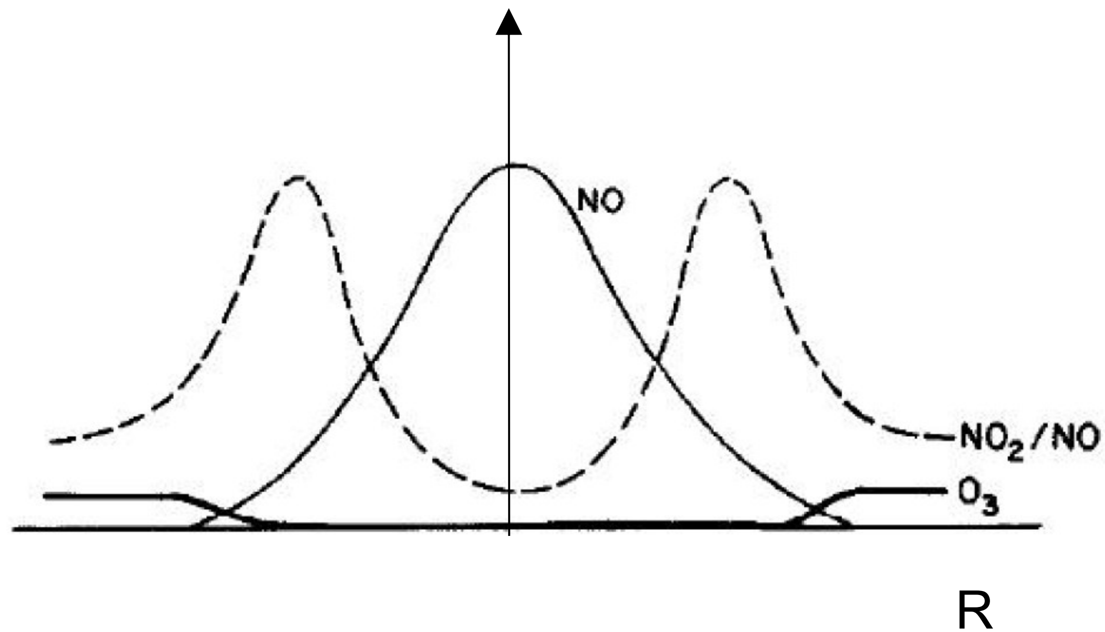
1) Incomplete NO → NO_2 conversion i.e. Leighton Ratio not yet reached at point of measurement

NO_X – Plume Cross-Section



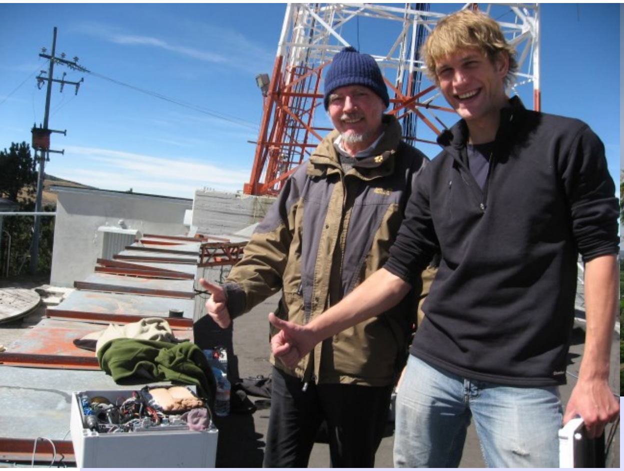
Hegg et al. 1977

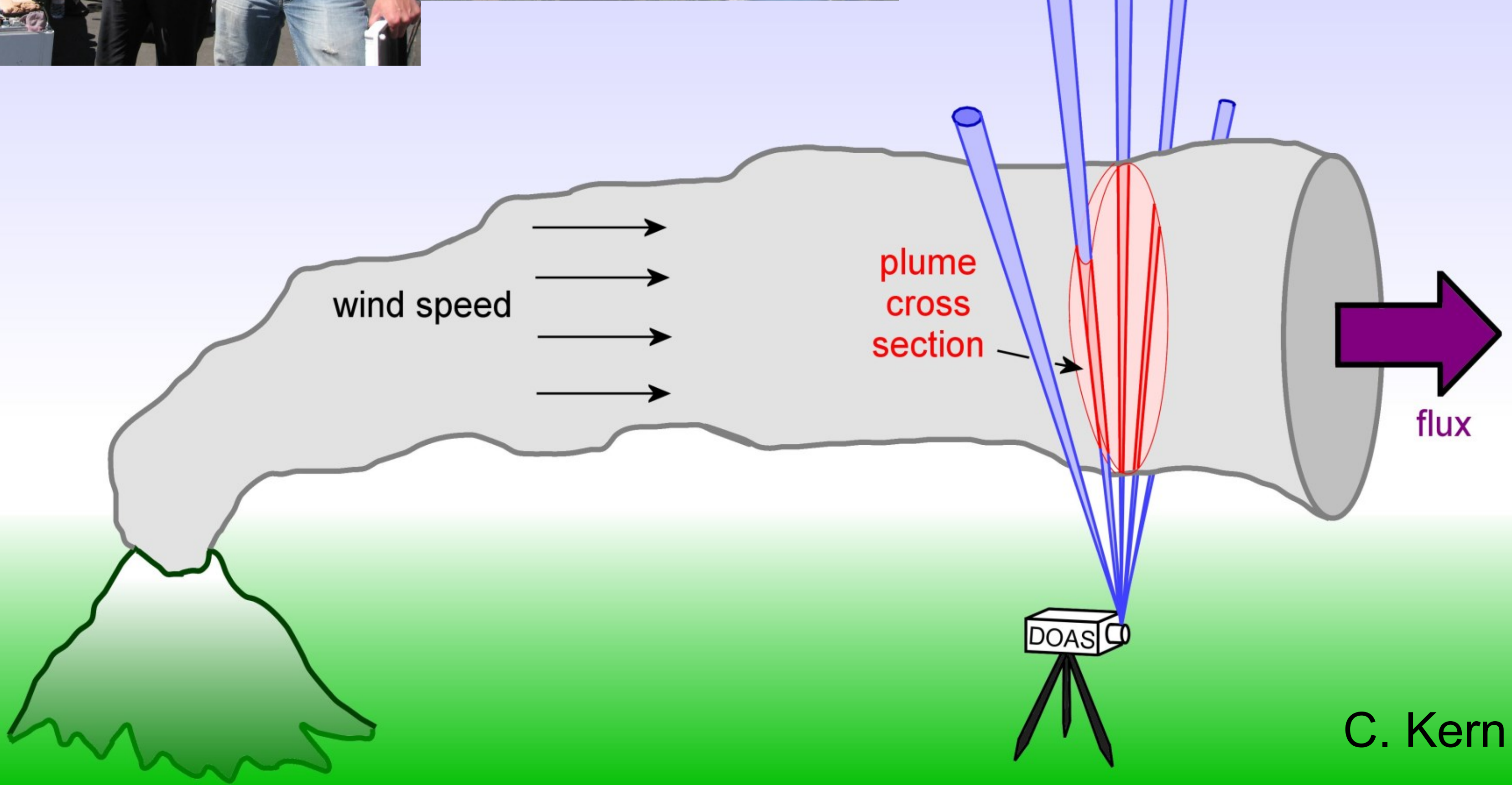
NO, O_3 concentrations and NO_2/NO-ratio as function of radius



2) Determination of (correct average) wind speed

DOAS - Flux Measurements of (Volcanic) Gases (SO_2, BrO, ...)





