Maritime Aerosol Network (MAN) as a component of AERONET

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activity is described. A brief historical perspective is given to aerosol optical depth (AOD) measurements over the oceans. A short summary of the existing data, collected onboard ships of opportunity during the NASA Sensor Inter-comparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) Project is presented. Globally-averaged oceanic aerosol optical depth (derived from island-based AERONET measurements) at 500 nm is ~0.11 and Angstrom parameter (computed within spectral range 440-870 nm) is calculated to be ~0.6. First results from the cruises contributing to the Maritime Aerosol Network are shown. MAN ship-based aerosol optical depth compare well to simultaneous island and near-coastal AERONET site AOD.

Introduction.

The World Ocean produces a large amount of natural aerosols that have an impact on the Earth's albedo and climate. Sea-salt is the major contributor to aerosol optical depth over the oceans [*Mahowald et al.* 2006; *Chin et al.* 2002; *Satheesh et al.* 1999; *Winter and Chylek*, 1997] and therefore affects the radiative balance over the ocean through the direct [*Haywood et al.* 1999] and indirect aerosol effect [*O'Dowd et al.* 1999]. Aerosols over the oceans (produced marine and advected from land sources) are important for various atmospheric processes [*Lewis and Schwartz*, 2004] and remote sensing studies [*Gordon*, 1997].

Recent publications emphasizing aerosol trends over the oceans based on the long-term satellite records [*Mishchenko et al.* 2007; *Chylek et al.* 2007; *Remer et al.* 2008] and the

Liu et al. [2004] in the global validation of two channel AVHRR aerosol optical depth retrievals.

In the current paper we present brief analysis of the historical SIMBIOS ship-borne and AERONET island-based aerosol optical depth data, describe the concept of MAN, and show first results from the cruises contributing to the Maritime Aerosol Network.

SIMBIOS data

The SIMBIOS (The Sensor Intercomparison for Marine Biological and Interdisciplinary Ocean Studies) program [*Mueller et al.* 1998; *McClain and Fargion*, 1999] began in 1997 and through 2003 collected data on aerosol optical depth over the oceans from various ships of opportunity using Microtops II hand-held sunphotometers. Measurement strategy and protocol, ship tracks, and statistics for various aerosol types and regions were presented in the paper by *Knobelspiesse et al.* [2004]. The SIMBIOS database was re-visited in order to better understand where we still have gaps in our knowledge on aerosol optical properties over the oceans. Daily averages were computed for all available cruises and after some additional screening data were divided into two subsets: oceanic and coastal (acquired within 100-150 km from the nearest shoreline). Additional quality control (screening) was typically minimal; however during one of the cruises aerosol optical depth demonstrated a consistent unusual spectral dependence, which implied calibration or instrumental problems. As a result these suspect data were removed from further consideration. Overall 458 measurement days spanning a 6 year period (1997-

of Japan intensively studied during the ACE-Asia experiment, though within a limited time frame (March-April 2001). Figure 1b shows relatively stable optical conditions on the West Coast with τ_a(500 nm) less than 0.20 and a variety of aerosol loadings on the East Coast where optical depth ranged from 0.05 to 0.60. Pollution and dust aerosol dominated aerosol optical properties during the ACE-Asia experiment and aerosol optical depth in some instances was over 1.00. The latitudinal dependence shown in Fig. 1b presents a clear picture that despite the tremendous effort in data collection the gaps dominate and therefore suggests how little we know.

AERONET data

The Aerosol Robotic Network (AERONET) is a world-wide network of sun/sky radiometers that operates over 300 sites worldwide [*Holben et al.* 1998]. Starting in 1996 AERONET has a number of operational island sites. Several publications based on the AERONET data [*Holben et al.* 2001; *Eck et al.* 2001; 2005; *Smirnov et al.* 2000, 2002, 2003a, 2003b] have analyzed aerosol optical properties over the oceans, including pollution and dust aerosol transport affecting and modifying those properties. Accumulated statistics on aerosol optical depth and Angstrom parameter afforded estimation of the globally averaged parameters over the oceans (from island-based measurements). Yearly mean aerosol optical depth and Angstrom parameter for various island sites are shown in Fig. 2 (a and b). Horizontal bars represent plus or minus one standard deviation. Locations of these AERONET sites are shown in Fig. 3, while Table 1 presents coordinates, measurement period, and number of measurement days used in

