Preliminary results on board the NOAA Research Vessel Ronald H. Brown
Leg1: October 20 – November 3, 2008
Leg2: November 10 – December 1, 2008
PSD Weather and Climate Physics Branch, North Carolina State University, and University of Miami

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December 1, 2008

1. Background on Measurement Systems

The Earth Systems Research Laboratory (ESRL) Physical Science Division (PSD) Weather and Climate and Physics branch conducted measurements of fluxes and near-surface bulk meteorology during the VOCALS field program on board the Ron Brown. VAMOS Ocean-Cloud-Atmosphere-Land Study Regional Experiment (VOCALS-REX) is an international field experiment designed to better understand physical and chemical processes central to the climate system of the Southeast Pacific (SEP) region. The climate of the SEP region is a tightly coupled system involving poorly understood interactions between the ocean, the atmosphere, and the land. Unlike past STRATUS cruises the 2008 recovery/deployment of the Woods Hole Oceanographic Institute (WHOI) Ocean Reference Station buoy at 20 S Latitude 85 W Longitude, recovery/deployment of the Deep-ocean Assessment and Reporting of Tsunami (DART) buoy, and shipboard measurements were just a small part of VOCALS.

The PSD flux system was installed initially on the Ronald H. Brown (RHB) in Charleston, SC, in late September 2008. It was tested on transit to Panama in early October, 2008. The official start of the experiment and data collection was 0500 UTC October 20, 2008 (YD 294) when we crossed into Ecuadorian waters. We arrived on station at the WHOI buoy Oct 24, 2008 (YD 298), departing 1400 UTC on Oct 27, 2008 (YD 301). Due to extenuating circumstances the Ron Brown was delayed over a week and had to steam from Panama to the WHOI buoy site foregoing the transect down 85W for a more direct route. Once on site there was only enough time to deploy the new and recover the old WHOI buoys before moving on to the DART buoy. This made for minimal inter-comparison between the ship-board systems and the buoy.

Measurements were made using a wide of array in-situ instruments and remote sensors (Figs. 1 and 2). Air-sea flux measurements consist of six components: (1) A fast turbulence system with ship motion corrections mounted on the jackstaff. The jackstaff sensors are: GILL Sonic anemometer, LiCor LI-7500 fast CO_2/hygrometer, and a Systron-Donner motion-pak. (2) A mean T/RH sensor in an aspirator on the starboard arm of the jackstaff. (3) Solar and IR radiometers (2 pair Eppley and 1 pair Kipp and Zonen pyranometers and pyrgeometers) mounted on a mechanically stabilized platform on top of a seatainer on the 02 deck. (4) A near surface sea surface temperature sensor consisting of a floating thermistor deployed off port side with outrigger. (5) A Riegl laser rangefinder wave gauge mounted at the very point of the bow. (6) An optical rain gauge mounted on the starboard arm of the jackstaff. Slow mean data (T/RH, PIR/PSP, etc) are digitized and averaged on a datalogger and transmitted as 1-minute averages to a central data acquisition computer that logs all sources of data via RS-232 digital transmission:

1. Sonic Anemometer
2. Licor CO2/H2O
3. Slow means (Campbell 21x)
4. Laser wave sensor
5. Systron-Donner Motion-Pak
6. Ship's Computer System
7. PSD GPS
8. PSD Heading

The 8 data sources are archived at 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 come from three sources: The PSD sonic anemometer (acquired at 10 Hz) the Ship's Computer System (SCS) (acquired at 0.5 Hz), and the PSD mean measurement systems (sampled at 1.0 Hz and averaged to 1 min). The sonic is 5 channels of data; the SCS file is 17 channels, and the PSD mean system is 77 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 and 30 minutes, computes fluxes, and writes new daily flux files. The 5 and 30-min daily flux files have been combined into 5 and 30 min average files: File structure is described in the original matlab files that write the data.

In addition to the flux system there were 10 remote systems and a Cloud Imaging Probe (CIP) operated by PSD. The first three sensors are all permanently mounted on the ship, but mentored by PSD.

1. C-band scanning-weather radar
2. Terascan Satellite receiver
3. 915 MHz vertically pointed Doppler wind profiler (down Leg 1)
4. Vaisala CL31 cloud base ceilometer
5. PSD W-Band Doppler cloud radar (mechanically stabilized)
6. U of Miami W-Band cloud radar (vertically pointing)
7. PSD 90 GHz micro-wave radiometer (MWR)
8. U of Miami 23 and 31 GHz micro-wave radiometer (Mailbox)
9. U of Miami 183 GHz micro-wave radiometer
10. PSD automated digital cloud camera
11. Cloud Imaging Probe

All results discussed and shown in the following report are preliminary and based on non-quality controlled data collected in the field. Some discrepancies have been identified and will be addressed in the post processing.

C-band scanning-weather radar

The C-band radar aboard the RV Ronald H. Brown is a single polarization scanning Doppler radar. The radar transmits a microwave pulse with a wavelength of 5 cm and a beam width of 1 degree. For the VOCALS project the C-band radar aboard the RV Ronald H. Brown was configured to have a pulse repetition frequency of 2000 Hz with a maximum range of 60 km and a Nyquest velocity of 26.8 m/s. The C-band radar features an active motion compensation system that will adjust the pointing direction of the radar antenna to compensation for the motion of the ship while at sea. The scan strategy for the VOCALS project alternated between PPI volume scans and RHI vertical cross-section scans. A PPI and RHI volume pair was collected every three minutes. For the PPI volume, the radar scanned at 6 elevation angles at 20 degrees per second azimuthal velocity. The elevations scanned were 1, 2, 3, 4, 5, and 6 degrees elevation. For the RHI volume, 4 vertical cross-sections were taken at orthogonal directions. For the RHI volume, the 35, 125, 215, and 305 degree azimuths were scanned. The azimuthal directions used in the RHI scans were based on the climatological mean wind directions for the Southeast Pacific stratocumulus region. Volume scans require approximately 2 mins and 10 secs to complete while the RHIs require 40 secs. All radar scans recorded total reflectivity, clutter filtered reflectivity, Doppler velocity, and spectral width. Data were archived in both the Sigmet IRIS proprietary format and the open source universal radar format (.uf). The purpose of the scanning strategy was to make high temporal resolution radar observations of marine stratocumulus. These radar observations would then be combined with in situ measurements, and satellite remote sensing data in order to investigate the dynamical and microphysical processes and evolution of marine stratocumulus in order to better understand their structure, evolution, and the transitions between open and closed cellular regimes. The principal investigator (PI) for this work is Dr. Sandra Yuter of North Carolina State University's (NCSU) Clouds and Precipitation Patterns and Processes Research Group.

The data from the C-band radar aboard the RV Ronald H. Brown were processed from UF format into netCDF format for coincident display with satellite data, sounding data, and other available data sources as needed. The conversion from UF to netCDF involves converting the radar's native polar coordinate system to the three-dimensional Cartesian grid with interpolation settings that are user configurable via the software settings. The processing software used by the NCSU research group is a customized version of the NCL processing package available from UCAR. NCSU uses Zebra as a display engine for the netCDF data. Zebra is also available from UCAR. Figures 3 and 4 show examples of PPI and RHI scans derived from the C-band Doppler radar using Zebra.

Polar Orbiting Satellite Receiver

A Terascan (SeaSpace) satellite receiver was operational for VOCALS and collected High Resolution Picture Transmission (HRPT) data from NOAA's polar orbiting satellites. HRPT data were archived to hard drive and quicklook images (VIS, IR, SST and TC) archived along with the flux data. Figure 5 is a satellite image taken when the ship (+) was located near the DART buoy. Pockets of open cell convection are visible to the SW of the ship.

915-MHz radar wind profiler

This system was set up to operate a vertical beam only to allow continueous retrieval of the atmospheric boundary layer depth. The system is performing poorly and was operated intermittently on Leg 1 of VOCALS; it was operated full time on Leg 2.

Vaisala CL31 cloud base ceilometer

The ceilometer is a vertically pointing lidar that determines the height of cloud bases from time-of-flight of the backscatter return from the cloud. The time resolution is 15 seconds and the vertical resolution is 15 m. The raw backscatter profile and cloud base height information deduced from the instrument's internal algorithm are stored in daily files. A ceilometer 24-hr time series of ceilometer backscatter for October 25 is shown in Fig. 6. This day was dominated by a stratocumulus layer with cloud bases at 1000m lifting to 1300m as denoted by the bright red trace.

PSD W-band cloud radar

The PSD W-band cloud radar operated during VOCALS was built in house and installed in a specially designed sea container for its first field deployment. The vertically pointing antenna is mounted on a mechanically stabilized platform designed after the platform used for the radiometers to take out the pitch and roll of the ship (Fig 7). Vertical motion will have to be removed during post processing using high resolution GPS data. The cloud radar can be used to deduce profiles of cloud droplet size, number concentration, liquid water concentration, etc. in stratus clouds. If drizzle (i.e., droplets of radius greater than about 50 μm) is present in significant amounts, then the microphysical properties of the drizzle can be obtained from the first three moments of the Doppler spectrum. Table 1 describes the characteristics of the W-band radar. A sample time-height cross section from the PSD W-band radar is shown for a 1-hr period on October 25 (Fig. 8). This figure shows the time-height image of the SNR, Doppler vertical velocity, and spectra width at 1100 UTC, 25 Oct 2008. The vertical stripes represent drizzle with red indicating the strongest periods. Precipitation sensors indicate that the drizzle was not reaching the ground or had become so light that it wasn't detected by the optical rain gauge. Although sensitive to these types of clouds and drizzle, the W-band had lost some gain part way through Leg 1. Figure 9 shows the very first data from the radar prior the gain loss. It appears that after the loss in gain the radar was only able to detect precipitating clouds. The stabilizer was turned off (antenna in fixed vertical position) starting Oct 20.

During the import in Arica the radar low-noise preamplifier was replaced and the problem with the radar controller was fixed. This prevented further occurrences of this problem. The platform control program was tuned by Sergio Pezoa on Leg 2 and ran very well. The system was run without the controlled for 6 hours on November 24 for future evaluation of its effectiveness. Assuming the absolute calibration we are using is accurate, the radar has a noise level equivalent to -39 dBZ at a range of 1 km with 25-m range gates and a dwell of 1/3 seconds.

Table 1: Radar Characteristics'

Application	Cloud Properties
Frequency	94.56 GHz
Peak/Avg Power	1750/5W
Antenna	12 in Cassegrain
Pulse Width	167ns (PM),
Range Cell Size	25 m
Number of Range Cells	120
Velocity Resolution	10.3 cms^{-1}
Max Radial Velocity	± 6.6 ms^{-1}
Antenna Beam Positioner	Pitch-Roll Compensation
Pointing Directions	Vertical
Signal Processing	Average FFT 0.33 s dwell time
Sensitivity	-27 dBz (R = 2km)
Power (estimate)	120 VAC @ 8 amps

Univ of Miami W-band cloud radar

The University of Miami UM) vertically-pointing W-band radar is under the supervision of Dr. Bruce Albrecht's research group. For the VOCALS project the radar was operated by David Painemal of the University of Miami and Matthew Miller of NCSU. The radar operates at 94 GHz (32 mm wave length) with a pulse repetition rate of 10,000 Hz resulting in a maximum unambiguous range of 15 km. The W-band radar is a cloud resolving radar and is capable of measuring the backscatter from non-precipitation sized hydrometeors. The UM W-band radar is vertically pointing only and is not configured to compensate for the motion of the ship. The radar data were archived in netCDF format in blocks of roughly 15 minutes. Table 2 describes the characteristics of the UM W-band radar.

