Mission Operations Plan

2014

Note: Some figures and contact information have been removed for sensitivity or brevity. Contact the Earth Science Project Office at NASA Ames for more info.

http://espo.nasa.gov/

1. HS3 SCIENCE OVERVIEW

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2.0 PROJECT FACILITIES

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3. AIRCRAFT FLIGHT OPERATIONS

3.1 Flight planning terms and rules

In 2014, HS3 will have 447 flight hours approved including 16 hrs for 2 aircraft range flights, 38 hrs for the transit of both to and from WFF, and 393 hrs for science (approx. 16 flights in 5 weeks). There are several key items to note for 2014:

- The plan is that all 3 pilots shifts and the pilot flight planner will be based at WFF.
- GH will attempt 3 back-to-back flights if needed which may then require a two-day break before next flight. Four flights can be requested but will need GH approval.
- NOAA is providing funds for the 5th week of deployment. The agreement is that HS3 will try to meet NOAA objectives on 5 of the flights conducted during the 5-week deployment rather than focus on NOAA flights the last week.
- The WB-57 may be flying in the same areas as HS3 GHs. They should be attending the group telecons and providing flight plans. They will be on the HS3 hurricane list serve as well.

3.1.1 Definitions

Alert (*the decision to ask the pilots to prepare for an upcoming flight date*)

The Alert decision is made no later than 48hrs prior to the flight. Notification must be before 15Z (0800 PDT, 1100 EDT) daily. A notional flight region with specific Flight Information Regions (FIRs) is required at this time. A detailed flight plan with drop locations is required to be submitted prior to 24hrs (1330Z; 0630 PDT, 0930 EDT). Small changes to the detailed flight plan can be made up to 3 hours prior but any changes after that and during the flight are real-time conditional with ATC concurrence. Flight pattern and dropsonde configurations would stay basically the same as the T-24hr plan but some changes such as adjustments for storm center or length of legs can be made. It is recommended that flight plans be designed to include predicted storm motion so plans are as close to actual as possible.

*** This assumes none of the country clearances require notice prior to these times. ***

Go-No go (*the decision before flight regarding the alerted aircraft flights*)

A Go-No go science decision is made no later than 15 hrs prior to the flight (before flight support crew goes off shift). A Go-No go decision is made when hazardous weather is expected at take-off and/or landing, critical instruments have discovered problems, or any other important issue is raised by the science leads.

Cancel (*the decision to cancel a flight*)

Flights can be cancelled at anytime by the aircrew or science leads. For general purposes science should make the call NLT 4 hrs prior to takeoff. The aircraft crew has full authority to cancel at any time. Last minute cancelled flights may disrupt crew duty hours, and may require a clock restart. If a flight is cancelled for more than two consecutive days, or exceeds the 72 hrs preflight limit, the preflight will have to be redone. The preflight will also have to be repeated if engines have been started or any aircraft panel is removed for access (in some cases this can be waived; it is the decision of the crew chief).

3.1.2 Daily schedules

Table 3-1 lists the daily schedule during the deployment.

Time (Zulu)	Time (EDT)	Time (PDT)	Daily Activity
12:00	8:00 AM	5:00 AM	Forecast briefing, NASA Science Instrument Status/Planning/Mission & Go-no-go
13:00	9:00 AM	6:00 AM	NOAA Go-no-Go
13:30	9:30 AM	6:30 AM	POD Submittal to CARCAH/AOC 1330-1400 [pg 19 has contact info] ncep.nhc.carcah@noaa.gov (cc: Jim McFadden, Paul Flaherty, Justin Kibbey, Rob Rogers, Paul Reasor, Jason Dunion, Michael Black)
14:00	10:00 AM	7:00 AM	Inter-Agency Webinar brief and objectives (NOAA/NASA/53rd/CARCAH); NASA detailed flight plan (T-1) with dropsonde locations (if applicable) to pilots
15:00	11:00 AM	8:00 AM	Alerts for next several days out. NASA draft flight region for 48hr (T-2) to pilots (cc CARCAH) (note: plane can change beyond 48hr, but FIRs should not).
16:00	12:00 PM	9:00 AM	NOAA weather brief and plans for following day
00:00	8:00 PM	5:00 PM	Forecast briefing, NASA Science Instrument Status/Planning

Table 3-1. Daily schedule.

3.1.3 Flight planning constraints and basic strategies

Flight Duration (*Planned time from take off until landing*)

Flight durations generally are not to be planned to exceed 26 hrs. Flight duration may be reduced during the mission if significant weather is forecast along return route to WFF or during landing time.

Flight Limitations (*FAA restrictions*)

Flight limitations are dictated by the particular COA issued by the FAA. They apply to specific FIRs as well as other aspects. During HS3, the GHs must take off and land at WFF during daylight hours only. Pilots will coordinate with chase plane or observers as needed. Because of the dropsonde system on AV-6, the FAA requires that we file a flight plan with dropsonde locations identified. During the 48 hours leading up to the flight and during flight, we may have very limited ability to adjust the flight pattern or dropsonde locations. The flexibility for making changes may vary among different Flight Information Regions. For AV-1, flight planners will typically define a circle in which the aircraft will fly and we will have full flexibility to make changes to the flight pattern during flight.

No-Fly Day (*No flight activities planned*)

No-fly days are non-flight days but allow PI access to the aircraft for installs / instrument access / checkouts during prescribed times.

Hard Down Day (*No access to aircraft*)

This is an aircraft crew no-work day and no access to the aircraft is allowed! No contact with pilots for flight planning is permitted. PIs may still work in their labs as needed. In 2012, aircraft crews were only permitted to work 9 days in a row, with the 10th being a mandatory 'hard down' day. In 2013, the WFF staffing was planned to manage fatigue so that hard down days were not required and similar fatigue management rules will be in place for 2014 to the extent possible.

Crew Limitations (*Workday standards*)

Some GH staffing issues are still in work but the basic plan is that pilots and ground crew will be working 2 shifts each day (whether flying, flight planning, or on call). Aircraft crews are only permitted to work 9 days in a row. Armstrong is staggering crew rest days to try to minimize the need for hard down days. Should hard down days be necessary, care should be taken to forecast such days ahead of time to avoid the hard down day occurring during HS3 intensive operations. By allowing the hard down day to occur earlier, the clock can be reset for the next period. Be aware that this may be adjusted based on crew staffing. To ensure the required ground crew are available when needed, it is being considered to make instrument access with power on the aircraft occur during normal working hours.

Note: AFRC has instituted a Fatigue Management Plan and Global Hawk management will be assessing the implications of this plan on personnel planning.

FAA requirements

Note that the FAA requires that flight plans be submitted 2 **business days** in advance for their review. For Saturday, Sunday and Monday flights, that means that flight plans must be submitted by Thursday. At this 2-business-day deadline, the requirement as of mid-deployment in 2013 is for boundaries of the flight region and inbound and outbound routes to be identified, with a more detailed plan 24 hrs before flight.

Flight operation timeline *(Operation timeline for planning only...Best possible case!)*

Take offs and landings will be after official sunrise and before official sunset. For a two aircraft operation, a 3-hr separation between landing and takeoff will be required. A simplified operation timeline is provided below.

T-48	Alert Initial Flight Plan *(Pilots requires 4 hrs before COB)*
	Instrument access
T-24	FAA Review – *(Requires 1 full business day before flight)*
	Detailed flight plan with dropsonde locations
T-13	Instrument preflight complete – *(Delays will affect Takeoff time)*
T-12	Begin Preflight and GH Refuel – *(Allows towing and 4 hr refuel)*
T-4	GH Preflight Complete– *(Both mechanical and electrical preflight)*
T-3	GH Staged – *(Allows for towing, GSE setup)*
	Final flight plan – *(Delivered to flight crew)*
T-1	GH Engine start – *(GHOC fully staffed)*
T-0	1st GH Takeoff – *(Daylight hours only)*
L-0	1st GH Land – (*Also Daylight hours only. Future timelines are offset)*
L+1	2nd GH Engine start – *(2nd GH pre-staged, allows towing of 1st GH only)*
L+1.5	Instrument access *(for those not requiring aircraft power)*
L+3	1st GH Post flight – *(Required before instrument access)*
	Second GH takeoff if applicable
L+4	Instrument access – *(First access for instruments requiring aircraft power)*

Consecutive flight days with two aircraft operations quickly get complicated. Currently the plan is to allow back-to-back flights. If fatigue management rules allow, a third and possibly fourth consecutive flight may be possible, contingent upon GH and Armstrong approval. The following example time line assumes that conditions allow for a three-flight surge and that there are no aircraft or instrument repair issues. A schematic is shown in Fig. 3-1.

*** The example below has been put together strictly for a science forecast exercise and has not been approved by the AFRC GH aircraft operations! ***

Times in EDT

Day 0 0900 – AV-6 Alert

Day 1 0900 – AV-1 Alert

1100 –AV-6 – Flight Box 1 (FB1) delivered

Day 2 0800 – AV-1 Instrument Access

FAA Review – FB1

0900 – AV-6 Alert

1000 – AV-6 Flight Plan 1 (FP1) with drop locations delivered

1100 – AV-1 – FB2 delivered

1700 – AV-6 Instrument preflight complete

1800 – AV-6 Preflight and refuel

Day 3 0200 – AV-6 Preflight complete

0300 – AV-6 Towed to staging area

Final version FP1 delivered

0500 – AV-6 Engine start

0600 – AV-6 Takeoff – FP1

0800 – AV-1 Instrument access

FAA Review – FB2

1000 – AV-1 Flight Plan 2 (FB2) delivered

1100 – AV-6 –FB3 delivered

2200 – AV-1 Instrument preflight complete

2300 – AV-1 Preflight and refuel

Day 4 0700 – AV-1 Preflight complete

0800 – AV-6 Land

AV-1 Towed to staging area

Final version FP2 delivered

FAA Review – FB3

0930 - AV-6 No-power Instrument Access

1000 – AV-1 Engine start

AV-6 Flight Plan 3 (FP3) with drop locations delivered

1100 – AV-1 Takeoff – FP2

1200 – AV-6 Post flight inspection & refueling

1300 – AV-6 Instrument access with power

Day 5 0100 – AV-6 Instrument preflight complete

0200 – AV-6 preflight and refuel

0900 – Alerts for succeeding days

1000 – AV-6 preflight complete

1100 – AV-1 Land

Final version FP3 delivered

AV-6 Towed to staging area

1230 - AV-1 No-power Instrument Access

1300 – AV-6 Engine start

1400 – AV-6 Takeoff – FP3

1500 – AV-1 Post flight inspection & refueling

1600 – AV-1 Instrument access with power

Day 6 1700 – AV-6 Land

1830 - AV-6 No power Instrument Access

2000 – AV-6 Post flight inspection & refueling

2100 – AV-6 Instrument access

Day 7 No-fly day

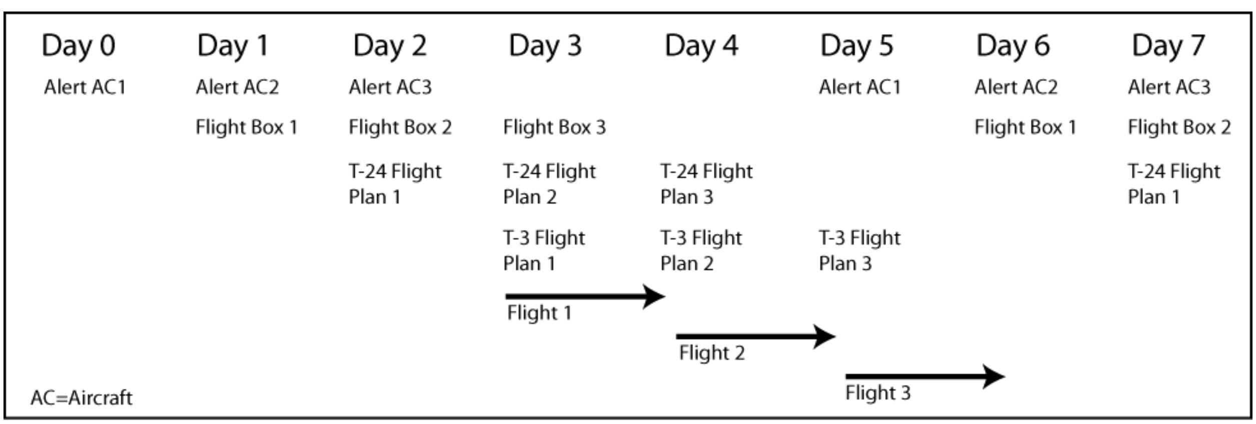


Figure 3-1. Schematic time line for multi-day, multi-aircraft operations.

Text removed for sensitivity.

HS3 must work under the following additional constraints for flight planning:

• The 2 business day deadline for giving the FAA one full business day to review the flight plan means that flights on Saturday-Monday need to have plans (notional box and inbound/outbound routes) sent to the FAA on Thursday. For Tuesday flights, the flight plan can be given to the pilots on Sunday for preparation, with FAA review on Monday.

• Regarding the bullet above, we can plan for an AV-6 flight at 48 h prior to flight, then switch to AV-1 24 h prior to flight as long as it is for the same target in the previously identified region (i.e., no changes in FIRs).

Additional considerations are as follows:

• AV-6 flight plans should account for track uncertainties and should generally not be dependent on flying a detailed pattern centered on the storm.

• Trade-off between sampling larger scales, but only doing a pattern once, versus a smaller-scale pattern that is repeated a second time. The latter option requires being able to effectively center the pattern over the storm, which may not always be possible for AV-6.

