EGU General Assembly
ITS2.5/CL4.14
Vienna | Austria | 23-28 April 2023

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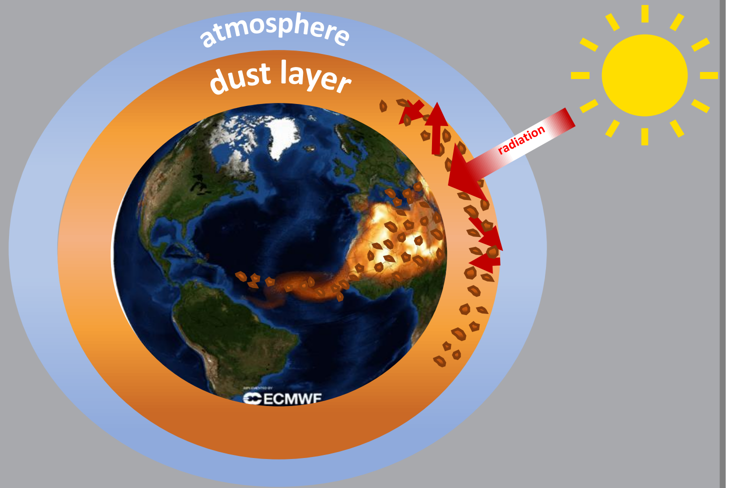
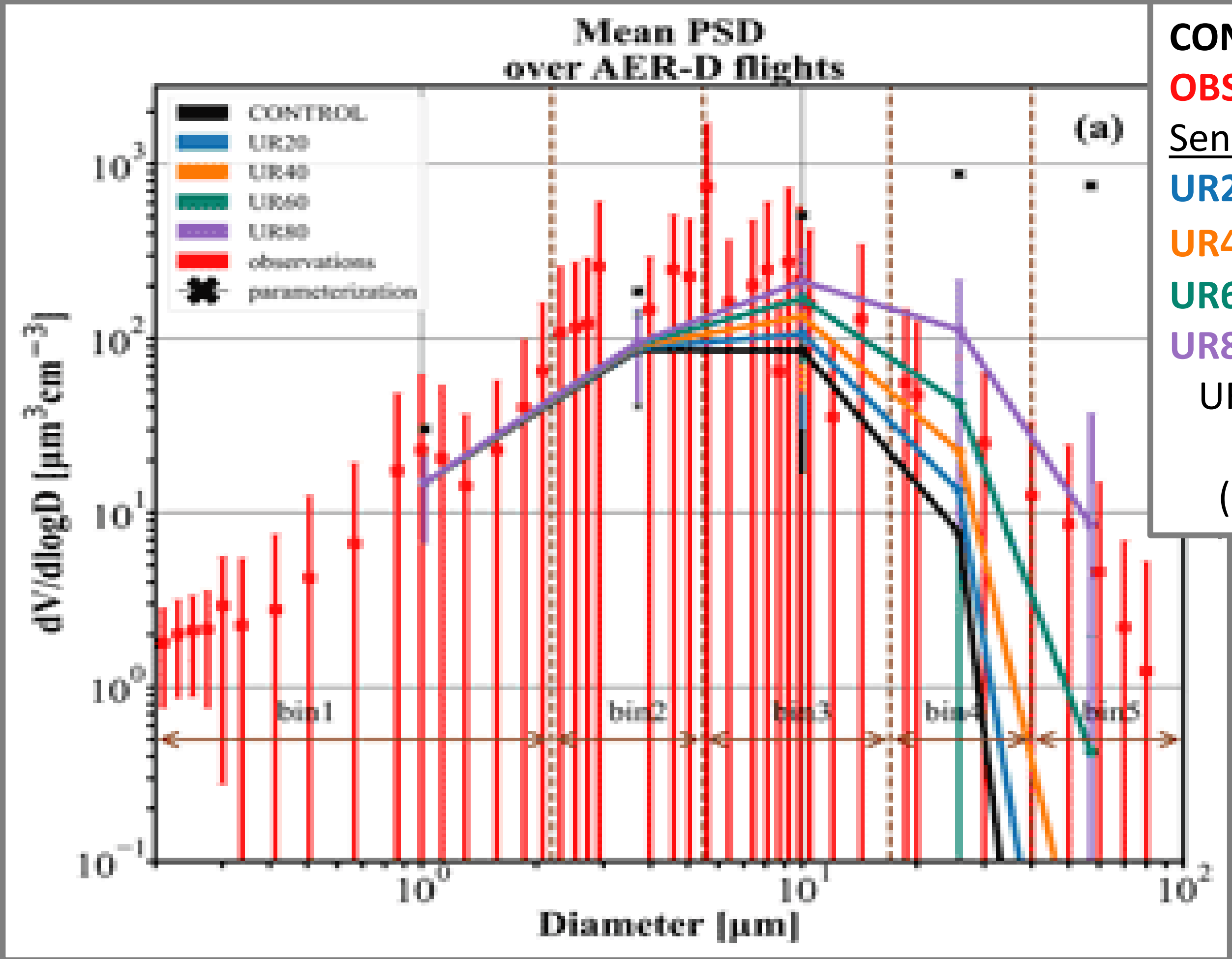
# Numerical diffusion on vertical advection due to gravitational settling in WRF: 2D simulations

Eleni Drakaki, Sotirios Mallios, Vassilis Amiridis, Alexandra Tsekeri, Demetri Bouris, and Petros Katsafados

## SUPER-COARSE AND GIANT DUST PARTICLES

Giant particles are a key piece of the puzzle that we need to understand in order to mitigate the impact of climate change.

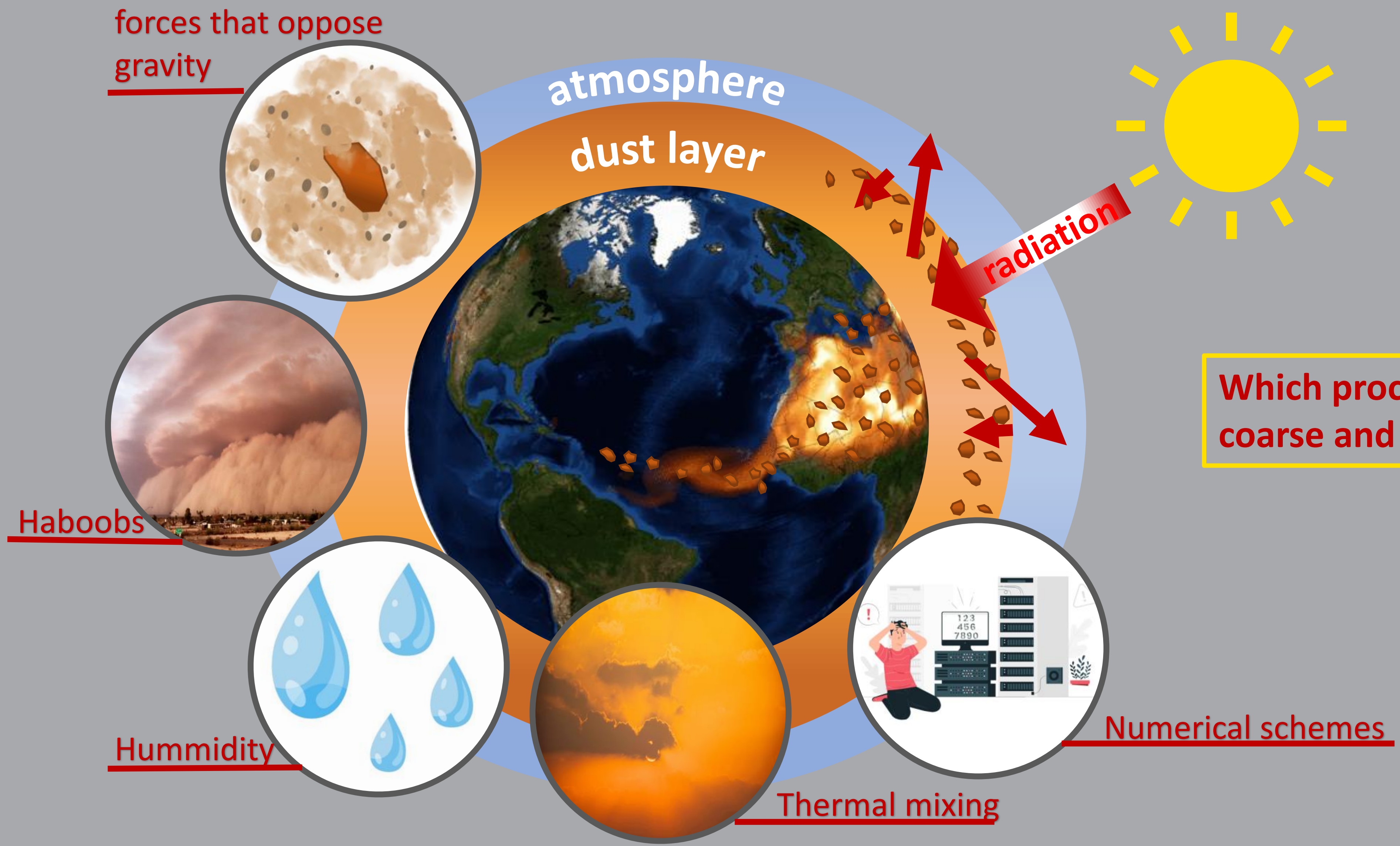



**CONTROL**
**OBSERVATIONS**
Sensitivity experiments:
**UR20: 20% reduction on settl. velocity**
**UR40: 40% >>**
**UR60: 60% >>**
**UR80: 80% >>**
UR: relative percentage particles' velocity reduction (same for all 5 model size bins)

Drakaki et al., 2022

**60-80 % reduction is needed for model to best fit observations**




**Which processes can keep super-coarse and giant particles aloft???**

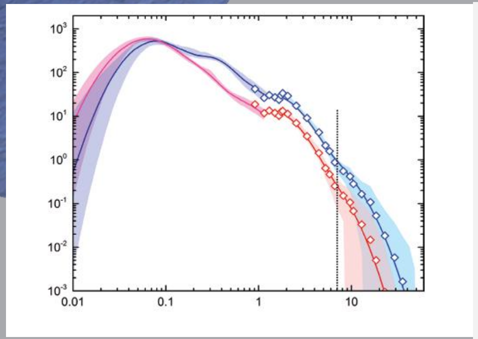
# 2D idealized WRF-L simulations

**Examining the impact of numerical diffusion in dust particles transport**

$$\frac{\partial Q}{\partial t} + \nabla \cdot (\boldsymbol{v}_{\text{settl}}\, Q) = 0$$

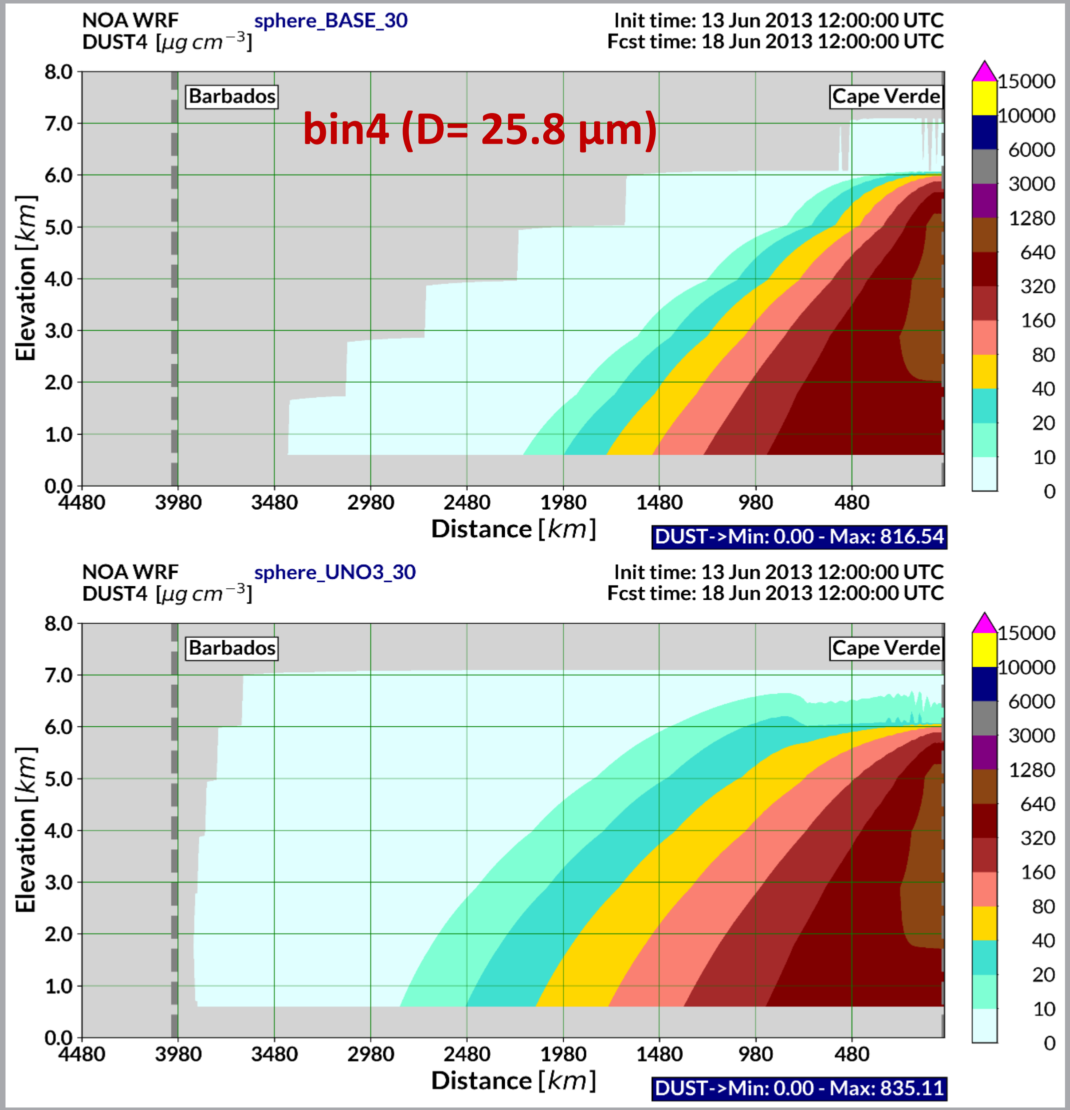
**3rd order scheme vs 1st order**

| | | |
|---|---|---|
| **BASE** | **WRF-Chem-v4.2.1 default scheme** | **1st order** |
| **UNO3** | **Upstream Non Oscillatory scheme** | **3rd order** |

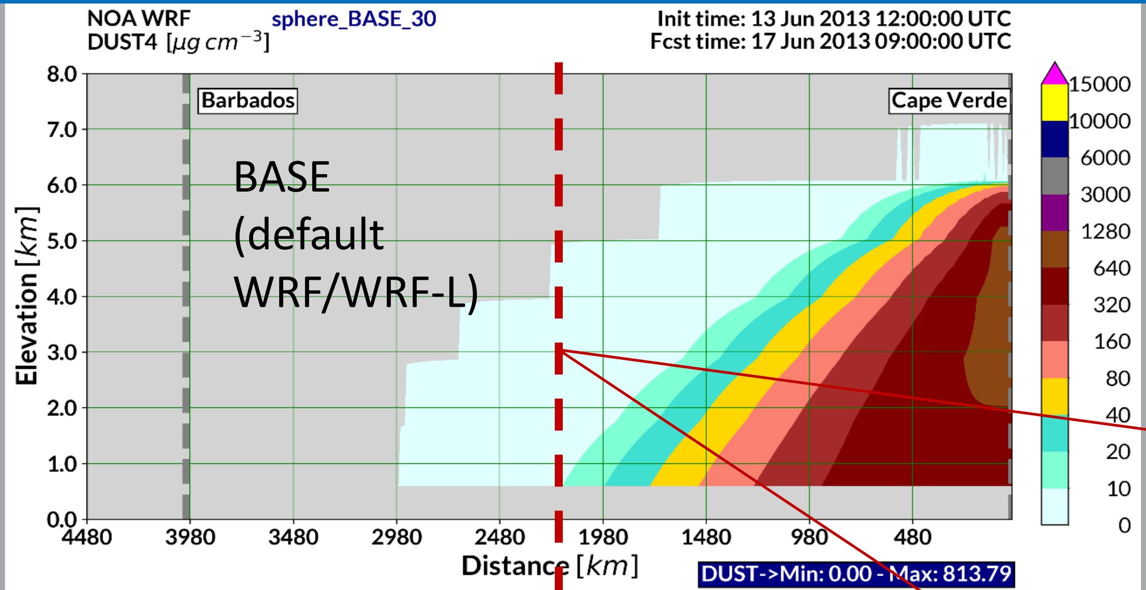

According to SALTRACE dN/dlogD

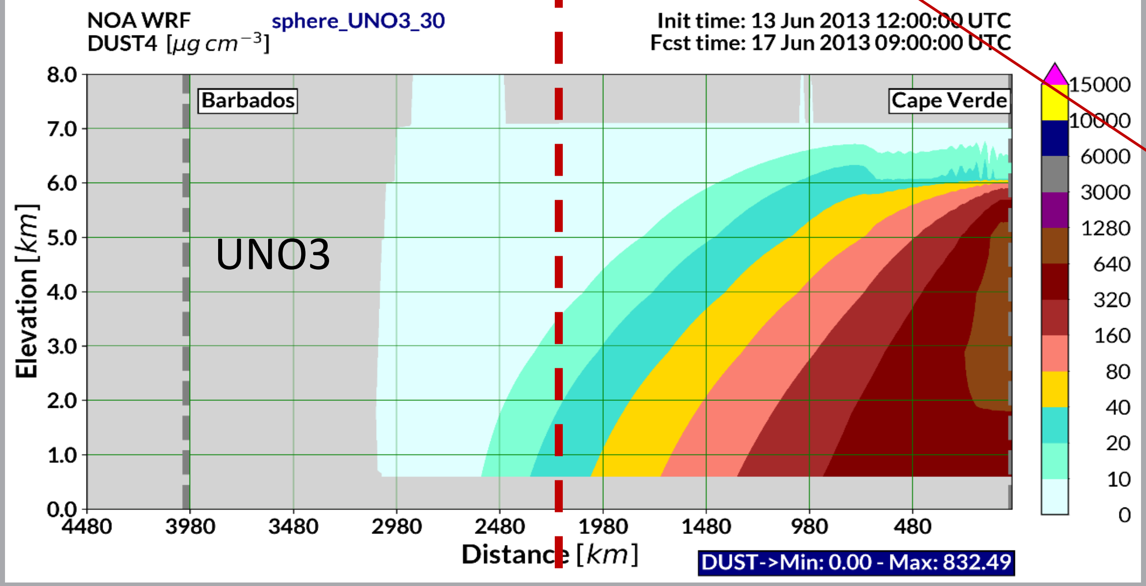
We initialize the field using the SALTRACE distribution at all model levels between 3.5-4.5 km



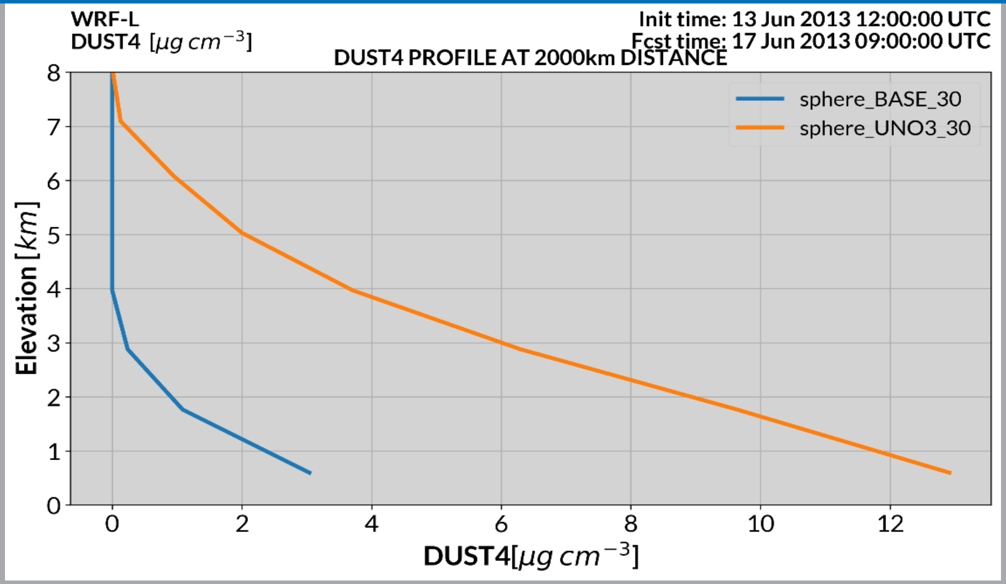

In UNO3:
The heavier particles (of bin4) are sustained in higher altitudes and can travel to greater distances more than 1000 km further away

