

Western Pacific Tropical Cyclone Adaptive Observing of Inner Core Life-cycle Structure and Intensity Change

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Document Number: N0001409WX20785

<http://met.nps.edu/~tparc/TCS-08.html>

LONG-TERM GOALS

Major goals for this project are three-fold: 1) provide a quality-controlled WC-130J airborne observation data set for the flights conducted during the Tropical Cyclone Structure 2008 field program (TCS-08), 2) diagnose the interaction of mature Western Pacific (WPAC) tropical cyclones (TCs) with their underlying ocean features and provide new observations simultaneously, both within the TC itself as well as the ocean below, to the developing Naval Research Laboratory (NRL) coupled TC modeling effort (COAMPS[®]¹-TC) and 3) utilize TCS-08 field program datasets to improve understanding of TC life cycle, especially genesis stage and rapid intensification mature-stage episodes associated with oceanic and large-scale atmospheric environmental changes.

OBJECTIVES

Specific objectives are four-fold (Elsberry, *et al*, 2009):

1. Coordinate an airborne program for observation of WPAC TCs that will lead to improved understanding and prediction of TC structure, intensity and track [from genesis through mature and extratropical transition (ET) stages of TC life cycle] and produce a data archive of WC-130J related aircraft data during the observation period.
2. Utilize enhanced WC-130J GPS dropsonde observations, flight level and surface wind, and thermal observation and airborne radar images; develop an analysis scheme for the monsoon and storm-scale circulation features that would:
 - a. Define large-scale context for detailed mesoscale observations from companion NRL P-3 aircraft in selected storm quadrants, including specification of surface radius of gale, storm and typhoon-force winds over time.

¹ COAMPS[®] (Coupled Ocean/Atmosphere Mesoscale Prediction System) is a registered trademark of the Naval Research Laboratory. COAMPS[®]-TC is a special version of the coupled system under development for tropical cyclone prediction.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 2009		2. REPORT TYPE		3. DATES COVERED 00-00-2009 to 00-00-2009	
4. TITLE AND SUBTITLE Western Pacific Tropical Cyclone Adaptive Observing Of Inner Core Life-cycle Structure And Intensity Change				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) SAIC, Inc. at Naval Research Laboratory, 7 Grace Hopper Avenue, Monterey, CA, 93943				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Major goals for this project are three-fold: 1) provide a quality-controlled WC-130J airborne observation data set for the flights conducted during the Tropical Cyclone Structure 2008 field program (TCS-08), 2) diagnose the interaction of mature Western Pacific (WPAC) tropical cyclones (TCs) with their underlying ocean features and provide new observations simultaneously, both within the TC itself as well as the ocean below, to the developing Naval Research Laboratory (NRL) coupled TC modeling effort (COAMPS?1-TC) and 3) utilize TCS-08 field program datasets to improve understanding of TC life cycle, especially genesis stage and rapid intensification mature-stage episodes associated with oceanic and large-scale atmospheric environmental changes					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 15	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

- b. Provide initial thermal and kinematic data for coupled COAMPS-TC model development during TC life-cycle.
 - c. Improve characterization of TC vertical structure by radius and storm quadrant for TC boundary layer and lower troposphere inner core regions.
3. Determine TC structure change by co-location of storm-scale kinematic analyses with satellite visible (VIS), infrared (IR) and microwave satellite data to study the dynamics of inner and outer eyewall/rainband evolution in time, especially eyewall replacement cycles.
 4. Assist with and validate current and advanced Dvorak intensity estimation schemes, and evaluate proposed new composite intensity estimation schemes, with observations of peak surface winds at all stages of WPAC TC life cycle.

APPROACH

The approach used to undertake the field observing phase of the TCS-08 project was to define a series of flight plans targeted at observing the 3D environmental structure during TC genesis and to observe TC mature-stage intensity and structure at the surface and mid-levels. To this end, a series of flight patterns were designed to be flown either east or west of the operating base (Black, 2009), an example of which is shown in Fig. 1. In addition, a communications scheme was set up between scientists at various other operations centers, especially the main operations center in Monterey, and with the two aircraft and the Guam operations center. A schematic of this communications plan is shown in Fig. 2. Once these plans were in place, the approach to achieving the objectives above was to maximize the opportunities for observation periods of storm-scale data sets with the WC-130J aircraft, timed to precede NRL P-3 Doppler radar observations of TC mesoscale observations.

The TCS-08 field program provided unique aircraft reconnaissance (recon) data that will be used to validate a suite of satellite-based TC intensity estimation methods. While Atlantic recon data has provided the only data to formulate these algorithms, WPAC data is sorely needed due to specific differences between TCs in both basins. Air Force WC-130J eye penetrations will be a key focus by incorporating dropsondes, Stepped Frequency Microwave Radiometer (SFMR) surface wind speeds, and flight-level winds. WC-130J center-fix derived minimum sea-level pressure (MSLP) and maximum sustained winds (Vmax) will form the basis for enhanced best track values used to validate all satellite-derived intensity values (Black, Hawkins, Elsberry, 2009).

WORK COMPLETED

1. Managed WC-130J aircraft program for TCS-08 including deployment of 24 drifting buoys: 12 ahead of Typhoon Hagupit and another 12 ahead of Super-Typhoon Jangmi; and development and calibration of Stepped Frequency Microwave Radiometer (SFMR) system for remote observation of surface winds.
2. Created mobile AXBT deployment, data receiving and processing system for WC-130J, as well as developed new system for recording airborne radar video for the first time.
3. Created an archive of all WC-130J aircraft data, including flight level, SFMR surface wind, dropsonde, radar video and AXBT data for each flight during TCS-08.

4. Conducted preliminary analyses from innovative new high-altitude genesis sampling strategy developed for TCS-08 genesis events.
5. Conducted preliminary analyses of drifting buoy, satellite-derived Ocean Heat Content (OHC) and satellite-derived SST to compare with dramatic changes in intensity and structure of TC Jangmi after passing the buoy array, but prior to landfall.
6. Assisted the TCS-08 “best track” team in creating a high quality TC intensity and location data set for use in validating satellite intensity estimates.
7. Assisted in the creation of TC surface wind fields by providing SFMR observations, which were complemented with satellite scatterometer remote-sensing surface wind speed data for incorporation into H*Wind objective analysis system.

