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A Summary of First Year Activities of the United Arab Emirates Unified Aerosol Experiment: UAE2

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‡National Center for Atmospheric Research, 3450 Mitchel Lane, Boulder, CO 80301 Greenbelt, MD 20771
*Climatology Research Group, University of the Witwatersrand, Private bag 3, Johannesburg, South Africa14. ABSTRACT
In August and September of 2004, scientists from two dozen international research organizations converged in the Arabian Gul
participate in the United Arab Emirates Unified Aerosol Experiment (UAE2). The four primary goals of the mission were to (a)
ground truth of a variety of environmental satellite and model products in this extremely complicated region of the world, (
assessment of the nature of aerosol particles in the Arabian Gulf, (c) determine the role of aerosol particles on the radiat
regions, and (d) understand how perturbations in the earth’s radiative balance can influence atmospheric flow patterns from
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reports from key investigators. Specific areas of intense interest include understanding the atmospheric flow patterns of So
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(MISR), the MODerate resolution Imaging Spectro-radiometer (MODIS), the Advanced Along Tract Scanning Radiometer (AATSR), an
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Part I: Mission Summary

1.0 Executive Summary:

In August and September of 2004 scientists from two dozen international research organizations converged in the Arabian Gulf region to participate in the United Arab Emirates Unified Aerosol Experiment (UAE2). The four primary goals of the mission were to a) provide the first ground truth of a variety of environmental satellite and model products in this extremely complicated region of the world, b) Perform the first assessment of the nature of aerosol particles in the Arabian Gulf c) Determine the role of aerosol particles on the radiative balance of desert regions, and d) Understand how perturbations in the earth’s radiative balance can influence atmospheric flow patterns from local to regional scales. In summary:

- Over 60 scientists from 8 countries and 24 institutions were involved.
- Fifteen satellite sensors, five models, two aircraft, and a multitude of ground stations were used.
- Twenty-one flights for over 80 hours were used to monitor the atmosphere and vertical distribution of pollution and dust.

Based on these measurements applied science research topics of importance to the United Arab Emirates have been advanced. The scientific community is now to the point where the UAE region can be evaluated and monitored with confidence, and approach significant fundamental research topics of significance to the region and world as a whole. This document presents a series of research topics that the UAE2 science team is currently analyzing. Research has essentially followed the primary goals above. Specific areas of intense interest include understanding the atmospheric flow patters of Southwest Asia using a suite of mesoscale and global models. The calibration/validation of specific satellite sensors such as the Multi-angle Imaging Spectro-radiometer (MISR) and the MODerate resolution Imaging Spectro-radiometer (MODIS), and the Advanced Very High Resolution Radiometer (AVHRR) was also very successful. Lastly, this mission has provided the very first complete study of the chemical, physical, and optical properties of pollution and dust particles in the United Arab Emirates.

This first year progress report is compiled for the UAE Ministry of Presidential Affairs, Department of Water Resource Studies (DWRS), NASA Radiation Sciences Program, the Office of Naval Research (ONR) Codes 32 and 35, and the Naval Research Laboratory (NRL) Base Program. Given is an overview of the program and individual reports from key investigators. Included are recommendations for the DWRS for further research.

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2.0 Background and Rationale for the UAE2 Mission:

The Arabian Gulf has one of the largest aerosol burdens in the world with frequent dust storms, smoke advection from the Indian subcontinent, and its own high emission rates of pollution from the petroleum industry and local construction. Particle size distributions and chemistries are highly variable. In addition, the Arabian Gulf exhibits extremely complicated meteorology, with variable sea surface temperatures, enormous latent heat fluxes, abrupt topography and strong mesoscale circulations. This combination of factors makes both modeling and remote sensing in the region extremely difficult. Consequently, although there have been large numbers of papers discussing atmospheric properties in the Arabian Sea and Indian Ocean, the meteorology and nature of aerosol particles in the Arabian Gulf region were until very recently mostly unstudied. The one exception is the international field measurements surrounding the 1991 Gulf War/Kuwaiti oil fires incident. These circumstances are certainly an anomaly and are problematic to apply to more typical conditions. There are a few studies that can be used to understand the regions fundamental meteorological properties.

The absence of environmental studies on the Arabian Peninsula is a direct result of its harsh environmental conditions. While the latest generation of remote sensing algorithms has greatly expanded the utility of space-based sensors to cover desert areas, they are still in a prototype form. Aerosol Optical Thickness (AOT), ocean color, temperature profiles, and cloud properties should be retrievable at unprecedented accuracy. But in hot desert regions and shallow coastal areas, this is not fully proven.

In response to the need for fundamental measurements in the Southwest Asian sub-continent a field campaign was necessary. The United Arab Emirates was chosen as the base area for this study, for a number of reasons. These include:

- The atmospheric environment of the Arabian Gulf is mostly unstudied. Hence, new science can be performed simultaneously with calibration/validation studies.
- Bright desert surfaces and shallow water disrupt satellite sensors on a number of levels. This region is also difficult for meteorology models to simulate. Thus, this is one of the few regions of the world that can be used to fully stress aerosol algorithms and assumptions.
- The infrastructure and available support in the UAE is much greater than other possible study locations. The resources of the DWRS are unsurpassed compared to other Arabian Gulf counties. This makes the UAE an ideal location to work to improve such satellite and meteorological systems.

- The DWRS was already funding an extensive cloud seeding program with the University of Witwatersrand and the National Center for Atmospheric Research. Consequently, necessary airborne assets were already in place for further research.
- Nowhere else in the world can the desert atmosphere be studied in such extensive detail. Dust and the desert atmosphere are important unresolved aspects of global climate change science.
-

Several spatial scales of the atmosphere can be studied simultaneously: From the afternoon sea breeze to large-scale patters that cover all of Southwest Asia.
For all of these reasons, the scientific community grew quickly excited when the United Arab Emirates Unified Aerosol Experiment (UAE2) mission was initiated. External sponsors included the UAE Dept. of Water Resource Studies, the United States National Aeronautics and Space Administration (NASA) Radiation Sciences Program, the United States Office of Naval Research (ONR), the United States Naval Research Laboratory (NRL), and several other international agencies. All involved agencies had similar goals that would benefit the UAE and the world.