Asian dust transport [*Eck et al.* 2005]. In fact when the spring (March through May) dust transport months are excluded the remaining 9-month average at Midway ~0.09. The AERONET record for the Atlantic shows a strong latitudinal dependence and optical depth is highly variable. Hornsund is located on Spitzbergen in the Arctic (77° N) and yearly average τ_a there (~0.08, this is only for 7 months due to polar night) is very close to the remote marine conditions, despite the presence of Arctic haze (from advected pollutants) in the spring months [*Shaw*, 1995]. Saharan dust transport strongly affects the aerosol optical properties over Cape Verde and Barbados. Industrial pollution can modify maritime aerosol over Bermuda and the Azores. Seasonal dust and biomass burning aerosol transport frequently influences the Ascension Island optical depth. The record for the Indian Ocean sites was not as long as for the Pacific and Atlantic. Optical depth data over Kaashidhoo (Maldives) were collected primarily during the dry season when the northeast monsoon brought heavily polluted air from the Indian sub-continent. A modest record from other sites in the sub-tropical and mid-latitude Southern Indian Ocean yielded average τ_a ~0.05-0.08.

We computed globally averaged τ_a(500 nm) and Angstrom parameter α (based on a spectral range 440-870 nm; computed by log-linear regression of 440, 500, 675 and 870 nm data, except for a few instruments that lacked the 500 nm channel) by simply weighting the mean optical parameter for a particular ocean with the area fraction of that ocean basin (see Table 2). Data acquired over Hornsund were considered representative for the Arctic Ocean and ship-based data reported by *Smirnov et al.* [2006] were taken as

The AERONET-based oceanic globally-averaged τ_a(500 nm) is ~0.11 (σ ~0.04); this value is very close to the satellite record reported by *Remer et al.* [2008] (0.13 for Aqua and 0.14 for Terra), *Zhang et al.* [2008] (0.12 for NAAPS with the assimilated MODIS data), *Mishchenko et al.* [2007] (0.11 for AVHRR), *Myhre et al.* [2005] (0.10-0.16 for AVHRR, SeaWifs, MODIS), *Zhao et al* [2005] (0.11-0.16 for AVHRR and MODIS). Coarse particles of the marine sea-salt and continental dust aerosol reduced the Angstrom parameter (mean of ~0.6) and made it lower by a factor of two compared to typical α values (~1.3-1.7) over continental regions that are not affected by desert dust (see e.g. Holben et al. [2001]).

Maritime Aerosol Network status

Accurate knowledge of atmospheric aerosol optical properties is a key to the success of atmospheric correction over the oceans. The NASA Workshop "Supporting in-situ and space-based measurements" (Montréal, Quebec, October 6-7, 2006) helped to formulate scientific questions and research challenges needing to be addressed: current atmospheric aerosol models should be updated and more data over the oceans should be collected. Therefore, the principal question of this workshop could be formulated as follows: what is to be done to improve our knowledge of aerosol optical properties over the oceans and fill the existing data gaps. We suggested the establishment of the Maritime Aerosol Network which would be a component of the Aerosol Robotic Network (AERONET), and would be affiliated with the AERONET calibration and data processing standards and procedures. The proposed activity evolved around hand-held sunphotometer optical depth in each channel does not exceed plus or minus 0.02, which is slightly higher than the uncertainty of the AERONET field (not master) instruments as shown by Eck et al. [1999]. A GPS should be connected to the sunphotometer to obtain the time of measurements and geographical position of the ship.

Each Microtops instrument is calibrated against an AERONET master-CIMEL sun/sky radiometer at GSFC, which was calibrated from morning Langley plot measurements on Mauna Loa. As a rule we put a master-CIMEL in a manual mode that enables it to take direct sun measurements every minute. The Microtops then takes 20-30 consecutive scans within an approximately 5-6 minute interval, side-by-side with the master-CIMEL. It is highly desirable to make inter-calibration measurements in clear (with AOD at 500 nm less than 0.25) and stable atmospheric conditions to ensure accurate and stable results. Figure 4 presents a calibration window that indicates that standard deviation of the aerosol optical depth during the calibration process (based on the CIMEL measurements) is less than 0.005. Aerosol optical depths and their standard deviations are shown for the master-instrument (top) and calibrated Microtops (bottom) for a time period of several minutes. New and old "extraterrestrial signal constants" are displayed with variation coefficients (standard deviation/mean; in %) for each spectral channel. The last column indicates the temporal change in calibration coefficients (in %). Aerosol optical depth is retrieved by applying the AERONET processing algorithm (Version 2) to the raw data [*Smirnov et al.* 2004; http://aeronet.gsfc.nasa.gov/new_web/Documents/version2_table.pdf].

points in the group); and a sequence of series in a day may be used to compute the daily average.