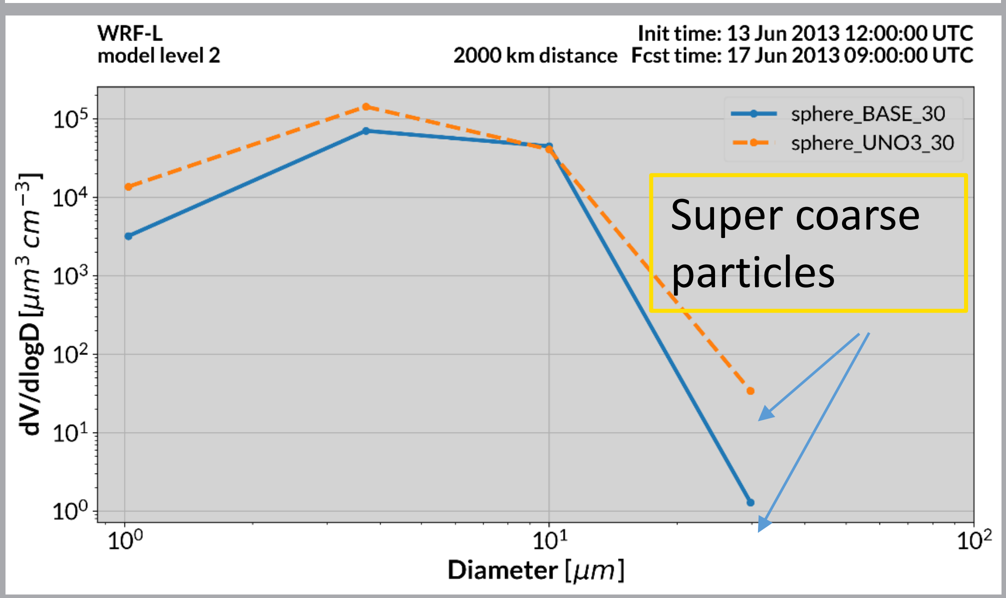
30 vertical layer (layer thickness: ~1000 m)




After 4 days of transport at 2000 km away from Cabo Verde

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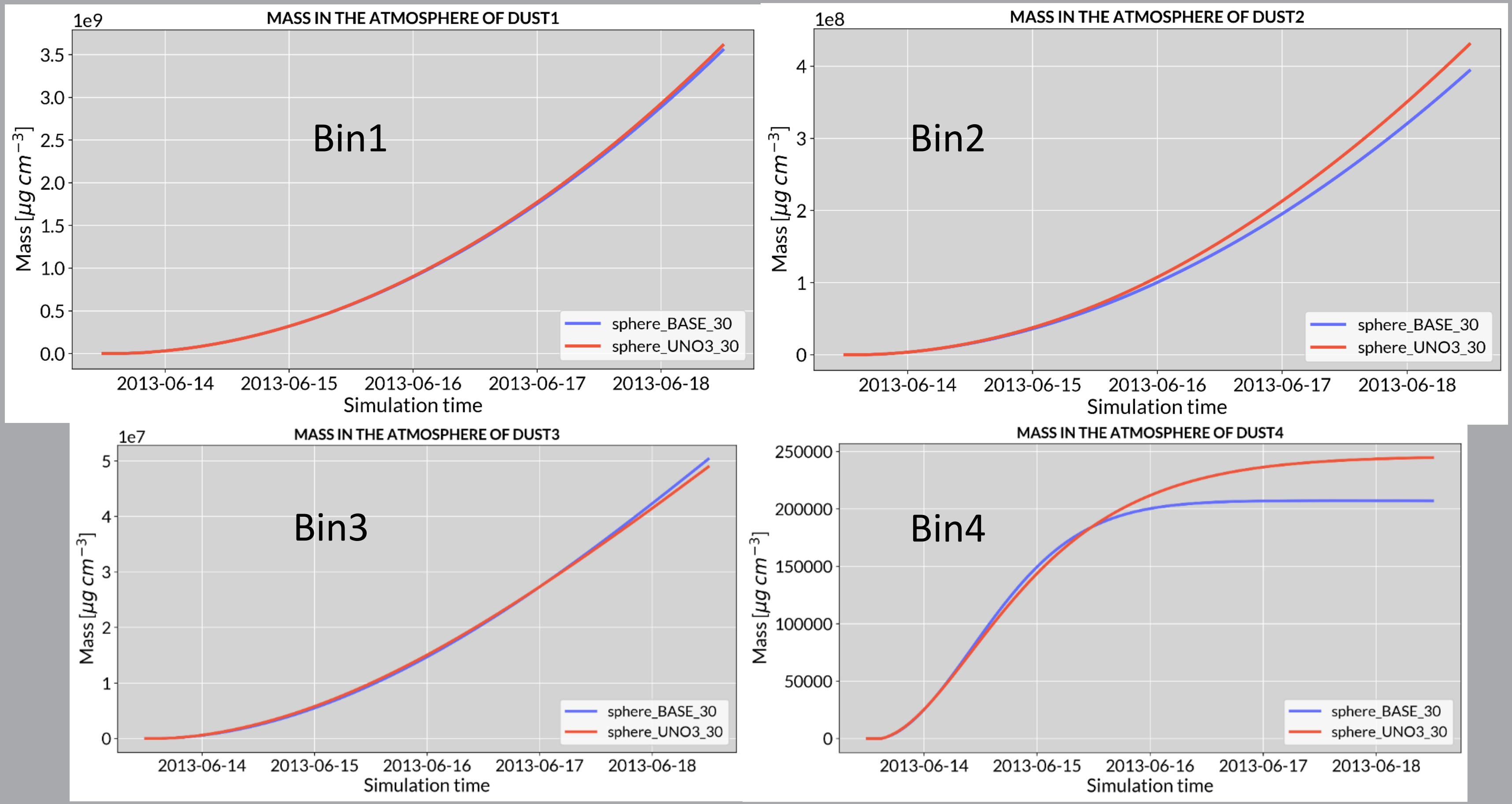
Outstanding Student & PhD candidate Presentation contest

# Evolution of dust mass concentration in the atmosphere




The performance is size dependence and is related with the particle lifetime/the simulation time

5 days simulation contains the full lifetime cycle of bin4:

In the first 2 days BASE outperforms, while in the rest simulation time UNO3 outperforms

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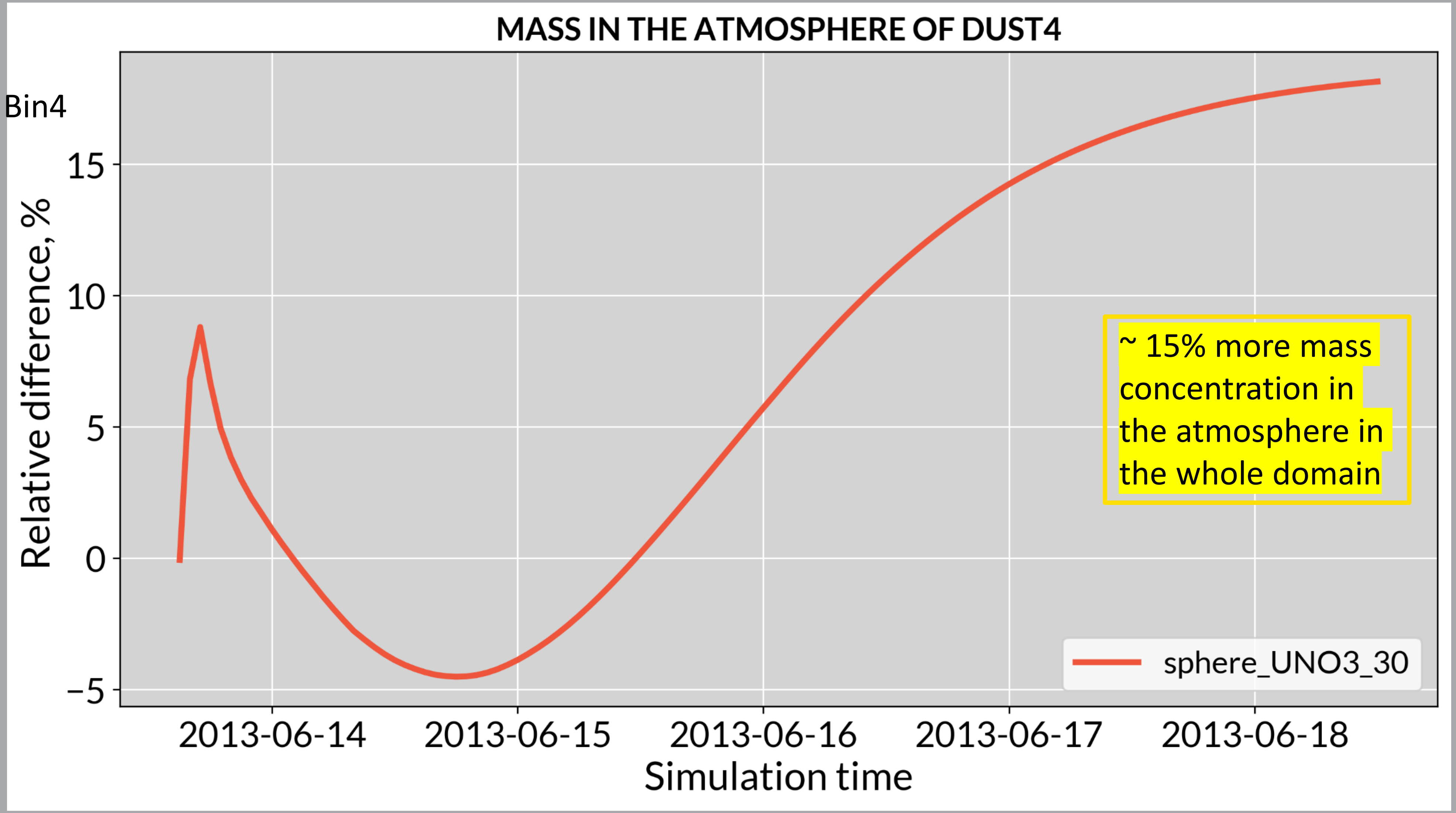


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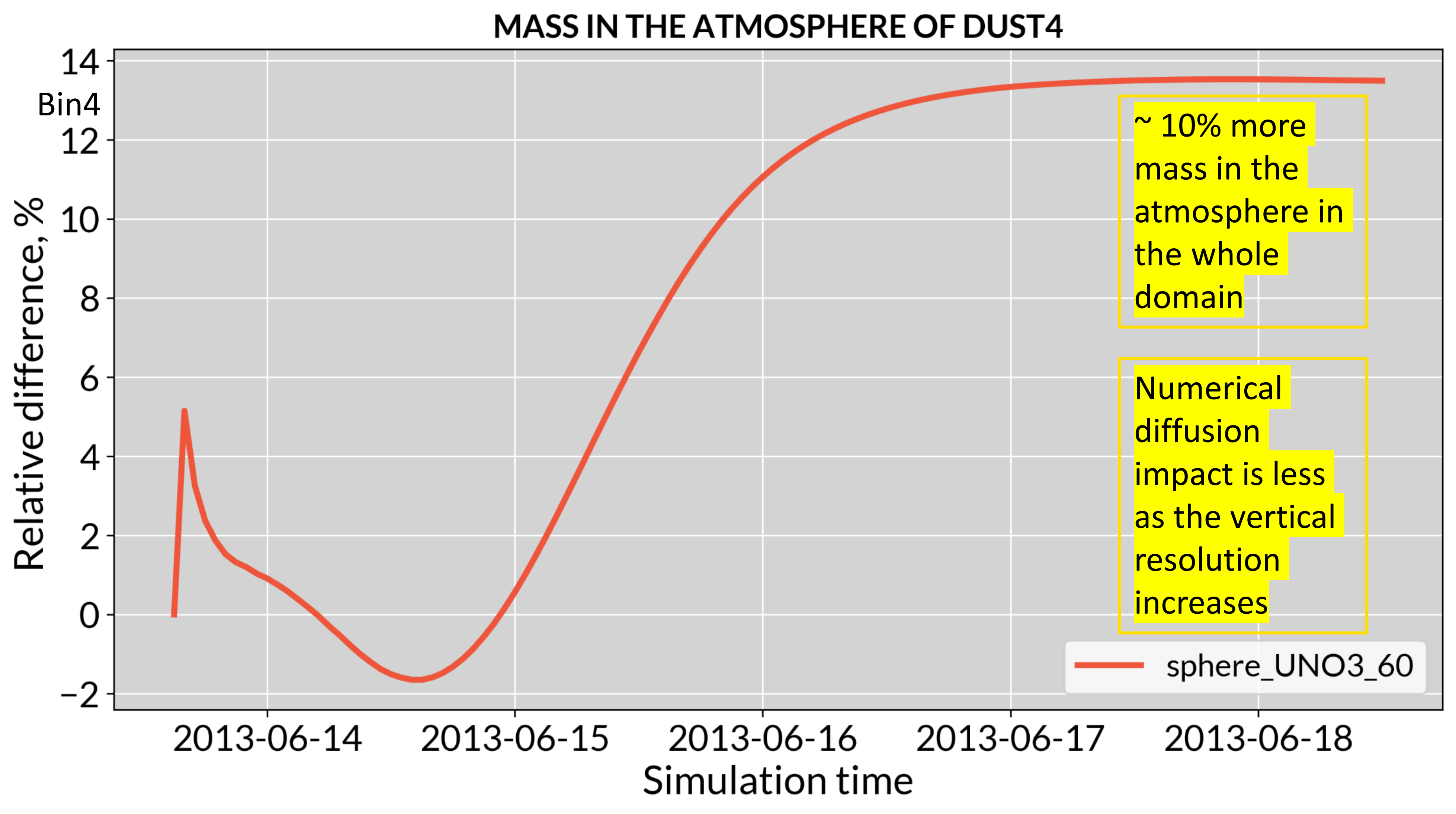


60 vertical layer (layer thickness: ~1000 m)

## CONCLUSIONS

- UNO3 is less diffusive than WRF scheme and preserves the aerosol mass of super-coarse particles longer in the atmosphere, in higher altitudes and changes the PSD of dust.
- There is a size dependence on the impact of numerical diffusion which depends on the particle lifetime and the simulation time.
- The impact of UNO3 is greater as the size is bigger (the lifetime of the particle is shorter) for a 5-days simulation
- There is a dependence on the vertical resolution. As the vertical resolution increases the numerical diffusion on both schemes is less and the results of the schemes (UNO3 and WRF) differ less between each other.

## SUPER-COARSE AND GIANT DUST PARTICLES

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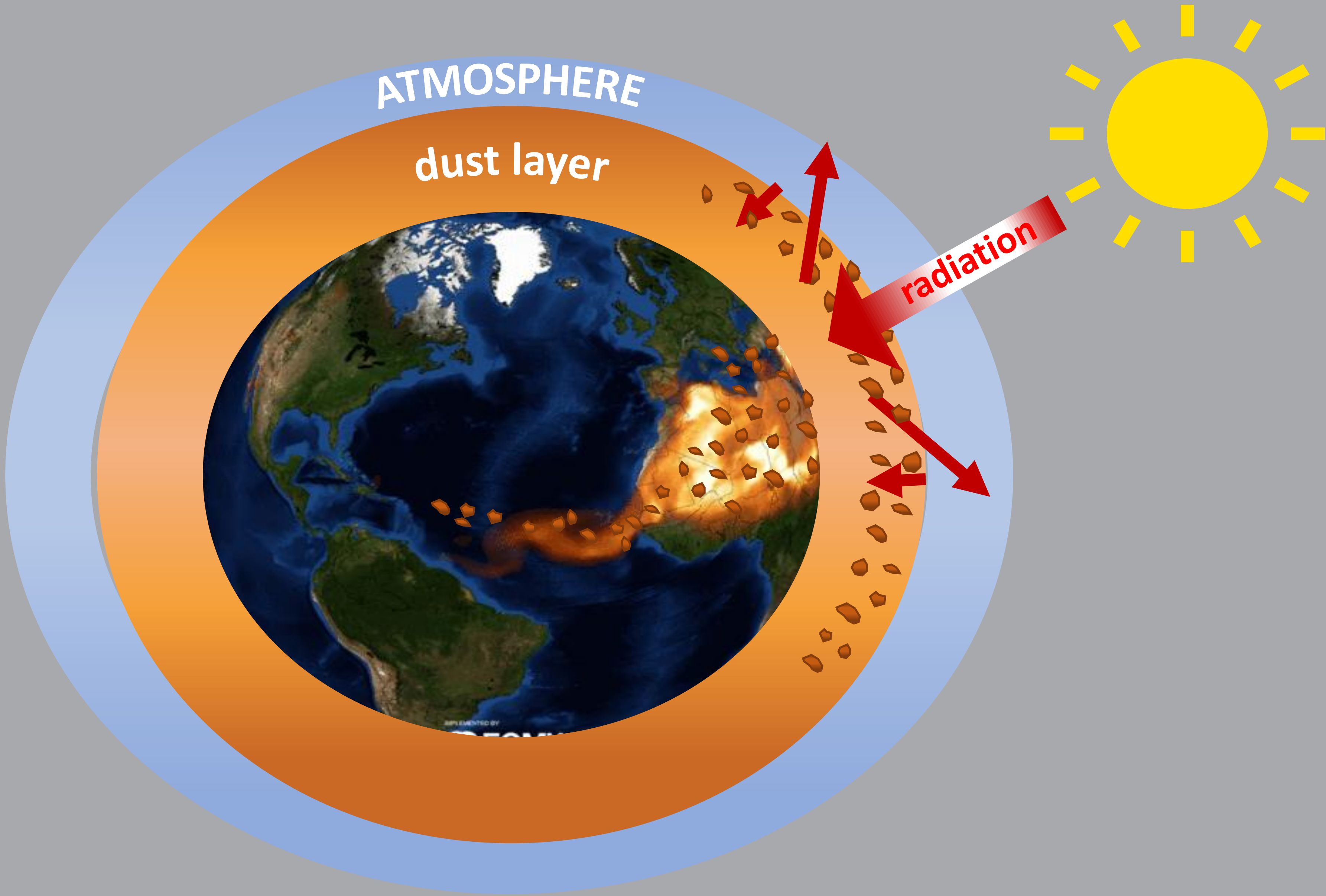

(1), (2) ,(3) the appropriate modifications implemented in the WRF-Chem GOCART-AFWA dust scheme for the inclusion of the giant dust particles

(4) the model validation activities.

