Observations from the Central Equatorial Pacific Experiment and Their Significance to Siting and Modeling Objectives of the Atmospheric Radiation Measurement Program

J. del Corral, E. Boer, W. Collins, W. Conant, D. Lubin,
G. McFarquhar, V. Ramanathan, and S. Sherwood
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, California

H. Grassl
Max Planck Institute for Meteorology
Hamburg, Germany

A. Heymsfield
National Center for Atmospheric Research
Boulder, Colorado

J. Spinhirne
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland

The Central Equatorial Pacific Experiment (CEPEX) was motivated by the fact that sea surface temperatures (SST) in the world's oceans exhibit significant spatial gradients, except for those regions where the SST exceeds 27°C (or 300K). In such warm oceans, the gradients diminish such that the maximum SST is within a few degrees of 27°C.

The tropical western Pacific is an important example of this outstanding and, as yet, unexplained phenomenon and is popularly referred to as the "western Pacific warm pool." Deep intensive convection, reaching as high as 18 to 20 km in altitude, forms over these warm oceans. Such deep convection is generally associated with extended anvil cirrus clouds.

Because they radiate to space at the cold cloud-top temperatures, cirrus clouds reduce by more than 100 W/m^2 the outgoing longwave radiation (OLR) emitted to space by the surface-atmosphere system. For example, OLR decreases from about 300 W/m^2 over the relatively clear skies in the eastern equatorial Pacific to about 160 W/m^2 over the cloudy western Pacific warm pool. Winds within the upper troposphere carry the cirrus far away from its region of formation into the mid-latitudes; this movement is evidenced by the southeastward extension of low OLR into the mid-latitude southern Pacific.

The extended cirrus clouds also reflect a large fraction (0.5 or more) of the incoming solar radiation back to space and regulate the solar heating of the sea surface. Recent work suggests that this link between the warm ocean, deep convection, cirrus formation, and reduction of sea surface solar heating regulate maximum SSTs like a thermostat.

CEPEX was conducted from March 5 to April 7, 1993. Ship observations were made from the R/V *Vickers* as it cruised from Honiara to Christmas Island (along 2S latitude). Buoy measurements were made from moorings and the Tropical Ocean Global Atmosphere-Tropical Atmosphere Ocean (TOGA-TAO) array in the western Pacific.

Aircraft operations from Fiji were conducted aboard the Aeromet Learjet and the National Aeronautics and Space Administration (NASA) ER-2. Flights were made in an eastern and western triangle to and along 2S latitude. The National Oceanic and Atmospheric Administration (NOAA) P-3 and the National Center for Atmospheric Research (NCAR) Electra aircraft flew out of Hawaii and made measurements around Christmas Island, along 2S latitude, and around Majuro. Measurements were taken by the geostationary satellites, the geostationary meteorological satellite (GMS) and GOES (geostationary operational environmental satellite), and the polar-orbiting satellites, NOAA11, NOAA12, and DMSP (Defense Meteorological Support Program).

H. Grassl's team launched vaisala sondes twice daily aboard the R/V *Vickers* as the ship cruised from the "warm pool" region (165W) to Christmas Island. Suppressed conditions were observed east of the dateline, and convective conditions were observed west of the dateline. The sonde relative humidity measurements were collocated with fields analyzed by the European Centre for Medium-Range Weather Forecasts (ECMWF) along the cruise track of the *Vickers*. General agreement was observed between the ECMWF analysis and the sonde profiles.

At the end of one of the Learjet flights, a dropsonde was released from the Learjet over Fiji as an upsonde was launched from the ground. As the dropsonde descended, the Learjet followed on a downward spiral path to take measurements with a dew point hygrometer at the same altitude and location of the dropsonde. This experiment resulted in a collocated comparison of three different instruments measuring water vapor and temperature. By plotting their profiles, one can analyze the characteristics of each instrument for future field experiments.

