Description of the Data Collected, the Visualization Tools Utilized, and the Statistical Properties of the Radar Reflectivities Observed by the X-band, Airborne, Weather Radar during the 2014 HAIC-HIWC Flight Campaign

UPDATED – Oct 2015

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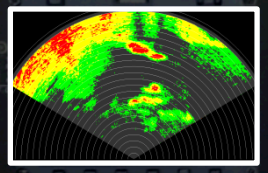

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HAIC-HIWC Science Team Meeting
09-13 November 2015

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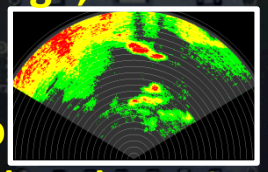
- Many IKP values were updated
  (new version 4 was released updating existing values)
- Additional IKP data was added
  (lengthening some records and added whole days to others)
- Reflectivities did not change; however, reflectivity statistics were recomputed
  UPDATES focus on these  changed statistics and their implications
- New IKP data brought to light operations (data collection) during flight in high reflectivity (RED) conditions (atypical of commercial operations)

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Flight Summary Data Table

(hh:mm)

Red Times indicate Missing data – either a late start or early shutdown

Gray Times indicate Ferry Flight – no data required

YELLOW highlighted times indicate ADDITIONAL data

Flight Number	Date	Radar Data (UTC)		AC State Data (UTC)		IKP (UTC)	
		Start	Stop	Start	Stop	Start	Stop
fs140001	1/16/2014	2:10	5:09	1:22	5:24	1:22	5:11
fs140002	1/16/2014	21:25	0:10	21:03	0:30	21:03	0:24
fs140003	1/17/2014	2:30	4:50	2:07	5:15	1:59	5:10
fs140004	1/18/2014	21:51	0:40	21:18	0:50	21:34	0:46
fs140005	1/21/2014	4:34	5:39	4:12	7:25		
fs140006	1/23/2014	22:09	23:19	19:34	23:25	19:36	23:20
fs140007	1/24/2014	20:08	21:24	19:38	22:40	20:10	22:36
fs140008	1/27/2014	20:43	23:14	20:03	23:16	20:16	23:14
fs140009	1/28/2014	21:08	23:38	20:46	23:49	20:55	23:44
fs140010	1/29/2014	20:06	23:07	19:34	23:22	19:27	23:22
fs140011	1/30/2014	1:13	2:16	0:45	2:26	0:52	2:23
fs140012	2/2/2014	20:35	23:39	19:49	23:50	20:24	23:46
fs140013	2/3/2014	4:05	6:28	2:37	6:36	3:40	6:33
fs140014	2/4/2014	20:34	23:45	19:51	23:56	20:26	23:50
fs140015	2/5/2014	23:27	2:29	22:56	2:35	22:58	2:32
fs140016	2/7/2014	23:23	0:12	19:42	0:20	19:44	0:19
fs140017	2/8/2014			1:36	3:57	1:36	3:53
fs140018	2/8/2014	20:48	23:56	20:16	0:12	20:13	0:03
fs140019	2/9/2014	20:48	0:14	20:11	0:19	20:06	0:16
fs140020	2/10/2014	2:07	3:56	1:33	4:04	1:33	3:59
fs140021	2/17/2014	6:27	8:27	6:07	8:36	5:58	8:33
fs140022	2/17/2014	21:43	0:48	20:56	1:07	20:56	1:05
fs140023	2/18/2014	21:37	0:38	20:51	0:52	20:51	0:47

ANALYSES - CONSTRAINTS & DISCLAIMERS

UPDATED

- A variety of analyses were conducted, both during the flight campaign (support flight ops) and post-flight to assess the radar properties of the HAIC atmospheric condition.
- Specific objectives were
  – use of radar's variable gain
  – use of antenna tilt (look above and below flight level)
  – use/need for geo-referenced radar visualization
  – extraction/categorization of radar reflectivities, and
  – a statistical description of these reflectivities
- Remember only the radar display bus was recorded so our "data" (a color) represents a range of radar reflectivities. In order to account for these multi-valued data and still allow for variable gain compensation (1 dBZ resolution), a single radar measurement results in a "count" in several adjacent reflectivity bins. All statistical results account for this distributed data and results in the "blocky" nature of these distributions.
- These results are not preliminary but the reflectivities that go into our analyses depend upon other instruments (eg, IKP). So changes to IWC values or the addition of data (NEW files) does change what reflectivities are used in these statistical analyses.

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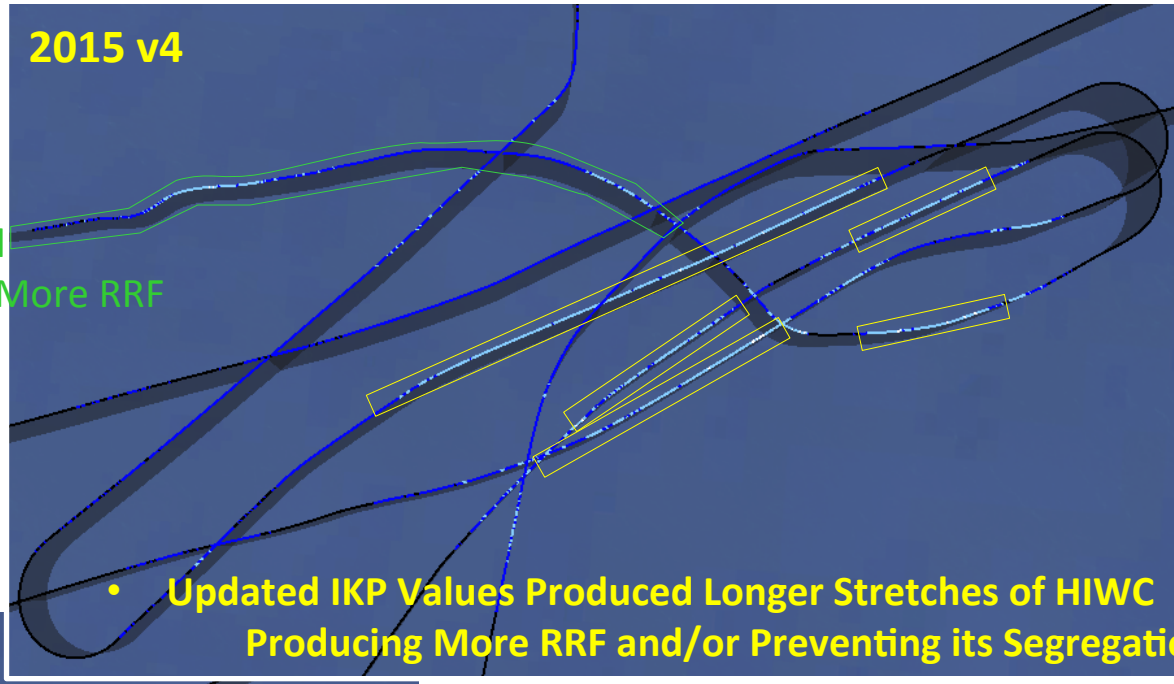
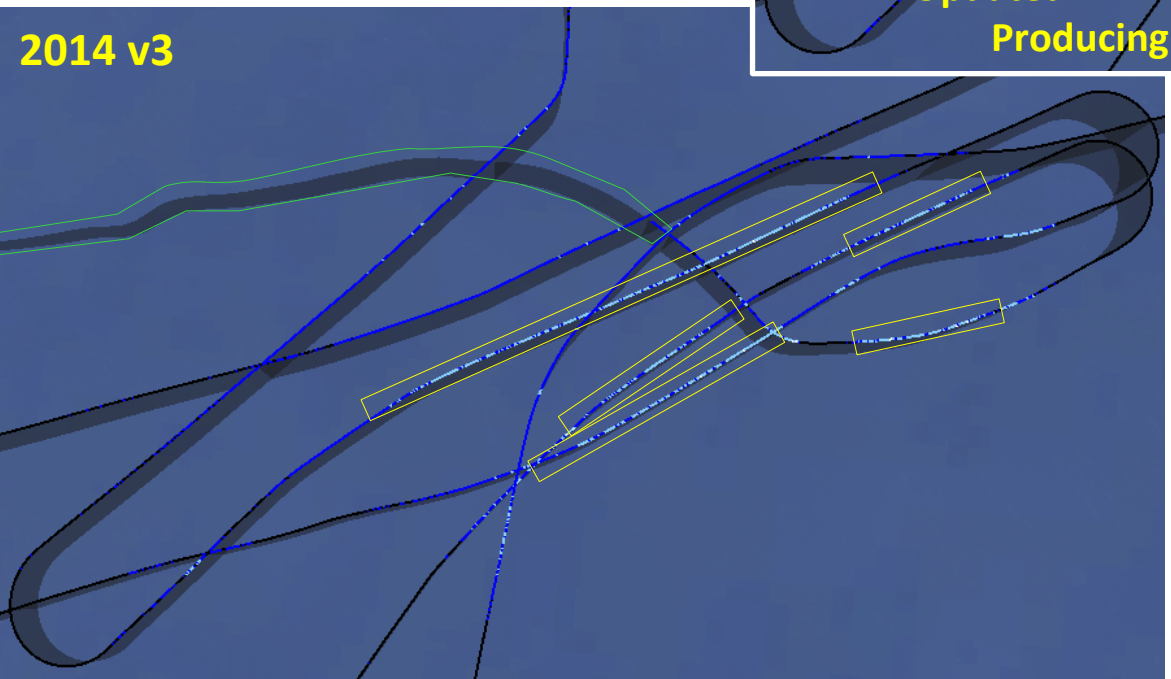
How Does IKP Change the Reflectivity Statistics?

- NEW Data Added to the IKP Record
  Produces more HIWC Regions and More RRF





Flight Duration (s)			
1 ≤ IWC < 2	2 ≤ IWC < 3	3 ≤ IWC	(g m^{-3})
17932	4214	478	v3
19381	4781	523	v4

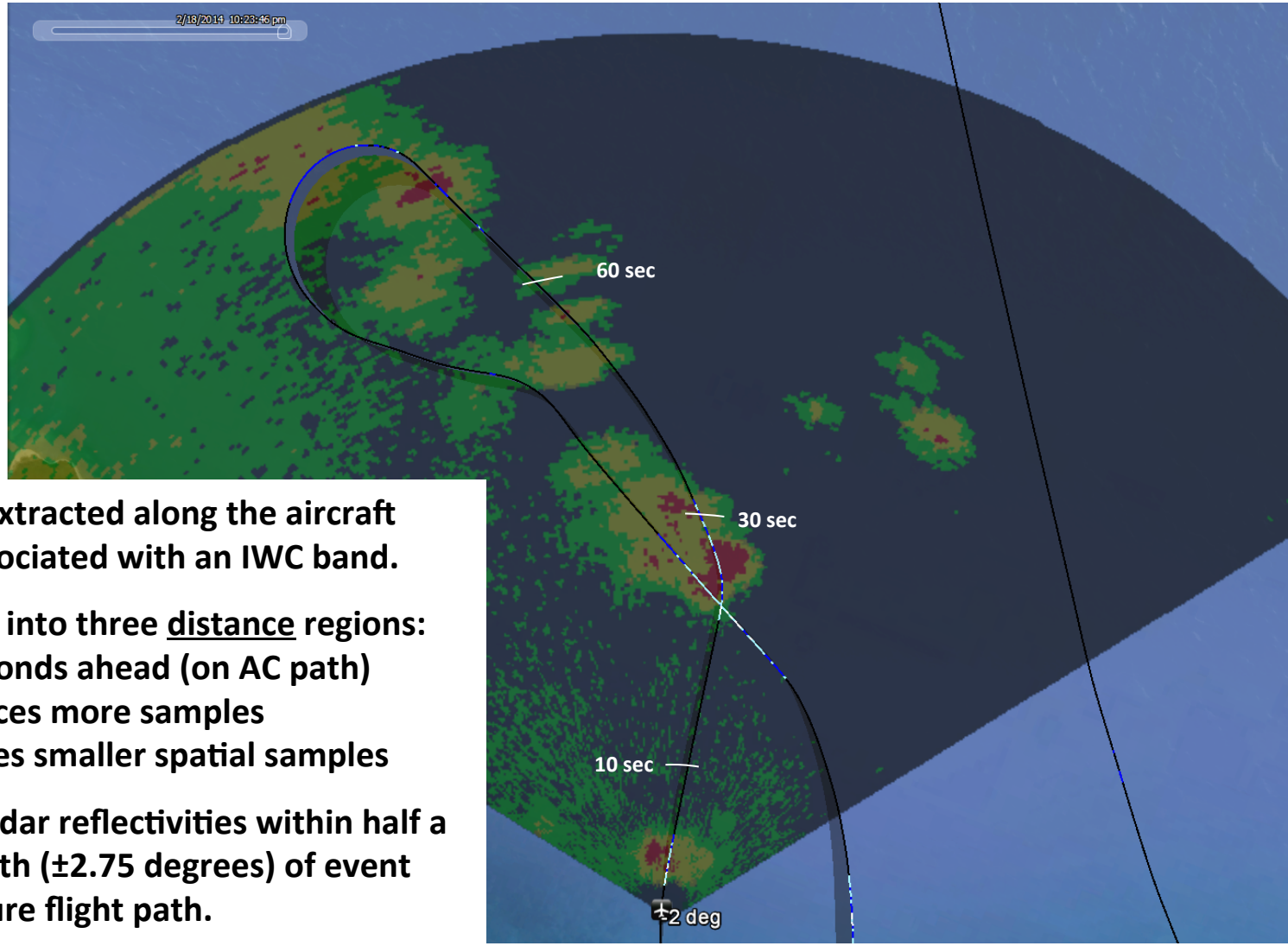
Gathering the Statistics

IKP Data (g/m^3)

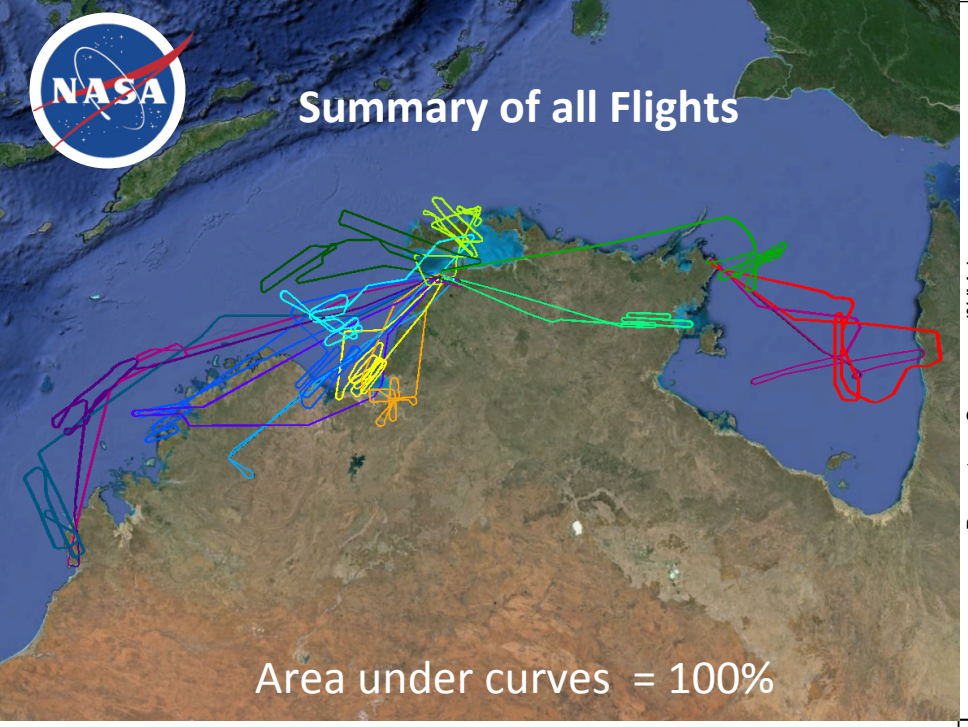
- 3 ≤ IWC
- 2 ≤ IWC < 3
- 1 ≤ IWC < 2
- IWC < 1

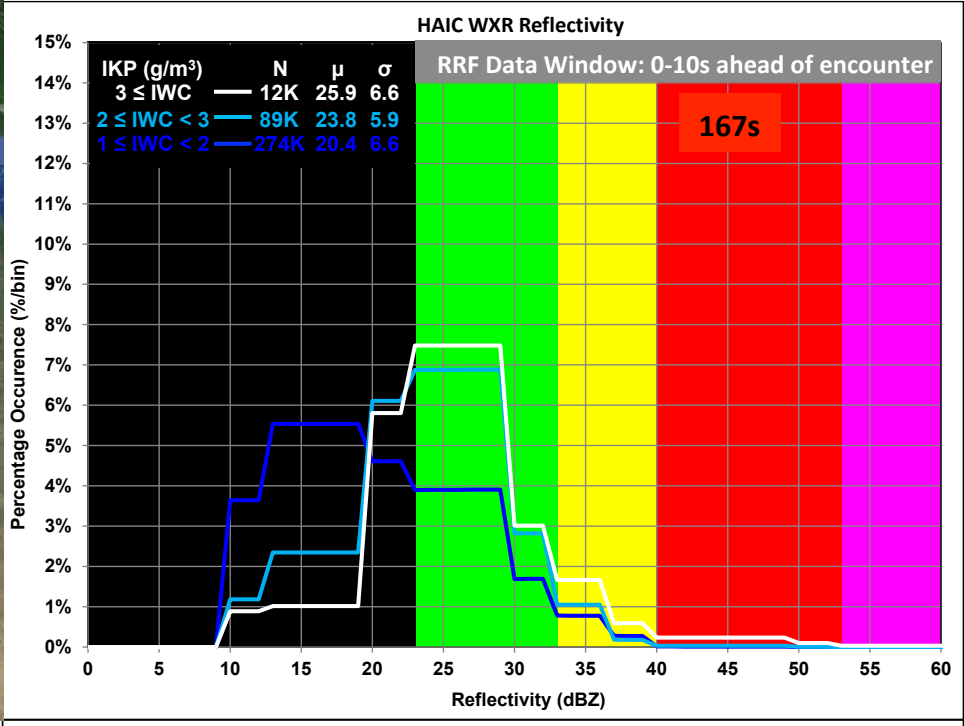
Radar Data

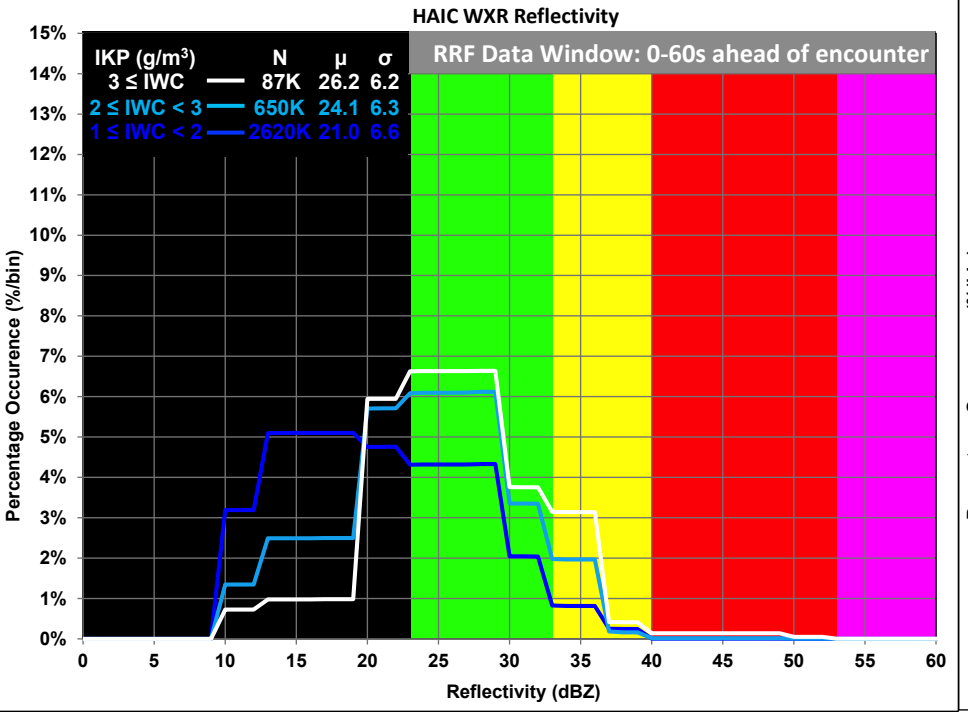
- dBZ < 23
- 23 ≤ dBZ < 33
- 33 ≤ dBZ < 40
- 40 ≤ dBZ

