EPIC2001 Field Program on the NOAA Ship Ronald H. Brown
Results from the ETL Flux Group Measurements,   October 8 - 23, 2001

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1. Background on Measurement Systems

The ETL air-sea flux group conducted measurements of fluxes and near-surface bulk meteorology during Leg II 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 five components: (1) A fast turbulence system with ship motion corrections mounted on the jackstaff. The jackstaff sensors are: Gill-Solent Sonic anemometer/thermometer, Ophir IR-2000 Infrared hygrometer, LiCor LI-7500 fast CO2/H2O gas analyzer, and a 3-axis Systron-Donner accelerometer/rotation rate sensor package; (2) a mean T/RH sensor (Vaisala) in an aspirator on top of the bow tower; (3) solar and infrared 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 ("seasnake"); (5) A set of four optical rain gauges mounted on the bow tower. The mean meteorological data (Tair, RH, solar, IR, rain, Tsea) 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/thermometer
2. Licor CO2/H2O
3. Slow means (Campbell 23x)
4. Unused
5. Ophir hygrometer
6. Systron-Donner Motion-Pak
7. Ship's SCS
8. 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 file 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 an ETL 915 MHz wind profiler. The ceilometer is a vertically pointing lidar that determines the height of cloud base from time-of-flight of the backscatter return from the cloud. The time and spatial resolutions are 15 second and 30 meters, respectively. 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. The ceilometer 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=293 (October 20, 2001). The time series of ocean and air temperature is given in Figure 1. The water temperature is about 18.5 C and the air temperature is about 17.5 C until it rises at mid-day to about 18.0 C. A perusal of the Leg II temperature plots shows the ubiquitous nature of the Leg II stratus environment, where the dynamics are suppressed and convective activity is at a minumum. The wind speed during that period is shown in Figure 2, with an initial value of about 9 m/s, dropping to around 7.5 m/s by the end of the Julian day. The solar flux time series (Figure 3) which shows maximum mid-day values around 1100 Wm^{-2}, with significant modulation of the incoming solar due to the stratus cloud ceiling. The effect of clouds on the downward IR radiative flux is illustrated in Fig. 4, where the daytime flux is relatively high (390 W/m/m), as the low-level water clouds are strong emitters of IR radiation and their presence causes the warming. Nighttime scattered clearing appears to show modulation of the flux. Figure 5 shows the time series of the four of the five primary components of the surface heat balance of the ocean (solar flux has been omitted for clarity). 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 (zero). Typical values in the Pacific warm pools (Leg II is conducted within the upwelling regime) 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 Figure 6, and this plot includes the contribution due to net solar radiative flux. The sum of the components in Figure 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 61 Wm^{-2}, indicating warming of the ocean mixed layer. The sea surface temperature is seen in Figure 7.

b. Ceilometer and Wind Profiler Data

A sample ceilometer 12-hr time-height cross section for October 20 (12 - 24 GMT) is shown in Figure 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 86% cloud cover and a steady cloud base of about 900 meters. As was typical for the Leg II regime, no rain fell during this day.

A sample radar wind profiler 24-hr time-height vector diagram is shown for October 20 in Figure 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 easterlies and southeasterlies of about 5 ms^{-1} which change to 10 ms^{-1} easterly above 1 km.

3. Cruise Summary Results

a. Basic Time Series

The 30-minute 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 ubiquitous nature of the dry stratus regime is 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 283 - 296, which encompasses the Leg II cruise. In Figure 15, we show the composite rainfall; Figure 16 the net heat flux; Figure 17 shows sea/air temperatures. Very little rain fell at the ship during the Leg II cruise, and the total rainfall (uncorrected) for the entire experiment was approximately 7 mm. The net heat flux shows the typical night time cooling is around 100 Wm^{-2}, while the average net heat flux for the entire experiment was about +90 Wm^{-2}. This is a stark contrast to the Leg I data, as net cooling of about 20 W/m/m occurred north of the Equator. For comparison, typical values in the tropical west Pacific warm pool are around +35 Wm^{-2}. The diurnal cycle of air temperature is smaller than that for SST, which is typical of this area and is, again, a stark contrast to the Leg I observations.

