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A global modeling study of aerosol-cloud interactions with EMAC

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Aerosols, Clouds, and Climate

Daniel Rosenfeld

The chemical composition of aerosol particles is much less important than their size in determining their ability to nucleate clouds, a result that will clarify aerosol effects on climate.

Size Matters More Than Chemistry for Cloud-Nucleating Ability of Aerosol Particles

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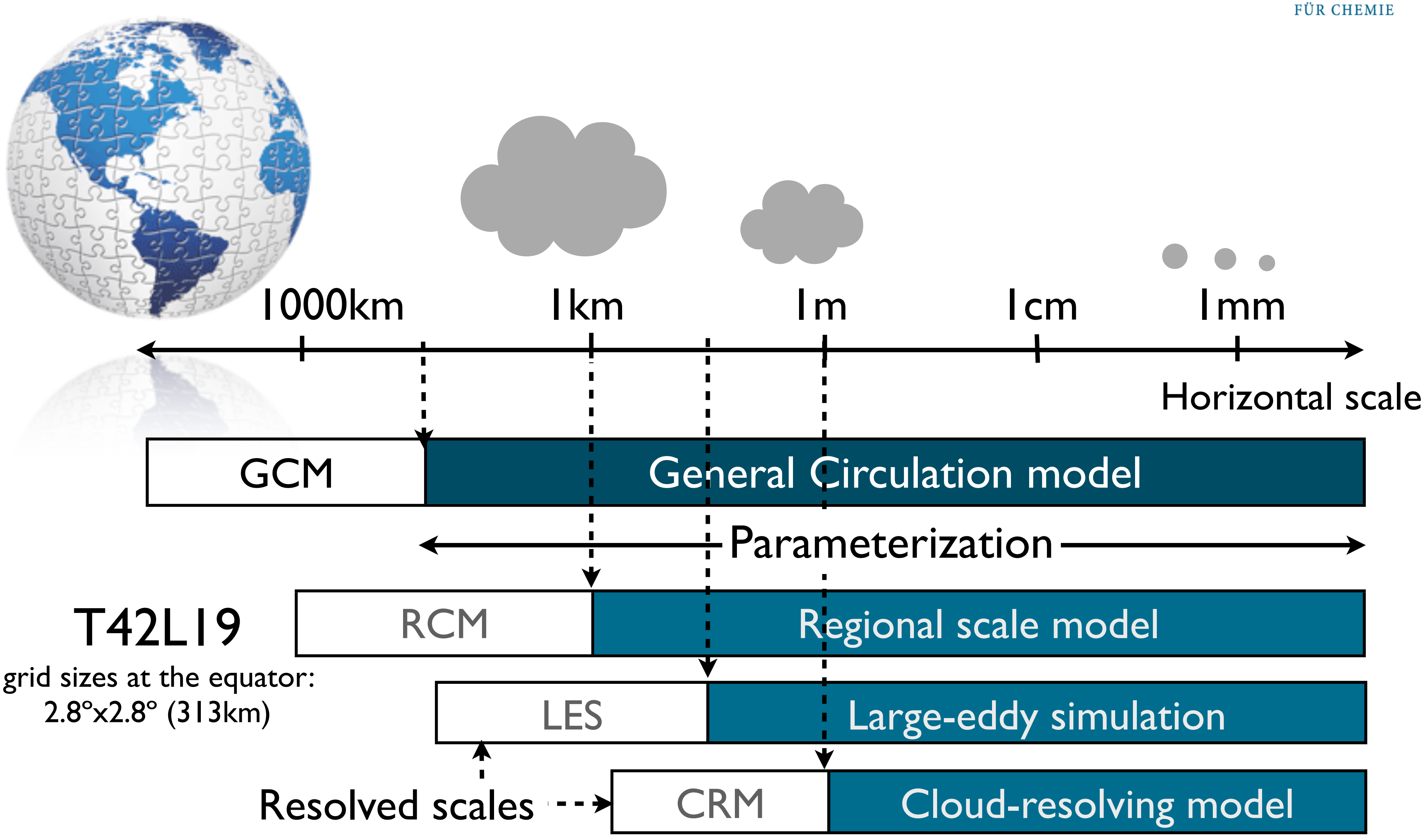
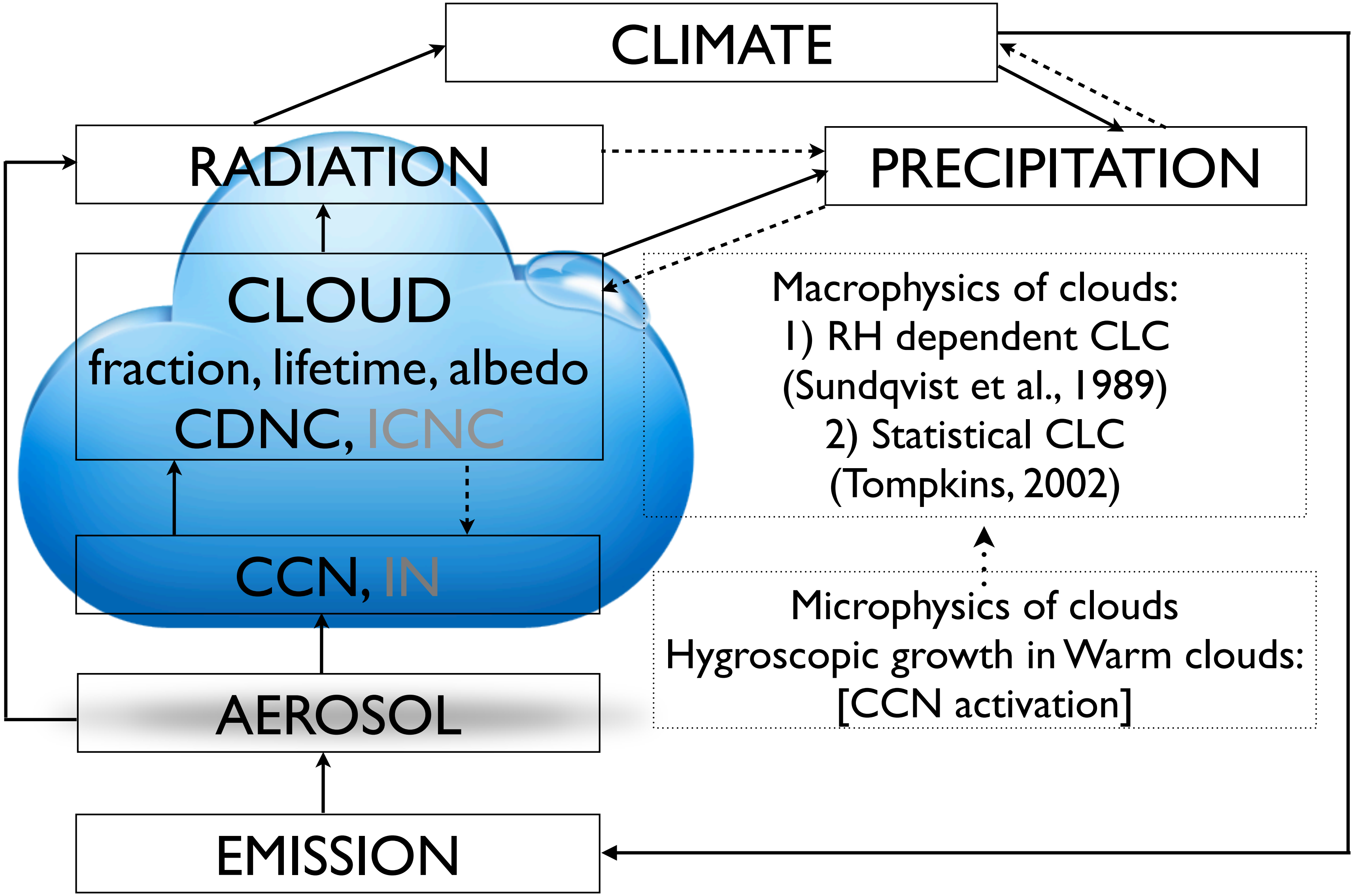
Size-resolved cloud condensation nuclei (CCN) spectra measured for various aerosol types at a non-urban site in Germany showed that CCN concentrations are mainly determined by the aerosol number size distribution. Distinct variations of CCN activation with particle chemical composition were observed but played a secondary role. When the temporal variation of chemical effects on CCN activation is neglected, variation in the size distribution alone explains 84 to 96% of the variation in CCN concentrations. Understanding that particles' ability to act as CCN is largely controlled by aerosol size rather than composition greatly facilitates the treatment of aerosol effects on cloud physics in regional and global models.

