First global overview on the representation of water uptake by ten Global Climate Models using a new in-situ benchmark hygroscopicity dataset

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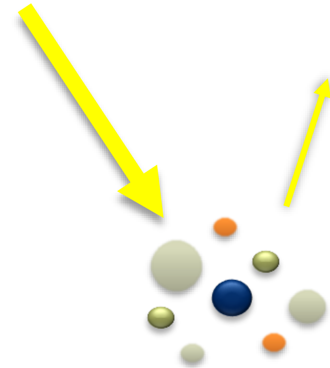
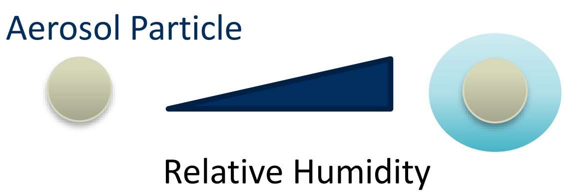
Aerosols and Climate



- **Aerosols have direct and indirect effects on the Earth's energy balance**
  - Scatter (σ_{sp}) and absorb solar radiation
  - Infleunce the number of cloud condensation nuclei



HYGROSCOPICITY:

Since aerosol particles can take up water, they can change in size and chemical composition depending on the ambient relative humidity (RH)

$\boldsymbol{\sigma_{sp}(RH, \lambda)}$**, strongly depends on RH**

The effect of water uptake is **relevant** for **climate forcing calculations** as well as for the comparison or validation of **remote sensing** with in-situ measurements and for the improvement of **Earth System Models**

SCATTERING ENHANCEMENT FACTOR

$$f(RH, \lambda) = \frac{\sigma_{sp}(RH, \lambda)}{\sigma_{sp}(RHdry, \lambda)}$$

How well do Global Climate Models represent aerosol optical hygroscopic growth?

This presentation summarizes our work, which is currently under review in ACP:

Submitted as: research article

20 Jan 2020

A global model-measurement evaluation of particle light scattering coefficients at elevated relative humidity

Review status

This preprint is currently under review for the journal ACP.

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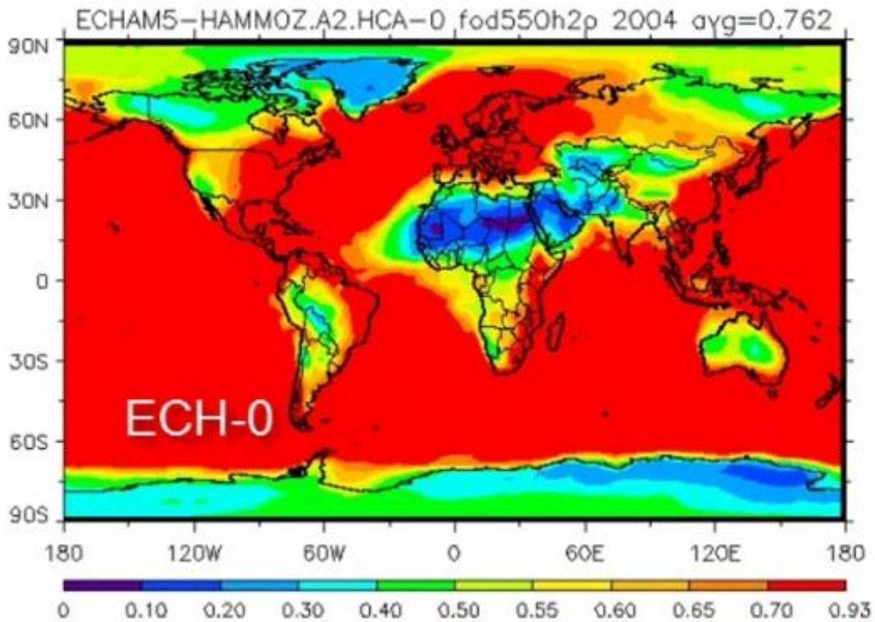
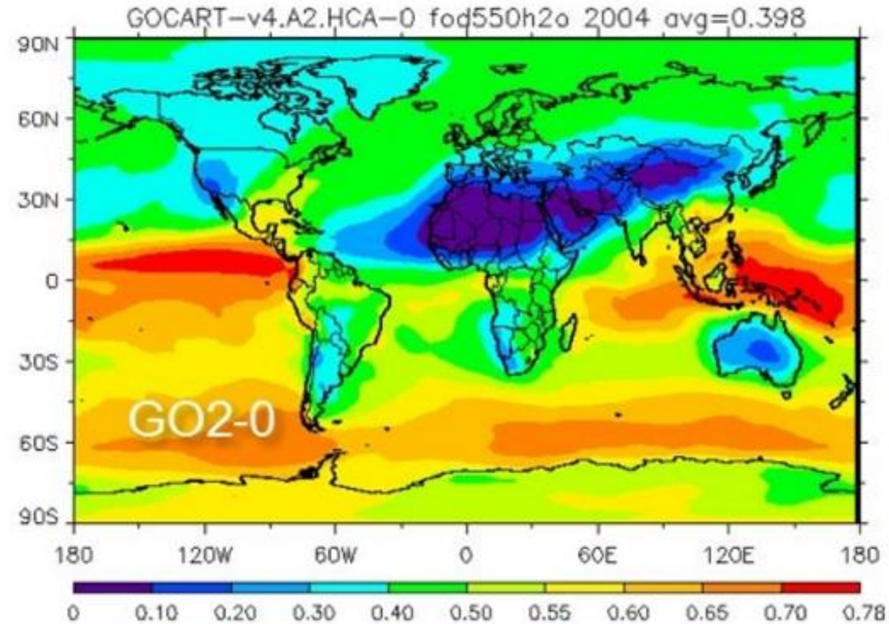
Hygroscopicity in Earth System Models:

