Global Aerosol Products Assessment (GAPA)

[Report from the GAPA Working Group (GWG) of the GEWEX Radiation Panel]

Zhanqing Li/Tom Zhao

- **1st GWG meeting, Sept. 14-15 at UMCP, USA**

Goals:

- **Form new GAPA working group (GWG).**
- **Set up objectives for the aerosol assessment.**
- **Review major global satellite aerosol products.**
- **Identify key issues in satellite aerosol retrievals.**
- **Develop strategies for identifying major discrepancies among the aerosol products.**
- **Discuss the roadmap for reconciling the differences and for generating unified consistent global aerosol products.**

Workshop Participants (20)

First row from left: A. Higurashi (NIES, Japan), C. Hsu (GSFC/NASA), L. Remer (GSFC/NASA), M. Chin (GSFC/NASA), O. Torres (UMD/NASA); Central row from left: R. Kahn (JPL/NASA), D. Diner (JPL/NASA), M. Wang (NOAA/STAR), I. Laszlo (NOAA/STAR), D. Winker (LaRC/NASA), Z. Obradovic (Temple University),; last row: H. Maring (HQ/NASA), B. Holben (GSFC/NASA), S. Vucetic (Temple University), Z. Li (UMD), S. Tsay (GSFC/NASA), C. Ichoku (UMD/NASA), T. Zhao (CICS/UMD & NOAA/STAR), M. Schulz (CEA, France), M. Mishchenko (GISS/NASA)

Major Topics of the Presentations

- Updates of various satellite products (AVHRR-GACP, -PATMOS, -NIES, TOMS, SeaWiFS, MODIS, MODIS-Deep Blue, MISR, CALIPSO) and detailed descriptions of the retrieval procedures.
- Evaluation of the satellite aerosol products through intercomparisons and surface validations.
- Long-term trend analysis.
- Update of the AERONET products that will be used actively in our assessment.
- New features in more advanced CALIPSO measurement and benefit for improving satellite aerosol retrievals.
- New aerosol model results and their intercomparisons
- Potential data mining application in the synergy of satellite aerosol products.

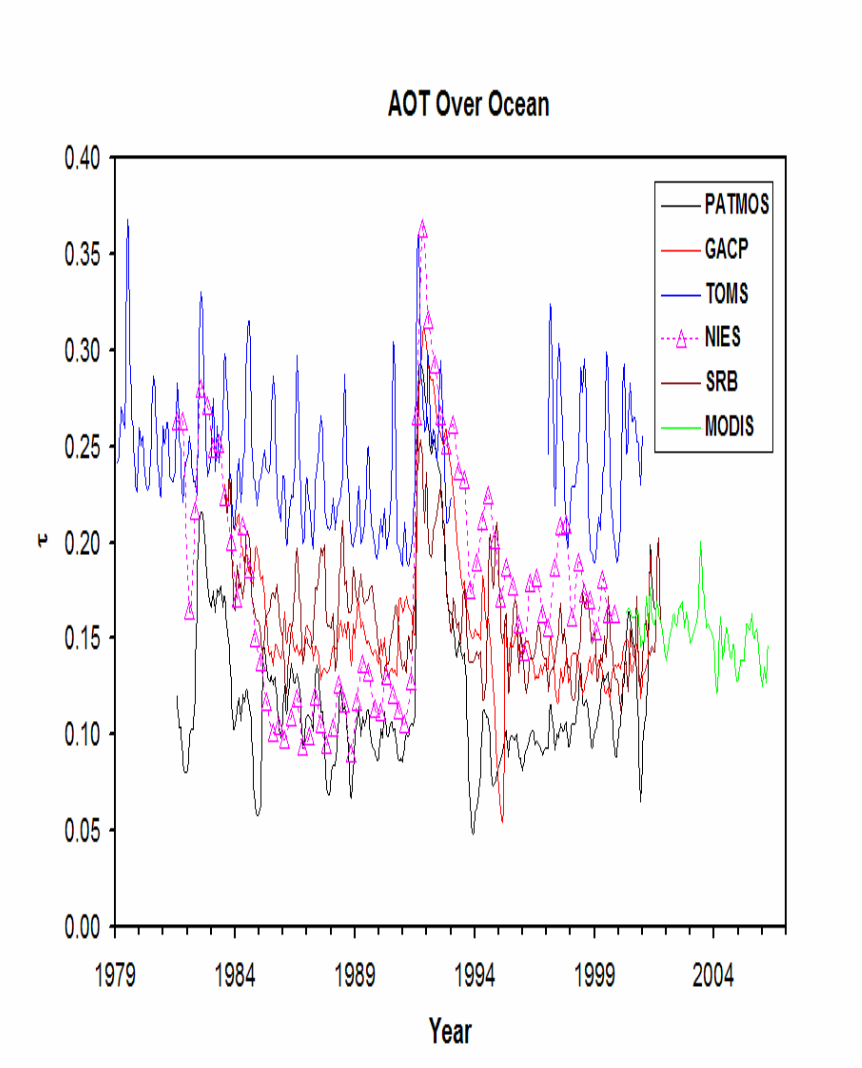
New GAPA Working Group (GWG)

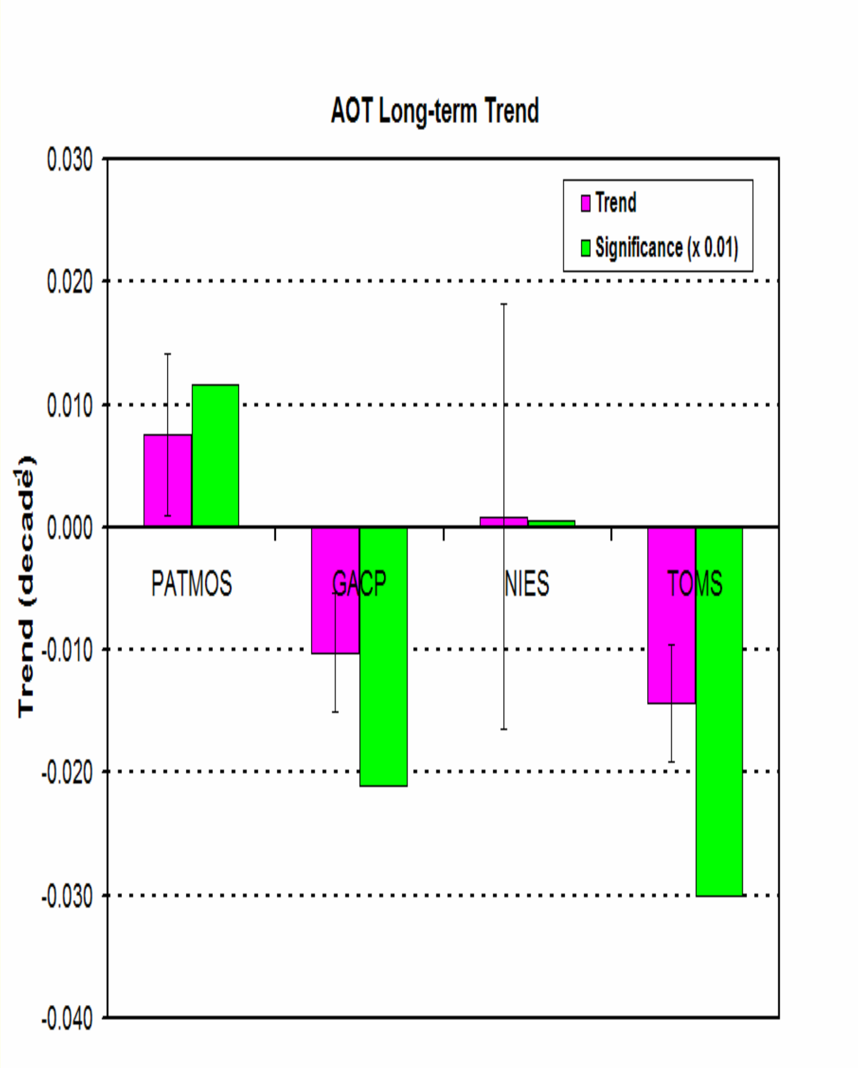
- 19 Members
- 9 Satellite Aerosol Groups
  - AVHRR (GACP, NIES, PATMOS), CALIPSO, MISR, MODIS, MODIS-Deep Blue, SeaWiFS, and TOMS
  - Missing ATSR2 and POLDER groups
- Two Surface Observation Groups
  - AERONET and SMART
- Two Modeling Groups
  - AeroCom and GOCART
- NASA, NOAA, Universities
- Japan, Europe, USA

