**Mesoscale Convective System Life-Cycle Stages in the Global Maritime Tropics**

*Ralph F. Milliff*; CIRES, University of Colorado

*Dudley B. Chelton*; Oregon State University

*Ziad S. Haddad*; NASA Jet Propulsion Laboratory

*Robert A. Houze, Jr*.; University of Washington

*David G. Long*; Brigham Young University

*Brian E. Mapes*; University of Miami

*Todd Pett*; Ball Aerospace and Technology Corporation

*David A*. *Randall*; Colorado State University

*Gail Skofronick*-*Jackson*; NASA Goddard Space Flight Center

*Frank Wentz*; Remote Sensing Systems

*1. What are the key challenges or questions for Earth System Science*

*across the spectrum of basic research, applied research, applications,*

*and/or operations in the coming decade?*

We seek the multi-parameter dataset necessary to facilitate transformative atmosphere-ocean science by resolving, in space and time, the life-cycles of mesoscale convective systems (MCS), system-by-system, throughout the global maritime tropics. The four-dimensional organization and energy transfers across scales in tropical convective systems is a fundamental and poorly understood process that underlies a broad spectrum of weather and climate phenomena that are among the most energetic on our planet. These include, tropical cyclogenesis, monsoon dynamics, the formation and initial propagation of atmospheric rivers, Madden-Julian Oscillation (MJO) active phases, El Nino/Southern Oscillation (ENSO) warm and cold events, and the dynamics of tropical convergence zones. Tropical convection processes provide the canonical examples of upscale energy transfers in turbulent geophysical systems, including dynamics and thermodynamics associated with vertical transports of momentum and material properties, changes in phase and the mechanisms for self-aggregation. Maritime tropical MCS provide a representative and resolvable target signal within the multi-scale ranges of these processes from which we might infer and quantify the organization and scale transfers leading to the larger-scale phenomena affecting the planet. Life-cycle stages for maritime tropical MCS define the time and space scales to be observed by multi-sensor systems necessary to capture essential dynamic and thermodynamic signals. To understand, quantify and predict larger-scale phenomena, we should seek to revisit evolving maritime MCS in their respective tropical ocean basins, several times during their individual life-cycles. This implies bursts of repeat sampling with revisits on the order of an hour in a variety of infrared and microwave frequencies, resolving spatial scales on the order of a few kilometers within areal coverages spanning thousands of kilometers. Essential dynamical and thermodynamical variables to be simultaneously measured directly and/or inferred include: surface wind convergence and divergence; sea surface temperature (SST); total column and multi-layer water vapor content; total-column and multi-layer temperature, surface rain rate; and cloud-top temperature. These data are not available, on hourly timescales, as a coordinated and simultaneously measured set, from existing or planned sensors: *an active/passive wide-swath sensor system in very low-inclination orbit is needed.*

Beyond fundamental scientific questions regarding conditions and processes of aggregation and convective organization, detecting important MCS evolutions on their naturally occurring timescales will enhance forecast and analysis systems, and add value to in-situ data and observations from existing and planned polar-orbiting systems that will cross the low-inclination orbit implied here up to 14 times each day. For example, as hourly, multi-sensor satellite observations targeting maritime tropical MCS establish an evolving background state, aircraft missions can be designed and modified in near-real time to detect essential fine-scale features of developing tropical storms and cyclones; thereby improving intensity estimates and forecasts on longer lead times. On longer timescales, repeated detection of the evolution and organization of MCS processes in tropical regions will enhance forecast estimates for onset and break periods in the monsoon systems of the global tropics. Repeated observations of MCS building-blocks during MJO active phases will help diagnose elusive propagation mechanisms and interactions with ENSO regimes, perhaps as functions of tropical Indian and western Pacific ocean basins.

The intricacies of the evolution of MCS moisture processes; i.e., at the air-sea interface, within and above the planetary boundary layer, and integrated over the tropospheric column, will help address problematic time and space scales in closing budgets for global, regional and local hydrologic cycles. Hourly, multi-platform observations in the global maritime tropics will anchor optimal interpolations that underlie important Level 3 and Level 4 datasets for rain rate, total column water vapor etc. These datasets are providing important new insights on land-falling rain systems in mid-latitude coastal regions (e.g., atmospheric rivers as in the "Pineapple Express" and others) that are required to manage extended periods of drought and shifts in rainfall patterns associated with a warming climate.

*2. Why are these challenges/questions timely to address now especially*

*with respect to readiness?*

Key science questions and feasible space-borne observations are just now converging such that technical risk is manageable and transformative dataset collection is possible. The relevant set of currently-feasible space-borne observations infer tropical convective system processes on scales that are now fine enough to capture MCS evolution; e.g., they are larger and longer than the scale of individual convective plumes, but fine enough to detect organized convective system behaviors. Conversely, the resolvable scales

from space document processes too fine to be resolved in the current state-of-the-art large-scale and global climate models (GCMs). Indeed, tropical dynamic and thermodynamic processes on the MCS scale are the objects of critical parameterizations receiving an abundance of current research attention. A minimal set of basin-by-basin observations, across several seasons, MJOs and ENSO regimes, will provide essential background for enhancing those critical parameterizations. More realistic simulations of monsoons, MJOs and ENSO warm events are necessary to add value to important climate forecasts with obvious societal implications.

