# Effect of water uptake on aerosol light scattering: comparison of a new in-situ benchmark dataset to nine Global Climate Models

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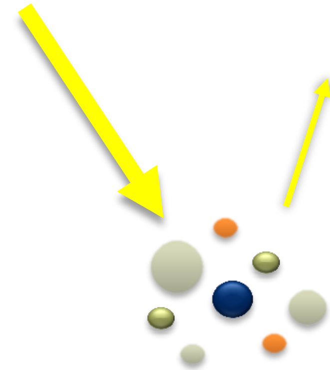
ASR Atmospheric System Research

CIRES

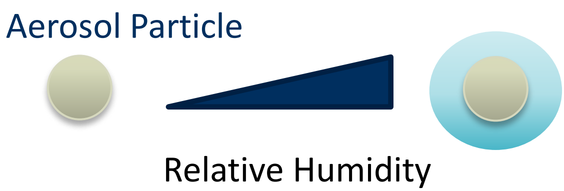
AeroCom – 24th September, 2019

Stockholm University

# Aerosols and Climate



- **Direct and indirect effects on the Earth's energy balance**
- Scattering ($\sigma_{sp}$) and absorption of solar radiation and the number of cloud condensation nuclei will be affected by aerosol concentration, size and chemical composition




**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**

## SCATTERING ENHANCEMENT FACTOR

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

Scattering coefficient at elevated RH

Dry scattering coefficient

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 **Global Climate Models**

How well do

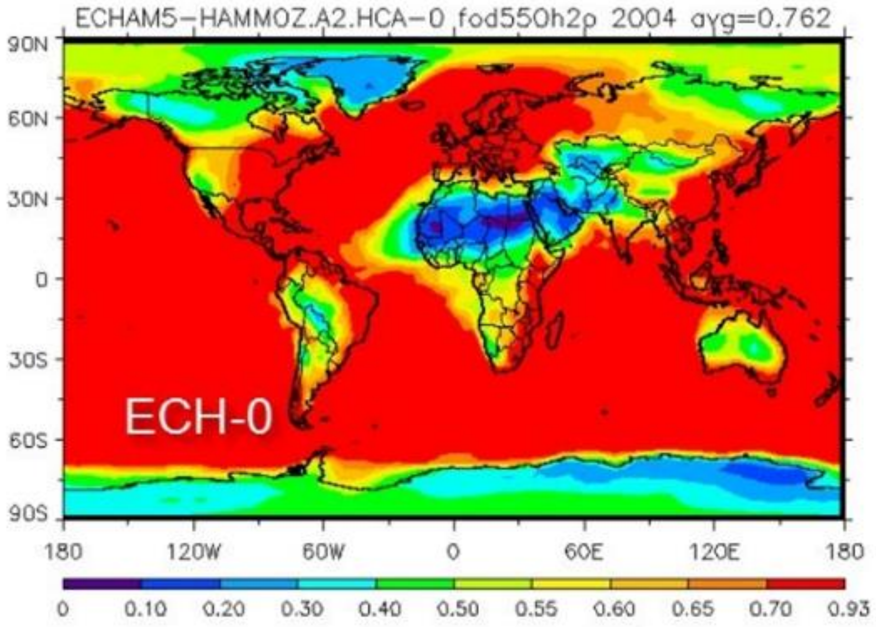
**Global Climate Models**

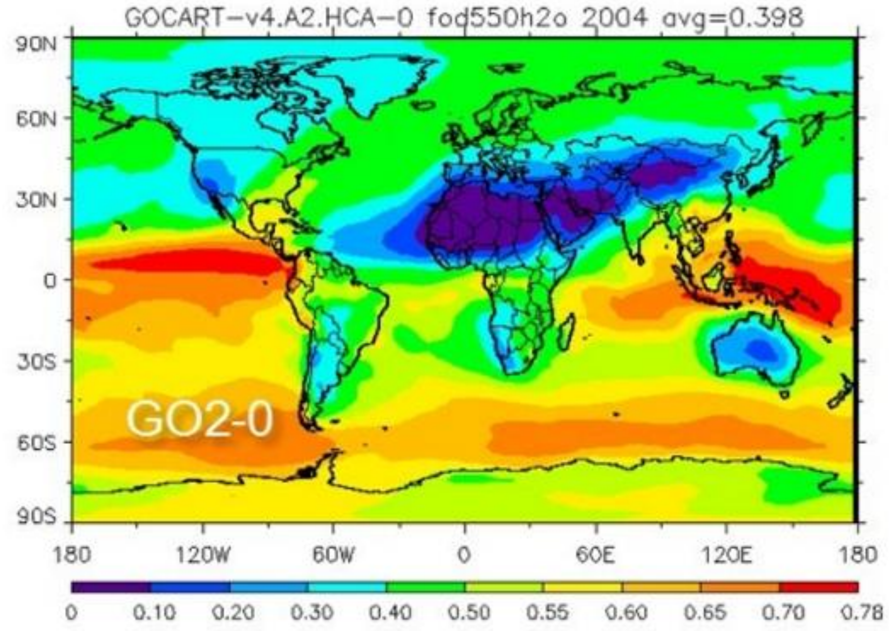
represent aerosol optical

**hygroscopic growth?**

# Hygroscopicity in GCM's

Fraction of aerosol optical depth (AOD) due to **water** in different models:




*Figures from Mian Chin (NASA Goddard)*

ECHAM5: global annual average **76%**

GOCART: global annual average **40%**

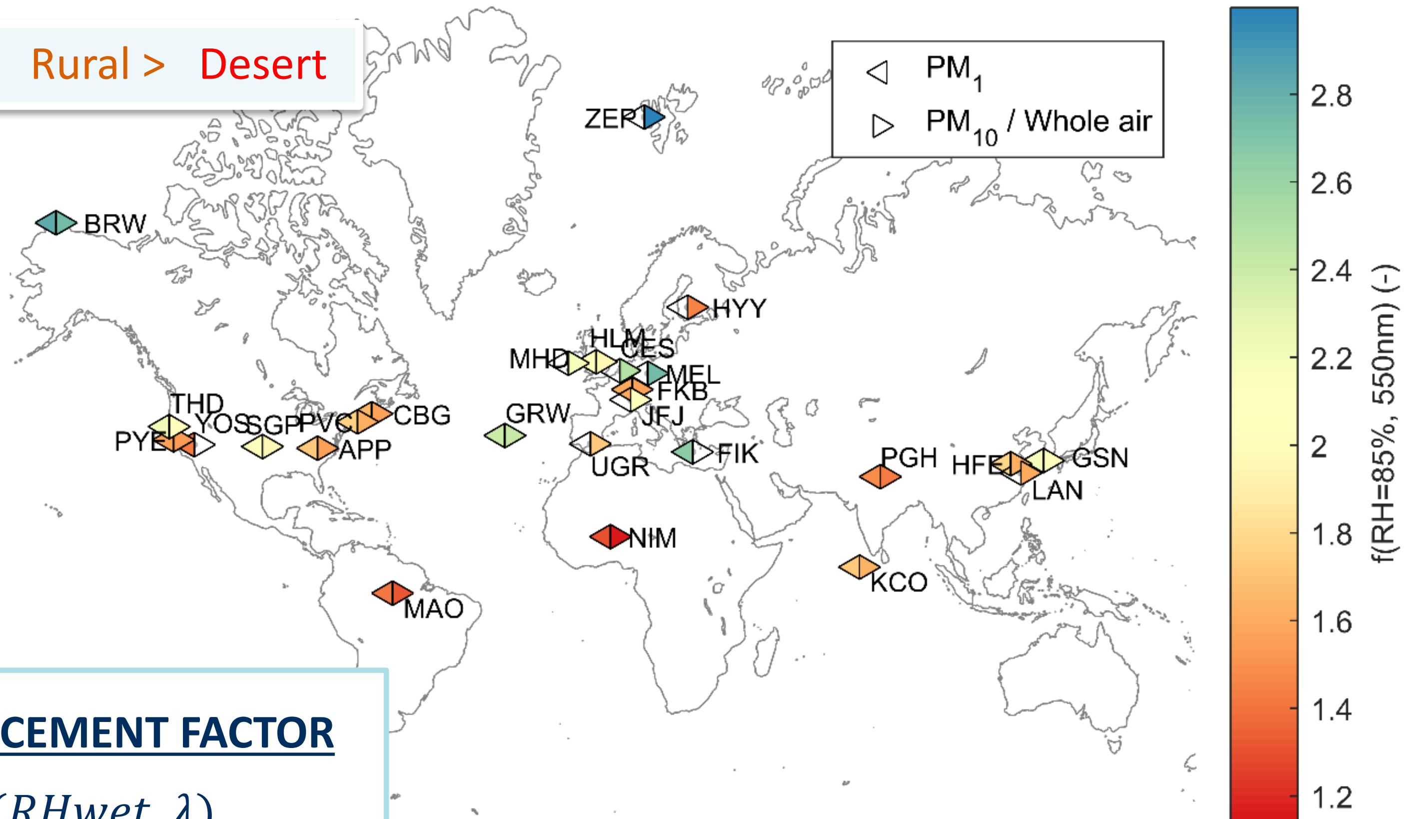
nature > scientific data > data descriptors > article

