CAMAERA

GA 2025, Lille

WP5/D5.3: PARTICLE DRY DEPOSITION, 0D COMPARISON

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PROGRAMME OF THE EUROPEAN UNION
Copernicus Europe's eyes on Earth
IMPLEMENTED BY ECMWF
Coordinated by HYGEOS

The outline

1. The aerosol dry deposition
2. The protocol of the intercomparison exercice
3. The results
4. Sensitivity
5. Links to other HYGEOS activities
6. Conclusions

1. The aerosol dry deposition -> aerosol lifetime

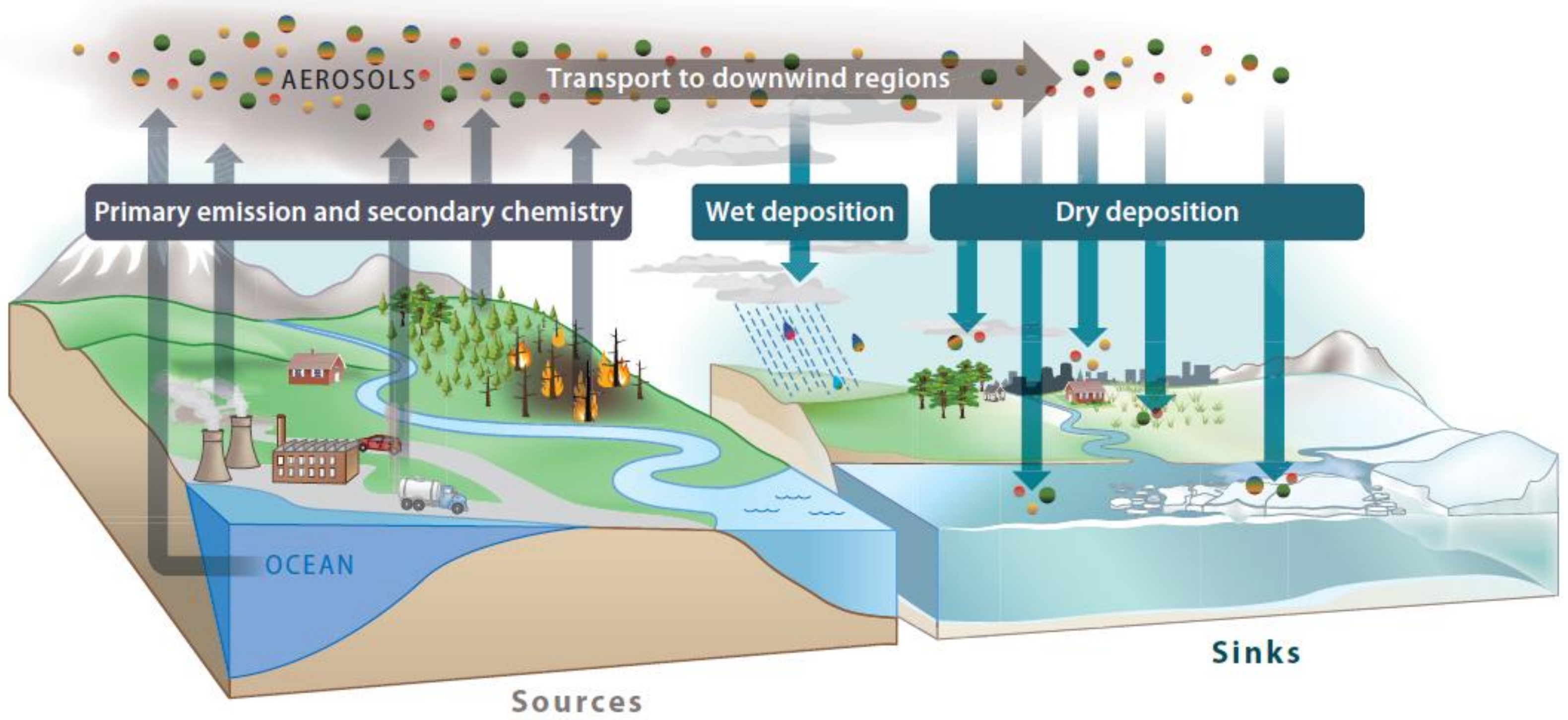

Figure 1

Primary emissions and secondary chemistry are key sources of aerosols in the atmosphere. Wet and dry deposition remove particles, determining the lifetime of these aerosols in the atmosphere. Deposition surfaces include forests, grasslands, ice, water, and urban environments, with each surface type removing particles at different size- and turbulence-dependent rates.

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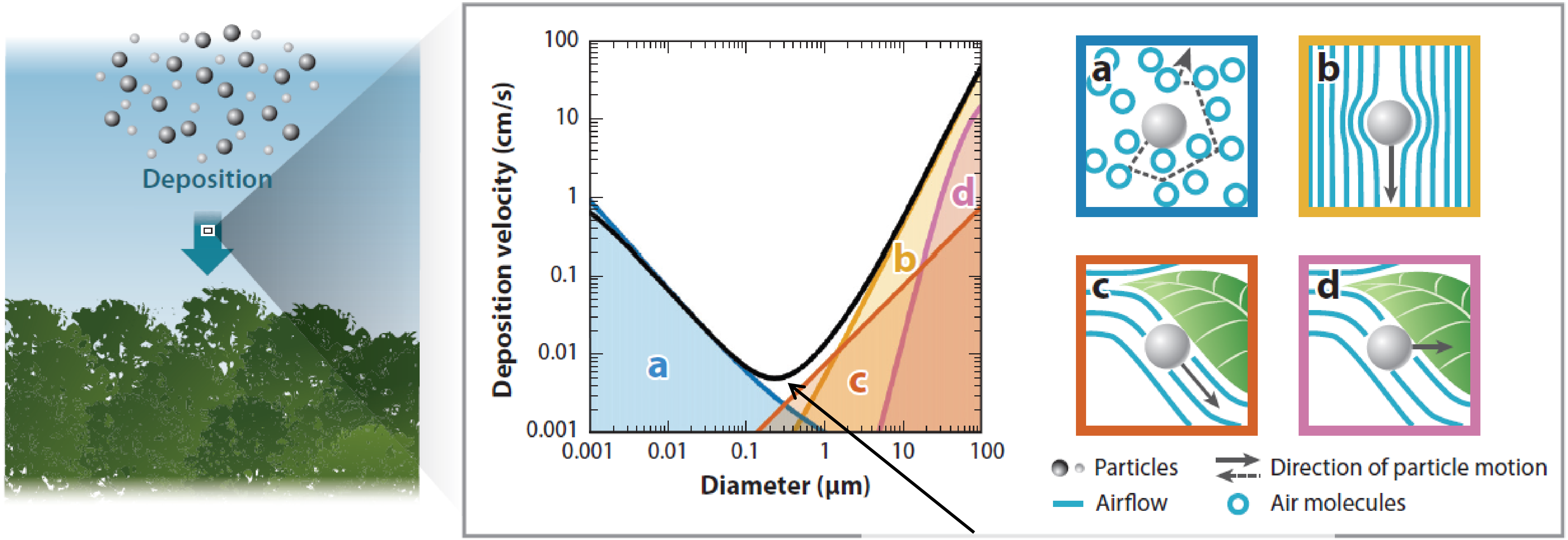
"the removal of these particles from the atmosphere [...] represents the single largest uncertainty in climate" **[Farmer *et al.* 2021]**

+ strong influence in air quality

1. The aerosol dry deposition. 4 processes



0.1-1 um: Minimum of deposition, because

1) decrease of Brownian with particle size, and
2) increase of sedimentation

Figure 2

Dry deposition velocities of particles are a function of particle diameter and are driven by a combination of processes, including (*a*) Brownian diffusion (*blue*), (*b*) gravitational settling (*yellow*), (*c*) interception (*orange*), and (*d*) impaction (*purple*). The relative importance of these processes varies with particle size and surface type, with the … these processes and the total calculated deposition velocity (*thick black line*) for a conifer forest. The direction of airflow in panels *a–d* is indicated by solid blue lines; the direction of particle motion is indicated by gray arrows. In the case of Brownian diffusion, particle movement is random, as indicated by the dashed gray arrow. The size of particles relative to gases is not drawn to scale.

