A Moist Quasi-Geostrophic Coupled Model: MQ-GCM2.0

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Introduction

- The Quasi-Geostrophic Coupled Model (Q-GCM) is an idealized mid-latitude coupled climate model.
- Consists of the 3-layer quasi-geostrophic (QG) ocean and atmosphere components coupled via ageostrophic mixed layers that regulate the exchange of momentum from atmosphere to ocean, and flux of heat in both directions.

Model Schematics

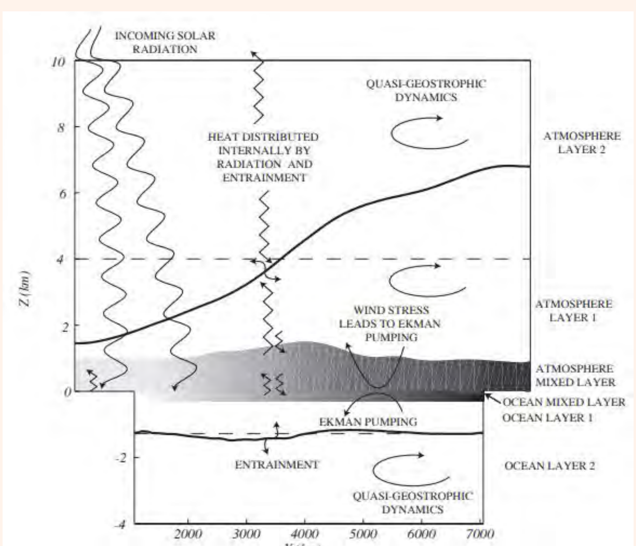

Figure 1: Schematic of (a two-layer version of) the Q-GCM. Source: Hogg et al. 2014.

1. Heat distributed by radiation and entrainment and spin up the atmosphere;
2. Wind stress leads to Ekman pumping and spinning up the gyres;
3. Heat and momentum are exchanged between the fluids by the mixed layers (fixed depths).

Moist Q-GCM

We developed a new, revamped version of the Q-GCM: Moist Q-GCM (MQ-GCM)

Updates to the original model:

•Improved radiative-convective scheme leading to a more realistic model mean state;

•A new formulation of entrainment in the atmosphere resulting in more efficient communication between the atmospheric mixed layer and free troposphere;

•A new temperature-dependent flow in the atmospheric mixed layer and partially coupled setup;

•The inclusion of the *HYDROLOGICAL CYCLE* and *LATENT HEAT* feedback (the precipitation rates and latent heat corrections are computed and used to adjust the entrainment rates).

Results

- Multiple model versions developed exhibit a lack of any detectable effect of mesoscale air–sea coupling (SST-wind feedback) on the model's free-atmosphere circulation, under both coarse and high horizontal resolution.
- Mesoscale air-sea coupling exerts a negative feedback on the ocean's eddy activity (cf. Hogg et al., 2009), thereby reducing the intensity of the oceanic mesoscale features and thus diminishing further the potential of these features to affect the MABL winds;
- A partially coupled model version in which this negative feedback is suppressed still exhibits no pronounced multi-scale coupled modes sensitive to ocean-induced SST anomalies.
- The above conclusions seem to be unaffected by the addition of the hydrologic cycle in the moist version of the model.

New Experiments: Atmosphere-only configuration's response to variable SST front

The goal is to understand the lack of free-atmosphere sensitivity to SST anomalies, in dry and moist versions of the Q-GCM model.

- Simulation period of 50 years;
- Resolution of 120 km atmosphere and 10 km ocean;
- Dry vs Moist;
- Temperature-dependent wind stress (TDWS) [Hogg et al., 2009] mode vs Control (CTRL) mode;
- Idealized SST front with the 3-yr period sinusoidal variation of latitudinal position, 25°C/1000km.

