



AEROSOLS IN POLAR REGIONS

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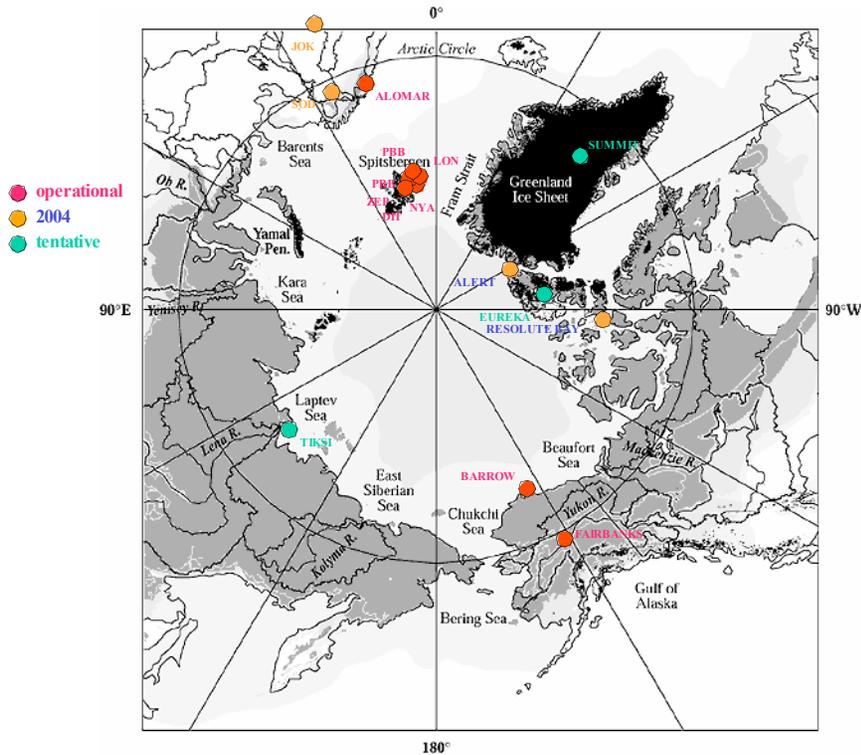
**2nd International Conference on Global Warming and the Next Ice Age,
*Santa Fe, New Mexico, July 17 – 19, 2006***



In order to study the radiative forcing effects directly induced by polar aerosols on the surface-atmosphere system in the remote regions of our planet, the POLAR-AOD project was proposed to the International Polar Year Committee in January 2005, as a contribution to the IPY.

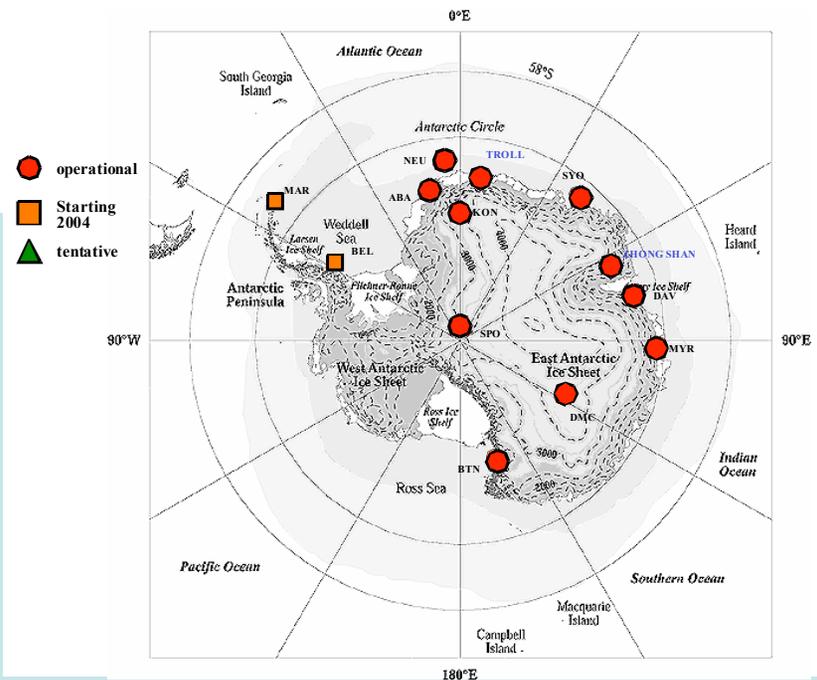
It was approved on November 30, 2005, through the Endorsement Letter of the International Polar Year committee, the research activities of the IPY programme (# 171) being planned in the period from March 2007 to February 2009 to define

the means, variability, and trends of the climate-forcing properties of aerosols in polar regions.



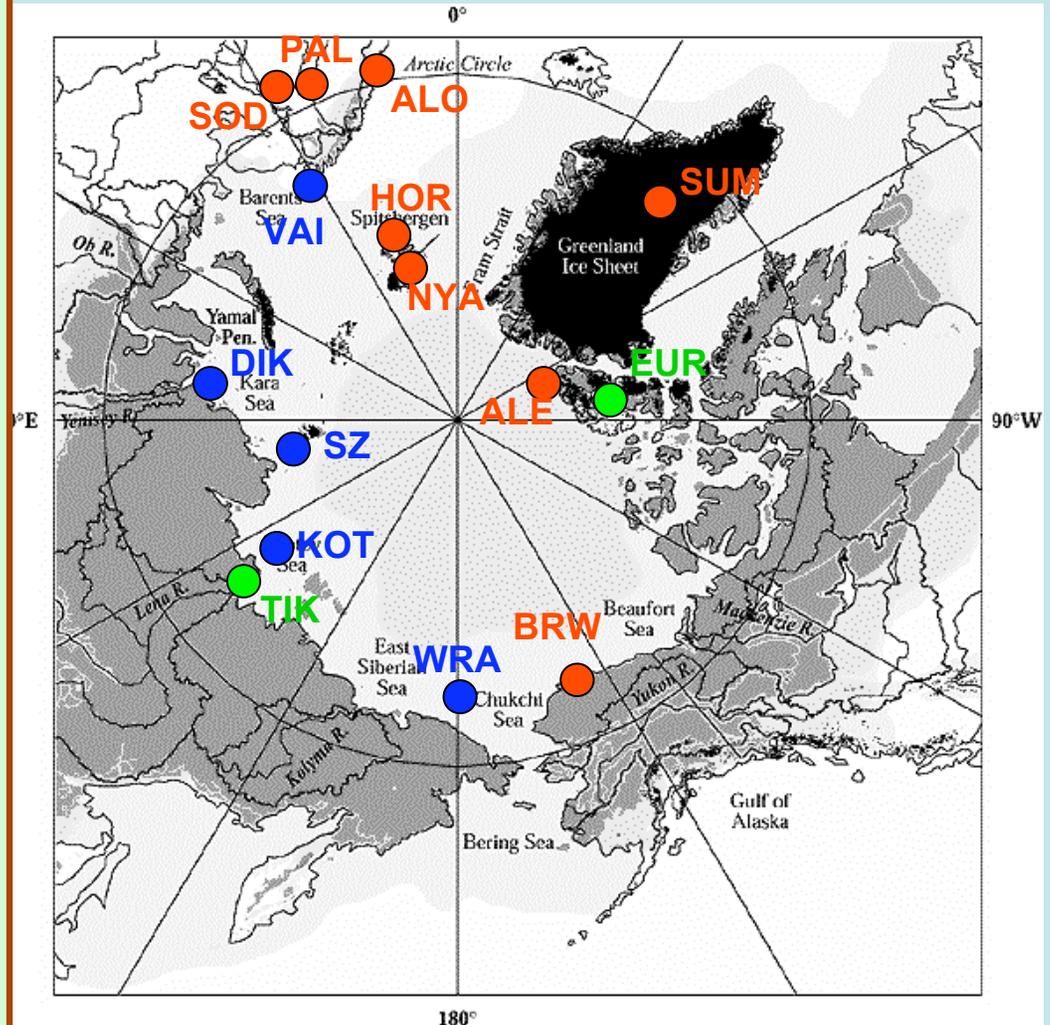
These 14 groups are presently carrying out sunphotometric AOD measurements and *in situ* measurements of the aerosol radiative parameters, having a network of 9 stations in the Arctic and 8 Antarctic stations. The POLAR-AOD project includes more than 30 research groups of 21 countries.

The results obtained at the various stations are presented, the first part dealing with the **Arctic** aerosols, and the latter with the **Antarctic** aerosols.





The historical data providing the monthly mean values of the aerosol optical depth $AOD(500\text{ nm})$ measured at some Siberian sites (Wrangel Island, Dikson Island, Severnaya Zemlya, and Kotel'ny Island, indicated by blue circles in the graph) from 1977 to 1991 can be shown to offer evidence of the long-term decreasing trend of $AOD(500\text{ nm})$, commonly attributed to diminished emissions of pollutants in Eurasia.





Time series of monthly mean values of $AOD(500\text{ nm})$ measured at three Siberian stations from 1981 to 1991



The data exhibit a gradual decrease in the AOD values from 1981 to 1991.

The spring values of $AOD(500\text{ nm})$ are in general higher than those measured in summer, presumably due to the occurrence of Arctic haze.

The historical data measured at the Siberian stations were then compared with

- (i) the time series of monthly mean values of $AOD(500\text{ nm})$, as measured by the AWI group at Ny Ålesund from 1991 to 2006,
- (ii) the 2-year smoothed time patterns of effective visible aerosol optical depth AOD_{eff} derived from sets of filtered pyrheliometer measurements performed at Barrow (Alaska) from 1977 to 2001 (see for instance E. G. Dutton and J. C. Christy, 1992, GRL, 2313 - 2316).
- (iii) the time series of monthly mean effective AOD_{eff} values recorded at Point Barrow from 1977 to 2003, and

The comparison shows that.....

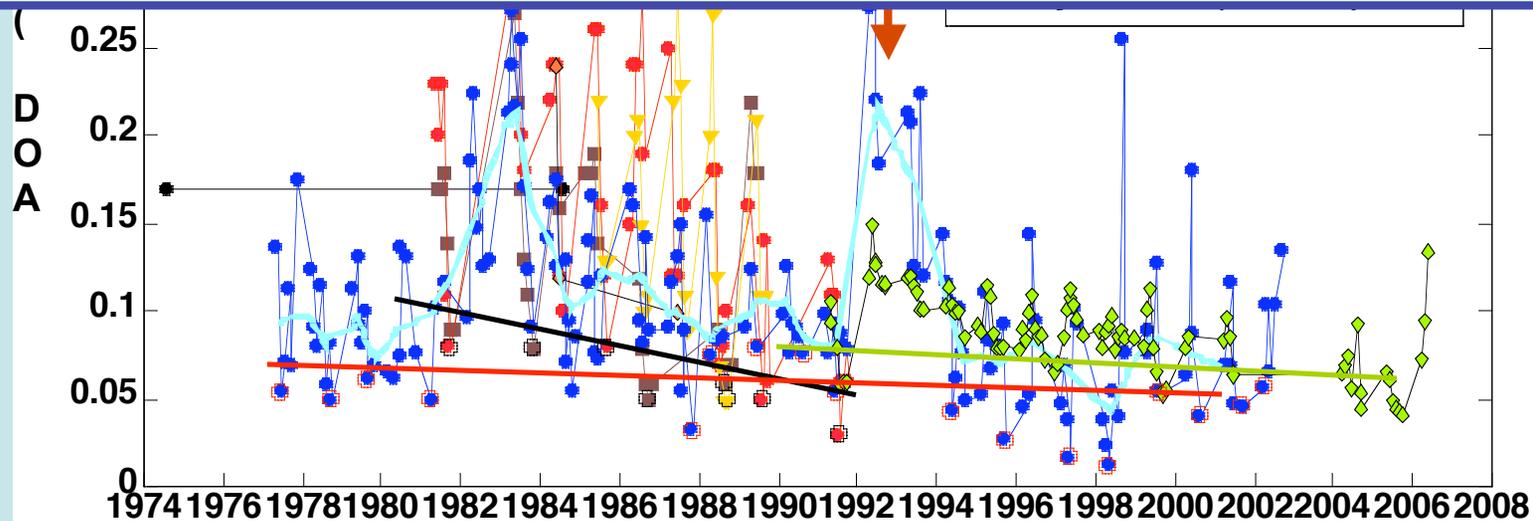


“Long-term” decreasing trends derived from historical data yielding sets of monthly mean *AOD(500 nm)* background values



