The GEWEX Aerosol Precipitation (GAP) initiative

Pan-GASS Meeting

Understanding and Modeling Atmospheric Processes

Monterey, USA

25/07/2022

Susan C. van den Heever (Colorado State University) & Philip Stier (University of Oxford)

GAP expert workshop contributions: Massimo Bollasina (Edinburgh), Matthew Christensen (PNNL), Guy Dagan (Jerusalem), Leo Donner (GFDL), Kerry Emanuel (MIT), Annica M. L. Ekman (Stockholm), Graham Feingold (NOAA), Paul Field (MetOffice), Piers Forster (Leeds), Andrew Gettelman (NCAR), Edward Gryspeerdt (Imperial), Jim Haywood (Exeter), Ralph Kahn (NASA), Ilan Koren (Weizmann), Christian Kummerow (CSU), Tristan L'Ecuyer (Wisconsin-Madison), Ulrike Lohmann (ETH), Yi Ming (NOAA), Johannes Mülmenstädt (PNNL), Gunnar Myhre (CICERO), Johannes Quaas (Leipzig), Daniel Rosenfeld (Jerusalem), Bjorn Samset (CICERO), Axel Seifert (DWD), Graeme Stephens (NASA), Kenta Suzuki (Tokyo), Wei-Kuo Tao (NASA), Rob Wood (Washington)

Do aerosols affect precipitation?

Publications
8,790
Total
From 1900 to 2022

Citing Articles
145,140 Analyze
Total
138,133 Analyze
Without self-citations

Times Cited
309,525
Total
35.21
Average per item
253,965
Without self-citations

201
H-Index

Times Cited and Publications Over Time

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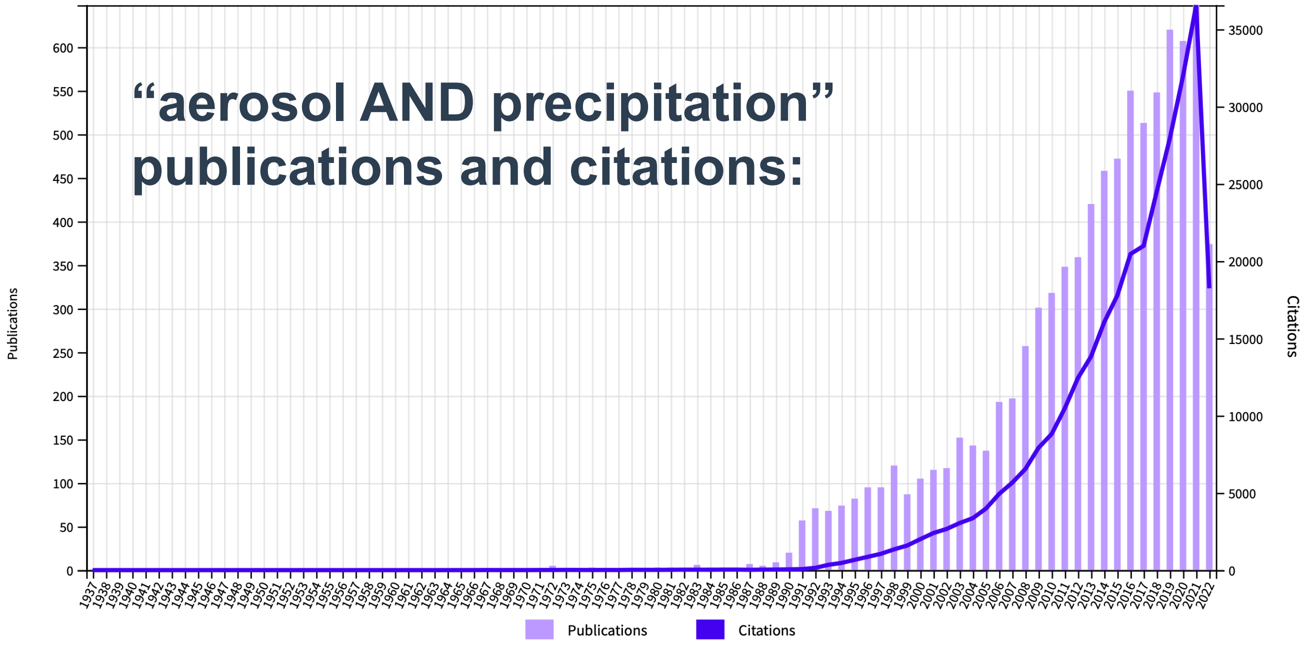

GEWEX Aerosol Precipitation (GAP) initiative

Co-chairs: Sue van den Heever & Philip Stier

Do aerosols affect precipitation?

Process studies:
ACPC, IGAC

Climate simulations:
CMIP, AirChemMIP, AeroCom

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GASS

GEWEX
GAP

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UNIVERSITY OF OXFORD NASA erc esa WCRP World Climate Research Programme GEWEX

The GEWEX Aerosol Precipitation (GAP) initiative

Goals:

1. Enhance our understanding of aerosol-precipitation interactions on a regional to global scale with a focus on energy and water budget constraints
2. Facilitate connections between all GEWEX cloud-aerosol-precipitation related activities
3. Interface with process-focused initiatives, such as the Aerosols, Clouds, Precipitation and Climate (ACPC) initiative with focus on aerosol and cloud processes from a local to cloud system scale

The GEWEX Aerosol Precipitation (GAP) initiative

The plan

1. Series of small expert workshops:
   i) Aerosol effects on precipitation (2017)
   ii) Observational evidence for aerosol effects on precipitation (2019)
2. Develop whitepaper and present to GEWEX community
3. GAP initiative for global aerosol effects on precipitation