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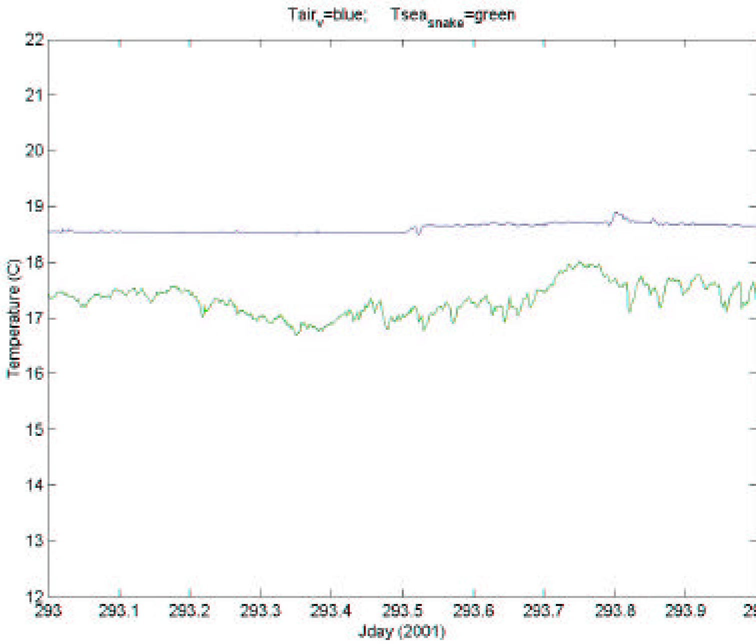
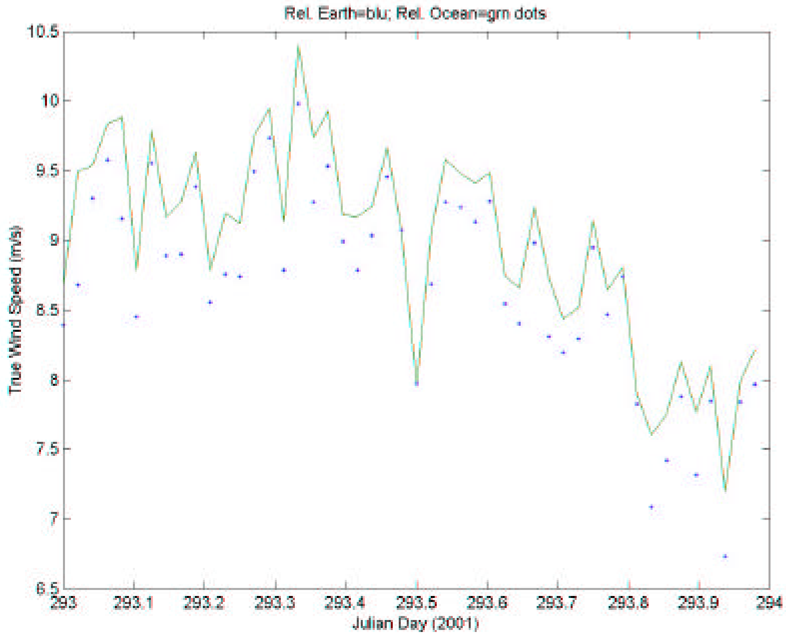
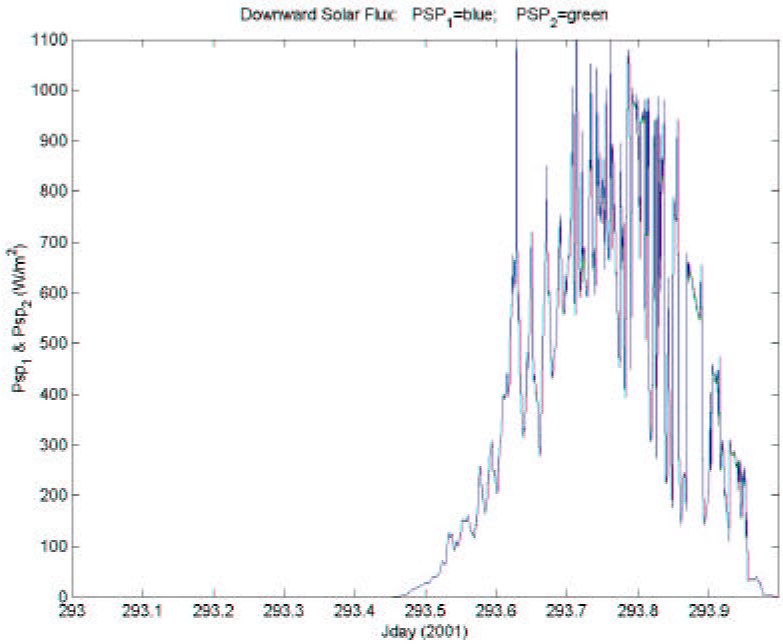
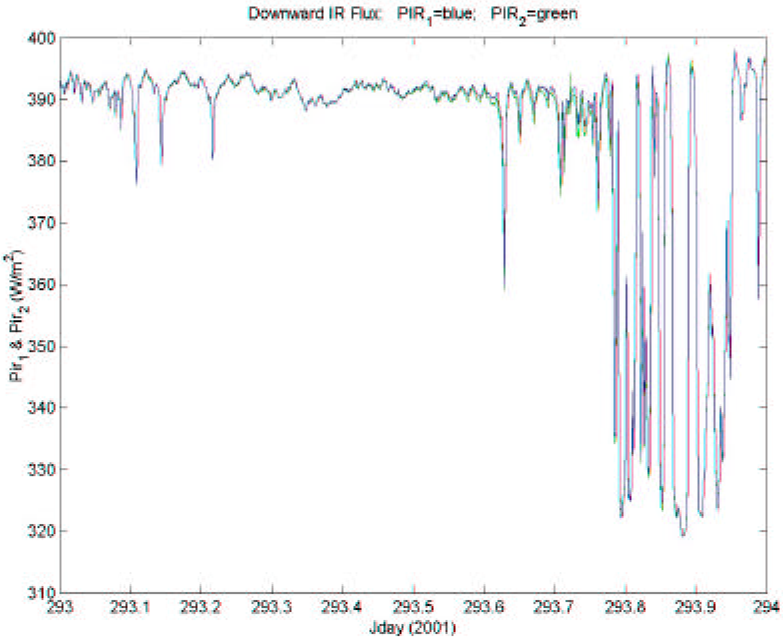