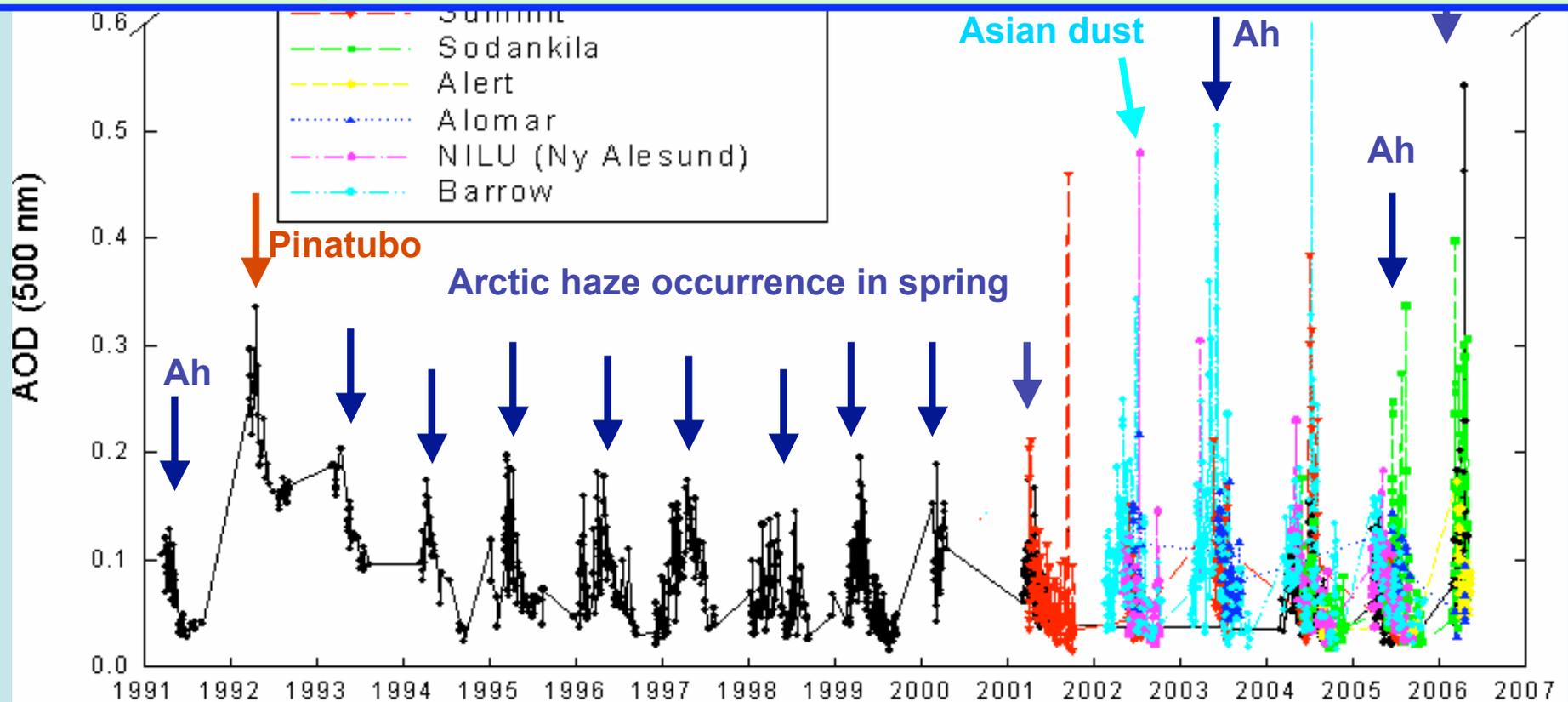
Parameter *AOD(500 nm)* was found to vary mainly between 0.12 and 0.25 during the Arctic haze episodes, assuming values comparable with those usually measured at mid-latitude stations in the continental areas of the Northern hemisphere.

It is important to notice that the Arctic haze episodes take place usually in spring periods, when the atmosphere cleaning due to the scavenging of particles by precipitations is particularly weak.



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The time patterns of the daily mean values of $AOD(500\text{ nm})$ give not only a measure of the changes in the columnar aerosol extinction features due to the Pinatubo eruption in 1991 but also offer evidence for the marked seasonal changes in AOD , due the presence of **Arctic haze** in the spring months, and other important transport episodes (**Asian dust** in April 2002, and **boreal smokes** in summer 2004).

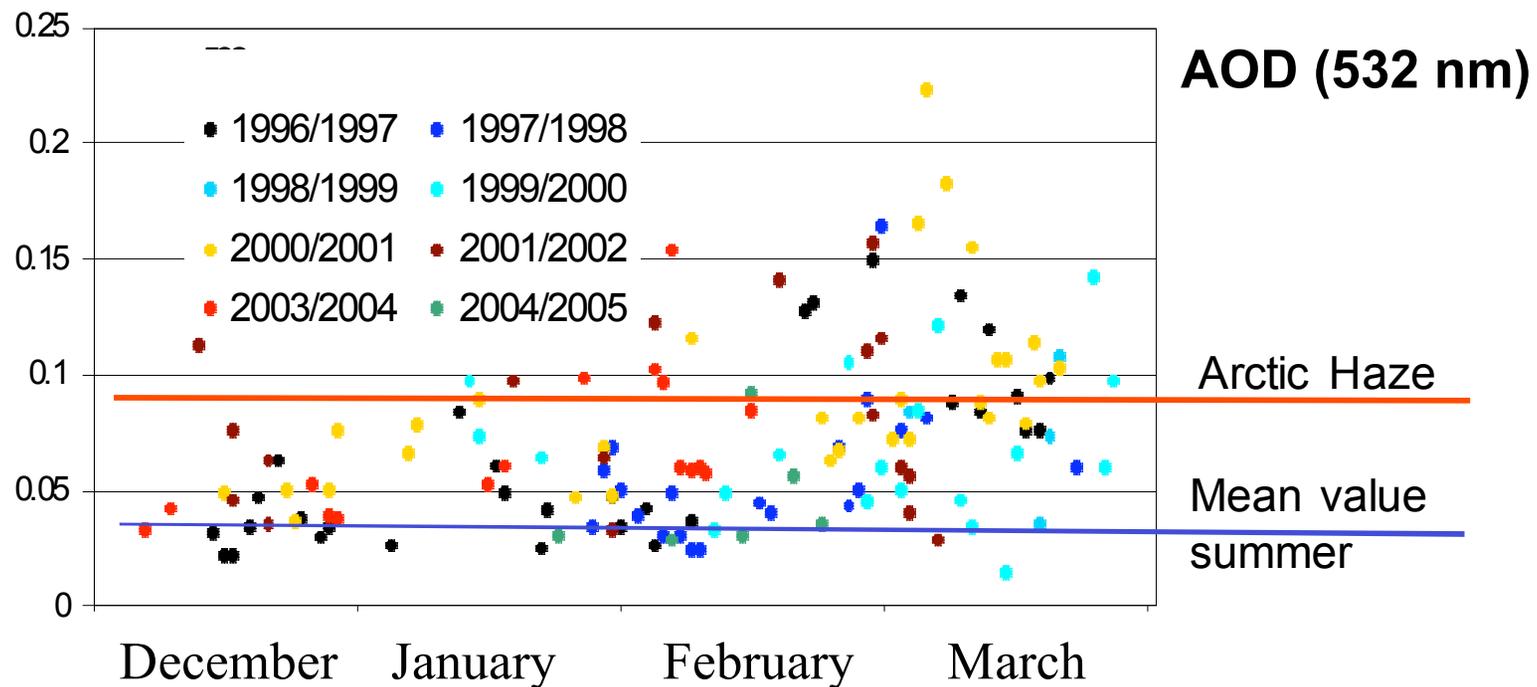




Seasonal variations in aerosol radiative parameters at the Arctic stations in the Svalbard region



From the Ny Ålesund (AWIPEV) measurements performed from 1996 to 2005, a set of daily mean values of $AOD(500\text{ nm})$ performed for Arctic haze conditions on the winter and spring days were determined, yielding an average value of about 0.09, compared to an average summer value of less than 0.04.





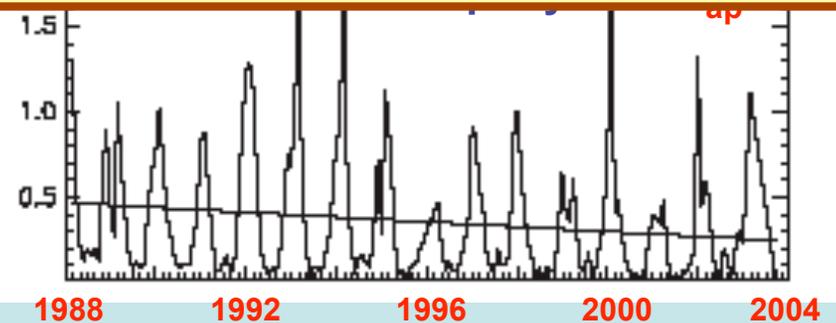
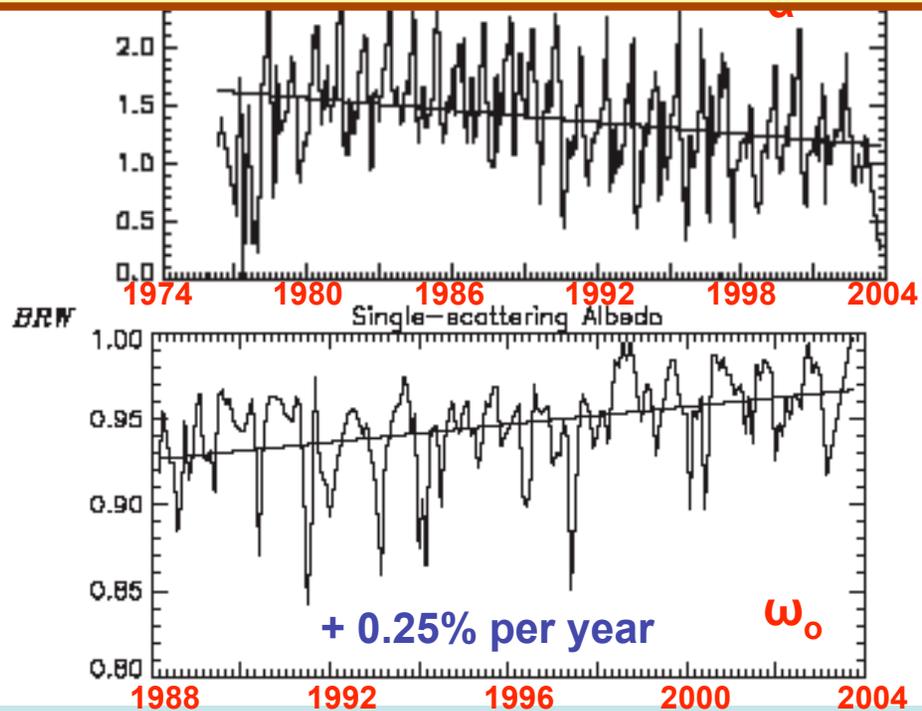
From the above results we conclude:

(1) AOD increases sharply when the Arctic haze is occurring and parameter α decreases in most cases from values higher than 1.5 to values lower than 1.0.

(2) This behavior of the Ångström exponent α is probably due to the increase in the number of larger particles with respect to the optical weight of the accumulation particle mode, which was found to be clearly predominant during the summer.

The negative trend of AOD was attributed by McComiskey et al. (CMDL Report No. 27, 2004) to the decrease in the anthropogenic emissions from Europe and Russia:

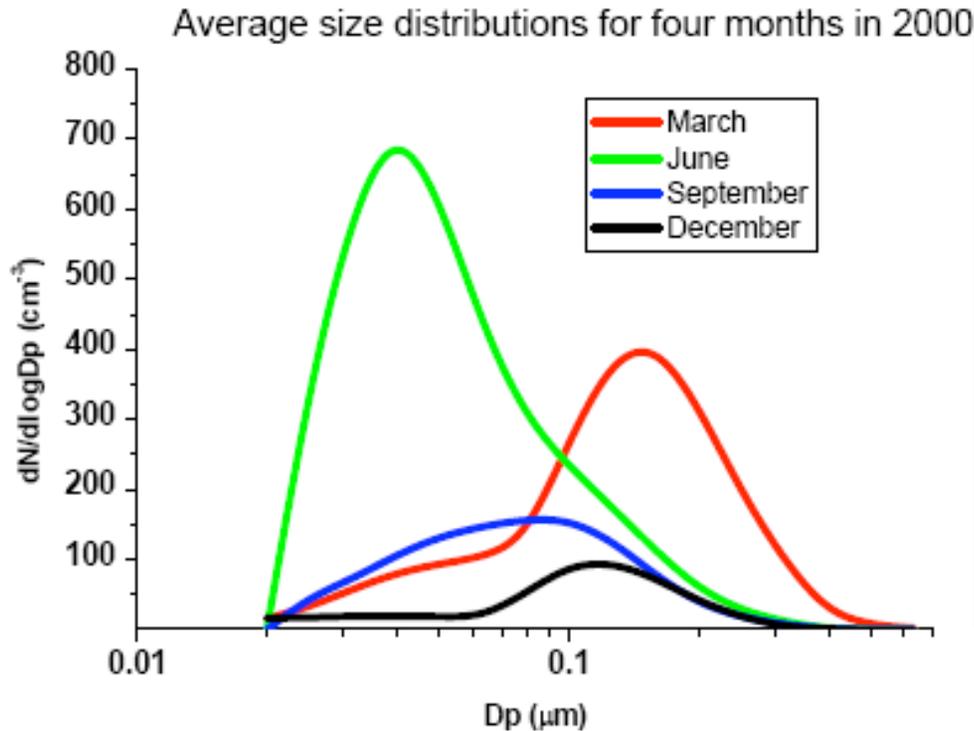
- (1) the volume scattering coefficient was evaluated to decrease by ~17% from 1976 to 2004,
- (2) parameter α was observed to decrease at Barrow from more than 1.6 to less than 1.2 from 1977 to 2004,
- (3) the volume absorption coefficient was found to decrease by more than 40% from 1989 to 2003, and
- (4) the yearly mean value of single scattering albedo ω_o increased correspondingly from ~0.93 to ~0.97.



