An Update on the Assessment of Appendix D/P Total Water Content from In-Situ Measurements of Deep Convective Clouds: Measurements from Two HAIC-HIWC Flight Campaigns and the HIWC RADAR Campaign

J. Walter Strapp (Met Analytics), Alfons Schwarzenboeck (CNRS-LaMP), Julien Delanoë (CNRS-LATMOS), Fabien Dezitter (Airbus), Chris Dumont (FAA), Alice Calmels (Airbus), Alexei Korolev (Environment Canada), Lyle Lilie (SEA), Rodney Potts (BoM), Alain Protat (BoM), Thomas Ratvasky (NASA Glenn).

Prepared by J. W. Strapp

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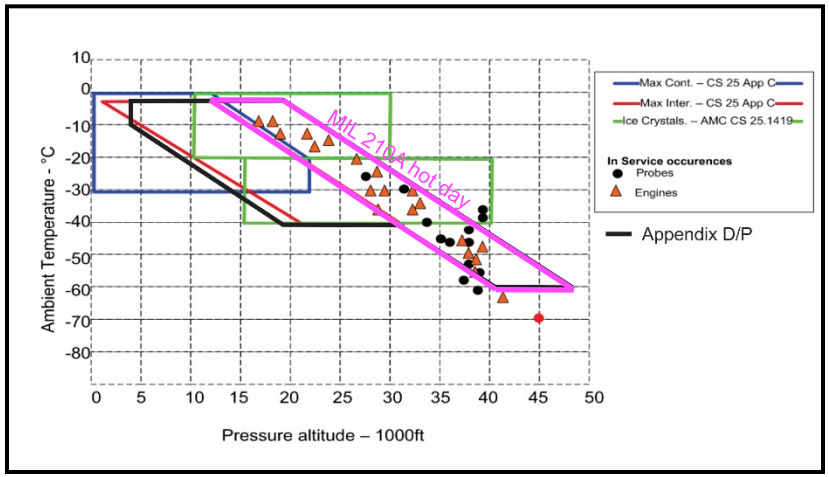
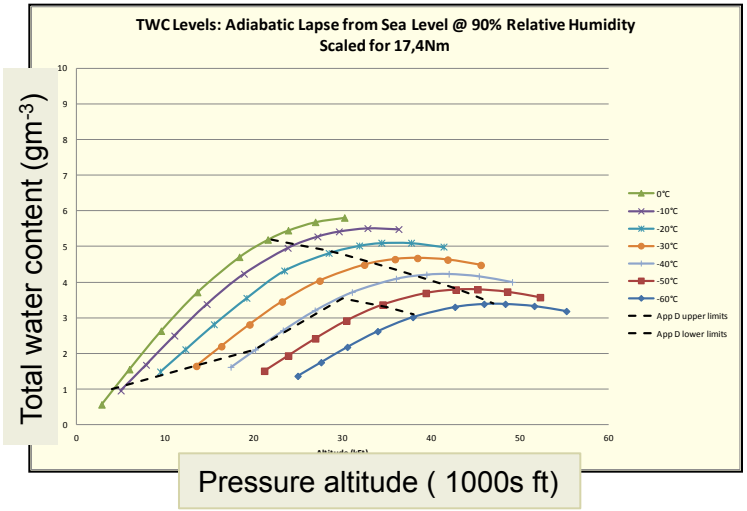
December 5th-8th, 2016, CIRA, Capua, Italy

New ice crystal envelope for aircraft certification

- FAA Appendix D [1] and EASA Appendix P (the same)
- resulted from discussions within the Engine Harmonization Working Group (EHWG) 2004-2006



APPENDIX D Temperature Envelope [1,2]



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

[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

Flights for In-Situ Appendix D/P Validation

- EHWG recommended new in-situ flight measurements in deep convective clouds, to assess the new ice crystal TWC envelope

- Target: collect 99th percentile TWC values and distance factor up to at least the 17.4 nm distance scale, in clouds similar to those that caused engine events, and with target TWC accuracy of 20%.
  - EHWG asked for data in four temperature intervals: : -10 C, -30 C, -40 C, and -50 C (each ± 5C); highest priority -50 C, lowest -10 C.
  - at least 100 17.4 nm data points at each level

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

- To obtain adequate reliability and accuracy, a new instrument (IKP) developed to measure TWC at high values and high airspeeds (see photo)

- Why 99th percentiles? Similar logic as Appendix C. Regulatory agencies and industry to determine how to apply 99th percentiles and distance factor to means of compliance

  - Particle size parameters … subject of a separate investigation, first paper of this session

Flight Programs providing data for Appendix D TWC assessment (IKP2)

- Darwin-2014 **HAIC-HIWC**[1,2] flight campaign (Australia)
  - SAFIRE Falcon-20 research aircraft
- Cayenne-2015 **HAIC-HIWC** flight campaign (French Guiana)
  - SAFIRE Falcon-20 research aircraft
  - NRC Canada Convair-580 aircraft
- Florida-2015 **HIWC-RADAR** flight campaign (USA and Caribbean)
  - NASA DC-8

French SAFIRE Falcon-20 aircraft

NASA DC-8 aircraft

[1] High Altitude Ice Crystals (HAIC) project (Europe)
[2] High Ice Water Content (HIWC) project (North America)

Canadian NRC Convair-580 aircraft

General information on data sets

	Darwin-14 Falcon-20	Cayenne-15 Falcon-20	Cayenne-15 CV580	Florida-15 NASA DC-8
Number of Flights:	23	18	12	10
Number of flights with IKP Appendix D/P cloud measurements:	16	17	10	10
Number of Flight Segments:	157	218	76	119
Total Distance in Segments (nm):	7648	8735	3469	10695
Avg. length of Segment (nm):	36.5	33.5	45.6	90
Avg. segment TWC (gm^{-3})	0.69	0.60	TBD	TBD

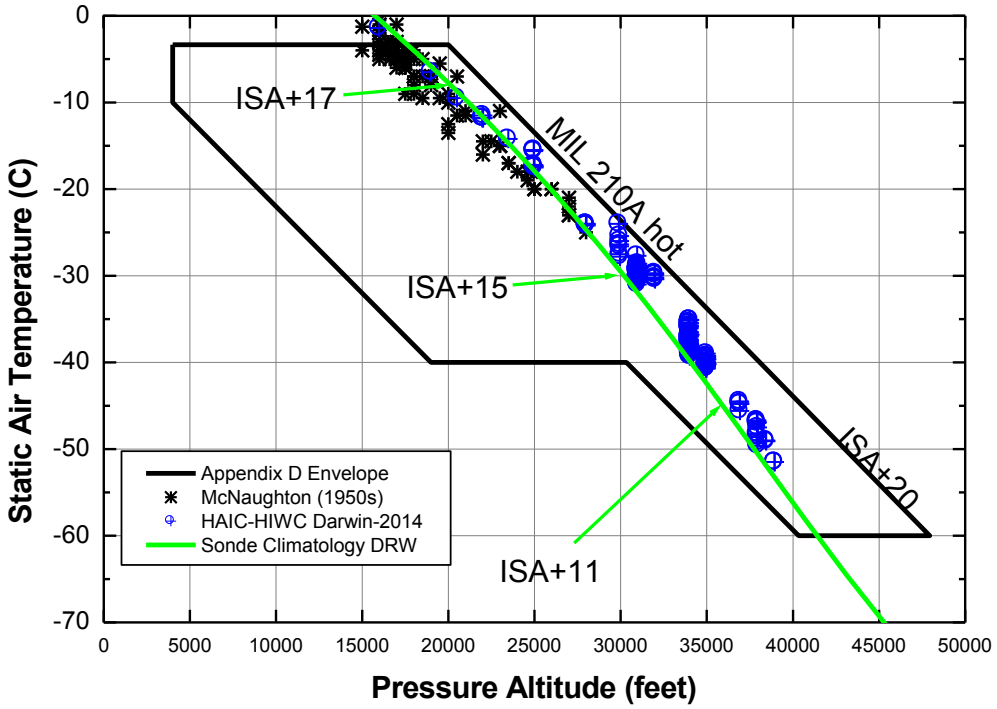
Will use only these three data sets in following comparisons to App. D/P