Tair$_v$=blue; Tsea$_{snake}$=green
Temperature (C)
Jday (2001)
22
21
20
19
18
17
16
15
14
13
12
293
293.1
293.2
293.3
293.4
293.5
293.6
293.7
293.8
293.9
294

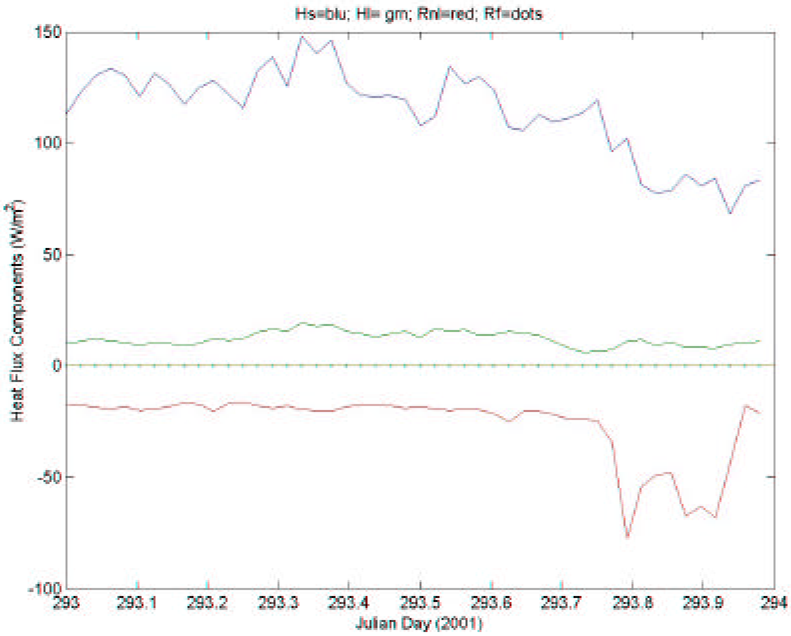

Rel. Earth=blu; Rel. Ocean=grn dots
True Wind Speed (m/s)
Julian Day (2001)
10.5
10
9.5
9
8.5
8
7.5
7
6.5
293
293.1
293.2
293.3
293.4
293.5
293.6
293.7
293.8
293.9
294

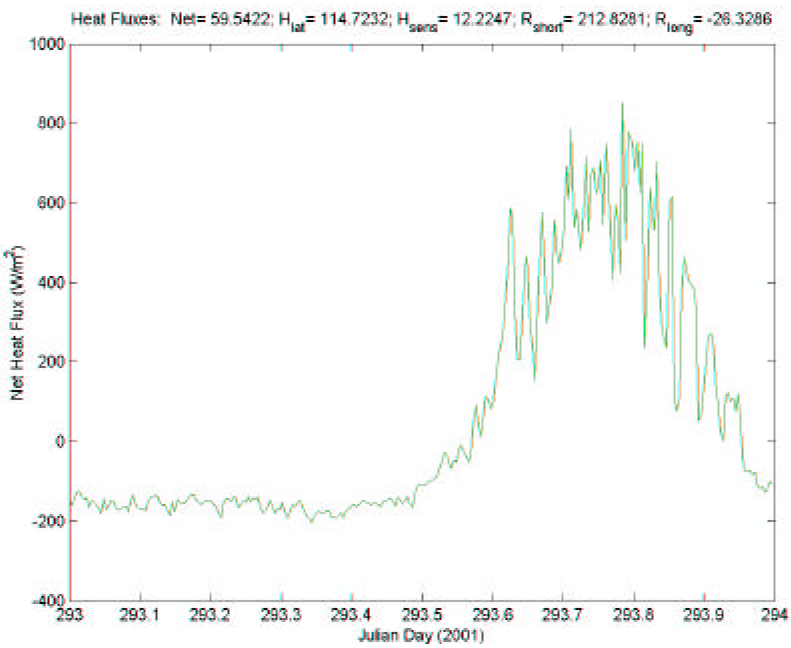


Downward Solar Flux: PSP1=blue; PSP2=green
Psp1 & Psp2 (W/m2)
Jday (2001)
0
100
200
300
400
500
600
700
800
900
1000
1100
293
293.1
293.2
293.3
293.4
293.5
293.6
293.7
293.8
293.9

