Natural and anthropogenic contributions to mineral dust aerosol

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Mineral soil dust – natural and anthropogenic

- Mineral dust is **typically considered a natural aerosol** in climate assessments
- BUT: **Human activities**, such as land cultivation, **contribute** to mineral dust emission
- Anthropogenic mineral dust impacts daily life, **not only in (semi-)arid areas**

Anthropogenic dust sources

- Dust source associated with **agricultural land use**
  - Mineral dust only (no urban pollution)
  - Not considered, because not wind-generated: Emissions from vehicles (dirt roads, tillage, recreational use); military operations
  - Not considered: Indirect anthropogenic sources, e.g. hydrological

→ **Global impact?**

source: ndr.de

Dust from anthropogenic sources

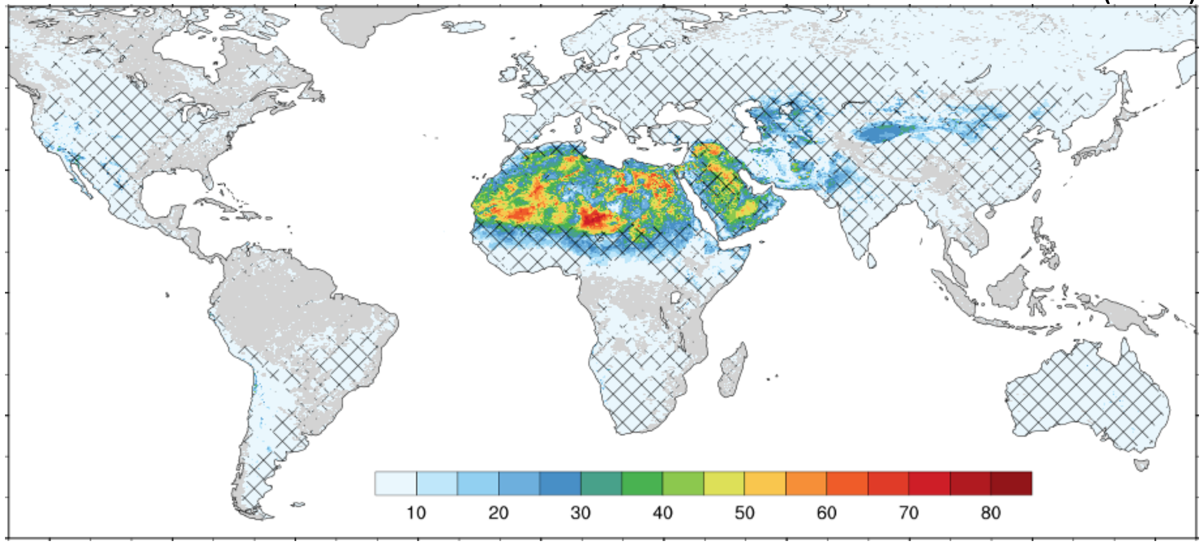
- Estimates range from < 10 to 50%

  (e.g. *Tegen and Fung*, 1995; *Sokolik and Toon*, 1996; *Tegen et al.*, 2004; *Mahowald et al.*, 2004)

- *Ginoux et al.* (2012) estimated that anthropogenic sources contribute 25% to total dust emissions
  - Areas with > 30% land use (HYDE 2, *Klein Goldewijk*, 2001) were considered as anthropogenic sources
  - FoO of MODIS DeepBlue dust optical depth (DOD) exceeding a threshold of 0.2
  - Resolution 0.1° × 0.1°
  - Offline dust emissions: *Ginoux et al.* (2001) parameterization with uniform threshold wind speeds, combined with FoO

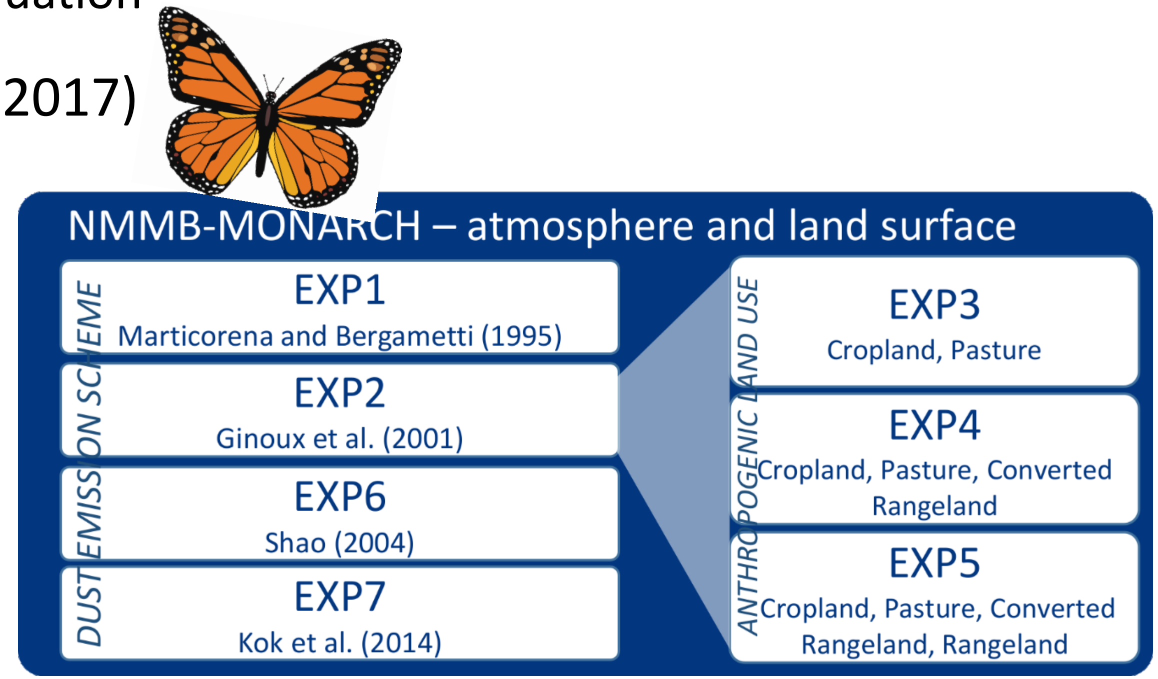
FoO of DOD > 0.2

Based on *Ginoux et al.* (2012)



Advanced constraining using numerical experiments

- Update recent advances from *Ginoux et al.* (2012) and combine with integrated numerical modeling system
  - **Updated land-use data set** (HYDE 3.2.1, *Klein Goldewijk et al.*, 2017)
  - **Fully coupled dust emission** parameterizations
  - Dynamic **threshold friction velocity** for sediment entrainment
  - Satellite-based representation of **photosynthetic and non-photosynthetic vegetation cover**
  - **4D dust concentration field** allowing in-depth evaluation
- NMMB-MONARCH (*Perez et al.*, 2011; *Badia et al.*, 2017)
  - Multiscale Online Non-hydrostatic AtmospheRe CHemistry model
  - Global setup (1° x 1.4° horizontal resolution)
  - 24 vertical layers
  - Currently 1 year (2007)
  - FoO used for tagging (no scaling)



