Prognostic emissions in GEOS

ICAP 10th working group meeting, 2018

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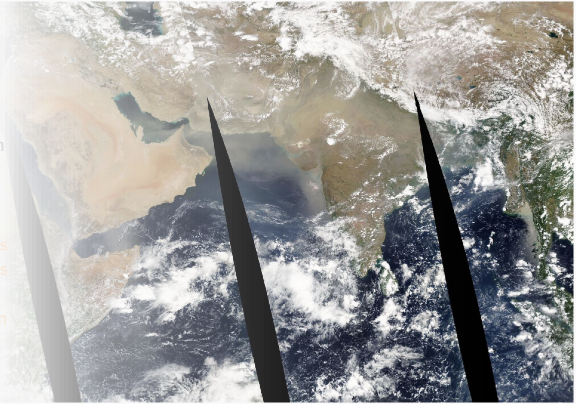
Motivation

Towards the development of a modeling system that enables and enriches Earth system science and applications

Goals guiding aerosol model development in GEOS

- Simulate global aerosol distribution and properties as constrained by observations
- Represent processes through which aerosols interact with and interlink the main components in the Earth system

Prognostic emissions of aerosols and trace gases enable seamless applications of atmospheric chemistry and aerosol models across scales and time. Prognostic emissions also facilitate direct and higher order interactions (feedbacks) between components in an integrated modeling system and thus enhance the model representativeness. On the other hand they also require more attention and strict validation to ensure model integrity.



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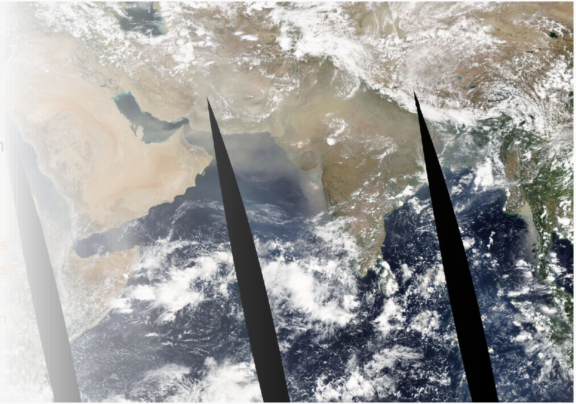

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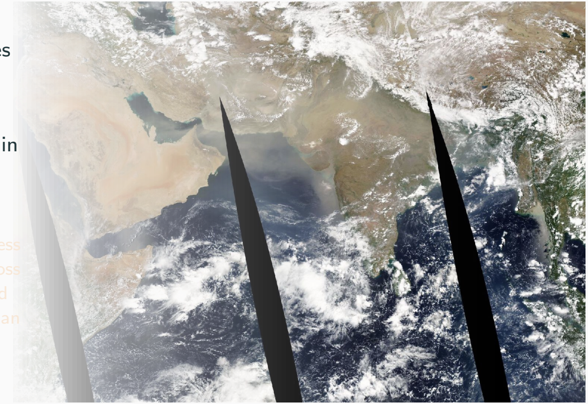

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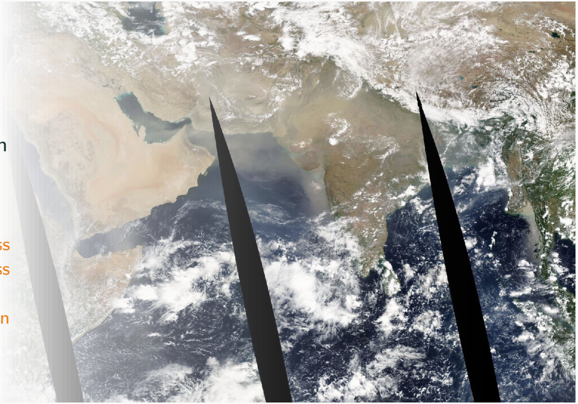

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Outline

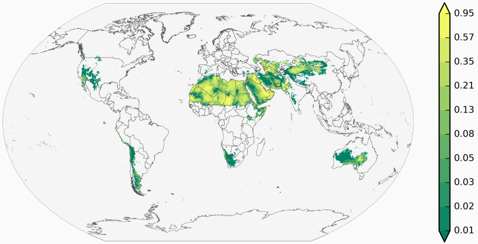
Assessment of the K14 dust emission scheme in GEOS

- Dust emissions in GEOS
- Methodology
- Results
- Conclusions

Evaluation of wind-wave based production of primary marine aerosols in GEOS

- Sea salt emissions in GEOS
- Implementation of the University of Miami Wave Model (UMWM)
- Results

Assessment of the K14 dust emission scheme in GEOS



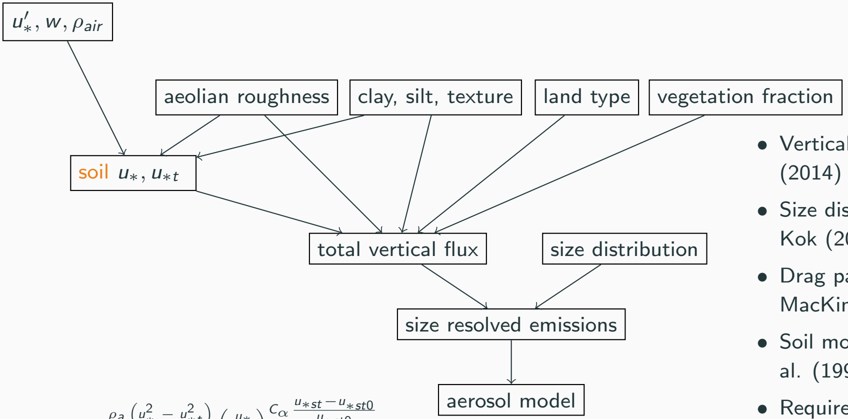
The source function (S) used in GEOS.

