

# 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)

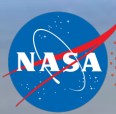
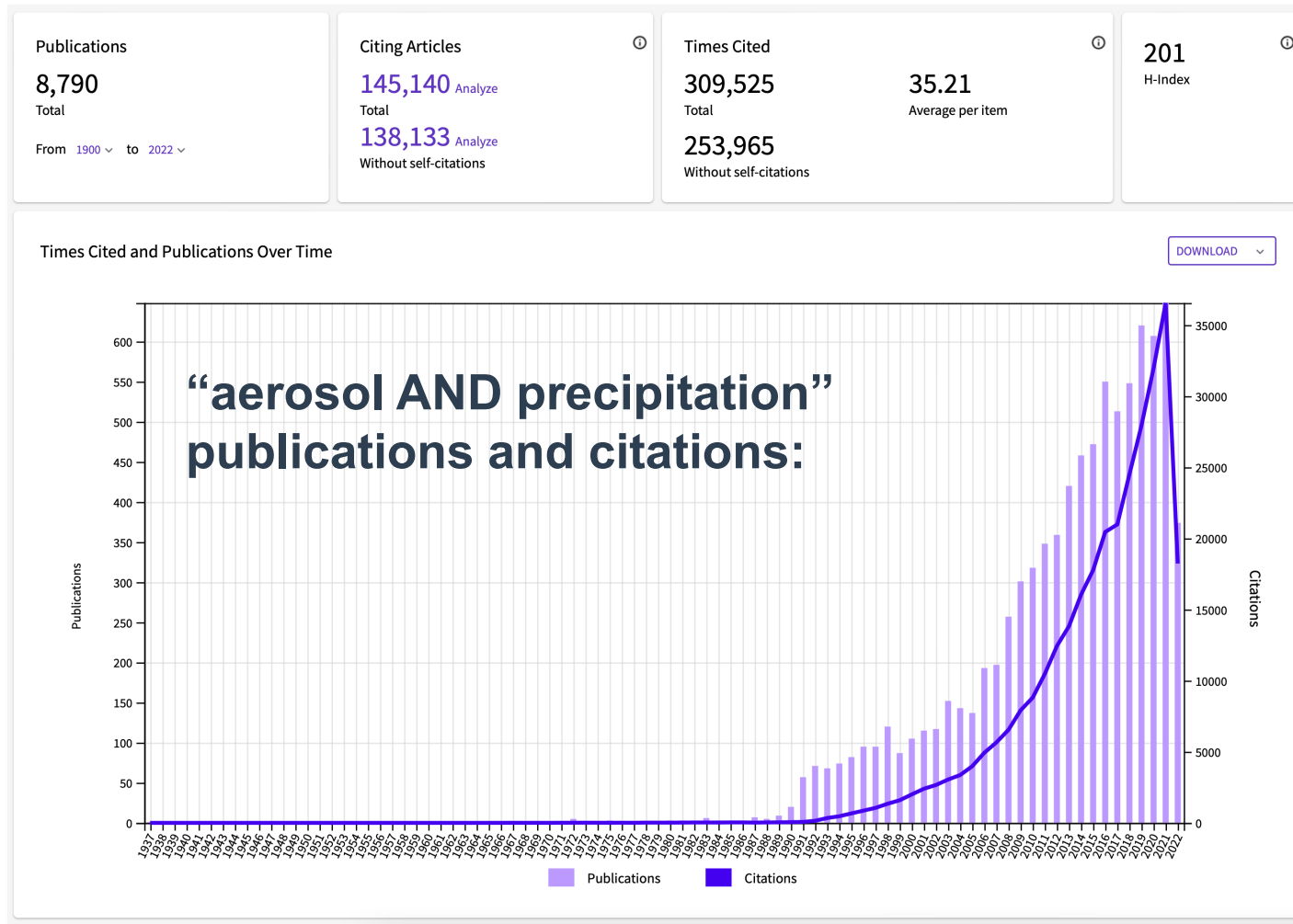