New GWG - Administrative Consideration

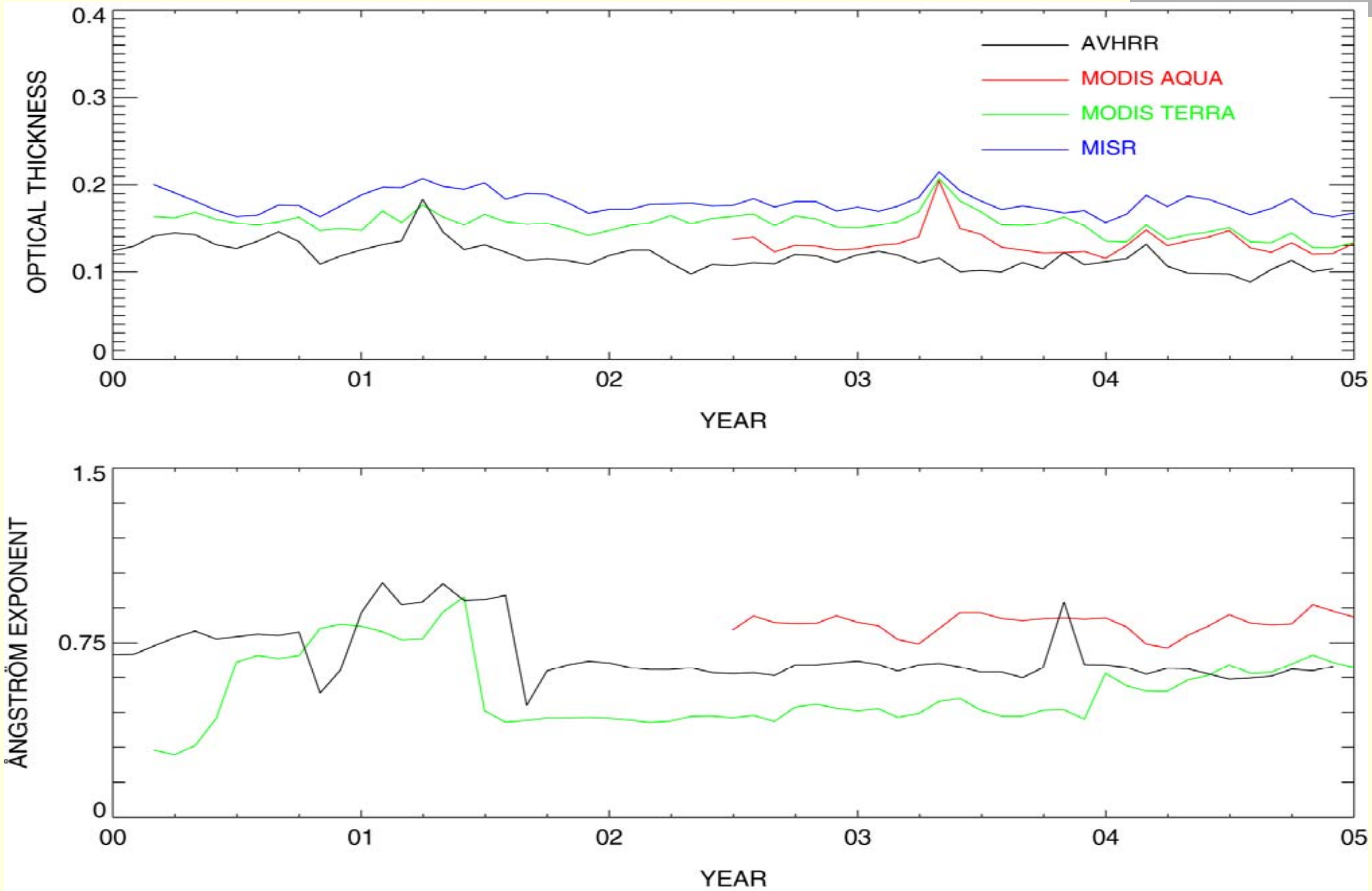
- 7 Subgroups
  - Calibration (T. Zhao/R. Kahn), Cloud Screening (Z. Li), Aerosol Model (Z. Li), Surface Effect (Ocean- M. Wang; Land – B. Holben), Algorithm (I. Laszlo/L. Remer), Validation (C. Ichoku/R. Kahn), Synergy (Z. Li/Z. Obradovic).
  - Responsible for writing the report for individual sections.
- Co-chairs of GWG (Z. Li/T. Zhao)
  - Coordinate assessment work and prepare report.
  - Organize workshop and teleconferences.
  - Set-up and maintain aerosol assessment web site at UMCP.
    - http://www.atmos.umd.edu/~zli/GAPA/gapa_main.htm

Why Coordinated Assessment?





Comparison of AVHRR (GACP) with MODIS and MISR



(by courtesy of Dr. Mishchenko)

Historical AOT Data Source, Platform and Method

Source	Platform	Resolution (degrees)	Method ($\lambda_{reference}$ (nm))	Contact
GACP	AVHRR	1.0x1.0	two-channel (550)	Mishchenko and Geogdzhayev
SRB	AVHRR + geo-sats.	2.5x2.5	broadband (550)	Laszlo
NIES*	AVHRR	0.5x0.5	two-channel (500)	Higurashi and Nakajima
PATMOS & -X	AVHRR AVHRR	1.0x1.0 0.5x0.5	one-channel (630)	NOAA/NESDIS Heidinger
GSFC	TOMS	1.0x1.0	two-channel (550)	Torres

***National Institute for Environmental Studies, Tsukuba, Japan. Data are available only for January, April, July and October.**

Three Objectives

- Use current data sets to assess and improve confidence level in the 30-years satellite aerosol climatology of aerosol optical depth (AOD or τ) and Angström exponent (AE or α) from the AVHRR and TOMS observations.

- Understand and resolve discrepancies among all major global satellite aerosol products and help document uncertainties.

- Produce improved, consistent, and unified global aerosol products that link historical, current, and future satellite observations for long-term trend analysis and climate studies.

Identified Aerosol Parameters for Assessment

- τ(550nm) and α for the Objectives 1-3.
- Fine/Coarse Fraction of τ and Single Scattering Albedo (ω) for the Objectives 2-3.
- Fraction τ of spherical particles for the Objectives 2-3.

Strategies

- **Validation, evaluation, and improvement of individual satellite aerosol retrieval algorithms and products by the developers.**
  - Has mostly been done for the AVHRR, TOMS, MODIS, and MISR aerosol products.
  - Encourage some evaluations of more sophisticated instruments (e.g., MISR) with well defined field campaigns.
- **Cross-comparison and evaluation of multiple products by third parties.**
  - Strongly encouraged.
  - Welcome the participation of satellite aerosol data producers.
- **Well-planned and coordinated efforts to tackle various common issues (calibration, cloud screening, aerosol model assumptions, surface treatment, and synergy)**
  - The 1st major task that this GWG should pursue.
  - Start from merging studies of individual product groups.
- **Development and application of "integrated algorithm" to "multiple sensors data" to generate unified product with optimized accuracies.**
  - The ultimate goal of the aerosol assessment of this GWG.