Drakaki et al., (2022)

| WRF-GOCART-AFWA | | | | | |
|---|---|---|---|---|---|
| Bins | 1 | 2 | 3 | 4 | 5 |
| $D_{lo} - D_u$ (μm) | 0.2–2.0 | 2.0–3.6 | 3.6–6.0 | 6.0–12.0 | 12.0–20.0 |
| $D_{eff}$ (μm) | 1.46 | 2.8 | 4.8 | 9.0 | 16.0 |
| $\rho_p$ (g cm$^{-3}$) | 2.5 | 2.65 | 2.65 | 2.65 | 2.65 |
| WRF-L | | | | | |
| Bins | 1 | 2 | 3 | 4 | 5 |
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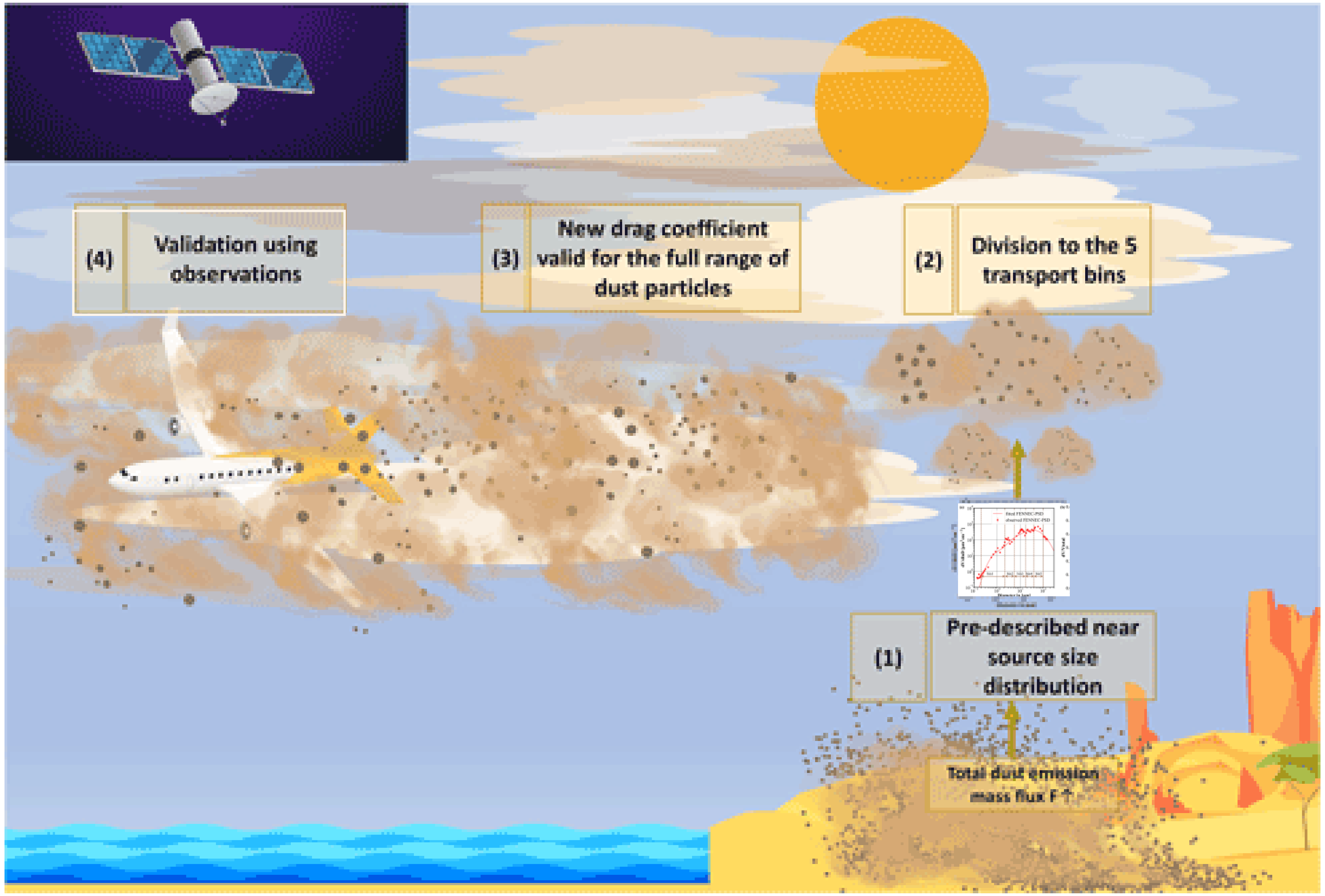
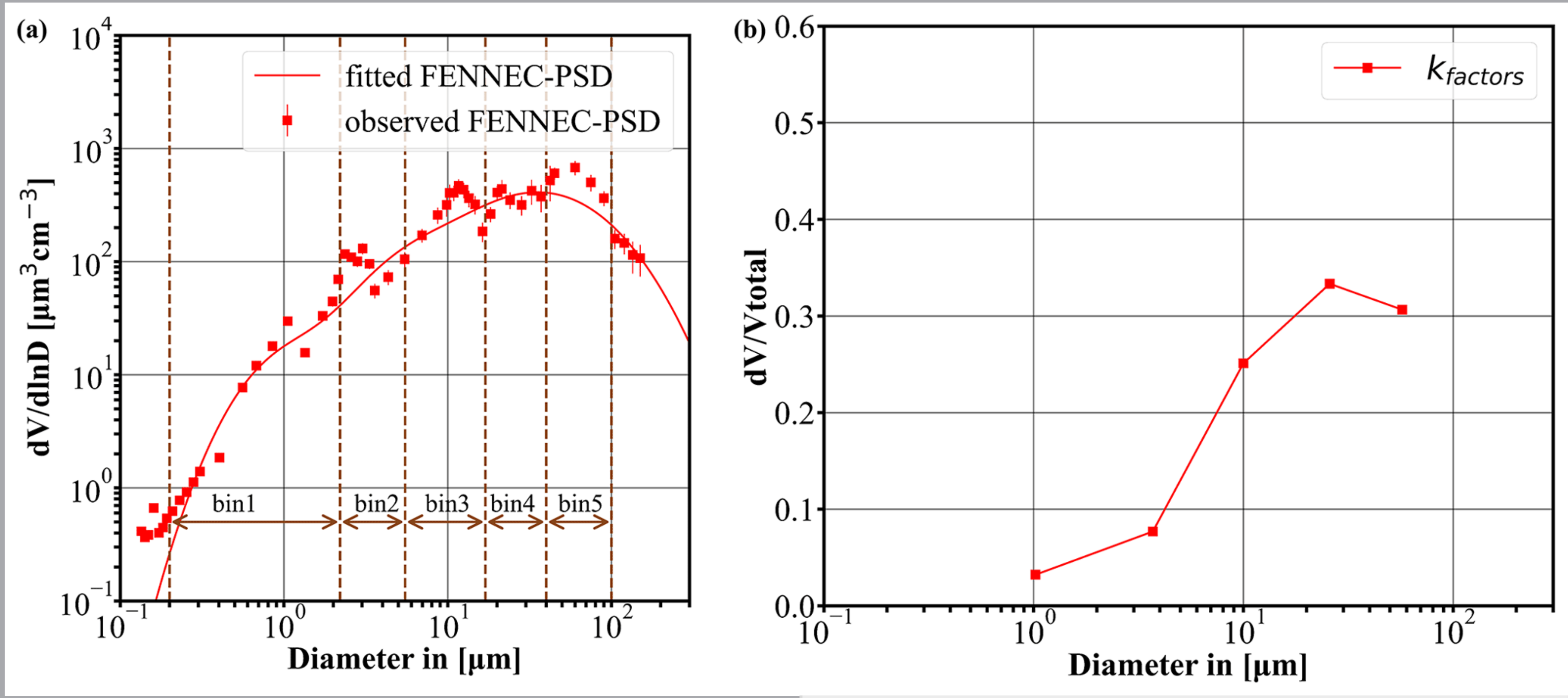


We use the mean average PSD derived from aircraft profile measurements at the lowest available height (1 km ) above Sahara sources




$$k_{\text{factors}} = \frac{\int_{D\text{lo},k}^{D\text{u},k} \frac{1}{D} \cdot \frac{dV}{d\ln D} \cdot dD}{\int_{D\text{lo},k_{\min}}^{D\text{u},k_{\max}} \frac{1}{D} \cdot \frac{dV}{d\ln D} \cdot dD},$$

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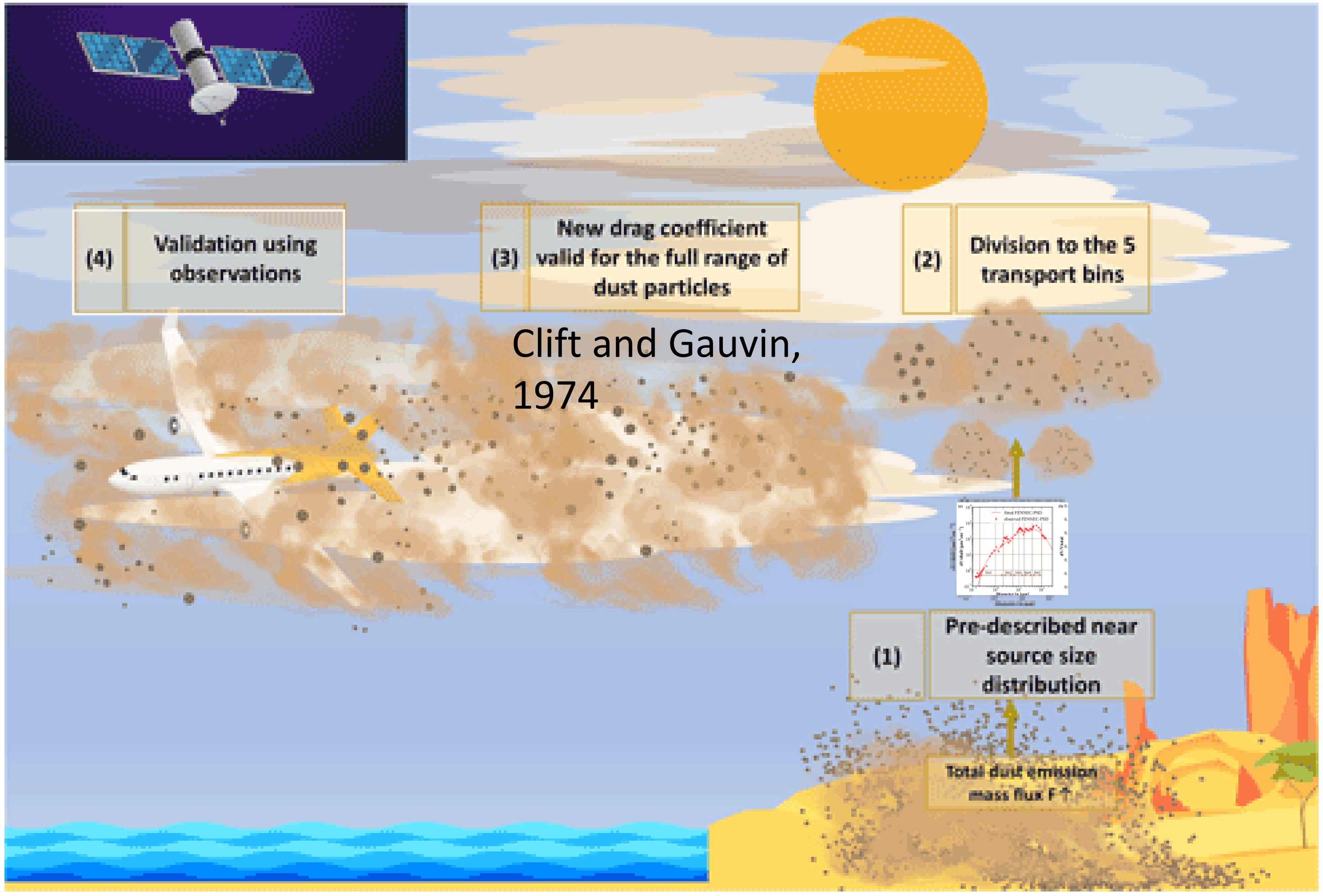
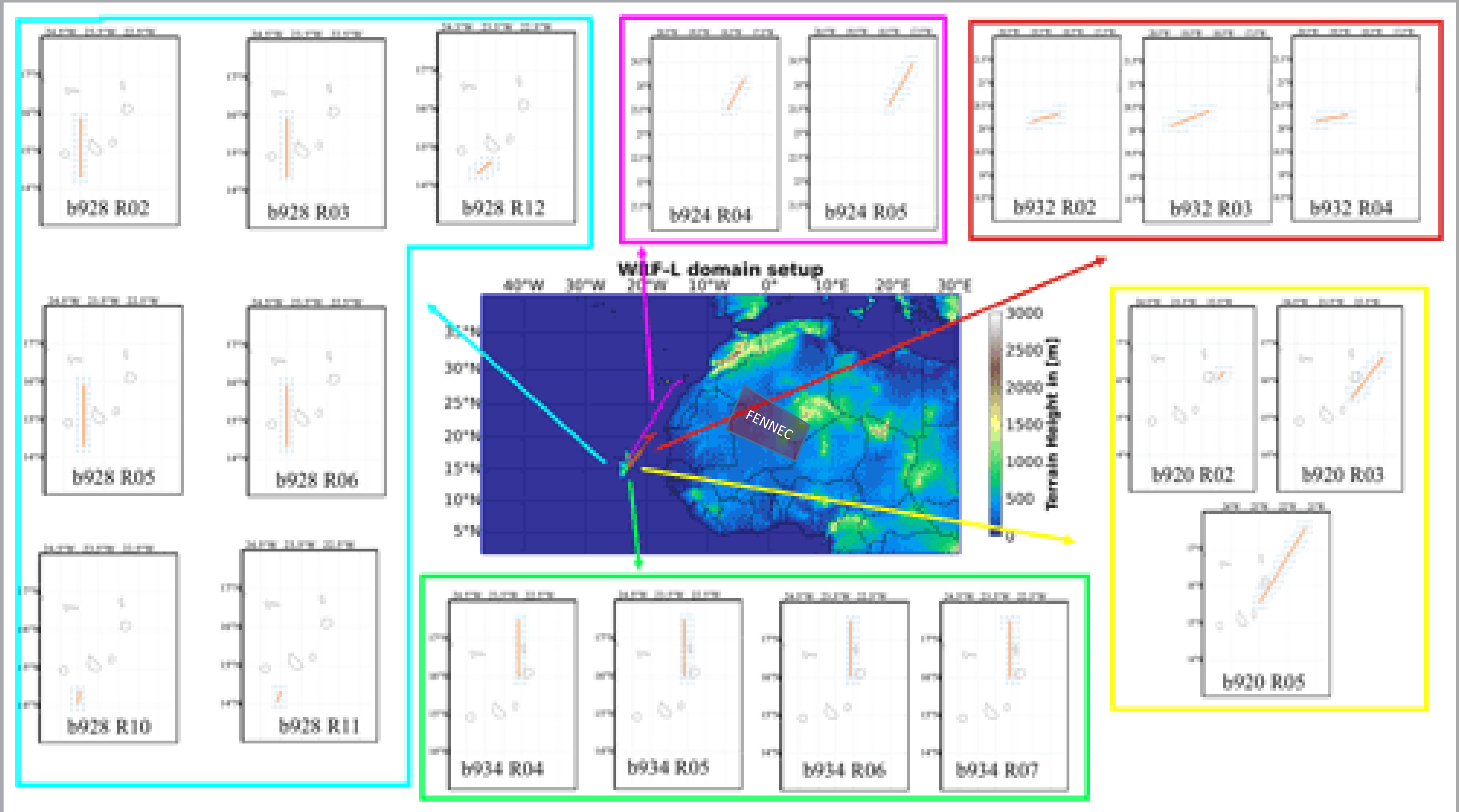
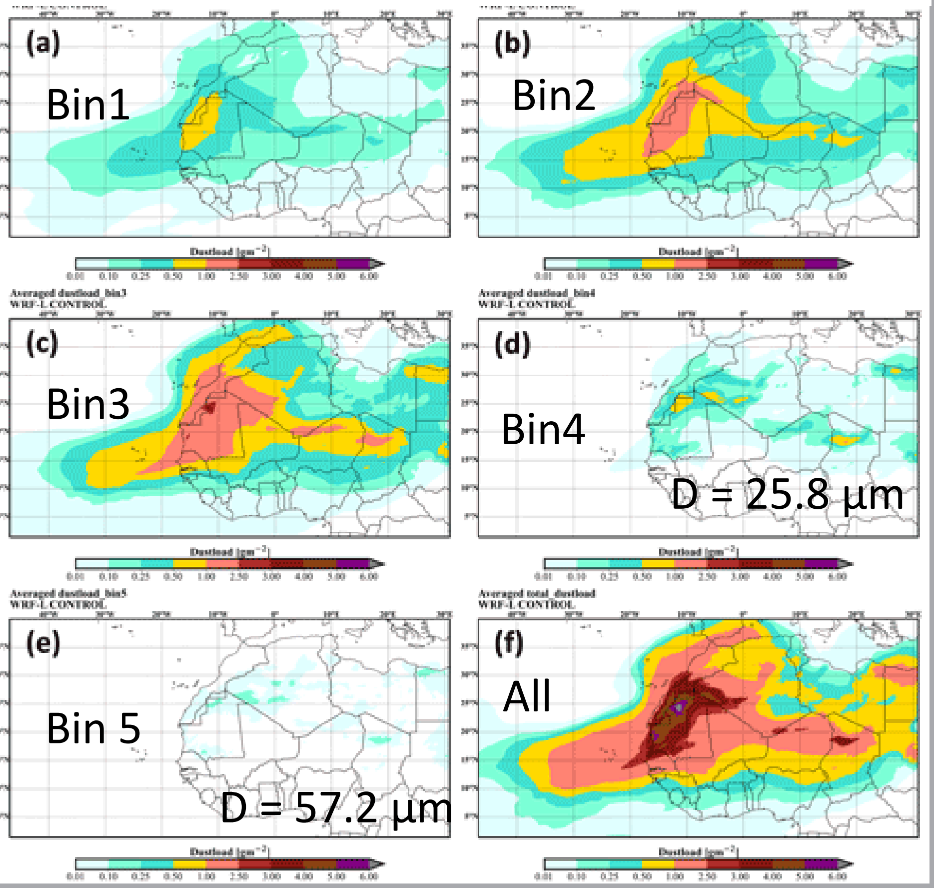



b928 R02
b928 R03
b928 R12
b924 R04
b924 R05
b932 R02
b932 R03
b932 R04
WRF-L domain setup
40°W 30°W 20°W 10°W 0° 10°E 20°E 30°E
35°N 30°N 25°N 20°N 15°N 10°N 5°N
FENNEC
3000 2500 2000 1500 1000 500 0
Terrain Height in [m]
b928 R05
b928 R06
b920 R02
b920 R03
b920 R05
b928 R10
b928 R11
b934 R04
b934 R05
b934 R06
b934 R07

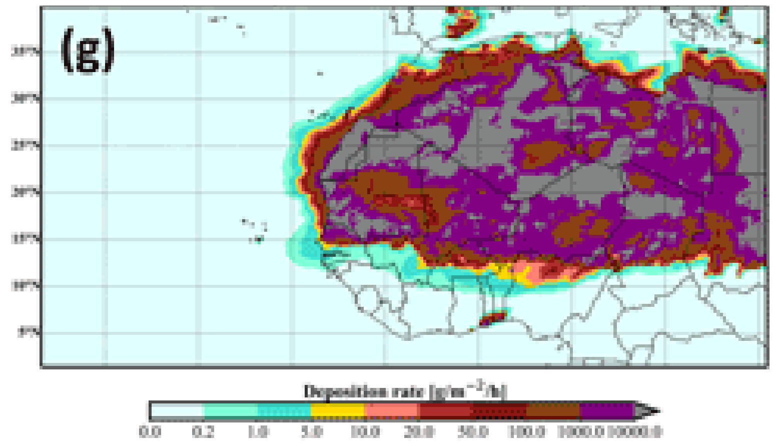
Drakaki et al., (2022)

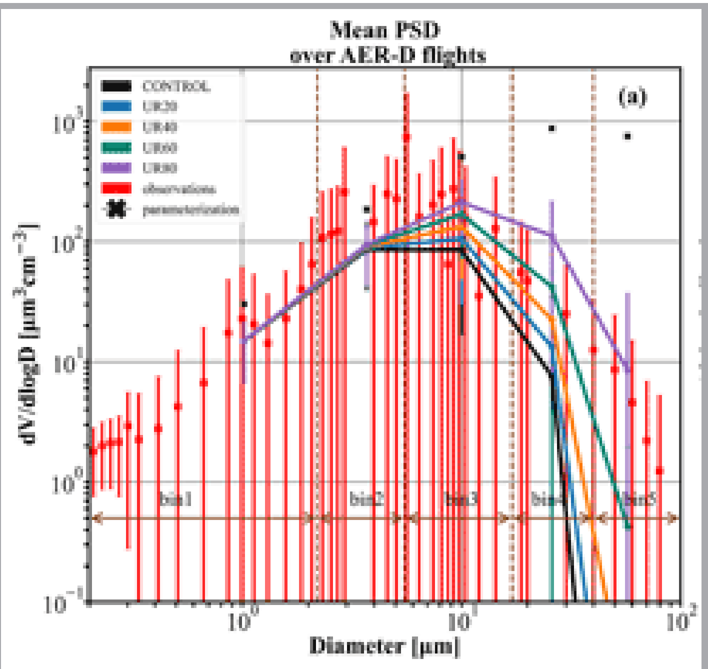
## Average DUSTLOAD [g m$^{-2}$]




(~1 month of simulation)

