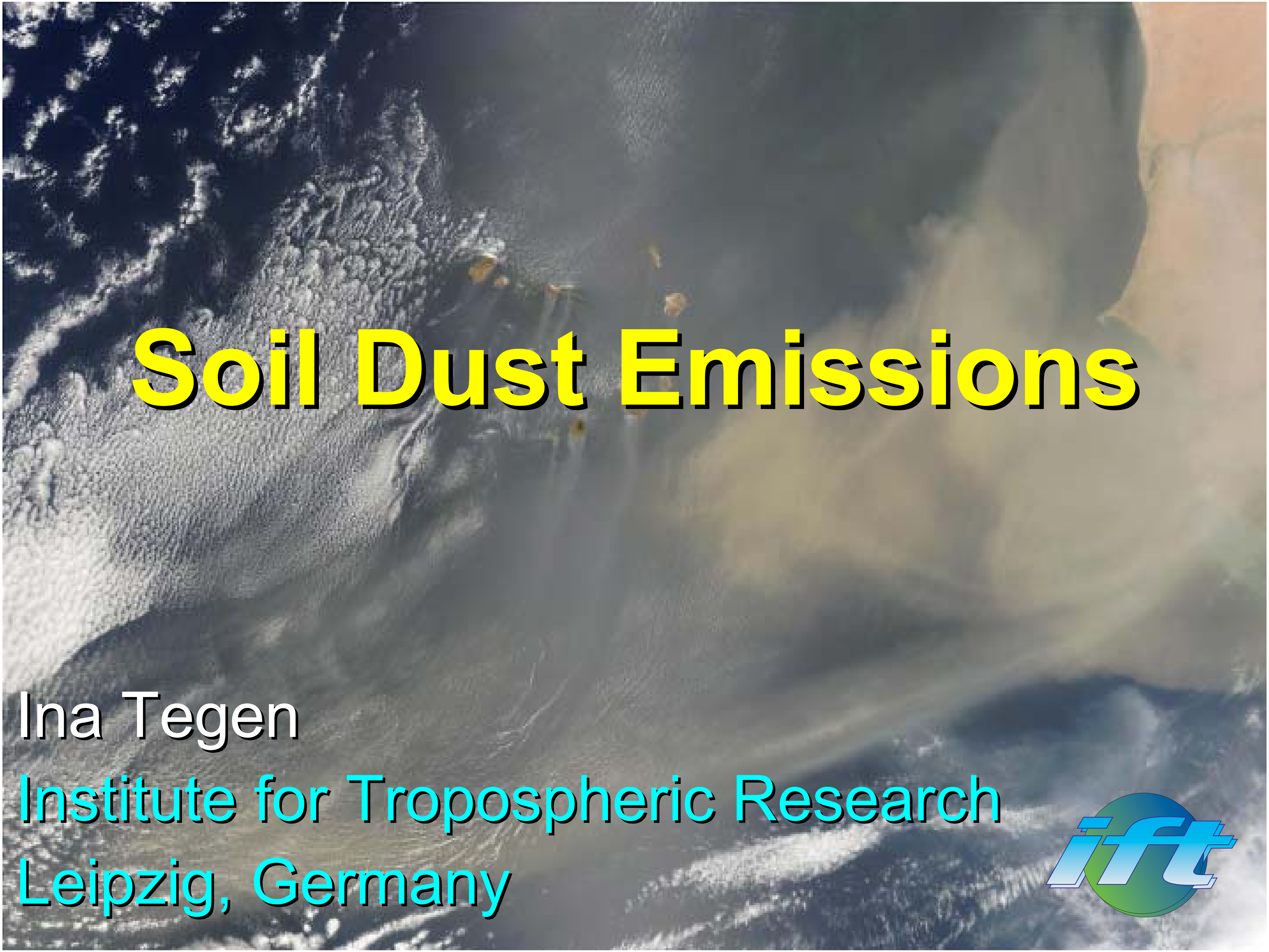


Soil Dust Emissions

Ina Tegen
Institute for Tropospheric Research
Leipzig, Germany

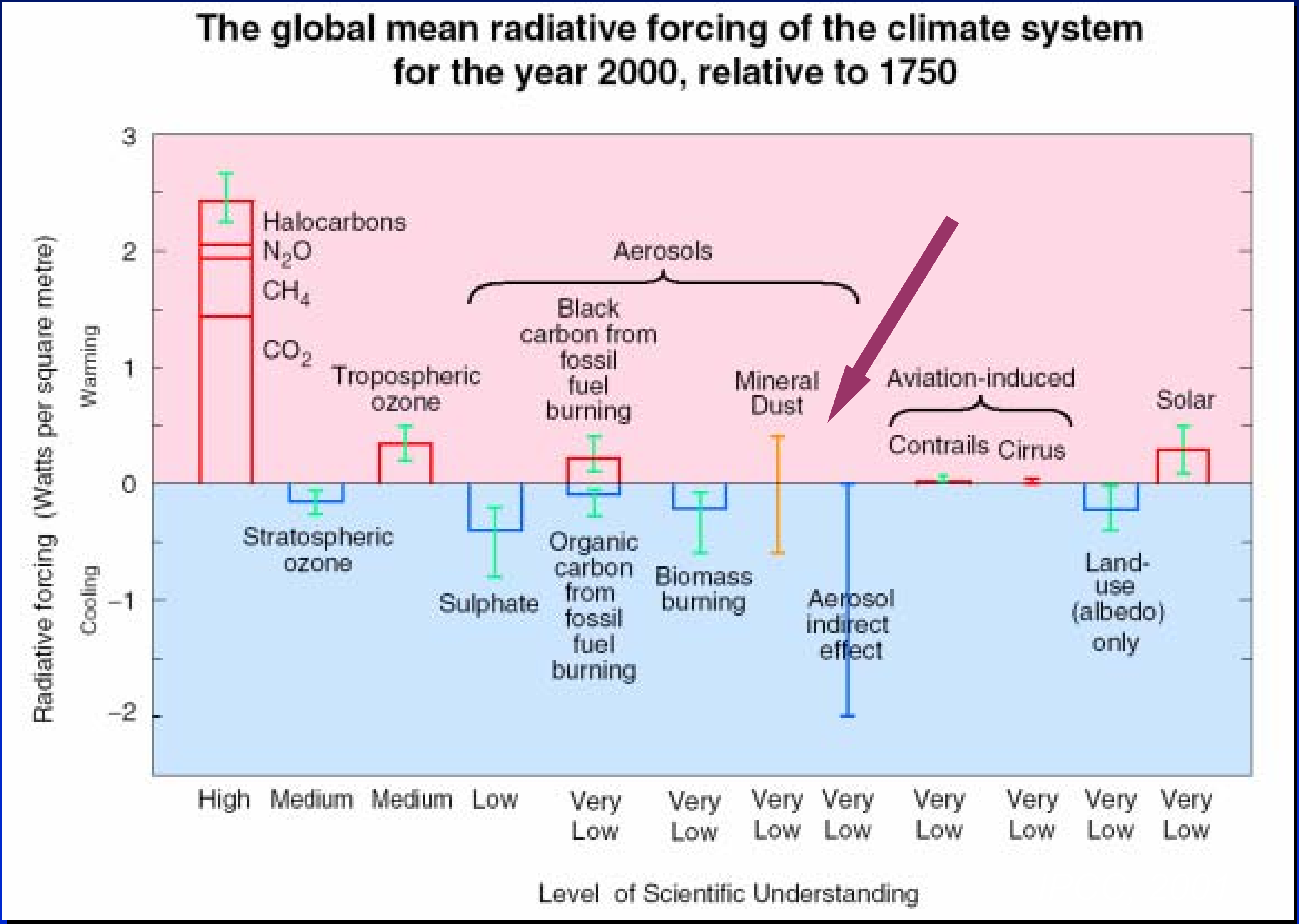

Saharan dust storm from Space Shuttle, 1992


Dead Sea

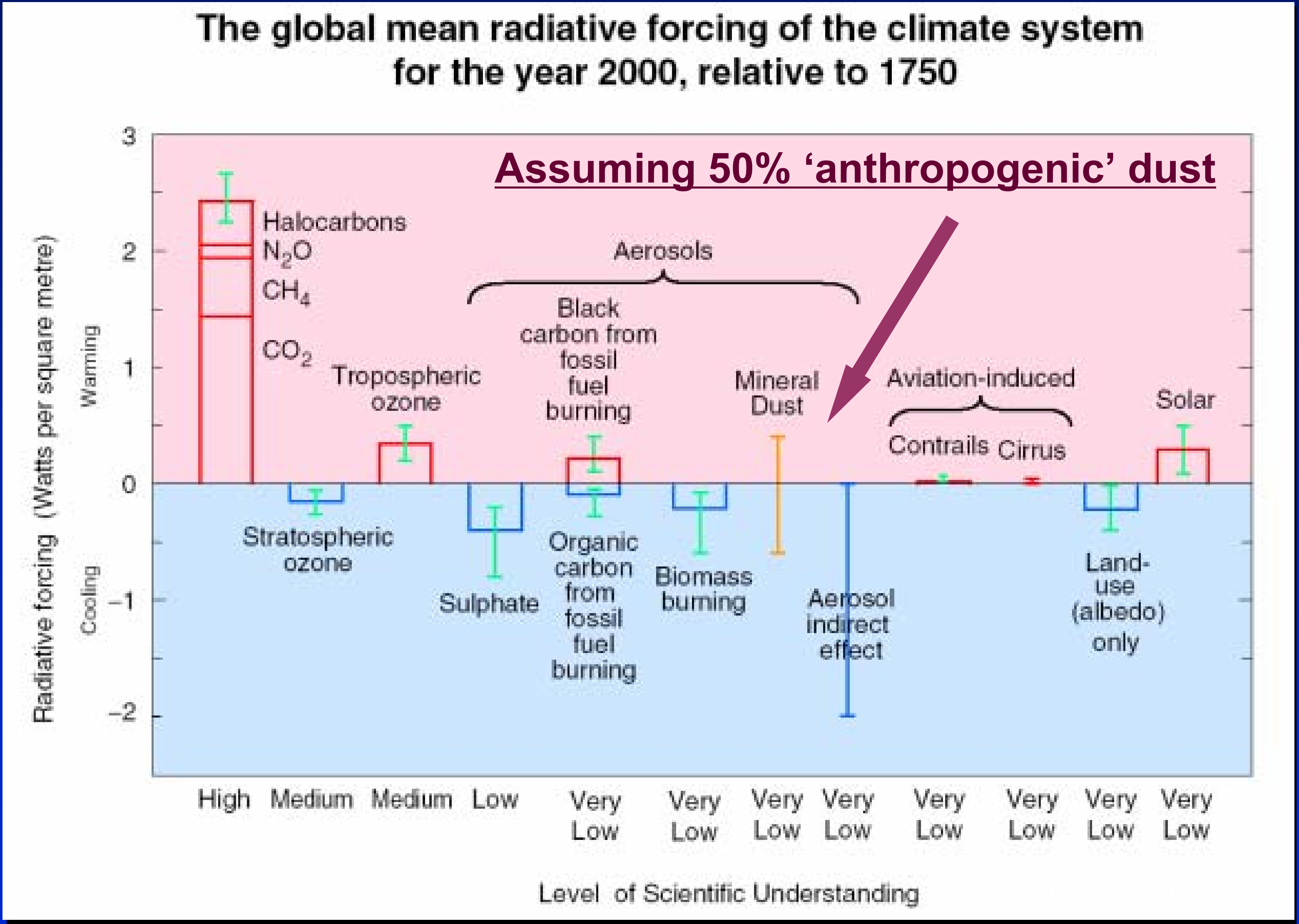
Big Spring, TX, 16.6.1997


Shanton, TX, 13.6.2002

IPCC, 2001:


The global mean radiative forcing of the climate system
for the year 2000, relative to 1750
Radiative forcing (Watts per square metre)
Warming
Cooling
3
2
1
0
−1
−2
Halocarbons
N_2O
CH_4
CO_2
Aerosols
Black carbon from fossil fuel burning
Mineral Dust
Aviation-induced
Tropospheric ozone
Contrails
Cirrus
Solar
Stratospheric ozone
Sulphate
Organic carbon from fossil fuel burning
Biomass burning
Aerosol indirect effect
