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How large is the contribution of cropland and grazing lands to the global dust cycle?

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Mineral dust – natural and anthropogenic

- **Anthropogenic dust source**: dust source associated with agricultural land use
  - Considered: Mineral dust only (no urban pollution)
  - Not considered: Emissions from vehicles (dirt roads, tillage, recreational use); military operations
  - Not considered: Indirect anthropogenic sources, e.g. hydrological
- Dust emissions from anthropogenic sources can impact daily life, not only in (semi-)arid areas
  - 1930s Dust Bowl, USA (***Fig. 1a***)
  - Traffic accidents, e.g. 2011 in northern Germany (***Fig. 1b***)

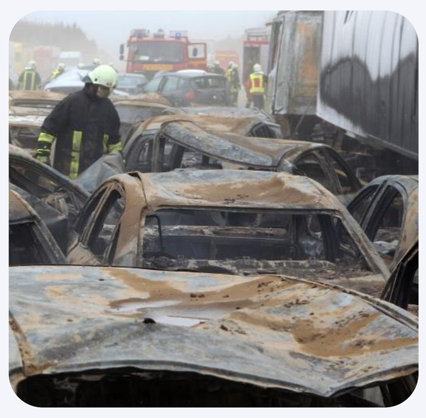


Fig. 1: *(a) "Dust Bowl" in the US (image credit: Arthur Rothstein/Wikipedia); (b) Pile-up on highway in Germany cause by a dust storm in 2011 (image credit: spiegel.de)*

Global impacts?

- The contribution of (anthropogenic) land use to present-day dust emission remains under debate, with values ranging 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

Objectives and Methods

We aim to better **estimate the contribution of anthropogenic (agricultural) and natural sources to global dust emission** by combining improved land-surface representations with advanced dust models and observational constraints

→ **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

Numerical Experiments

Model and Setup

- Multiscale Online Non-hydrostatic AtmospheRe CHemistry model – NMMB-MONARCH (*Pérez et al.*, 2011; *Badia et al.*, 2017)
- Global setup (1° x 1.4° horizontal resolution, 24 layers)
- Initially one-year simulations
- We use four different dust emission parameterizations (cf. ***Fig. 2***) to quantify uncertainty arising from the emission scheme.

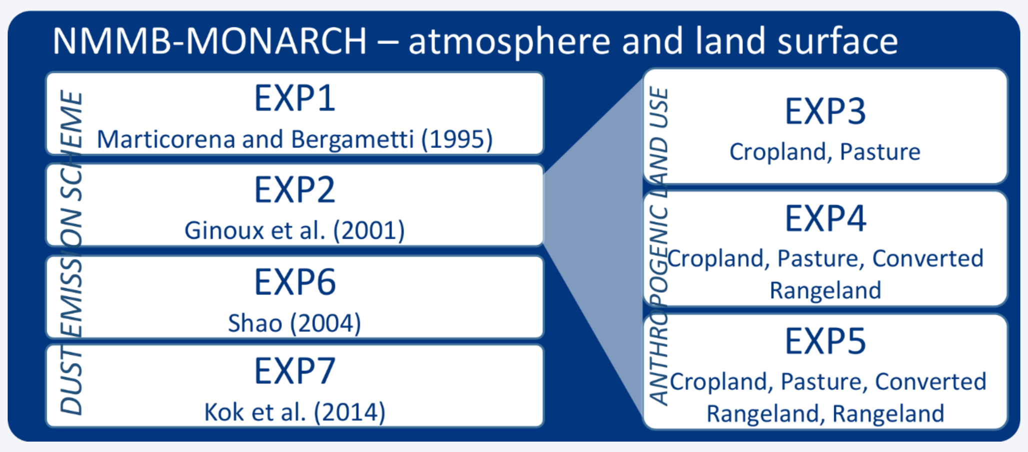
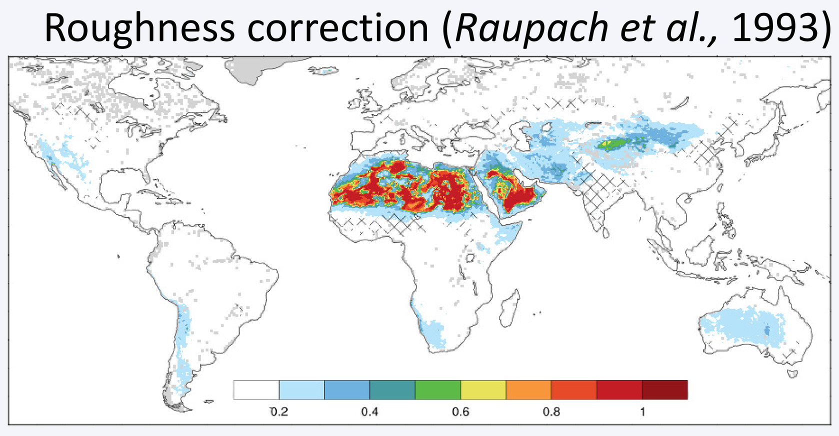