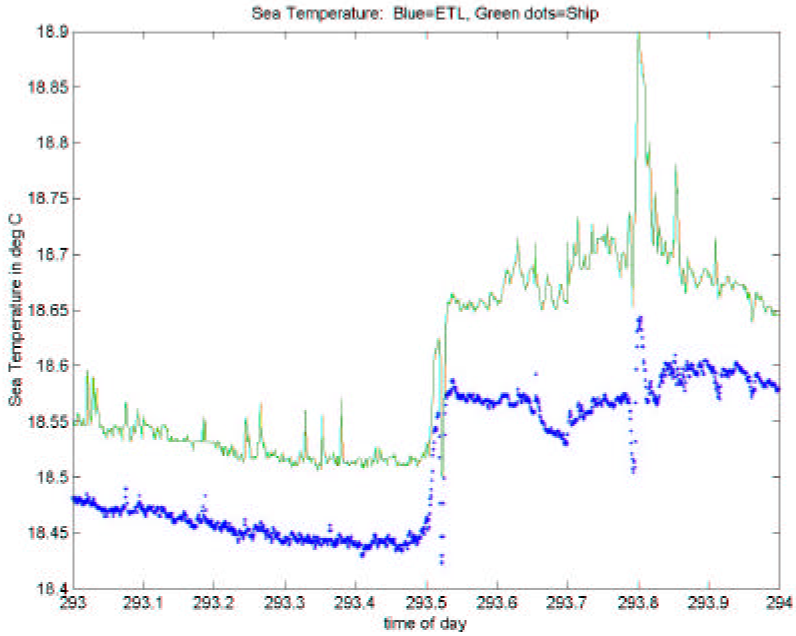


Downward IR Flux: PIR1=blue; PIR2=green
Pir1 & Pir2 (W/m2)
400
390
380
370
360
350
340
330
320
310
293
293.1
293.2
293.3
293.4
293.5
293.6
293.7
293.8
293.9
294
Jday (2001)

