Modeling impacts of dust mineralogy on fast climate response

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Outline

- **Motivation**
  - Dust can directly interact with radiation (DRE).
  - Dust direct radiative effect (DRE) is largely uncertain
  - Mineral composition varies across dust source regions

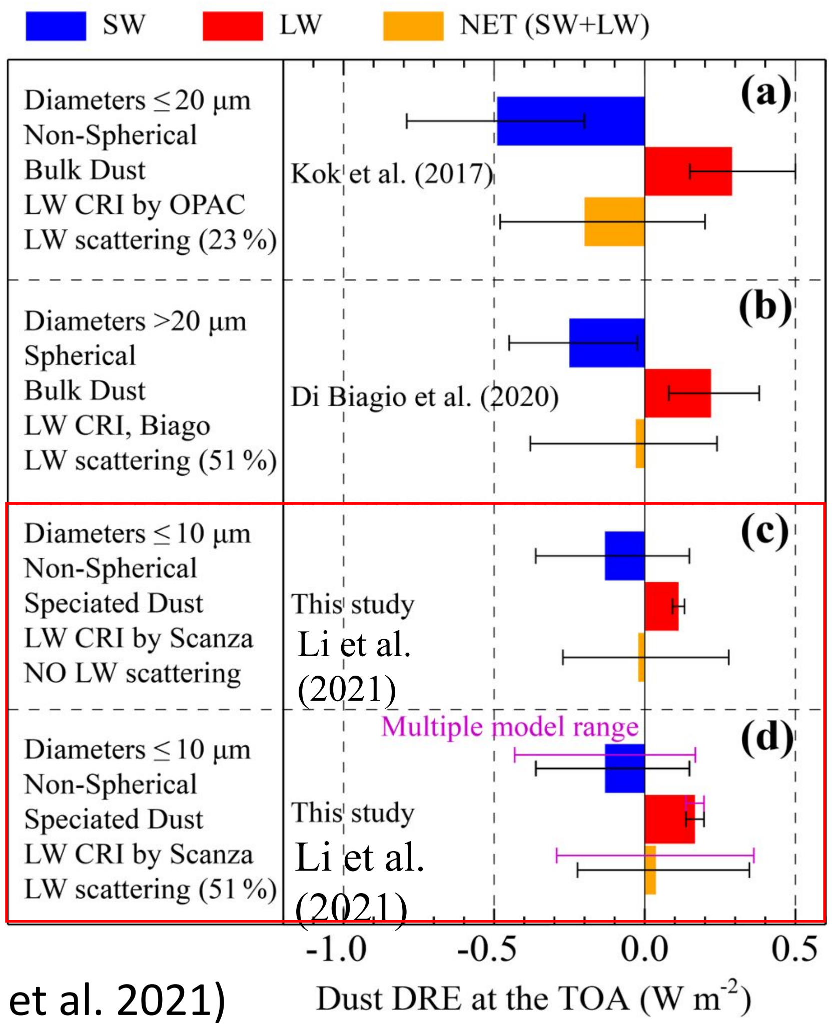
- **Implementation of dust mineralogy and interaction with radiation**
  - Dust optical properties and comparison with observations
  - Recommend reducing dust absorption for GFDL AM5

- **Impacts on fast climate response**
  - Radiation
  - Land surface temperature
  - Winds
  - Precipitation

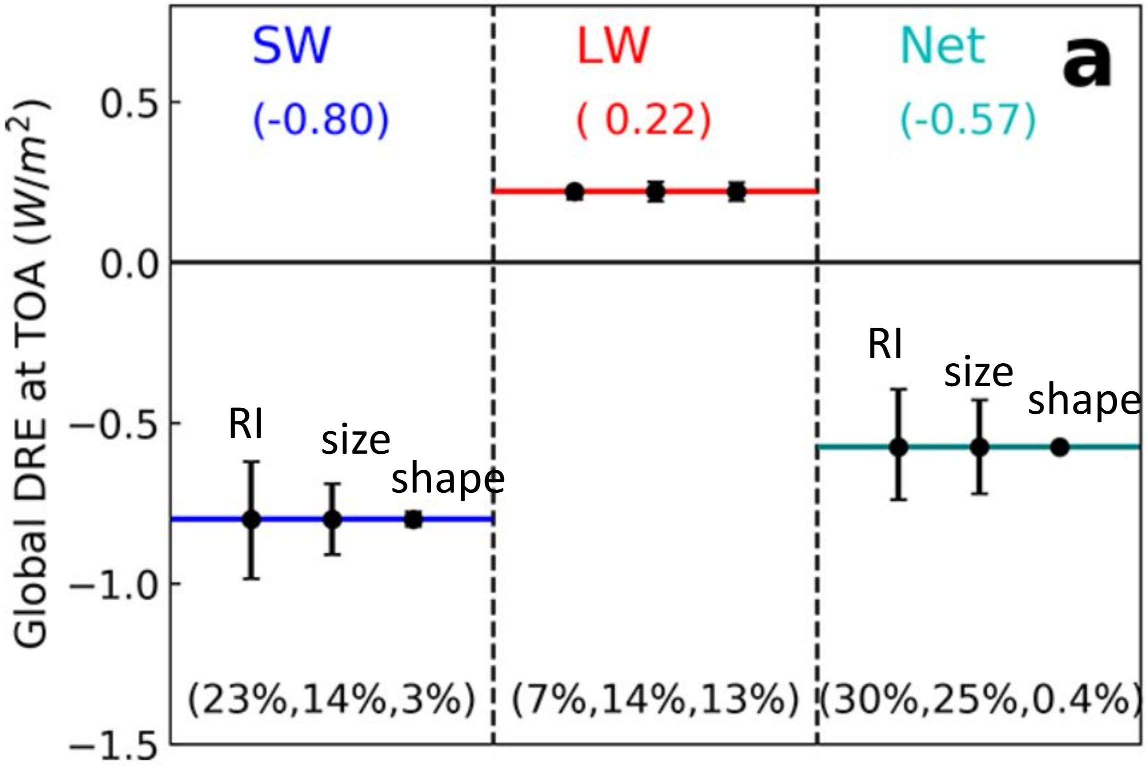
Dust Direct Radiative Effects (DRE)

Dust DRE is largely uncertain!

