Non-CO_2 impacts of aviation through aviation-aerosol-ice-cloud interactions

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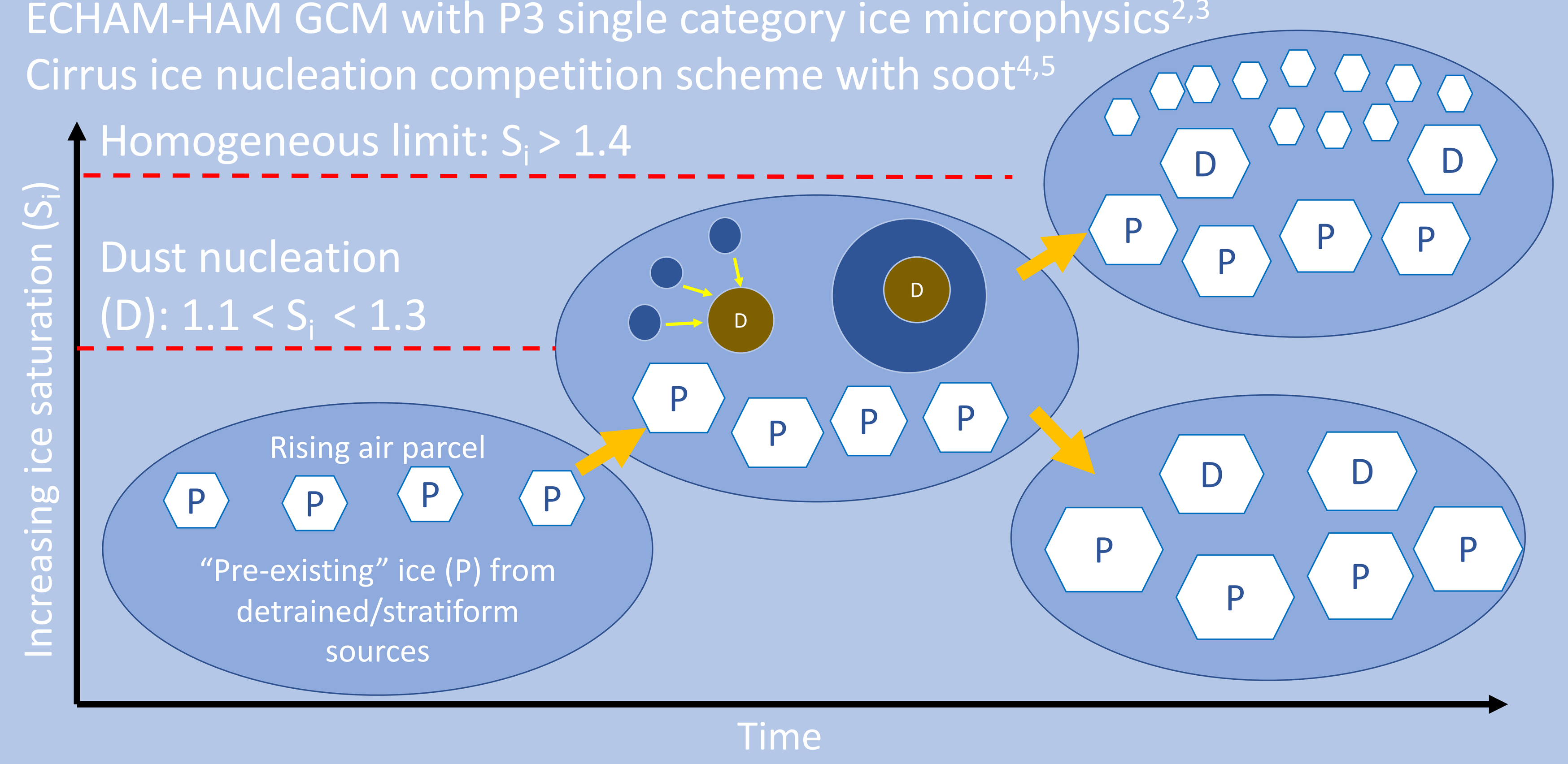
Introduction

