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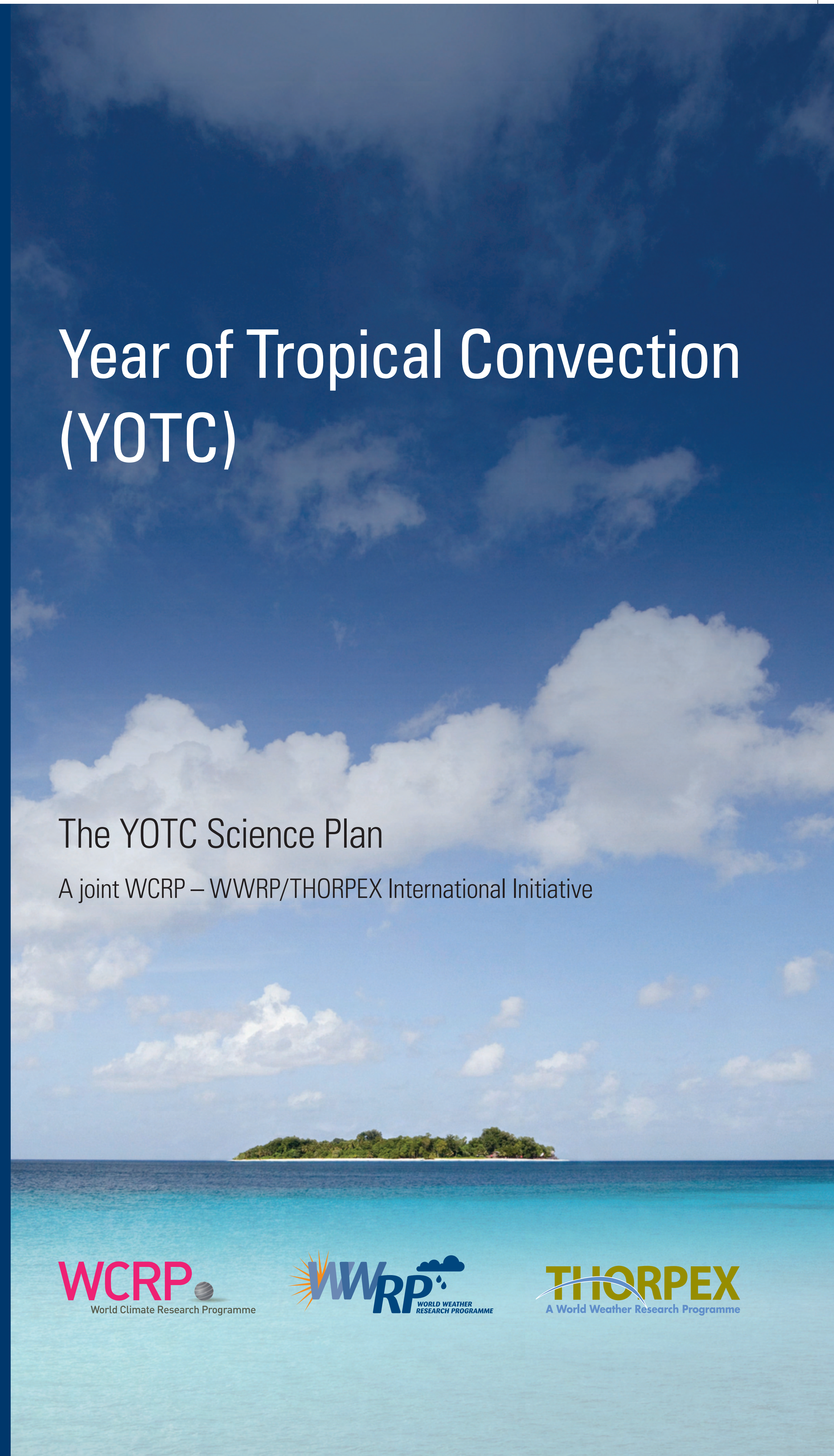

Year of Tropical Convection (YOTC)

The YOTC Science Plan

A joint WCRP – WWRP/THORPEX International Initiative

WCRP World Climate Research Programme
WWRP World Weather Research Programme
THORPEX A World Weather Research Programme

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WORLD METEOROLOGICAL ORGANIZATION

Year of Tropical Convection (YOTC)

The YOTC Science Plan
A Joint WCRP – WWRP/THORPEX International Initiative

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SYNOPSIS

The realistic representation of tropical convection in our global atmospheric models is a long-standing grand challenge for numerical weather forecasts and global climate predictions. Our lack of fundamental knowledge and practical capabilities in this area leaves us disadvantaged in modelling and predicting prominent phenomena of the tropical atmosphere such as the ITCZ, ENSO, TBO, monsoons and their active/break periods, the MJO, subtropical stratus decks, near-surface ocean properties, easterly waves, tropical cyclones, bulk budgets of cloud microphysical quantities, and even the diurnal cycle. Furthermore, tropical weather/climate disturbances strongly influence stratospheric-tropospheric exchange as well as the extratropics, with the latter mediated via poleward migration of synoptic systems or through initiating Rossby wave trains that can involve a range of processes and time scales.

To address this the challenge of tropical convection, WCRP and WWRP/THORPEX propose a Year of coordinated observing, modelling and forecasting of organized tropical convection and its influences on predictability as a contribution to the United Nations Year of Planet Earth to complement the International Polar Year (IPY). This effort is intended to exploit the vast amounts of existing and emerging observations, the expanding computational resources and the development of new, high-resolution modelling frameworks, with the objective of advancing the characterization, diagnosis, modelling, parameterization and prediction of multi-scale convective/dynamic interactions, including the two-way interaction between tropical and extra-tropical weather/climate. This activity and its ultimate success will be based on the coordination of a wide range of ongoing and planned international programmatic activities (e.g., GEWEX/CEOP/GCSS, AMY, EOS, GOOS), strong collaboration among the operational prediction, research laboratory and academic communities, and the construction of a comprehensive data base consisting of satellite data, in-situ data sets and global/high-resolution forecast and simulation model outputs relevant to tropical convection. The proposed timing, focus year approach and integrated framework of this effort is intended to leverage the most benefit from recent investments in Earth Science infrastructure as well as entrain a new generation of young scientists into tackling the outstanding problems in the field of weather and climate prediction.

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I. BACKGROUND

A 5-day workshop on the “Organization and Maintenance of Tropical Convection and the Madden-Julian Oscillation (MJO)” co-sponsored by the WCRP and WWRP/THORPEX was held at the International Centre Theoretical Physics (ICTP), Trieste, Italy in March 2006. Attended by an international cast of about 70 scientists, this workshop had the following objectives:

i) To review our fundamental knowledge of organized convection in the tropics, how it relates to tropical weather systems and how its simulation in weather and climate prediction models can be improved leading to advances in predictive capability;
ii) To review the state of knowledge and future directions in observing, simulating, modelling and predicting the MJO and its socio-economic implications; and
iii) To prepare a workshop report that includes priorities for THORPEX/WCRP research and forecast demonstration projects.

A large part of the presentations and ensuing discussions focused on the organizing scales and elements of tropical convection and its interaction with convectively-coupled equatorial waves. Still uncertain are: i) the degree and manner organized convection is influenced by, and feedbacks onto, the large-scale circulation; ii) the mechanisms that link the cloud, meso-, synoptic and planetary scales, including their influences on and from microphysical processes; iii) the means by which large-scale tropical convection systematically interacts with the extra-tropical circulation and its variability. Less uncertain is the appreciation that organized tropical convection, particularly in the form of convectively coupled waves, represents a fundamental process that drives tropical, and in some cases extratropical, atmospheric variability. This includes mean state features such as the ITCZ, seasonal variations associated with the monsoons, synoptic variability such as easterly waves and tropical cyclones, the MJO and the diurnal cycle, with many of these features imparting a significant impact on the evolution of extratropical weather and climate. For the first time, this problem is tractable from theoretical, numerical and observational perspectives. Figure 1 shows a selection of the themes addressed by the workshop. A summary of the workshop proceedings and its scientific context has been published (*1*).

Permeating the presentations and discussions at the Workshop was acknowledgement that the landscape from which the above problems are being addressed has rapidly and irreversibly changed over the last decade. Resources have expanded significantly and the implementation of global “cloud resolving” models is nearly a reality. This notion alone warrants a reconsideration of the most strategic manner the community approaches these problems. Moreover, with the implementation in recent years of a wide variety of basin/global scale *in-situ* and satellite observational programmes, there are altogether new opportunities for advancing our knowledge of the cloud-radiative-dynamical interactions within convective systems, including the links that lie between microphysical and global-scale processes as well as between the atmosphere and the ocean/land surface below. Notable was the fact that when queried as a group, the Workshop participants were unable to articulate the needs for specific field experiments beyond what is presently planned to address the above issues. In recent years, the resources and facilities have changed so measurably that our community has yet to fully exploit them in a consolidated manner for tackling issues such as the organization of tropical convection. With these points in mind, a primary recommendation of the WCRP/THORPEX workshop on convection was:

> *Conduct a Year of coordinated observing, modelling and forecasting of organized tropical convection and its influences on predictability (an ‘IOP’ every day concept). This is intended to exploit the vast amounts of existing and emerging observations and computational resources becoming available in conjunction with the development of new/high-resolution modelling frameworks, in order to better characterize, diagnose, model and forecast multi-scale convective/dynamic interactions and processes, including the two-way interaction between tropical and extra-tropical weather and climate circulations.*

