Observations & Modeling of Saharan Dust Interaction With A Tropical Cyclone

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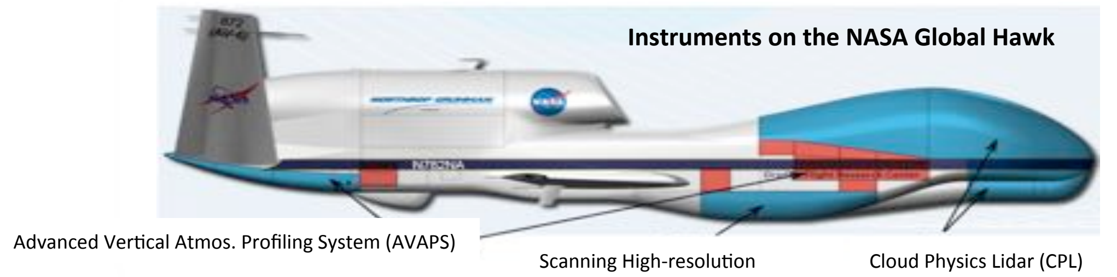
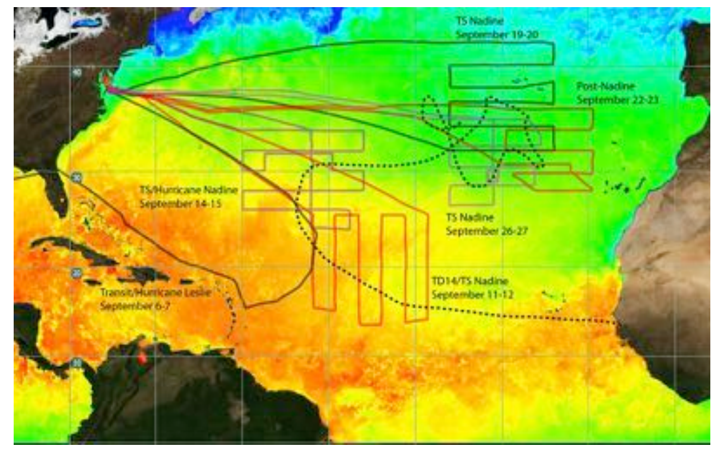
Introduction and Case Description

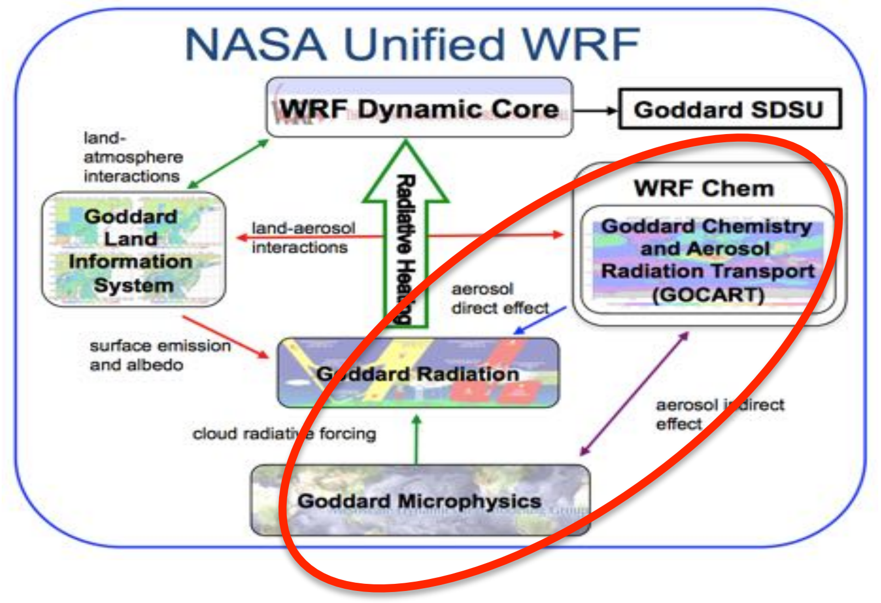
Conflicting views exist on the role of the Saharan Air Layer (SAL) pre- and post-genesis (Karyampudi and Carlson 1988; Dunion and Velden 2004; Zhang et al. 2007, 2009; Braun 2010; among others). Early dust-impact studies claimed negative impacts, but had unrealistic dust distributions (Zhang et al. 2007, 2009). More recent work with more realistic dust distributions suggest possible positive impacts in some cases (Herbener et al. 2014). In this study, we look at the impact of Saharan dust on the evolution and intensity of Hurricane Nadine (2012) observed during the first Hurricane and Severe Storm Sentinel (HS3) campaign.