17.4 nm data points versus temperature

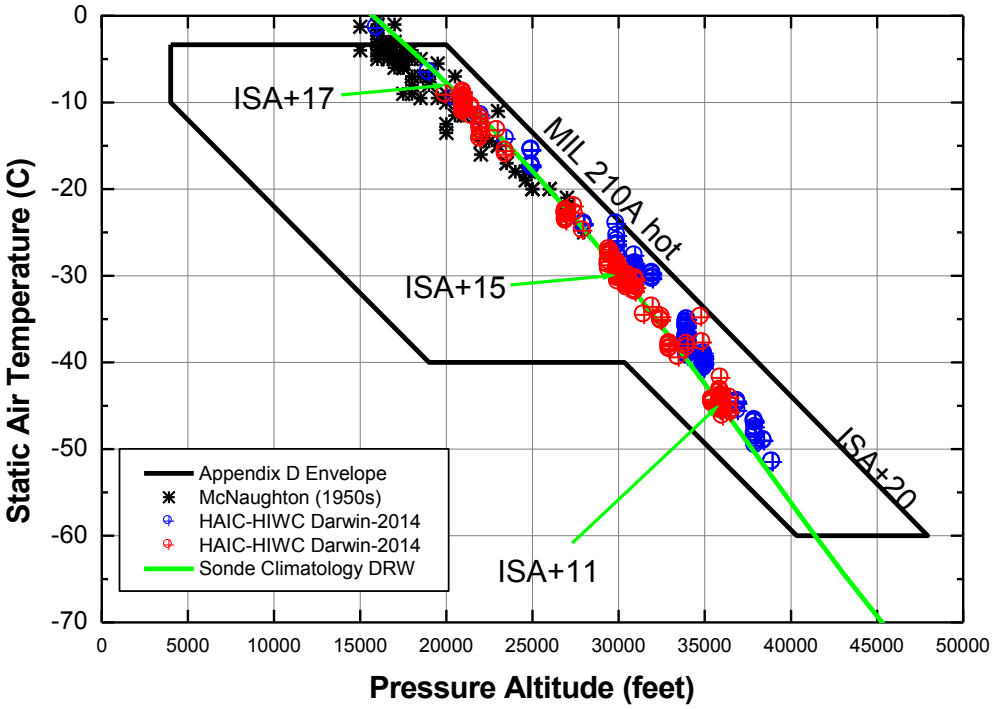
- Targeting a total of 100 or greater 17.4 nm data points at each temperature level

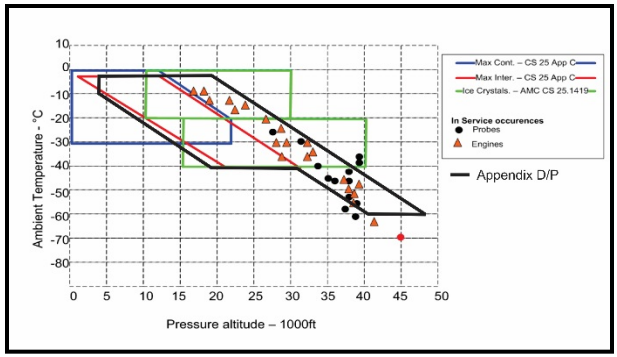
Number of 17.4 nm data points	Darwin-14 Falcon-20	Cayenne-15 Falcon-20	Cayenne-15 CV580	Florida-15 NASA DC-8	Grand Total
Total	381	395	158	554	1488
-50 C (-54.9<T<-45)	29	58	0	194	281
-40 C (-44.9<T<-35)	175	108	0	138	421
-30 C (-34.9<T<-25)	142	93	0	215	450
-10 C (-14.9<T<-5)	12	93	153	7	365
-20 C (-24.9<T<-15)	24	27	1	0	52

Appendix D Altitude-Temperature Envelope –DRW-14



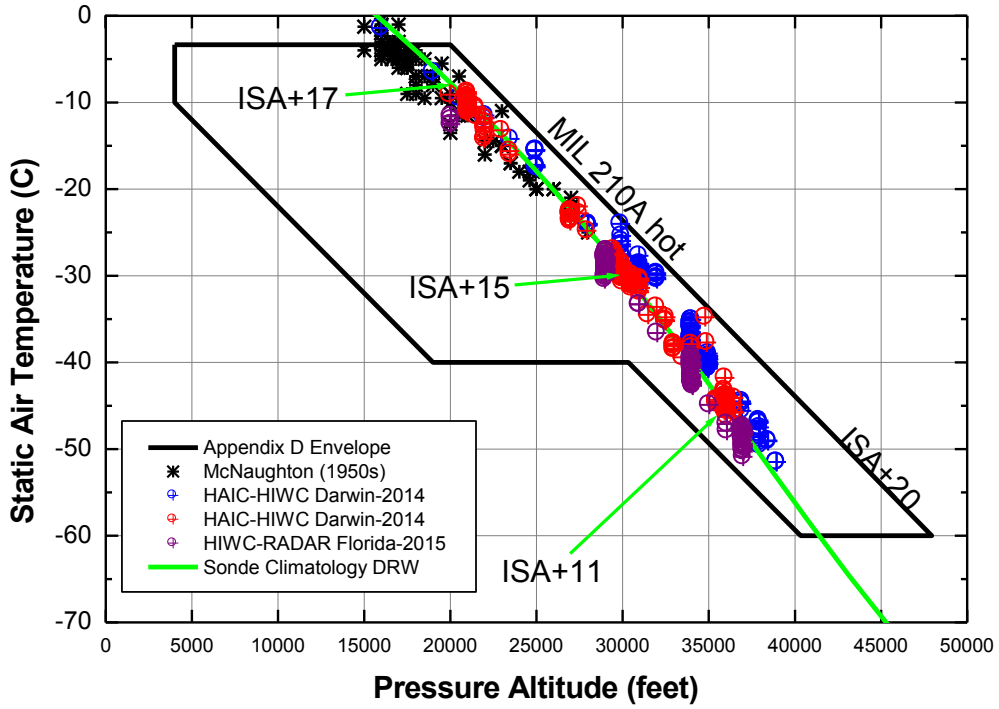
Appendix D Altitude-Temperature Envelope –DRW-14+CAY-15

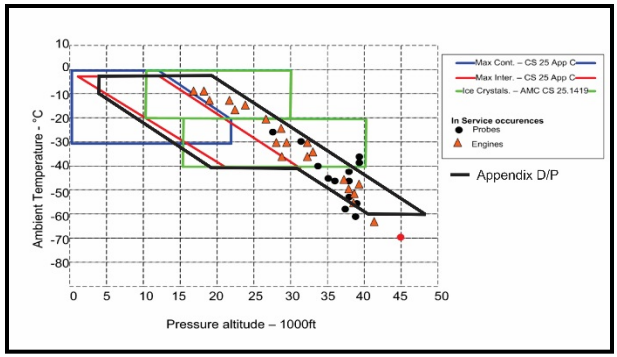




Engine event points and air data probe event points from Duvivier (2010)

