GACP 2nd Year Progress Report

Remote Sensing of aerosol over land with AVHRR

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PI - Larry L. Stowe
NOAA/NESDIS/ORA – Room 712
5200 Auth Rd.
Camp Springs, MD 20746-4304
Ph.: 301-763-8053x114
Fax: 301-763-8108
lstowe@nesdis.noaa.gov

Research Fellow - Kenneth R. Knapp
CIRA-NOAA/NESDIS/ORA – Room 711
5200 Auth Rd.
Camp Springs, MD 20746-4304
Ph.: 301-763-8053x195
Fax: 301-763-8108
kknapp@nesdis.noaa.gov

Form A. 2nd Year Progress Report

Abstract

This project is designed to retrieve aerosol optical depth over land from AVHRR when and where an aerosol signal is present using the Pathfinder-Atmosphere (PATMOS) data. Research began in the Autumn of 1999 with the hire of Ken Knapp to perform the research, thus research began during the second year of the GACP. Since then, research status and results have been presented at three conferences. Research has shown that there is an aerosol signal in the PATMOS data through comparisons with the Aerosol Robotic Network (AERONET). However, this signal is convoluted by the contribution of surface reflectance. Research showed that simplistic attempts to remove the surface bidirectional reflectance distribution function (BRDF) enhanced the aerosol signal. Further, the surface BRDF can be retrieved from temporal composites of observations, allowing correction for the surface and Rayleigh contribution to satellite-detected reflectance. This research is moving toward aerosol optical depth retrievals over land using the PATMOS data.

Goal

The goal of this research is to exploit the 19 years of AVHRR observations to estimate aerosol signal over land for the last two decades when and where an aerosol signal is present.

Objectives

The objectives stated in the 1st year progress report are:

1) Develop an automated algorithm for the retrieval of aerosol optical depth (AOD) over land where an aerosol signal is present in the cloud-free reflectance data
2) Validate this algorithm using regional spectral AOD datasets from NASA's AERONET
3) Explore ways of extending to other grid cells and times away from AERONET
4) Evaluate the performance of the algorithm when implemented into the GACP global AVHRR reprocessing system

These objectives remain the overall objectives of the research. Specifically, work is underway on objectives one and two: development of the algorithm and validation.

Tasks Completed

The future plans from the first year progress report were listed as:

> Our first year of research will empirically determine regions with an aerosol signal and analyze the error of applying the NOAA/NESDIS ocean like algorithm at AERONET locations. The second year will adjust the surface and aerosol properties in a radiative transfer model to minimize the errors detected in the first year. In the third year, ways will be developed to extend the LUTs developed at AERONET sites, to non-AERONET locations and seasons, and the validated retrieval algorithm will be delivered to the NASA/GACP processing center.

Research during the second year of the GACP, as mentioned in the first progress report, is actually the first year of our research efforts. Nonetheless, research has progressed in many of the above-mentioned areas, toward finding an aerosol signal in PATMOS data. However, the surface BRDF effect is large so we have attempted to minimize the BRDF effect both empirically and theoretically. Also, the AVHRR ocean aerosol algorithm was applied to land sites with no significant results. The problems with this application are also described below. Note: In the following, references to “cloud-free reflectances” refer to observations deemed cloud-free by the Clouds from AVHRR (CLAVR) algorithm which may contain aerosol as well; references to “clear-sky” refers to cloud-free observations hypothesized to be aerosol-free.

Ken Knapp hired to perform the research.

Ken Knapp was hired part-time in September 1999 to perform the research described in this report and moved to full-time in April 2000. Thus, the research described herein was performed from 6 months of part-time work and 4 months of full-time research.

Signal in PATMOS data found – BRDF effect is large

Initially, the AERONET data were compared to AVHRR cloud-free reflectances. Figure 1 compares channel 1 clear-sky reflectances with AERONET optical depth at 0.67μm for 1997 at Mongu (in Africa) and Goddard Space Flight Center (U.S.). The relationship is similar to that predicted from theoretical simulations (solid lines in figure 1) and the variation can be partly explained by varying surface conditions. Due to this, correlations are weakly positive at many sites. Analysis of the data shows that the land surface BRDF is dominating the TOA reflectance (e.g., figure 2).

Ocean LUT algorithm not useful over land

The ocean aerosol retrieval look up table (LUT) was applied to land sites. It was hoped that adjustments could be made to this algorithm to develop a land algorithm. However, there was little improvement over the initial comparisons as, again, the surface BRDF seemed to dominate the TOA reflectances.