## Average gravitational deposition rate [g m$^{-2}$ h$^{-1}$]




| Experiment | Code |
|---|---|
| CONTROL | WRF-L |
| UR20 | WRF-L with reduced settling velocities by 20 % of their settling velocity |
| UR40 | WRF-L with reduced settling velocities by 40 % of their settling velocity |
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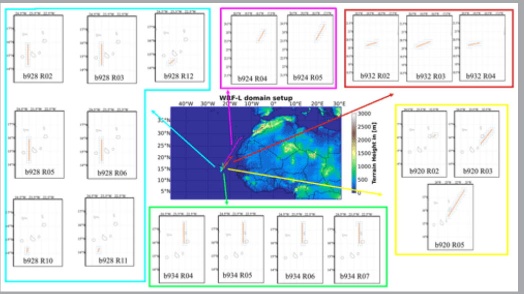
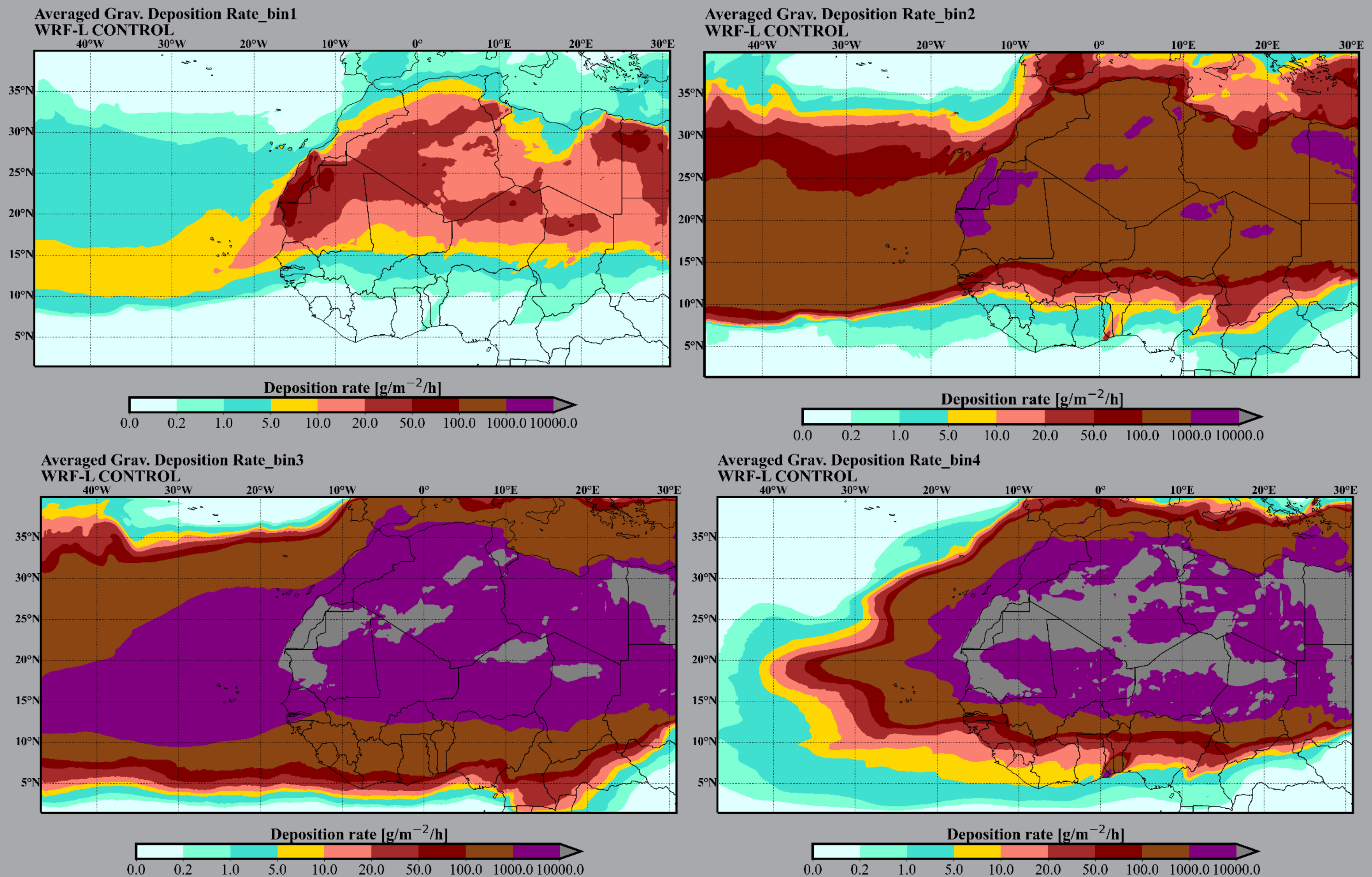
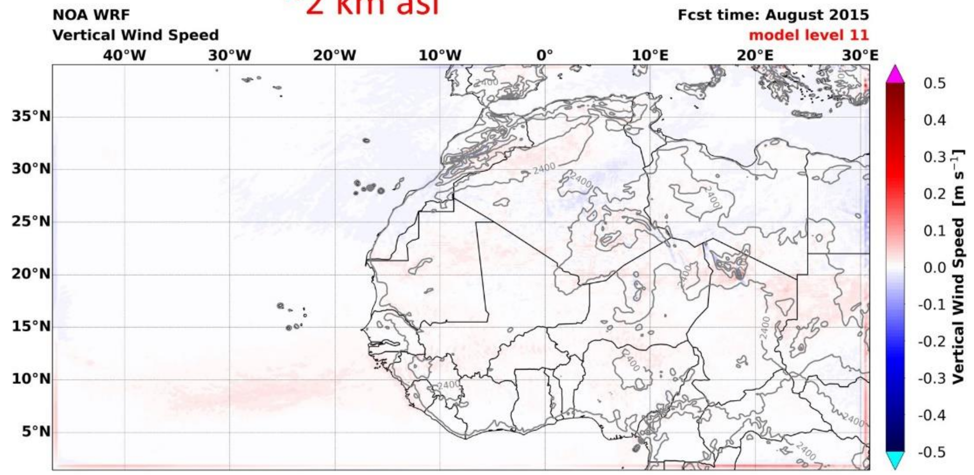
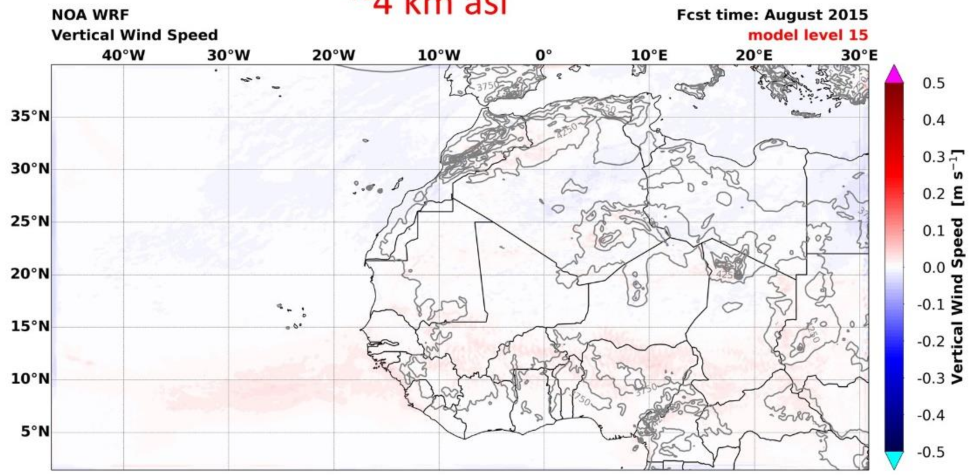



Averaged Grav. Deposition Rate_bin1
WRF-L CONTROL
Deposition rate [g/m−2/h]
0.0 0.2 1.0 5.0 10.0 20.0 50.0 100.0 1000.0 10000.0
Averaged Grav. Deposition Rate_bin2
WRF-L CONTROL
Deposition rate [g/m−2/h]
0.0 0.2 1.0 5.0 10.0 20.0 50.0 100.0 1000.0 10000.0
Averaged Grav. Deposition Rate_bin3
WRF-L CONTROL
Deposition rate [g/m−2/h]
0.0 0.2 1.0 5.0 10.0 20.0 50.0 100.0 1000.0 10000.0
Averaged Grav. Deposition Rate_bin4
WRF-L CONTROL
Deposition rate [g/m−2/h]
0.0 0.2 1.0 5.0 10.0 20.0 50.0 100.0 1000.0 10000.0

~2 km asl




~4 km asl

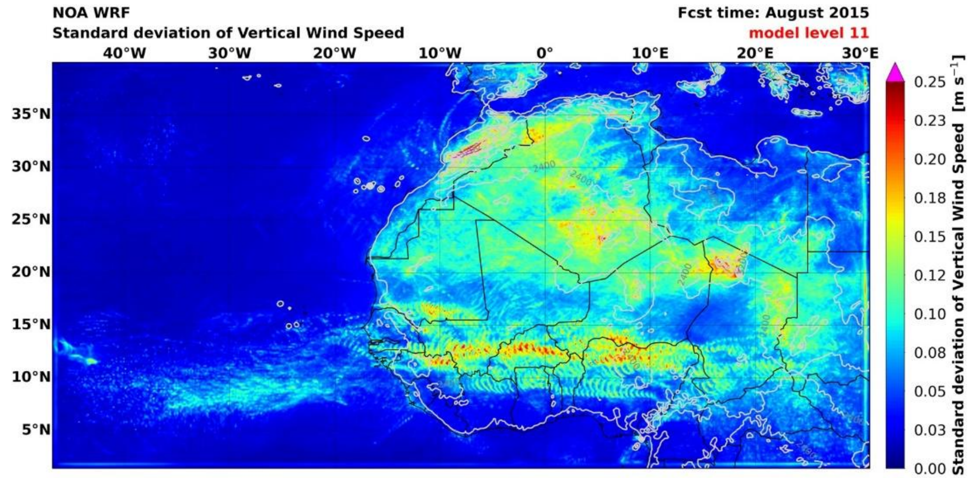


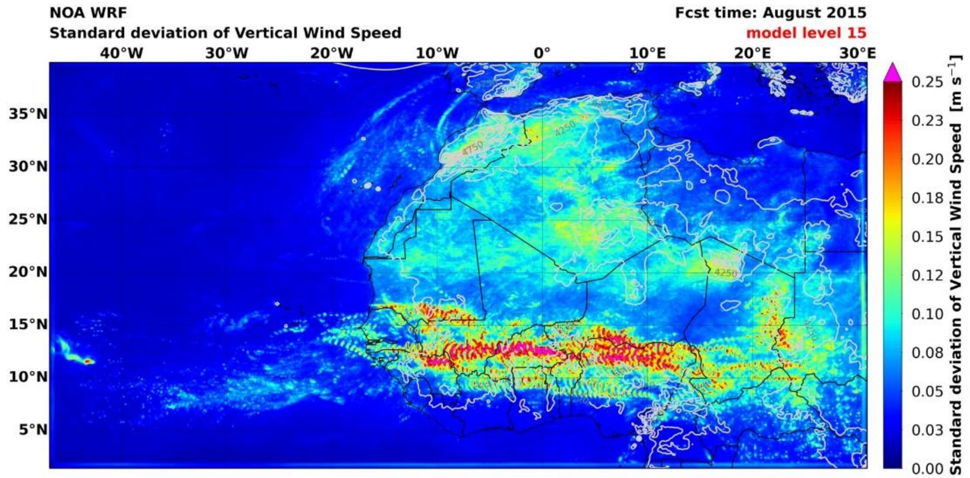

Maximum and minimum averaged values -> Min: -0.2 - Max: 0.3

Min: -0.1 - Max: 0.1

Max updraft 0.4m/s

Bin 5 settling velocity 0.23 m/s



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Drakaki et al., (2022)

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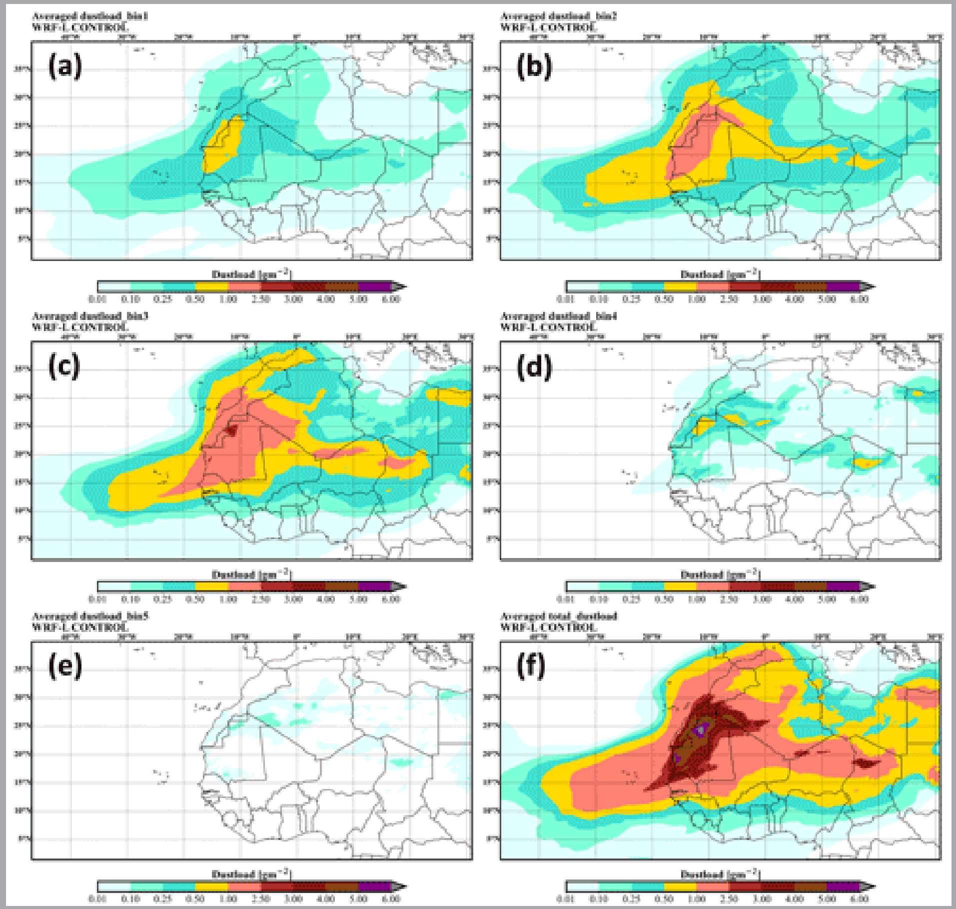


(~1 month of simulation)

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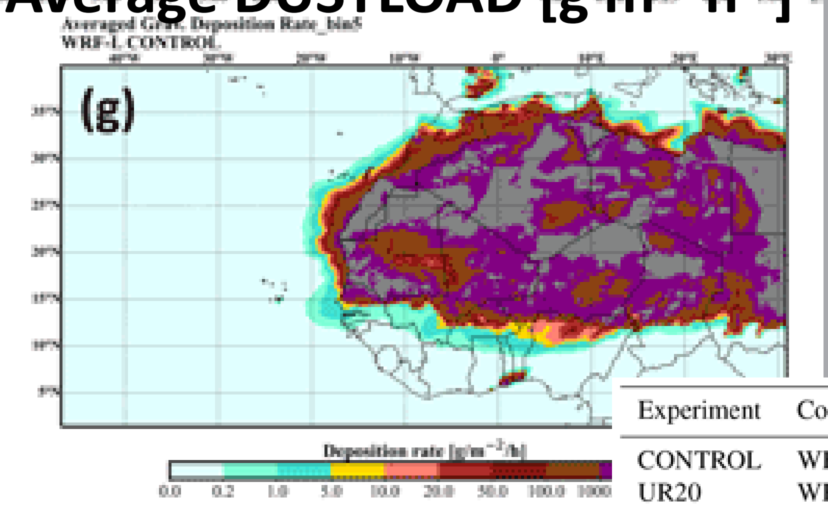


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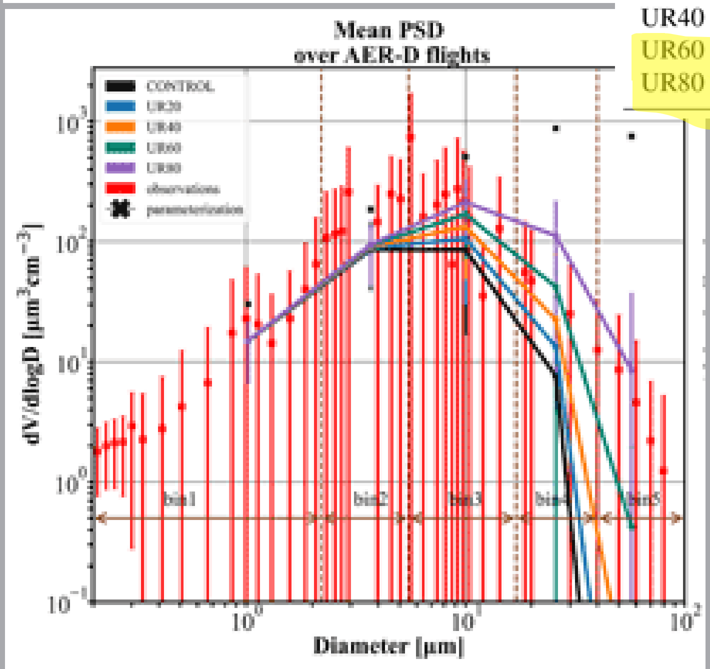
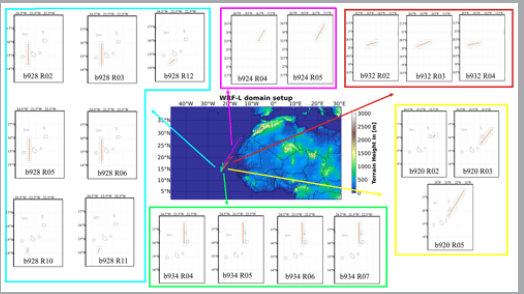
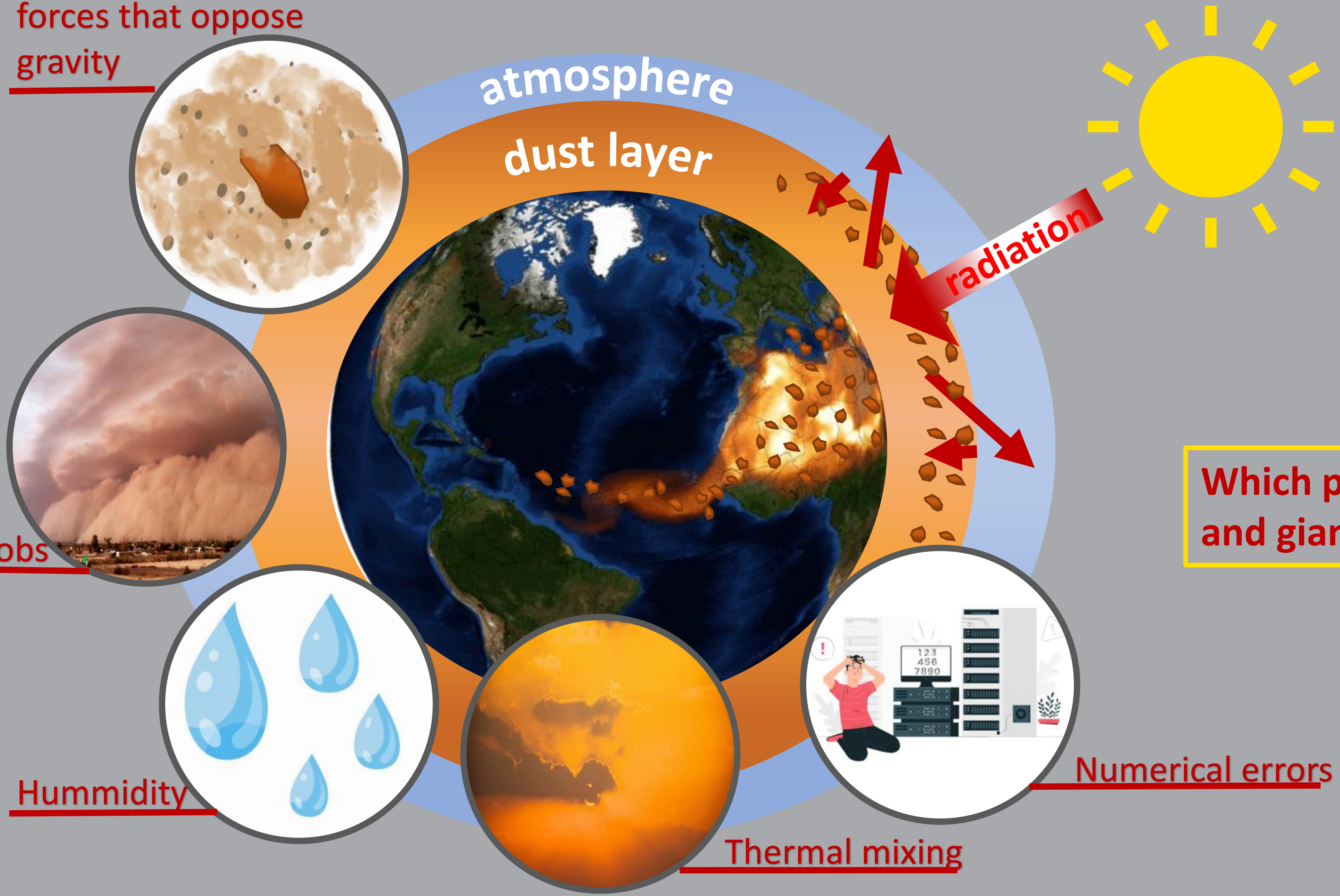


