# Evolution and Dynamics of Ice Supersaturation & Cirrus Clouds by Tracer Analysis


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## Instrument & Mission Overview

**VCSEL Hygrometer:**

| Mode | Wavelength (nm) | Detection Range (ppmv) |
|---|---|---|
| weak (*2f*) | 1853.38 (5395.555 cm$^{-1}$) | > 2,500 |
| strong (direct) | 1854.03 (5393.648 cm$^{-1}$) | 80 - 3,000 |
| strong (*2f*) | | 1 - 200 |

**DC3 Cirrus Cloud Statistics:**

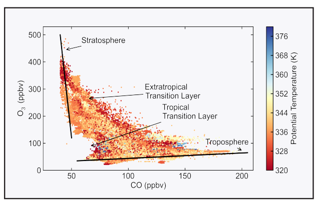
*Cold-temperature cirrus, $T < -40$ °C*

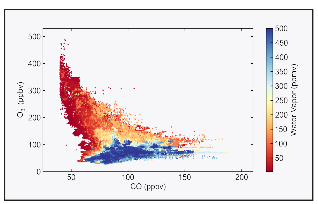
- In-cloud: 15.2 hours
- Clear-sky: 54.0 hours

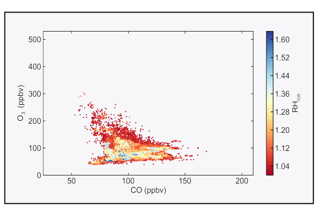
**DC3 Ice Supersaturation Region Statistics:**

- Number of ISSRs: 3444
- Max. ISSR length: 160148 m
- Min. ISSR length: 176 m
- Mean ISSR length: 2770 m
- Median ISSR length: 744 m
- St. Dev. ISSR length: 7062 m

## Establishing Sources of Air from Tracer Mixing Lines

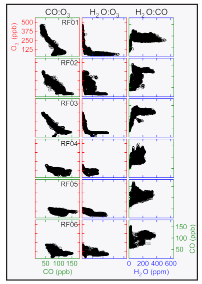


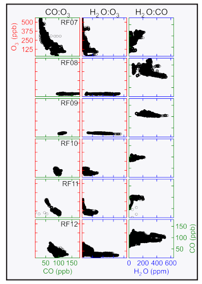



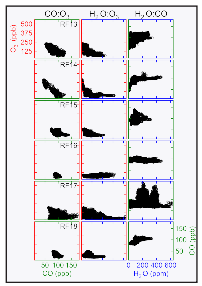



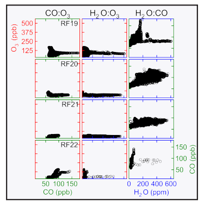

*TRACER-TRACER MIXING LINES: (top) Source of air established by $O_3$-CO mixing lines; (middle) Water vapor profile along tracer mixing lines. Convection can lead to irreversible transport of water into the stratosphere; (bottom) While ISSR are seen across mixing lines, the highest RH are limited to tropospheric air.*

## Flight-by-Flight Tracer-Tracer Profiles



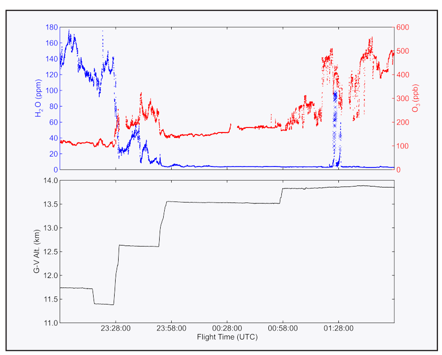




*TRACER-TRACER CORRELATIONS: whereas $O_3$ & CO are commonly used convective tracers, $H_2O$ can sometimes more clearly reveal short timescale features (c.f. RF07).*

## Evidence of Convective Injection of Water Vapor into Stratosphere?

Injection of water vapor into the lower stratosphere can influence chemistry. The understanding of the dynamics, evolution and frequency of these events is limited, largely a result of their small spatial scales and infrequent observation.




