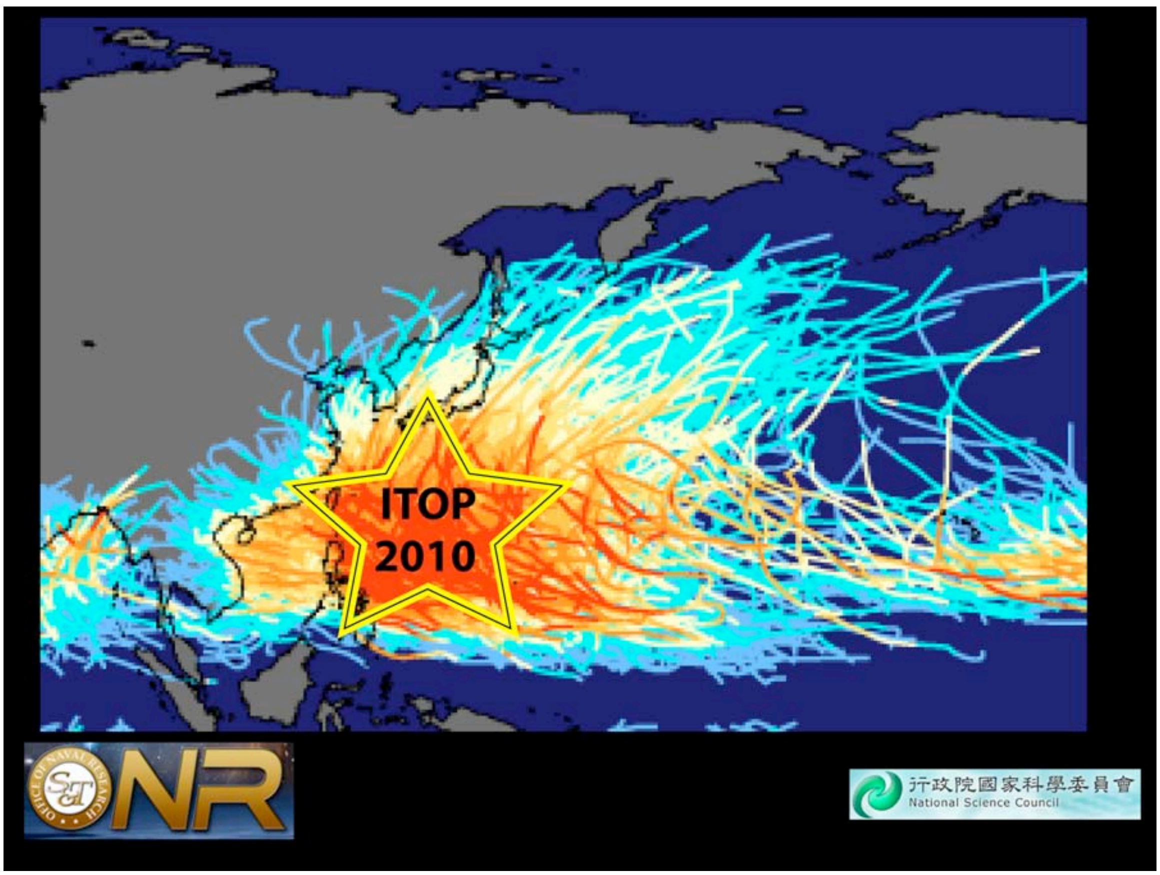
TCS-10 / ITOP

Impact of Typhoons on the Ocean in the Pacific

Experimental Plan
V4.2 July 31, 2010



www.eol.ucar.edu/projects/itop/

v1.0 July 7, 2009 – D’Asaro, Lee, Chen, Graber, Vincent
v1.1 Sep. 16, 2009 – editted by D’Asaro and distributed for comments
v2.1 Nov. 6, 2009 – editted by D’Asaro and distributed to PIs
v3.0 April 9, 2010 – edited by D’Asaro with input from PIs
v4.0 July 24, 2010 – editted by D’Asaro with input from PIs
v4.2 July 31, 2010 – editted by D’Asaro with input from PIs

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1. ITOP Experimental Goals

ITOP aims to study the ocean response to typhoons in the western Pacific Ocean, focusing on the following scientific questions:

- **How does the cold wake of a typhoon form and dissipate?**
  Typhoons produce a complex three-dimensional response of the underlying ocean including strong surface currents, upwelling of the thermocline, intense mixing across the thermocline, the radiation of near-inertial internal waves and the formation of a cold wake behind the storm. The cold wake persists for at least several weeks after the typhoon passage, with a combination of solar heating, lateral mesoscale stirring, lateral mixing by baroclinic instability and continued vertical mixing determining the rate and character of wake dissipation. The wake is also expected to modify the atmospheric boundary layer and the biology and chemistry of the upper ocean, particularly pCO_2. ITOP seeks to measure the ocean response in detail, with particular emphasis on the mechanisms of cold wake formation and dissipation, and to compare these measurements with model results.

- **What are the air-sea fluxes for winds greater than 30 m/s ?**
  Tropical cyclones draw their energy from the underlying warm ocean. Their intensity depends on the exchanges with the ocean; a greater flux of heat and moisture to the storm leads to a stronger storm, but a larger drag on the ocean leads to a weaker storm. These exchanges are poorly parameterized in existing typhoon forecast models leading to errors in the ability of these models to predict typhoon intensity. The first reliable estimates of the exchange coefficients at these high wind speeds, made during the last decade, have shown a dramatic decrease in drag coefficient relative to previous parameterizations. ITOP seeks to make additional measurements, at higher wind speeds and under a larger variety of conditions.

- **How do ocean eddies affect typhoons and the response to typhoons?**
  Ocean mesoscale eddies are expected to modulate the ocean response to typhoons by varying the depth of the pycnocline and thus the intensity and location of the cold wake. This, in turn, will change the air-sea fluxes and thus the intensity of the typhoon. Thus warm eddies act as typhoon boosters, by limiting the amount of cooling in the wake and cold eddies act as typhoon dampers. ITOP seeks to study these interactions in detail.

- **What is the surface wave field under typhoons ?**
  The air-sea exchange depends critically on the state of the ocean surface, most importantly characterized by the surface waves. The wave fields beneath typhoons are complex, with multiple dominant wave directions varying and interacting across the different storm quadrants. Modern coupled air-sea models of tropical cyclones include explicit models of the wave fields from which the air-sea exchange rates are computed. More practically, the enormous surface waves produced by typhoons are of great interest in themselves. ITOP seeks to measure the surface wave field underneath typhoons, to compare these measurements with models and to assess their impact on air-sea exchange and remote sensing signatures.

- **How is typhoon genesis related to environmental factors?**
  Over the tropical western North Pacific, the monsoon environment contains favorable large-scale conditions related to tropical cyclone formation and intensification. The monsoon and tropical cyclone activity vary in response to multiple synoptic-scale and intraseasonal phenomena such as waves in the monsoon trough and the Madden-Julian Oscillation. ITOP seeks to examine how these large-scale environmental factors affect the formation and intensification of tropical cyclones.

- **Typhoon forecasting**
  Although the primary aim of ITOP is typhoon research, much of the data gathered by ITOP will be immediately useful for operational forecasting of typhoons. ITOP seeks to make such data available to all regional forecasting organizations and, as much as possible, work with them to improve typhoon forecasting during the experimental period.

2. Experimental Strategy and Resources

ITOP will focus on typhoons in the Western Pacific Ocean. The experimental domain is approximately the region shown in the figure below, excluding the South and East China Seas. This is climatologically the region of highest tropical cyclone occurrence in the world. ITOP will use a variety of experimental approaches to measure typhoons and the ocean's response to them. The experimental measurements began in 2008, with enhanced measurements through the Spring, Summer and Fall of 2010 and an intensive measurement period in August – October of 2010.

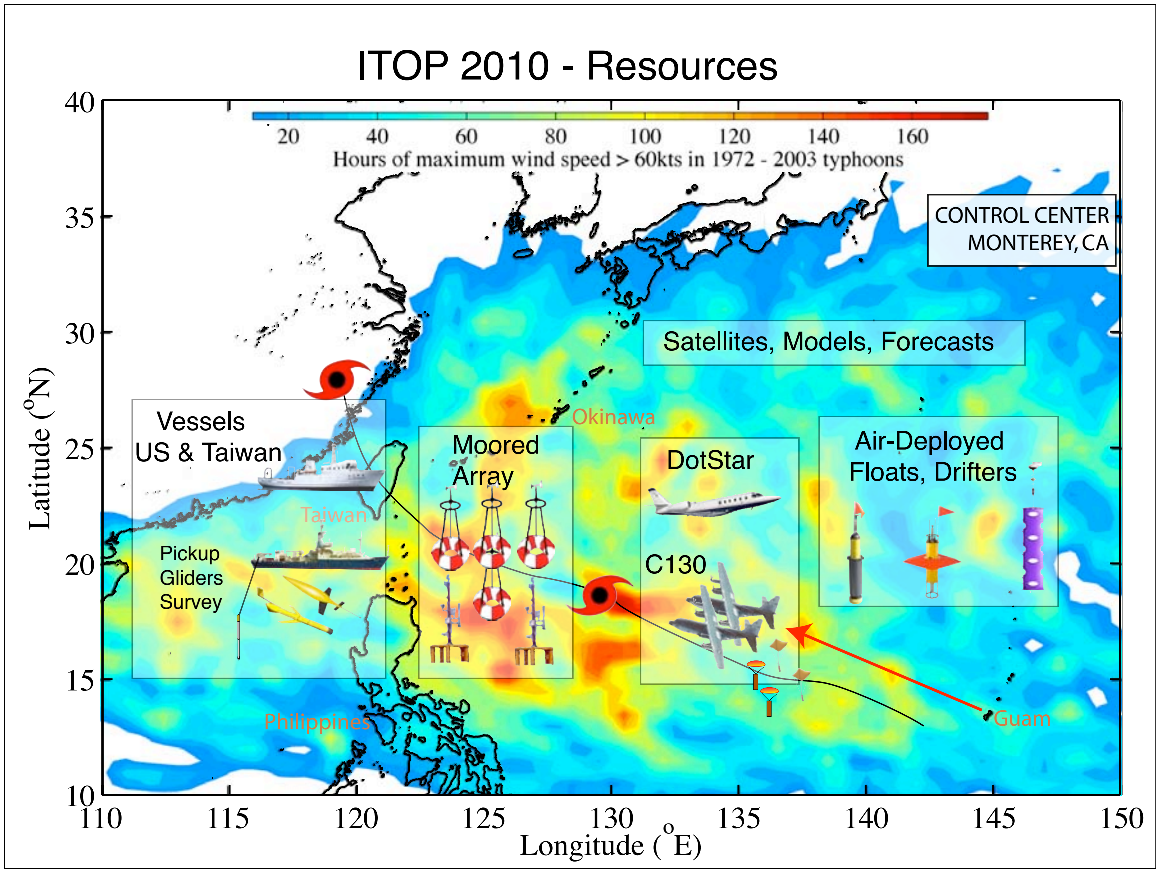


Figure 1. ITOP Resources

A **moored array**, located in the region of maximum typhoon, frequency was deployed starting in 2008. During ITOP, it will be enhanced with additional moorings deployed and recovered by US and Taiwanese **research vessels**. During the intensive measurement period, two **C130**s of the 53rd Air Force Reserve Hurricane Hunter Squadron will be based in Guam. These aircraft will measure the properties of typhoons using onboard sensors and deploy dropsondes. These efforts will complement those of the existing **DotStar** typhoon surveillance program based in Taiwan. The C130s will also deploy arrays of **floats** and **drifters** in front of typhoons to measure the ocean response. After the passage of the typhoon, additional floats and drifters will be deployed into the wake. A **US research vessel** will rapidly deploy into the typhoon's wake, **survey** the wake, deploy additional **gliders** and drifters and recover the air-deployed floats and drifters. The program will be guided by **satellite measurements** of the storm and the ocean and by numerical **models** of the atmosphere, ocean and of the coupled atmosphere-ocean evolution of the typhoons. During the intensive period, operations will be directed and coordinated from a **control center** located at the Naval Postgraduate School in Monterey, California and an **operations center** in Guam.

3. ITOP Moorings

3.1 Long-term Typhoon Moorings

Three ATLAS surface-buoy moorings and two subsurface ADCP-CTD-chain moorings have been deployed in the western Pacific Ocean since March 2009 and will be maintained until the end of 2010 typhoon season (Table 1). Each surface mooring is equipped with a suit of meteorological sensors and a series of more than 10 temperature sensors in the upper 500 m (Fig. 1). Some have conductivity sensors. Each subsurface mooring is equipped with one upward-looking 75-kHz Long Ranger and a chain of 7-8 SBE37 CTD sensors (Fig. 2). Measurements of air pressure, air temperature, sea surface temperature, wind speed and direction, humidity, solar radiation, subsurface temperature and buoy positions are transmitted via Iridium satellites every 2-6 hrs. In August 2010, one more surface mooring and one subsurface mooring will be deployed. A total of four surface ATLAS moorings and three subsurface moorings will be operational during the ITOP IOP.

