Progress Report: Pixel-Scale Cloud Retrievals and Aerosol Radiative Forcing for INDOEX

Michael A. Friedman, William R. Tahnk, and James A. Coakley, Jr.
College of Oceanic and Atmospheric Sciences
Oregon State University
Corvallis, OR 97331-5503

21st CERES Science Team Meeting
Hampton, VA
2 – 4 May 2000

1. Introduction

Work continues on the development of a pixel-scale retrieval scheme for cloud properties and the determination of the aerosol direct radiative forcing for INDOEX. Here, advances in the retrieval scheme since the last meeting and comparisons between cloud properties using this scheme and those retrieved using the CERES operational scheme are reported. In addition, the 2-channel aerosol retrieval scheme developed for INDOEX is applied to the VIRS radiances for the CERES 100% clear fields of view in the SSF data. SW radiances derived using the retrieved aerosol properties are compared with those observed by the CERES scanner.

2. Retrieval of Cloud Properties

Since the previous meeting, the retrieval scheme for obtaining cloud properties from VIRS radiances has been updated to derive a cloud altitude that is consistent with the temperature profile and the retrieved emission temperature. Sensitivity studies were performed to determine the effects of different temperature profiles, tropical and midlatitude summer climatological

profiles, on the retrieved properties. The retrieved properties were compared with those derived by the CERES operational scheme. In addition, a scheme for treating pixels that are only partially cloud covered was developed, but is still undergoing tests.

For overcast pixels, the retrieval of droplet radius, 0.63-μm optical depth, cloud emission temperature, and cloud altitude for single-layer water clouds follows that of Han et al. (1994). The scheme is depicted in Figure 1. Figures 2 and 3 show examples of retrieved cloud properties for two scenes. Retrievals are performed only in regions with sufficient cloud-free pixels so that reliable estimates can be made of the surface temperature. Cloud-free pixels contaminated by sun glint are likewise avoided.

Twenty scenes (261 pixels $\times$ 512 lines) were selected for comparison with the CERES operational retrieval scheme. The scenes were also used to determine the sensitivity of the retrieved products to various profiles of temperature, humidity, and cloud altitude. Figure 4 shows cloud properties retrieved using midlatitude summer and tropical profiles of temperature and humidity. Each point represents the average of the overcast pixels for a 26 $\times$ 32 pixel segment of a scene. As noted below, the droplet sizes retrieved using the CERES operational scheme were systematically larger than those retrieved using the current scheme. To test the effects of moisture above the clouds, retrieved properties obtained with the clouds at an altitude of 1 km in a tropical atmosphere were compared with those of clouds at 5 km in a midlatitude summer atmosphere. With the heavier vapor burden above the clouds, the retrieved droplet sizes were reduced by about 2 μm.

Cloud properties retrieved for overcast pixels using the current scheme were compared with those derived by the CERES operational scheme for all twenty scenes. Figures 6, 7, and 8 are images (courtesy of Sunny Sun-Mack) showing both sets of retrieval products and the magnitude of the differences for one of the scenes. For the twenty scenes, differences in cloud effective radius were consistently higher in the CERES operational product. The other cloud properties appeared to be in reasonable agreement.

Routines for retrieving the droplet radius, 0.63-μm optical depth, and fractional cloud cover for partly cloudy pixels have been developed and are undergoing testing. Figure 9 shows the steps in the retrieval process. Figure 10 shows preliminary results for the partly cloudy retrievals. Future work includes a thorough analysis of the differences in retrieved cloud products for the current retrieval scheme and the CERES operational scheme, the implementation of the retrieval scheme for partly cloudy pixels, the extension of these retrieval schemes to continental regions, and the treatment of multiple cloud layers.

3. Aerosol Radiative Forcing

INDOEX sought to determine the aerosol radiative forcing for the Indian Ocean during the January–March winter monsoon season. In order to estimate this forcing, a scheme for retrieving aerosol properties using the 0.63-μm and 0.85-μm reflectances obtained with the AVHRR was developed. Lookup tables for the reflectances were constructed using the average continental and tropical marine aerosol models described by Hess et al. (1998). The mixture of the average continental and marine aerosols and the optical depth for the mixture at a reference wavelength

were sought that matched the observed and calculated radiances. Optical depths retrieved using this scheme compare well at both visible and near infrared wavelengths with those obtained from the NASA Aeronet instrument at the Kaashidhoo Climate Observatory. The aerosol size index, as indicated by the ratio of the visible to near infrared optical depths, was found to be in better agreement with the ratios obtained from the Aeronet instrument than those that could be obtained with a single-channel retrieval scheme.

Optical depths and aerosol model mixing ratios have been retrieved for January–March, 1996–2000. These optical depths and mixing ratios are used in a broadband radiative transfer calculation to estimate the aerosol radiative forcing at the top of the atmosphere. The average radiative forcing is obtained by weighing the resulting forcing by the fraction of clear area, as deduced from the numbers of cloud-free and partly cloudy pixels. The fractional cloud cover assumed for the partly cloudy pixels is 0.3. The aerosol direct radiative forcing is taken to be zero for the overcast portions of the fields of view.

In order to determine the reliability of the broadband radiative transfer calculations, CERES SSF observations for 100% clear fields of view were analyzed for aerosol optical depths and broadband radiances. Only six hours of SSF data were available for the INDOEX region for February 1998. CERES SSF optical depths were analyzed for $1° \times 1°$ latitude $\times$ longitude regions for which observations from the NOAA-14 AVHRR were within 15 minutes. Optical depths derived from both the VIRS radiances in the SSF data and the nearly simultaneous AVHRR observations revealed considerable cloud contamination in the CERES 100% clear FOVs.

Within the CERES 100% clear FOVs, only a small fraction of the imager fields of view are deemed suitable for aerosol retrievals. Consequently, the aerosol optical depths reported on the SSF cannot be used to determine the aerosol direct radiative forcing without first identifying the fields of view for which cloud contamination is reasonably small. A suitable measure of cloud contamination is the fraction of aerosol coverage within the CERES FOV.

Comparison of CERES derived optical depths and the optical depths derived using the VIRS radiances reported for the CERES 100% clear fields of view revealed that an aerosol coverage > 30% avoided most effects due to cloud contamination. Less than 0.3% of the CERES FOVs met this criterion.

SW radiances derived using VIRS radiances for the CERES 100% clear FOVs with greater than 30% aerosol coverage were compared with the observed SW radiances. The observed and derived SW radiances were close even though the CERES and VIRS viewing geometries were different. The agreement suggests that the calculated SW radiances exhibit the correct anisotropy. In addition to the 2-channel, 2-aerosol model retrievals, single channel, single-model retrievals were also performed using the average continental and the tropical marine aerosol models separately. While the two-channel algorithm achieved the best agreement, the predicted and observed SW radiances were also well-correlated for the single-channel retrievals. This lack of sensitivity to aerosol model results from the narrow to broadband conversion factors being within 10% of each other for the two aerosol models, irrespective of viewing geometry. The

result suggests that despite the differences in the models, either model could be used to provide a reasonably accurate estimate of the top of the atmosphere aerosol direct radiative forcing.

References

Han, Q., W.B. Rossow, and A.A. Lacis, 1994: Near-global survey of effective droplet radii in liquid water clouds using ISCCP data. *J. Climate*, **7**, 465-497.

Hess, M., P. Koepke, and I. Shult, 1998: Optical properties of aerosols and clouds: The software package OPAC. *Bull. Amer. Meteor. Soc.*, **79**, 831-844.

Progress Report: Pixel-Scale Cloud Retrievals

M.A. Friedman and J.A. Coakley, Jr.

Oregon State University

21st CERES Science Team Meeting
May 2, 2000

- Radiative Transfer Calculations
- Overcast Retrievals and Comparisons
- Partly Cloudy Retrievals

Radiative Transfer Calculations

- Discrete ordinate method (DISORT)
- Ocean reflectance zero at 0.63 and 3.7 μm
- Kratz correlated-k models
- Standard lognormal size distribution used for distribution of cloud droplet sizes
- Range of mode radii and optical depths: 2 - 40 μm and 1 - 64
- Emission parameterized in terms of homogeneous, infinitesimally thin cloud embedded in plane-parallel atmosphere, in which emission by gases is held constant while emission by the surface and cloud vary with varying T_{sfc} and T_{cld}
- Emission calculated with separate routine that allows greater flexibility in assigning T_{sfc} and T_{cld}, and better efficiency in calculating emitted radiances

➡ Tropical and midlatitude profiles of temperature and atmospheric absorbers

➡ Variable cloud altitude for evaluation of atmospheric absorption and emission

Overcast Cloud Retrievals

- Retrievals only performed for pixels overcast by layered clouds

- No retrievals if pixel is identified as partly cloudy or multilayer

- There must be sufficient cloud-free pixels in neighboring region to retrieve surface temperature

- Retrieved cloud properties:
  - 0.63-μm optical depth
  - cloud emission temperature: the 11-μm temperature cloud would have if a blackbody
  - droplet radius: mode radius of lognormal distribution ($r_e = 1.55 \times r_m$)
  - cloud altitude: altitude corresponding to retrieved cloud temperature using tropical climatological lapse rate and a retrieved surface temperature