Table 2: Miami W-band Radar Characteristics'

Application	Cloud Properties
Frequency	94 GHz (32 mm wave length)
Range Cell Size	29.3 m
Number of Range Cells	512
Antenna Beam Positioner	None
Pointing Directions	Vertical

Mircowave Radiometers

Three microwave radiometers (MWR) were deployed during VOCALS (Fig 10) . The Univiversity of Miami 2 channel MWR (Mailbox) is the same model that has been deployed on numerous STRATUS and TAO/PACS cruises and on EPIC2001. This MWR operates at 23.8 GHz and 31.4 GHz frequency, with a bandwidth of 0.4 GHz. The two channels allow one to retrieve water vapor (23 GHz) and liquid water path (31 GHz) estimate. A continuous automatic self-calibration developed by the Atmospheric Radiation Monitoring (ARM) program is implemented for this instrument. This MWR was configured to get the retrievals at 90 degrees elevation angle, with a sample resolution of 48 sec. The 183 GHz MWR (Radiometrics MP-183A) can operate at 15 channels (170-184 GHz), however during the cruise the 183GHz MWR was operated at 6 channels (170-175 GHz). These high frequency channels are extremely sensitive to the liquid water and will provide accurate liquid water retrievals. This MWR was set to operate at 3 different elevation angles (20.15, 59.5 and 90 degrees) with a sampling period of 10 sec. The calibration of this instrument requires an external cryogenic target (liquid nitrogen). Two calibrations were carried using a manual tipcal process. The 90 GHz MWR is also sensitive to LWP. Manual tipcals are required with this system. Because of positioning restrictions on the ship, the tipcal procedure was modified so that all calibration angles were made looking forward in only a 90 degree arc. To mitigate the effects of water on the viewing windows of these instruments the 90 GHz MWR has a spinning reflective disk and the Mailbox and 183GHz MWRs have powerful blowers directed across the hydrophobic window.

Time series from the microwave radiometers for October 25 (YD 299) are shown in Fig 11. The panels top to bottom are: brightness temperature (TB) from the 90GHZ, Mailbox LWP and PWV, brightness temperature from the 182GHz, and rain rates from the PSD optical rain gauge. As expected there is strong correlation between the 3 MWR channels sensitive to LWP (31, 90, 170 GHz). There is also correlation to the periods where the optical rain gauge is measuring small fluctuations.

Cloud Imaging Probe (CIP)

Another instrument installed on the ship to compliment the W-Band radar in looking at cloud droplets was the Cloud Imaging Probe (CIP). Designed to fly under the wing of an aircraft at high speeds it was mounted on a platform on the O3 deck starboard side (Fig 12). Mounted in conjunction with the CIP was a sonic anemometer to measure the wind fluctuations close to the probe head. The sonic wind speed was integrated into the PADS software and chosen as the primary input for determining the sampling rate in place of the Pitot tube used when operating on an aircraft. Measuring size range from 25µm to 1550µm. The Cloud Imaging Probe (CIP) uses a fast 64-element photodiode array to generate 2-Dimensional Images of particles from 25-1550µm, as well as sizing in 1-Dimensional Histogram form, and includes housekeeping data. In addition to the primary outputs temperature, sonic anemometer wind components are also recorded. Calibration is achieved by placing a spinning disk in the image path

Automated Digital Cloud Camera

For the first time in order to capture sky conditions, an inexpensive automated camera system was put together and installed on the O3 deck railing. Pointing port, forward, and starboard taking a low-resolution image every ~ 1 min 40s. The goal of these images is to document sky conditions and cloud types. . Note: An all-sky camera was operated as part of the Lidar system of NOAA’s Chemical Science Division.

2. Selected Samples

a. Flux Data

Preliminary flux data are shown for October 25, 2008 (YD 299) as the RHB remained on station at the WHOI buoy site at 20 S 85 W (Fig. 13). The time series of ocean and air temperature is given in Fig. 14. The true wind direction and speed for the flux and ship sensors are shown in Figs 15 and 16. The relative wind direction shown in Fig 15 is used as an indicator for when sampling is and is not disturbed by the ship. In general this includes directions plus or minus 90 degrees from directly on the bow (270^o to 90^o True). The effect of clouds on the downward solar flux is shown in Fig 17 and on the IR flux in Fig 18 from both the flux and ship sensors. For the solar flux, broken clouds are apparent in the jagged form of the curve during the day. For IR flux, clear skies have values of about 320 Wm^{-2} and cloudy skies values around 385 Wm^{-2}. The IR flux suggests mostly cloudy conditions during the day with clearing late in the afternoon. Modeled clear sky values are shown in each figure for reference. Fig. 19 shows the time series of 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 (Hlat) flux, followed by the net IR flux (Rnet, downward minus upward plus); the sensible heat (Hlat) flux and the flux carried by precipitation are very small. We are using the meteorological sign convention for the turbulent fluxes. The time series of net heat flux to the ocean is shown in Fig. 20.

3. Cruise Summary Results

a. Flux Time Series

The ship track for the entire cruise is shown in Fig. 13 (inside Ecuadorian waters to Arica, Chile is the official time frame for data collection). The 5-min average time series for sea/air temperature are shown in Fig. 21 and for wind speed and N/E components in Fig. 22. The change in conditions for the first three days of the record is associated with the run south from Panama. On YD 301 we departed the WHOI location and moved toward the DART buoy at 20 S 74.8W. Fig. 22 shows a weak diurnal variation in the wind component. Primarily because of the consistent low-level cloud cover, there is very little diurnal signal in the sea surface temperature. Time series for flux quantities are shown as daily averages. Fig. 23 gives the flux components and Fig. 24 the cloud forcing for net surface radiative fluxes. Cloud forcing is the difference in the measured radiative flux from that which would be expected if there were no clouds. It is essentially a measure of the effect of clouds on the energy budget of the ocean. A negative cloud forcing implies the cloud cools the ocean (e.g., by reflecting solar flux). Figure 25 shows ceilometer cloud information for the same time period as Fig 24. Correlating the cloud fraction in the upper panel of Fig 25 to Fig. 24 one can see the effects less clouds where both components are near zero. Bulk meteorological variables and turbulent heat fluxes are shown for the transect from ~0 S to 20 S (Fig. 26). Winds remain fairly constant and strong. Unlike previous years, this N-S leg was not directly along 85W. Three East-West transects are combined in Figure 27.

b. Rawindondes

Beginning on October 15 and ending on November 3rd we completed 88 successful rawinsonde launches. Oct 20 until the end of the cruise rawinsondes were launched every 4 hours (6 times daily). Full time-height color contour plots show the synoptic patterns of temperature, moisture and winds Figures 28 and 29. A more detailed discussion of Leg 1 rawinsonde can be found in a separate document (VOCALS 2008 Leg 1 Rawinsonde Observations *Simon de Szoeke, Dan Wolfe, Matthew Miller, and David Painemal).* It includes how the rawinsonde works, launching procedures from the ship, data formats, example thermodynamic and wind profiles, and a discussion of the N-S and E-W transects (including time-height color contour figures).

4. Inter-comparisons

Inter-comparisons are a key strategy in data quality assurance for the climate reference buoys and the use of research vessel measurements for climate-quality data archives. The PSD flux system is intended to produce measurements of turbulent flux bulk variables and radiative fluxes that have the required accuracy for climate research. Prior to the cruise radiometers from WHOI and PSD were inter-calibrated.

*The PSD flux system acquired all relevant ship IMET-based measurements.

*PSD and ship radiative fluxes will be compared with the WHOI buoy (sitting on the deck) and an array of IMET radiative sensors (mounted in an array on the 03 deck).

a. Cloud-Precipitation Sensors

Remote sensors can also be inter-compared between each other and with in-situ sensors. Figure 30 is a comparison of the two W-band radars, CIP, and the optical rain gauge during a light drizzle event. The left panel is a 2-D image of the drizzle as captured by the CIP. The rain gauge shows 2 distinct rain events that match increased intensity and vertical velocities in the W-Band radars. Another comparison is the total column water vapor calculated from the rawinsondes which agrees extremely well with Mailbox values (Fig 31).

b. PSD-Ship Comparisons

We compared PSD and ship measurements for wind speed and direction, sea surface and air temperature, relative humidity, and solar and IR downward radiative flux. At the conclusion of Leg 1, unresolved discrepancies between the IMET and PSD sensors remain. The ship's IMET temperature and relative humidity sensor is a Rotronics sensor with specification of 2-second adjustment timescale. The relative humidity of the ship was on average 10% higher than the PSD Vaisala HMP335 sensor. The IMET RH had variations on the order of minutes, while the PSD measurement had only smooth hourly variations. The PSD temperature and relative humidity sensor was housed in a new R.M. Young aspirated radiation shield. The SeaSnake floating thermistor has an offset of +1.68 C relative to the ship's sea chest thermosalinograph. This was traced to an erroneous digit in the SeaSnake conversion from resistance to temperature. An offset has been applied in our final data output.

5. PSD Data Cruise Archive

Selected data products and some raw data were made available at the end of the cruise for the joint cruise archive. Some systems (radar, turbulence, microwave radiometer) generate too extravagantly to be practical to share. Compared to processed information, the raw data is of little use for most people. For the cloud radar we have made available image files only; full digital data will be available later from the PSD website. For the microwave radiometer, the time series after some processing and averaging. No direct turbulent flux information is provided; that will be available after re-processing is done back in Boulder. However, bulk fluxes are available in the flux summary file.

All data during the cruise were archived to an external hard drive in a structure similar to the structure below. These data will be put on an ftp site back in Boulder. The raw, raw_images, processed, processed_images directories can be found under each instrument category. Raw data from the radars is not normally useful to the basic data user and is not stored in this archive.
All the PSD cruises can be found through the web at: http://psd.etl.noaa.gov/psd/psd3/cruises/

```
VOCALS_2008
        RHB
                balloon
                        raw
                        raw_images
                        processed
                        processed_images
                ceilometer
                combined_sensors
                flux
                radar
                        cband
                        profiler
                        wband
                        um_wband
                radiometer
                        Mailbox-UM
                        180GHz-UM
                        90GHz
                Scientific_analysis
                                Reports
                                docs
                SCS
```

FOR Access to the FTP site:

```
        ftp voodoo.etl.noaa.gov
        username anonymous
        password (email address)
        cd et6/cruises/VOCALS_2008
```

Contact:
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303-497-6204 daniel.wolfe@noaa.gov
303-497-3253 chris.fairall@noaa.gov

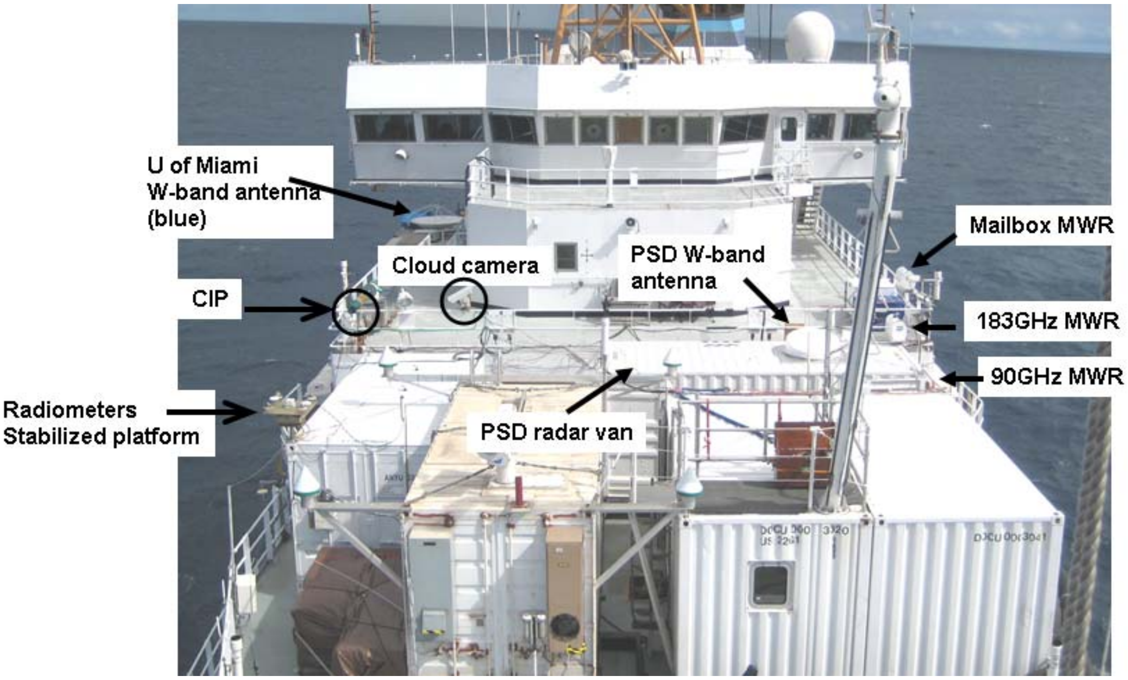

Figure 1. O2 deck PSD instrumentation

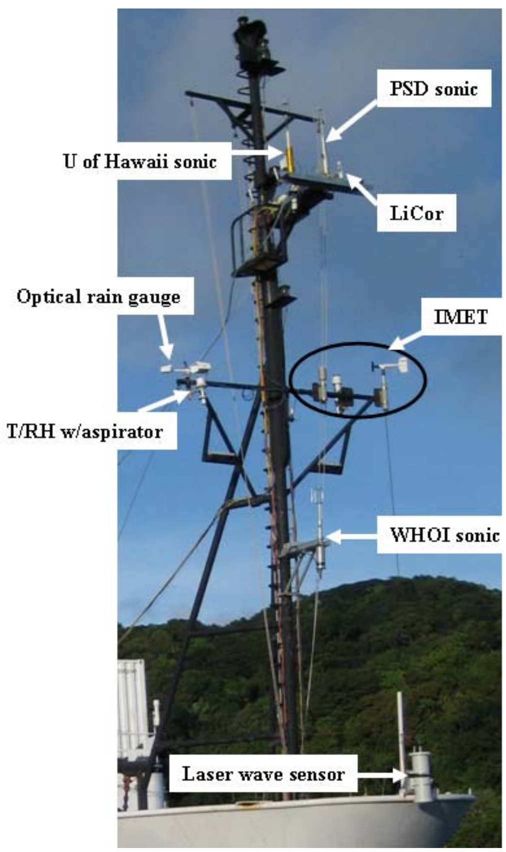

Figure 2. Forward mast (jackstaff) instrumentation. IMET is ship instruments (T/RH/P/Rain).

