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Comparisons of cirrus cloud properties between polluted and pristine air based on in-situ observations from the NASA ATTREX, NSF HIPPO and EU INCA campaigns

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Comparisons of cirrus cloud and ice supersaturation characteristics by using CO as a tropospheric tracer based on ATTREX, HIPPO, INCA and START08 campaigns

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NASA DLH hygrometer: Glenn Diskin, Josh DiGangi (NASA Langley)

Harvard HUPCRS instrument: Steven Wofsy, Bruce Daube, Jasna Pittman (Harvard)

VCSEL hygrometer PI: Mark A. Zondlo (Princeton)

Quantum Cascade Laser Spectrometer DUAL instrument PI: Steven C. Wofsy (Harvard Univ.)

ATTREX science team; HIPPO campaign science team; INCA campaign science team

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Advanced Study Program
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Outline

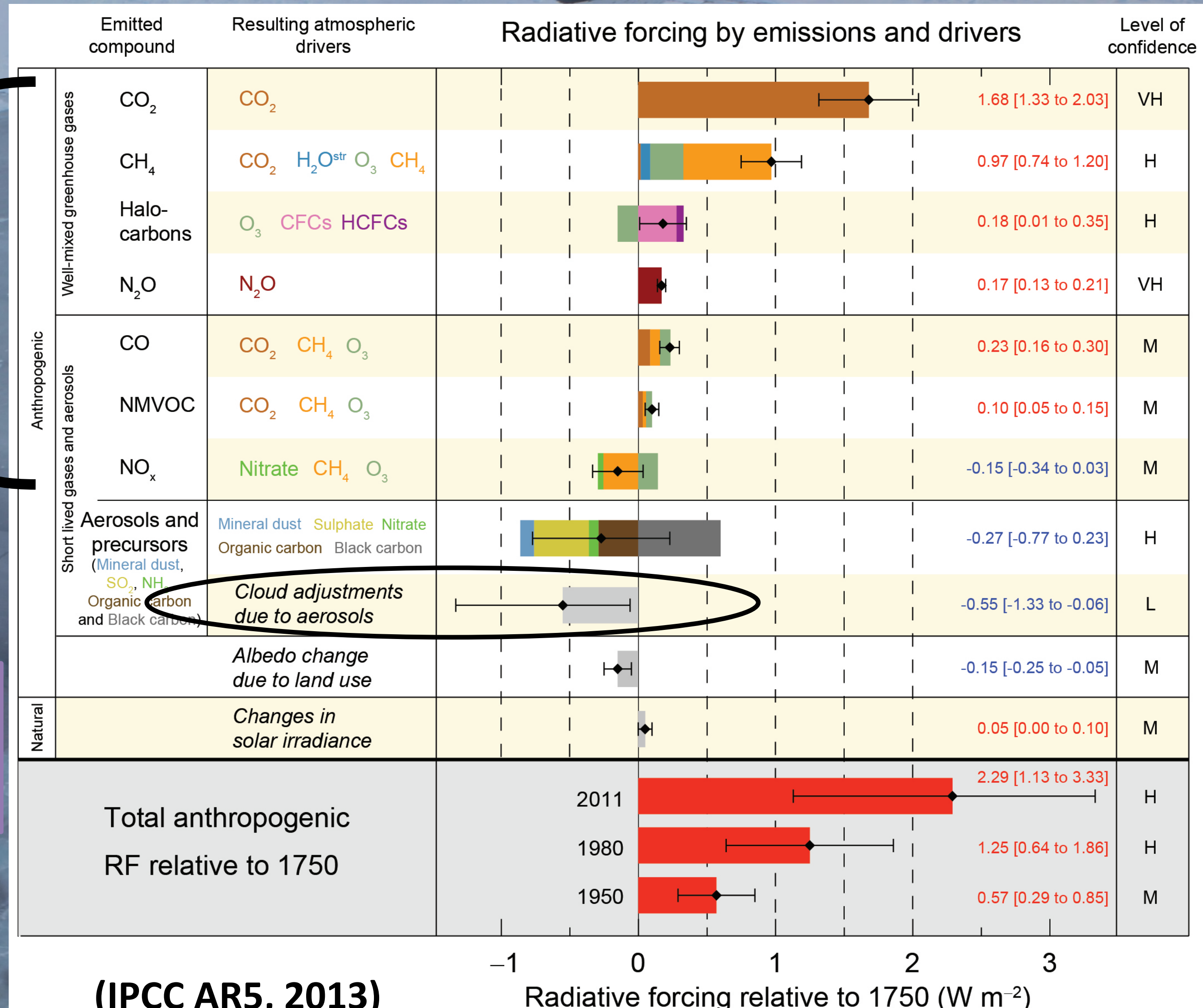
- **Motivation**
  - Climate effects of cirrus clouds
  - Large radiative forcing difference between cirrus and their birthplace – ice supersaturation
- **Datasets**
  - NASA Airborne Tropical TRopopause EXperiment (**ATTREX**) campaign 2014
  - The NSF HIAPER Pole-to-Pole Observations (**HIPPO**) Global campaign
  - The Interhemispheric Differences In Cirrus Properties from Anthropogenic Emissions (**INCA**) campaign funded by the European Union
  - The NSF Stratosphere-Troposphere Analyses of Regional Transport (**START08**) campaign
- **Analysis**
  - Distributions of ice supersaturation in relation to temperature and CO
  - Comparisons of cirrus microphysical properties by using CO as a tropospheric tracer
    - Ice crystal number concentration at different CO concentrations
    - Ice crystal number-weighted mean diameter at different CO concentrations
- **Discussions and future work**

Large uncertainties in cloud perturbations

Anthropogenic greenhouse gases: **~3 W m^{-2}**

Global cloud net forcing: **~- 20 W m^{-2}** *(Chen et al. 2000)*

~15% change of global cloud radiative forcing -> Anthropogenic GHG



(IPCC AR5, 2013)

Cirrus clouds and ice supersaturation

Cirrus clouds

- **235-185K, ~30% coverage** *(Wylie and Menzel*, 1999)
- **Warming and cooling effects**

  - Global net forcing +5.4 W m^{-2} *(chen et al. 2000)*

  - Microphysical & macroscopic properties
  (Liou 1992; Pruppacher and Klett 1996)

Important to understand the transition from ISS to cirrus clouds

(Solomon *et al.*, 2010, *Science*)

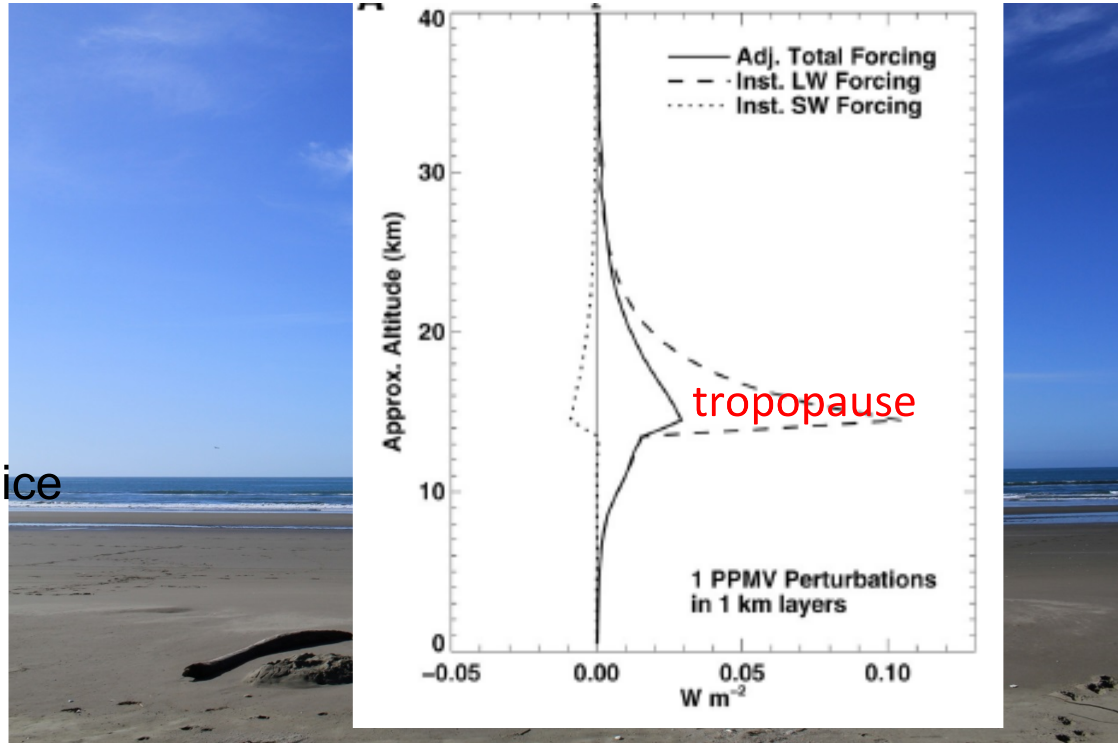
Ice Supersaturation (ISS)