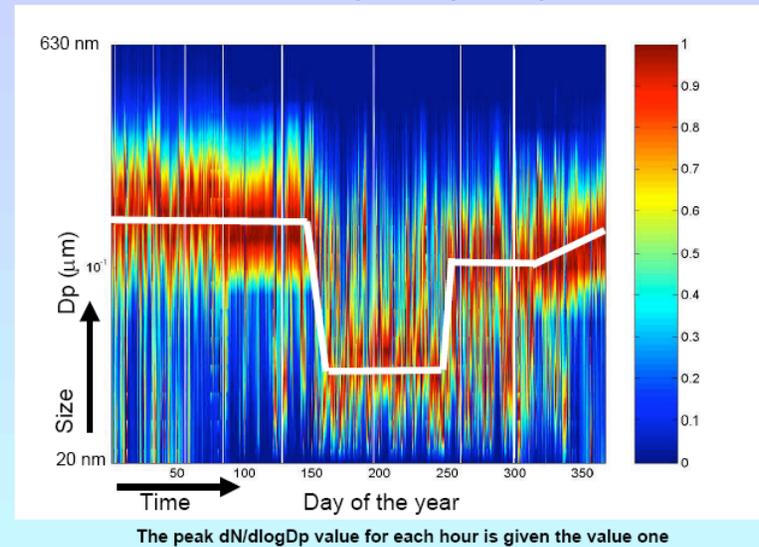
Long-term trends from 1974 to 2004 found at Pt. Barrow for the monthly averaged values of parameters **CN**, total scattering coefficient σ_{sp} (at 550 nm), Ångström exponent α , absorption coefficient σ_{ap} and single scattering albedo ω_o .



From data taken by J. Ström (Stockholm University) at the Zeppelin station (78° 54' N, 11° 53' E), close to Ny Ålesund in the Svalbard Islands (Norway)



Normalized hourly averaged $dN/d\log D_p$ as function of D_p and day of the year

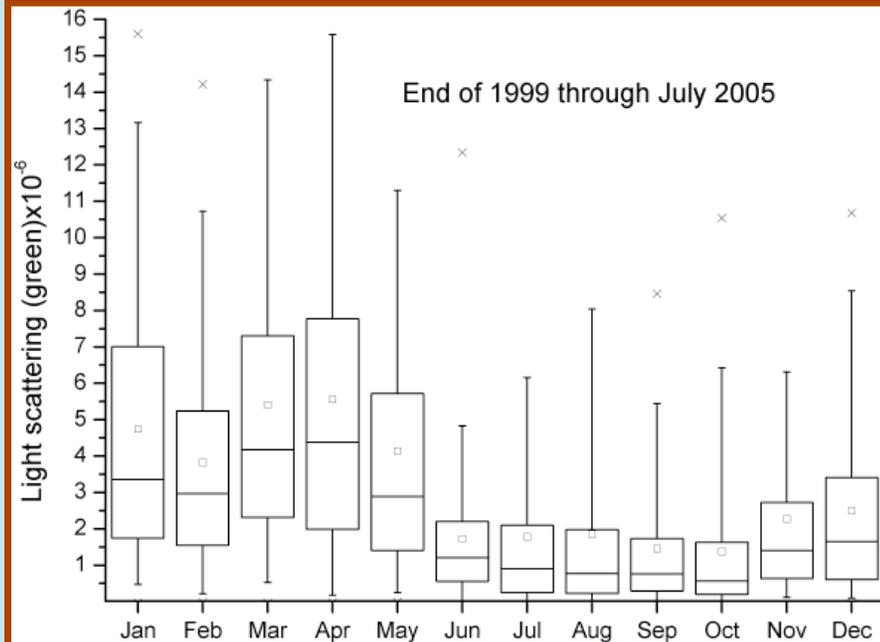


The sampling measurements performed at the Zeppelin station (Ny-Ålesund) using a Differential Mobility Particle Sizer (DMPS) show that the average particle number density size distribution is bi-modal in March (Arctic haze period) (with a submicron mode having mode diameter $D = 0.04 \mu\text{m}$ and a second accumulation mode with $D \approx 0.15 \mu\text{m}$), and mono-modal in the other months, with $D = 0.04 \mu\text{m}$ in June, $D = 0.08 \mu\text{m}$ in September and $D = 0.11 \mu\text{m}$ in December.



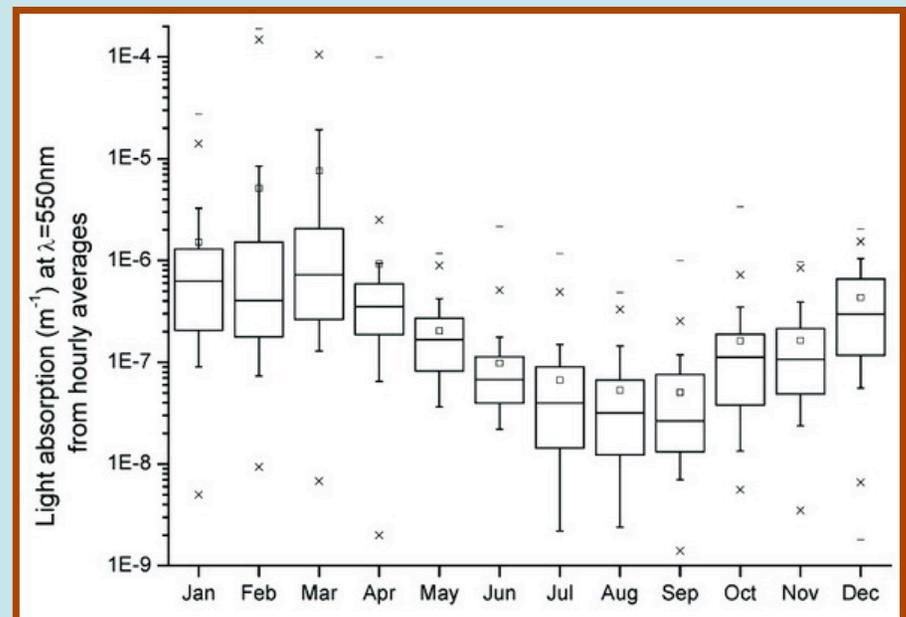


From the 5-year set of measurements performed at the Ny Ålesund Zeppelin station by the Stockholm University group



Yearly cycles of **volume scattering** (left) and **volume absorption** (right) coefficients determined from a 5-year data set (from late 1999 to July 2005) measured at the Zeppelin station (Ny Ålesund) showing that Arctic haze consists generally of natural marine aerosols and anthropogenic particles, presenting on the average a mass concentration of $1 - 3 \mu\text{g m}^{-3}$, in which only $\sim 0.2 \mu\text{g m}^{-3}$ are given by soot particles.

The radiative effects caused by the changes in the size distribution features are evidenced also by the measurements of the monthly mean values of the volume scattering and absorption coefficients performed at the Zeppelin station, from which the monthly mean values of single scattering albedo were found to gradually increase from 0.84 to 0.95 in the winter and spring seasons, to become stable in summer (~ 0.96) and decrease gradually in the fall months to less than 0.90.





The Arctic haze episode at Ny Ålesund on May 2 and 3, 2006



May 2, 2006

Ny Ålesund,
view from the
AWIPEV
station

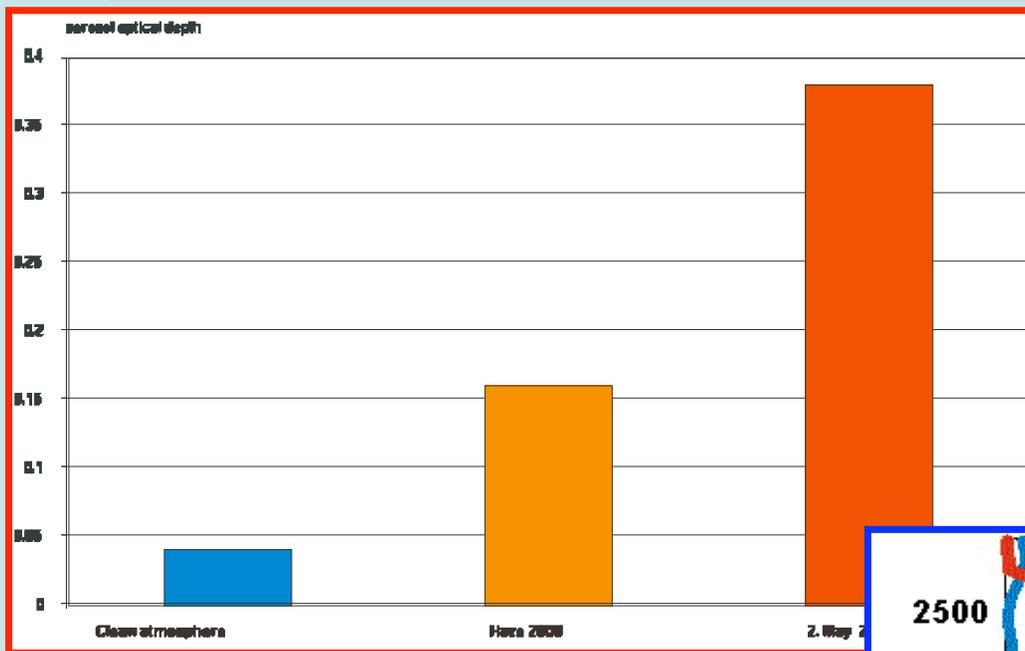


May 8, 2006

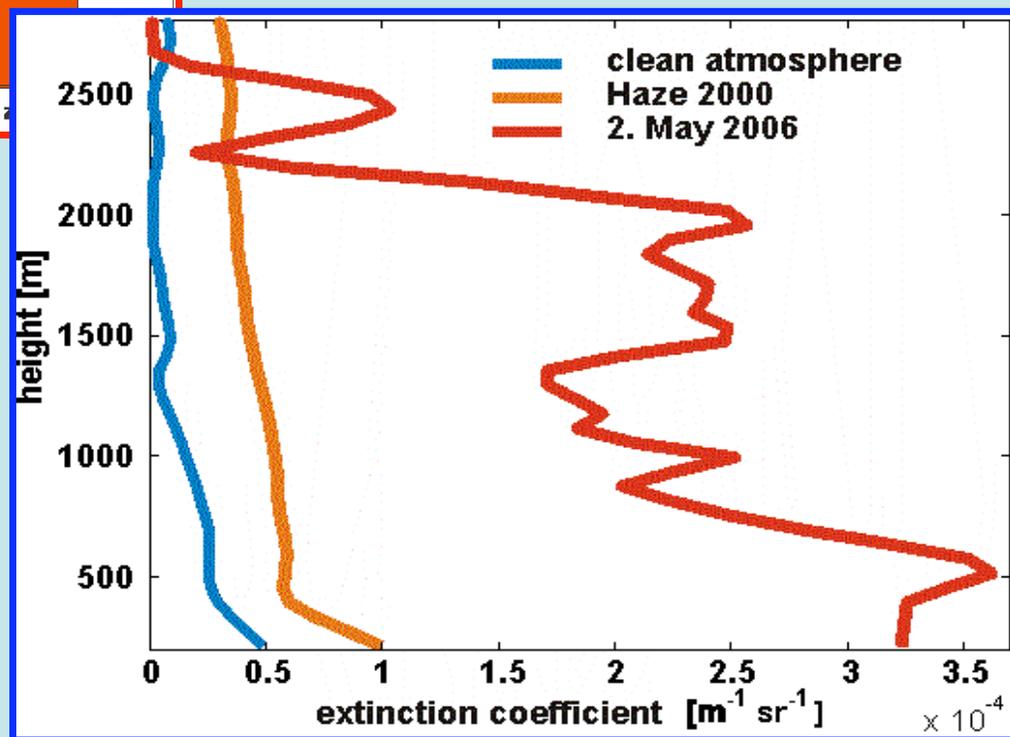


Ny Ålesund,
view from the
Zeppelin
station





Data on the Arctic haze episode observed at Ny Ålesund on May 2, 2006



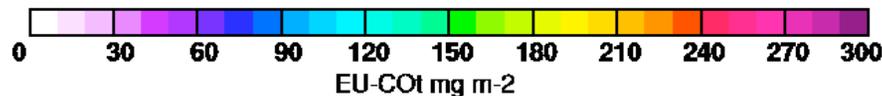
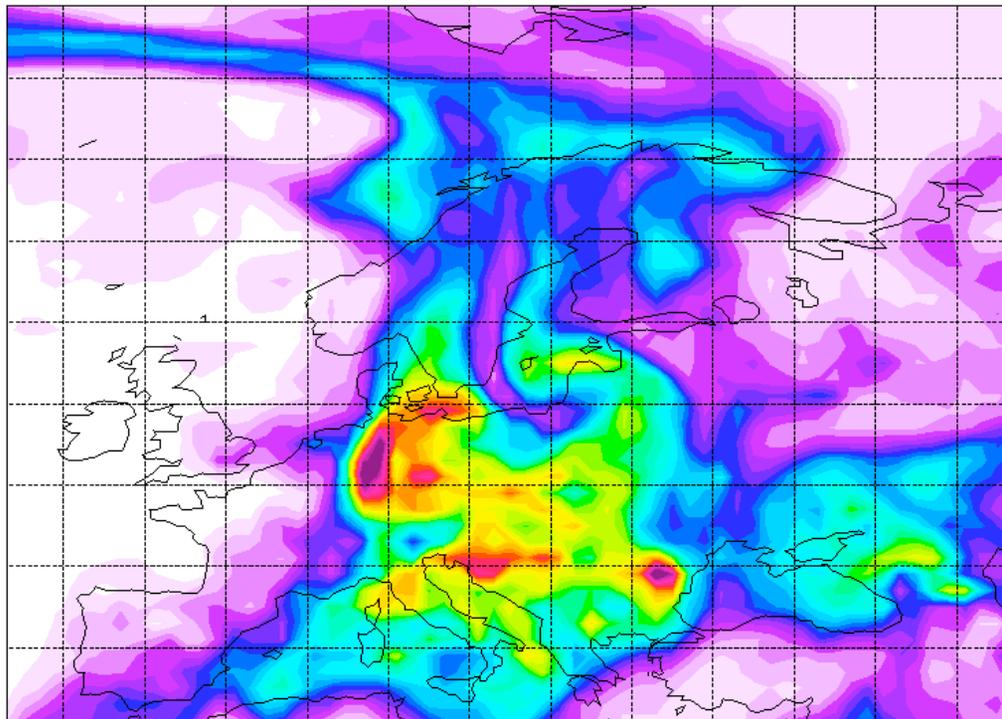