- Emissions are calculated for the five GOCART dust size bins: $F_i = CSs_i u_{10}^2 (u_{10} - u_{t,i})$
- Follows the empirical formulation of Gillette and Passi (1988)
- Relies on topographic source function
- Driven by 10-meter winds
- Size dependent threshold velocity modulated by soil moisture content

Motivation and objectives

- The Ginoux scheme works remarkably well in GEOS, but can we further improve the model by implementing a physically based emission scheme?
- Investigate the performance of Kok et al. (2014) scheme in GEOS.

Implementation of Kok et al. (2014) scheme in GEOS



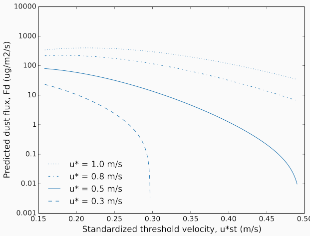
$$F_d = C_d f_{bare} \gamma \frac{\rho_a \left(u_*^2 - u_{*t}^2\right)}{u_{*st}} \left(\frac{u_*}{u_{*t}}\right)^{C_\alpha \frac{u_{*st} - u_{*st0}}{u_{*st0}}}$$

$$C_d = C_{d0} \exp\left(-C_e \frac{u_{*st} - u_{*st0}}{u_{*st0}}\right), \quad u_{*st} = u_{*t} \sqrt{\frac{\rho_a}{\rho_{a0}}}$$

- Vertical dust flux: Kok et al. (2014)
- Size distribution of emitted dust: Kok (2011)
- Drag partition correction: MacKinnon et al. (2004)
- Soil moisture correction: Fecan et al. (1999)
- Requires static and dynamic global datasets
- Low numerical complexity and cost

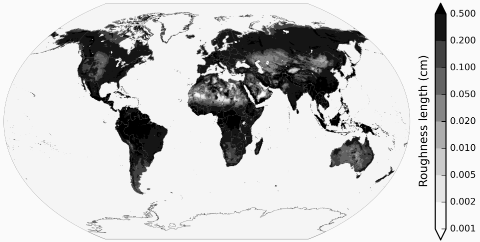
Thoughts on the threshold friction velocity in the K14 scheme

- K14 defines u_{*t} as the minimum friction velocity for which bare soil experiences erosion
- Initiation and termination of saltation occur at different friction velocities (fluid/static $>$ impact/dynamic threshold values)
- '...there is generally not a clear value of u_* above which saltation does occur and below which it does not...' - K14
- One can introduce effective u_{*t} by integrating the theoretical size dependent $u_*(D, \rho)$ over the soil size distribution, but this is also not so trivial (what are the proper size range, size distribution, etc.) The effect is to increase u_{*t} by 15%-30% depending on the soil size distribution.
- Tests indicated that using the minimum value predicted by the theoretical expression for u_{*t} over dry smooth surface that corresponds to soil particles with diameter of about $75 \mu m$ works well, however this likely introduces biases in some of the source regions
- On the positive side there is some freedom how to select u_{*t} which opens possibilities for optimizing this parameter in the models



Vertical dust flux as a function of the standardized threshold friction velocity u_{*st} for several representative values of the friction velocity u_*.

- GEOS AGCM was run at 50km×50km horizontal resolution
- MERRA2 meteorology and prescribed SST for 2015
- GOCART aerosols
- Radiatively interactive aerosols
- Control - standard dust emissions (Ginoux et al., 2001)
- K14(a) - K14 dust emissions (Kok et al., 2014)
- K14(b) - K14 scheme and ARLEMS surface roughness roughness over bare or sparsely vegetated surface



ARLEMS aeolian aerodynamic roughness length derived from ASCAT backscattering and PARASOL protrusion coefficient at 865nm (Prigent et al., 2012).

Aerosol data and selection criteria for dusty observations

Evaluation

AERONET: Level 2 AOT(550) and angstrom exponent $\alpha(440-870)$

OMI: Aerosol Index (AI)

MERRA2: aerosol analysis AOT(550)

Criteria for dusty conditions

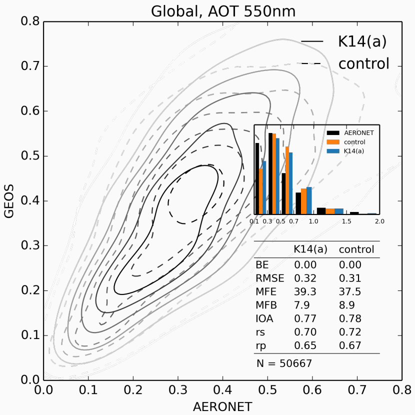
AERONET: $AOT(550) > 0.05$

AERONET: $\alpha(440-870) < 0.4$

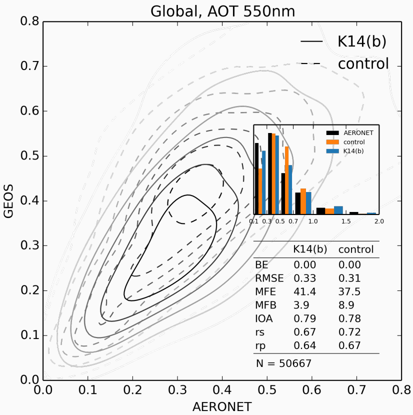
GEOS: $dustAOT(550)/AOT(550) > 0.8$

AERONET sites with dusty observations. Sites with more than 2% of the total number of dusty observations in 2015 are labeled. The sites in Tamanrasset INM (14%), Mezaira (13%), Dakar (12%) and Ilorin (10%) accounted for about half of the dusty observations.

