

# 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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## Collaborators:

Drs. Jorgen B. Jensen (Postdoc advisor, NCAR/EOL), Ulrich Schumann (German Aerospace Center (DLR)), Eric Jensen (NASA Ames), Xiaoxiao Tan and Yi Huang (McGill)

SPEC FCDP probe: Paul Lawson, Sarah Woods (SPEC Inc.)

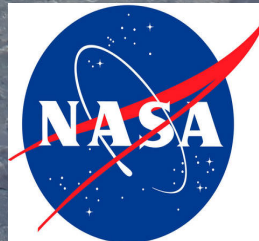
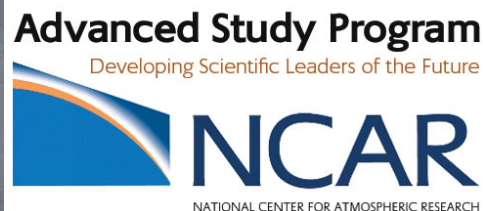
NASA DLH hygrometer: Glenn Diskin, Josh DiGangi (NASA Langley)

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 **2015-July-23**





# Outline

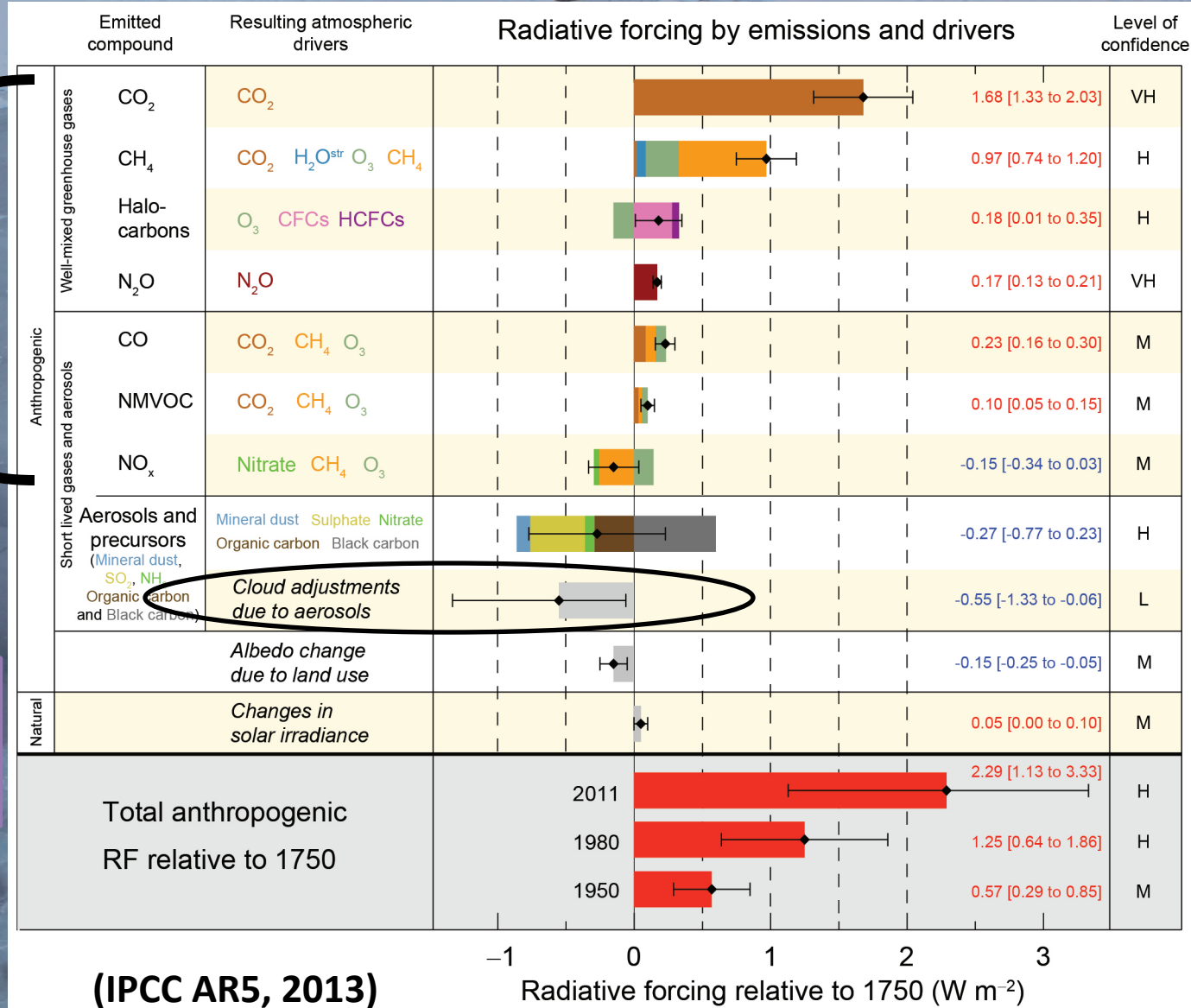
- **Motivation**
  - Climate effects of cirrus clouds
  - Large radiative forcing difference between cirrus and their birthplace – ice supersaturation
- **Datasets**
  - NASA Airborne Tropical Tropopause Experiment (**ATTREX**) campaign 2014
  - The NSF HIAPER Pole-to-Pole Observations (**HIPPO**) Global 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:**  
 $\sim 3 \text{ W m}^{-2}$

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

**$\sim 15\%$  change of global cloud radiative forcing  
 -> Anthropogenic GHG**





# 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<sup>-2</sup>** (*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*)

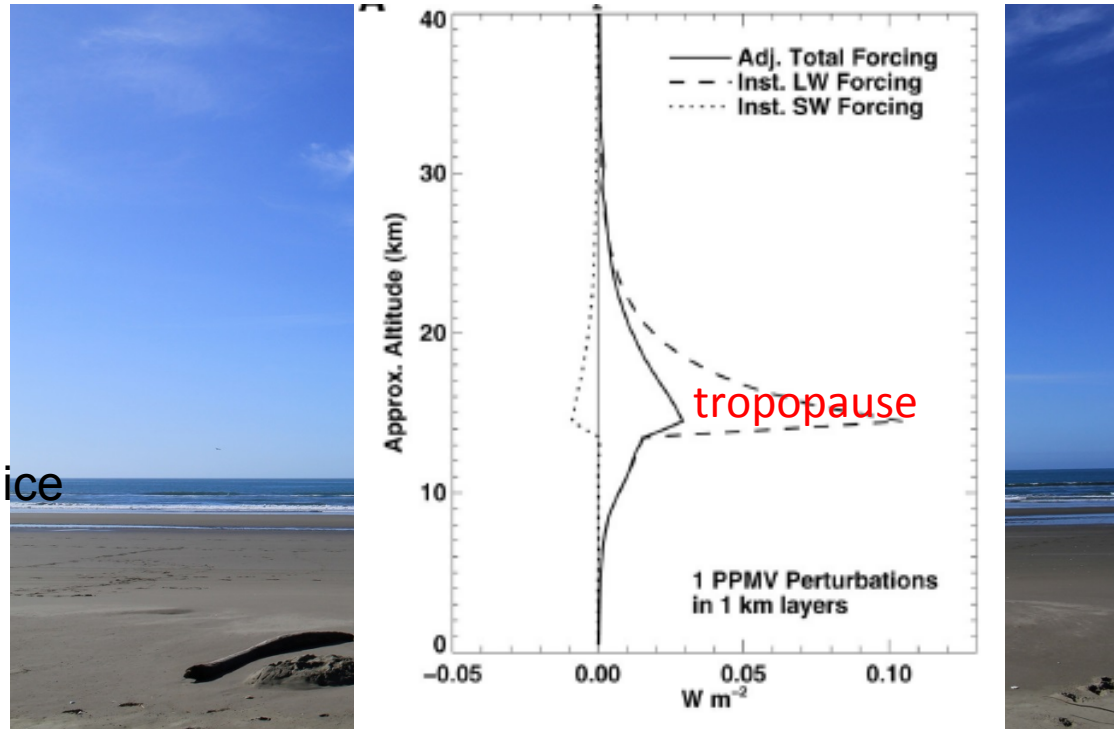
## Ice Supersaturation (ISS)