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





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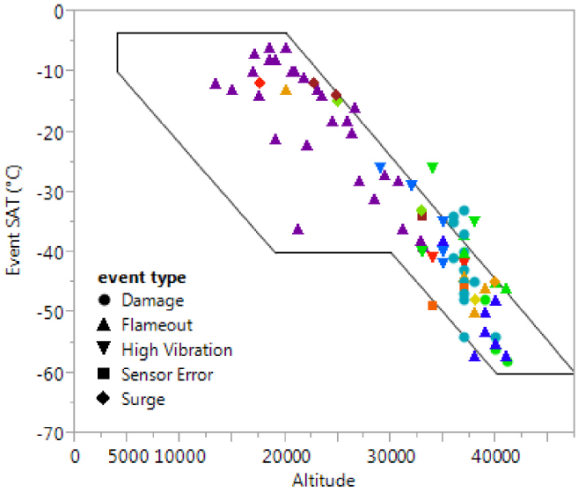
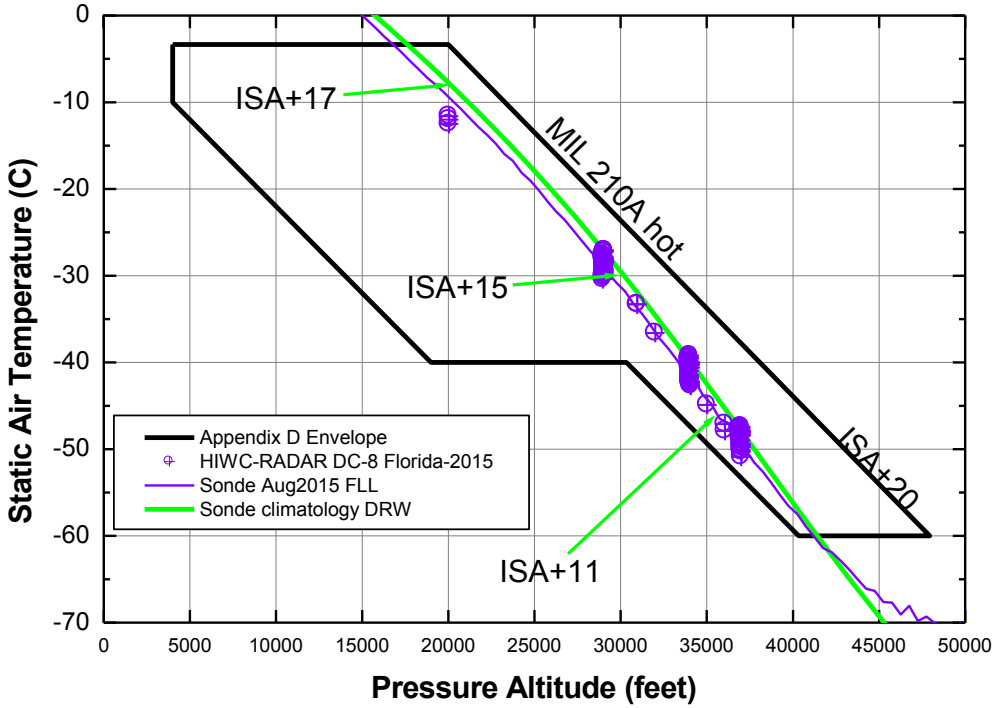
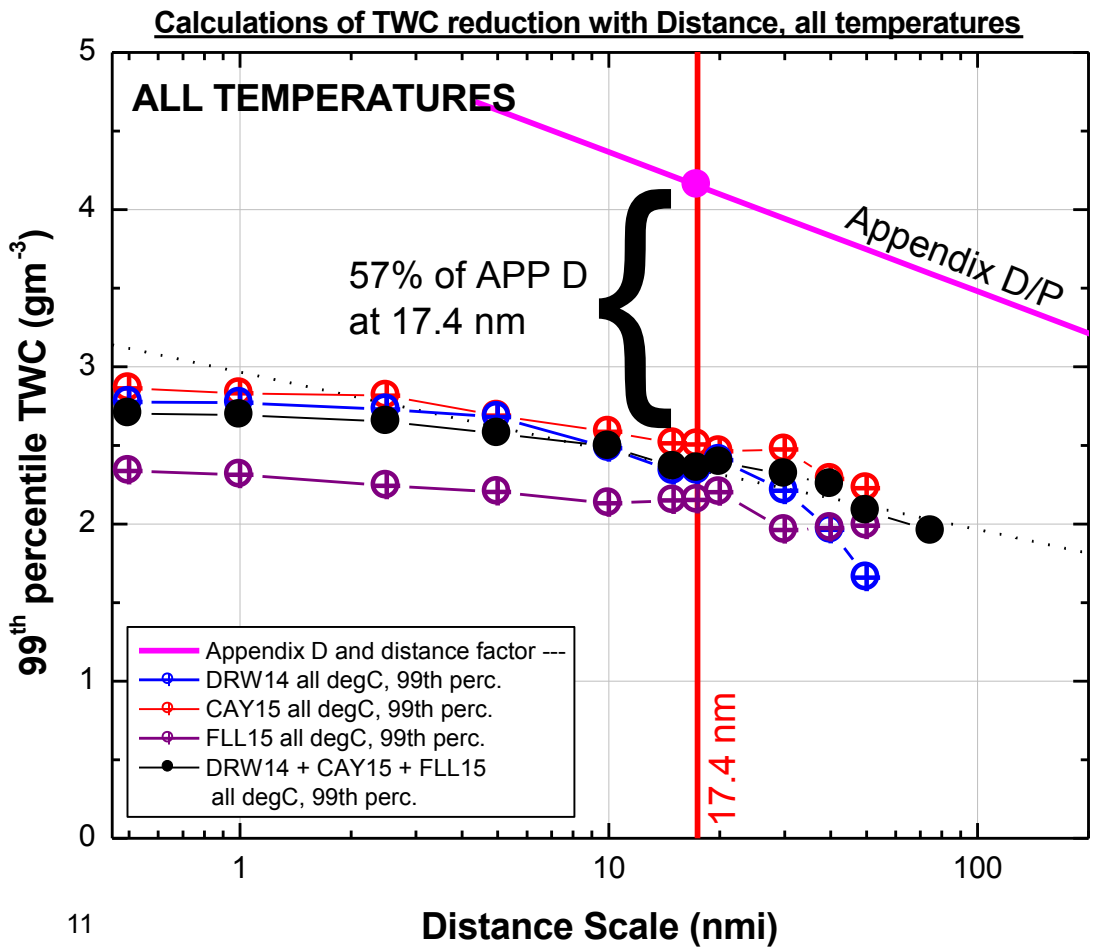


Most recent summary of Boeing engine event points from Grzych et al. (2015)

Appendix D Altitude-Temperature Envelope –FLL-15 and average sonde

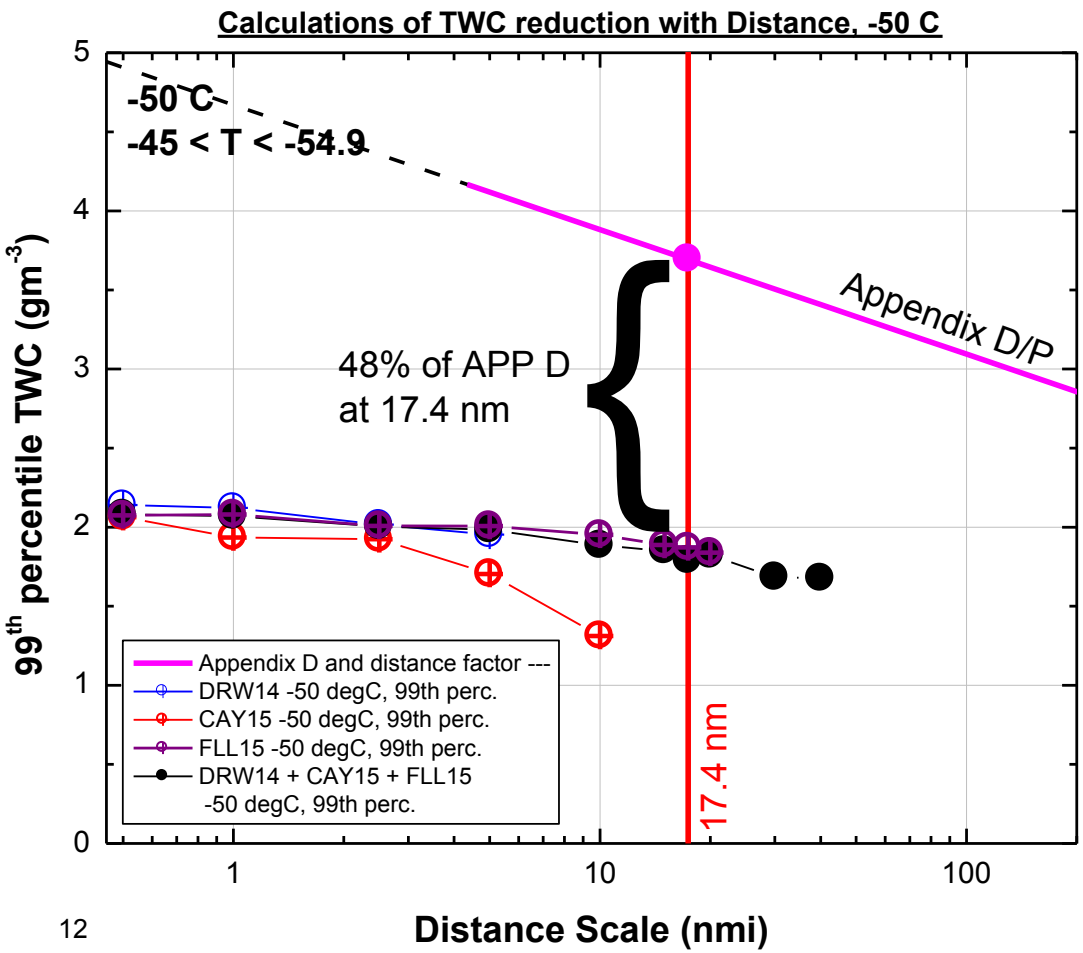


Appendix D/P 99th percentile TWC vs Distance Scale: DRW-14 + CAY-15 +FLL-15, All Temperatures