SCIENTIFIC DATA

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

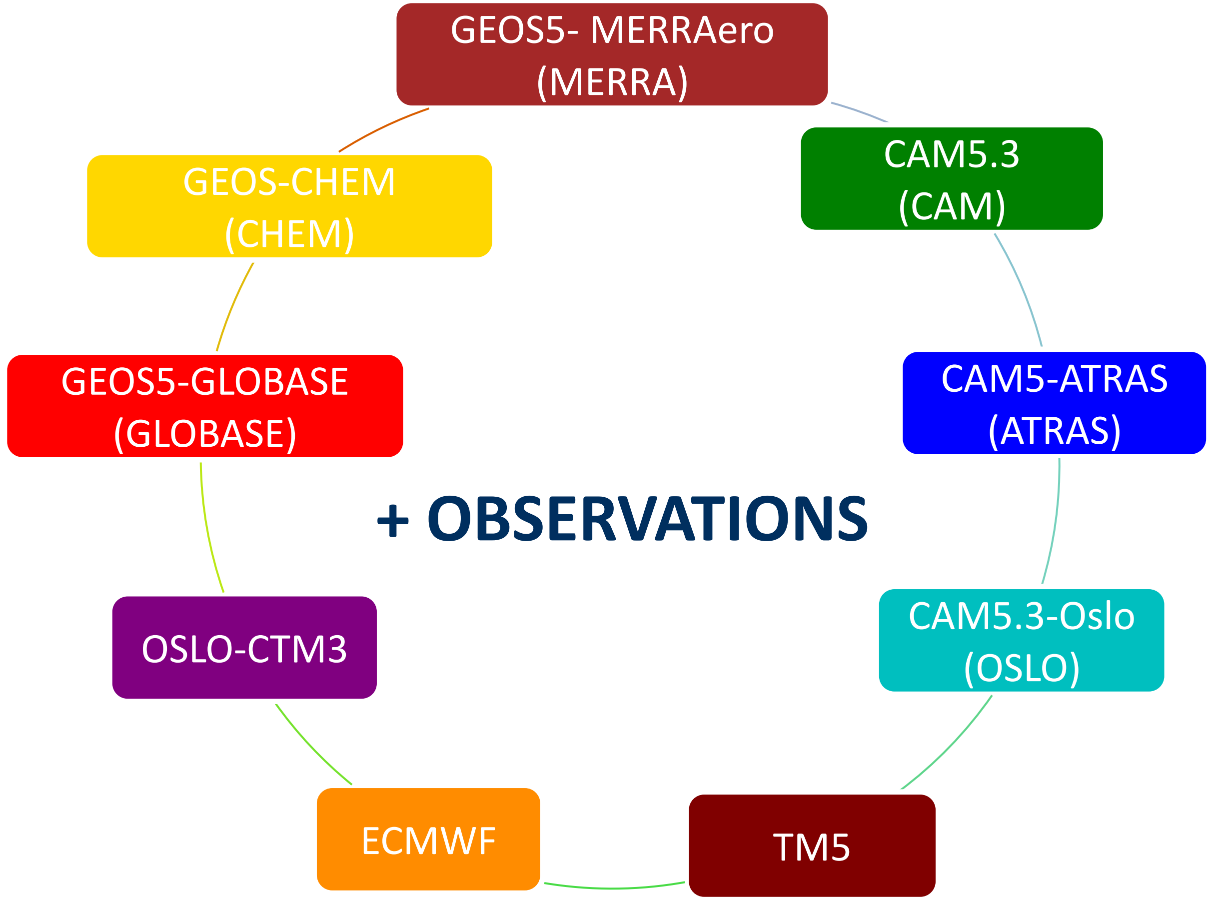
María A. Burgos, Elisabeth Andrews, Gloria Titos, Lucas Alados-Arboledas, Urs Baltensperger, Derek Day, Anne Jefferson, Nikos Kalivitis, Nikos Mihalopoulos, James Sherman, Junying Sun, Ernest Weingartner & Paul Zieger

Arctic > Marine > Rural > Desert



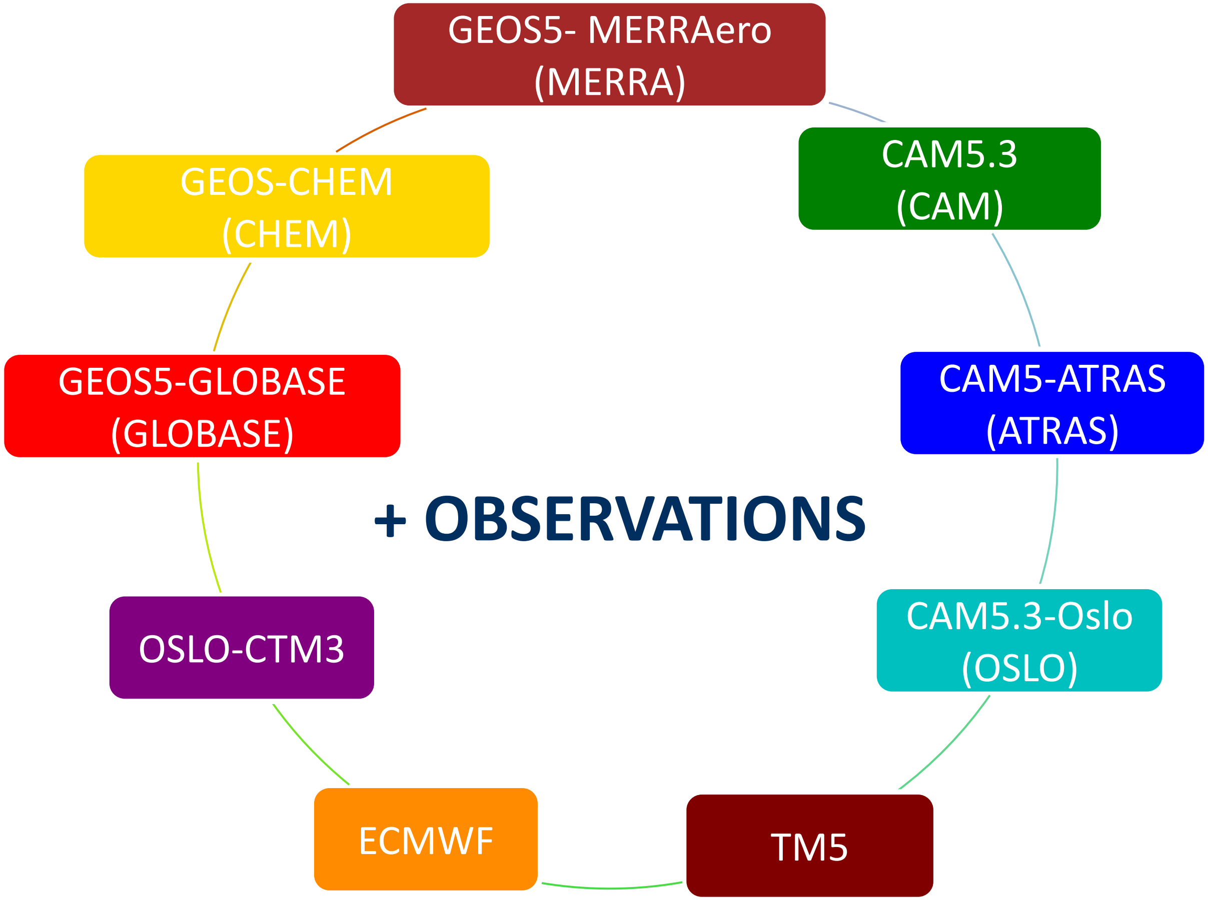

## SCATTERING ENHANCEMENT FACTOR

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




We encourage you to provide model data!!

**Data call: Common AeroCom phase III Diagnostics Request 2019**
(https://wiki.met.no/aerocom/phase3-experiments)



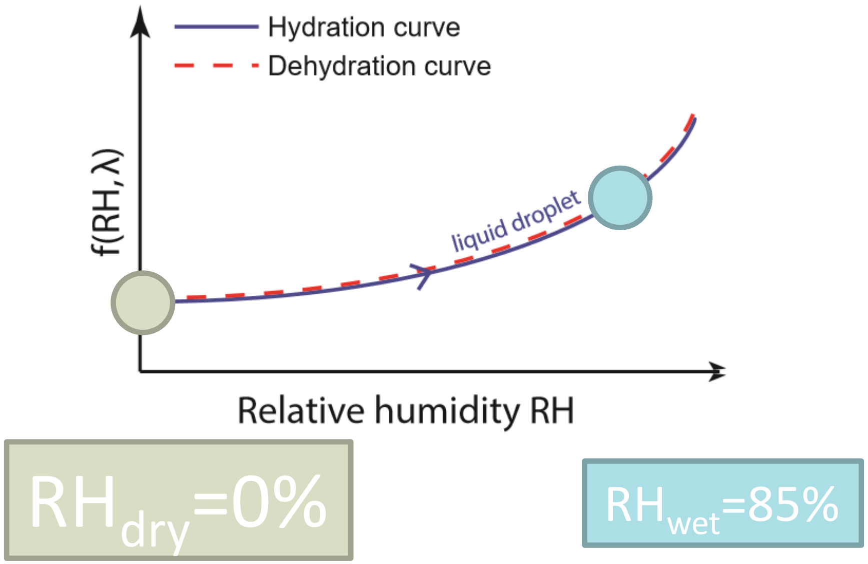

INSITU project within AeroCom Phase III:

