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) has a substantial impact on Earth's climate. Thus, we need to improve our understanding of the vertical convective transport and long-range horizontal transport of chemical species that impact the atmosphere's radiative forcing. This includes the large scale convection associated with tropical cyclones (TCs). Little is known about the atmospheric chemistry of TCs, and few studies have addressed the chemical transport associated with them. The only comprehensive chemical investigation of a TC was a DC-8 flight during NASA's PEM-West A mission through Typhoon Mireille. The SEAC⁴RS dataset from TC Ingrid will help fill the gap of information regarding TC chemistry and build upon prior research using high-resolution chemical transport modeling.

OBJECTIVES

- Re-examine Typhoon Mireille (1991) and study TC Ingrid (2013) that occurred during SEAC⁴RS using 3D high resolution (1-2 km) chemical transport modeling in one of two ways:
  - (1) Using the Weather Research and Forecasting with Chemistry (WRF-Chem) online chemical transport model
  - (2) Using the Advanced Hurricane WRF (Davis et al. 2008) and link it to a chemistry module
- Place flight data in context of overall simulated TC structure.
  - How representative is the chemical data from flights that have sampled TCs?
- Determine how well the in situ chemical data agree with WRF-Chem simulated structure.
- Compute vertical fluxes of key chemical species at various altitudes.
- Use the HYbrid Single Lagrangian Integrated Model (HYSPLIT) to examine the role of TC convection in transporting chemical species to the UTLS.
- Compare the transports for the TCs with each other as well as with those from middle latitude convection.

INITIAL MODEL CONFIGURATION

WRF ARW 3.5

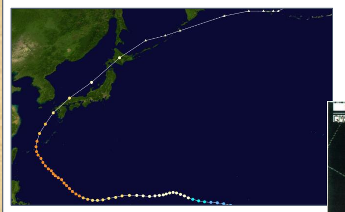
- 10 km resolution
- 50 vertical levels and 4 soil levels
- New Goddard longwave and shortwave physics
- YSU PBL scheme
- WSM-3 microphysics
- Kain-Fritsch CPS

	IC and BC	SST
Mireille	CFSR on a 0.5° global grid at 38 pressure levels. The boundary conditions were updated every 6 h.	Optimally interpolated SST (OISST) dataset on a 0.25° global grid.
Ingrid	GFS on a 0.5° global grid at 27 pressure levels. The boundary conditions were updated every 3 h.	Real-time, global, sea surface temperature (RTG_SST) analysis on a 0.5° global grid.

**The SST was held constant throughout simulation.*

CASES

MIREILLE



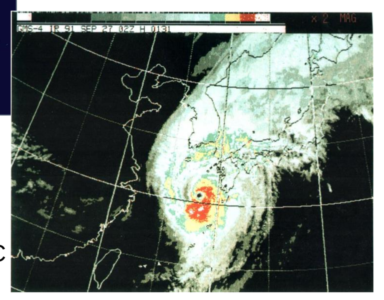


Figure 1. (Top) Track of Typhoon Mireille throughout its entire lifetime. (Right) Japanese Geostationary satellite image for 02:00 UTC at time of DC-8 take-off (After Newell et al. 1996).

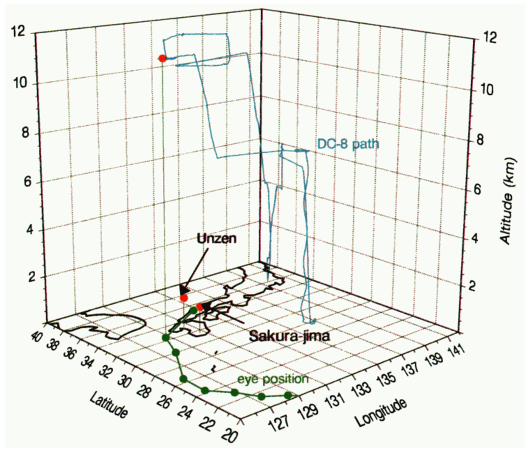
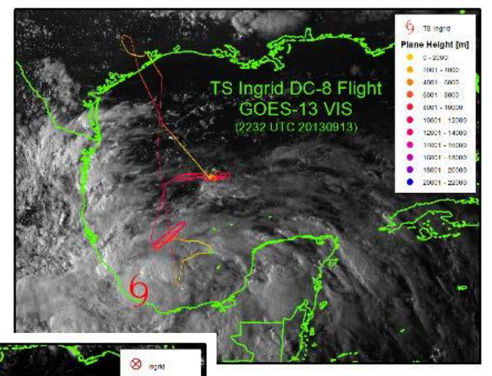


