

# **Cloudy/Clear Sky Relative Humidity in the Upper Troposphere Observed by AIRS, CloudSat, and CALIPSO: Quantifying Inter-hemispheric Humidity Differences**

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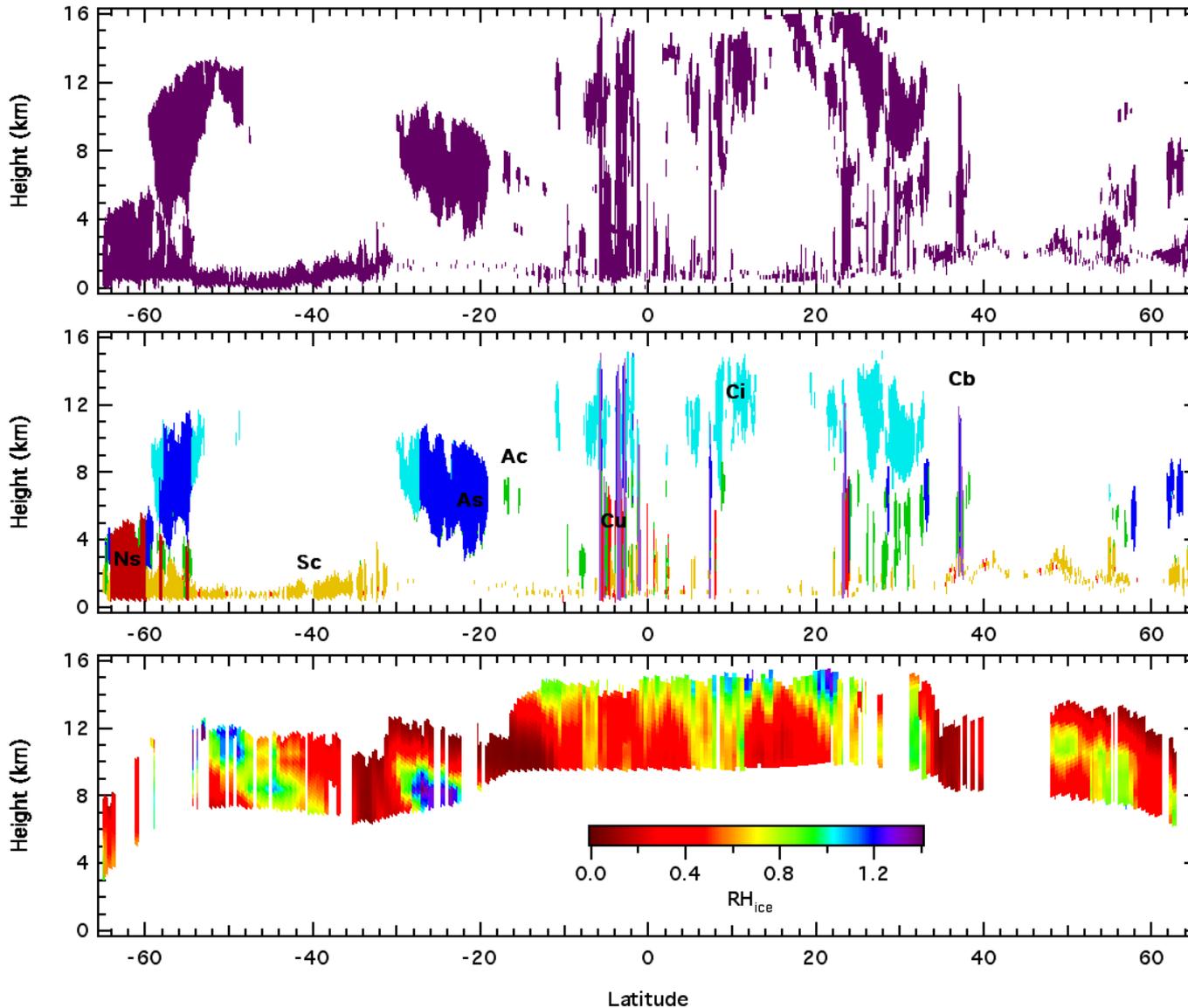
# Methods and Analysis

- **Part 1: Form an ice cloud/clear sky *RHI* climatology viewed by the A-train**
  - AIRS + CloudSat + CALIPSO: Partition cloudy/clear sky *RHI*
  - Seasonal and inter-hemispheric differences in *RHI*
  - Useful for more sophisticated model evaluation/improvement
  - Have not utilized other sources of data, e.g., MLS and TES
  
- **Part 2: Quantify reasons for seasonal/inter-hemispheric differences**
  - Test hypothesis that  $T$  and  $q$  means and variances control *RHI*
    - Kärcher and Haag (2004), *Ann. Geophys.*
  - Connection of *RHI* to dynamics and aerosol indirect effects

# Take-home Messages

- **Active + passive sounders discriminate for clear sky & few cloud types**
  - AIRS sampling limitations in some cloud types
- **Large seasonal, latitudinal, height, cloud/clear sky variations in *RHI***
  - General consistency with previous *RHI* climatologies (e.g., MLS)
  - Clear/cloudy discrimination more robust with CloudSat/CALIPSO
- ***RHI* histograms have seasonal and inter-hemispheric differences**
  - Seasonal differences in NH mainly controlled by seasonal cycle in  $\sigma_T$
  - Seasonal differences in SH controlled by seasonal cycle in mean  $T$  and  $\sigma_T$
  - Inter-hemispheric differences ***not*** consistent with mean  $T$  and  $\sigma_T$ 
    - Aerosol nucleation effects?

