# Testing the Sensitivity of Extratropical Cyclones to Variations in Environmental Conditions

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## Summary

- Current research shows that the controlling factors on extratropical cyclone strength may exert competing influences in a warming climate system.
- Dry and moist sensitivity studies were carried out using WRF in its idealized mode, with system variability accounted for through five environmental parameters.
- **While dry simulations suggest a straightforward relationship between changes in temperature and cyclone strength, addition of moisture leads to monotonic changes in minimum sea level pressure and non-monotonic changes in peak eddy kinetic energy of the cyclone.**

## Introduction

In considering the main drivers of mid-latitude weather conditions, extratropical cyclones (ETCs) should be considered one of the greatest influences, as they provide much of the precipitation throughout the planet's temperate zones (Heideman and Fritsch 1988). With wide-ranging impacts on agriculture, commerce, and society at large, understanding the changes to ETC strength in a warming climate is crucial.

Factors such as temperature, moisture content, jet strength, and baroclinicity all play a role in ETC evolution. Current research indicates competing effects on ETC strength in a warming climate, as for example:

- A weaker equator-to-pole temperature gradient (Solomon et al. 2007) leads to weaker ETCs.
- Increasing atmospheric moisture content (Held and Soden 2006) leads to stronger ETCs.

We utilize numerical modeling techniques in this study and examine ETC sensitivity to multiple environmental changes in a consistent and systematic manner.

## Model Setup

The Weather Research and Forecasting (WRF) model (Skamarock, et al. 2008), version 3.5.1, is run in an idealized mode with the following settings:

- Channel configuration (north and south boundaries of the domain are symmetric, eastern and western boundaries are periodic)
- Contains 81 x 181 x 50 grid points in the x, y, and z directions
- Grid spacing of 50km in the x and y directions.
- 14 day runtime, with the storm intensity peaking between days 10-12.

The baseline for our initial conditions is a modified version of the baroclinic wave test case (Booth et al. 2012):

- Ocean surface through the entire domain.
- A prescribed jet profile and designated "anchor" surface temperature.
- Zonal wind and temperature fields in thermal wind balance.
- Cyclone initiated with a domain-centered temperature perturbation .

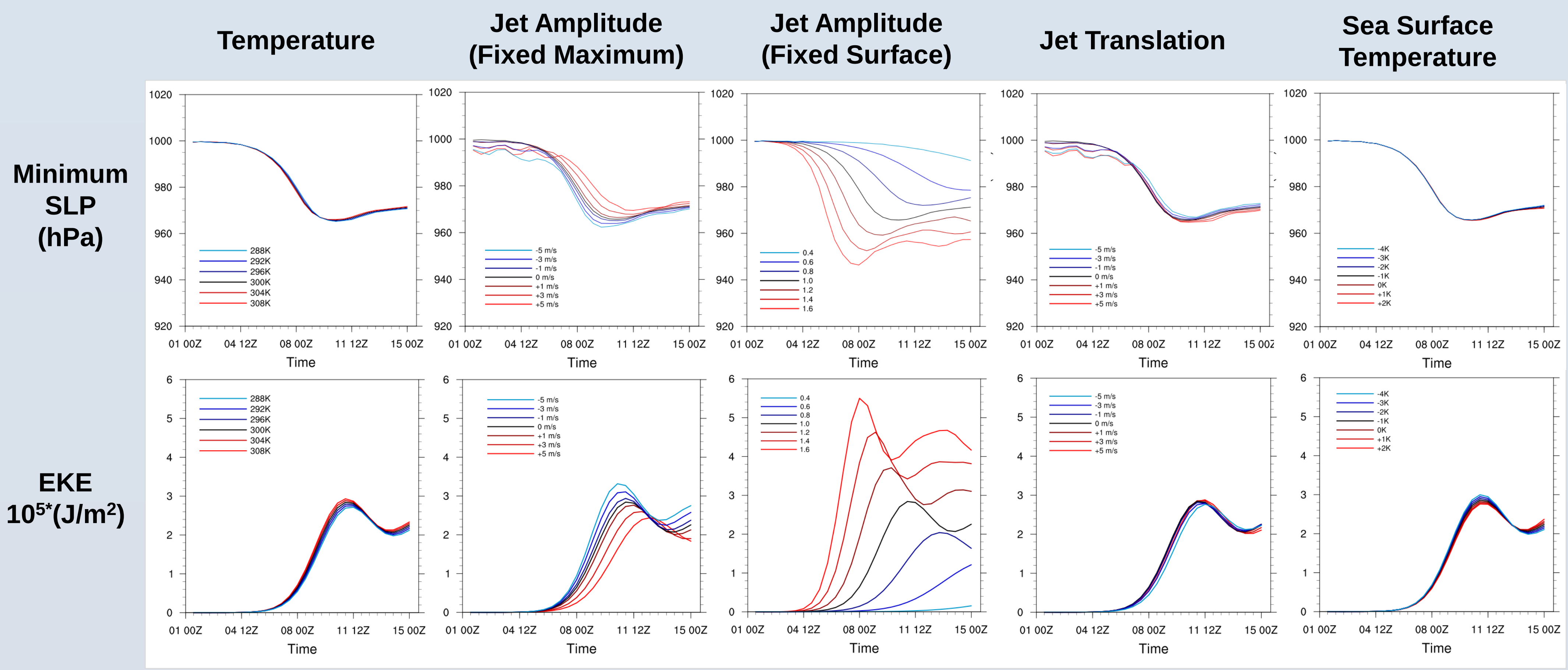
We devised parameters that allow systematic changes to the controlling influences as well as adding an adjustment for mass balancing when performing tests with water vapor in the domain. The governing parameters are described more fully in Table 1 below.