Prerequisite condition for ice crystal formation

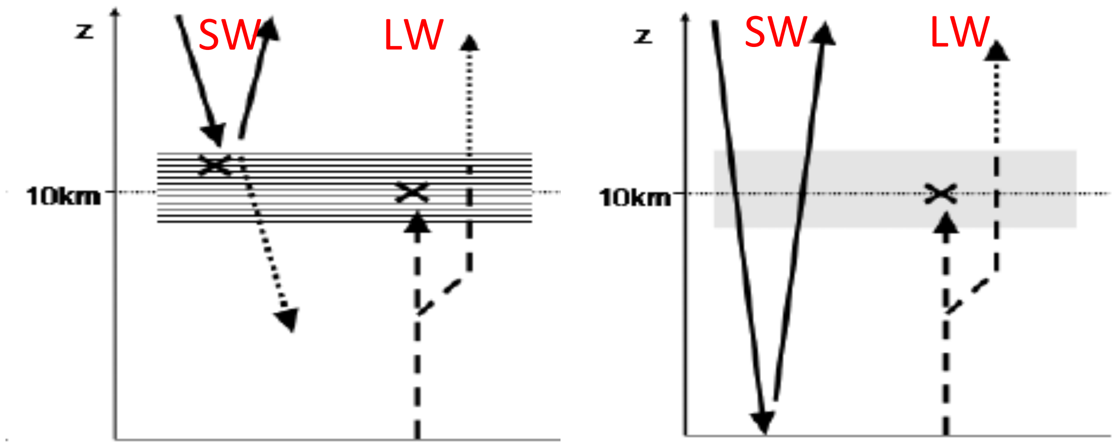
$$ISS = RHi - 1 = e / e_s - 1$$

e: water vapor pressure

e_s: saturation vapor pressure wrt ice



Difference in radiation between ISS and cirrus clouds



Cirrus clouds

Ice supersaturation

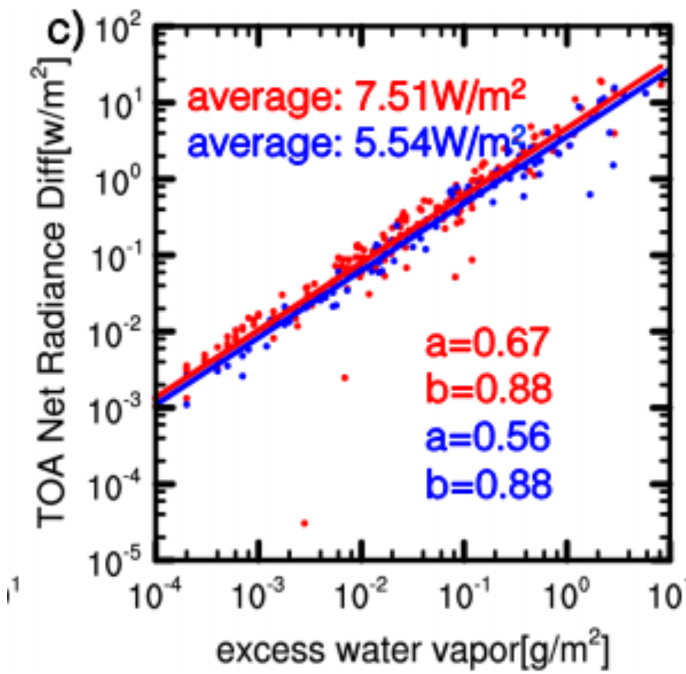
Up to **3 K d^{-1}** difference in vertical heating rate

(Fusina *et al*. 2007)

Differences in TOA net radiation (W/m^2)

RRTMG calculation: Replacing observed ISS with artificial ice crystals

NSF ***Stratosphere-Troposphere Analyses of Regional Transport (START08)*** campaign



Up to ~20-30 W/m2 differences in TOA net radiation

Red: Clear-sky ISS

Blue: In-cloud ISS

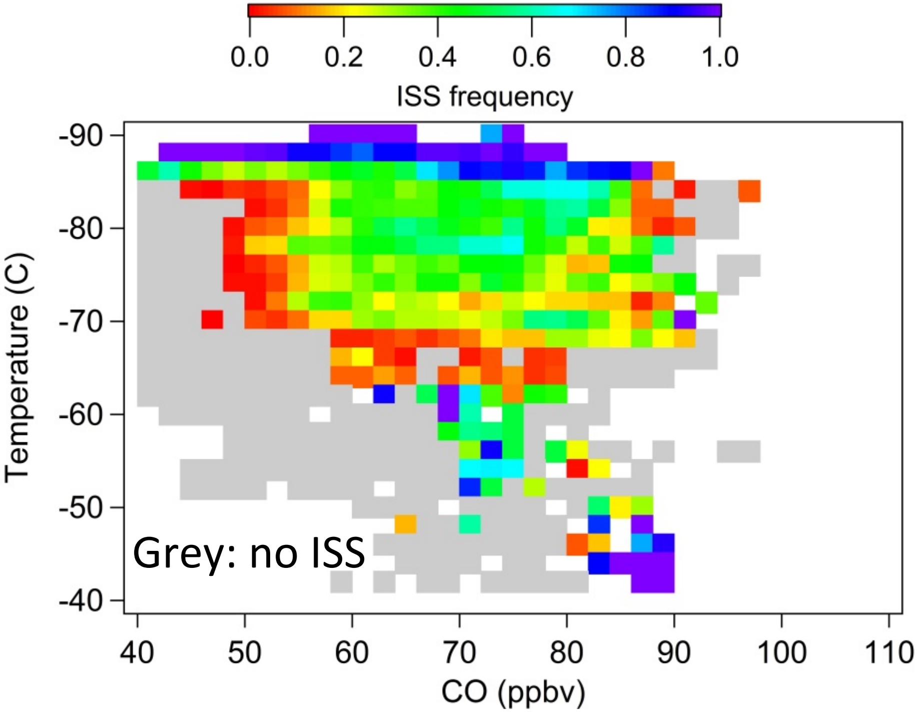
Collaboration with Xiaoxiao Tan and Dr. Yi Huang at McGill University, Canada

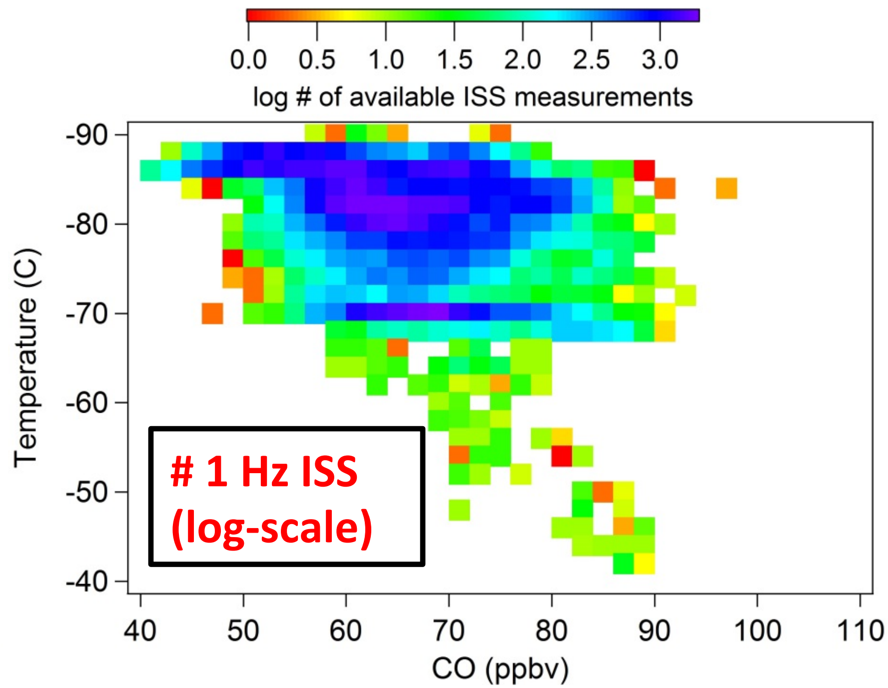
NASA Airborne Tropical TRopopause EXperiment (ATTREX) campaign 2014 deployment (Jan15–Mar14 2014)