Figure 2. 3D flight track of the DC-8 through Typhoon Mireille on 27 September. (After Newell et al. 1996)

- Typhoon Mireille is an excellent example of a mature storm whose chemical characteristics can be contrasted with those of a weaker, developing TC Ingrid.
- Simulating Mireille using WRF-Chem will give us a better understanding of the chemical evolution associated with the TC and put the data obtained from the DC-8 flight in better context.

INGRID



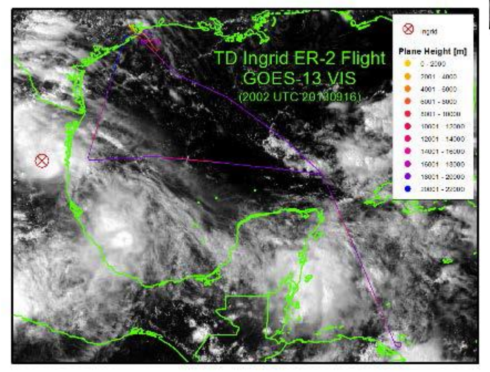
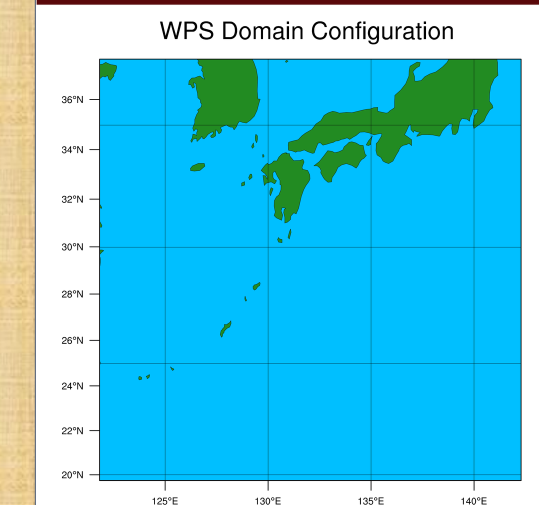


Figure 3. (Top) GOES-13 visible imagery at 22:32 UTC 13 September 2013 with DC-8 flight track and (left) at 20:02 UTC 16 September with ER-2 flight track through TC Ingrid during SEAC⁴RS. Altitudes of the flights are color coded.

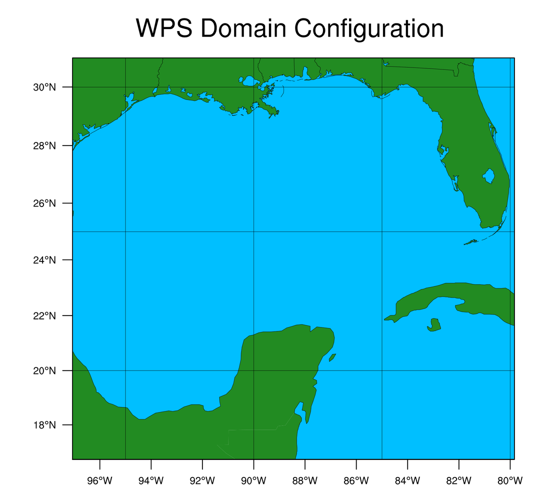
- TC Ingrid was named just before the DC-8 flight departed on 13 September and was still in its beginning stage.
- We will compare and contrast the surface and land emissions between Japan (Mireille) and the Gulf of Mexico (Ingrid) regions.

INITIAL WRF RESULTS



Mireille

Figure 4. The WRF domain at 10 km grid spacing with 200 x 200 grid boxes centered at 29°N, 132°E.



