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**THORPEX ICSC
GIFS TIGGE Working Group
Ninth Session**

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IPO REPORT

1. Meeting and Workshop Programme (2010/11)

Meeting Programme 2010/11

Meeting	Date	Location
1. AMS USTEC	17-21 January 2010	Atlanta
2. WCRP/JSC	15 – 19 February 2010	Turkey
3. GIFS-TIGGE Working Group Eighth meeting	22 – 24 February 2010	Geneva
4. GEO S&T Committee	22-24 March 2010	-
5. CONCORDIASI Workshop	29-31 March 2010	Toulouse
6. African Ministerial	20 April 2010	-
7. NARC meeting	19 – 20 May 2010	Mexico
8. ARC Workshop & meeting	2 – 4 June 2010	Korea
9. YOTC MJO Task Force	15-18 June 2010	China/Korea
10. DAOS Working Group Third meeting	8 – 9 July 2010	Montreal
11. PDP Working Group Third meeting	5-7 July 2010	Zurich
12. PDP Workshop on model diagnostics	7 – 9 July 2010	Zurich
13. EMS	13 – 17 September 2010	Zurich
14. CAS Mgt meeting	27-28 September 2010	Geneva
15. Polar Project Workshop	6 – 8 October 2010	Oslo
16. WGNE	18 – 22 October 2010	Tokyo
17. WCRP Polar meeting	25-29 October 2010	Bergen
18. Sub-Seasonal Prediction	1 – 3 December 2010	Exeter, UK
19. WWRP/JSC Fourth meeting	21-24 February 2011	Geneva
20. First International YOTC Science Symposium	16-19 May, 2011	Beijing
21. Joint Workshop on Representing model uncertainty and error in numerical weather and climate prediction models	20-24 June 2011	ECMWF, UK
22. PDP Working Group Fourth meeting	21 June 2011	ECMWF, UK
23. DAOS Working Group Fourth meeting	27-28 June 2011	Exeter, UK
24. GIFS-TIGGE Working Group Ninth meeting	31 August–2 September 2011	Geneva
25. ICSC Ninth meeting	21-22 September 2011	Geneva

2. Working Groups - highlights

2.1 GIFS-TIGGE Working Group

TIGGE

The number of registered users is now over 1000, but a more meaningful statistic is the number of distinct active users per month – about 60 in late 2010 (see Fig. 1). The amount of TIGGE data downloaded has continuously increased; the users triggered data processing on some 37 Tb in December 2010 and downloaded about 2.8 Tb.

Following the successful establishment of the TIGGE dataset, the main focus of the GIFS-TIGGE working group has shifted to the use of ensemble forecasts from multiple centres for research and development, including ongoing promotion of scientific investigations using the TIGGE dataset.

In order to help publicise TIGGE to the scientific research community, a new leaflet about TIGGE has been produced with the assistance of the THORPEX International Project Office, and is available for download from both the WMO THORPEX website and the TIGGE website at <http://tigge.ecmwf.int>.

GIFS

It was agreed that the GIFS-TIGGE WG would work with SWFDP and other WMO pilot projects on the development and evaluation of GIFS products, and formal links were established with the SWFDP SG. It was agreed that GIFS products, mainly based on combined ensembles, would be used to supplement products already available through the SWFDP, and evaluated in conjunction with the SWFDP.

Funding for TIGGE data bases in Europe - GEOWOW

A consortium of European institutions has submitted a proposal, GEOWOW (GEOSS Interoperability for Weather Ocean and Water), for funding through the European Union Framework Programme. GEOWOW proposes to:

- i. Consolidate global data discovery and enable global access to, and use of, Earth Observation data and resources (computing, data handling tools, model etc.) through the GEOSS Common Infrastructure (GCI)
- ii. Develop tools and protocols to promote the implementation of the GEOSS Data Sharing Principles, and the re-use and dissemination of Earth Observation data
- iii. Develop operational capabilities of the GCI through applications in three areas:
 - a. Weather, with a focus on unified access to Earth Observations and forecasting systems for hazard and extreme meteorological events
 - b. Water, with a focus on hydrological applications and run-off process using in-situ and satellite data
 - c. Ecosystem, with a focus on the implementation of GOOS by engineering and testing access to Ocean data via the GCI.
- iv. Enhance multidisciplinary interoperability