Fig. 2: *Overview of the numerical experiments designed to constrain the contribution of anthropogenic sources to the global dust cycle.*

Drag Partitioning

- "Drag partition" = separation of the total (surface) drag supplied by aerodynamic forces into a fraction on roughness element surfaces and on the ground surface. The latter is pivotal for dust emission.
- Drag partition is used to account for the effect of roughness elements, such as vegetation, on the emission.
- We use the drag partition parameterization of *Raupach et al.* (1993) in combination with estimates of photosynthetic (PV) and non-photosynthetic (NPV) vegetation cover (*Guerschman et al.*, 2015) and the conversion between cover fraction and frontal area index (input to the drag partition scheme) proposed by *Shao et al.* (1996).

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



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

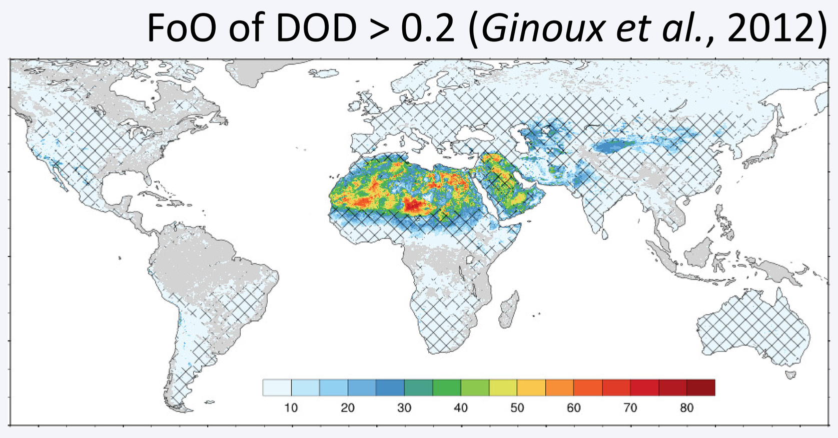


Fig. 3: *(top) Correction factor representing roughness elements; the factor is applied to the entrainment threshold friction velocity; (bottom) Frequency of occurrence (FoO) of dust optical thickness (DOD) > 0.2.*

- The roughness correction factor and the frequency of occurrence (FoO) of dust optical depth > 0.2 (*Ginoux et al.*, 2012) are remarkably similar (***Fig. 3***), demonstrating that roughness element cover and a dynamical representation of u_{*t} is key to reproduce observed atmospheric dust loadings.