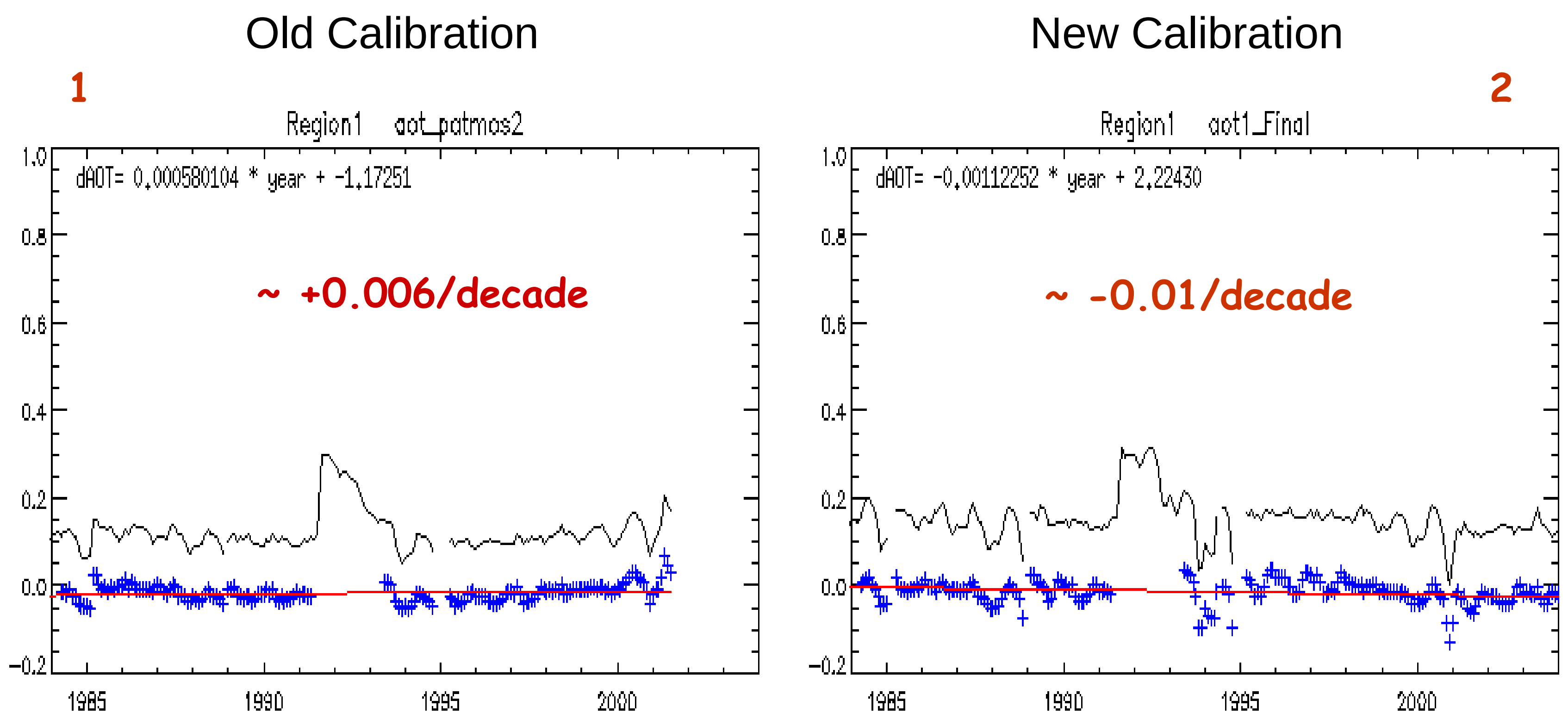
Five Key Issues

- Calibration
- Cloud screening
- Aerosol model selection
- Surface treatment
- Data synergy

Issue/Approach-Calibration

- **Requirements: <3% radiometric accuracy and 1% relative spectral accuracy; Stability should be 50% smaller than the accuracy requirement over a decade.**
- **Extra calibration efforts are needed for old instruments (AVHRR & TOMS).**
- **Careful refinement is needed for current instruments (MODIS, MISR, SeaWiFS).**
- **Suggested approach:**
  - **Close collaboration between calibration teams and aerosol product teams.**
  - **Cross comparison and cross calibration (SeaWiFS as the reference).**
  - **Product level calibration (e.g., low-light-level AOD, surface albedo).**
  - **Using surrogate calibration sites specifically identified for aerosol studies.**

Effect of Calibration on the Global AOT Long-term Trend
(AVHRR PATMOS)



The sign of the trend changes from positive (+0.006/decade) to negative (-0.01/decade) after SNOs calibration was applied.

Table 1. Summary for the calibration approach, accuracy, and precision of existing satellite aerosol instruments.

Instrument	Method	Note
ATSR2	On-board, intersatellite (??? accuracy, ??? precision)	
AVHRR-GACP	Pre-launch, ISCCP post-launch using deep convective clouds (accuracy unknown???, to be calibrated against MISR/MODIS, ~1% precision)	
AVHRR-NIES	Vicarious, Surface Direct Radiation (~3-5% accuracy, ??? precision)	Tropical Convective Cloud
AVHRR-PATMOS	Vicarious, Intersatellite (accuracy ~3-5% absolute, precision ~1%)	Libyan desert & SNOs
CALIPSO	532 nm parallel channel calibrated against mid-stratosphere molecular scattering (3-5% accuracy). Perpendicular/parallel 0.5% uncertainty. 1064 nm vicarious (5% accuracy)	
MISR	On-board, vicarious, lunar (~3% absolute; 1-2% channel-to-channel relative; 1% precision)	
MODIS	On-board, vicarious, lunar (~2% absolute, ???% precision)	Solar Diffuser
POLDER	Vicarious, intersatellite (~2% absolute, 1% inter-band, ???% precision)	
SeaWiFS/MODIS ocean	On-board, Vicarious, Lunar, comparison with in situ. (accuracy at 865nm ~+0.3%; band-to-band relative < 0.5%; precision ~0.3%)	
TOMS	Vicarious using ice and clouds (~2% accuracy, ~0.5% precision)	

Issue/Approach-Cloud Screening

- The source of largest uncertainties in AOD retrieval.
- Cloud boundary is an issue. More studies are needed
- Suggested approach:
  - Individual scene comparisons (ensemble statistics for clear, cloudy, partial cloudy, etc).
  - Examining the seasonality (see Jan., April, July, Oct., 2005) of the PDFs of radiances used in the aerosol retrievals.
  - Performing satellite-ground comparison by using ground-truth (such as total sky imager, time series of radiometric measurements, etc.)
  - Careful assessment of cloud-screening limitations under different natural conditions in consideration of instrument features.
  - Develop multiple-sensor cloud screening for the further improvement of cloud screening schemes.
  - Use CALIPSO to study aerosol-cloud continuum to address the cloud-boundary issue and study proper separation of aerosol and cloud.

Table 2. Summary of cloud screening schemes for the satellite aerosol retrievals.

Instrument	Method	Note
ATSR2	1x1km combined Vis/IR thresholds???	Kriebel et al., (1989 and 2003)
AVHRR-GACP	Modified ISCCP Cloud Detection Scheme based on the thermal IR channels	Mishchenko et al. (1999)
AVHRR-NIES	Thresholds of Ch-1 reflectance, Ch-4 BT, and spatial correlation	Higurashi et al. (2000)
AVHRR-PATMOS	CLAVR & CLAVR-X	Stowe et al. (1999) & Heidinger (ATBD, 2004)
CALIPSO	Signal thresholds and spectral ratios; clouds identified	Liu et al. (2004)
MISR	Multi-angle-based: Radiative camera-to-camera & stereo-derived cloud masks + angular smoothness and spatial correlation tests.	DiGirolamo et al (2003); Martonchik et al (2002); Diner et al (in preparation)
MODIS	Spatial variability at 0.67 micron over ocean, 0.46 & 1.38 μm over land; IR 1.38μm test for cirrus.	Martins et al. (2002) Remer et al. (2005)
MODIS Deep Blue	Spatial variability at 412 nm + aerosol index	Hsu et al. (2004) IEEE
POLDER	???	???
SeaWiFS/MODIS	Threshold of Rayleigh-corrected 0.865μm reflectance	Robinson et al. (2003) Wang and Shi (2006)
TOMS/OMI	Threshold of 0.36μm reflectance + TOMS AI Information	Torres et al. (2002)

Issue/Approach- Aerosol Model Assumptions

- **Aerosol model parameters need to be assumed, especially for old satellite instruments (AVHRR & TOMS), which produces large errors.**
- **Simple sensitivity tests by varying aerosol parameters are not sufficient.**
- **Suggested Approach:**
  - Each aerosol retrieval groups provide standalone version of their algorithm if feasible.
  - Alternation in the use of algorithm and input datasets (e.g., applying GACP algorithm to MODIS radiances)
  - Using observed quantities as much as possible to replace the assumed quantities (e.g., size distribution).
  - Algorithms by using multiple sensors should be explored and developed for the reduction of assumed quantities (e.g., Dubovik code).
  - Common data sets, including satellite simulators (such as RSP), ground, and airborne in situ measurements, need to be developed for testing and improving the new algorithms.