2. The protocol. 8 models

Model name	Group	Main reference	Reference in short
LOTOS-EUROS	TNO (Netherlands)	Zhang et al. [2001]	Z01
GEM-AQ	ios PIB (Poland)	Zhang et al. [2001]	Z01
SILAM	FMI (Finland)	Kouznetsov and Sofiev [2012]	KS12
MATCH	SMHI (Sweden)	Simpson et al. [2012]	S12
MINNI	ENEA (Italy)	Pleim and Ran [2011]	PR11
IFS_Z01	IFS-COMPO, 45R1-47R2 cycles	Zhang et al. [2001]	Z01
IFS_ZH14	IFS-COMPO, 47R3- cycles	Zhang and He [2014]	ZH14
IFS_P22	Potential candidate for future cycles of IFS-COMPO	Pleim et al. [2022]	P22

Thanks to all participants for the data, the model description, and the ongoing discussions

2. The protocol. 4 Land Use Categories (LUC)

Model name	Z01, P22	ZH14
Evergreen needleleaf forest	1	4
Deciduous broadleaf forest	4	7
grass	6	13-14
water	13	1, 3

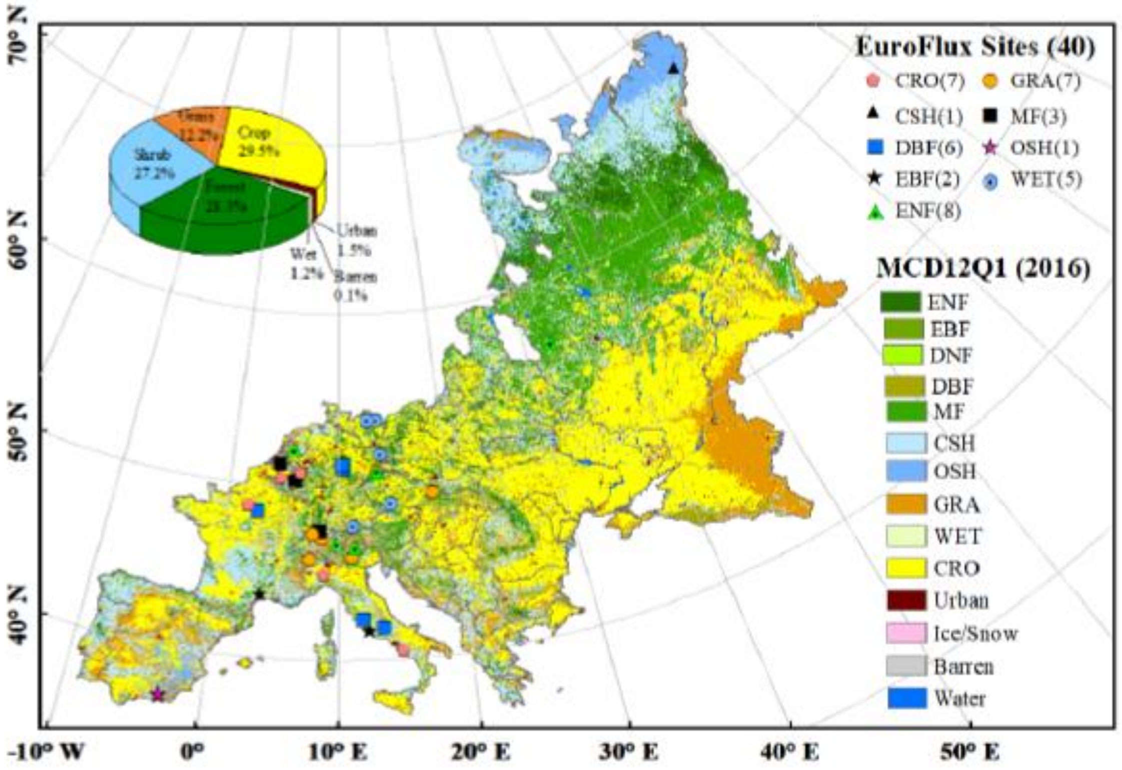


Figure 1. Spatial distribution of 40 EuroFLUX sites and land cover classification from MCD12Q1 in 2016 in Europe. Abbreviations: croplands (CRO), closed shrublands (CSH), deciduous broadleaf forest (DBF), deciduous needleleaf forest (DNF), evergreen broadleaf forest (EBF), evergreen needleleaf forest (ENF), grasslands (GRA), mixed forest (MF), open shrublands (OSH), and wetland (WET).

Remote Sens. 2023, 15, 1172. https://doi.org/10.3390/rs15051172

2. The protocol. Input data (0D comparison)

- Pa – air pressure [Pa]
- T_a – air temperature [C]
- u* – friction velocity [m s-1]
- z_0 – roughness length [m]
- z_r – computation height [m]
- Characteristic radius [m]
- $\rho_{air/p}$, air and particle densities [kg m^{-3}]
- LAI, leaf area index [m2/m2]

O. E. Clifton et al.: Ozone dry deposition across single-point models (Activity 2 of AQMEII4) 9915

Table 1. Variables related to forcing datasets for single-point models.

Variables in forcing data	Other common model variables
B – parameter related to soil moisture [unitless]	D_{O_3} – diffusivity of ozone in air [$m^2\,s^{-1}$]
[CO_2] – ambient carbon dioxide mixing ratio [ppmv]	D_w – diffusivity of water vapor in air [$m^2\,s^{-1}$]
d – displacement height [m]	D_{CO_2} – diffusivity of carbon dioxide in air [$m^2\,s^{-1}$]
f_{wet} – fraction of the canopy that is wet [fractional]	e_{sat} – saturation vapor pressure [Pa]
G – incoming shortwave radiation [$W\,m^{-2}$]	f_0 – reactivity factor for ozone [unitless]
h – canopy height [m]	H – Henry's law constant [$M\,atm^{-1}$]
LAI – leaf area index [$m^2\,m^{-2}$]	κ – thermal diffusivity of air [$m^2\,s^{-1}$]
[O_3] – ambient ozone mixing ratio [ppbv]	L – Obukhov length [m]
P – precipitation rate [$mm\,h^{-1}$]	M_{air} – molar mass of air [$g\,mol^{-1}$]
p_a – air pressure [Pa]	Pr – Prandtl number [unitless]
PAR – photosynthetically active radiation [$\mu mol\,m^{-2}\,s^{-1}$]	ρ – air density [$kg\,m^{-3}$]
RH – relative humidity [fractional]	Sc – Schmidt number [unitless]
SD – snow depth [cm]	v_d – ozone deposition velocity [$m\,s^{-1}$]
SH – sensible heat flux [$W\,m^{-2}$]	VPD – vapor pressure deficit [kPa]
T_a – air temperature [°C]	ψ_{leaf} – leaf water potential [MPa]
T_g – ground temperature near the surface [°C]	ψ_{soil} – soil matric potential [kPa]
u – wind speed [$m\,s^{-1}$]	
$u*$ – friction velocity [$m\,s^{-1}$]	
w_g – volumetric soil water content near the surface [$m^3\,m^{-3}$]	
w_2 – volumetric soil water content at the root zone [$m^3\,m^{-3}$]	
w_{fc} – volumetric soil water content at field capacity [$m^3\,m^{-3}$]	
w_{sat} – volumetric soil water content at saturation [$m^3\,m^{-3}$]	
w_{wlt} – volumetric soil water content at wilting point [$m^3\,m^{-3}$]	
z_0 – roughness length [m]	
z_r – reference height [m]	
θ – solar zenith angle [°]	

2. The protocol. Output data

Constant values:

- Dynamic and kinematic viscosities
- Mean free path of air molecules
- Aerodynamic resistance
- Stability function

Depending on the particle diameter Dp:

- aerosol dry deposition velocity Vd
- Aerosol gravitational settling velocity (sedimentation), Vg
- Surface/quasi-laminar boundary layer resistance
- Efficiencies: Brownian, impaction, interception
- Brownian diffusivity
- Stokes, Schmidt and Knudsen numbers