**Prerequisite condition for ice crystal formation**

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

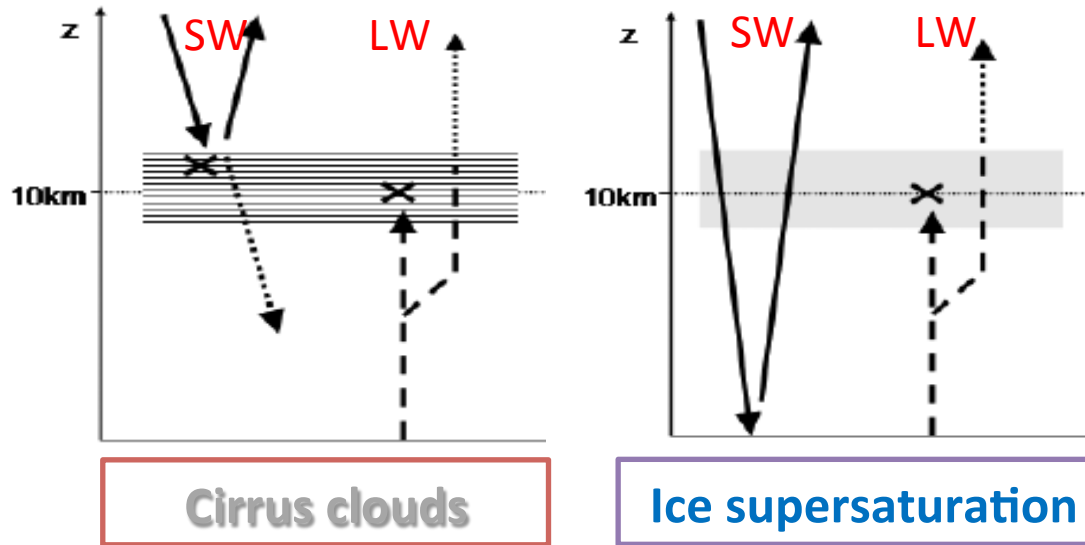
$e$ : water vapor pressure

$e_s$ : saturation vapor pressure wrt ice





# Difference in radiation between ISS and cirrus clouds

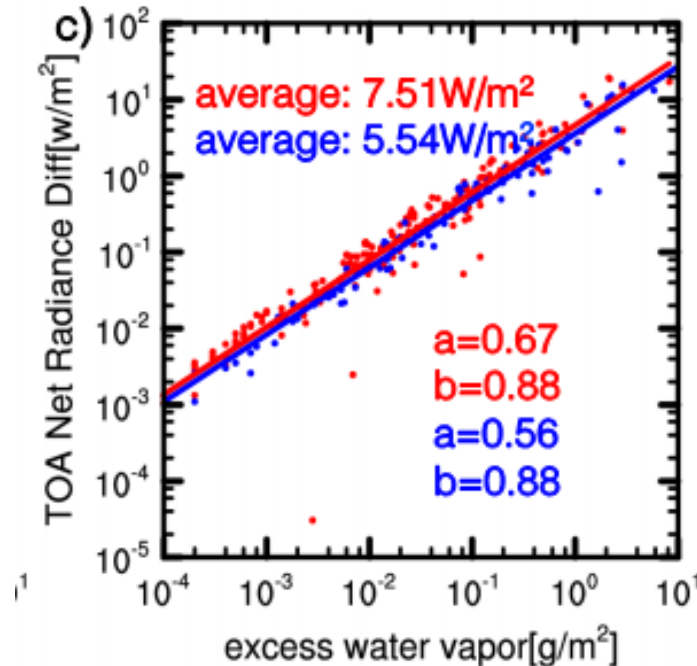


Up to **3 K d<sup>-1</sup>**  
 difference in vertical  
 heating rate  
 (Fusina *et al.* 2007)

## Differences in TOA net radiation (W/m<sup>2</sup>)

**RRTMG calculation:**  
 Replacing observed  
 ISS with artificial ice  
 crystals

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



Up to **~20-30 W/m<sup>2</sup>**  
 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  $T \leq -40^{\circ}\text{C}$** 
  - Cirrus cloud temperature range in ATTREX campaign is **much lower** (i.e., typically  $-65^{\circ}\text{C}$  to  $-80^{\circ}\text{C}$ ) than those in HIPPO and INCA campaigns (i.e., typically  $-40^{\circ}\text{C}$  to  $-65^{\circ}\text{C}$ ).

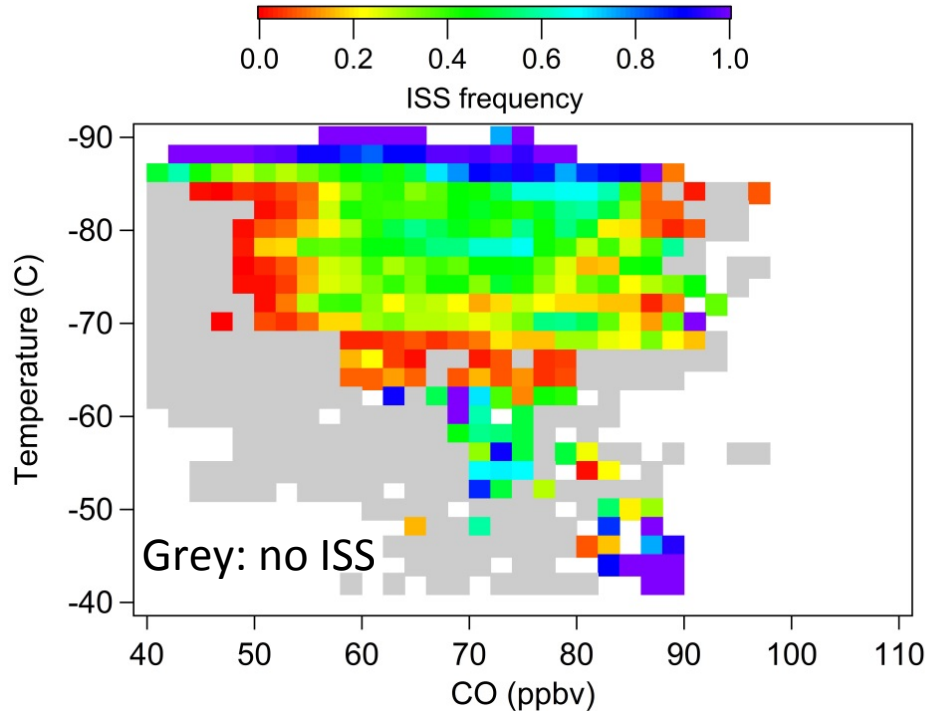


*Using CO chemical tracer as a tropospheric tracer:*

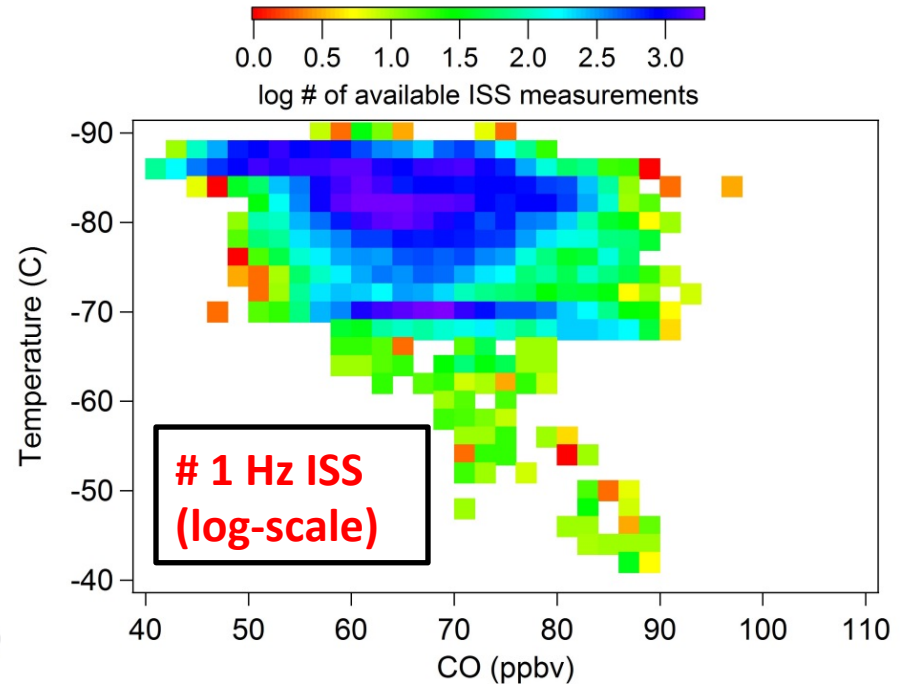
- Synchronized measurement with  $\text{H}_2\text{O}$  and ice crystals
- Less interaction with clouds



