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A ONE-YEAR CLIMATOLOGY OF CLOUD PROPERTIES DERIVED FROM GOES-8 OVER THE SOUTHEASTERN PACIFIC FOR PACS

J. Kirk Ayers*, Patrick W. Heck, and Anita D. Rapp
Analytical Services & Materials Inc., Hampton, VA

Patrick Minnis, David F. Young, William L. Smith, Jr., and Louis Nguyen
Atmospheric Sciences, NASA-Langley Research Center, Hampton, VA

1. INTRODUCTION

The overall goal of the Pan-American Climate Studies (PACS) program is to extend the scope and improve the skill of operational climate prediction over the Americas. The atmosphere over the southeastern Pacific (SEP) plays an important role in the general circulation, El Nino anomalies, and the weather over North, Central, and South America. Meteorological observations over the SEP are sparse causing large uncertainties in initialized model fields. Although not currently used in assimilations, cloud properties and radiation fields are important components of the weather and climate system and should be faithfully reproduced in models that simulate and predict the atmospheric state from the meso- to global scales. Satellite observations are the only practical means to acquire the necessary parameters over the SEP for model validation and future assimilation. This paper presents the results of an analysis of 3-hourly multispectral GOES-8 data to derive cloud macrophysical and microphysical properties as well as the radiation budget over the SEP and adjacent continental areas. Monthly mean values for cloud amount, height, phase, effective particle size, optical depth, and liquid/ice water path, shortwave albedo, and top-of-atmosphere longwave flux are derived on a 1.0° latitude-longitude grid for a domain encompassed by 20°N, 40°S, 60°W, and 115°W for the 2000 calendar year. Special attention is given to the period of April 20 through May 15 when National Oceanic and Atmospheric Administration research vessels (R/V) were collecting a wide range of meteorological and oceanographic data in the domain. Data from instruments aboard the R/Vs can be used to validate the cloud retrievals from GOES-8.

2. METHODOLOGY

This study utilizes the Visible Infrared Solar-Infrared Split Window Technique (VISST) to determine cloud properties during the day and the Solar-Infrared Infrared Split Window Technique (SIST) for determinations at night. VISST is a 4-channel model-matching method for plane parallel clouds. It is discussed further by Minnis et al. (2001). VISST uses Geostationary Operational Environmental satellite (GOES-8) 4-km data from the 0.65 µm (VIS), 3.9 µm (SIR), 10.8 µm (IR), and 12.0 µm (SWC) channels. SIST is a minimum error, iterative regression method that matches observations to parameterized model emittance calculations, (Minnis et al. 1998). SIST requires the SIR, IR, and SWC GOES-8 channels.

VISST and SIST also require several additional inputs for cloud analyses. Three-hourly, 1° European Centre for Medium-range Weather Forecasting (ECMWF) analyses provide skin temperatures and vertical profiles of temperature and humidity. Surface type is based on the IGBP 10'-resolution surface map. Clear-sky reflectances, and ice and snow masks developed for the Clouds and the Earth's Radiant Energy System (CERES) program are used for additional surface characterization (Trepte et al. 1999). Narrowband-to-broadband flux conversion functions, developed from correlations of coincident ERBE-scanner broadband and GOES narrowband fluxes are used to compute broadband shortwave and longwave fluxes from the GOES data. Only the daytime results are presented here.

3. RESULTS

Four examples of monthly mean cloud fraction *C* are shown in Figs. 1 - 4. These months were chosen to illustrate the variation in *C* due to the seasonal cycle. The *C* for January, shown in Fig. 1, ranges from greater than 80% in the stratocumulus region west of Chile, the southern hemispheric storm track region, and over the Amazon Basin to less than 20% over the Atacama Desert and north of the Intertropical Convergence Zone (ITCZ). The ITCZ is very strong and centered near 5°N. During April, shown in Fig. 2, the ITCZ is less continuous with a center near the isthmus of Panama. The cloud cover is slightly reduced over the Amazon Basin and the Southern Hemisphere storm track near 40°S. Cloud cover reaches a maximum over much of Pacific in this domain during July, Fig. 3, especially around Central America, the western coasts of Peru and Chile, and the storm track region. The ITCZ appears to weaken during October (Fig. 4) accompanied by a reduction in the marine boundary-layer clouds. Cloud cover over South America is reduced during July and October compared to the other 2 months. Cloudiness remains small over the Altiplano during all of the months.