3.0 Mission Philosophy and the “Unified” in the United Arab Emirates Unified Aerosol Experiment (UAE2)

While many elements of the UAE2 program can be categorized in the areas of aerosol microphysics, radiative transfer, satellite/model calibration/validation, and general meteorology, most are interdisciplinary. The ultimate goal of the program is to develop as complete an understanding as possible of aerosol-radiation-meteorology feedbacks in Southwest Asian region. In order to succeed, the principal areas of atmospheric research need to be “unified” into a coherent data assimilation and product system. This is summarized in Figure

3.1.
There are three principal areas of atmospheric investigation: Field Fundamental understanding through measurements and theory; monitoring through remote sensing; and extrapolation through modeling. The most fundamental research is in the direct observation of the environment, and its subsequent description through theory. However, localized observations rarely capture the full complexity of the global environment. To monitor on the global scales, one must ultimately resort to remote sensing systems where large spatial domains can be monitored frequently. From such data, field measurements and theory can be applied to produce additional products. Conversely, findings from remote sensing studies can be used to refine additional field measurement campaigns. But, remote sensing systems by nature are underdetermined. Somewhere fundamental assumptions on the atmosphere microphysics are made and the boundary conditions are in part assumed. For example, how does one monitor the existence of aerosol particles in heavily clouded regions or in

Field Measurements
and Theory

Goal: Determine the fundamental physical properties of the environment
Issue: Limited observations and extreme environmental conditions

Remote Sensing

Goal: Spatial and temporal monitoring
Issue: Tend to be underdetermined. Complicated microphysics and boundary conditions

Modeling
Data Assimilation and
Analysis
Products for Customers :Nowcasting, forecasting and understanding climate
Goal: Temporal/spatial extrapolation and physical inference
Issue: The world is a complicated place. Take a look outside…
.

Figure 3.1 Description of the four primary components of research in UAE2

complicated regions? To address this, extrapolation is made via numerical models. Models can reproduce the 4-dimensional nature of the environment. But their own boundary conditions must come from theory and field measurement derived parameterizations as well as remote sensing observations. Also, verification of model output can only come from these observing systems. But at present, the full complexity of the environment cannot be represented numerically.

Traditionally, theory, field measurements, remote sensing, and modeling studies have been relatively independent. But recent studies have begun to integrate these areas of research. The goal of the UAE2 campaign is to fully unify these research areas into a coherent data assimilation and analysis system. This will yield products for all of the mission’s customers from meteorological nowcasting and forecasting to understanding the region and globe’s climate.

4.0 Summary Results from the 2004 UAE2 Field Campaign

From August 1st – through October 5th, 2004, the Intensive Operations Period (IOP) of the United Arab Emirates Unified Aerosol Experiment (UAE2) officially took place. During this groundbreaking mission, the southern Arabian Gulf atmospheric environment was examined in unprecedented detail. Using satellites coupled with comprehensive ground and airborne monitoring, this experiment characterized the clouds, airborne dust and pollution of the UAE and surrounding region. This mission will allow scientists to understand how the complicated meteorology of this region fits into the global climate picture, as well as provide NASA with data to build better satellite sensors and algorithms to help UAE institutions monitor the local atmospheric and ocean environment.

There were a number of scientifically sound and pragmatic reasons for many scientists of the world to converge on the region for the UAE2. First and foremost, the atmospheric environment of southwest Asia is mostly unstudied. Dust and the desert atmosphere remain important unresolved aspects of global change science, and the Southwest Asian region defies assessment. This is partly because the region is so challenging to space based sensors: bright desert surfaces and shallow water disrupt satellite sensors. The hot desert, sharp mountains and seas also make the application of meteorological models difficult. Because the infrastructure and available support in the UAE is much greater than other potential study locations, the UAE is a logical location from which to study the region. In particular, because of its varying terrain and extensive mesonet of weather stations the UAE is an ideal location to work to improve such satellite and meteorology systems. Indeed, this is one of the best places in the world to study the desert and coastal atmosphere in extensive detail. Several spatial and temporal scales of the atmosphere can also be studied simultaneously. From the afternoon sea breeze to large-scale patterns that cover all of Southwest Asia, few places offer such interplay of varying meteorological phenomenon.

In this DWRS, NASA, NRL, and University of Witwatersrand led experiment, over 60 scientists from 8 countries and 18 research institutions were involved. A summary list presented in Table 4.1 Fifteen satellite sensors, five atmospheric models, two aircraft, and a multitude of ground stations were utilized. Much use was made of the South African Weather Service/University of Witwatersrand Aerocommander and Cheyenne research aircraft already on station as part of a DWRS funded cloud seeding program. For UAE2, these aircraft performed twenty-one flights totaling over 80 hours, to monitor the atmosphere, including the vertical distribution of pollution and dust. The end result of all of this work is that the latest state-of-the-art satellite and atmospheric products are being transitioned to the Office of H.H. the President, Department of Water Resource Studies (Currently in the Ministry of Presidential Affairs).

4.1 The Atmospheric Environment During the UAE2 Mission

As would be expected, the aerosol particle loadings in the UAE are dominated by airborne dust, with an important admixture of pollution aerosols. Typically, Total Suspended Particulate matter (TSP) was on the order of 100-300 µg m-3. We estimate Particulate Matter less than 10 microns diameter (PM10)

levels to be roughly two-thirds this value. The year 2004 showed higher dust concentrations than in the previous 5 years. The exact reason for this is unclear but is currently an area of study by mission scientists. Dust from the UAE, Iraq, Iran, Saudi Arabia, Qatar, and Afghanistan were all observed in the region during the mission.

Dust in general is composed of clays, alumina-silicates and various evaporates. However, the Arabian Peninsula is enriched with shallow oceanic deposits, with oceanic carbonate deposits underlying most of the region. This

Table 4.1 List of Primary UAE2 Organizations

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Stuart Piketh (Univ. of Witts): South Africa mission scientist, cloud physics
Jeffrey Reid (NRL): US mission scientist, microphysics & chemistry
Douglas Westphal (NRL): Meteorology team leader, Aerosol transport

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University of Hawaii, Honolulu HI
University of Maryland, Baltimore County, Baltimore MD
University of Maryland, Collage Park, MD
University of Witwatersrand, South Africa
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was well demonstrated in the aerosol data, with extremely high carbonate concentrations found during some of the dustiest days. These elemental signatures are enabling the team to estimate the exact source region of most dust. Dust sources also varied a bit more than expected. During the mission we observed a number of haboobs-dust storms that form in the outflow from thunderstorms. Clear regional air quality episodes can be linked to three such events.

The most significant dust event during the emission occurred on Sept 12, 2004. In the preceding days, a strong frontal boundary formed north of Iraq generating extremely high winds in the Tigris-Euphrates valley. Dust from that event was transported into the Southern Arabian Gulf causing extremely heavy air quality degradation and poor visibility throughout the UAE.

