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THE DRIFTSONDE OBSERVING SYSTEM DEVELOPMENT

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1. ABSTRACT[1]

The original motivation for developing a driftsonde observing system was to support research associated with the WMO's THORPEX program. The major goal for driftsonde is to develop a low-cost measurement system that can produce vertical profiles of in-situ measurements in forecast sensitive regions (i.e., targeted areas where numerical models predict that such measurements would improve the prediction of high impact weather events) as well as make soundings that will fill critical gaps in data coverage over oceanic and remote arctic and continental regions. Forecast sensitive regions that would be targeted for driftsondes are (1) relatively void of in-situ measurements from radiosondes and commercial aircraft, (2) covered with extensive cloud shields so that satellite measurements are limited (e.g. soundings from microwave sounders only and a lack of satellite-derived wind fields). The across the ocean driftsonde flights will provide synoptic-scale high-vertical-resolution atmospheric profiles made by GPS dropsondes that would be difficult or impossible to obtain by deployment of aircraft alone. The targeting ability of the driftsonde will be accomplished, when possible, by controlling the launch location, the launch time of the balloon, the time of dropsonde deployment and to a limited extent the initial mission altitude (i.e. the wind field). The GPS dropsonde currently in use measures wind, temperature, pressure and relative humidity.

The driftsonde system (Figure 1) consists of a low-cost zero-pressure polyethylene balloon with attached gondola. Housed in the gondola are the system electronics which includes an embedded computer, a GPS navigation system, flight level PTH sensors, a ballast control system, a battery power system, an Iridium satellite two-way communication system, and 20 dropsonde tubes. The gondola can carry up to 20 of the current GPS aircraft dropsondes that can be dropped at predetermined times by computer or on command through a satellite link. The driftsonde gondola system is presently being modified to carry up to 50 of a new small, lightweight dropsonde. The driftsonde balloon normally flies at an altitude of ~16 kilometers (100-75 hPa) in the lower stratosphere or upper troposphere above the clouds and weather systems. However, three sizes of zero pressure balloons have been developed to date: (1) a 100 hPa or 363 m^3 balloon, (2) a 50 hPa or 1200 m^3 balloon and, (3) a ~25 hPa or 2265 m^3 balloon. Discussions are also underway with the French (CNES) balloon program for a THORPEX driftsonde demonstration project with CNES for an African Monsoon experiment (AMMA) that would utilize CNES's new 12 meter diameter superpressure balloon and the NCAR driftsonde gondola carrying 50 dropsondes and flying at ~50 hPa to study African easterly waves and hurricane genesis. The design of the driftsonde system will be discussed as well as future development efforts and potential field programs using the driftsonde.

2. Background

The driftsonde development was conceptualized in response to the formation of the THORPEX program. The primary goal of the THORPEX is to accelerate the improvements in the prediction of high impact weather. The THORPEX program seeks to reach this goal through making advances on several operational and research fronts. One strategy is to obtain improved measurements in regions where numerical weather prediction models show a strong sensitivity to the need for additional measurements. Depending on the location of these sensitive regions and their character, it

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can be extremely difficult to obtain additional measurement. For example, during the winter sensitive regions often coincide with oceanic storm tracks, where it can be very expensive to obtain additional in-situ measurements (Fig. 2). The sensitive regions are often associated with cloudy conditions making it difficult to utilize passive satellite techniques. The presence of extensive cirrus cloud shields with developing storm systems often decreases the ability to obtain middle and lower level winds from satellite tracking techniques. While active satellite techniques, such as microwave sounders, provide great promise for probing these regions in-situ measurements are still needed for the aspects of the design, calibration, and validation of these microwave techniques. With these points in mind it was suggested that a basic need of THORPEX was to develop a strategy that could obtain accurate in-situ measurements of the vertical profile of wind, temperature and humidity over oceanic regions at lower costs than existing techniques.

The balloon and gondola strategy discussed here is NCAR's driftsonde effort. The driftsonde is being designed as a cost-effective observing system that will fill critical gaps in data coverage over oceanic and remote arctic and continental regions with large numbers of high-vertical-resolution GPS dropsonde profiles through the lower stratosphere and entire troposphere. The initial driftsonde strategy described here uses low-cost expendable balloons that will fly for up to 4-5 days. However, one of the basic goals of this engineering development is to produce a gondola driftsonde package that will allow the launch of dropsondes on command, while the system is at almost any location over the earth. Thus, the driftsonde gondola can be flown on other types of balloons and certain aspects of the development are relevant to aircraft systems.