Solar absorption by the tropical ocean surface as a function of cosine solar zenith angle was plotted using H. Grassl's observations and model results. The model values were obtained using a radiative transfer model developed by Li et al. Precipitable water was measured aboard the *Vickers* using radiosonde data. Clear-sky planetary albedo was obtained as a function of solar zenith angle from the March 1986 Earth Radiation Budget Experiment (ERBE) record. The measured values come from the downwelling shortwave flux measured aboard the *Vickers*. Downwelling fluxes were then converted to surface absorption using a parameterization for surface albedo given in Briegleb and Ramanathan (1982). This procedure is another way of comparing model results and observations, with the goal of improving both measurements and models.

D. Lubin regularly took Fourier transform infrared (FTIR) spectroradiometer measurements aboard the R/V *Vickers* during CEPEX. Emission spectra measured in the "warm pool" were compared with those in cooler waters. These measurements are noticeably different and point to the need of measuring the atmosphere in both cool and warm regions of the tropical Pacific Ocean to gain a better understanding of the climate there. D. Lubin also performed modeling comparisons to see how well radiation codes (MODTRAN2, LOWTRAN7, CCM2) correspond to actual measurements. These comparisons showed considerable agreement.

Microphysics measurements made by A. Heymsfield aboard the Learjet showed that ice water content and mass diameter of cloud droplets decreased as the altitude increased. This type of measurement affects cloud physics and radiation treatment in general circulation models (GCMs).

Using NOAA P-3 pyrgeometers and collocated GMS IR measurements taken during CEPEX, W. Collins estimated the longwave f factor as a function of SST. The f factor is the ratio of the surface to top of the atmosphere cloud longwave radiative forcing. We hope this estimate will aid GCM modelers in developing their radiation codes.

The ER-2 aircraft flew with a downward-looking 5-level lidar instrument from J. Spinhirne. Measurements from this instrument were collocated with cloud brightness temperatures measured by the GMS satellite. This brightness temperature was used to calculate a cloud-top altitude, which was compared with the cloud-top altitudes observed by the lidar. This type of comparison could be used to calibrate or validate the usefulness of GMS brightness temperature measurements as a means of obtaining regional scale estimates of cloud-top altitudes where aircraft or point measurements are not feasible.

Using GMS satellite brightness temperature and reflectivity measurements, V. Ramanathan, E. Boer, and J. del Corral developed a method of calculating size and reflectivity statistics for all the individual clouds. This method included placing clouds into distinct cloud types based on minimum brightness temperature. The region covered by this analysis was 20N 20S and 120E - 160W. In addition, E. Boer developed a technique for tracking individual mesoscale convective systems (MCS) during CEPEX. His technique uses hourly GMS measurements to follow the growth and migration of these systems.

These statistical calculations of the size and reflectivity of individual clouds during CEPEX give us a measure of the number count of the different size bins of clouds and the percent each contributes to cloud reflectivity for each type of cloud. The size bins range from 100 km^2 to a few million km^2. This information can be used to estimate which clouds (based on size and type) can be explicitly resolved in GCMs and which clouds still need to be parameterized. This estimate would need to be based on the GCM's spatial resolution (T213, T106, T42, ...) and could only be applied to the cloud radiation calculations in the model. This type of analysis should have a large impact on GCMs as more regions and seasonal periods are studied.

One of the most powerful analysis tools to come out of CEPEX is the CEPEX Integrated Data System (CIDS). This system is an on-going effort to provide scientists with a self-contained software and data system that will allow them to collocate any measurements taken during CEPEX, analyzed fields, and model results. CIDS will also provide a gridded synoptic scale estimate of the atmospheric column heat budget terms, binned by SST and convective activity. These estimates will be derived from all the available CEPEX measurements. This information will give GCM modelers more understanding of the tropical Pacific.

CIDS could be used to help Atmospheric Radiation Measurement (ARM) scientists plan for the tropical Western Pacific (TWP) site by allowing them to study in detail the various measurements taken during CEPEX by different science teams. This information may help them decide which instruments are needed and if more or different instruments are required for the TWP site. The measurements and synoptic scale estimates from CIDS could help ARM scientists understand the degree of variability encountered in the tropical Pacific Ocean. This variability could influence the amount and position of data-recording devices at the TWP site. Many of the aircraft measurements taken during CEPEX could provide ARM scientists with a resource to use when planning intensive operation periods (IOPs).