Data quality is assured in the following way. The Level 1.0 (unscreened) measurement series are formed from Level 1.0 points. The cloud and pointing error screening is applied to Level 1.0 data to produce a Level 1.5 data set. The following criteria are examined for cloud and pointing errors:

- within a series, the minimum aerosol optical depth for each point is identified at each wavelength (τ_{ai}^{min}).
- if the difference (τ_{ai} - τ_{ai}^{min}) for each spectral channel is less than the maximum of $\{\tau_{ai}^{min}$ *0.05, 0.02$\}$, then that point within a series is considered cloud-free and pointing error free.

If the above screening removes all but one point from a series, then an additional criterion below is applied to the spectral channels:
- if the Angstrom parameter computed using all available channels between 440 and 870 nm is greater than -0.1, then the point is considered cloud and pointing error free.

The Level 1.5 data series are raised to Level 2.0 (quality-assured) series after final calibration values are applied, spectral channels are evaluated for filter degradation and other possible instrumental problems or data anomalies; and manual data inspection is completed for possible cloud contaminated outliers.

authorship to Principal Investigators would be an expected sign of courtesy, however it is not a requirement.

Figure 7 presents the latitudinal dependence of aerosol optical depth in the Atlantic Ocean and in Antarctica based on a number of cruises. Cruise tracks allowed for sampling of several aerosol regimes over the Northern and Southern Atlantic. In remote oceanic areas not influenced by continental aerosol sources the aerosol optical depth is typically below 0.10 at 500 nm. Saharan dust transport in the Tropical Atlantic near to the coast of West Africa significantly increased the aerosol loading. Pollution sources in Europe can elevate optical depth in the coastal sampling areas to the north of 30 degrees. Measurements in the Arctic region yielded a low average optical depth ~0.05. During the Antarctic summer (January 2006 and January-February 2007) aerosol optical depth near the coastline of Antarctica was even lower yet ~0.02-0.03.

The whole data archive is mapped in Fig. 8. Daily averages from various cruises characterize regional aerosol optical depth and overall coverage of the network. Obviously vast oceanic areas still have no or very limited coverage (e.g. in the Pacific and Indian oceans; near the coast of the South-East Asia; in the Caribbean). Further efforts are needed to evaluate aerosol regimes over those oceanic regions.

Ship-based measurements were compared with the AERONET data obtained from the island and coastal sites along the cruise tracks. Island measurements always posed a question whether data acquired could be considered representative for the ocean areas or climate change and atmospheric radiation budget modeling, satellite validation studies, global and regional aerosol transport modeling, atmospheric correction and ocean color observations, etc. Employing simple, standard and commercially available instrumentation, traceable calibration, a scientifically sound processing scheme and easily accessible web-based public data archive, the network has strong growth potential. Expanded spatial coverage will contribute to enhanced understanding of aerosol optical properties over the oceans and improve our knowledge of physical processes of maritime aerosol production, transport and distribution. The database may help stimulate research and international collaboration in various scientific areas.

