SINGLE FOOTPRINT ALL-SKY RETRIEVALS FURTHER PROGRESS

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October 2017
Greenbelt MD

Overview

Outline

- Initial motivation : climate trending from our spectral rates!
- Cloud Representation : NWP multilayer cloud converted to Two Slab Clouds (ice/water)
- AMTD paper under review
- Show and tell
  - 2014/02/28 granule 220-222 (Atmospheric River)
  - 2011/03/11 granule 039 (TWP)
  - 2017/09/06 granule 177 (Hurricane Irma) : run off yesterday
    - took 5 hours (column O3, constant jac) which is 1.5 seconds/FOV
    - AIRS L2 is 1.5 sec/FOR, NUCAPS is 0.3 secs/FOR
    - have not tweaked the damping
- Sonde profile comparisons (ARM and GRUAN)
- 14 year nadir trends from our retrievals

Motivation

- started with kTwoStream for dust/ash; then heard about PCLSAM (Parametrization for Cloud Long-wave Scattering for use in Atmospheric Models, Chou et. al, J. Climate v12 pg 159-169 (1999))
- George started bugging me about comparing AIRS to NWP; Scott and I developed *N*-level to TwoSlab
- Larrabee wanted to include cloud effects when retrieving thermodynamic trends from AIRS spectral rates
- first we needed to test our conversions of NWP clouds, and our scattering RTA, plus different models (ERA, ECM, MERRA)
- so on the side I started playing with retrievals
- and it morphed into single footprint retrievals, run in embarrassingly parallel mode for $N \gg 1$ granules/days of data/sondes ....

Application to Single Footprint Retrievals

- Most of AIRS data contains cloud and/or aerosol effects
- Cloud retrievals can be complicated (need to guesstimate cloud top, amount, particle size,fraction, phase) typically for $N \leq 3$ cloud decks
- With a good first guess for ice/water clouds, our simple scattering model allows us to retrieve thermodynamic and ice and water clouds
- We use SARTA TwoSlab, with first guess from NWP (ERA/ECM/MERRA/GFS) in an Optimal Estimation Retrieval to improve retrieval yield on single footprints, with error diagnostics as part of output
- NOTE : L3/clim start is L3 profile for that region averaged over 10 years

SARTA TwoSlab

D of F calculations show there are typically only 2-5 pieces of cloud information SIMPLE CLOUDS!

TOA radiance is weighted sum of at most FOUR radiance streams

$$r(\nu) = C_{11} r_1(\nu) + C_{22} r_2(\nu) + C_{12} r_1 2(\nu) + C_{00} r_{clr}(\nu)$$

where $C_{11} = C_1 - C_{12}$, $C_{22} = C_2 - C_{12}$, $C_{00} = 1 - (C_1 + C_2 - C_{12})$
so on average code is x2 slower than SARTA clear

Cirrus : General Habit Model from Ping Yang/ Bryan Baum (2013)
Water : Mie scattering, Particle Size Distribution from MODIS L2

Retrieval

Retrieval Idea

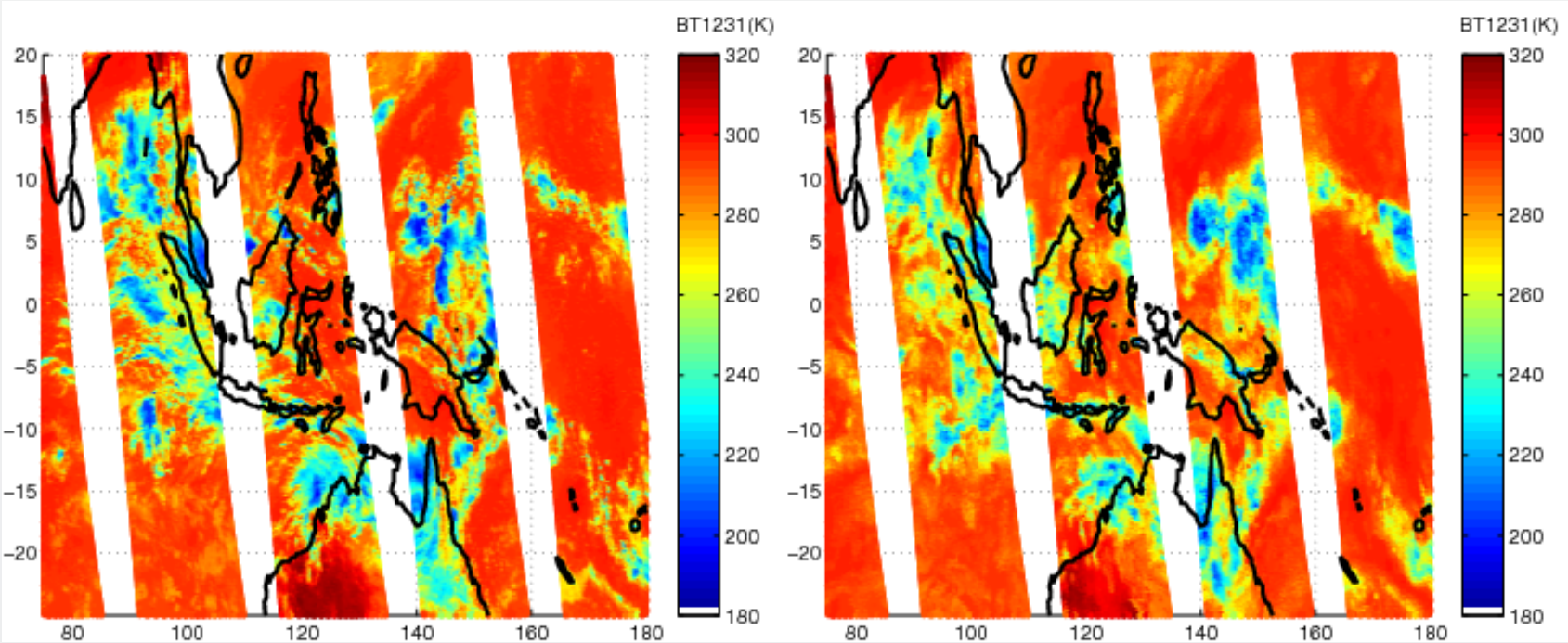
- Will use co-located ERA geo/cloud fields (more stable) to initialize
  - Here used ECM and climatology for testing
- For each pixel, initial guess is as follows
  - Clouds : Match "closest window BT simulation" to AIRS obs
  - Keep thermodynamic fields (clim, NWP,....)
  - In future may adjust cloud top, particle size (MBL and DCC)
- OEM retrieval, *simultaneously* solves cloud amounts for ice/water clouds, and T(z), WV(z), stemp(z), col O3, col CH4
- roughly 8 hours to do 12150 FOVS on one processor (2.0 sec per FOV), 100 layer jacs for WV and T, $\simeq$ 300 channels (from L2 neural net, T(z),WV(z),surf temp list)

A few Retrieval Details

- Cost function
  $J = (y - F(x))^T S_\epsilon^{-1} (y - F(x)) + (x - x_a)^T R(x)^{-1} (x - x_a) + J_{sat}$
  (Rodgers textbook, Phalippou 1996 QJRMS)
- nonlinear Gauss-Newton iterative solution (Rodgers textbook)
- use about 300 channels (so 5 min SARTA run → 1 min)
- Smoothing
  - right now using sum of Tikonov + exp decay covariance
- Run off OEM, for N=5 iterations at most, save AK, dofs etc
- throw out retrievals ($\leq$ 10%) where calcs are obviously wrong, RH > 150% etc (usually colocated with thick clouds)

TWP 2011/03/11

Left panel : AIRS observations. Right panel : SARTA 2S



General locations of the deep convection regions are correct, though there are substantially fewer DCC (cloud tops below 210 K) in the simulations.

Now for some results

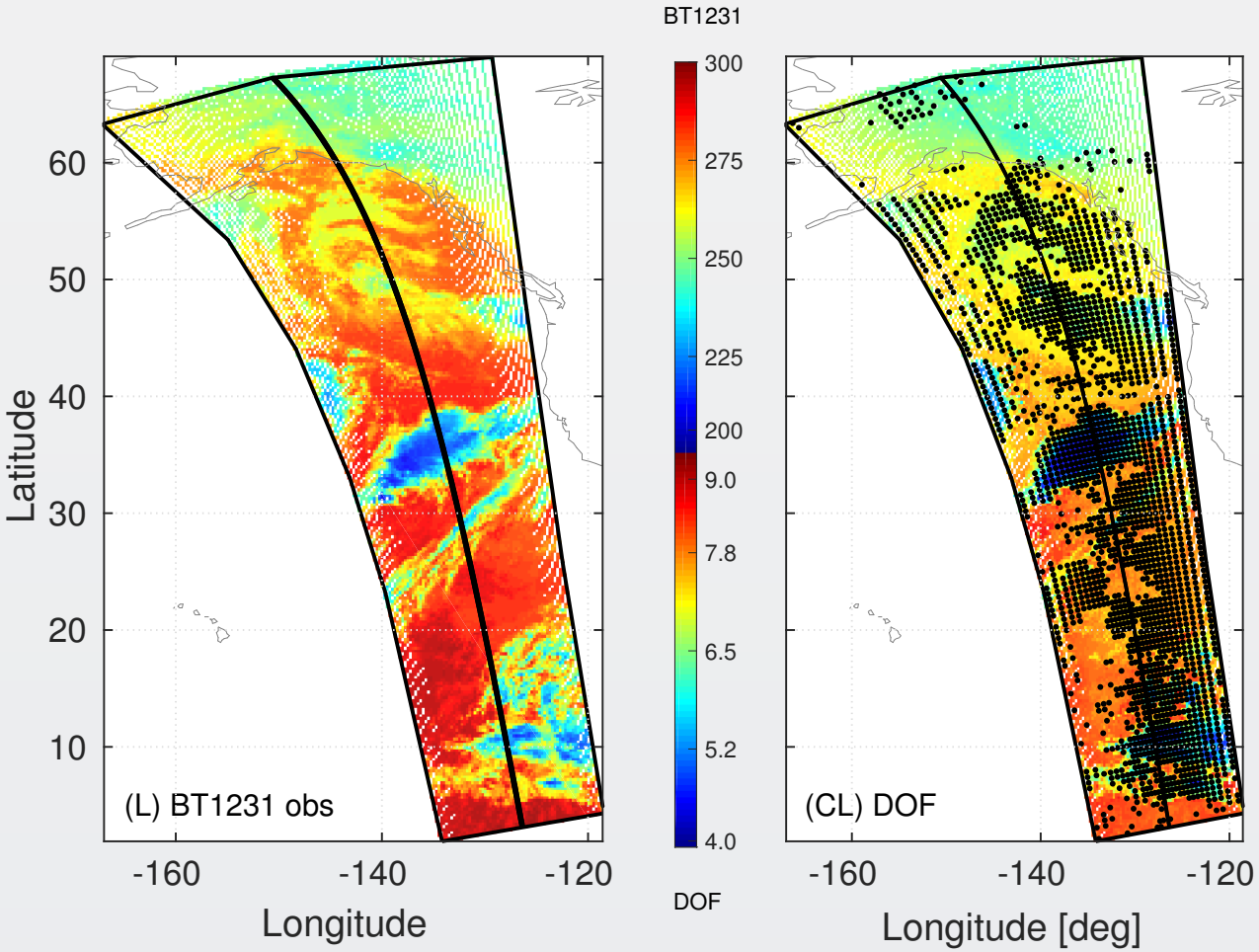
- Atmospheric River 2014/02/08
  - Shows that our method of looking for best cloud yield good comparisons to MODIS clouds
  - Also shows that our retrieval handles wide variety of clouds
  - Digress to 2011/03/11 g039 for cloud mapping
- Hurricane Irma 2017/09/06
  - Nicely shows the eye
  - Needs some work/comparisons (hurricane dropsondes??) but almost there!
- Sondes (TWP, SGP, LIN)
  - Show statistics

