Radiative forcing of anthropogenic aerosols on cirrus clouds using a hybrid ice nucleation scheme

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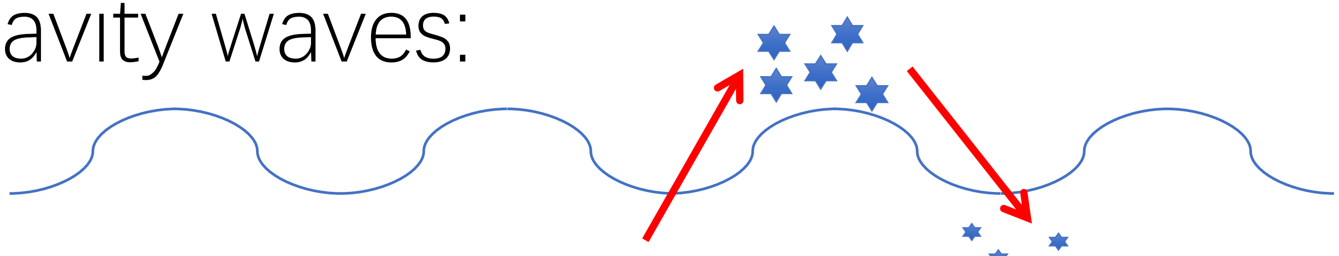
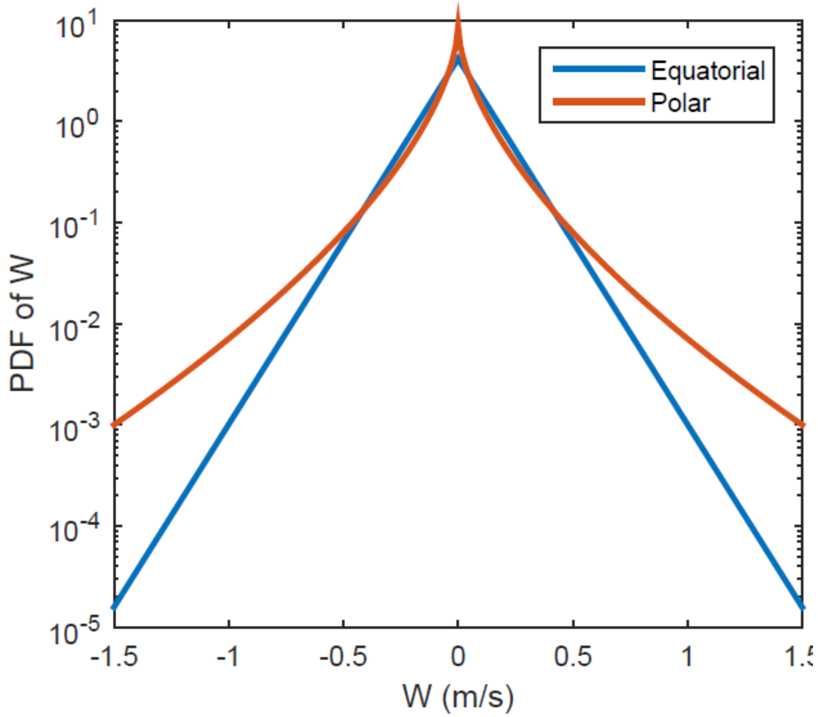
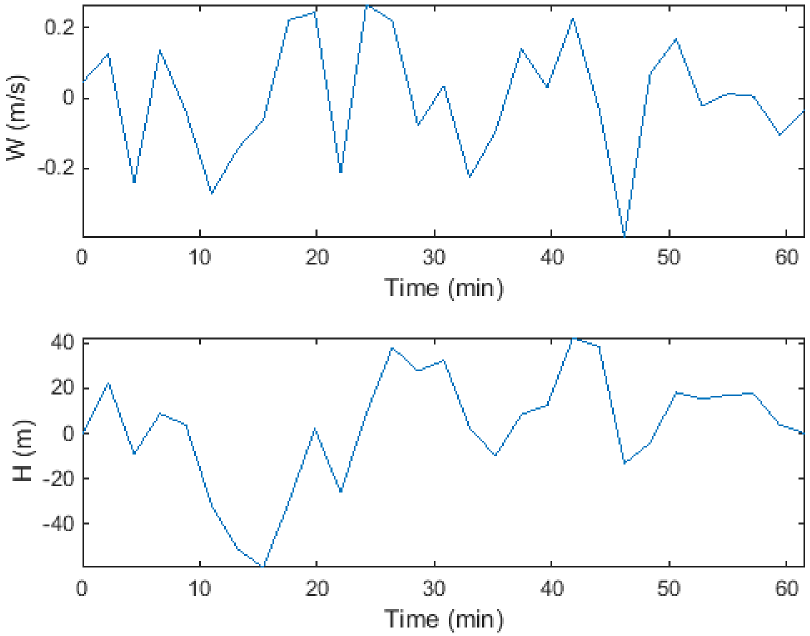
Penner et al. (2018) examined forcing in cirrus clouds using a scheme that follows updrafts/downdrafts within gravity waves:



We use roughly 15 updraft velocities within each 30 minute time step drawn from a Laplace distribution based on observations (Podglajen et al (2016)