Total column of species EU-COt for age class 0 - 20.00 DAYS

Actual time 20060426.120000

Mean value 0.239E+02 Maximum value 0.328E+03 Minimum value 0.000E+00

Distance of grid lines 5.0 deg



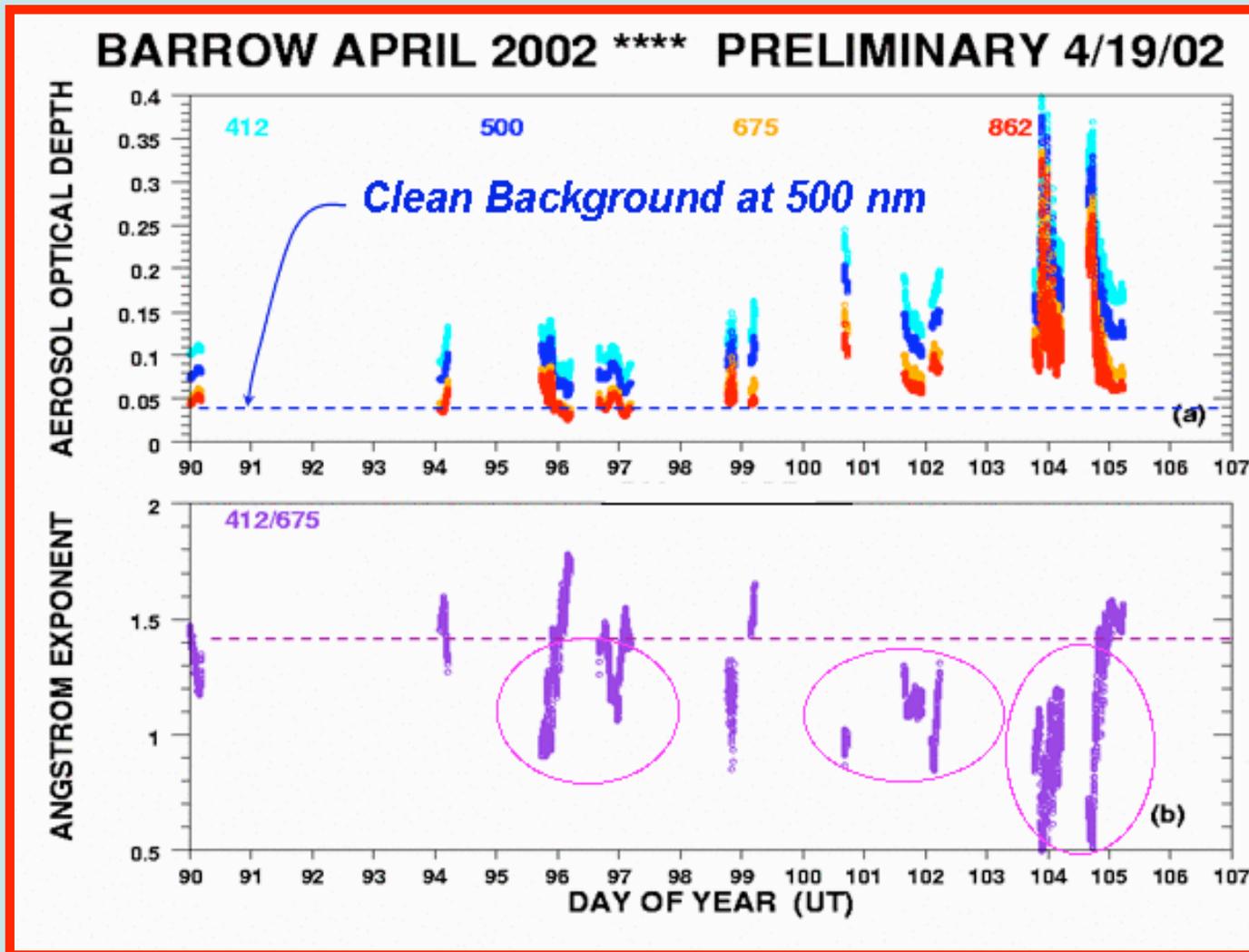
Arctic haze episode over the Svalbard region: the transport of anthropogenic aerosol from Europe during the period from April 26 to May 2, 2006, represented in time-steps of 3 hours using the total vertical content of CO as tracer (taken from NILU website).

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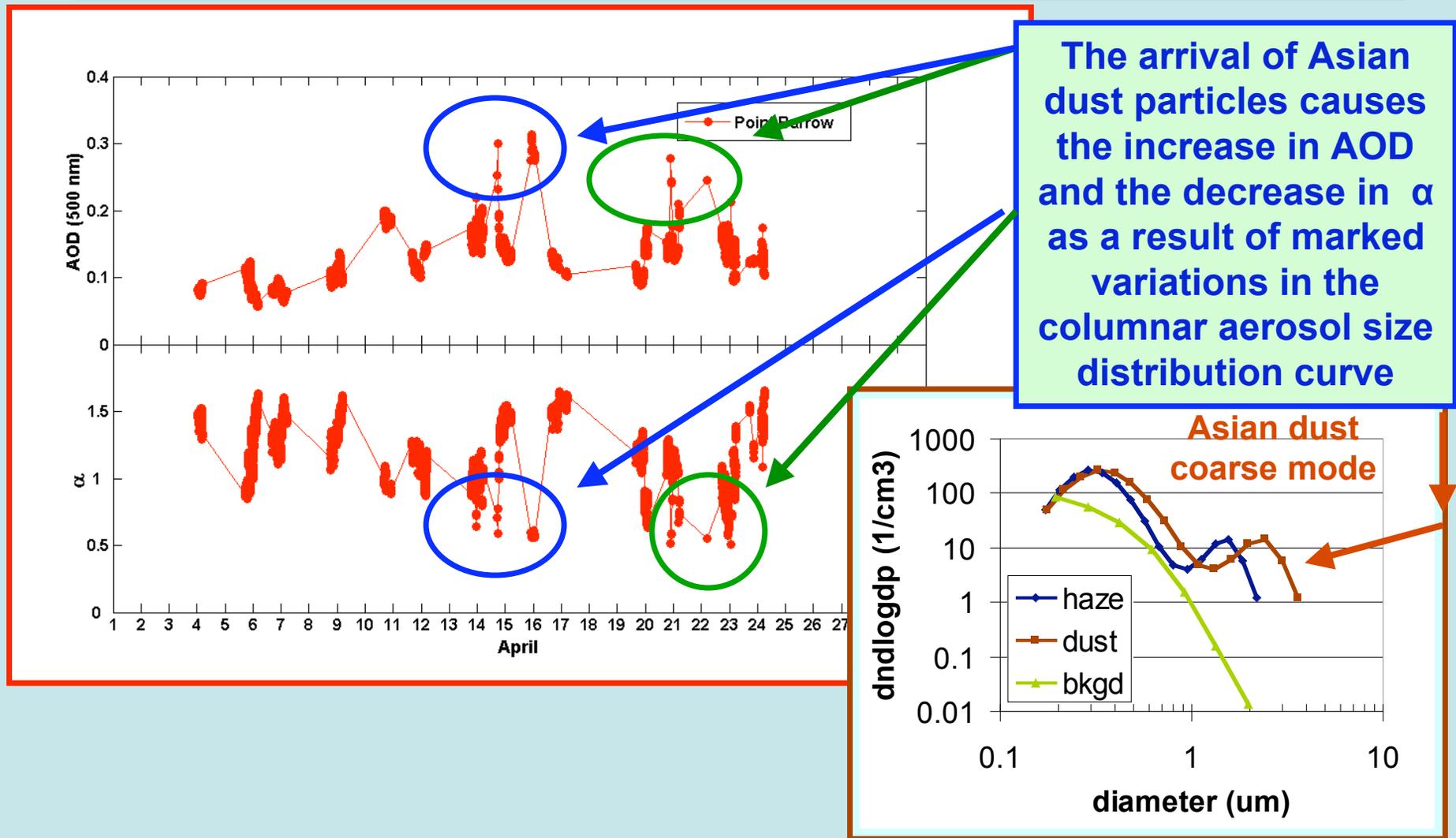
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The Asian dust transport episode at Barrow (April 2002),
as measured with the SP01-A sun-photometer
by the CMDL group



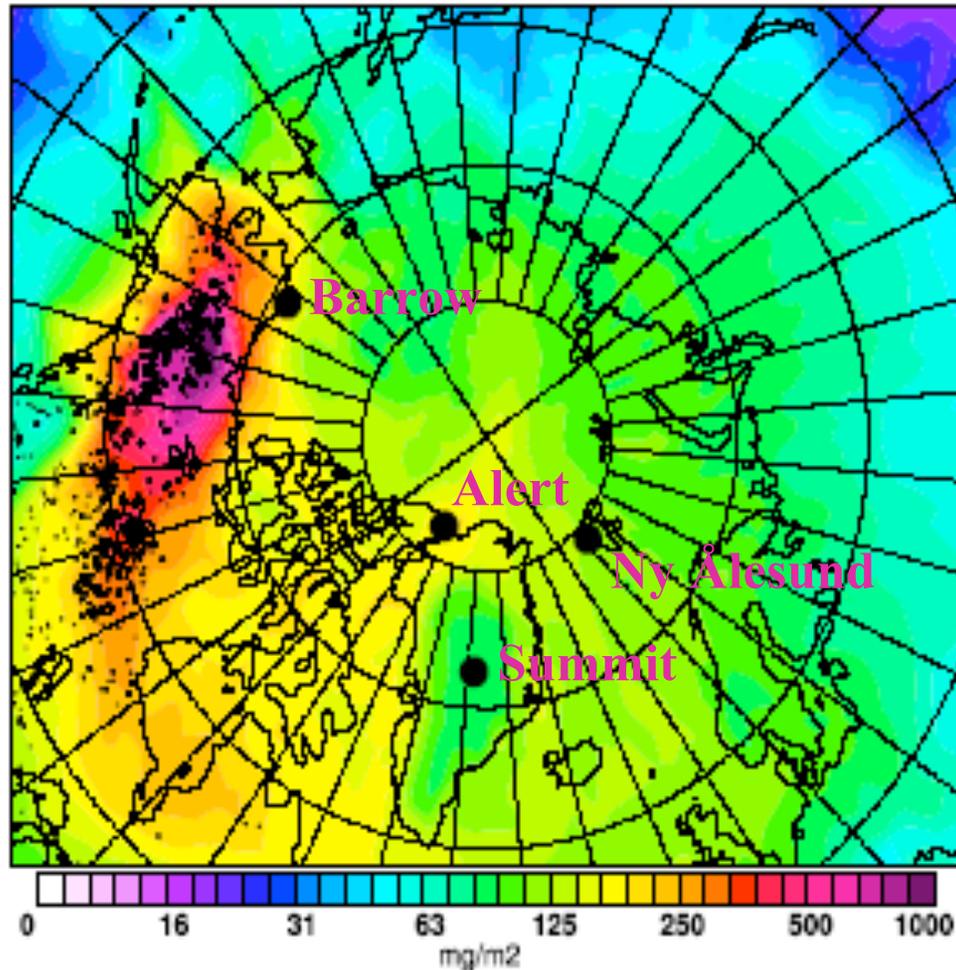
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From:

STOHL ET AL.: PAN-ARCTIC TRANSPORT OF BC FROM FOREST FIRES



Averaged map of the CO total column (used as tracer) over the months of July and August 2004, as obtained by **Stohl et al. (in review)** through the forward simulation: small black dots show all MODIS hot spot locations detected in July and August; large black dots are drawn at the position of measurement sites.