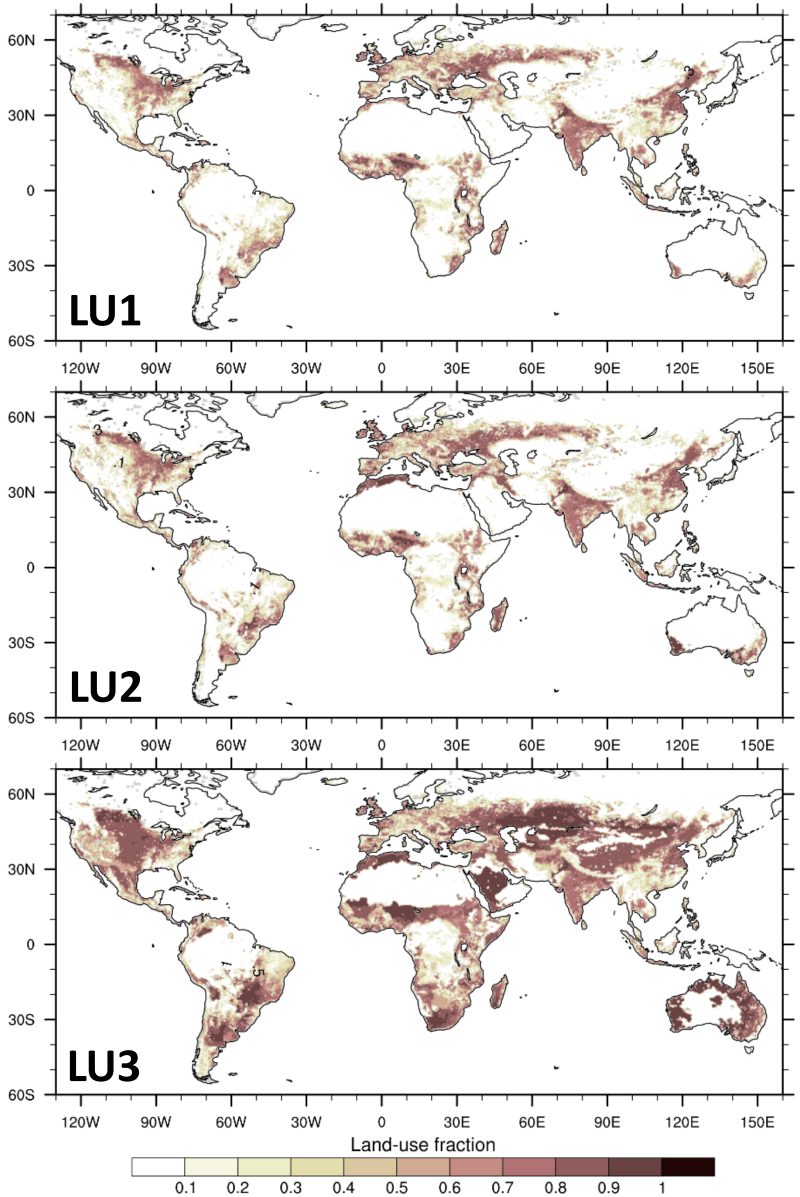
Anthropogenic land use

- **HYDE 3.2.1** (*Klein Goldewijk et al.*, 2017)
- Data on annual basis; spatial resolution ~0.1 degree resolution
- Land use categories considered here:
  - <u>Cropland</u>: Arable land and permanent crops
  - <u>Pasture</u>: grazing land with an aridity index > 0.5, intensively used/managed
  - <u>Converted Rangeland</u>: grazing land placed on potential forest area, less intensively used
  - <u>Rangeland</u>: natural, unconverted grazing land with an aridity index < 0.5, less or unmanaged
- Land-use configurations tested:

  (**LU1**) Cropland, pasture

  (**LU2**) Cropland, pasture, converted rangeland

  (**LU3**) Cropland, pasture, converted rangeland, rangeland



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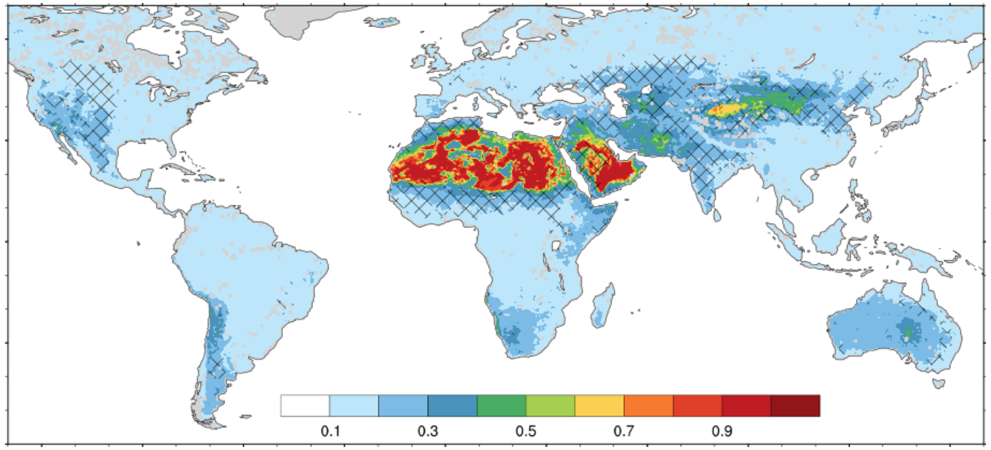
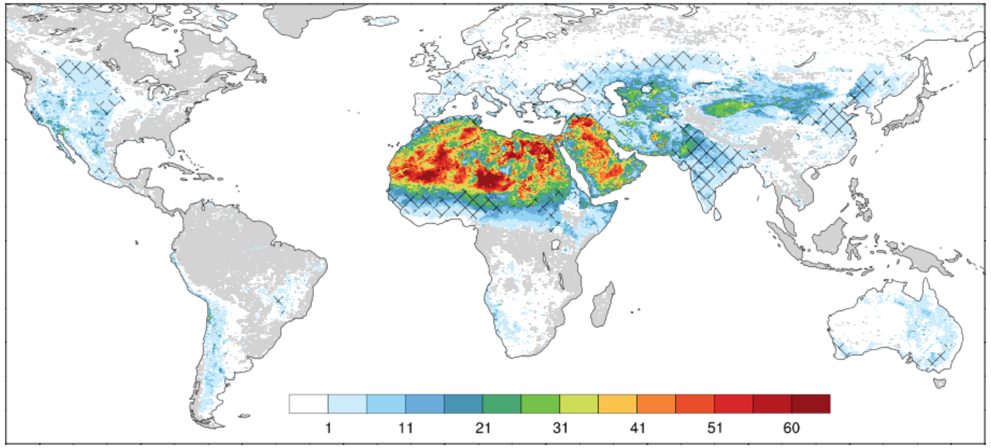
Threshold friction velocity for sediment entrainment

- **Dynamic threshold based on soil texture** (*Iversen and White*, 1992/*Marticorena and Bergametti*, 1995; *Shao and Lu*, 2000)
- Corrections for **roughness element cover** (*Raupach et al.*, 1993) and **soil moisture** (Fecan et al., 1999)
- Roughness element cover is based on **photosynthetic and non-photosynthetic vegetation** (*Guerschman et al.*, 2015)
  - Global coverage at 5km resolution on monthly basis
  - Vegetation input consistent between dust module and atmospheric/land-surface components in MONARCH

Roughness correction (*Raupach et al.*, 1993)



FoO of DOD > 0.2 (*Ginoux et al.*, 2012)



