Preliminary Mission Plan for a Puerto Rico Dust Experiment (PRIDE) for Summer 2000

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Summary

The Puerto Rico Dust Experiment (PRIDE) is an applied science field research study of the radiative, microphysical, and transport properties of Saharan dust, scheduled for June 27-July 25, 2000. A group of Navy, NASA, and university scientists intend to conduct a combined surface, airborne, satellite and modeling campaign out of the Roosevelt Roads Naval Station, Puerto Rico in an effort to measure the properties of African dust transported into the Caribbean. There will be two principal tasks:
1) Determine the extent to which the properties of dust particles and the spectral surface reflectance of the ocean surface need to be known before remote sensing systems can accurately determine optical depth and flux. 2) Evaluate/validate the skill in which the Naval Research Laboratory's Aerosol Analysis and Prediction System (NAAPS) predicts the long-range transport and vertical distribution of African dust. The results of these tasks will support Navy and NASA applied science objectives on satellite validation and the prediction of dust-induced visibility degradation. In addition, secondary tasks of PRIDE will address in situ issues of coarse mode particles and basic research issues on climate forcing, geochemical cycles, and meteorology. This document gives a brief overview of PRIDE's objectives, participants, and implementation.

1.0 Study Rationale and Philosophy

Visibility degradation due to airborne dust can hamper naval EO system performance in both visible and IR wavelengths. In many sensitive regions (such as the Persian Gulf and Yellow Sea) desert dust significantly impairs visibility on a regular basis. However, because of the large variability in dust particle properties atmospheric radiation models have difficulty in predicting EO propagation in coastal environments when dust is a significant factor. Satellite imagery can provide only semi-quantitative information on atmospheric dust loading. Accurate parameterizations of dust optical properties need to be incorporated into naval meteorological models and propagation codes for forecasting the performance of naval systems.

Just as the Navy is interested in the impact of dust on visibility in the visible and IR window wavelengths, earth scientists are interested in the impact of dust in these spectral regions because of possible impacts on the earth's climate. The physical problem studied by both the Navy and climate researchers is nearly identical-only the final application is different. Hence, in this case, both naval operations and basic climate research can benefit from a joint study on the properties of dust.

The biggest difficulty in determining the operational and climatic impact of desert dust is the development of acceptable optical, microphysical, and transport models. The nature of airborne dust is largely unknown. Few measurements of the vertical distributions of Saharan dust exist with virtually no information available on the vertical extent of the dust once it crosses the Atlantic.

- The chemical and microphysical properties of the dust are largely unknown, especially any evolution of the dust or addition of chemical coatings on the dust as it crosses the Atlantic.

- Discrepancies exist between in situ measurements, taken mostly in the surface layer, and remotely sensed measurements of microphysical and optical properties such as single scattering albedo.
- Technical difficulties associated with inlet efficiencies of in situ instrumentation remain a concern when making measurements of large particles.

- The effect of non-sphericity of the particles on the dust's radiative properties has never been resolved.

- No one has determined the importance of each of these issues for different applications and hence determine which require constant monitoring and which can be ignored.

Given this state-of-the-art, it is appropriate to conduct a small, field study in preparation for larger and more expensive field campaigns that will likely occur in the years ahead.

Currently there is need for a Navy/NASA/University field mission to study the physical and optical properties of airborne dust. Africa is the single largest source of dust in the world and dust of roughly similar composition and morphology frequently impacts naval operations in the Persian Gulf. As discussed by *Prospero* [1999], in the summer months large quantities of Saharan dust are transported from Africa across the Atlantic into the Caribbean (Figure 1). An analysis of AVHRR and AERONET data suggests that in July the mid-visible optical depth in the Caribbean can vary from 0.2 to 0.7, with a mean value of ~0.4. An example of this is presented for two years in Figure 2 [Husar et al., 1997]. Ten years of AVHRR data has consistently shown that he island of Puerto Rico frequently lies in the path of the dust plume from June through August. Climatologically, the bulk of the dust exists in a lyer above the marine boundary layer and below 5,000 meters.

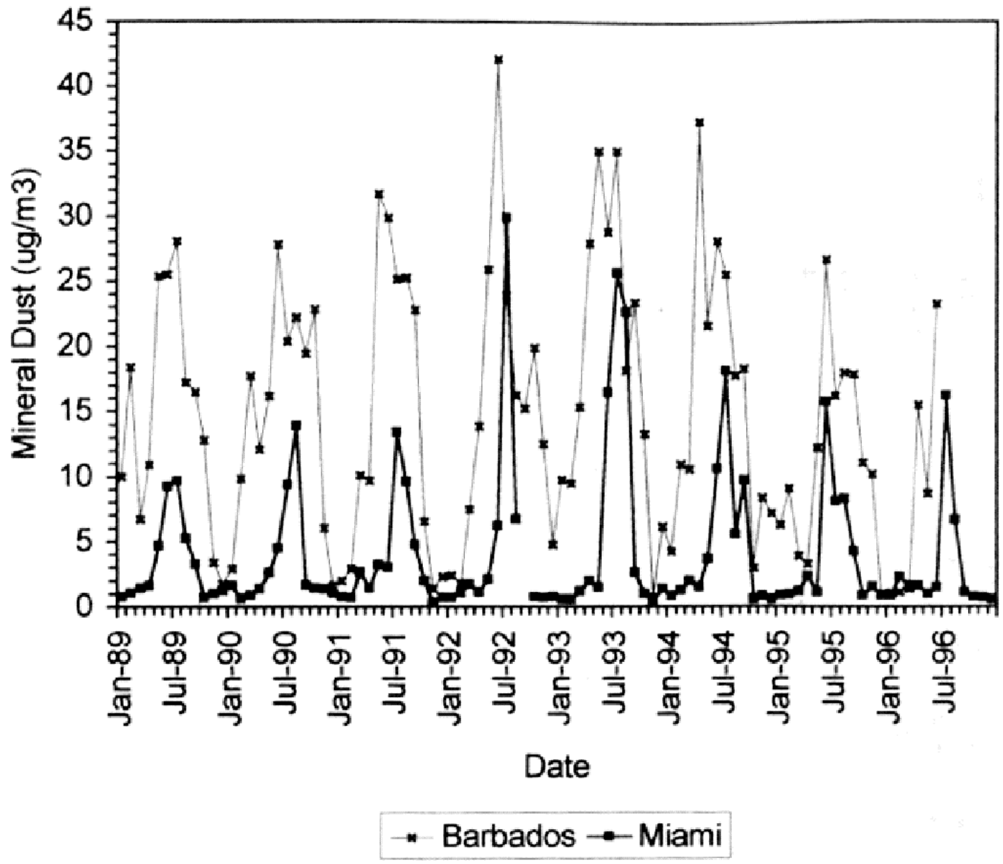

Figure 1. Surface mineral dust concentration over 8 years. Note: Puerto Rico midway between Barbados and Miami. Figure taken from Prospero, "Long-term measurements of the transport of African mineral dust to the southeastern United States: Implications for regional air quality." J. Geophys. Res., 104, 15,917-15,929, 1999.

A dust study in Puerto Rico has several advantages other than its geographic location. Most importantly, Puerto Rico is usually not impacted by other pollutants that would interfere with the analysis. Being a US protectorate Puerto Rico is considerably easier to operate from than Africa or the Middle East. A US naval base is present (Roosevelt Roads Naval Station) in a geographically good location on the East end of the island. Further, working out of a US Navy installation will dramatically reduce costs, improve logistics, and enhance participant's safety.