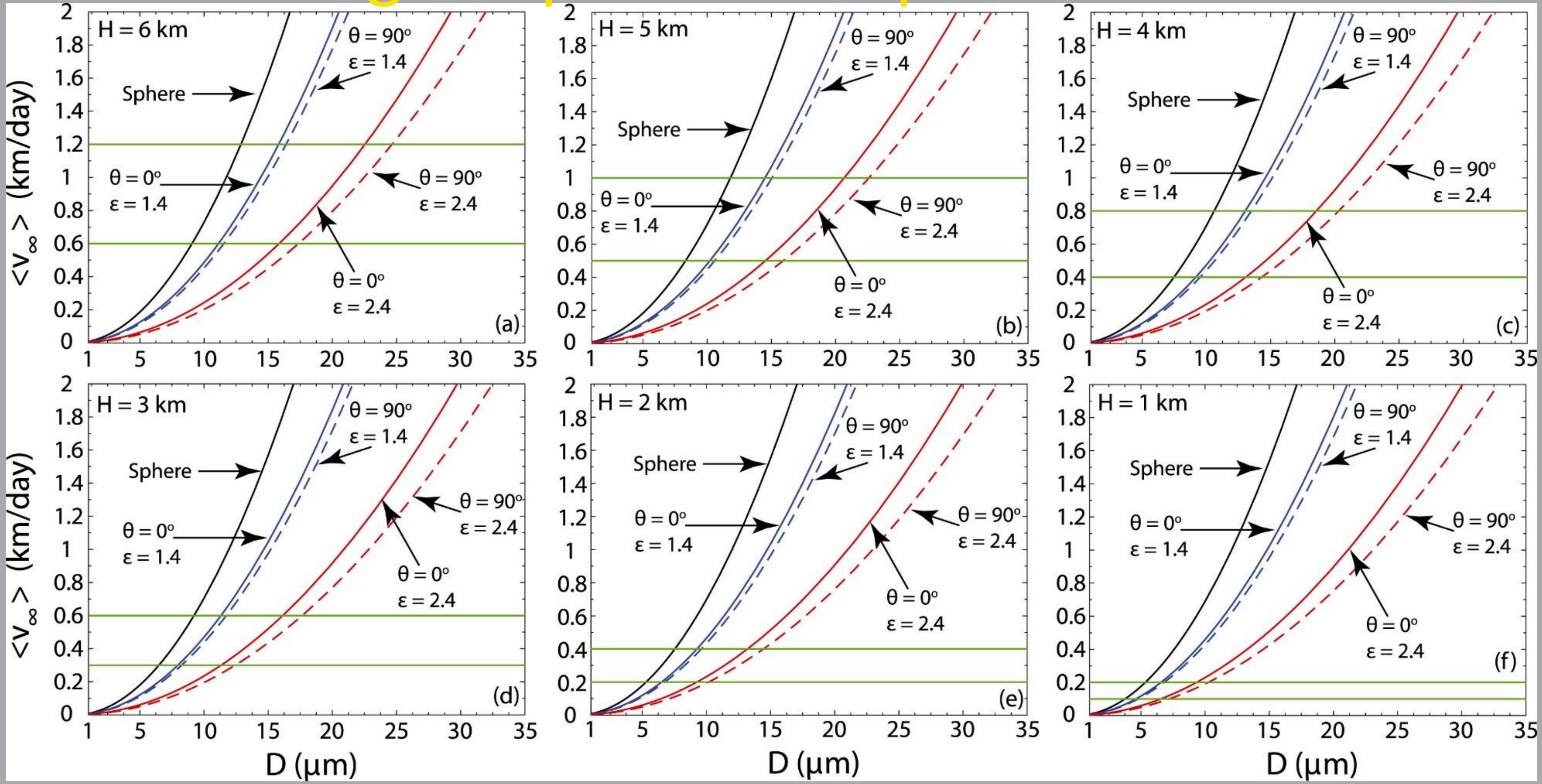






## Which processes keep super-coarse and giant particles aloft???

# Spheroids vs Spheres
# Testing the particle shape & orientation

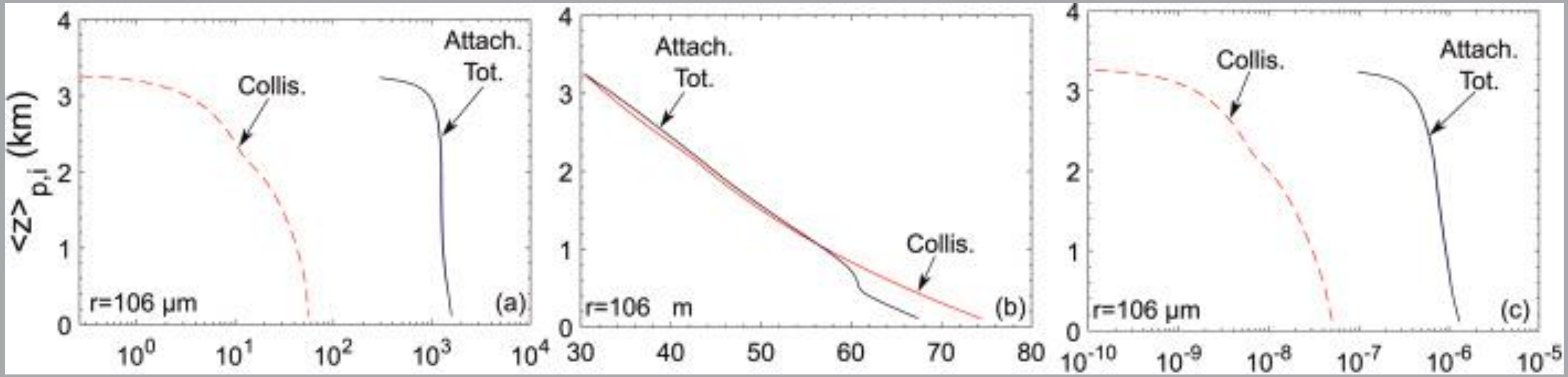
Mallios et al., 2021




Horizontally oriented Spheroids fall slower than their spherical counterparts

Mallios et al., 2022

# ion attachment and contact electrification




The electrical force is more than seven orders of magnitude less than gravity, and therefore does not influence the particle dynamics.

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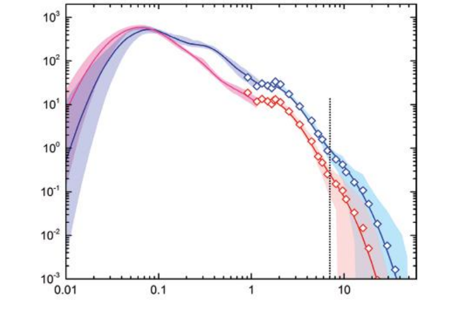


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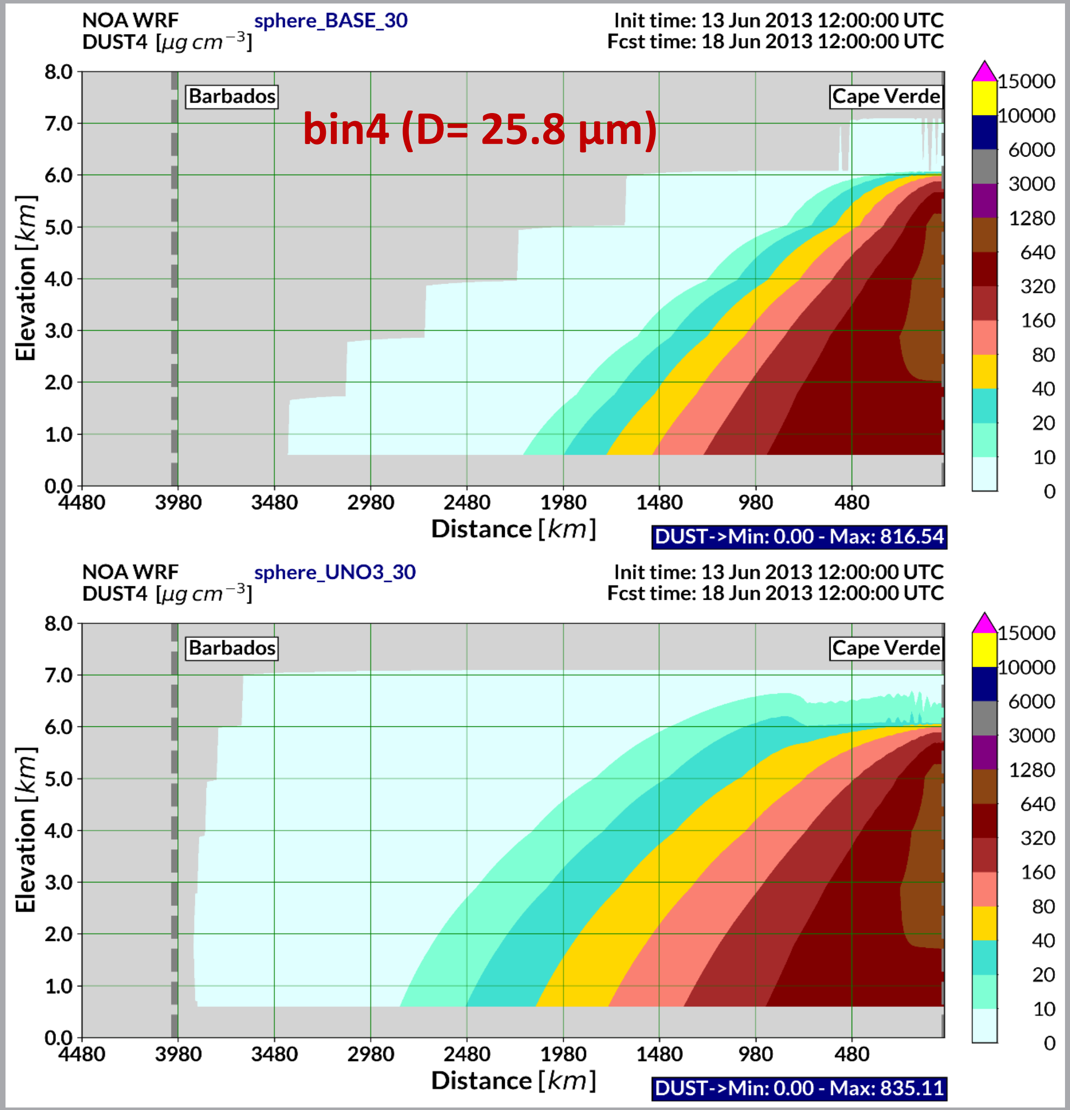


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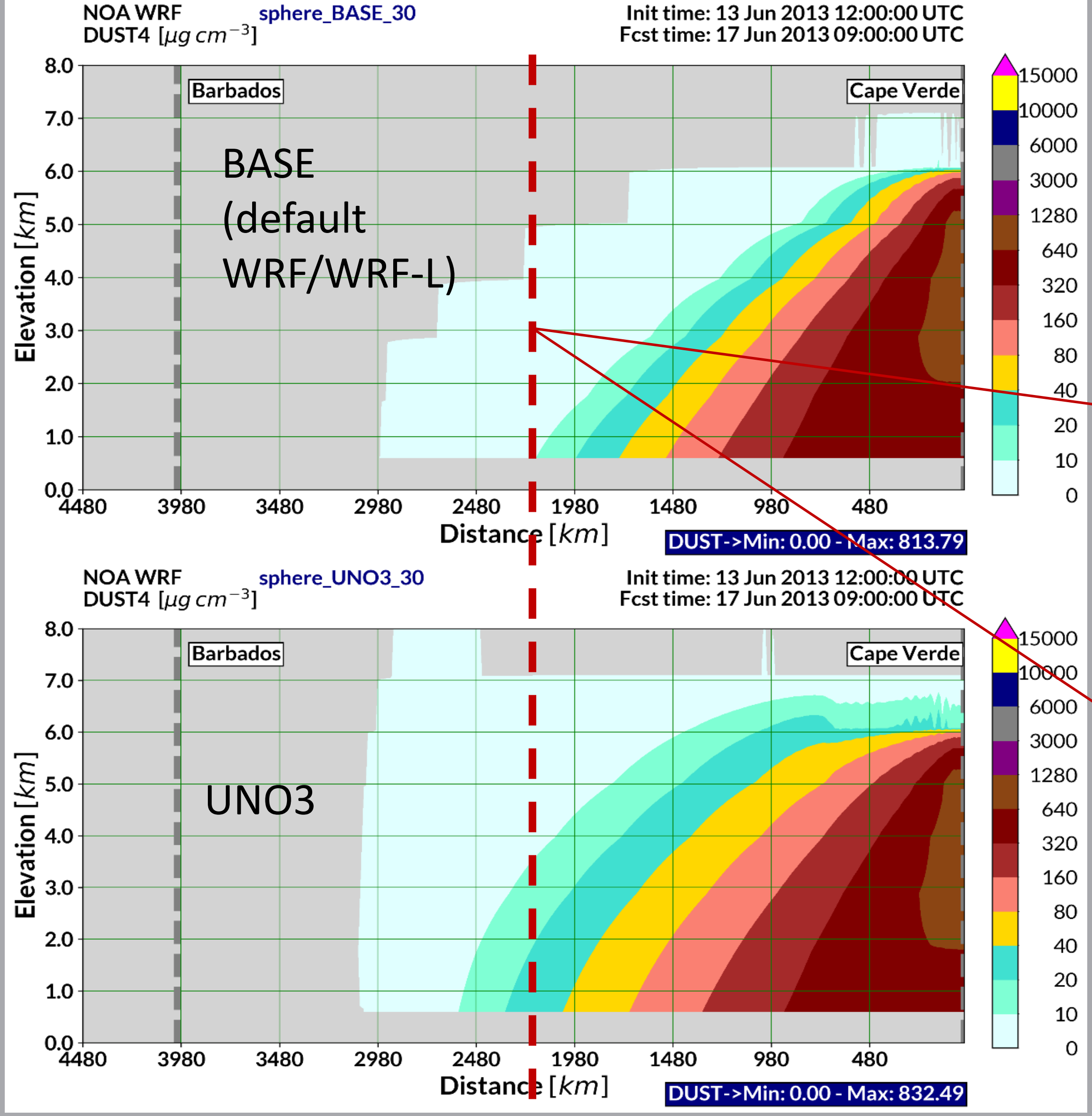
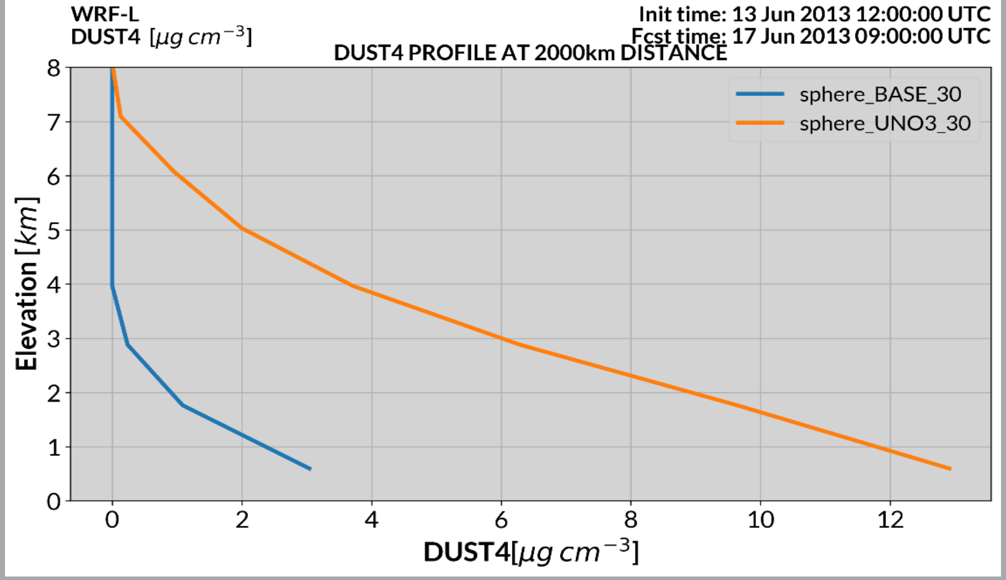
# ITS2.5/CL4.14

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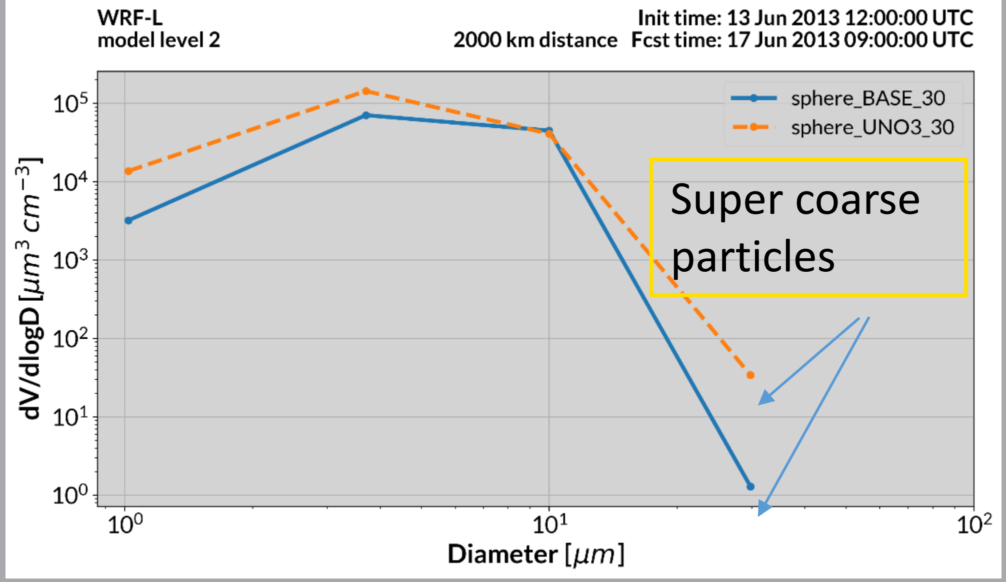


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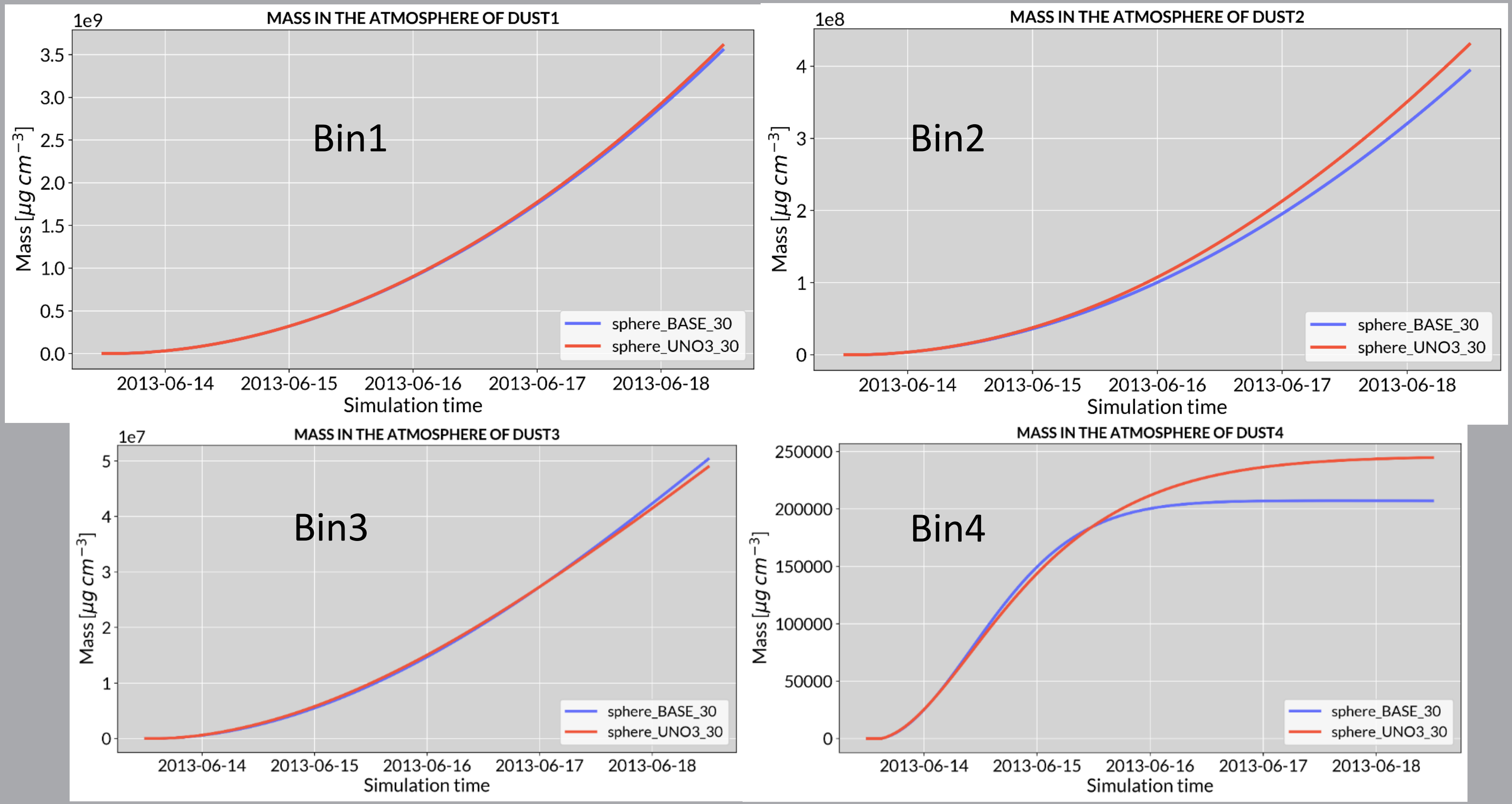