• For estimating times for flight patterns, an aircraft speed of 6 degrees per hour can be assumed.

• Although collaborative operations with other NOAA aircraft will be very welcome and a high priority, we must realize that NOAA has its own priorities. Our view is that we will sometimes need to plan flights that will yield useful information in the absence of NOAA collaboration, but that data collection will be enhanced if such collaboration occurs. In 2014, with NOAA's plans to forward deploy to St. Croix/Barbados, the opportunities for collaboration increase substantially.

• Dropping a fairly broad pattern of dropsondes in the first flight with one goal of getting the drops into the global operational models is highly desired. Thus, AV-6, with its dropsonde capability, should generally launch first. However, in a more mature storm, the opposite may be true because of the limited number of past flights for AV-1.

3.1.4 Country Clearances

No flights through Venezuela Flight Information Regions (FIRs) are allowed. No overflight of Cuba or Haiti is allowed, but we can fly in their FIRs. However, the area between Cuba and Haiti maybe too narrow for GH transit (too close to the Cuban and Haitian coast), so access to the Caribbean may have to be from west of Cuba or east of the Dominican Republic. (Fig. 3-2). We do have permission for overflight of the Bahamas, but dropsondes likely will not be possible near the islands.

3.2 Environmental GH sampling strategies

3.2.1 Basic flight patterns

The lawnmower is the primary option because it requires only an approximate centering on the storm center. The patterns are usually flown in a direction opposite the storm motion, i.e., if a storm is moving north, the pattern should move from north to south. The total time required to complete a pattern depends on the number of long transects in the pattern and the spacing (Δx) of the pattern. Figure 3-3 shows an example lawnmower pattern with 12° long north-south legs, 3° spacing between legs, and a 17° return diagonal (back to the NW corner) that would take ~15 hours to complete. The number, length, or spacing of legs would have to be reduced for total ferry times greater than ~9 hours.

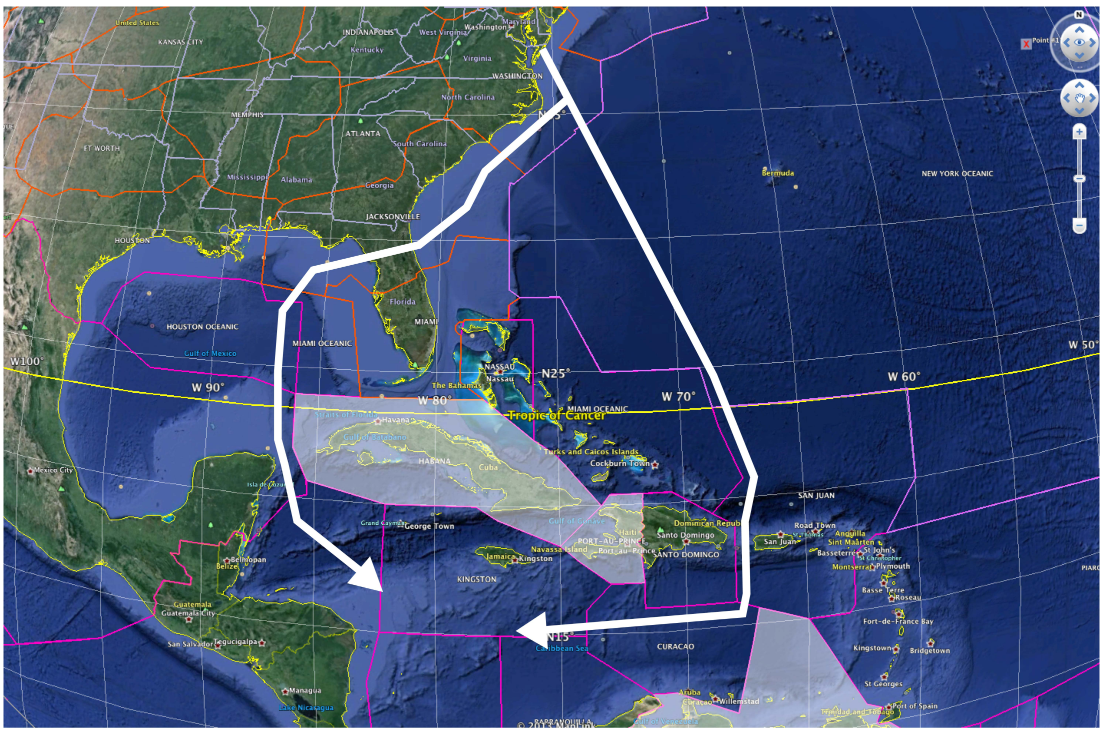


Figure 3-2. Approximate routes to the Caribbean.

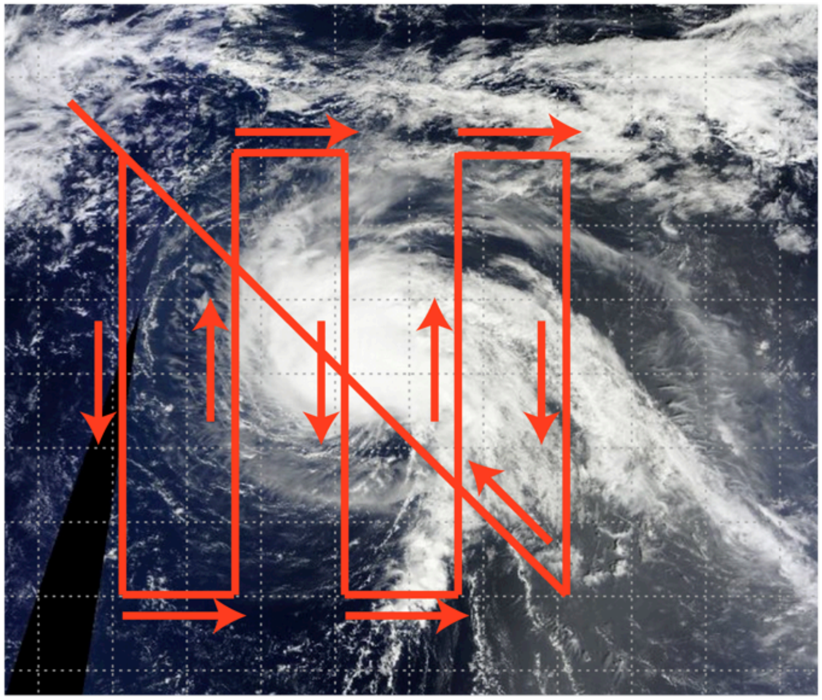


Figure 3-3. Example lawnmower pattern for a tropical cyclone flight. Latitude and longitudes are drawn at 2° intervals.

In 2012 and 2013, the lawnmower pattern was the preferred pattern due to uncertainty about the ability to make flight path and dropsonde location changes during the course of flight. Assuming that such changes are expected to be possible for a given flight, alternate flight patterns with legs positioned relative to the storm center can be considered. One possibility shown in Fig. 3-4 is the rotating figure 4 pattern. This pattern creates radial cross-sections at several different azimuths about the center. Figure 3-4a shows the pattern in a storm-relative reference frame. For a moving storm, flight planning prior to takeoff should estimate a storm motion so that the flight pattern in Earth-relative coordinates can be obtained (Fig. 4-3b).

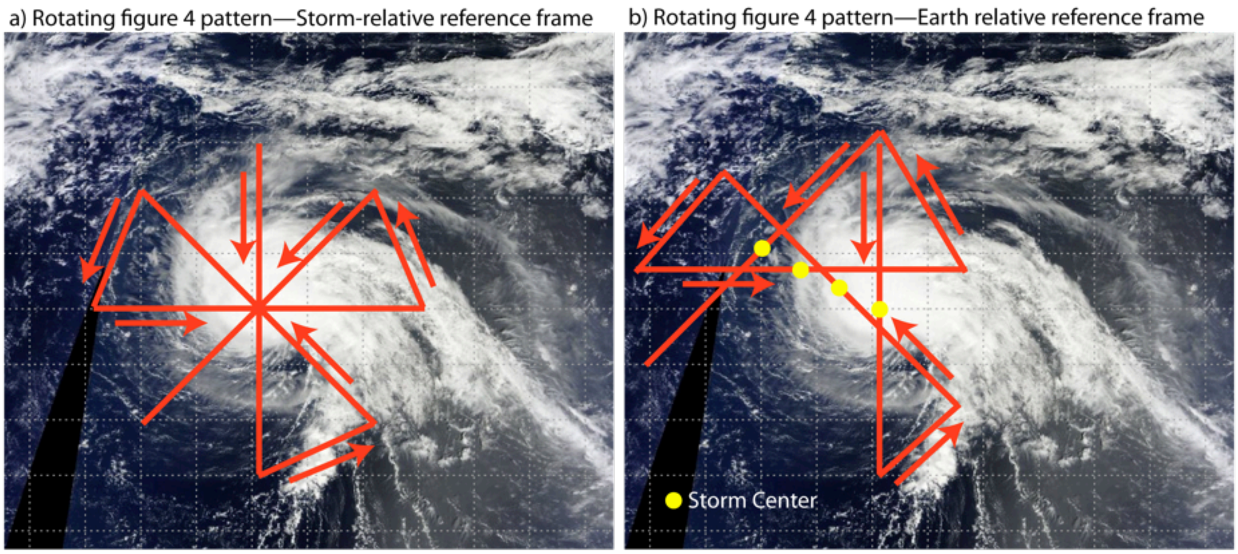


Figure 3-4. Example rotating figure-4 pattern in (a) storm-relative coordinates and (b) Earth-relative coordinates.

3.2.2 Add-on modules

Depending on HS3 and NOAA objectives, additional short modules may be added to the basic patterns described above (if approved by the FAA or other cognizant agency) including:

• A pass across the center of the storm or key portion of the SAL with additional drops,

• A set of passes across an outflow channel (a mini lawnmower or extension of existing flight lines).

• A set of passes across an approaching upper-tropospheric trough (a mini lawnmower or extension of existing flight lines).

• A repeating figure-4 pattern across the storm center in order to get more detailed information on inner-core structure.

Note that turns in a small-scale lawnmower or figure-4 pattern might affect dropsonde data collection after turns, particularly at lower levels. If not originally planned ahead of flight, specification of add-on modules will need to be drawn out in the flight planning software along with dropsonde locations and communicated to the pilots with sufficient time to coordinate with the FAA or other cognizant agency.

3.2.3 Hazard avoidance maneuvers

During AV-6 flights, there are two basic options for hazard avoidance if a substantial deviation is required. The preferred method for lawnmower patterns is to deviate around deep convection and discontinue drops (no new flight plan needs to be filed). This allows the pilot to begin the diversion as close as possible to the area of potential hazardous weather and return to the original flight plan as quickly as possible. Drops would resume upon return to the original pattern.

A second option, only likely for the rotating figure-4 environmental pattern, is to deviate around deep convection and continue drops. This method allows continued dropsonde releases, but will require that mission scientists identify the region to be avoided early enough for the pilots to file a revised flight plan (if needed) and get approval for new drop locations. This option might result in deviations around the convection that are somewhat more conservative and may result in missing a somewhat larger portion of the original flight path.

3.3 Over-storm GH sampling strategies

3.3.1 Basic survey patterns

For AV-1 flights, first some basic points.

- Pilots will file either a circle (of radius 200-300 nmi) or other appropriate shape, with a notional plan, but can make changes as needed within that region;
- There will always be trade-offs between sampling inner-core precipitation only vs. also getting the near-environment. In many cases (e.g., suspected interaction with the SAL or other dry air), it may be highly desirable to begin with a broader survey pattern to determine if dry air is encroaching on the inner-core, followed by smaller-scale patterns focused on the precipitation.
- Prior to flight, the mission science team will determine a default pattern (figure-4, butterfly, or rotating figure 4) that will be used as the default pattern for the flight. This default pattern will often be critical to effective assimilation of AV-1 data sets, so it should be used for a major fraction of the flight. During flight, we can break off from the default pattern to conduct more focused modules over a convective feature (eyewall asymmetry or outer eyewalls/rainbands), but should return to the default pattern after one or two of the convective modules. Convective modules could then be repeated (or altered) later in the flight.

Prior to takeoff, a notional plan should be agreed upon by the mission scientists, with a specified default pattern, specification of likely convective modules and their goals (determined by current structure and forecasted evolution), and the timing and frequency of such modules. The plan should be communicated with/distributed to all mission scientists, payload managers, and flight crew.

In most storms, the default flight pattern will be a variant of the figure-4 pattern shown in Fig. 3-5. The figure-4 offers frequent repeatability in time, but less azimuthal sampling. The rotating figure-4 offers excellent azimuthal sampling, but requires twice as much time to fly and requires that the pattern be inverted once completed and prior to beginning the next pattern (i.e., the pattern might start on the north side of the storm, but the plane exits the pattern on the southwest side when completed). The butterfly pattern is generally preferred as a compromise between obtaining good azimuthal sampling and short duration of the pattern. The pattern finishes at the same point where it begins. Therefore, we will consider the butterfly pattern to be the default pattern for most over-storm flights of mature storms (storms with identifiable centers and circular banding of precipitation). However, the figure-4 and rotating figure-4 can be implemented when appropriate.