Aerosol Effects on Precipitation

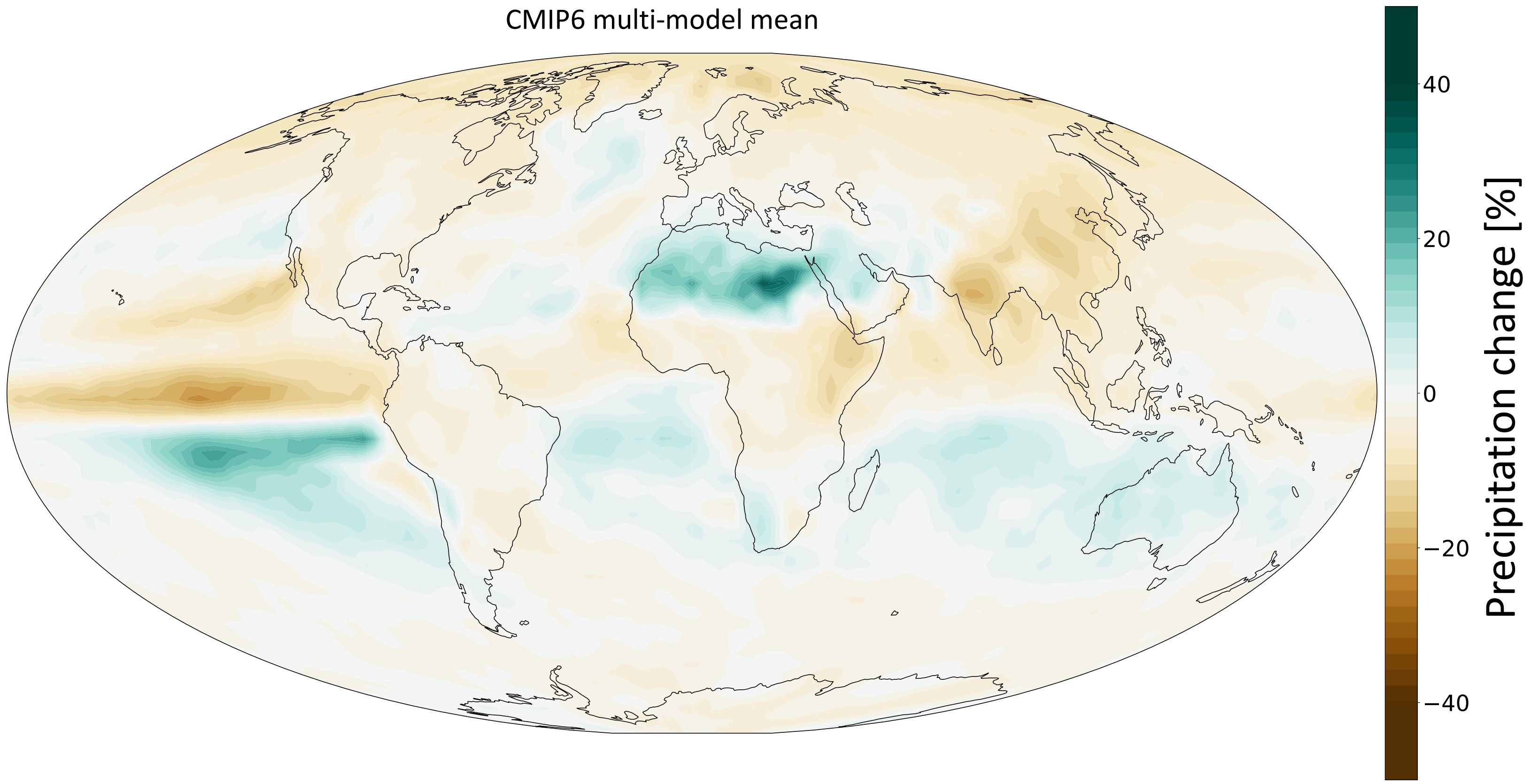
GEWEX Aerosol Precipitation (GAP) initiative

(GAP Expert Workshop, Oxford, 2017)

University of Oxford · NASA · erc · esa · WCRP World Climate Research Programme · GEWEX

Aerosol effects on precipitation

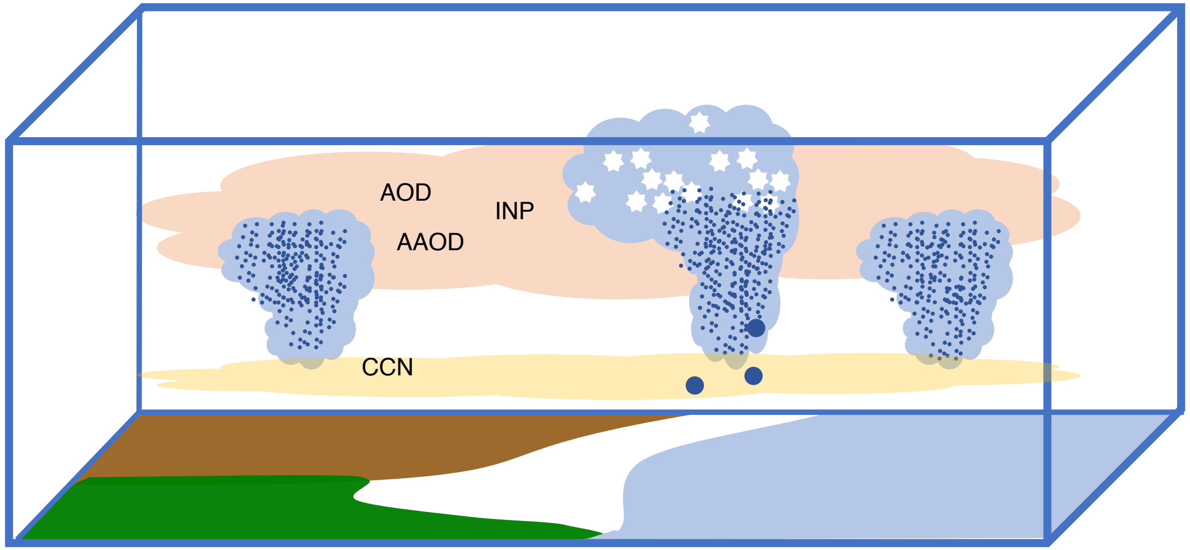
CMIP6 DAMIP effects of anthropogenic aerosols on precipitation:



