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# Convair580 IKP2 data set and background humidity

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# IKP-2 installation on the NRC Convair580

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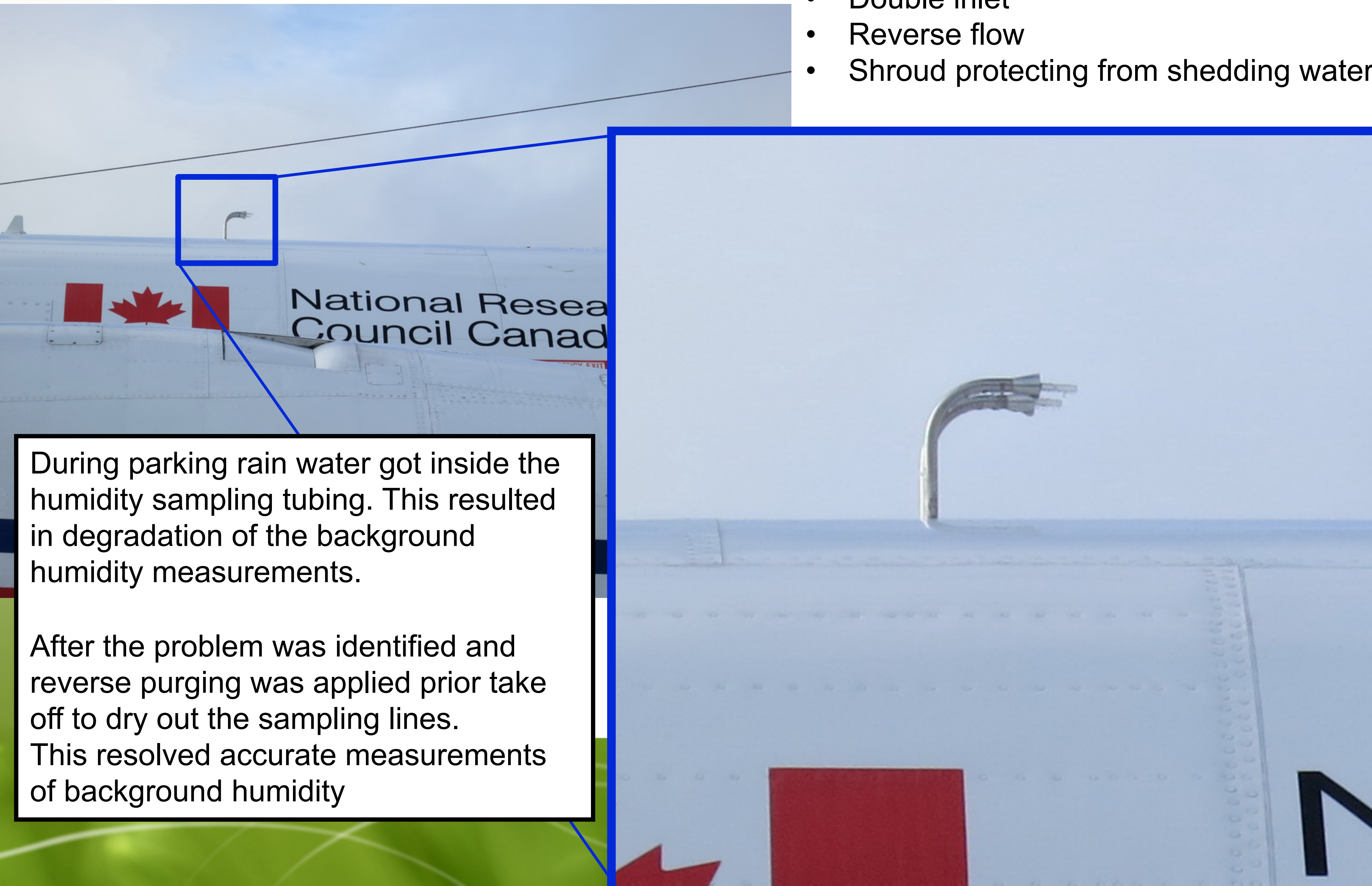
# Water vapor inlet

- Double inlet
- Reverse flow
- Shroud protecting from shedding water



During parking rain water got inside the humidity sampling tubing. This resulted in degradation of the background humidity measurements.

After the problem was identified and reverse purging was applied prior take off to dry out the sampling lines.
This resolved accurate measurements of background humidity

# Performance matrix of the IKP and background humidity measurements

| Flight# | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | 10-May-15 | 12-May-1 | 14-May-15 | 15-May-15 | 16-May-15 | 16-May-15 | 20-May-15 | 23-May-15 | 23-May-15 | 25-May-15 | 26-May-15 | 26-May-15 | 27-May-15 | 27-May-15 |
| IKP | Y- | Y | N | N | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Licor 840A/ 6262 | N | N | N | N | N | N | N | N | N | Y | Y | Y | Y | Y |
| Chilled Mirror | M- | M- | M- | M- | M- | M- | M- | M+ | M+ | Y | Y | Y | Y | Y |

- With the exception two days, the IKP performance during the Cayenne field deployment was satisfactory
- The background humidity measurements failed during the first half of the field campaign, and it was recovered during the second half.
- $TWC_{IKP}=F(RH_{IKP} - RH_{bkgr}, T, P)$
- Existing errors in $T$ and $P$ measurements have minor effect on the $TWC_{IKP}$ accuracy. However, $TWC_{IKP}$ calculations are sensitive to the accuracy of $RH_{bkgr}$.
- **What technique could be used to estimate the background humidity in ice clouds to recover the TWC IKP measurements?**

# Outline

1. Basic IKP data processing (flights with good background humidity)
   (a) Evaluation of the quality of background humidity
   (b) Data synchronizations
   (c) Adjustment of background humidity
   (d) Air temperature adjustment

2. Techniques to estimate background humidity (no background humidity)
   (a) Saturation humidity at air temperature
   (b) Air temperature adjustment
   (c) Quasi-steady humidity

3. Accuracy of different techniques, error analysis

4. Conclusions

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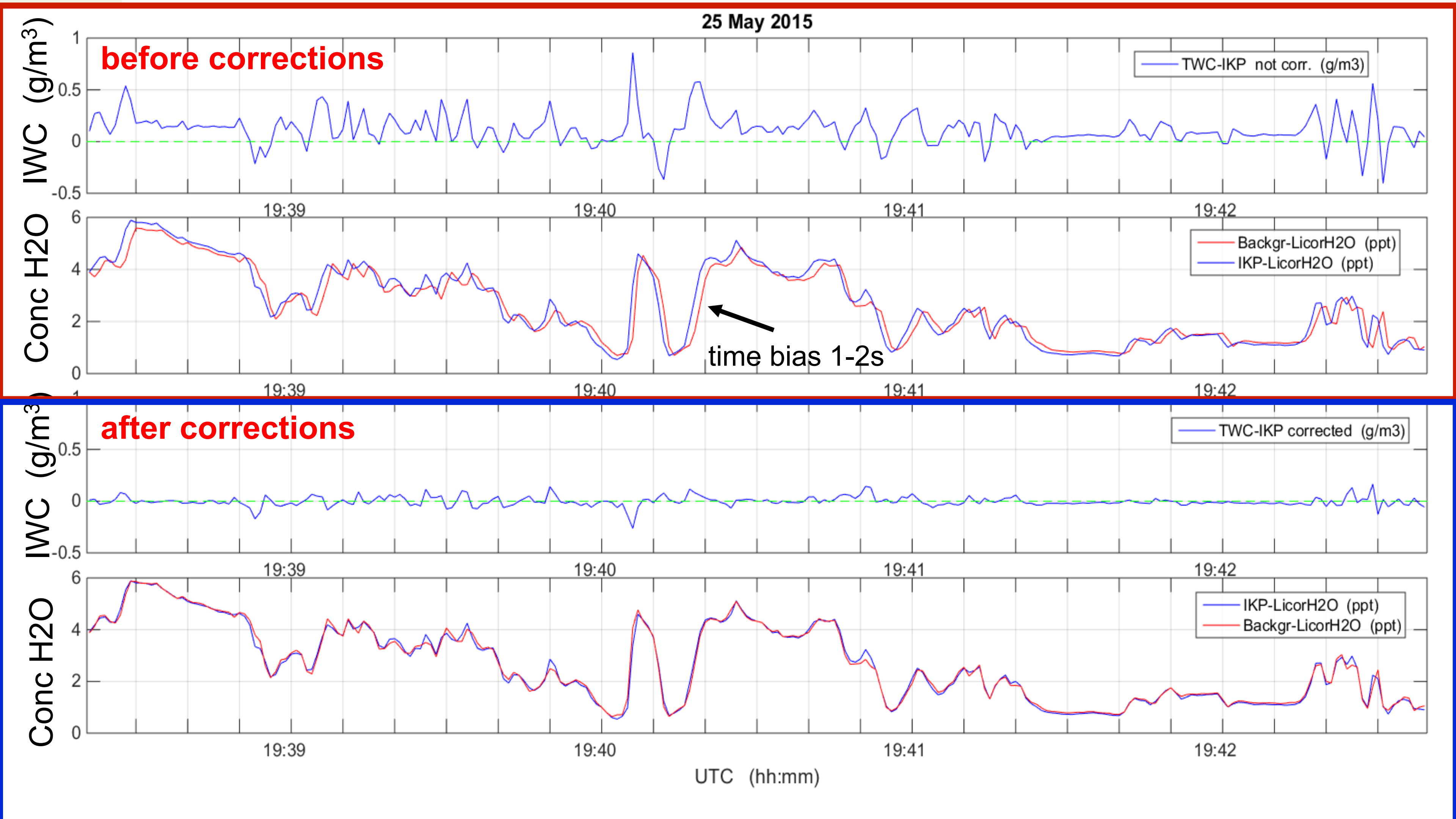
# Effect of synchronisation on IKP TWC calculations in clear sky



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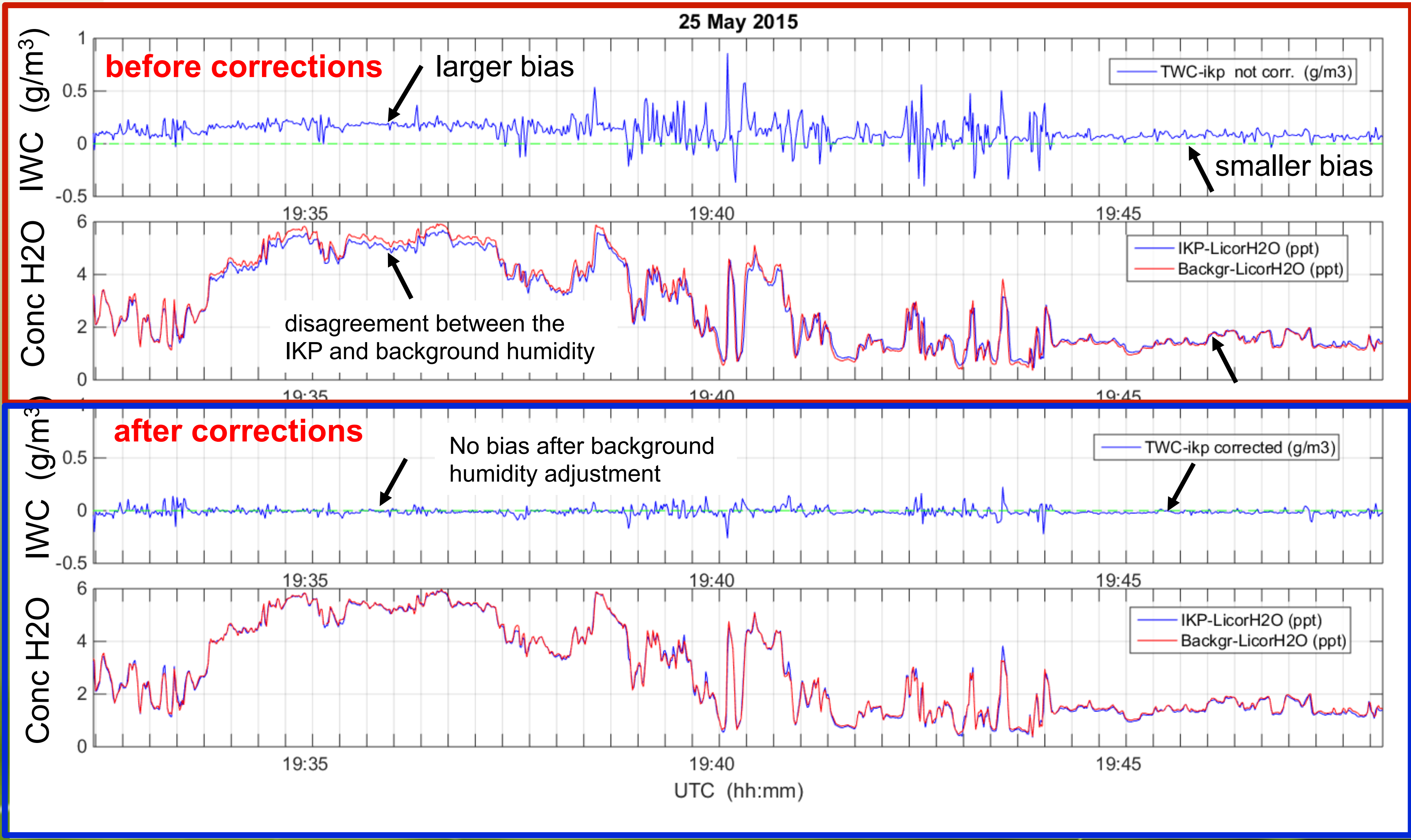
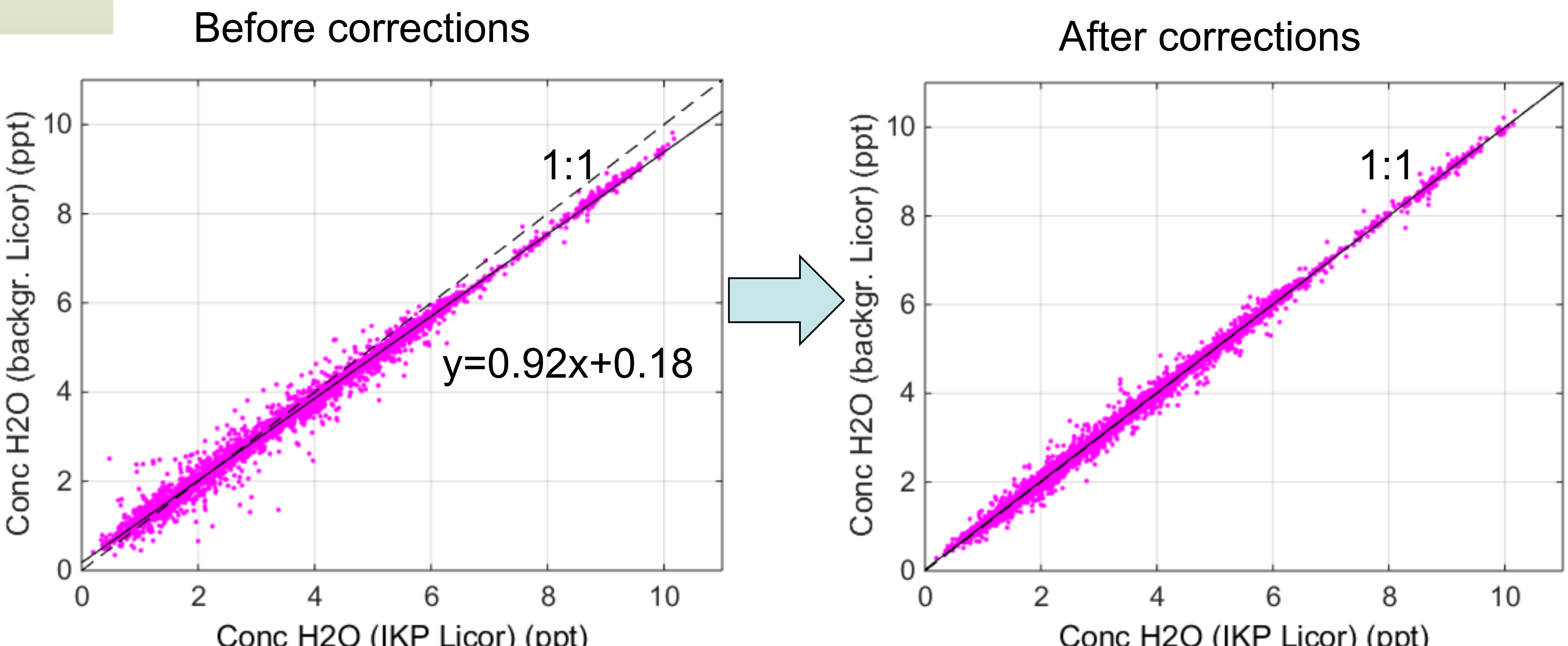
# Effect of background humidity corrections on IKP TWC calculations