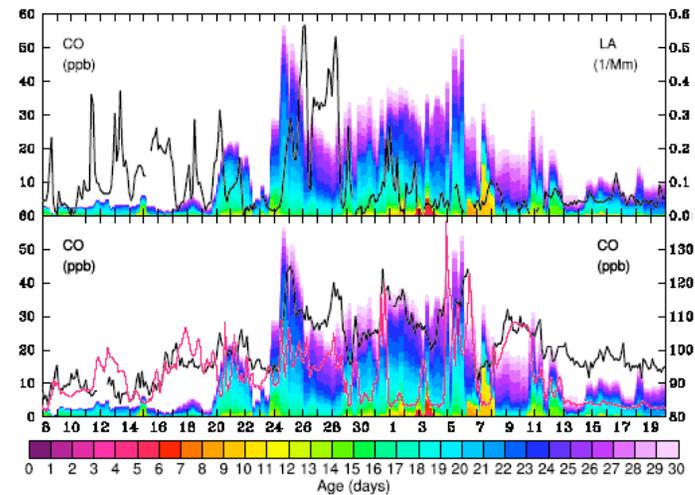
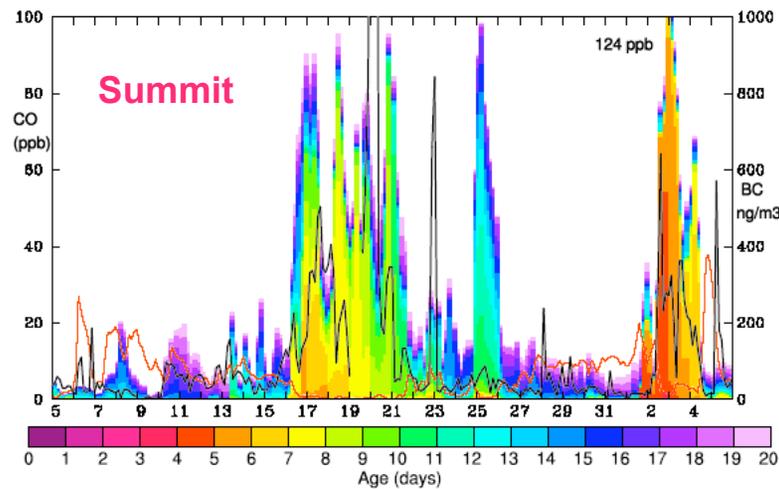
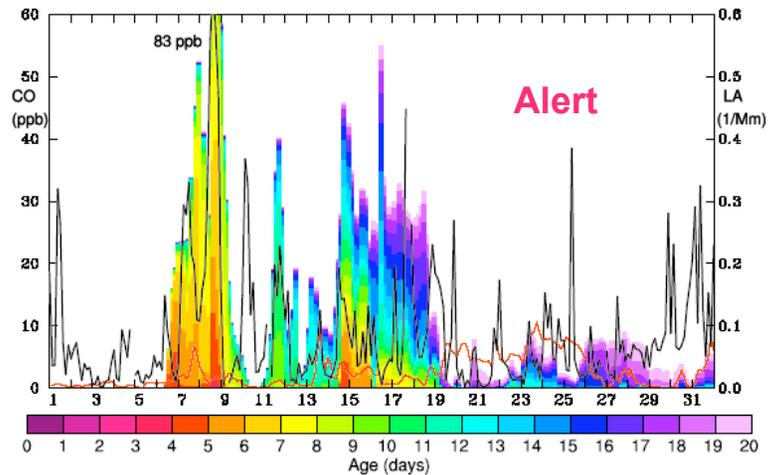
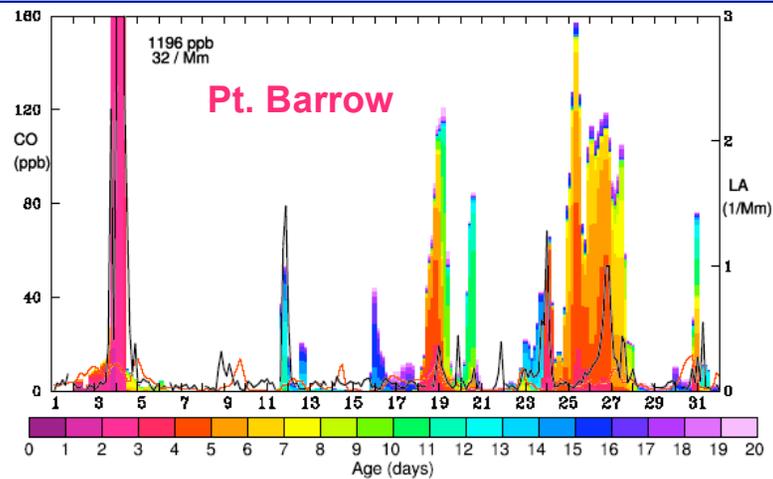
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From:

STOHL ET AL.: PAN-ARCTIC TRANSPORT OF BC FROM FOREST FIRES



NYA

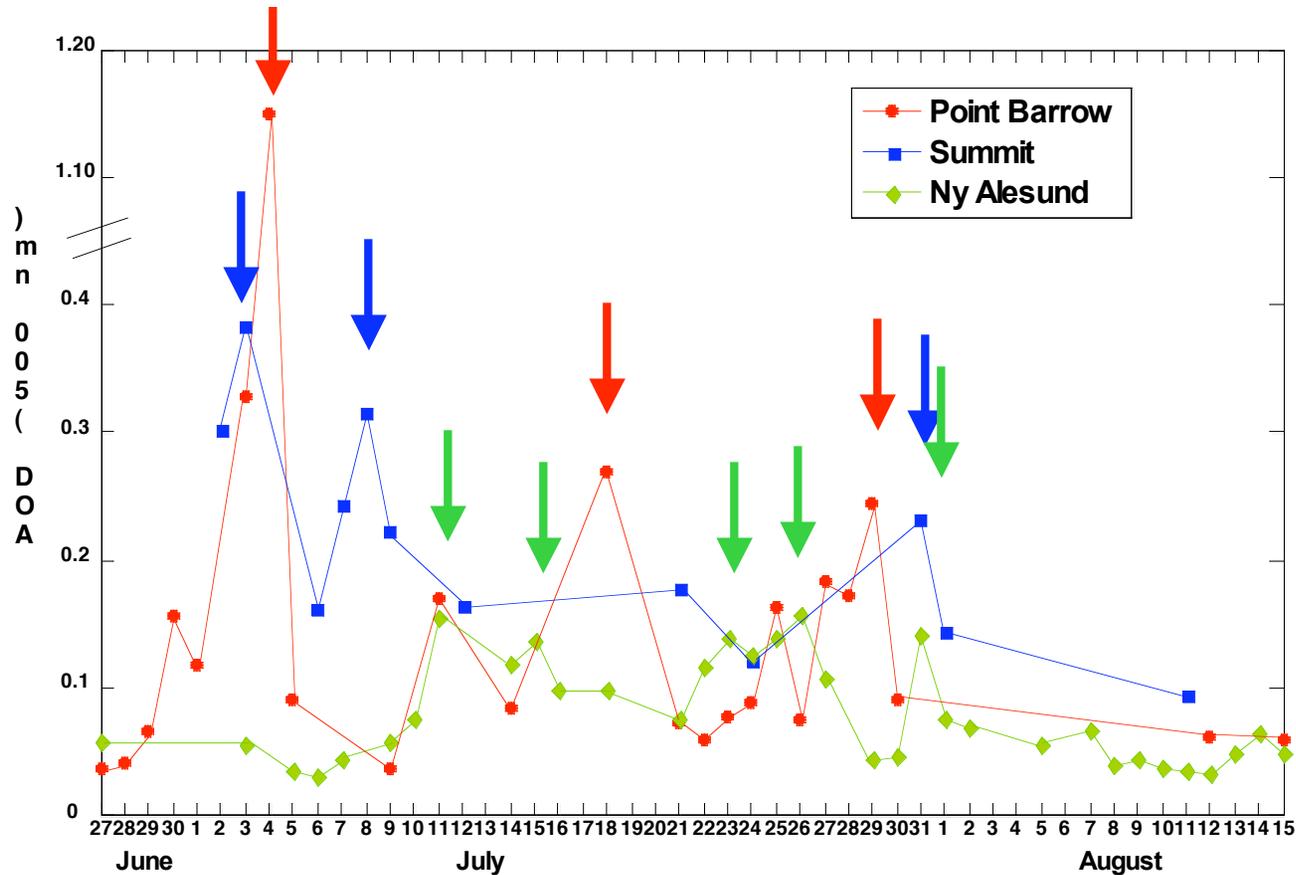
Comparison of the time series of 3-hour mean light absorption measured by the PSAP (black line, in Mm^{-1}) and CO tracer mixing ratios (ppb) obtained from the FLEXPART backward simulations, for Barrow, Alert, Summit and Ny Ålesund throughout July 2004. Anthropogenic CO tracer, accumulated over all 20 days of transport, is shown by the red line, whereas North American forest fire CO tracer is shown as stacked bars whose color indicates the age

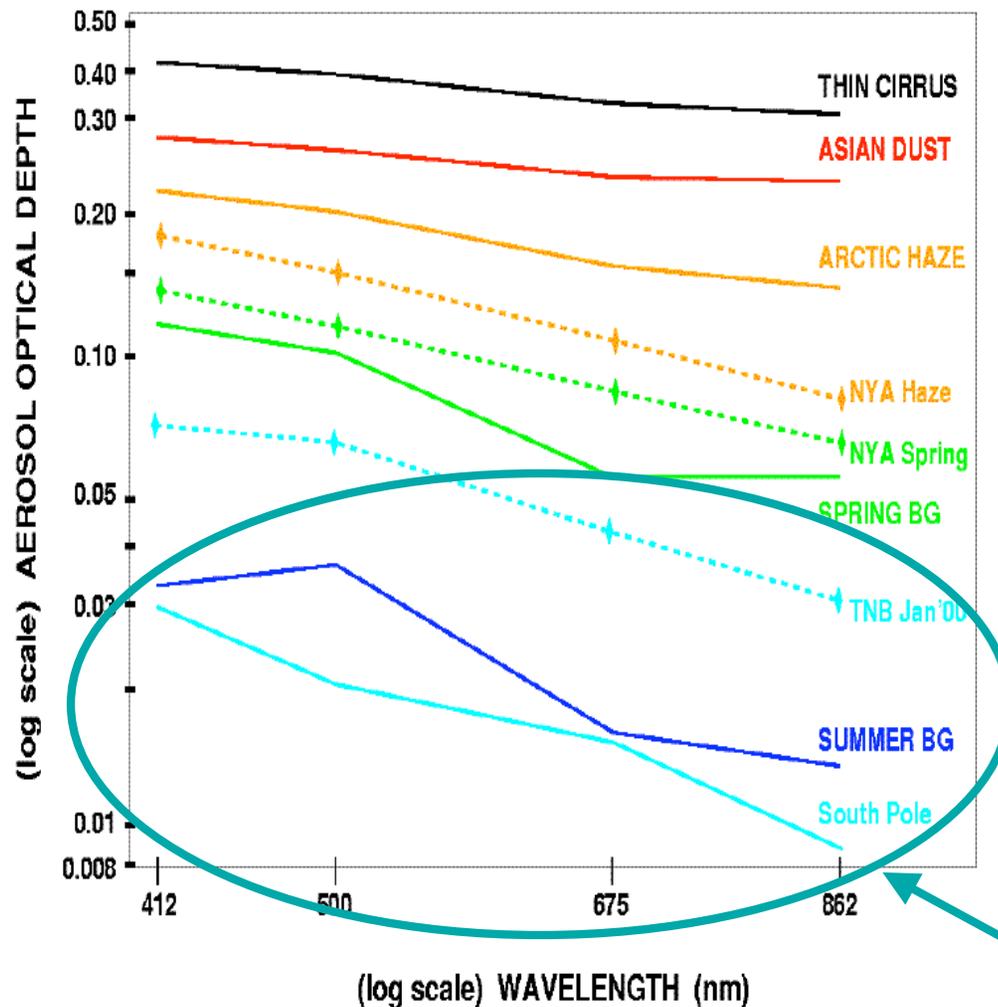


Time-patterns of $AOD(500\text{ nm})$ during summer 2004



The arrows indicate the arrival of boreal smoke particles above the stations showing that the $AOD(500\text{ nm})$ peaks were measured at the POLAR-AOD stations on the same days indicated by the FLEXPART backward simulations (Stohl et al., in review) in the previous graph.