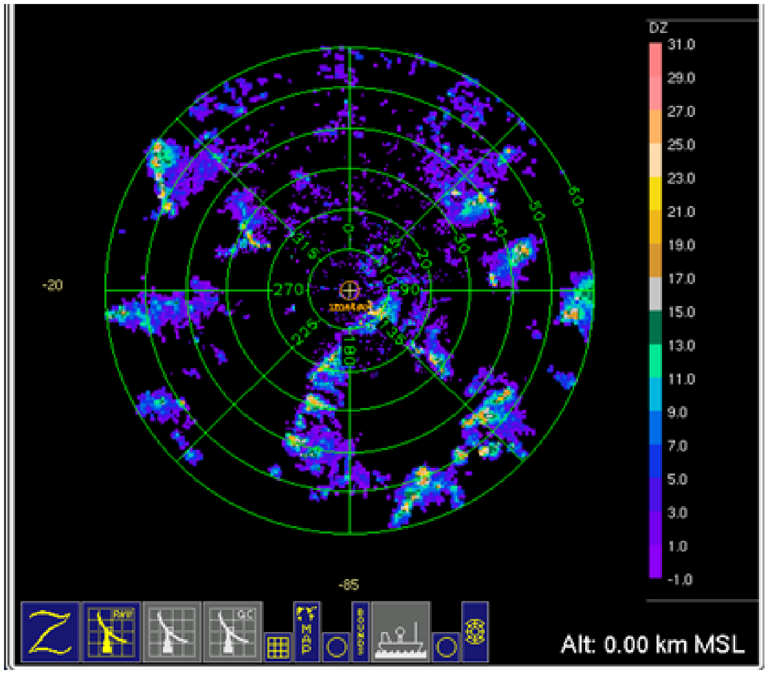

Figure 3. C-Band Doppler radar PPI scan. 1100 UTC October 25, 2008 created by Zebra

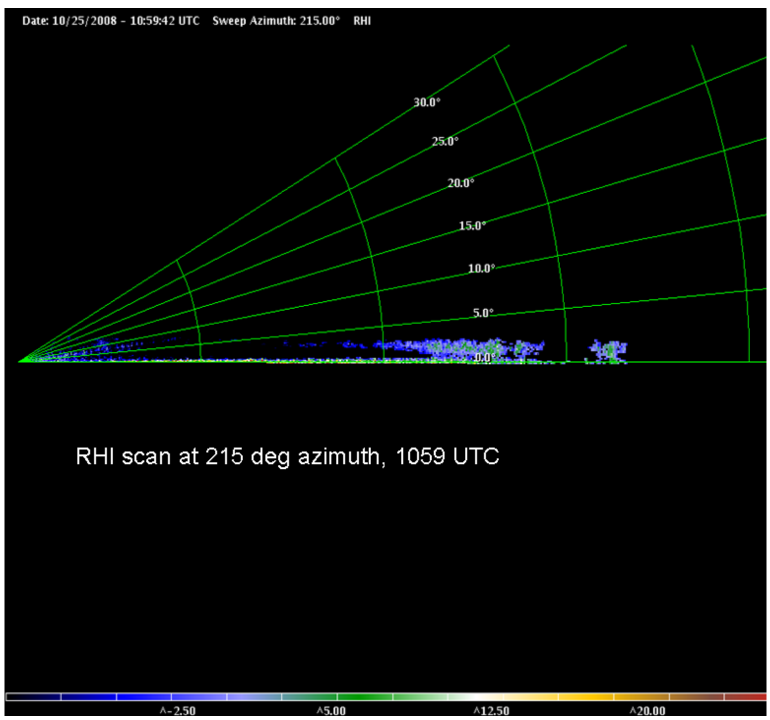

Figure 4. C-Band Doppler radar RHI scan. 1059 UTC October 25, 2008 created by Zebra

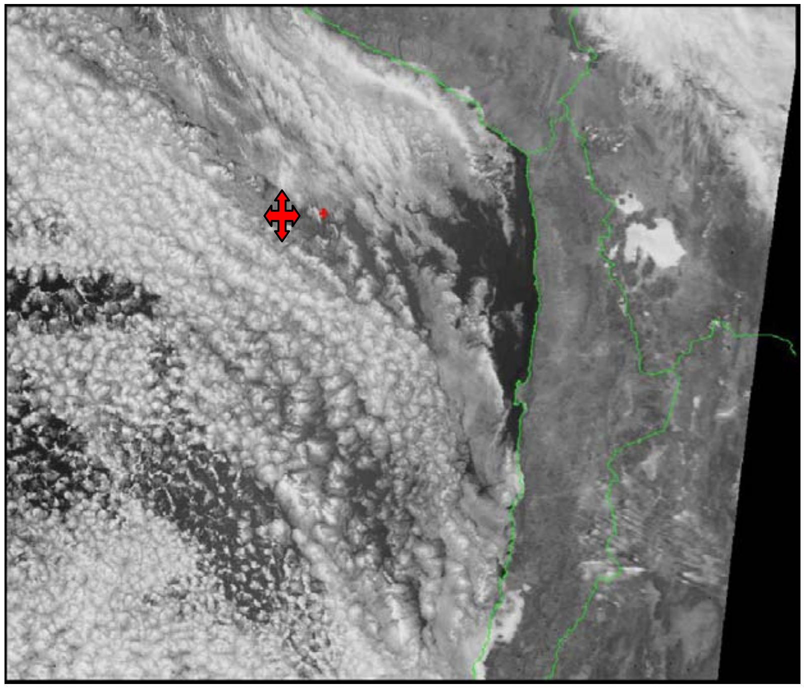

Figure 5. Terascan satellite visible 1442 UTC October 31, 2008. Red + is the location of the ship near the DART buoy (20 S, 75 W)

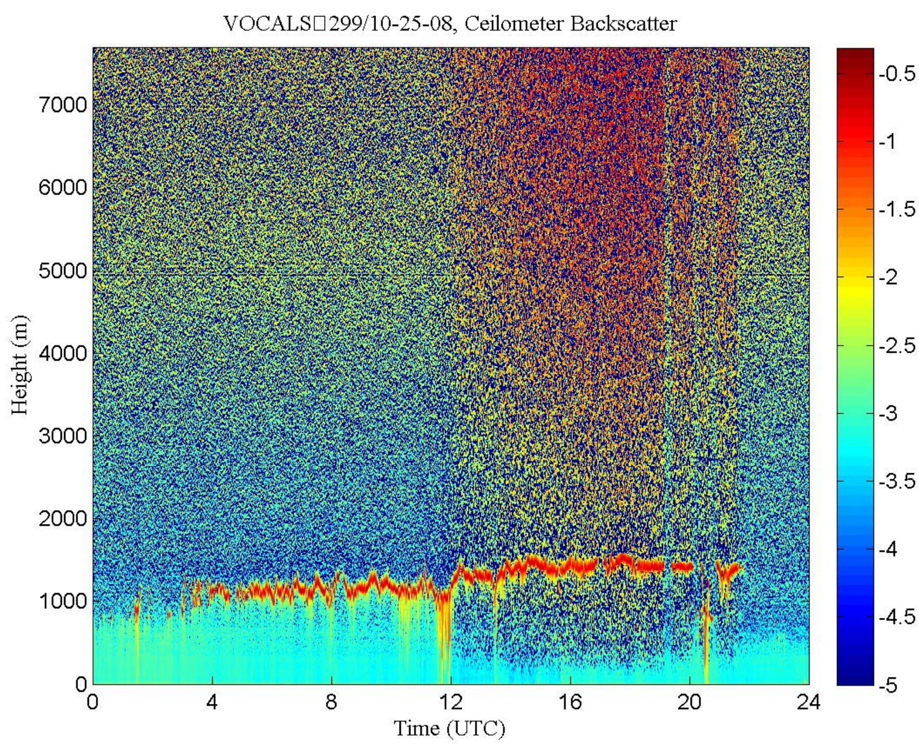

Figure 6. Ceilometer backscatter day 299 (Oct 25, 200)

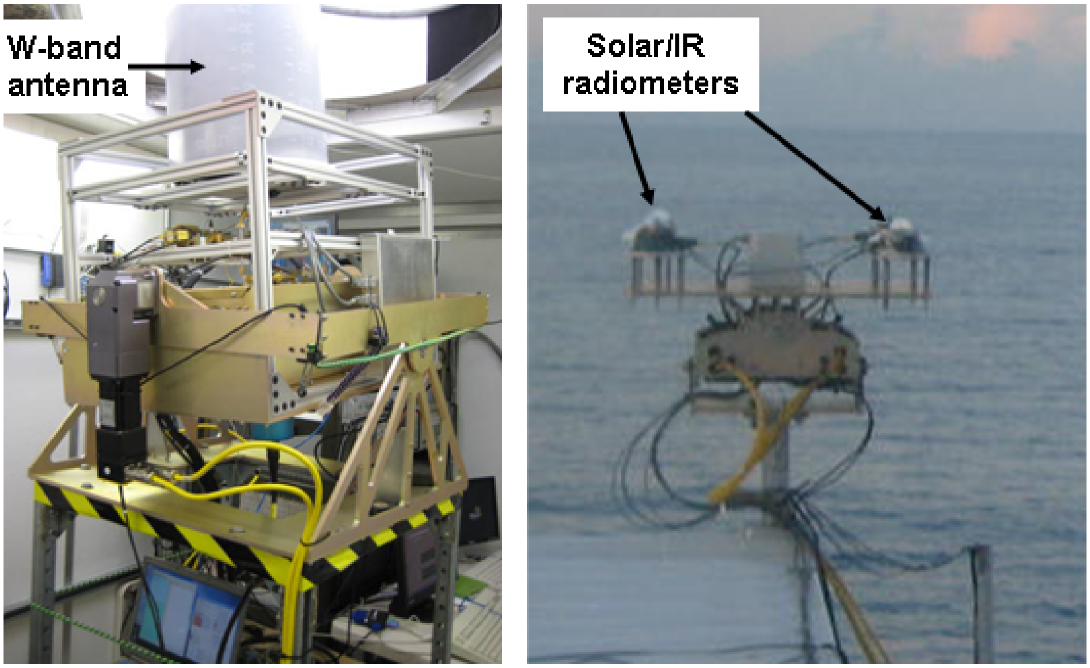

Figure 7. Left panel W-band stabilized platform, right panel radiometer stabilized platform

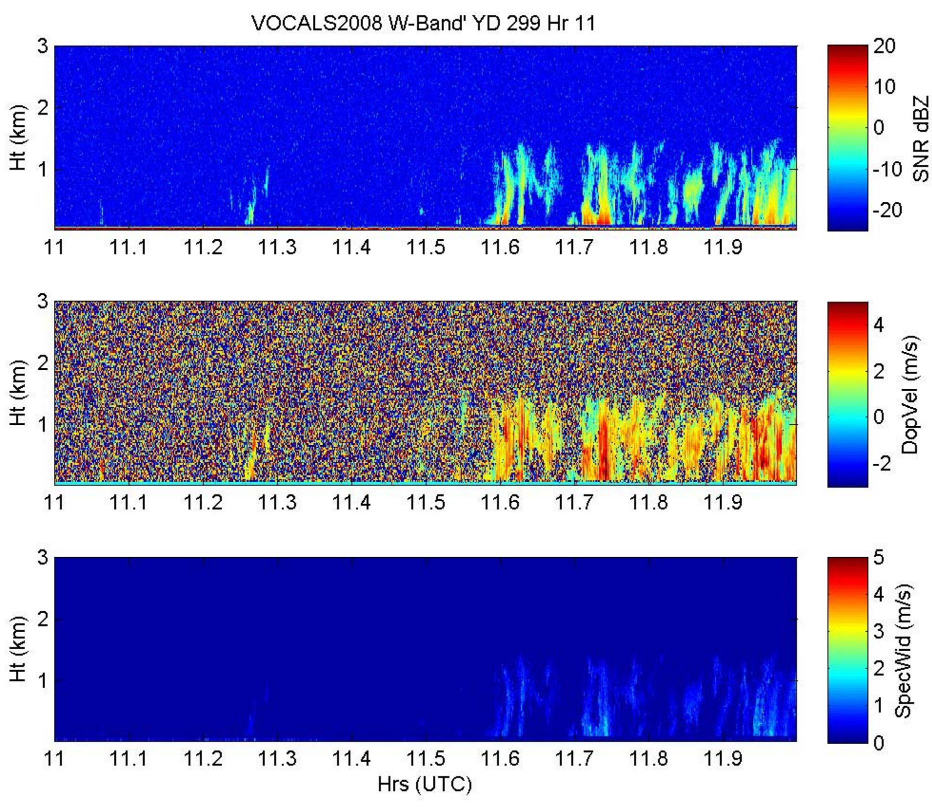

Figure 8. Time-height data from PSD W-band cloud radar data for day 299 (October 25, 2008): SNR, vertical velocity, and spectral width after loss in gain.