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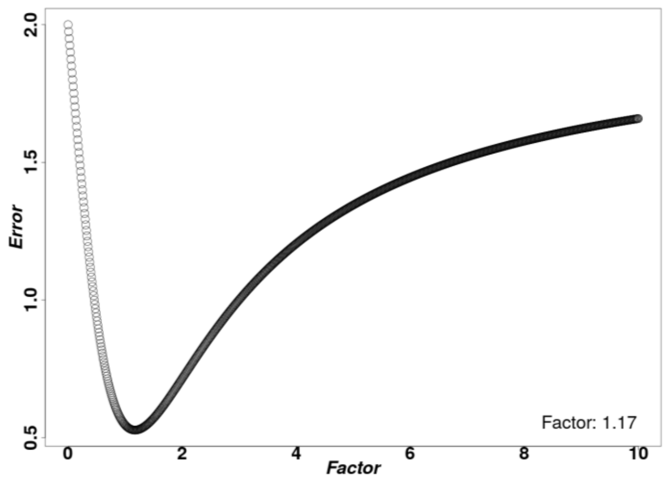
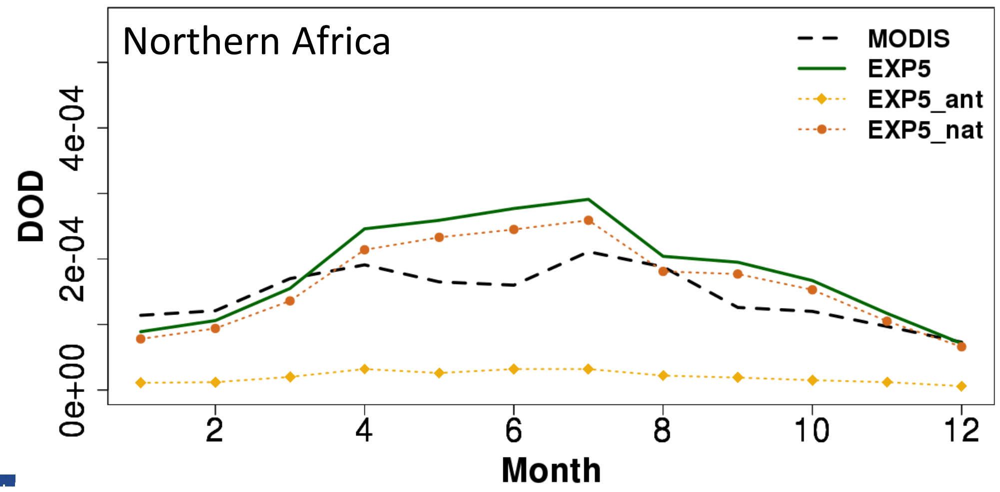
Constraining the dust cycle with observations

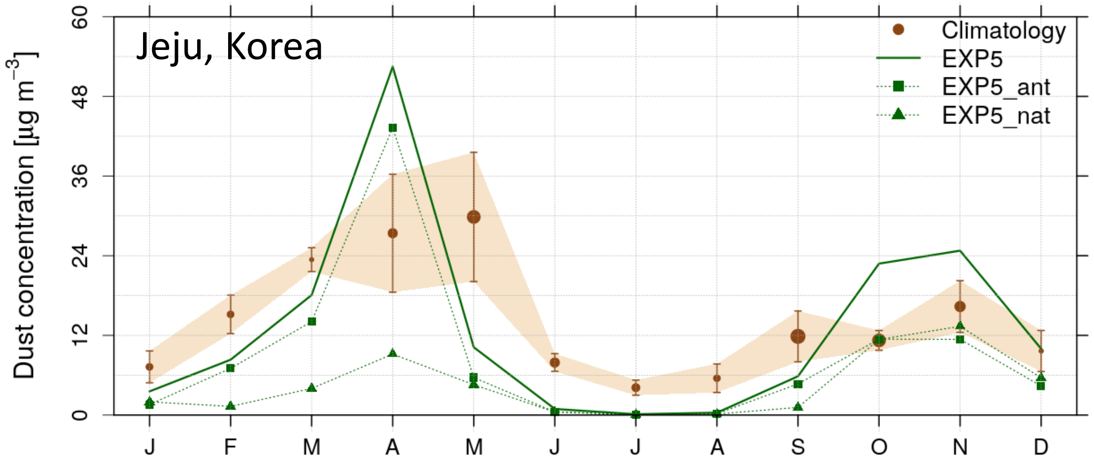
- Obtain a best-estimate by minimizing the error between model results and suit of measurements (*Cakmur et al.*, 2006)
  - ➢ DOD [AERONET, MODIS], dust concentration, dust deposition

  → model optimization factor



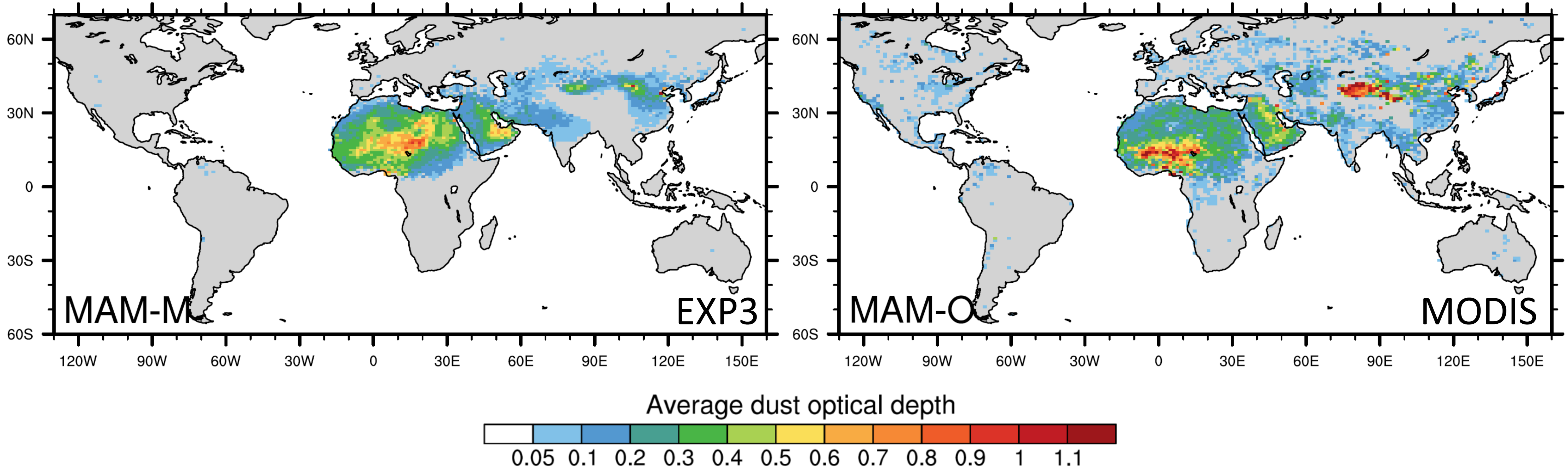
- Evaluating spatial and temporal distribution of dust, relative amount of dust load and deposition, etc. to **identify model weaknesses** and **test hypotheses**





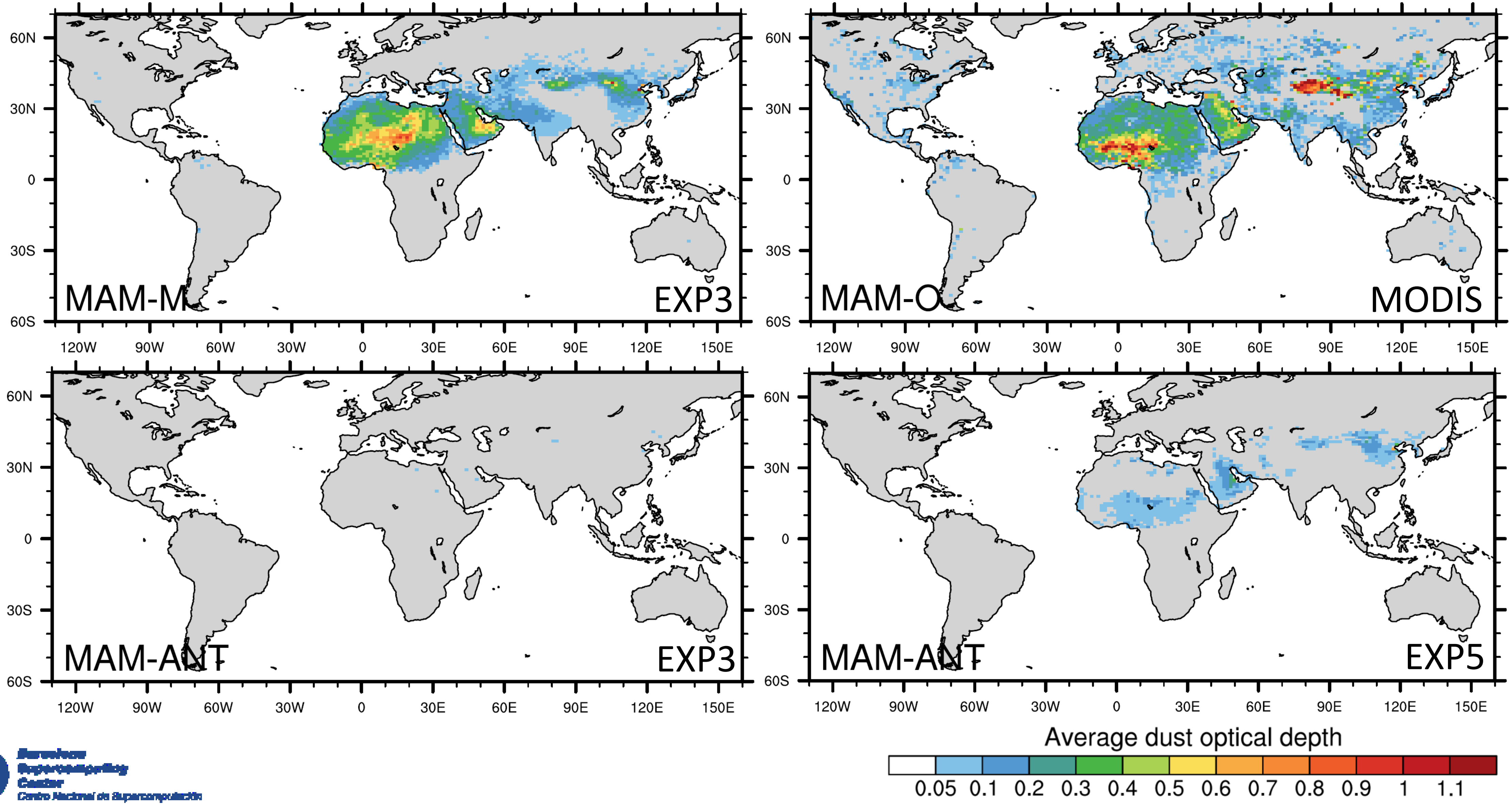
Climatological data: University of Miami Ocean Aerosol Network, D. L. Savoie and J. M. Prospero