Comparison with AERONET



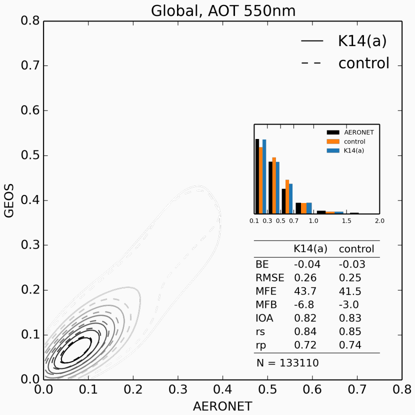
	K14(a)	control
BE	0.00	0.00
RMSE	0.32	0.31
MFE	39.3	37.5
MFB	7.9	8.9
IOA	0.77	0.78
rs	0.70	0.72
rp	0.65	0.67

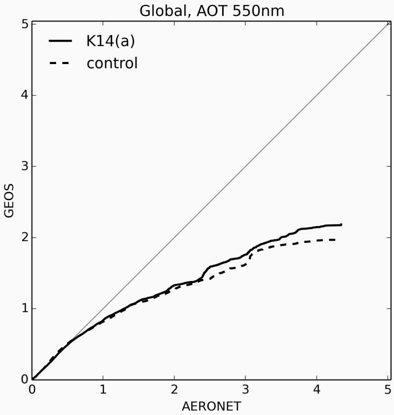


	K14(b)	control
BE	0.00	0.00
RMSE	0.33	0.31
MFE	41.4	37.5
MFB	3.9	8.9
IOA	0.79	0.78
rs	0.67	0.72
rp	0.64	0.67

The skills of the K14 modeling experiments are lower but comparable to the control.

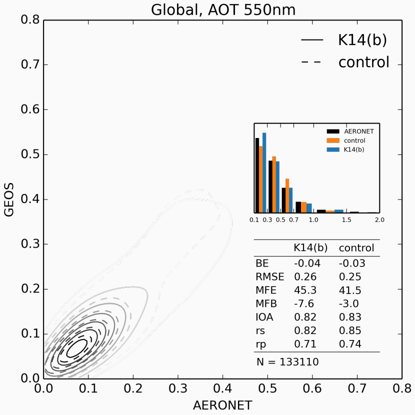
Comparison with AERONET: overall performance of K14(a)





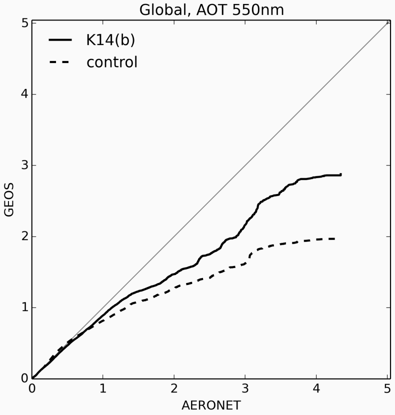
The control and the K14(a) experiment are unable to reproduce the dispersion in the AERONET data.

Comparison with AERONET: overall performance of K14(b)

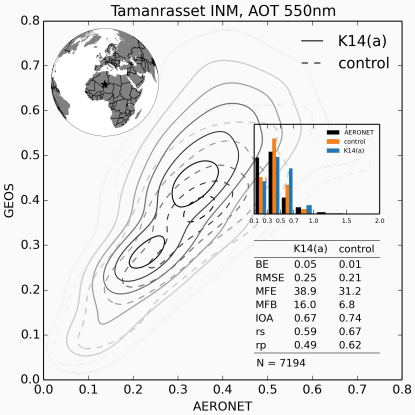


	K14(b)	control
BE	-0.04	-0.03
RMSE	0.26	0.25
MFE	45.3	41.5
MFB	-7.6	-3.0
IOA	0.82	0.83
rs	0.82	0.85
rp	0.71	0.74

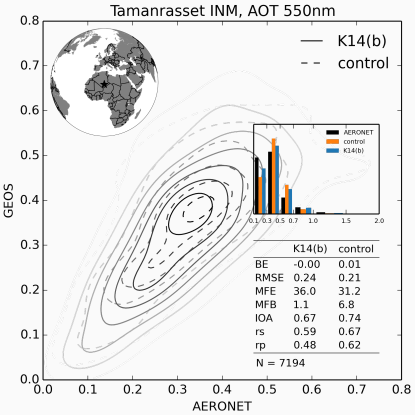
N = 133110



The distribution of AOT in the K14(b) is improved in respect to the control (it is more similar to the observations), however occurrences of AOT > 1.5 remain underpredicted in the model.