GEWEX Aerosol Precipitation (GAP) initiative

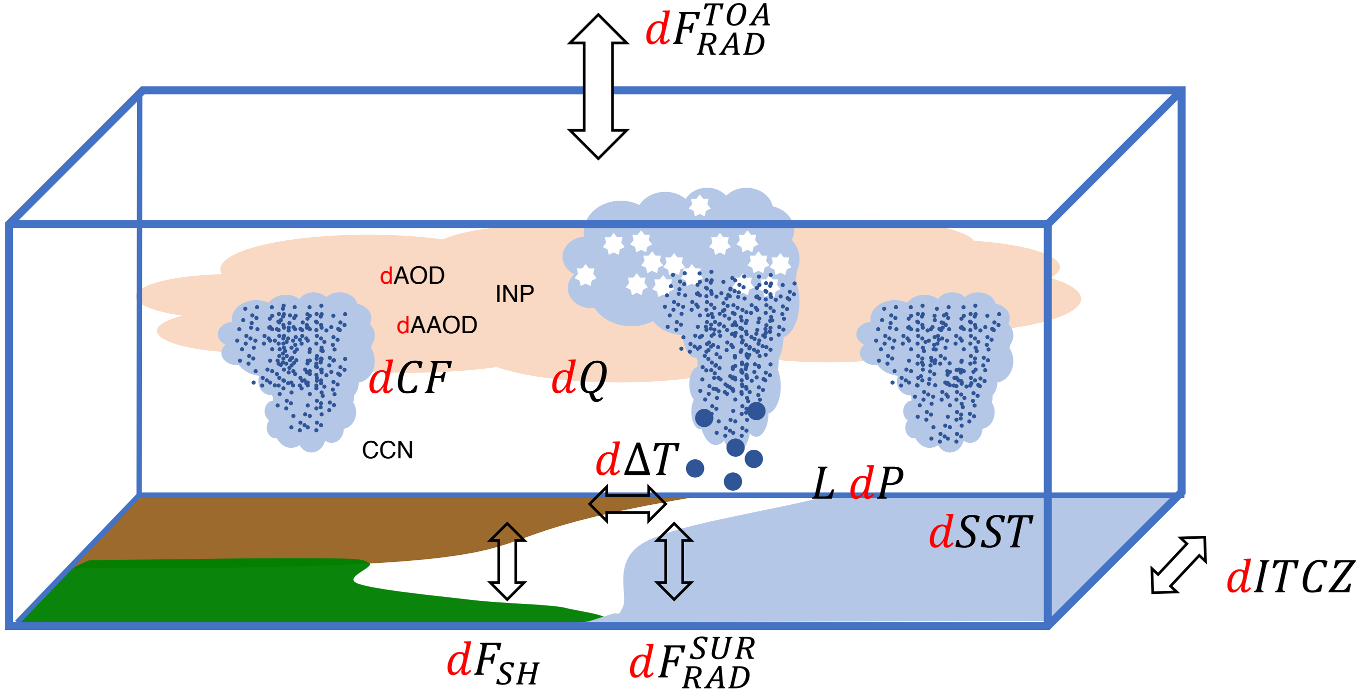
(Stier, van den Heever et al, in review)

Aerosol effects on precipitation



Aerosol effects on precipitation

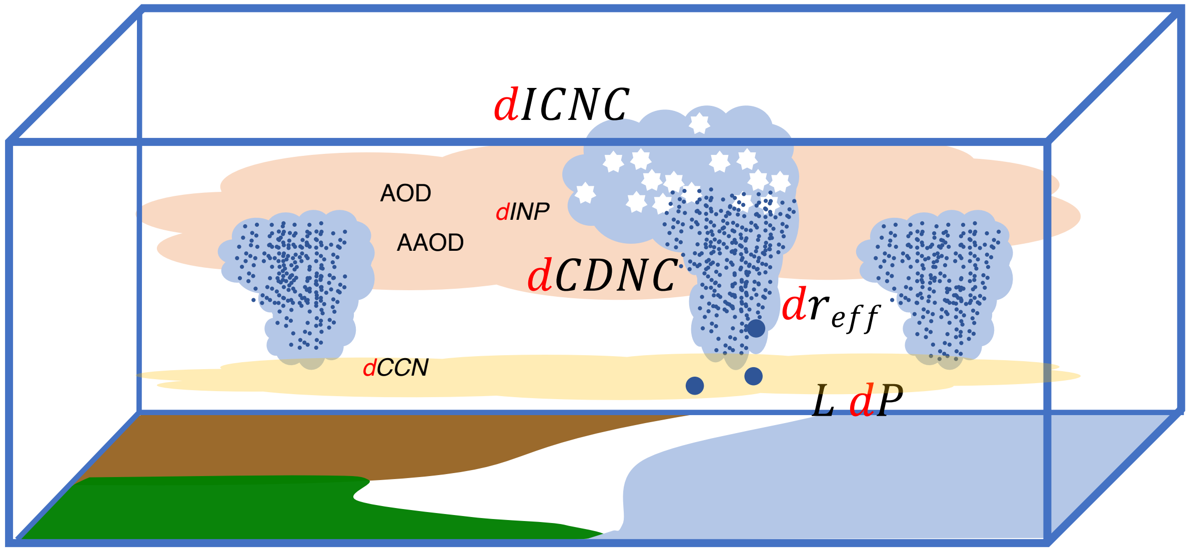
Radiative effects



Direct and indirect aerosol effects via: surface energy budget, atmospheric diabatic heating, semi-direct effects, regional scale precipitation and monsoon dynamics, sea surface temperature patterns, and hemispheric asymmetry in aerosol radiative effects.