2014/02/08

2014/02/08 : Obs

Left : AIRS BT1231 obs

Right : Retr DOF

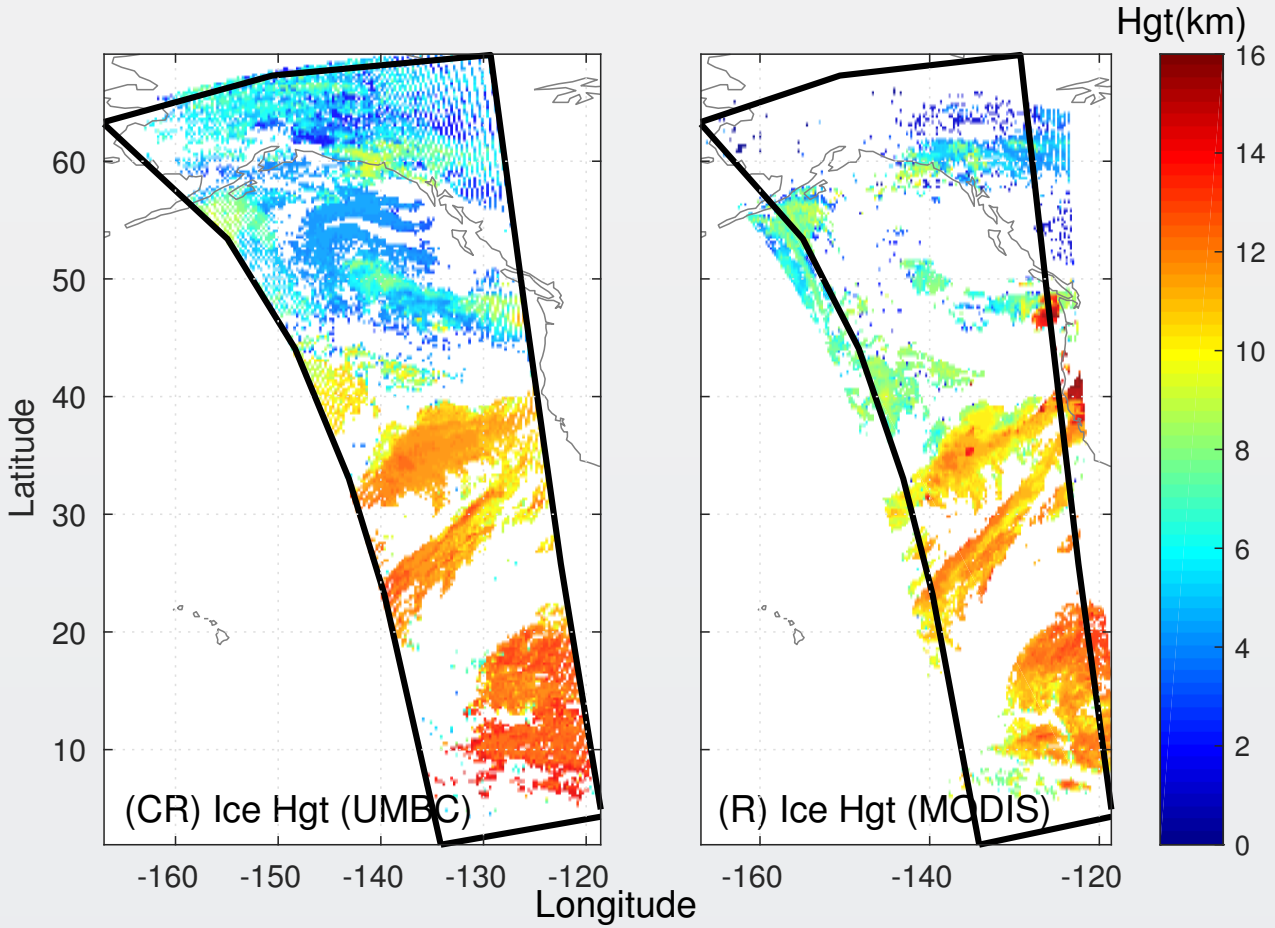


Black dots : AIRS L2 had poor surface/clear OLR QA

2014/02/08 : Clouds

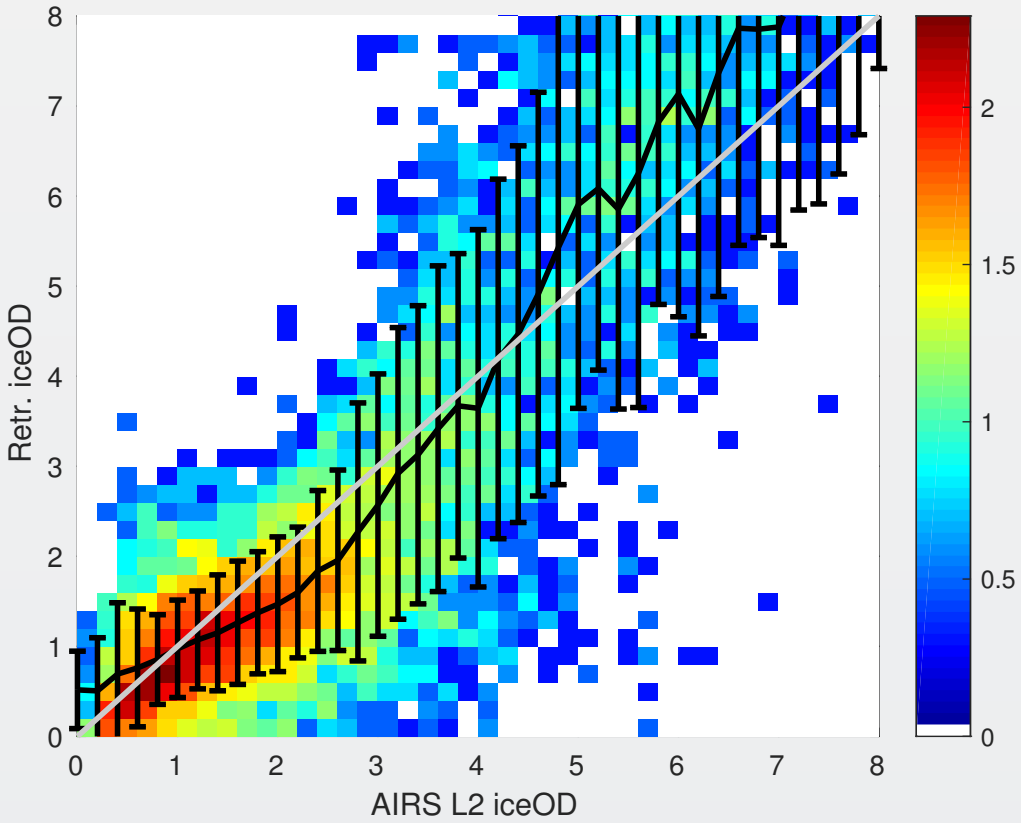
Left : UMBC IceCld

Right : MODIS L2 IceCld



Heights in km

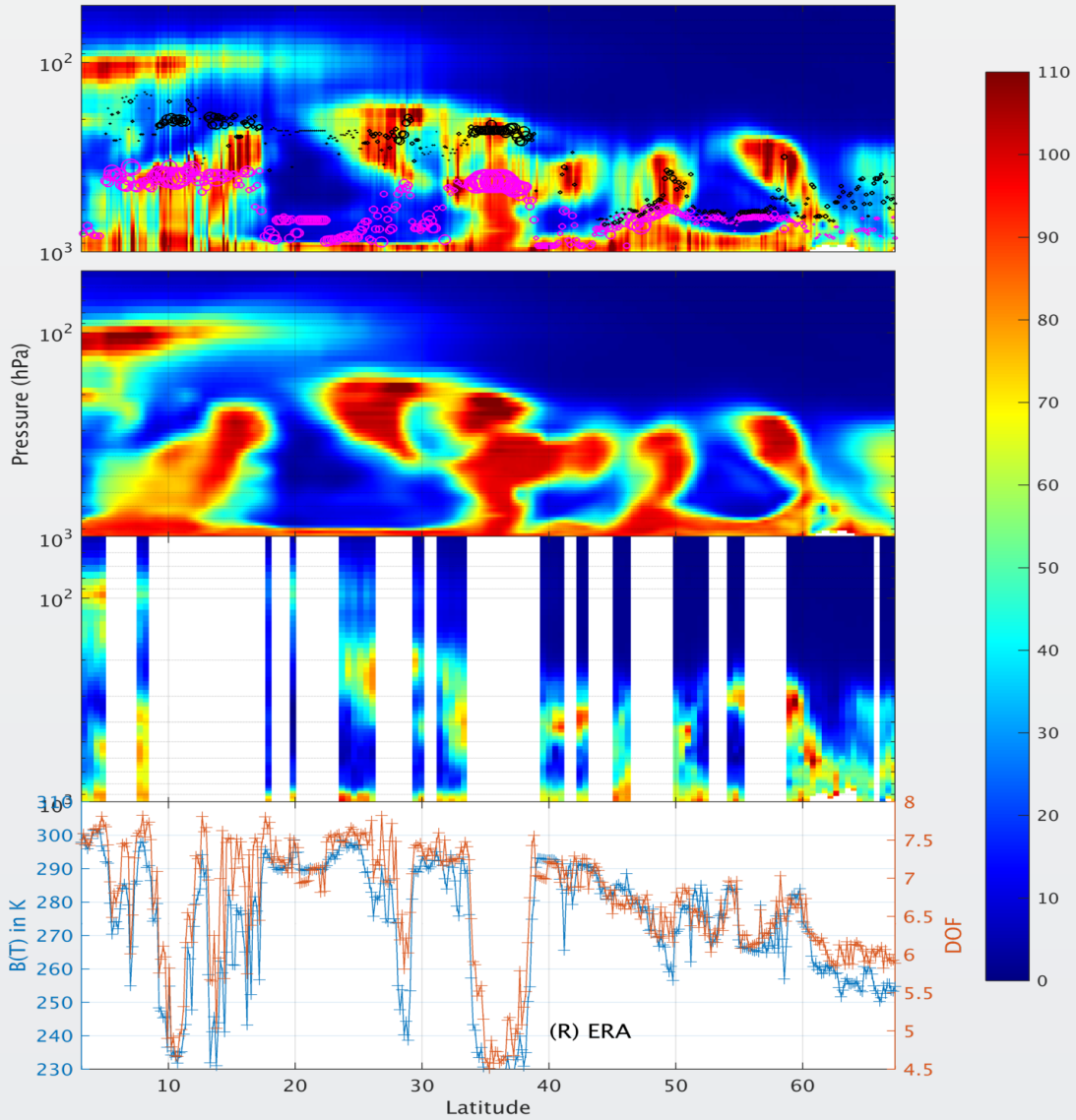
2014/02/08 : Clouds (contd)



Retrieved ice ODs versus those in AIRS L2 cloud product. Colorbar is $log_{10}(count)$ of the 2d histogram.

CLOUDS LOOK GOOD!!!

2014/02/08 : RH Curtain plots, start with ERA



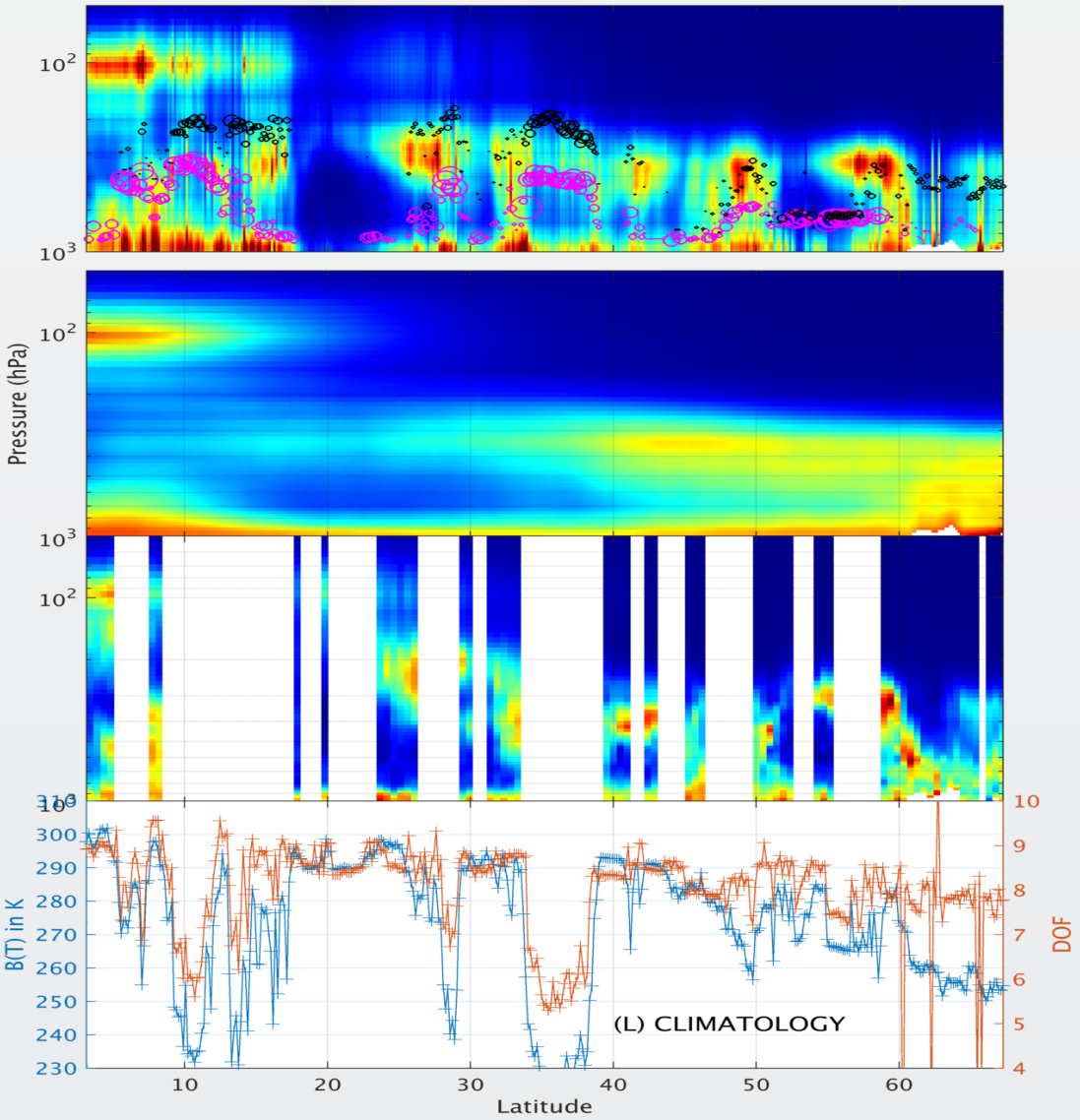
UMBC RH

ERA RH

AIRS L2 RH (QA)

Obs BT1231/DoF

2014/02/08 : Curtain plots, start with L3 clim



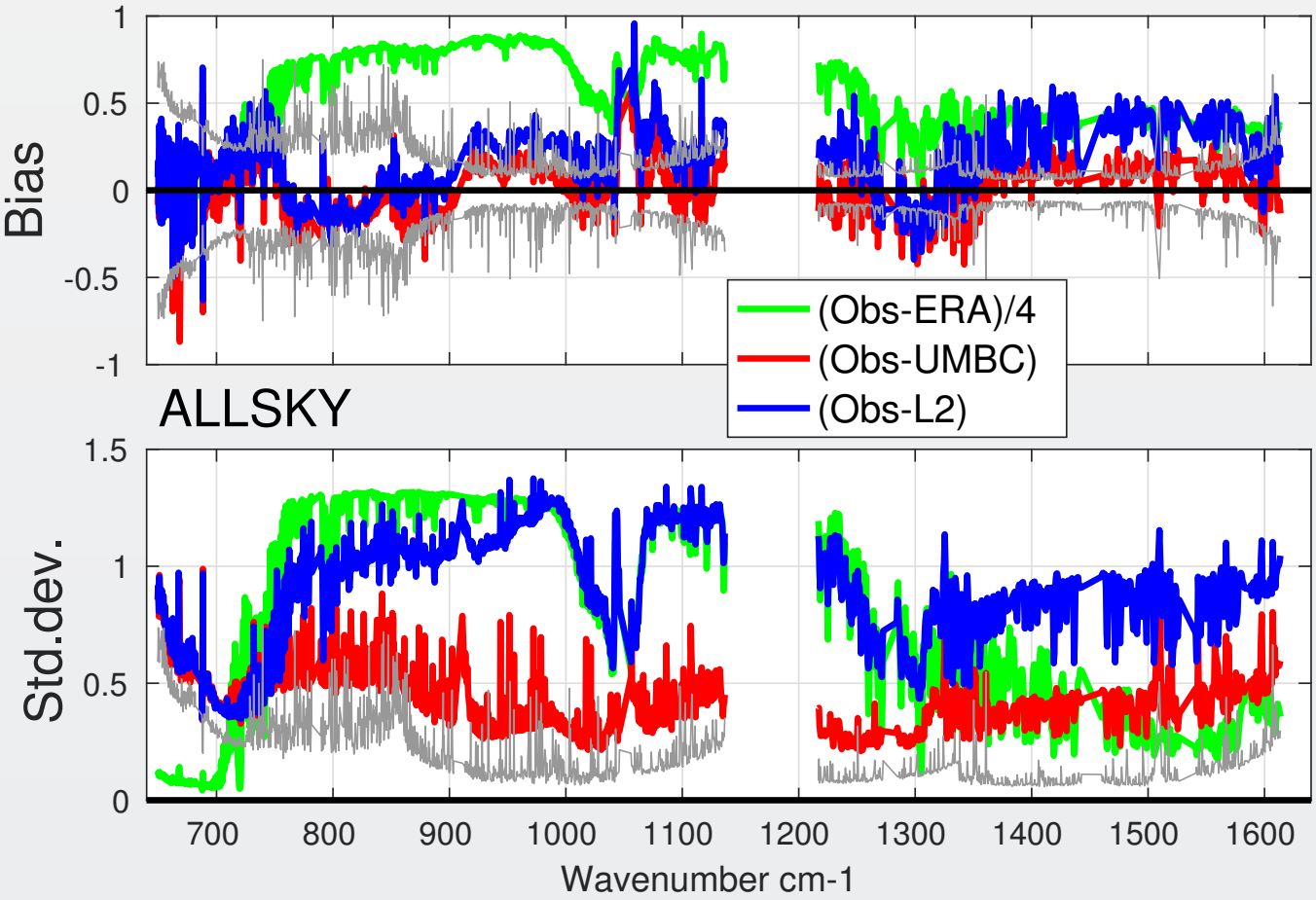
UMBC RH

L3 CLIM RH

AIRS L2 RH (QA)