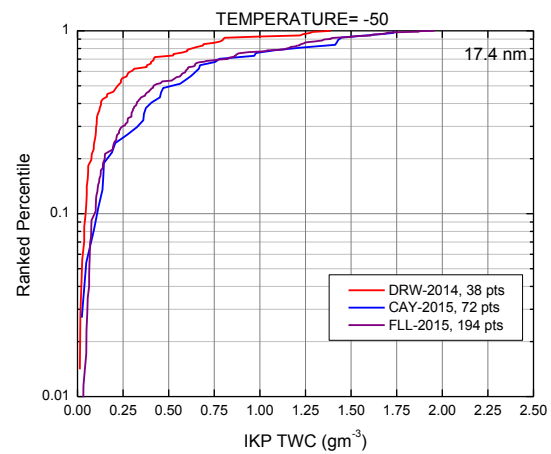


- Remarkably similar for DRW & CAY, two distant locations
- FLL-15 lower, especially at shorter distance scales
- Second project did not change the combined results very much

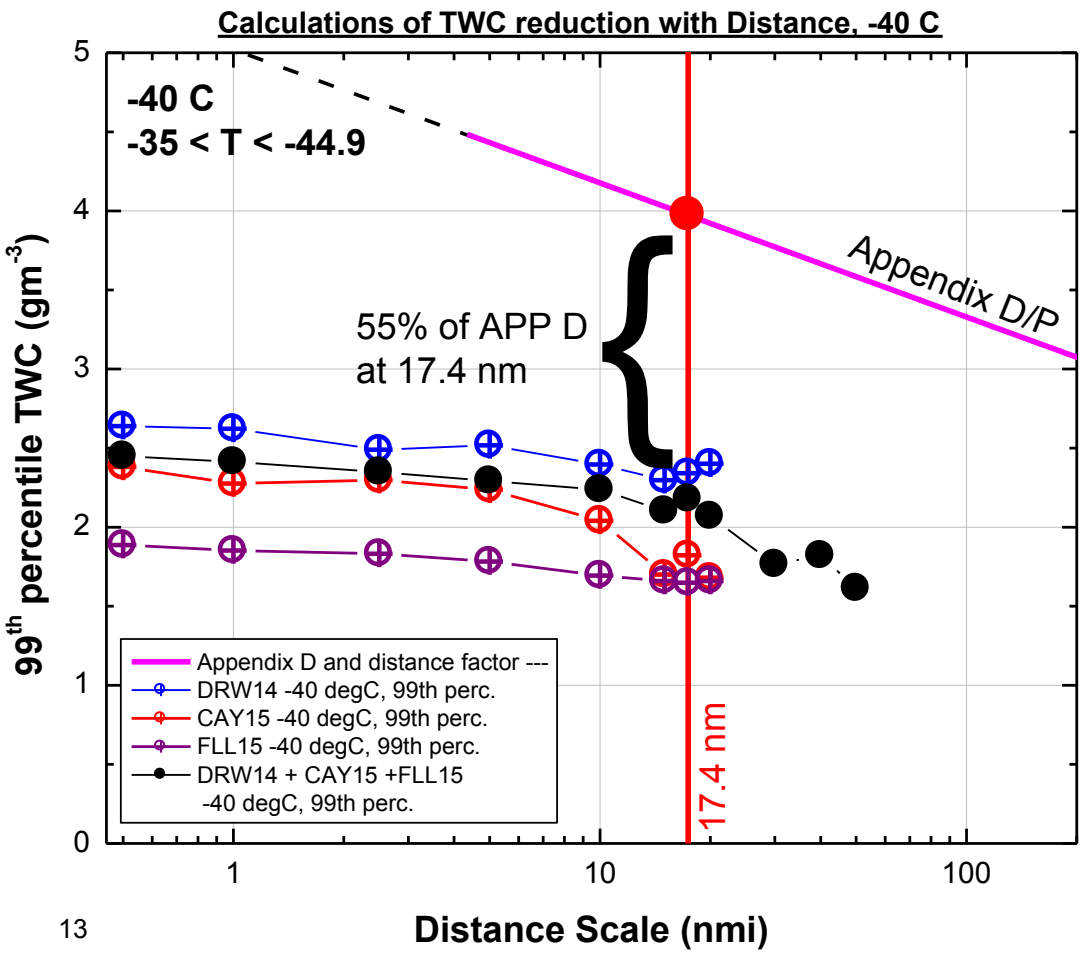
Appendix D/P 99th percentile TWC vs Distance Scale: DRW-14 + CAY-15 +FLL-15, T=-50 C



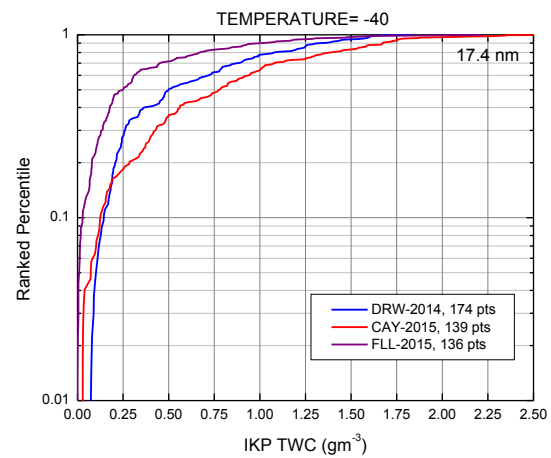
At 17.4 nm dist. scale	DRW-14	CAY-15	FLL-15
# points	38	72	194
Med. TWC (g/m^3)	0.52	0.25	0.42



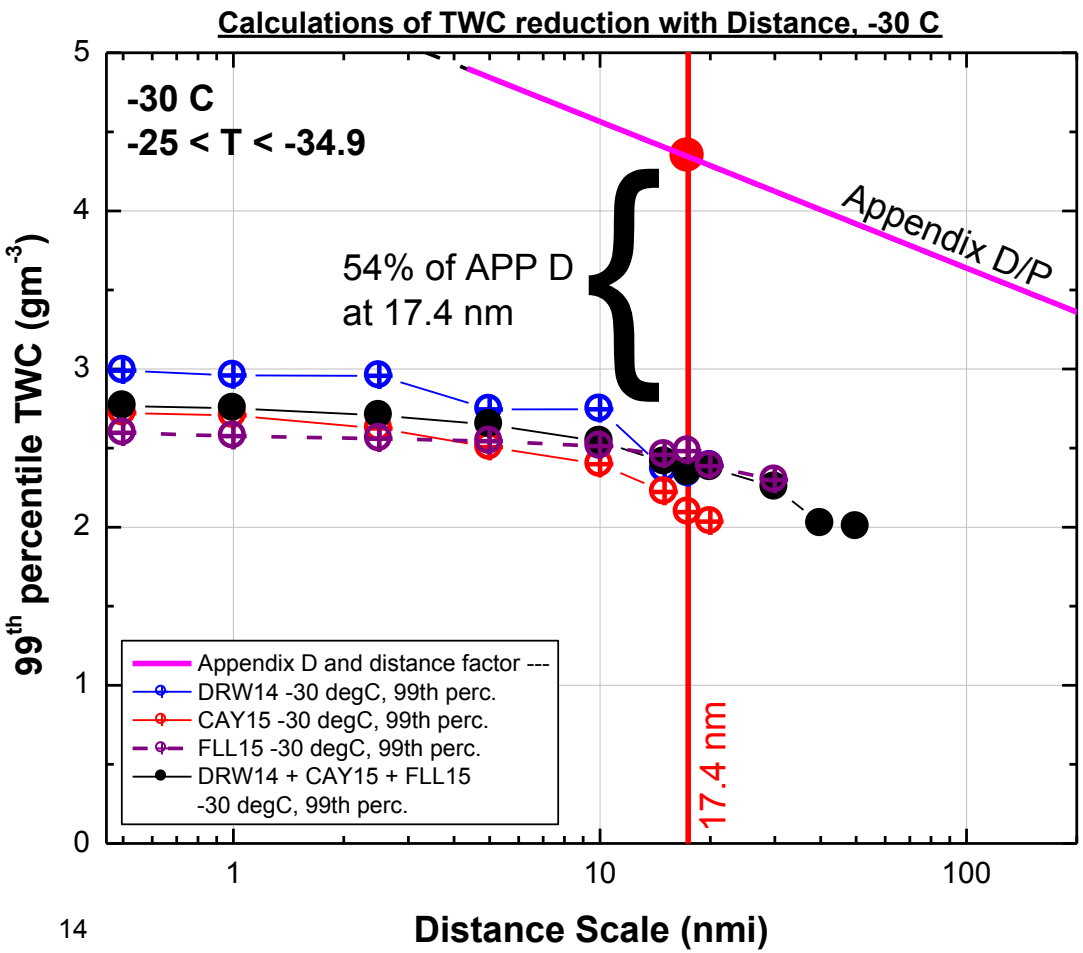
Appendix D TWC vs Distance Scale – DRW-14 + CAY-15, T=-40 C