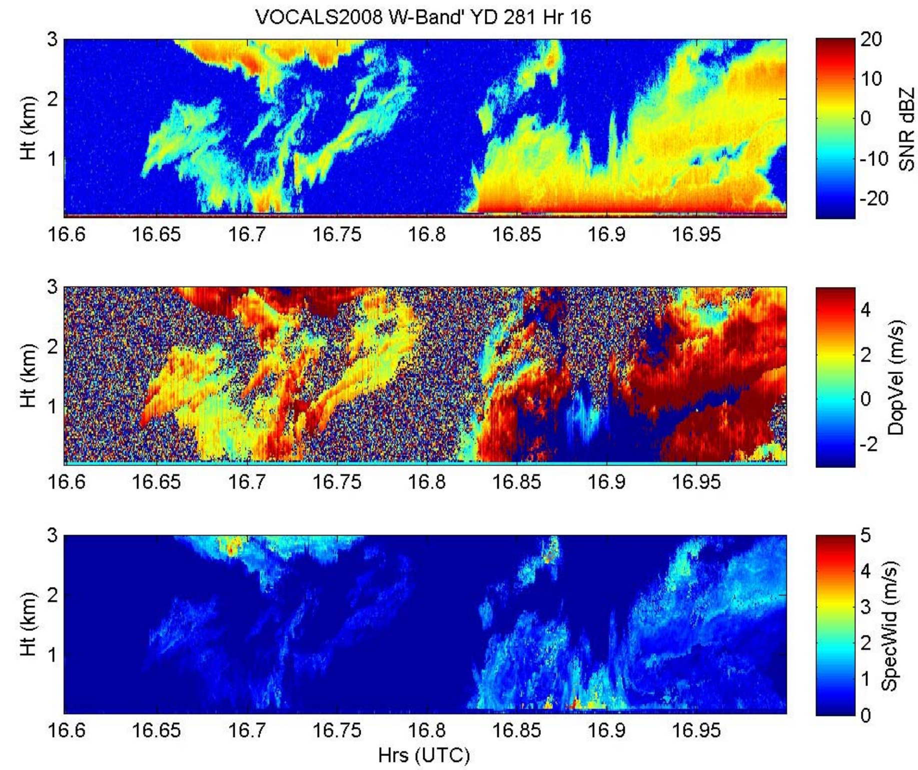

Figure 9. Time-height data from PSD W-band cloud radar data for day 281 (7 Oct) SNR, Doppler vertical velocity, and spectral width. This is the very first cloud image from the radar prior to loss in gain.

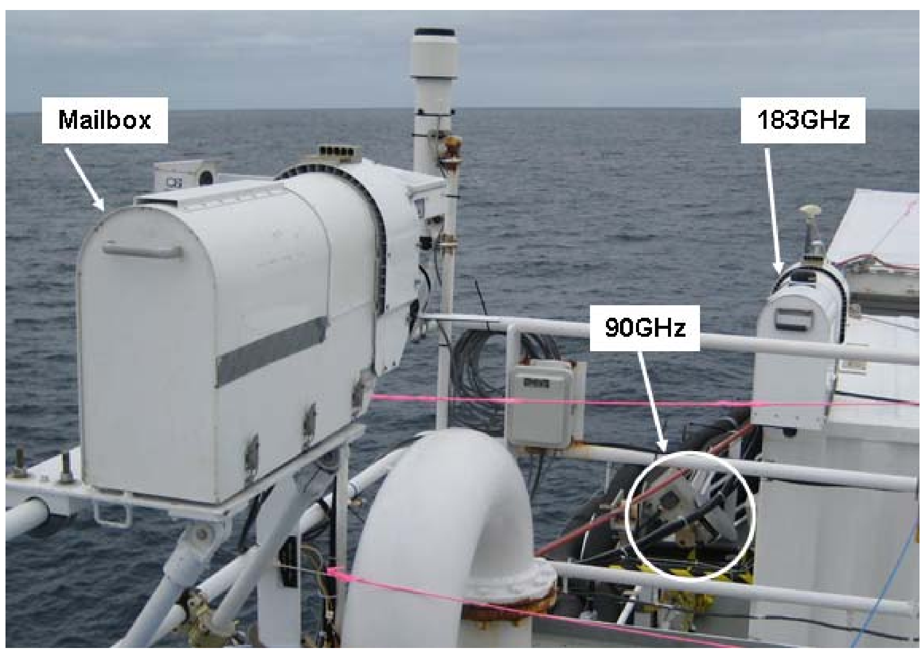

Figure 10. Microwave radiometers mounted on the O3 deck and W-band van

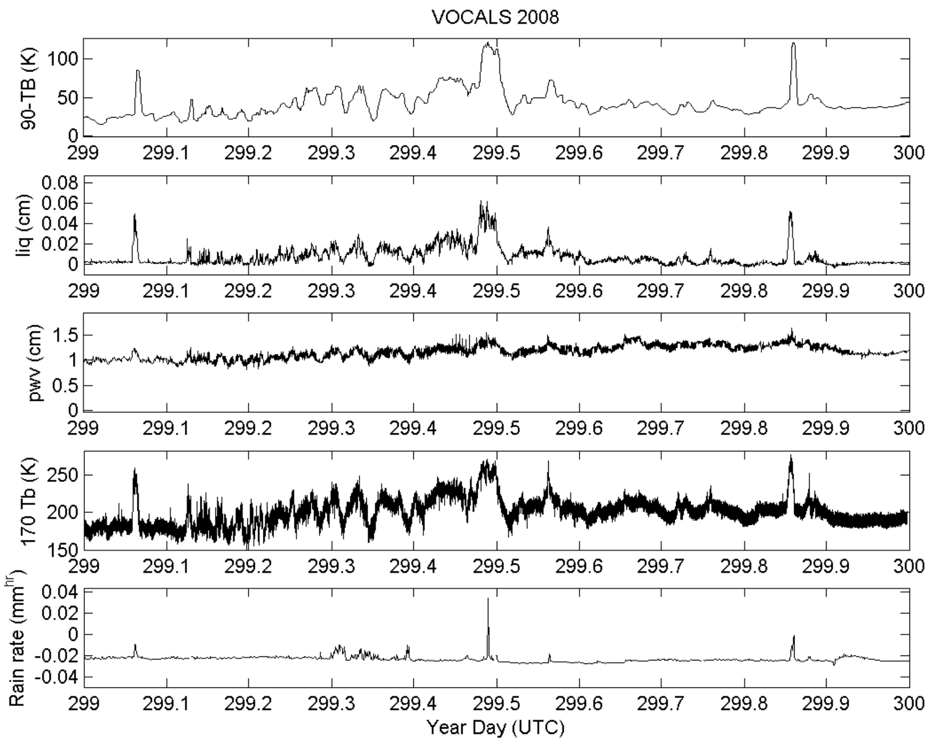

Figure 11. Time series from the microwave radiometers and optical rain gauge for day 299 (October 25, 2008). From top to bottom the panels are 90GHz TB, Mailbox LWP, Mailbox PWV, 170GHz TB, and optical rain gauge (mm/hr).

Figure 12. Cloud Imaging Probe and sonic anemometer mounted on O3 deck.

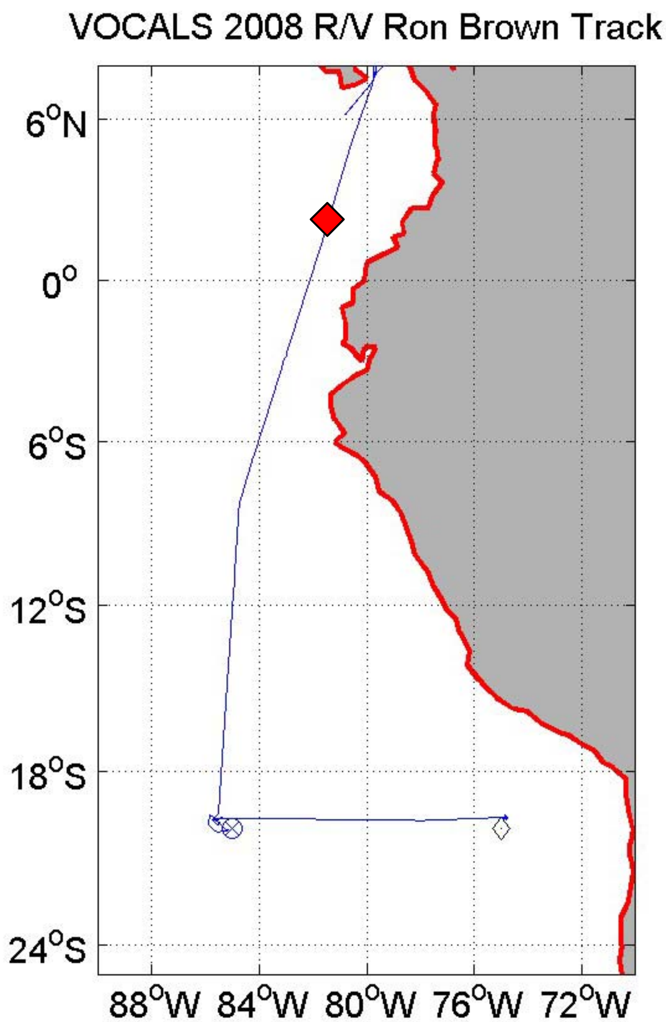

Figure 13a. Leg 1 cruise track for Ronald H. Brown from Panama City Panama to Arica, Chile. The x marks the WHOI buoy location; the diamond is the DART buoy. Start of formal sampling entering Ecuadorian waters (~2 ^{o} 8.6'N 81^{o}27.6'W red diamond).