Interestingly, most models are doing well in reproducing the total aerosol optical depth (AOD), but a closer look into the individual components reveals discrepancies between them, e.g. the fraction of aerosol optical depth due to water:



ECHAM5: global annual average **76%**



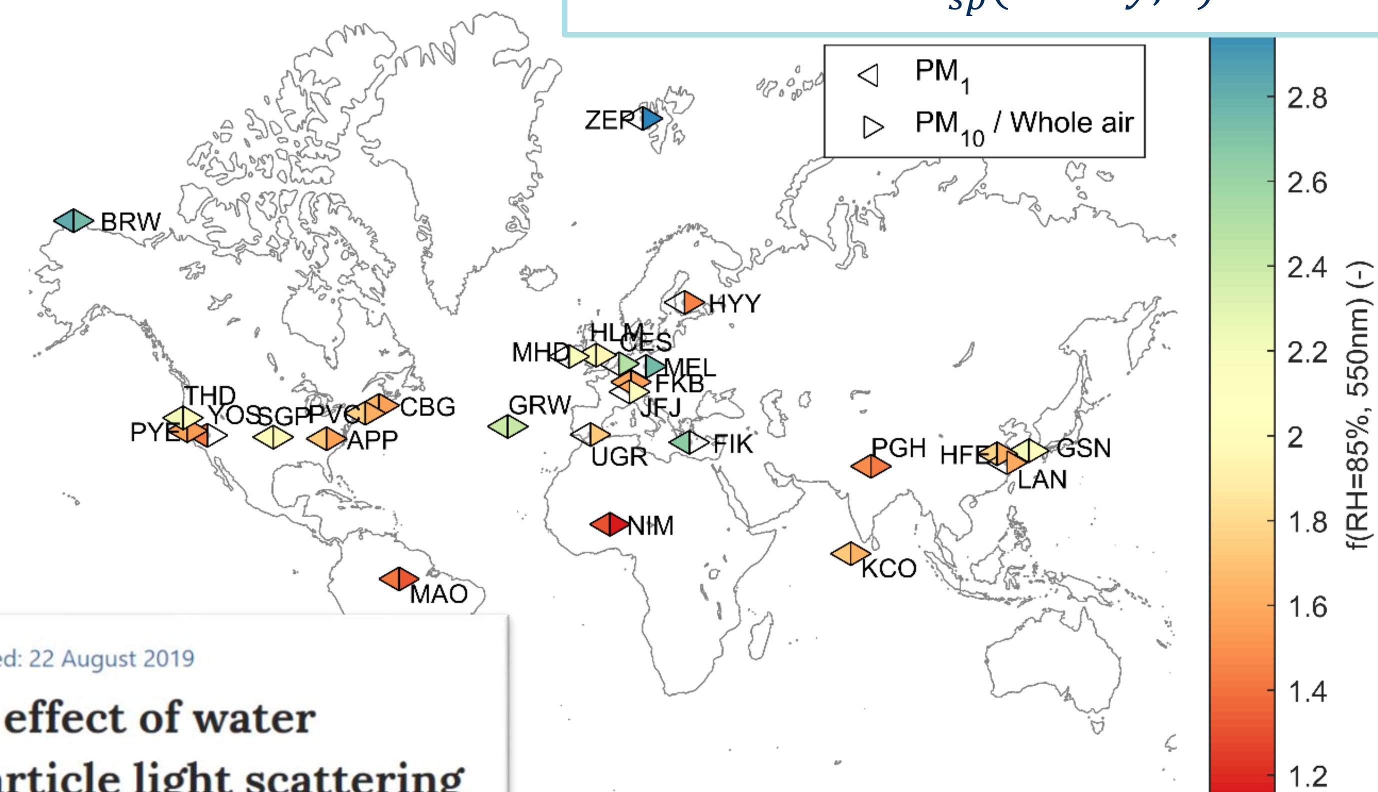
GOCART: global annual average **40%**

Figures from Mian Chin (NASA Goddard)

[Burgos et al., 2019:](#)
f(RH) measurements from in-situ sites around the globe used to create a benchmark dataset

SCATTERING ENHANCEMENT FACTOR

$$f(RH,\lambda) = \frac{\sigma_{sp}(RH,\lambda)}{\sigma_{sp}(RHdry,\lambda)}$$



Data Descriptor | Open Access | Published: 22 August 2019

A global view on the effect of water uptake on aerosol particle light scattering

María A. Burgos, Elisabeth Andrews, Gloria Titos, Lucas Alados-Arboledas, Urs Baltensperger, Derek Day, Anne Jefferson, Nikos Kalivitis, Nikos Mihalopoulos, James Sherman, Junying Sun, Ernest Weingartner & Paul Zieger

Scientific Data **6**, Article number: 157 (2019) | Cite this article

Arctic > Marine > Rural > Desert

MODEL DATA

INSITU project - AeroCom Phase III

- 10 Models used in this study:
  - Three CAM-family models: CAM-ATRAS, CAM5, CAM-Oslo
  - Three GEOS-family models: GEOS-Chem, GEOS-GOCART, MERRAero
  - Four further models: OsloCTM3, TM5, IFS-AER, SALSA
- We work with the following output:
  - Aerosol optical data, **absorption and extinction** at **RH=0, 40 and 85%**
  - Mass mixing ratio for five components: **black carbon, desert dust, organic aerosols, sulfates, and sea salt**
- The frequency is hourly or daily values for the **year 2010.** An important aspect is that time coverage is not always coincident with measurements
- The extracted model data is for the closest grid point to 22 observational sites
- We have used simulated surface data (regardless of site elevation)

MODEL DATA

INSITU project - AeroCom Phase III

The following table summarizes some of the most important characteristics of each model in relation to out work:

- Chemical composition: all models consider five basic components (black carbon, sulfate, organic matter, sea salt and dust), and some of them incorporate nitrates and ammonia
- The mixing state can be either external or internal
- Hygroscopic growth parameterizations can be made with κ-Köhler Theory, GADS (Global Aerosol Dataset, D'Almeida et al., 1991), or other parameterizations
    - Some species are assumed to not experience hygroscopic growth, g(RH)=1

