

## SIXTH INTERNATIONAL WORKSHOP on TROPICAL CYCLONES

### Session 2 b : **Special Focus Session THORPEX: a focus on tropical cyclone related research**

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#### 2b 1.0 Introduction

As recognition of this increasing value to society of improvements in weather prediction skill, the ~180 nations of the 14<sup>th</sup> World Meteorological Congress established the THORPEX (The Observing System Research and Predictability Experiment) research and development program. Specifically, THORPEX is a component program of World Weather Research Program within the World Meteorological Organization (WMO/WWRP). The THORPEX Science (Shapiro and Thorpe 2004) and Implementation Plans (EG-TIP 2005) outline an ambitious research agenda designed to accelerate improvements in the accuracy of 1-day to two-week forecasts of high-impact weather for the benefit of society, the economy, and the environment. THORPEX also seeks to improve the utilization of weather products, since, for example, the mitigation and response to a weather disaster also depend on decision-making, communication, allocation of existing resources, and the ability of governments and aid organizations to mobilize a response. The international component of THORPEX results from the realization that forecast improvements on the 1 to 14-day time-scale rest on global prediction models and the global observing system. The core objectives of the international THORPEX program (see Shapiro and Thorpe 2004 and <http://www.wmo.int/thorpex>) include advancing knowledge of the global-to-regional influences on the initiation, evolution and predictability of high-impact weather and contributing to the development of advanced data assimilation and ensemble prediction systems, and to the design of the future global observing system. The core objectives include international field campaigns focused on regional forecast problems facing Africa, Asia, Europe, North America and the Southern Hemisphere. For example, North America experiences, with some frequency, a variety of weather disasters with individual events that cause damage over a billion dollars and present a significant risk to public safety. Such weather events include floods, the dry gusty conditions of fire weather, severe convection outbreaks, tropical cyclones (TCs), and winter storms capable of freezing rain, high winds, snow, freezing rain, and heavy rainfall. For the Asian nations of the Pacific Rim, a key forecast problem is to better mitigate and respond to heavy rainfall and TCs, since these events are their most damaging natural disasters.

Recent research clearly points to the western North Pacific playing an important and unique role in defining many characteristics of the middle latitude 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 improved treatment and increased understanding of the dynamical linkages between the 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 these downstream events. Indeed the calculation of average forecast sensitive areas for prediction of high-impact weather events over North America for the time-scales ranging from ~2 to 5 days show a strong sensitivity to conditions over the western and central portions of the North Pacific basin (e.g., see Figure 4a, b of Reynolds and Gelaro 2001). Forecasts of weather events over Alaskan and portions of the Canadian Arctic also show a strong sensitivity to conditions over the North Pacific (e.g., Szunyogh 2002).

One 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. 2.b.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. Hakim (2003 and 2005) demonstrated that upper-tropospheric, eastward-propagating wave packets are a dominant source of forecast errors over the North Pacific. The forecast error patterns move with an eastward group velocity of about 30 -40 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. An example of Rossby wave trains apparently generated by high-impact events over the western Pacific associated with the lifecycle of TCs is shown in Fig. 2.b.1. These wave trains were associated with three major weather disasters on the western coast of the US. Thus, accurate short-range (<3 days) predictions of aspects of the lifecycle of a TC near the east Asian coast will mean an increased likelihood of accurate medium range (3-7 day) predictions of floods, wide-spread severe weather outbreaks and damaging extratropical cyclones downstream over North America. This connection is the underlying focus of the **THORPEX Pacific-Asian Regional Campaign (PARC)**.

