

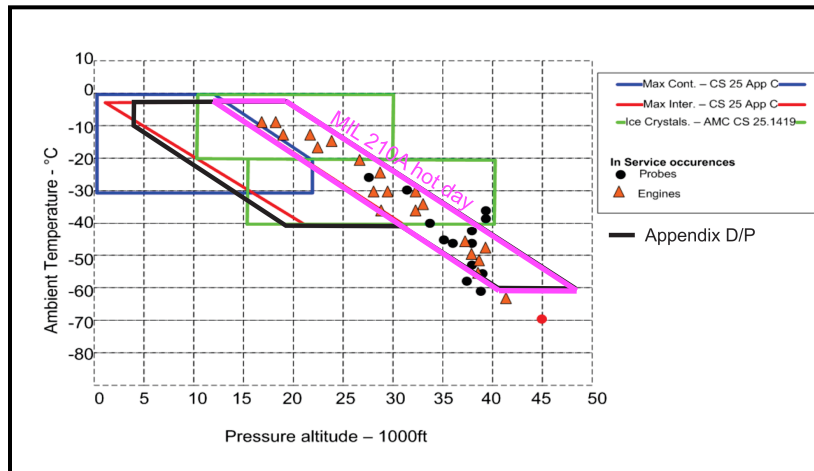
Preliminary Assessment of Appendix D/P Total Water Content from In-Situ Measurements of Deep Convective Clouds from the HAIC-HIWC Darwin-2014 & Cayenne-2015 Flight Campaigns

Prepared by J. W. Strapp

**Presented at the HAIC-HIWC Science Team Meeting,
17-May-2016, Toronto, Canada**

New ice crystal envelope for aircraft certification

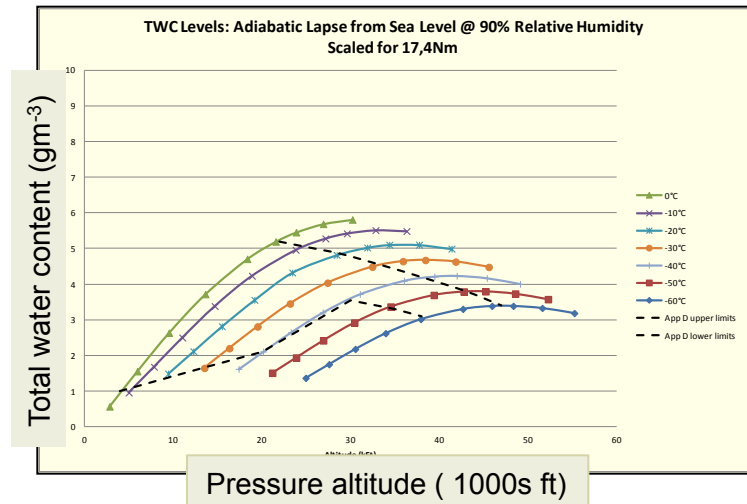
- New ice crystal envelopes resulted from discussions within the Engine Harmonization Working Group (EHWG) 2004-2006, resulting in.....
- FAA Appendix D¹ and EASA Appendix P, the same



APPENDIX D Temperature Envelope 1,2

¹ Mazzawy, Robert S., and J. Walter Strapp, 2007: Appendix D - An Interim Icing Envelope : High Ice Crystal Concentrations and Glaciated Conditions, *SAE Transactions, Journal of Aerospace*, 116, 634-642

² E. Duvivier, 2010, High Altitude Icing Environment. Intl. Air Safety and Climate Change Conf. 8-9 Sep. 2010, Cologne, Germany



APPENDIX D Total Water Content 1

- TWCs are theoretical maxima for air parcel deep-lift from low altitude , scaled down by factor 0.65 to 99th percentile 1950s RAE TWC data at 17.4 nm scale

Flights for In-Situ Appendix D/P Validation

- In-situ flight measurements in deep convective clouds recommended in EHWG Technical plan, to assess the new ice crystal regulatory envelope
- Target: collect 99th percentile TWC values on 17.4 nm distance scale, and its dependence on distance scale, in clouds similar to those that caused engine events, and with target TWC accuracy of 20%.
 - regulatory agencies and industry use 99th percentile values to test compliance, but under more extreme conditions (e.g. >>17.4 nm)
 - Necessary to develop and test a new instrument (IKP2) to measure TWC at high values and high airspeeds (NRC / Environment Canada / SEA / FAA / NASA / Met Analytics partnership): “IKP” → “IKP-2”
 - Partnership High Altitude Ice Crystals (HAIC) and High Ice Water Content (HIWC) projects for collaborative measurements on French Falcon-20 aircraft (Darwin-2014 and Cayenne 2015); previous paper in this HAIC-HIWC Science Forum)



Isokinetic TWC Evaporator on Falcon-20, unique new instrument for high IWC measurement

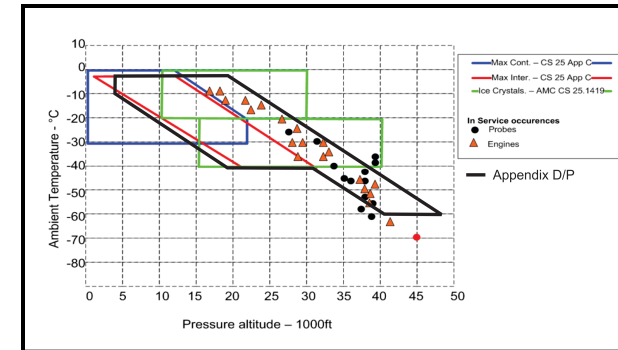
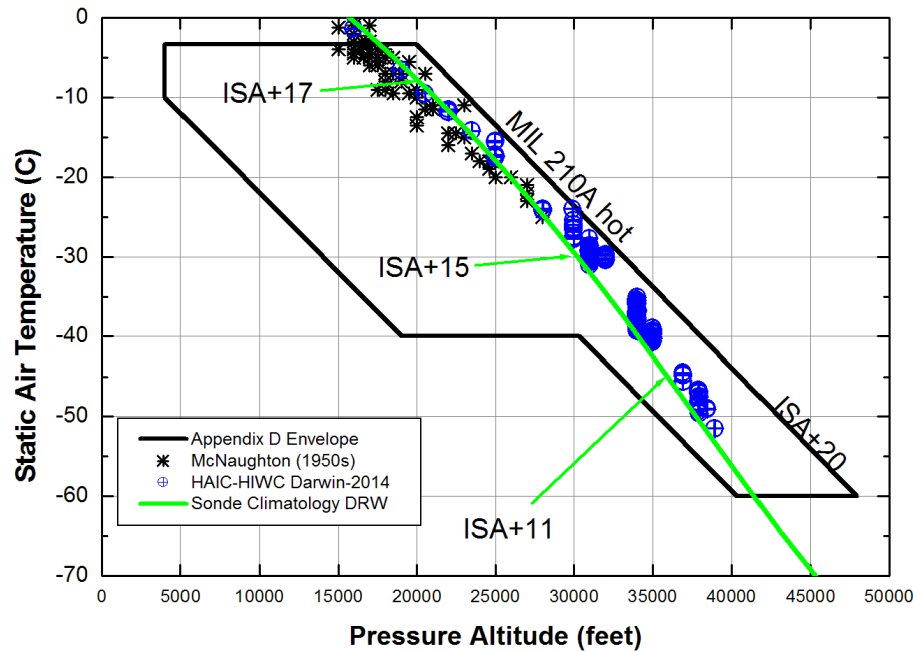
Data Sets and General Statistics