Obs BT1231/DoF

2014/02/08 : Spectral Difference



AIRS noise levels shown in light gray

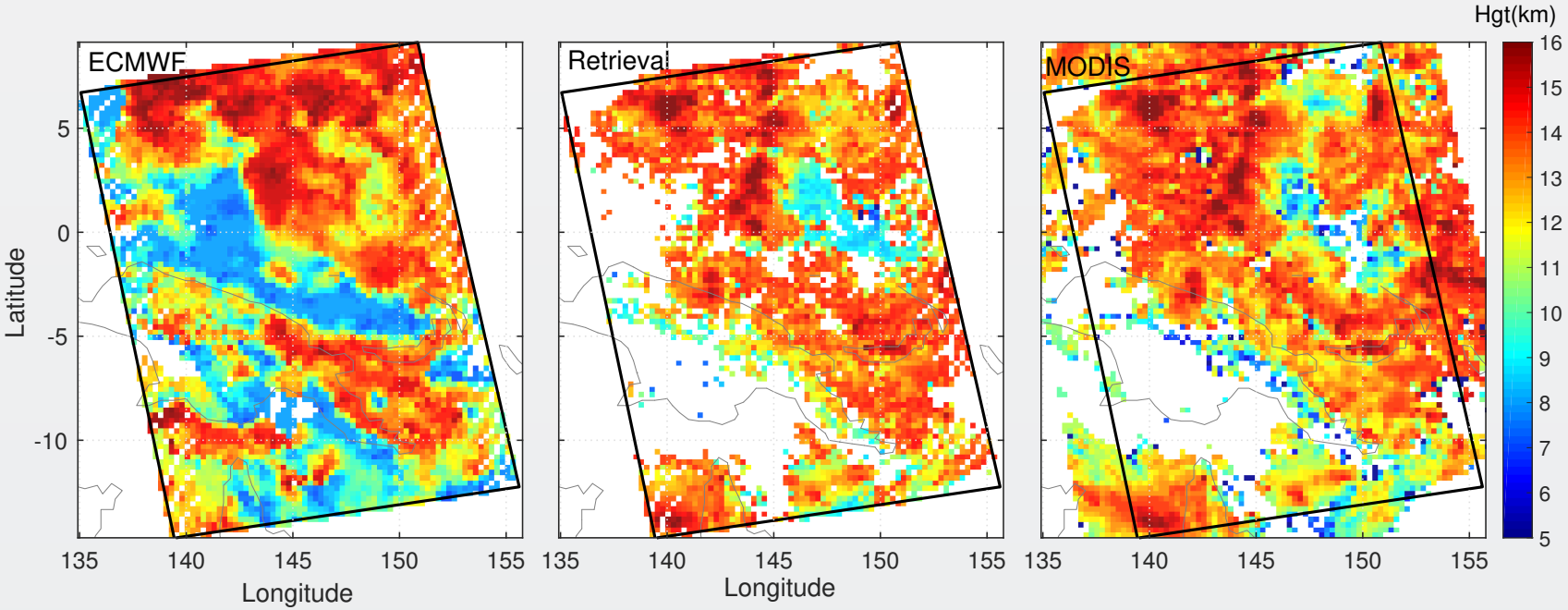
Use surface AIRS QA=0,1 to filter. Top : biases. Bottom : std.dev.

Note scale factor for green

2011/03/11

2011/03/11 : TWP Granule 039

A better example of handling a much bigger variety of clouds



(L) Orig ECM (C) UMBC (R) MODIS L2

Clouds masked for OD > 0.5. Notice how DCC clouds are now correctly positioned (relative to MODIS)

2011/03/11 : TWP Granule 137

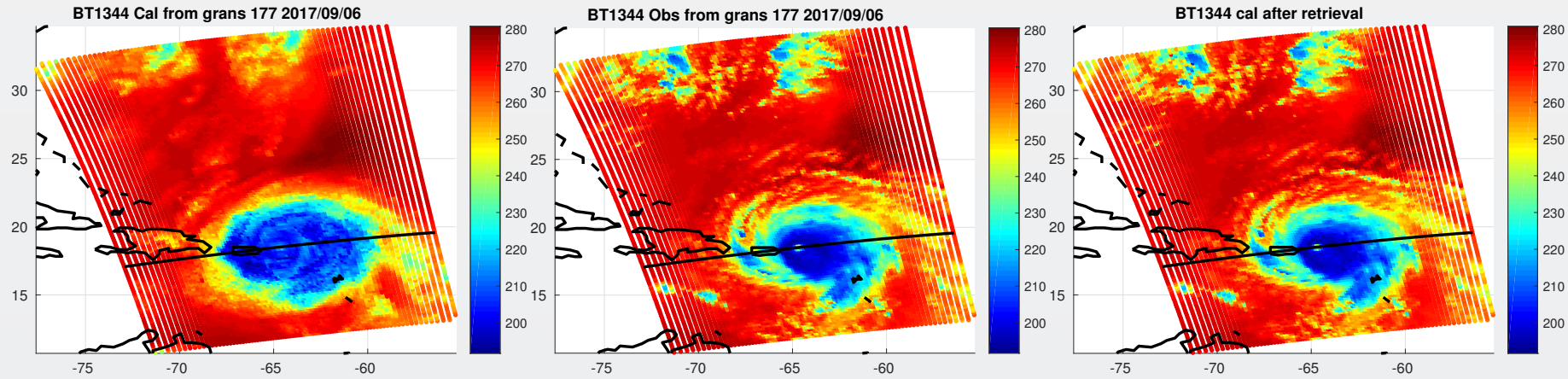
An example of handling MBL (mostly water) clouds

See End of Talk

2017/09/06

IRMA : 2017/09/06 : Obs vs Cal for BT 1322

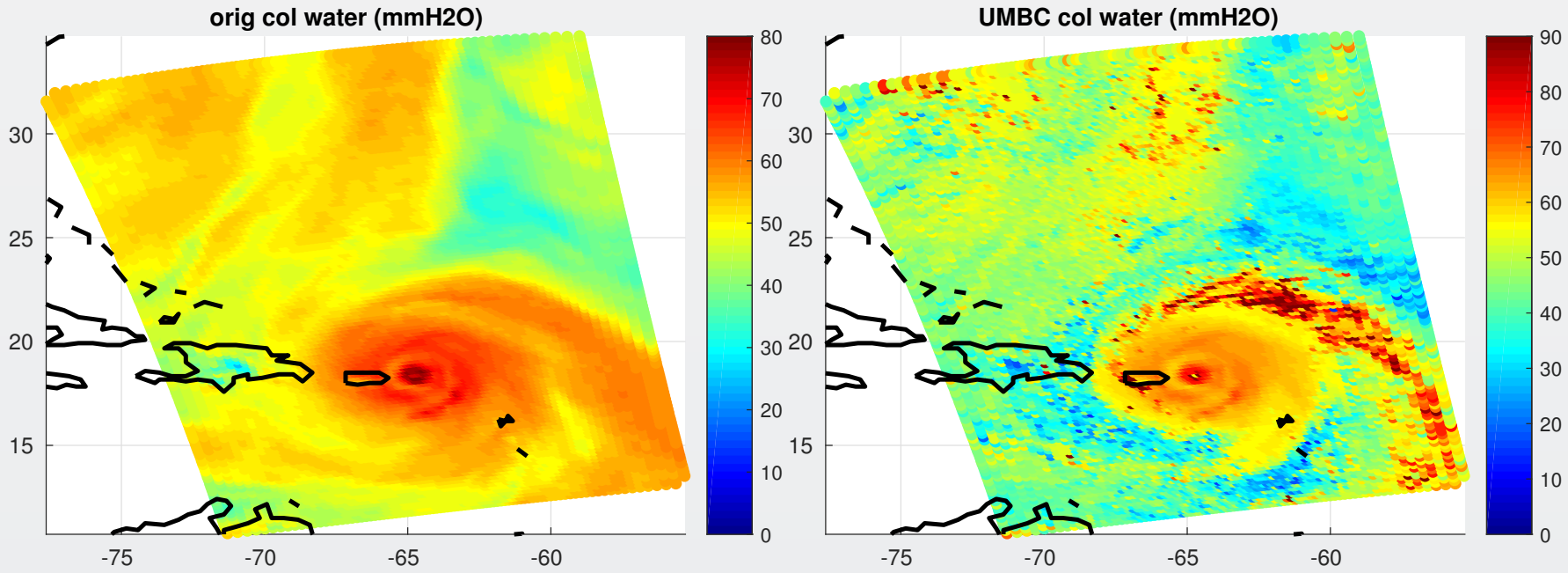
Left : ECM Center : AIRS Right : UMBC



IRMA : 2017/09/06 : Col W

Left : ECM

Right : UMBC

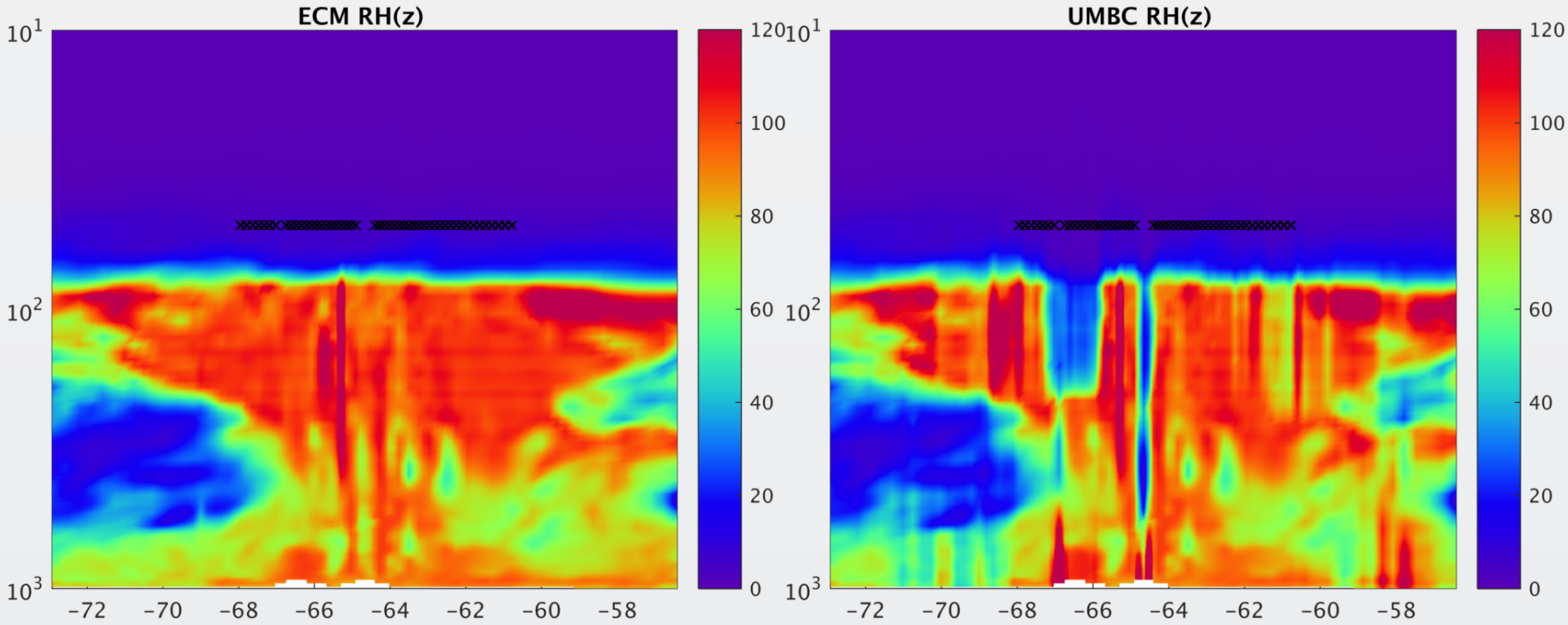


The NCAR Climate Forecast System Reanalysis (CFSR) also produced colW $\geq$ 80 mm (Rich Grumm, NWS)

