EPIC2001 Field Program on the NOAA Ship Ronald H. Brown
September 10 - October 5, 2001
Results from the ETL Flux Group Measurements

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## 1. Background on Measurement Systems

The ETL air-sea flux group in cooperation with Frank Bradley of CSIRO conducted measurements of fluxes and near-surface bulk meteorology during Leg I of the EPIC2001 field program. The ETL flux system was installed initially in San Diego in October 2000 and brought back into full operation in Seattle in mid-August, 2001. It consists of six components. (1) A fast turbulence system with ship motion corrections mounted on the jackstaff. The jackstaff sensors are: INUSA Sonic anemometer, OPHIR IR-2000 IR-hygrometer, L:iCor LI-7500 fast CO2/hygrometer, and a Systron-Donner motion-pak. (2) a mean T/RH sensor in an aspirator on top of the bow tower. (3) Solar and IR radiometers ( Eppley pyranometer/pyrgeometer) mounted on the tower. (4) A near surface sea surface temperature sensor consisting of a floating thermistor deployed off port side with outrigger. (5) A narrow-band IR thermal radiometers (mounted on the bow tower) used to measure the interfacial sea surface temperature. (6) A set of four optical rain gauges mounted on the bow tower. Slow mean data (T/RH, PIR/PSP, etc) are digitized on Campbell 23x datalogger and transmitted via RS-232 as 1-minute averages. A central data acquisition computer logs all sources of data via RS-232 digital transmission:

1. Sonic Anemometer
2. Licor CO2/H2O
3. Slow means (Campbell 23x)
4. Unused
5. OPHIR hygrometer
6. Systron-Donner Motion-Pak
7. Ship s SCS
8. ETL GPS

The 7 data sources are archived a full time resolution. At sea we run a set of programs each day for preliminary data analysis and quality control. As part of this process, we produce a quick-look ascii file that is a summary of fluxes and means. The data in this file comes from three sources: The ETL sonic anemometer (acquired at 20.83 Hz), the ships SCS system (acquired at 2 sec intervals), and the ETL mean measurement systems (sampled at 10 sec and averaged to 1 min). The sonic is 5 channels of data; the SCS file is 17 channels, and the ETL mean system is 39 channels. A series of programs are run that read these data files, decode them, and write daily text files at 1 min time resolution. A second set of programs reads the daily 1-min text files, time matches the three data sources, averages them to 5 or 30 minutes, computes fluxes, and writes new daily flux files. A set of time series graphs is also stored each day. The 30-min daily flux files have been combined and rewritten as a single file to form the file flux30_sum.txt . The daily graphs and the 5-min daily ascii flile are stored in the individual dayDDD directories (DDD=yearday where 000 GMT January 1, 2001 =1.00). File structure is described in epic_flux_readme.txt.

ETL also operated two auxiliary remote sensors: a Vaisala CT-25K cloud base ceilometer and a 915 MHz wind profiler. The ceilometer is a vertically pointing lidar that determines the height of cloud bottoms from time-of-flight of the backscatter return from the cloud. The resolutions is 15 second and 30 m. The raw backscatter profile is stored in one file and cloud base height information deduced from the instrument s internal algorithm is stored in another. File structure is described in ceilo_readme.txt. The 915 MHz wind profiler uses 5 beams (one vertical and four tilted at 15 degrees from zenith oriented N-S and E-W) to measure profiles of the wind vector from about 200 to 5000 m, depending on the scattering conditions. Raw data are processed to 1-hr consensus files. Preliminary images of daily time-height wind vector diagrams are presently available. Considerable reprocessing is needed to remove velocity effects of precipitation and eliminate outliers caused by ship maneuvers.

## 2. Selected Samples

### *a. Flux Data*

Preliminary flux data is shown for yearday=263 (September 20, 2001). The time series of ocean and air temperature is given in Fig. 1. The water temperature is about 29.5 C and the air temperature is about 27.5 C until it drops abruptly at 10 am GMT (4 am local) to about 24.5 C. After that the air temperature recovers steadily until it returns to close to the initial value. The steep drop is caused by a deep convective system that has moved through the area. Only about 1.5 mm of rain was recorded at the ship but the drop in temperature implies a fairly large system in the area. The effects of the scattered storms is shown in the wind time series (Fig. 2) where wind speeds swing from near zero to 8 $ms^{-1}$ . The night time activity cleared out by sunrise and the day was mostly sunny until late afternoon. This is apparent in the solar flux time series (Fig. 3) which shows values around 1000 $Wm^{-2}$
and deep decreases after that. The effect of clouds on the downward IR flux is illustrated in Fig. 4, where the clear daytime is indicated by low values of flux; low-level water clouds are strong emitters of IR radiation and their presence causes the maxima during the rainy night. The steady increase in IR flux near the end of the day shows increasing low clouds. Fig. 5 shows the time series of the four of the five primary components of the surface heat balance of the ocean (solar flux is left out). The largest term is the latent heat (evaporation) flux, followed by the net IR flux (downward minus upward), the sensible heat flux, and the flux carried by precipitation. Typical values in the Pacific warm pools for the first three are about 100 $Wm^{-2}$ for latent, -50 $Wm^{-2}$ for net IR, and 10 $Wm^{-2}$ for sensible heat. We are using the meteorological sign convention for the

turbulent fluxes so all three fluxes actually cool the interface in this case. The time series of net heat flux to the ocean is shown in Fig. 6. The sum of the components in Fig. 5 is about -160 $Wm^{-2}$, which can be seen in the night time values; the large positive peak during the day is due to the solar flux.. The integral over the entire day gives and average flux of 81 $Wm^{-2}$, indicating strong warming of the ocean mixed layer. The cooling of the ocean in the first twelve hours and subsequent warming is shown in Fig. 7.

*b. Ceilometer and Wind Profiler Data*

A sample ceilometer 12-hr time-height cross section for September 21 (12 - 24 GMT) is shown in Fig. 8. The upper panel shows cloud base heights as white dots and obscured conditions as purple dots. The lower panel is color-coded backscatter intensity. The vertical scale must be multiplied by 2 (i.e., maximum range is 8 km). This day had 80% cloud cover and a variety of cloud base heights. At least five different cloud bases can be seen in the figure with the lowest about 500 m and the highest about 4.5 km. Rain can be seen in the lower panel just before and just after 1800. A sample wind profiler 24-hr time-height vector diagram is shown for September 20 in Fig. 9. Note that time is plotted backwards in this graph. The arrows indicate wind direction and the colors wind speed. This day has low level westerlies of about 5 $ms^{-1}$ which change to 10 $ms^{-1}$ easterlies above 1 km.

