Comparison of INP Parameterizations for Dust Minerals in Climatological Simulations With a Global Model

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Motivation

- One aspect of reducing the uncertainty in weather and climate prediction due to deficits in the understanding of the role of ice nucleating particles (INP) in the formation of ice and mixed-phase clouds is using parameterizations for them in models, which represent the physical processes adequately.
- Mineral dust particles are efficient INP (among various other important roles of dust in weather and climate related processes), but not all mineral species are equally efficient INPs
- Recent laboratory studies: K-feldspar may be the most efficient INP at warmest temperatures (248 K – 268 K) for immersion freezing (e.g., Atkinson et al., 2013)
- Other dust minerals also can be activated as INP at colder temperatures: illite, kaolinite, quartz, hematite

→ Models should not treat all dust as equal, but take the mineralogy of dust into consideration for simulating INP number concentrations and ultimately ice and cloud formation

Questions for Study:

1) How do model calculated INP number concentrations from individual minerals differ between different types of parameterizations, which depend on different physical variables?

2) What effect do different assumptions for the dust mineral model have on INP numbers? Here we look especially at different assumptions for the size distributions of mineral fractions that are emitted from dust sources.

3) How do the answers for 1) and 2) differ between internal and external mixing assumptions for the dust minerals?

Model

- NASA GISS Earth system model ModelE2.1 (Kelley et al. 2019, submitted)
- Resolution: 2º x 2.5º latitude by longitude, 40 layers up to 0.1 hPa
- Version with individual dust mineral tracers (Perlwitz et al. 2015a). Emission of mineral mass fraction is based on soil mineral aggregation and brittle fragmentation theory (Kok, 2011), augmented with large particle emission
- Dust minerals: illite, kaolinite, smectite, carbonates, quartz, feldspar, iron oxides (hematite), gypsum, as well as accretions of iron oxides with the other minerals
- 5 dust size bins covering total range 0.1-32 µm particle diameter (0.1-2 µm, 2-4 µm, 4-8 µm, 8-16 µm, 16-32 µm) for emission, advection, and deposition of the dust mineral tracers

Experiments

1) SMF (soil mineral fraction) AeroCom Size: soil mineral fractions determine 1-to-1 the dust aerosol mineral fractions at emission; AeroCom dust size distribution used for emitted total dust, partitioned according to the soil mineral fractions for clay and silt

2) AMF (aerosol mineral fraction): emitted mineral mass size distributions are derived by aggregation of soil minerals, BFT, augmented with large particle emission (see Perlwitz et al., 2015)

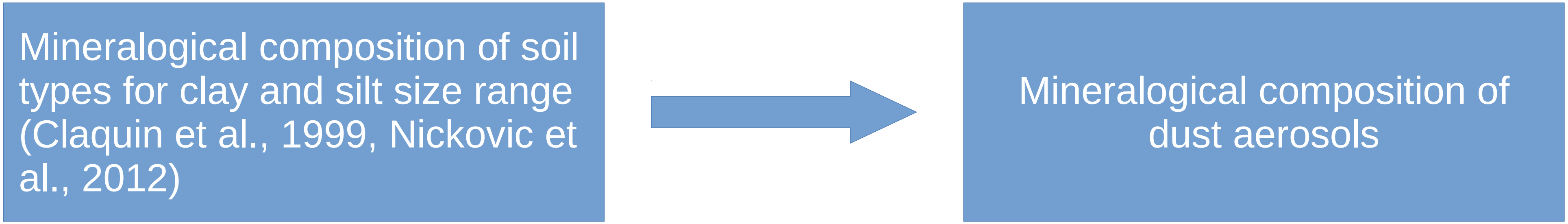
3) AMF mod. (modified) Feldspar: same as 2) but using measured quartz size distribution for deriving the feldspar size distribution to account for a bias in feldspar measurements

All: 20 model-year (1991-2010) simulations to calculate dust mineral and thermodynamic fields; prescribed variable SST and sea ice as lower boundary conditions; nudged with NCEP winds; dust emission and load in simulations are calibrated separately for the different size distribution assumptions

INP were calculated offline from monthly model output, the clay size range was divided into 4 subclay bins for the INP calculations

Why do we do the SMF Aerocom Size experiment?

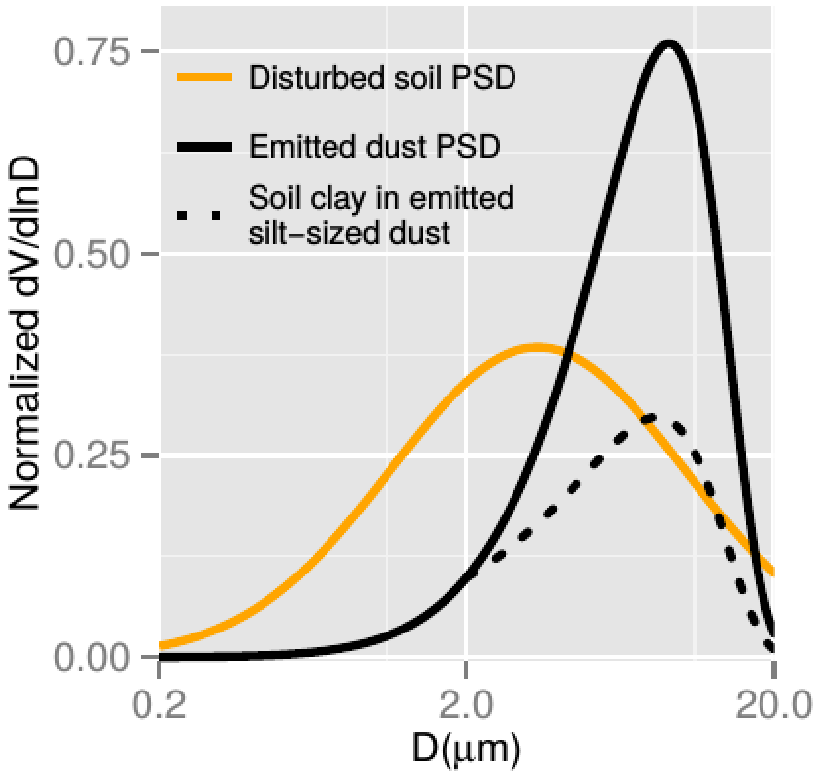
- A few studies have used dust mineralogy to calculate INP concentrations (Hoose et al., 2008; Atkinson et al., 2013; Wilson et al., 2015; Vergara-Temprado et al., 2017)



Assumption in these studies: 1-to-1 projection of the mineral composition of soil types in clay and silt to the size distribution of the mineral composition of the dust aerosols