- v. Analyse the benefits of GEOSS for Europe using models linking economy, environment, and society

The GEOWOW proposal, which includes a TIGGE weather element, is led by the European Space Agency (ESA). The weather element of the proposal involves further development and integration of the THORPEX Interactive Grand Global Ensemble (TIGGE) global weather forecasts data products into the GCI which will be undertaken by the European Centre for Medium-Range Weather Forecasts, the UK Met Office and Météo-France – the requested funding for the TIGGE weather element is 1.2 M€.

2.2 PDP Working Group

Field experiments

The three related THORPEX experiments T-PARC, TCS08 and Winter T-PARC were aimed at increasing understanding of *how and why* (a) Typhoons form (or do not form) in the West-Pacific TCS-08) (b) Typhoons or ex-Typhoon vortices interact with mid-latitude jet streams (T-PARC) and (c) supplemental targeted observations reduce or fail-to-reduce forecast error (TCS08, T-PARC and Winter T-PARC). The Major findings in the area of dynamical atmospheric processes and the ability of models to predict observed processes and associated recommendations are being written up. A summary of the review being prepared for Summer T-PARC may be found in Annex 1.

Key topics

A few key topics have been identified, to which the PDP WG will pay particular attention to during the coming years. The status of research on these themes will be regularly revisited at future WG meetings, if possible with invited external experts. Each year, one of these topics will be selected for (co-)organizing a specific workshop (e.g., with WGNE).

The list of these key topics includes:

- Climatologies of specific weather phenomena (frequency, intensity) – Heini Wernli & *members from Africa / China / SHEM*
- Organized tropical convection (YOTC, T-PARC) – Mitch Moncrieff, Pat Harr & *member from Asia*
- Ensemble-based data assimilation and forecasting, including stochastic parameterizations – Craig Bishop, Istvan Szunyogh, Olivier Talagrand
- Atmospheric dynamics and diabatic processes (e.g., T-NAWDEX, HYMEX, Rossby wave dynamics, tropical-extratropical interactions, polar meteorology, role of surface fluxes) – John Methven, Andreas Dörnbrack, Heini Wernli & *member from SHEM, polar expert*
- Sub-seasonal and seasonal prediction (dynamics and physics of coupled systems) – Thomas Jung, Adam Scaife, Ben Kirtman & *others*
- New diagnostic techniques to understand the origin of model errors – Thomas Jung, Andy Brown

PDP / WGNE cooperation

Both the ICSC and CAS recommended closer cooperation between the THORPEX PDP working group and WGNE. Better communication between the two groups has been established by naming focal points in each of the working groups and by attendance of these people at the respective working group meetings. Diagnosis of model error has been identified as one of the

key areas of future collaboration and it was decided to aim to formulate a set of specific joint projects (e.g. detailed numerical experimentation in support of T-NAWDEX). The joint workshop on the diagnosis of model error, held from 7-9 July 2010 in Zurich, was jointly organized by THORPEX-PDP and WGNE representatives with support from the THORPEX IPO – the workshop report is on the THORPEX website.

The other area in which close collaboration between THORPEX-PDP and WGNE would be beneficial is the area of stochastic processes and the representation of model uncertainty in ensemble and data assimilation systems. A workshop on this topic is planned to be held in June 2011 at ECMWF.

