# P1.98 THE THORPEX PACIFIC ASIAN REGIONAL CAMPAIGN (T-PARC) OBJECTIVE ON THE EXTRATROPICAL TRANSITION OF TROPICAL CYCLONES: OBSERVED CASES, THEIR STRUCTURE AND DOWNSTREAM IMPACTS

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## 1. INTRODUCTION

A unique aspect of the THORPEX-Pacific Asian Regional Campaign (T-PARC) was to address the shorter-range dynamics and forecast skill associated with high-impact weather events of one region (Eastern Asia and the western North Pacific) and their downstream impacts on the medium-range dynamics and forecast skill of another region (in particular, the eastern North Pacific and North America). To address this objective, a tropical-to-extratropical measurement strategy was designed. The primary focus of this strategy was the extratropical transition (ET) of tropical cyclones based on the poleward movement of a decaying tropical cyclone and the resulting intense cyclogenesis that may result from its interaction with the midlatitude circulation. Although an ET event severely impacts the region of the western North Pacific, the poleward movement of the decaying tropical cyclone represents a perturbation of moisture and momentum into the midlatitudes. The upper- and mid-level outflow from the decaying tropical cyclone may be associated with advection of vorticity through the divergent winds, which is a known Rossby wave source. Through excitation of Rossby-waves (Fig. 1), a decaying tropical cyclone that undergoes ET may impact the midlatitude circulation far downstream.

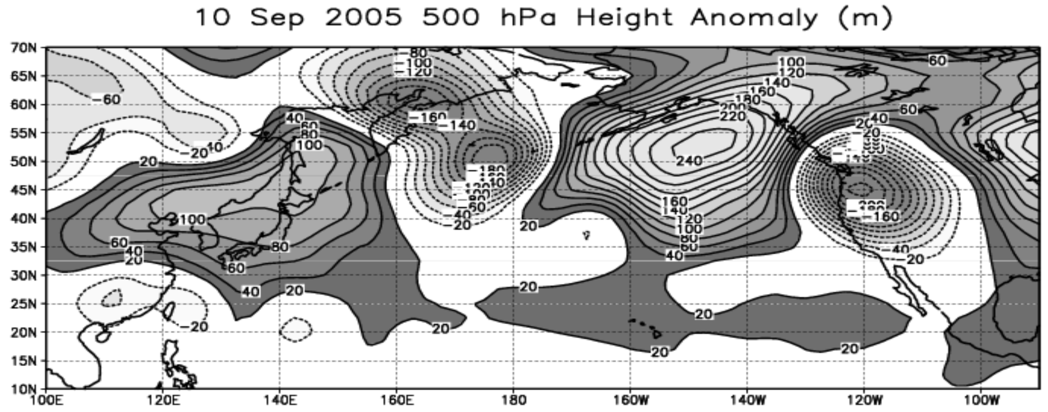
10 Sep 2005 500 hPa Height Anomaly (m)

*Figure 1. Anomalies of 500 hPa height (m) averaged for 0000-1200 UTC 10 September 2005 and representative of a Rossby-wave like pattern. The tropical cyclone symbol marks the ex-TY Nabi.*

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Because of the complex dynamical and thermodynamic environment associated with the extratropical transition process the observation strategy required the combination of multiple satellite and airborne reconnaissance platforms from a near global set of participants. This near global participation in the science objective associated with extratropical transition and downstream impacts is an indication that the scientific principles being examined with respect to downstream weather impacts by events upstream are applicable to many regions of the globe.

