Experiment Design Overview

THORPEX

Pacific Asian Regional Campaign
(PARC)

January, 2006

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1. Executive Summary

The continent of North America experiences some of the most severe weather in the world, which includes flash floods, droughts, tropical cyclones, tornadoes, damaging hail, blizzards, freezing rain, and heat waves. The impact of severe weather on North America often has global implications via impacts on such factors as economy and natural resources. Recent research results made possible by availability of reanalysis data sets and numerical weather prediction models have demonsrated the global aspects of separate regional high-impact weather events. Over the past several decades, there has been slow but steady progress in accuracy of forecasts of midlatitude weather systems with a rate of improvement of about one day per decade. The rate of advancement is very much slower for many parameters of critical interest to society, such as the prediction of heavy precipitation. However, increased understanding of the global nature of the regional high-impact events may be one factor that leads to an increase in the rate of advancement in forecast skill. The current slow, linear increase in forecast skill is outstripped by increased demand due to exponential growth of the world's population, economies that are increasingly global in nature, an urbanization of society that often includes dramatic increases in population densities in areas at risk, and infrastructures that can be disrupted by major weather disasters. Consistent with society's need for improved forecast skill, the 14th Congress of the World Meteorological Organization, which represents approximately 180 nations, initiated the THORPEX (THe Observing system Research and Predictability EXperiment) under the World Weather Research Program to accelerate the rate of improvement in forecast skill for high-impact weather and to increase the utilization of weather products for the benefit of society.

After reviewing the most promising avenues to achieve the THORPEX goals, the North American THORPEX committee has chosen a focus to advance knowledge, improve prediction, and society's response to high-impact weather events over North America, the Arctic and other locations whose dynamical roots and/or forecast errors often originate upstream over the North Pacific Ocean. The North American THORPEX objectives will be accomplished by collaborating with the Asian THORPEX group in a major international field campaign called Pacific Asian Regional Campaign (PARC) during August through December 2008. While the primary focus of the Asian THORPEX is on high-impact weather events over eastern Asia and the western North Pacific, the North American THORPEX efforts concentrate on the source and variability associated with downstream impacts over North America. PARC is unique with emphasis on shorter-range dynamics and forecast problems of one region and resulting medium-range dynamics and forecast problems of a downstream region. PARC research benefits society since it addresses events that have major societal impact and address the requirement for increased forecast skill. PARC includes research by the academic community and applied activities of major operational weather forecast centers with participation from China, Japan, Korea, U.S., Canada, and countries of the European Union.

The scientific goals of PARC include significant research challenges with the potential for advancing operational forecasting and societal needs. Objectives include improved understanding of the dynamics and factors that limit the predictability of high-impact weather events over North America that occur downstream of separate significant weather events such as the movement of typhoons into the midlatitudes and the resulting extratropical transition over the western North Pacific. Additional objectives include: i) the use of special observations collected during the field phase of PARC to develop, improve, and evaluate data assimilation strategies, together with an improvement in the utilization of satellite measurements; ii) evaluating improvement in local and downstream forecast skill afforded by high-resolution, non-hydrostatic modeling; iii) increase the understanding of error growth and scale interactions associated with predictions of downstream development from upstream high-impact weather events; iv) testing of new strategies for adaptive observing and modeling strategies; v) improvement of the utility of ensemble forecast systems; and vi) understanding and improving society's response to weather disasters, including the appropriate use and evaluation of probabilistic information.

This document provides an overview of the design, facilities, and management strategies for the field phase of PARC. Scientific hypotheses and objectives, which are detailed in the separate Scientific Program Overview (SPO), are summarized in Sections 2 and 3. The experiment design and observation requirements for achieving the science objectives are defined in Section 4. Project and data management, and data facilities required to obtain the necessary observations personnel are listed with personnel in the final section.

2. Program Rationale and Scientific Hypotheses

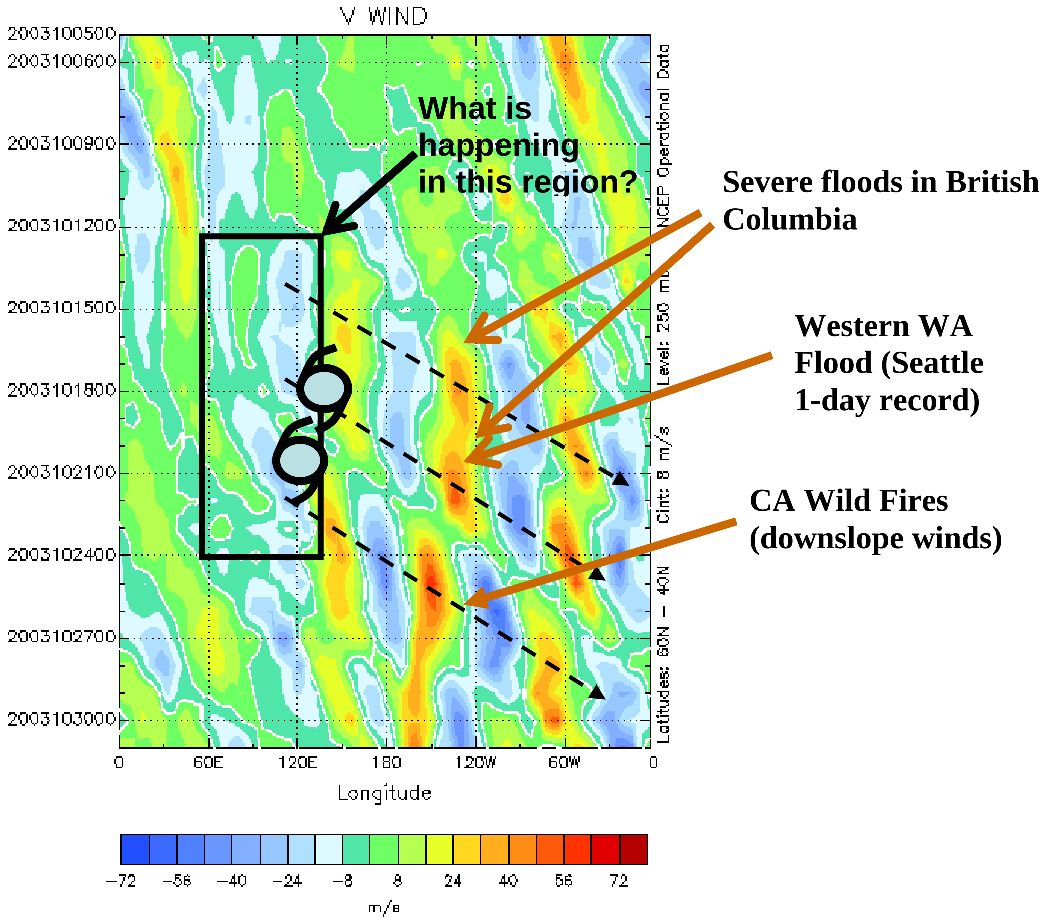
The long-term statistics on natural disasters are dominated by weather-related events that account for nearly three-quarters of the global occurrence of disasters, two-thirds of the property damage, and nearly 98% of fatalities. While the disastrous 2005 Atlantic hurricane season has focused attention on tropical cyclone-related disasters, North America experiences with some frequency a variety of other weather disasters with individual events that cause damages in the billions of dollars with risk to public safety and health. The ability of society to mitigate and respond to anticipated weather disasters depends on many factors. However, the response and mitigation of high-impact weather events ultimately begin with the accuracy of the forecasts at an adequate lead time. While accuracy of midlatitude weather forecasts has improved steadily, the progress has been slow with a rate of improvement of about one day per decade. This improvement has mostly been realized in the forecasts of large-scale weather features. The rate of improvement for many parameters, such as precipitation, that have a critical influence on society has been slower.

Recent research suggests that the region of the western North Pacific plays an important and unique role in defining many characteristics of the midlatitude circulation of the Northern Hemisphere. Over the western and central North Pacific, baroclinic energy conversion generates a large amount of kinetic energy that is instrumental in maintaining the storm tracks downstream over the eastern North Pacific, North America, and North Atlantic (Chang and Yu 1999; Orlanski and Sheldon 1995; Nielsen-Gammon and Lefevre 1996; Danielson et al. 2004). This implies that many of the high-impact weather events that occur over North America have a dynamical origin upstream over the western North Pacific basin. Furthermore, forecasts of downstream developments in the storm track over the eastern North Pacific that impact western North America often contain large errors (McMurdie and Mass 2004). Therefore, it is hypothesized that increased understanding of the dynamical linkages between development of high-impact weather events that occur over North America to specific weather systems upstream over the western North Pacific will lead to a significant increase in forecast skill of the downstream events.

One physical mechanism by which events over the western North Pacific may trigger downstream responses over the eastern North Pacific and North America is via upper-tropospheric wave packets (Fig. 1). Hakim (2003) and Chang (2005) have provided evidence that wave packets on the primary Asian waveguides increase the likelihood of the development of intense cyclones over the North Pacific. There are also indications that the wave packets are in turn invigorated by the cyclogenesis events, which makes their impacts farther downstream over North America potentially more significant.

The scientific framework for PARC addresses the relationships between development of high-impact weather events over North America and upstream sources over the western North Pacific and eastern Asia. While the upper-tropospheric wave packets provide a dynamical link between North America and the western North Pacific, the primary PARC hypotheses address the mechanisms that act to initiate wave packets and their role(s) in downstream predictability. An increase in understanding of the primary upstream forcing mechanisms and their variability will lead to increased predictability via strategies for adaptive control of the observing network and development of data assimilation techniques to best represent the important physical mechanisms. Hakim (2003 and 2005) demonstrated that upper-tropospheric, eastward-propagating wave packets are a dominant source of forecast errors over the North Pacific (Fig. 2). Furthermore, the forecast error patterns move with an eastward group velocity of about 30^o-40^o per day, which means that the leading edge of increased forecast error can reach western North America in about 3 days and the Great Lakes region in 4-5 days.