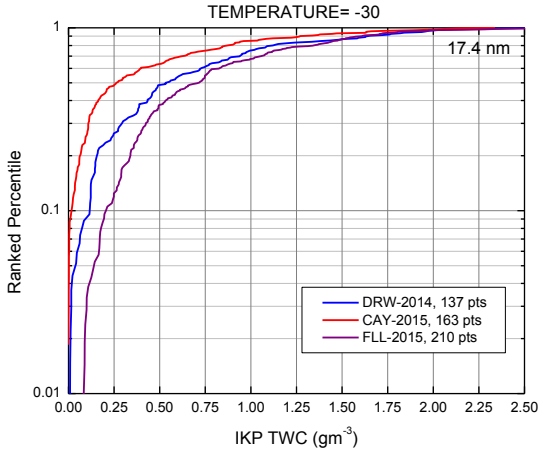
At 17.4 nm dist. scale	DRW-14	CAY-15	FLL-15
# points	174	139	136
Med. TWC (g/m^3)	0.78	0.25	0.50



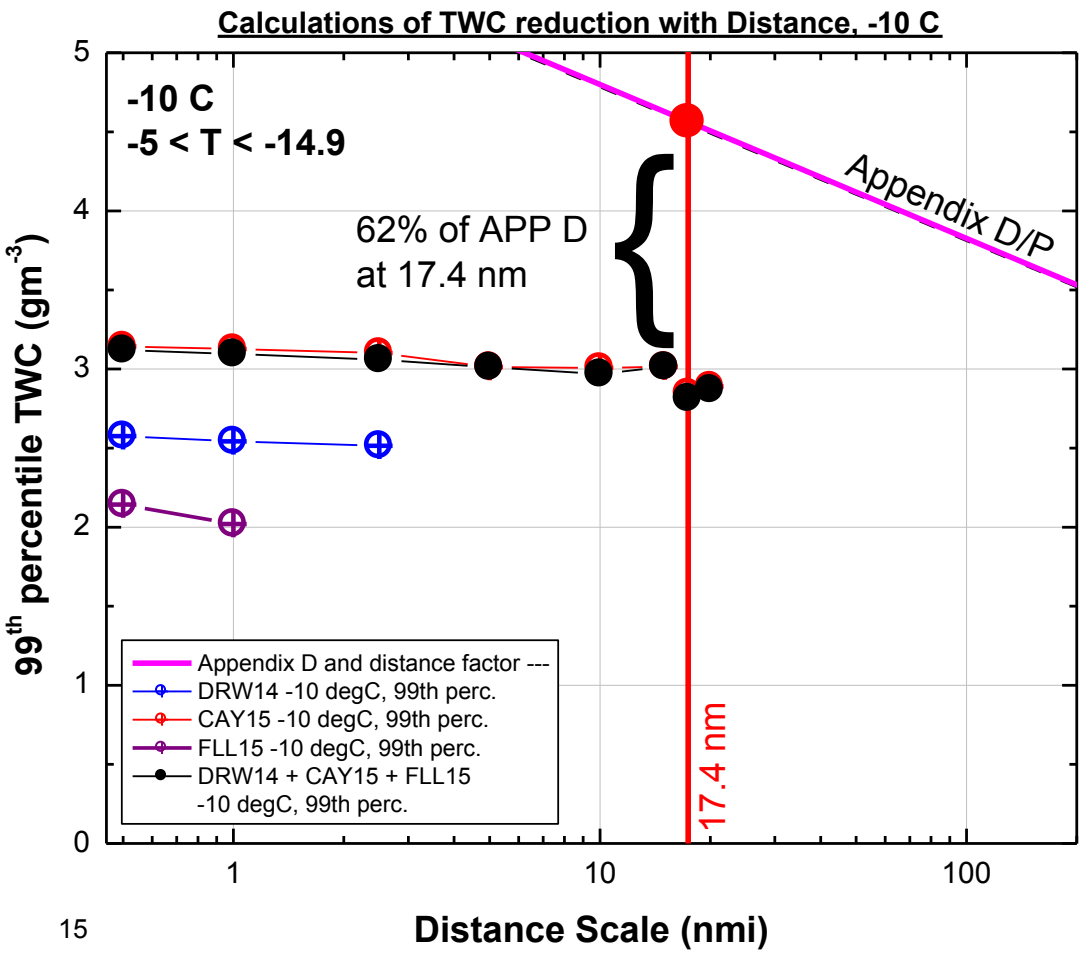
Appendix D TWC vs Distance Scale – DRW-14 + CAY-15, T=-30 C



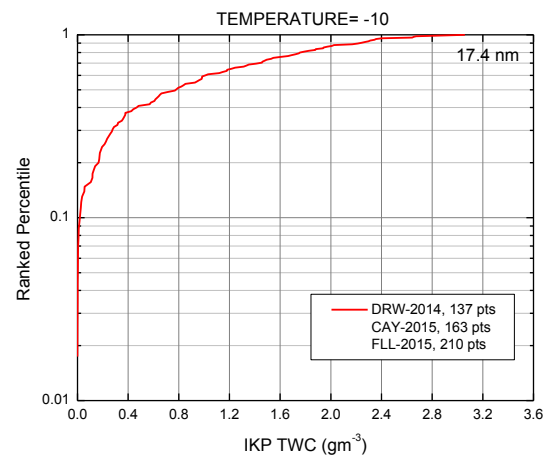
At 17.4 nm dist. scale	DRW-14	CAY-15	FLL-15
# points	137	163	210
avg. TWC (g/m^3)	0.53	0.26	0.71



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



At 17.4 nm dist. scale	DRW-14	CAY-15	FLL-15
# points	12	116	4
avg. TWC (g/m^3)	0.99	0.78	0.98



Sounding parameters, and cloud top

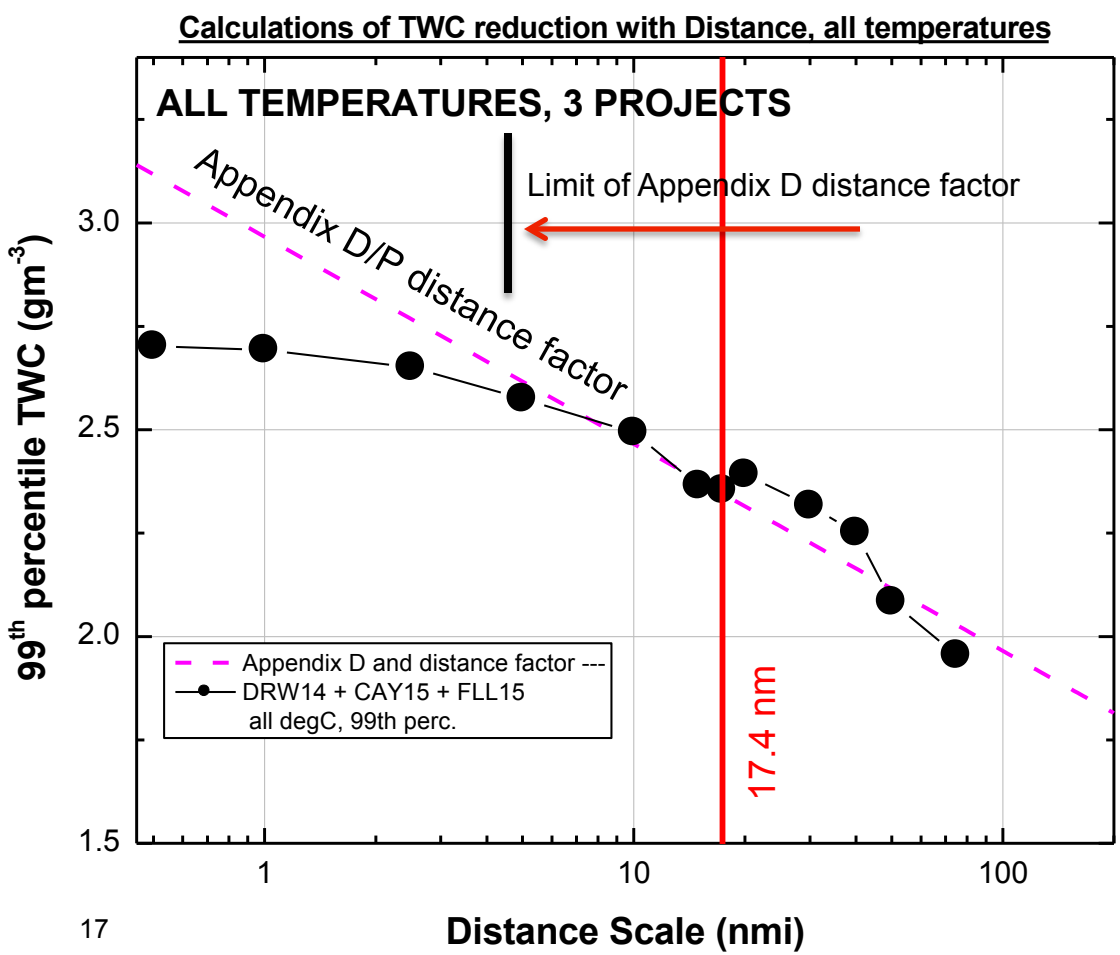
For days with flights :	DRW14 Falcon-20	CAY15 Falcon-20
Precipitable Water (median, mm)	64.6	62.3
Cold Point Tropopause (median, C)	-84	-82
Est. Equilibrium temperature (median, C)	-69	-65
IR temperature along flight track (avg. of track minima, C) – i.e. min. cloud top T	-84	-68