# Restrict to ice clouds: $RHI$ sampling dependent on cloud type



**Lidar + radar  
cloud mask**

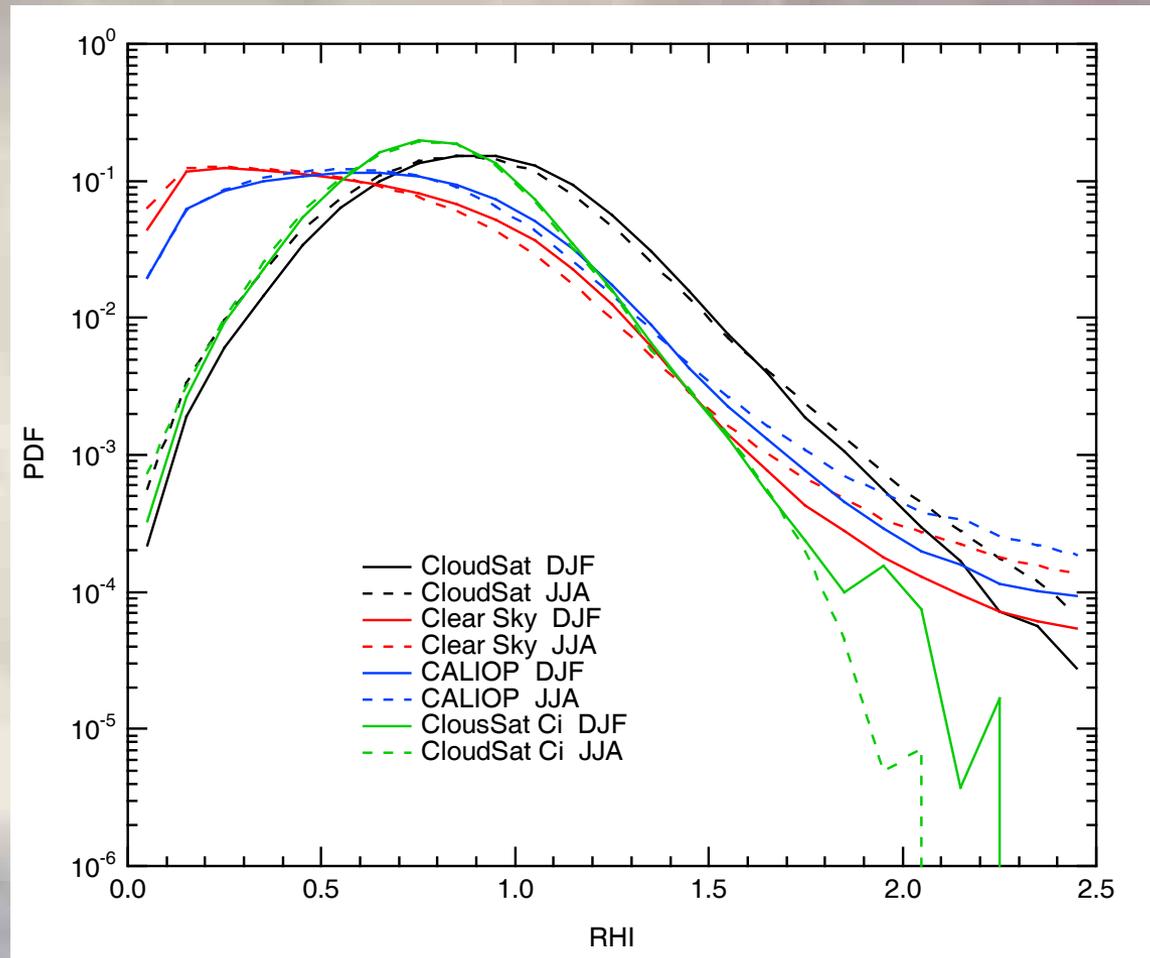
**Radar only  
cloud type**

**AIRS-derived  
 $RHI$**

# Combining cloud and humidity profiles not trivial

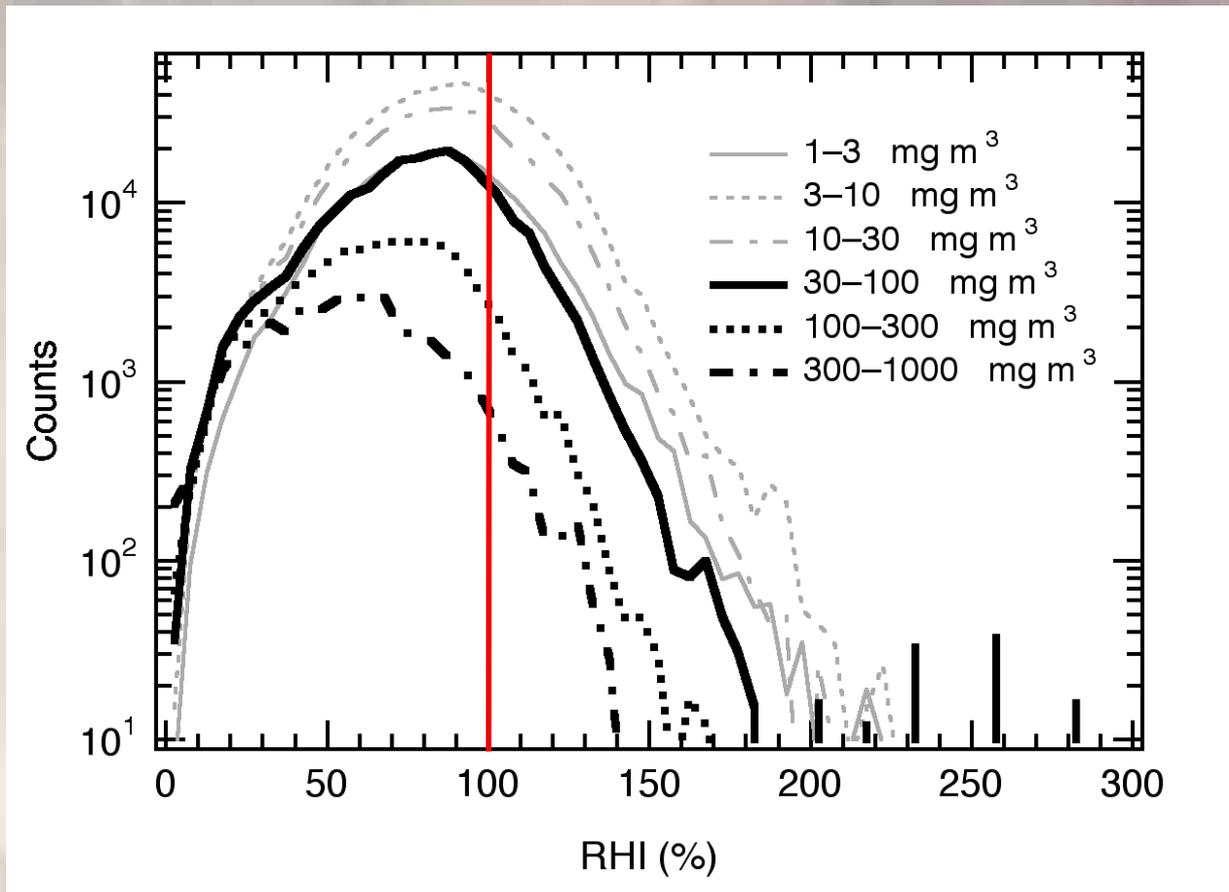
- **Biases/errors in  $T$  and  $q$  depend on clouds**
  - Susskind et al. (2006), *J. Geophys. Res.*
  - Validation by cloud type still lacking (Ci, Cb, As, Sc, etc.)
- **Few/no samples of  $q$  near TTL & within thick clouds (see previous slides)**
- **$RHI$  difficult to interpret: transparent vs. heterogeneous cloud cover**
- **Vertical resolution of  $T$  and  $q$  often greater than  $\Delta Z_{\text{cld}}$** 
  - Maddy and Barnet (2008), *IEEE TGARS*
  - Kahn et al. (2008), *Atmos. Chem. Phys.*; Lamquin et al. (2008), *J. Geophys. Res.*