Mineral Uncertainty



(Li et al. 2021)

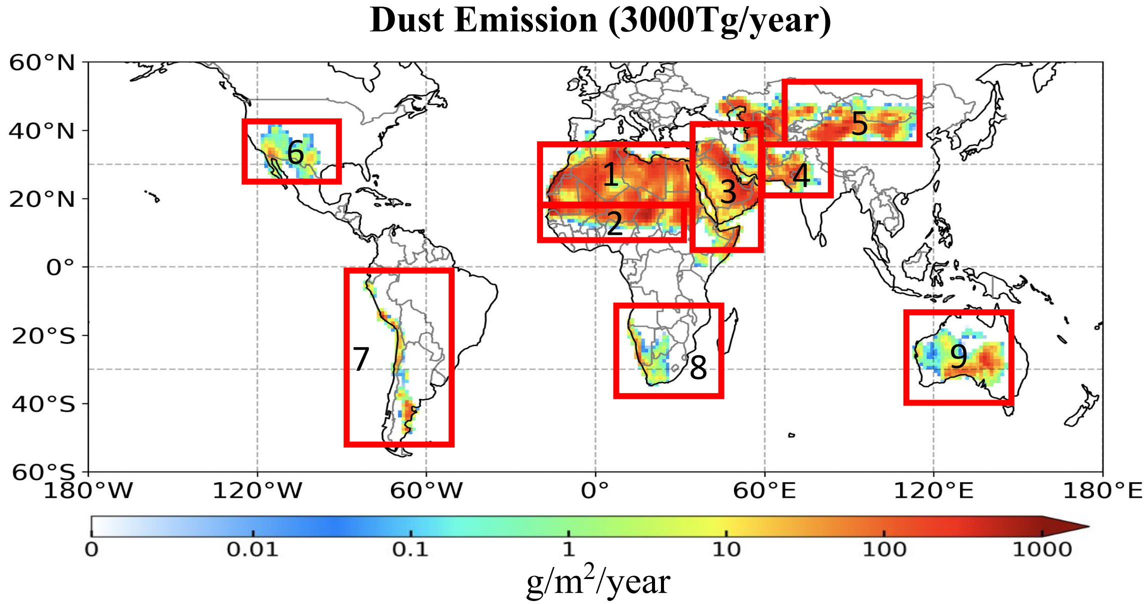


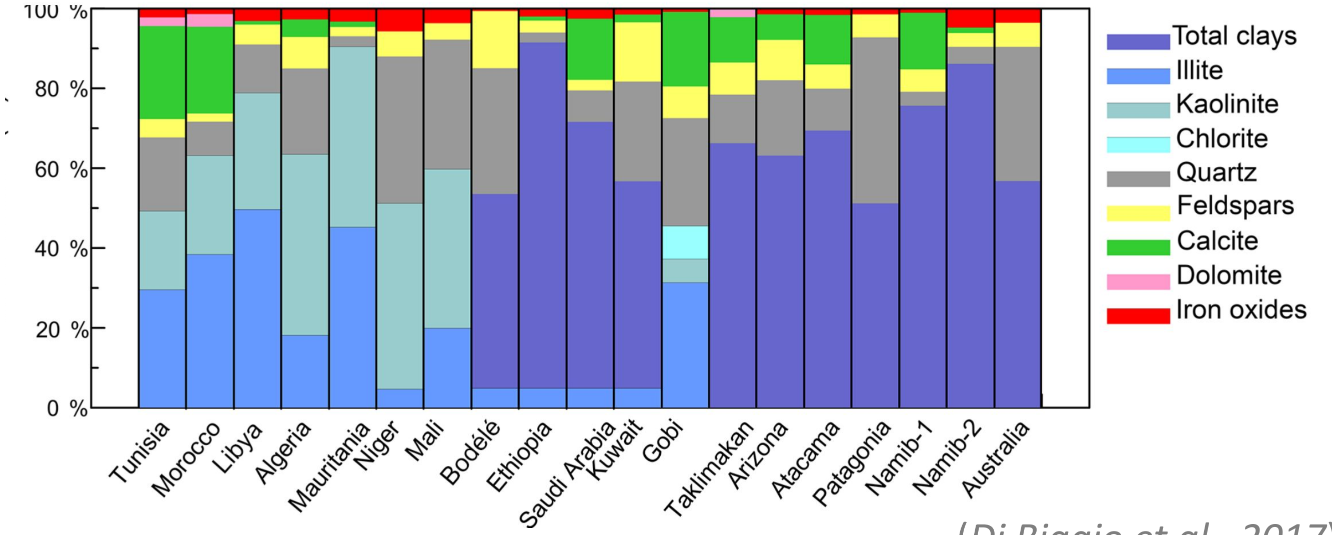
(Song et al. 2021)

- Dust DRE uncertainty is mainly attributed to dust RI (mineralogy) uncertainty.

Dust Mineralogy

Soil mineral composition (mineralogy) varies across dust source regions.





(*Di Biagio et al., 2017*)

- Dust mineral composition is important for a better understanding of dust radiation interaction.
- Dust mineral composition has a large spatial variations.
- Most climate models (including GFDL) still use fixed (homogeneous) dust mineralogy.

It is important to resolve dust mineralogy in models to investigate dust radiation interaction.

Dust Mineralogy

- Implement eight minerals, activate their interaction with radiation in the GFDL AM4.0 model.

  Eight minerals: Iron oxides(Hematite), illite, kaolinite, smectite, feldspar, gypsum, calcite, quartz

- Among all minerals, **Hematite** content controls **dust absorption** in visible spectrum.

Dust Mineralogy

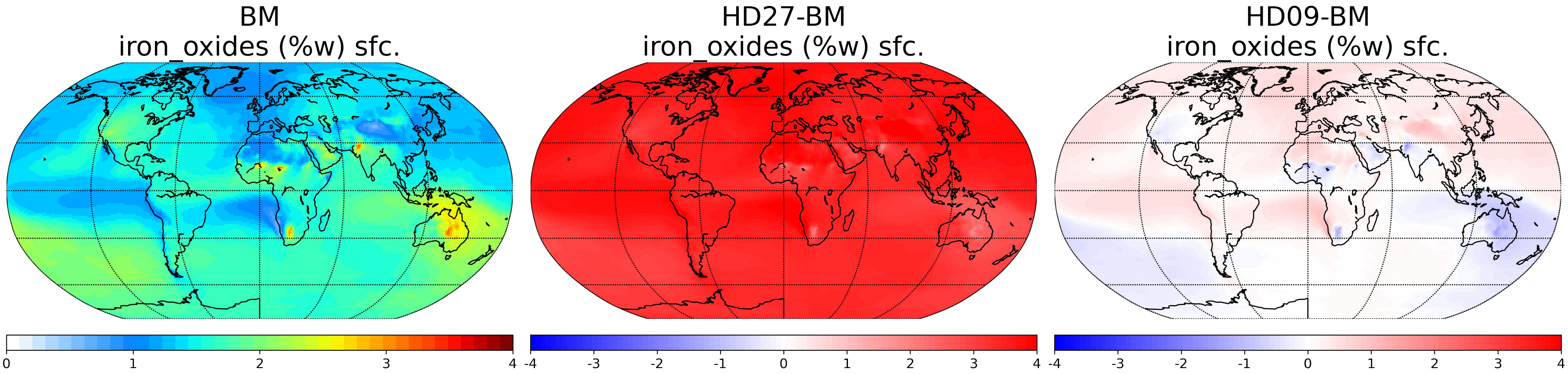
- Conduct 3 experiments using GFDL AM4.0 model.