Profiles can be obtained at specified data assimilation times or through interactive tracking when the balloon reaches a certain region and are not affected by cloud-cover or icing conditions because the balloon is flying in the upper troposphere or lower stratosphere (e.g. ≤ 100 hPa) above those conditions. A network of driftsondes can provide simultaneous profiles (at for example 3 or 6-hr assimilation times) over large expanses of data-sparse regions (Figure 3), which cannot be accomplished with the limited number of weather reconnaissance aircraft available for dropsonde deployment. The driftsonde system can be launched in almost all weather conditions depending on the local facilities at the launch site, although high surface winds can pose problems.

3.0 Driftsonde System Design

The driftsonde observing system includes a polyethylene balloon with an attached gondola (Figure 4) that carries a payload of up to 20 GPS dropsondes. The carrier balloon ascends to between 50 and 100 hPa, like a conventional radiosonde, and then drifts in the prevailing stratospheric westerlies for up to five days, deploying dropsondes at prescribed intervals over data-sparse regions of interest. Dropsonde sensors measure pressure altitude, air temperature, humidity and wind velocity (Figure 5) . Data is collected from each dropsonde and sent via a low-earth-orbiting satellite (LEO) to a ground station for transmission to the GTS in real-time. The gondola also measures pressure, temperature, humidity, balloon position and velocity every half hour and sends this data to the ground station. A parachute permits the dropsonde to descend to the surface in ~15 minutes with a fall velocity of 33 m/s at 100 hPa and 12 m/s near the surface. The dropsondes are stored in the lower portion of the gondola (Figure 6) where the GPS signals can be received by the dropsondes. Prior to release, a dropsonde is powered on to allow lock-on to the GPS satellite transmissions so that winds can be computed immediately upon sonde release. A typical weight of the gondola including electronics and batteries but excluding sondes is estimated at ~13.03 kg. The total estimated system weight for the gondola, balloon, ballast and dropsondes for a 5 day flight is ~68 kg. To ensure a flight duration of at least five days, ballast of about 35% of the gross system mass must be available. A balloon volume of 363 m^3 is required to carry the system to an initial float altitude of ~16 km (~100 hPa) and if the balloon integrity is preserved throughout the flight, the balloon will rise to ~19 km (~57 hPa) when all sondes are dropped and all ballast released. As the payload decreases (sonde drops) the balloon will gradually increase its float altitude to compensate for the decreased system mass. The balloon has an upward buoyant force when the system mass decreases until the air density is reduced enough to make the displaced air mass (fixed balloon volume x density) equivalent to the lower system mass. Ballast is released after sunset when the balloon's gas temperature decreases and reduces the balloon volume causing the balloon to descend. Ballasting is dependent on the balloon's expected float altitude (e.g. 16.0 km), however the ballasting will not occur, once activated, until it has descended below its minimum float altitude (e.g. 15.0 km, the start ballast altitude). Ballasting occurs when the following conditions are met:

Definitions:

- Activation altitude: No ballasting will occur if the gondola is below this altitude (i.e. balloon is ascending, as an example 14.0 km).
- Ballast altitude: No ballast control will occur if the gondola is above this altitude.
- When the gondola is between the activation altitude and ballast altitude, the following algorithm is followed:

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1. $\Delta t$ = 3 minutes,
2. A0 = current altitude,
3. Wait $\Delta t$,
4. A = current altitude,
5. rate = (A-A0)/$\Delta t$,
6. if rate <= 0 then
    a. dump ballast for 10 seconds.
7. if rate > -50 m/min i.e. negative rate means descending,
    a. wait 10 seconds (for first dump to drain)
    b. dump ballast for 10 seconds.
8. A0 = A
9. go to step 3.
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The on-board pressure altitude or GPS altitude is monitored by the system control computer, so when the altitude starts to decrease the control computer signals the ballast control valve to release ballast (i.e. at a rate of 28 grams/sec.) until the negative rate of change of altitude stops. The control computer monitors the altitude to see that it is maintained within the predicted range. Figure 7 shows a block diagram of the system electronics.

During test flight #2 from Tillamook, Oregon (November 14, 2002) a thermistor bead on a long lead was inserted through the top of the balloon and extended about a third of the way down into the balloon to measure the gas (helium) temperature so that the amount of daytime warming (supertemperature) and nighttime cooling could be determined. Figure 8 shows the ambient air temperature and the gas temperature as a function of GMT time of day (Local Time is 8 hours earlier than GMT). The supertemperature (gas – air) was constant at 12 to 14 ºC for sun angles from 26 degrees to 6 degrees above the horizon. The supertemperature dropped off linearly to 8 ºC from 6 degrees to 0 degrees sun angle. The balloon started to lose altitude when the sun angle decreased below ~10 degrees (Figure 9) and the first ballast drop occurred with a sun angle of 6 degrees when the automatic ballast system made two 15 second ballast drops for a total of ~0.85 kilograms of ballast. Another 30 seconds of ballast was automatically dropped when the sun angle decreased to 0 degrees (Figure 9). This second ballast drop returned the balloon to its initial float altitude. The thermal time constant for the balloon's reaction to a change in the radiation environment was calculated at ~4.5 minutes.

