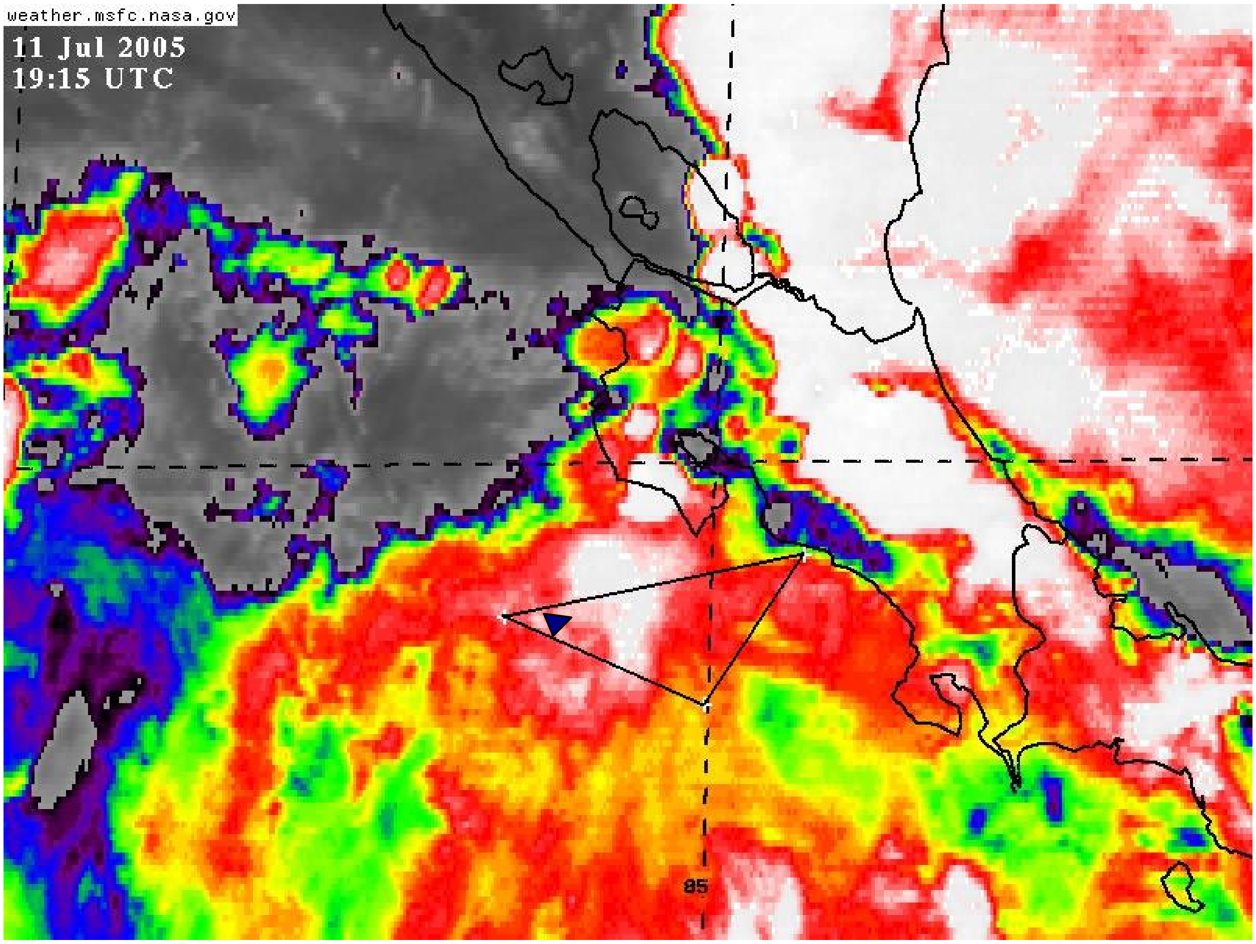
Aerosonde Mission Report:

NASA Tropical Cloud Systems and Processes (TCSP) Experiment Costa Rica, July 2005



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Distribution:
Aerosonde Internal, NASA TCSP Participants

Contents

Abbreviations

Term	Description
AC	Aircraft
Alt	Altitude
CR	Costa Rica
DGAC	Direccion General de Aviacion Civil
E SE	East South East
Ft	Feet
GPS	Global Positioning System
hPa	Hectapascal
Hr	Hour
Km	Kilometer
Lb	Pound
MCS	Mesoscale Convective System
Mi	Mile
Min	Minute
MHz	Megahertz (million cycles per second)
NASA	National Aeronautic and Space Administration
NOAA	Nation Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
SST	Sea Surface Temperature
TCSP	Tropical Cloud Systems and Processes
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency

1.0 Executive Summary

The NASA TCSP project was held July 1-30, 2005, in Costa Rica, with the intent of studying the processes associated with tropical waves passing over Central America to the Pacific where they eventually form tropical cyclones. The NASA ER2, NOAA P-3, and Aerosonde were to provide complimentary measurements in and around cloud systems associated with the waves.

Aerosonde operations were base out of Quepos, located on the Pacific Coast of Costa Rica. Despite many hurdles, the Aerosonde team successfully flew 8 flights for a total of 75 flight hours. The flights were designed to document the boundary layer both near shore and over the open ocean. Measurements of pressure, air temperature, humidity, and sea surface temperature were made during each flight. Flights consisted of soundings along track from 500ft up to 8600ft and varied in length from 8 hours to 18 hours. The weather experienced during the flights ranged from clear, benign conditions, to strong convective cells and heavy rain. The data obtained during these flights will provide a much need insight into boundary layer processes over the Tropical Pacific.

In addition to the successful data collection, this mission was the first mission Aerosonde and NASA have deployed to the field as a team under the Cooperative Agreement.

2.0 Aerosonde Overview

The Aerosonde is a small, long endurance unmanned aerial vehicle (UAV) and is operated globally by Aerosonde International, with companies in both the United States and Australia. It has been in operation since approximately 1995 and was the first UAV to cross the Atlantic Ocean. Aerosonde also holds the "all-comers" UAV endurance record of 32 hr and recently completed its 1000hr of flight in the Arctic

The aircraft has a 10ft wingspan and weighs approximately 30lb fully laden. It is launched from the top of a car or via a catapult launching system. The aircraft does a belly landing, allowing it to land on a variety of surfaces. The aircraft is a "pusher" with the propulsion in the back and is powered by a small single cylinder, 4 stroke, fuel injected engine. The engine uses premium unleaded petrol as fuel. The payload capacity of the aircraft is 5kg including fuel.

The Aerosonde system offers two modes of operation: field deployments and global operations. Specialized crews can be deployed to the field to operate aircraft locally under the direction of a principal investigator. In this mode, an Aerosonde crew works with a field program to provide all Aerosonde operations, including regulatory approvals and support services. In addition, Aerosonde has established a global aircraft operation, with a central command facility and aircraft operating from a distributed set of launch-recovery sites. This mode was successfully tested during operational trials for the Australian Bureau of Meteorology in early 1998. It became fully operational during missions for the Korean METRI in October 2001.

Aerosonde has flown in many locations and climates ranging from the desserts and tropics of Australia, Japan, Portugal, the Arctic, and South East Asia. Originally designed to fly tropical cyclone reconnaissance, the Aerosonde has since found a niche among many different applications, including atmospheric monitoring, aerial photography, and surveillance, to name a few. These applications have been made possible by the miniaturization of several instruments. Instruments include streaming video cameras, digital camera, infrared pyrometer, ozone sensor, hand held particle counter, and a sulfur dioxide sensor.

For more information regarding the Aerosonde system, visit http://www.aerosonde.com.

3.0 Mission Overview and Objectives

The Tropical Cloud Systems and Processes (TCSP) mission was a field research program sponsored by the National Aeronautics and Space Administration (NASA). NASA funded aircraft and surface instrumentation were used to study the dynamics and thermodynamics of precipitating cloud systems like mesoscale convective systems (MCS) and tropical cyclones. For more information regarding the specific goals of TCSP, visit http://tcsp.nsstc.nasa.gov/tcsp/.

The NASA ER-2, NOAA P-3, and Aerosonde aircraft provided complimentary measurements of all levels of the lower atmosphere during storm events as well as during clear sky events. Aerosonde was specifically tasked to provide basic meteorological and sea surface temperature (SST) measurements on a near continuous basis off the coast of Costa Rica. The main focus of the Aerosonde mission was to document boundary layer processes and how these are affected by the passage of tropical waves. The tropical oceanic regions are not well documented and the data obtained by the Aerosonde will help further the understanding of the basic processes occurring within the boundary layer.

The following report describes the Aerosonde operations in Costa Rica as part of TCSP, including a summary of the events leading up to field deployment, all flight and field activities, and an overview of the data collected.

4.0 Pre-Deployment

4.1 NASA Approvals

The flight request for Aerosonde participation in TCSP was approved on May 17, 2005. Because this mission was the first joint deployment with NASA under the cooperative agreement, several documents had to be written and other approvals had to occur before the team was sent to Costa Rica. These are summarized below.

