

# A Path to Improving Simulated Properties of Low Clouds over the Beaufort Sea using Airborne In Situ Observations of Subgrid-Scale Variability

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# A Path to Improving Our Understanding of the Arctic

Our ability to understand and assess future climate change rests significantly on the capability of Earth system models to simulate Arctic meteorology

Low level mixed phase clouds remain a difficult component of Arctic climate to simulate

One frequent stumbling block for models is realistically representing subgrid-scale (SGS) variability and its relationship with grid-scale (GS) cloud properties

Satellite data are commonly used to estimate SGS properties, but in situ observations from aircraft campaigns like ARISE and FIRE-ACE provide rare opportunities to double check these estimates

We at LaRC have been using aircraft data to examine the properties of Arctic clouds with the goal of aiding their simulation in climate models and reanalyses

# The Arctic Radiation-IceBridge Sea and Ice Experiment (ARISE) and First ISCCP Regional Experiment Arctic Clouds Experiment (FIRE-ACE) campaigns



ARISE conducted 16 flights over the Beaufort Sea during Sept 2014

FIRE-ACE operated during 1998; we use data collected by the University of Washington Convair-580 during May-June

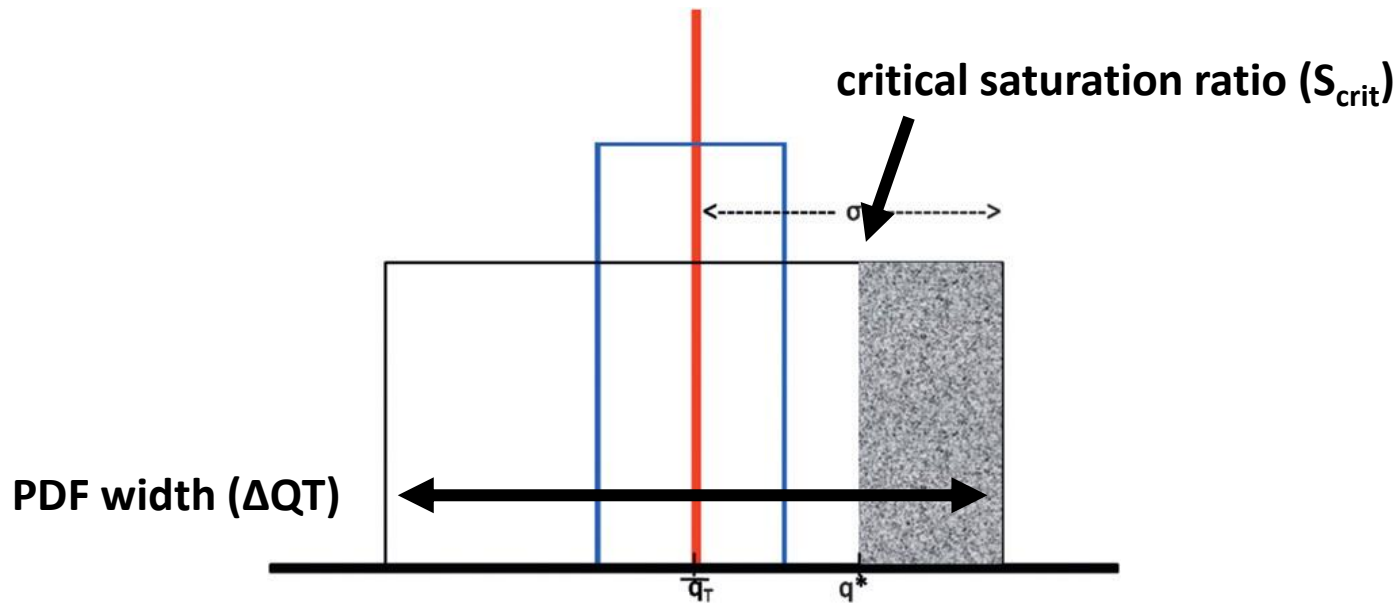
A wide range of hydrometeor, thermodynamic, and radiative flux observations were collected