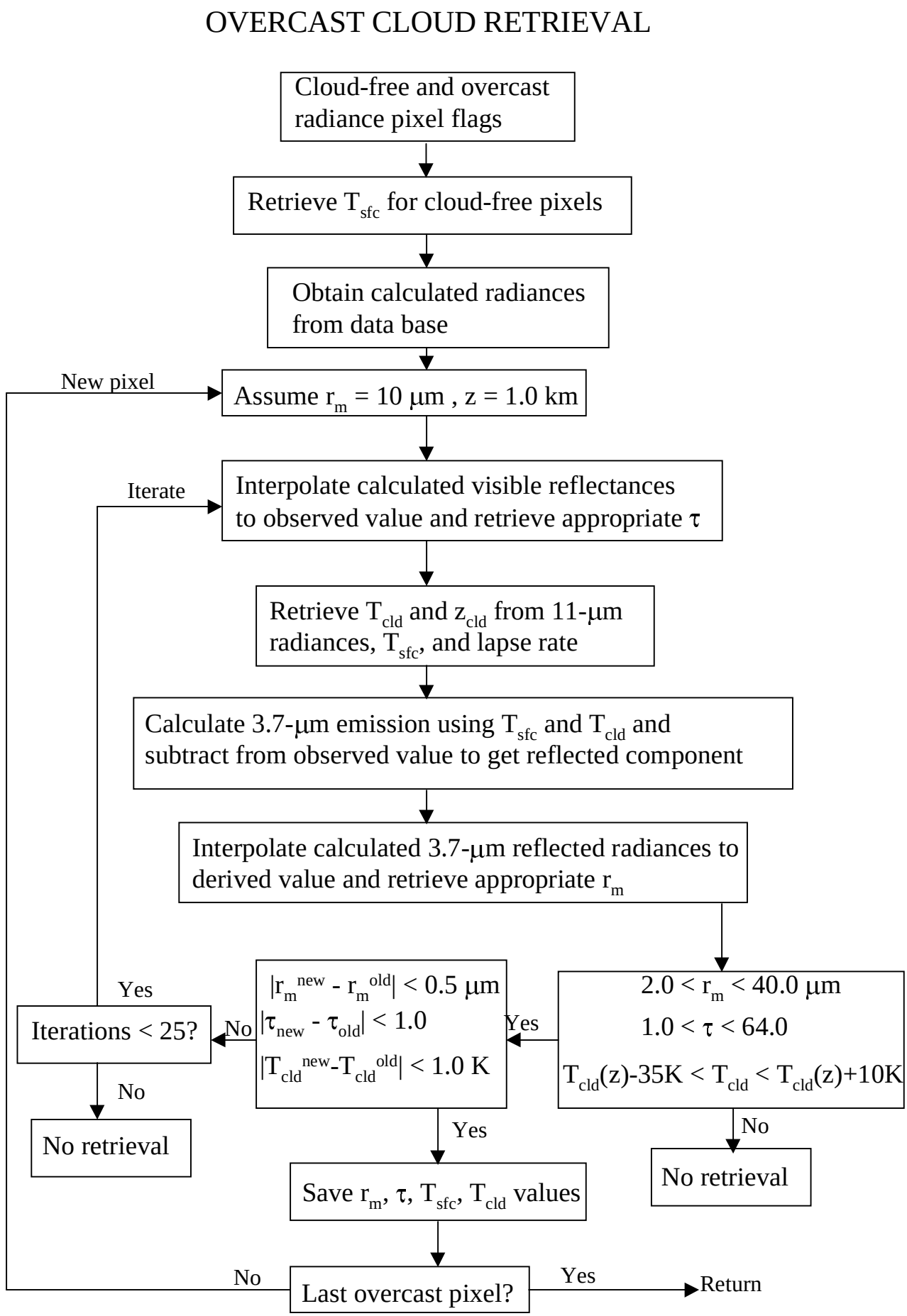


Figure 1. Overcast retrieval flow chart shows the steps taken in the analysis

RETRIEVAL PRODUCTS

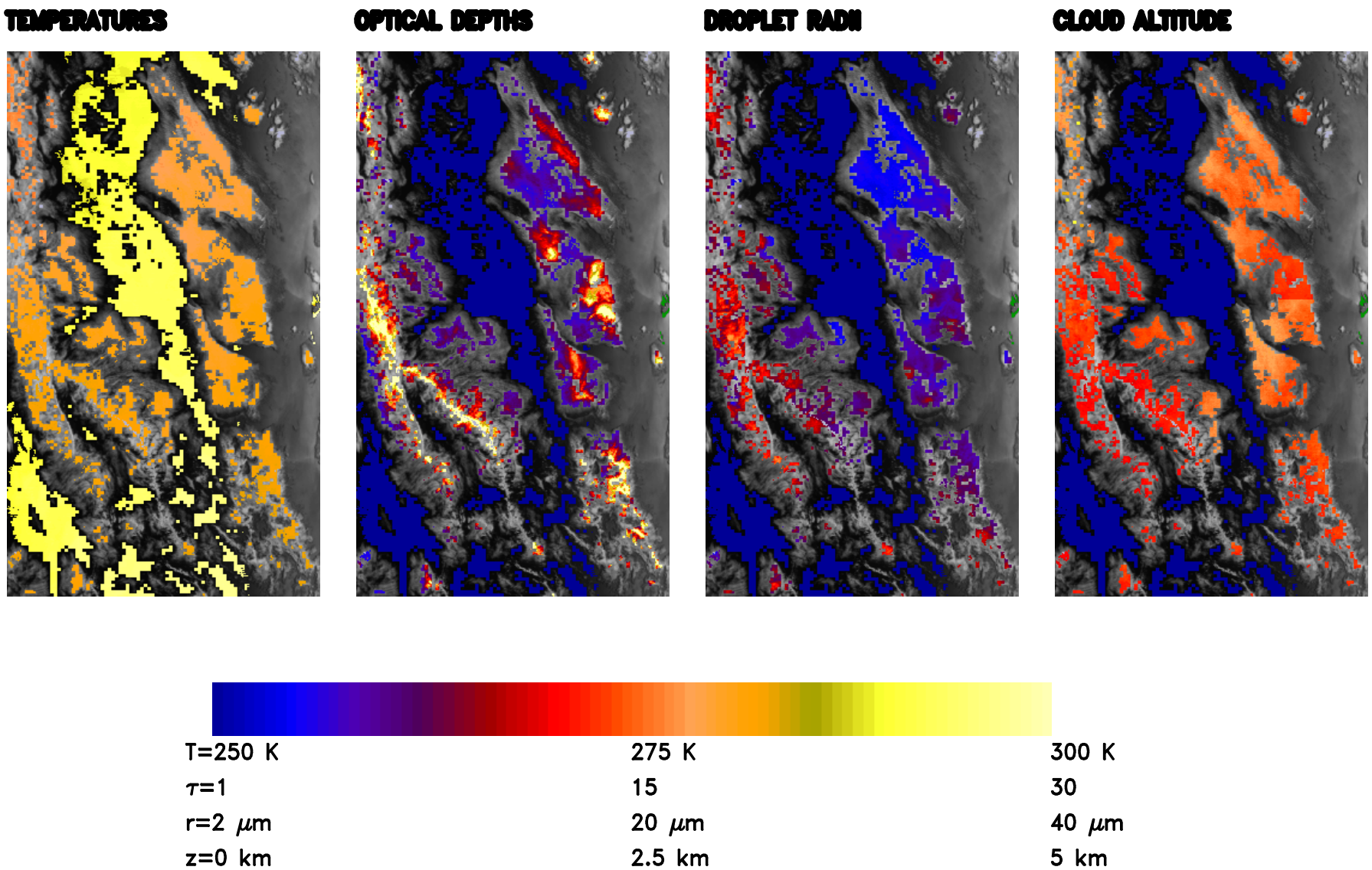


Figure 2. A set of retrieval products is shown for a region of the Pacific Ocean near Hawaii on February 10, 1998. Partly cloudy pixels appear in gray scale of visible reflectance. The values retrieve seem to be reasonable for low clouds.

RETRIEVAL PRODUCTS

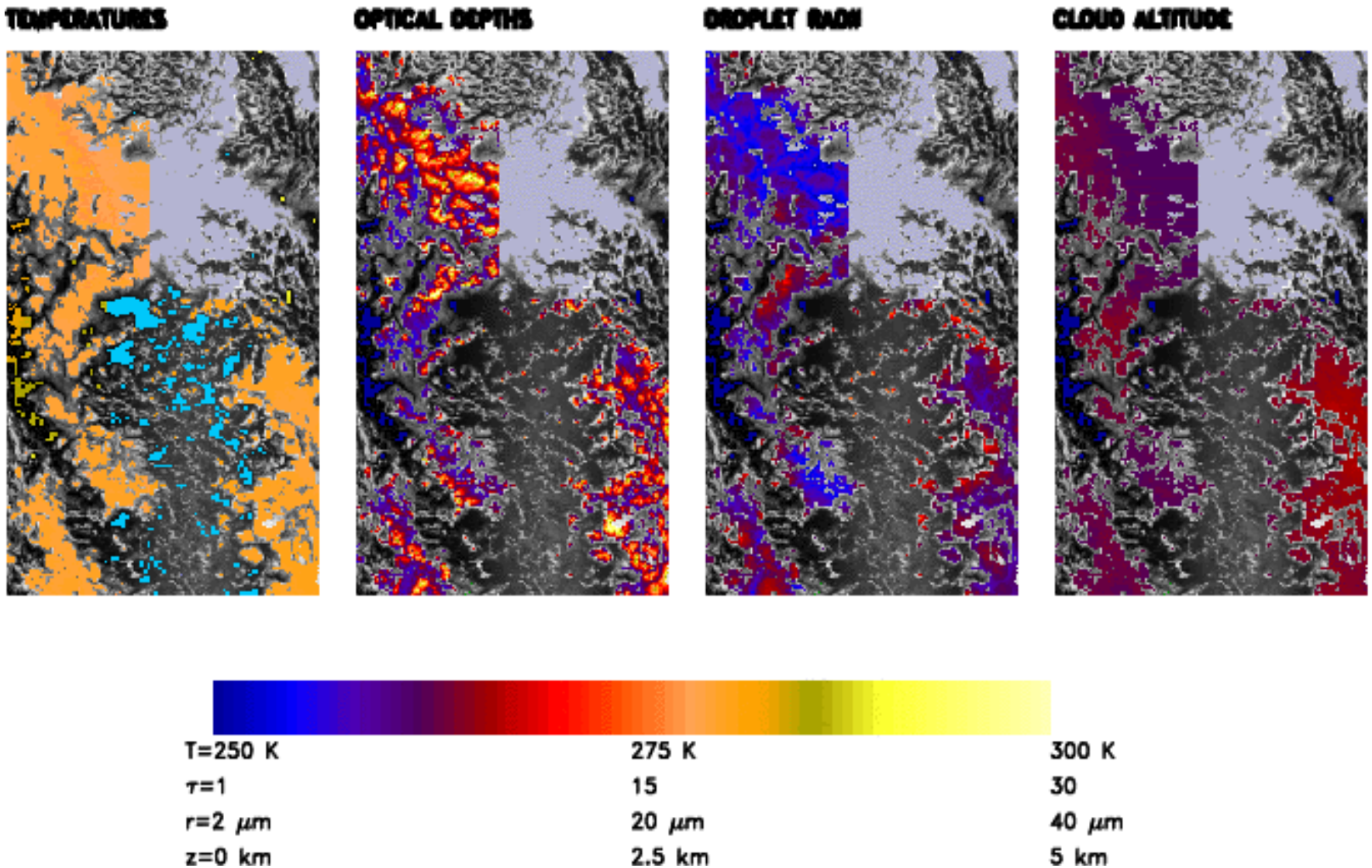


Figure 3. Retrieval products are shown for a region of the Pacific Ocean between Hawaii and California on July 5, 1998. Some overcast pixels shown in uniform gray are not analyzed due to lack of cloud-free pixels (upper right of panels). Cyan pixels in leftmost panel represent cloud-free pixels flagged for sun glint.

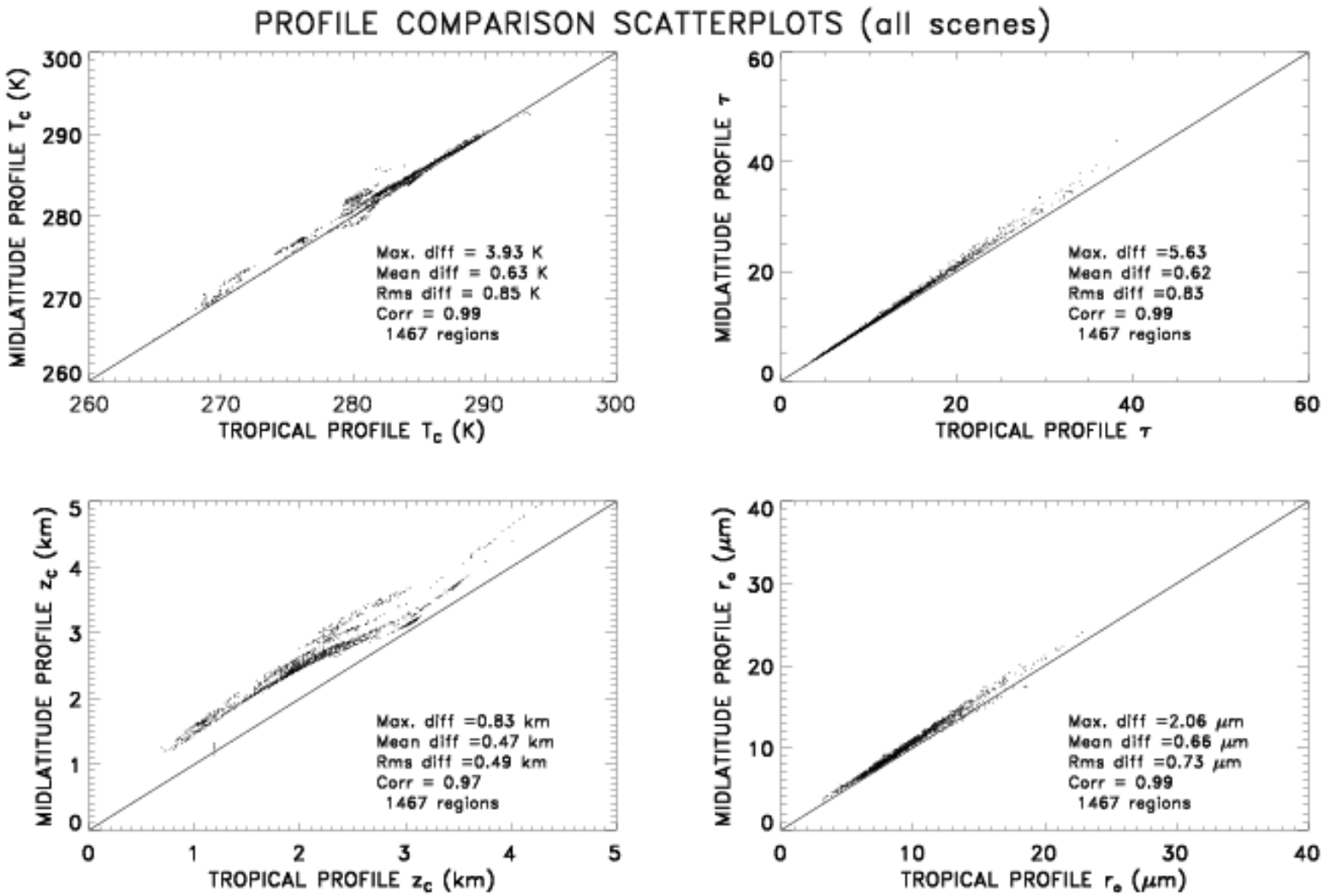


Figure 4. Scatterplots are shown comparing retrieval results using tropical and midlatitude profiles for all twenty comparison scenes. Each data point represents a mean value of a 29 x 32 pixel region. The scatter in optical depth is due to ozone amount differences. Differences in other properties are due to temperature and humidity differences.