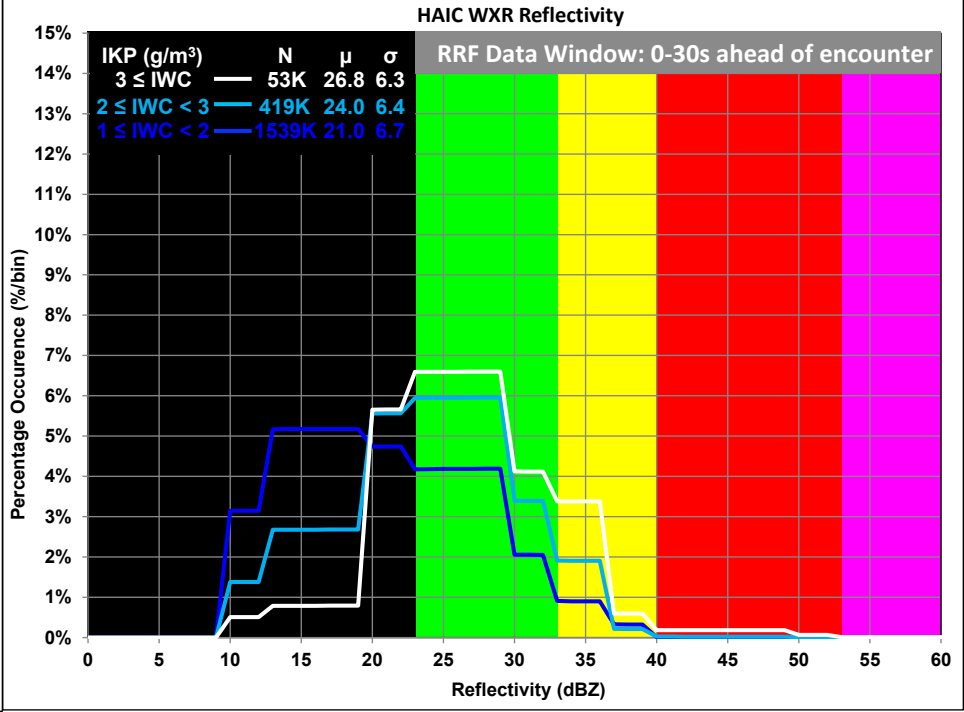


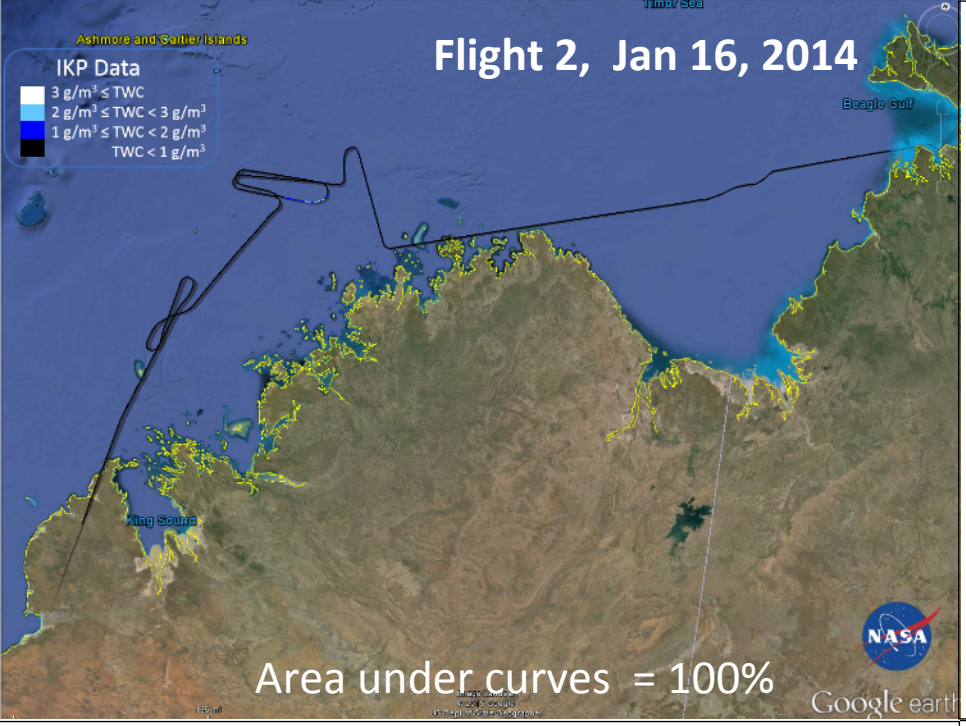
- **Reflectivities are extracted along the aircraft flight path and associated with an IWC band.**
- **Data is segregated into three <u>distance</u> regions: 60, 30, and 10 seconds ahead (on AC path)**
  - **farther: produces more samples**
  - **closer: produces smaller spatial samples**
- **Extract multiple radar reflectivities within half a azimuth beam width (±2.75 degrees) of event position along future flight path.**
- **Altitude of radar bin must be within ±500' of IKP altitude**

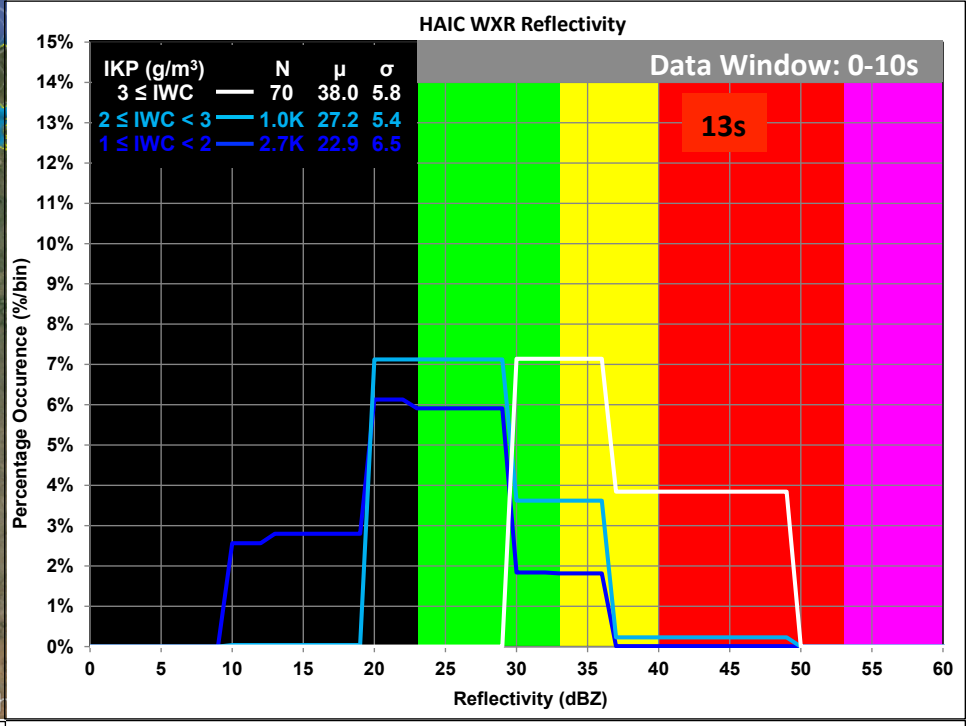

Summary of all Flights
Area under curves = 100%

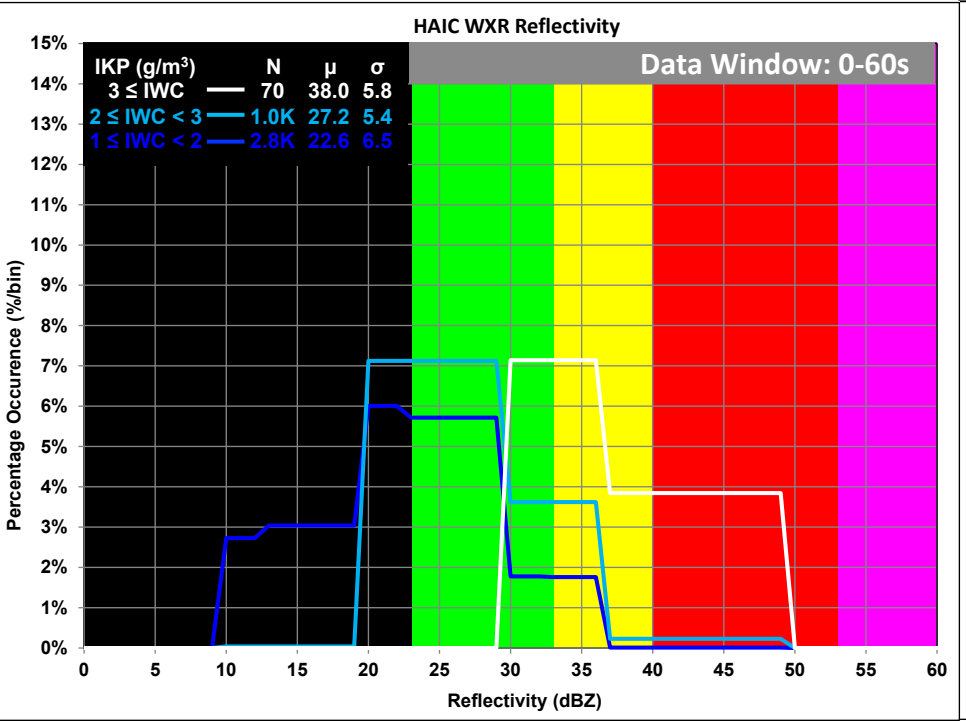

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 12K 25.9 6.6
2 ≤ IWC < 3 89K 23.8 5.9
1 ≤ IWC < 2 274K 20.4 6.6
RRF Data Window: 0-10s ahead of encounter
167s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

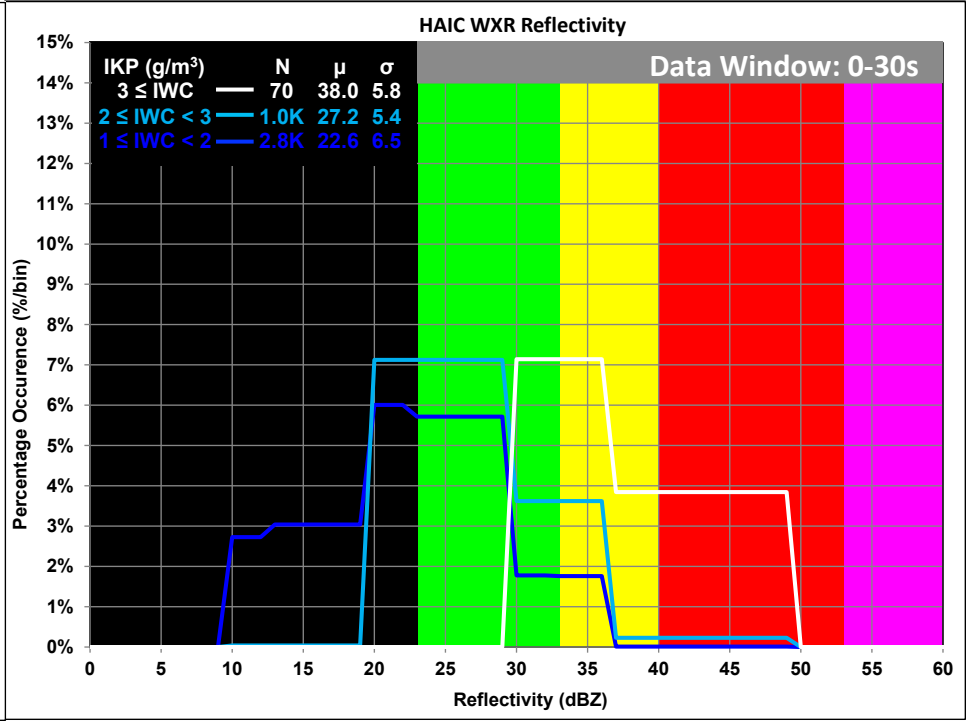

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 87K 26.2 6.2
2 ≤ IWC < 3 650K 24.1 6.3
1 ≤ IWC < 2 2620K 21.0 6.6
RRF Data Window: 0-60s ahead of encounter
Percentage Occurence (%/bin)
Reflectivity (dBZ)


HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 53K 26.8 6.3
2 ≤ IWC < 3 419K 24.0 6.4
1 ≤ IWC < 2 1539K 21.0 6.7
RRF Data Window: 0-30s ahead of encounter
Percentage Occurence (%/bin)
Reflectivity (dBZ)

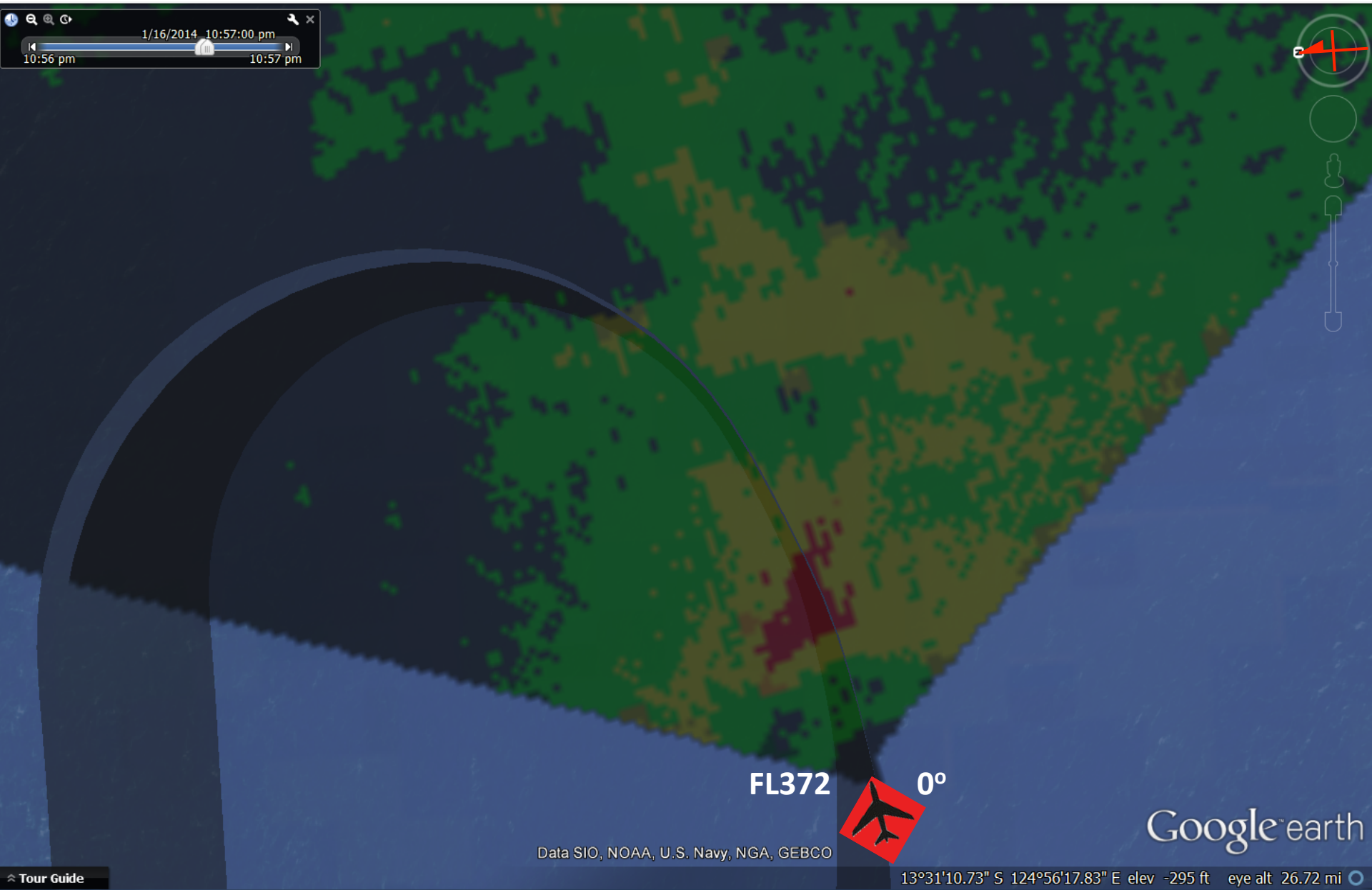

Flight 2, Jan 16, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Ashmore and Cartier Islands
Timor Sea
Beagle Gulf
King Sound
Area under curves = 100%
Google earth


HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 70 38.0 5.8
2 ≤ IWC < 3 1.0K 27.2 5.4
1 ≤ IWC < 2 2.7K 22.9 6.5
Data Window: 0-10s
13s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

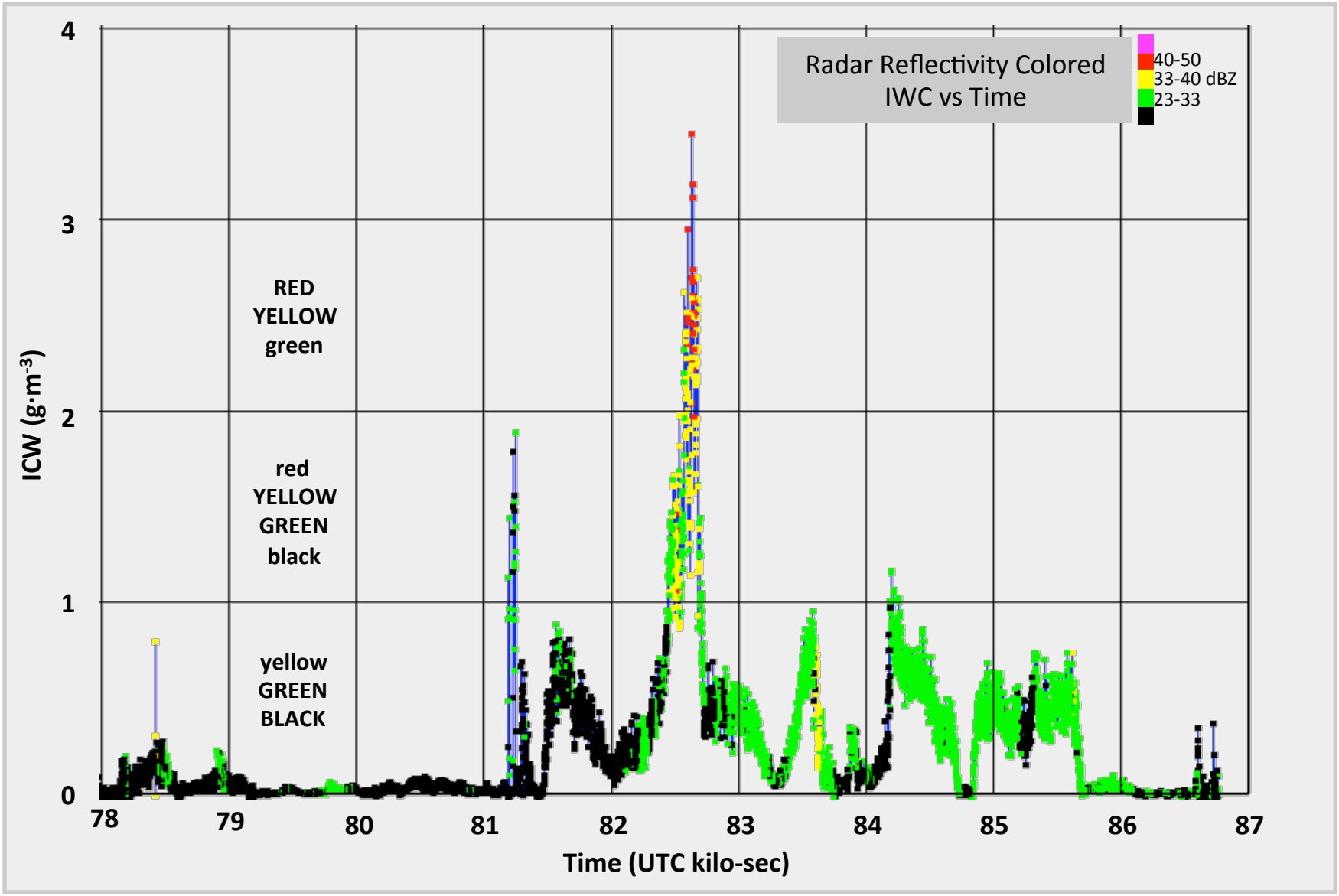

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 70 38.0 5.8
2 ≤ IWC < 3 1.0K 27.2 5.4
1 ≤ IWC < 2 2.8K 22.6 6.5
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)


HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 70 38.0 5.8
2 ≤ IWC < 3 1.0K 27.2 5.4
1 ≤ IWC < 2 2.8K 22.6 6.5
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