Table 3. Summary of aerosol models and instrument channels and angles used for satellite aerosol retrievals.

Instrument	Aerosol Model	Channels Used
ATSR2	External mixing of 6 basic components from OPAC (Hess et al., 1998)	2-Chs (658, 864nm)
AVHRR-GACP	Modified Power-law, n=1.5-0.003i fixed	Dependent 2-Chs
AVHRR-NIES	Bi-modal Log-N, n=1.5-0.005i	Dependent 2-Chs
AVHRR-PATMOS	Bi-modal Log-N, n=1.45-0.003i & 1.45-0.007i	Independent 2-Chs
CALIPSO	For BL aerosols, identify lidar ratio to convert to AOD; for elevated aerosols, use transmission	2-Chs (532, 1064nm) Lidar
MISR	Log-N; mixtures of up to 3 components, including non-spherical dust	9-angles x 2 spectral Chs over water (672, 867nm); 4-Chs over land
MODIS ocean	Bi-modal Log-N, 4 fine modes & 5 coarse modes. nr=1.36-1.53, ni=0-0.005	6 channels (ocean)
MODIS land	Multimodal Log-N models set by geography and season; identification of dust imposes special model.	3-Chs (land)
MODIS Deep Blue	Log-N distribution + empirical spectrally independent phase function for dust	412, 470, 650 nm
POLDER	???	???
SeaWiFS/MODIS	Bi-modal Log-N, SSA from 0.93-1.0 at 865nm	2-Chs (765, 865nm)/(748, 869nm)
TOMS	Bimodal Log-N, 3 Types, 21 aerosol models based on AERONET statistics	2-Chs (331, 360nm) Report at 380nm & 500 nm

Issue/Approach-Surface Treatment

- **Removal of surface effect, especially for turbulent ocean surfaces and bright land surfaces is a key to satellite aerosol retrievals (except MISR approach).**
- **Suggested approach:**
  - **For ocean, focus on the study of the uncertainties associated with wind speed, variable water-leaving reflectance, coastal problem, sun-glint effect, whitecap treatment (magnitude and spectral dependence).**
  - **For land, detailed comparison and assessment for the retrievals based on ratio approach (MODIS), clearest composite (Deep Blue and TOMS), and multi-angle (MISR) and polarization (POLDER).**
  - **Compare higher spatial resolution AOD retrieval (e.g., LandSAT) with low resolution AOD products.**
  - **Development of high resolution (including BRDF) surface spectral albedo data around all AERONET sites for validation use.**
  - **Pursue the studies of using multiple sensor data to minimize the sensitivity of aerosol retrieval to surface reflectance.**

Table 4. Summary of surface treatment for the major aerosol retrieval algorithms.

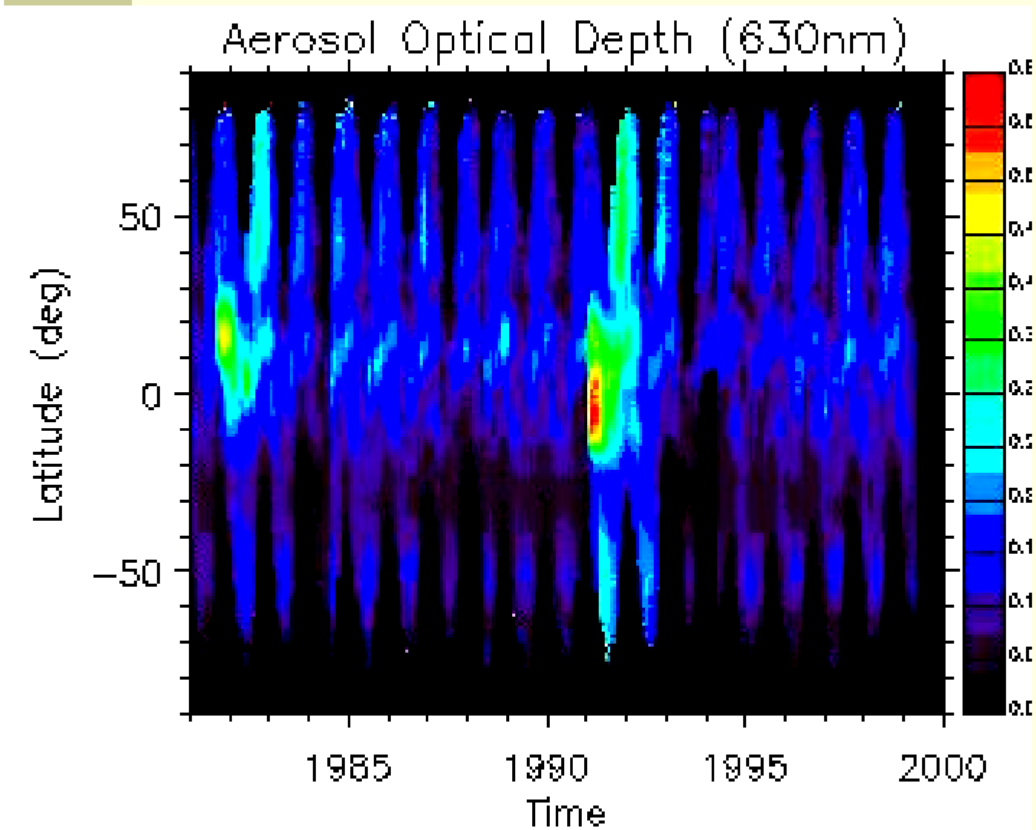
Instrument	Method	Note
ATSR2	????	???
AVHRR-GACP	Bi-Directional (Cox-Munk with variable wind speed taken from assimilation)	+ small Lambertian component
AVHRR-NIES	Bi-Directional (Nakajima and Tanaka[1983]) with variable wind speed taken from NCEP reanalysis	+ small Lambertian component
AVHRR-PATMOS	Bi-Directional (Cox-Munk) with fixed wind speed	+ small Lambertian component
CALIPSO	N/A	surface characteristics don't directly affect retrievals
MISR	Bi-Directional (Cox-Munk + whitecap over Ocean parameterized as fun. of wind speed; Spectrally invariant surface angular shapes plus empirically derived bidirectional reflectances from the data)	Lambertian spectral water-leaving reflectance retrieval being developed
MODIS	Bi-Directional (Cox-Munk) –Ocean Dark Pixel –Land assuming spectral ratios	+ small Lambertian component over ocean
MODIS Deep Blue	Minimum reflectivity binned by viewing geometry	
POLDER	????	????
SeaWiFS/MODIS	Bi-Directional (Cox-Munk) + whitecaps driven by wind speed	+corrections to account for ocean contributions at 765nm & 865nm
TOMS	Aerosol-corrected TOMS Climatology of minimum lambertian reflectance	
AERONET	Uses MODIS-generated surface albedos modified by NCEP snow/ice	