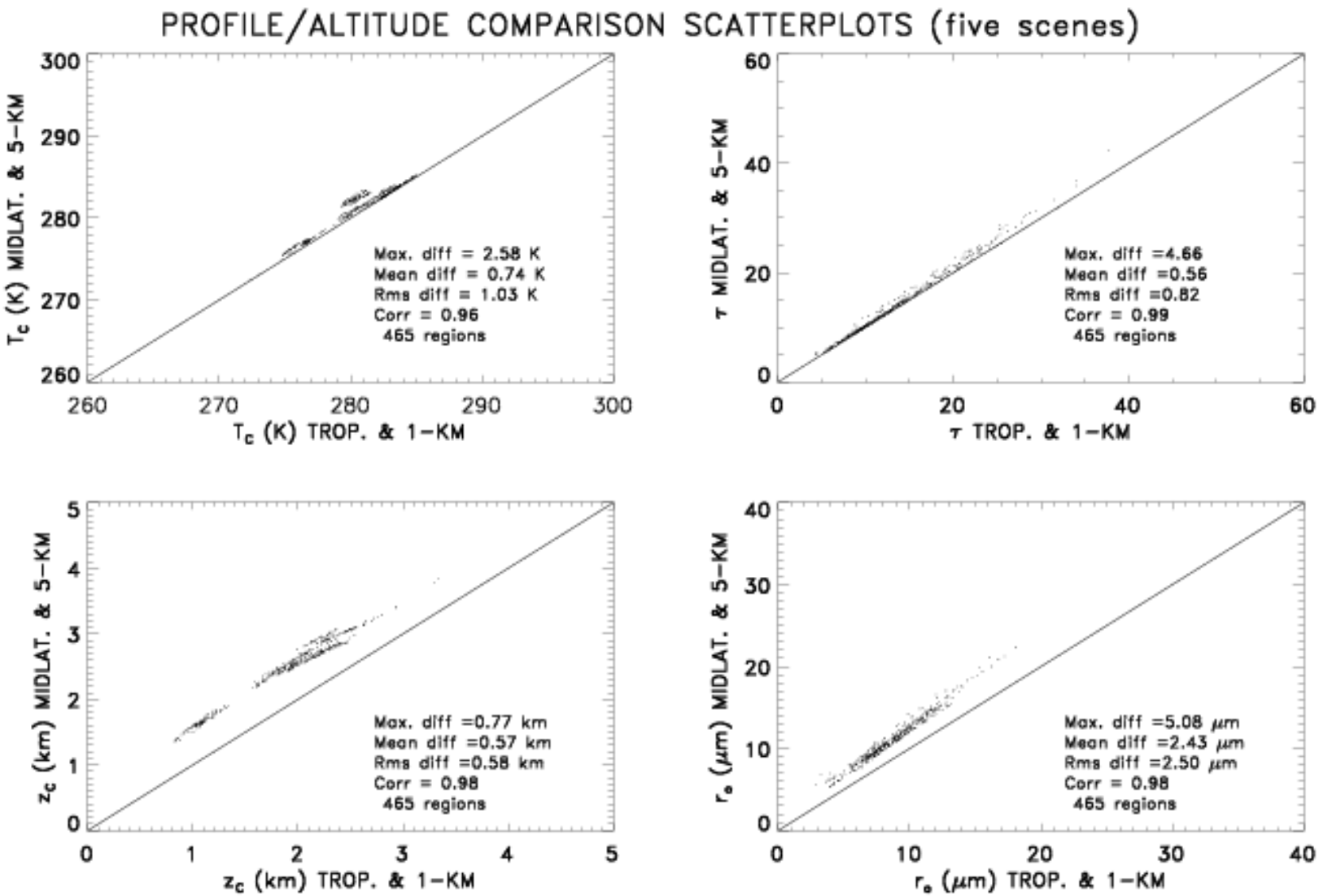


Figure 5. Scatterplots of retrieval results are shown where tropical profile was used with radiative transfer calculations for a cloud at 1 km, and midlatitude profile with 5-km cloud calculations. The largest effect is seen in the mode radius plot, where the rms difference is 2.5 μm higher for the midlatitude/5-km cloud case.

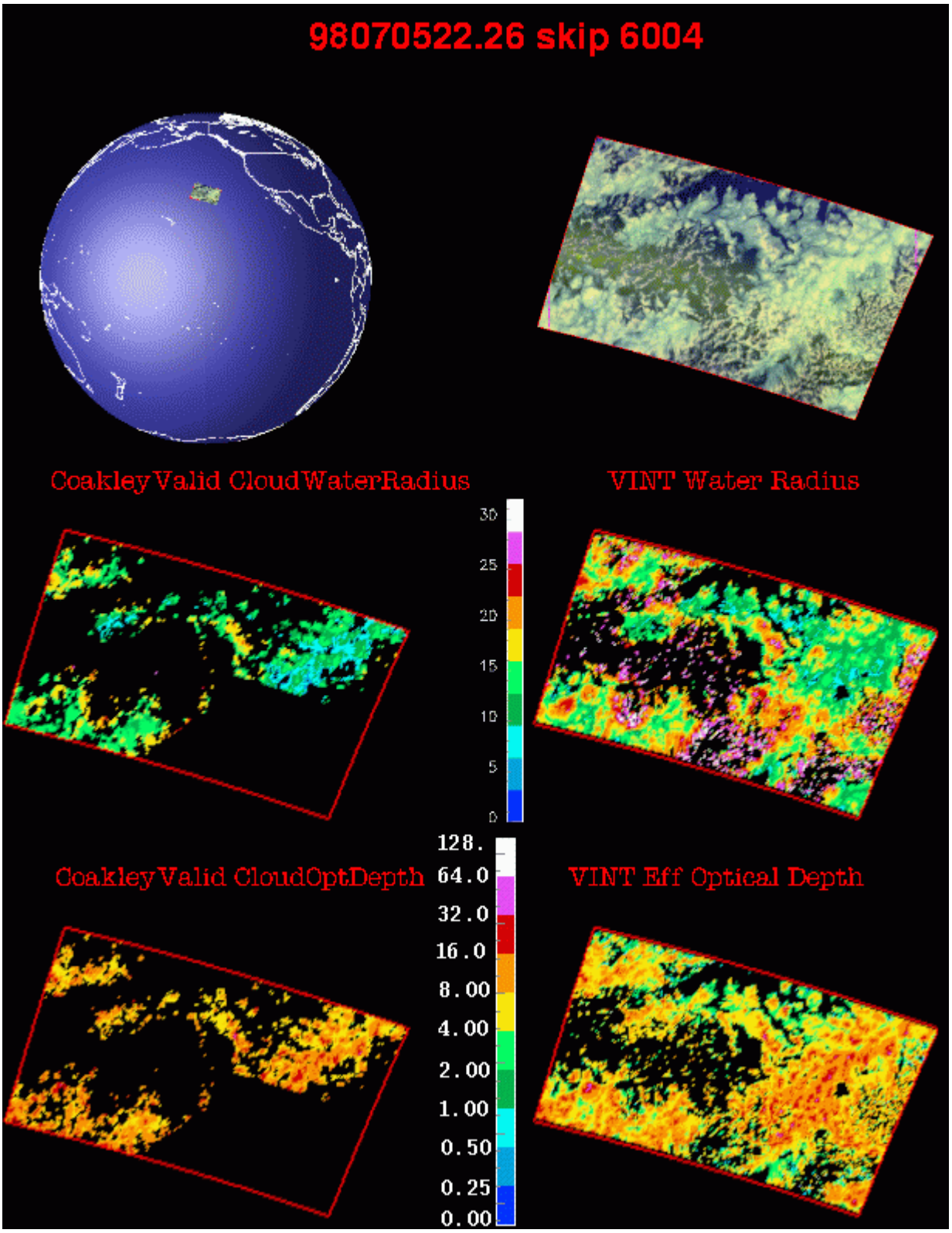


Figure 6. Retrievals of particle radius and optical depth are compared with CERES results for a Pacific Ocean scene on July 5, 1998. The largest differences are in particle radius, with CERES results 1 - 8 μm larger.

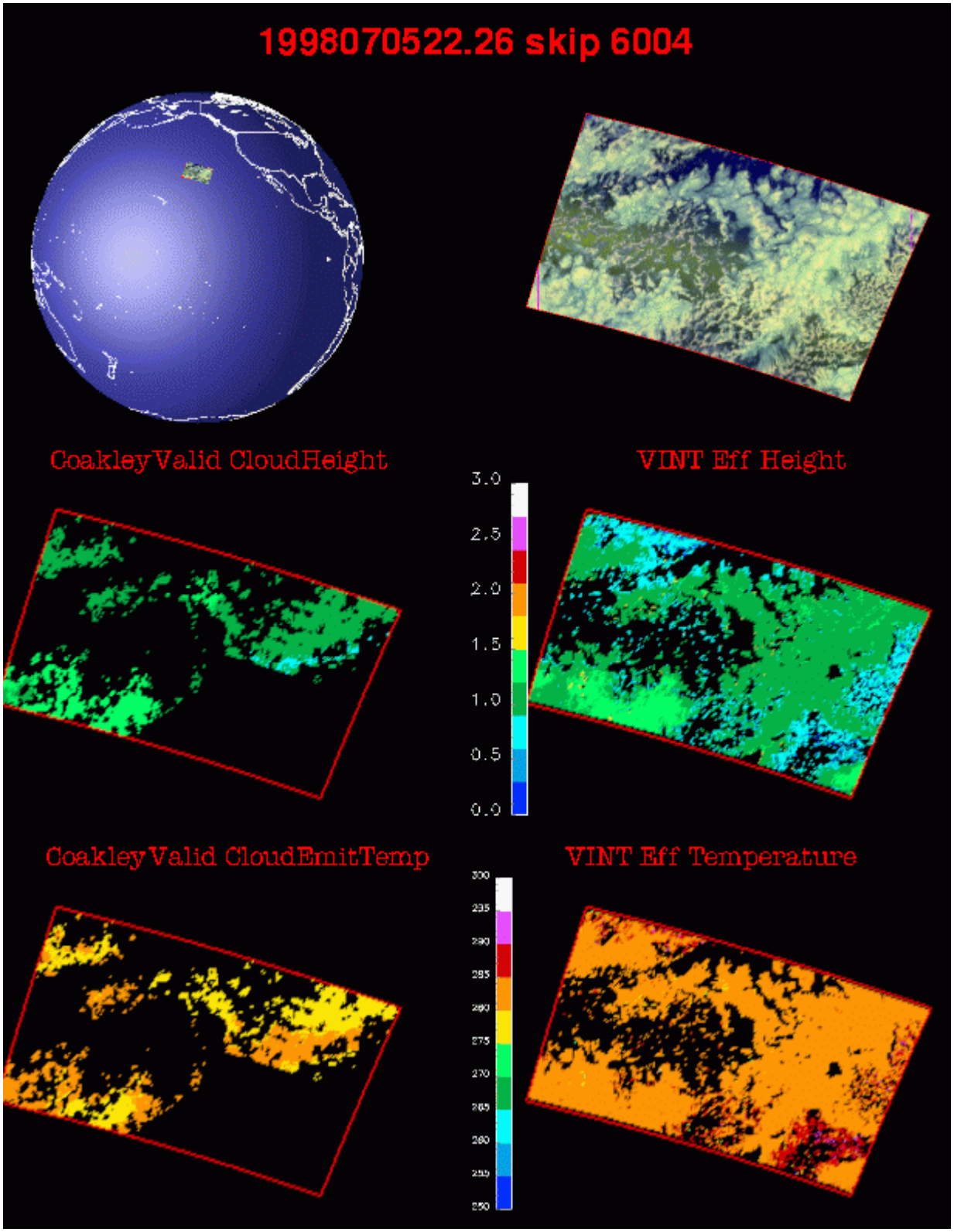


Figure 7. Retrievals of cloud height and temperature are compared with CERES results for a Pacific Ocean scene on July 5, 1998. Small differences are evident.

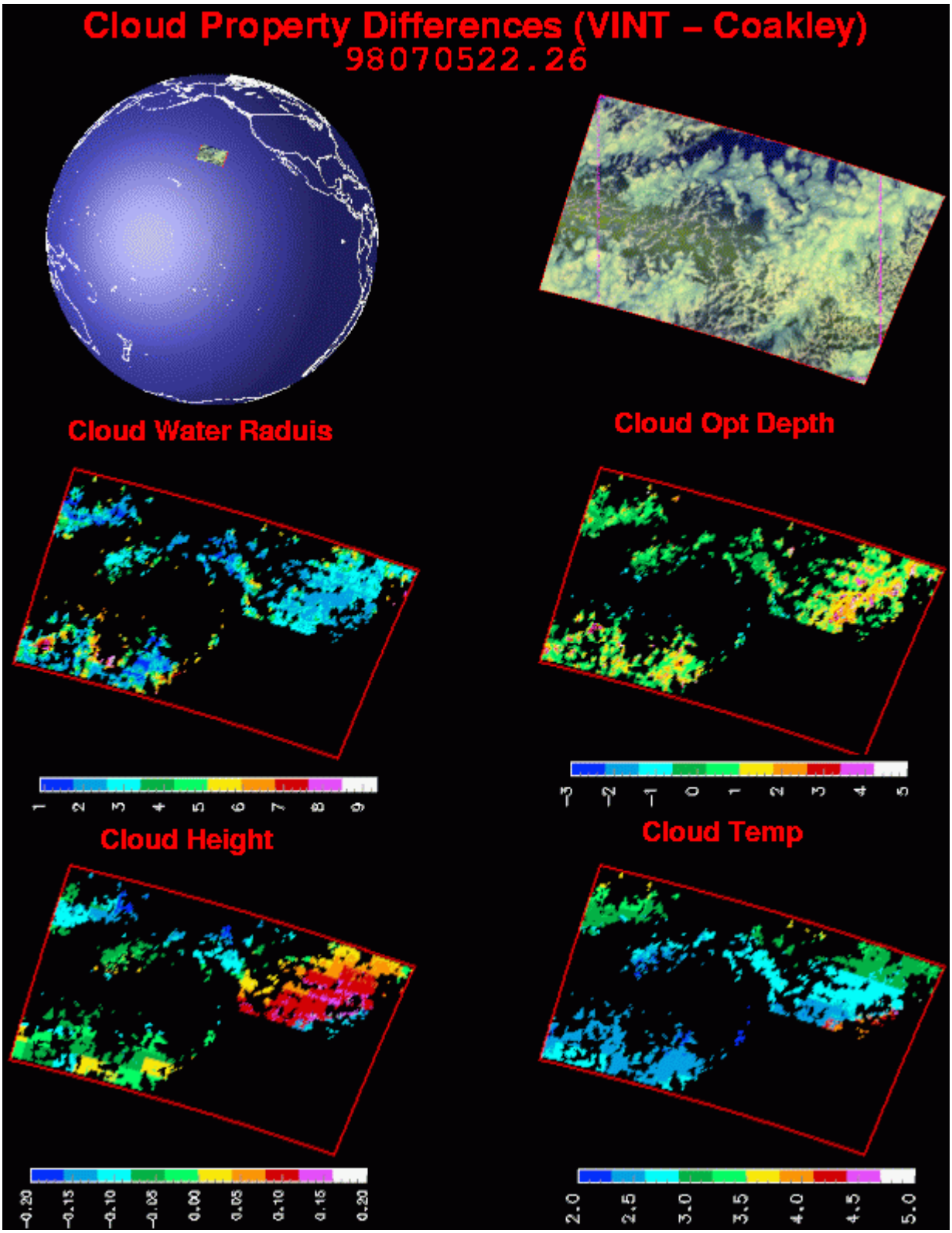


Figure 8. Differences between the cloud properties comparisons are shown for the July 5, 1998 case. Effective radius differences are 1 - 8 µm, optical depth differences are generally less than 2, cloud height differences are less than 0.2 km, and cloud temperature differences range up to several degrees.

