Air Quality, Climate & Health in the Anthropocene

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MAX PLANCK INSTITUTE
FOR CHEMISTRY

Outline

Anthropocene & Climate Change

- characteristics & beginnings of the Anthropocene
- aerosol-cloud-climate interactions & rainforest degradation in the Amazon

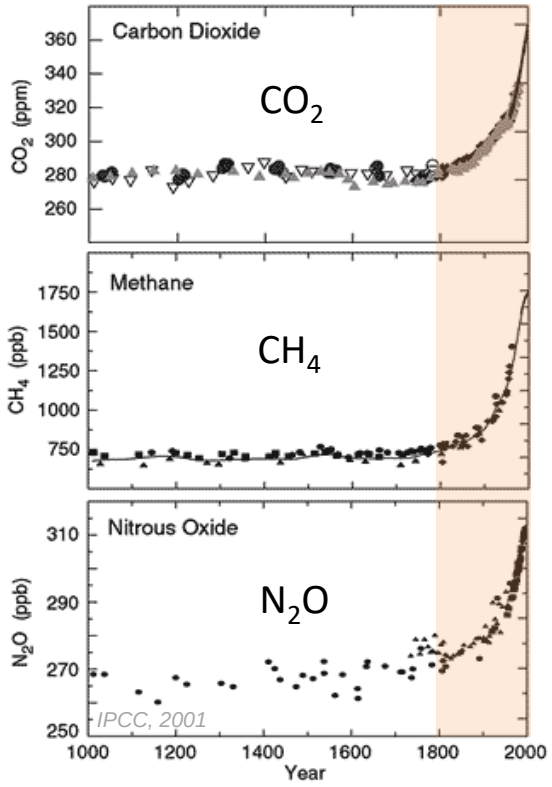
Air Pollution & Human Health

- epidemiology & toxicology
- chemical pathways to oxidative stress, inflammation & allergies

Open Scholarship & Epistemic Web

- transparency & critical rationalism for a prosperous Anthropocene

The Anthropocene: A new epoch in Earth history driven by human activity



THE ANTHROPOCENE

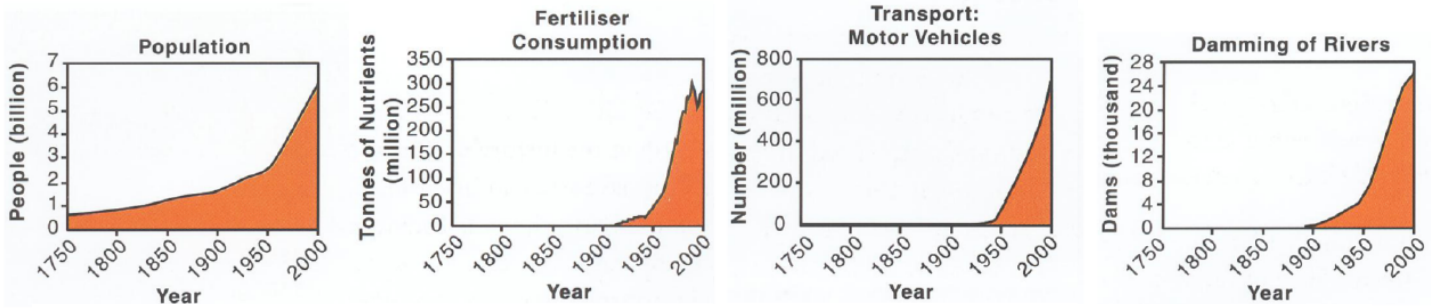
Globally pervasive & steeply increasing anthropogenic influence on planet Earth:
scientific curiosity & discovery meet practical challenges & philosophical questions –
from air quality, ozone hole & climate change to public health & human well-being (**"planetary health"**)

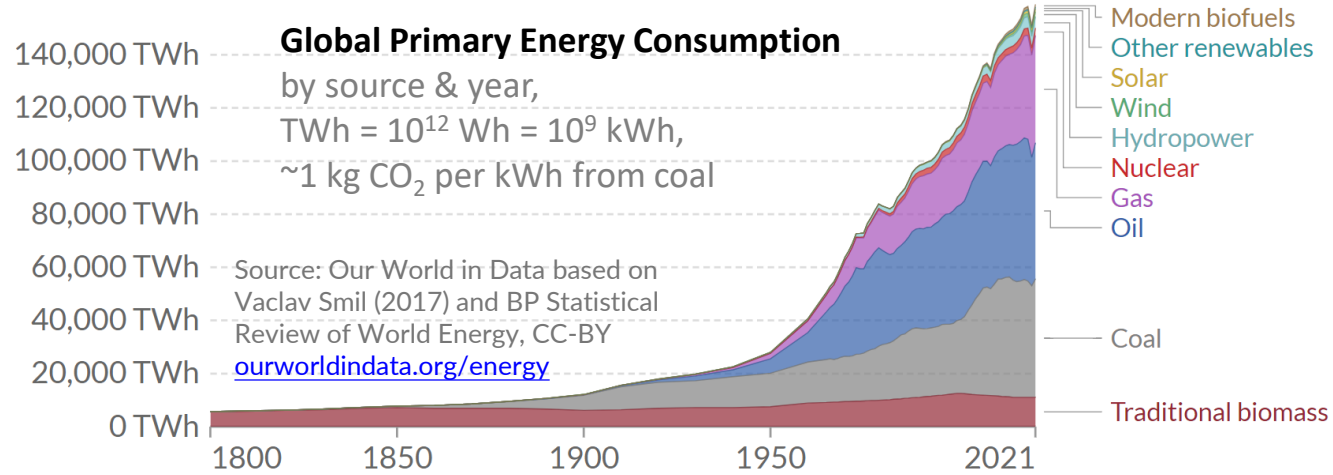
Scientific & societal message: we are shaping the planet, so let's try to get it right

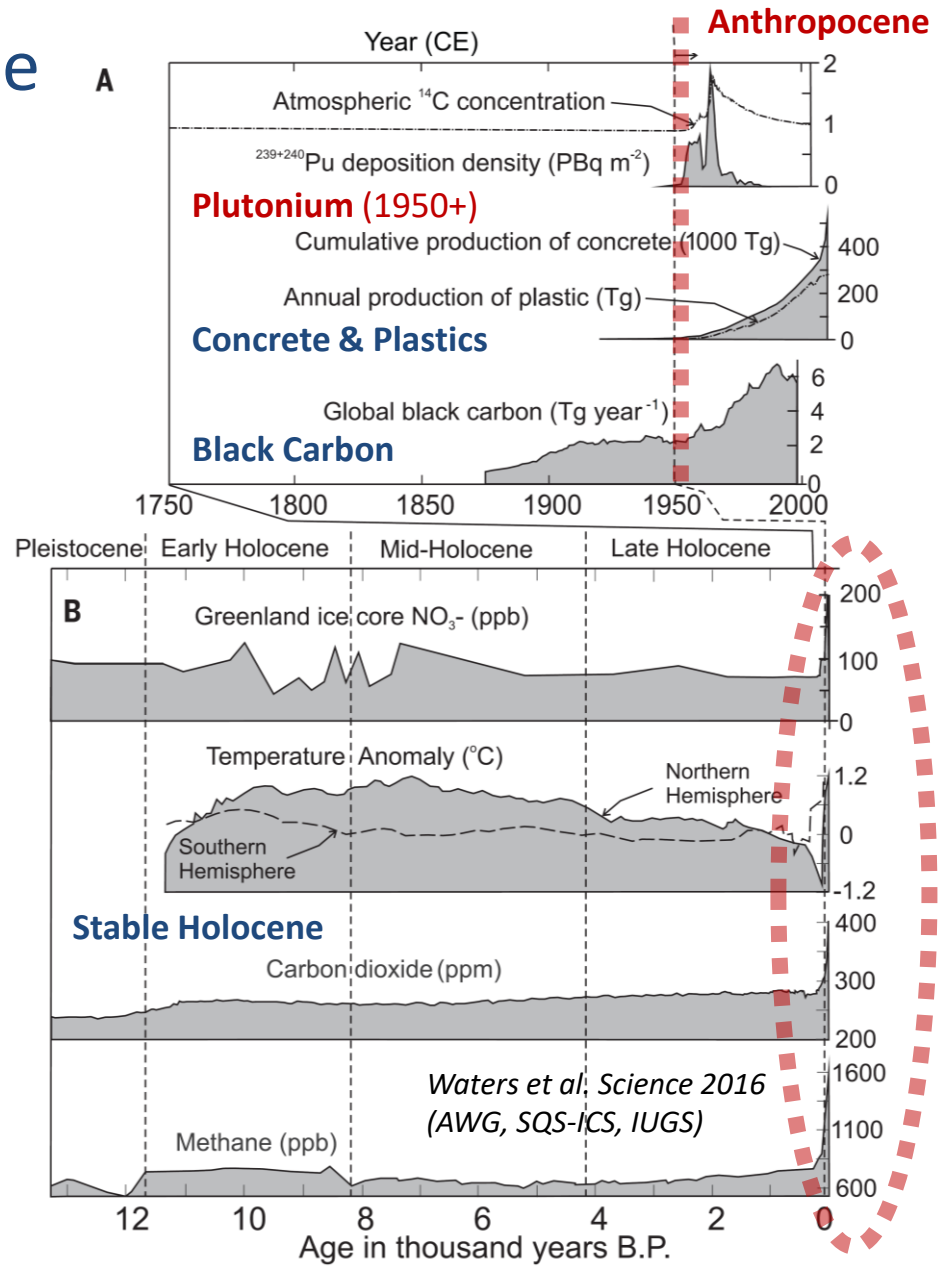
Crutzen Nature 2002; Pöschl et al. Chem Rev 2015, PAS 2017, Springer 2020, 2021; www.mpic.de/4677594/trauer-um-paul-crutzen#Condolences