Multi-scale interactions in the climate system



T42L19
grid sizes at the equator:
2.8°x2.8° (313km)

Model description



Experimental Design

MAX-PLANCK-INSTITUT FÜR CHEMIE

- EMAC (ECHAM5/MESSy1.10) http://www.messy-interface.org
  - Model resolution : T42L19 (2.8°x2.8°, ~10hPa)
  - Emission field the year of 2000
  - Free-running simulation for 10years (+1year spin-up)

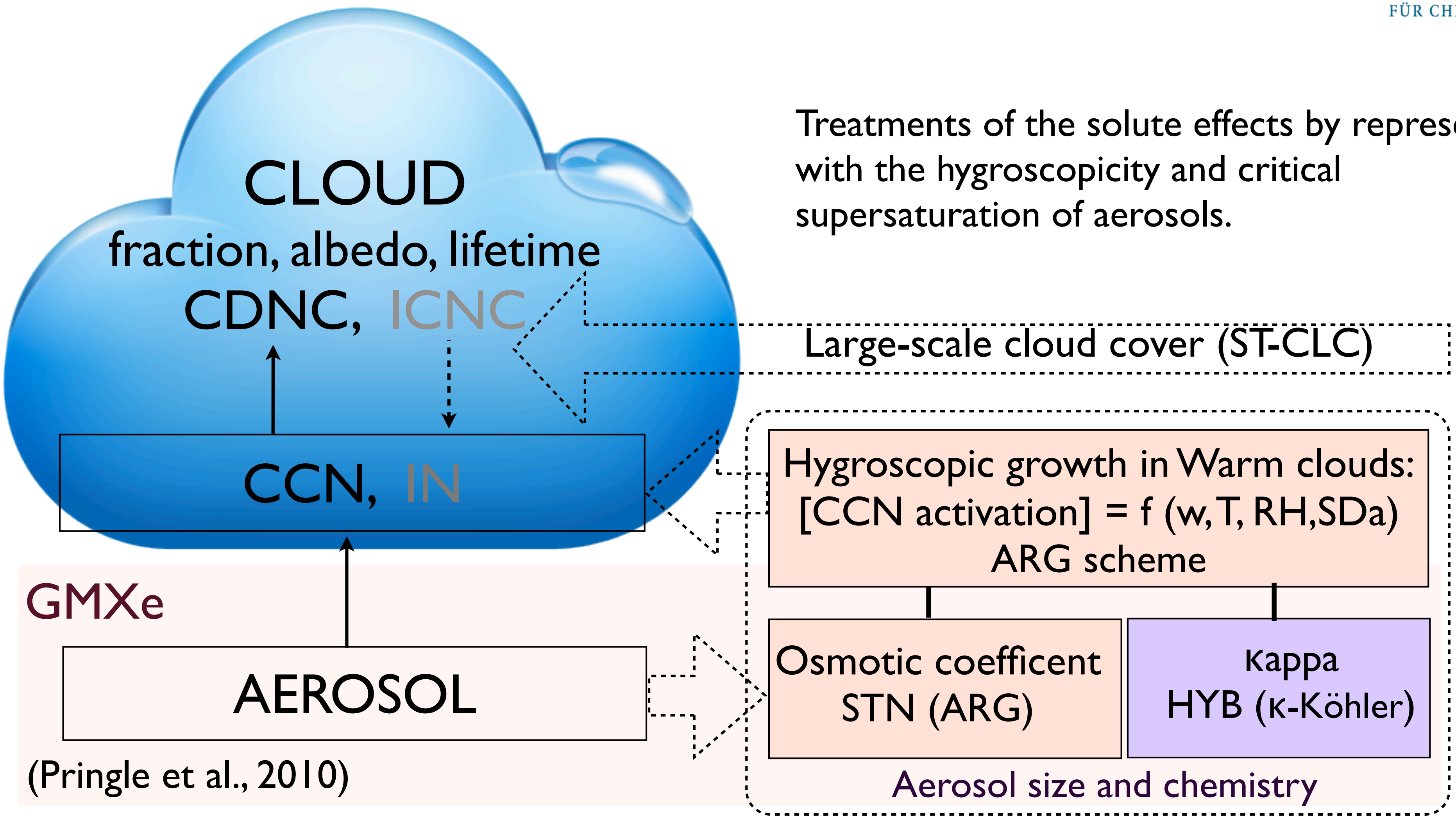
- Two moment Cloud microphysics (Lohmann, 2007)
- Statistical cloud cover scheme (Tompkins, 2002)
- Cloud droplet nucleation parameterization:
  ARG scheme (Abdul Razzak and Ghan, 1998, 2000, 2002)

STN (standard)	Osmotic coefficient
HYB (hybrid)	kappa value from (k-Koehler) :Petters and Kreiendweis (2007)

Model description

MAX-PLANCK-INSTITUT FÜR CHEMIE

Treatments of the solute effects by representing with the hygroscopicity and critical supersaturation of aerosols.