TECHNICAL RESULTS

Section 1: TCS-08 WC-130J Tropical Cyclone Genesis Preliminary Analysis

Approximately half of the TPARC²/TCS-08 WC-130J flights were flown in TC genesis situations in which GPS (global positioning system) dropsondes were deployed from an altitude at or near 300 mb. Nearly all of these were flown in the first five weeks of the project from 1 August to 7 September, 2008. These flights were flown into cloud clusters that exhibited a cohesive structure and which various models indicated had development potential. Airborne eXpendable BathyThermographs (AXBTs) were also deployed on these flights for diagnosis of the underlying ocean structure. We examined the potential for mitigating landfall impacts through improved observations of the genesis phase of TC development, which could result in increased lead times for preparation for potential landfall situations.

During TCS-08, flights were made into two disturbances that both exhibited ‘vortex pairs’ at different altitudes. These systems were labeled TCS-25 and TCS-37 and were flown with GPS deployment from 300 mb on 27-28 August and 6-7 September, respectively. Both features were propagating westward associated with a tropical wave interacting with an upper-level trough. Fig. 3 shows near-surface GPS dropsonde-derived wind barbs plotted on visible and microwave imagery in the upper left and lower right panels, respectively. These plots show a closed circulation at the surface with a center of circulation, entirely in the clear, located about 150 km north of a cluster of convective cells. Maximum winds within this circulation were westerly and southwesterly at about 15-18 kt to the southwest and southeast of the circulation center, just upstream and downstream from the convective activity. The upper right and lower left panels show the wind barbs at the 700 mb level. These winds also show a closed circulation, as do winds in the layer from 750 to 500 mb, but with the center of circulation imbedded within the convective region 120 km south of the surface circulation. Peak winds were westerly at 20 kt just south of the maximum wind band at the surface and southwest of the center of circulation.

² TPARC was the two-phase multi-national THORPEX Pacific Asian Regional Campaign held in summer 2008 and winter 2009. THORPEX (The Observing-System Research and Predictability Experiment) is a long-standing international research and development program organized under the World Meteorological Organization’s World Weather Research Program.

Fig. 4 shows the WC-130J airborne radar image superimposed on the microwave image that illustrates an incipient eye feature in the middle of the curved microwave convective feature. This observation together with the dropsondes, suggest that throughout the middle levels, rotation is taking place to the extent that cyclonically curved bands are forming. However, the low-level GPS dropsondes clearly show that no surface circulation exists beneath the mid-level center, but instead it is displaced 120 km to the north. TCS-25 never developed, but was a trackable entity for 4 days.

TCS-37 was a similar situation to TCS-25 in that it, too, exhibited the vortex pair characteristic, but with the mid-level vortex located at 400 mb, a somewhat higher level than that in TCS-25. In this case the surface and 400 mb vortices were separated by nearly 200 km (Fig. 5, with the surface center west of the 400 mb center that was imbedded within the convective cluster. The surface center was in the clear, as was the case for TCS-25. The peak winds associated with the surface center were 15 kt southerly winds located east of the center within the convective cluster. Peak 400 mb winds were southwesterly at 25 kt and located along the southern edge of the convective cluster within a region of growing convective clouds. This system also failed to develop, but was trackable for 3 days. Fig 6 shows a strong diurnal signal to the convection with active cluster development during the first half of the flight followed by rapid dissipation during the second half of the flight.

These two systems are likely typical of many incipient disturbances prior to any development. With an aircraft available to deploy GPS dropsondes within the region, it may be possible to not only diagnose the vortex pair development, but to eventually distinguish the conditions that lead to TC genesis from those that are followed by decay, and with a day or two more lead-time than is currently possible.

We are at an historic turning point in history for the improvement of TC genesis and intensity change observation and forecasting. The capability to observe winds over the TC surface and mid-level domain, concurrent with subsurface ocean thermal structure, matches or soon will match the improvements in coupled model capabilities to assimilate and model the total TC environment. This alignment should provide the next best opportunity for improving TC structure and intensity change forecasting. This study has shown that low-/mid-level vortex pairs are typical of potential TC formation events. The challenge is now to define conditions for development and decay. A new observing strategy was pioneered that hopefully can be repeated within the ITOP experiment in 2010.

Section 2: TCS-08 airborne deployment of expendable platforms for assessment of environmental impacts on TC intensity and structure.

The TPARC/TCS-08 project deployed numerous expendable platforms into TCs at various stages of their life cycle from the US Air Force Reserve aircraft, WC-130J during the period from 1 August to 27 September, 2008. These platforms were GPS dropsondes for measuring atmospheric vertical profiles of temperature, humidity and wind, AXBT types for measuring the ocean vertical temperature profile to 300- or 900- m and drifting buoys of two types: Adaptive Ocean Observing Platform (ADOS) and Minimet. The ADOS drifting buoys contained surface pressure sensors and temperature sensors at 10-m intervals to 140m while the Minimet contained surface pressure, surface wind speed and direction, and sea surface temperature. Deployments of 12 buoys each were conducted prior to typhoons Hagupit and Jangmi on 20 and 26 September, respectively, the later about 36 hours prior to landfall in Taiwan. We investigated the potential for mitigating landfall impacts through improved observations from air-deployed sensors ahead of and within landfalling TC's.

Major goals for this project are two-fold: 1) provide new observations simultaneously, both within the TC itself as well as the ocean below, to a developing NRL coupled TC modeling effort (COAMPS-TC) and 2) utilize Tropical Cyclone Structure 2008 (TCS-08) field program data sets to improve understanding of TC life cycle, especially Rapid Intensification (RI) mature stage episodes associated with oceanic environmental changes.

The approach used to undertake the field observing phase of the TCS-08 project was to define a series of flight plans targeted at observing the 3D environmental structure during TC mature stage and to observe intensity and structure at the surface and mid-levels. To this end, a series of flight patterns were designed to be flown either east or west of the operating base (Fig 1). In addition, a communications scheme between scientists at various other operation centers, especially the main operations center in Monterey and with the two aircraft and the Guam operations center (Fig 2).

Once this plan was in place, the objective was to select a case that would demonstrate the usefulness of simultaneous TC atmospheric and oceanic observations. Such a case was TC Hagupit followed less than one week later by Super-typhoon Jangmi.

As mentioned earlier, 12 drifters were deployed in front Hagupit and 12 more were deployed ahead of Jangmi. All drifters fell to the sea on parachutes and deployed properly. The deployment was described by Black in the first IWTCLP³ volume (Elsberry, et al, 2005). Fig. 7 shows the deployment pattern for Jangmi superimposed on the buoy positions from the Hagupit deployment. Coincidentally, the tracks of the two storms were nearly parallel, allowing observations in Jangmi from nearly 24 drifters. The drifter observations showed a cold eddy along the track of Jangmi which was verified by satellite observations (Fig. 8) and by AXBTs (Fig. 9). The surface manifestation of the cold eddy only became visible after the intense mixing took place in the region by the high winds ahead of Jangmi. Note in Fig 8 that the cold region produced by Hagupit and the southern boundary of this same cold eddy is still visible to the left of Jangmi's track. The region of deepening mixed layers produced by the storm, in excess of 100 m, as well as the relatively shallow mixed layers over the cold eddy is shown in Fig. 9.