Experiments	Description	Optics
HD27 (**Mineral Non-resolved**)	• Dust RI (mineralogy) is spatially and temporally uniform. • Dust is assumed to contain 2.7% of hematite by volume. • Represents dust in the standard GFDL AM4.0 model.	Balkanski et al. 2007
HD09 (**Mineral Non-resolved**)	• Dust RI (mineralogy) is spatially and temporally uniform. • Dust is assumed to contain 0.9% of hematite by volume.	Balkanski et al. 2007
BM (**Mineral Resolved**)	• Soil mineralogy from Claquin et al. (1999) is implemented in AM4.0 • Hematite (the portion of mass fraction < 5%) is internally mixed with clay minerals • All other minerals are externally mixed	Scanza et al. 2015

- 19-year (2001-2019) historical run with observed SST and sea-ice, and CMIP6 forcing.

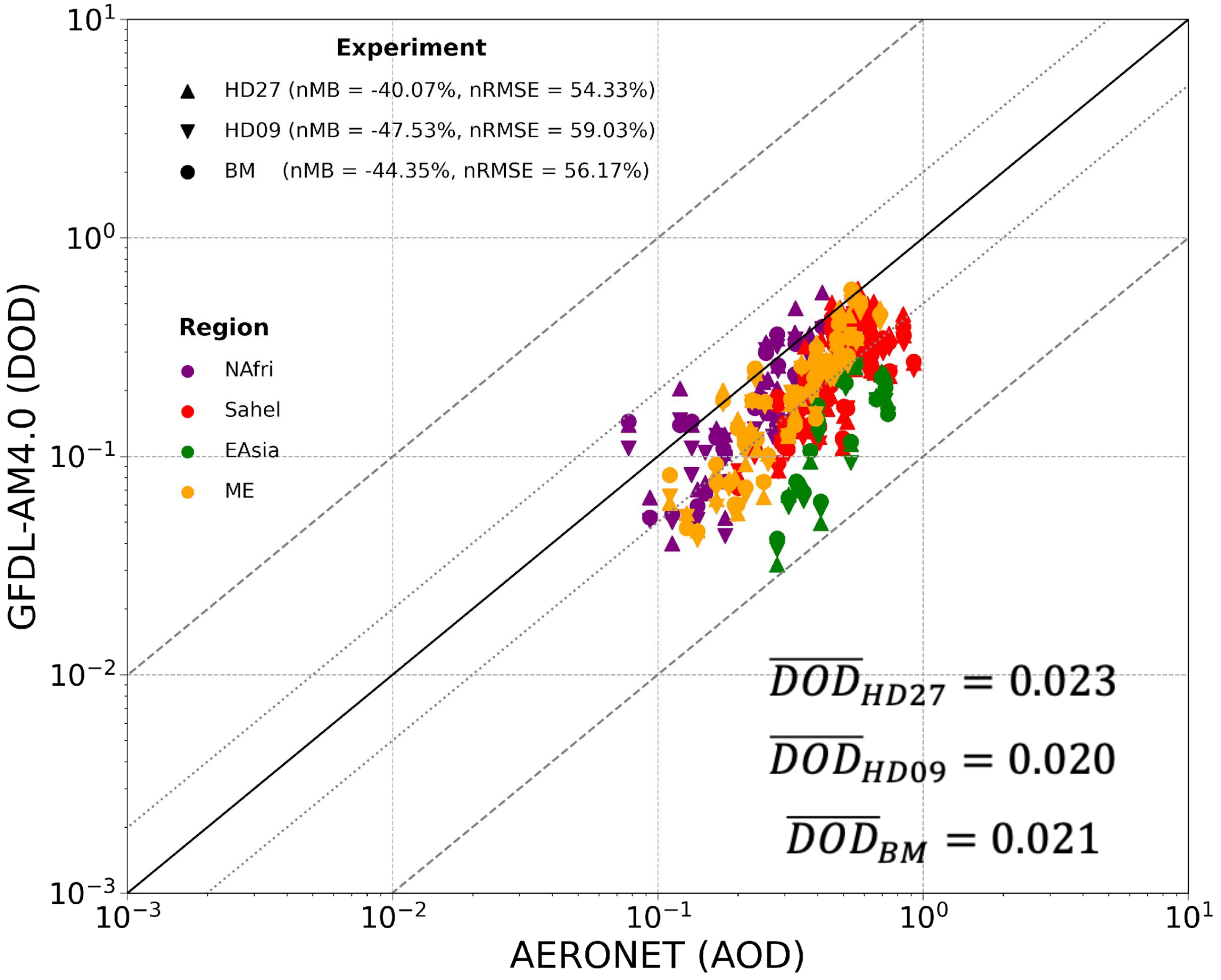
Dust Mineralogy

Hematite(iron oxide) surface mass fraction:



- HD27 overestimates hematite content (w%) worldwide compared to mineral-resolved case (BM).
- HD09 overestimates hematite content in some regions while underestimates in others. However, its hematite content matches global mean values of BM.

Dust Optical Properties (DOD)



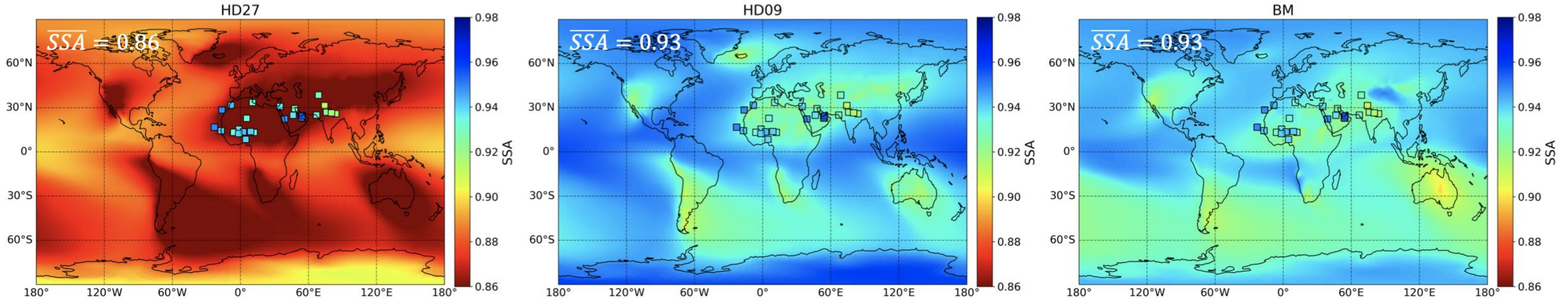
- Reducing homogeneous dust hematite content (HD09) and resolving mineralogy (BM) both do not affect their ability to match AERONET AOD.