A primary hypothesis to be addressed by the field phase of PARC is that wave packets propagate from eastern Asia and the western North Pacific in response to specific forcing events such as the extratropical transition of a tropical cyclone that has moved into the midlatitudes (Fig. 3) and by Rossby waves initiated by organized tropical convection over the Philippine Sea in conjunction with an active western North Pacific monsoon trough. The enhanced wave activity is responsible for downstream



NOAA–CIRES/Climate Diagnostics Center

Fig. 1 Time-longitude diagram of 250 hPa meridional winds (m s^{-1}) from 0000 UTC 5 October 2003 – 1200 UTC 31 October 2003 (Figure made at http://www.cdc.noaa.gov). The diagonal dashed lines highlight eastward-moving, upper-tropospheric wave packets that originated over eastern Asia and the western North Pacific. The tropical cyclone symbols denote the times and longitudes associated with TY Parma (top) and TY Ketsana moving poleward of 20°N. (Adapted from a presentation figure by Dave Parsons, NCAR, at the WMO/TMRP International Workshop on Tropical/Extratropical Interactions).

cyclone development or establishment of large-scale ridge-trough patterns that may trigger persistent weather patterns over North America (e.g., a blocking anticyclone that may trigger heat waves or “fire weather”). One such noteworthy event of downstream wave activity related to the extratropical transition of Typhoon (TY) Tokage (Fig. 3) was an unusually early-season, severe rain and snow event over central and southern California (Fig. 4). In conjunction with the wave packet that originated over the western North Pacific, an unusually deep trough formed over the northwestern United States (Fig. 3) and moved southward toward central California by 20 October where heavy coastal rains and mountain snows occurred (Fig. 4).

The predictability of the wave train across the North Pacific downstream of TY Tokage was very low as defined by maxima in the standard deviation of 500 hPa heights (Fig. 5) from the ensemble prediction system (EPS) of the National Centers for Environmental Prediction (NCEP). The decreased predictability associated with an ET event and the imposed downstream response may be associated with increased analysis errors and model uncertainties due to the complex physical and dynamical mechanisms that occur during the ET process. Therefore, the key scientific issues related to increasing the predictability downstream of the ET include identification of the primary mechanisms that induce downstream responses and influence the variability of the downstream response. Key observations and the increased understanding of the important characteristics of the ET event and midlatitude environments will be utilized to reduce the initial condition uncertainties that impact predictability. This may be accomplished via several methods that include targeting *in situ* observations, adaptive use of satellite observations, development of data assimilation techniques, and numerical experimentation.

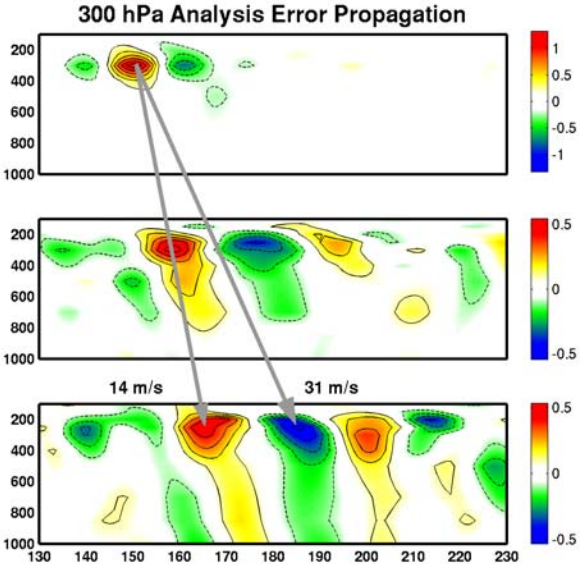


Figure 2. Height-longitude section of the propagation of forecast uncertainty across the North Pacific Ocean as determined by linear regression of meridional-wind uncertainties on analysis uncertainties at the point (150^{0}E, 300 hPa): (top) analysis uncertainty regression, (middle) 12-hour forecast uncertainty, and (bottom) 24-hour forecast uncertainty. Gray lines are estimates of the phase speed (14 m s^{-1}) and group speed (31 m s^{-1}). The analysis and forecast uncertainties are determined from an ensemble of operational global forecasts. Adapted from Hakim (2005).

While the focus of the North American component is on understanding factors that impact predictability of high-impact weather over North America, the PARC program is designed to fully utilize the global scope of the THORPEX program. Since the East Asian nations have been actively involved in the planning and implementation phase of THORPEX, the PARC program provides a unique opportunity for major international cooperation. One important example is the targeted observations program that is planned by Japan and South Korea for the 2008 typhoon season (between August and October). While these observations will primarily benefit the eastern Asia and western North Pacific region by improving the prediction of the tropical storm, past statistics indicate that about one third of the targeted storms will undergo extratropical transition (Klein et al. 2000 and 2002; Harr and Elsberry 2000; Harr et al. 2000),

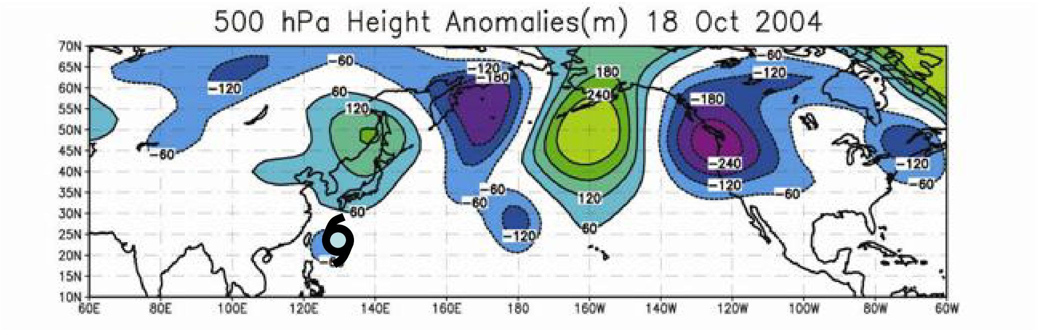


Fig. 3 Average 500 hPa height anomalies (m) for 0000 UTC 18 October and 1200 UTC 18 October 2004. The negative anomaly at 22^{o}N, 125^{o}E is due to TY Tokage. (Adapted from a presentation by Patrick Harr, Naval Postgraduate School, at the WMO/TMRP International Workshop on Tropical/Extratropical Interactions) .

which may lead to generation of an upper-level wave train that propagates faster downstream than the cyclone that undergoes extratropical transition. Furthermore, the wave train often triggers high impact weather events over North America (Figs. 3, 4). Because of the PARC hypothesis that predictability associated with these downstream impacts from an extratropical transition would be increased with key observations to reduce analysis errors and model uncertainty, the additional observational resources to maximize the downstream forecast benefits of the observations collected by Japanese and Korean reconnaissance planes will be important contributions for examination of the impact of the of the pre-transition environment and structure of the tropical cyclone on the post-transition predictability. PARC intends to co-ordinate and collaborate with the existing DOTSTAR program in the vicinity of Taiwan.

Another possible area for collaboration with China, Russia, and Japan is to investigate the forecast effects of improved analyses and forecasts along the upper tropospheric Asian waveguides. The existing, but currently underutilized, Russian radiosonde stations in Siberia could provide enhanced, or even adaptively controlled, observations in the field campaign. Chinese observing stations over the Tibetan Plateau will be expanded during 2008 for CHERES II to provide additional observations of the southern waveguide. In addition, the enhanced radiosonde network, that will be deployed to support air quality forecasts during the Bejing Olympics in the summer of 2008, could be further operated to support a field campaign that would run well into the cold season (e.g., until the end of December).

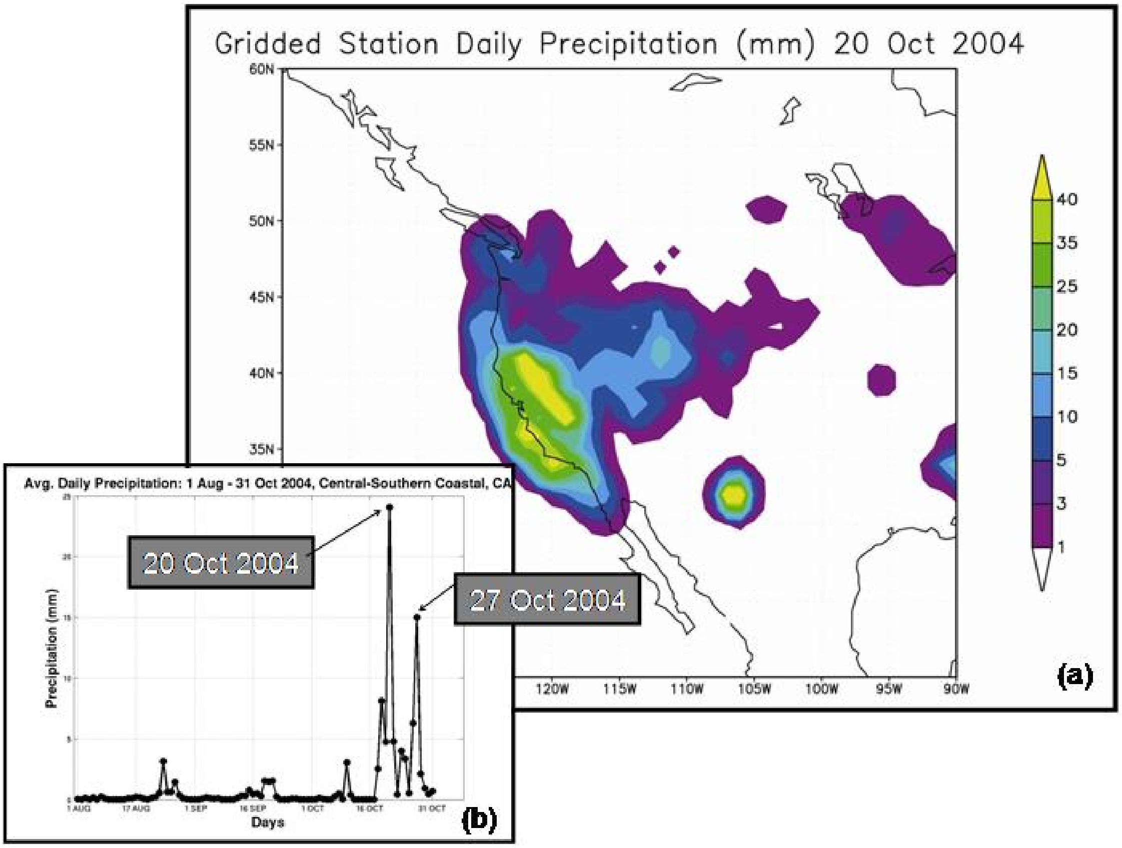


Figure 4. (a) Daily precipitation (mm) for 20 October 2004 constructed from surface observations that were placed on a lat./long. grid. (b) Accumulated precipitation (mm) for a region encompassing central and southern coastal California. (Adapted from a presentation by Patrick Harr, Naval Postgraduate School, at the WMO/TMRP International Workshop on Tropical/Extratropical Interactions)