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* *Corresponding Author Address*: J. K. Ayers, AS&M, Inc., 1 Enterprise Parkway Hampton, VA 23666;
E-mail: j.k.ayers@larc.nasa.gov.

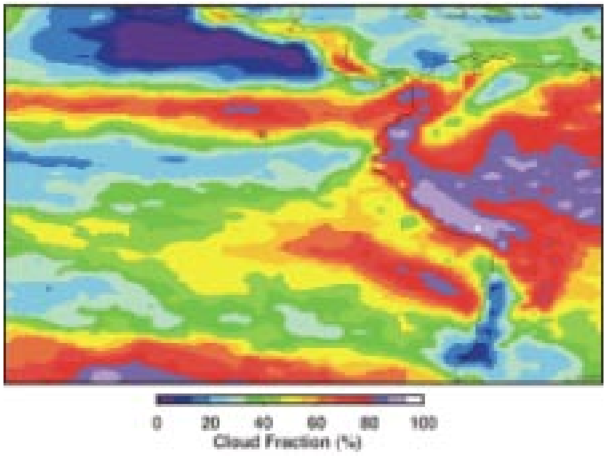

Fig. 1. Mean daytime cloud fraction, January 2000.

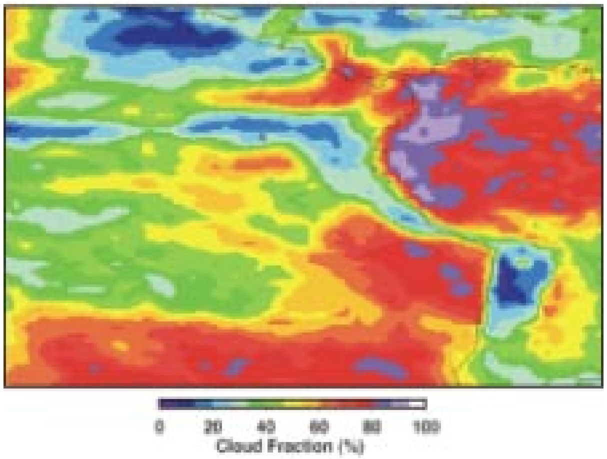

Fig. 2. Mean daytime cloud fraction, April 2000.

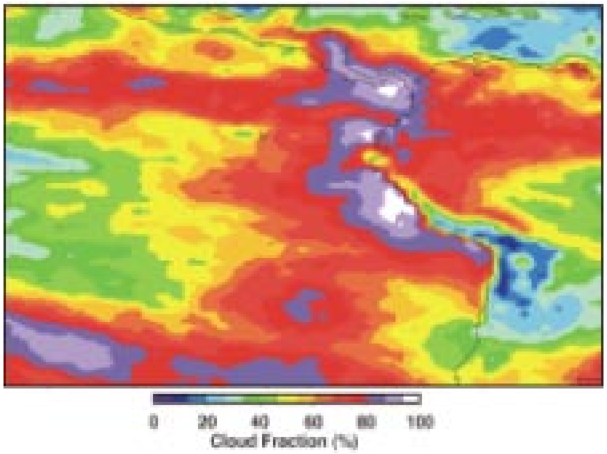

Fig. 3. Mean daytime cloud fraction, July 2000.

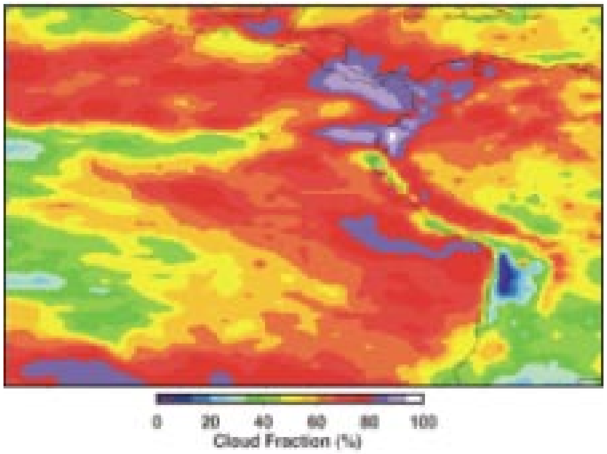

Fig. 4. Mean daytime cloud fraction, October 2000.