Issue/Approach-Synergy

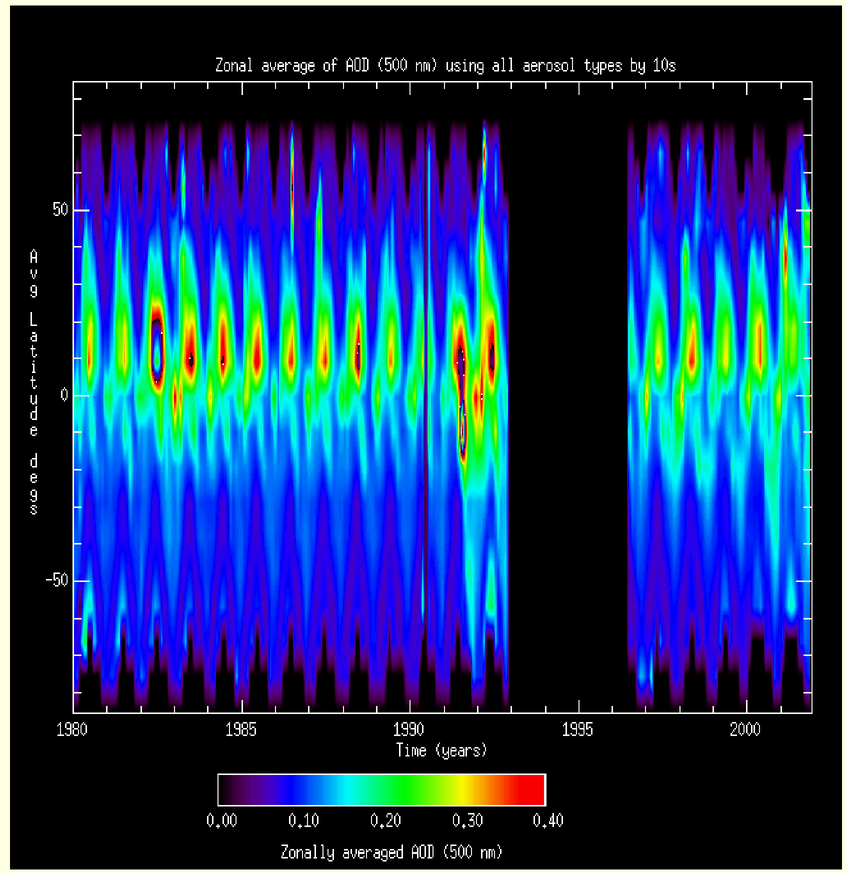
- **Different aerosol retrieval algorithms have their limitations and advantages.**
- **Synergy exploration should be pursued for a practical solution on producing unified global aerosol products for long-term trend analysis and climate studies.**
- **Suggested approach:**
  - RTM capable of simulating all useful sensors should be developed or adopted from the project of A-train for forward simulations of multi-sensor measurements.
  - Multi-sensor retrieval algorithm should be developed from combination of the observation from different sensors and tested and refined using the simulated data. Results should compare with that from single-sensor retrieval to examine the benefit of synergy.
  - Deterministic approaches will be compared to machine learning approaches (e.g., data mining, statistical), even to simple merging approach (e.g., data assimilation). The results will be compared with each other as well as with sub-orbital observations for the evaluation and for the final selection of the synergy approach.
  - the observations from the radiometers of AVHRR (historical), MODIS (current), and VIIRS (future) are more comparable than other instruments and can span a time of period of more than 50 years together. The synergy exploration should be based on these three observations. The observations from other instruments will be incorporated to refine and improve the information contents of these three basic observations.

Historical Aerosol Data-Long Time Record

AVHRR-PATMOS

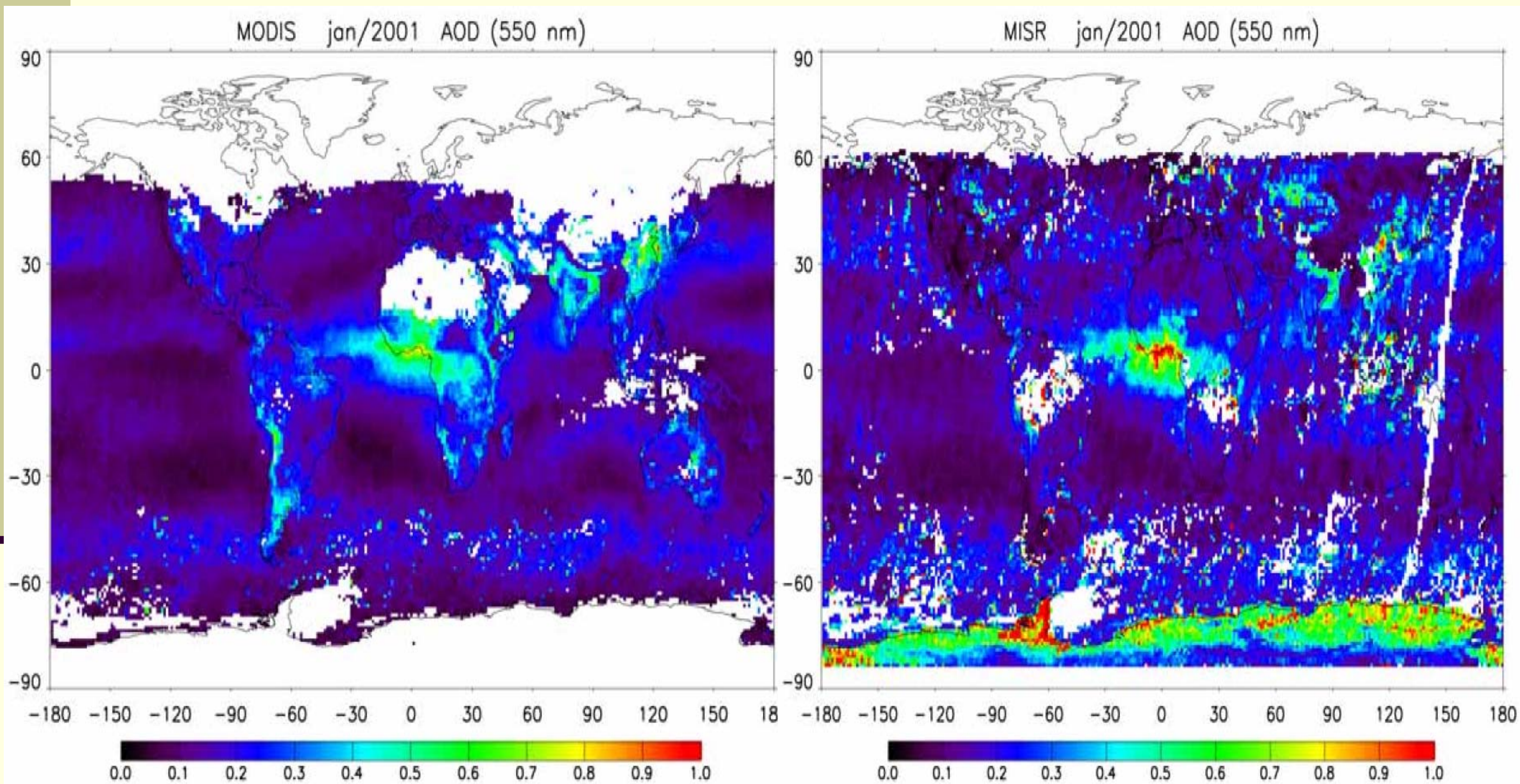


TOMS-V.2



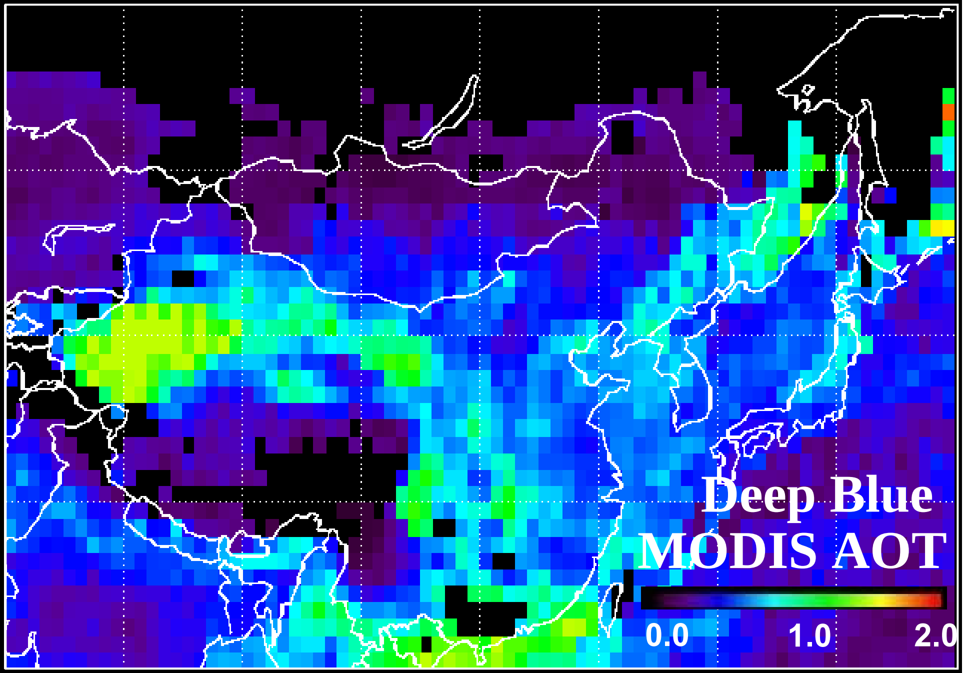
AOD(500nm)