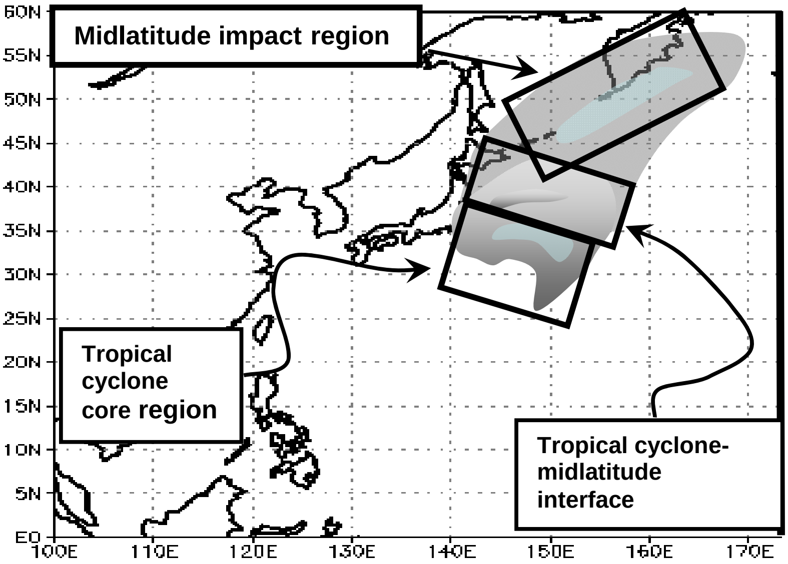

*Figure 2: Schematic of three regions associated with the ET of a tropical cyclone over the western North Pacific. The light gray shaded region represents overall cloud patterns. Shaded regions within the light gray areas indicate regions of concentrated cloud amounts defined by convection in the tropical cyclone core region, large-scale precipitation in the tropical cyclone midlatitude interface region, and cirrus in the midlatitude impact region.*

## 2. OBJECTIVES AND MEASUREMENT STRATEGIES

The primary scientific objectives associated with ET and downstream impacts due to ET events may be placed in a framework of mechanisms and predictability.

### 2.1 Mechanisms

To understand the influence of extratropical transition on high-impact downstream weather events, mechanisms responsible for the generation, intensification, and propagation of the Rossby wave-like disturbances need to be identified. The critical mechanisms and processes that may define the downstream response to an ET event over the western North Pacific occur in the three characteristic regions (Fig. 2) that represent the decaying tropical cyclone, the tropical cyclone-midlatitude interface, and the midlatitude impact region. The T-PARC measurement strategy was designed to observe characteristic features in each of the three regions during the interaction of a tropical cyclone with the midlatitude circulation into which it is moving.

### 2.2 Predictability

The impact of the ET event on downstream predictability may be examined in the context of increased standard deviation in mid-tropospheric heights among ensemble members generated with an operational global ensemble prediction system. During the ET of TY Nabi (Fig. 3), a series of localized maxima in ensemble

