18th AeroCOM Workshop/7th AeroSAT workshop

Cloud water adjustment to aerosol perturbation

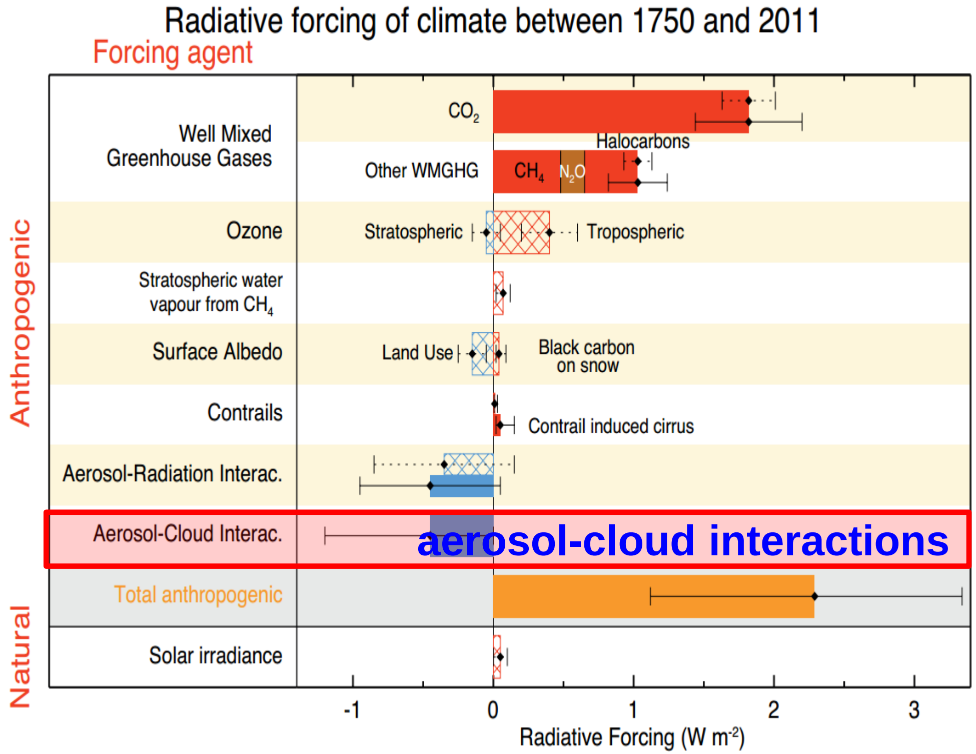
Minghuai Wang, Zhoukun Liu, Chongxing Fan

School of Atmospheric Sciences, Nanjing University

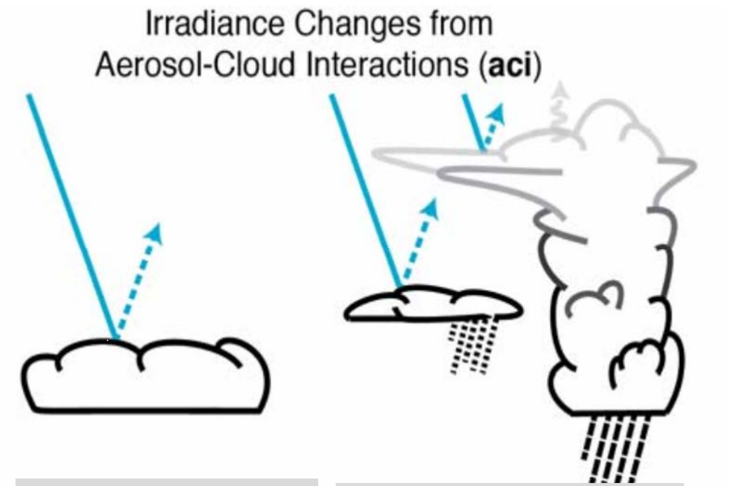
09/25/2019

南京大學
NANJING UNIVERSITY

Large uncertainties remain for radiative forcing from aerosol-cloud interactions



aerosol-cloud interactions



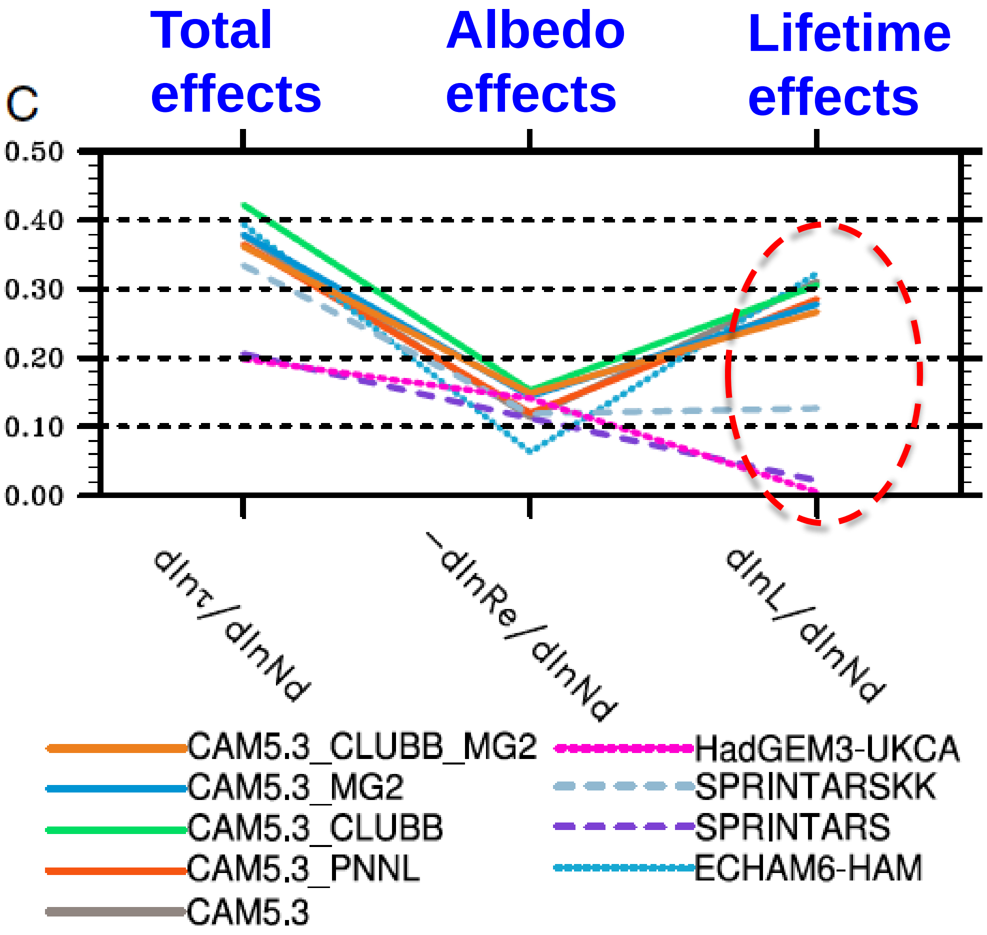
Cloud albedo effects

Cloud lifetime effects

Aerosol-cloud interactions

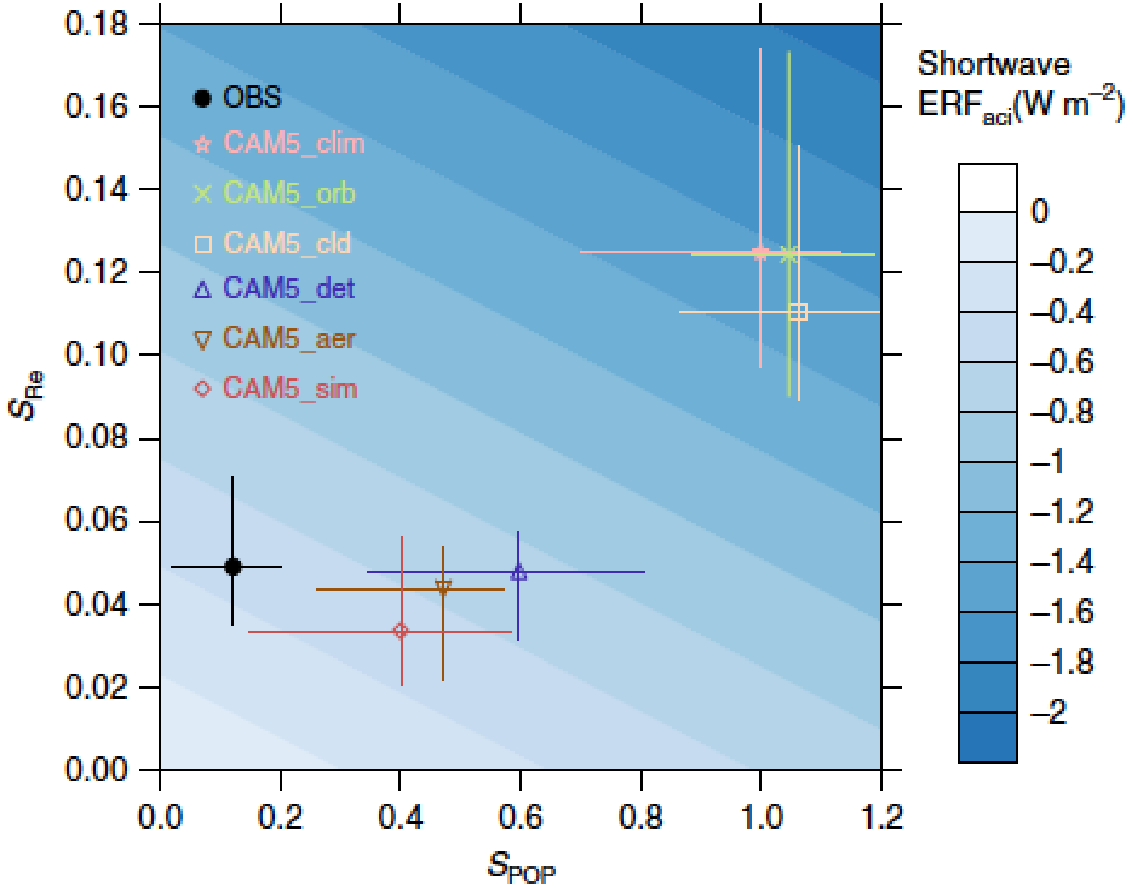
IPCC AR5

Cloud water response to aerosols often dominate uncertainties in aerosol-cloud radiative forcing