Improved approach for dust module in NASA GISS’s ModelE

based on soil aggregation and brittle fragmentation theory (Kok, 2011), applied to minerals to determine emitted volume size distributions of individual minerals



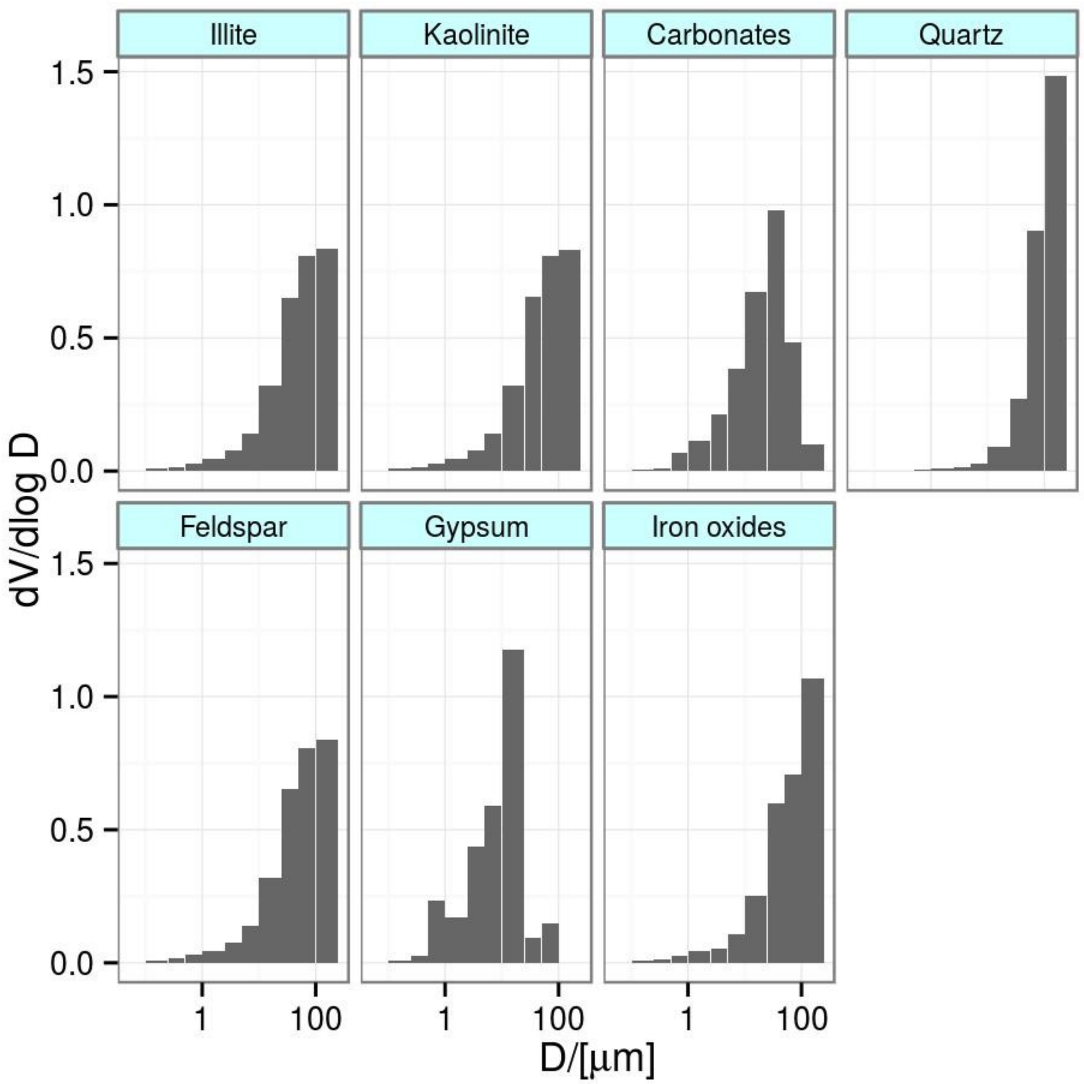
Fully dispersed mineral mass in soil → (Soil-aggregation / Partial fragmentation) → Reconstructed size-dependent mineral mass in emitted aerosols

Perlwitz et al., (2015a)

Only for emission by saltation!