# In-cloud/clear sky *RHI* using radar and lidar



Seasonal, cloud-type, and platform-dependent differences in *RHI* distributions

## High *RHI* corresponds to low IWC (and vice-versa)

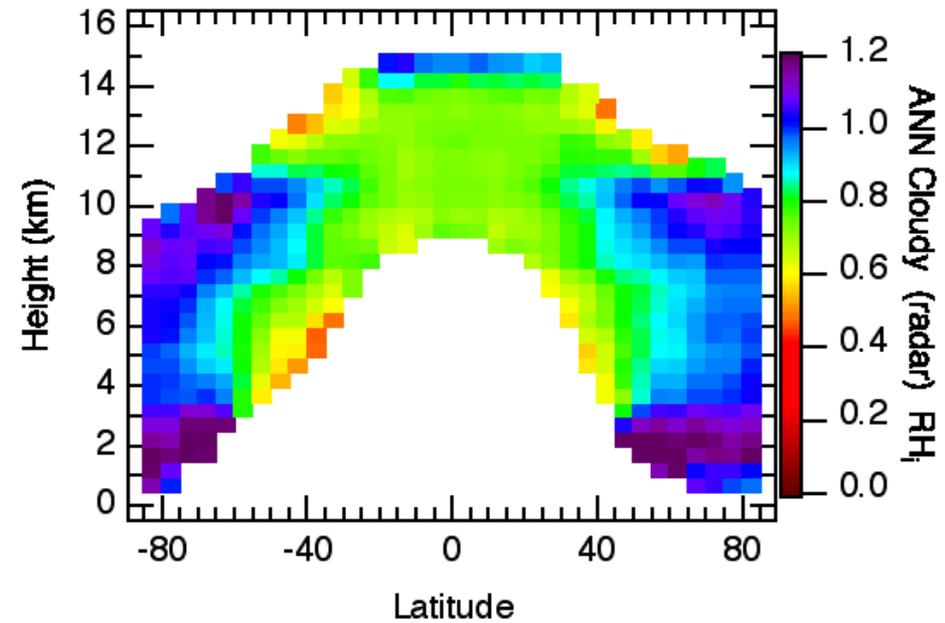
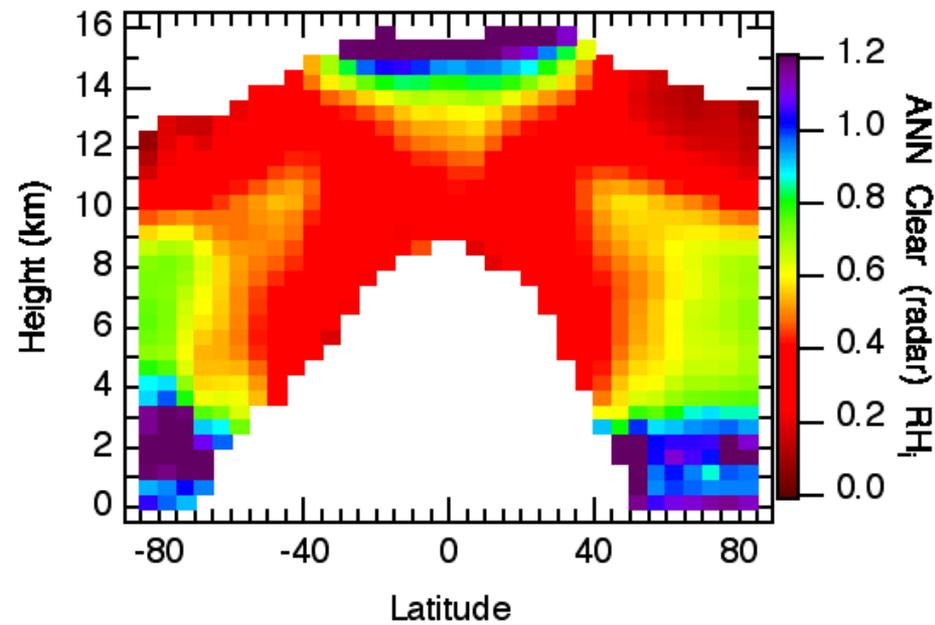