**GEWEX Aerosol Precipitation (GAP) initiative**

Co-chairs: Sue van den Heever & Philip Stier



# Do aerosols affect precipitation?



GEWEX Aerosol Precipitation (GAP) initiative

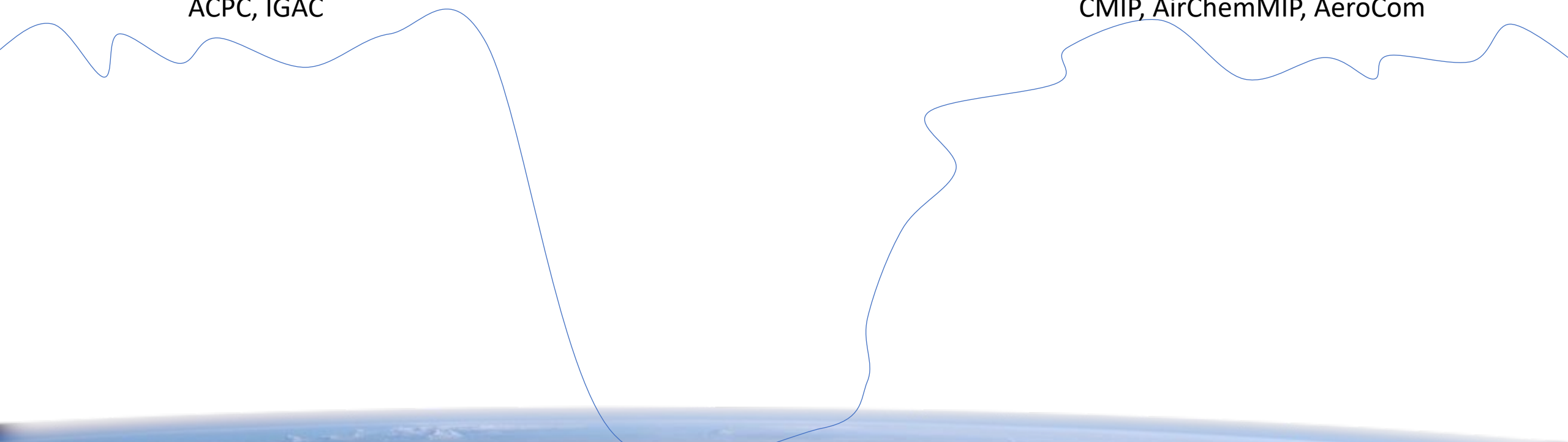
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# Do aerosols affect precipitation?

Process studies:  
ACPC, IGAC

Climate simulations:  
CMIP, AirChemMIP, AeroCom



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# Do aerosols affect precipitation?

Process studies:  
ACPC, IGAC



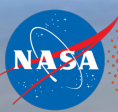
GASS

Climate simulations:  
CMIP, AirChemMIP, AeroCom



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# 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

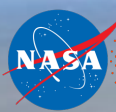


# Aerosol Effects on Precipitation

Do aerosols affect precipitation and if, how?



From the left: Sue van den Heever, Philip Stier, Graham Feingold, Graeme Stephens, Ralph Kahn, Tristan L'Ecuyer, Massimo Bolassina, Bjorn Samset, Gunnar Myhre, Ulrike Lohmann, Johannes Quaas, Annica Ekman, Heike Langenberg, Leo Donner, Matthew Christensen, Danny Rosenfeld, Axel Seifert, Kerry Emanuel, Paul Field, Christian Kummerow, Ed Gryspeerdt, Wei-kuo Tao, Jim Haywood, Ilan Koren, Yi Ming.



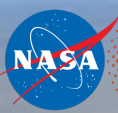
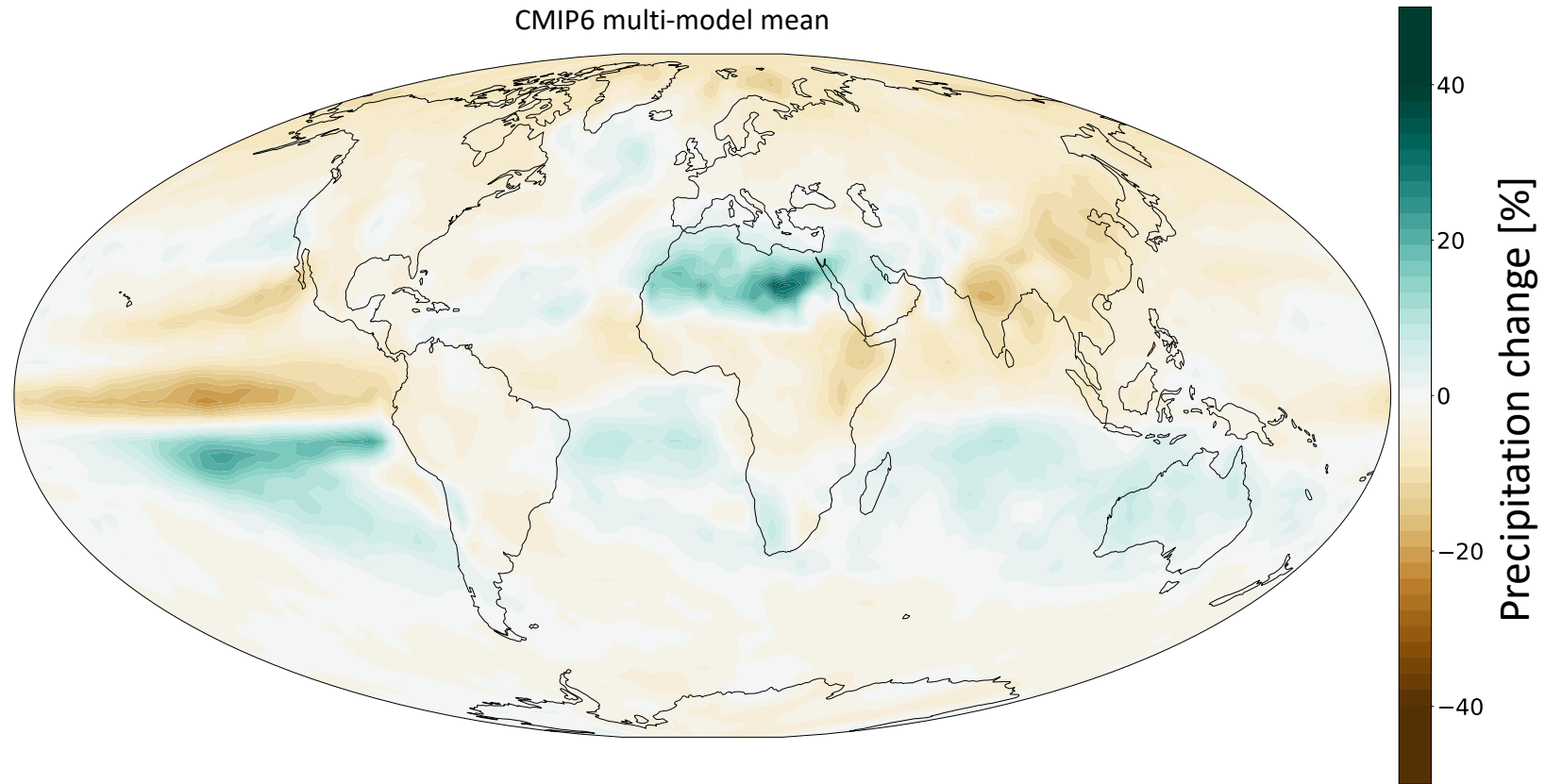
**GEWEX Aerosol Precipitation (GAP) initiative**