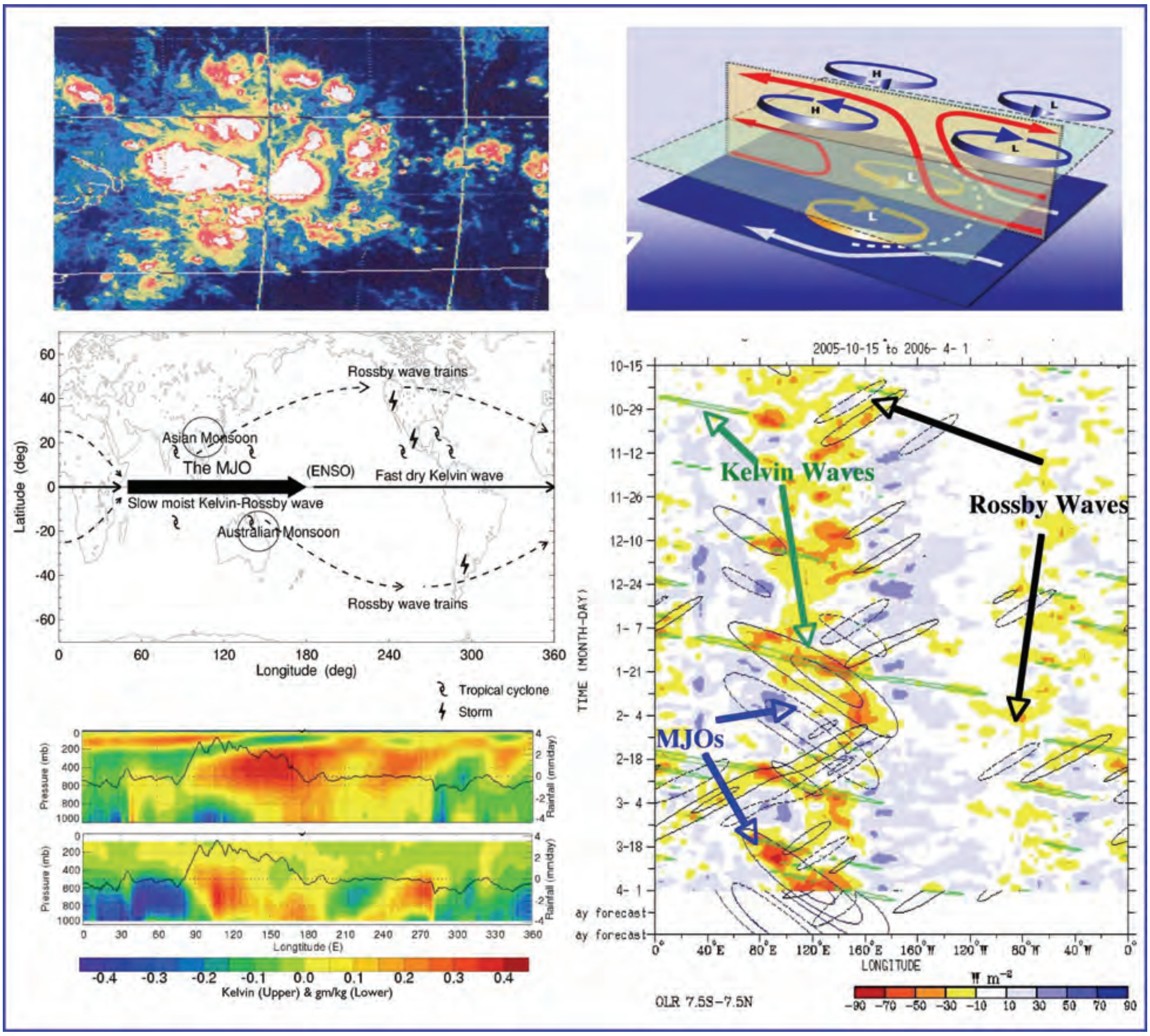

Figure 1. [Clockwise] (upper left) Mesoscale convective systems embedded in a supercluster observed from space on 20 Dec 2003 during TOGA COARE (*2*). (upper right) Idealization of the three-dimensional organization of a tropical convective system combining both meso-scale and large-scale elements (*2*). (Lower right) OLR anomalies averaged between 7.5N-7.5S (shading) and wavenumber-frequency filtered OLR (lines) for winter of 2005-6; showing MJOs (blue), Kelvin waves (green) and mode 1 equatorial Rossby waves (black), based on Wheeler and Weickmann (*3*). (lower left) Pressure-longitude equatorial sections (8N-8S) of temperature (upper) and specific humidity (lower) anomalies associated with the MJO, black line indicates rainfall anomalies (*4*). (center left) Schematic illustrating downstream and mid-latitude influences of the MJO (J. Lin, CDC/NOAA).

The YOTC Science Plan is a prospectus for addressing this ambitious recommendation, envisioned as a WCRP and WWRP/THORPEX contribution to the United Nations Year of Planet Earth[1] that would complement the International Polar Year (IPY) (*5*).

[1] In January 2006, the U.N. General Assembly proclaimed the year 2008 to be the U.N. International Year of Planet Earth. The Year's activities will span the three years 2007-2009 (www.yearofplanetearth.org/proclamation.htm).

II. MOTIVATION

a) The Challenge and Impacts of Organized Tropical Convection

Cumulus convection, the manner it influences cloud processes, and organizes on larger scales is of fundamental importance to the atmospheric circulation through affecting the transport of heat, moisture, and momentum, as well as the Earth's radiation budget. Until very recently, large-scale atmospheric circulation models have necessarily relied on parameterizations to represent cumulus convection and the accompanying physical processes. Despite impressive efforts of individuals and small research groups leading to notable improvements, the key area of parameterization remains under-resourced worldwide. Not surprisingly, significant deficiencies in cumulus/cloud parameterizations continue to plague studies and predictions of the atmospheric circulation on both weather and climate timescales. Notwithstanding the expected advances in computer technology, climate models, and Earth System Models in particular, will require convective parameterizations for the foreseeable future.

The representation of atmospheric convection and its multi-scale organization is intrinsically complex because it relies heavily not only on convective parameterization *per se*, but also on the parameterization of sub-cloud-scale processes (e.g. boundary layer and cloud microphysics) and, importantly, on how these processes interact across scales. Many processes remain poorly understood, which further reduces the fidelity of parameterizations. For example, we lack basic comprehension of how meso-scale, synoptic-scale and planetary-scale phenomena interact as a coupled dynamical system. We face similar challenges in regards to the transitions from stratocumulus to cumulus and between shallow to deep cumulus in association with the ITCZ/Hadley and Walker circulations and many large-scale tropical wave systems. This lack of fundamental knowledge and practical capability leaves us disadvantaged in modelling and predicting prominent phenomena of the tropical atmosphere such as the ITCZ, ENSO, TBO, monsoons and their active/break periods, the MJO, subtropical stratus decks, trade-wind cumulus, near-surface ocean properties, easterly waves, tropical cyclones, bulk budgets of cloud microphysical quantities, and even the diurnal cycle (the most basic forced variability of atmospheric motion). Furthermore, tropical weather/climate disturbances strongly influence the extra-tropics whether through poleward migration of synoptic systems and through initiating Rossby wave trains that can involve a range of processes and time scales (e.g., synoptic, MJO/intraseasonal, ENSO/seasonal-to-interannual). Figure 2 provides a cross-section of phenomena that illustrate well-known shortcomings in our model representations of mean climate, variability, climate change projections and extra-tropical weather forecasts. Many of these shortcomings can be directly ascribed to parameterizations of sub-grid scale processes and, notably, precipitating convection and its multi-scale organization.

While our knowledge of *physical processes* has improved tremendously in the past 40 years or so, comparatively little progress has been made on improving the representation of convection in large-scale models, particularly for organized convection. The reasons stem from the physical complexity and multi-scale nature of the processes involved (e.g. dynamics of convective updrafts/downdrafts, interaction between convective and stratiform clouds/rain, mesoscale organization, and the coupling among dynamics, microphysical and radiative processes), as well as the significant decline in the number of individuals and teams actively working on cumulus parameterization. Sorely needed is a focused activity/programme that will re-invigorate research on the parameterization of convection and related processes by creating focus on a particularly well-observed period via an activity that can also help to entrain a new generation of bright minds to the science.

Much of the recent scientific progress made has been the result of a coordinated use of observations, cloud-resolving models and large-scale models as advocated by international programmes such as the GEWEX Cloud System Study (GCSS) (*6, 7*). Due to computing and observational limitations many of these efforts have focused on the interaction of the convective and meso-scales. It is time to expand such efforts to include all relevant scales. This requires resolving and simulating the microphysical-to-global-scale interactions in a robust "computational laboratory"[2]. The fundamental challenges to addressing this problem have been three-fold: i) representing the broad range of scales applicable to the tropical organization problem (i.e. cumulus to planetary), ii) overcoming the lack of observations that adequately and simultaneously characterize this broad range of scales and that also provide three-dimensional information on thermodynamic, radiative and dynamical interactions, including cloud microphysical processes, and iii) transferring findings from observation, process and CRM studies into the parameterizations used in the operational prediction for weather, seasonal-to-interannual climate variability and climate change. In recent years progress associated with the first two challenges has been remarkable providing an altogether new opportunity to invigorate research and make significant gains in our understanding and predictions of tropical convection and related processes.