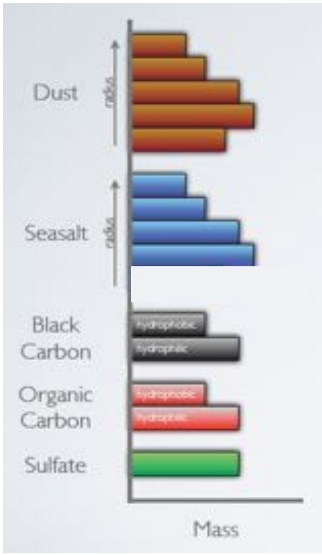




HS3 flights of interest:
Sept. 11-12, Nadine is a TS with SAL air advancing around northern side
Sept. 14-15, Nadine becomes a hurricane with SAL on eastern/northern sides

NUWRF Model and Simulation Description

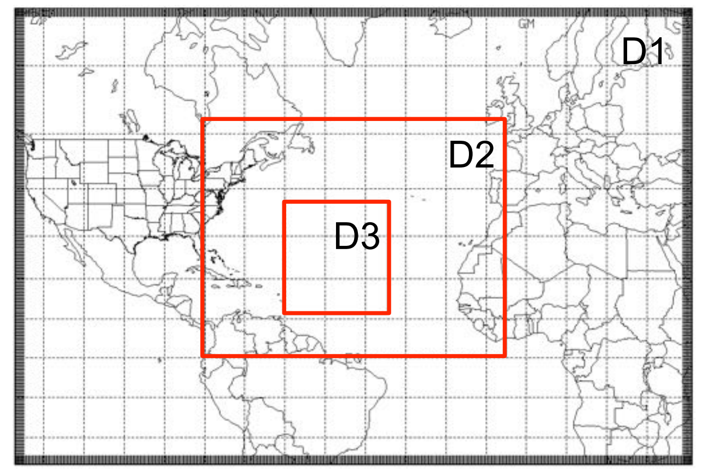




Aerosol-Microphysics Coupling (Shi et al. 2014)
(Goddard 5-class 3-ice microphysics scheme only)

- CCN based on Koehler curves (Koehler *et al.*, 2006; Andreae and Rosenfeld, 2008)
- IN based on Demott *et al.*(2010)
- Both CCN and IN are diagnostic parameters only

Aerosol-Radiation Coupling (Shi et al. 2014)
(Goddard LW/SW radiation schemes only)
• Aerosols predicted from WRF-Chem/GOCART are used to calculate radiative parameters to account for aerosol scattering and absorption effects in the atmosphere.



Physics:

- Grell-Freitas ensemble Cu parameterization
- Goddard microphysics 3-ice with aerosols
- 2014 Goddard radiation schemes for both longwave and shortwave
- YSU Boundary Layer scheme
- Monin-Obukhov (MM5) surface layer
- Unified Noah land-surface model

Simulation details:

- Resolutions: 27, 9 and 3 km
- Grid sizes: 601X421, 802X655, 832X931, and 61 vertical layers
- Starting time: 00Z 09/10/2012
- Ending time: 00Z 09/17/2012
- Initial and Boundary Conditions:
  - NCEP/GFS except SST
  - SST from ERA-Interim

Name	Description
CNTL	No aerosols
AMR1	Aerosols acting as CCN and IN, both microphysical and radiative coupling
AMR2	Aerosols acting as IN only, both microphysical and radiative coupling
AM1	Aerosols acting as CCN and IN, microphysical coupling only
AR1	Aerosol radiative coupling only

Left:
Summary of experiments. The default version of NUWRF allows dust to act as ice nuclei (IN), but not cloud condensation nuclei (CCN). Here, we run cases with and without dust as CCN.

References

Andreae M. O., Rosenfeld D., 2008. Aerosol–cloud–precipitation interactions. Part 1. The nature and sources of cloud-active aerosols. *Earth Sci. Rev.,* **89**, 13–41.

