Examining the Effect of Tropical Cyclones on Atmospheric Chemistry Using a High Resolution WRF-Chem Model

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INTRODUCTION

The transport of gases and aerosols to the upper troposphere/lower stratosphere (UTLS) impacts the Earth's climate. This study aims to improve our understanding of the vertical transport of surface-based species by examining the widespread convection associated with tropical cyclones (TCs). We focus on TCs in the western North Pacific (WNP) because it is the world's most active basin. It produces larger and stronger storms than any other basin, and TCs in the WNP often make landfall in East Asia, one of the world's most polluted regions.

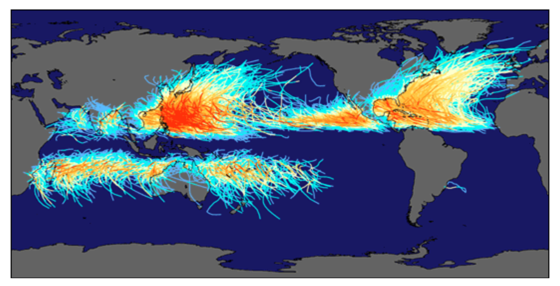

Figure 1. Global TC tracks over 150 years ending in 2006. The figure is from the following NASA site: *http://earthobservatory.nasa.gov.proxy.lib.fsu.edu/IOTD/view.php?id=7079.*

OBJECTIVES

- Re-examine Typhoon Mireille using the high-resolution WRF model with chemistry (WRF-Chem; Grell et al. 2005).
- Determine how well in situ chemical data agree with WRF-Chem simulations.
- Compute vertical chemical fluxes.

MODEL CONFIGURATION

WRF-Chem v3.7

- 27-9-3 km grid spacing

**The innermost domain (d03) will be used in future WRF-Chem simulations*

- Two-way nesting
- 48 h nudging period
- 60 vertical levels
- WSM6 microphysics
- RRTM longwave
- Dudhia shortwave
- YSU PBL scheme
- Kain-Fritsch CPS

Chemical Emissions

- RETRO anthropogenic
- MEGAN biogenic

IC and BC

Meteorology: ERA-Interim, 0.7° global grid at 38 pressure levels

Chemistry: MOZART-4, 1.9° x 2.5° with 56 vertical levels

BCs updated every 6 h

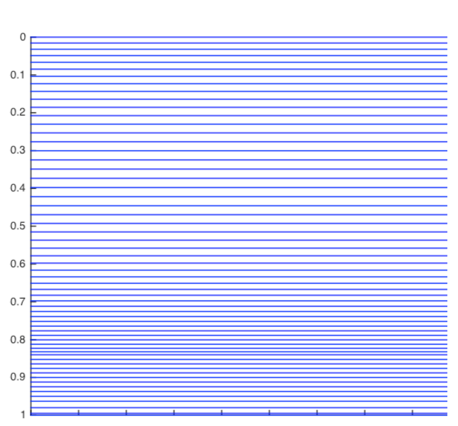

Figure 2. The 60 eta levels used as the vertical coordinate from the WRF-Chem simulations.

SST

OISST dataset on a 0.25° global grid

**SST valid for 18 Sep 1991 and held constant during simulation*

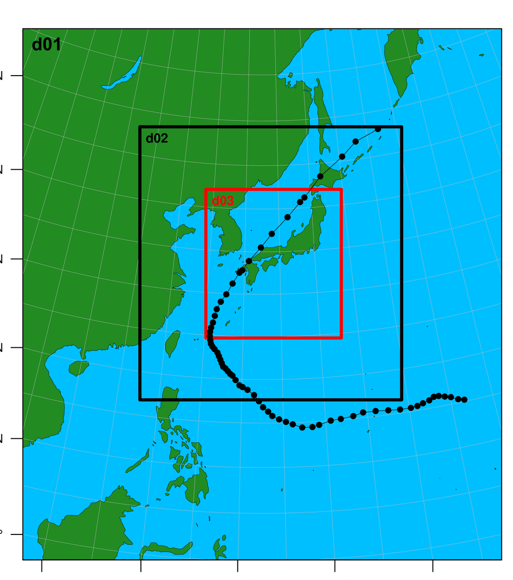

Figure 3. The outermost domain (d01) at 27-km grid spacing (entire area) used in the coupled WRF-Chem simulations. The black dots in the center of the domains show the best track of Typhoon Mireille.