2.3 DAOS Working Group

Impact of observations and data targeting

During the first half of THORPEX, the emphasis has been on the evaluation of the impact of observations, including targeted observations, based on results from field experiments (ATReC, AMMA, IPY, T-PARC), OSEs and OSSEs. The main outcomes from these impact studies may be summarized as follows:

- The value of extra-tropical targeted data has been found to be positive but small on average
- Observations taken in sensitive areas have more value than observations deployed randomly
- Past experiments do not provide evidence of a major impact obtained from just a few observations (when averaged over a large sample of cases)
- There are limitations to the current assimilation methods to be able to detect the small signal associated with precursors to the development of meteorological systems
- The methods employed to identify sensitive areas do not appear to be a major problem
- Additional observations around tropical cyclones have proven to be useful

These studies also suggest that additional benefit may be obtained from:

- Regional (versus highly localized) and systematic targeting during low predictability flow regimes on a continuous basis (periods of days to weeks)
- Adaptive processing and data selection of satellite data (e.g. Bormann and Bauer, 2010)

Review of the NOAA Winter Storm Reconnaissance flight data (2001 – 2008)

The Winter Storms Reconnaissance Programme (WSRP) was introduced following the FASTEX, NORPEX, CALJET and PACJET field experiments. The objective of the WSRP is to improve forecasts in the 24-96 hour time frame for significant weather events. Following identification of a “threat”, sensitive areas are determined in relation to the data-targeting area which is used to plan a short-term aircraft campaign to deploy and collect data from drop-sondes. The impact of these additional observations is then determined either in “near” real time or “off-line”. Case studies are conducted to compare forecasts with/without the additional data.

Generally speaking it was found that 70% of forecasts were improved with typically a 10-20% reduction in local forecast error for these cases of high impact weather. This equated to a 12 hour gain in prediction skill. It was also found that WSR data has 2.7 times more impact per observation than an observation from a random area.

As discussed at the most meeting of the THORPEX DAOS Working Group, NOAA and NCEP are sponsoring a re-evaluation of the Winter Storms Reconnaissance (WSR) Programme which

will be managed by Yucheng Song, Zoltan Toth and Tom Hamill among others for a few recent years. The last assessment of the value of WSR observations to NWP was Toth (2002). The value of observations to a given forecast has however been shown to be dependent on the quality of the NWP system, and given the improvements in NWP over the last decade it was considered that the value of these observations should be reassessed with the most up-to-date assimilation systems and models. This study will focus on the impact on one to four day forecasts over the continental US; the target forecasts for the WSR. While it is not possible to assess the socio-economic impact of individual forecasts the study will assess the feasibility and accuracy of predictions of the impact of adaptive data and how much of the forecast improvement is realized.

While the overall direction of the assessment has been accepted, there were considerable discussions within the DAOS Working Group as to how to quantify the forecast improvement. The current system is based on comparisons with radio-sondes within a 1000km radius of the initial target area which changes from one case to another. This can pose problems if there are only few observations in the verification domain. Suggestions have been made as to using larger fixed domains and using more relevant fields such as total energy norm and/or precipitation (although either of these would require the use of analysis fields). The suggestion was also made that the impact of the observations be judged against the general rate of improvements due to advances in assimilation systems etc., – which historically has been roughly one day gain per decade.

After discussion, at its most recent meeting, the DAOS Working Group made the recommendation for the conduct of re-evaluation studies:

The re-evaluation should be performed for at least the two recent years of the WSR, and more if feasible. Various verifications areas should be considered, those used for the original targeting and also larger areas (e.g. East Coast, West Coast and Alaska). To be able to compare with other results, common metrics should be used.

Future emphasis

The THORPEX DAOS WG is now the leading expert group for atmospheric data assimilation research in WMO which is so important for model development. There are however a number of other issues that are not part of the DAOS mandate which are covered in other programmes. SPARC has an interest in data assimilation and so has the GLASS working group which has an interesting project, PILDAS, on surface data assimilation. Mesoscale data assimilation is also an important area and will raise a number of scientific challenges as well. These should *not* be included in the mandate of the DAOS but linkages should be made so that the data assimilation issues can have a forum across all interests.

3. Workshops

3.1 PDP Workshop on “diagnosis of model errors” (Zurich, July, 2010)

The results presented in the workshop showed (i) state-of-the-art models still suffer from substantial errors and (ii) that diagnostic work has the potential to inform model developers about model problems at the process level and therefore provide information necessary to guide model development.