Comparison Summary

- Qualitative assessment:
  - Optical depth, cloud altitude, and cloud temperature results close
  - Particle radius results are smaller than LaRC results

Possible Reasons for Differences

- Solar constant
- Radiative transfer look-up tables
- Emission calculation/parameterization differences
- Use of AVHRR vs. VIRS filter functions

➡ Above explanations presently being investigated

Partly Cloudy Retrievals

- In addition to retrieving optical depth and particle mode radius, cloud fraction is retrieved, assuming:

$$z_{cld}(pc) = z_{cld}(oc) \qquad T_{cld}(pc) = T_{cld}(oc)$$

- Radiances are given by:

$$I = I_{cf}(1 - A_c) + A_c\, I_{oc}$$

- Retrievals are performed only for those regions where there is one cloud layer

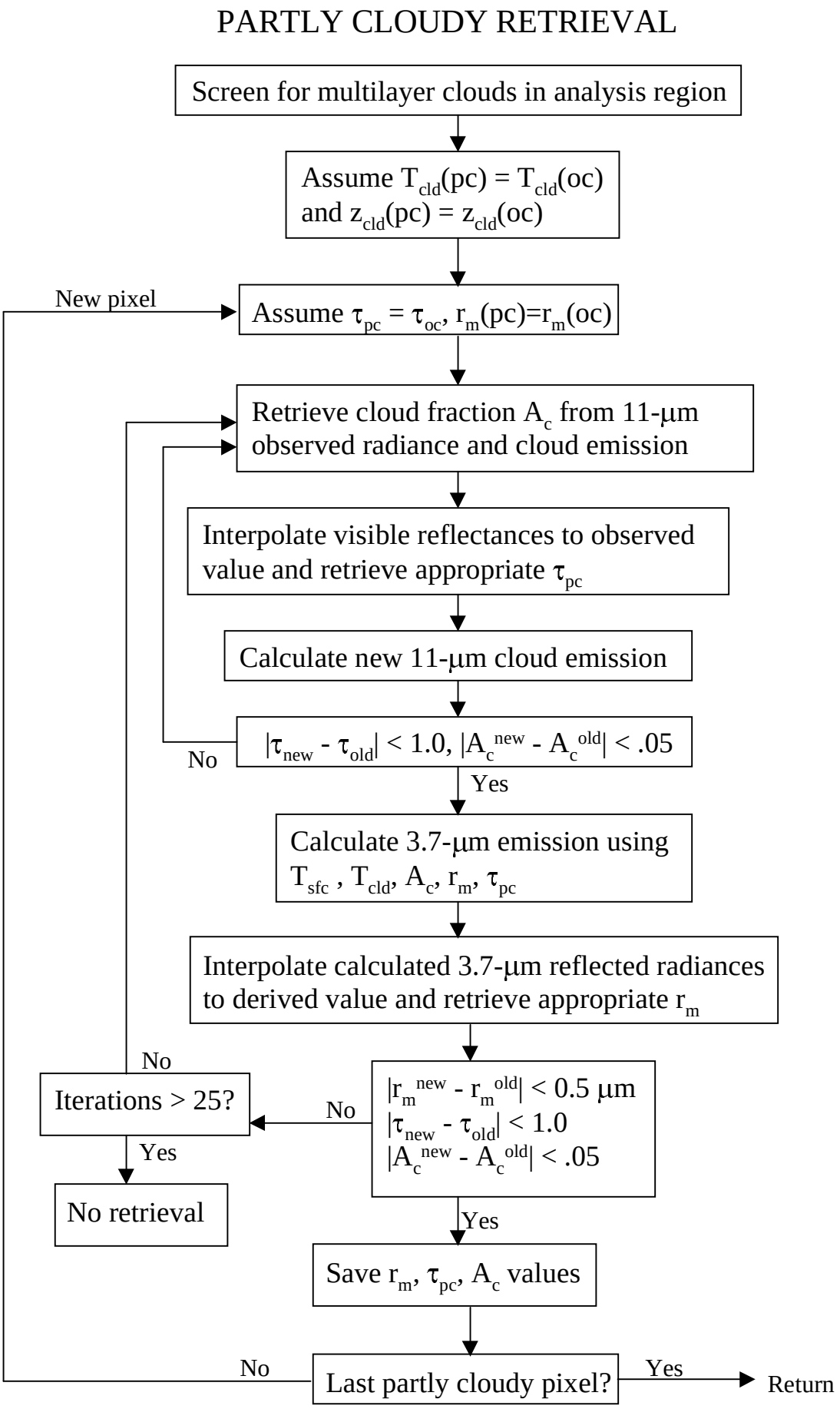


Figure 9. A flow diagram is shown for the partly cloudy retrieval algorithm.

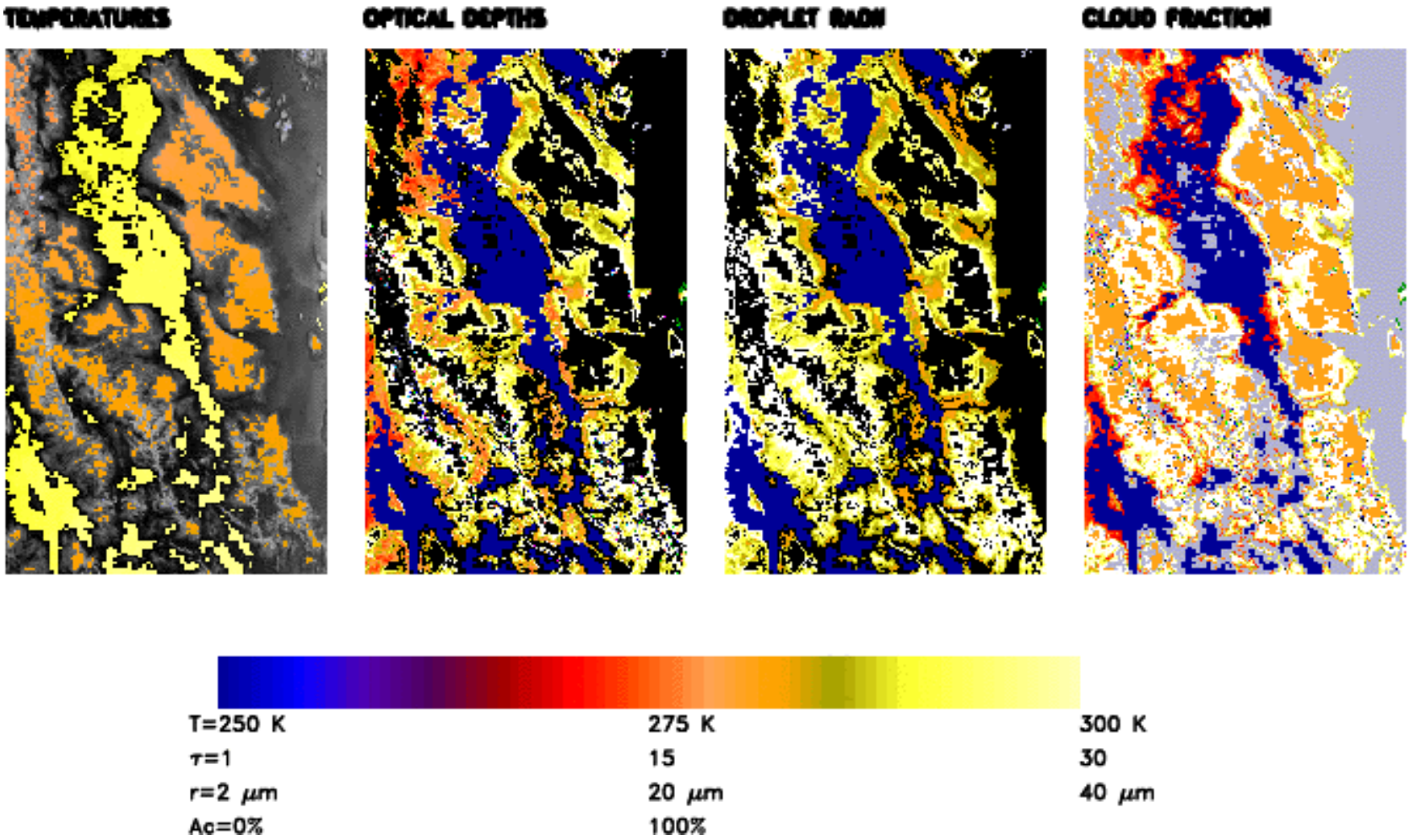


Figure 10. Preliminary results are shown for the partly cloudy retrievals.

Tasks

- Complete overcast retrieval comparison investigation
- Continue implementation of partly cloudy retrievals
- Compare retrieved properties for partly cloudy and overcast pixels, and their effects on top-of-atmosphere and surface radiative fluxes
- Obtain IGBP land surface classifications and incorporate into retrieval analysis to extend retrievals over land
- Separation of cloud layers for multilayered cloud systems

Direct Radiative Forcing by Aerosols in INDOEX

W.R. Tahnk and J.A. Coakley, Jr.

College of Oceanic and Atmospheric Sciences
Oregon State University

Goal: Compare aerosol direct radiative forcing derived using AVHRR with that derived using CERES – VIRS as found in TRMM SSF data.

Retrieval of Aerosol Properties from AVHRR

Two aerosol models, Average Continental and Tropical Marine as described by Hess et al. (1998) used in retrieval scheme to derive aerosol optical depth (0.55-μm) and mixing fraction from 0.63 and 0.85-μm NOAA-14 AVHRR reflectances.

Optical depths derived from AVHRR compared with NASA Aeronet optical depths and found to be in reasonable agreement at both visible and near infrared wavelengths.

Ratio of optical depths at visible and near infrared wavelengths in better agreement than those obtained using single-aerosol model, single-channel retrieval schemes.

Optical Depths and Direct Aerosol Radiative Forcing

Optical depths retrieved for January–March, 1996–2000.

Optical depth, τ, aerosol mixing fraction, *f*, and aerosol models used in broadband radiative transfer calculation to determine diurnally averaged direct radiative forcing due to aerosol, F_{CLEAR}.

Effects due to clouds allowed for by taking

$$F_{\mathrm{AVE}} = (1 - A_C) F_{\mathrm{CLEAR}}$$

with

$$A_C = \frac{n_{\mathrm{OVERCAST}} + 0.3 \times n_{\mathrm{PARTLY\ CLOUDY}}}{n_{\mathrm{TOTAL}}}$$

Comparison of Optical Depths for SSF

VIRS radiances for 100% clear CERES FOVs used in 2-channel INDOEX algorithm to derive aerosol optical depths.

Optical depths analyzed for $1° \times 1°$ regions observed within 15 minutes by both VIRS – TRMM and NOAA-14 – AVHRR.

Only 6 hours of SSF data (from different days) were available for INDOEX region for February 1998.

CERES 100% Clear FOVs Suitable for Direct Aerosol Radiative Forcing

Most VIRS fields of view identified as “clear” unsuitable for aerosol retrievals.

In most cases, less than 2% of the VIRS FOVs within CERES 100% clear FOVs used to derive optical depths.

How might CERES products be used to determine the aerosol direct radiative forcing?

Comparison of SSF optical depths and optical depths derived using INDOEX algorithm used to assess cloud contamination in CERES 100% clear FOVs.

Comparison of Observed SW Radiance and SW Radiances Estimated from INDOEX Retrievals

CERES 100% Clear with > 30% aerosol coverage appear to have low levels of cloud contamination.

Less than 0.3% of CERES FOVs have aerosol coverage > 30%.

SW radiances from CERES FOVs suitable for estimating aerosol direct radiative forcing compared with SW radiances derived from INDOEX retrieval algorithm.