Ingrid

Figure 5. The WRF domain at 10 km grid spacing with 176 x 160 grid boxes centered at 24°N, 88.5°W.

Typhoon Mireille 1991

25 SEPTEMBER 1991 06:00 UTC

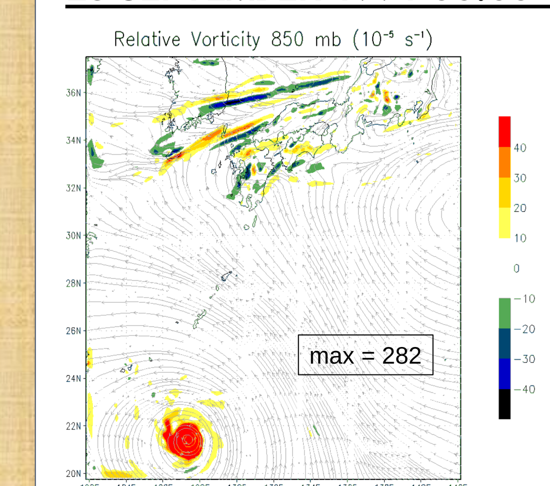


Figure 6. Relative vorticity at 850 mb overlaid with wind vectors at the same level. A large cyclonic rotation coincides with Typhoon Mireille at low-levels.

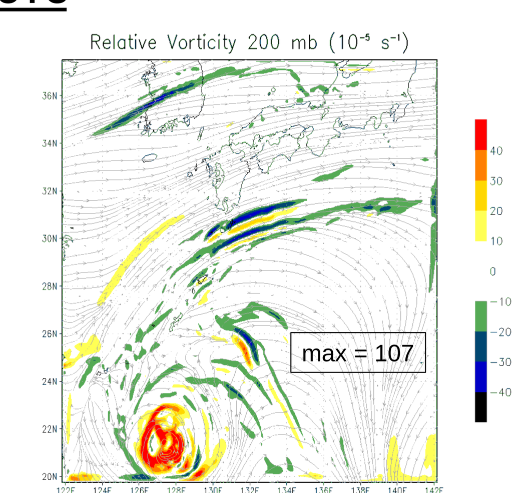


Figure 7. As in Fig. 6, but at 200 mb. The anticyclonic outflow (clockwise rotation) can be seen surrounding Typhoon Mireille at upper-levels.

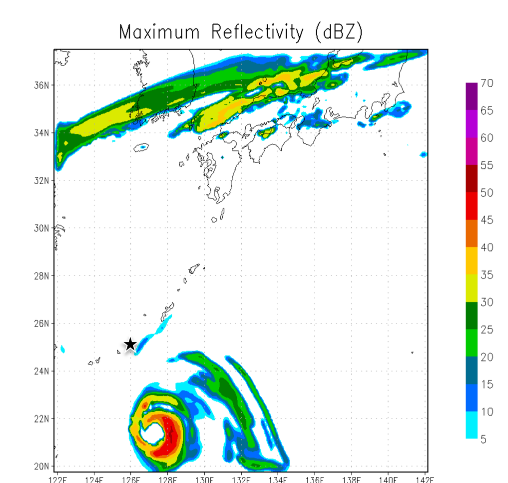


Figure 8. Maximum reflectivity shows Mireille's eyewall as it continues to intensify. The black star corresponds to the fixed location (25°N, 126°E) shown in Fig. 13.

26 SEPTEMBER 1991 06:00 UTC

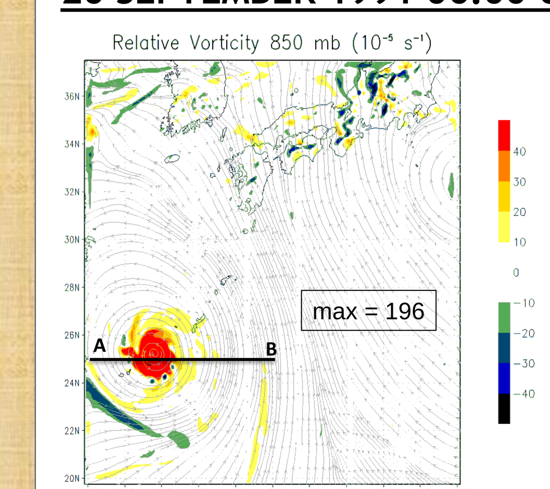


Figure 9. Relative vorticity at 850 mb overlaid with wind vectors at the same level. Mireille's cyclonic rotation has increased over the past 24h compared to Fig. 6. The A-B line corresponds to the vertical cross-section shown in Fig. 12.

