Solar Radiative Properties of Stratocumulus Clouds in EPIC2001

C. Fairall
NOAA ETL
4/18/02
chris.fairall@noaa.gov

Compared to other cloud types, stratocumulus clouds are well-described by simple plane-parallel radiative transfer concepts and models. The most basic characterization of the optical properties of such a cloud are its optical thickness, τ, its single scattering albedo, ω, which represents absorption by individual cloud droplets, and the asymmetry factor, g, which describes the mean angular distribution of scattering. From ω, τ, g, and a specification of the cosine of the solar zenith angle, μ, the bulk balance of reflection, transmission, and absorption of solar radiative flux can be estimated using any of a variety of radiative transfer models or simplified parameterizations of transfer model results (e.g., Stephens 1978).

The basic optical properties of the cloud are determined primarily by cloud microphysics. For marine stratocumulus clouds this boils down to the droplet size spectrum, n(r): the number of droplets per unit volume of radius r per radius increment, dr, which is a function of height in the cloud. Strictly speaking, the properties of competing absorbers and scatterers in the cloudy region and how the solar spectrum has been modified by passing through the atmosphere above the cloud also have a second-order effect. While droplet spectra occur with infinite variety, for radiative transfer purposes it is often sufficient to characterize the distribution with a standard mathematical form such as a log-normal distribution. That is, the spectrum is characterized with a mean or mode radius, r_m, a logarithmic width, σ_l, and a total number of droplets per volume, N.

For example, at some height z within the cloud the scattering coefficient, α, and liquid water content, q_l, are related to the second and third moments of the distribution. The entire cloud can also be characterized by integral properties such as the optical thickness and integrated water content, LWP

τ = integral (α dz)   and LWP = integral(q_l dz)

Similarly, effective radius, r_e, is a bulk representation of cloud droplet size associated with optical properties of the cloud

$r_e = 3*LWP /[2*\tau*\rho]$

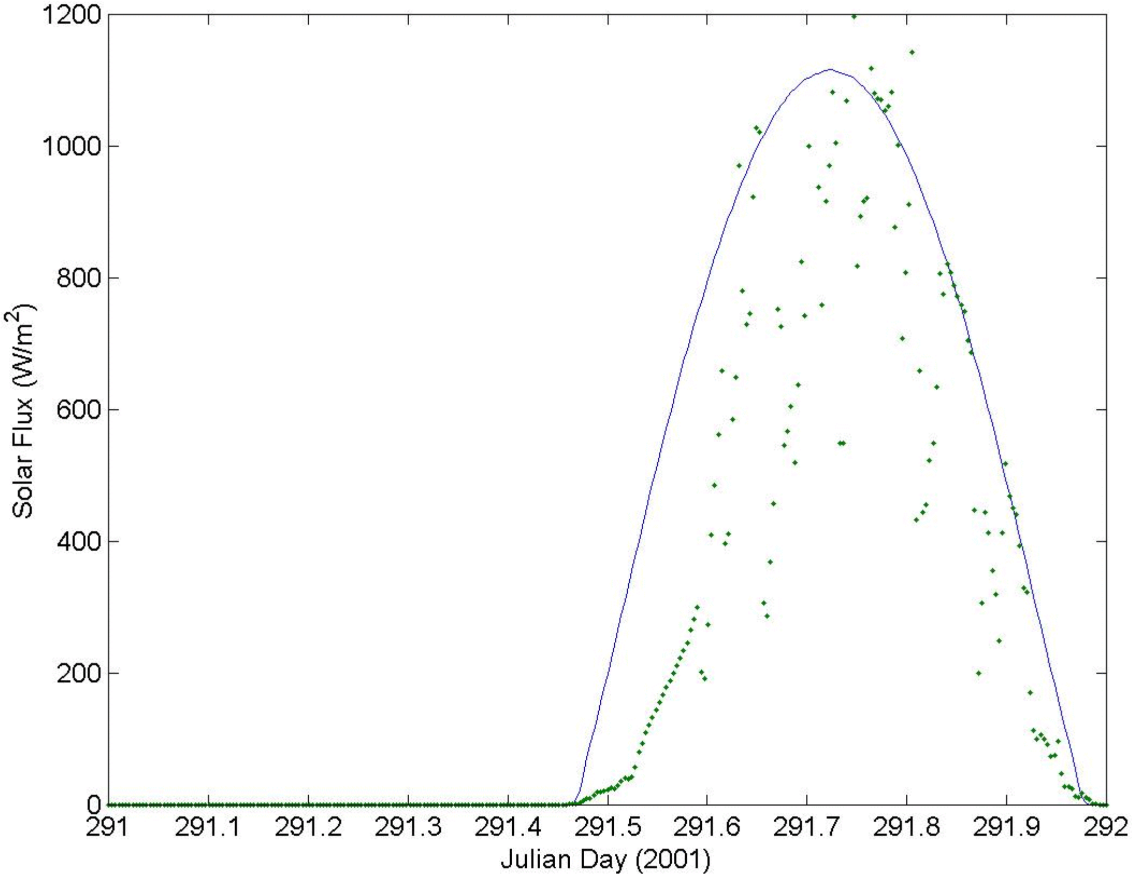
where ρ is the density of liquid water. Because LWP can be directly measured with surface-based and satellite-based microwave radiometers, a specification of r_e allows us to estimate τ and therefore how much solar flux the cloud blocks from the sea surface (i.e., the transmission coefficient).