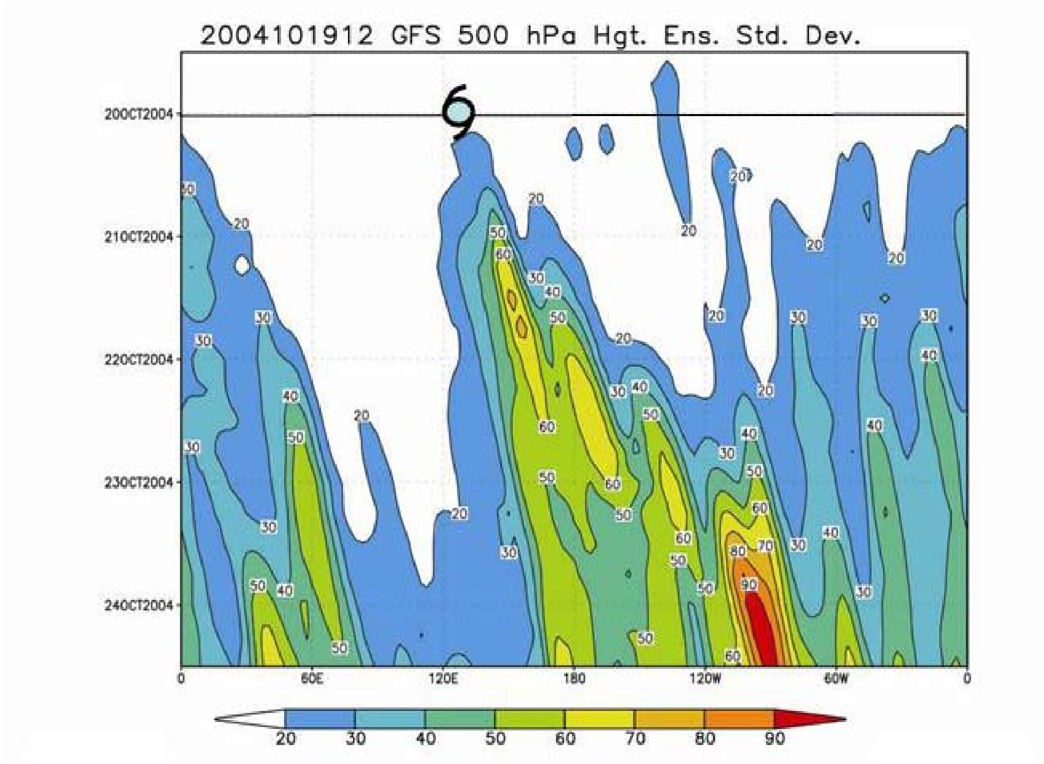


*Fig 5**.** Time-longitude diagram of the standard deviation in ensemble members for 500 hPa heights for the forecasts initiated at 1200 UTC 19 October 2004 with the Global Forecast System model run at the National Centers for Environmental Prediction. The horizontal line at 0000 UTC 20 October marks the time of the ET of TY Tokage, which is located at the longitude marked by the tropical cyclone symbol. The plume of increased standard deviations among ensemble members in the forecast sequence spreads downstream of the ET in association with a wave train (Fig. 3), that extends over North America. (Figure courtesy of Patrick Harr, Naval Postgraduate School.)*

3. Scientific Objectives

Although the Scientific Program Overview provides a detailed description of the scientific objectives of PARC, a brief summary is provided in this Section. The primary hypothesis of PARC is that increased understanding of the dynamical linkages between the developments of high-impact weather events over North America to specific weather events upstream over the western North Pacific will lead to a significant increase in forecast skill of the downstream events. Specific scientific objectives are twofold. One is to improve understanding of the dynamics, factors, and variability that contribute to downstream propagation of upper-tropospheric wave packets from specific weather events over the western North Pacific, such as the extratropical transition of tropical cyclones, organized tropical convection, and extratropical cyclogenesis in the primary eastern Asia wave guide. The second primary objective is to utilize the improved understanding of dynamic linkages across the North Pacific to increase forecast skill of the high-impact weather events over North America, the Arctic, and other locations that are impacted by events over the western North Pacific.

The PARC is a multi-national field campaign that addresses shorter-range dynamics and forecasts of one region and the resulting medium-range dynamics and forecasts of a downstream region. While PARC encompasses these varying time and space scales, the primary objectives of each region are the same, i.e., to increase understanding of the mechanisms that will lead to increased predictive skill of high impact weather events. The field phase of PARC is designed to leverage the multi-national efforts to address the overarching objectives.

3.1 Scientific Objectives Relevant to the North American THORPEX Participants

The movement of a tropical cyclone into the midlatitudes involves an interaction among many complex physical processes over a variety of space and time scales. To adequately address the primary objectives set forth by the North American THORPEX committee, there must be an increase in understanding of the mechanisms that govern the dynamics and predictability during the extratropical transition of a tropical cyclone over the western North Pacific. Factors that may limit forecast skill of extratropical transition events include the role(s) of the background westerly flow (Klein et al. 2002). Specifications of processes associated with the initiation and variability of upper-tropospheric wave packets during extratropical transition events are critical to understanding tropical-extratropical interactions. The interactions among different spatial and temporal scales must be understood to identify processes associated with reinforcing or destroying persistent circulation regimes (Sura et al. 2005) that may be initiated by forced upper-tropospheric wave packets. Although a very limited number of idealized studies (see references in Szunyogh et al. 2002) suggest that the leading edge of the downstream propagating wave packet is relatively well explained by linear theory, the interactions among scales may have implications concerning the limitation of the linear theory of Rossby-wave propagation. Further basic research of this problem would be important to better understand the limitation of the currently used linear techniques (adjoint sensitivity and the Ensemble Transform Kalman Filter of Majumdar et al. 2002) to predict the propagation of adaptively collected observation. Also it is important to explore the effects of the environment on the propagation of the Rossby wave packets.

Specific goals address additional factors that inhibit predictability, which include uncertainties in the physical processes during extratropical transition. The contributions of moist processes in the forcing of upper-tropospheric wave packets (Agusti-Panereda et al. 2004; Moore and Montgomery 2005) may be responsible for a large amount of the variability associated with the forcing of downstream responses from extratropical transition events. A critical need exists for evaluating model physics (i.e., convective parameterizations, representation of air-sea interactions) during the extratropical transition process. Field observations will increase knowledge of model strengths and weaknesses with respect to various components of the extratropical transition process and their roles in defining downstream impacts.

Increased predictability will be realized via observations of key physical characteristics to reduce model analysis uncertainty. This includes the use of *in-situ* measurements to advance satellite data assimilation with respect to the interaction of the decaying tropical cyclone and the midlatitude westerlies. The relative impacts of adaptive satellite observations and new non-local targeting techniques for initialization of extratropical transition and other cyclogenesis events will be examined with respect to propagation of model uncertainty downstream toward North America.

Additional factors governing the predictability of extratropical transition events include forecasts of the location, intensity, and structure of the tropical cyclone as it recurves through subtropical latitudes and moves poleward toward the midlatitudes. Evaluation of these factors will be addressed via collaboration with the Asian THORPEX component to PARC.

3.2 Scientific Objectives Relevant to the Asian THORPEX Participants

The science objectives of the Asian component to PARC address the increase in predictability associated with tropical cyclones over eastern Asia and the western North Pacific. As such, the objectives of the Asian component mesh closely with that of the North American component. The objectives of the Asian component can be viewed in the context of the life cycle of a tropical cyclone over the western North Pacific. Initially, the predictability associated with tropical cyclone formation will be examined in relation to the large-scale environment over the monsoon trough of the western North Pacific (Harr and Elsberry 1991). This objective is closely tied to the North American PARC objectives as tropical cyclone formation over the monsoon trough is typically related to periods of enhanced, wide-spread deep convection, which is a potential source of upper-level wave activity across the North Pacific (Harr and Elsberry 1995).

Further objectives of the Asian PARC component include assessment of the impact of existing and new approaches to targeted observations and adaptive satellite observations for tropical cyclone formation, track, landfall, and structure. Improved forecasts of the tropical cyclone characteristics are fundamentally linked to the predictability of the downstream impacts that occur at later times. The unique collection of in-situ data over the tropical western North Pacific will be used to improve data assimilation of satellite observations, validate remotely-sensed atmospheric profiles and assess high-resolution modeling of tropical cyclone formation, track, structure, and landfall.

The coordinated efforts of each national participant in collection and analyses of a comprehensive data set spans the evolution of high-impact weather events over the entire western North Pacific. With respect to the scientific goals of participants from the United States, the PARC experiment design provides a framework in which the downstream effects of improved analyses along the Asian wave guide may be examined for improving weather prediction over North America. A series of workshops will be scheduled to coordinate the multinational field phase and the requisite studies of model error growth, uncertainty, and observation sensitivities.

4.0 Experimental Design and Observational Requirements

In this Section, the overall experimental design is described regardless of the origin of support for each data facility. As stated above, PARC represents a multinational collaboration that incorporates a variety of funding sources. The description of the experiment schedule, design, and data requirements are defined relative to the Asian THORPEX program and the North American THORPEX program. The specific scientific objective(s) satisfied by the deployment of each data facility is defined relative to the objectives defined in Sections 2 and 3. Appendix A of this document and Section I of the SPO define the funding source of each data facility. Approximate costs are included for data facilities to be supported by the National Science Foundation.

4.1 Major Components and Schedule

The overall PARC period is scheduled for July-December 2008. During July and August 2008, the Asian THORPEX component of PARC begins with an emphasis on the objectives associated with increased predictability of tropical cyclone formation, track, structure, and landfall. During this period, data facilities will include manned and unmanned aircraft, driftsondes, and satellite data. Operational and experimental forecast products from several national weather centers will provide global ensemble forecasts, control forecasts, and identification of targeted areas for initial condition sensitivities. A portion of the Asian THORPEX program for PARC is comprised of the Dropwindsonde Observations for Typhoon Surveillance near the Taiwan Region (DOTSTAR) program (Wu et al. 2004), which has provided aircraft dropwindsonde observations of tropical cyclones over the Philippine Sea during the past several summer periods. While DOTSTAR is designed to examine tropical cyclones prior to recurvature over the East China Sea, Japan proposes to pursue aircraft dropwindsonde observations during and following recurvature to support sensitivity analysis and a downscaling of global ensemble forecasts of tropical cyclone track, intensity, and structure. These programs will be synchronized with the North American THORPEX PARC objectives for assessment of the impacts of increased predictability associated with the tropical cyclone prior to extratropical transition.

The North American THORPEX component of PARC proceeds from September – October 2008 to coincide with the climatological maximum in recurving tropical cyclones that undergo extratropical transition (Jones et al. 2003). The Asian THORPEX component will continue during the September period at a minimum. The North American THORPEX component consists of manned and unmanned aircraft, driftsondes, and satellite data. Because of the complex and varied physical mechanisms associated with extratropical transition and the forcing of eastward-propagating wave packets, which typically occurs over oceanic regions, a mix of aircraft capabilities is required to adequately sample relevant regions of the decaying tropical cyclone and the midlatitude environment into which it is moving.