Despite substantial improvements in diagnostic techniques in recent years *it is crucial to further support research to advance diagnostic techniques* to the point where they become of direct use for model development. While considerable attention is devoted to thermodynamic aspects (for example EU project ENSEMBLES) future progress will hinge on a better understanding of

physics-dynamics interactions—an area of research in which the PDP community has considerable expertise.

Model error diagnosis has been identified as one area where universities and research institution can make substantial contributions to the further development of models, thereby supporting the relatively small community of model developers.

It was highlighted that there is a lack of quantitative understanding how errors in the representation of different processes (for example latent heating in atmospheric “warm conveyor belts” versus convective contributions in cold air outbreaks) contribute to forecast failures. In order to be able to prioritize future model development it was recommended to carry out detailed research to obtain a better quantitative understanding of this issue.

It was decided to start joint projects to look more closely at two phenomena:

- Indian Summer Monsoon (ISM): The ISM is a large-scale phenomenon which is poorly handled by most models. The monsoon problem is an ideal test case to demonstrate that the use of different diagnostic techniques can provide information that leads to model improvements. It was appreciated that this project could profit from other activities within YOTC and the MJO/ ISM field experiment planned for 2011 (CINDY/DYNAMO, coordinated by University of Miami). *Next steps:* The project will start by building on the existing collaboration between ECMWF and the UK Met Office. Ongoing research will be discussed in a mailing list. For the future it is planned to invite other centres through WGNE. Progress will be reported in future meetings (for example PDP, WGNE and suitable conferences).
- Cyclonic systems (CS): What makes CS an attractive choice is that physics-dynamics interactions are crucial in CS and that CS are a major source of severe weather. Work is required to understand the influence of resolution and the relative importance of different processes for cyclone prediction. *Next steps:* Considerable work is in progress in refining existing diagnostic techniques to understand CS and how they are represented in models (for example ECMWF, University of Reading and ETH). It is proposed to compile the latest results and to kick-start the project by giving a joint presentation entitled *Diagnosis of Cyclonic Systems* at the Cyclone Workshop, which will be held at Monterey, USA, from March 27 - April 1 2011. This project has clear links to the activities planned in T-NAWDEX.

Both themes are ideal to link with the climate community and should be investigated both in NWP and climate models. Work on these topics will profit from Transpose AMIP activities. WGNE and PDP WG will be invited to specifically address these selected high priority issues. One potential outcome of these activities will be to better specify the essential observational needs (for example T-NAWDEX). Furthermore, it is crucial that both projects should consider developing a proposal that can be put forward to WGNE for advice and support through numerical experimentation.

The outcomes of the workshop and progress on the two special projects were reported at the 26th session of WGNE in October 2010 and the WWRP-JSC (February, 2011), in addition to the Cyclone workshop 2011 in Asilomar and the EGU 2011.

3.2 DAOS Working Group Workshop (Montréal, July 2010)

The main objective of the Third DAOS-WG workshop, held in Montréal, Canada in July 2010, was to review the use of adaptive observations in view of recent results and to assign tasks to

write a review paper on the value of adaptive observations for NWP. A draft manuscript to be submitted to BAMS is now available and being reviewed by the group.

3.3 Workshop on “Polar Prediction” (Oslo, October 2010)

The final Workshop report may be found at:

http://www.wmo.int/pages/prog/arep/wwrp/new/documents/Polar_NWP_Meeting_Outcomes_FINAL.pdf

Based on the outcome of this workshop and the feedback from EC-PORS and potential partners, a Joint Polar Prediction Project, similar to the Year of Tropical Convection (YOTC) project, supported by WWRP, WCRP, and THORPEX should be established.

This project will require a Steering Group (consisting of members with scientific and operational expertise and representatives of the user community). The first task for the Steering Group will be the preparation of an Implementation Plan which is consistent with the outcome of this workshop and which includes estimates of resources and a strategy for the coordination of polar prediction research.

Eventually, if the YOTC model is followed, a Project Office should be established at an institution with a major interest in polar prediction.