Table 1. ITOP Mooring Positions and Depths

Site	Longitude	Latitude	Nominal Depth
A2	123° 12.54’E	21° 07.47’N	5656m
SA2	123° 16.28’E	21° 13.94’N	5640m
A1	127° 38.24’E	20° 20.20’N	5628m
SA1	127° 32.00’E	20° 22.46’N	5685m
A3	126° 03.32’E	18° 54.26’N	5680m

Plots of real-time measurements are displayed in Taiwanese URL
http://140.112.68.246/~itop and an US URL
http://kirin.apl.washington.edu/~itop.
These web sites are password-protected. Password, meteorology data, and subsurface temperature data may be provided upon request by ITOP collaborators to Drs. David Tang, Yih Yang, or Ren-Chieh Lien.

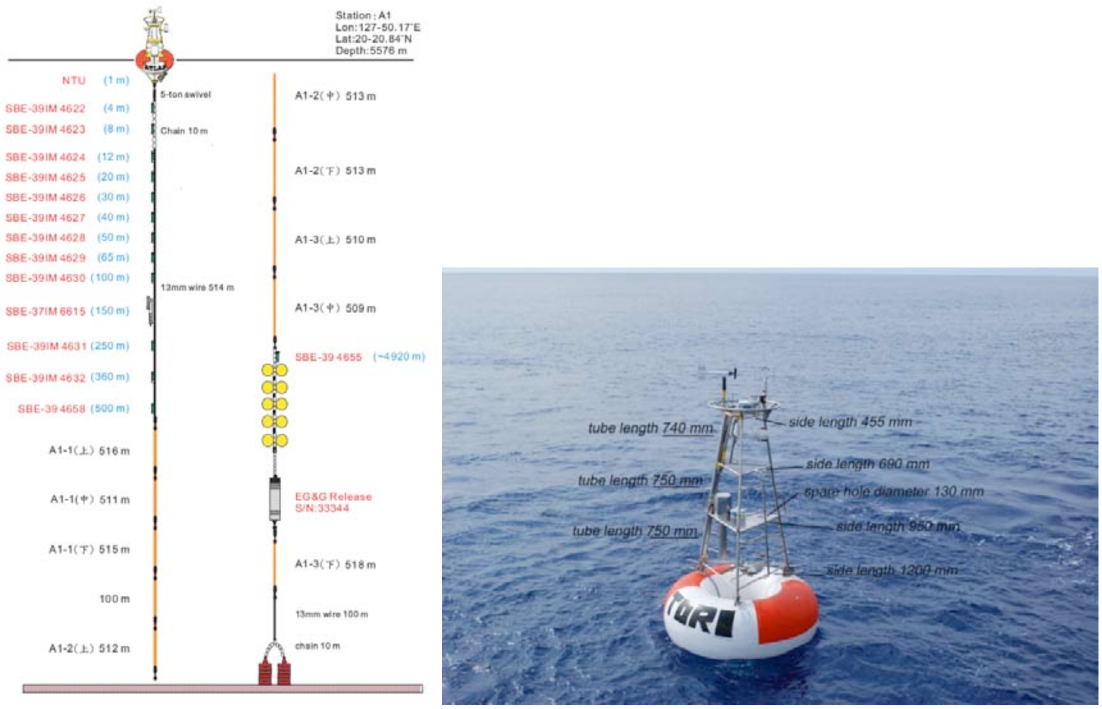


Figure 2. *Schematic diagram of mooring A1 and photo of ITOP buoy. Moorings of A2 and A3 are similar to that of A1.*

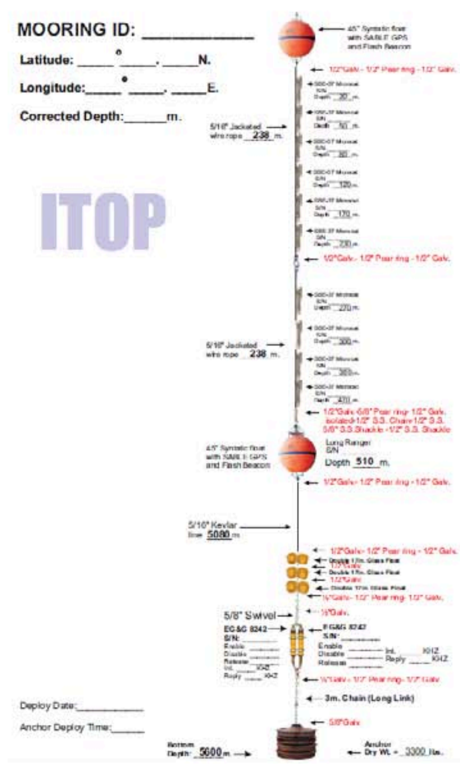


Figure 3. *Schematic diagram of subsurface mooring*

3.2 ASIS-EASI Moorings

The principal objective of the experiment is to observe the air-sea interaction during the passage of a typhoon. Two tandem moorings of an Air-Sea Interaction Spar (ASIS) and Extreme Air-Sea Interaction (EASI) buoys will continuously measure the atmospheric and oceanic properties in response to the forcing by a typhoon. The two sets of buoys will be deployed in pairs, an ASIS tethered to the moored EASI buoy.

Table 2. ASIS/EASI Pair Locations

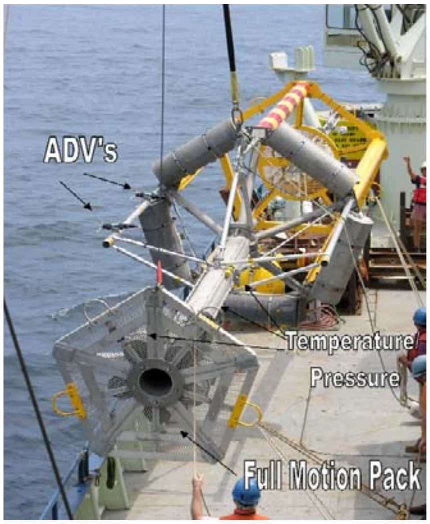
ASIS/EASI #1	21 00 N	127 00 E
ASIS/EASI #2	19 30 N	127 00 E

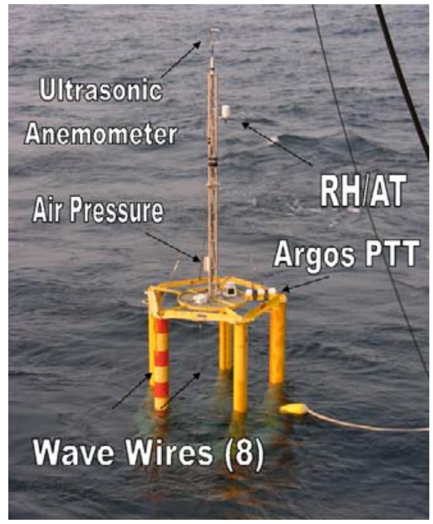
This spacing will be large enough to permit a better chance to capture the influence of a typhoon and measure different regions under the influence of the same typhoon. All two sets of buoys will be equipped to measure air-sea fluxes of momentum, heat and momentum as well as the directional ocean wave spectra. In addition, the buoys will also measure the mean meteorological and oceanographic parameters. Some statistics of the ASIS and EASI data (mean wind speed, wave heights, etc) will be available in near-real time and via ARGOS and/or Iridium.

Table 3: List of equipment to be deployed on EASI and ASIS buoys

Sensors	Measurement	Comments
EASI: Solent R2A sonic anemometer	3D wind, virtual temp.	
Pressure sphere anemometer	3D wind	
K-Gill anemometer	Wind (u,w)	
LICOR LI-7500 CO_2/H_2O analyzer	CO_2/H_2O fluctuations	
CLASP aerosol spectrometer	Sea spray aerosol	
Columbia Res Lab SA-307HPTX	Linear acceleration	
Precision Navigation TCM-2	Compass angle (yaw)	
Systron Donner GC1-00050-100	Angular motion (rates)	
Rotronic MP101A	Humidity, air temperature	
Brancker TL/Huygrun Seamon	Water temperature, depth	
WOTAN (ambient noise)	Wave breaking	
Setra 278 barometer	Pressure	
ASIS: Wave staff system	Surface elevation, MSS	
SonTek Dopbeam current meters	1D current, turbulence	
SonTek acoustic Doppler velocimeter	3D current, turbulence	
Brancker TL/Huygrun Seamon	Water temperature	
Columbia Res Lab SA-307HPTX	Linear acceleration	
Precision Navigation TCM-2	Compass angle (yaw)	
Systron Donner GC1-00050-100	Angular motion (rates)	
Gill anemometer vane	Wind speed	

Air-Sea Interaction Spar (ASIS) Buoy





Description:

The Air Sea Interaction Spar buoy is a surface measurement platform that was developed by the University of Miami, Environment Canada, and Woods Hole Oceanographic Institution in the mid 1990's to make directional wave and air-sea interaction measurements with a minimal drag profile. A typical instrument payload includes a capacitive wave wire array, wind, temperature and current sensors and a variety of other meteorological and oceanographic sensors with an ARGOS satellite uplink for mean measurements. The aluminum framework consists of multiple spar sections in a pentagonal shape (max width approximately 8 ft (2.4 m), length -including tapered section- of 15.5 ft (4.7 m) which contains 8 capacitive wave wires – the directional wave array- that taper down to a single main pipe that is 12 in (0.30 m) diameter and 14 ft (4.3 m) long. At the other end, a meteorological tower rises 10 ft (3.1 m) above the wave array section, giving the buoy a total length of about 40 ft (12 m) in the current configuration. The overall weight, with a full battery and electronics load is roughly 3300 lbs (1495 kg) and can vary by a few hundred pounds depending on the instrument loading.

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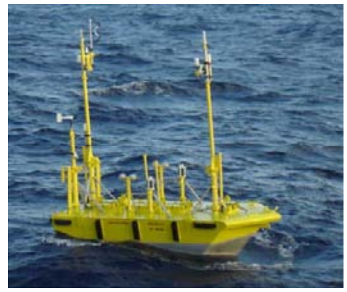
The Extreme Air-Sea Interaction Buoy

The **E**xtreme **A**ir-**S**ea **I**nteraction (EASI) buoy is a scientific measurement platform based on the venerable NOMAD 6 meter buoy design developed by the US Navy and used by NDBC among others. It measures a variety of oceanographic and meteorological parameters that are useful in determining fluxes of momentum and energy across the air-sea boundary- though the platform is versatile and can host a variety of instrumentation.



Dimensions: 10.5 ft (3.2m) wide, 20 ft (6.1 m) long, and 9.5 ft (2.9 m) high without masts, 21-26 ft (6.4-7.9 m) high with masts raised depending on configuration
Excess Buoyancy: approximately 18,000 lbs (8145 kg) for typical payload

Air Weight: 16,500 lbs (7466 kg) fully loaded with payload and masts
Typical Instrumentation Payload: Dual, redundant data acquisition systems (one fore and one aft) with full motion measurement package and data storage only limited by available hard drive capacity (typically several hundred Gb); Gill ultrasonic anemometers, Li-Cor CO_2-H_2O analyzer, Rotronic air temperature and relative humidity, Eppley PIR and PSP radiometers, Setra Air Pressure, platinum resistance thermometer for hull-based seawater temperature, and a variety of autonomous sea-spray, current, temperature, pressure, and salinity measurements made by instruments mounted on the mooring or external hull surfaces.
Telemetry: Argos one-way communications are already in use, with way plans to expand capabilities to two-Iridium communication in 2009.

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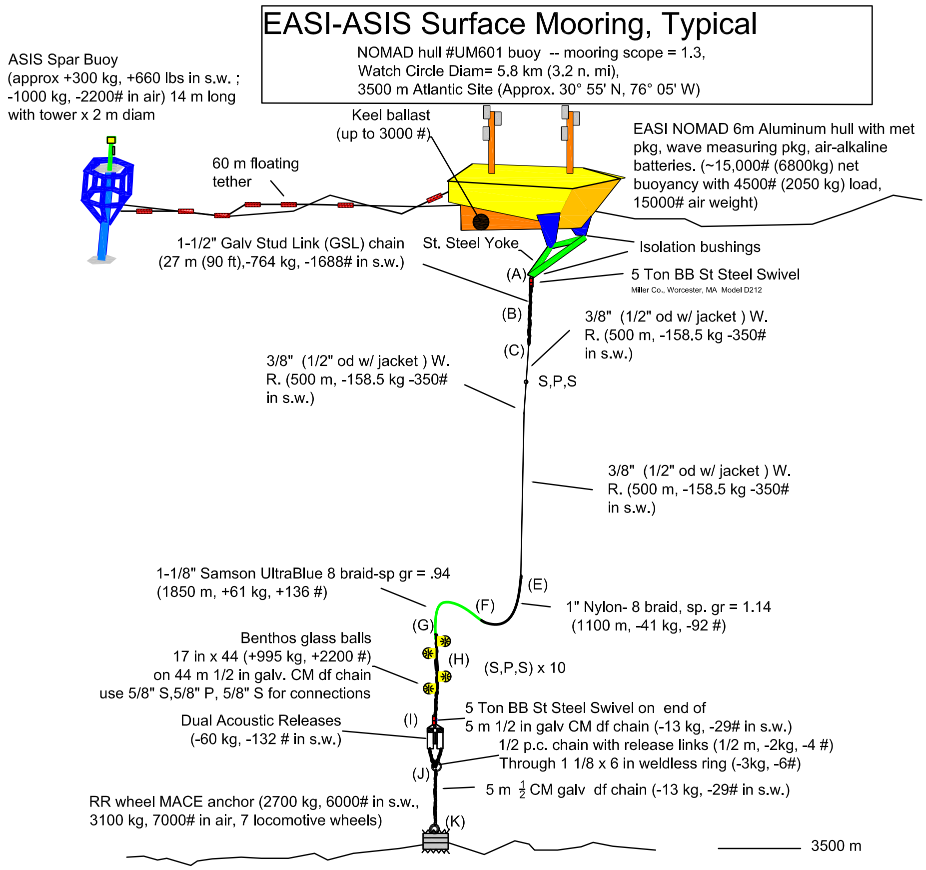

Note: $\frac{1}{2}$ in galv CM df = $\frac{1}{2}$ in galvanized CM long link dock fender chain

Terminations:
[unless noted by letter, all terminations are two 5/8 in galv safety anchor shackles (S) and one 5/8 in galv pear link (P).]