Simple polynomial BRDF correction enhances aerosol signal

First, a simplistic attempt was made to remove the surface effect. It is assumed that over a two-month period numerous cloud-free observations allow some clear-sky observations (which are the darker reflectance observations). A polynomial is then fit to the clear-sky observations, where deviation from this polynomial fit is assumed to be the aerosol signal. These deviations are then compared to AERONET optical depth.

First, cloud-free observations are grouped at two-month intervals. In most cases, this provides enough clear-sky observations to determine the reflectance of an atmosphere with little aerosol (hence, clear-sky). A fourth-order polynomial is then fit to this clear-sky reflectance. Examples of this method are shown for a South American site (Los Fieros) during 1998 in figure 3. Excellent fits are found from May through August, where the polynomial fit matches the darkest observations. During the wet season (October through February), there are fewer cloud-free observations, thus limiting the accuracy of the polynomial fit. Deviation of a cloud-free observation from the polynomial fit is then compared to AERONET optical depth (AOD) estimates. This is performed in figure 4 for Los Fieros from June/July/August data for 1998. The cloud-free reflectances are compared to AOD in figure 4a, where a large area of false signal occurs – the region where reflectances increase with no change in AOD. However, this region of false signal is significantly reduced through subtraction of the polynomial fit (figure 4b). Therefore, simplistic removal of the surface effect enhances the aerosol signal.

Modeled BRDF correction further enhances aerosol signal

The above analysis, however, has some disadvantages, specifically changes in the viewing geometry over the two months are not taken into account and polynomial fits are not required to be realistic (e.g., the poor fit for September/October in figure 3). Therefore, the observations were fit to a BRDF using a radiative transfer model as follows. A LUT was calculated using the Spherical Harmonics Discrete Ordinate Methods (SHDOM) radiative transfer model which allows the surface to be modeled according to the Rahman BRDF and the inclusion of Rayleigh scattering. Observations were grouped in a similar manner to that described above (two months or less) and the BRDF was determined (e.g., figure 5). An example of the performance of this fit is shown in figure 6. In general, the BRDF retrieval decreased the scatter at most AERONET sites.

Form B. Significant Highlights

While the research performed during this period represents progress toward the end goal, two significant highlights are:

1. The retrieval of surface BRDF and further enhancement of aerosol signal in AVHRR data shows promise toward the retrieval of aerosol properties, and
2. These results presented at the International Radiation Symposium 2000 won the award of Distinguished Poster for the Remote Sensing session.

Form C. 3rd Year Statement of Work

Further research will include information from other datasets as well as the development of an algorithm:

1. Temporal extension of current analysis.

   The current analysis of the aerosol signal uses only 1996-1998 data. Future work will extend the analysis to other time periods, such as 1993-1999 for AERONET data and 1991 through 1999 for MFRSR.

2. Extension of current analysis methods to other aerosol datasets.

   The current analysis is limited to AERONET observations, however, other data exists which could be used to validate the AVHRR algorithm. Possible data sets include: the Multi-Filter Rotating Shadowband Radiometer (MFRSR), Polarization and Directionality of Earth's Reflectance (POLDER) aerosol retrievals, Total Ozone Mapping Spectrometer (TOMS) aerosol index, and others.

3. Extend aerosol retrieval to regions which demonstrate an aerosol signal.

   The aerosol retrieval algorithm will be developed in areas where independent aerosol data sets exist (see part 2 above). Regions which demonstrate a strong aerosol signal will be classified through some means (e.g., NDVI) so that the retrievals can be extended to times and locations for which no ground truth is present. To this end, aerosol optical depth will be retrieved over land from 1981 through present from the PATMOS data.

Form D. GACP Bibliography

Poster Presentations

Knapp, K. R. and L. L. Stowe, An Approach to Deriving an Aerosol Optical Thickness Climatology over Land with AVHRR Data, at the Fall Meeting of the American Geophysical Union in San Francisco, CA, 1999.