Aerosol effects on precipitation

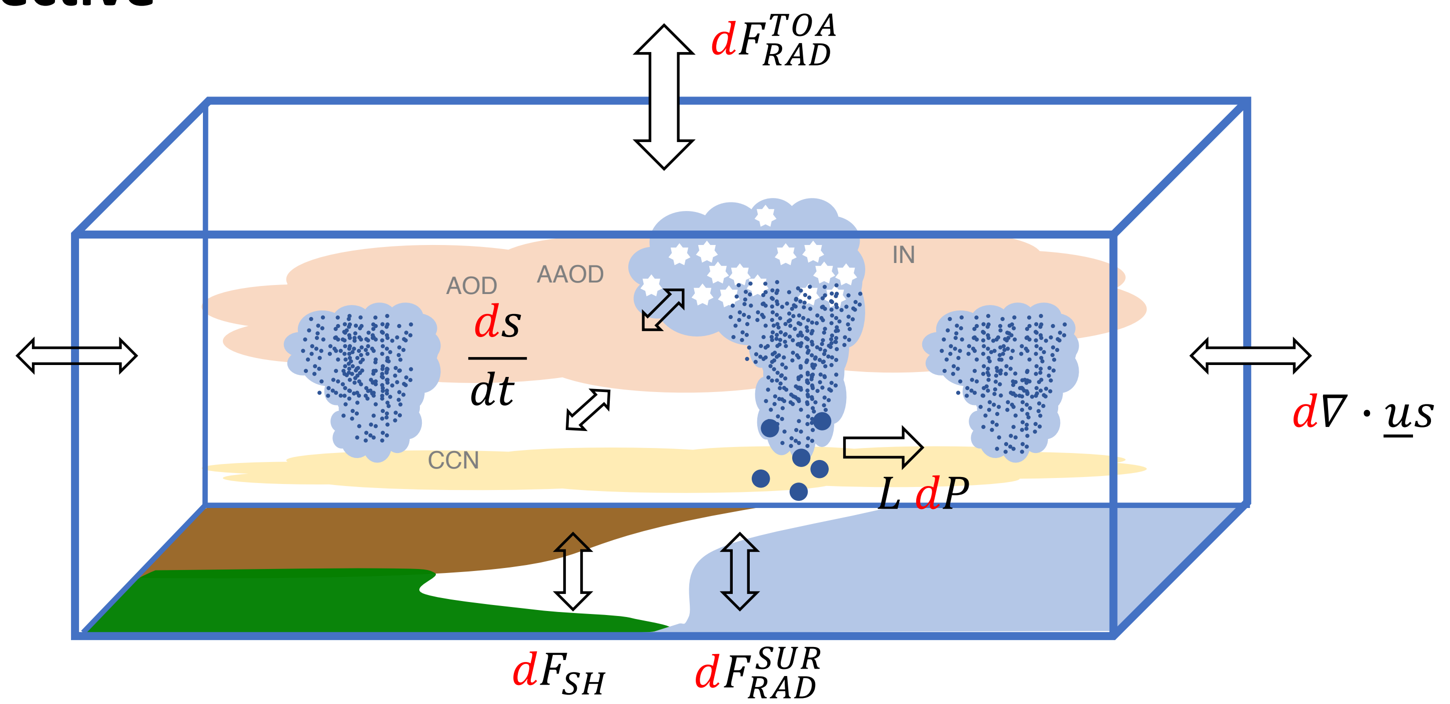
Microphysical effects



Aerosol cloud interactions via CCN and INP: on stratiform clouds, shallow convection and deep convection

Aerosol effects on precipitation

Energetic perspective



$$L\,dP = dQ + d(\nabla \cdot \underline{u}s) + \frac{ds}{dt}$$

Aerosol absorption
Aerosol cloud interactions

Latent heating | Diabatic heating | Divergence of dry static energy | Energy storage

Stier et al. (in review)
Dagan et al. (GRL, 2019a,b)
Dagan et al. (npjClimAtm, 2020)
Dagan et al. (JGR, 2021)

GEWEX Aerosol Precipitation (GAP) initiative
(Stier, van den Heever et al, in review)

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Aerosol effects on precipitation