(A) 1.5S,3/4S, BBS,3/4S,1.5S

(B) 1 S, $\frac{3}{4}$P each 5 m (total 5 of each)

(C)1.5S,3/4P,5/8S

(D) 5/8S,5/8P,5/8S (2 connections of 2 x 4 ball groups)

(E) 5/8S, 5/8P, 1-1/4S,1T, tape and coat connection

(F) end to end splice

(G) 1T,1-1/4S,3/4P,5/8S, tape and coat connection

(H) 5/8S,5/8P,5/8S (8 connections of 9 x 4 ball groups)

(I) 5/8S,3/4P,3/4S,BBS, 3/4S,5/8S

(J)5/8S, 1 1/8 x 6 R

(K) 5/8S, 5/8P,3/4S, 3/4P (rod welded to anchor)

S=bolt type safety shackle, P=weldless sling link (pear), R=weldless ring, BBS=ball bearing swivel, T=Galvanized Steel HD Thimble, CS=closed socket

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hardware

item	# req'd (min)
5/8 S---	35
3/4 S---	6
1 S---	5
1-1/4 S---	2
1-1/2 S---	3
5/8 P---	16
3/4 P---	8
1-1/8 X 6 R---	1
ORE RL- (release)	2
5T BBS -	2

EASI-ASIS Buoys in tandem mooring

For ITOP the goal will be to deploy the EASI and ASIS buoys in tandem with the ASIS buoy tethered to the EASI hull and the EASI hull moored to the bottom with an inverse catenary type mooring. Above is an image of the buoys tethered during a recent deployment in the Atlantic.

4. ITOP Aircraft Operations

4.1 C130 Aircraft

Two USAF C-130J aircraft will be operated from Guam during the intensive operations period. These are deployed from a fleet of several similar aircraft from the 53rd Weather Reconnaissance Squadron at Keesler AFB, MS. Aircraft, data system, dropwindsonde and SFMR system specifications are provided in the following Table.

Table 4.

General Specifications	
Aircraft type	WC-130H, J Model Aircraft
Powerplant	Allison Turboprop (4), 4000+ horsepower
Aircraft size	132' 7" wingspan, 99' 6" length, 38' 6" height
Speed	>350 mph
Ceiling	>33,000 ft.
Maximum Range	>4000 miles
Maximum takeoff weight	155,000 lbs.
Crew	6 (pilot, copilot, navigator, flight engineer, aerial reconnaissance officer, dropsondes system operator)
Flight level Data System Specifications	
Improved Weather Reconnaissance System	
Temperature	Rosemount thermistor
Dewpoint	Edgetech 137-C3 dewpoint hygrometer
Altitude	Radar altimeter
Pressure	AirResearch Pressure altimeter
Winds	Multiple pressure and navigation parameters
Position	Global Positioning System (GPS)
Sampling rate	1, 10 second selectable archive rates.
Dropwinsonde System Specifications	
Sonde system	AVAPS-II, Vaisala RD-94
Sonde expendable size	16" x 2.75" (diameter), 323g
Sonde fall rate	10.5 m/s, 2100 ft/min (depending on altitude)
Sonde position	GPS triangulation – 2Hz
Sonde winds	GPS derived with drift – 4Hz
Other measurements	Pressure, temperature, humidity – 2Hz
Data system	Relay to aircraft. Edited and formatted message to ground following end of each drop via satcom.
SFMR system Specifications	
Frequency	4.6-7.2 GHz
Channels	8
Mounting	Wing Pod
Output	Wind Speed and Rain Rate

Data system	Formatted message to ground via satcom
AXBT System Specifications	
Frequencies	Sonobuoy - UHF
Channels	3 AXBT, 1 AXCTD
Storage	Digital and backup analog tape
Data System	Post-flight processing and distribution via GTS

The C130's to be operational from August 20 to October 20, 2010. A total 300 flight hours available, 200 up to October 1 and 100 after October 1. About 800 dropsondes and AXBT will be available.

4.2 DOTSTAR aircraft

ITOP operations will be coordinated with the Taiwanese DOTSTAR program when appropriate. DOTSTAR uses an ASTRA-SPX aircraft with the following specifications:

Table 5

Flight time: 6 hours	Flight height: 43,000 feet
Flight speed: 720 km/hr	AIDC crews: 3 persons
On-board scientists: 3 persons	Instrument: Airborne Vertical Atmosphere Profiling System (AVAPS), Flight level data, satellite phone

Contact information for DOTSTAR

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4.3 Air-deployed Floats and Drifters

Lagrangian floats – PI Eric D'Asaro

A total of 10 Lagrangian floats will be air-deployed from the C-130 aircraft in 'L-size' boxes. After deployment, the floats will make a short profile, surface to relay their position and then slowly profile and settle onto a deep layer for about 12 hours, in order to equilibrate to the water. They then move upward into the surface boundary layer and follow the three-dimensional motion of the water parcels. After about a day they surface to send preliminary data and a position and then resume their boundary layer mission.

After the storm has passed they repeatedly profile and drift in the boundary layer, surfacing about once a day as shown in the figure below.

All floats measure pressure at two positions along the float at 1 Hz (to infer float depth and surface wave spectra) and temperature and salinity at the float bottom every 30 seconds. There will be 3 variants:

- 4 Gas floats – also measure broadband (30Hz-50kHz) sound, oxygen and gas tension. Label *'LGxx.'*
- 4 Vector floats – also measure temperature and salinity at the top of the float (1.4 m above the bottom sensors) and velocity relative to the float and pressure at 16 Hz, 0.5m below the float bottom, and broadband (30Hz-50kHz) sound. Label *'LVxx.'*
- 2 Wake floats – also measure downwelling PAR and downwelling E490, chlorophyll fluorescence and optical backscatter. Label *'LWxx.'*

Much of the data will be transmitted in near-real time. However, the floats will need to be **recovered** to obtain the high-frequency pressure, shear and sound data. Contact: Eric D'Asaro (dasaro@apl.washington.edu) or Michael Ohmart (ohmart@apl.washington.edu) 206-543-1300

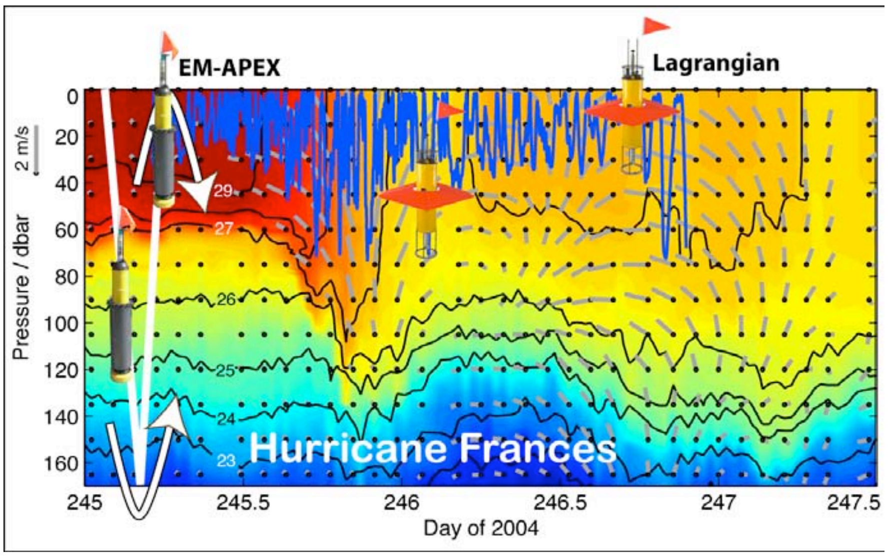


Figure 4. Missions of Lagrangian and EM-APEX floats.

EM-APEX floats – PI Thomas Sanford and Ren-Chieh Lien

A total of 14 EM-APEX floats will be air-deployed from the C-130 aircraft in 'L-size' boxes labeled *'LExx'*. These floats repeatedly profile from the surface to 200m with occasional deeper profiles at a speed of about 1 m/s. They measure temperature, salinity and velocity along the profiles with a resolution of about a meter, resulting in the well-resolved evolution of these quantities shown in the above Figure. The floats report data and a position at the top of each profile, in near-real time. Most of the data is transmitted in near-real time. **Recovery** of most of the units is desirable for use in future ONR programs. Contact: sanford@apl.washington.edu lien@apl.washington.edu (206) 543-1300

Typhoon Drifters – PI: Peter Niiler and Luca Centurioni

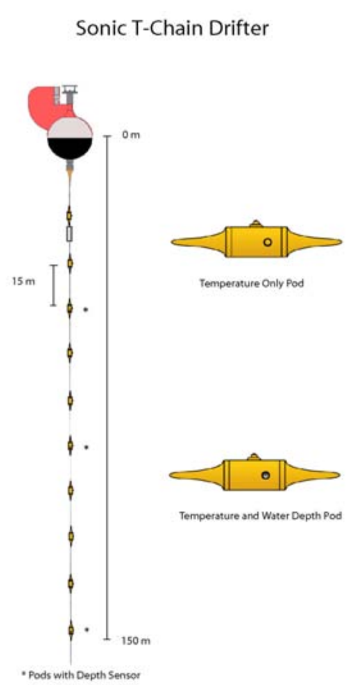
A total of 65 drifters will be air-deployed from the C130 in 45 boxes (42” cubes on pallets). All will be tracked by Argos, measure sea surface temperature (65), air pressure (45) and provide these data in near real time (2 hour delay) to the GTS system by Service Argos. There will be 3 variants, all with additional measurements:

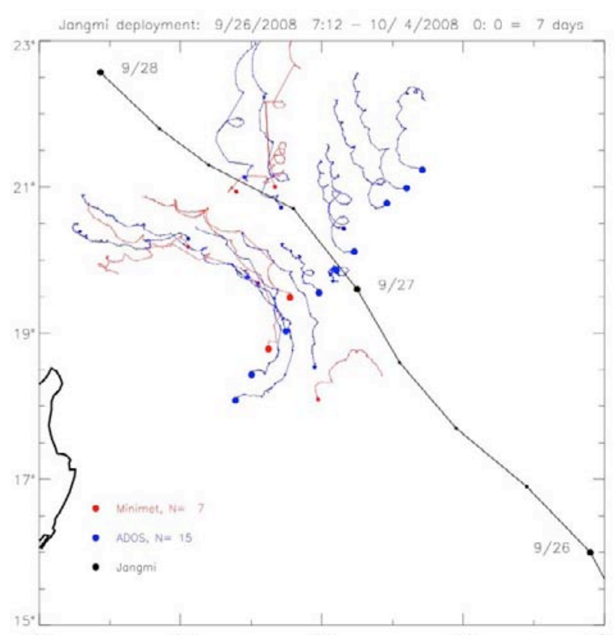
- In front of Typhoon deployment: (ADOS/SVP-B – 20 boxes with 2units each). ADOS (“Sonic T-Chain” schematic drifter below) also measures wind speed and direction and subsurface temperature every 15m to 150m. Expendable
- Wake deployment: (SVP-T(z) – 20 boxes with 1 unit each). Measure temperature at 11m and 19m. Expendable.
- Wake deployment: (Super-drifters – 5 boxes with 1 unit each) Super-drifters also measure wind speed and direction, downwelling radiation, temperature and 3-d velocity in variable resolution at 30 locations to 150. Subsurface data will be returned via IRIDIUM satellite phone and stored within drifter. Superdrifters will need to be **recovered**.

In addition to the GTS site for data that is maintained by Service Argos, SST, air pressure, wind and 15m resolution subsurface temperature will be displayed in near real time on the MBARI web site.

The C130 aircraft can carry 14 drifter boxes or 10 boxes if AXBT’s are also being deployed (Jangmi deployment in TCS- 2008). The aircraft cannot penetrate a storm with the boxes on board. AXBT’s cannot be launched until after the boxes have been deployed.