Land-use (albedo) only
High
Medium
Medium
Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Level of Scientific Understanding

IPCC, 2001:


The global mean radiative forcing of the climate system
for the year 2000, relative to 1750
Assuming 50% 'anthropogenic' dust
Radiative forcing (Watts per square metre)
Warming
Cooling
3
2
1
0
−1
−2
Halocarbons
N_2O
CH_4
CO_2
Tropospheric ozone
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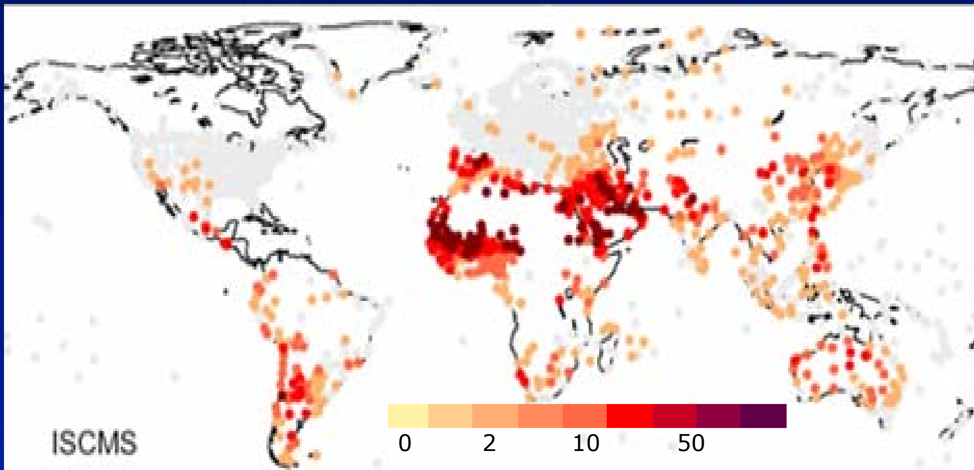
Global Dust Indicators



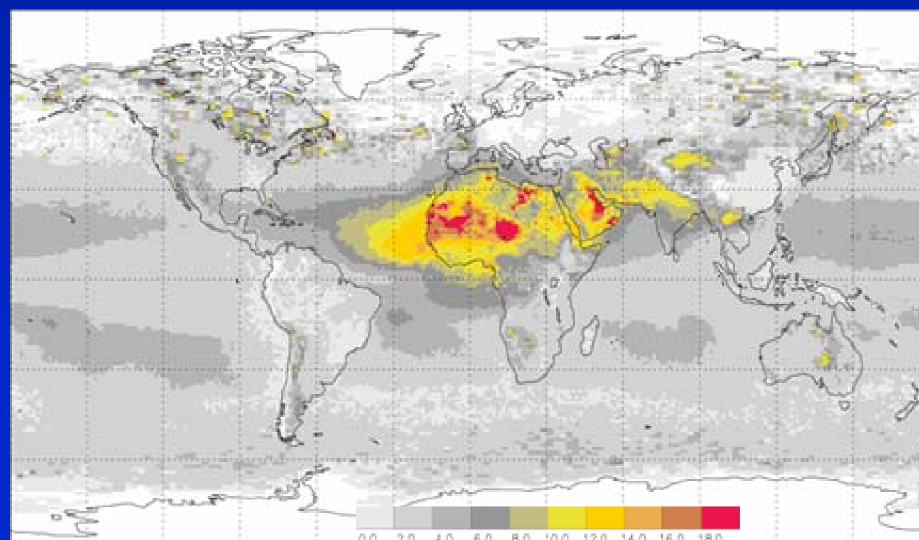
days/yr

Dust Storm Frequencies, 1970-1990s, (Visibility < 1km)

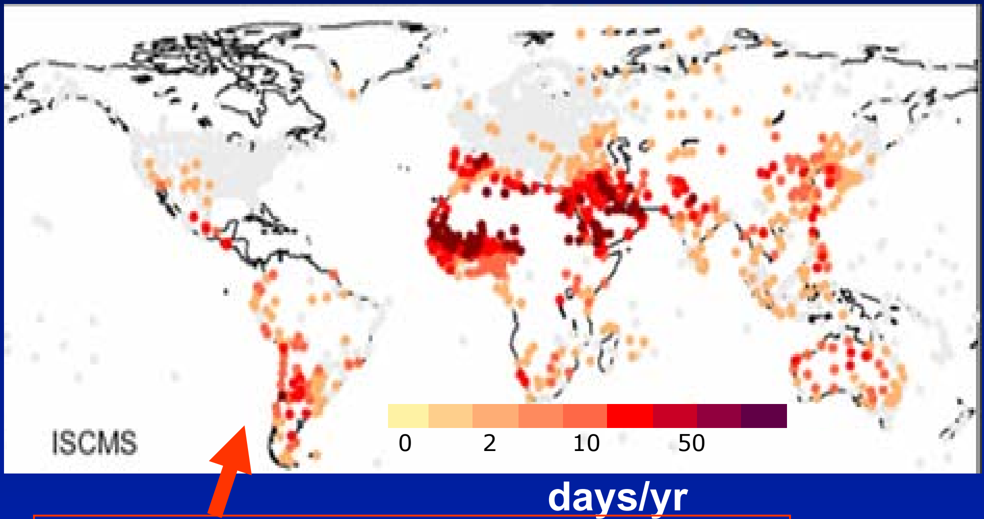
(International Station Meteorological Climate Summary (ISMCS) version 4.0)