IRMA : 2017/09/06 : RH curtain plot

Left : ECM

Right : UMBC



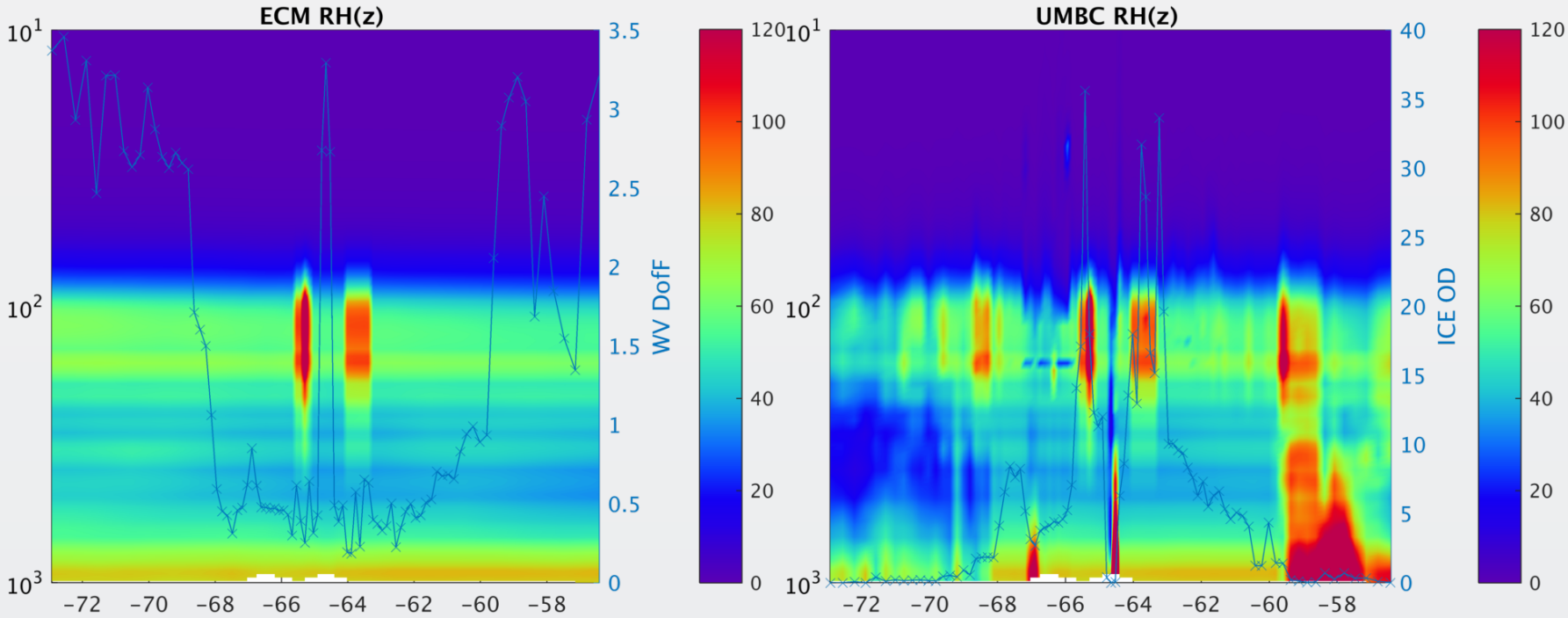
Note that when WV dof < 0.5, we have problems in the retrieval (black crosses)

The eye is DRIER than the average!

IRMA : 2017/09/06 : RH curtain plot start with CLIM

Left : CLIM

Right : UMBC



You can see that we do bring in info when DOF > 1

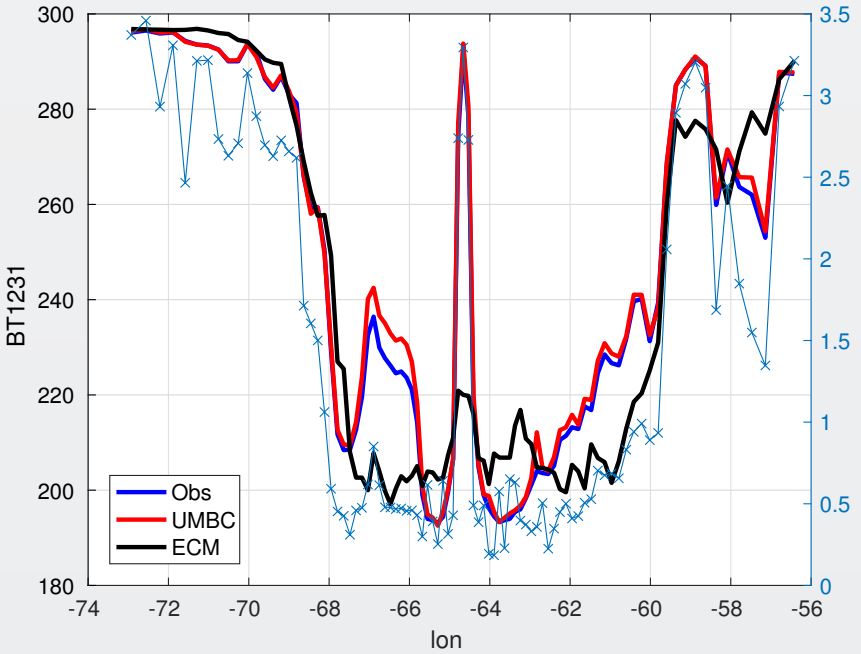
The eye is DRIER than the average!

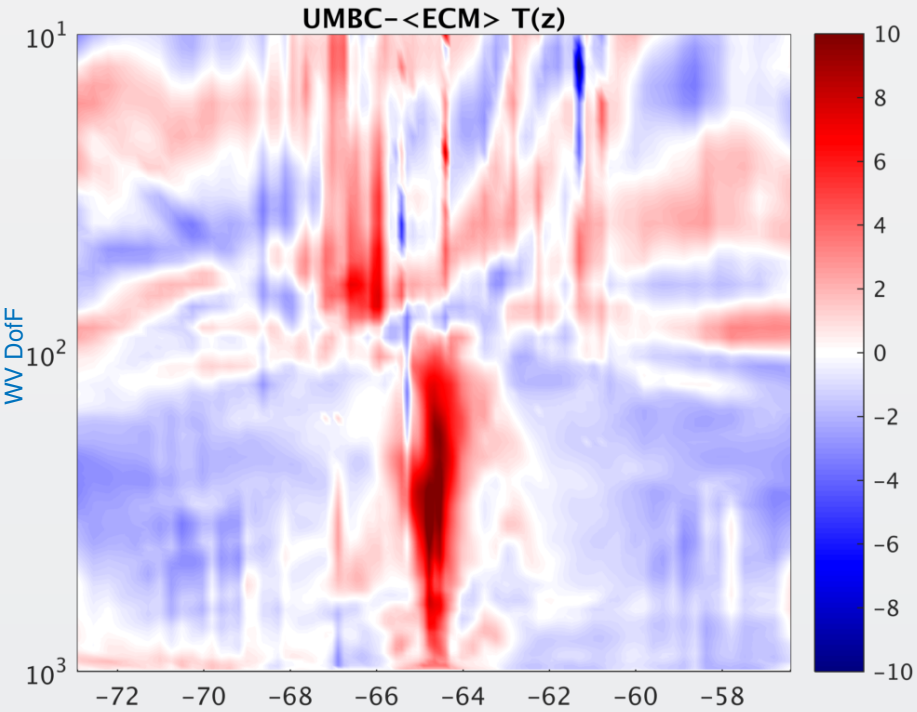
I know what the two red blobs are, I need to fix those ....

IRMA : 2017/09/06 : Misc.

Left : BT1231

Right : T(z)-<ECM T>





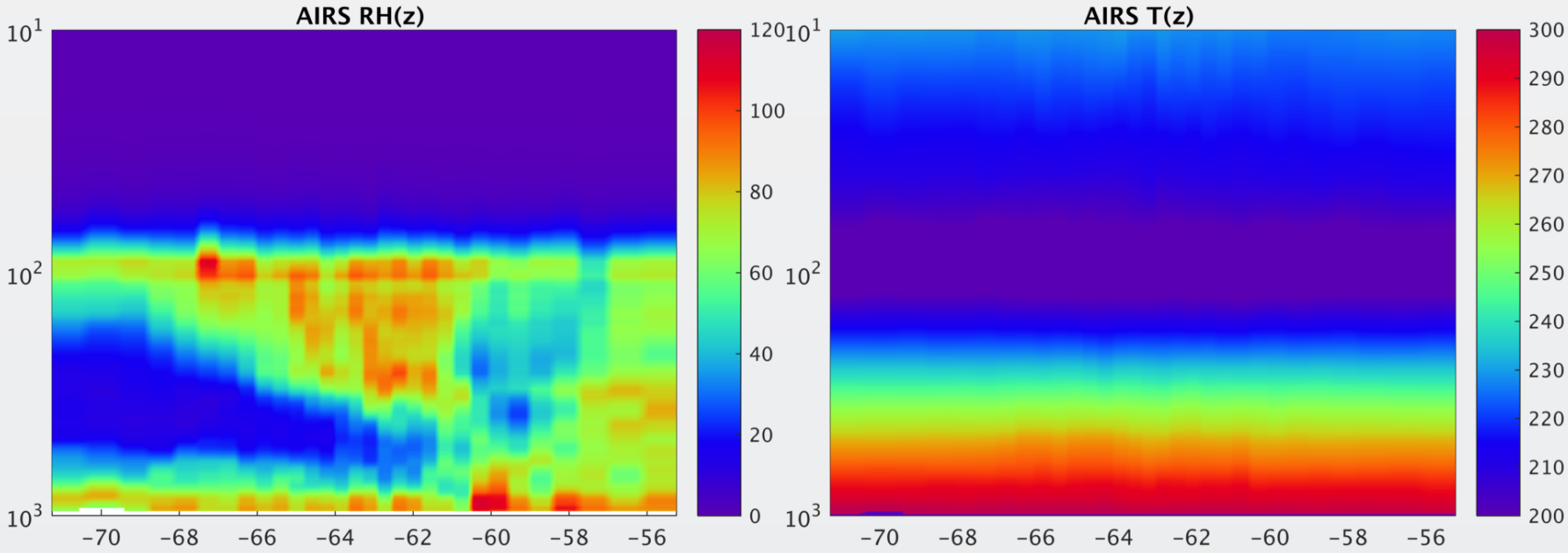
Note that when WV dof < 0.5, we have problems in the retrieval

The eye is hotter than the average!

IRMA : 2017/09/06 : AIRS L2

Left : RH

Right : T



Too tired to screen for QA .... but note no eye ...

Sondes

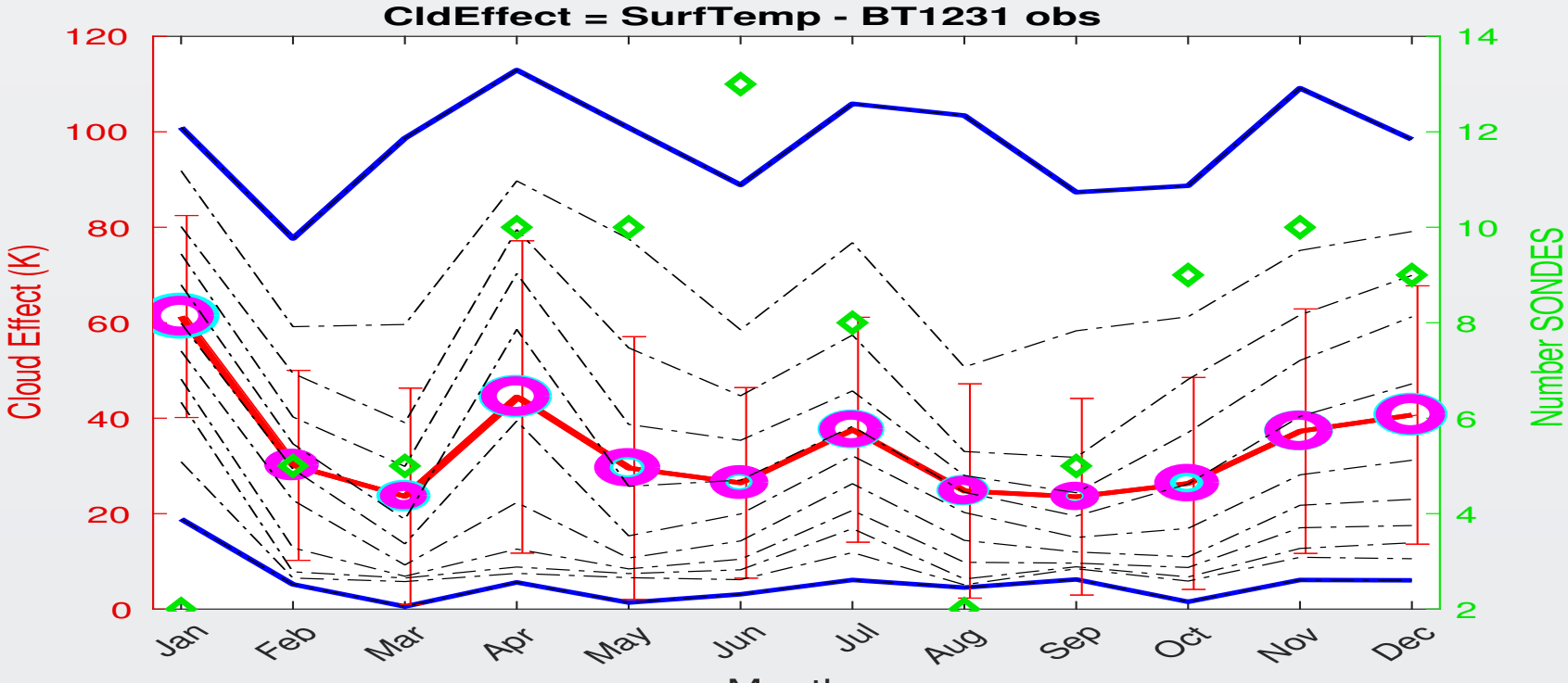
Comparisons to sondes

- Lindeberg, Germay (GRUAN); TWP and SGP (ARM) (start with AIRS <L3>)
- Select granule containing AIRS ovepasses within $\pm$ 1 hour of sonde launch, and within 100 km
- Typically this gives 100 AIRS observations, under various conditions (clear sky to thick cloud)
- Match AIRS observations to ECMWF thermodynamic/cloud profiles
- Compare retrievals to sonde, sonde*AK and ECM

ARM : TWP

- TWP site 2.05 S, 147.42 E
- had ECMWF data for 81 sondes, 5406 AIRS FOVS matchups
- mean ice/water OD = 1.4,14.3; mean stemp = 302 K, mean cldeffect = 33 K, mean colW = 56 mmH2O
- 80% success