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

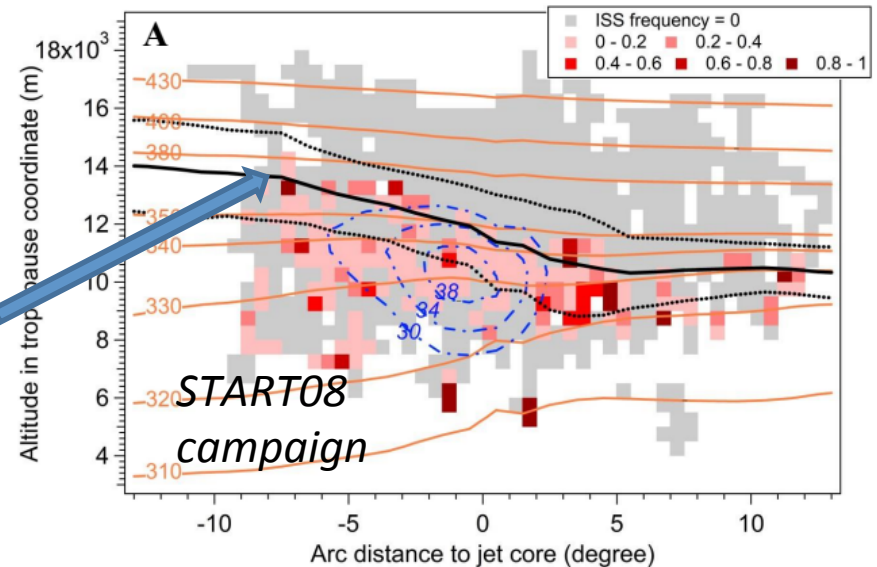


**1-Hz ISS occurrence frequency**



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

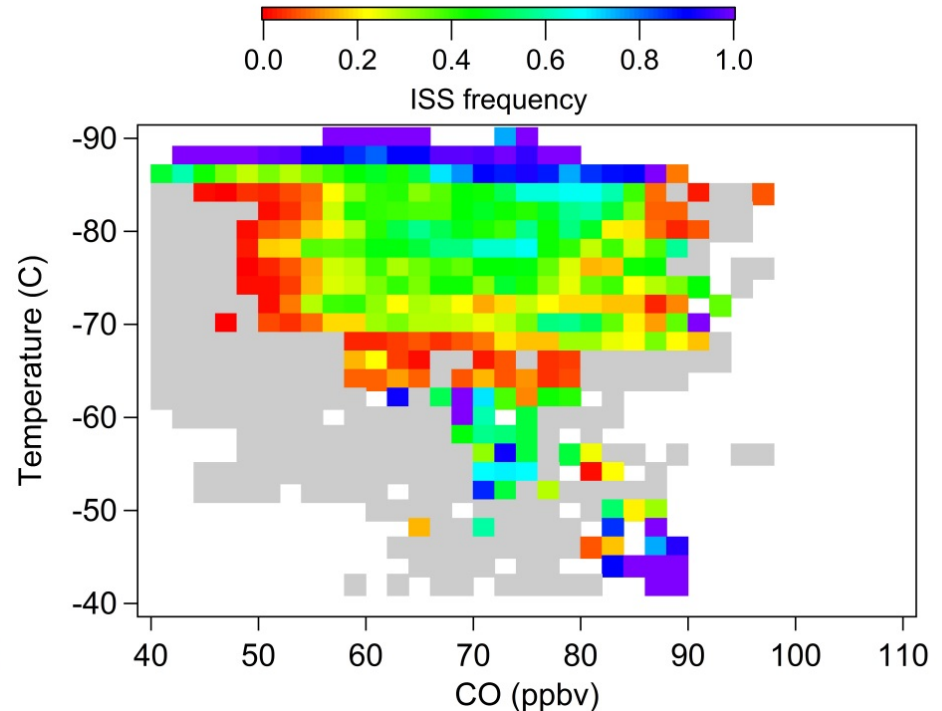
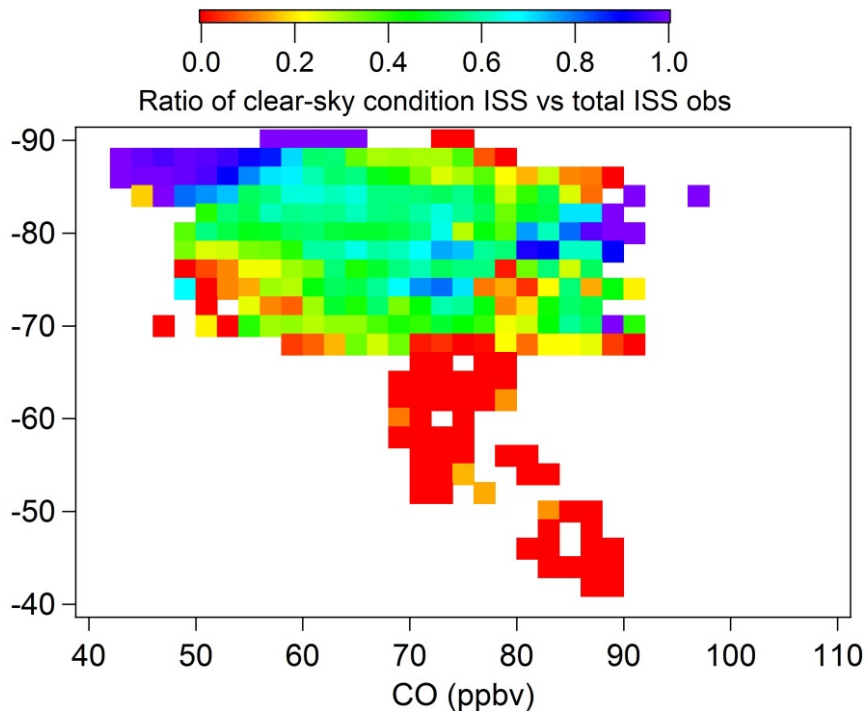
Needs more analysis of ISS distribution in relation to tropical tropopause



# 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



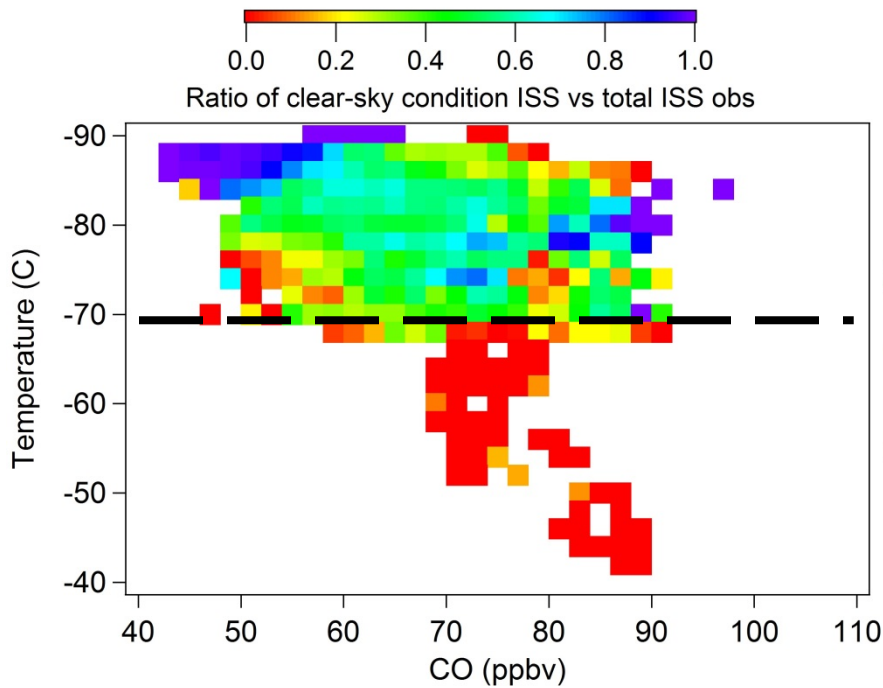
“In-cloud condition” defined as FCDP ice crystal number concentration ( $N_c$ )  $> 0 \text{ L}^{-1}$