From a climate modeling perspective, the issue is how to determine the transmission, reflection, and absorption of a 'model' cloud given variables computed in the climate model.

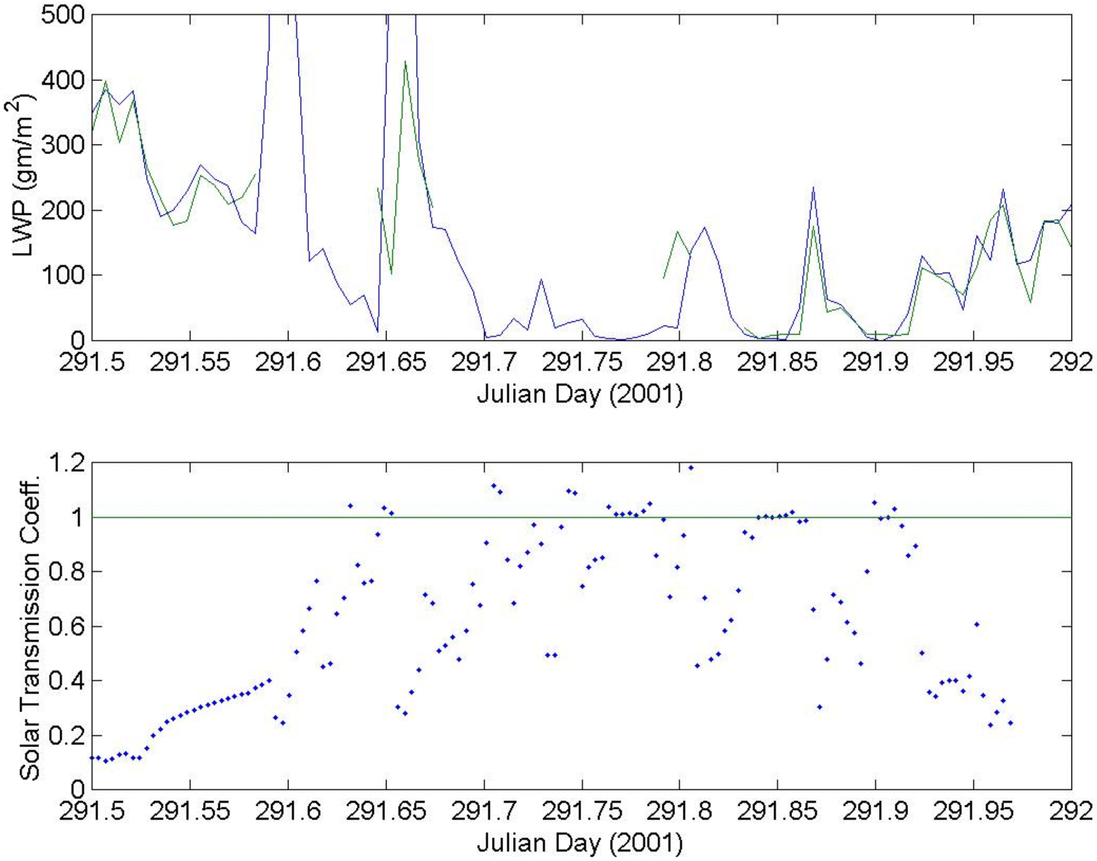
Climate models cannot compute droplet distributions from first principles, so parameterizations in terms of simple estimates of bulk cloud properties, such as LWP, are used. There are three levels to this problem: 1) the model must form the right kind of clouds in the right places, 2) it may not be straightforward to extract variables (such as LWP or r_e) from the model that yield parameterizations with high correlation, and 3) parameterizations linking bulk cloud properties to radiative properties must work across a broad range of conditions. The trick is to find *realizable parameterizations* that correspond to actual clouds in the real world; this requires observations.