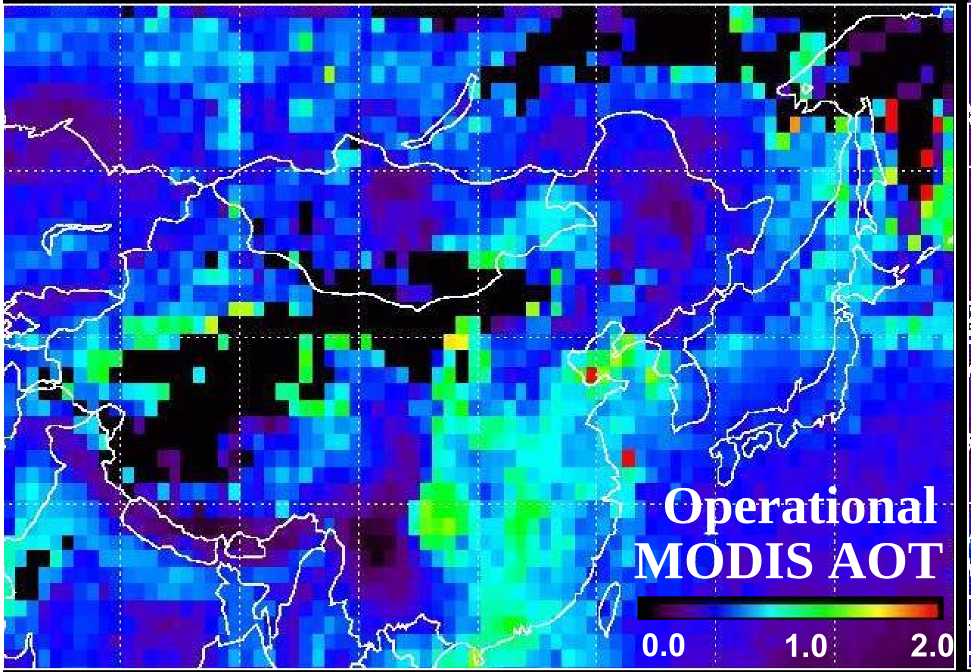
Current Aerosol Data-Better Coverage & Accuracy

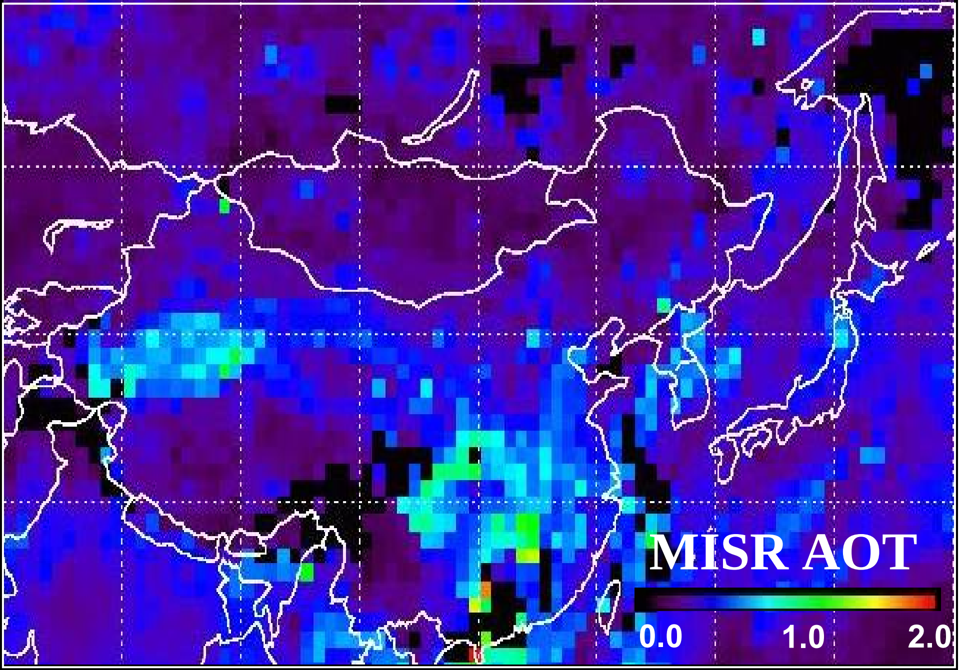


Intercomparisons of April 2001 Monthly Mean AOT Over East Asia

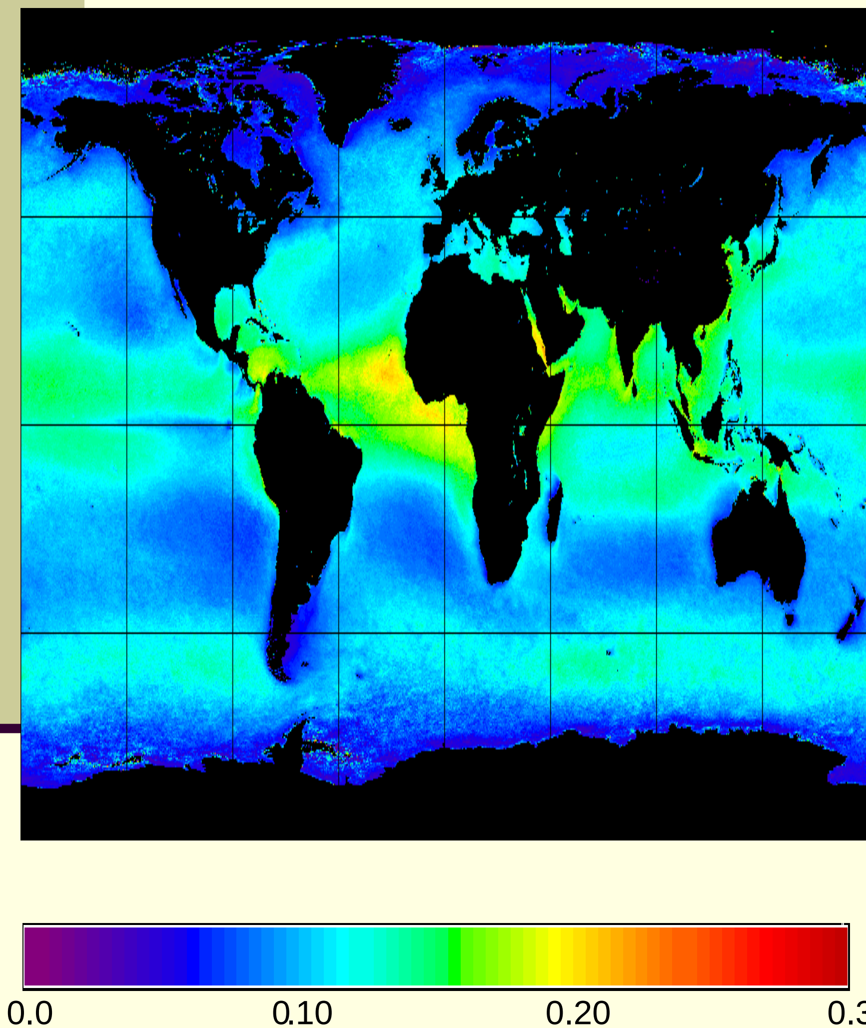
- ***Large Daily Variability in AOT***
- ***Frequent Presences of Clouds***