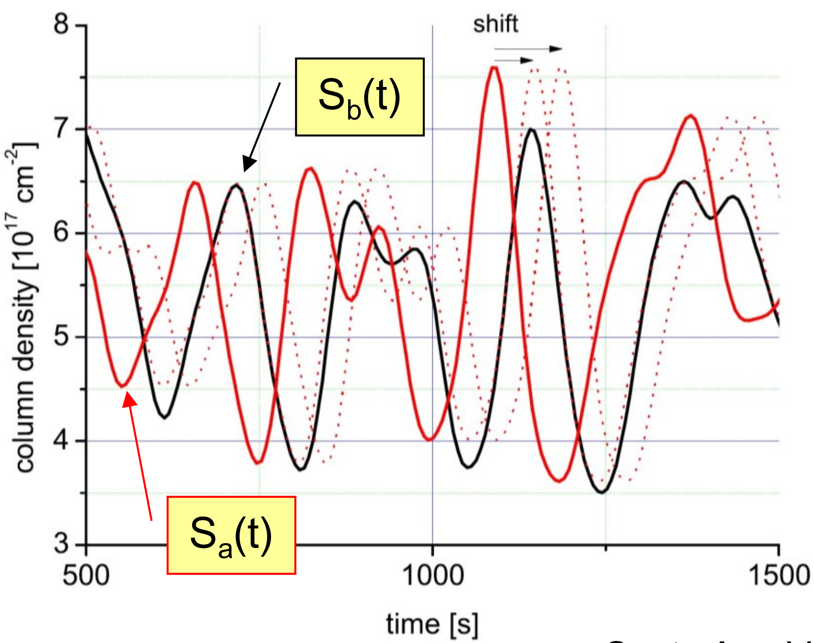
C. Kern

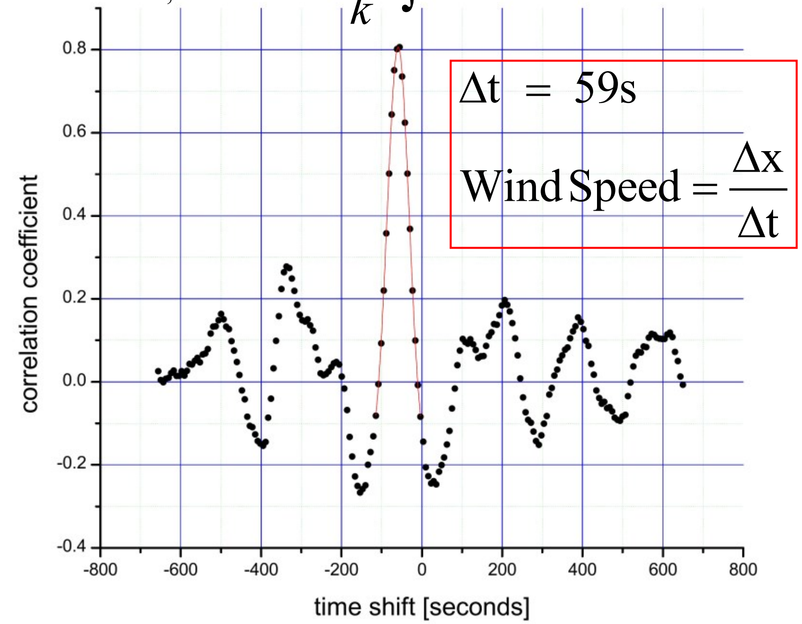
Wind Speed in Plume → Trace Gas Flux → Indicator for Eruptions

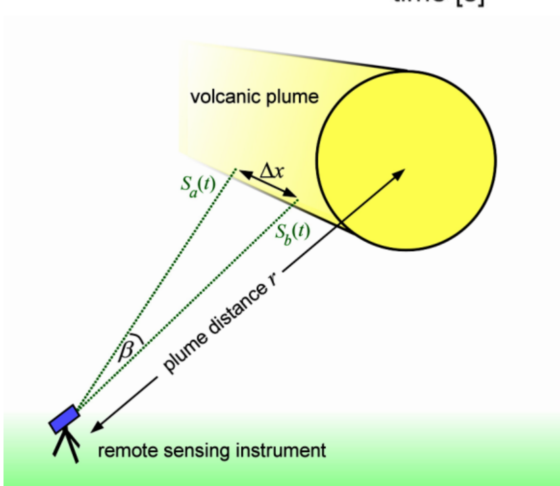
Two time series $S_a(t)$, $S_b(t)$ of the SO_2 column density at two different distances from source

Correlation coefficient between $S_a(t)$, $S_b(t)$:

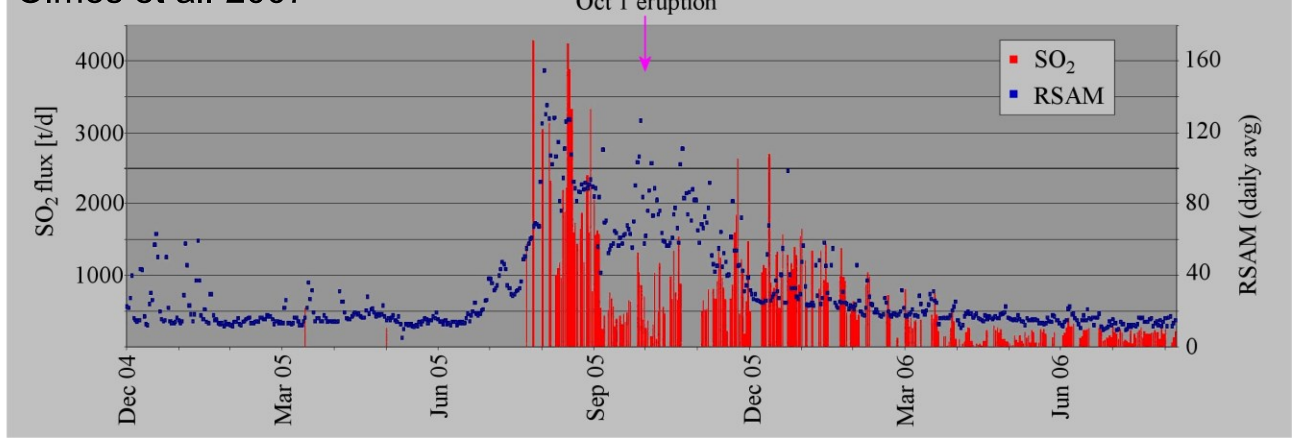
$$c_{a,b}(\Delta t) = \frac{1}{k} \cdot \int S_a(t) \cdot S_b(t+\Delta t) \cdot dt$$