## 3. Cruise Summary Results

*a. Basic Time Series*

The 30-m time resolution time series for sea/air temperature are shown in Fig. 10 and for wind speed and N/E components in Fig. 11. Time series for flux quantities are shown as daily averages. Fig. 12 gives the 24hr rainfall accumulation, Fig. 13 the flux components, Fig. 14 the net heat flux to the ocean. The cycles of convective activity are clearly evident in these time series.

*b. Diurnal Cycles*

We have computed mean diurnal cycles (in local time) for selected variables. The time period for the averages is days 255 - 274, which encompasses the period in the ITCZ: rainfall, Fig. 15; net heat flux, Fig. 16; and sea/air temperatures, Fig. 17. The double peaked structure of the rain fall is probably poor sampling statistics; the C-band radar actually shows area-averaged rainfall peaking about 4 am. Total rainfall (uncorrected) for the entire experiment was 720 mm and for the ITCZ period it was 580 mm. The net heat flux shows the typical night time cooling is around 180 $Wm^{-2}$. The average net heat flux for the entire experiment was -32 $Wm^{-2}$ ; for the ITCZ period it was -32 $Wm^{-2}$. Typical values in the tropical west Pacific warm pool are around +35 $Wm^{-2}$. The diurnal cycle of air temperature is actually larger than for SST, which is unusual and implies strong forcing of boundary layer temperatures by convection instead of by surface flux.

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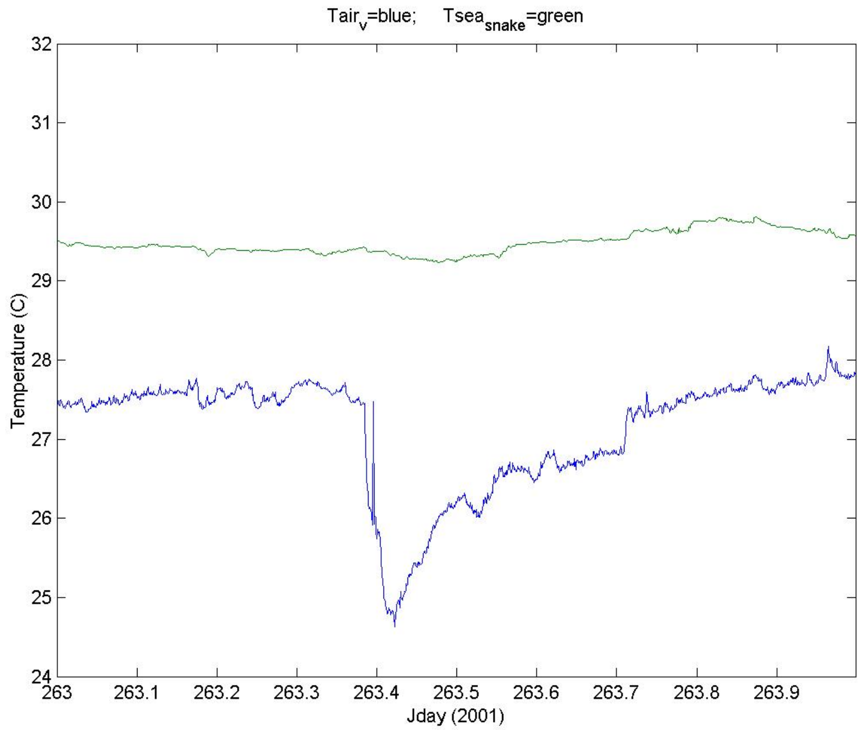