Most of the ISS observations below  $-70^\circ\text{C}$  have  
**~50% ISS at clear-sky condition** and **~50% ISS at in-cloud condition**

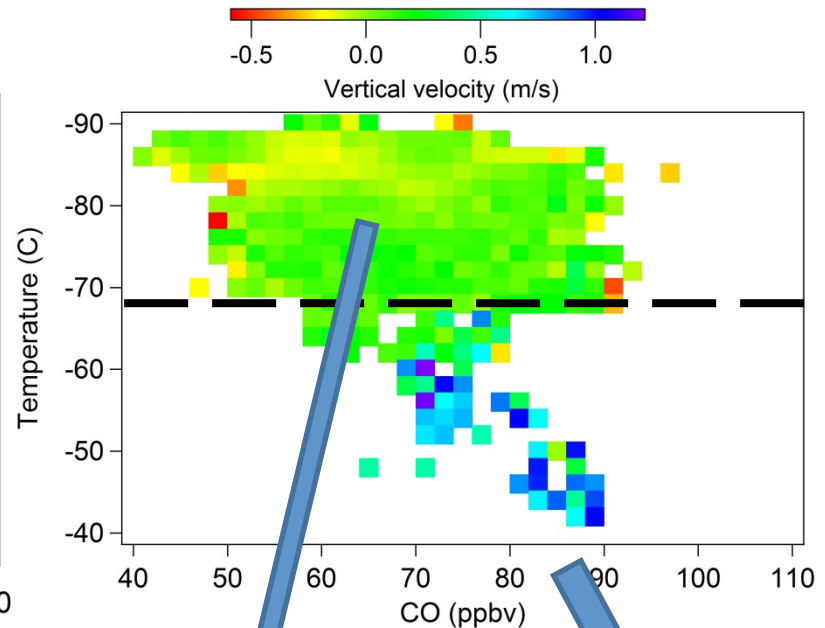


# ATTREX (2014): Ratio of clear-sky vs in-cloud ISS

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



Average vertical velocity for ISS  
observations

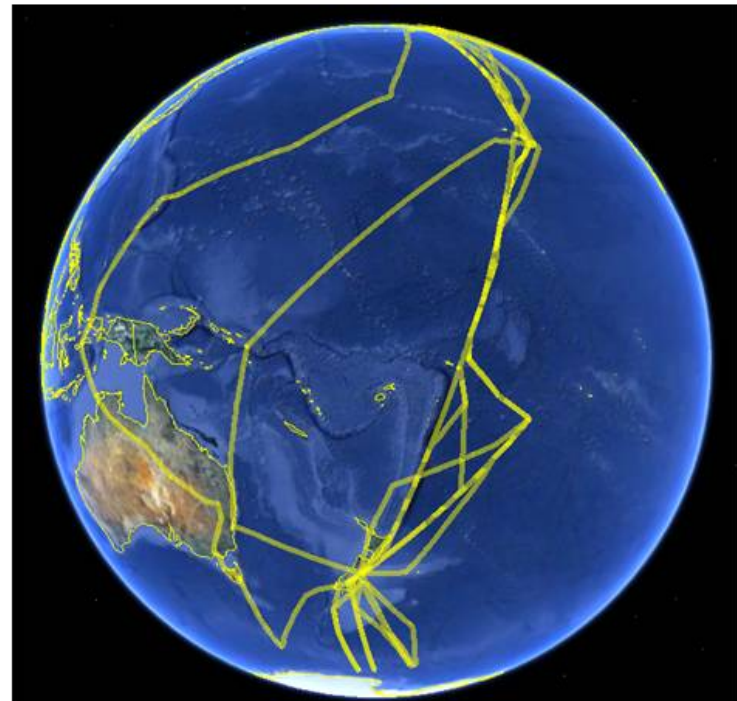
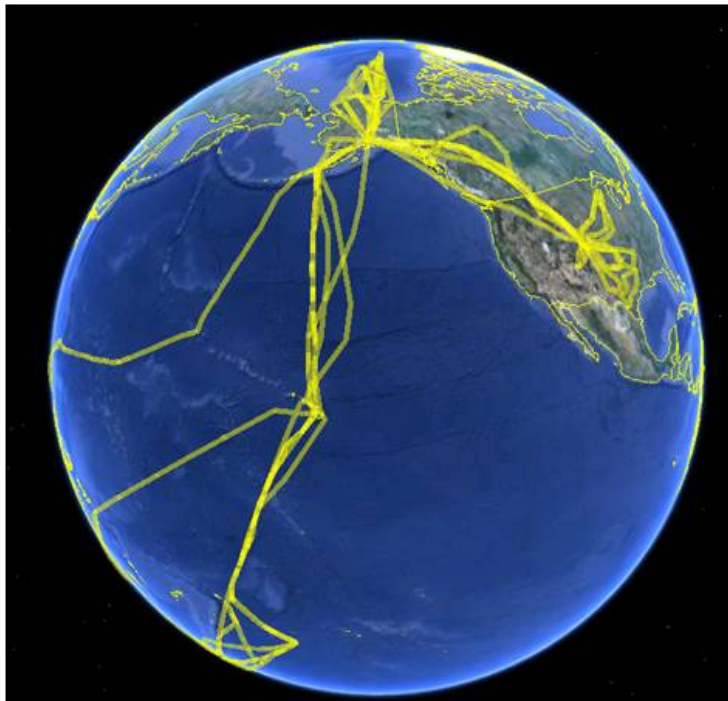