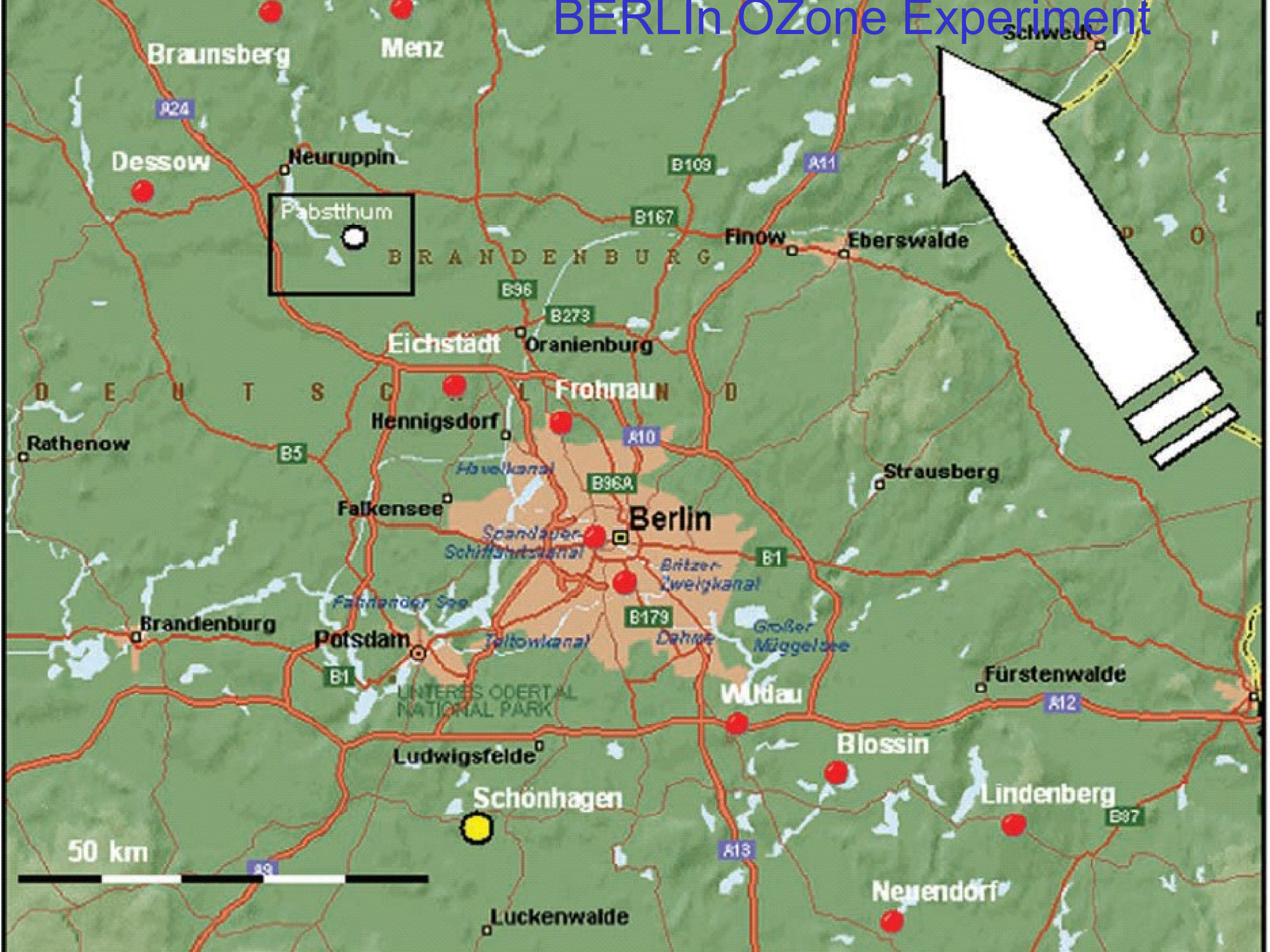




Santa Ana Volcano, El Salvador: Enhanced SO_2-flux preceeds eruption!
Olmos et al. 2007



