Investigating sensitivity to dust in tropical cyclone formation using the GEOS-5 adjoint model

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Workshop on Meteorological Sensitivity Analysis and Data Assimilation
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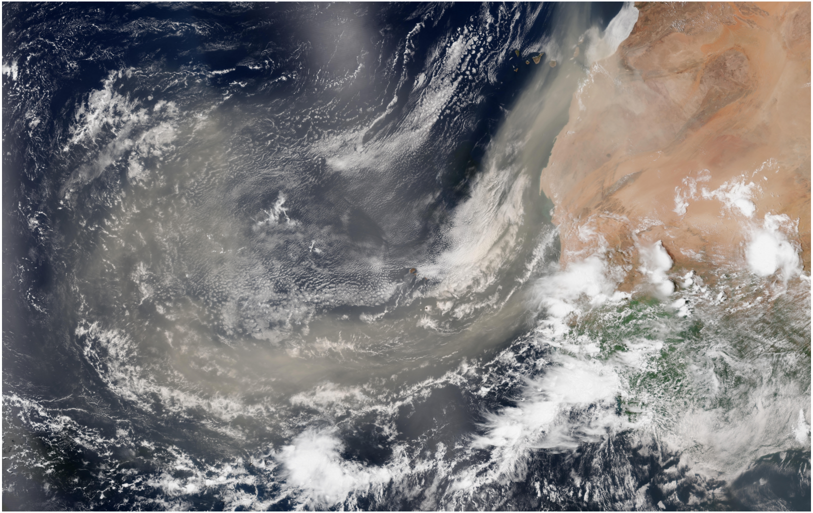
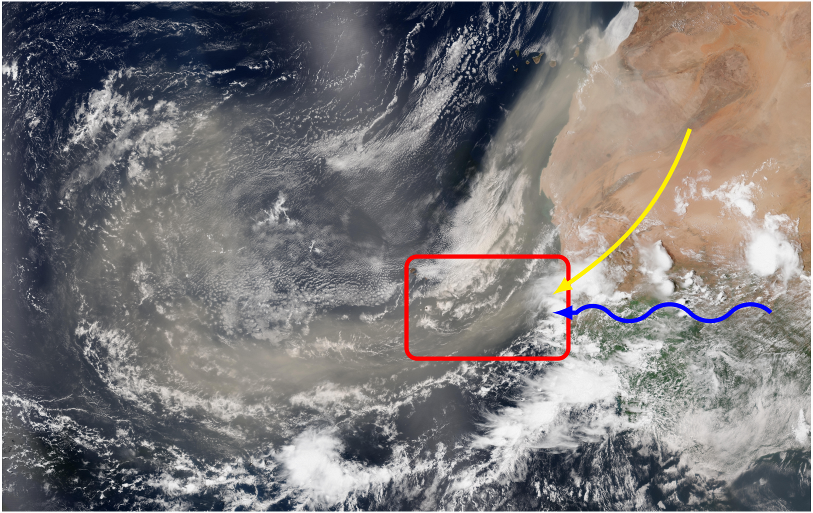


VIIRS on Suomi NPP 31-July-2013



VIIRS on Suomi NPP 31-July-2013

Motivation

How much (if at all) does Saharan dust affect the development of tropical cyclones?

Tropical cyclones need heat and moisture, but:

- Dust can absorb and reflect incoming radiation, cooling the atmosphere below
- As dry dusty air from the SAL is entrained it can reduce the available energy

On the other hand:

- Dusty layers can be warm due to absorption
- Dust can increase condensation through micro-physics

Here we examine the radiative effects using the GEOS-5 adjoint so effects of dust can be examined explicitly.