The locations of the convective cloud systems are more apparent in the distribution of mean cloud heights z_c. The map of z_c for April (Fig. 5) shows that most of the deep convective activity occurred over the Amazon Basin, Peru, and near Panama. Many of the marine boundary-layer clouds were located near 2-3 km, while the clouds over Argentina were mostly below 3 km. The distribution of mean cloud optical depth τ during April (see Fig. 6) is also consistent with heavy convection over the Amazon, the surrounding Andes, and over the ITCZ. The marine boundary layer stratus clouds covering much of the Pacific in Fig. 2 have mean optical depths ranging from 3 to 9. The low-level clouds over Argentina are denser with an average τ exceeding 9. The mean effective radii r_e of the liquid water clouds are plotted in Fig. 7 and for October 2000 in Fig. 8. In most

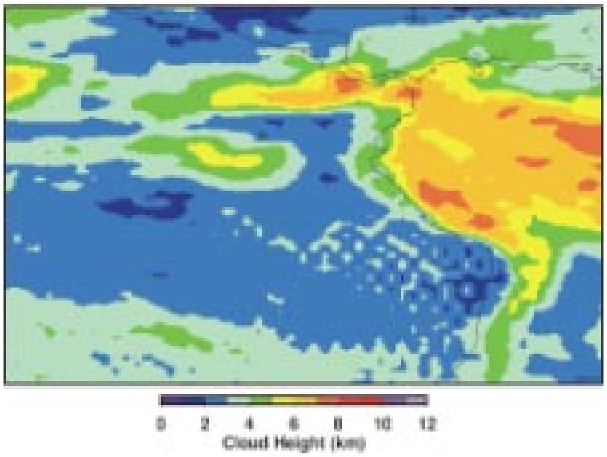

Fig. 5. Mean daytime cloud height, April 2000.

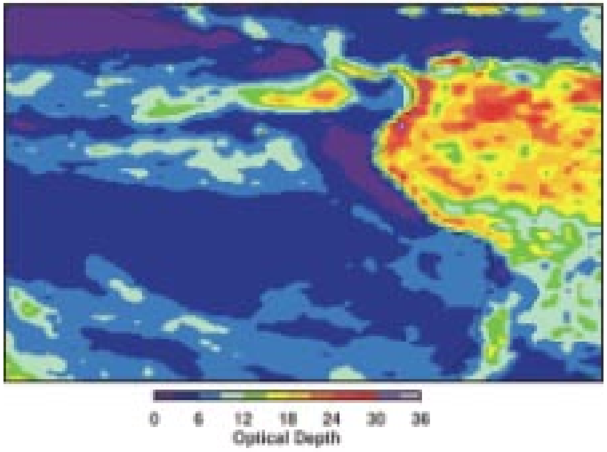

Fig. 6. Mean daytime cloud optical depth, April 2000.

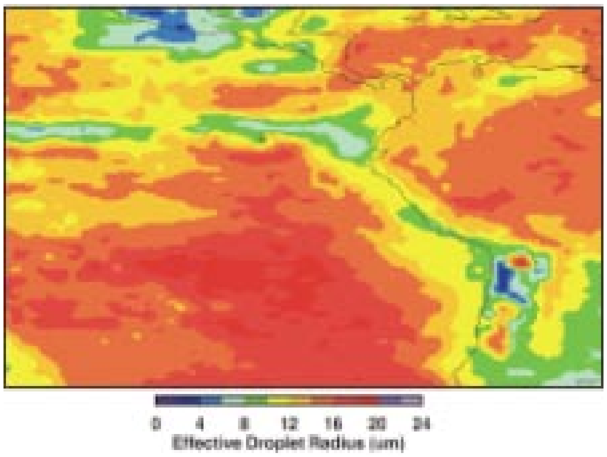

Fig. 7. Mean cloud water droplet effective radius, April 2000.