Braun, S. A., 2010: Reevaluating the role of the Saharan air layer in Atlantic tropical cyclogenesis and evolution. *Mon. Wea. Rev.*, **138**, 2007–2037.

Demott PJ, Prenni AJ, Liu X, Kreidenweis SM, Petters MD, Twohy CH, Richardson MS, Eidhammer T, Rogers DC. 2010. Predicting global atmospheric ice nuclei distributions and their impacts on climate. *Proc. Natl. Acad. Sci.,* **107,** 11217–11222.

Dunion, J. P., and C. S. Velden, 2004: The impact of the Saharan air layer on Atlantic tropical cyclone activity. *Bull. Amer. Meteor. Soc.*, **85**, 353–365.

Herbener, S. R., S. C. van den Heever, G. G. Carrió, S. M. Saleeby, and W. R. Cotton, 2014: Aerosol Indirect Effects on Idealized Tropical Cyclone Dynamics. *J. Atmos. Sci.*, **71**, 2040–2055.

Karyampudi, V. M., and T. N. Carlson, 1988: Analysis and numerical simulations of the Saharan air layer and its effect on easterly wave disturbances. *J. Atmos. Sci.*, **45**, 3102–3136.

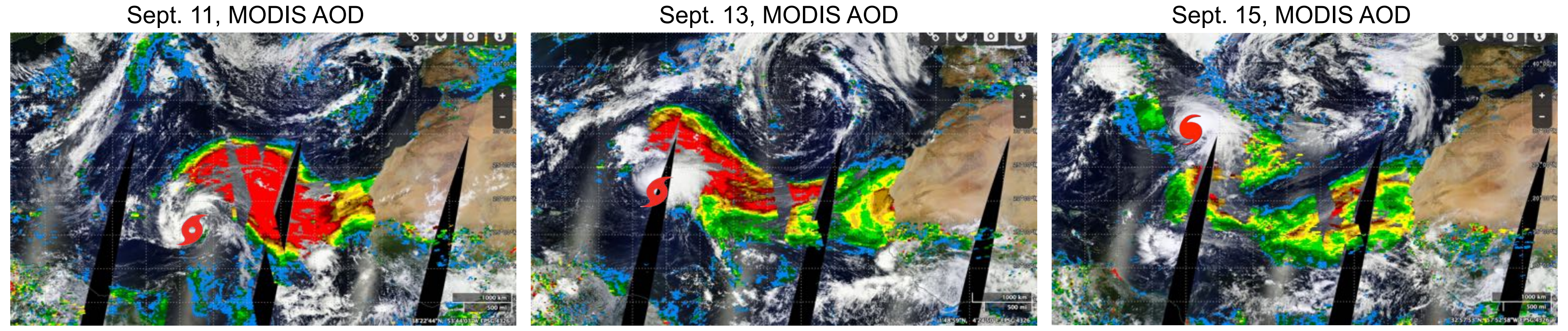
Koehler KA, Kreidenweis SM, DeMott PJ, Prenni AJ, Carrico CM, Ervens B, Feingold G. 2006. Water activity and activation diameters from hygroscopicity data. Part II: Application to organic species. *Atmos. Chem. Phys.,* **6**, 795–809.

Shi., J. J., and co-authors, 2014: Implementation of an aerosol–cloud-microphysics–radiation coupling into the NASA unified WRF: Simulation results for the 6–7 August 2006 AMMA special observing period. *Q. J. R. Meteorol. Soc.,* **140**, 2158 – 2175.

Zhang, H., G. M. McFarquhar, S. M. Saleeby, and W. R. Cotton, 2007: Impacts of Saharan dust as CCN on the evolution of an idealized tropical cyclone, *Geophys. Res. Lett.*, **34**, L14812