Aviation aerosols consist primarily of soot emissions from the incomplete combustion present in aircraft engines. In aircraft exhaust plumes soot particles can act as ice nucleating particles (INPs) and compete with other constituents in the plume to impact the formation of aircraft-induced-clouds (AIC)[1] called contrails, including long-lived persistent contrails and contrail cirrus. These AIC have their own climate impact that can be difficult to distinguish from naturally occurring ice clouds (cirrus) due to their subsequent evolution. We take a preliminary look at the climate impact of aircraft soot emissions by examining their role in ice formation processes, using a new soot parameterisation in our global climate model, ECHAM-HAM.

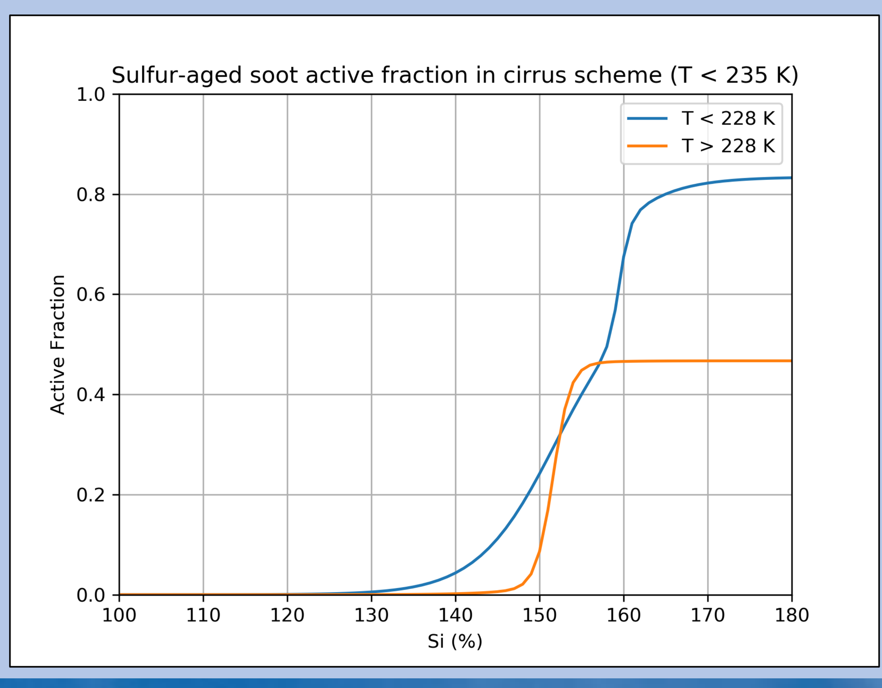
Method

- ECHAM-HAM GCM with P3 single category ice microphysics[2,3]
- Cirrus ice nucleation competition scheme with soot[4,5]