As the storm moved across the boundary between the warm and cold eddies within the Southern Eddy Zone on 27 Sept, the rapid deepening that produced a minimum pressure of 902 mb and super-typhoon status abruptly halted and was replaced by rapid filling over the next 24 hours (Fig. 10), making landfall with 57 m/s maximum winds rather than 77 m/s maximum winds, thus sparing Taiwan a worse catastrophe. Detection of these ocean features thus played a big role in explaining the rapid intensity change, a result that could eventually come into operational use in the future.

The dramatic change in the structure of Jangmi is shown in Fig. 11 with a rapid drying and thinning of the rainbands in the NW quadrant as the storm approached Taiwan. Coincidentally, this region of rain band decay is just downwind from the cold SST anomaly produced by the storm.

³ The IWTCLP is the International Workshop on Tropical Cyclone Landfall Processes, sponsored by the World Meteorological Organization's Tropical Meteorology Research Program's Commission for Atmospheric Sciences.

Fig. 12 shows the wind structure of Jangmi at its peak intensity based on analysis by airborne SFMR surface winds compared with the incomplete and rain-affected observations from Quikscat satellite scatterometer. Without the aircraft observations or satellite intensity estimates, the true knowledge of the high winds in the eyewall would not be fully known. Fig. 13 shows Jangmi's eyewall structure from the WC-130J airborne weather radar (Black and Hawkins, 2009).

IMPACT/APPLICATIONS

The impact of these observations is expected to be significant in three ways. First, it provides a unique set of GPS dropsonde and AXBT data observed simultaneously from high altitude, which allows for a unique analysis of the 3D atmospheric structure associated with convective cloud clusters in the genesis stage of WPAC TCs. More in-depth analysis will provide insight into structures that differentiate developers from non-developers. Second, detailed oceanographic observations were obtained simultaneously with detailed intensity and structure change observations from aircraft and satellite, which allowed preliminary diagnosis of environmental factors associated with RI and RF in TC Jangmi. That data can be related to oceanographic features leading to a large impact on TC landfall effects. Third, use of this data as input to the new generation of coupled TC model being developed at NRL (the COAMPS-TC model) is allowing for insights into TC intensity and track forecasting for model runs with and without ocean coupling, helping to diagnose the impacts of ocean features.

The successful TCS-08 field program will provide a wealth of digital data sets from multiple sensors that will help answer scientific TC questions by virtue of a) the unique western Pacific basin's TCs, b) the aircraft sensors utilized, c) the capture of TCs spanning from pre-genesis to Category 5, and d) the combination of multiple aircraft and satellite sensors for both cross-validation and composite views to address specific scientific thrusts.

RELATED PROJECTS

This project is closely related to the ONR-funded project, "Satellite-derived tropical cyclone intensities and structure change (TCS-08)" with PI Jeffrey D. Hawkins.

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Elsberry, R. L., M. T. Montgomery, D. Raymond, P. Black, J. Hawkins, P. A. Harr, C. Velden, E. A. Ritchie, W. C. Lee, M. Bell, D. Eleuterio, and R. Ferek, 2009, The Tropical Cyclone Structure (TCS-08) program: Objectives on tropical cyclone formation, intensification, and structure change, *Third THORPEX International Science Symposium*, Monterey, CA, Sept. 14-18, 2009.

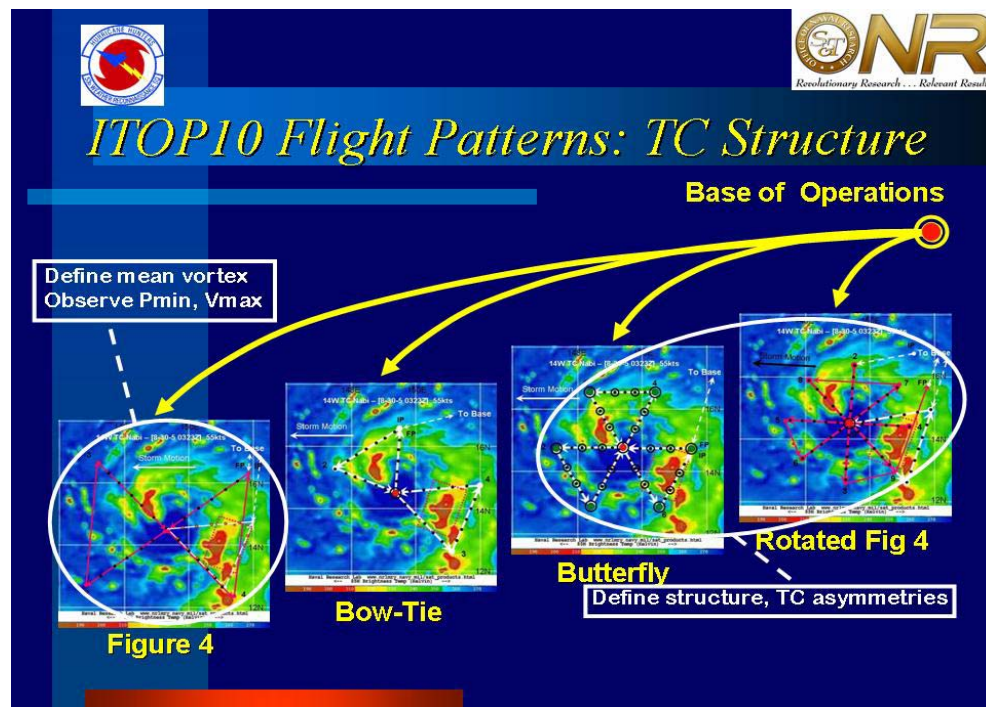


Figure 1. TCS-08 flight plan strategy.