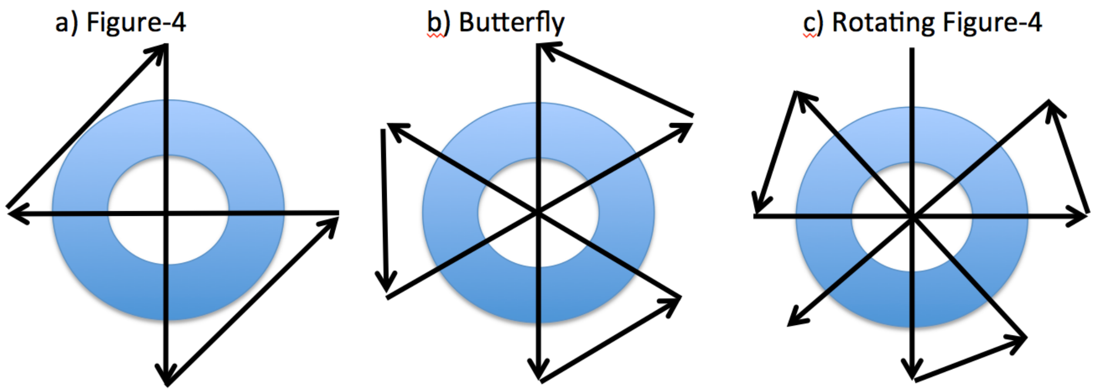


Figure 3-5. Survey patterns for the over-storm GH.

The type of survey pattern to be used during flight should be determined prior to flight and entered into the flight planning software (or an Excel spreadsheet) so that the pilots know the general pattern to be used. The flight planning software can also estimate the drift of the pattern to account for storm motion. However, given uncertainties in the forecasted track, it will be critical that waypoints be constantly updated during flight. The MTS drawing tool can be used to estimate positions of updated lines and determine new waypoints. These new waypoints should be communicated to the pilots (in degrees decimal minutes, e.g., 14° 23.45´´) before completion of the storm crossing prior to the new line. For example, for the butterfly pattern, if the aircraft is heading southbound across the storm, the new waypoints for the southeast-to-northwest leg should be communicated to the pilots prior to the completion of the southbound leg. These updates will be needed continuously during the flight and should be communicated to the pilots (typically via the flight-planning list serve, [*list serve name removed for sensitivity]*, or pilot email) by the mission scientist. At any time, if the mission scientists want to change the length of the legs, the number of legs (i.e., figure-4, butterfly, or rotating figure-4), or the headings, they should communicate such changes to the pilots and provide the new waypoints. Such changes in patterns should not be made frequently except to adjust for storm motion unless dictated by hazard avoidance needs.

When determining new waypoints, mission scientists should ALWAYS check the time stamp on the satellite imagery being used to ensure that the information is current.

3.3.2 Convective modules

On occasion during flight, a prominent convective feature might develop that may be a target for more focused measurements. This situation will likely arise more often in pre-genesis, tropical depression, and tropical storm stages and less often in hurricanes. Hurricane outer rainbands are not a specific target of HS3 except insofar as they may be a boundary between SAL air and the hurricane interior circulation or may represent the beginning of an outer eyewall feature. Figure 3-5 shows a set of examples of convective burst modules: racetrack, lawnmower, and rotating figure-4 patterns. The racetrack module crosses the storm feature with the goal of short duration and/or high repeatability. For a broad feature such as a major rainband, multiple crossing positions may be desirable and a lawnmower or figure-4 module might be optimal. One can orient the legs of the lawnmower so that they are not parallel, but instead approximately cross the storm either along radial legs or perpendicular to the local orientation of the rainband. These patterns can be very useful when the inner-core region cannot be flown due to frequent lightning that is expected to last for an extended time.

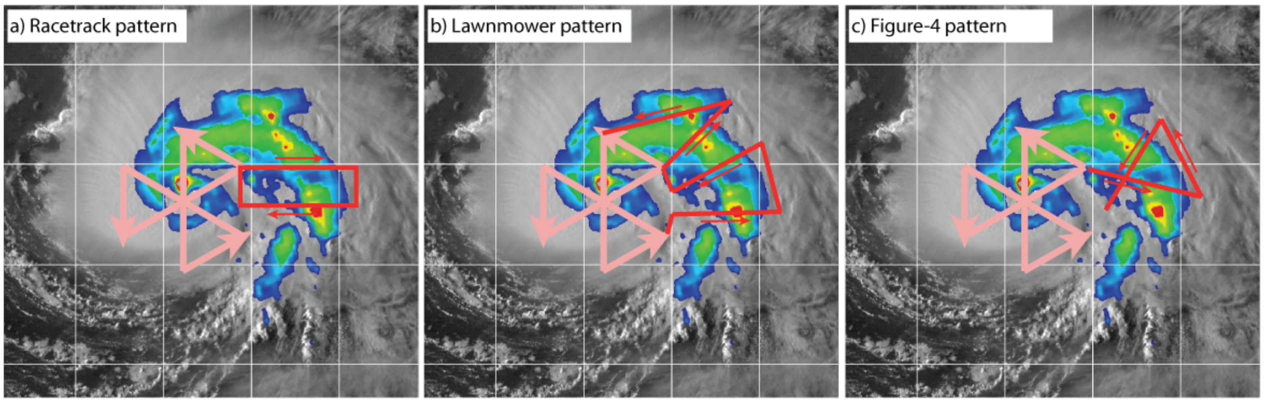


Figure 3-6. Convective feature modules that provide better coverage of convection than the survey patterns.

The convective modules are communicated to the pilots via a series of new waypoints, which can be determined using the drawing tool in MTS. Waypoints for a convective module should be provided in an Excel spreadsheet to the pilots at least 20-30 minutes ahead of the entry into the module. To the extent possible, keep the module within a single Flight Information Region (FIR). A greater lead time may be needed is the module crosses FIR boundaries. As the GH progresses through a module, waypoints for upcoming flight legs can be adjusted to keep the flight legs over the convective feature as long as the points are communicated to the pilots about 5-10 minutes in advance. Mission scientists will need to ensure that the satellite imagery used to determine the waypoints is up to date (and has the time stamp to prove it!). Waypoints should be specified in degrees and decimal minutes.

3.3.3 Determining when to use convective-feature modules

3.3.3.1 Tropical storm and hurricane stages

In general, these convective modules should not be used in the eyewall of stronger storms in which the area covered by the eyewall is likely small and the trajectory path of updraft air is often helical in nature such that the low-level updraft is located well upstream of the upper cold-cloud top. An example is given in Fig. 3-7 for Hurricane Earl (2010) which had a small inner-eyewall, a secondary eyewall, and outer rainbands. The inner eyewall feature is too small for a convective module and would be readily sampled by the butterfly module. In a storm like this, the convective modules would be better suited to the secondary eyewall (if highly asymmetric) or to the outer rainbands. The duration of the module should be kept short (repeated no more than 1-2 times depending on which pattern is used) and, once completed, the GH should resume the default pattern (e.g., butterfly).

Instruments on the over-storm GH require straight and level flight. When setting up flight lines, keep lines sufficiently long and straight to cover the features of interest.

In a mature, more symmetric storm, the butterfly pattern should be the default pattern, with legs sufficiently long to capture the main precipitation features. In the Hurricane Earl case, the pattern shown extends far enough to get all precipitation features. The legs could lengthened on the northeastern side to better cross the outer rainband and then position the line segment between radial legs so that it lies along the around band. The legs on the western side of the storm could be shortened to save time unless SAL or other dry air is present there and possibly interacting with the storm. During flight, the legs could also be shortened to improve the frequency of measurements of the inner and outer eyewalls, but exclude the outermost rainband.

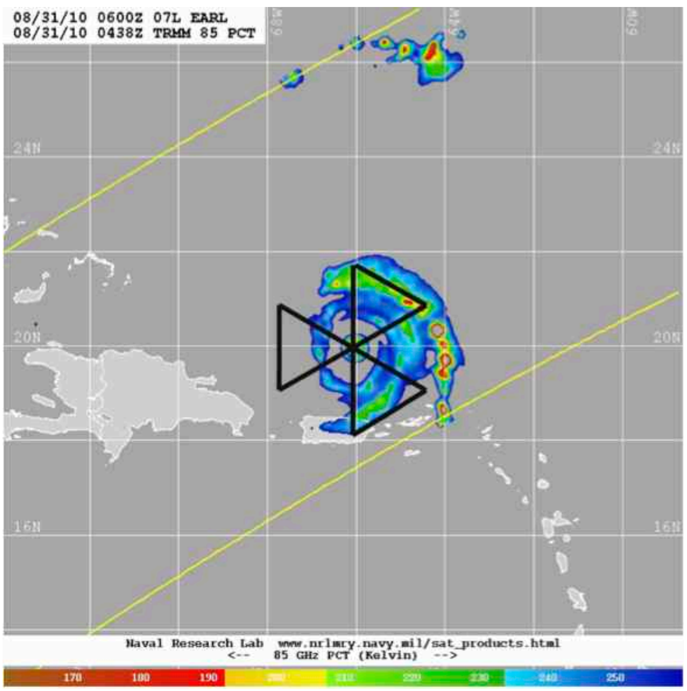


Figure 3-7. Passive microwave image from Hurricane Earl on 31 August 2010.

In a less organized storm or in a case where a SAL or other dry-air intrusion may be occurring (see Fig. 3-8), the initial pattern should consist of a broader survey (radius ~ 300 km; black and red lines in Fig. 3-8) that will sample the region of the likely intrusion and other surrounding near-environmental air. In this pattern, HAMSR data will provide the thermodynamic data needed to detect the dry air. Upon completion of the survey pattern, the leg lengths can be reduced substantially (to 100-200 km radius) in order to focus on the inner-core convection. If time permits, a second broad survey can be performed at the end of the flight.

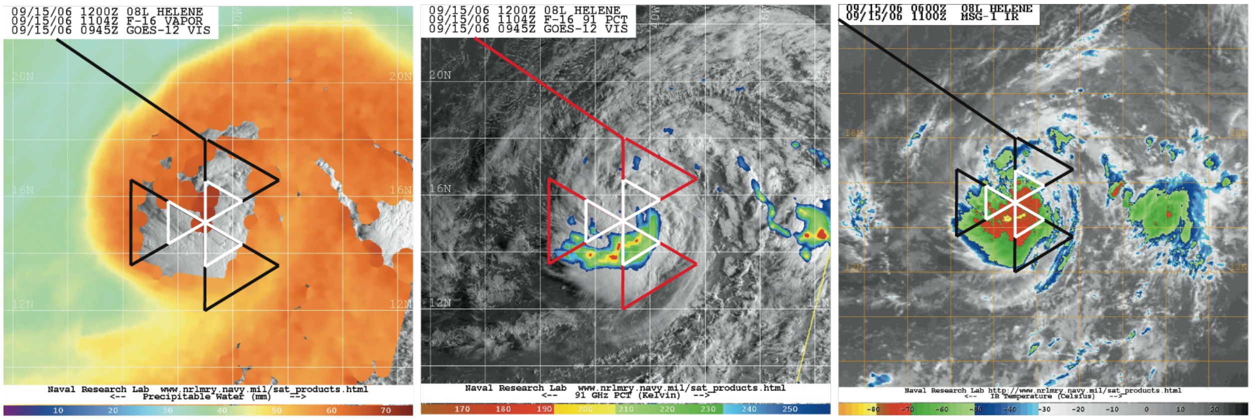


Figure 3-8. Example flight patterns for Hurricane Helene (2006). Satellite image shows (left) total precipitable water, (b) visible image and 91 GHz Polarization Corrected Temperature, and (right) IR cloud top temperature.

Since the larger butterfly pattern (radius of 300 km) takes approximately 4.5 hours to complete, it may be too time consuming to repeat or to even do in the initial pattern. An alternative would be to use a figure-4 pattern (with legs that are not necessarily orthogonal) to sample the dry air in less time, as shown in Fig. 3-9. In this case, the second leg of the figure-4 leads directly into the smaller-scale butterfly pattern.

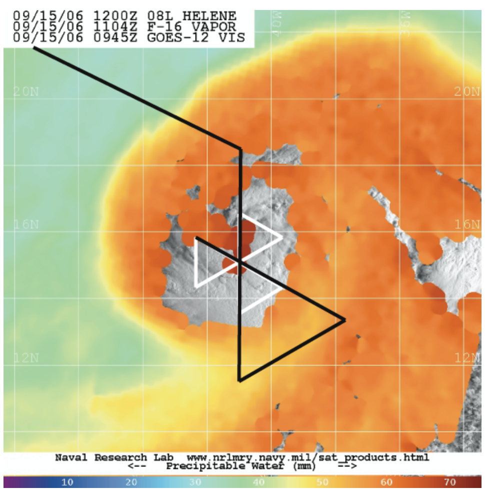


Figure 3-9. Same as the left panel of Fig. 3-8, but showing an abbreviated version of the initial survey of the near environment.

In a highly asymmetric event such as this, a convective module such as a lawnmower module can be flown for a short period to better sample the convective region, but the pattern should then move back to the default module. Focusing just on the convective feature could mean missing critical information on storm structure in the lightly precipitating regions, such as the formation of a cyan ring (Kieper and Jiang, GRL, 2013) that may precede intensification.

3.3.3.2 Genesis stage

During the genesis stage, a storm center may be difficult to identify. In order to provide context for convection modules, the pattern should start with a broad survey that allows HWIRAP to take measurements of the surface wind field (through scatterometry techniques in non-raining areas) and HAMSR to detect dry air layers. Although the center may not be well defined, a figure-4 or butterfly pattern can likely be set up to adequately define the vortex during post processing (not in real time). Following the survey pattern, AV-1 can then be directed to major convective areas to investigate storm structure, as in the example below.