- Ice crystals: SPEC **FCDP probe**, **1-50 micron**
- Water vapor data: NASA **DLH** instrument
  - 1 s data
- CO data: Harvard **HUPCRS** instrument
  - 10 s data
  - CO concentration is generally at 50–85 ppbv
- Vertical wind velocity: NASA Ames Research Center, Meteorological Measurement System (MMS) 3-D wind (1 Hz)
- **All ice crystal and ice supersaturation analysis is restricted to T ≤ -40°C**
  - Cirrus cloud temperature range in ATTREX campaign is **much lower** (i.e., typically -65°C to -80°C) than those in HIPPO and INCA campaigns (i.e., typically -40°C to -65°C).

Using CO chemical tracer as a tropospheric tracer:
- Synchronized measurement with H_2O and ice crystals
- Less interaction with clouds

ATTREX (2014): Ice supersaturation (ISS) conditions in relation to T and CO

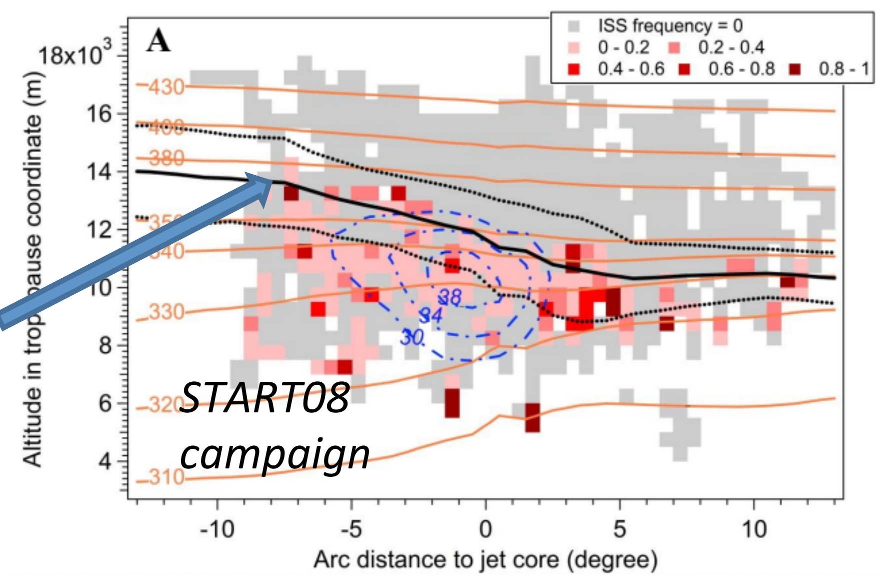




1-Hz ISS occurrence frequency

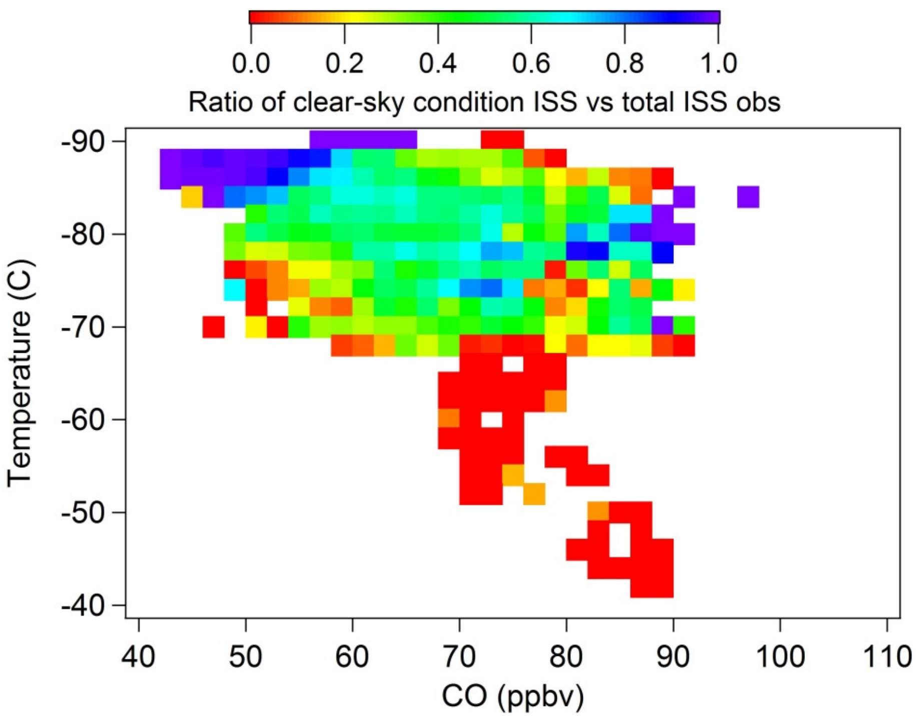
ATTREX: Higher ISS occurrence frequency around -85 to -89 C;
Consistent with high ISS frequency around ***extratropical tropopause (Diao et al. 2015 JGR)***

Needs more analysis of ISS distribution in relation to tropical tropopause

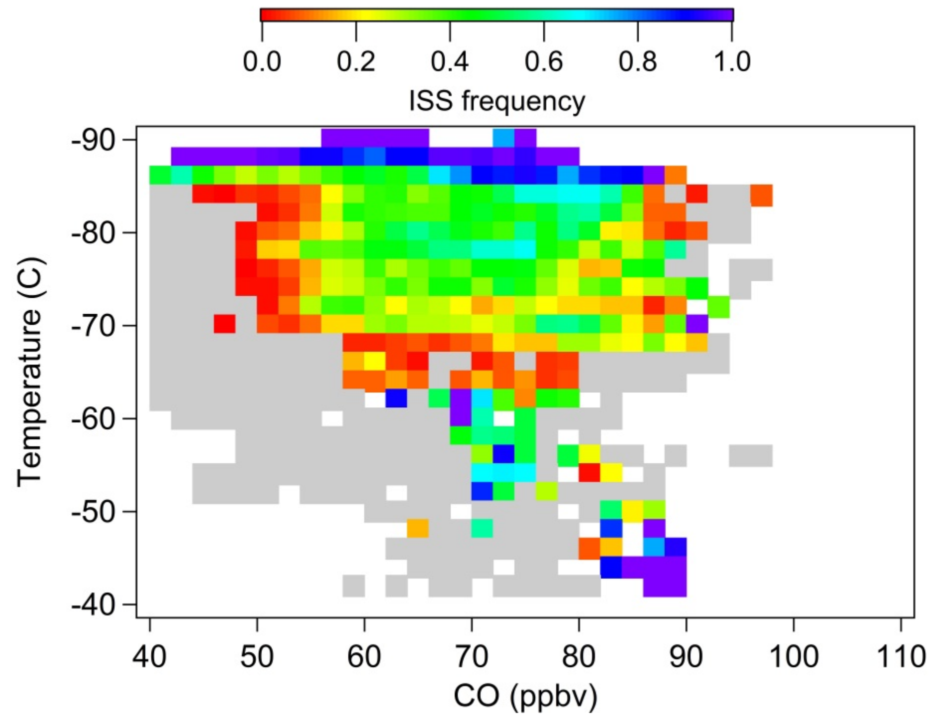


ATTREX (2014): ISS conditions in relation to Temperature and CO concentration

Ratio of 1-Hz ISS observations at
clear-sky vs. total (in-cloud + clear-sky) condition