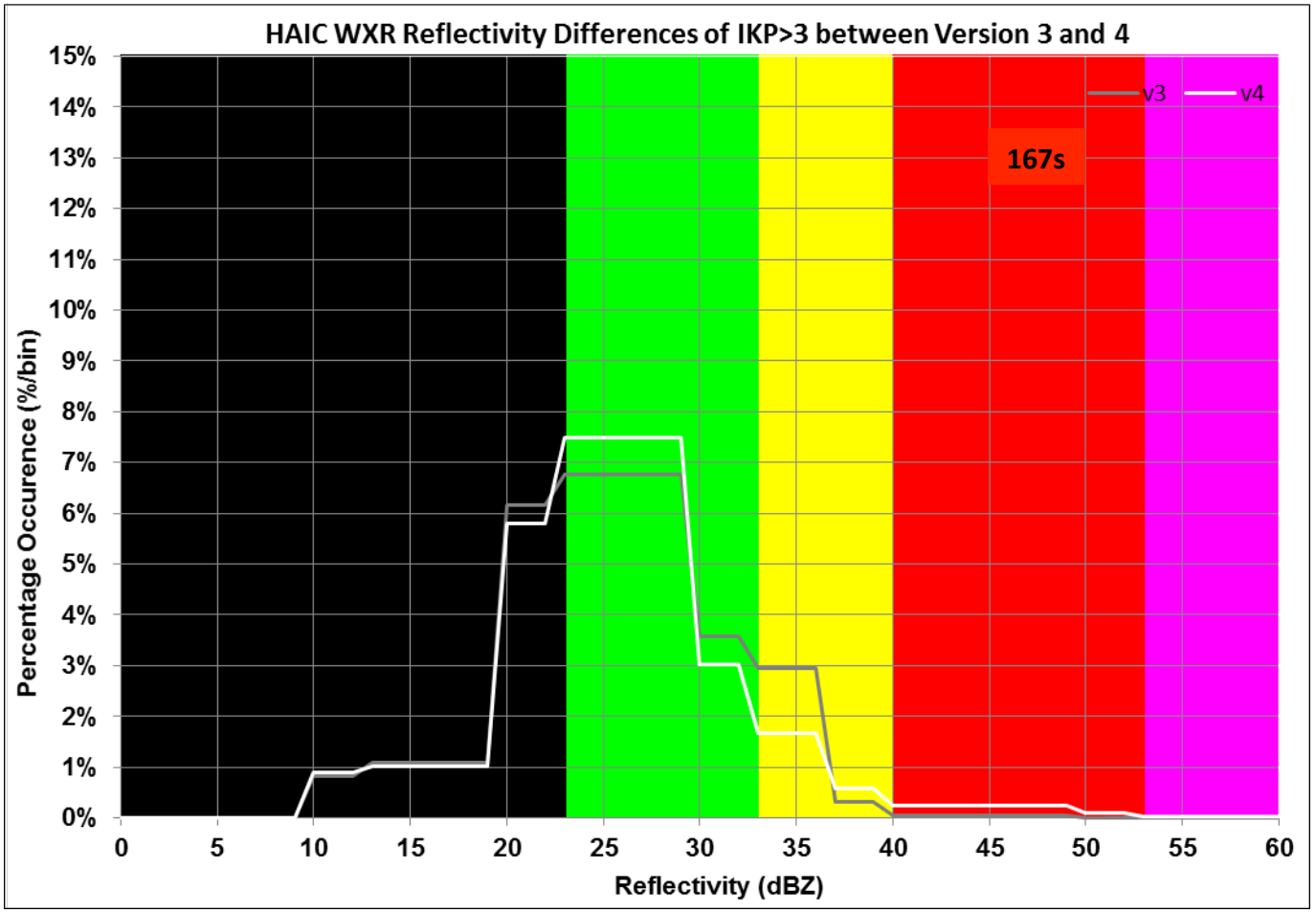
Radar Scan Just Prior to Entry into RED RRF
16 Jan 2014



Data collected and results “so far”



Flight into RED
Impact on Reflectivity Stats (Summary)



Note: minor increase in histogram's tail
produces negligible affect on mean
only slight increase in standard deviation

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UPDATED Conclusions (Additional)

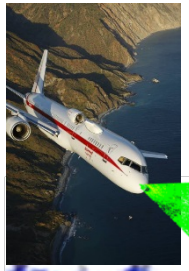
- NEW IKP dataset - redefines the regions (flight path segments) which we call HAIC and which we use to calculate/correlate with radar reflectivity.
- As a consequence of these added flight segments and especially in light of flight segments within regions of higher reflectivity (YELLOW/RED):
  - now see statistics over a broader range of radar reflectivities (previous results suggested a reflectivity upper bound while in HAIC conditions (unrealistic)).
  - concern that higher reflectivities may bias stats – while stats for individual days were sometimes affected, the small amount of time in these conditions has not altered the summary statistics.
  - Rain Gauge effects (ie, reflectivity proportional to TWC) were observed (however it is still not dominant effect). The previous data suggested a more truncated PSD and a different meteorology in HIWC conditions than normal convective storms.
- Radar Reflectivity Dominated by PSD Shape (more so than Rain Gauge effect)
  - consequently Radar Reflectivity ALONE is insufficient to estimating IWC (unless Alain's hypothesis is correct and OAT can collapse the IWC variability).

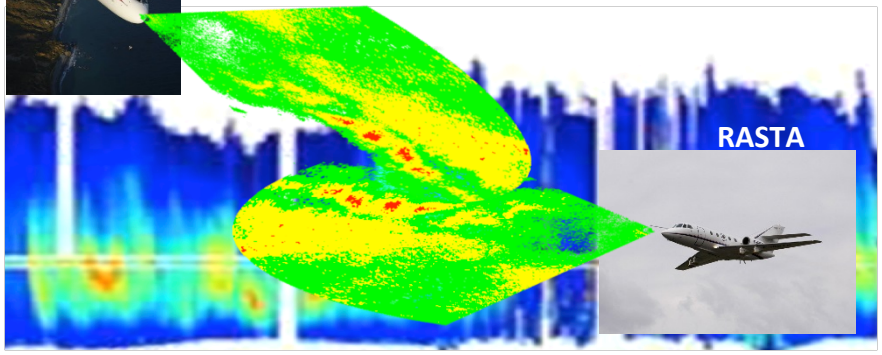
Future Work

Radar Reflectivity Comparison

- Compare different radar data observations of the same HAIC event
- Z_{F20} v Z_{757} v Z_{RASTA}
- Spatial and temporal correlation
- Post process Recorded I&Q data
- Compute reflectivity + other signature info

RDR-4000

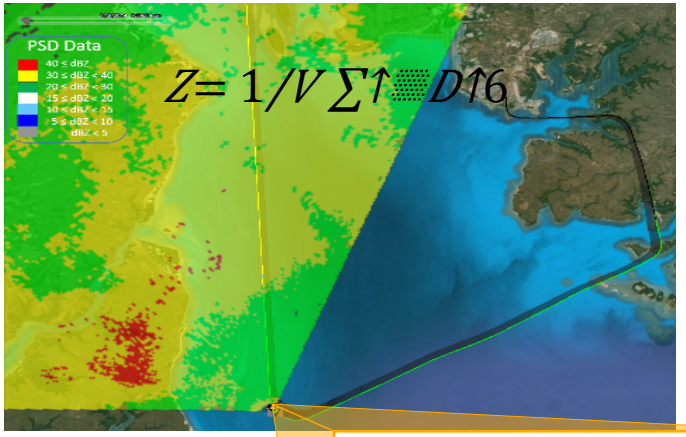


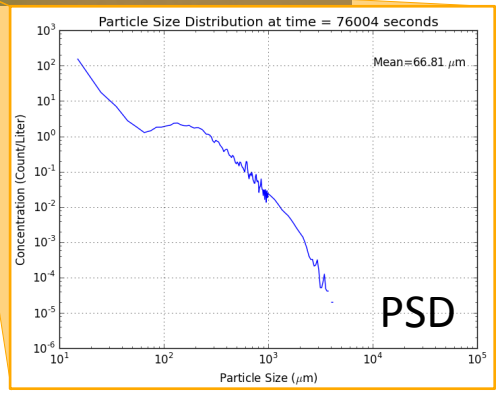


Primus-660

Radar Comparison to Particle Data

- Compute theoretical radar reflectivity from particle size distributions
- Z_X v Z_W v Z_{PSD}
- Correlate with radar measurements



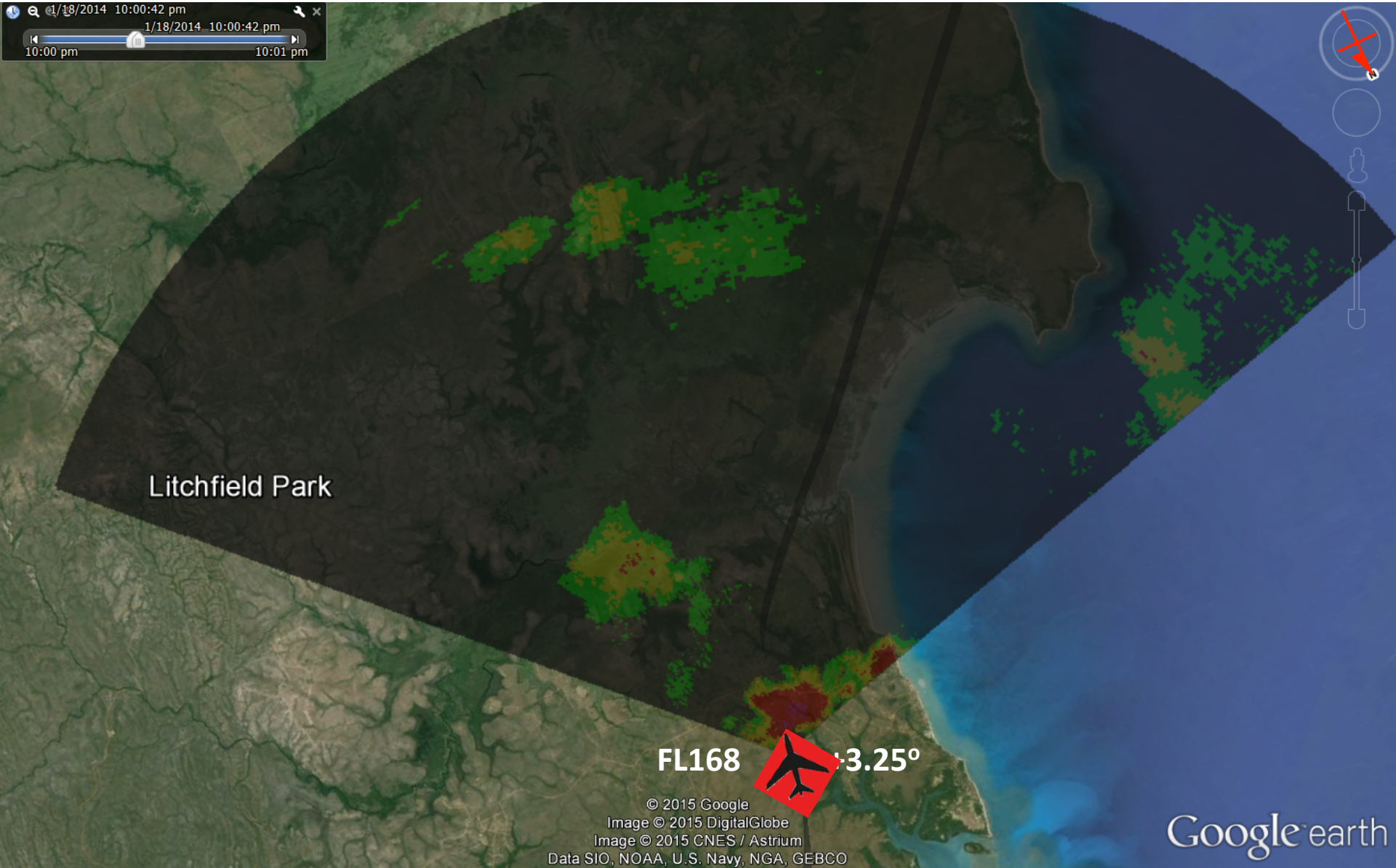


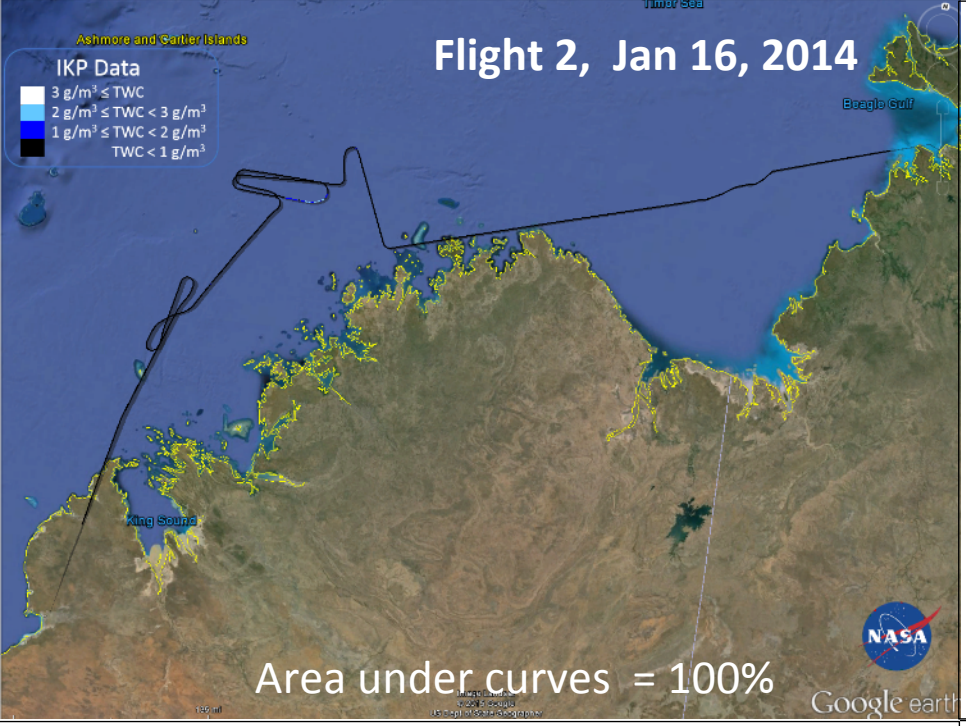
HAIC-HIWC Science Team Meeting
09-13 November 2015

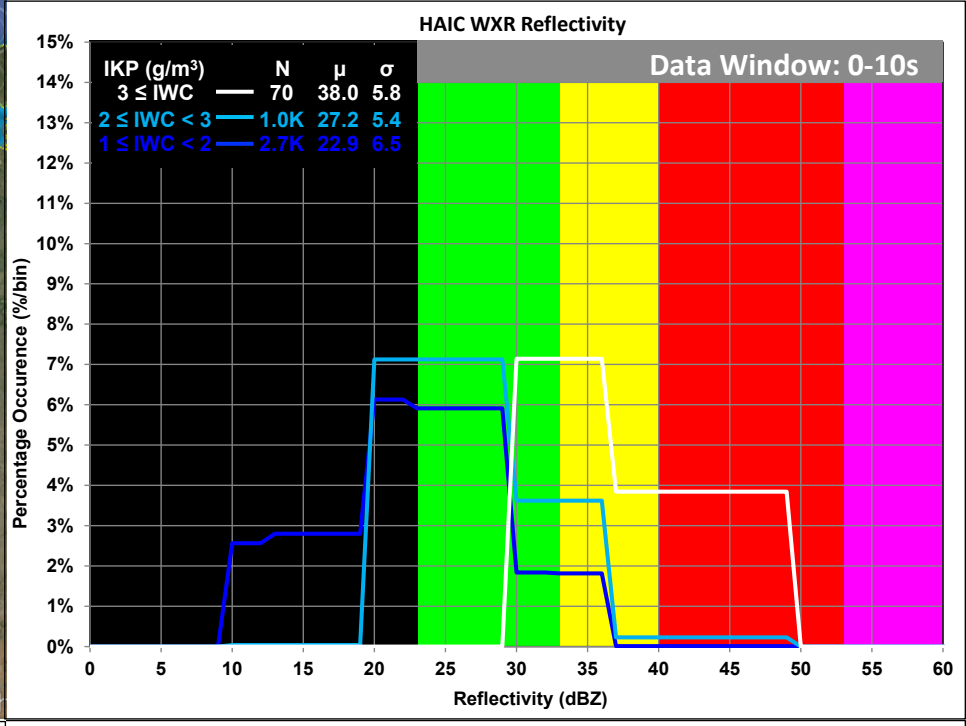
BACK-UP CHARTS

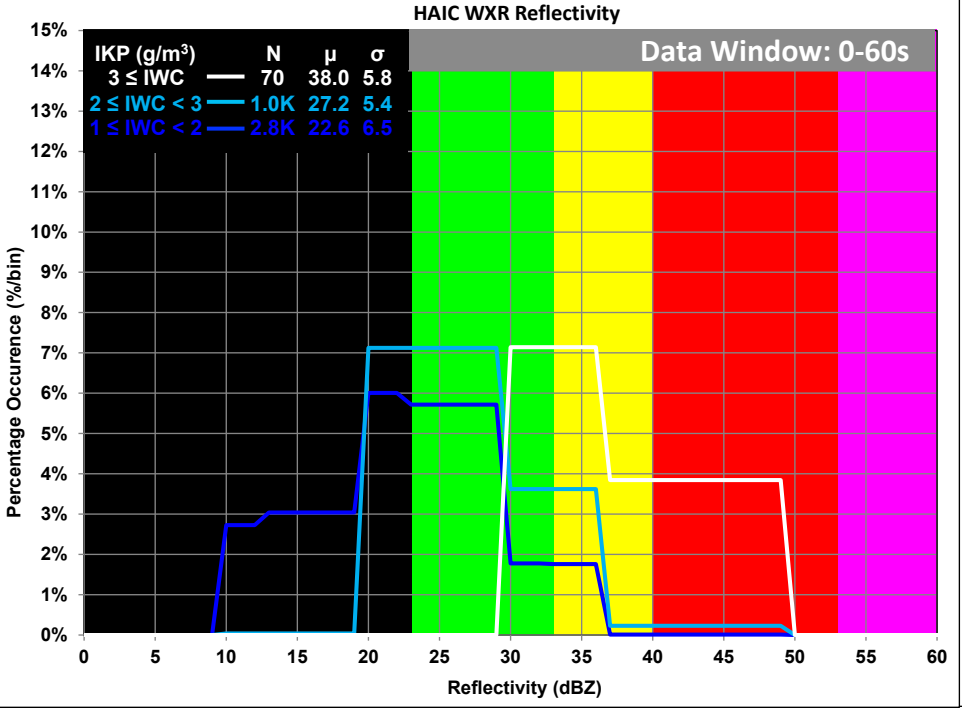
INCLUDING:
DAY-BY-DAY STATS
&
CHARTS FROM PREVIOUS (PARIS)
HAIC-HIWC SCIENCE TEAM MEETING

Radar Scan Just Prior to Entry in RED RRF
18 Jan 2014




Flight 2, Jan 16, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Ashmore and Cartier Islands
Timor Sea
Beagle Gulf
King Sound
Area under curves = 100%
Google earth


HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 70 38.0 5.8
2 ≤ IWC < 3 1.0K 27.2 5.4
1 ≤ IWC < 2 2.7K 22.9 6.5
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)