BERLIn OZone Experiment



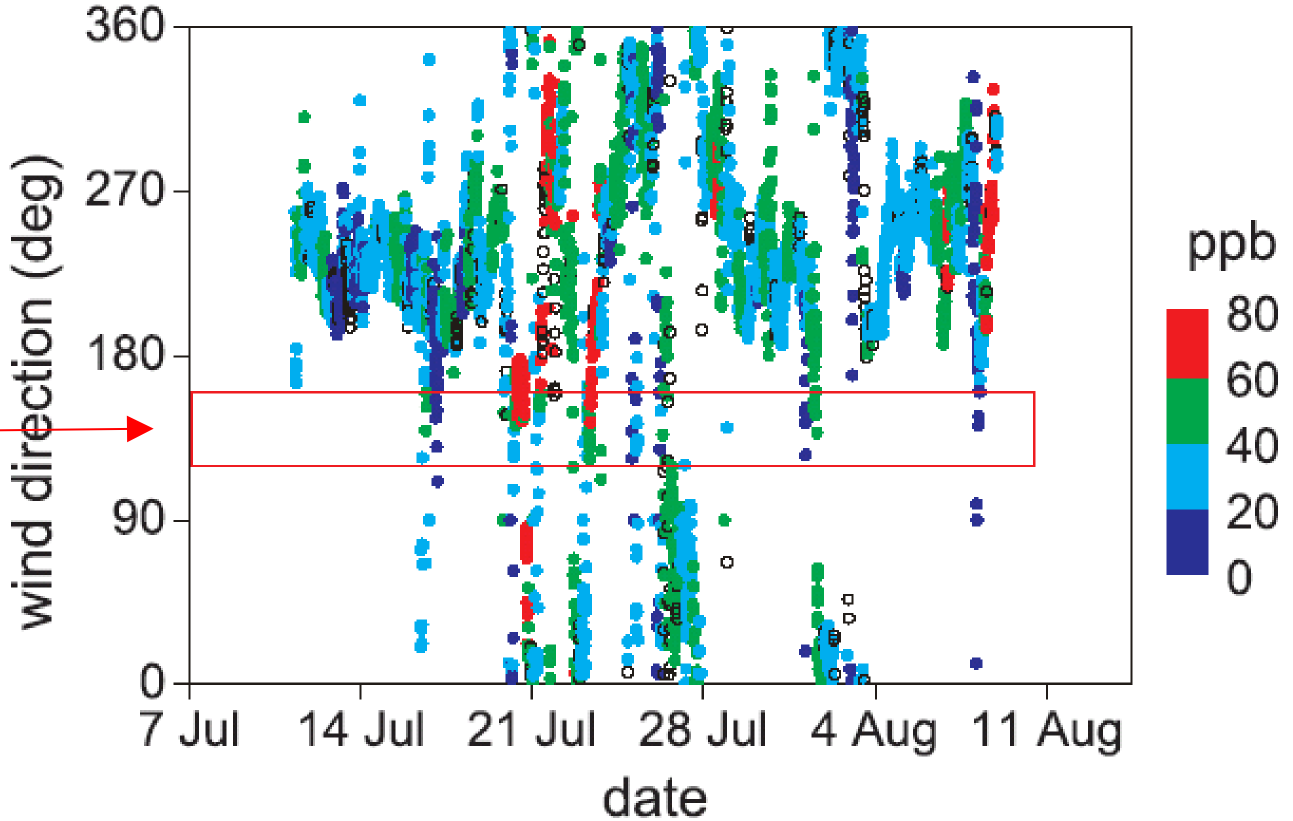
BERLIOZ - Problems

"Prescribed" wind direction given by the siting of the ground stations

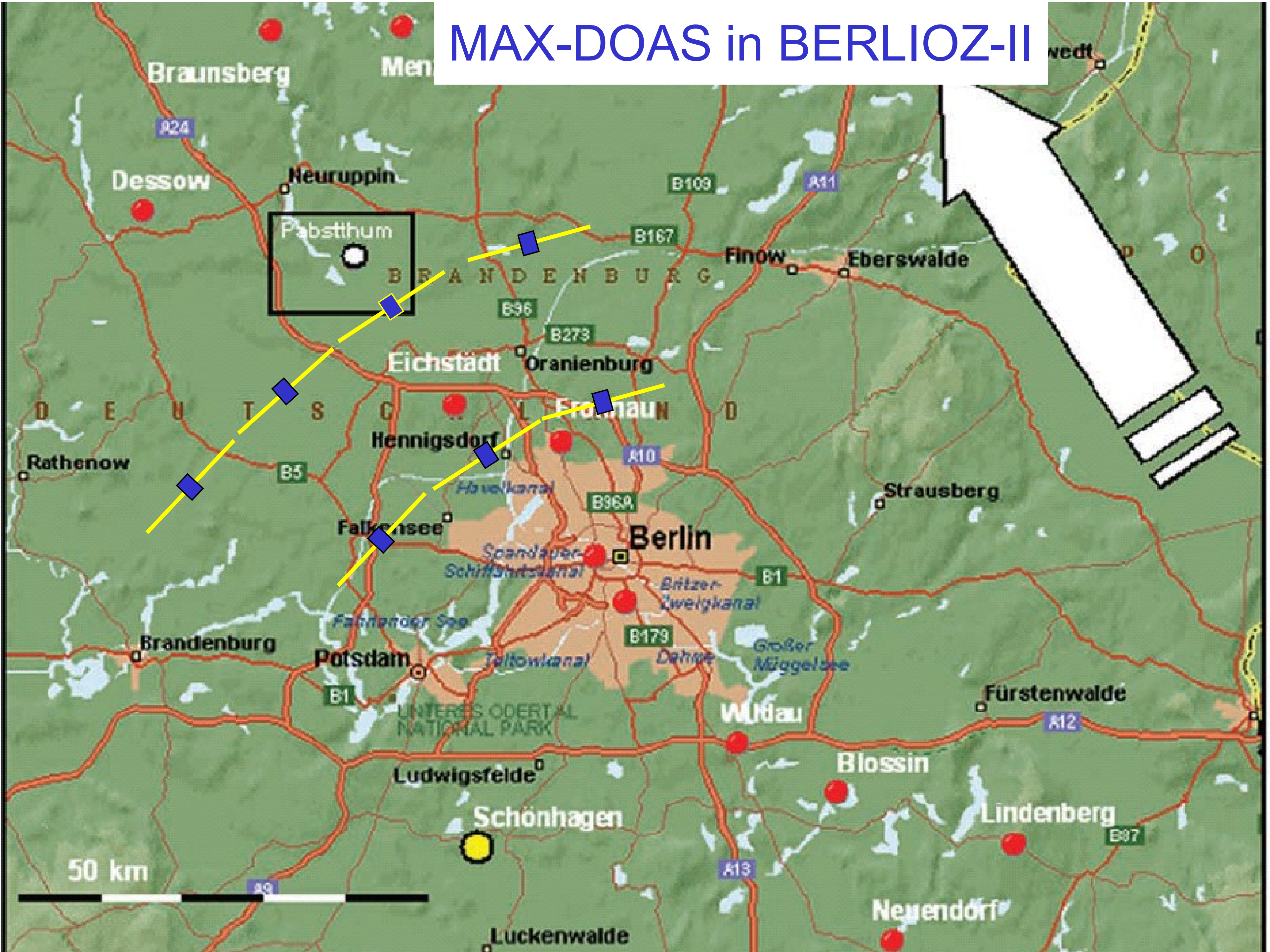
Expensive aircraft measurements

Wind directions and O3 (colour coded) during BERLIOZ) from: Volz et al., JGR 108, 8252, 2003