ω (vertical motion), T(temperature), RH (relative humidity), SD_a(size distribution of ambient aerosol)

Global annual mean of CCN activation

MAX-PLANCK-INSTITUT FÜR CHEMIE

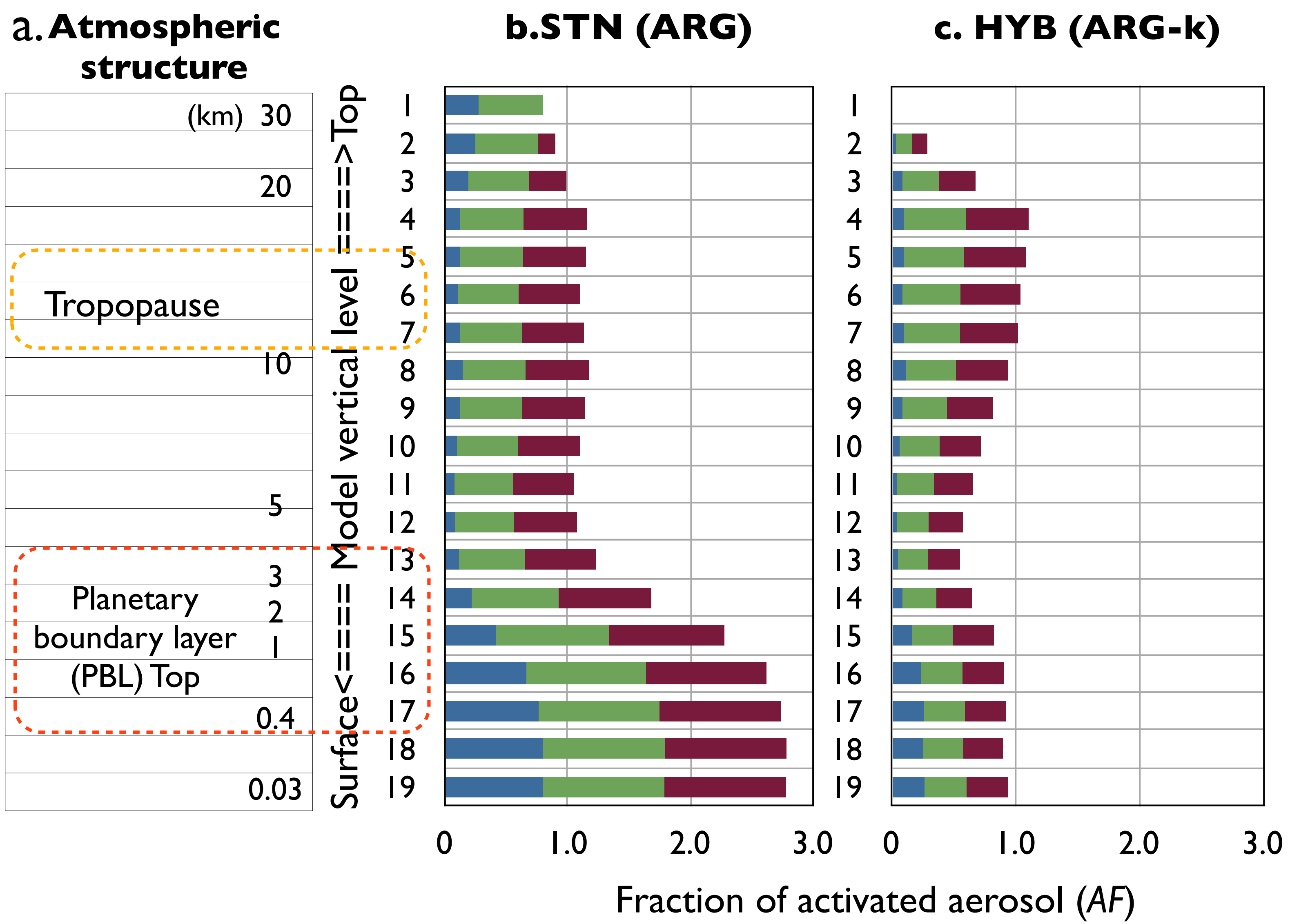
Aerosol activity (Size and Composition)

Large-scale cloud cover (Na size distribution)

From Surface to free troposphere

	Mode (i)	Nucleation	Aitken	Accumulation	Coarse
STN (ARG)	Activity (%)	0.12%	18.7%	58.6%	60.6%
	CCN(/m³)	4.90E+06	6.80E+07	3.30E+07	4.00E+05
HYB (ARG-k)	Activity (%)	0.06%	8.8%	31.3%	32.6%
	CCN(/m³)	5.30E+06	3.50E+07	1.00E+07	1.00E+05

Vertical distribution of aerosol activation



$$AF = \frac{Nact}{Na}$$

Relative error of TCC

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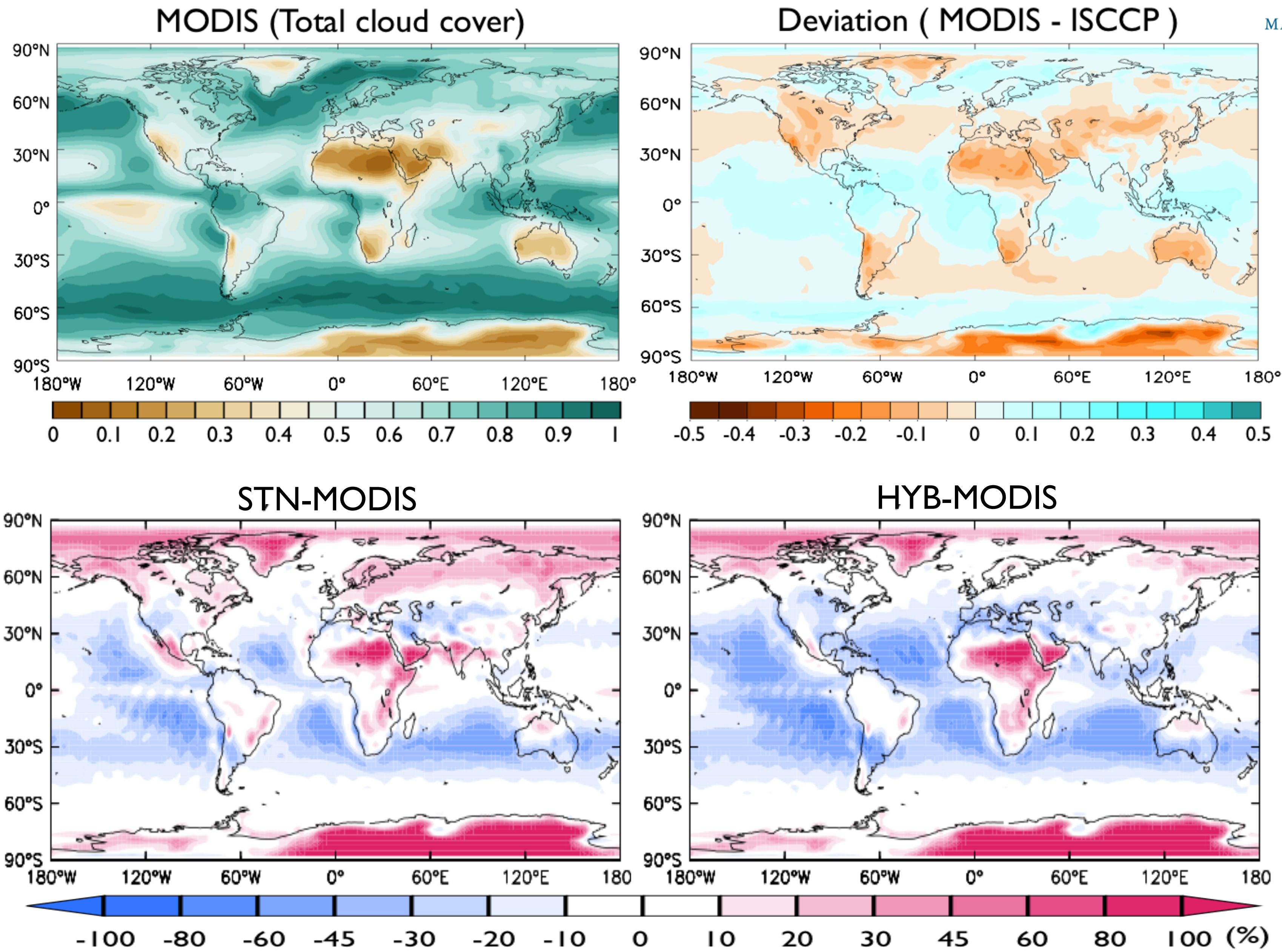
FÜR CHEMIE