Dust optical depth – MODIS and MONARCH (boreal spring)



- Spatio-temporal co-location between MODIS and model data
- Good agreement between model and observations
- Slight northward shift of high DOD in N Africa; underestimation of DOD in the Taklamakan Desert

Dust optical depth – MODIS and MONARCH (boreal spring)



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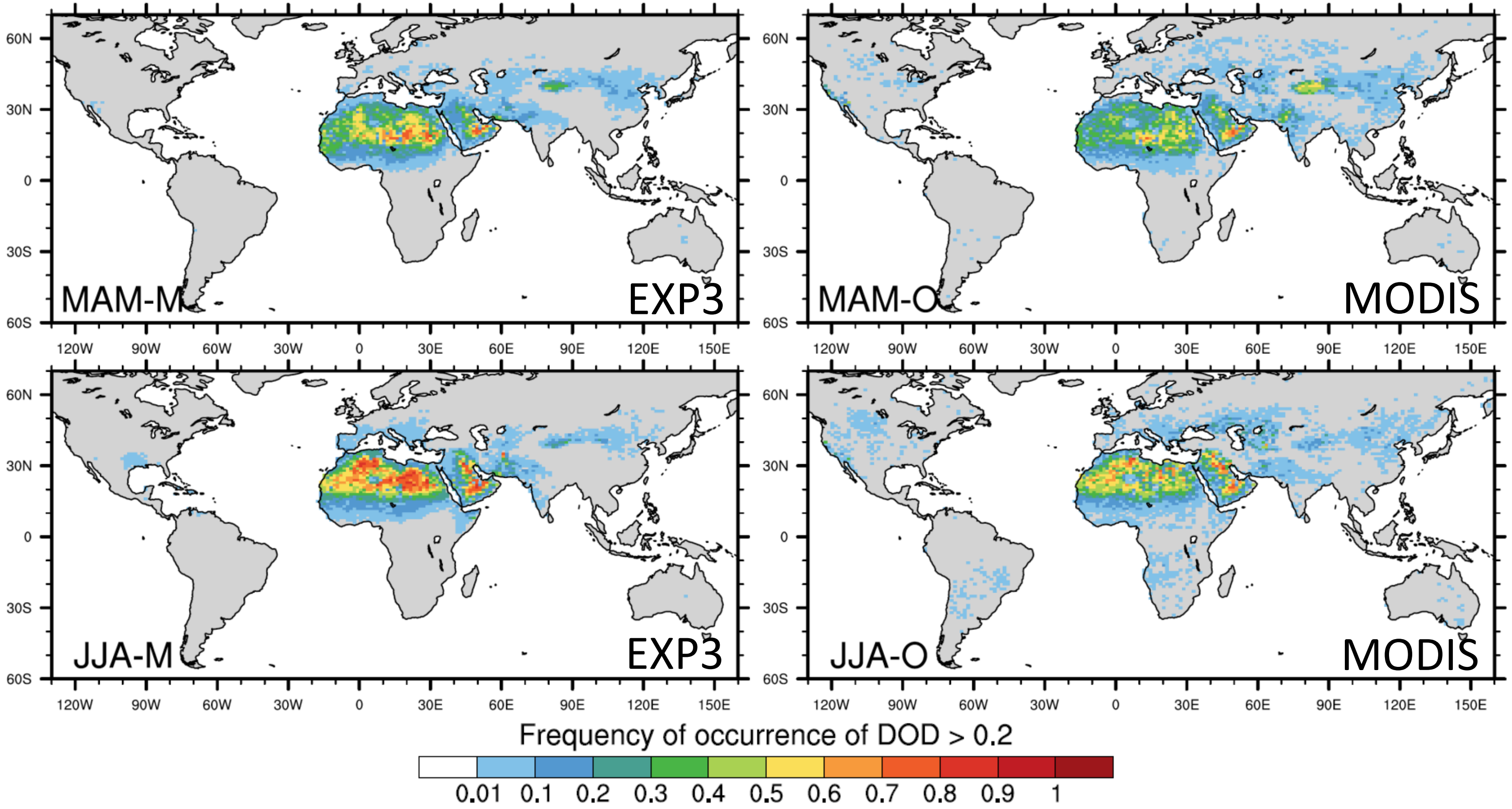
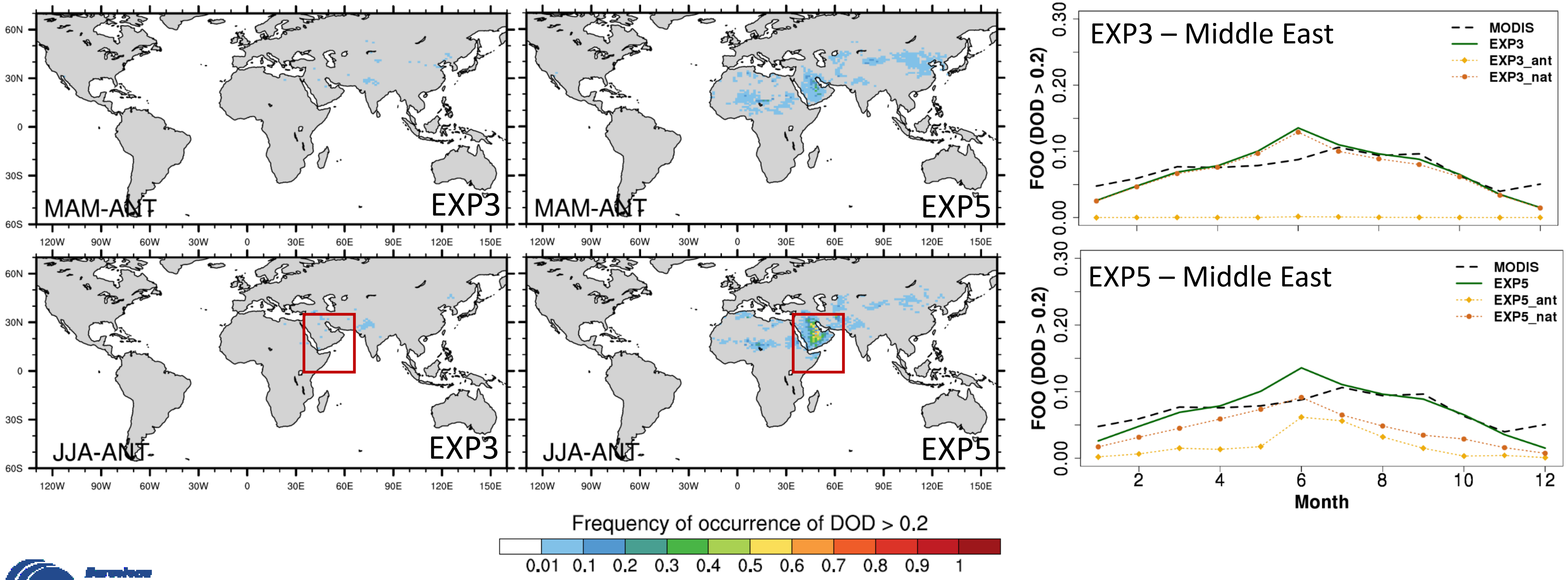
Frequency of occurrence – MODIS and MONARCH