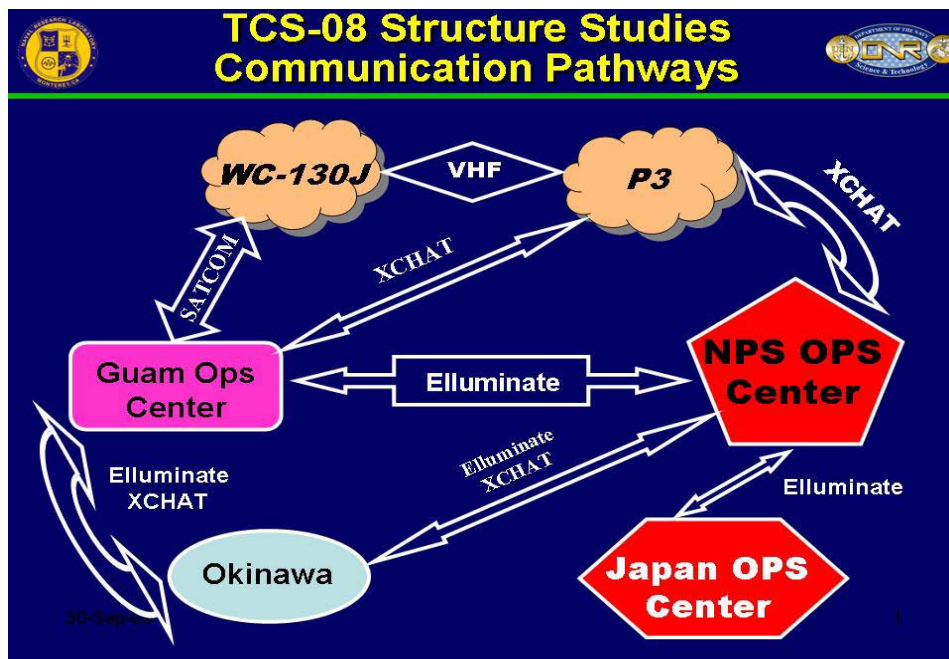


Figure 2. TCS-08 communications strategy.

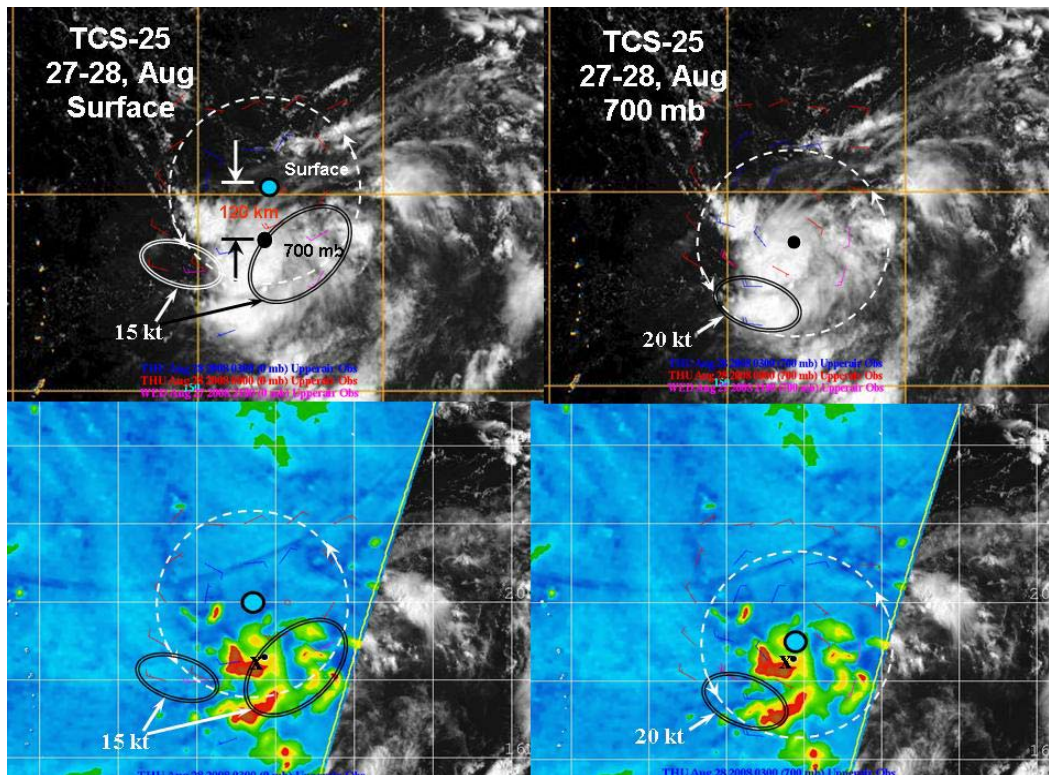


Figure 3. Visible and microwave satellite imagery for TCS-25 with GPS dropsonde surface winds plotted in the upper and lower left panels and 700 mb winds plotted in the upper and lower right panels. The ovals indicate the maximum wind regions, the dashed circle the approximate radius of maximum wind, the blue dot the surface circulation center, the black dot the 700 mb circulation center and the 'x' indicates the airborne radar incipient eye center.

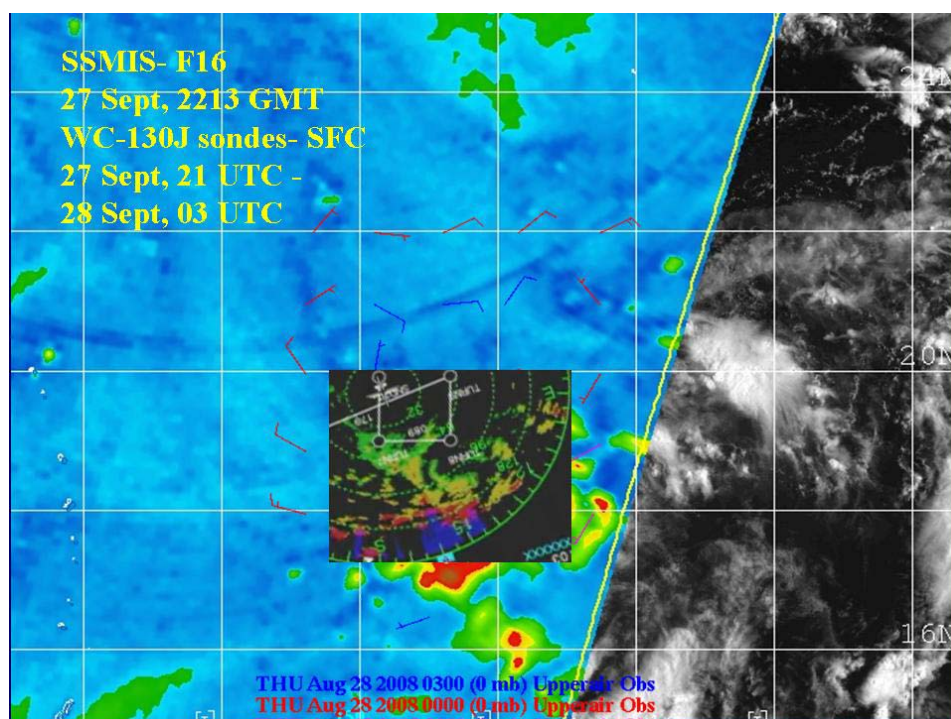


Figure 4. Airborne radar image superimposed upon satellite microwave image and 700 mb GPS dropsonde wind barbs.