(Engelstaedter et al. 2003)

Total Ozone Mapping Satellite Absorbing Aerosol Index (1985-1990)



Global Dust Indicators



Dust Storm Frequencies, 1970-1990s, (Visibility < 1km)

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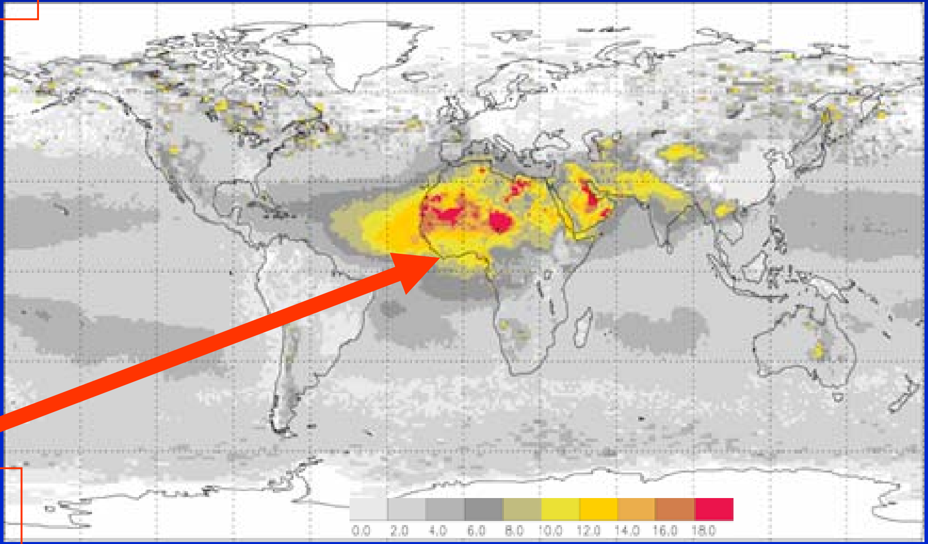
Bias to inhabited regions

Total Ozone Mapping Satellite Absorbing Aerosol Index (1985-1990)



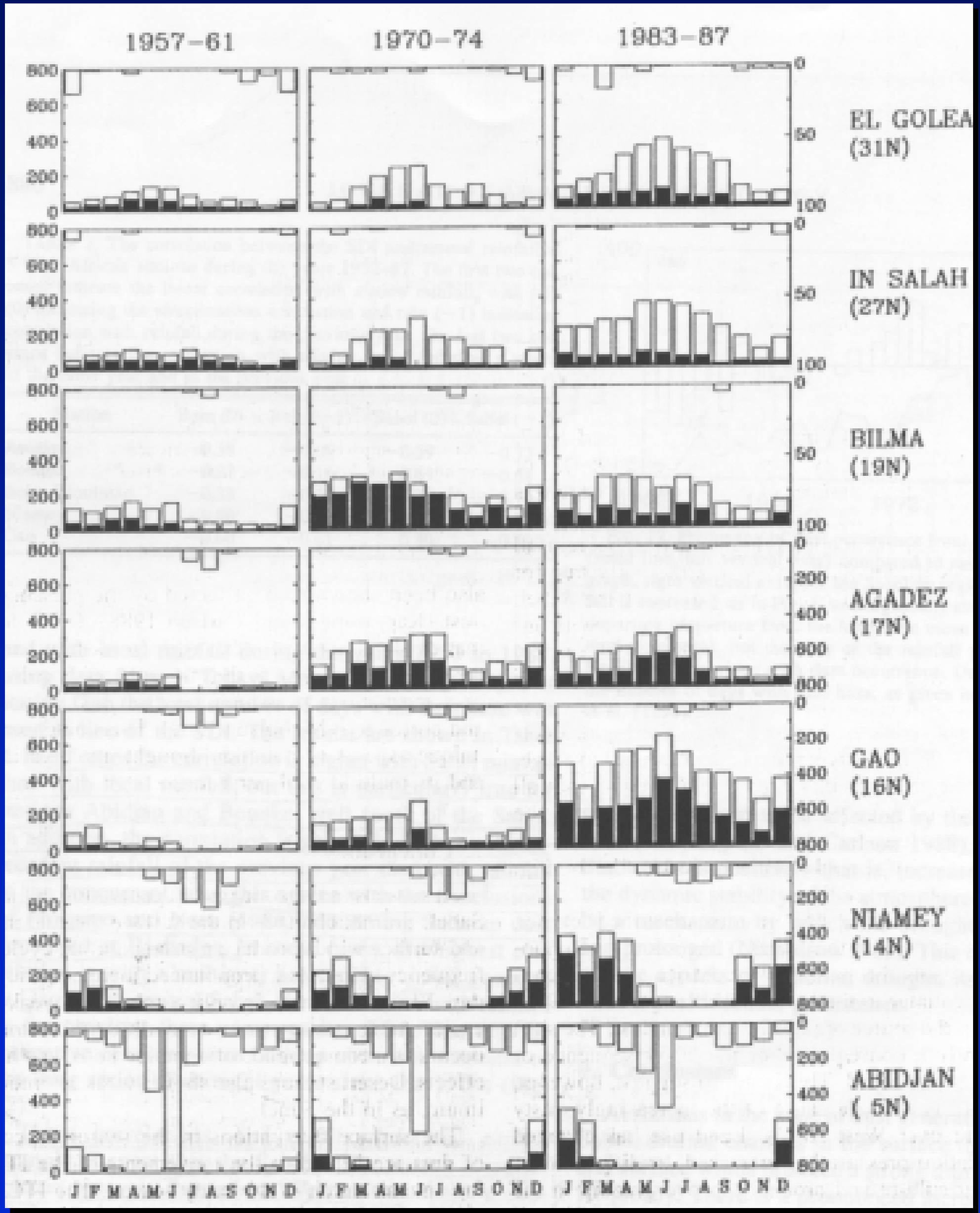
Dust originating in deserts

Do we understand dust variability on interannual to decadal timescales?

- Satellite: Few long-term records, consistency?
- Station data of dust concentration/ice cores:
  only sparse information