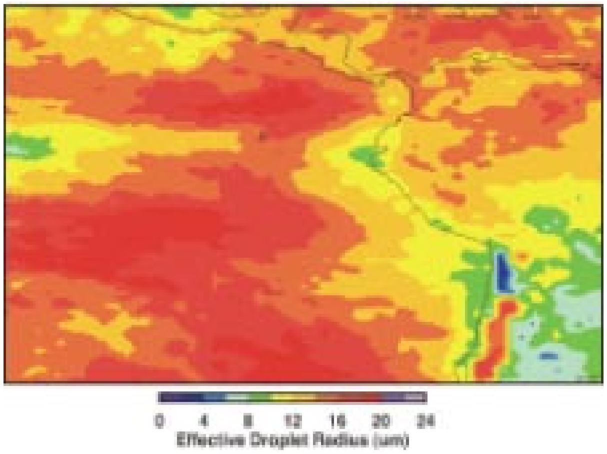

Fig. 8. Mean cloud water droplet effective radius, October 2000.

cases, r_e is smaller over land than over ocean. However, off the western coastlines and near the ITCZ, the cloud droplets are considerably smaller than over the vast pristine area of the southern Pacific. The areas with maximum r_e occur further to the west in the South Pacific during October and off the west coast of Central America. A relative minimum is still present along the South American coast, as it is during January and July (not shown). The greatest values of r_e are roughly 19 µm. The increase in r_e with distance from the Chilean coast was also observed during October 1999 (Garreaud et al. 2001) and may be related to a number of factors including a deeper boundary layer, fewer cloud condensation nuclei, and, for broken clouds, overestimation by the satellite retrieval. Most of the increase, however, is probably due to the first two factors because overcast conditions are very frequent.

The SEP is noted for dramatic diurnal variations of cloud and radiative properties. Figure 9 shows an example of some of the hourly mean cloud properties for the 4 months as a function of UTC hour for a 1° region at 35°S, 75°W off the coast of Chile. Local time is 5 hours earlier than UTC. Mean cloud fraction peaks during the early morning and decreases throughout the day during all 4 months. The greatest mean daily change in cloud