S. Galmarini et al.: Technical note: AQMEII4 Activity 1

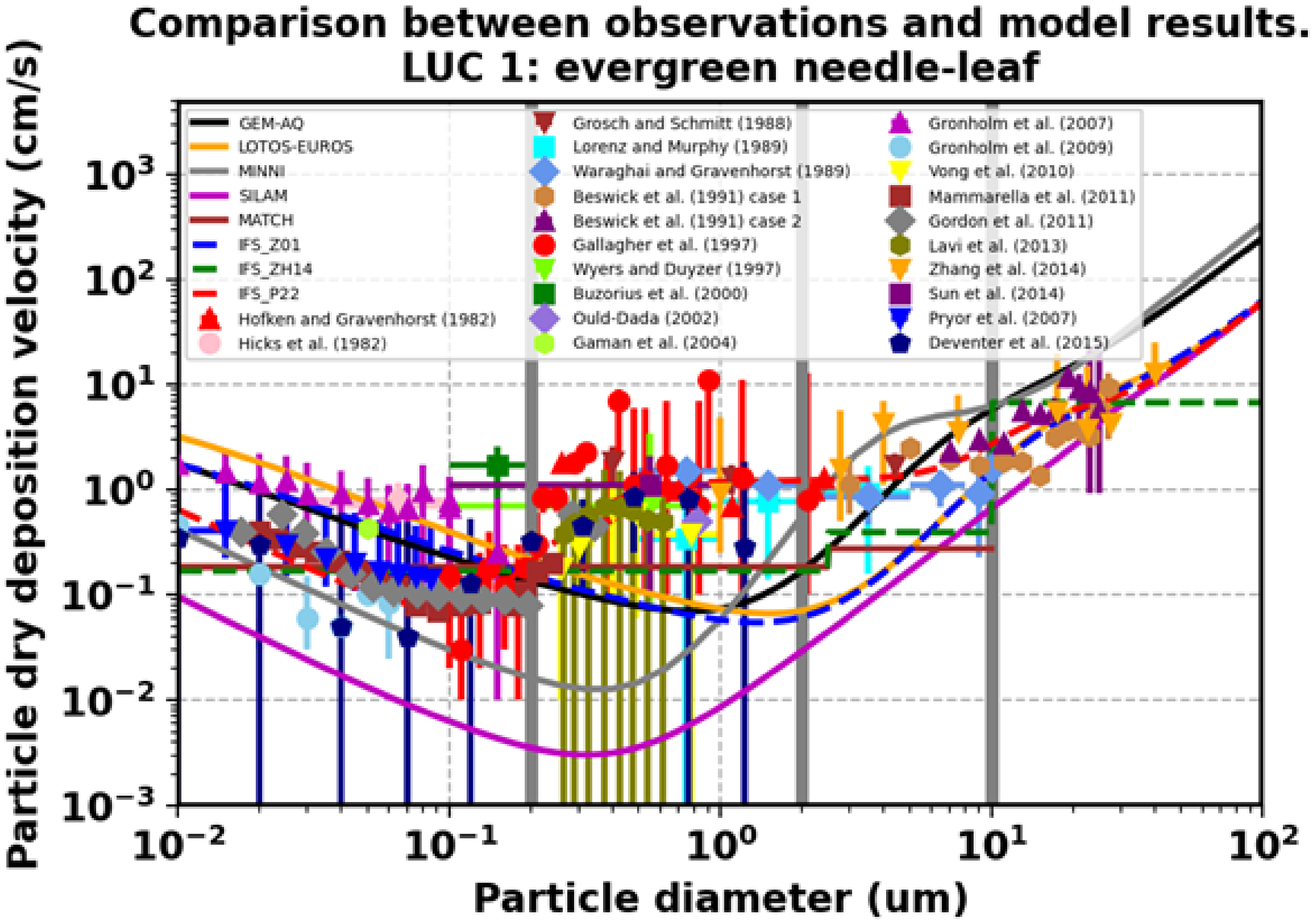
Table 4. AQMEII4 reported dry deposition diagnostic variables for gas-phase species.

Name	AQMEII4 name	Formula
V_d	VD	Deposition velocity
r_a	RES-AERO	Aerodynamic resistance
r_c	RES-SURF	Bulk surface resistance
r_s	RES-STOM	Stomatal resistance
r_m	RES-MESO	Mesophyll resistance
r_{cut}	RES-CUT	Cuticle resistance
E_{STOM}	ECOND-ST	Effective conductance associated with deposition to plant stomata
E_{CUT}	ECOND-CUT	Effective conductance associated with deposition to leaf cuticles
E_{SOIL}	ECOND-SOIL	Effective conductance associated with deposition to soil and un-vegetated surfaces
E_{LCAN}	ECOND-LCAN	Effective conductance associated with deposition to the lower canopy
$r_{b,\,stom}$	RES-QLST	Quasi-laminar sublayer resistance associated with stomatal pathway*
$r_{b,\,cut}$	RES-QLCT	Quasi-laminar sublayer resistance associated with cuticular pathway*
$r_{b,\,soil}$	RES-QLSL	Quasi-laminar sublayer resistance associated with soil pathway*
$r_{b,\,lcan}$	RES-QLLC	Quasi-laminar sublayer resistance associated with lower canopy pathway*
r_{dc}	RES-CONV	Resistance associated with within-canopy buoyant convection
	Post-processing fields: effective conductances times net flux divided by deposition velocity	
DFLX-LCAN		Fraction of flux via lower canopy pathway
DFLX-ST		Fraction of flux via stomatal pathway
DFLX-CUT		Fraction of flux via cuticle pathway
DFLX-SOIL		Fraction of flux via soil pathway

* Equal to r_b if this is pathway-independent for the resistance framework.

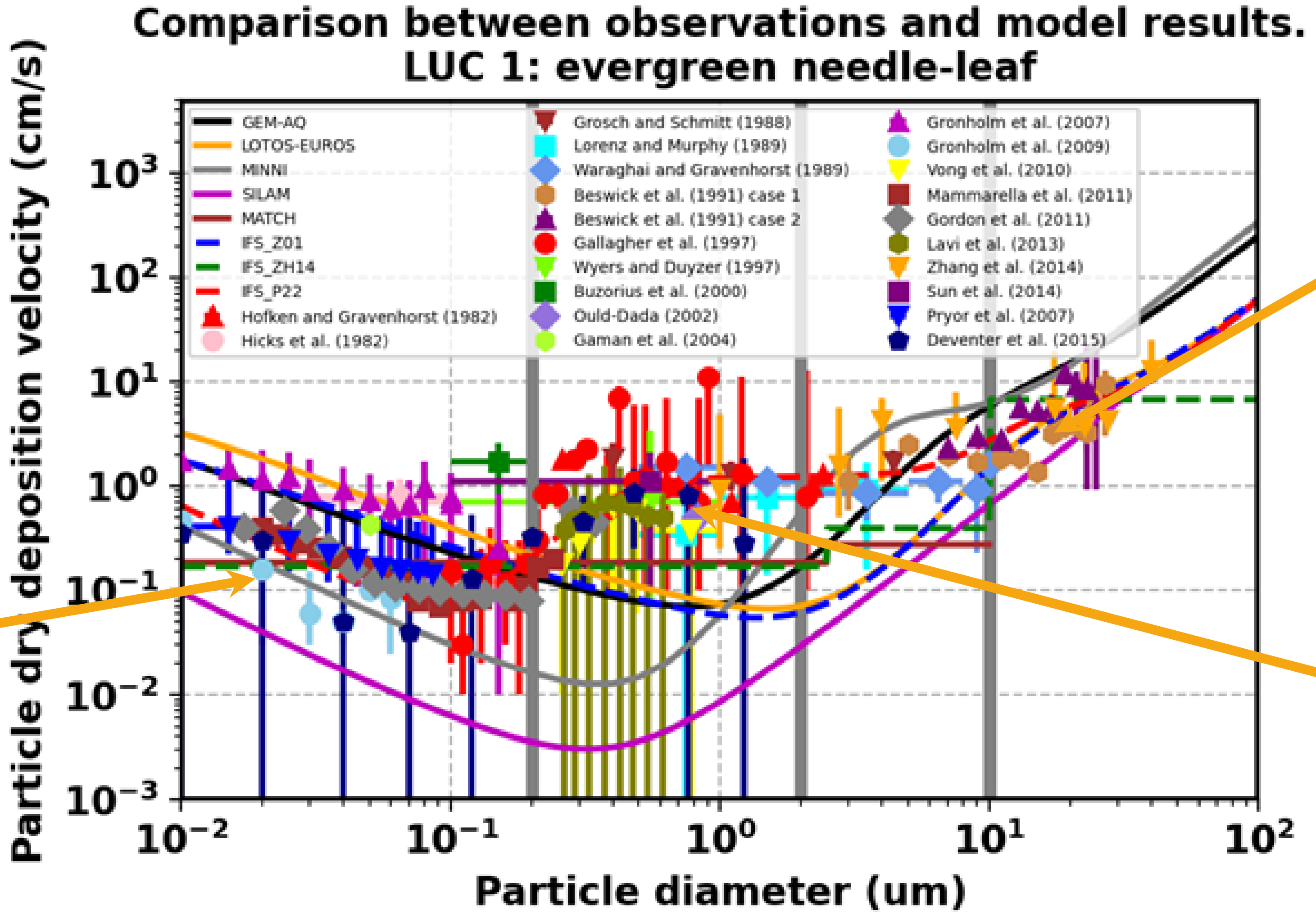
3. The results. Comparison to observation, evergreen needleleaf forest