*RF07 Timeseries: (top) Water vapor and ozone observed by the G-V during a stretch of RF07. While $H_2O$ & $O_3$ measurements indicate that this air is chemically akin to the stratosphere, a large transient increase in $H_2O$ can be seen and may have convective origine; (bottom) Flight altitude of G-V, the $H_2O$ peak is at ~ 46,000 ft.*

## Ice Supersaturation Regions (ISSRs)

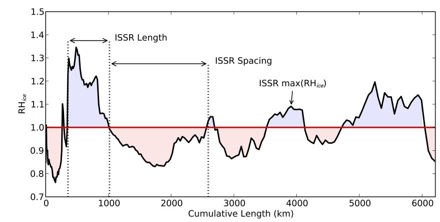
Ice Supersaturations Regions (ISSRs) are defined for regions with T < -40 °C (233 K) where:

$$RH_{ice} = \frac{e}{e_s} > 1$$

ambient water vapor pressure ($e$) is determined from VCESL data and the ice saturation vapor pressure ($e_s$) is calculated from the Murphy & Koop (2005) formulation.

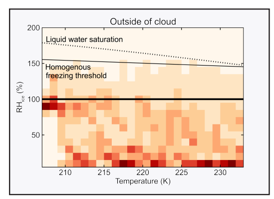
In general, ISSRs display the folllowing behavior:

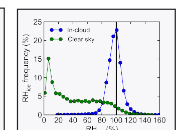
- Small scale events dominate
- Water vapor field controls small scale RH structure
- Higher maximum RH encountered in larger ISSRs
- ISSR growth reduces ISSR spacing



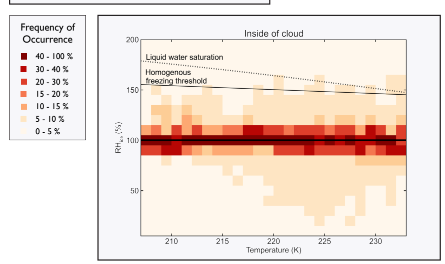

*ISSR DEFINITIONS: The length of an ISSR is derived from the cumulative product of airspeed and time any continuous segment where $RH_{ice} > 1$; ISSR spacing is the distance between the end of an ISSR and the start of a subsequent ISSR; the ISSR $RH_{ice}$ is the maximum RH measured inside of an ISSR. The data shown above represents ~5 minutes of flight time.*

## Cirrus Cloud Characteristics




*PDF: In-cloud & clear sky RH frequency of occurrence for all $T < -40$ °C during DC3.*




*$RH_{ice}$ FREQUENCY: (top) Clear sky frequency of occurrence within 1 K temperature bins for $T < -40$ °C. Observations are randomly distributed between RH of nearly zero to the homogenous freezing threshold; (bottom) Subsaturation indicates aged cirrus in the evaporation stage. Supersaturation is likely to occur in young cirrus directly following ice formation. The sharp distribution near 100 % is an indication of short relaxation times and the proclivity of warm clouds to live near saturation. The broadening distribution at $T < 215$ K may be a result of increased cloud relaxation times.*

## Cirrus Cloud Lifetimes

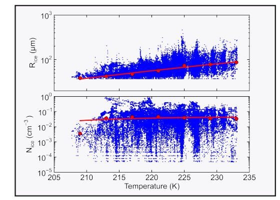
For clouds formed near homogenous freezing threshold, the time needed to reach dynamic equilibrium is the relaxation time (Korolev & Mazin, 2003):

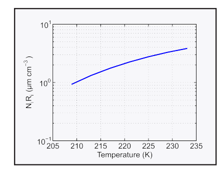
$$\tau = \frac{1}{a_0 \cdot u_z + (b_i + b_i^*) N_i R_i}$$

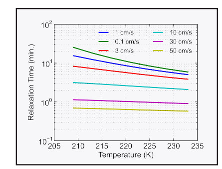
the main parameters influencing this are $u_z$, $T$ and $N_i R_i$. $N_i R_i$ is the integral ice particle radius, the product of mean ice particle size (radius) and ice particle number. Vertical velocity and temperature are given by $u_z$ and $T$, respectively. In-cloud relaxation times are (preliminarily) explored for growing cirrus during DC3.

Compared to previous observations by Krämer et al. (2009) longer relaxation times are derived, largely a result of increased particle size at warmer temperatures. This may help explain the observation for increased frequency of in-cloud supersaturation a $T < 215$ K.

*IN-CLOUD PARTICLE MEASUREMENTS: (top) Ice particle diameter as measured by 2DS. Red circles represent 4 K temperature bins. A 2nd order polynomial is used to fit the binned data; (bottom) Particle concentrations as measured by 2DS, binning and fitting same as above.*




*CIRRUS RELAXATION TIMES: (left) Integral ice particle radius from fits (above) of 2DS measurements; (right) The cloud relaxation time is calculated from $N_i R_i$ (left) for a variety of vertical updraft velocities. While there is large distribution in $N_i R_i$ this represents the mean value. Only at slow updraft velocities (< 20 cm/s) do relaxation times become significant.*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