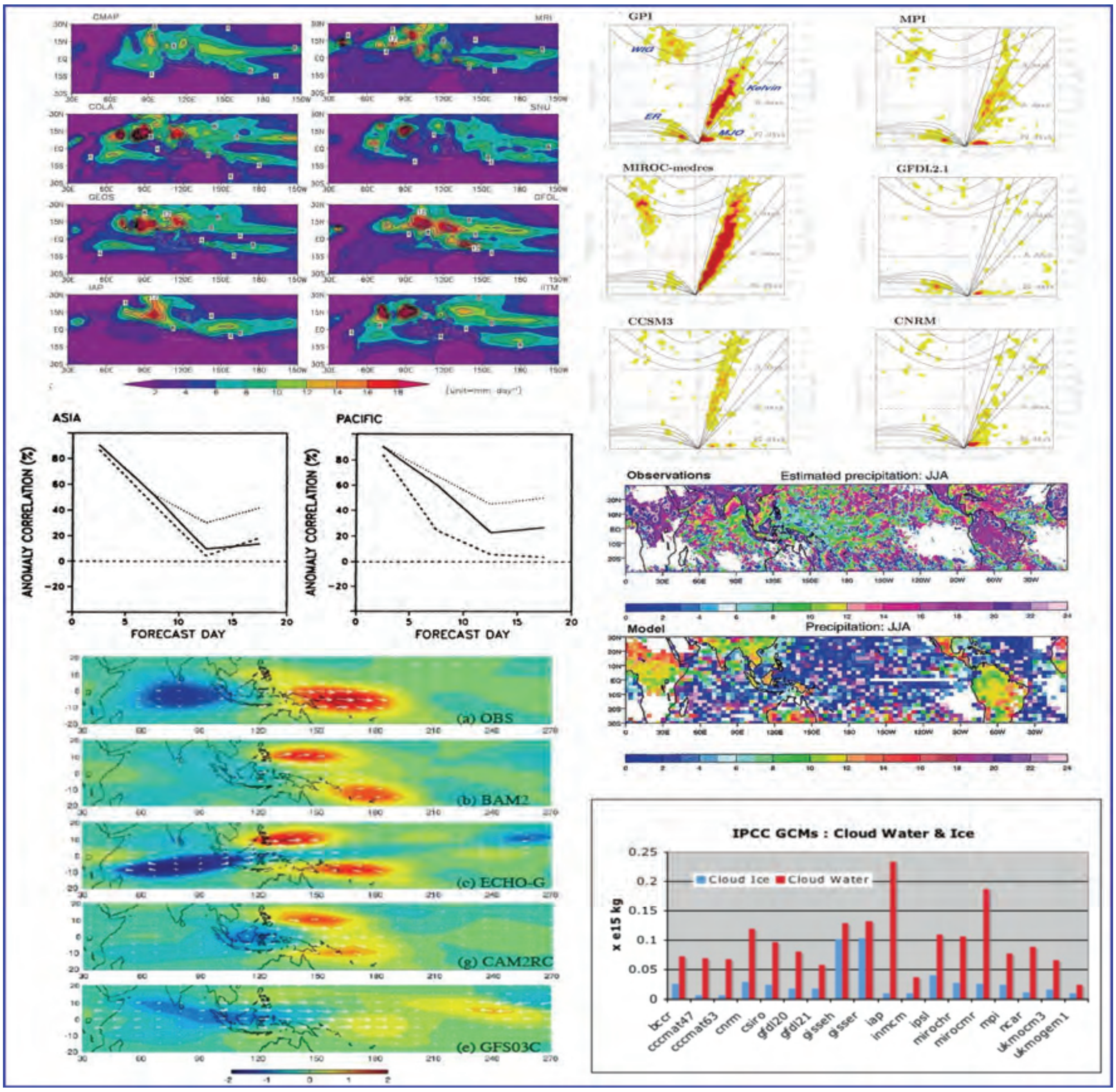

Figure 2. [Clockwise] (upper left) Climatological JJA precipitation from observations (upper left) and a select number of GCMs (*8*). (upper right) Wavenumber-frequency diagrams of equatorial precipitation from observations (upper left) and a select number of GCMs (*9*). (middle right) Phase of the diurnal cycle in precipitation for JJA from observations (upper) and a GCM (lower) (*10*). (lower right) Total tropical (30N-30S) integrated cloud water and ice from the 20th century simulations contributed to the 4th IPCC assessment. (lower left) Zero-lag regression of band-pass/MJO filtered U850 (vectors) and precipitation (colours, mm day-1) upon filtered U850 at 160°E and 0°N (*11*). (middle left) Extra-tropical 200 hPa potential vorticity forecast skill versus lead-time for operational model (solid) and when the tropics are nudged towards the verifying analysis during four MJO events (dotted) (*12*).

[2] The other main recommendation from the WCRP/THORPEX workshop.

b) Approaches of Past Field Campaigns

The 1974 Global Atmospheric Research Programme (GARP) Atlantic Tropical Experiment (GATE) was the first large international field programme to address the interaction of convective cloud systems with the larger synoptic scales in the tropics (*13, 14*). It was planned as a scale-interaction experiment (*15*) to collect data from rawinsondes, aircraft, radars, tethered balloons and surface measurements in the intertropical convergence zone of the eastern Atlantic. It had been recognized that predicting convective transports from the resolved large-scale fields, the problem of convective parameterization, was key to developing better models of the tropical circulation. It was hoped that case-study analyses of convective systems and composite and modelling studies of easterly waves could be used to test and develop convective parameterizations (*16*). The premise of GATE was that the convective and synoptic scales interacted but were separated in time and space scale, with a large gap between synoptic and convective scales. However, the rich GATE observational database revealed that the convection was organized into mesoscale systems with motions on scales intermediate between convective and synoptic scales (*16-19*), and that these intermediate scale motions altered vertical distribution of heating by convection (*17, 20-22*). The mesoscale circulations organized by deep convection, seen in GATE, conflicted with the simple notion of scale separation and this additional complexity of real convection is in part responsible for the slow development of parametric representation of convection (*23*). Important results of GATE were confirmed in the 1978-79 GARP Winter and Summer Monsoon Experiments (MONEX, *24*). These field campaigns over the South China Sea and Indian Ocean showed mesoscale organization of oceanic convection similar to that which had been seen over the tropical Atlantic in GATE (*25*), and as also confirmed through the analysis of longer periods of observations from geostationary satellites (*26*).

The 1979 First GARP Global Experiment (FGGE) was a major data and modelling enterprise involving detailed study of the whole atmosphere for a year. Collection of global data sets from both the surface/upper-air network and emerging space based systems provided for a relatively innovative opportunity for improving medium-range global weather forecasts. Observations from oceanic buoys, commercial aircrafts, ships of opportunity, satellite cloud tracked winds, satellite temperature retrievals, and special deployments of weather observations complimented the conventional World Weather Watch of that era. A key component was the refinement and application of multivariate optimal interpolation for carrying out global data assimilation. This thrust on global and comprehensive observations provided significant improvement in global skill scores for medium range weather forecasts. Numerous weather centres came of age with the recognition for data quality, coverage and data assimilation as the crucial components for forecast improvements. FGGE set the stage for the rapid advancement in global modelling that followed in the ensuing 25 years (Figure 3).

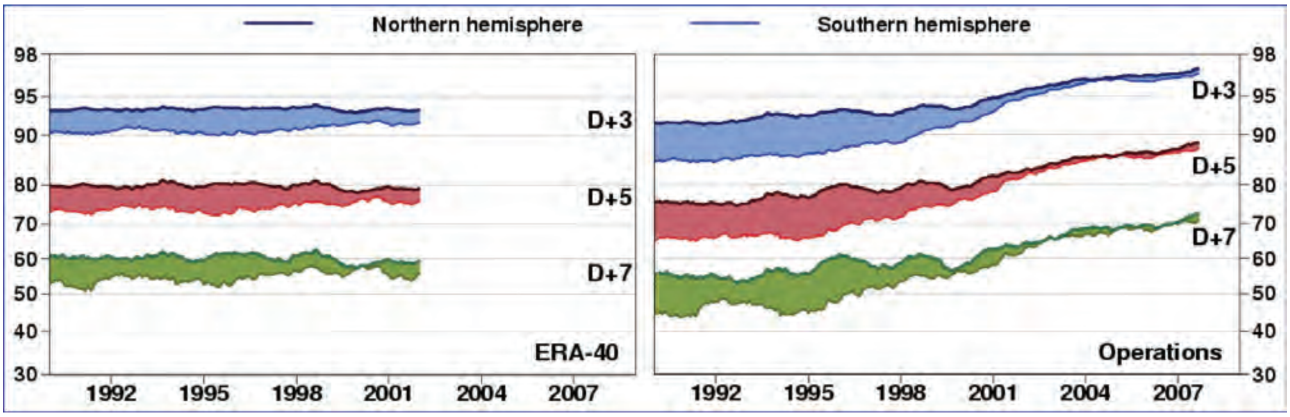

Figure 3. Improvements in medium-range NWP forecast skill; 12-month running mean of anomaly correlation (%) of 500hPa height forecasts. (left) Forecasts based on the ERA-40 system (i.e. initial conditions and associated model) – illustrates impact of additional data sources. (right) Forecasts based on the operational system at the given time – illustrates combined impacts of additional data sources, advances in data assimilation and model improvements. Courtesy of Adrian Simmons by way of Martin Miller.

The Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA COARE) was a joint atmosphere-ocean field experiment conducted over an extended four-month period in the equatorial western Pacific (November 1992 - February 1993). It was directed not only at the properties and behaviour of tropical convection – its organization and interaction with larger scales of motion – but also on mechanisms by which convection couples with the upper ocean (*27*). COARE was targeted for the western Pacific warm pool since this is a region where the climate system is critically sensitive to ocean-atmosphere coupling processes, particularly in connection with ENSO and MJO variability and teleconnections with midlatitudes. It should be emphasized that it was in conjunction with long-term geostationary satellite records that these tropical-extratropical and planetary-scale interactions were able to be documented (*26*). Aircraft and ship measurements in COARE again documented the mesoscale structure and motions of deep convection over the tropical ocean. But COARE went further by revealing aspects of the physical mechanism by which the mesoscale convective heating is translated upscale to larger-scale motions (*28*), and indicated that the mesoscale circulations organized by convective systems are important in the large-scale redistribution of momentum (*29, 30*). COARE further highlighted the importance of intermediate sized convection in the heat balance of the region (*31*). COARE has yielded insight on ocean-atmosphere coupling processes over a broad range of time scales, from the several-hour time scale of mesoscale convective systems, to the diurnal cycle, and all the way up to the 40-50 day time scale of the MJO (*32-34*). COARE has contributed to an improved understanding of a variety of phenomena and processes such as two-day waves, air-sea exchanges in light-wind conditions, ocean mixing, convective momentum transport, dry intrusions, cloud-radiation interactions, tropical cloud populations, the diurnal cycle, etc., although the incorporation of findings from COARE into regional and global scale numerical models has yet to be fully realized. Notable in the current context is that the present range of multi-sensor satellite observations were not available during COARE, which has compromised the evaluation, and limited the application, of multi-scale CRM simulations. And as with other field campaigns, COARE has helped motivate a new era of scientists and cross-cutting research that has continued.