	DRW14 Falcon-20	CAY15 Falcon-20	CAY15 CV580	Florida-15 NASA DC-8
Number of Flights:	23	18	12	10
Number of flights with Appendix D/P cloud measurements:	16	17	11	10
Number of Coastal/ Oceanic MCS flights:	14 (88%)	12	TBD	10
Number Continental convection flights:	2 (22%)	5	TBD	0
Number Isolated Cumulonimbus:	0	?	0	0
Number of Segments:	157	218	TBD	119
Total Distance in Segments (nm):	7648	8735	TBD	10695
Avg. length of Segment (nm):	36.5	33.5	TBD	90
Avg. segment TWC (gm ⁻³)	0.69	0.60	TBD	?

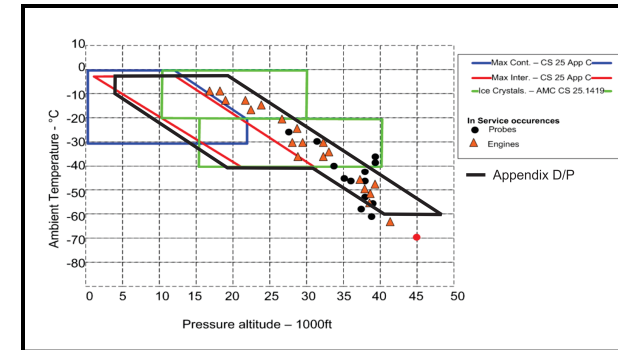
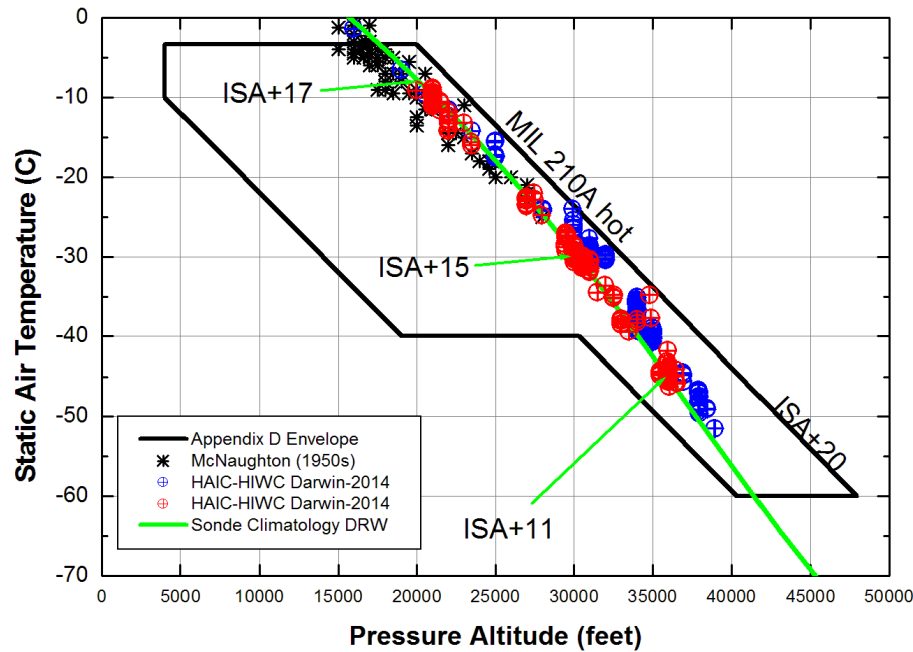
Data Sets and General Statistics (cntd)

Number of 17.4 nm data points	Darwin-14 Falcon-20	Cayenne-15 Falcon-20	Cayenne-15 CV580	Florida-15 NASA DC-8	Grand Total
Total	381	395	TBD	554	>1330
-50 C (-55<T<-44.9)	29	58	0	194	281
-40 C (-45<T<-44.9)	175	108	0	138	421
-30 C (-35<T<-24.9)	142	93	0	215	450
-10 C (-15<T<-4.9)	12	93	TBD	7	> 112

