The Cyprus Institute

Max Planck Institute for Chemistry

Air pollution and climate change hot spot in the Mediterranean and Middle East region

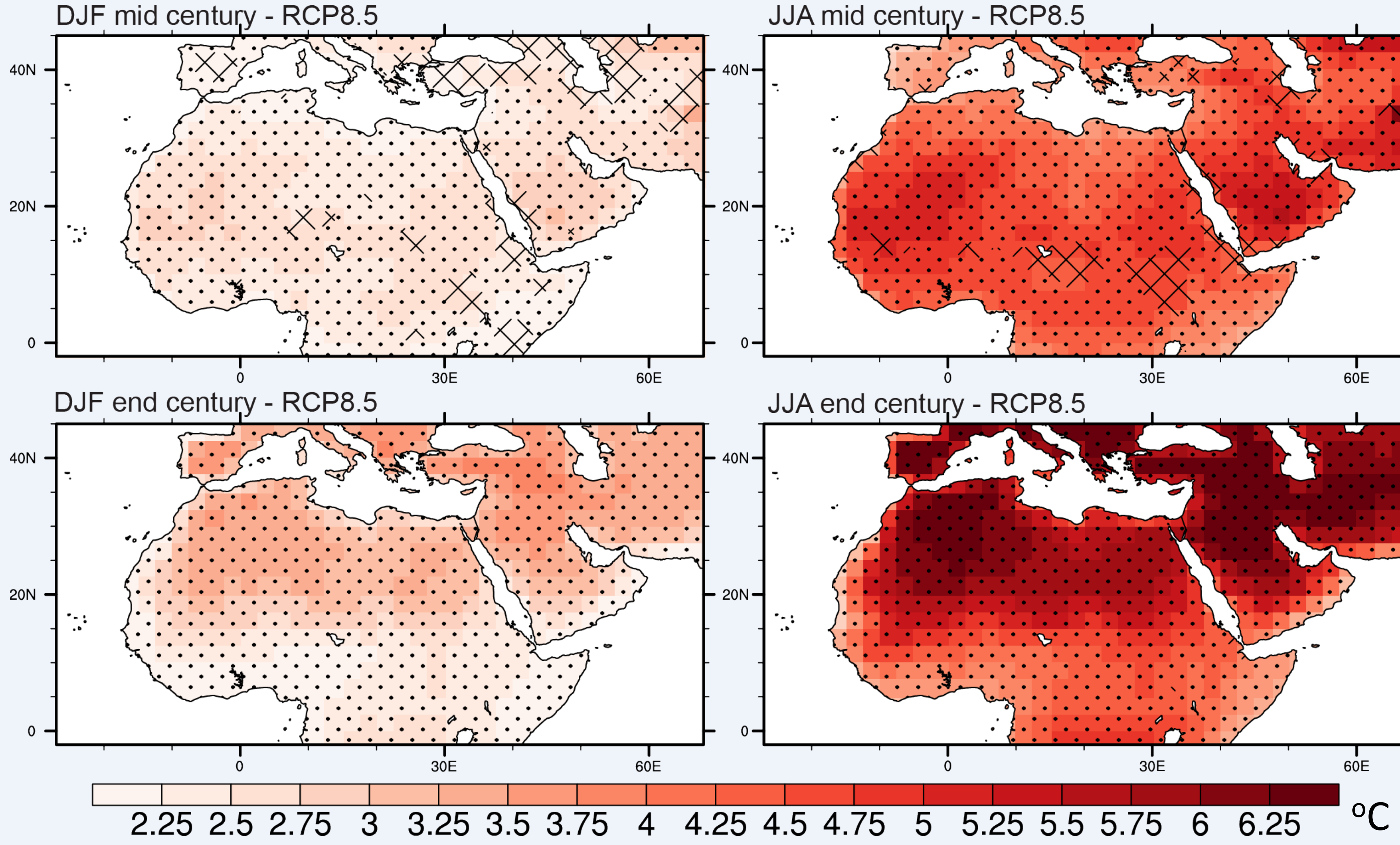
Jos Lelieveld

Integrated Environmental Health Impact Assessment of Air Pollution and Climate Change in the Mediterranean Area, ICTP Trieste, 23 April 2018

Contents

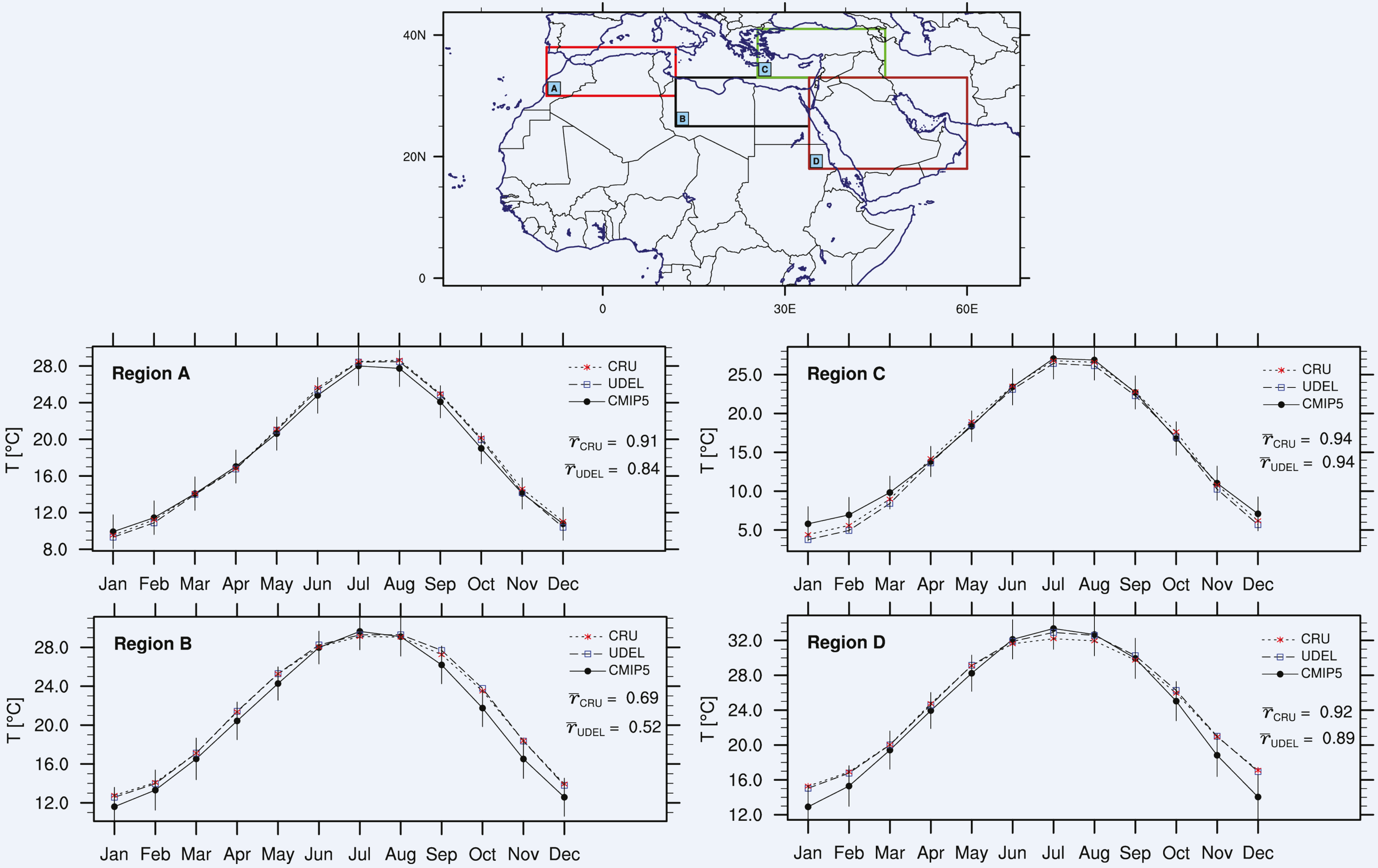
- Climate change and heat extremes (hot spot)
- Wind-blown (aeolian) dust
- Pollution trends observed from space
- Atmospheric chemistry, aerosol and climate modelling
- Tropospheric ozone and particulate matter (PM)
- Anthropogenic chemical processing (ageing) of mineral dust
- Global $PM_{2.5}$, health impacts and source attribution

Coupled Model Inter-comparison Project phase 5 – CMIP5: temperature projections

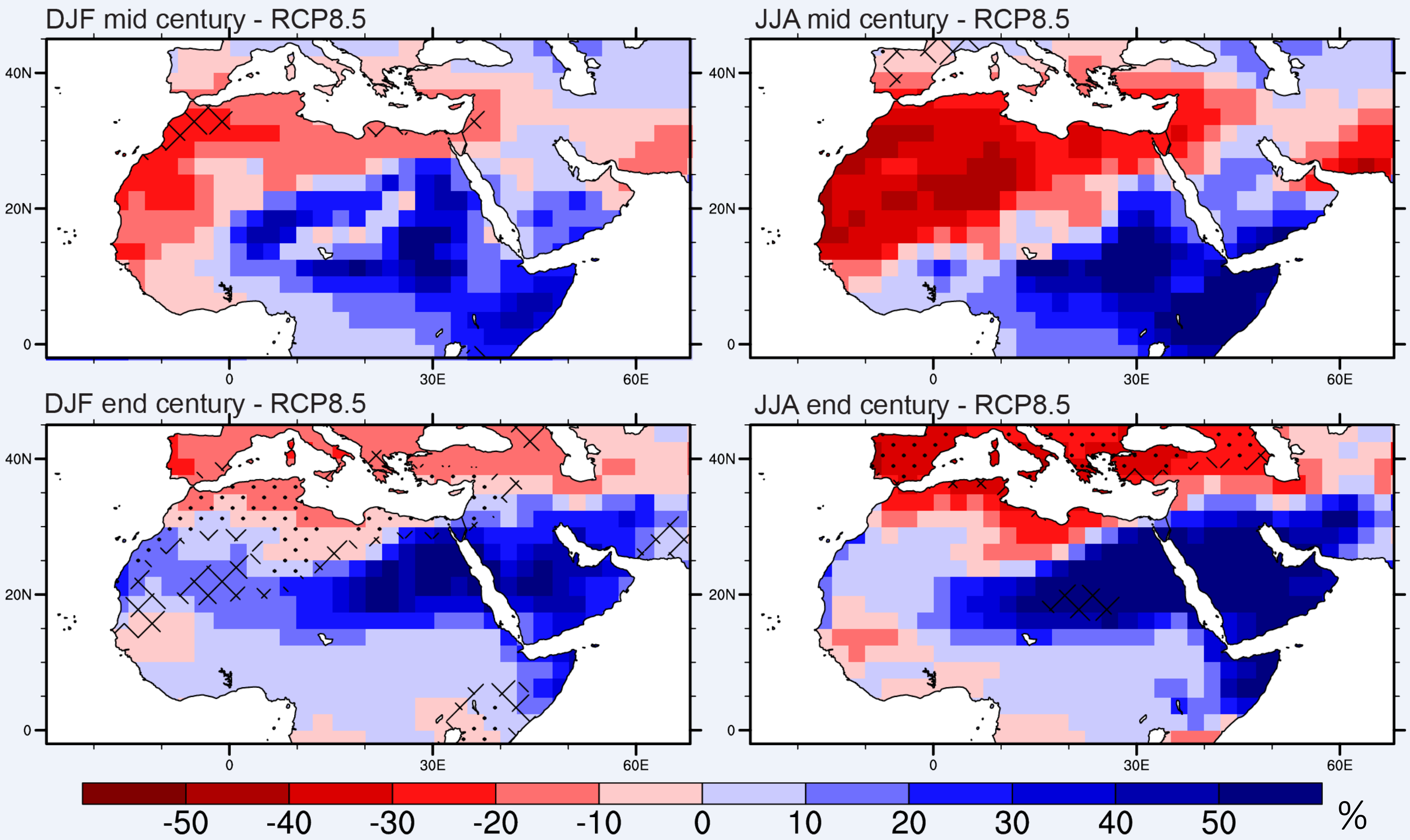


Model robustness: dots R ≥ 0.85, and cross-hatching 0.5 ≤ R < 0.85

CMIP5 temperature vs. observations in reference period (1986 – 2005)

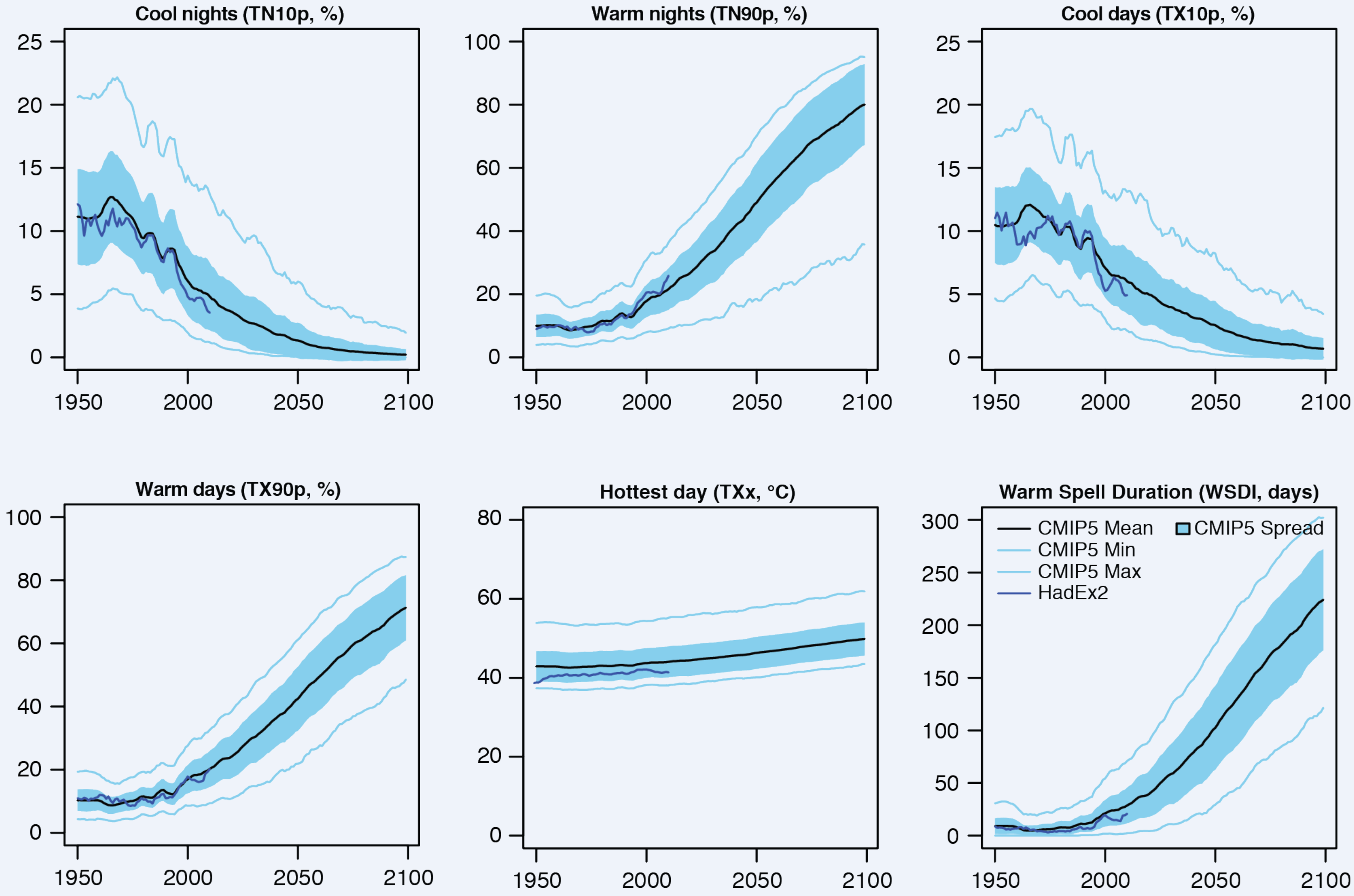


Coupled Model Inter-comparison Project phase 5 – CMIP5: precipitation projections