Beginnings & Characteristics of the Anthropocene

Great Acceleration, 1950er/1960er: orig. figures from Crutzen & Steffen et al. (2003)



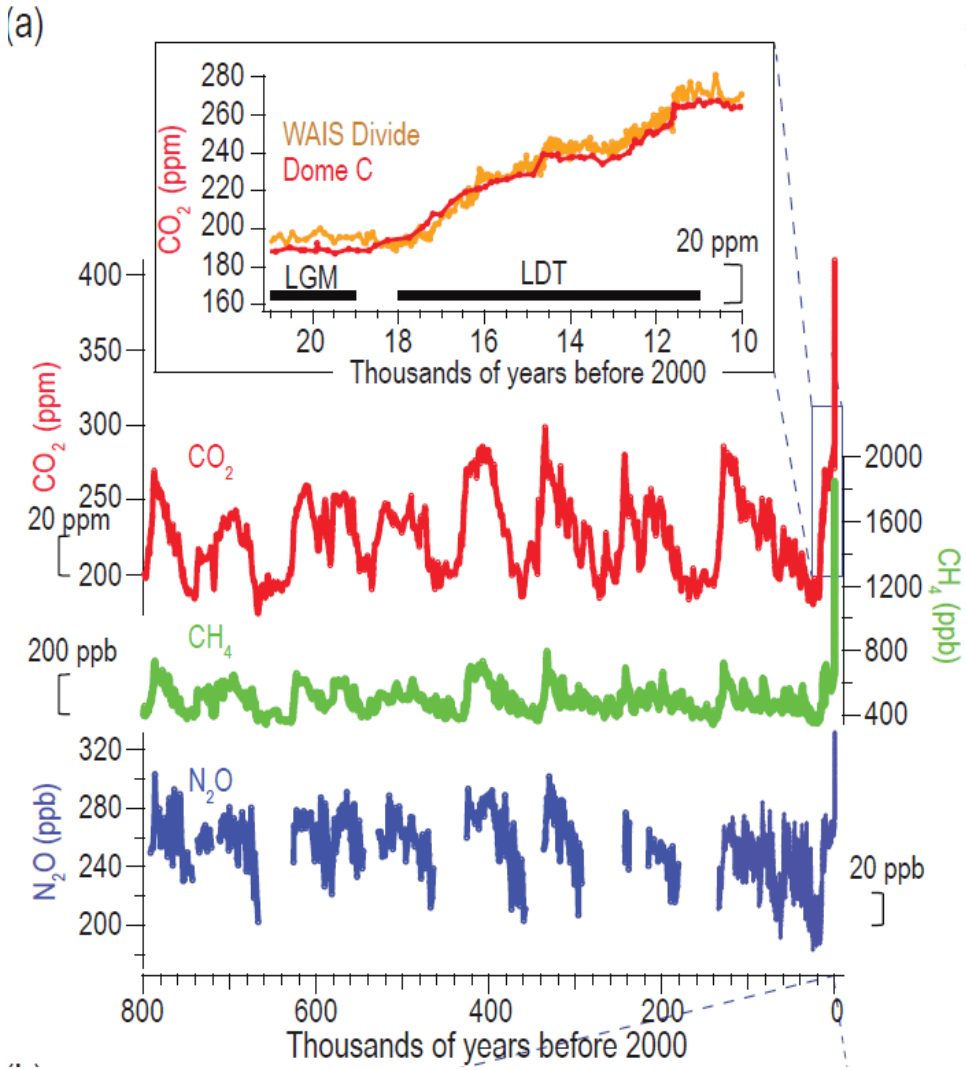


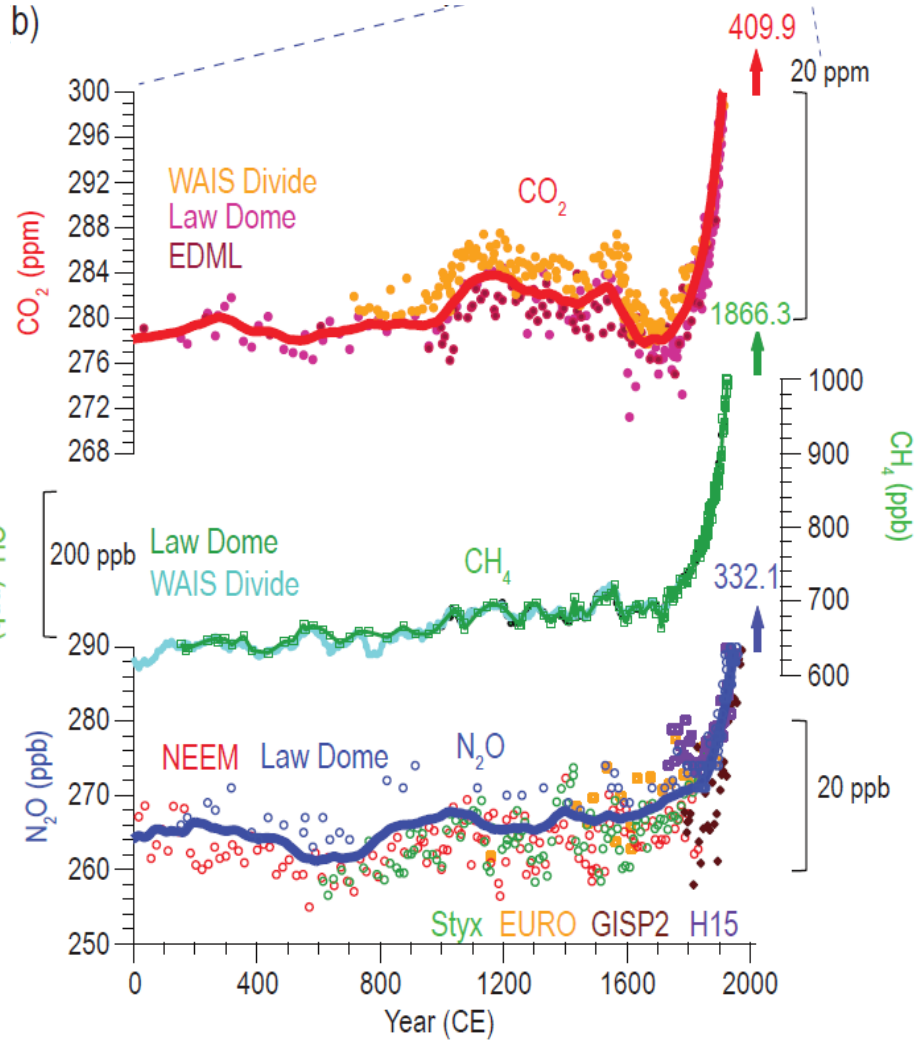


(1) Great Acceleration of human activities in 1950s/1960s & stratigraphic signals (nuclear fallout, concrete/plastics, black carbon etc., *Waters et al. 2016*);
(2) Steam Engine & Industrialization ~1800/1850 (*Crutzen et al. 2000/2003*); or
(3) Agriculture in Holocene/Neolithics ~7000 BP (*Ruddiman 2013*) **?**

(1) characteristic turning point of human population & activity growth (S curves) & discernible global warming ~1950-2000;
(2) 1850 as climate reference of late Holocene ("Paleoanthropocene", Foley et al. 2013); (3) Holocene overlap: epoch vs. event?

New Epoch or Event in Earth History & Geological Time Scale (GTS) ?