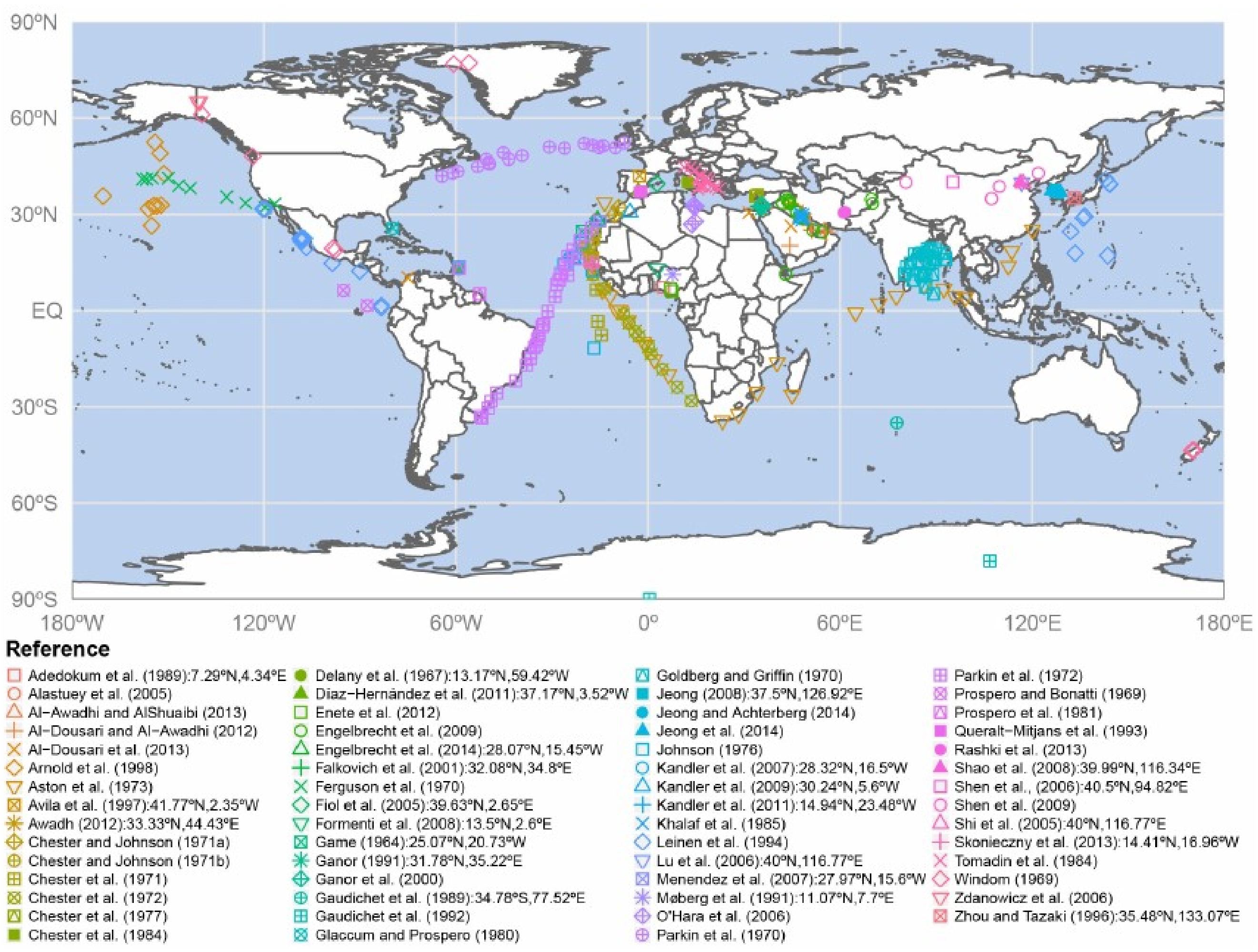
Large particle emission

Volume size distribution of minerals is derived from dust concentration measurements at Tinfou, Morocco (Kandler et al., 2009)



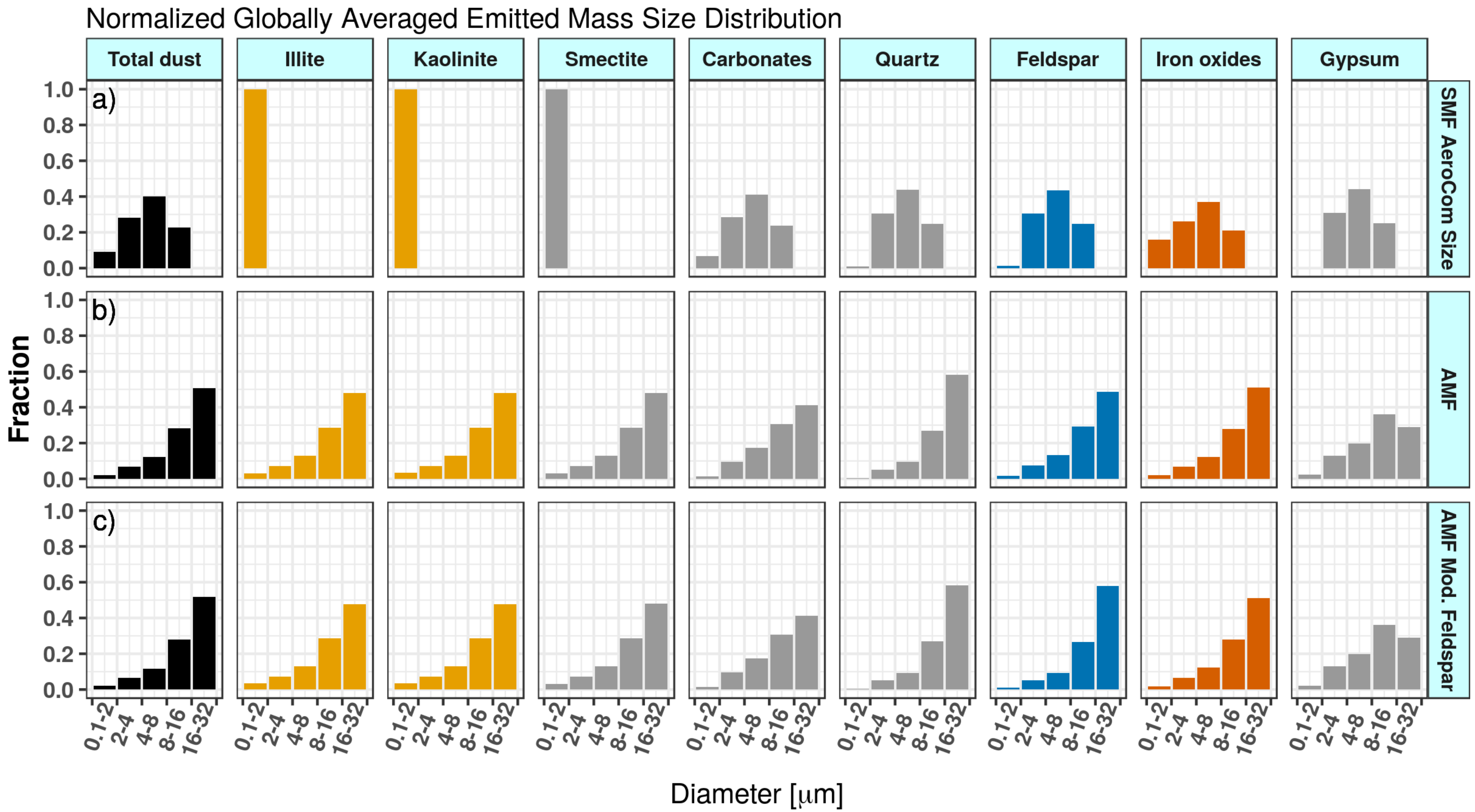
- Illite and kaolinite: Similar volume size distribution; most of the volume (mass) is found in higher particle size classes, even beyond silt size range (probably mostly due to aggregation)
- The carbonates and gypsum peak in the coarse silt size class
- Distinctive size distribution of quartz with steep increase in the volume distribution for largest particle sizes

Evaluation



- Perlwitz et al., (2015b)
- Pérez García-Pando, (2016): Representation of dust and elemental composition derived from simulated minerals versus measurements at Izaña (Tenerife, Canary Islands), Spain

Emitted Mineral Mass Size Distributions



Applied INP Parameterizations for Dust Minerals for Immersion Freezing

Singular description (active site parameterizations): INP number is a function of dust particle number, particle surface area, and temperature, but no time dependence

- K-feldspar: Atkinson et al. (2013)
- kaolinite: Murray et al. (2011)
- illite: Broadley et al. (2012), Diehl and Mitra, (2015)