very similar

quite different

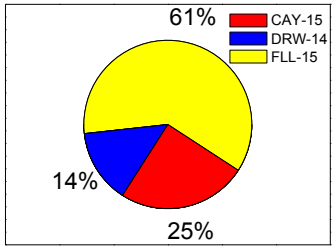
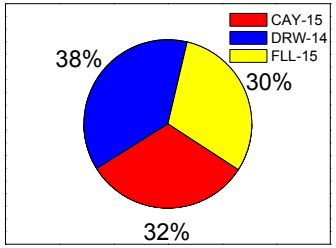
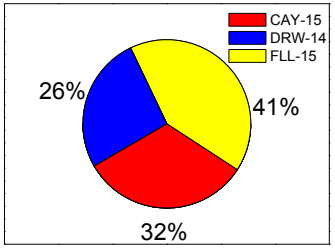
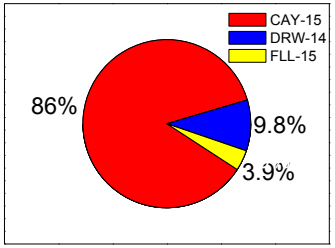
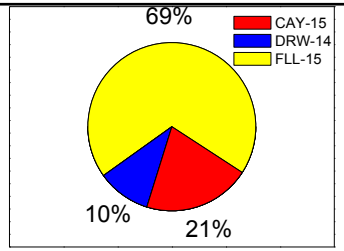
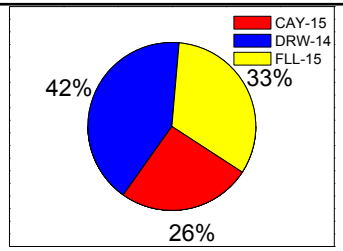
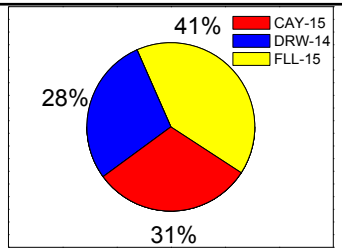
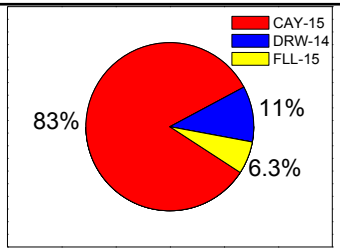
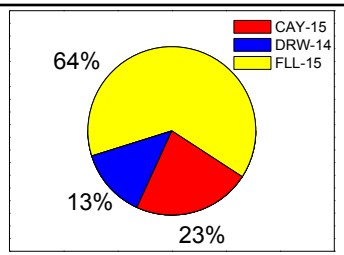
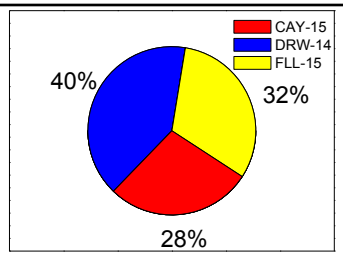
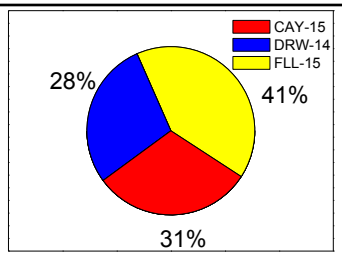
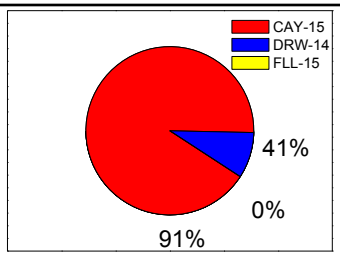
- Darwin and Cayenne atmospheric parameters are quite similar
- Largest difference is height of cloud tops; Darwin minimum temperatures 16 C colder than Cayenne
- May be a factor in lower Cayenne IWCs at -50 C…… too close to cloud top?

Appendix D Distance Factor



- Distance factor is multiplying factor wrt Appendix D TWC @ 17.4 nm f=a-b*log10(D)
- Dotted line uses same distance factor, but applies to measured 99th percentile (compare this to black line and pts)
- Distance factor not bad for d > 2 nm, overestimates < 2nm

Effect of adding FLL-2015, numbers of pts.

	-50 C (-55<T<-44.9)	-40 C (-45<T<-44.9	-30 C (-35<T<-24.9)	-10 C (-15<T<-4.9)
5.0 nm				
17.4 nm				
50 nm				

Effect of adding FLL-2015, 99th percentile TWC

	5 nm		17.4 nm		50 nm	
	DRW-14 + CAY-15	**DRW-14 + CAY-15 + FLL-15**	**DRW-14 + CAY-15**	**DRW-14 + CAY-15 + FLL-15**	**DRW-14 + Cay-15**	**DRW-14 + CAY-15 + FLL-15**
Total						
-50 C (-54.9<T<-45)	1.87 (421)	1.98 (1007 pts)	1.72 (110)	1.79 (285 pts)	1.24 (27)	1.54 (75 pts)
-40 C (-44.9<T<-35)	2.39 (1200)	2.29 (1726 pts)	2.27 (313)	2.18 (449 pts)	1.62 (78)	1.61 (114 pts)
-30 C (-34.9<T<-25)	2.68 (1158)	2.65 (1972 pts)	2.24 (300)	2.35 (510 pts)	1.71 (77)	2.00 (130 pts)
-10 C (-14.9<T<-5)	3.01 (490)	3.01 (510 pts)	2.82 (128)	2.81 (132 pts)	2.31 (34)	2.31 (35 pts)

Effect of adding FLL-2015, % of Appendix D/P TWC

	17.4 nm	
	DRW-14 + CAY-15	**DRW-14 + CAY-15 + FLL-15**
All temperatures listed below	56%	57%
-50 C (-55<T<-44.9)	46%	48%
-40 C (-45<T<-44.9)	54%	55%
-30 C (-35<T<-24.9)	50%	54%
-10 C (-15<T<-4.9)	62%	62%

Conclusions

- Collectively (all Ts), the 99th percentile TWCs remarkably similar between the 3 locations (2.3 ± 8% for 17.4 nm distance scale)

- Florida data set adds about 60% more data over DRW+CAY (F20+CV580)
  - Florida now dominates -50 C
  - Cayenne dominates -10 C
  - Fairly even mixture at -30 and -40 C

- Combined Darwin+Cayenne+Florida continues to show a steadily increasing 99th TWC with increasing temperature – trends similar to Appendix D changes with temperature

- Combined Darwin+Cayenne+Florida data set shows 99th percentile TWC is 48-62% of Appendix D (17.4 nm), depending on temperature; collectively 57%
  - Almost unchanged from Darwin + Cayenne only

- Distance factor from combined Darwin+Cayenne data set similar to Appendix D. But overestimates < 5 nm

Future work

- Incorporate final IKP TWC data sets:
  - NRC Convair 580 Cayenne data, rich at -10 C
- Target completion of IKP Appendix D analysis: end of December 2016
- Work with Protat and Delanoe to add remote W-band IWCs (e.g. -50 C while flying at -30 C, etc) as a secondary data set, and assess results