4.0 PHASE II: PROPOSED DEMONSTRATION PROJECTS AND FIELD CAMPAIGNS

Phase I showed that a driftsonde system could be developed, deployed and provide sounding capability over remote locations. Phase II focuses on moving beyond the single balloon proof-of-concept phase to large field deployments with multiple balloon deployments. The timing of the Phase II efforts is driven by several field efforts.

1. *ASHE (Atlantic Hurricane Seedling Experiment), THORPEX (The Observing System Research and Predictability Experiment) and Downstream AMMA (African MultidisciplanaryMonsoon Array): A Driftsonde Demonstration Project (August and September 2006).* A visit by the NCAR driftsonde team to the French/CNES facilities during late 2004 resulted in the following proposal for a driftsonde demonstration project. CNES and NCAR propose 15 driftsonde flights on CNES super pressure balloons. These balloons would be launched daily from a French military base in Chad using primarily CNES personal and two NCAR staff from ~1 September to 15 September 2006. The balloons would fly at ~50 hPa with flight durations of each system well in excess of 10 days. Figure 10 and 11 show the match between hurricane genesis events and driftsonde trajectories.

2. *Field Operations in 2008:*
    - Pacific THORPEX Regional Experiment to examine targeting, predictability, data assimilation, forecast errors and other dynamical issues. The campaign is proposed to occur during the Jan-March 2008 winter. A planning meeting will be held in Seattle on 6 to 8 June 2005.
    - PV structures in the polar vortices and their impacts on middle latitude weather, cold air outbreaks and the triggering of subtropical and tropical convection and ocean-atmosphere interactions. The experiment would most likely occur during 2008.
    - Very preliminary discussions have taken place to include the driftsonde in the American Maritime Monsoon Experiment in 2008, although the current approach is more likely to involve the NCAR/NSF HIAPER aircraft.

5.0 CONCLUSIONS

Phase I of the driftsonde development has been completed; the Phase I goals for the driftsonde development were to bring the system to the proof-of-concept phase to show that a stratospheric balloon could carry a gondola with sondes that could be deployed on command and that the system could be managed within current air traffic control considerations and air-safety regulations. Reaching these proof-of-concept goals involved developing solutions to overcome a variety of basic engineering hurdles. One hurdle was cost as the entire gondola system is meant to be disposable, which means that the cost must be minimized. In contrast, the software and hardware for an airborne dropsonde system for launches/data processing/communication cost in excess of ~150K. Another hurdle is developing a system that will work for many days or even weeks with very low power consumption, and minimal weight while coping with the very cold temperatures (~-45 to -70 C) of the lower stratosphere. The diurnal cycle of solar radiation also poses several problems including the potential for overheating the hardware during the day and a reduction in the height of a zero-pressure pressure balloon at night that must be compensated for by a corresponding reduction in ballast. The system also needs to meet air traffic concerns and maintain two-way communication while over any location in the world. Some aspects of this development are more similar to a satellite development than developing airborne instrumentation. The Phase I development consisted of the balloon and gondola design and the production and flight testing of five systems. The Phase I design and development was done at NCAR’s Atmospheric Technology Division (ATD) in Boulder, Colorado for the electronics and gondola and at GSSL Inc. in Tillamook, Oregon for the balloon, flight safety, and parachute. Local laboratory tests of the electronics and gondola were done at NCAR in Boulder and flight testing of the total system was done from the GSSL hanger in Tillamook. Table 1 is a brief synopsis of the Phase I flight test program and identifies the objectives, the date, duration and altitude of each flight. The final flight went for nearly three days. The flight was designed to reach the stratospheric easterlies to fly out over the Pacific and then reach a lower altitude and return to the Washington coast. The next phase of the driftsonde development wiil be the Phase II Demonstration Projects. Phase II will focus on moving beyond the single balloon proof-of-concept phase to large field deployments with multiple balloon deployments such as the ASHE, THORPEX and The Downstream AMMA Demonstration Project in August/September 2006.