A minimal set of key dynamic and thermodynamic processes in the life-cycle evolution of global maritime tropical MCS are now within reach of space-borne observing system capabilities. An integration and enhancement of existing infrared and active and passive measurement systems on a single platform, in a broad-swath and very low-inclination orbit configuration, will be an essential technical achievement. Given existing and planned US and international space-borne observing systems, these technical enhancements pose surprisingly low technical risk.

The essential component for the space-borne observing system to resolve global maritime tropical MCS life-cycle evolution is the very low inclination orbit necessary to resolve inherent temporal scales. Preliminary studies suggest that broad-swath coverage in orbits inclined from 12° to 18° would span the global tropics (i.e., ± 23.5°). Burst samples of 5 to 7 repeats, at 100 minute intervals, would precess around the globe such that tropical locations experience burst sampling about twice in every 24-hour period. Several years of data at these temporal resolutions, and at high spatial and radiometric resolutions, will provide basin-specific composites for MCS evolution that can be used to add value to a variety of future observations from polar-orbiting (i.e., higher inclination) systematic observing systems, leading to skillful parameterizations in regional and global forecast models.

Drivers for the dataset to quantify life-cycle stages of MCS in global tropical ocean basins derive from insights gained across a variety of research and operational communities given data from heritage instruments across multiple space-borne missions. Seminal datasets for surface convergence derive from an international line of scatterometer missions (e.g., ERS, NSCAT, QuikSCAT, ASCAT, OSCAT, etc.). Passive microwave observations leading to SST, total column and multi-layer moisture and temperature datasets derive from SSM/I's, AMSR's, WindSAT, TRMM, etc. Cloud profile and cloud-top temperature data build insights into MCS variability and stem from missions and programs like TRMM, CloudSat, GOES, Aura, Aqua and the MeteoSats. Examples of field programs focused on processes involving tropical MCS include DYNAMO and TOGA COARE. Relevant research and operational communities span the sub-fields of climate, air-sea interaction processes, geophysical fluid dynamics, weather and ocean forecasting. As impacts from a warming climate accumulate,the combined efforts of these communities will be required to address critical societal issues regarding fresh-water resources, natural hazards including droughts, floods and fires, and planning for and changes in agricultural practices (e.g., in response to changes in monsoons, MJOs and ENSO). The multi-parameter dataset defined here forms a basis for collaborations in data analysis and model-building across these communities.

*3. Why are space-based observations fundamental to addressing these*

*challenges/questions?*

While convective processes in general (i.e., including terrestrial systems, mid- and high-latitude systems) are fundamental to the general circulation and variabilities from mesoscale to synoptic to global scales, maritime tropical MCS occur and evolve on Earth in a low-latitude belt that uniquely affords frequent sampling revisits via space-borne platforms in low-Earth orbit, resolving timescales that match those of essential component dynamical and thermodynamical processes spanning the MCS life-cycle. The maritime tropical MCS targets are too large, and evolve and propagate too rapidly for sufficient coverage by in-situ or airborne observing systems. Cloud-penetrating microwave signals, both passive and active, afford coincident detection of component dynamical and thermodynamical variables within evolving maritime MCS (i.e., including SST, surface vector wind, rain rate, two layer and total column atmospheric temperatures and moisture, etc.).

Attempts to build and validate composite life-cycles for MCS, based on multi-platform space-borne and in-situ observations, have not been sufficient to support parameterizations leading to much-needed enhancements in simulations of monsoon, MJO, ENSO and/or tropical storm variability in our most sophisticated models. Instead, superparameterization methods embed higher resolution two-dimensional (x,z) cloud-resolving model "curtains" within GCM grid intervals to integrate GCM-scale thermodynamics on finer spatial and temporal scales, feeding back the integrated (and balanced) variables to the GCM each timestep. This suggests missing understanding possibly involving: a) basin-specific processes (e.g., differences in convective organization processes in the West Pacific warm pool vs. the Inter-Tropical Convergence Zone vs. the easterly wave regime in the tropical Atlantic, etc.); and/or b) MCS-specific interactions with regional large-scale circulations and regimes in which the MCS are embedded (e.g., including weather systems, tropical SST regimes, phases of the MJO, etc.). *Wide areal, system-by-system, high temporal and spatial resolution, coincident*

*multi-sensor observations of evolving global tropical maritime MCS will reveal mechanisms and provide insights necessary to enhance understanding and facilitate forecasts and simulations of manifold processes affecting weather and climate for the globe.*