Ice Age Cycles / Pleistocene

~ 1 million years (2.5 mio yrs):

CO_2: ~ 200 – 300 ppm (350 ppm)

CH_4: ~ 400 – 800 ppb

ΔT_{glob} ~ 5 °C

Holocene, ~ 10 thousand years:

CO_2: ~ 260 – 280 ppm

CH_4: ~600 – 800 ppb

ΔT_{glob} < 0.5 °C

Anthropocene, ~100 years:

CO_2: > **400 ppm CO_2**

CH_4: > 1800 ppb CH_4

ΔT_{glob} > 1 °C

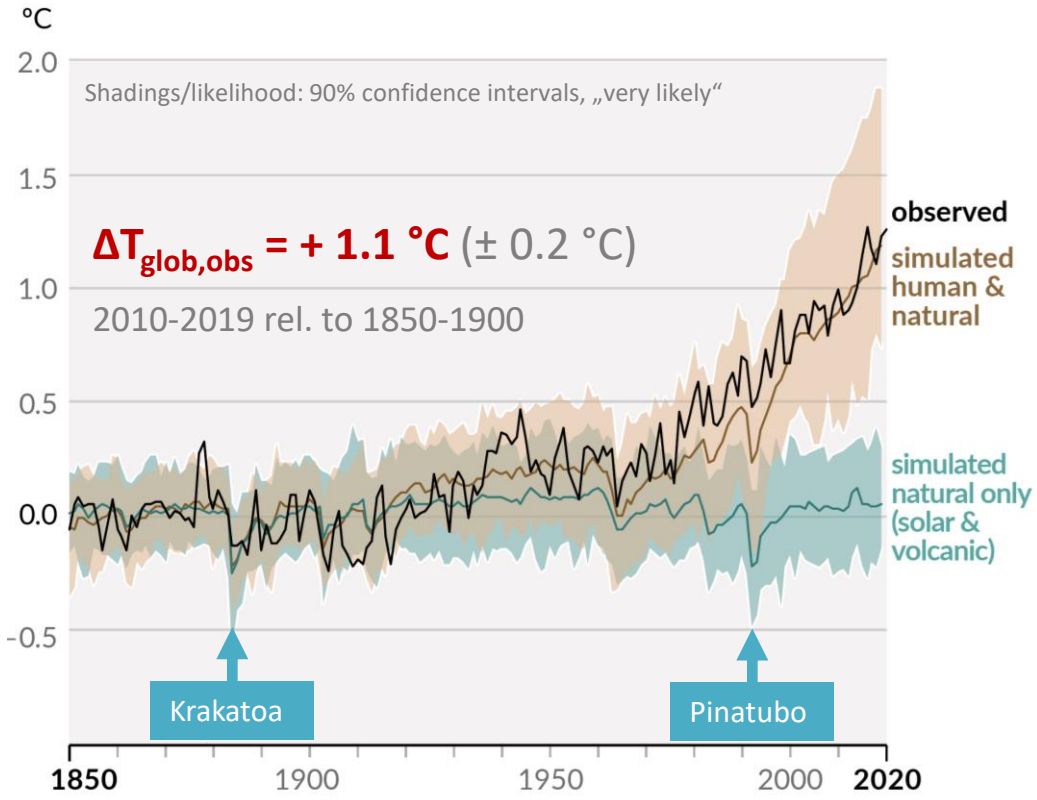
IPCC 2021 (AR6 Figs. 2.3, 2.4)

Recent changes of greenhouse gas concentrations & related parameters exceed natural variability of preceding epochs, Holocene & Pleistocene (!), clearly indicating a transition into a new state of the Earth system & new epoch in GTS

as discovered & proposed by P. Crutzen & colleagues (rather than just an event within Holocene as suggested by others)

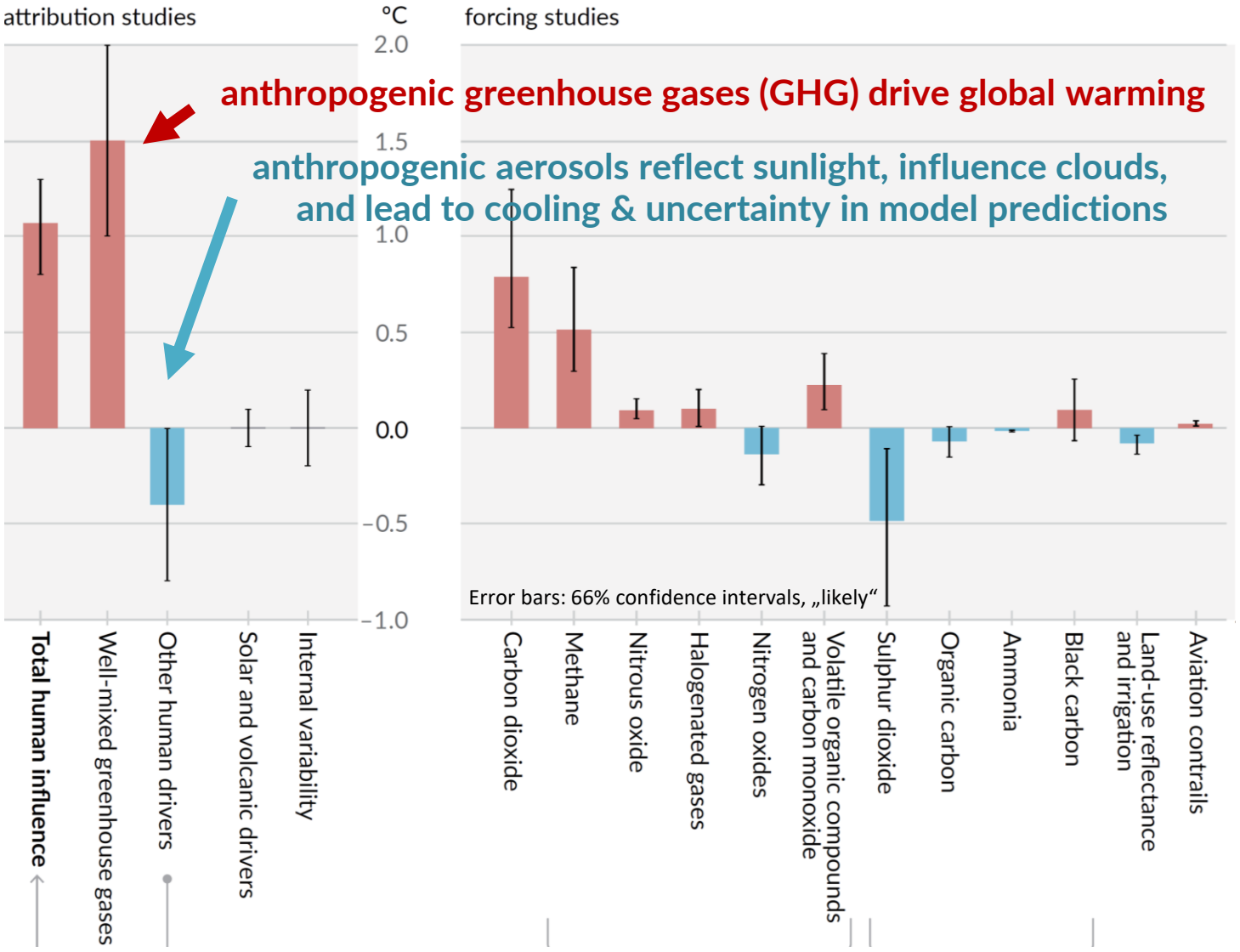
Drivers & Uncertainties of Global Warming

(b) Change in global surface temperature (annual average) as **observed** and simulated using **human & natural** and **only natural** factors (both 1850–2020)



(b) Aggregated contributions to 2010–2019 warming relative to 1850–1900, assessed from attribution studies

(c) Contributions to 2010–2019 warming relative to 1850–1900, assessed from radiative forcing studies

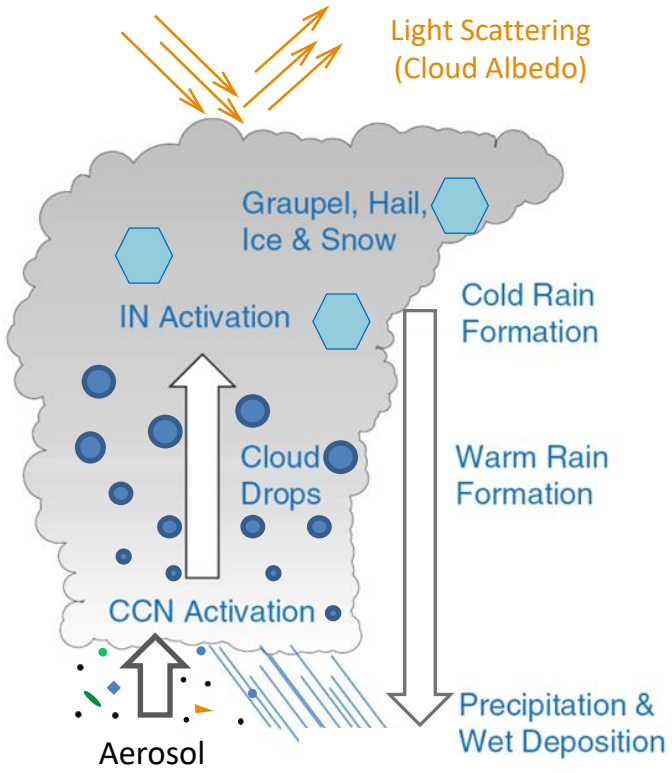


Human impacts explain obs. temp. increase:
GHG warming well known, aerosol cooling less certain.