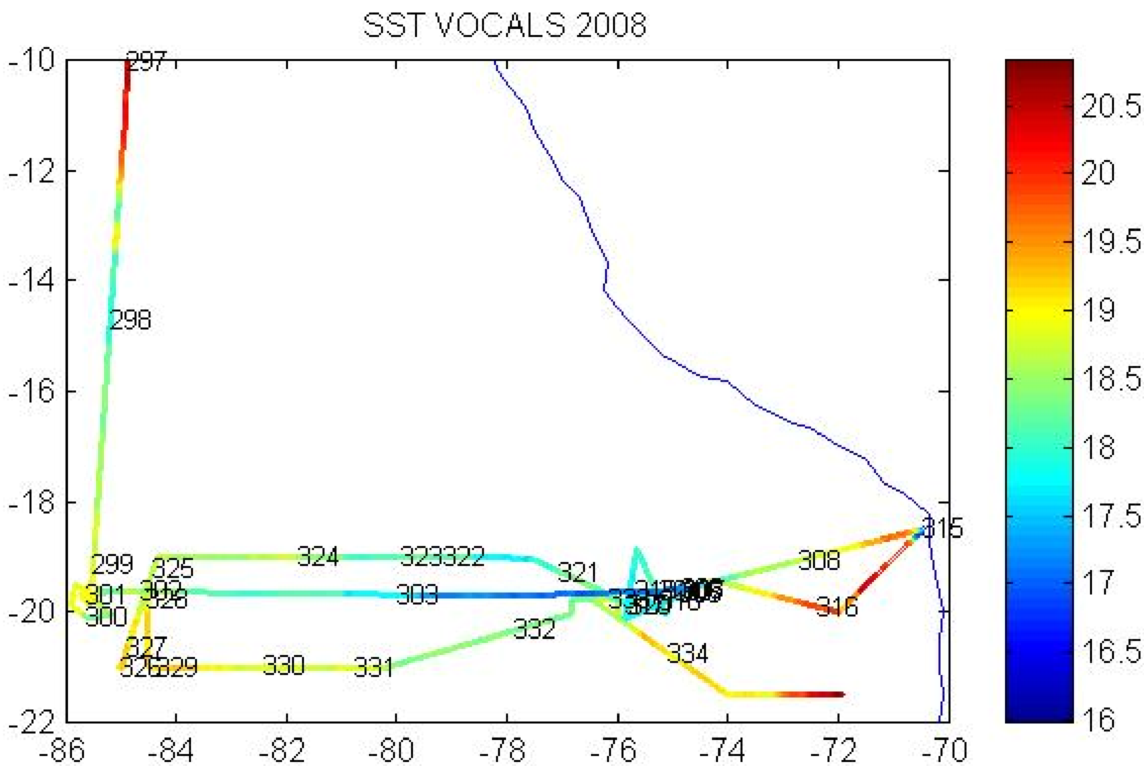

Figure 13b. Map of the VOCALS cruise track in the stratocumulus region with the color designating the SST (scale given on colorbar). The numbers on the track denote the Julian Day.

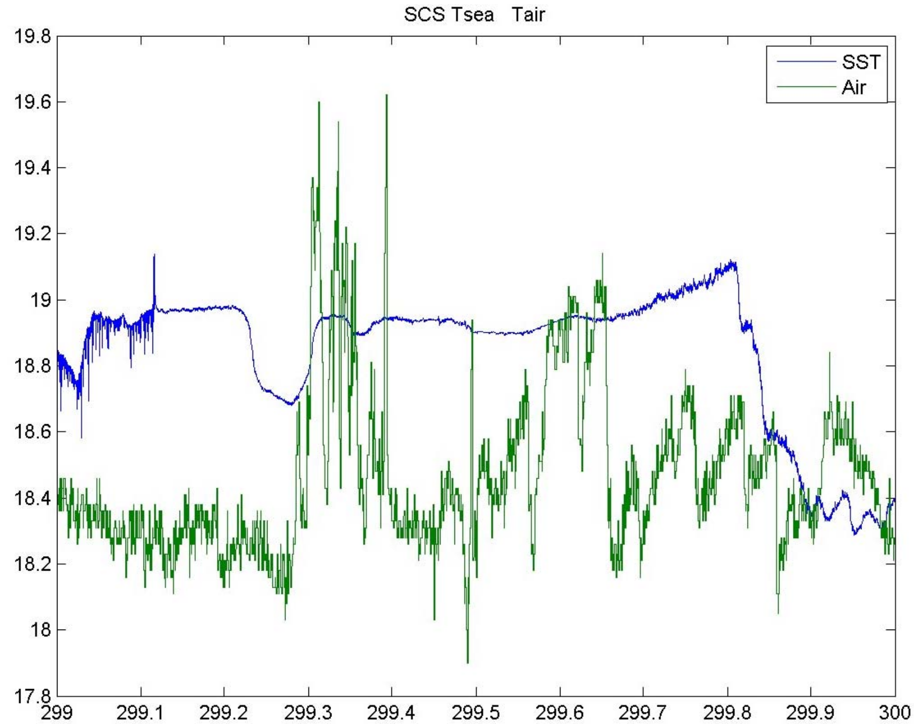

Figure 14. Time series of near-surface ocean temperature (blue) and 17-m air temperature (green).

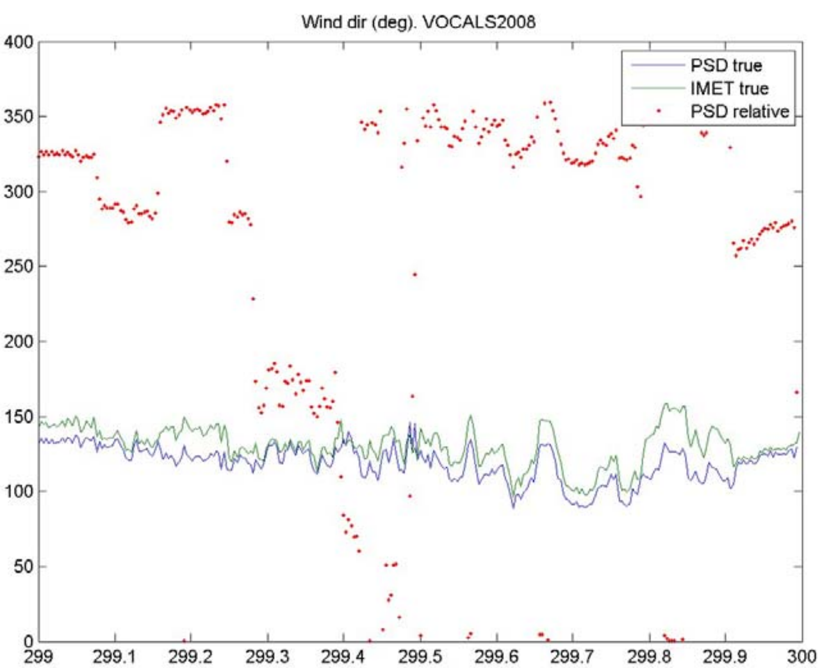

Figure 15. True wind directions from the PSD sonic anemometer (18 m) and IMET propvane (17 m). Red dots are ship relative winds from the jackstaff sonic. Winds from 0 degrees are head

on to the ship.

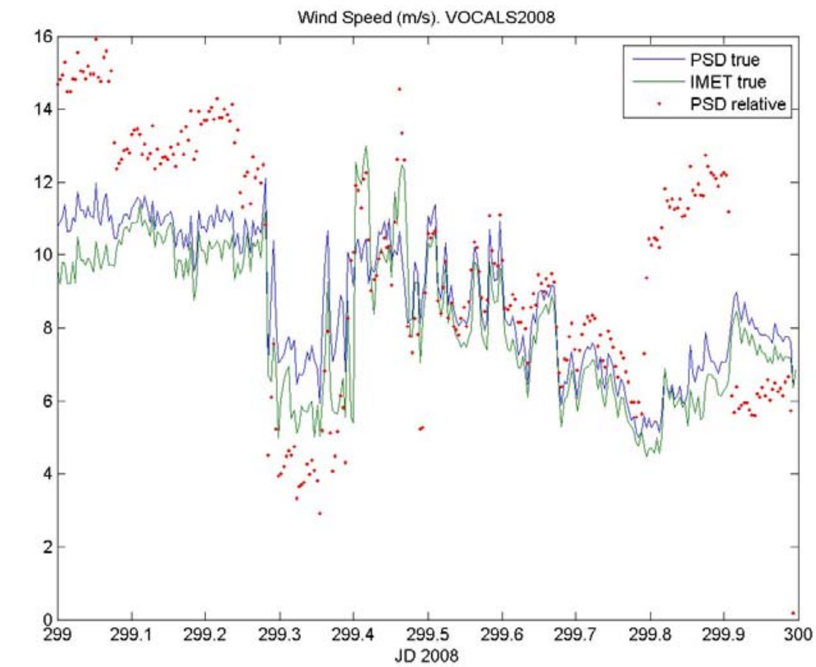

Figure 16. True wind speed from the PSD sonic anemometer (18 m) and the ship's propvane (15 m).

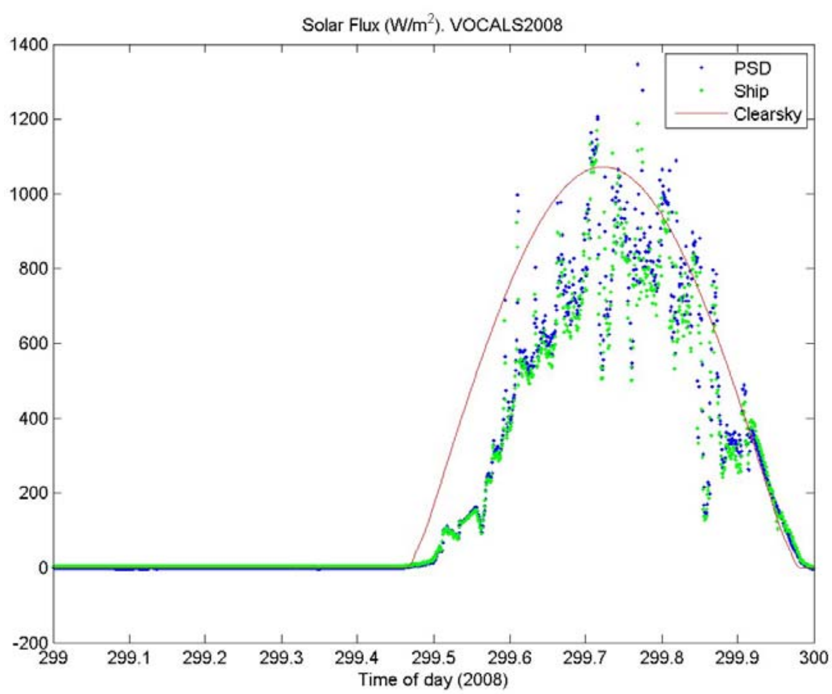

Figure 17. Time series of downward solar flux from PSD and ship Eppley sensors. The green

line is a model of the expected clear sky value.

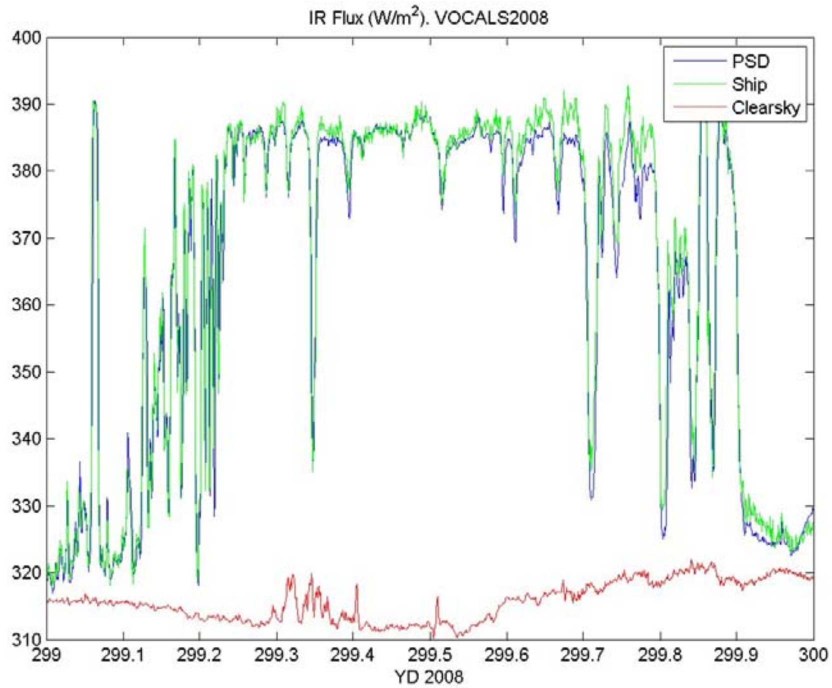

Figure 18. Time series of downward IR flux from PSD and ship Eppley sensors. The red line is a model of the expected clear sky value.