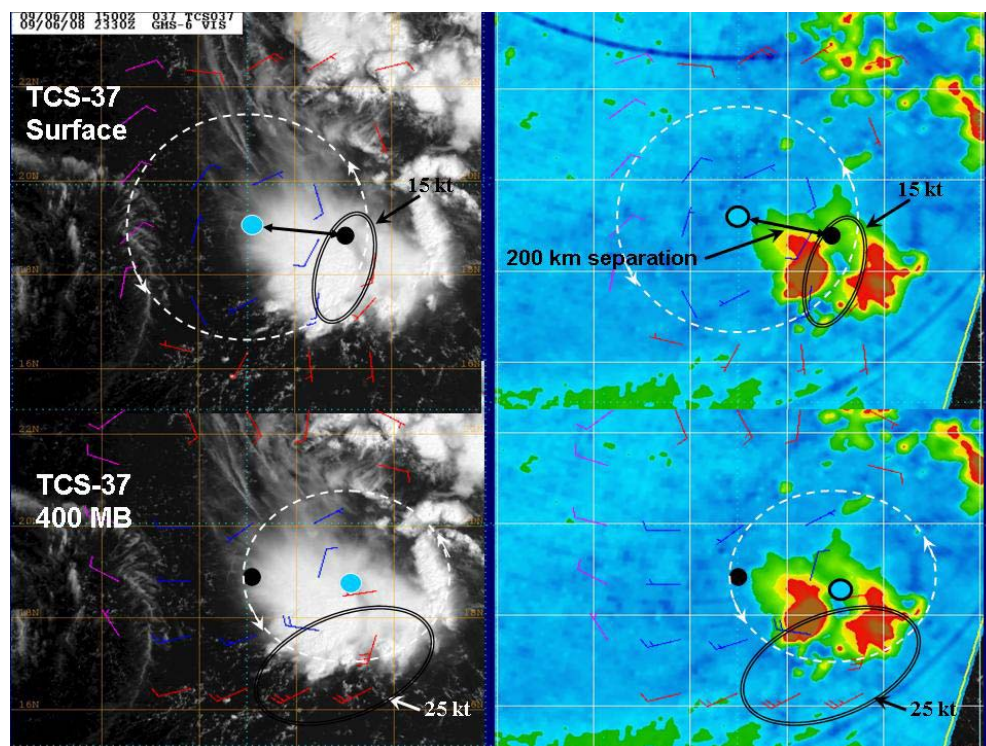


Figure 5. Visible and microwave imagery for TCS-37, 6-7 Sept. Upper left and upper right panels show the surface wind barbs. Lower left and lower right show the 400 mb wind barbs. The ovals indicate the wind maxima.

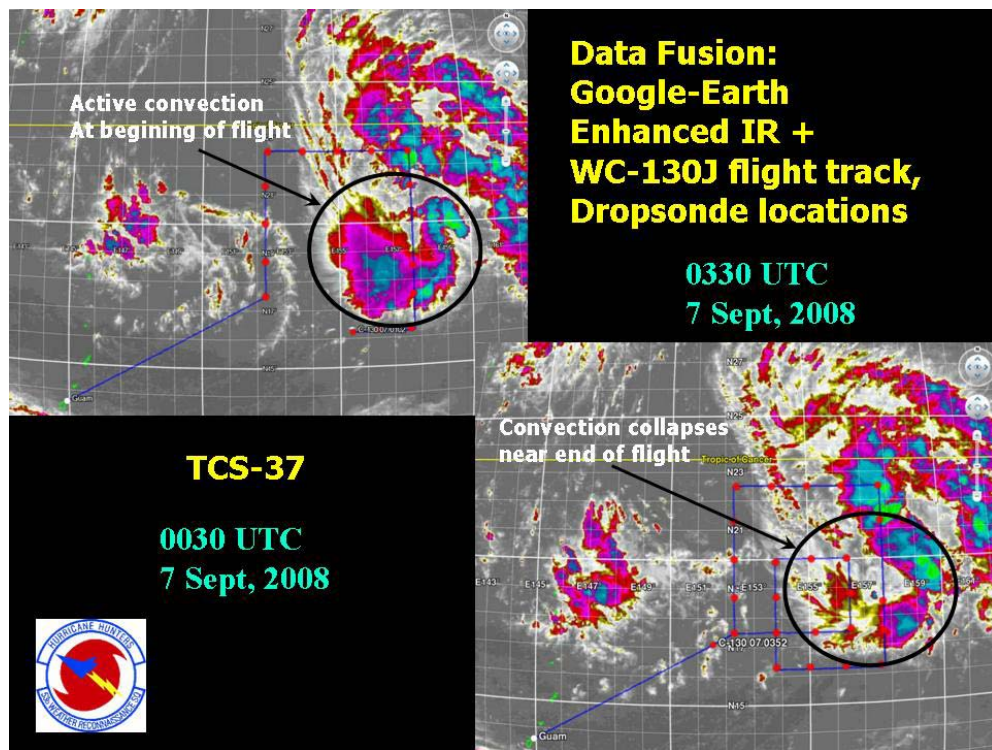


Figure 6. Infrared imagery near the beginning of the TCS-37 flight showing an intense convective cluster covering the eastern half of the intended flight track (upper left panel). This image is contrasted three hours later by an infrared image showing the convective cluster almost entirely dissipated near the end of the TCS-37 flight (lower right).