III. NEW ERA FOR PROGRESS

a) Global Observing Systems

Over the past two and half decades, there has been tremendous growth and expansion of our capabilities to observe the tropical ocean, atmosphere and land systems. For example, during the GATE experiment, the most useful satellite data was based on the first operational geostationary satellite (SMS-1) launched just shortly before the IOP. It captured cloud pictures every 30 minutes that provided information on clouds/convection and cloud-tracked winds. By the time of FGGE, there was a near-global fleet of operational geostationary satellites (e.g., GMS, Meteosat, GOES). This along with the increasing capabilities of the NOAA operational polar orbiters provided basic cloud information, coarse temperature and moisture soundings, and SST in cloud-free areas. For TOGA COARE, over ten years later, the key additions were relatively high quality precipitable water observations as well as estimates of surface wind speed, liquid water and rain rate from the DMSP's SSM/I sensor and the high quality radiation budget information from ERBE. In addition, just prior to TOGA COARE there was the implementation of the landmark, TOGA TAO ocean observing system for the Pacific, which at the time of COARE included about 40 buoys. The one component of the global observing system that has undergone degradation in recent decades is *in situ* radiosonde network, with the number of soundings decreasing 20-30% over the last two decades (*35*). While the results in Figure 3 suggest that operational satellite sounders can make up for deficiencies in the radiosonde network (e.g., S. hemisphere skill approaching N. hemisphere skill), satellite validation necessitates the need for a well-sampled radiosonde network and further loss, particularly in the tropics, may jeopardize this capability. On the other hand, there have been some sophisticated semi-operational sites instrumented by the DOE/ARM programme and the GEWEX CEOP. The discussion below highlights the vast resources available today for monitoring and characterizing tropical variability, as well as for assimilation and validation applications for prediction. *This brief review is meant to emphasize the* *rate and breadth of the changes that have occurred over the last decade and in turn motivate the proposed activity that is intended to coordinate and exploit their potential.*

i) Satellite Network

A new era of satellite observations began to take shape in the 1990's with a number of international collaborative efforts that led to several new and important retrieval products. These included surface vector wind information from ERS-1 (1991), ERS-2 (1995), QuikSCAT (1999) and now SeaWinds (2002), as well as sea level height information from Topex/Poseiden (1992) and Jason-1 (2004) altimeters. A hallmark addition to this new suite of satellites was TRMM (1997) radar and radiometer suite that has provided rain rate information with considerably higher quality and more detail - including vertical structure information, the ability to separate convective from stratiform precipitation, and the ability to determine SST in the presence of clouds. In conjunction with the above, was the planning and development of the Earth Observing System (EOS) programme of satellites. Starting with the launch of the EOS Terra platform in 1999, the EOS began to take shape. From there, the addition of the EOS Aqua (2002), EOS Aura (2004) and most recently the CloudSat/Calypso (2006) profilers have provided a staggering amount of resources relative to only ten years ago to better study tropical convection and its interactions with the environment and near surface ocean. The so-called A-Train constellation contains a number of these platforms flying in formation so that within minutes, near-simultaneous measurements are made of a wide range of quantities. Figure 4 illustrates the satellite growth rate associated with the EOS programme and a depiction of the A-Train configuration of satellites, while Table 1 lists a select sample of the satellite resources available today that are relevant to the study of tropical convection. To put these resources into perspective, it is useful to consider that for TOGA COARE, there were ~6000 radiosondes that augmented the 120-day IOP. While it is impossible to equate an in-situ sounding to a satellite estimate, it is still interesting to note that in a single day, AIRS provides about 100,000 temperature and moisture soundings and CloudSat provides about 90,000 cloud radar profiles in the tropics. Moreover, it is worth stressing that satellite data have made it possible to extrapolate many of the results of GATE, MONEX, and COARE regarding the mesoscale aspects of convection and the role of intermediate sized convection. In particular, TRMM's (*36*) ability to separate convective and stratiform precipitation, has illustrated the global distribution of the heating effects of mesoscale systems across the tropics and their likely influence on the larger-scale circulation (*37-39*) as well as the global distribution of shallow isolated convection (*40*).

Notwithstanding these new satellite resources, it should be emphasized that the (operational) geostationary satellites are the only ones that observe all the scales relevant to the organization of tropical convection. This includes both planetary scale synoptic views as well as resolution of the diurnal cycle. Chief among the products resulting from these satellites that is well suited to contribute to the problem of organized convection is the International Satellite Cloud Climatology Project (ISCCP), which includes global cloud characterization at 3-hour resolution extending back to 1983.

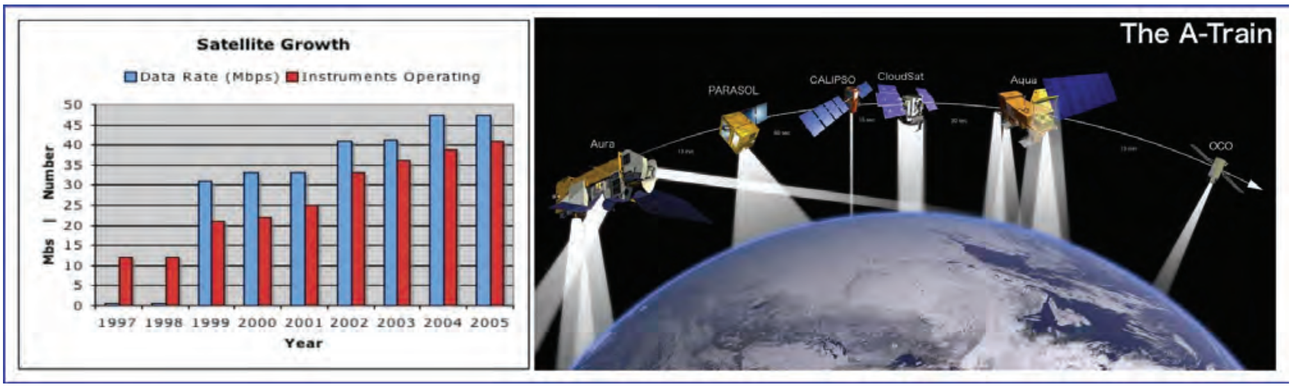

Figure 4. (left panel) Satellite growth rate of the EOS programme in terms of data rate (blue) and number of instruments operating (red).

Table 1. Select Sample of Satellite Products Relevant to Tropical Convection	
ATMOSPHERE	
2D Cloud Morphology	ISCCP, CLAUS, MODIS, AMSR-E, MISR, AIRS
3D Cloud Morphology	ISCCP, CloudSat, MISR, MLS, CALIPSO
Cloud Microphysics	CloudSat, CALIPSO, MISR, MLS, MODIS
Convection Characteristics	ISCCP, CLAUS, OLR, CloudSat, TRMM, AIRS, etc.
Radiative Energy Fluxes	CERES, MODIS, MISR, AIRS
Precipitation	TRMM, AMSR-E, SSM/I
Tropospheric Chemistry	TES, MOPITT, SAGE III, MLS
Aerosol Properties	MODIS, CALIPSO, MISR
2D Water Vapor	AMSR-E, AIRS
3D Atmospheric Temperature	AIRS/AMSU-A, MLS, TES, COSMIC/GPS
3D Atmospheric Water Vapor	AIRS/AMSU-A, MLS, COSMIC/GPS
OCEAN	
Surface Temperature	TMI, MODIS, AIRS, AMSR-E
Ocean Colour	MODIS
Surface Wind Fields	SeaWinds, AMSR-E
Ocean Surface Topography	Jason-1
LAND	
Surface Temperature	MODIS, AIRS, AMSR-E
Surface Wetness	AMSR-E

ii) Global Ocean Observing System

Rivalling the development of the satellite infrastructure is the manner and extent the ocean observing system in the tropics has developed since the early 1990's. Initially, spurred on by the international TOGA programme's focus on ENSO, and the WCRP WOCE programme, it has expanded to encompass a much broader range of objectives, including the Atlantic and more recently Indian Ocean variability – see Figure 5 for illustrations. Now referred to as the TAO/TRITON, the Pacific moored array now consists of approximately 70 buoys, and is co-sponsored by the US and Japanese governments. For the most part, each of these buoys provides subsurface thermal information and surface meteorology information – in some cases with radiation, and a few equatorial buoys provide current profiles. These data have contributed to a wide variety of research and operational forecast issues related to ocean and atmosphere variability in the Pacific. Based on the success of the TAO/TRITON array, France, Brazil and the US implemented the PIRATA array in the late 1990's with similar capabilities and objectives for the Atlantic. This array can provide valuable in-situ information relevant to the Atlantic ITCZ and the synoptic variability embedded in it, namely easterly waves and tropical storms/cyclones. The third basin observing system, the Indian Ocean Observing System, is largely just beginning implementation although a number of moored buoys and plans for a relatively complete array supported by a number of international partners has been developed (*41*). This array will be instrumental in better understanding airs-sea coupling in association with the Asian and Australian monsoons, the initiation and maintenance of the MJO, as well as a host of other relatively high frequency forms of ocean and atmosphere wave variability in the Indian Ocean. Finally, apart from these moored buoy systems has been the ever-growing drifter/float programmes. Starting its formal implementation phase in 1999, the ARGO programme, a WCRP CLIVAR and GODAE project, has managed to maintain about 2500 floats spread relatively uniformly over the global oceans. These floats provide temperature and salinity, and indirect velocity, profiles over the upper 2000m every 10 days. The objectives include initialization of ocean forecast models, data assimilation and studies of seasonal and longer climate variability. Complementary to the ARGO programme, is the global drifter programme that has developed over the last two decades and is maintained and supported by NOAA in conjunction with the VOS and a host of international partners. Presently there are about 1300 surface drifters deployed over the global oceans that report SST, in some cases with SLP, every 15 minutes. Such data are valuable in providing surface state information for weather forecast and climate prediction models, ground truth for satellite SST products, and estimates of ocean surface velocity (Figure 5).