One example of w series with std=0.17m/s



Two schemes used in previous models

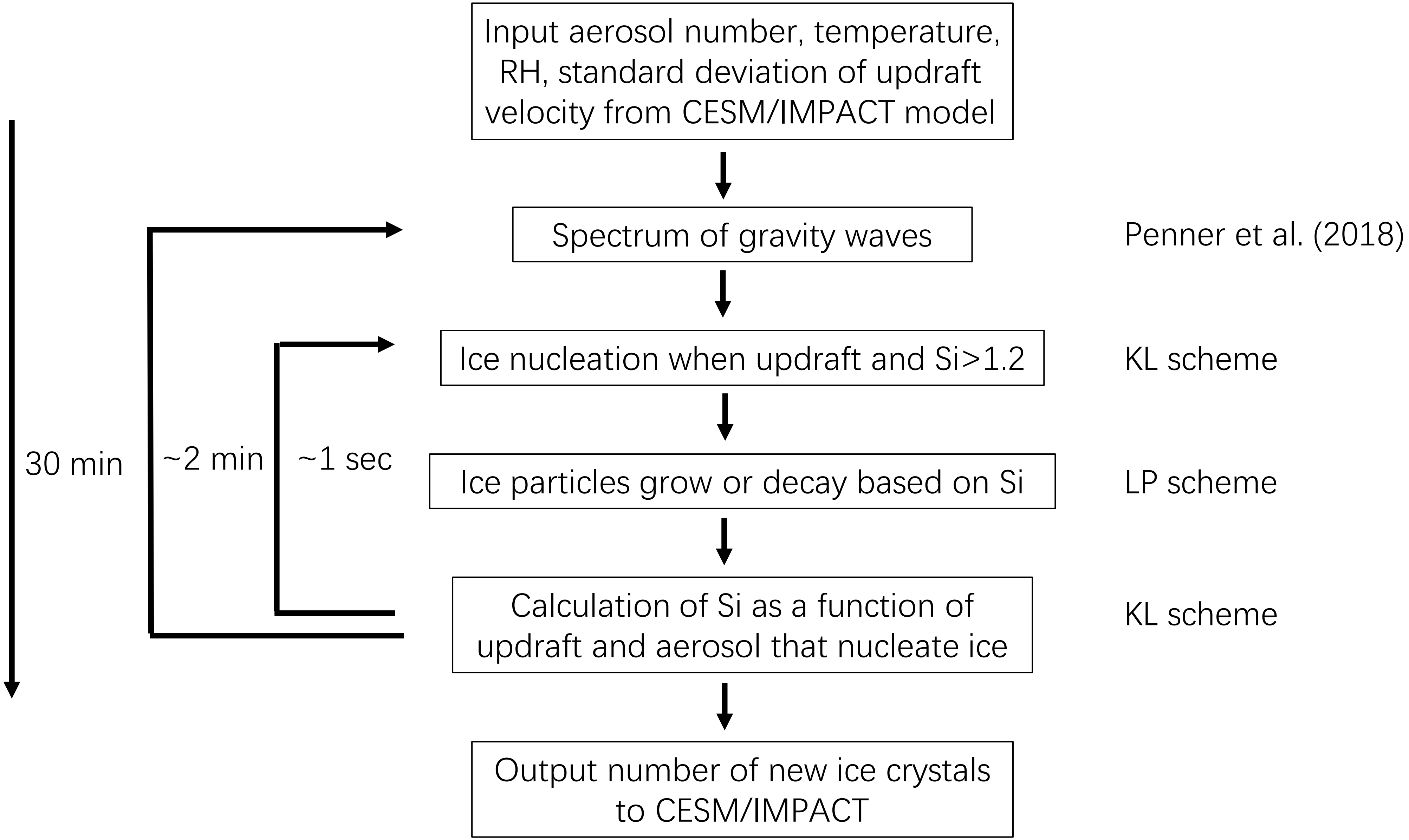
- **KL-gravity scheme:**

A parcel model parameterization of the relevant physics based on Kärcher et al. (2006). For each time step, the updraft velocity follows the influence of gravity waves during each time step based on observations (Penner et al., 2018). Ice number is that from the end of the time step. However, this scheme neglects the competition among different sizes of particles when ice nucleate.

- **LP (Liu and Penner, 2005) sheme:**

A parameterization derived from fitting the simulation results of a rising cloud parcel model with a constant updraft (Liu and Penner, 2005). For each time step the ice number is calculated from a pdf of updraft velocities that follow the distribution from Penner et al. (2018). Ice number at the end of the time step is the average of values from the pdf. However, this scheme is only able to treat cases for which the updraft velocity is positive, so the evaporation of drops during downdrafts is neglected.