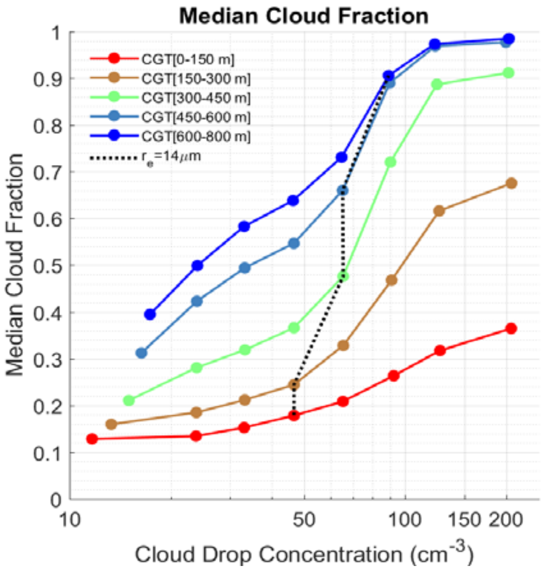
S. Ghan, et al., 2016, PNAS

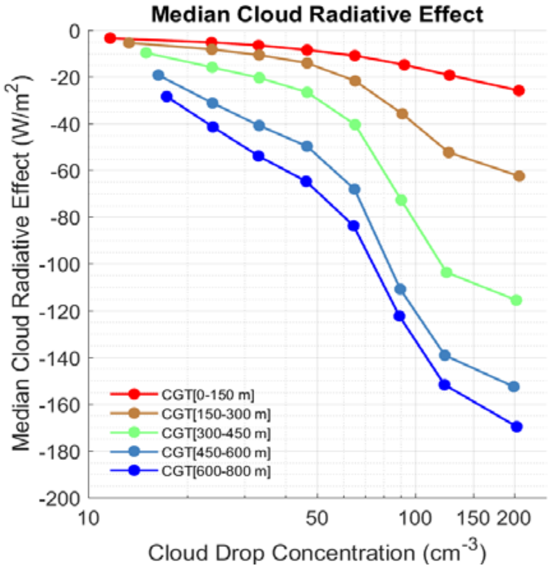
Using AOD as CCN proxy may underestimate cloud susceptibility to aerosols

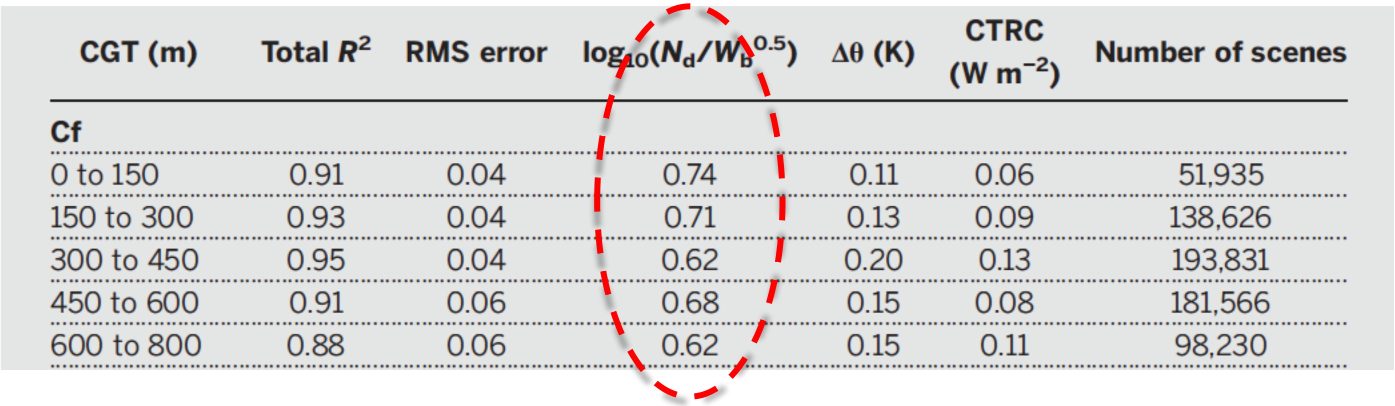


Ma et al., 2018, Nat Commun

Strong dependence of cloud amount on cloud droplet concentrations





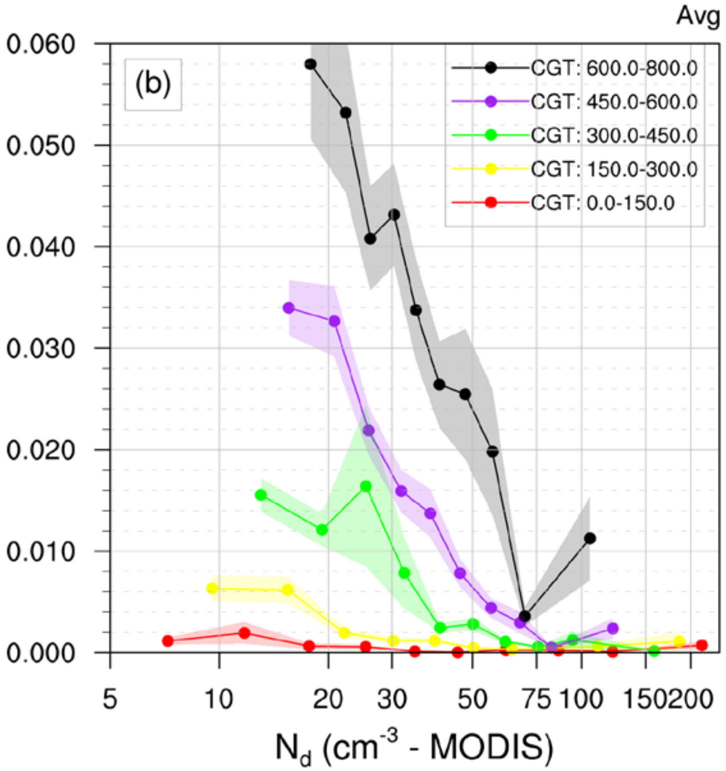


CGT (m)	Total R^2	RMS error	$\log_{10}(N_d/W_b^{0.5})$	Δθ (K)	CTRC ($W\ m^{-2}$)	Number of scenes
Cf						
0 to 150	0.91	0.04	0.74	0.11	0.06	51,935
150 to 300	0.93	0.04	0.71	0.13	0.09	138,626
300 to 450	0.95	0.04	0.62	0.20	0.13	193,831
450 to 600	0.91	0.06	0.68	0.15	0.08	181,566
600 to 800	0.88	0.06	0.62	0.15	0.11	98,230

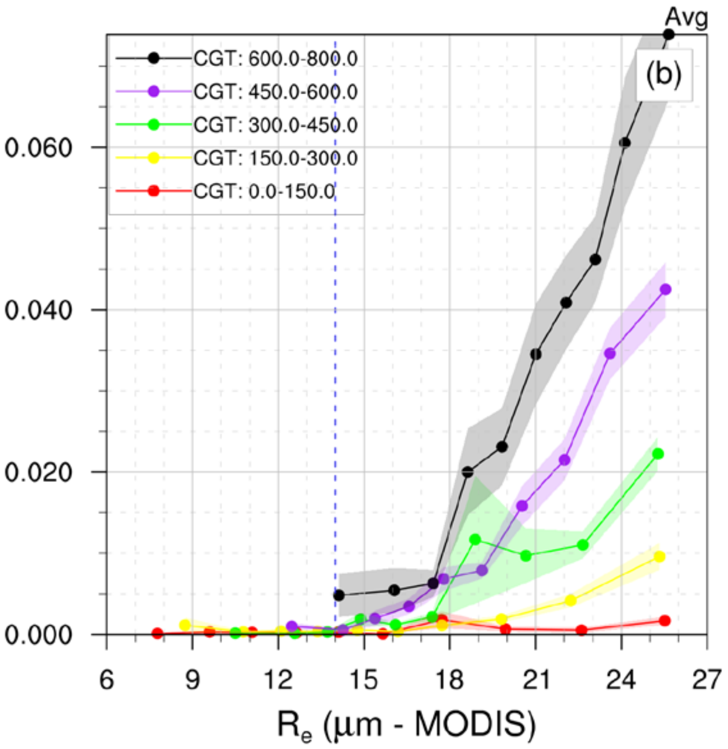
Rosenfeld et al., 2019, Science

Strong precipitation suppression by aerosols in marine low clouds

Rain rate (mm/h, GPM DPR)



Rain rate (mm/h, GPM DPR)

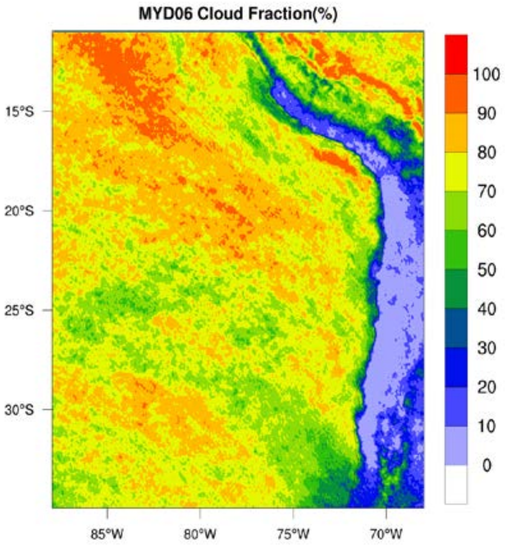


Fan et al., to be submitted

- Precipitation initiates at Re=14 um

WRF-Chem simulation of low clouds over Southeast Pacific（VOCALS Rex, 2008)

MODIS cloud amount



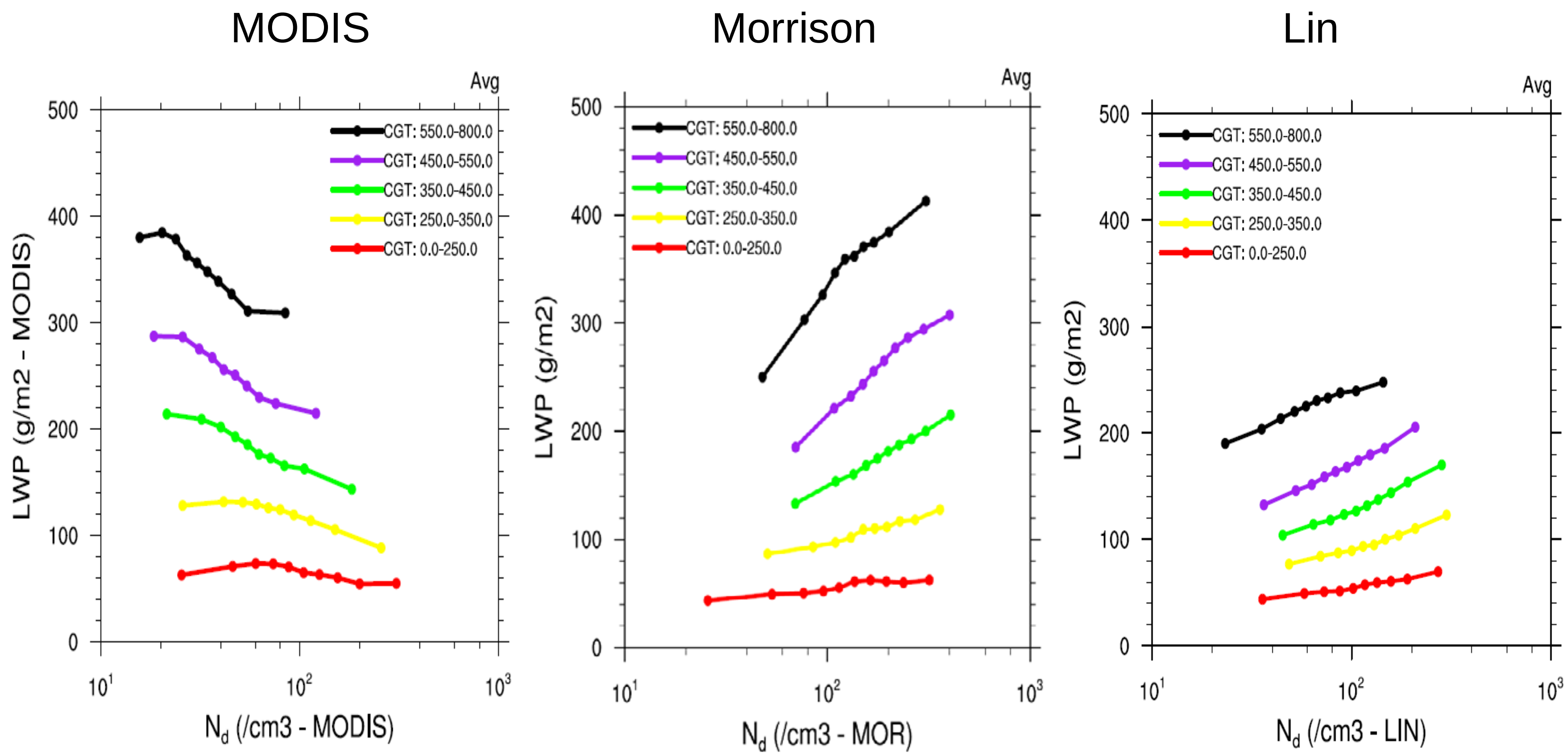
Time:
Oct.15~Nov.15,2008

Region: 11° ~34° S (287)
68° ~88° W (218)