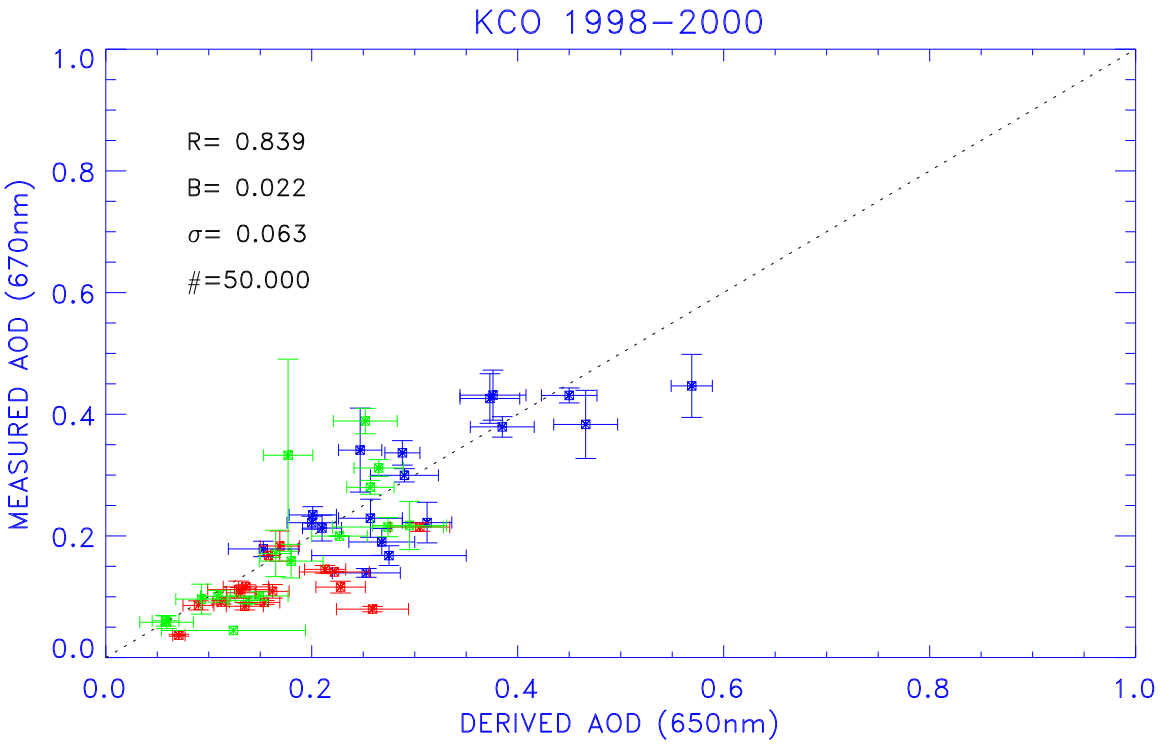
Conclusions

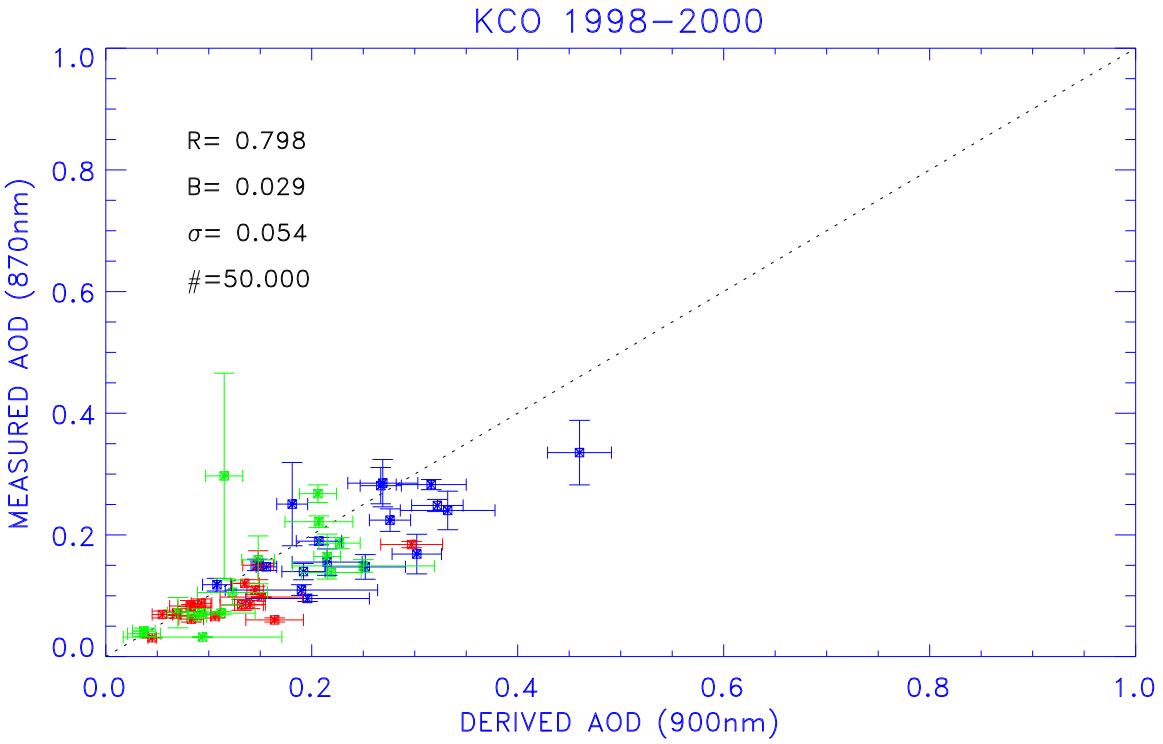
For tropical marine and average continental aerosols, difference in top of the atmosphere, narrow band to broadband radiance conversion factors is less than 10%, irrespective of viewing geometry.

Either tropical marine or average continental aerosol model would provide a reasonably accurate estimate of the aerosol direct radiative forcing.

RETRIEVED AND SURFACE AEROSOL OPTICAL DEPTHS

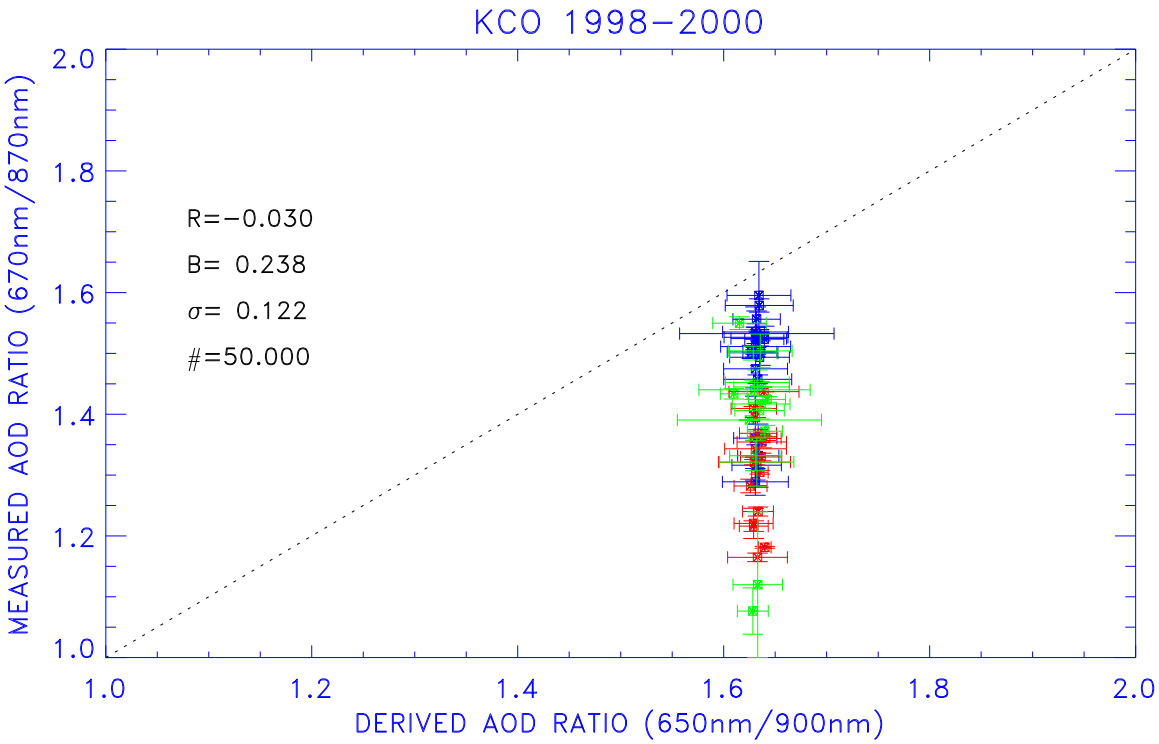
W. R. Tahnk and J. A. Coakley, Jr, OREGON STATE UNIVERSITY

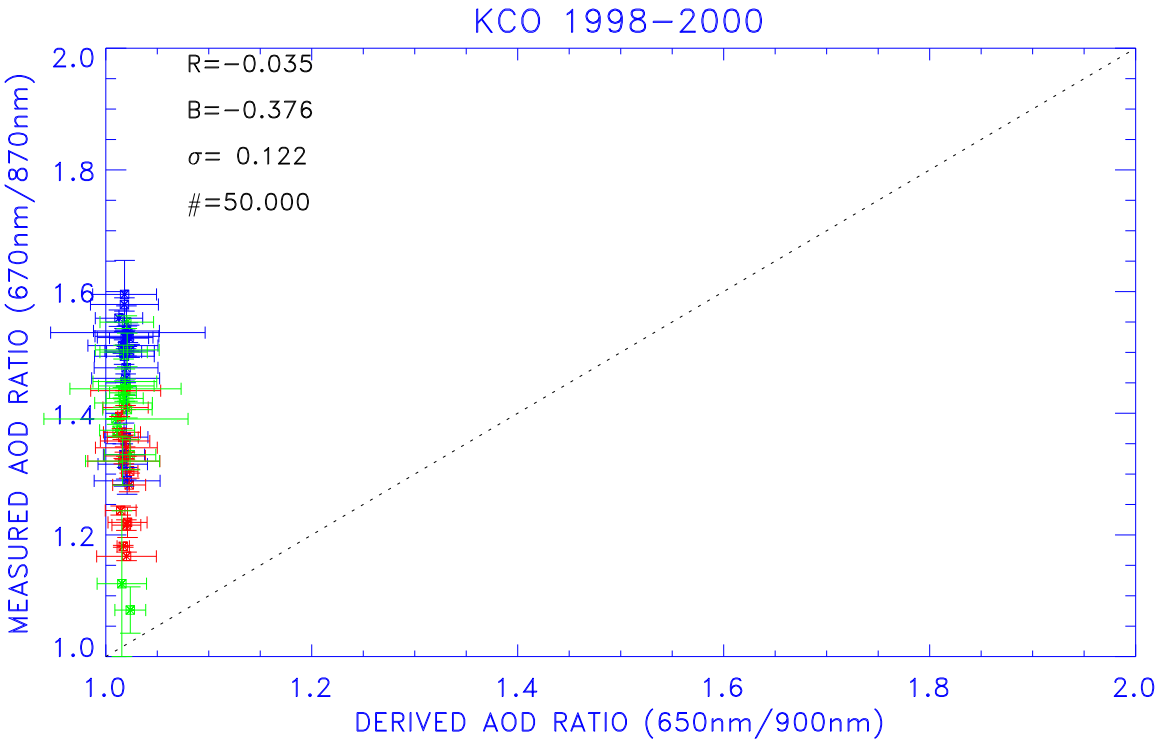




RETRIEVED AND SURFACE AEROSOL SIZE INDEX

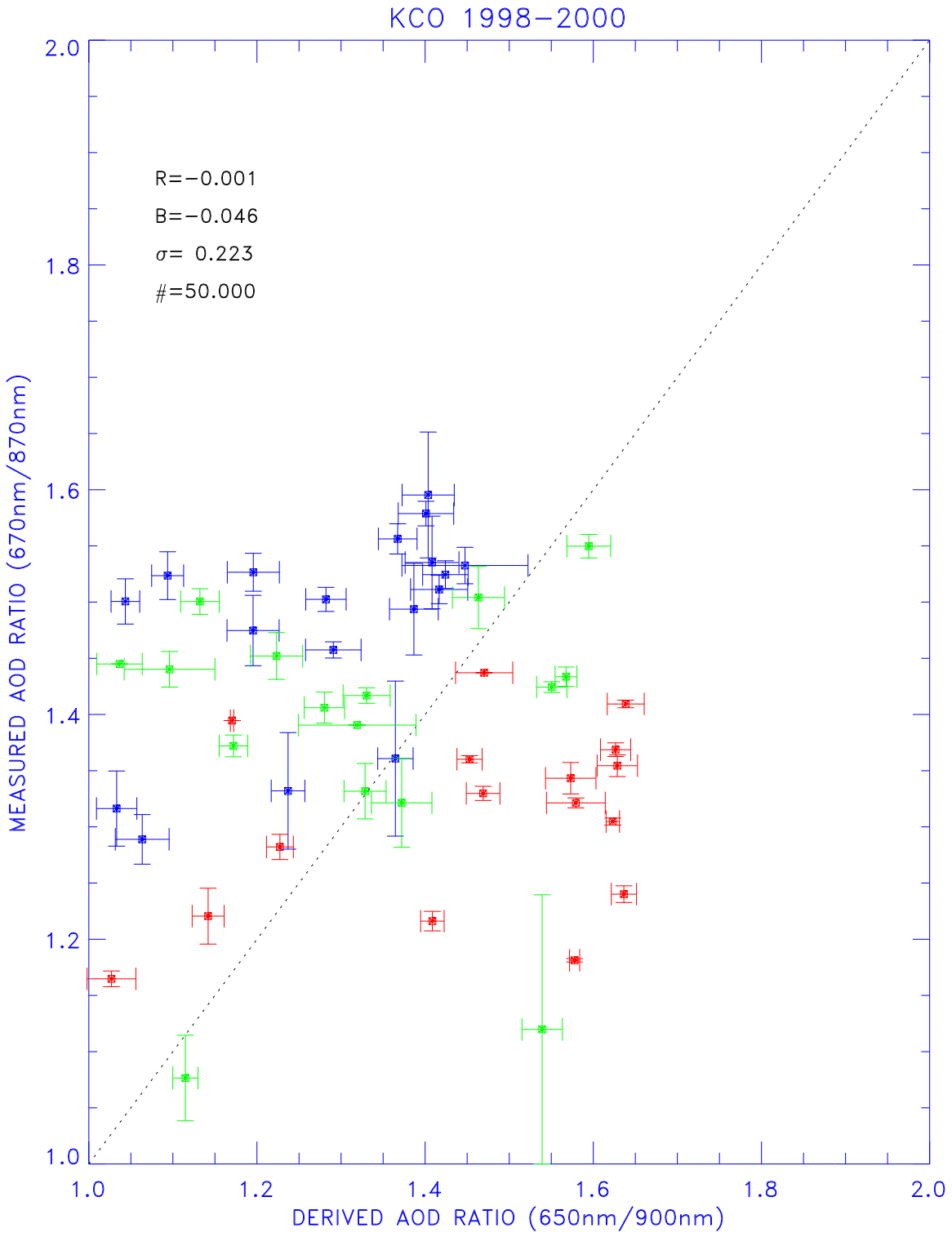
W. R. Tahnk and J. A. Coakley, Jr, OREGON STATE UNIVERSITY