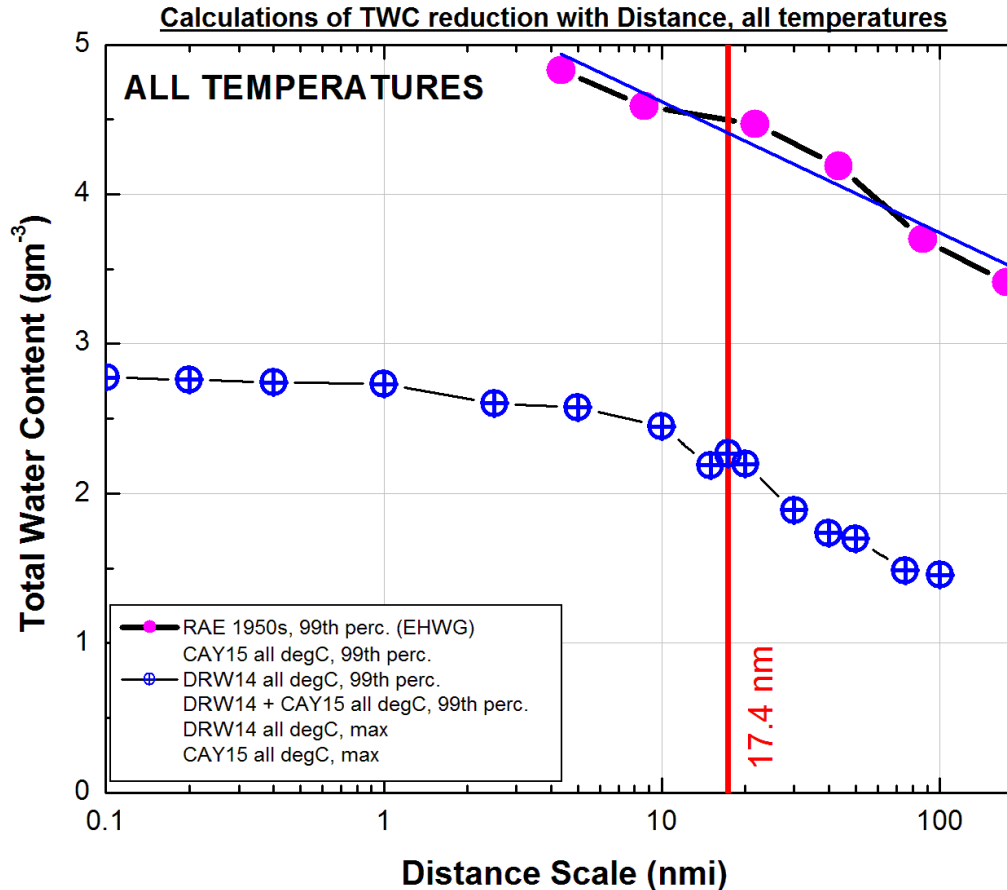
Appendix D Altitude-Temperature Envelope –DRW-14



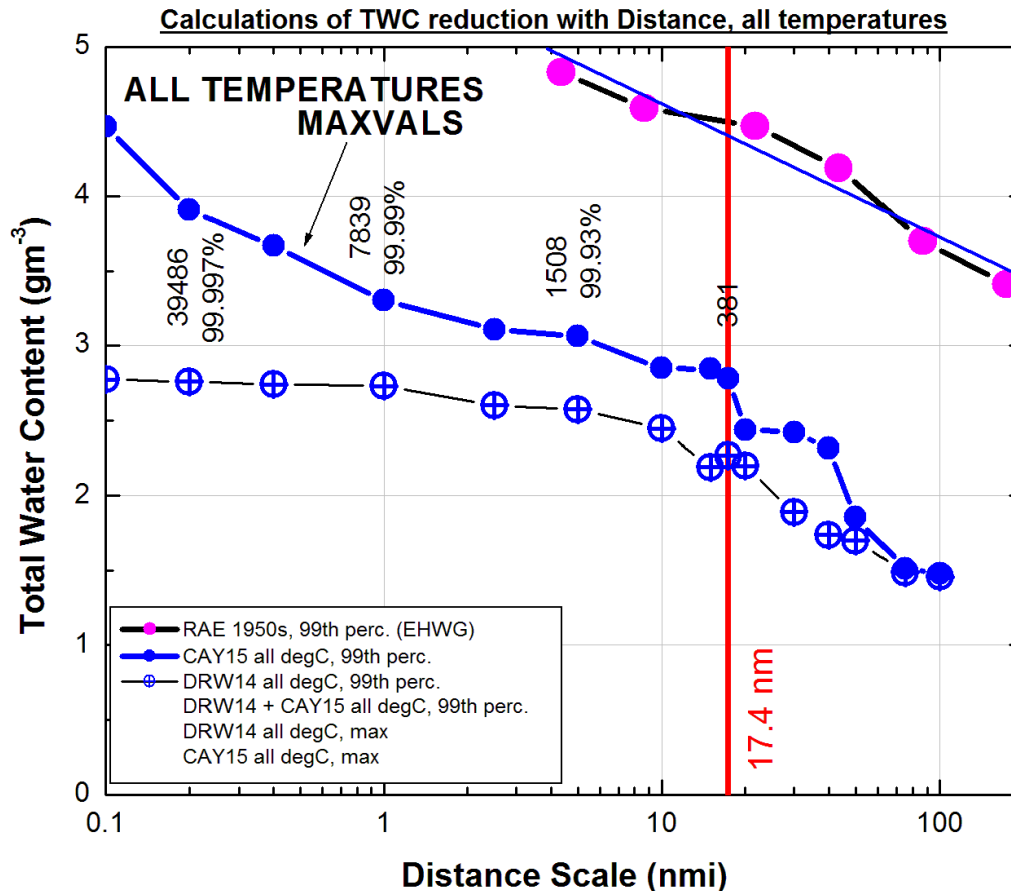
Appendix D Altitude-Temperature Envelope –DRW-14+CAY-15