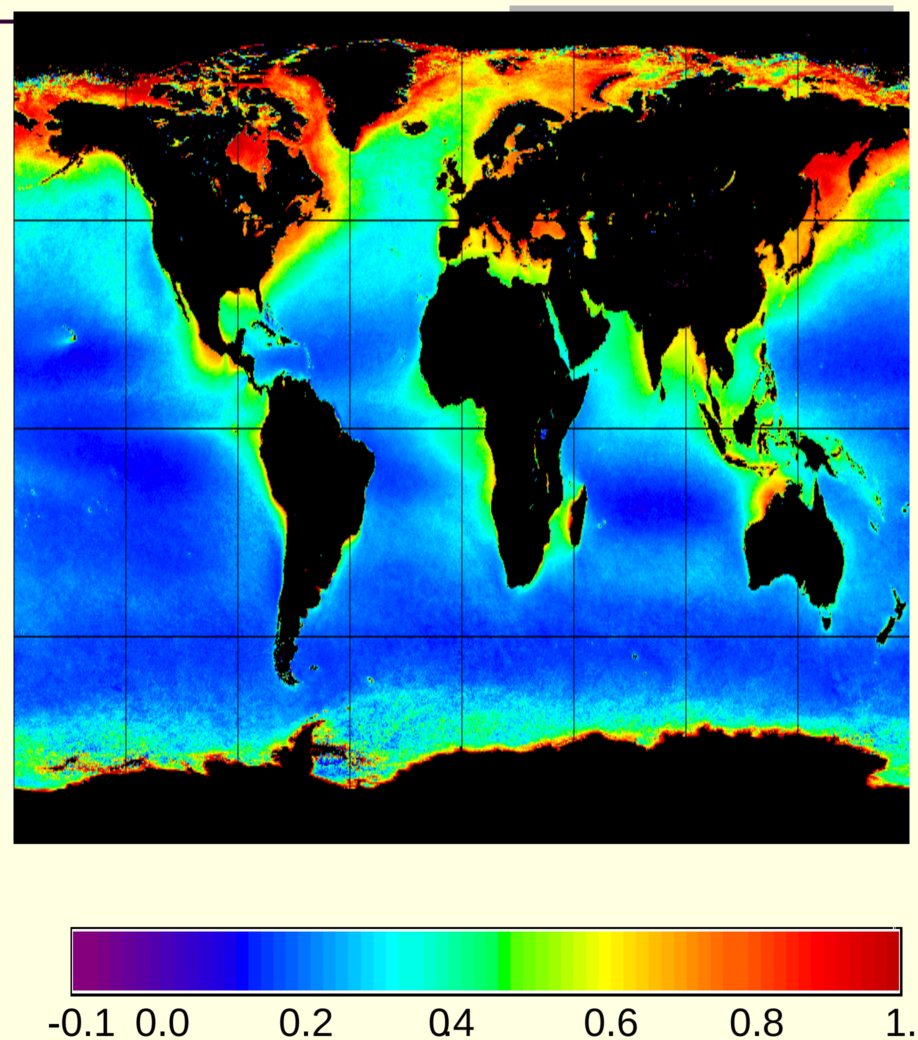




SeaWiFS Aerosol Optical Thickness
(October 1997-December 2003)
τ(865nm)

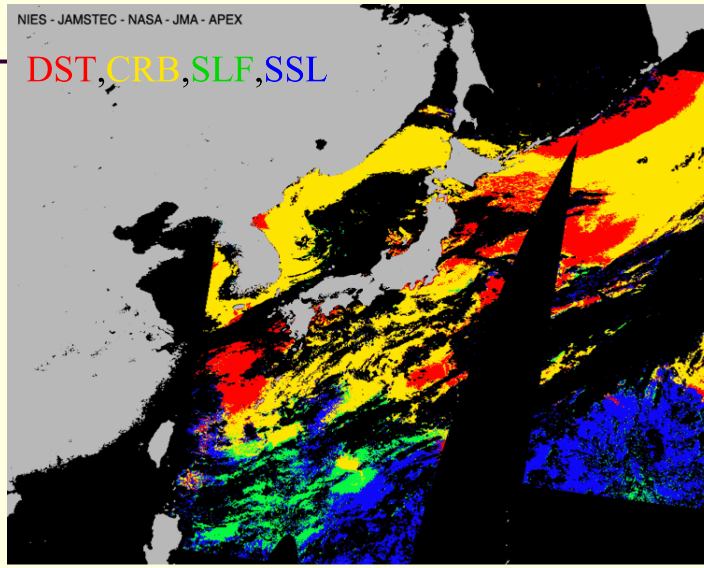


SeaWiFS Ångström Exponent
(October 1997-December 2003)
α(510,865)



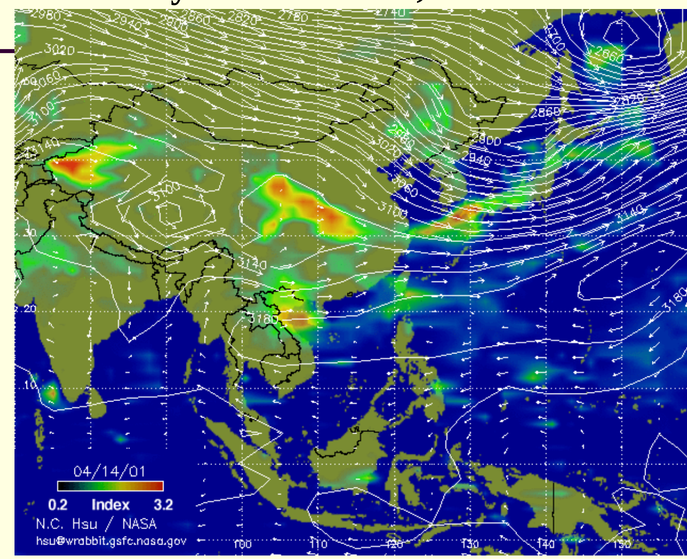
GLI Retrieval - Aerosol Types (April 14, 2001)