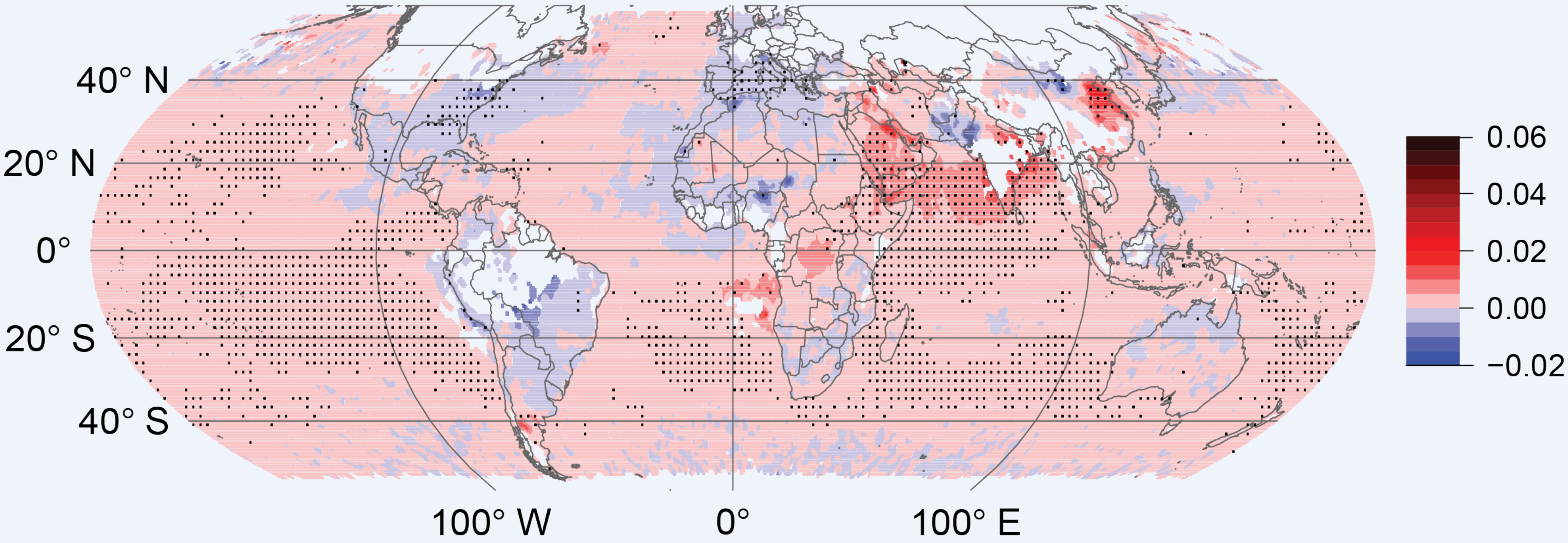


low robustness

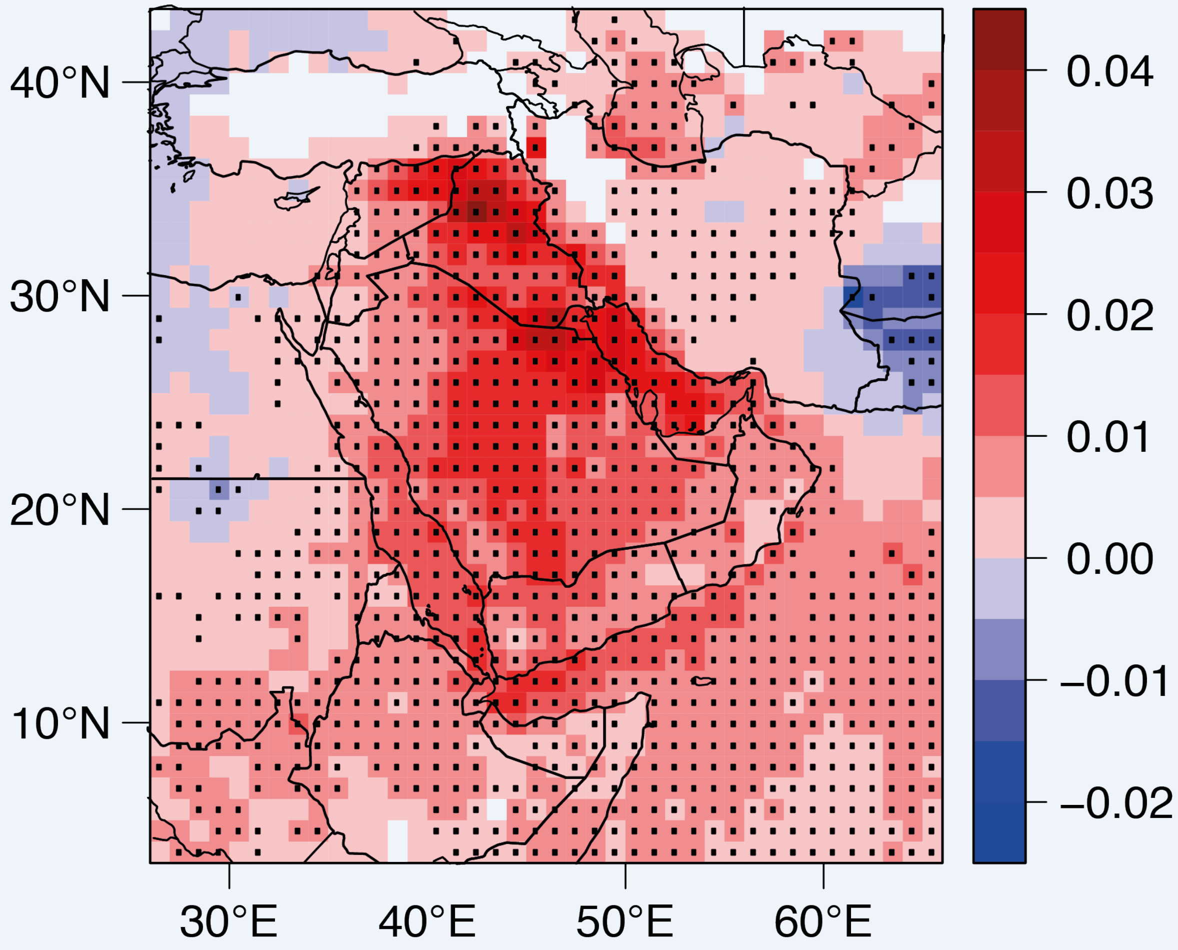
CMIP5: projected temperature indices, and observations in reference period



MODIS AOD (550 nm) trend (1/year), 2000 to 2015

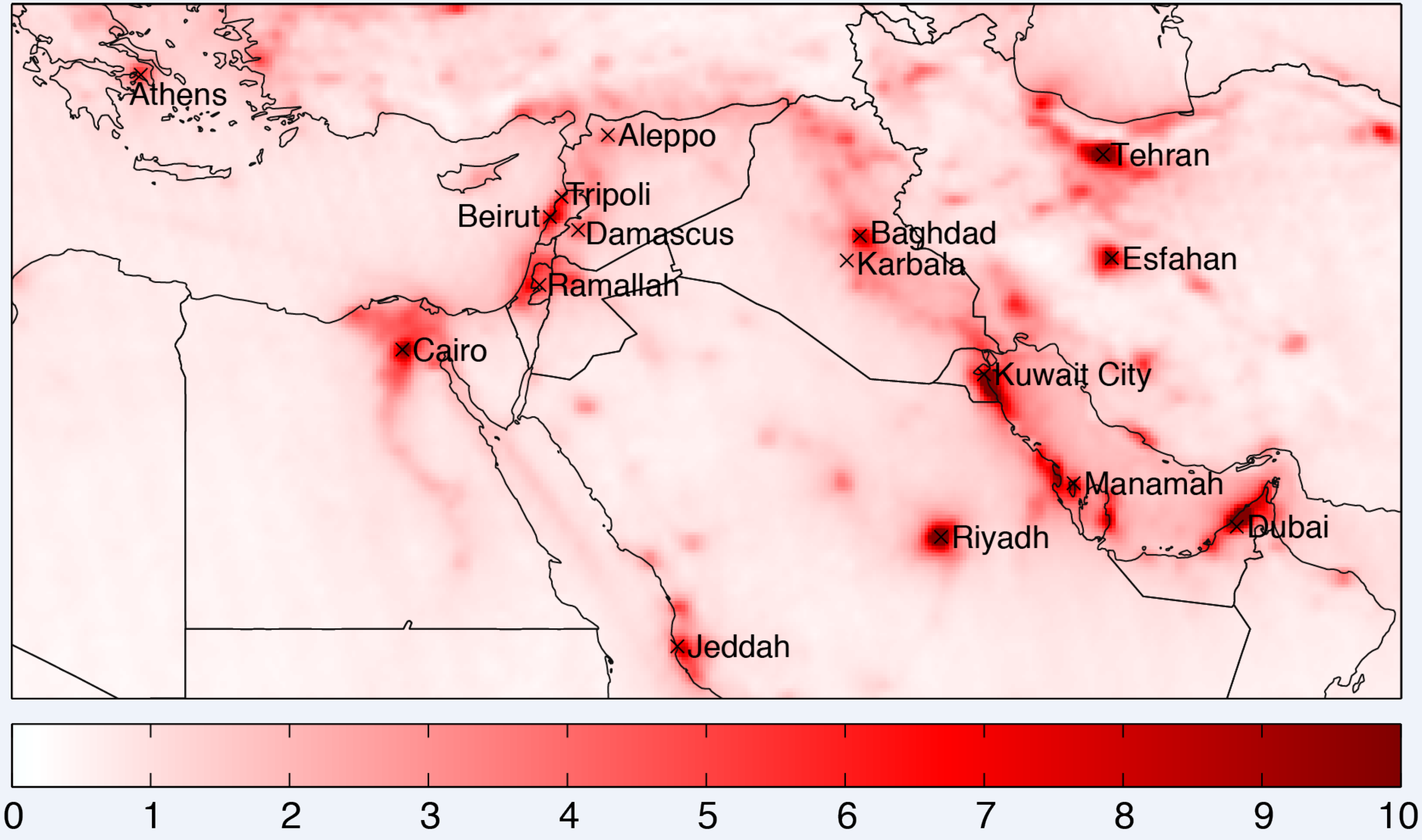


Aerosol optical depth trends ($year^{-1}$) over the Middle East from 2000 to 2015, from MODIS satellite data



Abrupt trend changes in atmospheric NO_2 and SO_2 over the Middle East

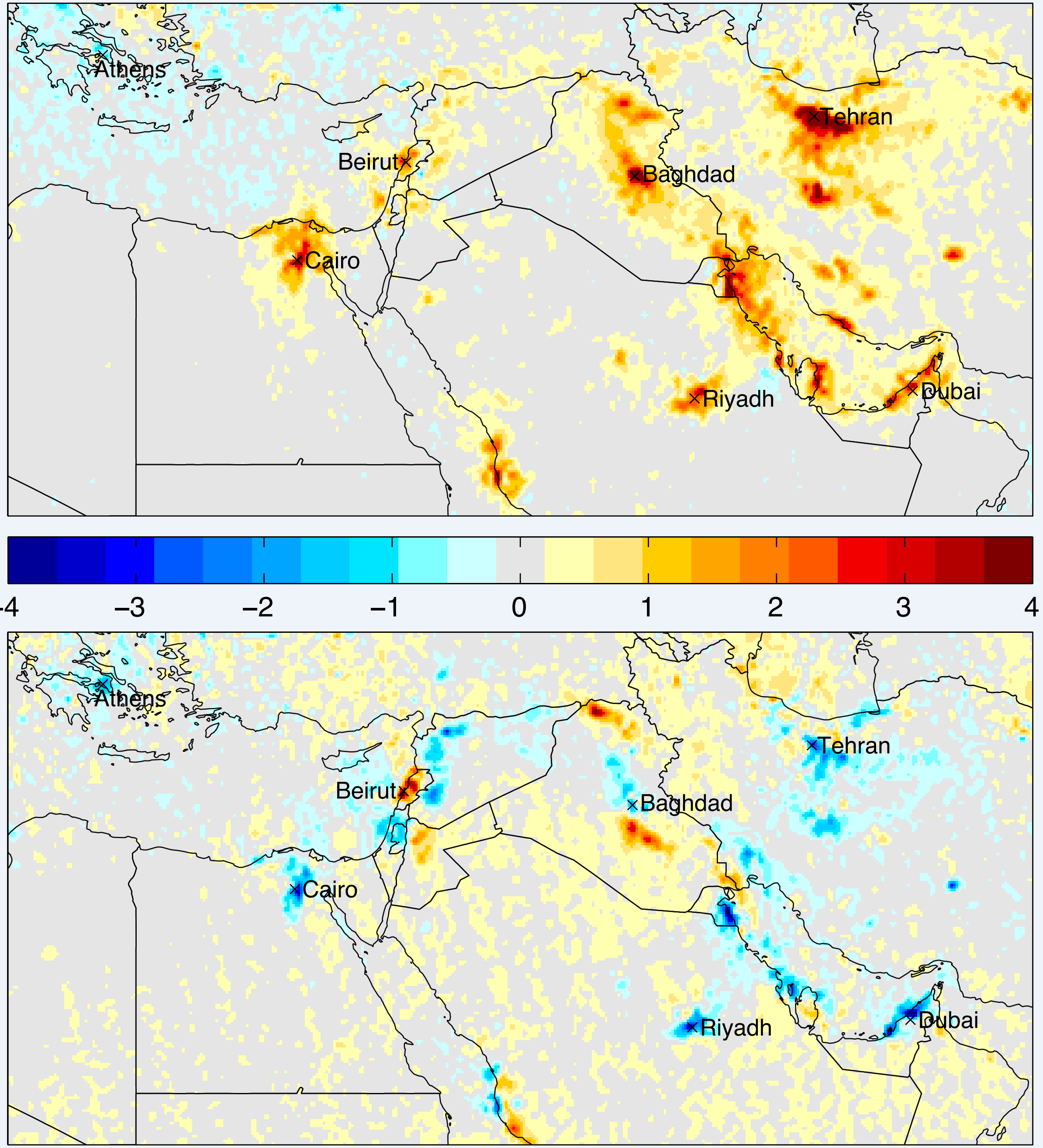
NO_2 column densities in 10^{15} molecules/cm^2 observed by OMI over 2005 – 2014