We examine the relationships between cloud water (liquid + ice, QC), temperature (T), specific humidity (QV), and relative humidity (RH)

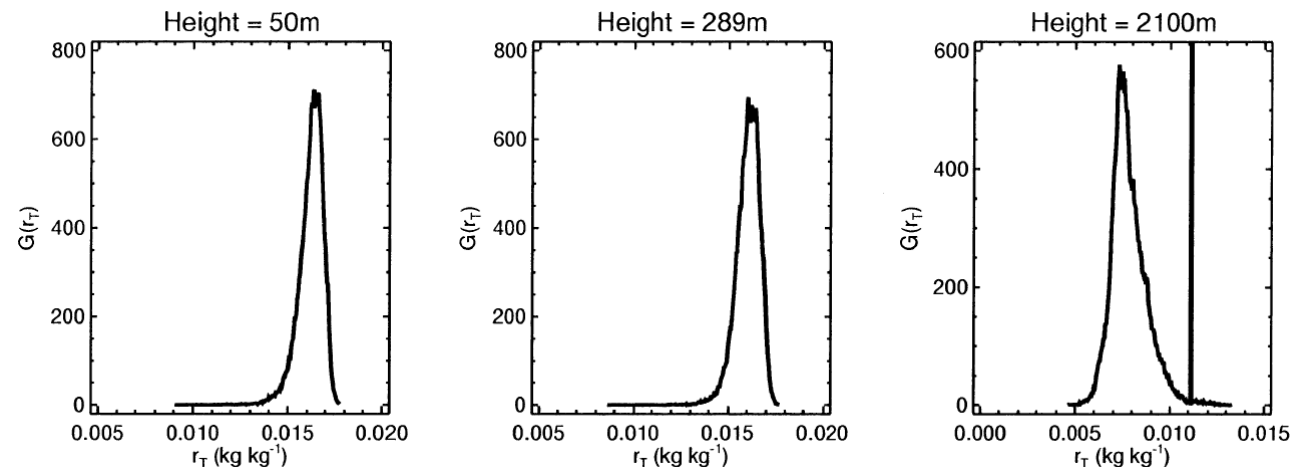
Using two campaigns increases our confidence of common results



# What is the role of subgrid-scale variability?



“top hat” scheme used in GEOS-5 (from Molod 2012)



PDFs derived from a CRM (from Tompkins 2002)

Many atmospheric models used assumed distributions of subgrid-scale total water variability ( $QT = QV + QC$ ) to calculate available water for QC conversion at each time step

Common assumed distributions are “top hat” even distributions and triangular distributions

The shape and width of the assumed distributions (denoted  $\Delta QT$ ) can have a major effect on the conversion of QC, and is a possible source of error

The partitioning of the SGS distribution by the critical saturation ratio ( $S_{crit}$ ) is also important for QC conversion

From ARISE and FIRE-ACE data, we see that the mean SGS PDF of QT resembles a triangle with Gaussian tails

# R1: SGS parameters vary greatly in observations

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We divide the full ARISE and FIRE-ACE datasets into  $\sim 15$  km long flight legs, and each leg represents a “grid box”