CASE STUDY: MIREILLE (1991)

Typhoon Mireille is the most chemically sampled TC (Newell et al. 1996), making it an excellent case for evaluating the WRF-Chem model. Chemical measurements were obtained from the NASA DC-8 from an altitude of 300 m (PBL region) to ~ 12 km (UTLS region) just before Mireille made landfall (black circle; Fig. 4).

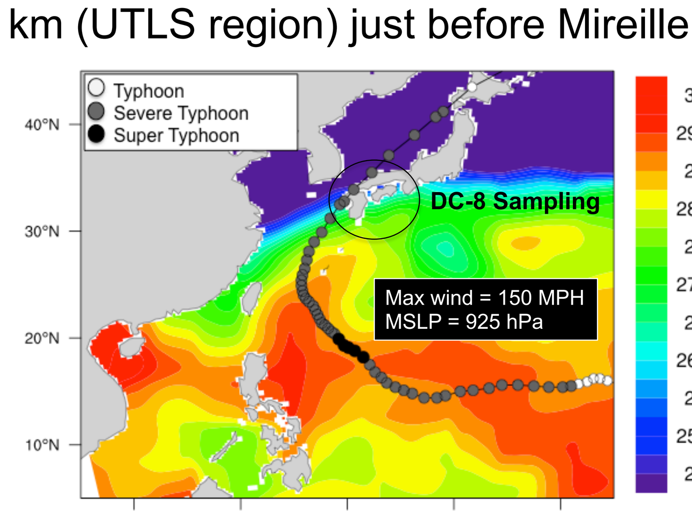

Figure 4. SST (°C) with Mireille's best track overlaid for the outermost domain (d01).

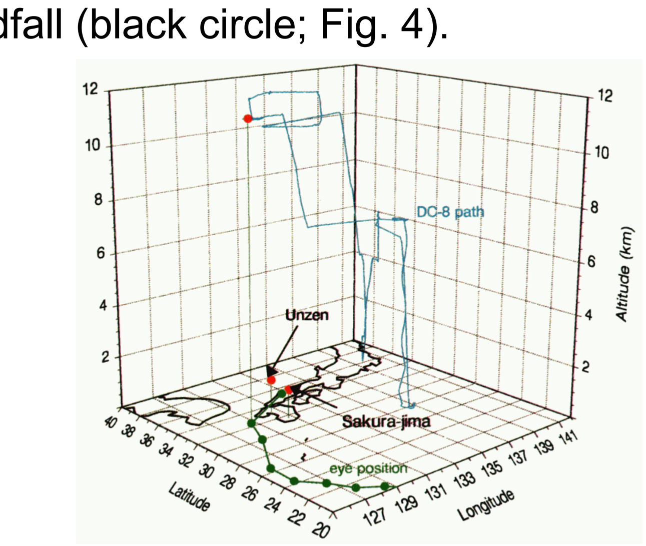

Figure 5. 3D flight track of the DC-8 through Typhoon Mireille on 27 September 1991. (After Newell et al. 1996)