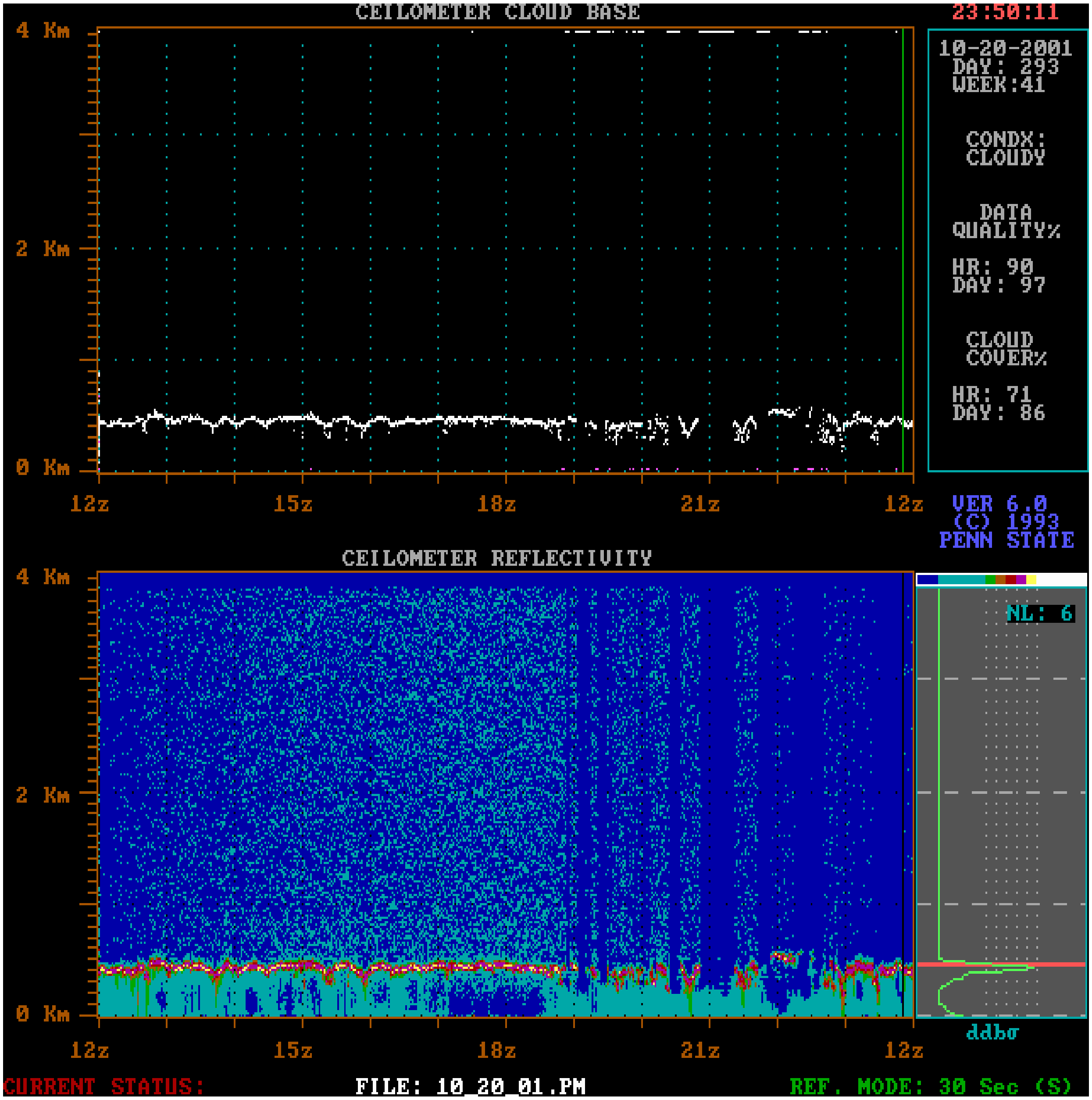

Hs=blu; Hl= grn; Rnl=red; Rf=dots
Heat Flux Components (W/m^2)
Julian Day (2001)
150
100
50
0
-50
-100
293
293.1
293.2
293.3
293.4
293.5
293.6
293.7
293.8
293.9
294

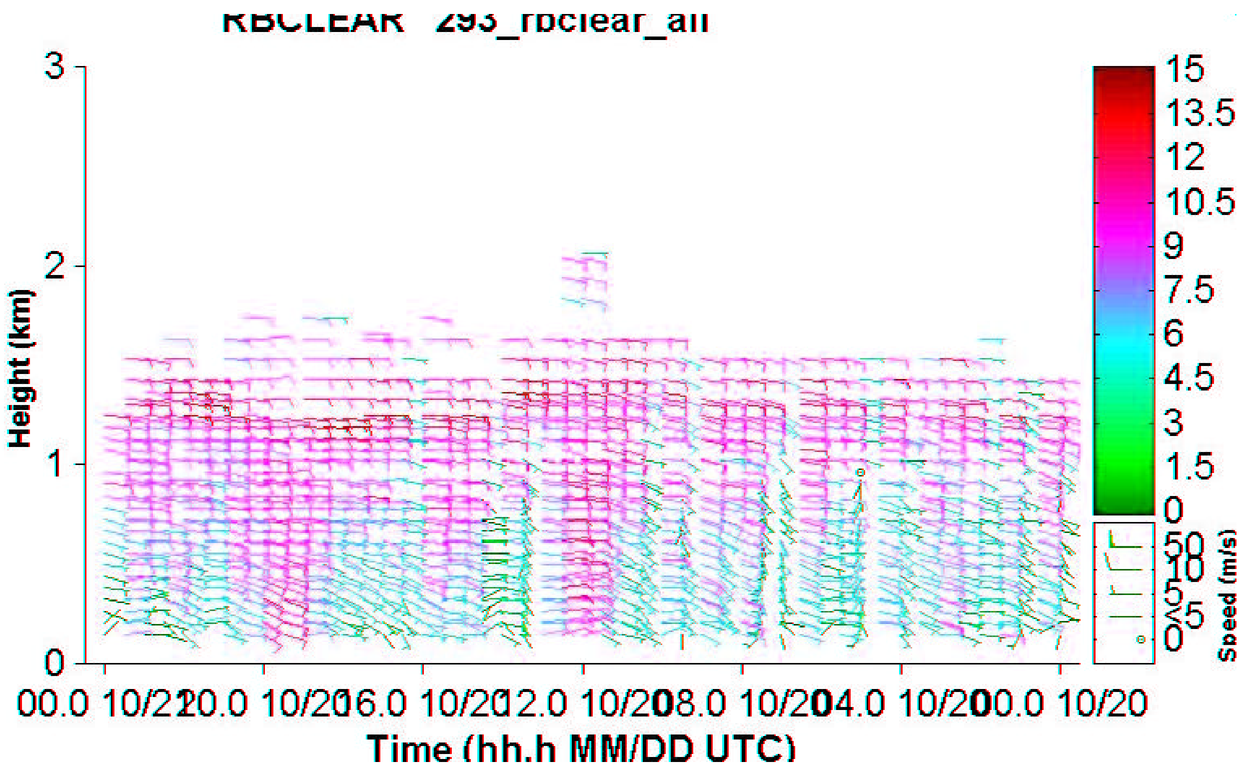


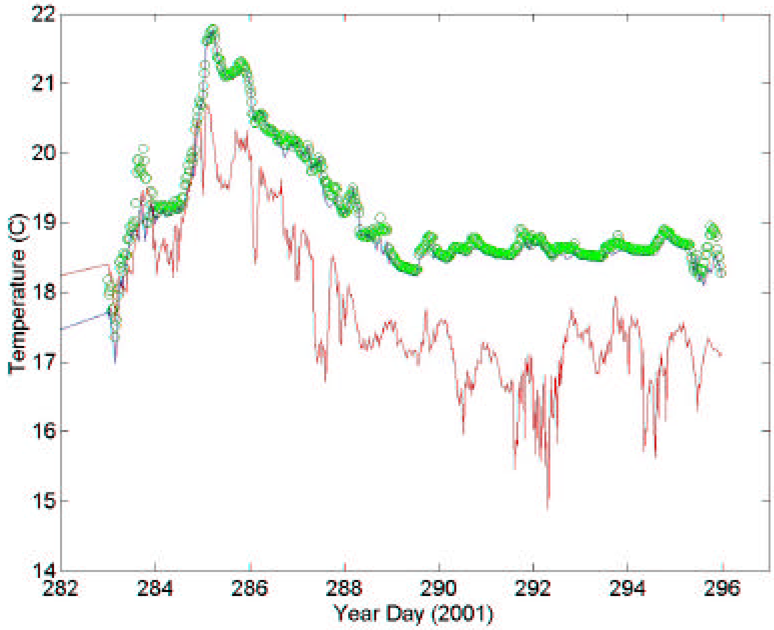
Heat Fluxes: Net= 59.5422; H_{lat}= 114.7232; H_{sens}= 12.2247; R_{short}= 212.8281; R_{long}= -26.3286
Net Heat Flux (W/m^2)
1000
800
600
400
200
0
-200
-400
293
293.1
293.2
293.3
293.4
293.5
293.6
293.7
293.8
293.9
294
Julian Day (2001)