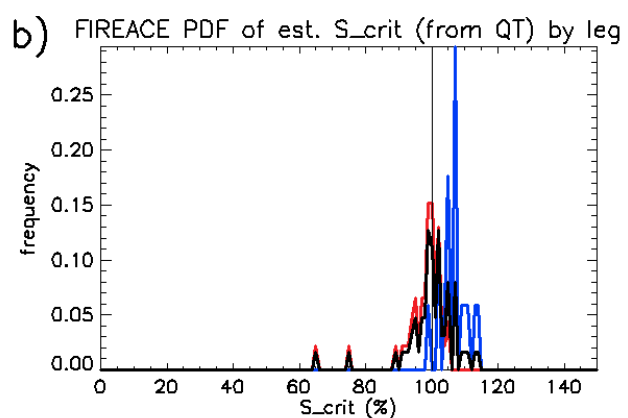
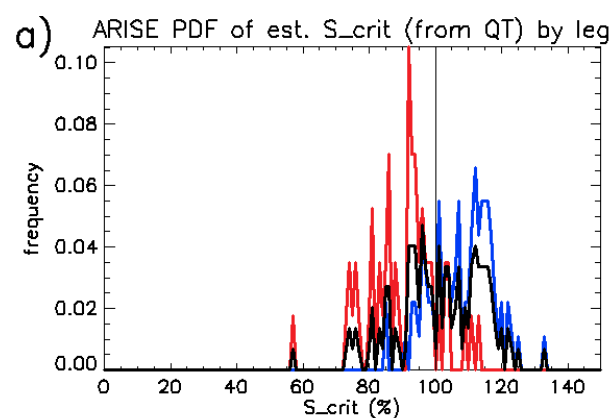
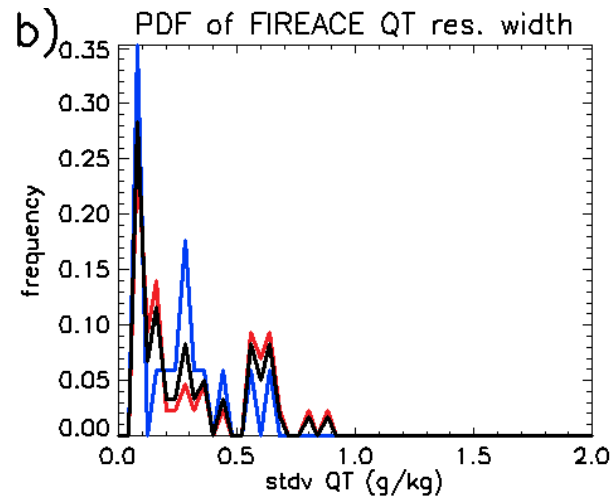
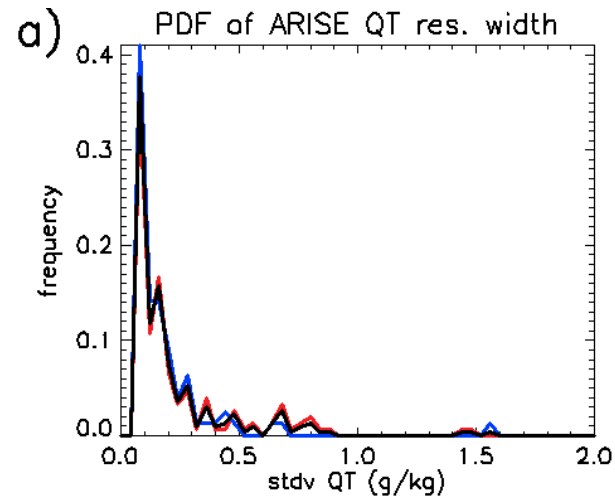
From the observed PDFs of QT and  $QC_{GS}$  for each flight leg, we can estimate a “best fit” QT and  $S_{crit}$  for that flight leg

The observations show considerable variability in both  $\Delta QT$  and  $S_{crit}$

Previous field studies have shown large variability in  $\Delta QT$  for different geographic regions and altitudes