1-Hz ISS occurrence frequency

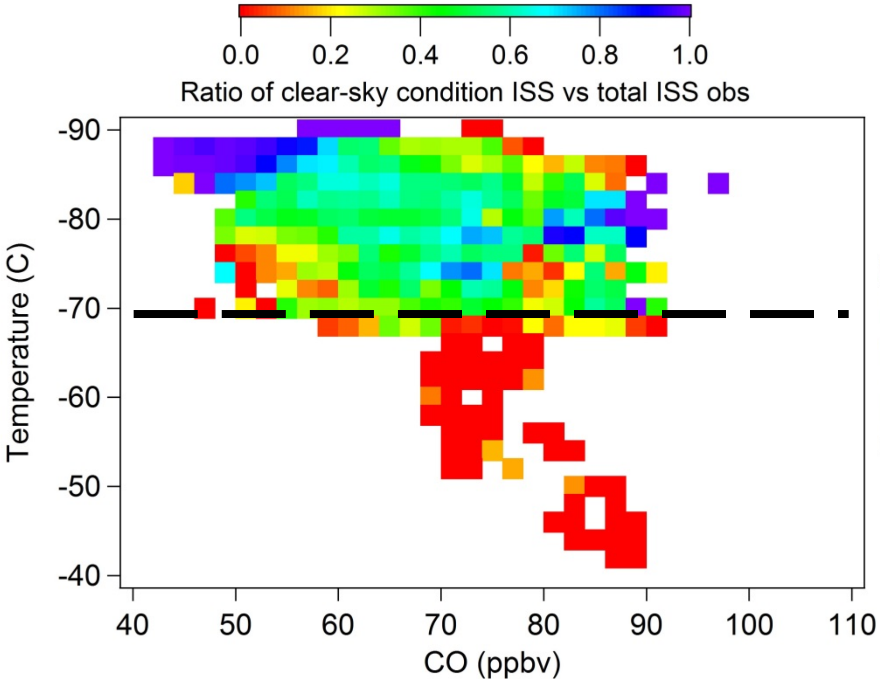


"In-cloud condition" defined as FCDP ice crystal number concentration (Nc) > 0 L^{-1}

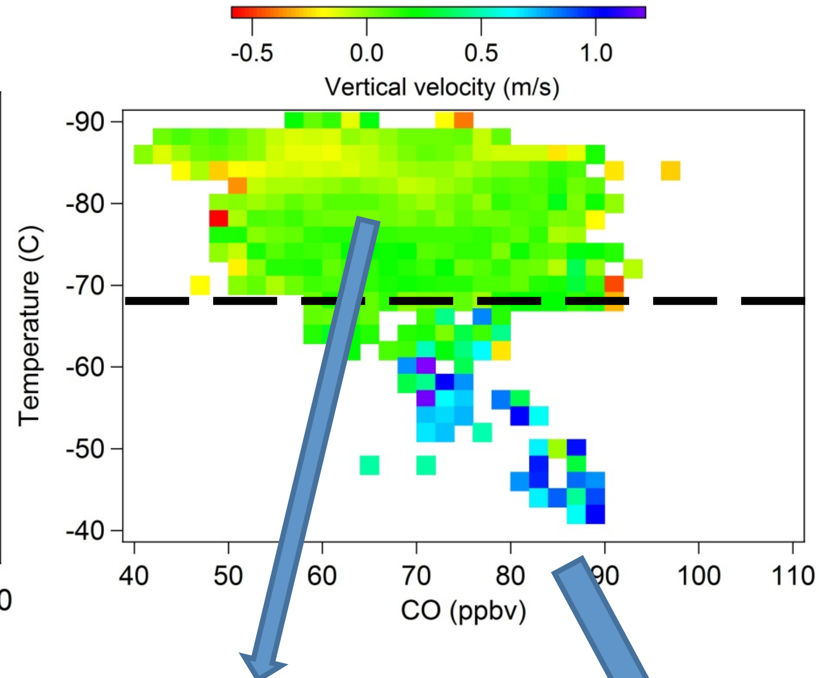
Most of the ISS observations below -70°C have **~50% ISS at clear-sky condition and ~50% ISS at in-cloud condition**

ATTREX (2014): Ratio of clear-sky vs in-cloud ISS

Ratio of 1-Hz ISS observations at
clear-sky vs. total (in-cloud + clear-sky) condition



Average vertical velocity for ISS observations

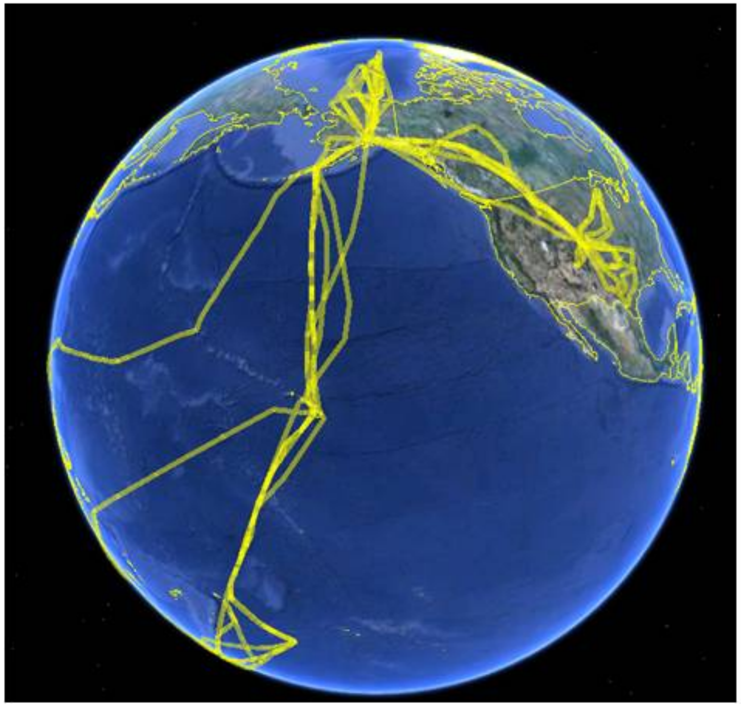


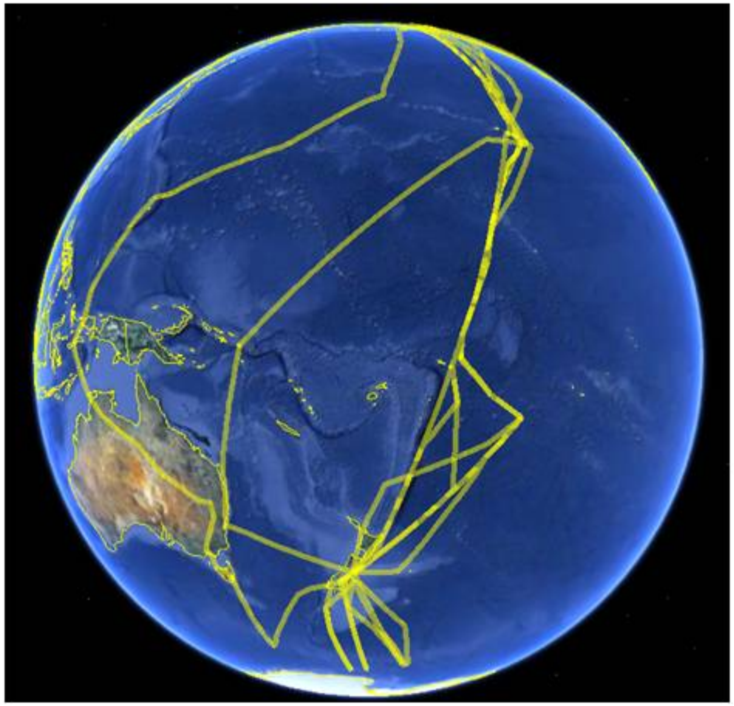
Average vertical velocity inside ISS mostly within +/- 20 cm/s