Regional air quality and pollution was also monitored successfully throughout the mission at the coastal MAARCO site (Figure 4.2). The sampling area around Taweela should be considered indicative of regional values and was not impacted by any significant local sources. Particulate Matter with diameters less than 2.5 µm (PM2.5), a key air quality index, averaged 35 µg m-3 during the study with a maximum value of up to 80 µg m-3. (on August 31st, 2004). Other significant pollution days were September 6th and Sept 12th (coexisting with the dust event), both at 65 . During most of the study period, however, pollution

MAARCO Mass Timeseries

Aug/8 Aug/17 Aug/26 Sep/4 Sep/13 Sep/22 Oct/2

Figure 4.1. Time series of daily average coarse mode (particles larger than 2.5 microns in diameter, and fine mode particulate matter less than 2.5 microns in diameter (PM2.5) during the UAE2 mission,

0
50
100
150
200
250
300
350
Coarse Mode
PM 2.5
Mass Concentration (µg m -3)
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loadings were relatively constant.

Pollution composition was surprisingly organic free. On a whole, simple ammonium sulfate accounted for nearly 60% of PM2.5 dry mass, followed by ~25% from intrusions from coarse mode dust. Only ~20% of mass can be contributed to black carbon (soot) or particulate organic matter. This mass separation is consistent with the bulk of the pollution coming from the petroleum industry and in particular flares and power plants. Samples near the city centers will most likely have increased contributions of black carbon and organic matter and higher mass concentrations.

The measured values for PM2.5 pollution are considered high by most western standards, but are considered typical or better than most of the world. For example, the regional "background" level is considered significantly higher by comparison to Canada, the EU, or the United States. However, loadings are half the regional values of Southeast Asia, East Asia, India and most of Africa.

In evaluating UAE air quality there are a number of issues that need to be considered. First, sampling was performed during the worst air quality months of the year. Further, most of the significant pollution events were easily identifiable as being a result of transport from northern and central gulf countries. Lastly, the presence of so much dust in the atmosphere of Southwest Asia makes any comparison to more industrialized parts of the world somewhat problematic.

Modulating the regional aerosol loadings was the complicated flow patterns of the region. It was clear during the study that on a daily basis the complicated land-sea breeze significantly influenced the relative vertical distribution of dust

Residual

Calcium
Organic matter carbonates
13.4%

4.6%
Alumino-silicates

Black carbon 10.5%
4.3%

9.4%

Sea salt
0.3%
(1.5%)

Ammonium
sulphate
57.5%
Figure 4.2. Average apportionment of PM2.5 pollution at the MAARCO site.

and pollution. While strong shallow stable layers form over the ocean effectively partitioning the near surface and mid level atmosphere, the steady oscillation of the sea/land breeze can vertically mix the atmosphere. The development of internal boundary layers during onshore flow was particularly interesting. Currently, the modeling team members are analyzing the data and will present first results in December.

4.2 Efficacy of remote sensing products in the region

One of the primary goals of the UAE2 mission is the calibration and validation of remote sensing systems that have traditionally had difficulty monitoring this part of the world. Science team members have focused on three principle areas: 1) The retrieval of aerosol particle properties from satellite over bright deserts and shallow water 2) the retrieval of land and water temperatures by satellite in the presence of absorbing dust and varying surface types, and 3) the inversion of aerosol particle optical properties from ground based AERONET systems. In each of these categories the UAE2 mission met its primary goals.

Most satellite systems determine the aerosol loading in the atmosphere by comparing the "brightness" of the planet from space to some theoretical clear sky result. Like clouds, aerosol particles such as dust and pollution "lighten" the image and reflect more light to space than an otherwise clear sky. Over dark water, it is very easy to see the lightening effect of aerosol particles. If the ground is bright, such as in deserts or in shallow water, it becomes much more difficult. Another difficulty is if there is dust in the atmosphere. Dust particles have irregular shapes and their optical properties are difficult to model. A key purpose of this mission is to develop systems that can overcome this issue. The UAE environment is perfect for performing these valuations.

Overall, the standard MODIS algorithm for monitoring aerosol particle loadings over water worked reasonably well. It tracked the relative changes in atmospheric loading of dust and pollution and even showed some skill in partitioning the relative amounts of dust and pollution. Typically, the MODIS over water algorithm was good to within 15% (Figure 4.3).

What we were most interested in, however, was the next generation of over desert algorithms, such as "Deep blue." This algorithm, takes advantage of the fact that deserts are fairly bright in red wavelengths, but are dark in the blue. So the hypothesis is that by using traditional over water methods but in shorter wavelengths, satellites can get a dark enough background to see the change in scene brightness due to dust and pollution. Preliminary results from the study are quite positive. Typically, the Deep Blue algorithm correctly determined the amount of dust and pollution over desert to within 30%.

A second satellite system utilized during the mission was the Multi-Image SpectroRadiometer (MISR), which determines the properties of the atmosphere by viewing the scene at nine angles, some as steep as 70 degrees. By looking at a progressively steeper slant paths through the atmosphere, the relative contributions of surface and skylight to the scene systematically increase. Early results from the mission show that in addition to optical depth, MISR is also sensitive to aerosol properties over bright surfaces.

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Figure 4.3. Scatter plots of the MODIS standard optical depth product compared to the Sir Bu Nair island site (upper-over water) and the new Deep Blue algorithm (lower over desert) over the Hamim site. Plot courtesy of Jianglong Zhang, NRL

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A second priority of the mission was to examine how satellites can determine the land and sea temperature (Figure 4.4). By using this information, meteorology models can much more accurately improve wind and cloud forecasting. Typically, temperature retrievals are performed at infrared or microwave wavelengths. The direct measurement of temperature from the infrared is straight forward with regard to land surface type, but is complicated by large airborne dust particles. The higher the dust is in the atmosphere, the colder it is and the more it affects the retrieval. Conversely, microwave retrievals of temperature are not affected by dust, but are more sensitive to the land surface underneath. During the mission we examined land and sea temperatures from space and are comparing them with field measurements.

Lastly, during the UAE2 mission we wanted to know how well ground based AERONET systems characterize the atmosphere. Just as a satellite system looks down and determines atmospheric properties by apparent changes in ground brightness, the AERONET sun photometer looks up at the sun and sky; based on variations in sun and sky brightness, it determines the loading and properties of aerosol particles above. The UAE environment is very challenging for such measurements because again the atmosphere is heavily loaded with complicated dust particles. Other issues include the bright desert surfaces that reflect more light into the sky, and the variable amount of pollution.

Figure 4.4. Examples of the diurnal cycle of regional temperature over the Middle East area.

