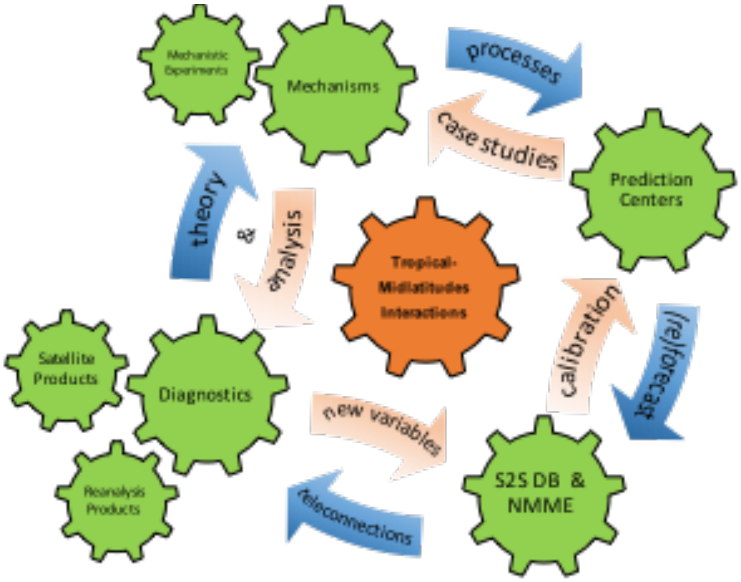
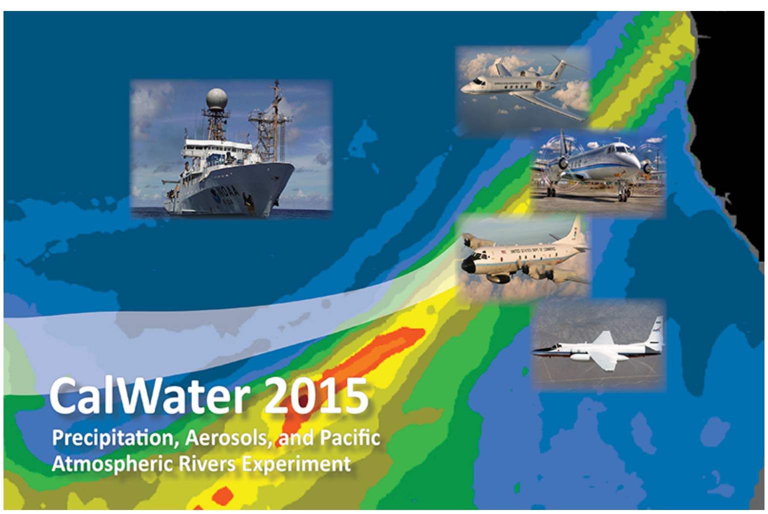


Whitepaper

YTMIT-CalWater2015

Atmospheric Rivers and their Teleconnections



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At a Glance

Goal:

To advance the scientific objectives of the Year of Tropics-Midlatitude Interactions and Teleconnections (YTMIT) activity to understand the role of tropical-extratropical interactions on the moisture sources and subseasonal predictability of atmospheric rivers using observations from CalWater-2015 combined with numerical experiments using two novel modeling frameworks.

In this Whitepaper:

- Introduction
- Working hypothesis
- Experiments
- Models and datasets

Outcomes:

- The proposed project would bring together two communities working on outstanding problems of atmospheric dynamics and water cycle
- The set of experiments will serve as the benchmark for a larger intercomparison project

Whitepaper

Atmospheric Rivers and their Teleconnections

Introduction

The teleconnections between the tropical and extra-tropical regions on subseasonal-to-seasonal time scales are emerging as a leading candidate to explain high-impact weather events in low- and midlatitudes in a changing climate. For example, the major storm that swept through Southern California in December 2014 was very likely the result of the interaction between the subtropical jet, a fragmented branch of the polar jet, and organized convective activity in the Tropics. Palmer (2014) suggested that the record-breaking 2013-2014 winter in the Midwest U.S. was caused by an intensification of the Northern Hemisphere jet stream in response to the enhanced convective activity in the tropical West Pacific. Vitart's (2013) evaluation of the ECMWF model indicates a significant improvement of the NAO forecast skill due to increasingly more realistic simulation of the MJO teleconnections in the Euro-Atlantic regions.