Following the termination of the PARC component dedicated to tropical cyclones and extratropical transitions, the focus turns to extratropical cyclogenesis in the primary Asian wave guide. During November this will primarily be monitored with unmanned aircraft, driftsondes and special satellite observations. During December 2008, it is possible that manned aircraft will be added to this portion of PARC if the NOAA G-IV becomes available.

4.2 Experiment Design and Observational Requirements Relevant to the Asian THORPEX Component of PARC

4.2.1 Tropical Cyclone Formation

During the typical August-September season over the western North Pacific, the environment is one of a low-level monsoon trough that appears equatorward of a subtropical ridge. Variability in the location and orientation of the monsoon trough is related to various large-scale circulations over the tropical western North Pacific, which often defines the predominant formation and track characteristics of tropical cyclones that form in the monsoon environment (Fig. 6). Although variability in the monsoon trough and tropical cyclone formation contains a component that is highly related to large-scale circulations, there is little forecast skill associated with monsoon trough variability and subsequent tropical cyclone formation. Therefore, a significant objective of the Asian THORPEX portion of PARC is to obtain observations of the large-scale environment over the monsoon region of the tropical western North Pacific.

The primary data facility for this portion of the PARC is the driftsonde system developed at the National Center for Atmospheric Research (NCAR). The driftsonde system will be deployed from various locations in the tropical western North Pacific monsoon trough environment (Fig. 7).

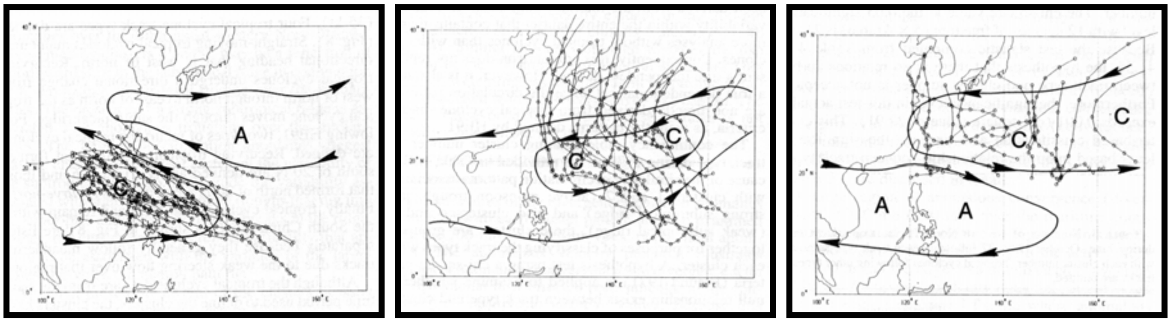


Fig. 6 Tropical cyclone tracks associated with anomalous patterns of the low-level monsoon trough and subtropical ridge over the western North Pacific (from Harr and Elsberry 1995).

The driftsonde utilizes a thin polyethylene balloon with a volume of 268 cubic meters to lift a gondola of 24 dropwindsondes to an altitude of about 50,000 - 60,000 feet (i.e., 100 hPa). The altitude can be maintained for approximately 5-6 days. The altitude of the balloon can be adjusted over a limited range to take advantage of the most favorable upper-level wind flow. Tests of the driftsonde system (Fig. 7) have been conducted with more extensive tests scheduled each year prior to the 2008 PARC period. The dropwindsonde data are transmitted via the Global Telecommunications System (GTS) for utilization in data assimilation systems at various operational weather forecast centers, extending the utility of satellite assimilation and investigations of model error.

Additional data sources to monitor the large-scale environment over the primary tropical cyclone formation region of the tropical western North Pacific will include rapid scan imagery from geostationary satellite (MTSAT) and associated products that may be produced during rapid scan operations. Driftsonde deployment will be coordinated with satellite operations to maximize observation coverage. Organized tropical convection over large scales such as the monsoon trough often represents a significant source of upper-level wave packets that propagate downstream over the North Pacific toward North America. Deep convection in the monsoon trough may contribute to advection of vorticity due to the divergent wind

(Sardeshmukh and Hoskins 1988) and the impingement of a balanced large-scale low potential vorticity anomaly on the midlatitude tropopause. Therefore, the driftsonde observations that

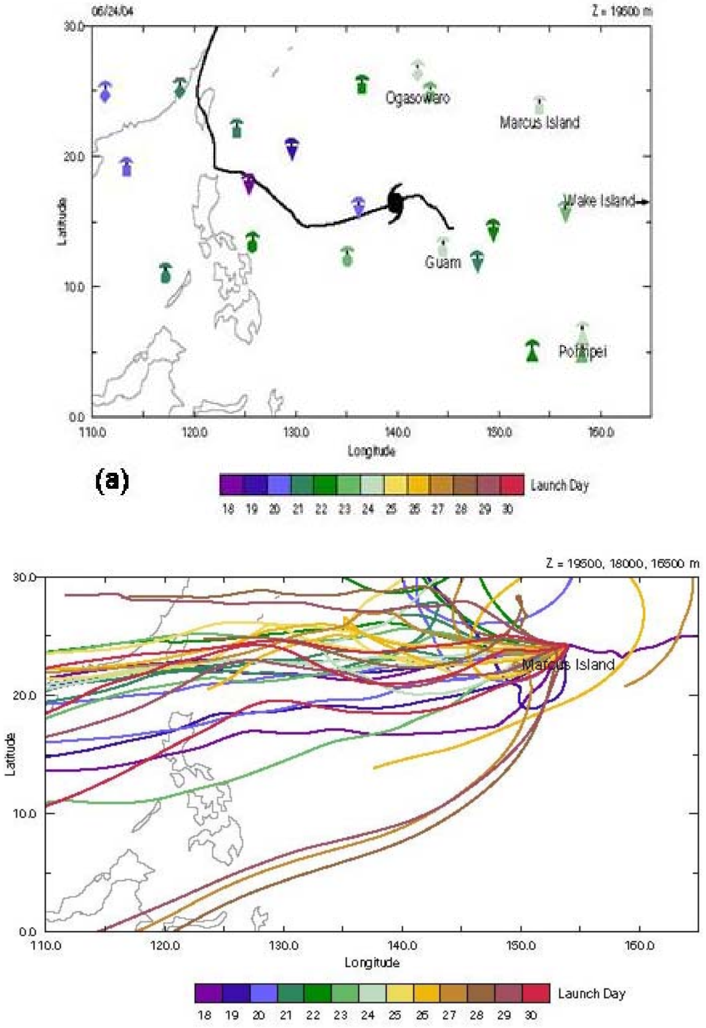


Fig. 7 The spatial distribution of dropwindsondes deployed by driftsondes during Typhoon Mindulle (2004). Driftsondes were released once a day beginning on 18 June 2004. The color represents the launch site and the symbol represents the location. (Figure supplied by Dave Parsons, NCAR).(b) Distribution of trajectories of driftsonde gondolas launched from Marcus Island at three different altitudes over a 13 day period. (Figure supplied by Wen Chau Lee, NCAR).

originate at upper levels will be instrumental in addressing the objective of examining factors that influence downstream impacts from the western North Pacific. This direct linkage between the objectives of the Asian THORPEX and North American THORPEX PARC campaigns will lead to utilization of the *in situ* observations of the deep tropospheric tropical environment for the investigations of the analysis uncertainties and their role in downstream predictability.

4.2.2 Tropical Cyclone Track

Following the formation of a tropical cyclone, the primary observation requirements for the Asian THORPEX components of PARC become focused on track prediction. There are two primary components to this portion of the field campaign. One is manned and unmanned aircraft observations in the environment surrounding the tropical cyclone together with observations in areas found to be sensitive to initial condition uncertainty. The second is utilization of the observations to produce track forecasts in a probabilistic framework based on a hierarchy of ensemble forecast systems. The issue of forecast track uncertainty is highlighted by the forecasts of the recurvature of TY Tokage in the ensemble prediction system (EPS) of the Japan Meteorological Agency (JMA) (Fig. 8). In this case, a clear indication of recurvature was not evident until close to the recurvature time (18 October 2004).

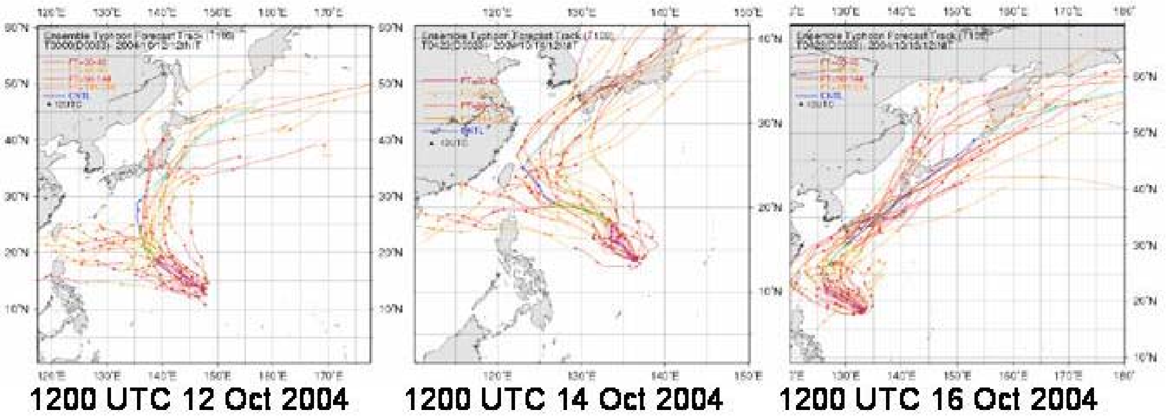


Fig. 8 Track forecasts of TY Tokage initiated at the indicated times from the ensemble prediction system (EPS) of the Japan Meteorological Agency (JMA). (Figure supplied by T. Nakazawa, Meteorological Research Institute, Japan Meteorological Agency)

The first component of the experiment strategy to be employed within Asian is extension of the ongoing DOTSTAR program (Wu et al. 2004). In this program, manned aircraft provide dropwindsonde observations in the surrounding environment of a tropical cyclone prior to recurvature over the Philippine Sea. The DOTSTAR program employs unique methodologies for observation strategies (Wu et al. 2005), which include sensitivity regions (Fig. 9) relevant to the tropical cyclone motion. These methods will be tested and implemented in PARC to provide critical observations for improved track prediction.