Average vertical velocity  
inside ISS mostly  
**within +/- 20 cm/s**

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

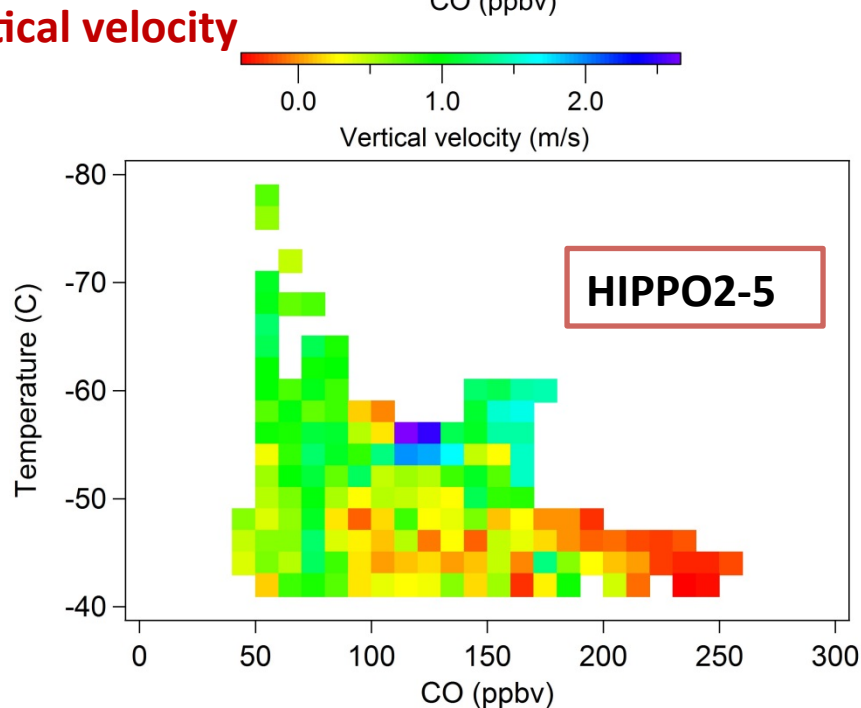
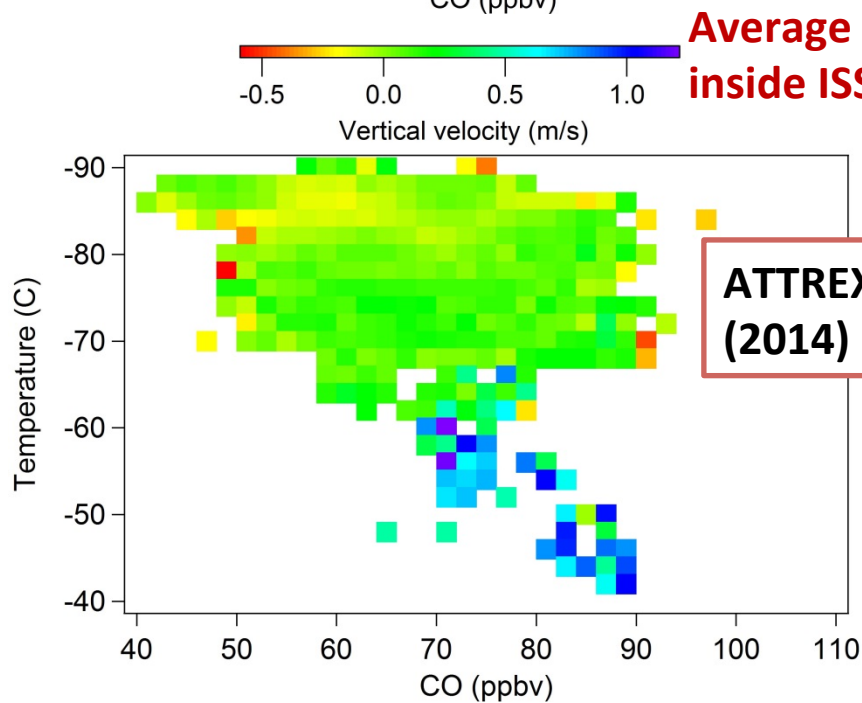
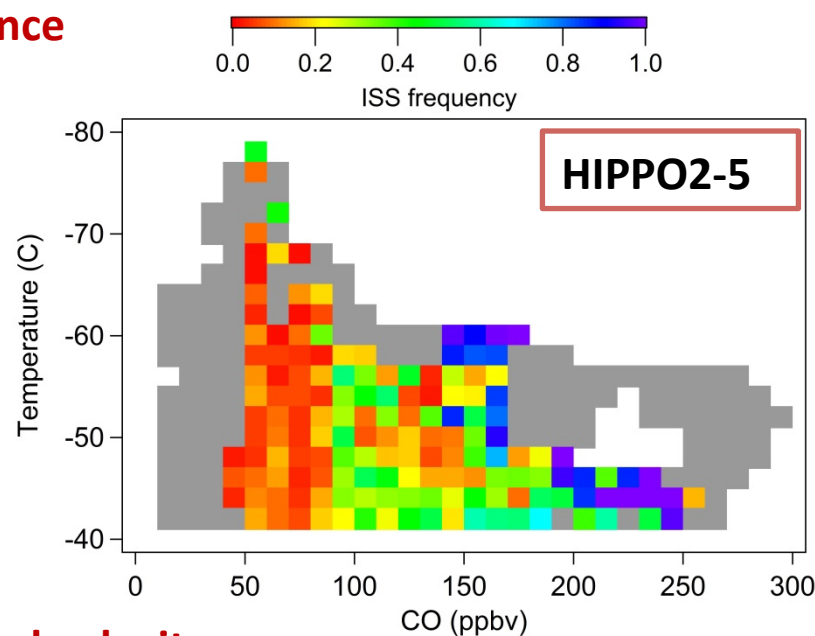
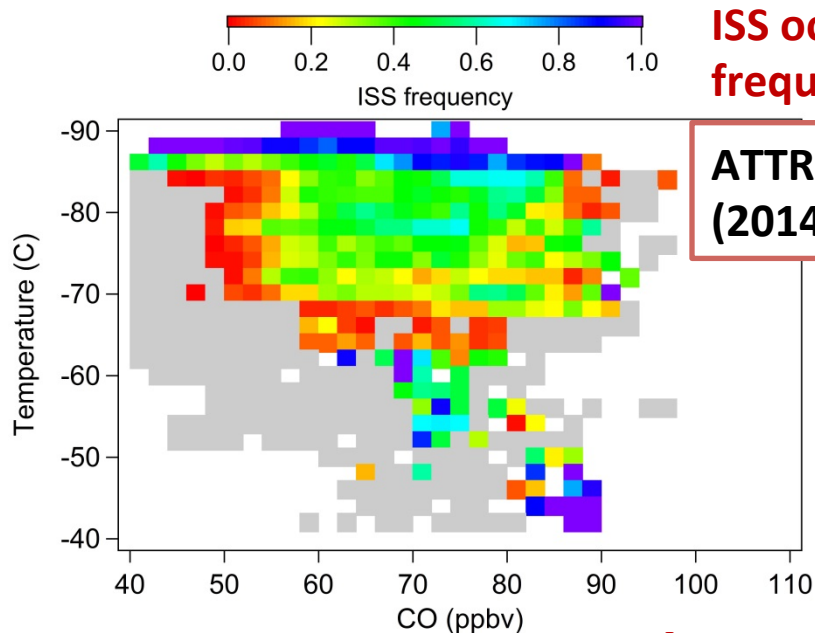
# NSF HIAPER Pole-to-Pole Observations (**HIPPO**) Global flight campaign #1-5 (2009-2011) (*Wofsy et al., 2011*)

- 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  $T \leq -40^\circ\text{C}$ ; Ice crystals (restrict to  $87.5 \mu\text{m} - 1600 \mu\text{m}$ );
- Most cirrus clouds observed in HIPPO were extratropical *in situ* cirrus.