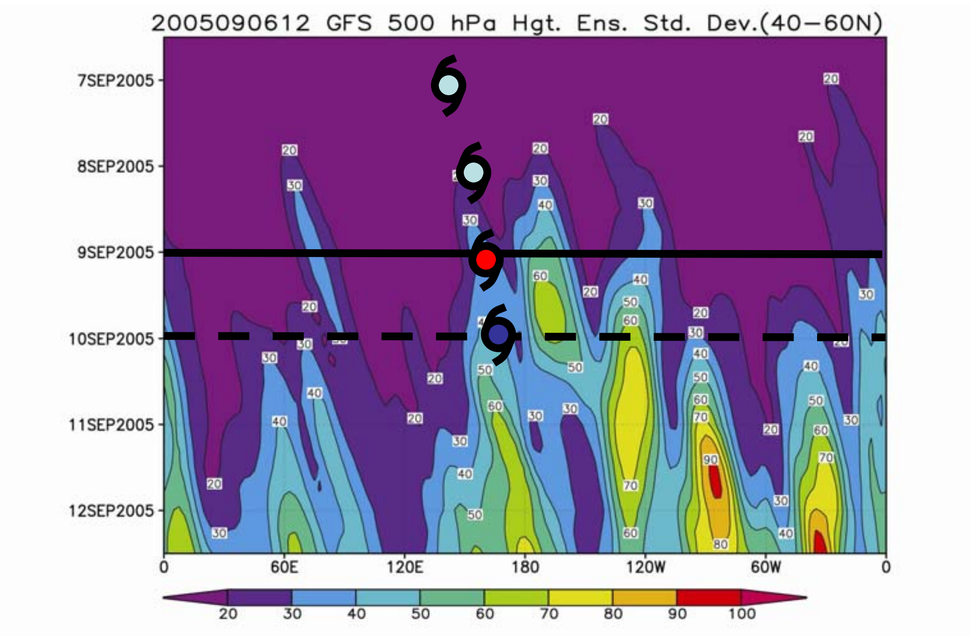

*Figure 3: Time-longitude diagram of the standard deviation (m) in ensemble members for 500 hPa heights for the forecasts initiated from 1200 UTC 6 September 2005 with the Global Forecast System model run at the National Centers for Environmental Prediction. The horizontal line at 0000 UTC 9 September marks the time of the ET of TY Nabi. The dashed horizontal line marks the time that the ex-Nabi intensified to a deep extratropical cyclone. The tropical cyclone symbols mark the longitude of Nabi.*

standard deviation spread downstream of the location of the decaying tropical cyclone.

An important objective of T-PARC is to examine the mechanisms by which physical characteristics associated with the regions of an ET event defined in Fig. 2 are related to a reduction in predictability downstream as indicated by the increased standard deviation in Fig. 3. Physical mechanisms to be examined include the poleward movement of heat and moisture along the eastern side of a decaying tropical cyclone, warm frontogenesis in the tropical cyclone midlatitude interface region, and the interaction of the tropical cyclone outflow and the midlatitude jet stream in the midlatitude impact region. Examination of the temporal evolution of the above characteristics during the ET process as they relate to impacts on the midlatitude circulation is also a primary objective of the T-PARC measurement strategy. Related to the temporal evolution of the ET process is identifying the importance of the re-intensification of the decaying tropical cyclone as an extratropical cyclone at the completion of the ET process on maintaining the downstream transport of energy as in a downstream development scenario.

## 3. T-PARC FIELD PHASE HIGHLIGHTS

During the field phase of T-PARC, several tropical disturbances moved poleward to undergo a transition into the midlatitudes. The character of these disturbances included a weak circulation associated with widespread deep convection, a midget tropical cyclone, a typhoon, and a super typhoon. Corresponding to the variety of tropical disturbances was a wide range of forecast and actual structural changes and downstream developments, which provide a broad spectrum of forcing and downstream impacts to be investigated.