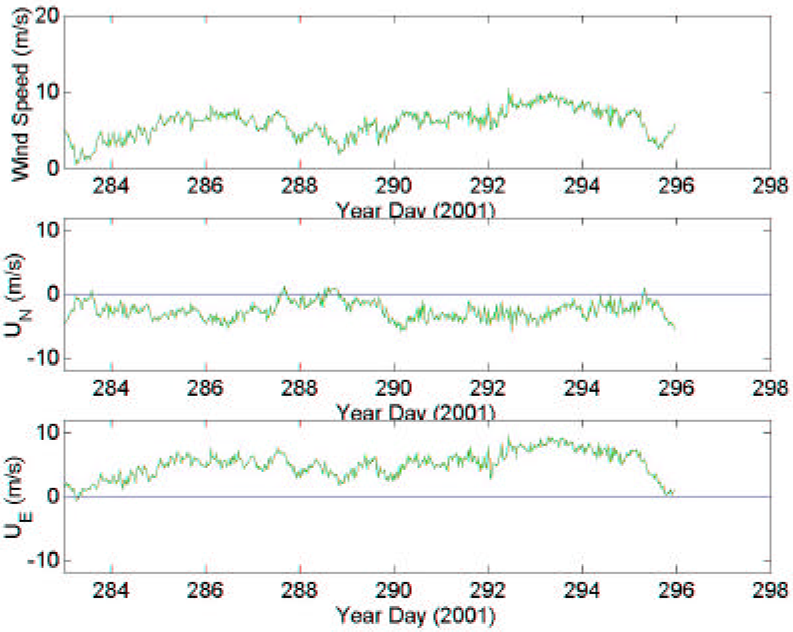
Sea Temperature: Blue=ETL, Green dots=Ship
Sea Temperature in deg C
time of day
18.9
18.85
18.8
18.75
18.7
18.65
18.6
18.55
18.5
18.45
18.4
293
293.1
293.2
293.3
293.4
293.5
293.6
293.7
293.8
293.9
294


CEILOMETER CLOUD BASE
23:50:11
4 Km
2 Km
0 Km
12z
15z
18z
21z
12z
10-20-2001
DAY: 293
WEEK:41
CONDX:
CLOUDY
DATA
QUALITY%
HR: 90
DAY: 97
CLOUD
COVER%
HR: 71
DAY: 86
VER 6.0
(C) 1993
PENN STATE
CEILOMETER REFLECTIVITY
NL: 6
ddbσ
CURRENT STATUS:
FILE: 10_20_01.PM
REF. MODE: 30 Sec (S)

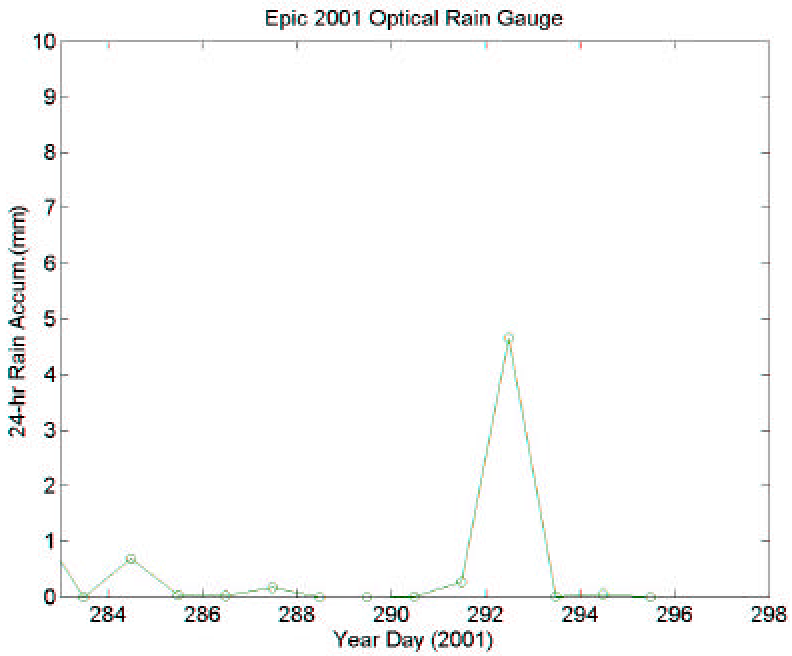

RBCLEAR 293_rbclear_all
Height (km)
Time (hh.h MM/DD UTC)
Speed (m/s)
15
13.5
12
10.5
9
7.5
6
4.5
3
1.5
0