| Name | Description | Minimum Value | Maximum Value | Default Value |
|---|---|---|---|---|
| **Temperature** | **The base temperature for construction of the vertical temperature profile in the domain.** | **288K** | **308K** | **300K** |
| **Jet Amplitude (Fixed Maximum)** | **A weighted constant added onto jet profile, with weights increasing from jet maximum (weight = 0) to the surface (weight = 1).** | **-5 m/s** | **+5 m/s** | **0 m/s** |
| **Jet Amplitude (Fixed Surface)** | **A multiplicative factor applied to the entire jet profile.** | **.4** | **1.6** | **1.0** |
| **Jet Translation** | **A constant added onto the entire jet profile.** | **-5 m/s** | **+5 m/s** | **0 m/s** |
| **Sea Surface Temperature (SST)** | **Constant subtracted off the temperature of the lowest model level to initialize SST.** | **-4K** | **+2K** | **-.5K** |

**Table 1.**
*Description of control parameters in the initialization routine*

## Results – Dry Simulations

**Figure 1:** Results of Dry Sensitivity Tests: Minimum SLP (top row) and EKE (bottom row)



## Results – Moist Simulations

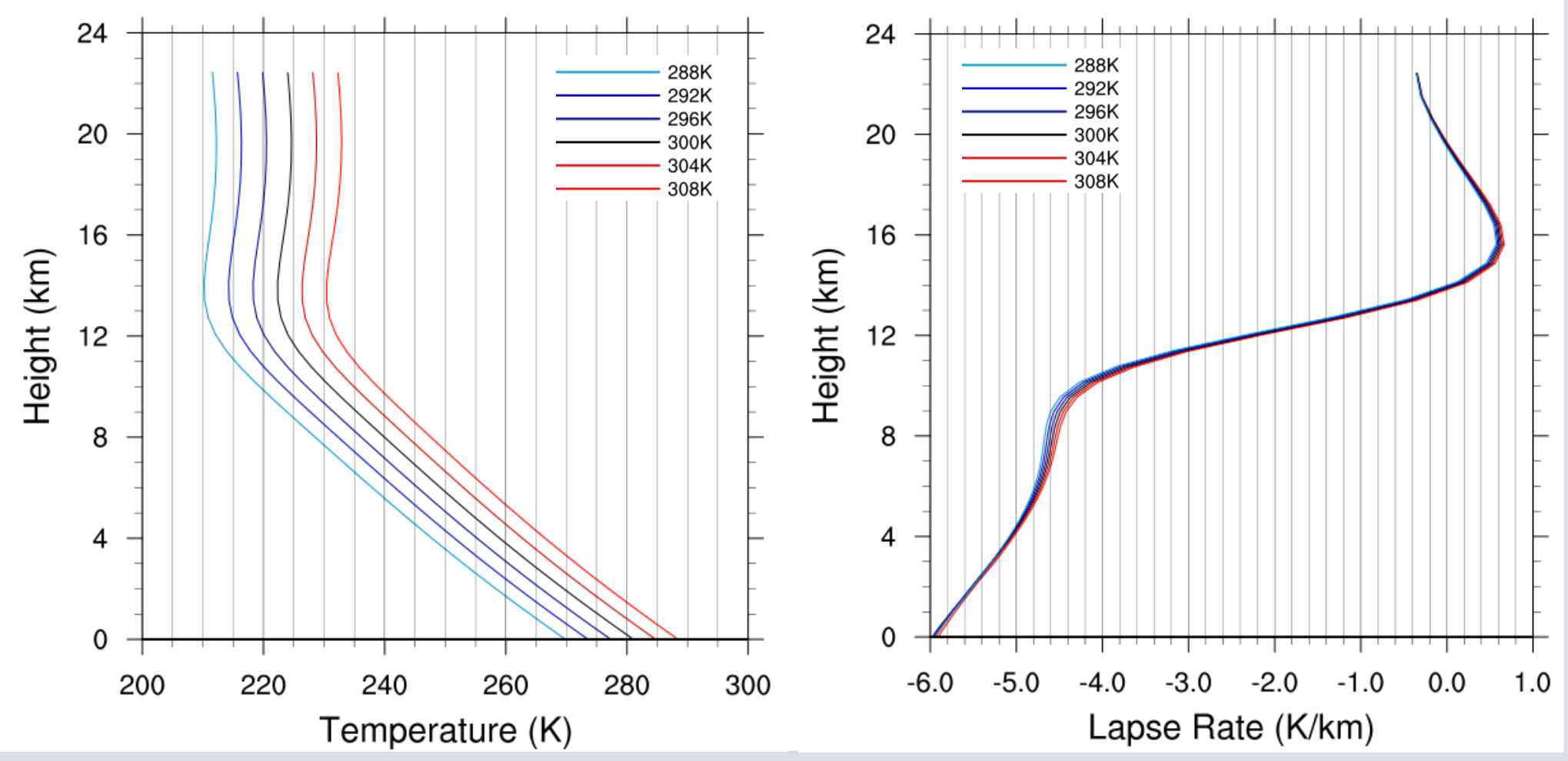


**Figure 2:**
Temperature Profiles (left) and Lapse Rates (right) in the center of the domain at initialization

**Figure 3:**
OLR (left) and SLP/850 hPa Theta (right) near peak storm strength (Day 10, 12Z)

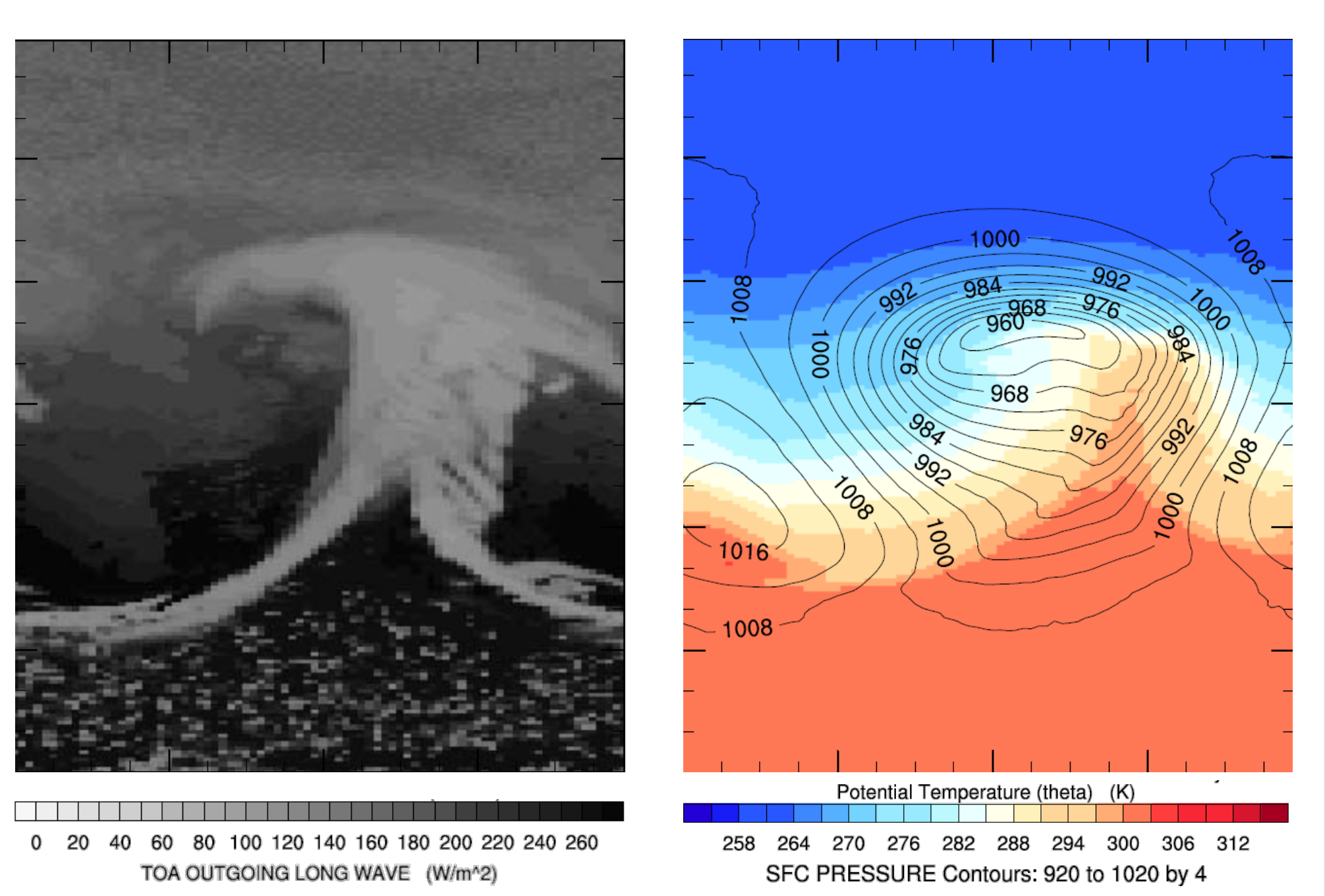
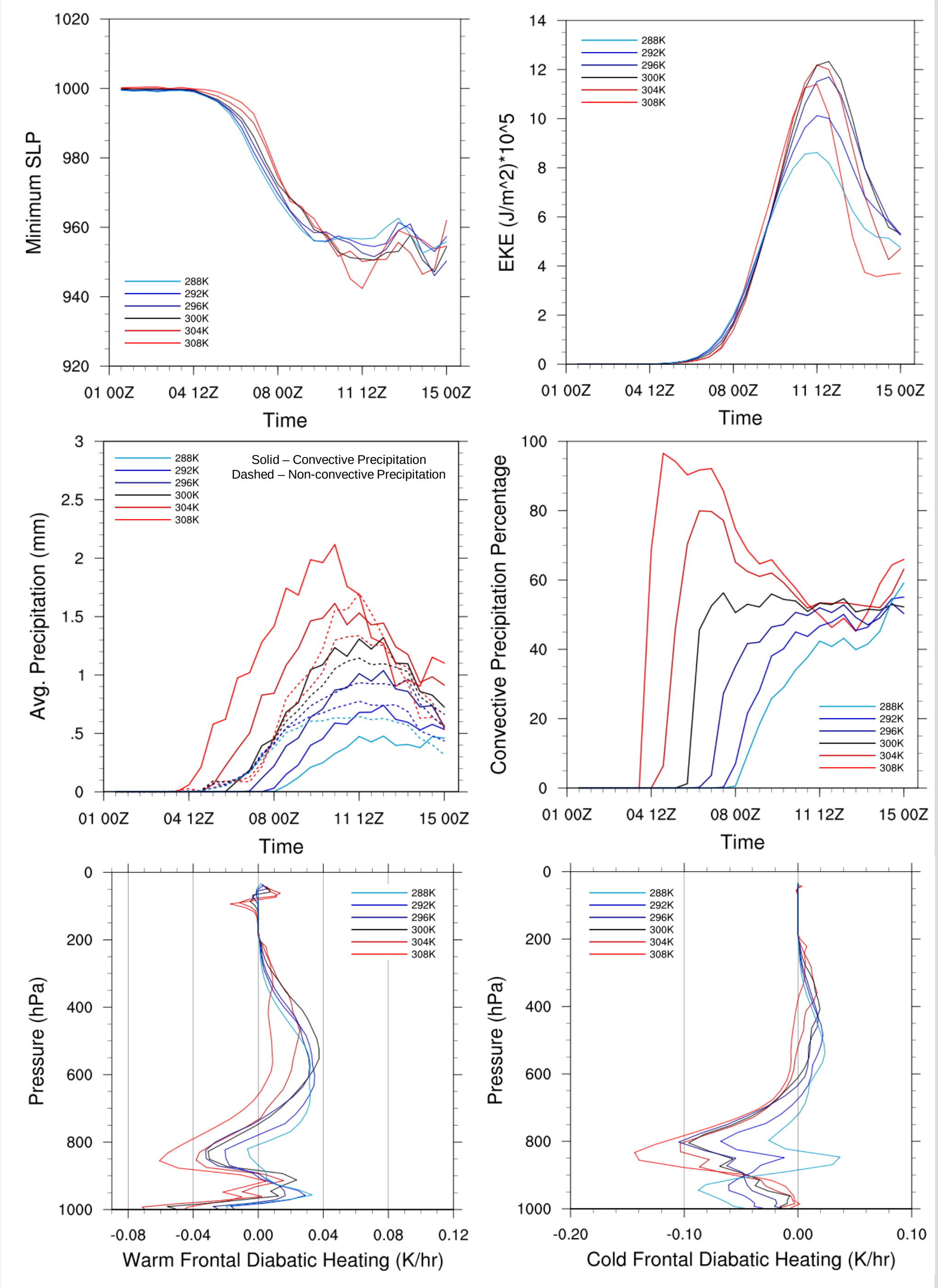