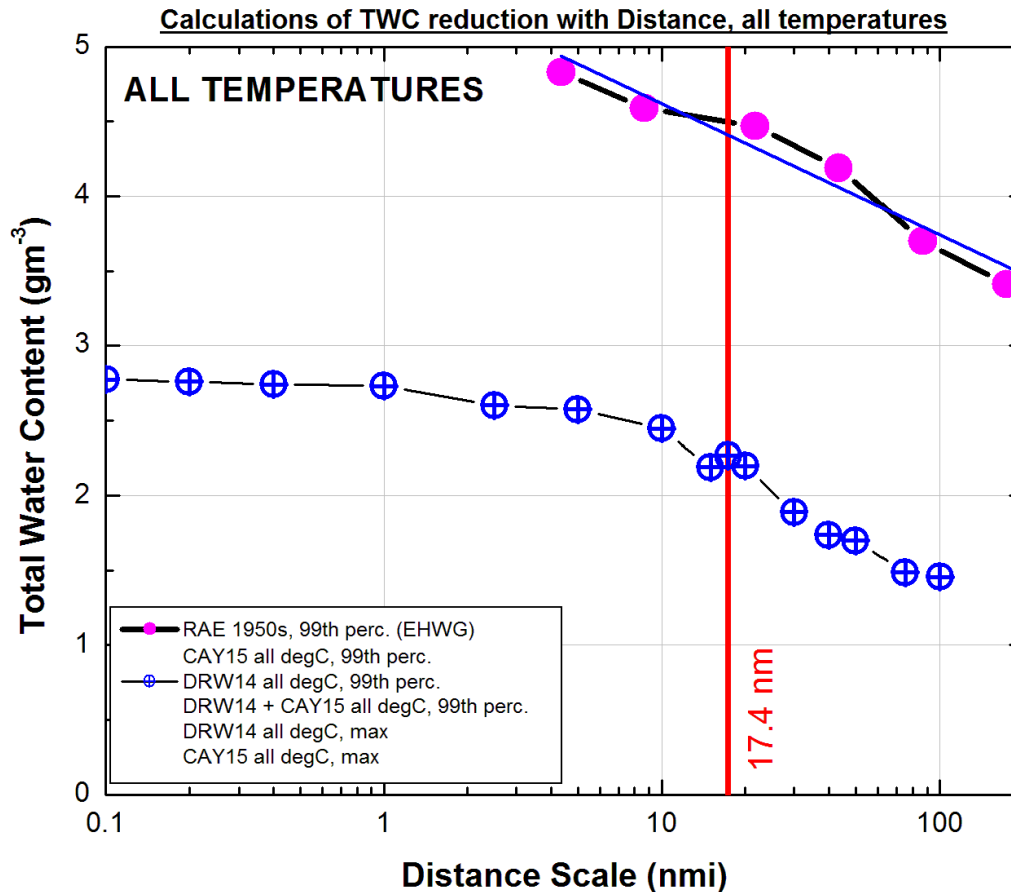
Appendix D TWC vs Distance Scale – DRW-14



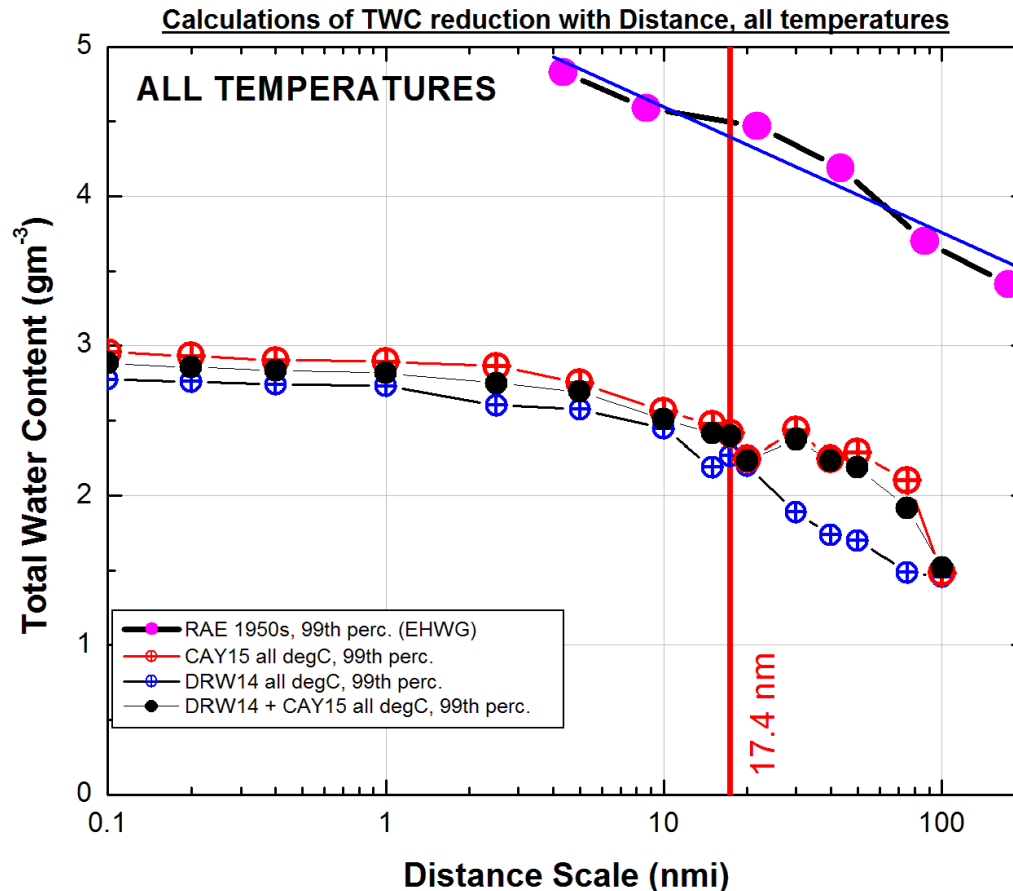
Appendix D TWC vs Distance Scale – DRW-14 with MAX. Values



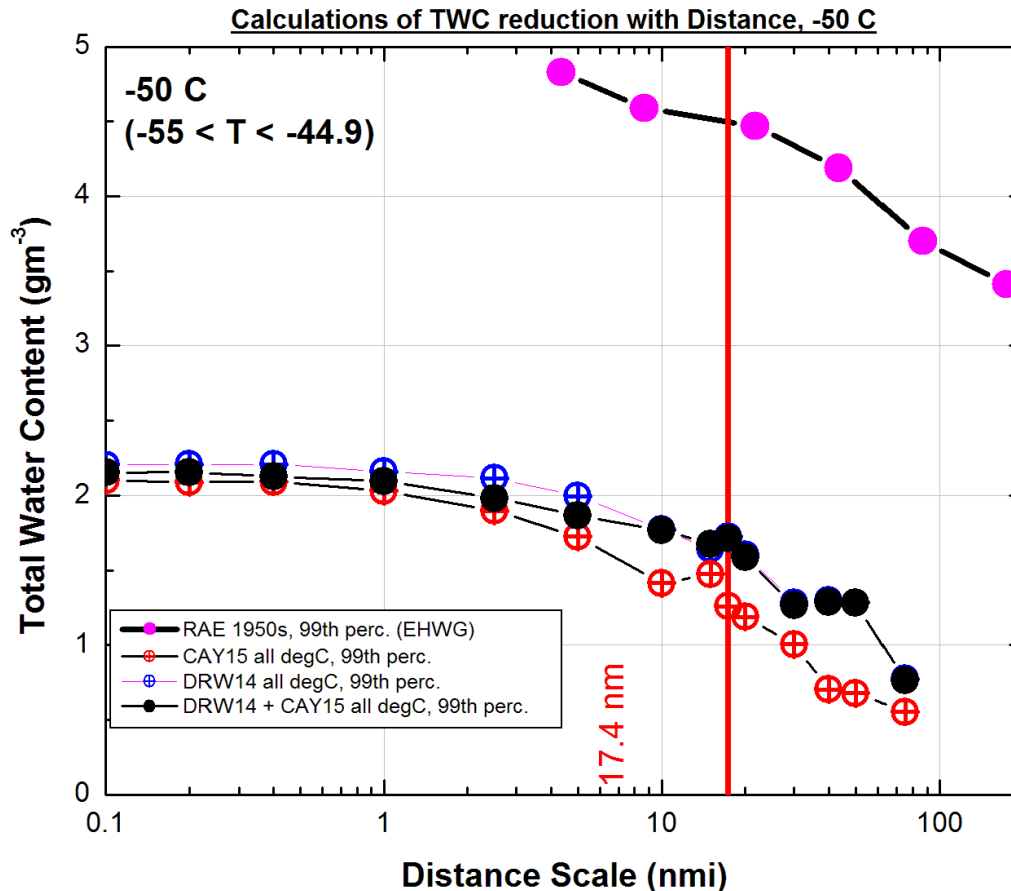
Appendix D TWC vs Distance Scale – DRW-14



