The Surface Longwave Radiation in the ECMWF Forecast System

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Abstract

The surface downward longwave radiation (LWR) was computed by the European Centre for Medium-Range Weather Forecasts (ECMWF) forecast system used for the 40-year reanalysis. The LWR is compared with surface radiation measurements for the April to May 1999 period, available as part of the Baseline Surface Radiation Network (BSRN), Surface Radiation Budget Network (SURFRAD), and Atmospheric Radiation Measurement (ARM) Programs. Comparisons on a one-hour basis are emphasized. This allows discrepancies to be more easily linked to differences between model description and observations of temperature, humidity, and clouds. It also allows the model and observed temporal variability in the surface radiation fluxes to be compared.

In this report, comparisons are only presented for the four ARM sites: Southern Great Planes (SGP), the Tropical Western Pacific (TWP) sites at Manus, Nauru, and Northern Slope of Alaska (NSA).

Introduction

As by-products of the reanalyses by the major weather forecast centres, a large number of the quantities produced by the parametrizations of the physical processes are archived, which can then be compared to observations not assimilated in the analysis process. Among other radiative fluxes and heating rates, one such parameter is the LWR at the surface, which mainly depends on the temperature and water vapor distribution in the planetary boundary layer and on the presence of clouds in the first few kilometers above the surface. Most of the general circulation model (GCM) studies aimed at validating the simulated surface fluxes have focused on comparisons performed on monthly mean time-scales, and of point measurements with model radiation fluxes representative of grids, which are usually 10^4 km^2 to 10^5 km^2. Moreover, in the case of the climate GCMs, the verification is further complicated by the model integration having possibly drifted away from the observed profiles in terms of temperature, humidity, and clouds. Wild et al. (2001) questioned the adequacy of the present generation of GCM-type LWR schemes at representing the clear-sky downward LWR. Apart from deficiencies in the absorption parameters used in the radiation schemes, Wild (1999) also explored the role of aerosols produced by biomass burning, particularly for surface downward shortwave radiation. Some of the biases found in the studies previously-mentioned could not be related to the mismatch between the temporal and spatial scales encompassed by observations and models with the local observations being used out-of-context with respect to the larger-scale GCM computations. One particular aspect in the systematic error in surface downward LWR concerns the difference between the height at the location of the observations and the model representation of the orography. This study will concentrate on shorter time-scales (one hour to one day) and try to account for the problems linked to the various temporal/spatial scales. The longwave radiative fluxes, obtained during the first 36 hours of operational 10-day forecasts by the ECMWF forecast system, are compared to a variety of well-calibrated surface radiation measurements (made as part of the BSRN [Ohmura et al. 1998], SURFace RADiation network, SURFRAD [1997], and ARM [Stokes and Schwartz 1994]). These measurements are available at a number of stations encompassing the various climatic regimes from polar to tropical latitudes. Working within the first few hours of the forecasts, when the model is still close to the analyzed initial conditions, should help pinpoint the reasons for discrepancies between model fields and observations. Also, such a study should reflect the evolution of the ECMWF model since the first ECMWF Re-Analysis (ERA-15: Gibson et al. 1997), which was performed with the forecast system operational at the beginning of 1995.

In the full study (Morcrette 2001, 2002), comparisons are first carried out at locations for which the spectral model orography differs from the actual station height. Sensitivity of the model fluxes to various algorithms to correct for this discrepancy is explored. A simple interpolation/extrapolation scheme for pressure, temperature, and humidity allows improved LW surface fluxes in most cases. In the full study, intercomparisons of surface LWR are also presented for the various LWR schemes operational since the 15-year ECMWF reanalysis (ERA-15) was performed. The Rapid Radiation Transfer Model (RAPRAD) of Mlawer et al. (1997), now operational at ECMWF is shown to correct for the major underestimation in clear-sky downward LWR seen in ERA-15.

Sensitivity calculations are also carried out to explore the role of the cloud optical properties, cloud effective particle size, and aerosols in the representation of the surface downward LWR.