WRF-Chem model configuration

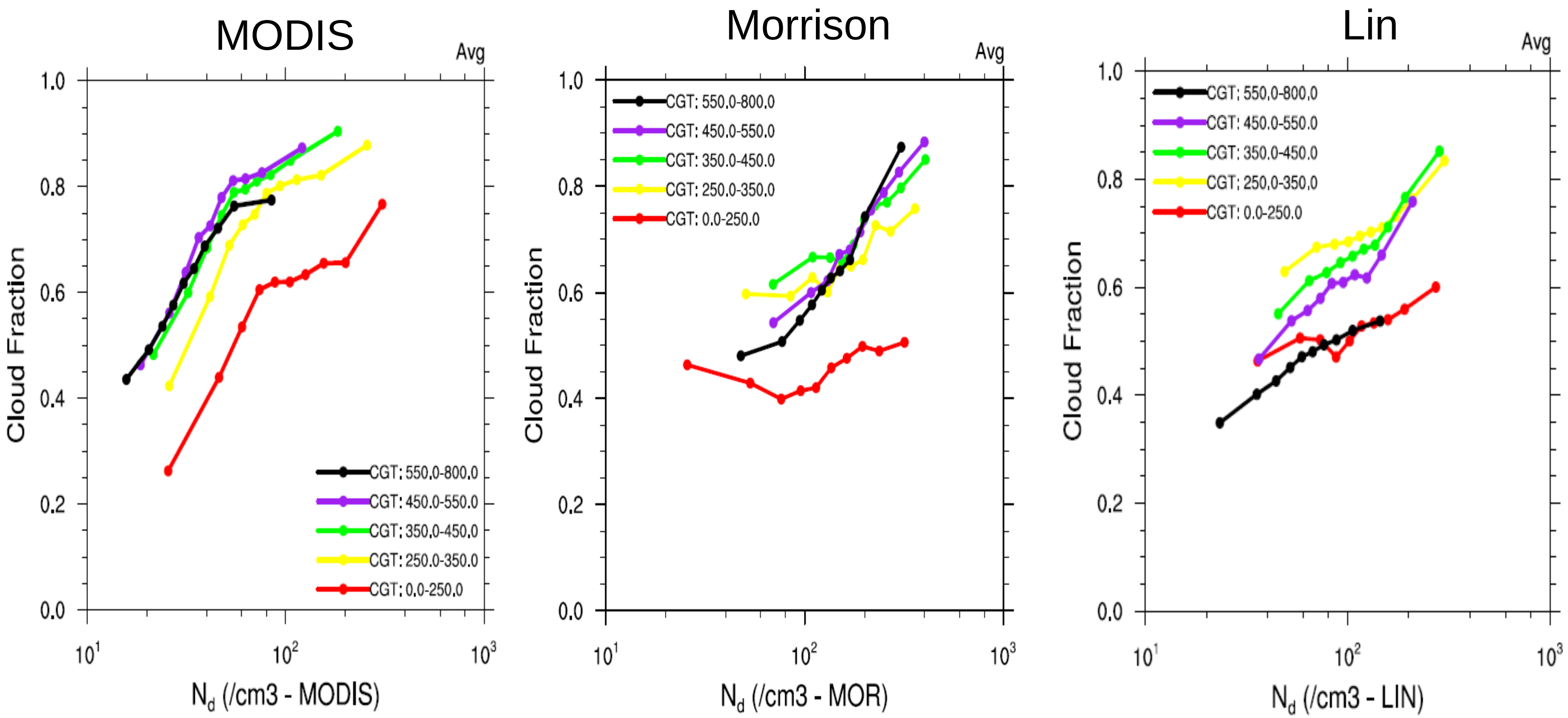
Vertical layer	74
Horizontal resolution	9 km
Longwave radiation	RRTM
Shortwave radiation	Goddard
Surface layer	MM5 similarity theory
Land surface	Noah
Boundary layer	YSU
Deep and shallow cumulus clouds	Turned off
Cloud microphysics	Morrison/Lin
Gas phase chemistry	CBM-Z with DMS reactions
Aerosol chemistry	8-bin MOSAIC
Photolysis	Madronich
Aerosol direct & semi-direct effects	Turned on

In-cloud LWP as a function of cloud droplet number concentrations



- LWP decreases with Nc in observations, but increases with Nc in simulations (Morrison > Lin)

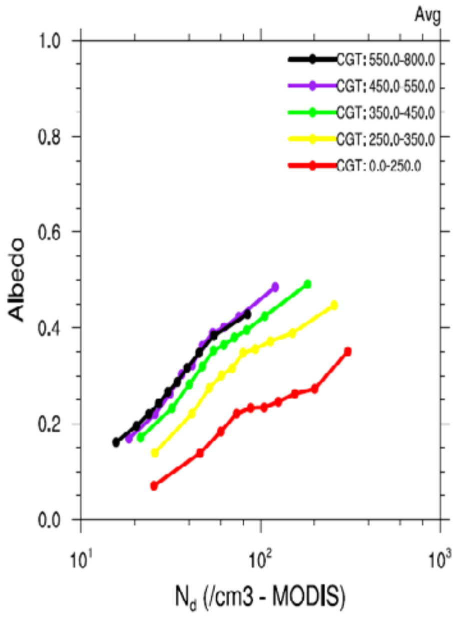
Cloud fraction as a function of cloud droplet number concentrations



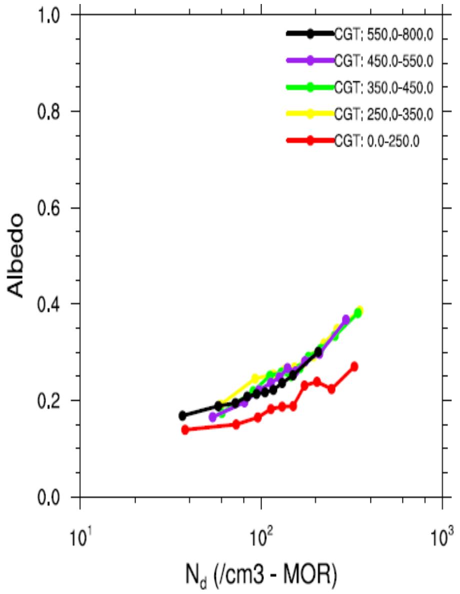
- Cloud amount increases with Nc in both satellite observations and models, but the rate is larger in observations.

Albedo (all-sky) as a function of cloud droplet number concentration

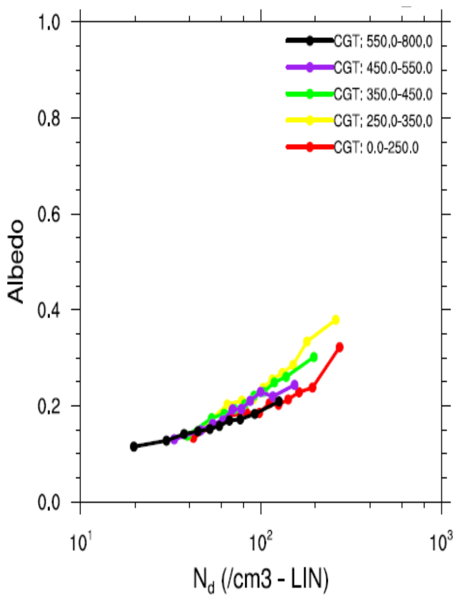
MODIS



Morrison



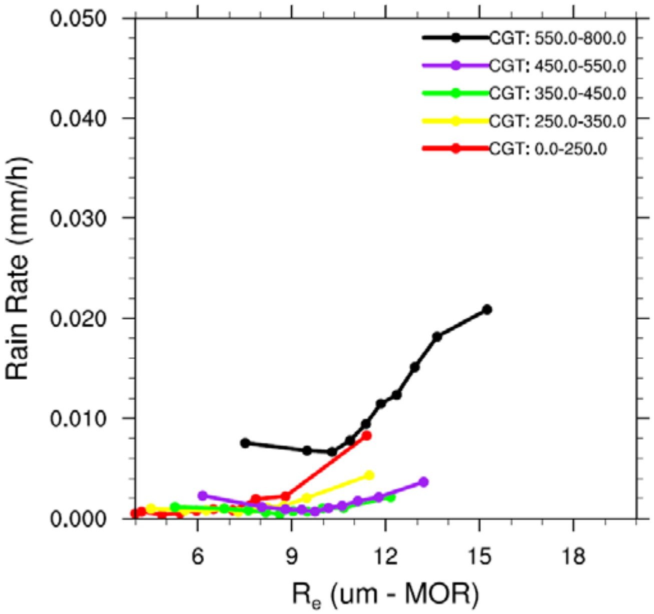
Lin



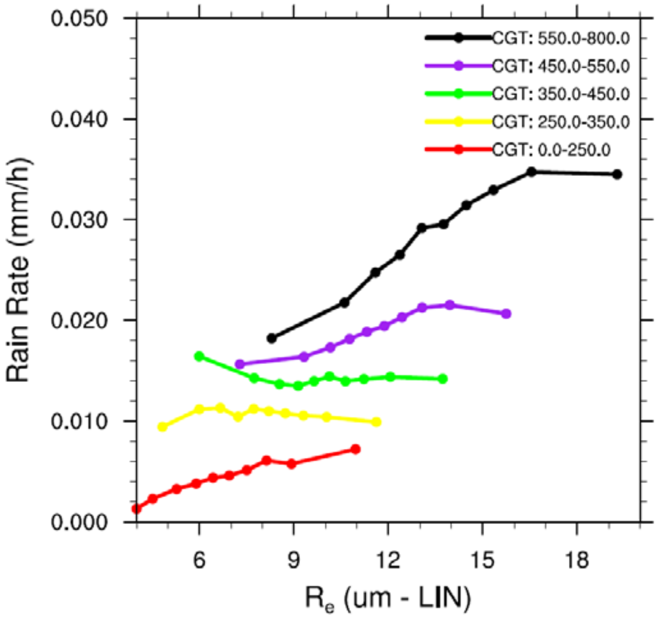
- All-sky albedo increases with Nc in both observations and models, but this dependence is underestimated in models.