- Aerosol optical data at **RH=0, 40 and 85%**
- **Hourly values for 2010** (time coverage not always coincident with measurements). Daily for Oslo-CTM2 (preliminary).
- Various locations -> **20 coincident sites** with observational data
- **Uncertainty** in measurements between 20-30%

# *f*(RH=85%, 550nm)

**Recommended dry conditions** in order to keep measurements comparable:
RH < 30 - 40%

**WMO/GAW.** Aerosol Measurement Procedures Guidelines and Recommendations, Report No. 153. World Meteorological Organization, Geneva, Switzerland (2003).




$$f(RH,\lambda) = \frac{\sigma_{sp}(RHwet = 85\%, \lambda)}{\sigma_{sp}(RHdry = 0\%, \lambda)}$$

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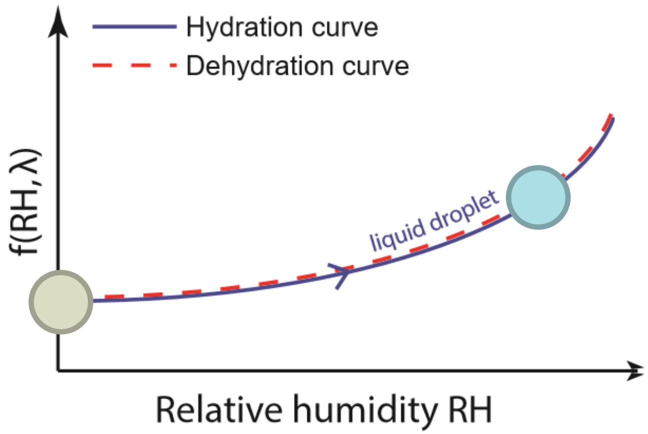


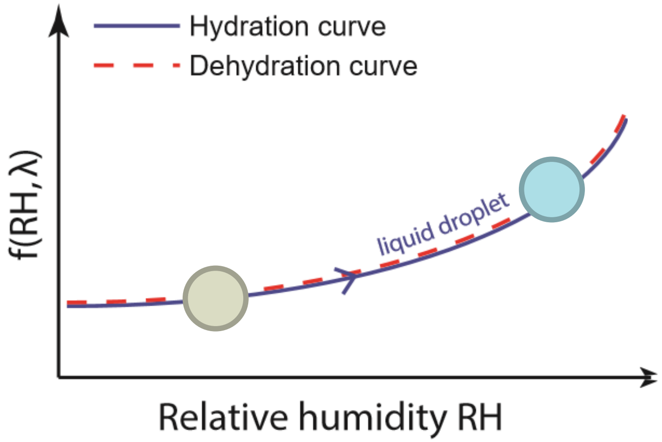


$RH_{dry}$=0%

$RH_{wet}$=85%

$RH_{dry}$=40%

$RH_{wet}$=85%

$$f(RH,\lambda) = \frac{\sigma_{sp}(RHwet = 85\%, \lambda)}{\sigma_{sp}(RHdry = 0\%, \lambda)}$$

$$f(RH,\lambda) = \frac{\sigma_{sp}(RHwet = 85\%, \lambda)}{\sigma_{sp}(RHdry = 40\%, \lambda)}$$

# Temporally collocated data for 2010: Annual Cycles

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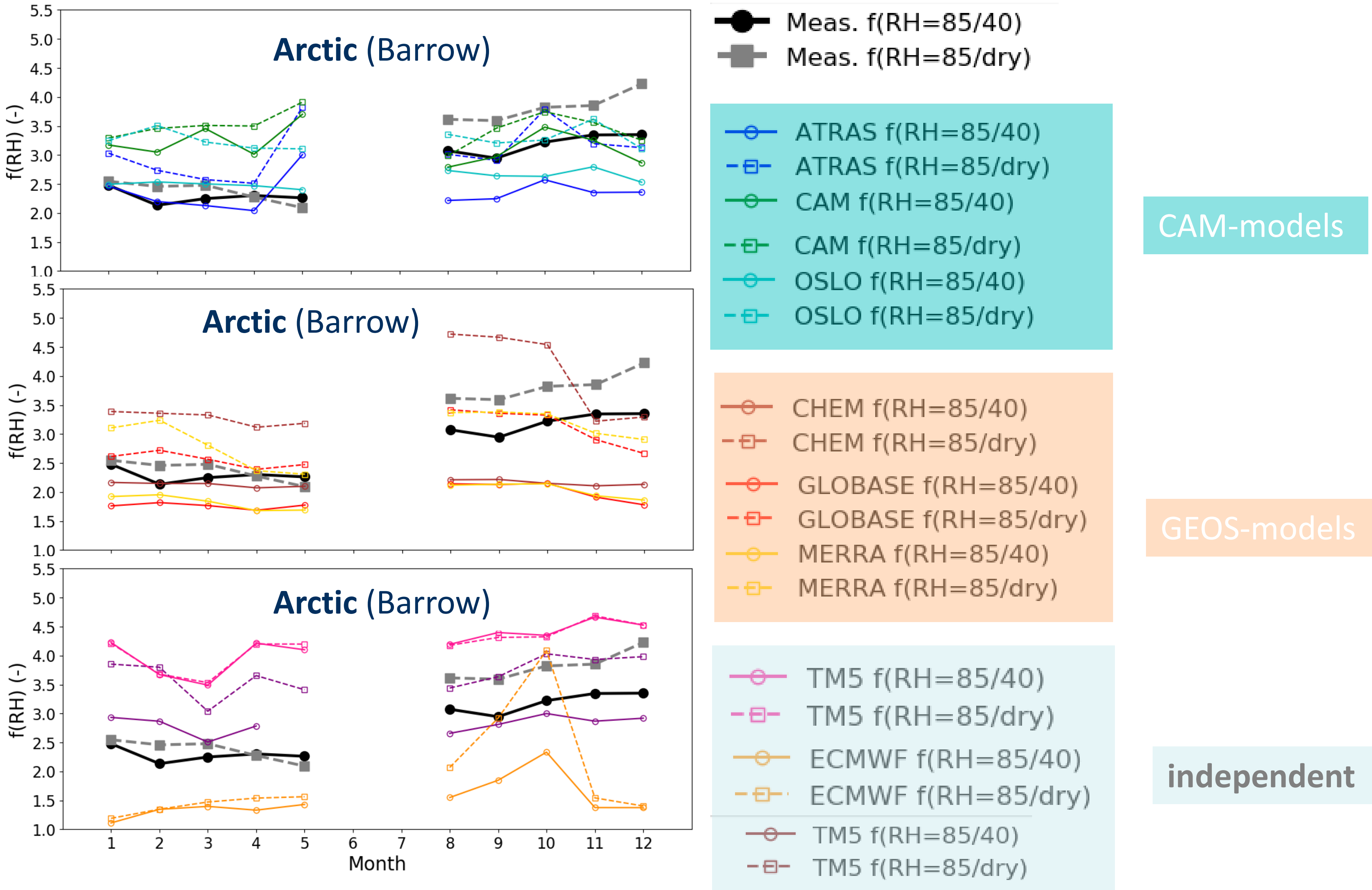
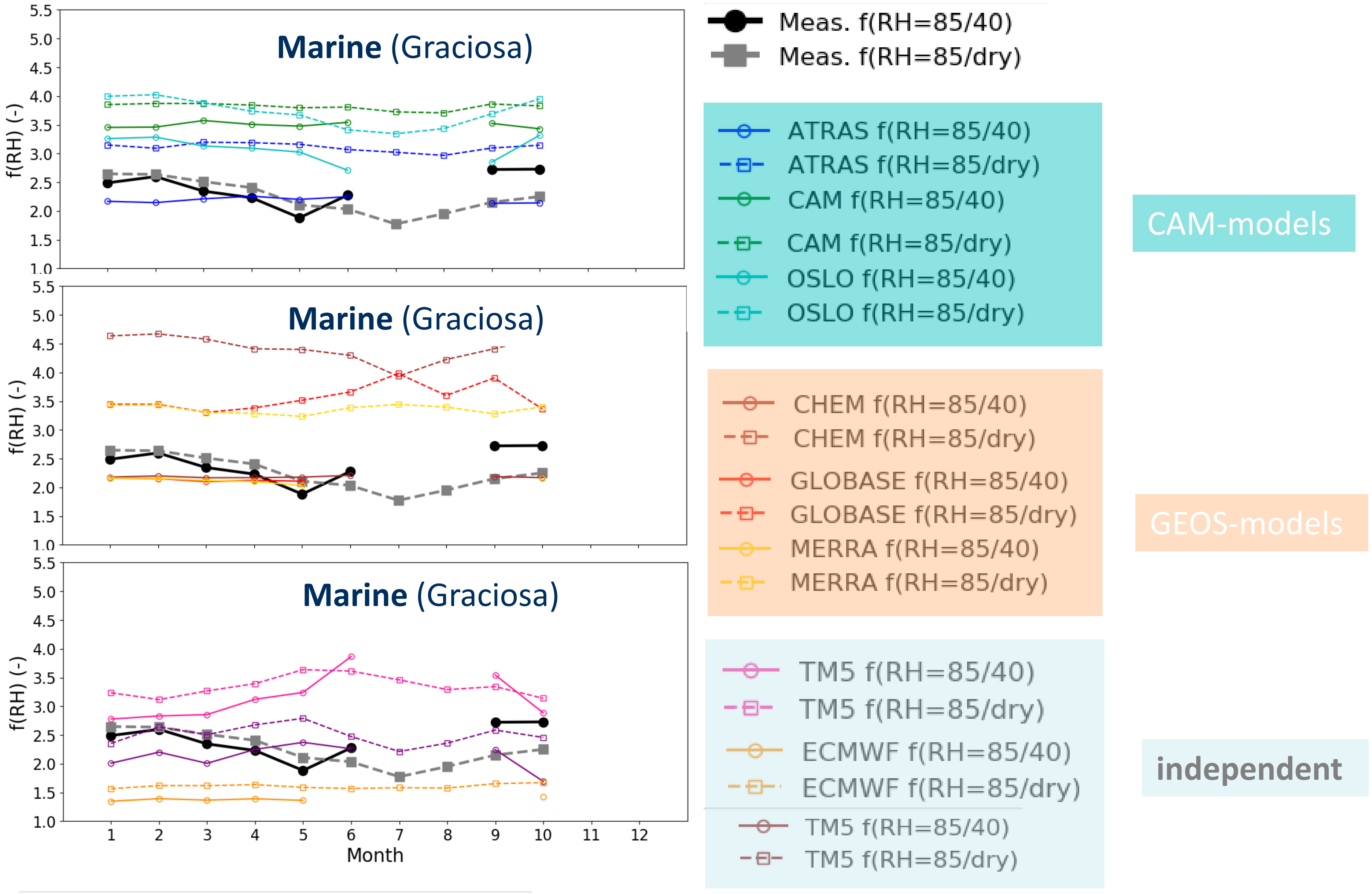