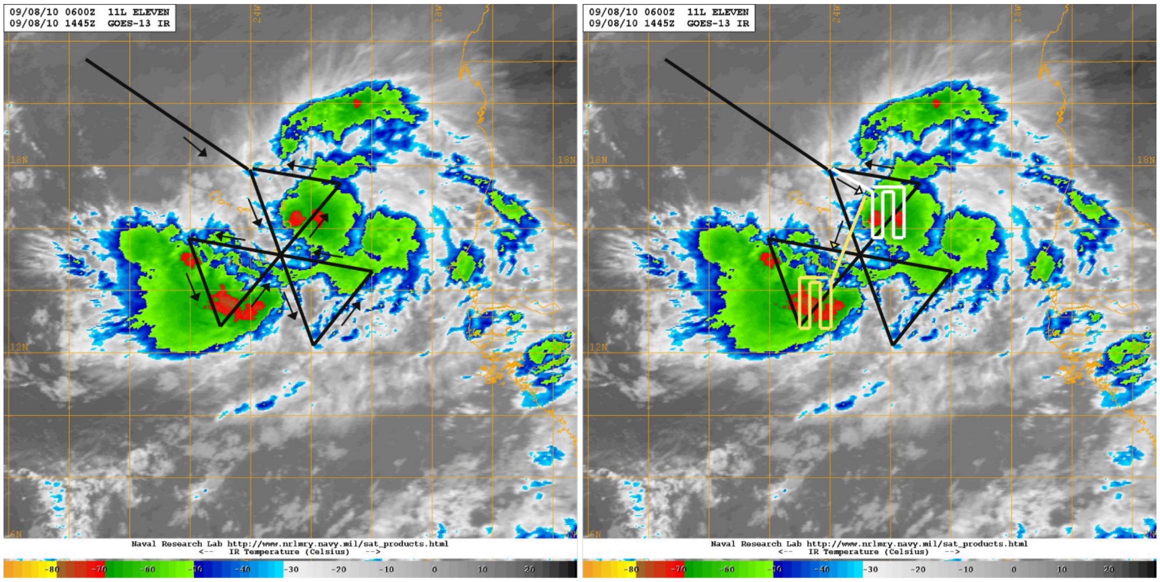


Figure 3-10. Example flight patterns for a weakly organized storm. The left panel illustrates the potential use of a butterfly survey pattern while the right panel adds two convective modules that can be repeated as necessary.

3.3.4 Hazard avoidance

3.3.4.1 Background

Key objectives for mission scientists and flight crew are: (1) Safe operation of the GH over tropical disturbances including tropical cyclones and hurricanes, and (2) obtaining data for HS3 science over the core of as many storms as possible without compromising objective (1).

Original flight rules from 2012, strictly interpreted, would have led to diverting around many deep cloud systems, losing opportunities for obtaining important datasets. Experience, backed up with data obtained in recent field programs, led to modifications of the flight rules in 2013 that enhanced both of the above objectives. Further refinements, as described in section 3.1.3 were put in place for 2014.

Significant turbulence is by far the most probable hazard when flying the GH above tropical storms. That is the reason that past and present flight rules have focused on overflying storms with tops above FL500 (50,000 ft. pressure altitude) or overflying storms with lightning, regardless of storm top, unless clearing the cloud tops by at least 5k to 10k ft. The existence of lightning is currently being used as an indicator of a storm that is intense enough to be a potential turbulence hazard.

3.3.4.2 Experience from NASA's history of overflying tropical cyclones:

Table 3-2 lists most known overflights of tropical cyclones using either the ER-2 or GH. It omits 3 flights by the ER-2 over cyclone Oliver in the Coral Sea in February 1993, and the 5 GH flights during HS3 (2012) mostly over Nadine. No turbulence was encountered during the HS3 flights because the missions were largely focused on the environment and deviated around the only intense convection to occur during the second Nadine flight.

The ER-2 and GH combined, therefore, have made about 35 flights over tropical cyclones, mostly without incident. However, there have been some turbulence encounters that caused concern. On July 17, 2005, the NASA ER-2 experienced significant turbulence overflying the eyewall of Hurricane Emily. There was also significant turbulence experienced by the ER-2 over Hurricane Georges on September 25, 1998, and Tropical Storm Chantal on August 20, 2001. In all of these events, considerable lightning was observed. More details on the Emily event are given below (see pgs. 3-5).

Date	Campaign	Plane	Storm	Reports (From G. Heymsfield field notes)
8/23/98	CAMEX-3	ER-2	Hurricane Bonnie	
8/24/98	CAMEX-3	ER-2	Hurricane Bonnie	
8/26/98	CAMEX-3	ER-2	Hurricane Bonnie	
9/2/98	CAMEX-3	ER-2	Hurricane Earl	A little turbulent at altitude (Heymsfield notes)
9/21/98	CAMEX-3	ER-2	Hurricane Georges	
9/22/98	CAMEX-3	ER-2	Hurricane Georges	
9/25/98	CAMEX-3	ER-2	Hurricane Georges	The pilot Dee Porter experienced considerable turbulence at 63 kft. He reported that the turbulence smoothed out once he increased his altitude to 65 kft. He described the clouds surrounding the eye as a "bubbling caldron."
9/27/98	CAMEX-3	ER-2	Hurricane Georges	No turbulence experienced. Near U. S. Gulf of Mex coast.
8/20/01	CAMEX-4	ER-2	T.S. Chantal	Light turbulence 62-64 kft on second pass
9/10/01	CAMEX-4	ER-2	Hurricane Erin	Small bump over eye reported
9/19/01	CAMEX-4	ER-2	T.S. Gabrielle	Some bumps reported; towers up to 55 kft.
9/23/01	CAMEX-4	ER-2	T.S. Humberto	
9/23/01	CAMEX-4	ER-2	Hurricane Humberto	Two towers came up closer to plane on NW to SE track
9/24/01	CAMEX-4	ER-2	Hurricane Humberto	
7/5/05	TCSP	ER-2	T.D. #4	
7/6/05	TCSP	ER-2	T.S. Dennis	
7/9/05	TCSP	ER-2	Hurricane Dennis	The pilot reported a 38 kt wind out of the east at the ER-2 altitude. He also reported very bad turbulence and some

				overshooting tops (doming) on the last leg across Dennis.
7/15/05	TCSP	ER-2	Pre- T.S. Eugene	
7/16/05	TCSP	ER-2	Pre- T.S. Eugene	
7/17/05	TCSP	ER-2	Hurricane Emily	Severe turbulence
7/24/05	TCSP	ER-2	T.D. #7	
7/25/05	TCSP	ER-2	T.S. Gert	
8/28/10	GRIP	GH	T.S. Frank	
9/2/10	GRIP	GH	Pre-T.S. Karl	
9/12/10	GRIP	GH	Hurricane Earl	
9/16/10	GRIP	GH	Hurricane Karl	
9/24/10	GRIP	GH	T.S. Matthew	

Table 3-2. Listing of NASA airborne overflights of hurricanes and reports, or lack thereof, of turbulence.

How can we recognize a tropical cyclone with a turbulence hazard for GH overflight? Short answer: We don't know for sure. However, the evidence is strong that the most important cause of significant turbulence above storm top is *a very strong updraft reaching the storm top* and penetrating the stable layer usually found there or just above (usually identified as the tropopause, typically at 50,000-54,000 ft). Like a rock dropping into a pond, the updraft penetrating this stable layer generates gravity waves that travel upward and outward from the tropical overshooting top (TOT). The hazard to the aircraft is clear; short-term, strong accelerations in the x, y, and z directions, and marked changes in indicated air speed that can cause control problems.

The obvious problem then becomes how to recognize a storm with potentially hazardous updrafts. This is not easy to do directly because we would first have to overfly with HIWRAP, instantly derive updraft speed below the aircraft, and that would tell the pilots that "they should not have flown there". *So our problem then becomes: What proxies can we use that have a good chance of differentiating a storm with strong updrafts from one without strong updrafts before we overfly it?* Potential proxy variables include storm cloud-top heights and TOTs derived from satellites, and lightning flash rate as depicted from global networks.

3.3.4.3 Tentative conclusions from past storms.

(a) The convective cell that caused serious concern about the safety of the ER-2 in Emily was especially strong for a tropical cyclone environment, probably as strong or stronger than any that was overflown by the ER-2 in 20 previous flights over tropical cyclones. Specifically, what made that cell a safety concern was the magnitude of the vertical velocity of the updraft, at least 20 m/s (4000 ft/minute) at the time the ER-2 overflew it. Such a strong updraft can generate strong gravity waves at and above the tropopause, posing a potential danger to aircraft far above the maximum altitude of the updraft itself or its associated cloud top. Indeed, the ER-2 was probably at least 9000 ft above that cloud top.

(b) Cloud-top height, *by itself*, is not an especially good indicator of the intensity of convection and the likelihood of turbulence. Nor is overflying high cloud tops (i.e. > 50,000 ft) of particular concern unless there is other evidence of very strong convective updrafts beneath those tops in the path of the aircraft.

(c) Lightning, especially lightning with a high flash rate, is well correlated with convective intensity. Lightning with a minimal flash rate (say 1-3 flashes per minute) is indicative of updraft speeds of about 10 m/s in the mixed phase region where charge is being separated, generally at altitudes about 20-25 kft in a hurricane. That is still stronger than typical updrafts (more like 5 m/s). An unresolved issue is whether there is a high and instantaneous correlation between vertical velocity in the middle troposphere (necessary for lightning generation) and near cloud top (more direct concern for overflights).

(d) Tropical overshooting tops (TOTs) indicate significant vertical velocity at a storm's cloud-top canopy that penetrate the stable layer at which surrounding cloud tops have spread out (anvil tops). An indirect indication of vertical velocity at cloud top is the magnitude of the brightness temperature difference between the coldest overshooting pixel (TOT) and the immediate surrounding anvil top. One should be especially cautious about overflying TOTs with deficits of 8-10 degrees K or more for newer cells and smaller values when embedded in existing cold cloud tops. Such tops may indicate updraft speeds > 10-15 m/s. However, we need more research on the use of this convective indicator, because it is suggested that the time scale of an individual TOT (if it is more like a small bubble rather than a deep jet) is normally less than 5-10 minutes. This is significant because the TOT that was a problem for the Emily flight (Fig. 2) was only detected in available GOES imagery as a potential hazard 3 minutes before the encounter.

3.3.4.4 Summary and revised flight rules for storm avoidance

The previous Global Hawk flight rules would probably not have been effective in the single event of greatest concern (the Emily encounter). The cloud top had not reached 50,000 ft until about 3 minutes before the encounter. The TOT and lightning data would not have been available until near the overflight time since this was a *rapidly growing cell*. Avoiding such a cell probably requires continual monitoring of the forward camera and stormscope (if operational), whether or not cloud tops have been exceeding specific limits. However, the 2012 and even the modified 2013 overflight rules as strictly interpreted would have prohibited significant fractions of the successful Global Hawk overpasses of Karl and Matthew that proved not to be hazardous.

We have some newly-developed tools (ACHA cloud-top heights, lightning from long-range networks, and TOTs) to diagnose potential hazardous conditions. However, these must be used carefully and collectively. The focus should not solely be on cloud top height, but also should incorporate indicators of the presence of intense convection, especially if they have persisted in a region of the TC for the past 30 minutes. Notably, these indicators include lightning with flash rates > 1-2 flashes per minute as indicated by current long-range networks, and TOTs, whose critical magnitude may vary with the extent or temperature of the background cloud canopy. Note that MTS does not provide flash rate information. Mission scientists should monitor flashes over multiple time periods to assess approximate flash rate. Any region with both these indicators of intense convection are "red flags" that could trigger the recommendation for avoidance if cloud-top heights are >50 kft or unless they can be overflown by at least 10,000 ft when cloud-top heights are <50 kft.

To have a better chance of avoiding overflight of truly intense "surprise" cells such as the Emily example, knowing that they are not necessarily related to particularly high cloud tops, any region exhibiting a sudden increase in lightning flash rate should be monitored using a combination of the stormscope and the forward video camera if they are operational. If there is evidence of a rapidly growing cell directly ahead of the Global Hawk, the pilots should consider a diversion to avoid it by at least 10-20 nm. The message here is that the satellite and ground-based remote sensing tools may not refresh in time for such cases.

Regions of cold cloud tops that have not exhibited indicators of intense convection as described above should be considered acceptable for overflights as long as the GH stays above cloud top. The occasional TOT or lightning flash should be cause to monitor the region carefully, but not necessarily cause for complete avoidance.

Based upon this analysis, the following rules (see also section 3.1.3) were proposed to GH management and accepted:

Text removed for sensitivity. To learn more about the flight rules, contact GH or ESPO.

Providing an exact definition of "frequent lightning" for the above rules is difficult since observed lightning frequency may depend on system evolution, lightning detection efficiency, and other factors However, as a general guideline for HS3 operations, frequent lightning will be defined as any cluster of strokes in a single area, roughly more than 2 events per 5-minute period and at least 2 consecutive 5-min periods. To be considered "without frequent lightning", an area should be below this threshold for approximately 10 minutes.

Notes:

• The lightning data is currently displayed as strokes, so a few might be plotted together that really all belong to a single flash (multiple strokes, milliseconds apart). If there is a cluster of strokes plotted in one minute, but very few in the preceding minutes, then the lightning is not necessarily cause for alarm. It will need to be monitored to see if the subsequent minutes show continued lightning.