HAIC WXR Reflectivity
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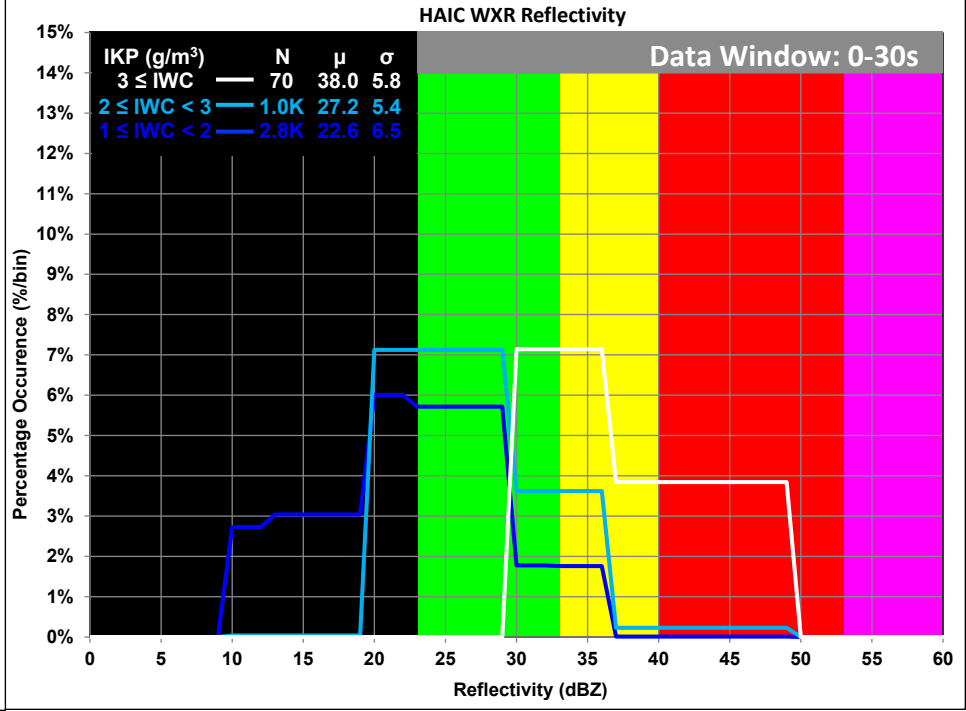
2 ≤ IWC < 3 1.0K 27.2 5.4
1 ≤ IWC < 2 2.8K 22.6 6.5
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)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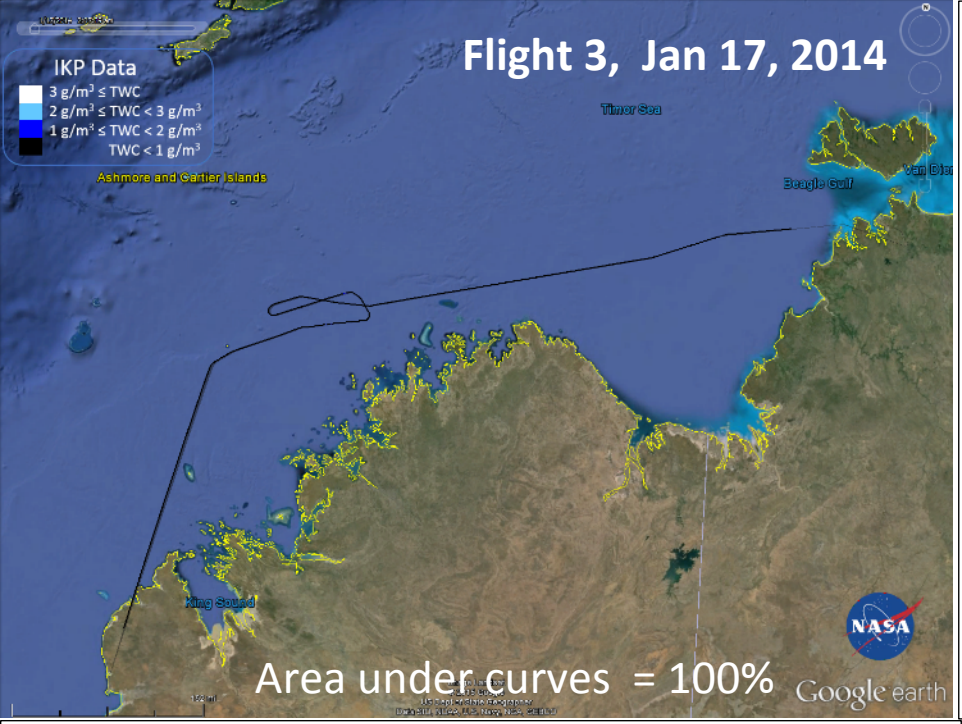
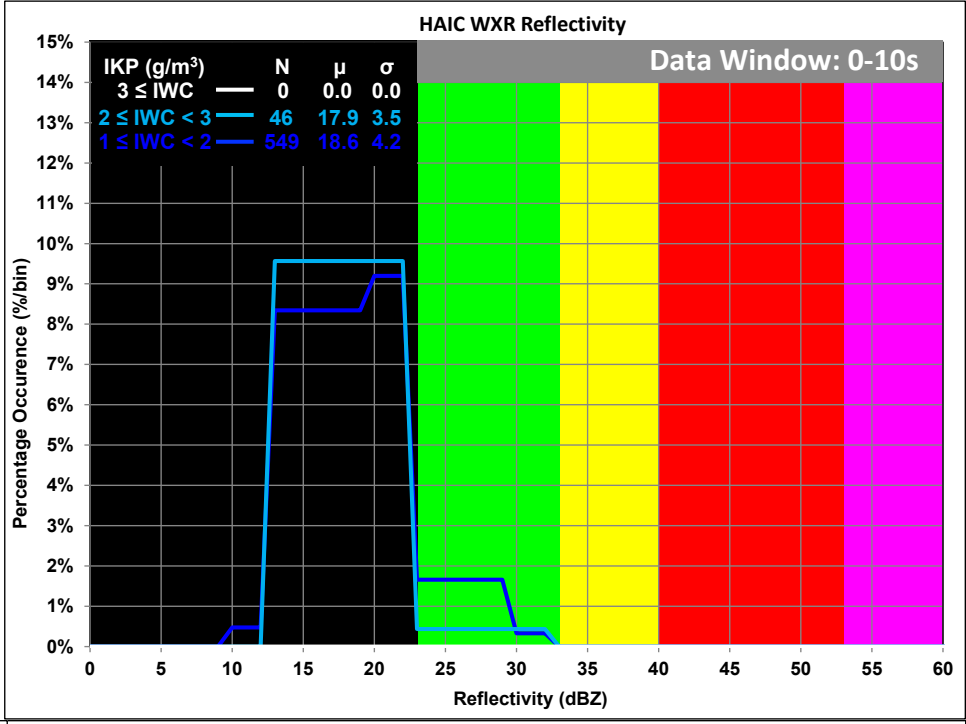
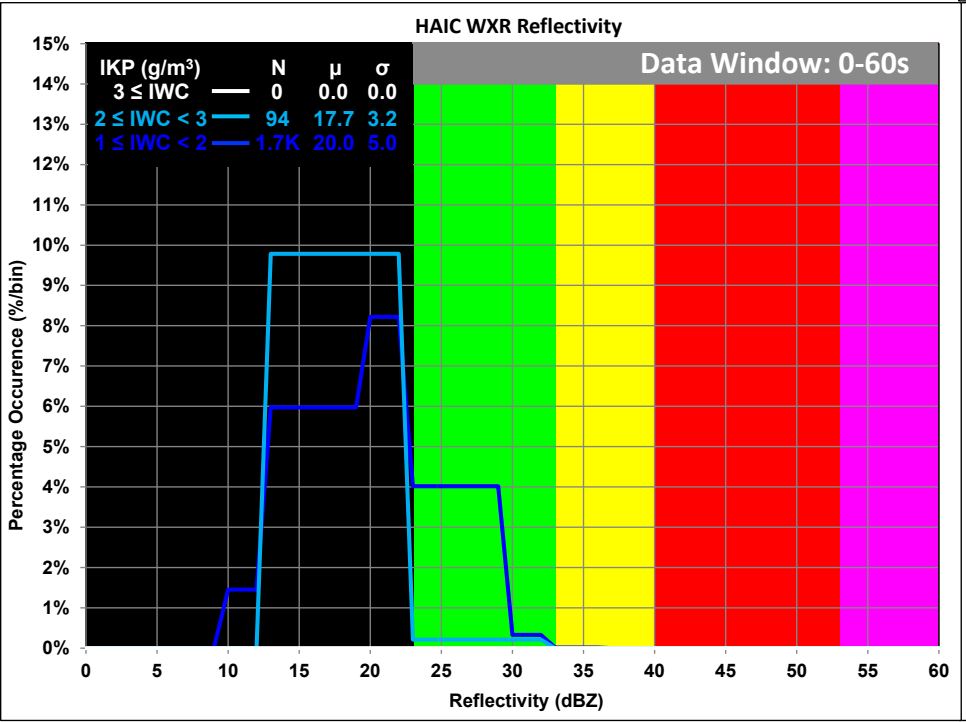
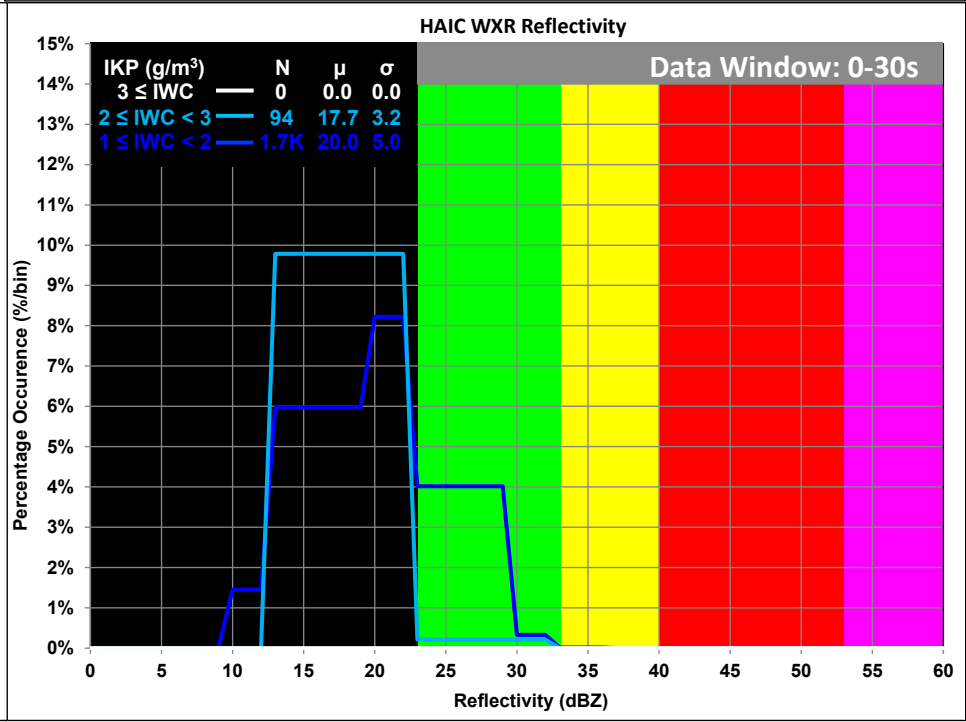
1 ≤ IWC < 2 2.8K 22.6 6.5
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)


Flight 3, Jan 17, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Ashmore and Cartier Islands
Timor Sea
Beagle Gulf
King Sound
Area under curves = 100%
Google earth


HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 46 17.9 3.5
1 ≤ IWC < 2 549 18.6 4.2
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)


HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 94 17.7 3.2
1 ≤ IWC < 2 1.7K 20.0 5.0
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)


HAIC WXR Reflectivity
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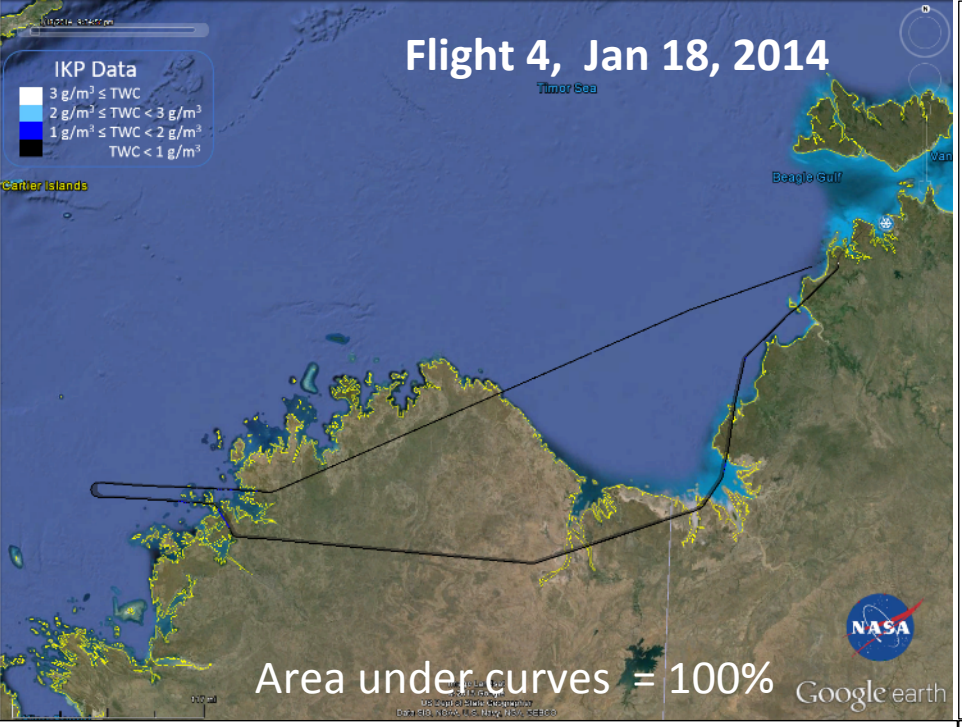
Flight 4, Jan 18, 2014
IKP Data
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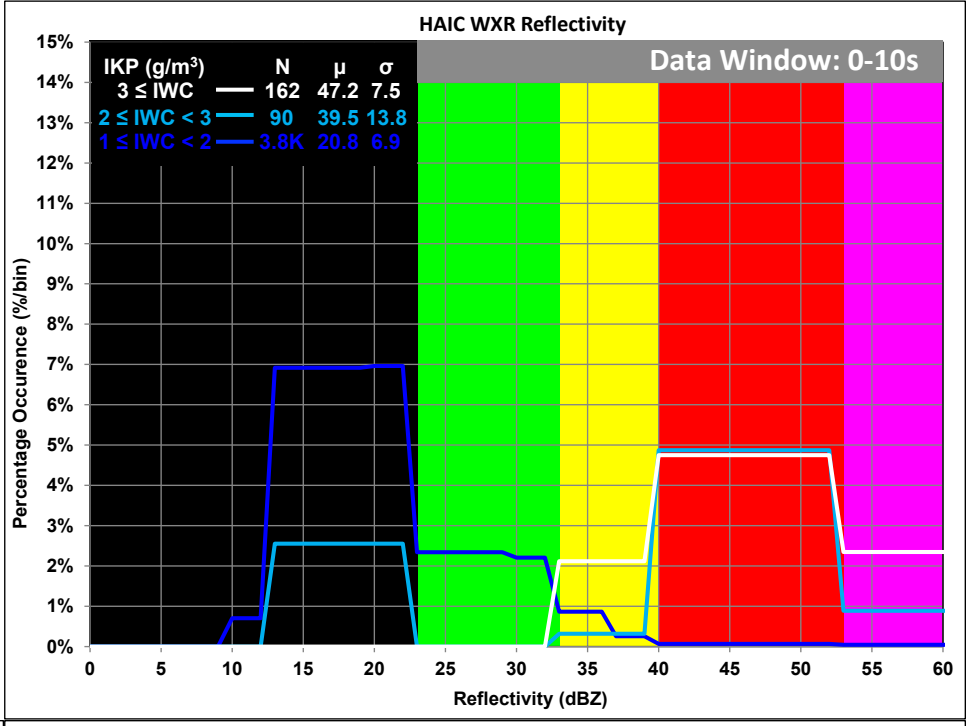
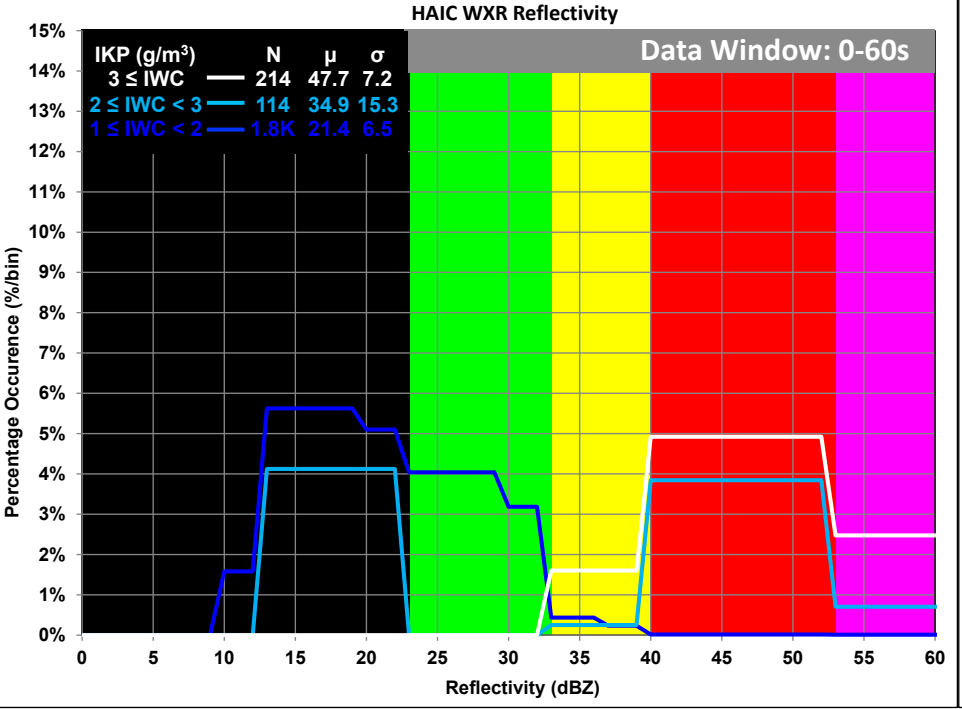
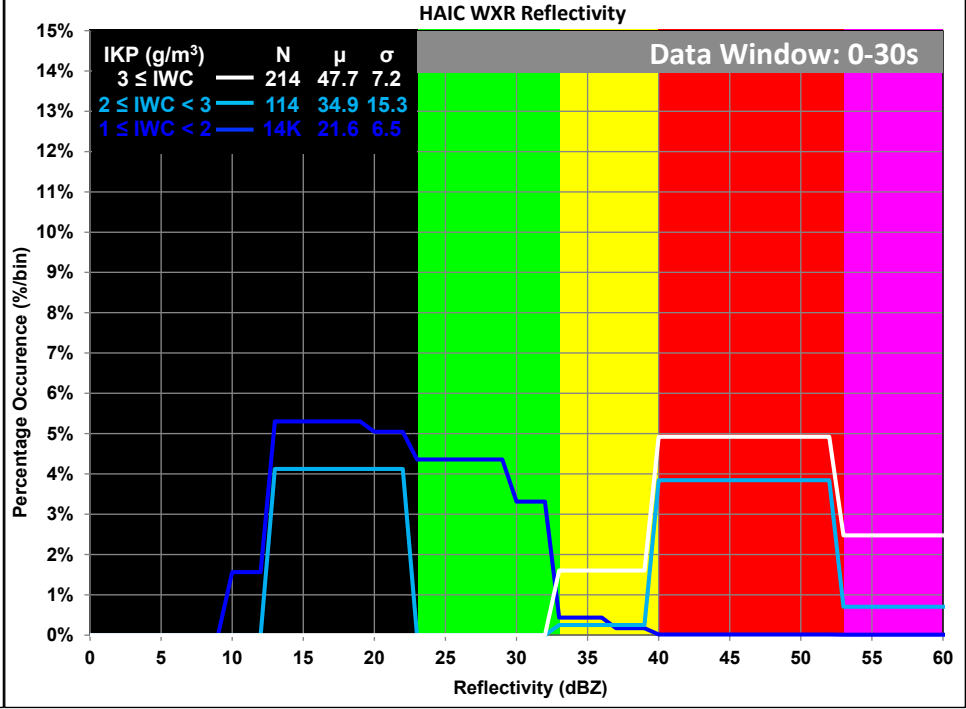
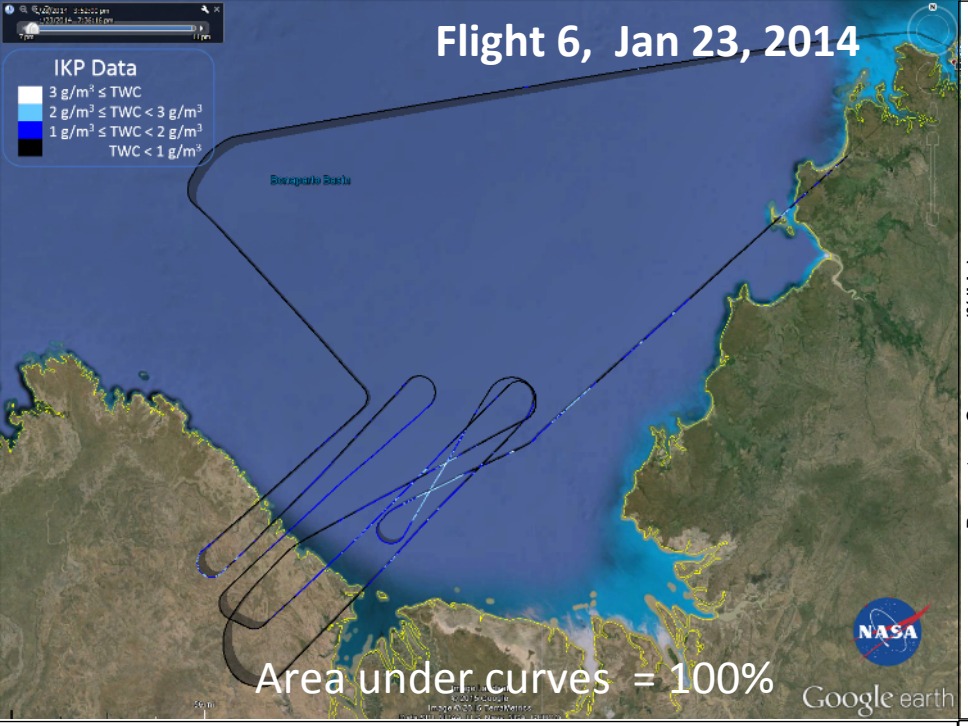
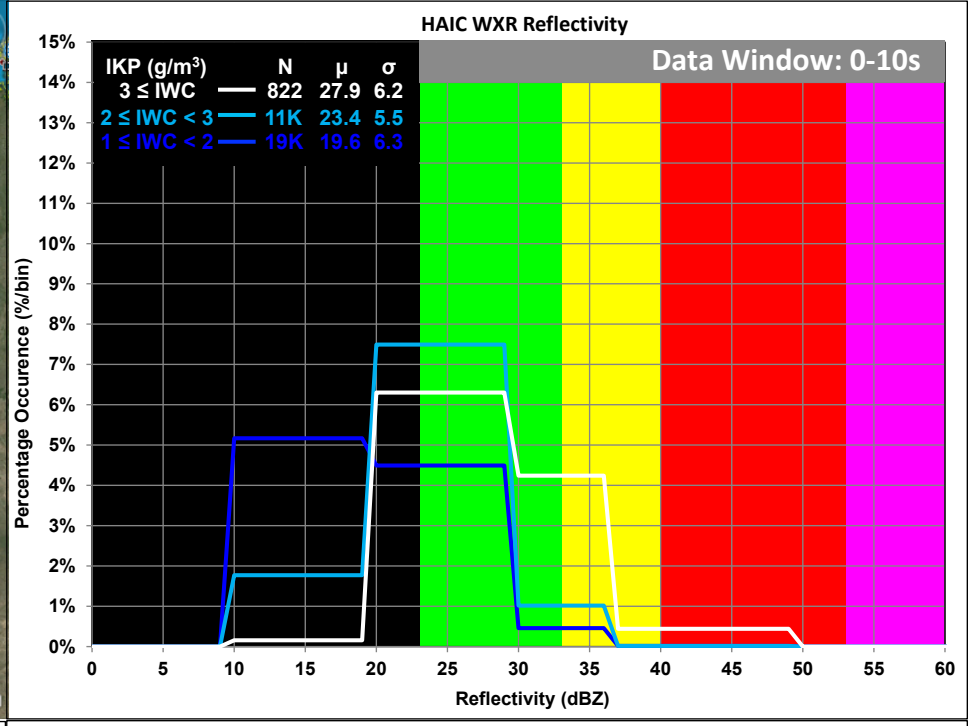
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Timor Sea
Beagle Gulf
Cartier Islands
NASA
Area under curves = 100%
Google earth