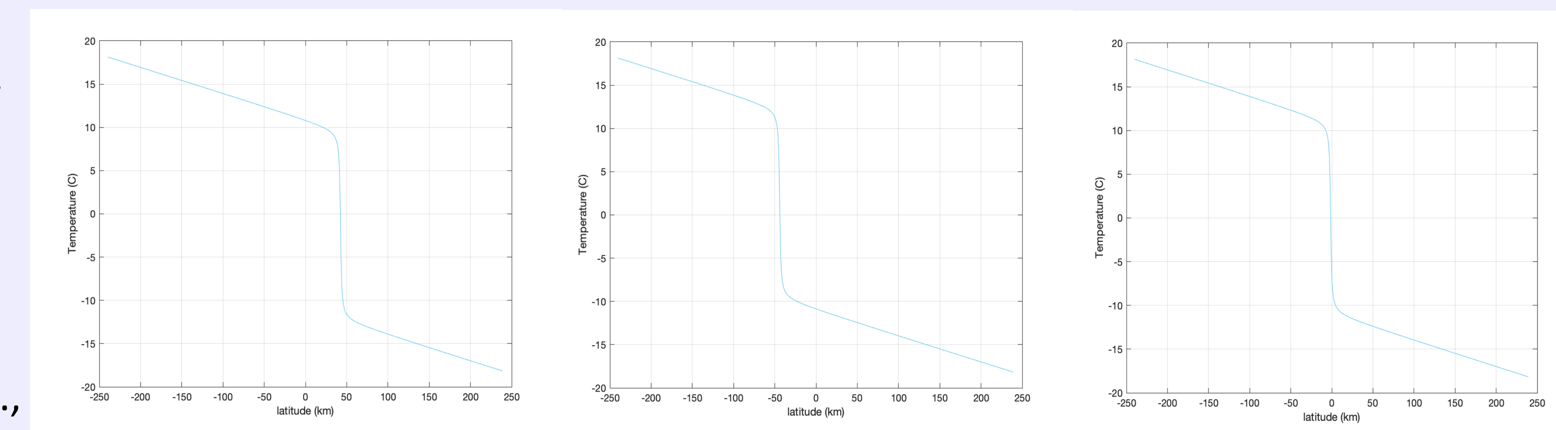

Figure 2: Magnitude and position of SST front at years 1, 2, and 3, respectively, relative to the middle of the ocean box. The front is at "zero" latitude initially ("zero" latitude refers to mid-ocean).

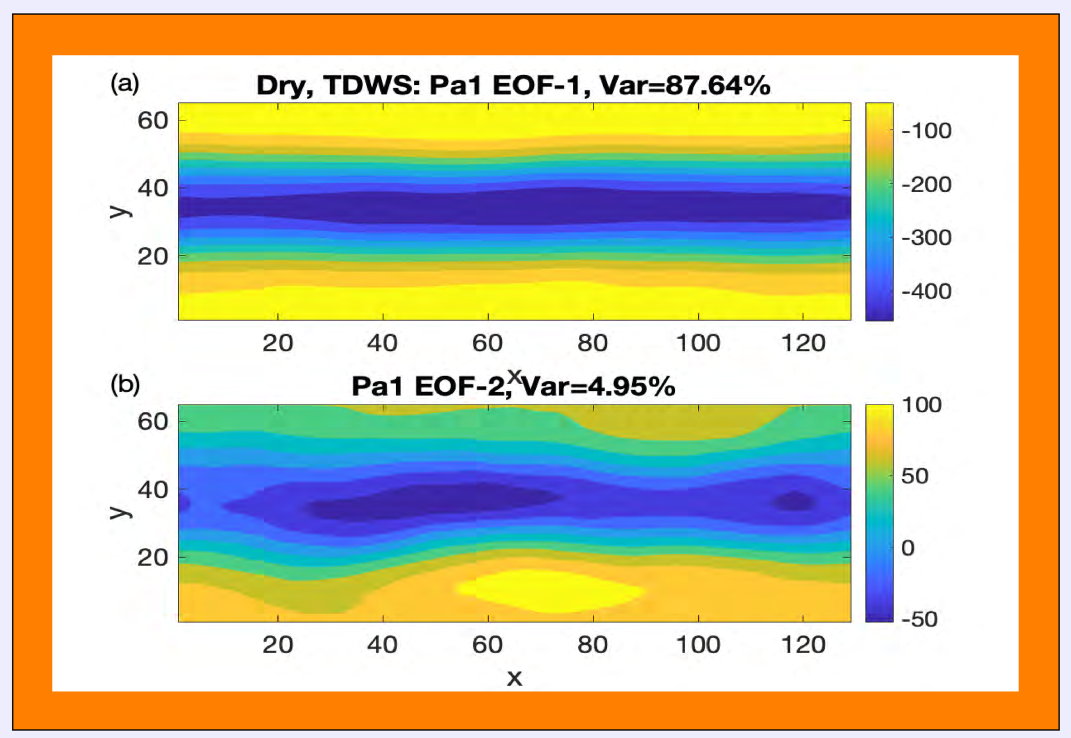

Figure 3: Dry – TDWS experiment: (a) EOF-1 pattern and corresponding variance of the atmospheric dynamic pressure of the lower layer (m²/s²); (b) same as (a) but EOF-2 and corresponding variance.