- High (low) *RHI* near cloud top (base) → opposite of IWC vertical structure
- PDFs consistent with evolution of Cirrus & growth of ice crystals

# Clear/Cloudy Sky Zonal Mean $RH_i$

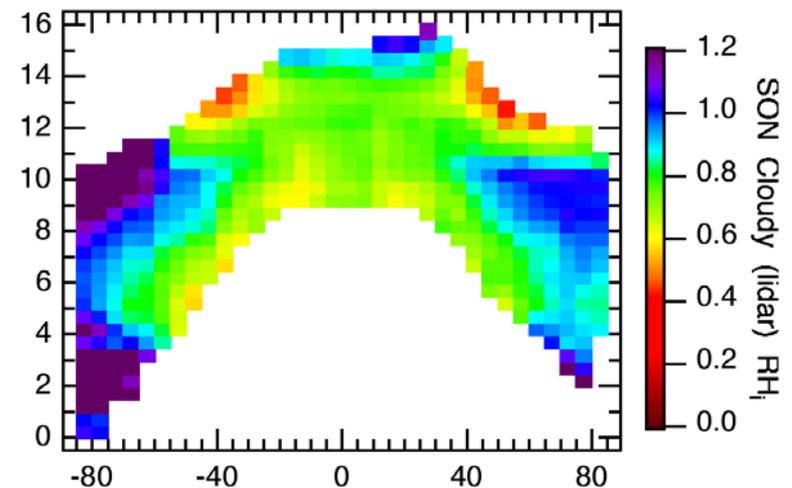
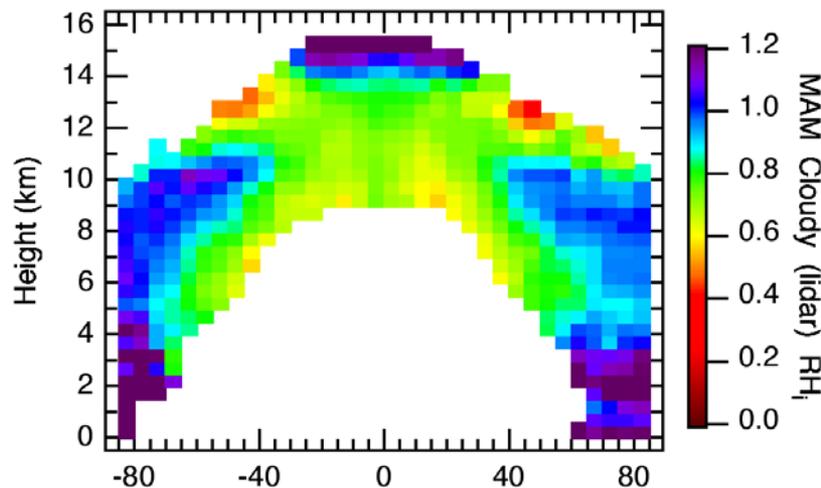
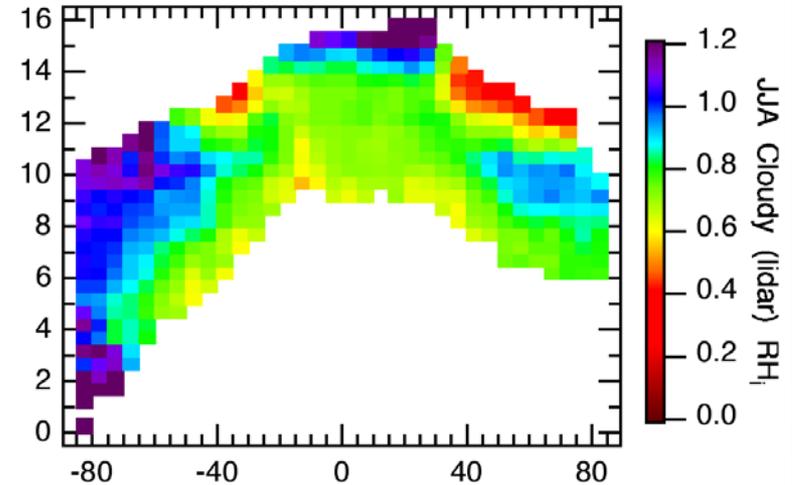
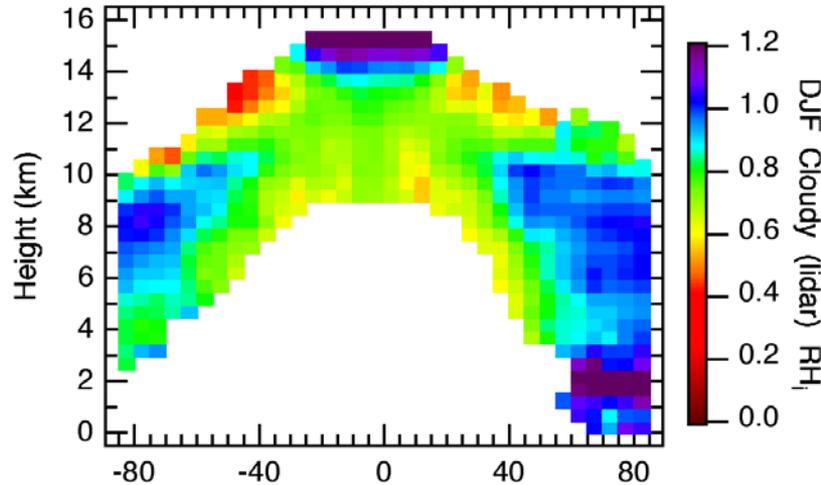
“Clear” (radar)

“Cloudy” (radar)