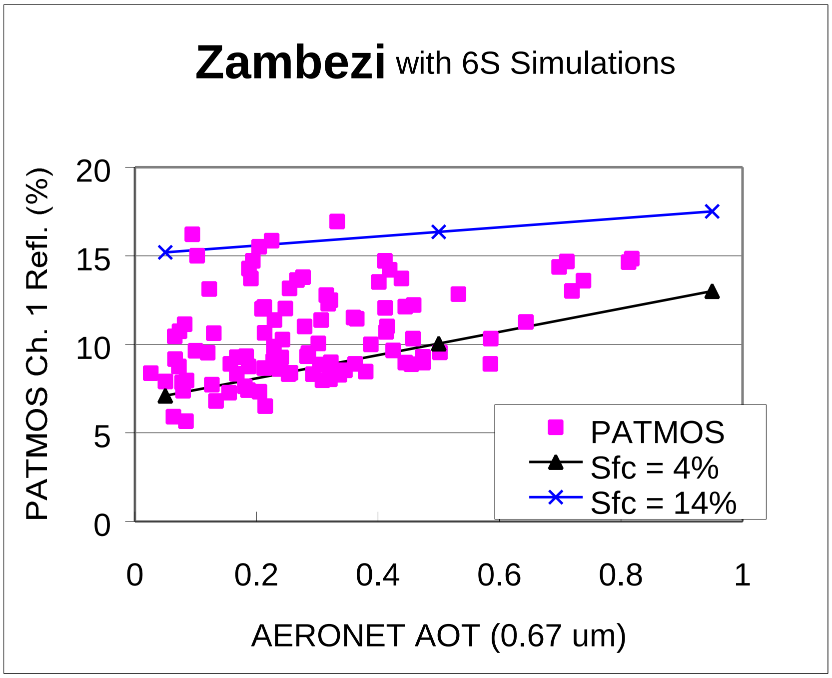
Knapp, K. R. and L. L. Stowe, Aerosol Optical Depth Signal over Land in the AVHRR Pathfinder Atmosphere Data Set, at the Spring Meeting of the American Geophysical Union in Washington, D.C., 2000.

Knapp, K. R. and L. L. Stowe, Deriving an Aerosol Optical Depth Climatology over Land with AVHRR Data, at the International Radiation Symposium in St. Petersburg, Russia, 2000.

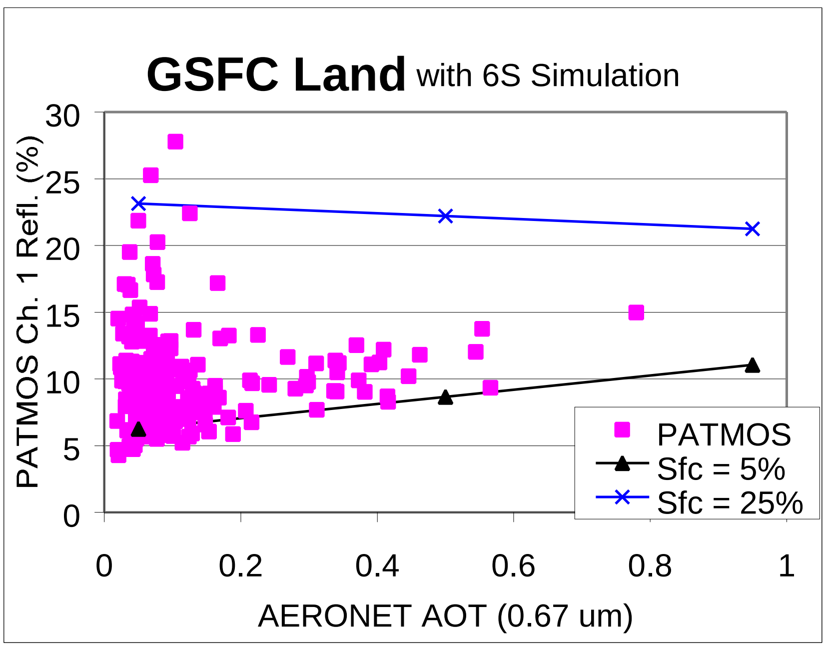
Upcoming Conferences

Knapp, K. R. and L. L. Stowe, Satellite remote sensing of aerosols over land from geostationary and polar orbiting satellites, at AAAR 19th Annual Meeting, Saint Louis, MO, 6-10 Nov. 2000.

Knapp, K. R. and L. L. Stowe, Inference of aerosol optical depth over land through the retrieval of surface BRDF parameters from the AVHRR pathfinder atmosphere data set, at the AMS 2001 Annual Meeting, 14-19 Jan. 2001.



A)



B)

Figure 1 – Comparison of PATMOS-1 Channel 1 cloud-free reflectances with AERONET optical depth measured at 0.67μm for a) Mongu (Africa) and b) Goddard Space Flight Center (U.S.). Solid lines represent 6S simulations of reflectance using different surface reflectance values.