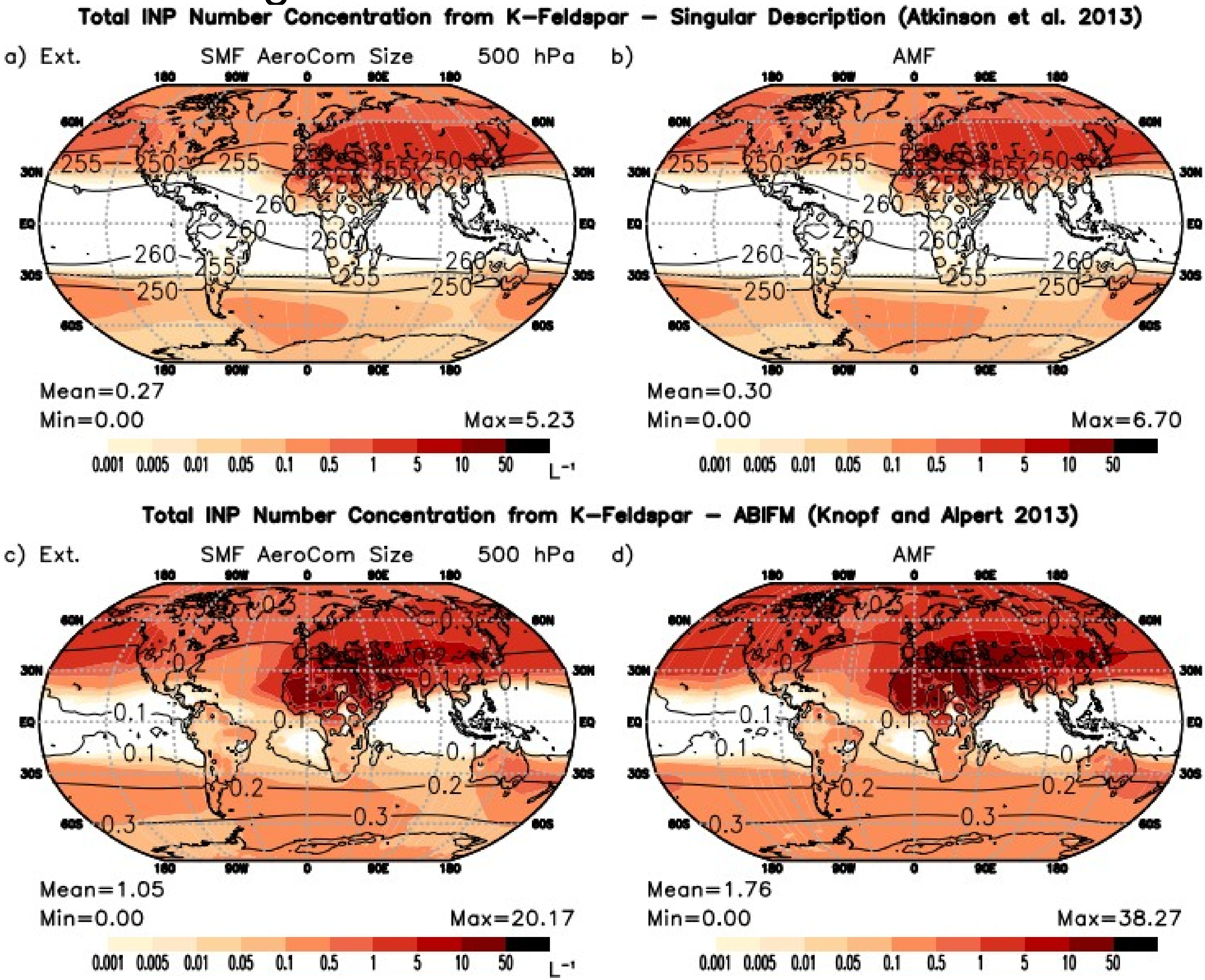
Water activity based immersion freezing model (ABIFM, Knopf and Alpert, 2013): INP number is a function of dust particle number, particle surface area, delta water activity (temperature, relative humidity), time

- K-feldspar, kaolinite, illite, hematite

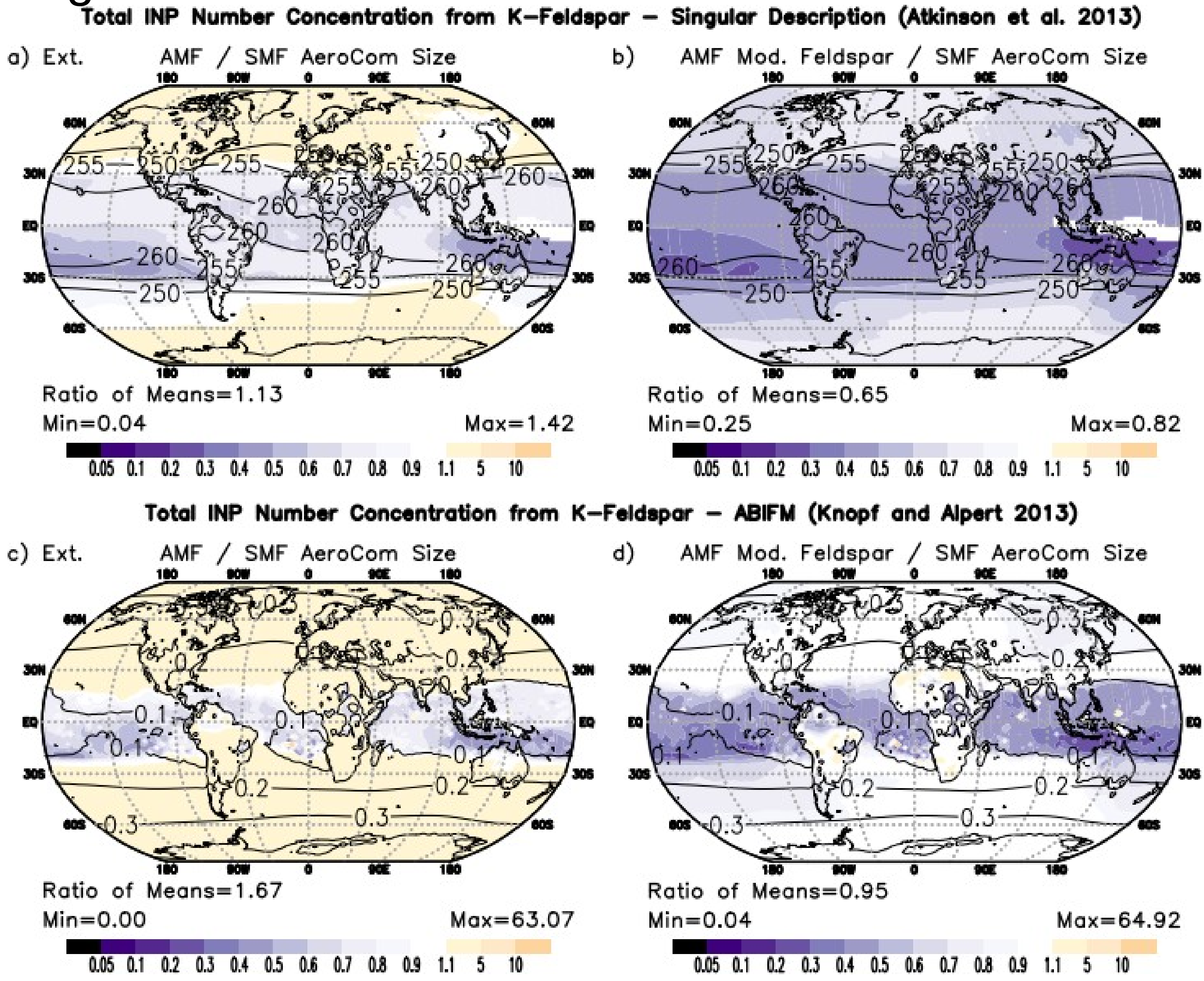
Singular description versus ABIFM – K-feldspar – external mixing of minerals