Dust Optical Properties (SSA)

Mineral Non-resolved (HD27)
Standard GFDL AM4.0

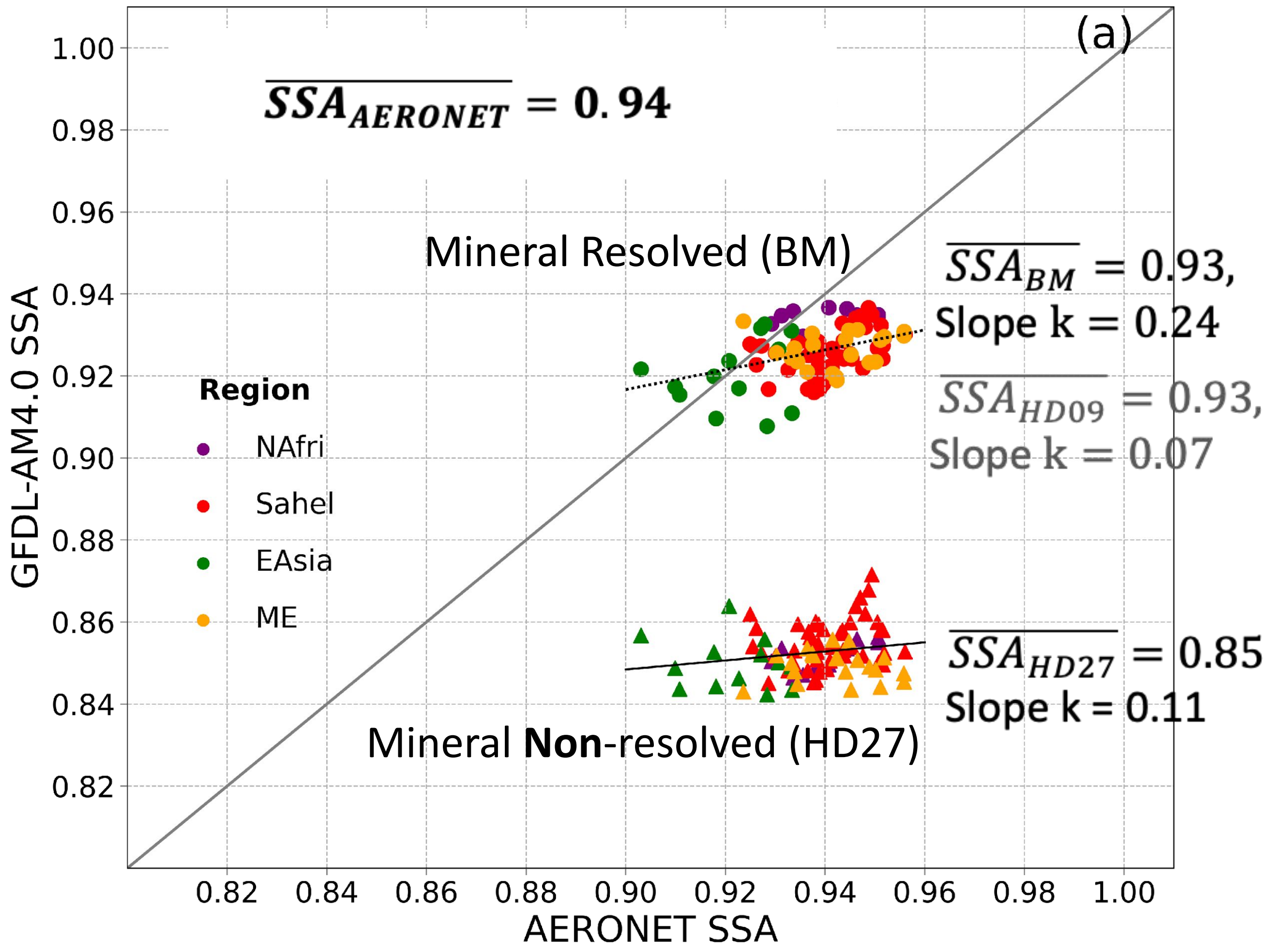
Mineral Non-resolved (HD09)
More scattering dust

Mineral Resolved (BM)
More scattering dust



- Among the three experiments, homogeneous (HD27) dust is overly absorptive.
- Reducing hematite content in dust from 2.7% (HD27) to 0.9% (HD09), reduce dust absorption to the same level as resolving mineralogy (BM).
- Given the same dust absorption on a global scale, resolving mineralogy affects the regional distribution of dust absorption.

Dust Optical Properties (SSA)



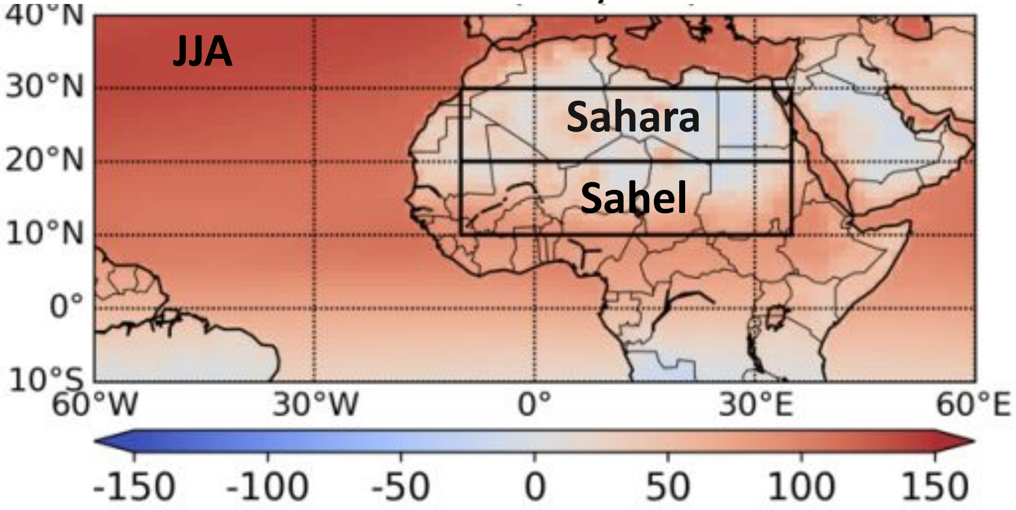
- Homogeneous (HD27) dust is overly absorptive.
- Reducing dust absorption (HD09 and BM) improves agreement with dust SSA$_{VIS}$ observations.
- Resolving dust mineralogy (BM) slightly enhances SSA regional variability. However, modeled regional variability in SSA still deviates significantly from AERONET.