**Figure 1**. Time series of near-surface ocean temperature and 15-m air temperature.

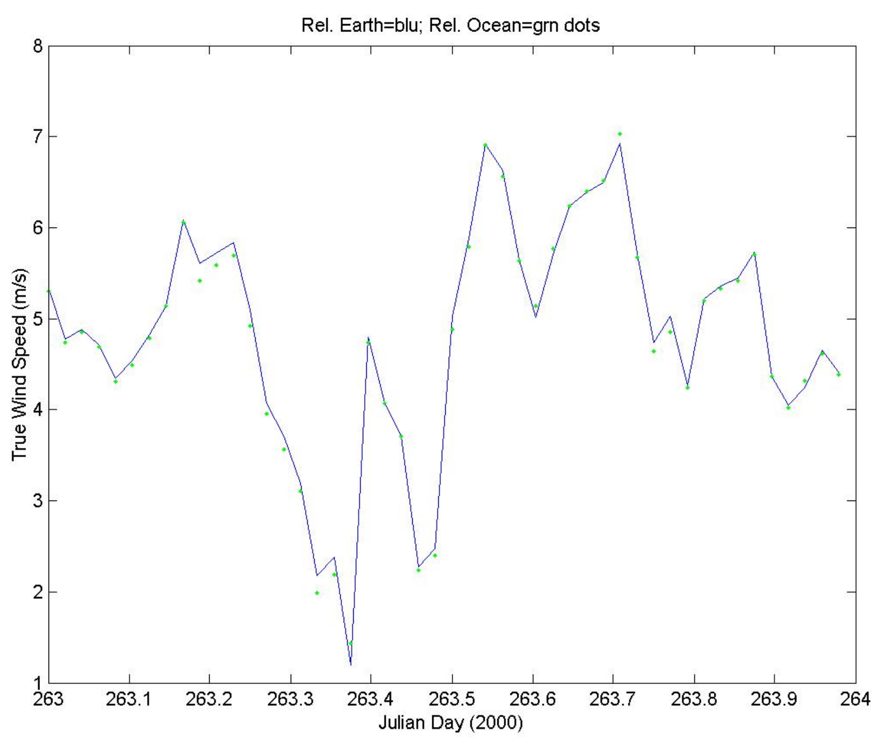


**Figure 2**. Time series of 18-m wind speed.

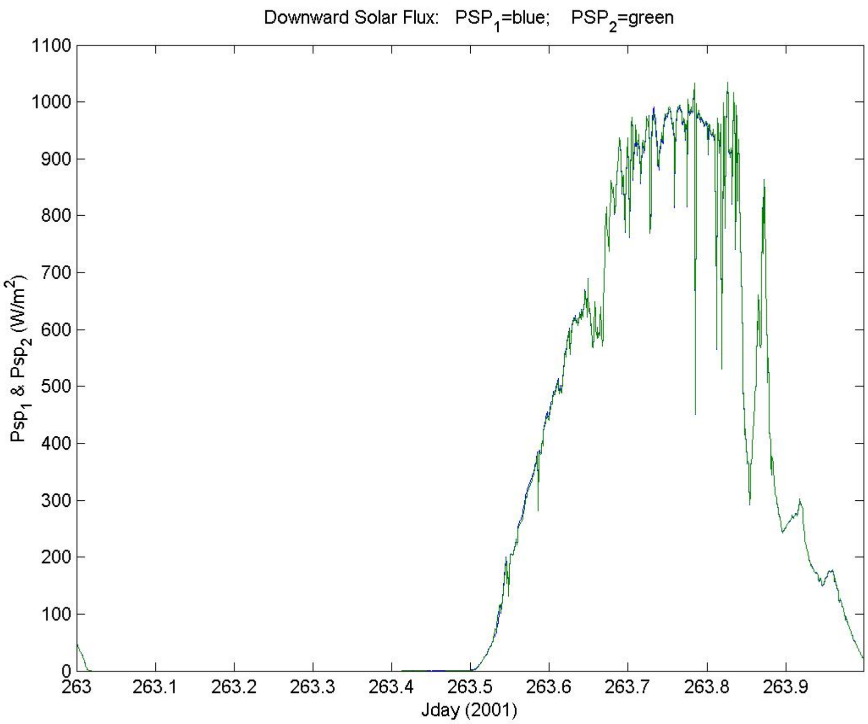


**Figure 3**. Time series of downward solar flux.

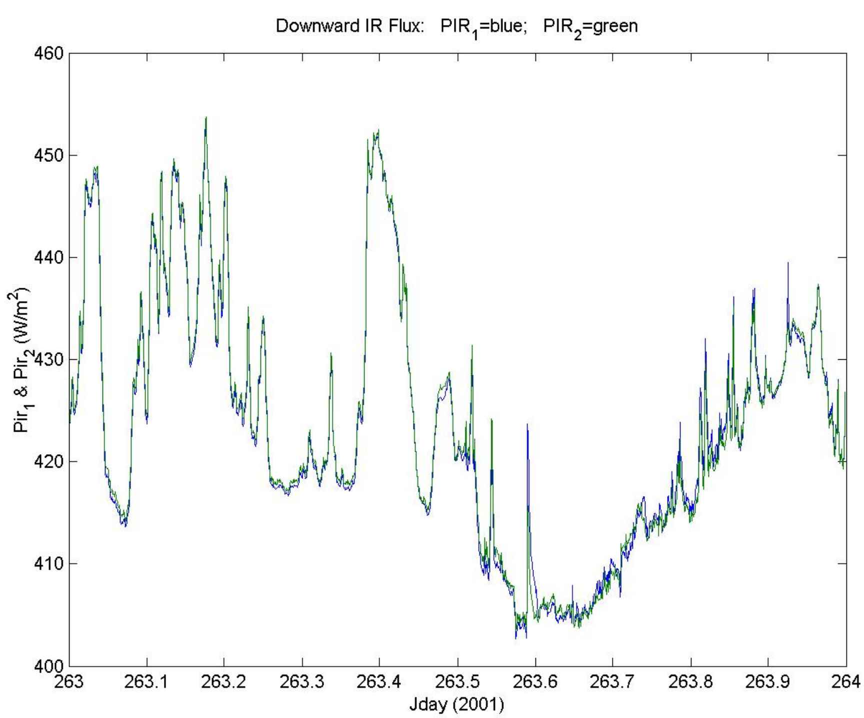


**Figure 4**. Time series of downward IR flux.

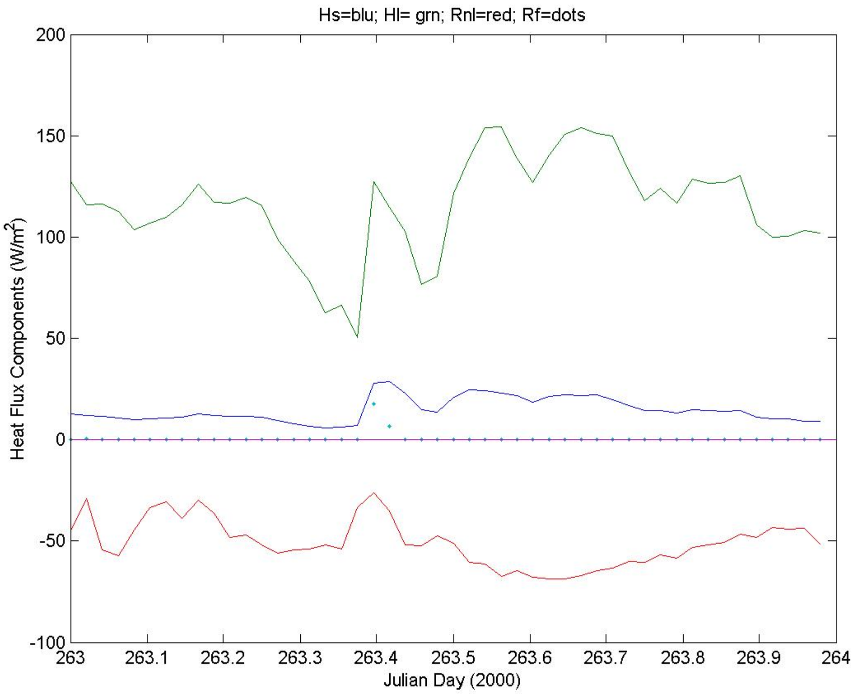