3.4 Workshop on “Sub-seasonal Prediction” (Exeter, December 2010)

The draft Workshop report may be found at:

http://www.wmo.int/pages/prog/arep/wwrp/new/documents/Report_Recommendations_14_3_2011.pdf

Considerable progress has been made in improving the skill of medium range weather forecasts and in developing operational seasonal forecasting. Forecasting in the intermediate range between medium range and seasonal is difficult as the importance of the initial conditions wanes, and the importance of slower boundary conditions such as sea surface temperature increases but has only a modest influence on the weather and climate, especially away from the tropical regions. Tropical sea surface temperatures play an important role not only in controlling the weather/climate in the tropics but in the extra-tropics also, through various tele-connections. The El Niño Southern Oscillation (ENSO) is the best-known long-lived source of predictability in the tropics but changes in SST in the Indian Ocean are also significant, though the forecast horizon is likely to be shorter than for ENSO. Predicting changes in the equatorial Atlantic SSTs has been less successful.

As discussed at the Workshop, recent results suggest that there is potentially useful predictability at sub-seasonal timescales, intermediate between NWP and seasonal timescales, and it is worth exploring this further and despite the difficulties in forecasting for this range it is worthwhile developing a research strategy to explore and exploit this potential.

The contribution that successful sub-seasonal predictions can make to the developing programme for Global Framework for Climate Services will be valuable in that

- All countries would benefit, but priority should be given to the needs of climate-vulnerable poor countries
- The primary focus must be greater access and use of climate information by users
- Framework activities should address three spatial scales: global, regional and national
- Climate information is primarily a public good and should be made widely available

- The Framework should respect national and international data policies while encouraging global, free and open exchange of climate-relevant data

In order to improve predictions at these ranges it is necessary to develop a seamless approach to weather and seasonal prediction. Similarly, it is also necessary to promote a seamless approach to the application of sub-seasonal predictions through physical and social science researchers, service providers and users and leveraging the work of existing programmes and such a collaborative initiative should be focussed (section 2 of this report) on

- Coupled global modelling
- Coupled data assimilation
- MJO and organised tropical convection
- Polar processes
- Surface-atmosphere interactions
- Stratosphere-troposphere interactions
- Ensemble prediction systems (EPS)
- Data bases for research
- Forecasting system design
- Societal and economic benefits from improved sub-seasonal to seasonal prediction

And, the utilization of these predictions will require

- Understanding how information at the weather/climate interface, including uncertainty, connects with decision-making and risk management
- User-oriented products

Recommendation

The major Workshop recommendation is that a Panel/Project for Sub-seasonal prediction research should be established. Panel members should include representatives from WWRP-THORPEX, WCRP, CBS and CCI and their relevant programme bodies. The first task for the Panel should be the preparation of an Implementation Plan which is consistent with the contents of this Workshop report.

The Implementation Plan should give high priority to:

- Sponsorship of a few international research activities
- The establishment of collaboration and co-ordination between operational centres undertaking sub-seasonal prediction to
 - ensure, where possible, consistency between operational approaches to enable the production of data bases of operational sub-seasonal predictions to support the application of standard verification procedures and a wide-ranging programme of research
- Facilitating the wide-spread research use of the data collected for the CHFP (and its associate projects), TIGGE and YOTC for research
- The establishment of a series of regular Workshops on sub-seasonal prediction

In a separate plan, or as part of the Implementation Plan, the WWRP/SERA Working Group and the WCRP should outline plans for a number of regional projects.

4. Outcome of WWRP/JSC4 (February, 2011) - highlights

4.1 DAOS Working Group

- Acknowledged the valuable work carried out by the DAOS Working Group in its comprehensive study of the impact of targeted observations
- Recommended that the DAOS Working Group establishes good links with the Mesoscale and Nowcasting Working Groups and improves its connections with groups involved in land-surface data assimilation
- Noted that assimilation of radar data is an issue for global scale and mesoscale data assimilation and also nowcasting
- Welcomed the efforts to develop common formats, which includes quality information, for the exchange of radar data and noted that this action benefits mesoscale data assimilation