Document/Meeting	Approval Date
NASA Project Plan	06/22/05
NASA Risk Analysis Report	06/23/05
NASA Ground Safety Plan	06/24/05
NASA Flight Safety Risk Analysis	06/23/05
NASA Flight Safety Plan	06/24/05
NASA Mission Operations and Safety Directorate (MOSD)	06/28/05
NASA Mission Readiness Review	06/23/05
NASA Permission to Proceed	06/29/05
Diplomatic Clearances – Costa Rica	06/26/05

4.2 Site Survey

A site survey was conducted by Brenda Mulac and Peter Bale of the proposed operations area in Costa Rica on May 30-June 2, 2005. While in San Jose, CR, a meeting with the Direccion General Aviacion Civil (DGAC), the Costa Rican FAA equivalent was held to determine the airspace approvals necessary. The site survey crew flew down to Quepos on May 31 and surveyed the airport grounds as well as potential workshop options. A hotel was identified near the airport for crew accommodations. The town was assessed as adequate in terms of available stores, restaurants, banks, etc. The hospital was located near the airport for easy access in case of emergencies. Inquiries of the air traffic in and around the airport resulted in the decision that the La Managua/Quepos airstrip was suitable for operations. A building on the airport grounds was secured for use as a workshop facility. The site survey crew flew back to San Jose June 1, and back to the US on June 2.

4.3 Packing and Equipment Shipment

The equipment and aircraft were to be flown from NASA Dryden to San Jose, Costa Rica, on an Air Force C-5 transport aircraft on June 22. Loading of the equipment was to commence June 21; all equipment was required to be at Dryden by June 20. Packing commenced at Wallops June 13 and was completed June 16. The NASA shipping department expedited the shipping process so the equipment would arrive the morning of June 20.

5.0 Overview of Field Operations

The operation required 5 Aerosonde personal, a NASA mission manager, and an interpreter (see Table below). The Aerosonde personal were deployed to the field June 27, 2005, followed by the NASA mission manager on June 30. Set up of the workshop area, local command center, and the launch and recovery site commenced June 29, 2005.

Team Member	Affiliation	Role
Brenda Mulac	Aerosonde North America	Mission Scientist/Team Leader
Nick Logan	Aerosonde Proprietary Limited	Co-Team Leader/ Ground Ops
Ryan Vu	Aerosonde North America	Manual Pilot
David Smith	Aerosonde North America	Technician
Jason Roadman	Intern, Aerosonde North America	Observer
David Easmunt	NASA Wallops Flight Facility	NASA Mission Manager
Fabian Garcia	Pilot, Costa Rica Police	Interpreter

5.1 Aircraft and Instruments

Three Mk3.0 aircraft were available for flights during TCSP: AC 126, AC 129, and AC 137. The aircraft configuration for all flights was the basic met package of two under-wing Vaisala RS902 sondes. A Heitronics KT11.k6 infrared pyrometer for sea surface temperature measurement and an iridium phone were added as additional payload.

5.2 Airspace and Area of Operations

Airspace usage was arranged with the Direccion General de Aviacion Civil (DGAC) of Costa Rica. It was agreed at a meeting with the DGAC during the site survey, that Aerosonde would define a corridor from the airstrip to 1nm offshore in which an altitude of 1500ft would be maintained. A blanket NOTAM was issued daily during the mission by the DGAC to alert aviators of Aerosonde's operations location and corridor at the La Ligia airport. Figure 1 shows the corridor and surrounding operations area around the airport.

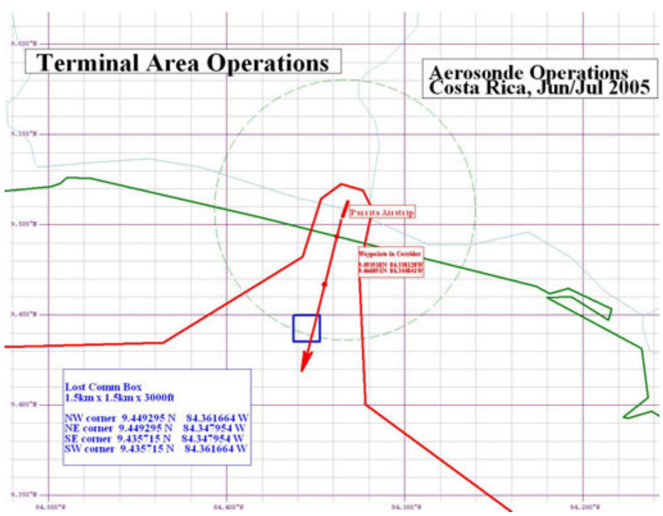


Figure 1. Corridor and operations boundary around La Liga airport.

Figure 2 shows the overall area of operations Aerosonde had available for flights. With the exception of the area around the corridor, the operations area began 5nm off the coast and avoided the Panamanian ADIZ. Flights were limited to a ceiling of 9000ft and a floor of 500ft.

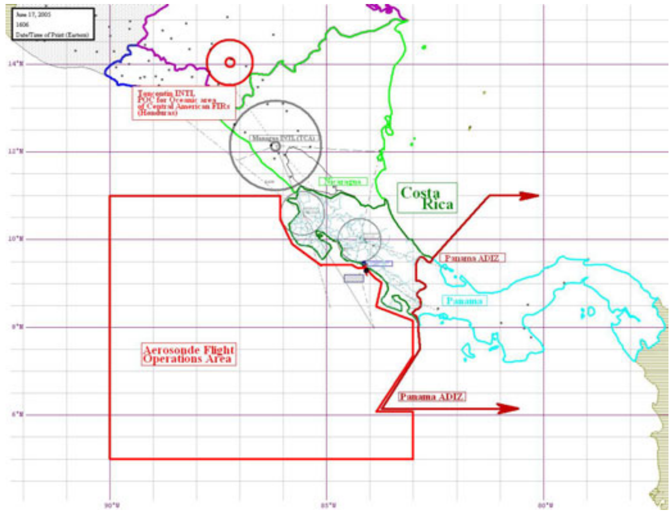


Figure 2. Aerosonde area of flight operations

5.3 Workshop

A building next to the La Managua airstrip was used as the workshop for the operation (Figure 3). The building provided a secure space for maintenance and preflight procedures, and had running water, a bathroom, and power.

Figure 3. The Aerosonde workshop, located at La Managua Airport.

5.4 Local Command Center

The Hotel Casa Grande, located just 300m from the La Managua airport, was set up as the local command center. An iridium antenna attached to a telescoping extension pole was secured to the outside of the team's villa. An iridium ground phone and a laptop computer for running ground base were set up on a table within the villa.

5.5 Launch and Recovery Site

Initially, the launch and recovery site was to be the La Managua Airport in Quepos. However, upon arrival, it became apparent that the airfield was much busier than originally thought. Commercial traffic was frequent and a large number of charter aircraft flew in and out of the airport. It was determined that the airfield was unsuitable for operations and a search for a new location was undertaken.

The La Ligia airstrip was identified and chosen as the new location for the launch and recovery site (Figure 4). Located near Parrita, approximately 25km north of Quepos, the dirt airstrip is privately owned and surrounded by rice fields. Air traffic consisted of a crop duster based at the airstrip. Antennas for long range UHF communications were set up at the field.

Figure 4. La Ligia airstrip

Nick Logan, Ryan Vu, David Smith, and Jason Roadman made up the launch and recovery team. The ground command center was housed in a 15-passenger van and a small 4-wheel drive vehicle was used as the launch vehicle.

Figure 5. Ground command center and launch vehicle

5.6 Communications

Because of the surrounding terrain and distances flown, the primary mode used for aircraft communications was Iridium satellite communications. UHF communications (413.475 MHz) were used while the aircraft was launching and under control from the ground command center.

6.0 Daily Summary of Flight Operations

A total of 75 flight hours were flown during 8 flights. The flights are summarized in the table below. All flights took measurements of air temperature, pressure, relative humidity, and sea surface temperature (SST). A summary of the daily operations as well as flight details for each specific flight is given in the rest of the section. Graphs of the science data from each flight have been provided Section 6.

Flight #	Date	Aircraft	Launch UTC (hh:mm)	Landing UTC (hh:mm)	Duration	Objectives
1	2005-07-05	126	21:03	22:19	1h 16min	Test Flight
2	2005-07-07	126	13:19	21:10	7h 51min	Soundings offshore
3	2005-07-10	126	12:55	20:48	7h 53 min	Soundings from 150-1500m along track
4	2005-07-11	129	13:40	21:37	7h 57 min	Soundings from 150-1500m along track
5	2005-07-13	126	13:00	20:29	7h 29 min	Soundings from 150-500m along track
6	2005-07-14	129	13:20	21:04	8h 29 min	Soundings from 150-1500m along track
7	2005-07-17	129	21:15	13:36	16 h 21 min	Soundings from 150-2600m along track
8	2005-07-21	126	20:40	14:10	17 h 30 min	Soundings from 150-2600m along track
				Total	**74h 46min**	

6.1 June 27 – July 4

The team arrived in San Jose, CR, on June 27 and drove to Quepos on the 28th. Set-up of the workshop and assembly of the aircraft commenced the following day. All aircraft were ground tested, including the iridium communications, and prepared for flight. The local command center was setup at the hotel. After determining the La Managua airstrip was unsuitable for Aerosonde flights, the search for a new airstrip commenced. The grass strip originally chosen for observing aircraft in the corridor to the ocean was found and determined unsuitable because of the large number of obstacles (trees, hills, etc). After further searching, the La Ligia airstrip was located near Parrita, approximately 25km to the north of the La Managua airstrip at Quepos. Surrounded by rice fields and only 1mi from the ocean, the La Ligia airstrip was privately owned and the only traffic was a crop duster aircraft. Permission to use the airstrip was obtained and the antennas were setup.