Outline

- Motivation
- Model/experiment setup
- Example 1: Circulation metric
- Example 2: Surface pressure metric

Adjoint setup

Use the GEOS-5 adjoint to propagate sensitivity,

$$\frac{\partial J}{\partial \mathbf{x}} = \mathbf{M}^\top \frac{\partial J}{\partial \mathbf{y}}$$

The cost function J is a metric relevant to the forming TC:

- Mean circulation
- Mean energy (KE/PE/Moist)
- Surface pressure

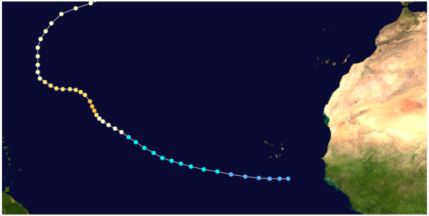
Build up understanding using different metrics, set to different areas and with different combinations of model layers.

Necessary Modifications

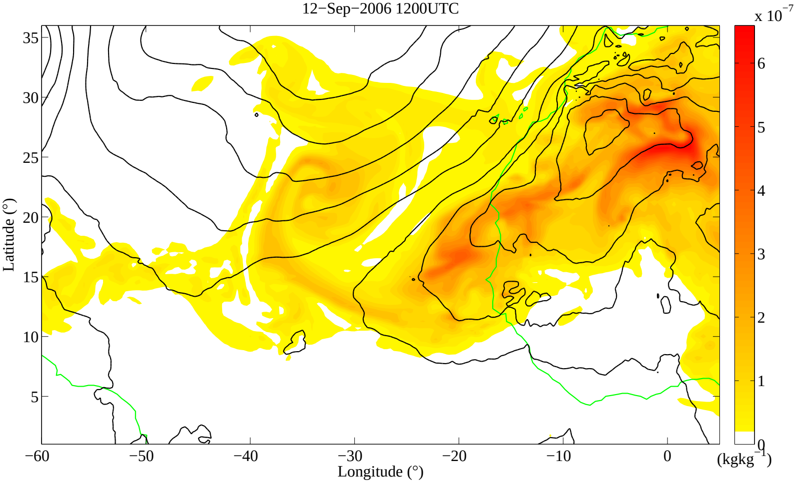
- Linearize the longwave and shortwave radiation schemes
- Linearize the Mie table lookups (No RH for dust)
- Include dust variables (5 bins from 0.1μm to 10μm)
- Linearized third order advection scheme
- Linearization of GOCART (10m winds, emissions, settling, dry deposition, no wet removal or scavenging)
- Ability to perturb aerosols in nonlinear model

Hurricane Helene

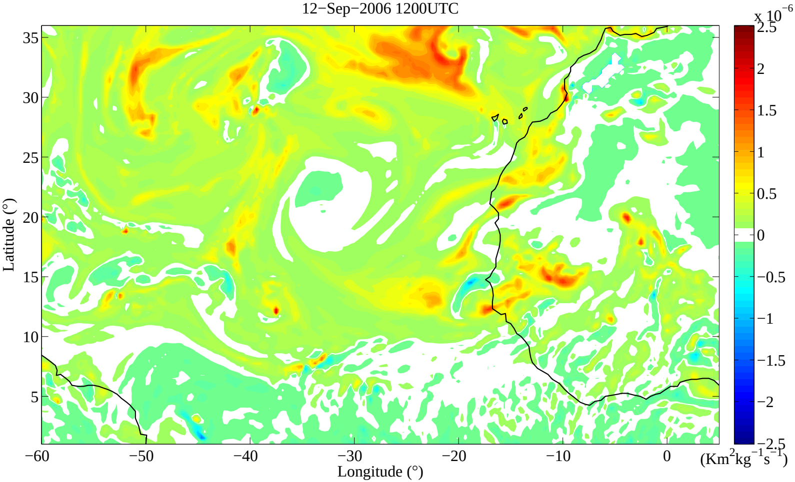
- 2006 season had an intense dust outbreak
- Results are shown for Hurricane Helene, TC on 12 Sep
- Forecasts produced with a 25km horizontal resolution
- TLM/adjoint is run at 50km (and 25km)
- 72h forecasts, initialized on September 9th at 21z