Observation compiled by P22



3. The results. Comparison to observation, evergreen needleleaf forest

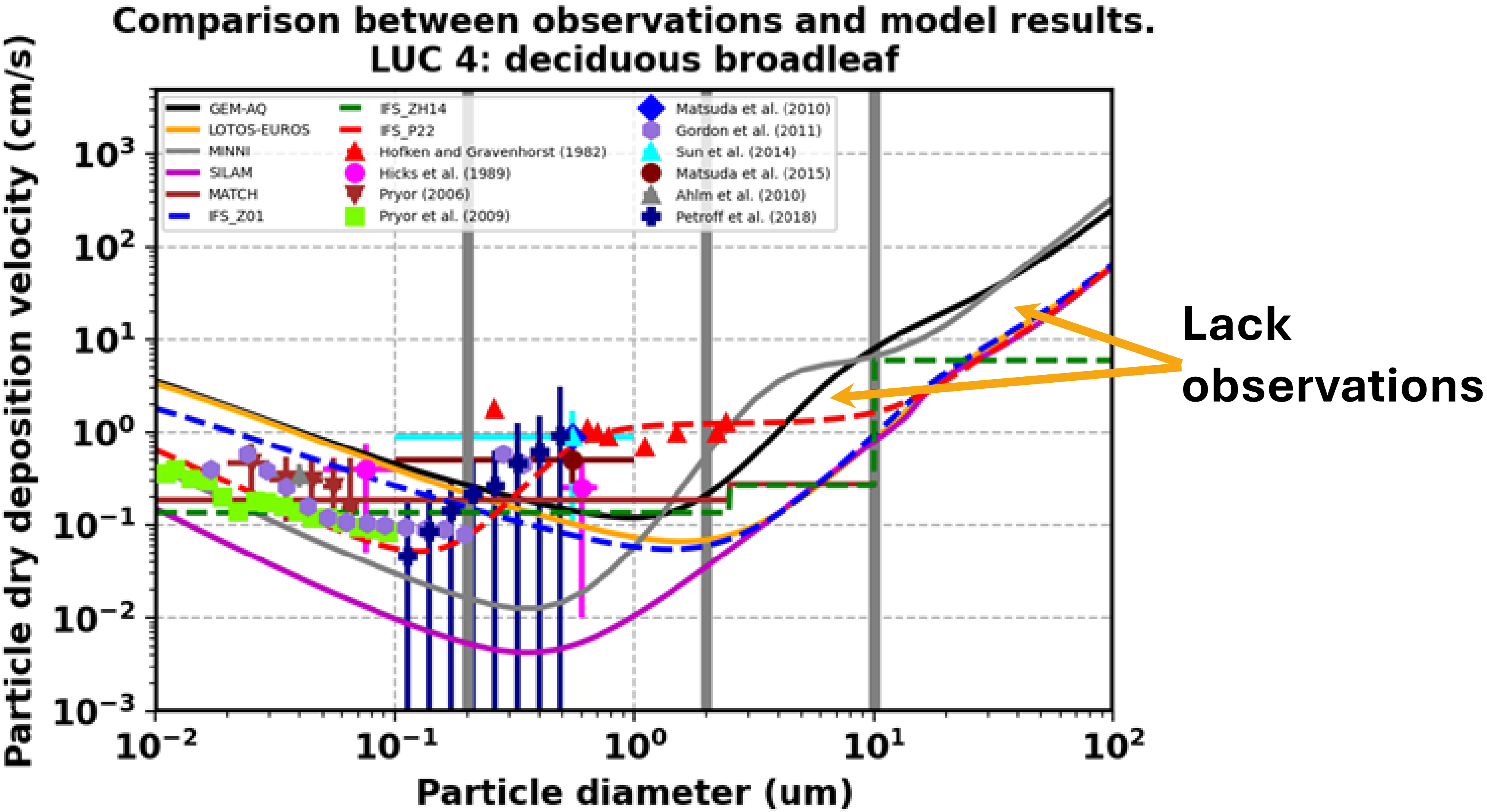
Large variability of BOTH obs and simulations (Brownian efficiency)