6.2 July 5

Aircraft 126 was launched at 21:03UTC for a 1hr 16min shake down flight over the airfield. All systems checked out. No science data was collected during this flight

6.3 July 6

The flight on the 5th brought to light some issues with the local ground command center setup. These issues were identified and addressed during the day. AC126 was prepared for the next day's science flight.

6.4 July 7

AC126 was launched at 13:19UTC carrying sondes and the KT11.k6. After circling overhead the runway for a few minutes, the aircraft was sent to the wait box located 3mi offshore (see Figure 1). Once in the wait box, control was handed off to the local command center. A straight line segment was flown from the wait box to a point approximately 200km to the E-SE at an altitude of 500ft. Soundings were performed at 70km and 200km from shore and are summarized below.

Sounding #	Distance from shore	Altitude
1	70km	500 – 6500ft
2	200km	500 – 4600ft

3	70km	500 – 5000ft

After the final sounding, the aircraft was flown back to the wait box, control was handed over to the remote control center and landed at 21:10UTC for a total flight time of 7hr 51min.

6.5 July 8-9

A test flight of AC129 was to be flown on July 8 from the La Ligia airstrip; unfortunately problems were encountered and the flight was scrubbed. July 9 was a hard down day for the crew.

6.6 July 10

AC126 was launched at 12:55UTC. Control was passed at the wait box, and the aircraft was directed to begin the flight plan. A triangle pattern was flown clockwise along which soundings were made from 500ft to 5000ft in a porpoising fashion (Figure 6). The total distance of the flight plan was 507km.

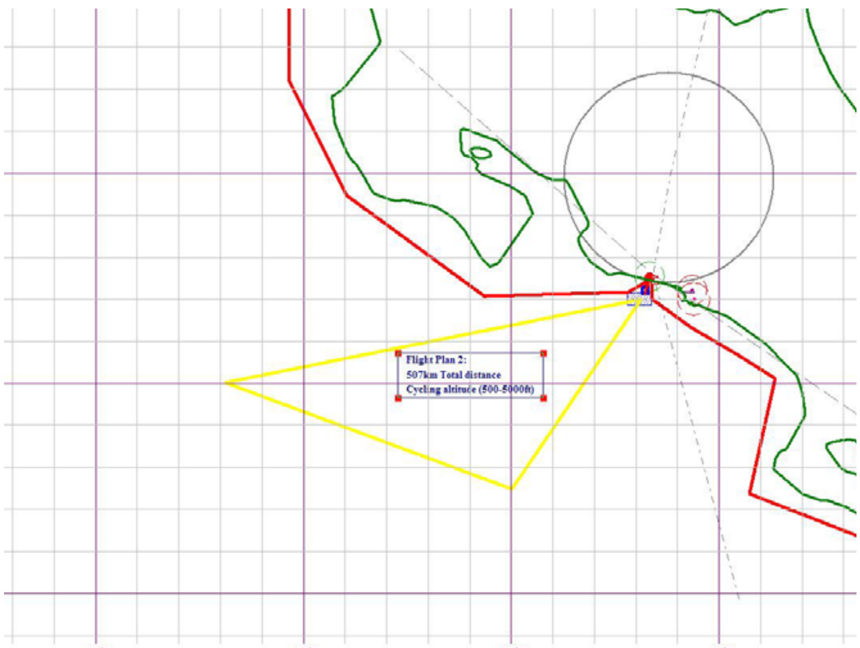


Figure 6. The triangle flight pattern

Upon completion of the flight plan, the aircraft was sent back to the wait box where control was given back to the local ground command center and subsequently landed at 20:48UTC, for a total flight time of 7hr 53min.

Synoptically, a tropical wave was approaching the Caribbean side of the country and forecasted to push through the country and out over the Pacific over the next two or three days. Daily flights with the Aerosonde during that period of before, during, and after the tropical wave passage would provide a useful dataset detailing the changes in boundary layer processes due to the tropical wave.

6.7 July 11

A combination test flight and science flight was flown on July 11. AC129 was launched at 13:40UTC and directed to the wait box offshore. The next hour was spent putting the aircraft through a series of exercises. Once the ground controller was satisfied with the aircraft performance, control was handed to the local command center on Iridium, and the aircraft was directed to begin the triangle flight pattern.

The flight pattern took the aircraft into and around a large mesoscale convective system (MCS). Satellite images of the system during different times of the flight are shown in Figure 7 Heavy rain was experienced during parts of the flight. Because of the heavy rain, the right sonde humidity sensor failed at approximately 21:12UTC, resulting in erroneous readings.

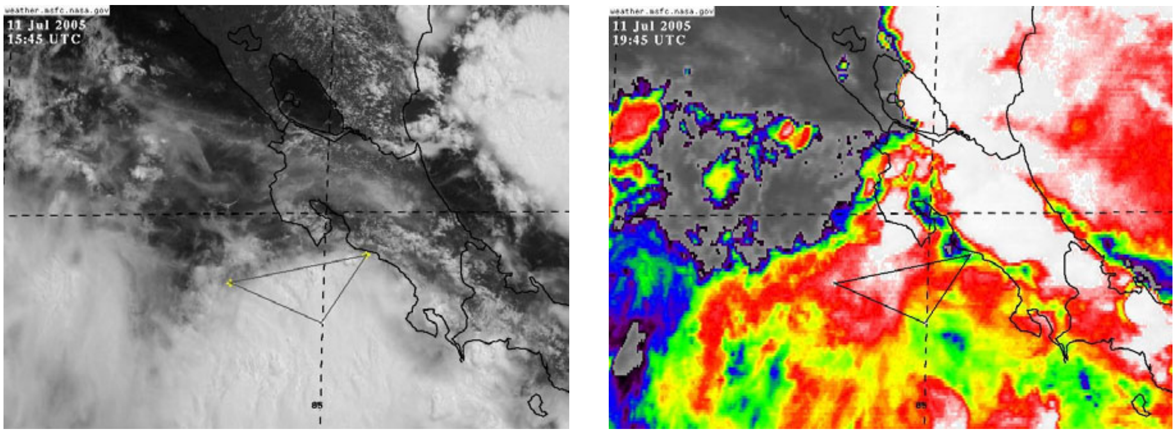


Figure 7. Satellite images of MCS during the flight.

Once AC129 completed the triangle pattern, it was sent to the wait box, where control was handed back to the local ground command center. The aircraft was safely landed at 21:37UTC, giving a flight length of 7hr 57min.

From a science perspective, this was a very exciting flight as it provided data on the boundary layer processes occurring within a tropical convective system. It also provides a good comparison to the flight from July 10, during which the flight region was under mostly clear skies.

6.8 July 12

AC126 was to be launched on July 12 to continue with the daily flights of the triangle flight pattern. Unfortunately, a mechanical problem arose and the flight was cancelled. The rest of the day was spent troubleshooting and fixing the aircraft. By the end of the day, AC126 was fixed, pre-flighted and ready for another flight.

6.9 July 13

Launch of AC126 occurred at 13:00UTC. Control was passed to the local command center and the aircraft began its flight around the triangle. Soundings along track were only flown to an altitude of 1500ft because the engine was reading excessively high cylinder head temperatures during climbs. Initially a small convective cell was encountered at the beginning of the flight but dissipated and quickly moved to the west of the flight track (Figure 8).

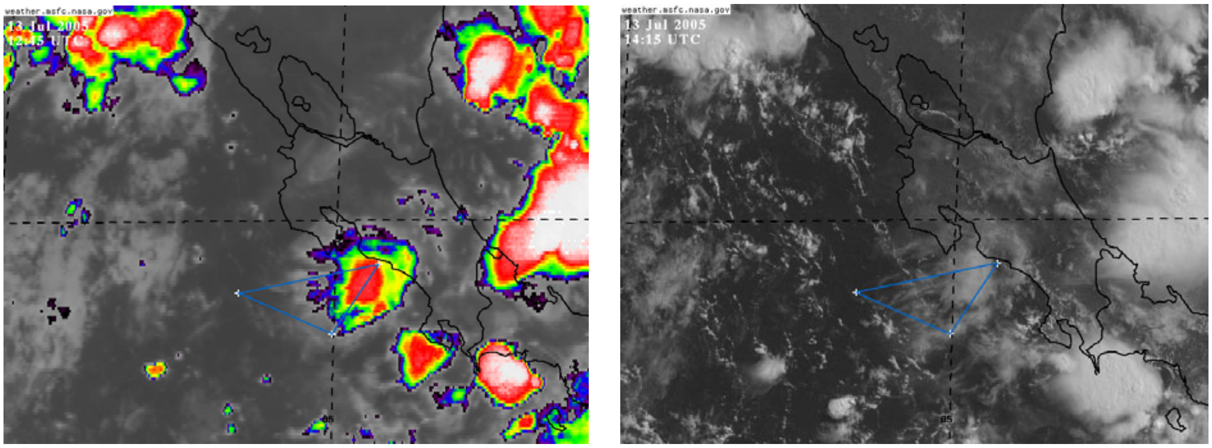


Figure 8. Satellite images showing weather conditions during first couple of hours of flight.