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:
  - ➢ Cropland: Arable land and permanent crops
  - ➢ Pasture: grazing land with an aridity index > 0.5, intensively used/managed
  - ➢ Converted Rangeland: grazing land placed on potential forest area, less intensively used
  - ➢ Rangeland: natural, unconverted grazing land with an aridity index < 0.5, less or unmanaged
- Land-use scenarios tested (***Fig. 4***):

  (**LU1**) Cropland, pasture

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

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

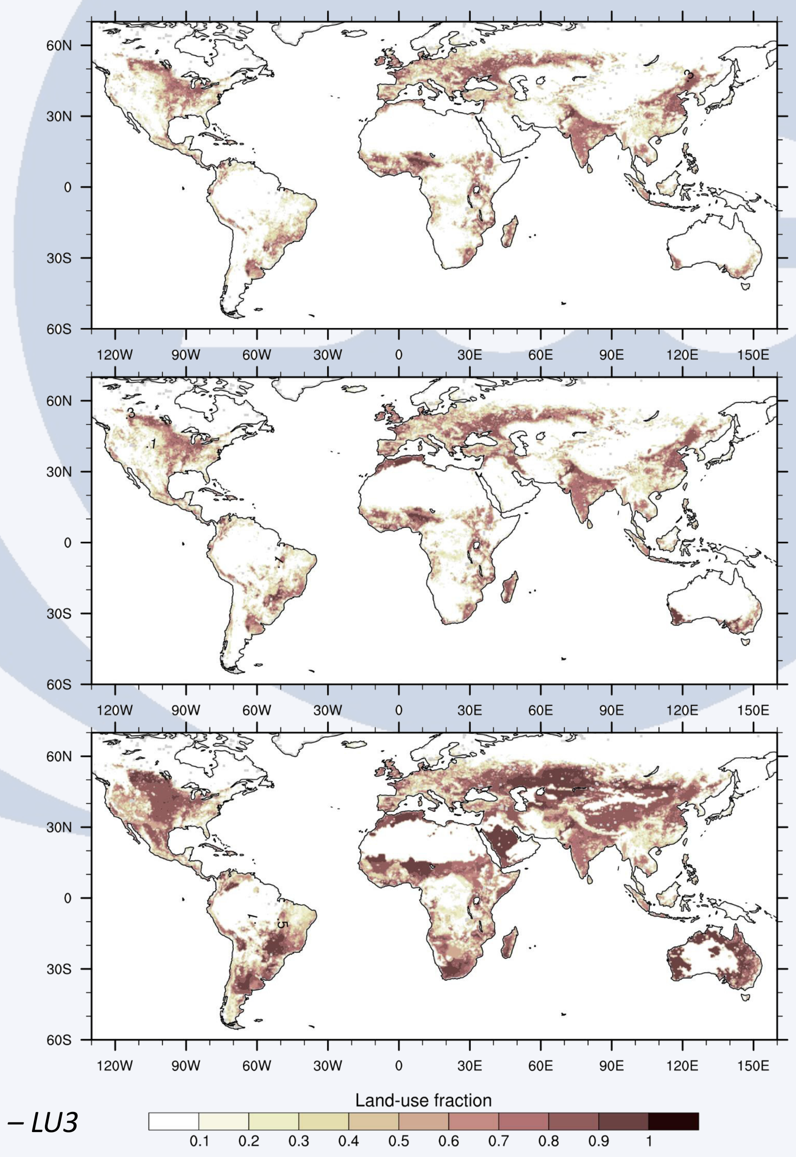


Fig. 4: *Land-use fractions obtained using scenarios LU1 – LU3*

Results

Dust optical depth – MODIS and MONARCH