Impacts on Radiation by resolving mineralogy
(Clear-Sky Net Radiative Flux at TOA)

Net Flux: SW + LW
Positive: Down

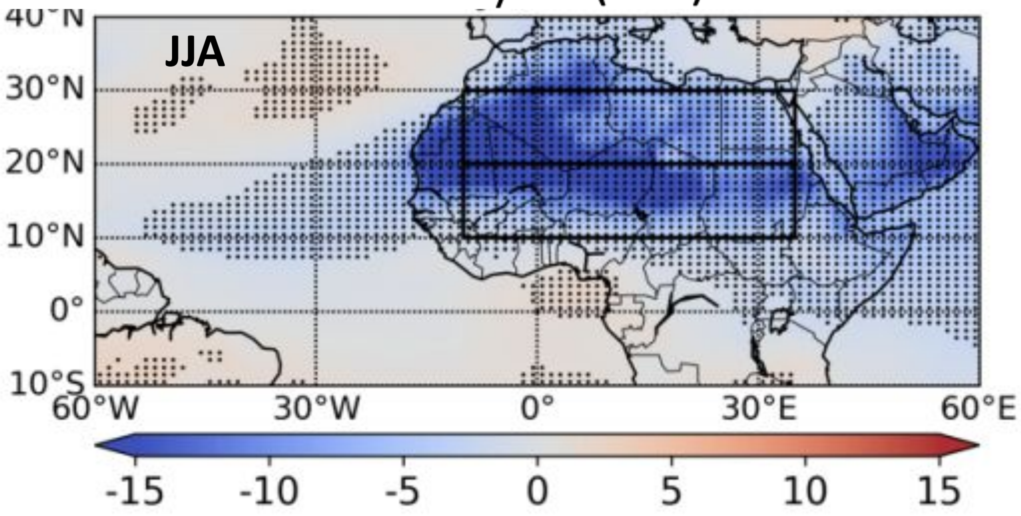
HD27

Sahara: 17 W/m^2
Sahel: 48 W/m^2



Difference (BM-HD27) induced by resolving mineralogy

Sahara: $-11\ W/m^2$ (66%)
Sahel: -10 W/m^2 (21%)

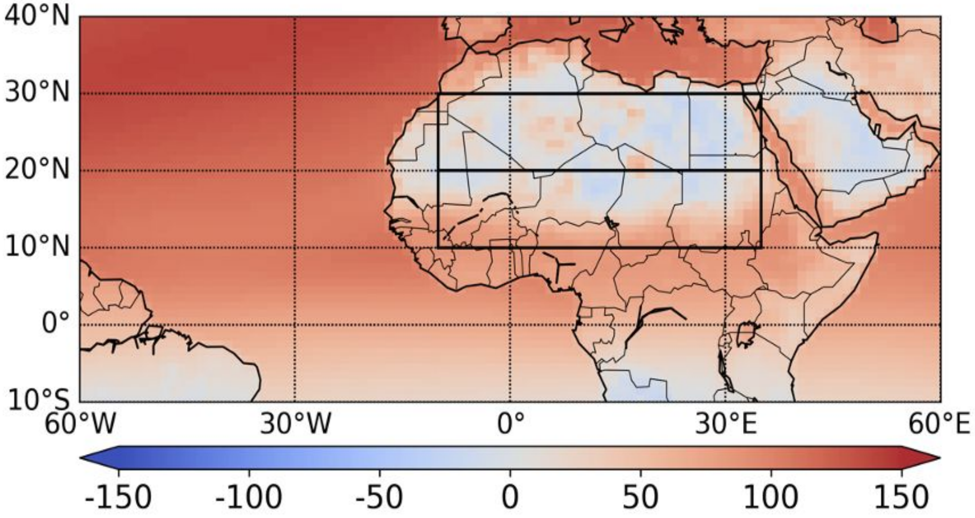


- Resolving mineralogy (BM) significantly decreases NET flux at TOA with respect to HD27.

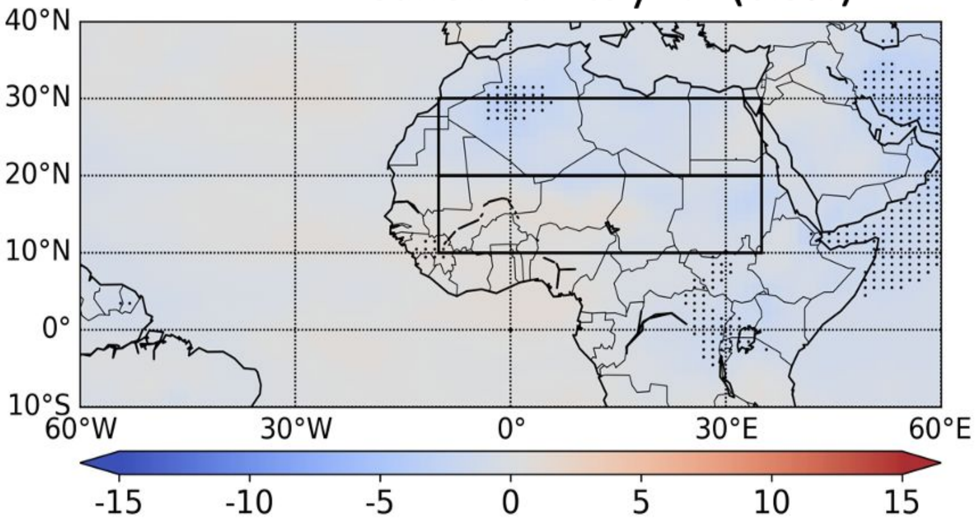
Impacts on Radiation by resolving mineralogy
(Clear-Sky Net Flux at TOA)

Net Flux:
Positive: Down
SW+LW

HD09
Sahara: 8 W/m^2
Sahel: 38 W/m^2



Difference (BM-HD09) induced by resolving mineralogy
Sahara: $-1.2\ W/m^2$ (15%)
Sahel: -0.2 W/m^2 (0.5%)



- Resolving mineralogy does not significantly change NET flux at TOA with respect to HD09.

Impacts on Radiation by resolving mineralogy

Clear-Sky Net Flux at TOA

	Observation	Model Simulations		
	Observation	Mineral Non-resolved		Mineral Resolved
	CERES	HD27	HD09	BM
Sahara	6	17	8	6
Sahel	36	48	38	38

- Reducing dust absorption (HD09 and BM) improves agreement with CERES observations.