The remainder of the flight was uneventful, as the flight region was again under partly cloudy skies, providing anther good set of data for comparison to the previous two flights. Upon completion of the flight pattern, the local ground command center took back control and landed the aircraft at 21:29UTC for a flight time of 7hr 29min.

6.10 July 14

With some offshore thunderstorms lingering in the area, AC129 was launched at 13:20UTC and directed to the wait box where control was passed the local command center. Flying the triangle pattern again (Figure 6), the bulk of the flight was fairly calm passed the storms just offshore. Approximately 1.5hr from the end of the triangle pattern, the aircraft climbed into and descended out of a small convective cell. Heavy turbulence and rain were encountered while in the storm. The aircraft flew through the cell without issue and the rest of the flight was uneventful. After reaching the wait box, control was handed back to the local ground commander and the aircraft was landed at 21:04UTC. Total flight time was 8hr 29min.

6.11 July 15-16

The TCSP science team requested a change in flight pattern from the daily triangle of the previous four flights to a box type flight that would take approximately 18hr. In order to facilitate the request, July 15 was used to perform maintenance on the aircraft and prepare for the overnight flights. July 16 was a crew rest day.

6.12 July 17-18

For the first overnight flight, AC129 was launched at 21:05UTC and directed to the wait box. Control was passed to the local command center under Iridium, and the aircraft was directed to the first leg of the flight pattern (Figure 9).

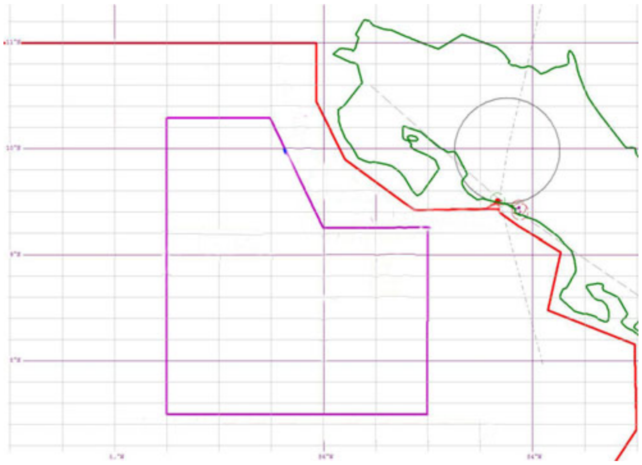


Figure 9. The flight pattern flown for the 18hr flights.

The total distance of the flight plan was 1200km and soundings were made along track from 500ft to 8500ft every 75km. The pattern was flown counterclockwise, beginning at the corner closest to shore. Flight altitude between soundings was maintained at 500ft. It was hoped that the sounding height would sufficient to identify the altitude at which low level jets form during the passage of tropical waves.

Because of the length of the flight, control of the aircraft was handed to a crew in Australia between 02:00UTC and 10:00UTC in order to allow the Costa Rica crew to rest. During the latter half of this period, heavy convective weather was encountered. At the time of the handoff of control back to the Costa Rica crew, the aircraft was being tossed about by very heavy turbulence and rain – airspeed fluctuations from $14ms^{-1}$ to $40ms^{-1}$ were experience within a period of a few seconds. Fortunately the aircraft was able to descend out of the worst of the weather without issue. Control was handed to the Costa Rica crew and the rest of the flight was fairly calm. Figure 10 shows a satellite image of some of the weather experienced.

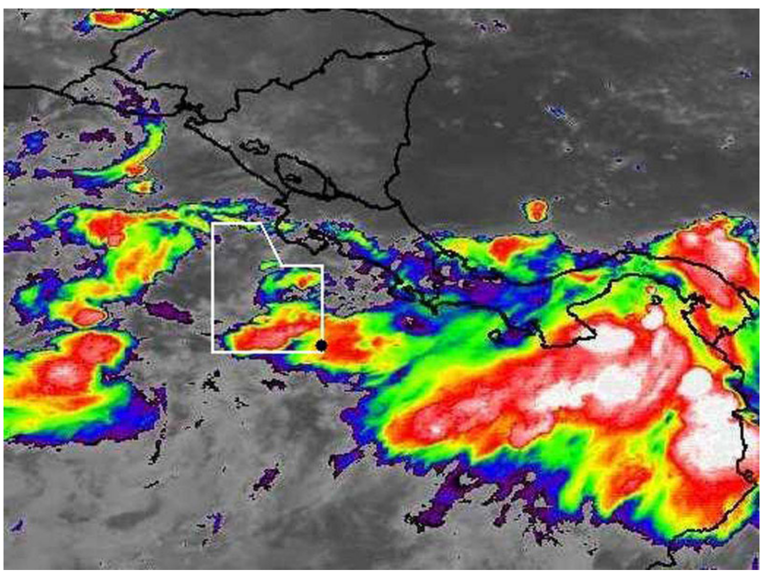


Figure 10. Satellite image of weather experienced during July 17-18 flight. Black dot shows location of aircraft at time of image.

Upon completion of the flight plan, the aircraft was directed to the wait box. While heading back to the wait box, the aircraft began to experience intermittent GPS failures. Control was quickly handed over to the ground command center and the aircraft was safely landed with out incident at 13:36UTC, July 18. Total flight time was 16hr 21min with 8 soundings completed during the flight.

6.13 July 19

Another overnight was planned for today. Unfortunately a test of the iridium connection failed during the pre-launch checkout and the flight had to be cancelled. It was later discovered that the Iridium network was experiencing problems and was thus not related to the aircraft and hardware.

6.14 July 20-21

With the Iridium network back online, AC126 was launched at 20:40UTC and control was passed to the local command center once the aircraft was established in the wait box. The aircraft was directed to begin the flight pattern as flown on July 17 (Figure 9). Soundings were spaced approximately 75km as before. The crew in Australia took control at 02:00UTC while the Costa Rica crew rested. Control was returned to the Costa Rica crew at 10:00UTC. Unlike the previous flight, the weather was very benign. The flight plan completed, the aircraft was directed to the wait box where the local ground command center took control. The aircraft was landed at 14:10UTC July 21, for a total flight time of 17hr 20min.

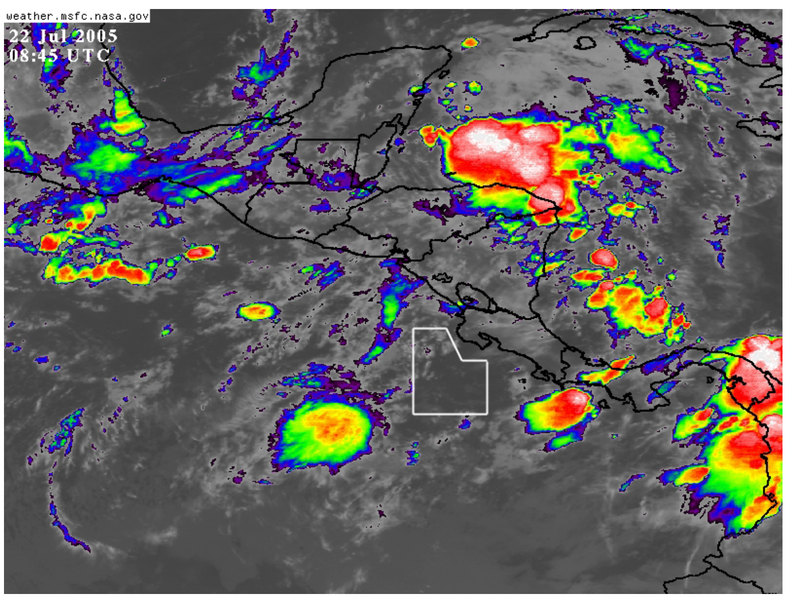


Figure 12. Satellite image from the July 20 flight

A total of 8 soundings were performed during the flight. The data collected during the flight on July 20 will provide a good contrast to that of the previous flight because of the calm weather conditions.