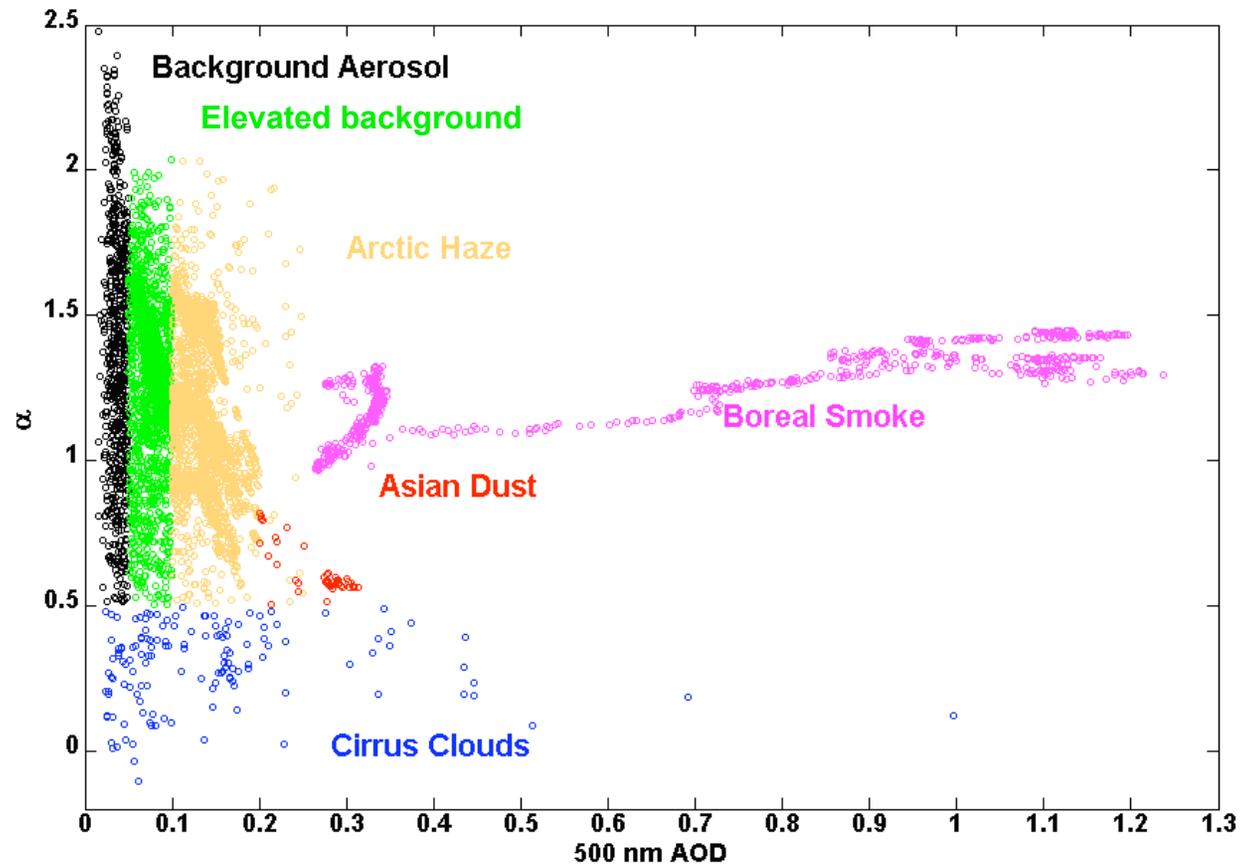
There is need for improved optical parameterizations of the diverse aerosol species present in the Arctic region to quantify the radiative effects produced by the different aerosol particle populations.

The AOD values measured in the Arctic region result to be usually considerably higher than those measured in Antarctica.

Antarctic data



In order to offer evidence for the different radiative properties of aerosols, exponent α was plotted versus AOD, to distinguish the various aerosol species.



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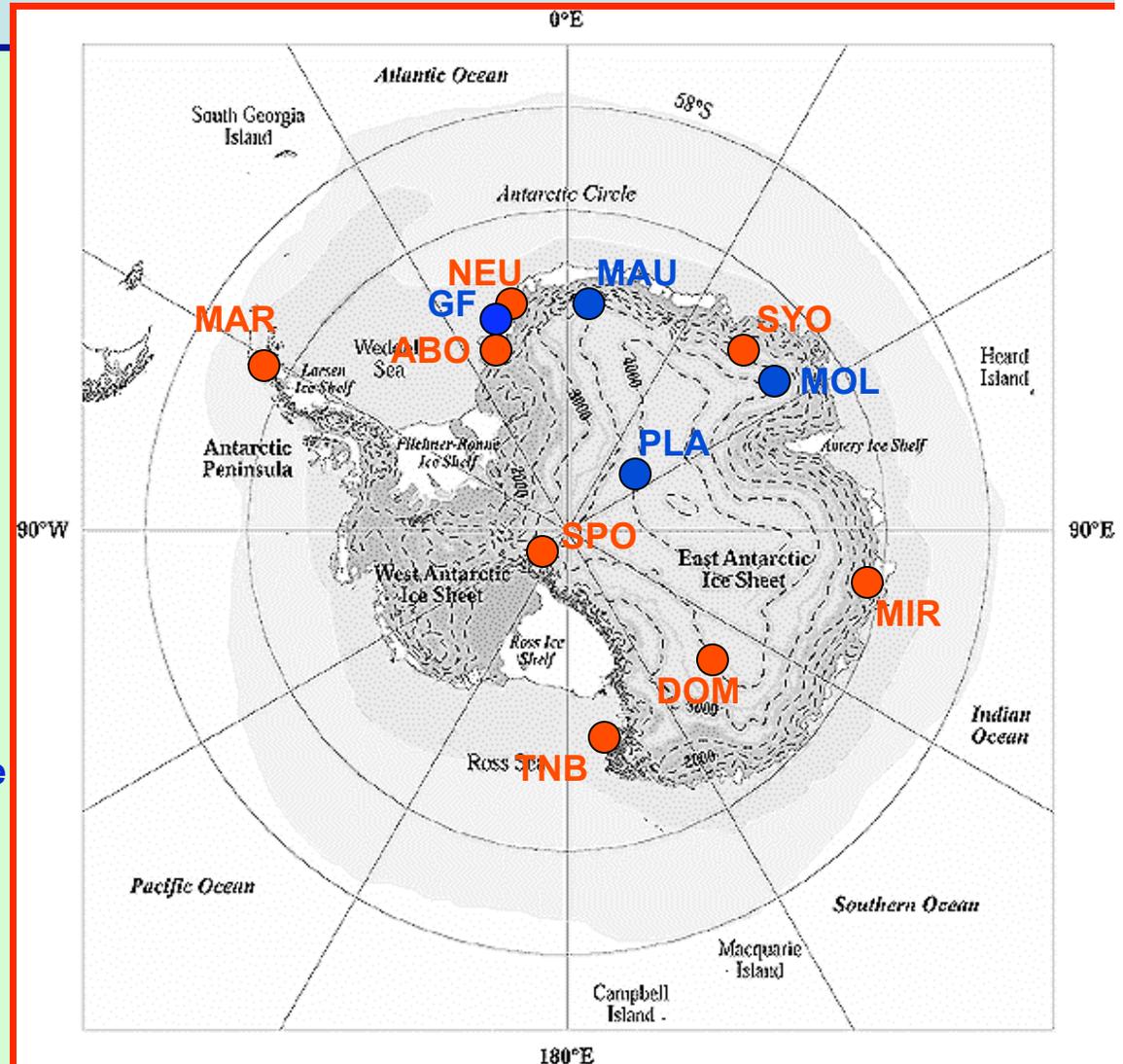


Measurements of aerosol radiative and composition parameters were carried out during the last years at the following Antarctic stations:

Mario Zucchelli station (TNB)
Dome C (DOM)
South Pole (SPO)
Neumayer (NEU)
Mirny (MIR)
Marambio (MAR)
Syowa (SYO)
Aboa (ABO)

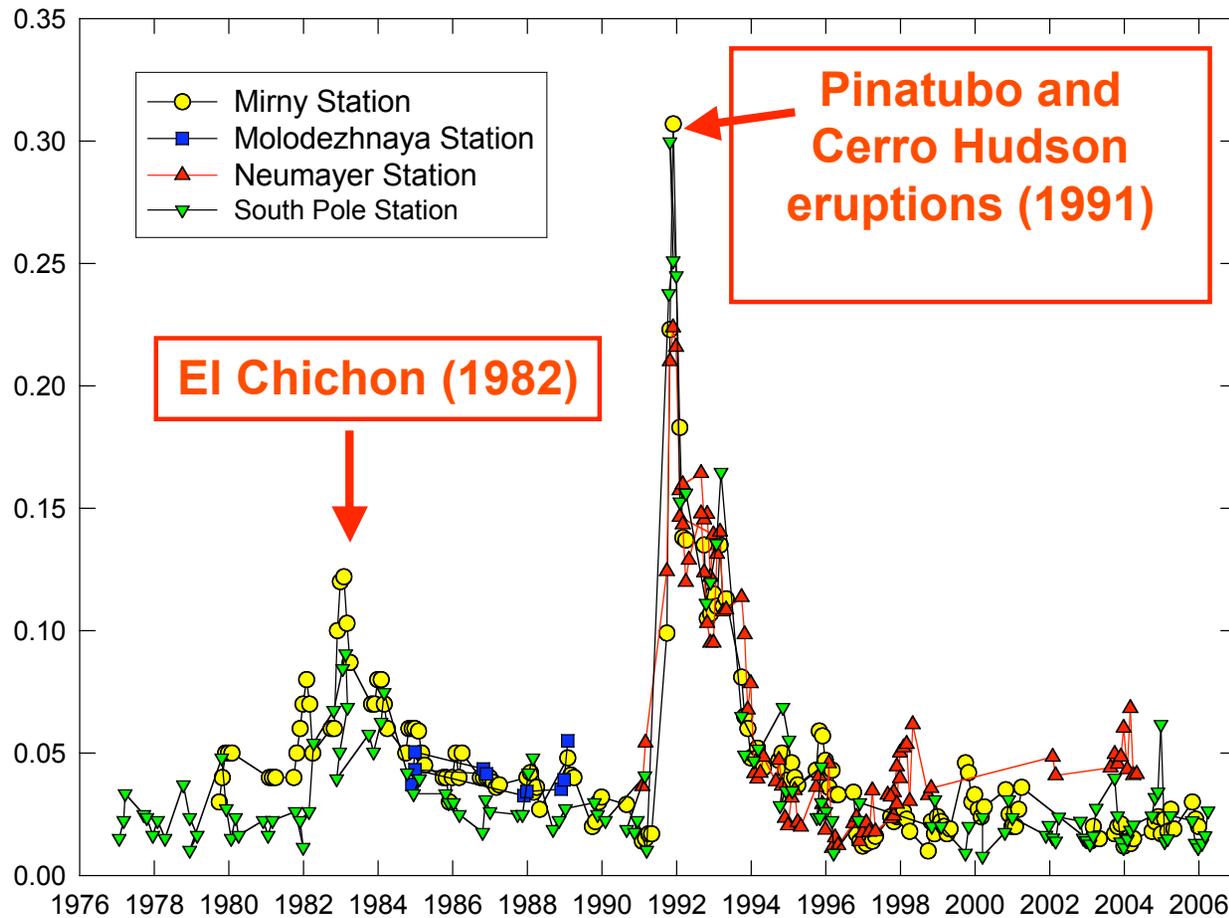
In the years from 1950 to 1990, irregular measurements of solar radiation flux were performed by AARI to determine AOD, at the following stations:

Georg Forster (GF)
Molodezhnaya (MOL)
Maudheim (MAU)
Plateau (PLA).