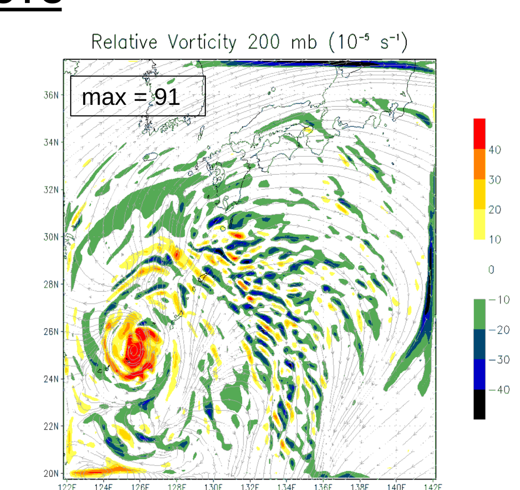


Figure 10. As in Fig. 9, but at 200 mb. The anticyclonic outflow can be seen as air exits Mireille in the UT.

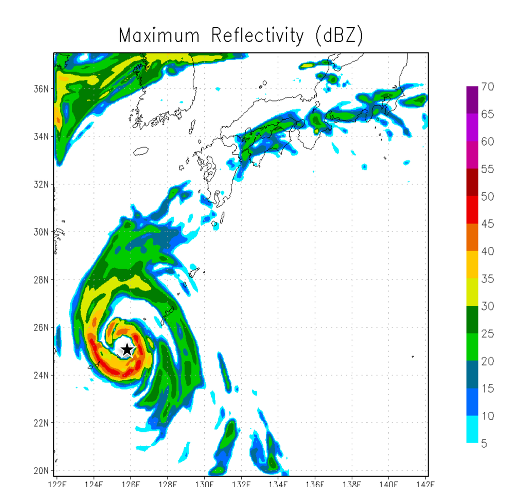


Figure 11. Maximum reflectivity shows heavy precipitation in the eyewall and outer rainbands of Typhoon Mireille. The black star refers to the fixed location of the time series shown in Fig. 13.