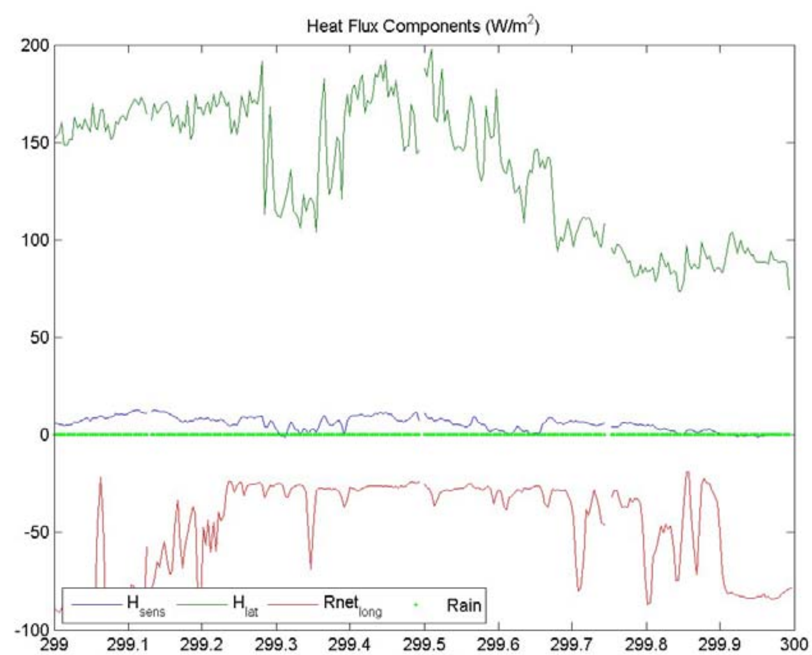

Figure 19. Time series of non-solar surface heat flux components.

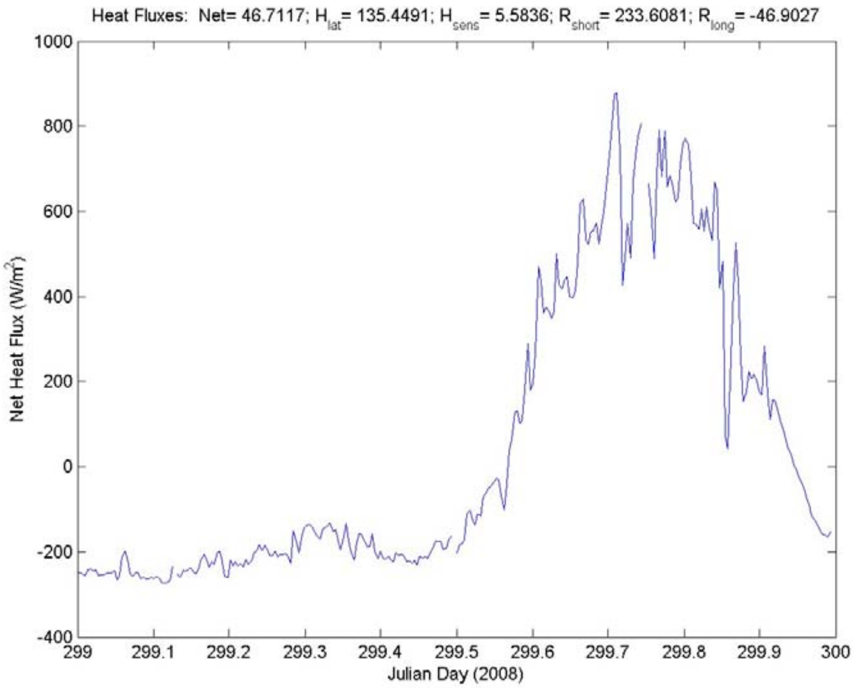

Figure 20. Time series of net heat flux to the ocean surface. The values at the top of the graph are the average for the day for each component of the flux.

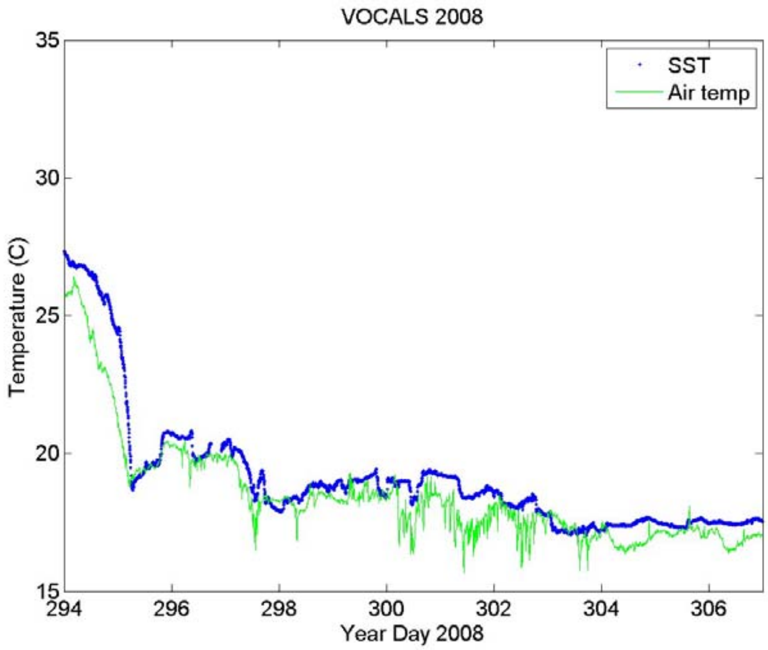

Figure 21a Leg 1 time series of near-surface ocean temperature (blue) and 15-m air temperature (green) for the 2008 RHB Stratus cruise.

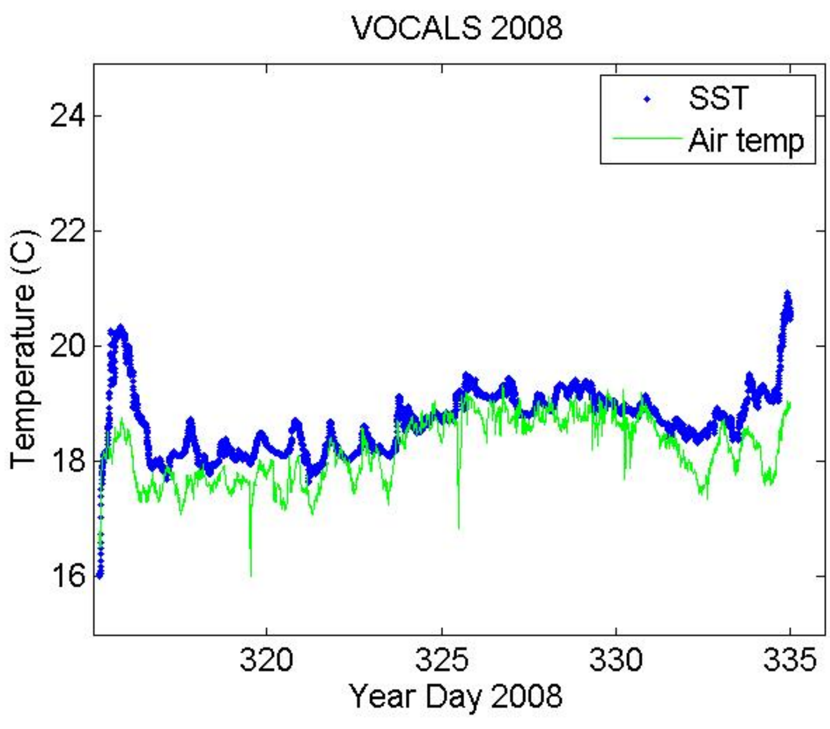

Figure 21b Leg 2 time series of near-surface ocean temperature (blue) and 15-m air temperature (green) for the 2008 RHB Stratus cruise

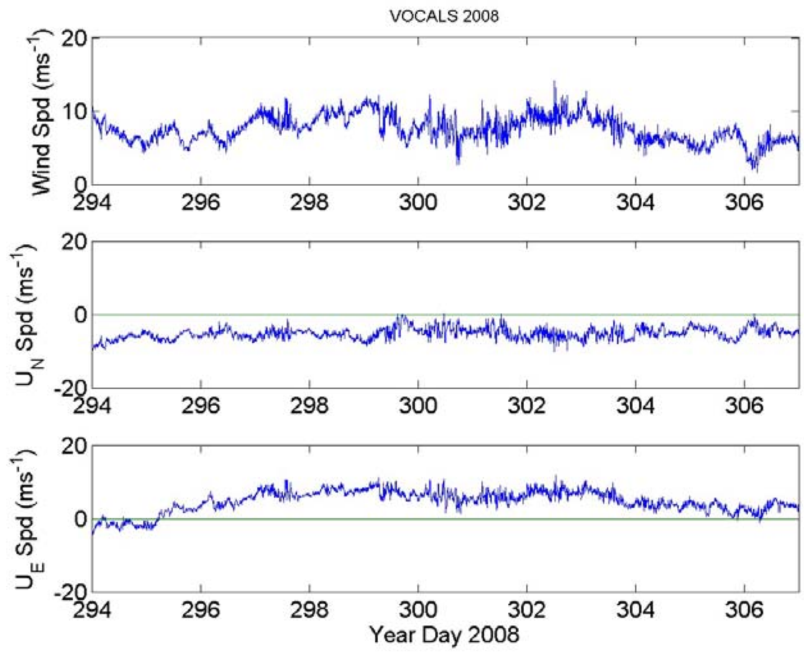

Figure 22a. Leg 1 time series of wind speed (upper panel), northerly component (middle panel), and easterly component (lower panel.

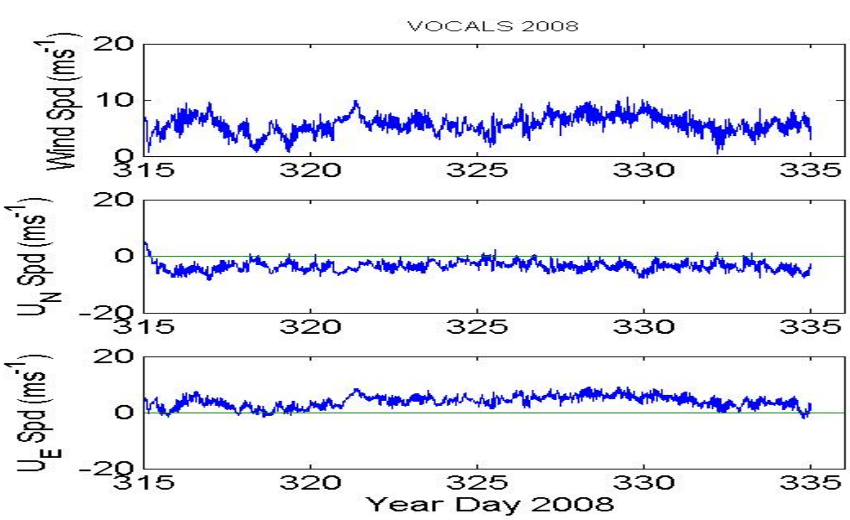

Figure 22b. Leg 2 time series of wind speed (upper panel), northerly component (middle panel), and easterly component (lower panel.

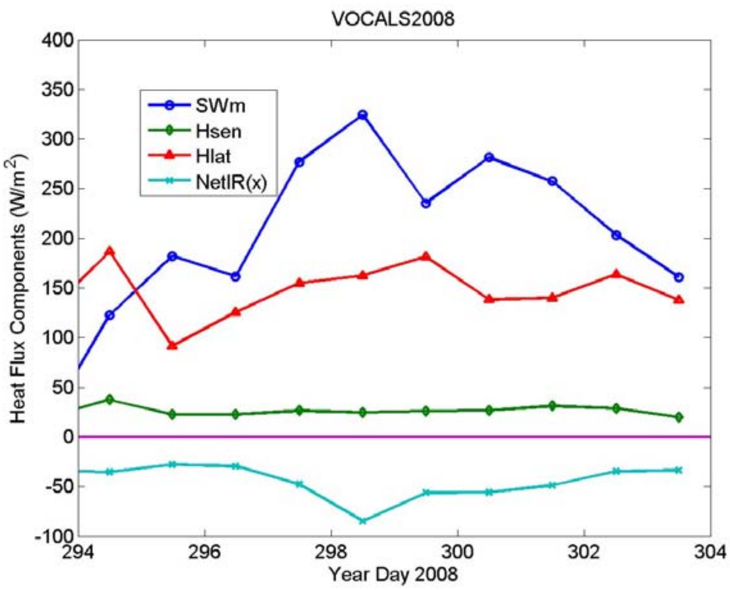

Figure 23a. Leg 1 time series of 24-hr average heat flux components: SWm-solar flux; Hlat-latent heat flux; Hsen-sensible heat flux; NetIR-net IR flux.