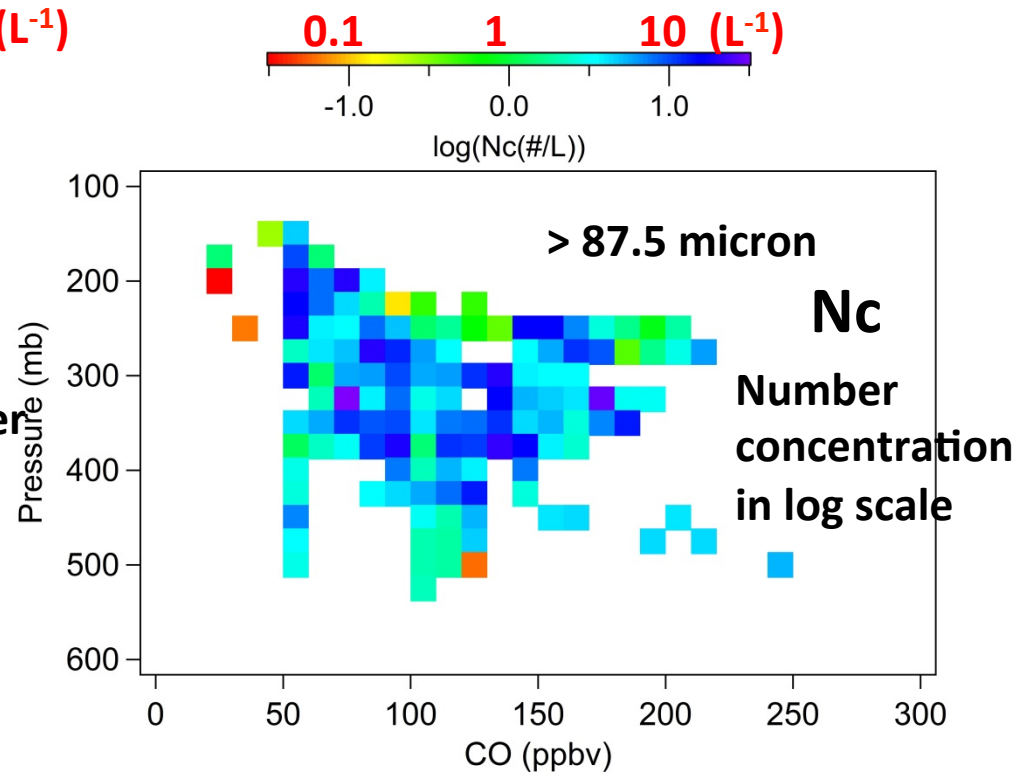
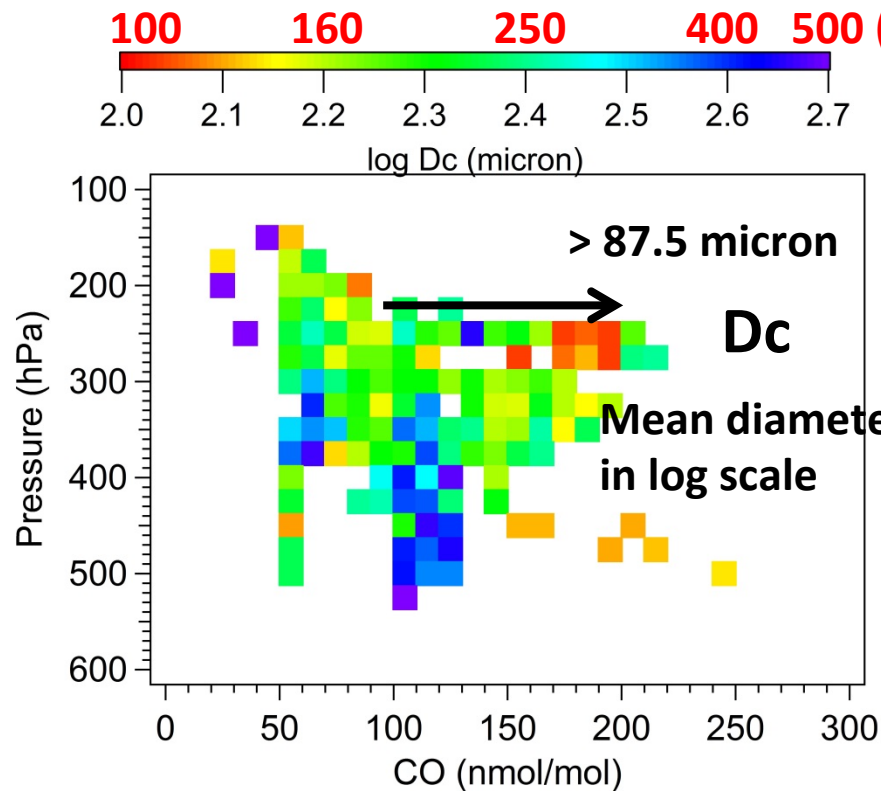




# Comparison of ISS conditions between ATTREX 2014 and HIPPO#2-5:



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



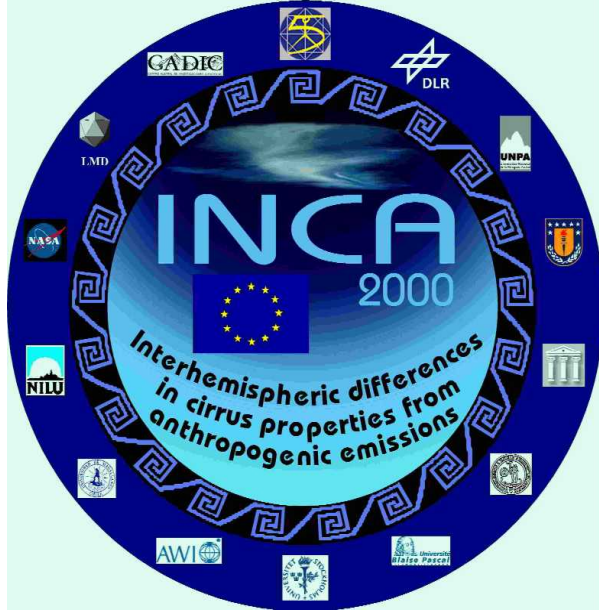
## Remaining questions:

- Lack of measurements of small ice crystals in HIPPO
- What other factors can also contribute to the smaller  $D_c$  values?

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

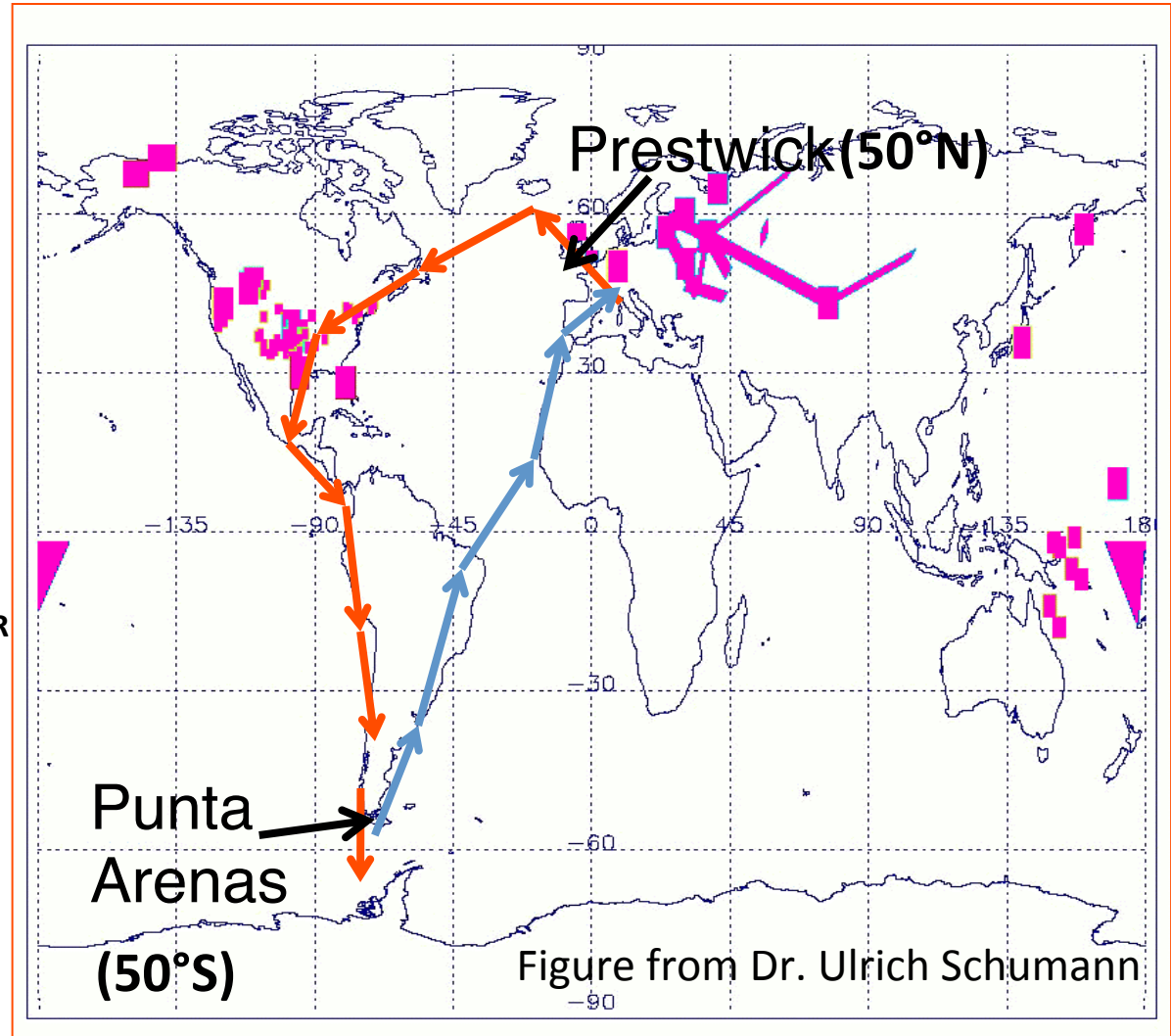
- [1] Relative humidity
- [2] Vertical wind speed
- [3] Temperature
- [4] Aerosol content and concentrations