# Temporally collocated data for 2010: Annual Cycles



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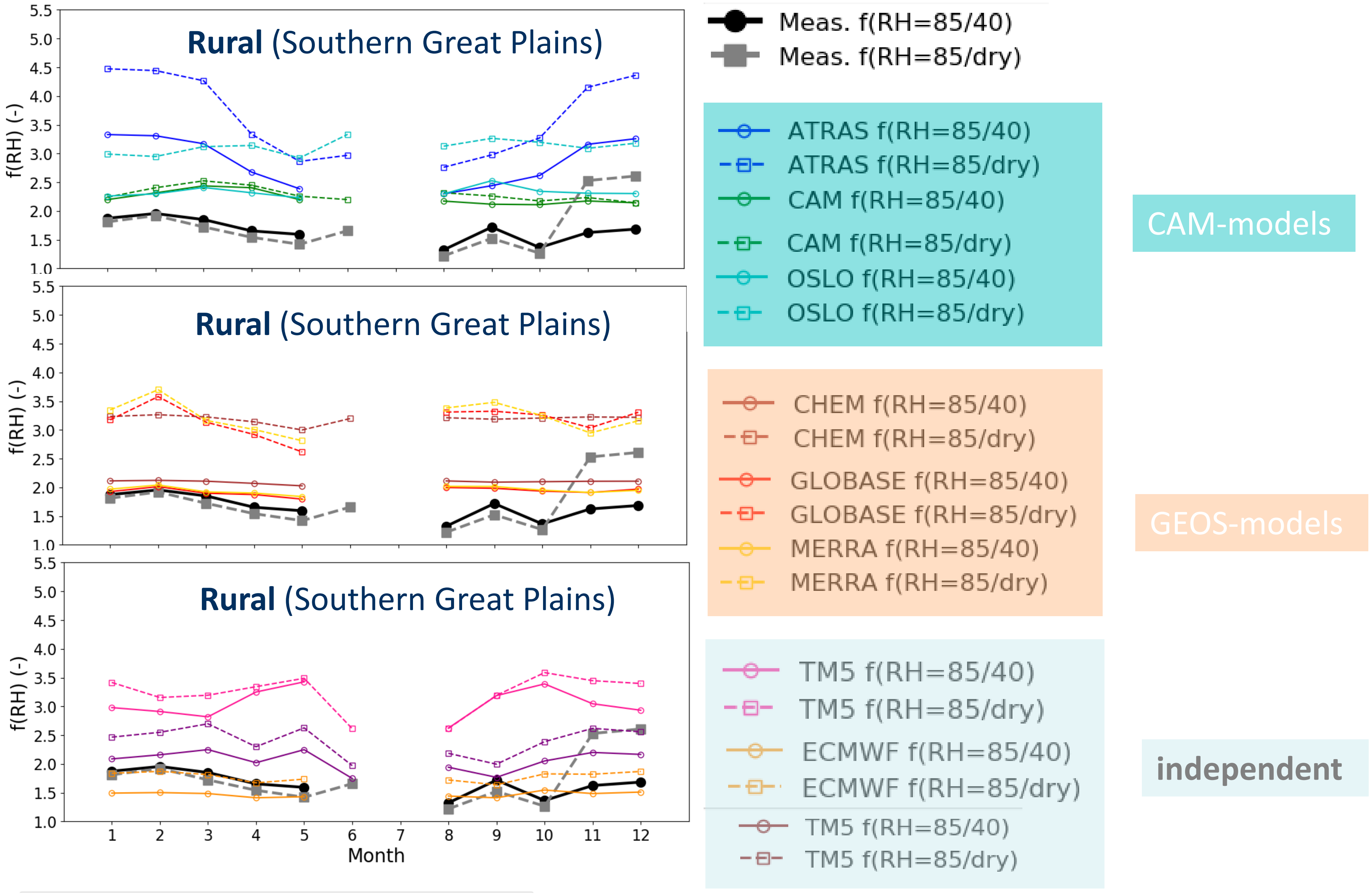
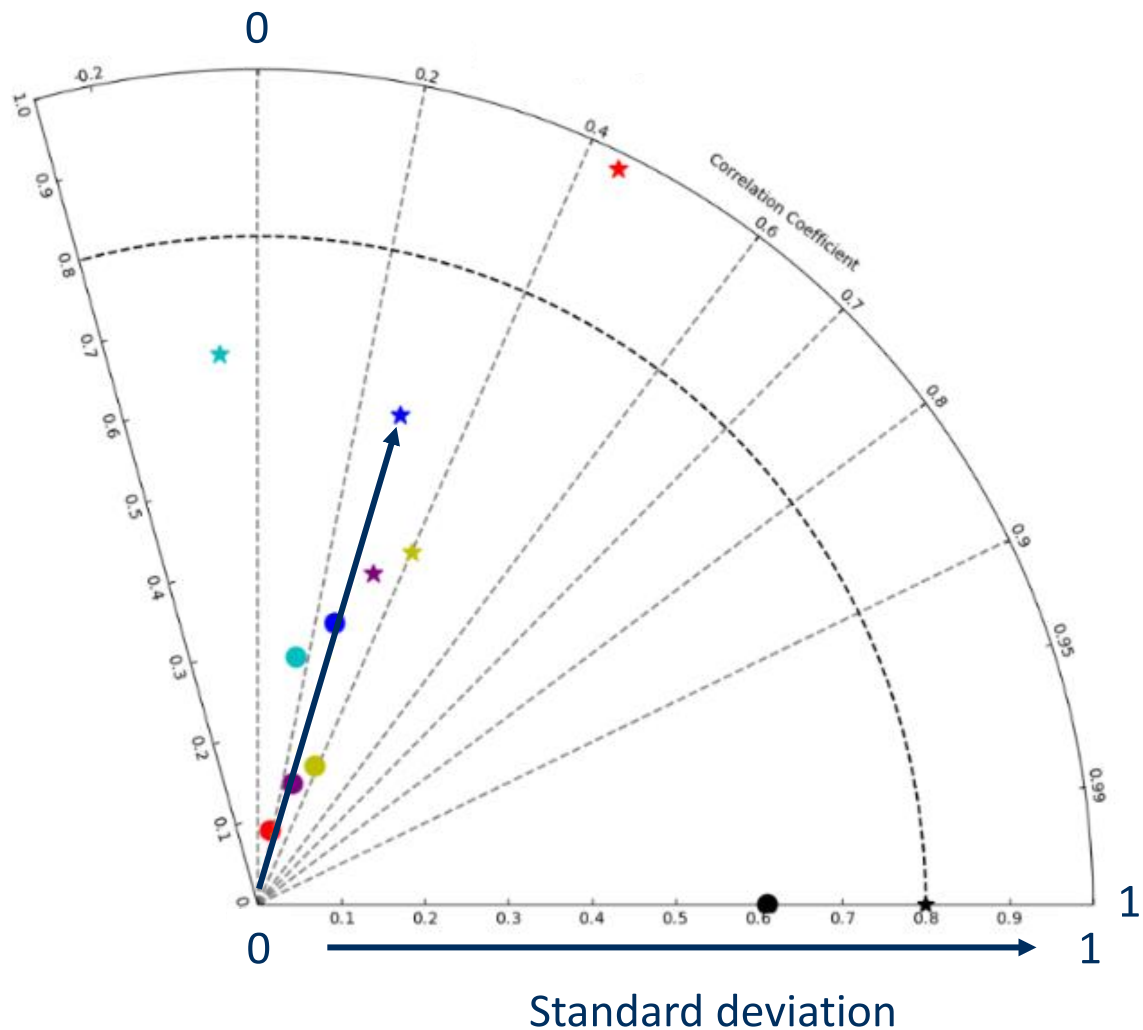