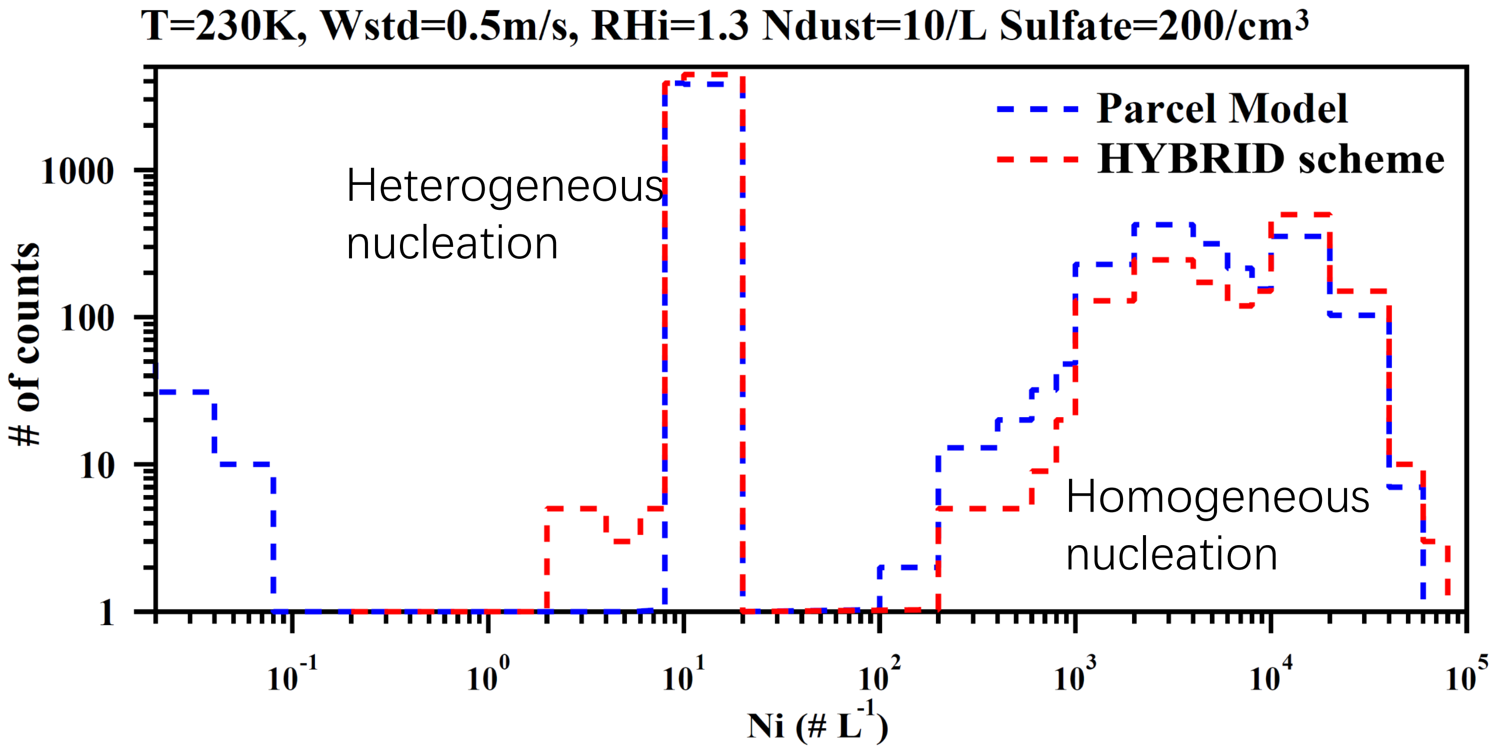
HYBRID nucleation scheme designed



Evaluation of the HYBRID scheme

Box model using HYBRID scheme vs Adiabatic parcel model

(10,000 simulations, 30min run-time, updraft velocity updated every 2.2 min, same initial conditions)



The results in the simulations dominated by heterogeneous nucleation are mostly similar for the two models

The HYBRID scheme overestimates the Ni from homogeneous nucleation by 7.3%

The HYBRID scheme uses the LP parameterization for every small time step of 2.2 min. Since the LP parameterization was built using the largest Ni in an ascending parcel after 30 min, there is a tendency for the HYBRID scheme to overpredict *Ni,* but the results are reasonable compared to the results from the parcel model.

Experiments

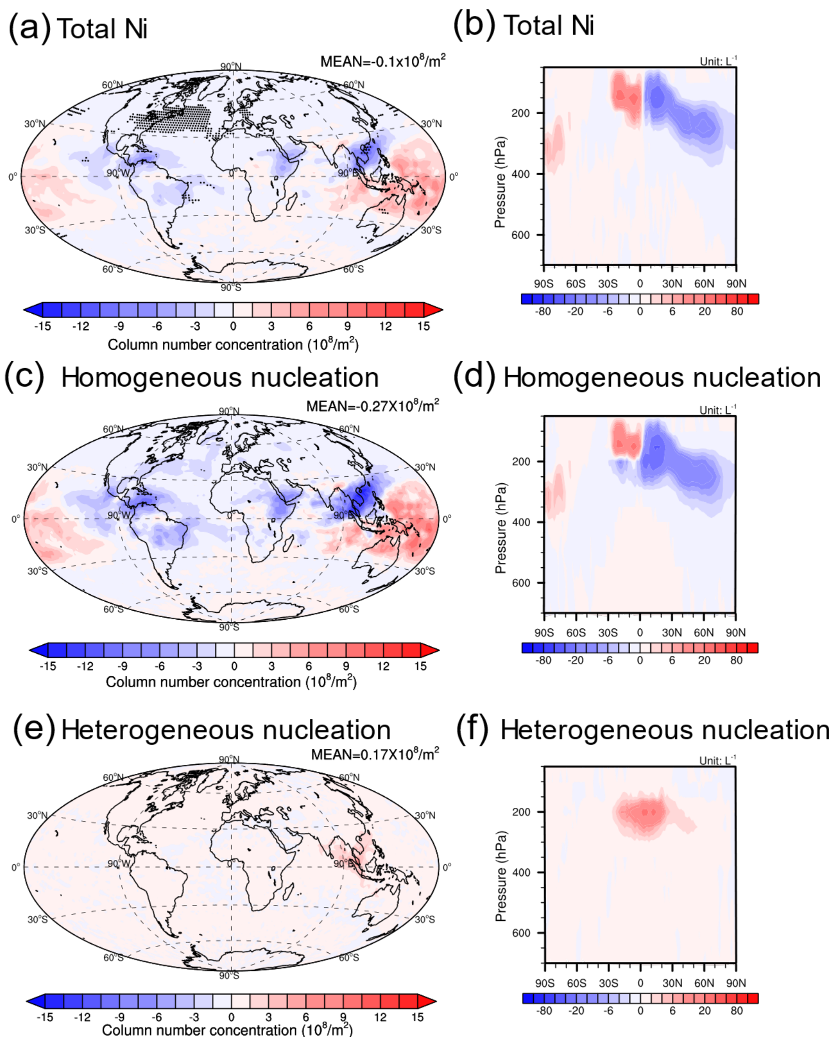
Investigate the radiative forcing of aircraft soot, sulfate, anthropogenic aerosols on cirrus clouds as well as the impact of including INPs from newly formed SOA particles