MODEL SENSITIVITY TESTS

DIFFERENT CUMULUS/MICROPHYSICS

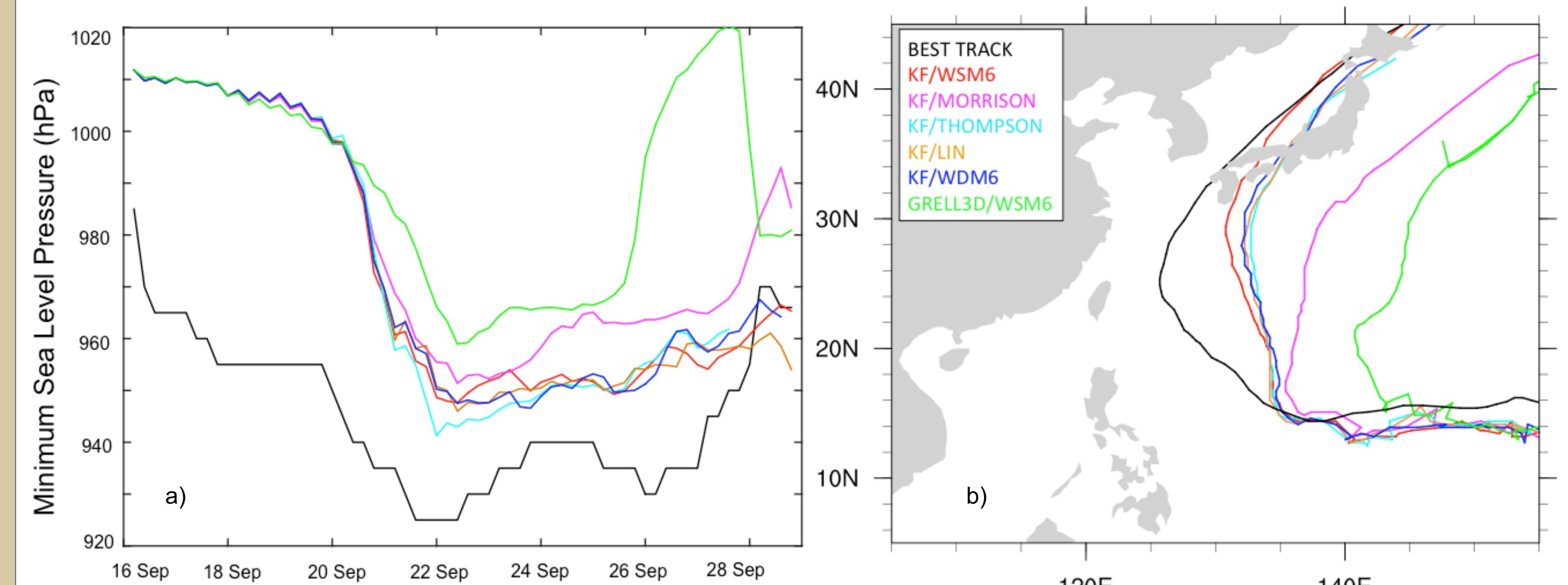

Figure 6. One-domain WRF-Chem simulation using different physics combinations. Plots show Typhoon Mireille's (a) intensity (MSLP) and (b) track (location) as it evolves over time.

METEOROLOGY OUTPUT (d01 and d02)

SEA LEVEL PRESSURE

1200 UTC 25 SEP

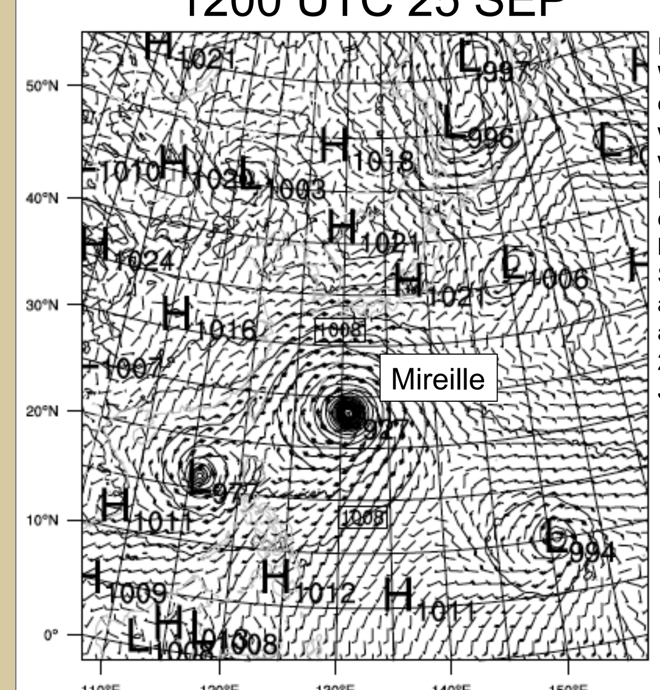

Figure 7. Two-domain WRF simulation showing contours of SLP (hPa) with overlaid surface wind vectors. Typhoon Mireille's simulated central pressure is 927 hPa at 1200 UTC 25 September 1991. This is approximately 2 days after peak intensity and 2 days before landfall in Japan.