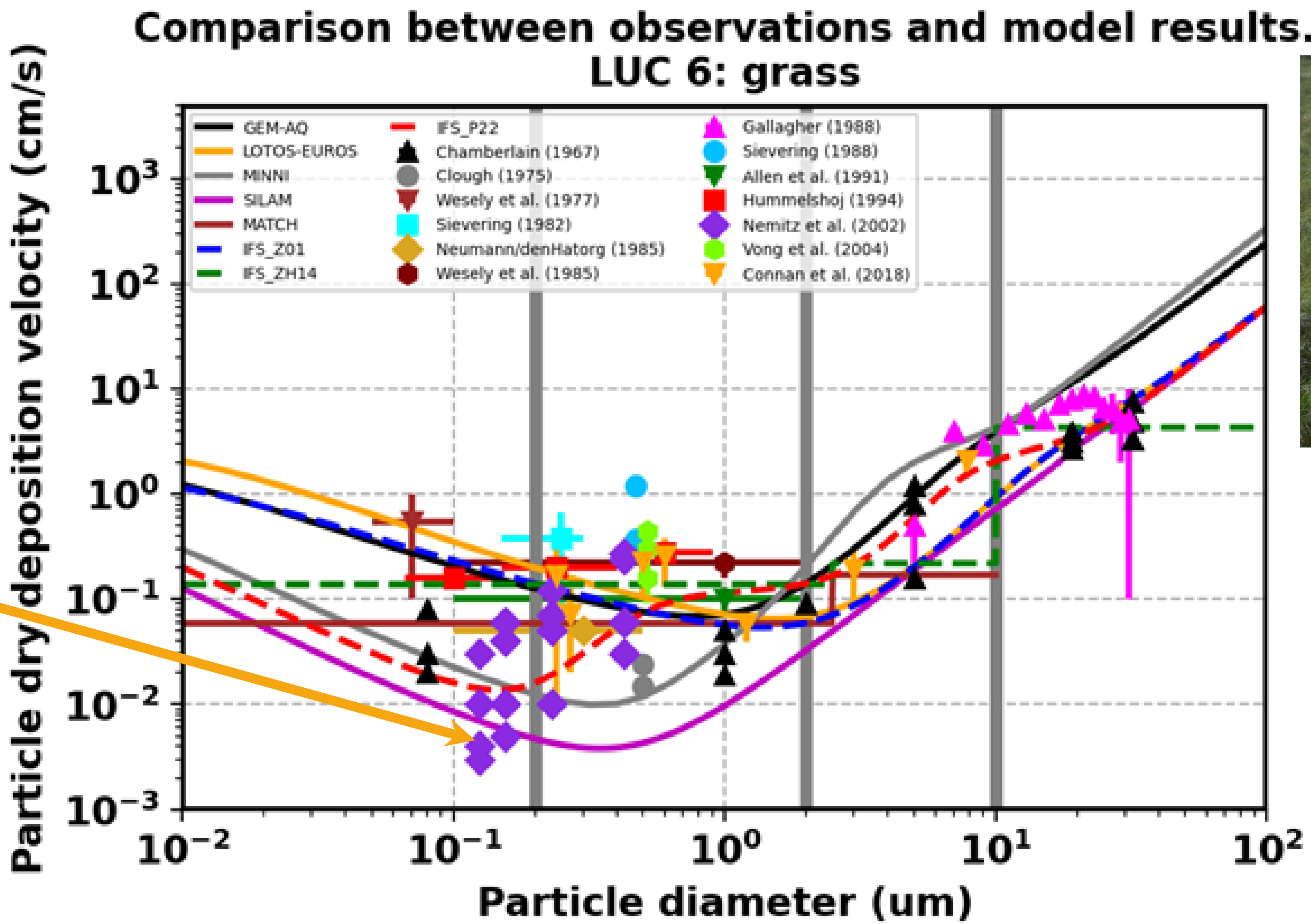
General agreement

Underestimation of obs by most models, except P22

3. The results. Comparison to observation, deciduous broadleaf forest

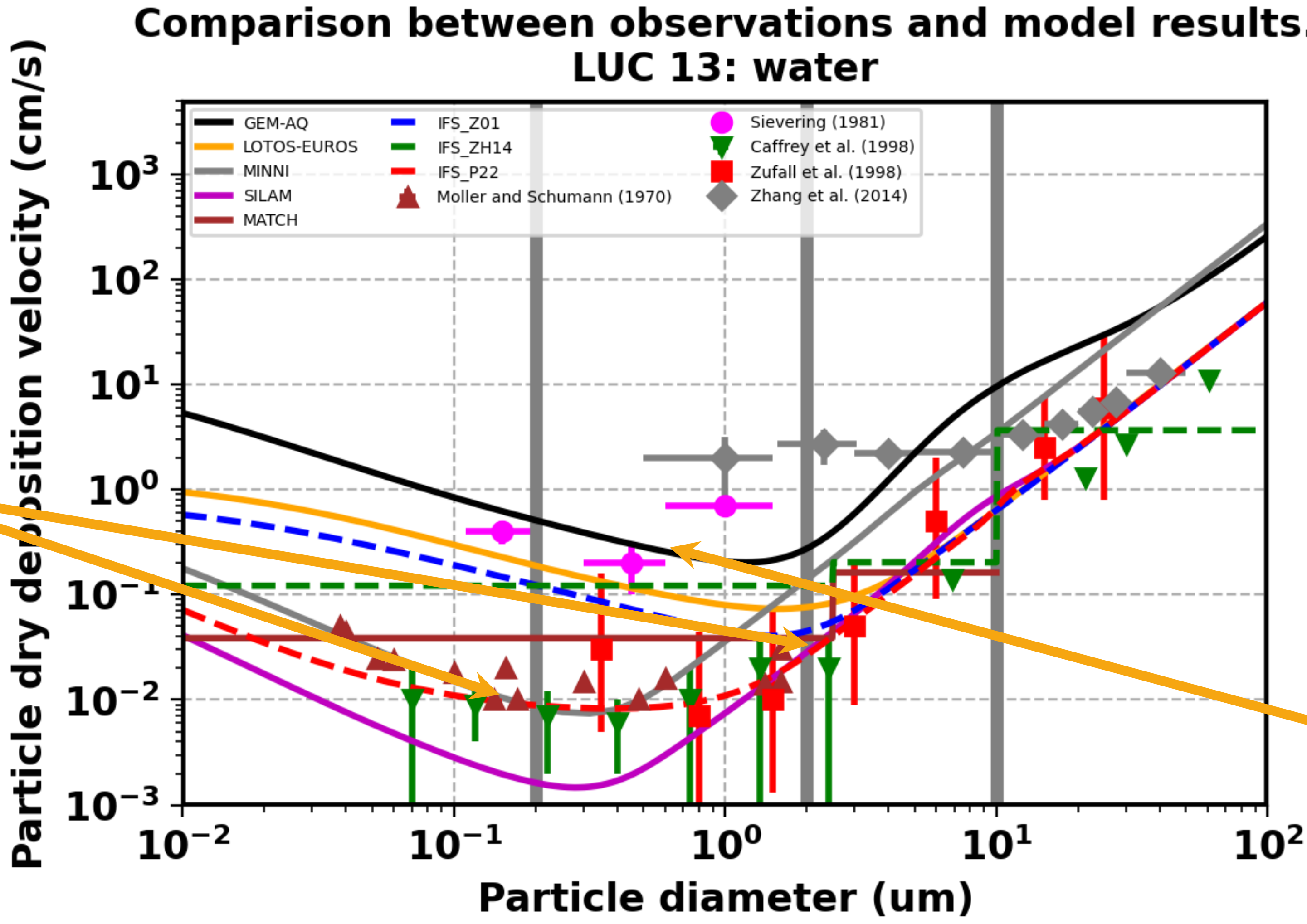


3. The results. Comparison to observation, grass



Large variability of the observations, and beyond model variability

3. The results. Comparison to observation, water

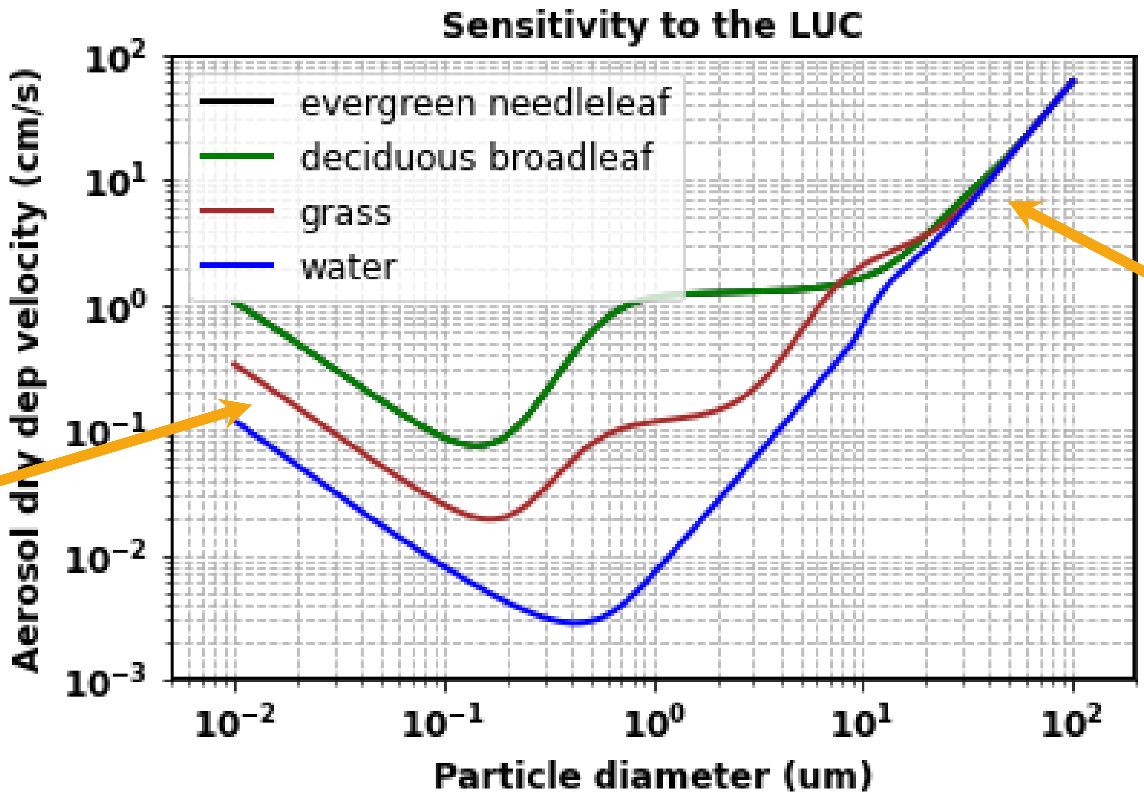


Nice agreement

Large variability of obs more or less reproduced by modelling

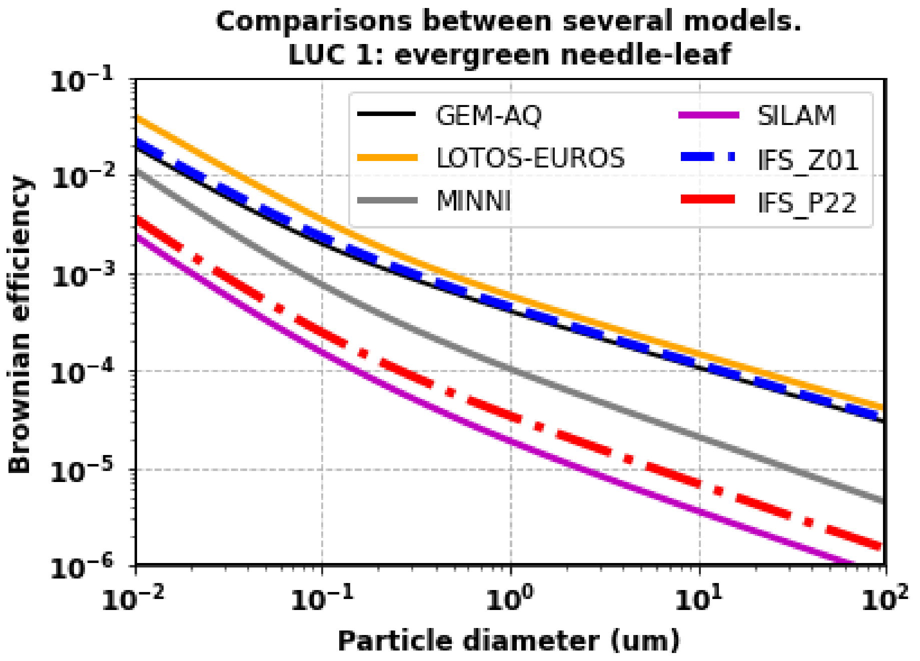
4. Sensitivity to the LUC

The Brownian diffusion depends on the land use category (and on the friction velocity)
As well for impaction and interception