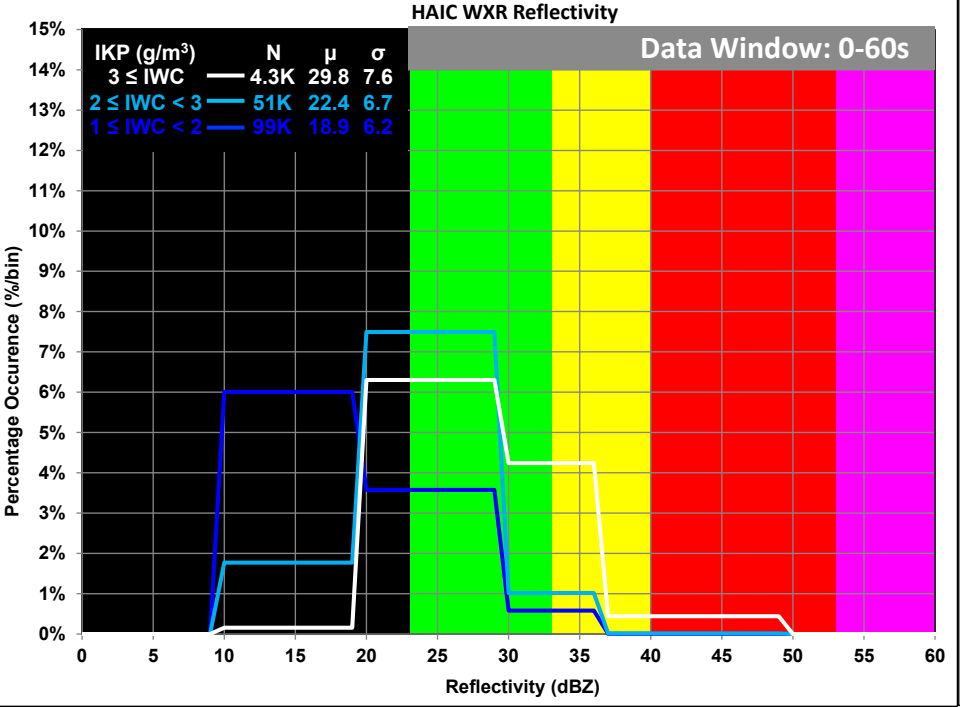

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 162 47.2 7.5
2 ≤ IWC < 3 90 39.5 13.8
1 ≤ IWC < 2 3.8K 20.8 6.9
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

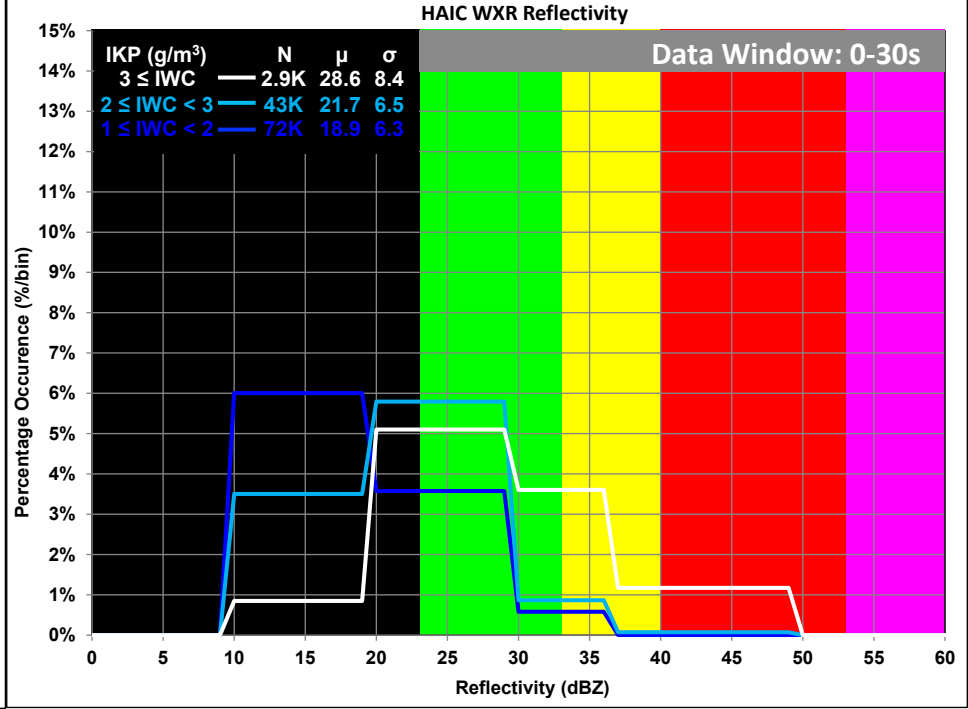

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 214 47.7 7.2
2 ≤ IWC < 3 114 34.9 15.3
1 ≤ IWC < 2 1.8K 21.4 6.5
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

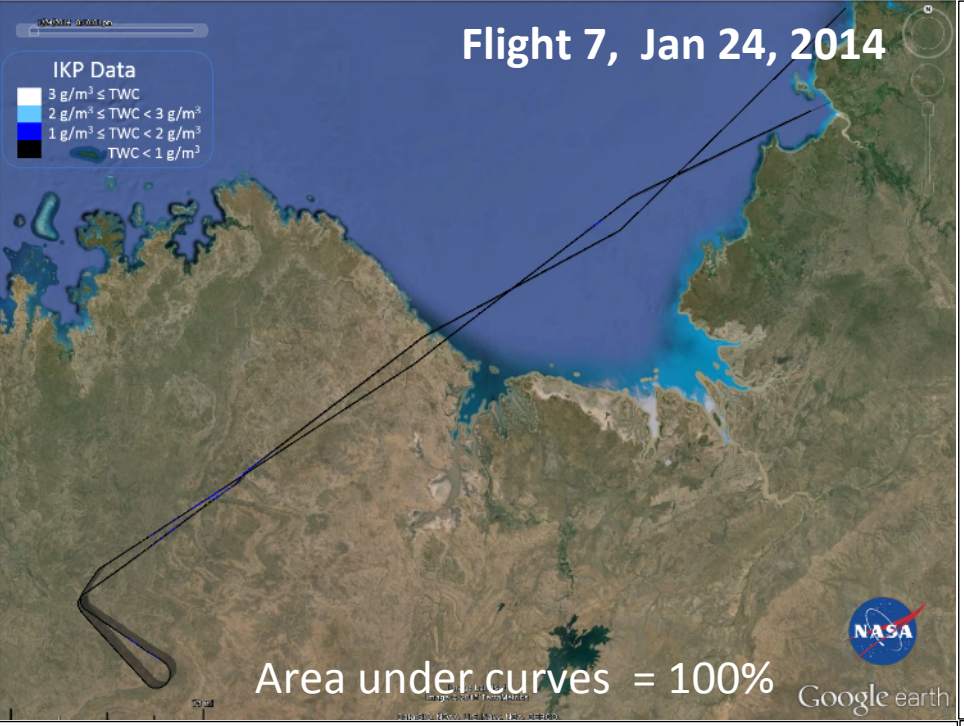

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 214 47.7 7.2
2 ≤ IWC < 3 114 34.9 15.3
1 ≤ IWC < 2 14K 21.6 6.5
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

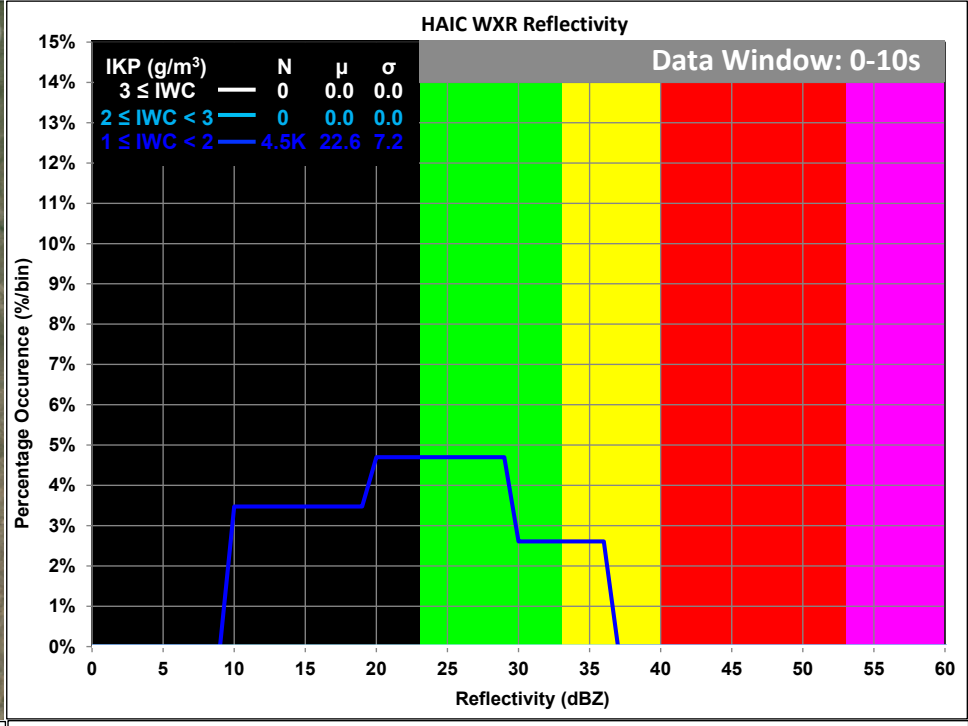

Flight 6, Jan 23, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
NASA
Google earth

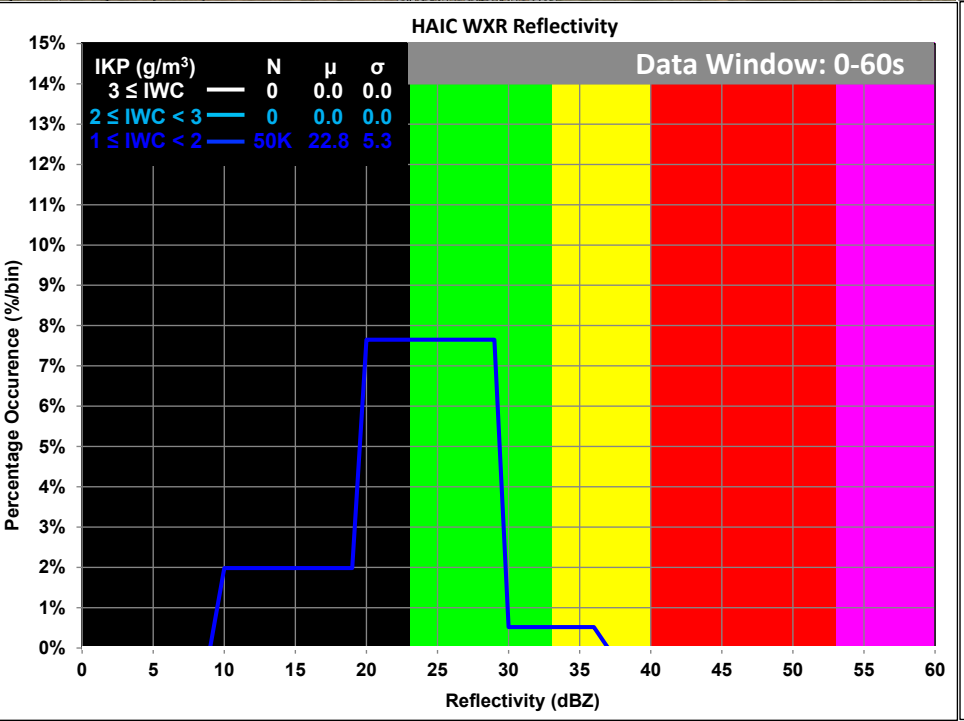

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 822 27.9 6.2
2 ≤ IWC < 3 11K 23.4 5.5
1 ≤ IWC < 2 19K 19.6 6.3
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

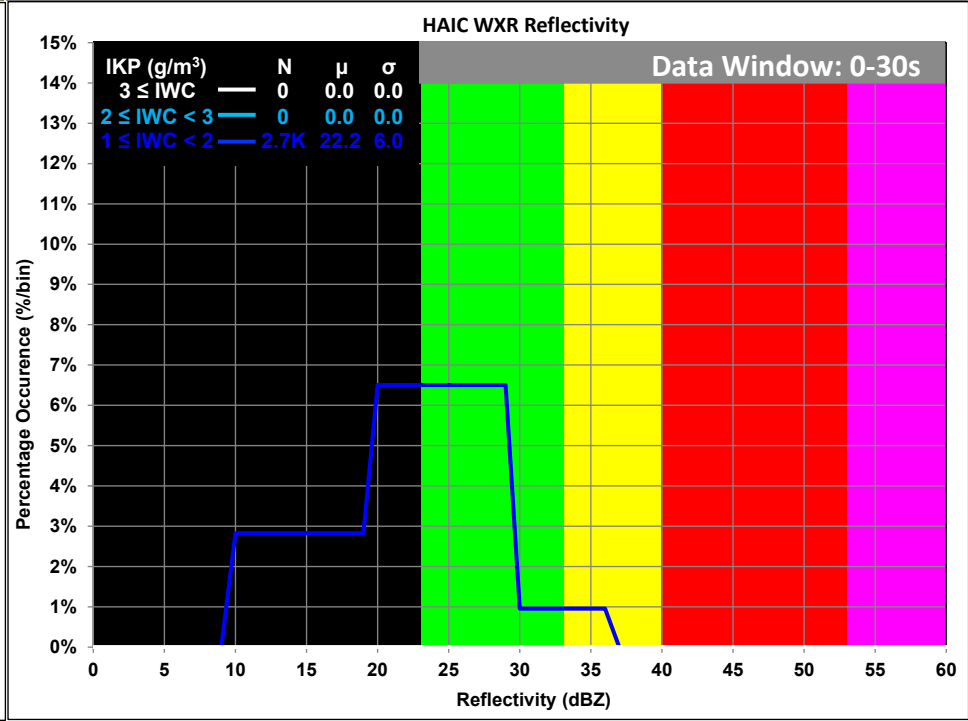

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 4.3K 29.8 7.6
2 ≤ IWC < 3 51K 22.4 6.7
1 ≤ IWC < 2 99K 18.9 6.2
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

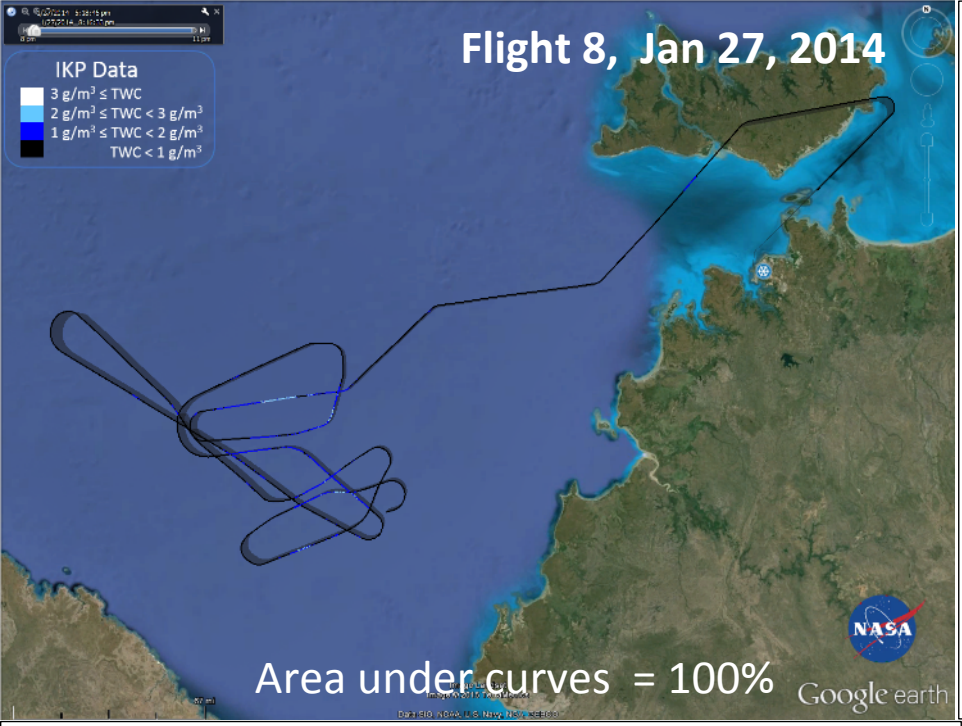

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 2.9K 28.6 8.4
2 ≤ IWC < 3 43K 21.7 6.5
1 ≤ IWC < 2 72K 18.9 6.3
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

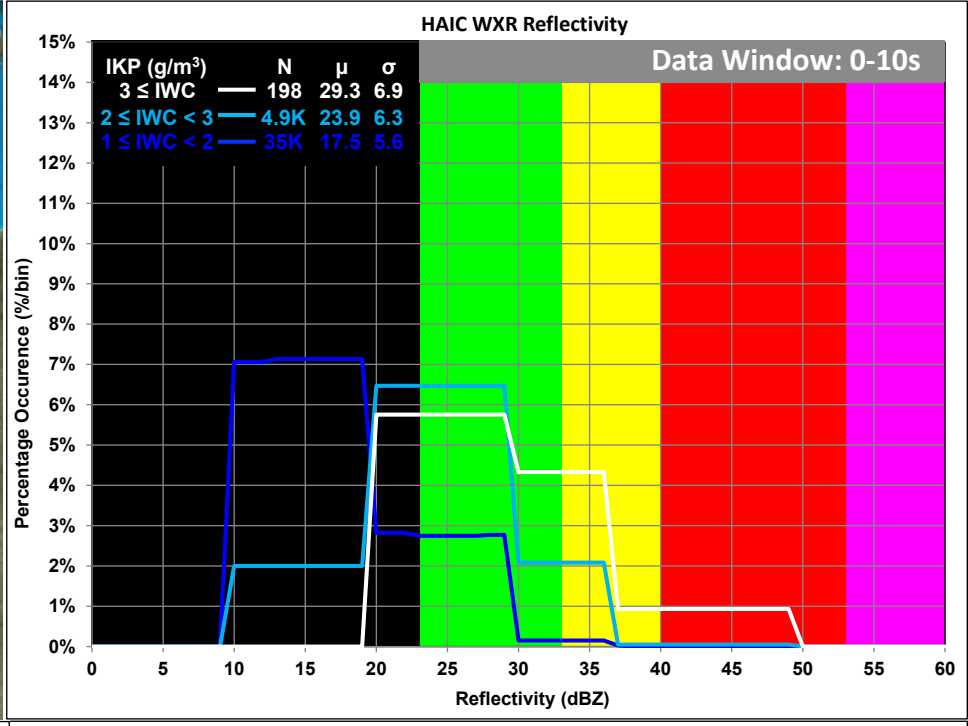

Flight 7, Jan 24, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
Google earth

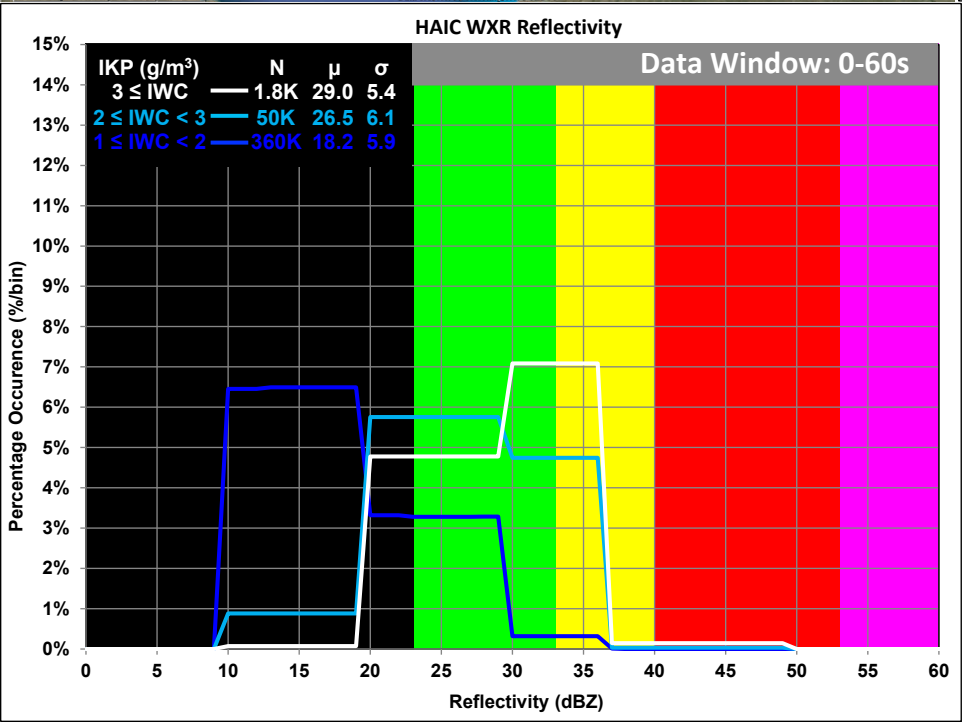

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 0 0.0 0.0
1 ≤ IWC < 2 4.5K 22.6 7.2
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