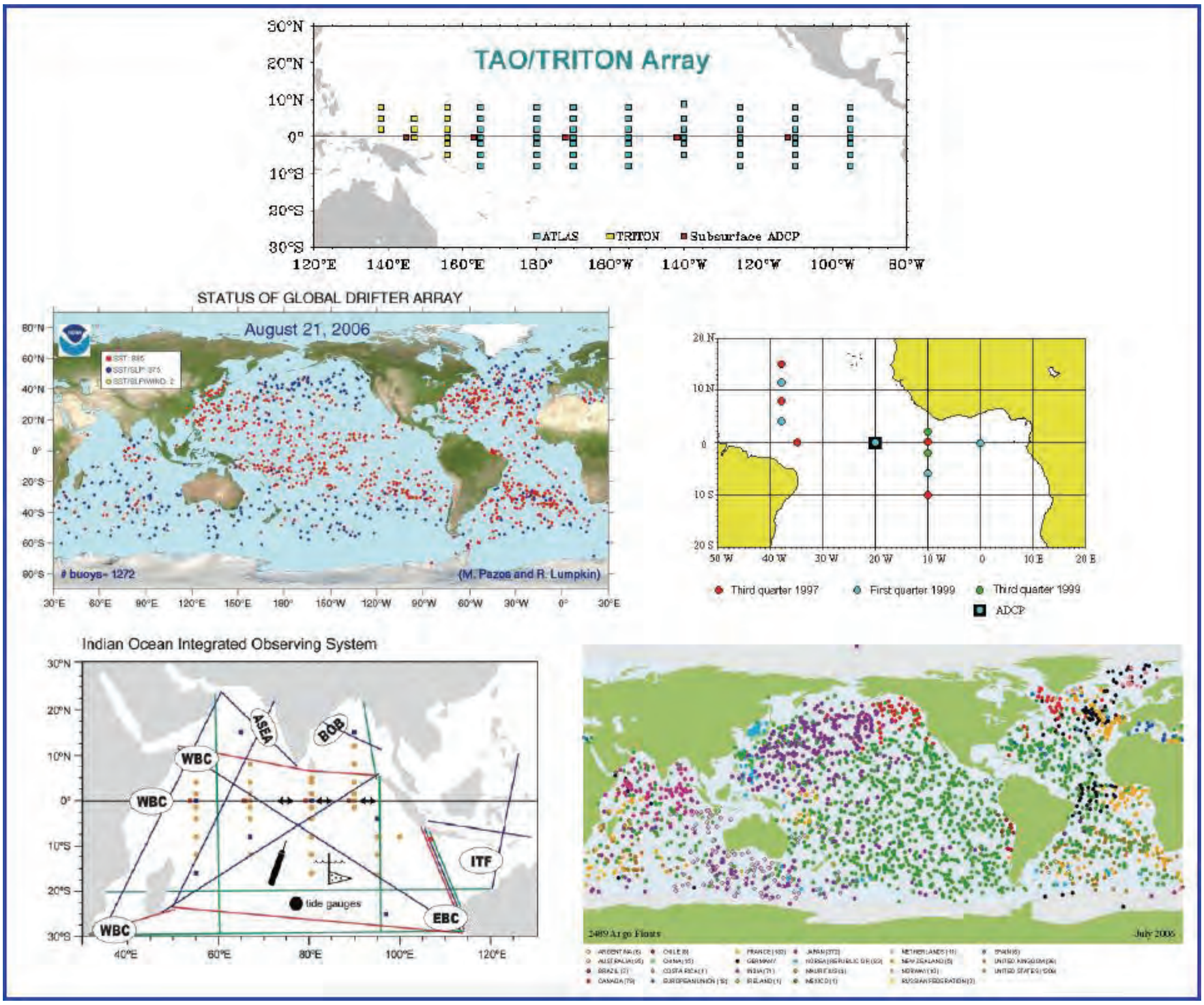

Figure 5. [Clockwise] (upper) Schematic of TAO/TRITON moored buoy array. (middle right) Schematic of PIRATA moored buoy array. (lower right) Snapshot of the locations and sponsor country (colour) of the (~2500) Argo float deployment as of July 2006. (lower left) Present and planned structure of the Indian Ocean Integrated Observing System. (middle left) Snapshot of the locations and capabilities (red: SST, blue: SST/SLP) of the (~1300) surface drifters as of August 2006.

iii) Other In-situ Programmes

The Coordinated Enhanced Observing Period (CEOP), established in 2001 by WCRP's Global Energy and Water Cycle Experiment (GEWEX), was motivated by international efforts focused on measuring, understanding and modelling of the water and energy cycles within the climate system. The CEOP in-situ observation network presently consists of 35 globally distributed Reference Sites (see Figure 6) that, *in most cases,* provide enhanced observations of sub-surface (soil profiles), surface (standard meteorological and radiation), near surface (flux tower), and atmospheric profile (rawinsonde and profiler) quantities, as well as ancillary data sets (radar, special observations). While the exact sites and their measurement capabilities continue to undergo scrutiny and change, the CEOP Reference Sites are expected to be operating at least through 2010.

The U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Programme has established a number of elaborate surface observation (i.e. ARM) sites with the objective of improving the treatment of cloud-radiation interactions in global climate models (*42, 43*). Toward that end, surface measurement sites have been deployed in the central continental U.S., the north slope of Alaska, and the tropical western Pacific (TWP). These sites include both active and passive sensors designed to continuously measure and/or infer the column atmospheric and cloud properties, as well as the surface boundary conditions. More specifically, they include upward and downward, diffuse and direct, shortwave and longwave radiation, radiosondes and surface meteorology, upward looking microwave and cloud radar/lidar, total sky imager, etc. as well as collocated values from ECMWF analyses and from a fairly broad array of operational (e.g., GOES, AVHRR, TOMS) and in some cases research (e.g. OMI) satellites. The ARM site suite of observations provide knowledge of cloud properties on both macro- and micro-physical scales important to revealing their interactions within both the large and small-scale environments. The three TWP facilities (illustrated in Figure 6) began collecting data in August 1996 for Manus, Papua New Guinea, in November of 1998 for the island nation of Nauru, and in April 2002 for Darwin, Australia; with all expecting to be operating through the period of the proposed coordinated activity in 2008.

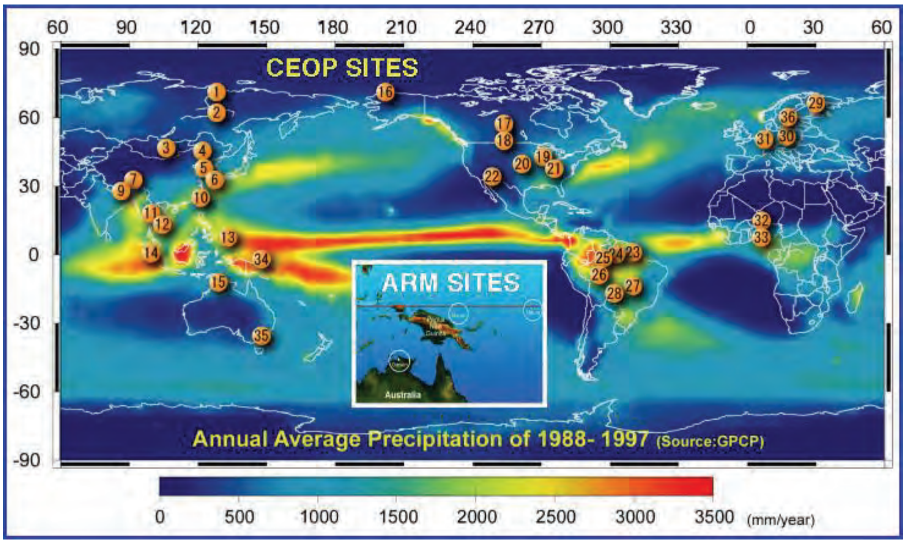

Figure 6. (large map) GEWEX CEOP Reference Sites. More specifics regarding these sites can be found at: www.ceop.net. (small inlay map) ARM Intensive Observation Sites – Darwin, Nauru Island and Manus Island. More specifics regarding these sites can be found at www.arm.gov.

b) Modelling Infrastructure

i) Computing Capabilities

Since the time of FGGE and COARE, computational resources have increased by orders of magnitude. Figure 7 shows that since the time of COARE along, we have witnessed at least a 10^4 increase in computer performance. The advent of this increase provides the means by which CSRMs on a regional-to-global scale become tractable considerations, and in turn offer the ability to more realistically represent the wide range of time and space scales in our models of tropical convection. Over the next 5 years, the architectural trends for supercomputers point toward increasing parallelism and stagnating clock speeds that are limited mainly by power and heat-dissipation limitations in microprocessor design. Although clock speeds are likely not to increase substantially in coming years, vendors are seeking to realize future performance increases by placing more and more processors cores on a single chip. Thus, the exponential performance trends illustrated in Figure 7 will become, over time, an exponential trend in levels of parallelism. Fortunately, CSRMs will require 10's of millions of horizontal grid points, leaving exploitable parallelism for our community to realize continued improvements in modelling capabilities.

ii) Modelling Approaches

A notable aspect of the THORPEX/WCRP workshop was the number of relatively new modelling approaches and the capacity afforded by the ever-increasing computation capabilities (a factor of about a million over 30 years ago). These approaches offer new opportunities for quantifying convective organization involving both up- and down-scale interaction among meso-synoptic-planetary scales. In particular, the past decade has witnessed a revolutionary application of cloud-system resolving models (CRMs; *grid-spacing a few kilometres*) in the cross-scale and large-scale context. This is far from the inaugural use of CRMs as cloud process models in the 1970s. A key aspect of CRMs is that they couple small-scale processes that must be parameterized (cloud-microphysics, turbulence, surface exchange) to the resolved scales of motion. This explicit approach side-steps many unsolved physical problems that are inadequately represented in contemporary convective parameterizations, such as transport, closure and triggering. Because the physical resolution of a numerical model is 7-10 times its grid-spacing, the mesoscale organization of convection is approximated with considerable fidelity whereas the explicit representation of cumulus convection in CRMs is still questionable at these resolutions. Nevertheless, CRMs represent the life-cycle of convection and convective organization with far better accuracy than contemporary convective parameterizations.

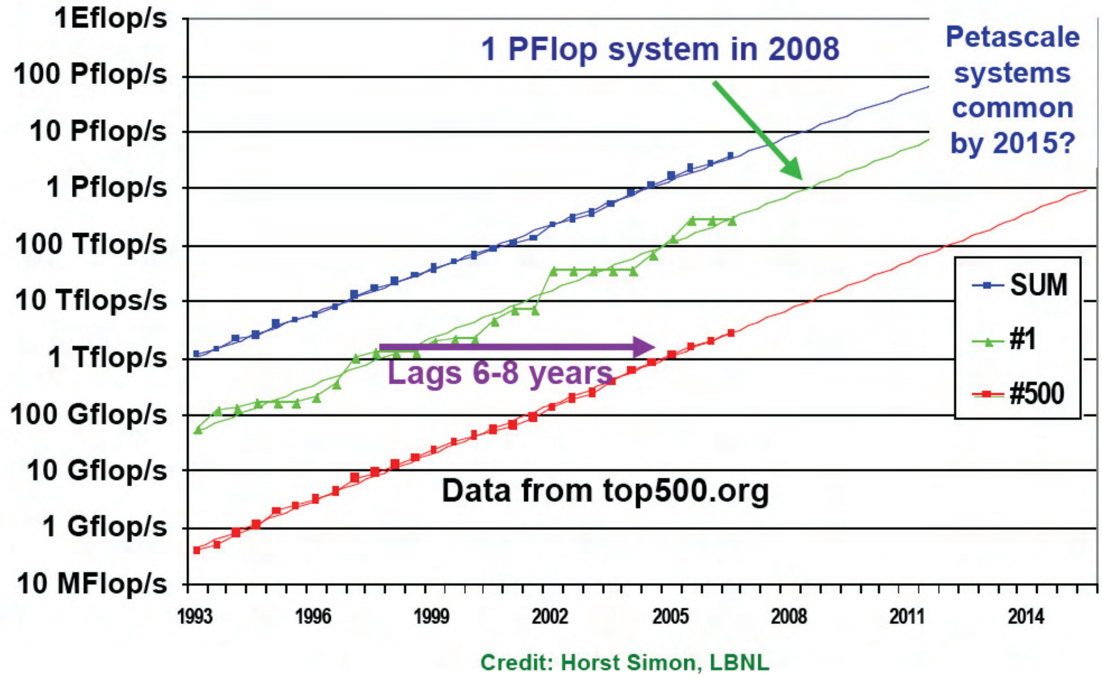

Figure 7. This computer performance data, collected from the world's 500 fastest supercomputers (top500.org), shows the steady, exponential rate of progress system performance. The axes of the plot show performance in terms of the FLOPS rate sustained in the High Performance Linpack (HPL) benchmark as a function of time. The HPL benchmark usually achieves close to a system's theoretical peak speed. Data for both the fastest (#1), five hundredth fastest (#500), and aggregate speed of all top 500 systems (SUM) are shown. The plot illustrates: i) if past trends continue, a 1 PetaFLOP system will be benchmarked in 2008; and ii) PetaFLOPS systems will be common by 2015. Such systems are expected to provide significant modelling capabilities; for example, enabling use of cloud-system resolving models on up to multi-decadal time scales.