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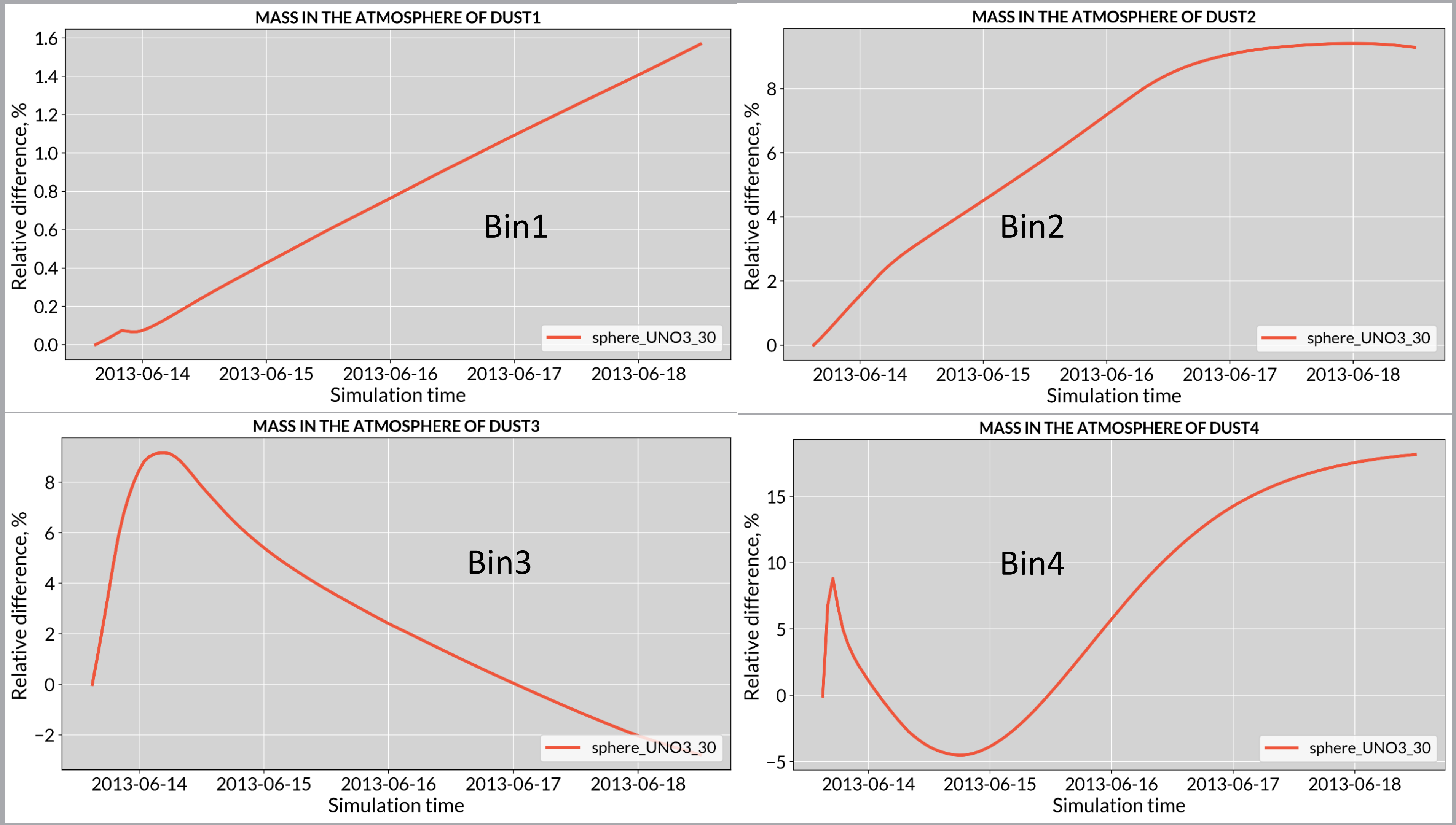


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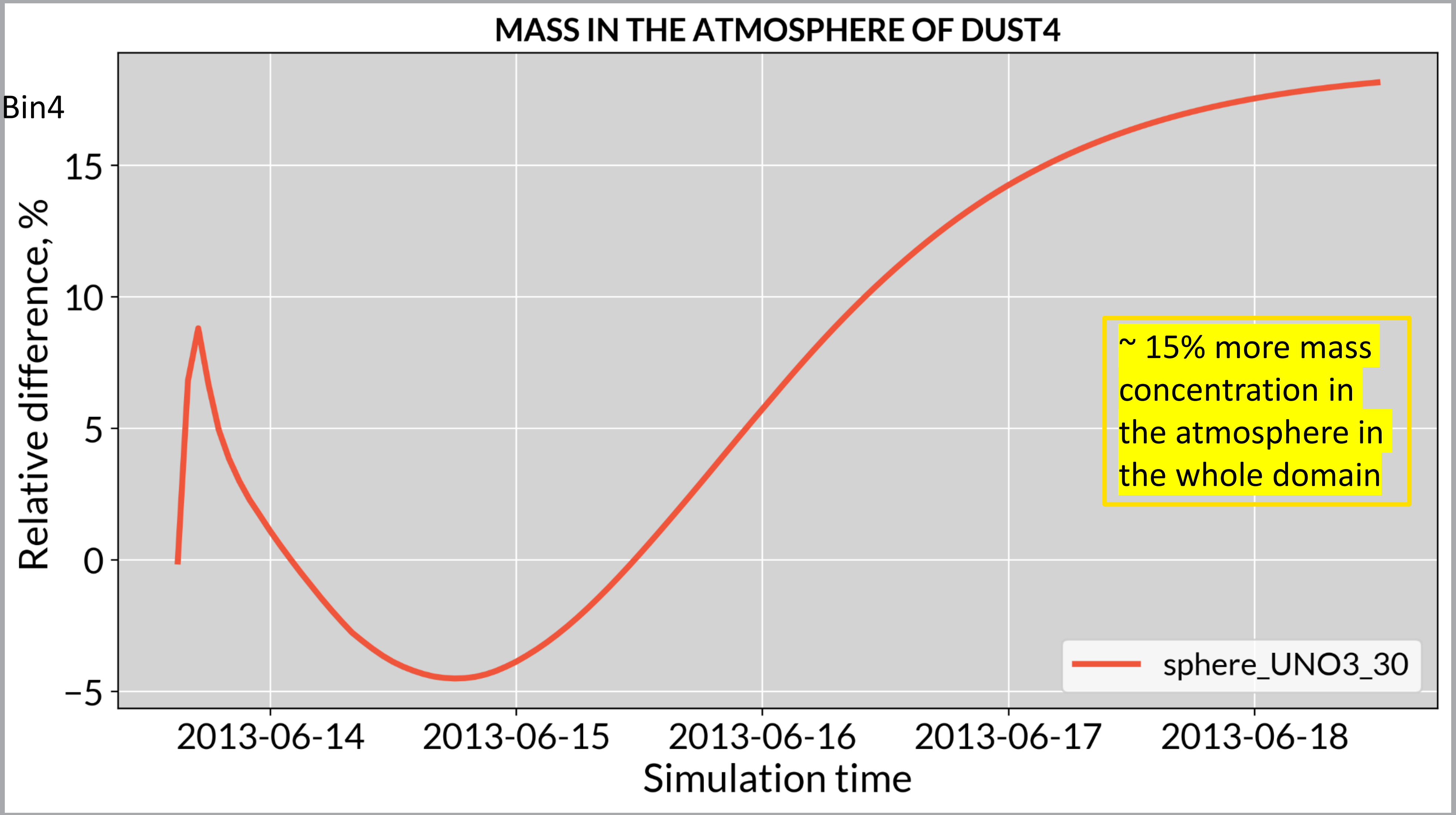


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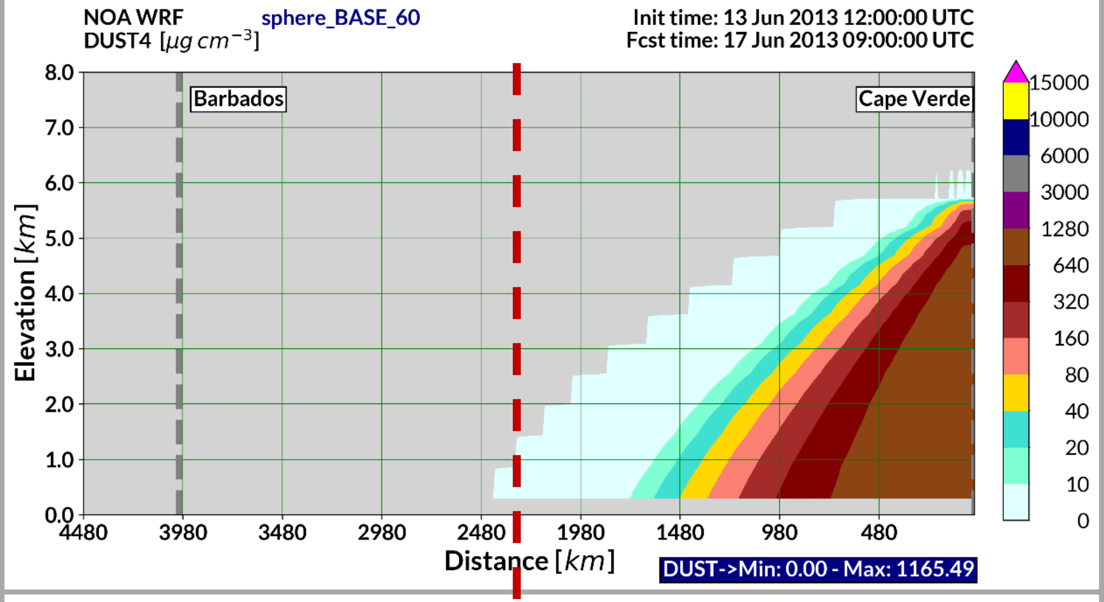


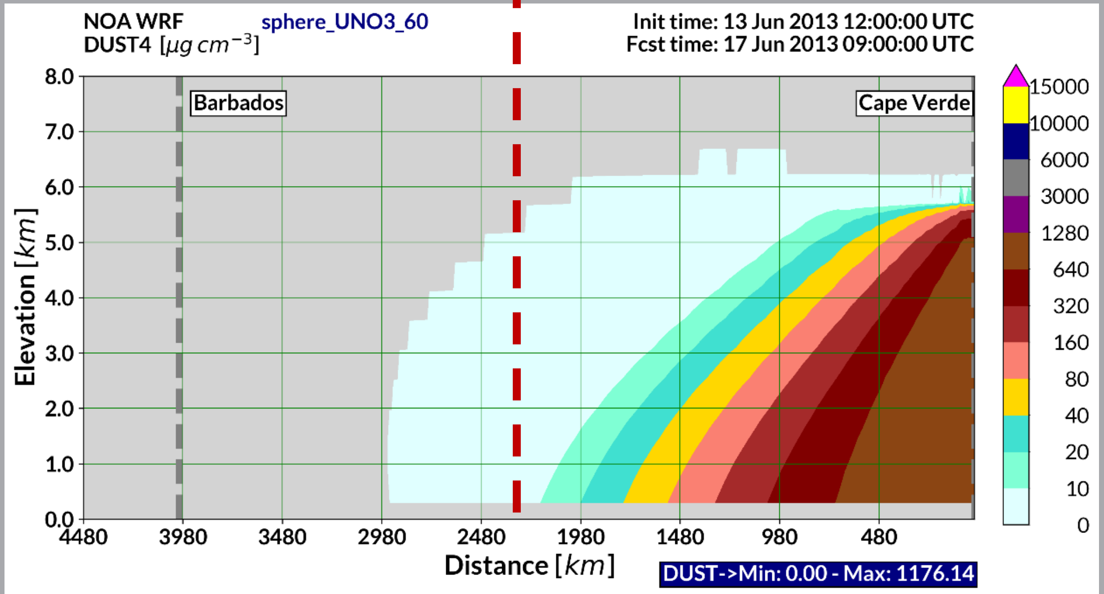


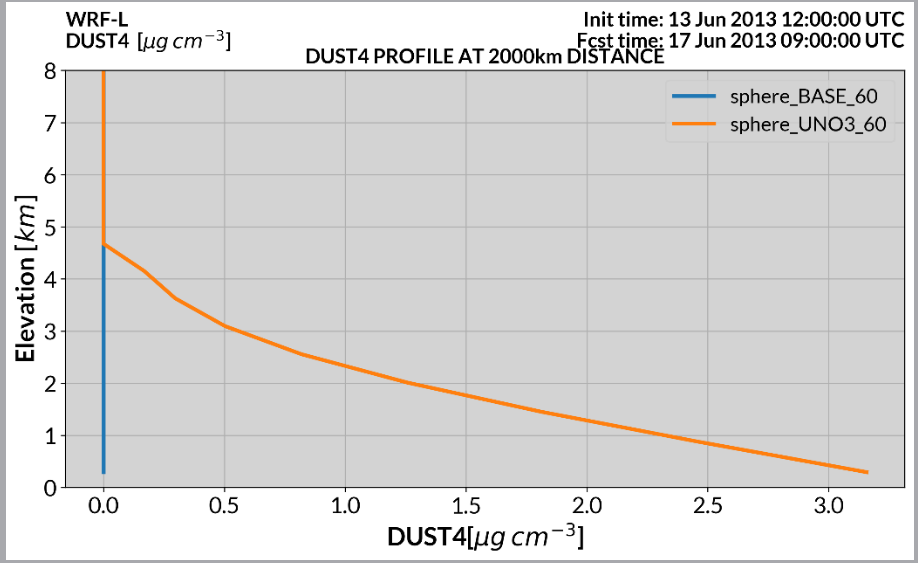


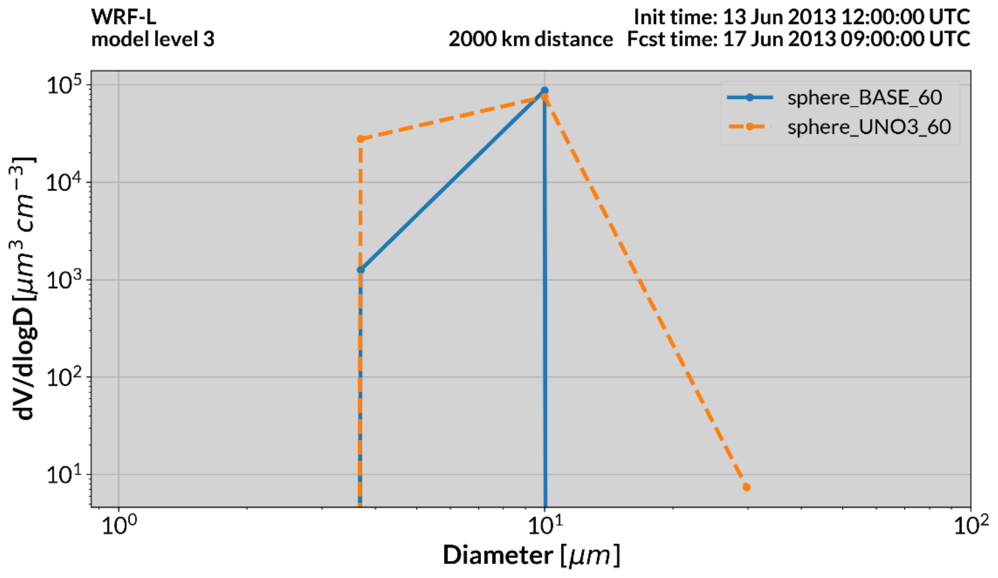


60 vertical layers

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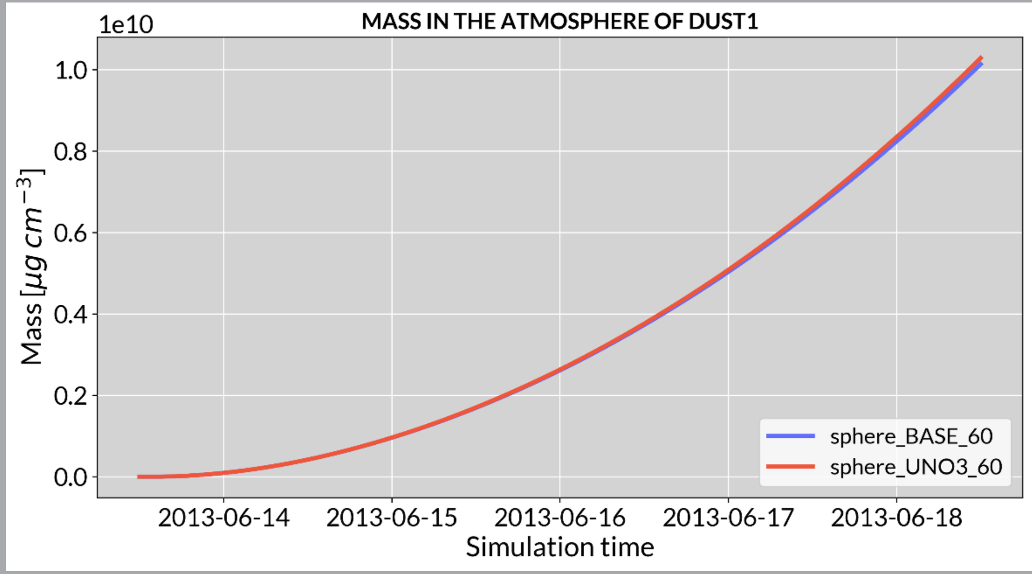
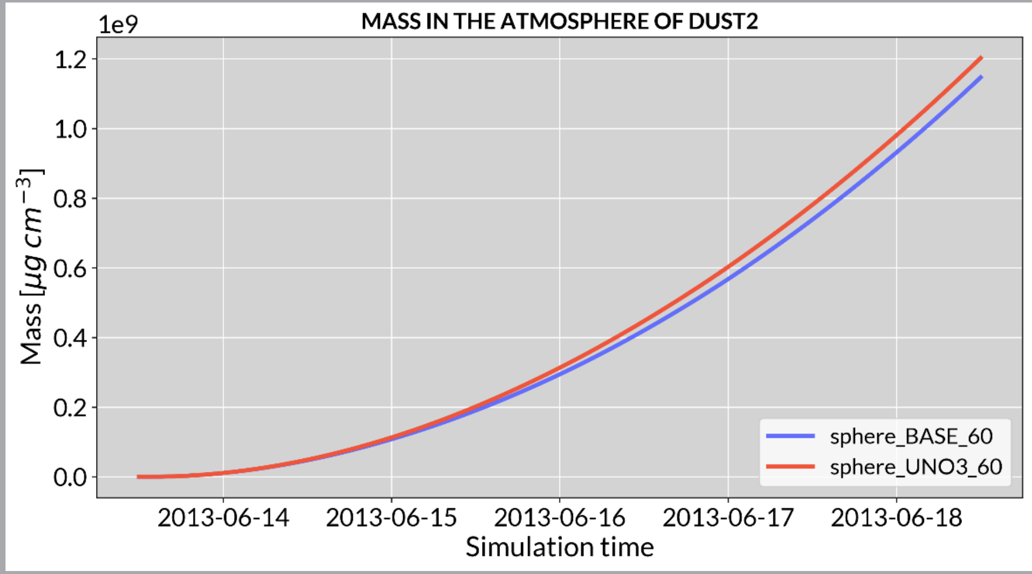
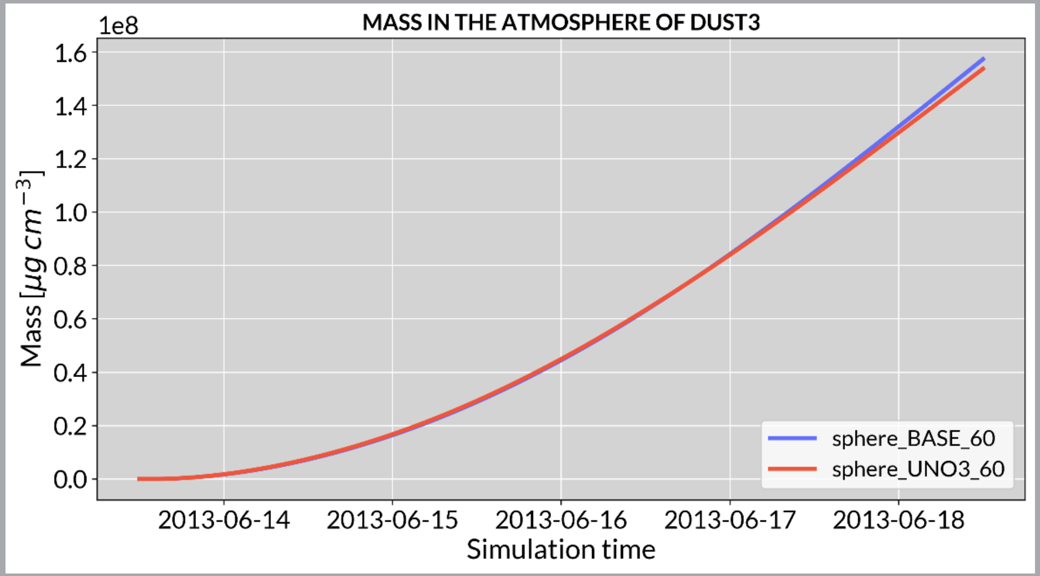
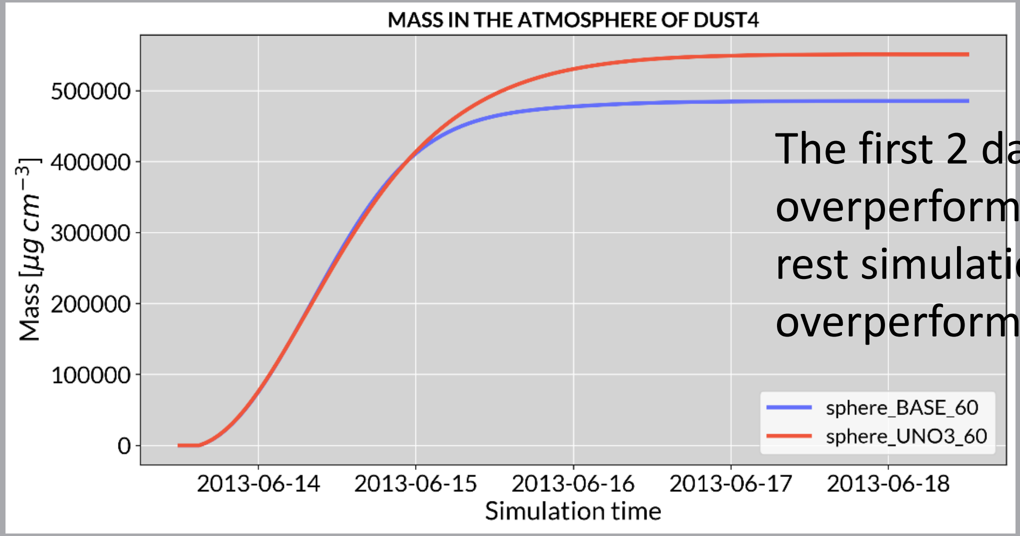