6.0 REFERENCES

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Shapiro, M. and A. Thorpe, 2003: Executive Summary of the International Science Plan, *WMO Bulletin*, **52** , 419-420

Table 1

Phase I Driftsonde Development flights

Flt. No.	Date	Duration	Altitude	Objectives
1	2/28/02	4-3/4 hrs.	16.88 km (55,400 ft.)	1. Engineering tests of the gondola systems; thermal control, altitude control (ballasting), battery power system, Obcomm satellite communication system (failed due to interference).
2	11/14/02	5.0 hrs.	16.4 km. (53,800 ft.)	1. Same as Flt. #1. Obcomm system delay was too great.
3	2/10/03	22-1/2 hrs.	16.4 km. (53,800 ft.)	1. Test new Iridium satellite communication system, Iridium stopped operating after ~12-1/2 hrs.); 2. Drop sondes by command (3 – NCAR and 1 – Vaisala sondes were dropped & data received on the ground); and 3. 1st test of auto-ballast system (due to pressure sensor failure the system was manually ballasted through Iridium).
4	8/19/03	11-1/2 hrs.	17.6 km. (57,775 ft.)	1. Verify Flt #3 problems were corrected, 2. Drop multiple sondes (4 – NCAR and received on gondola, 4 – Vaisala sondes dropped & received on ground), and 3. Test the auto-ballast system and pressure cutdown.
5	9/2/03	63-1/2 hrs.	~24 km. avg. (78,700ft.)	1. Operate over the ocean for multiple days with auto ballasting (operated for ~3 days with 4 auto-ballasts), 2. Drop multiple sondes (8 – NCAR sondes dropped & received on gondola), and 3. Gather data on sonde multi-path interference over water .

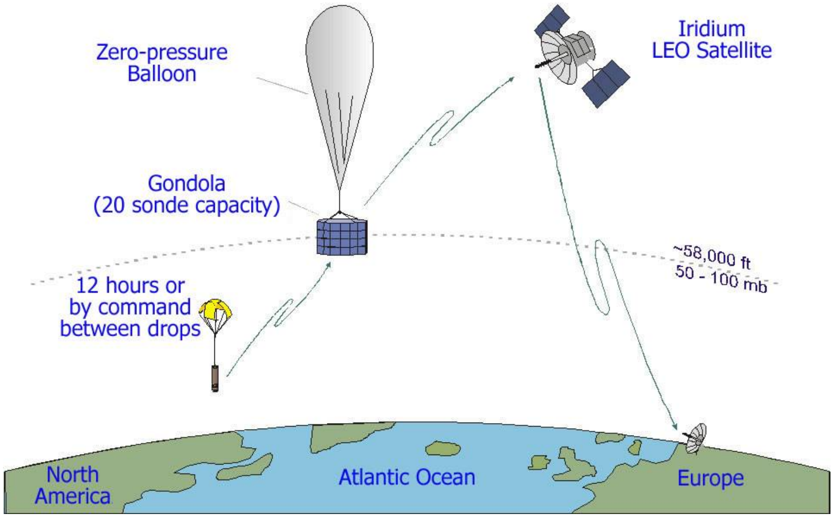

Figure 1: Overview of the Driftsonde System

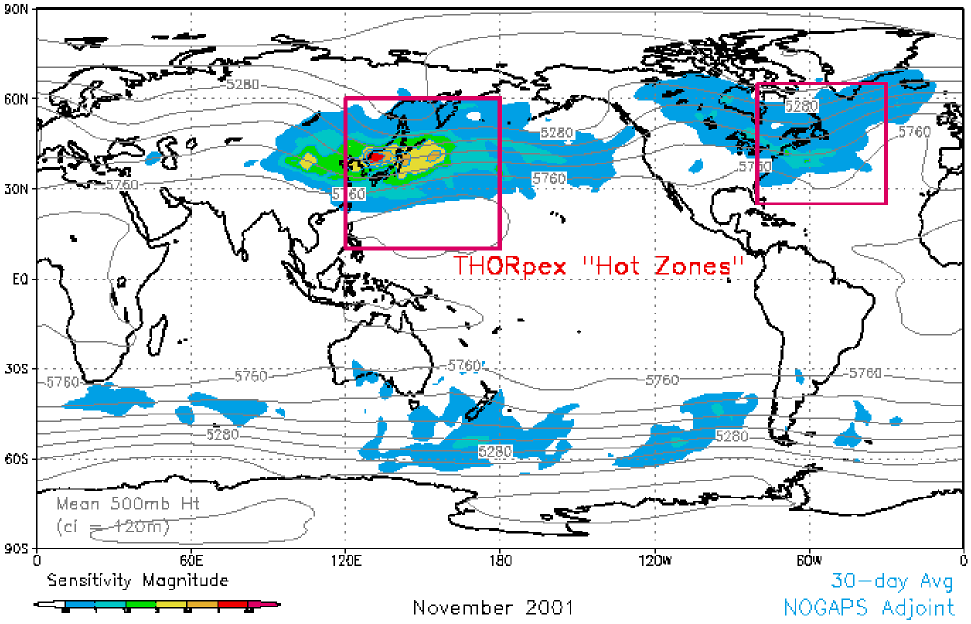

Figure2: Sensitive regions for November 2001 based on 30-day average of the NRL NOGAPS model (color coded). The contours are the 500 hPa height field. Courtesy of Alan Thorpe, Rolf Langland, and Melvyn Shapiro from THORPEX planning presentations.