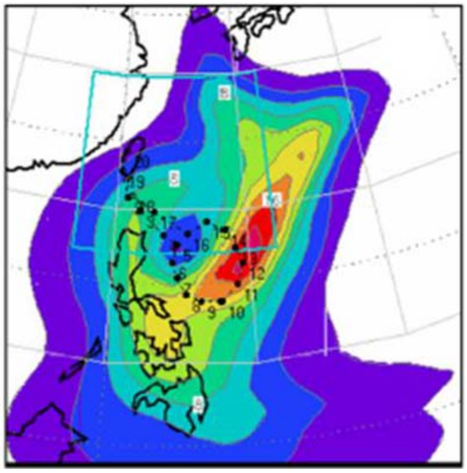


Fig. 9 Initial condition sensitivity (contours) based on the singular vector product of the Navy Operational Global Atmospheric Prediction System (NOGAPS). The singular vectors maximize perturbation total energy within a designated forecast verification area that extends through the depth of the model atmosphere from 150 hPa to the surface. Areas of maximum sensitivity are computed based on a method in which the absolute maximum field value of the leading SV is used to compute a threshold value against which all other values are compared. The sensitivity map was used for flight planning purposes that then led to dropwindsondes at the locations denoted by the black dots.

As a target tropical cyclone moves toward recurvature over the East China Sea, manned aircraft observations based from Japan using a Gulfstream-II aircraft will continue to sample the relevant sensitivity areas associated with initial condition uncertainties in the location and timing of the recurvature. The scenario depicted in Fig 10 defines the experiment strategy for providing high-resolution forecasts of the recurvature scenario. Often, tropical cyclone track forecasts contained within an EPS exhibit large variability as depicted in Fig. 8 and by the curved thin lines in Fig. 10a. This variability is associated with uncertainty in the forecast position and intensity of a midlatitude trough that acts to weaken the subtropical ridge and allow the tropical cyclone to move poleward. This midlatitude trough is often responsible for the many characteristics associated with the eventual extratropical transition (Klein et al. 2002) and downstream impacts. Based on a sensitivity analysis utilizing a verification region as defined in Fig. 10a, targeted aircraft observations will be utilized to reduce initial condition uncertainty. Then, an updated forecast will be produced using the JMA EPS and a downscaling technique to a regional product that incorporates probabilistic forecasts of tropical cyclone track and structure.

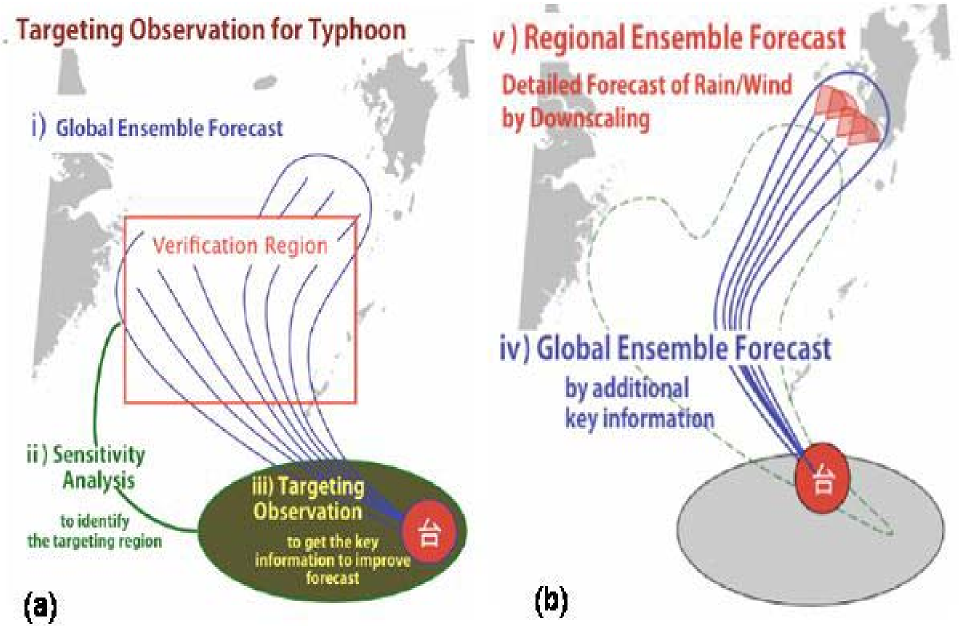
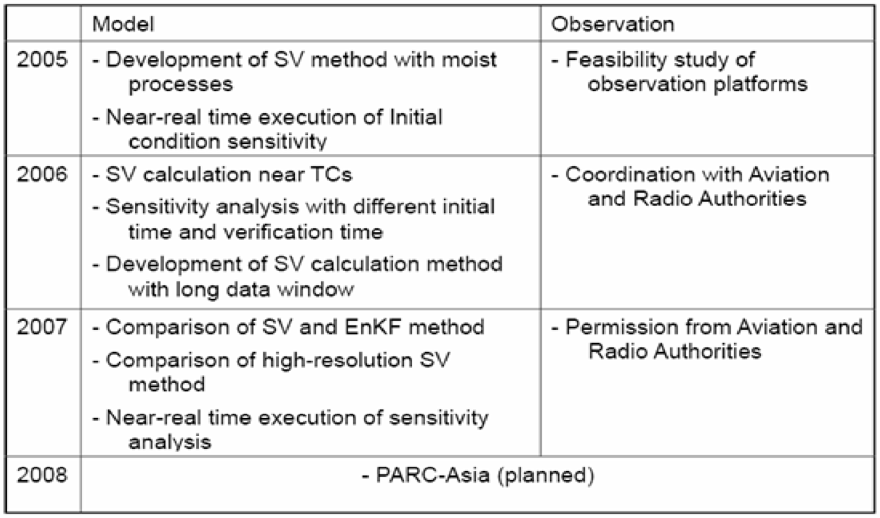


Fig. 10 Schematic of the experiment strategy to be employed for observation and forecasts of tropical cyclone recurvature utilizing the Japan Meteorological Agency ensemble prediction systems. (a), Initially, the global ensemble system is utilized to define targeted observation regions. (b), Then, updated forecasts are produced and a regional ensemble forecast system is utilized to provide probabilistic forecasts of tropical cyclone track and structure. (Figure supplied by T. Nakazawa, Meteorological Research Institute, Japan Meteorological Agency).

During the period leading to PARC, several key programs are scheduled to be completed for implementation in 2008 (Fig. 11). These programs will lead to a state-of-the-art global and regional data assimilation system. The special observations will lead to critical evaluations of the sensitivities associated with initial conditions and model error distributions. Furthermore, the primary objective of improved prediction of the tropical cyclone track and structure prior to, during, and following recurvature are critically linked to the objectives of the North American THORPEX PARC program for improved prediction of the extratropical transition process and downstream impacts. The Asian THORPEX observations, analysis, and forecasts will provide crucial evaluation of the dependence of the downstream predictability across the North Pacific to improved forecasts of the tropical cyclone movement into the midlatitude environment.



	Model	Observation
2005	- Development of SV method with moist processes - Near-real time execution of Initial condition sensitivity	- Feasibility study of observation platforms
2006	- SV calculation near TCs - Sensitivity analysis with different initial time and verification time - Development of SV calculation method with long data window	- Coordination with Aviation and Radio Authorities
2007	- Comparison of SV and EnKF method - Comparison of high-resolution SV method - Near-real time execution of sensitivity analysis	- Permission from Aviation and Radio Authorities
2008	- PARC-Asia (planned)	

Fig. 11. Planned developments at the Japan Meteorological Agency prior to PARC in 2008. (Figure supplied by T. Nakazawa, Meteorological Research Institute, Japan Meteorological Agency).

4.3 Experiment Design and Observational Requirements Relevant to the North American THORPEX Component of PARC

The poleward movement and extratropical transition of a tropical cyclone initiates complex interactions with the midlatitude environment that often results in a high-impact midlatitude weather system with strong winds, high seas, and large amounts of precipitation. The experiment framework associated with the North American THORPEX component of PARC is designed to examine the interactions among various components of a decaying tropical cyclone and the midlatitude environment into which it is moving. As stated above, the objectives of the North American focus to PARC are to increase understanding of these complex interactions for the purpose of improving predictability of high-impact weather events initiated downstream of the extratropical transition via observations that reduce analysis uncertainty and model error propagation. The extratropical transition process may be characterized by complex physical interaction within three interrelated regions (Fig. 12). To understand the impact 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. All three regions of the extratropical transition process likely play important roles in the mechanisms responsible for downstream impacts due to extratropical transition. A Rossby wave response may be forced by advection of vorticity due to the divergent wind (Sardeshmukh and Hoskins 1988), which may result from the tropical cyclone core. A similar mechanism may be associated with diabatic Rossby waves (Moore and Montgomery 2005) due to upward motion along sloping isentropic surfaces that exist at the tropical cyclone-midlatitude interface (Harr and Elsberry 2000). Finally, the midlatitude impact region provides the avenue by which the wave energy impacts the midlatitude circulation into which the decaying TC is moving. Furthermore, the downstream response to extratropical transition events exhibits large spatial and temporal fluctuations, which may be related to specific characteristics of each of the three extratropical transition regions.

To increase predictability associated with extratropical transition and its downstream impacts, the importance of key *in-situ*, targeted, and adaptive measurements to a forecast model must be established. This includes development and testing of advanced data assimilation and ensemble techniques applied to extratropical transition events. Because of the varied physical characteristics of the three primary extratropical transition regions (Fig. 12), a mix of data types and platforms are required to obtain the necessary observations. Since the tropical cyclone core region and the tropical cyclone-midlatitude interface region may be sources of Rossby wave-like disturbances, it is important to establish optimal data

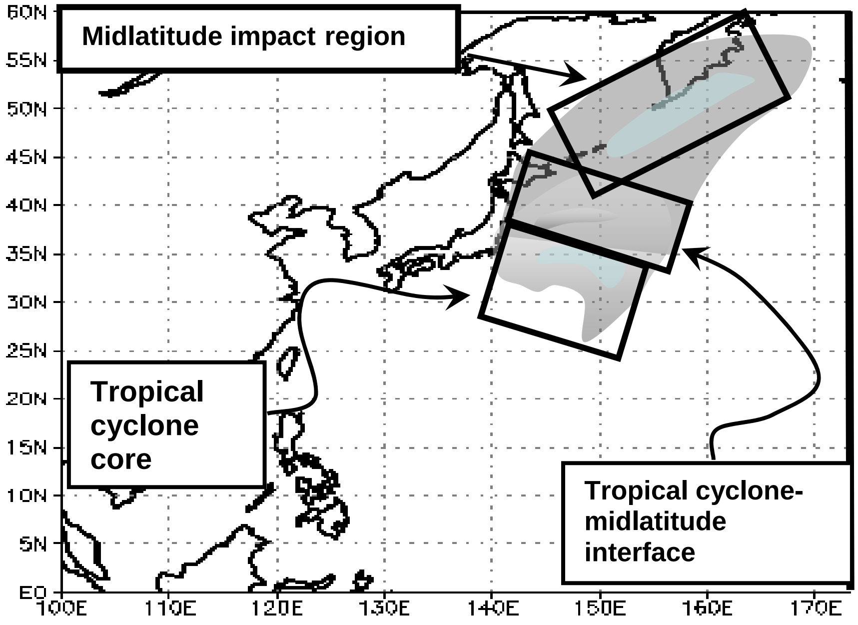


Fig. 12 Schematic of three regions associated with the ET of a decaying tropical cyclone over the western North Pacific. The light gray shaded region represents overall cloud patterns. Shaded regions within the light gray areas indicate regions of concentrated cloud amounts defined by convection in the tropical cyclone core region, large-scale precipitation in the tropical cyclone midlatitude interface region, and cirrus in the midlatitude impact region.

sampling strategies for these regions. A variety of low-, mid-, and upper-level observations are required to fully sample the complex physical and dynamical conditions during extratropical transition. Therefore, development and testing of targeting strategies applied to extratropical transition and source regions of downstream-propagating waves are required.