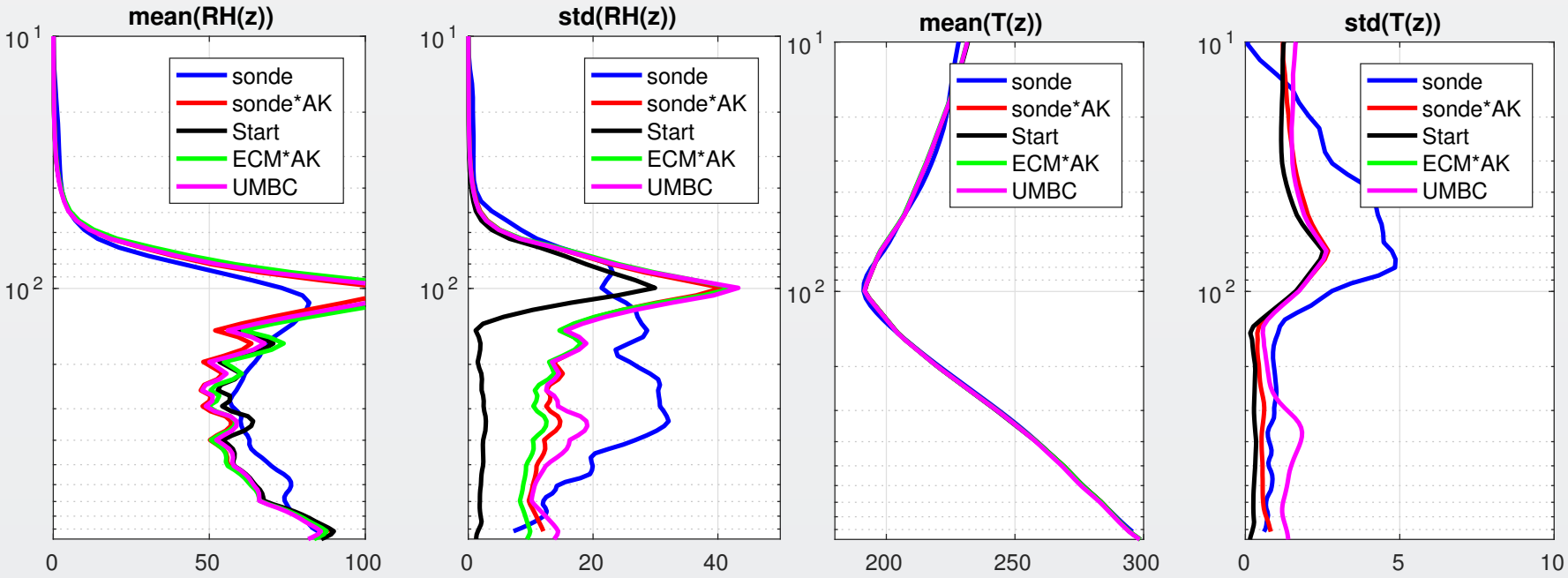
Dashed lines : Cld Forcing quiantiles, solid circles : Cloud ODs



ARM : TWP : variability

Left : RH(z)

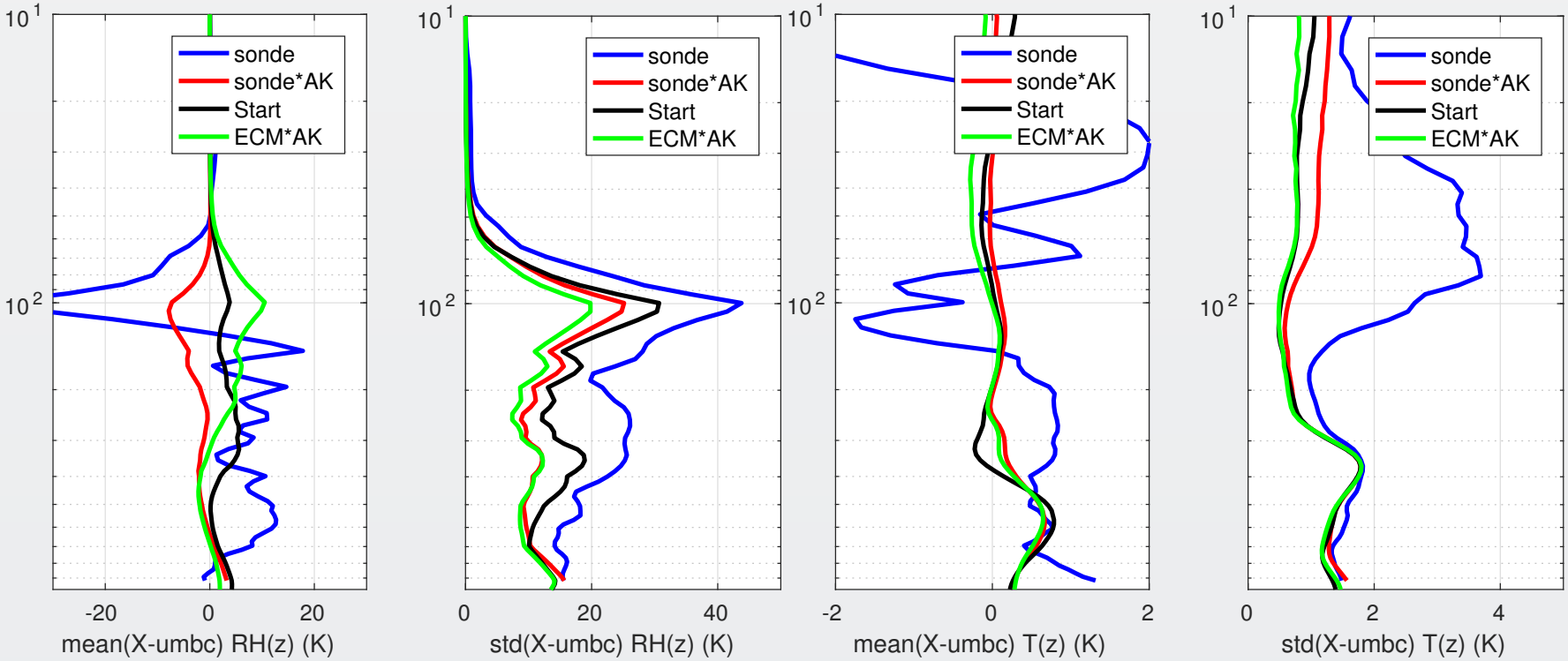
Right : T(z)



ARM : TWP : X-UMBC

Left : δ RH(z)

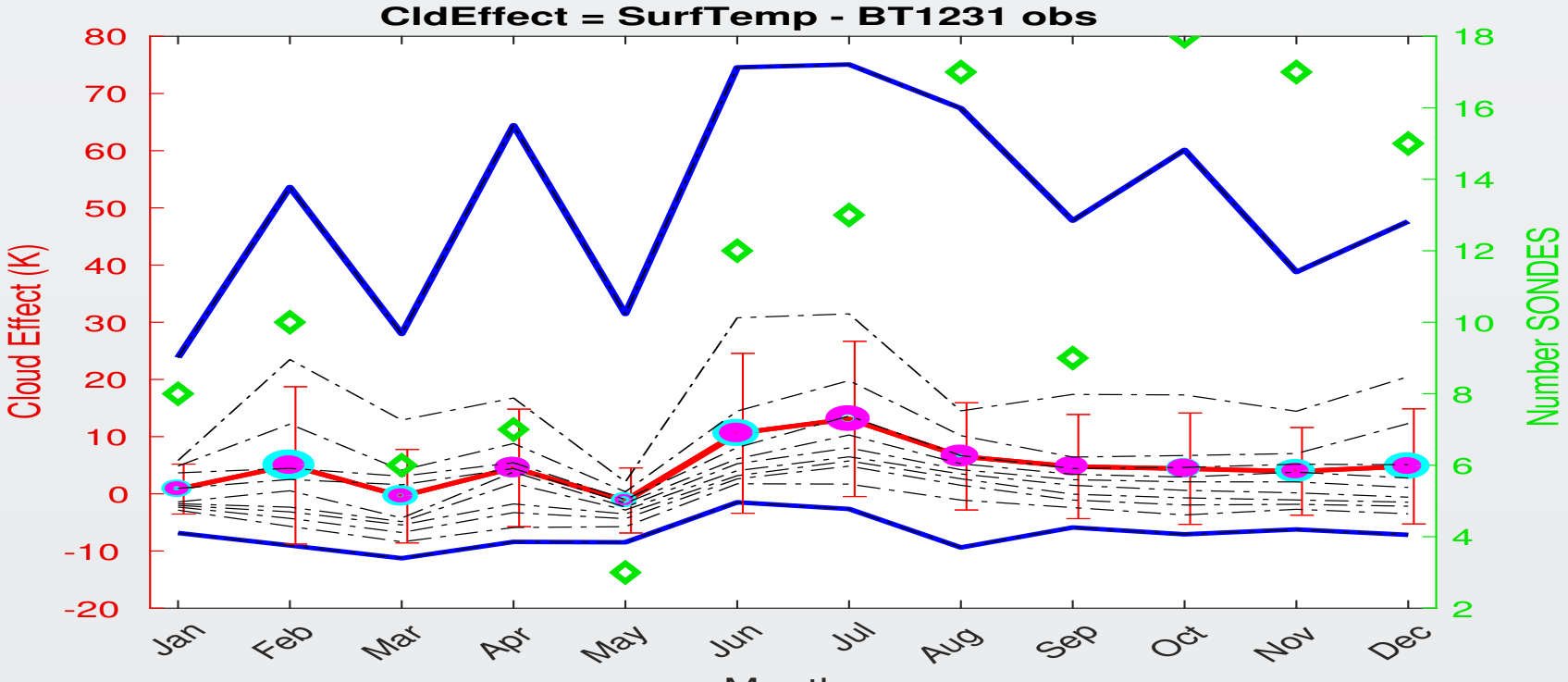
Right : δ T(z)



ARM : SGP

- SGP site 36.5 N, 96.5 W
- had ECMWF data for 112 sondes, 8773 AIRS FOVS matchups
- mean ice/water OD = 0.32,8.7; mean stemp = 282 K, mean cldeffect = 7 K, mean colW = 22 mmH2O
- 86% success, plots cut off ~ 960 mb (avg sonde start press)

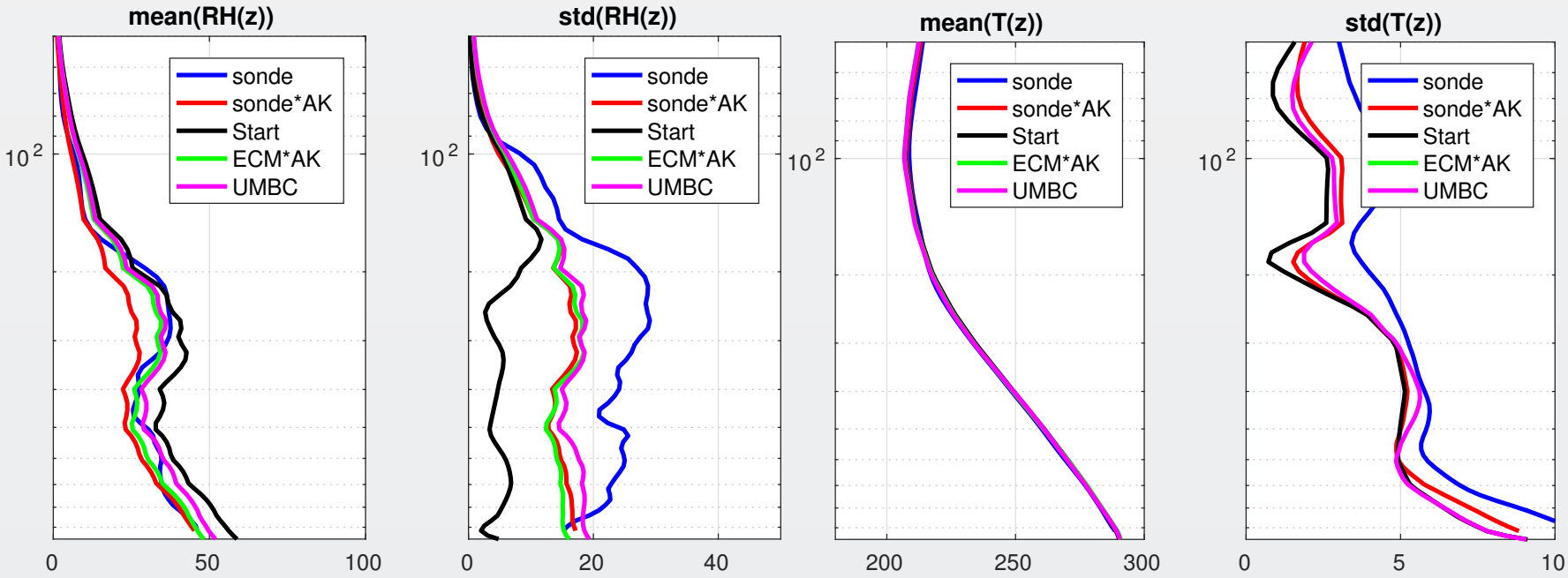
Dashed lines : Cld Forcing quiantiles, solid circles : Cloud ODs



ARM : SGP : variability

Left : RH(z)

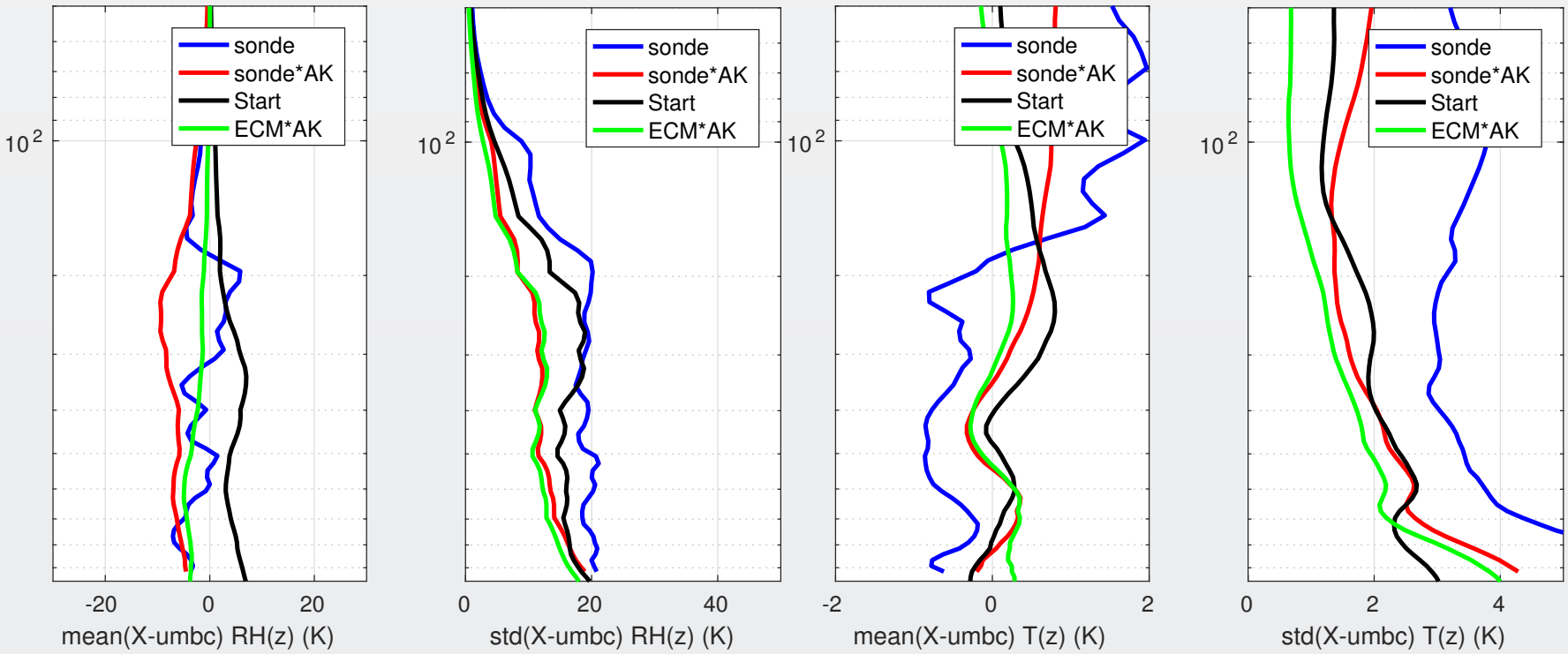
Right : T(z)