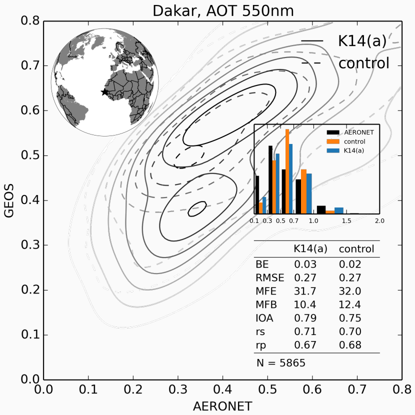


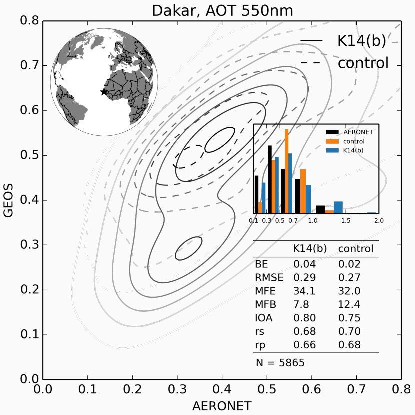
Tamanrasset INM, AOT 550nm
K14(a)
control
AERONET
control
K14(a)
GEOS
AERONET
	K14(a)	control
BE	0.05	0.01
RMSE	0.25	0.21
MFE	38.9	31.2
MFB	16.0	6.8
IOA	0.67	0.74
rs	0.59	0.67
rp	0.49	0.62
N = 7194



Tamanrasset INM, AOT 550nm
K14(b)
control
AERONET
control
K14(b)
GEOS
AERONET
	K14(b)	control
BE	-0.00	0.01
RMSE	0.24	0.21
MFE	36.0	31.2
MFB	1.1	6.8
IOA	0.67	0.74
rs	0.59	0.67
rp	0.48	0.62
N = 7194

Comparison with AERONET - Saharan dust





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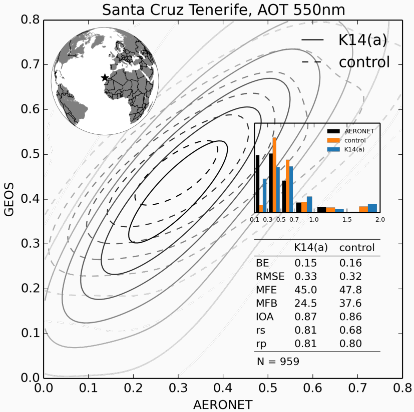
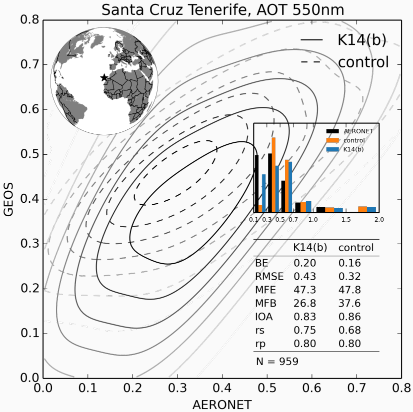


	K14(a)	control
BE	0.15	0.16
RMSE	0.33	0.32
MFE	45.0	47.8
MFB	24.5	37.6
IOA	0.87	0.86
rs	0.81	0.68
rp	0.81	0.80

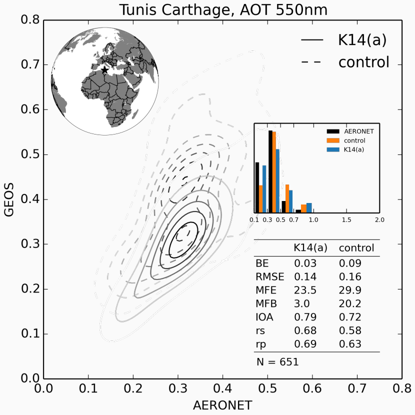
N = 959

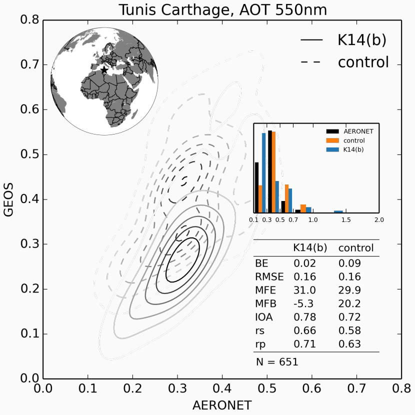


	K14(b)	control
BE	0.20	0.16
RMSE	0.43	0.32
MFE	47.3	47.8
MFB	26.8	37.6
IOA	0.83	0.86
rs	0.75	0.68
rp	0.80	0.80