MODIS
(2001-2010)
ISCCP
(2001-2008)

Relative error of NCRE at TOA

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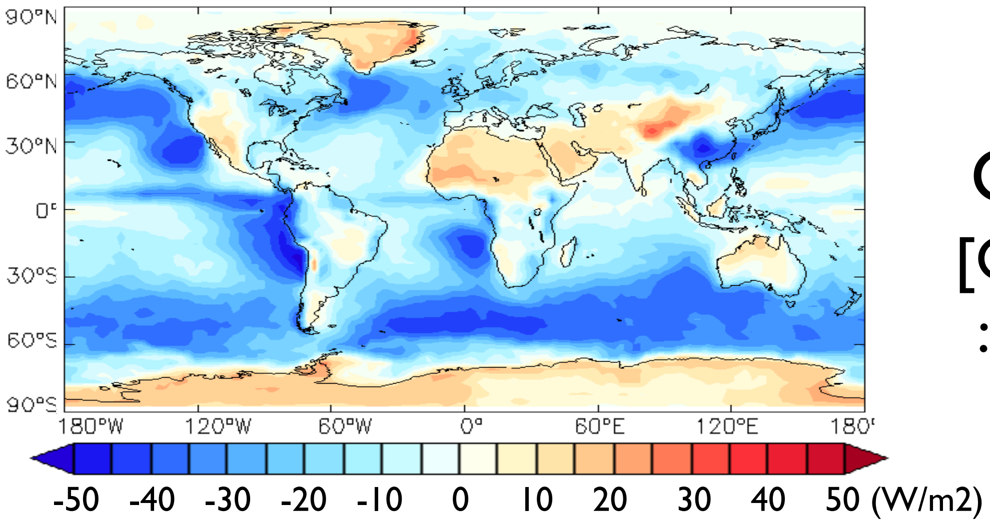
FÜR CHEMIE

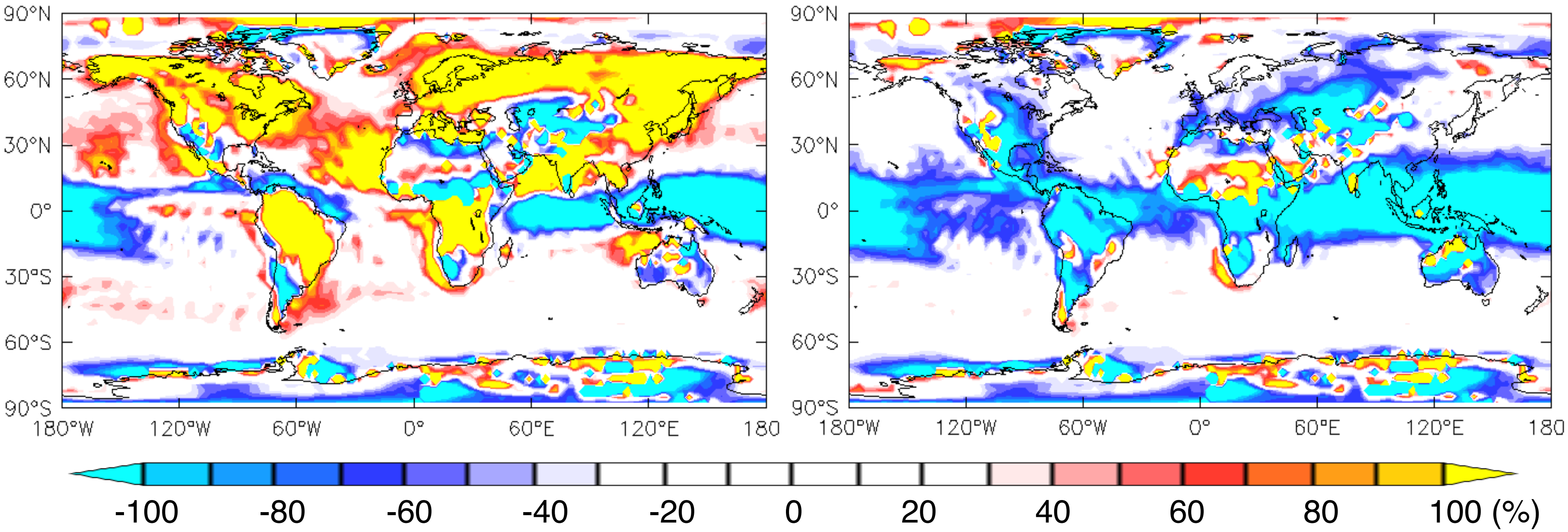


OBS (W/m2)
[CERES EBAF
:2000-2010]

Rel. Error(%) in NCRE
= (Model-OBS)/OBS ×100 (%)

STN-OBS

HYB-OBS



Summary and Conclusion

Chemicstry is important on cloud droplet nucleation and these activated aerosol impact on cloud properties and climate.