Data and Methodology

In the full study, the comparisons are made between 27 individual stations operational during April and May 1999. The stations are part of the BSRN, SURFRAD, or ARM networks. These stations span a large range of latitudes from high northern latitudes to the South Pole. The conventional meteorological observations have been extracted from the Global Telecommunication System (GTS) over the study period for those radiosonde observation (RAOB) and synoptic observations (SYNOP) sites closest to the radiation-measuring stations. Only a few sites have the radiation measurements exactly collocated with the RAOB and SYNOP. Therefore, we selected radiosoundings from the geographically closest RAOB sites and from SYNOP sites, which are the closest in terms of location (and height when several are within the same radius from the radiation-measuring station). For most of the locations considered in this study, the RAOB and SYNOP are within 10 kilometers to 20 kilometers from the location of the radiation measurements.

All model data used in this study are taken from series of forecasts, starting 24 hours apart, between the March 31, 1999, 12 Universal Time Coordinates (UTC) and the May 31, 1999, 12 UTC, run when preparing for the introduction of a new LWR scheme, the Rapid Radiation Transfer Model (RRTM) (Mlawer et al. 1997), into the ECMWF forecasting system. The analyses from which the forecasts were started are obtained through the operational 4DVAR, a four-dimensional variational assimilation of all the observations during a 6-hour window keep around the analysis time. The model used in this study is the so-called cycle 23R1 version of the ECMWF forecast system, operational between the end of June and mid-September 2000.

Together with the RRTM LW scheme, the model configuration used in Section 3 uses the cloud LW optical properties from Smith and Shi (1992) for liquid water clouds, and those from Ebert and Curry (1992) for ice water clouds. A fixed effective radius of 10 µm over land and 13 µm over the ocean is assumed for the liquid water cloud droplets. The effective particle dimension De varies between 30 µm and 60 µm for the ice particles, following the temperature dependence parametrization of Ou and Liou (1995) with provision made for the precipitation of all ice particles with De larger than 60 µm (Jakob and Klein, 2000). Mixed phase clouds are considered between 0° and -23°C following Matveev (1984). All optical thicknesses, before entering the radiative computations, are scaled by the 0.7 inhomogeneity factor according to Tiedtke (1996).

Results

The one-hour time-series of the surface downward LWR during the April 1999 to May 1999 period are presented in Figures 1 to 4 for the NSA, SGP, and the TWP sites at Manus and Nauru. These stations cover a large range of atmospheric humidity from the dry and cold high latitudes to the moist tropical conditions over the West Pacific.

The model is generally successful at representing the intradiurnal and day-to-day variability of the atmosphere, with a usually good representation of the successive minima and maxima of the downward LWR. No station appears to display a behavior systematically different from the observations. Generally, high-latitude stations show the model to underestimate the high values, corresponding to cloudy events. Positive values of the difference Model-Observations correspond to the model producing low-level clouds when the observations are actually of clear-sky. In the deep tropics over the West Pacific, the average level of SDLW is well-represented, but due to the large effect of the background water vapor absorption, it is rather difficult to judge the success of the model at representing the small amount of temporal variability linked to the variability in cloudiness.

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References

Ebert, E. E., and J. A. Curry, 1992: A parameterization for ice optical properties for climate models. *J. Geophys. Res.*, **97D**, 3831-3836.

Gibson, J. K., P. Kallberg, S. Uppala, A. Nomura, A. Hernandez, and E. Serrano, 1997: The ECMWF Re-Analysis: ERA Description. ECMWF Re-Analysis Project Report Series, 1.