1200 UTC 27 SEP

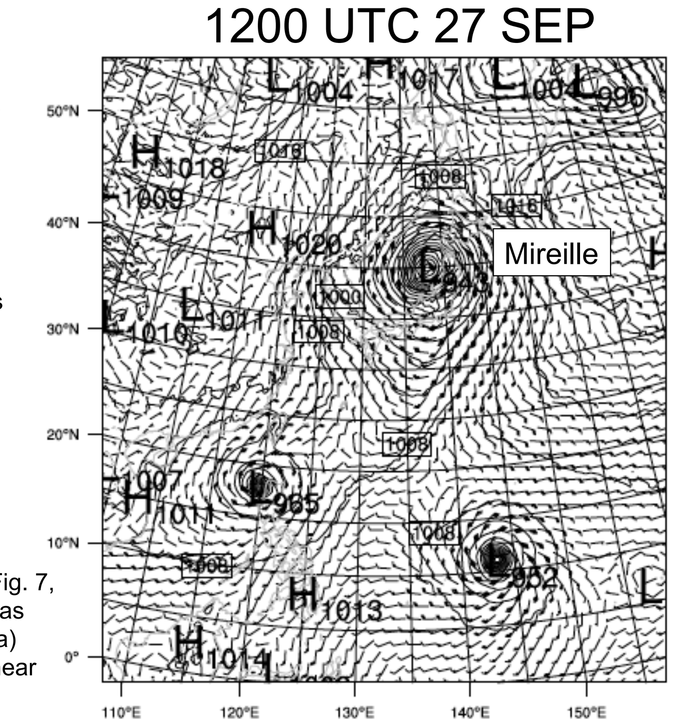

Figure 8. As in Fig. 7, but 2 days later as Mireille (943 hPa) makes landfall near Kyushu, Japan.

REFLECTIVITY AND SATELLITE IMAGERY

1200 UTC 27 SEP

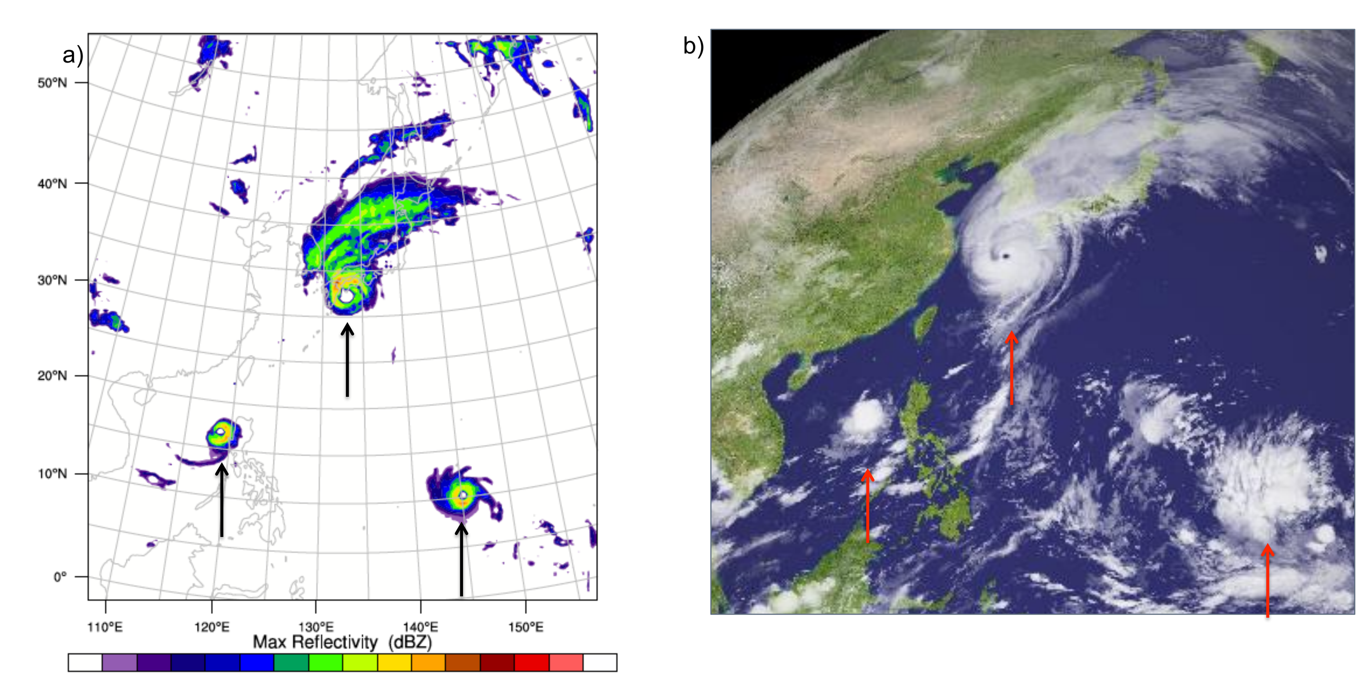

Figure 9. (a) Two-domain WRF run showing simulated composite reflectivity (dBZ) in d01 at 0000 UTC 27 September 1991. Mireille's simulated TC center is located at 32° N, 133° E. (b) Himawari-4's Visible satellite image at the same time. The arrows indicate similar corresponding features.