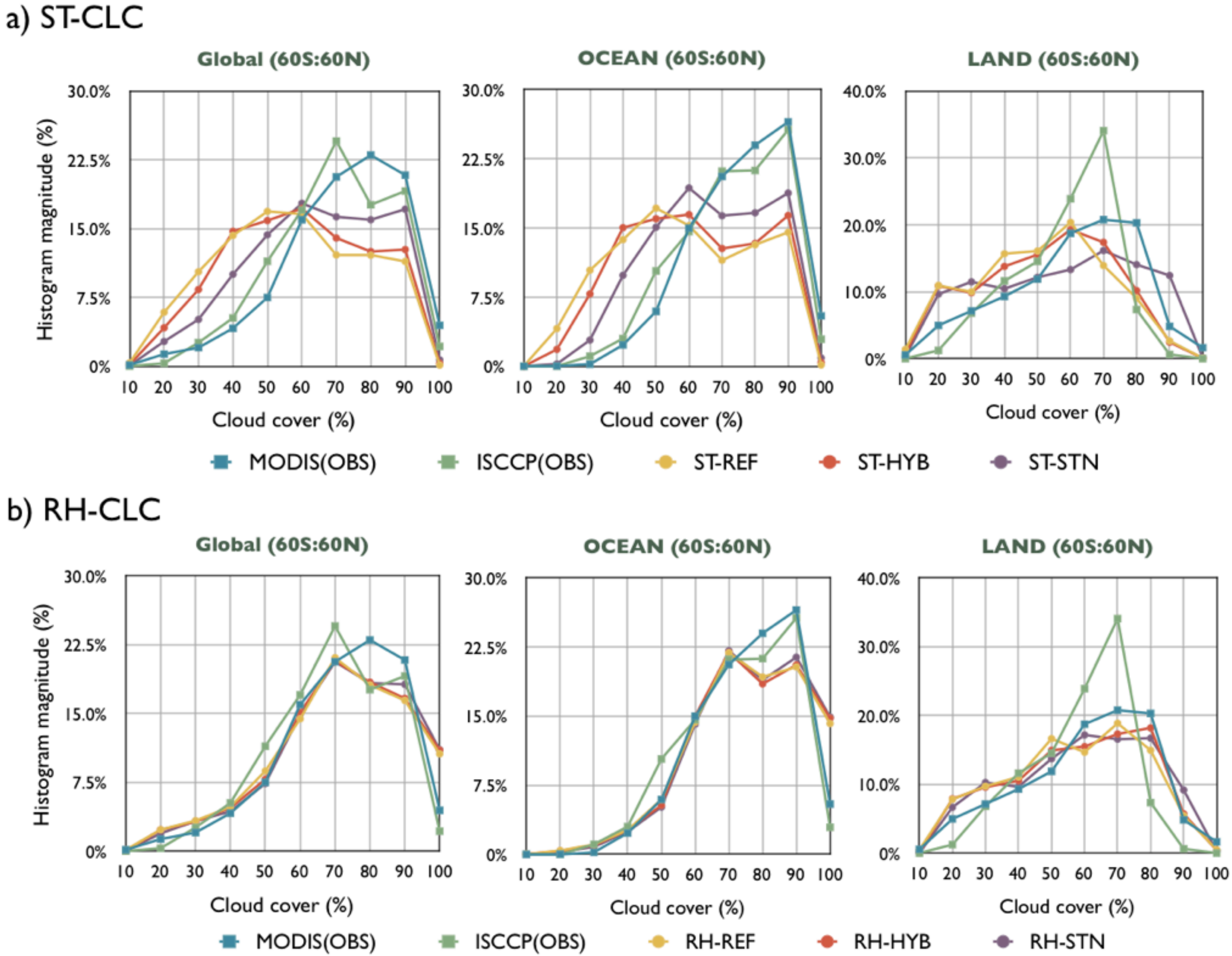
Sensitivity of aerosol activity patterns and cloud fraction

Large effect on NCRE

- ☑ over tropical continents
- ☑ Outflow of Atlantic oceans from Sahara
- ☑ Lands over Mid- and High latitude be more realistic

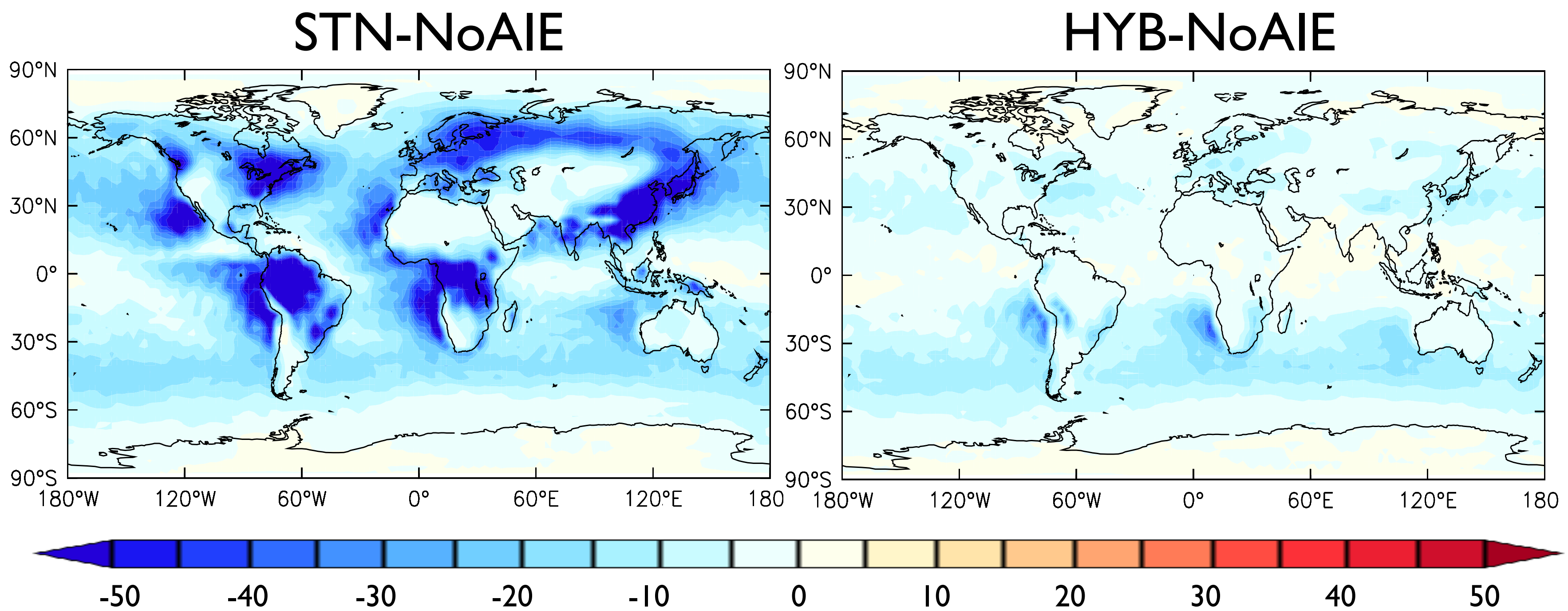
in future

meauserment of the chemical composition of aerosol populations


a) ST-CLC
Global (60S:60N)
OCEAN (60S:60N)
LAND (60S:60N)
Histogram magnitude (%)
Cloud cover (%)
MODIS(OBS)
ISCCP(OBS)
ST-REF
ST-HYB
ST-STN
b) RH-CLC
Global (60S:60N)
OCEAN (60S:60N)
LAND (60S:60N)
Histogram magnitude (%)
Cloud cover (%)
MODIS(OBS)
ISCCP(OBS)
RH-REF
RH-HYB
RH-STN

AIE on NCRE (W/m2)