(GAP Expert Workshop, Oxford, 2017)



# Aerosol effects on precipitation

CMIP6 DAMIP effects of anthropogenic aerosols on precipitation:

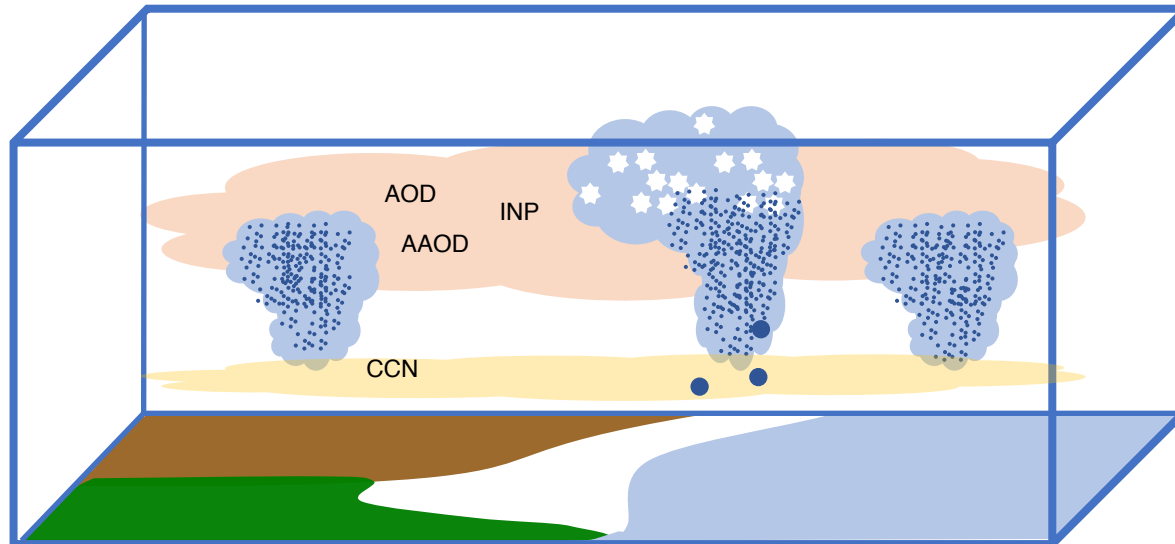


GEWEX Aerosol Precipitation (GAP) initiative  
(Stier, van den Heever et al, in review)