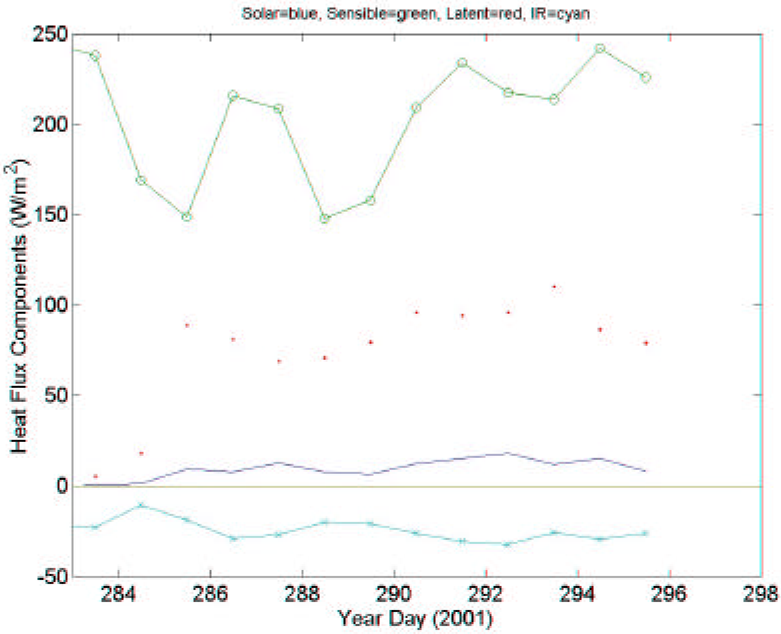
Temperature (C)
22
21
20
19
18
17
16
15
14
282
284
286
288
290
292
294
296
Year Day (2001)



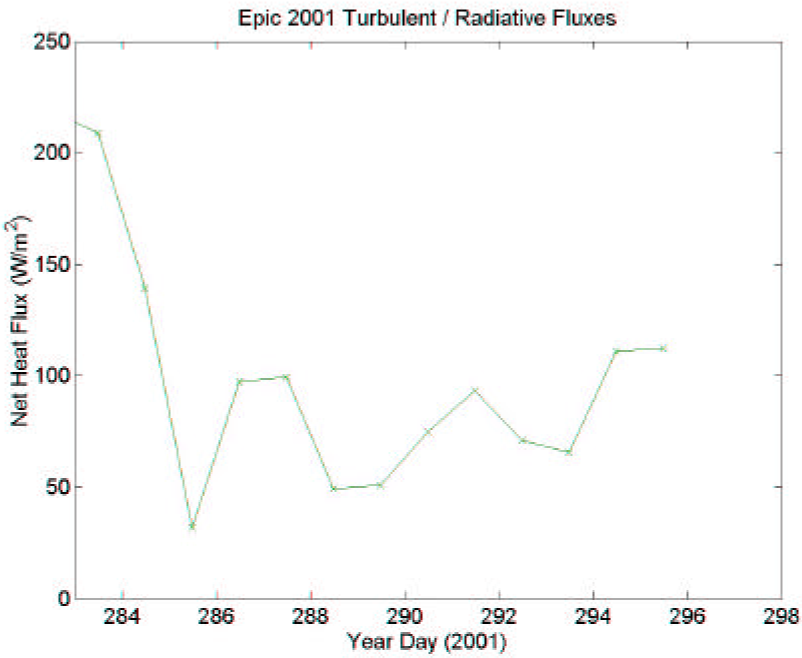
Wind Speed (m/s)
20
10
0
284
286
288
290
292
294
296
298
Year Day (2001)
U_N (m/s)
10
0
-10
284
286
288
290
292
294
296
298
Year Day (2001)
U_E (m/s)
10
0
-10
284
286
288
290
292
294
296
298
Year Day (2001)