**Figure 5**. Time series of surface heat flux components: sensible, latent, net IR and rain.

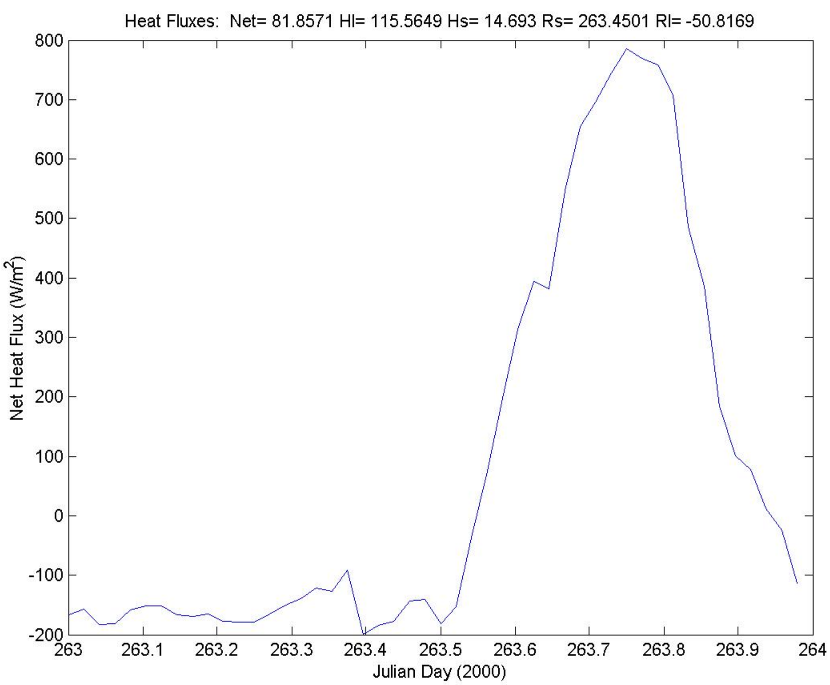


**Figure 6**. Time series of net heat flux to the ocean. Daily averages shown at top.

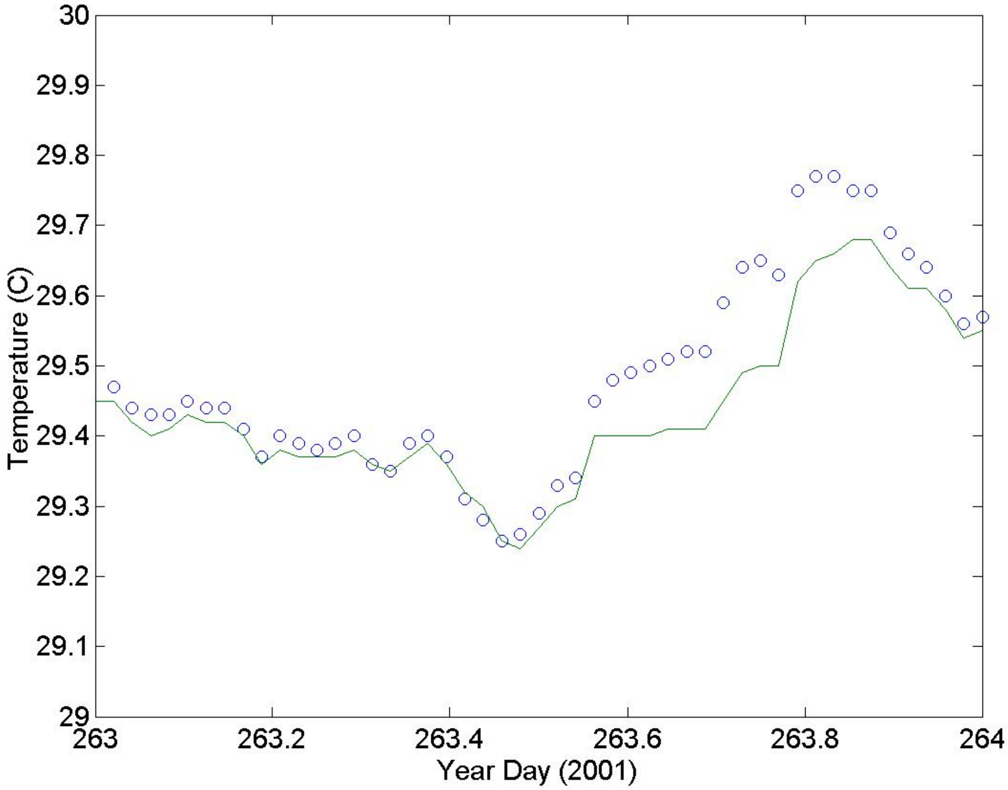


**Figure 7**. Time series of ocean temperature: line, 5-m depth; circles, 5-cm depth.

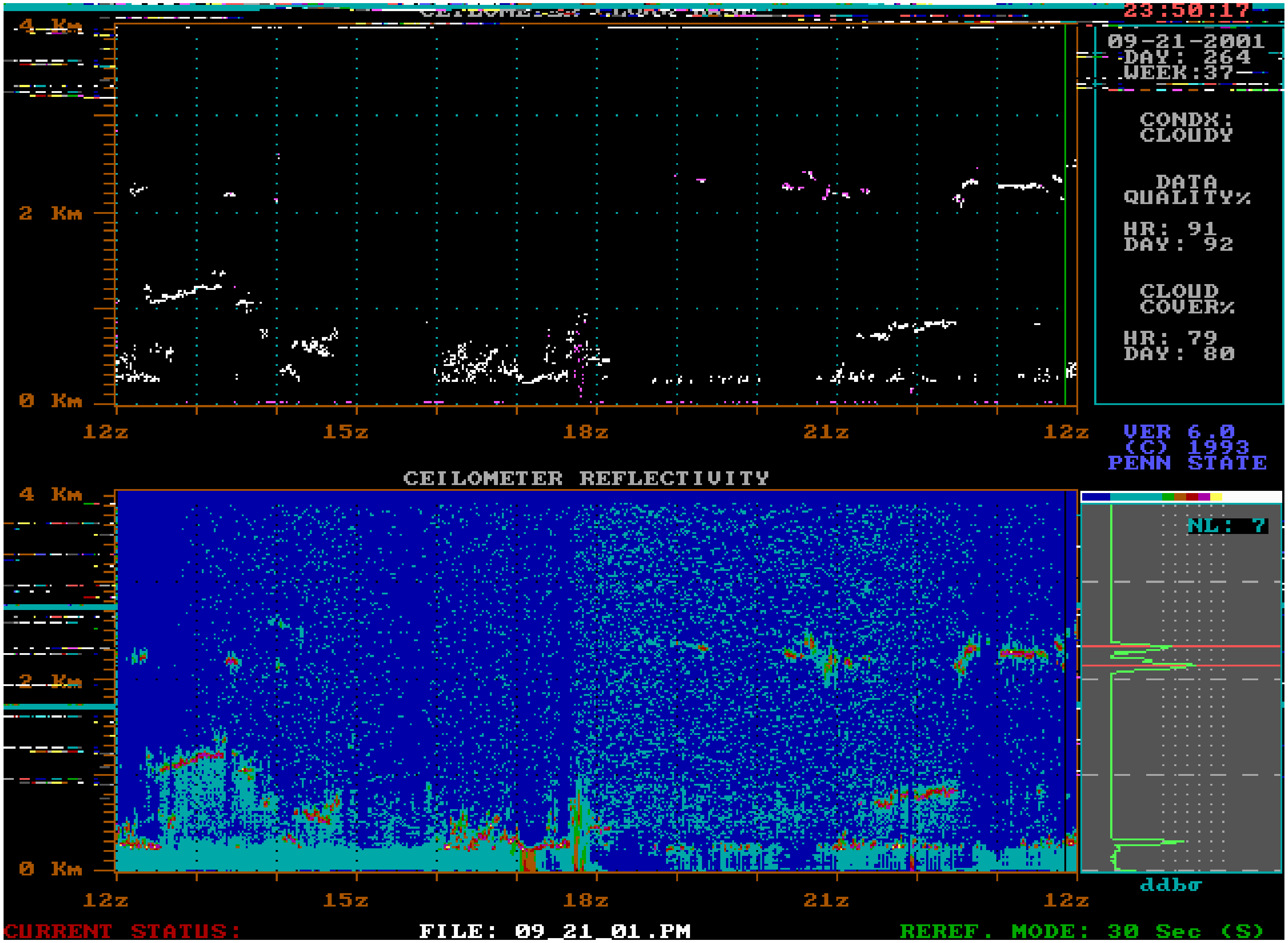