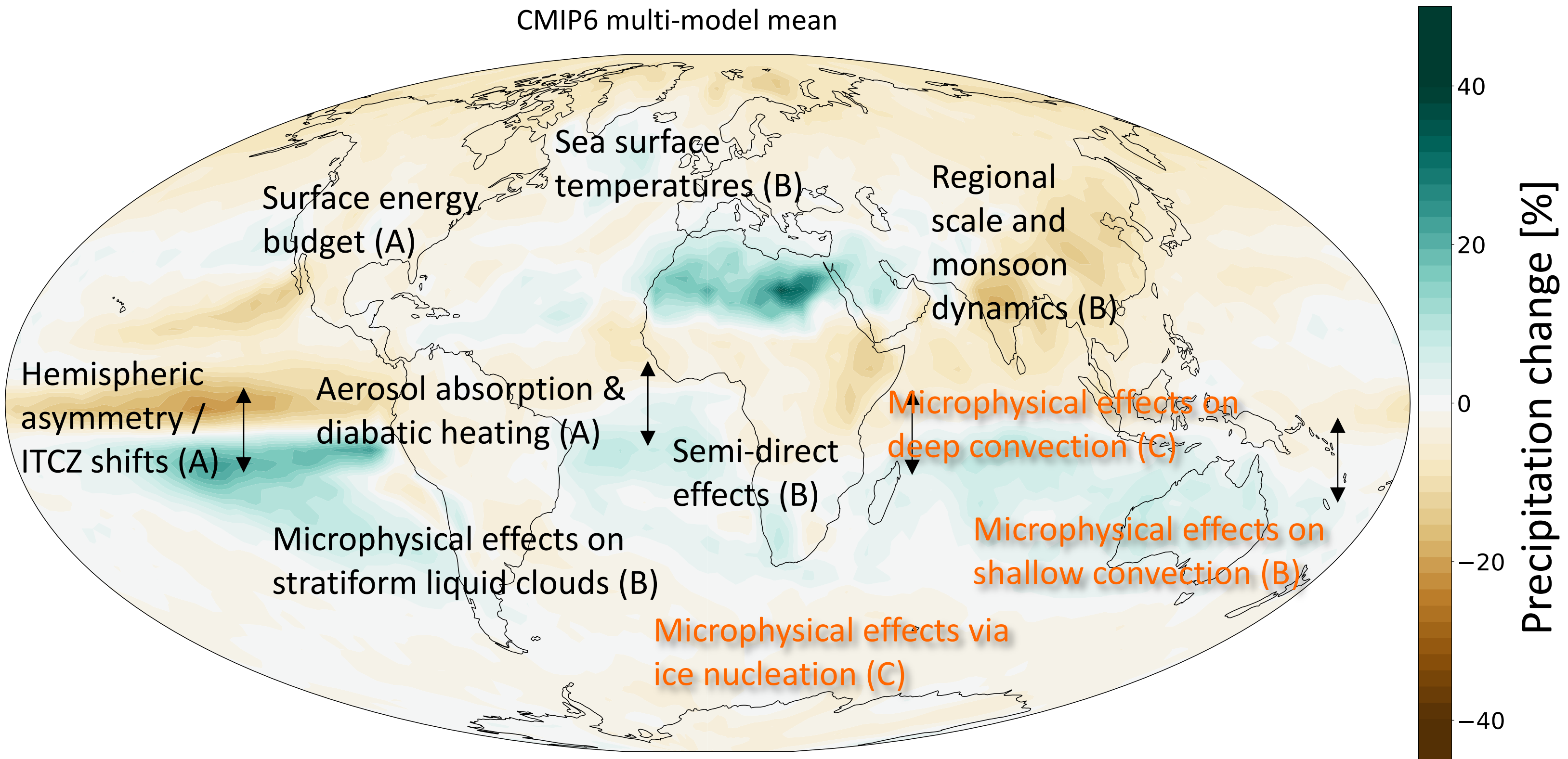
CMIP6 DAMIP effects of anthropogenic aerosols on precipitation:

Assessment:

A: strong evidence / broad consensus

B: some evidence / limited consensus

C: hypotheses / no consensus



Not currently included in CMIP GCMs

GEWEX Aerosol Precipitation (GAP) initiative

(Stier, van den Heever et al, in review)

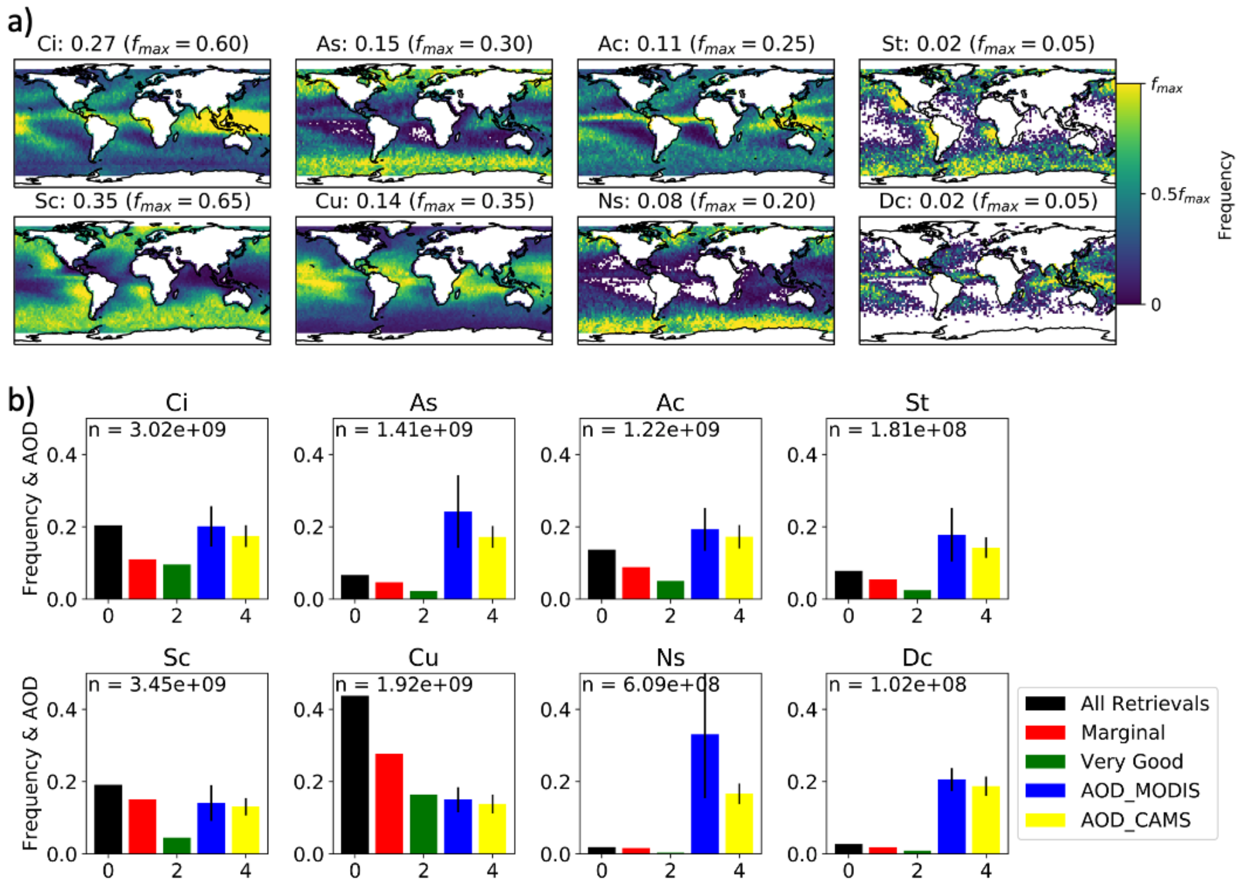
Observational evidence for aerosol effects on precipitation

Observational evidence for aerosol effects on precipitation

Regime based analysis of observational constraints:

Cloud regime in the 2B-CLDCLASS-LIDAR CloudSat product

Frequency of successful MODIS AOD retrievals and average AOD from MODIS and CAMS.