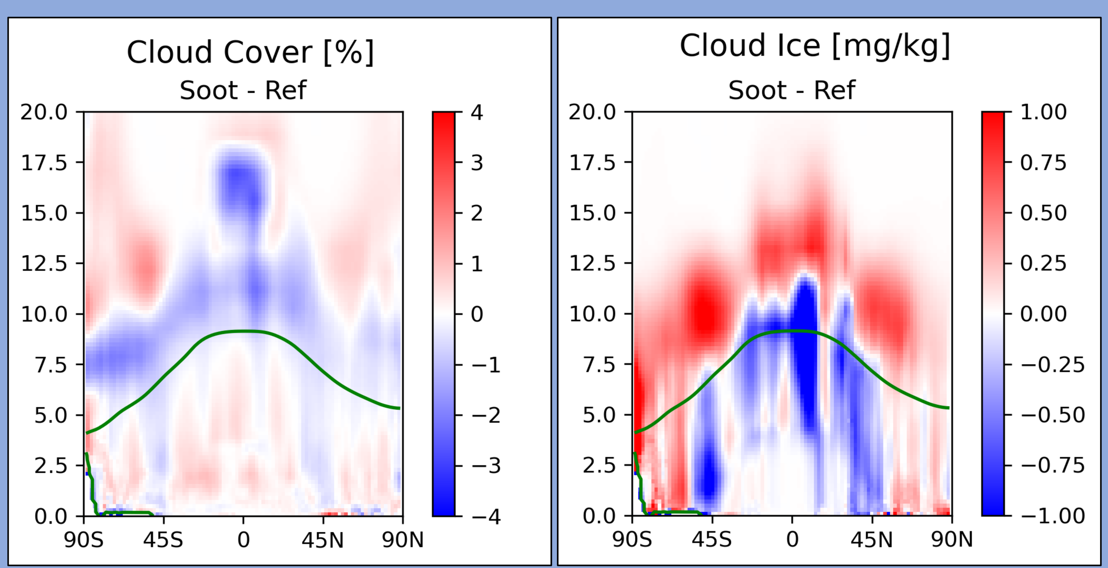


Lohmann et al. (2020) Soot Parameterization[6]

- Sulfur-aged soot used
- Aitken, accumulation, and coarse size mode soot particles
- Ice supersaturation-dependent soot ice active fraction
- Soot competes with dust for water vapor consumption
- Simulated five years: 2000-2004



Explanation



Nadja Omanovic: Cloud cover and cloud ice differences between P3 soot and P3 Ref simulations, the green line represents the -35°C line

- More numerous, active soot particles "out-compete" dust INP for water vapor
- Shift to fewer and optically thicker cirrus clouds
- Results indicate cloud height feedback, but additional tests are needed