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5.0 Recommendations for DWRS

The science teams operating with DWRS have five primary recommendations for future transformations and research. These are listed below from the most broad to the specific.

a) With its computer and hardware infrastructure the DWRS is in a unique position in the Southwest Asian region. The earth science research projects it has hosted far exceed those of neighboring countries. DWRS is the logical host organization for developing the UAE’s applied earth science corporate laboratory. Its mission and goals should expand to cover all the UAE’s earth sciences needs. This should include not only precipitation and hydrology, but also oceanography, pollution and applied science engineering.

b) A high priority for DWRS studies is the evaluation of the impact of pollution and dust particles on cloud microphysics and precipitation. This should include not only periods of intensive operations but also longer-term monitoring. As part of this program the DWRS should become a member of the AERONET network with three instruments (and preferably four). These should be located at an island site in the Arabian Gulf, at a coastal location, and a third in the interior in an inflow region for mountain convection. A fourth instrument (perhaps jointly with Oman) should be placed on the Omani side of the Jebel Muqaylit to monitor inflow from the Arabian Sea.

c) DWRS is in a position to begin state-of-the-art monitoring of UAE pollution emissions and transport from neighboring countries. Although there already exist air quality programs in individual emirates, such data needs to be unified into a common database and standardized auditing procedure need to be developed. This will not only help the emirates understand their own environment, but will also allow for informed negotiations on other climate related issues such as the Kyoto Protocol on greenhouse gas emissions.

d) Effort should be made to develop updated forecasting tools to improve precipitation forecasting. The geography and flow patterns are rigid enough that a series of observations can go into conditional empirical analysis for the next days forecast.

DWRS should start systematically collecting remote sensing earth science data, including regional level 1b and 2 MODIS and MISR data. Such data is freely available at the DAACS via website and efforts should be made to regularly gather and process the products.

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Part II: Individual Reports and Summaries

A.1 AERONET Advances and UAE2

Principal Investigator: Brent Holben, NASA Goddard Space Flight Center

Co-Investigators: Tom Eck, Alexander Smirnov, David Giles, and Ilya Slutsker

A.1 Nature of the problem

The sun and sky scanning spectral radiometers that make up the AERONET network automatically measure the intensity of the sunlight and directional sky brightness in the UV (340 nm) through the near infrared (1,640 nm) in 9 spectral band passes throughout the day. These data are relayed by satellite to NASA’s Goddard Space Flight Center where they are processed in near real time to retrieve aerosol optical depth, particle size distribution and complex index of refraction available through the public access website: http://aeronet.gsfc.nasa.gov.

Given the nearly continuous daylight observations, AERONET has provided a significant contribution to the aerosol research community since the first observations in 1993 of biomass burning in Brazil’s Amazon basin. The program has grown from a few instruments making local observations to approximately 300 globally distributed sites in 2005 (Fig. A.1). The UAE2 campaign of 2004 ushered in a new era in research from ground-based aerosol characterization that has here-to-fore not been attempted, that is mesoscale aerosol observations with a sufficient dense network of instruments to provide a new understanding of aerosol transport processes, evaluate aerosol properties with respect to local and regional sources and characterize aerosol distributions in time space (Fig. A.2). The UAE2 AERONET data while providing regional and local aerosol characterization (see Eck case study in this report), also allowed opportunities to research new measurements unique to the program including polarization (see Smirnov summary this report), ocean leaving radiances and evaluation of new processing algorithms to be implemented on the entire AERONET database. Finally the mesoscale AERONET network in concert with the DWRS mesoscale meteorology network is providing the opportunity to understand and improve mesoscale aerosol transport models (see Reid and Westphal this report), validation of new and/or improved satellite aerosol algorithms (see Kahn and Hsu, this report).

Figure A.1 The global distribution of AERONET sites covers all major aerosol types however the sites are widely spaced resulting in relational connectivity between station observations.

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Figure A.2 shows the mesoscale spatial distribution between the AERONET sites during the UAE2 campaign.

A.2 AERONET Version 2 summary and implications for UAE2

AERONET Version 2 (V2) for the sun measurements (V2S) was released in July 2005. This will be followed in September with V2 for the inversion retrievals (V2R). Our philosophy towards the processing algorithms has not changed, that is we are using published community accepted algorithms and data sets to process the direct sun and sky radiance data…, but with a caveat as described later. If you, the users, prefer to make your own corrections, we also provide the total optical depth as well as the component optical depths for each spectral measurement in V2S. If you find an error or discrepancy in the V2S database, please contact me immediately so that I can alert the community using the data and we can solve the problem quickly.

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A.3 V2S Application to the Database:

All V2 processing will be retroactive for the entire AERONET database dating back to 1993. The old ‘AERONET Version 1’ (V1) processing will continue in parallel through at least December 2005 to insure continuity for those wishing to complete data sets or investigations. Access, availability and website appearance will remain exactly as in the past. The V2 data are available from the same website (http://aeronet.gsfc.nasa.gov) as are the complete and updated V1 database. Both data sets are clearly labeled. Until V2R products are operational, the only retrievals that will be available are the legacy products based on V1 inputs. All climatologies have been recomputed thus providing a V1 and V2 AOD and water vapor climatology. Although the direct sun V2S products are inputs to the retrievals there will be no mixing V2S with V1R products. Quality controlled data, levels 1, 1.5 and 2.0, are available in V2S.

A.4 V2S Summary-what is the net effect?

Please refer to Table A.1 and A.2 for a V1 and V2S comparison and the discussion below. Table A.3 with references is the complete description of the changes implemented in V2S.

Ozone: We replaced London’s global average O3 climatology with TOMS 30 year climatology. In all but extreme cases this is a difference of less than 0.003 AOT at 675 nm. Other affected bands are less.

Table A.1 Algorithm modifications from Version 1: Rayleigh, Solar flux, NO2, O3, CH4, H20, CO2

Parameter Version 1 Version 2
Rayleigh optical Edlen 1966 Bodhaine et al. 1999
thickness
Air Pressure 1013.25 mb & height eq. NCEP interpolated
pressure ht
Solar Flux Neckel and Labs 1981; Woods et al. 1996
and Frohlich and Wehrli
1981
Ozone London et al. 1976 TOMS O3 1979-2004
NO2 None Schiamachy monthly
climatology
Water Vapor Content Bruegge et al. 1992; Michalsky et al. 1995;
Reagan et al. 1992 Schmid et al. 1996
Water vapor correction None LBLRTM
for AOD (1020 nm)
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NO2: Caveat-NO2 is optically present in very small quantities in the stratosphere but is highly variable in the lower troposphere being highest in urban/industrial regions due to fossil fuel combustion. We ignored this absorption in V1 due to lack of widespread observations. V2S uses a 2 to 3 year climatology by month from SCIAMACHY. Although the SCIAMACHY data are not fully independent observations, comparisons to GOME and ground-based observations indicate the SCIAMACHY data are relatively accurate (but we feel slightly underestimate the measured concentration) and thus merits inclusion in our correction scheme. Net effect ~ 0.01 at 380 nm in urban areas but globally is <0.003 depending on wavelengths between 340 nm through 500 nm.

Rayleigh: The algorithms are only slightly improved to account for polarization effects. The overall difference between V1 and V2 is insignificant, maximum of

0.003 at 340 nm at sea level.