**Figure 4:** Results of Moist Temperature Sensitivity Test



## Conclusions and Future Work

- Without moisture present, the main controlling factor on extratropical cyclone strength is baroclinicity (controlled via tuning of the jet profile), rather than variations in the temperature profile.
- When moisture is included, an ETC will strengthen much more then its dry analog. Also, temperature begins to have a larger controlling influence on the system, demonstrating the effect of diabatic forcing.
- With moisture added, the minimum SLP of a system decreases monotonically with increasing temperature. However, peak EKE has a non-monotonic trend, increasing until a tipping point between 300-304K, after which it beings to decrease.

Steps to further this work include:

- Removing the effect of convective schemes by running at convection-permitting scales. We have currently run down to mesoscale-resolving grid spacing (See Figure 5), and will conduct tests at 4 km grid spacing in the next few months.
- Completing moist sensitivity tests for the remaining 4 parameters.
- Determining a more precise adjustment for mass balancing when adding moisture into the model.
- Multivariate explorations of the parameter space in order to understand how these controlling factors might interact and feedback in the climate system.

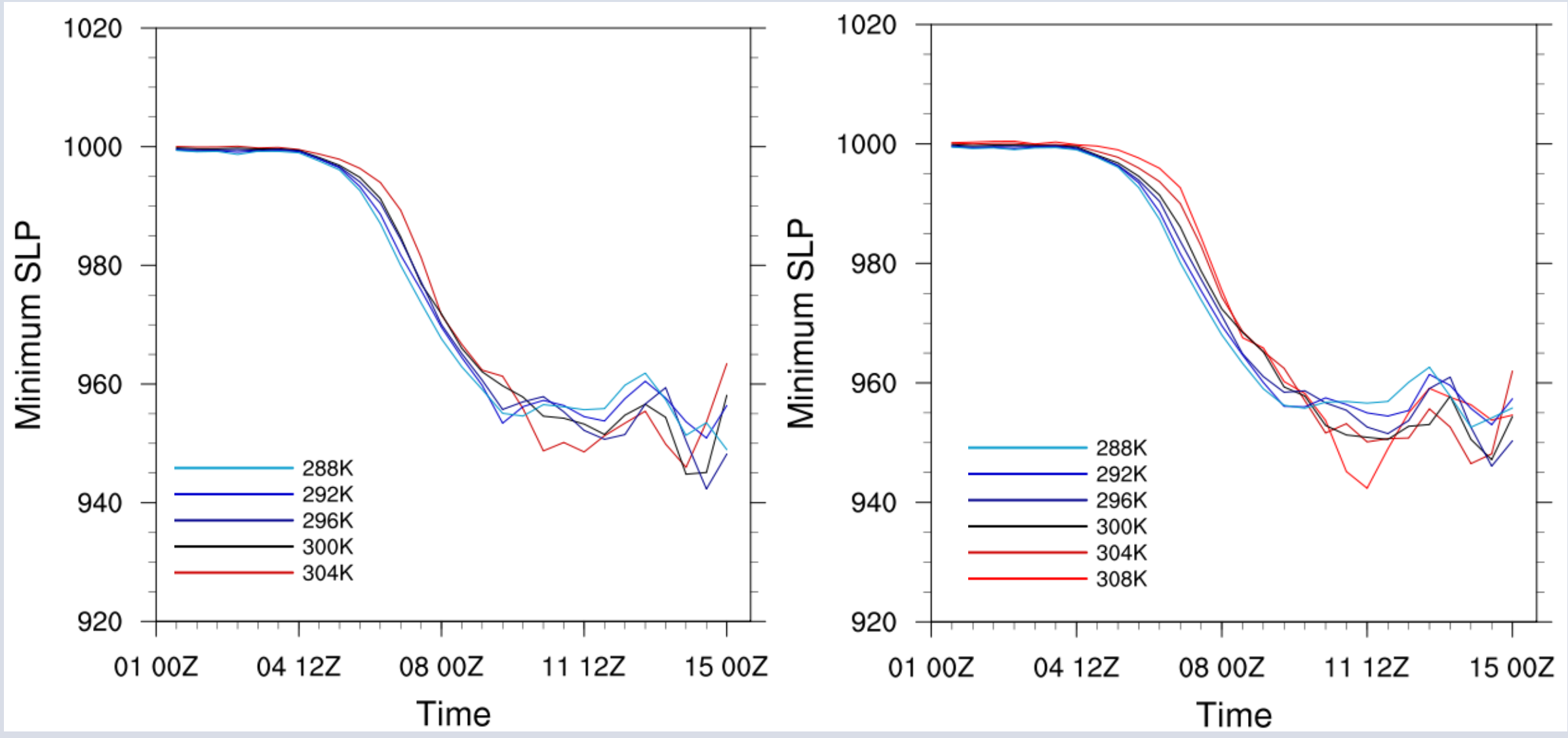


**Figure 5:** Comparison of Minimum SLP for 25km grid spacing (left) and 50km grid spacing (right)

## References

Booth, J. F., S. Wang, and L. Polvani, 2012: Midlatitude storms in a moister world: lessons from idealized baroclinic life cycle experiements. Clim Dyn, 41, 787-802

Heideman, K. F., and J. M. Fritsch, 1988: Forcing mechanisms and other characteristics of significant summertime precipitation. Wea. Forecasting, 3, 115-130.

Held, I.M., Soden, B.J., 2009: Model projected changes of extreme wind events in response to global warming. J Clim, 19:5686-5699

Solomon, S. et al., Climate change 2007: The Physical Science Basis. In: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York.

Skamarock, W.C., et al., 2008, A description of the advanced research WRF Version 3, NCAR Technical Note.

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