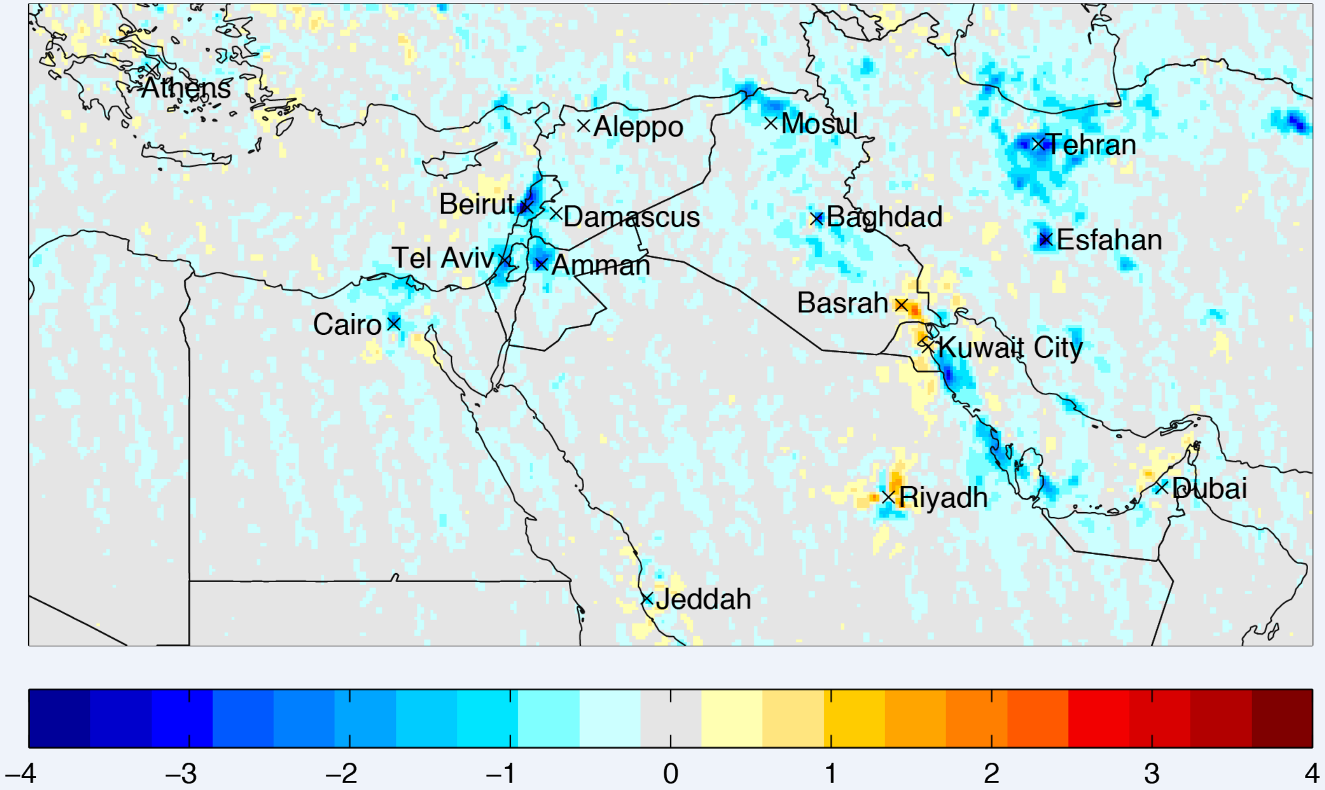
NO_2 changes in 10^{15} molecules/cm^2

2005 to 2010

2010 to 2014

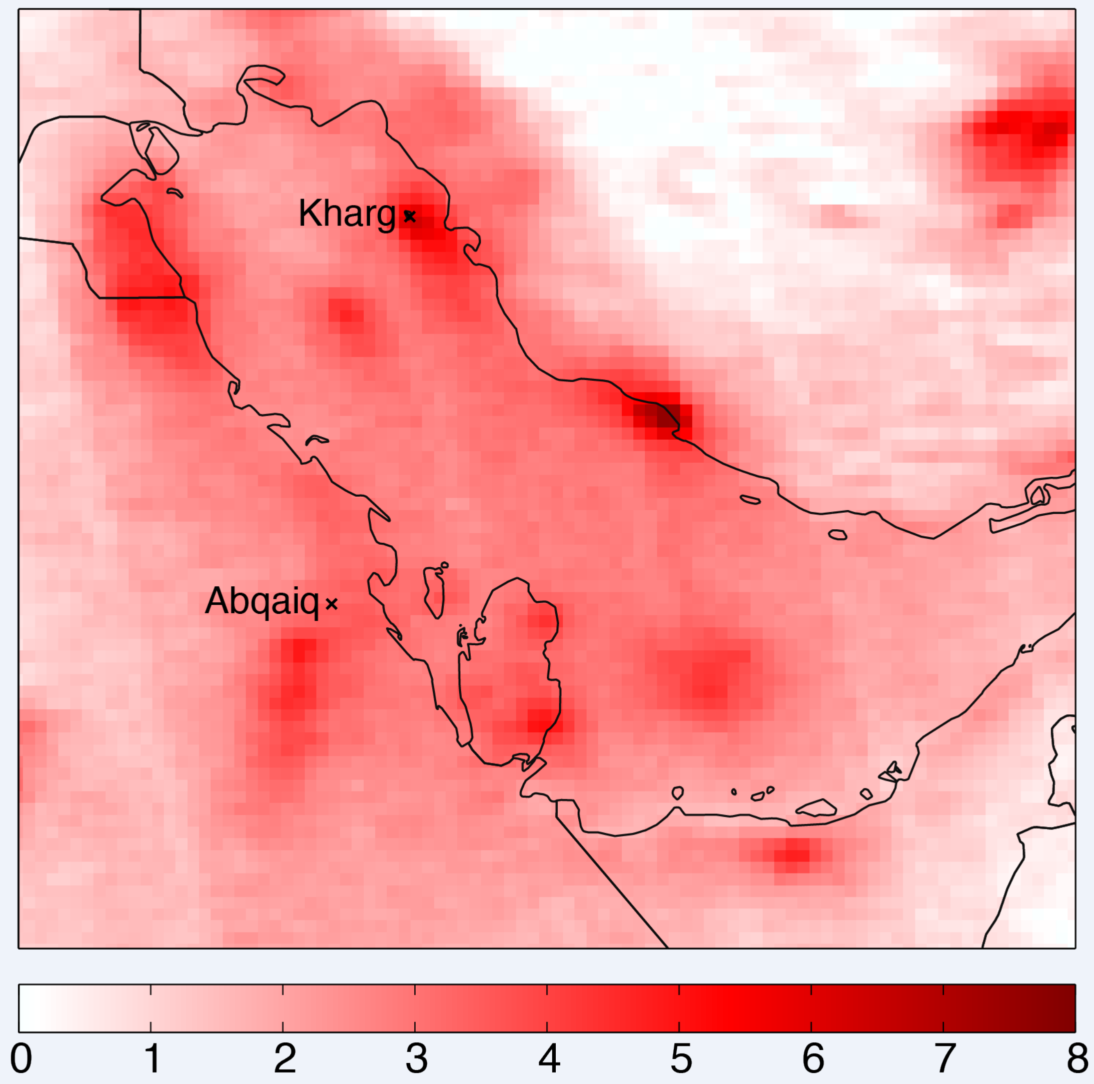


2014 to 2015

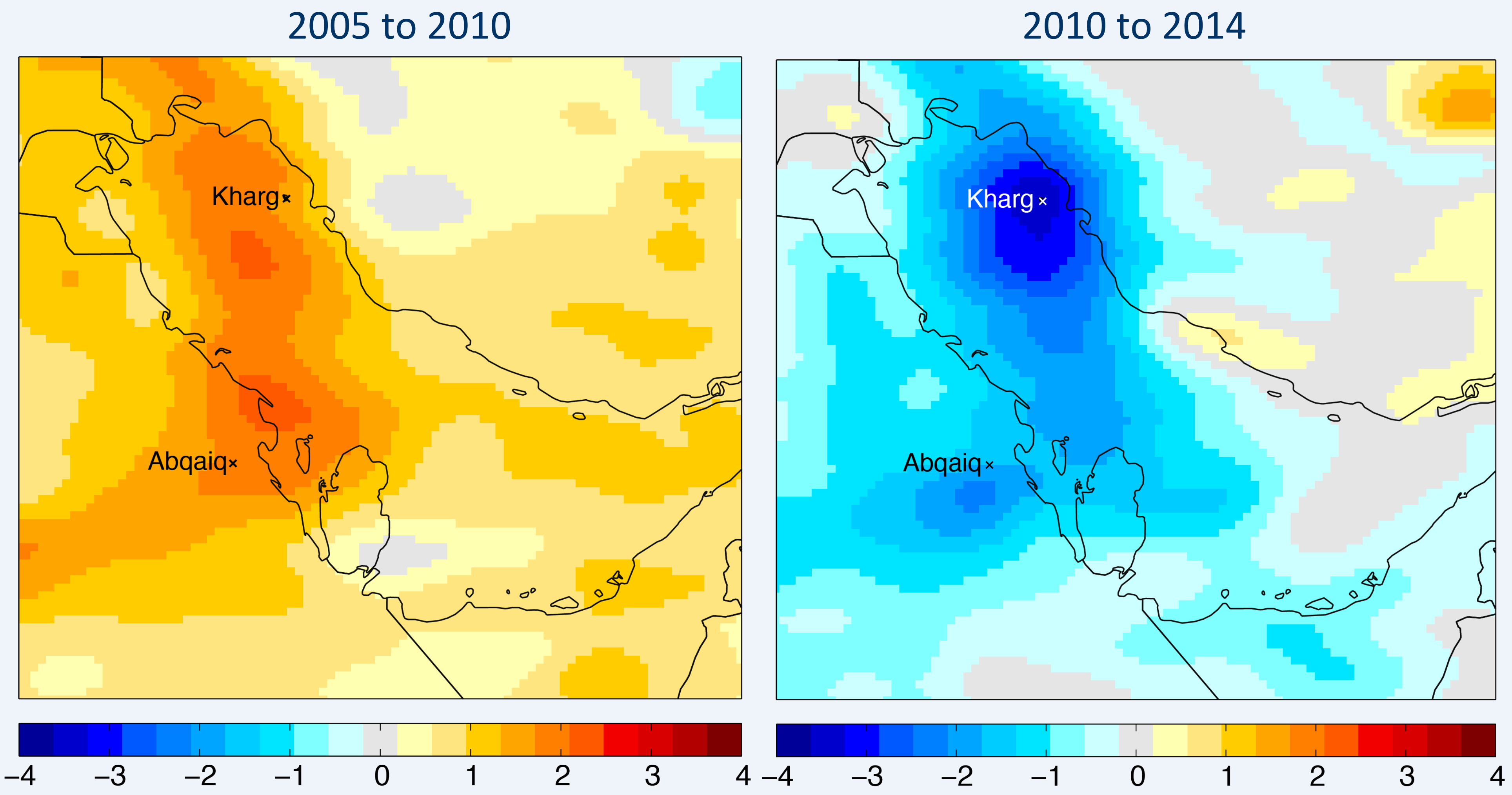


NO_2 changes in 10^{15} molecules/cm^2

SO_2 observed by OMI over the period 2005 – 2014

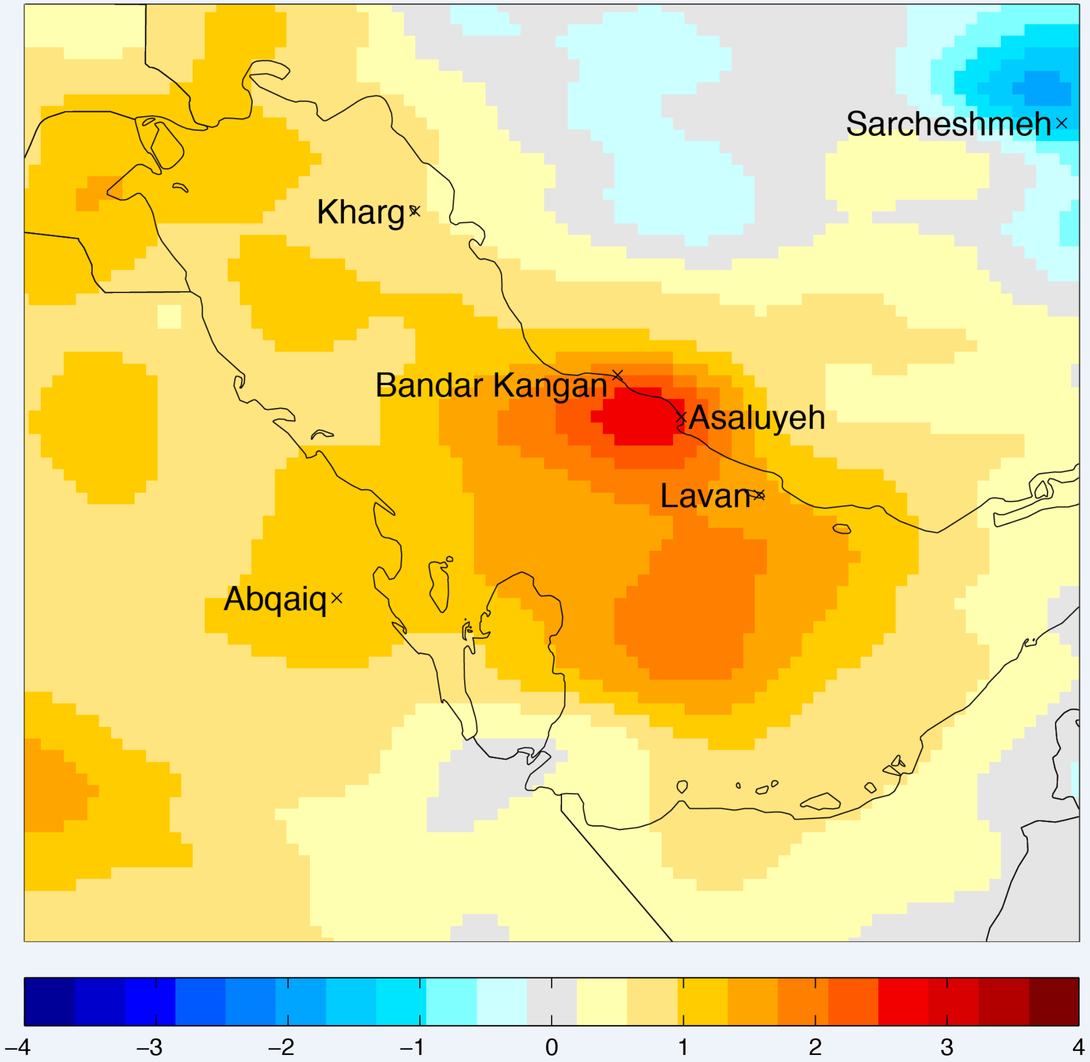


10^{15} molecules/cm^2



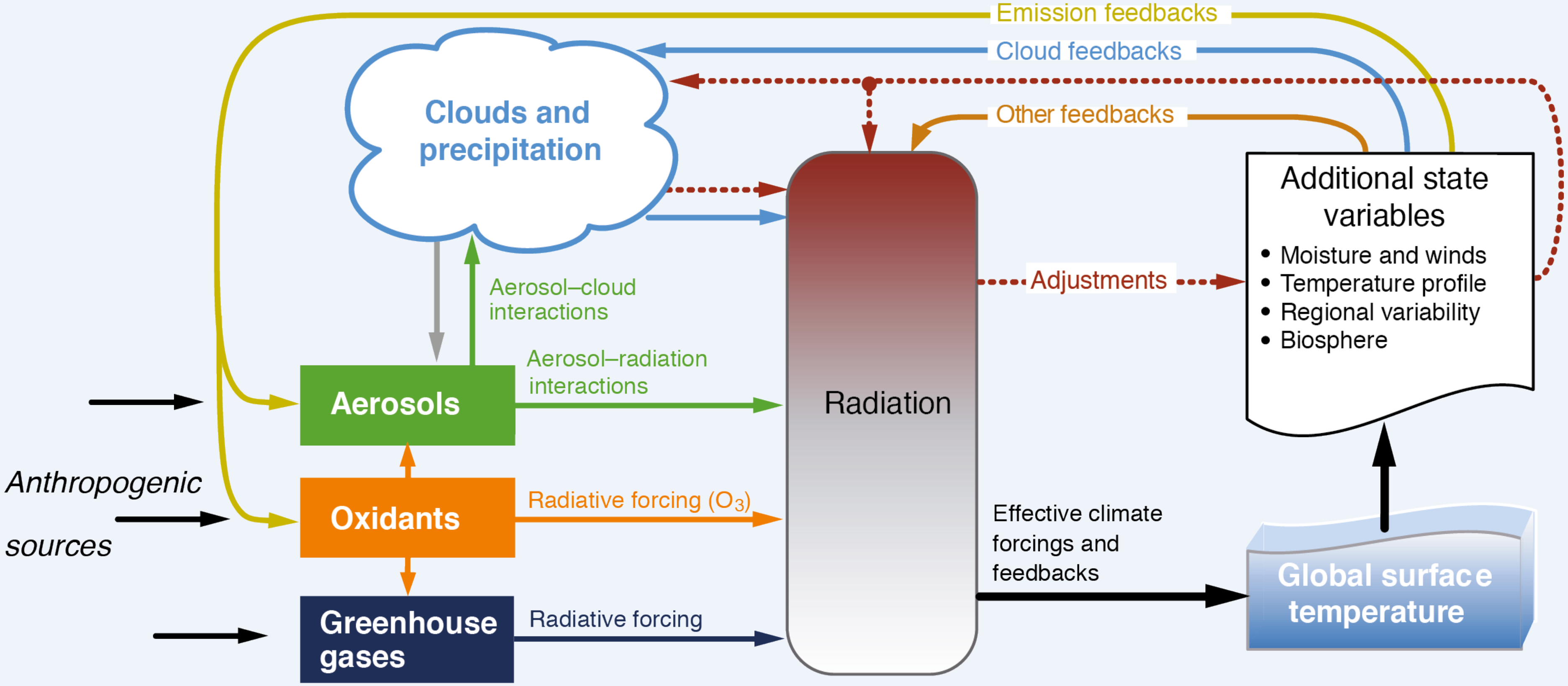
SO_2 in 10^{15} molecules/cm^2

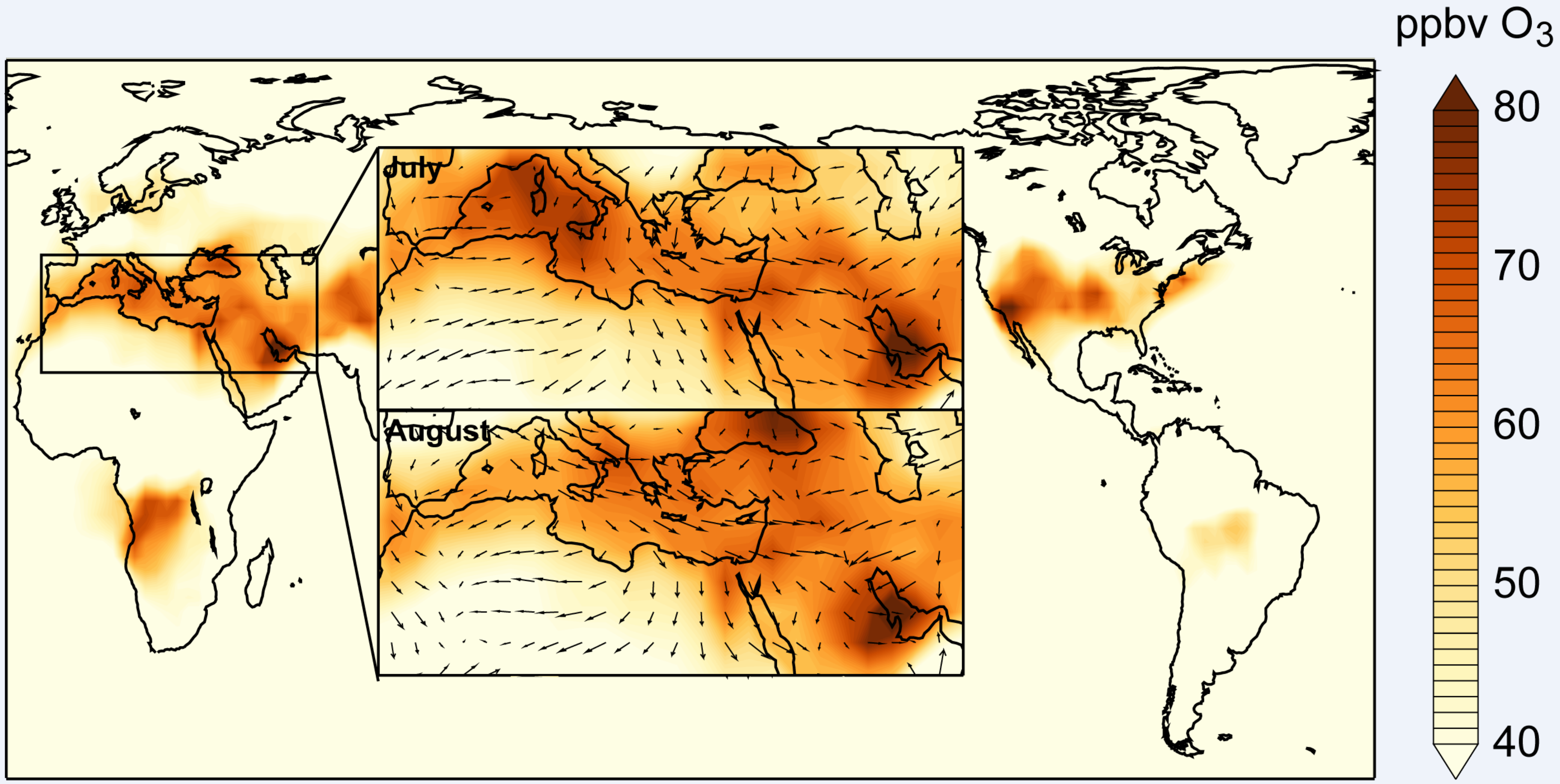
2014 to 2015



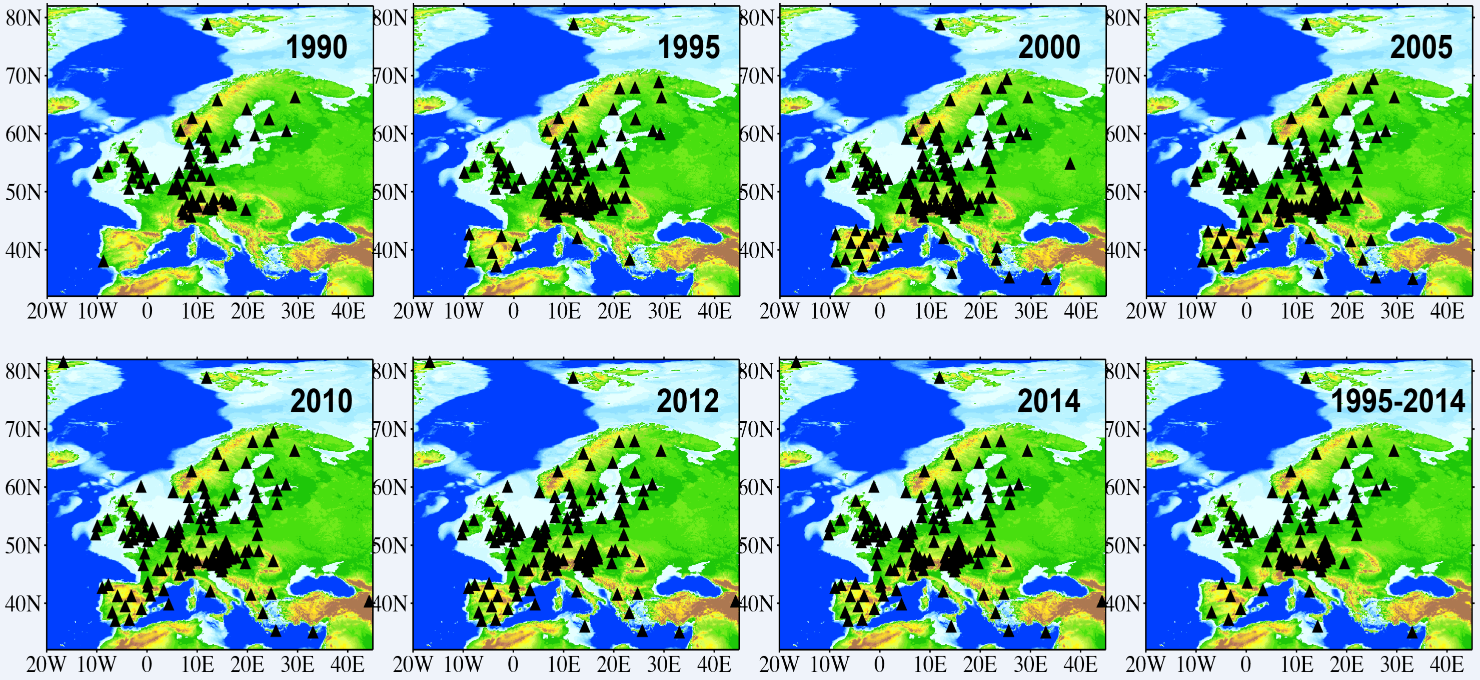
SO_2 in 10^{15} molecules/cm^2

Atmospheric chemistry and aerosol – climate modeling