Contact: Peter Niiler (pniiler@ucsd.edu. 858-534-4100) or Luca Centurioni (lcenturioni@ucsd.edu. 858-534-6182)





4.4 Operations overview

The aircraft operations will have the following goals:

1. Conduct surveillance on developing storms
2. Deploy oceanographic floats and drifters ahead of storms
3. Conduct reconnaissance into storms passing over the oceanographic array
4. Deploy oceanographic floats and drifters into the storm wake
5. Study ocean-storm interactions using AXBTs and dropsondes
6. Make detailed meteorological studies of storms

The typical sequence of storm flights is shown in the figure below

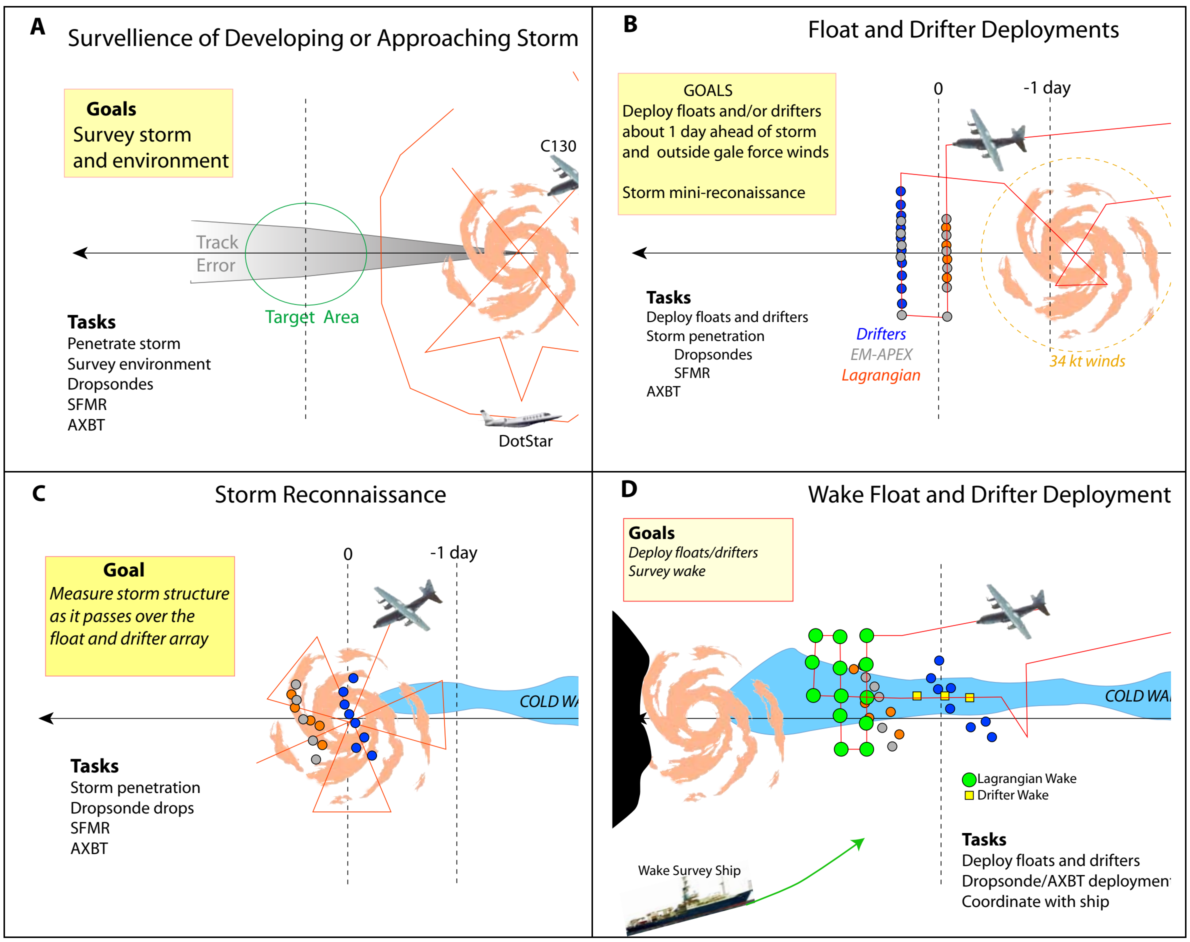


Figure 5. Typical sequence of aircraft operations: A. Surveillance flights are made ahead of the storm. B. Floats and drifters are deployed ahead of the storm. C. Reconnaissance is made into the storm. D. Floats and drifters are deployed into the wake.

As a suitable storm enters or develops in the operations area, a series of surveillance flights will be targeted to better characterize the storm and to improve forecasts of its track and intensity. If the storm is near Taiwan, this will be done cooperatively with the Taiwanese DOTSTAR aircraft. A decision to deploy oceanographic sensors into the storm will trigger the following sequence of flights.

One or more lines of floats and drifters will be deployed across the expected track by a C130. The lines will provide measurements on both sides of the storm and allow for the expected uncertainty in the predicted storm track. Deployments will be made 24-26 hour hours ahead of the storm passage over the deployment area and in winds below gale force.

Once the deployment is made, one or more reconnaissance flights measuring the structure of the storm as it passes over the oceanographic array are required. Some of these measurements can be made on the return flight from the deployment, as shown in Fig. 5B. The main reconnaissance missions, however, will be done on dedicated mission using a butterfly or similarly dense patterns over the storm (Fig. 5C).

The typhoon will mix the underlying ocean creating a region of colder water called the “cold wake” typically forming to the right of the storm track. Additional flights will focus on measuring this region. Floats and/or drifters will be deployed into the wake, most likely near the previously deployed array. One or more additional flights may survey parts of the wake not sampled by the floats and drifters using AXBTs. These flights may be coordinated with survey work by the *R.V. Revelle* in the cold wake.

Dedicated meteorological and storm-ocean flights will also be conducted, particularly on storms in which floats and drifters are not deployed. These flights will use dropsondes, AXBT and SFMR measurements.

Depending on the storm location, it may be appropriate for some flights to recover to Kadena AFB on Okinawa rather than recovering to Guam. For example, the aircraft conducting the buoy deployment flight (Fig. 5B) might recovery to Guam and then conduct a storm reconnaissance flight (Fig. 5C) the following day.

4.5 Catalog of Float and Drifter Deployment Scenarios

The following pages show some of the expected float and drifter deployment scenarios. Actual deployments may differ in detail from those shown. Other variations, not shown here may also be required.

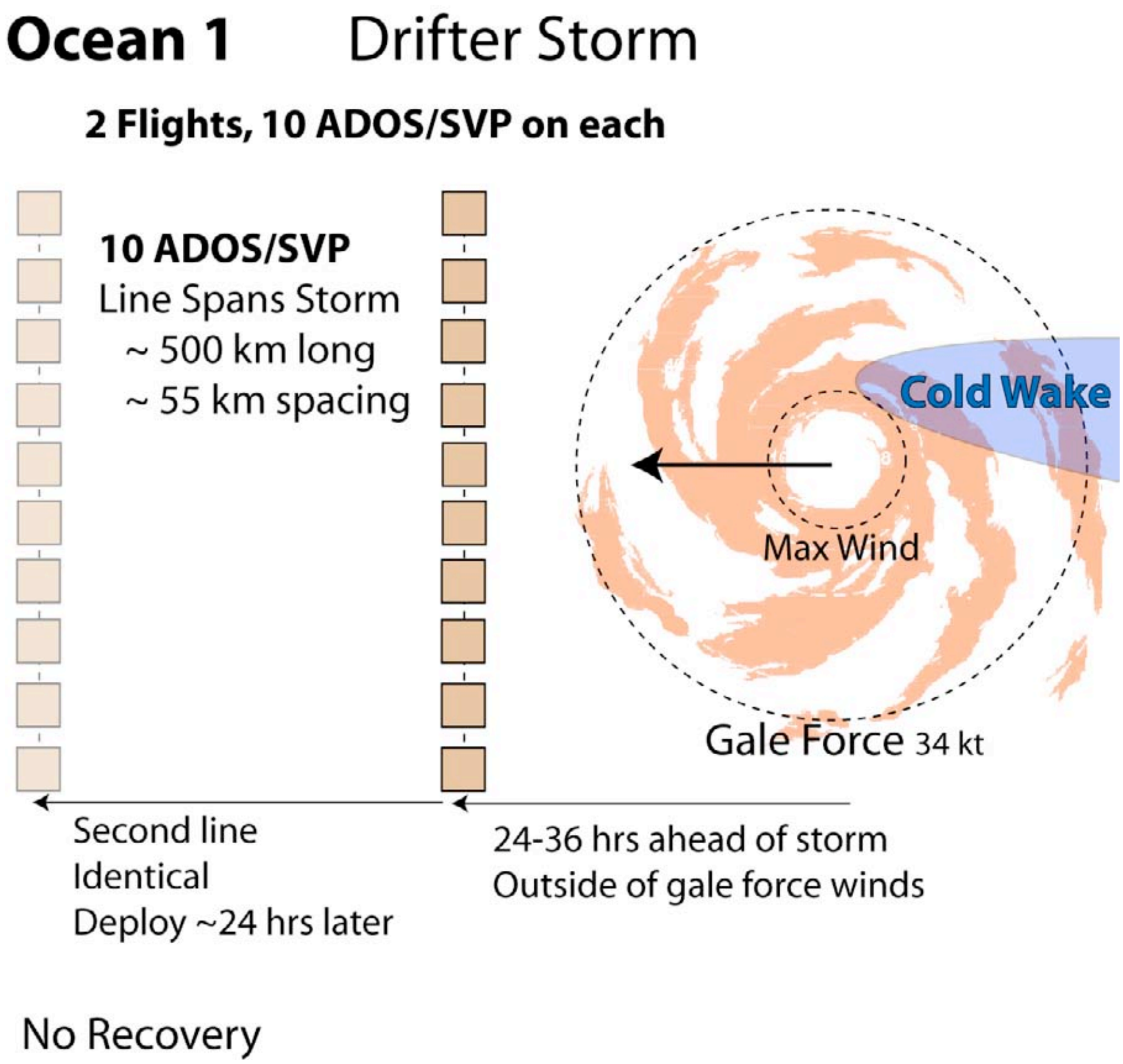

Ocean 1 Drifter Storm
2 Flights, 10 ADOS/SVP on each
10 ADOS/SVP
Line Spans Storm
~ 500 km long
~ 55 km spacing
Cold Wake
Max Wind
Gale Force 34 kt
Second line
Identical
Deploy ~24 hrs later
24-36 hrs ahead of storm
Outside of gale force winds
No Recovery

Figure 6

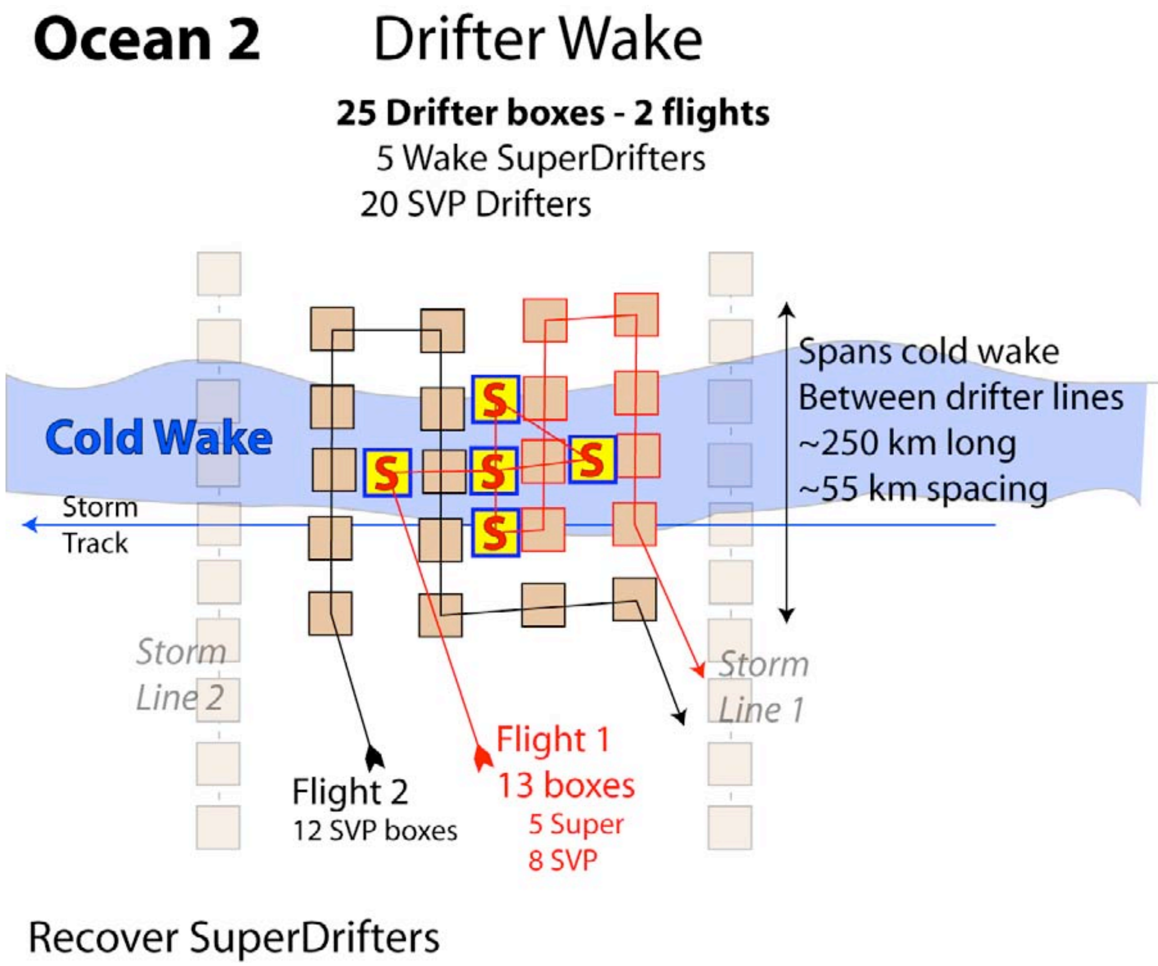

Ocean 2
Drifter Wake
25 Drifter boxes - 2 flights
5 Wake SuperDrifters
20 SVP Drifters
Cold Wake
Storm
Track
Spans cold wake
Between drifter lines
~250 km long
~55 km spacing
Storm
Line 2
Storm
Line 1
Flight 1
13 boxes
5 Super
8 SVP
Flight 2
12 SVP boxes
Recover SuperDrifters