Intermediate Conclusion: HD27 to HD09

- These results indicate that more realistic dust representation can be achieved by decreasing dust absorption, in particular moving from 2.7 to 0.9% hematite content. We further found that we can use one single homogenous composition rather resolving full mineralogy.

- For the second part of my presentation, I will focus on the effects of reducing dust absorption (From HD27 to HD09) on fast climate response.

Impacts on Temperature by reducing dust absorption
(Clear-Sky Net Flux absorbed in the Atmos.)

HD27

Sahara: -57 W/m^2

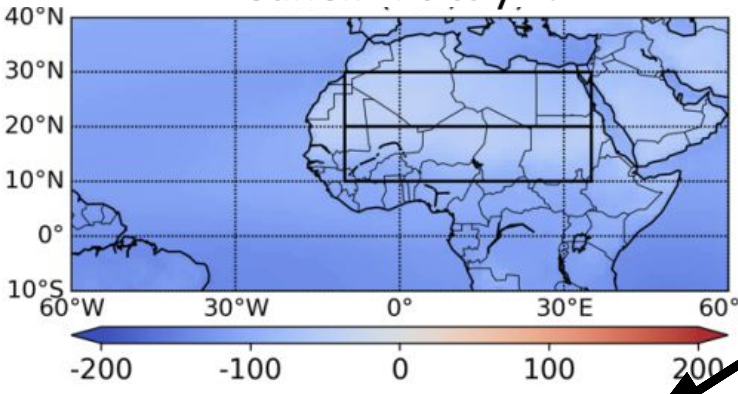
Sahel: -70 W/m^2

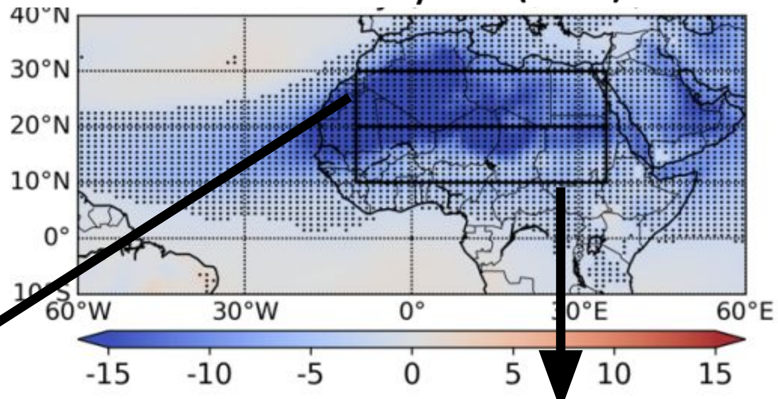
Difference induced by reducing dust absorption (HD09 – HD27)

Sahara: $-16\ W/m^2$ (28%)

Sahel: -12 W/m^2 (17%)

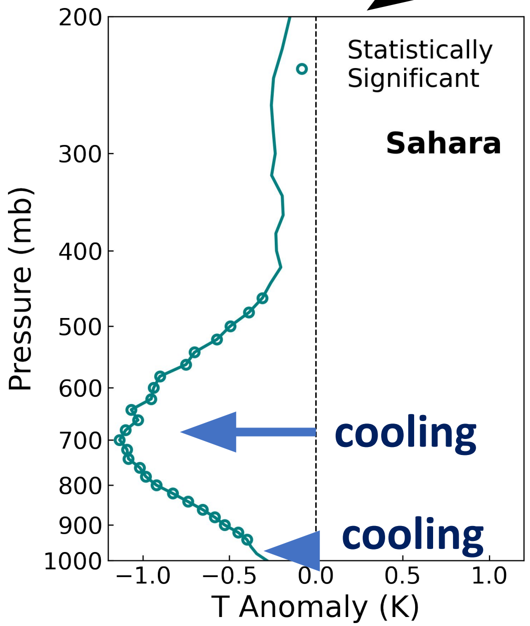
ATMOS.

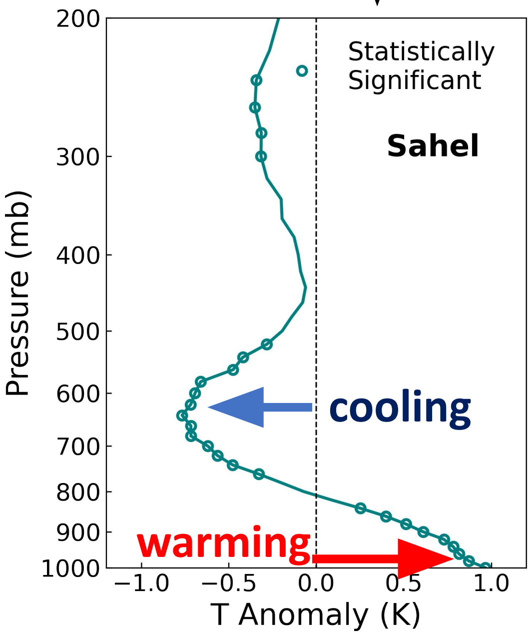




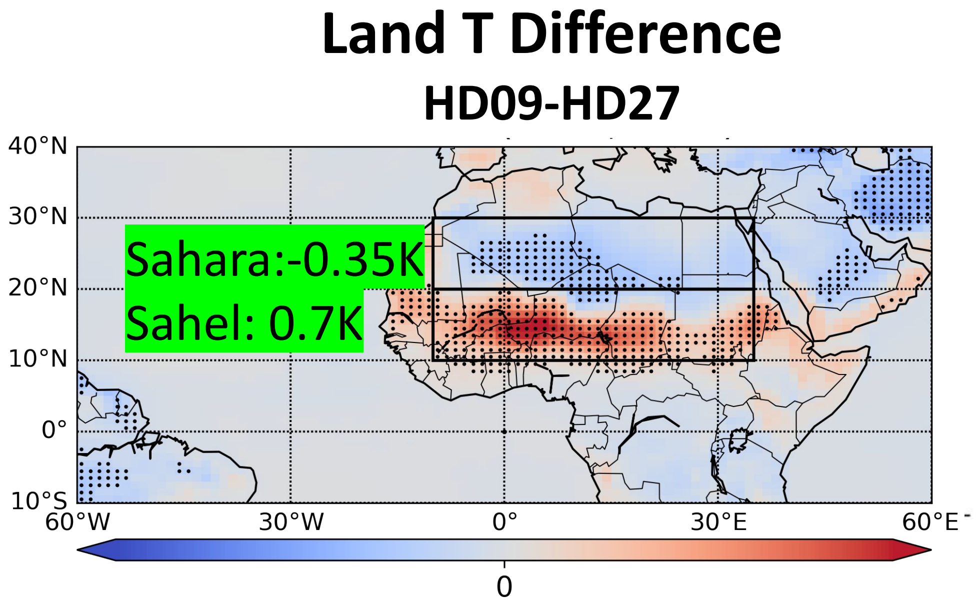
- Lower absorption dust induces cooling (decrease T) in the atmosphere.