Rain rate as a function of cloud droplet number concentration

Morrison



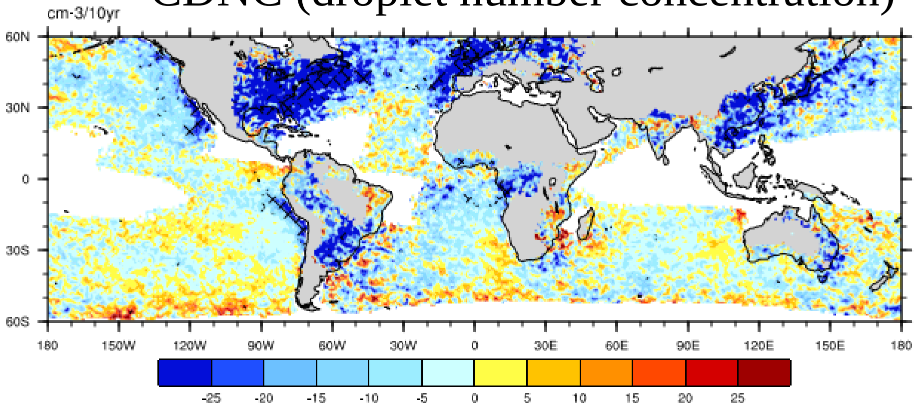
Lin

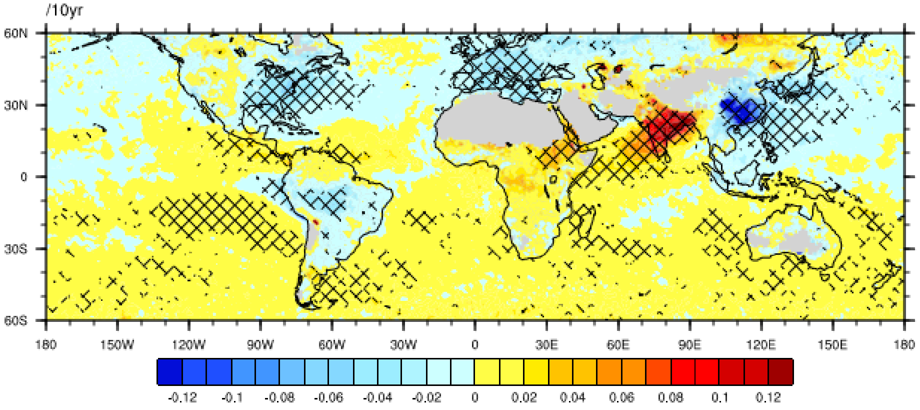


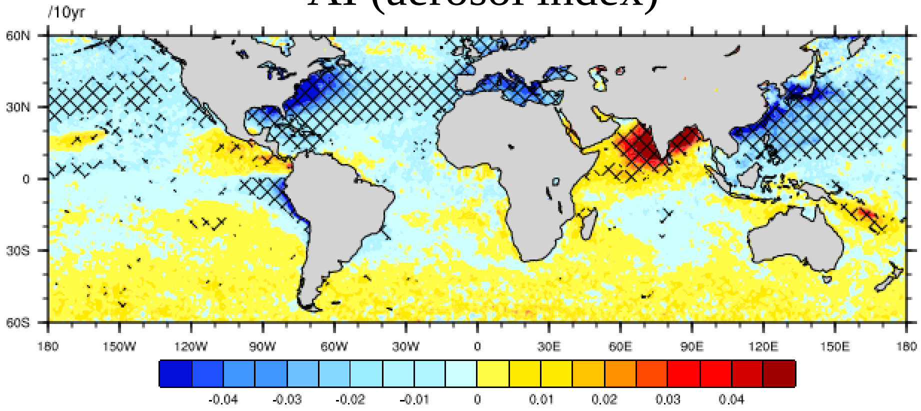
Liu et al., in preparation

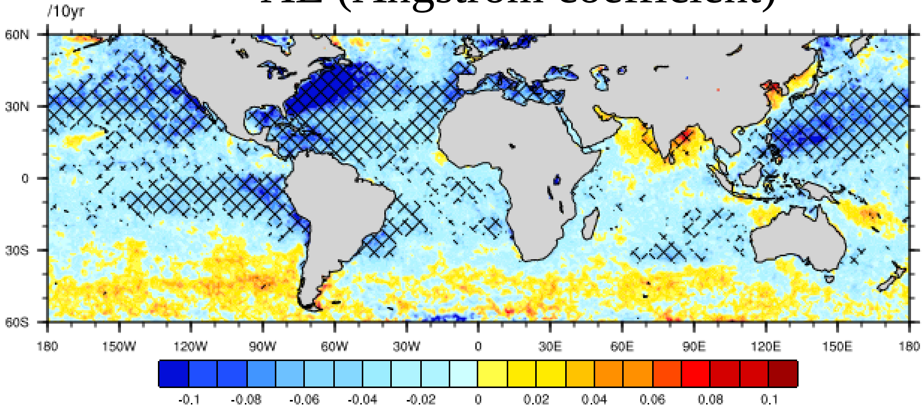
- In models, rain initiates well before Re reaches 14 um

Cloud and aerosol trends from MODIS (2002-2017)


CDNC (droplet number concentration)


AOD


AI (aerosol index)


AE (Angstrom coefficient)

- CDNC decreases over regions with negative AOD trend

Bai et al., JGR, submitted

CDNC trends in MODIS and CMIP6 models

MODIS

UKESM1

HADGEM3

GFDL CM4

CESM2

CNRM

0 -5 0 5 10 20 30 40

We welcome more groups to join us for this analysis!

Yawen Liu (liuyawen@nju.edu.cn); Minghuai Wang (minghuai.wang@nju.edu.cn)

Summary

- Satellite observations show strong precipitation suppression by aerosols, which contributes to strong dependence of cloud amount on aerosols
- Model predicts positive dependence of in-cloud LWP on Nc, and satellite observations shows negative dependence
- Models predict overall weaker dependence of all-sky albedo on Nc than observations, mainly from weaker dependence of cloud amount on Nc in models.

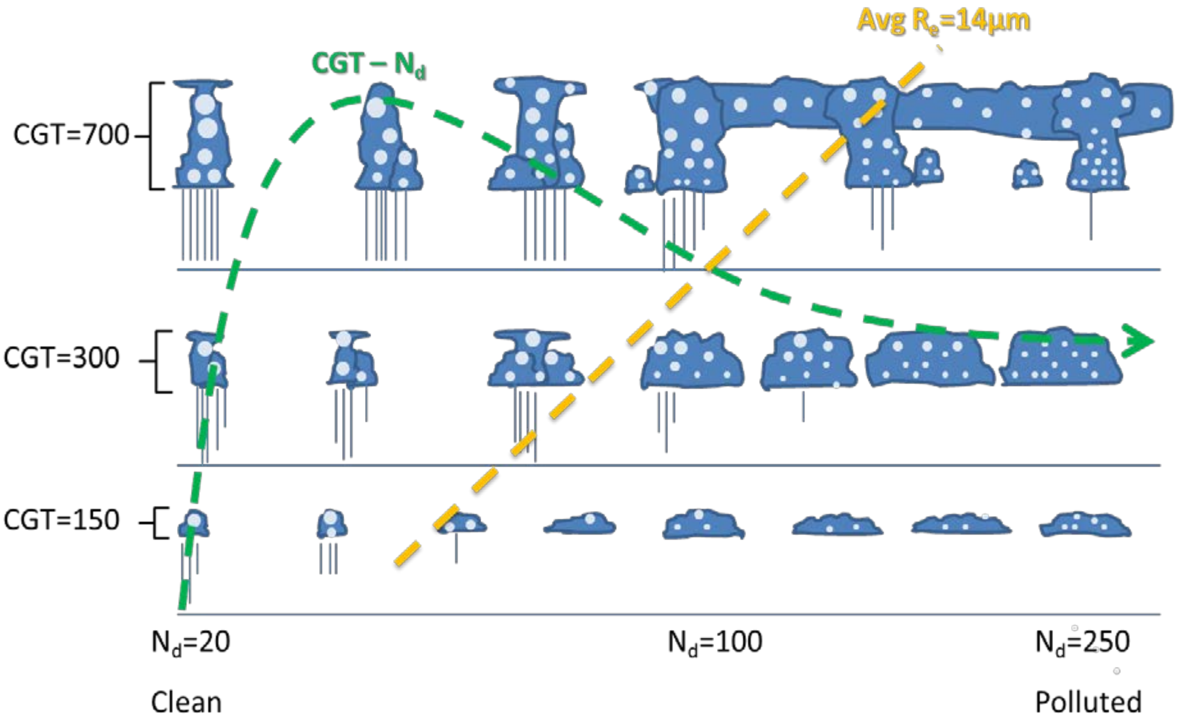
Thanks!

Acknowledgements

- Nanjing University: Jihu Liu, Hao Wang, Yawen Liu, Heming Bai
- Hebrew University: Daniel Rosenfeld
- Shanxi Meteorological Institute: Yannian Zhu
- University of Maryland-Baltimore County: Zhibo Zhang

南京大學
NANJING UNIVERSITY

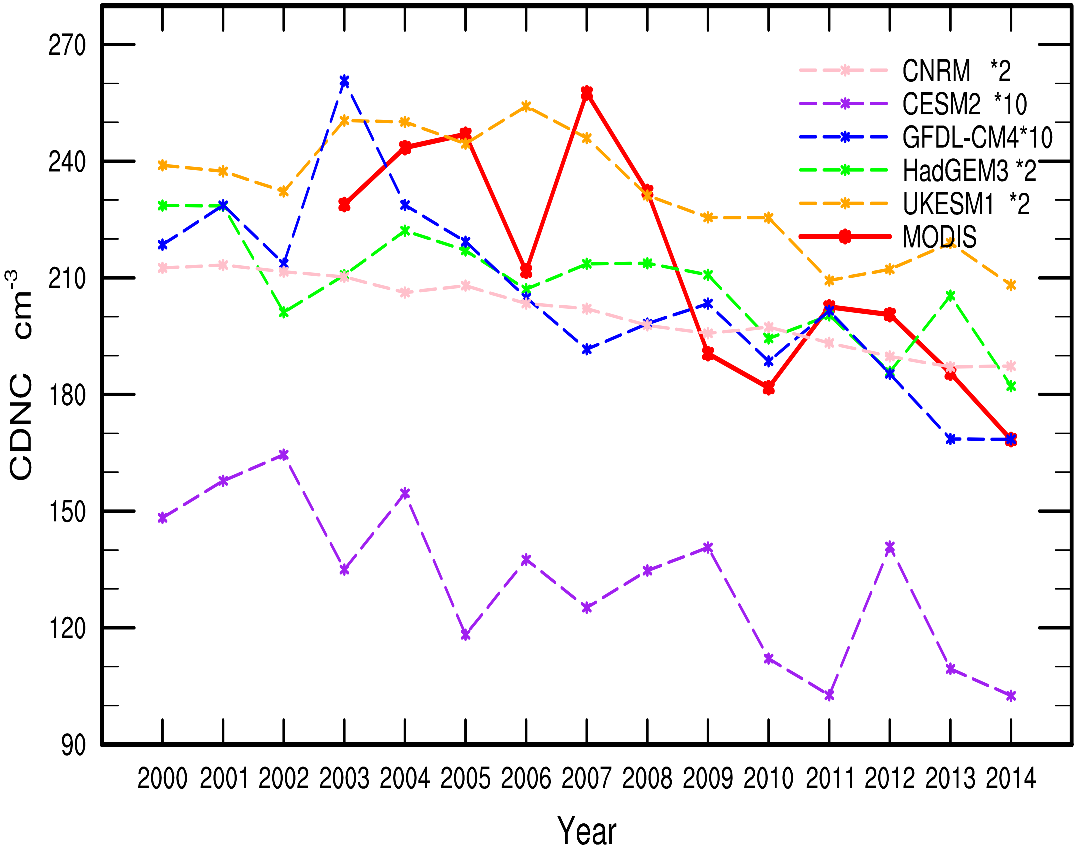
Aerosol-Cloud-Precipitation Interactions