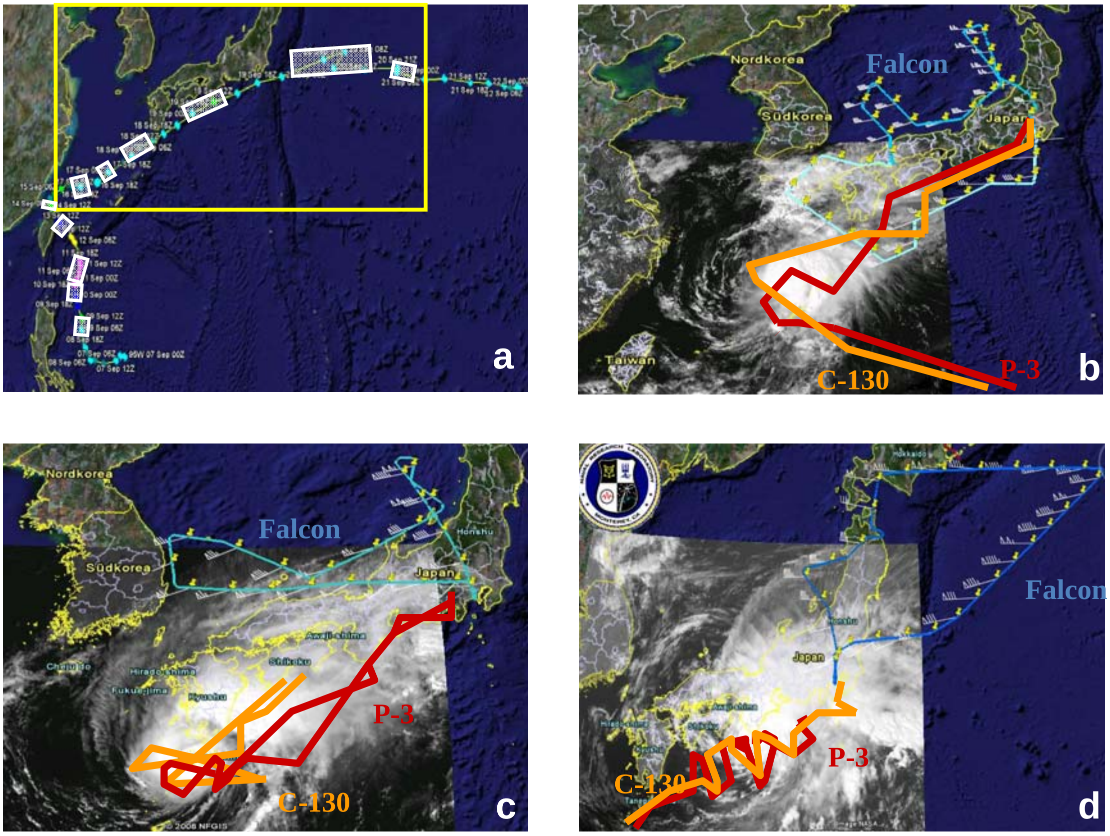

*Figure 4 (a) Track of TY Sinlaku in 6-h intervals. The shaded boxes define times when aircraft missions were conducted. The yellow box defines the ET portion of TY Sinlaku. (b) Flight tracks of the WC-130J (orange), NRL P-3 (red), and DLR Falcon (blue) for the aircraft missions from 2100 UTC 16 September to 1115 17 September 2008. (c) As in (b), except for the aircraft missions from 2240 UTC 17 September to 0725 18 September 2008. (d) As in (b), except for the aircraft missions from 0015 UTC to 0710 UTC 19 September 2008. Visible imagery from Naval Research Laboratory, Monterey.*

### 3.1 Typhoon Sinlaku

Typhoon (TY) Sinlaku formed over the Philippine Sea due east of Luzon, Philippines and moved northward to landfall on Taiwan as a category four storm (Fig. 4a). After landfall, a weakened TY Sinlaku made a sharp recurvature as it approached a strong zonal westerly flow over the subtropical latitudes. Under the influence of strong vertical wind shear that began near 0600 UTC 15 September, only a low-level center remained intact until deep convection began to occur near 0600 UTC 17 September (Fig. 4b). At the time of the re-initiation of deep convection, the WC-130J and NRL P-3 were flying in the environment of the re-intensifying tropical cyclone (Fig. 4b). These flights were defined to examine the decaying tropical cyclone core region and the midlatitude tropical cyclone interface region (Fig. 2). At this time, the DLR Falcon aircraft was flying in the region of the midlatitude interface to obtain observations of the outflow from TY Sinlaku. During these flights, important observations of the re-intensification of the tropical cyclone under strong vertical wind shear were obtained. Twenty-four hours later (Fig. 4c), a similar measurement strategy was followed with the WC-130 and NRL P-3 making observations in the tropical cyclone core and midlatitude interface regions, and the DLR

FALCON observing the outflow from the reintensifying typhoon into the midlatitude jet. At this time, the circulation was intensifying to typhoon strength before eventually entering the transformation stage of ET over the next 24 h (Fig. 4d). During the transformation stage of ET, a three-plane mission was again conducted to follow the same measurement strategy as defined during the prior two missions. A fourth mission on 20 September (not shown) was conducted near the end of the ET process in which the WC-130 and NRL P-3 again examined the principal physical characteristics of the ET of TY Sinlaku. A final DLR Falcon mission on 21 September (not shown) examined the circulation of the remnants of Sinlaku and the midlatitude jet.