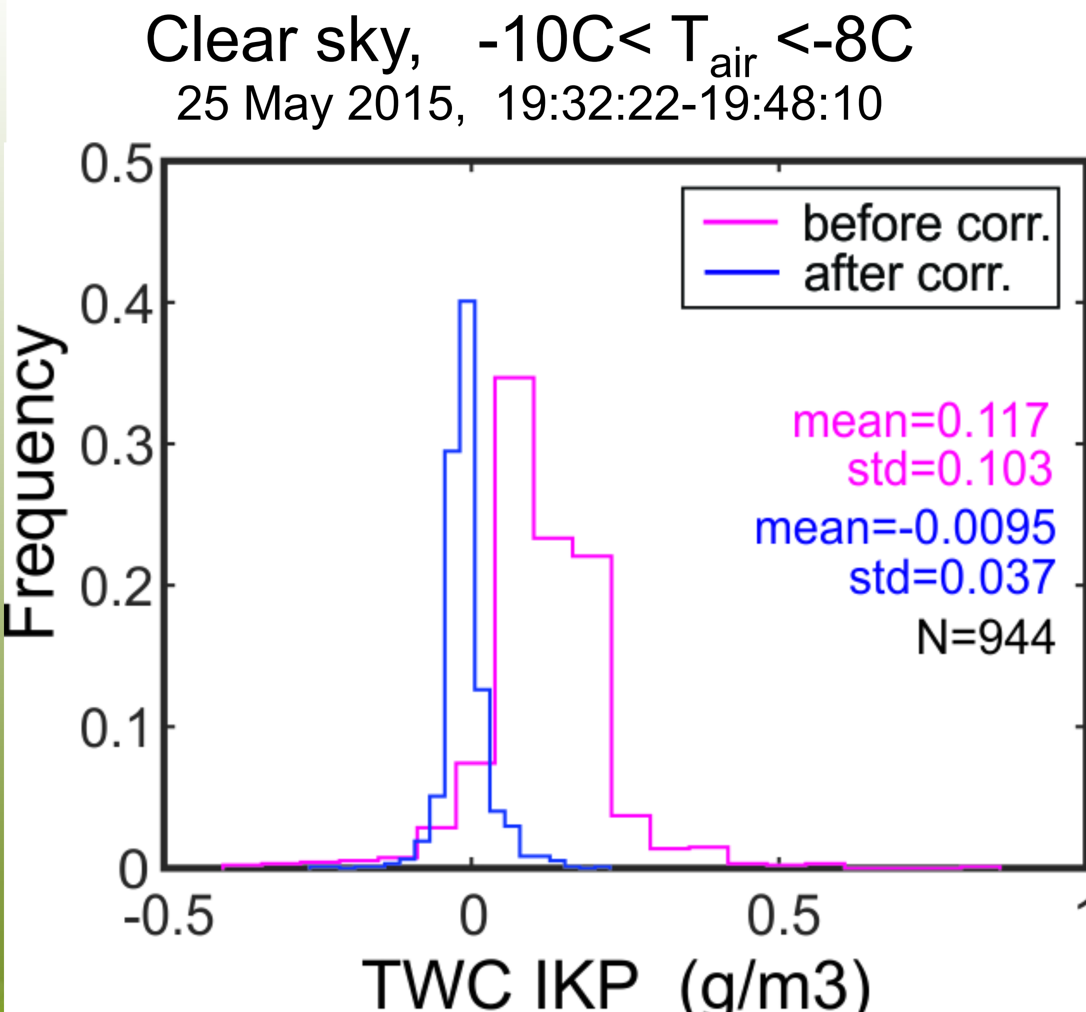
IKP and background humidity measurements in clear sky



# Adjustment of the background humidity to align with the IKP humidity in clear sky

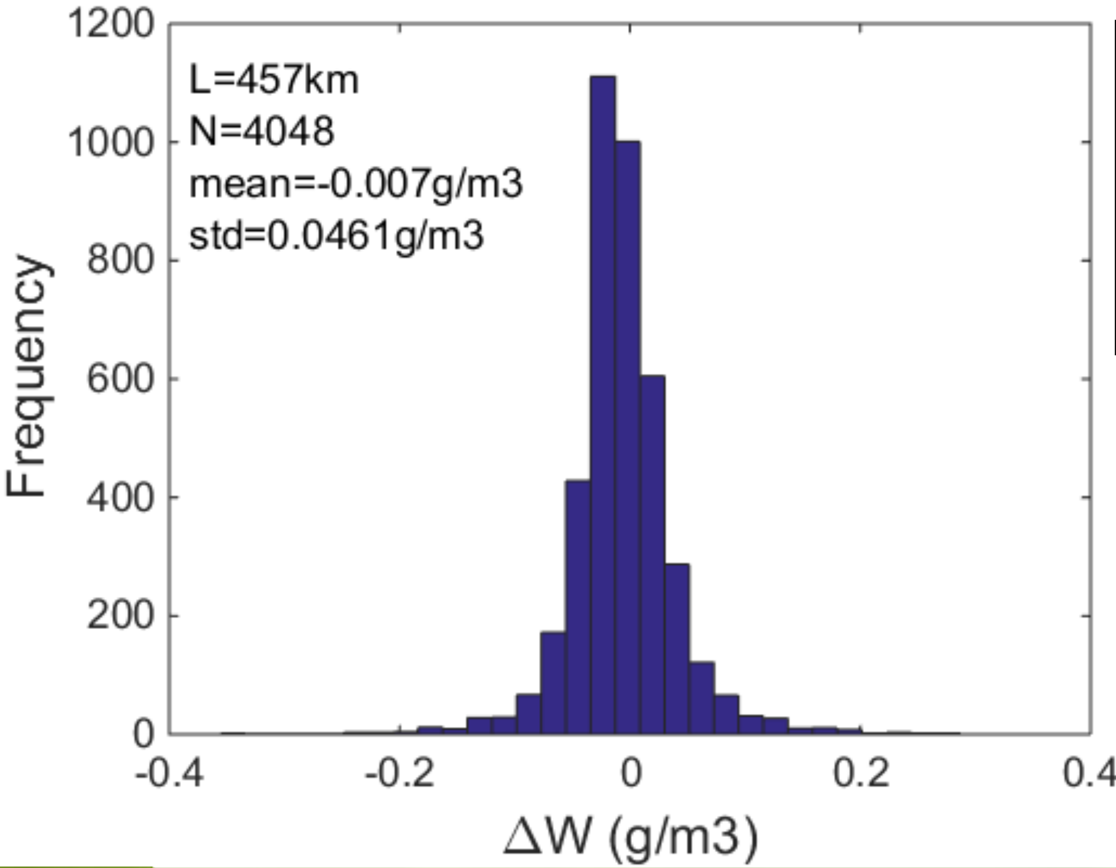


# Effect of background humidity corrections on IKP TWC calculations



# IKP response in clear sky

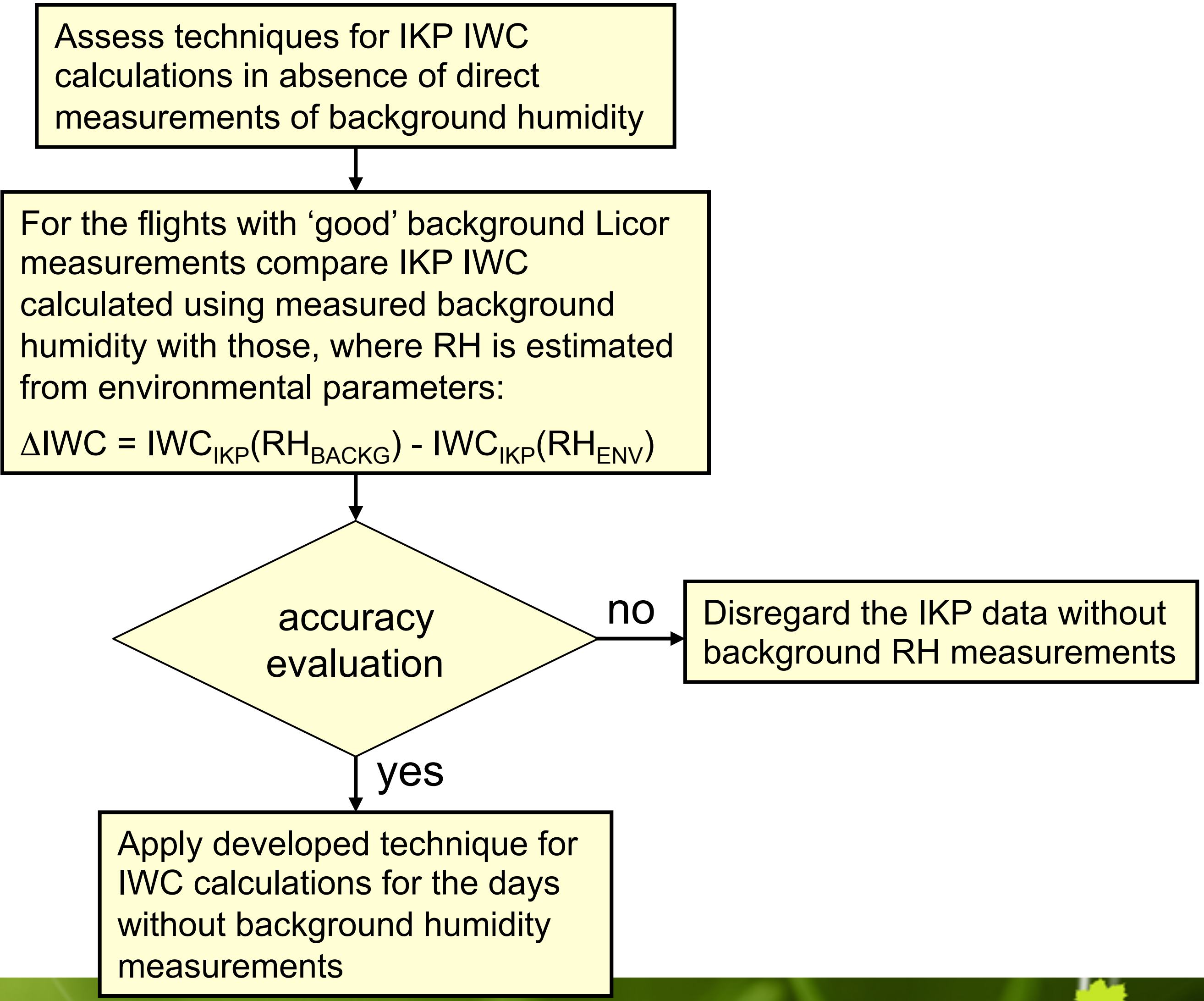
IWC = 0g/m$^3$; -15C < $T_{air}$ < -5C




For the IKP2 and background Licor arrangements on the NRC Convair580 the accuracy of the IKP IWC measurements for the temperature range -15C<T<-5C is estimated as ~0.05g/m$^3$.