• Detection efficiency is greater closer to the East Coast, so for operations in the Central Atlantic, mission scientists should evaluate any sustained lightning activity and assess whether a deviation in track is necessary.

• When overshooting tops exceed ~54-55k ft, but lightning is absent, the 5k ft clearance requirement means that the GH would have to be above ~60k ft for overflight, which won't be until near the end of the mission, so at most times overflight of such overshooting tops will not be possible. Even if aircraft altitude is sufficient, mission scientists should assess whether greater caution than stated in the flight rules should be taken.

3.3.4.4 Hazard avoidance flight changes

It is the responsibility of the mission scientist to frequently update the pilots about the possible hazards present in a storm. During an AV-1 flight, the mission scientist will generally be providing to the pilots frequent corrections to waypoints in order to align legs across the storm center or to execute a convective module. **It is important that the potential for hazardous conditions also be communicated to the pilots along with the waypoints, preferably in advance of each flight leg**. Please be particularly cognizant of the requirement to avoid significant hazards, as defined above, by 25 n mi (~45 km) and to maintain appropriate cloud-top clearance at all times. MTS now has a tool for adding range rings centered on an aircraft or a coordinate that will prove very useful for steering clear of potential hazards. Please familiarize yourself with this tool (see section 3.4.2).

In the event that the potentially hazardous convection is very isolated so that the 25 nmi deviation does not prevent operations in most of the eyewall region, one option (Fig. 3-11b, left) is a straightforward deviation to the right or left of the convective cell by 25 nmi. The GH simply deviates around the convection and then resumes the butterfly pattern as quickly as possible. This will generally be the preferred option. **Because of the need for straight-and-level flight for AV-1, setting this course correction prior to beginning the flight leg is ideal if the intense convection is seen early enough and is likely to persist.** In the event of expected very persistent (>30 min) lightning, the entire butterfly pattern can be rotated so that the hazardous area is in between the butterfly cross-storm legs. Note, however, that in some situations, the flight legs surrounding the convective event may still require additional adjustments to maintain 25 nmi separation.

In situations in which lightning or overshooting top activity is more widespread (e.g., covering up to half or more of the eyewall, see Fig. 3-11c-f)), then the 25 nmi separation requirement might make sampling the eyewall with the standard modules difficult. In these situations, alternate flight modules can be implemented that sample the portions of the eyewall that are still safe to fly or address other objectives of the flight (dry air intrusions, outer rainbands) until it is safe to return to the default module in the eyewall region. Alternate flight objectives should be discussed prior to takeoff and communicated via the mission scientist list serve *[list name removed for sensitivity]* and the Mission Scientist Exchange message board on MTS so that all mission scientists are clear on the primary and secondary goals of the flight.

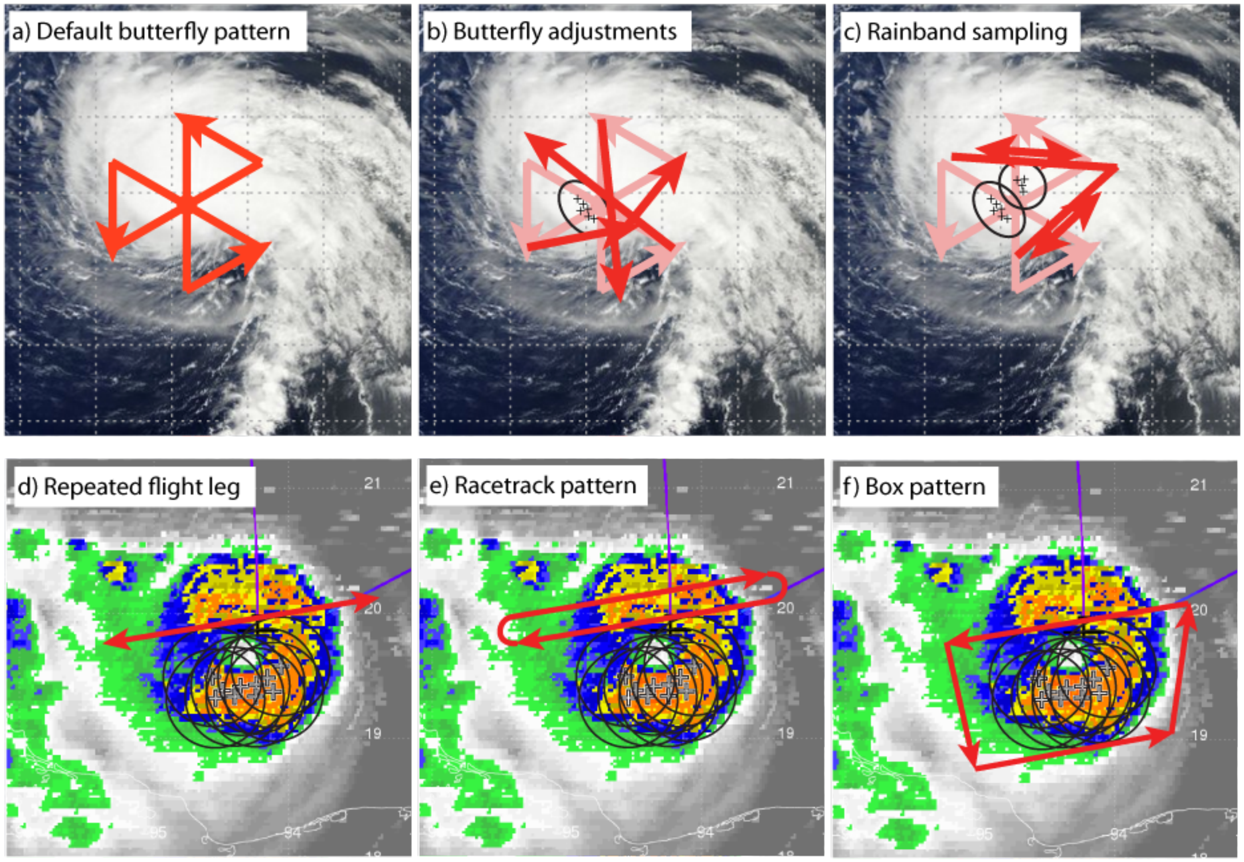


Figure 3-11. Illustrations of possible hazard avoidance maneuvers around isolated significant convection.

3.4 Mission Tools Suite (MTS)

The NASA Airborne Science Mission Tool Suite supports the Airborne Science Program (ASP) and the NASA Science Mission Directorate (SMD) Earth Science Division by providing a suite of web-based capabilities to support Airborne Science Missions. ASP Mission Tool Suite is the ground complement to the NASA SensorNet project, which is developing the airborne networking infrastructure to enable high speed SATCOM of aircraft parameter data, and instrument data during flight missions. The ASP Mission Tools Suite provides a common operating picture for improved situational awareness for all participants in NASA Airborne Science missions from scientists and engineers, to managers, as well as the general public. The intent of the system is to encourage more responsive and collaborative measurements between instruments on multiple aircraft, satellites, and on the surface in order to increase the scientific value of the measurements, and improve the efficiency and effectiveness of flight missions. At its most basic, ASP Mission Tool Suite provides a means for visualizing the position of the aircraft and instruments during the course of the mission. Such information is made more useful when compared with or overlaid upon other datasets and model outputs used for mission planning and science data analysis. Additionally, ASP Mission Tool Suite facilitates communication between mission team members to enable analysis and discussion of multiple data sources to help plan and execute science missions.

The Mission Tool Suite contains a core set of tools that provide Airborne Science Participants with a host of capabilities:

- remotely monitor real-time aircraft location
- view current and archived flight tracks
- ability to add information overlays from a curated product registry
- customized user workspaces
- team communication and collaboration tools
- integrated single and multi-user chat client
- plotting and graphing
- FIR overlay (plan to shade those we do not get as well as those with 72-hr notice requirements)

To access MTS, go to http://mts.nasa.gov/. You can request an account on this page. Please specify the HS3 as the project that you plan to support; you must be an approved team member.

Documentation for MTS can be found at mts.nasa.gov/docs. A "How-To" guide can be found in the HS3 MTS Documents folder in a subfolder called "HOW TO".

All HS3 Mission Scientists are expected to have become proficient at using the MTS. Because Mission Scientists will be responsible for determining new waypoints for center crossings and for hazard avoidance, they must especially familiarize themselves with the MTS drawing tool and the HS3 Products bundle.

The following sections describe different sections of the MTS HS3 workspace.

3.4.1 HS3 Communications

The HS3 MTS site contains a communications page (Fig. 3-12) that includes announcements, links to ESPO web sites, schedules and report information, and other links. The page also contains a list of message boards. The Mission Scientist Exchange message board is of particular importance. Before flight, messages can address the primary and secondary goals of the flight and any particular issues that are anticipated, such as current detection of hazardous weather and possible avoidance strategies. During flight, mission scientists in the GHOC should update the message board for significant events such as flight deviations, instrument issues, insertion of convective modules, and so on. Doing so will allow mission scientists in other shifts to see what is happening while off duty or to get a history of prior events when they show up for duty. Since such events will usually be entered into the flight report, the active mission scientist can easily cut and paste the same entry into the message board.

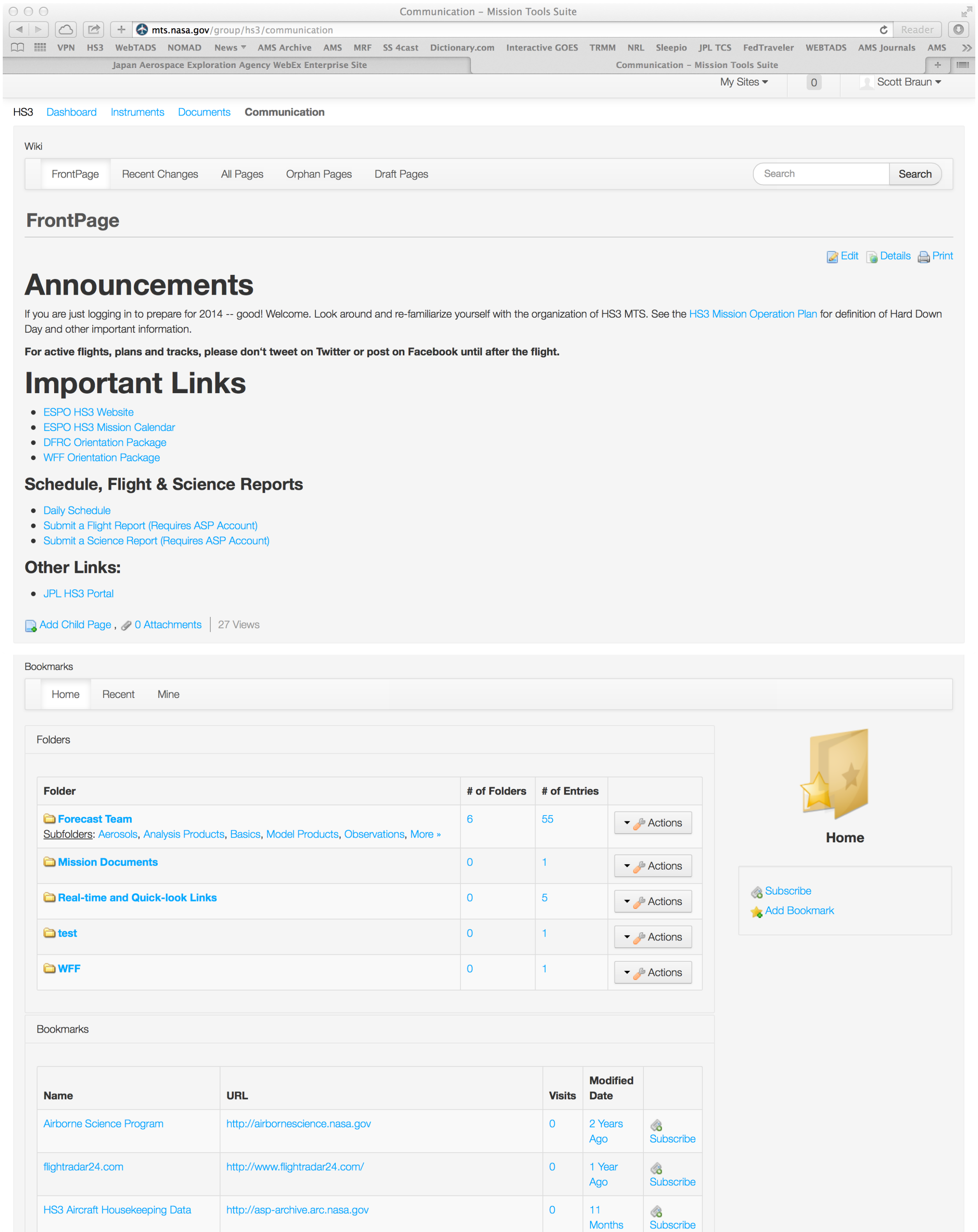


Figure 3-12. MTS HS3 Communications page.

3.4.2 Mission Dashboard

The MTS mission dashboard (Fig. 3-13) is used for flight tracking, hazard avoidance monitoring, real-time data product viewing, and x-chat communications. The dashboard allows for tracking a number of aircraft including the GH and NOAA aircraft. For coordinated flights with the WB-57 (carrying the Yankee dropsonde system), that aircraft should also be tracked.

In addition to aircraft tracks, the dashboard can be used to overlay the tracks of various satellites including GPM, TRMM, TERRA, Aqua, CALIPSO, CloudSat, NPP, and NOAA sounders. SSMI satellites are not currently available.