# Compact visualization of statistical values with Taylor diagrams



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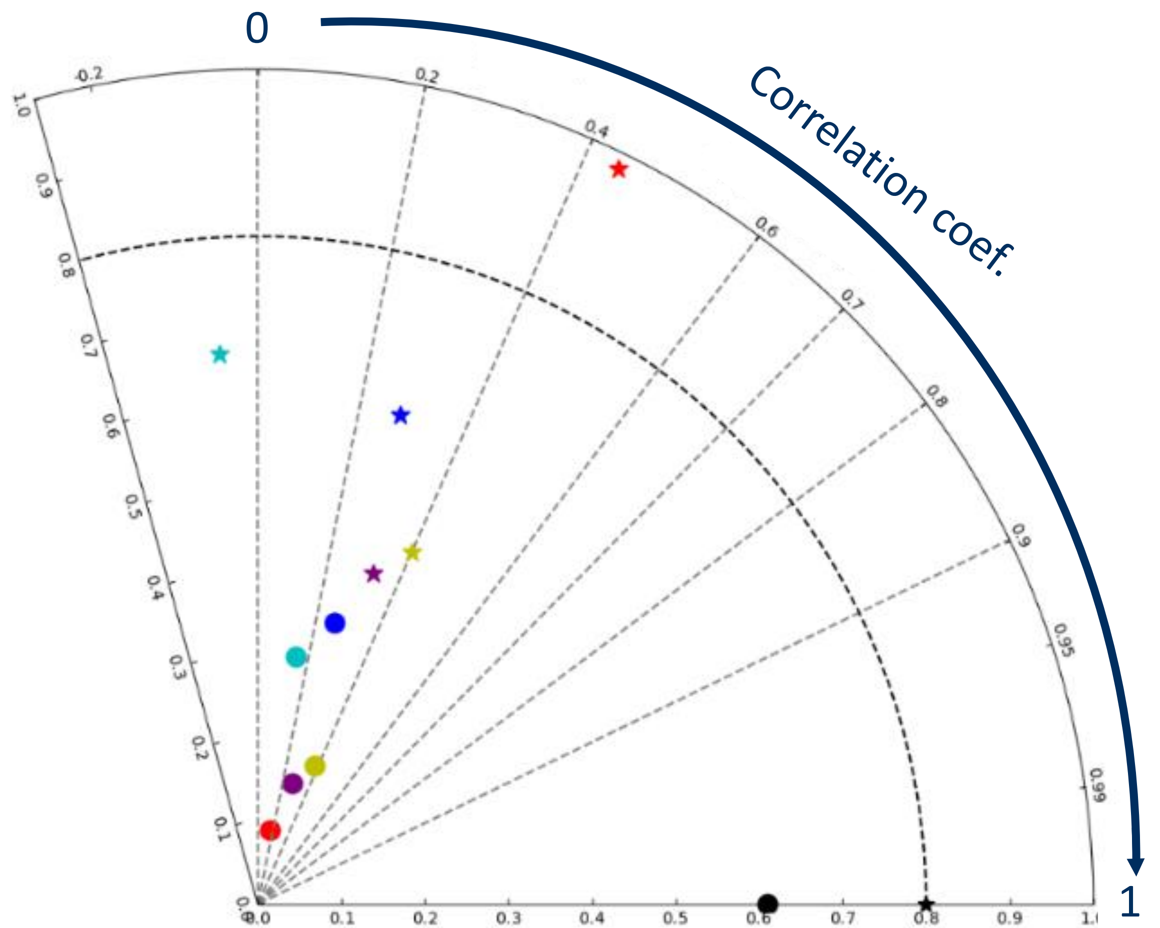
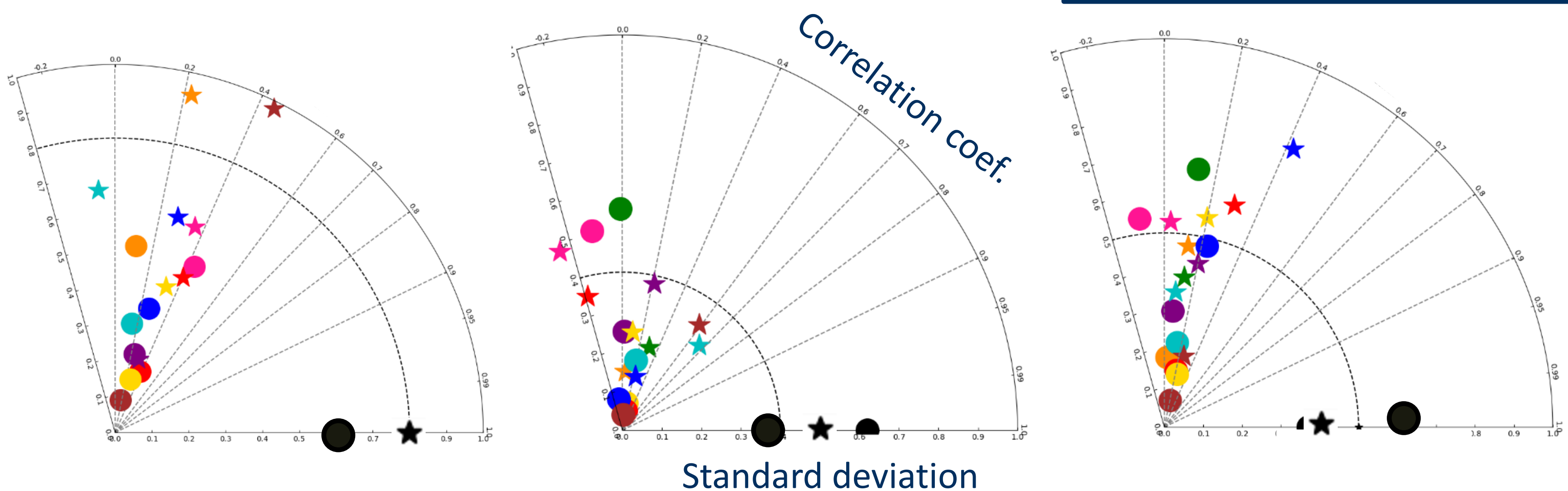


# Compact visualization of statistical values with Taylor diagrams

**Arctic** (Barrow) | **Marine** (Graciosa) | **Rural** (Southern Great Plains)




- ★ fRH (85/dry)
- ● fRH (85/40)

ATRAS, CAM, Oslo, MERRA, GLOBASE, CHEM, OSLO-CTM3, ECMWF, TM5

# Entire dataset -> seasonally collocated (but different years!)

**Warning! Model** outputs from **2010** have been compared with in-situ **measurements, collocating by month,** while years may be different!