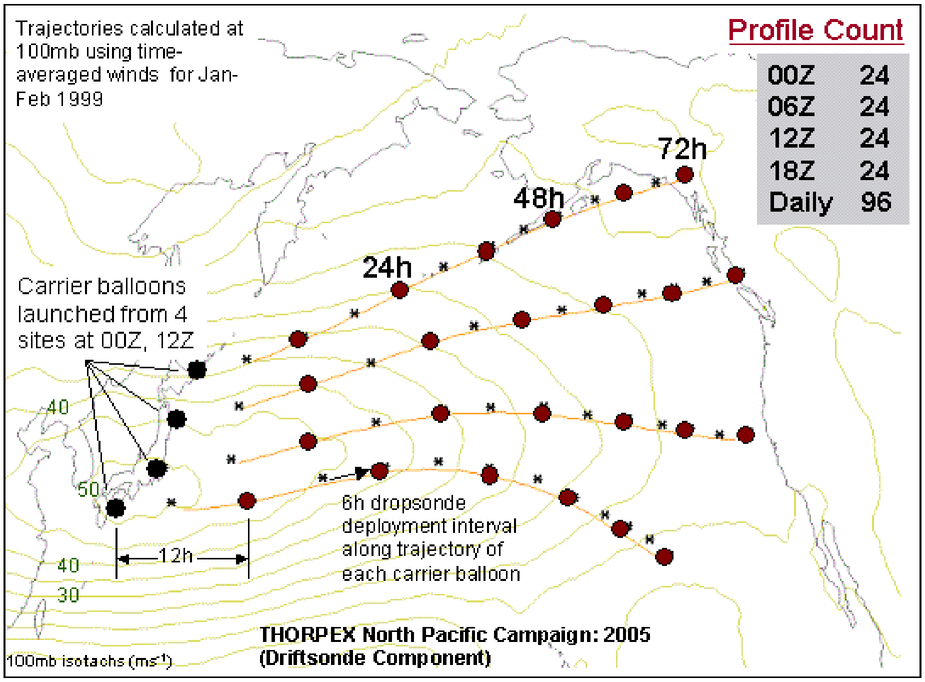

Figure 3: Potential driftsonde coverage illustrated from carrier balloons launched at four locations in Japan and dropsondes launched every 6 hours along the flight track of the balloon. The trajectories were based on flights at 100 hPa using time average winds (Jan.-Feb 1999). From Rolf Langland.

Figure 4: Driftsonde Balloon, Parachute & Gondola

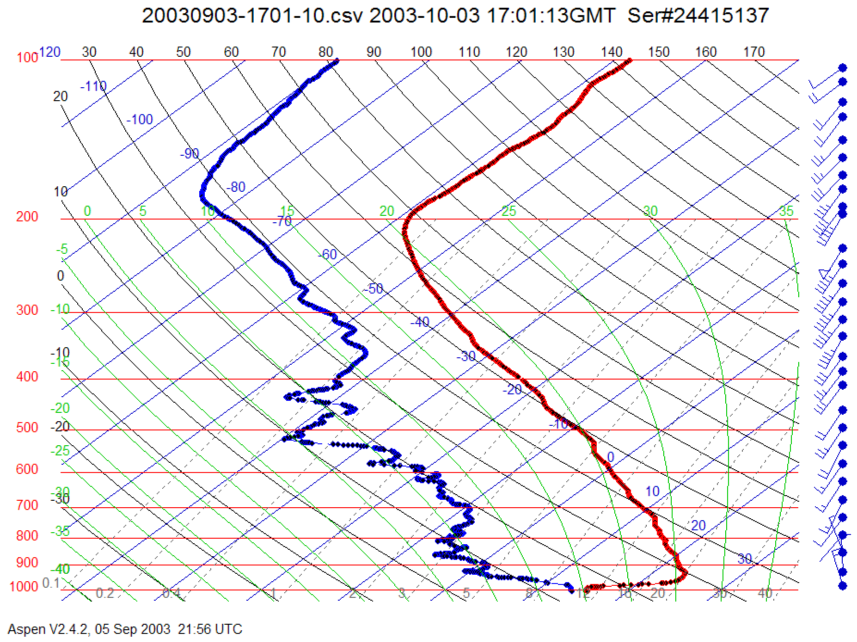

Figure 5: Temperature, humidity, and wind velocity plotted on a skew-t from a dropsonde launched from the 5th driftsonde flight off the NW coast. The general finding is that data quality is quite high for dropsondes launched from driftsondes since the balloon remains quite close in distance to the descending dropsonde (in contrast an aircraft typically moves rapidly away).