One critical issue is the relationship between LWP, r_e, and the number of cloud droplets, N. Because the dynamics of the cloud lead to a given amount of LWP, r_e is depends directly on $N^{-1/3}$. However, N is directly influenced by the concentration of cloud condensation nuclei (CCN); thus, the optical properties of the cloud are strongly influenced by the aerosol properties of the boundary layer. If aerosol concentrations are high, the liquid water is distributed on larger numbers of smaller, but only slightly smaller, particles. This leads to clouds with higher albedo and lower transmission coefficients.

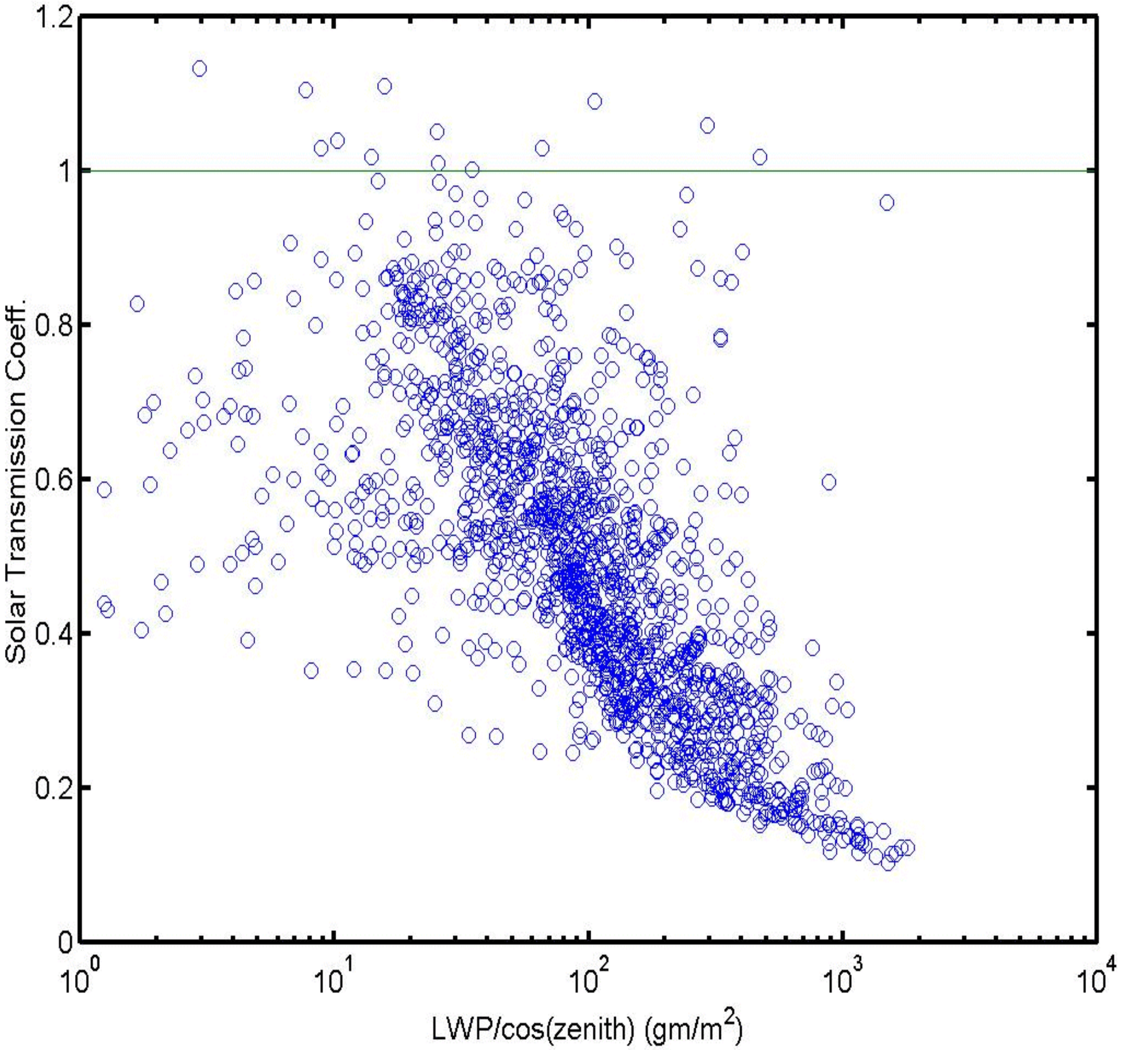
During EPIC2001 ETL made observations of cloud macrophysical (i.e., cloud base height and thickness), microphysical (LWP and radar backscatter coefficient), and radiative (solar transmission coefficient, Tr) properties. From these, we can infer cloud optical thickness and relate it to LWP; we can also compute N and r_e. Examples are given in the following figures.