# $IWC_{IKP}$ calculations in absence of background humidity measurements

# General strategy



The foregoing analysis is based on the following two studies

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## Supersaturation of Water Vapor in Clouds

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*Center for Earth and Space Research, George Mason University, Fairfax, Virginia*

(Manuscript received 18 October 2002, in final form 2

ABSTRACT

A theoretical framework is developed to estimate the supersaturation in li
An equation describing supersaturation in mixed-phase clouds in general for
for this equation is obtained for the case of quasi-steady approximation, that is
It is shown that the supersaturation asymptotically approaches the quasi-stea
creates a basis for the estimation of the supersaturation in clouds from the c
lations. The quasi-steady supersaturation is a function of the vertical veloci
and ice particles, which can be obtained from in situ measurements. It is sl
the evaporating droplets maintain the water vapor pressure close to saturat
analytical estimation of the time of glaciation of mixed-phase clouds. The l
proximation in clouds with different phase composition are considered here.
as well as the effect of the characteristic time and spatial scales of turbulent

Theoretical framework describing phase transformation of a three-phase colloidal system.

activation of droplets and then monotonically decreases. Squires (1952) derived a relationship between supply and depletion of water vapor in a vertically moving cloud parcel. The solution of the Squires equation suggested that, to a first approximation, the supersaturation is linearly related to a vertical velocity and inversely proportional to the concentration and the average size of the cloud droplets. This relationship was later used

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## Relative Humidity in Liquid, Mixed-Phase, and Ice Clouds

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(Manuscript received 17 May 2005, in final form 24 February 2006)

ABSTRACT

The results of in situ observations of the relative humidity in liquid, mixed, and ice clouds typically stratiform in nature and associated with mesoscale frontal systems at temperatures $-45°C < T_a < -5°C$ are presented. The data were collected with the help of instrumentation deployed on the National Research Council (NRC) Convair-580. The length of sampled in-cloud space is approximately $23 \times 10^3$ km. The liquid sensor was calibrated in liquid clouds with the assumption that the air in liquid clouds is saturated with respect to water. It was found that the relative humidity in mixed-phase clouds is close to saturation over water in the temperature range from $-5°$ to $-35°C$ for an averaging scale of 100 m. In ice clouds the relative humidity over ice is not necessarily equal to 100%, and it may be either lower or higher than saturation over ice, but it is always lower than saturation over water. On average the relative humidity in ice clouds increase
saturatio
large fra
undersat

Experimental justification of the KM2003 theoretical analysis

### 1. Introduction

Water vapor insi
life cycle and precipitation formation. The understanding of the relationships between the vapor pressure and

circulation models (GCMs) is usually specified as a function of temperature (e.g., Fowler et al. 1996; Jakob

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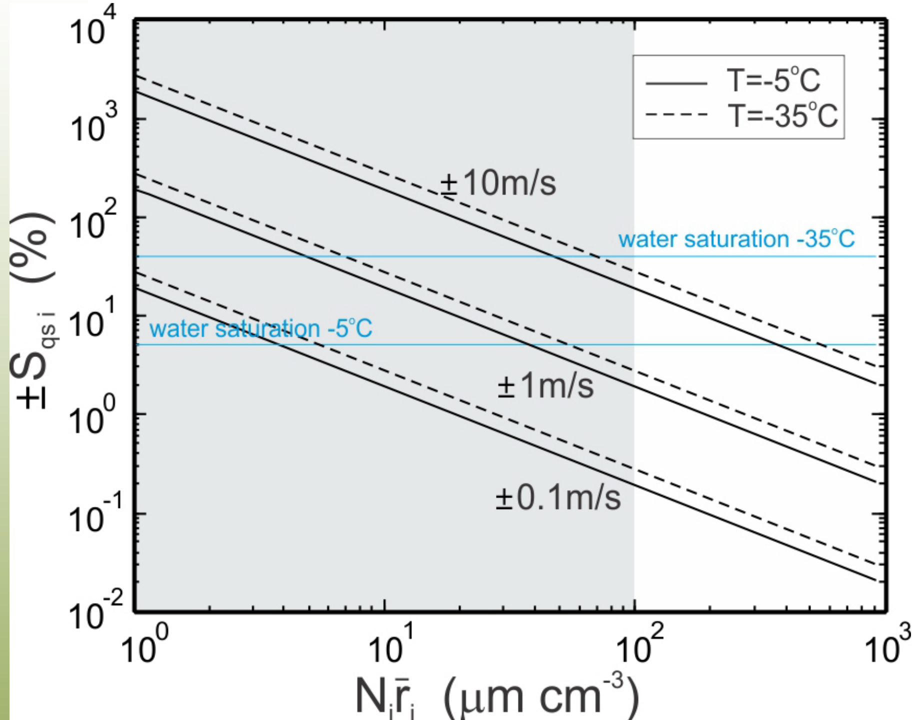
## Quasi-steady supersaturation

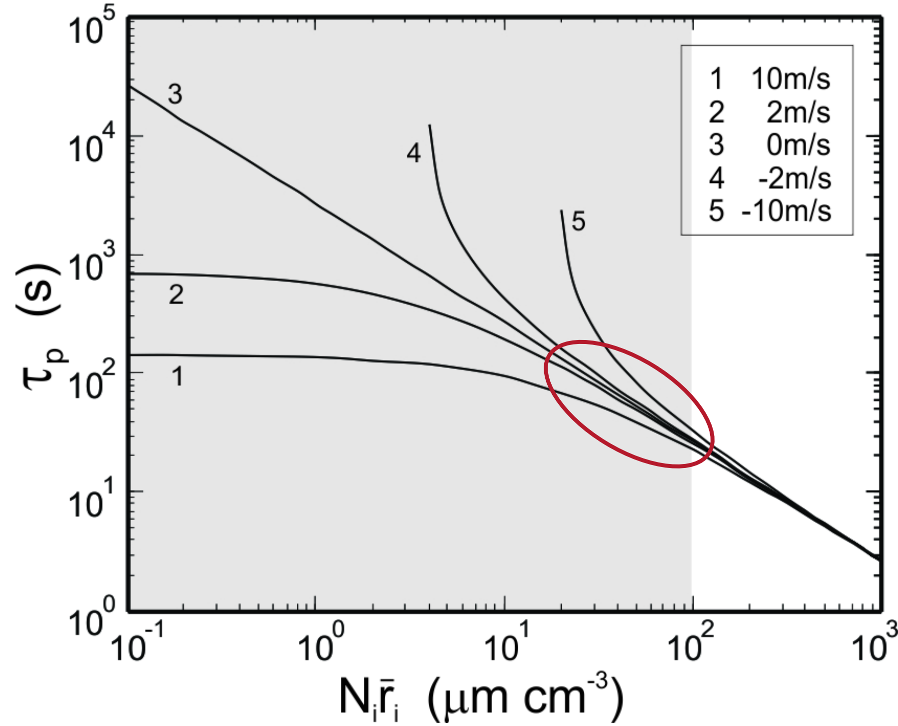



$$S_{qs\ i} = \frac{a_{0i} u_z}{b_i N_i \bar{r}_i}$$

Equilibrium vapor supersaturation, which the humid air in ice cloud tends to approach.

$S_{qsi}$ depends on vertical velocity $\underline{u_z}$ and integral particle radius $N_i r_i$

## Phase relaxation time in ice clouds



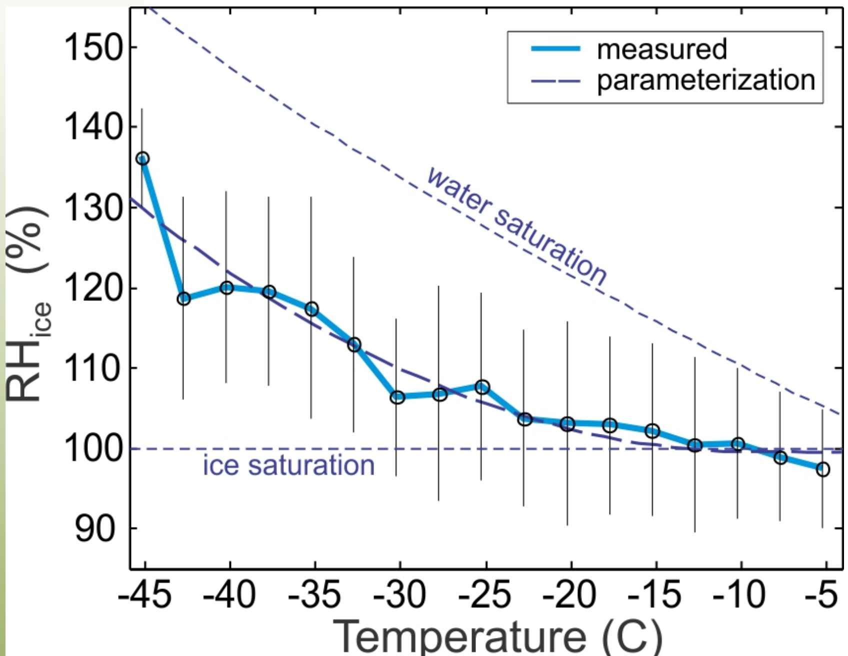

$$\tau_p = \frac{1}{a_0 u_z + b_i N_i \bar{r}_i} \approx \frac{1}{b_i N_i \bar{r}_i}$$

Time of phase relaxation determines the characteristic time of relative humidity approaching to its equilibrium value $S_{qsi}$

Korolev and Mazin, 2003

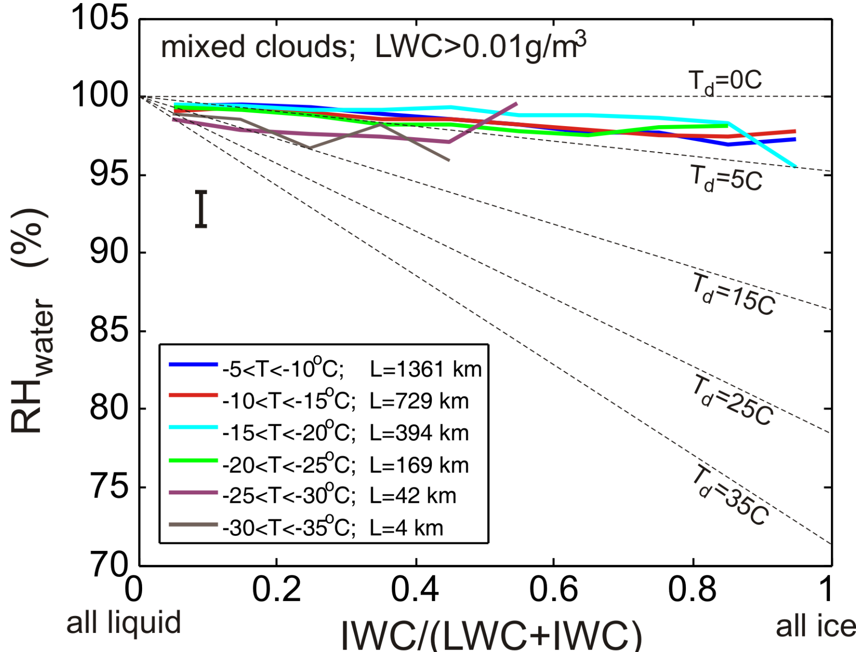
# Statistics of humidity clouds

## Average RH in ice clouds




In ice clouds due to large time of phase relaxation the air can be both undersaturated or supersaturated with respect to ice,
i.e. possible both $T_{air} < T_{frost}$ or $T_{air} > T_{frost}$

## Average RH in mixed phase clouds




In liquid and mixed phase cloud the air in most cases is close to saturation with respect to water, i.e $T_{air} \approx T_{dew}$

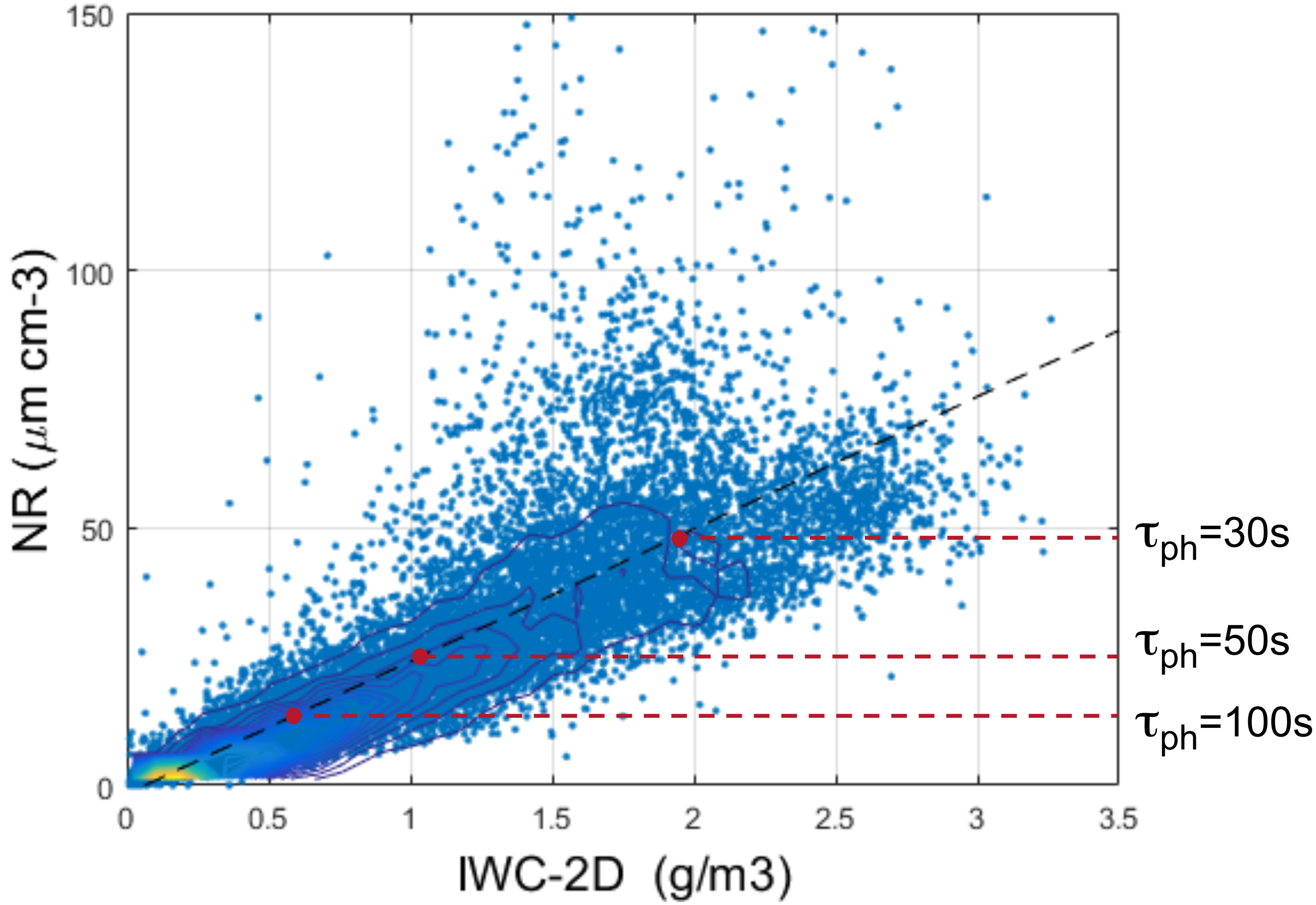
Korolev and Isaac (JAS, 2006)

# Two approaches to estimate background humidity

1. Quasi-steady humidity $RH_i = aU_z/N_i r_i + 1$,
   where $U_z$ is the vertical velocity of the cloud volume and $N_i r_i$ is the integral particle radius.