The ideal scenario will be a poleward-moving tropical cyclone that is just offshore of eastern Asia as it enters the transformation stage of extratropical transition (Klein et al. 2000). The optimal mission will be designed to examine each of the three primary regions of the extratropical transition (Fig. 12). A list of primary structural characteristics in each region is provided in Table 1 together with critical observation parameters. The purpose is to establish a framework of observation criteria that would be used to identify critical mechanisms that serve as a basis for developing and testing targeting strategies and data assimilation techniques to reduce initial condition and model uncertainty associated with an extratropical transition event.

In an optimal setting, up to three manned aircraft and two unmanned aircraft will participate in staggered missions to observe the physical characteristics listed in Table 1. The changes in the decaying tropical cyclone core characteristics may be monitored via satellite, ground-based radar if the system is within proximity of radar coverage from Japan, or with the NRL P-3 if the conditions permit. It is not expected that the NRL aircraft will penetrate a mature tropical cyclone. Due to the interactions with the midlatitude baroclinic environment, the structural characteristics of the three primary regions may change rapidly. Therefore, proper staggering of aircraft missions must be considered along with distances to each structural region.

In the following subsections, the various aircraft facilities and instruments are summarized. Then, some specific flight scenarios are presented with respect to the various science objectives detailed in the SPO and summarized in Sections 2 and 3.

Table 1. Physical characteristics to be observed in each area(Fig. 12) of a tropical cyclone that is in the transformation stage of extratropical transition plus optimal data platform level, instrumentation, and type. In the platform column, the proposed data platforms that would be used to observed the listed environmental characteristics are defined in brackets.

Tropical cyclone-midlatitude interface			
Purpose	**Vertical Level**	**Instrumentation**	**Platforms**
Examine the thermodynamic structure of the decaying TC environment to assess the presence of potential instability and conversion to slantwise or gravitational instability. Important for the change from deep convection to organization of heavy precipitation that may be important for generation of diabatic Rossby waves.	Middle troposphere (20,000-30,000 ft) and below	GPS dropwindsondes Doppler radar Geostationary and polar-orbiting satellite data – precipitation rates, thermal structure in the vertical Wind lidar	Mid- and high-level aircraft [HIAPER, NRL P-3. DLR Falcon] Driftsondes, Satellite
Examine the regions of continuing deep convection with special emphasis on vertical depth, impacts of vertical wind shear, divergent outflow.	Low- and mid-level troposphere for the convective environment. Upper-level divergent flow	GPS dropwindsondes Doppler radar Satellite data from geostationary and polar-orbiting platforms – precipitation rates, thermal structure in the vertical	Mid- and high-level aircraft [HIAPER, NRL P-3] Driftsondes, Satellite
Examine the low-level environment of the warm sector to the east of the decaying tropical cyclone core with emphasis on moisture content, thermodynamic characteristics, and measurements of the building thermal ridge.	Low- to mid-troposphere	In situ instrumentation on unmanned aircraft Water vapor Lidar Wind Lidar	unmanned aircraft DLR Falcon
Examine the low-level environment of the cool sector to the west of the decaying tropical cyclone core with emphasis on moisture content, thermodynamic characteristics, and measurements of the digging thermal trough	Low- to mid-troposphere	In situ instrumentation on unmanned aircraft Water Vapor Lidar Wind Lidar	unmanned aircraft DLR Falcon

TC/Midlatitude Impact Region

Purpose	Vertical Level	Instrumentation	Platforms
Examine the interactions between the TC outflow and the midlatitude environment into which the decaying TC is moving. Upper-level jet structure.	Upper troposphere (45,000 ft) and below	GPS dropwindsondes Doppler radar Satellite-derived winds	High altitude aircraft [HIAPER] Geostationary and polar-orbiting satellite data Driftsondes
Examine the low-level thermodynamic and wind fields – warm frontogenesis, precipitation rates, and diabatic Rossby wave generation	Middle troposphere and below	Doppler radar Water vapor Lidar Satellite data from geostationary and polar-orbiting platforms – precipitation rates, thermal structure in the vertical	High- and mid-level platforms [HIAPER, NRL P-3, DLR Falcon] Satellite data

TC Core

Purpose	Vertical Level	Instrumentation	Aircraft
Examine the decay and tilt of the warm core aloft in response to increased vertical wind shear associated with the midlatitude environment. Examine the interactions between the tropical cyclone core and upper-level synoptic-scale features Rossby-wave source due to divergent outflow from the decaying tropical cyclone	Upper troposphere	GPS dropwindsondes Doppler radar Scanning visible and IR sensor and scanning radiometer for cloud top height and temperature, total column water vapor, water vapor profiles	High-level platforms [HIAPER, driftsondes] mid-level aircraft [NRL, P-3] Satellite
Examine the evolution of deep convection in response to increased vertical wind shear in the midlatitude environment	Upper troposphere	GPS dropwindsondes Doppler radar Scanning visible and IR sensor and scanning radiometer for cloud top height and temperature, total column water vapor, water vapor profiles	Variety of mid- and upper-level platforms Satellite data Driftsondes
Examine the evolution of extratropical cyclone characteristics such as frontogenesis, asymmetric wind distribution, and warm and cold temperature advection	Middle troposphere and below	GPS dropwindsondes Doppler radar	Mid-level platforms [NRL P-3, DLR Falcon]

4.3.1 Aircraft and Instrumentation

The proposed manned aircraft include the Gulfstream-V High Performance Instrumented Airborne Platform for Environmental Research (HIAPER) under the management of the NCAR Earth Observing Laboratory (EOL). The primary instrumentation package to be used with the HIAPER is the Global Positioning System (GPS) dropwindsondes. Dropwindsondes will target the midlatitude impact region (Fig. 12) and be released at altitudes above 40,000 feet ASL. Scientific objectives to be addressed by the HIAPER and dropwindsonde systems include investigations of the three-dimensional structure of the interface between the decaying tropical cyclone outflow and the midlatitude circulation into which it is moving as specified in Sections 2 and 3. Along with mapping of the tropical cyclone/midlatitude interface, direct measurements will be made of the structural changes of the decaying tropical vortex as it enters the increased westerly shear of the midlatitudes. In an ideal scenario such as depicted in Fig. 12, it is anticipated that two missions into the midlatitude impact region will be possible. The first mission will occur in the initial transformation stage (Klein et al. 2000) of the extratropical transition when the decaying tropical cyclone is typically between 25^{o}N and 35^{o}N latitude. A second mission would then occur as the extratropical transition proceeds to the advanced transformation stage with enhanced interactions with the midlatitude circulation as depicted in Figs. 12 and 17.

It is proposed that the operations base for the HIAPER be at the U. S. Air Force Base, Yokota, Japan. Because a decaying tropical cyclone undergoing extratropical transition may accelerate rapidly to the northeast, it is proposed that a secondary base of operations for recovery be at the U.S. Marine Air Base at Misawa, Japan.

If dropwindsondes are released above 40,000 feet and assuming a 25 minute period to reach the ground and a 4 channel system, it is anticipated that typical speeds of the HIAPER and an on-scene time of about 6 h will allow sonde spacing of 100-120 km or approximately 60 n mi. Therefore, approximately 30-35 sondes would be released per mission.

A critical component to identification of the mechanisms responsible for forcing and variability of downstream responses to an extratropical transition event is the mapping of a comprehensive three-dimensional structure of the airflow and thermodynamic characteristics in the tropical cyclone-midlatitude interface region and the midlatitude impact region. To accomplish these measurements, the Navy Research Laboratory P-3 aircraft with the NCAR Electra Doppler Radar (ELDORA) will be used. The primary observing strategy would be to have the P-3 map the tropical cyclone-midlatitude interface region while the higher-flying HIAPER maps the midlatitude impact region. The ELDORA system is critical to mapping the three-dimensional airflow characteristics associated with the interface region in which several complex dynamic and thermodynamic mechanisms interact. It is these interactions that are hypothesized to be sources of downstream forcing and the variability downstream associated with the forcing. Therefore, these observations would be critical for assessing impacts of detailed specification of the mechanisms for reducing analysis uncertainty and increasing predictability downstream toward North America. The GPS dropwindsonde system on the NRL P-3 would be utilized in a manner similar to that discussed with the HIAPER. However, sondes would be released from mid-tropospheric levels near 25,000 feet ASL.

The operations base for the NRL P-3 is proposed to be the same as for HIAPER with a primary location at the U.S. Air Force Base, Yokota, Japan and a secondary base for recovery at the U.S. Marine Air Base at Misawa, Japan.

Additional aircraft assets would include the Aerosonde unmanned aircraft that would be used for investigations in the near environment of the decaying tropical cyclone during the extratropical transition phase. Required instrumentation includes the standard payload of meteorological sensors. Since there is some experience in operating the Aerosonde from Anderson Air Force Base, Guam, it is proposed that during PARC operations be conducted from the U.S. Air Force Base, Yokota, Japan.

The Dassault Falcon 20-E5 aircraft managed by the German Aerospace Center (DLR) will examine atmospheric characteristics in the environment of the extratropical transition. The primary instrumentation will include a water vapor and wind lidars for operating in cloud-free regions from altitudes near 6000 m. Also, a GPS dropwindsonde system is available for use with the Falcon aircraft.

Finally, it is planned that the Convair 580 that is managed by Environment Canada will participate in support of the Canadian THORPEX component to PARC. These flights will be managed by the Canadian THORPEX effort and be operated over the eastern North Pacific with an operations base in British Columbia.