# Aerosol effects on precipitation

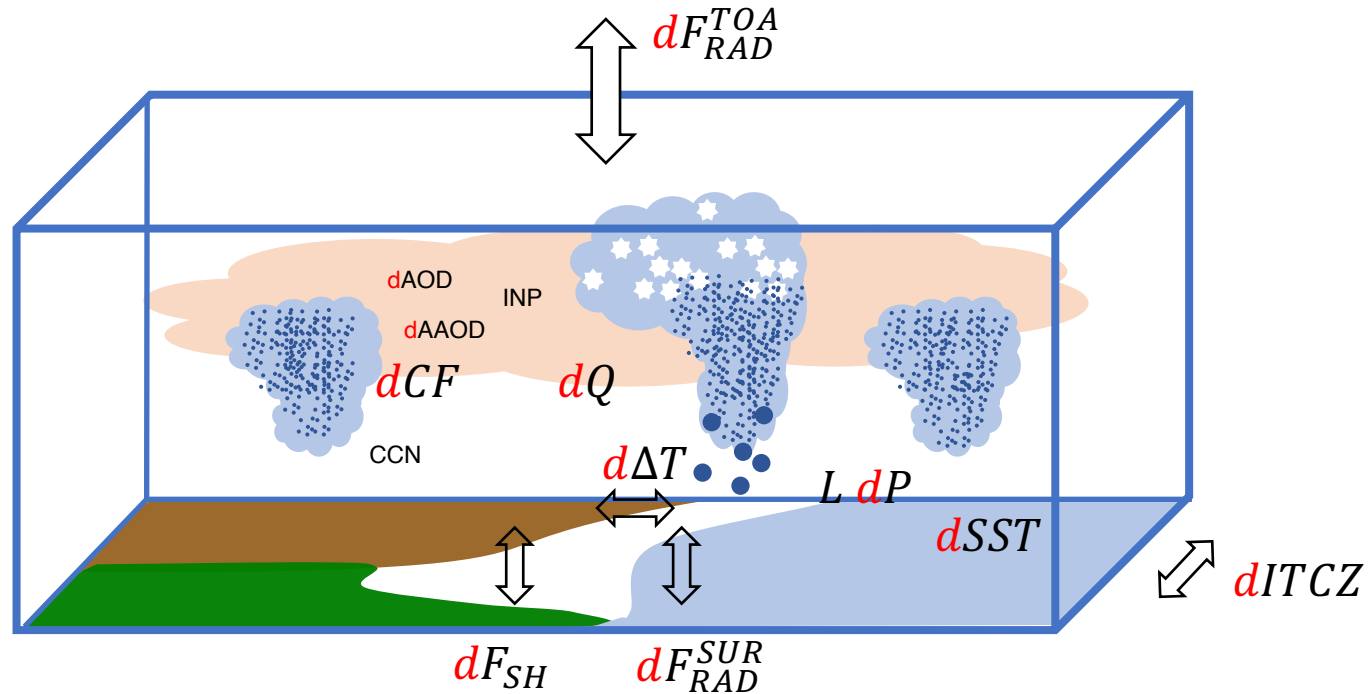


GEWEX Aerosol Precipitation (GAP) initiative  
(Stier, van den Heever et al, in review)



# 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.

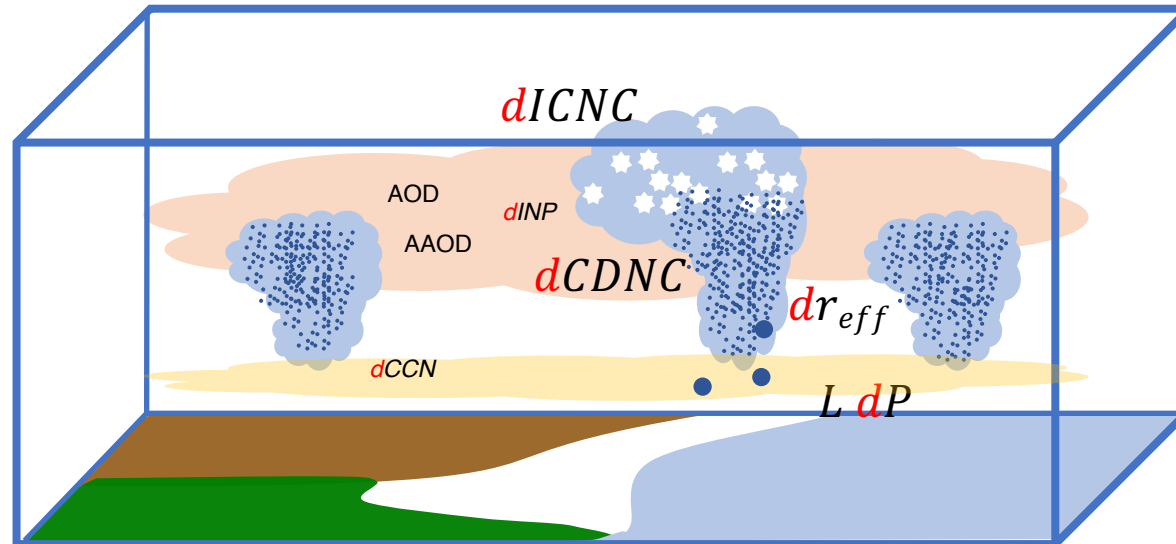


GEWEX Aerosol Precipitation (GAP) initiative  
(Stier, van den Heever et al, in review)