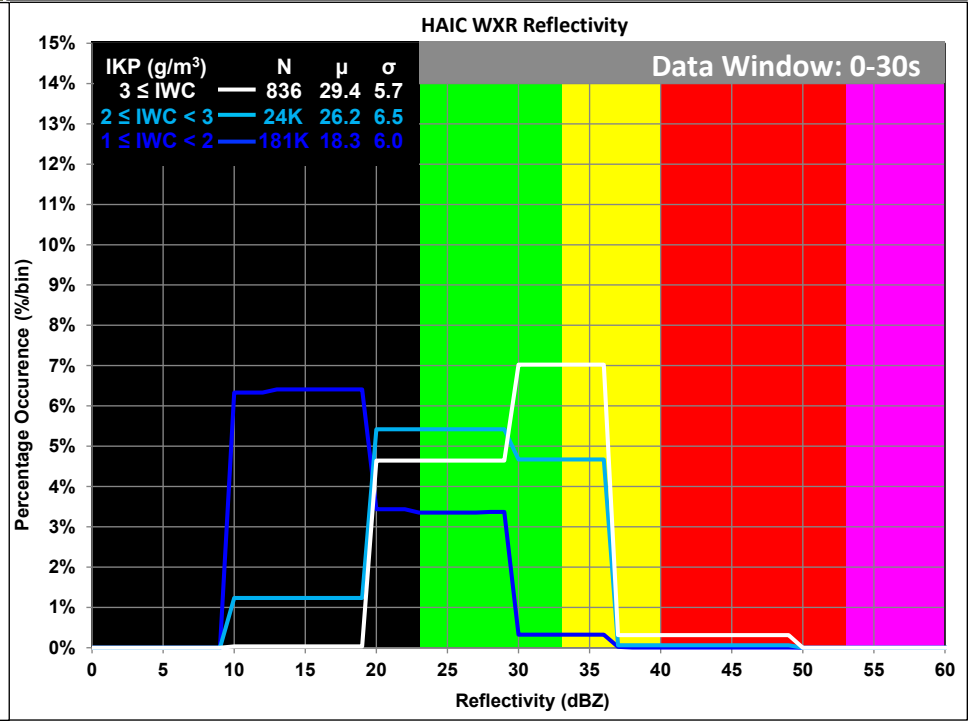

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 0 0.0 0.0
1 ≤ IWC < 2 50K 22.8 5.3
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

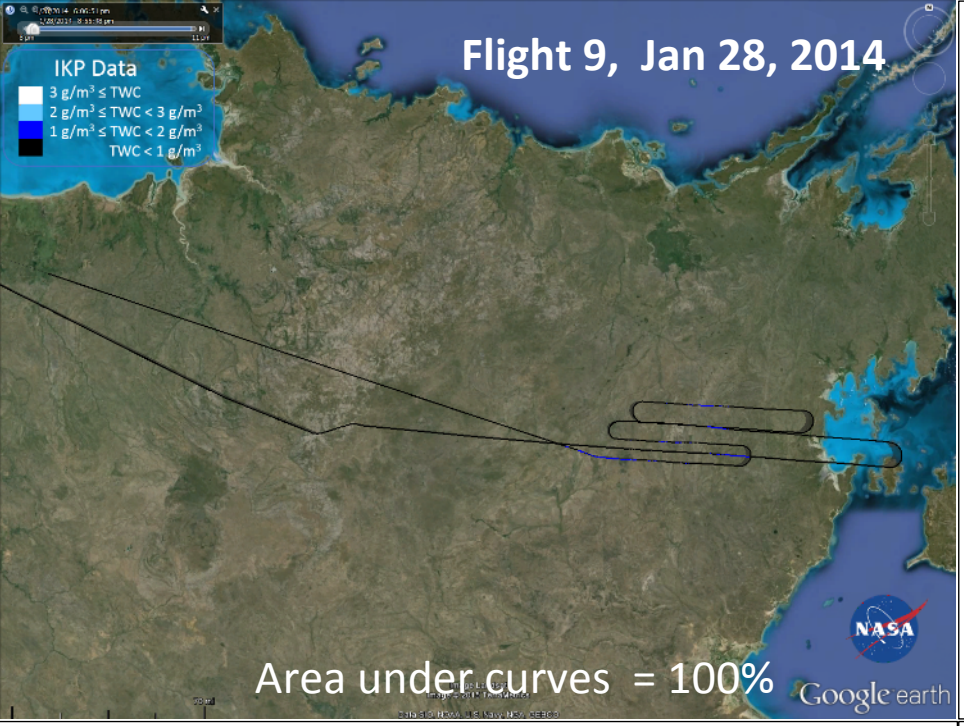

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 0 0.0 0.0
1 ≤ IWC < 2 2.7K 22.2 6.0
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

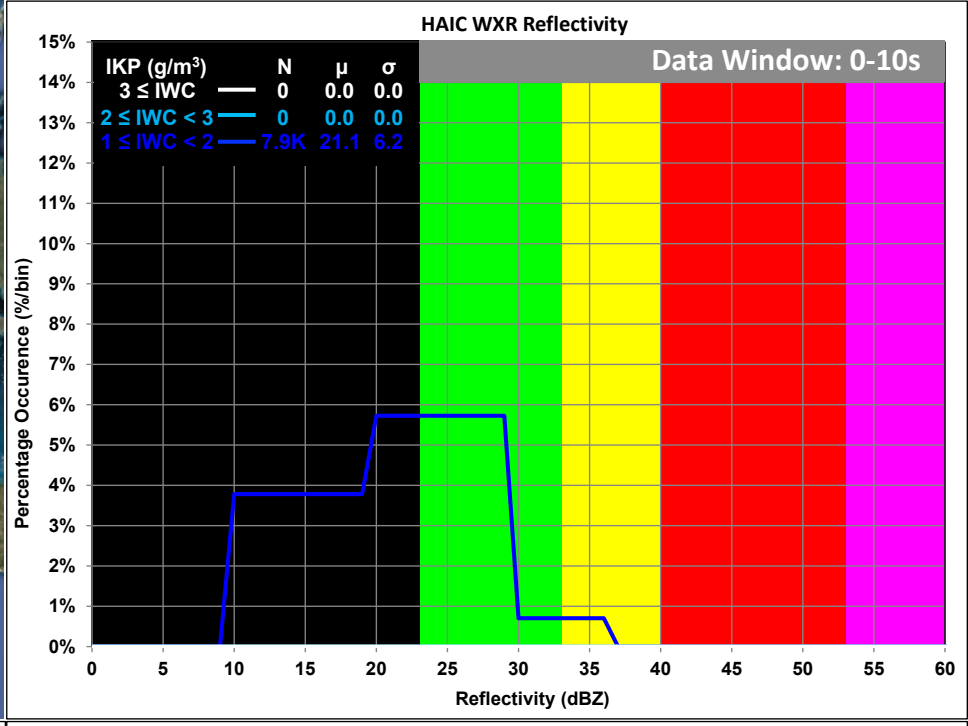

Flight 8, Jan 27, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
Google earth

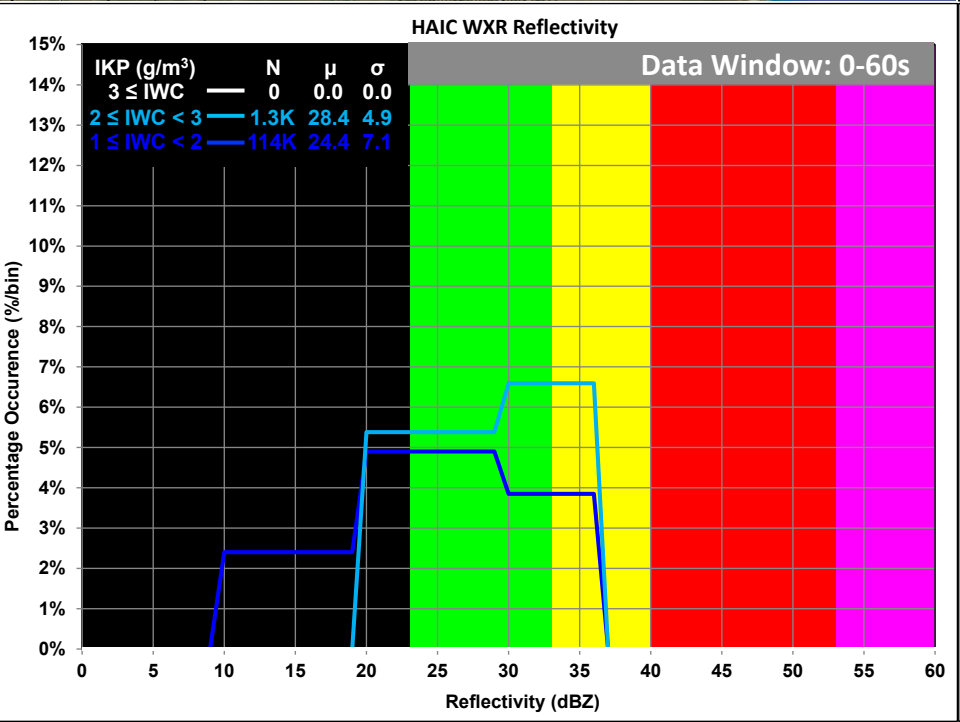

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 198 29.3 6.9
2 ≤ IWC < 3 4.9K 23.9 6.3
1 ≤ IWC < 2 35K 17.5 5.6
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

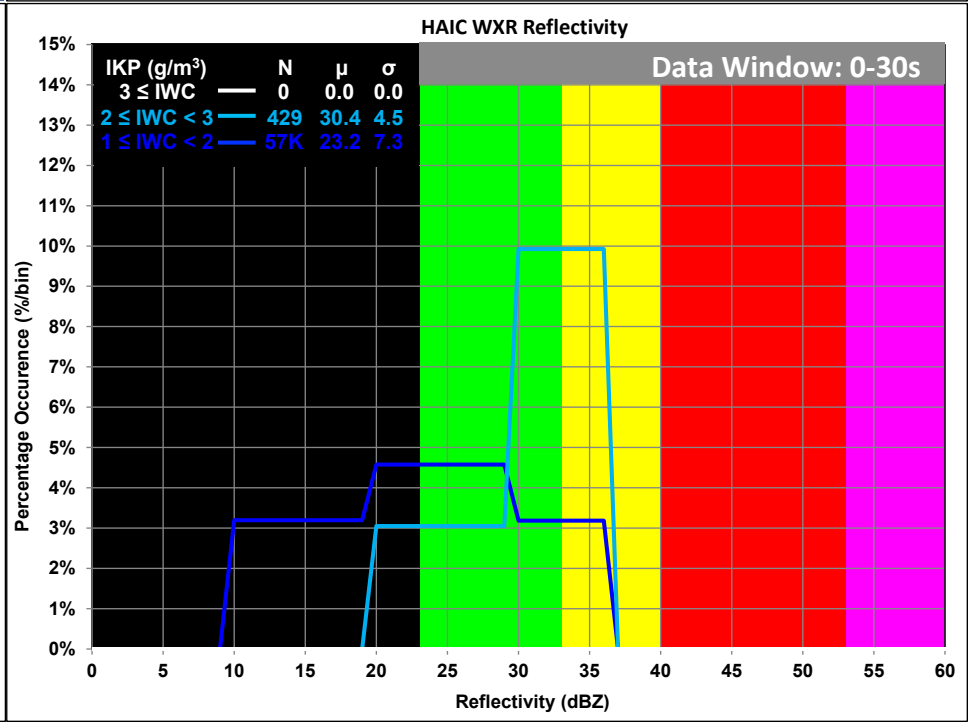

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 1.8K 29.0 5.4
2 ≤ IWC < 3 50K 26.5 6.1
1 ≤ IWC < 2 360K 18.2 5.9
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

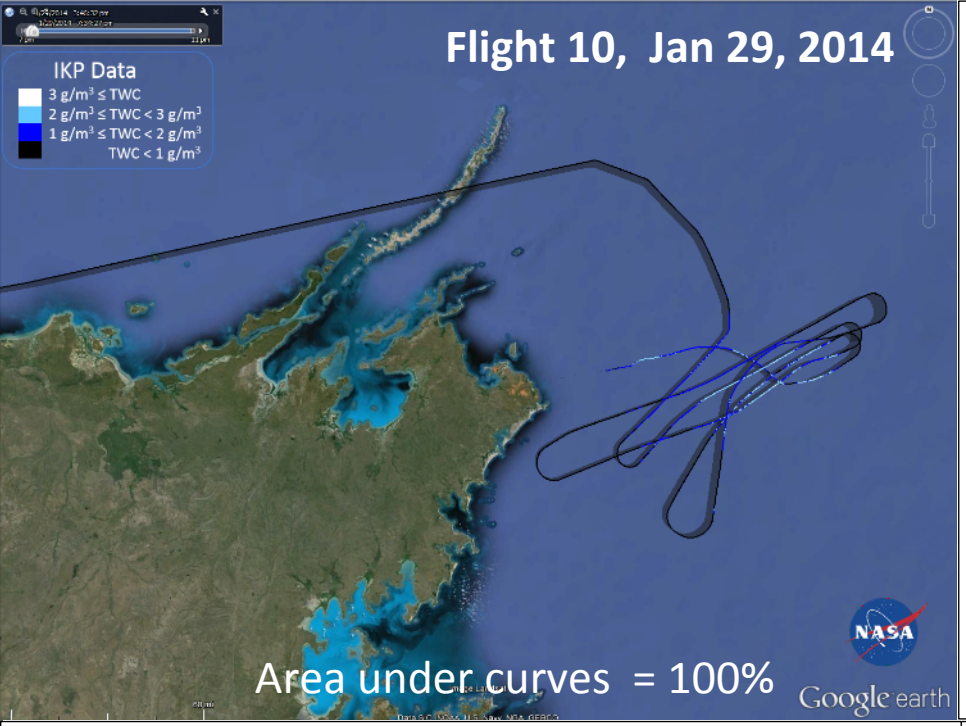

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 836 29.4 5.7
2 ≤ IWC < 3 24K 26.2 6.5
1 ≤ IWC < 2 181K 18.3 6.0
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

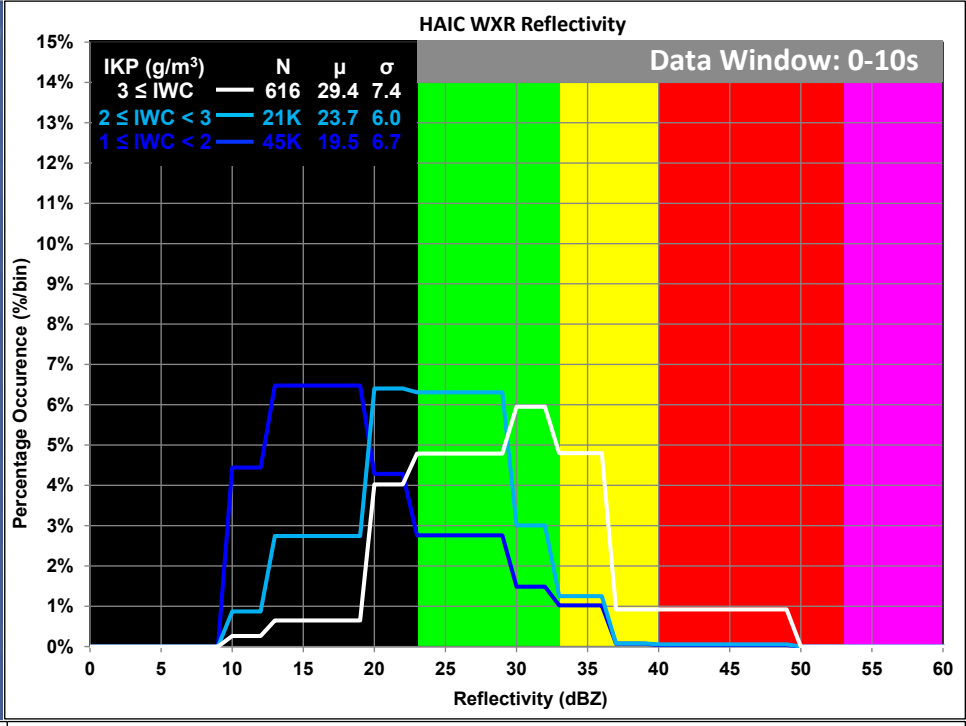

Flight 9, Jan 28, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
NASA
Google earth

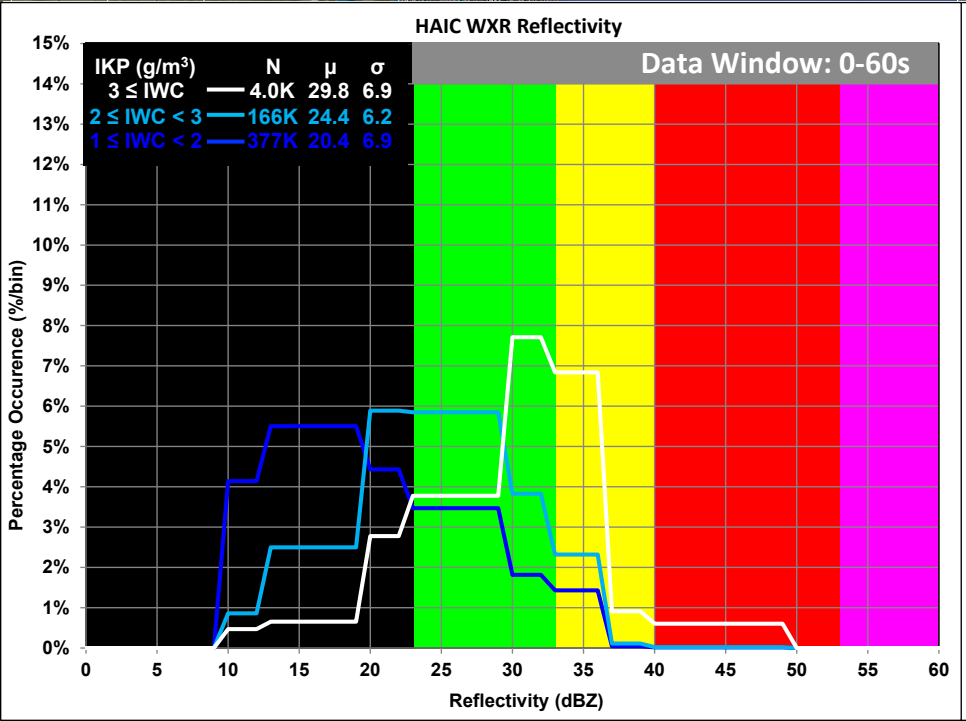

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 0 0.0 0.0
1 ≤ IWC < 2 7.9K 21.1 6.2
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

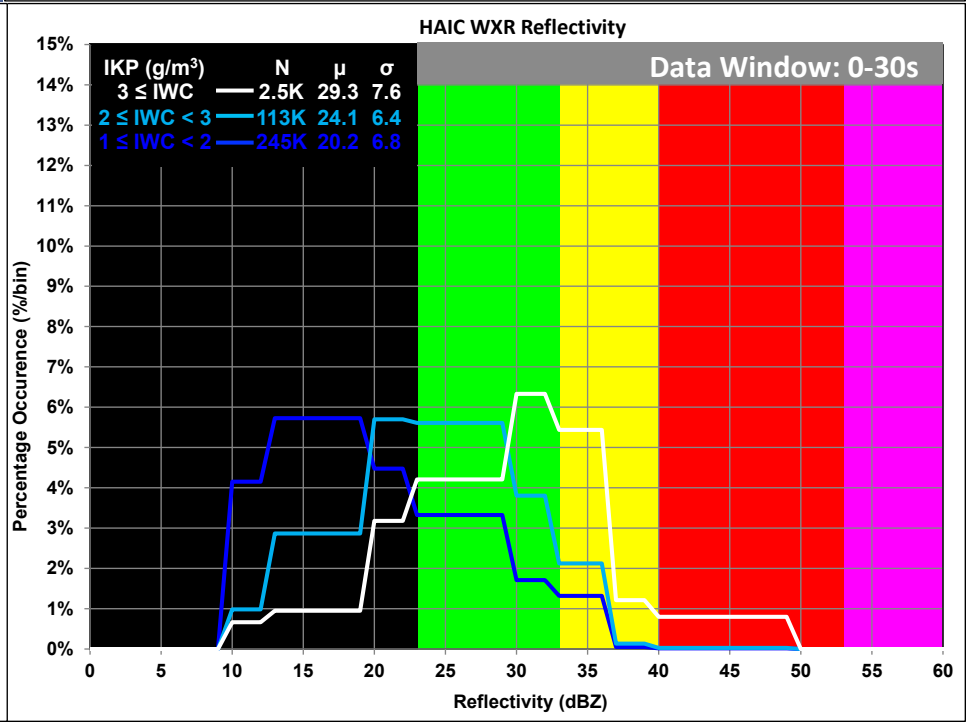

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 1.3K 28.4 4.9
1 ≤ IWC < 2 114K 24.4 7.1
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

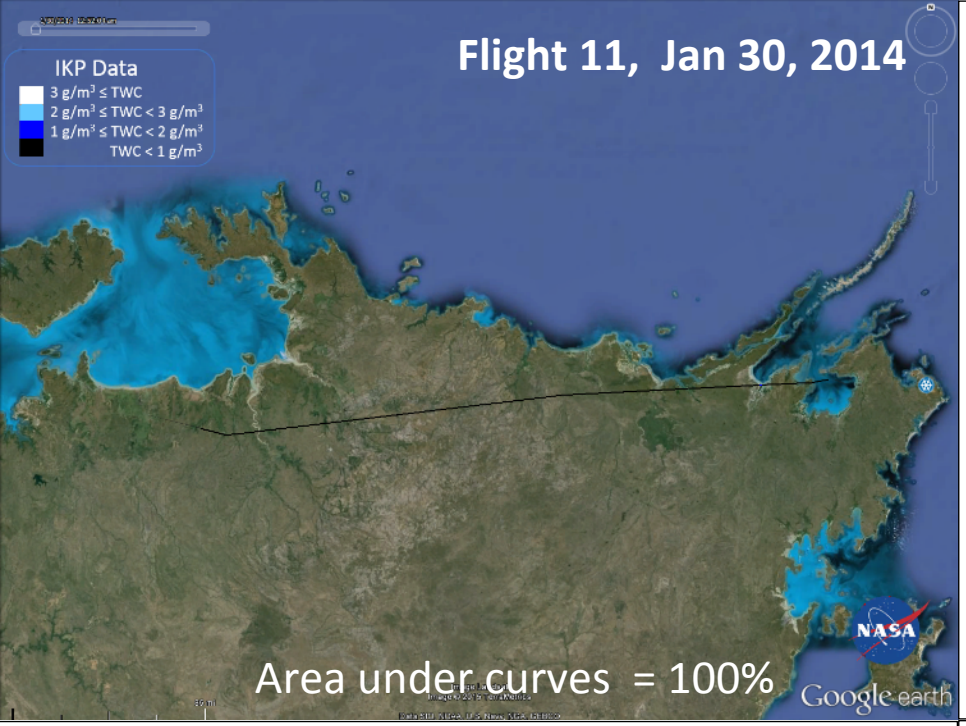

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 429 30.4 4.5
1 ≤ IWC < 2 57K 23.2 7.3
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

