

Year of Tropical Convection (YOTC)

A Joint WCRP–WWRP/THORPEX International Initiative¹

The YOTC Science Planning Group²

ABSTRACT

The realistic representation of tropical convection in global models is a long-standing, grand challenge for both numerical weather prediction and climate projection. Incomplete knowledge and practical issues in this area disadvantage the modeling and prediction of prominent phenomena of the tropical atmosphere across a wide range of scales. Notable in this regard are the InterTropical Convergence Zone (ITCZ), El Nino-Southern Oscillation (ENSO), Tropical Biennial Oscillation (TBO), monsoons and their active/break periods, the Madden-Julian Oscillation (MJO), subtropical stratus, upper-ocean properties, easterly waves, and tropical cyclones. The diurnal cycle and cloud-microphysical processes are involved at a basic level. Furthermore, as a result of various convection-wave interactions, tropical convection has far-reaching effects on stratospheric-tropospheric exchange, the large-scale circulation of the upper-atmosphere, and the extratropics.

To address the above challenge, WCRP and WWRP/THORPEX have initiated a year of coordinated observing, modeling, and forecasting with a focus on organized tropical convection, its prediction, and predictability (Year of Tropical Convection, YOTC). The intent is to exploit the vast amounts of existing and emerging observations, the expanding computational resources and the development of new, high-resolution modeling frameworks. This focused activity and its ultimate success, will benefit from the coordination of a wide range of ongoing and planned international programmatic activities and collaboration among the operational prediction, research laboratory and academic communities. The timing, focus-year approach, and integrated framework of YOTC will leverage the most benefit from recent major investments in Earth-science infrastructure. Another motivation is to inspire a new generation of scientists to tackle key challenges facing Earth-system science.

In some respects, YOTC is a modern equivalent of the tropical components of the First GARP Global Experiment (FGGE). Global databases of satellite data, in-situ data, and high-resolution model analysis and forecasts will be constructed. Together with accompanying research, the aim of YOTC is to advance basic knowledge, diagnosis, modeling, parameterization, and prediction of multi-scale tropical convection and two-way interaction between the tropics and extra-tropics with emphasis the intersection between weather and climate.

The inaugural YOTC activity will, for each day of the Year, archive ECMWF T799 (i.e., 25 km) prediction products: i) complete (i.e., 4 × per day) global analysis; ii) one 10-day forecast; and iii) extra diabatic fields every 6 h of the 5-day forecast. This activity will start in the summer 2008 in order to contribute to the Asian Monsoon Year (AMY) and the THORPEX Pacific Area Regional Campaign (TPARC), as well as to the United Nations Year of Planet Earth and the International Polar Year.

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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:

- 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.
- To review the state of knowledge and future directions in observing, simulating, modeling and predicting the MJO and its socio-economic implications.
- To prepare a workshop report that includes priorities for THORPEX/WCRP research and forecast demonstration projects.

The Workshop examined the organizing scales and elements of tropical convection and their 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 atmospheric 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 association with convectively-coupled waves, represents a fundamental mechanism 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. All these features constitute important uncertainties that significantly impact weather and climate. Figure 1 shows a selection of the themes addressed by the workshop. Summaries of the Workshop proceedings (1) and its broader context (2) are available.

The Workshop acknowledged that the landscape from which the above problems can be addressed has rapidly and irreversibly changed over the last decade. New theoretical, numerical and observational approaches and resources are available. Computational resources have expanded to the extent that global “cloud-system resolving” models are reality in the research context. This alone warrants reconsideration of the strategic manner the community approaches these problems. Moreover, the implementation of a wide variety of basin/global scale *in-situ* and satellite measurements provide new opportunities for measuring key issues such as cloud-radiative-dynamical interactions within convective systems, the coupling between microphysics and dynamics, multi-scale convective organization and various interactions among the atmosphere, ocean, and land surface.

Notably, the Workshop was unable to articulate the needs for specific field experiments beyond those presently planned capable of addressing the above issues in a comprehensive way. The key point is that resources and facilities have changed so measurably in recent years that our community has yet to fully exploit them in a consolidated and integrated manner. Consequently, a strategic recommendation of the Workshop was:

Conduct a Year of coordinated observing, modeling and forecasting of organised 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 modeling frameworks, in order to better characterise, 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.

The YOTC is a flexible way to address the above ambitious recommendation, and at the same time make a WCRP and WWRP/THORPEX contribution to the United Nations Year of Planet Earth³ and complement the International Polar Year (IPY) (6).