"Required" Wind Direction



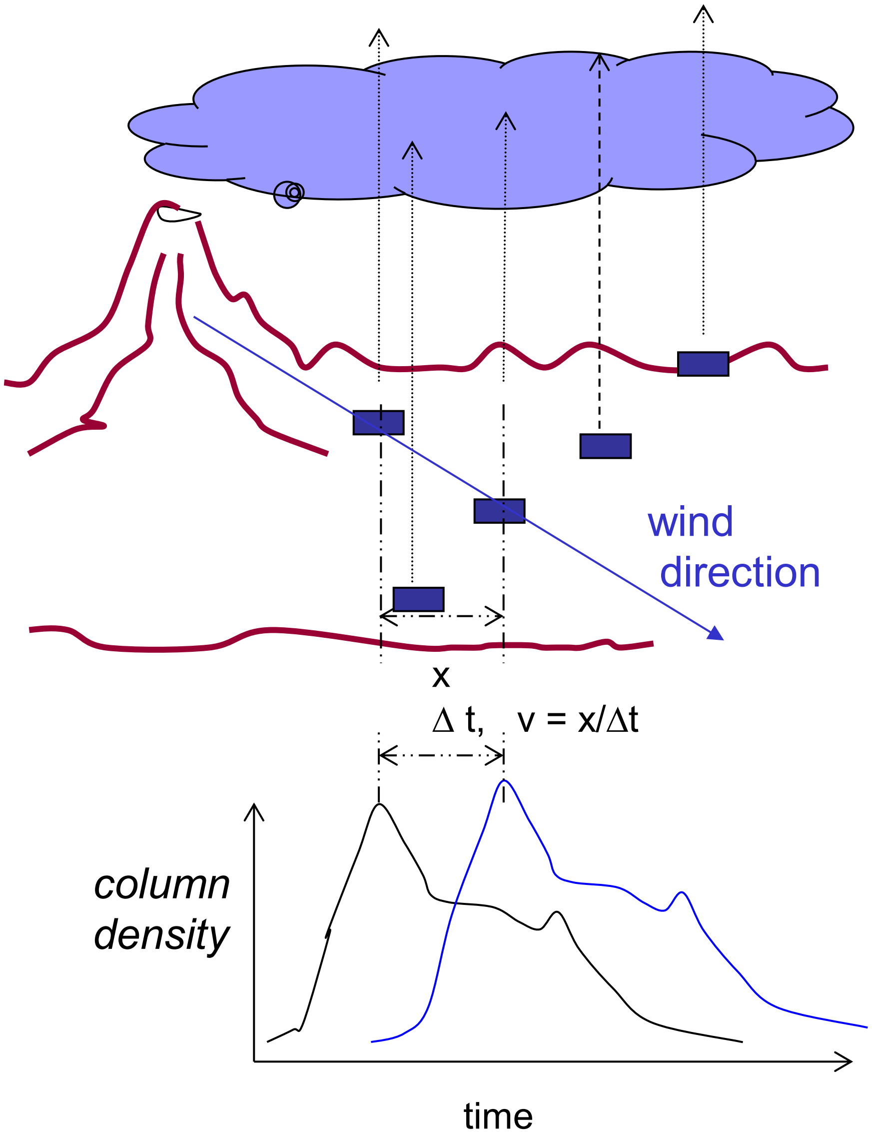
MAX-DOAS in BERLIOZ-II



Static Multi-Spectrometer DOAS System

Setup of a static multi-spectrometer DOAS system for plume observation.

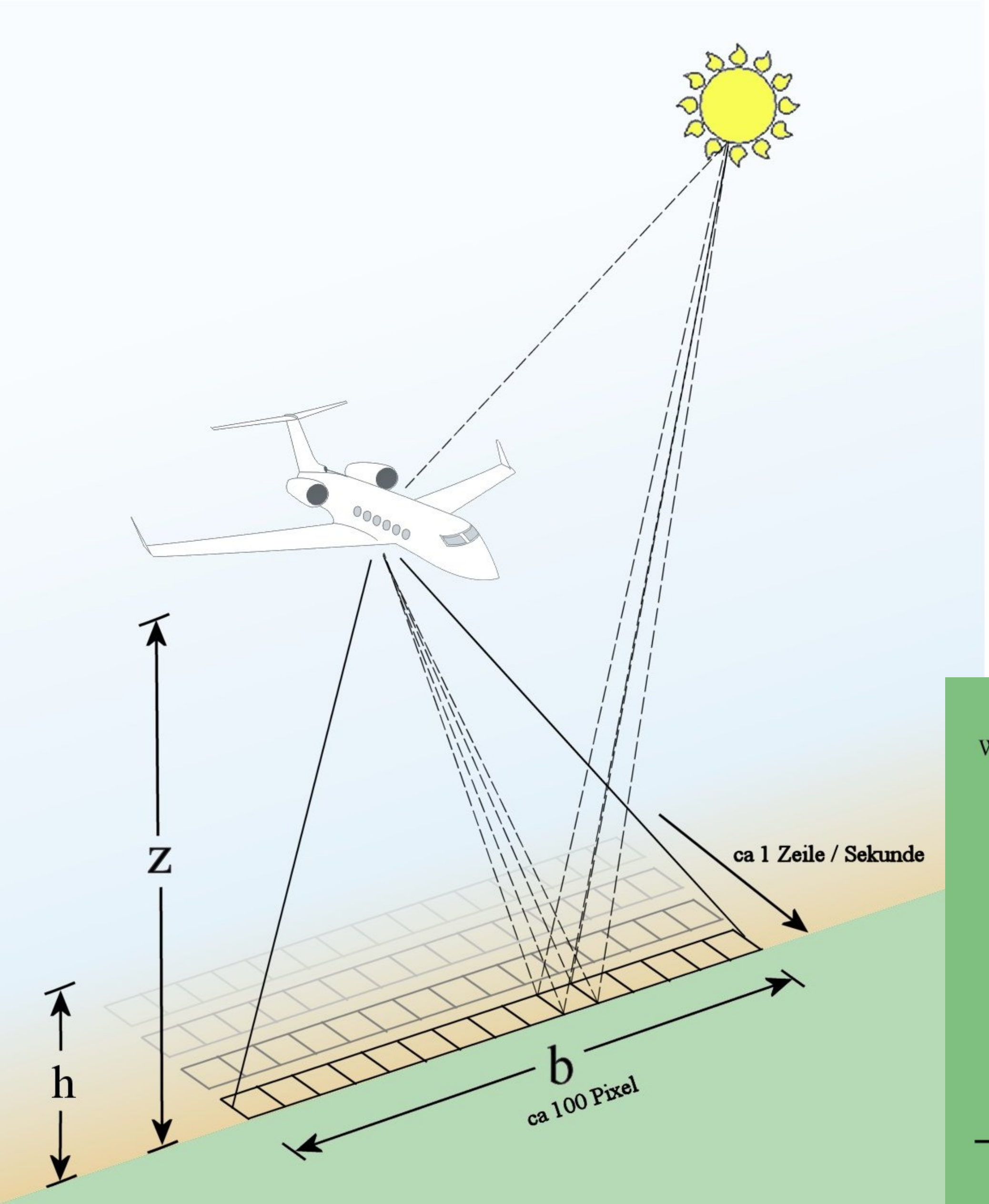
Wind speed of the plume (and thus its source strenght) can be determined by the time delay of two time series of the column density