The potential of CRMs in the weather-climate context was quickly recognized by WCRPs GEWEX in the form of the GEWEX Cloud System Study (GCSS) inaugurated in the early 1990s (*6, 7, 44*). Recalling that mesoscale convective organization is a key uncertainty (viz. above remarks concerning GATE and TOGA COARE) a year of coordinated observations and modelling, as we propose, gives prospect for quantifying the role of the meso-to-large scale organization of tropical convection both regionally and globally. Significant progress is anticipated since simulated organized convection will be validated by the integrated satellite and field-campaign datasets. For the first time, convective organization across scales is being comprehensively addressed.

On regional scales, CRMs represent moist processes and scale interactions up to continental and ocean-basin scales and are being used to develop new mesoscale parameterizations (*45*). In nested regional climate models mesoscale organization is represented by progressively finer-resolution domains interactively embedded (nested) in global models. This enables organized tropical convection to be quantified at up to interannual temporal scales. Hence, unprecedented progress in quantifying the interaction between organized convection and the large-scale environment is anticipated. In respect to the over-arching global perspective of THORPEX, the extension of CRMs to the global domain is a major step forward (*46*). Along with the superparameterization approach, wherein two (or three)-dimensional CRMs are embedded in general circulation models (*47, 48*), this enables the global role of the tropics and its two-way interaction with the higher latitudes to be quantified.

Along with the above numerical approaches and the applications of observational/validation data, it is vital that theoretical-dynamical modelling of organized convection be performed in parallel. Thereby, the inherent complexity of organized convection and its nonlinear scale-interaction can be reduced to basic principles (4). This is a practical as well as a theoretical requirement because, for the foreseeable future, mesoscale organization will have to be parameterized in long climate model integrations. Figure 8 gives a glimpse of the potential of global climate models of the future that will be characterized by a grid spacing of about 10km. At this spatial resolution, the simulated global atmosphere becomes 'dynamically alive' not only in terms of the large-scale organization of tropical convection but also in terms of high-impact events such as hurricanes. Moreover, the tropics are connected to the higher latitudes by convective disturbances in ways not evident at coarse resolution. Planetary waves and the incursion of mid-latitude frontal activity into the deep tropics also become clearly evident.

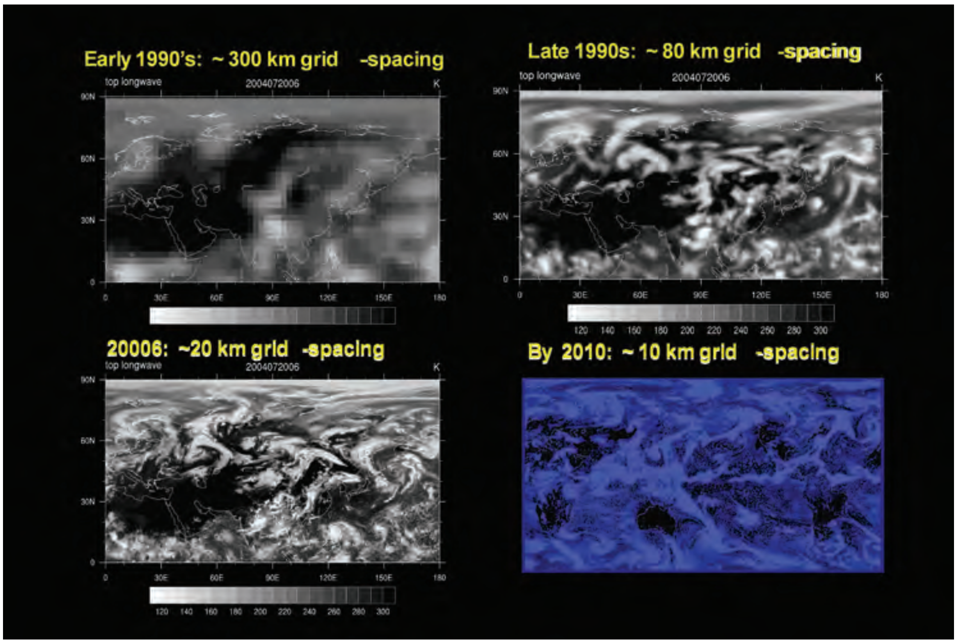

Figure 8. a) Global NWP model the early 1990s and contemporary climate models, grid-spacing about 300 km; b) Global NWP in the late 1990s and experimental climate models, grid spacing about 80 km; c) Modern global NWP, grid-spacing about 25 km, and d) Global NWP model for weather in the 2010 time frame, future climate models, grid spacing approximately 10km. Courtesy T. Enemoto and the Earth Simulator.

An additional recent development is the recognition of the value of complementing to the diagnosis of model shortcoming of climate and seasonal prediction models in their conventional simulation framework by using of a forecast framework as is traditional in NWP. It has long been recognized that systematic model errors emerge early in an NWP system (within a few days). This can be exploited by exposing climate and seasonal prediction models to the test of essentially running weather forecasts with them. Efforts in this area in the past were hampered by the lack of availability of data to initialize the models. The recent reanalysis efforts together with some targeted research into model initialization using those data have overcome many of the existing stumbling blocks. The UK MetOffice has operated a unified (weather and forecasting) model since the 1990's. A highly relevant recent effort is the CAPT[3] (*49*). Running climate models in NWP initial-value mode identifies errors responsible for the long-term climate drift of the model associated with fast processes such as atmospheric convection. Clearly, this approach is resource efficient since model integrations are relatively short and can be targeted to meteorological phenomena and validation data sets. Figure 9 illustrates the connection between forecast error and errors in the long-term model climate for a study using the NCAR CAM3.0 model (*50*).

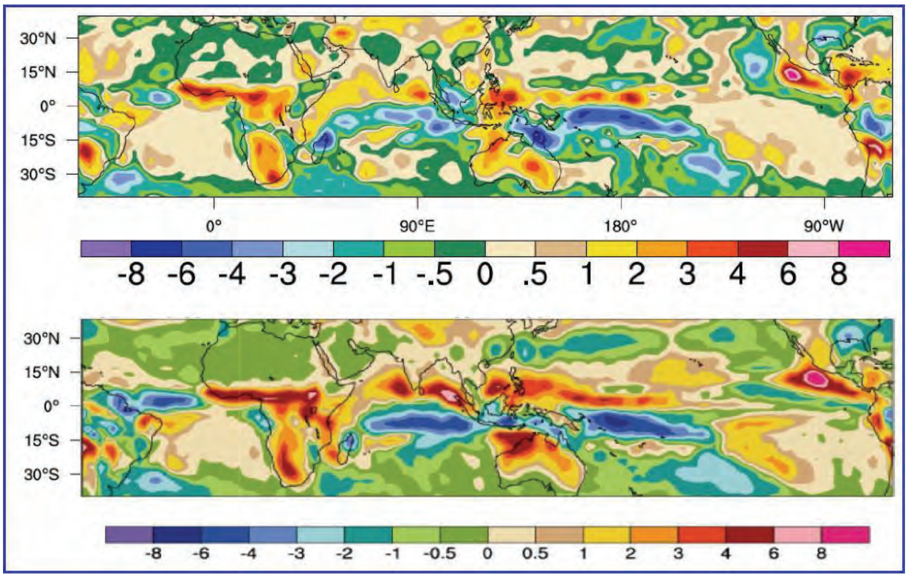

Figure 9. (top) Mean differences between observed precipitation and 3-day forecast values using the NCAR CAM3.0 AGCM for the 1992-3 DJF period. (bottom) Same, except for the mean DJF from a 10-year simulation using NCAR CAM3.0 with observed SSTs.

IV. PROPOSED ACTIVITY

The discussions in the sections above highlight: 1) the pervasive shortcomings in our understanding and model representations of tropical convection which have ramifications on environmental predictions on a wide range of time scales extending well into the extra-tropics; 2) the long heritage associated with the tropical convection problem and some key past efforts that have helped to make modest but tangible gains in addressing this problem; 3) the incredible growth in the last two decades of our observational infrastructure of the tropical ocean-atmosphere-land system, mostly notably in terms of tropical convection, clouds, circulation, air-sea interaction, microphysics, etc – *in short, the tropical environment has never been so well observed*; 4) significant advances in computational capabilities provide for altogether new opportunities in modelling finer scale and more comprehensive aspects of convection and clouds.