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Figure 1a

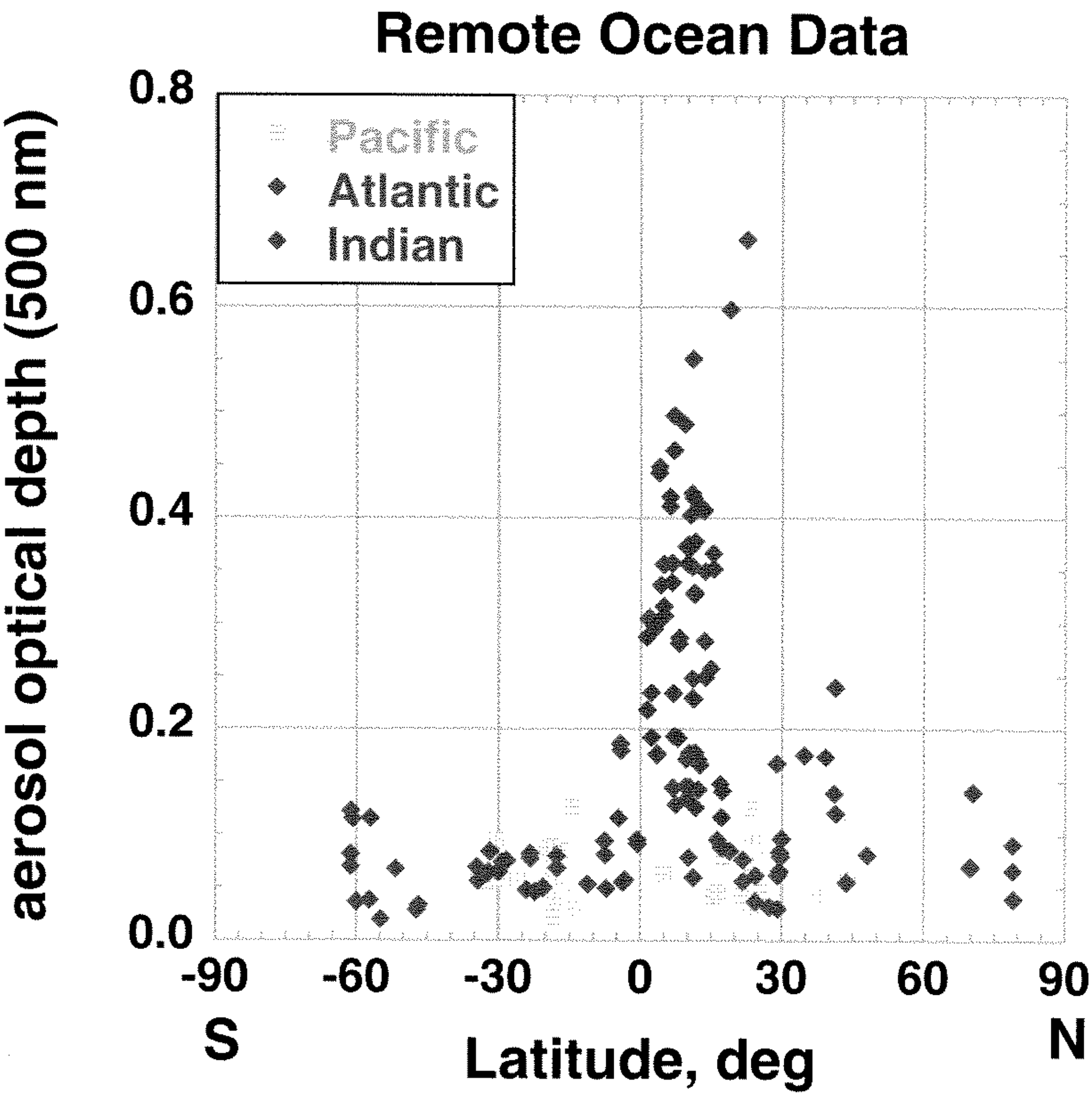

Remote Ocean Data
Pacific
Atlantic
Indian
aerosol optical depth (500 nm)
0.0
0.2
0.4
0.6
0.8
-90
-60
-30
0
30
60
90
S
N
Latitude, deg