Summary: WRF meteorology output (i.e., MSLP, reflectivity, etc.) from the two-domain simulation agree closely with available observations.

CHEMICAL EMISSIONS (d01 only)

ANTHROPOGENIC EMISSIONS

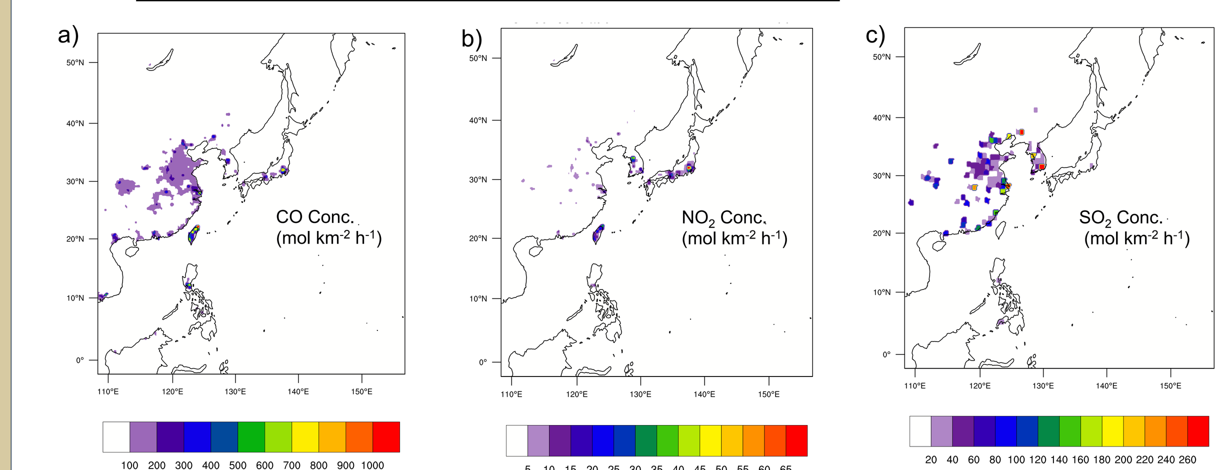

Figure 10. Surface anthropogenic emissions of (a) CO concentration (mol km^{-2} h^{-1}), (b) NO_2 concentration (mol km^{-2} h^{-1}), and (c) SO_2 concentration (mol km^{-2} h^{-1}) at 1200 UTC 16 September 1991 for d01.

BIOGENIC EMISSIONS

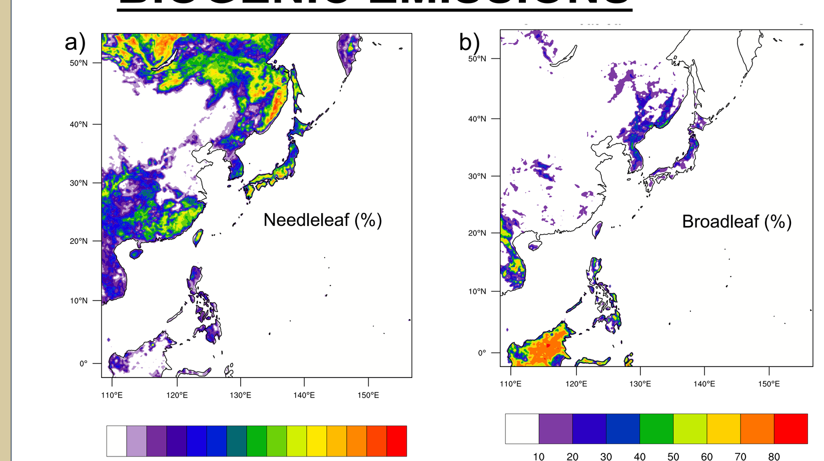

Figure 11. Surface biogenic emissions of (a) Needleleaf coverage (%) and (b) Broadleaf coverage (%) during September 1991 for the outermost domain (d01).