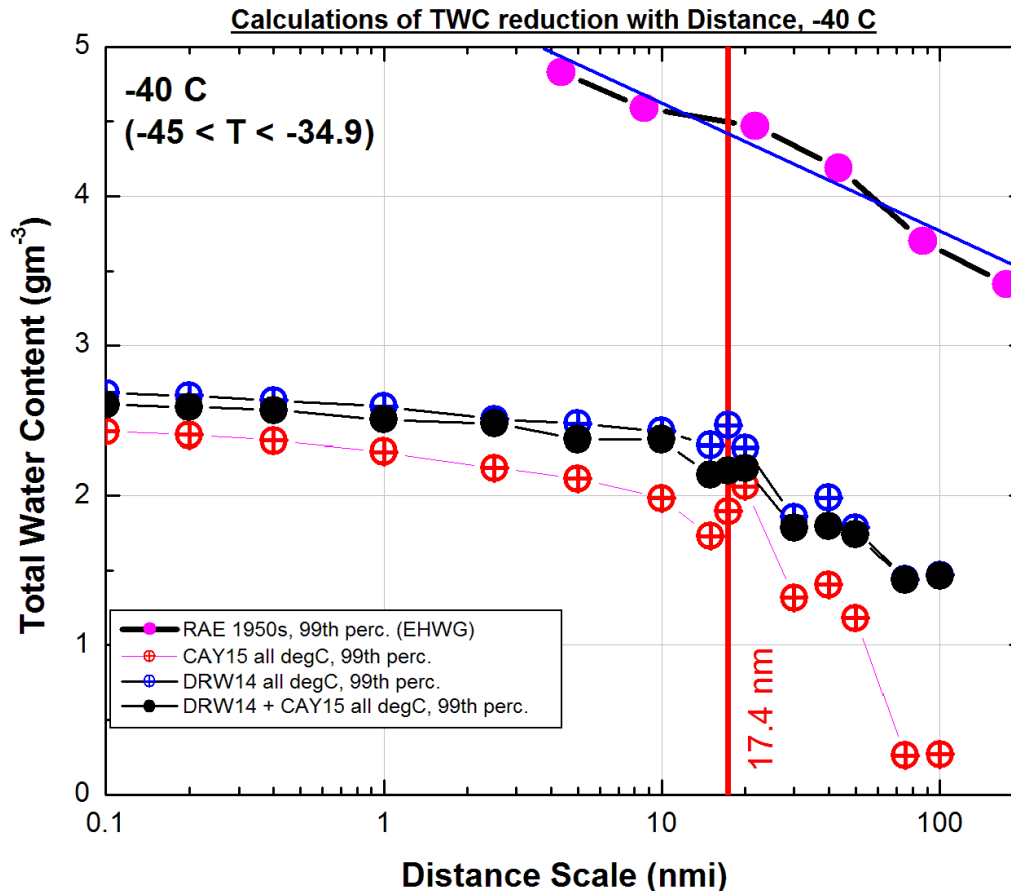
Appendix D TWC vs Distance Scale – DRW-14 + CAY-15



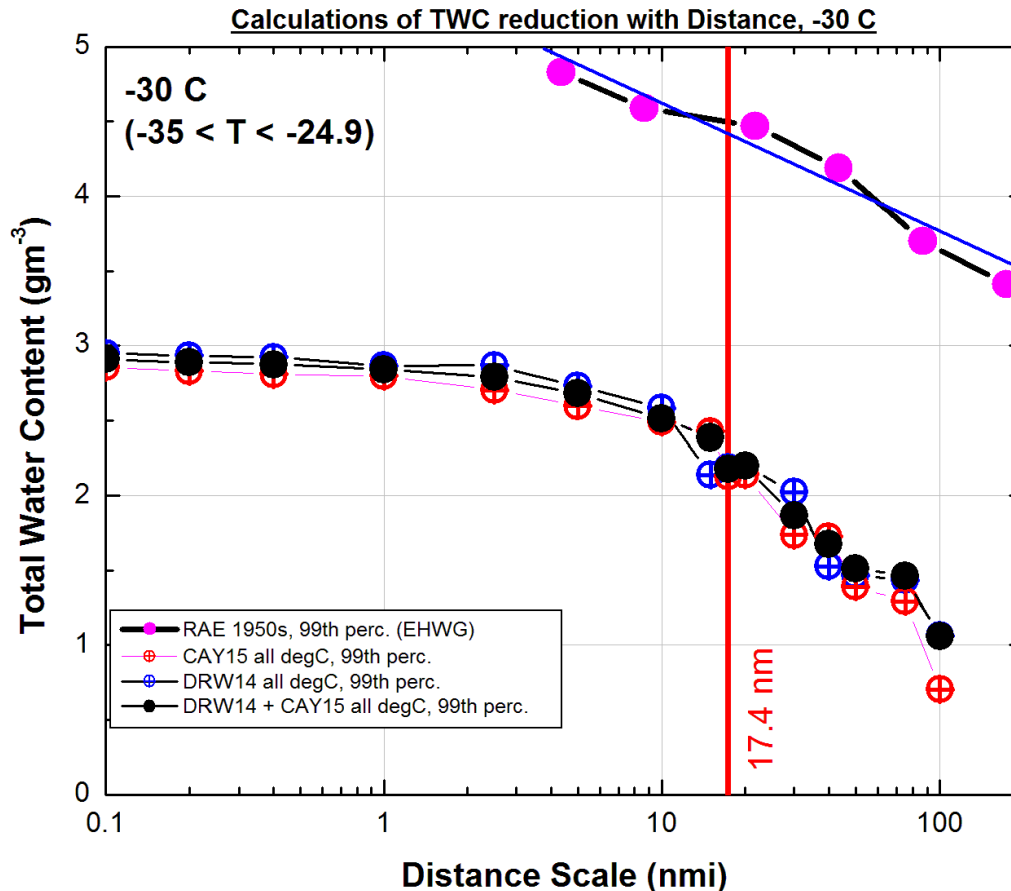
Appendix D TWC vs Distance Scale – DRW-14 + CAY-15, T=-50 C