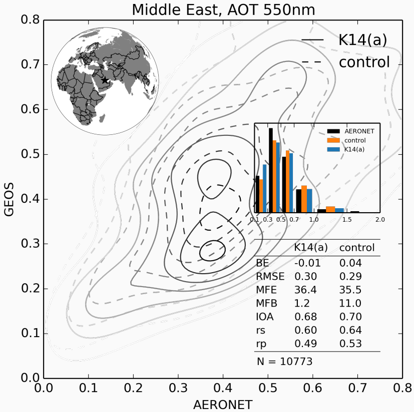
N = 959

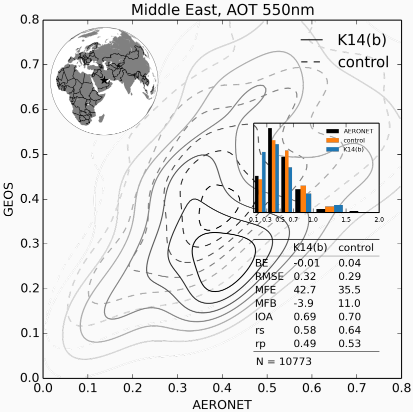
Comparison with AERONET - Saharan dust



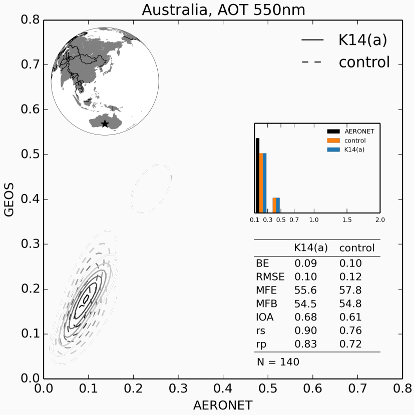


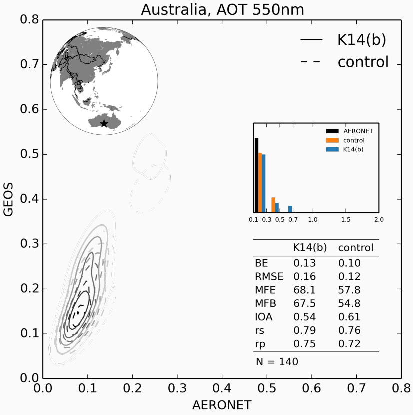
Comparison with AERONET - Middle East sources



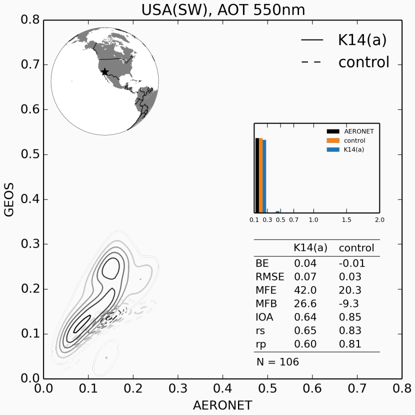


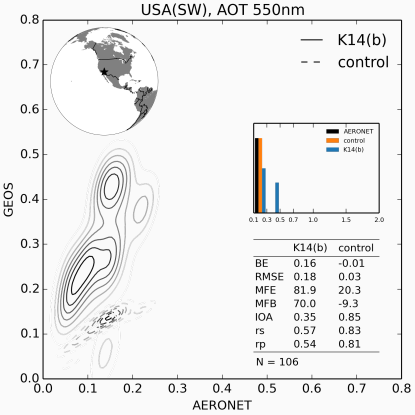
Comparison with AERONET - Australia



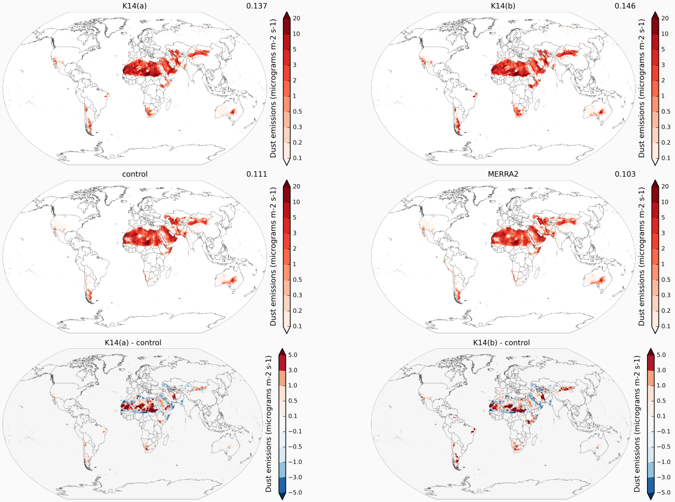


Comparison with AERONET - Southwestern US





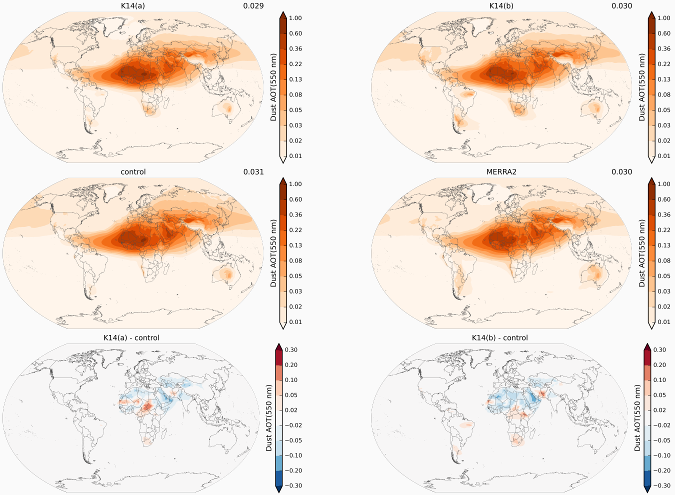
Dust emissions



- The major dust sources are represented well in the control and the K14 experiment
- Global emissions:

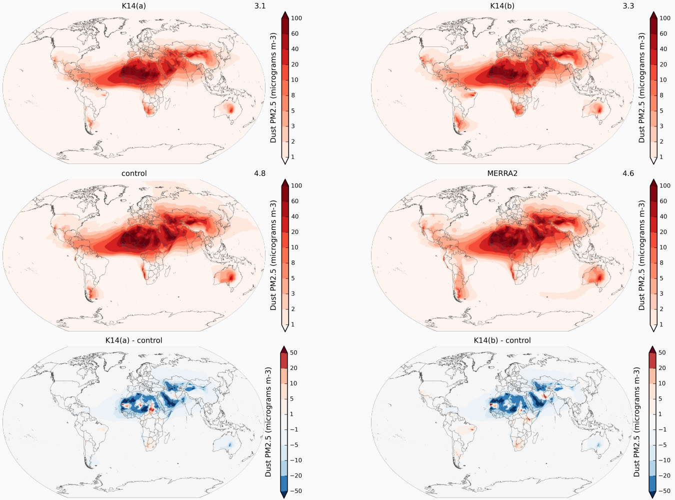
  control = 1800 Tg/yr
  K14(a) = 2200 Tg/yr (+20%)
  K14(b) = 2350 Tg/yr (+30%)