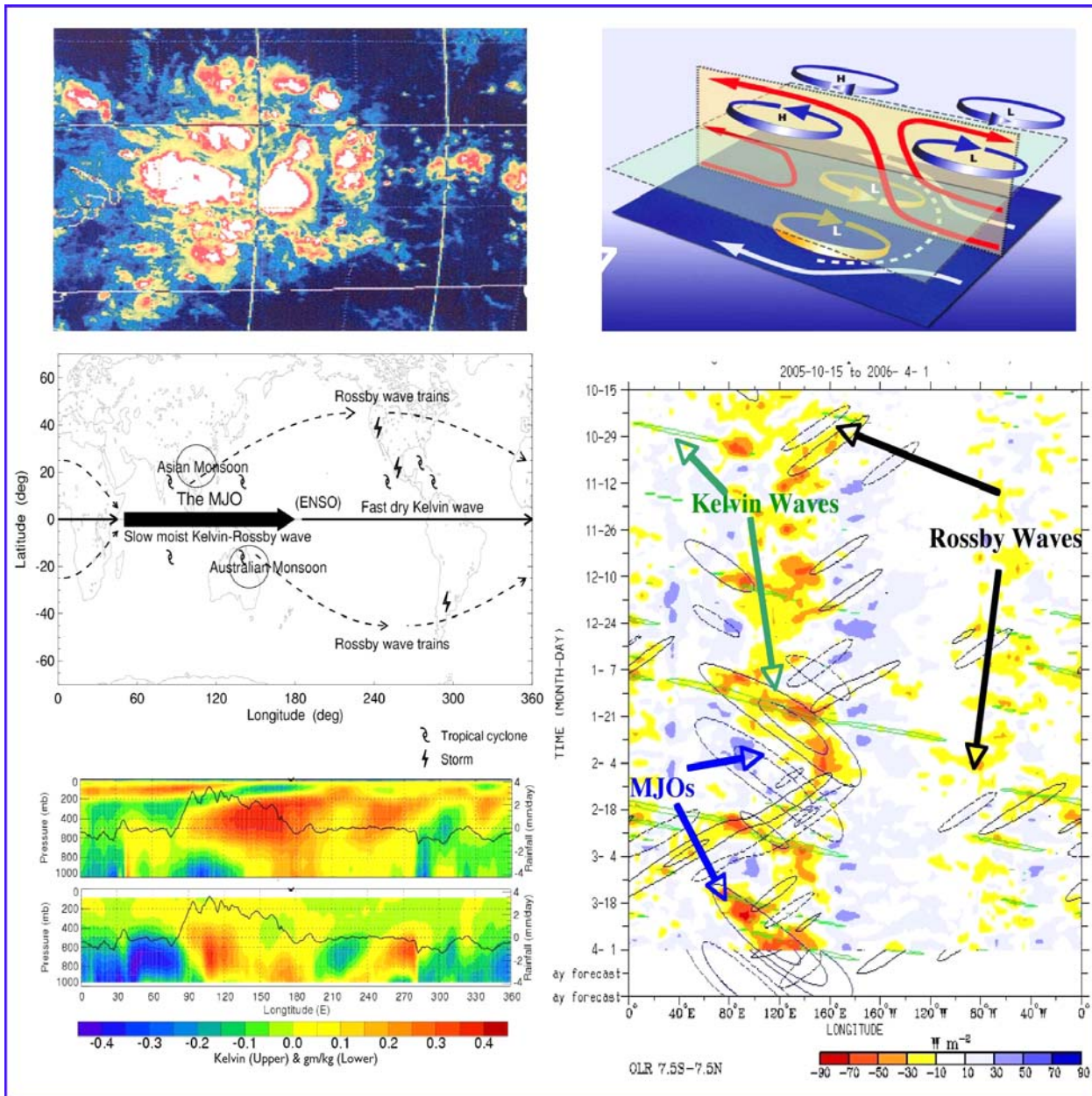


FIGURE 1: Clockwise from upper left: Mesoscale convective systems embedded in a supercluster observed from space on 20 Dec 2003 during TOGA COARE (3); Idealization of the three-dimensional organization of a tropical convective system combining both meso-scale and large-scale elements (3); OLR anomalies 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 (4); Pressure-longitude equatorial sections (8N-8S) of temperature (upper) and specific humidity (lower) anomalies associated with the MJO, black line indicates rainfall anomalies (5); Schematic illustrating downstream and mid-latitude influences of the MJO (J. Lin, CDC/NOAA).

³ 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

- Challenge and Impact of Organized Tropical Convection

Precipitating convection, the manner it influences cloud processes, and organizes on larger scales has a fundamental effect on the atmospheric circulation through the transport of heat, moisture, and momentum, and its effects on the Earth's radiation budget. Until very recently, large-scale atmospheric models have necessarily had to rely on parameterizations to represent cumulus convection and 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 especially, will require convective parameterizations for the foreseeable future.

Precipitating convection is highly nonlinear, intrinsically complex, and organizes across a wide range of spatio-temporal scales. The parametric representation of precipitating convection involves not only convective parameterization *per se*, but also the parameterization of accompanying sub-cloud-scale processes (e.g. boundary layer, cloud-radiation interaction, and cloud microphysics) and, furthermore, on how these processes interact. Many processes remain poorly understood which further reduces the fidelity of contemporary parameterizations. In addition, our knowledge of how mesoscale, synoptic-scale and planetary-scale phenomena interact at a fundamental level as a coupled dynamical system is far from complete. This leaves us severely disadvantaged in modeling and predicting key 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, cloud-microphysical properties, and the diurnal cycle (a basic forced variability of atmospheric motion). Furthermore, tropical weather/climate phenomena strongly influence the extratropics through poleward migration of synoptic systems and through initiating Rossby wave trains that can involve a range of time scales (e.g., synoptic, MJO/intraseasonal, ENSO/seasonal-to-interannual). Figure 2 illustrates shortcomings in the representation of mean climate, variability, climate-change projections and extra-tropical weather prediction. Many of these shortcomings can be directly ascribed to incomplete parameterizations of sub-grid scale processes; notably, precipitating convection.

While our description and modeling of *physical processes* have improved tremendously in the past 40 years or so, progress in the *parameterization* of convection in large-scale models has been slow by comparison. For the most part, parameterizations have focused on thermodynamic aspects whereas convective organization has intrinsic dynamical connotations across a wide range of scales (e.g interaction between convective and stratiform clouds/rain, mesoscale organization, and the coupling among dynamical, microphysical and radiative processes). The significant decline in the number of individuals and teams working directly on parameterization is a major concern. Direly needed is a focused activity/program designed to invigorate research on parameterization, exploit new approaches, and attract a new generation of bright minds: this is a backdrop to YOTC.

Significant progress has stemmed from the coordinated use of observations, cloud-system resolving models and large-scale models advocated by the international GEWEX Cloud System Study (GCSS) (7, 8). Due to computing, observational, and people limitations efforts GCSS focused mainly on convective- and meso-scales. Recent developments include *Cascade*, based in Reading University in the UK, and Center of Modeling of Atmospheric Processes based at Colorado State University in the US. *The time has come to integrate high-resolution model data, multi-sensor satellite data, and field-campaign data as a "virtual computational-observational laboratory"*⁴ and to motivate and apply basic research on multi-scale convection, with convective organization high on the agenda. The challenges are formidable: i) the wide range of scales associated with the convective organization in the tropics i.e. cumulus to planetary; ii) the

⁴ The second main recommendation from the WCRP/THORPEX workshop.

lack of observations that adequately and simultaneously characterize multi-scale properties; and iii) transfer of findings from observations, process studies, and modeling studies into parameterizations. The intent of YOTC is to meet these challenges in a collaborative way.