MODEL	Chemical composition	Mixing State	Hygroscopicity [g(RH=90%)]					
			parameterization	ss	so4	bc	oa	dd
ATRAS	bc,so4,oa,ss,dd + no3/nh4	I	κ-Köhler Theory	2.3	1.9	1.0	1.2	1.0
CAM	bc,so4,oa,ss,dd	I	κ-Köhler Theory	2.3	1.8	1.0	1.2	1.2
CAM-Oslo	bc,so4,oa,ss,dd	I,E	κ-Köhler Theory	2.27	1.8	1.0	1.3	1.2
GEOS-Chem	bc,so4,oa,ss,dd + no3/nh4	E	GADS	2.4	1.6	1.4	1.6	1.0
GEOS-GOCART	bc,so4,oa,ss,dd	E	GADS	2.4	1.8	1.4	1.6	1.0
MERRAero	bc,so4,oa,ss,dd	E	GADS	2.0	1.8	1.4	1.6	1.0
OsloCMT3	bc,so4,oa,ss,dd + no3	I	Fitzgerald, 1975	-	-	-	-	-
TM5	bc,so4,oa,ss,dd + no3/nh4	I, E	Vignati, 2004	-	-	1.0	1.0	1.0
IFS-AER	bc,so4,oa,ss,dd + no3/nh4	E	Bozzo, 2019	2.36	1.73	1.0	1.6	1.0
SALSA	bc,so4,oa,ss,dd	E	ZSR equation	2.4	1.9	1.0	1.5	1.0

I. Comparison of modelled vs. measured *f*(RH) (+ organic mass fraction)

II. Annual cycle for BRW, GRW and SGP sites

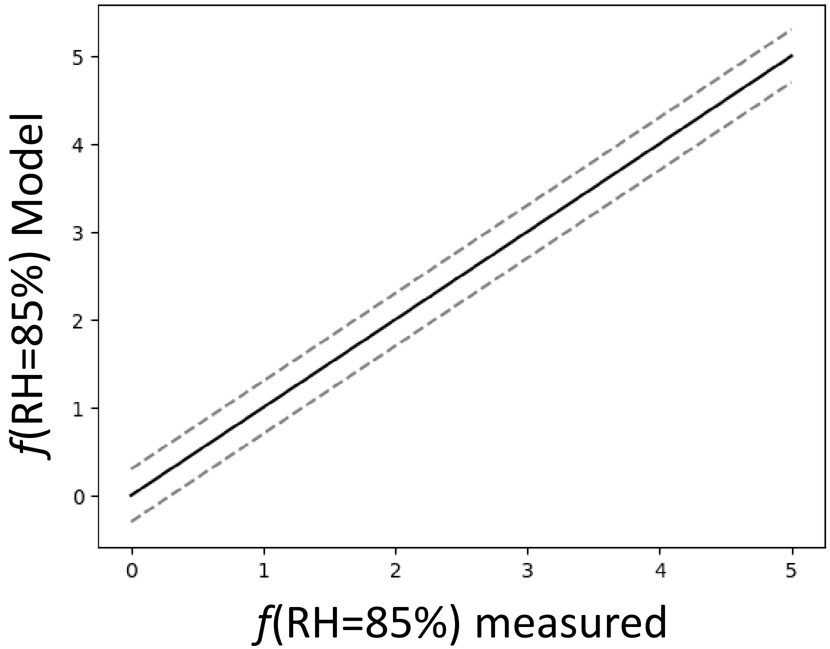
III. Analysis of the implications of the different definitions of RH_{ref}

In this presentation we focus on the results of the comparison of modelled vs measured *f*(RH) and the organic mass fraction (I).

To see the rest of the results (II and III), please take a look at our paper at [ACPD]

The following results (slide number 12) show the median values of the modelled (y-axes) and measured (x-axes) *f*(RH), each point stands for one site, and these are color-coded by site type.