As described above, the measurement strategy associated with the case of TY Sinlaku was defined to observe the important physical mechanisms associated with the ET process in each of the key regions defined in Fig. 2. Important observations include ELDORA measurements of the evolution of deep convection in the tropical cyclone core and warm frontogenesis regions. Additionally, the ELDORA-derived winds provide important measurements of the three-dimensional structure associated with the ET process that can be used to identify the relative roles of physical processes such as poleward advection of heat and moisture, and contributions to the process of warm frontogenesis. Wind and water vapour lidar as well as dropsonde measurements will help to define the outflow – jet interaction.

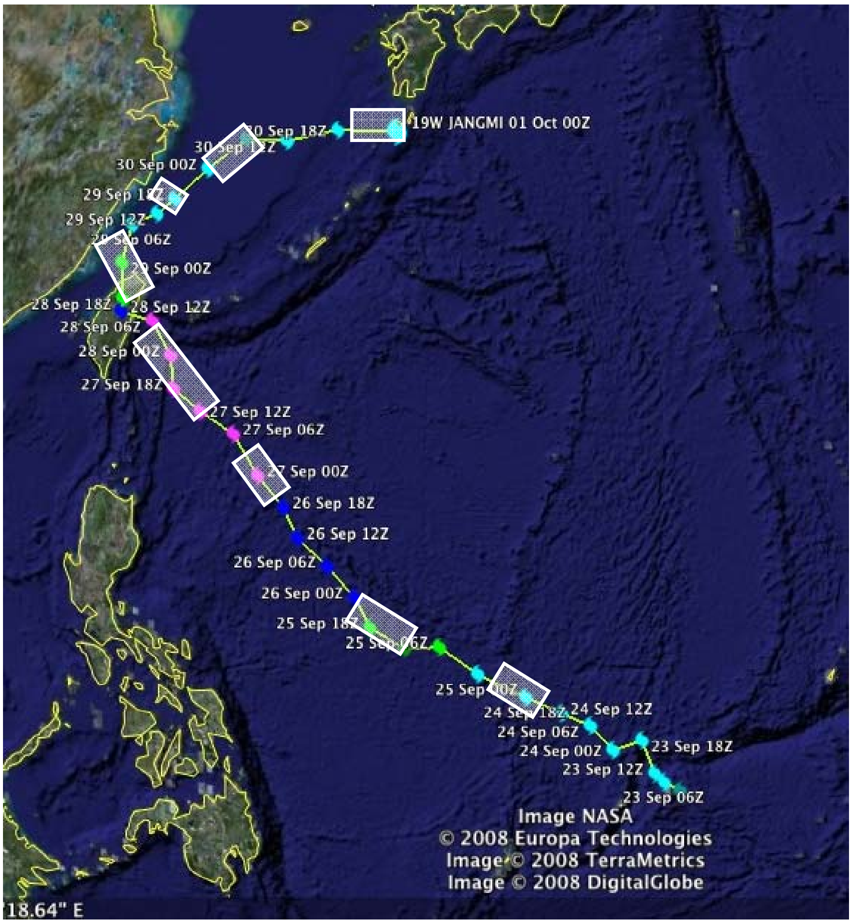

*Figure 5 Track of TY Jangmi. The shaded boxes define the periods in which aircraft missions were conducted.*

### 3.2 Typhoon Jangmi

TY Jangmi formed over the Philippine Sea and moved northwestward to become a category five storm as it approached central Taiwan (Fig. 5). As Jangmi passed over the central mountain range of Taiwan, it also came under the influence of strong vertical wind shear due to strong midlatitude westerly flow. This flow pattern also recurved the storm as it passed over Taiwan. There was large uncertainty in both deterministic and ensemble forecasts of recurvature and ET. Following recurvature, Jangmi remained highly sheared with reduced deep convection. Although Jangmi did not undergo a period of re-intensification as TY Sinlaku did, mesoscale model forecasts, radiosonde observations and satellite derived atmospheric motion vectors indicated that the outflow from the decaying tropical cyclone was moving into the strong midlatitude flow that was north of Jangmi.