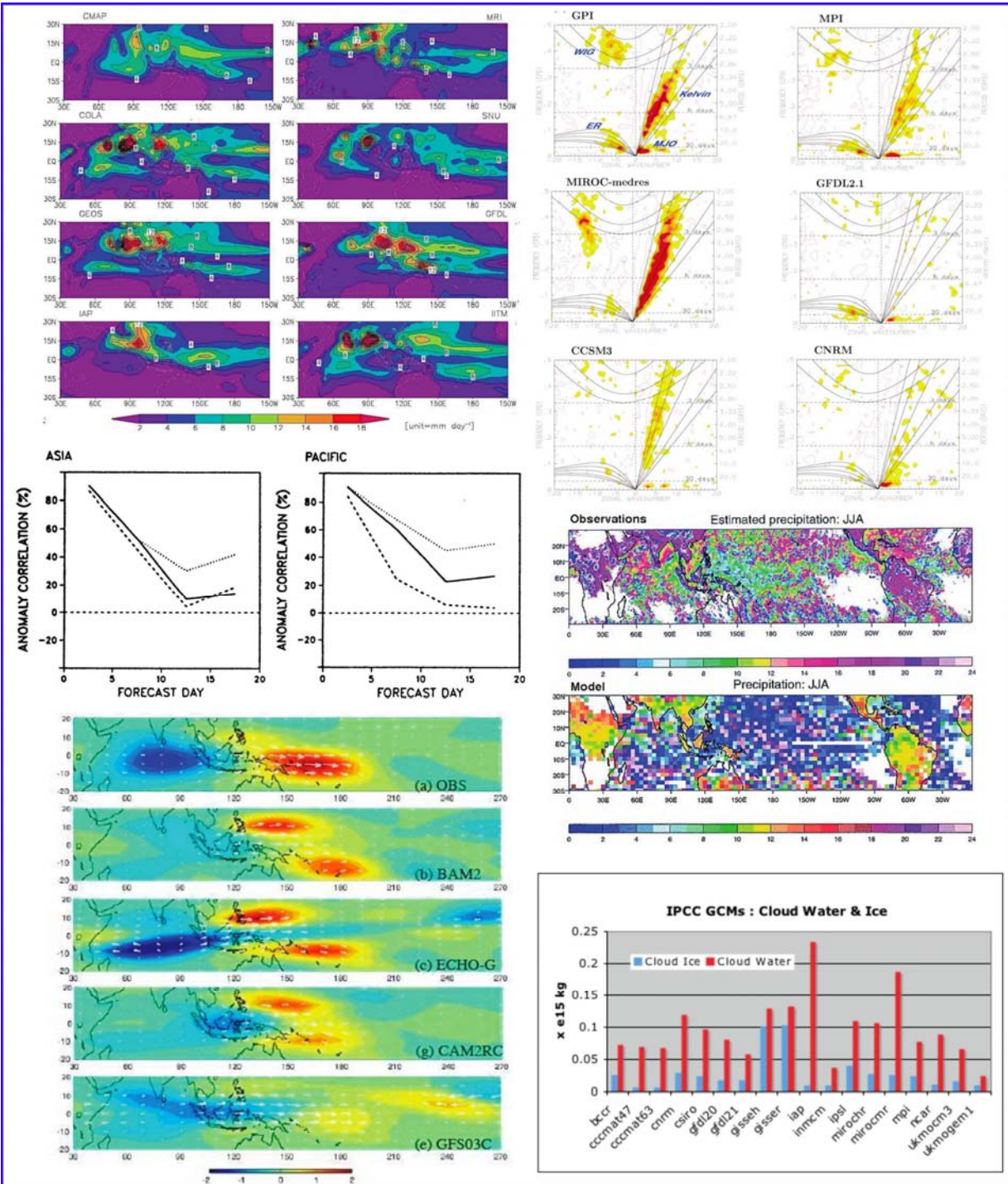


FIGURE 2: Clockwise from upper left. Climatological JJA precipitation from observations and selected number of GCMs (9); Wavenumber-frequency diagrams of equatorial precipitation from observations and a selected GCMs (10); Phase of the diurnal cycle in precipitation for JJA from observations and a GCM (11); Total tropical (30N-30S) integrated cloud water and ice from the 20th century simulations contributed to the 4th IPCC assessment; Zero-lag regression of band-pass/MJO filtered U850 (vectors) and precipitation (colors, mm/day) upon filtered U850 at 160°E and 0°N (12); 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) (13).

- Approaches of Past Field Campaigns

The 1974 Global Atmospheric Research Programme (GARP) Atlantic Tropical Experiment (GATE) was the first large international field program to address the interaction between convective cloud systems and the larger synoptic scales in the tropics (14, 15). It was planned as a scale-interaction experiment (16) to collect data from rawinsondes, aircraft, radars, tethered balloons and surface measurements in the intertropical convergence zone (ITCZ) 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 improved models of the tropical circulation. It was hoped that case-study analyses of convective systems and composite and modeling studies of easterly waves could be used to test and develop convective parameterizations (17). The premise of GATE was that the convective and synoptic scales interacted but were separated in time and space, with a large gap between synoptic and convective scales. However, GATE revealed that the convection was organized into mesoscale systems with motion on scales intermediate between convective and synoptic scales (17-20), and that these intermediate-scale motions altered the vertical distribution of convective heating (18, 21-23). The mesoscale circulations organized by deep convection conflicted with the simple notion of scale separation. This additional complexity is in part responsible for the slow development of the parametric representation of convection (24).

Key results of GATE were confirmed in the 1978-79 GARP Winter and Summer Monsoon Experiments (MONEX, 25). These field campaigns over the South China Sea and Indian Ocean revealed mesoscale organization of oceanic convection broadly similar to that over the tropical Atlantic in GATE (26). This is also confirmed through the analysis of longer periods of observations from geostationary satellites (27).

The 1979 First GARP Global Experiment (FGGE), a major international data and modeling enterprise, involved a 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 an innovative opportunity for improving medium-range global weather forecasts. Observations from oceanic buoys, commercial aircraft, 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 significantly improved global skill scores for medium-range weather forecasts. Numerous weather centers 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 modeling that followed during the ensuing 25 years (Fig. 3).

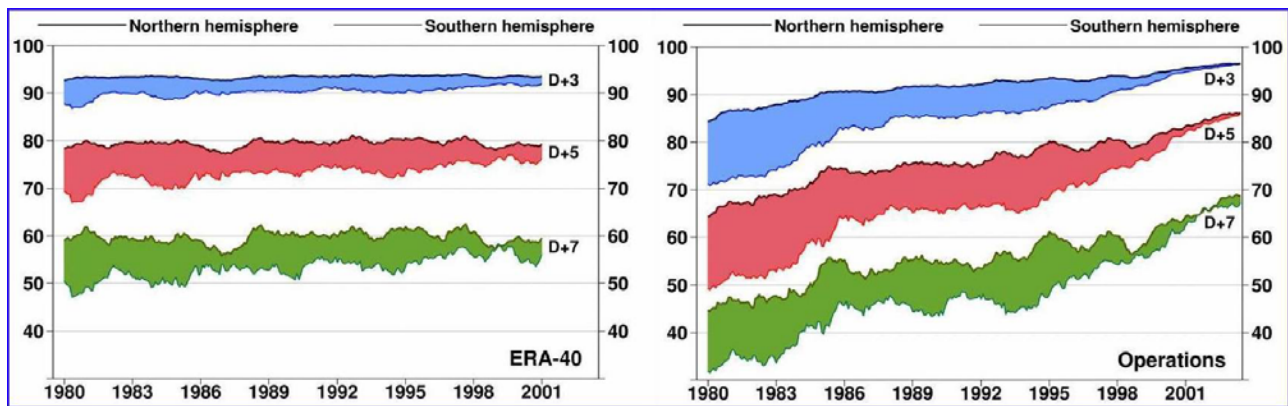


FIGURE 3: Improvements in medium-range NWP forecast skill; 12-month running mean of anomaly correlation (%) of 500hPa height forecasts. (Left), forecasts based on the ERA-40 system (i.e. initial conditions and associated model) – illustrates impact of additional data sources. (Right) Forecasts based on the operational system at the given time – illustrates combined impacts of additional data sources, advances in data assimilation and model improvements. Courtesy: 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 a four-month period in the equatorial western Pacific (November 1992-February 1993). COARE was directed at the properties and behavior of tropical convection – organization and interaction with larger scales of motion – and also the mechanisms of convection/upper-ocean coupling (28). COARE targeted the western Pacific warm pool where the climate system is critically sensitive to ocean-atmosphere coupling processes, particularly in connection with ENSO and MJO variability and teleconnection with midlatitudes. It should be emphasized that COARE proceeded in conjunction with long-term geostationary satellite records that enabled tropical-extratropical and planetary-scale interactions to be documented (28). Aircraft and ship measurements documented the mesoscale structure of deep convection over the tropical ocean. As with other field campaigns, COARE helped motivate a new era of scientists and cross-cutting research. Significant advances were made such as: i) physical mechanisms by which mesoscale convective heating translates upscale to larger-scales (29); ii) mesoscale circulations organized by convective systems strongly affect the large-scale redistribution of momentum (30, 31); iii) the importance of intermediate-sized convection in the heat balance of the region (32); iv) insight into ocean-atmosphere coupling processes from the several-hour time scale of mesoscale convective systems, to the diurnal cycle, and up to the 40-50 day time scale of the MJO (33-35); v) improved understanding of a variety of phenomena and processes such as two-day waves, air-sea exchange in light-wind conditions, ocean mixing, convective momentum transport, dry intrusions, cloud-radiation interactions, tropical cloud populations, the diurnal cycle, etc.

However, incorporating the physical findings from COARE into improved regional- and global-scale numerical models has yet to be fully realized. Notable in this regard is that the current suite of multi-sensor satellite observations were not available during COARE, which has compromised the evaluation, and limited the application, of multi-scale modeling and prediction.