INITIAL CHEMICAL OUTPUT (d01 only)

SURFACE CHEMICAL CONCENTRATIONS

1800 UTC 16 SEP

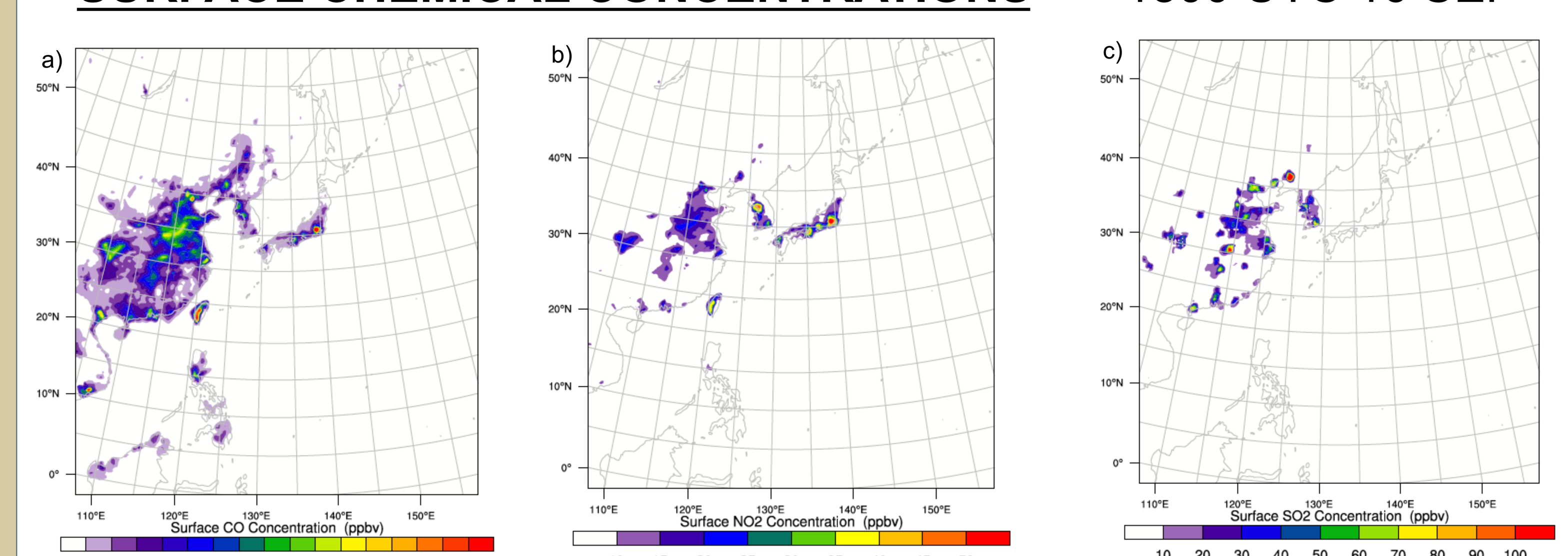

Figure 12. WRF-Chem simulated surface concentrations of (a) CO (ppbv), (b) NO_2 (ppbv), and (c) SO_2 (ppbv) at 1800 UTC 16 September for d01.

Summary: The greatest concentrations of surface pollutants are located in Southeast Asia which agrees well with previous studies.

FUTURE RESEARCH

- Add innermost nest of 3 km grid spacing to explicitly resolve convection (Fig. 3).
- Compare WRF-Chem simulated output to DC-8 chemical measurements.
- Analyze forward/backward trajectories using HYSPLIT to increase understanding of the role TCs play in distributing chemical species.
- Compute vertical chemical fluxes at various levels to quantify a TC's impact on the upper atmosphere energy (chemistry) budget.
- A more recent WNP TC (2004-present) also will be studied.

REFERENCES

Grell, G. A., S. E. Peckham, R. Schmitz, S. A. McKeen, G. Frost, W. C. Skamarock, and B. Eder, 2005: Fully coupled "online" chemistry within the WRF model, Atmos. Environ., **39**, 6957-6975.

Newell, R. E., and Coauthors, 1996: Atmospheric sampling of Supertyphoon Mireille with NASA DC-8 aircraft on September 27, 1991, during PEM-West-A. *J. Geophys. Res.*, **101**, 1853-1871, doi:10.1029/95JD01374.