Dust Impact and Forecast Evaluation During HS-3

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One of the scientific goals of the NASA Hurricane and Severe Storm Sentinel (HS-3) field campaign is to better understand the role of the Saharan Air Layer (SAL) in tropical storm formation over the tropical North Atlantic Ocean. During last summer's HS3 deployment, the NASA GEOS-5 AGCM provided 5-day forecasts that were used to design flight plans aimed at capturing tropical storm development in the presence of any dry and/or dusty SAL air. Here, we evaluate last year's dust forecasts by focusing on the HS3 flight that occurred on 9/11/12 – 9/12/12, where dust was observed to the north and east of a developing Hurricane Nadine (Figure 2). In particular, we focus on how the horizontal and vertical dust plume position changed with decreasing forecast lead time by comparing to observations of column aerosol optical thickness (AOT) from the MODIS – Aqua satellite and an AERONET sunphotometer at Cape Verde, as well as total attenuated backscatter observed by the Cloud Physics Lidar (CPL) onboard the Global Hawk. In addition to running in forecast mode, GEOS-5 may run in 'replay' mode, where MERRA reanalyses and/or MODIS AOT are used to constrain the dynamical state of the model and column AOT, respectively. We utilize this capability to explore how the inclusion of MERRA reanalyses and MODIS AOT influence the simulated dust plume position. Finally, we investigate any role of the direct radiative effect of dust aerosols on the development of Nadine by comparing a set of 5-day GEOS-5 forecasts with and without direct radiative feedback from aerosols.

Dust Forecast Evolution for 9/11/12 – 9/12/12 Flight

In this section, we present how the GEOS-5 dust forecast improved as takeoff approached for the 9/11/12 – 9/12/12 flight. Four days prior to flight (9/7), GEOS-5 was less aggressive in the amount of dust that was circulating cyclonically around the developing Nadine. Two days prior to takeoff (9/9), the forecasted dust loading increases and wraps cyclonically around the system, which persists through the day of the flight (9/11). Comparing the forecasts to the MODIS – Aqua AOT nearest the valid forecast time, we see that GEOS-5 captures the observed magnitude and location of the dust plume beginning two days prior to takeoff. Vertically, we see increased dust mass mixing ratio sampled along the Global Hawk flight track, particularly between 0Z – 3Z on 9/12. Comparing GEOS-5 to the observed CPL profile on total attenuated backscatter, the all forecasts accurately capture the timing of the dust plume that would be sampled along the Global Hawk track.

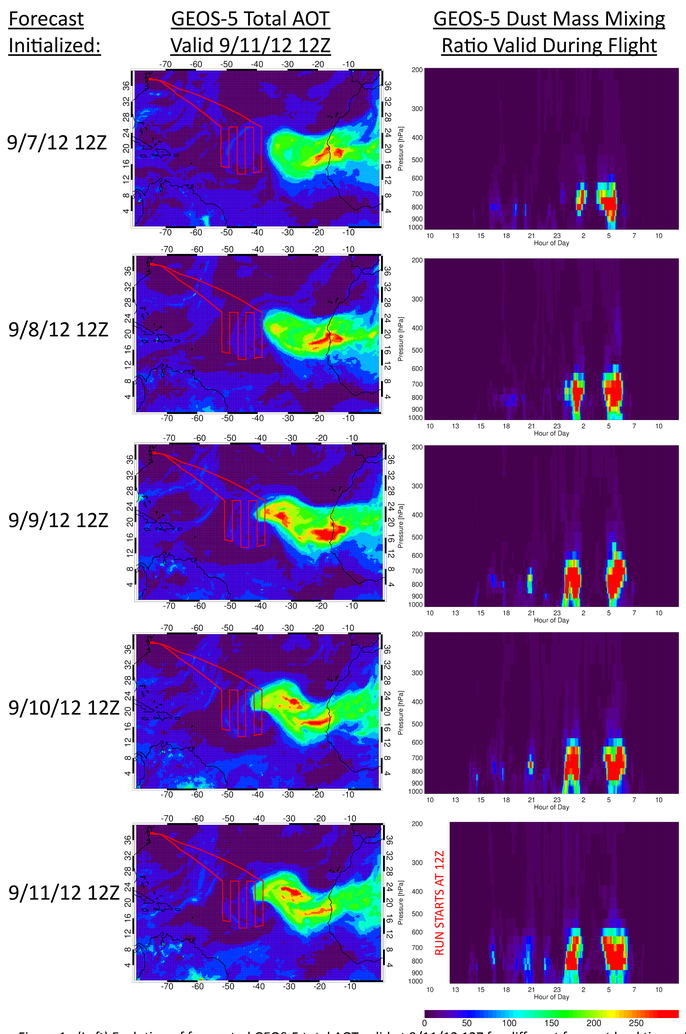

Figure 1. (Left) Evolution of forecasted GEOS-5 total AOT valid at 9/11/12 12Z for different forecast lead times. (Right) Evolution of forecasted dust mass-mixing ratio sampled along the Global Hawk track for different forecast lead times.