Average for Sept. 2006 – Aug. 2007

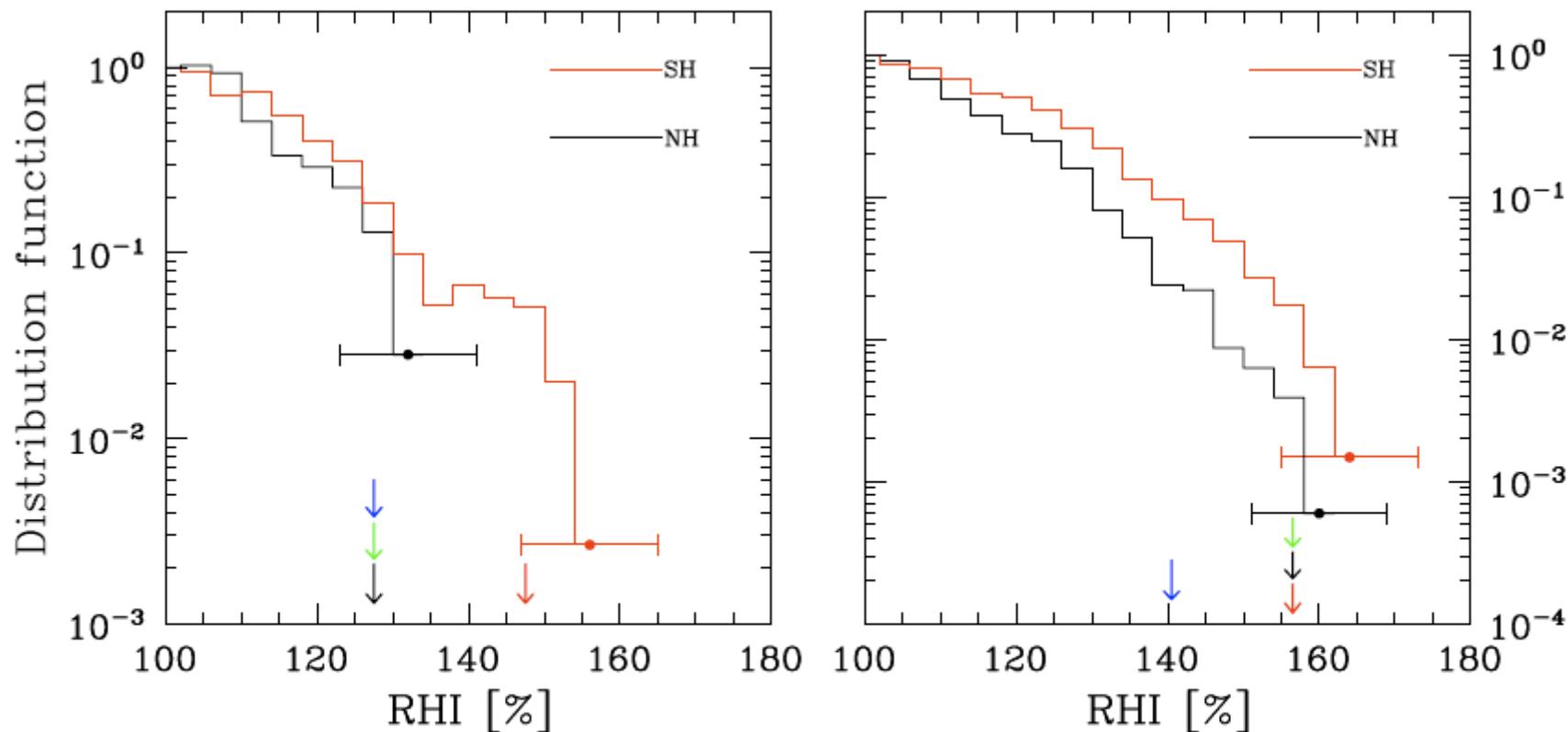
# Cloudy (radar) Zonal Mean $RH_i$ – Seasonal Variance