Thank you

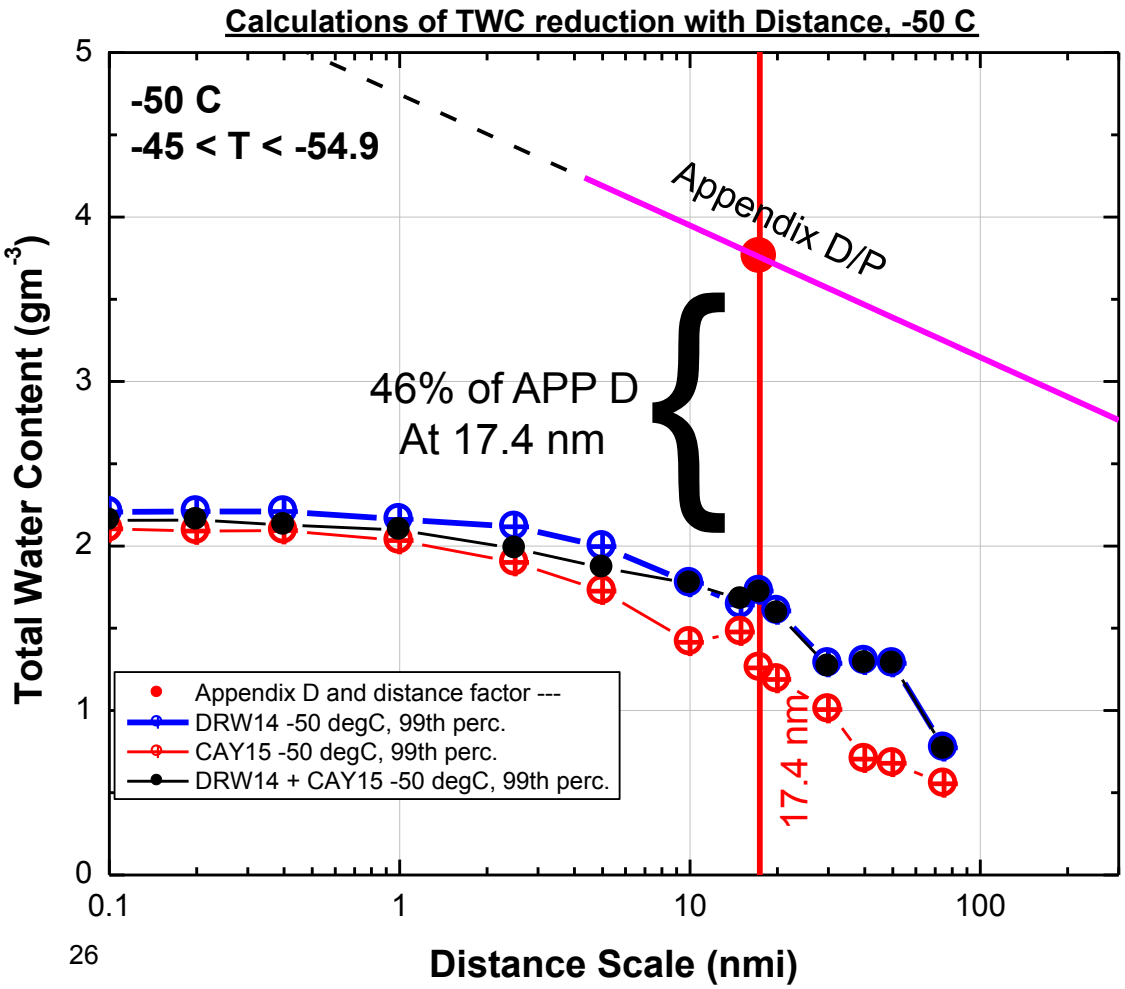
walter.strapp@gmail.com

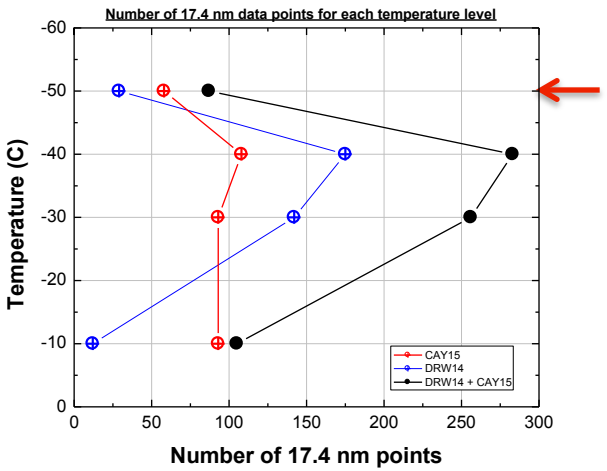
Backup Slides

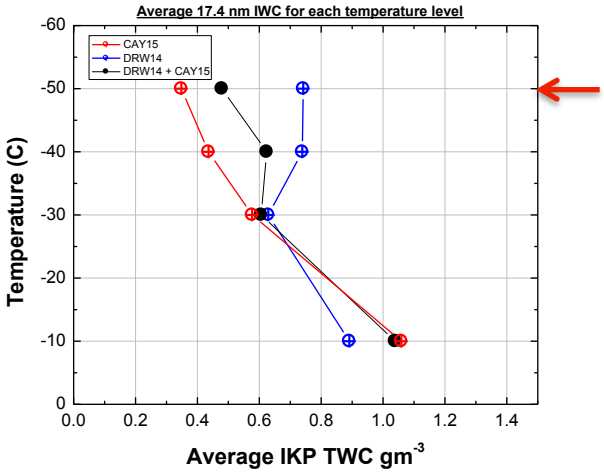
Review of last update (June 2015)

- Data presented for Darwin-2014 only
- 99th percentile TWC at 17.4 nm, combining all temperatures, about 50% of Appendix D (to be shown again this presentation)
- Data lacking at -50 C and -10 C
  - Focus for Cayenne-2015 project
- Properties of Darwin-2014 clouds very similar to those of Japan/ Southeast Asia engine events, as described by Bravin et al. (2015)

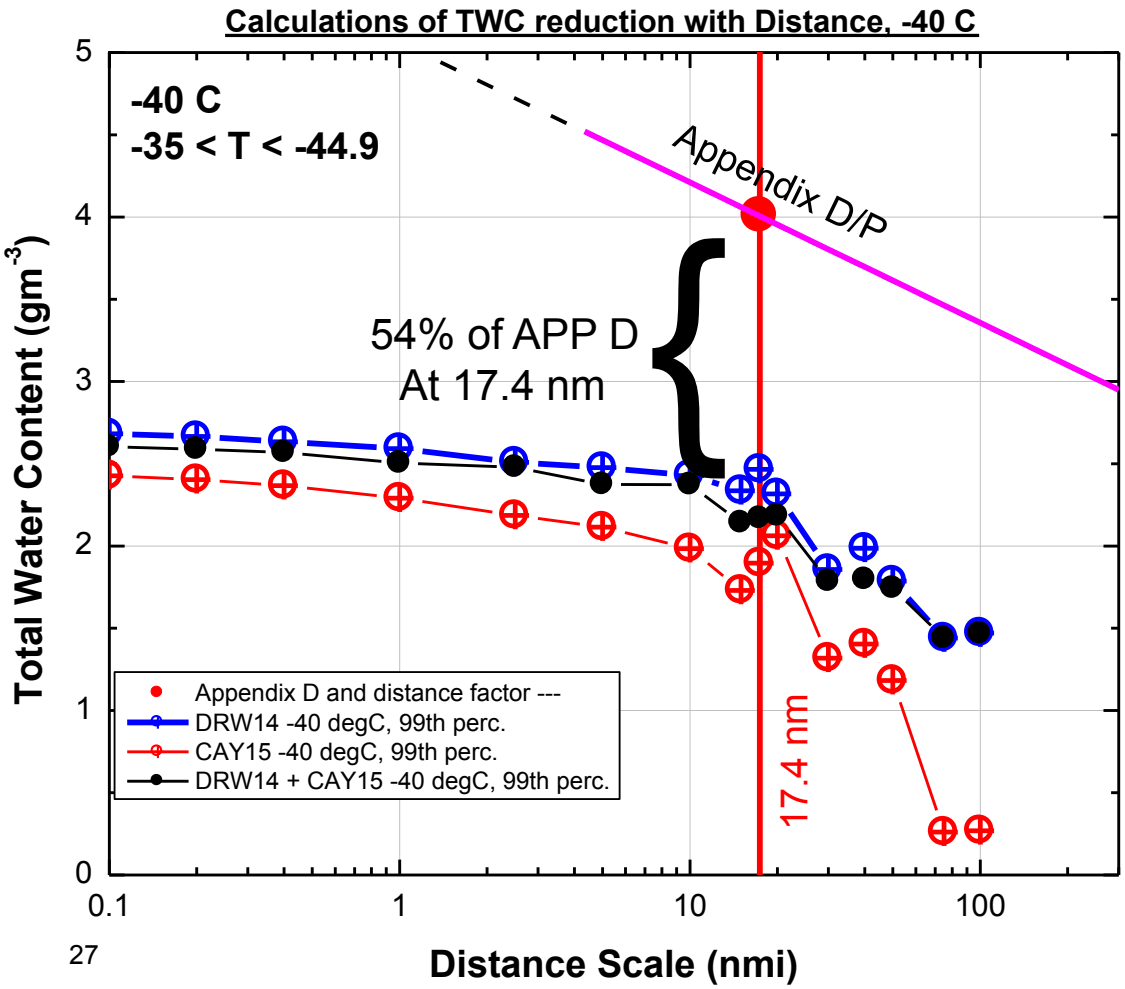
Appendix D TWC vs Distance Scale – DRW-14 + CAY-15, T=-50 C