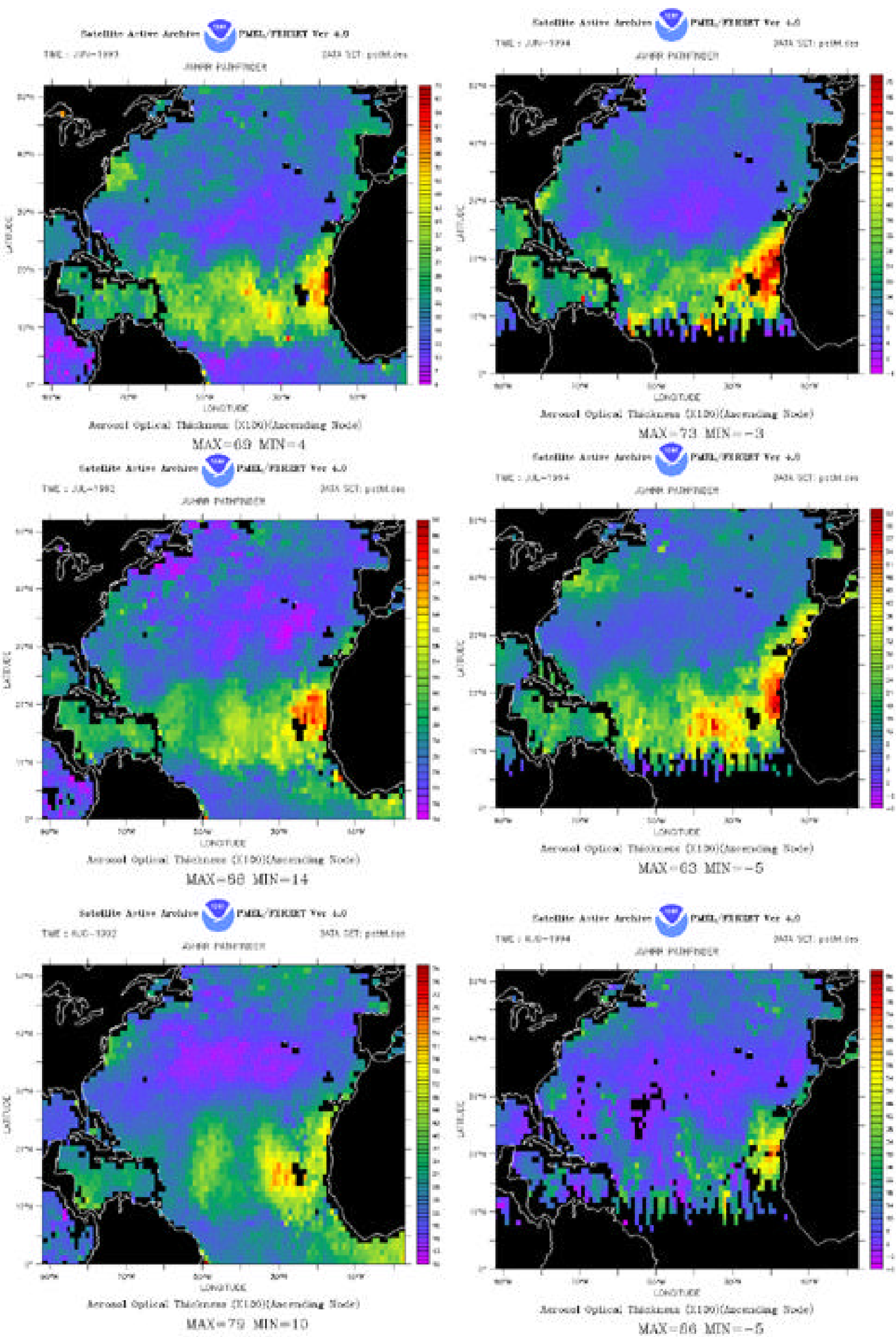

Figure 2. AVHRR pathfinder optical depth products for June, July and August 1992 and 1994.

SPAWAR Systems Center (SSC) San Diego, NRL, NASA and several universities are sponsored by ONR and NASA to conduct a one-month airborne and surface field mission in Puerto Rico for July 2000. The principal tasks of this study are:

- Determine the extent to which the properties of dust particles need to be known before remote sensing systems can accurately determine optical depth and flux.

- Evaluate/validate the skill in which the NRL Aerosol Analysis and Prediction System (NAAPS) predicts the long-range transport and vertical distribution of African dust.

These tasks will be achieved by frequently and consistently characterizing Saharan dust composition, size distribution, horizontal/vertical distribution, and intensive optical properties over a four-week period. This baseline data set will then be utilized for remote sensing/radiative transfer algorithm development and transport model validation. Collaborators working on secondary mission objectives (e.g. climate, geochemical cycles, instrumentation, etc.) will have open access to all data sets as well.

2.0 Expanded Mission Goals and Methodology:

This study will employ ground-based, airborne, satellite and modeling components to accomplish the mission tasks. The underlying philosophy of the study is to keep the sampling plan simple and consistent. At the surface, aerosol samplers, sizers, transmissometers and a nephelometer will be used to characterize surface layer dust particles. In addition, a micropulse LIDAR, radiometers, sun photometers, and a cloud camera will characterize the atmospheric column. These will be calibrated and validated by regular vertical profiles provided by the SSC San Diego Navajo outfitted with basic meteorology instrumentation, particle sizing probes (PCASP and FSSP-100), and a hyperspectral Pilewskie radiometer. The Navajo will be joined by a Cessna 172 (operated by the University of Miami) outfitted with meteorological and aerosol instrumentation. The NCAR C-130 will intermittently participate out of Saint Croix. The University of Puerto Rico will augment these aircraft with the R/Vs Chapman and Isla Magueyes, scheduled to take cruises in the middle of the study.

In the following sections a more expansive description of mission goals, methods and personnel is provided. Work will be categorized into three project areas based on the mission objectives. First, an aerosol microphysics and radiation integration project will address the issues relating Task 1, that is, determining what key properties of the dust are important and consequently integrating our knowledge of dust aerosol microphysics and chemistry into remote sensing and radiation algorithms. A second project area, Task 2, will encompass meteorology and transport issues and will emphasize the validation of the NAAPS model.

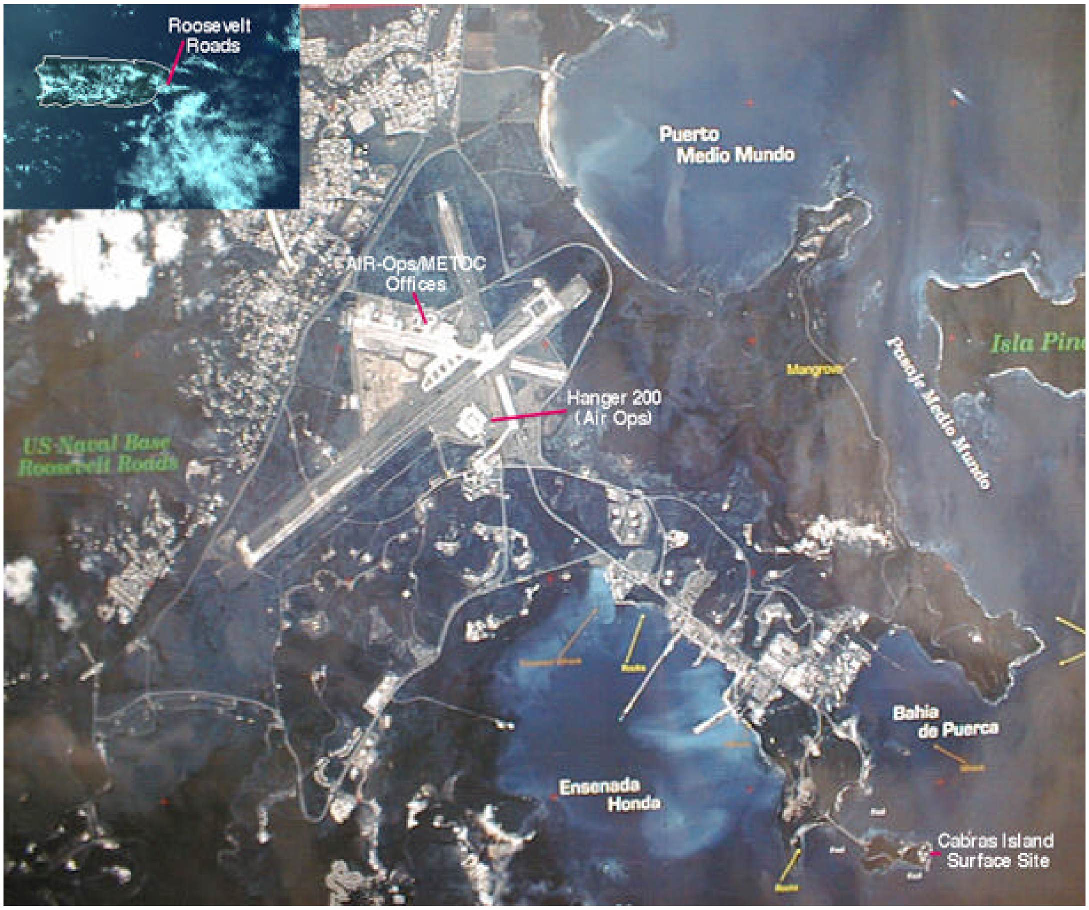

Figure 3. Roosevelt Roads Naval Station

2.1 Aerosol Microphysics and Radiation Integration

One of the largest obstacles in the modeling and remote sensing measurement of dust clouds lies in the accurate parameterization of dust particle microphysical and optical properties. Some have hypothesized that dust particle mineralogy and shape must be very precisely measured before accurate optical models can be established. This may be true, but others have hypothesized that we can find shortcuts in remote sensing that will bypass the need for precise optical models. During PRIDE we will test these hypotheses and attempt to determine the necessary criteria for the accurate remote sensing of dust particles. To this end, work will be divided into two teams. The first team (Aerosol Microphysics and Radiation) will be tasked with making the required in-situ measurements of dust particles. This will be done by employing a vareity of surface instruemtns (Appendix B), the SSC-SD Navajo (Appendix C), the University of Miami Cessna Light Aircraft Aerosol Package (LAAP-Appenix D), NCAR C-130 (Appendix E), and a University of Puerto Rico research vessel (Appendix F). The second team (Remote

Sensing) is tasked with compiling and analyzing necessary remote sensing data for the completion of the mission (Overpass times in Appendix G). After a preliminary analysis of the data collected for PRIDE, the teams will join to complete Task 1. A description of the team's missions follows.

2.1.1. *Aerosol Microphysics and Radiation*
Team Coordinator: J. Reid
Members: Q. Ji, H. Jonsson, B. Holben, J. Livingston, Hal Maring, P. Pilewskie, J. Prospero, L. Remer, P. Russell, D. Savoie, D. Tanre, and S.C. Tsay

The team's underlying goal is to measure how the microphysics and chemistry of dust particles influence their bulk radiative properties. To this end, the team's participants are charged with the in-situ measurement of dust particle size, shape, and chemistry as well as the atmosphere's bulk radiative properties (an operations/deployment plan is presented in Appendix B). It is expected that there is sufficient dynamic range in dust properties on vertical and horizontal scales that we will be able to relate changes in particle radiative properties with changes in size and chemistry.
Three significant instrument sets will operate during PRIDE: SSC-SD, NASA, and University of Miami. Jeffrey Reid (SSC San Diego) and Haflidi Jonsson (NPS/CIRPAS) will deploy the SSC San Diego Navajo (~65 flight hours, anticipate 4-5 flights per week). The Navajo will perform regular vertical profiles up to 200 km away from Roosevelt Roads to observe the spatial variation in the dust. These missions will provide information on dust particle size and chemistry as a function of distance and altitude. Particle concentration/size will be measured with PMS PCASP and FSSP-100 probes. Optical depths will be measured on-board with the NASA/Ames 6-channel Airborne Tracking Sun photometer (AATS-see Appendix G) and perhaps a hand held Microtops sun photometer. The spectral reflectance of the ocean's surface will be characterized with an Analytic Spectral Devices (ASD) FieldSpec spectrometer that measures reflected solar radiance from 400 to 2500 nm.