GEWEX Aerosol Precipitation (GAP) initiative

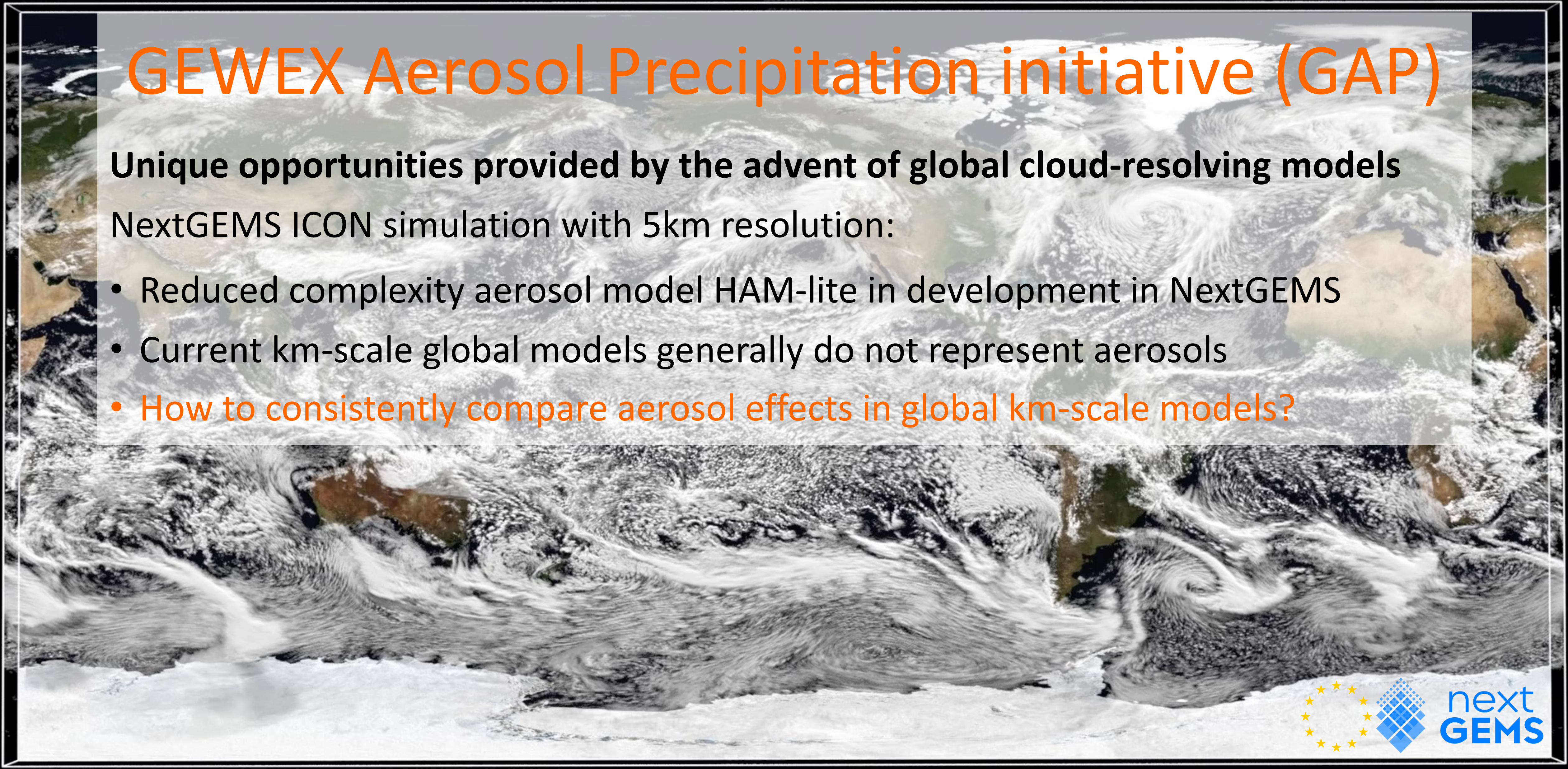
(Gryspeerdt, Christensen, Mülmenstädt et al., in prep.)

GEWEX Aerosol Precipitation initiative (GAP)

Unique opportunities provided by the advent of global cloud-resolving models

NextGEMS ICON simulation with 5km resolution:

- Reduced complexity aerosol model HAM-lite in development in NextGEMS
- Current km-scale global models generally do not represent aerosols
- How to consistently compare aerosol effects in global km-scale models?