Figure 7

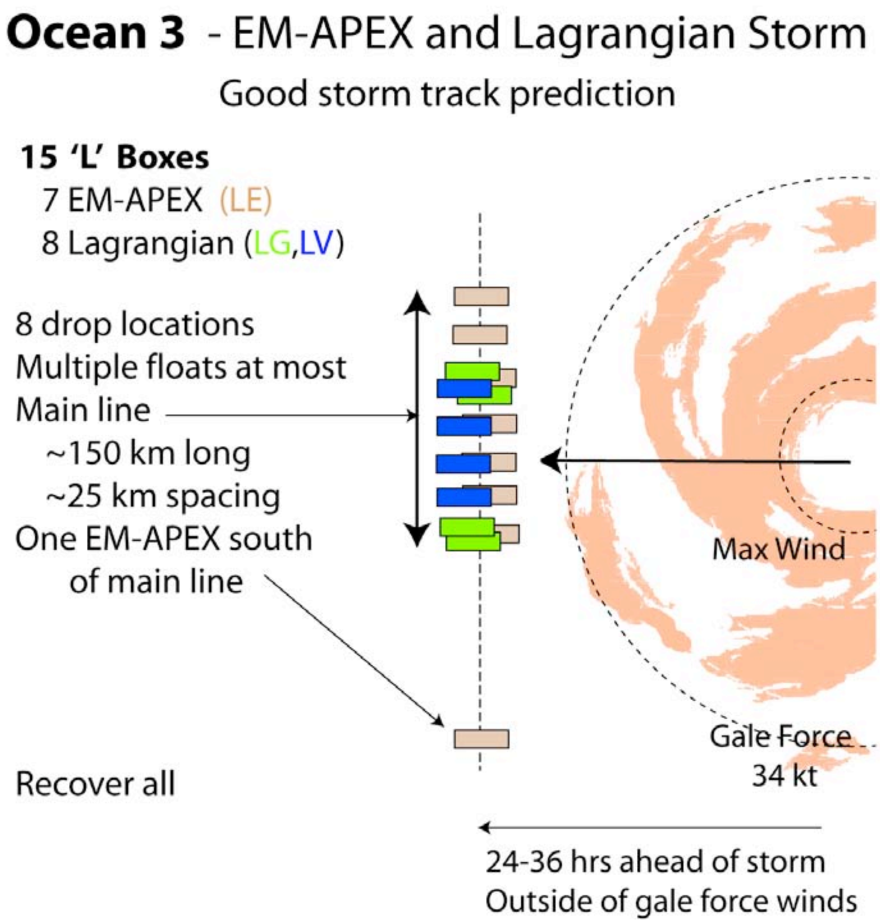

Ocean 3 - EM-APEX and Lagrangian Storm
Good storm track prediction
15 'L' Boxes
7 EM-APEX (LE)
8 Lagrangian (LG,LV)
8 drop locations
Multiple floats at most
Main line
~150 km long
~25 km spacing
One EM-APEX south
of main line
Recover all
Max Wind
Gale Force
34 kt
24-36 hrs ahead of storm
Outside of gale force winds

Figure 8

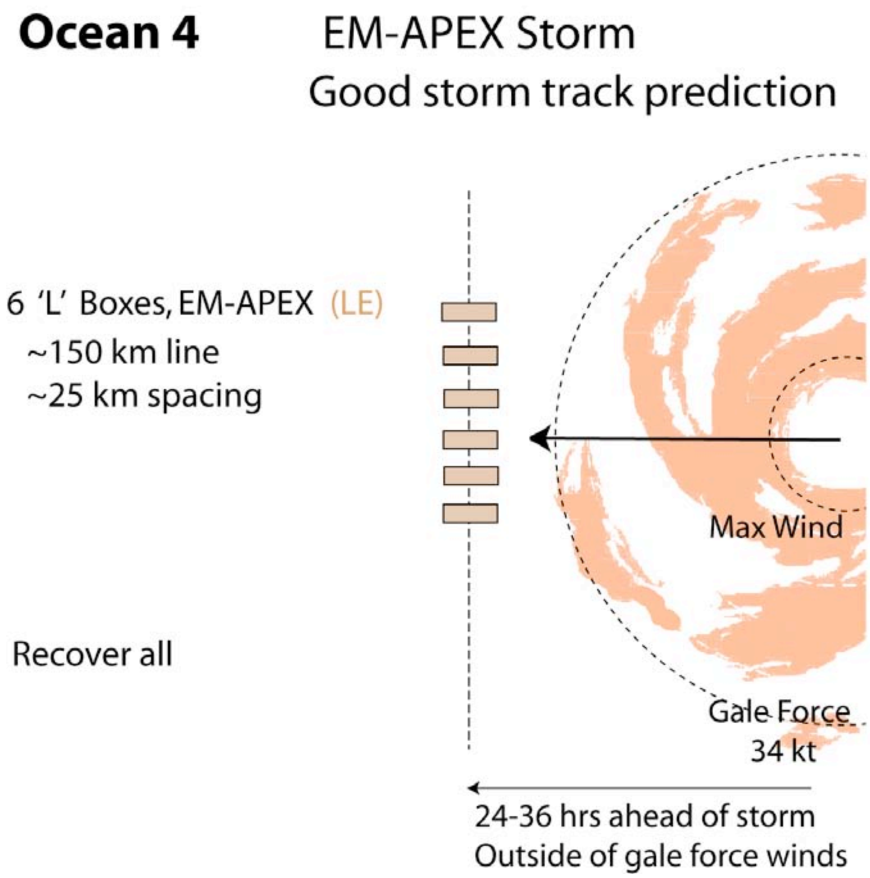
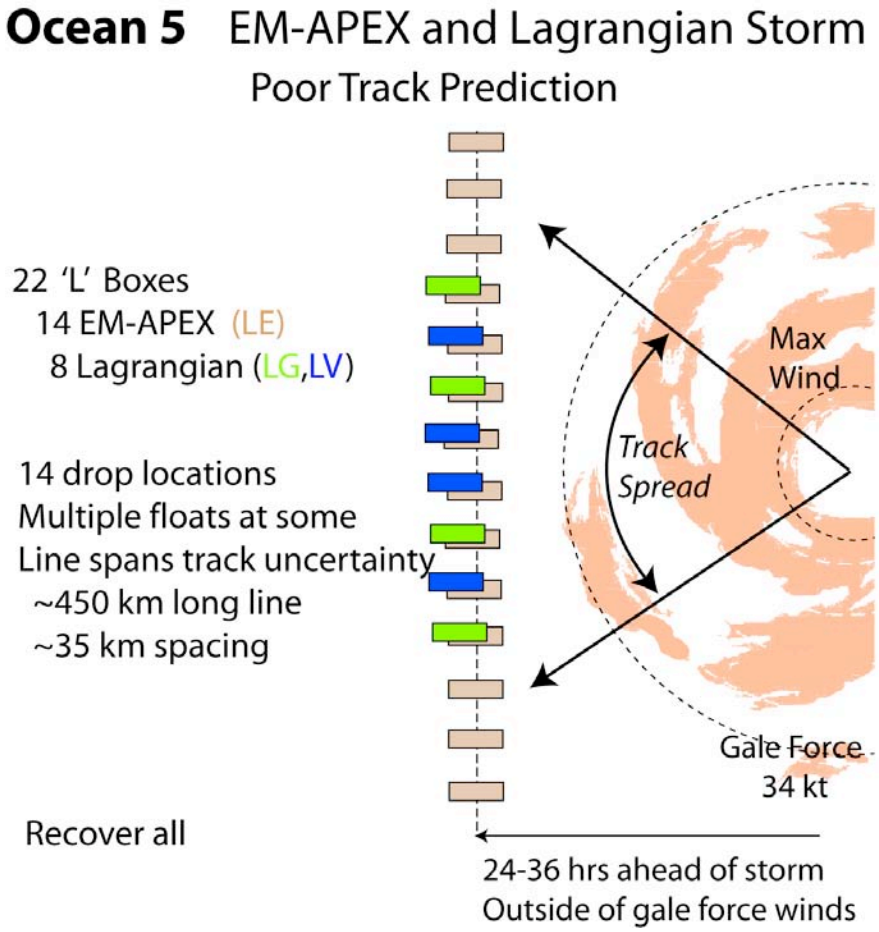

Ocean 4
EM-APEX Storm
Good storm track prediction
6 'L' Boxes, EM-APEX (LE)
~150 km line
~25 km spacing
Recover all
Max Wind
Gale Force
34 kt
24-36 hrs ahead of storm
Outside of gale force winds

Figure 9



Ocean 5 EM-APEX and Lagrangian Storm
Poor Track Prediction
22 'L' Boxes
14 EM-APEX (LE)
8 Lagrangian (LG,LV)
14 drop locations
Multiple floats at some
Line spans track uncertainty
~450 km long line
~35 km spacing
Recover all
Max Wind
Track Spread
Gale Force 34 kt
24-36 hrs ahead of storm
Outside of gale force winds

Figure 10

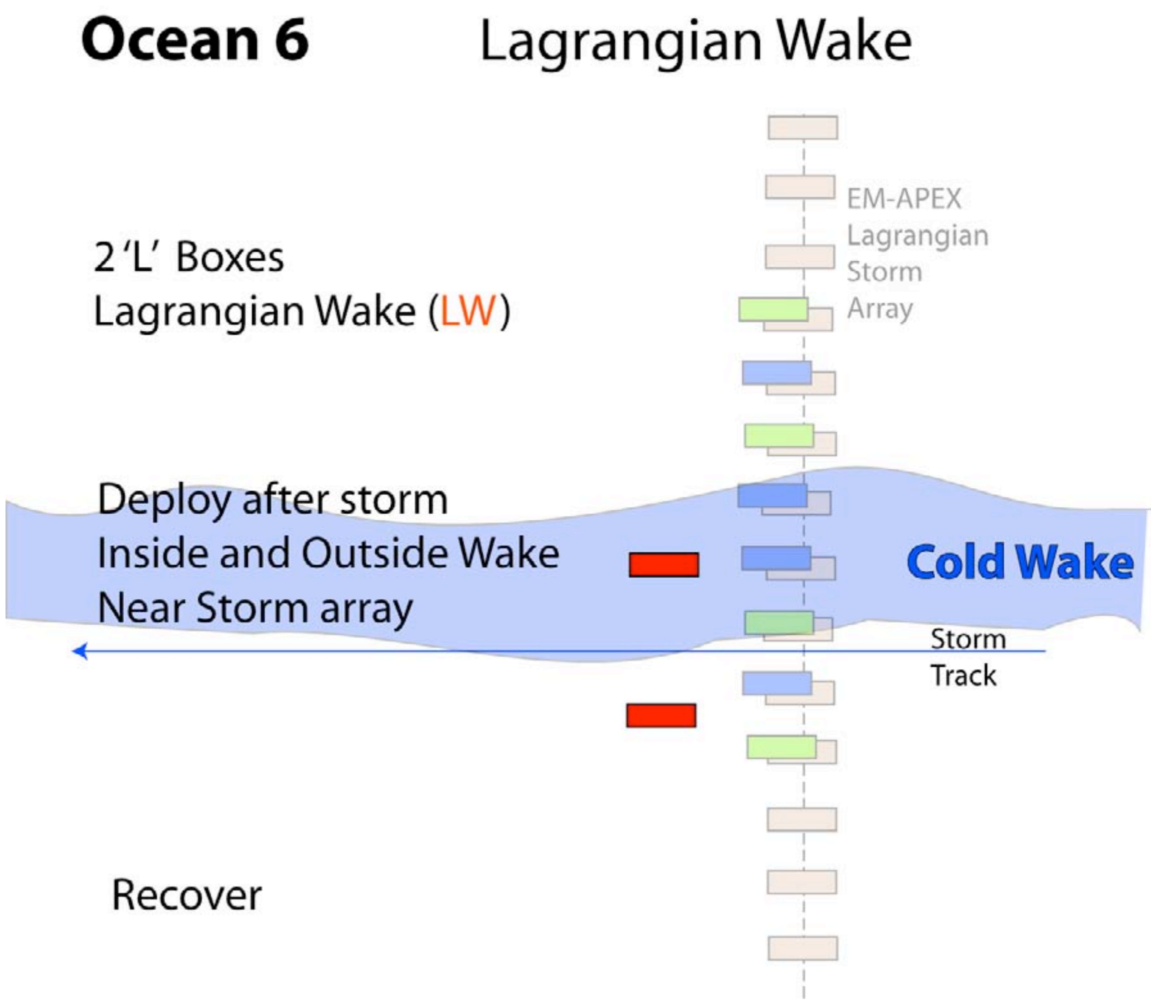

Ocean 6
Lagrangian Wake
EM-APEX
Lagrangian
Storm
Array
2 'L' Boxes
Lagrangian Wake (LW)
Deploy after storm
Inside and Outside Wake
Near Storm array
Cold Wake
Storm
Track
Recover

Figure 11

4.6 Catalog of Storm Flights

The following pages show several storm penetration flights. Actual deployments may differ in detail from those shown. Other variations, not shown here may also be required.