Peter Pilewskie (NASA Ames) will manage airborne radiometric measurements made on-board the Navajo. Onboard will be the NASA Ames Solar Spectral Flux Radiometer (SSFR) and other various broad band radiometers. The SSFR has zenith and nadir viewing light collectors for measuring solar spectral upwelling and down-welling irradiance from 300 to 1700 nm at 10 nm resolution. This data will be used to determine the net solar radiative forcing of dust (and other) aerosol, to quantify the solar spectral radiative energy budget in the presence of elevated aerosol loading, and to support satellite algorithm validation. The SSFR is calibrated for wavelength, absolute power, and angular response at the NASA Ames Research Center in conjunction with the Ames Airborne Sensors Facility in round-robin calibration comparisons with NIST and the University of Arizona. The Airborne Sensors Facility is also responsible for calibrating flight simulation sensors, such as the MODIS Airborne Simulator (MAS), and the use of identical standards will allow us to trace SSFR calibrations to MAS.

NASA Goddard will be responsible for managing the radiation ground truth station at Roosevelt Roads. Brent Holben (NASA/GSFC) will deploy an AERONET sun photometer to measure optical depth. Dr. Si-Chee Tsay will deploy a suite of radiometers and sun photometers to provide surface flux measurements. Dr. Tsay will also deploy a micropulse LIDAR to continuously monitor the vertical distribution of the dust. A cloud camera will be used to screen data. Dr. Pilewskie may also employ a zenith viewing ground-based SSFR (for no additional cost to the project) at the selected surface site.

The University of Miami will make the principle aerosol ground-based measurements for the study. A spectrally-resolved transmissometer (λ=450, 550, 710 nm) will be deployed along a 3.5 km path at 20 meters above the ocean surface. Concurrent measurements of aerosol physical, chemical and optical properties will be made form an instrumented trailer. U of Miami will analyze 12- to 24-hour MOUDI samples for major ions (sulfate, nitrate, chloride, sodium, ammonium and mineral dust). Hi-vol. filter samples will also be collected for mass and ionic composition. U. of Miami will measure a subset of these aerosol properties with altitude using a Light Aircraft Aerosol Package (LAAP) deployed over the site in a single engine Cessna 172 aircraft.. The U. of Miami is also charged with managing other surface based aerosol instrumentation deployed for PRIDE. For example, it is probable that organic aerosol measurements will be made on behalf of Tico Novakov, Lawrence Berkely Laboratories. John Porter's (U of Hawaii) polar nephelometer will also likely be deployed. They will manage the deployment of the Tom Cahill's (UC Davis) DRUM impactor to collect size-resolved aerosol samples (Eight-hour DRUM samples will be analyzed intermittently by XRF and SEM/EDX analysis to determine bulk and single particle elemental composition, respectively. SEM analysis will yield information on particle shape)
Between the NASA, SSC San Diego, and U. of Miami instrumentation, a complete set of parameters describing particle chemistry, microphysical and radiative properties will be measured. From these, we will determine three intensive microphysical parameters commonly used in modeling aerosol radiative transfer: Mass extinction efficiency (α_e), single-scattering albedo (ω_o), and the aerosol phase function.

First, the University of Miami will use their a three-wavelength transmissometer at the surface. By sampling the dust aerosol mass concentration at the transmissometer receiver, and performing periodic over-flights with the Cessna and Navajo aircraft's, the aerosol mass can be determined along the transmission path and α_e can be computed. By relating changes in extinction with changes in aerosol species loading (dust, salt, etc.), the dust mass extinction efficiency can be regressed out. A second method of computing α_e involves taking multiple vertical profiles with the research aircraft in elevated dust layers and relating changes in optical depth with altitude (measured with the Navajo and Cessna sun photometers) changes in mass loading (as computed by the particle probes).
By comparing nephelometer and transmissometer data, U of Miami will gather information on aerosol single scattering albedo at the surface. Additionally, *Dubovik* [2000] inversions of ground-based AERONET measurements of sky radiance will also yield information on ω_o on a routine basis, as long as the sky is relatively cloud free and homogeneous. Furthermore, a technique using satellite radiometric measurements over bright surfaces

will be applied to appropriate land targets and ocean sun glint. Finally, single-scattering albedo will also be inverted out of radiometric measurements by comparing optical depth versus hyperspectral flux measurements on both the surface and on the Navajo.

Information on dust particle hygroscopicity will be determined by comparing dried and ambient size distributions. It is expected that the dust volume median diameters will be less than 3 mm. If so then we can compare size distributions from the dried PCASP and ambient FSSP-100. At the U. of Miami surface site, size distributions measured with a CSASP (ambient) will be compared to dried size distributions from an APS 3310.

The particle phase function will be the most difficult radiative quantity to measure during PRIDE. For the most part, the investigators will rely on inversions of the dust aerosol phase function from AERONET sun photometer almucantar inversions. We are currently attempting to place the University of Hawaii's airborne polar nephelometer at the surface. In addition some information will be extracted by flux/optical depth measurements made on the research aircraft.

2.1.2 *Remote Sensing*

Team Coordinator: L. Remer, NASA GSFC

Members: R. Armstrong, S. Christopher, R. Kahn, Y. Kaufman, R. Kleidman, R. Levy, J. Morrel, S. Schollaert, D. Tanré, and O. Torres

Data collected by the aerosol microphysics and radiation team members will be compiled and distributed to researchers working on remote sensing systems. For this study, an emphasis will be placed on the Terra satellite and in particular on the MODerate resolution Imaging Spectrometer (MODIS), although a suite of other sensors (e.g. AVHRR, CERES, GOES, Meteosat, MISR, SeaWiFS, TOMS, VIRS, etc.) will be used.

2.1.2.1 MODIS Validation

The MODIS aerosol algorithms are actually two separate algorithms, one designed to retrieve aerosol optical thickness and aerosol mass over land targets (Kaufman et al., 1997) and one designed to retrieve aerosol properties over ocean targets [*Tanré et al.,* 1997]. Both algorithms were tested prior to launch of the Terra satellite by using images from the MODIS Airborne Simulator (MAS) and the Airborne Visible-InfraRed Imaging Spectrometer (AVIRIS) and also from the Landsat Thematic Mapper. The land algorithm was tested for smoke aerosol in Brazil [*Chu et al.,* 1998] and urban/industrial aerosol in the mid-Atlantic region of the eastern United States [*Kaufman et al.*, 1997]. The algorithm for over-ocean retrievals was tested for Saharan dust off the coast of Senegal, urban/industrial pollution off the coast of the eastern United States and smoke aerosol off the coast of Washington state [*Tanré et al,* 1997]. The algorithm was given more rigorous testing for urban/industrial aerosol during the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX) in 1996 [*Tanré et al.*, 1999].

Now that MODIS is in orbit aboard Terra, an opportunity exists to validate the algorithms by using MODIS data directly. For the over-land algorithm, the procedure is straightforward. We will compare MODIS retrievals with ground-based measurements from the automatic AERONET sun/sky radiometers. For the over-ocean algorithm, the validation procedure is more difficult. There are several AERONET instruments located at island sites, and these sites will definitely contribute to the validation. However, during the analysis of TARFOX data, we found that inhomogeneity in the aerosol field could introduce substantial differences between the retrieval and validation data, and that careful matching of the data in space and time was essential. In order to make a careful match between a MODIS over-ocean retrieval and "ground" validation observations we will need to acquire such data specifically in short-term validation studies.

Although we could choose to begin the over-ocean algorithm validation with some other type of aerosol, we would prefer to take advantage of the opportunity to validate with dust aerosol. Dust is important to the earth's climate and biogeochemical cycles, and for these reasons it is essential for MODIS algorithms to properly quantify the dust transported over the oceans. Furthermore, the TARFOX results gave us confidence in the aerosol retrieval algorithms as applied to aerosols dominated by the accumulation model, specifically urban/industrial pollution. We have had fewer opportunities to apply the algorithm to aerosols dominated by the coarse mode (dust) in carefully controlled match-ups between the retrieval and the "ground" observations.

In addition to simple validation in which MODIS retrievals are compared with near-to-the-surface column optical thickness measurements, we would use the opportunity of a short-term validation study to observe simultaneously other important factors. Spectral reflectance of the ocean surface, aerosol size distributions, chemical composition, vertical profiles of humidity and flux measurements will all contribute to better understanding retrieval discrepancies as they occur, and also give us a better understanding of the characteristics of the dust aerosol after being transported across the Atlantic.

One of the largest uncertainties in the MODIS retrievals of dust is the degree of dust nonsphericity. Although our intuition suggests that mineral dust should be irregularly shaped, recent analysis suggests nonsphericity effects are minor for dust leaving the west coast of Africa [*Tanré et al.* 2000]. Further evaluating the effects of possible nonsphericity on the MODIS retrievals will be one of our main goals during the Puerto Rico experiment.