GEWEX Aerosol Precipitation (GAP) initiative

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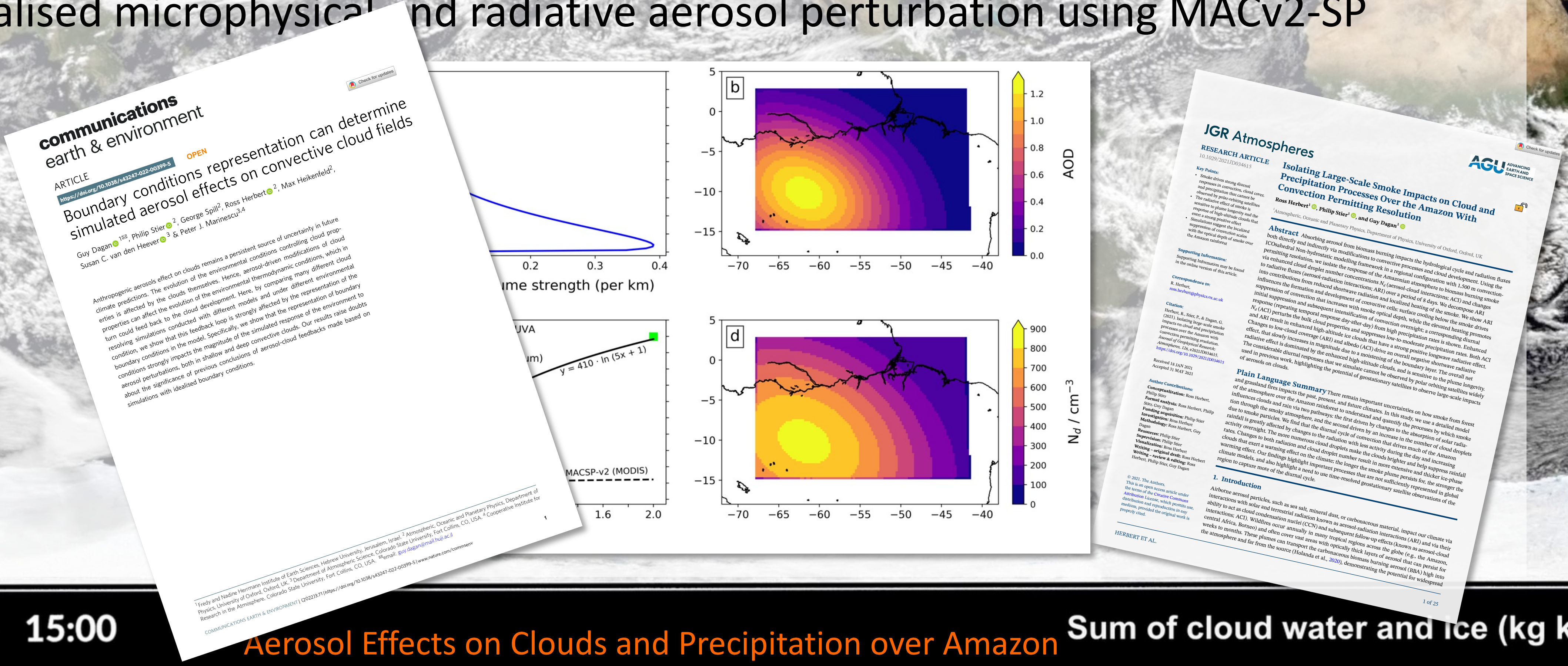
GEWEX Aerosol Precipitation initiative (GAP)

Build on our experience with large-domain regional CRM simulations

ICON CRM simulations over the Amazon (3000 x 2000 km, 1500 m resolution):

- Idealised microphysical and radiative aerosol perturbation using MACv2-SP



05/02/2020 15:00

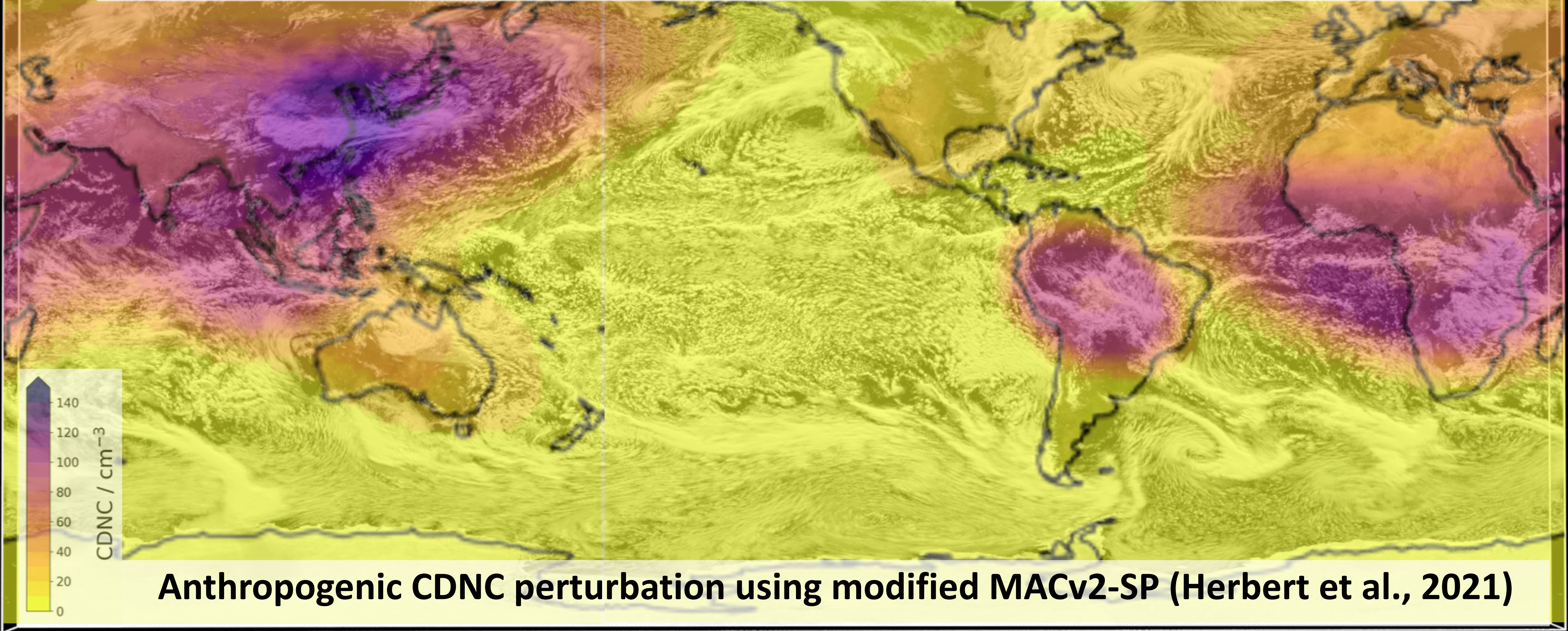
Sum of cloud water and ice (kg kg^{-1})

(C) CEN/MPI-M/UHH

Aerosol Effects on Clouds and Precipitation over Amazon

(Herbert et al., JGR, 2021; Dagan et al., Nature CommsEnv, 2022)