INP conc. follow temperature field

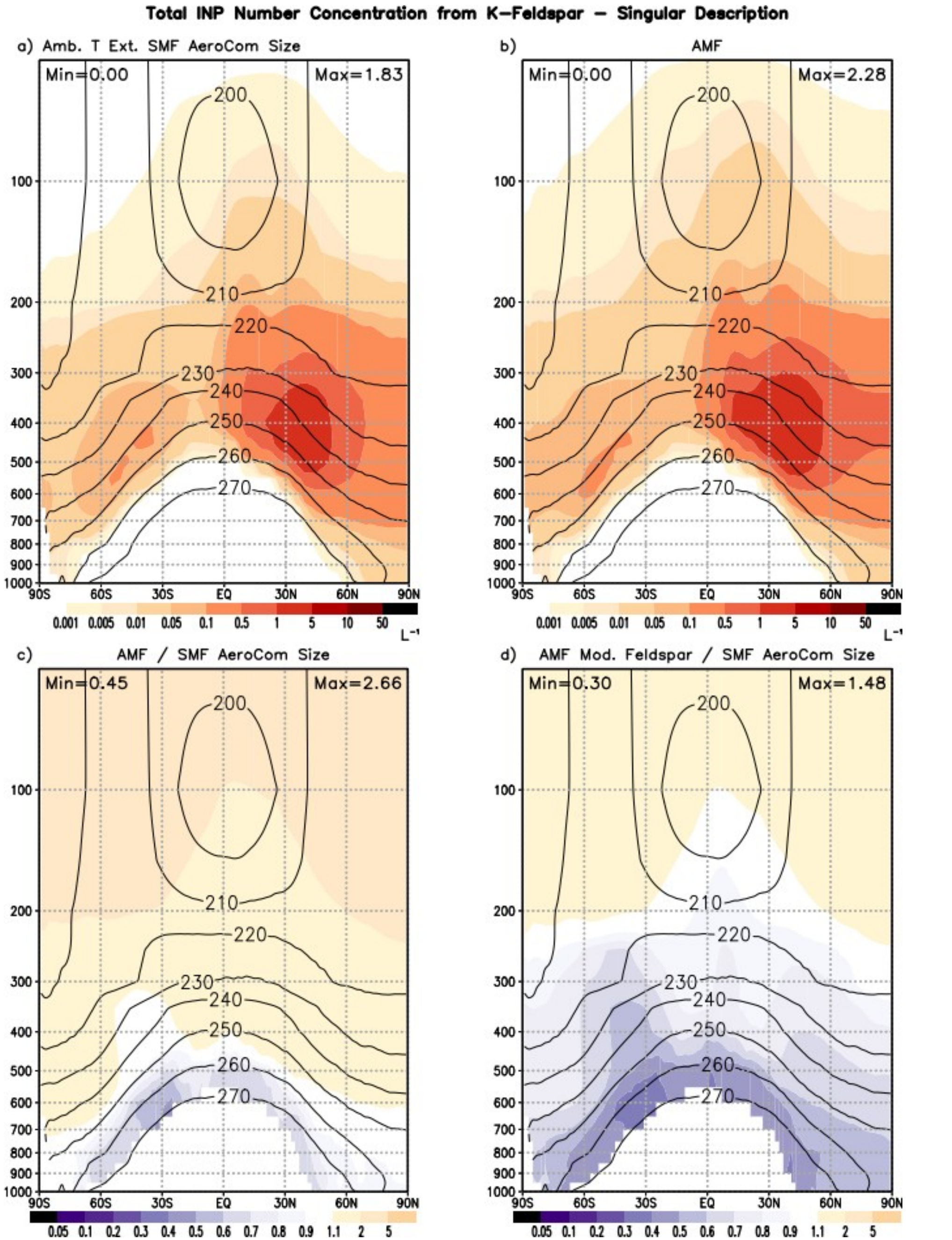
INP conc. follow water activity field

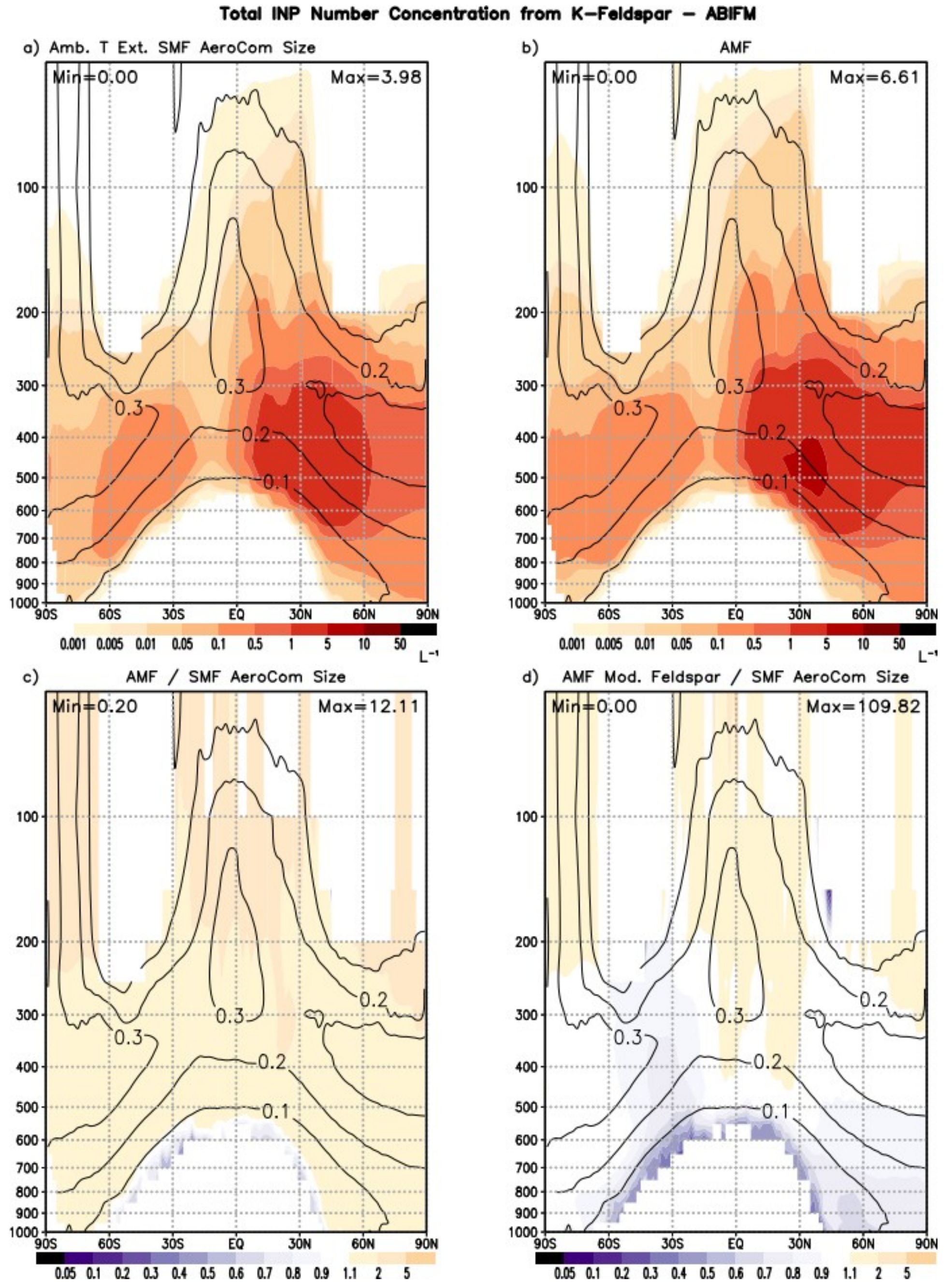


Sensitivity to dust size distribution – K-feldspar – external mixing of minerals