The interplay between aerosol and clouds is of prime importance. The MODIS algorithm is biased towards cloud-free conditions. Measuring dust aerosol properties both near to clouds and far from clouds will tell us whether the clear-sky bias introduces bias in MODIS-derived dust aerosol properties. For example, does the aerosol effective radius or optical thickness increase as clouds are approached?

Finally, this experiment also provides opportunities to develop new remote sensing techniques. Previous studies [*Kaufman*, 1987; *Kaufman et al.* 2000] describe a remote sensing method for determining the aerosol single scattering albedo by observing aerosol over a bright surface such as the desert. We would like to explore the possibility of using sun glint over ocean as the bright surface in which to measure aerosol absorption. The development strategy will require an independent determination of the aerosol absorption or, in lieu of that measurement, possibly a measure of the aerosol iron content.

This experiment will be conducted by underflying Terra in the Navaho ±30 minutes of satellite overpass for both glint and non-glint views,. The flight begins by measuring the sea surface spectral reflectance at low altitude with an ASD spectrometer. Simultaneously, we will measure spectral optical thickness from the same platform with a sun photometer. The handheld Microtops instruments can be used if the AATS-6 is not available. This procedure will be repeated as often as possible. Data taken without glint will be used to validate MODIS retrieval. Data taken of the bright ocean surface will be used to develop the new technique for determining absorption and also to validate water vapor retrieval over glint. The largest difficulty will be to find areas of the relatively cloud-free ocean during episodes of dust at the time of Terra's overpass. After the satellite overpass, aircraft flight hours should be used to broaden our understanding of the vertical and horizontal extent of the dust, and to explore spatial inhomogeneity in relationship to clouds. The aircraft will also make measurements in a vertical column above the island-based radiometric and in situ instruments in order to coordinate ground-based and aircraft measurements.

We also expect validation points at a minimum of two island-based sunphotometer sites, preferably upwind and downwind of the large island of Puerto Rico.

2.1.2.2 CERES

In-situ data will also be utilized by VIRS and CERES retrievals. Top-of-atmosphere radiative forcing of dust aerosols will be estimated from a combination of VIRS/CERES on TRMM (Tropical Rainfall Measuring Mission) and MODIS/CERES on Terra. By using both the TRMM and Terra platforms, we can obtain diurnally averaged dust aerosol radiative forcing values.

The VIRS is a five-channel scanning radiometer that measures reflected and emitted radiation from the earth-atmosphere system from a 350-km orbit with a swath width of 720 km at a nadir spatial resolution of 2.11 km. The five channels are centered at 0.63 ($\rho_{0.63}$), 1.6 ($\rho_{1.6}$), 3.75 ($T_{3.75}$), 10.7 ($T_{10.7}$), and 12.0 ($T_{12.0}$), µm, where ρ and T denote reflectivity and brightness temperature respectively. The CERES scanner is a broadband instrument that measures the TOA radiance in three bands (0.3 to > 50 µm (total), 0.3 - 5 µm (shortwave), 8-12 µm (longwave)) at a spatial resolution of about 10 km at nadir (for TRMM). The measured broadband radiances are converted to TOA fluxes using angular dependence models that were developed as part of the ERBE program.

This analysis starts with the identification of the Saharan dust plume by VIRS using spectral techniques. CERES data will then be collocated with the VIRS data. A new angular dependence model for dust aerosols will then be constructed using radiative transfer calculations and subsequently top-of-atmosphere fluxes and optical depths will be generated in dust and "dust+cloud-free" regions. This will result in a quantification of aerosol radiative forcing as a function of aerosol optical depth. These findings will then be validated by aerosol and radiometer data collected on the Navajo for the MODIS effort.

MISR

JPL will use PRIDE as a validation study to support the Multi-angle Imaging SpectroRadiometer (MISR) program. The plan for MISR is to acquire co-located Local Mode data over a 300 km along-track x 360 km across-track region (the largest allowed coverage for a Local Mode site) when we are able. Local Mode means all MISR channels acquire data at the highest spatial resolution possible (0.275 km) [*Diner et al.,* 1998], giving us the best opportunity for spatial co-location with field activities. Mission requirements for MISR validation are almost identical to those required for MODIS: Direct sample measurements of particle properties (size distribution, shape distribution, chemistry), vertical profiles of particle concnetration and spectral radiance, upwelling and diffuse down-welling spectral and/or integral SW radiance near surface, etc.

We have 2 research-level aerosol retrieval algorithms that can be run over any known (or modeled) surface, one generic [*Kahn et al.*, 1998] and the other climatological [*Kahn et al.,* 1999]. The preferred sites for validating these retrievals are over dark water, where they are likely to provide the tightest constraints on aerosol microphysical properties. We also have algorithms that self-consistently solve for surface and aerosol properites, which are designed to be used over heterogeneous land and dense, dark vegetation (DDV) [*Martonchik et al.,* 1998]. If possible, we will attempt to validate these algorithms as well.

SeaWiFS

The SeaWiFS atmospheric correction is not designed to handle absorbing aerosols such as mineral dust. Adjacent to the Sahara in the eastern North Atlantic, the SeaWiFS retrievals suffer algorithm failure during dust outbreaks. By the time the dust reaches the western North Atlantic, however, the SeaWiFS algorithms do not fail and the atmospheric correction appears to adequately apportion atmospheric radiance from water-leaving radiance. We are not sure why this is. Perhaps the larger particles more prevalent near the Sahara are the cause of the SeaWiFS algorithm failure there. By the time the dust reaches the eastern North Atlantic, perhaps enough en route deposition has occurred to minimize the aerosol absorption at the SeaWiFS bands. Ground-truth information about the aerosol concentration, particle sizes, and vertical distribution will be useful for validating and improving the SeaWiFS atmospheric correction and will improve the accuracy of the water-leaving radiance and chlorophyll concentration calculations.

SeaWiFS products available and expected to assist with this experiment include aerosol optical depth and Angstrom exponent at any of the following wavelengths: 412nm, 443nm, 490nm, 510nm, 555nm, 670nm, 765nm, 865nm, in addition to chlorophyll-a concentrations and water-leaving radiances at the lower six SeaWiFS bands. The University of Rhode Island (Stephanie Schollaert) will acquire and process in near real-time both the level 1 SeaWiFS Global Area Coverage (GAC) and Local Area Coverage

(LAC) data. The 4km resolution SeaWiFS GAC data will be used in large-scale spatial comparisons with the NAAPS fields. The GAC data will allow validation of NAAPS horizontal distribution and timing. The 1km resolution SeaWiFS LAC data will be compared to the ground-truth Saharan dust characterization for evaluating the effects of dust aerosols on the SeaWiFS bands.

2.1.2.5 TOMS and GOES

TOMS and GOES will participate in PRIDE mostly in terms of large scale aerosol monitoring and mission planning. The TOMS images of aerosol index separate absorbing aerosol from non-absorbing. We can use these images to separate dust aerosol from aerosol originating from North America, which is mainly a non-absorbing type. The images will allow us to follow dust aerosol plumes across the Atlantic visually and prepare to intercept these plumes in Puerto Rico.

The most important issue affecting TOMS retrieval of aerosol optical thickness or aerosol index on the west side of the Atlantic during the dust season, is the height of the dust layer. TOMS must make assumptions of aerosol height and the final result is sensitive to this assumption. A secondary issue for TOMS retrievals is the absorption by the aerosol in the UV. The PRIDE results and characterization of the dust aerosol plume in Puerto Rico will aid in TOMS algorithm validation and development.

2.2 Aerosol Transport

Team Coordinator: D. Westphal
Members: M. Liu, J. Prospero, and J. Reid

Few measurements of the vertical and size distributions of Saharan dust exist. These few were made with primitive equipment during GATE (1976) and BOMEX (1969). These revealed sharp vertical boundaries at the dust cloud top, some aerosol particles in the marine layer below, and ultra-giant particles several thousand kilometers from Africa.

Ultra-giant Asian dust particles have also been detected thousands of kilometers downwind of Asia. Size-resolving models have had difficulty in successfully transporting the ultra-giant particles away from the coast. The models can successfully transport particles up to 16 μm in diameter (*Westphal et al*. 1987, 1988), but the larger ones rapidly fall out. Simple calculations with Stokes settling velocities confirm this. No amount of twiddling the particle shape and density can explain the presence of the ultra-giant particles. Similarly, ‘deep convective mixing’ over the Sahara or Asia does not sufficiently prolong the transport.

Concern over accurately modeling these particles may be misplaced, considering the low numbers, surface area, and mass contained in the ultra-giant particle mass. However, if the models do not properly transport the ultra-giant particles, then there may be deficiencies that affect the transport of other particle sizes.

In situ particle measurements during PRIDE would help to document the presence of ultra-giant particles and give us an 'end point' for studying the severity of the model deficiency. Similar measurements upwind, over Africa and the West Atlantic, are eventually required but are beyond the present experiment. Because of the low optical depth attributed to these particles, they cannot be detected by remote techniques. Numerical transport models also have difficulty maintaining vertical and horizontal gradients of aerosol. During several days of transport, the top of the Saharan Air Layer (SAL) can numerically decay from a sharp gradient to a diffuse one, greatly affecting radiative transfer. Parameterized convective mixing can also have this affect, but hopefully it is modeling a real process.

Vertical profiling through the entire depth of the SAL would allow us to validate the model's vertical mixing (real or otherwise). The top must be penetrated for the profile to be of value. Profiles to the ocean's surface would allow us to validate mixing across the marine inversion and sedimentation. Measurements of the state variables are necessary since the ability of the dynamical model to maintain the SAL must be verified. We don't know how well it is preserved during the several-day transit. There are no aerosol radiative affects in NOGAPS; must this be included to achieve accurate SAL simulations? The Navy and others that forecast tropical cyclones would be interested in the answer to that question. P. Alpert has presented some evidence to its importance based on systematic biases in data assimilation fields.