Natural variability rel. minor (solar, volcanic):
Pinatubo 1991, Krakatoa 1883, Tambora 1815
(“year without summer” 1816): ***aerosol cooling < 0.5 °C***

IPCC 2021 (AR 6 Figs. SPM 1, SPM 2)

Aerosol-Cloud-Climate Interactions over the Amazon



Major challenge & uncertainty in climate prediction

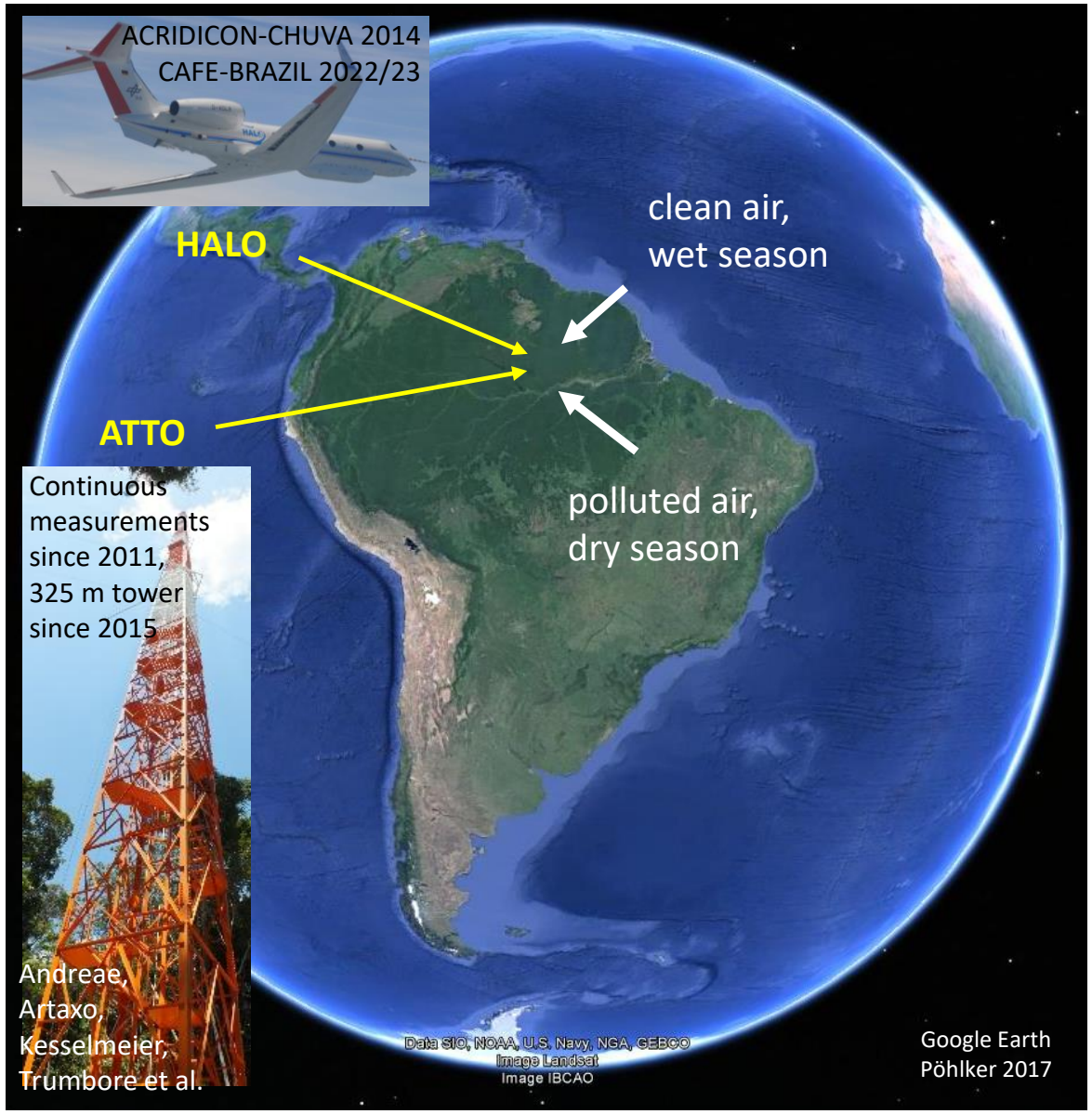
- quantify aerosol effects on clouds & precipitation

Amazon as cloud laboratory & "time machine"

wet vs. dry season, clean vs. polluted conditions

→ approximate pristine pre-industrial baseline

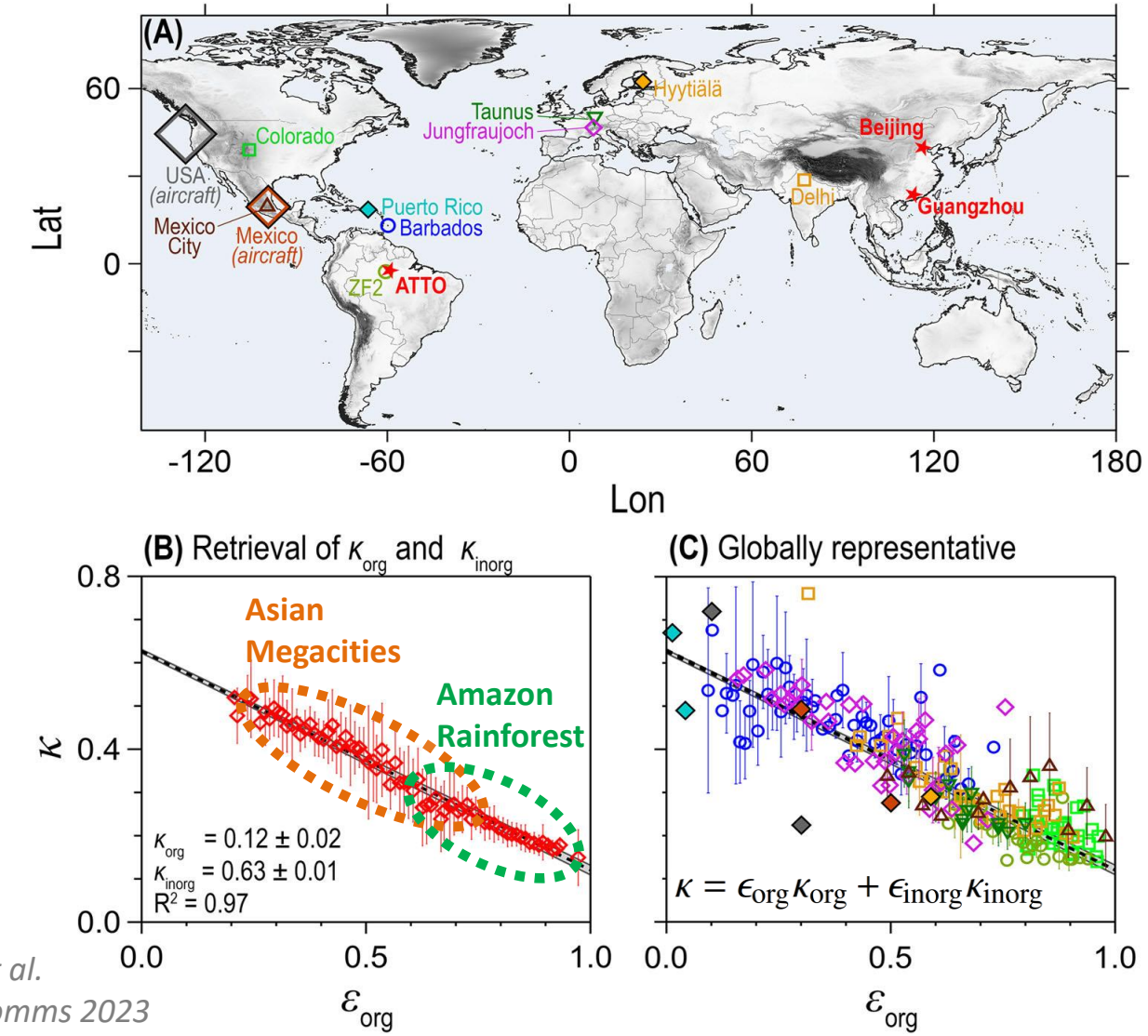
→ contrast by biomass burning pollution



Andreae et al. Science 2004, Pöschl et al. Science 2010, Andreae et al. ACP 2015, Wendisch et al. BAMS 2016, Pöhlker et al. ACP 2016, 2018, 2021, Liu et al. ACP 2023

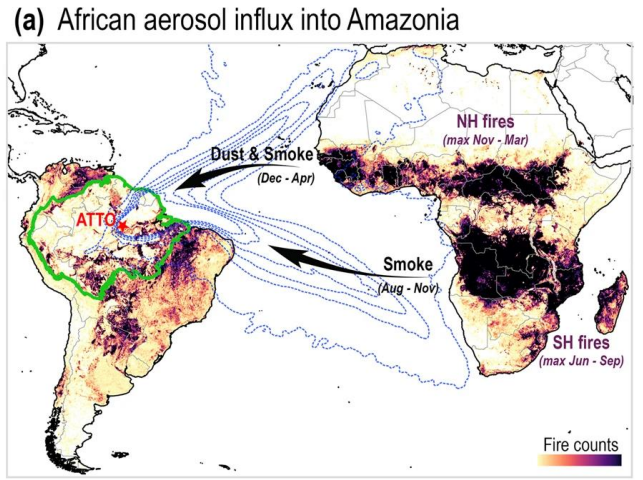
Quantification of Aerosol Particle Properties & Sources