- South America (Patagonia and Sertao), Southern Africa (Kalahari, Namib, Karoo), Sahel and Gobi sources are more active in the K14 experiments



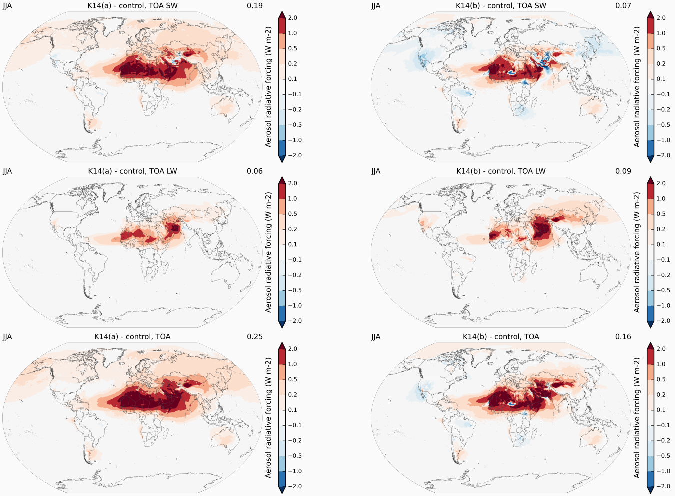
- The control and the two K14 experiments have similar global dust AOT
- Recent estimate (Ridley et al., 2016) of global dust AOT is 0.030 ± 0.005
- The K14 runs have lower dust AOT in the Northen Hemisphere and higher dust AOT in the Southern Hemisphere

Dust PM2.5



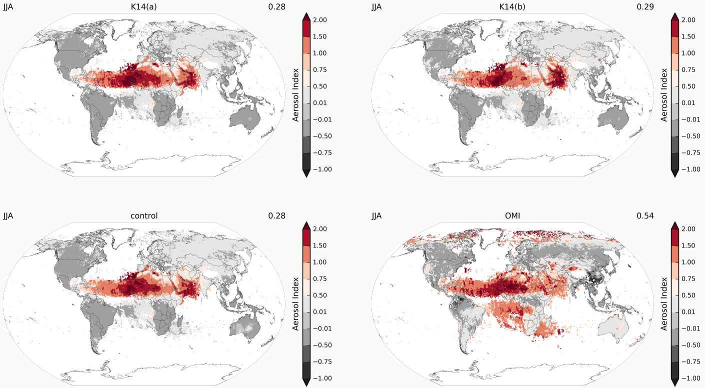
- Dust PM2.5 is generally higher in the control than in the K14 experiments
- In the K14 experiments, countries downwind of dust sources in Sahara and the Middle East are exposed to smaller amount of harmful fine dust particles

Radiative effect: TOA All-sky



- There is less SW cooling (more heating over bright surfaces) at TOA in the K14 experiments
- There is more LW heating at TOA in the K14 experiments

UV Aerosol Index



- The control and K14(a) reproduce very well the OMI data in the regions affected by Saharan dust
- AI is overpredicted over the Middle East in the three experiments
- AI is underpredicted in Taklamakan and Australia

Why did K14 not outperform the less sophisticated empirical scheme?

- We used AOT to assess the performance and did not tune other aspects of the system (e.g. removal processes)
- Longer simulations are essential for robust statistics and representation of intermittent sources
- K14 uses more inputs, each introducing errors that affect the emission estimates
- K14 is more sensitive to threshold friction velocity
- K14 may be more sensitive to wind speed so errors in winds are amplified

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Summary

- The Kok et al. (2014) scheme was independently implemented in GEOS
- The performance of the new dust emission scheme was found to be very similar to that of the default parameterization based on Ginoux et al. (2001)
- Noticeable differences were observed in the predicted dust emissions, PM2.5 and radiative effect of dust at TOA - we attributed these differences primarily to the coarser size distribution of emitted dust in the K14 scheme

- The K14 scheme is staged for inclusion in the next GEOS system, pending acquisition of MODIS NRT vegetation indexes and generation of vegetation fraction product

NASA support

This work was supported by the NASA ROSES (2015) CloudSat and CALIPSO Science Team Recompete program and NASA GMAO.

Project: Constraining the Modeling of Dust Aerosol and Climate Impacts Using CALIPSO, CloudSat, and Other A-Train Satellite Measurements

PI: Xiaohong Liu

Evaluation of wind-wave based production of primary marine aerosols in GEOS

Overview of sea spray aerosol source functions

Heavy weather in the Gulf of Alaska. Photo: Crew and Officers of NOAA Ship FAIRWEATHER, NOAA Photo Library.