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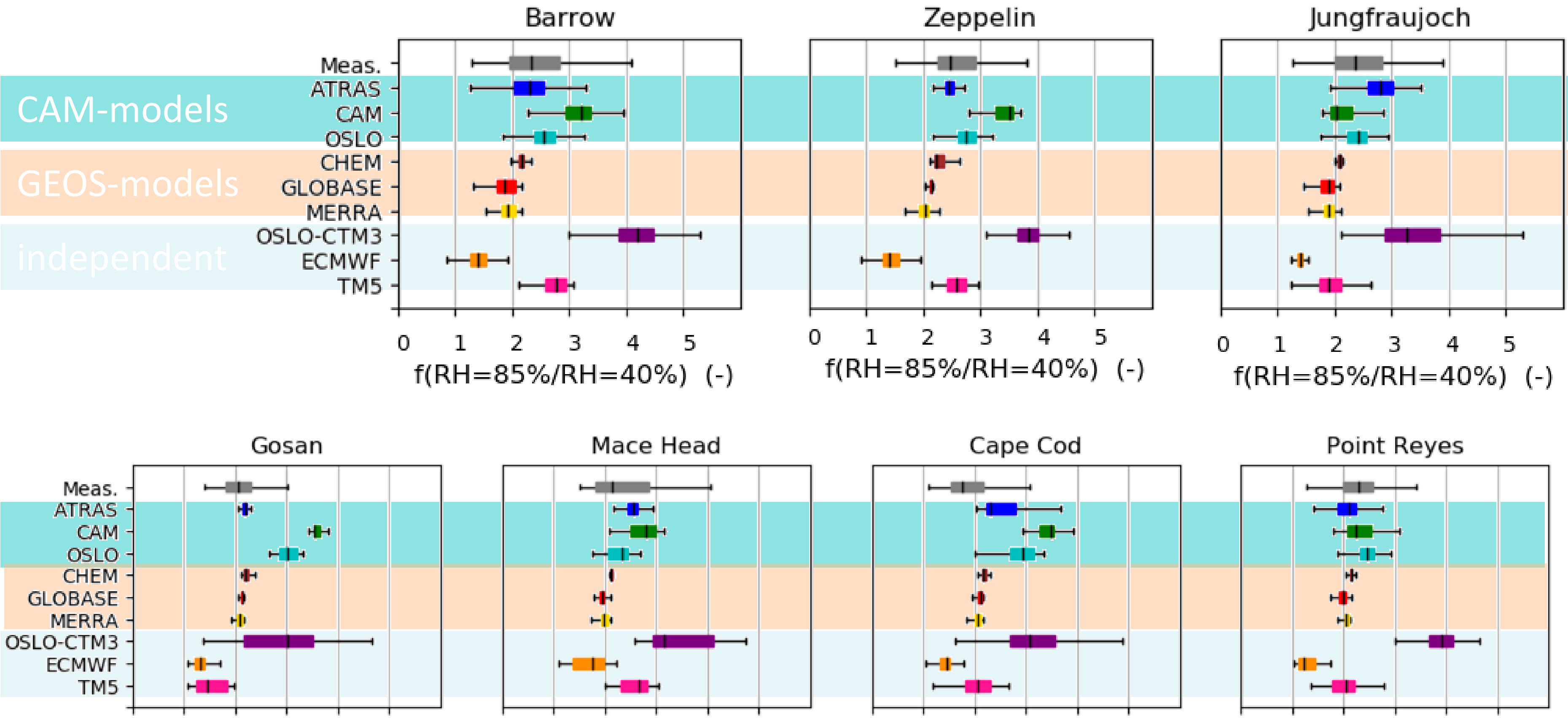
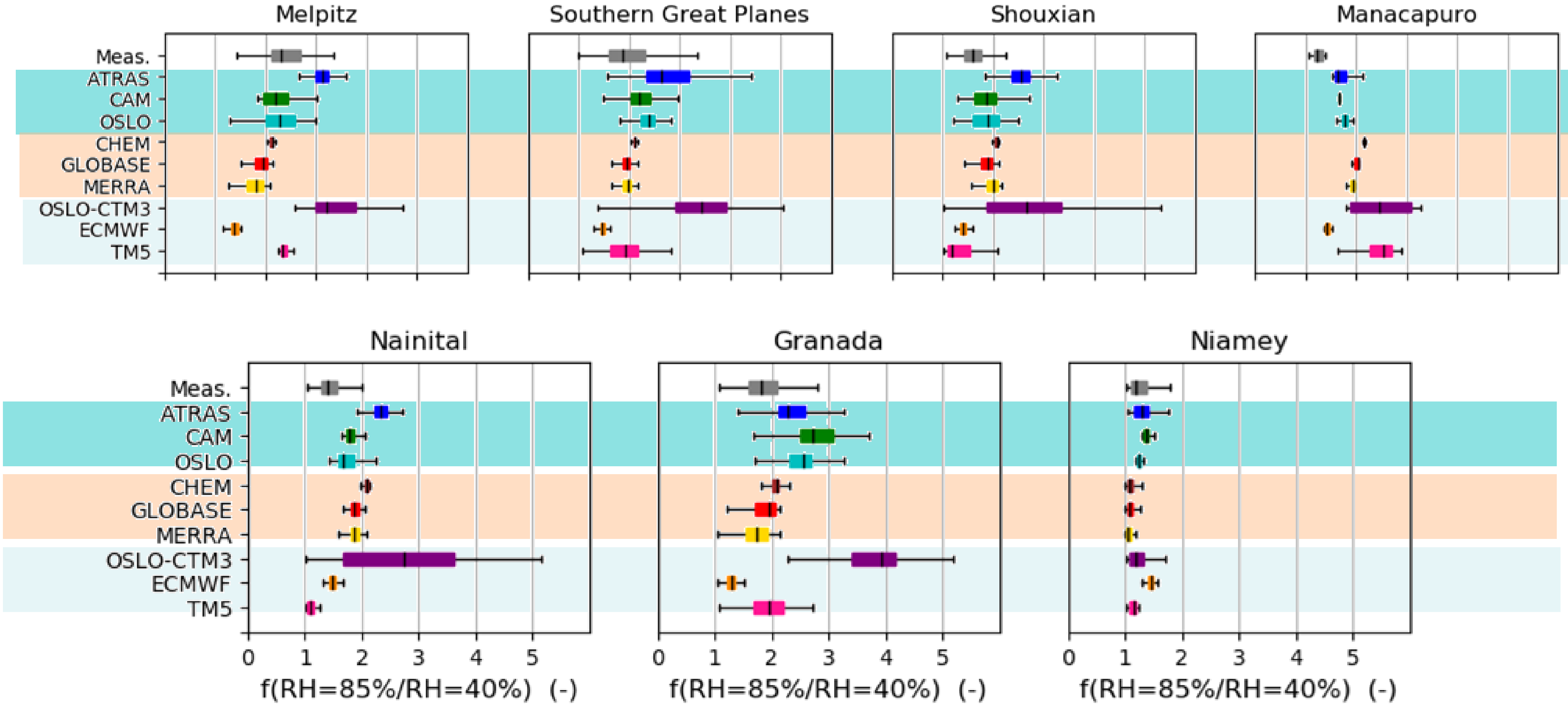



- GEOS models exhibit less variability
- CAM models tend to overestimate more than GEOS models at Arctic, marine and rural sites

# Entire dataset -> seasonally collocated (but different years!)




- Oslo-CTM2 stands out due to its variability -> PRELIMINARY! daily values
- ECMWF is the model that underestimates more sites
- TM5 model exhibits the best agreement at all site types

**Different representation** of

- **Aerosols:** aerosol size distribution, mixing state, attachment state, composition, and internal structure
- **Processes**: primary emissions, new particle formation, coagulation, water uptake, and activation to form cloud droplets

CAM-models

| Model | Hygroscopicty | Mixing State | Size distribution |
|---|---|---|---|
| **CAM5.3** Liu et al. 2012, GMD | Köhler theory (Table S3: e.g. 1.16 for sea salt) | Internal and external mixing | Aitken, accumulation and coarse |
| **CAM5-ATRAS** Matsui et al. 2011, JGR | Köhler theory (1.16 for Na and Cl) | Multiple mixing states for each size bin | 128 aerosol bins |
| **CAM5.3-Oslo** Kirkevåg et al. 2018, GMD | Köhler theory (growth factor ~2 for RH=80%, sea salt) | Internal and external mixing | 44 size-bins with radii (r) ranging from 0.001 to 20 µm |

**Different representation** of

- **Aerosols:** aerosol size distribution, mixing state, attachment state, composition, and internal structure
- **Processes**: primary emissions, new particle formation, coagulation, water uptake, and activation to form cloud droplets

GEOS-models

| Model | Hygroscopicty | Mixing State | Size distribution |
|---|---|---|---|
| **GEOS5-Globase**<br>Chin et al. 2002, AMS | (growth factor of 2 at RH=80% for sea salt) | External mixing | Sulfate, BC and OC (2 bins each), dust and sea salt (5 bins each) |
| **GEOS-Chem**<br>Bey et al. 2001, JGR | Table 1, Martin et al., 2003, JGR (growth factor of 2 at RH=80% for sea salt) | External mixing | Sulfate-nitrate-ammonium, OC, BC (bulk-mass approach) Dust (4 bins), sea salts (2 bins) |
| **GEOS5-MERRAero**<br>Buchard *et al.* 2015, ACP | OPAC and Tang et al., 1997 | External mixing | OC and BC (2 bins), sulfate, dust (5 bins), sea salt (5 bins) |

I. The **new benchmark dataset** of RH-dependent particle light scattering coefficients and scattering enhancement factors *f*(RH) has been finalized and successfully tested against nine GCM's

II. Models generally **overestimate** *f*(RH) but comparison **improves** if $\mathbf{RH_{dry}=40\%}$ is taken as reference RH

III. Models show a **large diversity** in *f*(RH) with respect to magnitude and temporal evolution (e.g. seasons)

IV. Reasons are manifold: differences in model parametrizations of e.g. hygroscopicity, size, sources + strength, mixing state, removal processes, etc.