6.15 July 22-26

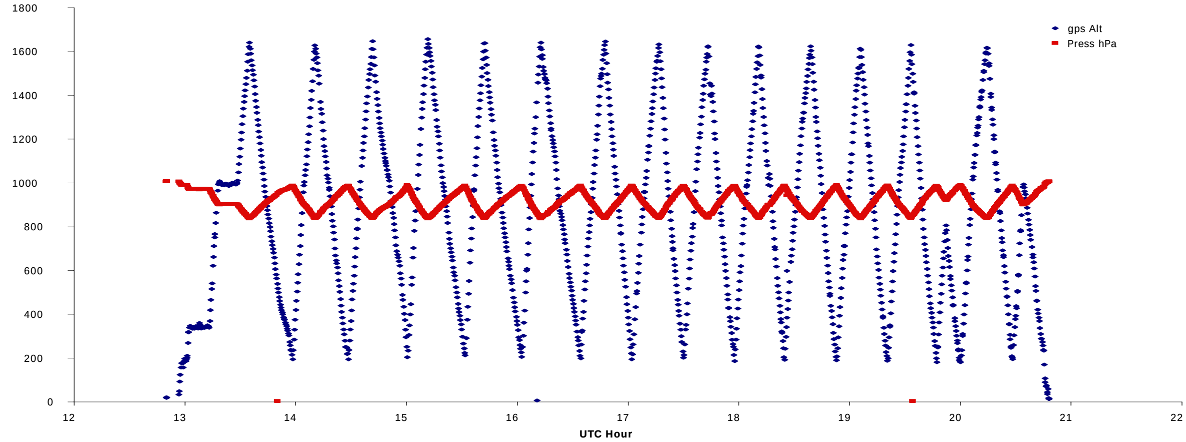
On July 22, an attempt to launch was scrubbed due to mechanical problems. The crew spent the day performing maintenance on the aircraft and troubleshooting. July 23 was taken as a crew rest day. A launch was scheduled for July 24, however, the aircraft was still experiencing difficulty and it was determined that none of the aircraft remaining were fixable in the field. The team leader called an official end to the mission, and the crew commenced the tear down and packing of equipment. Packing was completed on July 25, and the equipment was driven back to San Jose on July 26 to be loaded onto the C-5 for transport back to the US.

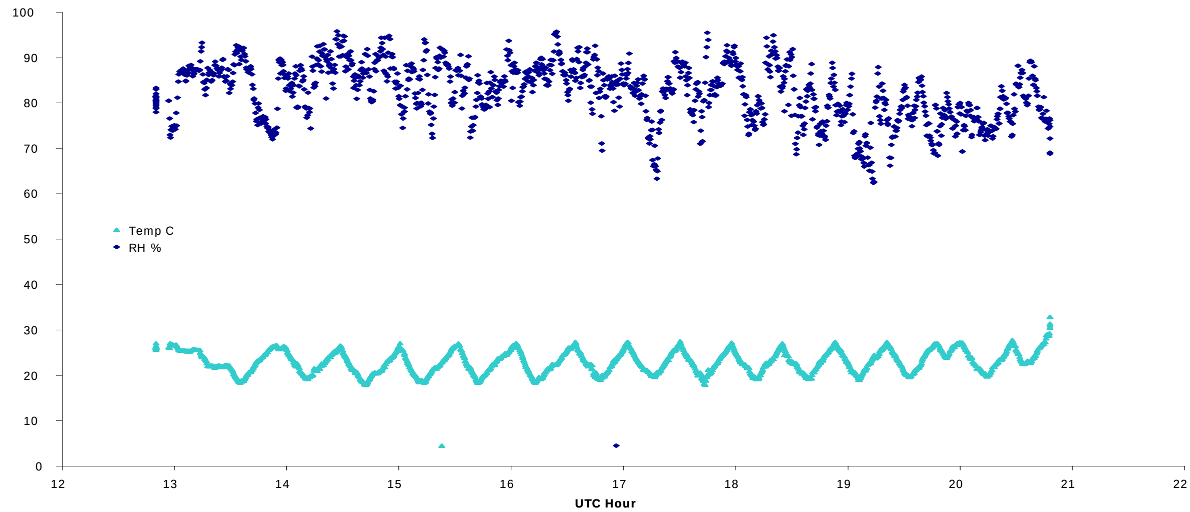
7.0 Science Results

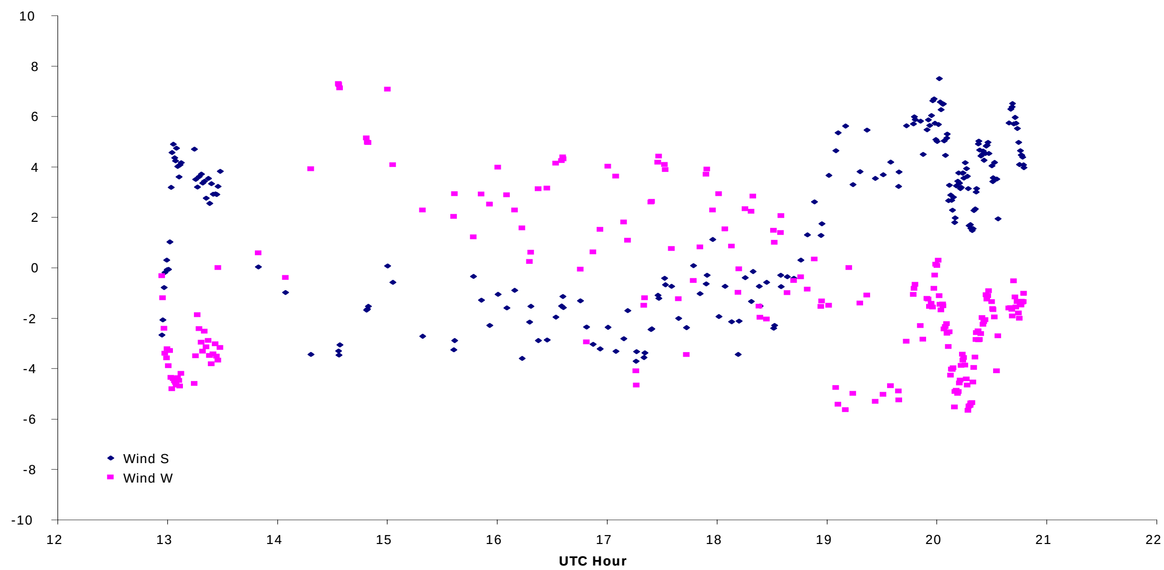
The data collect during the Aerosonde TCSP flights had not been closely analyzed at the time of the writing of this report; however it had been quality controlled and is now available in the NASA TCSP data archive. Because of the variety of weather that occurred during the flights, the complete dataset provides an excellent snapshot of the different processes that occur within the boundary layer and just above. Flights 3-6 provide a look at the diurnal processes as well as a comparison of clear sky processes to convective process. The flights also potentially capture how processes change before and after the passage of a tropical wave. Flights 7 and 8 document the difference between processes that occur near shore and over the open ocean, while giving a snapshot of the processes that may be occurring in the lower atmosphere above the boundary layer.

The data for each flight has been graphed and present in the rest of this section.