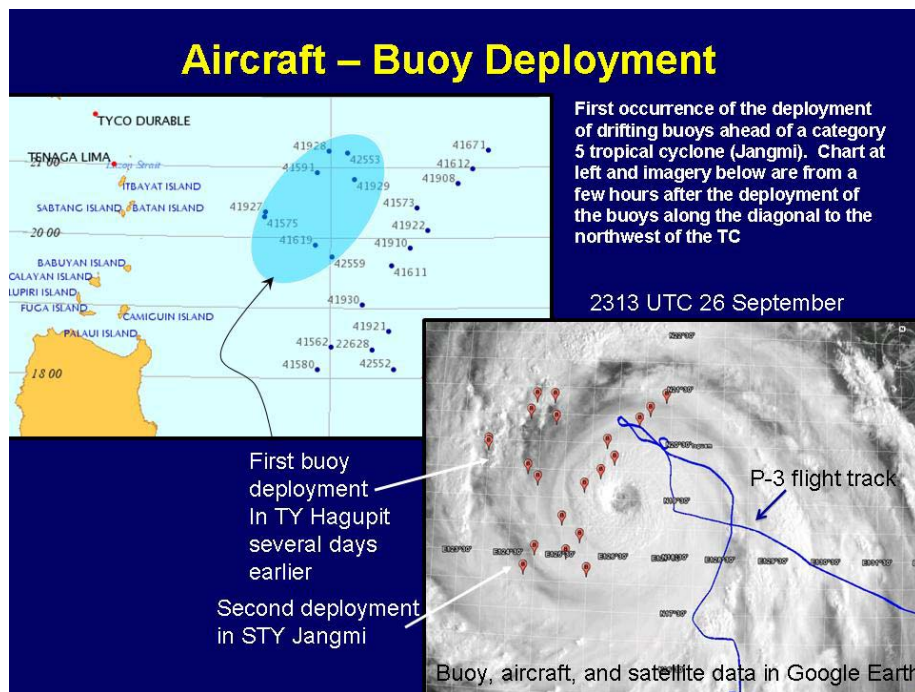


Figure 7. The drifting buoy locations in front of TC Jangmi are shown shortly after deployment. Data and positions were transmitted via satellite (Service Argos).

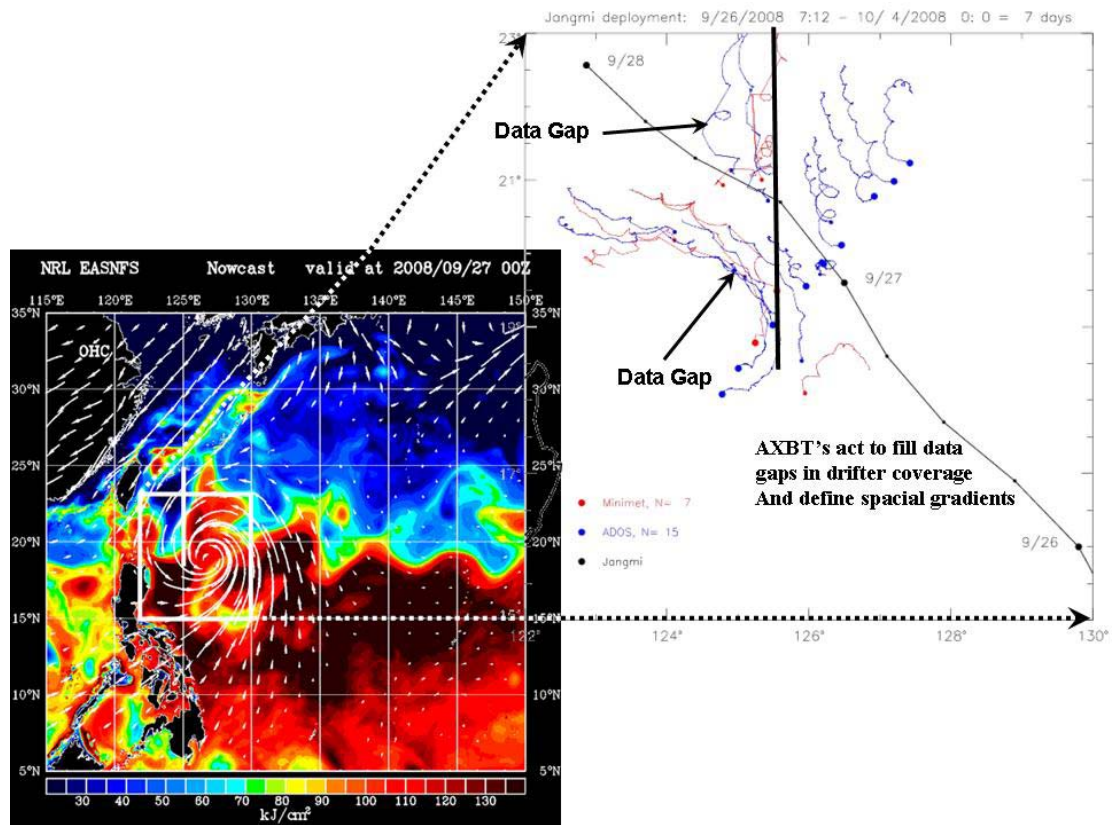


Figure 8. Ocean Heat Content from NRL Stennis ocean model (left) together with drifter trajectories relative to storm track and boundary between cold, cyclonic and warm eddies.

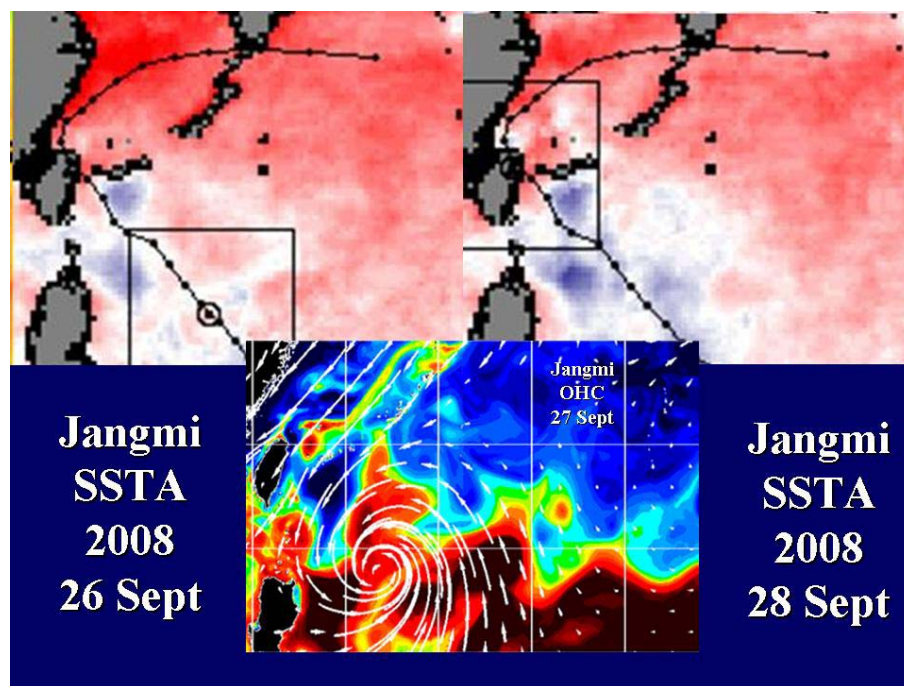


Figure 9. SST anomaly observed by IR and microwave sensors (Remote Sensing Systems) for Jangmi on 26 and 28 September together with Stennis Ocean Model OHC for 27 September.