**Figure 8**. Time height cross section of low cloud data 12-24 GMT, day 263. Upper panel is ceilometer estimates of cloud based height; lower panel is profile of lidar backscatter intensity. Vertical scale must be divided by 2.

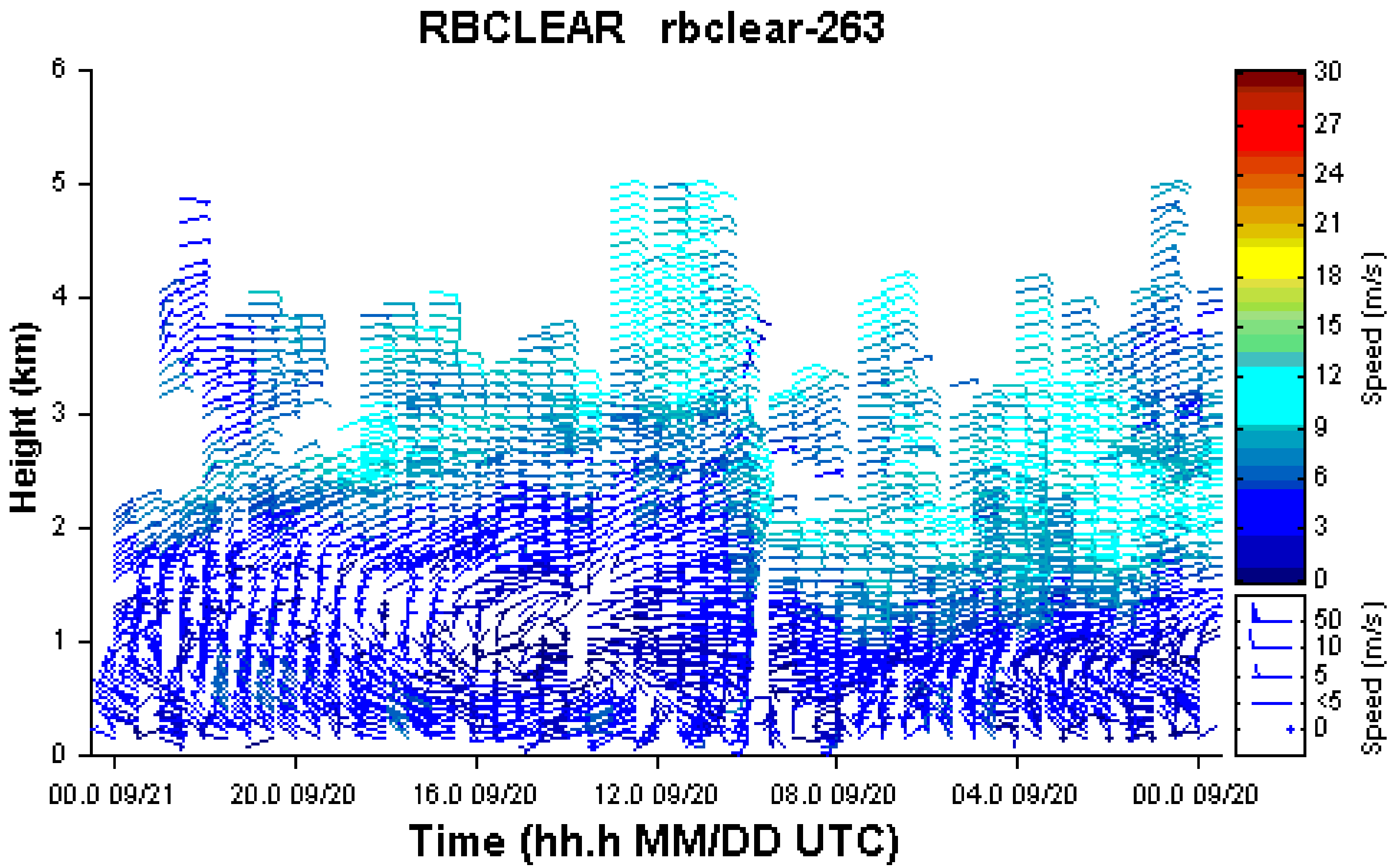


**Figure 9**. Time height cross section of horizontal wind vectors from 915 MHz wind profiler. Note, time goes right to left; arrows indicate wind direction (from west in lower atmosphere, from east in upper).