We are also greatly interested in horizontal boundaries of the outbreaks. The timing of the passage of 'dust fronts', as detected by LIDAR, and the quantitative measurements or horizontal gradients from aircraft will allow us to test the modeling of the source and the dynamical forcing behind the transport.

NAAPS will be validated by a combination of satellite, airborne, and surface data. Daily MODIS and AVHRR products will be used to determine horizontal extent of the dust outbreaks. SeaWiFS and GOES/AVHRR retrievals may also be available. Aircraft transects through plume will be performed to allow the calibration of the satellite retrievals (total aircraft range ~350 km). The vertical distribution of the dust will be determined by Dr. Tsay's micropulse LIDAR and frequent aircraft vertical profiles. Also, sun photometers positioned in Africa and the Caribbean will be used to observe column dust loading and size (inverted from almucantar) to estimate NAAPS skill.

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Appendex A.
Principal Mission Participants

Ronald Ferek (ONR)	Program Management
Jeffrey Reid (SSC San Diego)	Project Field Coordinator, Navajo PI
Lorraine Remer(NASA GSFC)	Project Remote Sensing Coordinator
Douglas Westphal (NRL Monterey)	Project Meteorology Coordinator
<u>Mission Core Investigators:</u>	
Roy Armstrong (U. of Puerto Rico)	Chlorophyll Retrieval, R/V PI
Thomas Cahill (UC Davis)	Chemistry
Sundar Christopher (U. of Alabama)	AVHRR, CERES, GOES, VIRS
Steve Cliff (UC Davis)	Chemistry
LCDR Daniel Eleutario (USN)	POC, Meteorology
Berry Huebert (U. of Hawaii)	Inlet Evaluation, C-130 PI
Brent Holben (NASA GSFC)	AERONET
Qiang “Jack” Ji (NASA GSFC)	Radiative Transfer
Haflidi Jonsson (CIRPAS/NPS)	Microphysics
Ralph Kahn (JPL/CIT)	MISR/Terra
Yoram Kaufman (NASA GSFC)	MODIS/Terra
Richard Kleidman (NASA GSFC)	MODIS/Terra
Robert Levy (NASA GSFC)	SeaWiFS, MODIS
John Livingston (SRI/NASA Ames)	Radiative Transfer
Hal Maring (U. of Miami)	Chemistry, Radiation, Cessna PI
Julio Morell (U. of Puerto Rico)	Chlorophyll Retrieval, Oceanography
Peter Pilewskie (NASA Ames)	Hyperspectral radiometery
John Porter (U. of Hawaii)	Polar Nephelometry
Joseph Prospero (U of Miami)	Microphysics, Transport
Philip Russell (NASA Ames)	Airborne Sun photometer
Dennis Savoie (U of Miami)	Chemistry, Radiation, Surface Station PI
Beat Schmid, (BAERI/NASA Ames)	Radiative Transfer
Stephenie Schollaert (U of RI)	SeaWiFS
Didier Tanre (d'Optique Atmospherique)	Microphysics, Transport
Omar Torres (U. of MD)	TOMS
Si-Chee Tsay (NASA GSFC)	Radiative Transfer
Judd Welton (NASA/SSAI)	Micro-pulse LIDAR

Appendix B
Surface-Based Mission Assets

Surface based assets for PRIDE will be managed by the University of Miami science team in cooperation with scientists from NASA GSFC, NASA Ames, SSC-SD, and several universities. Most instrumentation will be deployed in a 20 ft shipping container converted into laboratory space by the U. of Miami. The container will be placed on a flatbed trailer and positioned at the Roosevelt Roads drone launching facility on Cabras Island.

The overall objective of the program is to characterize the radiative properties of aerosols over the ocean so as to understand the factors that affect radiation transmission in the marine atmosphere as it relates to climate, visibility and satellite data evaluation and validation. By deploying a complete surface station measurements can be made by more diverse instruments and at much higher temporal scales than can be done with aircraft The specific objectives for this portion of the field experiment are to:

- Characterize the optical properties (mass scattering efficiency and single scattering albedo) of important aerosol types in the marine boundary layer, especially dust, as a function of wavelength, and

- Describe the short term temporal and vertical distributions of those aerosols.

To this end we will perform field studies in which we will make ground-based measurements of the spectrally-resolved transmission properties of the marine atmosphere while making concurrent measurements of aerosol physical, chemical and radiative properties.

The aerosol measured aerosol properties will be used in a radiative model to ascertain if the model can duplicate the atmospheric transmission measurements. The degree of agreement between the transmission measurements and the model results is a measure of the adequacy of the characterization of the aerosol properties and the radiative model. The comparison (commonly referred to as "closure") will be the ultimate test of the completeness of our knowledge of atmospheric radiative properties.

The surface based program consists of five parts:

- Ground-based measurement of size-segregated and bulk aerosol composition,
- Ground-based measurement of aerosol physical and optical properties,
- Long-path length measurement of aerosol light extinction,
- Bulk radiative transfer measurements
- Micro-pulse LIDAR measurements of dust vertical distribution

The ground-based measurement of size-segregated and bulk aerosol composition will include the sampling of aerosols using Micro-Orifice Uniform Deposit Impactors (MOUDI Model 100), high volume Whatman 41 filters, and a UC Davis DRUM impactor. MOUDI and hi-vol samples will be collected on a 12- to 24-hour basis. These samples will be analyzed at the University of Miami for major ions (sulfate, nitrate, chloride, sodium, ammonium and mineral dust). These samplers will be controlled based on local meteorology so as to exclude aerosols produced by local sources. DRUM impactor samples will have 8 hour time resolution for 6 size ranges. Particles will be analyzed by XRF for the elements Si-U, and qualitative SEM/EDAX. We also intend to collect samples for T. Novakov for the determination of organic and elemental carbon concentrations in aerosols.

The ground-based measurements of aerosol physical and optical properties will include the determination of light scattering and absorption, aerosol number concentration, aerosol number size distribution and aerosol mass concentration. These parameters will be measured continuously and averaged over periods ranging from 1 to 20 minutes. The following instrumentation will be used:

- aerosol light total and backscattering at 450, 550, 700 nm; TSI 3563 Integrating Nephelometer,
- aerosol light absorption at 565 nm; Radiance Research Particle/Soot Absorption Photometer,
- aerosol number concentration from 15 to 1000 nm; TSI 3010 Condensation Particle Counter,
- aerosol number size distribution from 3 nm to 15 µm; TSI 3025a Condensation Particle Counter, TSI 3934L Scanning Mobility Particle Sizer, TSI 3310 Aerodynamic Particle Sizer, PMS CSASP.
- aerosol mass concentration; R & P 1400a Tapered Element Oscillating Microbalance, and
- spectrally resolved aerosol absorption via diffuse reflectance measurements from 300 to 1100 nm at intervals of 10 nm on bulk high volume samples giving total aerosol absorbance and on rotating MOUDI samples for size resolved aerosol absorbance; Optronics OL 740A Spectroradiometer with an OL 740-70 Diffuse Reflectance Attachment (integrating sphere).

Particle chemistry and microphysics data will be combined with a complete set of radiametric measurements to get a full description of the atmosphere. U. of Miami will deploy long-path length measurement of aerosol light extinction will be measured using an Optec LPV2 Transmissometer operating at 450, 550, and 710 nm. The transmissometer will operate continuously and be averaged over 1-minute periods. NASA GSFC and NASA Ames will deploy a complete set of radiametric instruments, including an AERONET Sun photometer and a shadow-band radiometer to measure optical depth, a microwave radiometer to measure column integrated water vapor, solar, IR, and hyperspectral flux radiometers to measure surface energetics, and a cloud camera to measure total cloud cover over the site. A micro-pulse LIDAR will be used to measure the vertical distribution of the dust.

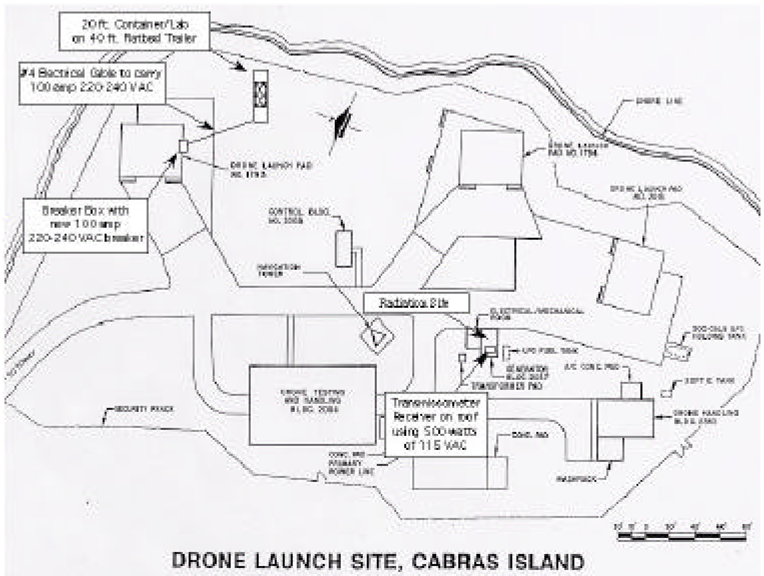

Figure B.1. Surface site for PRIDE located on the eastern tip of Roosevelt Roads, PR.