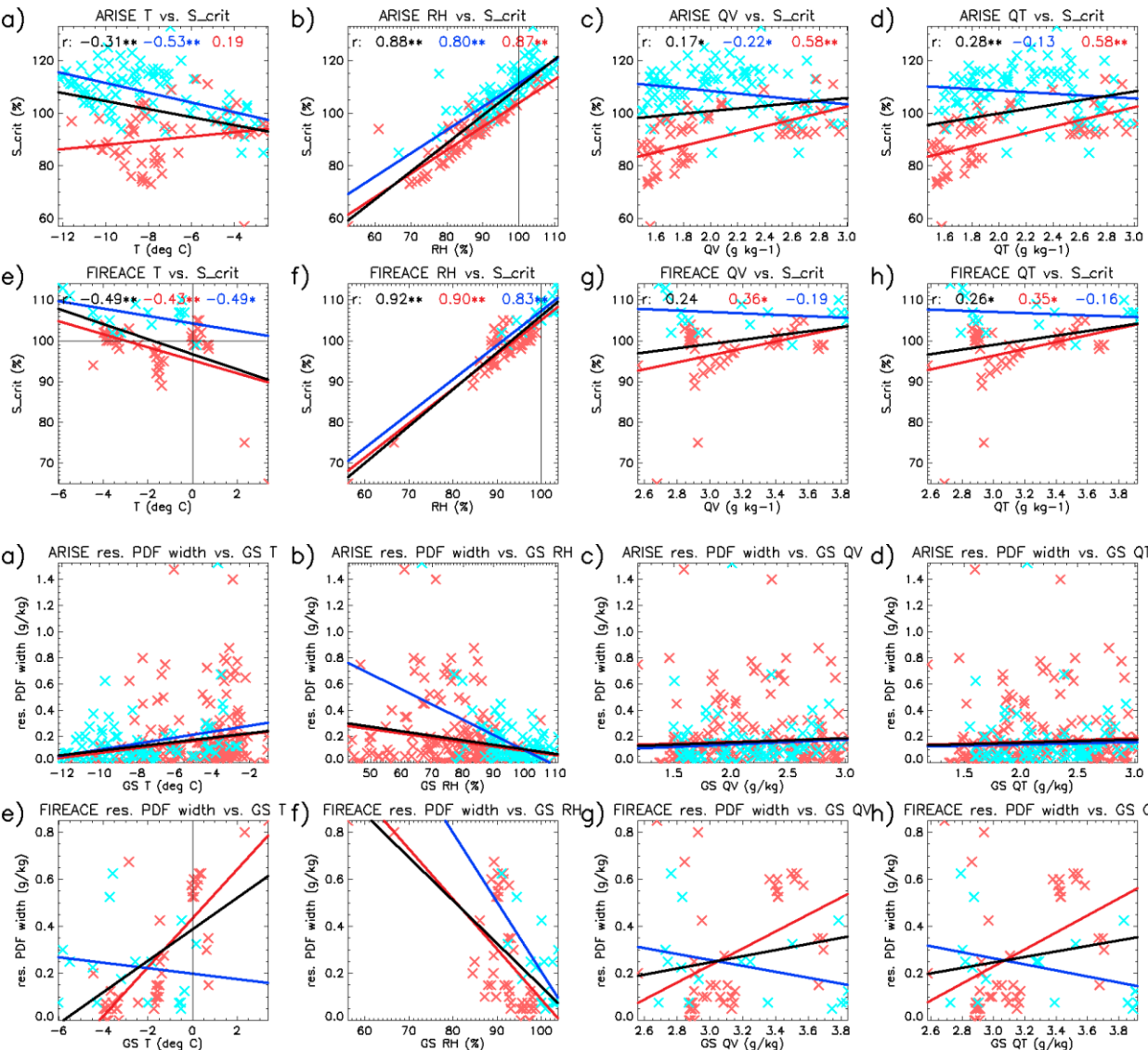
But ARISE and FIRE-ACE display large variability specifically in the low-level Arctic

$S_{crit}$  can vary by  $>10\%$  about the assumed value of 100%



# R2: Critical sat. ratio is strongly related with GS rel. humidity

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Because of the large variability of  $S_{crit}$ , we want to find a means to prognose the value of  $S_{crit}$  for a given “grid box”

But the variability of  $S_{crit}$  may be controlled by several meteorological factors

Both ARISE and FIRE-ACE suggest that  $S_{crit}$  is sensitive in particular to grid-scale relative humidity ( $RH_{GS}$ )