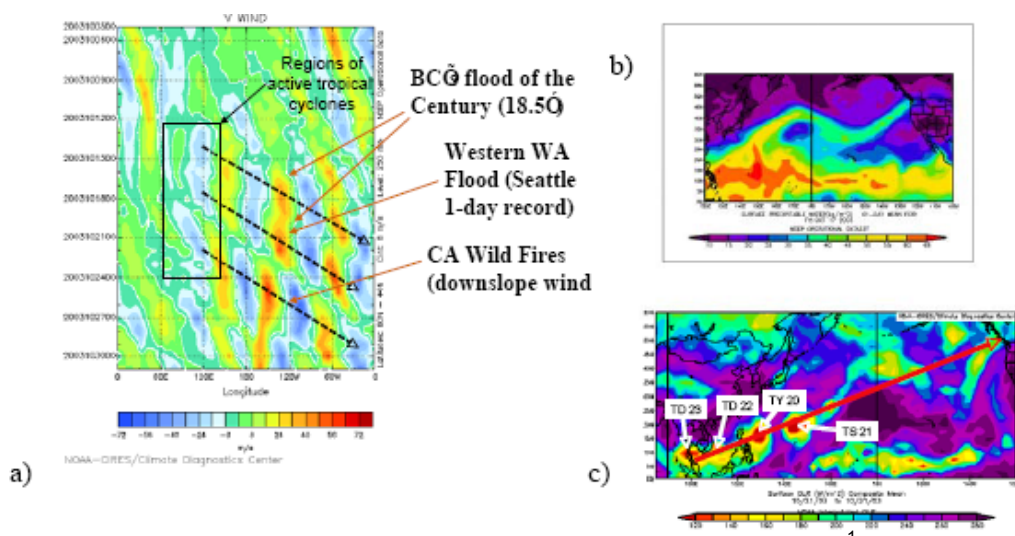


Fig. 2.b.1 a) Time-longitude diagram of 250 hPa meridional winds ( $\text{m s}^{-1}$ ) from 0000 UTC 5 October 2003 – 1200 UTC 31 October 2003 (Figure made at <http://www.cdc.noaa.gov>). The diagonal dashed lines highlight eastward-moving, upper-tropospheric wave packets that originated over eastern Asia. Three relatively poorly predicted major west coast weather events are shown. b) Integrated water vapor on the 17<sup>th</sup> of October coinciding with the record flood in British Columbia showing the tropical moisture plume from the western Pacific being advected into the region with this first Rossby wave train. c)

Outgoing longwave radiation for the 21 October 2003 showing four tropical convective events (at this time one typhoon, one tropical storm and two tropical depressions) in the region of the genesis/intensification of the Rossby wave trains. The red arrow shows the propagation wave train from the tropical convection as suggested in the OLR for the western Washington flood. All figures are constructed from the NOAA/CDC website and provided by Dave Parsons, NCAR based on analysis by Melvyn Shapiro (NOAA), Lynn McMurdie (U Washington) and Parsons.

The discussion that follows, focuses on the scientific challenges and objectives, as well as the experimental design within the proposed THORPEX: Pacific-Asian Regional Campaign. Many of these challenges are common to other basins. However, for the purposes of this special session, PARC serves as the best example of a THORPEX research initiative focused on tropical cyclones.

## **2b 2.0 Scientific Challenges associated with Predictability of High-Impact Weather**

There are a number of scientific challenges associated with advancing knowledge of high-impact weather in the vicinity of the Asian Pacific rim, including the generation of downstream high-impact events over North America and the Arctic. These challenges include advancing knowledge and the impact on forecast skill of:

1. genesis and evolution of tropical cyclones
2. extratropical transitions
3. upper tropospheric wave trains

Improved forecasting accuracy for all these events would have significant societal benefits.

### **2b 2.1 Advancing knowledge and the predictability of the genesis and evolution of tropical cyclones**

One of the primary foci of the THORPEX Asian Regional Committee is a strong need for accurate predictions of TC track and landfall with the goal of improved prediction and extending the forecast lead-time. The life cycle of a TC may be divided into several phases, including cyclogenesis, development and motion of a mature cyclone, the subsequent extratropical transition and/or landfall. Each phase brings a new spectrum of issues related to physical and dynamical processes, and their predictability.

Only a small fraction of tropical disturbances eventually become TCs. The challenges of advancing understanding of the dominant mechanisms and factors that limit the predictability of tropical cyclogenesis in a broader context have recently received increasing attention in both research and operational prediction. For example, the leading scientists from the research community and operational centers that comprise the WMO/CAS Working Group on Numerical Experimentation (WGNE) recommended that the operational centers provide statistics on genesis. Accurate forecasts of genesis would open up the possibility of greatly increasing the time scales of when typhoon predictions have utility with a variety of benefits (e.g., ocean shipping, energy production, planning and carrying out evacuations, rescue and early recovery efforts especially for urban centers, organization of international aid) as well as improving downstream predictions. Initial studies have shown some level of skill at relatively long lead times, but this research also raises questions about false alarms and missed events. The ability of numerical models to accurately represent physical quantities relevant to genesis such as warm core magnitude, the vertical wind shear, convective instability and mid-level moisture requires assessment. Unfortunately, the lack of detailed data sets and hence quality of analysis compromises our ability to evaluate critical aspects of model performance and confirm or deny current hypotheses. The combination of high-resolution, cloud-resolving models in conjunction with in-situ observational data collected during PARC is necessary to address the issues on the processes, scale interactions and predictability of tropical cyclogenesis.