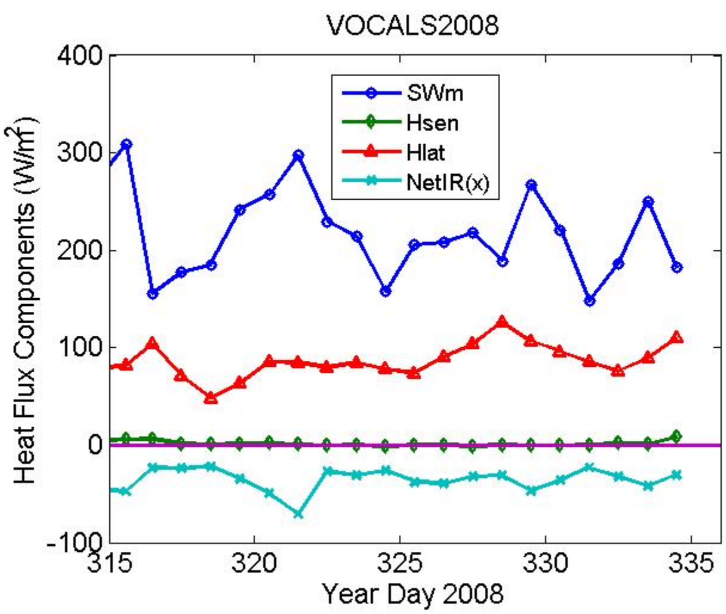

Figure 23a. Leg 1 time series of 24-hr average heat flux components: SWm-solar flux; Hlat-latent heat flux; Hsen-sensible heat flux; NetIR-net IR flux.

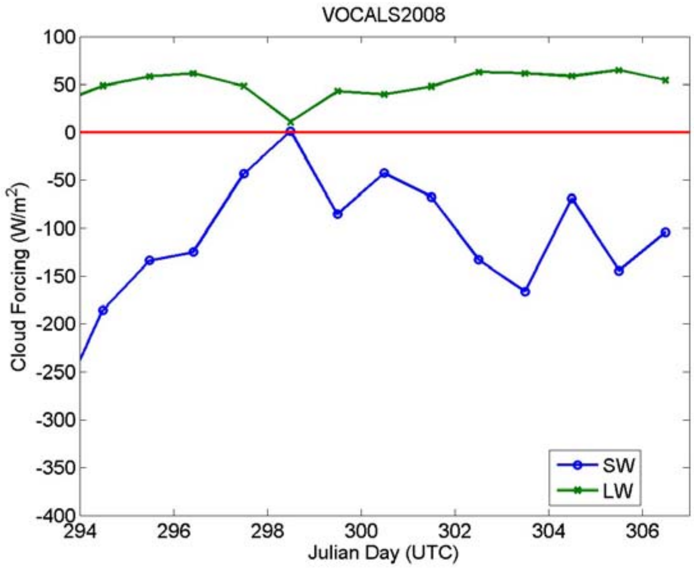

Figure 24a. Leg 1 time series of daily averaged radiative cloud forcing.

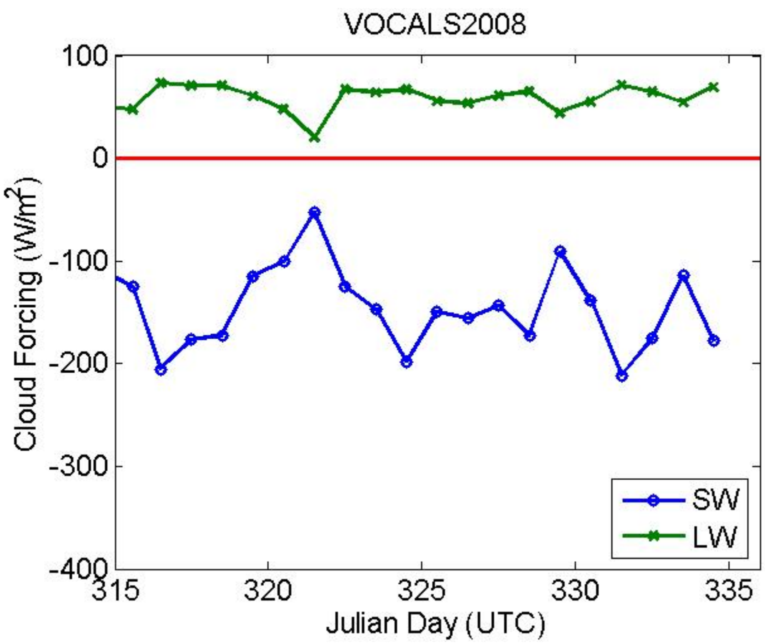

Figure 24b. Leg 2 time series of daily averaged radiative cloud forcing.

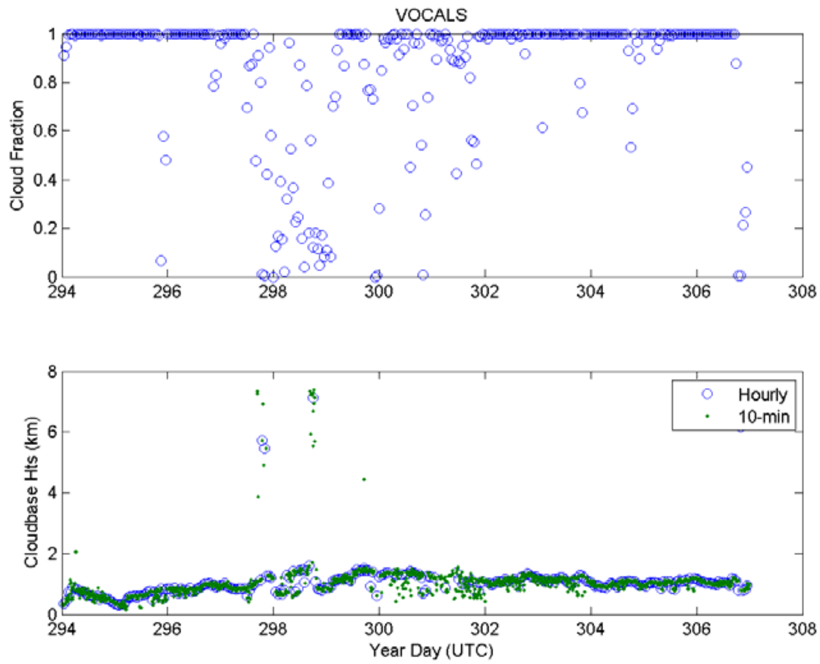

Figure 25a. Leg 1 time series of ceilometer cloud base bottom panel) and cloud fraction (top panel).

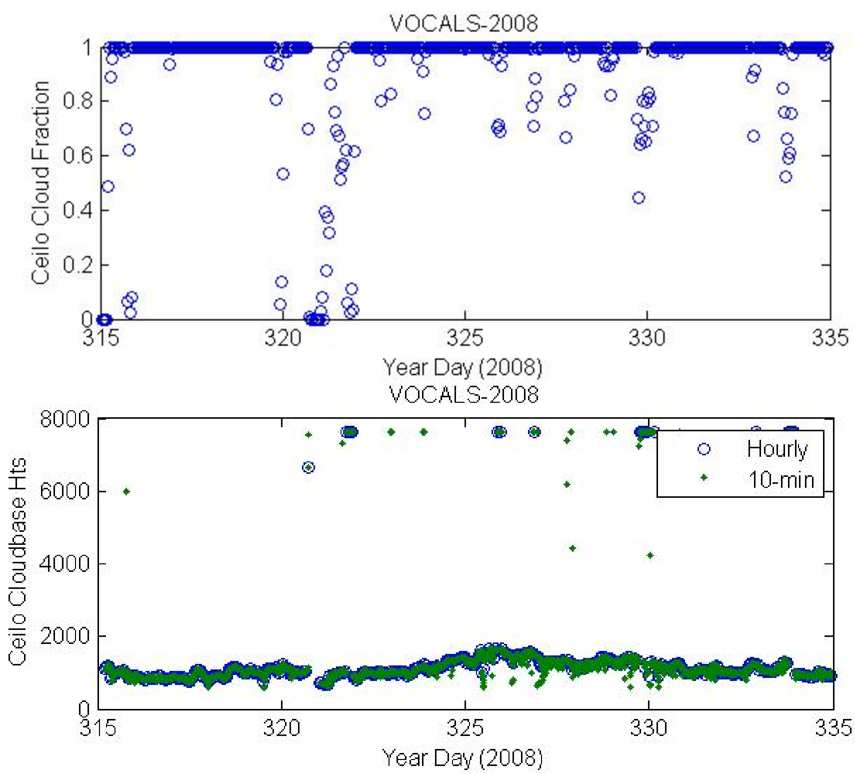

Figure 25b. Leg 2 time series of ceilometer cloud base bottom panel) and cloud fraction (top panel).

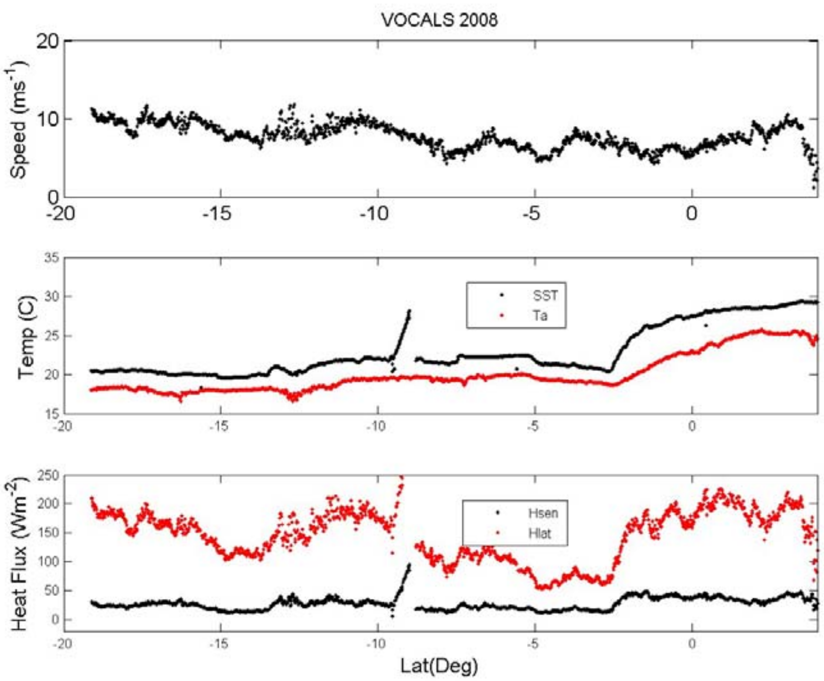

Figure 26. Selected variables from the N-S transect along 85 W. Upper panel is wind speed; the middle panel is sea surface and air temperatures; the lower panel shows sensible (Hsen) and latent (Hlat) heat fluxes.

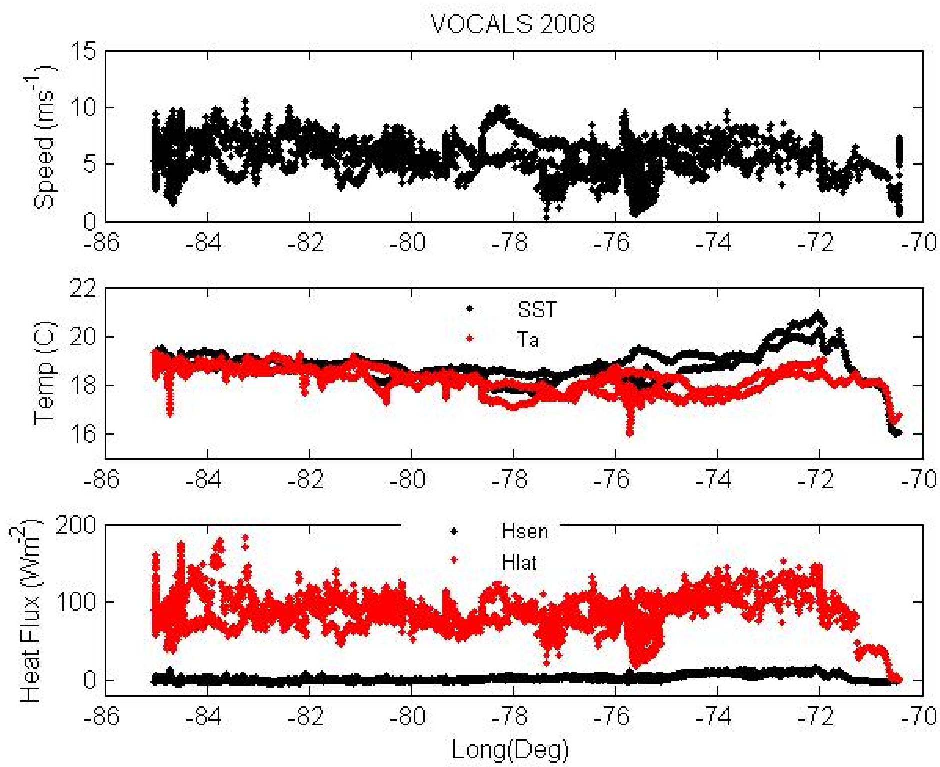

Figure 27. Same as Fig. 26, but for the W-E transect along 20 S from 85 W to 70 W.