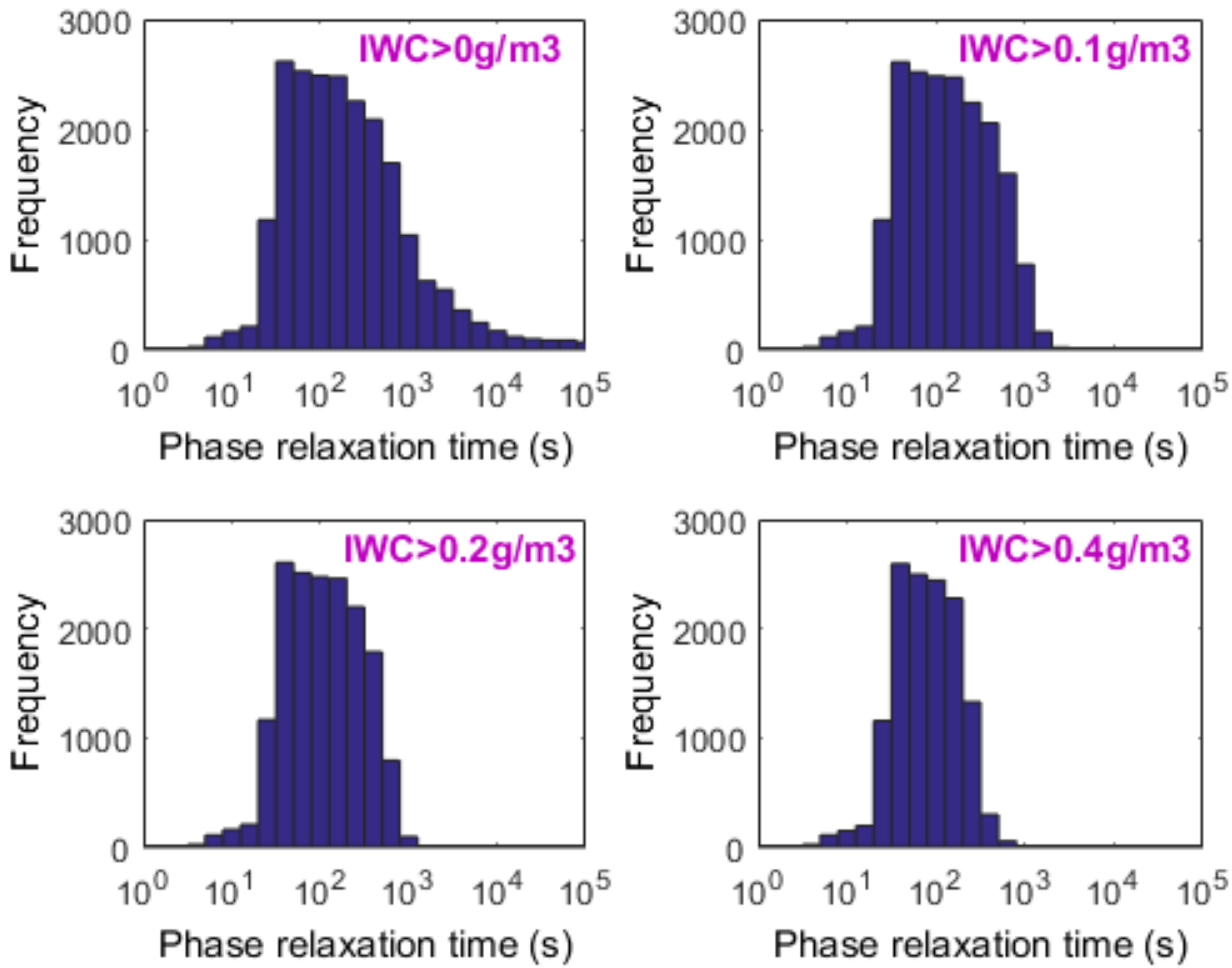
2. Based on the assumption that humidity in ice clouds is saturated with respect to ice $RH_i$=1, which means that $T_{air} = T_{frost}$. This assumption presumes that the time of phase relaxation $\tau_{ph}$ is short enough (or $N_i r_i$ is large).

# Dependence of $N_i r_i$ vs *IWC* for all Convair580 flights at -15C<T<-5C



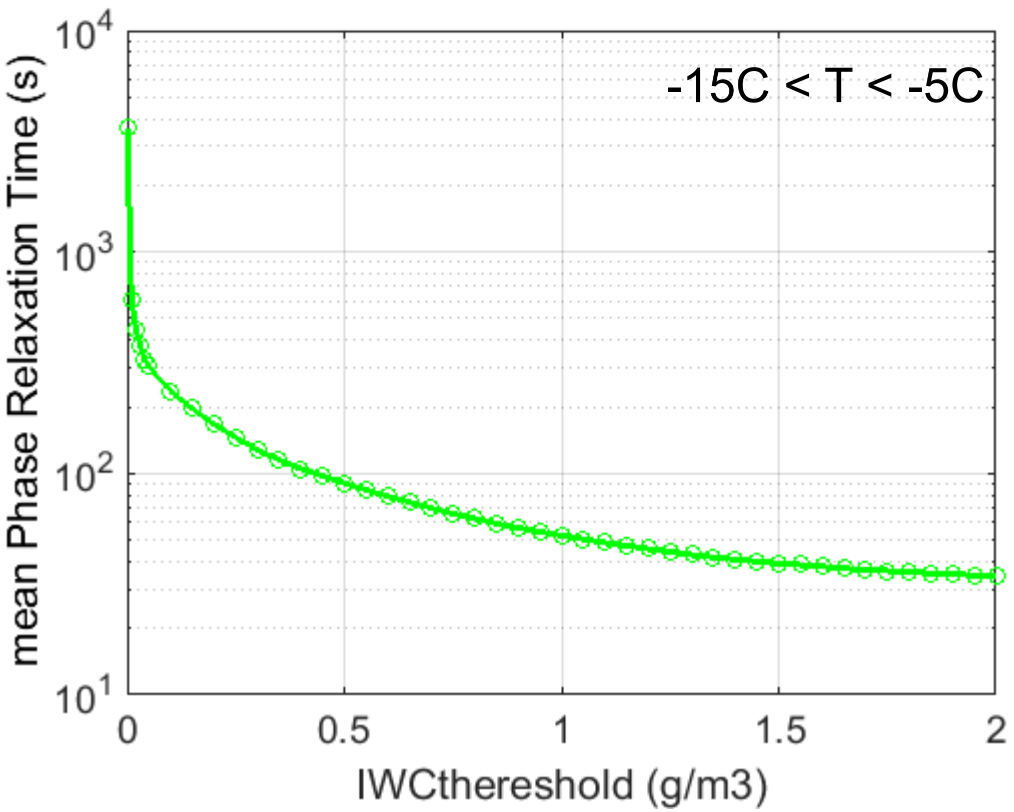

- $10s < \tau_p < 100s$ anticipated small IWC errors
- $10^2 s < \tau_p < 10^3$ anticipated large IWC errors

# Time of phase relaxation calculated for different IWC thresholds



# Average time of phase relaxation calculated for all Convair580 flights

IWC > $IWC_{thresh}$



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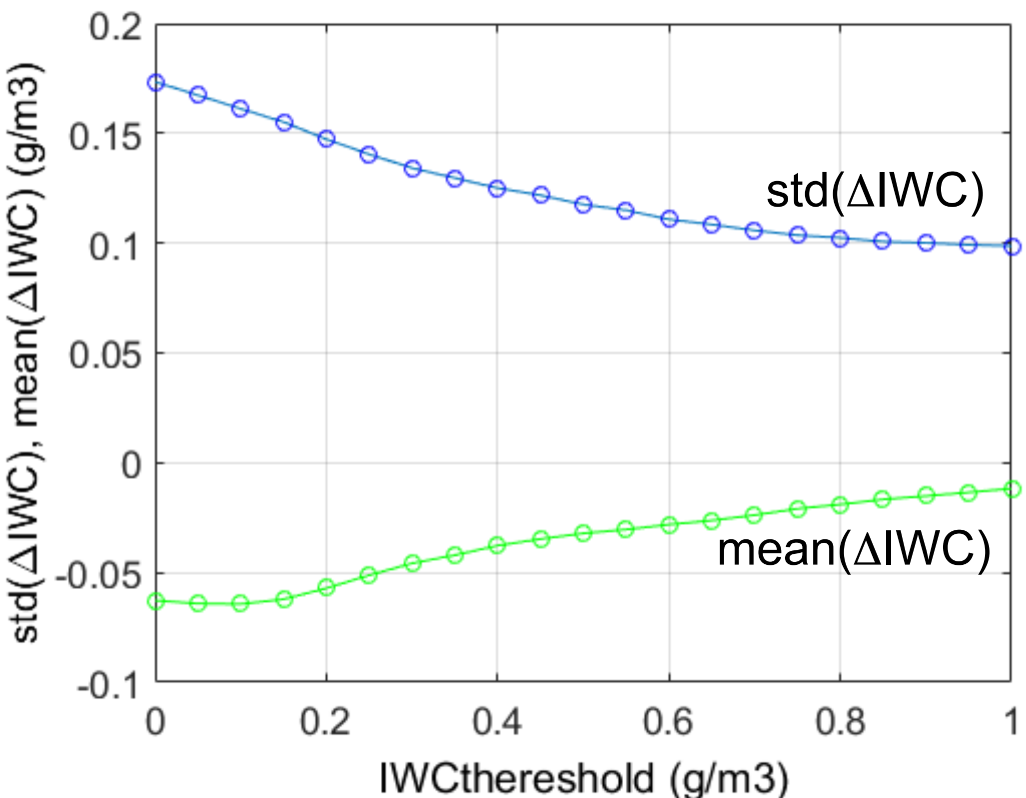
Estimation of the error in $IWC_{IKP}$ calculations for the background humidity in assumption $T_{air}=T_{frost}$

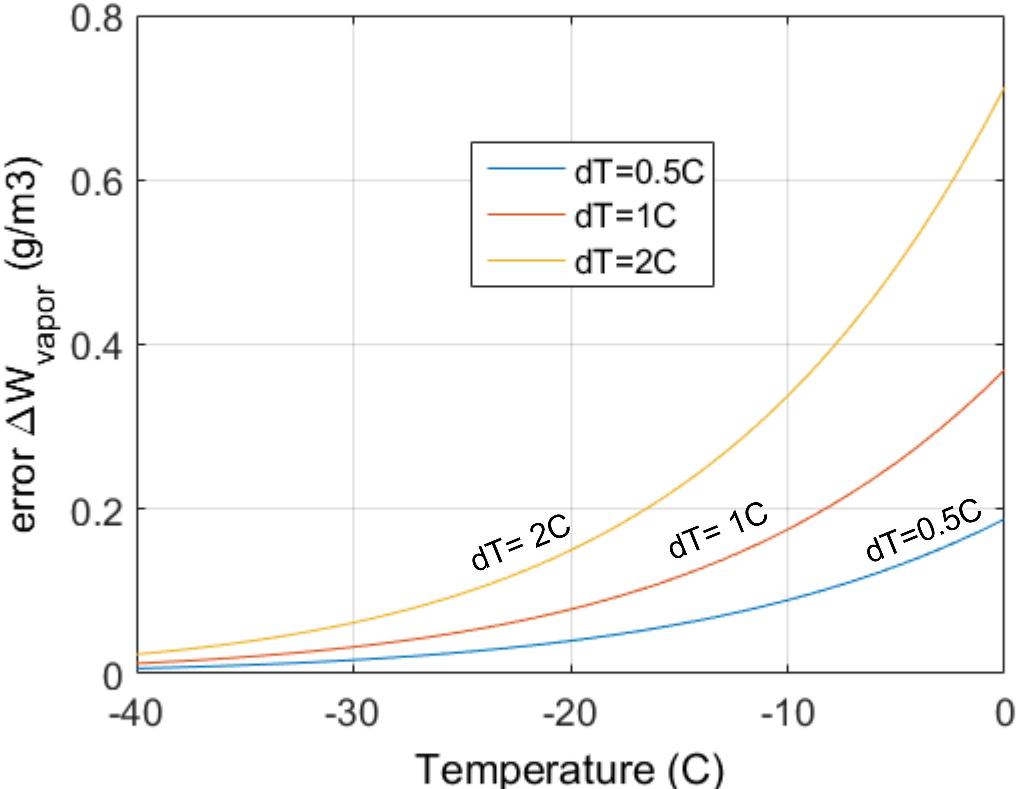
$$\Delta IWC = IWC_{IKP}(\text{backgrLicor}) - IWC_{IKP}(RH_i=S_{qs}+1)$$




Under assumption $RH_i=S_{qs}+1$ the error in $IWC_{IKP}$ calculations gradually decreases with increase of IWC from 0.2g/m$^3$ at $IWC \sim 0$ to 0.1g/m$^3$ for $IWC \sim$1g/m$^3$.