Products not included in the HS3 bundle can be readily added for display if in the appropriate format. Available formats include KML/KMZ, WMS, and TMS layers. One can also add products from the ASP product registry.

An HS3 bundle of products have been created that includes the products listed in Table 3-3. Of particular importance is the Pilot Situational Awareness bundle that includes cloud-top height (CTH) estimates from the CIMSS GOES cloud-top height algorithm (in pressure altitude coordinates), the CIMSS tropical overshooting tops (TOTs) product, and lightning from the ground-based lightning detection networks; as well as combined CTH/lightning and CTH/TOT/lightning products. CTH and TOTs are updated as new GOES imagery becomes available. The combined products will be updated every minute in order to update lightning information even though the GOES imagery may not have changed. The lightning will display large symbols for lightning within the past 5 minutes and small symbols for lightning within the past 15 minutes. Users must regular check the time stamps on the products

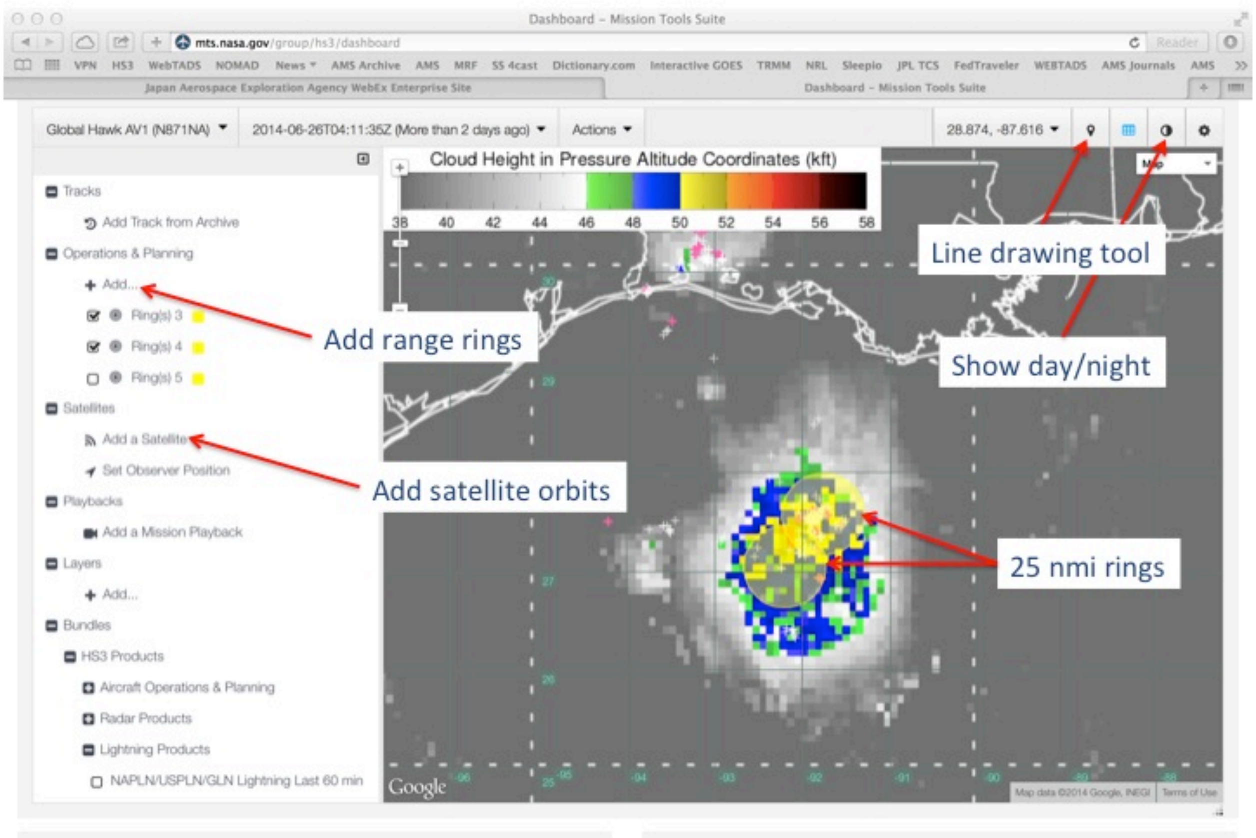


Figure 3-13. MTS HS3 Mission Dashboard.

Below the Dashboard in the default configuration are two windows (not shown). To the left is the x-chat client for real-time communications with other HS3 participants, NOAA, and CARCAH. To the right is the ASP camera feed that can display data from the GH low-light (expected for both AV-1 and AV-6), a downward looking daylight camera (AV-1), the HD-vis camera (AV-6) and real-time products from CPL. Camera views dependent upon whether cameras are functioning properly.

Source	Product
Pilot Situational Awareness	Cloud top heights, overshooting tops, lightning, and combined products that will provide the critical situational awareness for all flights
GOES standard products	IR, VIS, WV
NRL products	Cloud top heights, TPW, AOD, WV, multisat IR, multisat VIS, TPW anomaly
CIMSS products	GOES winds and derived products, SAL analyses, rapid scan products, overshooting tops, cloud top heights
LaRC products	VIS, IR, WV
JPL products	SST, TPW, VIS, IR, WV, AOD, AIRS RH, ASCAT winds, PMW rain
Lightning products	Lightning over the last 60, 30, 15, 5, and 1 minutes
Forecast/model products	NPS pouch, GEOS-5 aerosols, SUNY Albany wave products, NRL model sensitivity products
U.S. radar products	NEXRAD base reflectivity
Aircraft operations and planning	FIR boundaries, temporary flight restrictions, special use airspace, VACAPES test tracks
Aircraft payload	HAMSR, AVAPS, SHIS quicklooks
Planned flight tracks	Planned tracks for the GHs, ER-2, and DC-8
Tropical cyclone tracking	Active TC tracks, forecasted tracks

Table 3-3. List of products in the MTS Mission Dashboard.

3.4.3 Instruments

The Instrument link allows the user to plot time series data from some instruments. The menu includes the low-light and HD-vis cameras, CPL quicklooks, stormscope lightning strikes, and instrument and aircraft status information. Please see the MTS documentation for additional information.

3.4.4 Documents

The documents section of the MTS site includes links to a number of folders for HS3 communication and archival. At the highest level are the HOW-TO folder for MTS, the latest flight plans, and links for documents for each of the HS3 operations years (2011 test flights and 2012-2014 science flights). Within the 2014 folder are additional folders for

• kml flight track files

• CARCAH plans of the day (PODs)

• Contacts and schedules (including mission scientist and forecaster schedules)

• Files for the 2014 dry run (Aug. 4-15)

• Daily flight planning spreadsheets

• Daily forecast team presentations and summaries

• Daily mission science reports

• Operations documents

• Real-time and quicklook products

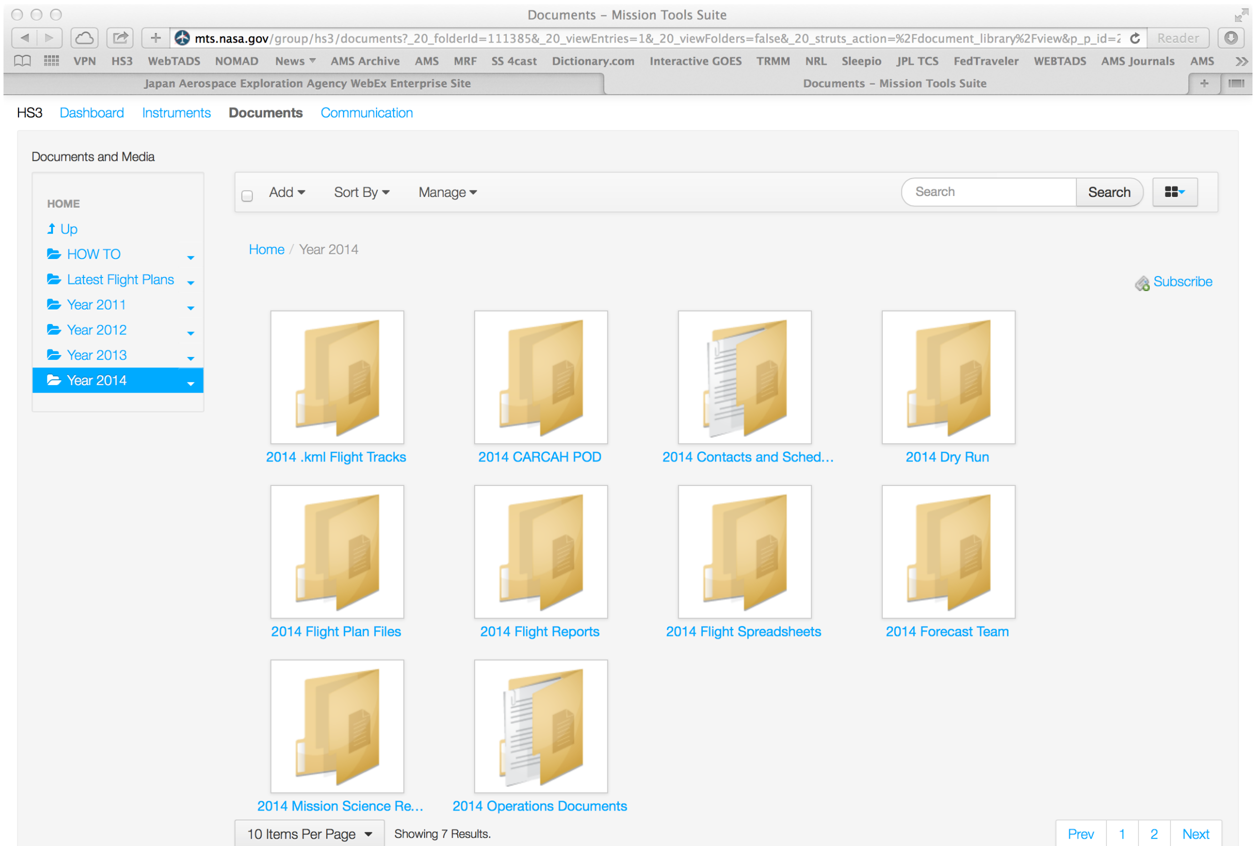


Figure 3-14. MTS HS3 Documents page.

4. HS3 OPERATIONS CENTER (HOC)

4.1 Functions of the HOC

An essential function of the HOC is its role as the center of daily planning activities for HS3 (see Sec. 5 below). These planning activities will provide structure and management for the development of flight plans and conduct of the GH flights, as well as coordination of the NASA GH operations with NOAA flight operations.

4.2 Location and layout of the HOC

For 2014 Aircraft and science operations will take place out of the D-1 hangar as it was in 2013. The viewing area of the runway near the N-159 hangar may be used to view takeoffs and landings. The map below shows the locations of the two hangars relative to the entrance to WFF and the runways.

Maps and room/building layouts have been removed for sensitivity.

5. SCIENCE MISSION PLANNING PROCESS

5.1 Mission scientists' roles and responsibilities in the HOC

Shift 1 0800-1700 UTC (0400-1300 EDT)

- Get report from previous shift mission scientists (in oral or written form) on changes to flight plans since the last shift. Shift 1 MSs have flexibility on their duty cycle on non-flight days (should start no later than 6am to prepare for day's activities).
- If previous flight plan developed during 48-72 h stage, update flight plan and dropsonde locations based upon preliminary forecasts
- Lead 1200 UTC (0800 EDT) forecast discussion and planning meeting.
    - For T-24h, MS makes decision on go/no-go for next day's flight
    - For T-48h, MS makes decision to submit flight plan to pilots for new alert
    - For T-72h, MS makes decision to issue new alert (not to pilots), to begin flight planning process for the next day
- Verify instrument and aircraft status, and brief GH management and pilots on current plans following planning meeting 1300 Z (0900 EDT). If alerting for a flight, provide pilots with initial plan.
- Submit POD to CARCAH by 1330 UTC (0930 EDT) on the day before the flight. Only need to send when there is a flight planned. Include on email:

  Emails removed for sensitivity.

- Send final flight plans to *[list name removed for sensitivity]* the day before the planned flight.
- Hold 1400 UTC (1000 EDT) coordination meeting with NOAA.
- Attend 1430 UTC (1030) "cage" meeting with GH management.
- Create and submit daily morning Mission Scientist planning report and updated flight planning calendar (xls spreadsheet)
- Discuss events with incoming mission scientist for the 1600-0100 UTC (noon-0900 pm EDT) shift.
- Optional: Call in to NOAA HRD forecast discussion at noon EDT.

Shift 2 1600-0100 UTC (1200-2100 EDT)

- Get report from previous shift MS (in oral or written form) on changes to flight plans since last shift. Shift 2 MSs have flexibility on their duty cycle on non-flight days (can shift either toward morning or evening shift).
- Work with flight planner to design new flight plan based upon new alerts (72 h ahead of possible flight)
- Ensure that forecasters are addressing any specific requirements for subsequent flight planning
- Verify instrument and aircraft status, and brief GH management and pilots, if necessary, on updated plans prior to crew departure (1600 EDT).
- Discuss events with incoming mission scientist for the 0000-0900 UTC (2000-0500 EDT) shift.