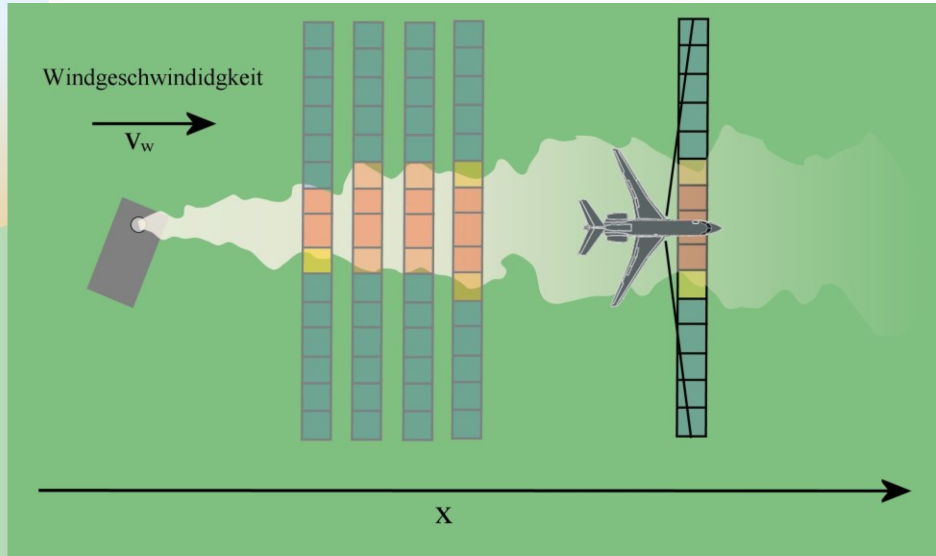
NOVAC – EU project

First DORSIVA Campaign in Valencia and Alcaniz (Spain)
April 20 to May 6, 2004

Aircraft-Based Imaging DOAS

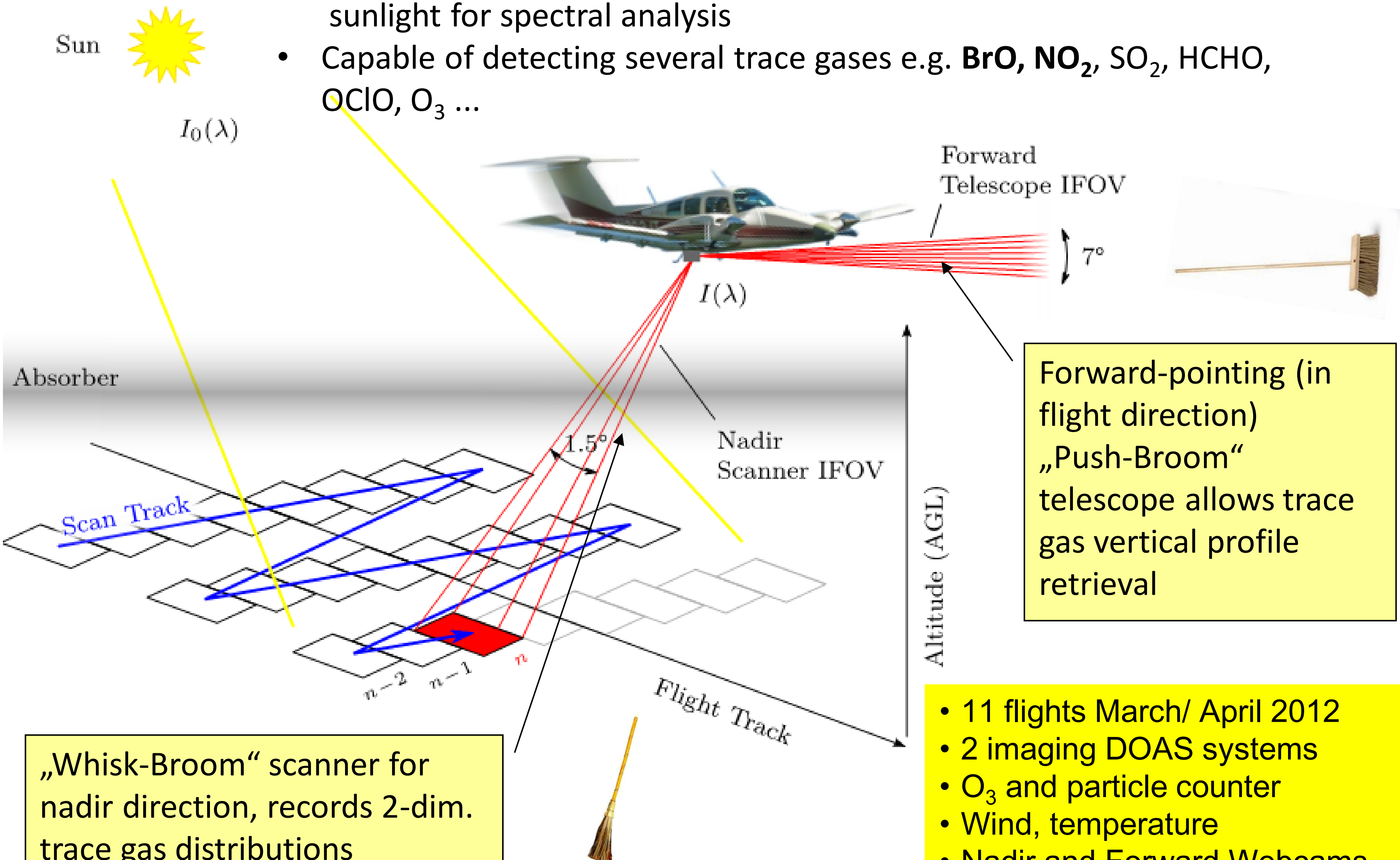


Determine 2D distributions of trace gas (e.g. NO_2, SO_2, CH_2O) column densities along „stripes“ (≈10km width) along the flight track.



Airborne Imaging DOAS on the ALAR Aircraft

- Two independent, passive DOAS systems using scattered sunlight for spectral analysis
- Capable of detecting several trace gases e.g. **BrO, NO_2**, SO_2, HCHO, OClO, O_3 ...



Forward-pointing (in flight direction) „Push-Broom“ telescope allows trace gas vertical profile retrieval