III. The Emerging New Era

- Global Observing Systems

The past two and half decades has witnessed tremendous growth and expansion of our capabilities to observe the tropical ocean, atmosphere and land systems. For example, during the GATE, the most useful satellite measurements derived from the first operational geostationary satellite (SMS-1), launched shortly before the IOP, captured cloud images every 30 minutes and provided information on clouds/convection and cloud-tracked winds. By the time of FGGE a near-global fleet of operational geostationary satellites existed (e.g., GMS, Meteosat, GOES). Along with the increasing capabilities of the NOAA operational polar orbiters, this provided basic cloud information, coarse-resolution temperature and moisture soundings, and SST in cloud-free areas. For 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, 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 Fig. 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, sophisticated semi-operational sites have been instrumented by the DOE/ARM program and the GEWEX CEOP. The vast resources available today for monitoring and characterizing tropical variability, as well as for assimilation and validation applications for prediction are summarized below. *The purpose of the following brief review is 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/Poseidon (1992) and Jason-1 (2004) altimeters. A hallmark addition was the TRMM (1997) radar and radiometer suite that provided rain-rate information of unprecedented high-quality and detail including vertical structure, and also the ability to determine SST in the presence of clouds. In conjunction with the above, notable is the planning and development of the Earth Observing System (EOS) program of satellites, starting with the launch of the EOS Terra platform in 1999, followed by EOS Aqua (2002), EOS Aura (2004) and the CloudSat/Calypso (2006) profilers. Compared to just ten years ago, this suite provides staggering resources for the measurement of tropical convection and its interactions with the environment and upper-ocean. The 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 program 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, during TOGA COARE just ~ 6000 radiosondes augmented the 120-day IOP. While it is impossible to equate an in-situ sounding to a satellite estimate, it is nevertheless 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, 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 (37) ability to separate convective and stratiform precipitation, has illustrated the global distribution of the heating effects of organized mesoscale systems across the tropics and their likely influence on the larger-scale circulation (38-40) as well as the global distribution of shallow isolated convection (41).

Notwithstanding these new satellite resources, (operational) geostationary satellites provide the most complete measurements of the primary scales relevant to organized tropical convection. This includes planetary-scale and synoptic views as well as 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.

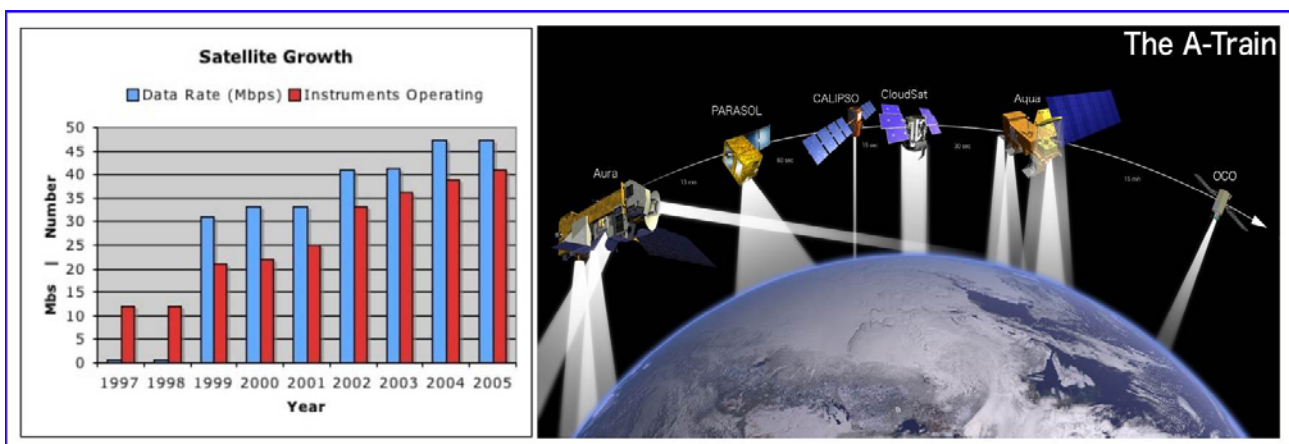


FIGURE 4: Left panel, growth rate of the EOS program in terms of data rate (blue) and number of operating instruments (red).

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
3D Atmospheric Water Vapor	AIRS/AMSU-A, MLS
OCEAN	
Surface Temperature	TMI, MODIS, AIRS, AMSR-E
Ocean Color	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 program's focus on ENSO, and the WCRP WOCE program, it has expanded to encompass a much broader range of objectives, including the Atlantic and more recently Indian Ocean variability – see Figure 5. 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 buoy provides subsurface thermal information and surface meteorology information – in some cases with radiation. 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-scale observing system, the implementation of the Indian Ocean Observing System, is just beginning. Moored buoys and plans for a relatively complete array supported by international partners have been developed (42). This array will be instrumental in better understanding air-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. Apart from these moored buoy systems has been the ever-growing drifter/float programs. Starting its formal implementation phase in 1999, the ARGO program, 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 program, the global drifter program has developed over the past two decades, maintained and supported by NOAA in conjunction with the VOS and 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 (Fig.5).

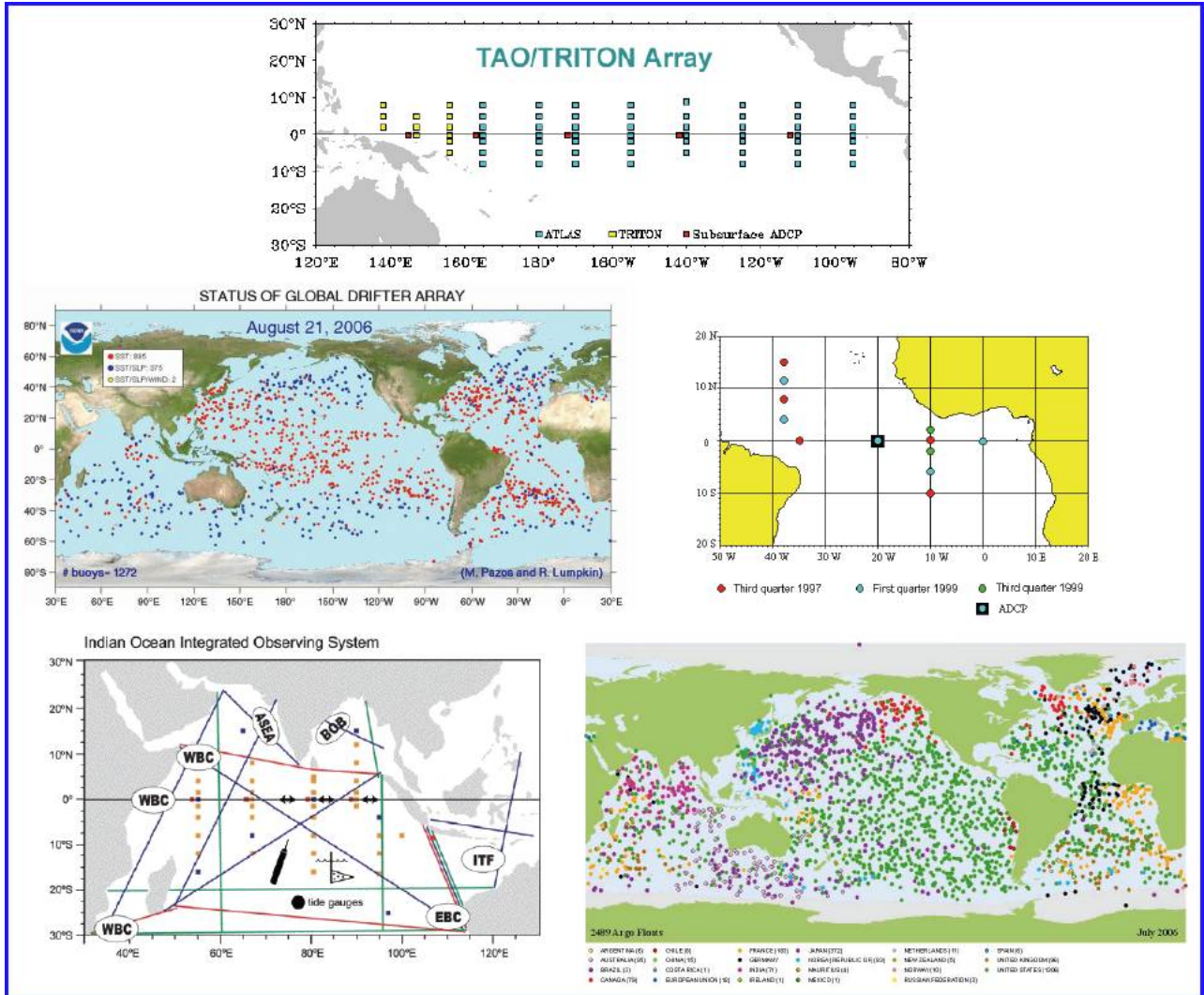


FIGURE 5: Clockwise from top: i) Schematic of TAO/TRITON moored buoy array; ii) schematic of PIRATA moored buoy array; iii) Snapshot of the locations and sponsor country (color) of the (~2500) ARGO float deployment as of July 2006; iv) Present and planned structure of the Indian Ocean Integrated Observing System; v) Snapshot of the locations and capabilities (red: SST, blue: SST/SLP) of the (~1300) surface drifters as of August 2006.

iii) Other In-situ Programs

The U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program 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 (43, 44). 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. 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 sites 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 (Fig. 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. The expectation is that all will operate during the coordinated YOTC activity.