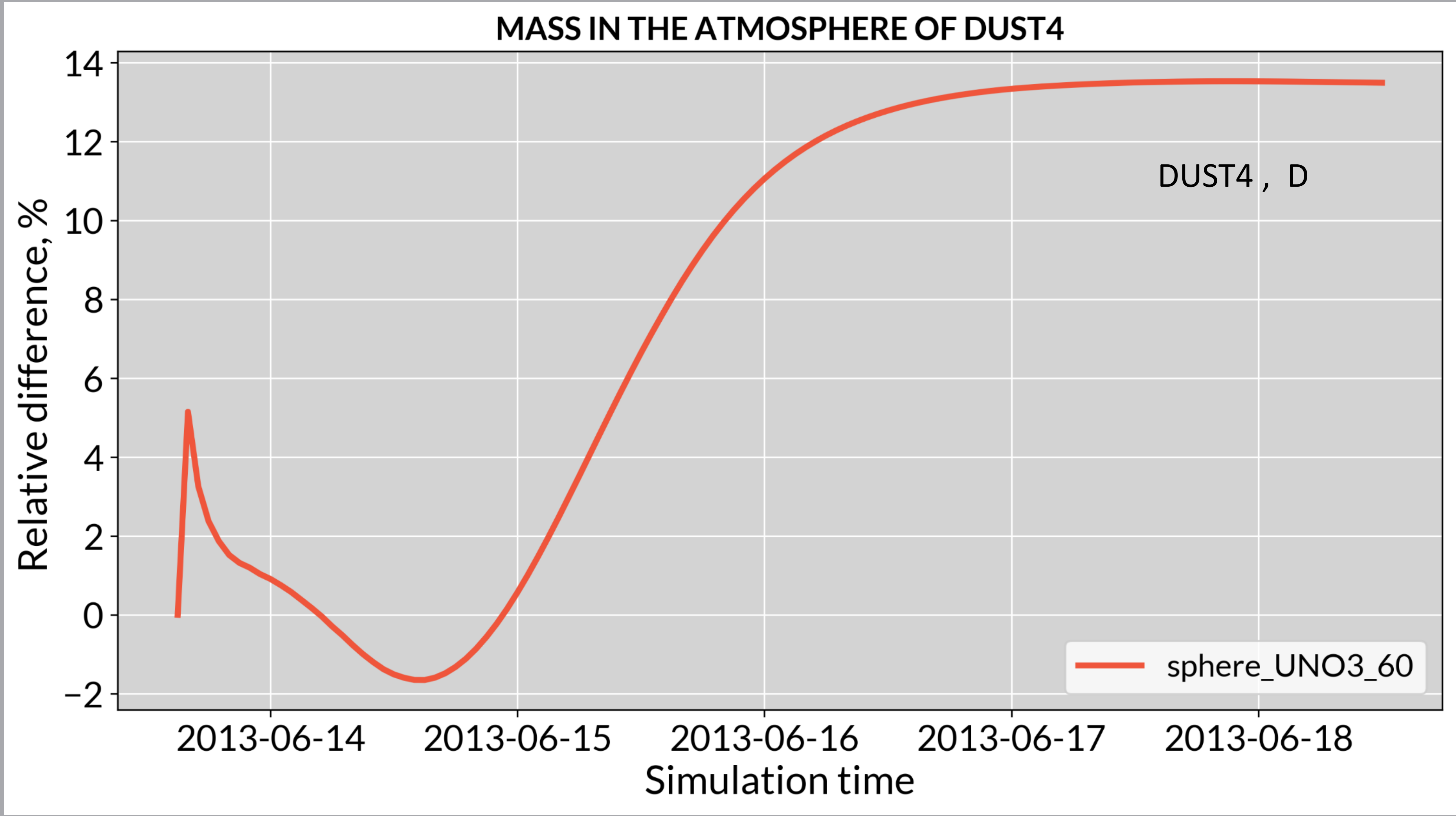

The performance is size dependence and is related with the particle lifetime




The first 2 days BASE overperformes , while for the rest simulation time UNO3 overperforms

60 vertical layers




~ 10% more mass in the atmosphere in the whole domain

60 vertical layer

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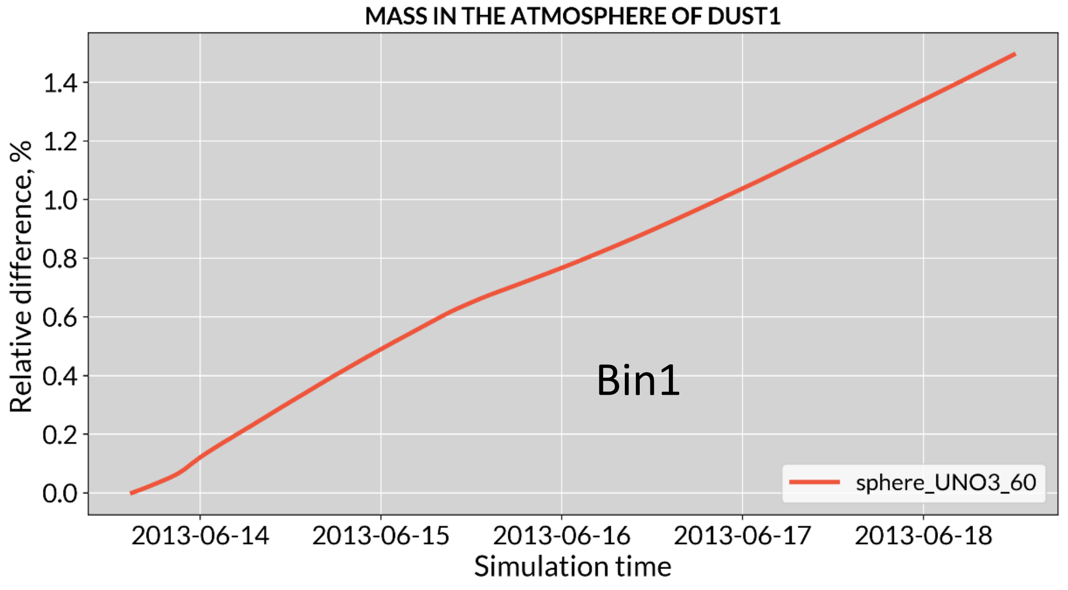
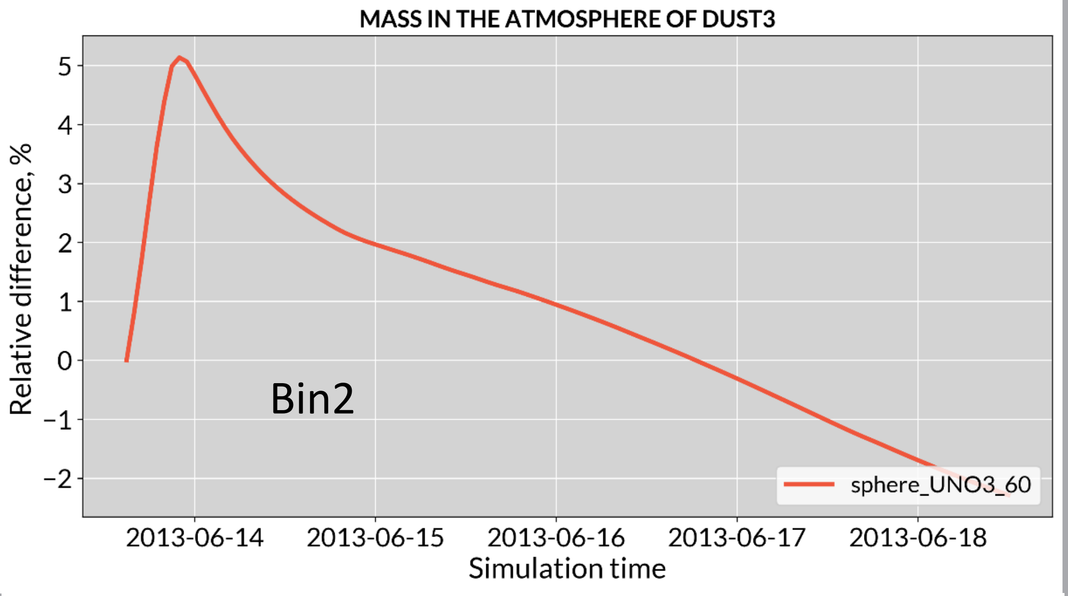
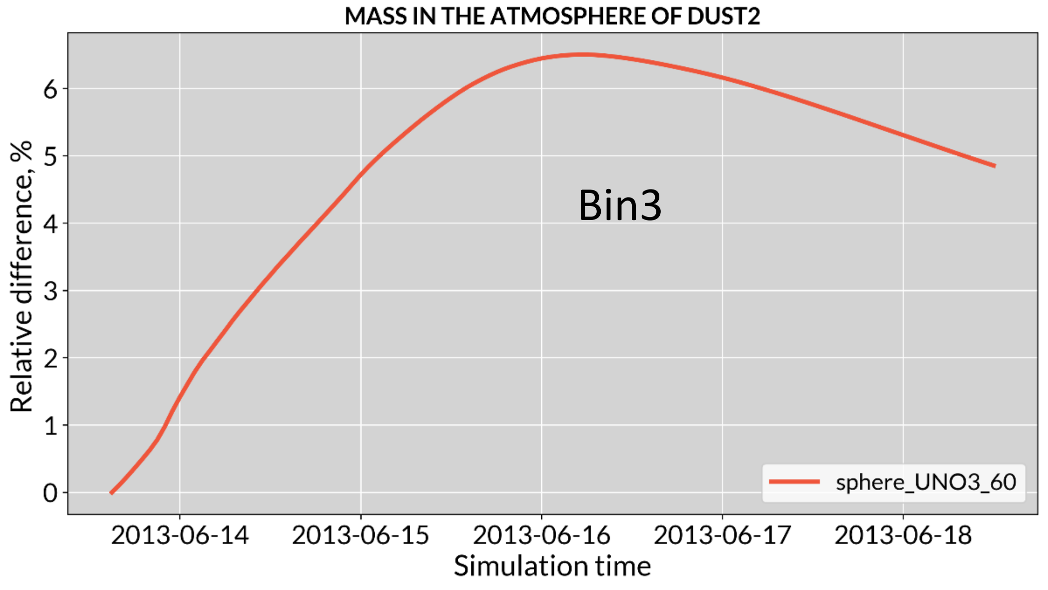
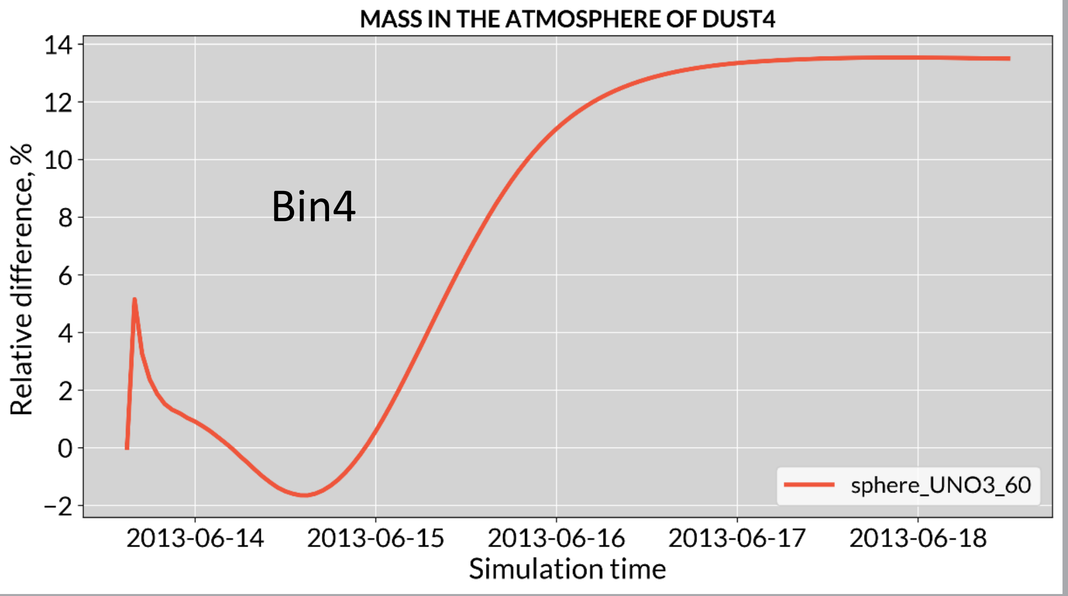
# ITS2.5/CL4.14