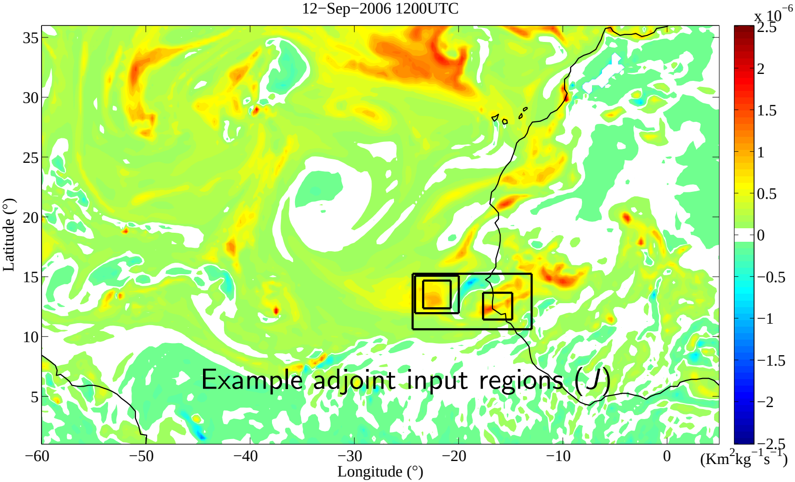
Dust mixing ratio at 850hPa / Sea Level Pressure



Potential Vorticity at 850hPa



Potential Vorticity at 850hPa



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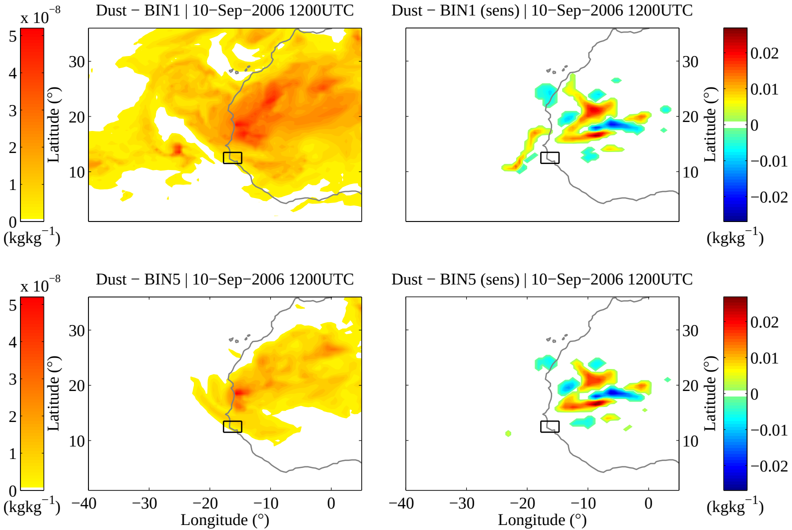
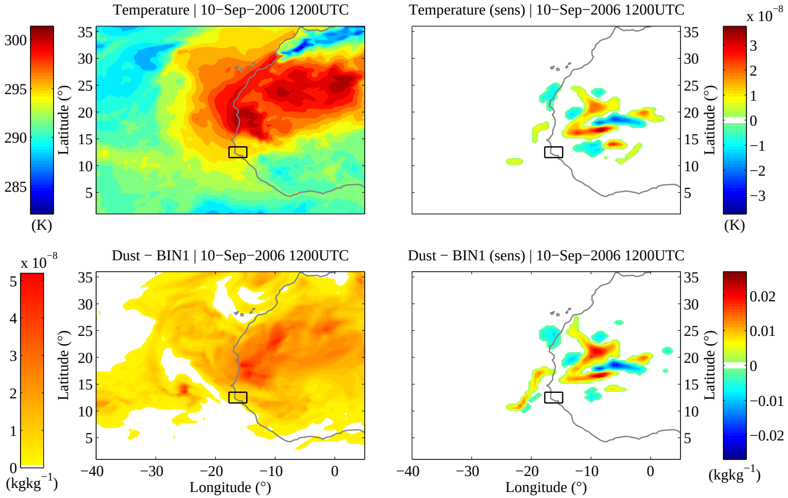
Sensitivity to Dust (850hPa, 48 hours before)