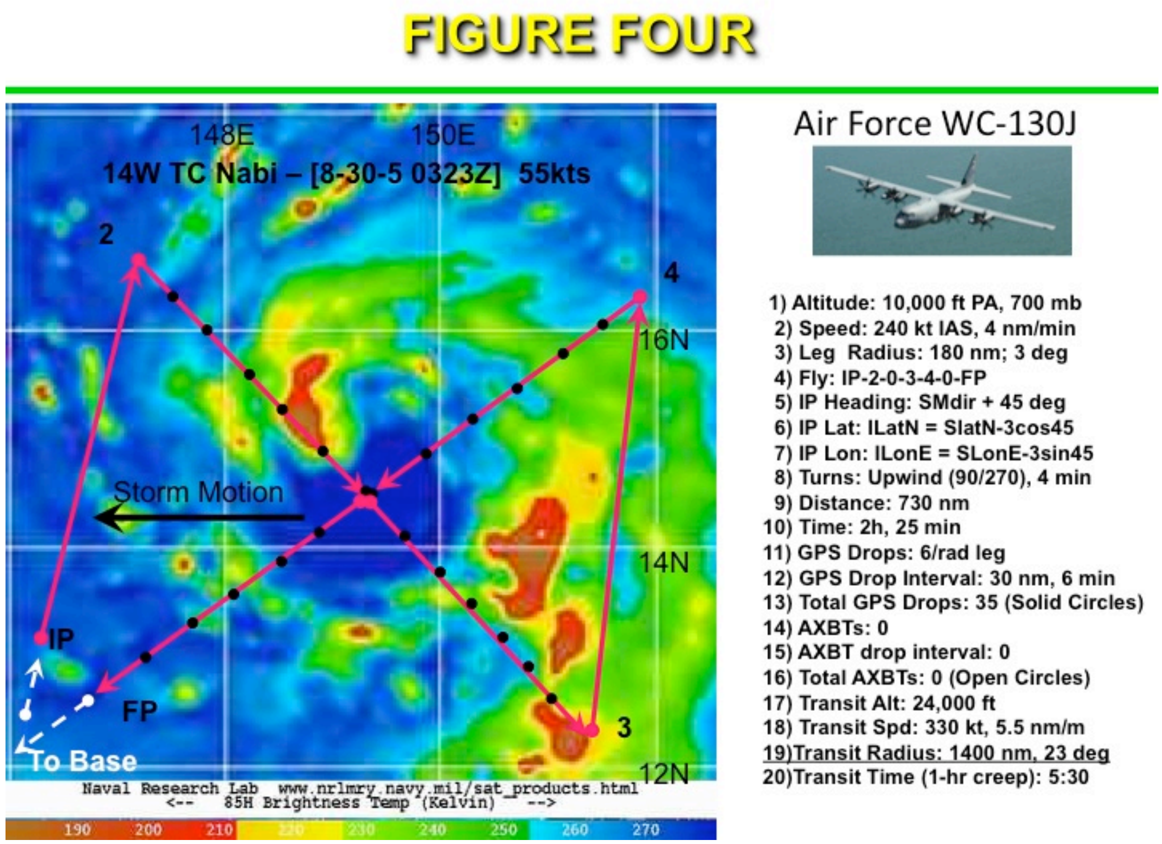


Figure 12

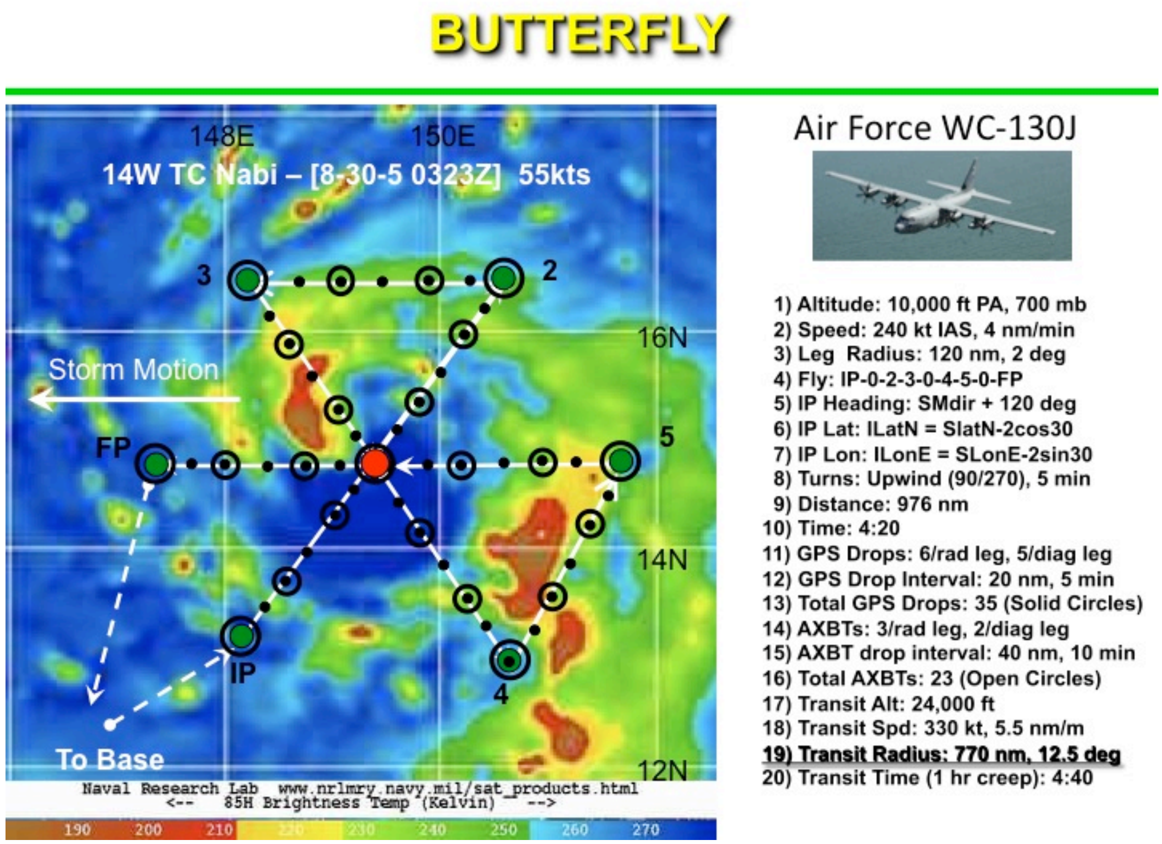
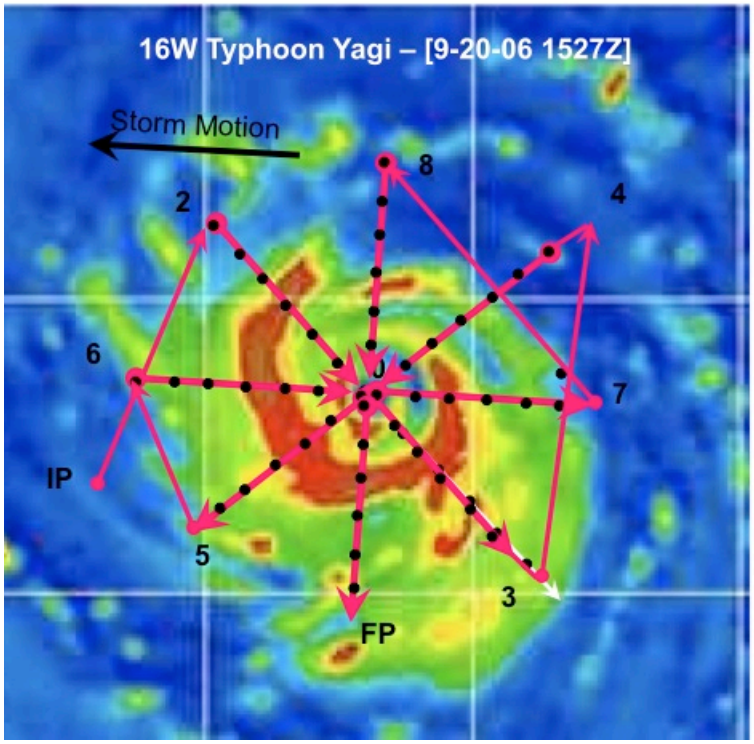

BUTTERFLY
148E
150E
14W TC Nabi – [8-30-5 0323Z] 55kts
3
2
16N
Storm Motion
FP
5
14N
IP
4
To Base
12N
Naval Research Lab www.nrlmry.navy.mil/sat_products.html
<-- 85H Brightness Temp (Kelvin) -->
190 200 210 220 230 240 250 260 270
Air Force WC-130J
1) Altitude: 10,000 ft PA, 700 mb
2) Speed: 240 kt IAS, 4 nm/min
3) Leg Radius: 120 nm, 2 deg
4) Fly: IP-0-2-3-0-4-5-0-FP
5) IP Heading: SMdir + 120 deg
6) IP Lat: ILatN = SlatN-2cos30
7) IP Lon: ILonE = SLonE-2sin30
8) Turns: Upwind (90/270), 5 min
9) Distance: 976 nm
10) Time: 4:20
11) GPS Drops: 6/rad leg, 5/diag leg
12) GPS Drop Interval: 20 nm, 5 min
13) Total GPS Drops: 35 (Solid Circles)
14) AXBTs: 3/rad leg, 2/diag leg
15) AXBT drop interval: 40 nm, 10 min
16) Total AXBTs: 23 (Open Circles)
17) Transit Alt: 24,000 ft
18) Transit Spd: 330 kt, 5.5 nm/m
19) Transit Radius: 770 nm, 12.5 deg
20) Transit Time (1 hr creep): 4:40

Figure 13

Rotated Figure 4

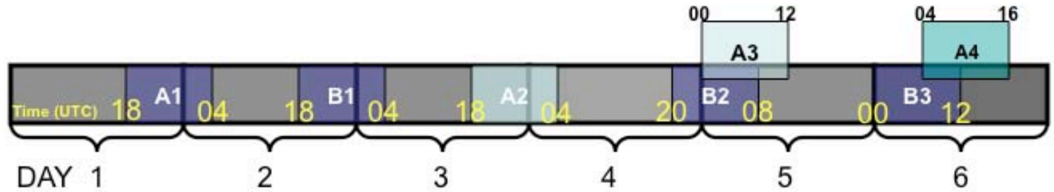


Air Force WC-130J

1) Altitude: 10,000 ft PA, 700 mb
2) Speed: 240 kt IAS, 4 nm/min
3) Leg Radius: 90 nm; 1.5 deg
4) Fly: IP-2-0-3-4-0-5-6-0-7-8-0-FP
5) IP Heading:
6) IP Lat:
7) IP Lon:
8) Turns: Downwind, 2 min
9) Distance: 1550 nm
10) Time: 6h, 30 min
11) GPS Drops: 6/rad leg, 5/diag leg
12) GPS Drop Interval: 20, 22 nm, 5 mi
13) Total GPS Drops: 35 (Solid Circles)
14) AXBTs: 0
15) AXBT drop interval: 0
16) Total AXBTs: 0 (Open Circles)
17) Transit Alt: 24,000 ft
18) Transit Spd: 330 kt, 5.5 nm/m
19) Transit Radius: 415 nm, 7 deg
20) Transit Time (1-hr creep): 5:30

Figure 14

4.7 Typical Flight Sequence



Flight	Time	Duration	Purpose
A1	Days 1-2: 1800 – 0400 UTC	10 h	Storm surveillance
B1	Days 2-3: 1800 – 0400 UTC	10 h	Storm surveillance
A2	Days 3-4: 1800 – 0400 UTC	10 h	Deployment – Line 1 mini storm reconnaissance
B2	Days 4-5: 2000 – 0800 UTC	12 h	Storm reconnaissance over line 1
A3	Day 5: 0000 – 1200 UTC	12 h	Deployment – Line 2 mini storm reconnaissance
B3	Day 6: 0000 – 1200 UTC	12 h	Storm reconnaissance over line 2
A4	Day 6: 0400 – 1600 UTC	12 h	Wake deployment

Mission Hours: Aircraft A: 44 h Aircraft B: 34 h Total flight hours = 78 h

Figure 15

The above figure shows the flight sequence developed during a 'dry run' exercise in October, 2009 for Typhoon Melor. The 6 day sequence begins with 2 surveillance flights, one per day using aircraft A and then aircraft B. A line of drifters is then deployed by aircraft B with a short storm reconnaissance on the same flight (i.e. Fig. 9B). The next day includes two flights, a reconnaissance by aircraft B over the previously deployed line and deployment of a second line by aircraft A. Two flights also occur on the following day, reconnaissance over the second line by aircraft B and a wake flight by aircraft A.