Since CIDS uses a common data format (NetCDF), new model results and new measurements can be easily incorporated. Various studies comparing model results and actual measurements could be done with CIDS, and ARM TWP measurements could be incorporated into CIDS. The resulting data system would be more valuable than the sum of its parts. Both spatial and temporal extent would be broadened. ARM has adopted NetCDF as the data format for all its field measurements, except satellite data. Compatibility with CIDS would be complete if units and naming conventions could be agreed on, with eventual integration as a goal.

We invite inquiries concerning CIDS and its availability to the public (scheduled for early 1995). A release of CIDS to friendly users and institutions will be made in late 1994.

The CEPEX Science Team and Participating Institutions are listed below.

Aeromet, Inc.

Tulsa, Oklahoma
PS: R. Harris-Hobbs
L. Rose

(Learjet operations and facility instrumentation, including several microphysics instruments)

Center for Clouds, Chemistry, and Climate (C4)

California Space Institute
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, California

PI: W. Collins (satellite operations); D. Cutchin (mission PI, R/V *Vickers*); P. Flatau (radiometers, P-3); D. Lubin (FTIR radiometer, *R/V Vickers*); V. Ramanathan (chief scientist CEPEX; PI, data integration); S. Diggs (data integration); E. Boer (data integration)

Colorado State University

Fort Collins, Colorado
PI: S. Rutledge (radar, *R/V Vickers*)

Dynamics of the Geosphere Research Center

Juelich, Germany
PI: D. Kley (ozone sondes, *R/V Vickers*); H. G. Smit (ozone sondes, *R/V Vickers*)

Harvard University

Boston, Massachusetts
PI: J. Anderson (Lyman-alpha hygrometer and in situ absorption photometer, ER-2)

Max-Planck Institute for Chemistry

Mainz, Germany
PI: P. Crutzen

Max-Planck Institute for Meteorology

Hamburg Germany
PI: H. Grassl and P. Schluessel (SST, radiometers, and Vaisala sondes, R/V *Vickers*); L. Bengtsson (regional models)

National Aeronautics and Space Administration

Ames Research Center
Moffett Field, California
PS: J. Arvesen and J. Barrilleaux (aircraft and facility instruments, ER-2)

PI: F. Valero (mission scientist, ER-2; PI, radiation measurement system instrument, ER-2 and Learjet); P. Pilewski (co-PI)

Goddard Space Flight Center
Greenbelt, Maryland
PI: J. Spinhirne (lidar, ER-2)

National Center for Atmospheric Research

Boulder, Colorado
PI: A. Heymsfield (microphysics and thermodynamics, Learjet)

National Oceanic and Atmospheric Administration

Environmental Research Laboratory
Boulder, Colorado
PI: S. Oltmans (hygrometer sondes and ozone sondes, R/V *Vickers*)

Aircraft Operations Center
Tampa, Florida
PS: J. McFadden and J. Parrish (aircraft and facility instruments, P-3)

Hurricane Research Laboratory
Miami, Florida
PI: P. Willis (radar, P-3)

University of Colorado

Boulder, Colorado
PI: R. Grossman (evaporation; mission PI, P-3); W. Emery (SST and radiometers, R/V *Vickers*)

University Corporation for Atmospheric Research

Boulder, Colorado
PS: J. Kuettner (Chair, Scientific Steering Committee); R. Dirks(field project manager); S. Williams (dropsonds, data management coordination); K. Sawyer and J. Rush (international coordination; administrative logistics); J. Moore (technical logistics)

References

Briegleb, B., and V. Ramanathan. 1982. Spectral and diurnal variations in clear sky planetary albedo. *J. Appl. Meteor.* **21**:1160-1171.

Li, Z., and H. G. Leighton. 1993. Estimation of SW flux absorbed at the surface from TOA reflected flux. *J. Climate*, 317-330.