Deviation between prognostic CDN (STN, HYB) and NoAIE

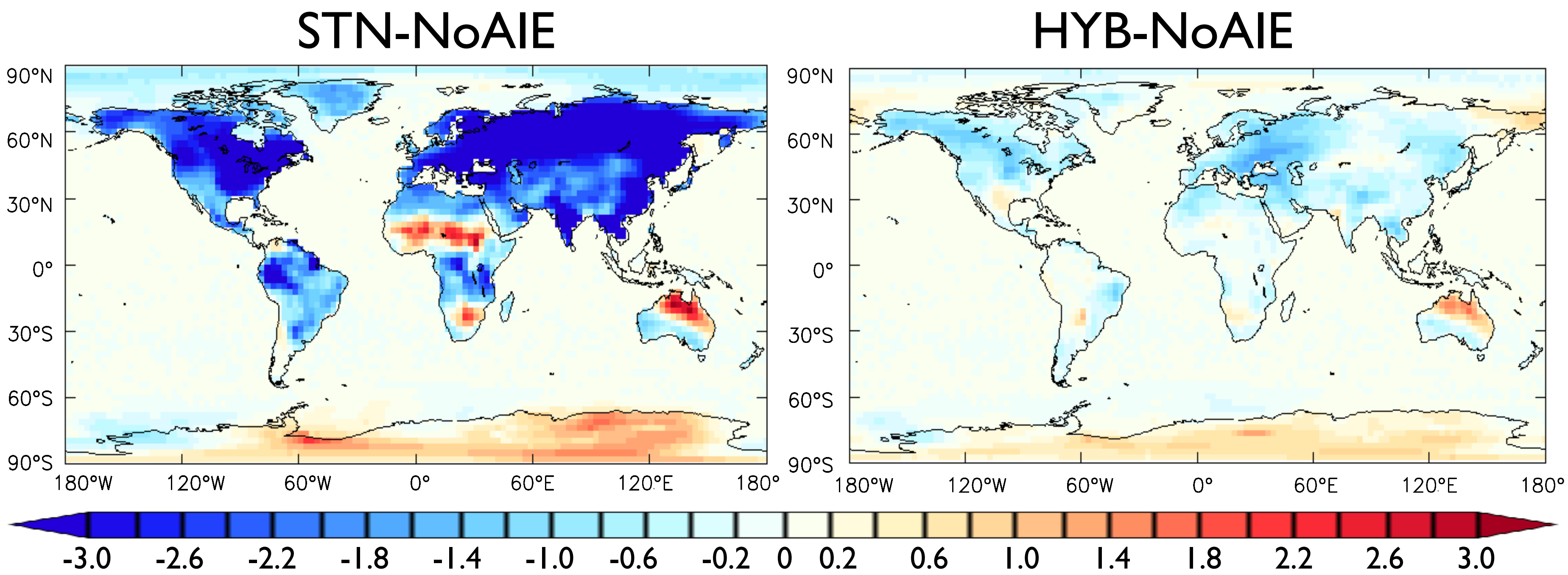


Deviation of NCRE (W/m2)

AIE on the surface temperature

MAX-PLANCK-INSTITUT FÜR CHEMIE

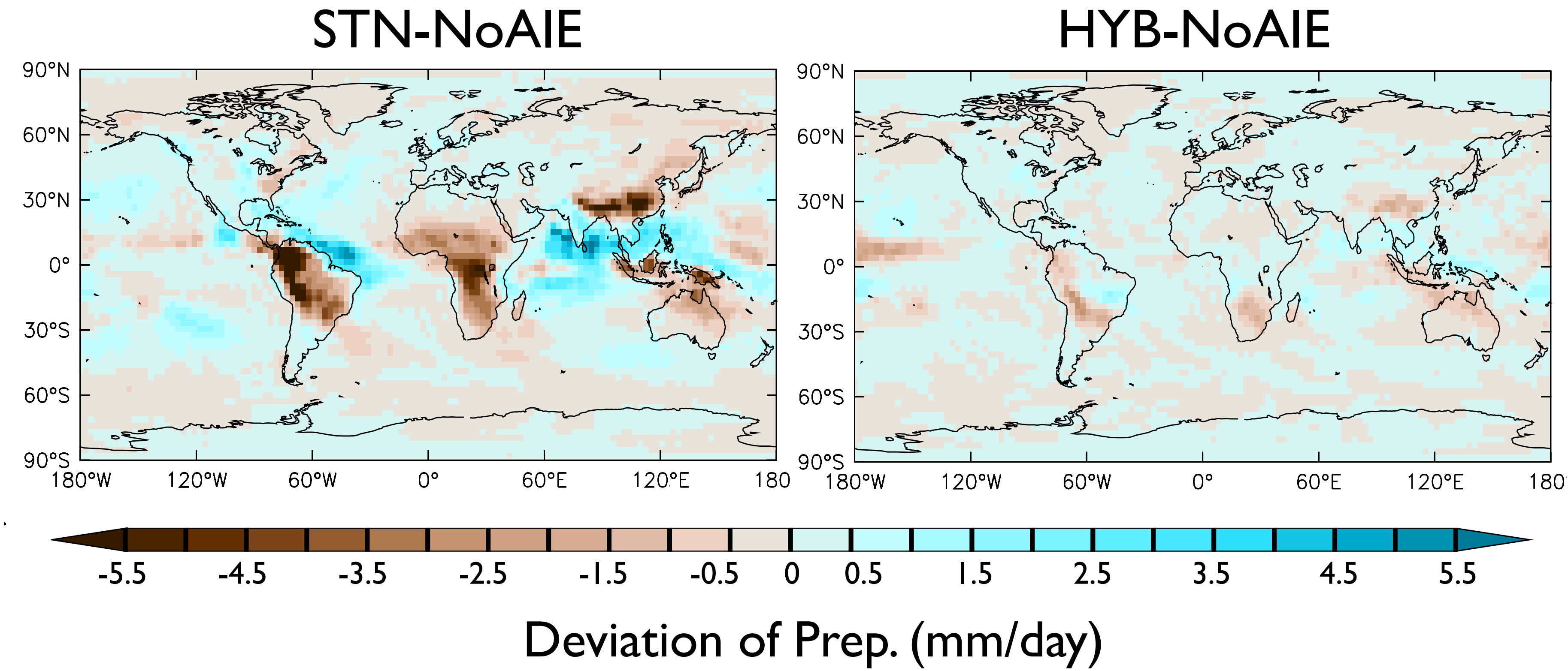
Deviation between prognostic CDN (STN, HYB) and NoAIE



Deviation of Tsurf (K)