Case name	Description
PD_Base	Emissions for the present day (≈2000) for anthropogenic sulfur, surface and aircraft soot
PI_cSoot	As in PD_Base without INPs from pre-activated aircraft soot in contrails
PI_SO4	As in PD_Base, but with the anthropogenic sulfur emission for the preindustrial period (≈1750)
PI_ALL	As in PD_Base, but with the anthropogenic sulfur emission and surface soot emission for the pre-industrial period (≈1750) and without aircraft soot
PD_SOA	As in PD_Base, but adding INPs from newly formed SOA particles in present day
PI_SOA	As in PI_ALL, but adding INPs from newly formed SOA particles in preindustrial period

Ice number concentrations

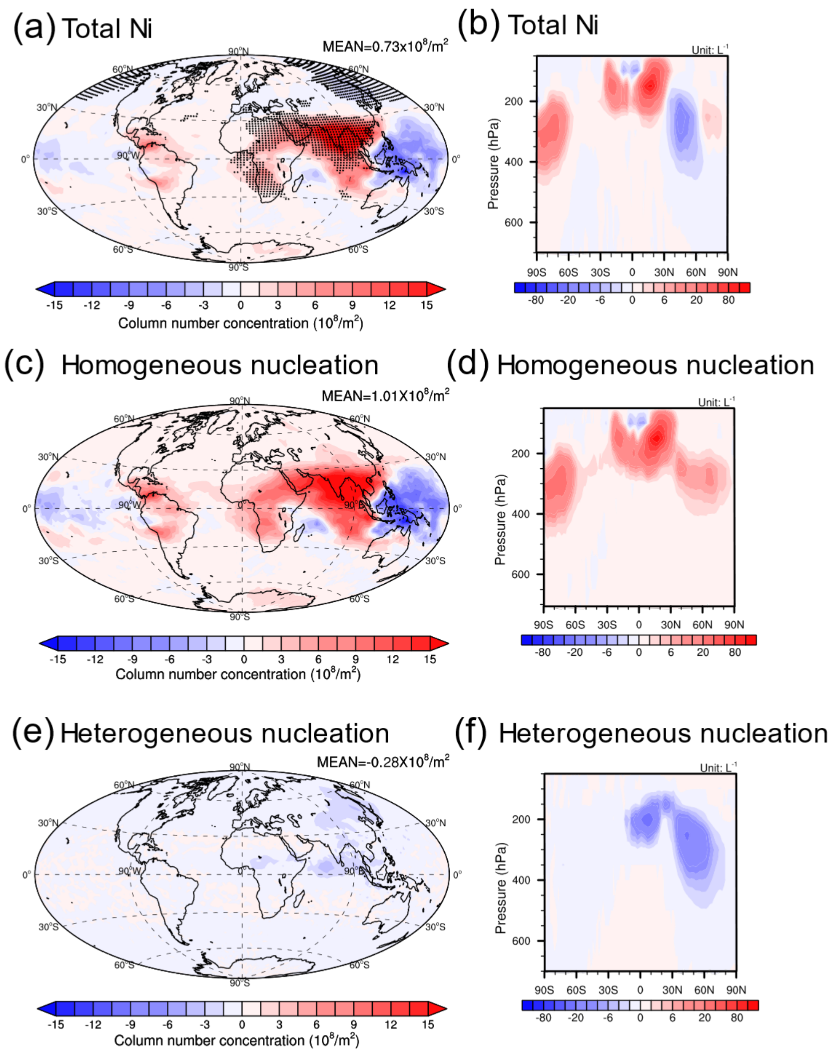
Aircraft Soot

PD_Base - PI_cSoot



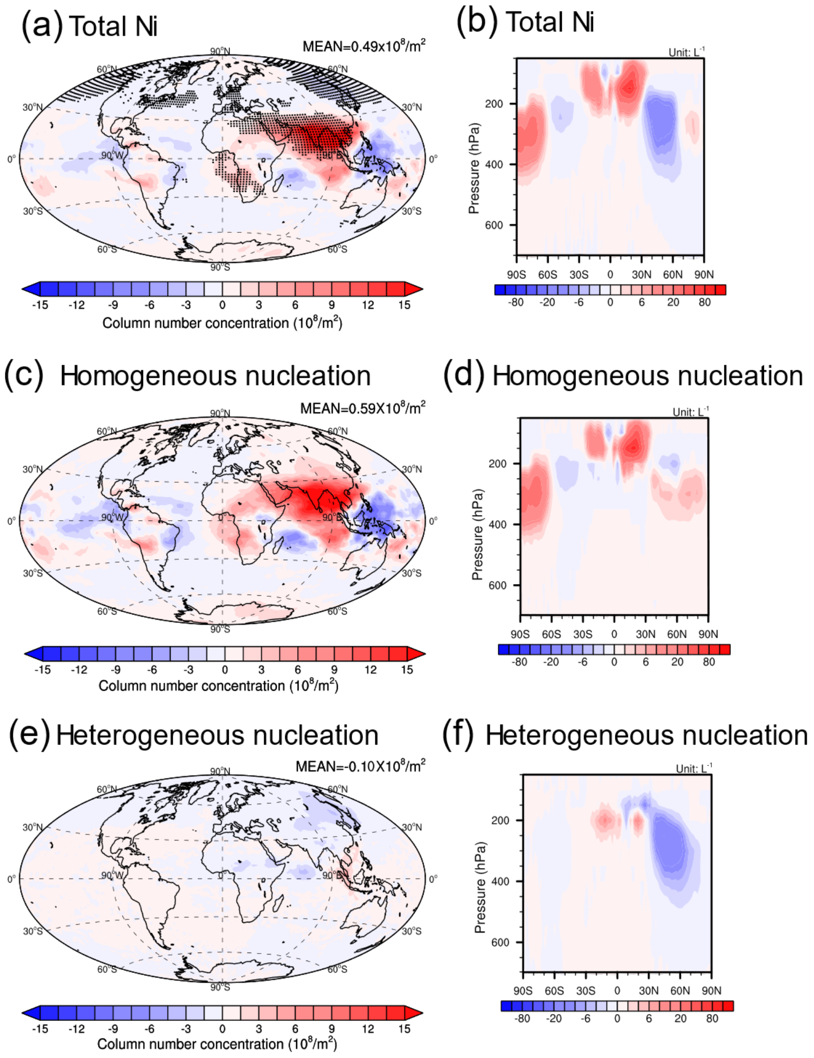
Anthropogenic Sulfur

PD_Base - PI_SO4



Anthropogenic Aerosols

PD_Base - PI_ALL