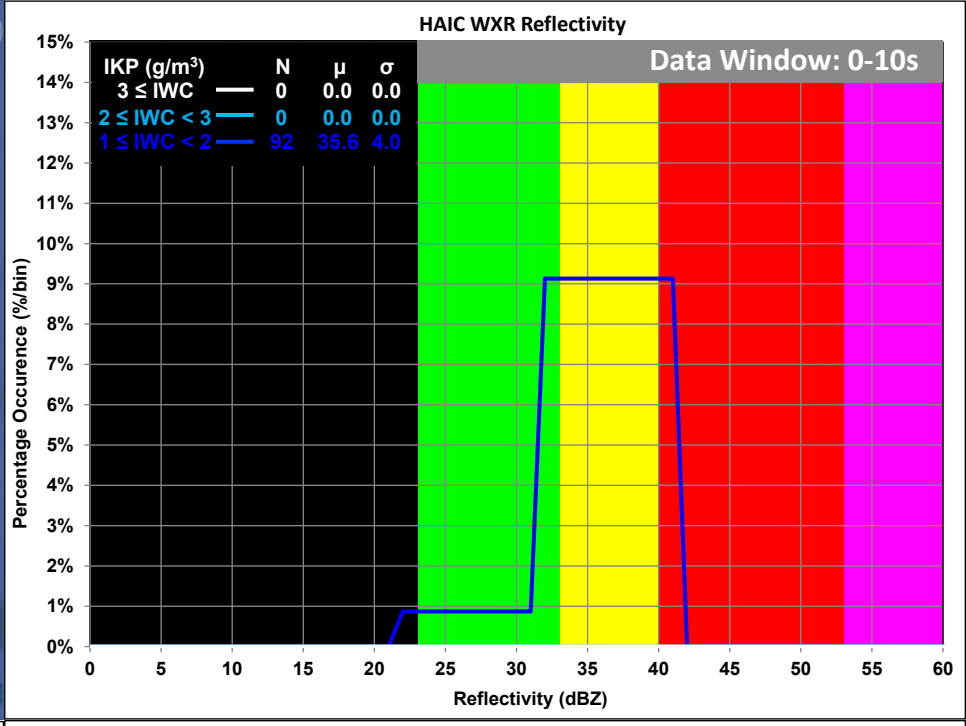

Flight 10, Jan 29, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
NASA
Google earth

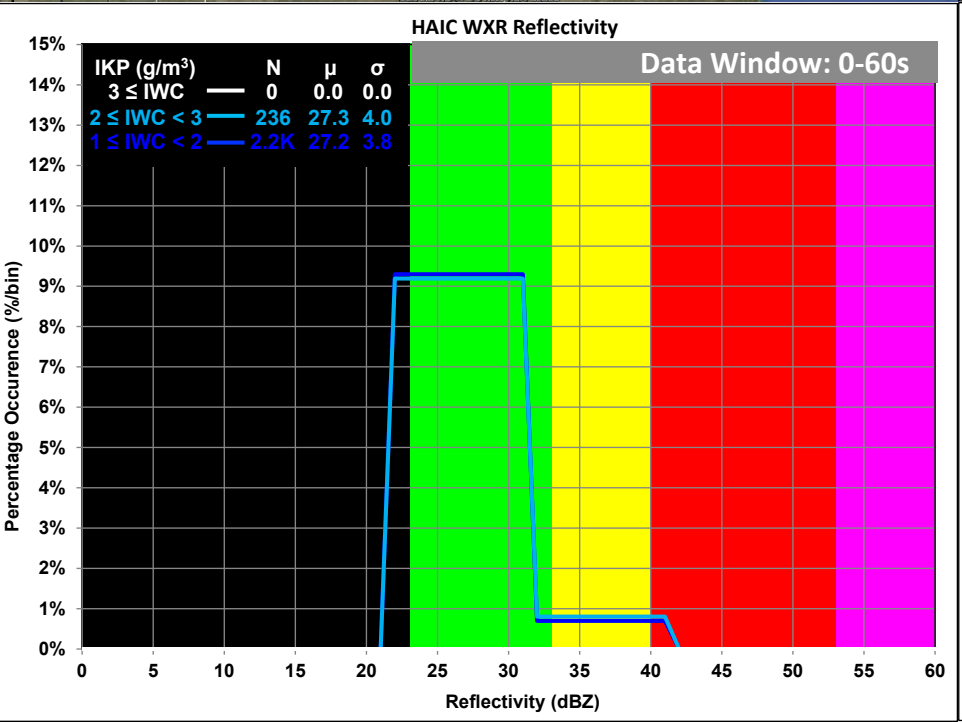

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 616 29.4 7.4
2 ≤ IWC < 3 21K 23.7 6.0
1 ≤ IWC < 2 45K 19.5 6.7
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

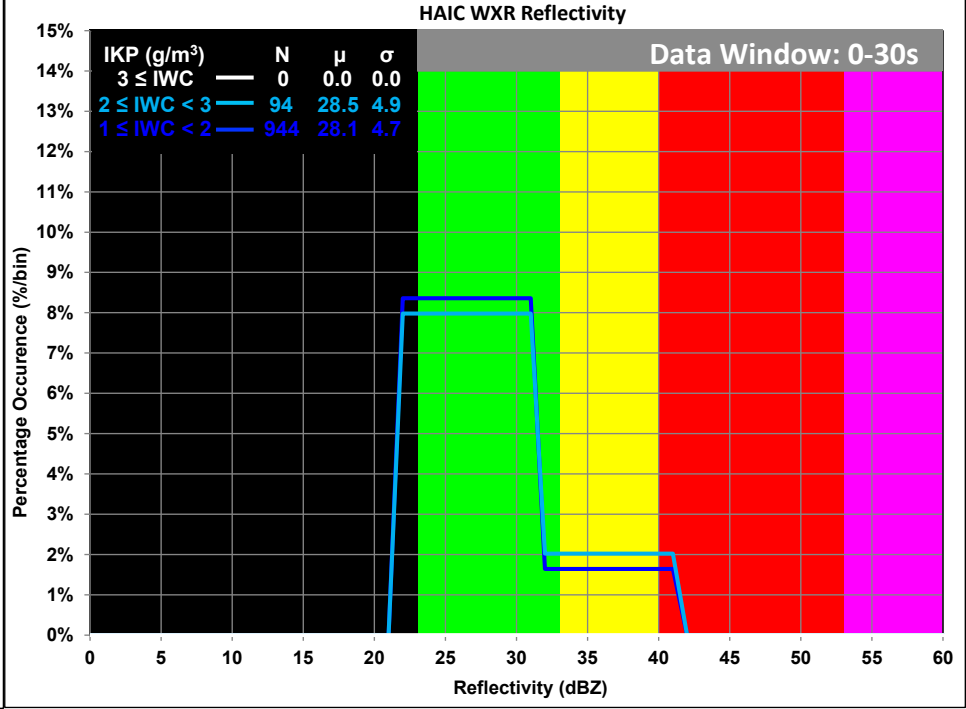

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 4.0K 29.8 6.9
2 ≤ IWC < 3 166K 24.4 6.2
1 ≤ IWC < 2 377K 20.4 6.9
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

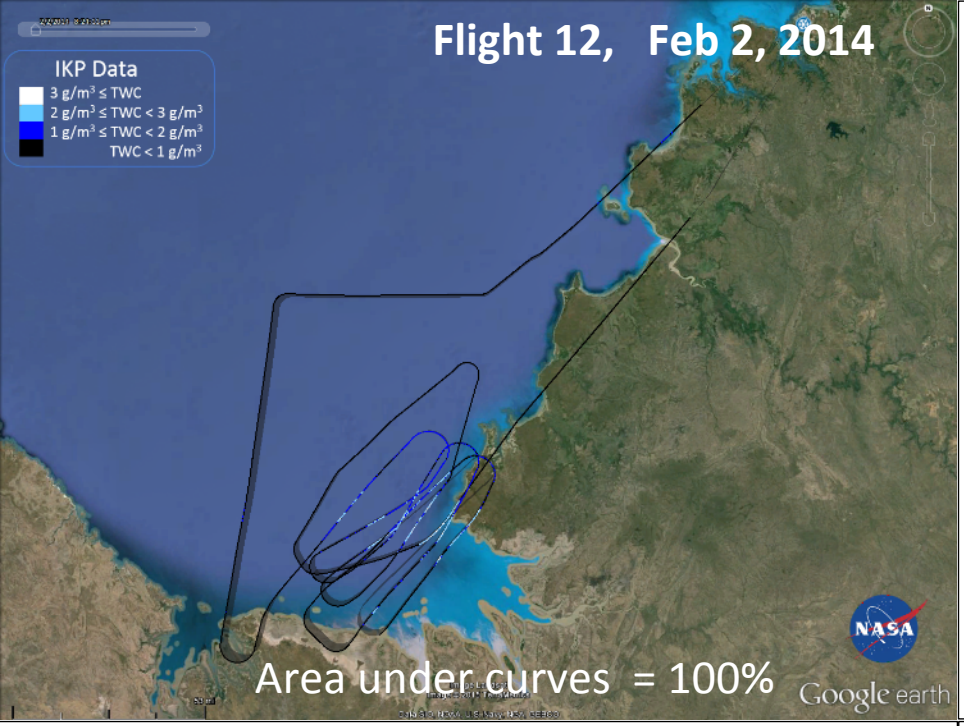

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 2.5K 29.3 7.6
2 ≤ IWC < 3 113K 24.1 6.4
1 ≤ IWC < 2 245K 20.2 6.8
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

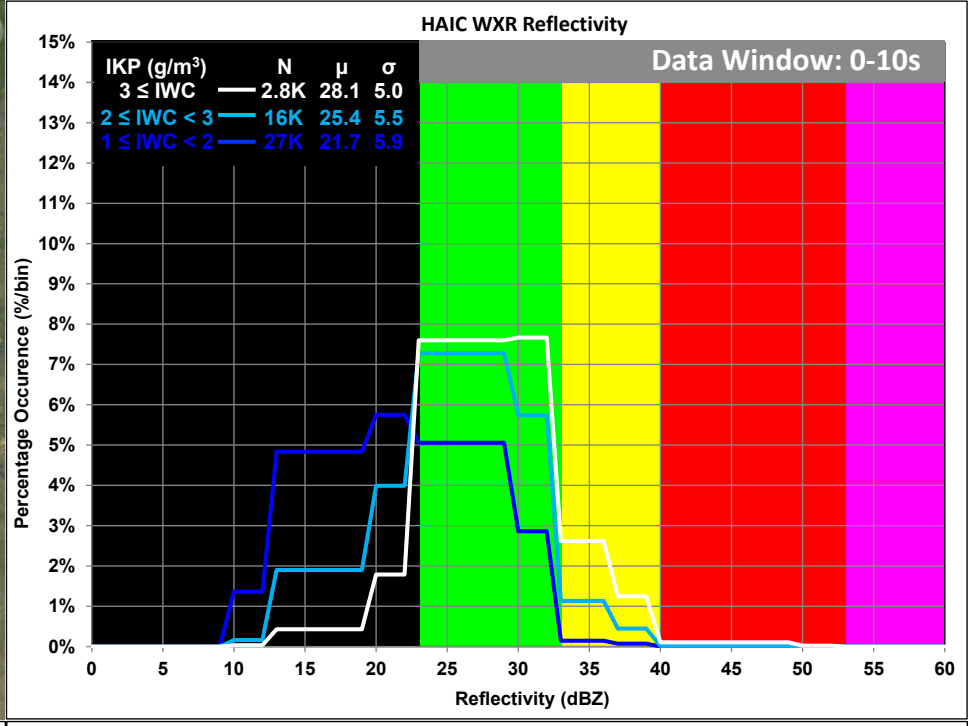

Flight 11, Jan 30, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
NASA
Google earth

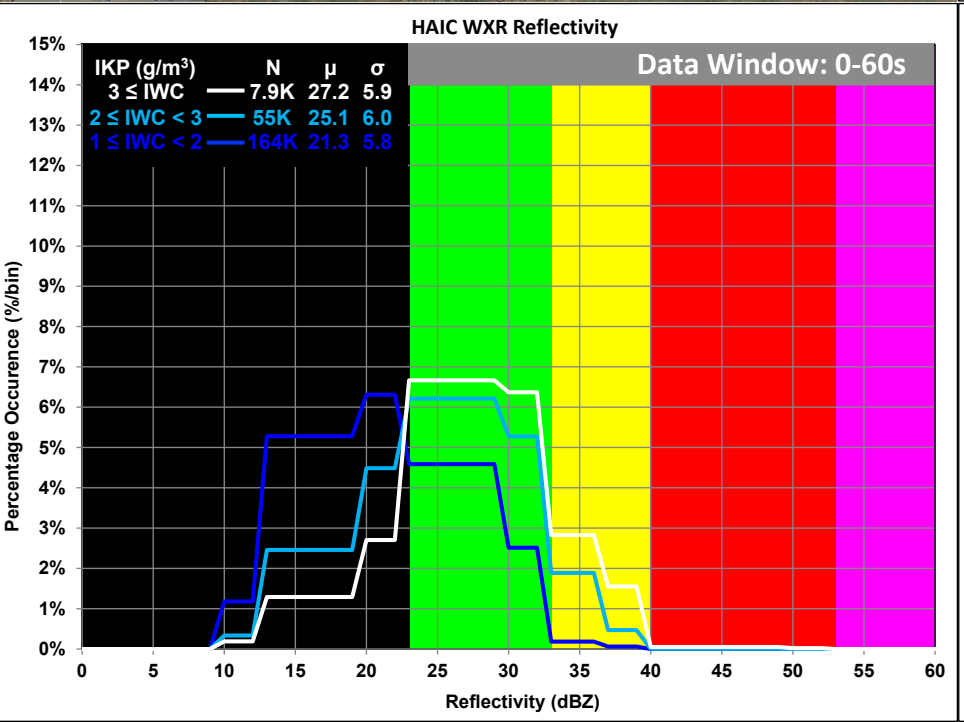

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 0 0.0 0.0
1 ≤ IWC < 2 92 35.6 4.0
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

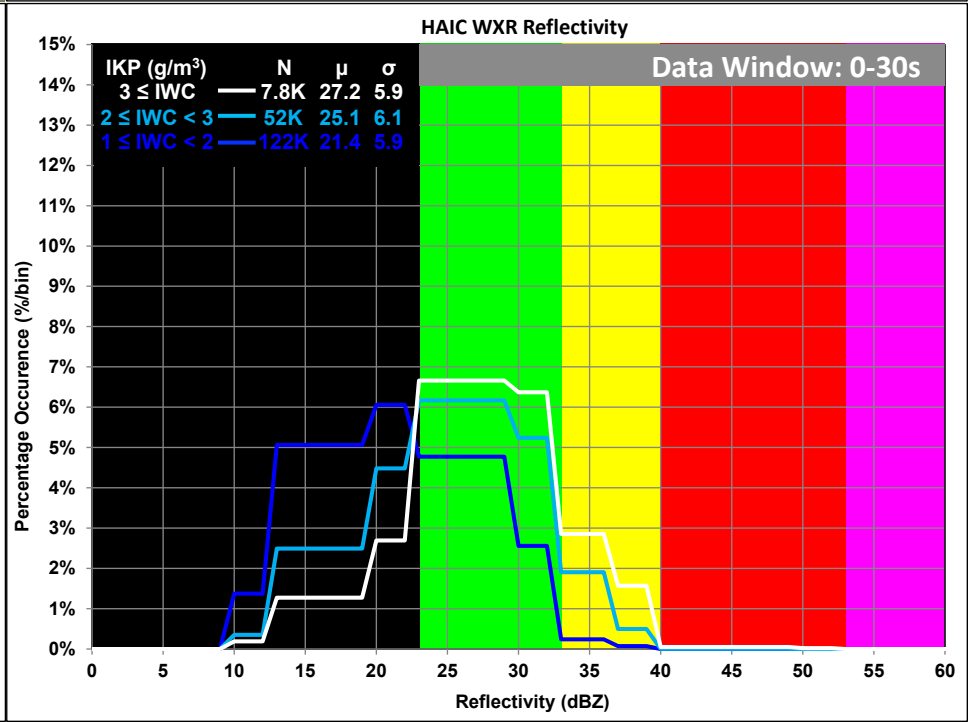

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 236 27.3 4.0
1 ≤ IWC < 2 2.2K 27.2 3.8
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

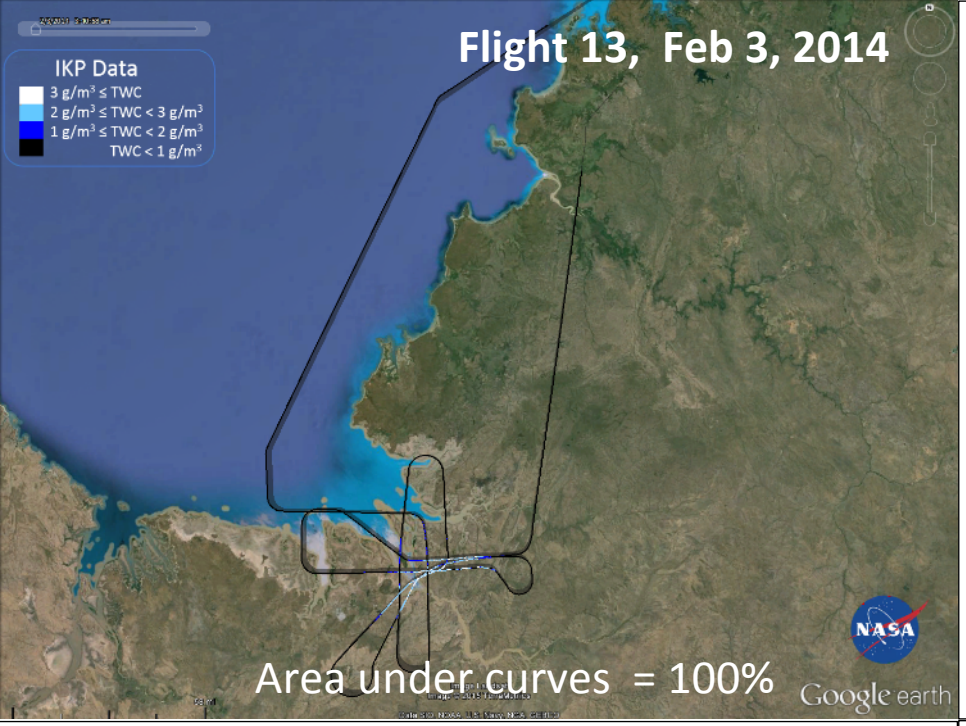

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 94 28.5 4.9
1 ≤ IWC < 2 944 28.1 4.7
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

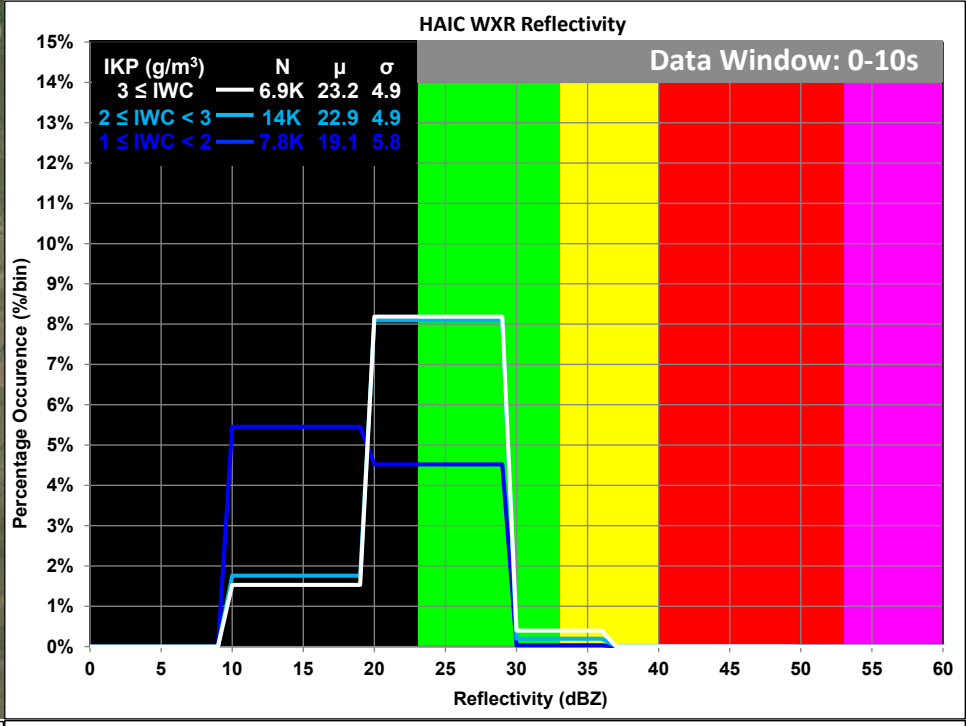

Flight 12, Feb 2, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
NASA
Google earth