## **2b 2.2 Advancing knowledge of extratropical transitions and their impact on forecast skill**

One aspect of the Asian THORPEX interest in tropical cyclones is the improved understanding and prediction of recurvature and extratropical transition (ET), which are critical forecast problems for Japan, Korea and parts of China. This objective is a key link between the North American and Asian THORPEX studies in PARC and also with the International Polar Year (IPY), because ET storms also directly impact the Arctic as they move northward and such storms have dramatic meteorological effects downstream. The poleward movement of a TC in the western North Pacific during summer and fall leads to an interaction with the midlatitude baroclinic zone and jet stream that can result in an extratropical transition. The primary scientific issues associated with ET and downstream impacts due to ET events may be placed in a framework of mechanisms, predictability, and strategies for increasing predictability. Periods of low predictability are expected from uncertainty theory because the ET involves complex physical interaction between the tropical cyclone and the mid-latitudes. Furthermore, during the transformation stage from a TC to the initial development of an extratropical cyclone, phenomena with high-societal impacts include strong winds, high waves, and heavy precipitation. ET events can trigger upper-level wave trains that propagate faster than the ET event. The dynamic and physical properties during the ET that lead to this wave train are not well known. Furthermore, propagation of the wave train downstream from the ET event may trigger high-impact events over North America.

## **2b 2.3 Advancing knowledge of upper-tropospheric wave trains and their impact on forecast skill**

Recent research, based on modern statistical techniques applied to reanalysis data sets, diagnostic techniques applied to numerical weather forecasts, satellite imagery, idealized model experiments, and case studies with state-of-the-art numerical weather prediction models, suggests that the western North Pacific region plays a unique role in shaping the circulation of the Northern Hemisphere (NH) extratropics. The evidence for this relationship includes:

- i) the role of the maintenance of the storm track by the generation of a vast amount of kinetic energy by baroclinic energy conversion in the western and central North Pacific
- ii) studies of mid-latitude analysis and forecast errors<sub>1</sub> suggest that errors in the western North Pacific spread downstream at a speed of about 30 m s<sup>-1</sup>, with their effects reaching the U.S. and Canada within a few days
- iii) studies into the skill of North American and Arctic forecasts show a strong sensitivity to areas over the NW Pacific.

Many forecast failures in the prediction of Northern Hemisphere extratropical storms have their roots in the western and central North Pacific. The number of forecast failures is significant, as shown by McMurdie and Mass (2004), with average errors, for example, in the 48-h prediction of west coast winter cyclones measured in terms of 100s of kilometers. The proposed research aims to reduce the number of these forecast failures by improving the analysis and modeling of the processes that initiate and maintain the primary cyclogenesis in the western and central North Pacific and of those that propagate these effects downstream

## **2b 3.0 Scientific Objectives of PARC**

PARC is THORPEX's first scale-interaction experiment and perhaps the community's first field effort focused to a large degree on medium range weather phenomena and prediction. The experiment brings together research facilities from Asia, Europe and North America with participation ranging from

the academic research community to scientists at the operational centers. We envision the PARC experiment to be embedded within a longer-term observational, theoretical and numerical THORPEX research focus on the scientific goals associated with PARC.

An overall important scientific goal includes the improved understanding of the dynamics and factors that limit the predictability of downstream high-impact weather events as discussed in 2b Section 2.0 above. Some other specific objectives include:

- i) Developing, improving, and evaluating data assimilation strategies; understanding error growth and scale interactions; and the improved utilization of satellite measurements,
- ii) Testing the improvement in local and downstream forecast skill afforded by high-resolution, non-hydrostatic modeling;
- iii) Testing new strategies and observational systems for adaptive observing and modeling strategies;
- iv) Improving the interpretation and utility of ensemble forecast systems; and
- v) Understanding and improving society's response to weather disasters, including the appropriate use and evaluation of probabilistic information.