GEWEX Aerosol Precipitation initiative (GAP)



05/02/2020 15:00

Sum of cloud water and ice (kg kg^{-1})

(C) CEN/MPI-M/UHH

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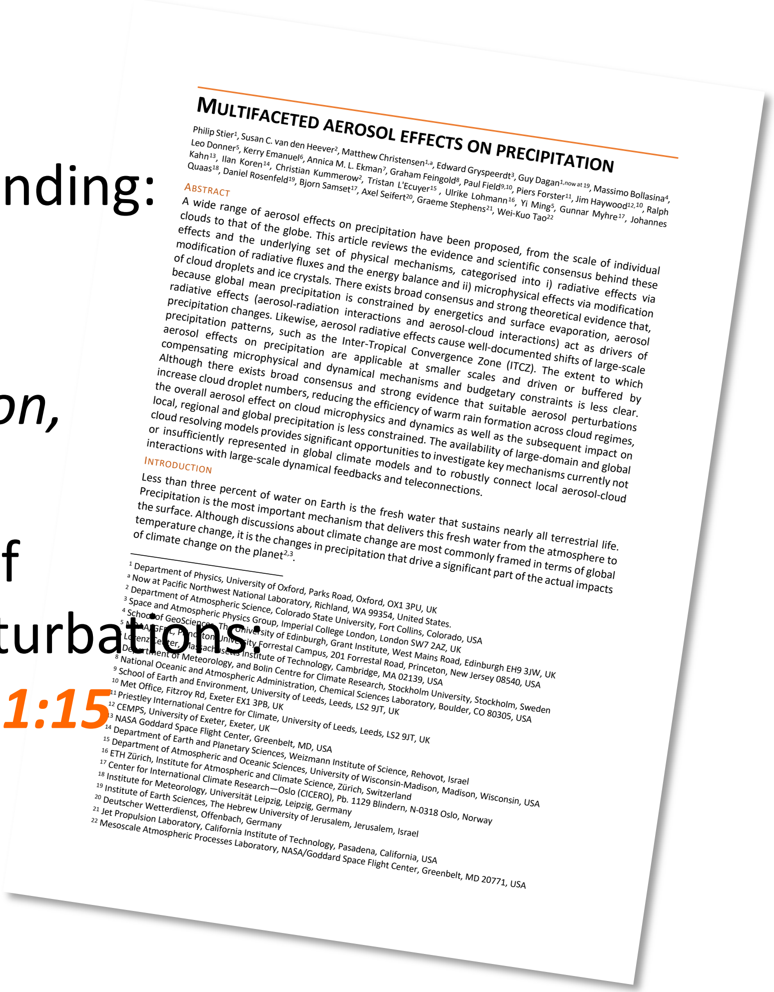
The GEWEX Aerosol Precipitation (GAP) initiative

Summary and next steps

1. Series of small expert workshops, with two publications pending:
   i) Multifaceted aerosol effects on precipitation,
   (Stier et al., Nature Geosci., in review)
   ii) Observational evidence for aerosol effects on precipitation,
   Gryspeerdt et al. (in prep.)
2. GAP initiative for global km-scale model intercomparison of aerosol effects on precipitation using idealized aerosol perturbations:
   *Presentation of first results with ICON this **Wednesday at 11:15***
3. GAP whitepaper:
   *- Breakout group this **Thursday at 11:00***
   - GASS webpage for community consultation



Multifaceted Aerosol Effects on Precipitation

Philip Stier[1], Susan C. van den Heever[2], Matthew Christensen[1,a], Edward Gryspeerdt[3], Guy Dagan[1,now at 19], Massimo Bollasina[4], Leo Donner[5], Kerry Emanuel[6], Annica M. L. Ekman[7], Graham Feingold[8], Paul Field[9,10], Piers Forster[11], Jim Haywood[12,10], Ralph Kahn[13], Ilan Koren[14], Christian Kummerow[2], Tristan L'Ecuyer[15], Ulrike Lohmann[16], Yi Ming[5], Gunnar Myhre[17], Johannes Quaas[18], Daniel Rosenfeld[19], Bjorn Samset[17], Axel Seifert[20], Graeme Stephens[21], Wei-Kuo Tao[22]

Abstract

A wide range of aerosol effects on precipitation have been proposed, from the scale of individual clouds to that of the globe. This article reviews the evidence and scientific consensus behind these effects and the underlying set of physical mechanisms, categorised into i) radiative effects via modification of radiative fluxes and the energy balance and ii) microphysical effects via modification of cloud droplets and ice crystals. There exists broad consensus and strong theoretical evidence that, because global mean precipitation is constrained by energetics and surface evaporation, aerosol radiative effects (aerosol-radiation interactions and aerosol-cloud interactions) act as drivers of precipitation changes. Likewise, aerosol radiative effects cause well-documented shifts of large-scale precipitation patterns, such as the Inter-Tropical Convergence Zone (ITCZ). The extent to which aerosol effects on precipitation are applicable at smaller scales and driven or buffered by compensating microphysical and dynamical mechanisms and budgetary constraints is less clear. Although there exists broad consensus and strong evidence that suitable aerosol perturbations increase cloud droplet numbers, reducing the efficiency of warm rain formation across cloud regimes, the overall aerosol effect on cloud microphysics and dynamics as well as the subsequent impact on local, regional and global precipitation is less constrained. The availability of large-domain and global cloud resolving models provides significant opportunities to investigate key mechanisms currently not or insufficiently represented in global climate models and to robustly connect local aerosol-cloud interactions with large-scale dynamical feedbacks and teleconnections.

Introduction

Less than three percent of water on Earth is the fresh water that sustains nearly all terrestrial life. Precipitation is the most important mechanism that delivers this fresh water from the atmosphere to the surface. Although discussions about climate change are most commonly framed in terms of global temperature change, it is the changes in precipitation that drive a significant part of the actual impacts of climate change on the planet[2,3].

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