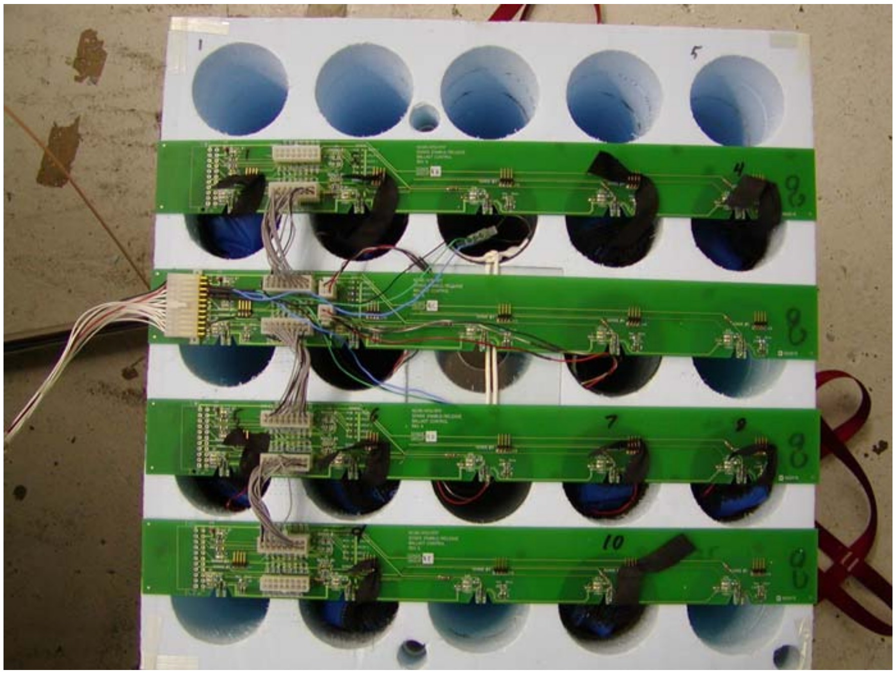

Figure 6: Gondola Lower Section Showing Dropsonde Tubes

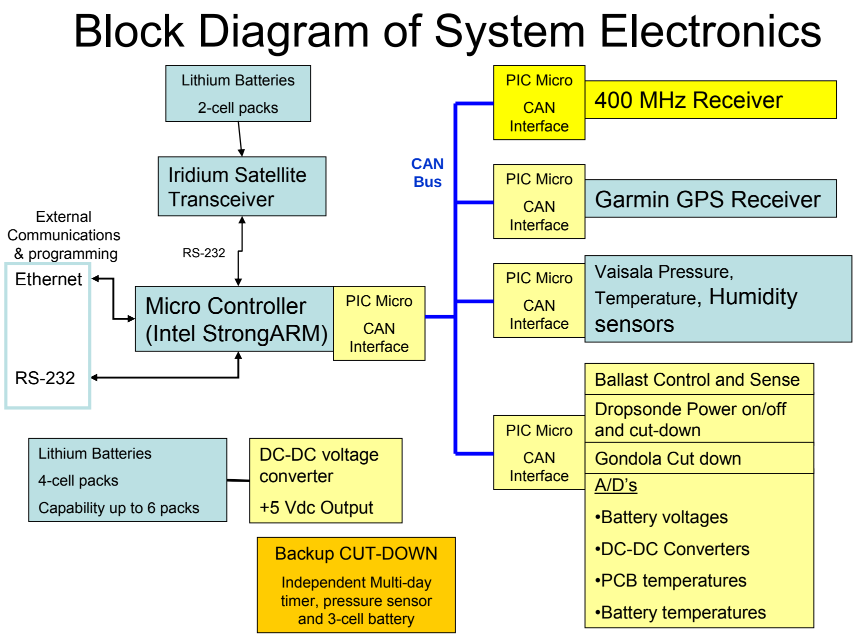

Figure 7
Block Diagram of Driftsonde Electronics

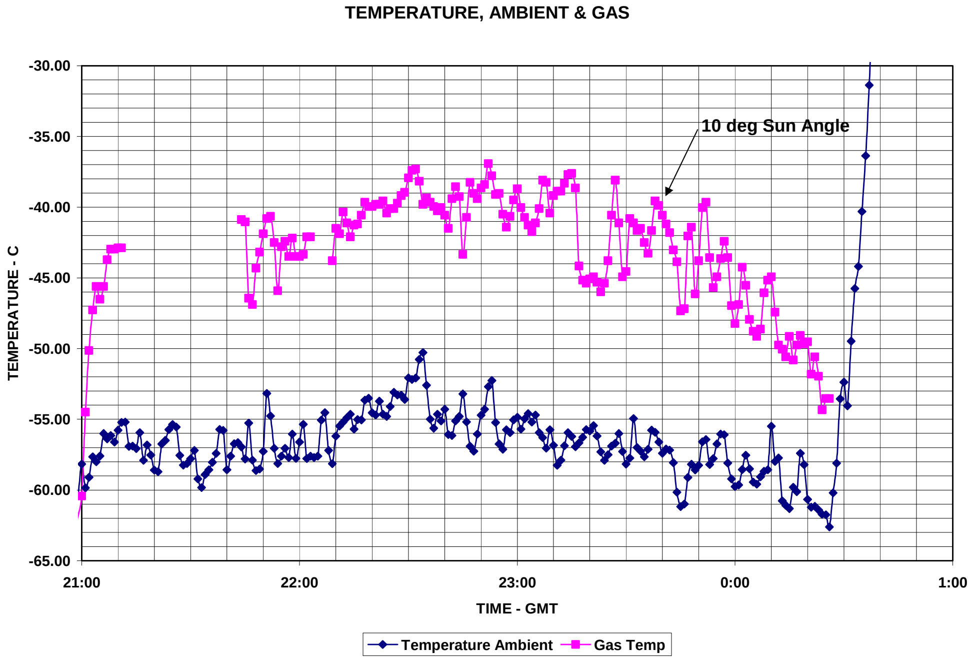