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



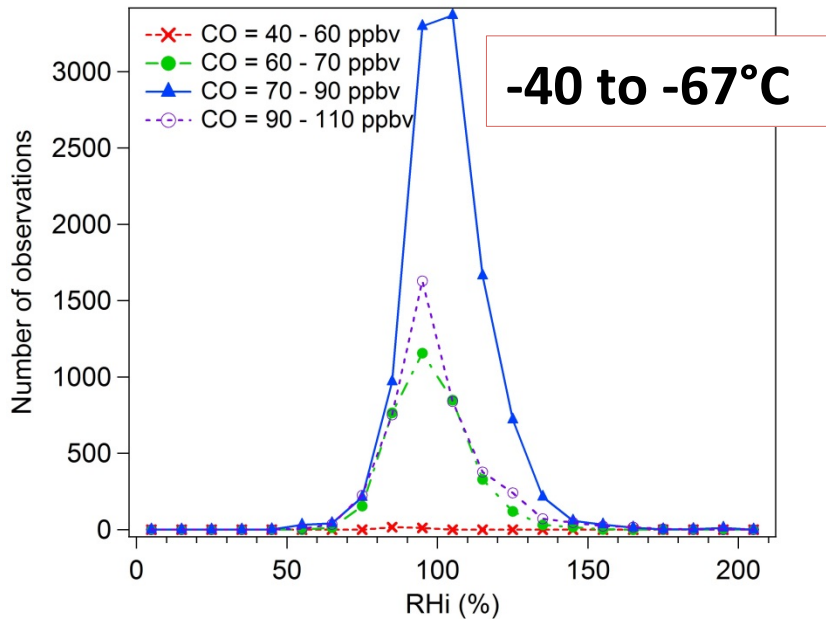
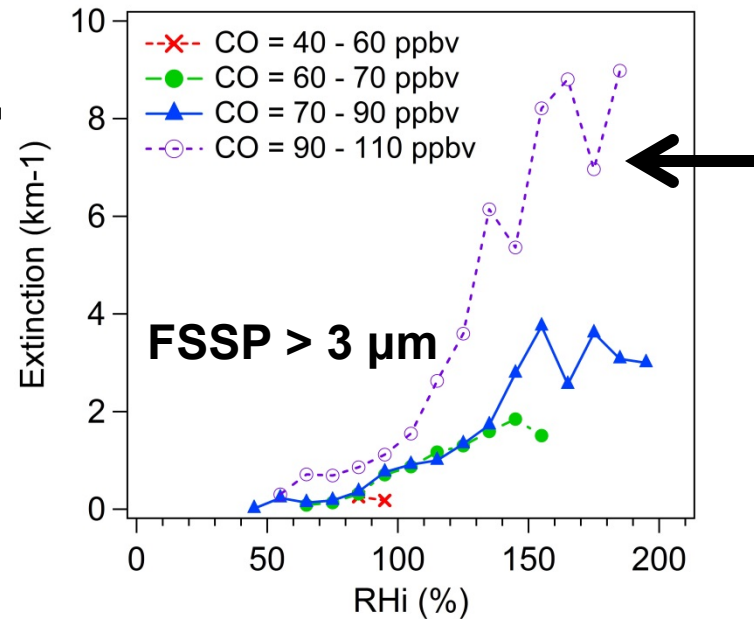
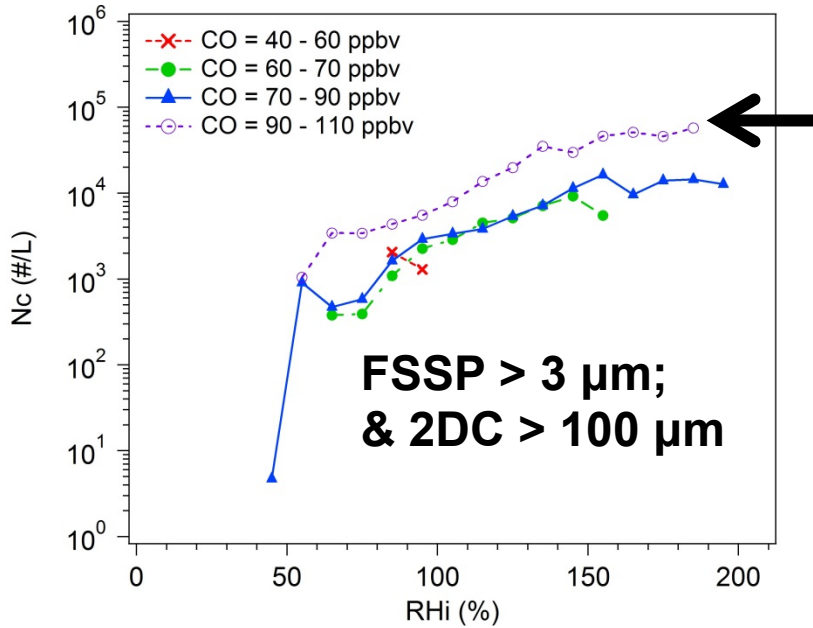
- European Community, Fifth Framework Programme
- *Partners:*
- Stockholm University (Coordinator), SW
- DLR (German Aerospace Centre), DE
- University of Helsinki, FI
- LaMP, University of Clermont-Ferrand, FR
- NILU (Norwegian Institute for Air Research), NO
- LMD (Laboratoire de Météorologie Dynamique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

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





# INCA data: Ice crystal concentration ( $N_c$ ) at different CO concentrations



## INCA campaign:

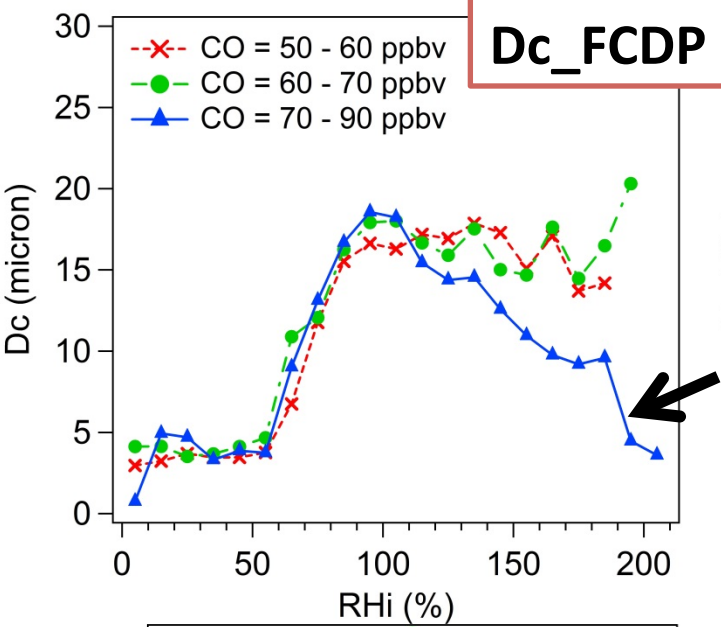
Analyzing **both** smaller ice crystals (**3-20  $\mu\text{m}$** ) and larger ice crystals (**100-800  $\mu\text{m}$** ).

## Remaining question:

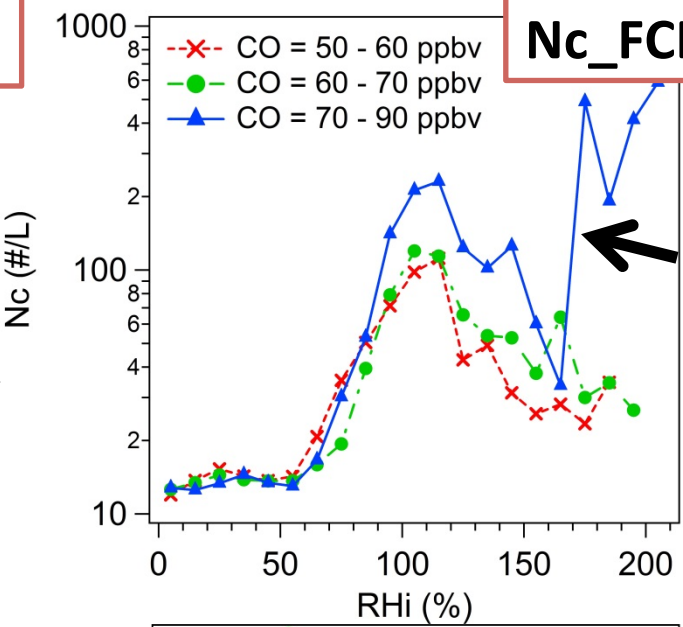
FSSP-300 instrument in INCA campaign was subject to **shattering** effect. Does shattering occur more frequently at higher CO concentrations?

