Monsoons: Nonlinear Behavior of the Tropical Atmosphere.

Phd Proposal Abstract
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Historically, the development of atmospheric sciences has been more focused on the extra tropics. But in relatively recent years, the importance of the tropical regions has become apparent as determining factor of the global climate. It also became clear that simple extrapolation of previous concepts and models does not always work at low latitudes. This failure results from the vanishing of Coriolis parameter, the weak temperature gradients, the close coupling of the atmosphere with land and ocean, and the exaggerated effects of moisture and convection in tropical regions.

These peculiar conditions allows for the development of phenomena unique to the tropics. Among these, Intraseasonal oscillations, such as those related to the Madden Julian Oscillation (MJO), and the Monsoon active and break phases have received a great deal of recent attention. Significant efforts have been made to study their dynamics. However, serious complications have also become apparent. For instance, the inclusion of soil moisture in the dynamics or, more fundamentally, the vanishing of the Coriolis parameter, leads to interesting, and often complicated, nonlinear effects. A new framework might be needed if one intends to understand the dynamics of the tropical atmosphere.

The main focus of this doctoral work will be on the Monsoonal zones (i.e. those regions where marked wet and dry seasons occur during the year). They are of particular interest as all of the above dynamics comes into play (Webster, et al. 1998). Moreover, the spatial extent of these phenomena is considerable and they serve as a laboratory where ideas about tropical dynamics can be tested. We will start simple, and build up slowly in complexity, a road that has been proved useful in the atmospheric and climate sciences. In particular we start by studying the threshold behavior of tropical circulations.

For this, we first study the response of a dry atmosphere to a localized forcing, intended to simulate the effects of heating. Even from this level of simplification interesting behavior emerges; for instance, there is a threshold for the amplitude of the heating which determines if cross equatorial flow would develop (Plumb and Hou 1992). We proceed further by evaluating the effect of an elevated heat source that would emulate the effects of the Tibetan Plateau. This is a good question as recently its importance in the Monsoonal circulation has been put in doubt. We hope to expand further the understanding of its effects.

An effort is made in approaching this study with focus on the nonlinear problems that emerge. The linear methods, which have been greatly influential and useful, have inherent limitations that only nonlinear thinking could alleviate. An effort will be made to understand our results, especially as the complexity increases, in the framework of recent development in nonlinear sciences. Here the main focus is centered in the phase space of the dynamical systems, and the goal is to find robust structures (such as periodic orbits), that have shown to be important in recovering statistical measures of the system (Cvitanović, et al. 2009). We seek then to understand its implications for climate.

In summary, we will use the Monsoon regions as our laboratory, and will design our experiments depending of the results we obtain along the way. It is hoped that this will allow us to build on the present state of the knowledge in tropical dynamics.

References:

- Webster, Peter J., et al. "Monsoons: Processes, predictability, and the prospects for prediction." *Journal of Geophysical Research*, 1998: VOL 103, NO. C7, PAGES 14451-14510.
- Cvitanović, P., et al. *Chaos: Classical and Quantum.* Niels Bohr Institute, Copenhagen, 2009.

- Plumb, R. A., and A. Y. Hou. "The response of a zonally symmetric atmosphere to subtropical thermal forcing - threshold behavior." *Journal of the Atmospheric Sciences*, 1992: Volume: 49:19, Pages: 1790-1799.

Essential knowledge list (taken from EAS graduate handbook)

This document serves as a summary of the background knowledge and skills that are expected of PhD level students studying atmospheric and climate dynamics at Georgia Tech. The information listed here is primarily covered in a series of "core" atmospheric science courses, advanced specialty courses, disciplinary seminar series, and individual research endeavors. Undergraduate technical training in chemistry, mathematics (up to vector calculus and ordinary differential equations) and calculus-based physics is assumed and is not explicitly covered in the core atmospheric science courses. The graduate-level core courses include Introductory Fluid Dynamics and Synoptic Meteorology, Introduction to Climate Change, Thermodynamics of Atmospheres and Oceans, and Environmental Data Analysis. Although these courses are not requirements per se, they are first-year graduate courses that most students will take.