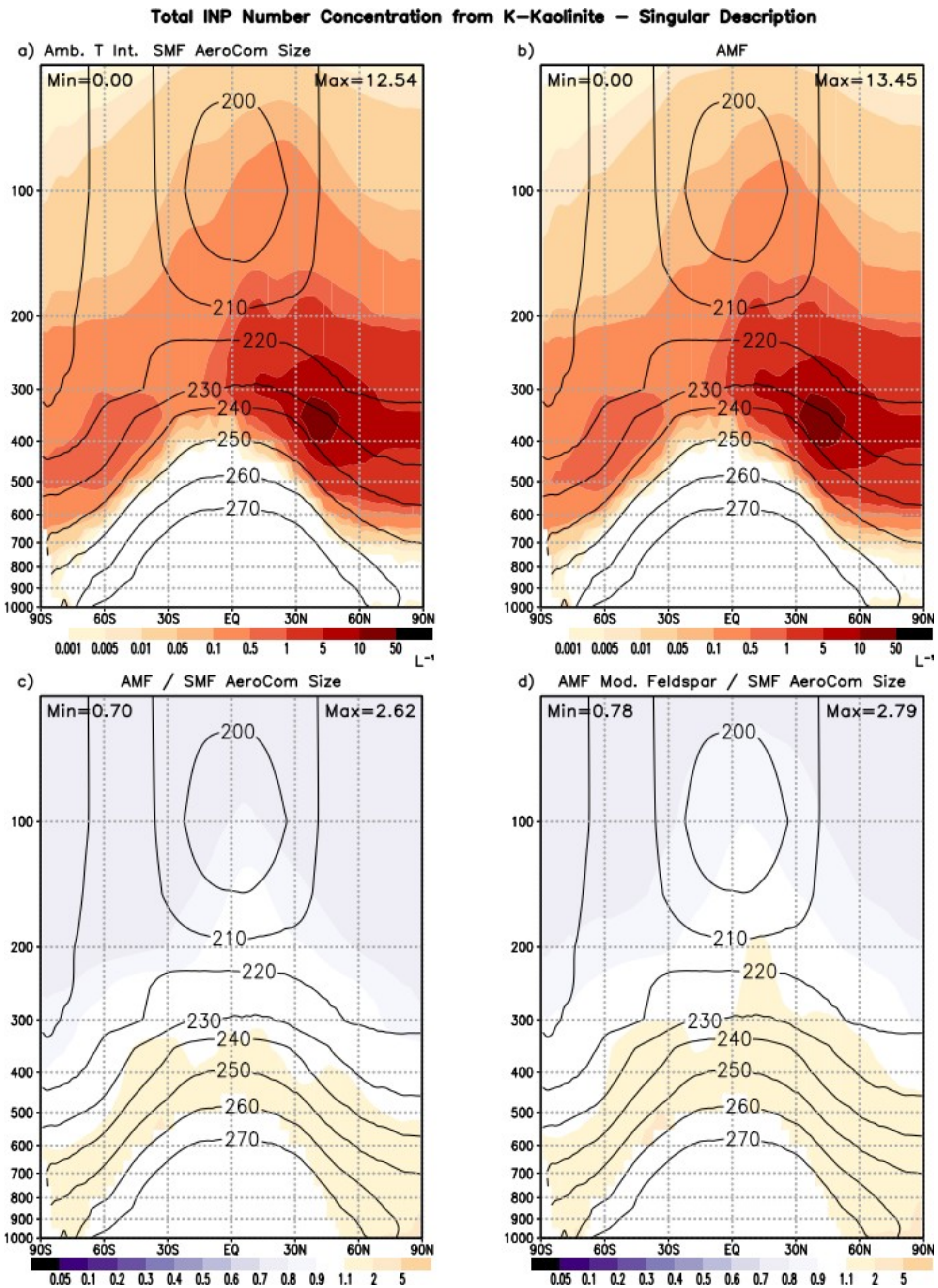


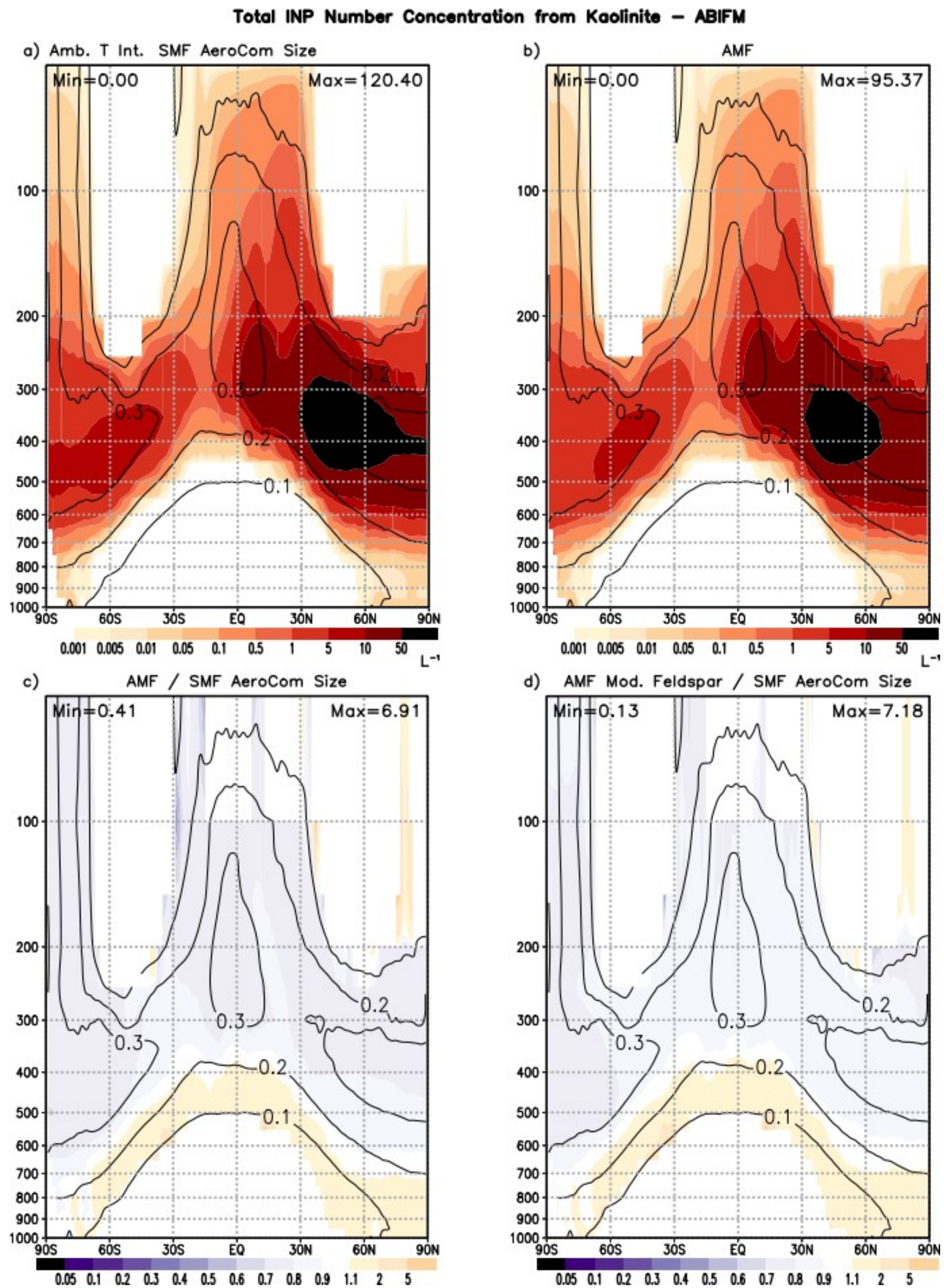
Singular vs. ABIFM - K-feldspar – external mixing – Differences visible mostly in stratosphere because of sole