Latitude

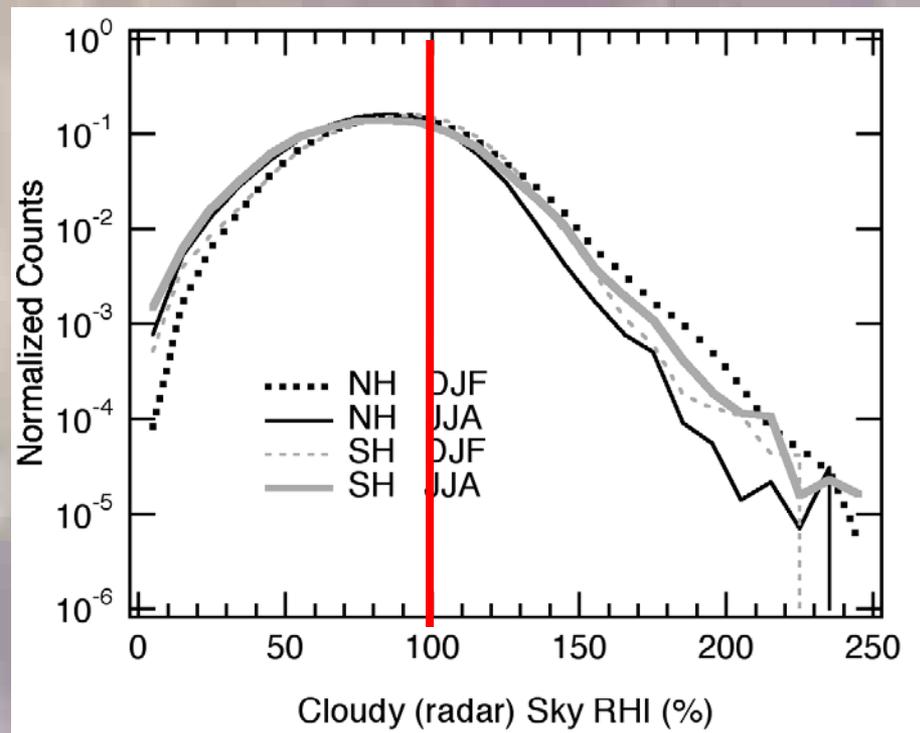
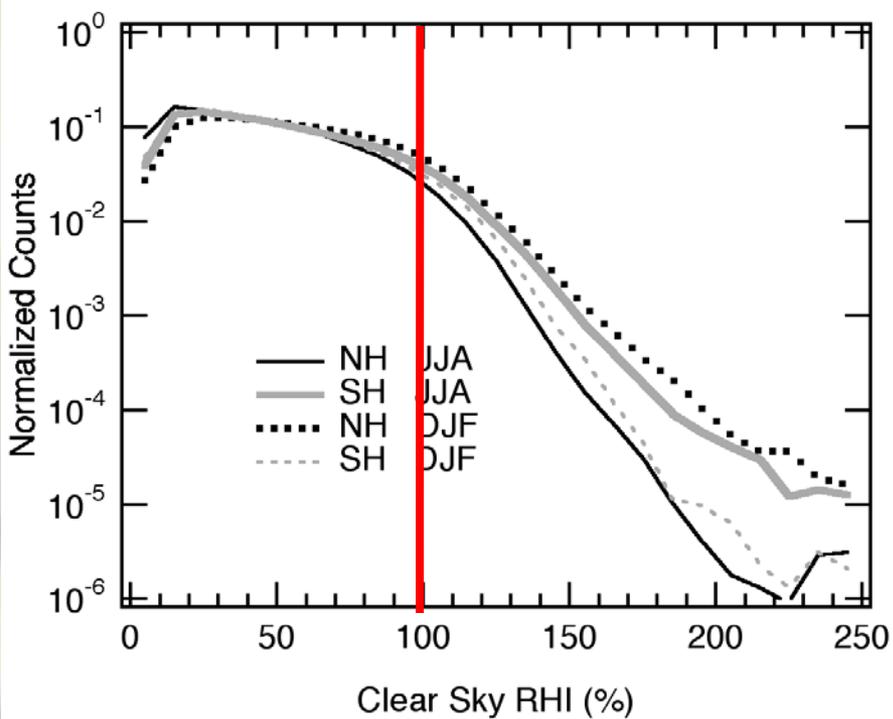
Latitude

# Aircraft in situ observations of cloudy/clear sky *RHI*: A hint about ice nucleation pathway?

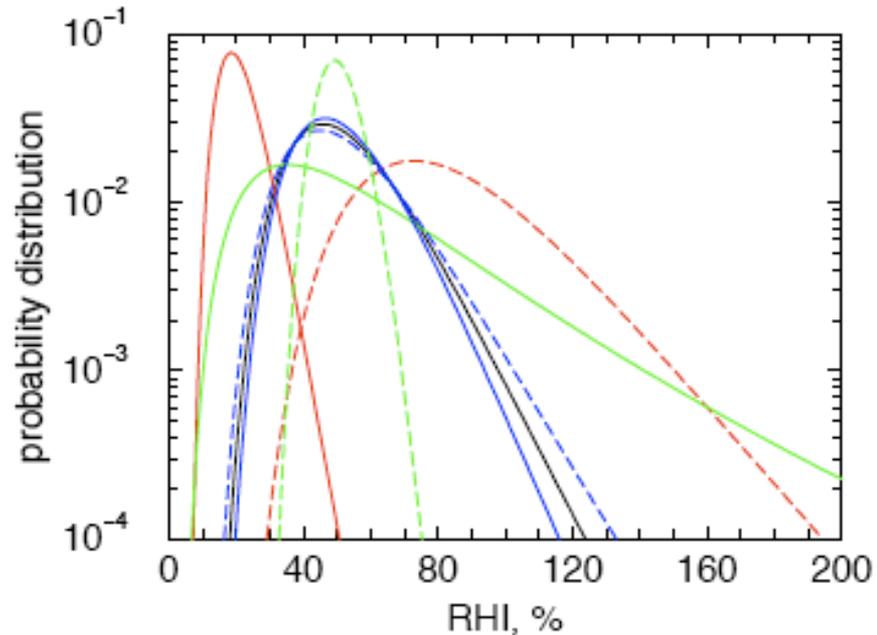


**Fig. 2.** Distributions of RHI above ice saturation outside of (left panel) and inside (right panel) cirrus clouds measured during INCA in Punta Arenas (SH) and in Prestwick (NH). The distributions are normalized with the number of data points in the respective 100% bin and all RHI values were binned into 4% intervals. The precision of the RHI measurements is  $\pm 3\%$  ( $1\sigma$ -limits), with horizontal bars depicting the  $3\sigma$ -limits. The colored arrows mark the cut-offs derived from the modeled distributions, taken from Fig. 1 (HOM: red, HET: blue, MIX 0.1: black, MIX 0.001: green).