➢ Analysis of dust storm frequency data

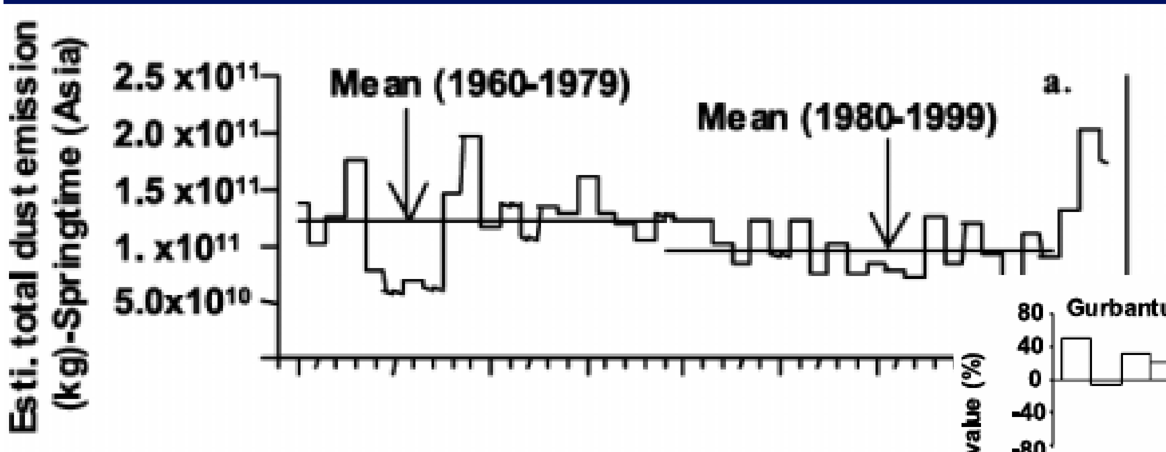
Dust Storm Frequency Changes in Africa

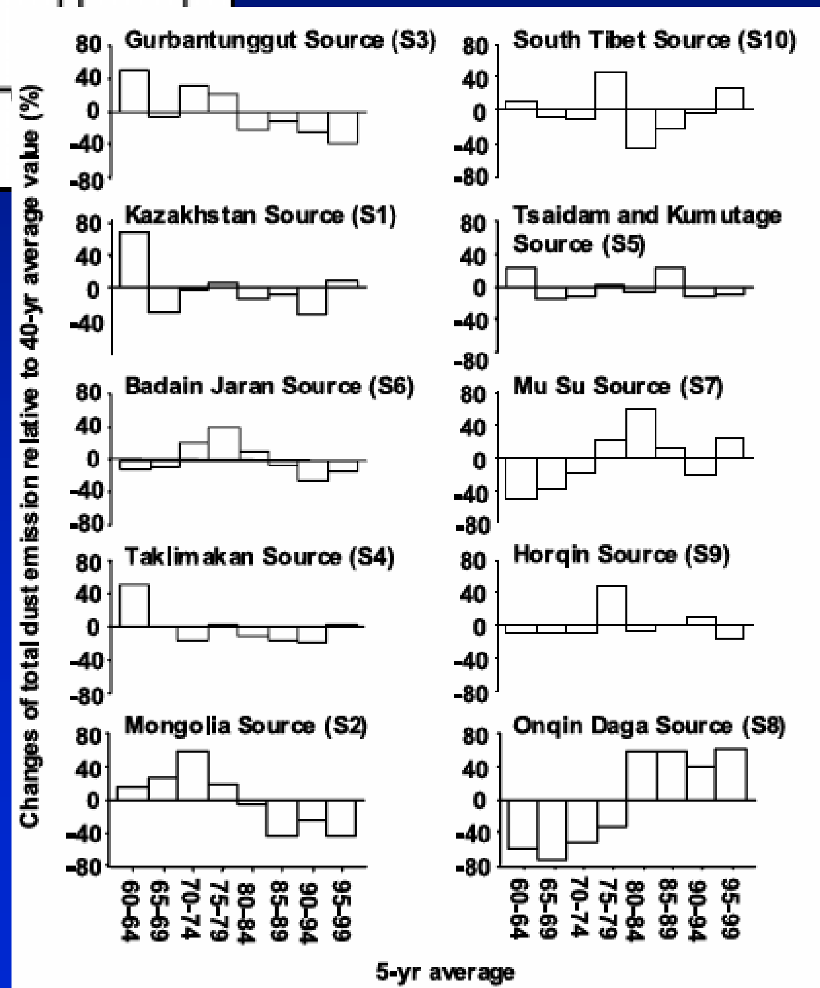


N'tchayi Mbourou et al. (1997)

Zhang et al, 2003

Dust Changes in China





Do we understand dust variability on interannual to decadal timescales?

- Satellite: Few long-term records, consistency?
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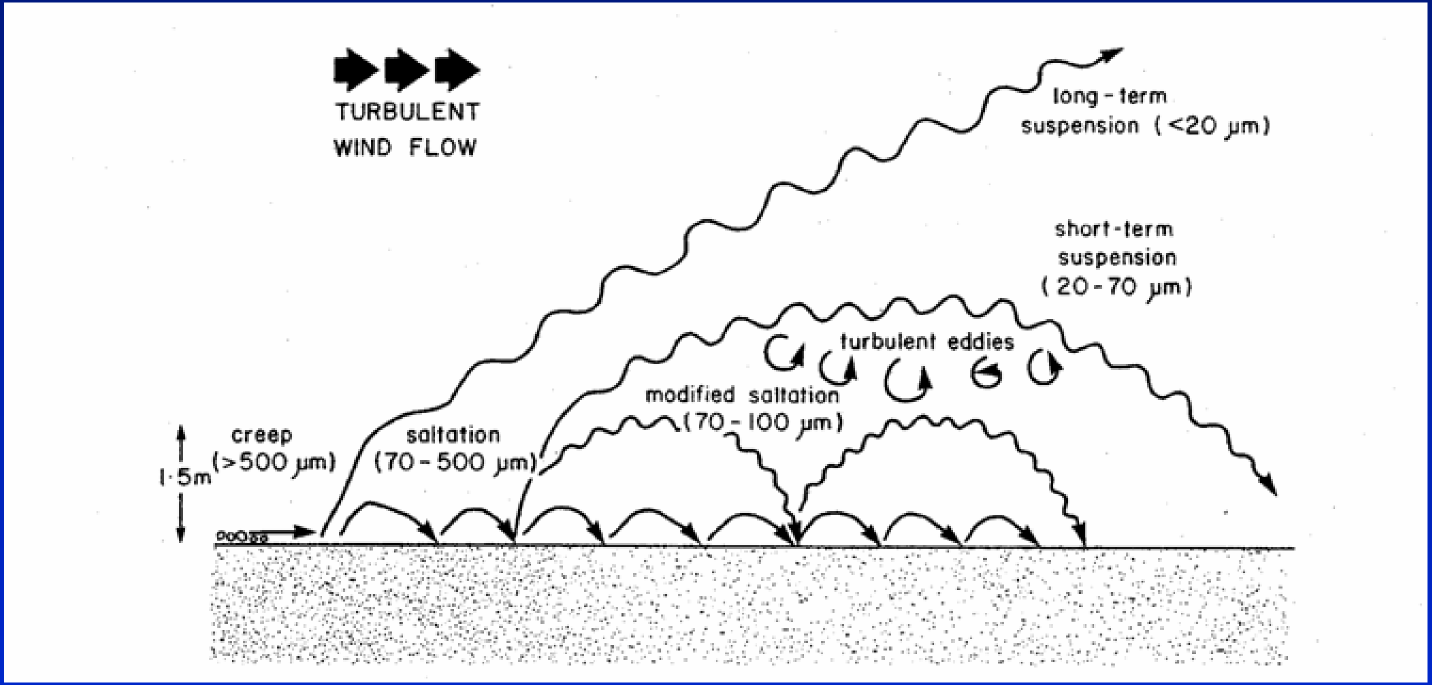
➢ Analysis of dust storm frequency data
➢ Transport models using meteorological fields
  from a series of reanalysis years

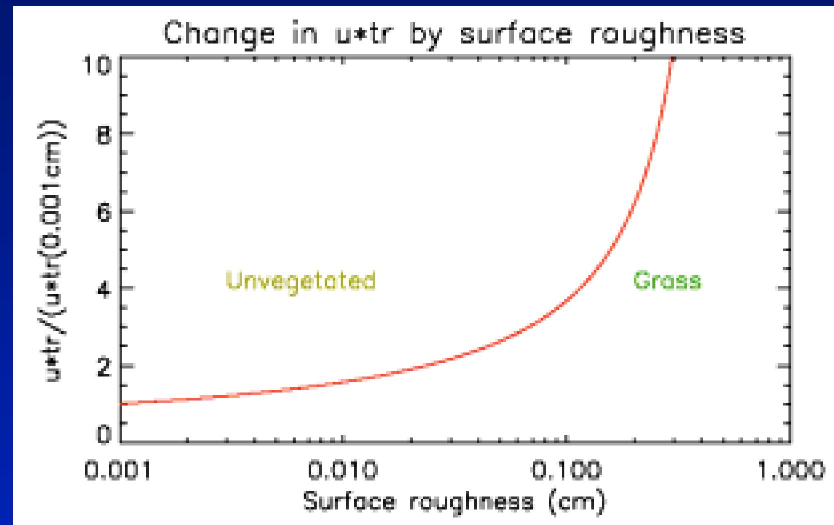
Processes of Soil Particle Movement



Pye (1987)

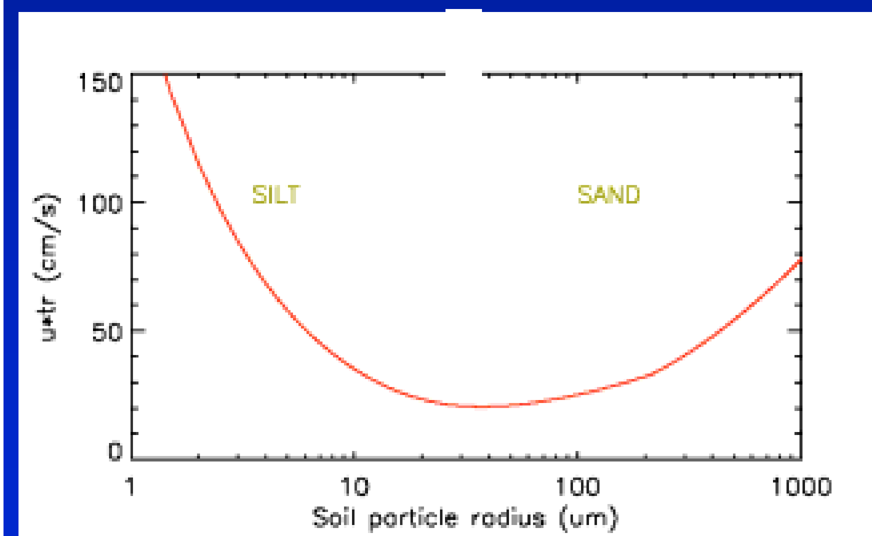
(Numbers in brackets indicate typical particle diameters)