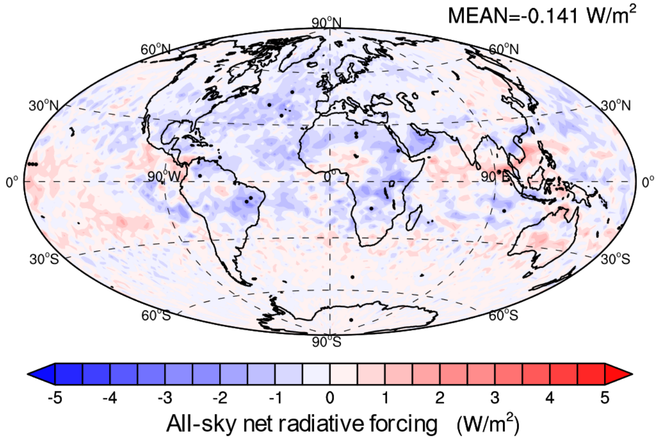


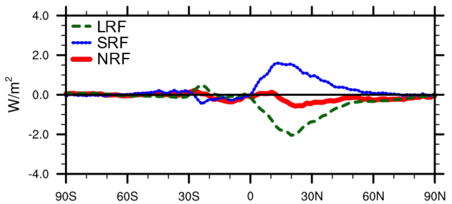
Radiative forcing

Anthropogenic Sulfur

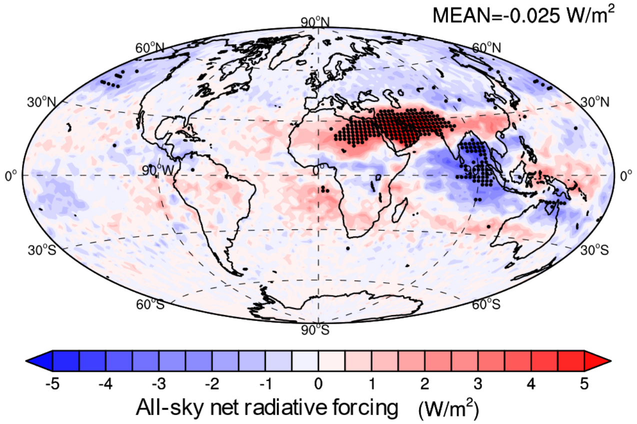
Aircraft Soot

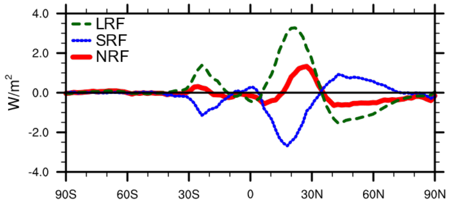
PD_Base - PI_cSoot





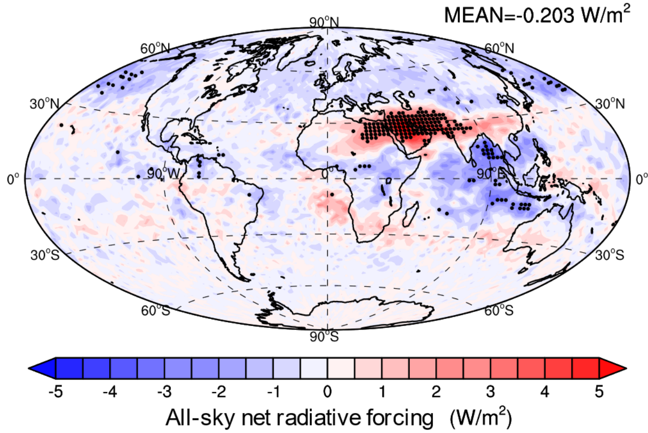
PD_Base - PI_SO4

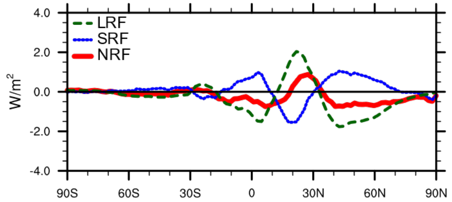




Anthropogenic Aerosols

PD_Base - PI_ALL





Parameter	PD_Base-PI_cSoot	PD_Base-PI_SO4	PD_Base-PI_ALL
Ni (10^7 m^{-2})	-1.00±2.40	7.26±2.88	4.93±1.80
IWP (g m^{-2})	-0.13±0.06	0.07±0.06	-0.13±0.04
LWP (g m^{-2})	-0.19±0.04	0.16±0.07	-0.05±0.08
SRF(W m^{-2})	0.35±0.13	-0.36±0.10	0.10±0.06
LRF(W m^{-2})	-0.49±0.09	0.33±0.05	-0.30±0.06
NRF(W m^{-2})	-0.14±0.07	-0.02±0.06	-0.20±0.05

SRF: all-sky shortwave radiative forcing
LRF: all-sky shortwave radiative forcing
NRF: all-sky net radiative forcing