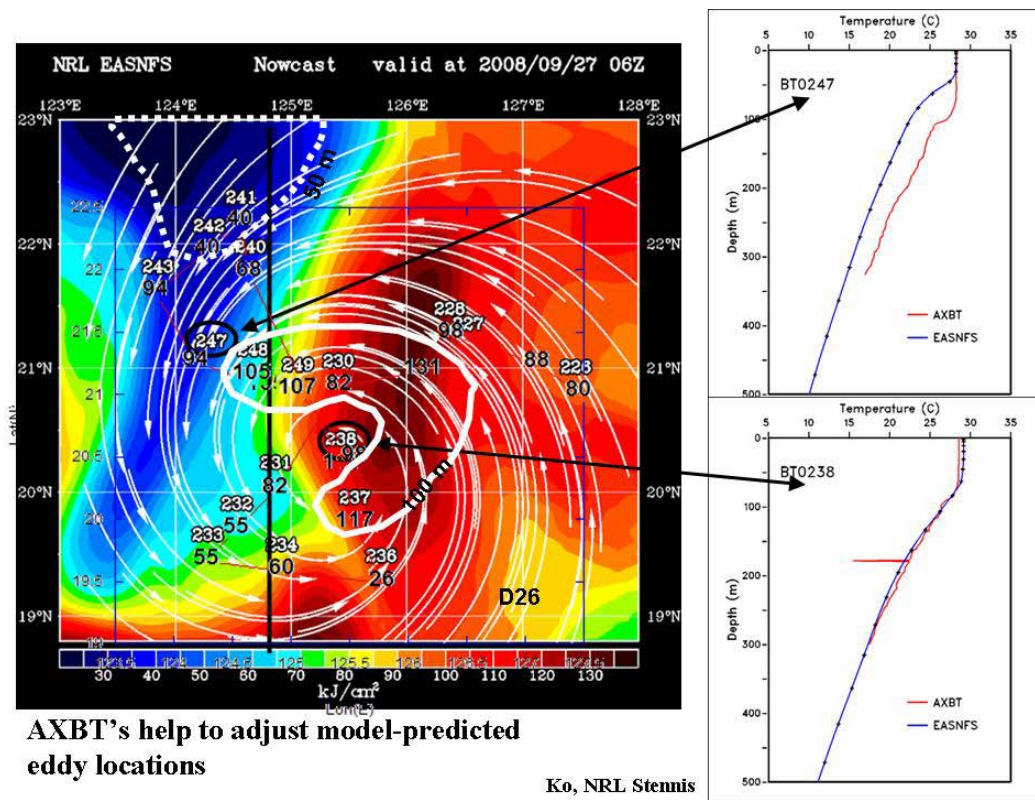


Figure 10. AXBT observations superimposed upon OHC together with 100 m contour (white solid) and 50 m contour (dotted) for the bottom of the ocean mixed layer.

TCS08
Jangmi Sept, 2008
Track,
Intensity Change

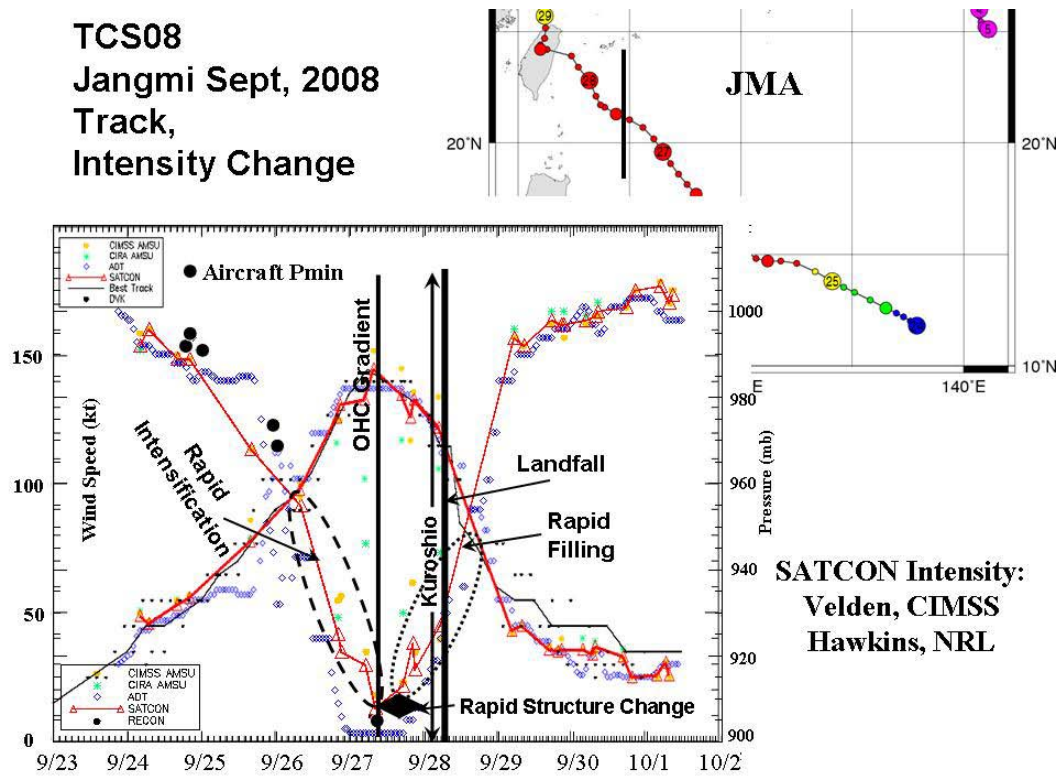


Figure 11. Vmax and Pmin profiles relative to the OHC gradient at the eddy boundary just offshore from the Kuroshio and landfall on Taiwan. Track in upper left shows eddy boundary (solid black line).