### **2b 3.1 Developing, improving, and evaluating data assimilation strategies; understanding error growth and scale interactions; and the improved utilization of satellite measurements**

Improved assimilation of satellite observation data is essential to PARC (and overall THORPEX) goals for deterministic and ensemble weather prediction, and also for establishment of high-quality atmospheric analyses required for climate monitoring. The Pacific basin is a region of particular importance for satellite data assimilation because it is a vast area in which in-situ observations are sparse or non-existent, and it produces a wide variety of high-impact weather events that affect adjacent heavily populated areas of Asia and North America. Recent and ongoing increases in the amount, quality, and variety of satellite atmospheric observations represent a tremendous opportunity for progress in numerical weather prediction, including improved local and downstream forecasts of devastating TCs, subsequent ET events and intense winter cyclogenesis. Currently, space-based observations represent more than 80 percent of all data assimilated for operational numerical weather prediction. The ultimate goal is assimilation of satellite data at the scale of the observations. Progress towards this goal depends on improved techniques for satellite data assimilation and on increases in computational capability. Whereas developing new satellite technology represents an investment of billions of dollars by many nations, only a very small percentage of this large technology investment has been spent on research to make better use of the satellite data that are provided. THORPEX can accelerate progress in satellite data assimilation that is needed to improve weather prediction and climate monitoring.

Recently developed four-dimensional assimilation methods, such as the Ensemble Kalman Filter and 4D-Var, have new capabilities for the description of developing dynamical features. An understanding of the inherent qualities and limitations of each method may be gained via a combination of Observation System Simulation Experiments (OSSEs), Observing System Experiments (OSEs), and operational frameworks. PARC will provide a focal point for the community to conduct experiments to advance data assimilation techniques through testing these advances on a challenging set of problems with significant societal and economic benefits for a large portion of the world's population. The DA issues that require attention include:

- (a) Cycling of flow-dependent error covariance matrices.
- (b) Model uncertainty..
- (c) Multi-scale observations and increments.
- (d) Correlated observation error statistics..
- (e) Linearity. Conventional DA methods assume Gaussian error statistics and linear dynamics

### **2b 3.2 Testing the improvement in local and downstream forecast skill afforded by global high-resolution, non-hydrostatic modeling**

PARC is associated with the challenging phenomena of TC and extratropical transition events and how these events and other systems excite of these Rossby wave trains associated with downstream high-impact weather. Another source of Rossby wave excitation is the deep organized convection associated with Madden Julian Oscillation (MJO)/ El Niño–Southern Oscillation (ENSO) events (see Ferranti et al. 1990). The ENSO/MJO effect the frequency of TCs in both hemispheres (e.g., Keen 1982; Lander 1990) with some recent suggestions that TCs can also impact the ENSO events (Sobel and Camargo, 2005). The MJO is generally poorly simulated in weather and climate models. To capture the MJO, the modulation of deep convection and the global dispersion of Rossby waves, as well as the downstream high-impact events, the ideal situation would be to have a global model with cloud-resolving capabilities. Simulations and sensitivity experiments are planned using high-resolution numerical models, theoretical studies, and comparison of model results with observations and analyses. In particular, the Canadian GEM model will be used to simulate cases of MJO and radiation of Rossby wave packets. In view of these high-resolution simulation studies, an unprecedented convective-scale to continental-scale simulation will be done on the Earth Simulator Center (ESC). This simulation and others with lower resolution will be used to examine the expected implication of MJO for numerical weather forecasting. More specifically, diagnostics studies, such as Charron and Brunet 1999) and sensitivity experiments will be made to determine the important parameters that affect MJO and Rossby wave radiation that affect the North American and European regions.

### **2b 3.3 Testing new strategies and observational systems for adaptive observing and modeling strategies**

It is important to build on previous targeting results, including such operational programs in the US for winter storms and hurricanes, and the previous Atlantic THORPEX regional program, when deploying resources to investigate adaptive sampling strategies during PARC. Three general topics arise concerning adaptive targeting during PARC.