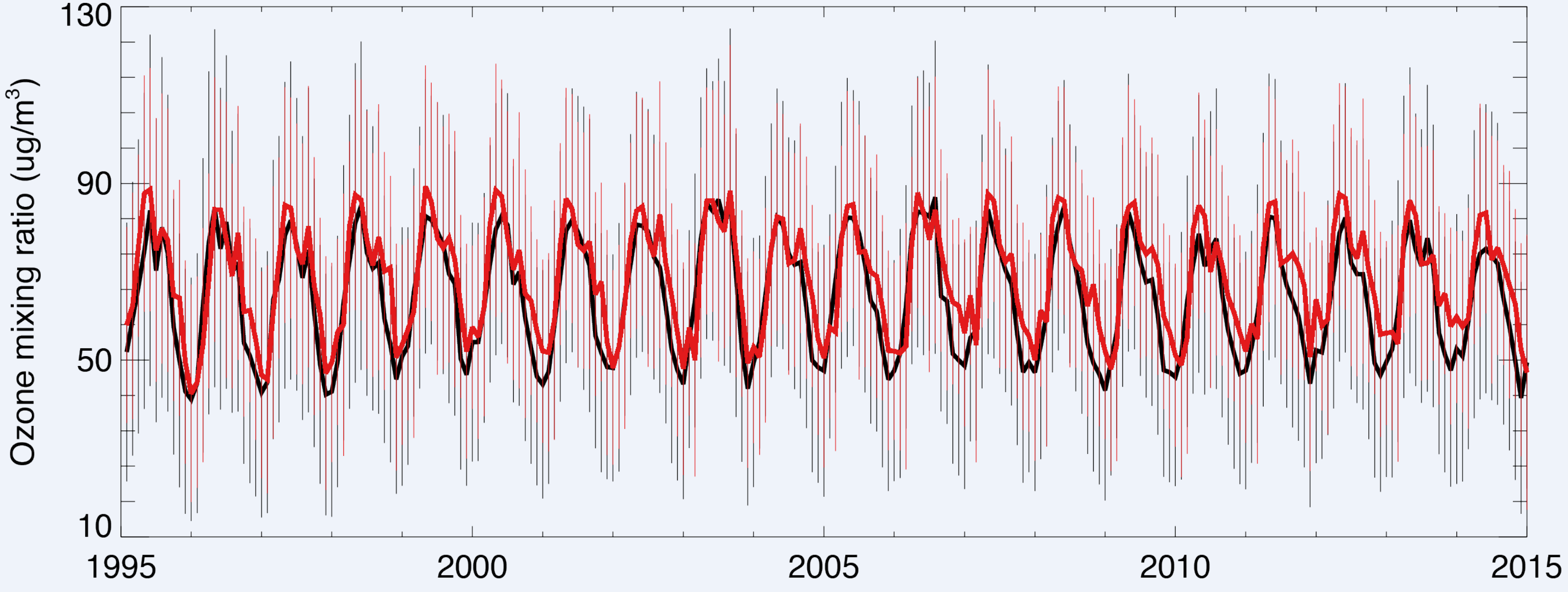




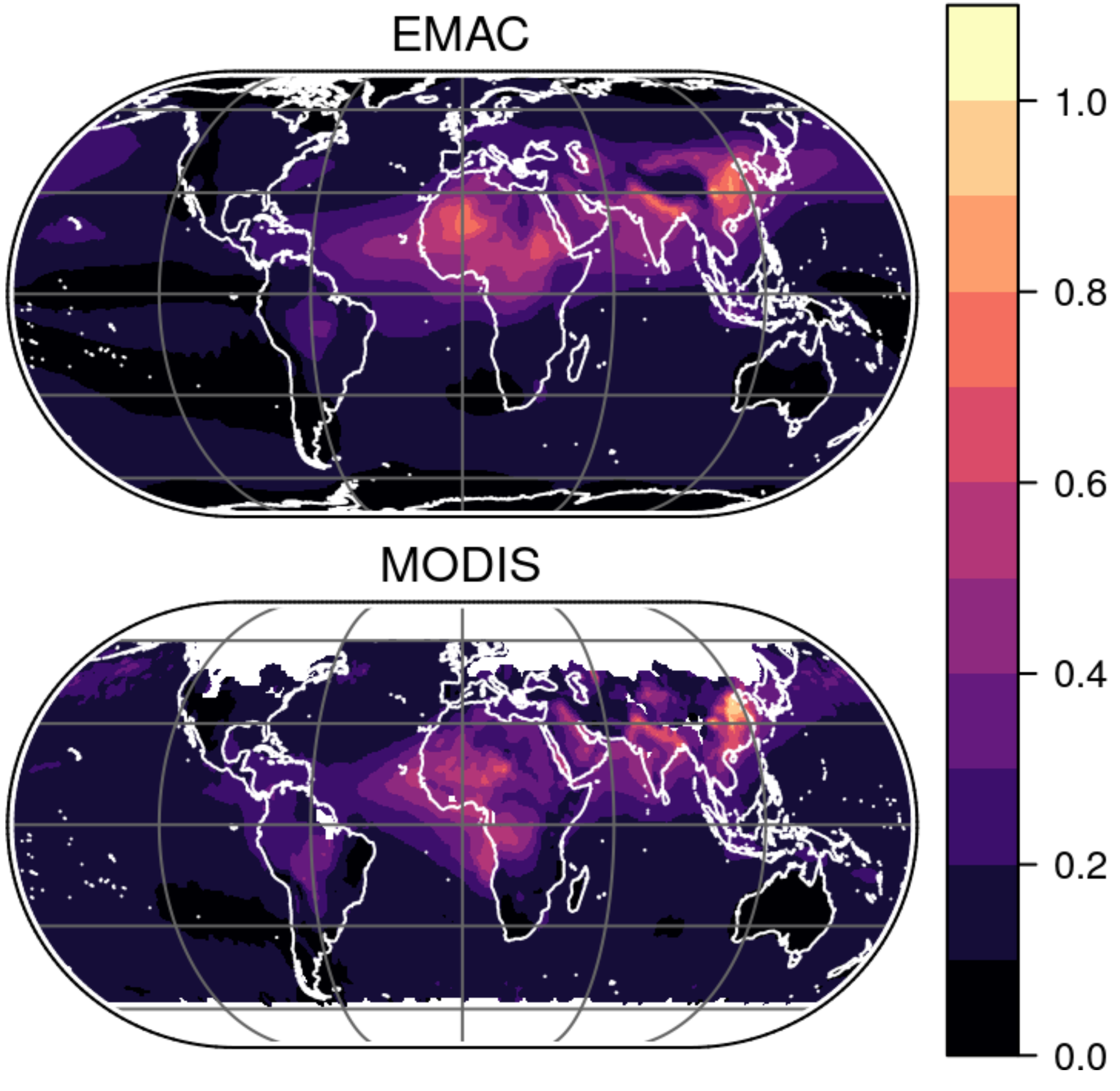
EMAC modeled surface ozone in summer (JJA)

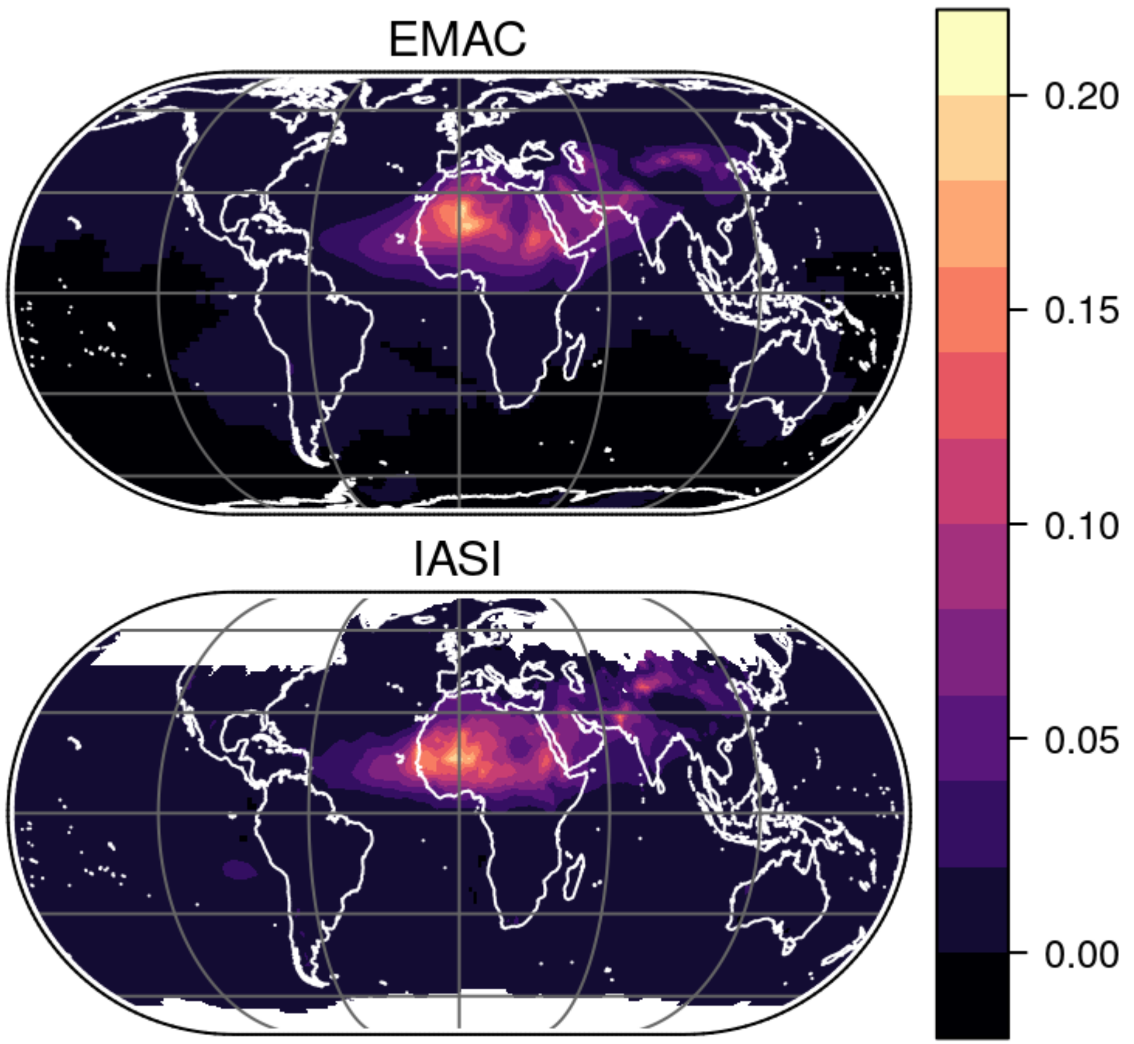


O$_3$ at 93 air quality stations (black)
compared with a course grid global model (red)

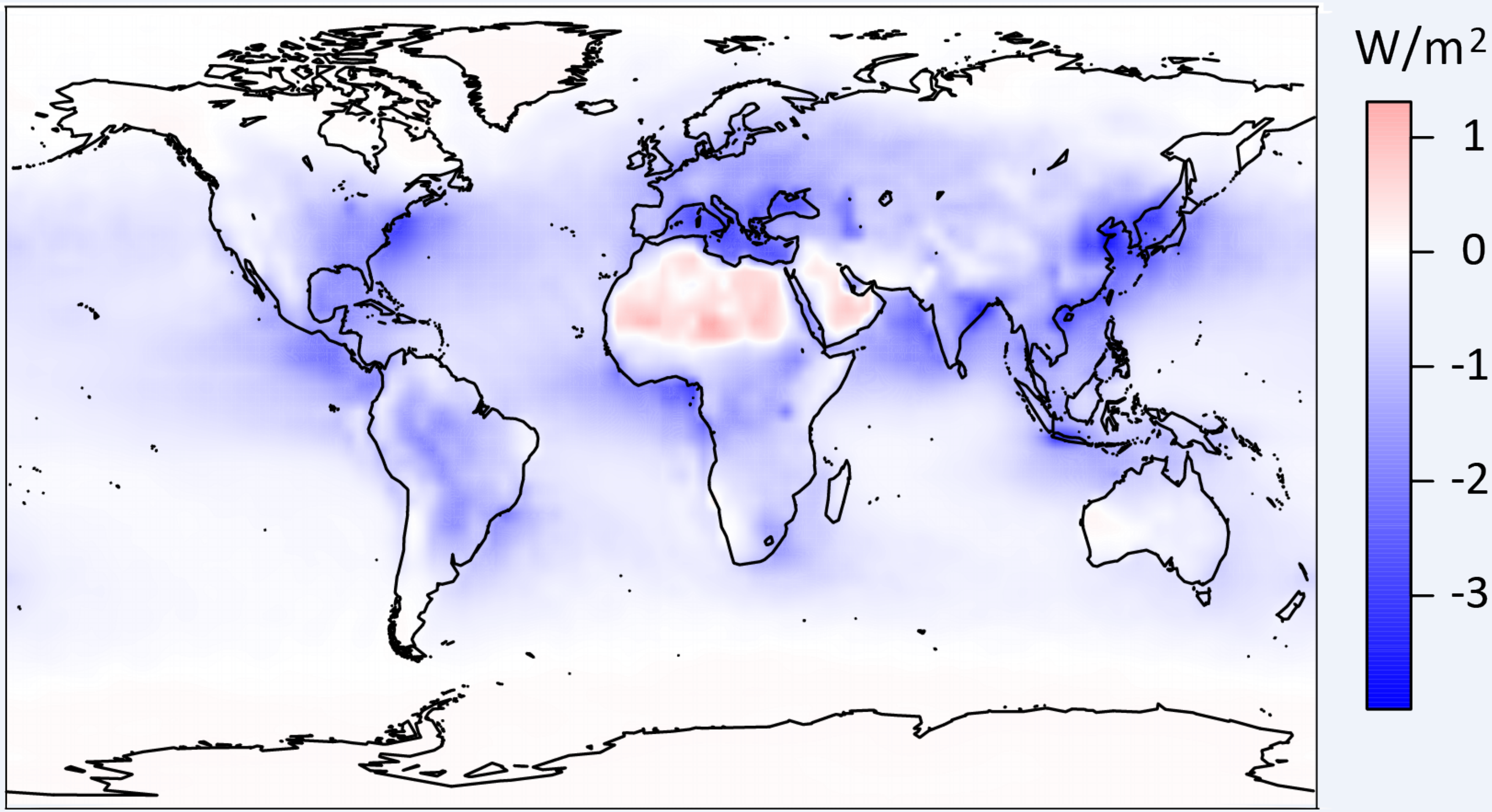


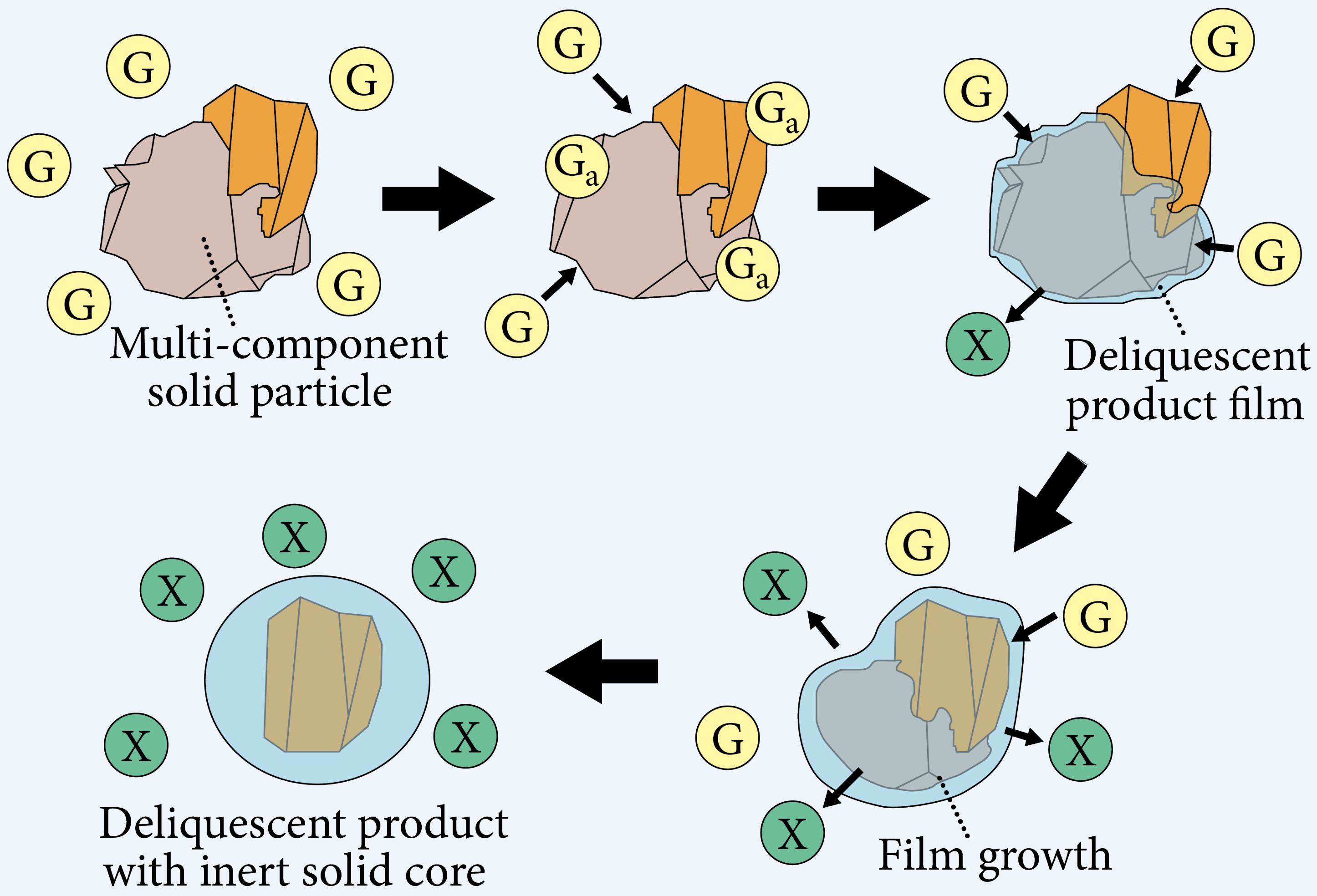
Model calculated and satellite observed aerosol optical depth (AOD) at 550 nm (left) and 10 µm (right) wavelength. The latter shows aeolian dust related aerosol optical depth. MODIS is the Moderate Resolution Imaging Spectroradiometer (NASA) and IASI the Infrared Atmospheric Sounding Interferometer (EUMETSAT).