But not the sedimentation

4. Sensitivity. Brownian efficiency



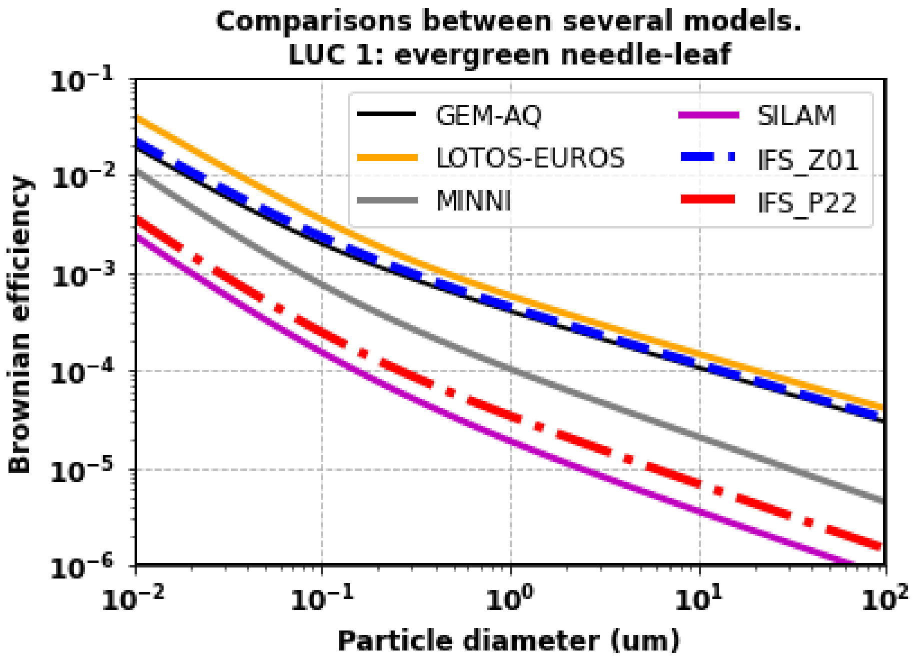
$$E_B = \frac{Cv}{Cd} Sc^{-\gamma}$$

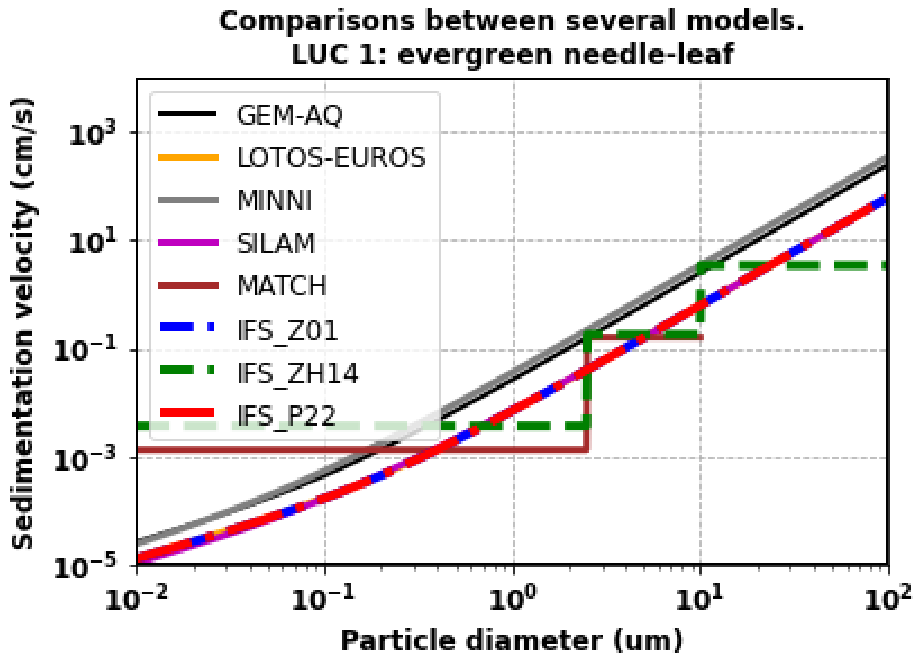
From 0.5 to 2/3

From 1/3 to 1

Small variability in the mean free path

4. Sensitivity. More in the D5.3 deliverable





$$E_B = \frac{Cv}{Cd} Sc^{-\gamma}$$

From 0.5 to 2/3

From 1/3 to 1

Small variability in the mean free path

$$V_g = \frac{g\, \rho_p\, D_p^2}{18\, \mu} C_c$$

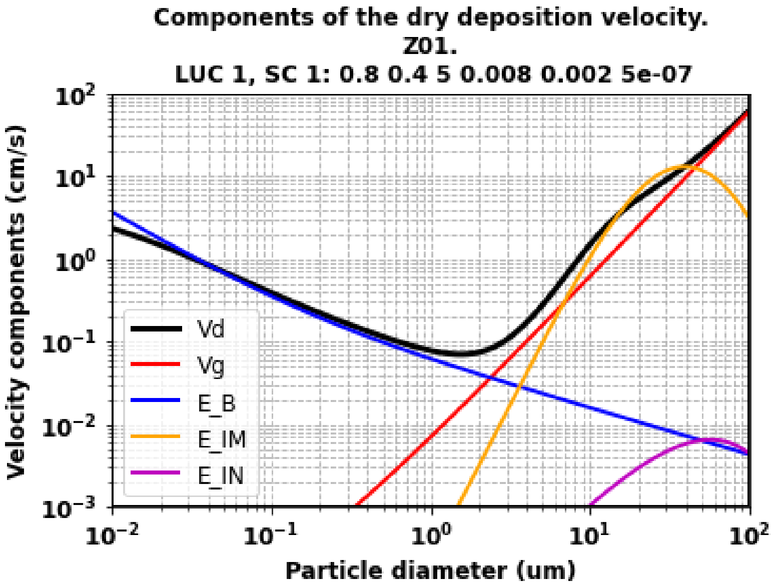
5. Links to other projects: CAMS2_35bis (2025-

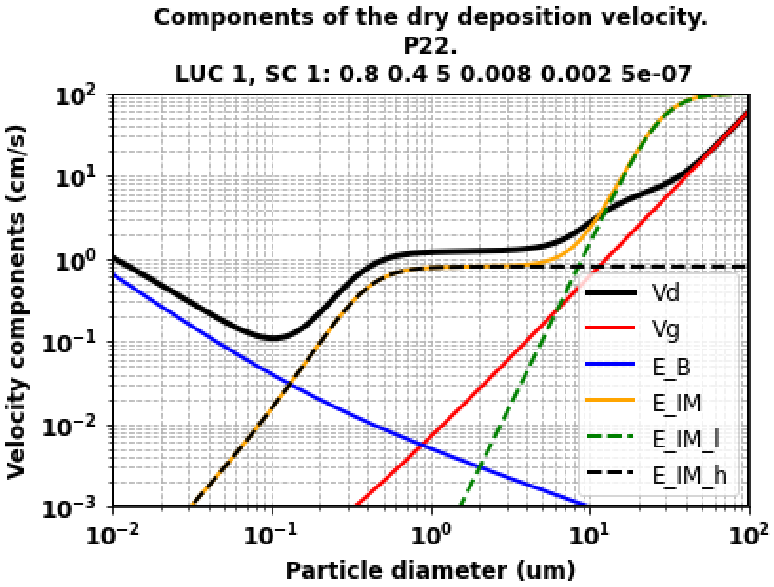
Improvement of IFS-COMPO used in CAMS: testing Pleim et al. [2022] in replacement of ZH14

Improvement in spatial and temporal fields of PM2.5 ? AOD ? Etc

“Saylor et al. (13) […] found that fine particle concentrations varied from 5 to 15% depending on the deposition algorithm, with total deposition varying by over 200%.” [Farmer *et al.*, 2021]

“Emerson et al. (14) revised the Zhang et al. parameterization […] and noted that global surface accumulation mode number concentrations increased by 62%” [Farmer *et al.*, 2021]