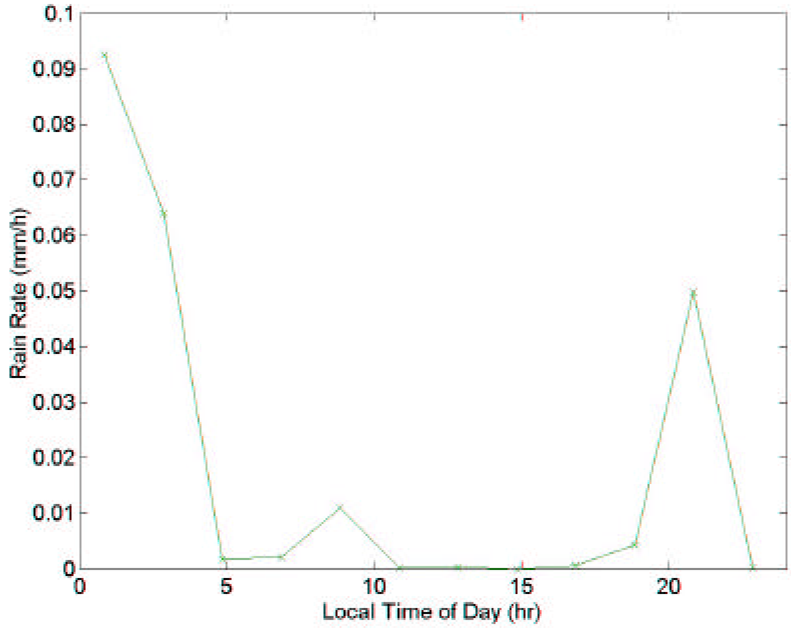


Epic 2001 Optical Rain Gauge
24-hr Rain Accum.(mm)
Year Day (2001)
0
1
2
3
4
5
6
7
8
9
10
284
286
288
290
292
294
296
298

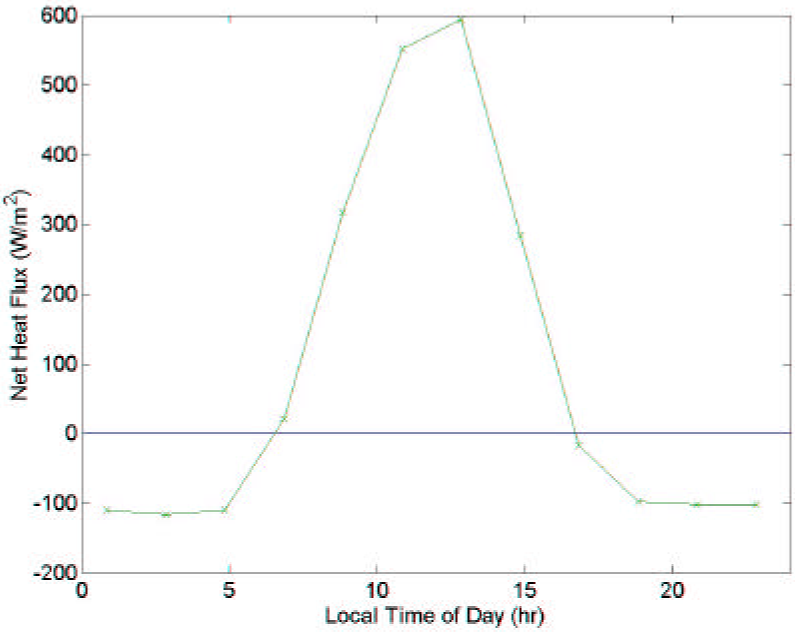


Solar=blue, Sensible=green, Latent=red, IR=cyan
Heat Flux Components (W/m^2)
250
200
150
100
50
0
-50
284
286
288
290
292
294
296
298
Year Day (2001)

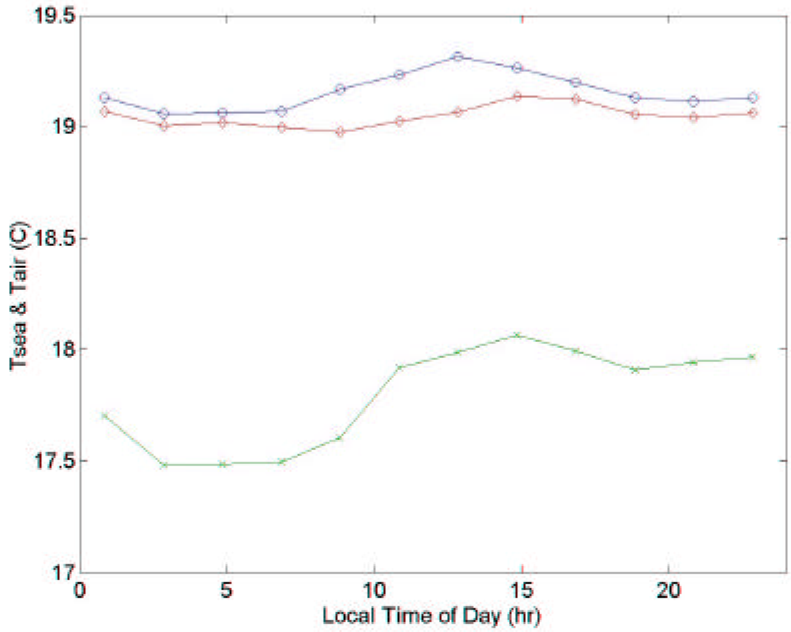

Epic 2001 Turbulent / Radiative Fluxes
Net Heat Flux (W/m^2)
250
200
150
100
50
0
284
286
288
290
292
294
296
298
Year Day (2001)



0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Rain Rate (mm/h)
0
5
10
15
20
Local Time of Day (hr)



Net Heat Flux (W/m²)
600
500
400
300
200
100
0
-100
-200
0
5
10
15
20
Local Time of Day (hr)



19.5
19
18.5
18
17.5
17
Tsea & Tair (C)
0
5
10
15
20
Local Time of Day (hr)