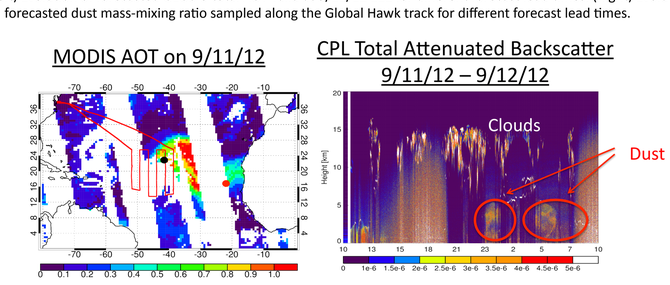

Figure 2. MODIS-Aqua AOT on 9/11/12 with Global Hawk track overlaid (left) and CPL total attenuated backscatter observed on 9/11/12 - 9/12/12.

Data Impact on Simulated Dust Distributions

In this section, we show how the inclusion of MERRA reanalyses and MODIS AOT to adjust the dynamical state and column AOT of the model impact our simulated dust distributions. Figure 3 shows the forecasted total AOT (colored lines) initialized at 12Z on 9/7 through 9/11 at Cape Verde and at a point along the Global Hawk track (red and black dots on Figure 2, respectively). Also shown on each plot are replay simulations from a version of the model that is similar to the version used for last year's forecasts that includes both dynamical and AOT adjustment (dashed line) and a recent version of the model that is dynamically adjusted by MERRA, but does not have AOT correction by MODIS (solid black line). At Cape Verde, the observed AOT by AERONET is also included (diamonds). Prior to the forecast initialized on 9/10, the GEOS-5 forecasts miss the intensity of the observed dust plume around 12Z on 9/10, but are able to simulate the duration of the passing dust plume from 9/10 – 9/12. Comparing the replay simulations, it is clear that the assimilation of MODIS AOT significantly impacts the simulated AOT, which otherwise would be too low in magnitude if only MERRA reanalyses are used to adjust the model. This feature manifests itself further downwind along the Global Hawk track as the replay simulation without MODIS AOT assimilation simulates a less intense dust plume.

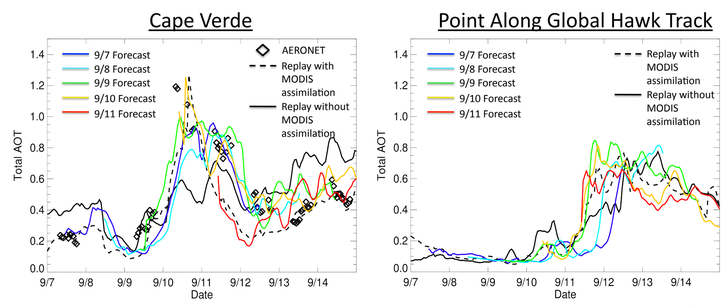

Figure 3. Total AOT at Cape Verde (left) and at a point along the Global Hawk track from the 9/11/12 – 9/12/12 flight (right). Forecasts are marked by colored lines and are initialized at 12Z for each respective day. MERRA replay simulations with and without MODIS AOT are marked by dashed and solid black lines, respectively. Observed AOT at Cape Verde is marked by diamonds.

Figure 4 shows the total AOT for our replay simulations with and without MODIS AOT assimilation during the Global Hawk flight on 9/11/12 – 9/12/12. Early in the flight at 12Z on 9/11, our replay simulation with MODIS AOT simulates relatively less dust over the region where Nadine is developing. Later at 6Z on 9/12, there is still less dust over the region where Nadine is developing in our simulation with MODIS AOT assimilation, however, the AOT is greater over the northern legs of the flight which coincides with the SAL. This can clearly be seen by comparing extinction profiles along the Global Hawk track, as there is greater AOT (red curve) and contribution of dust to the total AOT (orange curve) in our replay simulation that includes MODIS AOT assimilation.