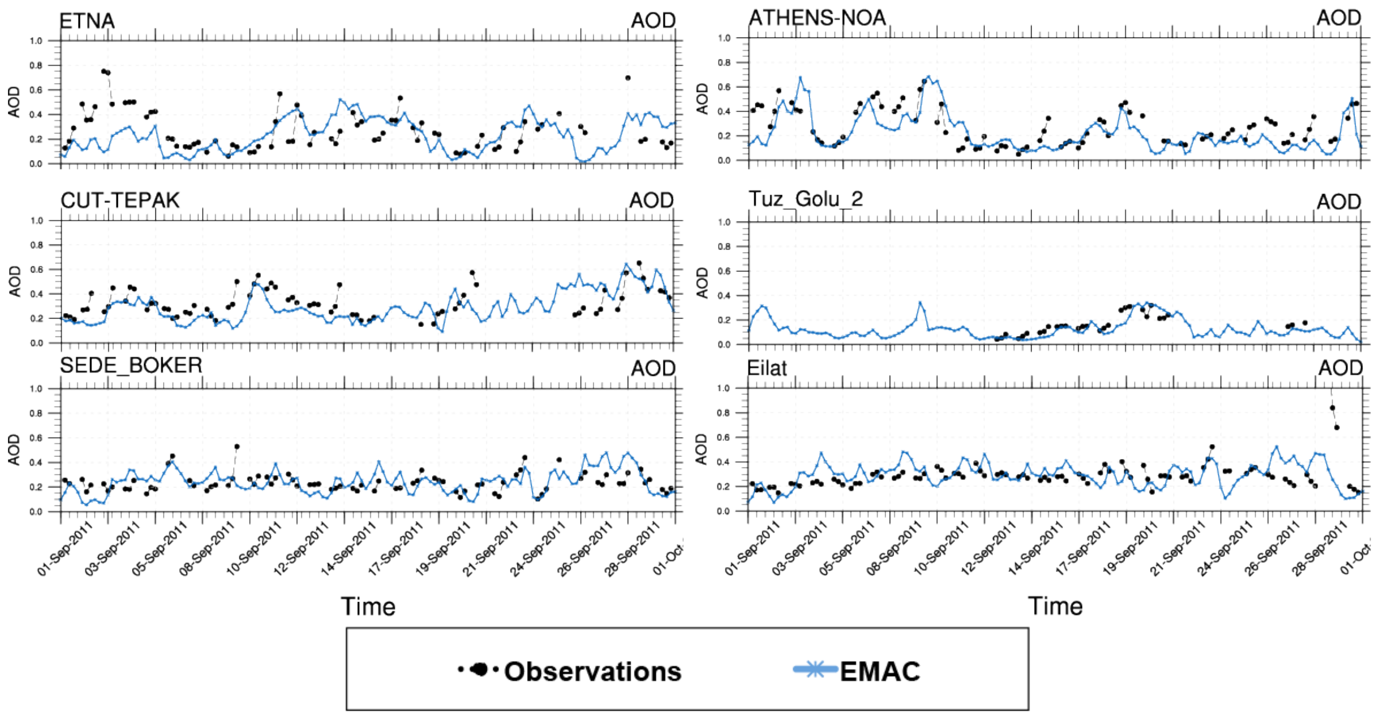




Aerosol radiative forcing at the TOA

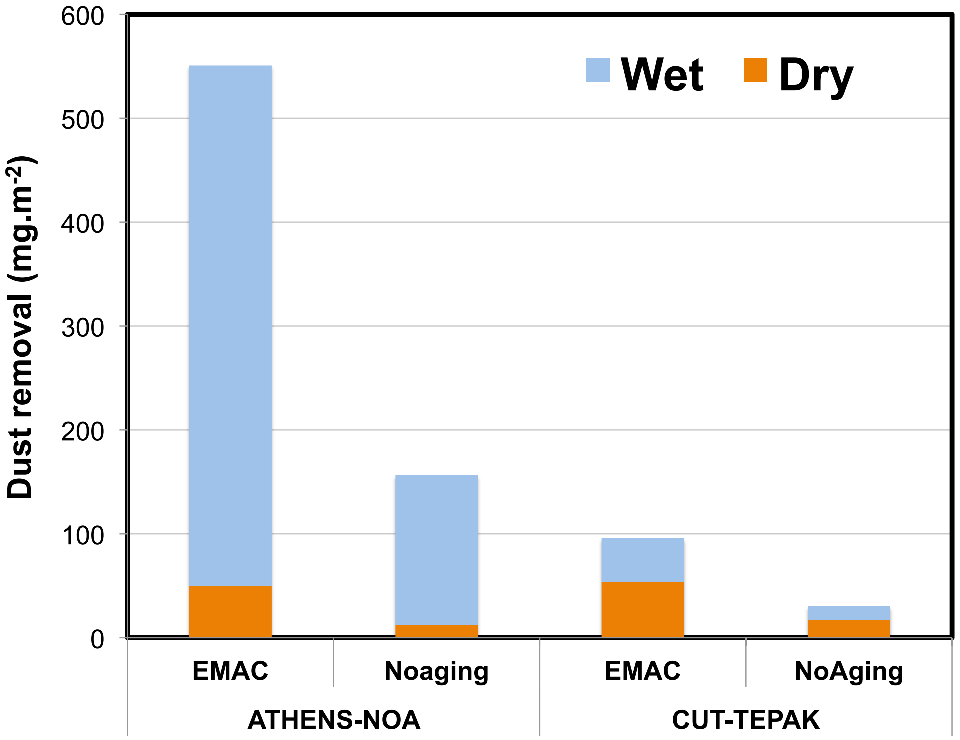



G
Multi-component
solid particle
G_a
Deliquescent
product film
X
Film growth
Deliquescent product
with inert solid core

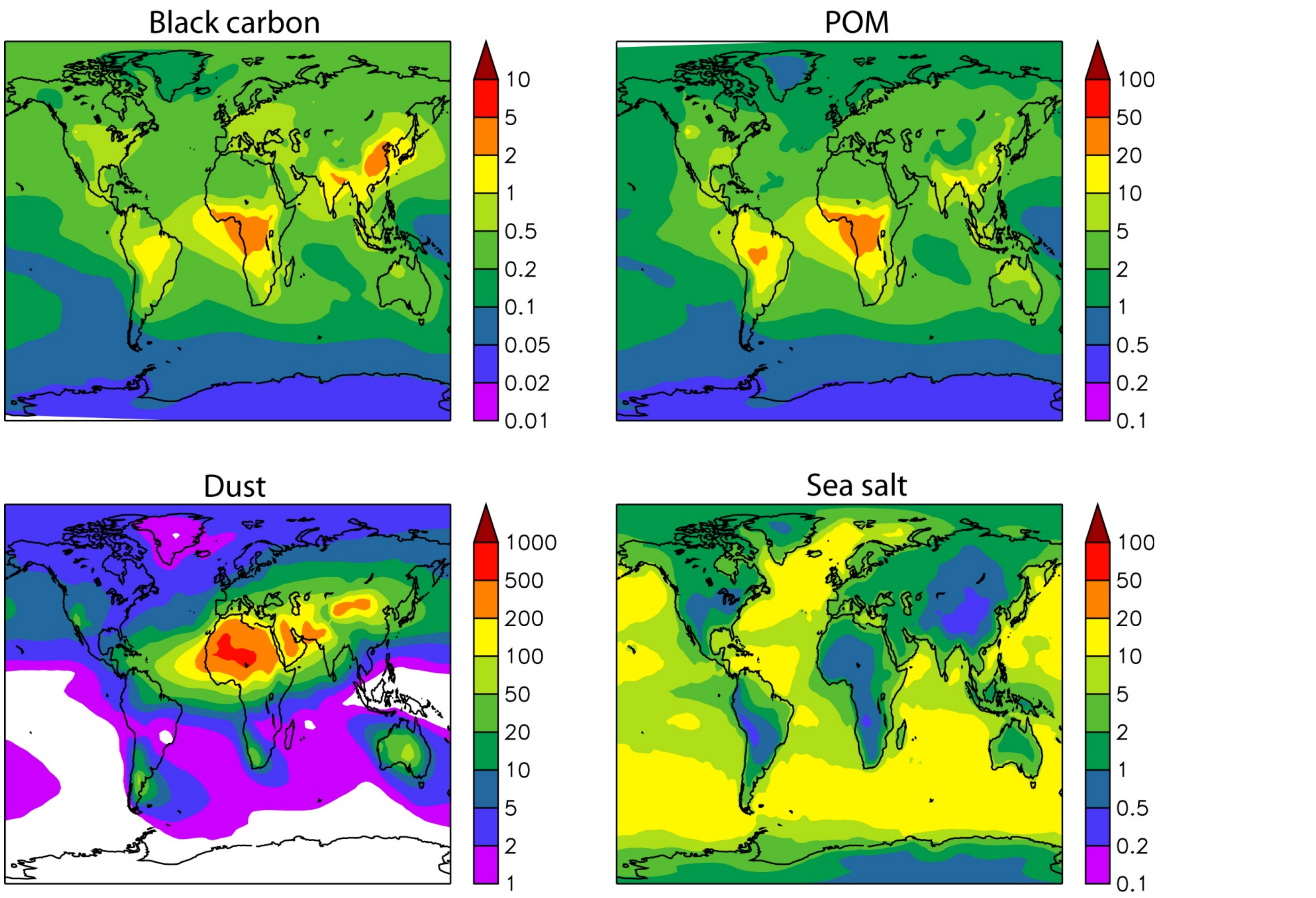


Sensitivity of dust deposition (wet and dry) to dust aging by pollution uptake

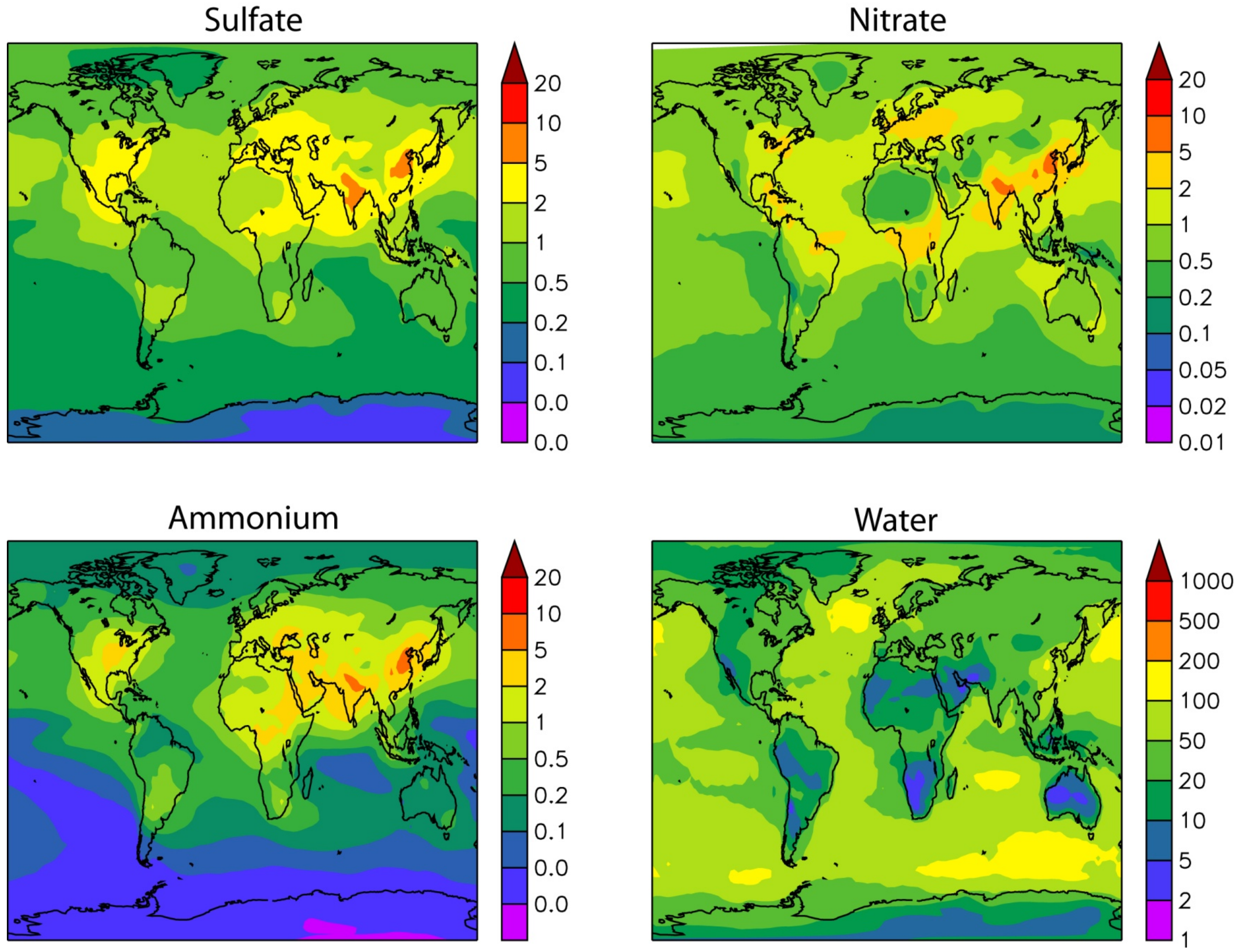
Integrated dust removal over the eastern Mediterranean