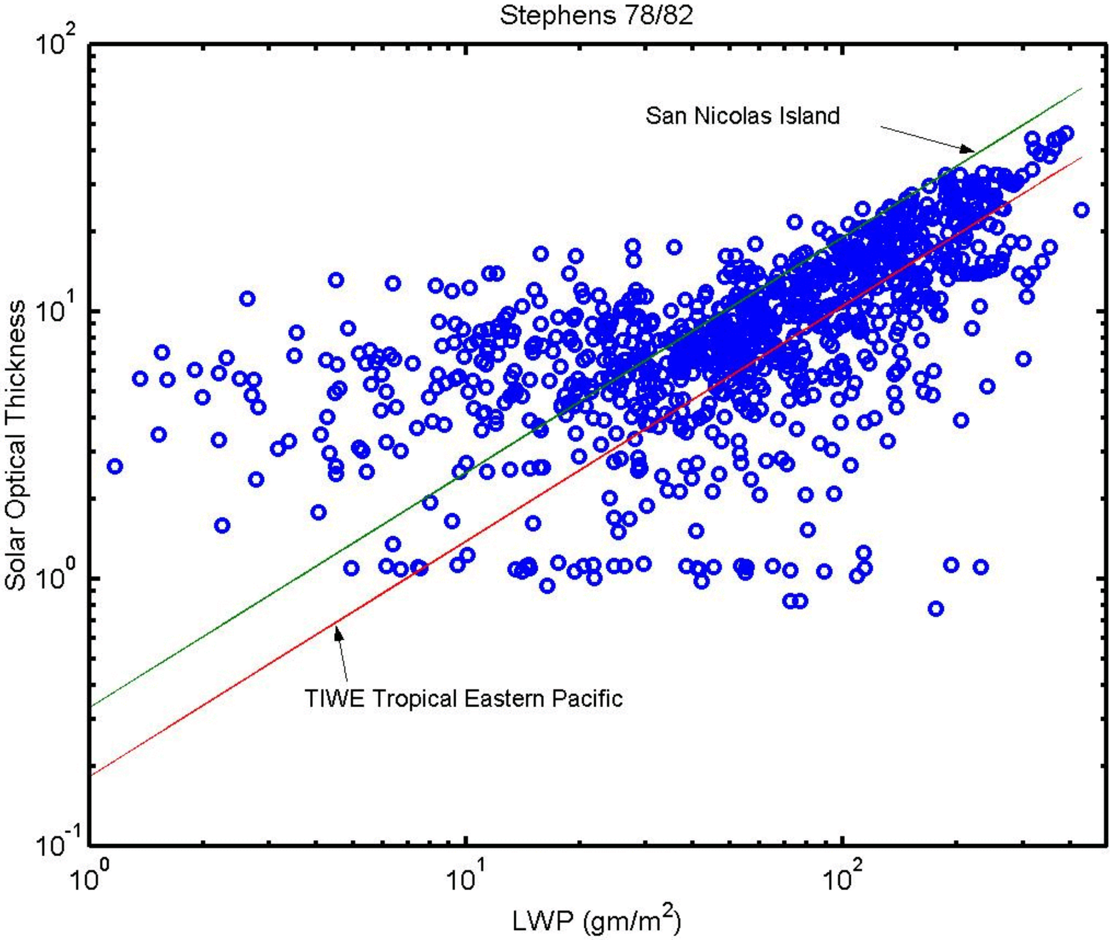
solclear291. Time series of measured downard solar flux, Rsdm (dots), and a model calculation of the expected solar flux for cloudless sky conditions, Rsclear (line).