(1) Adaptive targeting of tropical cyclones for improved prediction: A focus of the THORPEX Asian Regional Committee for PARC on adaptive measurements for typhoon prediction is prompted by successful dropwindsonde observations in the synoptic environment of typhoons (Wu et al. 2004; 2005) and hurricanes (Aberson 2003) to improve operational forecasts. Studies such as Aberson (2003) have shown that incorporation of dropwindsonde data around TCs approaching landfall has significantly increased the rate of increase in forecast skill. Although these aircraft-borne observations have been shown statistically to improve the accuracy of global model track forecasts (i.e., the average improvement typically ranges between 20 and 30%), the scientific premise of how observations influence forecasts of TC motion and structure remains unexplored. Another basic research topic to be explored is increase the scientific understanding of the significant differences in the prediction of targeting locations by different targeting techniques (Majumdar et al. 2006). The techniques include sensitivity to conditions near the cyclone, but sometimes also include features within the middle latitudes. For the first time in a targeting experiment, we have the opportunity to oversample to better understand the impact of following different targeting experiments. Moreover, the benefits of assimilating additional observations from different platforms, including airborne and satellite remote sensing, on multiple spatial and temporal scales using novel data assimilation methods have not been studied. For example, studies will be provided to determine the relative contributions from in-situ adaptive measurements versus new satellite systems such as COSMIC or whether complementary approaches (in-situ winds only) should be developed.

(2) Impact of adaptive measurements for tropical cyclones on the predictability of downstream events:

ET events are a major source of downstream uncertainty as well a trigger for the downstream

generation of high-impact weather. Since research to date suggests that track forecasts of tropical system will improve through adaptive measurements, the question arises as to whether adaptive measurements taken to improve typhoon track prediction will improve the prediction of ET and downstream effects? Such an improvement is expected, since one would expect improvement in the prediction of where and when a TC enters the middle latitude westerlies. For this reason adaptive measurements will be taken during the recurvature of the TC. Alternate hypotheses are that the uncertainty lies with the middle latitude westerlies, a lack of resolution of the vortex moving into the westerlies or in the cyclogenesis process itself.

(3) Adaptive techniques for middle latitude events: The case for in-situ targeting in winter storms is the subject of active debate, since the results are generally positive, but with the exception of a few events, relatively weak. Many of the issues associated with targeting of middle latitude systems are discussed in Langleid (2006), Shapiro and Thorpe (2004) and in the report from the THORPEX Data Assimilation and Observing System Working Group (Rabier 2006).

### **2b 3.4 Improving the interpretation and utility of ensemble forecast systems**

Since the early 1990s, ensembles of global model forecasts have been issued daily at individual operational centers. Assuming that errors in the initial conditions and numerical models are well captured, the ensemble provides an estimate of uncertainty of a particular forecast. For example, a tight cluster of TC track forecasts provided by the ensemble increases forecaster confidence in the prediction, thereby reducing the necessary area of coastal evacuation, mitigating costs and increasing public confidence. In contrast, a wide spread of TC track forecasts necessitates the evacuation of a large stretch of coastline, even though the majority of the evacuation area will likely be relatively unscathed. In addition to the prediction of uncertainty, the weighted average of a multi-model ensemble of forecasts has generally proven to be more accurate than a single forecast, even of higher resolution.

Currently, only a limited number of forecasts (10-100) have been considered in the ensemble, and partially because of this, more sophisticated applications than those given above have not been tested. The implementation of a multi-center, bias-corrected ensemble hosted in North America, known as the North American Ensemble Forecast system (NAEFS), to be integrated within the THORPEX Interactive Grand Global Ensemble (TIGGE), will open new possibilities for advanced ensemble-based research and forecasting applications based on several thousand forecasts. In addition to improved estimates of uncertainty of forecast track, other benefits can be derived. For example, probabilistic forecasts of tropical cyclogenesis out to 2 weeks may be realized, and hence information on the likelihood of TC activity can be provided to users. A large ensemble will yield more reliable probability distributions that are often non-Gaussian, such as a bimodal distribution of track depending on the timing of the interaction of a TC and a mid-latitude trough. On a more advanced level, probability distributions of the wind field and rainfall amount would be useful in estimating the risks, and accordingly making decisions on evacuations, closure of businesses and schools, and emergency management preparations. While the wind probabilities issued by the NOAA National Hurricane Center since 2006 are currently based on an average of historical forecast errors, these distributions can in the future be based on a reliable ensemble of the actual forecast.