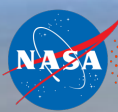


# Aerosol effects on precipitation

## Microphysical effects



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

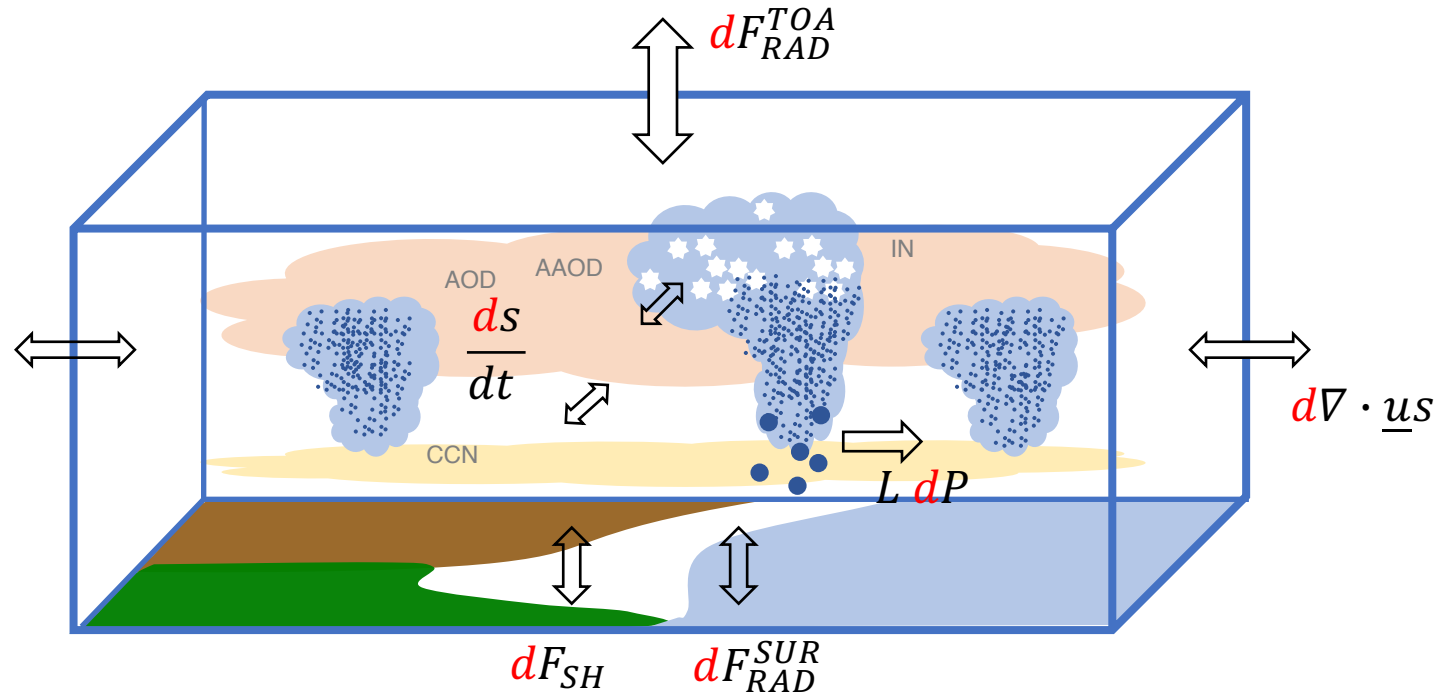


GEWEX Aerosol Precipitation (GAP) initiative  
(Stier, van den Heever et al, in review)



# 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

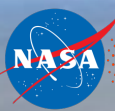
Diabatic heating

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)