VERTICAL CROSS-SECTION AND TIME SERIES

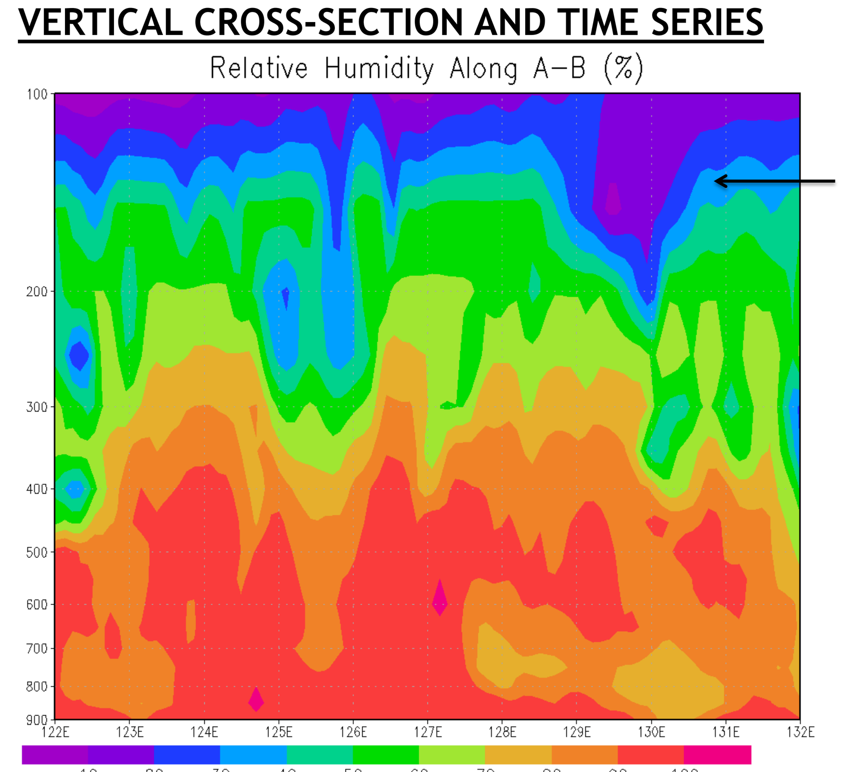


Figure 12. Vertical cross-section of relative humidity along line A-B. Note that the moistening extends to ~ 125 mb.

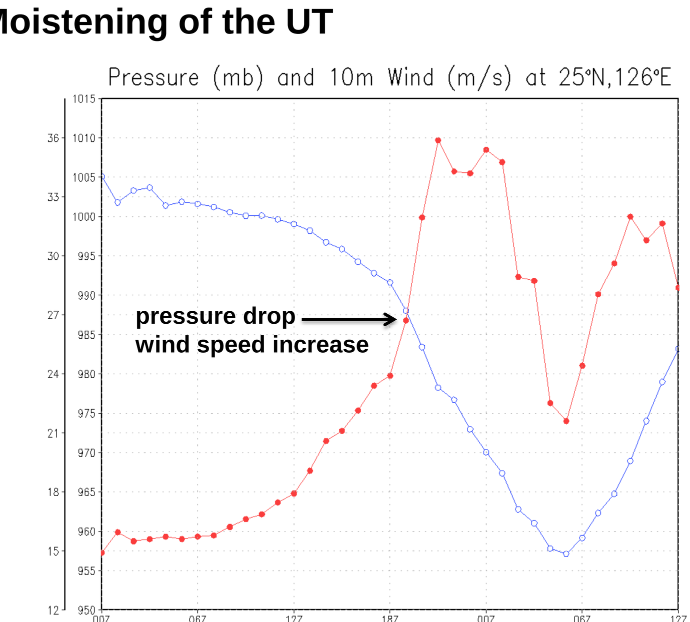


Figure 13. Pressure (blue) and 10 m wind speed (red) time series shows the outer rainbands of Typhoon Mireille passing over 25°N, 126°E near 20:00 UTC 25 September 1991 as indicated by the initial pressure drop and wind speed increase.

TC Ingrid 2013

13 SEPTEMBER 2013 18:00 UTC

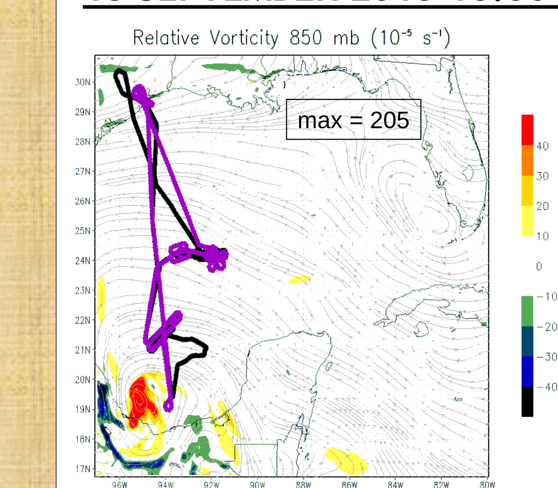


Figure 14. Relative vorticity at 850 mb overlaid with wind vectors at the same level. A large cyclonic rotation coincides with TC Ingrid at low-levels. The DC-8 flight track is in black and the ER-2 flight track is in purple.