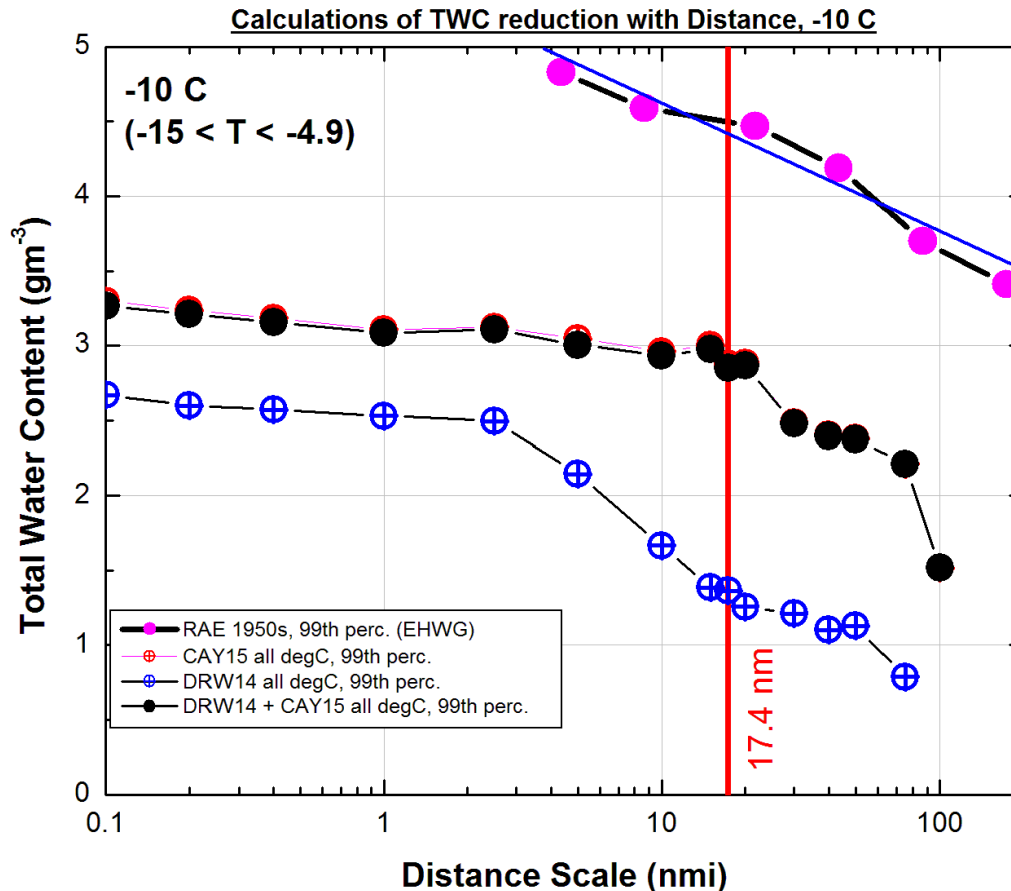
Appendix D TWC vs Distance Scale – DRW-14 + CAY-15, T=-40 C



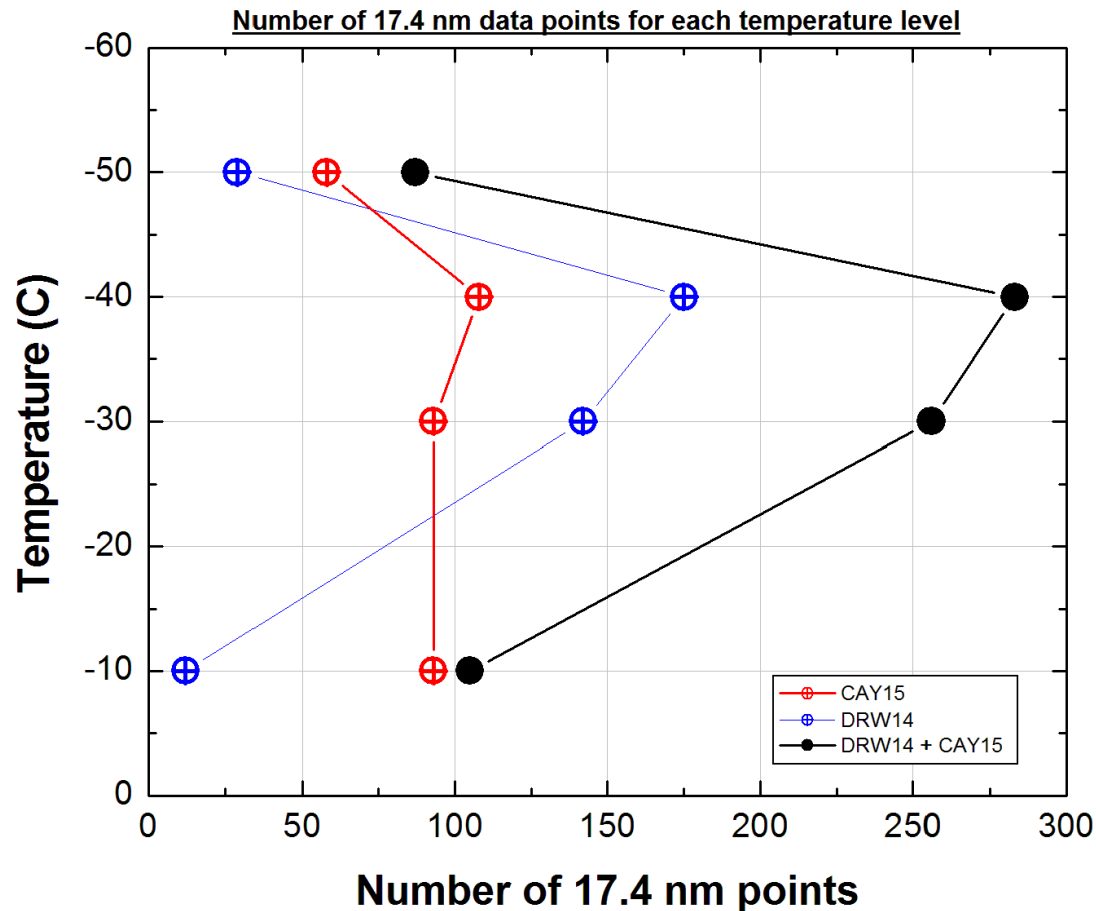
Appendix D TWC vs Distance Scale – DRW-14 + CAY-15, T=-30 C