# Effect of the temperature errors *dT* on the accuracy of IWC calculations in assumption that $T_{air} = T_{frost}$

$$\Delta W = \rho_v(T_{frost}) - \rho_v(T_{frost}+dT)$$




For the temperature range -15C<T<-5C

dT=±0.5C $0.05 g/m^3 < \Delta IWC < 0.1 g/m^3$

dT=±1C $0.1 g/m^3 < \Delta IWC < 0.3 g/m^3$

Error ΔIWC is sensitive to accuracy of temperature measurements at *T* >-15C

Accuracy of the airborne temperature measurements is usually 0.5C to 1C. Regular biases may be of the order of 1C to 2C

Is there any way to calibrate air temperature during flight operations?

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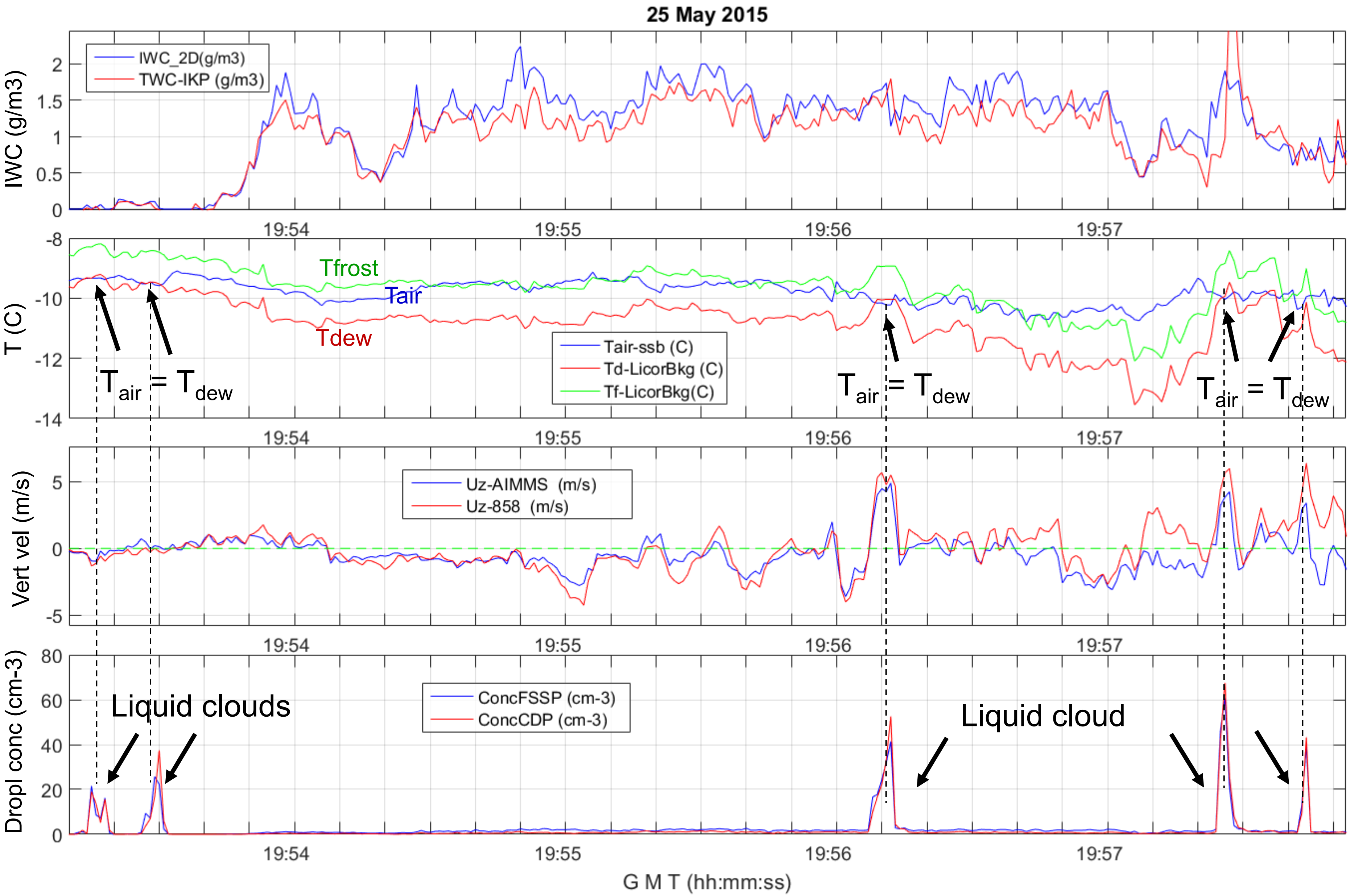


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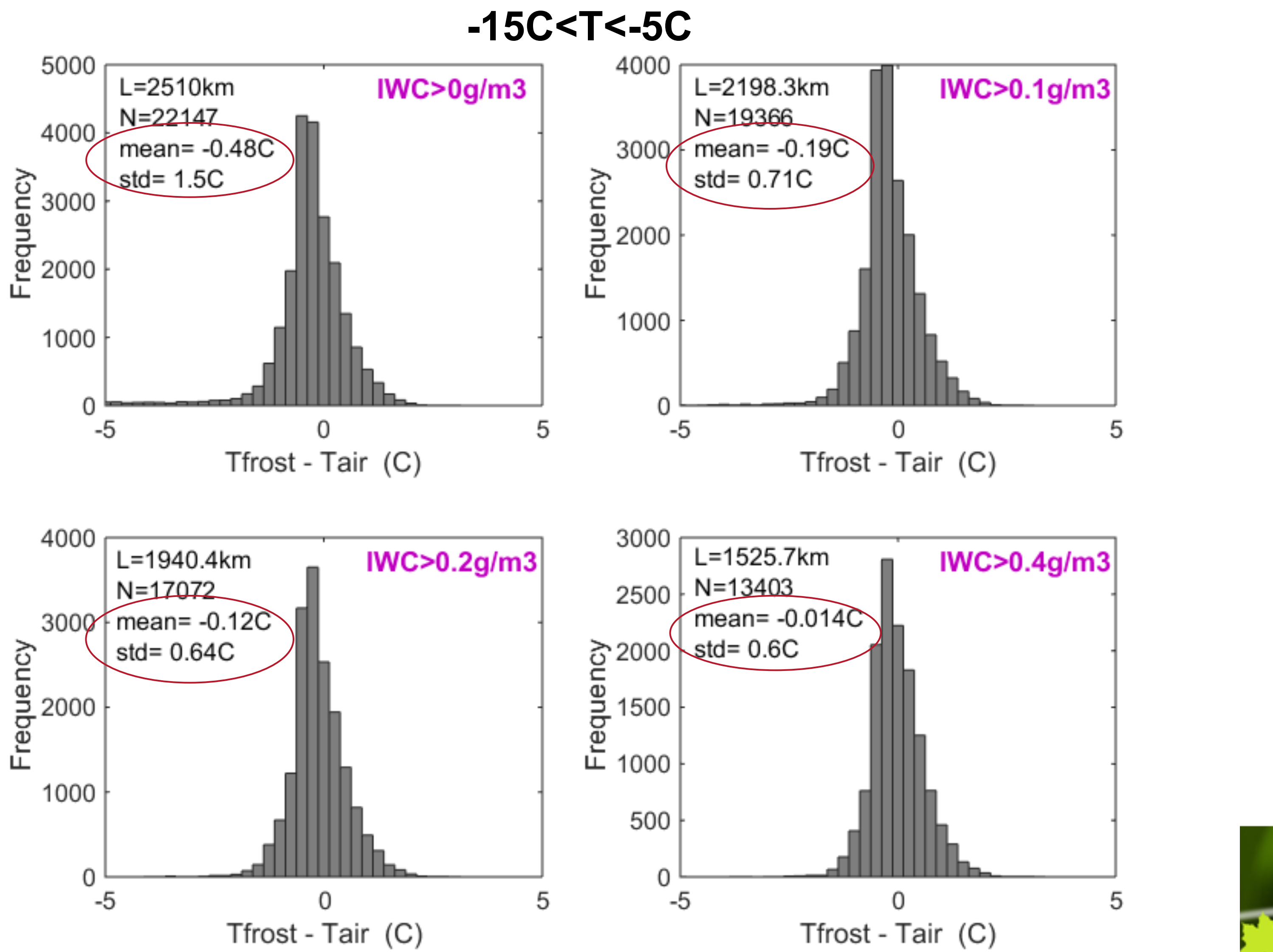
# Deviation of $T_{air}$ from $T_{frost}$ in ice clouds for different IWC threshold for the Convair580 flights with good background humidity



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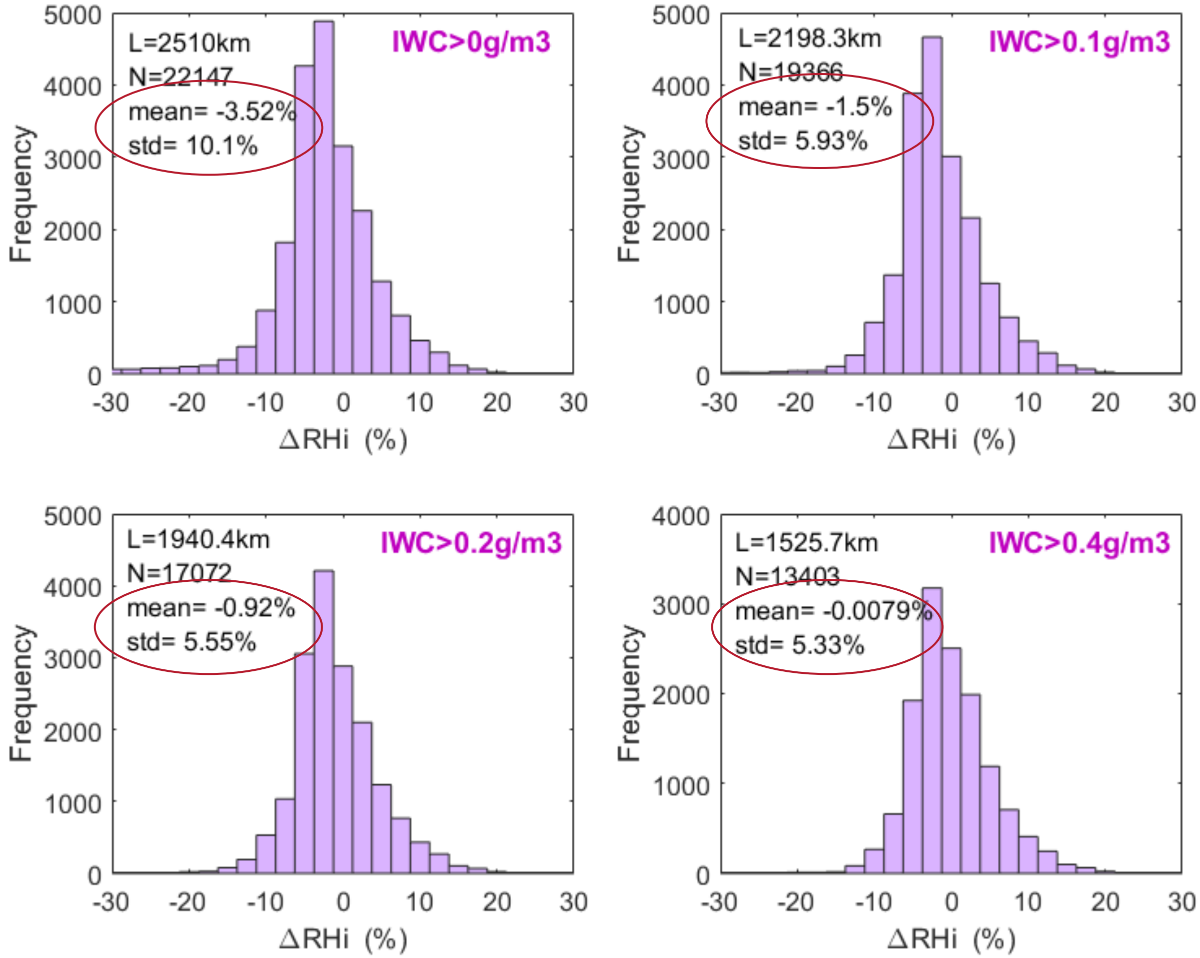
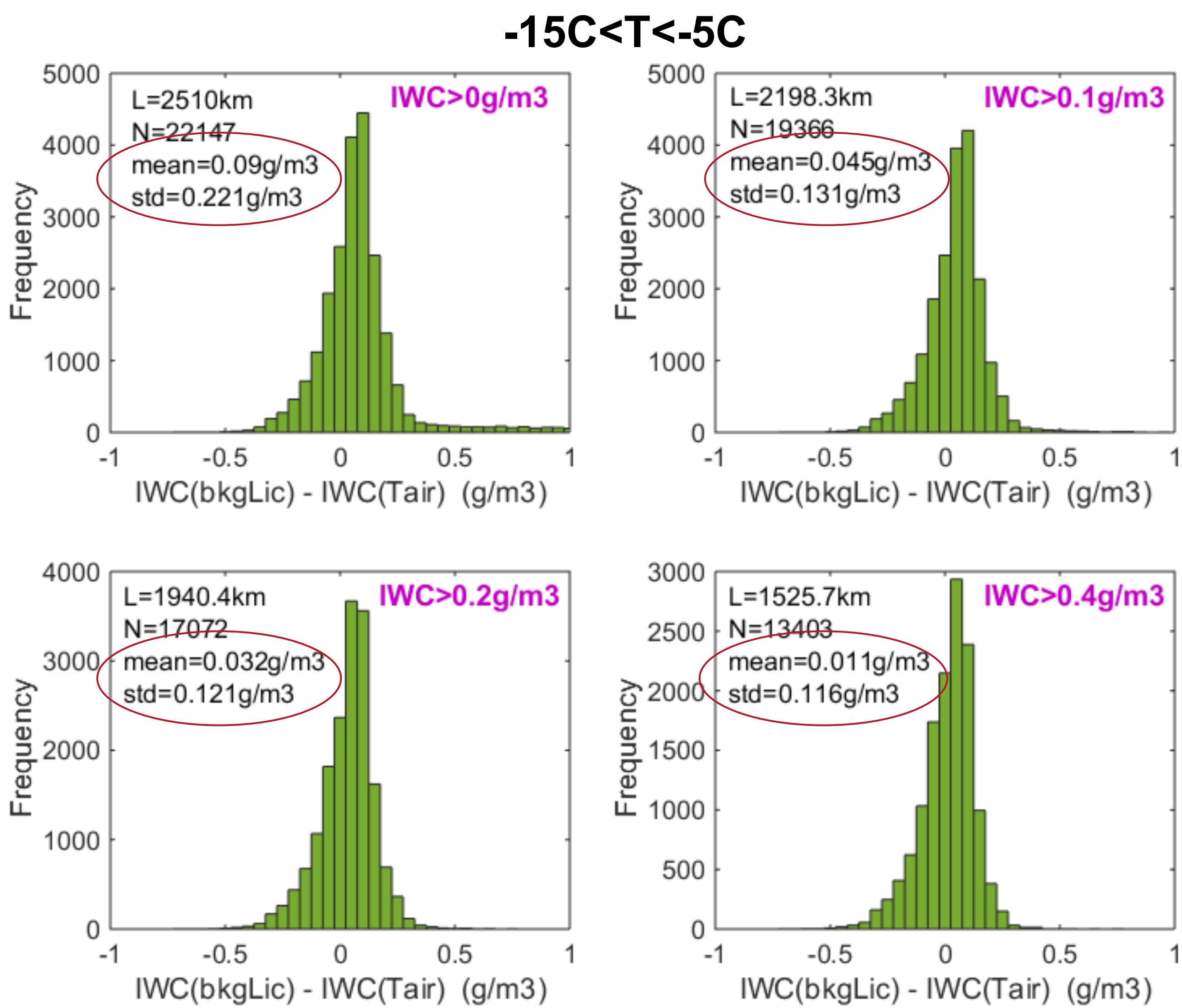
# Distributions of ΔRHi in ice clouds in assumption $T_{air} = T_{frost}$ for different IWC threshold for the Convair580 flights with good background humidity