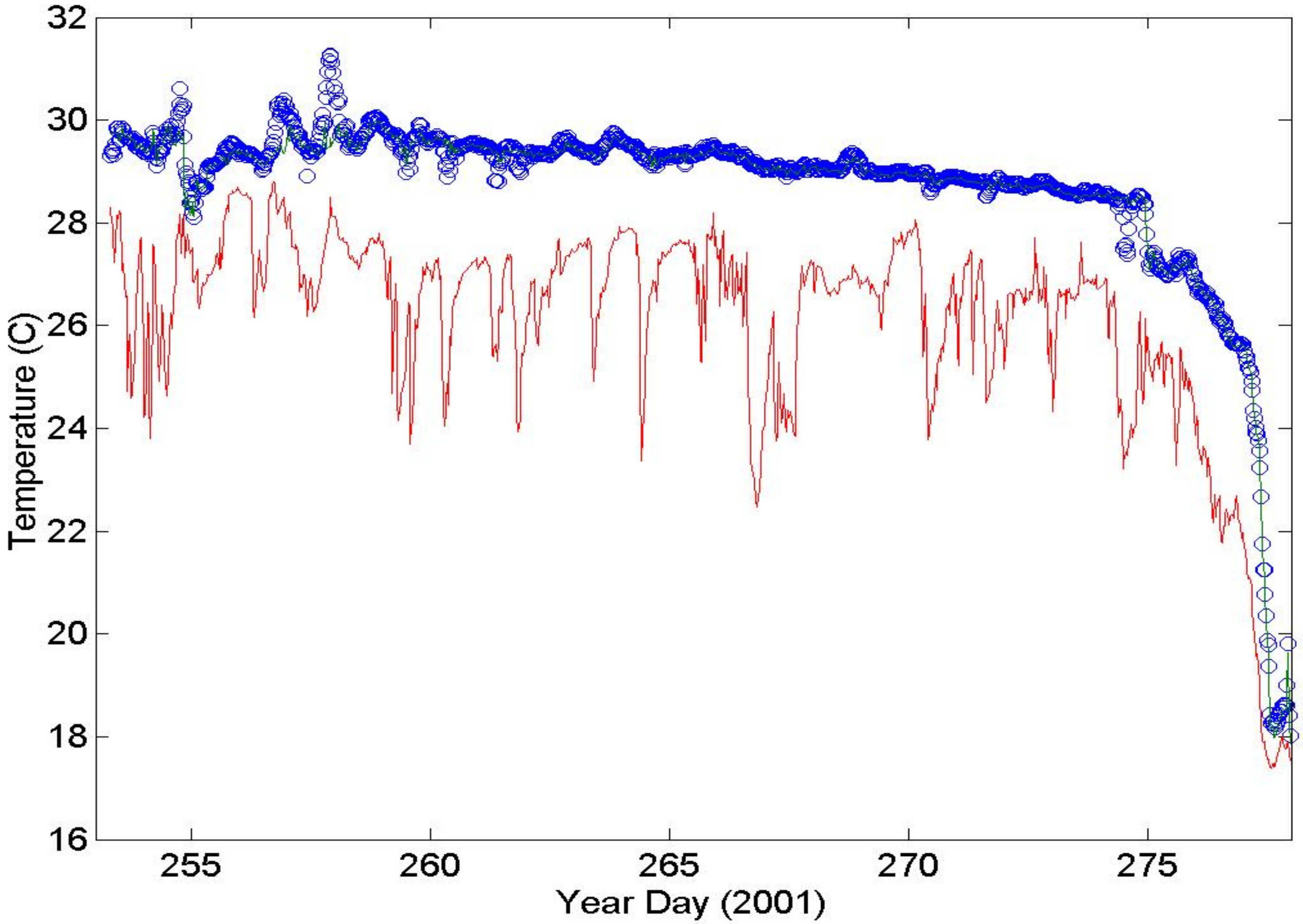


**Figure 10**. Time series of sea surface and air temperature for EPIC2001.

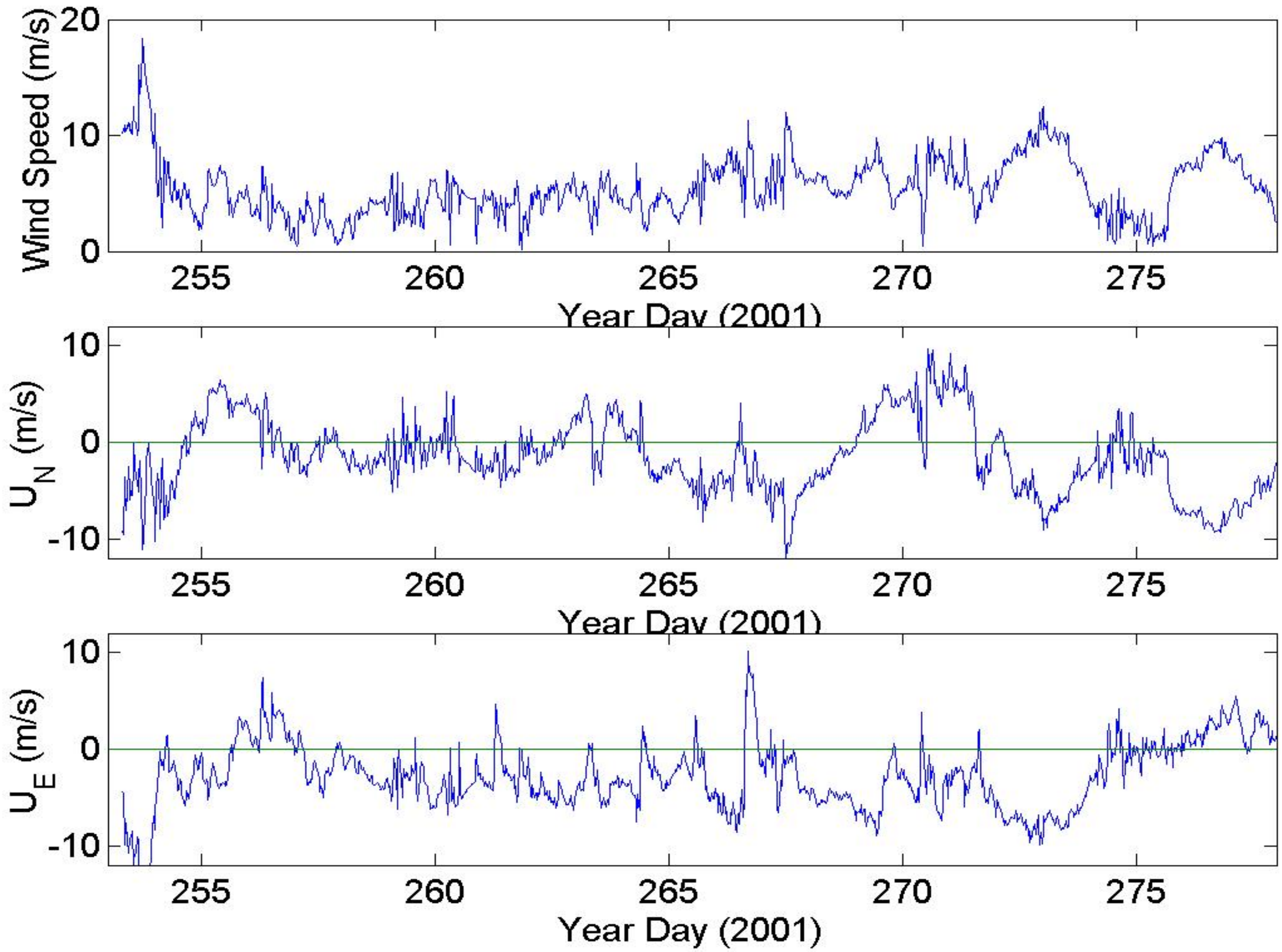


**Figure 11.** Time series of winds speed (upper panel), northerly component (middle panel), and easterly component (lower panel).