The NCAR-developed driftsonde system will participate such that launch sites will be located along the Japan Islands for deployment during an extratropical transition event. Specific driftsonde capabilities are defined above with respect to the tropical cyclone formation component associated with the Asian THORPEX effort. Each driftsonde system will carry a gondola of 24 dropwindsondes. The driftsondes will be released at altitudes near 60,000 feet ASL to provide a structural mapping of the conditions associated with all three phases of the extratropical transition event (Fig. 12). It is proposed that driftsonde systems be staggered in time such that the environment prior, during, and following the movement of the decaying tropical cyclone be examined.

Various operational and special satellite products will be utilized during PARC. These include the full-suite of polar-orbiting measurements plus special rapid-scan MTSAT observations.

4.3.2 Sample mission scenarios

In this Section, several sample mission scenarios are presented. In each scenario, a combination of aircraft is utilized to map each of the three structural regions of the extratropical transition (Fig. 12). A specific mission will be chosen based on the characteristics of the case, which include translation speed and structural details. Only aircraft that will be funded by U. S. resources are highlighted in these scenarios. Other aircraft, such as the DLR Falcon, will participate in coordinated roles. Specific objectives to be addressed by all data facilities are listed in Table 1, which also includes sensor requirements.

As one example, a decaying tropical cyclone that is moving rapidly would dictate that the tropical cyclone-midlatitude interface be high priority for observations as the midlatitude interface region may quickly become out of range. In this case, the scientific objectives to be emphasized would include the role(s) of diabatic processes associated with warm frontogenesis, a building thermal ridge, and digging thermal trough in defining perturbations on the midlatitude flow due to the poleward movement of the tropical cyclone. In this case, two subset scenarios may be possible. One is that the high-flying HIAPER fly a modified figure-4 ALFA patterns at an altitude of at least 45,000 ft centered over the remnant tropical cyclone core region (Fig. 13). The patterns are rotated to observe the region north and east of the center, which is the prime isentropic-upslope region associated with warm frontogenesis, and the region south and east, which is associated with the import of descending, dry air from upstream midlatitudes into the decaying tropical cyclone region. Therefore, this pattern would capture the start of the change in primary energy mechanisms from latent heat release to baroclinic conversion of available potential energy to eddy kinetic energy. During the same time, the P-3 will fly a “lawnmower” type pattern throughout the tropical cyclone-midlatitude interface region (Fig. 14). The P-3 will map the three-dimensional structure ahead of the decaying tropical cyclone in the region hypothesized to be related to generation of diabatic Rossby waves. Departure times will be staggered to provide maximum overlap in coverage.

Both aircraft will deploy GPS dropwindsondes once they have entered their respective patterns. Dropwindsondes will be deployed at each waypoint and at evenly spaced intervals along each leg. Optimal spacing would be near 60 n mi for the P-3 and 100 n mi for the HIAPER.

Additionally, two Aerosondes will be utilized to obtain measurement of lower-tropospheric atmospheric profiles. One Aerosonde will be directed to fly through the warm sector to the east of the ex-tropical cyclone center while the second will fly through the thermal trough to the west of the center (Fig. 15). A release strategy will be employed to take advantage of the slower airspeed of the Aerosonde such that launch will occur well in advance of the decaying tropical cyclone such that initial profiles will sample the pre-storm environment and later profiles will capture the environment of the extratropical transition

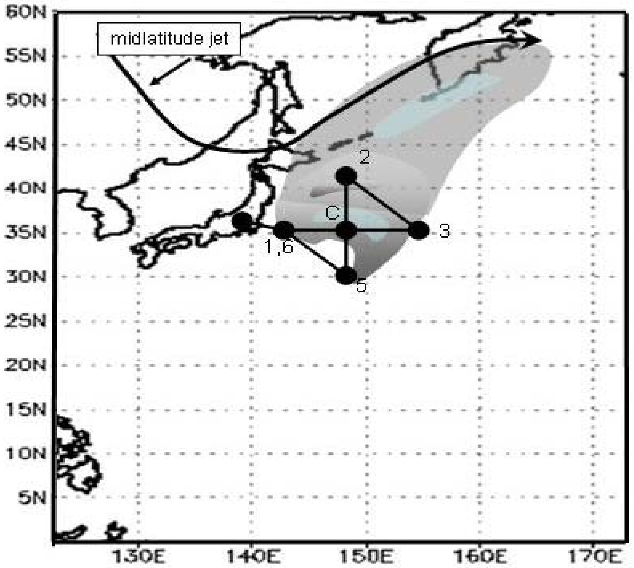


Fig. 13 Sample flight plan for a HIAPER mission over the decaying tropical cyclone that is in the transformation stage of extratropical transition. Waypoints are marked by number in sequence. The waypoint labeled C marks the center of the pattern. Shading as in Fig. 12.

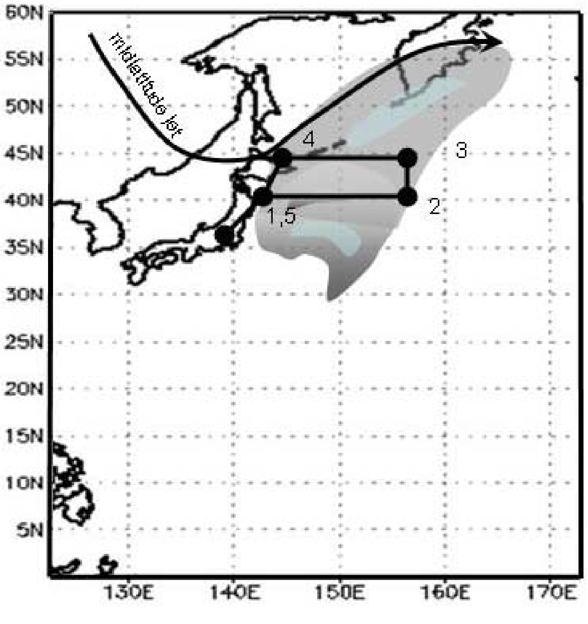


Fig. 14 Sample flight plan for a NRL P-3 mission over the decaying tropical cyclone that is in the transformation stage of extratropical transition. Waypoints are marked by number in sequence. Shading as in Fig. 12.

A modification to the above scenario may be made such that the HIAPER mission is directed more ahead of the decaying tropical cyclone (Fig. 15). The purpose of this plan would be to measure the upper troposphere in association with the tropical cyclone outflow as it enters the midlatitude interface region. In this plan, the HIAPER would fly a slanted figure 4-ALFA pattern at an altitude of 45,000 feet. The GPS dropwindsondes would be released as specified above, which includes each waypoint and regular-spaced intervals. Coordination between the HIAPER and NRL P-3 would insure that a full tropospheric mapping of the decaying tropical cyclone-midlatitude interface was completed.

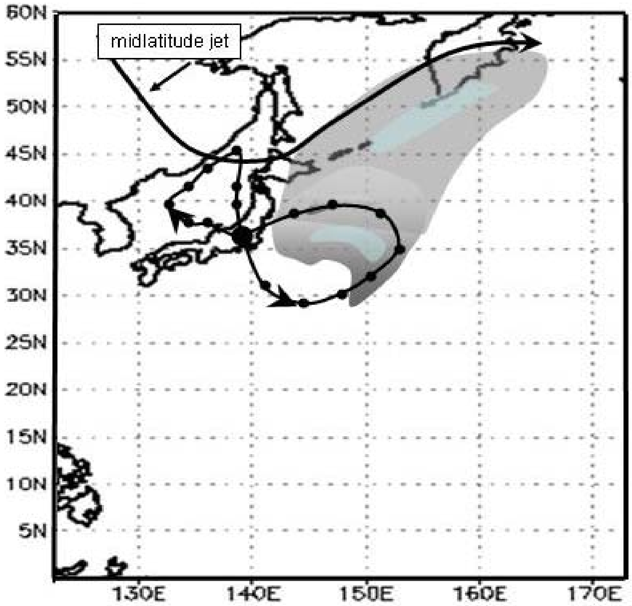


Fig. 15 Sample flight plans for two Aerosonde missions over the decaying tropical cyclone that is in the transformation stage of extratropical transition. Black circles represent locations where the Aerosonde will undertake limited vertical profiles. Shading as in Fig. 12.

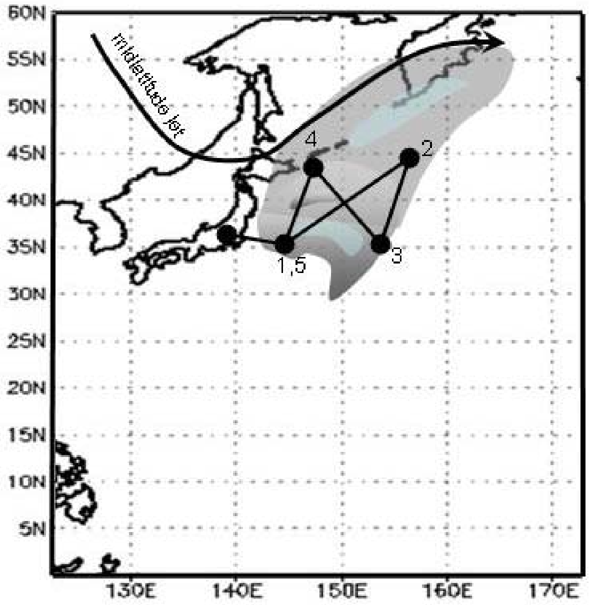


Fig. 16 Sample flight plan for a HIAPER mission that is placed ahead of the decaying tropical cyclone that is in the transformation stage of extratropical transition. Waypoints are marked by number in sequence. Shading as in Fig. 12.

A final sample flight scenario is presented in which the primary objective is a complete mapping of the midlatitude interface region (Fig. 17). In this scenario, the NRL P-3 would fly a mission similar to that described above in relation to Fig. 14. Also, the Aerosondes would fly coordinated missions as in Fig. 15. However, the HIAPER would proceed out ahead of the decaying tropical cyclone to provide one high-altitude pass through the tropical cyclone-midlatitude interface region, then proceed north to the midlatitude impact region. Over the impact region, HIAPER would fly a modified ALFA pattern at an altitude of 45,000 ft. Dropwindsondes would be released at each waypoint and at regular intervals along the legs. The purpose of this plan is to examine the mechanisms associated with the impact of the tropical cyclone outflow on the midlatitude jet, which is hypothesized to be one source of downstream wave packet propagation.

Additional resources that would be included in these scenarios include the NCAR-developed driftsonde system. Driftsonde locations would be established along the Japan Islands with staggered release times from individual stations. This will insure a deep-tropospheric profile of the dynamic and thermodynamic characteristics throughout the extratropical transition process. Then, the driftsondes will be over the North Pacific to sample downstream impacts as they propagate toward North America.