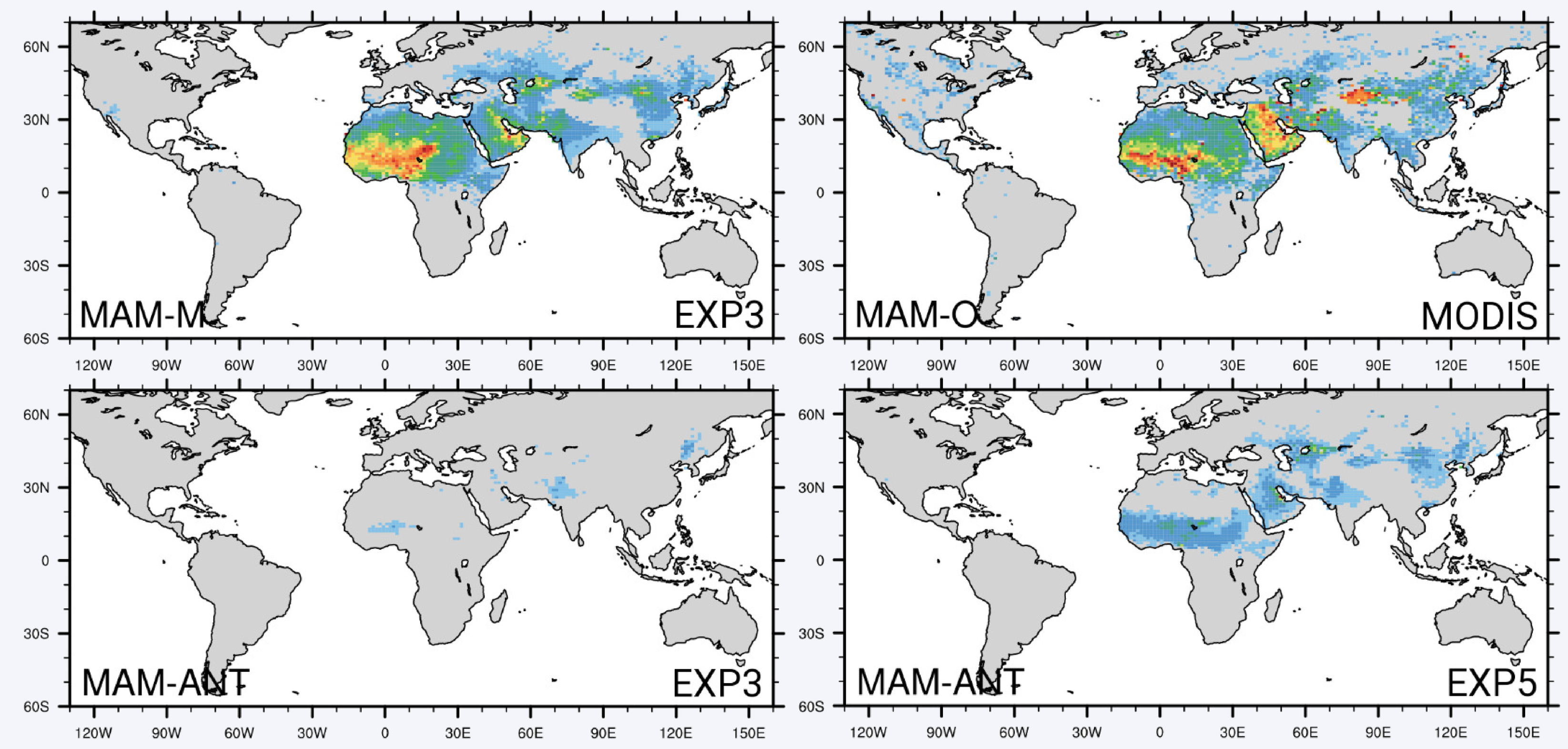


Fig. 5: *Total dust optical depth for northern hemispheric spring (March, April, May) obtained using EXP3 (top-left) together with the corresponding anthropogenic fractions based on EXP3 (bottom-left) and EXP5 (bottom-right). MODIS Deep Blue dust optical depths is shown as a reference (top-right).*

- Spatio-temporal co-location between MODIS and model data
- Good agreement between model and observations
- Slight underestimation of DOD in the Arabian Peninsula and the Taklamakan Desert; slight overestimation around the Bodele Depression
- The contribution of anthropogenic sources is minor when considering cropland and pasture only; the addition of rangeland yields a substantial increase in anthropogenic dust