5. Links to other projects: CAMEO/WP4

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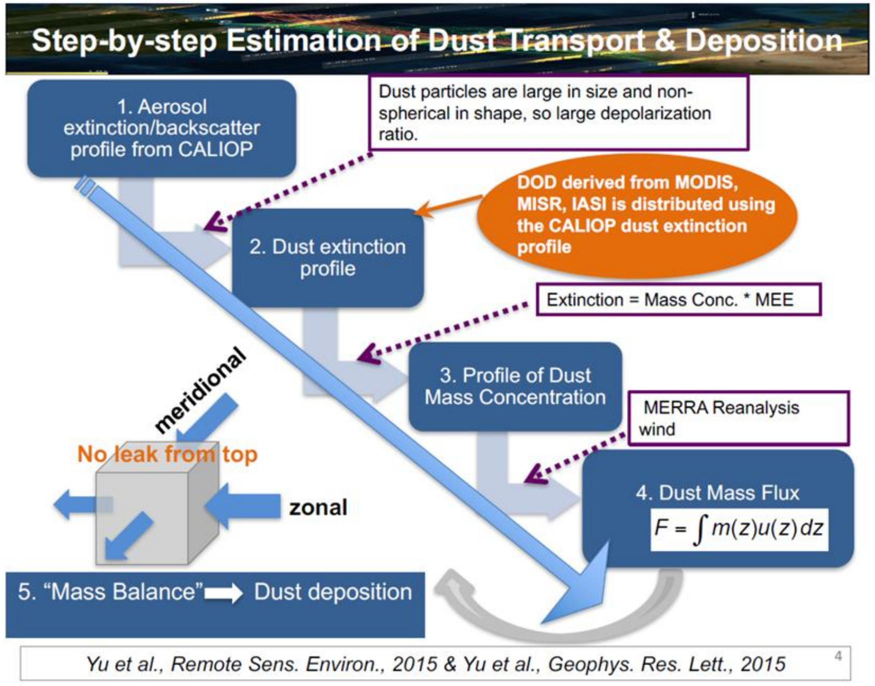
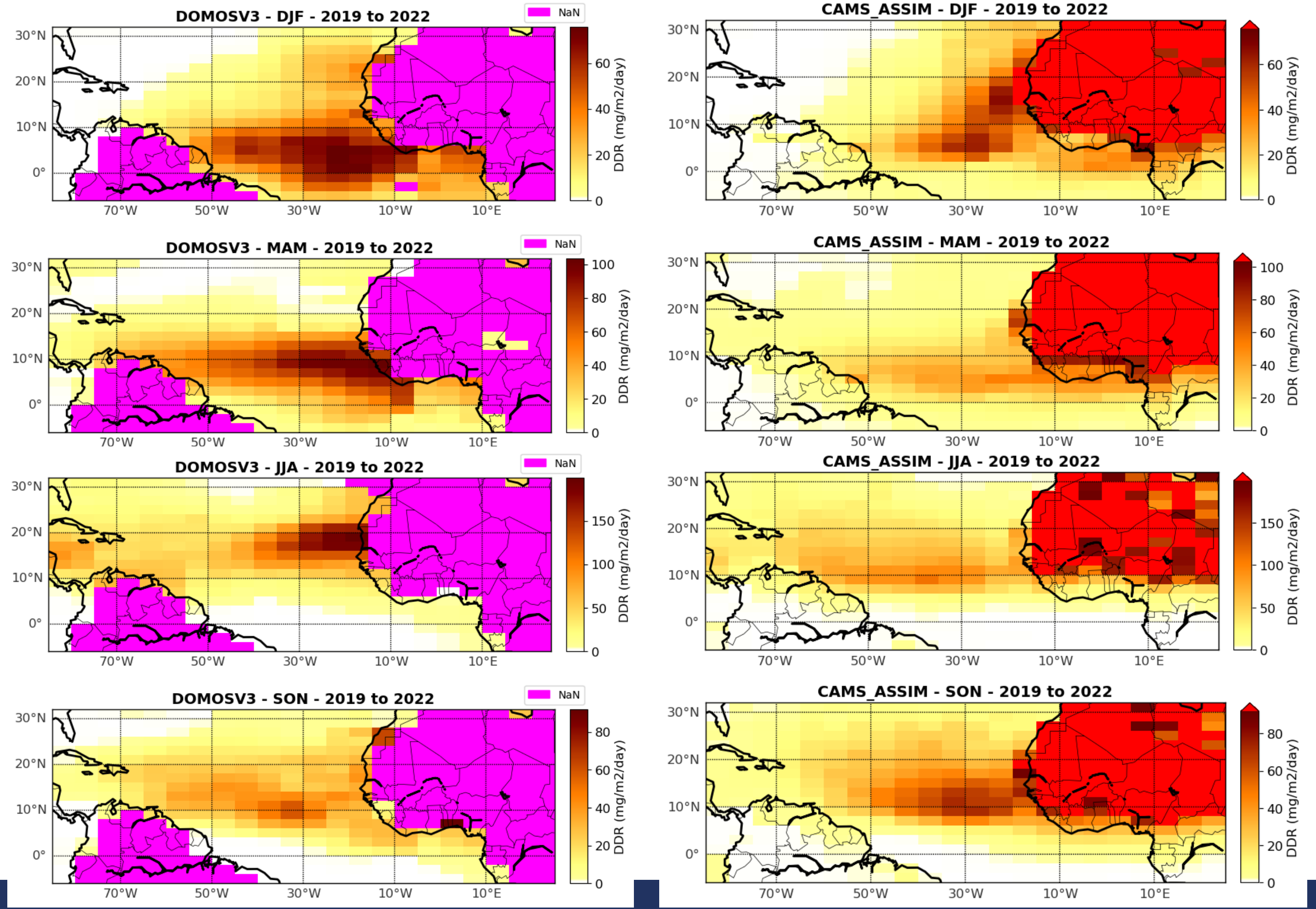
Mass balance methodology



Comparison between DOMOS and CAMS_NRT dust (total) deposition flux over ocean



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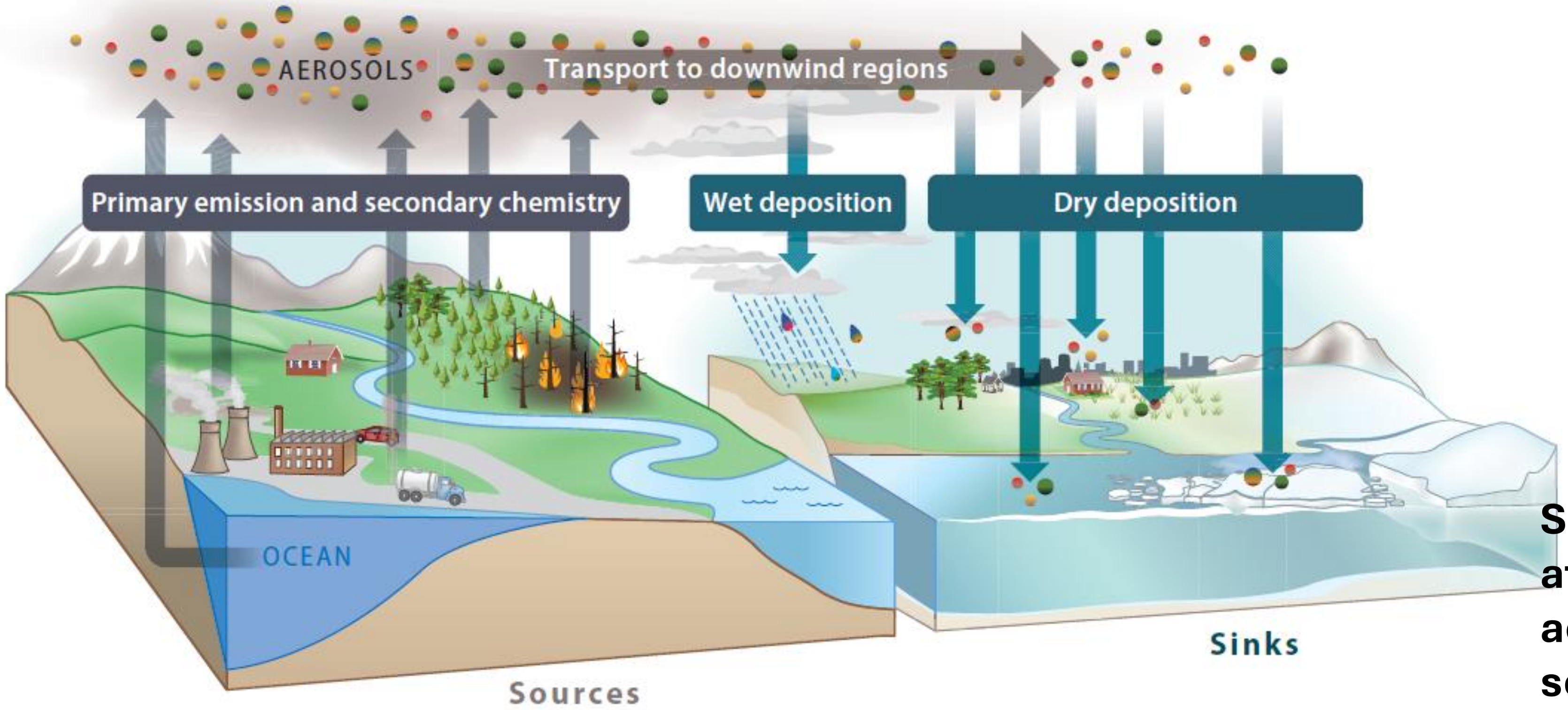

Figure 1

Primary emissions and secondary chemistry are key sources of aerosols in the atmosphere. Wet and dry deposition remove particles, determining the lifetime of these aerosols in the atmosphere. Deposition surfaces include forests, grasslands, ice, water, and urban environments, with each surface type removing particles at different size- and turbulence-dependent rates.