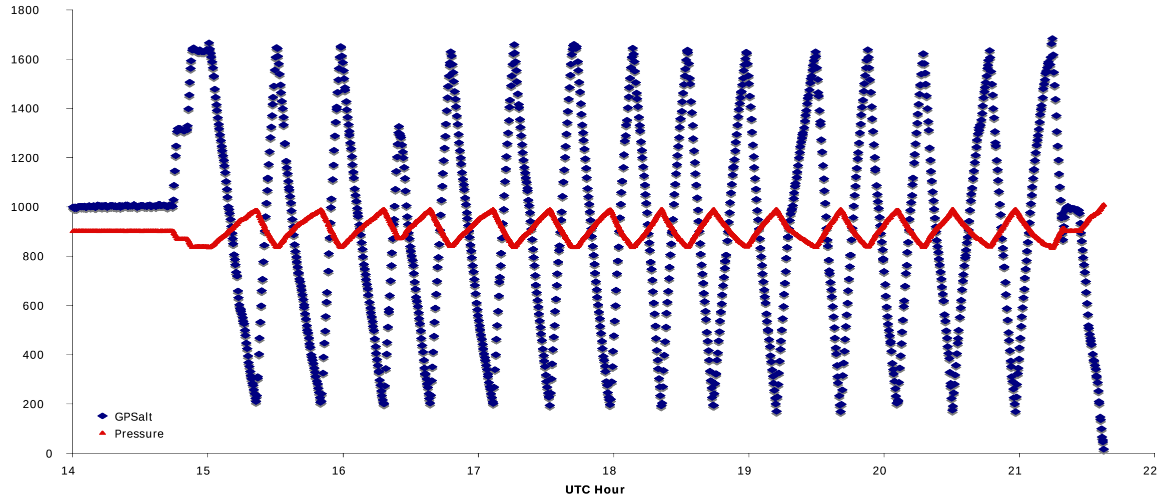
7.1 Flight 3 – July 10

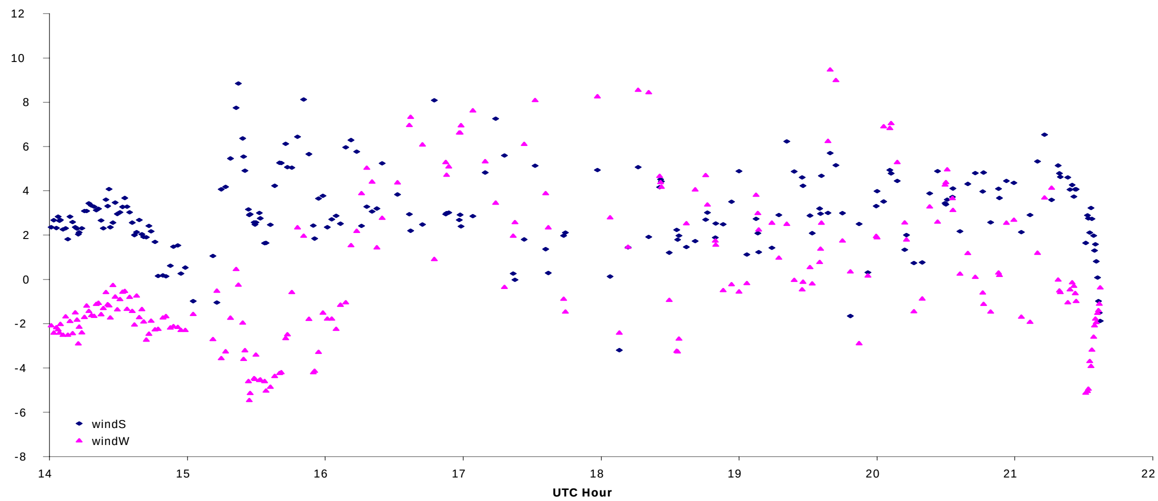


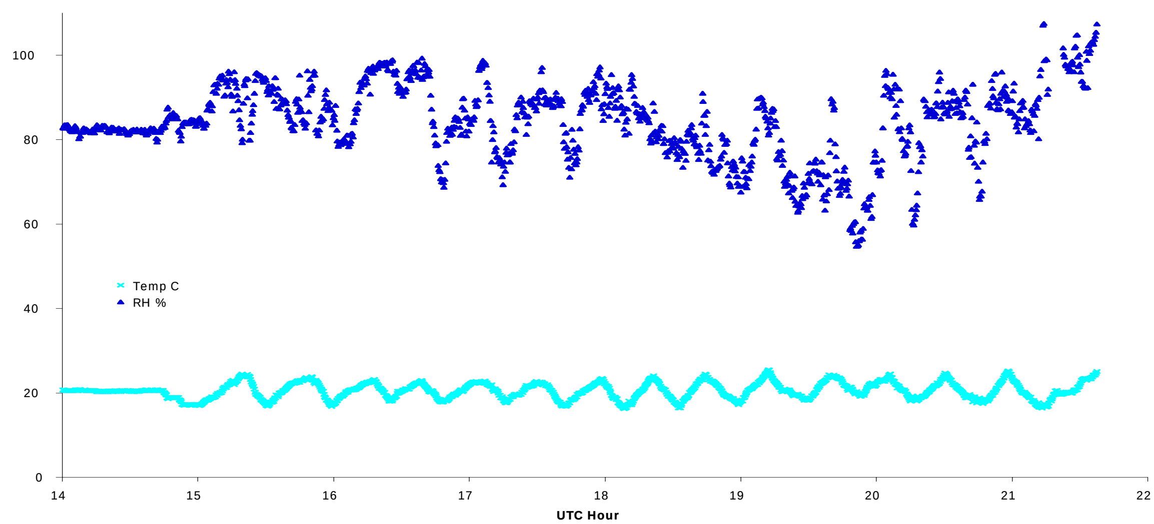




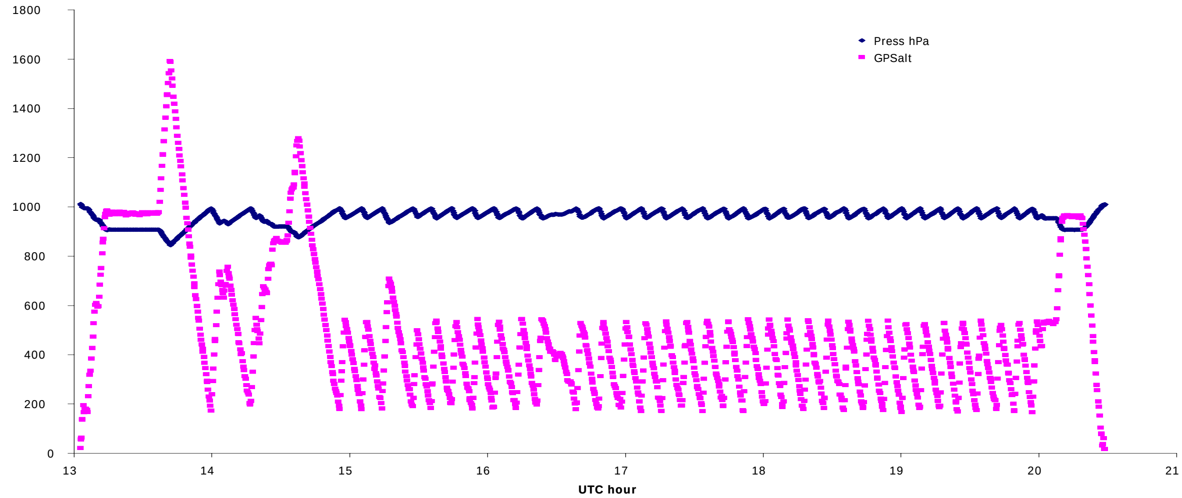
7.2 Flight 4 – July 11

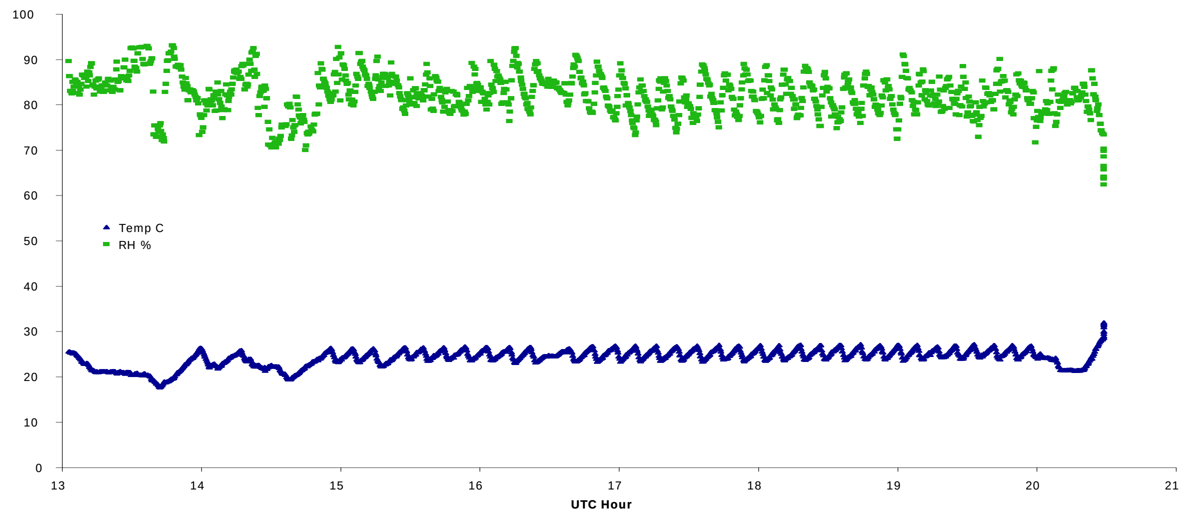


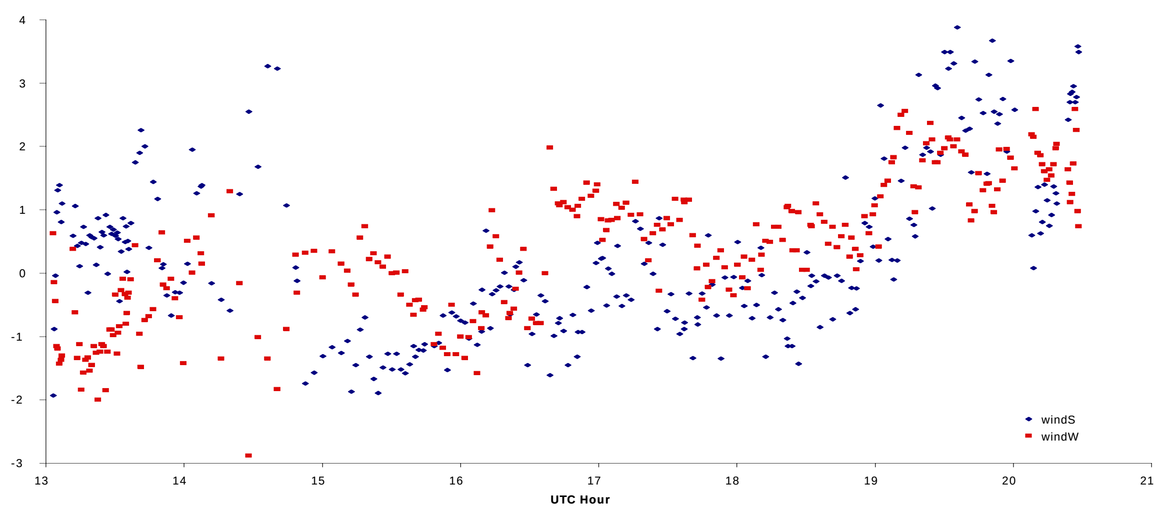