To take advantage of these new in-situ and satellite observational resources, computational capabilities and high-resolution/alternative modelling frameworks, as well as exploit the strengths of past activities addressing the tropical convection problem, WCRP and WWRP/THORPEX propose a Year of Coordinated Observations, Modelling and Forecasting of Tropical Convection [a.k.a Year of Tropical Convection (YOTC)]. This activity is meant to blend the strengths of the global, focus-year approach of FGGE with the Intensive Observation Period approach of GATE/COARE, where in this case, the "intensive observations" come from the vast new resources discussed above. The time frame for this focus year is during 2008-9, with the specific period being determined through the development of the implementation plan. This target provides enough time

[3] Climate Change Prediction Programme – ARM Parameterization Testbed carried out by the Programme for Climate Model Diagnostics and Intercomparison (PCMDI) at the U.S. Department of Energy (DOE) Livermore National Laboratory.

to coordinate the needed resources and also takes advantage of the current zenith of available and pertinent satellite data (e.g., TRMM is past its scheduled lifetime, CloudSat was designed as a 2 year mission). It is worth stressing that this proposed activity is largely based on coordinating existing resources and focusing the community's talents and interest on the remaining challenges of organized tropical convection. In line with this, and relevant to planning and funding considerations, is the fact that many of the data sets needed for this activity (e.g., analyses, forecasts and satellite products) can be acquired in retrospective fashion and thus the planning and implementation of this *virtual* field programme is very different from a traditional one. The details provided below describe the overarching goals of the proposed activity, the key science questions, initial thoughts on targeted phenomena for the focus year, and a preliminary discussion regarding implementation.

a) Overarching Goals

Significant tangible benefits to society are afforded from improved weather and climate predictions and realistic representations of tropical convection in our forecast models are a linchpin to exploiting the inherent predictability within many components of our weather and climate system. Through better understanding, improved data assimilation techniques/resources, and modelling capabilities associated with tropical convection, the goal of YOTC is to achieve significant gains in forecast skill (e.g., Figure 3; as seen early 1980s, late 1990s) by ~2012 in the following areas:

1. Short and medium-range tropical weather forecasts, particularly disturbed conditions associated with organized convection.
2. Extended-range/subseasonal (i.e. 1-3 week) forecasts of the MJO.
3. Medium-to-extended range extra-tropical forecast derived from improved representation of tropical weather/climate and tropical-extratropical interactions (e.g., *middle-left* Figure 2).

b) Fundamental Science Questions

Making progress on the following three science questions lie at the heart of meeting the above programme goals:

1. What are the global and regional characteristics of tropical convection over both land and ocean, including variability on diurnal to seasonal time scales?
2. What are the characteristics and relative roles of processes occurring (1) within the large-scale circulation, (2) on the mesoscale, and (3) internally on the storm scale that influence the development, organization, and maintenance of tropical convection?
3. What physical processes are behind the transitions from stratocumulus to cumulus convection, and between shallow, congestus and deep cumulus convection that are exhibited in features such as the ITCZ/Hadley circulation and some large-scale tropical wave activity?
4. Under what circumstances and via what mechanisms is water vapour, energy, and momentum transferred across scales ranging from the mesoscale to the large (or planetary) scale?
5. How does organized tropical convection interact with the extra-tropical circulation?

c) Targeted Phenomena

In any field experiment, plans are made to increase the probability of observing the phenomena/process of interest. In this case, the interest is in observing, modelling and predicting any recurring processes and phenomena that play an important role in our weather and climate system in terms of their influence on organized convection. Given that the scale of the activity encompasses the global tropics, there is a wealth of possibilities to consider for targeted research. However, to facilitate planning and keep the scope manageable, it is necessary at this stage to develop rationale and strategies for a select number of phenomena that are expected to be manifest during the given year, yield valuable insight into the tropical convection problem, and for which advances in our understanding and modelling capabilities will yield tangible improvements in forecast skill. The list below provides some *preliminary* thoughts on what these targeted phenomena might be and an associated set of science questions for each that could be addressed via the YOTC activity.

i) Madden-Julian Oscillation/Convectively-Coupled Waves (CCEW)

The most prominent form of intraseasonal atmospheric variability in the tropics. Advances in our modelling capabilities in the MJO are expected to lead to significant untapped predictability in tropical weather forecasts, monsoon onsets and breaks, extra-tropical weather, and provide a bridge between weather and climate predictions. Underlying the MJO are CCEW; considered to be important building blocks of tropical convective variability and its organization on a wider range of time scales. It is essential that such fundamental modes of variability be properly represented in our weather and climate models. Specific waves of note would include Kelvin, lowest-order Rossby, and mixed Rossby-gravity waves. Note that in the discussions below MJO is meant to include the boreal winter and summer mode, where the latter is often referred to as the intraseasonal oscillation (ISO) or monsoon ISO (MISO).

1. What is the current level of prediction skill attained for the MJO by operational numerical prediction models? Does this skill translate to extended-range (i.e., 1-3 week) predictability of tropical rainfall?
2. Similarly, are the operational models able to successfully assimilate and predict the higher-frequency convectively-coupled equatorial waves, and what distinguishes cases of success versus failure?
3. Do systematic relationships exist between the MJO's large-scale characteristics (e.g., propagation speed, growth/decay) and its fine-scale/multi-scale convective structure (e.g., westward versus eastward-moving fine-scale components, shallow versus deep convective elements), and to what extent do models capture these relationships? Are these relationships indicative of an upscale cascade, or downscale conditioning?
4. Can we use the new satellite resources (e.g., CloudSat, CALIPSO, GPS), in conjunction with in-situ observations (e.g., ARM, CEOP) to characterize the space-time variability of the planetary boundary layer in the context of the MJO and CCEW, and do numerical weather and climate models properly represent this variability?
5. Can we use the new satellite resources (e.g. TRMM), in conjunction with in-situ observations (e.g. ARM), to better characterize the 4-dimensional structure of latent heating in the context of the MJO and CCEW, and do numerical weather and climate models properly represent this variability?

ii) Easterly Waves & Tropical Cyclones

Easterly waves represent an important organizing mode of variability that is crucial for accurately forecasting high impact weather events as well as properly simulating an important land-atmosphere-ocean interaction process and its impact on mean state features, such as the ITCZ. In particular, easterly waves are known to be important triggering mechanisms for tropical depressions, storms and cyclones. Tropical cyclones continue to be one of the most influential/catastrophic extreme events and our full predictive capabilities have yet to be exploited.

1. What improvement in prediction skill of tropical cyclone motion and genesis can be achieved by exploitation of advanced ensemble prediction systems that are becoming available in the timeframe of YOTC?
2. What are the dynamical and thermodynamic processes by which African easterly waves (AEWs), CCEWs, and the MJO contribute to the favourable or unfavourable conditions for tropical cyclone formation?
3. How are these processes dependent on the background state, including aerosol loading?

4. How can new satellite observations of convection and related processes be incorporated into numerical models to allow for more time- and location-specific predictions of tropical cyclone formation and evolution?

iii) Diurnal Cycle

Our shortcomings in representing arguably the most basic and strongest forced mode of variability on the planet demands attention. Moreover, there are suggestions in both observation and model studies indicating that processes occurring at the diurnal scale can rectify onto longer time scales (e.g. monsoon precipitation characteristics, maritime continent and MJO variability). The fact that this process involves a strongly forced signal, with distinguishing features between land and sea, should be viewed as a fortuitous opportunity to make gains in the convection problem in a more controlled environment that may in fact have positive consequences for other phenomena and time scales.

1. Why and how does the diurnal phasing of convection over the open ocean vary regionally?
2. What are the effects of land-sea contrasts, coastal geometries, mountainous terrain and the open-ocean on the diurnal cycle? For example, how do convex and concave coastal geometries and major mountain ranges affect the diurnal variation of convection? Are there unifying principles underlying the effects from these physical features on the diurnal cycle?
3. How does the diurnal cycle of convection vary in relation to the scale of the diurnally triggered convection, i.e. how does a diurnal regime of isolated, short-lived convective elements differ from a diurnal regime which produces mesoscale convective systems? How is the diurnal cycle of convection changed when diurnal triggering results in long-lived mesoscale convective systems rather than isolated convection? Does the diurnal heating cycle affect the demise of mesoscale convective systems as well as trigger new convection?
4. How do cold pools from convection generated diurnally by heating of high terrain lead to subsequent convection at downslope locations? What role do gravity waves play in the diurnal generation of mesoscale convective systems off the coasts of large land masses (e.g., India, Peru, Borneo). Where and when do nocturnal low-level jets lead to long-lived mesoscale convective systems?
5. What physical processes or relationships are missing in global models that limit their fidelity in capturing the main features of the diurnal cycle (e.g. phase and amplitude)? What aspects of achieving a realistic representation of the diurnal cycle in global models are strongly dependent on sub-grid scale processes, variability and/or boundary conditions (e.g. topography)?

iv) Tropical/Extra-Tropical Interactions

It is well known that convective variability in the tropics influences mid-latitude weather and climate. However, our predictions of the latter suffer due to poorly understood and simulated tropical convection. Moreover, there are still significant questions regarding the manner that the extra-tropics influences convection in the Tropics.

1. What aspects of tropical convection are most important to the excitation of extra-tropical Rossby wave trains (e.g., vertical profile of heating, time and space scales, convective momentum transport)? How well do global models simulate and predict the excitation of Rossby wave trains by Tropical convection? Are shortcomings related strictly to the representation of convection or are there other factors associated with the circulation (e.g., mean state, gravity waves) that are also important and not properly represented?
2. By what mechanisms does tropical convection play a role in transporting moisture into the mid-latitudes? Do global models simulate these processes? What time and space scales of tropical convection account for the dominant contributions of this transport?

3. To what extent can extra-tropical forecast skill be improved via better simulations of CCEWs and the MJO in global forecast models? Which of these tropical phenomena have the most impact and at what forecast lead-times? On what aspects of the extra-tropical circulation, and in what regions, is the impact from tropical convection greatest?
4. By what manner do Rossby waves propagating into the Tropics impact tropical convection? For example, do these waves trigger and/or help to maintain the MJO or other CCEWs?

v) Monsoons

These are complex multi-scale processes and within the proposed activity could be considered as the ultimate challenge or integrating theme as their variability is strongly influenced by the diurnal cycle, CCEWs, the MJO, and land-atmosphere-ocean interaction. Moreover, there may be no other phenomena through which better predictions would translate into greater societal benefit.