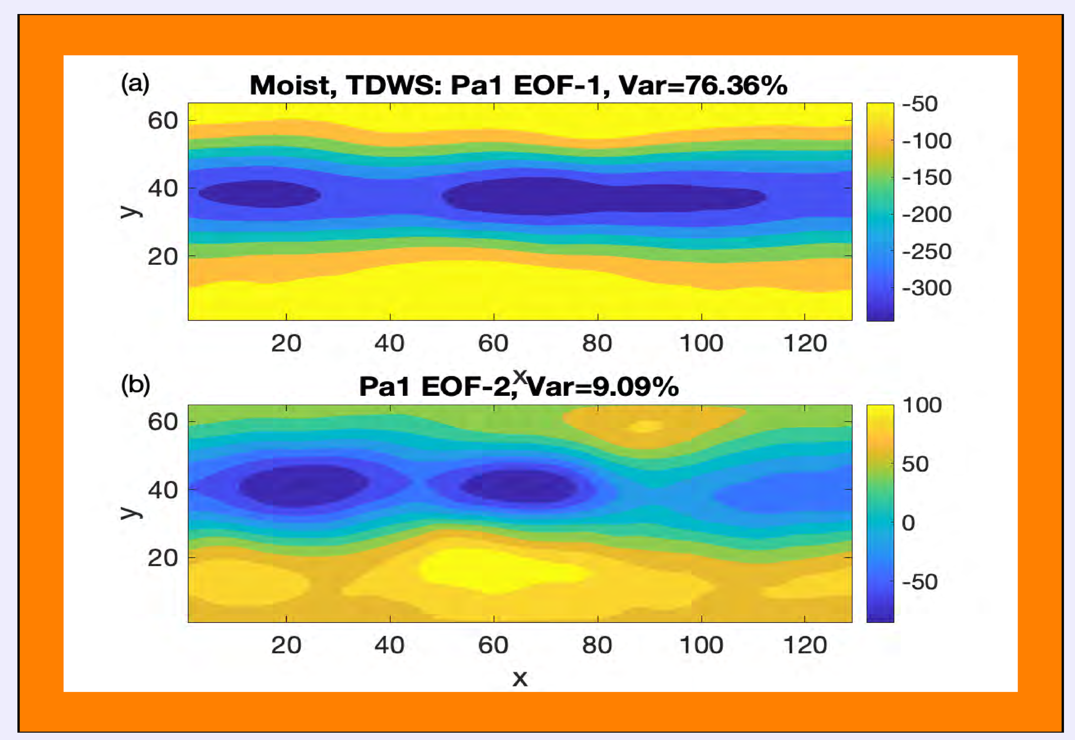

Figure 5: Same as Figure 3, but for Moist – TDWS experiment.