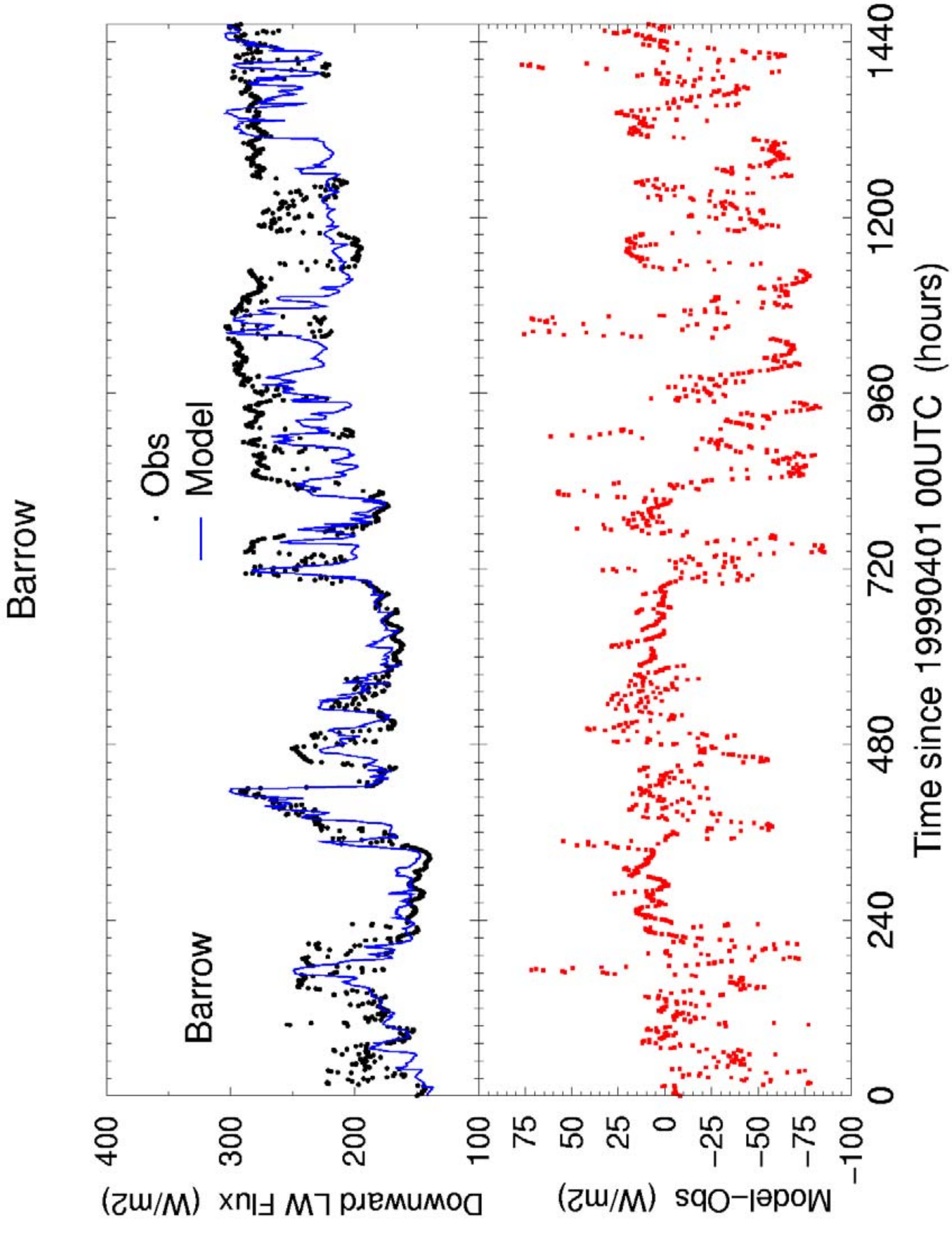

Figure 1. The surface downward LWR over the high-latitude station of Barrow (ARM-NSA). Top panel is the observed and model fluxes, bottom panel is the difference Model-Observation. All fluxes in Wm^{-2}.