Dust optical depth – Modis and MONARCH

- **Global anthropogenic fraction on average 8%** when using emission scheme from *Ginoux et al.* (2001) and HYDE 3.2.1 cropland and pasture (EXP3).
- Considering **rangeland as anthropogenic source leads to estimate of about 35%**, similar to that using HYDE 2 (cropland and pasture) **→ large uncertainty due to anthropogenic area**.
- The largest anthropogenic emission fractions are found in **North America, Southwest Asia, and Europe**, although the contributions of these areas to the dust cycle are small (Tab. 1).
- The **large uncertainty** associated with the anthropogenic emission fractions listed in Tab. 1 is due to the different land-use scenarios.
- **Inclusion of additional dust emission parameterizations will lead to larger variability** of both the regional contribution to total emission and the anthropogenic emission fraction and will help to **better constrain the uncertainty**.

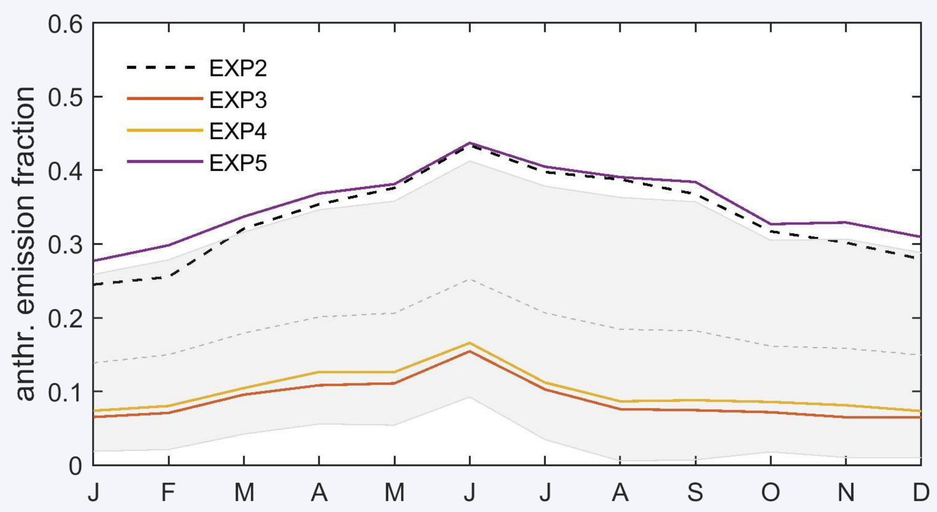


Fig. 5: *Anthropogenic emission fractions modeled with NMMB-MONARCH based on EXPs 2-5.*

Region	Anthro. emission fraction (avg ± std)	Regional contribution to total emission (avg ± std)
N Africa	10.8 ± 9.3	50.6 ± 0.2
S Africa	0.2± 0.3	0.2 ± 0.0
Middle East	21.1 ± 21.7	28.2 ± 0.1
NW Asia	27.6 ± 32.9	8.6 ± 0.0
SW Asia	47.0 ± 3.2	5.3 ± 0.0
NE Asia	33.8 ± 20.2	8.9 ± 0.0
Australia	17.1 ± 19.6	0.2 ± 0.1
S America	27.9 ± 22.9	1.2 ± 0.3
N America	47.1 ± 19.9	1.5 ± 0.1
Europe	43.4 ± 17.0	2.4 ± 0.0

Tab. 1: *Regional fractions of anthropogenic emissions together with the regional contributions to global dust emissions. Averages and standard deviations are based on EXPs 3-5.*

Conclusions and Outlook

- Anthropogenic dust sources contribute to the global dust load.
- The main uncertainties are due to the land-surface condition, dust emission, and meteorological dust drivers.
- Diverse numerical experiments and thorough comparison with observations help to constrain the anthropogenic emission fraction.

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