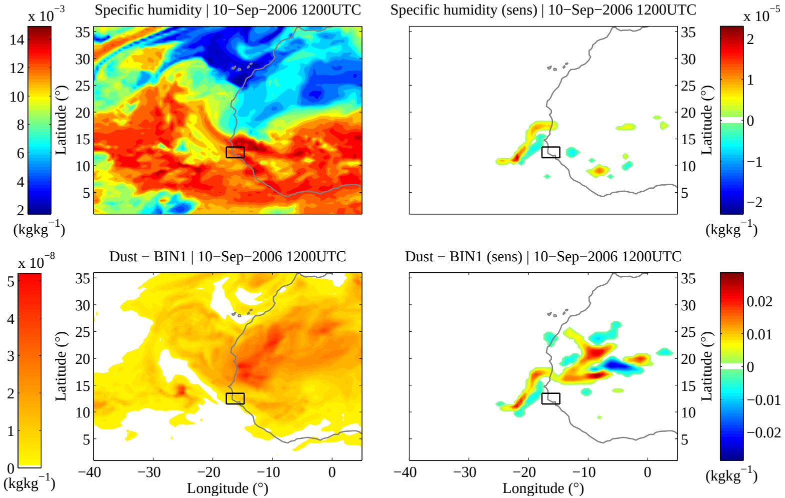


Comparison with sensitivity to temperature



Moist physics

Run with linearized convection and single-moment microphysics.



Perturbation Construction

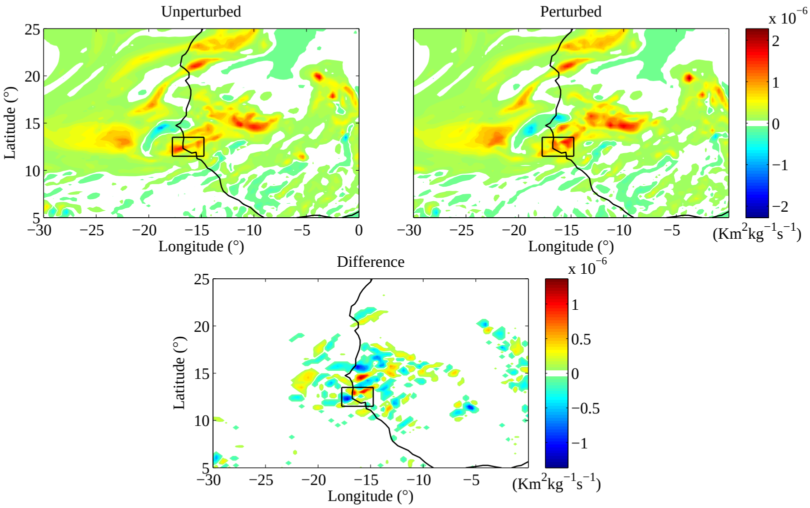
Now wish to construct and test some perturbations to:

- Understand the extent of the adjoint validity
- See what effects they have on the developing storm
- Understand how much dust can alter temperature

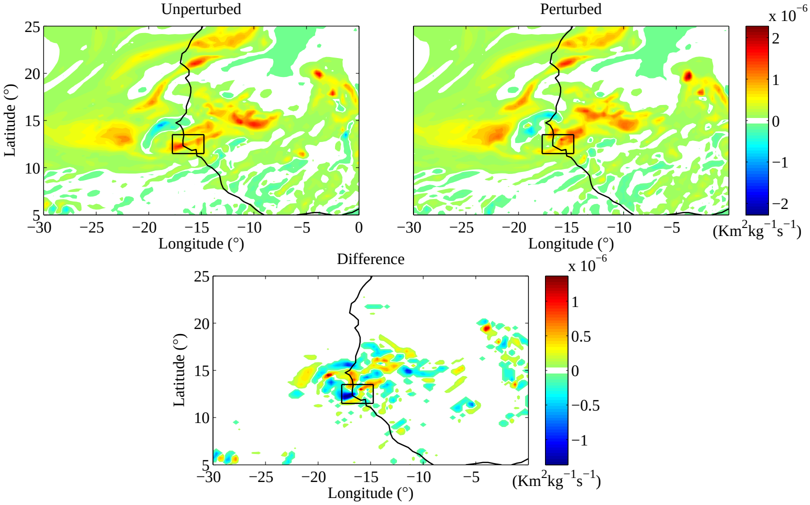
There is a lot of flexibility when constructing a tracer perturbation.