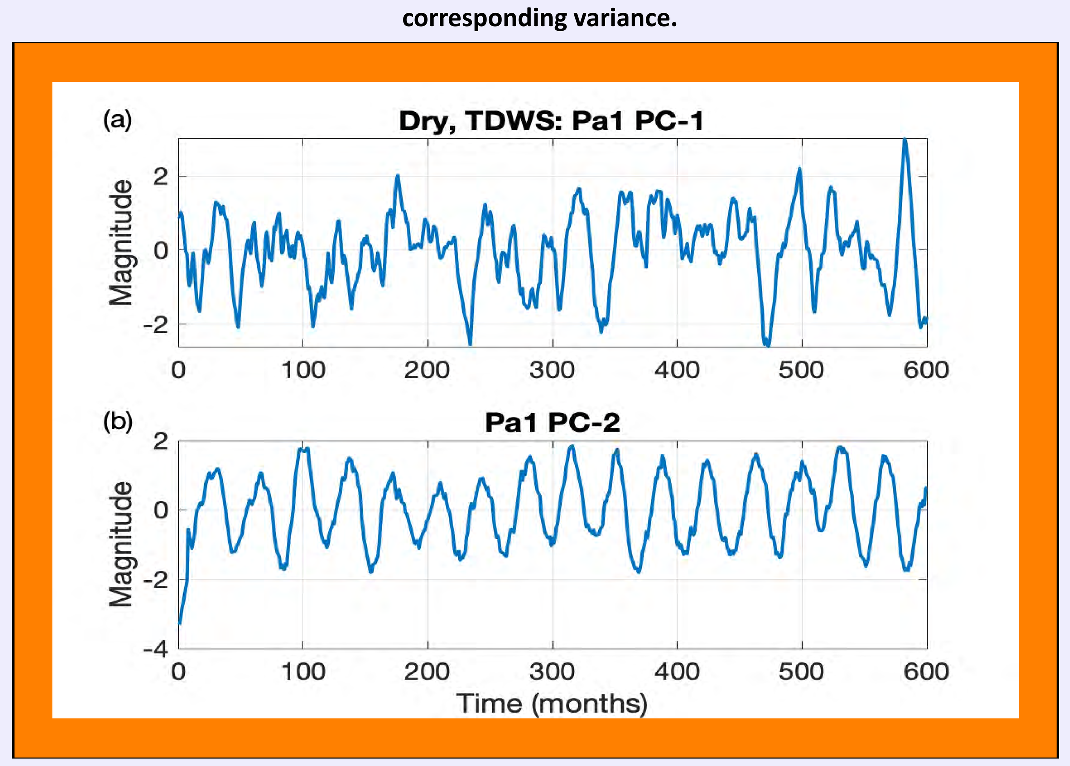

Figure 4: Dry – TDWS experiment: (a) PC-1 of the atmospheric dynamic pressure of the lower layer; (b) same as (a) but PC-2.

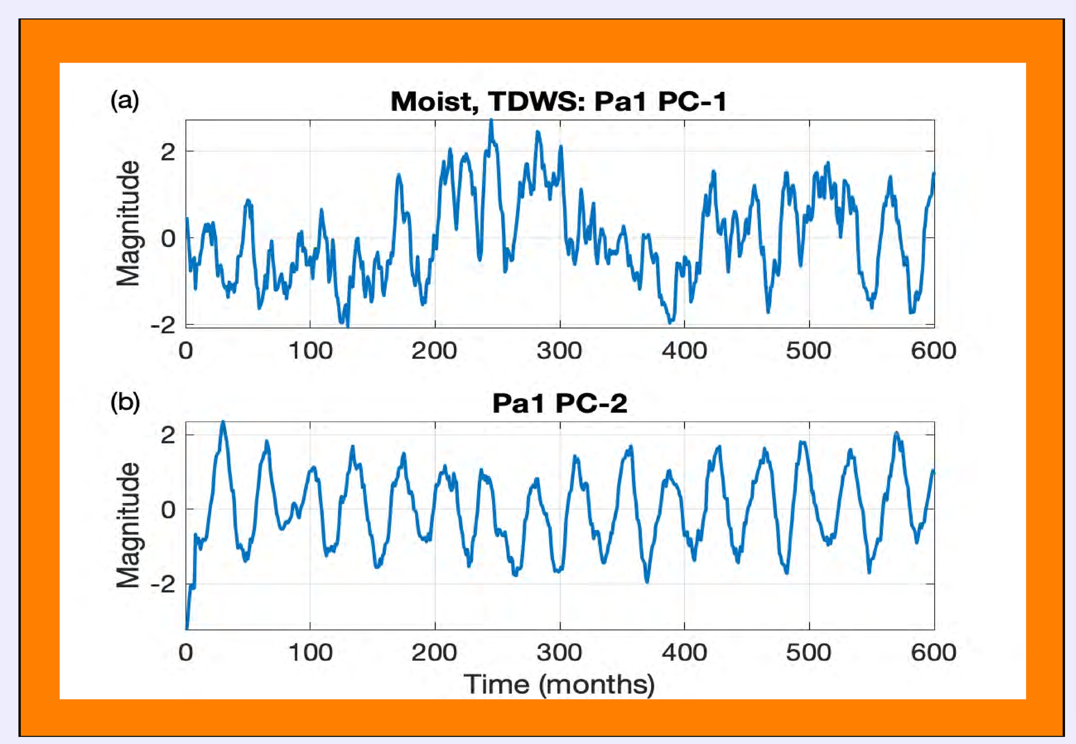

Figure 6: Same as Figure 4, but for Moist – TDWS experiment.

- **Shown are the results of the Empirical Orthogonal Function (EOF) analysis of the 1-yr boxcar running-mean smoothed lower-layer streamfunction.**
- **Both of the leading EOFs have patterns associated with the atmospheric jet shift.**
- **Leading EOF is internal red noise, while the second EOF clearly describes the response to the periodic SST variations.**
- **Free atmosphere is sensitive to the periodically shifting SST front, even with the coarse resolution.**
- **Signal-to-noise ratio is larger in the moist run (9/76 vs 5/88, or 12% over 5%), but still low.**

Discussion

- However, even this larger signal-to-noise ratio is still small and apparently still insufficient to produce a detectable effect on the free atmosphere in the coupled run, where the SST anomalies are less coherent than in the present.
- We hypothesize that the improvement in the atmospheric sensitivity is due to the inclusion of the HYDROLOGICAL CYCLE and LATENT HEAT feedback.

Future Work

- Improving the latent heat parametrization in the MQ-GCM model by iterating the solution of the moisture equations at a given time step to achieve mutually consistent estimates of both precipitation and entrainment in the interior QG layers.

References

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For further information

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- MQ-GCM model is uploaded to Zenodo and DOI is https://doi.org/10.5281/zenodo.5250828