temperature vs. water activity dependence





Kaolinite – internal mixing



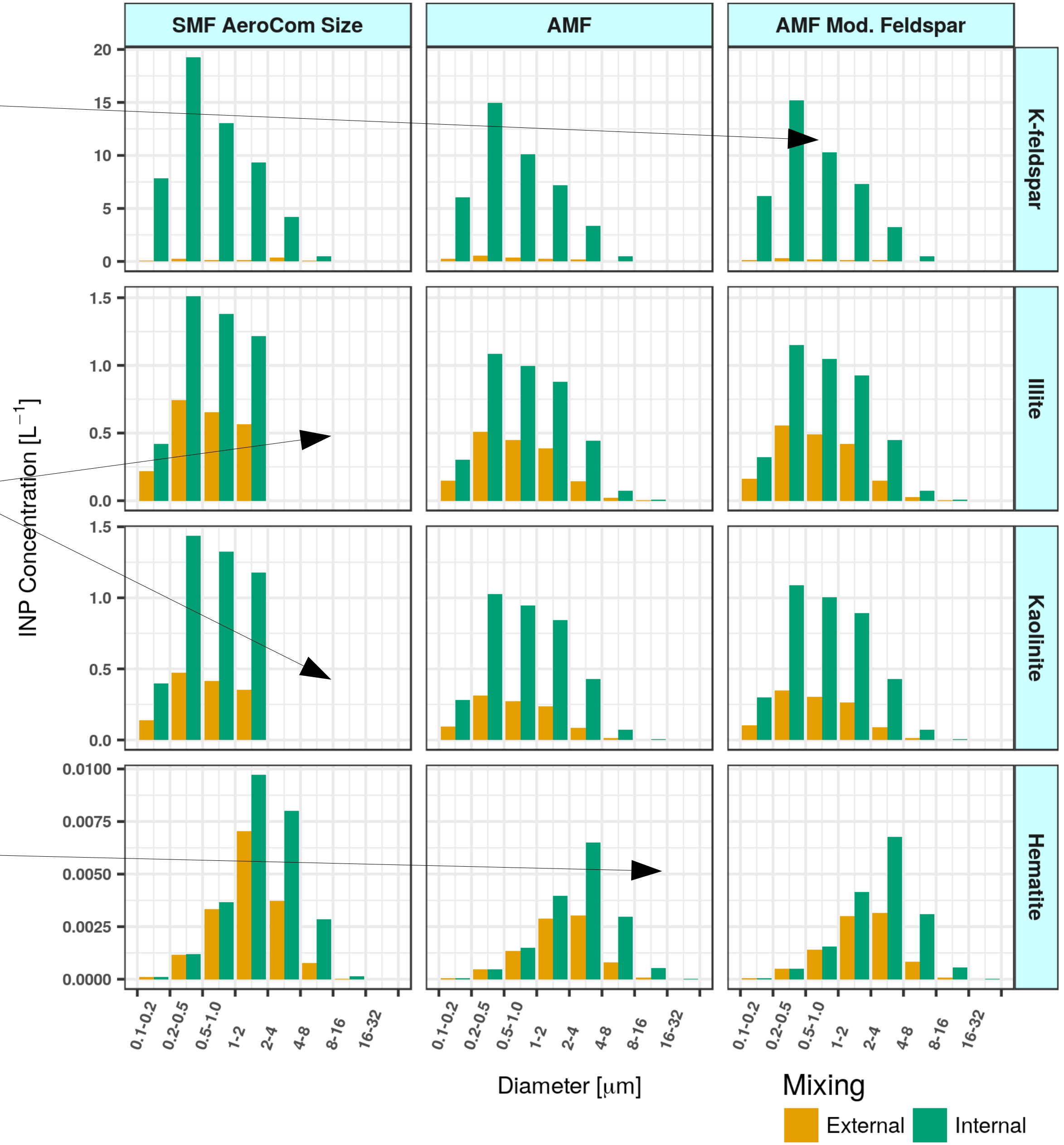


Size resolved INP number concentration from minerals for ABIFM for external and internal mixing