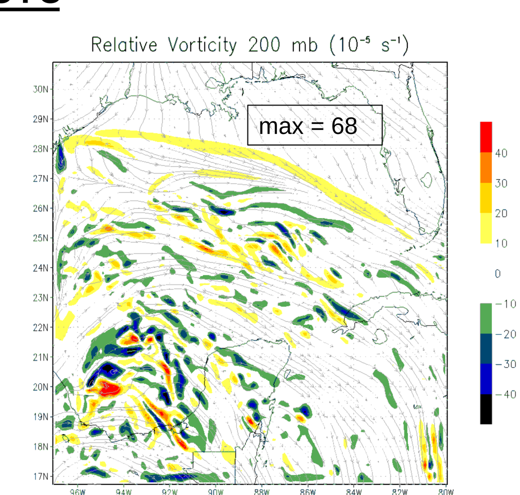


Figure 15. As in Fig. 14, but at 200 mb. The anticyclonic outflow (clockwise rotation) can be seen surrounding TC Ingrid at upper-levels.

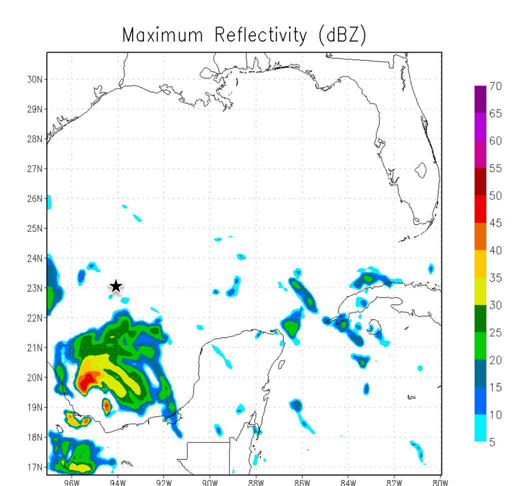


Figure 16. Maximum reflectivity as TC Ingrid propagates north into the Gulf of Mexico.

16 SEPTEMBER 2013 00:00 UTC

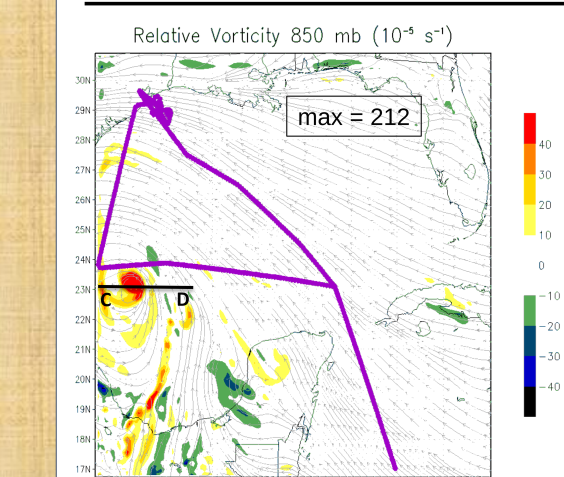


Figure 17. Relative vorticity at 850 mb overlaid with wind vectors at the same level. The ER-2 flight track is in purple. The C-D line corresponds to the vertical cross-section shown in Fig. 20.

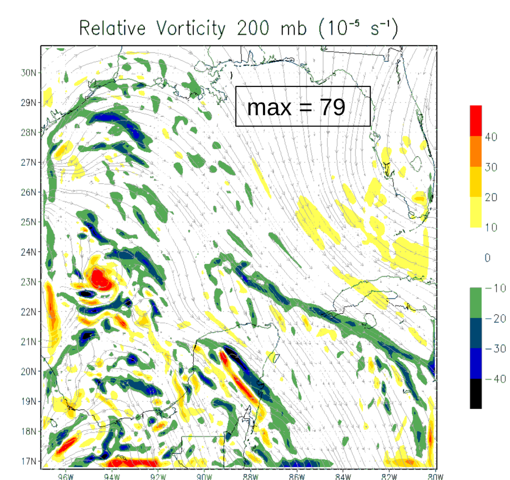


Figure 18. As in Fig. 17, but at 200 mb.