Dependence of threshold wind shear for dust emission on z_0



after Marticorena and Bergametti, 1995

Minimum u* required for dust emission



after Iversen and White (1982)

Some dust emission schemes used in global models

Tegen et al., 1994:

$$F = \sum_i (C_i (u - 6.5 m/s) u^2)$$

C: Calibration constant

Marticorena et al., 1997

$$F = \alpha \frac{\rho}{g} u_*^3 \sum_i \left[\left(1 + \frac{u_{*tr_i}}{u_*}\right)\left(1 - \frac{u_{*tr_i}^2}{u_*^2}\right) s_i \right]$$

α: depending on soil type

Ginoux et al, 2001

$$F = CS \sum_i \left[(u - u_{tr_i}(\text{soil moisture})) u^2 s_i \right]$$

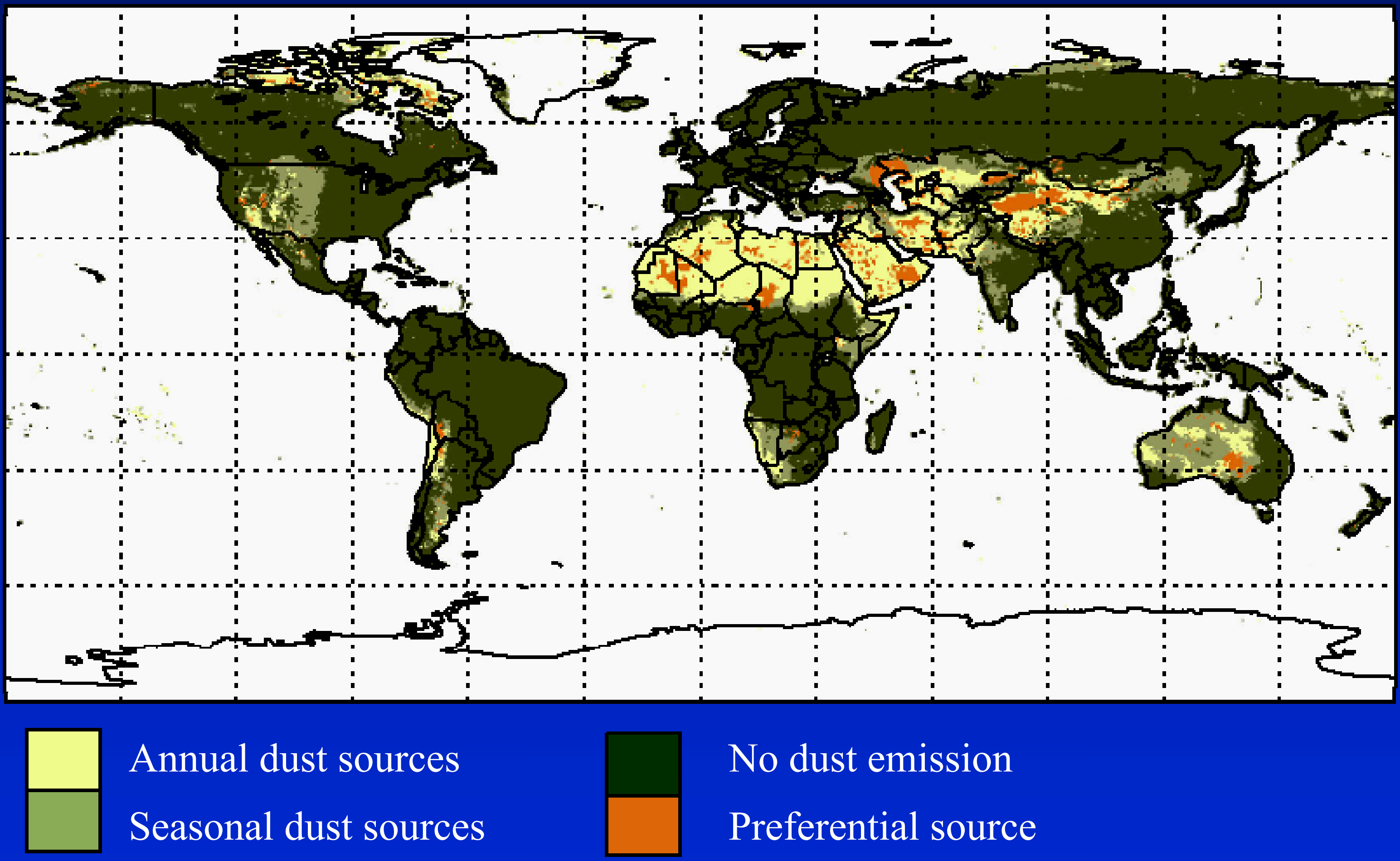
S: topography factor

for $u > u_{tr}$ (or $u_* > u_{*tr}$)

F: dust flux, *u*: surface wind speed, u_{tr}: threshold wind speed, u_* surface wind shear, s_i: fraction of particles in size bin i, ρ= air density, *g*: gravitational constant

Usually areas with high vegetation and soil moisture are masked out

Dust source areas: Vegetation mask



Dust Budget Estimates

Reference	*Emissions E* *Tg yr*$^{-1}$	*Time* τ *Days*	*Burden M* *Tg*
Duce et al. [1991]	(910)		
Tegen and Fung [1994]	3000		
Tegen and Fung [1995]	1222	5.6	18.8
Andreae [1996]	1500	4	8.4
Prospero [1996]	(358)		
Mahowald et al. [1999]	3000		
Penner et al. [2001]	2150		
Ginoux et al. [2001]	(478)\1814	7.1	35.9
Chin et al. [2002]	1650	6.3	28.7
Werner et al. [2002]	1060 ± 194	2.8 ± 0.5	8 ± 3
Tegen et al. [2002]	1100	7.4	22.2
Zender et al. [2003]	(314)1490 ±160	4.3 ± 1.0	17.4 ± 2
Luo et al. [2003]	1654	5.1	23
Mahowald and Luo [2003]	1654	5.1	23
Miller et al. [2004]	1018	5.2	14.6
Tegen et al. [2004]	1921		

Zender et al., 2004

Human Impact on Dust Emissions

Impact on soil surfaces by:

- Cultivation in arid and semi arid regions (+)
  - (Soil protection, irrigation) (-)
- Overgrazing (+)
- Deforestation (+)
- Unpaved roads, construction (+)
- Military activities in deserts (+)

Human Impact on Dust Emissions

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- Deforestation (+)
- Unpaved roads, construction (+)
- Military activities in deserts (+)

Impact on climate:

- Changes in meteorology (wind, precipitation) (+/-)
- Changes in natural vegetation (+/-)

Human Impact on Dust Emissions

Impact on soil surfaces by:

- Anthropogenic Dust of First Kind
  1. Direct emission by mechanical impact
  2. Wind erosion of disturbed soils

Impact on climate:

- Anthropogenic Dust of Second Kind

(Zender et al, 2004)

Methods to estimate anthropogenic contribution from global models:

- Global models: Increase of dust emissions by either enhancing emission factor or decreasing u^*_{tr} in regions with disturbed soils

$$F = \alpha \frac{\rho}{g} u_*^3 \sum_i \left[\left(1 + \frac{u_{*tr_i}}{u_*} \right) \left(1 - \frac{u_{*tr_i}^2}{u_*^2} \right) s_i \right]$$

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Human Impact on Dust Emissions

Global estimates of dust fluxes from anthropogenically disturbed soils:

- IPCC, 2001: up to 50% (determines radiative forcing)

  ⇨ *based on model/satellite AOT comparison (ocean)*

Human Impact on Dust Emissions

Global estimates of dust fluxes from anthropogenically disturbed soils:

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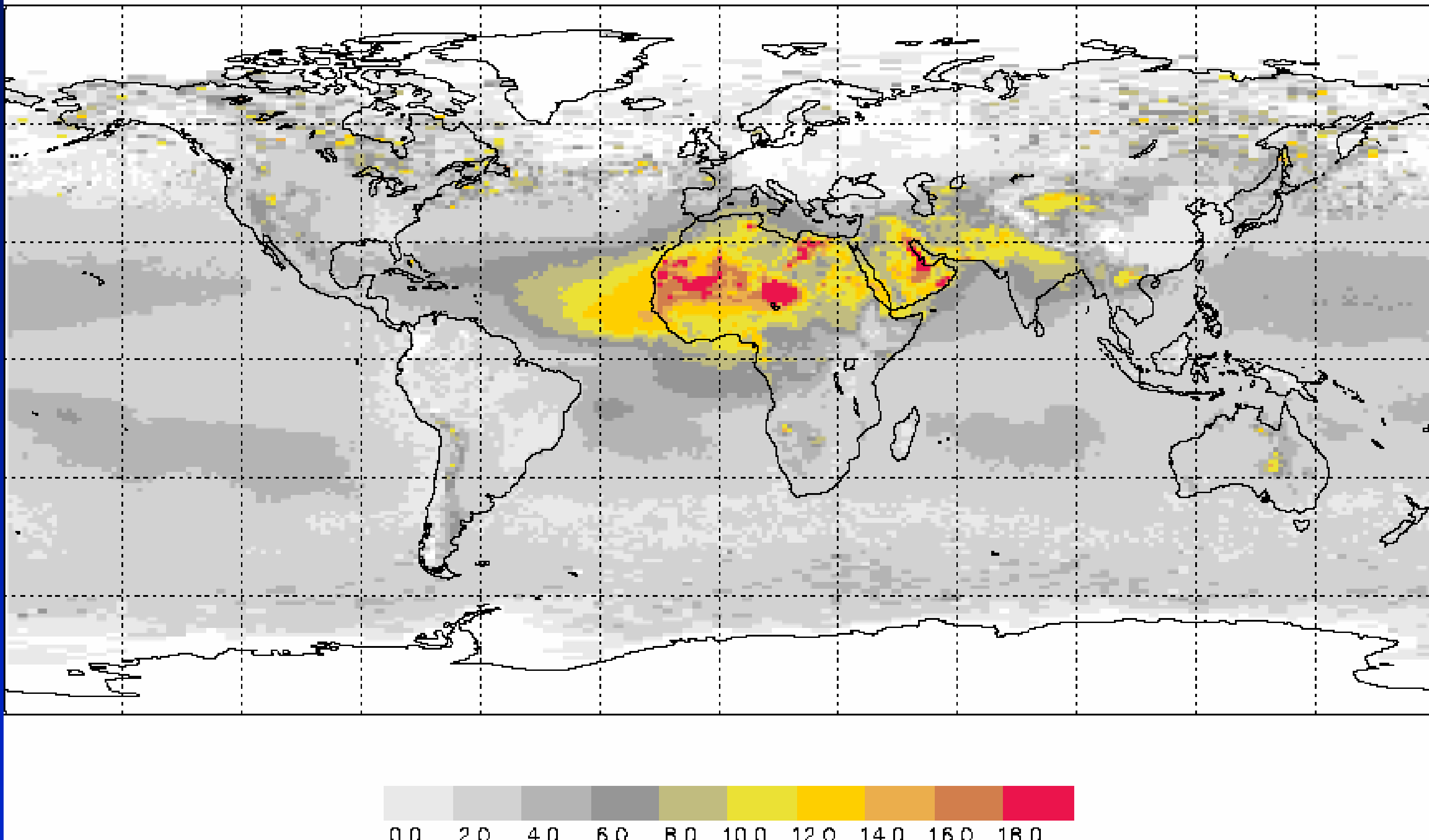
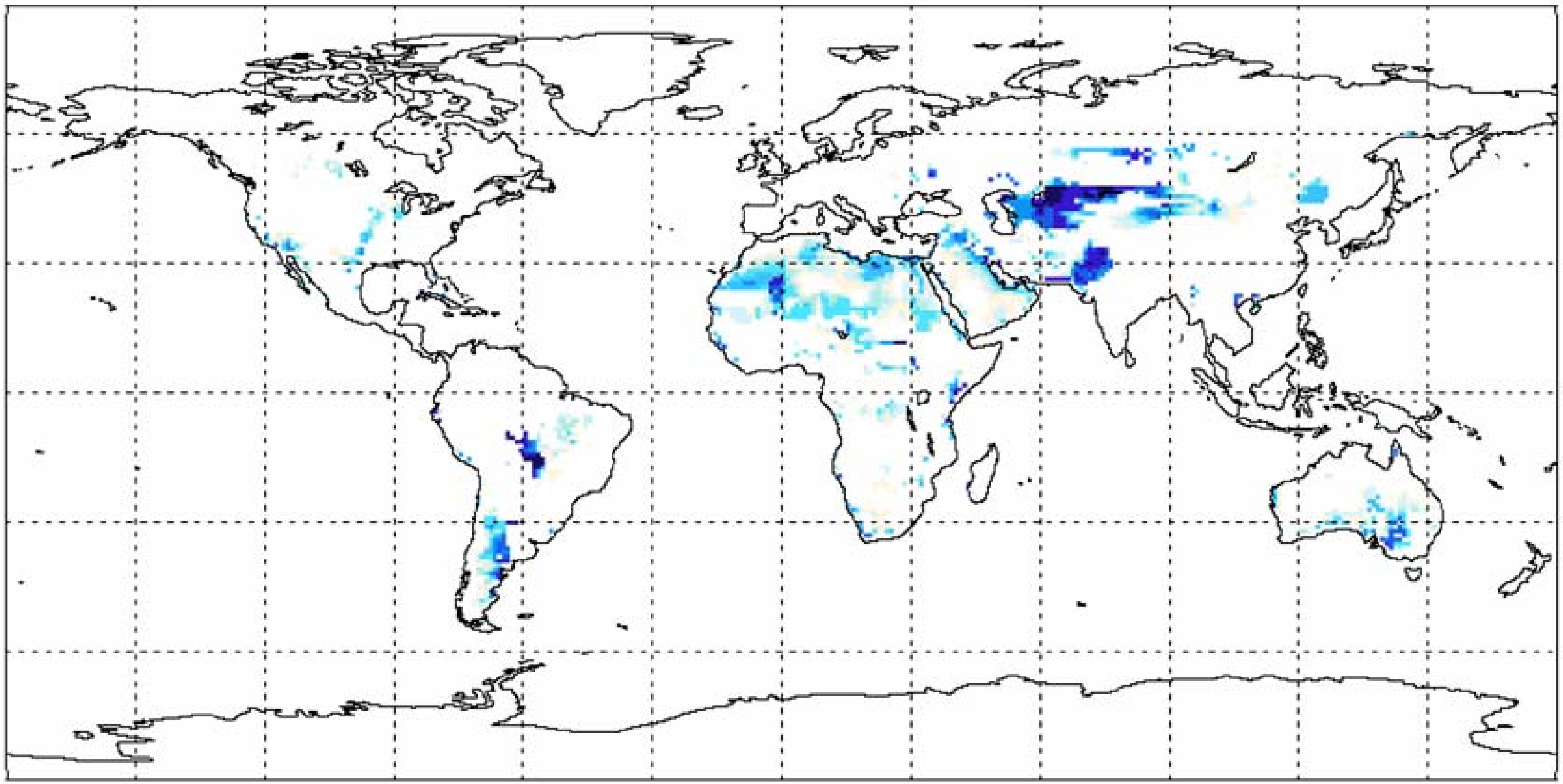
- Prospero et al, 2002: small (Natural sources dominant)

TOMS absorbing aerosol index 1985-1990



- "Dust mostly originates from deserts 'hot spots' in uncultivated regions"

Preferential Dust Source Areas



Ginoux et al., 2001

Human Impact on Dust Emissions

Global estimates of dust fluxes from anthropogenically disturbed soils:

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⇨ *based on comparison of different model scenarios with concentration data from surface stations*