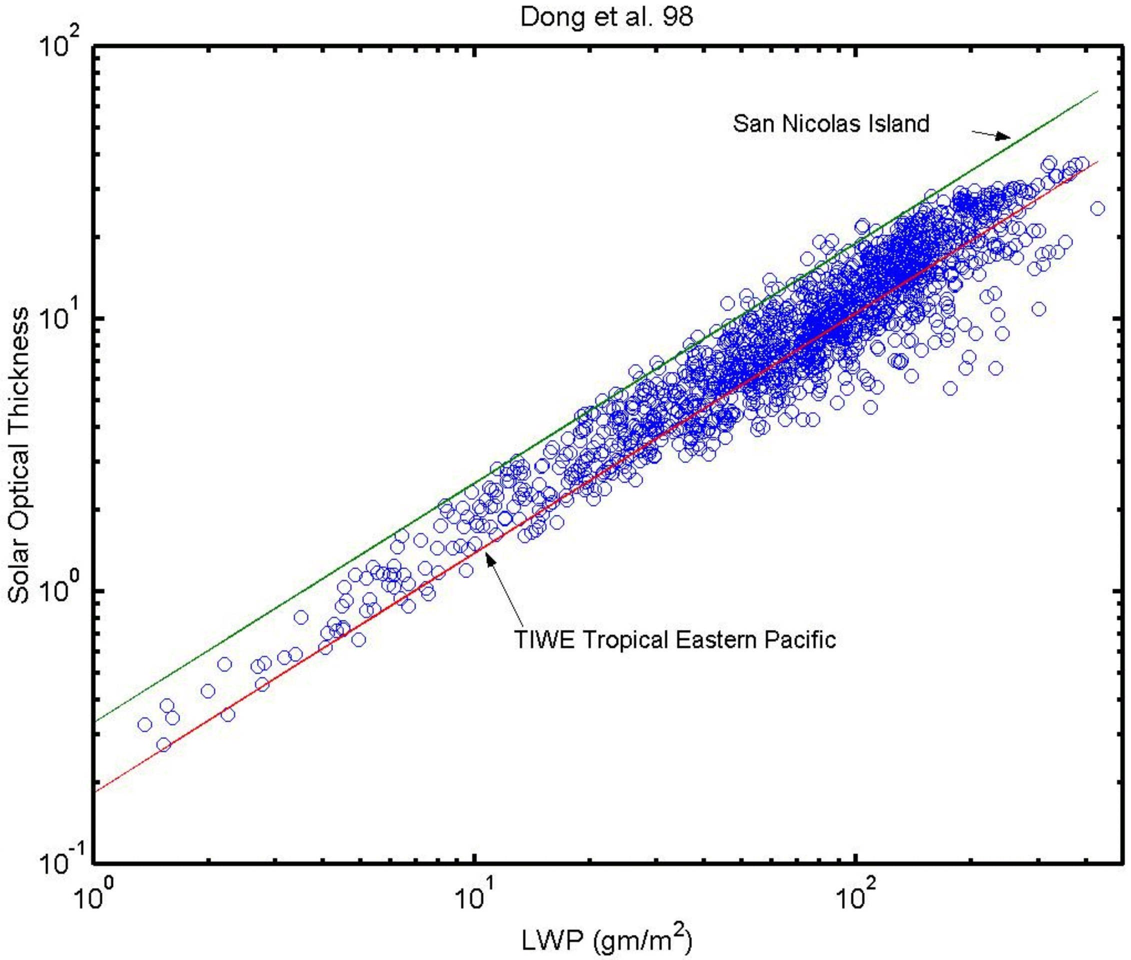
sol_LP291. Time series of cloud LWP (upper panel) and solar transmission coefficient, Tr=Rsdm/Rsclear (lower panel). A value of Tr=1 implies clear sky conditions. Points exceeding one on this graph are caused by clouds in the field of view that do not block the sun's direct beam but reflect radiation to the sensor.