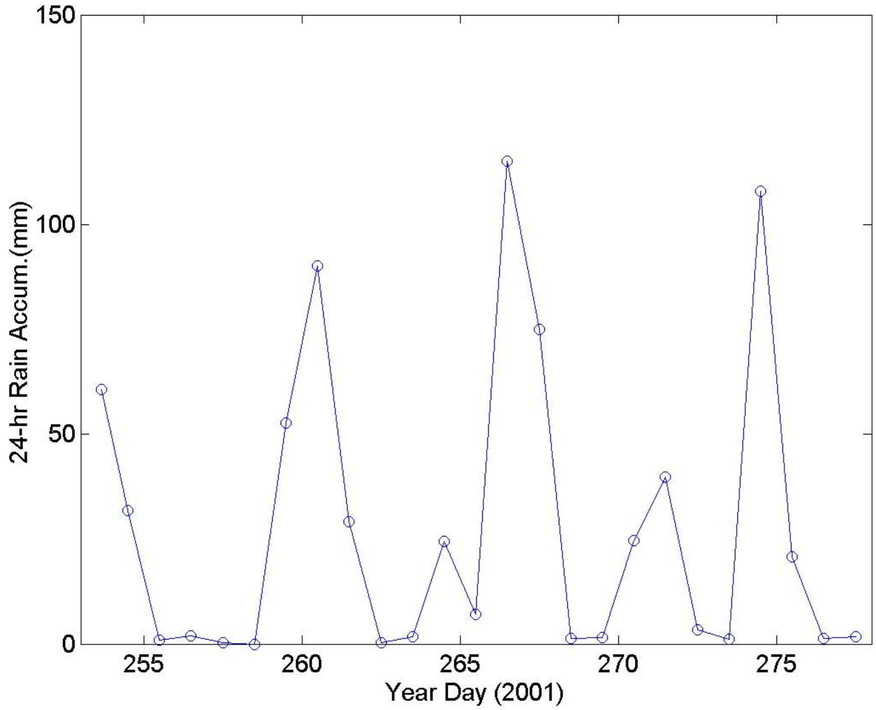


**Figure 12.** Timer series of 24-hr rain accumulation.

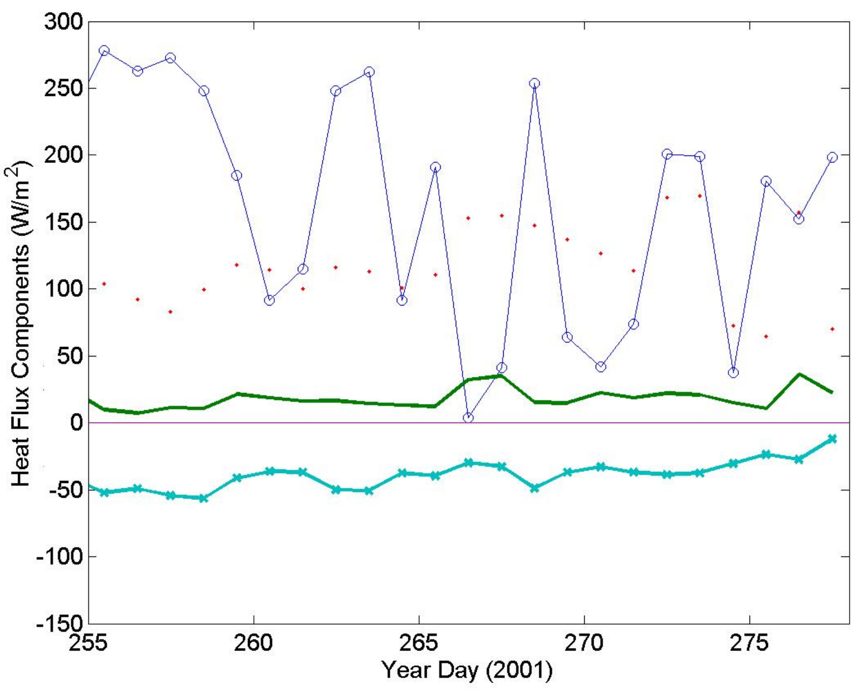


**Figure 13.** Time series of daily-averaged flux components: solar flux - dashed line; net IR flux - x s; sensible heat - solid line; latent heat - dots..