**-15C<T<-5C**



Error in $IWC_{IKP}$ calculations in assumption $T_{air} = T_{frost}$ for different IWC threshold for the Convair580 flights with good background humidity



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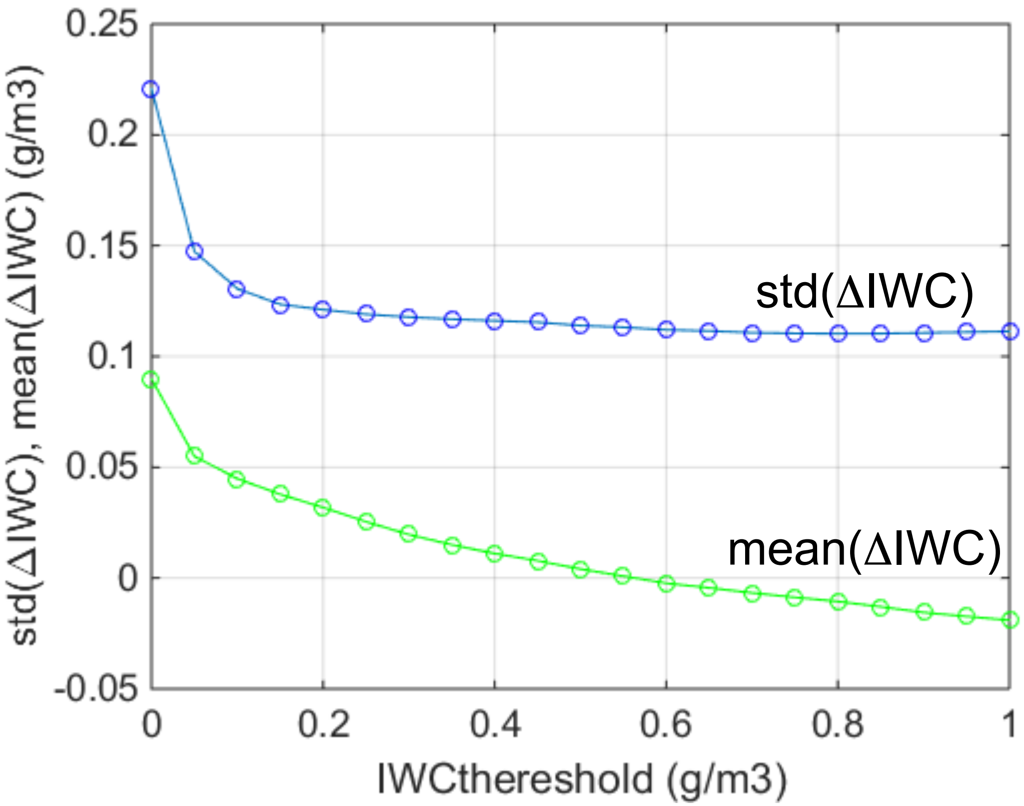
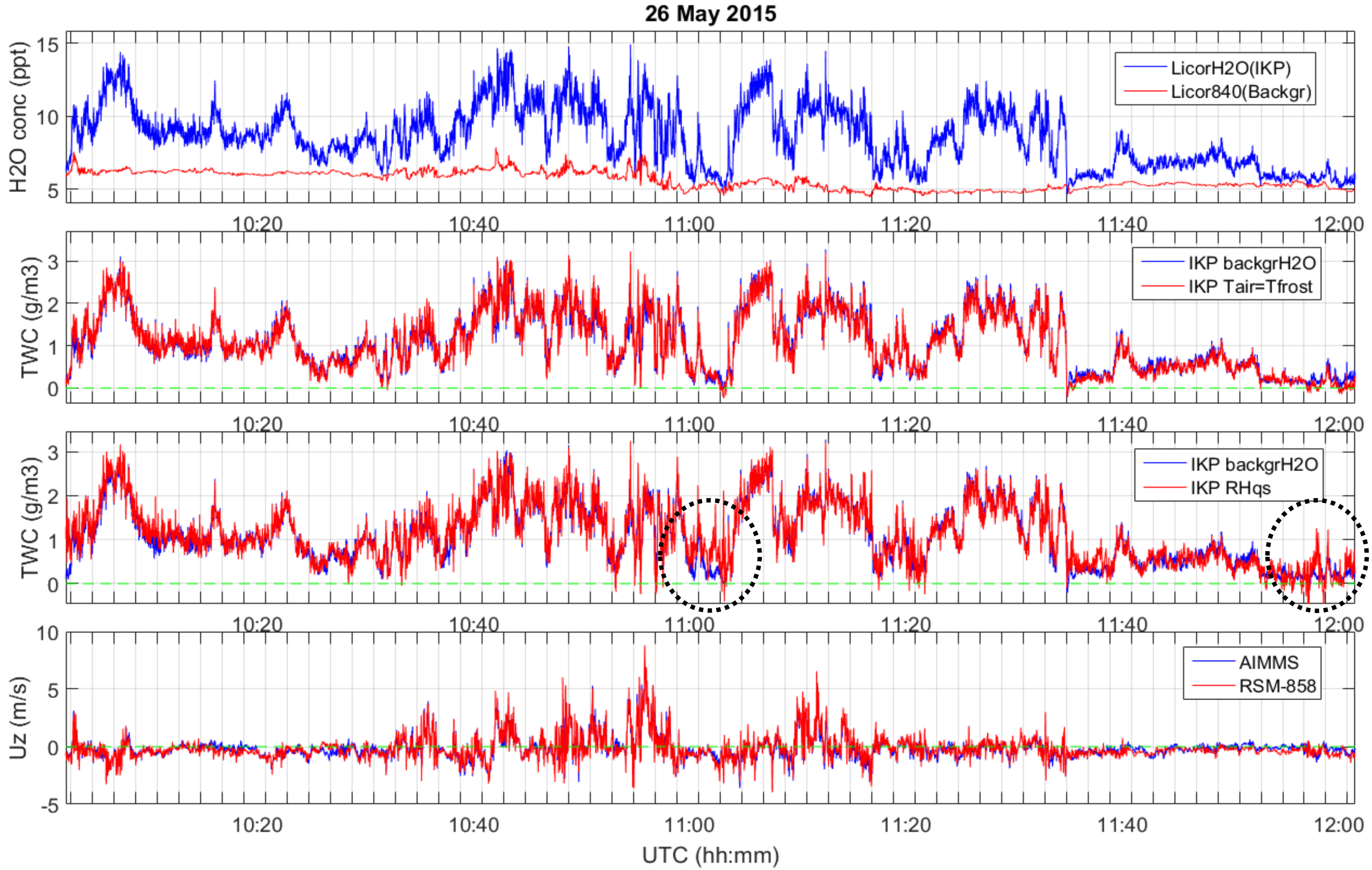
## Estimation of the error in $IWC_{IKP}$ calculations for the background humidity in assumption $T_{air}=T_{frost}$

$$\Delta IWC = IWC_{IKP}(backgrLicor) - IWC_{IKP}(Tair=Tfrost)$$

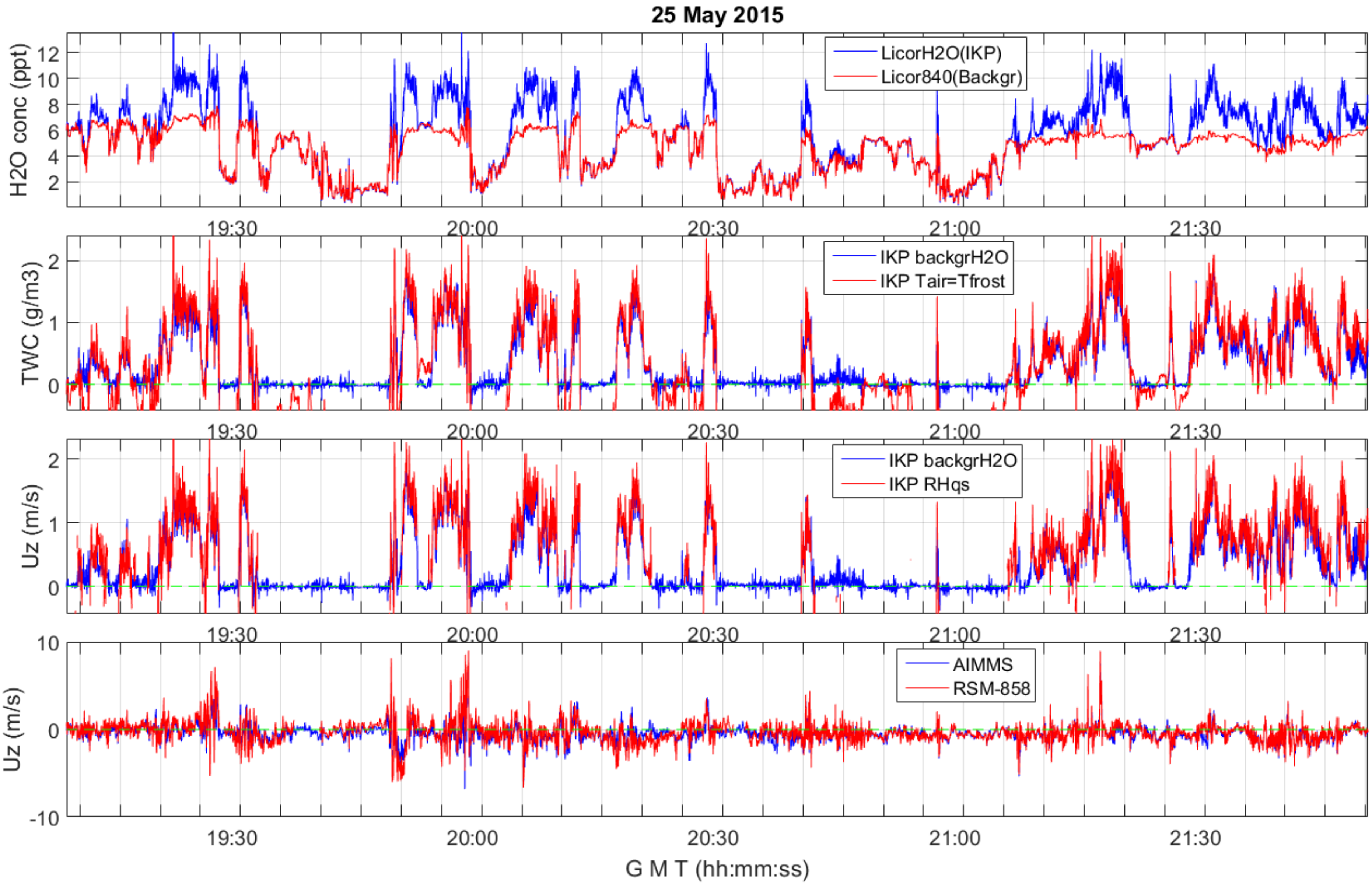



Under assumption $T_{air}=T_{frost}$ the error in $IWC_{IKP}$ calculations decreases with increase of IWC and it remains approximately constant $\Delta IWC$ ~ 0.12g/m$^3$ for $IWC$ > 0.2g/m$^3$.