Updraft of 60 to 120 cm/s at higher CO concentration

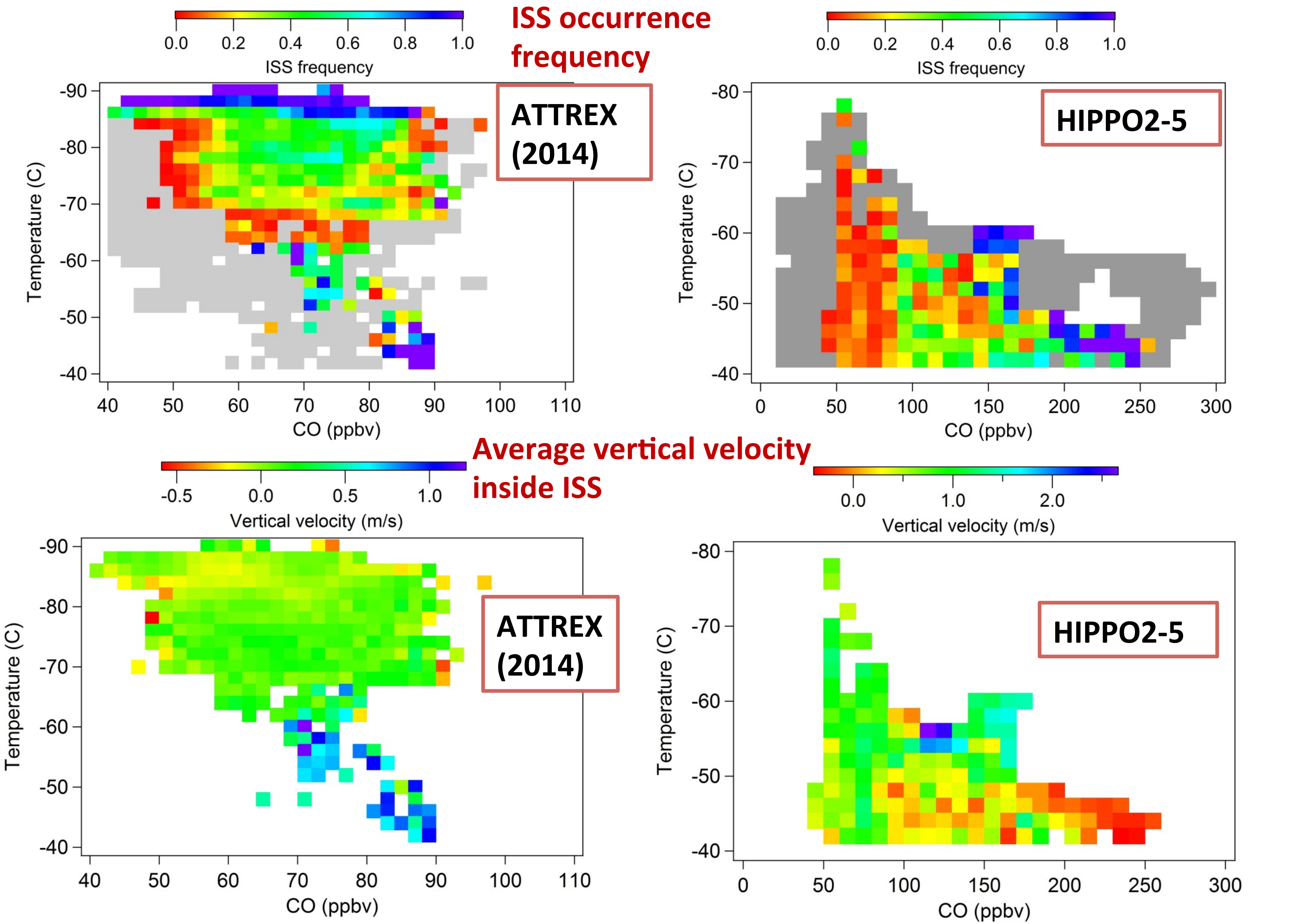
NSF HIAPER Pole-to-Pole Observations (HIPPO) Global flight campaign #1-5 (2009-2011) *(Wofsy et al., 2011)*

- **Latitudinal: 87°N to 67°S**
- **Vertical: ~600 transects** from surface to the upper troposphere and lower stratosphere (UT/LS)
- **Resolution: ~200 m; Duration: ~400 hr; 1-Hz observations**
- **All analysis restricted to T≤-40°C;** Ice crystals (restrict to 87.5 μm - 1600 μm);
- Most cirrus clouds observed in HIPPO were extratropical *in situ* cirrus.

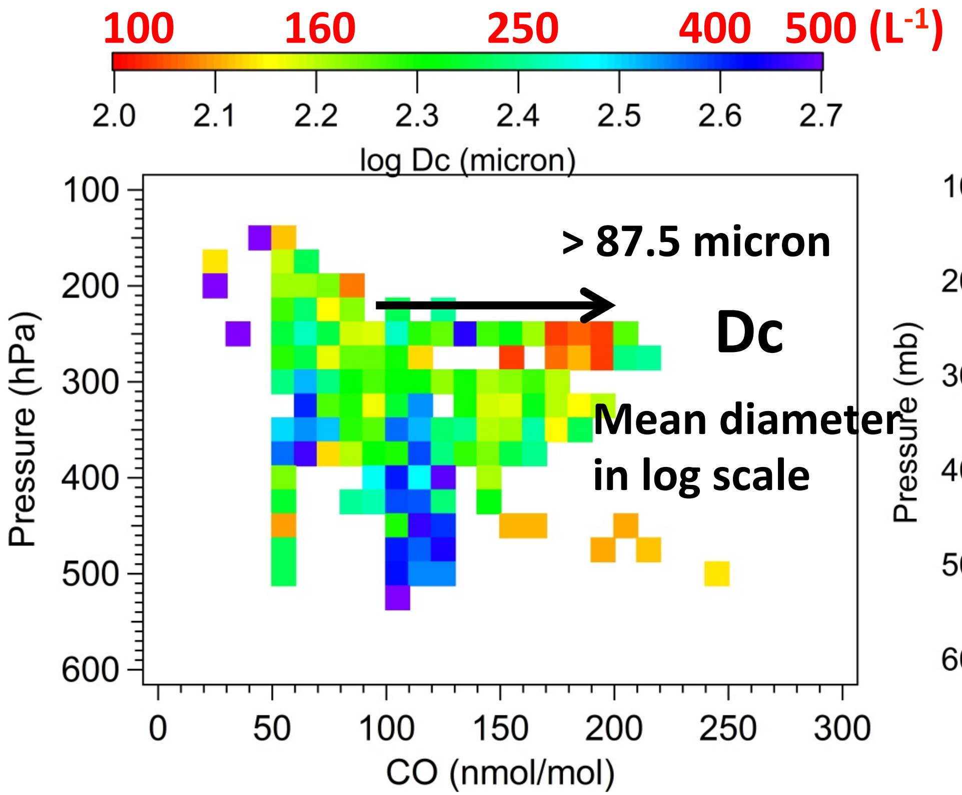


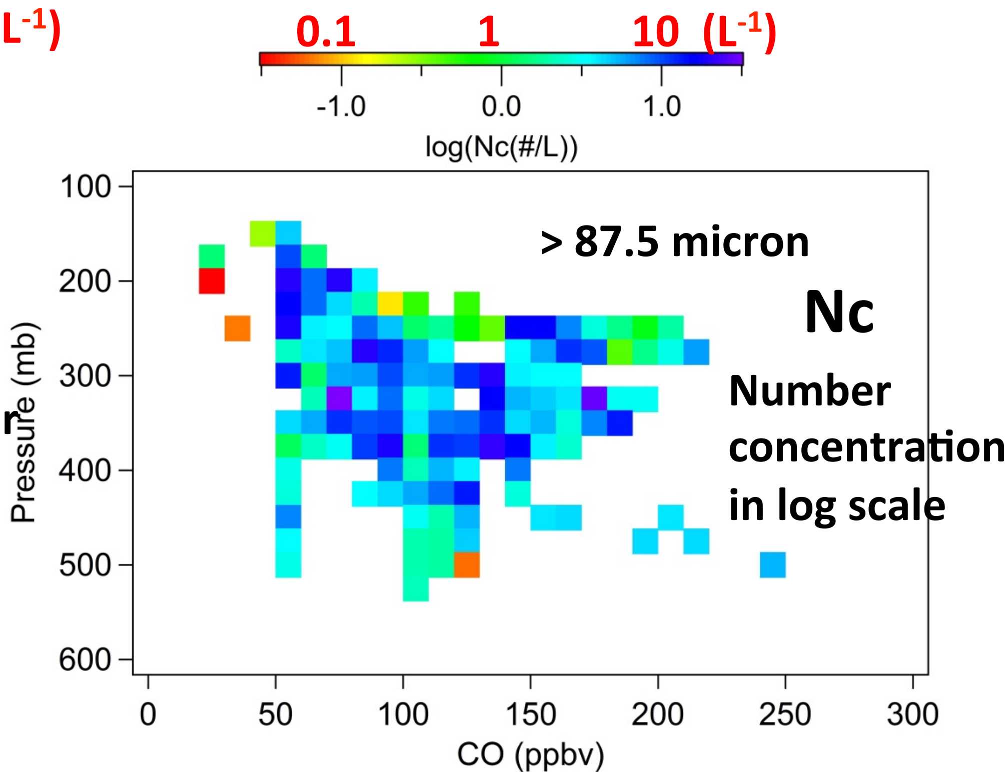


Comparison of ISS conditions between ATTREX 2014 and HIPPO#2-5:



HIPPO#2-5: Distributions of F2DC number-weighted mean diameter (Dc) and ice crystal concentration (Nc) in relation to carbon monoxide (CO)





Remaining questions:
- **Lack of measurements of small ice crystals in HIPPO**
- What other factors can also contribute to the smaller Dc values?