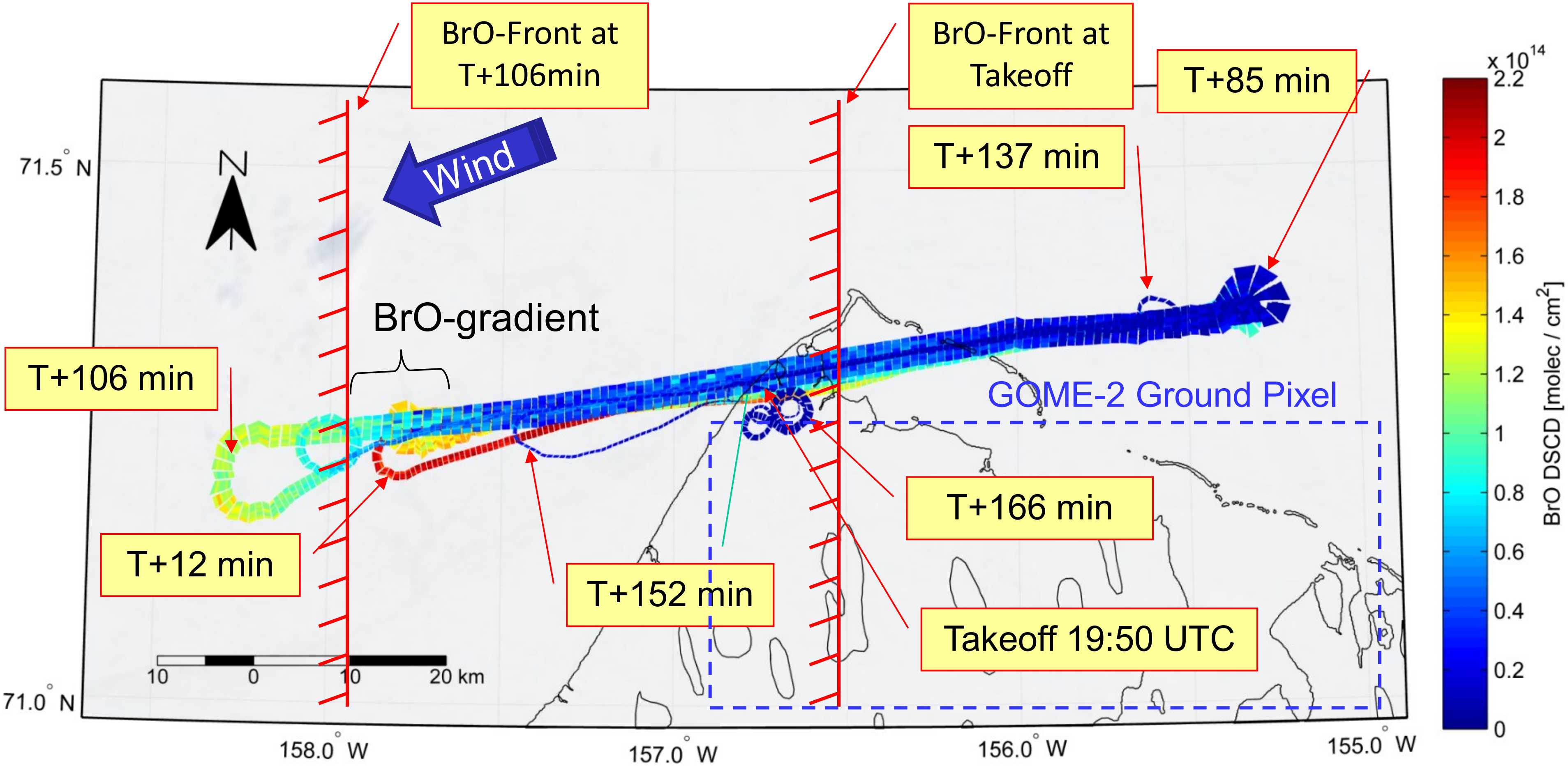
„Whisk-Broom“ scanner for nadir direction, records 2-dim. trace gas distributions

- 11 flights March/ April 2012
- 2 imaging DOAS systems
- O_3 and particle counter
- Wind, temperature
- Nadir and Forward Webcams

Flight on March 13, 2012 Barrow, AK

Flight Duration: 19:50 – 22:45 UTC / 11:50 – 14:45 LT

Wind: 75°, 5 m/s, **Flight altitude:** up to 3500m **Note:** High altitude → wide track!

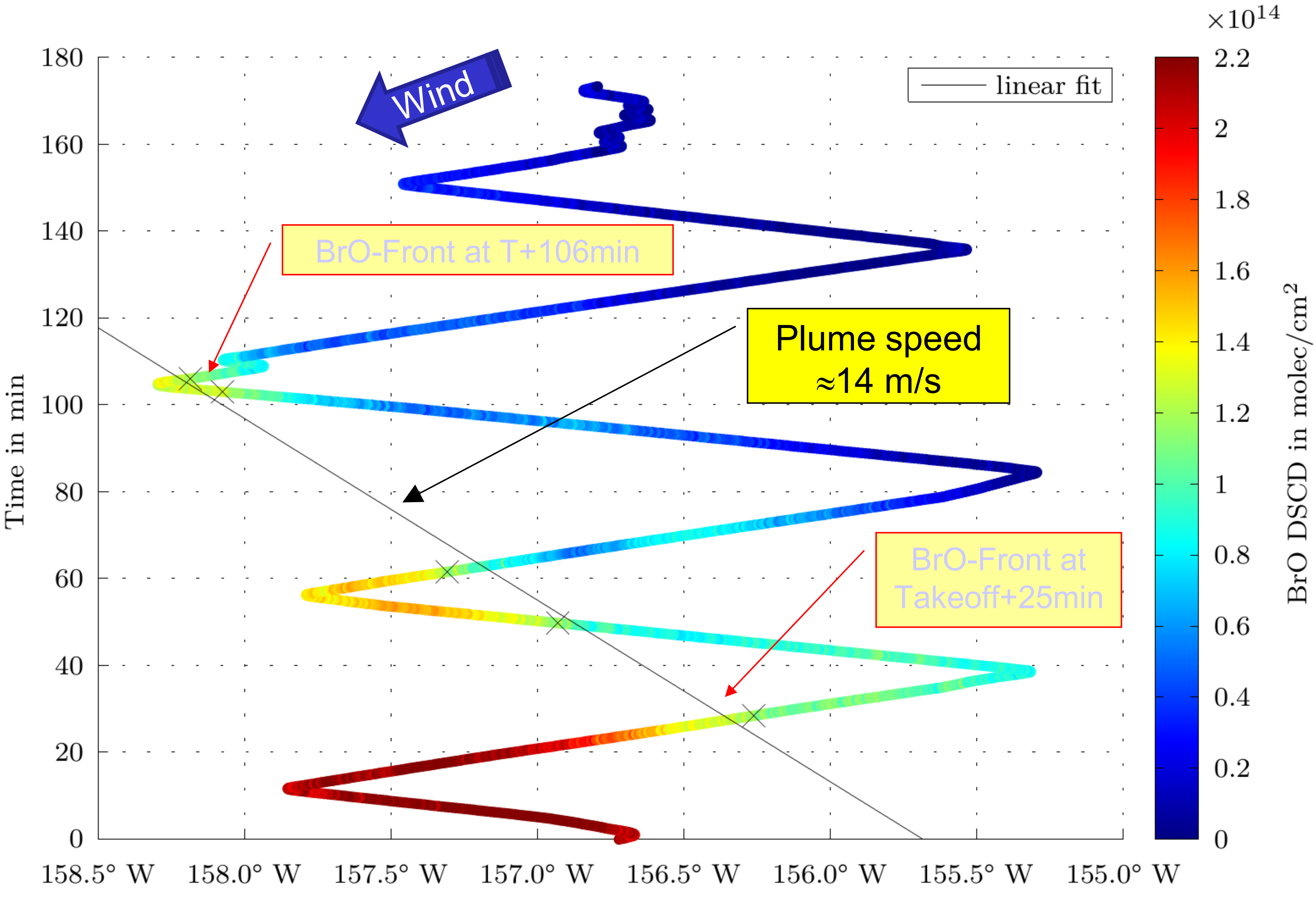


BrO DSCD's up to $15 \cdot 10^{13}$ molec/cm^2 → VCD > $4 \cdot 10^{13}$ molec/cm^2
(would correspond to 66 ppt BrO in 200m layer)

Horizontal gradient in BrO (column) Factor of 2 within <10 km!