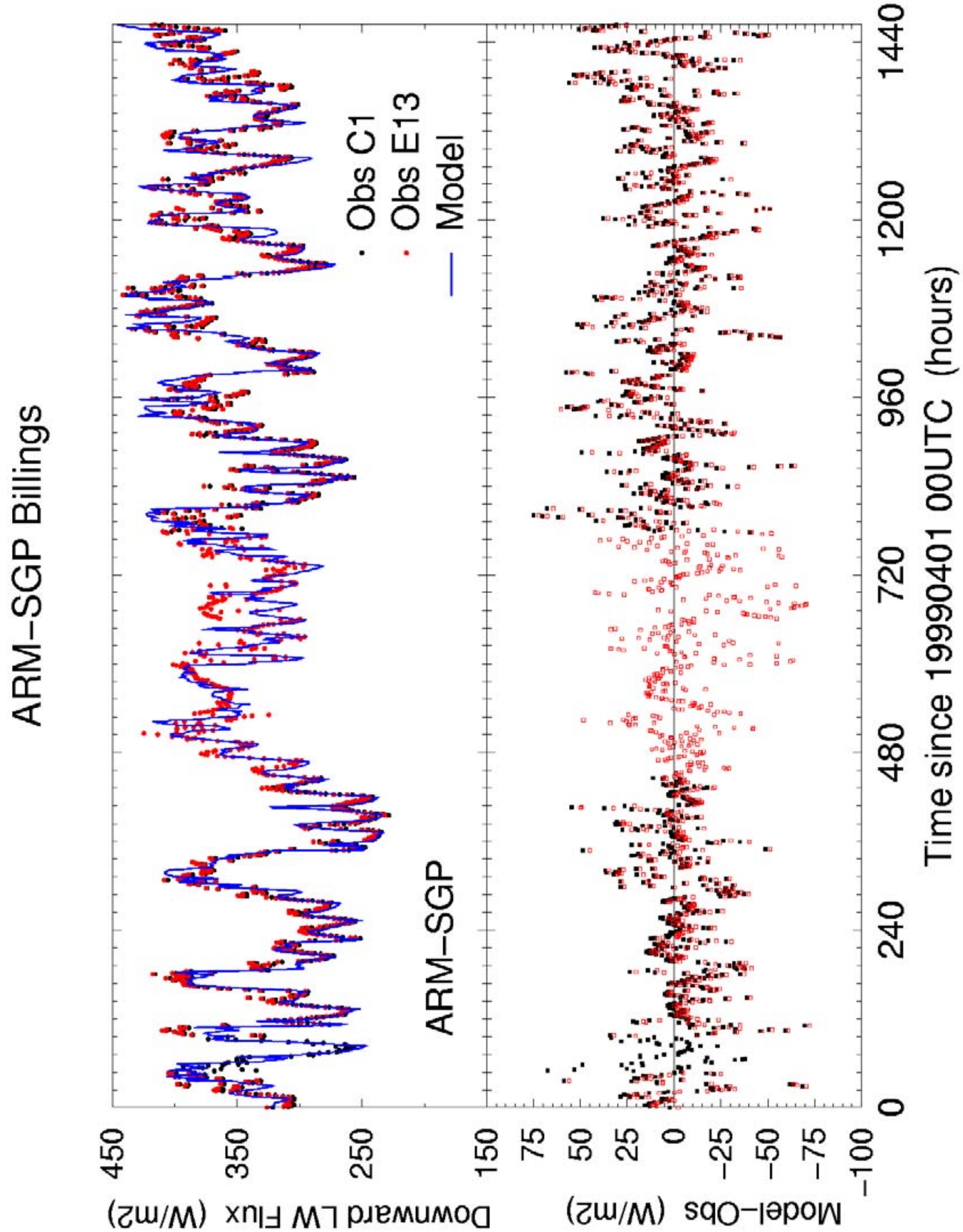

Figure 2. As in Figure 1, but for the ARM SGP site of Billings.