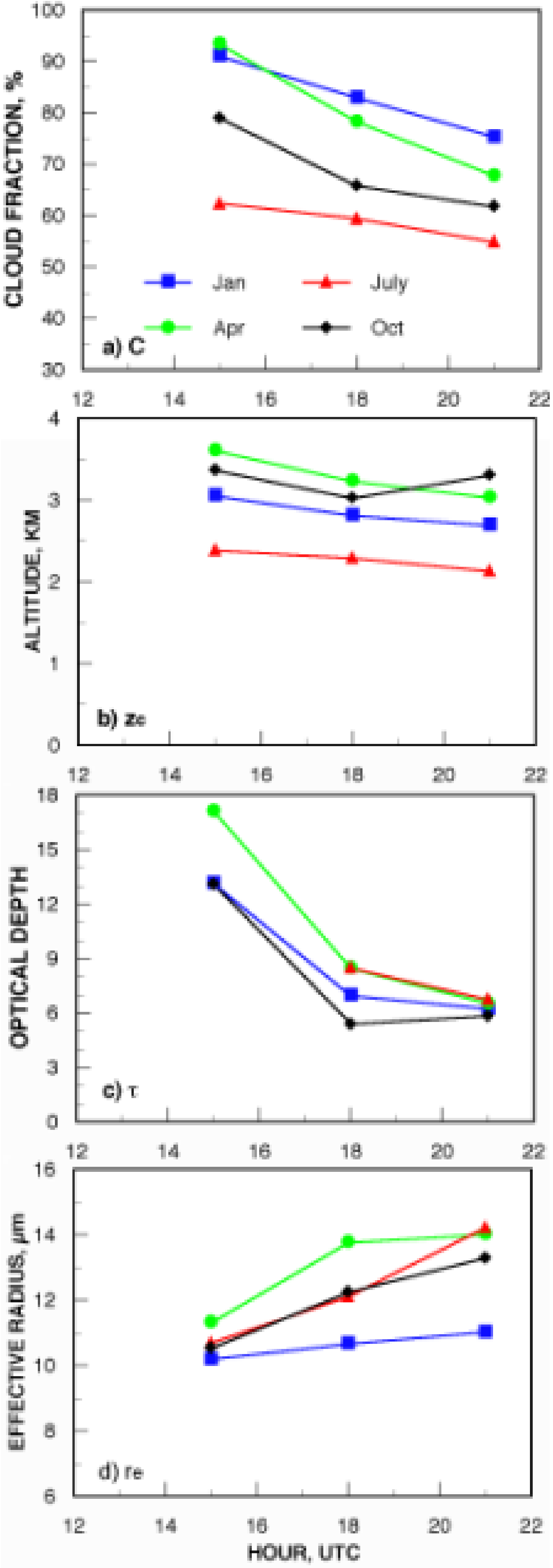

Fig. 9. Mean hourly cloud properties during 2000 35°S, 75°W.

amount occurred during April when *C* dropped by almost 30% in 6 hours. The drop in cloud amount coincides with a decrease in mean cloud height (Fig. 9b). The mean cloud height for the region ranges from a maximum of 3.3 km in April to 2.4 km during July. The diurnal range in mean z_c peaks during April at 0.6 km. Mean cloud height and amount change the least during October.

The mean cloud optical depth, shown in Fig. 9c, ranges from a maximum of 17.1 at 1500 UTC during April to a minimum of 5.4 at 1800 UTC during October. Optical depth decreases during the daylight hours for all months. The greatest change occurs between 1500 and 1800 UTC when the optical depth decreases by approximately 50% for most of the observed cases. The mean effective droplet radius, shown in Fig. 9d, ranges from 14.2 to 10.2 µm with the maximum occurring at 2100 UTC during July. The increase in mean droplet size during the daylight hours corresponds to decreasing cloud cover, height, and optical depth. The change in all of these parameters results in a diurnal cycle in cloud liquid water path LWP (not shown) that is characterized by a factor of 2 decrease during all of the months except October when mean LWP remains steady throughout the day at about 65 gm^{-2}. The values for *LWP* range from a maximum of 121.6 gm^{-2} at 1500 UTC during April to a minimum of 44.4 gm^{-2} during January at 2100 UTC.

4. VALIDATION

Because of the remoteness of the SEP, the availability of in situ data for validation of the derived properties is rare. However, the NOAA *R/V Ron Brown* has recently concluded several cruises of the SEP and collected a wide range of meteorological and oceanographic data. Data from the ceilometer, cloud radar, and microwave radiometer aboard the *Brown* will be used to validate some of the satellite retrievals. The VISST-derived cloud properties averaged over a 0.5° box centered on the ship location will be compared with half-hourly means from the ship data. Cloud amount is computed from the ceilometer data by dividing the number of cloud returns by the total number of shots. Cloud-top height is derived from the radar data and *LWP* is computed from the microwave radiometer measurements. Ayers et al. (2001) used data from an October 1999 cruise to verify some of the parameters over a limited area. The comparison of VISST-derived cloud fractions with those from the ceilometer showed very good agreement when *C* was either above 80% or less than 20%. For *C* between 20% and 80% there was less agreement, but the difference in the mean *C* was only 3%. The comparison of cloud height also showed good agreement with VISST results. The heights from VISST were lower than the cloud radar by 0.15 ± 0.55 km, a value similar to that found by Garreaud et al. (2001). The ship and satellite-derived LWPs were well correlated but some differences, attributed to the interpretation of the ship data, were found for small LWP values. Additional work is required for a full validation. The latest validation results will be presented at the conference.

5. CONCLUDING REMARKS

The SEP contains a variety of interesting features that should be reproduced in climate or regional forecast models. For example, variations in cloud particle size may be correlated with SST, the intensity of the subtropical high, or the availability of cloud condensation nuclei. Significant changes in cloud amount, optical depth, and *LWP* occur as a function of time. Such characteristics should be taken into account when modeling the atmosphere in this area.

Initial validations from this study indicate that the VISST applied to GOES data can produce reliable cloud macro- and microphysical properties over the SEP. Additional study using observations from other cruises will be analyzed to improve the statistical reliability of the validations and to better understand the retrievals. GOES-8 data will be analyzed continuously both day and night for a long period beginning in 1996 to develop a more complete cloud climatology for this region.

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