Longitude – Time Plot

Flight on March 13, 2012 Barrow, AK



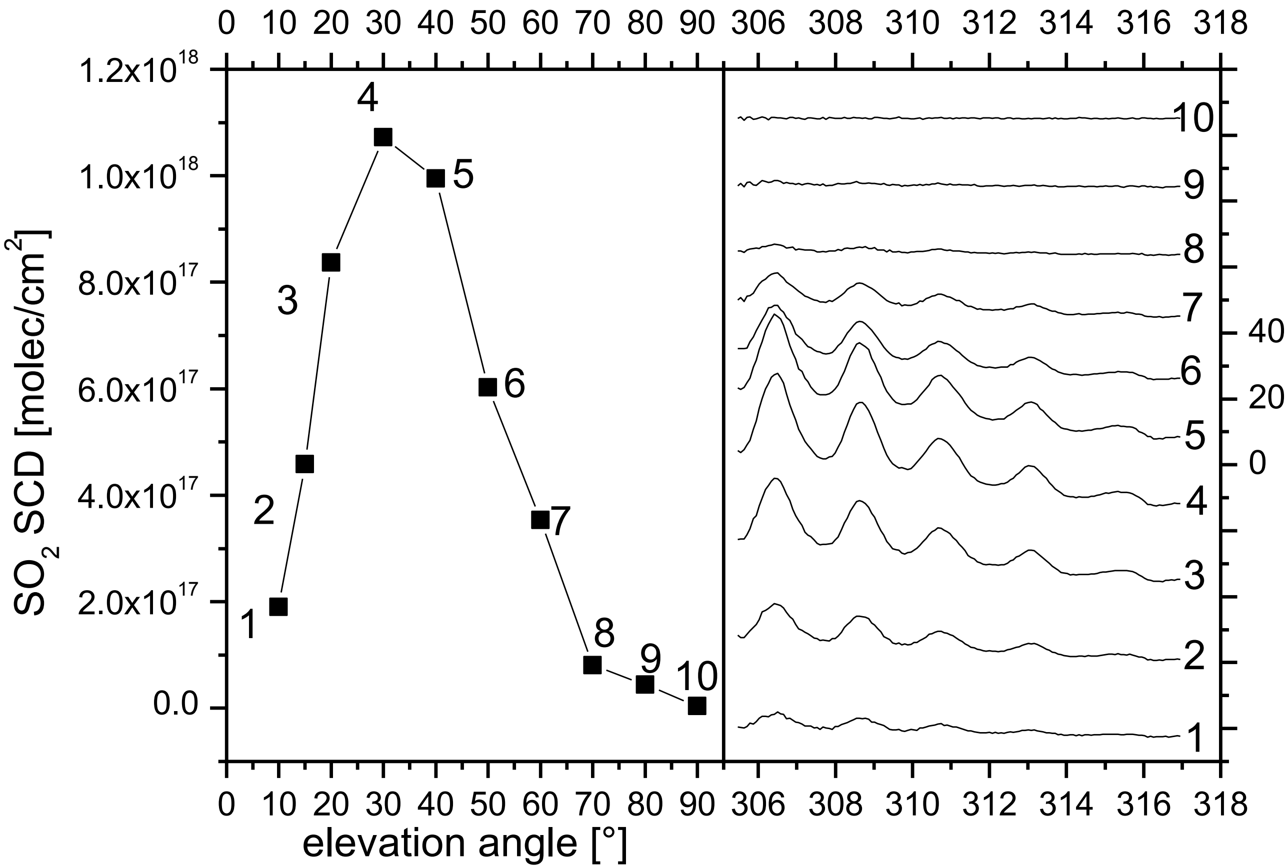
Conclusions

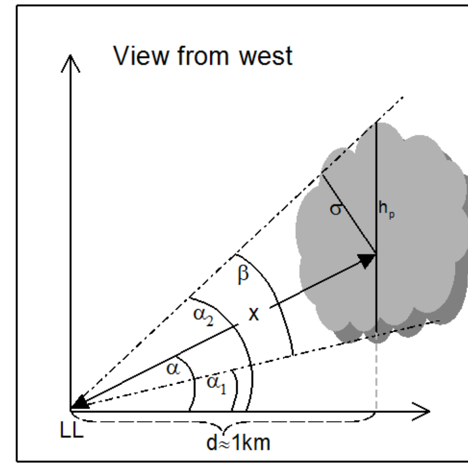
Several Techniques have been used successfully during recent years to study fluxes from point and area sources:

1. Auto-MAX-DOAS (Tram, Train, Ships, … still to be explored).
2. Not yet tested: Fence in Source Area with many MAX-DOAS instruments
3. Map out area with Airborne Imaging DOAS measurements

Mini - MAX-DOAS Instrument near Kilauea Volcano (Hawaii), Dec. 2002 (U. Platt, B. Huebert)

Example: Plume height Determination by Scanning MAX-DOAS



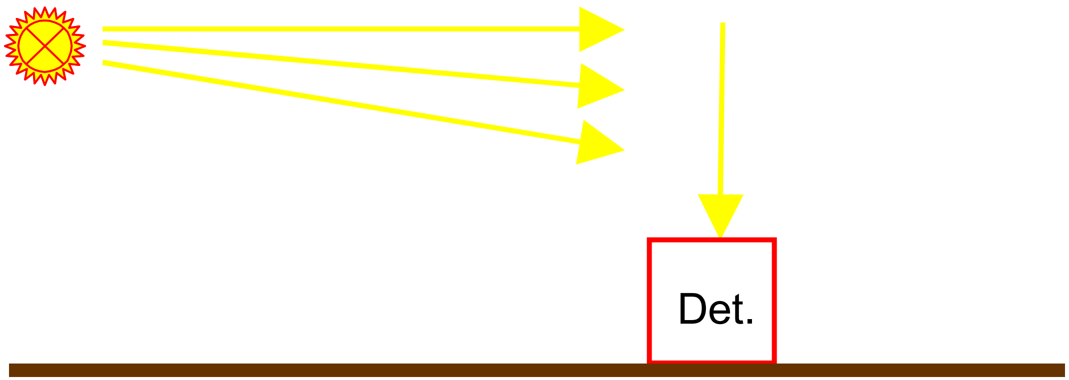


SO_2 from Soufriere Hills Volcano on Montserrat, Caribean, May 25, 2002, Bobrowski et al. 2002

Passive DOAS Spectroscopy in the Atmosphere

Passive DOAS: Use **natural** light source (sun, moon, stars ...)

4) Zenith Scattered Light (ZSL-DOAS)



5) Multi Axis DOAS (MAX-DOAS)