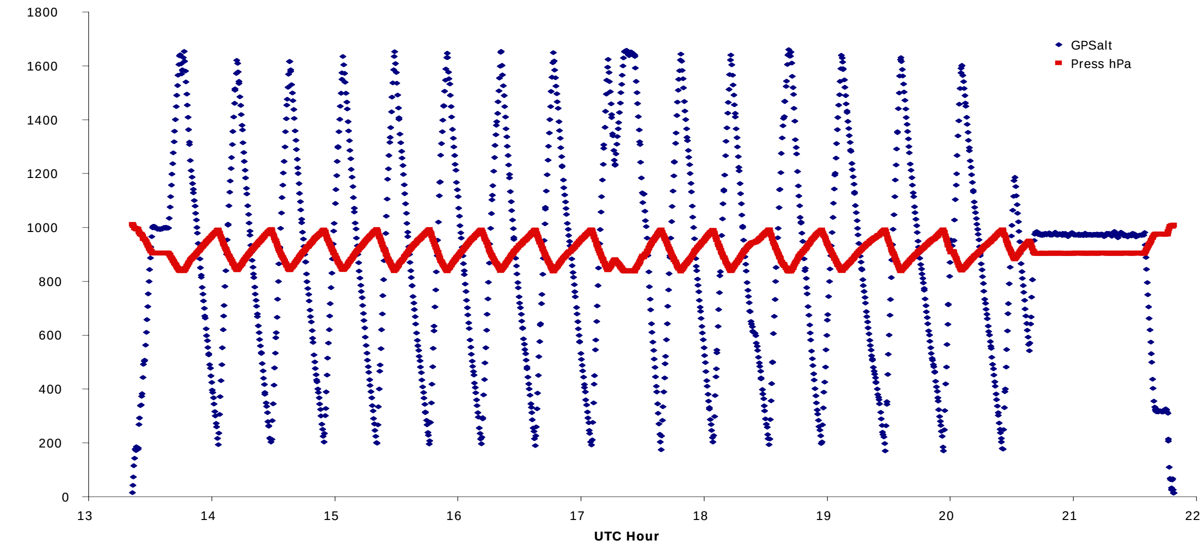
7.3 Flight 5 – July 13

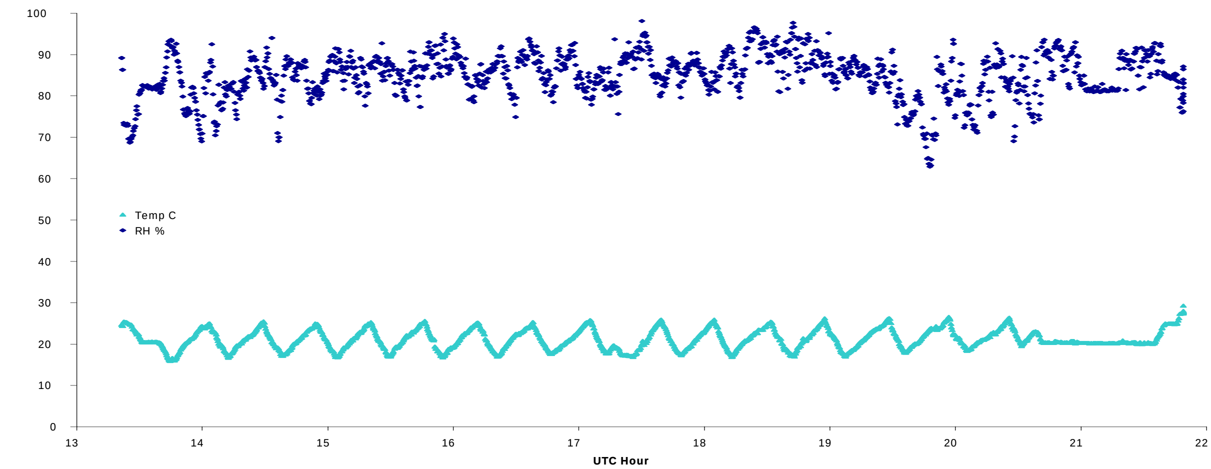


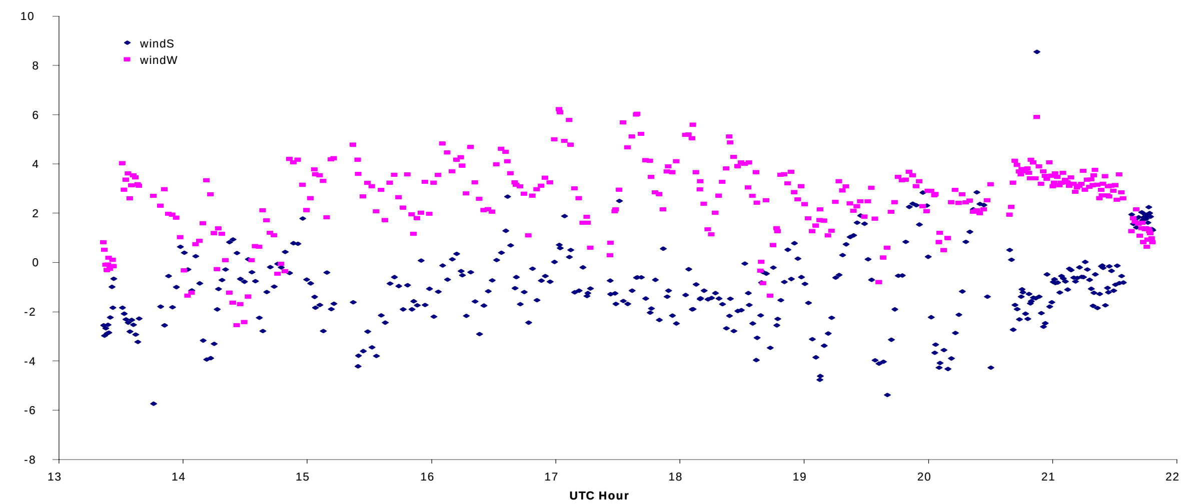




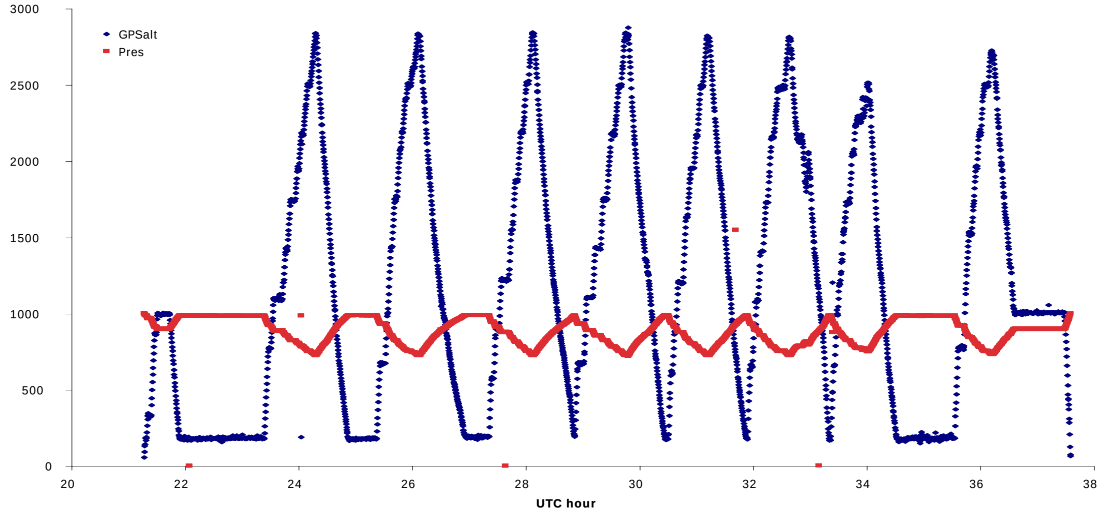
7.4 Flight 6 – July 14

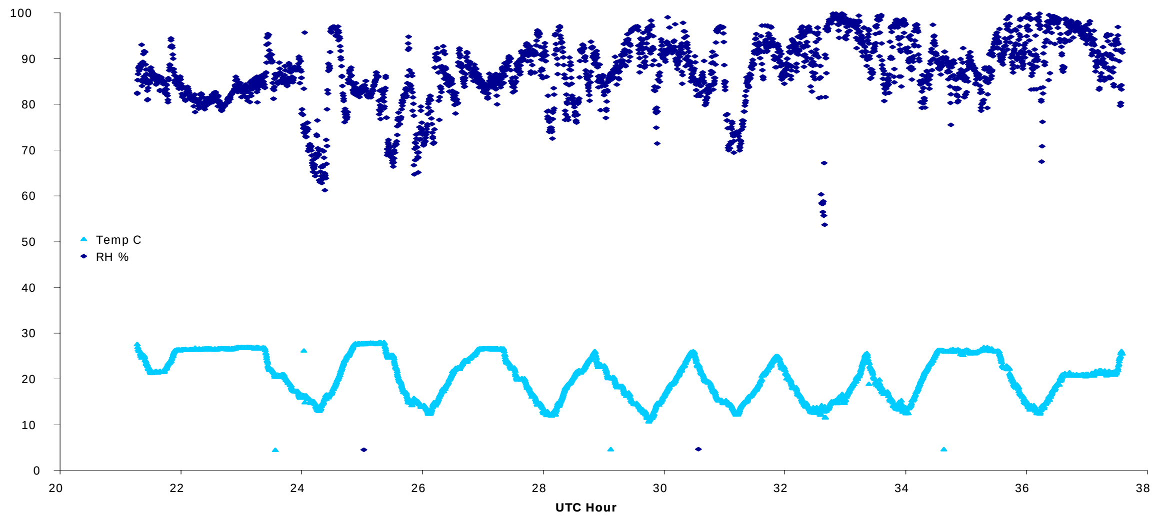


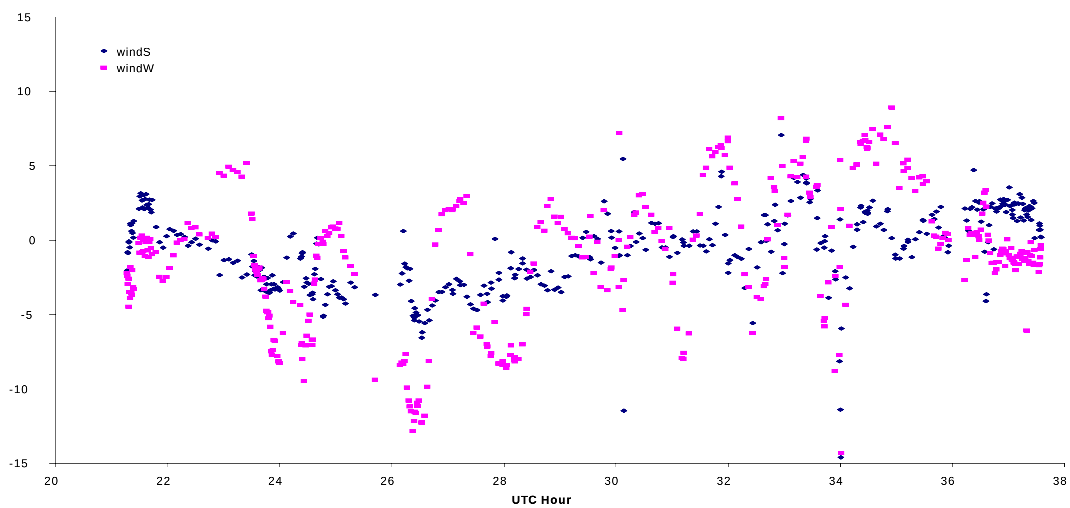