Fan et al., to be submitted

- Precipitation suppression by aerosols contributes to strong dependence of cloud amount on aerosols

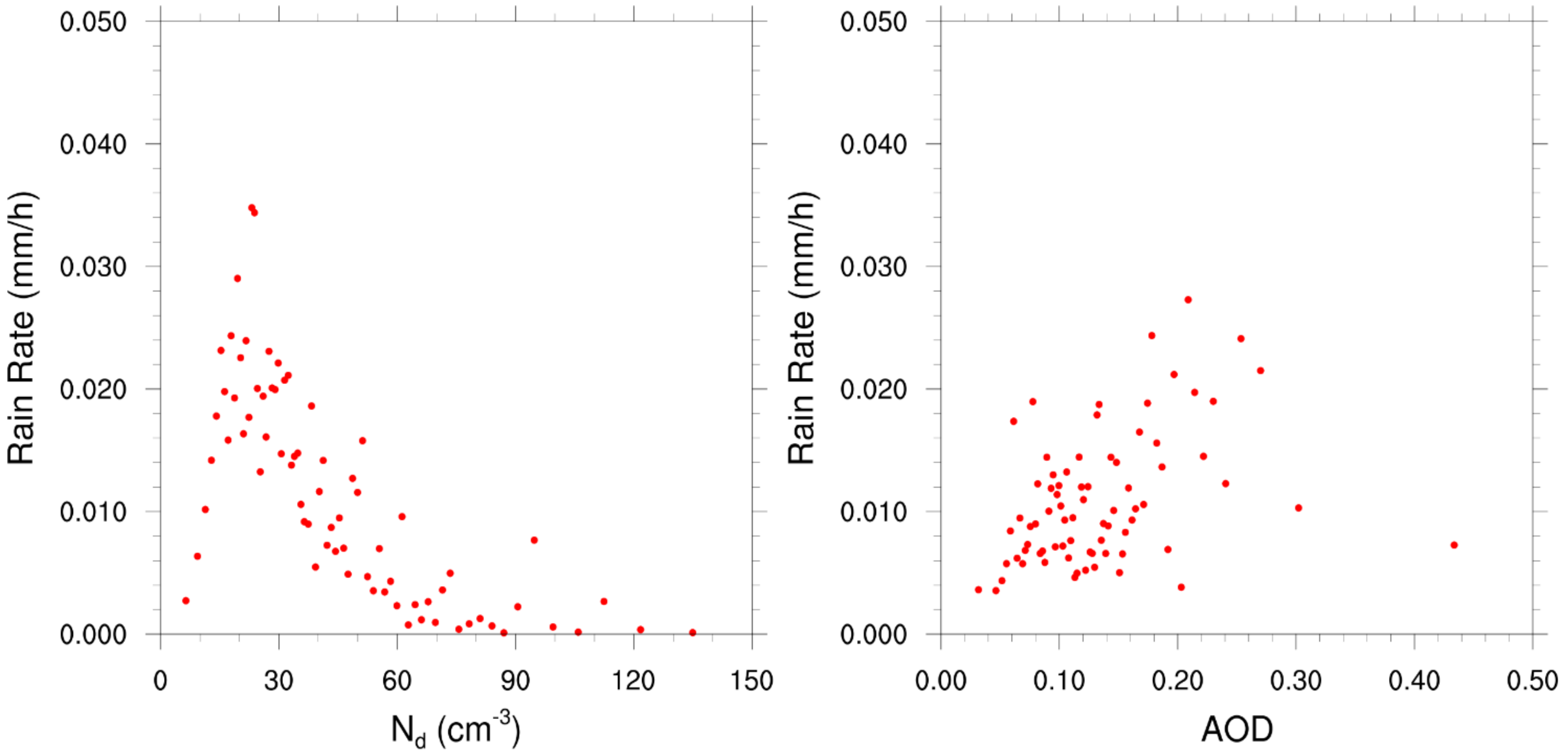
CDNC time series over US East coast



● (212.5 -63.9* -30.1%*) ● (104.0 -12.0* -11.5%*) ● (13.2 -3.4* -25.5%*)

● (116.1 -13.0* -11.2%*) ● (20.5 -4.5* -21.7%*) ● (100.5 -10.1* -10.1%*)

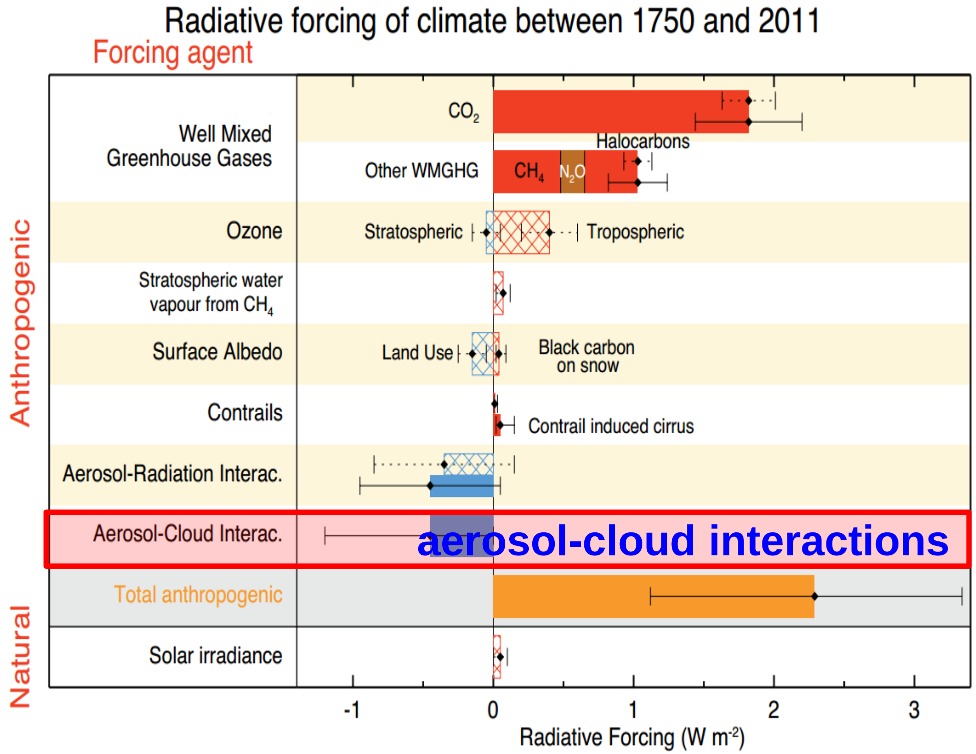
降水和Nd及AOD的关系



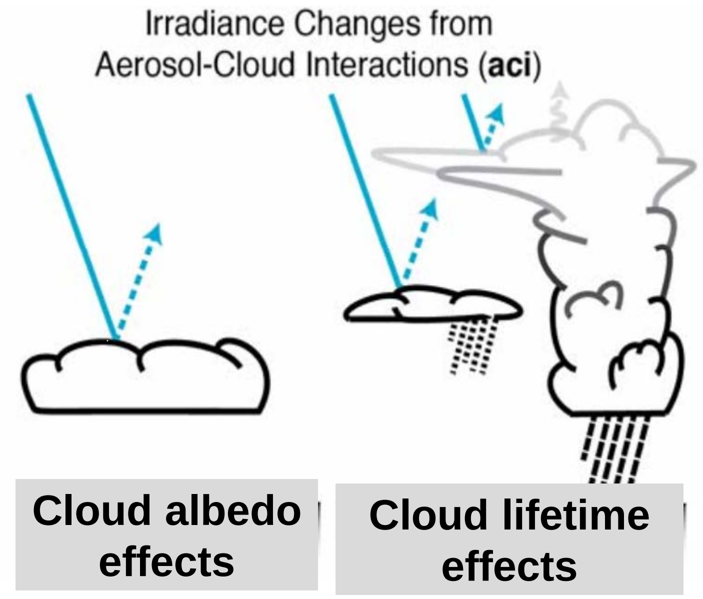
- ▶ AOD与降水正相关（与Koren et al., 2014, Science一致），难以表征CCN与降雨的真实关系