ARM : SGP : X-UMBC

Left : δ RH(z)

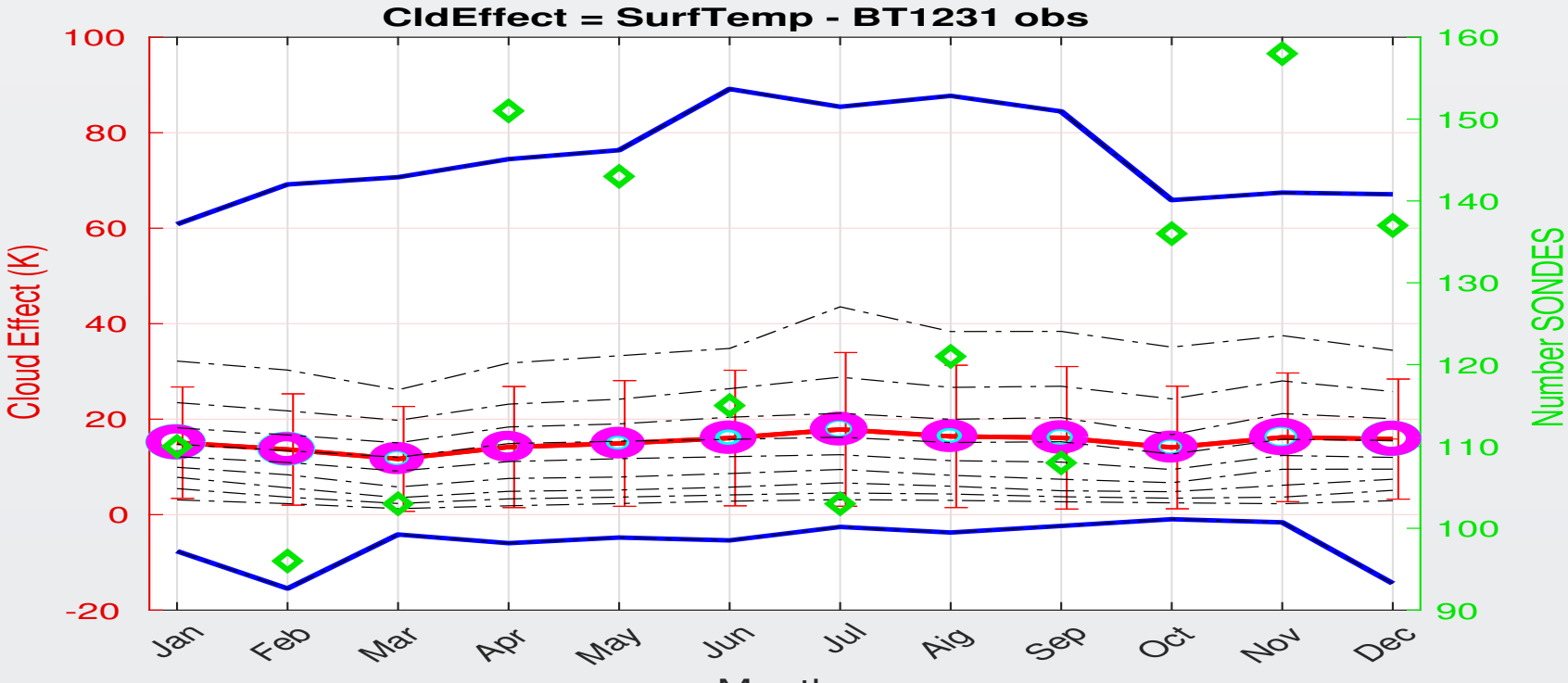
Right : δ T(z)



GRUAN : Lindenberg, Germany

- Lindeberg, Germay 52.21N, 14.12 E, 98 m asl
- ECMWF data for 1140 sondes, 101521 AIRS FOVS matchups
- mean ice/water OD = 0.92,10.1; mean stemp = 283 K, mean cldeffect = 8.1 K, mean colW = 15.5 mmH2O
- 83% success

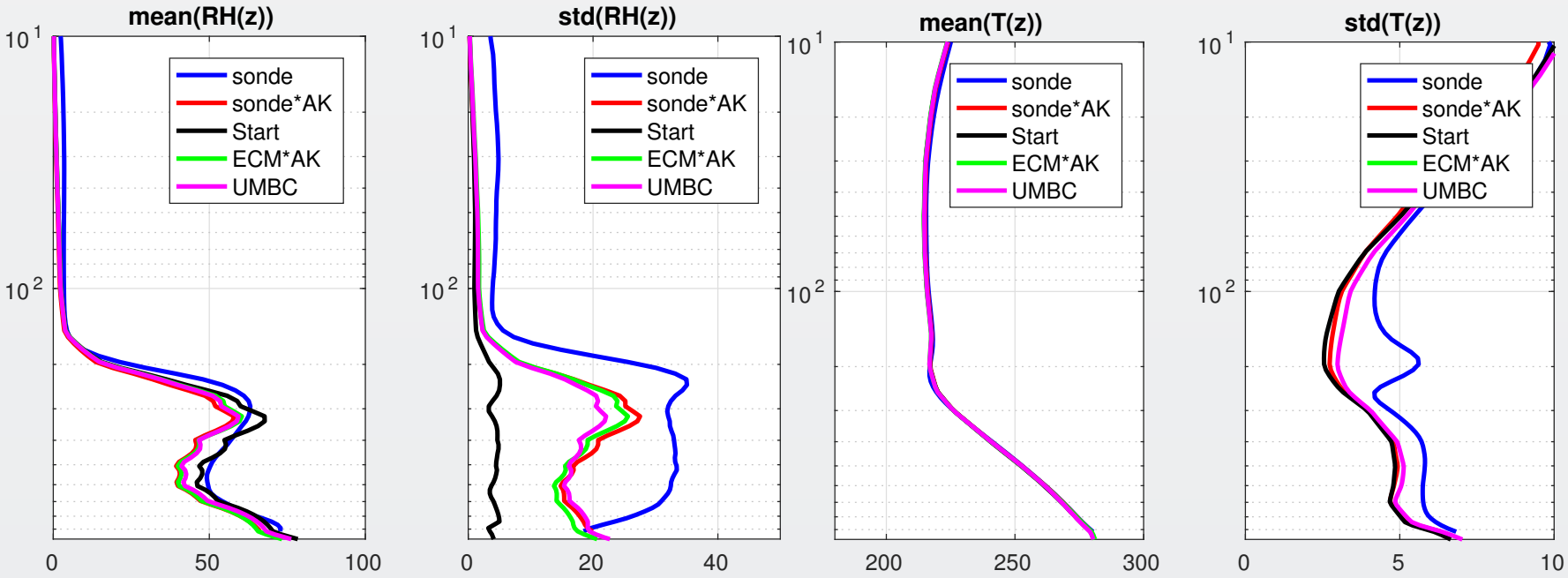
Dashed lines : Cld Forcing quiantiles, solid circles : Cloud ODs



GRUAN : LIN : variability

Left : RH(z)

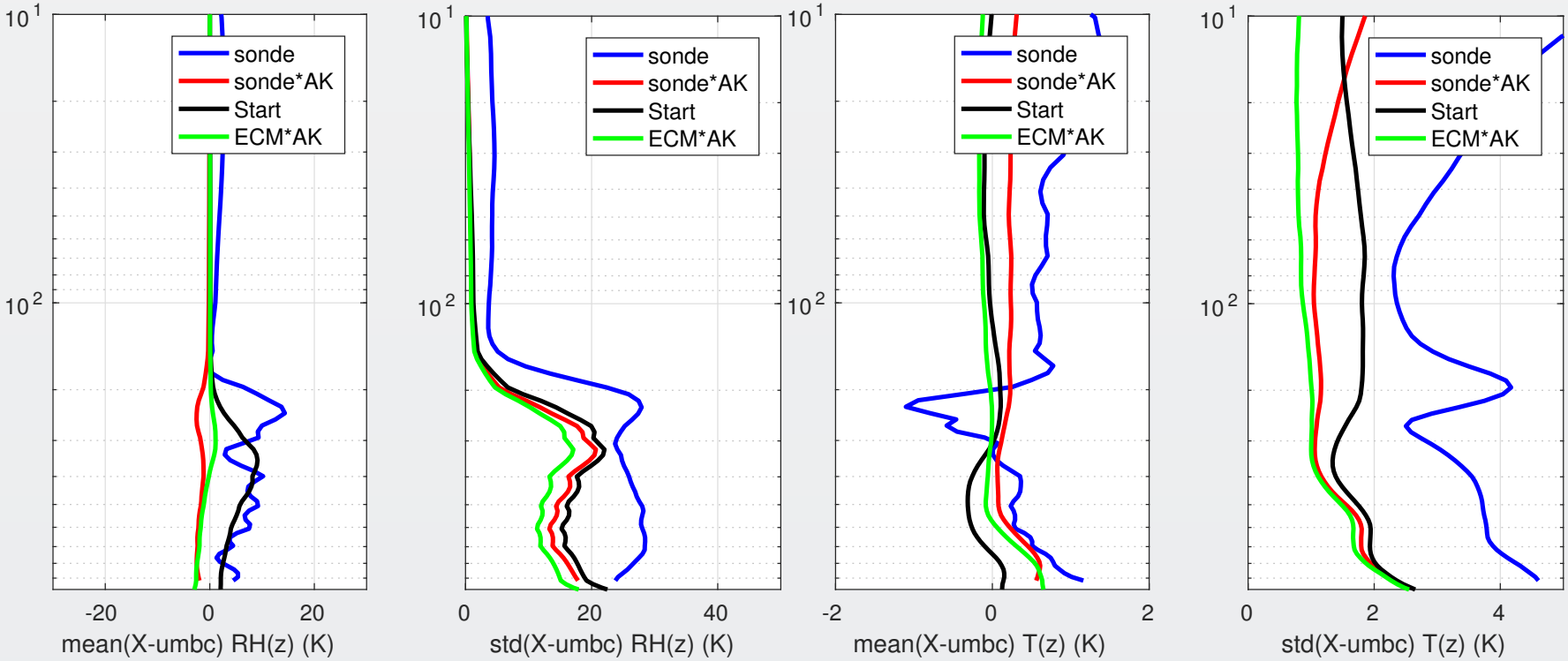
Right : T(z)



GRUAN : LIN : X-UMBC

Left : δ RH(z)

Right : δ T(z)



General Points

- as cloud OD increases, have smaller δ RH,T in lower trop
- have higher yield when starting with ECM profiles (90%)
- biggest differences : starting SurfTemp, final cloud ODs
- Have turned off water clouds and compared to sondes
  - start with ECM : marginally larger StdDev in retrieved profiles; ice clouds – OD is bigger, and cloud top lower
  - start with <AIRS L3> : noticeable degradation eg 0.5 K mean/std dev T(z), 5-10% RH(z)

14+ years

Climate : N years of AIRS data

- Larrabee and I present talks on deriving geophysical rates from 14+ years of AIRS radiance trends
- They come from daily random allsky nighttime nadir AIRS obsservations, spectral linear trends, binned zonally and daily averaged
- Then do geophysical rate retrieval on resulting linear spectral trends, comare to AIRS L3, ECM
- Take same random AIRS obs, start with monthly AIRS L3 climatology (with temporal and spatial varying CO2 amount
- Do OEM retrieval on these 10000 obs/day, find geophysical trends from retrieval

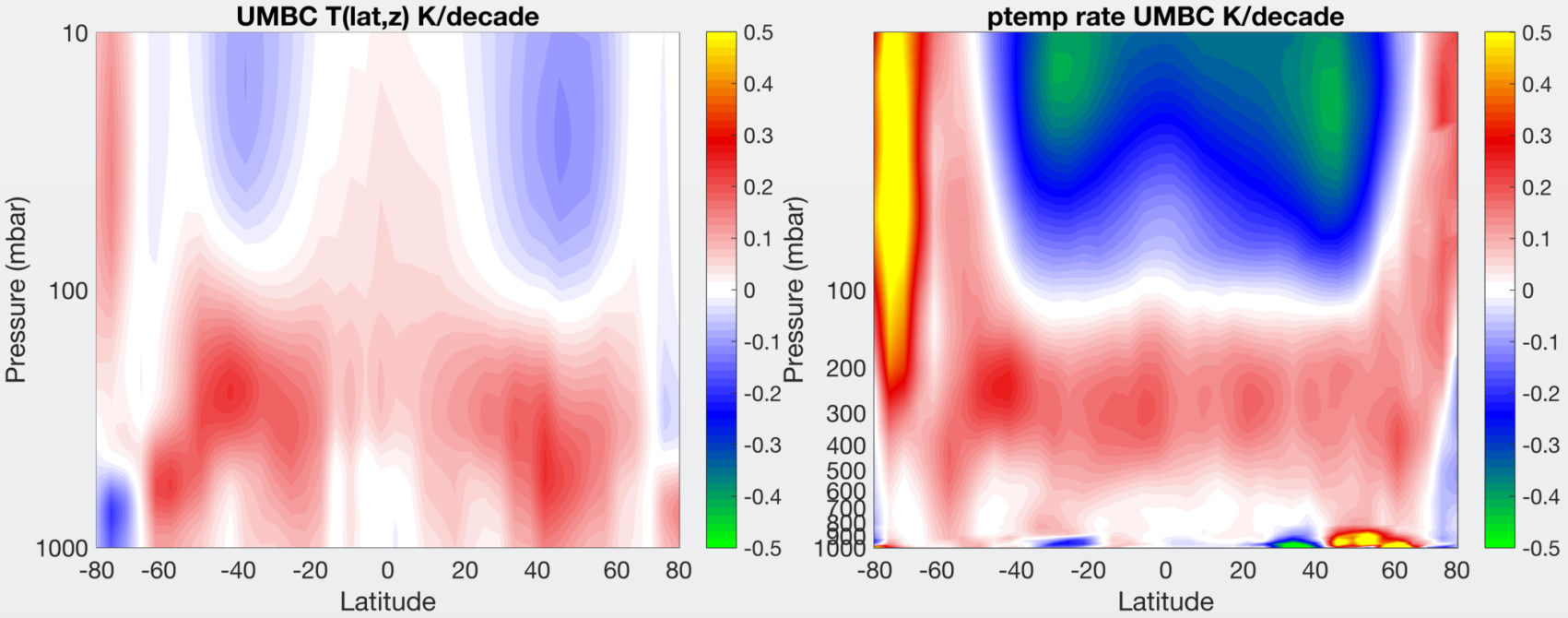
Re-processing times

Task	Language	Run time
Pre-Processing L1B data		
co-locate NWP fields to AIRS	Matlab	30 secs
change NWP fields to slab clouds	Matlab	70 secs
change levels to layers	f77	8 secs
compute SARTA clear radiances	f77	3.9 mins
compute SARTA allsky radiances	f77	6.1 mins $\sim$ 0.03 secs/FOV
Actual OEM 100 layer retrieval	Matlab/f77	8 hours < 2.5 secs/FOV