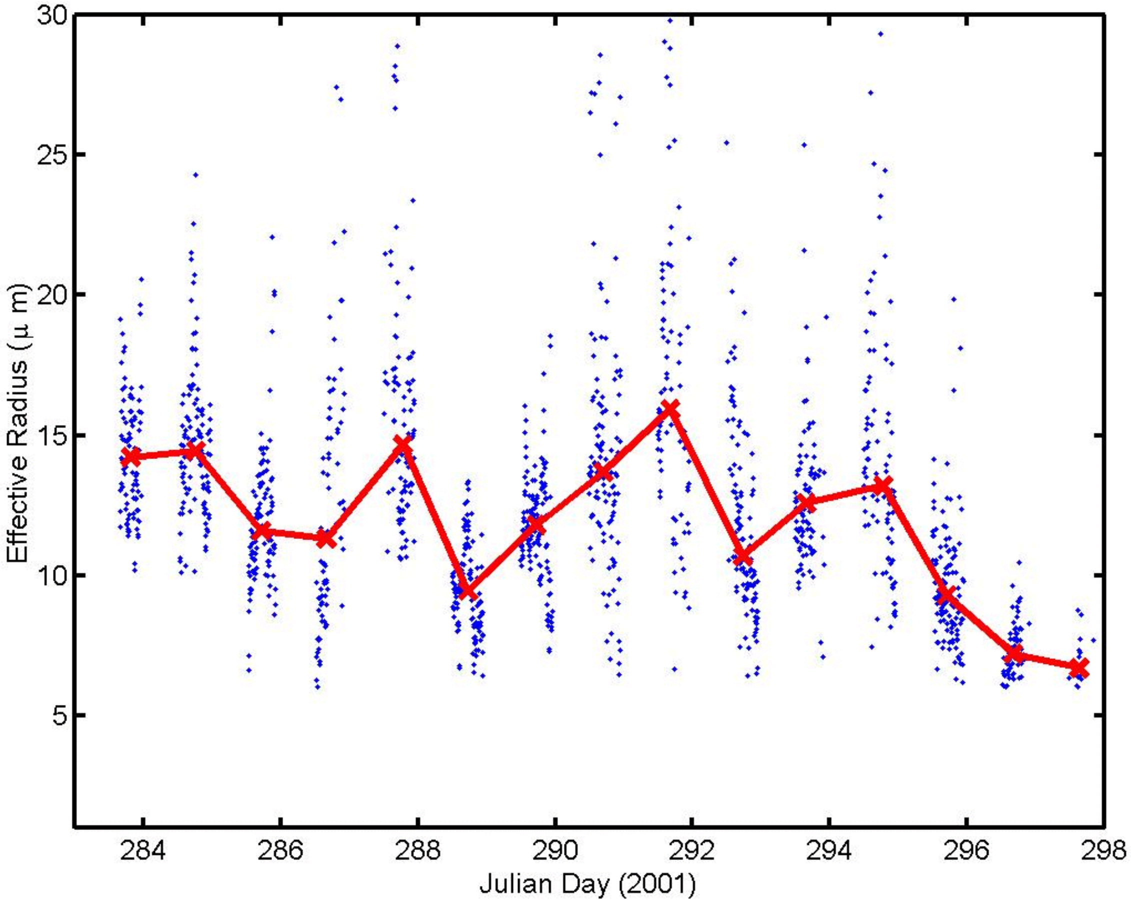
trans_lwp1. Measured transmission coefficient as a function of LWP in the direction of the sun. Increasing values of LWP decrease the solar transmission, but once LWP exceeds about 100 gm/m^2, the effect begins to saturate.