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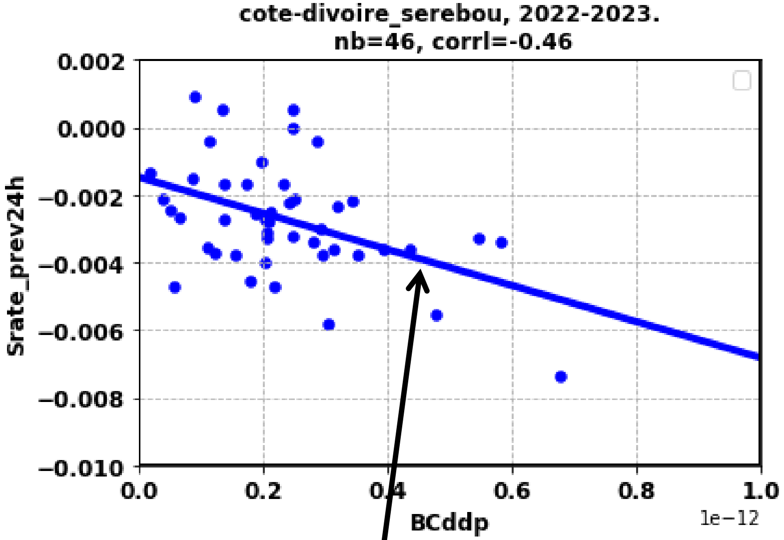
Sink of atmospheric aerosols BUT source for Earth's surfaces (acids, ions, metals, ...) -> Milestone

5. Links to other projects: CAMEO/WP4

Application: solar energy

Soiling of solar panels by deposited aerosols

In-situ measurements of the soiling rate (day^{-1}) in Côte d'Ivoire



Correlation with CAMS parameters ?
(here dry deposition from CAMS)

Preliminary study on 1 site and 1 year.
Requires to be extended over ~30 sites.

6. Conclusions

Importance of dry deposition modelling for climate and air quality

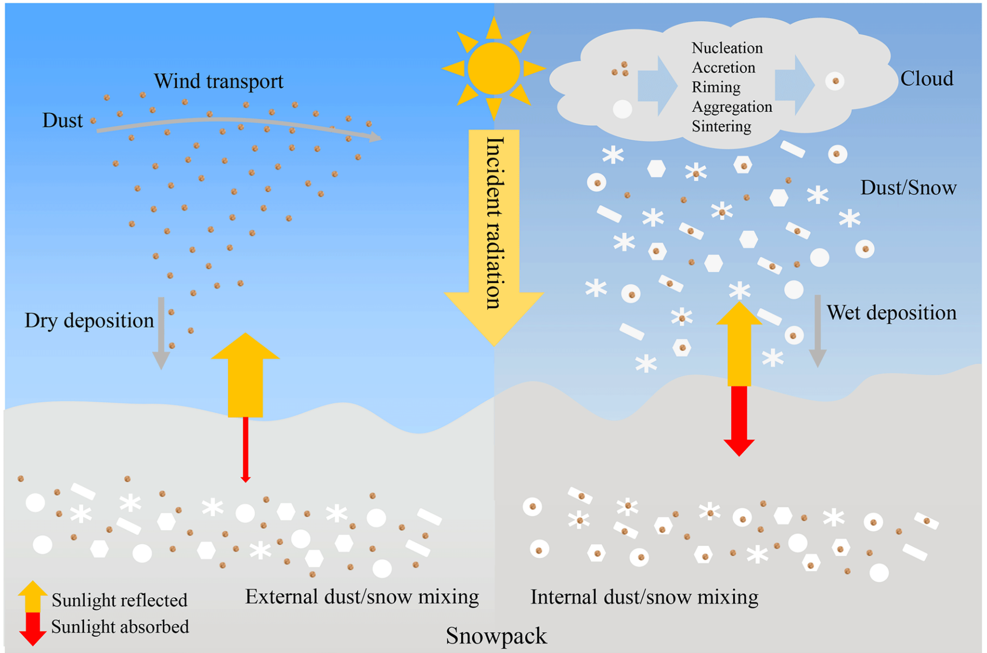
Variability in model results and observations

Requires more observation

What is exactly measured ?

-> Recommendation by Farmer et al. [2021]: validation by observation of deposition of BC

+ independent measurement of snow albedo - > validation of BC deposition ?

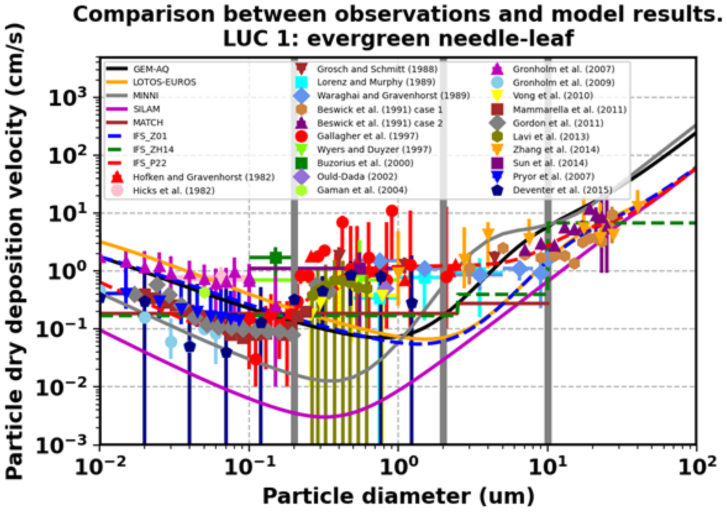


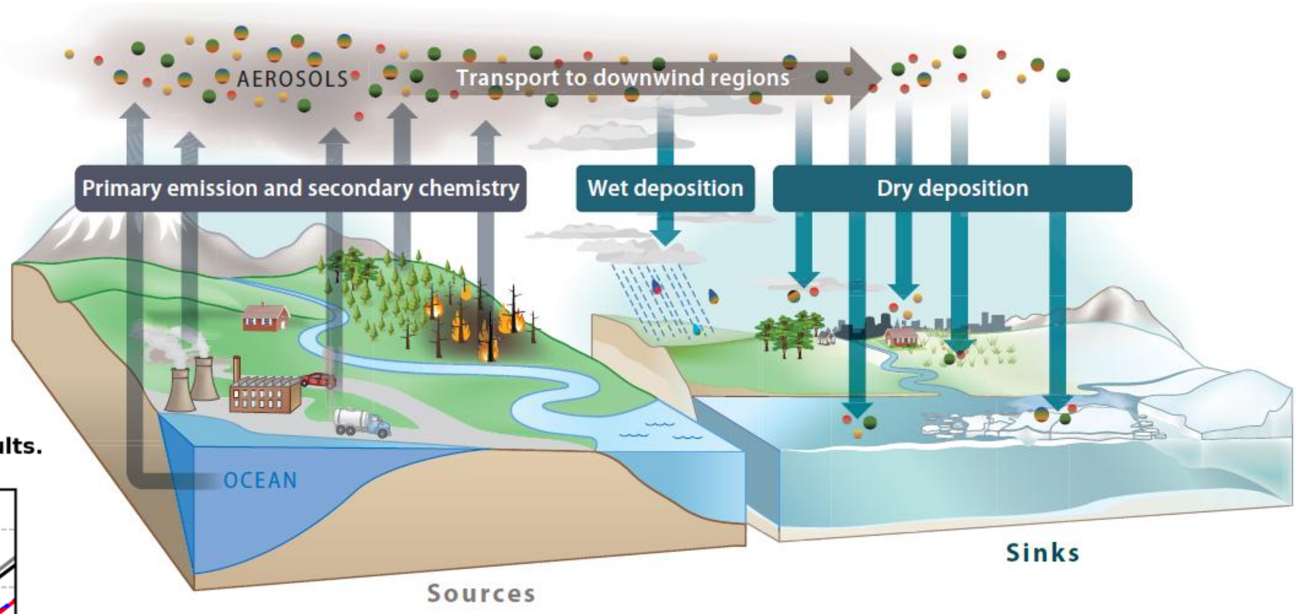
Shi, T., Cui, J., et al., Atmos. Chem. Phys., 21, 6035–6051, https://doi.org/10.5194/acp-21-6035-2021, 2021.

6. Conclusions

Thanks

Contact: te@hygeos.com





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