Comparisons of three ways of RH estimates in calculations of $IWC_{IKP}$:
(a) background RH; (b) $RH(T_{air} = T_{frost})$ ; (c) $RH_i = S_{qs} + 1$



Comparisons of three ways of RH estimates in calculations of $IWC_{IKP}$:
(a) background RH; (b) $RH(T_{air} = T_{frost})$ ; (c) $RH_i = S_{qs} + 1$



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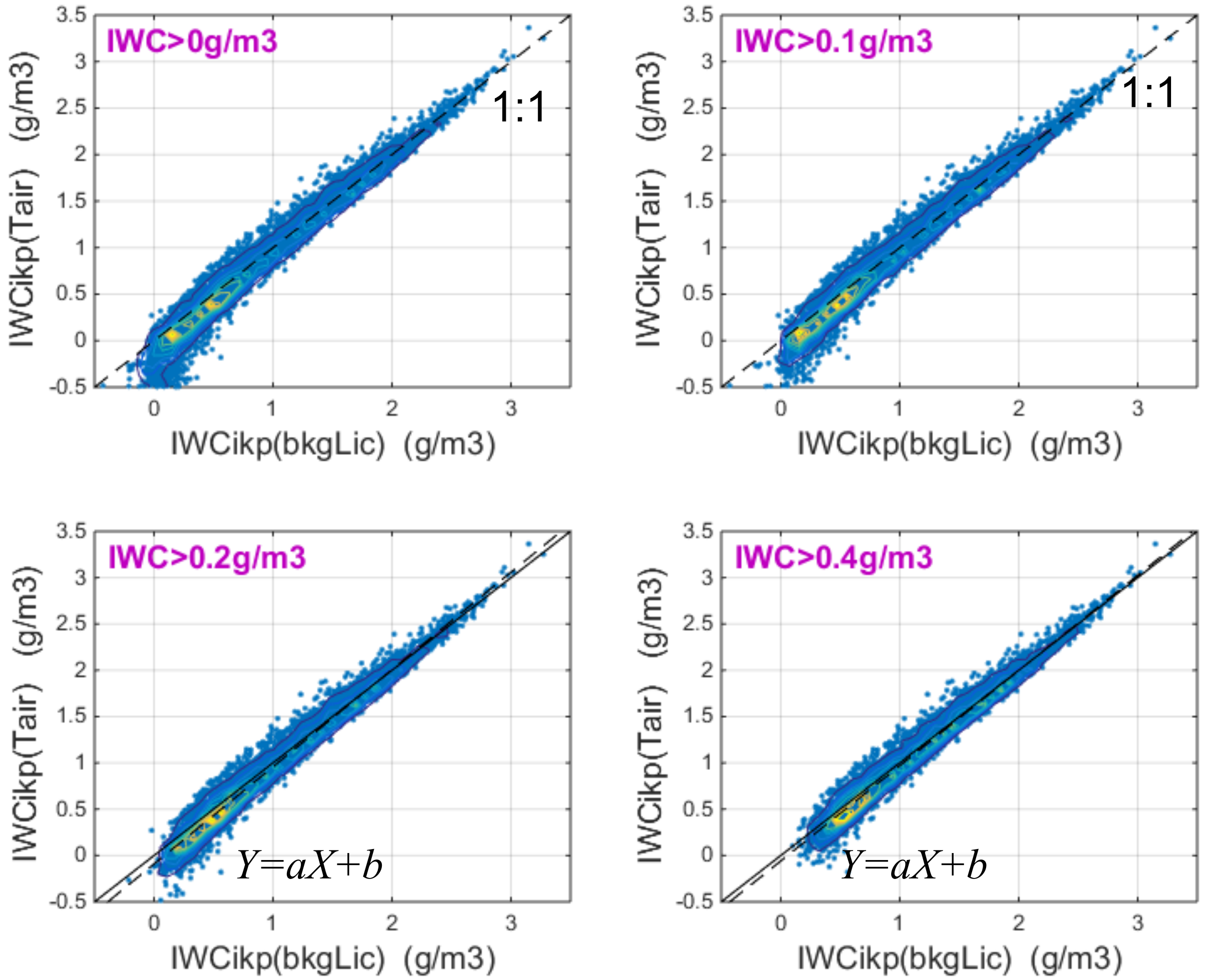
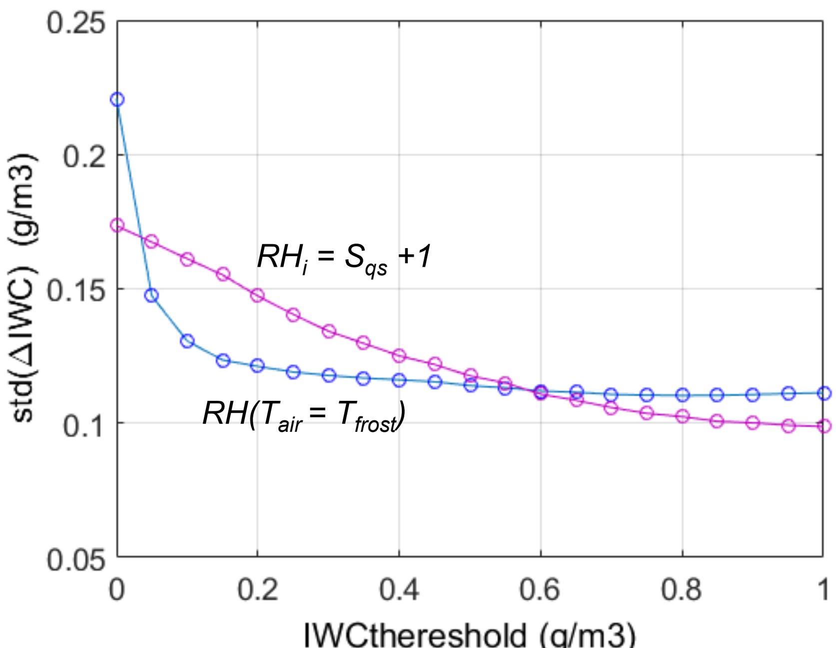
$IWC_{thresh}$=0.2g/m3, a=1.0503, b=-0.092447
$IWC_{thresh}$=0.4g/m3, a=1.0281, b=-0.059053



# Overall assessment of accuracy of two methods for IWC>0.1g/m³

| method | std(ΔIWC) | mean(ΔIWC) |
|---|---|---|
| $RH_i = S_{qs} + 1$ | 0.16 g/m³ | -0.06 g/m³ |
| $RH(T_{air} = T_{frost})$ | 0.12 g/m³ | 0.05 g/m³ |

the winner



# Conclusions

1. Accuracy of $IWC_{IKP}$ with the Licor background humidity is estimated as 0.05g/m$^3$ based on the assessment of noise in clear sky at -15C <T <-5C. This error estimate represents random error, and it does not include regular biases which may occur during measurements in clouds.

2. In absence of instrumental measurements of background humidity, *RH* can be estimated: (a) from quasi-steady humidity $RH_i=aU_z/N_ir_i+1$; (b) from assumption $T_{air}=T_{frost}$.

3. The first method requires additional measurements of the vertical velocity $U_z$ and calculation of the integral particle size $N_ir_i$ from PSDs measurements. These additional measurements may degrade accuracy of $IWC_{IKP}$ due to errors in $N_ir_i$ and $U_z$

4. The second method is more robust and it provides a slightly better accuracy, than the first method. Average error of the $IWC_{IKP}$ is decreasing with increase of *IWC*. *IWC*<0.2g/m3 should not be used as unreliable.

5. For future IKP measurements it is recommended using isokinetic (open path) background humidity measurements.

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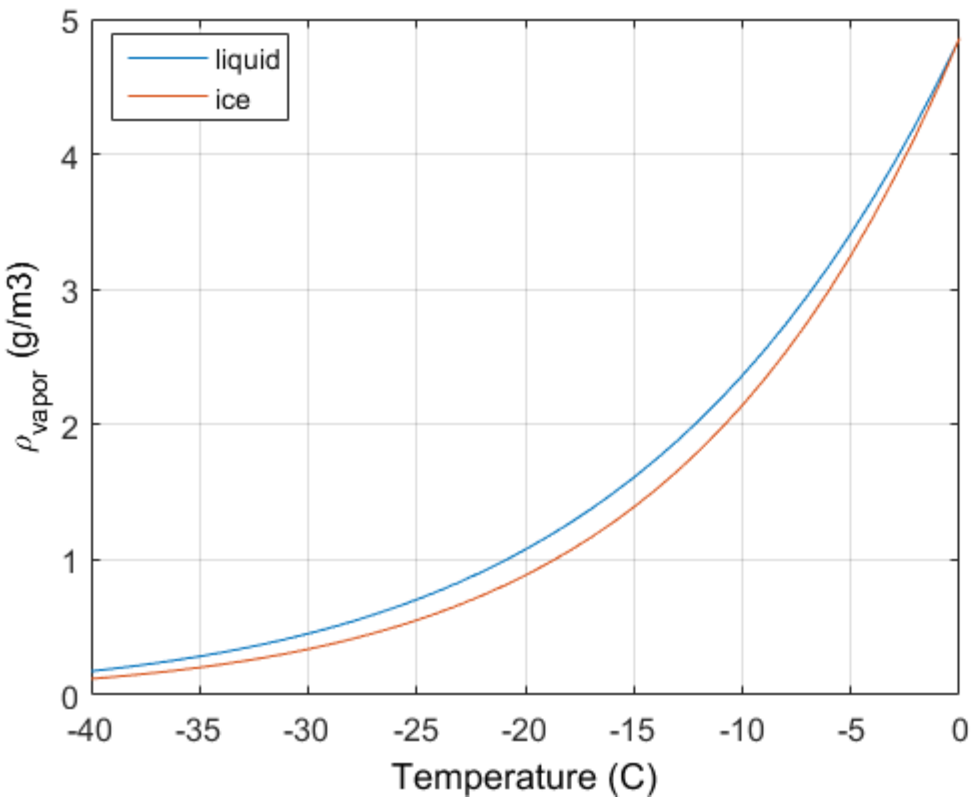
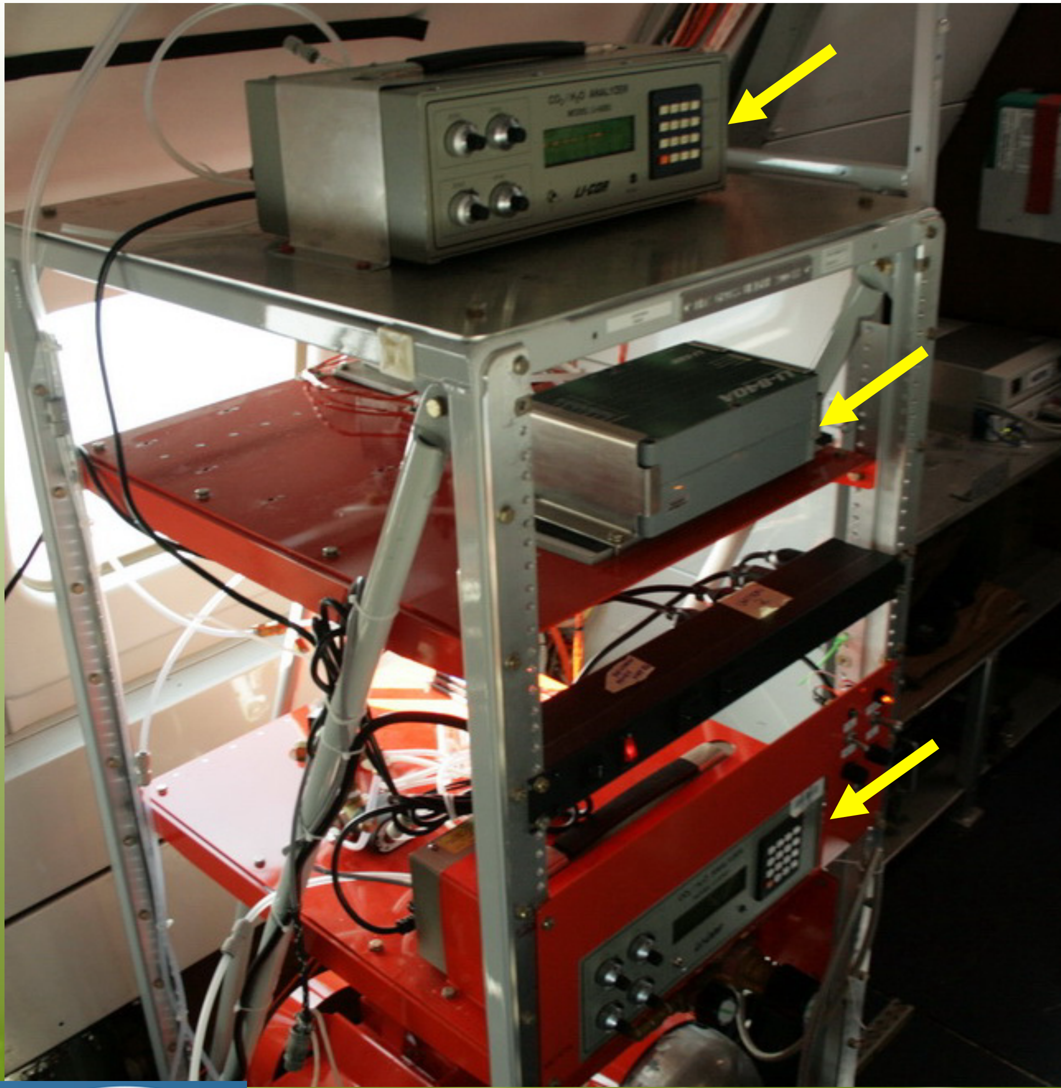
**High Ice Water Content (HIWC) Program**