# ATTREX (2014): SPEC FCDP ice crystal concentration ( $N_c$ ) and number-weighted mean diameter ( $D_c$ ) at different CO concentrations

**Dc\_FCDP**



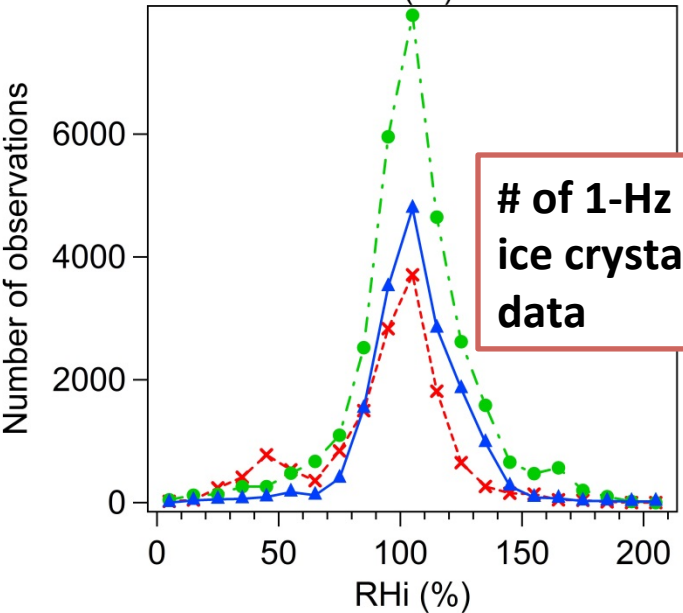
**Nc\_FCDP**



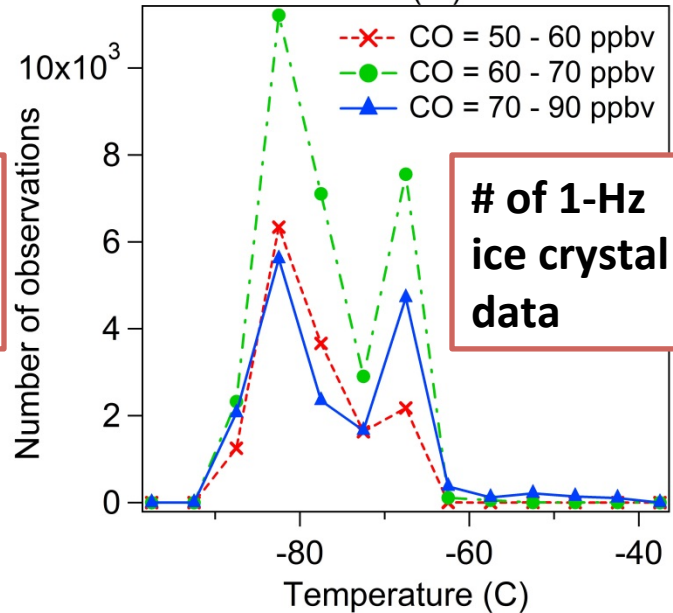
**ATTREX campaign:**  
Analyzing ice crystals at **1-50  $\mu\text{m}$** , using the SPEC FCDP probe.

**T = -40 to -89°C**

**# of 1-Hz ice crystal data**

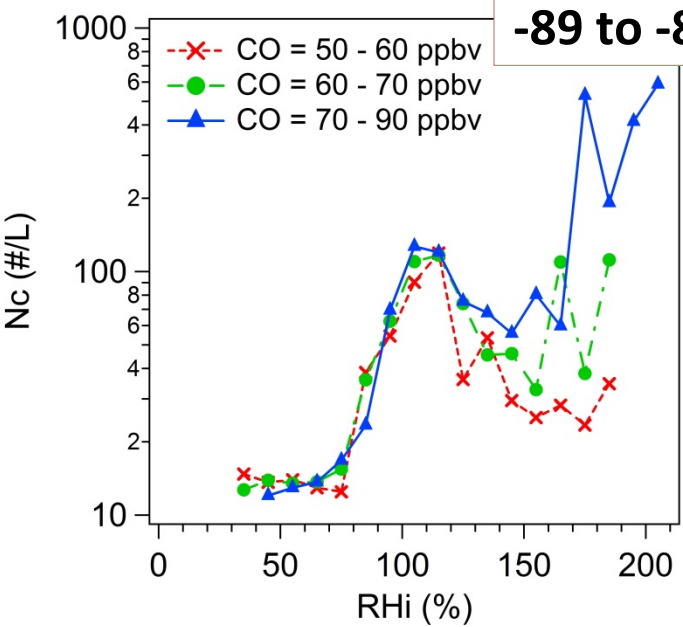


**# of 1-Hz ice crystal data**

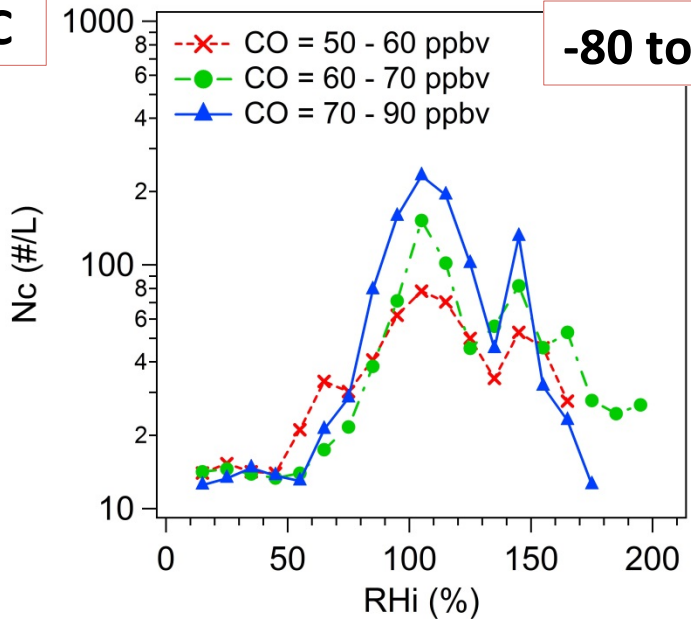


# ATTREX (2014): SPEC FCDP ice crystal concentration ( $N_c$ ) at different CO concentrations

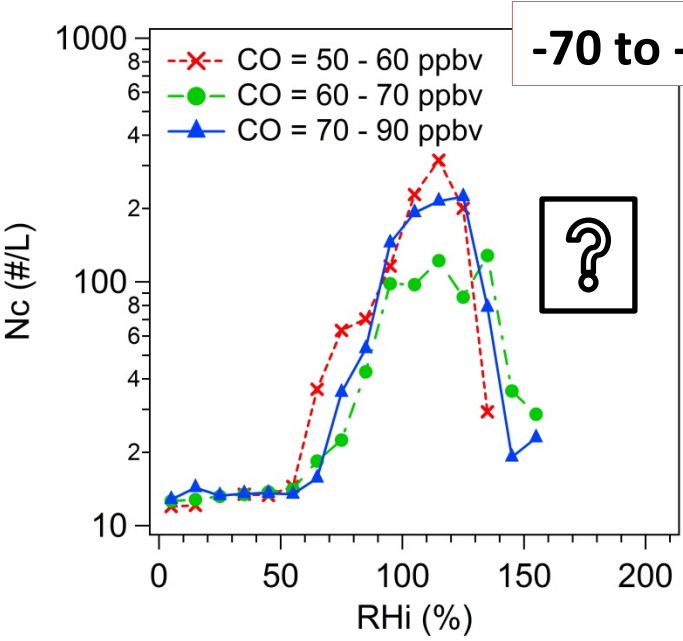
**-89 to -80°C**



**-80 to -70°C**



**-70 to -60°C**



## ATTREX campaign:

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

Whether  $N_c$  and  $D_c$  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?**