Descriptive Knowledge of the Atmosphere and Climate

- *Atmospheric composition and global vertical structure*
- *General circulation characteristics and seasonal variability*
- *Principal atmospheric scales and periodicities*
- *Extratropical weather systems: Air masses, fronts, cyclones, teleconnections and weather regimes*
- *Tropical weather systems: Tropical storms, monsoons, El Niño-Southern Oscillation, Intraseasonal Oscillation*
- *Atmospheric boundary layer*
- *Current and past climate characteristics*
- *Role of the atmosphere in the Earth System*
- *The atmospheric hydrologic and carbon cycles*

Atmospheric Fluid Properties, Statics, and Kinematics

- *Continuum hypothesis, ideal gas, equation of state*
- *Hydrostatic balance, pressure as a vertical coordinate, geopotential*
- *trajectories and streamlines, horizontal divergence and deformation, circulation and vorticity*
- *Nondivergent and irrotational flows, streamfunction and velocity potential*
- *Total derivative, material conservation principle and spatial advection*
- *Lagrangian and Eulerian characterizations of fluid time evolution*

Thermodynamics of the Atmosphere and Ocean

- *First Law of Thermodynamics, adiabatic processes in the atmosphere and ocean*
- *Entropy, Second Law of Thermodynamics, transport and time dependency*
- *Moist thermodynamic processes, static stability, buoyancy and convection*
- *Cloud and precipitation microphysics, cloud characteristics and radiative properties*
- *Surface exchange of heat and moisture, energy and salinity budget, ocean mixed layer*

Fundamental Conservation Laws and Equations of Motion

- *Conservation of mass: Continuity equation*
- *Conservation of energy: Thermodynamic equation*
- *Conservation of momentum: Navier-Stokes equations*
- *Inertial and noninertial reference frames*
- *Conservation of angular momentum and spherical coordinates*
- *Rotating reference frame, Centrifugal force, Coriolis force, effective gravity*
- *Primitive equations (rotating spherical reference frame)*

Fundamental Approximations and Large-Scale Balanced Circulations

- *Rossby number and scale analysis of the primitive equations*

 Geostrophic approximation and the thermal wind equation
 Inertial, geostrophic, gradient and cyclostrophic circulations
 Quasi-geostrophic approximation and diagnostic application
 Circulation theorem, Vorticity and potential vorticity equations
 Large-scale dynamical balance for the tropical atmosphere

Atmospheric Waves and Instability
 Linear theory , perturbation methods and wave properties
 Acoustic, gravity, and Rossby waves,
 Equatorial wave theory: Rossby-gravity and Kelvin waves
 Baroclinic, barotropic, inertial and convective instability

Global Energy Cycle and Global Climate
 Global energy balance and the greenhouse effect
 Solar and infrared radiative transfer in the atmosphere
 Radiative-convective equilibrium and role of clouds
 Regional energy balance and poleward energy transport
 Surface energy balance and the atmospheric boundary layer
 Roles of hydrologic cycle and oceanic circulation in climate

General Circulation and Climate Variability
 Zonally averaged circulation and angular momentum budget
 Longitudinally varying seasonal mean circulation (stationary waves)
 Lorenz energy cycle and the role of large-scale Rossby waves
 Coupled climate variability (land surface, biosphere, cryosphere, thermohaline circulations, El Nino)
 External natural climate forcing (orbital and solar variability, volcanic eruptions)
 Anthropogenic influences (greenhouse gases, tropospheric & stratospheric ozone, sulfate aerosols)
 Climate feedback processes, climate sensitivity, and climate equilibria
 Numerical simulation and prediction of climate variability

Basic Computing and Mathematical Skills
 Needs will vary: Suitable combination of Matlab, IDL, Fortran, GrADS, Ferret, or similar
 Basic Unix/Linux, Unix shell scripting, operating on multi-dimensional datasets (e.g., netCDF, GRIB)
 Vector calculus operations, matrix and vector algebra, Taylor series, linear differential equation solutions
 Basic statistical inferences, data fitting and least square theory, time series analysis, regression analysis
 Spectral analysis, orthonormal functions, Fourier series, principle component analysis, wavelet analysis
 Numerical methods, discretization schemes, error and stability analysis, nonlinear systems, inverse methods

Nonlinear Dynamics (not present in the original knowledge list)
Fundamental concepts: Lyapunov exponents, Poincaré Sections
Low dimensional flows: Lorenz attractor, Rössler flow.
State space representation, Maps, Liouville Equation.
Concepts of Periodic Orbit Theory

Specialized Skill Sets
 Tropical dynamics: Scale analysis, equatorial wave theory, steady forced motions, tropical cyclone physics
Key Textbook Resources
 An Introduction to Dynamic Meteorology, James R. Holton, Elsevier/Academic Press
 Global Physical Climatology, Dennis L. Hartmann, Elsevier/Academic Press
 Thermodynamics of Atmospheres and Oceans, Judith Curry and Peter Webster, Elsevier/Academic Press
 Discrete Inverse and State Estimation Problems, Carl Wunsch, Cambridge Press
 Statistical Methods in the Atmospheric Sciences, Daniel Wilks, Elsevier/Academic Press