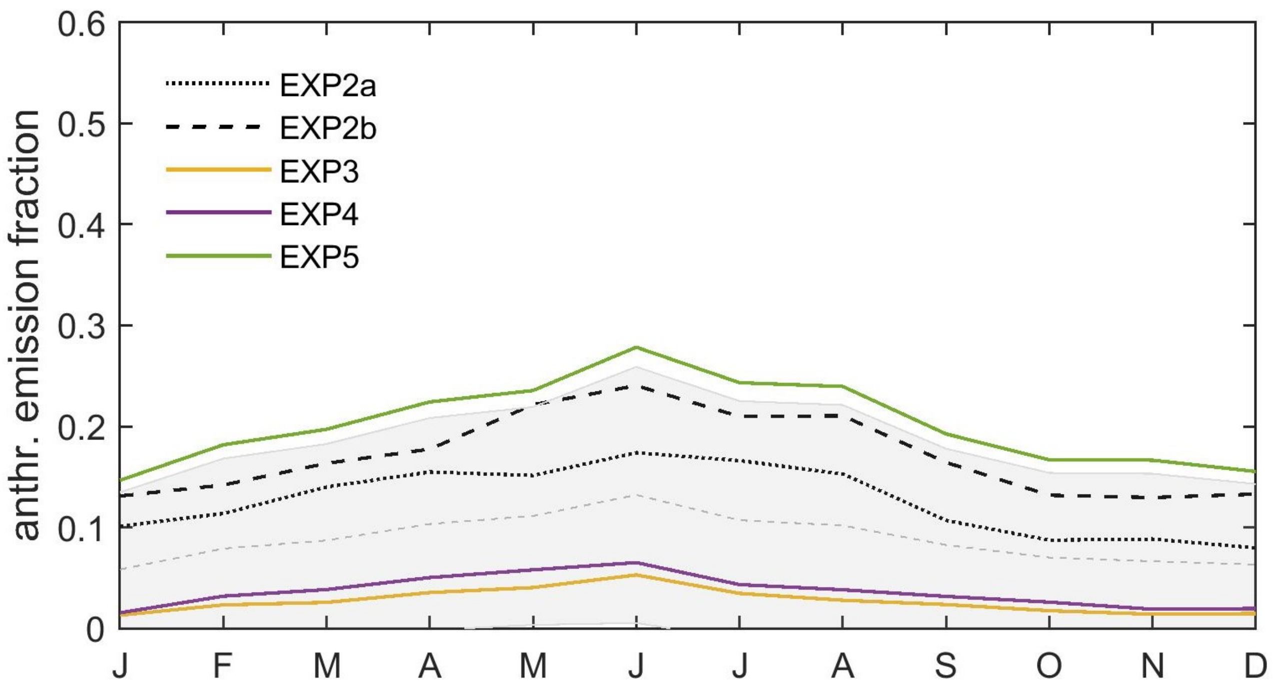
- Comparison with MODIS helps to **evaluate source activity** in terms of both **area and intensity**
- Good agreement; overestimation over NE Africa in summer

Frequency of occurrence – MODIS and MONARCH

- Extent of anthropogenic source area determines seasonal variation of anthropogenic dust contribution



Anthropogenic dust emission – preliminary results



- **Global anthropogenic fraction about ~3%** when using emission scheme from *Ginoux et al.* (2001) and HYDE 3.2.1 cropland and pasture (EXP3)
- Consideration of rangeland in anthropogenic fraction leads to **~22%**, similar to that using HYDE 2 (cropland and pasture) → **large uncertainty due to anthropogenic area**
- Ongoing: Tests using **different emission schemes** (EXP6: Shao, 2004; EXP7: Kok et al., 2014) will provide additional **insight into variability**

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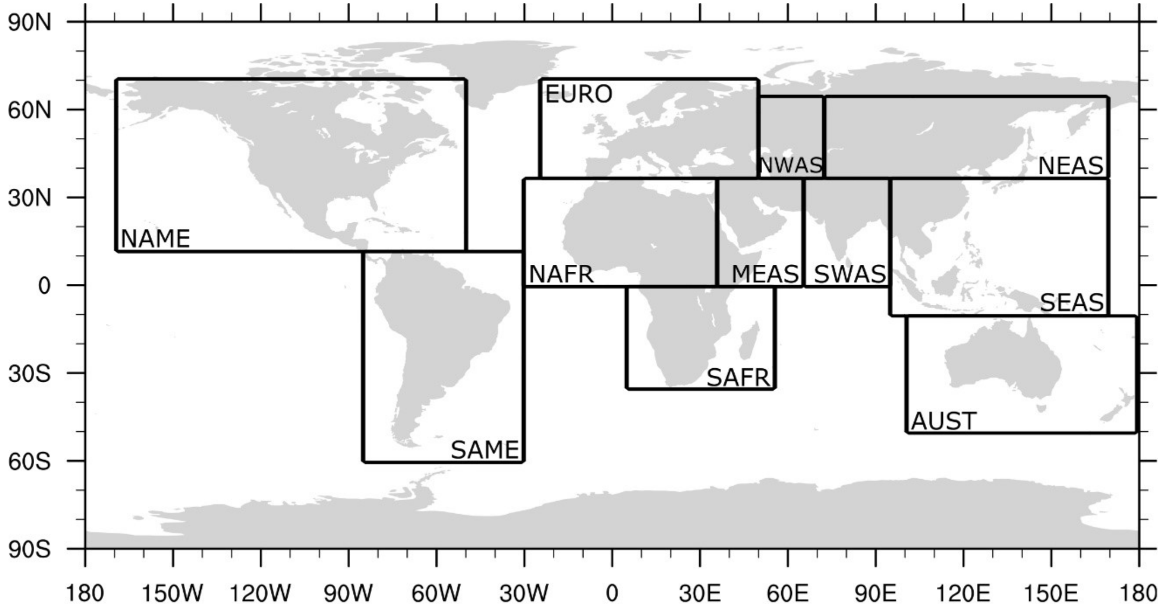
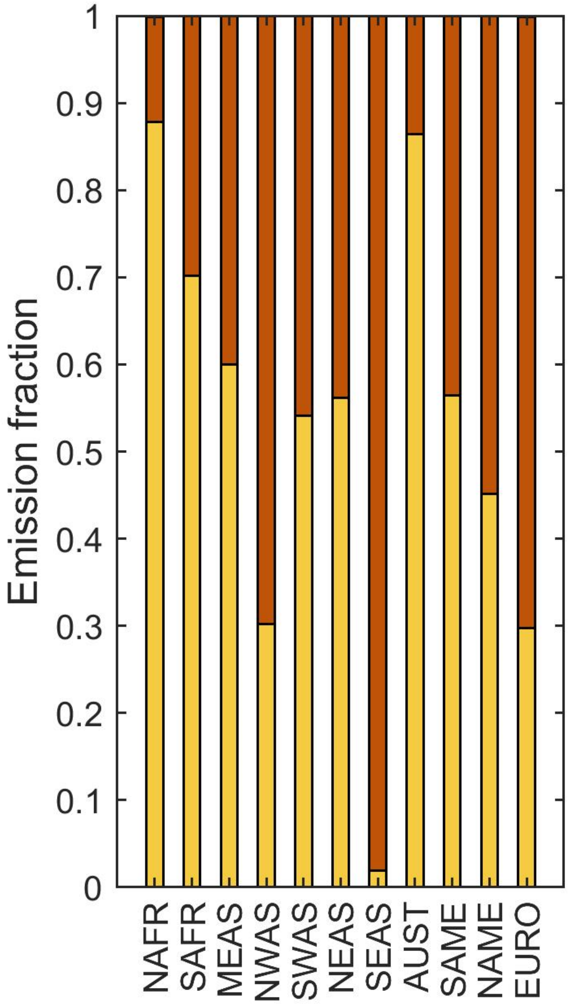
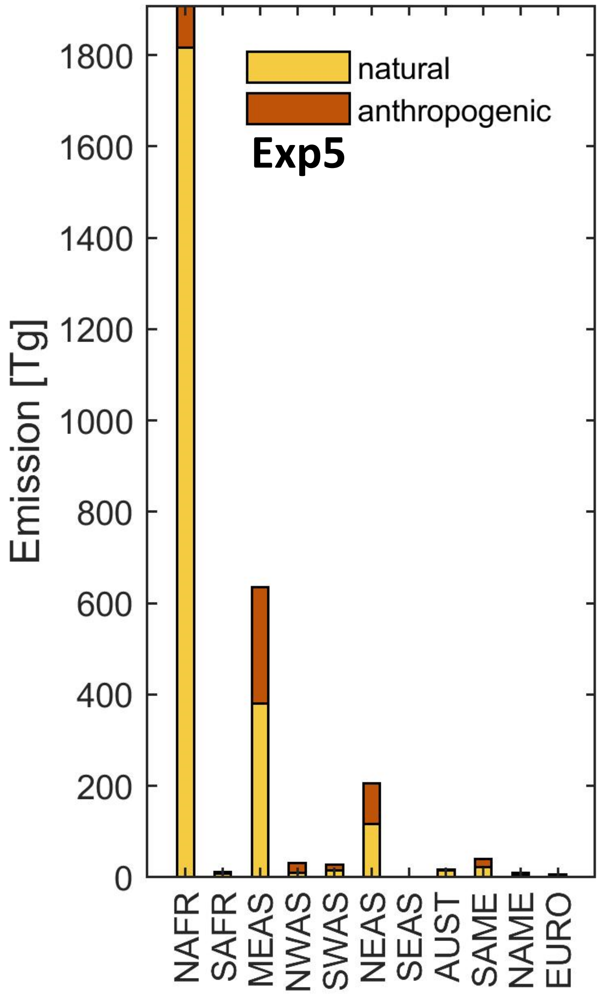
Regional anthropogenic contributions