- Typical area weighted sampling of daily AIRS $\sim$ 20000 FOVs
- Multiple days can easily be processed on a High Performance Cluster (HPC) in an embarrassingly parallel mode
- Following results produced in half a month (processed 14 years of the sub-sampled ($\sim$ 8000 night-time observations per 24 hour) AIRS data on 128 processors)

UMBC decadal temperature trends

Start with ERA thermodynamic/cloud fields



Left : from spectral rates
Colorbar dT(z)/dt K/decade)

Right : from daily retrievals

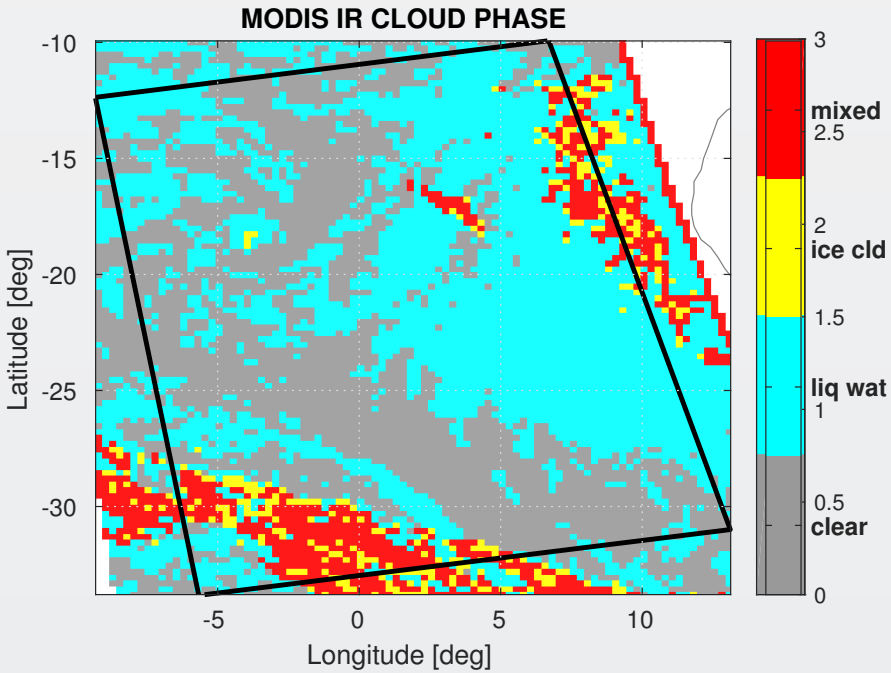
Conclusions

- TwoSlab is very fast method, Can easily be used to compute jacobians for OEM
- Use NWP thermodynamic and *reasonably accurate cloud fields*
- Retrieve thermodynamic profiles, surf temp, col trace gases (CO2, CH4, O3), ice and water cloud parameters
- typically have about 90% yield ECM and 80% yield CLIM (problems usually for very thick clouds)
  - AIRS cloud clearing has problems under almost clear conditions
- Larrabee/Howard have the AIRS to CrIS conversion in great shape, so will use same algorithm for AIRS (09/2002 →) and CrIS (02/2012 →)
- Improvements (TBD)
  - allow cloud top, partice size to be retrieved (MBL,DCC)
  - further tune covariance matrices and channels
  - trapezoid jacobians (Broyden Rank 1 update)