Fan et al., in preparation

气溶胶辐射强迫是人为辐射强迫估计不确定性的主要来源



aerosol-cloud interactions



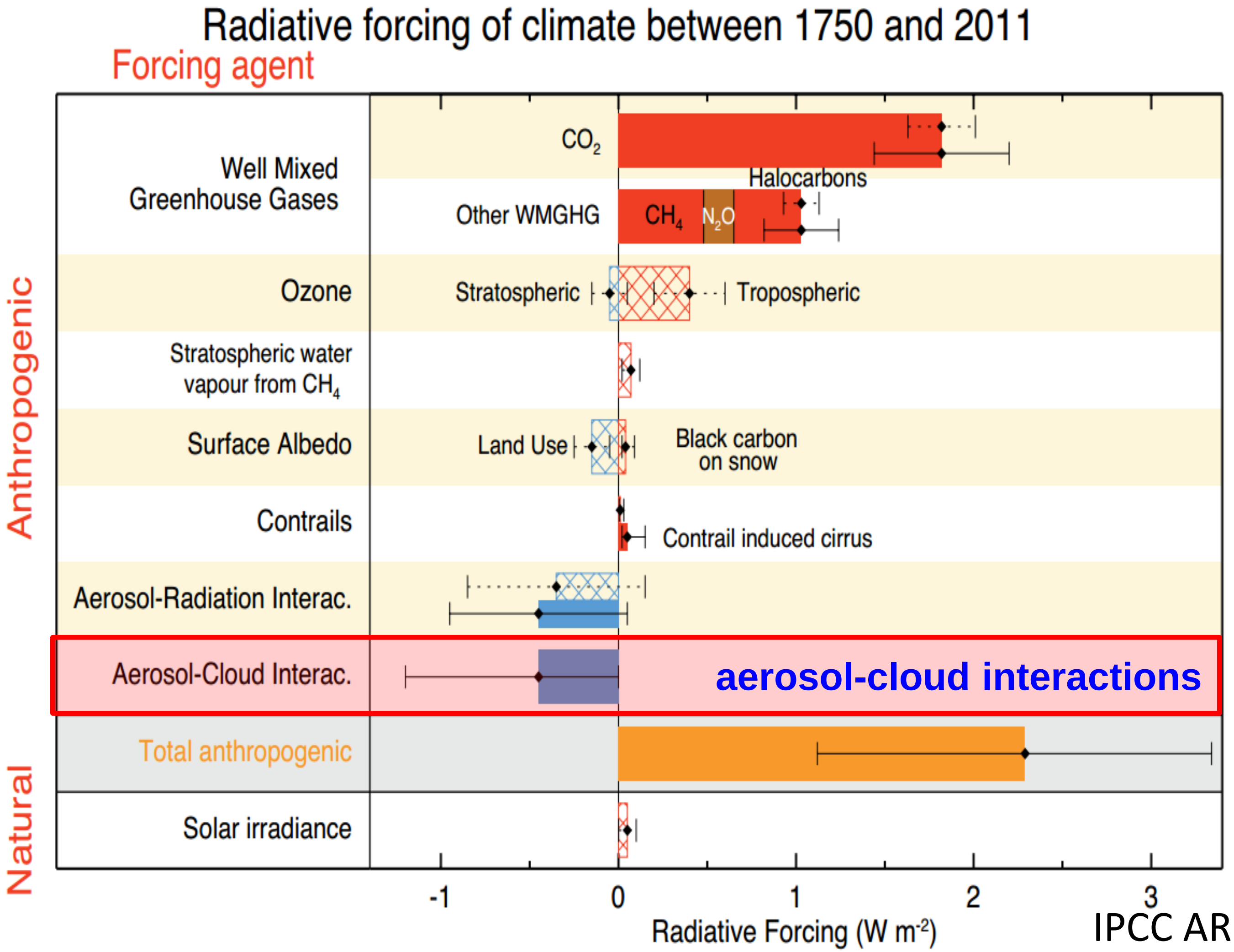
Cloud albedo effects

Cloud lifetime effects

Aerosol-cloud interactions

IPCC AR5

气溶胶辐射强迫是人为辐射强迫估计不确定性的主要来源



IPCC AR5

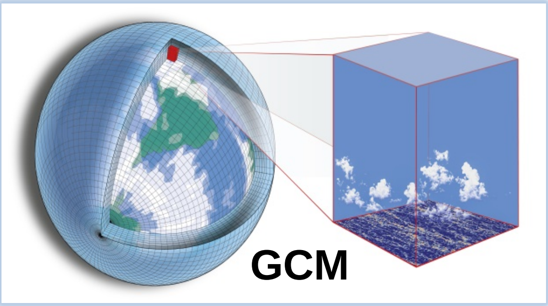
挑战：通过观测提高和约束模式

卫星与地面观测资料

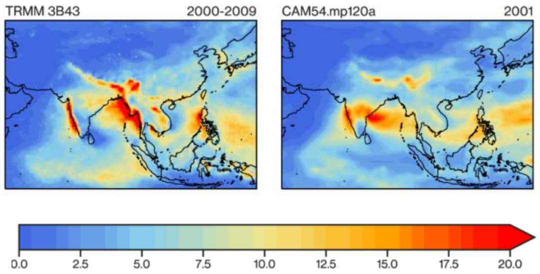
?

评估与约束模式

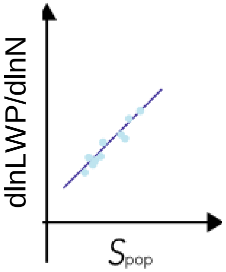
提高模式的模拟能力

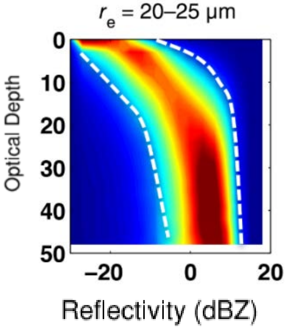


要素的简单验证

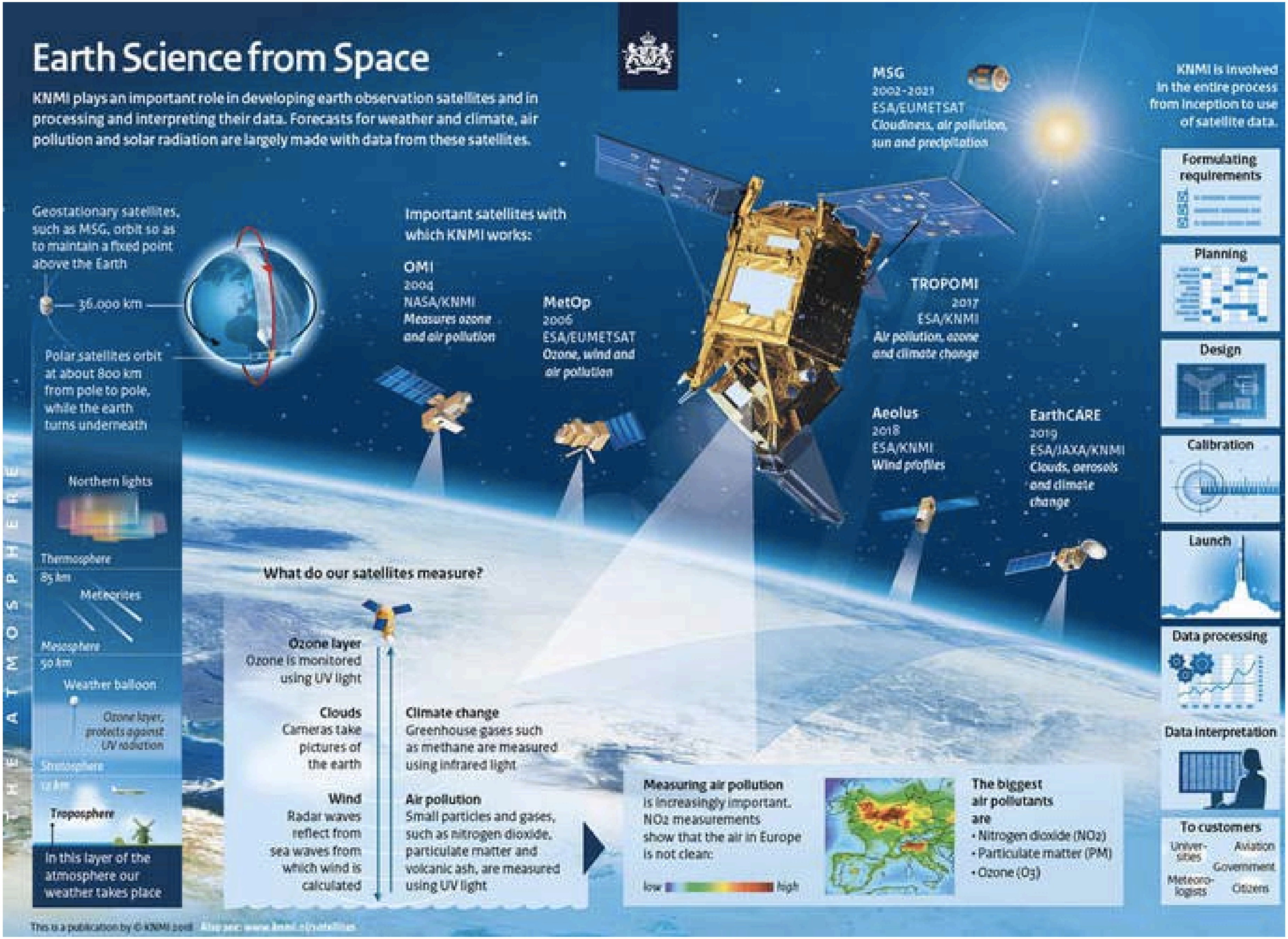


基于过程的诊断和约束





如何发展基于过程的诊断分析方法评估和约束气溶胶-云相互作用？



Earth Science from Space

KNMI plays an important role in developing earth observation satellites and in processing and interpreting their data. Forecasts for weather and climate, air pollution and solar radiation are largely made with data from these satellites.

Geostationary satellites, such as MSG, orbit so as to maintain a fixed point above the Earth

36.000 km

Polar satellites orbit at about 800 km from pole to pole, while the earth turns underneath

THE ATMOSPHERE

Northern lights

Thermosphere

85 km

Meteorites

Mesosphere

50 km

Weather balloon

Ozone layer, protects against UV radiation

Stratosphere

12 km

Troposphere

In this layer of the atmosphere our weather takes place

Important satellites with which KNMI works:

OMI
2004
NASA/KNMI
Measures ozone and air pollution

MetOp
2006
ESA/EUMETSAT
Ozone, wind and air pollution

MSG
2002-2021
ESA/EUMETSAT
Cloudiness, air pollution, sun and precipitation

TROPOMI
2017
ESA/KNMI
Air pollution, ozone and climate change

Aeolus
2018
ESA/KNMI
Wind profiles

EarthCARE
2019
ESA/JAXA/KNMI
Clouds, aerosols and climate change

What do our satellites measure?

Ozone layer
Ozone is monitored using UV light

Clouds
Cameras take pictures of the earth

Wind
Radar waves reflect from sea waves from which wind is calculated

Climate change
Greenhouse gases such as methane are measured using infrared light

Air pollution
Small particles and gases, such as nitrogen dioxide, particulate matter and volcanic ash, are measured using UV light

Measuring air pollution is increasingly important. NO2 measurements show that the air in Europe is not clean:

low — high

The biggest air pollutants are
- Nitrogen dioxide (NO2)
- Particulate matter (PM)
- Ozone (O3)

KNMI is involved in the entire process from inception to use of satellite data.

Formulating requirements

Planning

Design

Calibration

Launch

Data processing

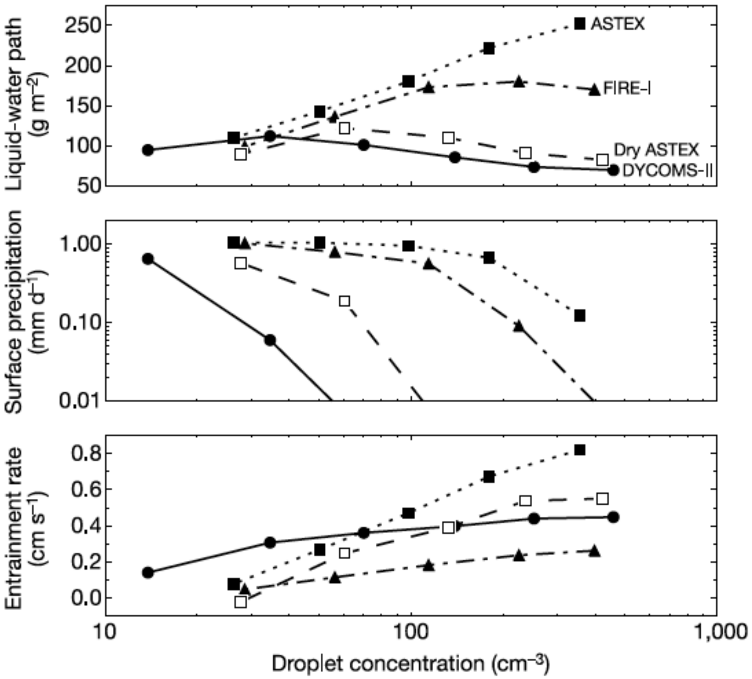
Data interpretation

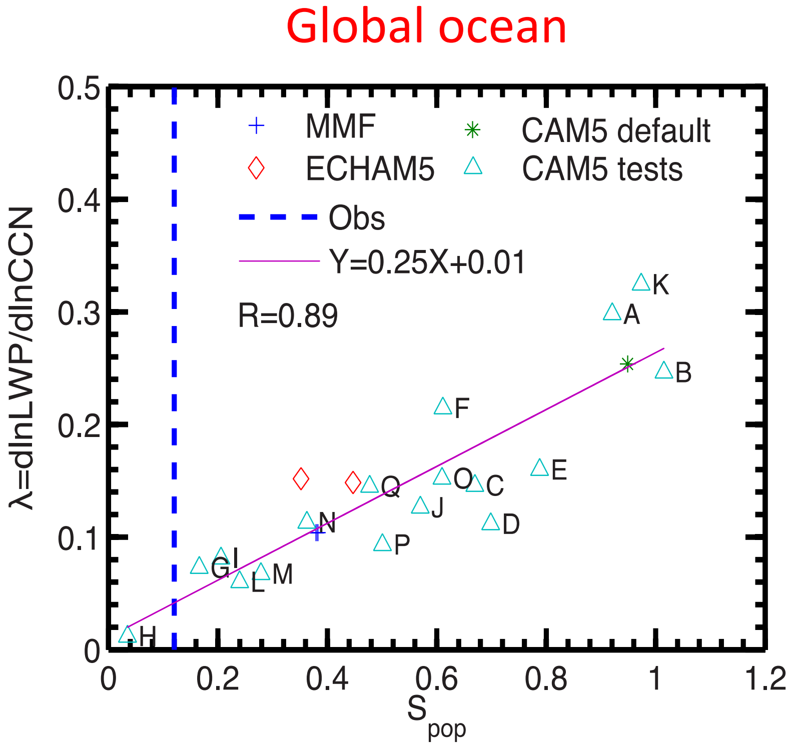
To customers
Universities
Aviation
Government
Meteorologists
Citizens