- Sea salt emissions over the ocean are commonly parameterized as a function of wind and SST
- In global models the functional dependence is further simplified and expressed as the product of 10-m wind, SST and size dependent terms: $dN/dD = W(u_{10m})T(SST)S(D)$
- In GEOS we use the size distribution of Gong (2003), wind forcing term proportional to $u_*^{2.41}$ and a SST correction term derived from AOD

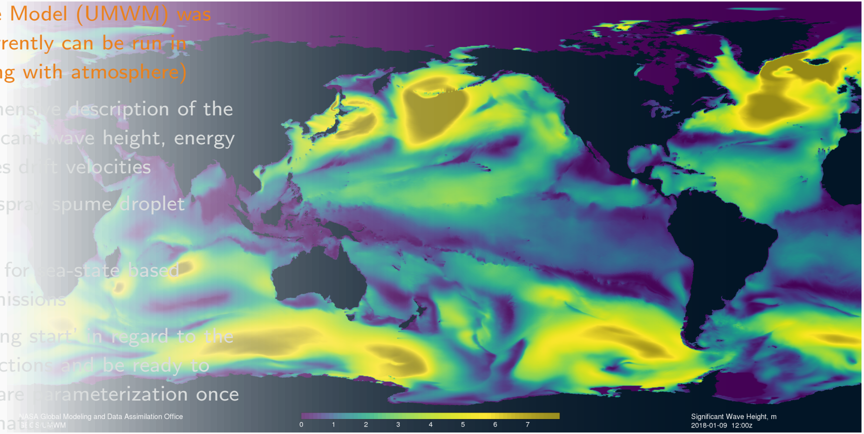
Motivation and objectives

- There are large uncertainties in the predicted emission fluxes
- The implementation of a wave model in GEOS enables the use of physically based parameterizations of marine aerosol emissions and gas exchange between atmosphere and ocean

Strengthen ocean-atmosphere coupling through implementation of wind-wave model in GEOS

The University of Miami Wave Model (UMWM) was implemented in GEOS and currently can be run in passive mode (one-way coupling with atmosphere)

- UMWM provides comprehensive description of the sea-state, including significant wave height, energy dissipation rate and Stokes drift velocities
- Can be coupled with sea spray spume droplet production module
- Provides necessary inputs for sea-state based primary marine aerosol emissions
- We want to have a 'running start' in regard to the marine aerosol source functions and be ready to transition to sea state aware parameterization once the wave model is more mature



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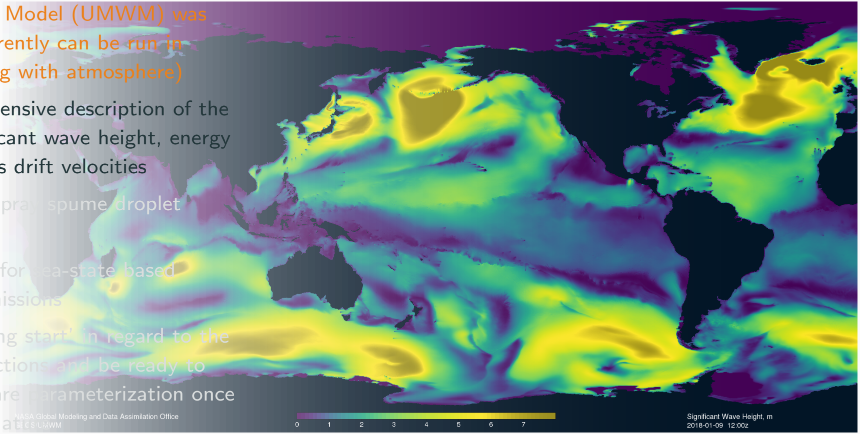

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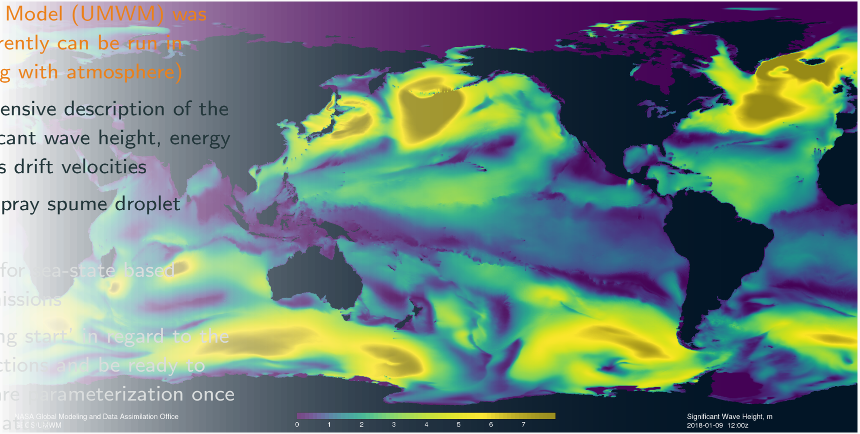

Strengthen ocean-atmosphere coupling through implementation of wind-wave model in GEOS

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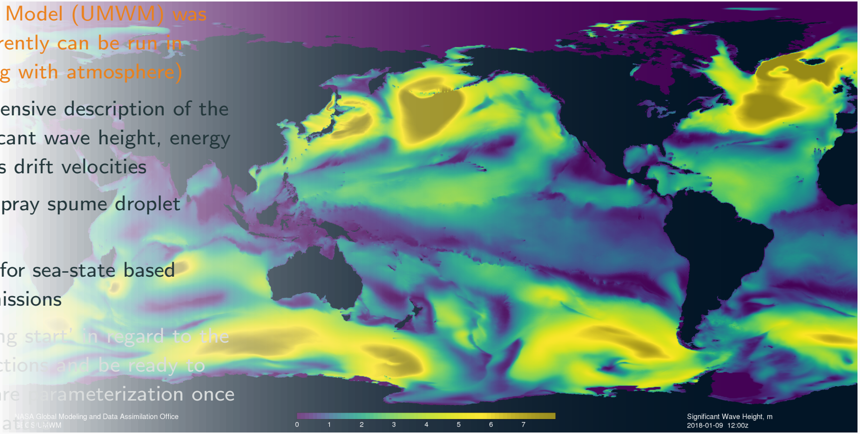