Figure 2a

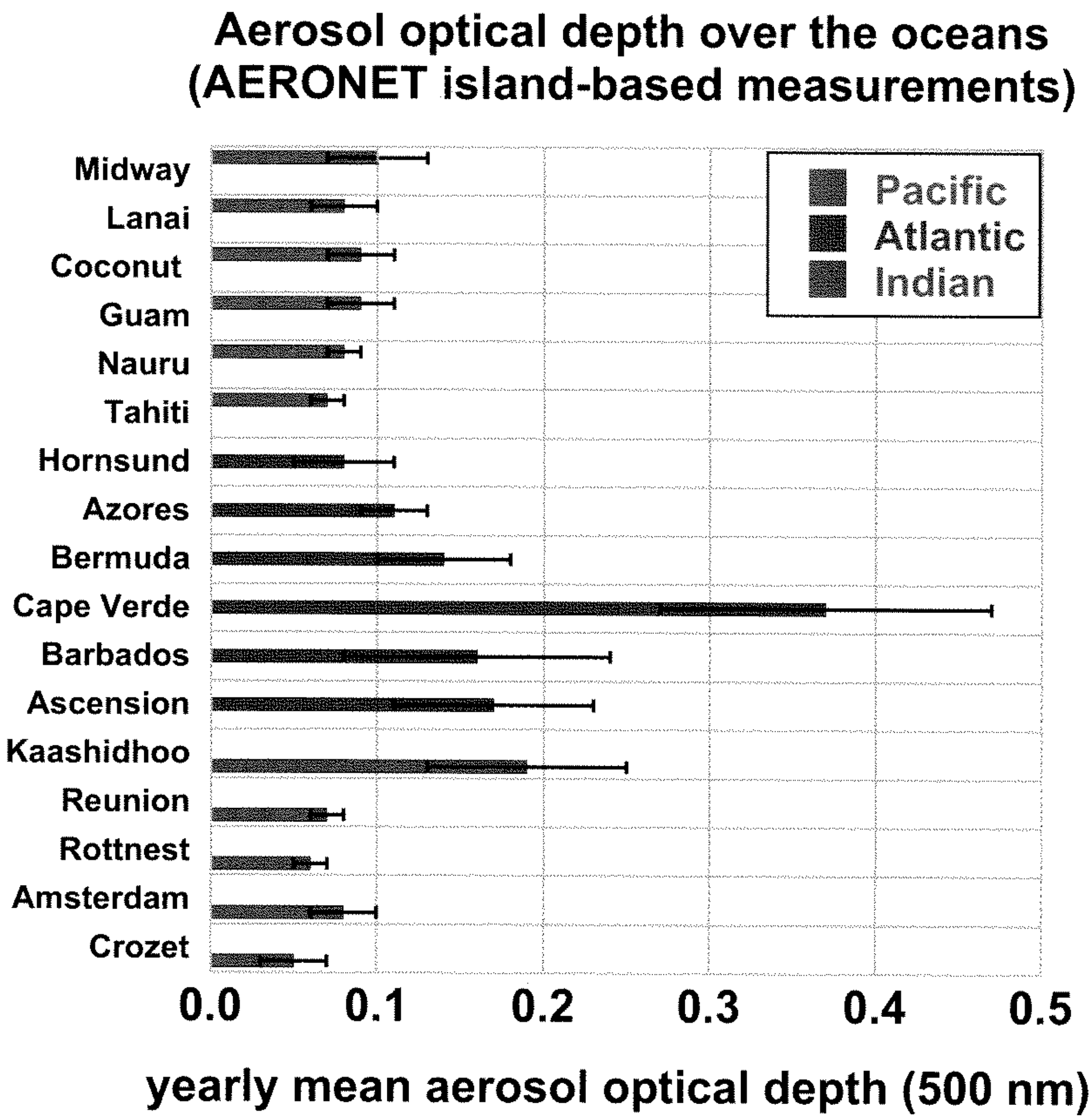

Aerosol optical depth over the oceans
(AERONET island-based measurements)
Midway
Lanai
Coconut
Guam
Nauru
Tahiti
Hornsund
Azores
Bermuda
Cape Verde
Barbados
Ascension
Kaashidhoo
Reunion
Rottnest
Amsterdam
Crozet
Pacific
Atlantic
Indian
0.0
0.1
0.2
0.3
0.4
0.5
yearly mean aerosol optical depth (500 nm)