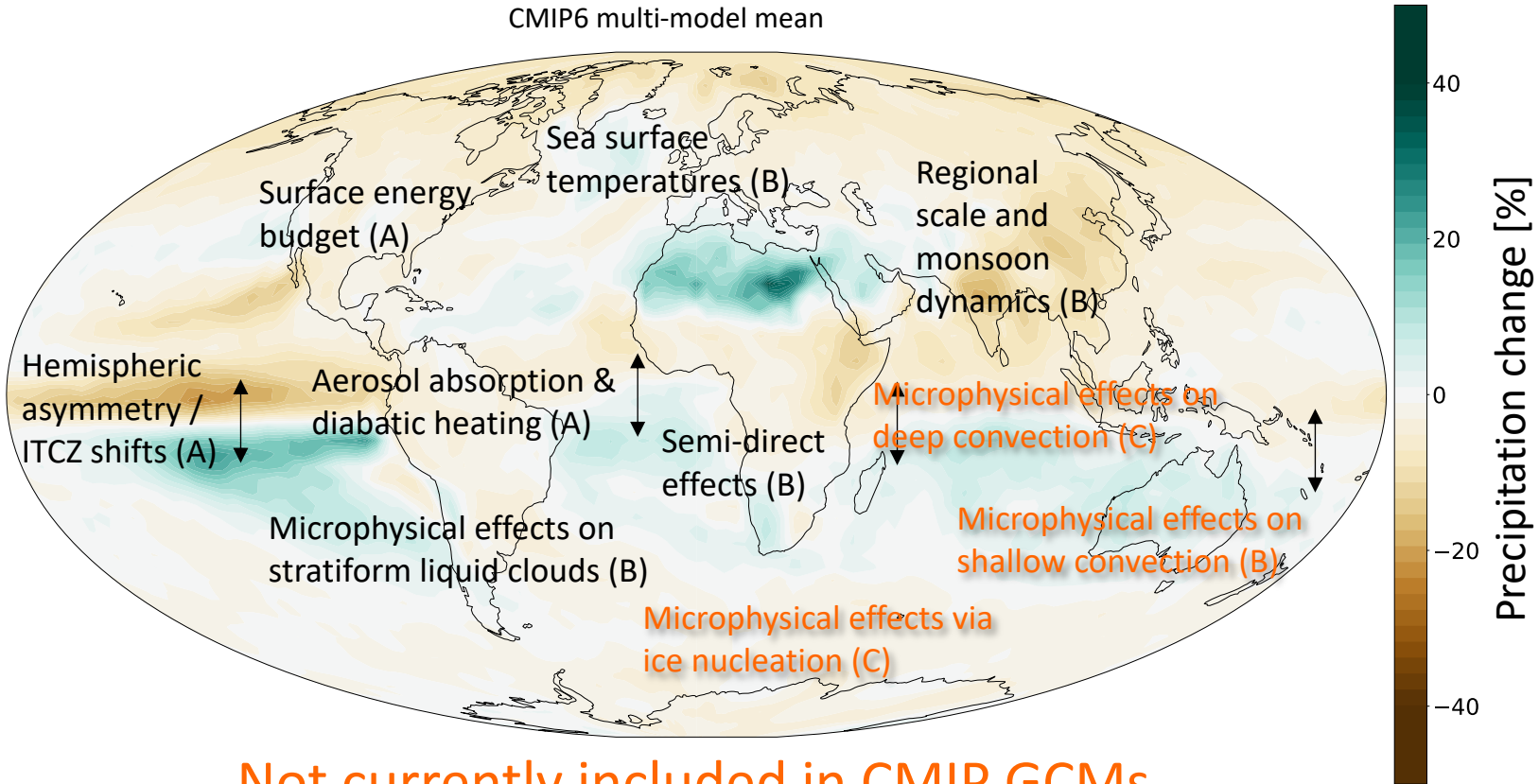


# Aerosol effects on precipitation

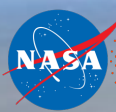
CMIP6 DAMIP effects of anthropogenic aerosols on precipitation:

## 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)

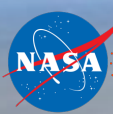


# Observational evidence for aerosol effects on precipitation

What is the observational evidence for aerosol effects on precipitation?



From the left: Graeme Stephens, Tristan L'Ecuyer, Andrew Gettelman, Rob Wood, Philip Stier, Sue van den Heever, Kentä Suzuki, Matt Christensen, Ed Gryspeerd, Johannes Mülmenstädt



**GEWEX Aerosol Precipitation (GAP) initiative**

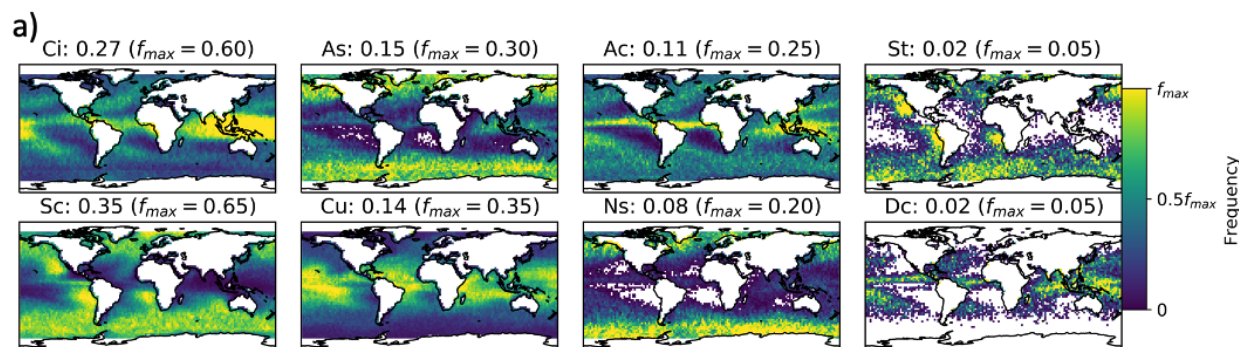
(GAP Expert Workshop, Oxford, 2019)



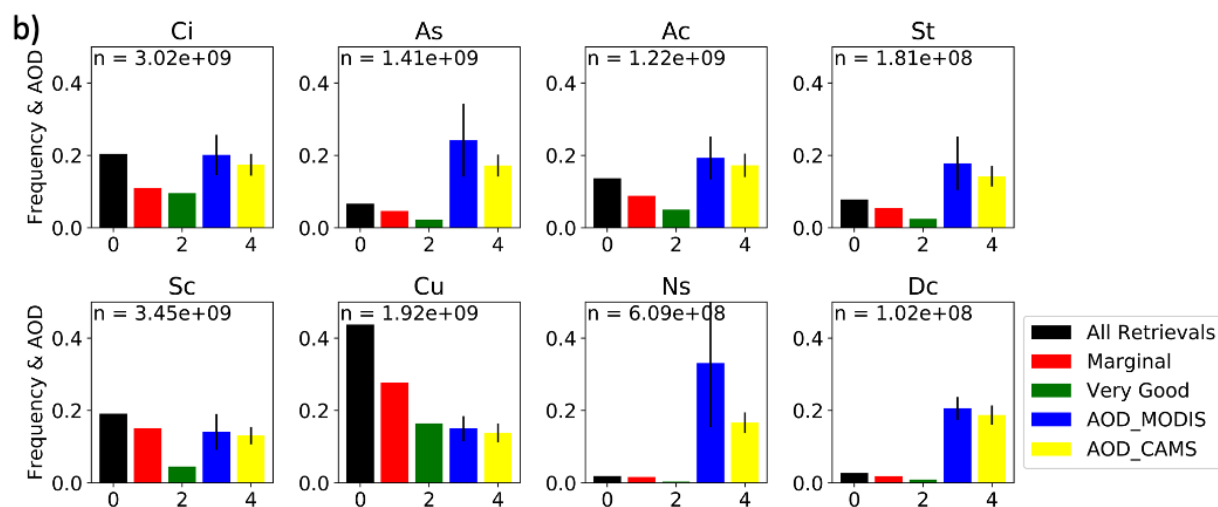
# Observational evidence for aerosol effects on precipitation

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 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?