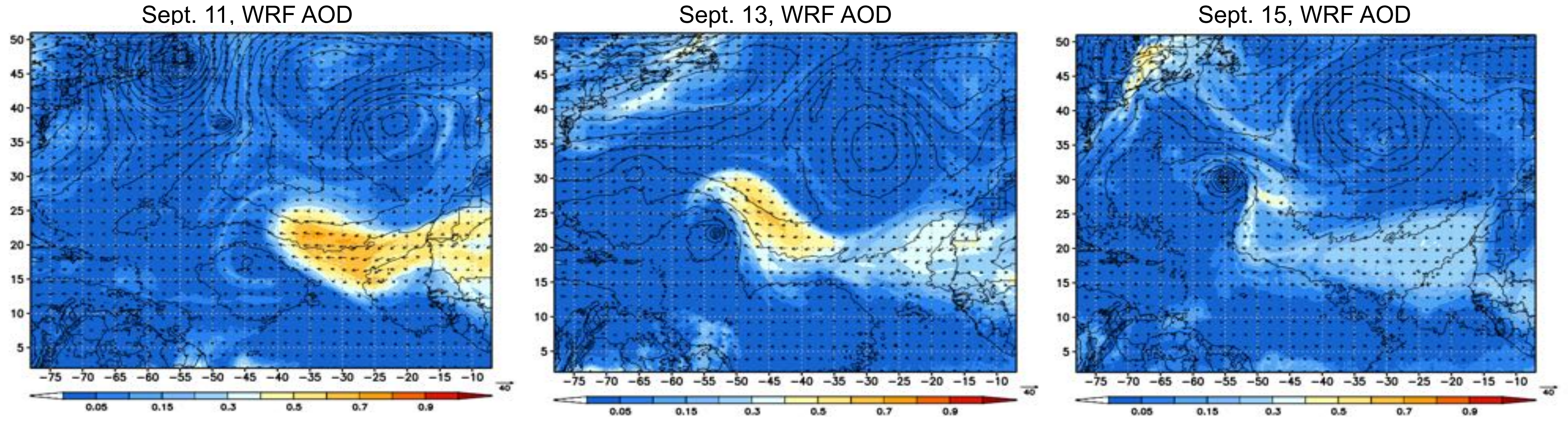
Zhang, H., G. M. McFarquhar, W. R. Cotton, and Y. Deng, 2009: Direct and indirect impacts of Saharan dust acting as cloud condensation nuclei on tropical cyclone eyewall development. *Geophys. Res. Lett.*, **36**, L06802

MODIS AOD Evolution


Sept. 11, MODIS AOD
Sept. 13, MODIS AOD
Sept. 15, MODIS AOD

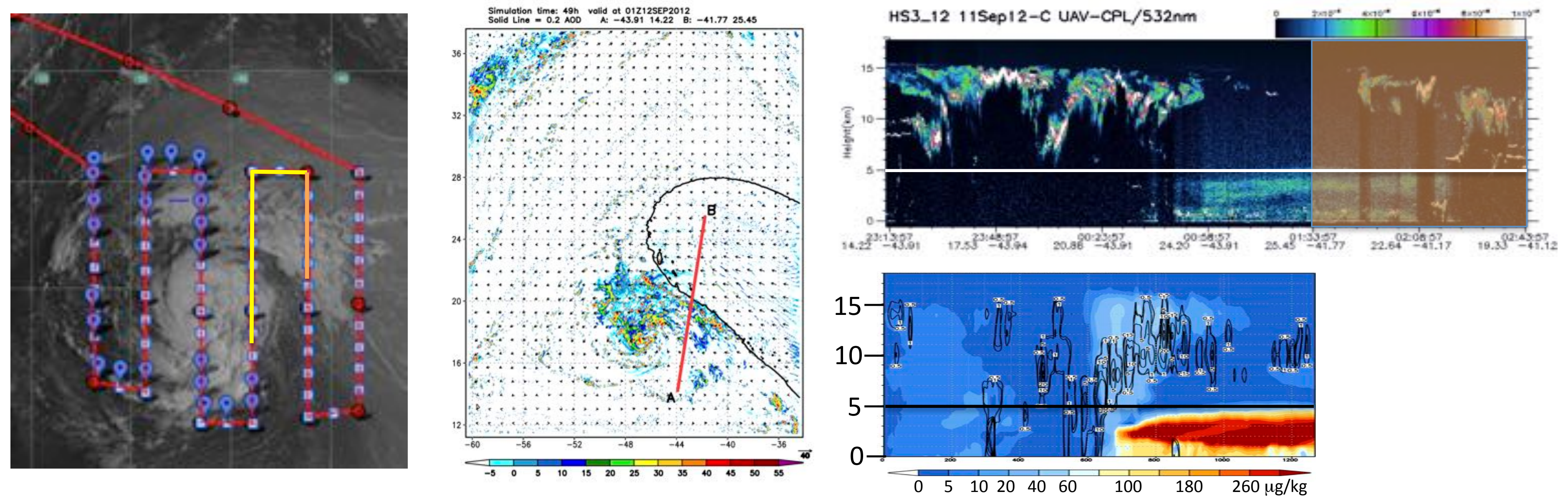
Above: Evolution of Saharan dust as depicted by MODIS over Sept. 11-15. Colors range from blue (AOD=0.2) to red (AOD>0.7). The question for this poster, did the dust slow or delay intensification of Nadine?