Ice formation in cirrus clouds

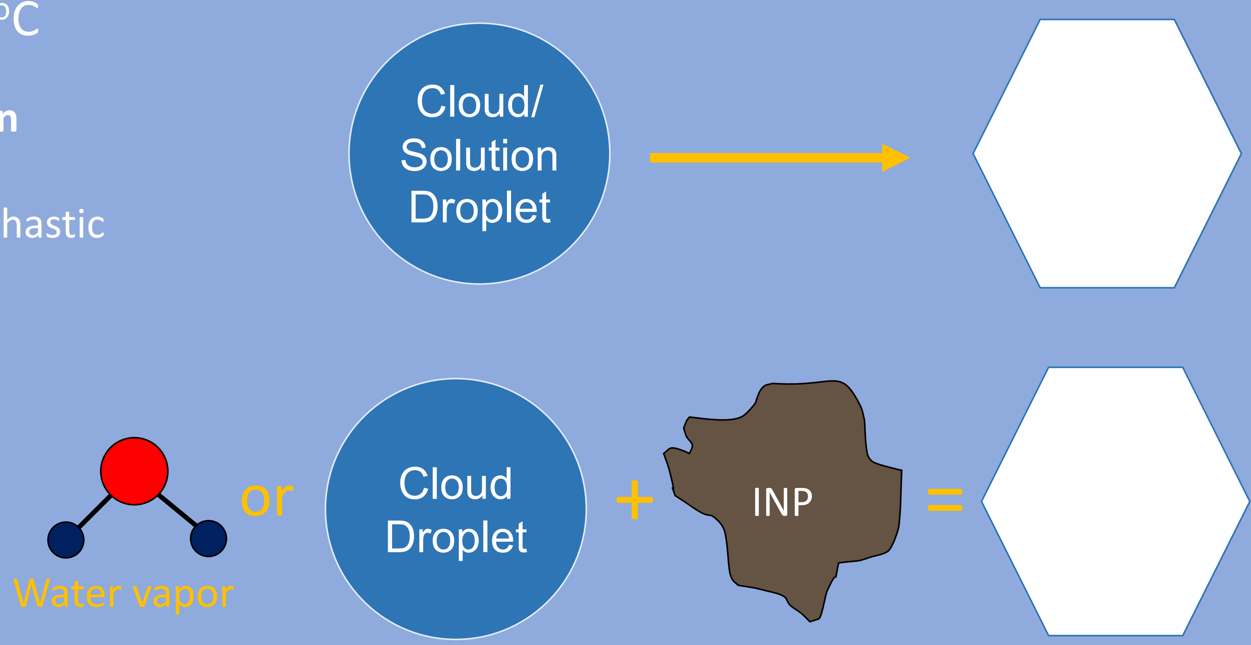
- Temperature < -38°C

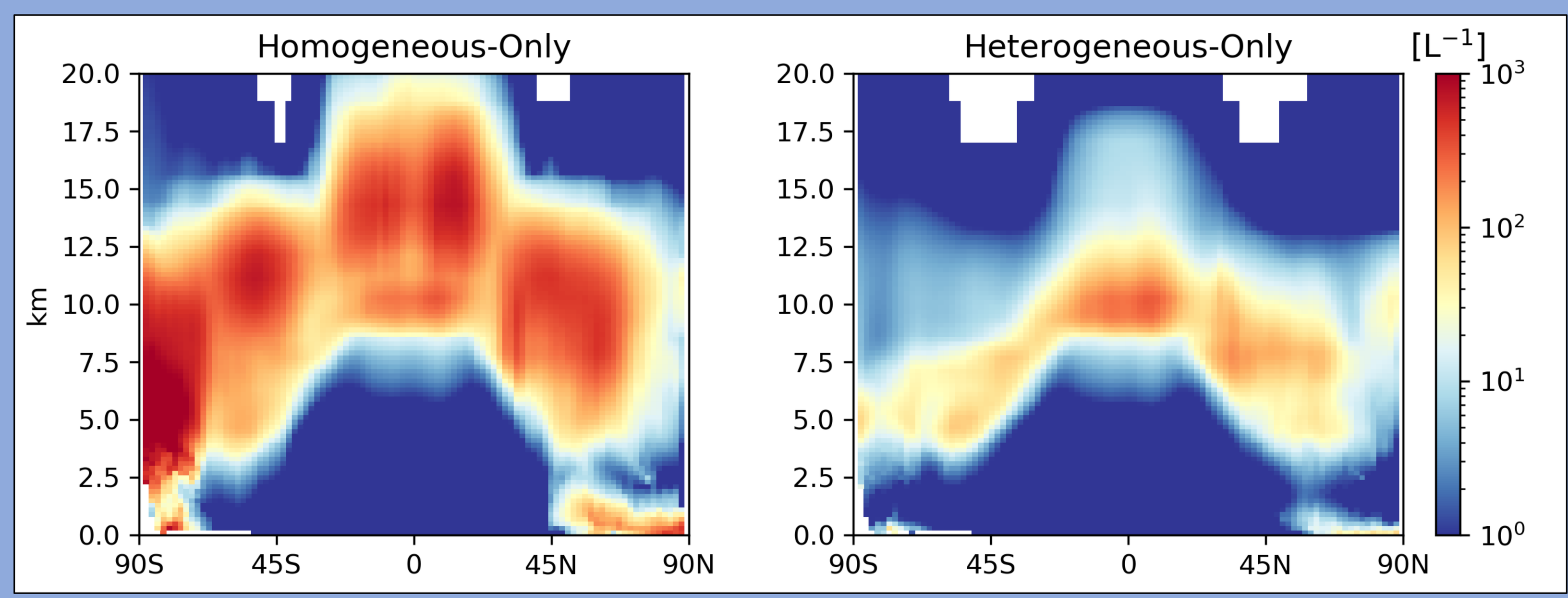
Homogeneous Nucleation

- $S_{ice} > 1.4$
- Spontaneous and stochastic freezing

Heterogeneous Nucleation

- $S_{ice} < 1.4$

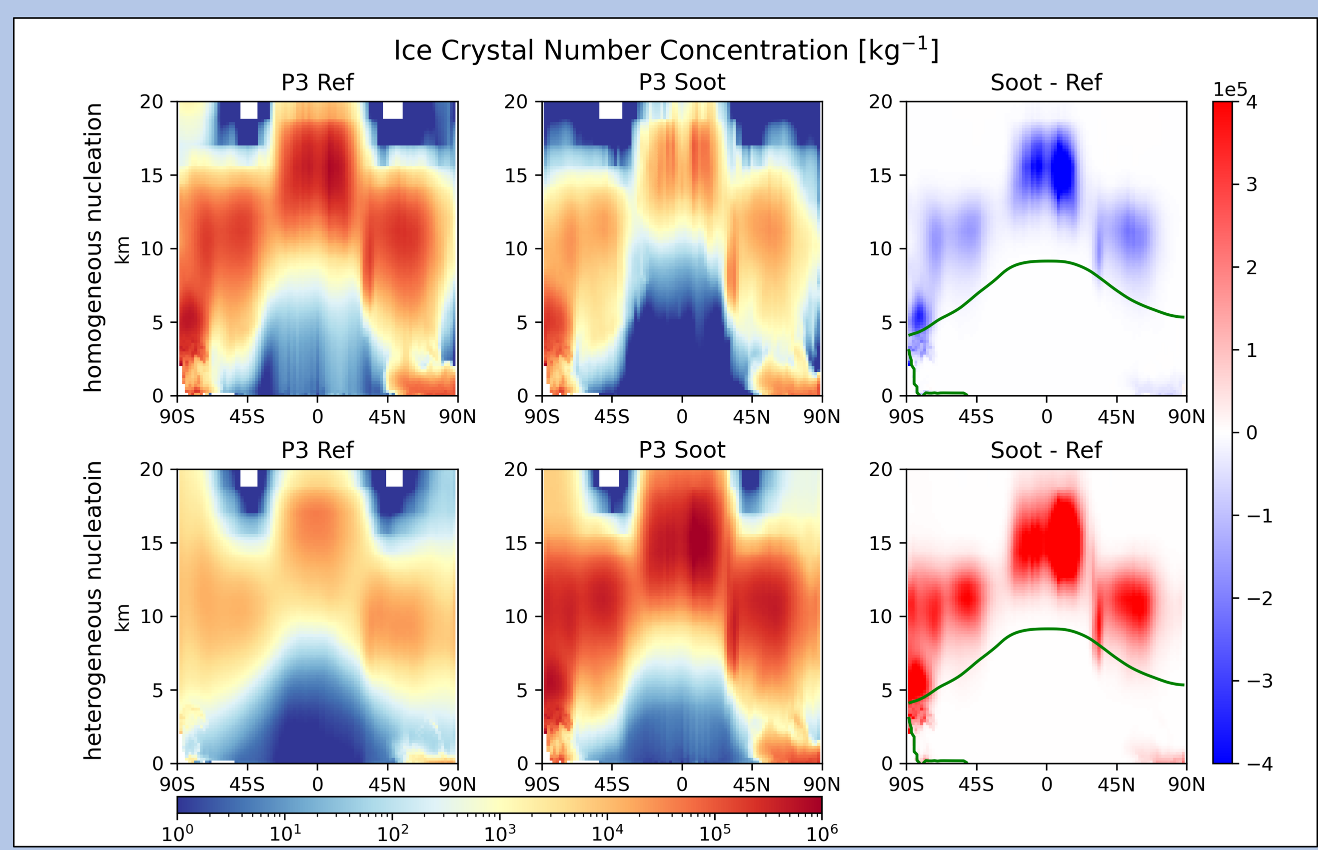




P3 reference (no soot parameterization) in-cloud ice crystal number concentration (L[-1]) for homogeneous-only and heterogeneous-only (on dust INP only) nucleation in cirrus clouds

Results

- Inclusion of soot switches homogeneous-dominant cirrus ice nucleation to heterogeneously dominated cirrus