Shift 3 0000-0900 UTC (2000-0500 EDT)

- Get report from previous shift MS (in oral or written form) on changes to flight plans since last shift
- Lead 0000 UTC (2000 EDT) forecast discussion and planning meeting.
    - For T-12h, MS makes decision on go/no-go for next day's flight
    - For T-60h, MS makes decision to continue the new (T-72h) alert (not to pilots), to update flight planning process for the next day
- If previous flight plan developed during 60-72 h stage, update flight plan and dropsonde locations based upon 00 UTC forecast. This updated plan will be used by the morning-shift MS to make the final submittal to the pilots.
- Create and submit daily evening Mission Scientist planning report and update flight planning calendar (xls spreadsheet).
- Discuss events or prepare written report for incoming mission scientists for the 0800-1300 UTC (0400 am-1300 EDT) shift. Shift 3 MSs have flexibility on their duty cycle on non-flight days.

5.2 Forecast planning process

• Forecast briefings for 2013 were held at 0830 and 2030 LST so that post-analysis of the 0600/1800Z forecast products could be completed. That timing often greatly compressed the schedule for delivering the CARCAH POD, which needed to be completed by 0930 LST. For 2014, we are moving back to the 2012 schedule times of 0800/2000Z.
• Local forecasts provided by WFF forecasters during weekdays, upon special request for weekends/holidays
• If local weather provided by HS3 forecasters, runway directions are 101.9/281.9° for runways 10/28 and 43.7/223.7 for runways 4/22.
• When possible, 2 forecasters per shift. On flight days, a minimum of one forecaster for

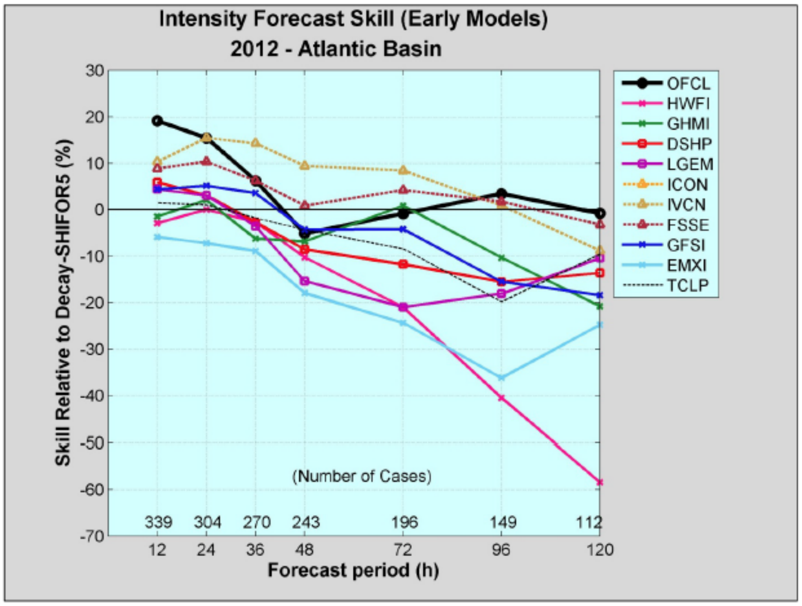
0800/2000 LST briefings and 2 during core science flight hours (usually overnight hours). On non-flight days, night shift can work relaxed hours (shifted toward late afternoon/evening).

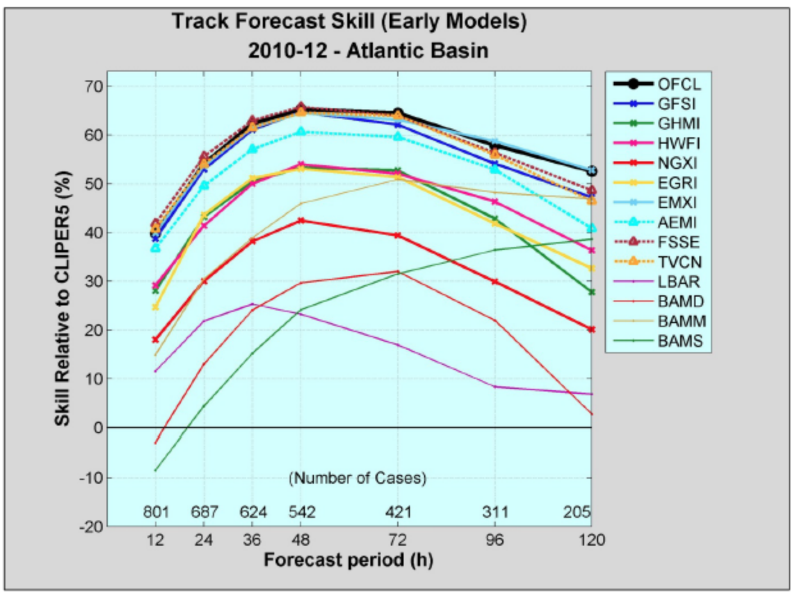
• Forecasters should call in to HRD forecast discussions when possible.

• When preparing tropical cyclone forecasts, forecasters should use the provided forecaster template and examine at least the following core forecast products:

1. Satellite products (GOES/MODIS AOD/PMW/SST)
2. Pouch products
3. SHIPS track/intensity forecasts and probability of RI
4. Operational guidance/ensembles (GFS/ECMWF/GEOS-5/GFDL/HWRF), with focus on track/intensity uncertainty
5. Experimental guidance such as WRF/ENKF system at PSU
6. Operational forecasts – track/intensity and genesis probability

• When examining numerical guidance, forecasters need to be keenly aware of the caveats associated with the products they are examining. There are several locations to get this information, including: http://www.nhc.noaa.gov/modelsummary.shtml and http://www.ral.ucar.edu/hurricanes/guide/. The complete list of tech identifiers can be found at ftp://ftp.nhc.noaa.gov/atcf/docs/nhc_techlist.dat. In particular, forecasters should be aware of which lines represent which products (i.e., statistical, dynamical, consensus, etc.) in the 'spaghetti' plots and have knowledge of the best-performing models or consensus products relevant to the situation. As seen below, recently the best-performing track forecasts have come from the ECMWF and GFS models as well as TVCN and FSSE ensemble/consensus products. For forecasts of TC genesis, global models are preferred (note: SHIPS is not intended for systems below TS strength), and Halperin et al. (2013, WAF) discusses performance of the models over the past few years. Individual model error from current storms (either single-run or average over all forecasts) can be obtained from http://www.tropicalatlantic.com and going to the page for the storm of interest.





• Forecasters should keep in mind that the official NHC forecasts tend to outperform model guidance (see above), so if they significantly deviate from NHC, there should be a concomitant explanation of why. It is also always nice to see where the official forecast track lies within the guidance envelope (e.g., http://www.tropicalatlantic.com, http://ruc.noaa.gov/tracks, or another site that does such overlays that are easy to toggle on/off). Websites such as http://www.ral.ucar.edu/hurricanes/realtime/current/ have spaghetti plots, but the inability to toggle certain track forecasts on/off is cumbersome at times.

• Forecast time ranges:

1. 0-48 h forecasts should focus on cloud system evolution, synoptic environment,

track/intensity guidance, guidance for preparation of final flight plan

2. 48-72 h forecasts should focus on potential targets for immediate flight planning for submittal of plan 24 h later
3. 72-120 h forecasts should evaluate likelihood of potential targets. Should we continue to alert for an ongoing target or are new and better targets likely?

• Key web sites:

Synoptic overview:

Please include and discuss -

- OPC surface analysis from either http://www.opc.ncep.noaa.gov/UA/Atl_Tropics.gif or http://www.opc.ncep.noaa.gov/UA/OPC_ATL.gif
- NOAA SSD tropical cyclone formation probability (objective) http://www.ssd.noaa.gov/PS/TROP/TCFP/index.html and/or NHC tropical cyclone formation probability (subjective) http://www.nhc.noaa.gov
- AOML sea-surface temperature and heat content http://www.aoml.noaa.gov/phod/cyclone/data/
- CIMMS deep layer mean steering analysis http://tropic.ssec.wisc.edu/real-time/dlmmain.php?&basin=atlantic&sat=wg8&prod=dlm5&zoom=&time=
- CIMMS wind shear analysis http://tropic.ssec.wisc.edu/real-time/windmain.php?&basin=atlantic&sat=wg8&prod=shr&zoom=&time=
- CIMMS precipitable water http://tropic.ssec.wisc.edu/real-time/mimic-tpw/natl/main.html
- CIMMS Saharan air layer analysis http://tropic.ssec.wisc.edu/real-time/salmain.php?&prod=splitE&time
- Real-time MODIS AOD analysis http://earthdata.nasa.gov/labs/worldview/

Forecasts and Individual systems

Please include and discuss -

- Latest NHC advisory http://www.nhc.noaa.gov
- NOAA SSD floaters http://www.ssd.noaa.gov/PS/TROP/floaters.html and/or CIMMS storm coverage http://tropic.ssec.wisc.edu/ and/or NRL Monterey satellite products

http://www.nrlmry.navy.mil/tc_pages/tc_home.html

- NCEP operational model fields
  http://mag.ncep.noaa.gov and/or
  FSU TC operational forecast parameters
  http://moe.met.fsu.edu/tcgengifs/ and/or
  Wunderground model/track overlays
  http://www.wunderground.com/wundermap/

- NASA GMAO HS3 forecast (AOD)
  http://gmao.gsfc.nasa.gov/projects/HS3/
- Pouch tracking (if applicable)
  http://met.nps.edu/~mtmontgo/
- Operational model intensity and track**
  http://www.tropicalatlantic.com or
  http://ruc.noaa.gov/tracks/ or
  http://www.ral.ucar.edu/hurricanes/realtime/current/ (toggle unavailable)
- Experimental products (e.g., stream 1.5, etc.; if applicable)
  http://www.hfip.org/products/ and/or
  http://hfip.psu.edu/realtime/AL2012/forecast_track.html and/or
  http://storm.aoml.noaa.gov/hwrfxprojects/?projectName=HFIP+Demo+2010

**http://www.tropicalatlantic.com also offers the ability to load forecast tracks, reconnaissance data, etc. in Google Earth, which can be very useful

5.3 Mission selection

During mission planning, the following criteria should be considered when selecting a target for flight, particularly when multiple targets are available:

1) Relevance
   a. Will it address core mission goals
   b. Will it involve a single flight or multiple flights
   c. Relevance to national interests (major landfalling storm?)
   d. Additional targets expected soon?
2) Storm location and time-on-station (generally should be west of 40°W)
3) Partner (NOAA, USAF) flights
4) Flight difficulties
   a. Too many islands, e.g., Bahamas
   b. Too many FIR boundaries
   c. Too close to coast (perhaps more an issue for the environmental GH)
5) AV-1 or AV-6
   a. When first beginning flights for a particular storm, AV-6 is the preferred aircraft for first flight so that AVAPS data can get into the forecast models.
   b. For other opportunities for multiple flights, AV-1 might often be the preferred option for first flight in the series given the paucity of good AV-1 fights to date.

5.4 Flight planning requirements and interaction with GH pilots

Mission scientists should work with the flight planners to design all flight plans. Flight plans consisting of the general region (and FIRS) and inbound/outbound routes need to be reviewed by the FAA 1 business day prior to takeoff, so this general flight plan, or flight box, needs to be provided to the pilots 2 business days prior to takeoff. Because plans take some time to prepare initially, flight planning should begin within 72 hours of an anticipated flight opportunity. The flight planner will lay out a draft flight track based upon requirements from the Mission Scientists and using available forecast model products to account for forecasted track and track uncertainty in order to produce the best estimate of the potential flight box.

HS3 will have a pilot solely dedicated to the flight planning process. It is easy for mission scientists to get distracted with ongoing flights, so careful attention should be given to whether new flight plans need to be developed for subsequent days. If there is any reasonable chance that a flight might be desired, a preliminary flight box should be drafted and provided to the pilot. Do not let a forecast for bad weather at WFF stop the flight planning process as forecasts may improve.

Draft dropsonde locations need to be provided with the flight plan 24 h prior to AV-6 flights. AVAPS is capable of deploying up to 88 dropsondes per flight and HS3 will have more than 600 dropsondes for the 2014 deployment. Based upon experience from 2012-13, it is recommended that most of the dropsondes be distributed in a grid pattern along the lawnmower module, with an adequate number of dropsondes reserved for intensive series of drops along one or two center crossings or for other add-on modules for outflow jet or trough interactions.

Although draft plans (flight boxes) are due to the pilots 48 h before flight, the flight planning process should begin 72 h before a potential flight (at least for AV-6 flights) so that only small adjustments to the box are needed just prior to the 48-h deadline.

When designing an environmental flight plan, avoid going within 60 nmi of FIR boundaries and 12 nmi from land/islands unless absolutely necessary and try to minimize the number of FIR boundary crossings.

5.5 Notification of CARCAH and other agencies

5.5.1 Format of the Plan of the Day (POD) input for CARCAH

CARCAH will prepare the actual POD. HS3 will provide input in the format indicated below. This input is not needed if no flight is planned during the period.

HS3 Tropical Cyclone Plan of the Day

[Mission Scientist Name]

Valid: 13/1100Z to 14/1100Z September 2012

1. NASA 872 Flight previously scheduled for takeoff Sept 13/10Z has been postponed for 24 hours to diagnose problems with dropsonde release system experienced on flight of Sept 11-12.