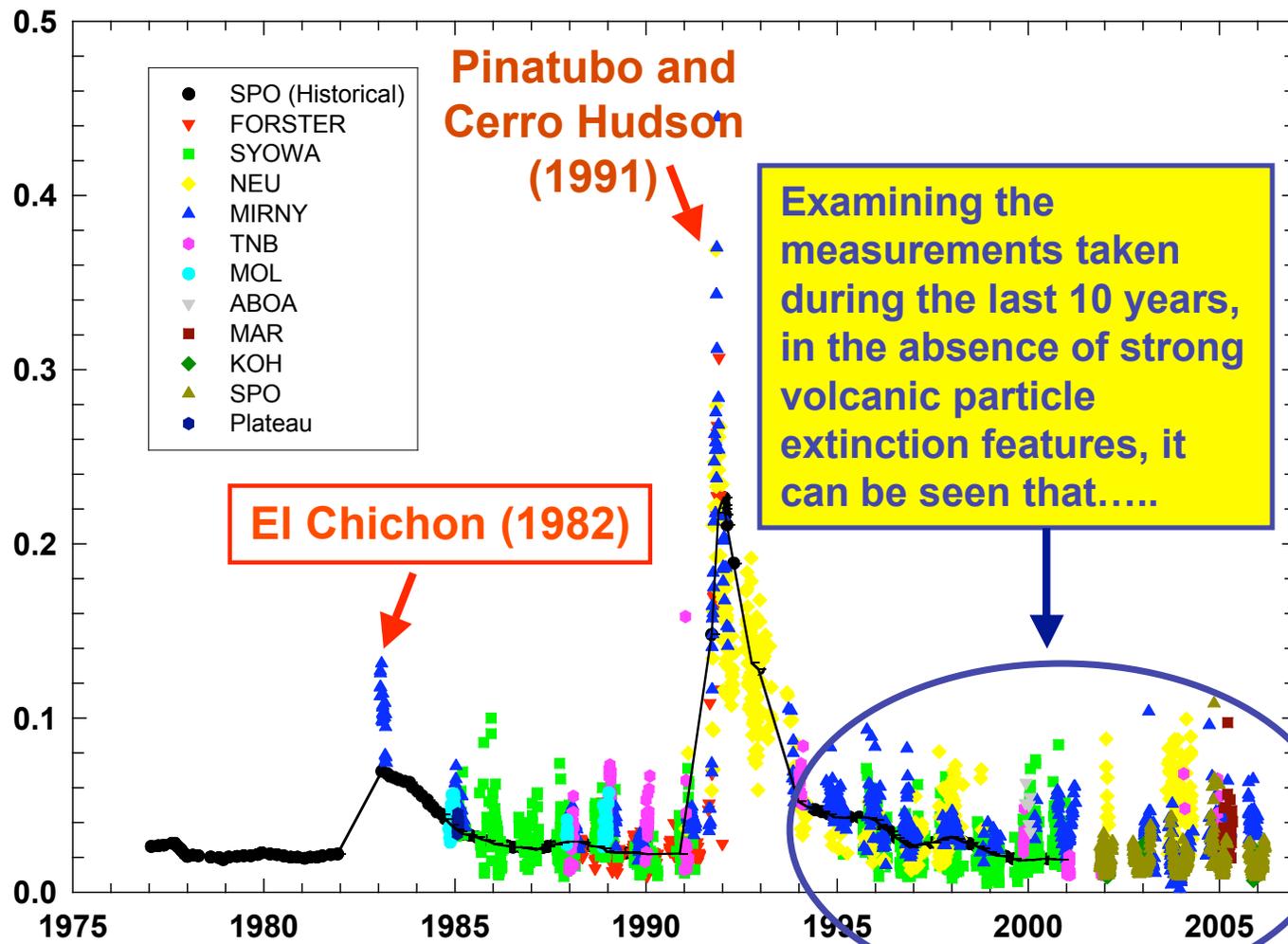
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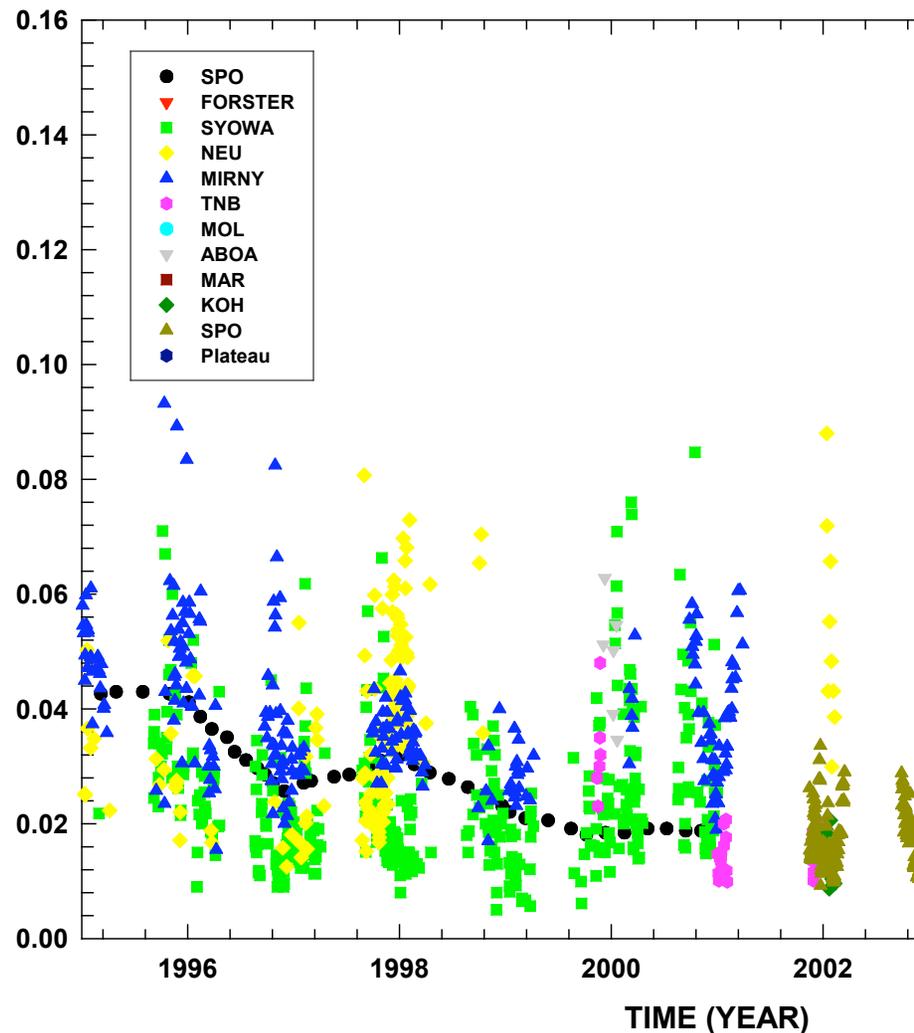


The monthly mean values of AOD(500 nm) measured at three coastal stations (Mirny, Molodezhnaya, and Georg Forster) and the Plateau high-altitude station from 1966 to early 1991 have been derived from the AARI records. The measurements performed since 1989 were taken using multi-spectral sunphotometers.

These data do not offer evidence for the existence of a long-term trend of the background (cloudless) AOD

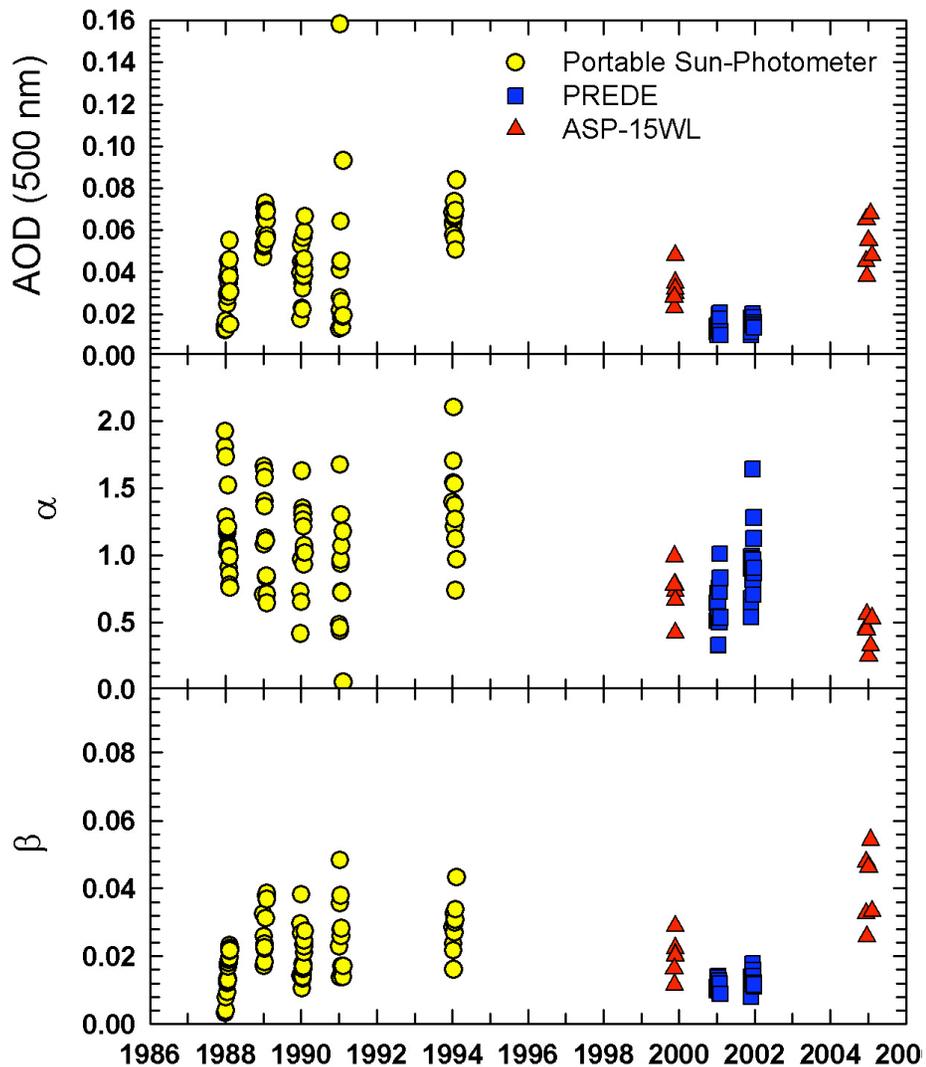


Time series of the daily mean values of $AOD(500\text{ nm})$ measured in Antarctica for cloudless conditions at six coastal sites (Terra Nova Bay, Mirny, Neumayer, Syowa, Aboa and Marambio) and three high-altitude stations (South Pole, Dome C, and Kohlen).



.....parameter $AOD(500\text{ nm})$ measured at coastal sites varies mainly between 0.02 and 0.08 and, hence assumes appreciably higher values than those found at the high-altitude stations.

Correspondingly, parameter α was found to assume values varying between 0.6 and 1.9 at the coastal sites and between 1.0 and 2.1 at the high-altitude stations.



Terra Nova Bay
(10 m a.m.s.l.),
(74° 42' S : 164° 07' W)

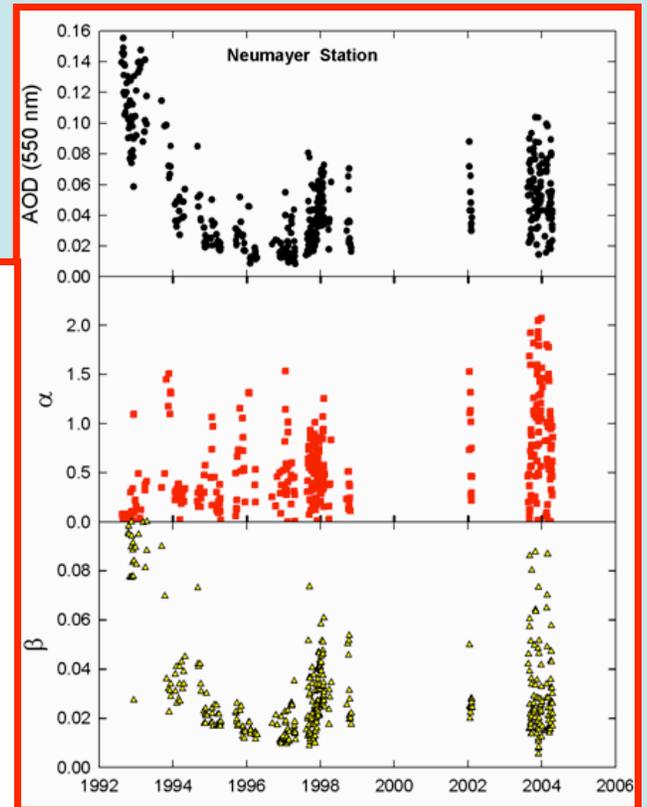
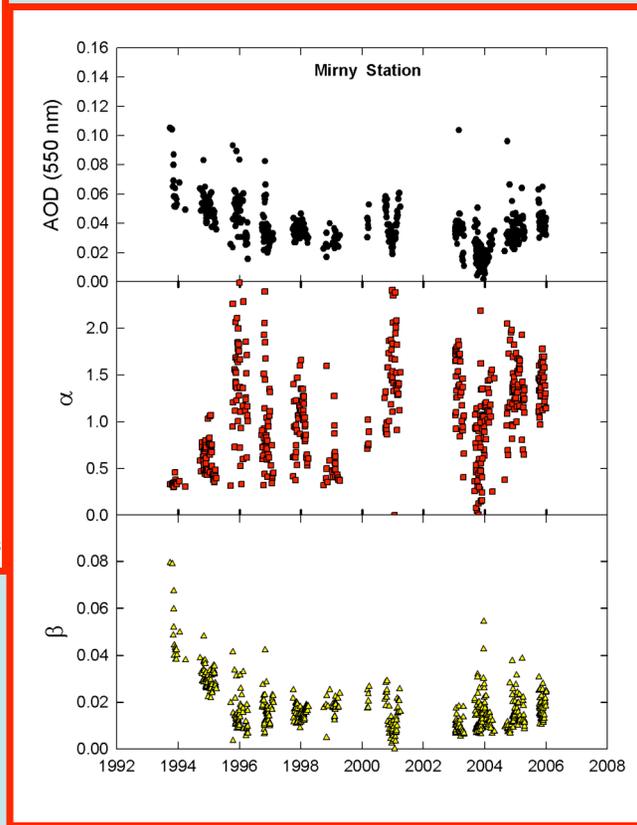
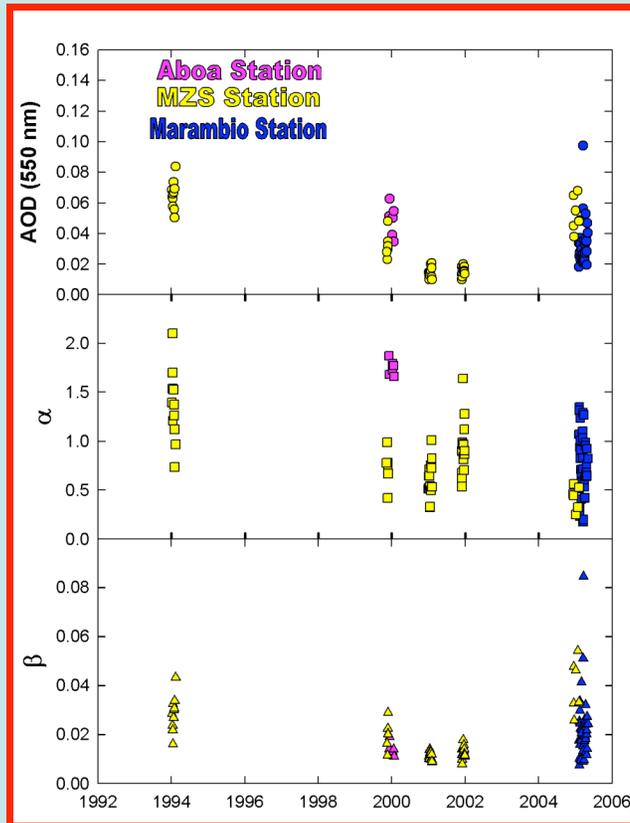


Different multi-spectral sunphotometers were employed at Terra Nova Bay by the ISAC-CNR group from 1987 to 2006: UVISIR, FISBAT, ASP-15WL and PREDE POM 01L.