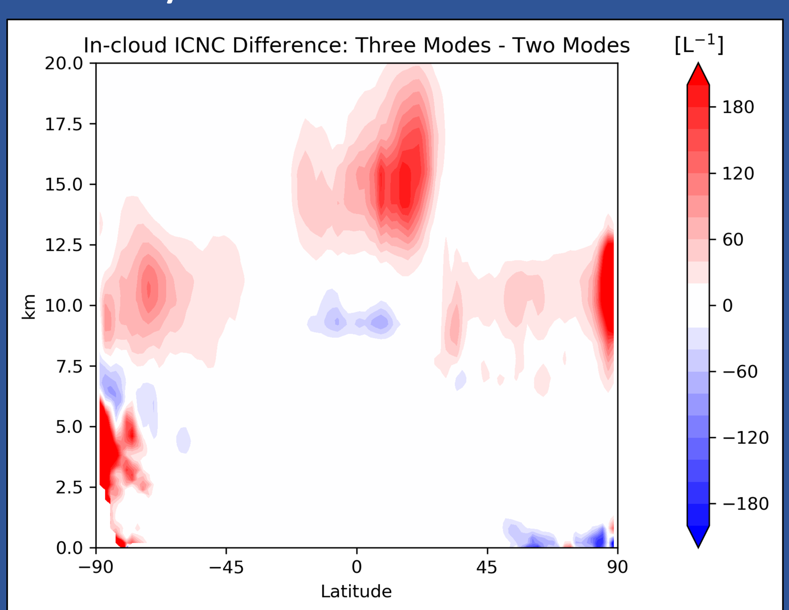
Nadja Omanovic: P3 Ref is with only dust INP in the cirrus scheme for heterogeneous nucleation, P3 soot is the same as P3 Ref, but with aircraft soot as an additional INP in the cirrus scheme

- Considerable warming with soot
- Nearly 70% of warming due to clouds effects
- Decrease in cloud cover counterintuitive at first

Parameter	Soot - Ref
ΔTOA Wm^{-2})	1.2
ΔCRE (Wm^{-2})	0.8
ΔCloud fraction (%)	-0.5
ΔIn-cloud ICNC (L^{-1}) Vertical mean	25.4

Additional Sensitivity Test

- One-year run with less soot modes (only accumulation and coarse)



Parameter	Three Modes - Two Modes Difference
ΔTOA Wm^{-2})	0.9
ΔCRE (Wm^{-2})	0.7
ΔCloud fraction (%)	0.1

Conclusions

- Adding soot as an extra heterogeneous nucleation mode in cirrus scheme leads to considerable warming through a shift in nucleation mode dominance, accompanied by changes in cloud cover and possibly and cloud height
- Results are similar to "overseeding" when adding artificial INP for cirrus cloud seeding[7]
- Is soot "too active" with all size modes or is the response related to the new P3 microphysics, single-category-ice scheme with prognostic sedimentation?
- Additional sensitivity test shows less warming and fewer ice crystals formed with only the larger soot size modes*

**Longer simulation times needed to account for annual variability*

References

1. Kärcher, B.: Formation and radiative forcing of contrail cirrus, *Nat. Comms.*, doi:10.1038/s41467-018-04068-0, 2018.
2. Dietlicher, R., Neubauer, D., and Lohmann, U.: Prognostic parameterization of cloud ice with a single category in the aerosol-climate model ECHAM(v6.3.0)-HAM(v2.3), *GMD*, doi:10.5194/gmd-11-1557-2018, 2018.
3. Dietlicher, R., Neubauer, D., and Lohmann, U.: Elucidating ice formation pathways in the aerosol–climate model ECHAM6-HAM2, *ACP*, doi:10.5194/acp-19-9061-2019, 2019.
4. Kärcher, B., Hendricks, J., and Lohmann, U.: Physically based parameterization of cirrus cloud formation for use in global atmospheric models, *JGR*, doi:10.1029/2005JD00621, 2006.
5. Kuebbeler, M., Lohmann, U., Hendricks, J., and Kärcher, B.: Dust ice nuclei effects on cirrus clouds, *ACP*, doi:10.5194/acp-14-3027-2014, 2014.
6. Lohmann, U., Friebel, F., Kanji, Z.A., Mahrt, F., Mensah, A.A., and Neubauer, D.: Future warming exacerbated by aged-soot effect on cloud formation, Nat. Geo., doi:10.1038/s41561-020-0631-0
7. Gasparini, B. and Lohmann, U. : Why cirrus cloud seeding cannot substantially cool the planet, *JGR*, doi:10.1002/2015JD024666, 2016.

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