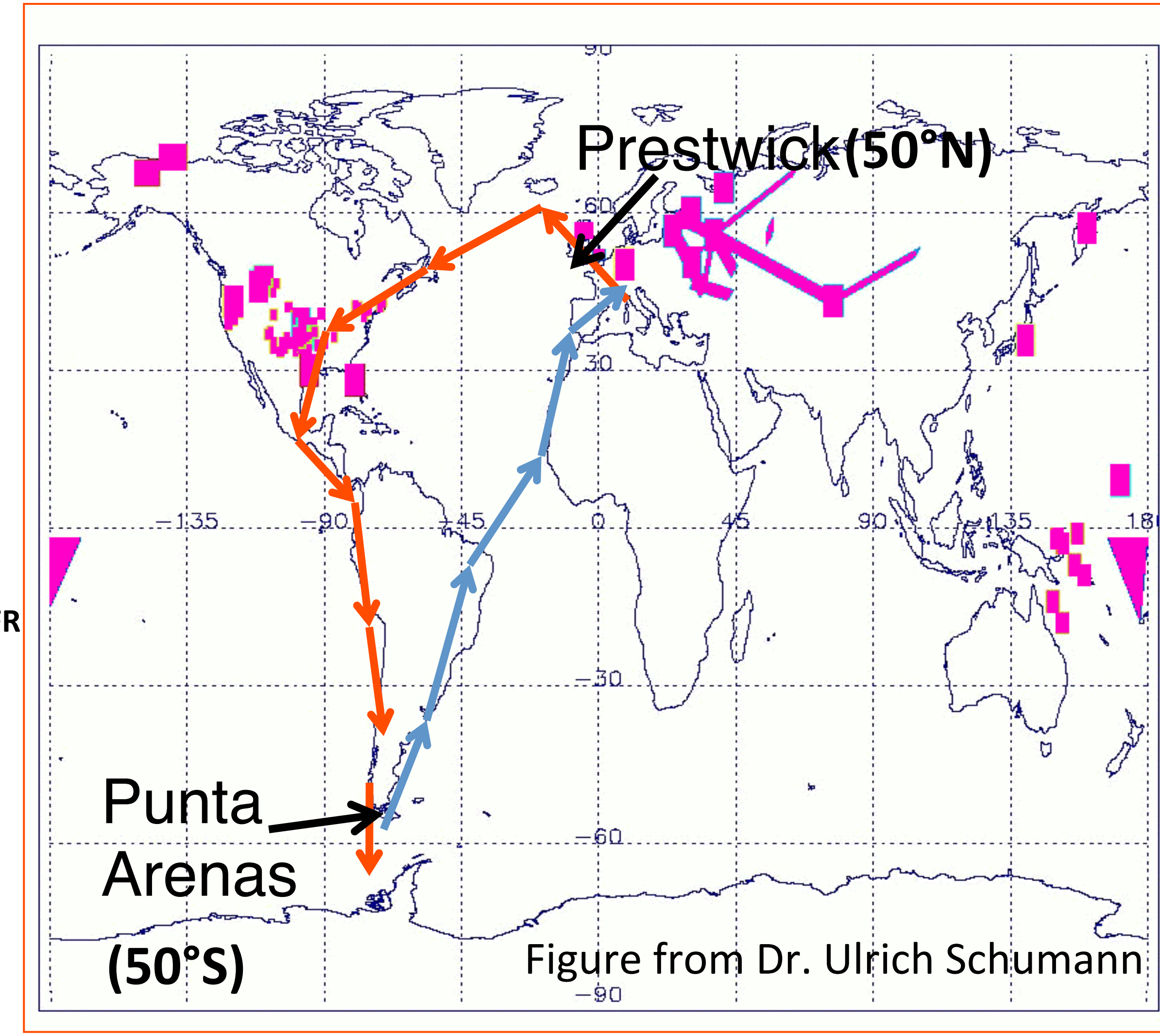
Complex problem: Multiple factors can potentially influence ice crystal formation:

[1] Relative humidity
[2] Vertical wind speed
[3] Temperature
[4] Aerosol content and concentrations

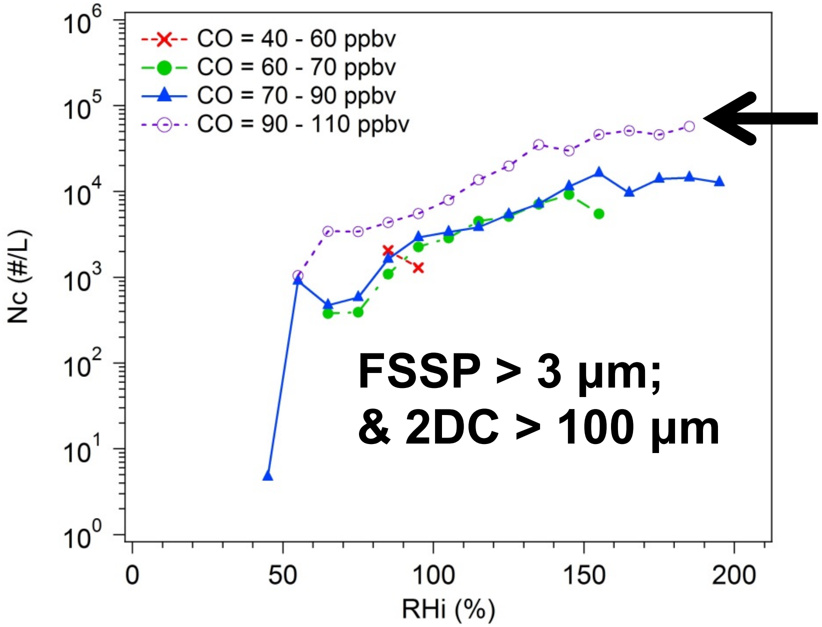
Interhemispheric Differences in Cirrus Properties from Anthropogenic Emissions: The INCA Project 2000 - 2002

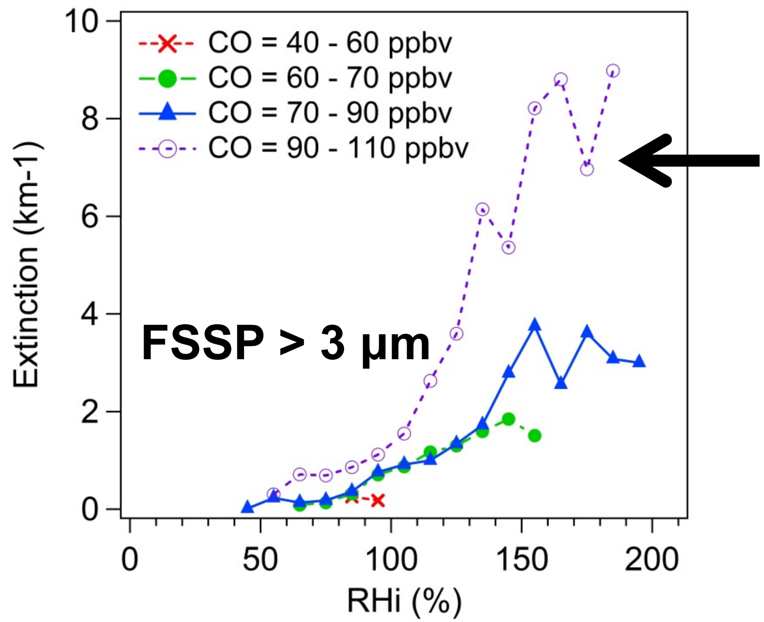
- **European Community, Fifth Framework Programme**
- ***Partners:***
- **Stockholm University (Coordinator), SW**
- **DLR (German Aerospace Centre), DE**
- **University of Helsinki, FI**
- **LaMP, University of Clermont-Ferrand, FR**
- **NILU (Norwegian Institute for Air Research), NO**
- **LMD (Laboratoire de Météorologie Dynamique du CNRS), FR**