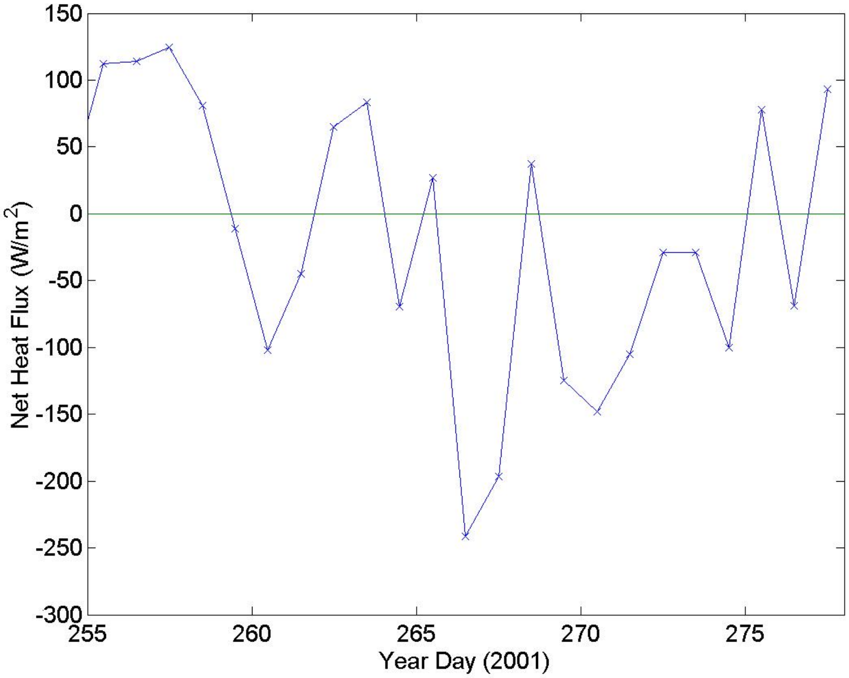


**Figure 14.** Time series of daily-averaged net heat flux to the ocean.

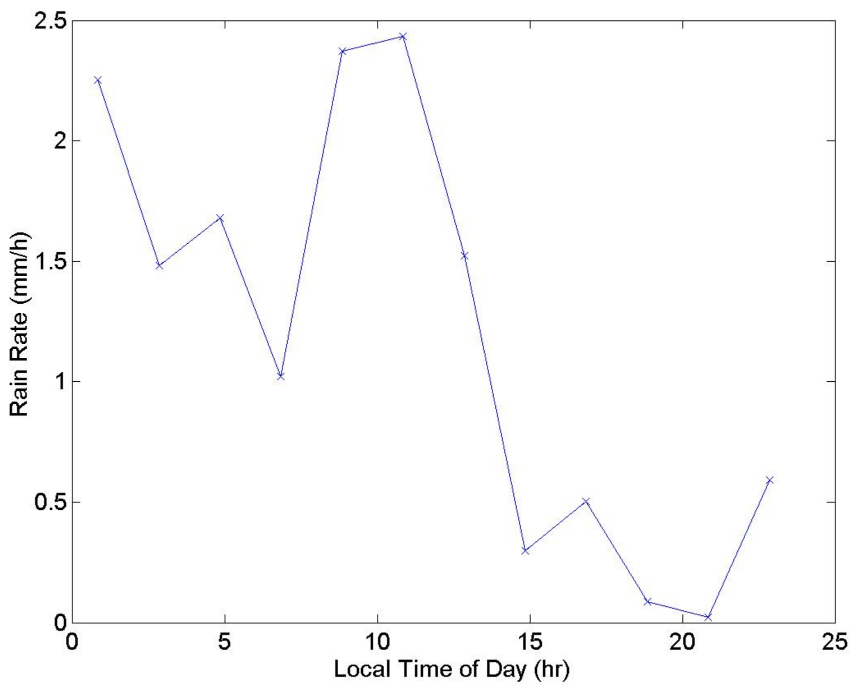


**Figure 15.** Diurnal average of rainfall for the ITCZ period (days 255 - 274).

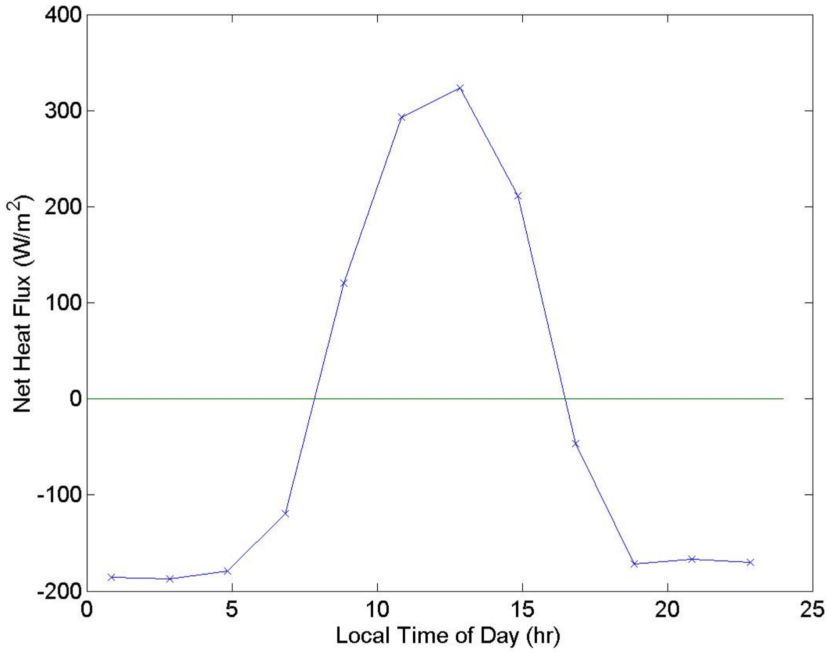


**Figure 16.** Diurnal average of net heat flux for the ITCZ period (days 255 - 274).

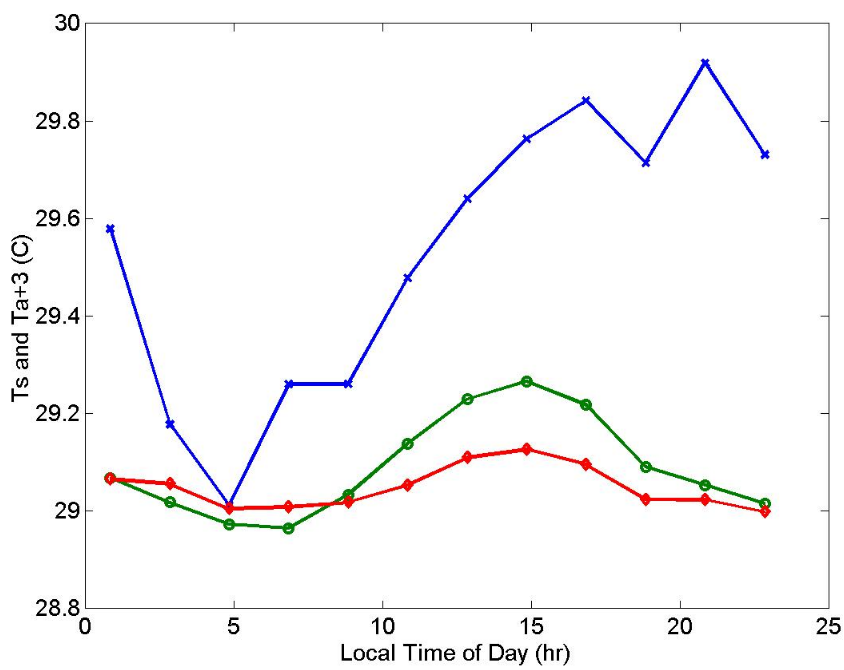


**Figure 17.** Diurnal average of temperatures (red - 5-m TSG; green - 5 cm; blue - 15-m air) for the ITCZ period (days 255 - 274).