WRF AOD Evolution


Sept. 11, WRF AOD
Sept. 13, WRF AOD
Sept. 15, WRF AOD

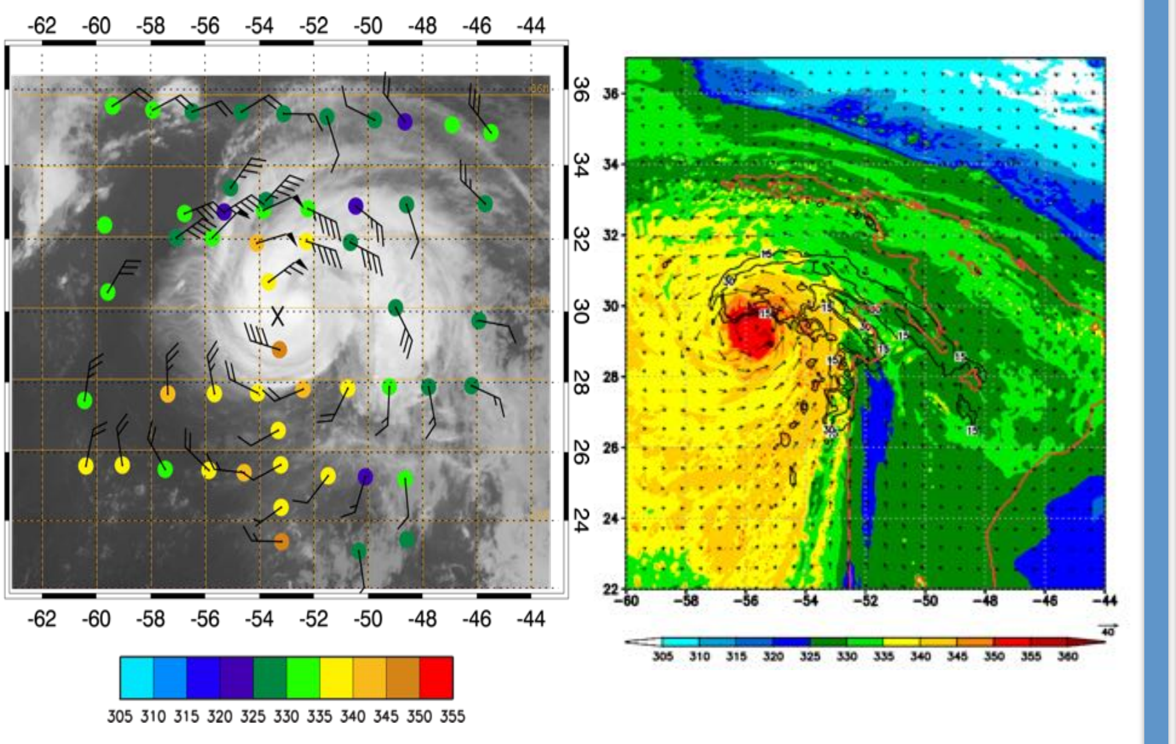
Above: Simulated AOD for ARM1 (shading) and sea-level pressure (contours) for times (12 UTC) corresponding to the approximate times of the MODIS images above. The WRF simulation captures the evolution of AOD quite well.