4.3.3 Additional Data Applications: Satellite validations and COSMIC

An important objective of PARC is identification of the primary mechanisms responsible for downstream impacts during extratropical transition and the utilization of observations of these mechanisms to reduce initial condition uncertainty. Downstream of the field phase of PARC, the primary observation platforms over extratropical transition events will be remotely sensed meteorological profiles. Whereas these profiles will continue to come from current geostationary and polar-orbiting satellites, an important new source of atmospheric profiles will be the GPS radio occultation soundings. The Constellation Observing System for Meteorology/Ionosphere and Climate (COSMIC) program will be launched in March 2006 and will provide nearly 2,500 GPS radio occultation soundings per day almost uniformly distributed around the globe. Recent statistics indicate that at least 50% of the soundings will penetrate to below 0.5 km, with 90% penetrating below 1 km. Therefore, COSMIC soundings will be important contributors to the core objectives of THORPEX-PARC.

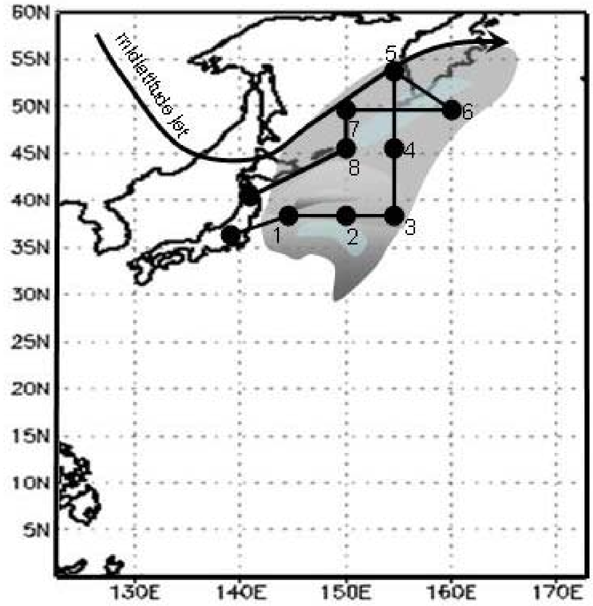


Fig. 17 Sample flight plan for a HIAPER mission that has a mapping of the midlatitude interface as a primary objective. Waypoints are marked by number in sequence. Shading as in Fig. 12.

The COSMIC soundings will have been calibrated with rawinsondes over land and some islands by the time of PARC. Further calibrations (especially of moisture) near upper- and lower- level fronts in the North Pacific will be possible during PARC. That is, *in situ* measurements from dropwindsondes released from aircraft and driftsondes would be highly valuable for a COSMIC validation study. Effective flight planning is feasible as the location of COSMIC GPS radio occultation soundings are determined by the positions of the COSMIC Low Earth Orbiting Satellites and the GPS satellites, which can be determined with high accuracy. Therefore, the PARC program will play an important role in the further validation of one of the most promising measurement systems to come online. Also, the validated COSMIC data will serve as test sets for data assimilation studies for assessing their role in reducing analysis uncertainty and increasing predictability downstream over North America, which is the prime objective of the North American THORPEX portion of PARC.

5.0 Project Management

The multinational nature of THORPEX-PARC requires extraordinary coordination and support from participating facilities, operations directors, facility coordinators, forecasters, and participating scientists to ensure that the scientific objectives are fulfilled. One primary operations center will serve as a focal point for coordination of the various components of PARC (i.e., Asian components associated with tropical cyclone formation and track, and North American components associated with extratropical transition and downstream impacts). This operations center will be responsible for synthesizing forecast support, real-time decision making, data collection, and interim analysis components.

It is recognized that there are unique requirements associated with the deployment of aircraft, driftsondes, and unmanned aircraft. Discussions will be required to gain necessary approvals of local, regional, and national air traffic authorities. Furthermore, mission scenarios that include multiple aircrafts at varying altitudes with varying instruments will require proper safety and notification strategies. Site surveys will be made to properly place aircraft and instruments such that operations are executed without interference to local organizations and appropriate data collection facilities are available.

Proposed aircraft locations for U. S. supported facilities are defined in Section 4. While individual national components will have operation centers associated with national forecast centers, one overarching THORPEX-PARC operations center will be maintained. Because of modern facilities in global communications and data transfer, it is not necessary for the primary THORPEX-PARC center to be located on scene. As of this writing the possibility of the Japan Meteorological Agency hosting the operations center is being explored via the World Meteorological Organization (WMO). An alternate location is Monterey, California, USA where the Fleet Numerical Meteorology and Oceanography Center, Navy Research Laboratory, and the Naval Postgraduate School are located. Both locations have access to global telecommunication services and comprehensive operational data support systems. It is proposed that the vast amount of satellite data be coordinated at the Cooperative Institute for Meteorological Satellite Studies at the University of Wisconsin.

5.1 Mission Planning and Operations

Within the myriad of science objectives, the PARC scientists will have primary responsibility for setting priorities associated with mission assets, scenarios, and cases. Mission planning teams will be comprised of participants who will have primary responsibilities for proposing flight plans, data sampling strategies, data collection procedures, and initial assessment responsibilities. Operations teams composed of aircraft personnel, instrument technicians, flight engineers, and in-field science representatives will be responsible for execution of missions designed by the mission planning teams.

The coordination among the various regional THORPEX PARC components will be accomplished through representatives in the primary operations center. The national/regional operations centers will be responsible for assessing environmental conditions, case recommendations, instrument maintenance, and aircraft readiness in support of the primary operation center decision-making function. The operations teams will be responsible for advance notification and coordination with appropriate regional and local authorities for air-traffic control, safety, and procedure effectiveness.

It is expected that the mission planning team will be composed of one science director appointed for each component of PARC (i.e., tropical cyclone formation, tropical cyclone track, extratropical transition, downstream impacts, targeting, and data assimilation considerations). One operations director will be appointed to lead daily planning meetings to update all participants on operations, weather, and potential future activities. Also, items requiring special attention with respect to maintenance, availability, and scheduling will be assessed daily throughout the field phase.

Because the various components are staggered in time with the primary Asian component in August-September and major North American Component in September-October there will be varying membership in the mission planning and operations teams. However, it is expected that the science director will be appointed for the full PARC period to ensure smooth operation during each phase.

Pending participation by U. S. facilities and scientists, a request will be made to NCAR Earth Observing Laboratory (formally the UCAR Joint Office of Science Support) to provide support in terms of experiment planning, operations coordination, and data management. This will require operation as in past international field campaigns such as FASTEX and IHOP. Special consideration will be required for coordination with the German DLR flight activities, DOTSTAR, Japan aircraft, and special land-based observations that may be arranged over eastern Asia.

A series of workshops will be scheduled to initiate coordination of pre-field campaign numerical studies associated with data assimilation technique developments and data sampling strategies to assist the field campaign planning process. Workshops will coordinate the multi-national aspect of the PARC program and refinement of scientific goals.

5.2 Real-time Communication

The complexity of the various mission scenarios with a variety of data facilities will require a reliable communications system and links to ensure the effective and safe operations of aircraft and transmission of data. Critical data include real-time observations, navigation components for unmanned data facilities, and avoidance issues related to dropwindsondes and lidar operations. Finally, communications to aircraft via voice, internet chat, or direct aircraft-to-aircraft communication via VHF radio will be required for transmission of information such as updated weather conditions.

6.0 PARC Data Management

The final objective of the THORPEX PARC program is development and maintenance of a comprehensive data management system. The goal will be to provide a complete dataset to the science community as soon as possible following completion of the field phase of PARC. A data coordinator will be appointed to oversee the data management procedures with collaborators from various data facilities, which will include aircraft, dropwindsonde, radar, and satellite systems.

Prior to the initiation of the field phase, the data coordinator will supply a data operations plan that details the overall strategy for data management during and following the field campaign. During the field phase, the operations team will be responsible for cataloging data collected during each mission and reporting on the status of all data systems. The data management plan will provide for “first-look” analyses and accountability for real-time transmission of special observation data.

Since a primary goal is the increased predictability associated with critical observations for reduction of analysis uncertainty and model error, a major portion of the data management plan will address the post-field experiment model data that are produced based on experiments and development of new data assimilation strategies. In this way, the utility of the different data types collected in the field in contributing to increased predictability will be assessed.

As part of the planning workshops, special sessions will be held to define the data management plan.

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APPENDIX A: Facilities, Equipment, and Other Resources
(Section I of SPO)

Institution or Facility	Instrument	Principal Investigator	Anticipated Sponsor	Status of the Request
NCAR	HIAPER [150 h, 15 missions @ 10 h each plus ferry time]		NSF/Deployment Pool, assuming pool covers 20% of flight hours plus other costs	To be submitted
NCAR	Electra Doppler Radar on Naval Research Laboratory (NRL) P-3 aircraft	Wen-Chau Lee	NSF/Deployment Pool	To be submitted
NRL	P-3 Aircraft [120 h, 15 missions @ 8 h each plus ferry time]	P. Harr	Assuming NSF deployment pool, but with NRL covering 80% of flight hours	To be submitted
NCAR	300 Dropsondes for NRL P-3, [30 per mission, 10 missions]		NSF/Deployment Pool	To be submitted
NCAR	300 Dropsondes for HAIPER [30 per mission, 10 missions]		NSF/Deployment Pool	To be submitted
NCAR	Driftsonde[1] – 840 sondes, Typhoon genesis – Guam (35 gondola missions with 24 sondes each)	D. Parsons, W.-C. Lee, and C.C. Wu	NSF Deployment Pool with partial Taiwan National Science Council support	To be submitted
NCAR	Driftsonde – 840 sondes, Winter cyclones – Japan (35 gondola missions with 24 sondes each)	D. Parsons and Zoltan Toth	NSF Deployment Pool with partial Canadian and NOAA support	To be submitted
NOAA	G-IV, [100 h, 6 missions @ 8 h each plus ferry time], winter storm reconnaissance with 120 dropsondes			To be submitted
US AF and Asia	Aerosonde		US Air Force has Guam aerosonde operation , plus other Asian contributions	Partly funded

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[1] Driftsonde is a new system and the numbers from EOL may be subject to change.

NCAR	Aerosondes (8)	G. Holland	NSF	To be submitted
DLR	Falcon [100 h, 10 missions @ 5 h each plus ferry time] with in-situ instrumentation	Andreas Doernbrack	DLR, DFG	To be submitted
DLR	Falcon aircraft Airborne Doppler and water vapor lidars	Andreas Doernbrack	DLR, DFG	To be submitted
CES	Canadian Convair	J. Abraham	CES	To be submitted
Japan/MRI	Gulfstream II [60 h, 10 missions @ 6 h each]	T. Nakazawa	MRI	To be submitted
Taiwan, National Science Council	ASTRA Jet: DOTSTAR flight hours and dropsondes	Chun-Chieh Wu	National Science Council	Funded