Reduced total and peak INP from feldspar, but increase of contribution of larger INP to total for AMF methods

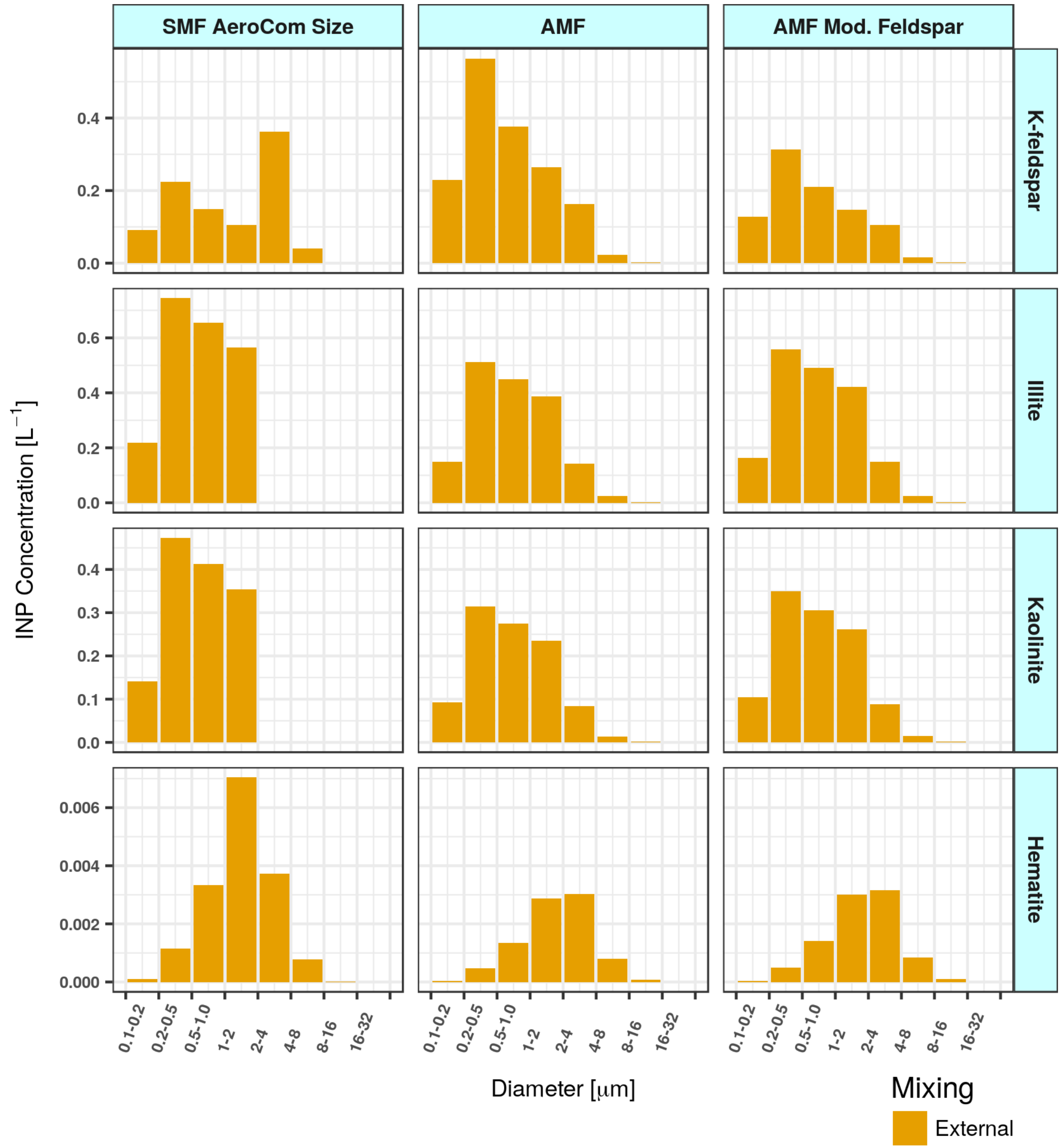
SMF method cannot simulate illite or kaolinite INP > 2 µm

Shift of hematite INP size distribution to larger particles sizes for AMF methods



Size resolved INP number concentration from minerals and experiments – ABIFM – external mixing only

Unrealistic INP size distributions for SMF method



Conclusions

- Total INP numbers from singular description and ABIFM are similar in middle and high latitudes in troposphere. Differences in tropics, especially over land areas, since temperature fields and delta water activity fields are different. Stratospheric zonal mean vertical distributions of the INP fields are different, too.
- Uncertainty in the total INP number due to dust size distribution error, when soil mineral aggregation is not considered is smaller than uncertainties from other sources. However, looking at the total INP number obscures substantial errors in the size distribution of the INP numbers (artifacts, the shift of the peak INP number to larger sizes for hematite, and an increase in the relative contribution of larger particle sizes to total INP). Size distributions matter!
- The higher the INP efficiency, the larger the difference between the INP numbers for assuming internal or external mixing of minerals.
- The INP efficiency seems to be inversely correlated with the sensitivity of the INP number size distribution to the emitted dust size distribution.

Next steps

- Repeat simulations and analysis with high-frequency model output, instead of monthly averages, to account for INP activation related to short-term variability (e.g. convection); Hypothesis: differences between parameterizations as well as sensitivities to dust size distributions will be robust, qualitatively, but there may be changes in magnitudes of the calculated INP number concentrations.
- More detailed analysis, e.g. looking at differences between areas close to source of dust aerosols and remote regions after transport, or looking at differences and sensitivity for sampled ranges of temperatures, relative humidity, and dust number concentrations.
- Compare model predicted INP number concentrations, using the different parameterizations, to measured atmospheric INP numbers.

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