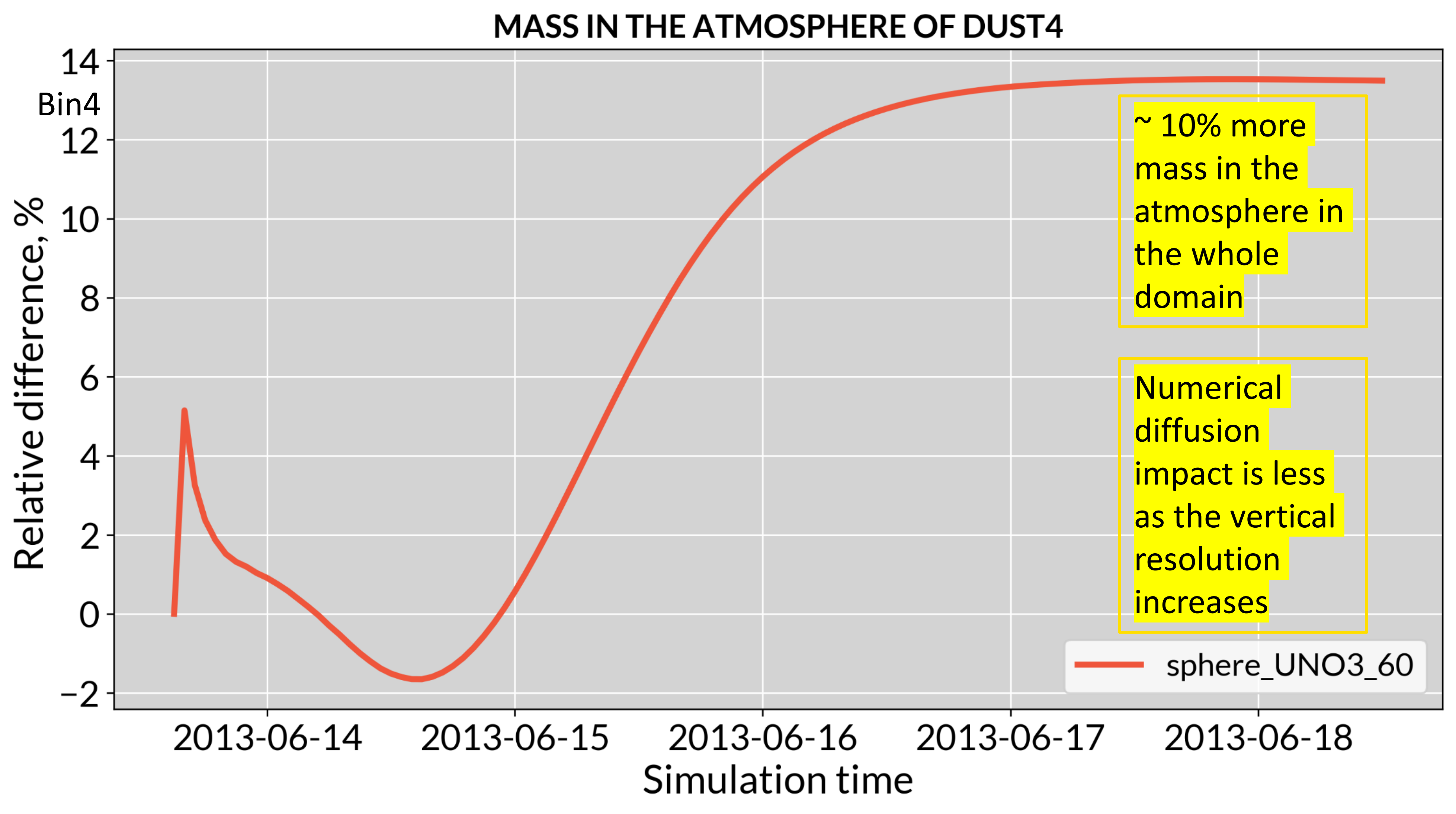


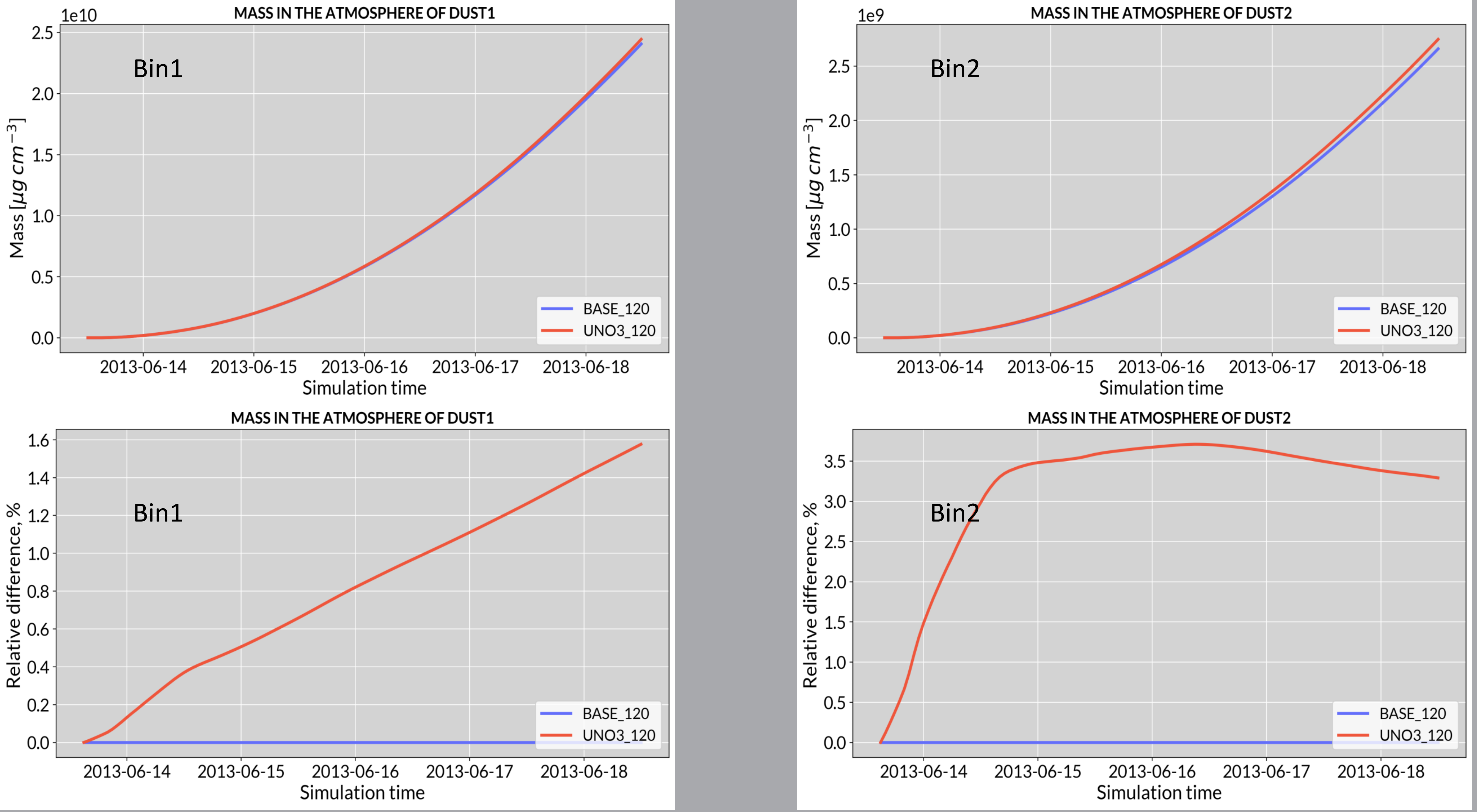



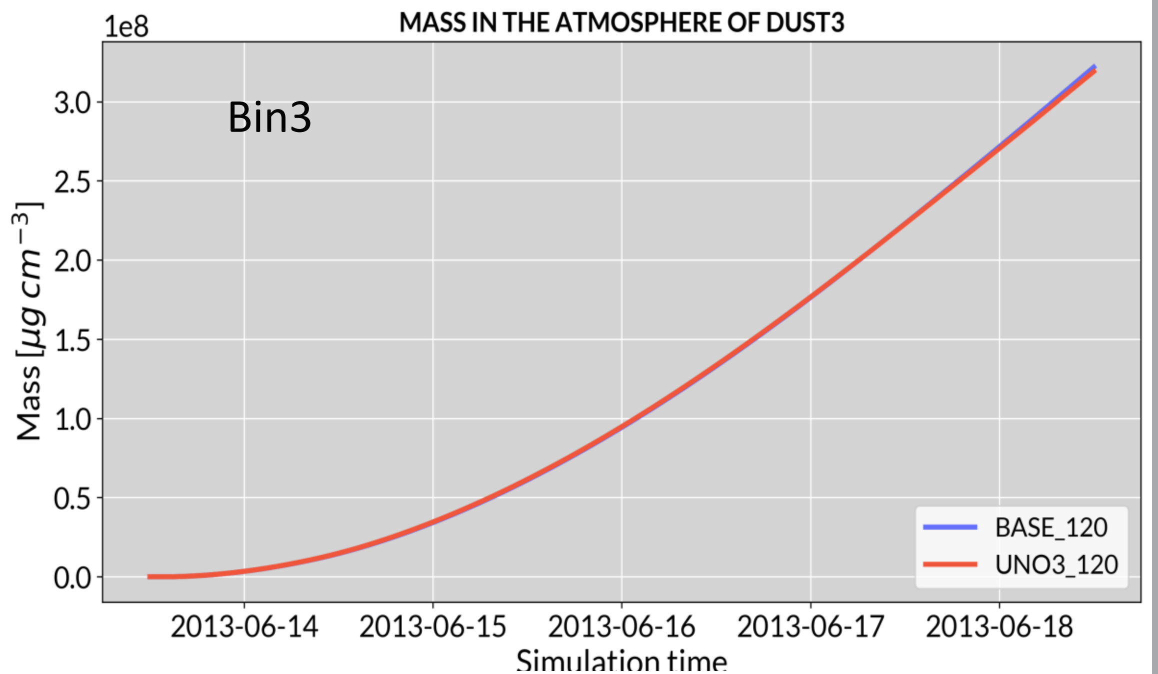

60 vertical layers

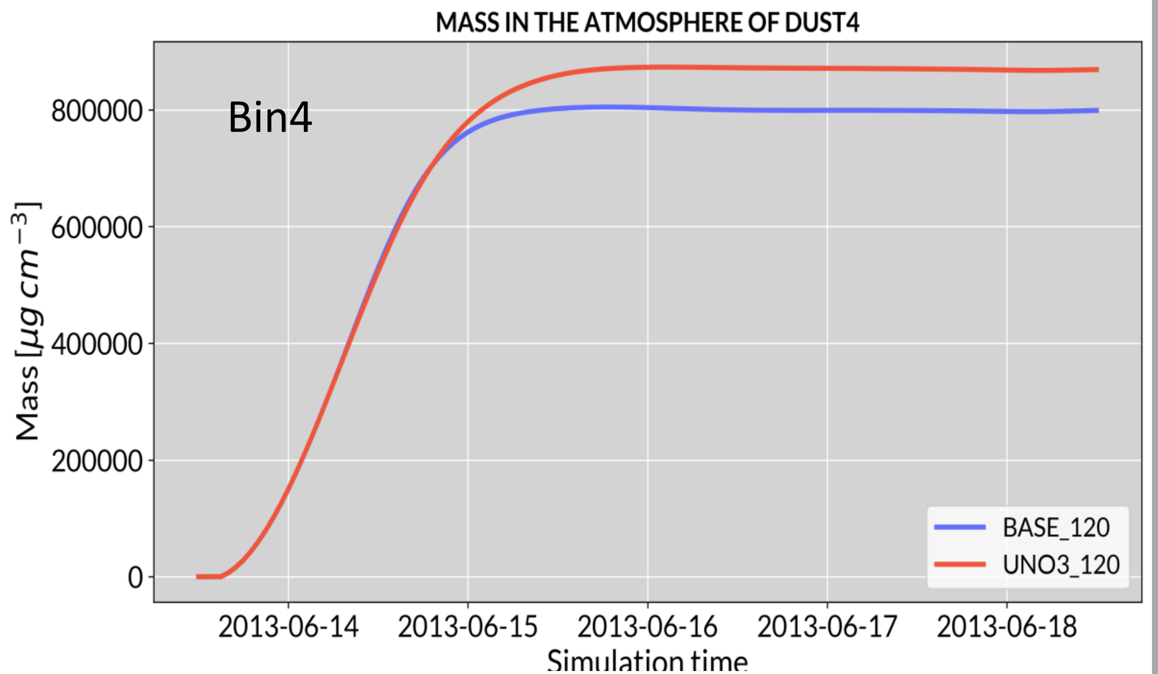


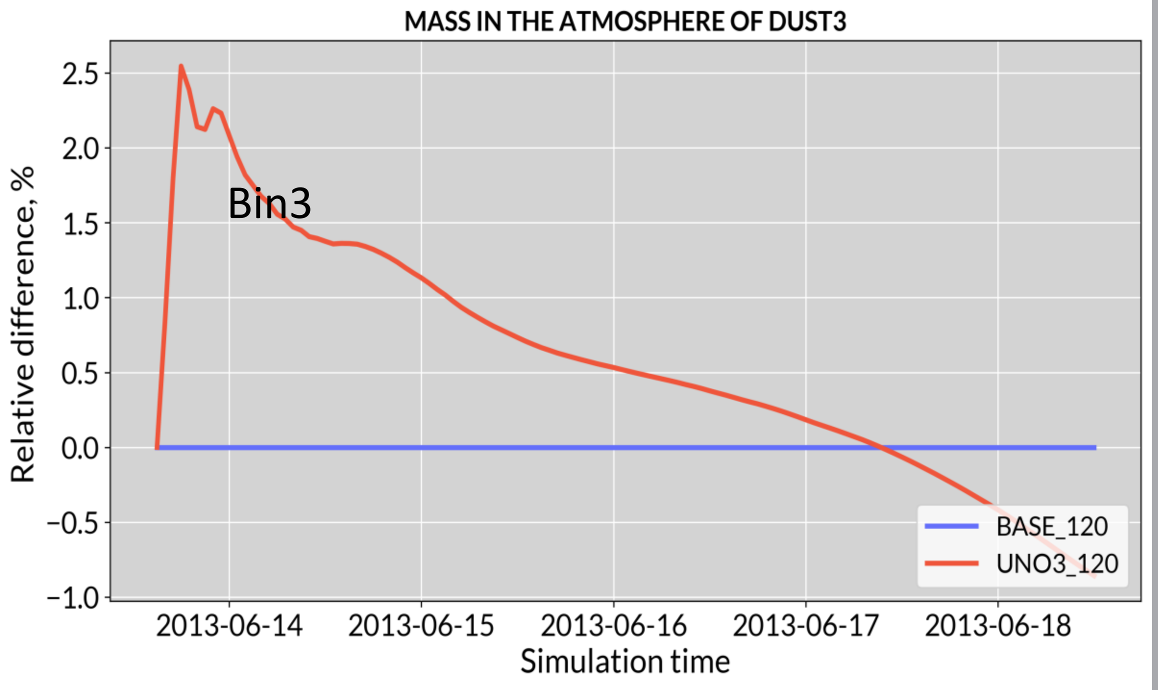

60 vertical layers

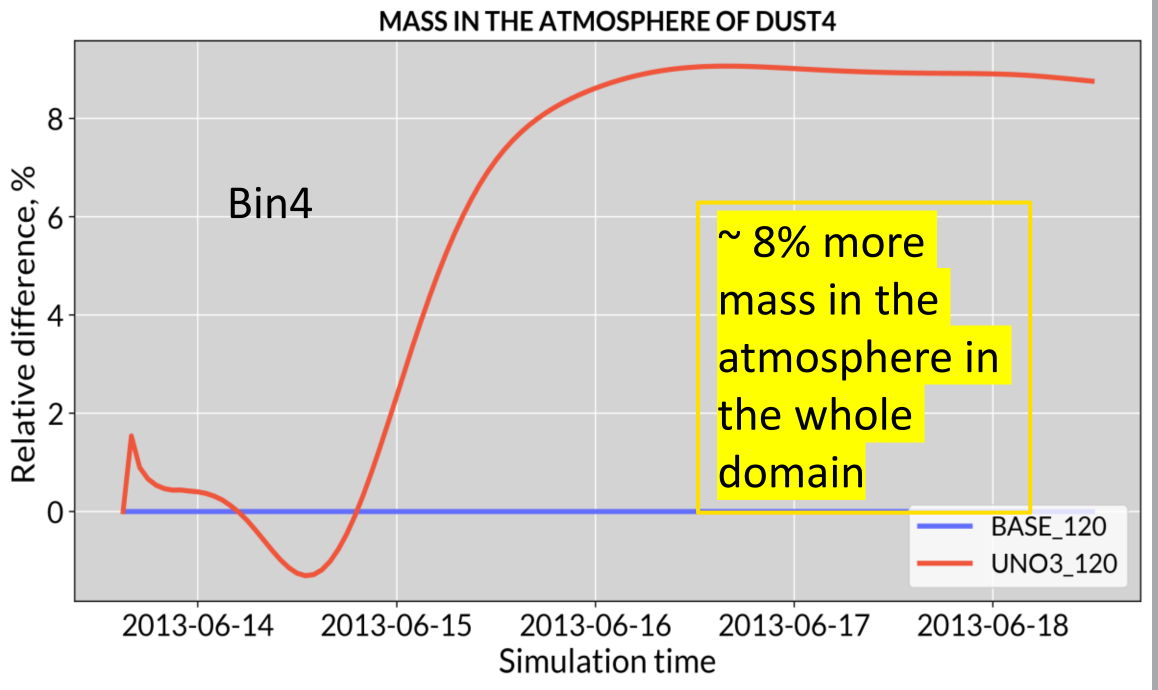



120 vertical layers

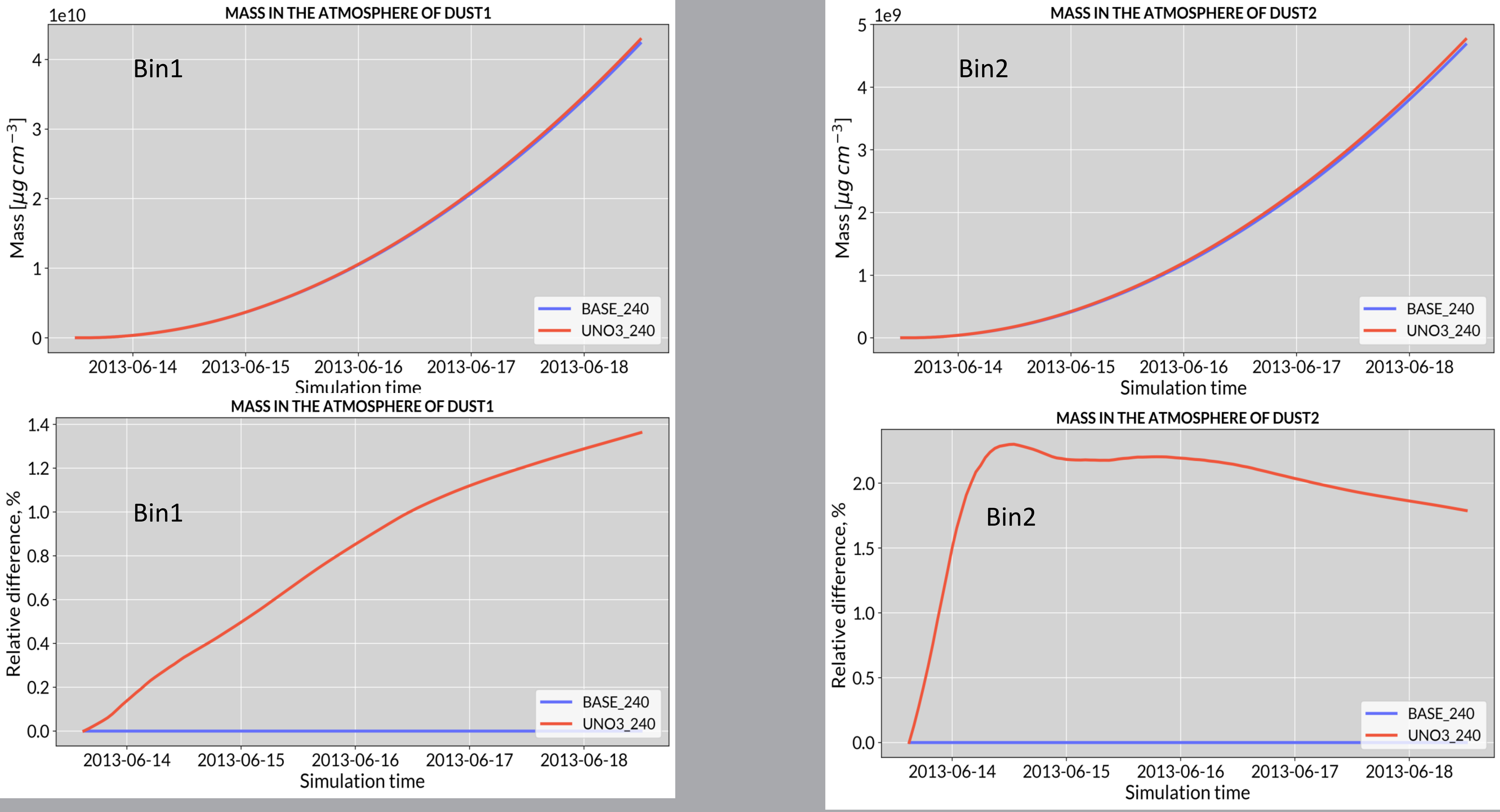


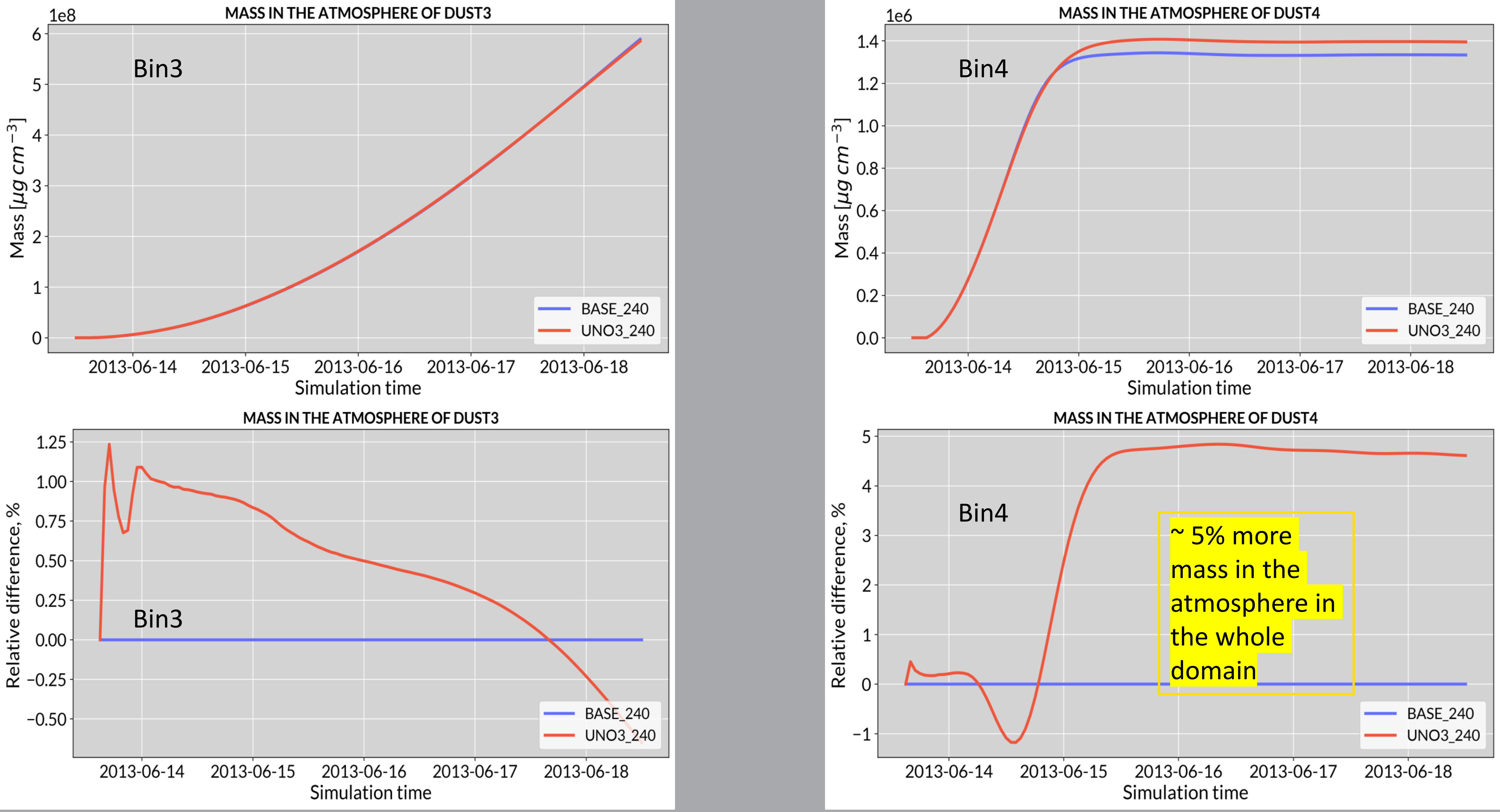




120 vertical layers




240 vertical layers




240 vertical layers

- We perform 2-D experiments utilizing WRF-L to test the impact of numerical diffusion on the advection equation of gravitational settling
- We compare the 1$^{st}$ order default scheme in WRF with the 3$^{rd}$ order UNO3 scheme which is less diffusive
- We assume a continuous dust flow in ~4km above ground

# CONCLUSIONS

- UNO3 is less diffusive than WRF scheme and preserves the aerosol mass of super-coarse particles longer in the atmosphere, in higher altitudes and changes the PSD of dust.
- There is a size dependence on the impact of numerical diffusion which depends on the particle lifetime and the simulation time.
- The impact of UNO3 is greater as the size is bigger (the lifetime of the particle is shorter) for a 5-days simulation
- There is a dependence on the vertical resolution. As the vertical resolution increases the numerical diffusion on both schemes is less and the results of the schemes (UNO3 and WRF) differ less between each other.