Comparisons to HS3 Data

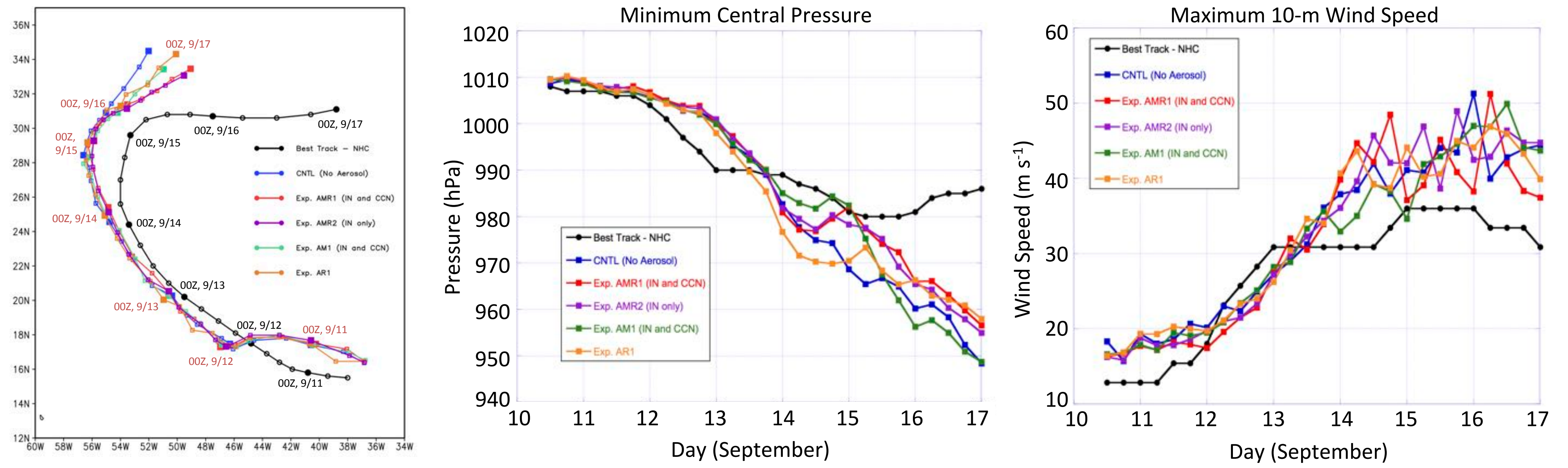


Above: (Left) September 11-12 GH flight track. Yellow-orange segments correspond to the CPL image (top-right) where the orange shaded region corresponds to the orange line. (Middle) Simulated 900-hPa radar reflectivity, winds, and dust boundary (AOD=0.2) at 0100 UTC September 12. Red line indicates the location of the vertical cross section (bottom-right) of dust mass (shading) and total hydrometeor content (contours).

Lower section: (Left) Dropsonde-derived 800-hPa θe and storm-relative wind barbs. Dropsonde positions adjusted for storm motion and dropsonde drift for a reference time of 00 UTC 15 September. (Right) Simulated 800-hPa θe (shading), simulated radar reflectivity (black contours at 15, 30, 45 dBZ), and 0.2 AOD boundary (red) from the AMR1 simulation at 00 UTC September 15. Reflectivity and AOD fields have been smoothed to improve readability.