While the existence of teleconnections from tropical heating and SST variability has been well documented, fundamental questions regarding the underlying mechanisms remain unanswered. Are mid-latitude teleconnections from the fluctuating tropical heating fundamentally just time-lagged stationary wave responses to the heating, or does time-dependent wave interference play a role? Why are the North Atlantic weather regimes so influenced by MJO-related heating in the distant Indian and Pacific Oceans? Is the excitation of fundamental modes of barotropic instability an important player? What is the role of synoptic–scale transients? On shorter time scales, how does intense tropical storm-related heating impact the low-frequency extra-tropical circulation fluctuations?

We know that tropical convection itself may be excited and/or maintained by extra-tropical influences, yet many unanswered questions remain. Is extra-tropical forcing affecting primarily the initiation of tropical convection, or can it organize tropical convection on intraseasonal time scales? What is the role of PV streamers? What regions favor the propagation of extratropical signal into the tropics? Does extratropical excitation have a significant impact on the life cycle of tropical intraseasonal oscillations? How do intense mid-latitude storms and poleward propagating tropical storms interact with the polar vortex?

YTMIT

Virtual field campaign to understand and predict sub-seasonal tropical-extratropical interaction pathways

CalWater2015

Precipitation, Aerosols, and Pacific Atmospheric Rivers Experiment sponsored by NOAA, DOE, NSF, NASA, and NRL

In order to extend our ability to predict the probability of significant circulation anomalies and associated weather events beyond the limit of deterministic weather predictability, we need to make progress in understanding tropical-extratropical two-way interactions. We must identify those properties of tropical heating that are critical in producing extra-tropical subseasonal responses, and similarly for the extratropical influence on the tropics. Toward these ends *an intense coordinated effort involving existing observational data, forecasts and applications, diagnostics, theory and modeling experiments*: The Year of Tropics-Midlatitude Interactions and Teleconnections (YTMIT) has been proposed (Stan et al. 2016). This program is designed to foster relationships between research, forecasting, and stakeholder communities, and will facilitate the sharing of common interests to explore the links between the tropics and midlatitudes. This international program will include an integrated observations component (using existing products of Global Observing System, reanalyses, and field campaigns), an operational forecast and reforecast component (using the S2S and NMME databases), an applications component, and a research component aligned with the research priorities of the S2S/Teleconnection sub-project science plan, WWRP and WCRP missions. The research component will consist of a combination of theoretical, diagnostic, and modeling studies and will focus on understanding the physical nature of the tropical-midlatitude interactions and teleconnections and their potential as sources of predictability. All the components will interact and provide feedbacks as suggested by the cover diagram, to help make more rapid progress.

The CalWater-2015 field campaign provides a unique opportunity for addressing the YTMIT goals because data were collected using multiple observing platforms sponsored by multiple agencies to study atmospheric rivers, which is an important phenomenon discussed in the S2S teleconnection framework with significant modeling challenges and societal implications.

Working hypothesis

One of the unsolved problems of atmospheric rivers (ARs) is the tropical or extra-tropical origin of their moisture sources (Dacre et al. 2015), which has implications to the precipitation produced by ARs upon landfall and their S2S predictability. Ryoo et al. (2015) categorized the AR events into events of tropical origin and extra-tropical origin.

To further understand the difference between the two categories of ARs, we need to develop diagnostics that will evaluate the events in connection with the tropics-midlatitude teleconnections and validate them using observations and numerical experiments. We hypothesize that tropical-extratropical interactions can influence the pathways for ARs propagation and extend the subseasonal predictability of ARs in the North Pacific along with their associated moisture signature and precipitation.

Intraseasonal Teleconnections

Two-way interactions between the tropics and the mid- and high-latitudes *on intraseasonal time scales* of 20 to 100 days

Numerical Experiments

Previous studies have demonstrated predictability of AR moisture signature (Wick et al. 2013) and AR extreme precipitation (Lavers et al. 2014) in extended medium-range weather forecasts. To test our hypothesis, a set of relation experiments will be performed. In the first type of experiments, subseasonal forecasts for AR events with a tropical trajectory will be made with the midlatitude large-scale environment relaxed towards a climatological value. Cristiana Stan is writing a paper showing that midlatitudes in the Northern Hemisphere have intra-seasonal oscillations, which are independent of MJO. Phases of these oscillations can have a significant impact on the teleconnections. In the second type of experiments, forecasts for AR events with an extratropical trajectory will be made with the tropical large-scale environment relaxed towards climatology. These forecast cases will be selected from the 17 Pacific ARs observed during CalWater-2015 between mid-January to early-March of 2015. These simulations will be compared to control simulations without relaxation of the midlatitudes or tropics towards climatology to determine processes in the tropics and extratropics that favor, suppress, or influence the development of the ARs and their moisture budgets. All simulations will be compared with observations from CalWater-2015.