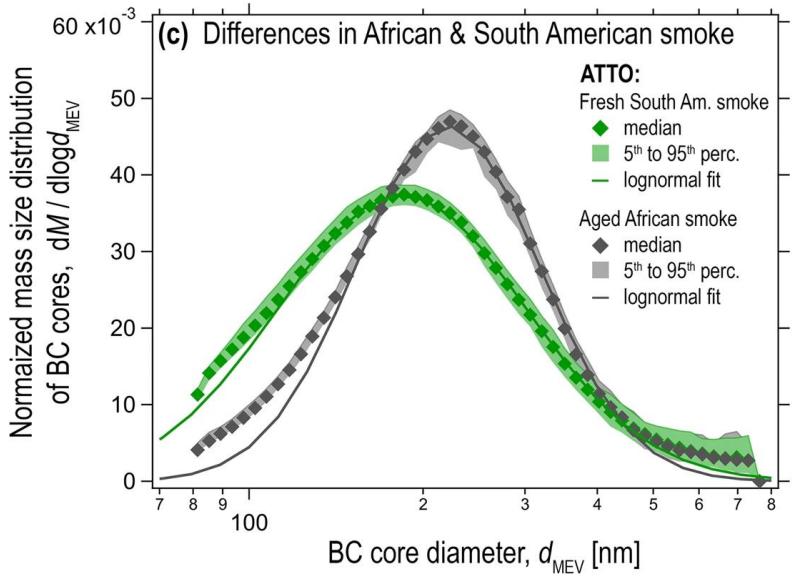
Aerosol water uptake & cloud droplet formation: comprehensive global measurements & robust parameterization of hygroscopicity parameter (κ) depending on organic & inorganic aerosol mass fractions (ε)



Pöhlker et al. Nature Comms 2023

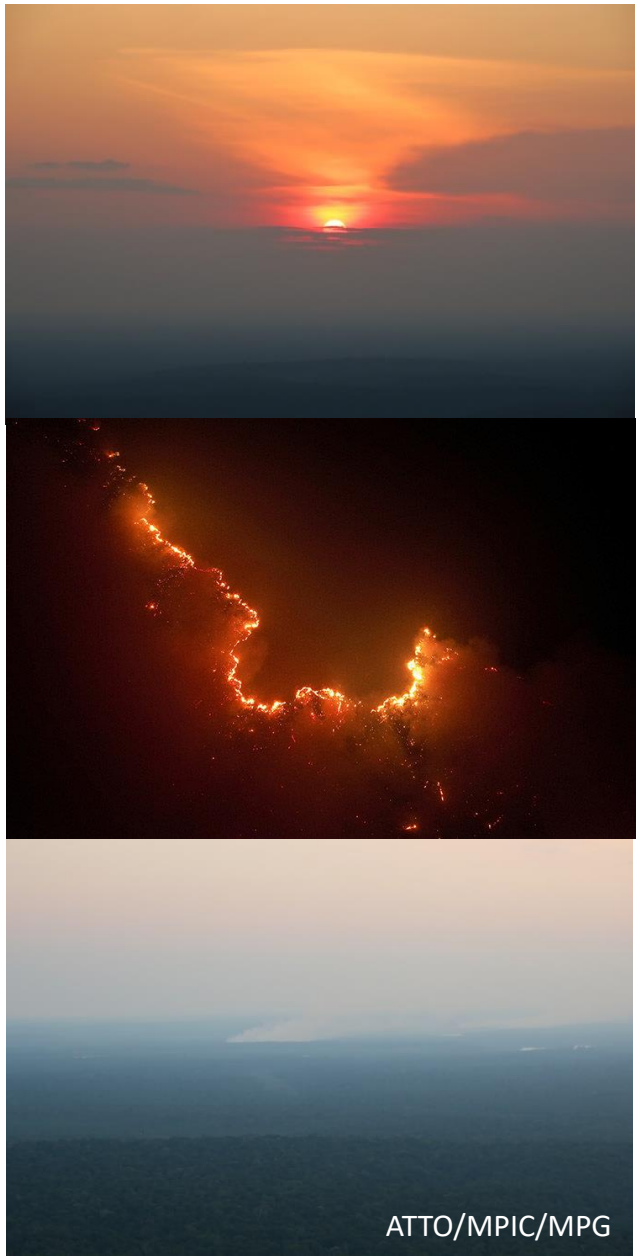
Black carbon (BC) particles from biomass burning in Africa & South America: long-range transport, seasonal variations, & size distributions of major light absorbers

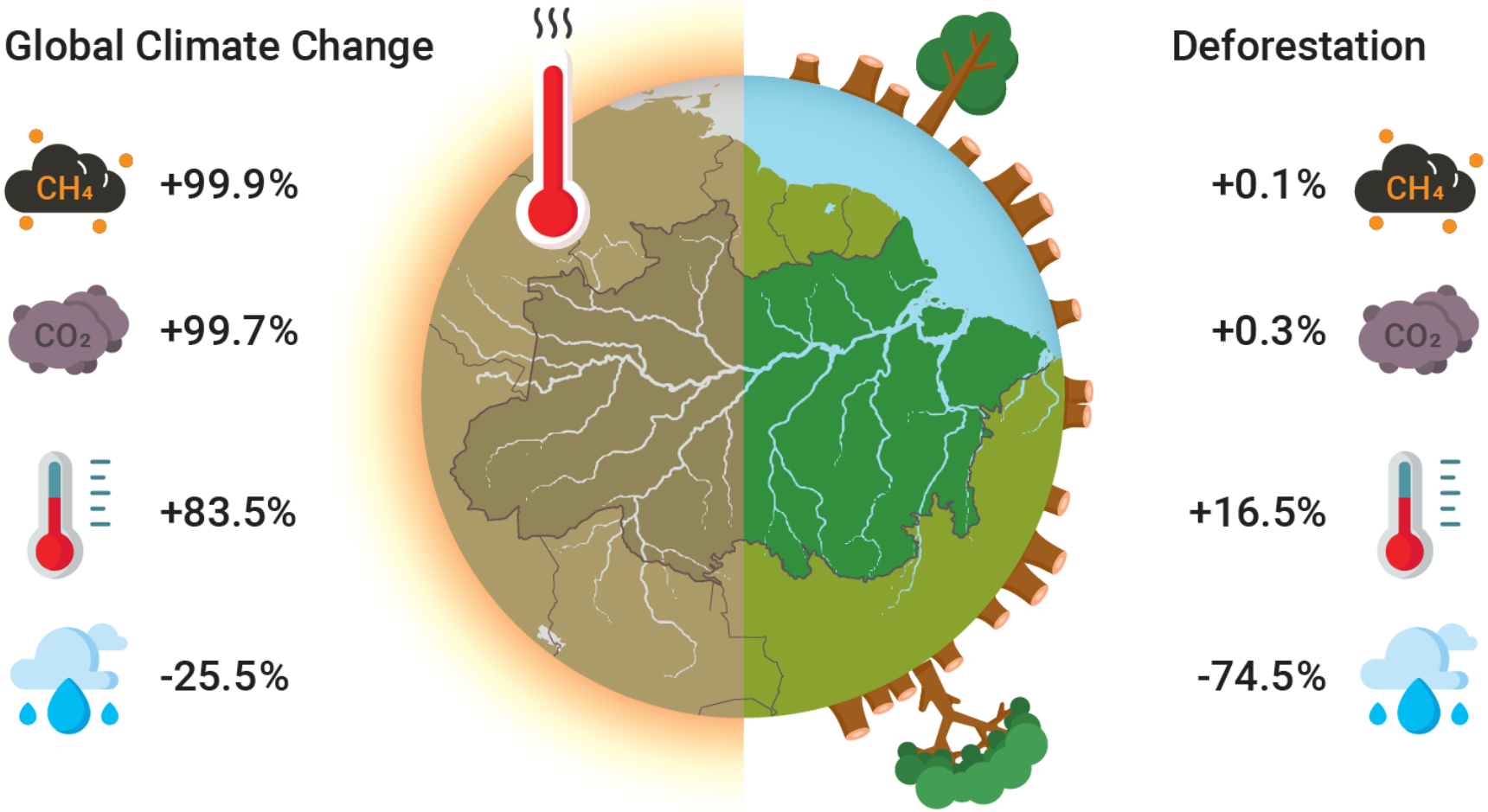




Holanda et al. Commun Earth Environ 2023

Amazonian Rainforest Degradation: Global Climate & Local Deforestation





M. Franco & L. Machado et al. 2024

Massive droughts & fires in the Amazon 2024:
unlike past, fires now spread to untouched primary forests

Air Pollution & Human Health

Epidemiology

Air pollution (ambient & household), incl. fine particulate matter (PM2.5) ozone (O_3), and nitrogen dioxide (NO_2), among global top 2 risk factors for death (1990 #1, 2021 #2)

Global estimates:

Deaths (attributable)**:** ~8 million/year

Years of life lost (YLL)**:** ~230 million years/year

Loss of life expectancy (LLE)**:** ~3 years
cf. ~2 yr tobacco, ~0.6 yr vector-borne diseases *(malaria, dengue etc.)*, ~0.2 yr violence *(personal/collective)* …

Attributable diseases: cardiovascular *(IHD/heart attack, CEV/stroke)*, respiratory *(COPD, LRI, lung cancer)*, diabetes …

Attributable fractions: ~8% of total disease burden;
~28-48% of deaths by IHD, LRI, COPD; ~34% of preterm births ..