Grid-scale temperature ( $T_{GS}$ ) is a secondary factor

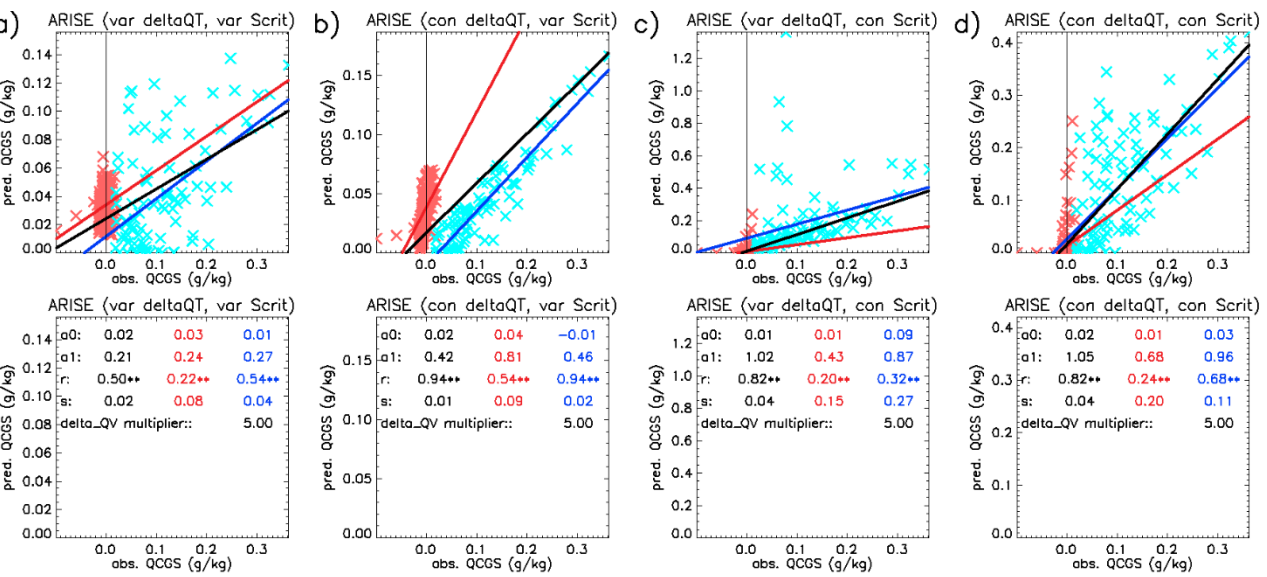
Grid-scale specific humidity ( $QV_{GS}$ ) is not a factor

$T_{GS}$ ,  $RH_{GS}$ , and  $QV_{GS}$  are not independent

There is also some evidence of a relationship between  $\Delta QV$  and  $RH_{GS}$ , but is much weaker

# R3: Grid-scale cloud water is more sensitive to critical saturation ratio than SGS

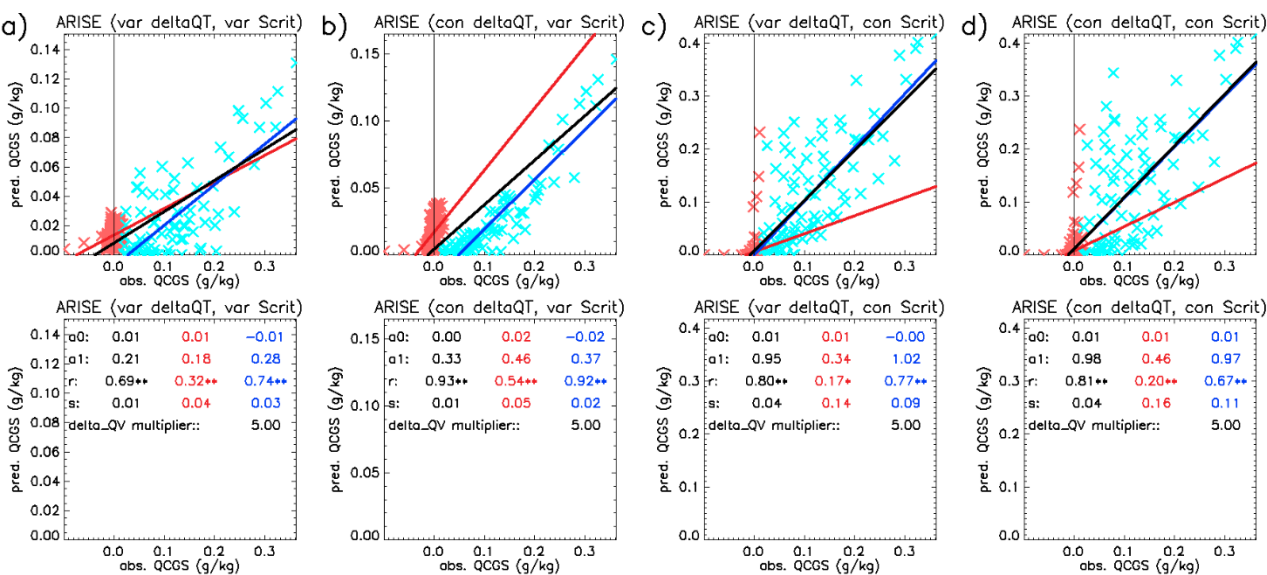
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We use the first two results to estimate  $QC_{GS}$  from SGS variability  
 For each flight leg,  $\Delta QT$  and  $S_{crit}$  are calculated using a linear relationship with RGGs, with slope and intercept values derived from Result 2