05/02/2020 15:00

GEWEX Aerosol Precipitation (GAP) initiative

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

Co-chairs: Sue van den Heever & Philip Stier

(C) CEN/MPI-M/UHH



# 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):

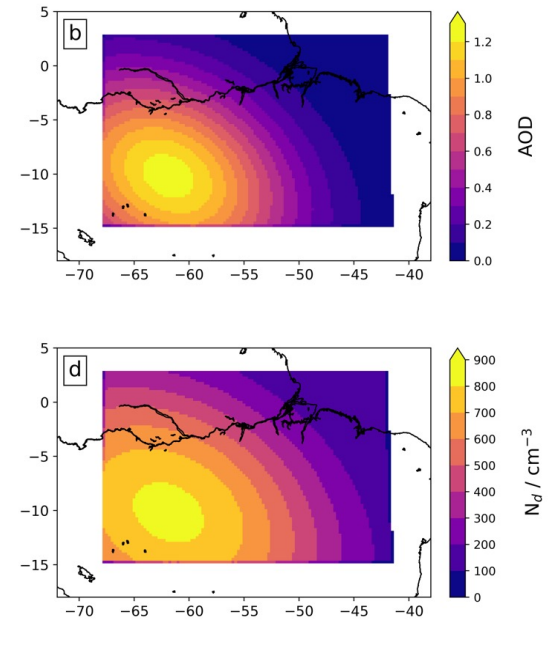
- Idealised microphysical and radiative aerosol perturbation using MACv2-SP

**communications earth & environment**  
 ARTICLE  
<https://doi.org/10.1038/s43247-022-00397-5> OPEN  
**Boundary conditions representation can determine simulated aerosol effects on convective cloud fields**  
 Guy Dagan<sup>1</sup>, Philip Stier<sup>2</sup>, George Spill<sup>2</sup>, Ross Herbert<sup>2</sup>, Max Heikenfeld<sup>2</sup>, Susan C. van den Heever<sup>3</sup> & Peter J. Marquis<sup>2,4</sup>

Anthropogenic aerosols effect on clouds remains a persistent source of uncertainty in future climate predictions. The evolution of the environmental conditions controlling cloud properties is affected by the evolution of the environment. Hence, aerosol-driven modifications which can affect the evolution of the environment and aerodynamic conditions, which in turn could lead back to the cloud development. Here, by comparing many different model setups, we show that this feedback loop is strongly affected by the representation of boundary conditions in the model. Specifically, we show that the representation of boundary conditions strongly impacts the magnitude of the simulated response of the environment to aerosol perturbations, both in the shallow and deep convective clouds. Our results raise doubts about the significance of previous conclusions of aerosol-cloud feedbacks made based on simulations with idealised boundary conditions.

1. Freely and Nadine Herberichs Institute of Earth Sciences, Hebrew University, Jerusalem, Israel; 2. Atmospheric, Oceanic and Planetary Physics, Department of Physics, University of Oxford, Oxford, UK; 3. Department of Atmospheric Science, Colorado State University, Fort Collins, CO, USA; 4. Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, CO, USA. \*Email: guy.dagan@huji.ac.il

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**JGR Atmospheres**  
 RESEARCH ARTICLE  
 10.1029/2021JD003615  
**Isolating Large-Scale Smoke Impacts on Cloud and Convection Permitting Resolution**  
 Ross Herbert<sup>1</sup>, Philip Stier<sup>2</sup>, and Guy Dagan<sup>3</sup>

**Abstract**  
 Absorbing aerosol from biomass burning impacts the hydrological cycle and radiation fluxes in a regional configuration with 1,500 m vertical resolution. We isolate the impact of the Amazonian atmosphere to biomass burning smoke on radiative fluxes (net shortwave radiation, NSWR) and convection (precipitation, P) using a regional configuration with 1,500 m vertical resolution. We isolate the impact of the Amazonian atmosphere to biomass burning smoke on radiative fluxes (net shortwave radiation, NSWR) and convection (precipitation, P) using a regional configuration with 1,500 m vertical resolution. We isolate the impact of the Amazonian atmosphere to biomass burning smoke on radiative fluxes (net shortwave radiation, NSWR) and convection (precipitation, P) using a regional configuration with 1,500 m vertical resolution.