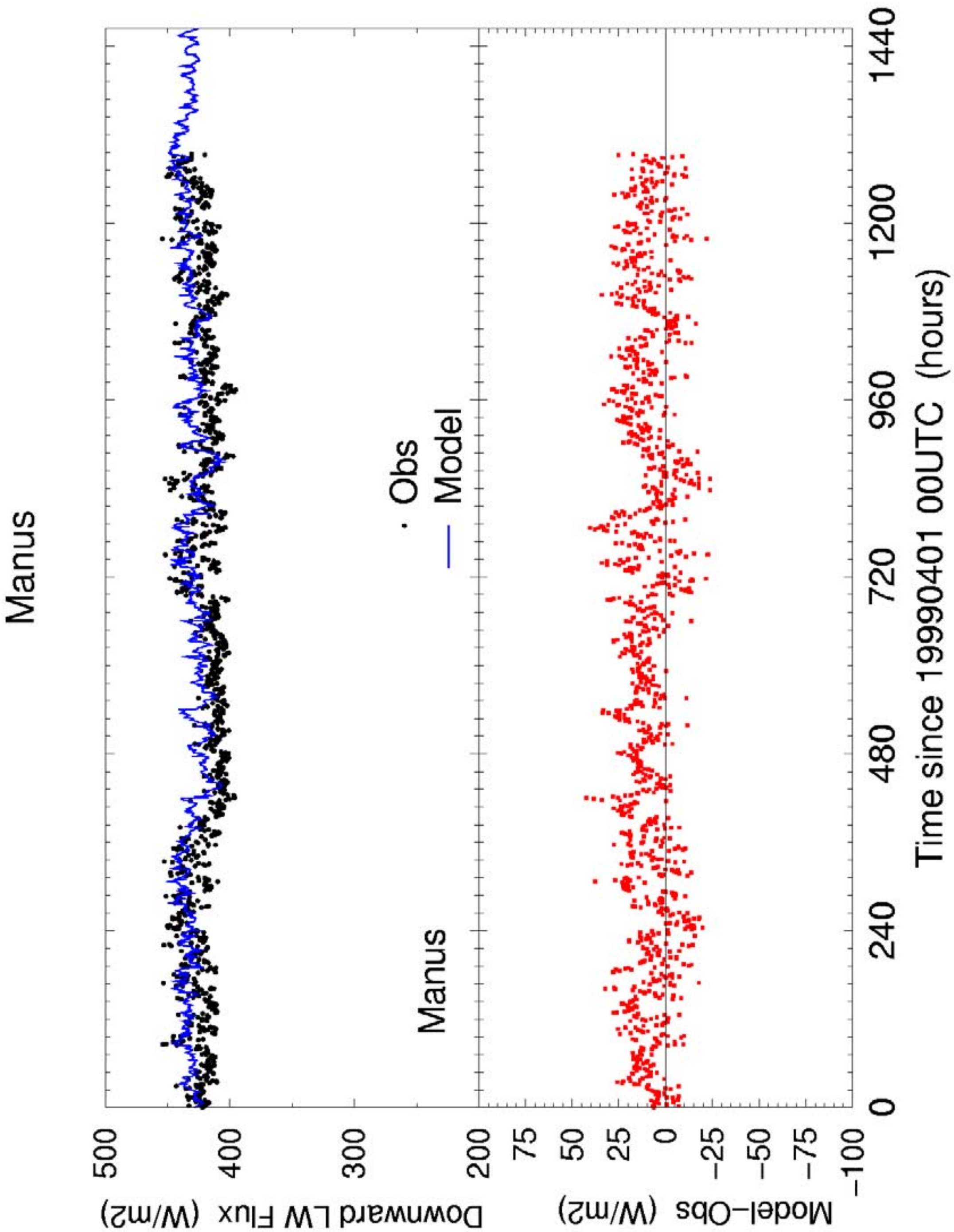

Figure 3. As in Figure 1, but for the ARM TWP site of Manus.