- Typical low-emission areas have largest contributions of anthropogenic dust
- Anthropogenic emission fractions:

  NAFR 12%; MEAS 40%: NEAS 44%

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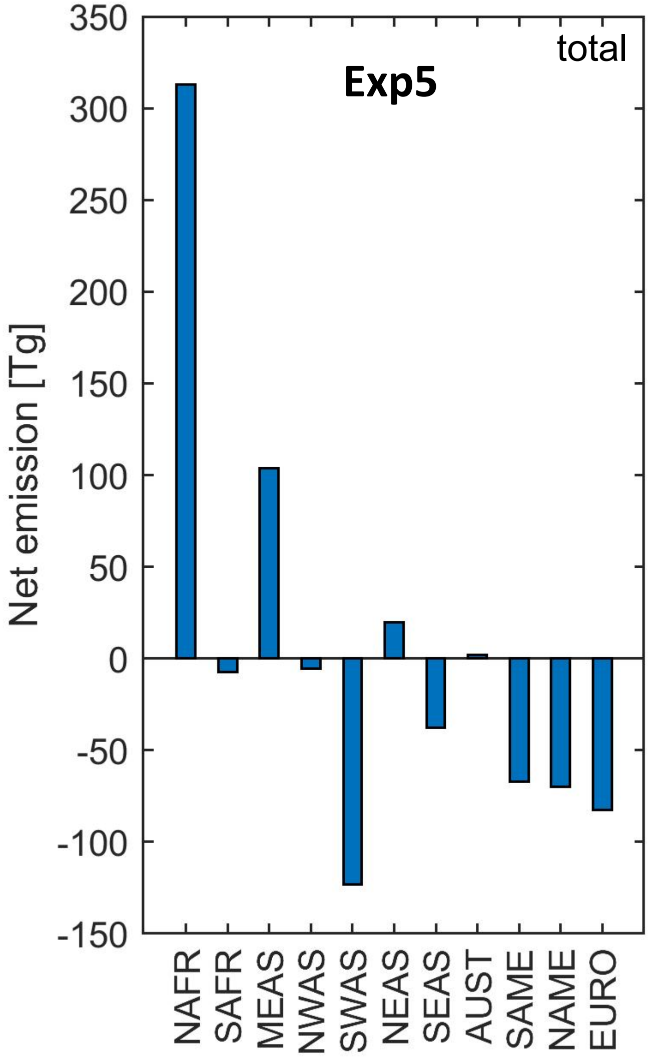
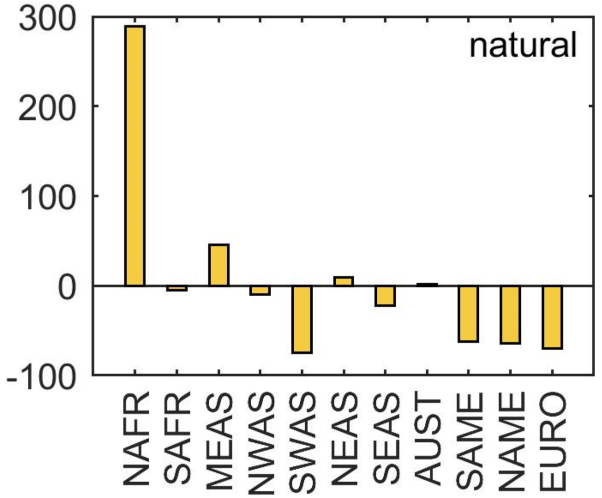
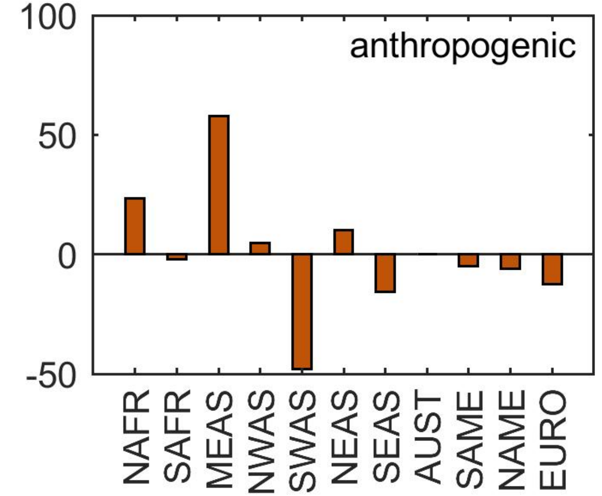
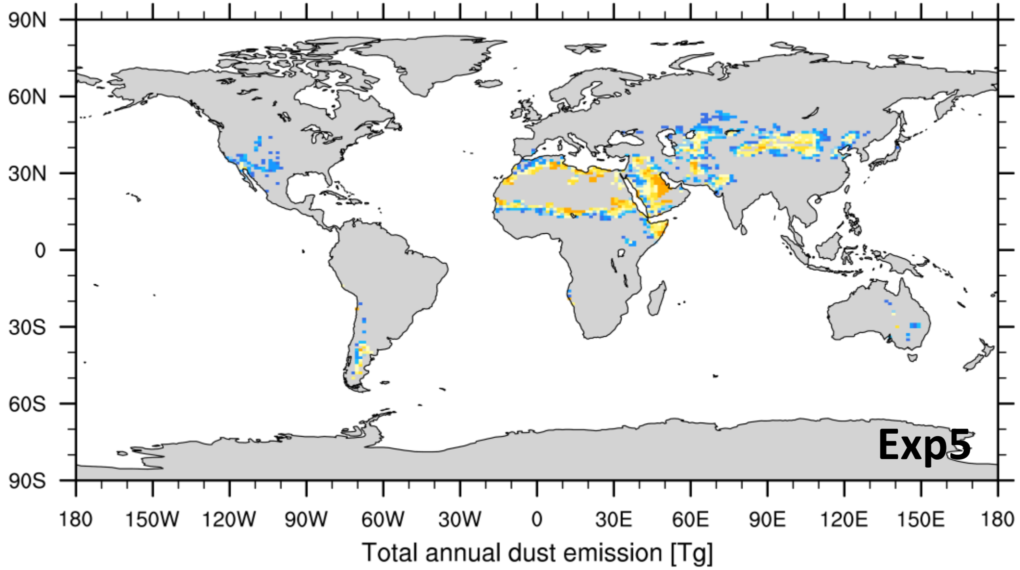
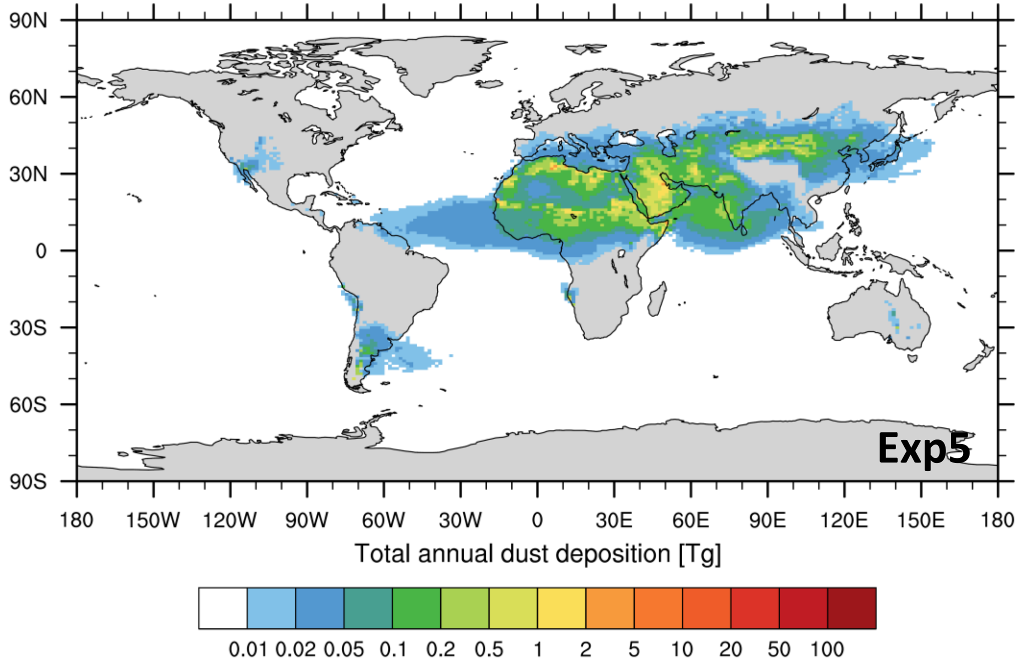
Regional anthropogenic contributions