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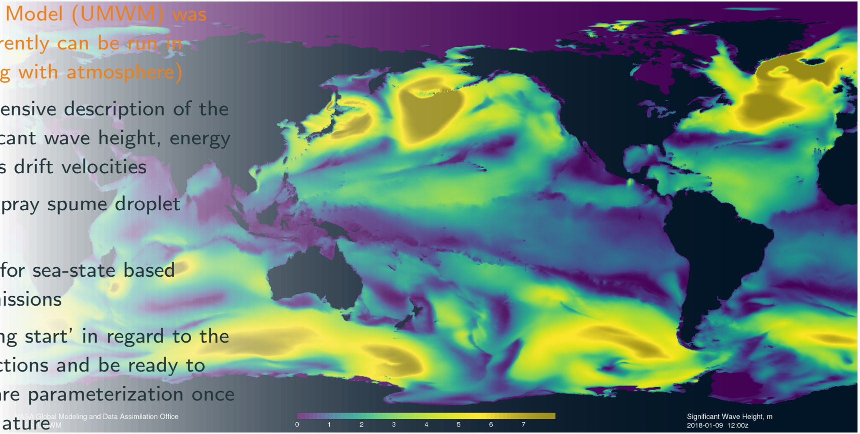


Wave state based source functions implemented in GEOS/UMWM

Porthole view of rough seas in the Gulf of Mexico. Such views remind one of looking into a washing machine. Photo: Officers and Crew of NOAA Ship PISCES; Collection of Commander Jeremy Adams, NOAA Corps, NOAA Photo Library.

O14 - based on Ovadnevaite et al. (2014) and Partanen et al. (2014)

- Size resolved emissions are parameterized as a function of the wave Reynolds number $Re_{Hw} = u_* H_s / \nu_w$
- One of the few parameterizations with size distribution that depends on wind and wave characteristics

D17 - based on Deike et al. (2017) and Anguelova and Hwang (2014)

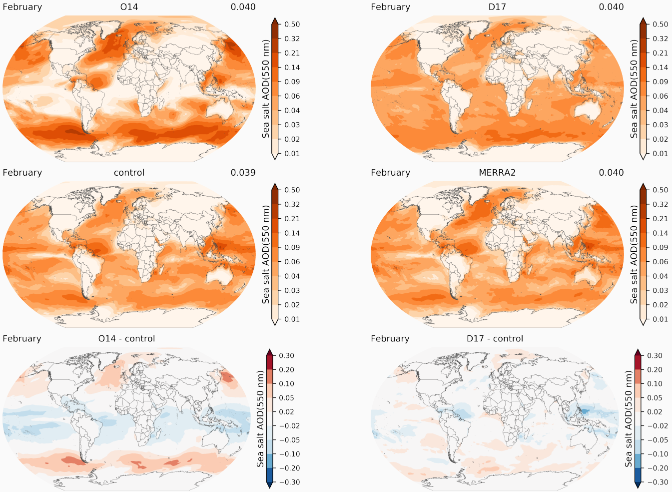
- Volume of air entrained by breaking waves: $V_A / c_p = \chi_1 (c_p / u_*)^{-\xi_1}$ or $V_A / c_p = \chi_2 (u_* / \sqrt{g H_s})^{\xi_2}$
- Observed good linear relationship between active whitecap fraction W_A and V_A
- I used the results from A&H (2014) to parameterize W_A / W as a function of 10-m winds, thus $V_A \rightarrow W_A \rightarrow W \rightarrow$ sea salt emissions

Aerosol simulations

- GEOS/UMWM was run at 50km×50km horizontal resolution
- MERRA2 meteorology and prescribed SST for 2017
- GOCART aerosols
- Radiatively interactive aerosols
- Control - standard sea salt emissions in GEOS
- O14 - based on Ovadnevaite et al. (2014)
- D17 - based on Deike et al. (2017) and Anguelova and Hwang (2014)

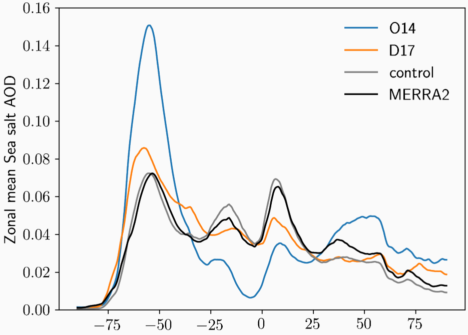
Sea surface during Hurricane Isabel at 400 feet altitude. Photo: NOAA/OAR/AOML/Hurricane Research Division, NOAA Photo Library.

Sea salt aerosol optical thickness



- The sea salt emissions in O14 and D17 were scaled to match the monthly MERRA2 sea salt AOT
- O14 emissions and AOT are lower in the low latitudes and resemble G03
- D17 and the nominal GEOS parameterization have more uniform emissions

Summary and model development plans



Zonal mean profiles of sea salt AOT from the considered here source functions.

- The results from the O14 and D17 trial runs look promising
- More thorough analysis is needed to assess the performance of the new parameterizations
- Next we plan to implement and evaluate source function(s) based on wave energy dissipation rate, e.g., Petelski et al. (2005) : $F_E = aE_d^{\alpha} + b$, $\alpha \approx 2/3$
- Improve the speciation of marine aerosols by implementing emissions of primary marine organic mater
- Assess the impact of the new parameterizations on clouds

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Questions?