Ship observations over the southeast tropical Pacific Ocean for climate model evaluation

Simon de Szoeke1,2, Paquita Zuidema3, and Chris Fairall1

1NOAA/ESRL Physical Sciences Division, Boulder, Colorado, USA
2CIBERS, University of Colorado, Boulder, Colorado, USA
3Rosensiel School of Marine and Atmospheric Science, University of Miami, Florida, USA

Background

The mean climate, seasonal cycle, and interannual variability of the eastern tropical Pacific Ocean and atmosphere depend strongly on rich coupled ocean-atmosphere processes. Sea surface temperature (SST) depends on upwelling, offshoring transport, and wind-evaporation-SST feedback, which are driven by wind along the shore of South America. Also among these processes, stratus-clouds cool the surface by shading solar radiation. Clouds are significant source of uncertainty to climate models, which have considerable errors in the eastern Pacific.

Because of its remoteness, few observations of the eastern tropical Pacific Ocean exist to quantify processes, improve parameterization, and assess and improve climate models. To address this deficiency, 6 NOAA research cruises were deployed in 2001 and 2003-2007 off of 20°S, 85°W in the stratoscumulus region offshore of Chile and Peru. Ships measured surface meteorology, turbulent and radiative fluxes, cloud thickness and optical properties, and aerosols, and profiled the atmosphere with radiosondes.

Surface flux in GCMs: cloud errors and compensating errors

Ships outfitted with surface meteorology sensors capable of measuring surface fluxes traversed 75 to 85°W along the 20°S parallel in autumn of 2001 and 2003-2007. Fig. 2 shows ship fluxes along 20°S (blue). Too much incoming solar radiation and too little outgoing longwave radiation are a sign of too little clouds in the models. Despite the strong solar radiation in models, excess longwave, sensible, and latent cooling result in less net surface warming than observed.

Cloud observations from ships

Digital global positioning system (GPS) rawinsondes were released the ships, profiling the temperature, humidity, and surface pressure in the atmosphere. Fig. 3 shows the potential temperature (left) and specific humidity (right panels) with color shading in the lower 2.5 km of the atmosphere along 20°S, 75-85°W for cruises in 2001, 2003, 2004, and 2007. The potential temperature and humidity both show a well-mixed marine boundary layer strongly capped by a trade inversion, beneath the stratified free troposphere. Where soundings are available, the 296 K potential temperature (green) and 4 g kg⁻¹ specific humidity (black) contours describe the height of the trade inversion well. The crosses in Fig. 3 show the height of the minimum temperature at the inversion base.

Cloud heights are measured by radar and lidar instruments on the ship. Pulses from a 915 MHz wind profiler are scattered by refractive index changes at the inversion. Magenta dots show the height of the inversion in Fig. 3. Cloud top height is believed to be below the inversion, near the inversion base. Cloud height is based by a lidar ceilometer. The inversion rises noticeably toward the west in 2001, 2005, 2006, and 2007, as expected of a cold-advection boundary layer traveling westward over progressively warmer water.

In Fig. 4 the cloud top and base height and the LCL of all 6 cruises are averaged in 2.5° longitude bins. The inversion and cloud base rise to the west, while the cloud thickness and LCL remain constant. The separation between the surface parcel LCL and the stratoscumulus cloud base indicates entrainment of free-troposphere air drying the boundary layer. Figure 5 shows integrated liquid and vapor path from a 2-channel 20.6 and 3.65 GHz passive microwave radiometer, averaged over all cruises along 20°S. While vapor vapor path constant from 75-85°W, the liquid water path increases to the west.

The roses at the top of Fig. 4 are 24-hour clock Histograms showing the number of samples at each longitude as a function of local time. There are many samples around the clock at 75 and 85°W because the ship was stationed there, but there are diurnal sampling biases between where the ship was underway. The diurnal cycle of cloud base and height, and column-integrated liquid and vapor are shown in Fig. 6. From midnight to 8 hours cloud thickness exceeds 300 m and the cloud rises 50 m. From 8-17 hours the tops sink 150 m; at 12 the thickness is minimal at 75°W. From noon to midnight, the cloud base is constant and the top 100 m. Liquid water path is minimal in the afternoon at 50 m and maximal before sunset at 145 m. Water vapor path and LCL are relatively constant at 20 mm and 650 mm, respectively.

Summary

Observations of clouds, surface meteorology, and fluxes are available from 6 years of stratus cruises to the southeastern tropical Pacific. These data provide context for the upcoming VAMOS Ocean-Cloud Atmosphere Land Study (VOCALS) regional experiment planned for October 2008, and provide ground truth provide ground-truth for verifying and improving climate models in a region where they have large errors. The data from all cruises have been averaged to a consistent format, and are provided for download on the web: https://www.esrl.noaa.gov/psd/people/Simon.deSzoeke/synthesis.html.

References


Coastal section in 2007

In 2007 the NOAA ship Ron Brown made one unique transect along south from the coast, traveling within 300 km of shore. Fig. 7 shows the path of the ship with 6-hour red dashes. Blue vectors show the surface wind, which was nearly parallel to the coast. SST (red), surface air temperature (blue), humidity (green), and wind speed (purple) along the track are displayed as a function of latitude to the left. There are two distinct regimes: warm equatorial processes, stratiform clouds cool the surface by shading solar radiation. Clouds are significant.