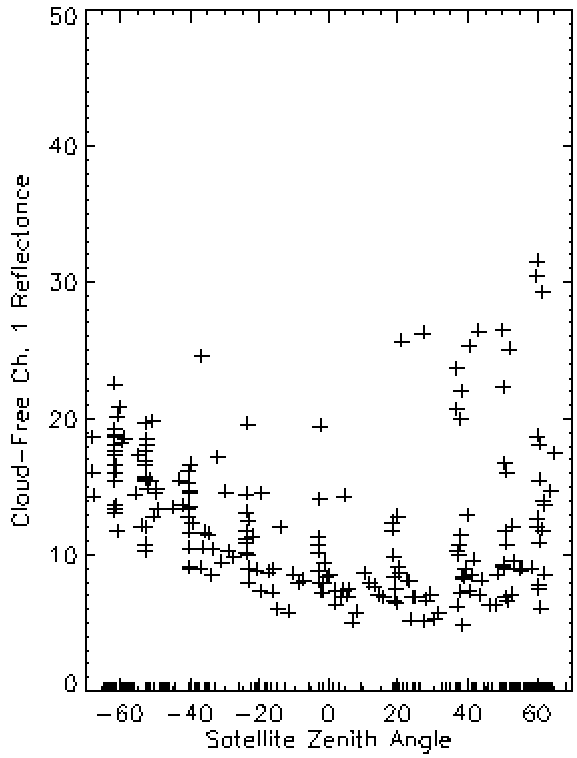


Figure 2 – Channel 1 cloud-free reflectances for one grid cell over South America for 1998 versus satellite zenith angle (values of zero cloud-free reflectance represent no cloud-free observations