The identification of how initial condition errors and errors in the models contribute to the reduction in forecast skill is also possible with a large, multi-model ensemble, and would in turn lead to improved construction of new ensemble forecasts. An increasingly widespread use of ensembles is to prescribe error covariance statistics in data assimilation, and preliminary research suggests potentially significant advantages over operational data assimilation schemes.

The utilization of probabilistic forecast guidance necessitates new collaborative efforts between researchers and forecasters. Among the key areas are: the calibration of the ensemble, the

conversion of a discrete ensemble forecast into a continuous probability density function, and the creation of new products that are relevant to the forecaster. The forecaster then has the responsibility to convey the complex information to users.

During PARC, researchers will have direct (and for the first time, easy) access to the ensemble forecast outputs from TIGGE and NAEFS. These outputs will be used to provide improved ensemble-based adaptive sampling guidance. TIGGE will also allow for study of whether ensemble-based methods are able to produce improved probabilistic forecasts of high-impact events, as well as providing for new insights into TC structure and dynamics. The TIGGE data sets will allow for easy access of societal and impact researchers to probabilistic data. Basic research and development are required to develop approaches that meet the decision-making needs of specific forecast users and to accurately represent the overall economic benefit.

Hydrological Ensemble Prediction Experiment (HEPEX): The hydrological community is making a large effort to utilize ensemble modeling for hydrological applications. PARC focuses on precipitation events over Asia, the Arctic, and North America. An opportunity exists for significant collaboration between PARC, and HEPEX to further the utilization of weather information in ensemble prediction systems for a season.

### **2b 3.5 Understanding and improving society's response to weather disasters, including the appropriate use and evaluation of probabilistic information**

PARC and all THORPEX programs include a strong societal and economic impacts (SEA) subprogram. Specific SEA research opportunities in PARC, related to quantifying the benefits of the program and improving the utilization of weather information include:

Forecasting west coast severe weather: PARC investigators will work with several forecast offices on the west coast of the US and Canada to quantify the impacts of PARC research and additional measurements on their forecasts. The work will include gaining insight into the forecast improvements made from PARC measurement strategies, development and testing of conceptual models of the global to regional dynamics of high-impact weather, and improved understanding of the user needs and forecasters view of model shortcomings.

Heavy rainfall, tropical cyclones, comparative human responses, and hazard mitigation/response: In terms of damage and human misery, typhoons are the overwhelming disaster of developing countries of temperate and tropical eastern Asia. PARC research activities will include: i) Undertake studies to identify populations specifically vulnerable to weather hazards and assess methods for improving forecast, warning, and response systems specific to the needs and capabilities of this/these populations; ii) Estimation of the health impacts of weather of heavy rainfall/typhoons and the degree to which negative outcomes can be mitigated; iii) Decision making in emergency management, how weather information is utilized in the face of major risk, and whether probabilistic information can be used to improve decisions and communication; iv) The different responses of the developing and developed world to significant weather disasters.

User-specific forecast use and benefits: Research will investigate the use of weather forecast information and its value in decision-making for specific groups of forecast users in Asia, Western North America and/or other regions affected by PARC forecasts. This will include research on users' perceptions of and preferences for different types of weather forecast information, the role of different types of forecast information in users' decisions, and the value of different types of forecast information services. The effort will focus on current and improved short- to mid-term (up to 14 days) weather forecast information related to PARC, including (TIGGE and NAEFS) probabilistic forecasts and other information about forecast uncertainty. Possible user groups to study include households (the public), water managers, energy sector decision makers, and/or emergency managers in developed countries.

The intent is to use state-of-the-art survey, and comprehensive multivariate analysis of the results.

User-driven verification and evaluation of forecast quality: Traditional forecast verification approaches often do not link forecasts and the decision making process of users, due to their reliance and focus on single-measure scores to summarize forecast performance.

#### **2b 4.0 Experimental Design and Observational Requirements**

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.

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.

#### **2b 5.0 Discussion**

The PARC initiative is an excellent example of a tropical cyclone related research study within THORPEX. The IWTC-VI special session will also include a broad discussion on THORPEX, with input from the research and forecast community on PARC, as well as other potential tropical cyclone related activities within THORPEX.

## 2b 6.0 Bibliography

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