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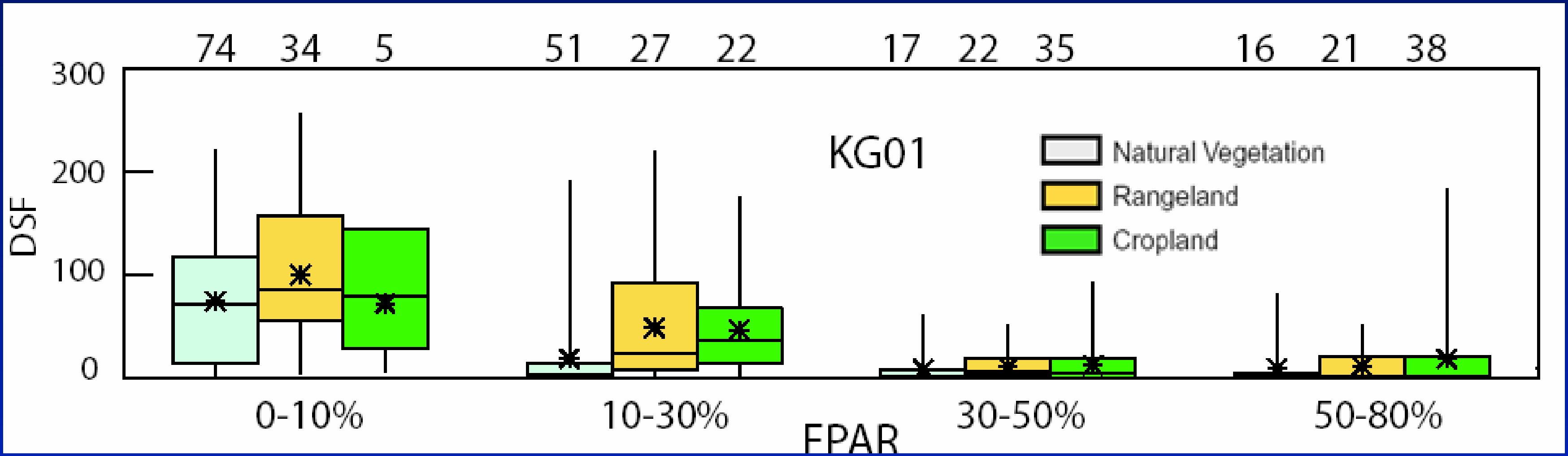
- Tegen et al., 2004: <10% (Agricultural soils)

⇨ *based on comparison of different model scenarios with DSF climatology data*

Observed differences between dust storm frequencies in different source regions

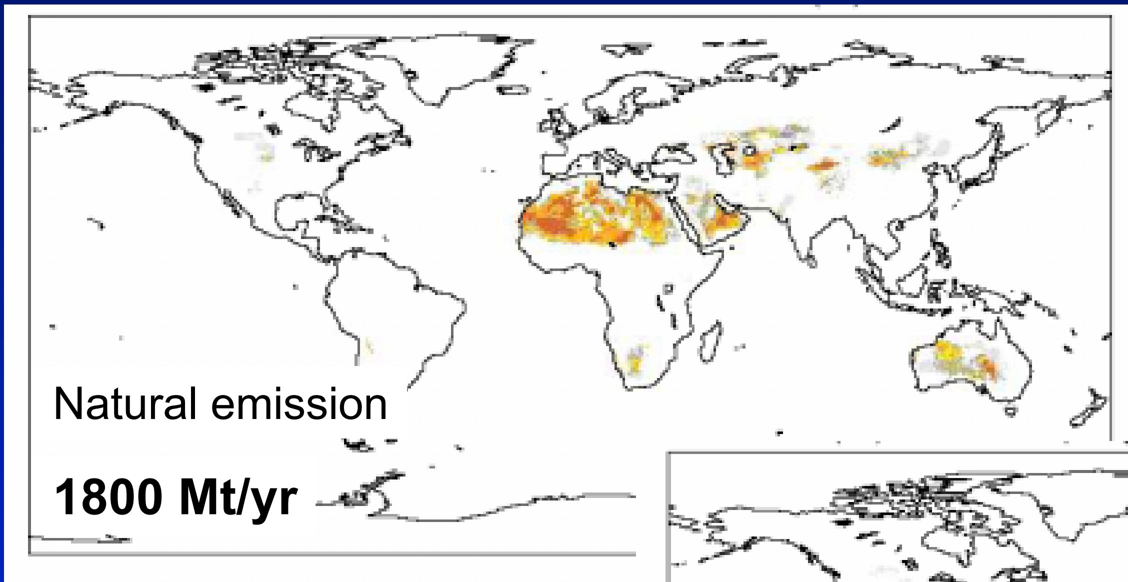


Vegetation cover

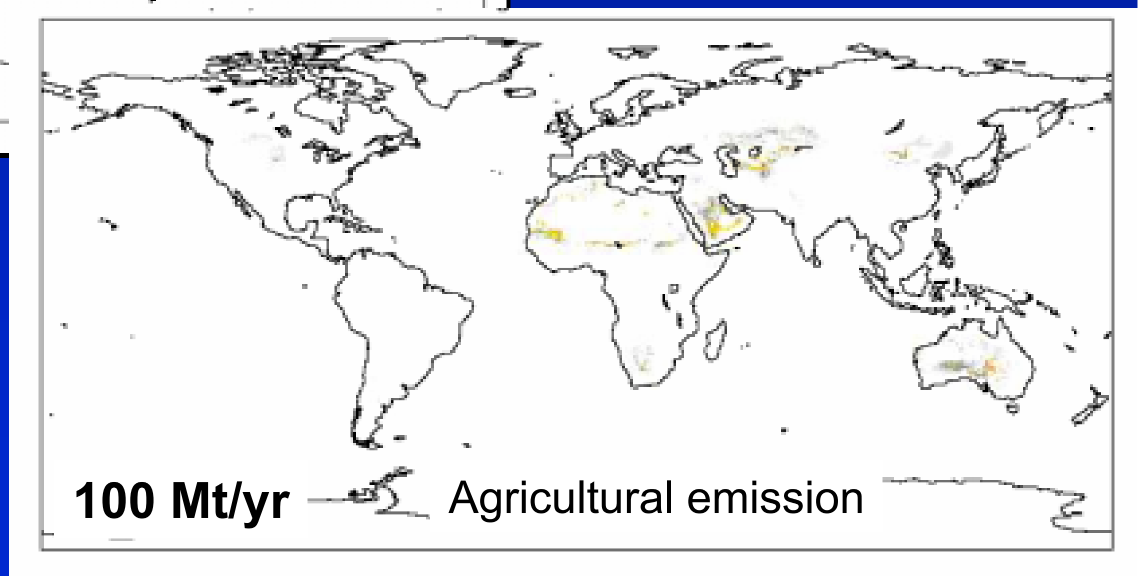
Tegen et al., 2004

- Small but significant increase in cultivated areas for locations grouped according to vegetation cover.

Dust Emissions from Natural and Cultivated Soils



- *Satellite z_0*
- *ECMWF ERA15*
- *Year 1987*



Percent dust from cultivation:

- ERA15, const. z_0: **7%**
- ERA15, ERS z_0: **6%**
- NCEP: **8%**

Human Impact on Dust Emissions

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➔ *Large uncertainties!*

Regional Soil Studies: Wind Erosion Prediction

WEQ: Wind Erosion Equation

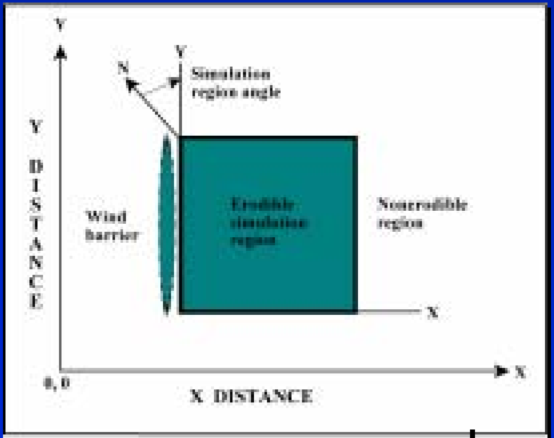
E = f (I, K, C, L, V)

E: potential soil loss, I: erodibility index,
K: roughness factor, C: climate factor, L: unsheltered distance across field, V: equivalent vegetative cover.

WEPS: Wind Erosion Prediction System (USDA)

Process based, process sub-models:

- Weather
- Crop Growth
- Decomposition
- Hydrology
- Soil
- Erosion
- Tillage



WEPS simulation geometries.