in the grid cell for that day), where satellite zenith angle less than 0° is backward scatter and vice versa.

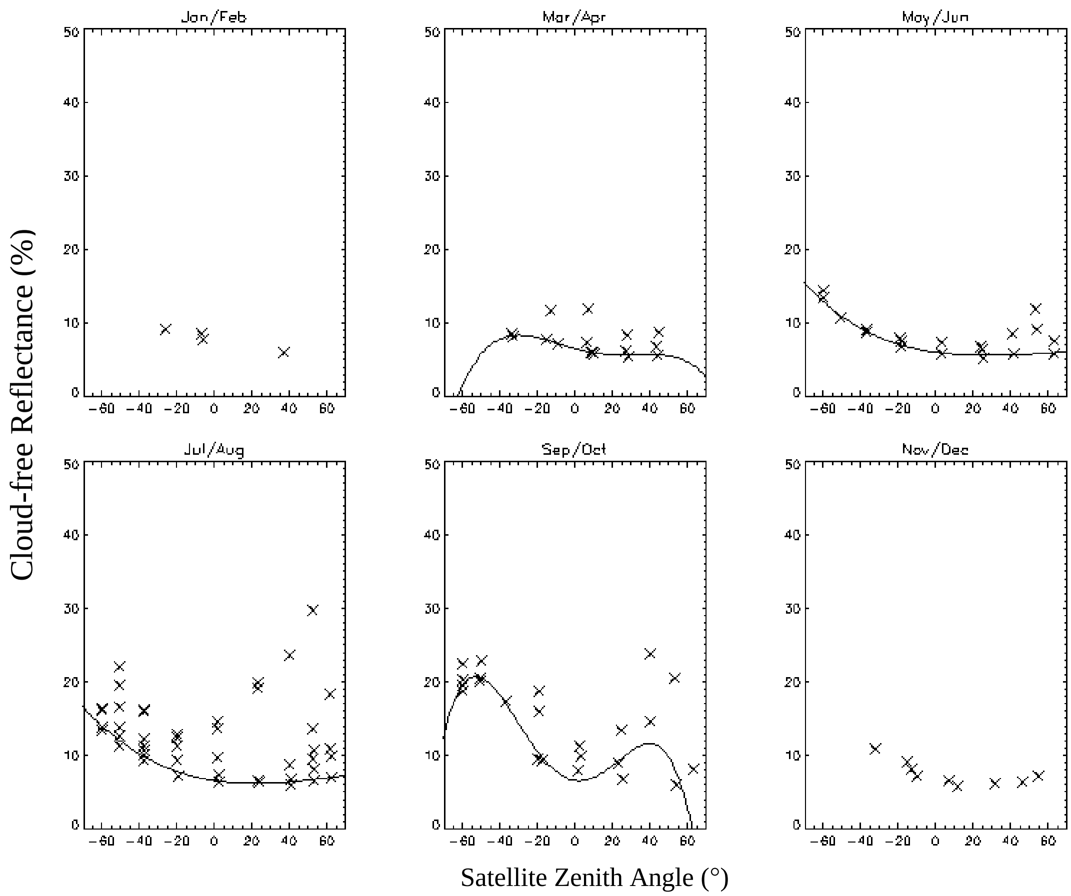
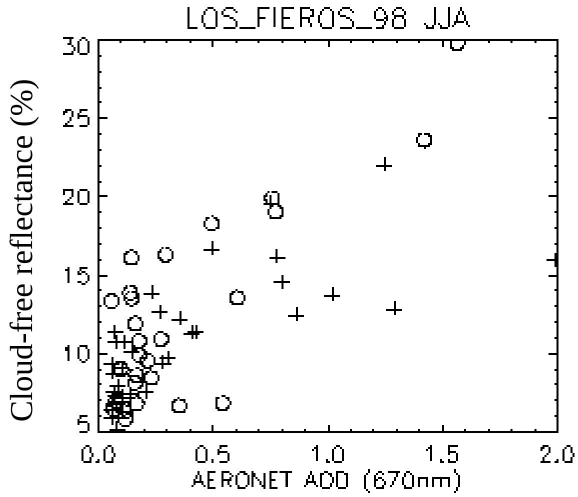
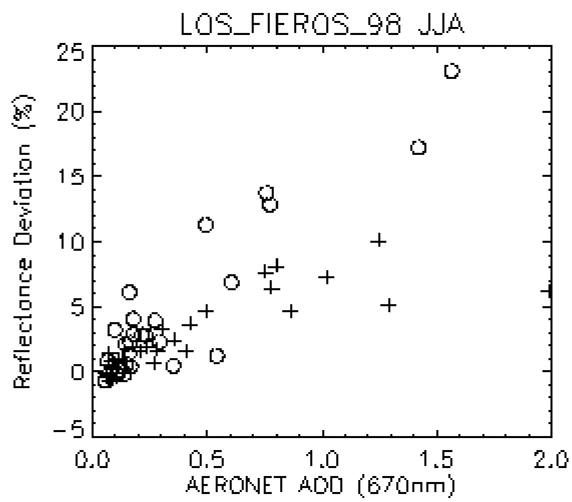