# AIRS Doesn't Match INCA – But Lots of Seasonal Variation

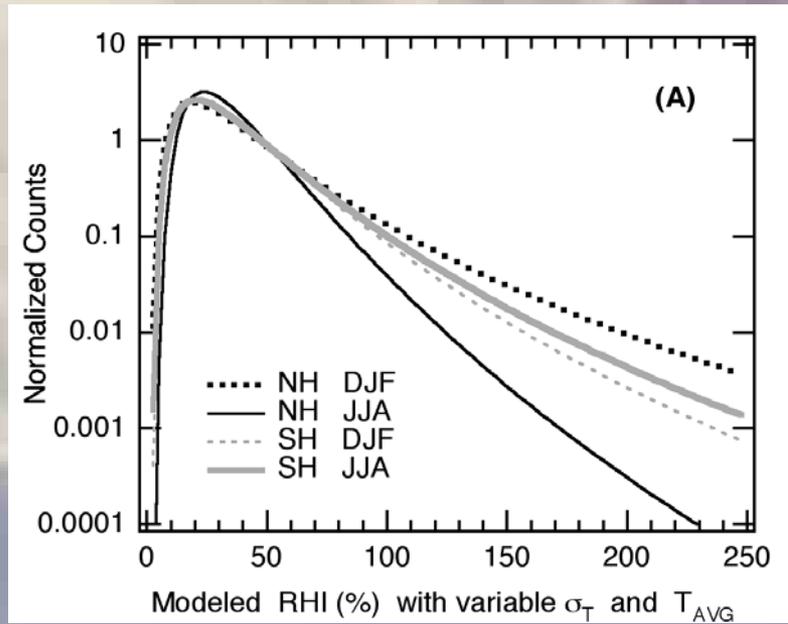
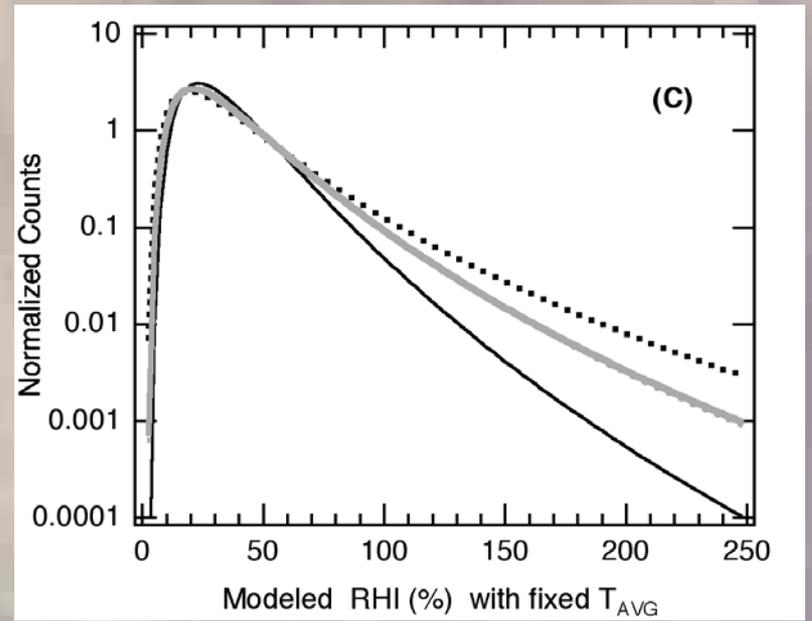
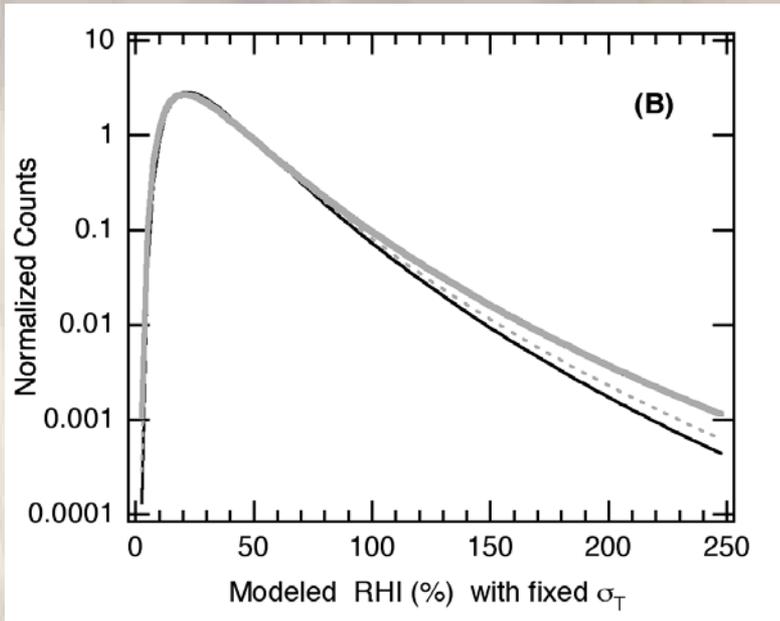


## Use Analytical Approach to Calculate *RHI*

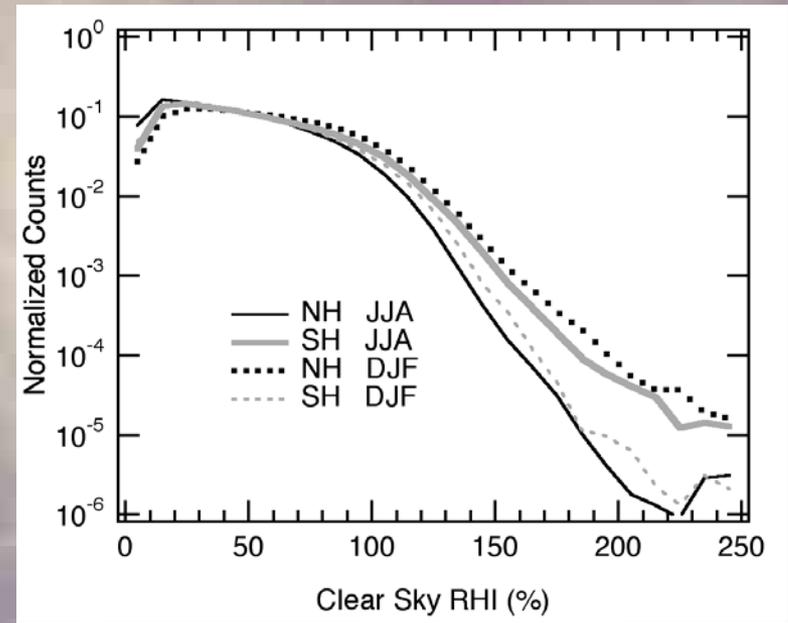
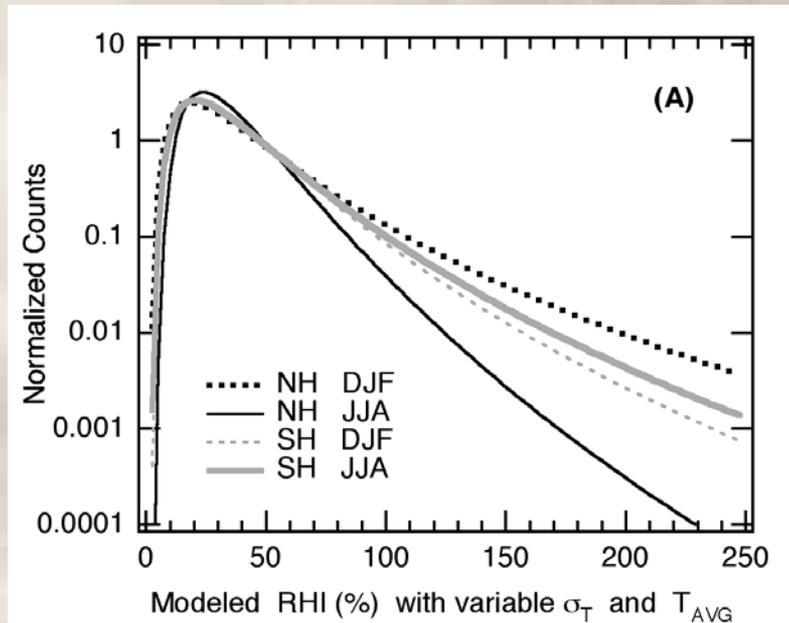