This is a publication by © KNMI 2018 Also see: www.knmi.nl/satellites

前期的多项工作认为云生命周期效应较小

- LES结果表明气溶胶对云水路径的负影响（Ackerman et al., 2004, Nature）





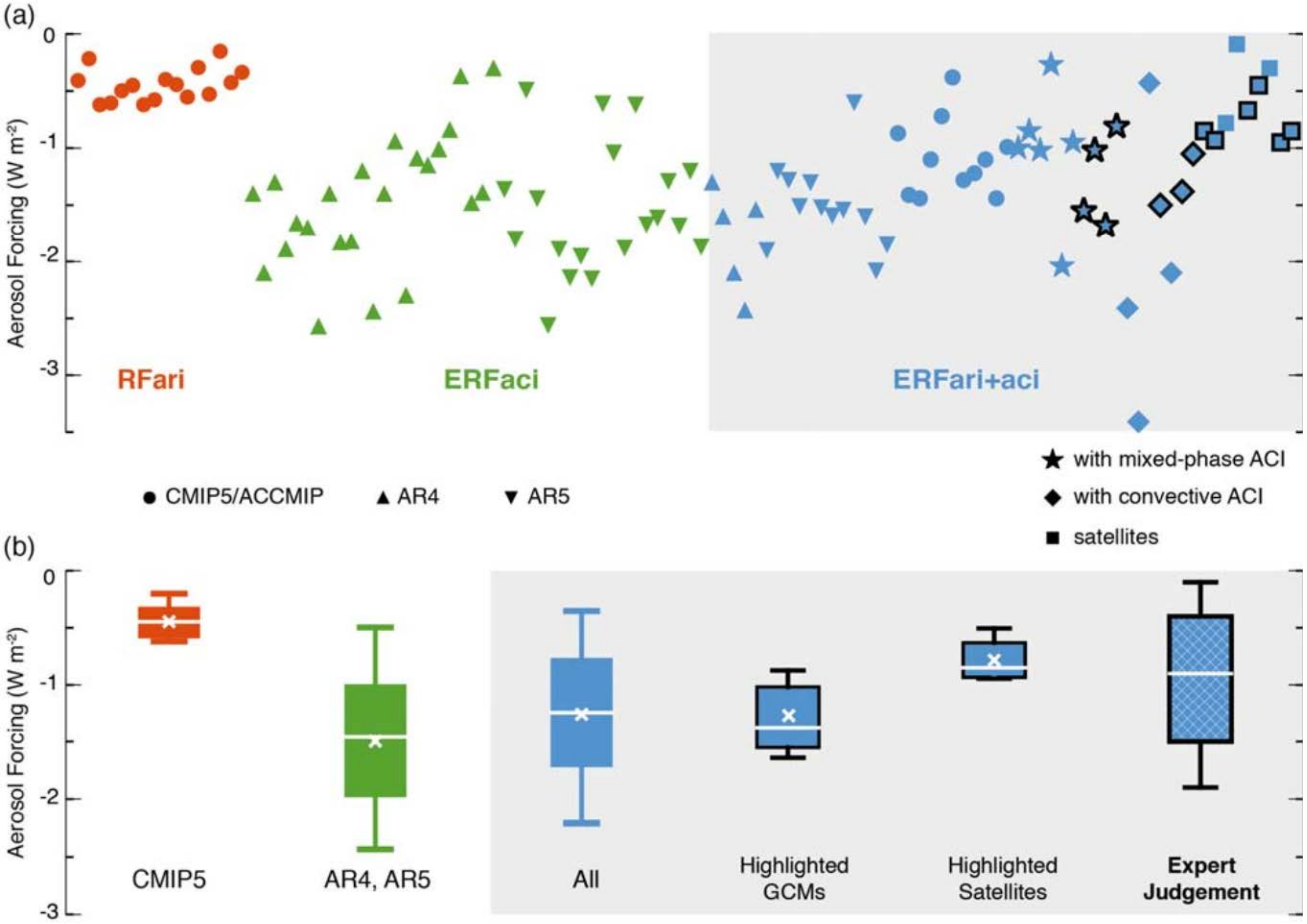
S_{POP}=-dlnPOP/dlnAI

降雨频率敏感度

- 降雨频率敏感度表明全球模式高估云生命周期效应

（Wang et al., 2012, GRL）

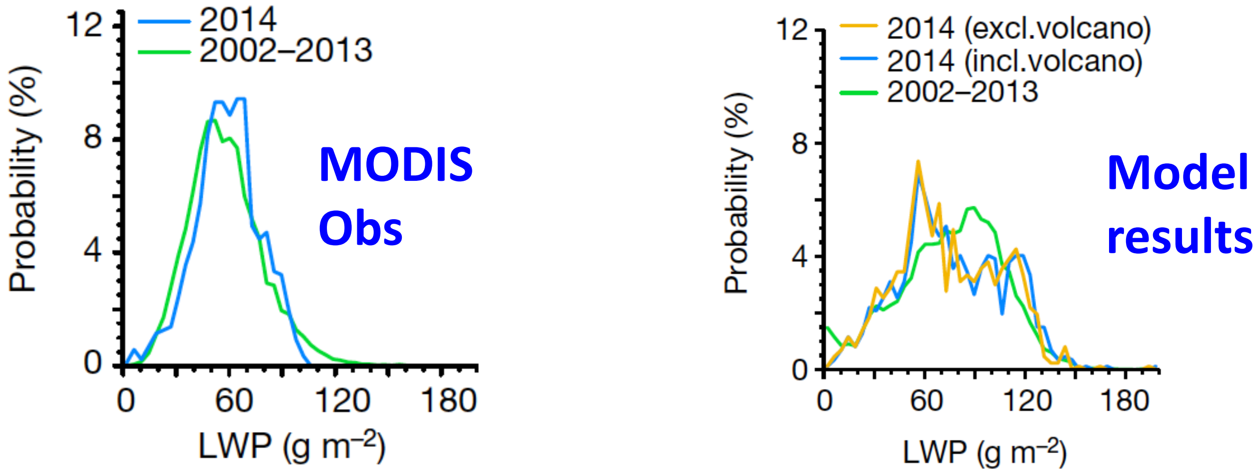
IPCC第五评估报告降低气溶胶间接气候效应辐射强迫的估计



Chapter 7, IPCC AR5, 2013

最近的工作进一步认为气溶胶云生命周期效应较小

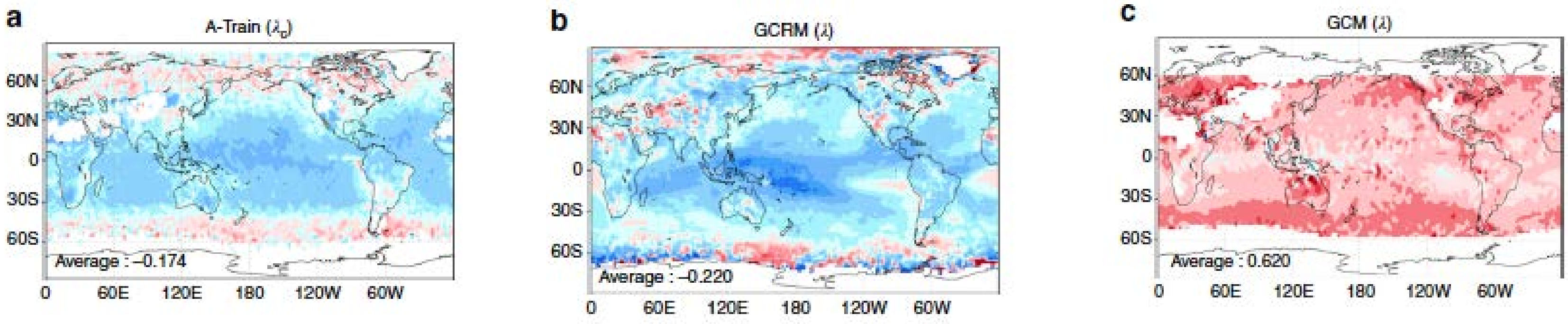
- 来自火山爆发的约束（Malavelle et al., 2017, Nature）