$S_{crit}$  variability has a much greater improvement on estimated QCGS than  $\Delta QT$

Surprisingly, the shape of the assumed PDF (top hat, triangle, or “triangle with tail”) has much less effect than  $S_{crit}$  variability



# Conclusions and Future Work

The high frequency observations of cloud water and thermodynamic variables from ARISE and FIRE-ACE show subgrid-scale variability resembling triangular distributions with Gaussian-like tails about the grid box mean

The width of the total water PDFs and the critical saturation ratio both vary considerably from assumed values in the Arctic boundary layer

The observed variability of critical saturation ratio is correlated with grid-scale meteorological conditions, in particular relative humidity

We are currently completing a paper draft that describes these results and many more

The upcoming ARCSIX aircraft campaign (spring/summer 2024) will provide a wealth of additional high-quality observations of the Arctic climate system

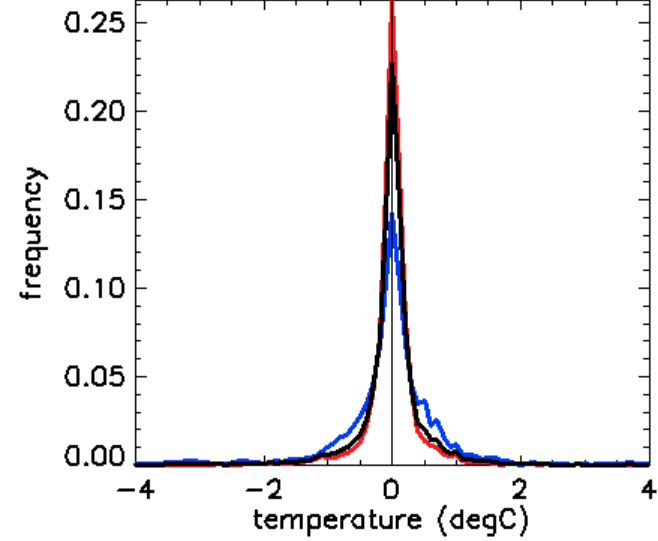
# References

Molod, A., 2012: Constraints on the Profiles of Total Water PDF in AGCMs from AIRS and a High-Resolution Model. *J. Climate*, **25**, 8341–8352, <https://doi.org/10.1175/JCLI-D-11-00412.1>.

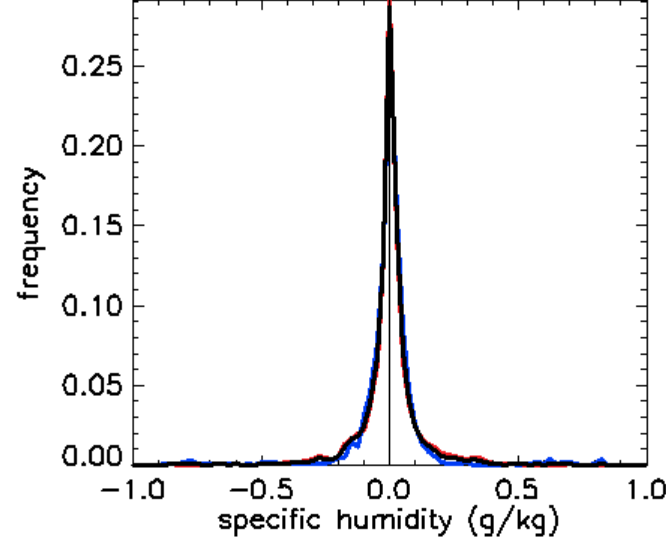
Tompkins, A. M., 2002: A Prognostic Parameterization for the Subgrid-Scale Variability of Water Vapor and Clouds in Large-Scale Models and Its Use to Diagnose Cloud Cover. *J. Atmos. Sci.*, **59**, 1917–1942, [https://doi.org/10.1175/1520-0469\(2002\)059<1917:APPFTS>2.0.CO;2](https://doi.org/10.1175/1520-0469(2002)059<1917:APPFTS>2.0.CO;2).