**Fig. 2.** Probability distributions of RHI obtained with normal distributions of  $T$ . The black curve is equal to the baseline case shown as the blue curve in Fig. 1. Red, green, and blue curves are obtained by varying  $RHI_0$ ,  $\sigma$ , and  $T_0$ , respectively. See text for details.

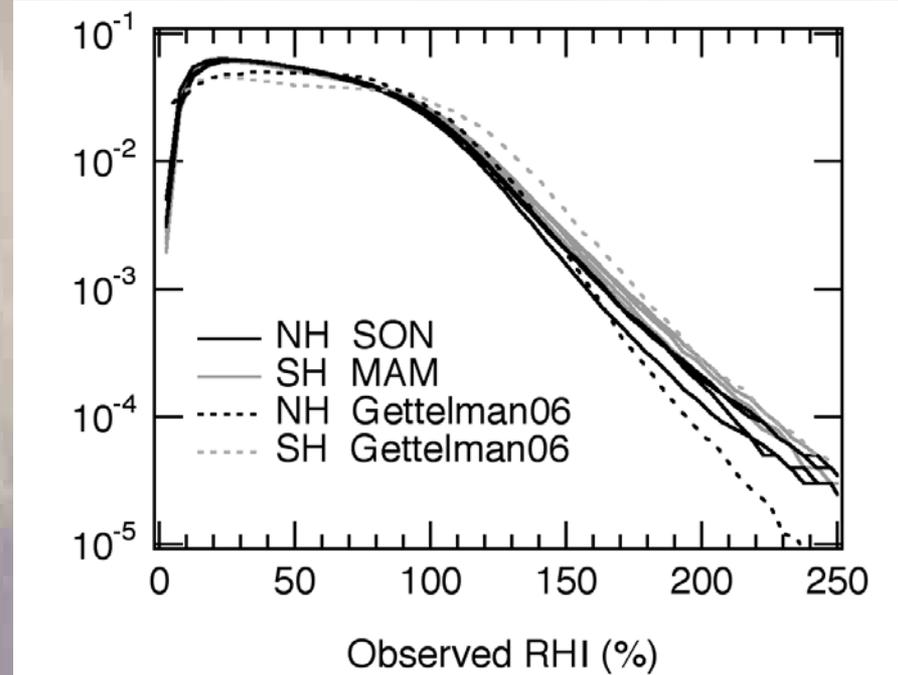
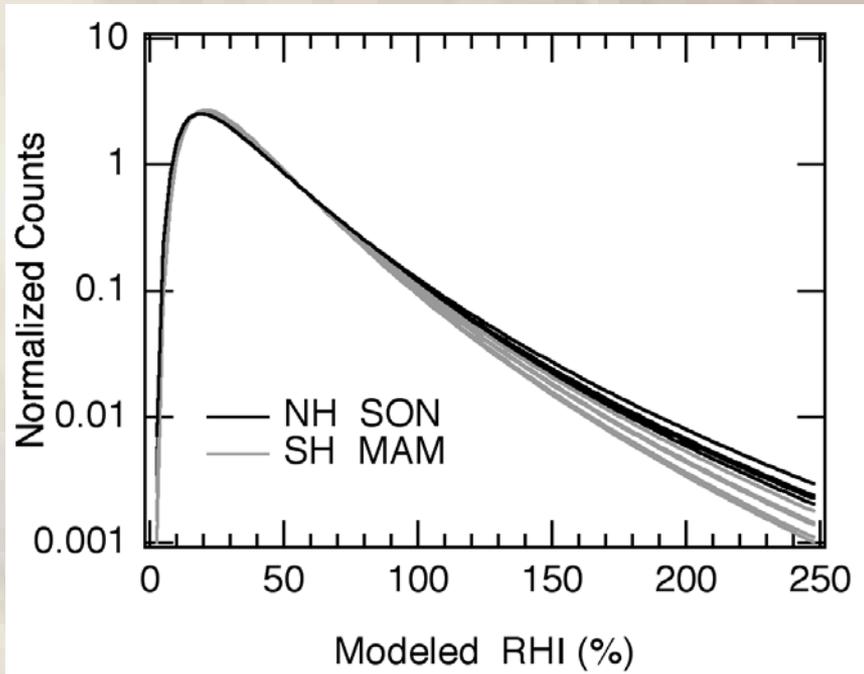
# Calculate Analytical RHI PDFs from AIRS T Obs.



# Analytical and Observed *RHI* PDFs Somewhat Agree



# AIRS-INCA Time Period Comparisons



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