Air Pressure: This input to the Rayleigh algorithms is extremely important especially for the UV and blue bands. In V1 we used a constant pressure of 1013.25 adjusted by elevation of the station. For high elevation sites and moderate elevation continental sites, the calculated ‘station pressure’ was sometimes off by more than 20 hPa resulting in miss-correcting AOD at 340 nm by more than 0.015.

The NCEP/NCAR Reanalysis 6-hourly data access base provides global mean sea-level pressure and standard pressure level heights (1000, 925, 850,

Table A.2: Spectral Corrections/components

Standard
Wavelengths (nm)
Version 1 Version 2
340 (2nm) Rayleigh, O3 Rayleigh, NO2, O3
380 (4 nm) Rayleigh Rayleigh, NO2
440 (10 nm) Rayleigh Rayleigh, NO2
500 (10 nm) Rayleigh, O3 Rayleigh, NO2, O3
675 (10 nm) Rayleigh, O3 Rayleigh, O3
870 (10 nm) Rayleigh Rayleigh
940 (10 nm) Aerosol: Interpolate 870 to
1020
Aerosol: Extrapolate 440
thru 870 to 940

1020 (10 nm) Rayleigh Rayleigh, H2O
1640 (25 nm) Rayleigh Rayleigh, H20, C02, CH4
Sea-Prism
Wavelengths (nm)
Version 1 Version 2
412 (10 nm) Rayleigh Rayleigh, NO2
555 (10 nm) Rayleigh, O3 Rayleigh, NO2, O3

700, 600 hPa). These pressure level data are used to interpolate and fit the pressure at the station elevation. Our analysis shows that 95% of all observations are within 1 hPa of measured station pressure and difficult sites such as Mauna Loa, owing to it’s high elevation, had 95% of all observations within 2 hPa of recorded station pressure. NCEP air pressure inputs for Rayleigh corrections represents the most significant improvement in V2S processing and, because of ready access to the data, is highly recommended for sun photometry in the absence of measured station pressure.

The NCEP/NCAR Reanalysis 6-hourly data has a 2.5 by 2.5 degree spatial resolution and are normally available after a four to five week delay. Thus we compiled a monthly climatology (from a 50 year record) to use for the real time level 1 and 1.5 data. Histograms of the climatology to measured station pressure show 95% of observations less than 2 hPa deviation for Goddard and 4 hPa at MLO. The 6-hourly will replace 1, and 1.5 as it becomes available and will always be used for level 2.0 data.

H20: LBLRTM was used to compute the A and B coefficients for all 940 filters where the filter function was available to more accurately account for water vapor absorption. The resulting water vapor retrievals showed a decrease of approximately 13 to 19% from V1 retrievals. This is in agreement with published biases of Schmid and comparisons to ~7000 GPS retrievals at GSFC showed a bias of ~2% thus suggesting great improvement over V1. We will now support a quality assured product (level 2.0) for water vapor.

Measured filter functions for each filter in the network, including the 940 water vapor absorption band, were consistently available back to 1997 and only about 50% of the 940’s prior to that. Because we require the filter function to determine the A and B coefficients, only water vapor retrievals from those instruments with measured filter functions will be raised to level 2. Prior to 1997, depending on circumstances, batch filter function was determined from a measured subset and was applied to each instrument’s 940 filter to compute coefficients A and B, calibration coefficients and finally the column integrated water vapor. This effort will only result in level 1.5 data. As we continue to uncover more spectral curves from the past or measure the filter function (we have most of the filters in the AERONET museum), we will be able to promote more of the early data to level 2.

Due to temperature dependence and water vapor absorption in 1020 nm filters the resulting AOD is slightly more uncertain compared to other channels. Thus we decided to extrapolate from 440 through 870 nm to 940 nm to estimate the AOD component rather than interpolate between 870 and 1020 nm as in V1.

Water vapor absorption is removed from the 1020 nm and 1640 nm filters based on the improved H20 algorithm.

Trace Gasses: CH4 and CO2 optical depths are computed for each filter function using profiles from US 1976 standard atmospheric model. Absorptions are removed from the 1640 nm filter according to the NCEP height-pressure relationship. This replaces the standard air pressure vs height algorithm of V1.

Table A.3: AERONET Version 2 Direct Sun Algorithm

Ancillary Data
Set Corrections
Data Product Spatial Resolution Temporal Resolution Source
NO2
[Reference 1]
Total column
concentration
[molec/cm2]
Global: 0.25 x 0.25
degrees resolution
Monthly climatology
(2003-2005)
ESA SCanning Imaging
Absorption SpectroMeter for
Atmospheric CHartographY
(SCIAMACHY)
O3
[Reference 2]
Total column

concentration
[Dobson Units]
Global: 1 x 1.25 degrees
resolution
Monthly climatology
(1978-2004)
NASA Total Ozone Mapping
Spectrometer (TOMS): Earth
Probe and Nimbus
Pressure
[Reference 3]
Station pressure [hPa]
derived from standard
pressure level heights
[m] and sea-level
pressure by using
quadratic fit in
logarithmic space
Global 2.5 x 2.5 degrees
resolution
Six pressure level
heights: sea-level, 1000,
925, 850, 700 600 hPa
Use 6-hourly when
available and default to
monthly climatology
(1993-2004)
NCEP/NCAR Reanalysis
Corrections Explanation Implication
O3 Absorption
[Reference 4]
Integration of ozone spectroscopy and fitted to
filter function for each wavelengths to obtain
ozone absorption coefficients.
Improved ozone wavelength-dependent absorption correction
NO2 Absorption
[Reference 5]
Integration of NO2 spectroscopy and fitted to filter
function for each wavelength to obtain NO2
absorption coefficients.
Improved NO2 wavelength-dependent absorption correction
CO2
[Reference 6]
Constant value of 0.0089 at standard atmospheric
pressure and temperature; adjusted by P/Po.
Affects extended wavelength instruments (e.g., channel
1640nm)
CH4
[Reference 7]
Constant value of 0.0036 at standard atmospheric
pressure and temperature; adjusted by P/Po.
Affects extended wavelength instruments (e.g., channel
1640nm)
Filter Functions
[Reference 8]
Filter functions have been updated for instruments
after 1997.
Improved data quality.
Rayleigh
Optical Air
Mass Formula
[Reference 9]
Updated Kasten 1965 to Kasten and Young 1989. Very small differences in air mass calculations at high solar
zenith angles.
Ozone Optical
Air Mass
Formula
[Reference 10]
Updated to Komhyr et. al. 1989. The ozone layer is no longer fixed at 22km. The ozone layer
height is adjusted by latitude to provide a more accurate
representation of the ozone height layer.
Water Vapor
Optical Air
Mass
[Reference 11]
Implement Kasten 1965. Account for the water vapor optical air mass.
Water Vapor A
and B
Coefficients
Recalculated
[Reference 12]
Water vapor transmission (Tw) was modeled as Tw
= exp[−A(mw)B] using the radiative transfer code
from Alexei Lyapustin. Constants A and B are
unique to the particular filter and w is the vertical

	column water vapor content.	Improved water vapor calculations by up to 20%.
Rayleigh [Reference 13]	Rayleigh equation suggested by Bodhaine et. al. (1999)	<0.001-0.007 change in the tR depending on latitude and elevation.
H_2O [Reference 14]	Absorption optical depth computed for channels 1020 and 1640nm using instantaneous water vapor calculation (derived from the channel 940nm).	Affects channels 1020 and 1640nm.
Earth-Sun Distance [Reference 15]	The effective Vo is calculated using the earth-sun distance correction.	Improved calculation of the effective Vo for each wavelength.