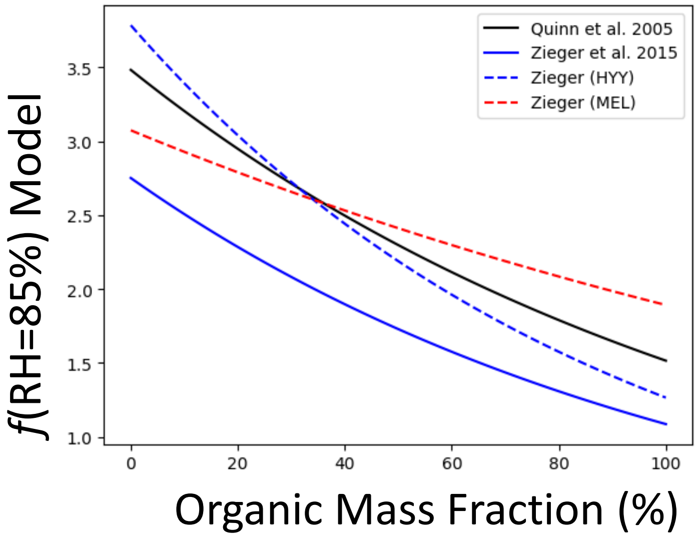
The solid black line represents the 1:1 relationship and the dotted lines the 30% error interval



$$f(RH, \lambda = 550nm) = \frac{\sigma_{sp}(RH = 85\%)}{\sigma_{sp}(RH = 40\%)}^{*}$$

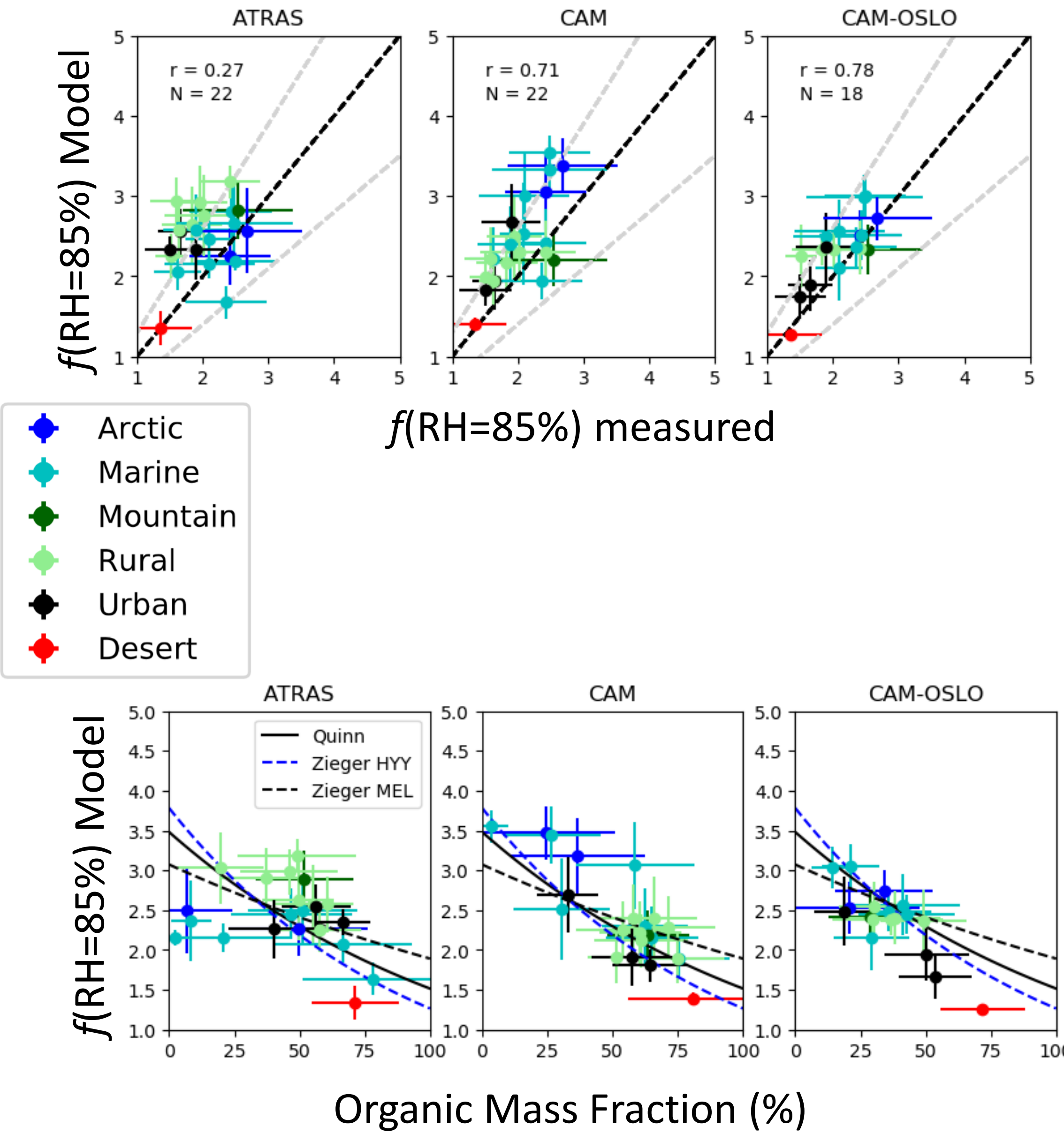
*Chose RH=85% to minimize potential issues with hysteresis