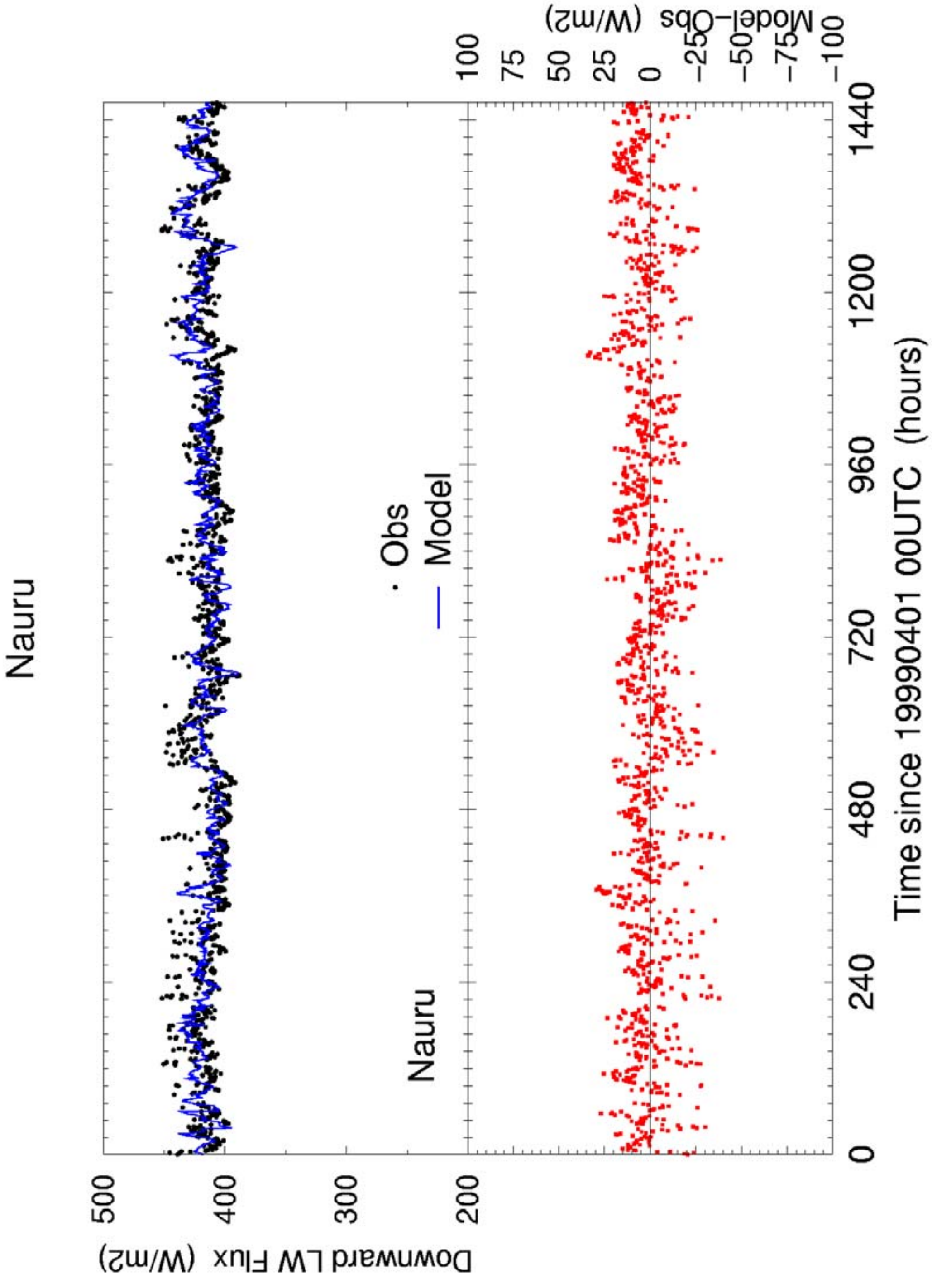

Figure 4. As in Figure 1, but for the ARM TWP site of Nauru.

Jakob, C., and S. A. Klein, 2000: A parametrization of the effects of cloud and precipitation overlap for use in general circulation models. *Quart. J. Roy. Meteor. Soc.*, **126C**, 2525-2544.

Matveev, L. T., 1984: Cloud Dynamics, D. Reidel Publish. Co., 340 pp.

Mlawer, E. J., S. J. Taubman, P. D. Brown, M. J. Iacono, and S. A. Clough, 1997: Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave. *J. Geophys. Res.*, **102D**, 16,663-16,682.

Morcrette, J.-J., 2001: The surface longwave radiation in the ECMWF Forecast System. ECMWF Technical Memorandum No. 339, July 2001, 34 pp

Morcrette, J.-J., 2002: The surface longwave radiation in the ECMWF Forecast System, to appear in *J. Climate*, in press.

Ohmura, A., E. G. Dutton, B. Forgan, C. Frohlich, H. Gilgen, H. Hegner, A. Heimo, G. Konig-Langlo, B. McArthur, G. Muller, R. Philipona, R. Pinker, C. H. Whitlock, K. Dehne, and M. Wild, 1998: Baseline Surface Radiation Network (BSRN/WCRP): New precision radiometry for climate research. *Bull. Amer. Meteor. Soc.*, **79**, 2115-2136.

Ou, S. C., and K.-N. Liou, 1995: Ice microphysics and climatic temperature feedback. *Atmosph. Research*, **35**, 127-138.

Smith, E. A., and Lei Shi, 1992: Surface forcing of the infrared cooling profile over the Tibetan plateau. Part I: Influence of relative longwave radiative heating at high altitude. *J. Atmos. Sci.*, **49**, 805-822.

Stokes, G. M., and S. E. Schwartz, 1994: The Atmospheric Radiation Measurement (ARM) Program: Programmatic background and design of the cloud and radiation testbed. *Bull. Amer. Meteor. Soc.*, **75**, 1201-1221.

Tiedtke, M., 1996: An extension of cloud-radiation parameterization in the ECMWF model: The representation of sub-grid scale variations of optical depth. *Mon. Wea. Rev.*, **124**, 745-750.

Wild, M., 1999: Discrepancies between model-calculated and observed shortwave absorption in Equatorial Africa. *J. Geophys. Res.*, **104D**, 27361-27371.

Wild, M., A. Ohmura, H. Gilgen, J.-J. Morcrette, and A. Slingo, 2001: Evaluation of the downward longwave radiation in general circulation models. *J. Climate*, **14**, 3227-3239.