Figure B.2. Pictures of Cabras Island Site.

Appendix C.
SPAWAR Systems Center-San Diego Piper Navajo Flight Plan

During the PRIDE mission SSC-SD will deploy its contracted Piper Navajo aircraft (Gibbs Flite Center Owned/operated). We are budgeted for 80 flight hours over the 4 week study, with an anticipated usage of 70. We intend to conduct a 4 hour flight every other day (weather permitting) for the duration of the mission. We will have 4 additional "floater" flights for special missions as opportunities present themselves. SSC-SD will deploy with the Navajo two full time pilots Michael Kane and Mike Hubbell), a flight engineer (James Kinney), and mechanic (Lyle Richards, first week only).

The Navajo flies at 55-65 m s^{-1}, a maximum rate of climb of 500 ft min^{-1}, and will have an anticipated flight endurance of ~4 hours. Decent rates will vary on environmental conditions (rapid decent in moist conditions leads to condensation on probe optics). Since aviation fuel is not accessible to the Navajo at Roosevelt roads, ~20 minutes at the end will be used to refuel for the next flight. The Navajo is outfitted with aerosol, meteorology, and radiation instrumentation. A summary is listed below:

Navigation	Meteorology	Particles	Radiation
TANS Vector Attitude	Pressure	PCASP (0.1-3 μm)	Russell 6-λ Sun Photometer
Secondary GPS Position	Temperature (2)	FSSP (0.75-15 μm)	ASD Spectrometer
Radar Altitude	RH/Dew point (2)	47 mm Bulk Filter	MicroTopps Sun Photometer
Pressure Altitude	SST		Pilewskie Radiometer
	Conductivity		

The flight crew for the Navajo will be a pilot, copilot, and two research personnel operating instrumentation. Duane Allen or John Livingston (NASA Ames) will operate the 6-λ sun photometer. Jeff Reid, Haflidi Jonsson, or James Kinney will operate all other instrumentation and direct the flight.

The Navajo will support 3 specific missions:

1. Dust particle microphysics and radiation integration.
2. Satellite Validation
3. Dust transport

Each of these missions requires specific (and sometimes mutually exclusive) needs. To support microphysics and radiation integration work, the SSC-SD Navajo need to fully characterize the atmospheric column in a fast/tight "figure –8" path over the LIDAR at the primary radiation site on Cabras Island, as well as longer straight flight legs to support radiometers and particle probes. For satellite validation the Navajo needs to fly at 30 m over the water in a direction parallel to the satellite track. For transport model validation, the Navajo needs to fly at constant level or porpoise at varying levels in the Saharan air layer for 140+ km. To full fill all of these needs, the Navajo will perform the following basic flight plan on most flights.

1. Flight will begin with a close 500 ft/min upward spiral over the Cabras Island site to support the sun photometer and ground LIDAR (or any clear patch as close as possible). This spiral will continue up to the top of the dust layer or 5 km (maximum elevation for the aircraft). This maneuver will also give us a rough estimation of the vertical extent of the dust for directing the rest of the flight. Estimated flight time: ~30 minutes

2. At the top of the dust layer (~5 km in elevation) we begin a +/- 10 km downward vertical profile (~400 ft min^{-1}) over the same spot the Navajo did the up-spiral to get the particle size information and to support the radiometers. Descend will continue to the top of the MBL. There, the decent will slow to 200 ft min to examine the MBL/dust layer boundary to prevent condensation on the probes. Depending on conditions, we may continue to decend at 400 ft min to the surface, or break of at the MBL level and continue with the mission: ~45 minutes

3. Climbing back into the dust layer, the Navajo will head out to the north or south to a predetermined point roughly 100-200 km away. If the University of Puerto Rico research vessel is at sea, we will go to that point. Along the way, the SSC-SD Navajo will porpoise up and down or fly flat legs in the layer to determine if there is any special inhomogeneity. Porpoising may be only +/- 2 km, or could include the whole layer, depending on conditions. 45 minutes.

4. When the outer way-point is reached, perform a similar downward vertical profile as step 2. ~40 minutes.

5. Return in a direction toward the base in a direction parallel to the terra satellite track at ~30 m above the surface to support satellite validation efforts. (Note, our pilots would prefer to do this maneuver at the end of the flight when the Navajo has burned most of its 2,200 lbs. of fuel)~ ~45 minutes.

Total mission time:~3.5 hours +30 minutes for maneuvering and refueling run.

This plan will be flown on almost all flights (scheduled for every other day, weather permitting). Ordering changes are also likely (e.g., 3, 4, 5, 1, 2) if morning thunderstorms have not cleared off of Roosevelt Roads at takeoff. In addition, the Navajo will have 4 flights reserved for special circumstances. One of these additional flights will be to support the University of Puerto Rico research vessel, giving it air support for 5 of its 7 days at sea. The flight plans for the additional 3 flights will be determined in the field. Other examples of these flights could be: a) Dispense with Legs 1 and 2 when the Cabras island site is totally clouded over and proceed to the maximum range of the Navajo for additional satellite validation time and to explore spatial inhomogeniety, b) On cloudy days explore the possibility of cloud mixing, and dispense with Legs 4 and 5

c) Fly continuously in the MBL and lower SAL to study mixing between the two layer.

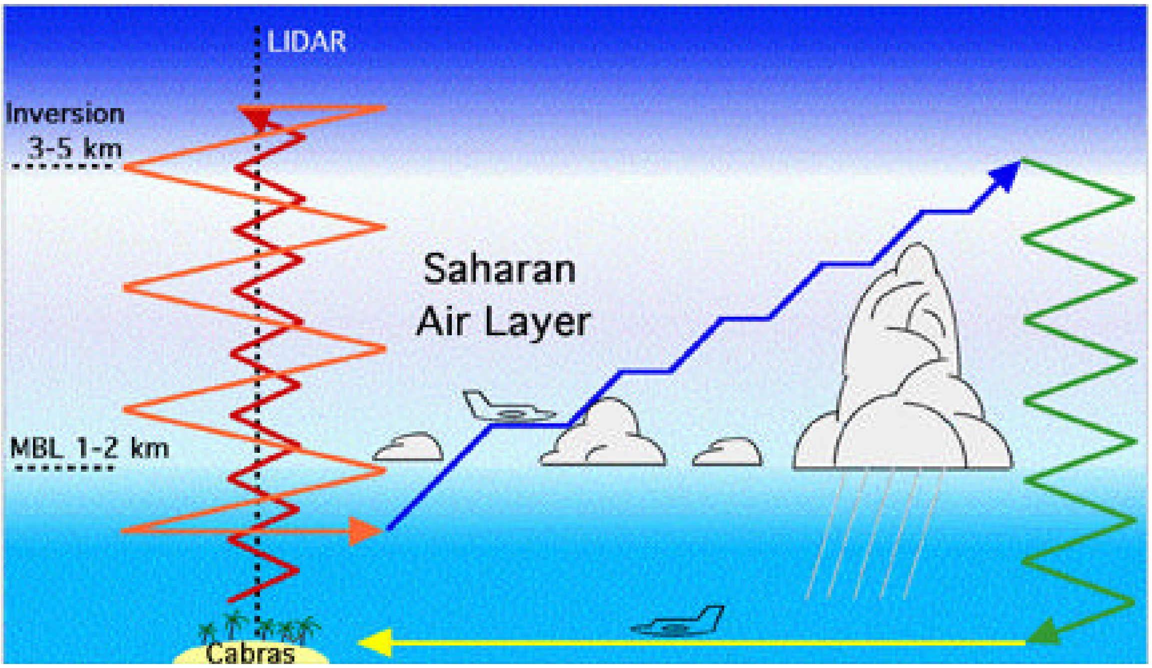

Figure C.1. Principal flight track for the SSC-SD Piper Navajo.

Figure C.2. SSC-SD Piper Navajo

Appendix D.
University of Miami Cessna 172 Flight Plan

During the PRIDE mission the University of Miami will deploy its Light Aircraft Aerosol Package (LAAP) in a Cessna 172 rented from the Navy Flying Club located on Roosevelt Roads Naval Station on Puerto Rico. We are budgeted for up to 100 flight hours over the 4-week study, with an anticipated usage of approximately 80 hours. We intend to conduct a 4 to 5 hour flight approximately five days out of every seven (weather permitting) for the duration of the mission. Necessarily, this schedule will be flexible on a daily basis. We will use pilots from the Navy Flying Club and Dr. Hal Maring of the University of Miami will be the primary chief scientist for aircraft flights.

We intend to fly the Cessna 172 at approximately 60 knots over an altitude range of 100 to 3,000 m asl. At those speeds the Cessna 172 flight endurance is longer than the pilot and scientist can tolerate. Since aviation fuel may not be accessible at Roosevelt Roads, ~20 minutes at the end of each flight will be used to refuel for the next flight. The flight crew will be a pilot and research personnel to operate instrumentation. The LAAP includes the following aerosol, optical, meteorology, and radiation instrumentation.. The LAAP currently is capable of measuring:

- aerosol number concentration from 15 to 1000 nm; TSI 3760 Condensation Particle Counter,
- aerosol number size distribution from 0.1 to 5 µm; MetOne 237B and 237H Optical Particle Counters,
- aerosol light absorption at 565 nm; Radiance Research Particle/Soot Absorption Photometer,
- aerosol light scattering at 530 nm of aerosols <10 µm and <1 µm; Radiance Research M903 Integrating Nephelometers,
- aerosol chemical composition; 47 mm bulk filter,
- location; Garmin GPS III Pilot, and
- temperature and relative humidity; Vaisala Humitter.