The corrections to the AOD retrievals, as with the water vapor retrievals, uses individual filter functions in our analysis available since 1997, prior to that batch average filter functions were applied because transmittances were not measured for all filters. Given our improved filter tracking and computational horsepower in V2S we are now convolving each spectral band pass to the solar spectrum, evaluating O_3 and NO_2 absorption cross sections absorption spectra at 0.1 nm resolution. Compared to the previous center wavelength analysis this makes a difference of only a few thousandths and overall is likely randomly distributed. Batch averaged filter functions are processed identically and can be raised to level 2 status.

Optical Airmasses: We have implemented optical airmasses in our algorithms for Rayleigh, H_2O, O_3 as detailed in Table A.3.

What is yet to come in V2S?

Three additional products will come on line for V2S:

- SeaPRiSM ocean leaving radiances driven by Giuseppe Zibordi,
- the tf and tc and eta from AOD observations developed by Norm O’Neill
- direct normal spectral irradiances

These will be released and announced over the next few weeks as we evaluate the new algorithms and determine the screening criteria for level 2 quality assurance. Also under evaluation for V2S will be cloud screening options and the potential for corrections from station observations.

A.5 Application of V2 to UAE

In order to assess the overall impact of the new V2S changes to a range of conditions we have compared the monthly averaged AOD in the midvisible (500 nm) and column integrated water vapor at four unique sites during the UAE2 campaign: Sir Bu Nair Island, MAARCO (coastal site), Mezira (inland low desert), Jabal Hafeet (high elevation interior. Table A.4).

The data show that the AOD was reduced on average of less than 0.01 which is close to our theoretical expectations. The largest effect is due to air pressure for computation of Rayleigh optical depth. Expectations would have the largest effect on Jabal Hafeet due to more precise elevation computation of air pressure in version 2. The water vapor retrievals are closer than expectations. Non UAE comparisons indicate a 15% decrease in version 2 but during the UAE2 campaign the decrease was from 1 to 6 %. This bears further investigation and comparison to microwave radiometers and radiosonde data taken during the campaign.

Table A.4, The September comparison of water vapor and aerosol optical depth

	V1		V2S	
Site	AOD (500 nm)	PW (cm)	AOD (500 nm)	PW (cm)
Sir Bu Nair	0.48	2.86	0.47	2.85
MAARCO	0.45	2.69	0.45	2.54
Mazira	.38	2.29	0.38	2.23
Jabal Hafeet	.33	1.65	0.32	1.61

A.6 SeaPRISM-ocean leaving radiances

The SeaPRISM is a AERONET site adapted to measure the reflected energy from the ocean surface when mounted on a platform above the sea surface (Fig. 3). Abu al Bukoosh (ABK) oil platform was used as the measurement site from

September through December 2004. This is a new application of the AERONET measurement program that potentially is capable of replacing very expensive ocean optics systems. Zibordi et al provided a systematic comparison between the two systems showing scientifically acceptable comparisons for ocean color research. Those and all previous comparisons were in relatively low optical depth midlatitude environments. The high aerosol regime of the Arabian Gulf provided unique opportunity to assess the SeaPRISM technique under dust and fossil fuel emissions. Figure 4 shows preliminary ocean leaving radiance observations in reflectance units from the ABK site. These values represent

Figure A.3, AERONET radiometer showing the viewing modes of the SeaPRISM.

expected deep water values and will be used to assess over water aerosol retrievals from satellites.

Further assessments of the AERONET data will be made from the collected data set including a robust assessment of the new AERONET inversion algorithms expected in September. Further synergism with lidar and hyperspectral satellite data will be pursued along with radiative forcing estimates under dust and pollution conditions. AERONET thanks the foresight of DWRS for supporting the UAE2 campaign and particularly support for the mesoscale network established for this campaign. AERONET, NASA and the scientific community will greatly benefit from continued collaboration with DWRS.

Figure A.4 The computed hemispherical reflectance vertical axis vs spectral wavelength (nm) show reasonable values for a family of ABK curves representing a variety of conditions and times of day.

Acknowledgments:

Development of V2S has been a time consuming effort requiring meticulous research, analysis and reanalysis by the following team members. Great kudos goes to Norm O’Neill for advocating NO2 corrections for years and providing the initial correction efforts. Ilya Slutsker has written and implemented a battery of programs to populate a new expanded and flexible database that everyone utilizes but few appreciate the intricacies. Many thanks also to David Giles who creatively implemented the ancillary data sets with skill and insight and always managed to provide the web based solutions to keep the rest of us in the game. Alexei Lyapustin willingly provided LBLRTM modeling for our water vapor analysis. Alexander Smirnov demonstrated his masterful meticulousness in every phase of V2S: algorithm research, development, implementation and critical analysis. Lastly Tom Eck’s great insight into the algorithms and the data combined with his broad perspective allowed a deep and thorough evaluation of the V2S database that we can all confidently use for our scientific research.

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B.0 Spatial and Temporal Variability of Aerosol Optical Depth in the UAE

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Co-Investigator: Brent N. Holben, Oleg Dubovik, Alexander Smirnov, A. Sinyuk, J. S. Reid, D. Giles, J. S. Schafer

B.1 Nature of problem

In this investigation we are studying the spatial distribution of the atmospheric aerosol optical depth (AOD; integrated vertical aerosol extinction) and the temporal dynamics of AOD. The spectral dependence of the aerosol optical depth provides information on the relative optical influence of the coarse mode particles (desert dust) versus the fine mode particles from pollution sources. Information on AOD magnitude and spectral dependence is important in determining the potential climatic effects of aerosol perturbations to the radiation budget and also in making atmospheric corrections for satellite retrievals of earth surface properties. Additionally, the data provided by the ground-based Aerosol Robotic Network (AERONET) sun-sky radiometers are very important in validating satellite retrievals of AOD. The geographical location of the UAE includes strong desert dust aerosol sources from the arid lands in the region, and also strong pollution particle sources from petroleum and natural gas processing facilities. This variability of atmospheric particle type and size in conjunction with highly variable regional meteorology results in some days that are dominated by large particle desert dust, some dominated by fine particle pollution, and many days that are a mixture of the two aerosol types. This study attempts to quantify the dynamics of AOD in the late summer season in the UAE. In the near future when new retrieval products derived from sky radiance scans become available, we intend to study the dynamics of aerosol size distribution retrievals and aerosol absorption also.