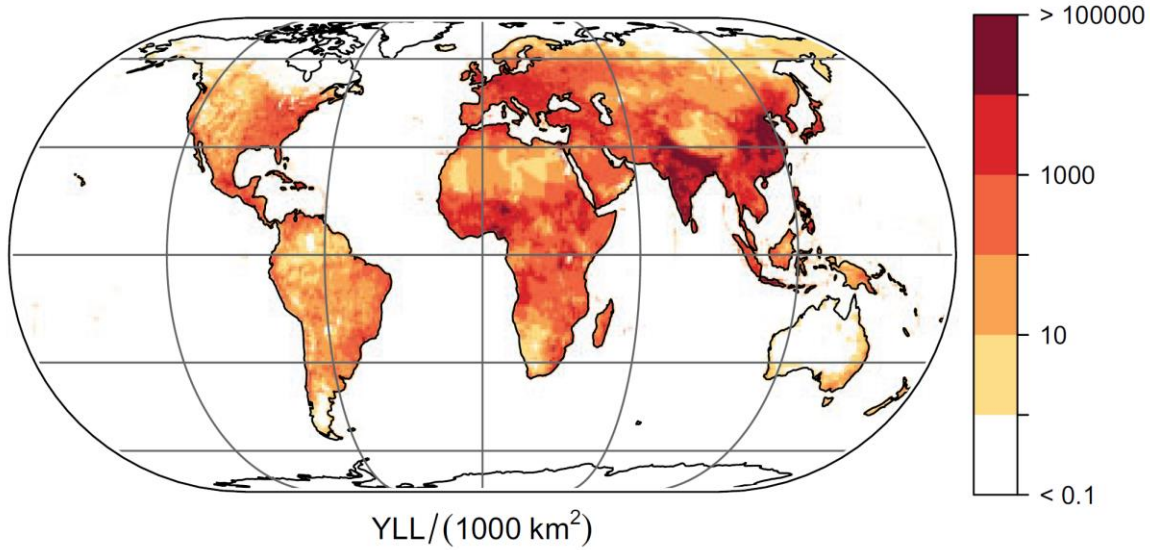
Major contribution of fossil fuels: ~50% or more

Toxicology

PM2.5, O_3, and NO_2 shown to cause oxidative stress, acute/chronic inflammation, cellular & molecular damage; detailed mechanisms & differential toxicity unknown

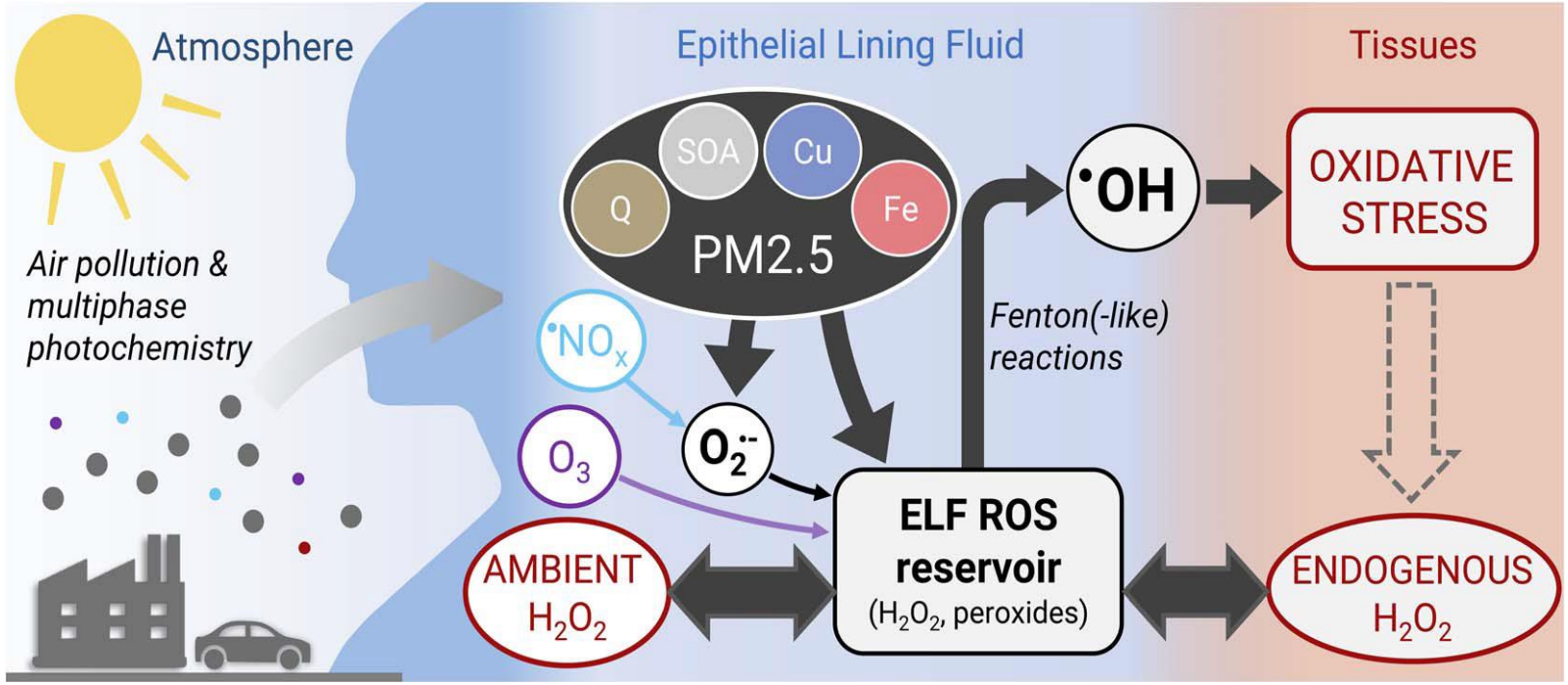
Global risk factors for death (GBD, IHME, 2021/2024)

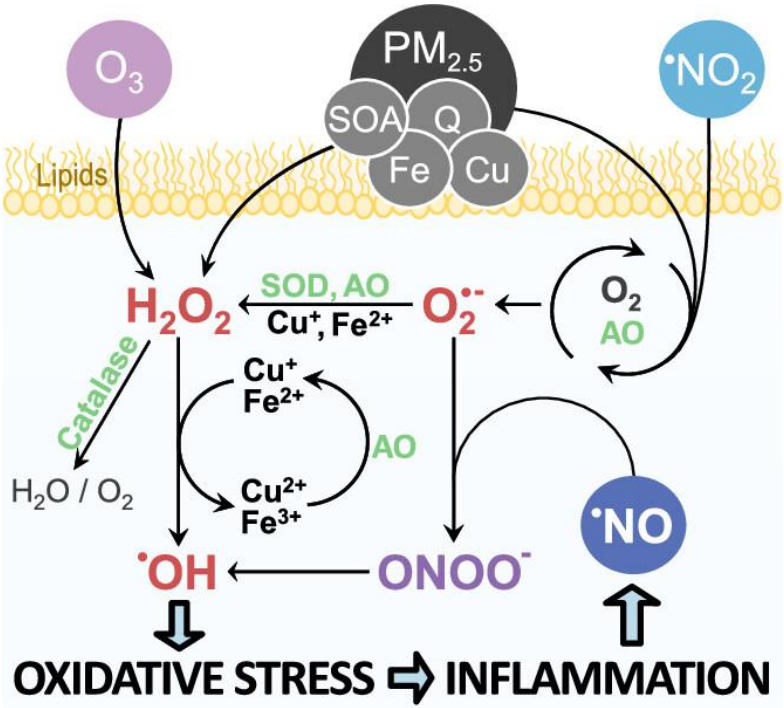
Rank	Total global population	Children under 5 years
1	High blood pressure	Malnutrition
2	Air pollution	Air pollution
3	Tobacco	Water, Sanit., Hygiene
4	Diet	High/low temperature
5	High fast. plas. glucose	Tobacco