Figure 3 – Example of fourth-order polynomial fits to 1998 PATMOS-1 data for Los Fieros in South America (fits are performed at two-month intervals) showing the advantages and disadvantages of using this method: insufficient clear-sky observations (November through February), insufficient observations with no aerosol (September/October) and sufficient observations for a polynomial fit to the darker observations (May through August).



A)



B)

Figure 4 – a) Comparison of PATMOS channel 1 cloud-free reflectances during June/July/August of 1998 to AERONET optical depth at 0.67µm. b) same comparison except the polynomial fit, simulating the surface contribution, has been removed. Pluses (+) and circles (o) represent backward and forward scatter, respectively.

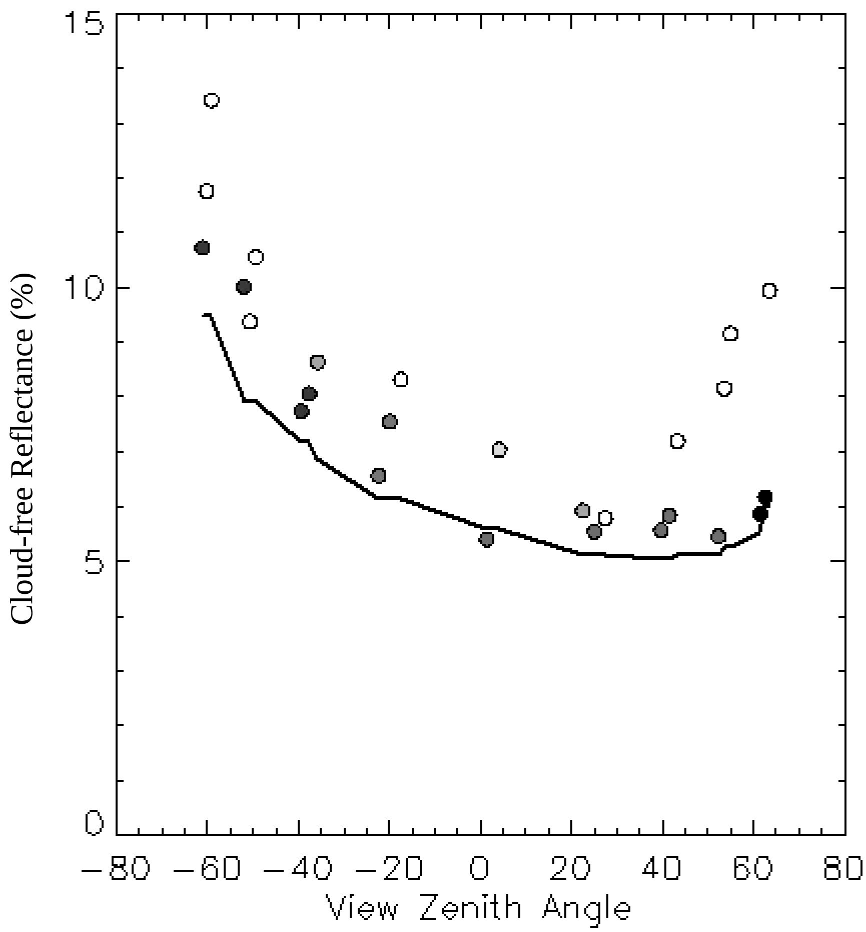
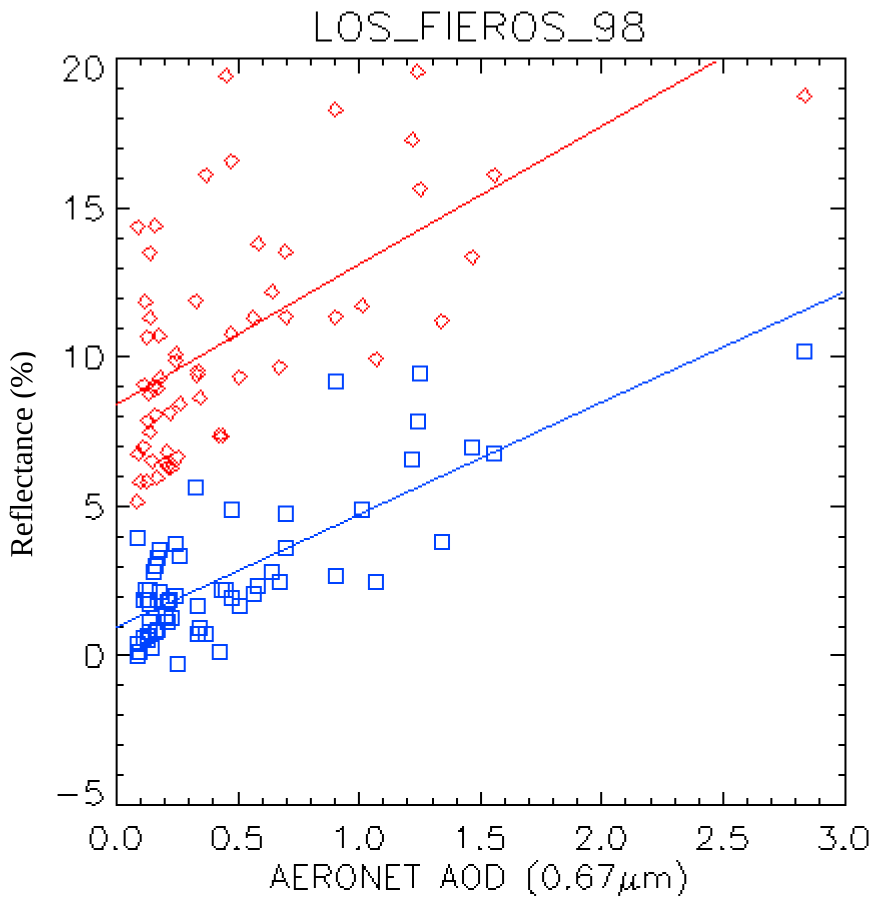


Figure 5 – An example of the BRDF fit: cloud-free observations (versus view zenith angle, circles) are fit using the LUT with the BRDF fit (solid line) and a weighting scheme which gives darker observations more weight (shading of circles).



$\rho = 4.64\tau + 8.45$ $\chi^2 = 8.99$ $r = 0.617$

$\Delta\rho = 3.74\tau + 0.97$ $\chi^2 = 2.37$ $r = 0.776$

Figure 6 – Cloud-free reflectance (diamonds) and reflectance deviation from the BRDF fit (square) versus AERONET AOD at Concepcion for 1996-1998 (solid lines are the linear regression).