AIE on the daily precipitation

Deviation between prognostic CDN (STN, HYB) and NoAIE



Relative error of Precipitation

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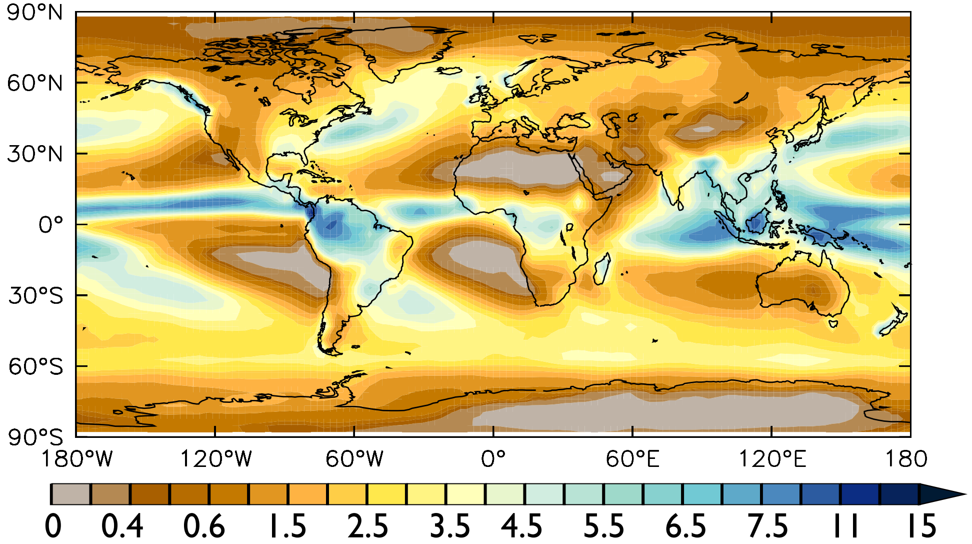
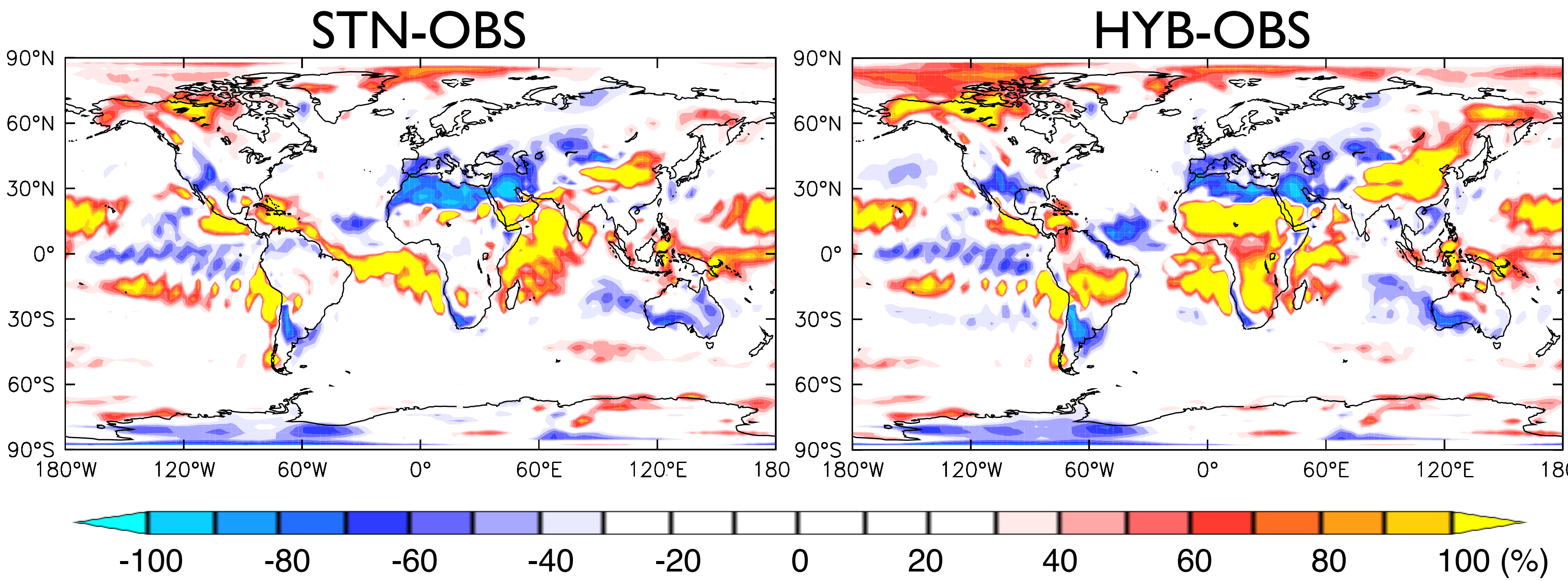
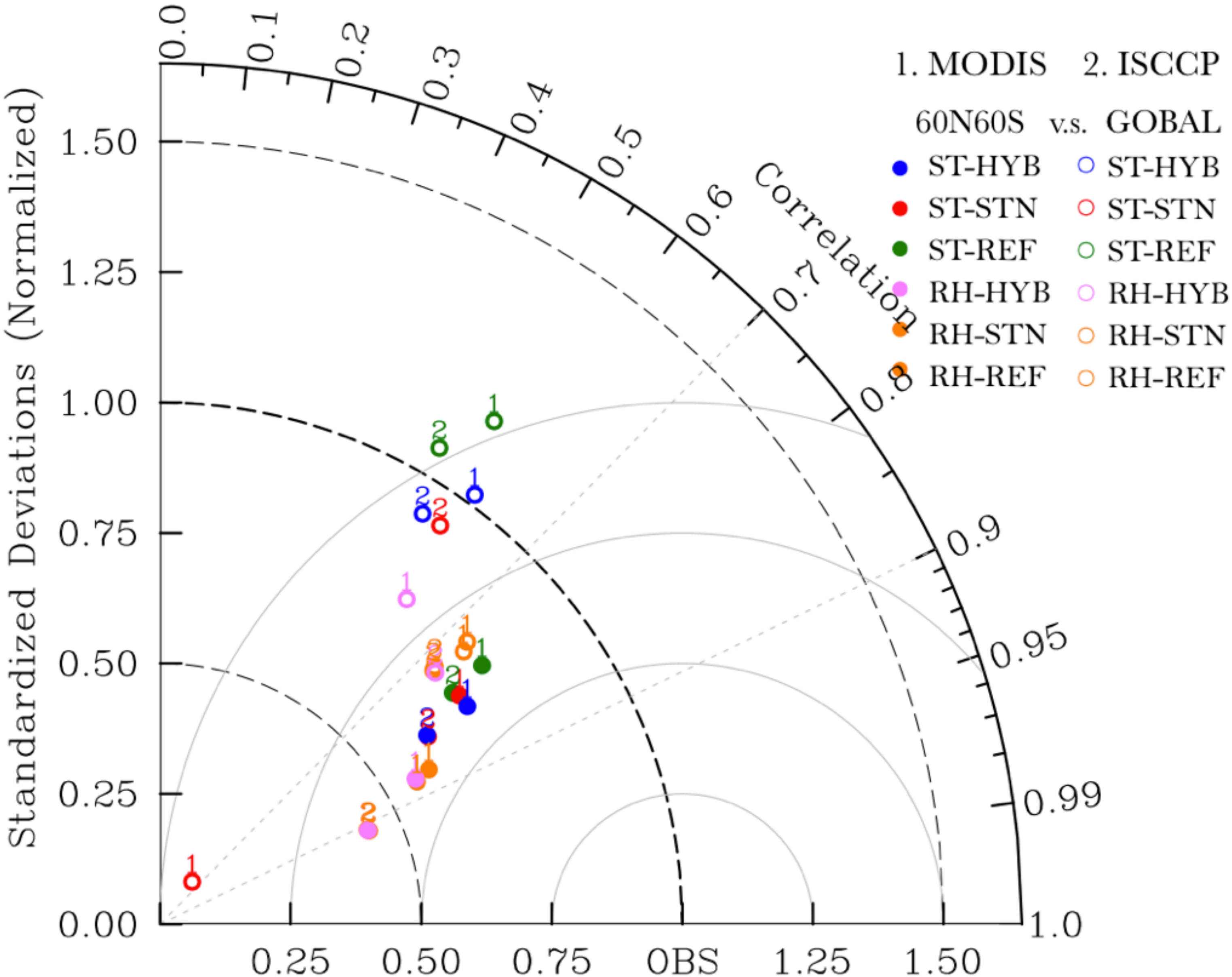
Rel. Error(%) in Precip.
= (Model-OBS)/OBS
x100 (%)