**Plain Language Summary**  
 This study presents important uncertainties on how smoke from forest fires impacts the Amazon rainforest. In this study, we use a detailed model to investigate the impact of smoke on the Amazon rainforest. We find that the impact of smoke on the Amazon rainforest is not as simple as it seems. Smoke can have both cooling and warming effects on the Amazon rainforest. The cooling effect is due to the absorption of solar radiation by smoke particles. The warming effect is due to the absorption of longwave radiation by smoke particles. The warming effect is due to the absorption of longwave radiation by smoke particles.

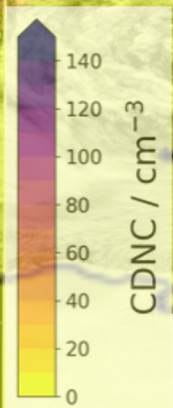
**1. Introduction**  
 Airborne aerosol particles, such as sea salt, mineral dust, or carbonaceous material, impact our climate via their ability to act as cloud condensation nuclei (CCN) and subsequent droplet activation (ADA) and via their ability to scatter and absorb solar radiation. Aerosols also impact the Earth's energy budget via their ability to scatter and absorb solar radiation. Aerosols also impact the Earth's energy budget via their ability to scatter and absorb solar radiation.

HERBERT ET AL.

05/02/2020 15:00

Aerosol Effects on Clouds and Precipitation over Amazon Sum of cloud water and ice ( $\text{kg kg}^{-1}$ )  
 (Herbert et al., JGR, 2021; Dagan et al., Nature CommsEnv, 2022) (C) CEN/MPI-M/UHH

# GEWEX Aerosol Precipitation initiative (GAP)



Anthropogenic CDNC perturbation using modified MACv2-SP (Herbert et al., 2021)

05/02/2020 15:00

GEWEX Aerosol Precipitation (GAP) initiative

Co-chairs: Sue van den Heever & Philip Stier

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

(C) CEN/MPI-M/UHH

# 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<sup>1</sup>, Susan C. van den Heever<sup>2</sup>, Matthew Christensen<sup>3</sup>, Edward Gryspeerdt<sup>4</sup>, Guy Dagian<sup>5,6,7,8,9,10</sup>, Massimo Bollasina<sup>11</sup>, Leo Donner<sup>12</sup>, Kerry Emanuel<sup>13</sup>, Annica M.L. Ekman<sup>14</sup>, Graham Feingold<sup>15</sup>, Paul Field<sup>16</sup>, Piers Forster<sup>17</sup>, Jim Haywood<sup>18,19</sup>, Ralph Kahn<sup>20</sup>, Han Koren<sup>21</sup>, Christian Sommerow<sup>22</sup>, Tristan L'Ecuyer<sup>23</sup>, Ulrike Lohmann<sup>24</sup>, Yi Wang<sup>25</sup>, Gunnar Myhre<sup>26</sup>, Ralph Quaka<sup>27</sup>, Daniel Rosenfeld<sup>28</sup>, Bjorn Samset<sup>29</sup>, Axel Selner<sup>30</sup>, Graeme Stephens<sup>31</sup>, Wei-Kuo Tao<sup>32</sup>

#### 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 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, 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<sup>1</sup>.

<sup>1</sup> Department of Physics, University of Oxford, Parks Road, Oxford, OX1 3PU, UK  
<sup>2</sup> Now at Pacific Northwest National Laboratory, Richland, WA 99354, United States  
<sup>3</sup> Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado, USA  
<sup>4</sup> Space and Atmospheric Physics Group, Imperial College London, London SW2 2AZ, UK  
<sup>5</sup> School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, Georgia, USA  
<sup>6</sup> School of Earth and Atmospheric Sciences, 201 Forrestal Road, Edinburgh EH9 3JW, UK  
<sup>7</sup> National Oceanic and Atmospheric Administration, Grant Institute, West Mains Road, Princeton, New Jersey 08540, USA  
<sup>8</sup> National Oceanic and Atmospheric Administration, Chemical Sciences Laboratory, Boulder, CO 80505, USA  
<sup>9</sup> School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK  
<sup>10</sup> Met Office, Fitzroy Rd, Exeter, EX1 3PB, UK  
<sup>11</sup> Priestley International Centre for Climate, University of Leeds, Leeds, LS2 9JT, UK  
<sup>12</sup> CEMPS, University of Exeter, Exeter, UK  
<sup>13</sup> NASA Goddard Space Flight Center, University of Leeds, Leeds, LS2 9JT, UK  
<sup>14</sup> Department of Earth and Planetary Sciences, Greenbelt, MD, USA  
<sup>15</sup> ETH Zürich, Institute for Atmospheric and Oceanic Sciences, Weizmann Institute of Science, Rehovot, Israel  
<sup>16</sup> Center for International Climate Research, University of Wisconsin-Madison, Madison, Wisconsin, USA  
<sup>17</sup> Institute for Earth System Research—Oslo (IESR), Oslo, Norway  
<sup>18</sup> Institute of Earth Sciences, University of Leipzig, Leipzig, Germany  
<sup>19</sup> Deutscher Wetterdienst, Offenbach, Germany  
<sup>20</sup> Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA  
<sup>21</sup> Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA  
<sup>22</sup> Mesoscale Atmospheric Processes Laboratory, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, USA