GBD, IHME, HEI 2021,2024; Lelieveld et al. 2015,2017,2019,2020,2023 …

Oxidative Stress & Inflammation





Recent advances through Kinetic Multilayer Models (KM-SUB-ELF etc.) resolving mass transport & chemical production of reactive oxygen & nitrogen species (ROS/RNS) in inhaled air, epithelial lining fluid (ELF), cells/tissues, blood:

- **total ROS in ELF effectively buffered** by endogenous H_2O_2 (blood flow)
- **conversion of endogenous H_2O_2 into OH** more important for oxidative stress than exogenous H_2O_2 production

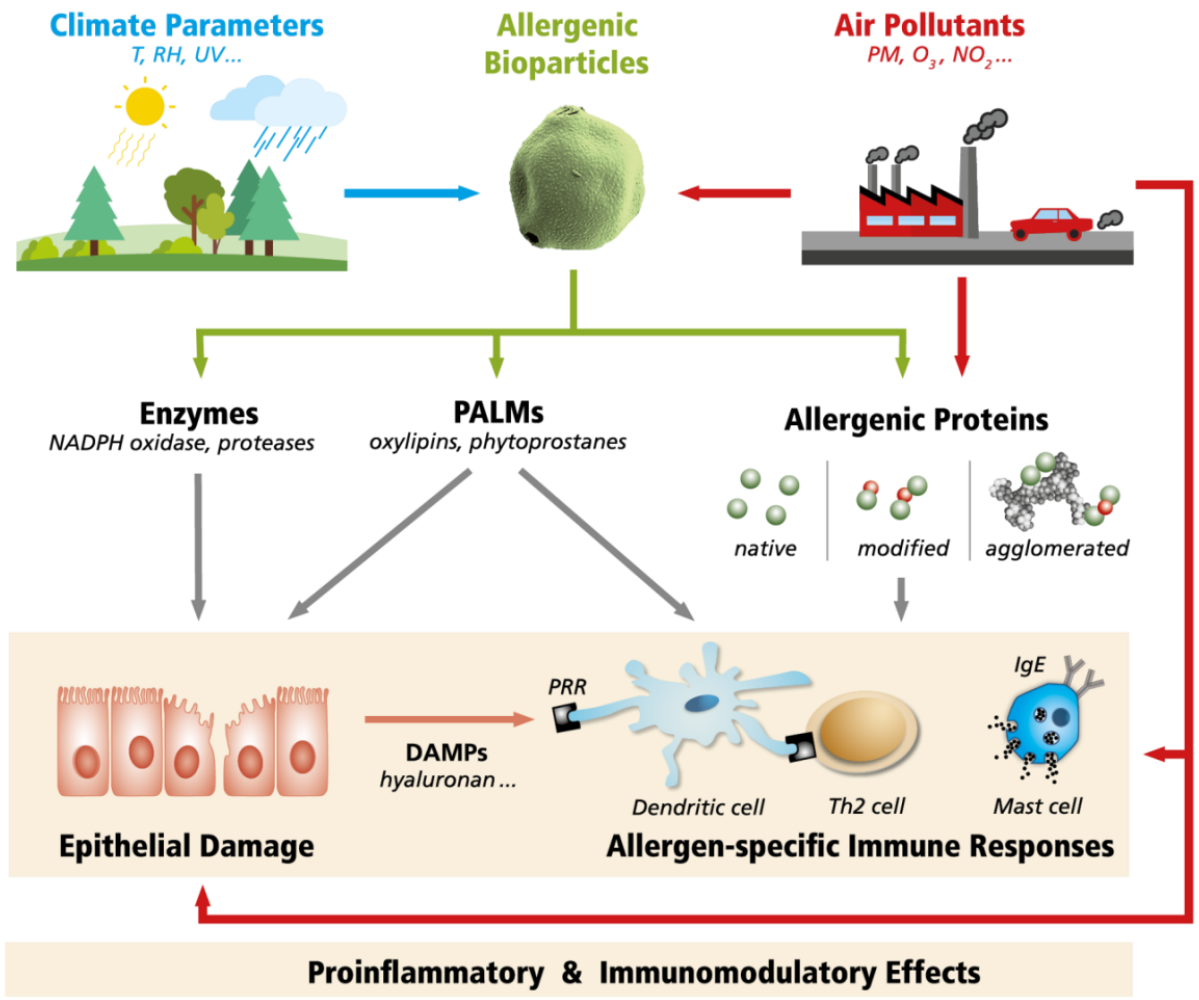
→ **paradigm shift**: air pollutants as catalysts rather than fuels for ROS/RNS production & oxidative stress (oxid. pot. assays?)

- **endogenous nitric oxide can enhance oxidative stress** caused by air pollutants (analogy to atmospheric chemistry)

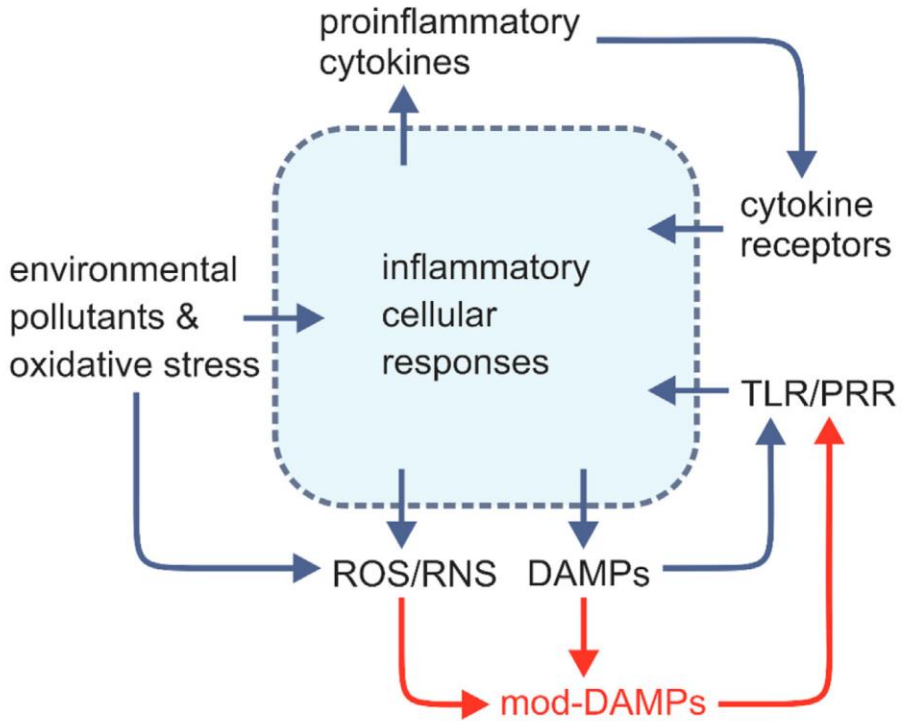
→ **explanation** for higher susceptibility of individuals with pre-existing inflammatory disorders

Dovrou et al. Environ Sci Atmos 2023, Lelieveld S. & L. et al. EST 2024

Immune Responses & Allergic Reactions



How may climate & air pollution trigger/enhance allergies, i.e., false alarms of the immune system ?



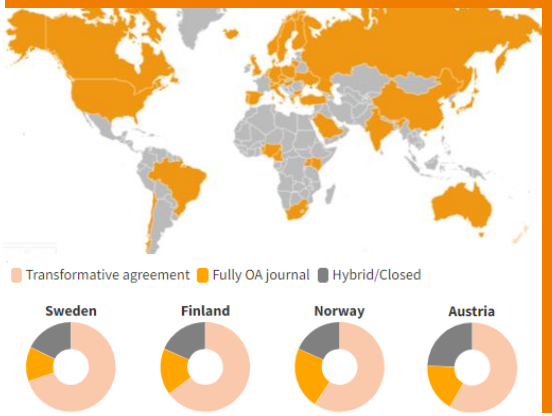
Pathways for climate parameters & air pollutants to influence the release, potency, and effects of allergens and adjuvants

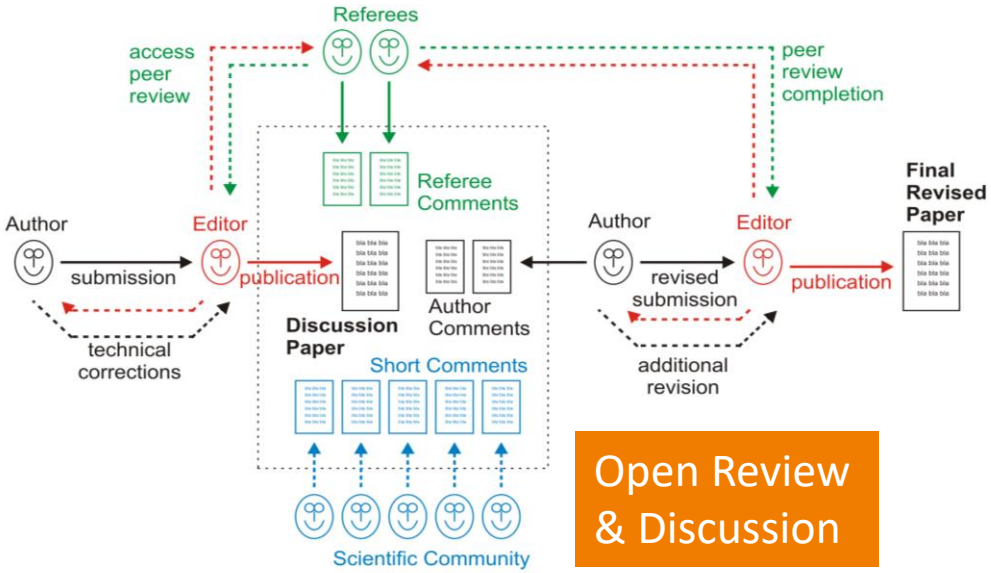
Molecular rationale: chemical modification of proteins by atmos. & physiol. reactive species (O_3, NO_2, ONO_2^- …) may trigger immune reactions & chronic inflammation