1. Take just the negative or positive parts of the sensitivity
2. Weight the sensitivity by the mass of the layer
3. Adjust at each level to reflect some realistic values of dust for that layer (for this case around 20% change)

Positive Dust Perturbation (850hPa PV difference)



Negative Dust Perturbation (850hPa PV difference)



General observations

- Largest sensitivity occurs over Northern Mali/Algeria
- Sensitivity structure is similar at other levels (up to around 500hPa)
- Sensitivity is largest in bin 1 (0.1μm to 1μm)
- Sensitivity to dust is smaller than other fields (but uncertainty is likely higher)
- 'Positive' sensitivity is more widespread than 'negative' sensitivity
- Mostly dry dynamics at this stage of Helene's life cycle

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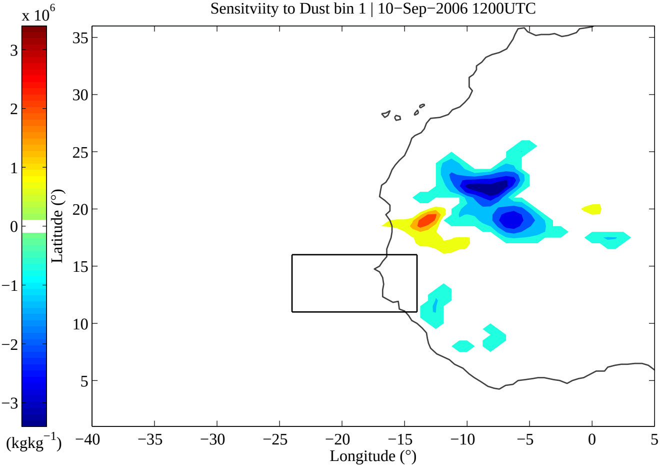
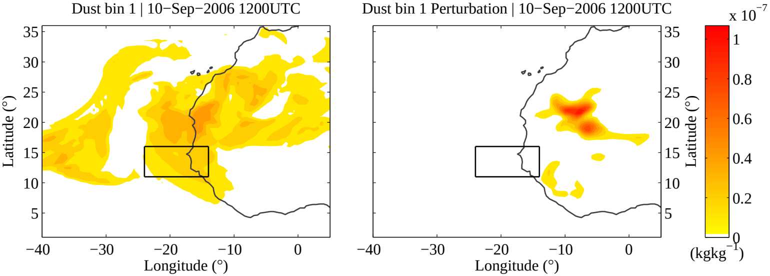
Surface pressure sensitivity to dust 550hPa



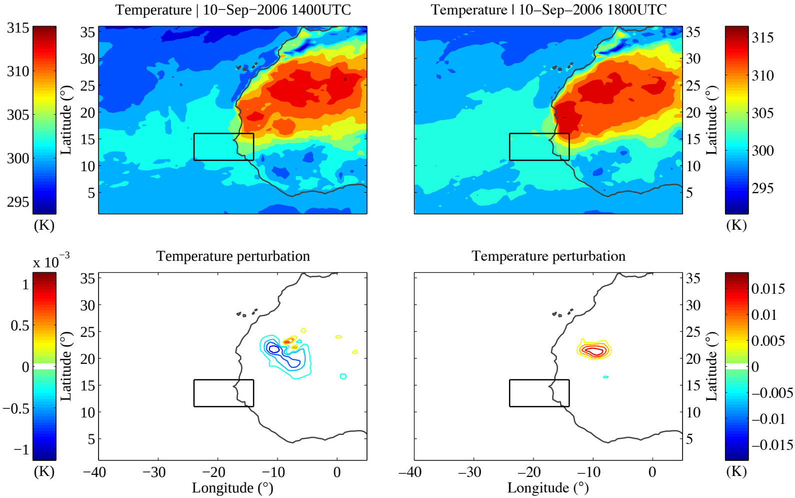
Warming/cooling below

Can we create a warming/cooling in sensitive region by perturbing dust above?