Intermittent handheld sunphotometer measurements will be made with a MicroTopps II Sun Photometer

The goals of the LAAP program are:
1. Aerosol microphysics, optics, chemical and radiation integration.
2. Satellite evaluation
3. Dust transport

The measurements of the LAAP are intended to be comparable to the more detailed, high-resolution measurements we will be making at ground level. In this way, we intend to extend our characterization of atmospheric aerosols at least to 3000 m asl. Thus we plan to fly between 100 and 3000 m asl in the vicinity of our ground site on Cabras Island. For satellite evaluation we will fly as low as possible over the water at the times of the satellite over passes. For transport model validation, we will make measurements with altitude on subsequent days to compare with model predictions.

1. Flight will begin with a close upward spiral over the Cabras Island site to characterize the vertical profiles of various aerosol properties. This spiral will continue up to the top of the dust layer or 3 km (maximum elevation for the aircraft). This maneuver will also give us a rough estimation of the vertical extent of the dust for directing the rest of the flight. Estimated flight time: ~40 minutes

2. At the top of the dust layer (or ~3 km in elevation) we will begin a downward vertical spiral (~400 ft min^{-1}) over the same spot as the up-spiral. This will enable us to characterize the variability in aerosol properties over relatively short periods. We will descend at least to 100 m asl. Flight time ~40 minutes

3. Based on discussions with the science team prior to the flight, we will go to a specified altitude or set of conditions and collect a sample for chemical analysis. Estimated flight time : ~120 minutes.

4. We may perform another ascending and descending spiral, depending on conditions. Estimated flight time: ~80 minutes.

Total mission time: ~3.3 to 4.7 hours +30 minutes for maneuvering and refueling.

This plan will be flown on most flights.

Appendix E.
NCAR C-130 Flight Operations

C-130 Flights for Low Turbulence Inlet (LTI) Assessment in Dust
Coordinator: Barry Huebert

The University of Hawaii has acquired the NCAR C-130 to conduct an in-flight evaluation of a low turbulence aerosol inlet (LTI) that is being developed by researchers at Denver University (Chuck Wilson, Russ Seebaugh, and Bernie Lafleur). Two hypotheses will be tested:

A. The LTI has a demonstrably higher aerosol sampling or transmission efficiency than both the CAI (the NCAR C-130 community aerosol inlet) and traditional solid diffusers for particles in the 1-7 micron diameter range.

B. It is possible, using the LTI, to sample and characterize the number-size and surface area-size distributions of ambient dust and sea salt inside an aircraft with enough accuracy that uncertainties arising from inlet losses will contribute less than 20% to the assessment of radiative impacts.

The focus of this mission is to study aerosol sampling and transmission efficiency, but specific needs in this regard are determined by scientific questions regarding aerosol radiative forcing of climate. We will determine size-dependent sampling efficiencies in the 1-10 μm diameter range. Since our goal is to assess radiative forcing in ACE-Asia, we need to use both dust and sea salt as test aerosols. We expect dust to generally be dry, while sea salt will be wet and will change its size due to evaporation while being brought into the aircraft. Thus, the tendency of particles to adhere to the inlet may be very different for dust and sea salt.

Three 5-hour flights will be conducted in both dust and marine boundary layer (6 flights total). The hope is to fly all 30 research hours in out of Saint Croix. Our proposal will be to integrate in late June and to conduct the flights during the first three weeks of July, 2000. The exact flight time has yet to be determined.. If we fly in July, we plan to give NSF a report and recommendation by the end of August, 2000; they will use this information to decide on the deployment of the C-130 for ACE-Asia.

Hypothesis A can be tested relatively simply, since it only requires measurements inside the aircraft, on several air streams that have already been decelerated. We propose to use three matched aerodynamic particle sizers (TSI Model 3320 APSs) to measure the physical size distribution behind our three test inlets: the LTI, the CAI, and a solid diffuser/curved tube inlet that has been used on many programs by Tony Clarke. The difference between the APS distributions will provide a direct test of Hypothesis A. Nephelometers will be used to compare the scattering behind each inlet and to provide a real-time signal in flight to guide the tests. They will also provide a relevant integral measure of light scattering that is appropriate to the tests and one of the goals of ACE-Asia, radiative transfer.

We will also collect filter samples for chemical analysis behind each of these inlets. For the sea salt, we will measure the total sodium concentration (IC analysis by Barry

Huebert's group). If we can arrange for impactors that can work in each of these flow regimes (Clarke's inlet is designed for smaller flows) we will also measure chemical size distributions. In the dust regime, Jim Anderson will analyze mineral aerosols using EM (electron microscopy) to count and size the particles that have passed through each inlet. The EM will be set up to quantify large particles (without chemical analysis), so that it can get statistics on thousands of particles quite readily. The high volume of material (up to 12 m^3 of air can be sampled per hour) will ensure robust statistics even in the larger size ranges.

Hypothesis B is considerably more difficult to test, since it involves comparing aerosol distributions behind the LTI to those in ambient air. The crux of the problem is to measure the ambient (reference) distribution with a system that does not itself suffer from inlet or other artifacts. The two devices that are the least likely to exhibit inlet losses are FSSPs and Total Aerosol Samplers (TASs). Virtually all other samplers and OPCs (even wing-mounted ones) derive their samples from some type of inlet, whose potential for losses would compromise the tests.

One of the most defendable references is the bulk concentration of particles, as measured by the TAS designed and built by NCAR's shop. This external sampler permits an analysis of every particle that enters the inlet tip, whether it has been deposited on the inside of the diffuser or collected on its filter. The diffuser is lined by removable cones, which are replaced with each filter sample and extracted after the flight. As long as we sample isokinetically, we can be assured that the sum of the cone extract and its filter contains every particle that entered the TAS tip, regardless of its size. This will be used to measure the reference total sodium concentration when flying in sea salt. The FSSP can then be used to determine the peak diameter and shape of the sea salt distribution, for comparison with the Na on an impactor behind the LTI. When sampling dust, the size of mineral aerosol is preserved in the TAS extract (assuming there were no aggregates of big particles), so that the ambient and LTI size distributions will be measured directly from filters by EM.

In summary, we will make three 5-hour flights that are focused on sampling dust. If the concentrations are large enough, we will sample at several altitudes in the hope that the size distributions will be slightly different in each. The useful product for the Puerto Rico dust experiment would be size-dependent number concentrations of mineral particles at several altitudes. The TAS samples could also be analyzable for mineralogy and chemical composition; note that they will include the *entire* spectrum of ambient sizes. The LTI samples will be truncated by the size-dependent efficiency of the inlet and plumbing (which ought to be much better than traditional inlets), but will be accompanied by continuous measurements of number-versus-size from the APS.

While our focus is on testing the LTI, the TAS and LTI will generate data on the vertical variation of dust size distributions that is freer from artifacts than what any other airborne system can deliver. We would welcome the opportunity to collaborate on the use of this data to do science related to the impact of elevated dust layers on radiative transfer.

Appendix F.
University of Puerto Rico Research Vessel

In collaboration with Roy Armstrong of the University of Puerto Rico the NASA/GSFC aerosol group will be collecting ground truth data from the R/V Chapman and R/V Isla Magueyes during PRIDE. The R/V Chapman will be deployed for a 5-day cruise (July 3-7). The R/V Isla Magueyes will be available for day cruises, on a stand-by basis. Both vessels dock on the southwest coast of Puerto Rico. The vessels cannot be operated simultaneously.

During the July 3-7 cruise the R/V Chapman will be equipped with a spectrometer to measure water leaving radiance, and will be collecting bio-optical and chlorophyll measurements. These measurements will be under the direction of Roy Armstrong and will be performed either by himself or his students. In addition the Chapman will carry a NASA Microtops sunphotometer to measure spectral optical thickness and precipitable water vapor.

Aboard the R/V Isla Magueyes, during the day cruises, the measurements will include water leaving radiance, chlorophyll amounts, aerosol optical thickness and precipitable water vapor, but no measurements of bio-optical properties. Both vessels will carry a satellite telephone in order to maintain communication with the ground-based and aircraft science teams at Roosevelt Roads.

The purpose of these measurements is to provide additional validation points for satellite retrievals of both aerosol optical thickness and ocean biological properties such as chlorophyll concentrations. Atmospheric aerosol obscures space views of the ocean surface and introduces significant difficulty in retrieving biological information from satellite. Dust is an especially difficult aerosol type to correct for, because like chlorophyll, dust absorbs at blue wavelengths. It mimics the chlorophyll spectral signal. The converse is also true. Chlorophyll in the water confuses retrievals of dust aerosol properties, especially remote sensing of dust spectral signature that provides the size distribution information. The simultaneous measurements of shipboard dust optical thickness, water reflectance and chlorophyll concentrations during satellite and airborne observations provides the data base for unraveling these intertwined spectral signals.

The vessels will be directed to coordinate with the PRIDE Navajo crew to find a location either north or south of the island, clear of clouds and under or within the dust plume. The 5-day Chapman cruise allows the vessel to operate on the eastern side of the island, closer to Roosevelt Roads, weather and dust trajectories pending. This will provide easier access for coordinated missions with the Navajo aircraft. The Isla Magueyes will be confined to the western side of the island, within a half-day's cruise of port. Scientific results will be maximized if satellite glint angles can be avoided.