B.2 Executive summary

A time series of daily average AOD at 500 nm from August 9 though October 1, 2004 for four AERONET station sites in the UAE is shown in Figure B.1a. It is noted that the 500 nm AOD is typically quite high in this season, exceeding ~0.3 on most days. The ~2 month average AOD for the island site of Sir Bu Nuair (0.50) and the coastal site of Umm Al Quwain (0.53) are approximately 25% higher than for the two inland sites in the desert, Mezaira (0.40) and SMART (0.44). The SMART site is located at the Al Ain airport. The higher AOD for sites in or bordering the Arabian Gulf may be due to the combination of very high humidity at these sites coupled with sources of fine mode particle pollution originating from petroleum industry operations at offshore platforms, on islands, and on the coast. These fine mode aerosols contain sulfates that are very hygroscopic, therefore they grow in size in high humidity environments, which thereby increases the particle scattering optical depth. The time series of the daily average Angstrom wavelength exponent (computed from 440 to 870 nm AOD data) for the same sites and dates is shown in Figure B.1b. The Angstrom wavelength exponent is the slope of the AOD versus wavelength in logarithmic coordinates, and is a basic measure of the optically active particle size. An Angstrom wavelength exponent of near zero occurs when all aerosol particles are large (radius greater than 1 micron), while at the other extreme an Angstrom wavelength exponent of 2.0 occurs for fine mode pollution or smoke particles (radius less than 0.3 microns). At the four UAE sites in Figure B.1b, the Angstrom exponent averages 0.75 for the Gulf island site of Sir Bu Nuair, 0.63 for the coastal site of Umm Al Quwain, and 0.56 and 0.50 at the inland desert sites of Mezaira and SMART respectively. Therefore the higher Angstrom exponent values for the Gulf sites indicate that fine mode pollution particles are present in greater concentrations there than at inland sites. It is also noted in Figure B.1b that the Angstrom exponent is quite variable, ranging from ~0.2 to ~1.6, as a result of some days being dominated by strong desert dust events and some days where pollution aerosol in predominant.

We compare the AOD and Angstrom exponents at Dhadnah, located near the coast of the Gulf of Oman and at Umm Al Quwain near the Arabian Gulf coast in Figure B.2. These two sites are at the same latitude and both are located at relatively low altitude (<80 m) but are ~70 km apart in the east-west direction with a mountain range between them. Scatter plots of daily average matched AOD and Angstrom exponents in Figure B.2 show that there is relatively high correlation in AOD between the sites (~52% of the variance explained) and even higher in Angstrom exponent (~78% of the variance explained). Therefore on most of the days in August and September 2004 the mountain range in the northern UAE between these sites did not act as a separation barrier for aerosol type, as the aerosol size mixture was very similar on both sides of the mountains. These plots are preliminary and the correlations will increase when the data are matched in day and time rather than matched in day only as in Figure B.2.

0.0
0.2
0.4
0.6
0.8
1.0
1.2
220 230 240 250 260 270
UAE Aug. 9- Oct. 01 , 04 - Level 2.0 Data
Sir Bu Nuair Ave = 0.50
Umm Al Quwain Ave = 0.53
Mezaira Ave = 0.40
SMART Ave = 0.44Aerosol Optical Depth (500 nm)
Day of Year
0.0
0.5
1.0
1.5
2.0
220 230 240 250 260 270
UAE Aug. 09- Oct. 01 , 04 - Level 2.0 Data
Sir Bu Nuair Ave = 0.75
Umm Al Quwain Ave = 0.63
Mezaira Ave = 0.56
SMART Ave = 0.50Angstrom Exponent (440-870 nm)
Day of Year

Figure B.1 Time series of AOD and Angstrom exponent at 4 AERONET sites in the UAE.

Measurements were also made at the top of the mountain ridge at Jabal Hafeet at 1059 meters altitude were compared to measurements made at the SMART site in Al Ain at 250 meters in order to investigate the vertical partitioning of AOD in the region. The sites were only 28 km apart in horizontal distance but differed in altitude by about 800 meters. The AOD at both sites were very highly correlated as expected from their close horizontal proximity, while the AOD at Jabal Hafeet averaged 75% of the value measured at the SMART site. Therefore only ~25% of the total column aerosol AOD was attributed to the lower 800 meters above ground level. This altitude difference is similar to the altitude difference between the coast and the mountain range separating the sites of Dhadnah and Umm Al Qwain. Therefore since ~75% of the AOD occurs above the altitude of the mountain ridge this explains the high correlation between these sites separated by the mountains, as shown in Figure B.2.

Aerosol Optical Depth (500 nm)Angstrom Wavelength Exponent (440-870 nm)
Arabian Gulf vs. Gulf of Oman ComparisonArabian Gulf vs. Gulf of Oman Comparison
Daily Averages (Dhadnah - Level 1.5) Daily Averages (Dhadnah - Level 1.5)

0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
y = 0.17764 + 0.59701x R= 0.71772
AOD (500 nm) - Umm Al Quwain
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
y = 0.013147 + 0.99927x R= 0.88249
WEXP (440/868) - Umm Al Quwain
0.2
0.4 0.6 0.8 1 1.2 1.4 0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
AOD (500 nm) - Dhadnah WEXP (439/869 nm) - Dhadnah

Figure B.2 Scatter-plots showing correlation of AOD and Angstrom exponent between northern UAE sites separated by a mountain range.

0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
220 230 240 250 260 270 280
Daily Average 440 nm AODJabal Hafeet and SMART
Jabal Hafeet 1059 m
SMART 250 m
Aerosol Optical Depth [440 nm]
Day of Year
Jabal Hafeet Daily Ave. = 0.355SMART Site Daily Ave. = 0.475
0.50
0.55
0.60
0.65
0.70
0.75
0.80
0.85
0.90
220 230 240 250 260 270 280
Ratio of Daily Average [Jabal/SMART]
440 nm AOD
Ratio AOD 440 [Jabal/SMART]
Day of Year
Ave. Ratio = 0.750

Figure B.3. AOD comparison at the Jabal Hafeet and SMART sites which are only 28 km apart in horizontal distance but differ in altitude by ~800 meters.