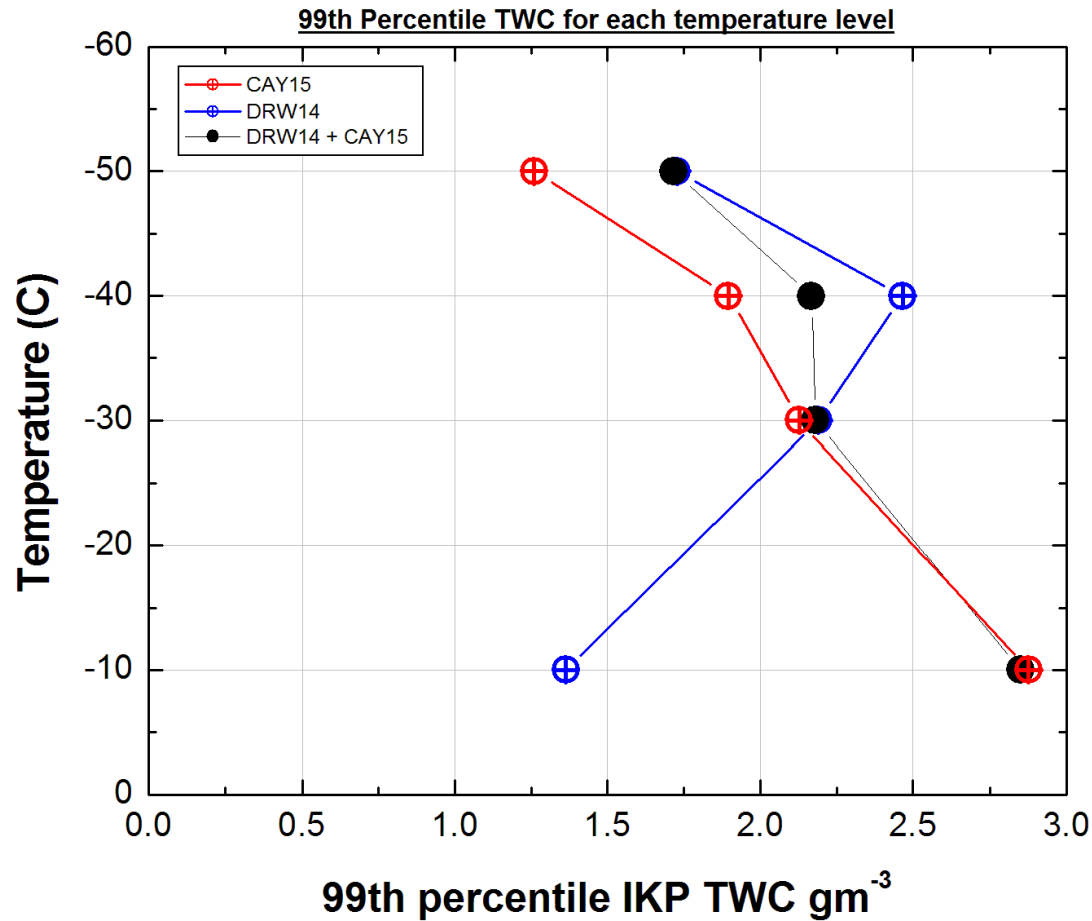
Appendix D TWC vs Distance Scale – DRW-14 + CAY-15, T=-10 C



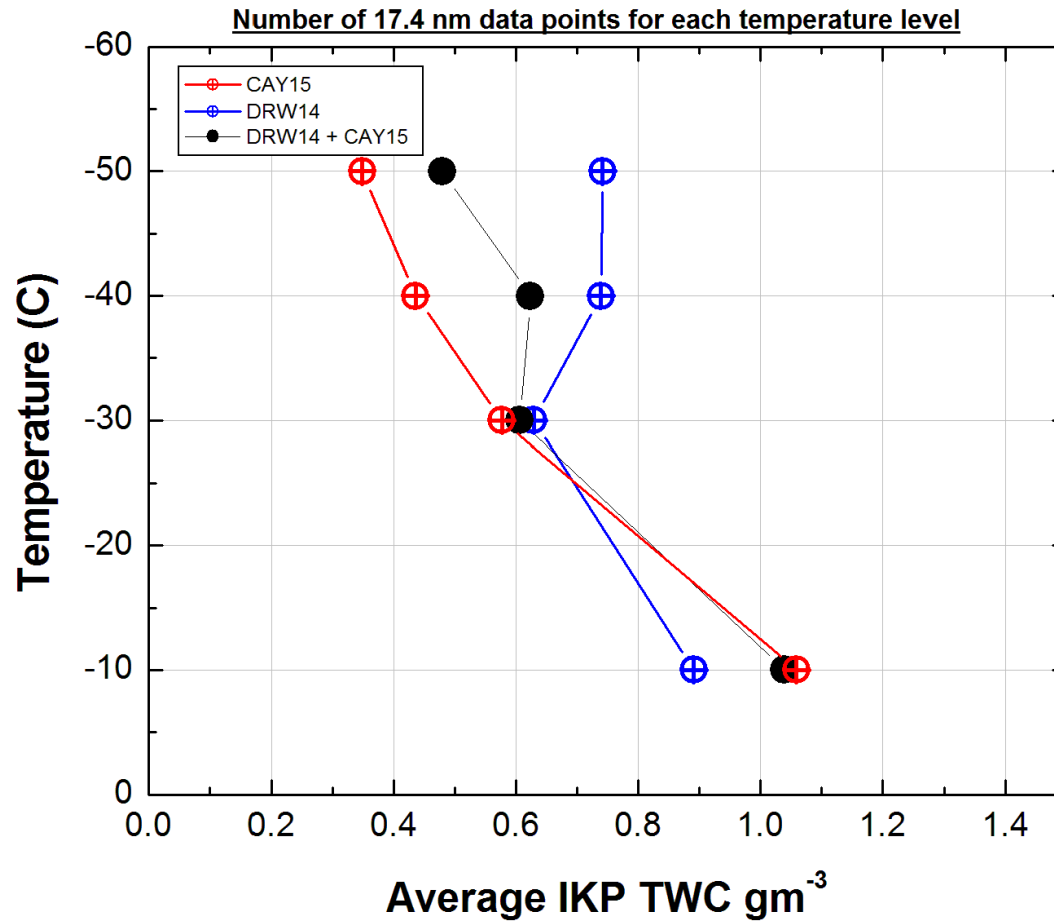
17.4 nm Distance Scale–DRW-14 + CAY-15, # Samples vs. Temperature