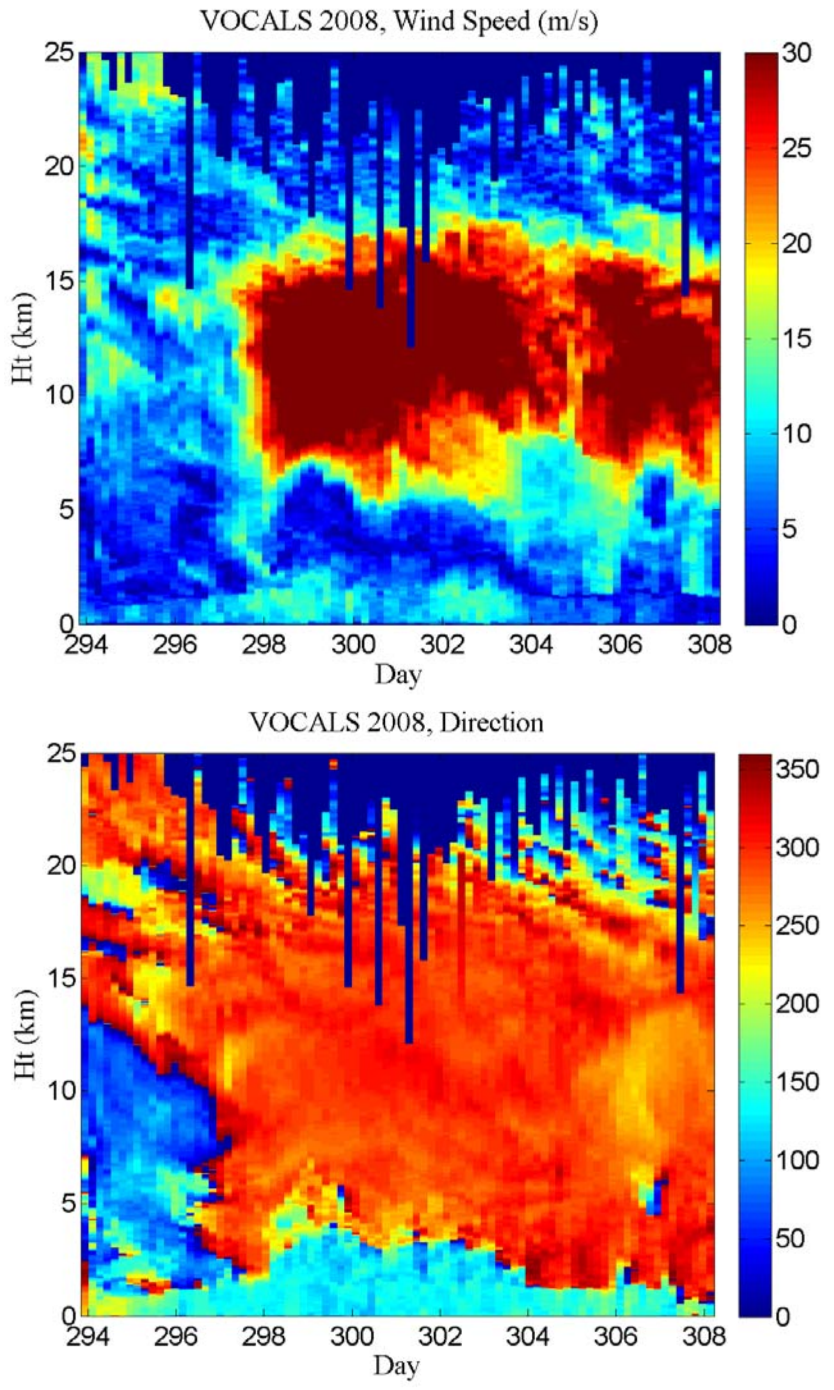

Figure 28. Time-height color contour plots from radiosondes launched during the 2008 Stratus cruise. The upper panel is wind speed and the lower panel is wind direction

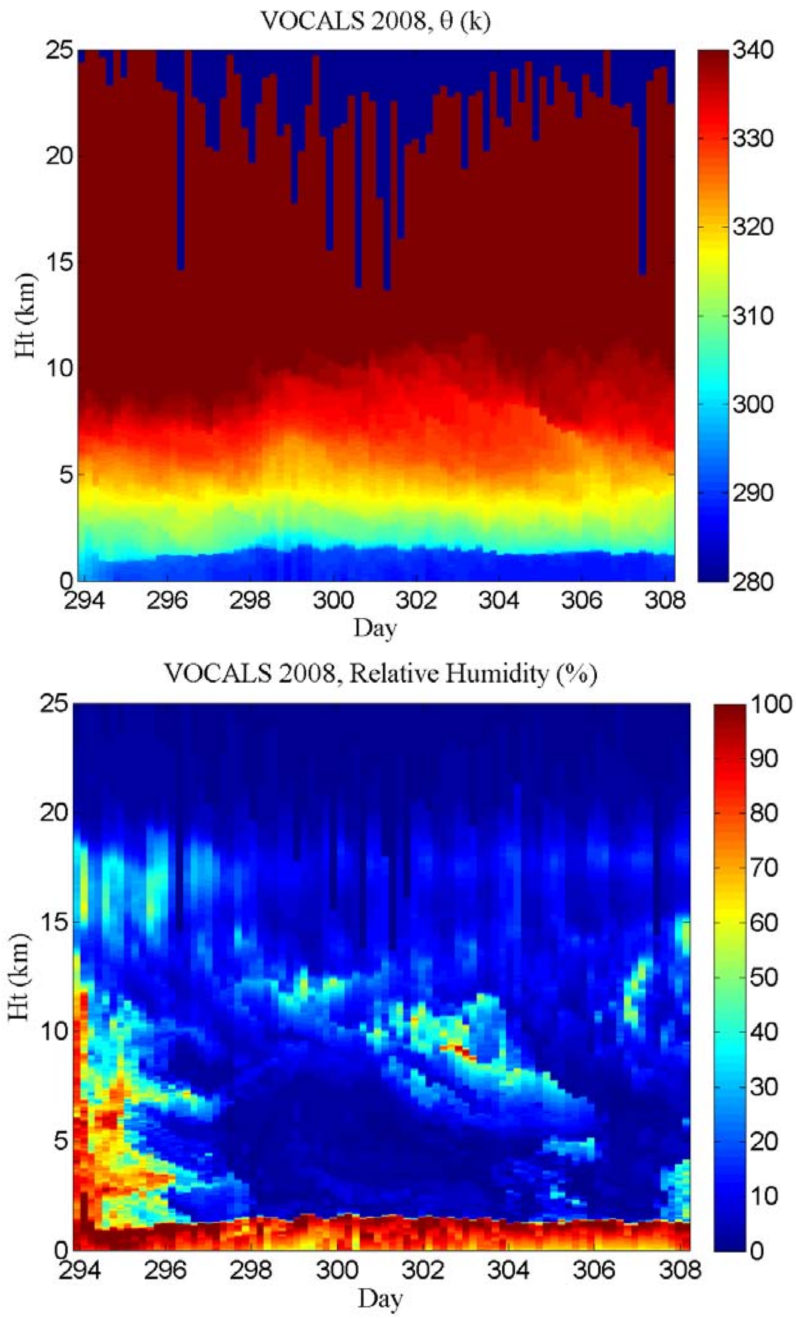

Figure 29. Time-height color contour plots from radiosondes launched during the 2008 stratus cruise. The upper panel is theta; the lower panel is relative humidity with respect to ice.

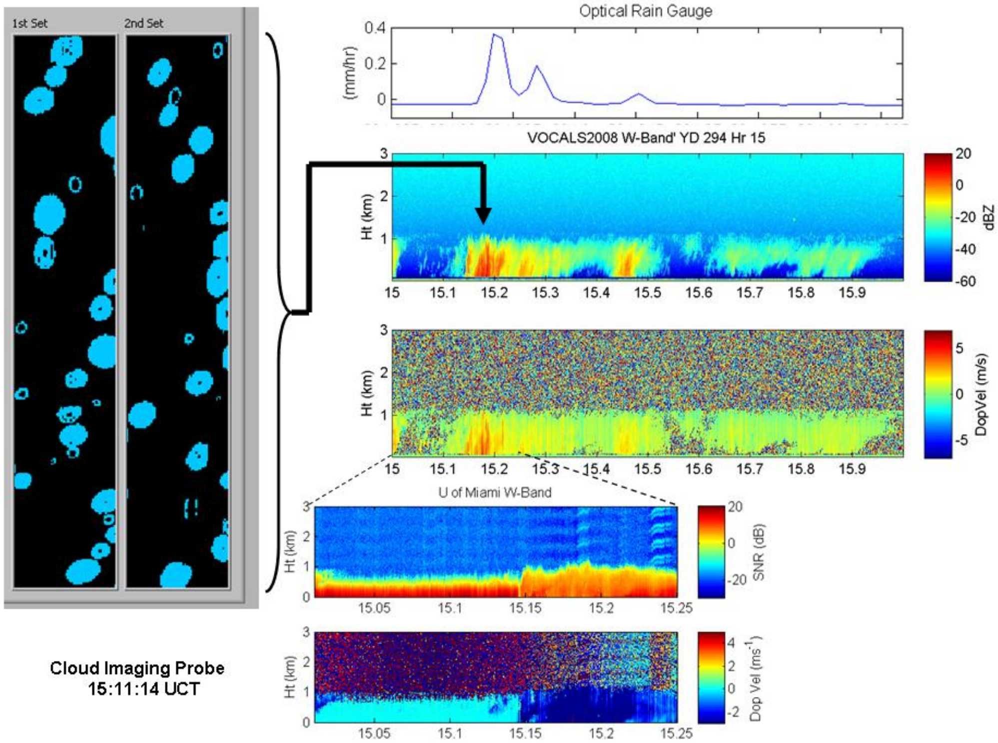

Figure 30. Inter-comparison of drizzle case on Oct 20, 2008. Left panel is Cloud Imaging Probe 2-D depiction of light drizzle, upper right panel is time series of rain rate (mm/hr) from the optical rain gauge, the middle right 2 panels are reflectivity and Doppler vertical velocity from the PSD W-band radar for 15-16 UTC and the lower right 2 panels are SNR and Doppler vertical velocity from the U of Miami W-band radar for 1500-1515 UTC.

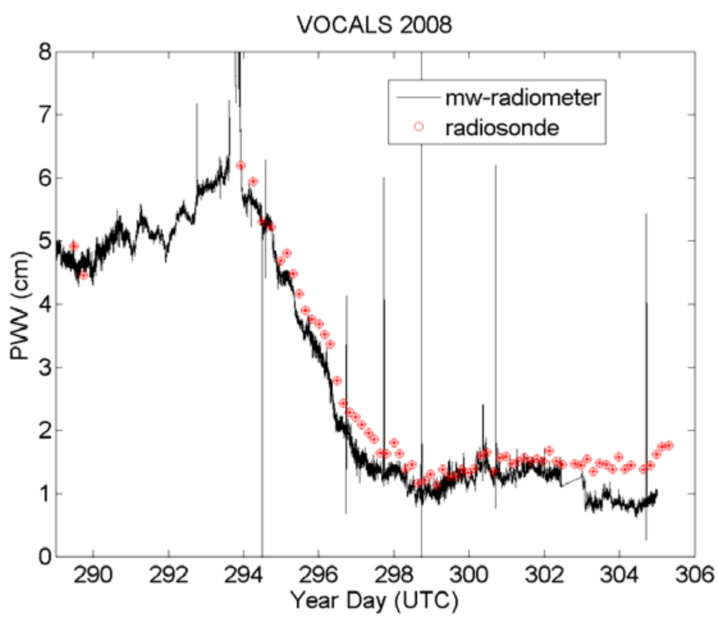

Figure 31. Time series of column integrated water vapor for the microwave radiometer and column and the radiosonde.