# Backup 1: Residual PDFs are (Mostly) Triangular with Tails

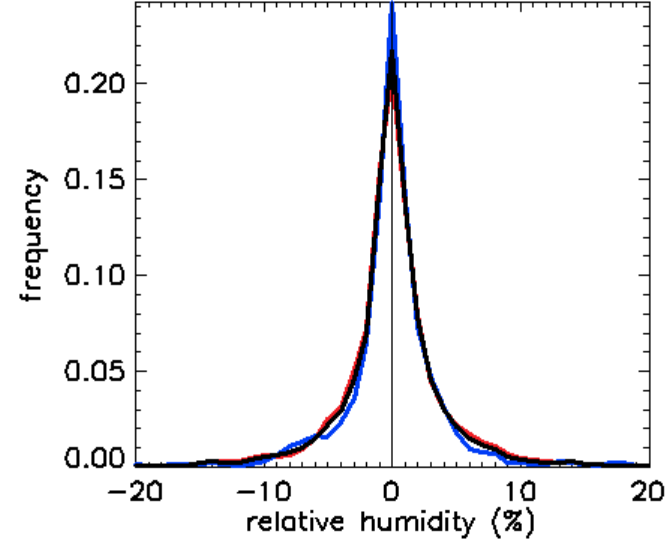
ARISE T PDF, 1 hz – grid box mean



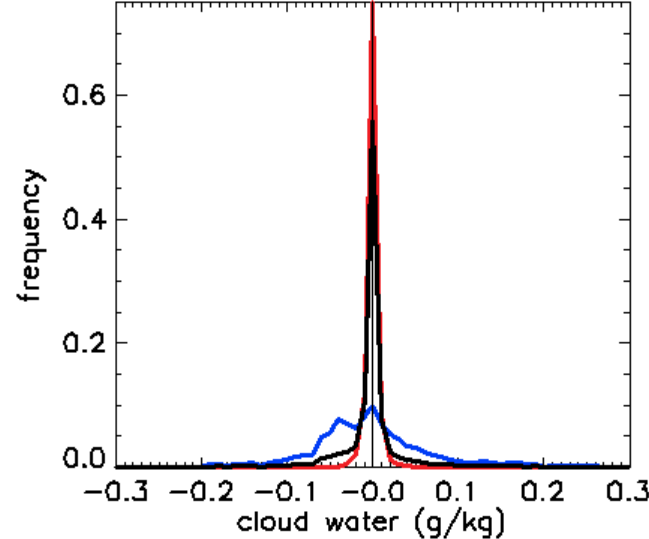
ARISE QV PDF, 1 hz – grid box mean



ARISE RH PDF, 1 hz – grid box mean



ARISE QC PDF, 1 hz – grid box mean



These are residual PDFs of cloud water (liquid + ice, QC), temperature (T), specific humidity (QV), and relative humidity (RH), for various gridbox-mean cloud conditions

Cloudy gridboxes are defined as mean QC > 0.02 g/kg

QC PDF is cloudy is shifted towards low QC, but has long tail of large QC values

T PDF is broader for cloudy conditions than clear

QV PDF is similar for all conditions

RH PDF is narrower for cloudy conditions than clear (likely constrained by 100% RH in-cloud)

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