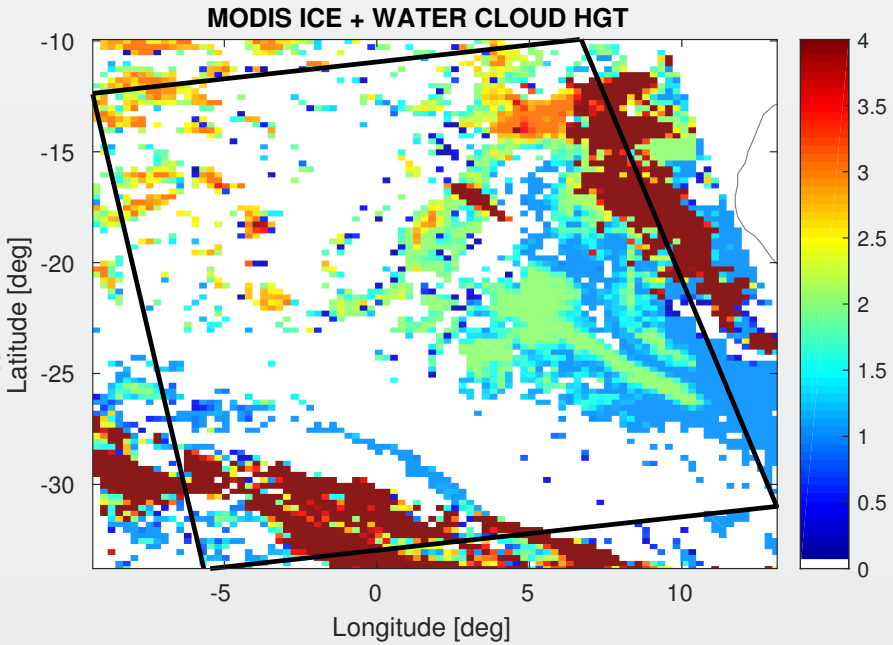
Extra Slides : MBL

MBL 2011/03/11/ g137

Left : MODIS L2 phase



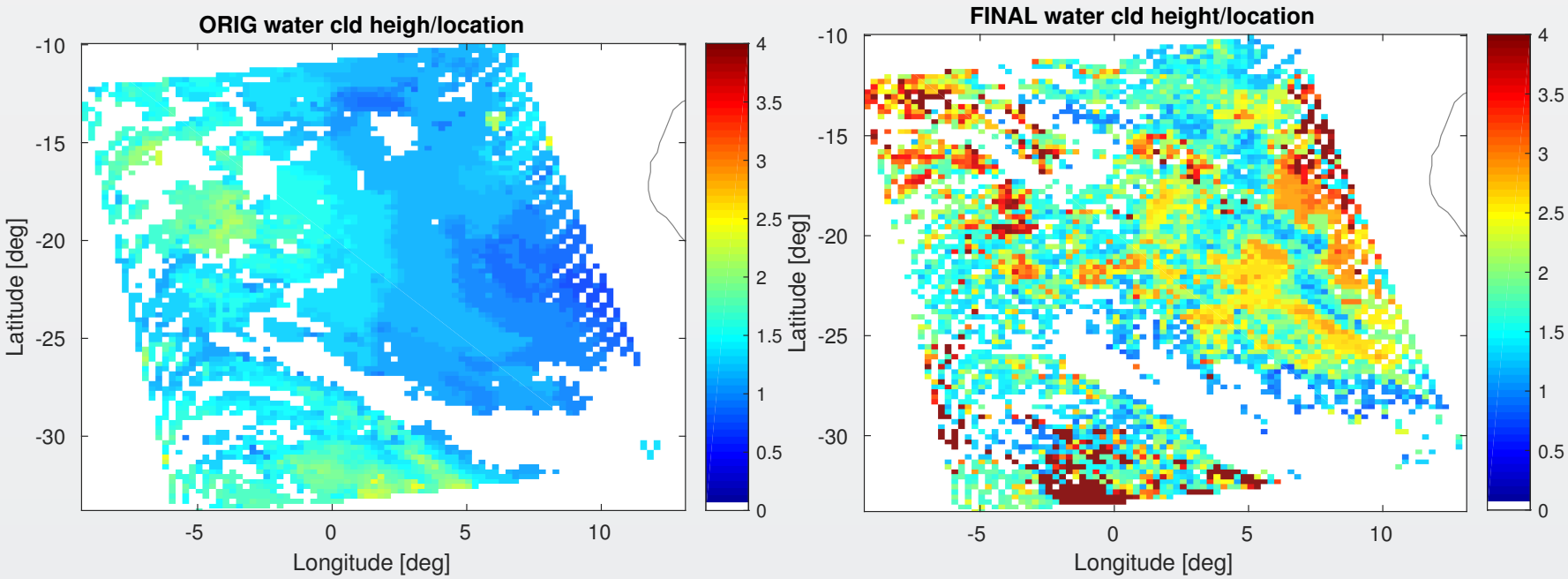
Right : MODIS L2 hgt



MBL 2011/03/11/ g137 + CLIM initialization

Left : UMBC water start

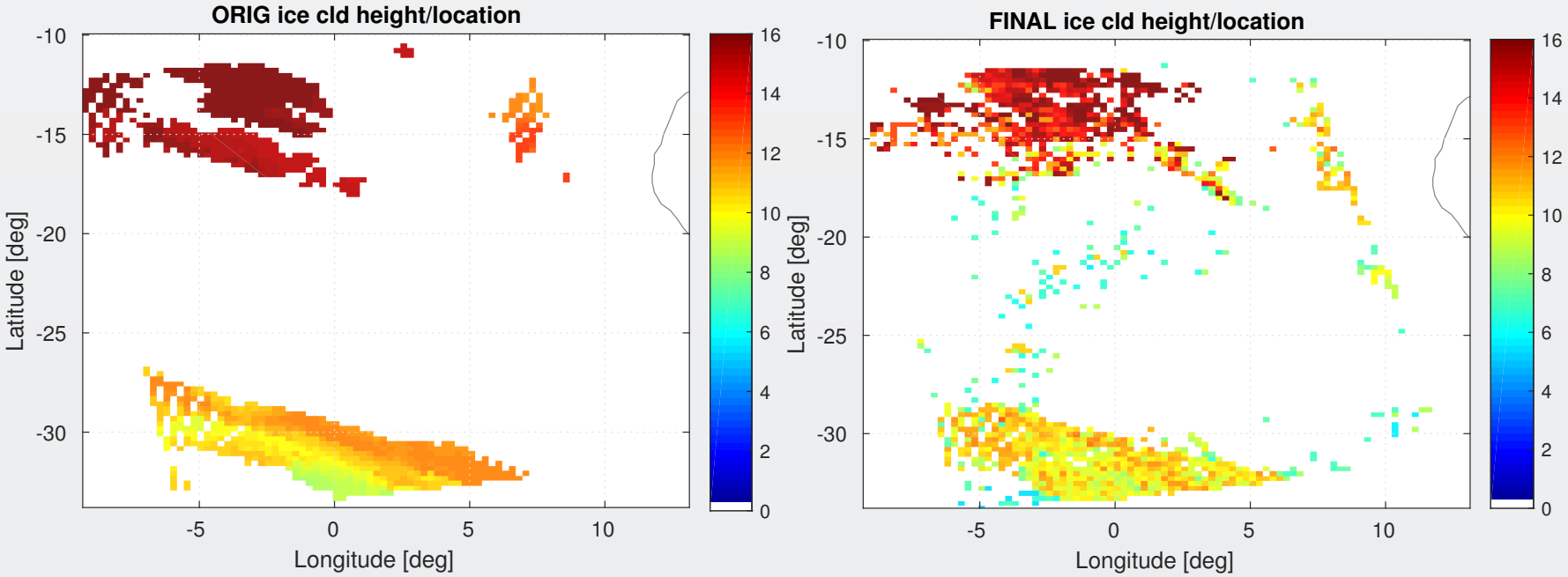
Right : UMBC water final



MBL 2011/03/11/ g137 + CLIM initialization

Left : UMBC ice start

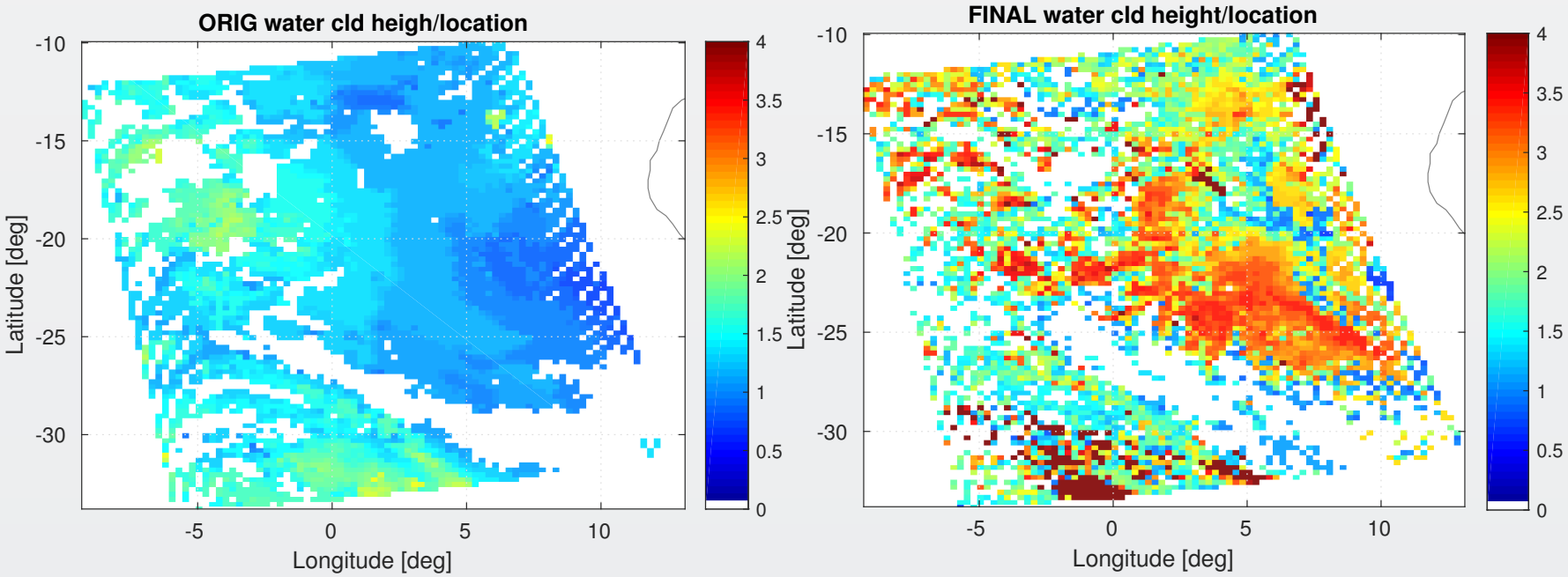
Right : UMBC ice final



MBL 2011/03/11/ g137 + ECM initialization

Left : UMBC water start

Right : UMBC water final



MBL 2011/03/11/ g137 + ECM initialization

Left : UMBC ice start

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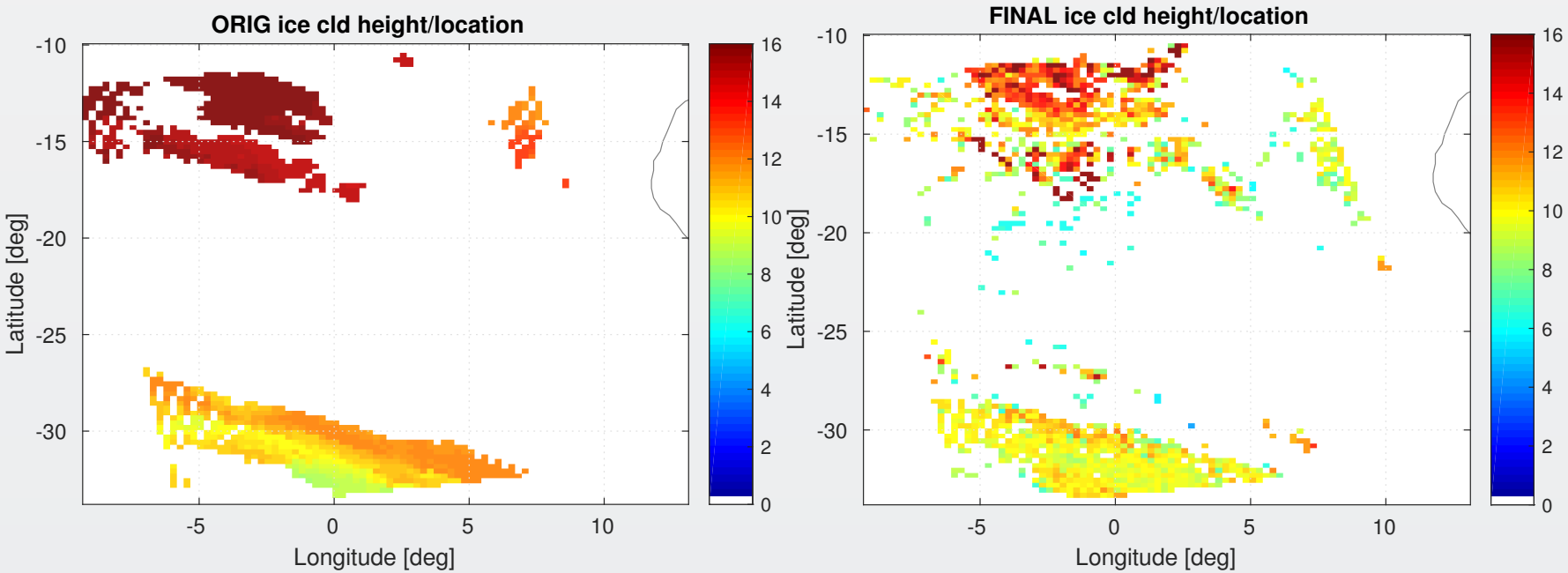
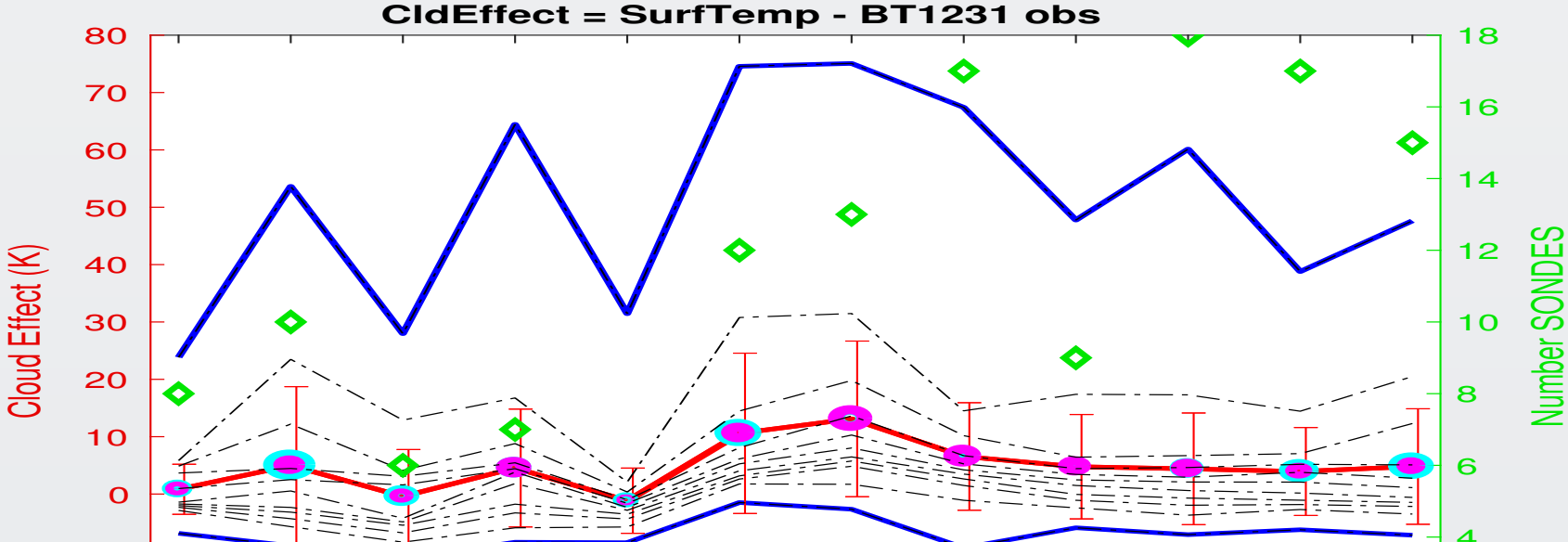


Extra Slides : Sondes + ECM init

ARM : SGP

- SGP site 36.5 N, 96.5 W
- had ECMWF data for 135 sondes, 11158 AIRS FOVS matchups
- mean ice/water OD = 0.4,2.0; mean stemp = 293 K, mean cldeffect = 5 K, mean colW = 17 mmH2O
- 90% success abs(obs-cal) $\leq$ 1K, δ(colW) $\leq$ 5 mmW
- Plots cut off at about 960 mb since that was the average sonde start pressure

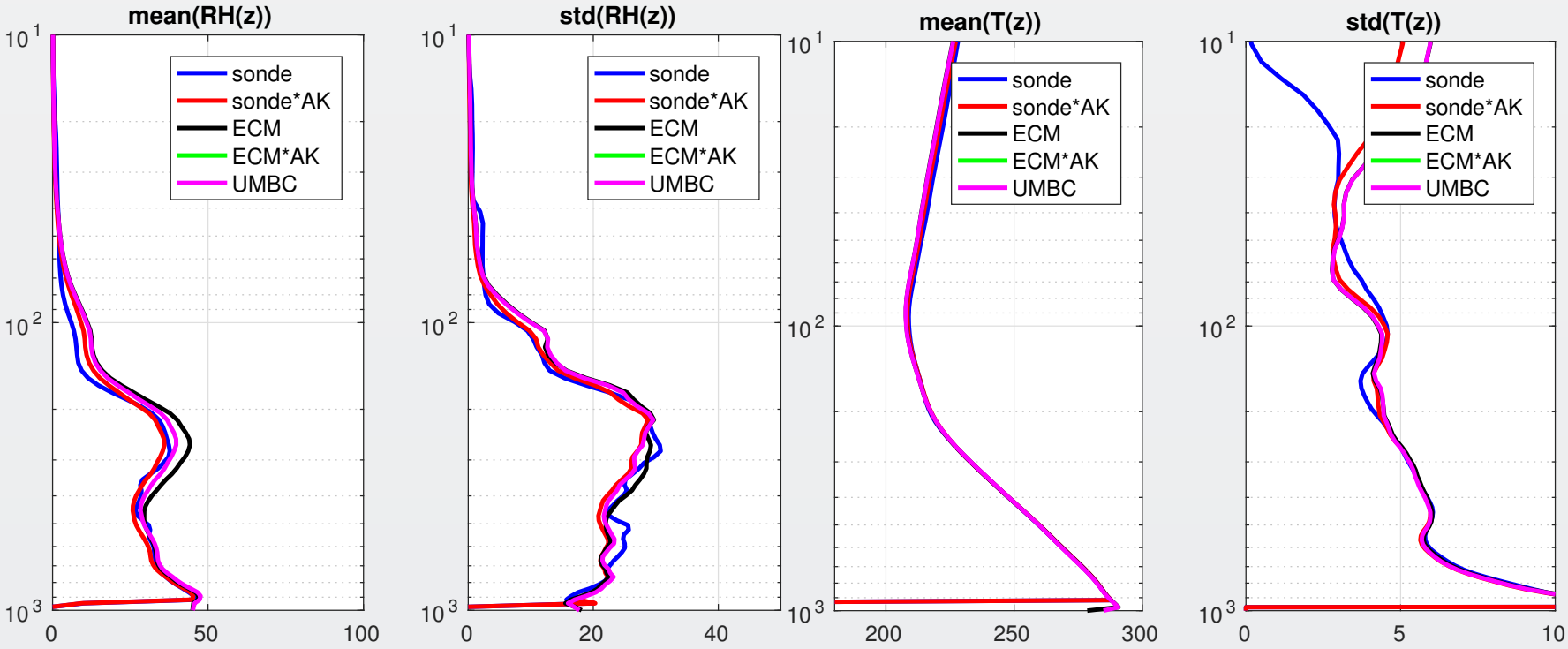
Dashed lines : Cld Forcing quiantiles, solid circles : Cloud ODs



ARM : SGP : variability

Left : RH(z)

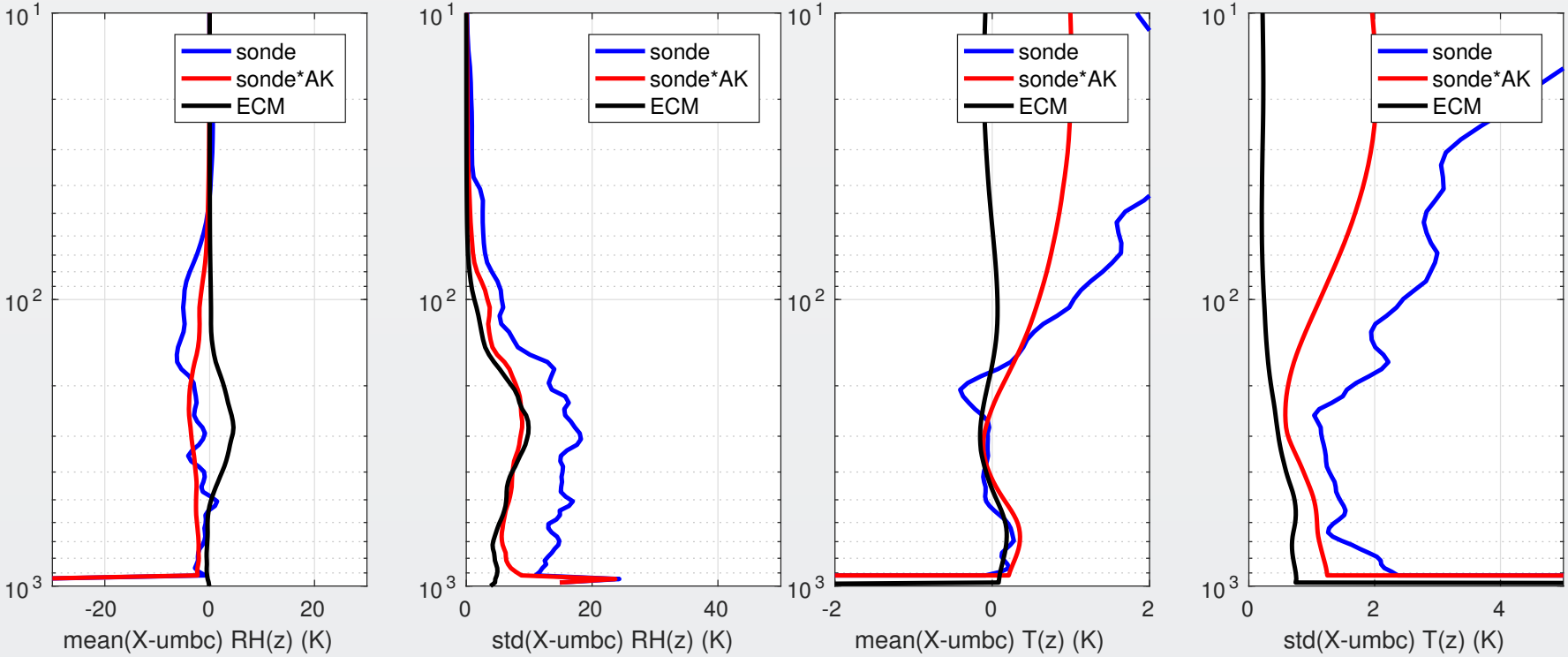
Right : T(z)



ARM : SGP : X-UMBC

Left : δ RH(z)

Right : δ T(z)



GRUAN : LIN : DOFS

See how retrievals change with DOFS

Quantile DOFS [0 0.1 0.5 0.9 1.0]

Left : δ RH(z) Right : δ T(z)