MODIS Obs

Model results

- 全球云系统解析模式（Sato et al., 2018, Nat Commun）

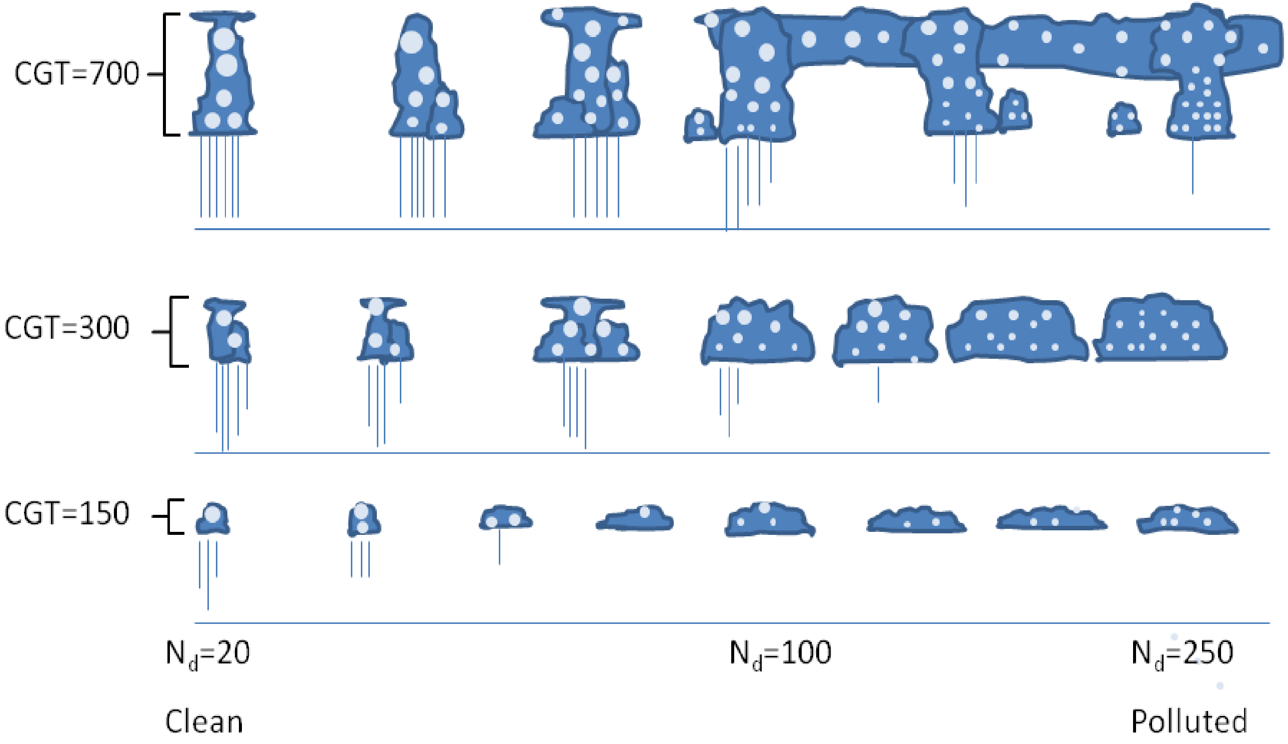


Obs

GCSRM (Δx=13 km）

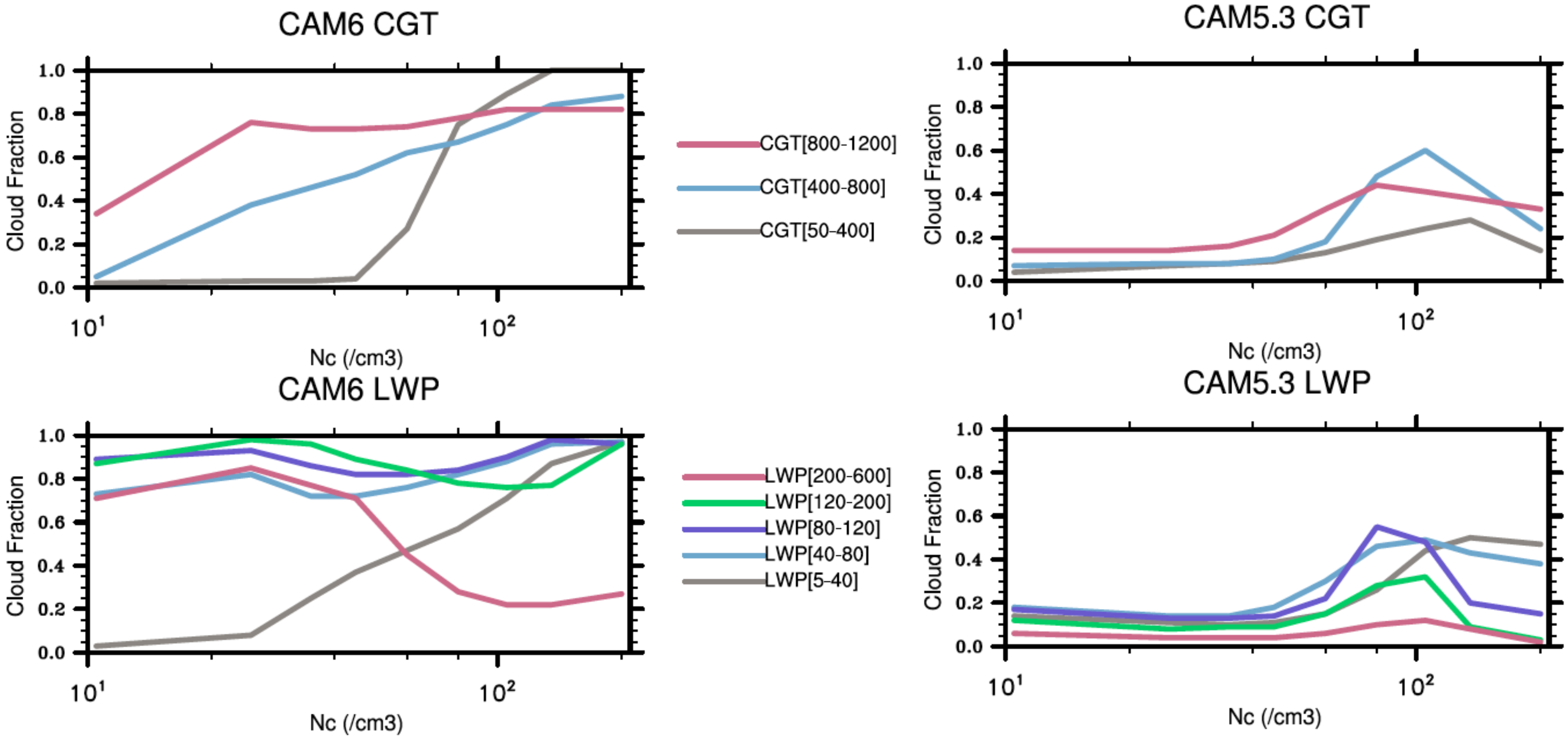
GCM

气溶胶对云水和云量影响的概念模型



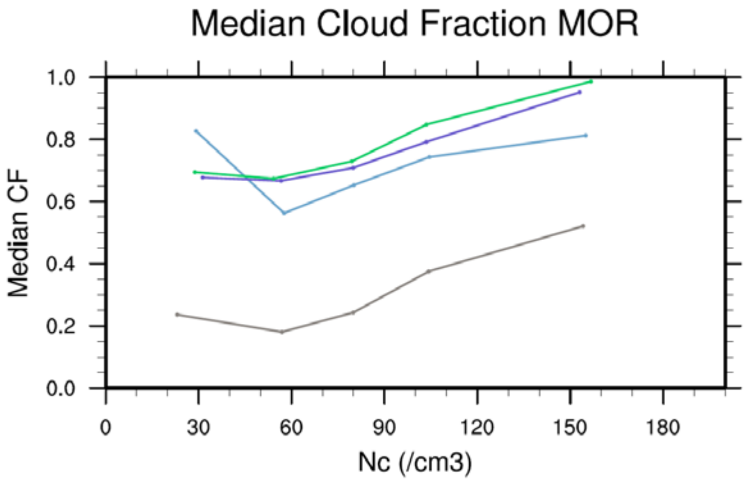
Rosenfeld et al., 2019, Science

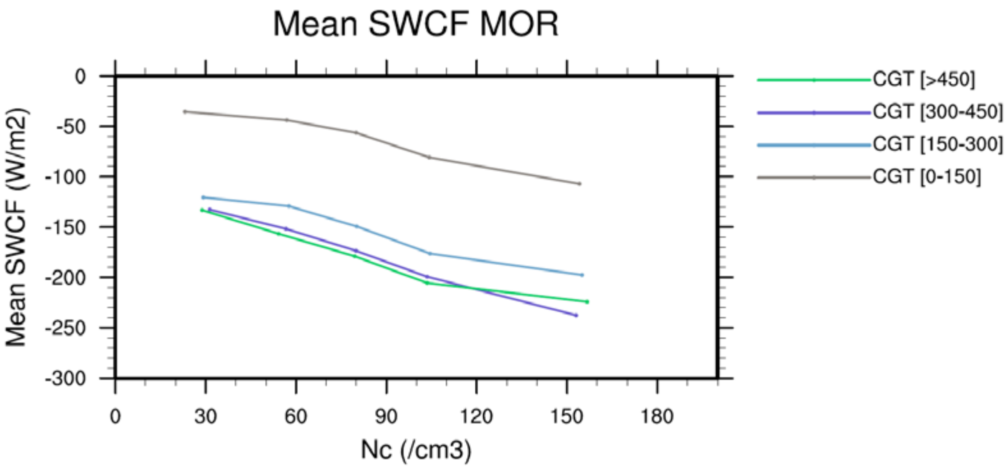
全球模式结果(NCAR CAM5和CAM6）

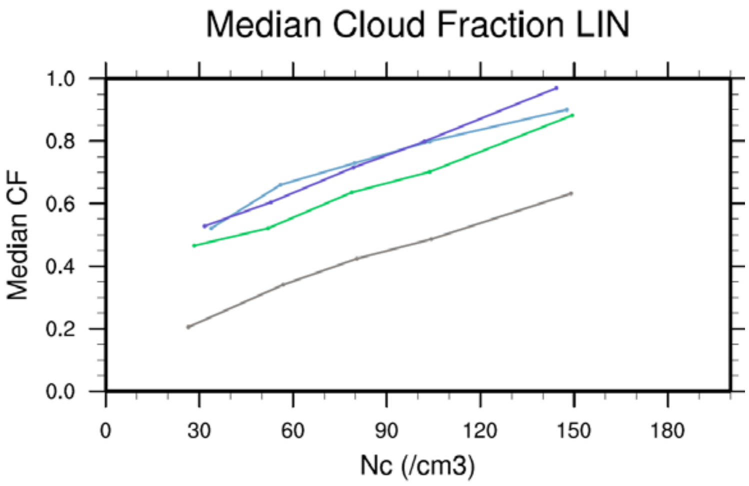


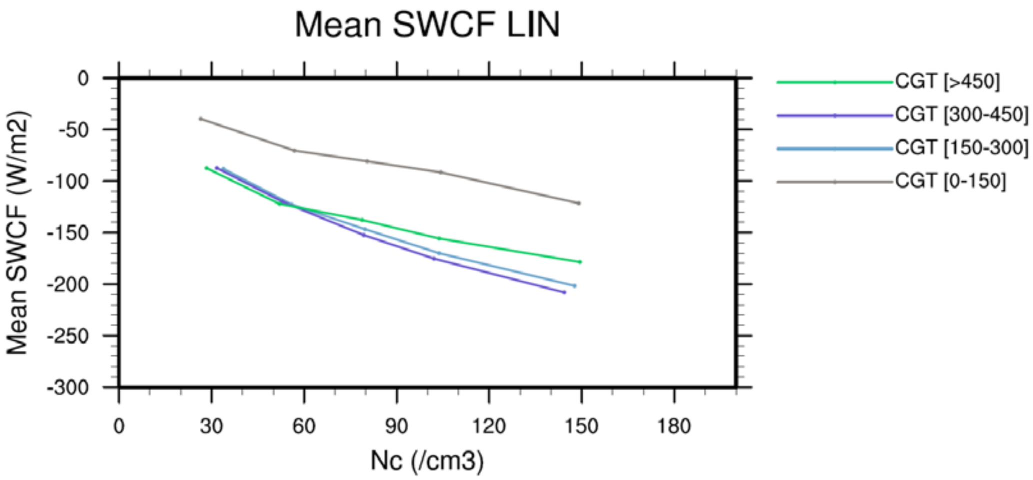
Wang et al., in preparation

WRF-Chem simulations over Southeast Pacific during VOCALS Rex (2008)


Median Cloud Fraction MOR


Mean SWCF MOR


Median Cloud Fraction LIN


Mean SWCF LIN

CCN浓度反演及云几何厚度的计算

- 对破碎云中云滴数浓度Nd的反演：针对最亮的10%的云（对流云核）（Zhu et al., 2018, JGR）
- 云底垂直速度Wb的反演（Zheng et al., 2016, GRL; Zheng and Rosenfeld, 2015, GRL）
- 云几何厚度计算 (从海表面到云底是干绝热递减率，从云底到云顶是湿绝热递减率）