This sequence of flights uses about 78 flight hours about half the floats and drifters, and about one third of the dropsondes and AXBTs. A total of 2-3 such deployments are expected. It is likely that storm flight sequences will include several more surveillance flights and that some of the storms investigated by these flights will not be suitable for float and drifter deployments.

5. ITOP Ship-based Operations

5.1 Ship Tasks

The ITOP ships need to accomplish the following tasks:

- Deploy the 3 long-term moorings
- Deploy the ASIS/EASI moorings
- Survey one or more cold wakes
- Deploy regular and microstructure gliders into one or more cold wakes
- Recover up to 29 air-deployed floats and drifters
- Recover the long-term and ASIS/EASI mooring

The following sections describe currently scheduled cruises and additional needs.

5.2 Mooring Deployment, *March -April, 2010, R.C. Lien*

The R/V Revelle services the Taiwanese moored array

5.3 ASIS/EASI Deployment*, 24 July-Aug. 12, 2010, H. Graber*

The R/V Revelle will deploy two ASIS/EASI moorings.

5.4 ITOP and IWISE Cruises, *15 Aug. – Oct. 20 Various PI*

This block of R/V Revelle time will be shared between ITOP cold wake surveys and IWISE pilot work with the detailed schedule depending on the occurrence of typhoons.

5.4.1 IWISE (M. Alford) August 15 (or earlier) to Sept. 10 (or earlier).

Internal tide study in Luzon Strait (27 days). Interrupted if there is a typhoon. If the cruise is interrupted early (with more than 2 weeks of ship time left), the IWISE group will probably return after the ITOP operations (6 weeks).

5.4.2 COLD WAKE SCIENCE CRUISE (chief scientist: S. Jayne).

This cruise focuses on measuring the evolution of the cold wake of a typhoon. The goal is to get to the wake as soon as possible and sample for as long as possible (up to 3 weeks). This cruise will occur during the aircraft period, between Aug 20 and Oct 23. Starting on 8/20, the two basic scenarios are:

1. If there is a storm before 9/25, the ship will sail as soon as a suitable storm occurs, returning after 3 weeks. A float and drifter recovery cruise will follow.
2. If there is no typhoon before 9/25, the ship will sail on 9/25 and conduct measurements of the Kuroshio and internal tides near Luzon Strait. When a storm occurs, it will position itself to avoid the storm and enter the wake as soon as possible.

Ship operations include underway-CTD, glider deployments, micro-structure profiles, CTD/LADCP stations, water sampling and float, drifter and glider recoveries as convenient.

5.4.3 FLOAT RECOVERY CRUISE (chief scientist: TBA) Up to 3 weeks.

The non-expendable floats and drifters air-deployed near typhoons will be recovered during the Cold Wake Science cruise if it does not hinder the science operations, but others will need to be recovered on a second cruise with a limited science party. This cruise will recover the most valuable assets with the priorities set by the ITOP control center.

5.4.4 OR-1 Cruises

Several OR-1 cruises during this period will service the Taiwanese moored array and perhaps conduct additional cold wake surveys. These may present additional opportunities to recovery floats and gliders.

5.5 Final Recovery, Nov. 6- Nov. 26, 2010 – R.C. Lien

This R/V Revelle cruise will recover all fixed assets and as many remaining mobile assets, floats, drifters and gliders, as is possible.

6. ITOP Synthetic Aperture Radar Program

The SAR program will have the following goals:

1. Imaging of storms with SAR
2. Generate wind and wave fields as well as pressure fields from SAR data
3. Derive storm morphologic parameters
4. Collect additional satellite data for environmental parameters such as scatterometer, altimeter, passive microwave, EO sensors etc.
5. Collect high resolution SAR images of storm centers to study surface roughness and details of storm center
6. Collect marine radar data from ship of winds and waves away from storm center
7. Collect all available satellite data for SST fields

Figure 1 shows a nominal satellite collection plan (carpet planning) to cover the different development stages of typhoons.

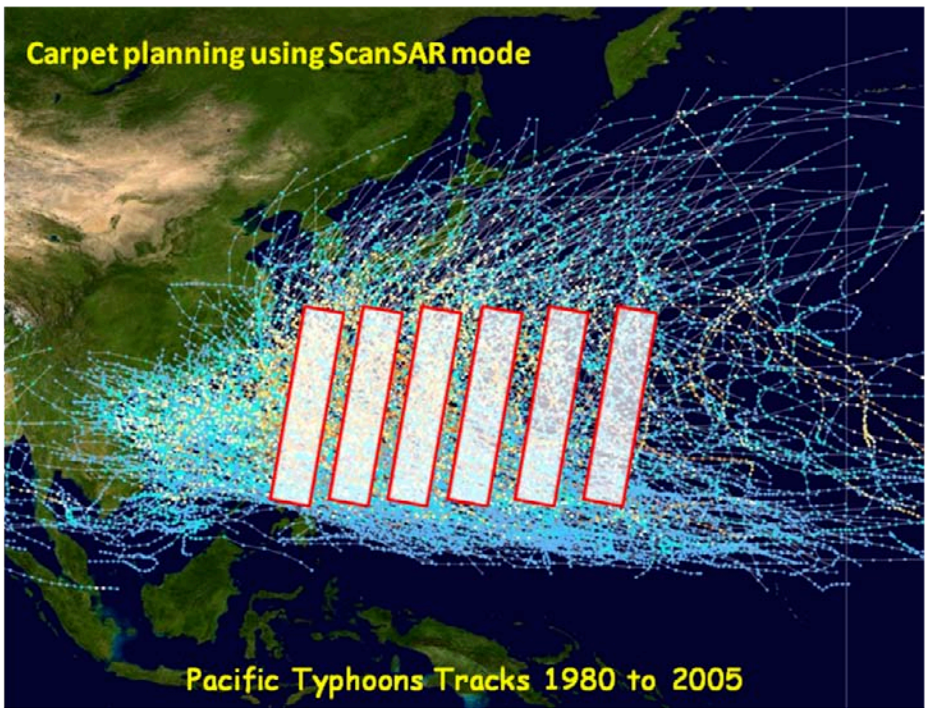


Figure 16

Nominal satellite collection plan.

A satellite collection plan will be developed in advance to cover the ITOP region with nearly continuous SAR and EO imaging during the intensive observation period. As storms develop we plan to make also special collects using high resolution imaging modes and multi polarization to determine more details of storm characteristics, especially near the eye and eye wall.

The satellite data will be directly downlinked to different ground stations, some in the ITOP region like USAF EagleVision in Guam and/or ground stations in Taiwan and Singapore for near real time acquisitions. For somewhat delayed downlinks using store&forward or relay services, CSTARS will acquire and process data to generate wind and wave fields for modelers, aircraft and ship researchers. All data will be archived and processed at CSTARS.

Satellite Assets

SAR sensors

RadarSat-1	**(C-band, microwave SAR – ScanSAR mode)**
ERS-2	**(C-band, microwave SAR – StripMap mode)**
ENVISAT-ASAR	**(C-band, microwave SAR – WideSwath mode)**
ALOS/PALSAR	**(L-band, hi-res optical & microwave SAR)**
RadarSat-2	**(C-band, very hi-res microwave SAR)**
TerraSAR-X	**(X-band, very hi-res microwave SAR)**
Cosmo-SkyMed	**(X-band, very hi-res microwave SAR)**

EO sensors

SPOT-4	**(hi-res electro-optical visible)**
SPOT-5	**(very hi-res electro-optical visible)**
ENVISAT-MERIS	**(med-res electro-optical visible)**
FormoSat-2*	**(very hi-res electro-optical visible)**
MODIS-TERRA/AQUA	**(med-res electro-optical visible)**

7. ITOP Operations Center

7.1 Operations Center Staff and Functions

ITOP operations can require up to 24 hour per day support in the Monterey Operations Center (MOC) during Intensive Operations Periods (IOPs). It is necessary to have two teams of key staff in the MOC to support operations. Team 1 (T-1) will be the daily shift of people to handle typical support operations when there are no IOPs planned or underway. Team 2 (T-2) will be the special shift to support activities during IOPs or other special operational periods, as required. It is important to note that in some cases more than one of the key functions may be handled by a single individual.

7.2 Team-1 (T-1)

7.2.1 Science Director

Responsibilities as a member of the OCT are:

- May make go/no-go decisions for day's mission;
- Can be responsible for real time coordination of aircraft, depending on the timing of operations;
- May participate in aircraft post-flight debriefing.

7.2.2 Operations Director

- Convenes and co-chairs the Daily Planning Meeting;
- Provides Status Report summary to Daily Planning Meeting;
- Responsible for form and content of Daily Operations Summary;
- Communicates mission plans to facility managers;
- Communicates notification requirements to airspace agencies (civilian and military) in coordination with aircraft facility staff;
- Implements the daily ITOP Operations Plan;
- Assigns duties to OCT personnel;
- Coordinates aircraft post-flight debriefings;
- May have an operations support assistant to help complete the duties described above within critical timing constraints of the project planning process.

7.2.3 Facility Status Coordinator

- Monitors the status of all ITOP facilities, including the use of all expendable resources;

- Provides daily (or more frequent) updating of the ITOP Field Catalog status report;
- Presents a summary status briefing at the Daily Planning Meeting;
- Maintains an allocation/utilization account of flight hours and expendables for the SSC.

7.2.4 Lead Weather Forecaster

- Responsible for the preparation and presentation of planning forecast information for the PIs, MPT and operations staff for the Daily Science Meeting and the Daily Planning Meeting;
- Responsible for scheduling forecasting and nowcasting support for the MOC;(in coordination with the Operations Director);
- Responsible for the form and content of the daily forecast summary to be included in the Field Catalog.

7.2.5 Forecast support staff (2-3 people)

These people will assist the lead forecaster with the preparation of all forecasts, documentation and imagery during the shift. This support will also include the uploading of products and imagery to the ITOP Field Catalog for use with the Elluminate software during the daily planning process.

7.2.6 Lead Oceanographer

- Responsible for the preparation and presentation of oceanographic environment and predictions at the Daily Science Meeting and the Daily Planning Meeting;
- Responsible for scheduling oceanographic support for the MOC;(in coordination with the Operations Director and lead forecaster);
- Responsible for the form and content of the daily ocean summary to be included in the Field Catalog.

7.2.7 Oceanographic support staff (2 people)

These people will assist the lead oceanographer with the preparation of all forecasts, documentation and imagery during the shift. This support will also include the uploading of products and imagery to the ITOP Field Catalog for use with the Elluminate software during the daily planning process.

7.2.9 Ship Coordinator

- Acts as a representative of the ship operations group at the MOC.
- Attends daily briefing, perhaps via Elluminate

- Responsible for ensuring that ship group is aware of upcoming and ongoing aircraft operations that might require ship support.
- Responsible for ensuring requirements for float and buoy recoveries placed on the ship group by proposed aircraft operations can be accomplished by the ship group.

7.2.10 Communications Specialist

- Establishes, monitors and maintains telecommunications (utilizing Elluminate software, chat or other tools) between MOC and other coordination sites during DSM, DPM and other special meetings;
- Supports exchange of special operational data products between MOC and other coordination sites.

7.3 Team-2 (T-2)

7.3.1 Mission Scientist

- Monitors mission operations;
- Supports onboard Flight Scientists via chat and image (where possible) updating;
- Considers and approves mission changes and modifications that may be required during flight operations;
- Position may rotate on an IOP basis.

7.3.2 Operations Director-2

- Responsible to carry out the research mission prescribed by the MPT;
- Coordinates all operational aspects of IOP assuring efficient, effective and safe utilization of facilities in a dynamic weather environment;
- Orchestrates aircraft missions and is cognizant of facility limitations and operational constraints especially when alterations to original mission plans are requested or required by weather conditions or equipment failure;
- Leads preflight briefings;
- There may be assistants on hand to aid in the completion of key tasks by the operations director during IOPs;
- Position may rotate on an IOP basis.

7.3.3 Aircraft Coordinator

- Primary point of contact between MOC and on-board flight scientists;
- Provides updated information to aircraft during flight operations;

- Participates in pre-flight briefings and debriefings.

7.3.4 Float Pilot

- Responsible for monitoring operation of EM-APEX and Lagrangian floats
- Modifies float sampling programs to reflect changes in deployment plans or storm changes
- Task may be shared by multiple persons, some of whom may be offsite and participate via Elluminate.

7.3.4 Realtime Data Coordinator

- Responsible for coordinating the special observations from all field system including dropsondes from aircraft and data from floats and drifters
- Responsible for relaying any special driftsonde launch requests to the Driftsonde Coordination Center.

7.3.5 Lead Nowcaster

- Responsible for the preparation of preflight briefing packages for all aircraft participating in the IOP;
- Monitors weather conditions and short term forecasts during IOP operations, providing continuing updates to the Mission Scientist and Operations Director;
- Provides reports and products for the aircraft Flight Scientists, as appropriate;
- May have additional assistants to the nowcaster to assure that key deadlines and information flow are maintained during the IOPs.

7.3.6 Communications specialist

- Sets up, maintains and monitors chat links with all aircraft during flight operations;
- Assures timely and complete upload and download of data products between MOC and aircraft during flight operations;
- Assists Aircraft Coordinator, especially during multi-aircraft operations.