Aerosol Types



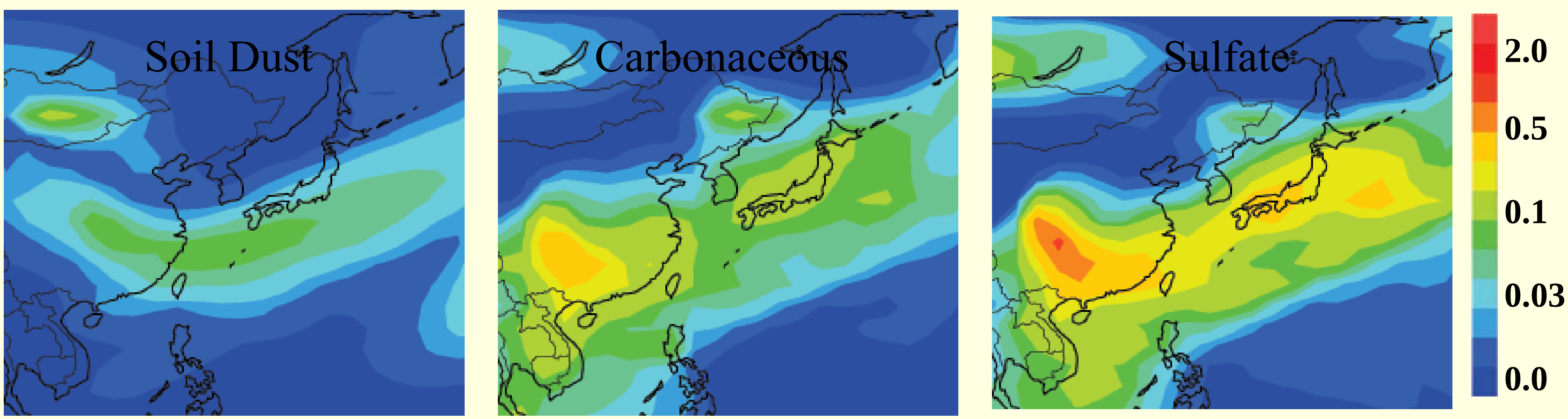
TOMS Aerosol Index

by Dr. N. C. Hsu, NASA



SPRINTARS simulated aerosol optical thickness

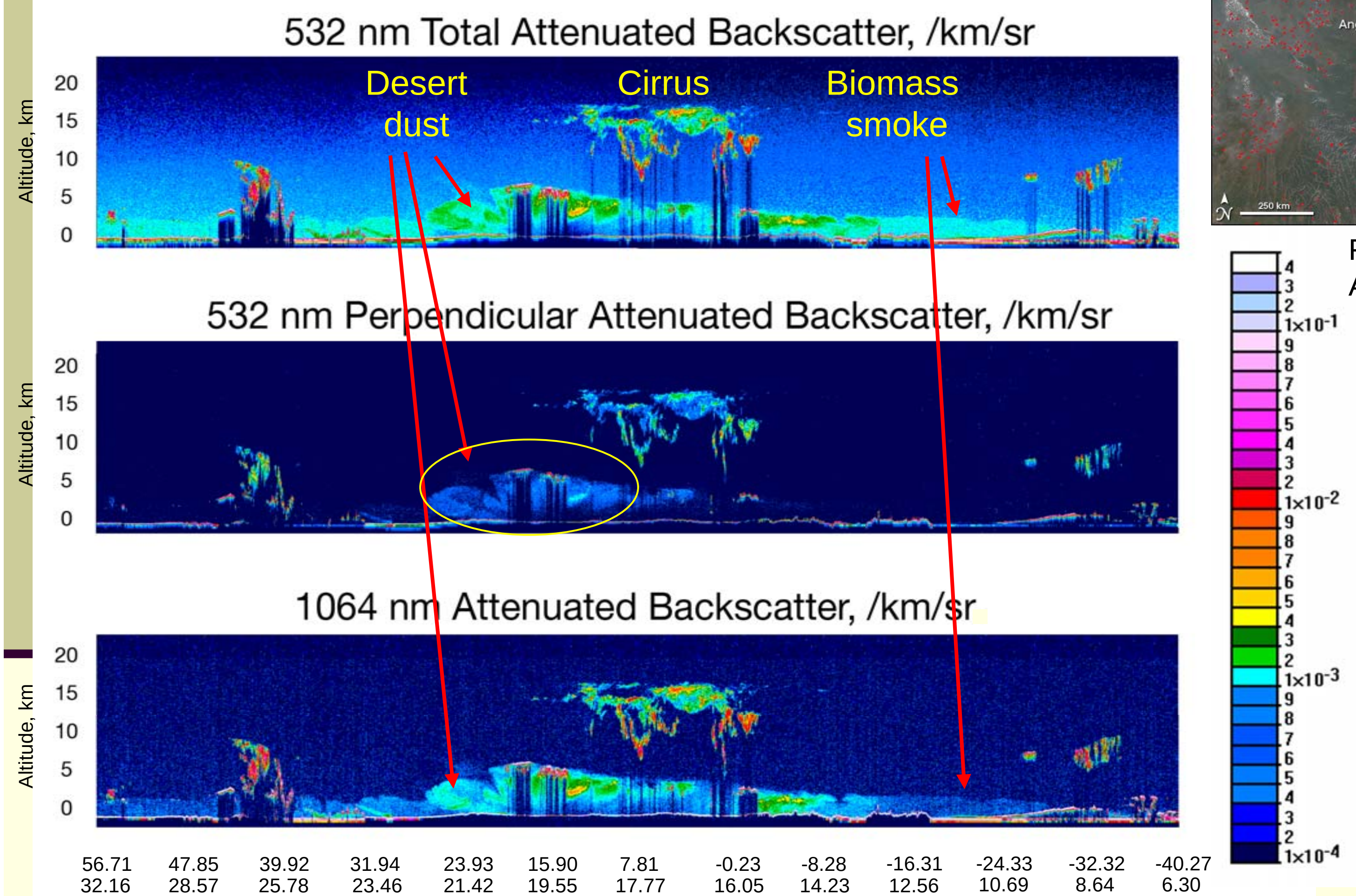
by Dr. Takemura, RIAM / Kyushu Univ.

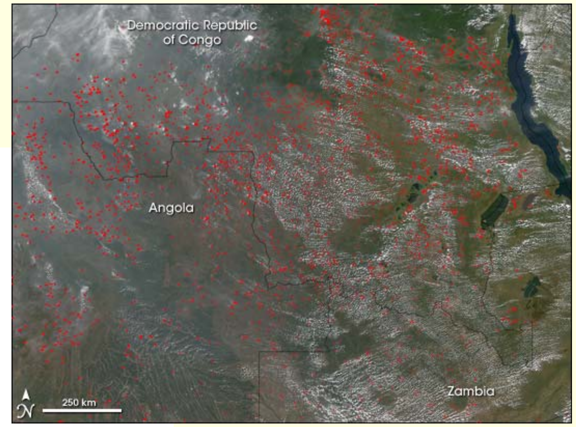


CALIPSO First-Light Observations

All 3 Lidar Channels

9 June 2006





Fire locations in southern Africa from MODIS, 6/10/06

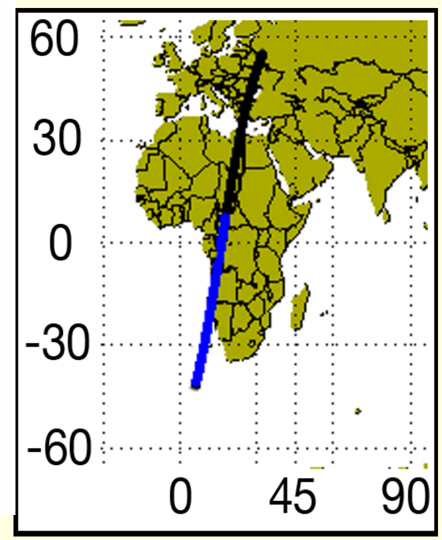


Table 5. Outline of limitations and attractions of major satellite aerosol retrieval algorithms.

Instrument	Limitations (for monthly mean products)	Attractions
ATSR2	???	???
AVHRR-GACP	no on-board cali., Cutoff AOT of 1.5, ocean only, only 2 channels	30 year record
AVHRR-NIES	no on-board cali., ocean only	20 year record, portable to other sensors for intercomparison.
AVHRR-PATMOS	no on-board cali., Fixed aerosol model, ocean only	25 year record, simple, easily adopted to other sensors for intercomparison.
CALIPSO	Sparse global coverage	Vertical profile, better cloud detection, day and night. High sensitivity.
MISR	Small swath-width results in ~weekly revisits	All surfaces and better surface treatment, aerosol types. Good calibration, stable.
MODIS	no retrieval over bright surface, except for **Deep Blue Algorithm**	Aerosol type parameters retrieved, high spatial and temporal resolutions. Global covg. every 2 days Good calibration. Compatible with future NPOESS/VIIRS and past AVHRR Anchor sensor for long-term data.
POLDER	???	Polarization???
SeaWiFS/MODIS	Cutoff AOT of ~0.3-0.4 at 865nm, ocean only	Stable and high accuracy in calibration, > 9-years records
TOMS	Large pixel size results in cloud screening difficulty.	Land and ocean, aerosol absorption. 25-year record.

Additional Suggestions and Comments

- Common validation data sets (e.g., AERONET, airborne, etc.), common assumptions (e.g., size distribution, refractive index, etc.), and common input data (e.g., cloud screened radiances, surface albedo, etc.) should be used as much as possible for testing and cross comparisons.
- Some issues also need to be specifically attended: 1) sampling differences, 2) spectral conversion, 3) co-location in space and time and footprint mismatches, and 4) new observation requirements.
- Invite the participations of POLDER and ATSR2 aerosol groups as the members of GWG.
- Invite the participation of radiation (such as CERES) and land groups in the future GWG workshops.