Daily mean values of $AOD(500\text{ nm})$ and parameters α and β measured at the stations of Aboa, Terra Nova Bay, Marambio, Mirny and Neumayer



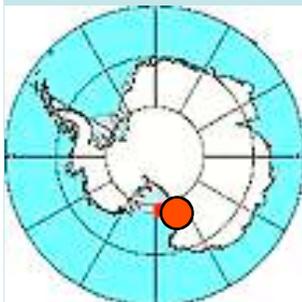
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Differences between the columnar aerosol contents at coastal and high-altitude Antarctic sites are due to:

(i) the coastal sites are strongly influenced by the surrounding ocean and hence the aerosol size distributions exhibit a strong component of sea salt aerosol, and

(ii) the Antarctic Plateau stations are mainly influenced by the subsidence of aerosols from the free troposphere transported over long distances.



(from R. Hillamo, I. Allegrini, R. Sparapani, and V.-M. Kerminen, *Intern. J. Environ. Anal. Chem.*, Vol. 71, pp. 353-372, 1998).

The mass size distributions of major inorganic ions in aerosol particles and their atmospheric precursor gases were studied at **Terra Nova Bay** between January 30 and February 18, 1995.

Major ions	Mass concentrations (ng/m ³) and mass percentages (%) at Terra Nova Bay during austral summer 1994/95									
	Overall		Mode 1 (Aitken nuclei)		Mode 2 (Accumulation particles)		Mode 3 (Coarse particles)		Mode 4 (Coarse particles)	
SO ₄ ⁻	458.7	19.9%	7.89	34.9%	238.8	72.1%	74.0	14.7%	138.0	9.5%
NH ₄ ⁺	28.2	1.2%	4.40	19.4%	18.1	5.5%	2.3	0.5%	3.4	0.2%
NO ₃ ⁻	44.5	1.9%	2.50	11.0%	6.1	1.8%	26.3	5.2%	9.7	0.7%
Cl ⁻	1043.2	45.2%	7.84	34.7%	31.4	9.5%	230.0	45.7%	774.0	53.3%
Na ⁺	658.6	28.5%	-	-	30.6	9.2%	152.0	30.2%	476.0	32.8%
Mg ⁻	76.1	3.3%	-	-	6.4	1.9%	18.6	3.7%	51.1	3.5%
Total	2309.3	100%	22.63	100%	331.4	100%	503.2	100%	1452.2	100%
Mode radius (μm)			0.069 ± 0.011		0.285 ± 0.016		~ 2		~ 6.5	

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Aerosol measurements performed at the coastal station of Aboa showed that the mass particle size distributions are multi-modal, each mode consisting of various inorganic ions (with a high fraction of ammonium in the accumulation mode, and sulfate ions in the coarse-particle modes, together with lower percentages of sodium, chloride, and nitrate ions), dust and soot components being limited to a few percents (Teinilä et al., 2000).

Major ions	Mass concentrations (ng/m^3) and mass percentages (%) at Aboa in austral summer 1998									
	Mode 1 (Aitken nuclei)		Mode 2 (Accumulation particles)		Mode 3 (Accumulation particles)		Mode 4 (Coarse particles)		Mode 5 (Coarse particles)	
nss SO_4^{--}	13.6	63.0%	120.8	65.8%	45.6	56.9%	9.8	27.3%	5.4	13.7%
NO_3^-	-	-	0.1	0.05%	-	-	2.5	7.0%	6.3	16.0%
Cl^-	-	-	-	-	0.6	0.8%	3.9	10.9%	14.4	36.7%
Na^+	-	-	-	-	4.4	5.5%	14.4	40.1%	10.3	26.2%
NH_4^+	6.3	29.2%	21.2	11.5%	13.0	16.2%	0.8	2.2%	0.9	2.3%
MSA	1.7	7.8%	41.6	22.65%	16.5	20.6%	4.5	12.5%	2.0	5.1%
Total	21.6	100%	183.7	100%	80.1	100%	35.9	100%	39.3	100%
Mode radius (μm)	0.15÷0.20		0.30		0.5 ÷ 0.8		1.3 ÷ 1.9		3 ÷ 10	

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At the Aboa (coastal) station



The monthly mean values of aerosol **black carbon** concentration were found to range **between 0.3 and 2.0 ng m⁻³**, describing a seasonal cycle with peaks in January/February (austral summer) and an overall maximum in October (Wolff and Cachier, JGR, 1998).

4	0.23 – 0.34	1.458
3	0.15 – 0.23	1.470
2	0.086 – 0.15	1.495
1	0.045 – 0.086	1.505

Values of real part of refractive index over the whole particle size-distribution for imaginary part $k = 0.00$ (first line) and $k = 0.01$ (second line)

Wavelength (nm)		
450	550	700
1.445 ± 0.074	1.431 ± 0.072	1.436 ± 0.086
1.456 ± 0.075	1.439 ± 0.073	1.446 ± 0.095

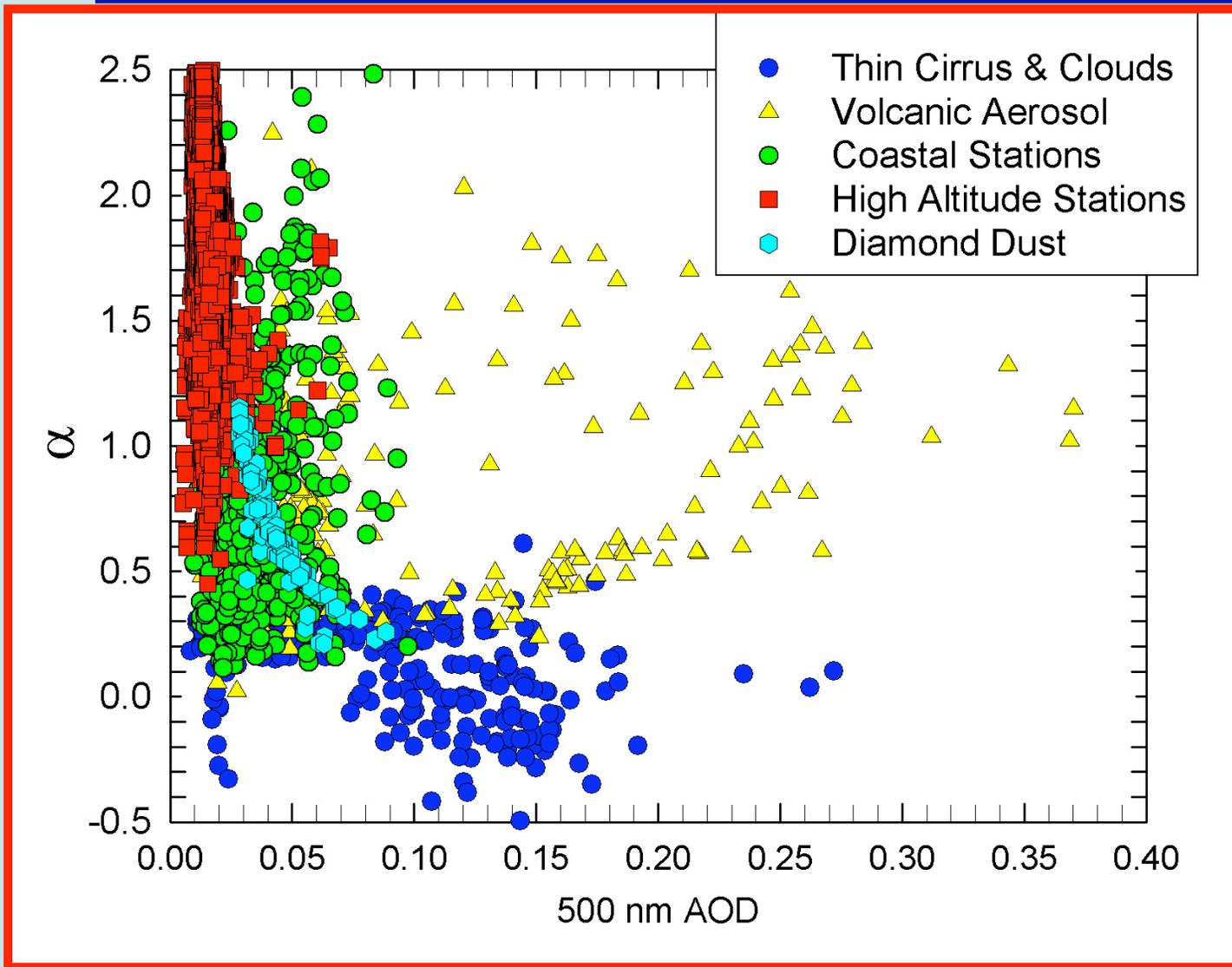
As shown in the lower table, the real part of refractive index at visible wavelengths was evaluated to assume values varying between 1.43 and 1.46, associated with values of the imaginary part lower than 0.01.



The composition data confirm that the Antarctic Plateau stations are influenced mainly by the subsidence of aerosols from the free troposphere transported over long distances.

Intrusions of sea salt aerosols are observed at **South Pole** only occasionally, when storms reach the interior from surrounding oceans regions. In these cases, clear signatures distinguish air masses carrying coarse (sodium) and small (sulfate) particles, with peak sodium concentrations associated with flow from the Weddell and Ross sea regions.

Hogan et al. (1979) analyzed impactor samples taken at the South Pole and found that in the particle size range $0.3 \mu\text{m} < D_p < 12 \mu\text{m}$ the real part n_r of particulate refractive index was ≈ 1.54 with a range from ~ 1.50 to 1.58 .



Parameter α was plotted versus $AOD(500\text{ nm})$ for different aerosol classes in order to offer evidence for the aerosol differences between coastal and high-altitude stations.

The exponent α is closely related to the shape of the multi-modal size distribution of the aerosol.



AEROSOL-INDUCED RADIATIVE FORCING CALCULATIONS need to know all the parameters defining the aerosol radiative properties as determined through the use of radiometric and chemical analysis techniques:

- (1) the **spectral series of AOD**;
- (2) the **complex refractive index** of columnar particulate matter;
- (3) the **size distributions** of aerosol particles;
- (4) the **phase function and asymmetry factor** of columnar aerosols;
- (5) the **single scattering albedo** of columnar aerosols; and
- (6) the **surface reflectance** (measured albedo).



CONCLUSIONS

1. The large differences observed in polar records of AOD highlight the importance of assimilating similar data from various sites to better characterize aerosols spatially and temporally.

2. The activities of the **POLAR-AOD IPY Project** have to achieve more homogeneous evaluations of the spectral series of AOD and the related aerosol parameters at the various Arctic and Antarctic stations.



3. The POLAR-AOD IPY Programme objectives will be pursued through the following planned activities:

- **Deploying advanced sun- and star-radiometers;**
- **Planning regular campaigns for inter-comparing the various models of sun- and star-photometers employed by the POLAR-AOD groups and inter-calibrating them;**
- **Using more precise spectral values of Rayleigh scattering optical depth in polar atmosphere models;**
- **Using realistic absorption models for field measurements of the columnar contents of ozone, nitrogen dioxide, oxygen dimer, and water vapor;**
- **Adopting a common best-fit procedure for the calculations of the Ångström turbidity parameters;**
- **Improving the aureole sunphotometer techniques (SKYRAD CODE 4) for the analysis of the sky-brightness measurements in almucantar;**
- **Determining more realistic (anisotropic) surface reflectance models,**
- **Using satellite radiance data to retrieve the aerosol parameters and achieve a better spatial and temporal coverage of the polar regions,**
- **Planning to develop systematic *in situ* measurements of the physical and radiative aerosol parameters and assimilate aerosol composition data at the various sites, to better characterize aerosols spatially and temporally, and**
- **Establishing a data bank for spectral sun-photometric measurements (AOD archive), *in situ* measurements and any other aerosol related parameters that are useful for quantifying the aerosol radiative effects (including lidar and satellite data).**