Further we will also show the median modelled value of f(RH) vs the modelled organic-sulfate mass fraction to compare with previously published experimental parameterizations



$$OMF = \frac{organics}{(organics + sulfate)}$$

- Quinn et al. 2005: parameterization based on measurements at CBG, GSN, KCO
- Zieger et al. 2015: same approach for MEL and HYY sites.
- Zieger et al. 2015: Solid line including nitrate, black carbon, ammonia, and Cl



CAM-family models

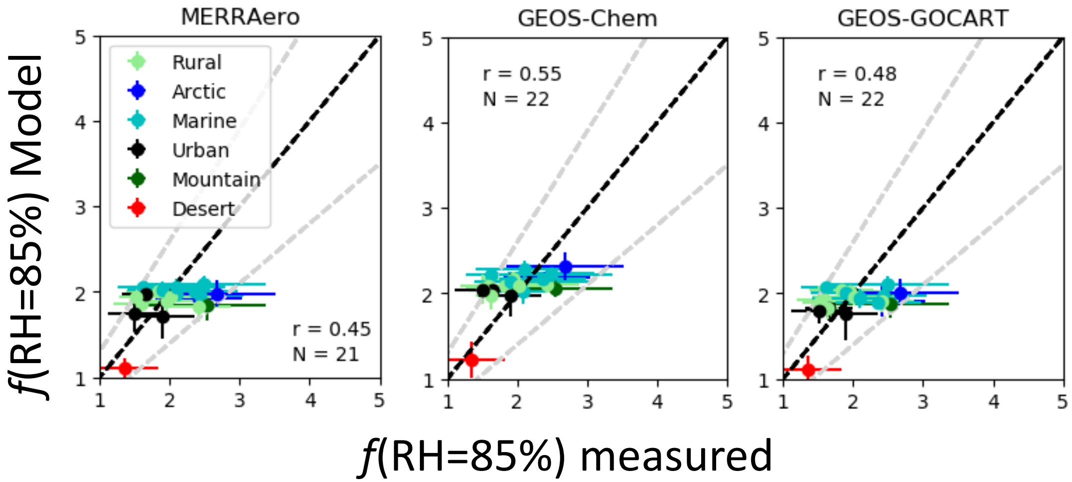
f(RH=85%) model vs measured:

- Models reproduce the range in measured *f*(RH)
- Good correlation coefficients for CAM and CAM-Oslo

f(RH=85%) model vs OMF:

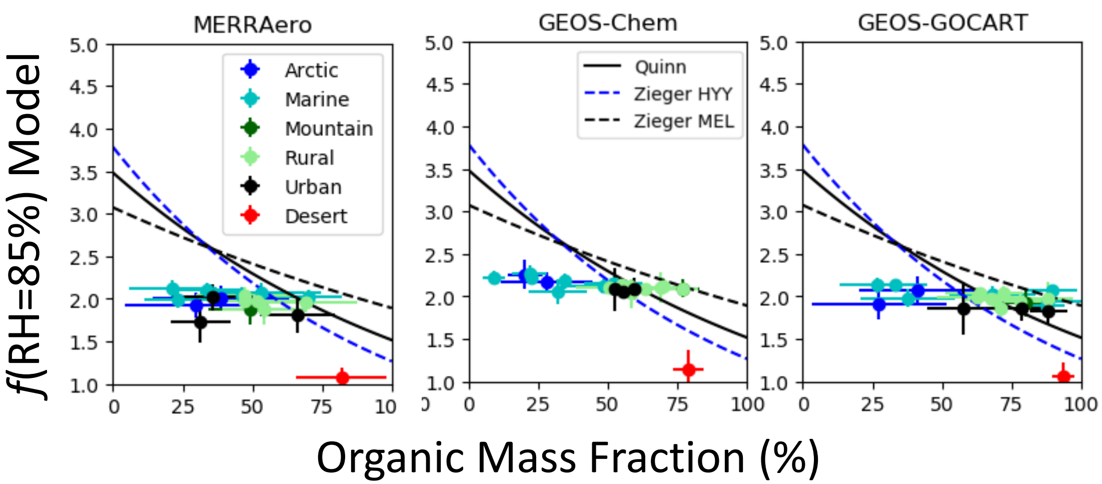
- CAM and CAM-Oslo exhibit similar relationship between *f*(RH) and Organic Mass Fraction as suggested by Quinn and Zieger parameterizations

GEOS-family models



f(RH=85%) model vs measured:

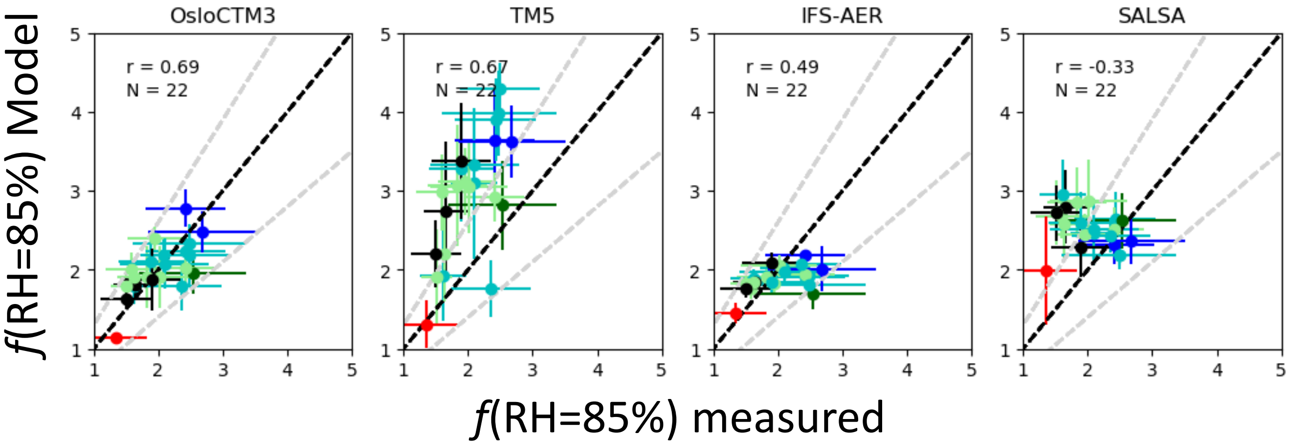
- Models do not reproduce the range in measured *f*(RH) but values fall within 30% uncertainty
- Lower correlation coefficients than for CAM-models