1. Are there any fundamental differences between boreal summer and boreal winter MJO that are important to their impacts on monsoon variability? Are the multi-scale structures different and how might this effect the high-frequency variability of the monsoons?
2. How do the errors in simulating the MJO impact the simulation of interannual monsoon variability? How do low-frequency components of monsoon climate modulate the MJO and its statistical properties? What is the influence of MJO on tropical storm and cyclone variability associated with the monsoons?
3. To what extent are active and break cycles of the monsoon dictated by the MJO? In cases where the MJO is not playing a dominant role, what other processes determine transitions to active and break phases? In the monsoon regions, what roles doe atmosphere-ocean and atmosphere-land interaction play in sustaining, modelling, and predicting MJO and other synoptic and subseasonal variability that influences the monsoon?
4. What are the impacts of absorbing aerosols (dust and black carbon) and scattering aerosols (sulphate) on the monsoon water cycle? What are the microphysics effects on clouds and rainfall from natural sources and mixing with anthropogenic aerosols? Through their impacts on clouds and convection, do aerosols weaken or strengthen Asian monsoon?

d) Coordination and implementation

The advantage of the YOTC framework is that it can represent a standalone activity or a ‘proof of concept’ that can be enhanced, extended for more years or applied to other target years in the future. It is proposed that this initial phase be coordinated as follows:

- The research agenda will be coordinated via the Scientific Planning Group (SPG), the chief interfacing body between the activity’s programmatic sponsors (e.g., WCRP, WWRP/THORPEX) and the research and forecasting communities. The SPG would also play an important role in motivating the programme and reporting its progress to principal funding agents. The 2007 JSC meetings of WCRP and WWRP recommended the SPG (see Section VII) refine and complete the Preliminary Science Plan and draft an Implementation Plan (IP).
- Subsequent to this, an international workshop (scientists, forecasters, funding agencies) would be conducted to solicit feedback on the implementation plan. From this workshop, a set of more formal Working Groups would be established that would lead the focused research efforts on the agreed upon targeted processes/phenomena and associated science questions (e.g., Section IVb).
- At the mid-point of the focus year, the Working Groups would meet to refine the target phenomena science questions and associated implementation details based on the

phenomena realized to date and the status of the logistical components of the programme (e.g., data resources and modelling developments).

- Once the focus year is over, a second workshop would be held to foster community involvement and educate them on the data and modelling resources derived from the activity as well as the associated plans/objectives developed by the Working Groups.
- A "final" international workshop would be held to present the programme's findings with a key goal to articulate follow-on efforts, including other focus periods, specific experimentation, and/or field studies.

A paramount endeavour of this inaugural activity is the construction of a global database consisting of satellite, in-situ and simulation/prediction model data sets relevant to the study of tropical convection and its impacts on the extra-tropics. The satellite data are envisioned to be those highlighted in Section IIIa. The in-situ and field-campaign data are highlighted in part in Section IIIa. The field-campaign data will depend strongly on the specific period chosen and thus will be described in more detail in the IP. The model data sets are primarily envisioned to be: i) high-resolution models analysis from NWP centres (e.g., ECMWF, NCEP); ii) research analyses, simulations and forecast outputs (e.g., NCAR channel model, climate models in forecast mode, nested regional climate models, and CRMs), with possible contributions to some activities from iii) the THORPEX TIGGE data set.

The result will be a comprehensive database that has practical-minded archive and dissemination capabilities, and likely some level of reformatting to facilitate its use by both the weather and climate communities as well as across the operational and research (e.g., laboratory and graduate school) communities. In regards to carrying out this effort, it is worth drawing the following analogy and distinction. In a typical field-oriented intensive observation period (IOP), resources are marshalled to deploy in the field, measure phenomena and return a coordinated and comprehensive data set for use in process studies. In this case, the measurement and operational modelling infrastructure are already in place through past and ongoing investments. Thus rather than a need for an "observation" period (IOP), the implementation focus for YOTC is to carry out an intensive "acquisition and integration" phase (IAIP), from which the process-level studies of a scope needed to make tangible gains in our ability to simulate and predict tropical convection.

The global and comprehensive database discussed above, along with the efforts to address the science questions posed in Section IV, will put YOTC in a position to make major contributions to WWRP efforts on Monsoon Meteorology through the WWRP Working Group on Tropical Meteorology and to WCRP's International Monsoon Study (IMS) which is a 5-year (2007-2012) strategy of WCRP monsoon research across all monsoon regions, including studies of the multi-scale interactions between the tropics and monsoon regions. In addition, the data sets and targeted science focus of YOTC will uniquely contribute to the scientific goals of the THORPEX Pacific-Asian Regional Campaign (T-PARC) and the Tropical Cyclone Structure (TCS08) experiment. These campaigns address issues associated with tropical cyclones in Northwestern Pacific Basin that include develop a i) better understanding of the interaction between convective processes and tropical cyclone genesis, evolution, structure and intensity, ii) a comprehensive look at the effects of adaptive measurements on tropical cyclone prediction through satellite, Doppler wind lidar and novel in-situ techniques (driftsonde and multiple aircraft) measurements and iii) the unique role of tropical cyclones in this region to define many characteristics of the middle latitude circulation in the Northern Hemisphere and iv) the dynamics of the extratropical transition of tropical cyclones.

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VI. LIST OF ACRONYMS

ARM	Atmospheric Radiationi Measurement
CLIVAR	WCRP's Climate Variability and Predictability Programme
CEOP	Coordinated Energy and Water Cycle Observations Project
COARE	Coupled Ocean Atmosphere Response Experiment
CMA	Canadian Meteorological Agency
DMSP	Defense Meteorological Satellite Programme
GCM	General Circulation Model
ECMWF	European Centre for Medium-Range Weather Forecasting
FGGE	First GARP Global Experiment
GARP	Global Atmospheric Research Programme
GATE	GARP Atlantic Tropical Experiment
GEWEX	Global Energy and Water Cycle Experiment
GODAE	Global Ocean Data Assimilation Experiment
ICTP	International Center for Theoretical Physics
IOP	Intensive Observation Period
ITCZ	Intertropical Convergence Zone
MJO	Madden Julian Oscillation
NCAR	National Center for Atmospheric Research
PIRATA	Pilot Research Moored Array in the Tropical Atlantic.
TAO	Tropical Atmosphere Ocean
TIGGE	THORPEX Interactive Grand Global Ensemble
TOGA	Tropical Ocean Global Atmosphere
WCRP	World Climate Research Programme
WIS	WMO Information System
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
GCSS	GEWEX Cloud System Study

VII. SCIENCE PLANNING GROUP AND OTHER CONTRIBUTIONS

Science Planning Group

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VIII. SCIENCE PLANNING MEETING

The draft science plan was discussed and endorsed at the Science Planning Meeting held in Arlington, VA on November 13-14 2007. This meeting was sponsored by WWRP/THORPEX and WCRP with logistical support from US CLIVAR.

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Agenda

Tuesday, November 13, 2007: Introduction, Science Plan & Resources

[Day of Presentations with Discussion]

08:30-08:45 **Opening Remarks**

(5) Welcome, Logistics - Cathy Stephens

(5) Welcome and Programmatic Background - Jim Caughey

(5) Welcome, Scientific Background and Agenda Overview - Mitch Moncrieff

08:45-10:30 **Science Plan/Questions**

(20) Overview Presentation of YOTC - Duane Waliser

(10) Feedback from May'07 US National Academy of Sciences - Climate Research Committee Meeting – Duane Waliser and Rick Rosen

(15 each) Targeted Phenomena & Associated Science Questions

- Organized convection/MJO/CCEW - Matt Wheeler
- Easterly waves/tropical cyclones - Russ Elsberry
- Diurnal cycle - Dick Johnson
- Tropical/Extratropical Interaction - Mel Shapiro/Istvan Szunyogh
- Asian-Australian Monsoon - Bin Wang

10:30-10:45 **Break**

10:45-11:30 **Modelling Challenges and Opportunities**

(15) Convective Parameterization - Christian Jakob

(15 each) Bridging Parameterization and Explicit Approaches:

UK *Cascade* - Steve Woolnough

NCAR/University - Mitch Moncrieff

11:30-12:30 **Resources**

(15) TIGGE – Zoltan Toth

(15 each) NWP Centres:

NCEP Analyses/predictions - Zoltan Toth

ECMWF/T799 global dataset and predictions - Martin Miller

(15) Satellite Products and integration

Global Datasets - Bill Rossow

12:30 -13:30 **Lunch**

13:30-14:45 **Resources – continued**

(15) Satellite Data Contributions from NCDC/NOAA – Lei Shi

(10) New/Prototype Tropical Cyclone Satellite Data Set - Duane Waliser

(20) Planned/Overlapping Field Programmes – Dick Johnson

(15) AMMA - Chris Thorncroft

(15) Summer T-PARC – Jim Caughey/Dave Parsons

(15) Winter T-PARC - Zoltan Toth

14:45-15.00 **Break**

15:00-16:45 **Programmatic input**

(10) The YOTC / CCSP Relationship - Randy Dole

(10) GEWEX – Rick Lawford

(10) Tropical Meteorology Research Programme – Russ Ellsberry

(10) WCRP Monsoon Panel and Activities – Bin Wang

(10) SPARC - Norm McFarlane

(10) CLIVAR – David Legler

(10 each) US Funding Perspectives

NSF - Jay Fein

NOAA - Rick Rosen

NASA – TBD

(15) International Funding Perspectives and Open Discussion

16:45-17:30 Open Discussion

Dinner/evening informal discussions as needed

Wednesday, November 14, 2007: Implementation Plan

[Day of Moderated Discussion]

08:30-09:30 **Discuss Refinements to Science Plan/Questions** (Mitch Moncrieff – moderator)

9:30-10:45 **Core Modelling Activities, Contributions and Data Sets** (Martin Miller – moderator)

- NOAA/NWS/NCEP prediction (tropics/ N. American weather/climate interactions)
- ECMWF T799 global data set
- TIGGE and TIGGE Enhancements
- Research Consortia (e.g., Cascade, NCAR, CMMAP, FRCGC)

10:45-11:00 **Break**

11:00 -12:15 **Specifics on Integrated Satellite Data Sets** (Bill Rossow – moderator)

- Integrated multi-sensor satellite data sets
- Consolidation questions (e.g. common formats, gridding, Level 2 and/or 3)
- Archiving and Dissemination Needs

12:15 -13.30 **Lunch**

13:30 -15:00 **Discussion of the YOTC Framework and Activities**

Model datasets and research aspects (Mitch Moncrieff – moderator)

ECMWF T799 global dataset; NOAA/NWS/NCEP prediction including winter T-PARC; Parameterization development; involvement of Cascade, NCAR, CMMAP, FRCGC; involvement of research institutions in the deep tropics.

Observations (Duane Waliser – moderator)

Choice of the “The Year” and targeted phenomena; field-campaign and satellite data integration; working groups and focused workshops; international conference; prospective follow-on activities.

15:00 -15:30 **Overall Data Management Issues** (Fred Branski – WIS Discussion & moderator)

15:30–15.45 **Break**

15.45-16.35 **Pathway for Funding and Implementation** (TBD – moderator)

16:35-17:30 **Wrap up** (Duane Waliser)

- Actions, assignments, timelines for refining Science Plan
- Actions, assignments for completing the Implementation Plan

17:30 **Adjourn**