Thanks for your attention

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# BackUp slides

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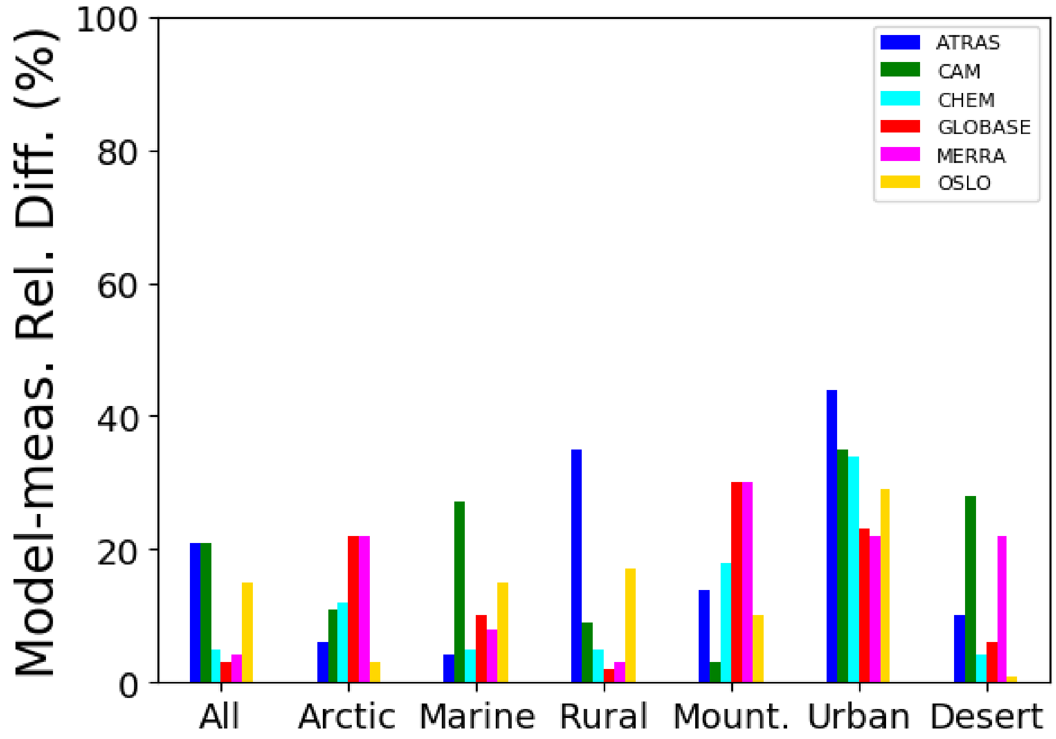
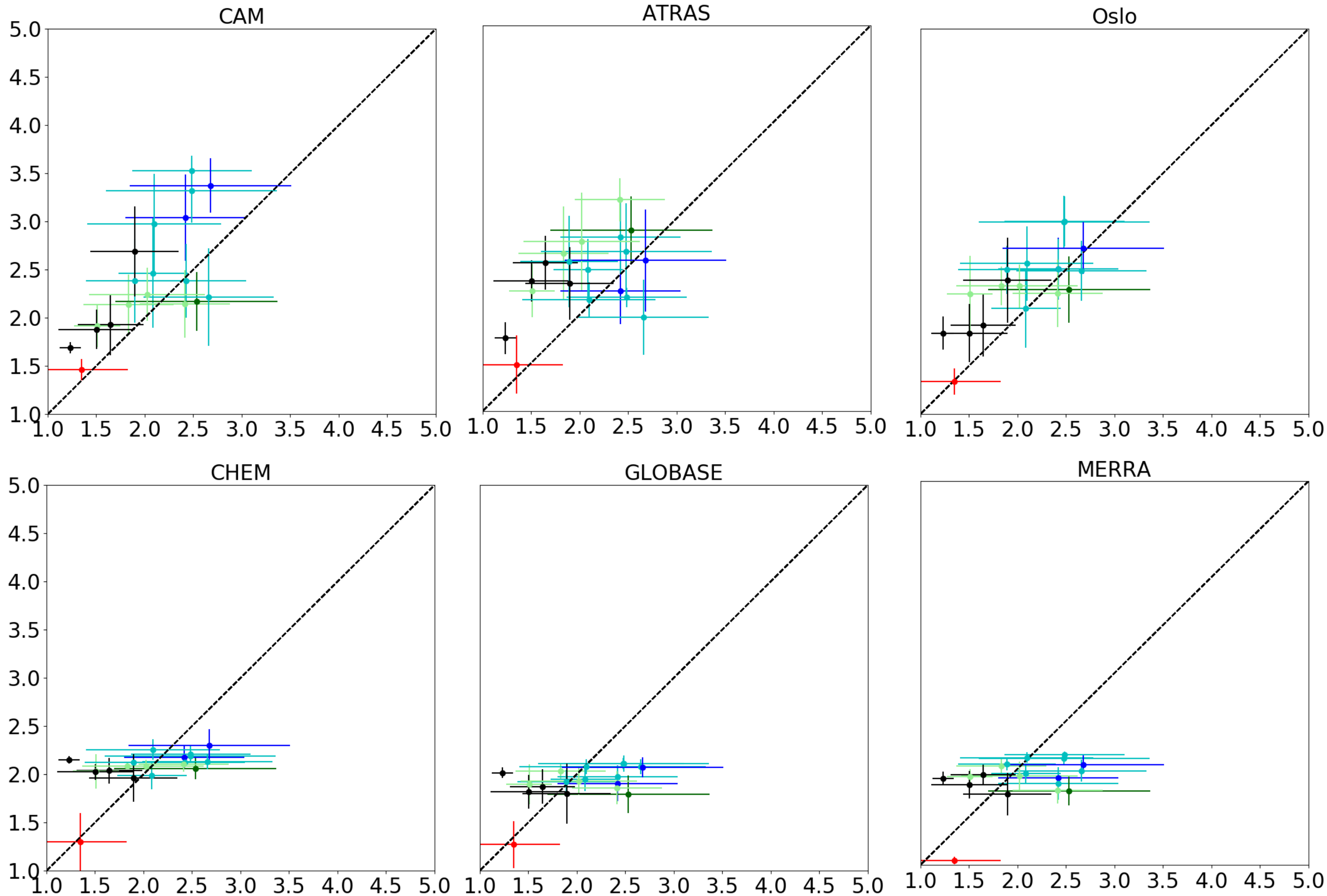
# Model vs Measurements: relative difference




- **Large differences** (**25% - 75%**) between models and measurements
- Largest differences found for **Rural and Urban** sites for all models
- Models perform better at **Arctic and Desert** sites




Arctic Marine Rural
Mountain Urban Desert

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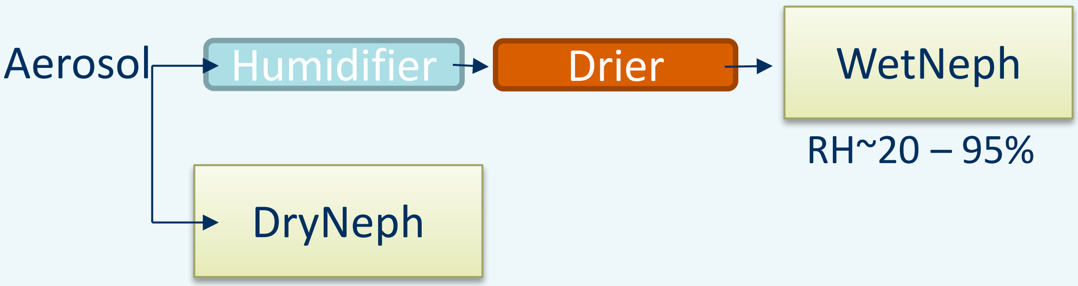
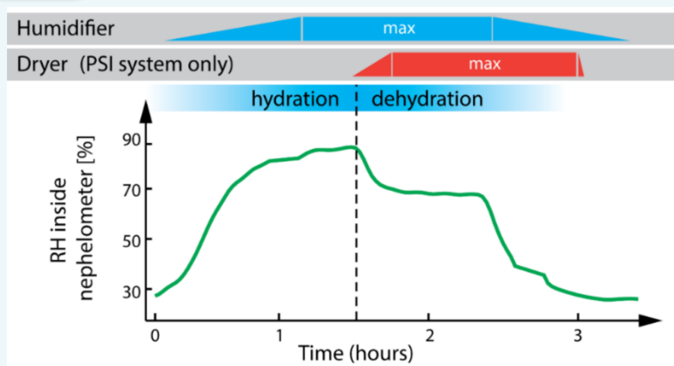
# Tandem Humidified Nephelometer