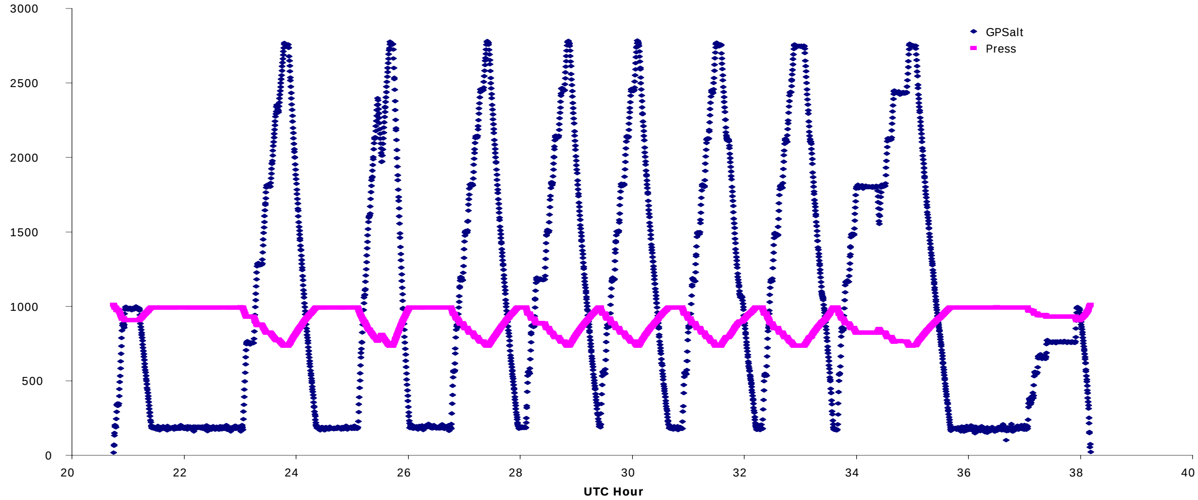
7.5 Flight 7 – July 17/18

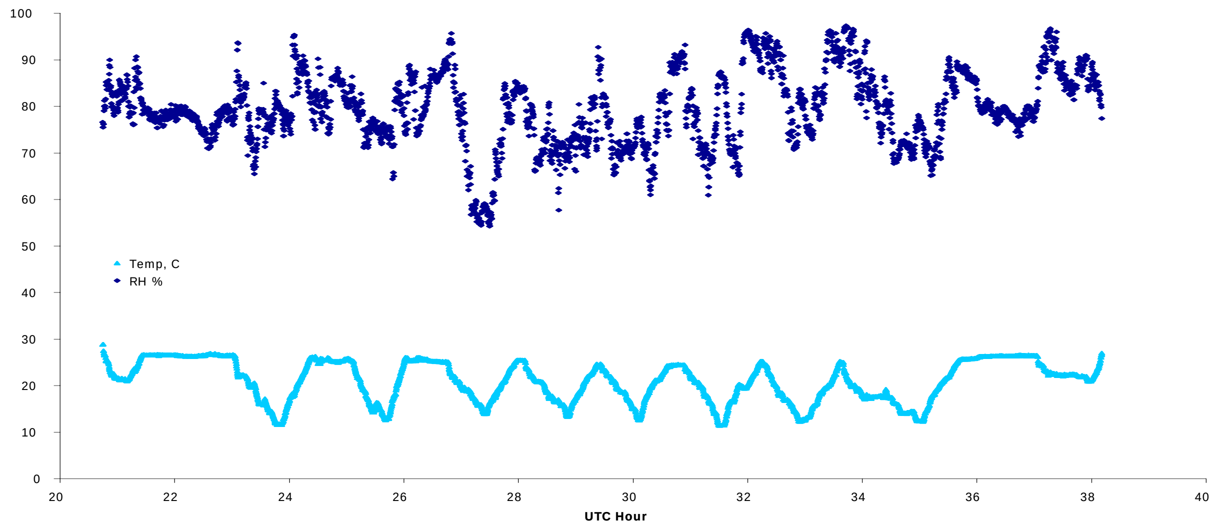


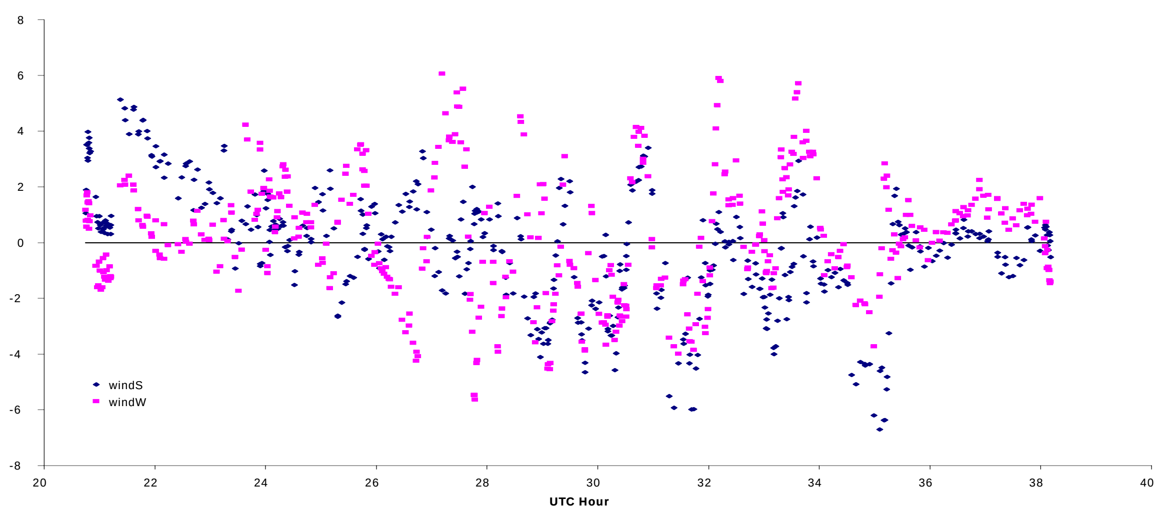




7.6 Flight 8 – July 20/21







8.0 References

1. AeNA SSR-001CR: "Aerosonde Operations Site Survey: Quepos, Costa Rica"