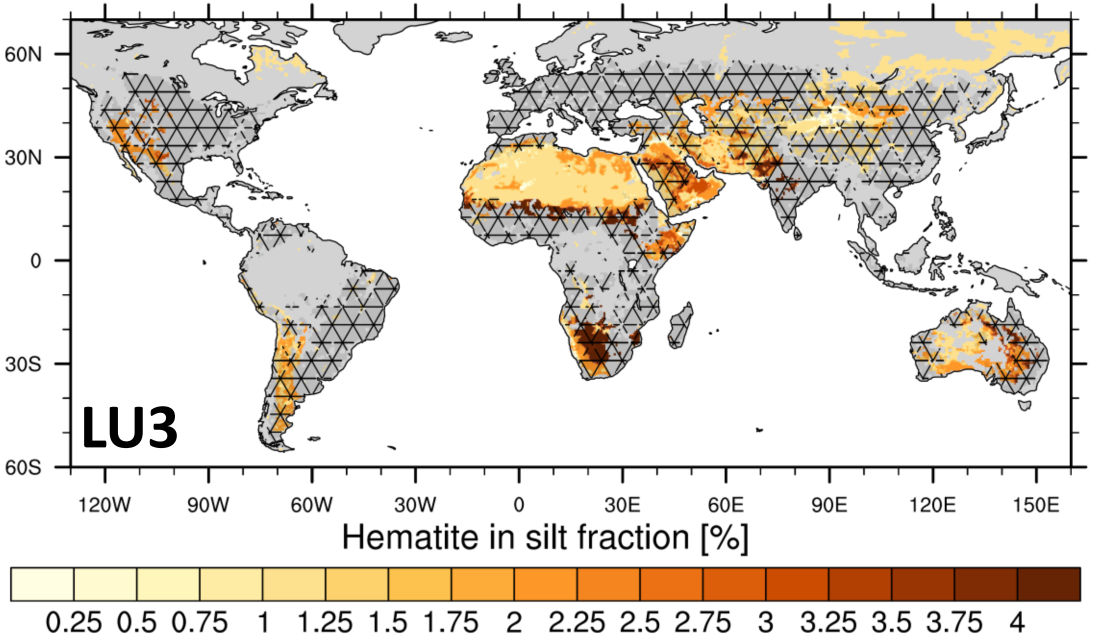




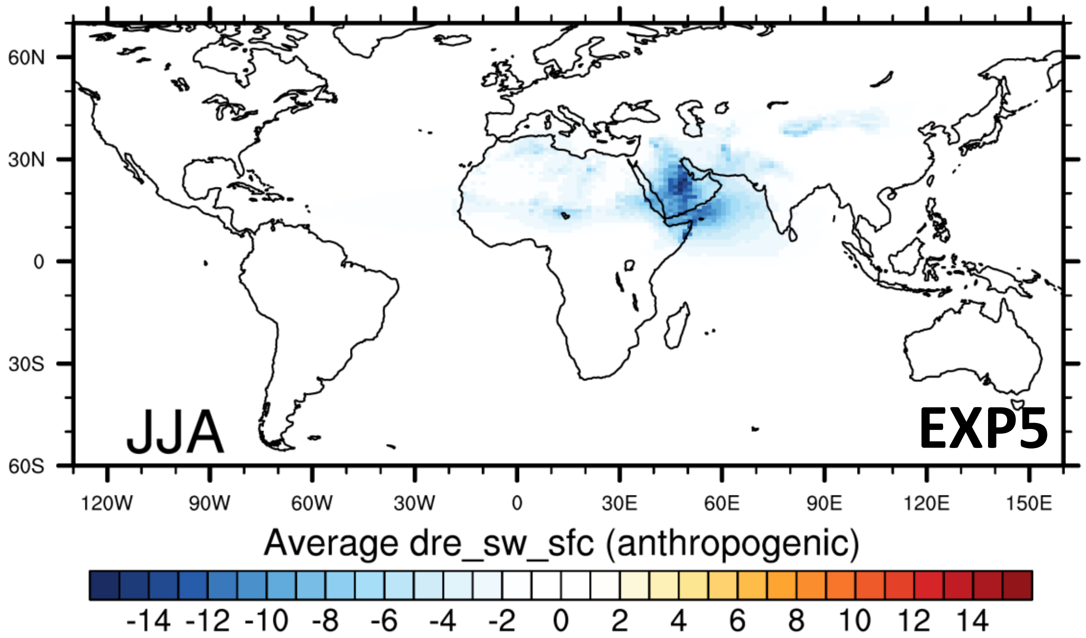




Anthropogenic dust effects



Hematite after Claquin et al. (1999); data from M. Gonçalves Ageitos
Land use from HYDE 3.2.1, case LU3