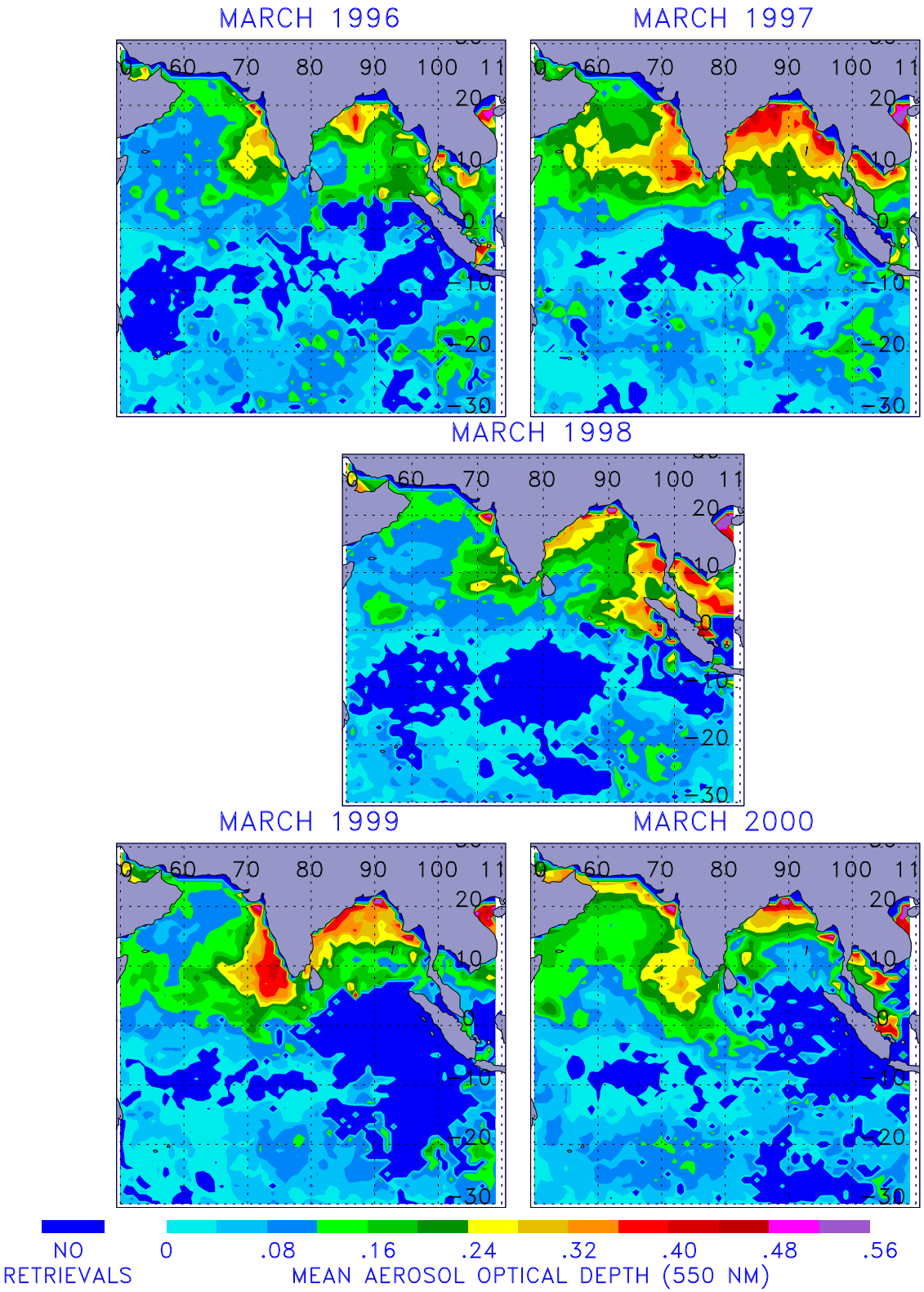
RETRIEVED AND SURFACE AEROSOL SIZE INDEX

W. R. Tahnk and J. A. Coakley, Jr, OREGON STATE UNIVERSITY



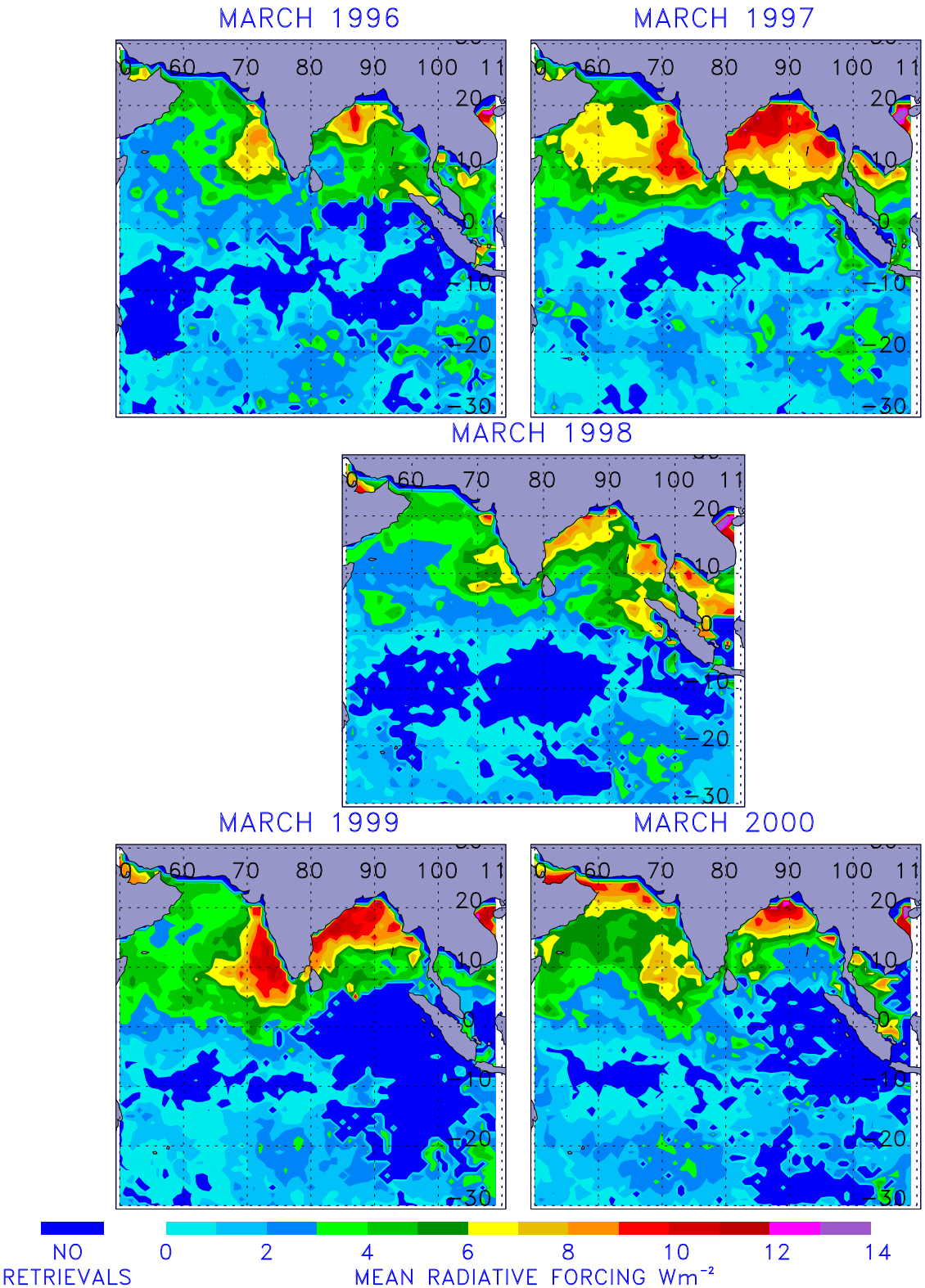
INDOEX OPTICAL DEPTHS DERIVED FROM AVHRR

W. R. Tahnk and J. A. Coakley, Jr, OREGON STATE UNIVERSITY

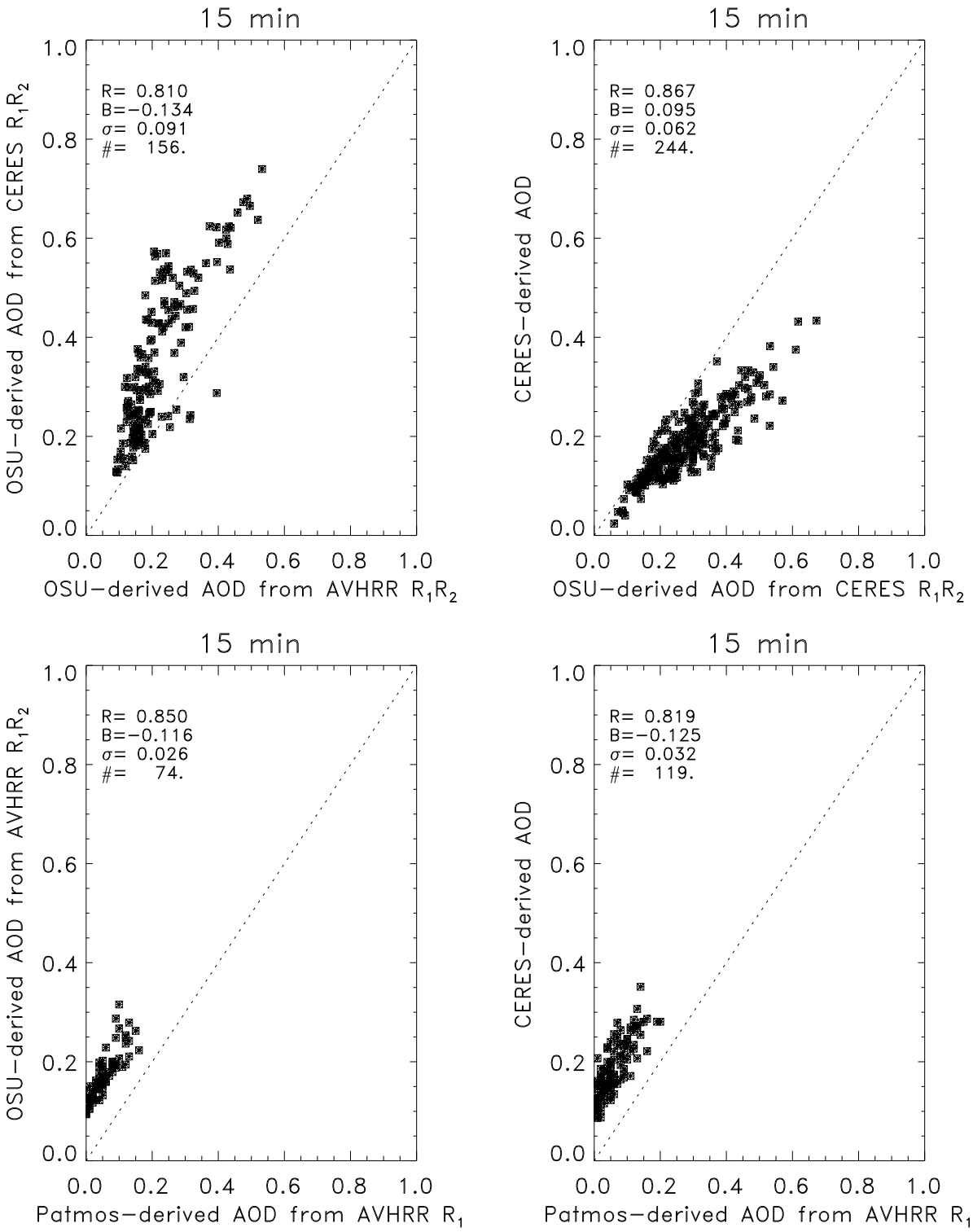


TOA RADIATIVE FORCING DERIVED FROM AVHRR

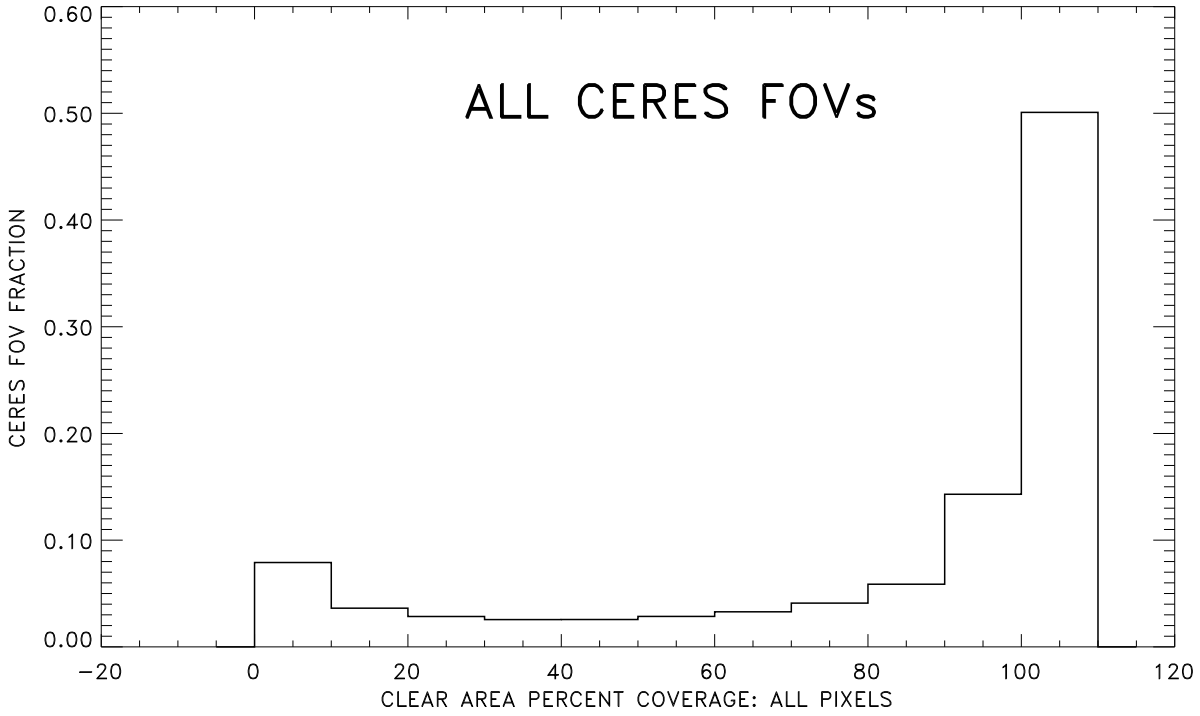
W. R. Tahnk and J. A. Coakley, Jr, OREGON STATE UNIVERSITY