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 modeling of the water and energy cycles within the climate system. The CEOP in-situ observation network presently consists of 35 globally distributed Reference Sites (Fig. 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.

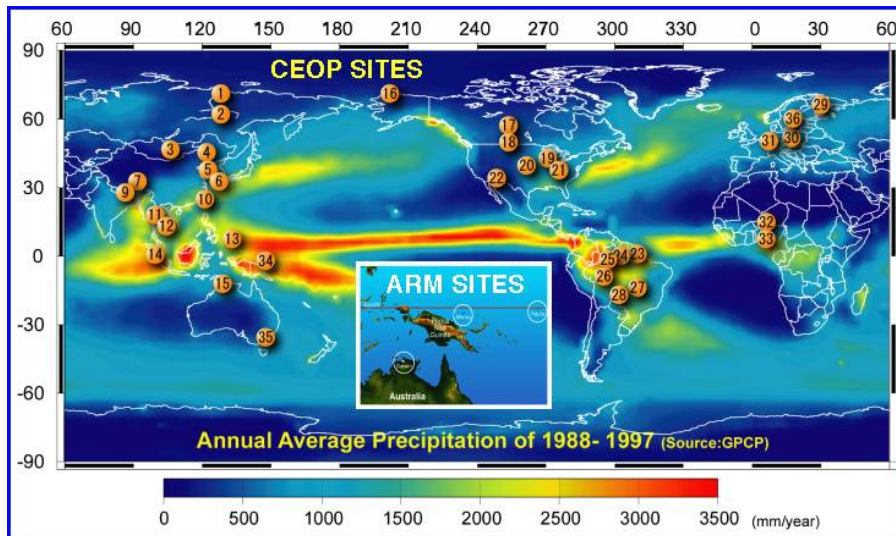


FIGURE 6: (large map) GEWEX CEOP Reference Sites. More specifics regarding these sites can be found at: www.ceop.net. (small inlay) ARM Intensive Observation Sites – Darwin, Nauru Island and Manus Island. More specifics regarding these sites can be found at www.arm.gov.

- Modeling Infrastructure

- i) *Computing Capabilities*

Since the time of FGGE and COARE, computational resources have increased by many orders of magnitude. Figure 7 shows that since COARE alone, we have witnessed at least a 10^4 increase in computer performance. 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 (Fig. 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 modeling capabilities.

- ii) *Modeling Approaches*

A notable aspect of the ICTP workshop was the number of relatively new modeling 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. Notable in this respect during the past decade is the remarkable advancement of Cloud-system Resolving Models (CSRMs; grid-length a few kilometers) which far exceeding their inaugural use as cloud process models during in the 1970s and 1980s. CSRMs with computational domains ranging from regional-to-global provide explicit representations of the entire spatio-temporal range of organized multi-scale tropical convection. A key point is that CSRMs couple small-scale processes that must be parameterized (cloud-microphysics, turbulence, surface exchange) explicitly to the resolved scales. This side-steps certain unsolved problems associated with convective

parameterizations (transport, closure and triggering). Because the physical resolution of a numerical model is about 7 times its grid-spacing, in CSRMs the mesoscale organization of convection is approximated but the explicit representation of cumulus convection is incomplete. CSRMs represent the life-cycle of convective organization with far greater fidelity than contemporary convective parameterizations provide.

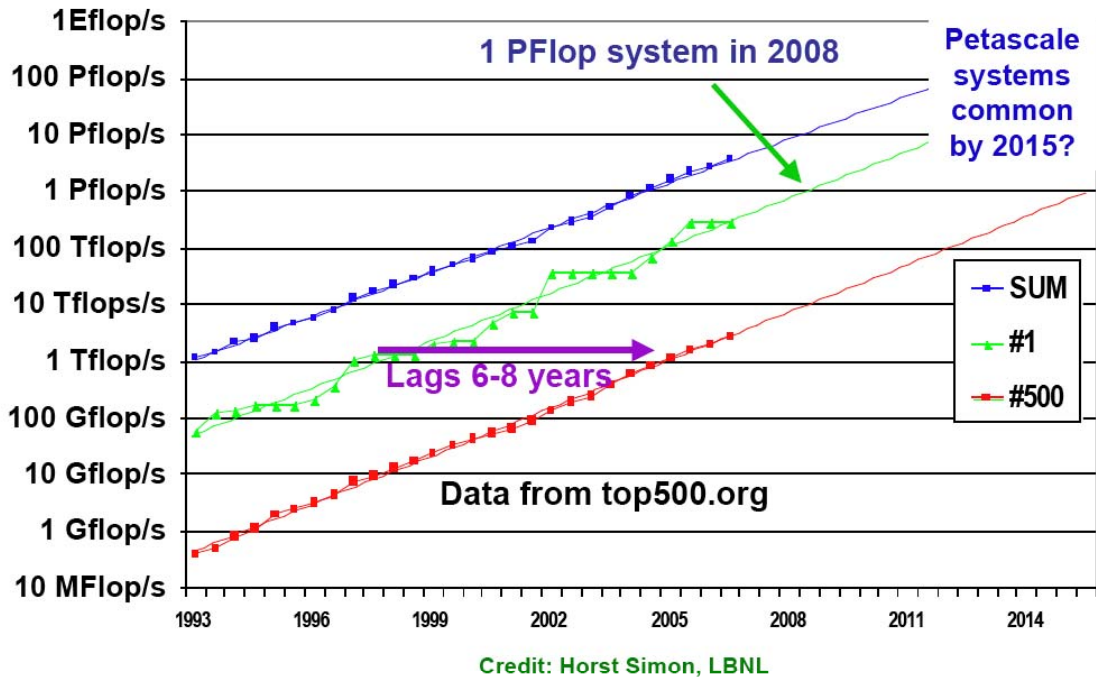


FIGURE 7: This computer performance data, collected from the world’s 500 fastest supercomputers (top500.org), shows the steady, exponential rate of progress system performance. The axes of the plot show performance in terms of the FLOPS rate sustained in the High Performance Linpack (HPL) benchmark as 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 modeling capabilities; for example, enabling use of cloud-system resolving models on up to multi-decadal time scales.

The potential of CSRMs in the weather-climate context was quickly recognized by WCRPs GEWEX program in the form of the GEWEX Cloud System Study (GCSS) in the early 1990s (7, 8, 45). Recalling that mesoscale convective organization is a key uncertainty (viz. above remarks concerning GATE and TOGA COARE) a year of coordinated observations and modeling, as we propose, gives prospect for quantifying the effects of convective organization regionally and globally. Because the simulated multiscale convection will be validated by the integrated satellite and field-campaign datasets, convective organization across scales can be addressed comprehensively.