Figure 8: Ambient Air Temperature & Gas Temperature vs GMT Time

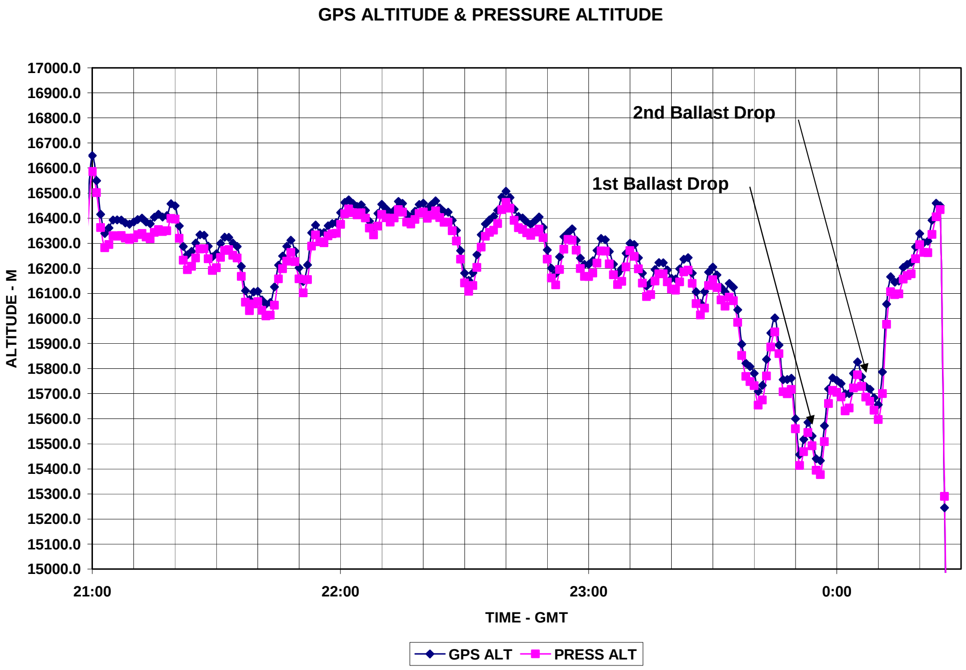

Figure 9: GPS/Pressure Altitude vs GMT Time

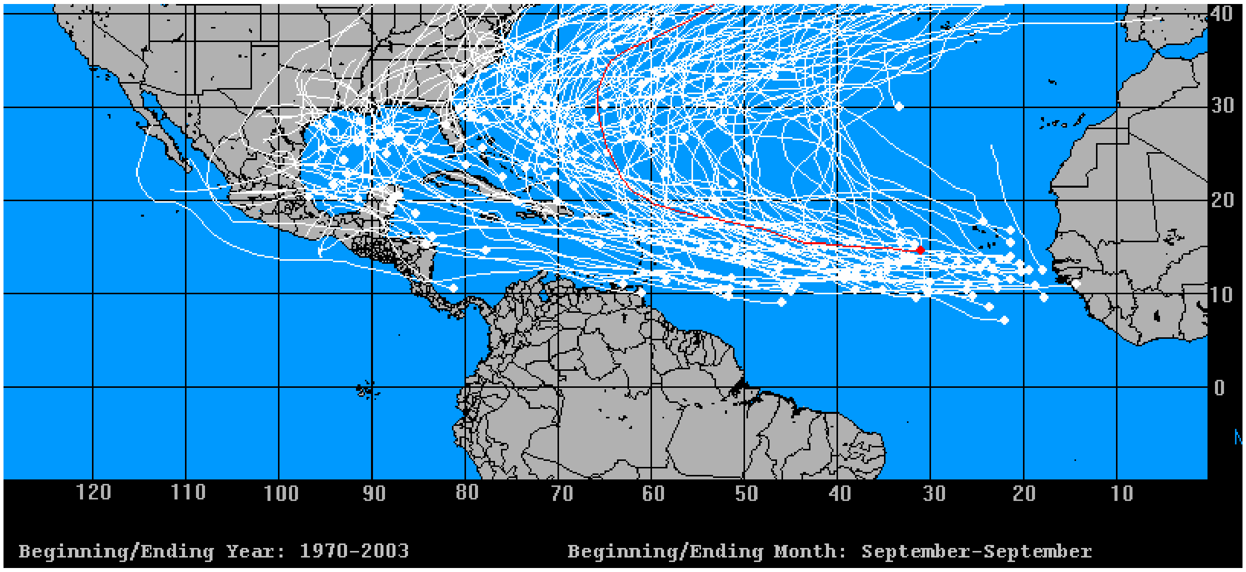

Figure 10: Tracks of hurricane genesis and