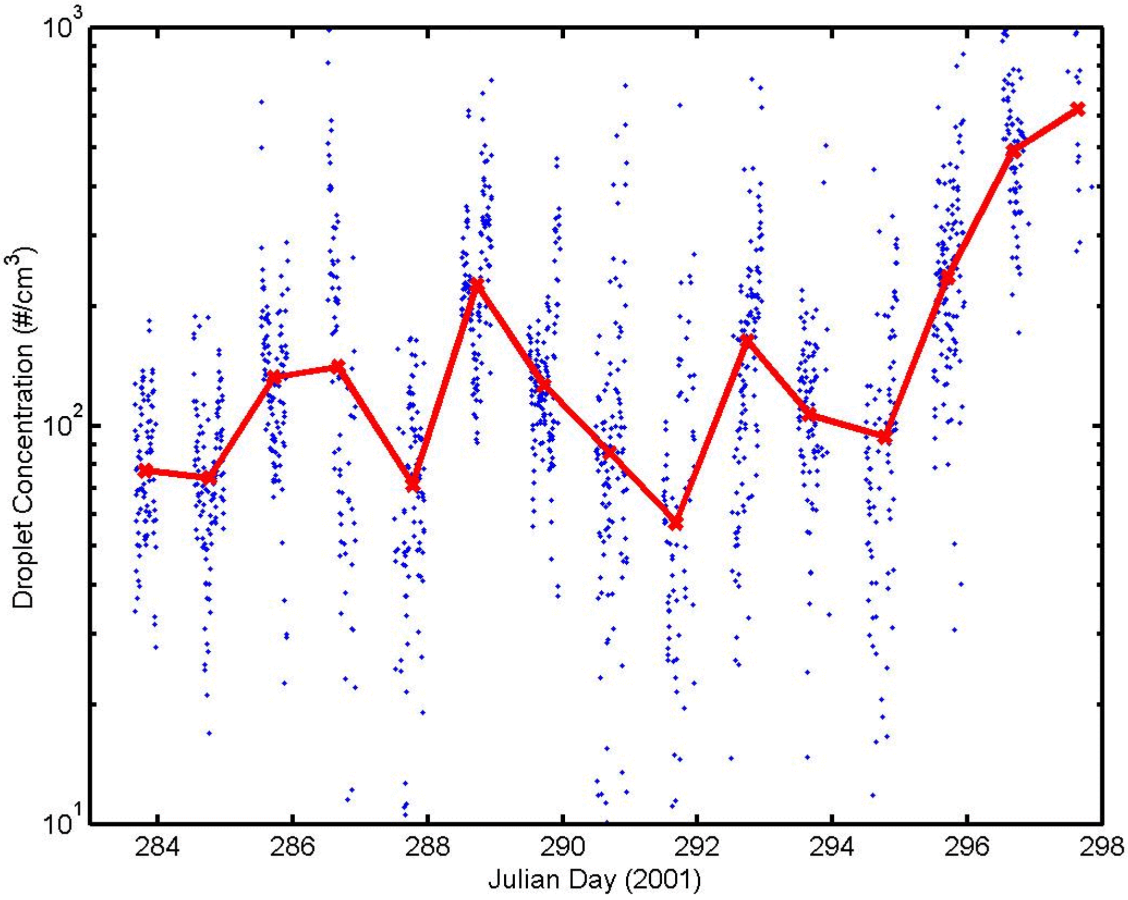
tau_lwp1. Optical thickness computed from μ and Tr using the model of Stephens (1978) as a function of LWP. The green line is a mean curve from measurements made at San Nicolas Island off the coast of California in 1987. The red line is from ship measurements made near the equator at 145 W longitude in 1992. These characteristic lines are typical of the kinds of relationships used in climate models.



tau_lwp2. Optical thickness computed from μ, Tr, and LWP using the model of Dong et al. (1998) as a function of LWP. The green line is a mean curve from measurements made at San Nicolas Island off the coast of California in 1987. The red line is from ship measurements made near the equator at 145 W longitude in 1992. These characteristic lines are typical of the kinds of relationships used in climate models. This correlation is much higher than with Stephens parameterization because measured LWP is included.



reffect_time1. Time series of effective radius deduced from τ and LWP. The dots are individual 5-min values; the red x's are daily medians. The rapid drop at the end of the time series is attributed to increased aerosol concentrations as the ship neared the coast of Chile.



dropconcen_time1. Cloud droplet concentrations computed from r_e, LWP, and cloud thickness. The dots are individual 5-min values; the red x's are daily medians. The rapid increase at the end of the time series is attributed to increased aerosol concentrations as the ship neared the coast of Chile.