Model: column concentration in mg/m^2

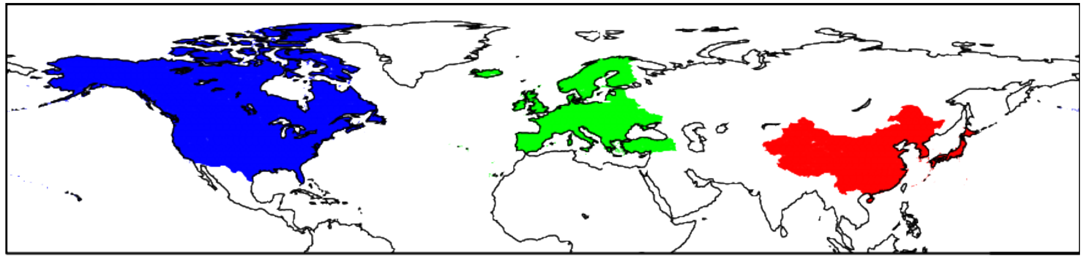


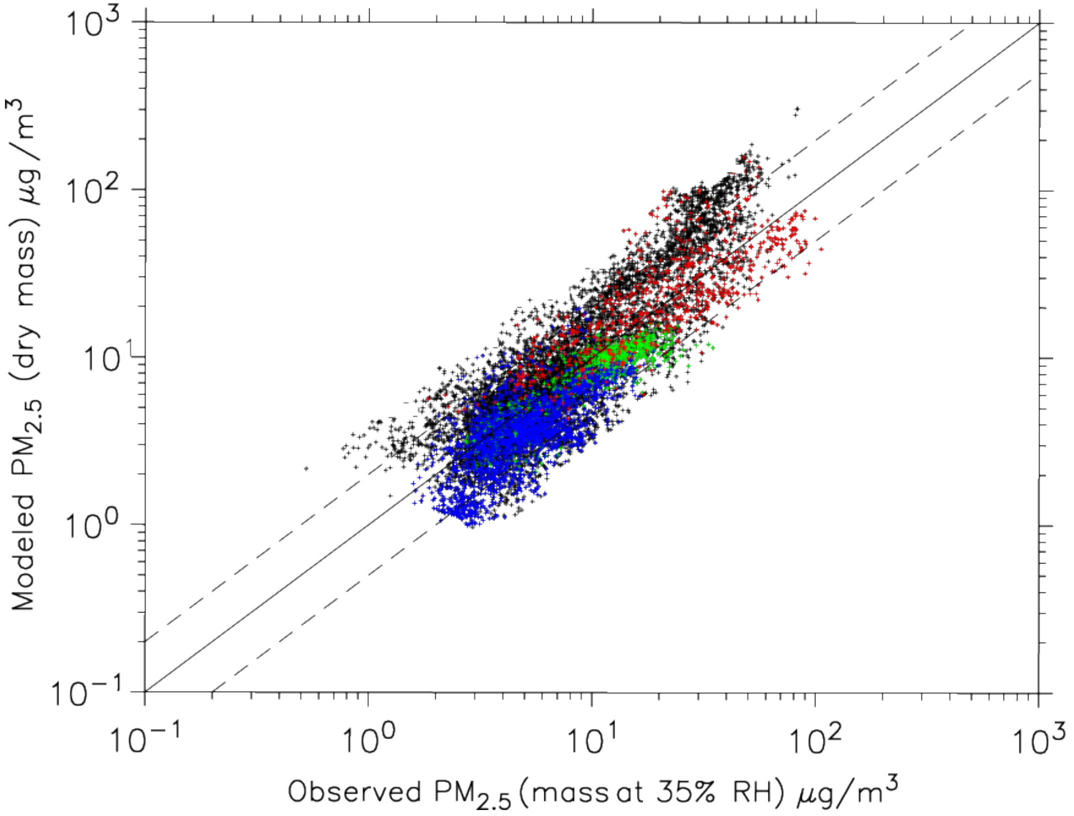
Model: column concentration in mg/m^2

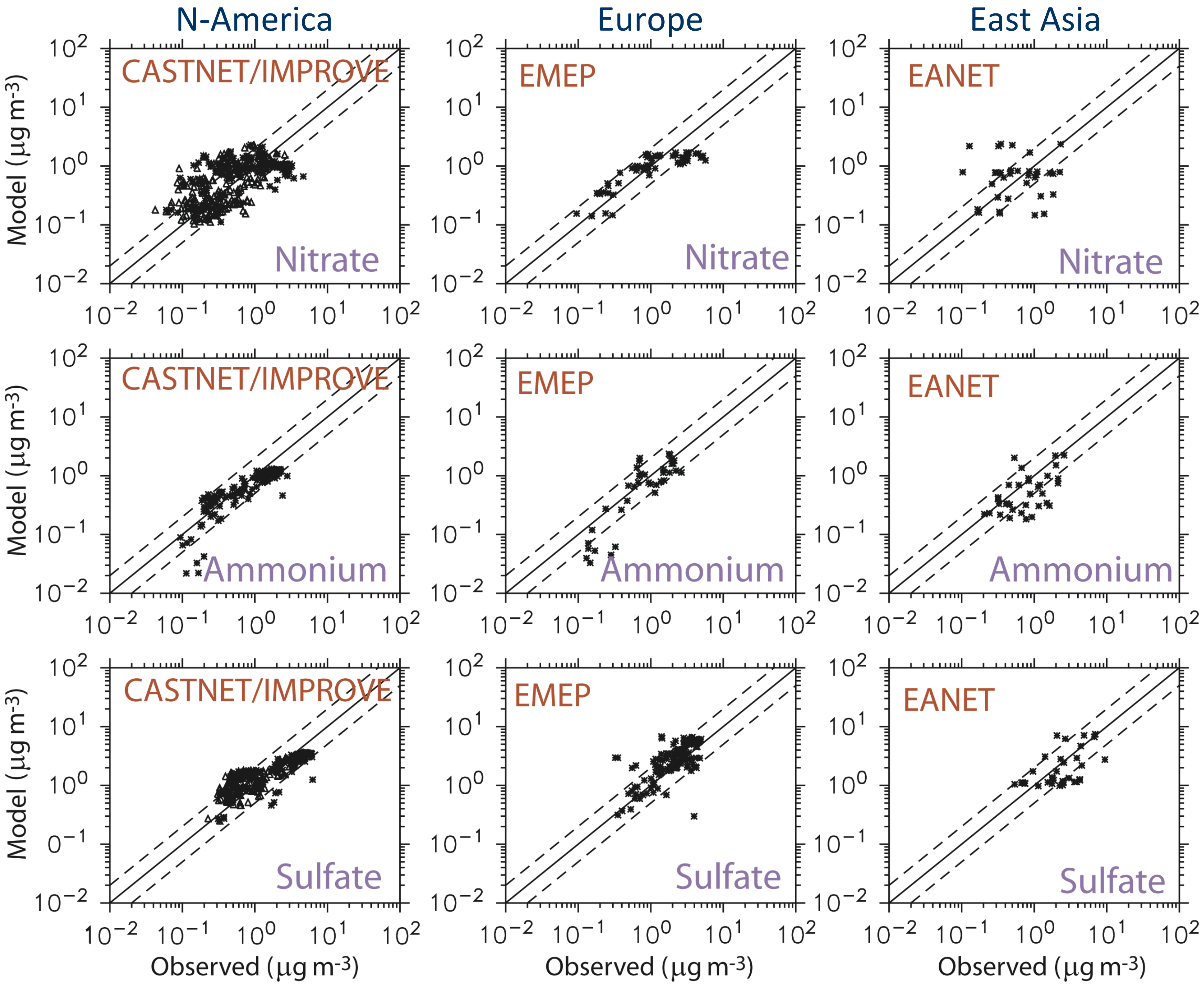


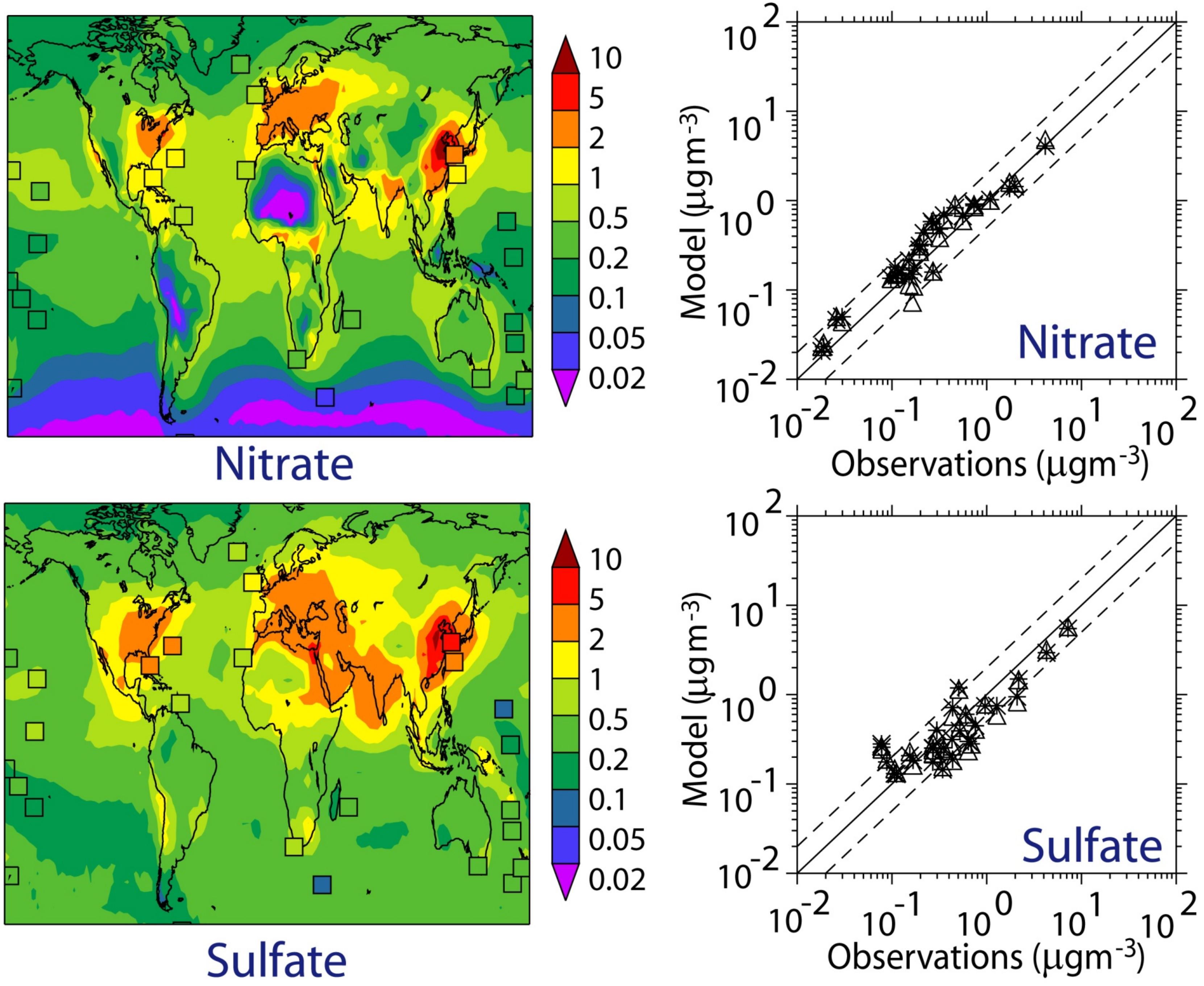
EMAC model results and ground-based measurement data of $PM_{2.5}$

– reasonable agreement –

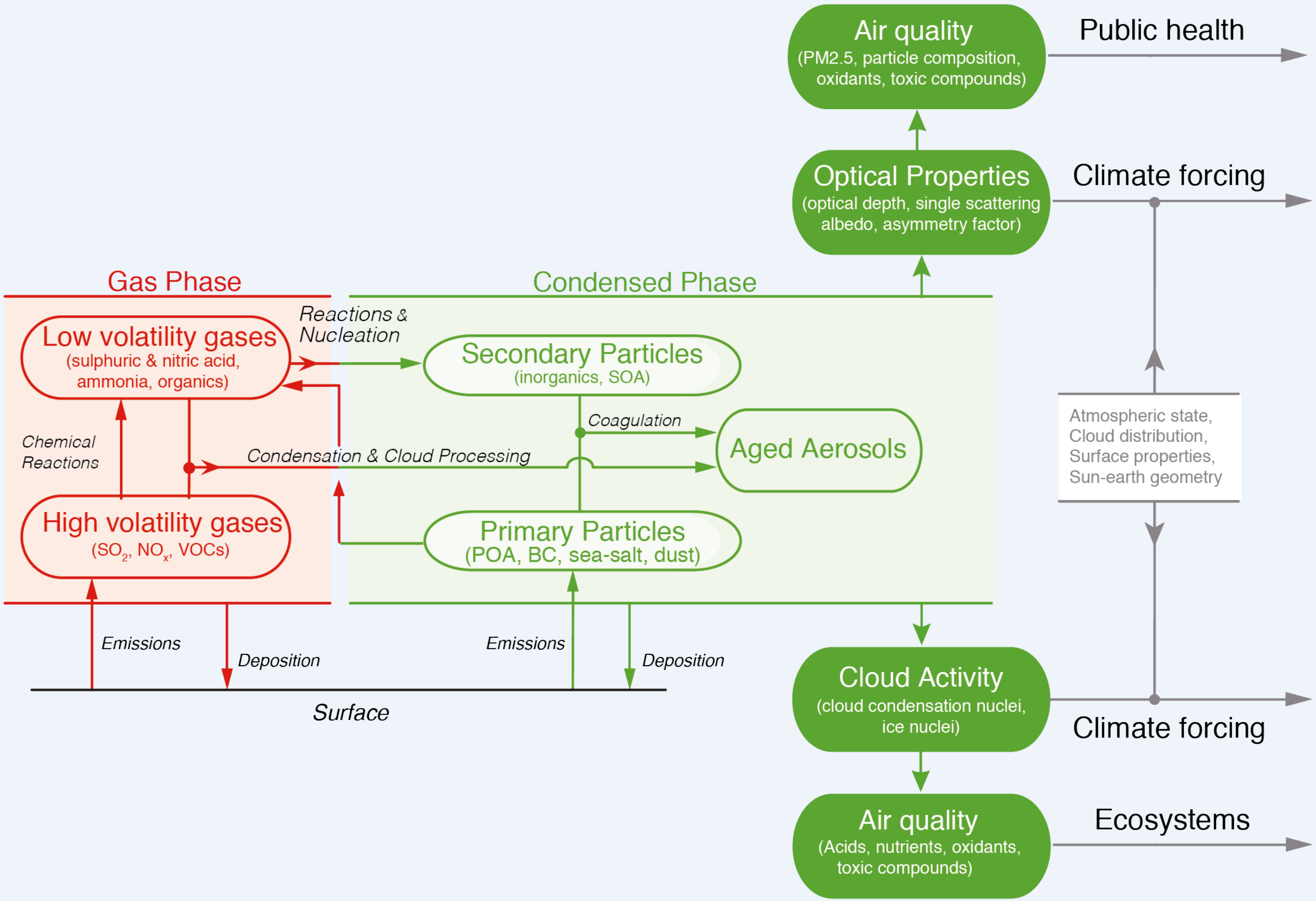





N-America
Europe
East Asia
CASTNET/IMPROVE
EMEP
EANET
Nitrate
Ammonium
Sulfate
Model (μg m-3)
Observed (μg m-3)
10^2
10^1
10^0
10^-1
10^-2



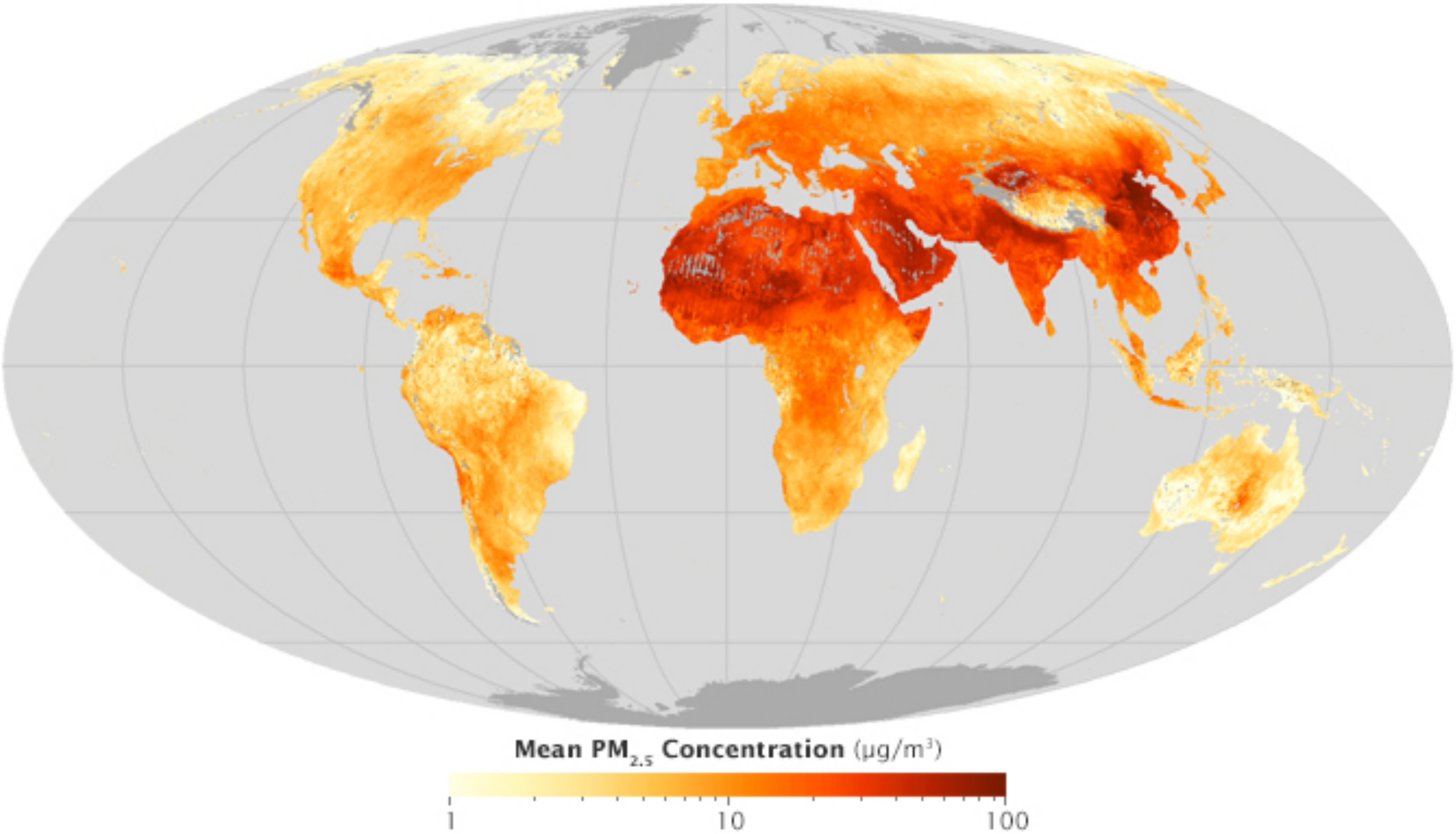
Nitrate
Sulfate
10
5
2
1
0.5
0.2
0.1
0.05
0.02
Model (μgm-3)
Observations (μgm-3)
10-2
10-1
100
101
102
Nitrate
Sulfate



Air quality
(PM2.5, particle composition, oxidants, toxic compounds)
Public health
Optical Properties
(optical depth, single scattering albedo, asymmetry factor)
Climate forcing
Gas Phase
Condensed Phase
Reactions & Nucleation
Low volatility gases
(sulphuric & nitric acid, ammonia, organics)
Secondary Particles
(inorganics, SOA)
Coagulation
Aged Aerosols
Chemical Reactions
Condensation & Cloud Processing
High volatility gases
(SO_2, NO_x, VOCs)
Primary Particles
(POA, BC, sea-salt, dust)
Atmospheric state,
Cloud distribution,
Surface properties,
Sun-earth geometry
Emissions
Deposition
Emissions
Deposition
Surface
Cloud Activity
(cloud condensation nuclei, ice nuclei)
Climate forcing
Air quality
(Acids, nutrients, oxidants, toxic compounds)
Ecosystems

Global mean $PM_{2.5}$ derived from satellite observations (NASA)

More than 90% of people (~7 billion) exposed to $PM_{2.5}$ levels higher than the WHO air quality guideline of 10 μg/m^3



Following method of the GBD to compute health outcomes and mortality from long-term exposure to air pollution

$$Mort = y_o \times AF \times Pop \qquad \text{with } AF = RR - 1/RR$$

$$RR = 1 + a\{1 - exp[-b(X - X_o)^p]\}$$

Mort = mortality from *ischemic heart disease* (IHD), *cerebrovascular disease* (CEV), *chronic obstructive pulmonary disease* (COPD), *lung cancer* (LC) and *lower respiratory tract infections* (ALRI)