17.4 nm Distance Scale–DRW-14 + CAY-15, 99th Perc. TWC vs. Temp.



17.4 nm Distance Scale–DRW-14 + CAY-15, Average TWC vs. Temp.



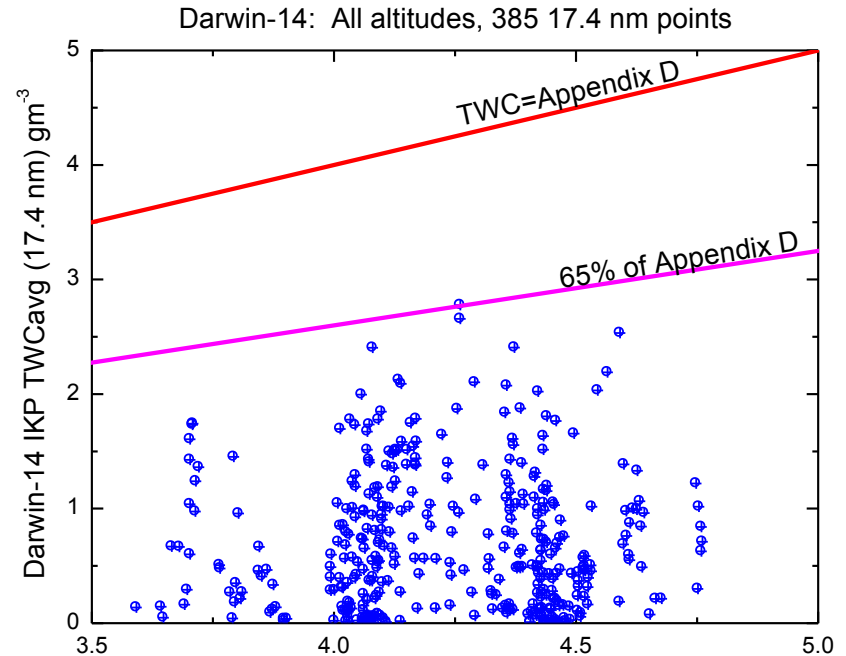
Data Sets, Sounding, cloud top

For days with flights :	DRW14 Falcon-20	CAY15 Falcon-20
Precipitable Water (median, mm)	64.6	62.3
Cold Point Tropopause (median, C)	-84	-82
Est. Equilibrium temperature (median, C)	-69	-65
IR temperature along flight track (minimum, C)	-84	-68

- Darwin and Cayenne atmospheres are quite similar
- Largest difference is height of cloud tops; Darwin minimum temperatures 16 C colder than Cayenne
- May explain lower F20 IWCs at -50 C. too close to cloud top.

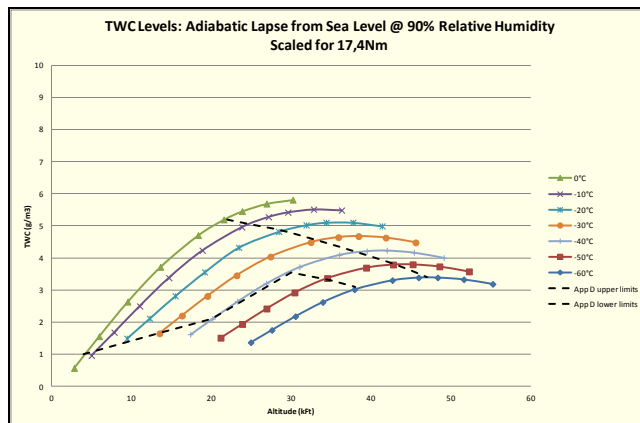
Appendix D comparison Darwin only – TWCs average over 17.4 nm

- Very little LWC was observed in Darwin-2014. Data are highly dominated by ice crystals.
- Maximum IKP TWC values averaged over 17.4 nm are falling below about 65% of Appendix D



Appendix D TWC 17.4 nm (0.65 factor)

99th percentile TWC for all points above is 2.5 gm^{-3}



Conclusions

- Cayenne data set adds high IWC at -10 C lacking in Darwin data due to lack of sampling at that temperature level
- Cayenne -50 C data set shows lower IWCs than Darwin data set – perhaps too close to cloud top in Cayenne (clouds were deeper in Darwin)
- Combined Darwin/Cayenne data set now shows a steadily decreasing 99th TWC with increasing altitude
- Preliminary assessment of the Darwin-2014 + Cayenne data yields statistics on TWC values:
 - Maximum 0.4 nm TWC ~ 4.2 gm⁻³
 - 99th percentile TWC ~ 2.40 gm⁻³, % Appendix D TBD, but probably < 65% like Darwin

Future work

- Prepare final DC-8 IKP-2 data set, and incorporate in Appendix D analysis
- Incorporate Cayenne Convair-580 data (-5 C to -15 C)
- Continue to work with Boeing on alternate approach for defining data points
- Finalize all TWC data sets
- How to incorporate MMD into Appendix D analysis. Need to start discussing.
- Target completion of Appendix D analysis: December 2016 (need to reduce other activities)



Thank you

walter.strapp@gmail.com