- **For climate impact studies need particle size information!**

Climate Change Impact: Projected Future Dust Emission Changes

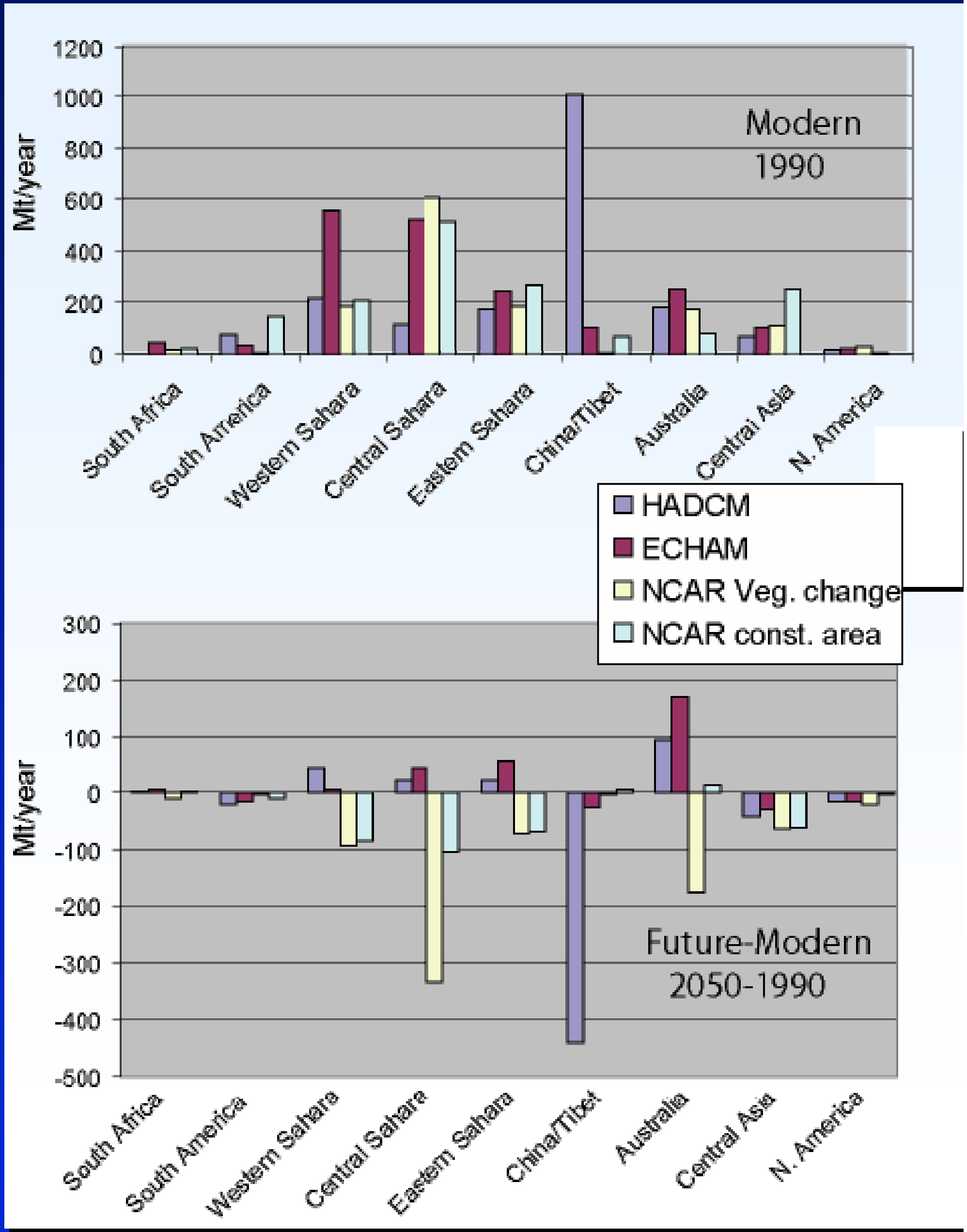
- Changes in meteorology
  - Computing dust emission using meteorological fields extracted from ECHAM4 and HADCM3 IPCC future scenarios (IS92a Greenhouse warming).
- Changes in vegetation cover (as consequence of climate change)
  - Vegetation changes computed with BIOME4 vegetation model.
- Changes in cultivation patterns
  - Changes in emissions from cultivated regions computed using results from the IMAGE2.2 model (RIVM), based on IPCC SRES scenarios.

Regional Dust Emission Changes: Projection for 2050

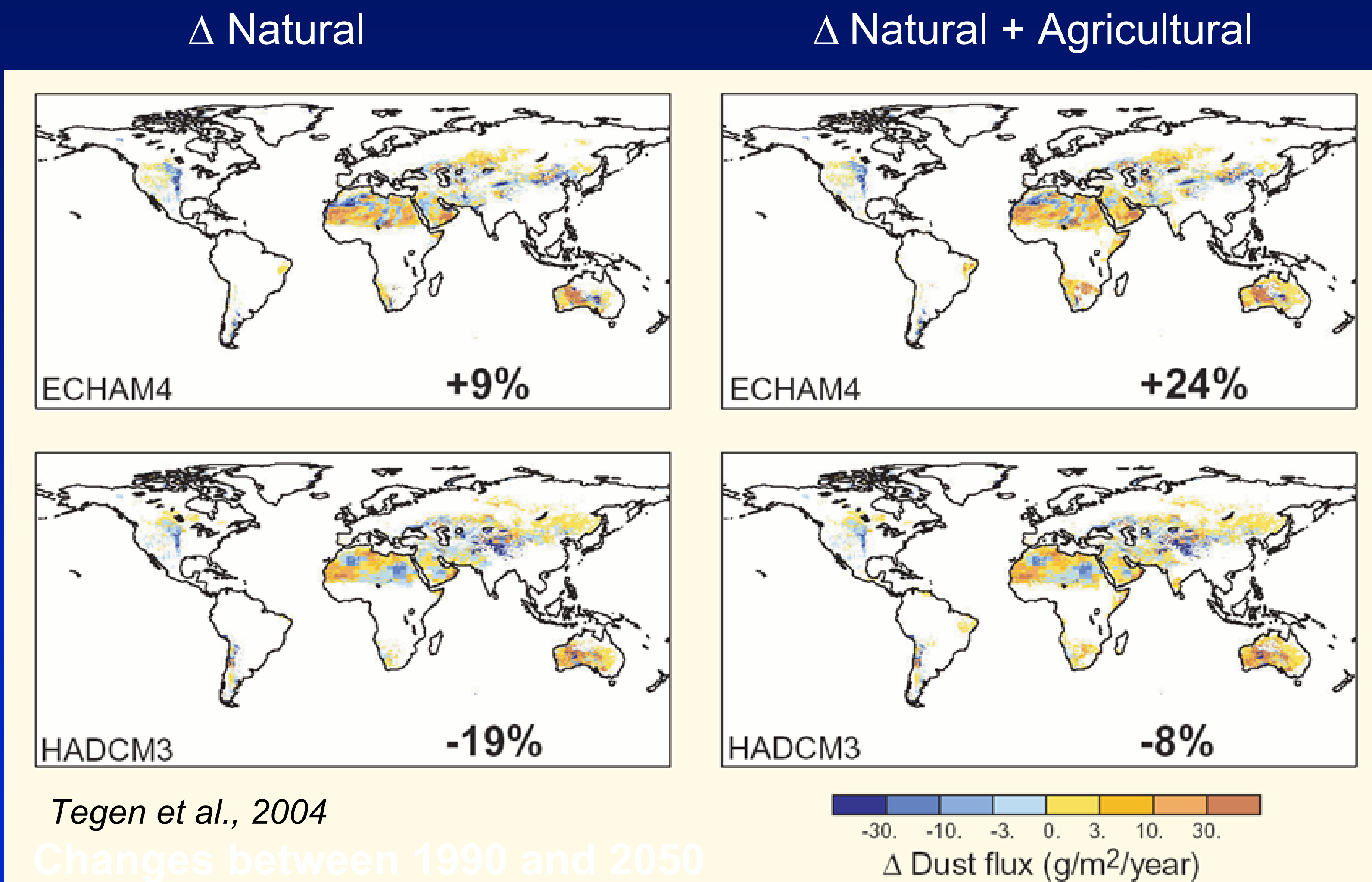
- Tegen et al., 2004:
  HADCM, ECHAM
- Mahowald and Luo, 2003:
  NCAR

Global: -60-+20% change in emissions

➢ Future estimates in dust changes vary greatly due to uncertainties in climatology and parameterization of dust emissions in global models



Projected Future Dust Emission Changes



Tegen et al., 2004

For comparison: Mahowald and Luo, 2003: 60% reduced dust emission in 2090

More sources of anthropogenic soil dust

- Agricultural tillage: Europe: Probably more important than wind erosion? (Goossens et al., 2001)
- Deforestation: ?? Treat as unvegetated areas for wind erosion, possibly small contribution (Tegen and Fung, 1995)
- Offroad traffic: Depending on vehicle speed and weight, PM10 – climate relevance? Small areas (Gillies et al. 2005, Etyemezian, 2004)
- Construction: Climate relevance? Small areas (Kinsey et al., 2004)

Summary

- Dust emissions can by impacted by human influence on land surfaces or as consequence of anthropogenic climate change.
- Global ‘antropogenic’ dust emissions have been estimated to be up to 50% (IPCC 2001). Recent results indicate that probably less than 10-25% of global dust emissions originate from agricultural soils.
- Changes in dust on global scale are likely to be more controlled by changes in climate and natural vegetation rather than by changes in cultivated areas.
- Regional impacts of anthropogenic soil dust may be large.
- Better quantification of anthropogenic dust emission requires upscaling of wind erosion measurement/ model results, plus size resolved information (PM2.5).