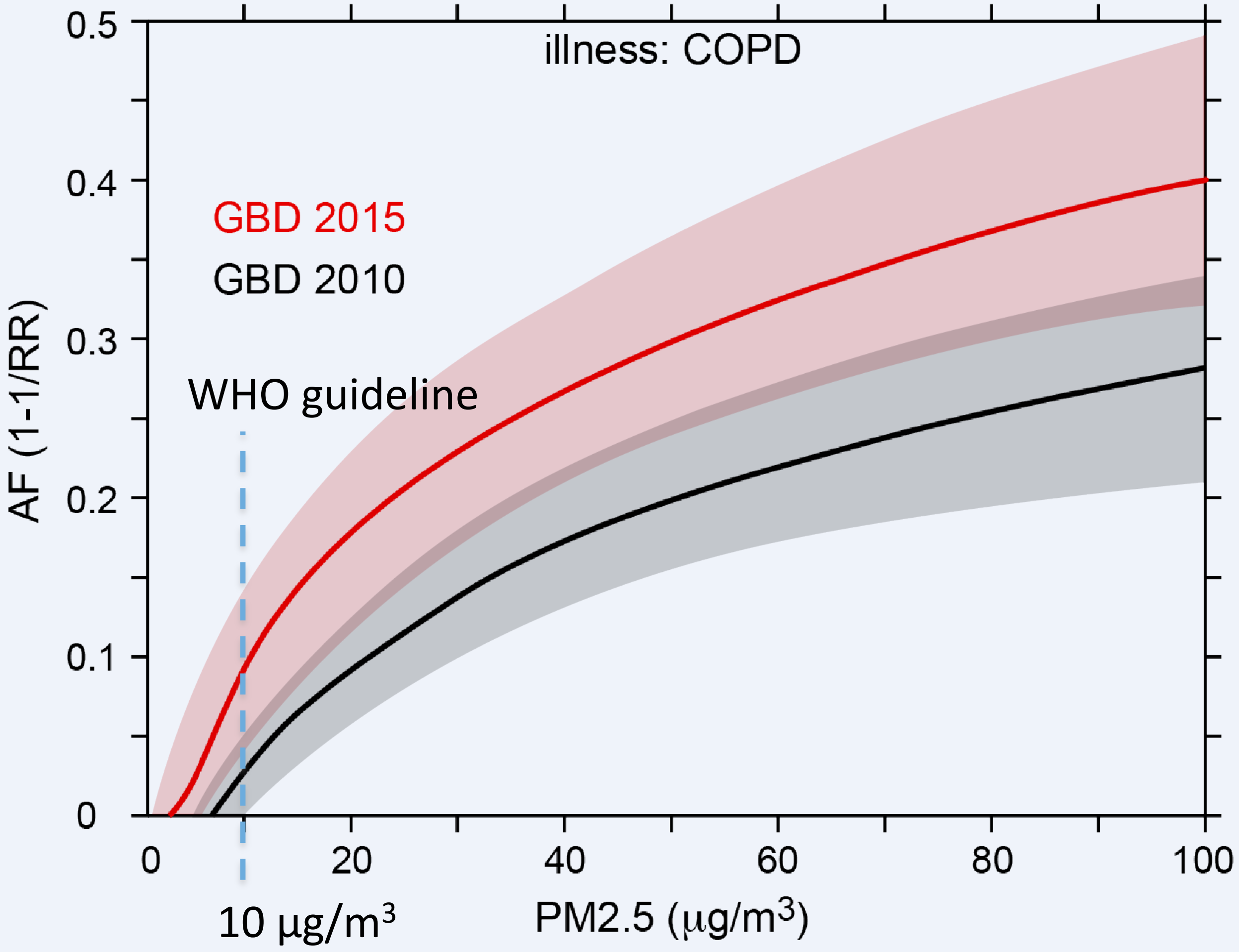
y_o = baseline mortality rates for a given population related to different disease categories (WHO)

Pop = population exposed to pollutant *X* (UNDP)

RR = relative risk (Burnett et al., 2017), *AF* is attributable fraction

$X - X_o$ = *annual mean* concentration of pollutant *X* in excess of threshold X_o ($PM_{2.5}$, O_3)

Mortality attributable to air pollution (Burnett et al., 2014, 2017)



Attributable fraction (*AF*) of disease (COPD) leading to mortality by air pollution, with uncertainty bounds (shaded), used in integrated exposure-response functions.

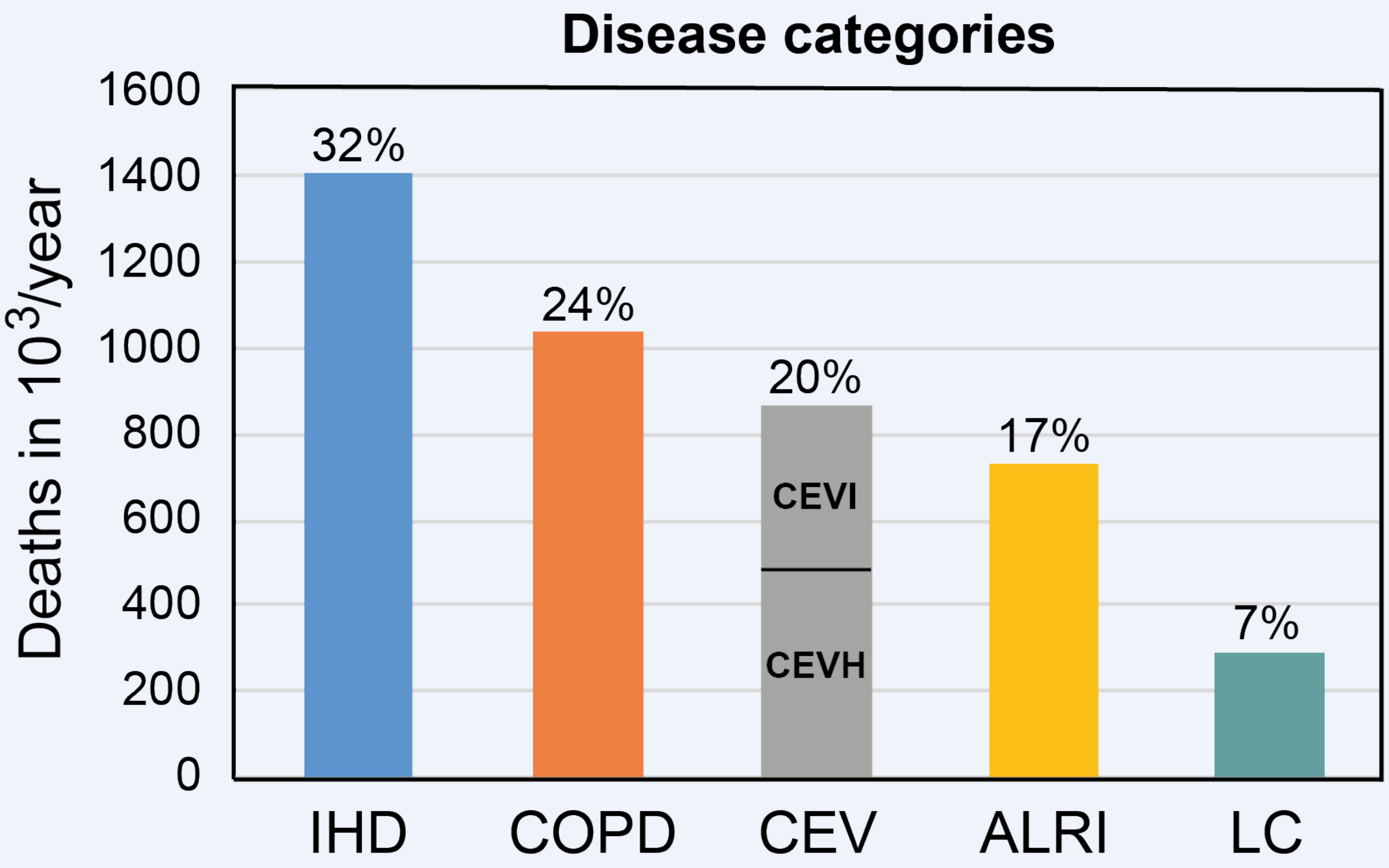
Updated *AF* for 2015 increased relative to 2010, based on new epidemiological studies.

The "safe" threshold decreased from ~7.3 μg/m^3 to ~4.2 μg/m^3.

Estimated global mortality attributable to ambient air pollution in 2015

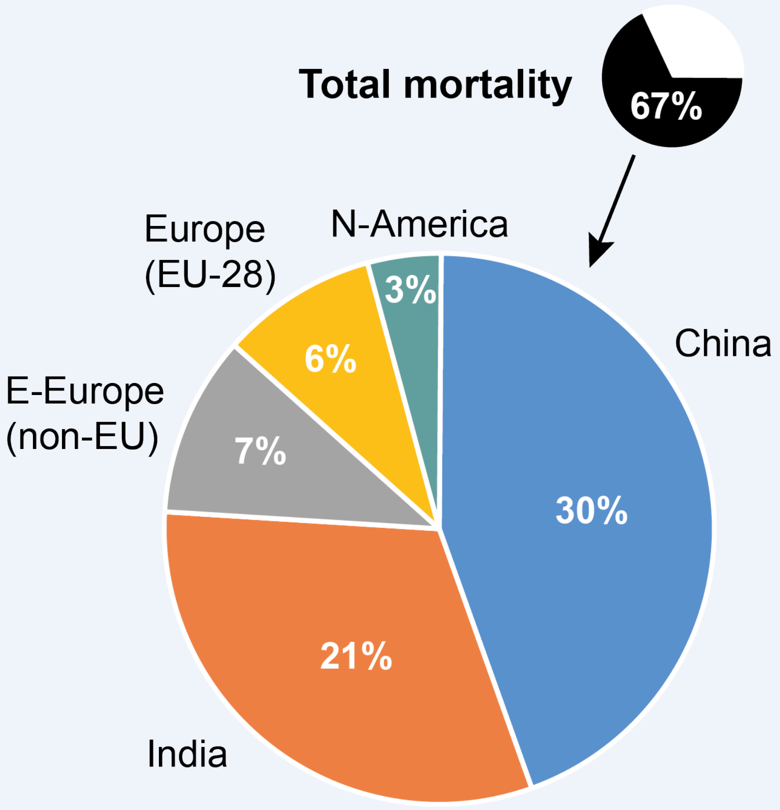
$PM_{2.5}$ mortality	**4.28** $\times 10^6$/yr
O_3 mortality	**0.27** $\times 10^6$/yr
Total	**4.55** $\times 10^6$/yr (95% CI about **±30%**)

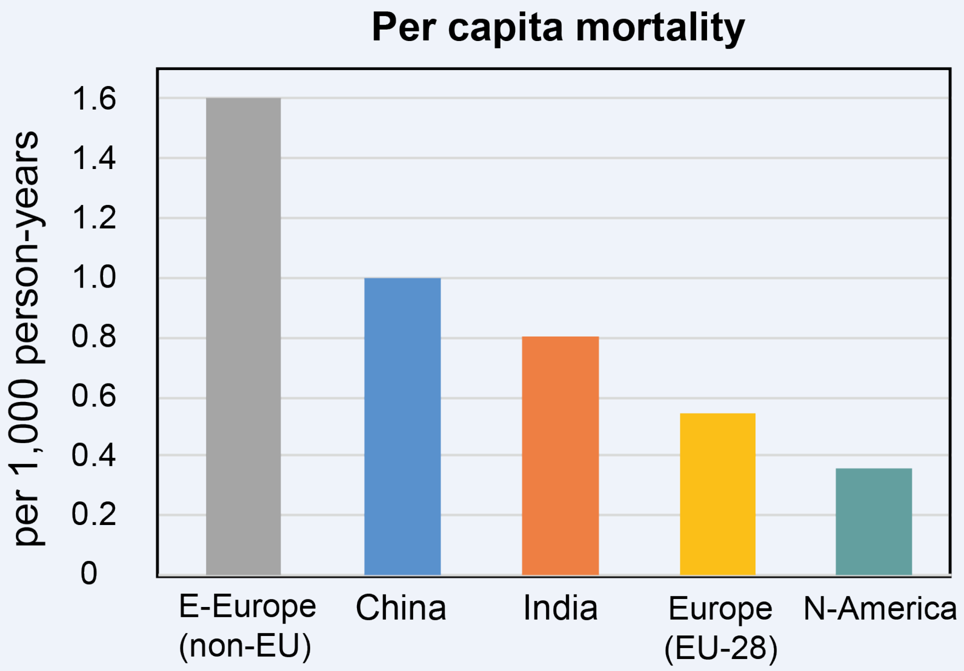
Ischemic heart disease (heart attack)	**1.5** $\times 10^6$/yr
Chronic obstructive pulmonary disease	**1.1** $\times 10^6$/yr
Cerebrovascular disease (stroke)	**0.9** $\times 10^6$/yr
Lower respiratory tract infections	**0.7** $\times 10^6$/yr
Lung cancer	**0.3** $\times 10^6$/yr



Air pollution related mortality by ischaemic heart disease (IHD), chronic obstructive pulmonary disease (COPD), cerebrovascular disease (CEV) through ischaemic and haemorrhagic stroke (CEVI and CEVH), acute lower respiratory tract infections (ALRI) and lung cancer (LC)

Mortality attributable to air pollution in China, India, Eastern Europe (Russian Federation, Ukraine, i.e. non-EU), Europe (EU-28) and North America, together 67% of 4.55 million in the year 2015. Right: per capita mortality per 1,000 person-years.





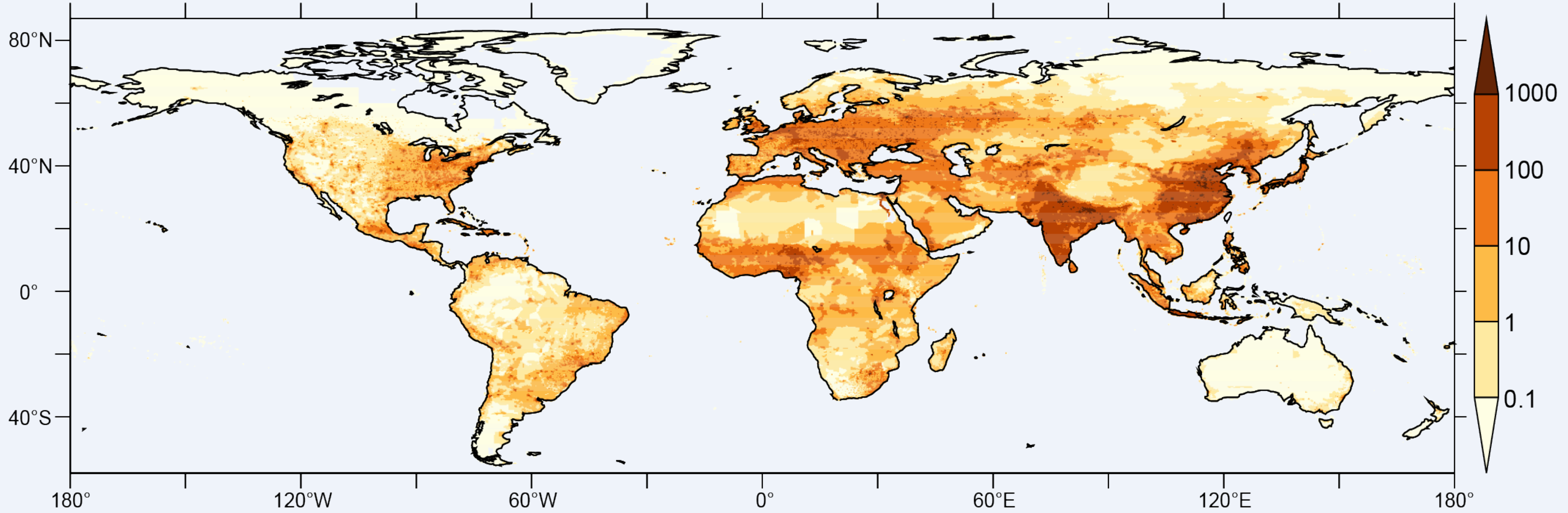
Summary for 2015: Mortality attributable to outdoor air pollution is ~4.5 million/year; i.e., the main environmental health risk globally, and one of the "top five" overall (with high blood pressure, diabetes, tobacco smoking and being overweight).

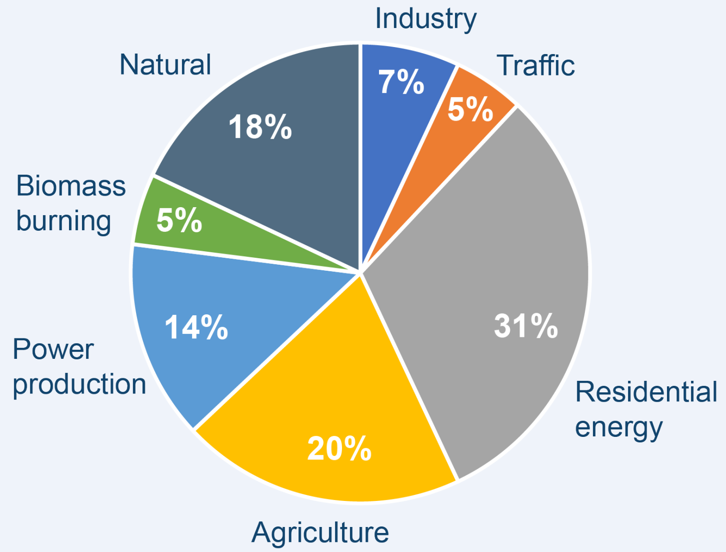
The global number of years of life lost (YLL) by air pollution is ~120 million per year, which implies that each individual who dies prematurely due to air pollution loses about 28 life years.

The number of deaths from smoking is still larger, ~6.4 million/year, however, the number of YLL per individual affected is 24 years. This is higher for air pollution (28 years, and *unvoluntary*) as it also causes infant mortality (LRI).