## PSI system:

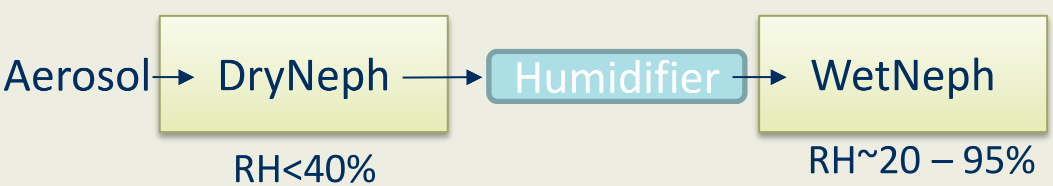



RH<40%




*(Fierz-Schmidhauser et al., 2010)*

## NOAA system:

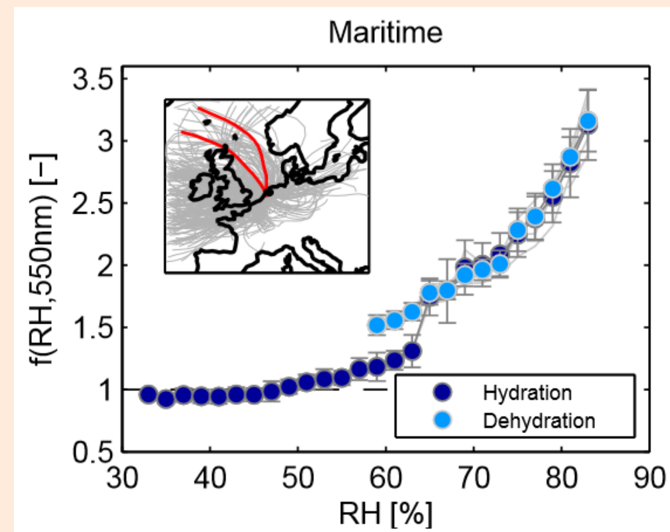



Humidograms can be **parameterized**:

$$f(RH) = \alpha\,(1 - RH)^{-\gamma}$$

*Carrico et al., 2003*

**Problem** for sea salt aerosols (deliquescence)




*Zieger et al., 2011*

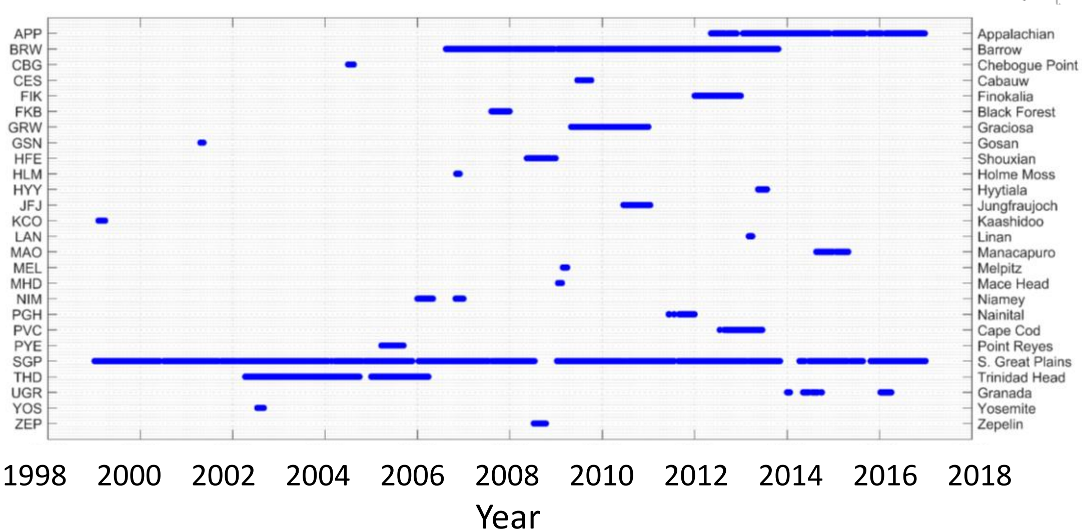
- **Fit separately** for RH>75% or RH<65% *(Zieger et al., 2010)*
- Several **equations** *(Titos et al., 2016)*

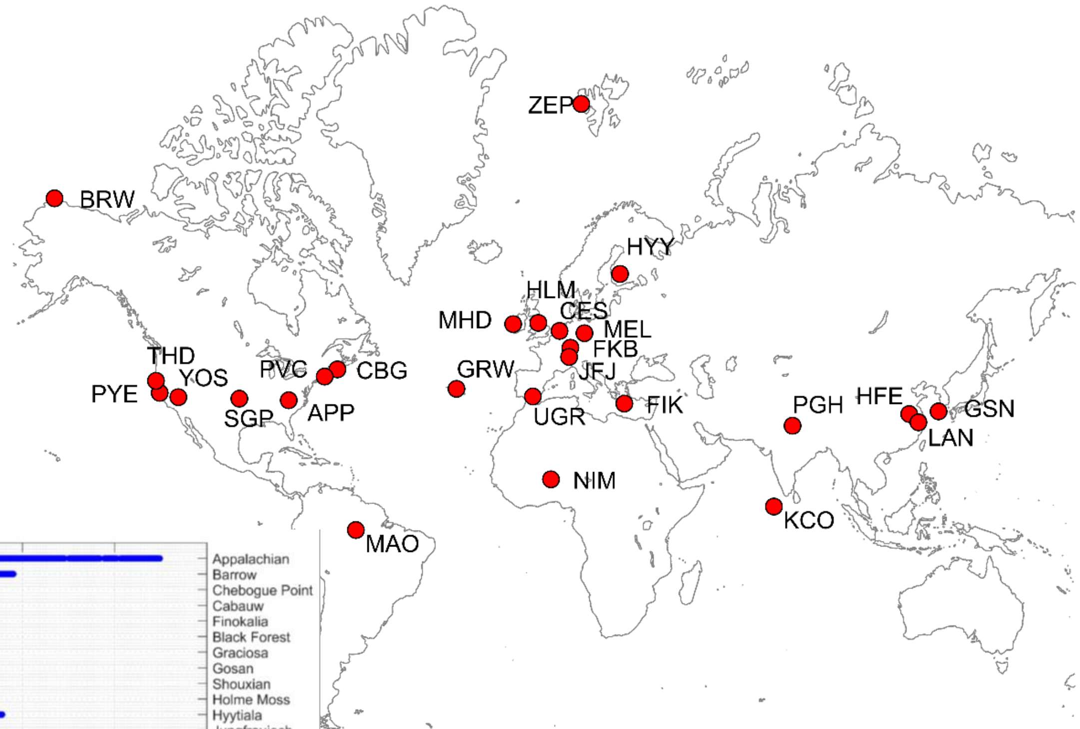
DoE project:
"Evaluation and improvement of the parameterization of aerosol hygroscopicity in global climate models using in-situ surface measurements" (2016-2019)

**HARMONIZED DATA SET**

- covering 18 years

compare with GCM's

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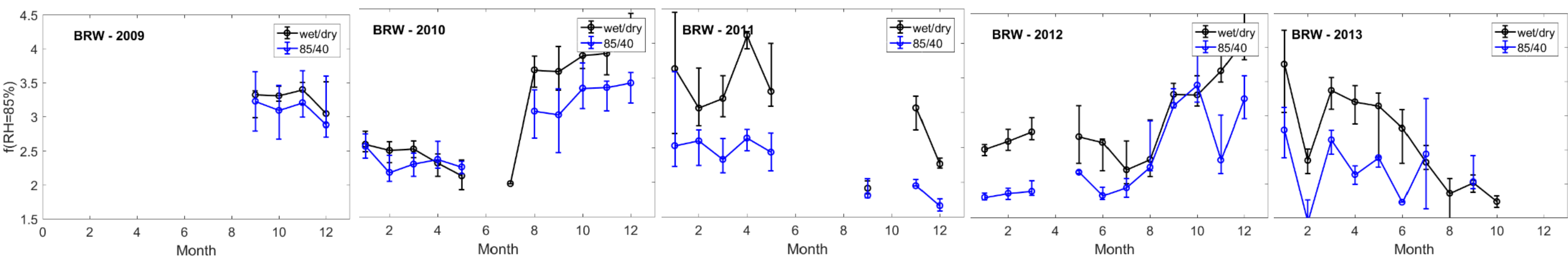
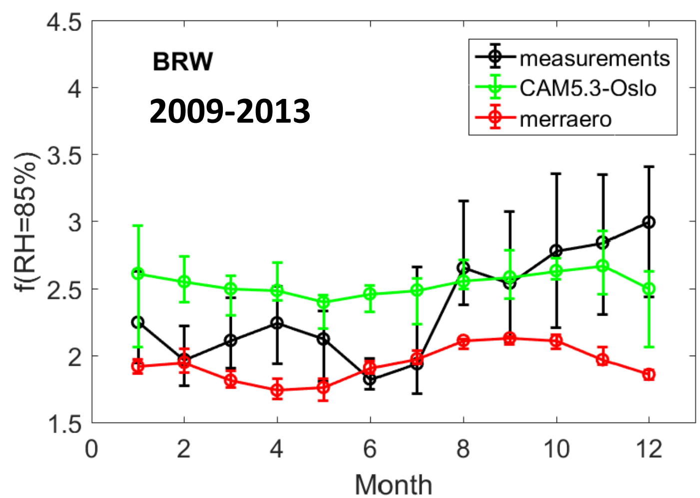
# Checking the time series of BRW for the measurements

Wet/dry
N.data(2009)=[0,0,0,0,0,0,0,0,5,13,33,11]
N.data(2010)=[51,78,39,17,0,1,36,28,32,19,52]
N.data(2011)=[24,23,34,24,3,0,0,0,19,0,3,73]
N.data(2012)=[34,63,63,0,11,11,5,4,15,26,19,60]
N.data(2013)=[92,33,75,54,9,6,8,5,14,2,0,0]

85%/40%
N.data(2009)=[0,0,0,0,0,0,0,0,2,5,16,9]
N.data(2010)=[19,43,58,15,10,0,0,20,19,19,16,49]
N.data(2011)=[21,20,25,24,2,0,0,0,5,0,3,25]
N.data(2012)=[19,34,41,0,2,4,2,3,5,4,12,40]
N.data(2013)=[36,12,50,40,6,1,2,0,3,0,0,0]

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