Appendix G.
Airborne Sunphotometry and Integrated Analyses of Dust, Other Aerosols, and Water Vapor in the Puerto Rico Dust Experiment (PRIDE)

PI: Philip B. Russell

Co-Is:
Beat Schmid, Bay Area Environmental Research Institute, 650-604-5933
Jens Redemann, Bay Area Environmental Research Institute, 650-604-6259
John M. Livingston, SRI International, 650-859-4174
Peter Pilewskie, NASA Ames Research Center, 650-604-0746

Objectives:
1. Improve understanding of dust, other aerosol, and water vapor effects on radiative transfer, radiation budgets and climate in the Caribbean region.
2. Test and improve the ability of satellite remote sensors (such as MODIS, MISR, CERES, TOMS, AVHRR) to measure these constituents and their radiative effects.

Tasks:
(a) Integrate an Ames Airborne Tracking Sunphotometer on a PRIDE aircraft (e.g., AATS-6 on the SPAWAR Navajo, or AATS-14 on the CIRPAS Twin Otter).
(b) Calibrate AATS before and after PRIDE.
(c) Provide continuous realtime measurements of aerosol and thin cloud optical depth spectra and water vapor column contents during PRIDE flights (e.g., transects across dust gradients, vertical profiles through aerosol layers).
(d) Use these data in flight direction and planning.
(e) Compare results to those of the satellite sensors listed above (cf. Figure 1a,c); in cases of disagreement, investigate causes and retrieval algorithm improvements.
(f) For aircraft profiles derive profiles of aerosol extinction spectra (cf. Figure 1b,d) and water vapor density.
(g) Combine these data with those from the Pilewskie SSFR and conduct new analyses of aerosol radiative forcing sensitivity, single scattering albedo, and the solar spectral radiative energy budget.
(h) Derive aerosol size distributions from optical depth and extinction spectra.
(i) Combine data with in situ measurements of chemical composition, size distribution, hygroscopic growth, and single-scattering albedo to provide tests of closure and integrated assessments of aerosol and trace gas radiative effects.

Outputs (what and when):
1. Aerosol and thin cloud optical depth spectra (380 to 1020 or 1558 nm) and water vapor column contents, in real time color displays. Produced continuously throughout A/C flight when sunphotometer's view of sun is not blocked by thick clouds (τ>~3) or A/C obstructions (e.g., tail, antennas).
2. For A/C profiles, haze extinction spectra profiles (380 to 1020 or 1558 nm) and water vapor concentration profiles. Produced after flight from smoothed profiles of data resulting from #1. Requires reasonable horizontal/temporal homogeneity.
3. Integrated analyses (see above) and publications. Produced several months to years after measurements, depending in part on availability of others' data and analyses, plus funding levels.

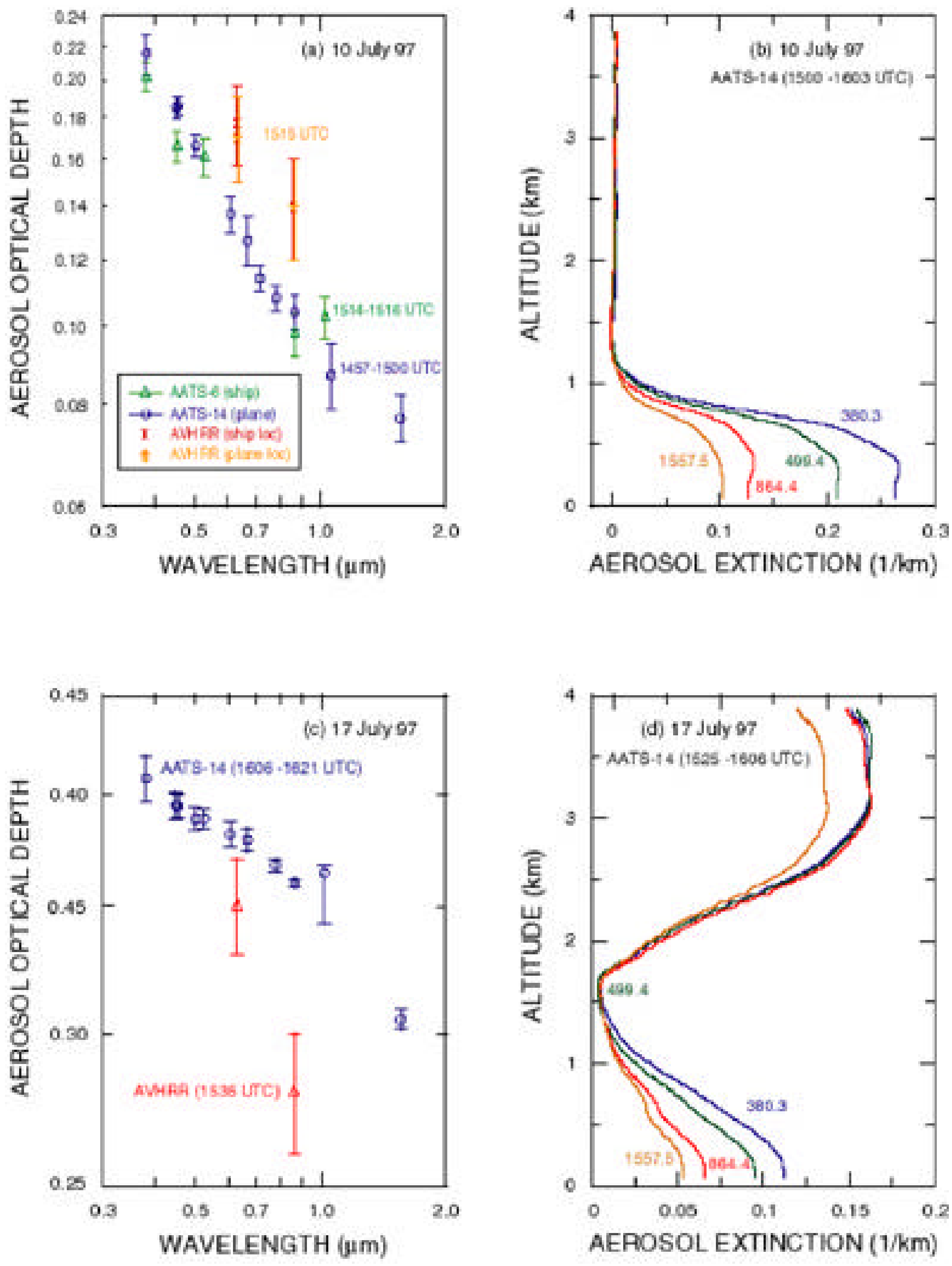

Figure G.1. (a) Comparison between aerosol optical depths derived from AVHRR radiances and measured by AATS-14 on the Pelican aircraft and AATS-6 on the ACE-2 ship, for a case with no elevated dust layer present. (b) Vertical profiles of aerosol extinction coefficient for the case in (a). (c) Comparison between aerosol optical depths derived from AVHRR radiances and measured by AATS-14, for a case with an elevated dust layer. (d) Vertical profiles of aerosol extinction coefficient for the case in (c).

Appendix H.
Satellite Calendar

TOMS: 11:18 am local time

		MODIS				MISR	SeaWiFS		
Date	Day of Year	Time* (Local)	Look Angle	F/B	Glint	Over flight path	Time (Local)	Look Angle	Glint
June 26	178	10:58	21.41	B	NG		12:24	23.98	G
June 27	179	11:41	39.33	F	G		13:06	51.57	NG
June 28	180	10:46	47.64	B	NG		12:12	37.26	NG
June 29	181	11:06	21.76	B	NG		12:55	43.07	NG
June 30	182	10:34	54.88	B	NG		12:00	47.93	NG
July 1	183	11:16	3.06	B	G	Path 4	12:43	30.58	NG
July 2	184	11:59	53.3	F	NG		11:48/13:25	54.78/59.17	NG
July 3	185	11:04	26.6	B	NG		12:31	20.44	G
July 4	186	11:47	45.2	F	NG		11:36/13:14	59/55.2	NG
July 5	187	10:52	42.4	B	NG		12:19	28.79	NG
July 6	188	11:34	31.2	F	G		13:02	48.81	NG
July 7	189	10:39	51.9	B	NG		12:07	41.86	NG
July 8	190	11:22	9.5	F	G	Path 5	12:50	38.68	NG
July 9	191	12:04	56	F	NG		11:55	51	NG
July 10	192	11:10	16.2	B	NG		12:38	25.3	G
July 11	193	11:52	49.6	F	NG		11:43/56.7	56.7/57.8	NG
July 12	194	10:57	35.9	B	NG		12:26	21.75	NG
July 13	195	11:40	38.7	F	G		11:31/13:09	60.2/53.0	NG
July 14	196	10:45	48	B	NG		12:14	34.47	NG
July 15	197	11:28	20.6	F	G		12:57	45.17	NG
July 16	198	10:33	55.2	B	NG		12:02	46.19	NG
July 17	199	11:15	4.5	B	G	Path 4	12:45	33.19	NG
July 18	200	11:58	53	F	NG		11:50/13:28	53.78/59.7	NG
July 19	201	11:03	27.7	B	NG		12:33	21.11	G
July 20	202	11:46	44.5	F	NG		11:38/13:16	58.45/56.0	NG
July 21	203	10:50	43.2	B	NG		12:21	26.63	G
July 22	204	11:33	30.2	F	G		13:04	50.01	NG
July 23	205	10:38	52.4	B	NG		12:09	40.2	NG
July 24	206	11:21	7.7	F	G	Path 5	12:52	40.34	NG
July 25	207	12:03	55.7	F	NG		11:57	50.07	NG
July 26	208	11:09	17.8	B	NG		12:40	26.88	G

* UTC is 4 hours ahead of local time

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