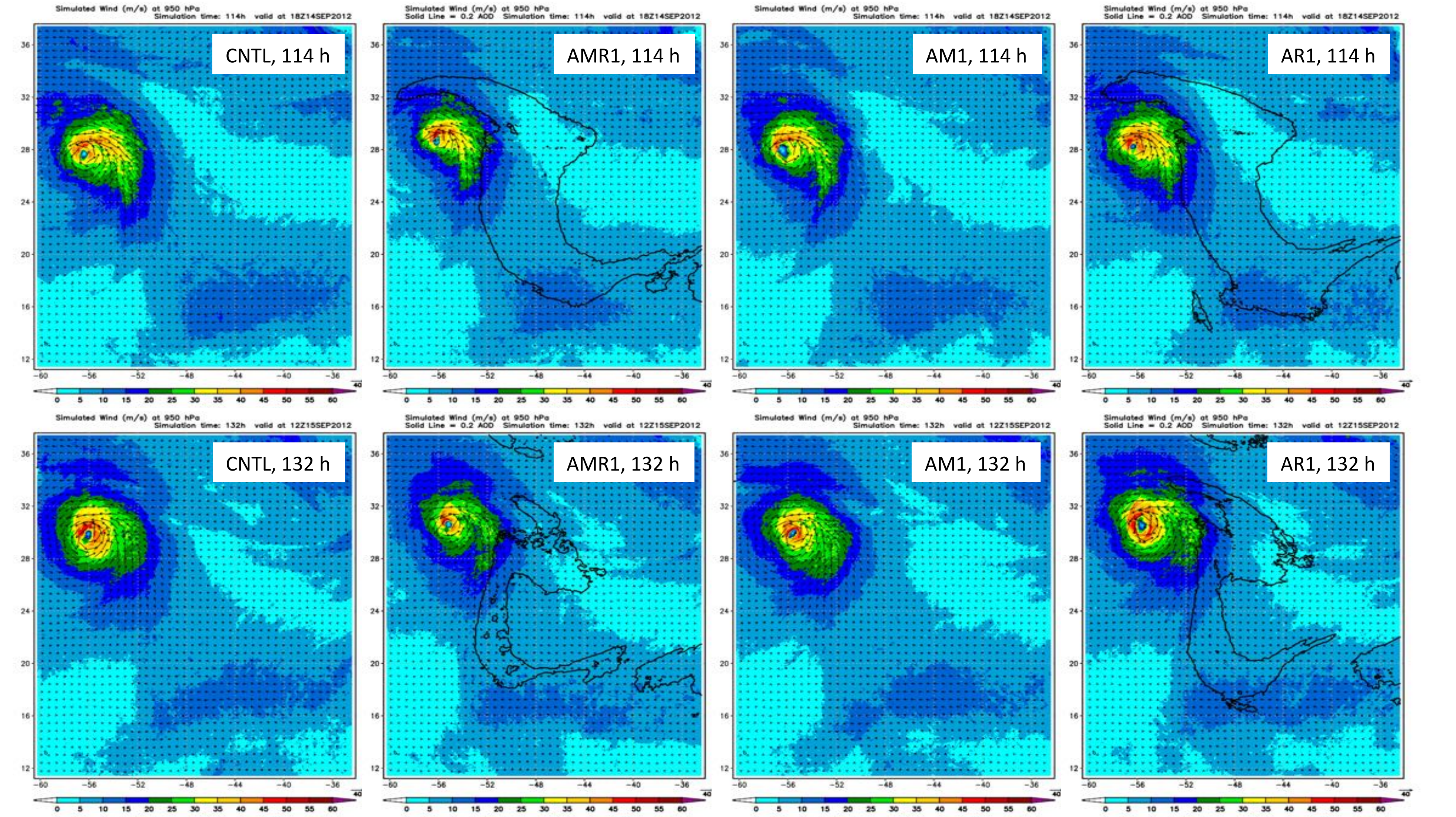


The Impact of Saharan Dust on Simulated Intensity and Track



Above: All simulated tracks suggest weaker environmental westerly winds compared to observations, particularly after 96 hours. The weaker environmental westerlies likely resulted in weaker vertical shear and storms that are stronger than observations after 96 h. While there is a slight weakening in intensity in terms of MSLP in some of the aerosol cases (primarily associated with microphysical effects) after 96 h, the maximum winds are not consistently different than the control run.

Impact of Saharan Dust on Wind Structure



Above: Simulated wind speeds at 950 hPa at 114 h (top row) and 132 h (bottom row) for the indicated experiments. Through 90 h, wind structures were only slightly different (not shown), but differences emerge by 96 h and continue to grow at later times (above). The case with both the microphysical and radiative coupling with dust tend to produce a smaller and generally weaker storm. The cases with only radiative coupling and only microphysical coupling do not "combine" to match the case with both.

Conclusions

Significant dust impacts do not emerge until after ~5 days of simulation. Inclusion of dust impacts improves the simulated tracks, but impacts on storm intensity show considerable variability. If one considers the full wind structure rather than the local (point) measurement of intensity, then the dust impact (both microphysical and radiative) was to weaken the storm. However, when dust impacts on microphysics or radiation are evaluated separately, no consistent weakening of the storm is found. Because stochastic processes may be leading to some of the differences, ensemble simulations for CNTL and AMR1 will be performed for future studies.