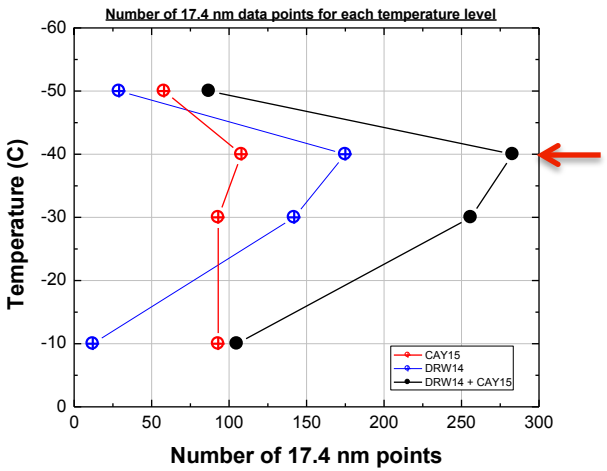


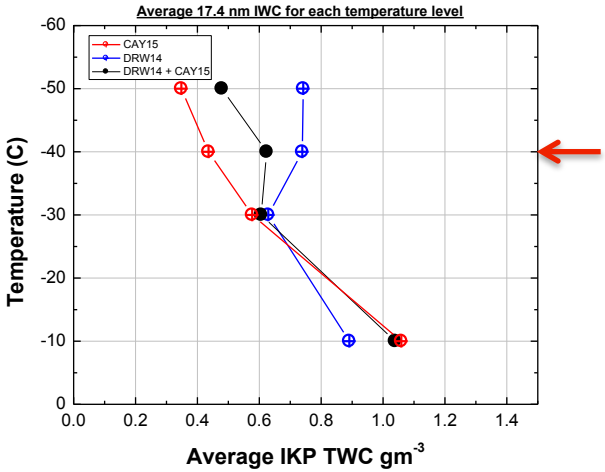




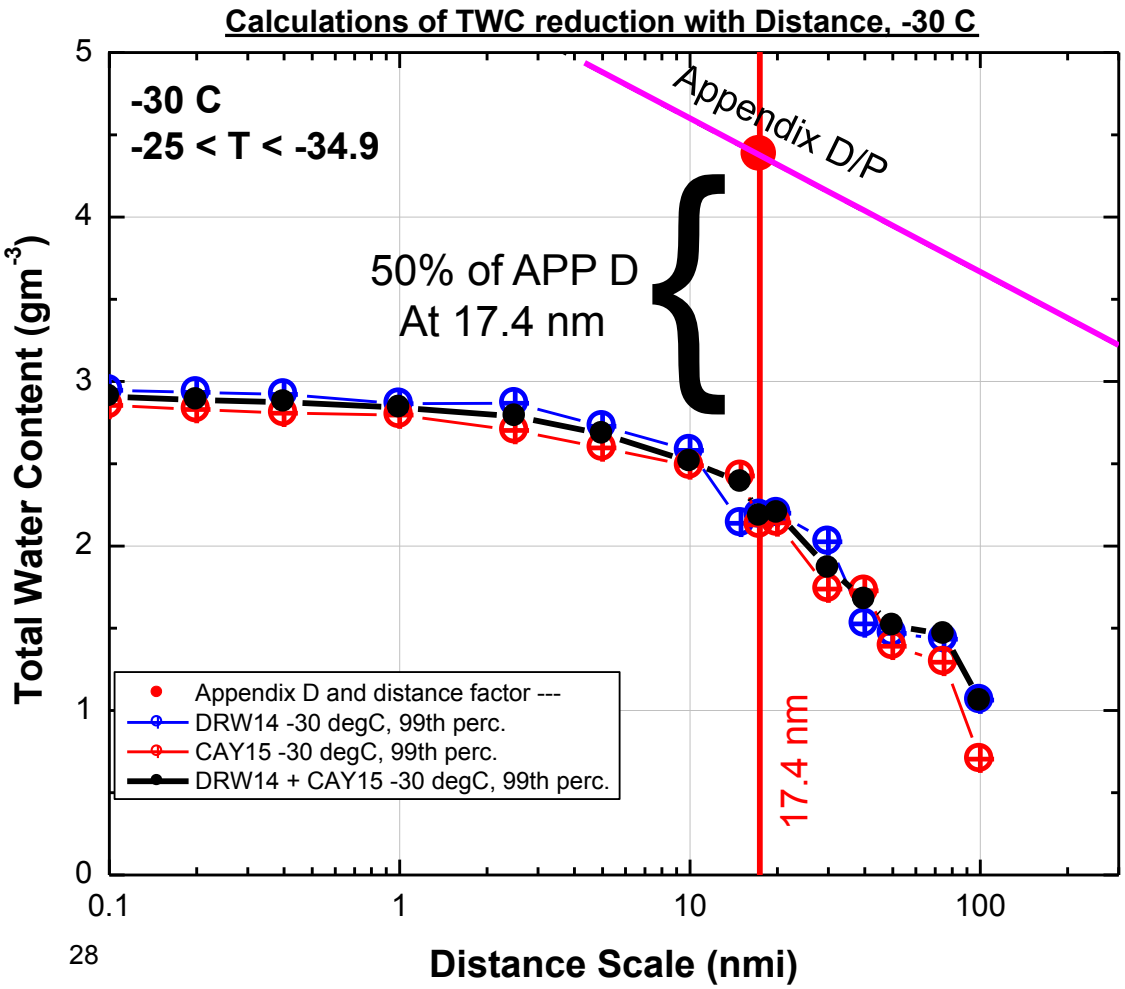
Appendix D TWC vs Distance Scale – DRW-14 + CAY-15, T=-40 C

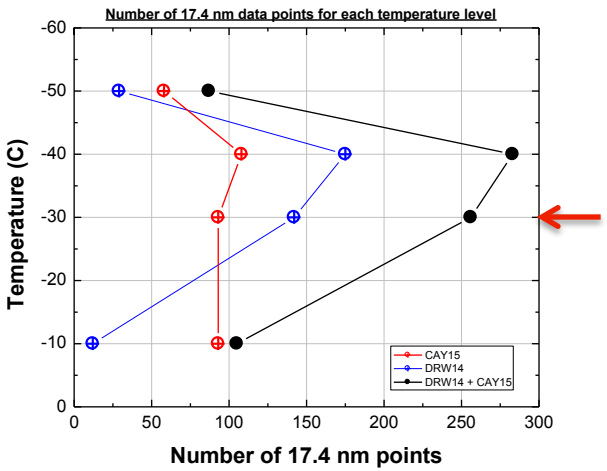


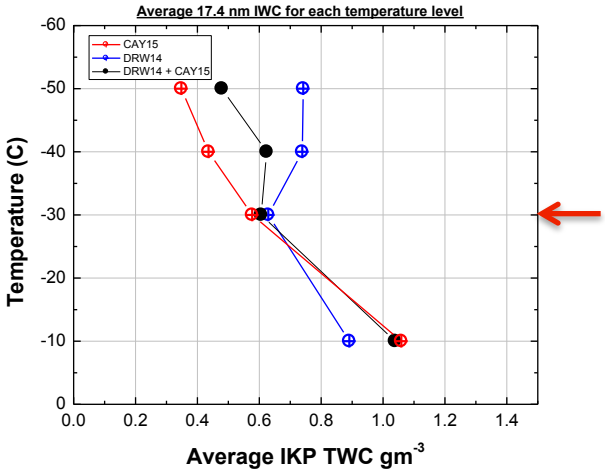




Appendix D TWC vs Distance Scale – DRW-14 + CAY-15, T=-30 C







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