4.2 PDP Working Group

- The JSC stated that the PDP group was tackling some of the main mission objectives of THORPEX and was a key to the long term success of THORPEX and that there is a real need to continue to identify the important areas where progress is likely to be made in order to push predictive skill forward. Boundary layer moisture and cold air outbreaks have been identified as important areas on which to focus in the future, but achieving continuous progress remains a difficult challenge which needs the support of the whole THORPEX programme and resources
- It was noted that understanding errors remains a major topic. The YOTC data sets could be very helpful for understanding the errors in tropical regions especially because of the availability of physical process tendencies and the JSC encouraged intensive use of the YOTC datasets

4.3 GIFS-TIGGE Working Group

- Queried the future of TIGGE archiving since the data bases are to expanding rapidly; however, it was expected that archiving would continue for the time being in the absence of pressure from the archive centres to reduce data volumes
- Progress in establishing really effective links with the SWFDPs was also queried but this was said to be proceeding steadily if somewhat slowly - the importance of this aspect was emphasized
- It was also noted that advances and activities were mainly in the N. Hemisphere but this was felt due to a lack of relevant resources in the S. Hemisphere
- Noted the changed emphasis of the work for Global Interactive Forecast Systems (GIFS), away from seeking to establish GIFS Demonstration Projects, towards the development of tools for the probabilistic prediction of high impact weather for use in SWFDPs for example

5. Training Workshops

5.1 International Summer School on “Atmospheric Predictability” in Banff

The THORPEX Predictability and Dynamical Processes Working Group (PDP WG) have organised a Summer School on Advanced Mathematical Methods to Study Atmospheric Dynamical Processes and Predictability. The summer school will take place at the Banff International Research Station (BIRS) for Mathematical Innovation and Discovery, Alberta, Canada, 10 to 15 2011.

The main aim of the summer school is to provide an overview of the state-of-the-art of the applied mathematical techniques of weather and climate forecasting. Topics that will be covered include

- The partial differential equations that govern atmospheric motions
- Wave solutions of the atmospheric governing equations
- Idealized models of atmospheric motions
- Potential vorticity based diagnostics
- Numerical techniques to solve the atmospheric governing equations
- Diagnostic techniques to assess model deficiencies
- Data assimilation: 3D-Var and 4D-Var
- Data assimilation: Ensemble based Kalman filters
- Data assimilation: Assimilation of remotely sensed observations
- Forecast Sensitivity: Assessing the forecast impact of observations
- Observation targeting: Predicting the impact of future observations
- The concept of atmospheric balance
- The main concepts of dynamical systems theory
- Generation of ensemble initial perturbations
- Verification of ensemble based probabilistic forecasts

The following lecturers have confirmed their participation:

- i. C. Bishop (Naval Research Laboratory, Monterey)
- ii. T. Jung (European Centre for Medium-Range Weather Forecasts)
- iii. P. Lynch (University College Dublin)
- iv. A Majda (New York University)
- v. E. Ott (University of Maryland, College Park)
- vi. Szunyogh (Texas A&M University)
- vii. O. Talagrand (Laboratoire de Météorologie Dynamique, Paris)
- viii. H. Wernli (ETH Zurich)

32 students have been selected from amongst the 90 applicants – with 7 reserves. Included amongst these 32 are 1 student from Africa, 5 students from Asia (including 3 who are currently studying in North-America), 2 students from South-America, 1 student from Australia and 2 from Eastern Europe.

6. Developing country support, workshops and reports

Africa

Progress with the THORPEX Africa Implementation Plan was presented at the WMO Regional Association I meeting that will take place in Morocco in November 2010. The main issue that was raised is the crucial need for the funding agencies within and outside Africa to support the components of the THORPEX Africa Plan.

In addition, the potential benefits to RA I Members from the YOTC project were described and African countries were encouraged to participate in this research effort which aims at improved representation of tropical convection and its two-way interaction with large-scale circulations in both weather and climate models. These improvements in modelling capabilities would, inter alia, produce improved predictions of tropical cyclones, monsoons and heavy rainfall, which are particularly relevant to RA I.