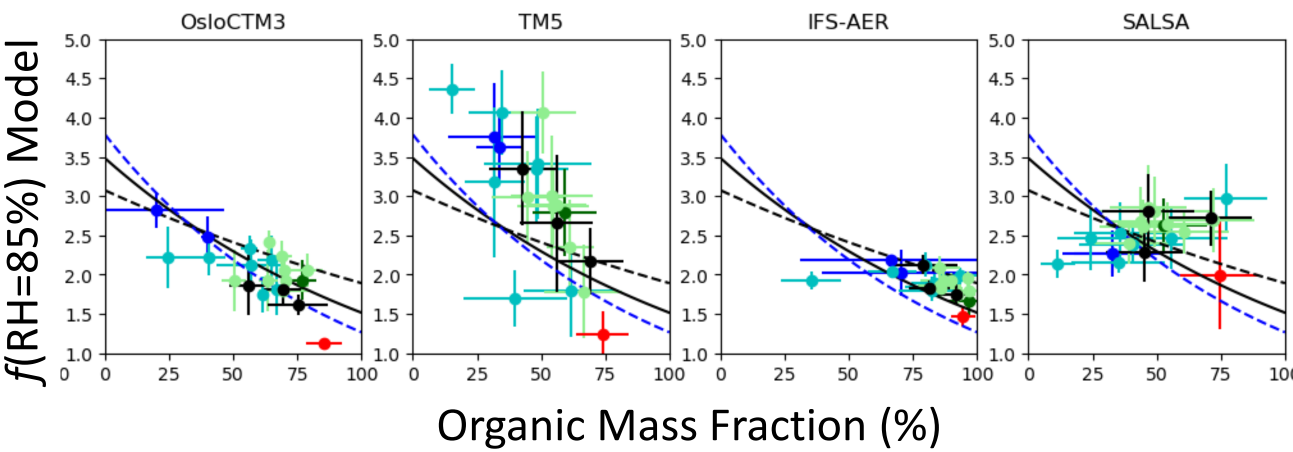
f(RH=85%) model vs OMF:

- Models do not exhibit same Organic Mass Fraction - *f*(RH) relationship as observations

OsloCTM3, TM5, IFS-AER, SALSA



Diversity of behaviors:
- Good correlation for OsloCTM3 and TM5
- Inverse correlation for SALSA



- OsloCTM3 and IFS-AER agree well with parameterizations
- IFS-AER simulates aerosol dominated by organics
- TM5 exhibits same tendency as paramerterizations but overestimates *f*(RH) relative to Organic Mass Fraction
- SALSA behaves different

Summary of main results:

- GEOS-family models assign too much hygroscopicity to all species (except dust) so almost regardless of simulated composition the resulting *f*(RH) will be high (exception is dust dominated site)

- GEOS models all use GADS so this high *f*(RH) is consistent with findings by Zieger et al., 2013 showing overestimates at low RH

- Model consideration (or lack thereof) of hysteresis is probably not a factor since only one model (CAM-Oslo) considers it and we are looking at RH values above deliquescence

- Another common feature of GEOS-family models is that they show a narrow *f*(RH) range, and all of them assume external mixing. Nevertheless, there are contradicting results in the literature about the importance of mixing state (e.g. Curci et al., 2015 and Reddington et al., 2019), SALSA model also has external mixing but does not show this narrow range in *f*(RH).

In conclusion:

1. Measurements of **particle light scattering enhancement factors** have been compared to a set of 10 Earth System Models

2. We see a **high diversity** in the comparison between models and measurements due to the variability in the different assumptions related to hygroscopic growth and chemical composition

3. In addition mixing state and size, as prescribed in the models, can have an importance influence too. Accounting for the exact contribution of each of these factors is a **challenge** and more research needs to be carried out

4. **Organic Mass Fraction** can be used as a constraint or "sanity check" for the modelled *f*(RH)

Further results… check out our paper currently in ACPD

1. **Temporal collocation** between models and measurements was done for three sites. This allows to study for example the **annual cycle.** Three sites (Arctic, marine and rural) all showed an **overall overestimation** of the monthly medians, with GEOS-family models showing slightly more accurate results

2. The **definition of the reference RH is essential** for the model-measurement comparison

Check out our project website

Thanks for your attention

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For Questions, feel free to contact me at:
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