Vertical Profile of T difference (HD09 - HD27)





Impacts on Land Temperature



Land Surface Temperature

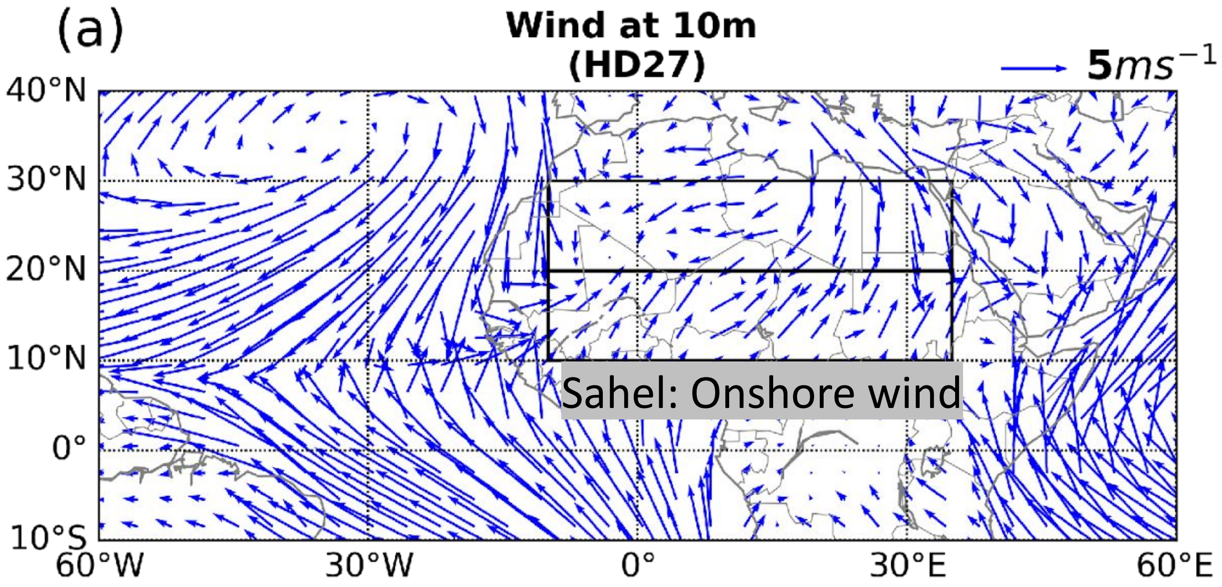
	observation	Model Simulations	
	CRU (Observation)	HD27 (More absorptive)	HD09 (Less Absorptive)
Sahara-Sahel Contrast	1.7 ± 0.5	3.4 ± 0.98	2.3 ± 1.2

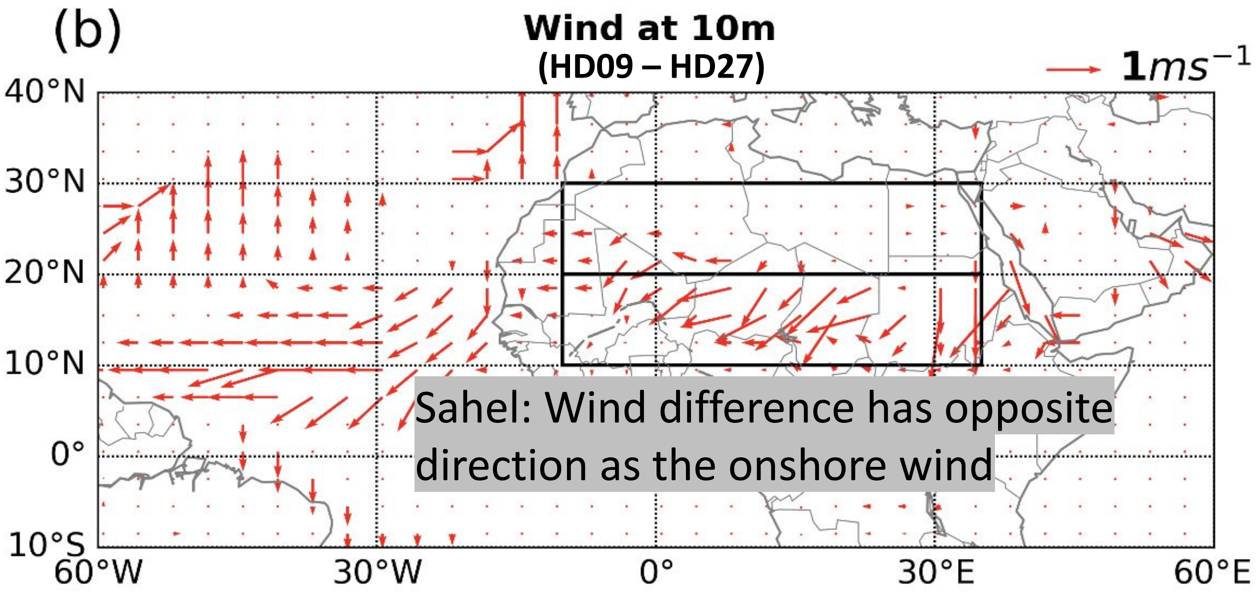
- Reduction of dust absorption reduces T contrast over Sahara and Sahel, which improves the agreement with CRU observations.