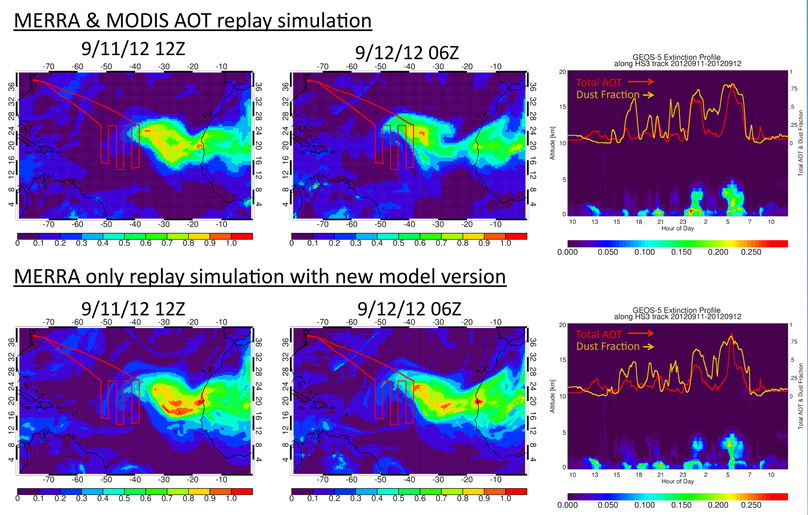

Figure 4. Total AOT at 9/11/12 12Z (left), 9/12/12 06Z (center), and total extinction profiles along the Global Hawk Track for the 9/11/12 – 9/12/12 flight (right) for our replay simulations with (top) and without (bottom) MODIS AOT assimilation. On the extinction plots, the along track total AOT is marked by the red curve and the dust contribution to the total AOT is marked by the orange curve.

Impact of Dust Direct Radiative Forcing on Forecasts

As previously mentioned, one of the key scientific goals of the HS3 field campaign is to better understand the role of the SAL in tropical storm development. In this section, we present a set of 5-day forecasts with and without direct radiative forcing by aerosols during Nadine's development using our most recent version of the model. The forecasts were initialized at 22Z on 9/7/12 and allow for the radiative impacts of dust to interact with the atmosphere for 5 days before the 9/11/12 – 9/12/12 Global Hawk flight. Figure 5 shows the total AOT at 12Z on 9/11/12 for our 5-day forecasts with (top) and without (bottom) direct radiative forcing from aerosols. Though very comparable in terms of dust plume position and magnitude, our forecast without aerosol forcing is more aggressive in circulating dust around developing Nadine. Comparing profiles of total extinction along the Global Hawk track (Figure 5), we see that there is little impact of aerosol forcing on the sampled total AOT and contribution of dust to the total AOT for this case.

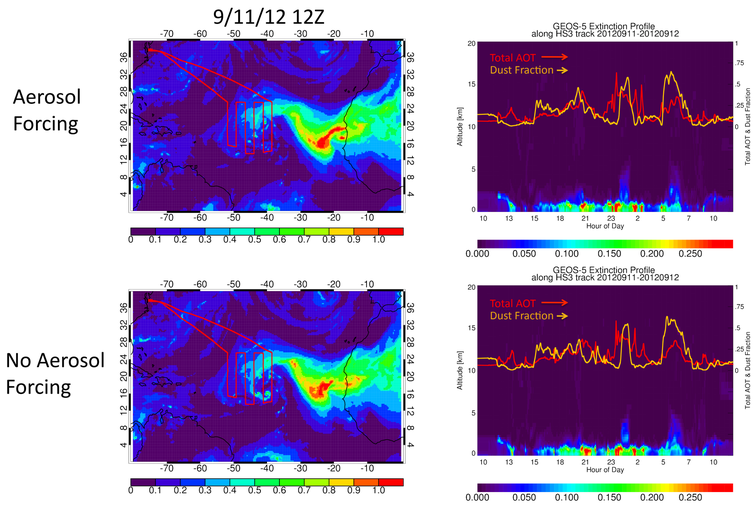

Figure 5. Total AOT at 9/11/12 12Z (left) and total extinction profiles along the Global Hawk Track for the 9/11/12 – 9/12/12 flight (right) for our forecast with (top) and without (bottom) radiative forcing from aerosols.

Conclusions & Future Work

We have evaluated the dust forecasting system in the NASA GEOS-5 AGCM for the HS3 Global Hawk flight on 9/11/12 – 9/12/12 and found the following:

- GEOS-5 5-day forecasts were able to accurately simulate the timing and placement of a dust plume that was in close proximity to tropical storm Nadine during development. The accuracy of the forecast greatly improved 48 hours prior to takeoff. Compared to CPL backscatter observed during the flight, GEOS-5 was able to predict when the Global Hawk would fly over dust.
- Comparing our forecasts to replay simulations, we found that the assimilation of MODIS AOT greatly improves the observed magnitude and timing of simulated dust plumes when compared to a replay simulation that did not assimilate MODIS AOT.
- We found little difference in the magnitude of our simulated dust plume in our 5-day forecasts with and without direct radiative forcing from aerosols, though our simulation without aerosol forcing was more aggressive in transporting dust into the developing region of Nadine.
- While the number of case studies where dust potentially interacted with tropical storm development was limited in 2012, we plan to extend this analysis to the flights on 9/6/12 and 9/14/12 where smaller dust loadings were observed by CPL.
- We look forward to participating again in the 2013 deployment. GEOS-5 forecasts are available at https://gmao.gsfc.nasa.gov/projects/HS3

Acknowledgements

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