Franze et al. EST 2005, Pöschl & Shiraiwa Chem Rev 2015, Reinmuth-Selzle et al. EST 2017, Ziegler et al. Redox Biol 2020, Mishra et al. EST 2024

Open Scholarship

Berlin Declaration 2003, OA2020, Plan & Coalition S, ESAC …





Open Review & Discussion

Open Access: free online **availability & use** of scholarly research articles

- more & better information for scholars & society (teaching, innovation …)
- equal opportunities (social/global) & copyright (Creative Commons)
- re-integrate scholarly & common knowledge (e.g., Wikipedia figures, validated vs. alternative facts, climate change, pandemic measures ...) …
- advance scholarly evaluation & quality assurance: open review & discussion, new metrics beyond citation counting oligopoly (ALM) …

Interactive OA Publishing & Open Peer Review:

- combine & integrate strengths of traditional peer review with virtues of transparency & self regulation in scientific quality assurance
- free speech; document scientific discourse; save reviewer capacities …
- **ACP/EGU** (since 2001): top quality & visibility at low rejection rates; large volume at low cost; financial sustainability & substantial income: 19 journals; >50,000 papers; >180,000 public comments, ~5 Mio EUR/yr
- **F1000 Research, SciPost Physics**/arXiv … since 2012

Pöschl Learned Publishing 2004, Frontiers Comp. Neurobiol. 2012, Copernicus Medal 2015, Preusker Medal 2018, FWF Scilog 2020;
www.mpic.de/4123205/open-access; www.egu.eu/news/926/egu-expands-open-access-to-scientific-knowledge-and-discussion

Open Peer Review at Work in Climate Science

Atmospheric Chemistry and Physics
An interactive open-access journal of the European Geosciences Union

Atmos. Chem. Phys., 16, 3761-3812, 2016
http://www.atmos-chem-phys.net/16/3761/2016/
doi:10.5194/acp-16-3761-2016

ACP Online Library ***"Most Commented Papers":***
acp.copernicus.org/most_commented.html

Research article

22 Mar 2016

Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 °C global warming could be dangerous

James Hansen et al.

Hansen et al. 2016 (UN-FCCC CoP 21, Paris 2015):
110 comments, > 290 000 views
acp.copernicus.org/articles/16/3761/2016/acp-16-3761-2016-discussion.html

Download

- Final revised paper (published on 22 Mar 2016)
- Supplement to the final revised paper
- Discussion paper (published on 23 Jul 2015)
- Supplement to the discussion paper

Interactive discussion

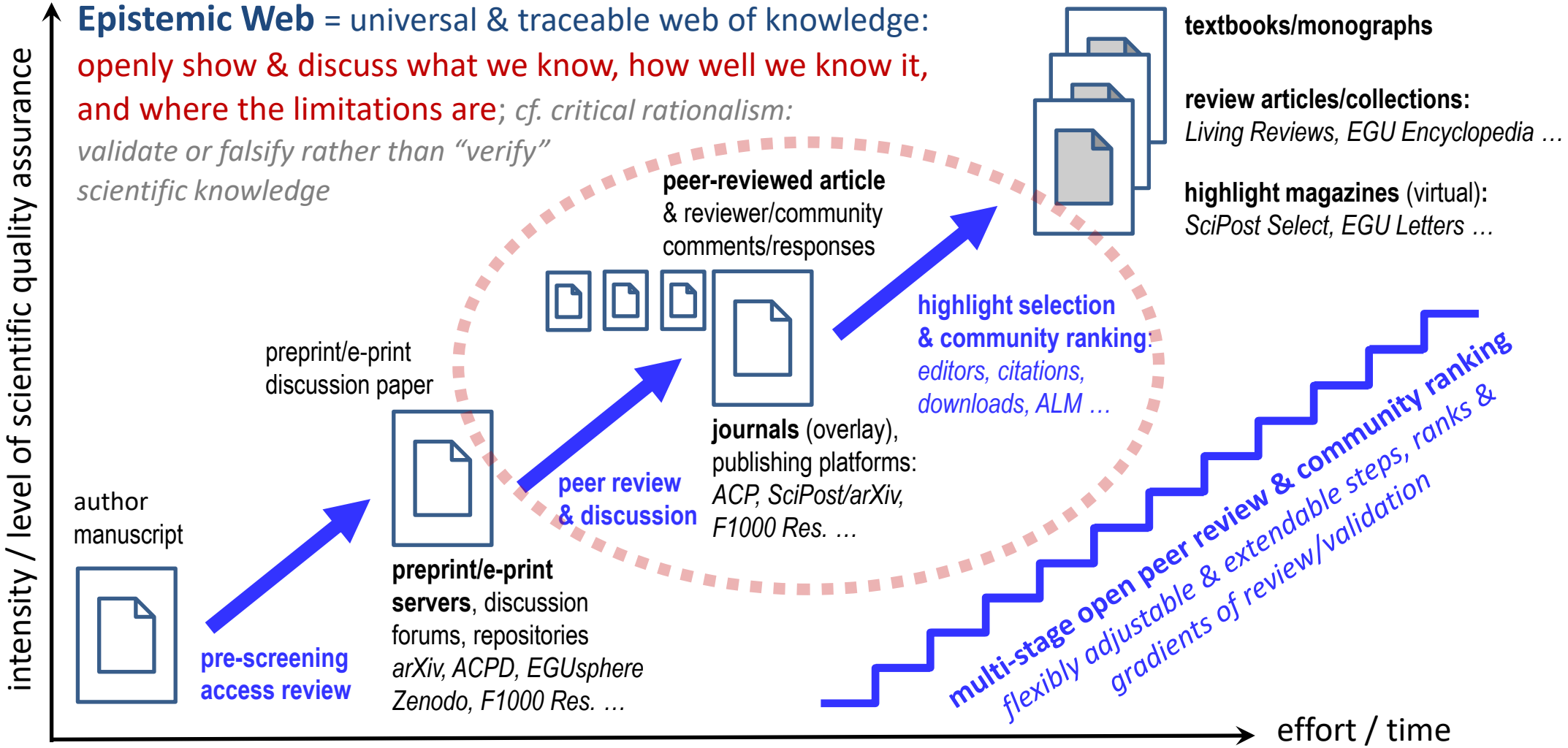
Status: closed

AC: Author comment | **RC**: Referee comment | **SC**: Short comment | **EC**: Editor comment

- Printer-friendly version S - Supplement

SC C5202: 'SC Two papers that conflict with section 2.2. argument for Eemian "superstorm" activity', Andrew Revkin, 26 Jul 2015
SC C5522: 'Is a 10% increase in wind speed enough to increase wave heights enough to move the Bahamian boulders in the Eemian?', Michael Wehner, 31 Jul 2015
AC C8101: 'Response to SC C5522', James Hansen, 15 Oct 2015
AC C5615: 'Boulders in the Bahamas: Response to Comment by A. Revkin on paper Ice Melt, Sea Level Rise and Superstorms', James Hansen, 04 Aug 2015
SC C5885: 'Boulders show mega-tsunamis and multi-metre sea level rise could result from rapid Arctic warming; both precautionary and preventative actions are required urgently', John Nissen, 13 Aug 2015
AC C7872: 'Response to SC C5885', James Hansen, 12 Oct 2015
SC C6270: 'Speculations on superstorms', Max Engel, 26 Aug 2015

Epistemic Web



Practice & demonstrate transparent & rational approach of solving complex questions & problems through open science in global commons of scholarly knowledge *(open access, open data, open review, open source …)*

⇒ **role model for societal decision processes**

Pöschl, Front Comp Neurosci 2012, Hyman & Renn, Edition OA 2012; Popper Unended Quest 1974/2004; www.mpic.de/4123205/open-access

Acknowledgement

Scientific Insights & Exchange: mentors/mentees, students/postdocs, colleagues/partners

Open Science, OA Publishing & Open Peer Review: contributors from global (geo)scientific community

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www.mpic.de/3537984/Multiphase_Chemistry