Mortality attributable to ambient air pollution

Units: Individuals per area of 1,000 km^2/year

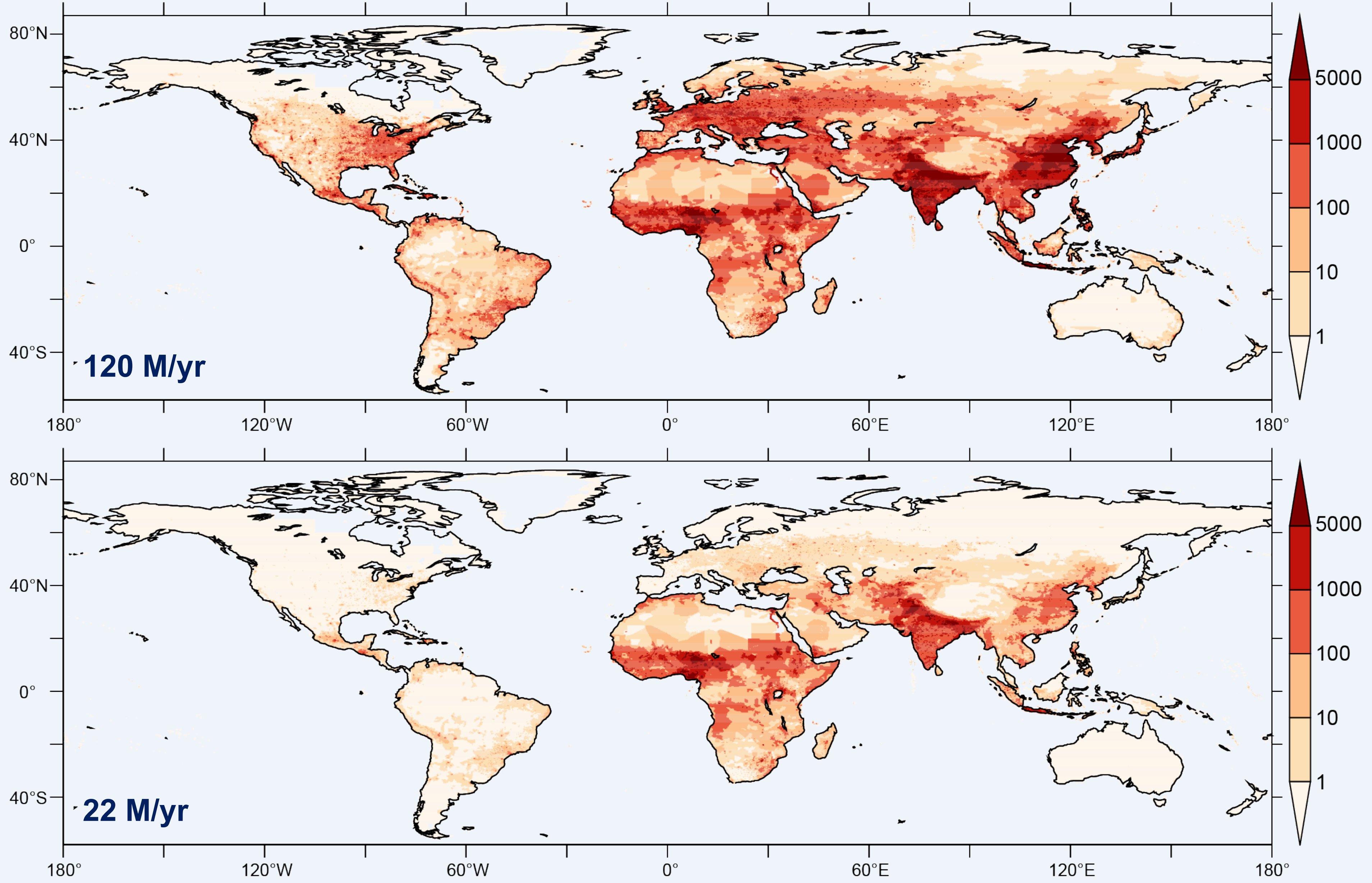




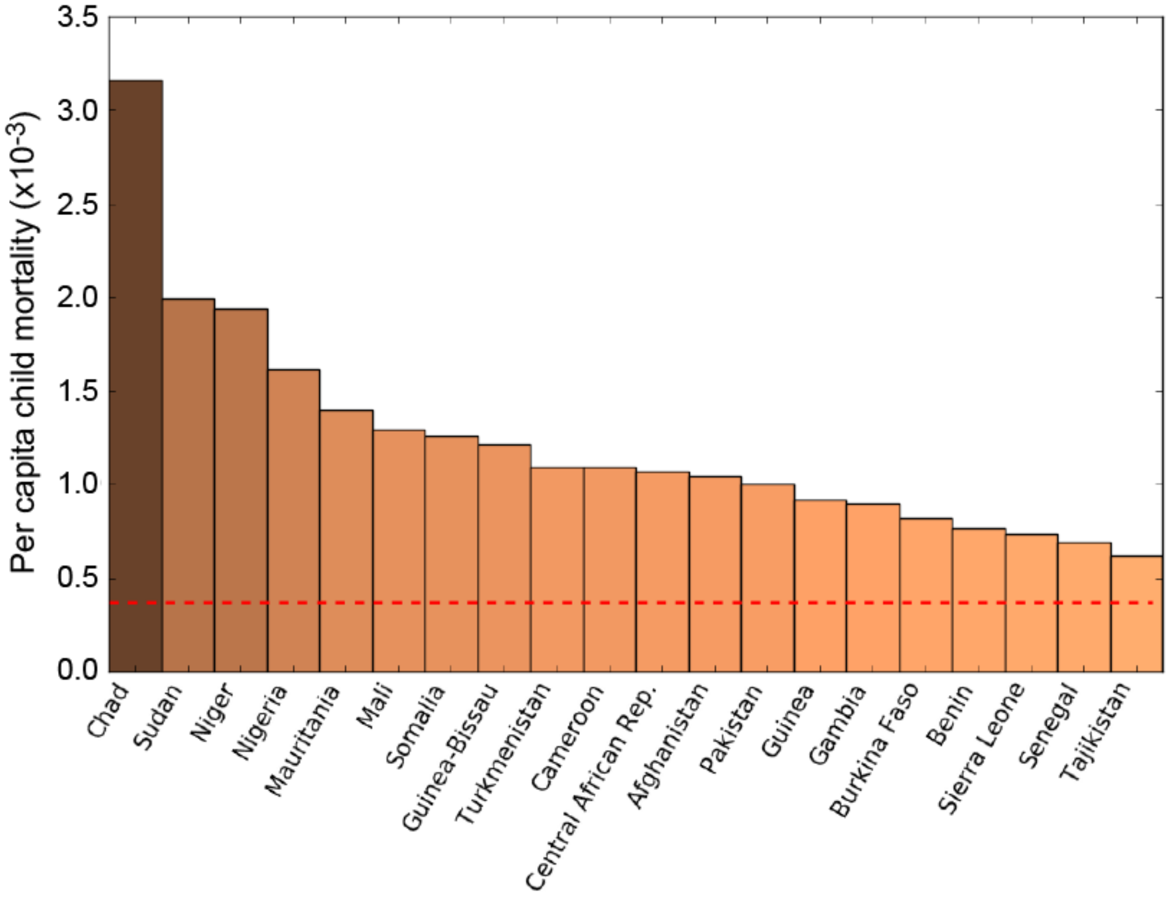
Years of life lost from ambient air pollution

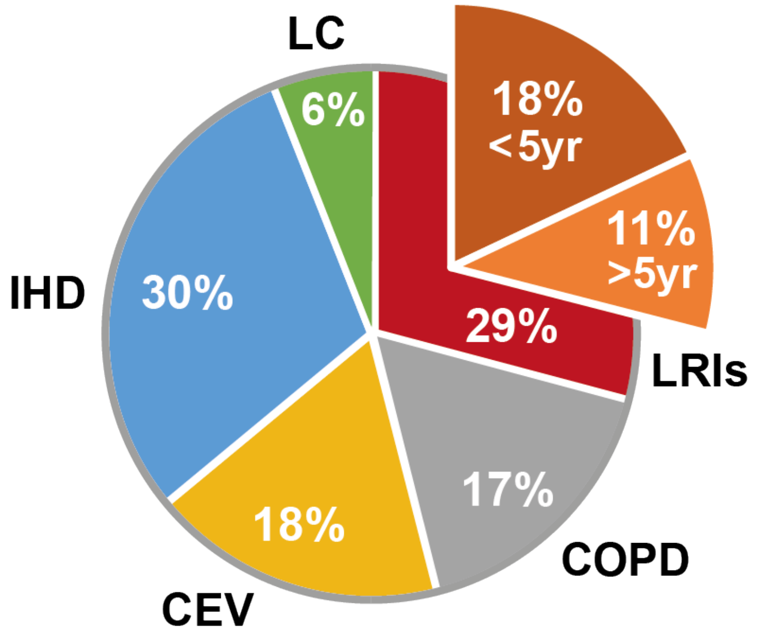
Top: all ages – **Bottom:** children younger than five

Units: Annual YLL per area of 1,000 km^2



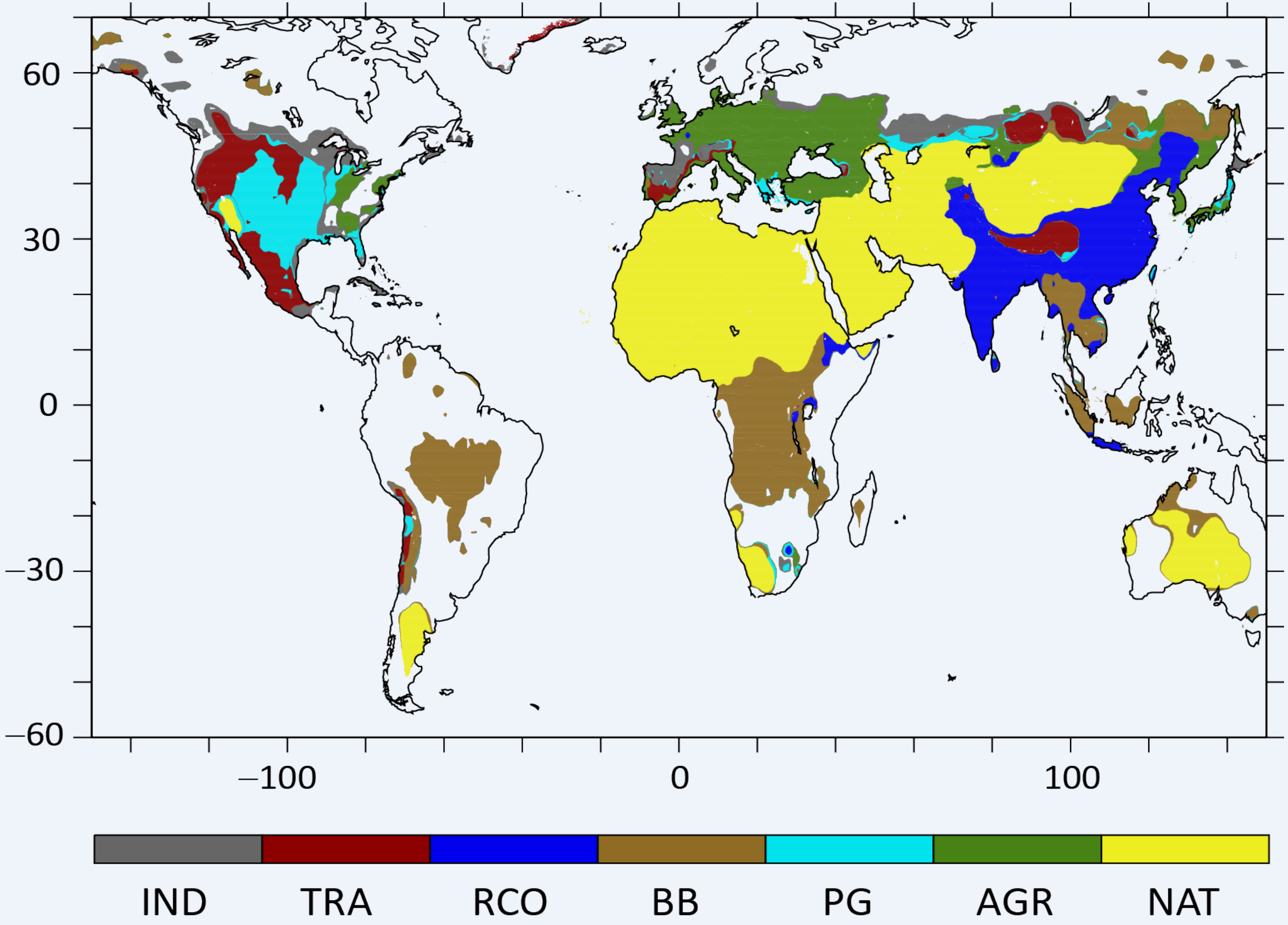
Years of life lost from ambient air pollution of children < 5 years old
Total YYL is 120 M/yr, 18% in children





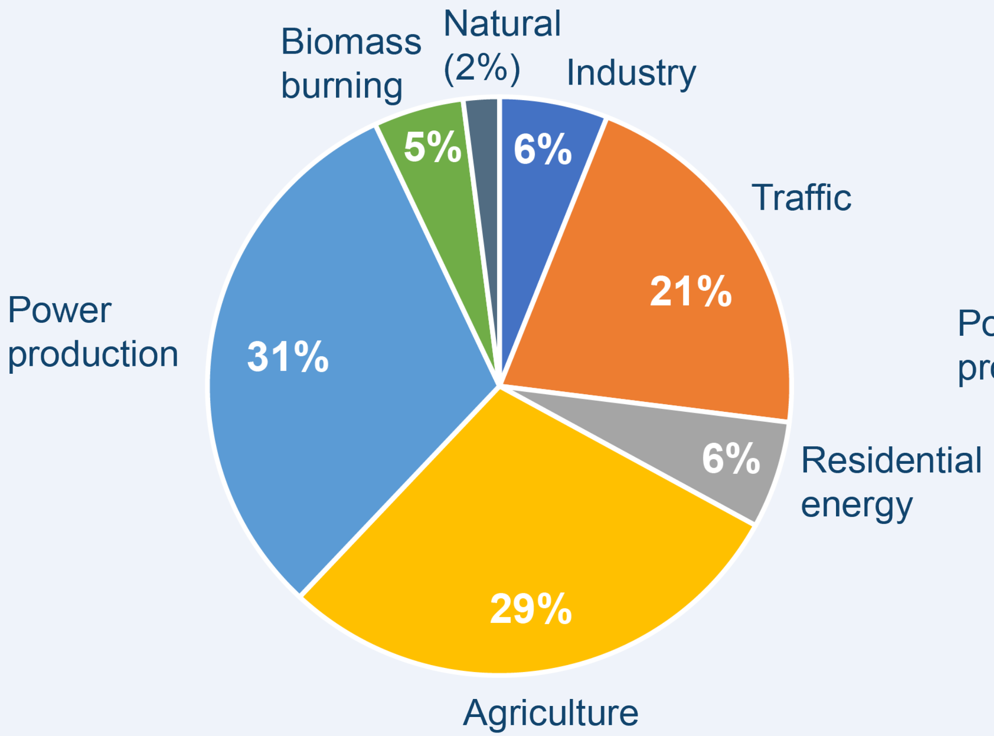
Source categories responsible for the largest impact on mortality

IND is industry, TRA is land traffic, RCO is residential energy use (e.g., heating, cooking)
BB is biomass burning, PG is power generation, AGR is agriculture and NAT is natural

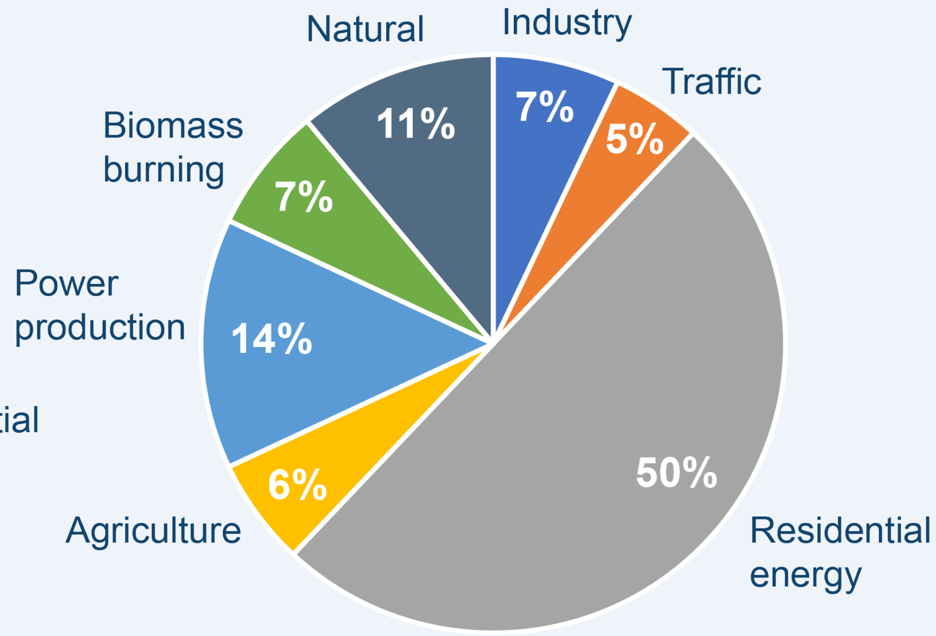


Annual mortality attributable to air pollution that could be avoided in the USA and India by controlling source sectors (global total is 4.5 M/year)

USA (120 T/yr)



India (967 T/yr)



Fossil fuel related

~58%

~26%

Health impacts of air pollution

- Outdoor air pollution causes respiratory and cardiovascular diseases, leading to 4.5 million premature deaths/year globally (95% CI about ±30%), mostly in Asia (~75%)
- Residential energy use (household combustion emissions) is the dominant source category due to prevalence in China and India
- Fossil energy use (power production, industry, traffic) is the second largest source through $PM_{2.5}$ and O_3
- Agriculture (NH_3) is a main $PM_{2.5}$ source category in Europe, Northeast USA and East Asia
- Childhood LRIs in low-income countries contribute 5% to attributable deaths, and 18% to the life expectancy decrease, about 22 million YLL/year
- Implementing the WHO guideline for $PM_{2.5}$ (10 $\mu g/m^3$) globally would reduce mortality attributable to air pollution by ~50%; further reduction will be needed