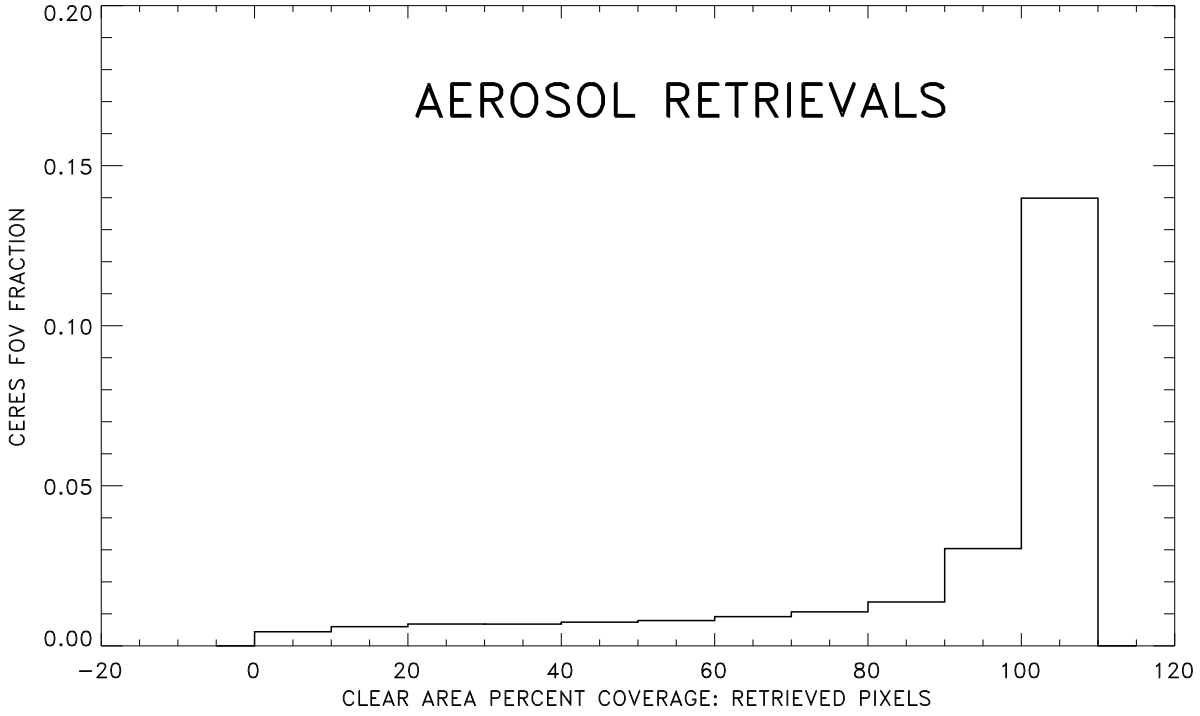


CERES SSF OPTICAL DEPTH COMPARISONS

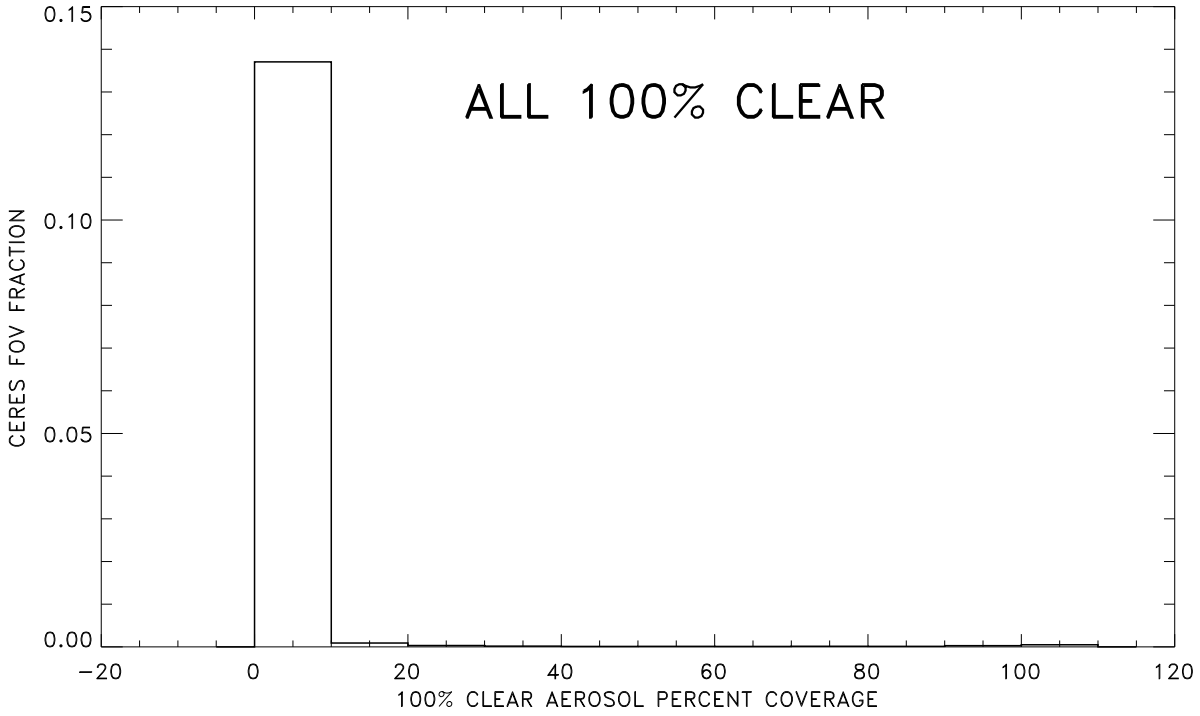


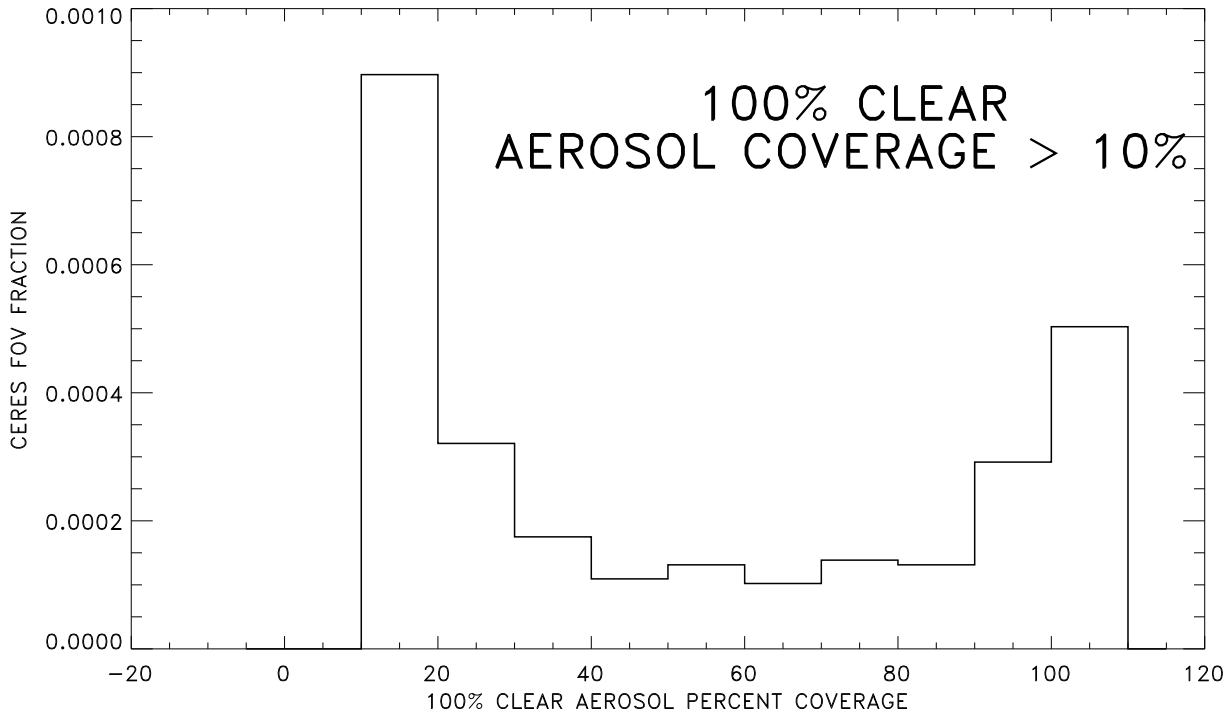
CERES SSF CLEAR AREA FRACTIONS
INDOEX REGION FEB 1998