Figure 3

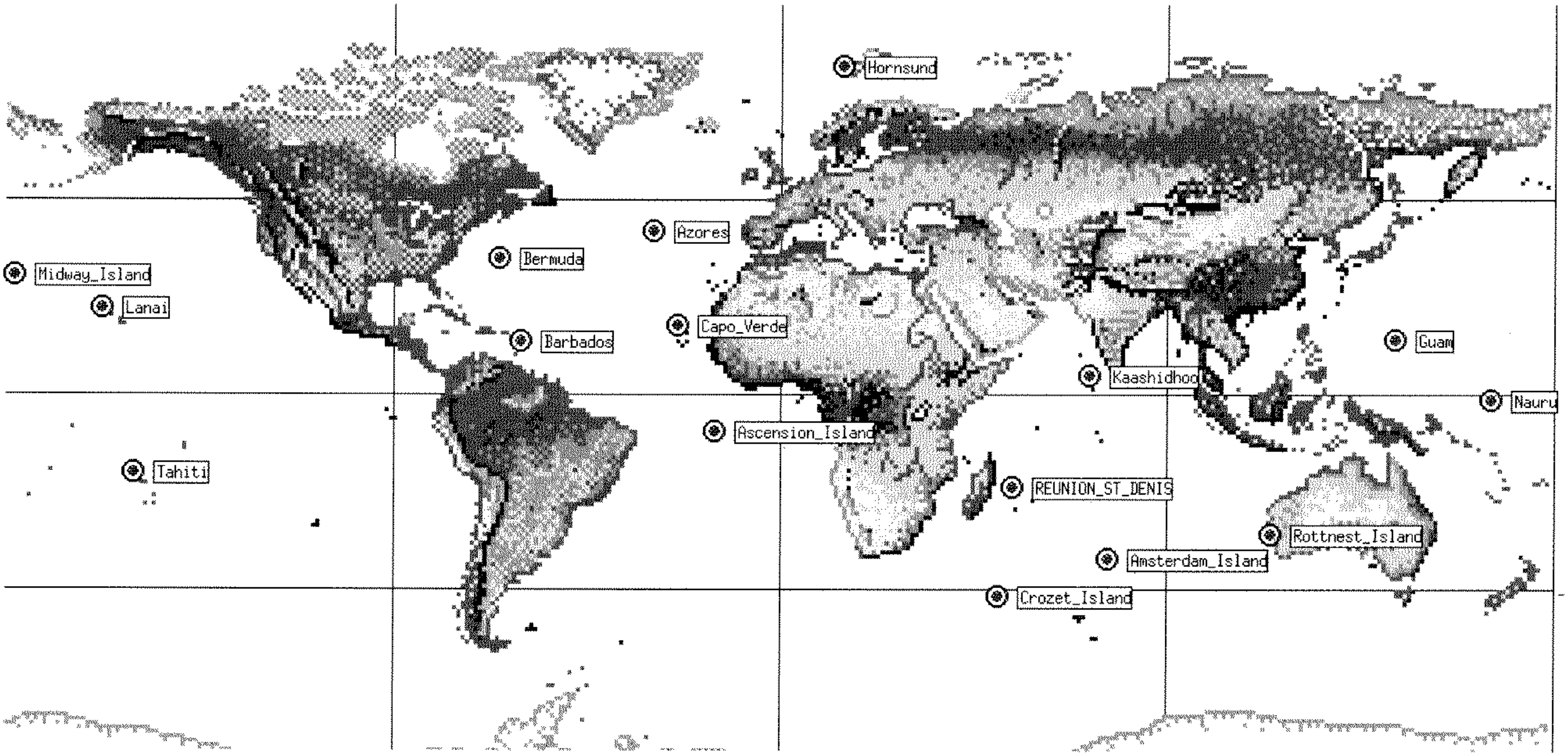

Hornsund
Azores
Bermuda
Midway_Island
Lanai
Barbados
Capo_Verde
Guam
Kaashidhoo
Nauru
Ascension_Island
Tahiti
REUNION_ST_DENIS
Rottnest_Island
Amsterdam_Island
Crozet_Island

Figure 5

INTERCAL ACTIVE HISTORY NEW SEARCH SORT HOME LEGEND HELP

Total 22 PREVIOUS NEXT

Inst	S_N	Date	Filters	A B Constants	Sun1	Data Status	Maint	Clean	Sun2	Shipped	Received	Contact Person	Current Status
470	3768	**5/12/2008**	440, 500, 675, 870, 936	A=0.6928 B=0.604	X			X	X	**6/12/2008**	6/18/2008	Joaquim Goes	Bering Sea
472	3765	**6/4/2008**	440, 500, 675, 870, 936	A=0.6749 B=0.6024				X	X	**6/17/2008**	6/23/2008	Peter Croot	Atlantic Ocean
473	5395	**5/19/2008**	440, 500, 675, 870, 936	A=0.6597 B=0.5899	X			X	X				GSFC
474	5396	**3/13/2008**	440, 500, 675, 870, 936	A=0.6088 B=0.5825	X			X	X	**3/28/2008**	4/7/2008	Tymon Zielinski	Sopot, Poland
475	3770	**7/25/2008**	440, 500, 675, 870, 936	A=0.6928 B=0.604	X			X	X				GSFC
476	5376	**7/25/2008**	380, 500, 675, 870, 1640		X			X	X	**8/12/2008**	8/12/2008	Lorraine Remer	GSFC
481	3125	**7/25/2008**	340, 440, 675, 870, 936	A=0.6548 B=0.574	X			X	X				GSFC
482	3657	**6/30/2008**	340, 440, 675, 870, 936	A=0.6749 B=0.602	X			X	X	**8/11/2008**		Tony Bromley	New Zealand
483	3755	**1/28/2008**	440, 500, 675, 870, 936	A=0.6928 B=0.604	X			X	X	**3/3/2008**	3/10/2008	Pierre Larouche	Quebec, Canada
484	3759	**7/25/2008**	340, 440, 675, 870, 936	A=0.6928 B=0.602	X			X	X				GSFC
485	3766	**7/1/2008**	440, 500, 675, 870, 936	A=0.6928 B=0.604	X			X	X				GSFC
486	3767	**12/3/2007**	440, 500, 675, 870, 936	A=0.6928 B=0.604	X			X	X	**12/26/2007**	1/3/2008	Zhanqing Li	China
487	3771	**7/7/2008**	440, 500, 675, 870, 936	A=0.6928 B=0.604	X			X	X				GSFC
488	3774	**6/6/2008**	440, 500, 675, 870, 936	A=0.6928 B=0.604	X			X	X	**6/25/2008**	7/3/2008	Giuseppe Zibordi	Gulf of Bothnia
489	3775	**5/28/2008**	440, 500, 675, 870, 936	A=0.6928 B=0.604	X			X	X	**6/25/2008**	7/6/2008	Andrey Proshutinsky	Beaufort Sea
490	3769	**3/4/2008**	440, 500, 675, 870, 936	A=0.6928 B=0.604	X		X	X	X	**5/14/2008**	6/24/2008	George Tolkachenko	Sevastopol, Ukraine
501	4080	**6/6/2008**	380, 400, 500, 675, 870		X			X	X	**7/3/2008**	7/7/2008	Patricia Quinn	Seattle, WA
502	3803	**6/6/2008**	380, 400, 500, 675, 870		X			X	X	**7/3/2008**	7/7/2008	Patricia Quinn	Seattle, WA
503	3763	**7/25/2008**	340, 440, 675, 870, 936	A=0.6928 B=0.604	X			X	X	**8/12/2008**	8/12/2008	Lorraine Remer	GSFC
507	4079	**7/22/2008**	380, 400, 500, 675, 870		X			X	X	**8/12/2008**		Ken Voss	Miami, FL
508	7388	**7/28/2008**	500, 675, 870, 936, 1020	A=0.6548 B=0.574	X			X	X			Arnon Karnieli	GSFC
509	12601	**8/11/2008**	440, 500, 675, 870, 1020		X							Giuseppe Zibordi	GSFC