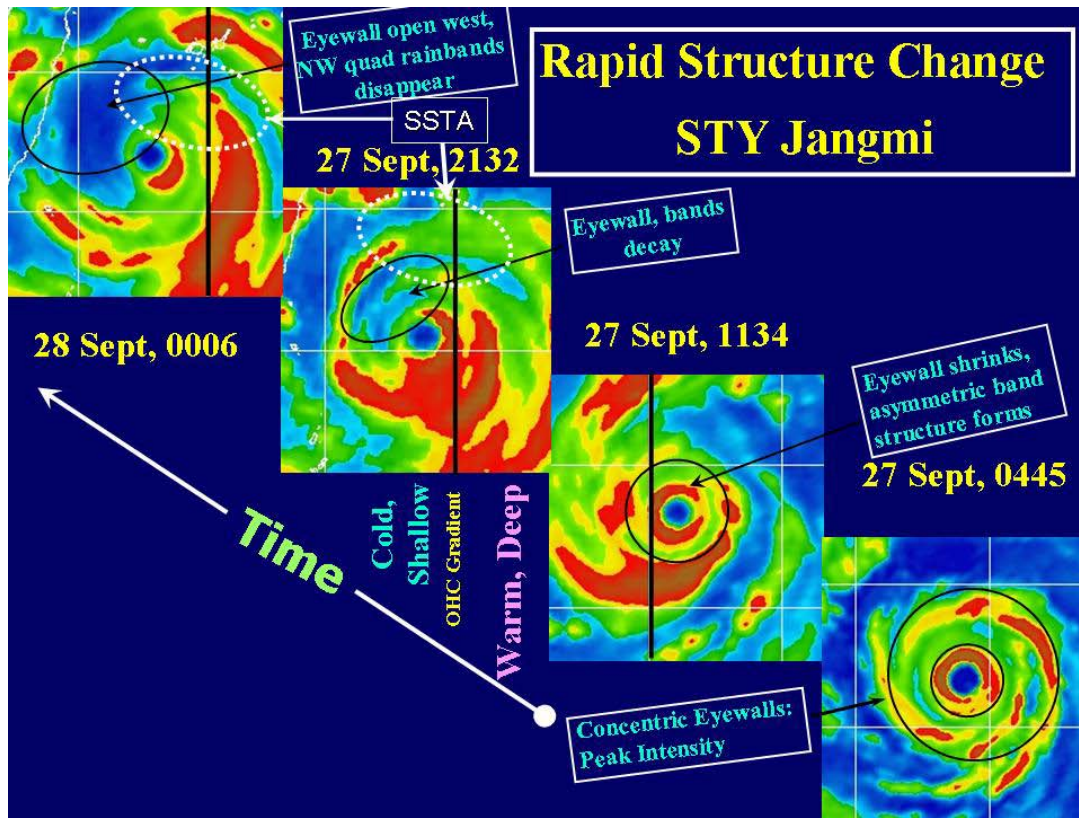


Figure 12. Rapid change in Jangmi structure while passing eddy boundary, shown by solid black line. Thin black oval shows region of rainband decay downstream from maximum SST anomaly shown by dotted white oval.

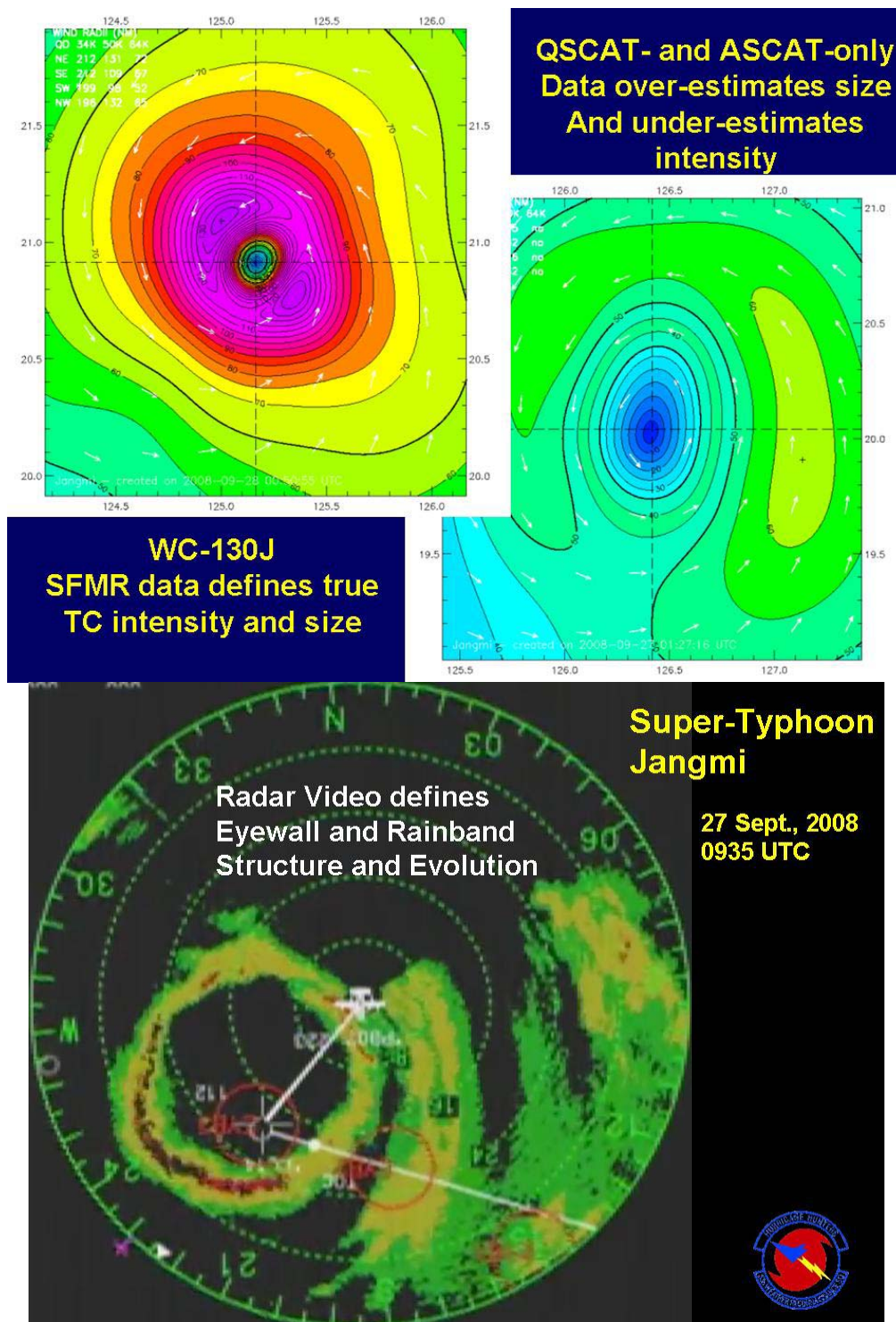


Figure 13. Surface wind field in Jangmi from airborne SFMR (upper-left) compared with windfield derived from satellite scatterometer measurements (upper-right). Lower panel shows airborne radar display of eyewall structure (north is up) taken as the aircraft prepares to enter the eyewall.