CSRMs represent moist processes and scale interactions up to continental and ocean-basin scales, and are being used to approximate mesoscale circulations in convective parameterizations (46) which, recall, addresses a problem dating back to GATE. In nested regional climate models (e.g., the NCAR WRF-based model) mesoscale organization is represented by progressively finer-resolution domains interactively embedded (nested) in global models. Simulations of organized tropical convection on long timescales provide the prospect of understanding (and ultimately predicting) the effects of organized convection on the large-scale environment. In particular, global CSRMs provide opportunities for advancement in regard to the global role of multiscale convective organization (47), along with superparameterization (CSRMs embedded in general circulation models, 48, 49).

Figure 8 glimpses at future global NWP models and, eventually, climate models of 10-km grid-length. At this resolution, the global atmosphere becomes ‘dynamically alive’ in respect to the large-scale organization of tropical convection and high-impact weather events such as hurricanes. The tropics and the higher latitudes are interconnected in ways not possible at coarse resolution e.g., the incursion of mid-latitude frontal activity into the deep tropics, moisture flares emanating from the tropics, and convection-wave interactions.

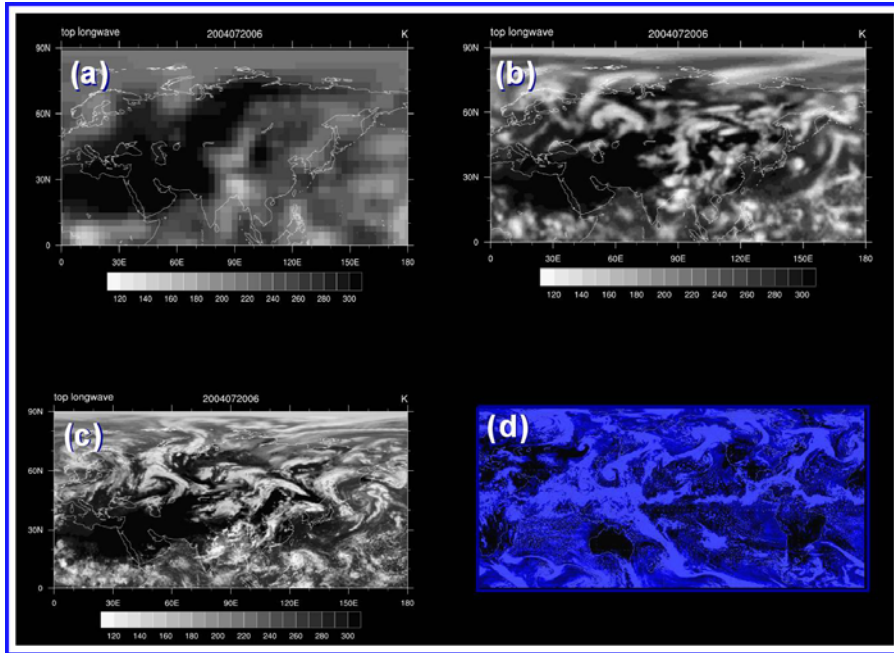


FIGURE 8: a) Global NWP model the early 1980s and contemporary climate models, grid-spacing about 300 km; b) Global NWP in the late 1980s and experimental climate models, grid spacing about 80 km; c) Modern global NWP, grid-spacing about 25 km, and d) Global NWP model for weather in the 2010 time frame, future climate models, grid spacing approximately 10km. Courtesy T. Enemoto and the Earth Simulator.

Systematic errors associated with precipitating convection may emerge early in a NWP model (within days), identifying the value of running climate models in initial-value (NWP) model. Efforts in this area in the past were hampered by the lack 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 stumbling blocks. The UK MetOffice has operated a unified (weather forecasting and climate) model since the 1990's. Running climate models in NWP mode identifies issues responsible for the long-term climate drift of the model associated with fast processes such as atmospheric convection. This approach is resource-efficient since model integrations are relatively short and can be targeted on meteorological phenomena and specific validation data sets. A highly relevant recent effort is the CAPT⁵ (50). Figure 9 illustrates a connection between forecast uncertainties and uncertainties in the long-term model climate for a study using the NCAR CAM3.0 model (51).

⁵ Climate Change Prediction Program – ARM Parameterization Testbed carried out by the Program for Climate Model Diagnostics and Intercomparison (PCMDI) at the U.S. Department of Energy (DOE) Livermore National Laboratory.

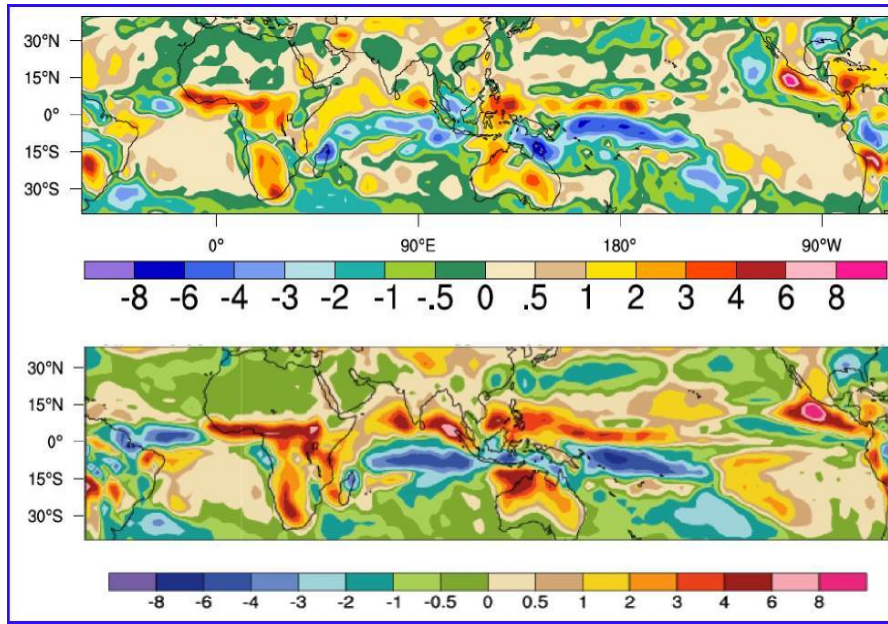


FIGURE 9: (top) Mean differences between observed precipitation and 3-day forecast values using the NCAR CAM3.0 AGCM for the 1992-3 DJF period. (bottom) Same, except for the mean DJF from a 10-year simulation using NCAR CAM3.0 with observed SSTs.

It is important to note that the challenge of the multi-scale organization of tropical convection and its interaction with the upper-ocean and the global atmospheric circulation will not be met completely through enhanced-resolution numerical models alone, especially considering that organized convection must be parameterized in climate models for the foreseeable future. Idealized numerical models and dynamical analogs help quantify fundamental issues, such as the effects of upscale transport (heat, momentum and vorticity) on the evolution and maintenance of multi-scale precipitating systems in the tropics. For example, meso-convective organization is interlocked with Rossby-gyre dynamics in the convectively-coupled systems such as the MJO and Kelvin waves (52, 53). Multiscale analogs that incorporate a dynamically active troposphere, a passive planetary boundary layer, and simplified parameterisations of precipitating convection, surface heat exchange, and radiative cooling reveal large-scale MJO-type convective organization (54). The second-baroclinic vertical mode of heating is vitally important (55), for example, through the effects of upper-tropospheric stratiform heating behind, deep cumulus within, and low-to-mid tropospheric cumulus congestus heating in front of MJO systems, in agreement with observations (32).