Figure 7

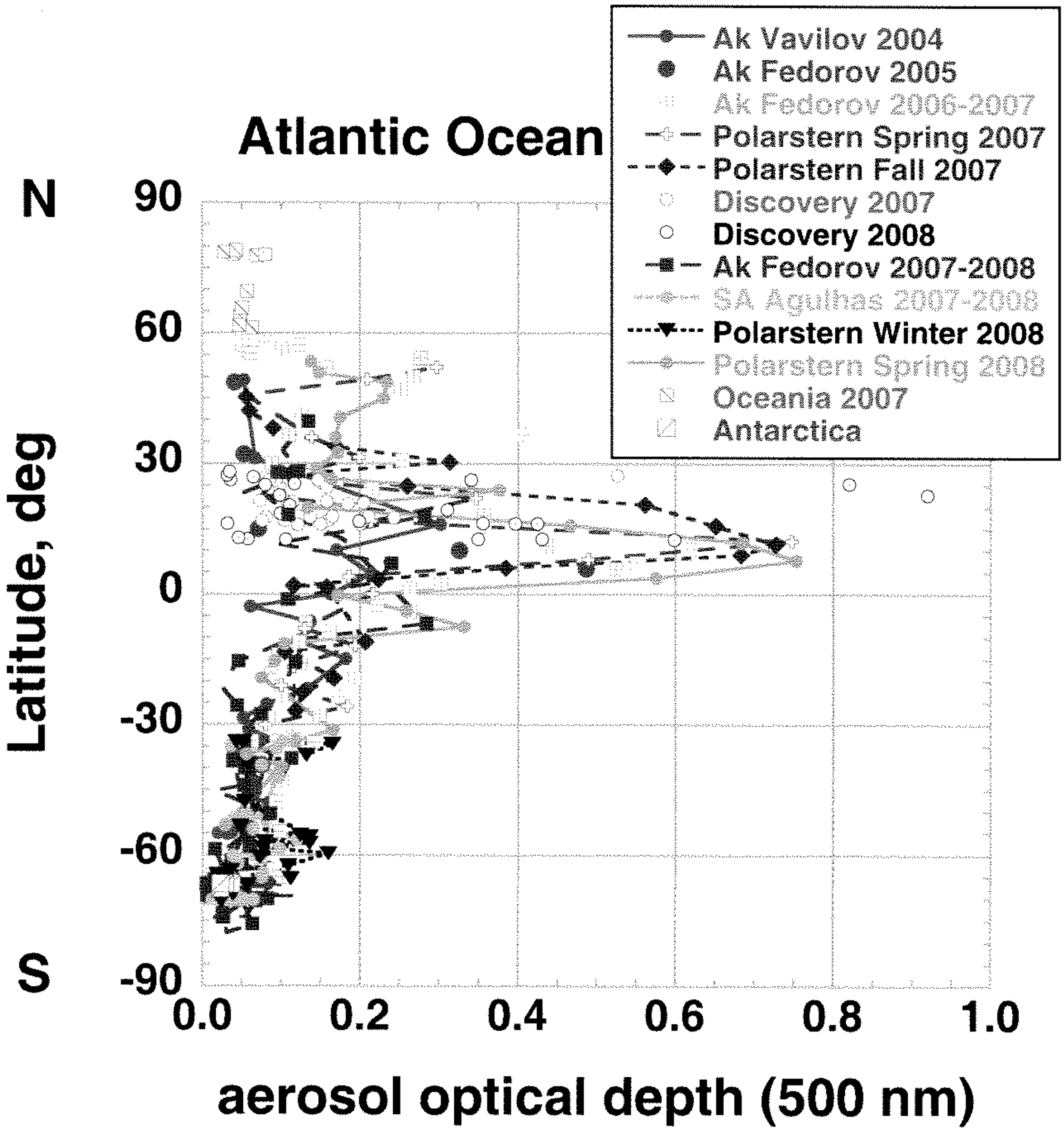
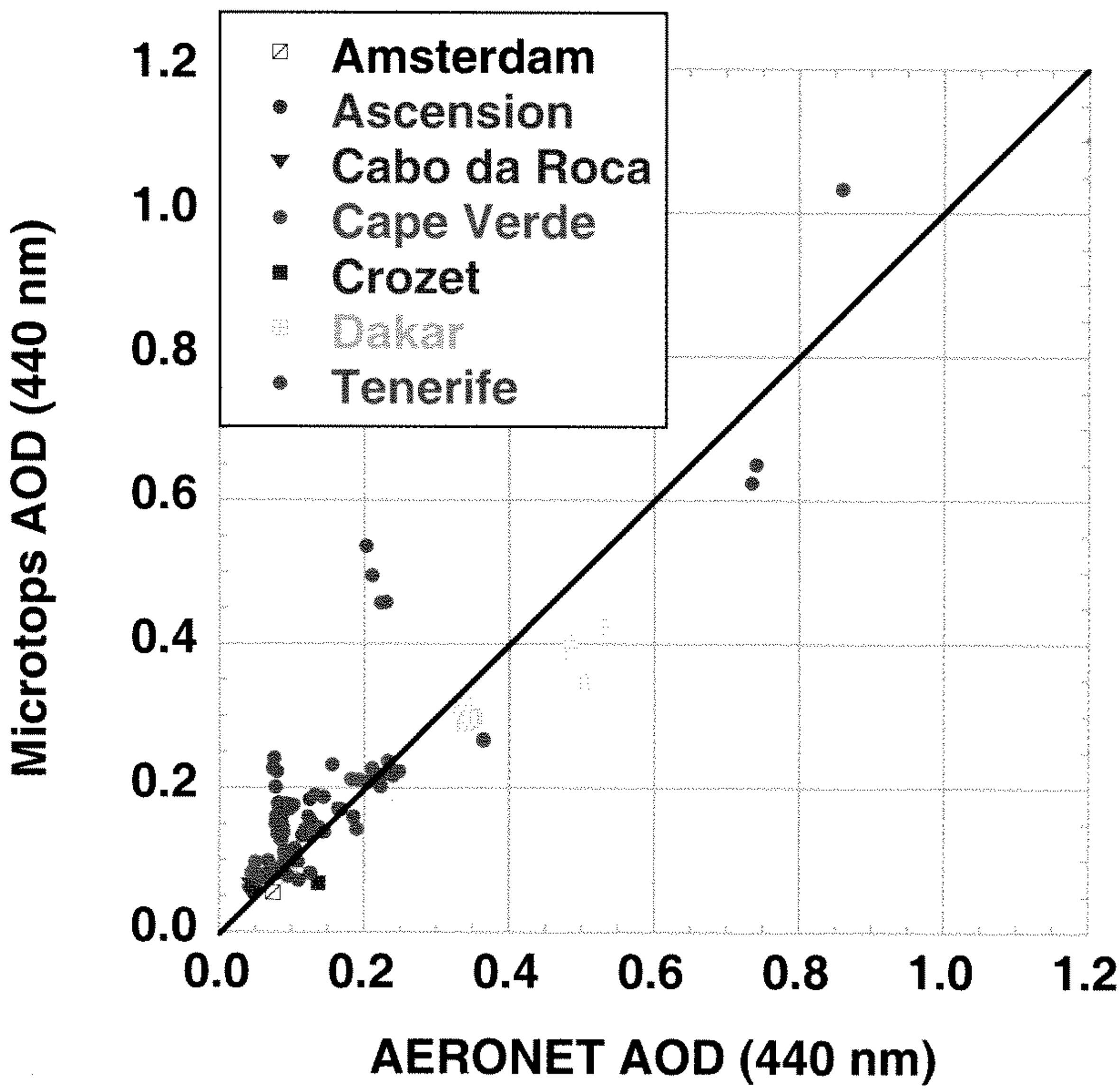

Atlantic Ocean
Ak Vavilov 2004
Ak Fedorov 2005
Ak Fedorov 2006-2007
Polarstern Spring 2007
Polarstern Fall 2007
Discovery 2007
Discovery 2008
Ak Fedorov 2007-2008
SA Agulhas 2007-2008
Polarstern Winter 2008
Polarstern Spring 2008
Oceania 2007
Antarctica
N
S
90
60
30
0
-30
-60
-90
Latitude, deg
0.0
0.2
0.4
0.6
0.8
1.0
aerosol optical depth (500 nm)

Figure 9



Amsterdam
Ascension
Cabo da Roca
Cape Verde
Crozet
Dakar
Tenerife
Microtops AOD (440 nm)
AERONET AOD (440 nm)
0.0
0.2
0.4
0.6
0.8
1.0
1.2