7.4 Aircraft Support Center Staff and Functions

3.4.1 Guam Aircraft Support Center

There are key functions that will be supported on Guam. These positions are supported throughout the deployment period but not on a 24 hour a day basis.

Facility and Center Support Coordinator

- Acts as liaison between EOL facilities support staff and NRL P-3 operations;
- Primary point of contact between Guam Aircraft Support Center and MOC for mission planning and operations support;
- Acts as liaison between EOL staff and Andersen AFB.

Ground Mission Support Scientist

- Acts as Liaison between USAF 53rd Weather Wing, MOC and other project scientists during mission planning and flight operations;
- Provides real time text to the USAF C-130 during flight operations via USAF communications system.

In Field Data Management Specialist

- Provides ground support for processing of ELDORA radar data including Quick-look datasets, analysis, and ELDORA imagery for the ITOP Field Catalog.

In Field Float and Drifter Specialist

- Prepares floats and drifters for deployment in cooperation with the 53rd Weather Wing.

7.5 Control Center Operations

7.5.1 Daily Science Meeting (DSM)

There will be an informal meeting at the MOC of interested Science Group members beginning each day at approximately 2100 UTC to discuss potential mission objectives for the new or continuing Intensive Observing Period (IOP). A member of the forecast team will provide a brief weather and ocean update covering the next operational period. All project participants are encouraged to participate in this Daily Science Meeting (DSM). Remote participation via conference call, using web-based Elluminate software and the EOL Field Catalog tools are also encouraged. The DSM may be cancelled if no operations are likely for the next day. The key results from the DSM should be a set of primary and secondary science objectives that will be discussed and finalized in the Daily Planning Meeting (DPM).

7.5.2 Daily Planning Meeting (DPM)

The ITOP field program will have a general meeting each day to discuss relevant issues, remaining resources and status, science objective status, current weather, synoptic situations and outlook as well as PI science mission proposals. This meeting will involve participants from all nations involved in the project. The ITOP Daily Planning Meeting will be convened at 2300 UTC (1600 Local Time [LT] in Monterey, CA, 0900 LT in Guam and 0800 LT in Tokyo, Japan) by the ITOP Monterey

Operations Center and supporting centers in Guam, Japan, Korea and China (see Fig. 4.1). This time was chosen to allow participation of as many groups as possible across 10 time zones. The DPM will be held seven days per week throughout the field season beginning 17 August and concluding 20 October 2010.

The Daily Planning Meeting will be co-chaired by the ITOP Science Director and Operations Director. The agenda for the meeting will be consistent each day and include the following items:

- Status of aircraft, ship, float and drifter systems;
- Data management and communications status report;
- Forecast discussion from 24-36 hours, special products; outlook to 72 hours;
- Report on the status of scientific objectives and results of the last mission and/or update on the status of an on-going mission;
- Mission selection, staff assignment, and schedule of operations;
- Logistics or administrative matters;
- Other announcements.

7.5.3 Daily schedule and IOP Preparations

The typical schedule for daily project planning will include onset activities of an IOP in ITOP. In addition to the scientific planning and priority setting during the DSM and DPM and priority decisions by the MPT, it is important that key personnel assignments be made for the upcoming IOP. These include:

- Lead mission scientist(s) (located in the MOC). These will be selected to match science objectives and required facilities;
- On-board flight scientist(s), air reconnaissance weather officer, mission observer for each aircraft;
- Other scientific personnel on each aircraft
- Key operations center staff (i.e. Operations Director-2, Nowcaster, Aircraft Coordinator).

Notifications will be made directly to all flight, ship and float/drifter facilities immediately at the end of the MPT meeting. Notifications will be provided to all participants and collaborating international participants via the preparation and timely distribution of the Daily Operations Summary under control of the Operations Director (usually available by 0100 UTC). This document will be made available via the ITOP Field Catalog and will be openly accessible by all interested project participants. The Daily Operations Summary will be prepared at least once a day following the DPM but will be updated by the Operations Director as changing plans warrant. Content will include:

- Summary of ongoing and planned ITOP operations and data collection;
- Proposed mission objectives for the upcoming or next phase of an IOP;
- Schedule details for all aircraft and other special observations as appropriate;
- Facility status;
- Other schedule highlights for the next 24 hours.

The preparation of aircraft flight tracks, dropsondes, AXBT and float/drifter drop locations (if required) for submission to controlling air traffic agencies will be accomplished immediately following the daily planning process described above. Each aircraft facility and mission scientists at the aircraft support centers will be responsible for preparing the flight plans. These flight plans will then be submitted to the air traffic agencies as required. The advance notification will typically be 24 hours ahead of launch time with the provision for updating if required.
Advanced notification of MTSAT rapid scan satellite data will typically need to be made several days in advance of an event. These requests will be through the JMA using agency channels established prior to the field season.

7.5.4 Mission Update

During rapidly changing or uncertain weather situations a special weather update will be provided at approximately 1800 UTC for the Science Director and Operations Director to confirm or modify the next day's mission plan.

7.5.5 Pre-flight Planning Process

Typically, a pre-flight briefing is held about 2 hours ahead of the scheduled aircraft take-off These briefings are meant to provide any update in facility status, adjustments to flight plan, if possible, current observations, and short term weather forecast for the area of interest. The content will be similar for all facilities.

7.5.9 Aircraft Mission De-briefing

Aircraft flight crew and scientists will participate in a de-briefing following each research flight. This will include aircraft facility and instrument status, a brief summary of flight operations and mission highlights, and aircraft availability for the next mission. Any operational or in-flight coordination issues will be brought up and discussed at this time. Typically, the Operations Director and Science Director/Mission Scientist in the MOC will facilitate this meeting.

7.5.10 Forecast preparation

The T-PAC Forecasting Team will be organized to support all aspects of project planning and operations. The Lead Forecasters will reside at the MOC and will develop a support staff to provide forecasting and nowcasting expertise on all operational days of the projects as well as before and during IOPs.

7.6 Software support for ITOP Operations

ITOP operations will be supported by interactive databases based at NCAR Earth Observing Laboratory (EOL), at the Monterey Bay Aquarium Research Institute (MBARI) and at the Naval Research Laboratory, Monterey (NRL). All of these can be accessed through the ITOP 'Front Page' at www.eol.ucar.edu/projects/itop/ .

EOL will have primary responsibility for collecting and distributing atmospheric data and model output and in supporting the forms and tables used to specify flight operations.

MBARI will have primary responsibility for collecting and distributing oceanographic data and model output.

NRL will have primary responsibility for collecting and distributing remote sensing information.

8. Operations and Support Logistic

8.1 ITOP Monterey Operations Center

The ITOP Monterey Operations Center (MOC) is located at the Naval Postgraduate School (NPS) in Monterey CA. The MOC has overall responsibility for the conduct of operations during the field phase of ITOP. The Daily Science Meeting (DSM) and DPM both originate from the MOC and are open to all project participants using the *Elluminate*® real-time Internet video teleconferencing system. Daily operations summaries are generated at the MOC as well as Science Summaries and other updates as required.

8.2 Guam Operations Center

Two USAF C-130 Reconnaissance Aircraft with dropsondes, deployable floats and buoys and SFMR will be based at Andersen AFB on the island of Guam. Both aircraft will normally conduct operations in the vicinity of Guam (approximately 1000 nmi radius) to support tropical cyclone formation missions. or they can fly a mission and recover in Okinawa, Japan, at Kadena AFB.

The Guam operations center as well as lodging for project participants will be at the Guam Marriott in the hotel area on Tumon Bay in west central Guam. It is approximately a 30-minute drive from Tumon Bay to the Main Gate at Andersen AFB. Participants will need to clear security and vehicle inspection before proceeding into the base. Foreign nationals may need to be escorted by a U.S. citizen in order to gain access to the base.

9. Modeling, Simulation and Prediction

9.1 Modeling Goals

One of the primary goals of the ITOP program is to improve the understanding of how typhoons and the upper ocean interact sin order to improve typhoon and upper ocean models.
Models and simulations will be used in ITOP to:

1) Provide accurate state estimation of the Western Pacific Ocean and overlying atmosphere through data assimilating ocean and atmosphere prediction systems
2) Provide forecast of typhoon formation, track, intensity to assist in selecting individual storms for study in the field program
3) Provide estimates of the impact of the typhoon on the ocean (stratification, currents, waves) to assist in selecting storms for study in the field program
4) Provide estimates of the interaction of the typhoon cold wake with ocean mesoscale features
5) Provide simulations of the evolution of the typhoon cold wake
6) Provide estimates of critical ocean and atmospheric parameters real time or in post-storm analyses that can be compared to observations made in the field program to validate model predictions, to provide error estimates and to look for consistent variations that may help point to improved model physics or parameterizations.

9.2 Models

The typhoon models will include all generally available operational typhoon prediction models runs made by the major weather prediction centers (ECMWF, JMA, NCEP, FNMOC, JTWC) and a variety of new R&D coupled atmosphere-ocean models currently under development. High resolution LES type models of the upper ocean will look at oceanic processes on the scale of a subsection across the typhoon cold wake. Some of the coupled atmosphere-ocean models will include a surface wave component.

The following table provides a current list of models expected to be used or run during the experiment. The current aim is to have all research models operational for the Intensive Operational Period with output going to the Operations Center. It is expected that after the field program a series of reanalyses will be made incorporating new physics or parameterizations arising from the ITOP program.

Model	**Type**	**Lead**	**Output to**
NOGAPS	Operational	EOL	Operations Center
HWRF	Operational	EOL	Operations Center
ECMWF	Operational	EOL	Operations Center
JMA	Operational	EOL	Operations Center

GFS	Operational	EOL	Operations Center
UKMet	Operational	EOL	Operations Center
GNCOM	Operational	Allard	Operations Center from NRL-S
EASNFS	Op/R	Ko/Chao	Operations Center from NRL-S
Hycom	OP/R	WHO?	Operations Center from NRL-S
Coupled MM5/PWP/WW3 "UMCM"	R	Shuyi Chen	Operations Center from UMiami
Coupled WRF/ARW/PWP CWRF	R	Shuyi Chen	Operations Center from UMiami
COAMPS/SWAN/ NCOM (ESMF)	R	Allard/Cook	Operations Center from NRL-S/M
COAMPS-TC No waves	R	Hao/Wang S.Chen/Doyle/Jin	Operations Center from NRL-M
COAMPS-TC+ Swan/WW3	R	Hao/Wang S.Chen/Doyle/Jin	OPERATIONS CENTER from NRL-M
COAMPS-Adjoint	R	Hao/Wang S.Chen/Doyle	OPERATIONS CENTER from NRL-M
Wake LES UW	R	Harcourt	Operations Center from UW
Wake LES NCAR	R	Sullivan	Operations Center from NCAR
PWP3D	R	Price	Operations Center

The Research Models expect to get initial and boundary conditions from one or more of GFS, NOGAPS, JMA, ECMWF and GNCOM, HYCOM and NRL-M WWIII.

In post field campaign reanalyses, agreements may be reached on consistent conditions for initiation and forcing.

10. ITOP Principal Investigators

PI	MOORING	AIR CRAFT	SHIPS	REMOTE SENS	Models	Ops Center	pre iop	prestorm	storm	post-storm	analysis
Allard					x	x					
Black		x		x	x	x	x	x	x	x	x
Centuroni		x	x				x	x	x	x	x
Chao					x						x
Chen		x			x	x	x	x	x	x	x
Sue Chen	x	x			x	x		x	x	x	x
D'Asaro		x	x		x	x	x	x	x	x	x
Doyle		x			x	x	x	x	x	x	x
Elsberry		x	x	x	x	x					
Foster		x		x	x	x		x	x	x	
Graber	x		x	x	x	x	x		x	x	x
Harcourt											
Harr		x		x	x	x	x	x	x	x	x
Jayne			x	x					x	x	x
Ko				x	x	x	x	x	x	x	x
Lien	x		x				x	x	x	x	x
Lee			x								
Sanford	x	x		x		x	x	x	x		
Rainville		x	x							x	
Price				x	x	x		x	x	x	
St.Laurent			x	x					x	x	x
Sullivan					x			x	x	x	
Velden		x		x	x					x	x
Wackerman		x		x				x	x	x	x
Walker		x		x				x	x	x	x
Wang				x	x	x		x	x	x	x

PI	MOORING	AIR CRAFT	SHIPS	REMOTE SENS	Models	Ops Center	pre iop	prestorm	storm	post-storm	analysis
Tang, TY	x		x			x	x	x	x	x	x
Wu, CC		x			x	x	x	x	x	x	x
Chang, MH	x		x			x	x	x	x	x	x
Chern, CS					x		x	x	x	x	x
Lin, II				x	x	x	x	x	x	x	x
Wang, J			X			X	X	X	X	X	X
Jan, S			x		x		x	x	x	x	X
Huang, CF							x	x	x	x	X
Ho, CR				x	x		x	x	x	x	X
Chien, H				x			x	x	x	x	X
Liang, WD					x		x	x	x	x	x
Shiah, FK						x	x	x	x	x	X
Yang, Y	x		x			x	x	x	x	x	X
Lee, YH							x	x	x	x	X
Yang, YJ	X		x			x	x	x	x	x	x