Progress is being made in convective parameterization development. A basic issue with important practical implication concerns connections between intraseasonal variability of the MJO and interannual variability of ENSO. This problem has been investigated for the past two decades (58). A coupled GCM operating an improved convection parameterization suggests that the representation of deep convection and its organization gives a plausible explanation of the genesis, development and termination of 1997/98 El Niño event as the result of atmosphere-ocean interaction (59). An important property of the improved parameterization is that moist convection occurs less frequently, is better organized, and is closer to TRMM satellite observations (see the precipitation frequency in Fig. 10). In coupled GCMs, deep convection is a measure of stochastic forcing on the ocean. In the improved parameterization, stochastic forcing is less frequent but stronger. This enhanced MJO activity acts as a coherent forcing for the ocean circulation through enhancing the westerly-wind anomalies and hence the development of El Niño. The development of easterly anomalies due to the cold SST anomalies over the western Pacific during the peak of an El Niño event has the opposite effect: the development of oceanic Kelvin waves that lead to the demise of El Niño as the cold-water anomalies propagate eastward across the Pacific and upward to the ocean surface.

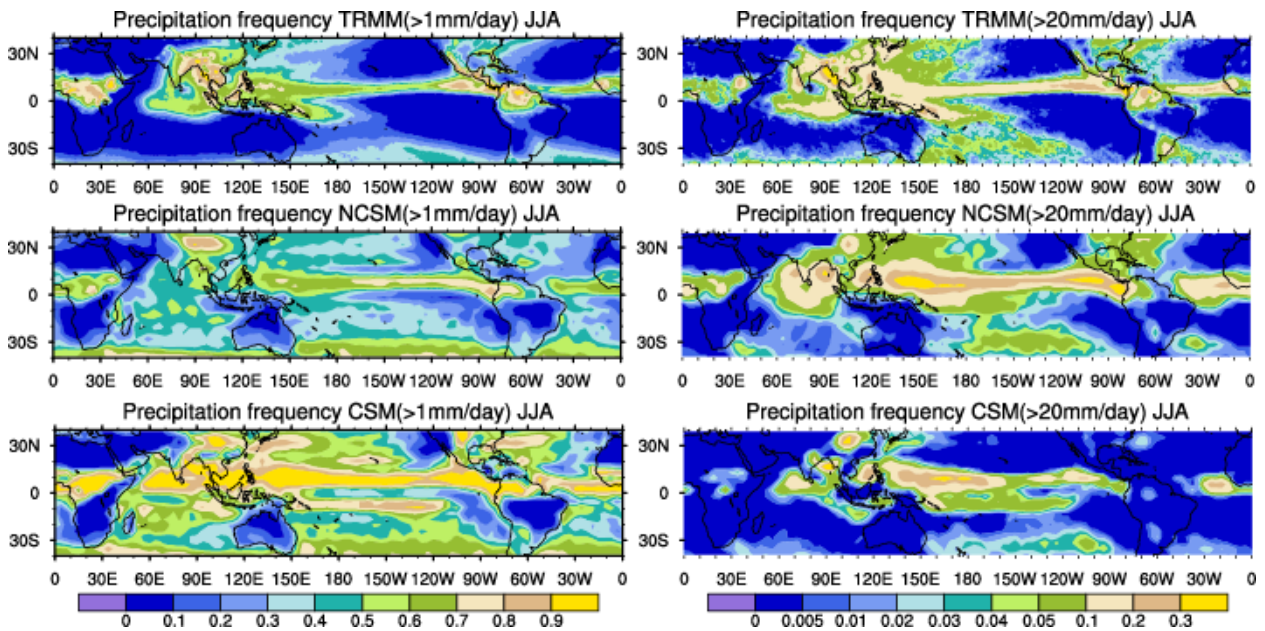


FIGURE 10: June, July and August (JJA) daily precipitation ($>1 \text{ mm day}^{-1}$, left; $>20 \text{ mm day}^{-1}$, right) frequencies (%) from TRMM 3B42 satellite observations (1998-2003, top), the GCM with improved convection scheme (NCSM, years 80-89, middle), and the standard GCM (CSM, years 80-89, bottom). NCSM rains much less frequently compared with the standard CSM over the Indian Ocean, the Pacific and the Atlantic (left panel), while NCSM produces more heavy precipitation than CSM over North, Central and South America, the Indian Ocean and the Western Pacific (right panel).

An ultimate need is a parameterization of convective organization since it is a process not presently represented in parameterizations. Within a few years, global NWP models will have a 10 km grid-length and, in a 10-15 year timeframe, it is likely that this resolution will be achieved by IPCC-type climate models. It is important to thoroughly examine 10-km grid-length models where a new issue occurs: parameterization of cumulus *and* an explicit representation of convectively-generated mesoscale circulations are required ('hybrid representation'). Because the hybrid approach involves the approximation of mesoconvective dynamics it is a research challenge that has direct application to the operational community. Towards this end, prototype hybrid parameterizations have been constructed (46, 57).

IV. The YOTC Concept

The discussions in the above sections highlight: i) the pervasive shortcomings in knowledge and model representations of tropical convection which have ramifications on environmental predictions across a wide range of time scales and extending into the extra-tropics; ii) the long heritage of the tropical convection problem and some past efforts that have helped to attain modest but tangible gains in addressing this problem; iii) the incredible growth in the last two decades of our observational infrastructure of the tropical ocean-atmosphere-land system, notably in terms of tropical convection, clouds, circulation, air-sea interaction, microphysics -- *the tropical environment has never been so well observed*; iv) advances in computational capabilities provide altogether new opportunities for modeling convection and clouds at fine-scale.

In order to exploit new in-situ and satellite observational resources, computational capabilities and high-resolution/alternative modeling 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, Modeling and Forecasting of Tropical Convection* (a.k.a *Year of Tropical Convection, YOTC*). The YOTC concept is 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 start-date is August 1 2008 in order to take full 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).

For the most part, the YOTC will use and coordinate existing resources with a focus on selected phenomena associated with organized tropical convection. In line with this, and relevant to planning and funding considerations, many of the needed data sets (e.g., satellite products) can be acquired retrospectively. Therefore, the planning and implementation is along the lines of a *virtual field program*, and distinct from a traditional field campaign. The detail provided below describe the overarching goals, the key science questions, initial thoughts on targeted phenomena for the focus year, and a preliminary discussion regarding implementation of YOTC.

a) Overarching Goals and Questions

Immense tangible benefits to society are afforded from improved weather and climate predictions. Realistic representations of tropical convection in 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 modeling capabilities associated with tropical convection, the goal of YOTC is to achieve by ~2012 significant gains in forecast skill compared to Fig. 3 (early 1980s to late 1990s) in the following areas:

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

Making progress on answering the following questions lie at the heart of YOTC goals:

- What are the global and regional characteristics of tropical convection over both land and ocean, including variability on diurnal to seasonal time scales?
- What are the characteristics and relative roles of processes occurring: i) within the large-scale circulation, ii) on the mesoscale, and iii) internally on the storm scale that influence the development, organization, and maintenance of tropical convection?
- Under what circumstances and via what mechanisms is water vapor, energy, and momentum transferred across scales ranging from the mesoscale to the planetary scale? How does organized tropical convection interact with the extra-tropical circulation?

b) Targeted Phenomena

In field experiments, it is usual to make plans to increase the probability of observing the phenomena/process of interest. In YOTC the interest is in observing, modeling and predicting any recurring processes and phenomena that play an important role in our weather and climate system principally in terms of organized convection. Given that the scale of the activity encompasses the global tropics, there is a wealth of possibilities for targeted research. However, to facilitate planning and keep the scope manageable, it is necessary to develop rationale and strategies for selected 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 modeling capabilities will yield tangible improvements in forecast skill. The list below provides is a selection of targeted phenomena together with an accompanying set of science questions to be addressed.

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

The MJO is the most prominent form of intraseasonal atmospheric variability in the tropics. As shown in Section III above, the MJO may affect the lifecycle of ENSO. Advances in our modeling 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, which are considered to be key building blocks of tropical convective variability and its organization across 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 include Kelvin, lowest-order Rossby, and mixed Rossby-gravity waves. Note that the items below includes the boreal winter and summer mode of the MJO. The summer mode is often referred to as the intraseasonal oscillation (ISO) or monsoon ISO (MISO).