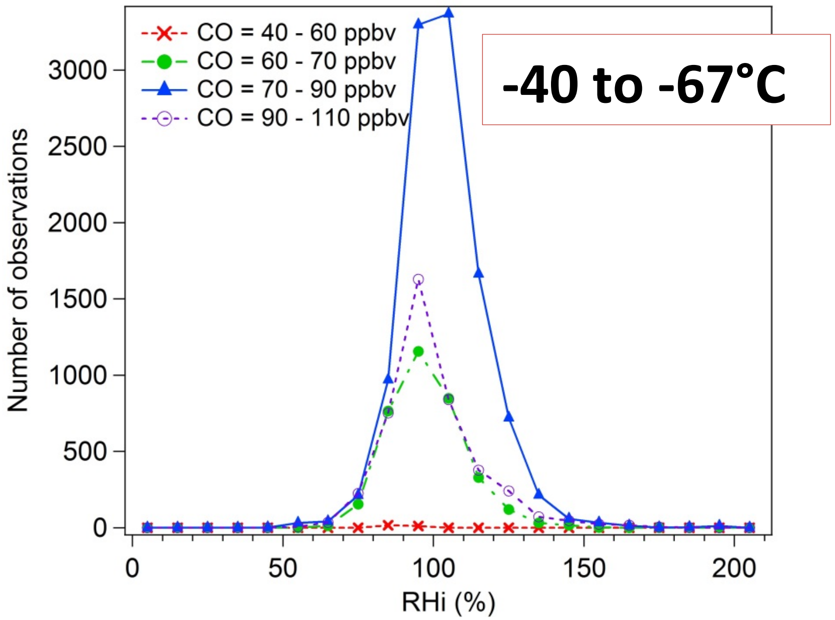
INCA:
aerosol/cirrus measurements near **50°S** and **50°N**.



INCA data: Ice crystal concentration (Nc) at different CO concentrations



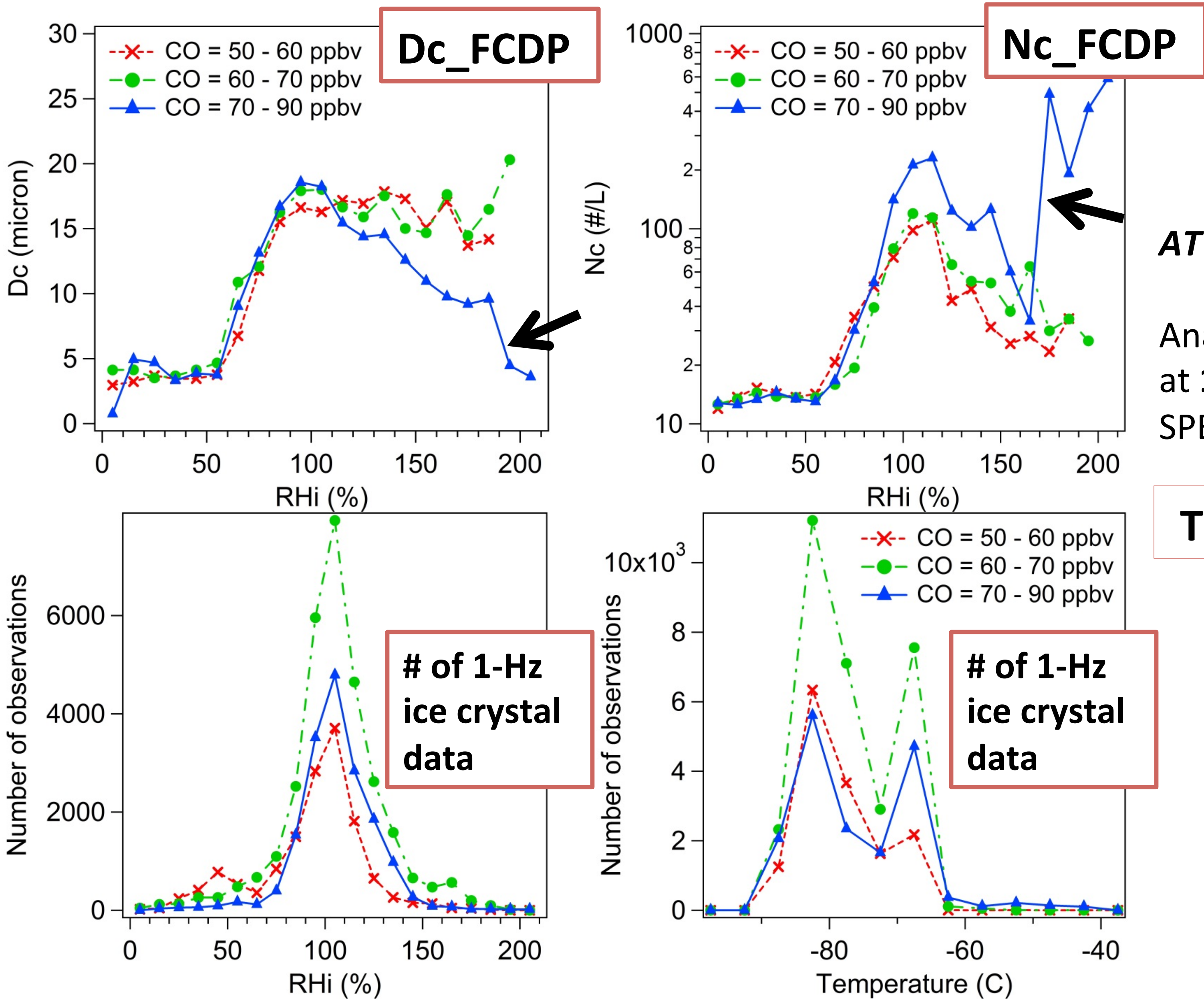




INCA campaign:
Analyzing **both** smaller ice crystals (**3-20 µm**) and larger ice crystals (**100-800 µm**).

Remaining question:
FSSP-300 instrument in INCA campaign was subject to **shattering** effect. Does shattering occur more frequently at higher CO concentrations?

ATTREX (2014): SPEC FCDP ice crystal concentration (Nc) and number-weighted mean diameter (Dc) at different CO concentrations