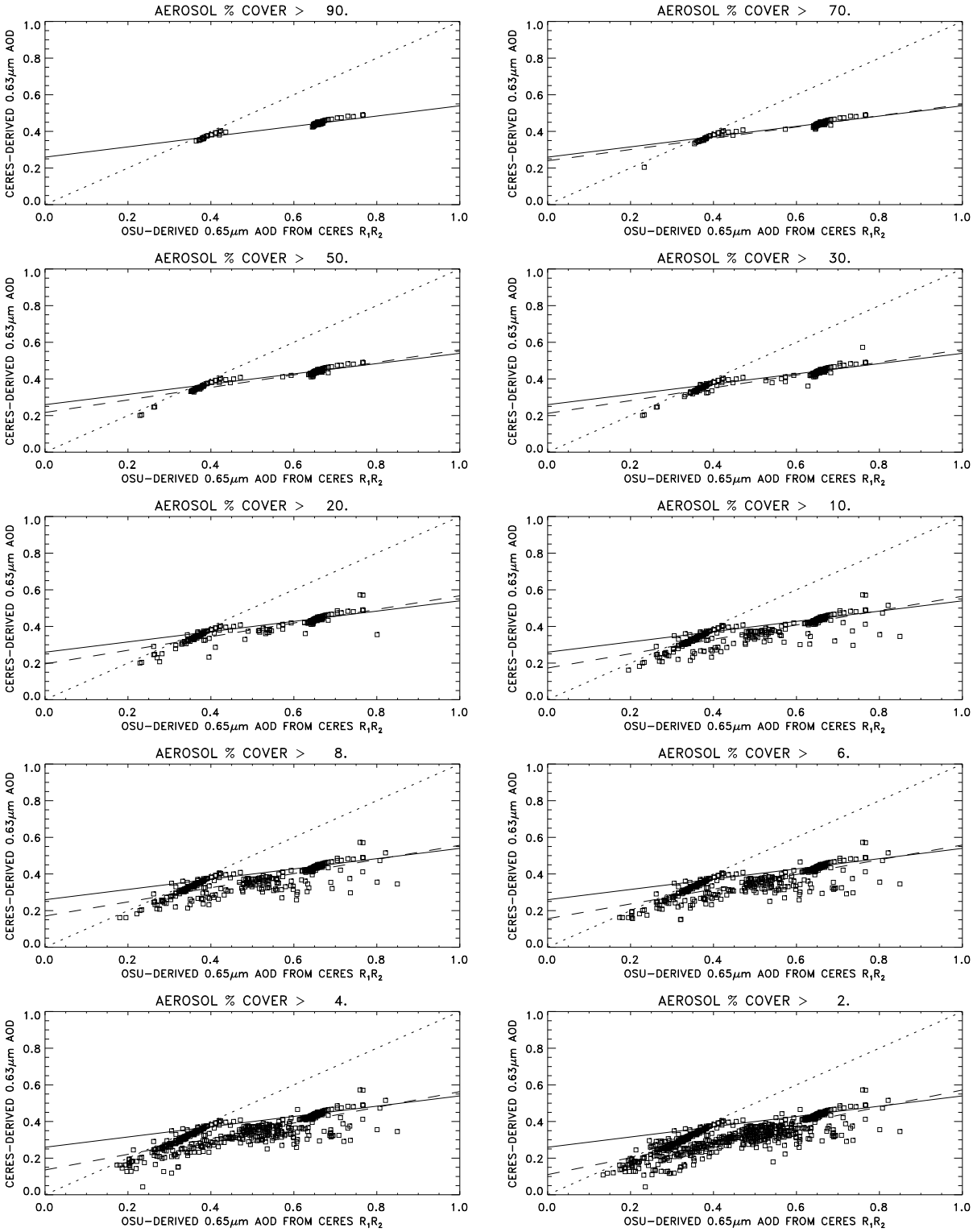


CERES SSF AEROSOL RETRIEVAL COVERAGE
100% CLEAR AREA COVERAGE

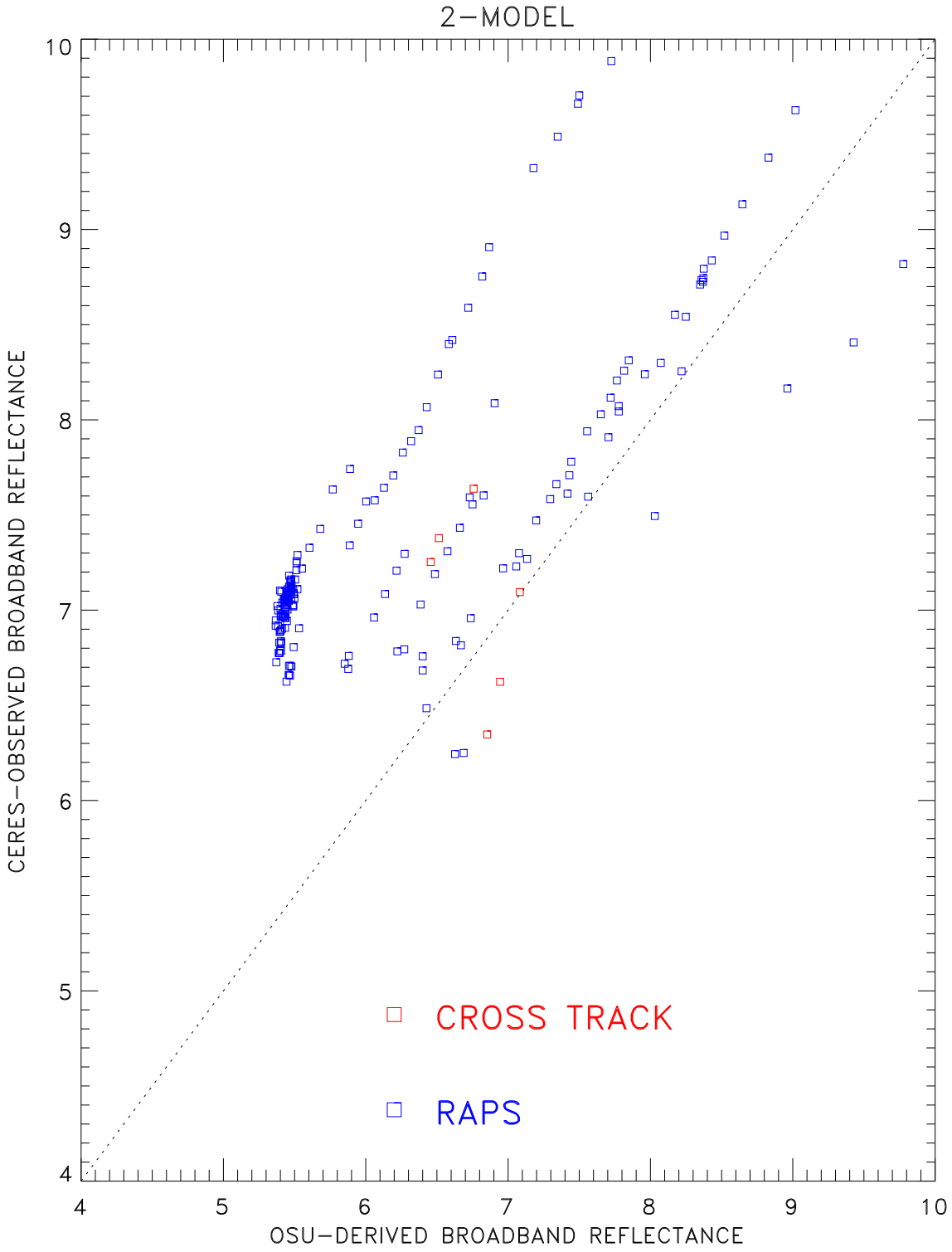




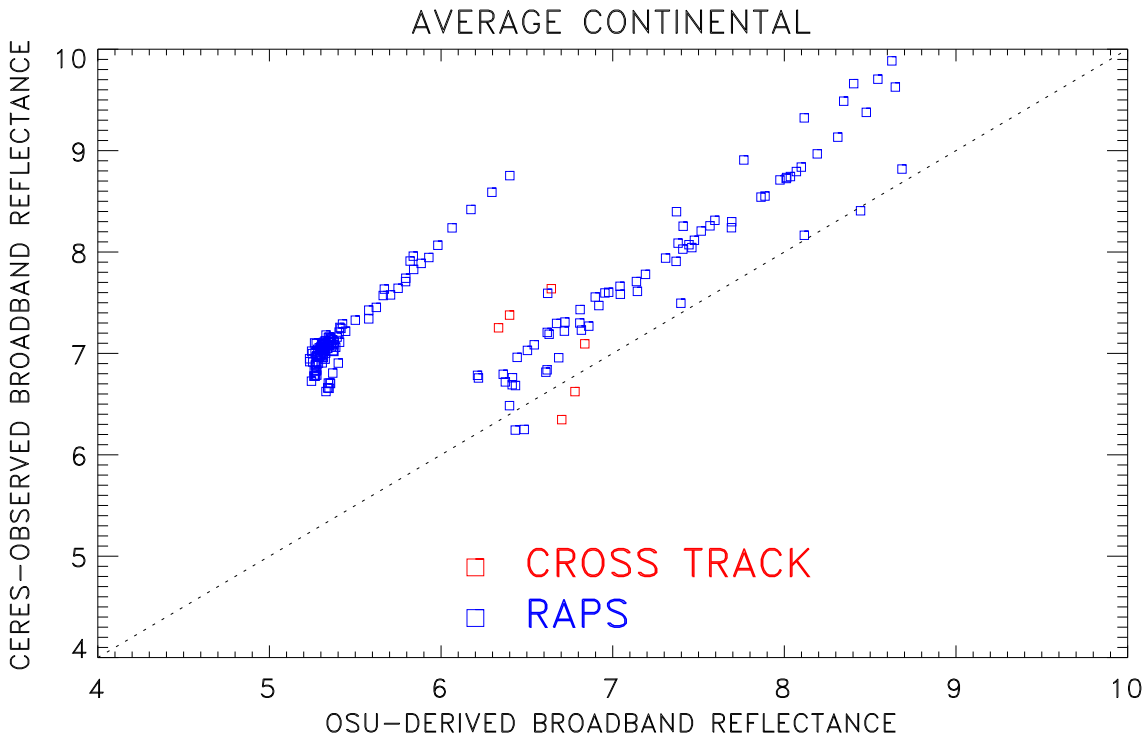
CERES SSF AEROSOL RETRIEVAL COMPARISONS

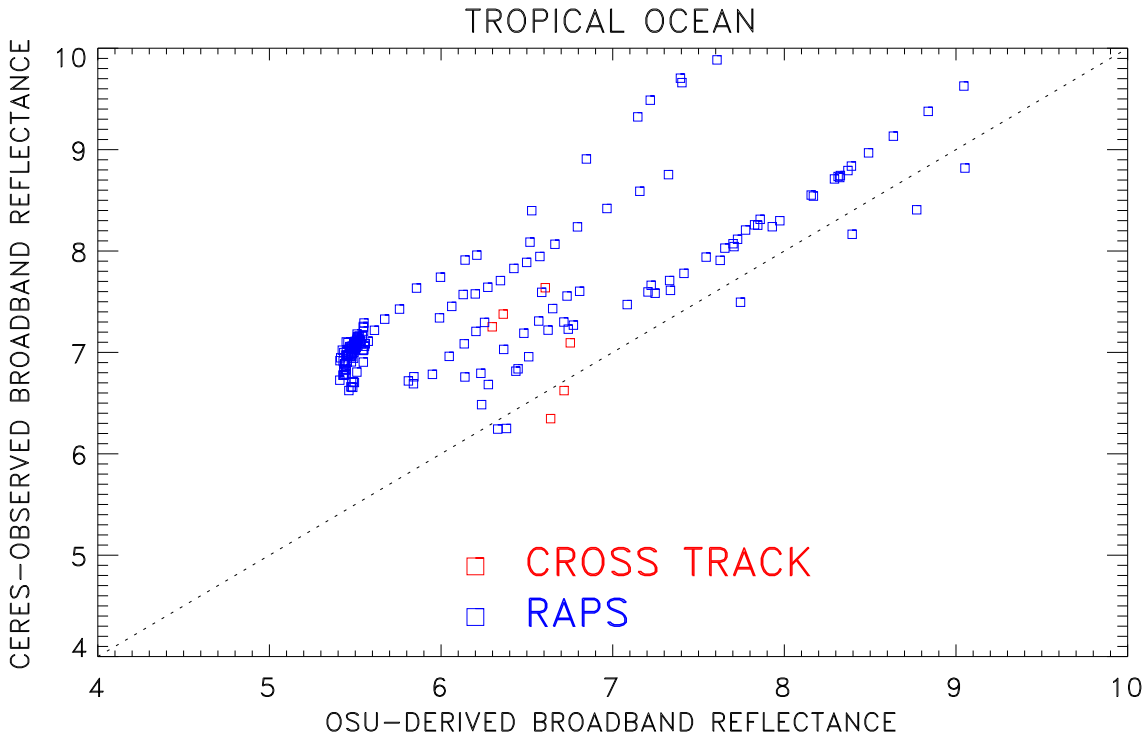


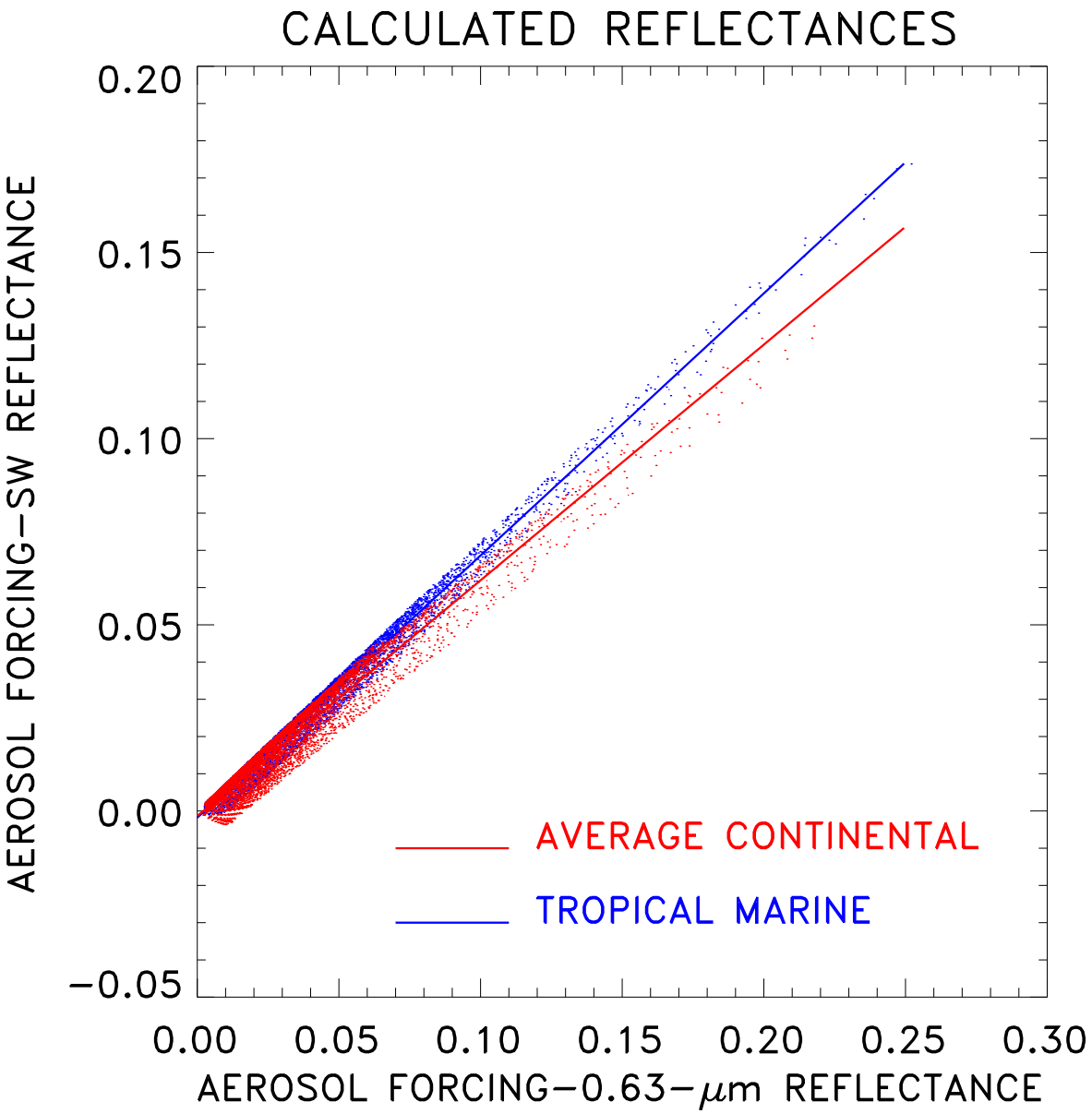
PREDICTED AND OBSERVED SW REFLECTANCE
100% CLEAR >30% AEROSOL COVERAGE
INDOEX REGION FEB 1998



PREDICTED AND OBSERVED SW REFLECTANCE
100% CLEAR >30% AEROSOL COVERAGE
INDOEX REGION FEB 1998






CALCULATED REFLECTANCES
AEROSOL FORCING−SW REFLECTANCE
0.20
0.15
0.10
0.05
0.00
−0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
AEROSOL FORCING−0.63−μm REFLECTANCE
AVERAGE CONTINENTAL
TROPICAL MARINE