- 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.
- Similarly, are operational models able to successfully assimilate and predict the higher-frequency convectively-coupled equatorial waves, and what distinguishes success versus failure.
- 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)? To what extent do models capture these relationships? Are these relationships indicative of an upscale cascade, or downscale conditioning?
- How should the new satellite resources (e.g., CloudSat, CALIPSO, GPS) be used in conjunction with in-situ observations (e.g., ARM, CEOP) to characterize the spatio-temporal 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?
- How should the new satellite resources (e.g. TRMM) be used 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 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 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:

- What improvement in predictability of the environmental effects on tropical cyclone motion can be achieved through the use of the new satellite observations, and advanced ensemble prediction systems that are becoming available through the YOTC?

- What are the dynamical and thermodynamic processes by which the convectively-coupled waves and the MJO contribute to the favorable conditions for tropical cyclone formation in different environments?
- How should new satellite observations of convection be incorporated in numerical models to allow more time- and location-specific predictions of tropical cyclone formation?
- What are the physical processes by which the MJO contributes to enhanced tropical cyclone formation in the eastern North Pacific and even the Gulf of Mexico far downstream of where the active convection portion has disappeared?

iii) *Diurnal Cycle:*

The present shortcoming in representing the diurnal cycle, arguably the most basic and strongest forced mode of variability on Earth, demands attention especially considering both observation and model studies indicate 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 these processes involve a strongly forced signal, with distinguishing features between land and sea, is a fortuitous opportunity to make gains in the convection problem that may have positive consequences for other phenomena and scales.

- Why and how does the diurnal phasing of convection over the open ocean vary regionally?
- 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? Do unifying principles underlie the effects of these physical features on the diurnal cycle?
- How does a diurnal regime of isolated, short-lived convective elements differ from a diurnal regime which produces mesoscale convective systems e.g., in association with mountainous terrain? How does the diurnal cycle of convection change 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?
- How do cold pools from convective downdrafts in high-terrain generate subsequent convection at down-slope 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?
- 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 Interaction:*

There are significant questions regarding the manner in which the extra-tropics influences convection in the Tropics.

- 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?

- 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?
- 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?
- 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:*

Monsoons affect about half the world's population, often catastrophically: phenomena that translate improved prediction into societal benefit. Involving complex multi-scale processes, within the YOTC the monsoons are an ultimate challenge or integrating theme, i.e., monsoon variability is strongly influenced by the diurnal cycle, CCEWs, the MJO, and land-atmosphere-ocean interaction.

- Are there 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?
- 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?
- 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 do atmosphere-ocean and atmosphere-land interaction play in sustaining, modeling, and predicting MJO and other synoptic and subseasonal variability that influences the monsoon?
- What are the impacts of absorbing aerosols (dust and black carbon) and scattering aerosols (sulfate) on the monsoon water cycle? What are the microphysical 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?

c) Coordination, outreach and implementation: the global database

Flexibility is the keyword here. YOTC can be either a once-off, stand-alone activity (i.e., proof of concept) or enhanced and extended to other target years in future. The 'Year', defined as the time-span of the data collection and integration must start no later than August 1, 2008⁶ in order to be useful for the THORPEX Pacific Area Regional Campaign (TPARC). However, the research component of YOTC must be

⁶ A request has been made by the monsoon community to move forward the start date (i.e., to May 2008) in order to archive two summer- monsoon seasons. Unofficially, the ECMWF seems to be in a position to meet this new date but a final decision has not been reached.

considerably longer (say, 3 years) to enable research activities to achieve fruition. In other words, the initial YOTC phase is August 1 2008 – 31 July 2011.

i) Coordination

- YOTC will be coordinated by a small Scientific Planning Group (SPG), the chief interface between the programmatic sponsors (e.g., WCRP, WWRP/THORPEX) and the research and forecasting communities. The SPG would report progress to the international community and principal funding agents.
- An international workshop in late 2008/early2009 will decide upon who does what in regard to the phenomena and the associated science questions (Section IVb herein). Input will be solicited on the implementation of /progress with the global data base(s).
- Mid-term (late 2009/early 2010) a workshop will be convened to report on progress in the research context.
- An international conference (late 2011) will articulate YOTC findings and discuss possible follow-on efforts, including other focus periods, specific experimentation, and/or field studies.

iii) Outreach

- Input will be solicited from countries having a direct involvement in tropical convection in both research and operational respects (e.g., China, India, Japan and Korea). Leading scientists in these countries have expressed interest in YOTC.
Action item: co-chairs Moncrieff and Waliser will circulate the YOTC Science Plan to leading representatives of tropical countries and solicit input.
- Much remains to be discussed in terms of coordination of/contribution to work that is/will be ongoing in *Cascade* in the UK, and CMMAP in the US.

iv) Implementation of the global data bases

YOTC will provide a global database for broad community use (weather/climate, laboratory, university). The purpose of the following analogy and distinctions is to identify the YOTC concept. In a typical field-oriented intensive observation period (IOP), resources are marshaled to deploy in the field, measure phenomena, and return a coordinated data set to the community. In YOTC, the measurement and operational modeling infrastructure are mostly in place as a result of extensive past and ongoing investments, but a comprehensive integrated database does not exist. Therefore, appropriate identifying phrases are: *virtual computational-observational laboratory, virtual observation periods, intensive acquisition and integration phases*.

An important activity of YOTC is the construction of a global database(s) consisting of satellite, in-situ and simulation/prediction model data sets relevant to tropical convection and its impacts on the extra-tropics.

- Satellite data will be a subset of the data set highlighted in Section III: in-situ and field-campaign data are highlighted, in part, in Section III; field-campaign data will be described in more detail in a future YOTC Implementation Plan (IP) with attention to TPARC.

- Operational prediction model data sets: i) the THORPEX TIGGE; ii) high-resolution models analysis from participating operational NWP centers (e.g., ECMWF, NCEP).

Significant progress has been made since the YOTC Science Planning Group Workshop, 12-13 November 2007, Arlington VA in terms of the global NWP dataset. Supported jointly by the Office of Naval Research (ONR) and NSF, the ECMWF has accepted an invitation by YOTC to provide, each day for one year, a complete global analysis and a 10-day forecast at T799 spectral truncation (equivalent to about 25 km in physical space). It is anticipated this unique dataset will be used extensively by the international YOTC community.

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VI. List of Acronyms

ARM – Atmospheric Radiation Measurement
 CLIVAR – WCRP’s Climate Variability and Predictability Program
 CEOP - Coordinated Energy and Water Cycle Observations Project
 COARE – Coupled Ocean Atmosphere Response Experiment
 CMA – Canadian Meteorological Agency
 DMSP – Defense Meteorological Satellite Program
 GCM – General Circulation Model
 ECMWF – European Centre for Medium-Range Weather Forecasting
 FGGE - First GARP Global Experiment
 GARP – Global Atmospheric Research Program
 GATE – GARP Atlantic Tropical Experiment

GEWEX - Global Energy and Water Cycle Experiment
 GODAE - Global Ocean Data Assimilation Experiment
 ICTP – International Centre 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
 TBO – Tropical Biennial Oscillation
 TIGGE – THORPEX Interactive Grand Global Ensemble
 TOGA – Tropical Ocean Global Atmosphere
 WCRP – World Climate Research Program
 WIS - WMO Information System
 WMO – World Meteorological Organization
 WOCE – World Ocean Circulation Experiment
 GCSS – GEWEX Cloud System Study
 TRITON
 VOCALS
 TACE

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