Atmospheric Rivers

Deliver most of the water vapor associated with major storms along the U.S. west coast

New generation of models with resolutions finer than 1 deg (typical resolution of the CMIP5 models) offer opportunities to better simulate and understand the dynamics of AR events. High resolution is necessary for simulating upper level Rossby wave breaking, which is an important ingredient of linkages between the tropics and extra-tropics, and it is potentially important for simulating a more realistic jet and water vapor transport, especially during ENSO events.

Models

- MPAS-CAM5
- SP-CAM5

Datasets

- ERA-I
- dropsonde observations from NOAA G-IV
- surface fluxes from NOAA Ron Brown
- Radiosonde observations launched from Ron Brown
- cloud and radiation measurements from DOE AMF2 on Ron Brown

Studies conducted by the WACCEM team show that the frequency of ARs in climate simulations is very sensitive to the position and strength of the jet stream (Gao et al. 2016), with a hint of convergence at resolutions in the range of 0.25-0.5 degrees (Lu et al. 2015). At such resolutions, the equatorward bias of jet stream position robustly found in CMIP5 models may be mitigated. While the proposed experiments can be done using high resolution global models, global variable resolution models offer a modeling framework using regional refinement to computational savings that can be used for ensemble modeling.

Experiment	Length	Ensembles
Control re-forecast	30 days	10 ICs 5 days apart
NHMID-T	30 days	10 ICs 5 days apart
TROP-T	30 days	10 ICs 5 days apart

In the Northern Hemisphere Midlatitudes Troposphere (NHMID-T) relaxation experiment the model will be relaxed over the 35^0-65^0N domain and leave the model unchanged everywhere. In the TROP-T relaxation experiment the model the tropical troposphere between 20^0S-30^0N will be relaxed and leave the model unchanged everywhere.

The relaxation is implemented by adding an extra term to the model state vector ($\boldsymbol{X}$):

$$\frac{d\boldsymbol{X}}{dt} = \boldsymbol{F}(\boldsymbol{X}) - \boldsymbol{\lambda}(\boldsymbol{X} - \boldsymbol{X}^{ref})$$

where $\boldsymbol{X}^{ref}$ represents the analysis data, and $\boldsymbol{\lambda} = \boldsymbol{\lambda}(\boldsymbol{\lambda}, \boldsymbol{\varphi}, \boldsymbol{z})$ is the relaxation parameter. For the NHMID-T experiment, parameters to be relaxed include zonal and meridional wind components, temperature, and the logarithm of surface pressure. For the TROP-T experiments parameters to relax include diabatic heating and/or zonal and meridional wind components.

Models and Datasets

This project will use two state-of-the-art climate models: the Model for Prediction Across Scales (MPAS) coupled to the physics package of the Community Atmosphere Model (CAM5) (Zhao et al. 2016) and the super-parameterized (SP) version of CAM5. MAPS is well suited for high-resolution atmospheric simulations and SP-CAM uses a quasi-explicit representation of cloud processes.

The re-forecasts will be initialized using ERA-I reanalysis. In the relaxation experiments the model will be relaxed toward the monthly mean ERA-I reanalysis. The control re-forecast experiments will be evaluated against high-resolution reanalysis and dropsonde and radiosonde observations of water vapor transport along transects of the ARs from NOAA G-IV and Ron Brown, respectively, surface fluxes, precipitation, and cloud measurements from the ARM Mobile Facility (AMF2) on Ron Brown, and satellite retrievals of cloud liquid/ice water path and cloud top height and temperature.

Pacific Northwest NATIONAL LABORATORY

Outcomes

The proposed project would bring together two communities working on outstanding problems of atmospheric dynamics and water cycle as "two arms of the same body" to support the advancement of knowledge of climate variability on intra-seasonal time scales. The project also advances the legacy of the CalWater-2015 field campaign beyond its defined scope of the activity focusing on improving AR forecast at weather time scale and understanding the aerosol-cloud interactions on AR precipitation.

GEORGE MASON UNIVERSITY

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