- Anthropogenic sources often coincide with areas of high hematite content

→ Inclusion of mineralogy likely leads to more positive shortwave DRE

Summary and outlook

- Anthropogenic dust sources contribute to the global dust load

Main uncertainties are (to reduce and/or understand):

- **Land-surface conditions, in particular for coarse global grid**
  - Refined use of source attribution using new dataset and scenarios
  - Expansion of observational constraints
- **Dust emission**
  - Dynamical threshold friction velocity and drag partition
  - Use of different dust emission parameterizations
- **Meteorological dust drivers**
  - Moist convective dust storms (haboobs)
- Preliminary results suggest anthropogenic sources contribute between 3 and 23% to global dust emissions, depending on the **definition of anthropogenic sources**
- Amount and **properties of anthropogenic dust** determine its impact

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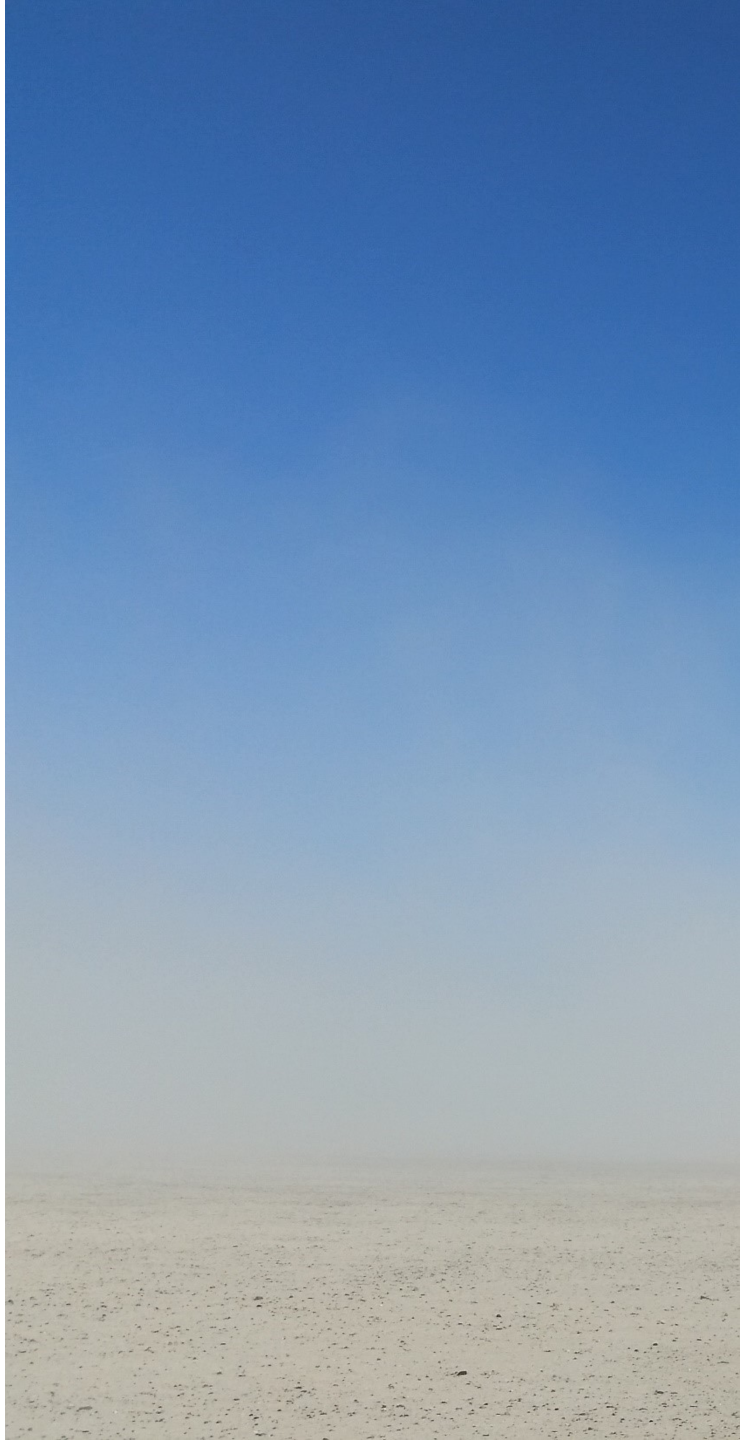

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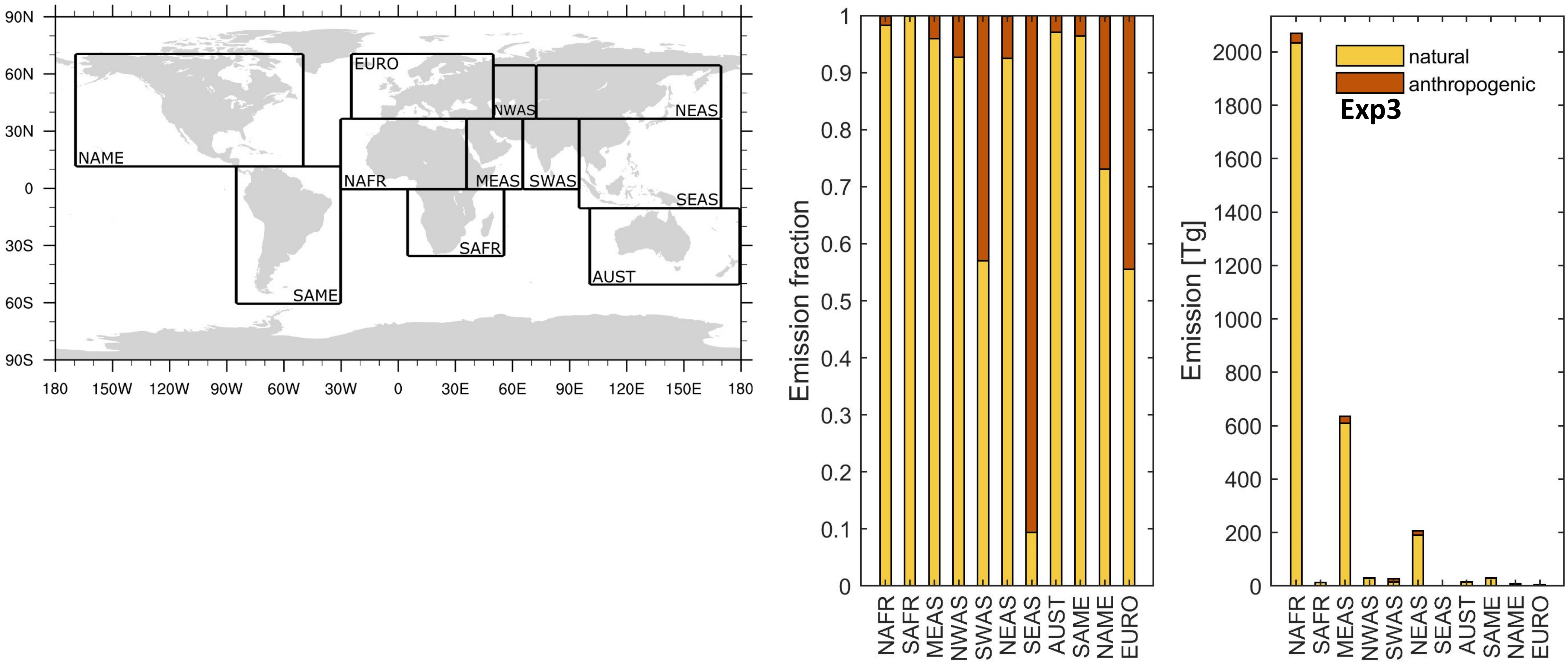
Regional anthropogenic contributions



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