2. Current plan for the flight for takeoff Sept 14/1015Z:

a. *Aircraft: NA872*
b. *Storm/Area of Interest: Nadine*
c. *Departure: 0615 EDT (1015 UTC) 14 September*
d. *Mission Duration: 24 h 06 m*
e. *Beginning and end of on-station: 1248 UTC 14 Sep. – 0610 UTC 15 Sep.*
f. *On-station time (period in which sondes are deployed): 17 h 22 m*
g. *Dropsondes deployed: 70 dropsondes*
h. *Altitude: 55,000 to 65,000 FT*
i. *Pattern: Center 28.5N 53.W. Lawn mower, 6 legs, oriented W – E, each one 2 degrees farther south, then one last pass from S – N through center of storm.*

3. *Outlook for Succeeding Day: Flight of NASA 871 on Sept 15, takeoff at 10 UTC for 24 hour mission to study inner-core structure. Flight pattern consists of rotating figure-4s.*

5.5.2 Submittal of the POD and flight plans

Submit POD to CARCAH by 1330 UTC (0930 EDT) on the day before the flight. Only need to send when there is a flight planned. Include on email:

Email addresses removed for sensitivity.

Send final flight plans to the appropriate mailing list the day before the planned flight.

5.5.3 Daily teleconference with NOAA

Each day, an assigned mission scientist will be responsible for participating in a joint telecon with NOAA to discuss HS3 flight plans, get information on NOAA flight plans, and explore options for joint data collection. NOAA flight times are typically tied to operational model initialization times while HS3 flights will usually take off and land in morning hours.

5.6 Mission Science summaries

5.6.1 Daily written reports

Below is an example mission science summary of the morning or evening forecast briefing. The summary should be completed before the end of the shift in which the forecast briefing occurs so that it is available for the next shift to see.

HS3 Deployment Mission Science Planning Summary

Wed Sept 12, 2012 (0800 EDT)

<u>Mission Scientist</u>*: NAME*

Aircraft conditions: *The dropsonde problem was reproduced. Some sondes had loose plastic caps that became dislodged and interfered with the plunger in the release mechanism that resulted in a stuck sonde. The solution has been to be rigorous with quality checking the state of the dropsondes as they are loaded onto the plane. Approximately 2% of the sondes were found to have loose caps. Otherwise, AV-6 is ready to fly. AV-1 is still undergoing integration activities at Armstrong.*

WFF WX: *Forecaster 1 and Forecaster 2 gave the weather briefing. Weather for take-off Sep 14 6:15 EDT is forecast to be fine (risk level - green) but cloudiness is expected to increase for a return (risk level - yellow). For landing Sep 15 6:15 EDT risk level for winds and cloudiness is yellow and should be monitored.*

Targets:

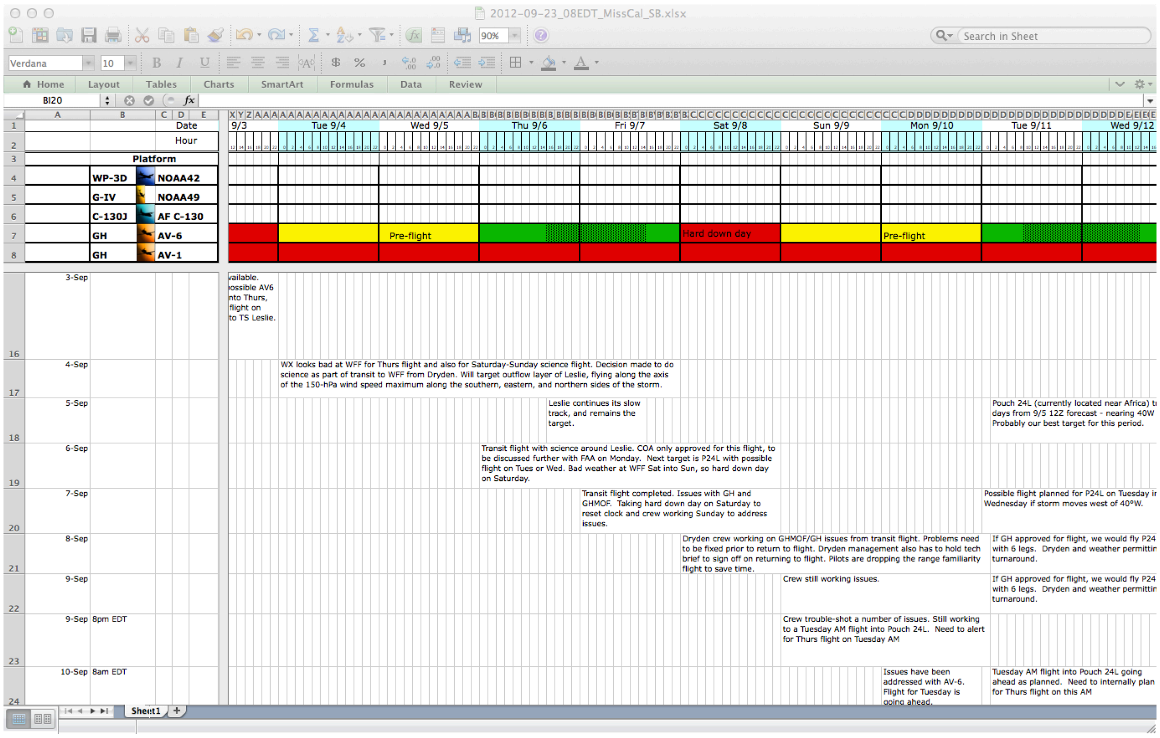
- ***TS Nadine*** *is the target for tomorrow's flight. Most models maintain this at tropical storm strength tomorrow strengthening to a Cat-1 hurricane by Saturday afternoon.*
- ***P27L:*** *In the East Atlantic, remains rather weak and disorganized and models forecast weakening over next 60 hrs.*
- ***P28L:*** *This is now arriving at the coast and is forecast to be around 40°N by Tuesday.*

Plan: *We proceed with plans for a flight into Nadine with takeoff at 0615 EDT (1015 UTC) on Friday Sept 14. Flight plan is a lawn mower pattern, starting with a W-E pass along 34N, progressing south in 2 degree lat. increments ending with the E-W pass along 24N. This is to give the storm time to move northward through the pattern, centered at 29N 53W in the middle of the flight. The last leg will be cut a little short, so that we can return to 24 N 53 W for a final S-N leg through the center (eye?). Duration is a little more than 24 hours.*

After that, the plan is for a hard down day on Sunday and for maintenance on Monday. The earliest possible date for the next flight would be Tuesday (18th) or Wednesday (19th) with P28L being the most likely target. Flight plans should be prepared in the next two days with the plan to share with the pilots first thing on Monday morning.

5.6.2 Daily mission science calendar

Below is an example of the mission science calendar that shows past and current flights as well as future flight options. For each forecast briefing, a high-level summary should be provided within the appropriate Excel cell. Windows at the top, left, and top-left corner keep aircraft time lines, forecast briefing dates, and aircraft descriptions, respectively, visible at all times while the main window gradual moves downward and to the right as the deployment progresses.



5.7 Flight reports

- The Mission Scientist Flight Report is the “real-time” record of events during the flight. It is not a “recollection” that is written days after the completion of a flight. Readers should be able to reconstruct the events during a flight from the MS perspective.
- The mission scientist at the start of the flight is responsible for initiating the report.
- See examples under “recent documents”
- Task 1: Initial discussion on the flight plan prior to takeoff
  - Objectives of the mission, obstacles that the flight might encounter (intense convection)
  - Map of flight track and synoptics/mesoscale overview of the storm and its environment
  - Mission scientist schedule (who is working each shift)
- Save frequently
- Note *all events* of mission importance with the GMT time in front of all statements.
  - Significant meteorological events
  - Payload problems
  - Explanations of flight deviations, etc.

- You can cut images out of various Firefox windows by pressing "Alt" and "PrtScn" simultaneously. <CNTRL> V will paste the image into your document. Alternately, you can use the Windows Snipping tool to select portions of the screen to copy and then save the image. Make sure all images are saved to disk, not just pasted in the document. All images inserted into the report should have at least a brief caption.
- Occasionally do an "instrument" poll to make sure all instruments are working.
- At the end of the flight: last mission scientist uploads the document in mission tools

6. HS3 GHOC-E OPERATIONS

6.1 The GHOC

6.1.1 Interior layout

Figure of GHOC floorplan removed for sensitivity.

Figure 6-1. Layout of the GHOC-E showing the Flight Operations Room (FOR) and Payload Operations Room (POR). **Mission scientists will be at terminals MS3E, MS2E and MS1E.** Each instrument team has two seats. It is recommended that the MS1E handle flight planning issues, MS2E handle hazard avoidance and MS3E work on the flight report. All three are encouraged to save images and take notes if time permits.

6.1.2 Environment

It's often cold in there! Dress appropriately.

6.2 Operations

The POR is the science operations area for the GH. Staffing includes the Mission Scientists (MS), the Payload Manager (PM), the IT specialist, and instruments Investigators (IIs).

- The POR needs to be staffed prior to GH engine start. Late arrivals cause late take-offs
- The POR should be staffed by IIs and MSs during the entire flight. Relief periods and furloughs are allowable per agreement and approval of the PM.
- Each station has an intercom & Windows PC. Several phones are available. Internet connectivity is available, but bandwidth limits and rules on appropriate use apply.
- Laptops are allowed (but discouraged) in the POR – must be scanned by NASA IT personnel.
- Cell phones and cameras are allowed, but in the event of an aircraft incident, all recording devices (laptops, tablets, cell phones, cameras, flash drives etc.) will be impounded.

- Quiet should be maintained for creating an operations-friendly work environment. Head-set mics should generally be "off" except for monitoring the GH and communicating with other team members.

- Guests in the POR require the approval of the PM.

- Food and beverages are allowable, but liquids must be in closed containers. A refrigerator and a Keurig coffee maker are available down the hall.

- There is no POR janitorial service. Police your area and pack out trash.

6.3 Mission science and instrument team duties

For every flight, there will be up to 3 Mission Scientists (MSs) and 3 instrument teams. While MSs will usually work closely together on all aspects of mission, they will each be given a primary mission responsibility.

• The MSs are the decision makers for all science issues during a GH flight. As such, they must be fully aware of the flight's objectives, the status of the payloads, the status of the GH and other coordinating aircraft, and the meteorological situation.

• The lead MS is in charge of coordinating with the PM and pilots for a successful mission outcome. This involves re-routing of the aircraft, decisions on shortening flights (e.g., because of instrument failures), storm passes, dropsonde dispersal, etc.

• When possible, especially during AV-1 flights, another MS takes lead responsibility for updating pilots frequently on possible hazardous weather for upcoming flight legs in situations where conditions warrant. The MSs should provide a regular update (~every hour to as short as every flight segment) of weather conditions along the projected flight path to the PM, mission director (MD), and pilots. This would include cloud tops, lighting, storm location, etc. See section 3.3.4.

• One MS should be in charge of maintaining the flight report, although all MSs can take notes and save relevant data/images.

• The PM is the point of contact between the MD and the IIs. The PM should keep the team apprised of aircraft issues (via headset and chat).

• The MSs and PM are also in charge of updating the team (via headset and chat). Regular updates on the mission progress is necessary for the mission management, mission planner, and later shifts. For example, the forecasters and flight planners follow the flight via MTS, chat, and the headsets.

• The IIs should keep the MSs and PM apprised of instrument performance. Furthermore, the IIs should monitor their real-time products on the mission tools for accuracy and timeliness.

• The IIs are also responsible for notifying the MSs of interesting features that are observed in their data.

6.4 Requesting changes to the flight plan

- Altering the GH flight plan in mid-flight requires coordination amongst the MS, science team (ST), PM, MD, and Pilots (P)

- There are several scenarios for the MSs to keep in mind. 1) A correction that requires immediate action (i.e., a fast developing convective system that will pop over FL500), 2) adjustments to the flight pattern to account for storm motion or insertion of a new module (particularly with AV-1), (3) P or MD adjustments for various reasons, and (4) instrument failures.

- Scenario 1: Hazard avoidance diversion

  – MS notifies MD, PM, and P of the lat/lon location and other details of the burst. Indicate the module diversion that you prefer.

  – Notify the mission forecasters and flight planners, if needed

  – Be aware of regions that you "re-direct" towards. A convective burst seen 60-min prior to arrival may collapse, and a region you re-direct towards may develop.

- Scenario 2: MS changes to flight path

  – Time permitting, MSs should first map out the course correction in coordination with the flight planners and forecasters. Things to keep in mind:

    - Drop patterns and other "location" maneuvers and operations planned for after the course correction may need to be eliminated or altered.

    - Landing times will change – mind the fuel.

  – If you've decided on a course correction, notify the PM, MD, and P that you are planning a course correction. Indicate when you'll have a plan put together and how you'll communicate the plan to them.

  – Pass the course correction to the P. This is best done digitally to avoid transcription errors. Lat/lon should be in degrees and decimal minutes (DD MM.decimal minutes). Distances should be in nautical miles. Pilots will be well briefed on the modules, so it is best to stick to those modules and not try to "free-fly" the GH.

  – Discuss the correction with the pilots to make sure that the correct pathway is being implemented.

  – Notify the Science Team of the course adjustment (via headsets and chat).

- Scenario 3: Pilot adjusted course. The Ps or MD may decide on a course correction for aircraft purposes, independent of the science requirements.

  – The Ps and MD should notify the PM and MSs of the course correction. The MSs or PM should pass this along to the science team (via headsets and chat).

  - The MSs should adjust the flight plan to account for this change, if necessary, and they should quickly inspect the new path for weather.

- Scenario 4: Instrument failures. Does the instrument failure mean the science objectives cannot be met?
  - Can the remaining instruments still provide valuable data?
  - Can the GH return to base sooner (unless there is an emergency, the GH would have to return during daylight hours only)