Influence of SOA on *Ni*

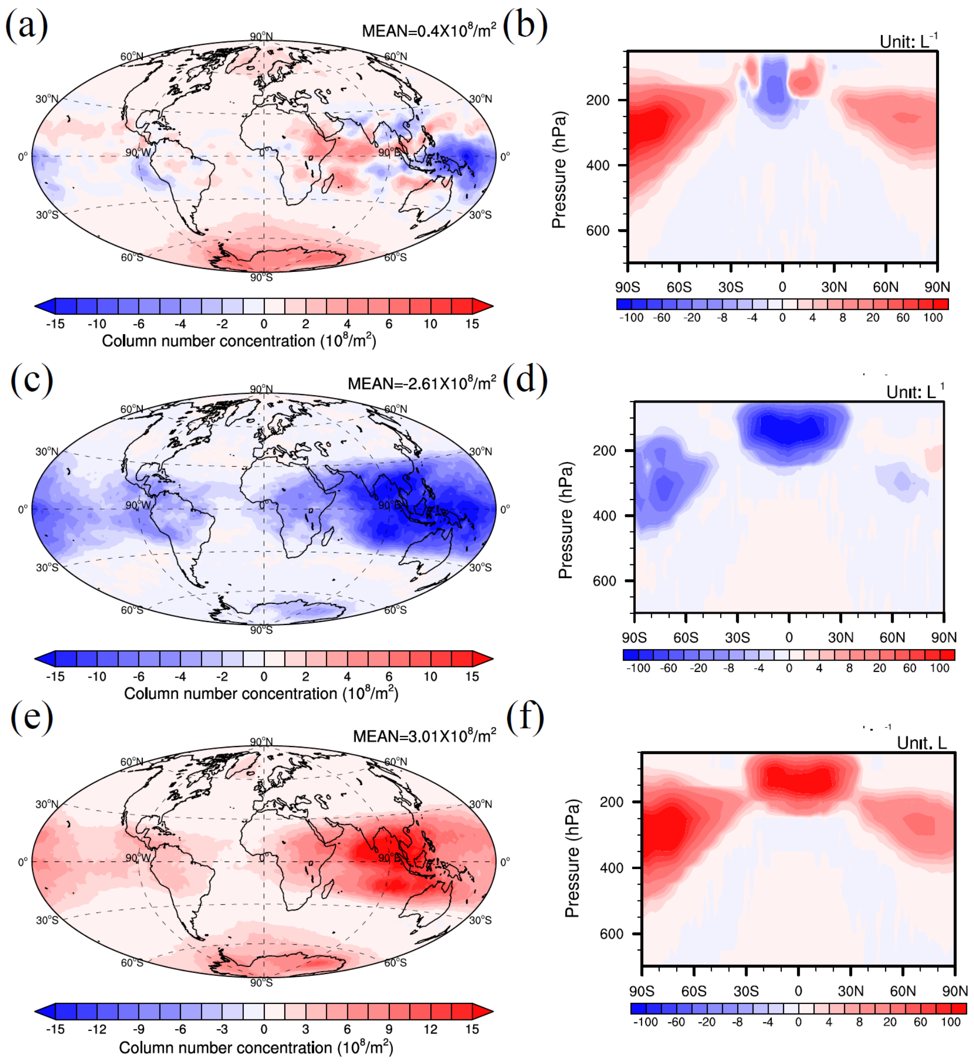
Change in Ni in PD due to SOA

PD_SOA – PD_Base

Total Ni

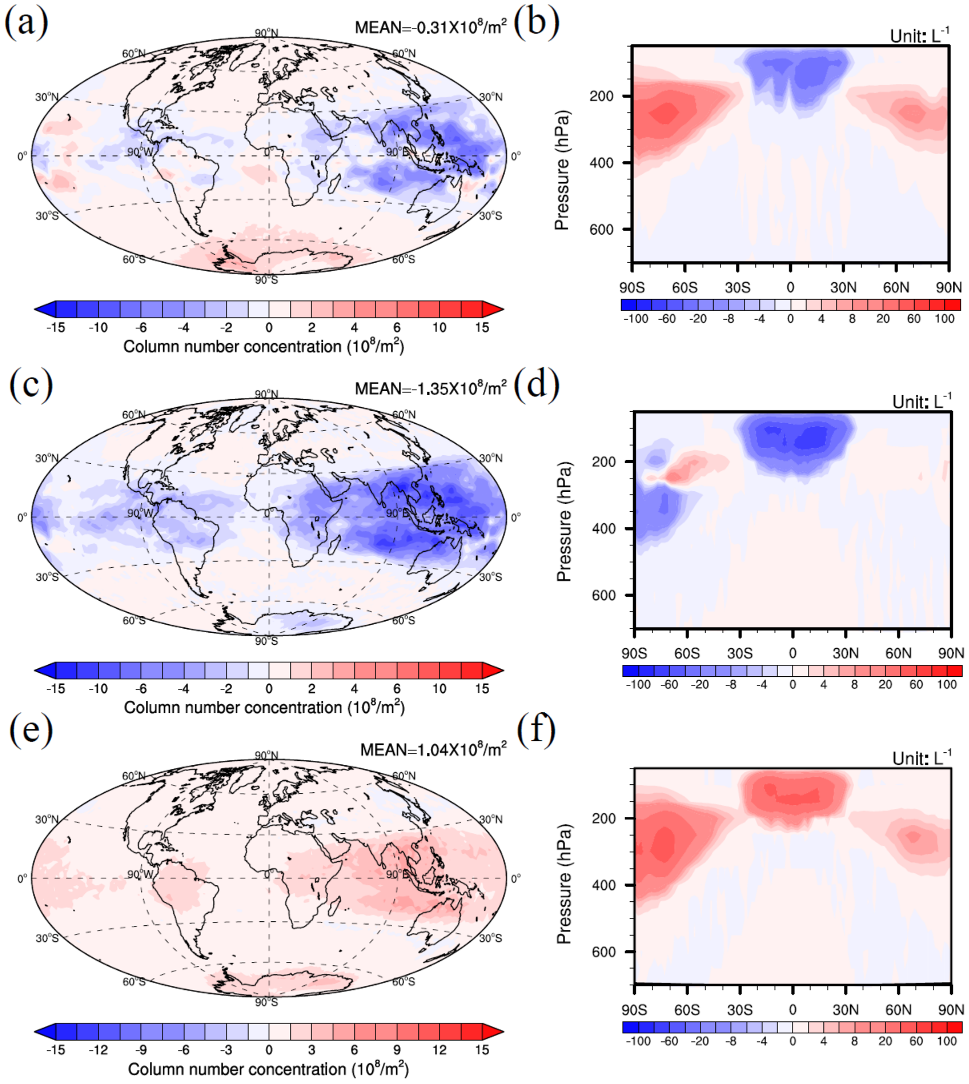
Ni from homogeneous nucleation

Ni from heterogeneous nucleation



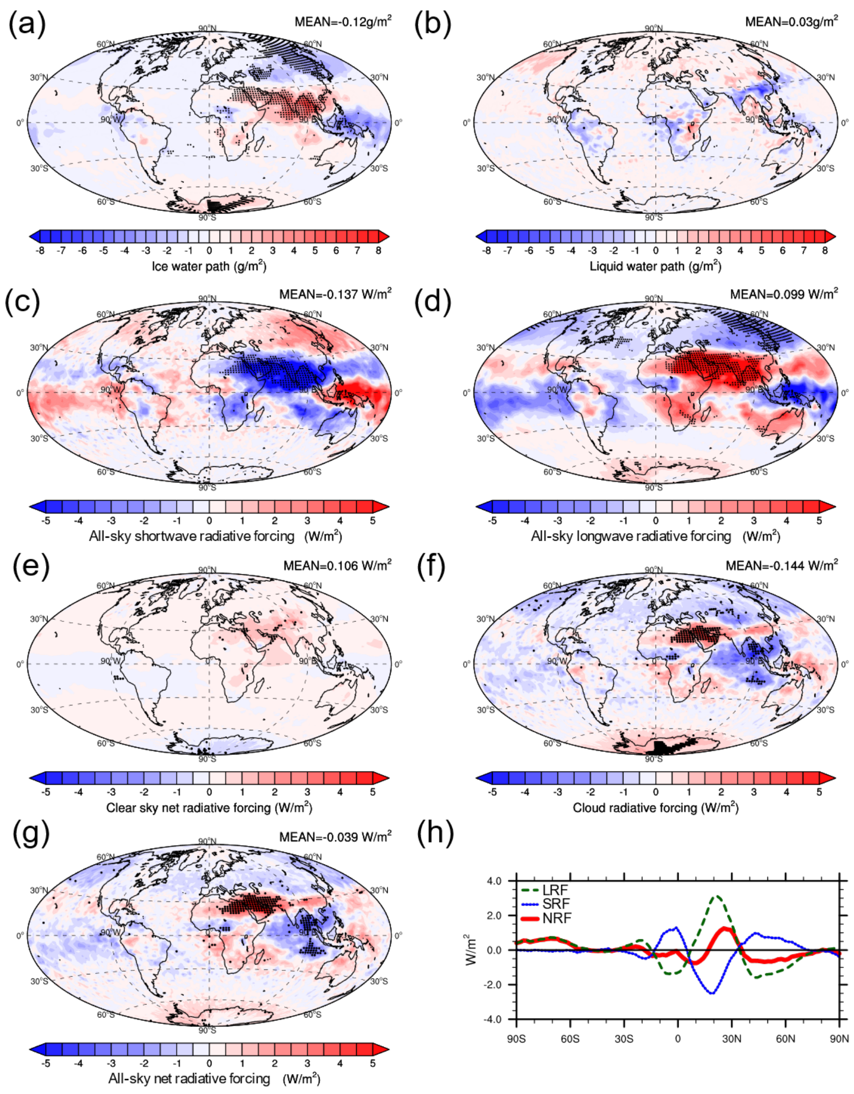
Change in Ni in PI due to SOA

PI_SOA – PI_ALL

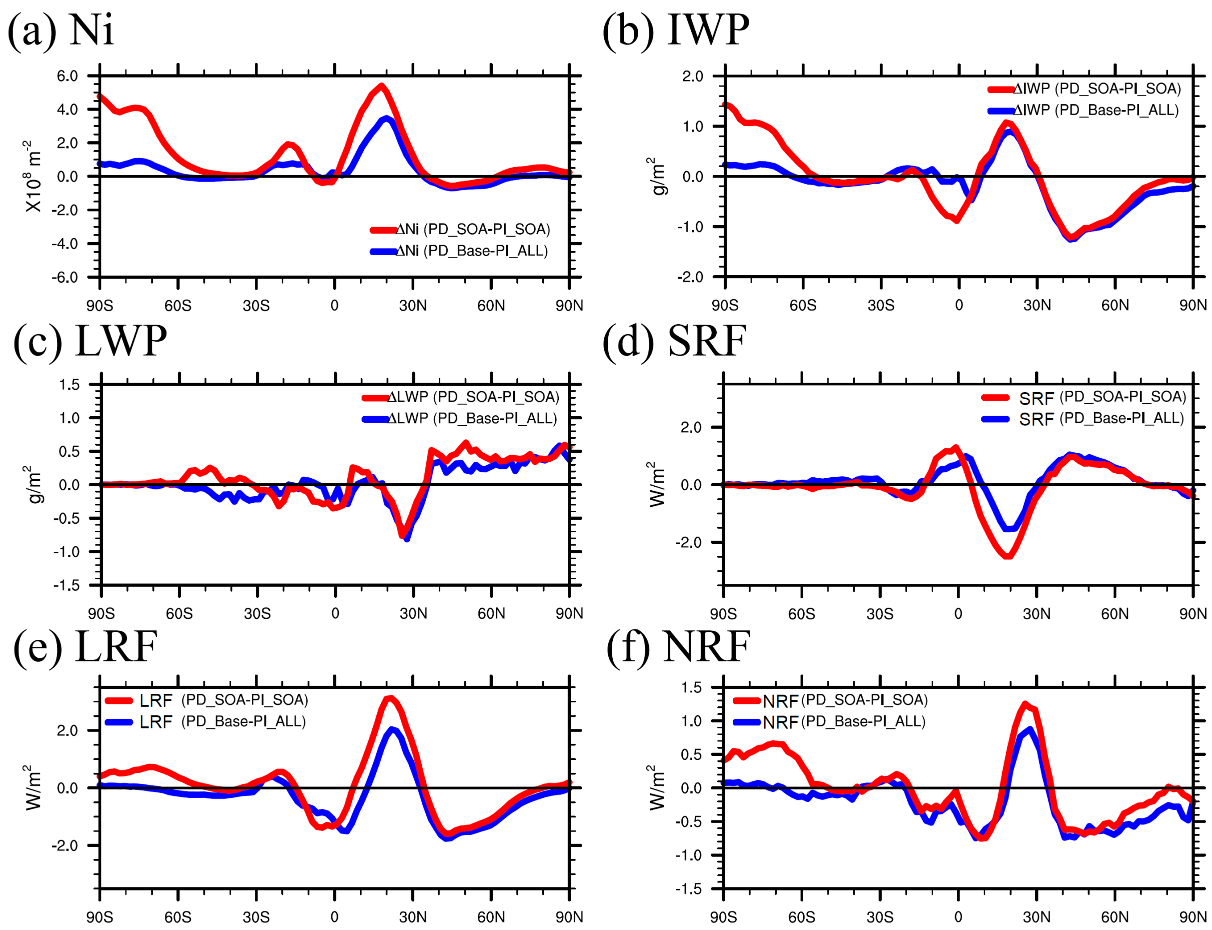


Influence of SOA on anthropogenic forcing

Changes in IWP, LWP, Radiative forcing due to anthropogenic emission after include SOA



With SOA vs Without SOA



Summary

- This work develops a new ice nucleation parameterization, HYBRID, which is a combination of the LP and KL parameterizations. The global model using this new scheme is able to simulate the growth and decay of ice particles in the updrafts and downdrafts associated with gravity waves and the competition among different aerosol size bins for water deposition.
- the emission of aircraft soot has a negative global average NRF of -0.14±0.07 W m^{-2} in large-scale cirrus clouds, while the changes in the sulfur emissions from the PI to the PD lead to a small negative global average NRF of -0.02±0.06 W m^{-2}.
- The global average NRF due to all anthropogenic emissions from PI to PD, which is estimated to be -0.20±0.05 W m^{-2}, is dominated by the NRF caused by increased sulfur emissions.
- The additional INPs from SOA increase the changes in *Ni* due to the changes in anthropogenic emissions from PI to PD. The inclusion of SOA results in a less negative NRF of -0.04±0.07 W m^{-2} associated with the change in all anthropogenic emissions.

More information please refer to Zhu, J. and Penner, J. E.: Radiative forcing of anthropogenic aerosols on cirrus clouds using a hybrid ice nucleation scheme, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2019-1055, in review, 2020.