OBS (mm/day)
[GPCP:1981-2010]




1. MODIS 2. ISCCP
60N60S v.s. GOBAL
ST-HYB
ST-STN
ST-REF
RH-HYB
RH-STN
RH-REF
ST-HYB
ST-STN
ST-REF
RH-HYB
RH-STN
RH-REF
Correlation
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.95
0.99
1.0
Standardized Deviations (Normalized)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
0.25
0.50
0.75
OBS
1.25
1.50

General evaluation of EMAC

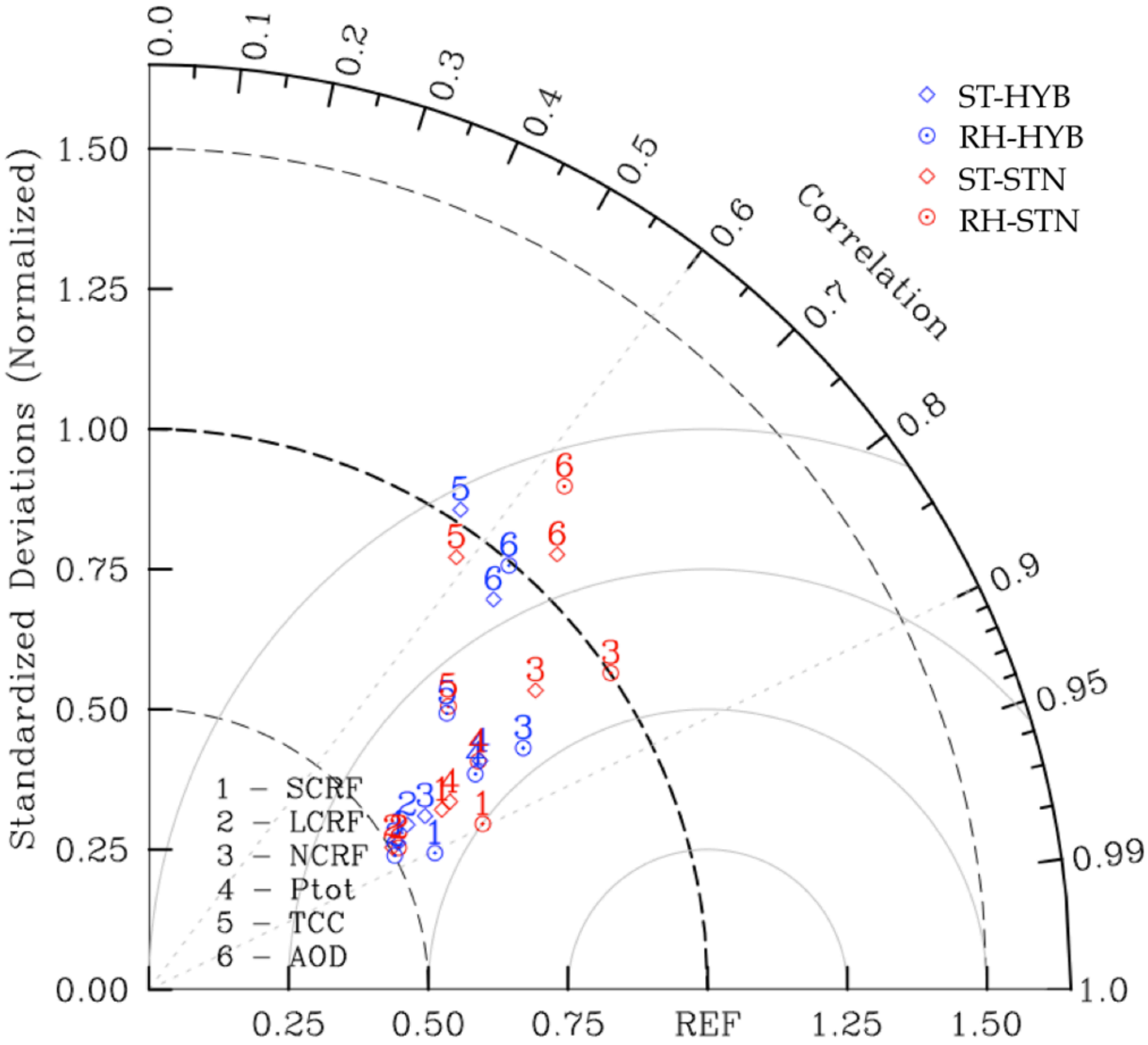


Table 3. Summary of main difference between STAND and HYBRID.

Parameter	STAND (ARG)	HYBRID (ARG-κ)
Critical saturation	$s_{c,i} = 1 + S_{C,i}$	$s_{c_\kappa,i} = a_w exp\frac{A}{D_i} = exp\left(\sqrt{\frac{4A^3}{27\kappa_i D_i^3}}\right)$
Critical supersaturation	$S_{C,i} = \frac{2}{\sqrt{\bar{B}_i}}\left(\frac{A}{3a_{c,i}}\right)^{\frac{3}{2}}$	$S_{C_\kappa,i} = s_{c_\kappa,i}$ -1
Kelvin effect	$A \equiv \frac{2\tau M_w}{\rho_w RT}$	$A \approx 0.66 \times 10^{-6} Km \times T^{-1}$
Solute effect	$\bar{B}_i \equiv \frac{M_w \sum_{j=1}^{J} r_{i,j}\mu_{i,j}\phi_{i,j}\epsilon_{i,j}/M_{a_{i,j}}}{\rho_w \sum_{i=1}^{J} r_{i,j}/\rho_{a_{i,j}}}$	$a_w = \frac{1}{1+\kappa_i\left(\frac{V_s}{V_w}\right)}$, $\kappa_i = \sum_{j=1}^{J} \hat{\epsilon}_{i,j}\kappa_j$

. S_C is the critical saturation ($s_c \cong S_C + 1$) in STN and is comparable to S_{C_κ} (= s_{c_κ} -1) in HYB.

. a_c is the dry radius of the smallest activated aerosol and is used for estimating the fraction of aerosol activation.

. M_w is the molecular weight of water vapor, ρ_w is the density of water; τ is the surface tension for water ($\tau = (76.10 - 0.155[T - T_{melt}])10^{-3}$) (Pruppacher and Klett, 1978), $R = 8.315 JK^{-1}$ is the ideal gas constant, and T is temperature (K).

. $r_{i,j}$ is the mass mixing ratio, $\mu_{i,j}$ is the number of ions the salt dissociates into water, $\phi_{i,j}$ is the osmotic coefficient, $\epsilon_{i,j}$ is the mass fraction of soluble material, and $M_{a_{i,j}}$ is the molecular weight, $\rho_{a_{i,j}}$ is the density of the aerosol fraction of component j and mode i (i=1,7).

. a_w is the water activity, κ_i is the hygroscopicity of aerosol mode (i), the volume of the dry particle (V_s) and the volume of water (V_w).

. $\hat{\epsilon}_{i,j}$ is the volume fraction of chemical component j in mode i, and κ_j is an independent hygroscopicity parameter of aerosol species (j).

Chang et al.,2013 in preparation