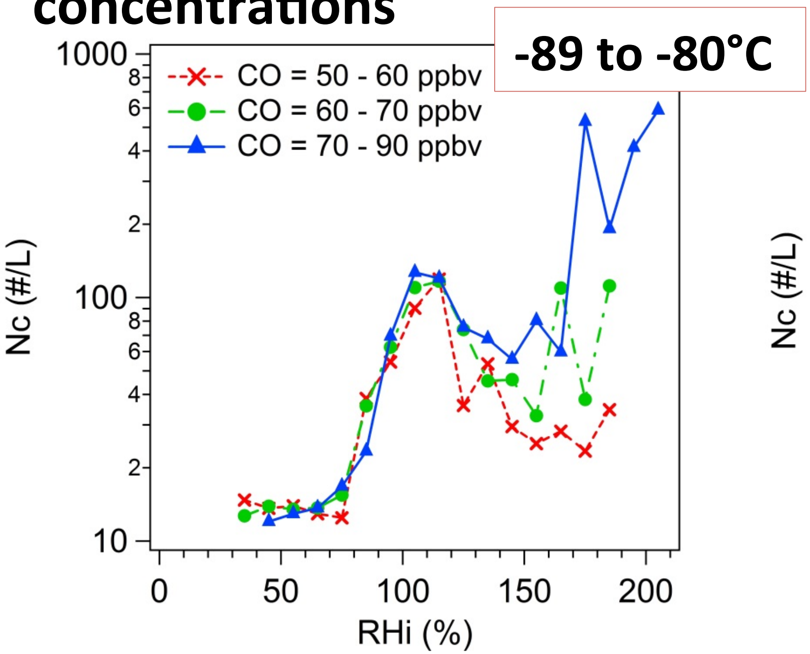


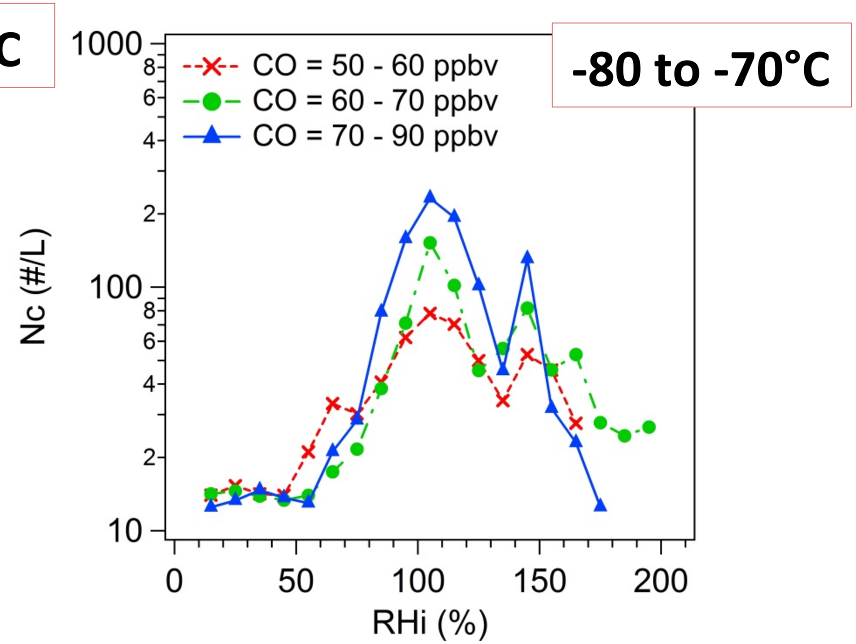
ATTREX campaign:

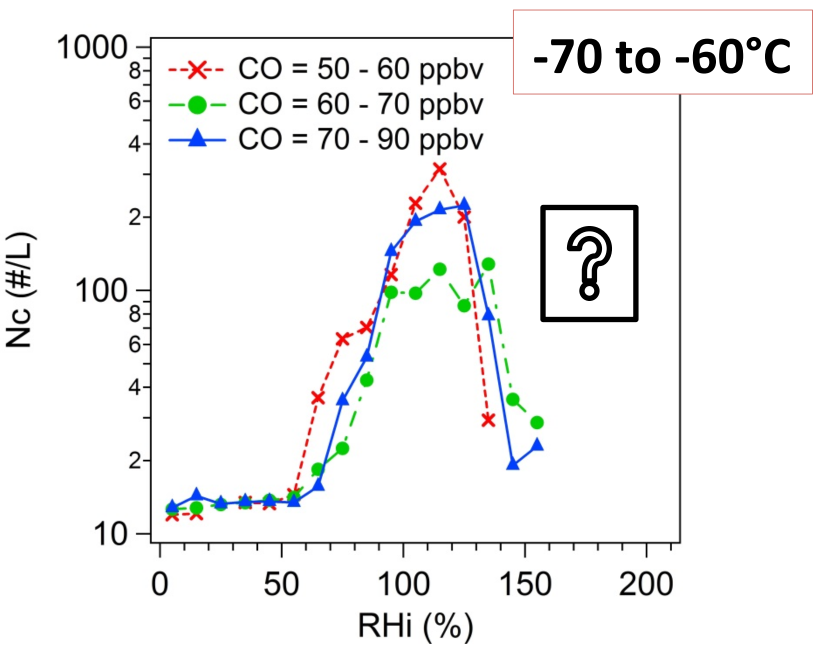
Analyzing **ice crystals** at **1-50 µm**, using the SPEC FCDP probe.

T = -40 to -89°C

ATTREX (2014): SPEC FCDP ice crystal concentration (Nc) at different CO concentrations







ATTREX campaign:

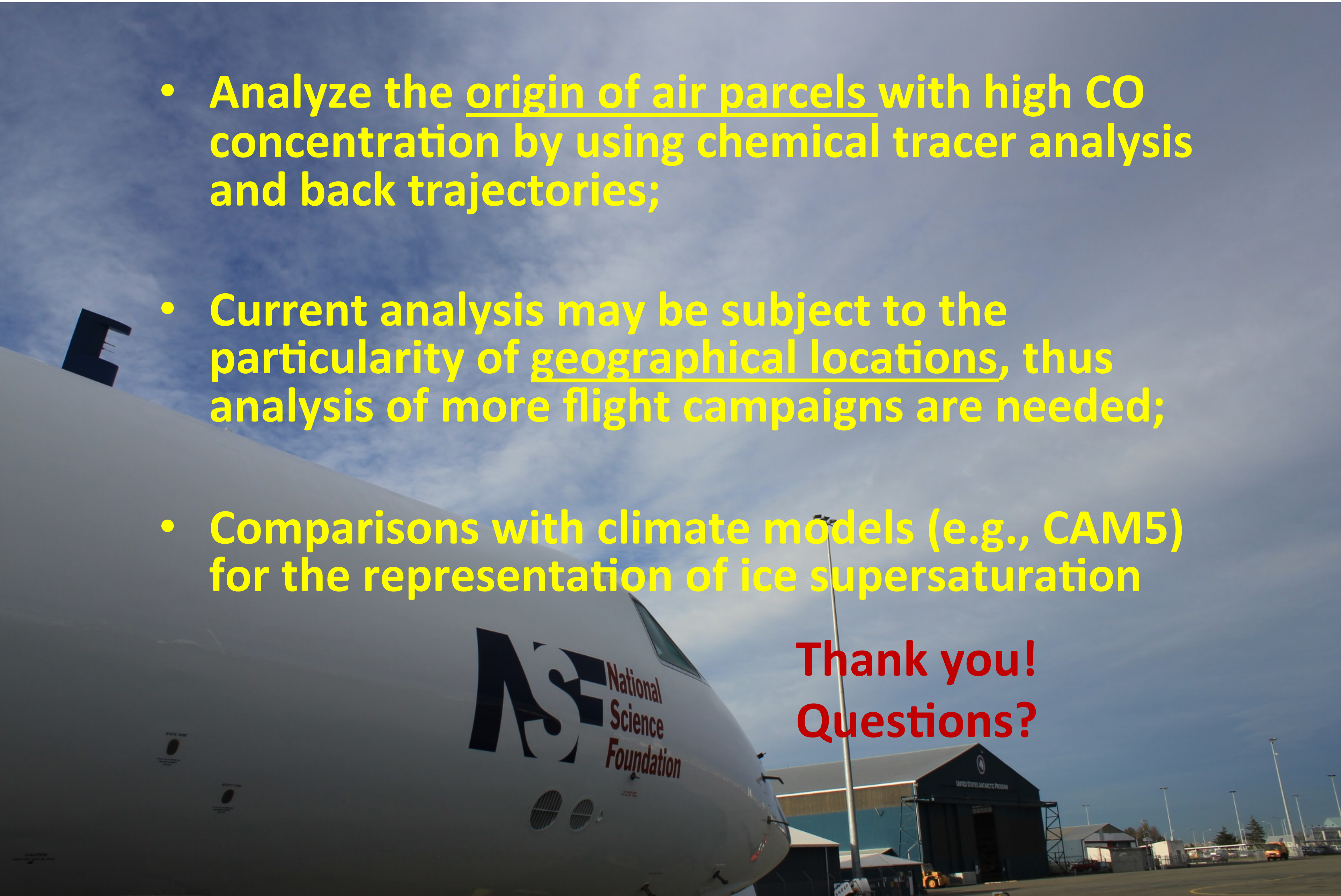
For **-70 to -80°C and -80 to -89°C**, Nc values seem to ***differ*** between higher and lower CO concentrations, but not for **-60 to -70°C**

Whether Nc and Dc distributions differ between higher and lower CO concentration is still an open question

Future work: separating other factors' influences (such as T, w) and investigate the **size distributions** of ice particles.

Future work

- **Analyze the origin of air parcels with high CO concentration by using chemical tracer analysis and back trajectories;**
- **Current analysis may be subject to the particularity of geographical locations, thus analysis of more flight campaigns are needed;**
- **Comparisons with climate models (e.g., CAM5) for the representation of ice supersaturation**



Thank you!
Questions?