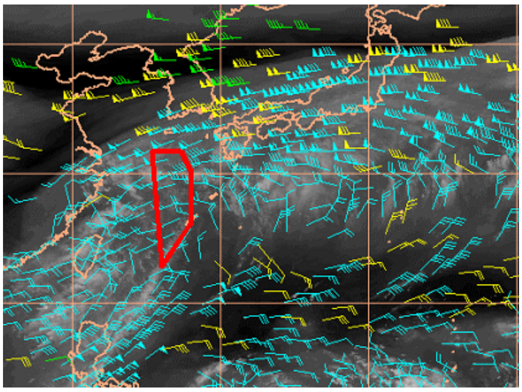

*Figure 6: DLR Falcon flight track (red line) centred near 0000 UTC 29 September 2008 superimposed on mid-upper-level MTSAT water vapour winds (blue 100-250 hPa, yellow 251-300 hPa, green 351-500 hPa) from CIMSS / SSEC / University of Wisconsin.*

A sequence of DLR FALCON missions from 28 – 30 September combined targeting objectives with sampling the outflow (e.g. Fig. 6) into the midlatitude impact region north of the decaying tropical cyclone. A final mission on 1 October 2008 sampled the structure of the remnants of Jangmi. During these missions, valuable observations from dropsondes, DIAL and Doppler wind lidar were obtained to characterize the interaction of Jangmi with the midlatitude jet.

### 3.3 Other Disturbances

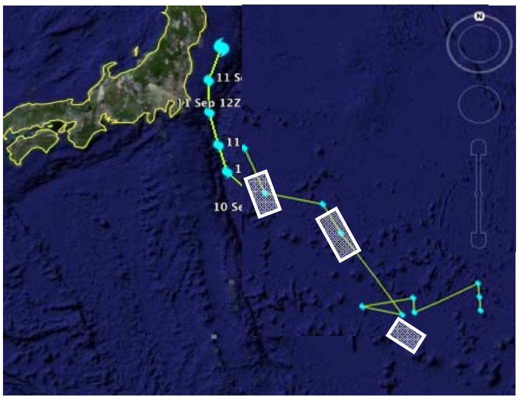

*Figure 7: Track of Tropical Depression (TD 16W) between 0000 7 September – 1200 UTC 11 September 2008*

During the course of the T-PARC field program, other tropical disturbances moved into the midlatitudes as either a midget tropical cyclone (Fig. 7) or significant subtropical circulation systems. Several aircraft missions were conducted into these systems to document mechanisms such as transport of significant amounts of tropical moisture into regions undergoing baroclinic development of extratropical cyclones. For two such systems NRL P-3 and WC-130 observations were made in the early stages of the tropical circulation and DLR Falcon missions documented the interaction with the midlatitude flow on later days. These data sets are unique in the sense that *in situ* measurements of the tropical-extratropical interactions are rarely obtained but rather these impacts are estimated from remotely-sensed data obtained from satellite.

## 4. SUMMARY

A primary objective of the field phase of T-PARC was the direct measurement of physical characteristics associated with the movement of tropical cyclones into the midlatitudes. During the field phase, a variety of poleward-moving tropical circulation were observed by a wide range of instruments designed to observe the complex physical processes associated with the poleward movement of a tropical cyclone. These observations will provide a basis for examining the impact of the tropical circulations on the region of the midlatitudes into which they are moving and their downstream impacts through a variety of physical mechanisms.

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