subsequent movement (from G. Holland, NCAR).

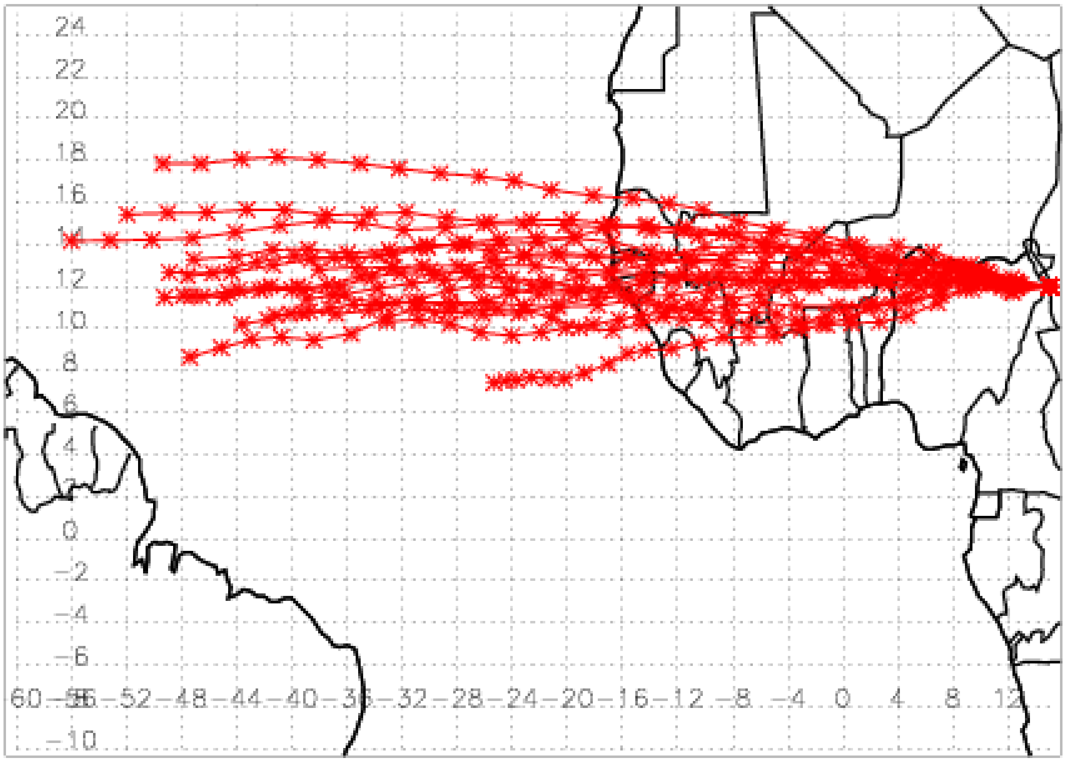

Figure 11: Driftsonde trajectories for 10-daily balloon launches from Chad using reanalysis winds for 15 Aug to 1 Sept. 2000 (from C. Flamant, U Paris).