C.0 An Overview of MPLNET Data Collected During the UAE2 Campaign

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The NASA Micro-pulse Lidar Network (MPLNET) [Welton et al., 2001] consists of micro-pulse lidar sites co-located with AERONET [Holben et al., 1998] sun photometers. Data sets and more information on MPLNET are available on our website, http://mplnet.gsfc.nasa.gov. During UAE2, MPL systems were deployed to both the MAARCO and SMART-COMMIT sites. The micro-pulse lidar (MPL) system is a single channel (523 nm), autonomous, eye-safe lidar system that is used to determine the vertical structure of clouds and aerosols [Spinhirne et al., 1995]. Raw MPL data were acquired at 1-minute time resolution, and 75 m vertical resolution. The raw data were converted into uncelebrated lidar signals [Campbell et al., 2002; Welton and Campbell, 2002] and are used to infer the altitude of aerosol and cloud heights.

Figures C.1 and C.2 display MPL signals from MAARCO and SMARTCOMMIT, respectively, during the entire campaign. The x-axis displays the time in UTC (day of year), and the y-axis altitude in kilometers. The colors represent aerosol and cloud layers that have backscattered laser pulses from the MPL. Hotter colors indicate more backscatter than cooler colors, deep blue shows the free troposphere where only molecular scattering occurs. Aerosols were present from the surface to 5 – 6 km at both UAE2 sites during the experiment. The top of

18235 237 239 241 243 245 247 249 251 253 255 257 259 261 263 265 267 269 271 273 275

17

16

15

14

13

12

11

10

9

8

7

6

5

4

3

2

1

Altitude (km)

Day of Year (UTC)

-0.2 0.3 0.9
Prelim Level 1 Signals

Figure C.1 MPL signals acquired at the UAE2 MAARCO site.

Altitude (km)

18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

237 239 241 243 245 247 249 251 253 255 257 259 261 263 265 267 269 271 273 275
Day of Year (UTC)

-0.5 1.0 2.5
Prelim Level 1 Signals

Figure C.2 MPL signals acquired at the UAE2 SMART-COMMIT site.

the aerosol layer is visible as the pale blue-green layer bordering the free troposphere. Periods of intense apparent backscatter (red and white) appear in both MAARCO and SMART data sets, and are due to temperature fluctuations in the trailers. These effects are currently being calibrated to fix the problem, and final data will not be affected.

The MPLNET data will be used to characterize the height distribution of aerosols during UAE2, and to study diurnal changes. The MPL also displays areas of cloud and aerosol co-location (see days 243-246, the white scattering layer at 6 km is due to clouds). Such information is helpful for studies of aerosol-cloud interaction. Finally, MPLNET data will provide information needed to help analyze satellite lidar data collected by new NASA sensors as they fly over the Arabian Gulf region. Figure C.3 shows lidar signals acquired by NASA’s Geoscience Laser Altimeter System (GLAS) [Spinhirne et al., 2005] on the ICESat spacecraft during October 2003. The orbit track crosses the United Arab Emirates, and shows similar aerosol height characteristics as observed during UAE2. The complex aerosol mixtures in this region present a problem for accurate satellite lidar retrievals, and MPLNET data from UAE2 will be used to help construct algorithm look-up tables to analyze GLAS data, and results from NASA’s next satellite lidar – Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) [Winker et al., 2004] scheduled to launch in September 2005.

Figure C.3. GLAS satellite lidar signals during an orbit track over the UAE in October 2003.

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D.0 Aerosol Retrievals Over Land and Water using Deep Blue Algorithm from SeaWiFS and MODIS

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D.1 Nature of problem

When strong winds blow over the desert, mineral dust gets lifted from the surface and into the atmosphere. Since these airborne particles sometimes travel very far distances from their source regions, their microphysical and optical properties may change, thus creating different impacts on the environment along the transport pathway. The science questions we would like to address are:

(1) How do mineral dust aerosols interact with solar radiation not only in the downwind regions, but also over the source regions?
(2) Can we monitor the movements and track the evolutions of dust plumes from sources to sinks using satellite data?
By addressing these questions, we will obtain a better understanding of the aerosol effects on the solar heating/cooling processes. Such an understanding is crucial to improving the prediction of aerosol and climate interactions (i.e., wind and precipitation patterns). Field campaigns such as UAE2 provide us with golden opportunities to gain a detailed and comprehensive understanding of the mineral dust and fine-mode pollution aerosol properties. Information of this kind is critical for improving the accuracy of satellite aerosol retrievals, which rely on the use of realistic libraries of aerosol characteristics. The measurements obtained by aircraft and ground based instruments help us to better interpret the results of studies that use satellite observations to determine aerosol effects on the radiation budget in the entire atmospheric column. The experiences gained in such campaigns is extremely valuable in helping scientists learn the strengths and weaknesses of satellite algorithms that use SeaWiFS and MODIS data to retrieve aerosol properties and to monitor large scale dust storms over desert and semi-desert regions.

D.2 Executive summary

During the UAE2 field campaign, we used satellite measurements to provide a "big-picture" look at the aerosol loading distribution over the region. In particular, we provided near-real time SeaWiFS aerosol products of aerosol optical thickness and Angstrom exponent over the region of interest during August and September 2004 to support flight planning. For the post-mission analyses, we now have MODIS aerosol products of aerosol optical thickness and Angstrom exponent available from both Terra and Aqua over desert and semi-desert regions, which we derived using the recently developed Deep Blue algorithm [Hsu et al. 2004]. The ability to compare and contrast Terra (10:30 AM local time) and Aqua (1:30 PM local time) results from these products provided us with a powerful new method to track the movements and evolution of aerosol plumes that were previously hard to detect over bright-reflecting source regions such as deserts. In Figure D., the RGB images and the retrieved aerosol optical thickness at 500 nm are shown over the Middle East for both sensors on 12 September 2004. In the Terra images, we can see a few prominent dust plumes as they began to develop over Iraq. By the time Aqua passes overhead, the dust storm had grown to cover an extensive area. We can also see the dispersal of a dust plume in southern Saudi Arabia, while the intensity and location of dust clouds over Sudan remained fairly constant.

We are currently analyzing these satellite data, in conjunction with the aircraft and ground-based measurements, to conduct research such as the following:

(1) Characterizing the temporal and spatial variability of aerosol loading over the entire region of interest, including over desert and semi-desert areas for the duration of the intensive observation period;

0.0 1.0 2.0
Aqua AOT
1:30 PM LST
9/12/04
MODIS/Aqu
0.0 1.0 2.0
Terra AOT
10:30 AM LST
MODIS/Terra – 12 September
9/12/04

Figure D.1 Dust storms frequently occur over places like northern Africa and southwest Asia all year round. Numerous dust clouds were observed from space over Sudan, Iraq, Iran, and the southern part of the Arabian Peninsula in this September 12, 2004 satellite image from NASA’s Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on the Terra and Aqua satellite. The corresponding intensity of the dust plume is also depicted using a quantity called “optical thickness”. The higher the dust optical thickness, the more dust.

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