7. Publications (in the open literature)

The following major paper on YOTC has been submitted to BAMS:-

Waliser, D. E., M. Moncrieff, D. Burridge, A. Fink, D Gochis, B. N. Goswami, B Guan, P Harr, J Heming, H.-H. Hsu, C Jakob, M. Janiga, R. Johnson, S Jones, P. Knippertz, J Marengo, H Nguyen, M Pope, Y Serra, C Thorncroft, M Wheeler, R. Wood, and S. Yuter (2010), The "Year" of Tropical Convection (May 2008 to April 2010): Climate Variability and Weather Highlights, Bulletin of the American Meteorological Society.

Annex 1 - Review of the data impact studies carried out for Summer T-PARC (including TCS 08)

Patrick A. Harr (Naval Postgraduate School, Monterey, CA, USA) and Sarah C. Jones (Karlsruhe Institute for Technology, Karlsruhe, Germany) have prepared an extensive review of the outcome of the data impact studies carried out for Summer T-PARC (including TCS 08). The following paragraphs are a summary of their review.

The Observing System Research and Predictability Experiment (THORPEX) is a decade long global atmospheric research program of the World Meteorological Organization/World Weather Research Program (WMO/WWRP) with a goal of improving skill of 1-14-day forecasts of high-impact weather. Throughout the THORPEX program, several regional campaigns have been undertaken to address specific high-impact weather events. One such program was conducted during August-September 2008 over the western North Pacific as the summer component of THORPEX Pacific Asian Regional Campaign (T-PARC).

Although many significant weather events occur over eastern Asia and the western North Pacific, the focus of T-PARC has been on various aspects of typhoon activity, which include formation, intensification, structure change, motion, and extra-tropical transition. Because of the significant impact of typhoon activity on the region of eastern Asia and the western North Pacific, the field phase of T-PARC was defined by a partnership among several national programs and co-sponsorship with the WMO/WWRP Tropical Meteorology Research Program (TMRP). These programs and their national sponsor include:

- Tropical Cyclone Structure-2008 (TCS-08) [United States];
- Typhoon Hunter-2008 (TH-08) [Japan];
- Predictability and Observation Experiment (PROBEX) [South Korea];
- Tibetan Plateau Experiment [China];
- The South China Sea Experiment [China];
- Dropsonde Observations for Typhoon Surveillance near the Taiwan Region (DOTSTAR) [Taiwan].

As a multi-national field campaign and research initiative, T-PARC/TCS-08 addresses the shorter-range dynamics and forecast skill of one region (eastern Asia and the western North Pacific) and its downstream impact on the medium-range dynamics and forecast skill of another region (eastern North Pacific and North America). High impact weather events over regions examined in T-PARC/TCS-08 have strong dynamical links. For example, persistent deep tropical convection or the extra-tropical transition of tropical cyclones can trigger downstream responses over the eastern North Pacific, North America, and beyond via upper-tropospheric wave packets on the primary mid-latitude wave guides. Then, wave packets can be invigorated by subsequent downstream cyclogenesis events that are often associated with reduced predictability. High-impact weather events over North America driven by these processes have included intense extra-tropical cyclones, orographic precipitation, floods, severe weather and hot, dry winds that increase the risk of wild fires and the severity of droughts. While T-PARC/TCS-08 objectives encompass mesoscale and synoptic-scale processes associated with tropical cyclones over the western North Pacific and eastern Asia, they also address medium-range forecast skill associated with downstream impacts across the North Pacific and beyond.

The collaborative programmes allowed for an experimental design that addressed three primary components. (1) A tropical measurement strategy examined circulations of the tropical western North Pacific monsoon environment as they related to enhanced and reduced periods of wide-spread deep convection, tropical cyclone formation, tropical cyclone intensification, and tropical cyclone structure change. (2) The measurement strategy for the extra-tropical transition and

downstream impacts was based on the pole-ward movement of a decaying tropical cyclone and the resulting intense cyclogenesis that results from its interaction with the mid-latitude circulation. (3) The targeted observation measurement strategy focused on identification of regions in which extra observations may reduce numerical forecast error growth. In T-PARC/TCS-08, the targeted observations were aimed at reducing errors associated with forecasts of tropical cyclone track over the western North Pacific. In particular, this includes whether a tropical cyclone will recurve, the longitude of recurvature, and the orientation and speed along the track following recurvature.