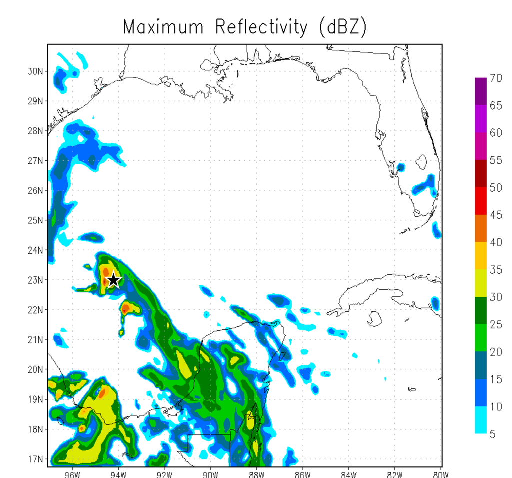
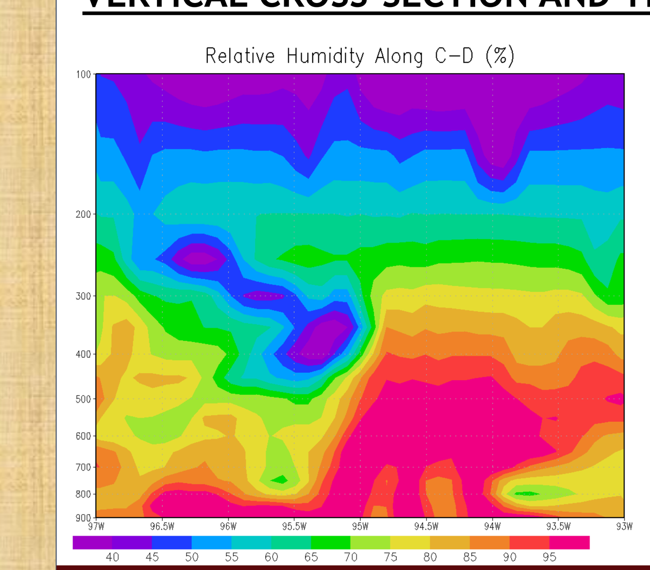


Figure 19. Maximum reflectivity shows TC Ingrid as it diminishes over the Western Gulf.

VERTICAL CROSS-SECTION AND TIME SERIES



Moisture with TC Ingrid does not extend as high

Figure 20. Moistening of the UT does not extend as high as with Typhoon Mireille.

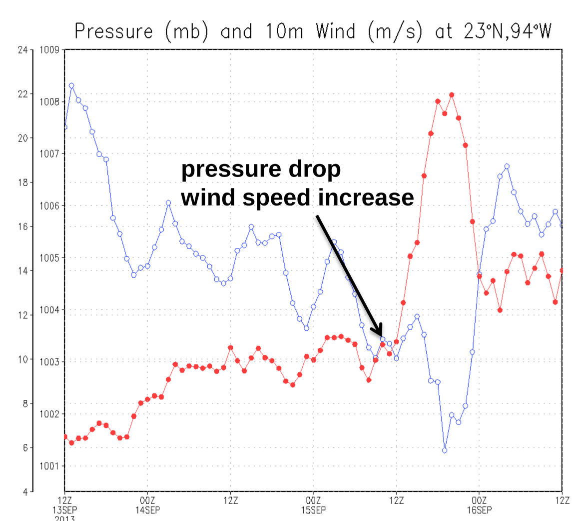


Figure 21. The pressure (blue) and 10 m wind speed (red) time series shows the initial passage of TC Ingrid over 23° N, 94° W at approximately 12:00 UTC 15 September 2013.

FUTURE RESEARCH

- Use the most recent release of WRF-Chem for the TC simulations.
- Adjust the initial model configuration and parameterization schemes in WRF-Chem until it closely simulates observations.
  - Experiment with the Grell-3D cumulus parameterization.
- Increase the horizontal resolution using a nested approach with 4 domains. (27, 9, 3, 1 km grid spacing)
- Analyze forward/backward trajectories using HYSPLIT to increase our understanding of the role TCs play in distributing various chemical species.
- Use an integrated research approach by combining the simulations with satellite observations.
- The lack of chemical flight data has hindered research of TC chemical transport.
  - **The proposed research will help fill this gap of information by putting the flight data in context of overall simulated TC structure.**

REFERENCES

Davis, C., and Coauthors, 2008: Prediction of landfalling hurricanes with the Advanced Hurricane WRF Model. *Mon. Wea. Rev.*, **136**, 1990-2005.

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.