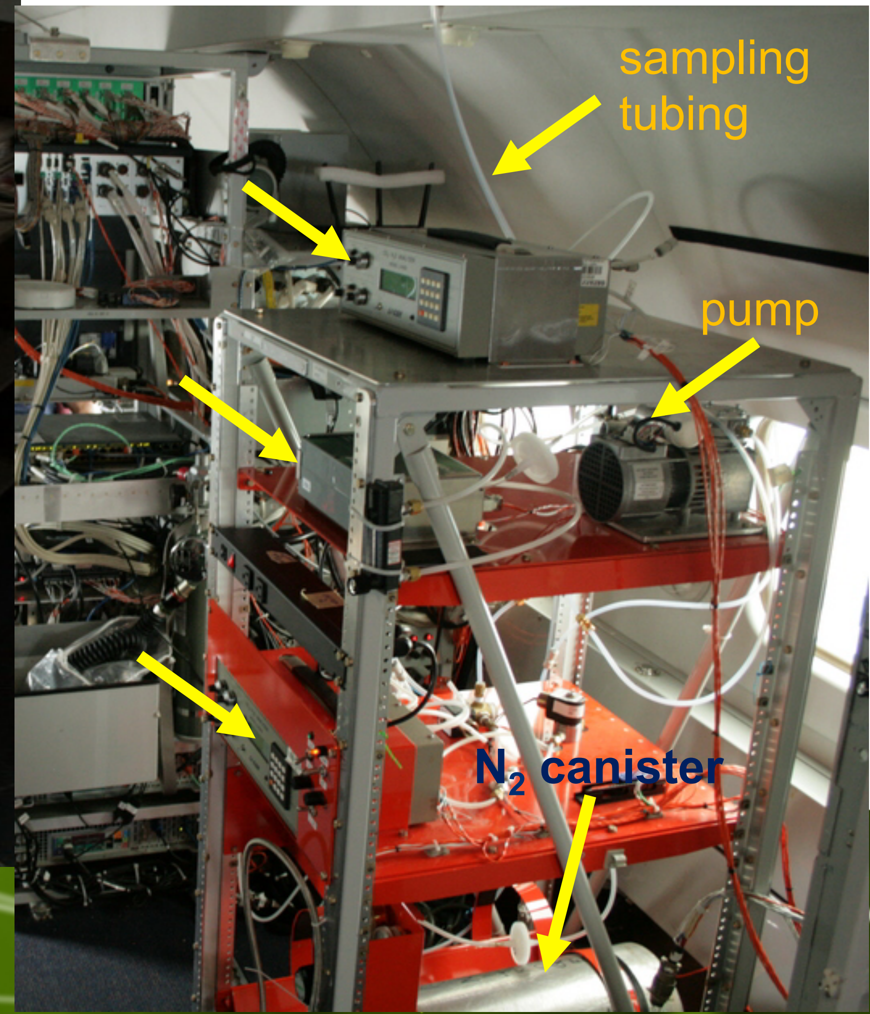
# Spare slides


liquid
ice
$\rho_{vapor}$ (g/m3)
Temperature (C)
0
1
2
3
4
5
-40
-35
-30
-25
-20
-15
-10
-5
0

# Background humidity measurements



Licor 6262
Licor 6262
Licor 840A



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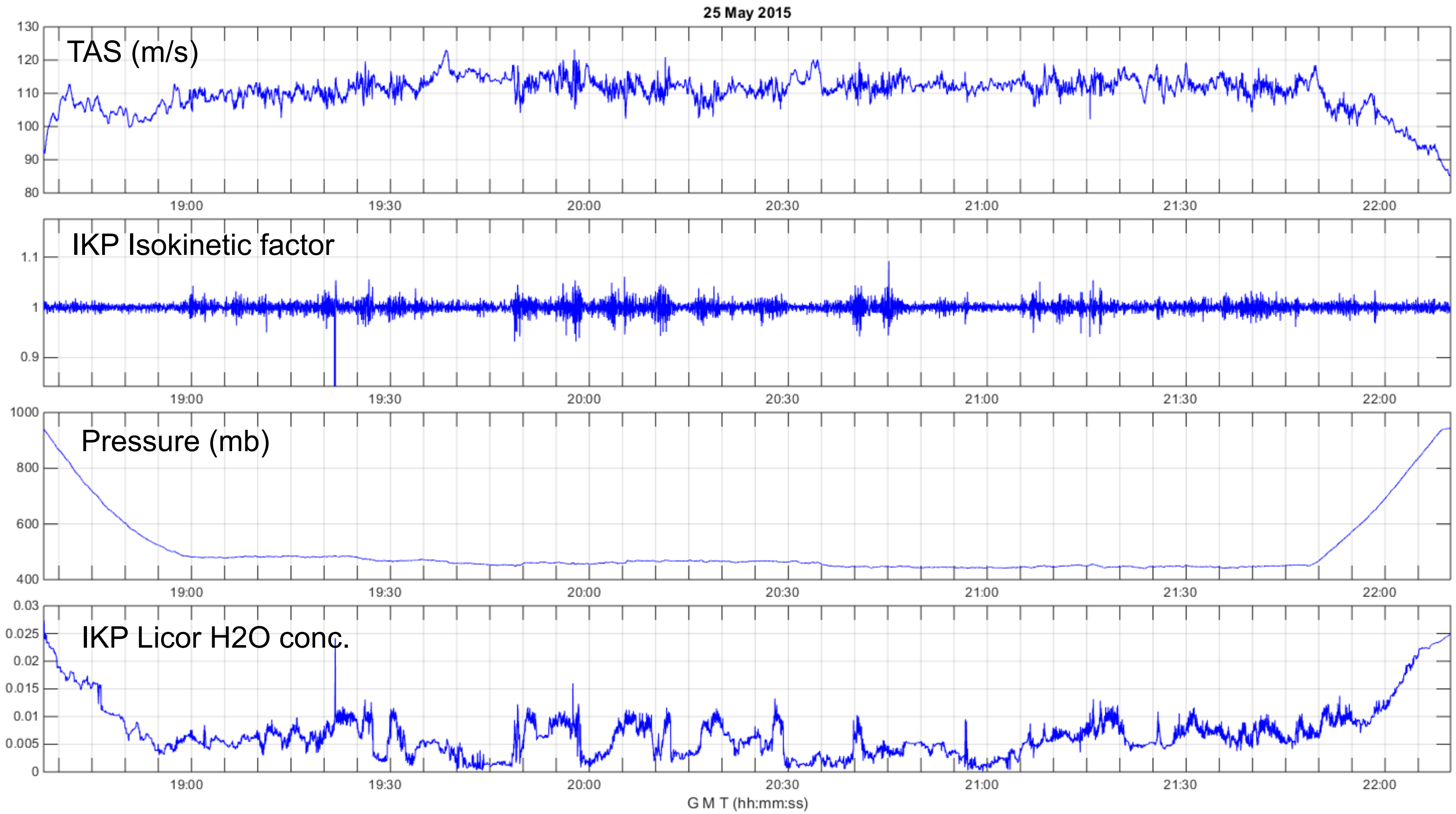
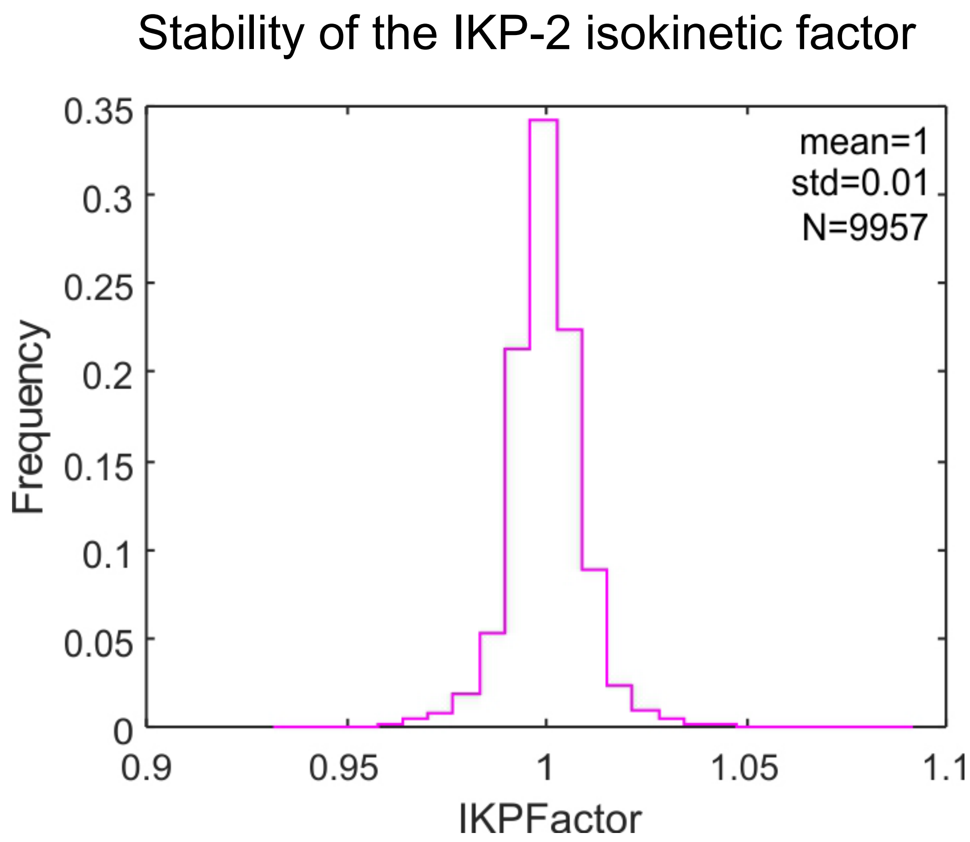
# IKP data quality control

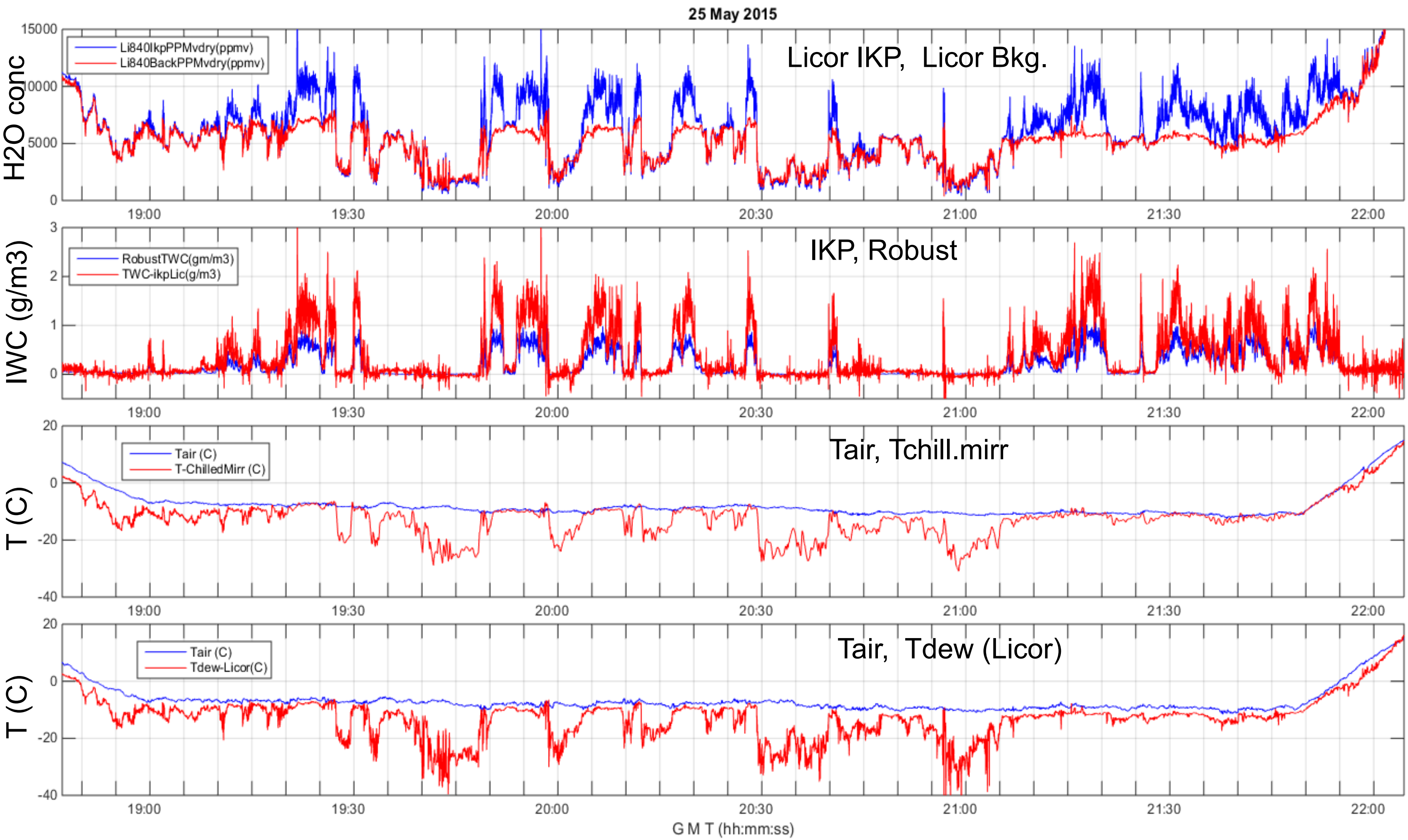
## Stability of the IKP isokinetic factor



# IKP data quality control



# IKP data quality control



# IKP data quality control

Performance of the IKP and background humidity measurements