To accomplish the primary objectives of T-PARC/TCS-08, it was imperative to employ a complete tropical-to-extra-tropical measurement strategy. For example, predictability associated with an extra-tropical transition event depends on the intensity and structure of the tropical cyclone, where and when the tropical cyclone arrives in the mid-latitude westerlies, and the characteristics of the mid-latitude wave guide that impact the extra-tropical transition-related cyclogenesis, and the downstream propagation and evolution of the wave packets.

During the field program period of 1 August – 4 October 2008, four typhoon, four tropical storms, and four tropical depressions occurred over the western North Pacific. In addition to these circulations for which official forecasts were issued by the Regional Specialized Meteorological Centre (RSMC, Tokyo), a separate set of 51 tropical circulation systems were identified by the T-PARC/TCS-08 research team. These systems were defined as tropical cloud clusters, low-level waves, or subtropical circulations of interest to the project.

During the period, 500 aircraft mission hours were flown during a total of 76 missions. The missions were flown into 4 typhoons, one tropical depression, and 5 tropical cloud clusters. Overall, 72% of the flight missions were flown into the four typhoons. A significant number of flight hours were dedicated to each objective listed above.

A number of the T-PARC and TCS-08 field mission types and accomplishments had never been done in the region of the western North Pacific or any other tropical cyclone ocean basin. During T-PARC/TCS-08, the first systematic data targeting operation applied to tropical cyclones over the western North Pacific was conducted. This included comparison of several methods from a variety of operational and research organizations. A consistent set of verification regions was used for each product and the displays were produced in a systematic manner. A majority of the products were made available via the Data Targeting System at the ECMWF.

Another first-time accomplishment was the four-plane operation within Typhoon (TY) Sinlaku at category four intensity. The combination of aircraft types and special observing capabilities allowed for data to be gathered in the storm inner core, near-storm environment, and remotely-located targeted regions. This capability has led to studies of the sensitivity of track forecast accuracy to data type and location with respect to a tropical cyclone.

Two missions were conducted to deploy drifting buoys directly in the path of TY Hagupit and TY Jangmi, respectively. At the time of the buoy deployment in TY Jangmi, the storm was of category five intensity. In both cases, the typhoon passed directly over the buoy arrays. These observations are critical for examining the role of air-ocean processes in the extremely high-wind environment as they impact tropical cyclone intensification.

For the first time, the entire process of ET was investigated by aircraft in such a manner that the impact of the ET on the mid-latitude circulation can be examined with respect to important physical processes that occur over regions of the decaying tropical cyclone and the interface with the mid-latitude circulation. The systematic observations of the two ET cases identify factors that impact forecast and observed downstream development and modify the mid-latitude jet structure. Additionally, the relative impacts of observations during ET may be examined to

relate changes in predictability to the representation of important physical characteristics in a numerical model.

The T-PARC/TCS-08 program was the first operation of the Driftsonde in the equatorial Pacific. The balloons were launched from Hawaii and dropsondes were deployed based on commands given from the operations centre in Monterey, CA. Data were retrieved and transmitted to the GTS for use in operational numerical weather forecast models.

Finally, during T-PARC/TCS-08 and affiliated programs, many instruments were deployed for the first time into the environment of a west Pacific tropical cyclone. These included the ELeCtra DOppler RAdar (ELDORA) and the Twin Otter Doppler Wind Lidar (TOWDL) on the NRL P-3, the Stepped Frequency Microwave Radiometer on the USAF 53rd Weather Squadron WC-130J, and the DLR Doppler wind lidar and Differential Absorption Lidar (DIAL) water vapour lidar.

Overall, the field phase of the T-PARC/TCS-08 and affiliated programs were conducted with great success. The results of the data collection strategies during the field programs were such that sufficient resources were applied to each objective, which will lead to significant advances in understanding and increase in predictability of high-impact weather over eastern Asia, the western North Pacific, and regions downstream.