- Initialize the adjoint with surface pressure metric over larger box
- Generate initial perturbations around level 55 ($\approx$ 700hPa)
- Very large $>$ 100% positive perturbation



Temperature perturbation lowest level



Impact on Surface Pressure TLM vs NLM

Result of large perturbations of dust at all levels on surface pressure.

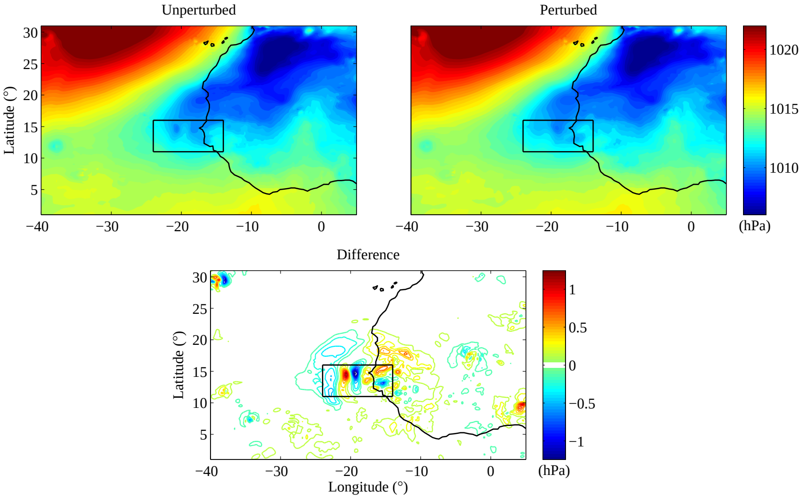
TLM

- Mean pressure reduction in the box: 0.28hPa
- Max pressure reduction in the box: 0.40hPa

NLM

- Mean pressure reduction in the box: 0.04hPa
- Max pressure reduction in the box: 1.39hPa

Nonlinear Sea Level Pressure

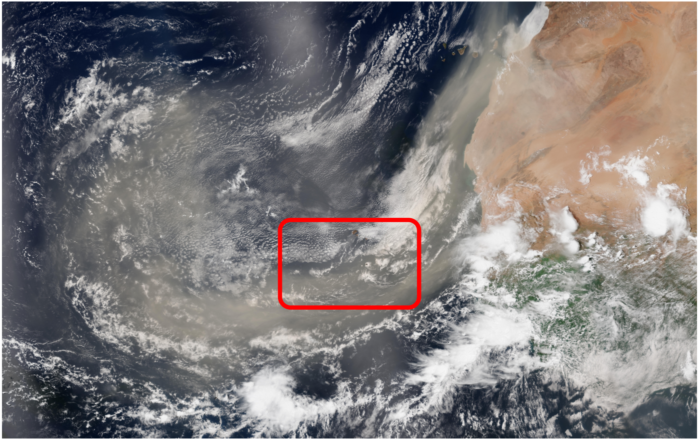


Conclusions

- The adjoint is shown to be a useful tool for examining sensitivity to dust (aerosols) through radiation
- 48 hours is about the limit for dry GEOS-5 (shorter for moist)
- Dominant sensitivity is direct warming/cooling
- Secondary effects hard to study in this context
- ‘Positive’ sensitivity dominates
- Increasing dust shown to increase strength and vice versa
- Sensitivity smaller than for other fields
- Adjoint may under-predict sensitivity
- Sensitivity to dust for region looked at is over Sahara and inland

Future work?

- Downstream (limited by physics)



- Look at impact of observations in sensitive region