Impacts on Surface Wind

2001-2019 JJA

Wind Difference induced by reducing dust absorption

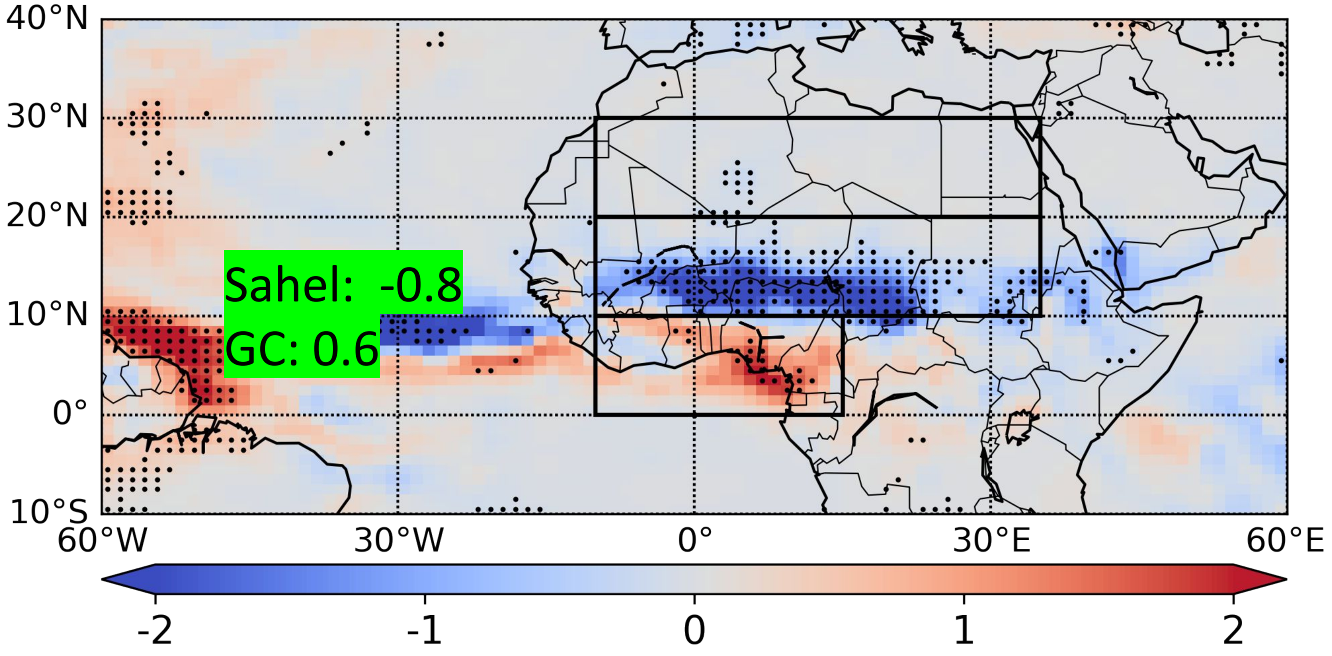




- Less absorption of HD09 dust causes less warming, **suppress ascent**.
- **Onshore wind is suppressed** over Sahel relative to HD27.

Impacts on Precipitation

Precipitation Difference: HD09-HD27 (mm/day)



- Over the Sahel:
  - The suppression of ascent
  - The suppression of onshore wind (Less moisture)

  } Reduce Precipitation
- Over GC:

  The suppression of ascent over the Sahel suppresses the subsidence over GC - > Enhance Precipitation

Impacts on Precipitation

	Observation	Model Simulations	
Region	CRU (mm/day)	HD27 – CRU (mm/day)	HD09 – CRU (mm/day)
Sahara	0.08 ± 0.013	-0.03 ± 0.03	-0.03 ± 0.07
Sahel	2.99 ± 0.27	0.16 ± 0.56	-0.62 ± 0.43
Guinea Coast	6.16 ± 0.49	-0.28 ± 0.90	0.28 ± 1.02

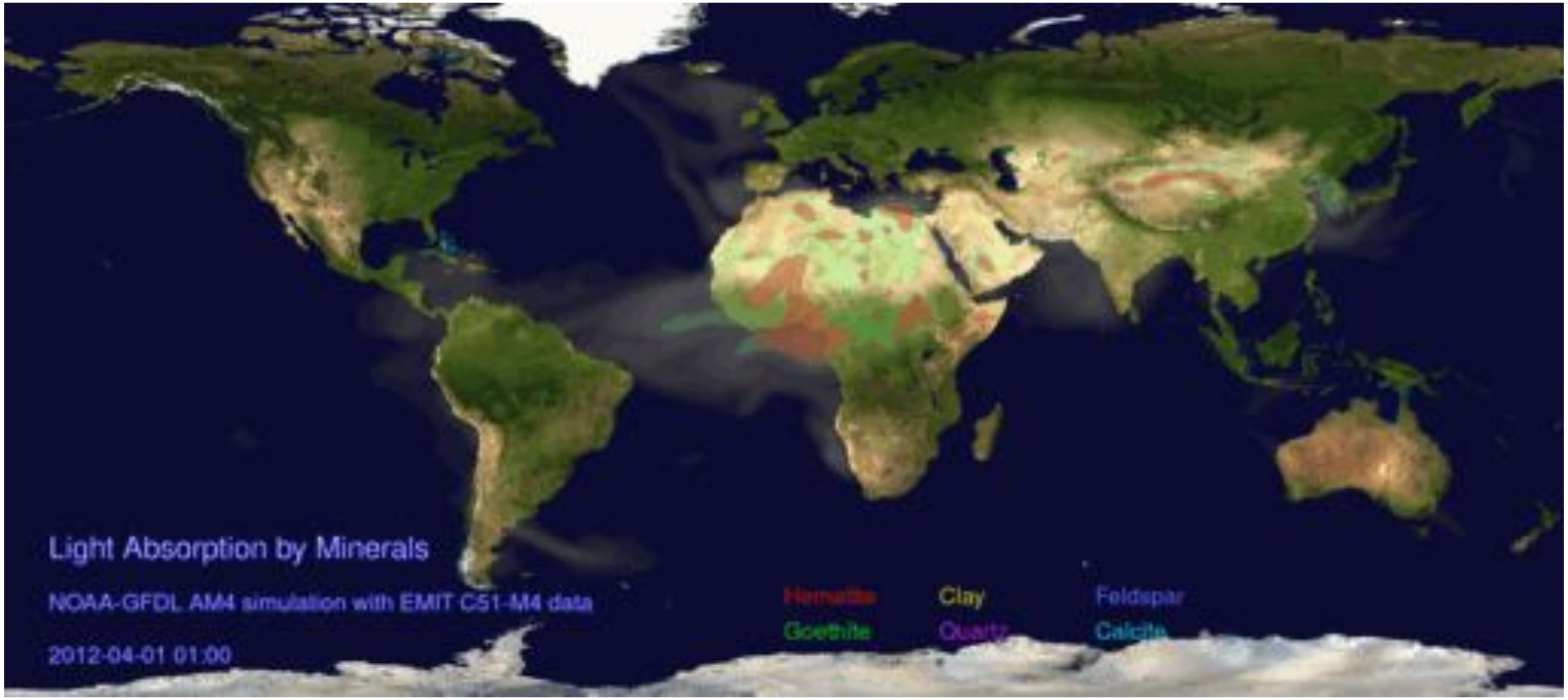
- Reducing dust absorption worsens the agreement in precipitation with observations.
- This could be due to the omission of energy balance over the ocean.

Limitation

- **AMIP versus fully coupled ocean/atmosphere climate model**
- **Uncertainties associated with dust mineralogy: global distribution inventory, optical properties (RI), mixing (aggregates), etc.**

THANK YOU

EMIT (Earth Surface Mineral Dust Source Investigation)



Light Absorption by Minerals

NOAA GFDL AM4.0 simulation with 1st version of EMIT soil map