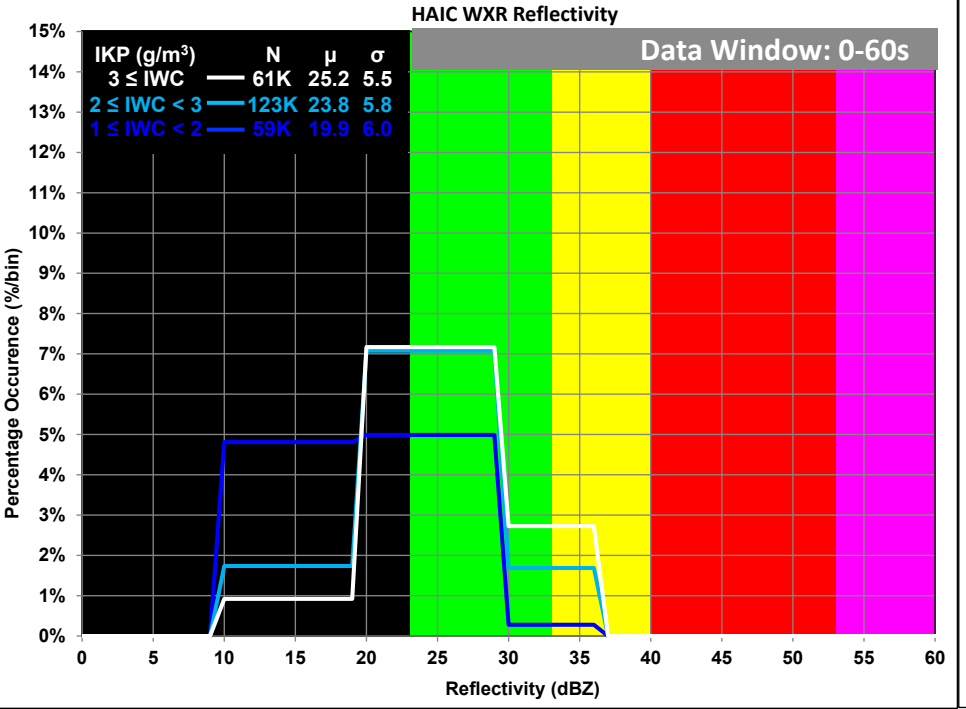

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 2.8K 28.1 5.0
2 ≤ IWC < 3 16K 25.4 5.5
1 ≤ IWC < 2 27K 21.7 5.9
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

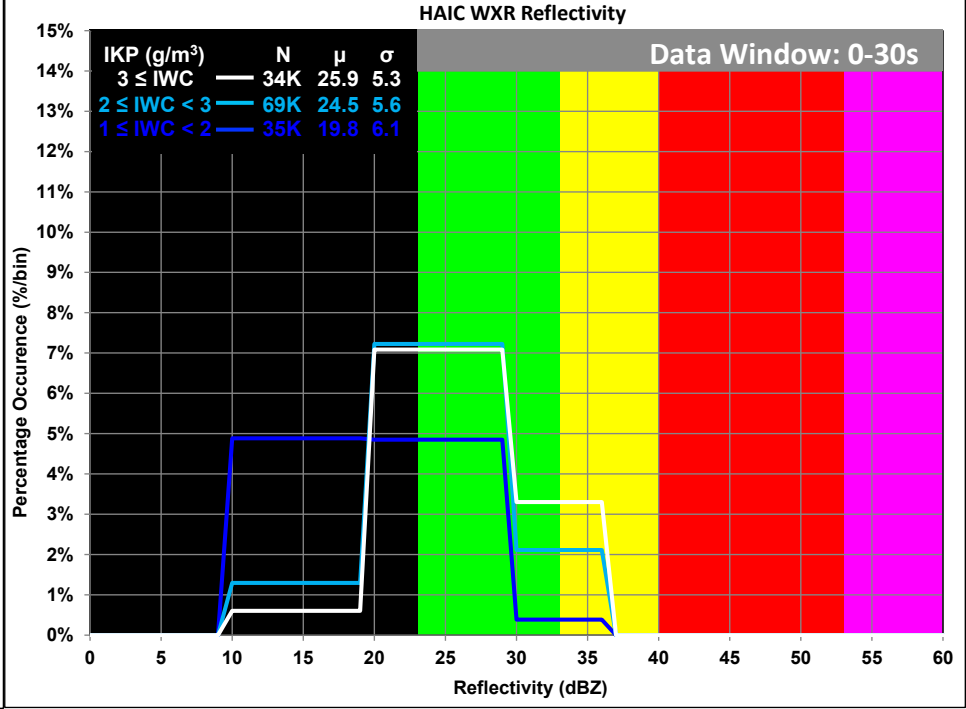

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 7.9K 27.2 5.9
2 ≤ IWC < 3 55K 25.1 6.0
1 ≤ IWC < 2 164K 21.3 5.8
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

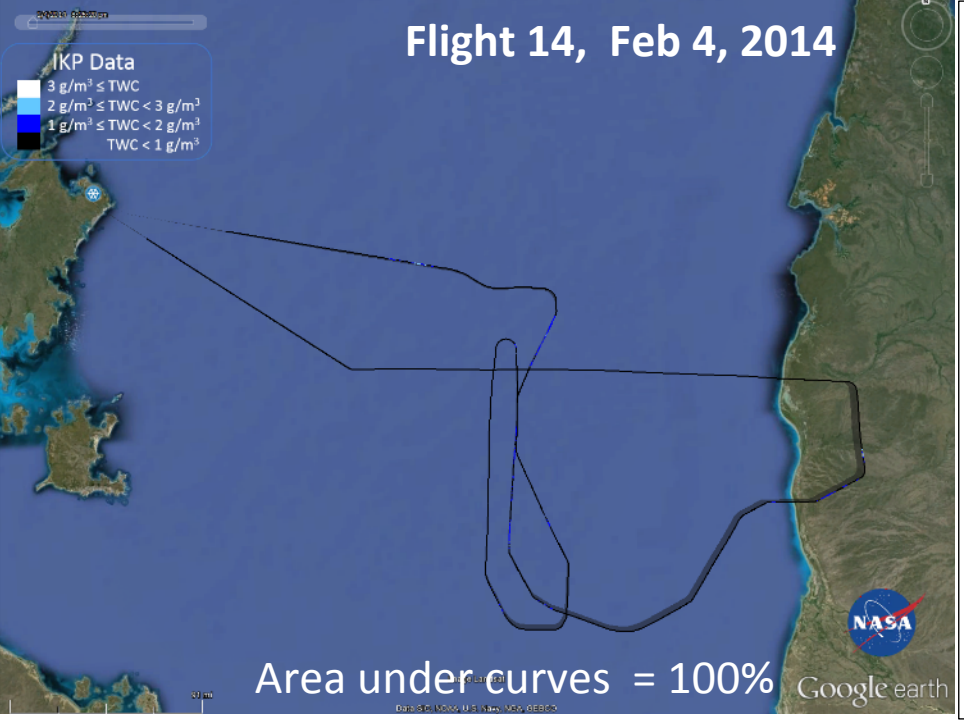

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 7.8K 27.2 5.9
2 ≤ IWC < 3 52K 25.1 6.1
1 ≤ IWC < 2 122K 21.4 5.9
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

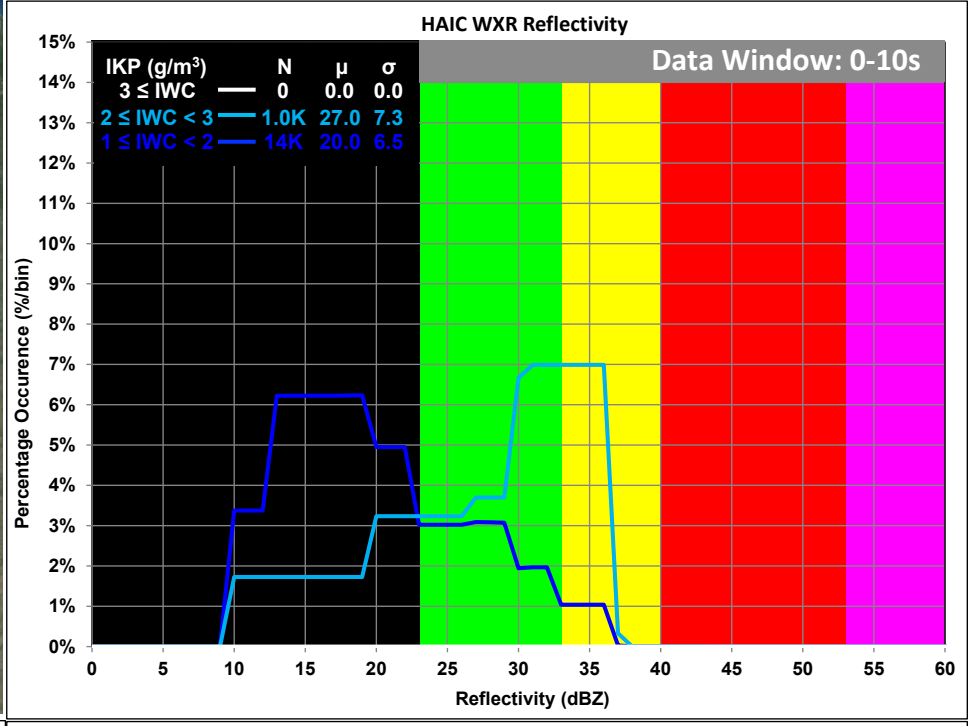

Flight 13, Feb 3, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
NASA
Google earth

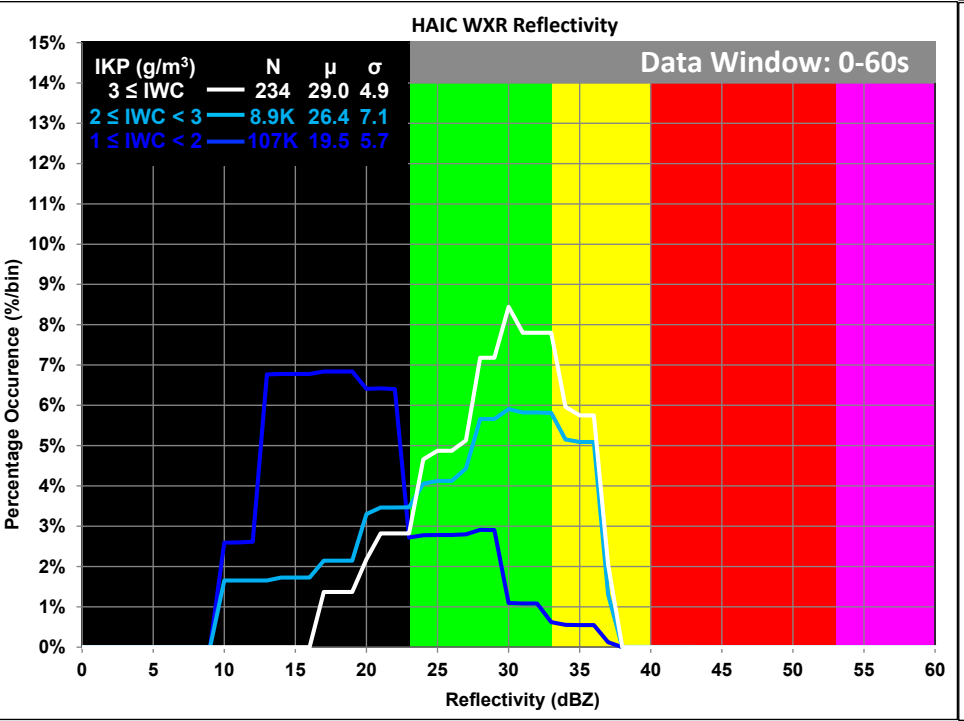

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 6.9K 23.2 4.9
2 ≤ IWC < 3 14K 22.9 4.9
1 ≤ IWC < 2 7.8K 19.1 5.8
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

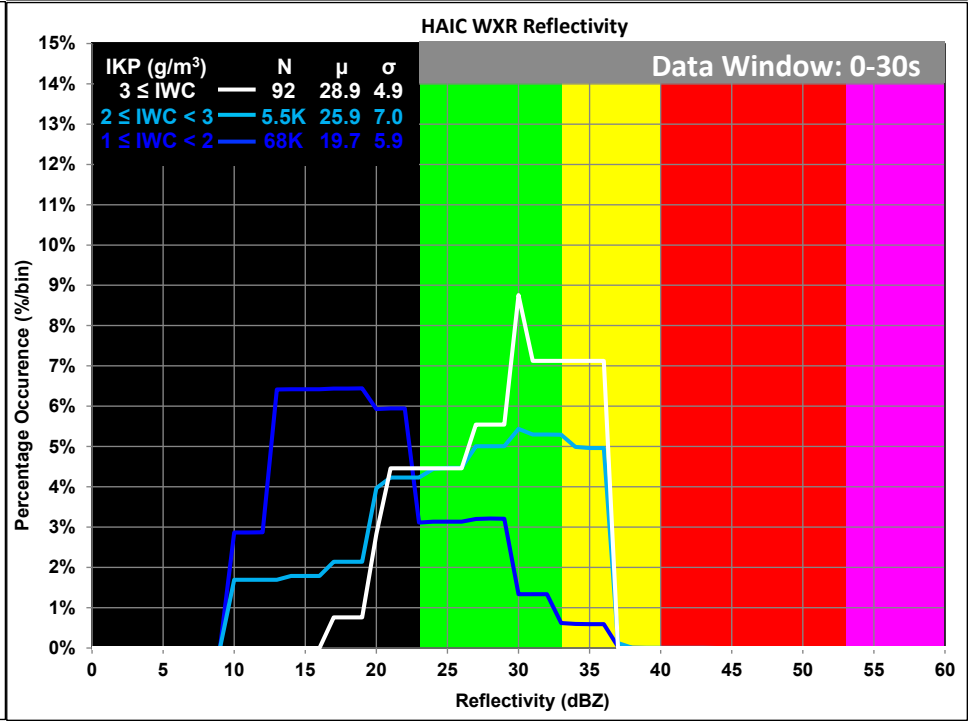

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 61K 25.2 5.5
2 ≤ IWC < 3 123K 23.8 5.8
1 ≤ IWC < 2 59K 19.9 6.0
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

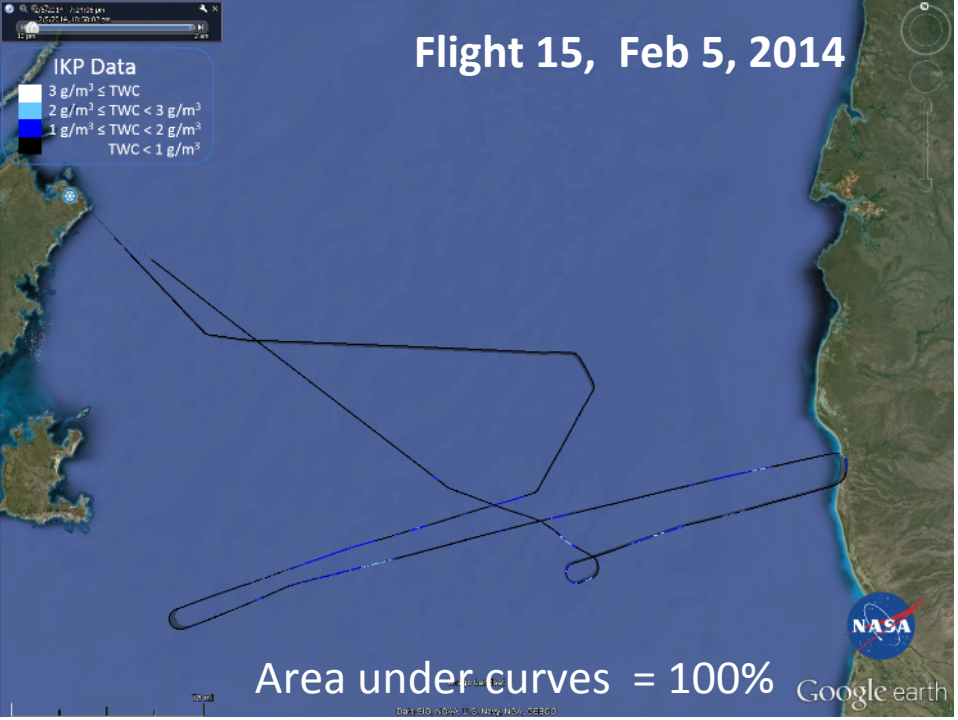

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 34K 25.9 5.3
2 ≤ IWC < 3 69K 24.5 5.6
1 ≤ IWC < 2 35K 19.8 6.1
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

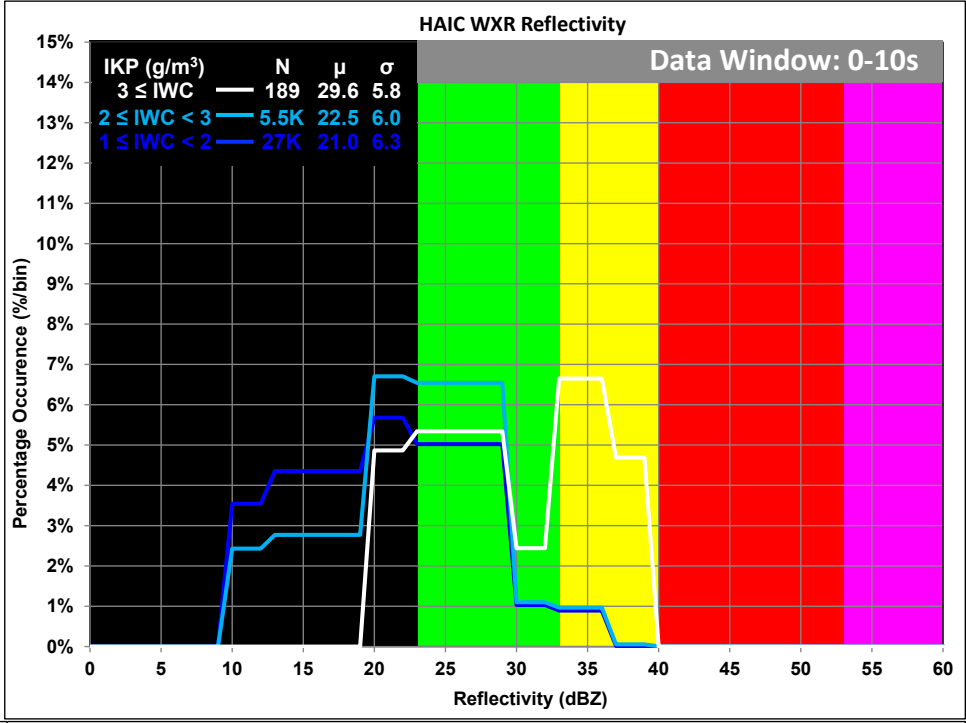

Flight 14, Feb 4, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
Google earth

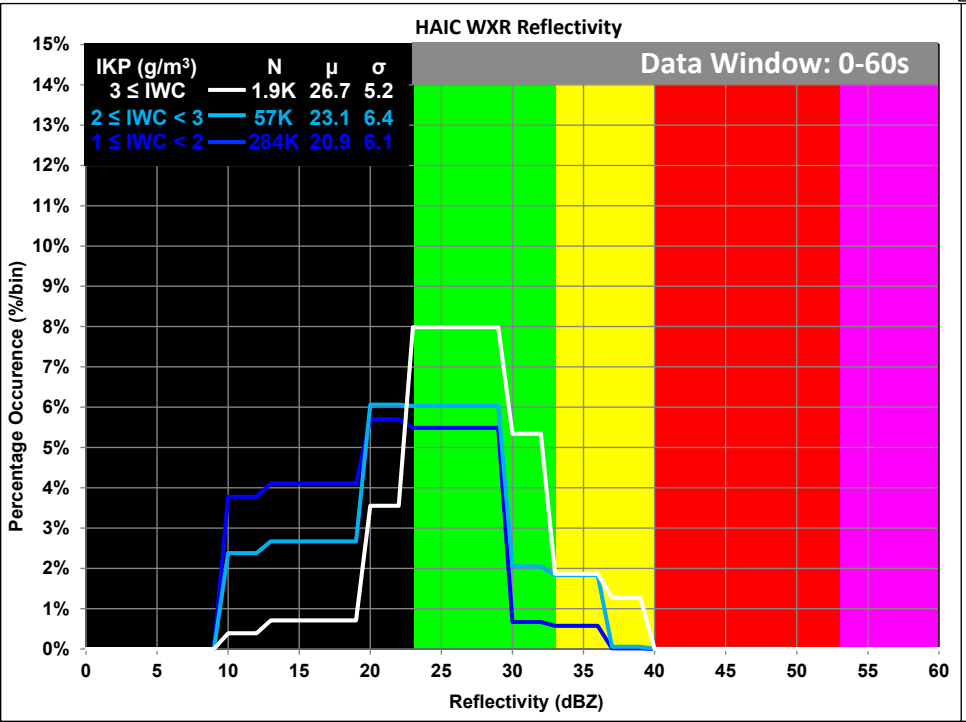

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 1.0K 27.0 7.3
1 ≤ IWC < 2 14K 20.0 6.5
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

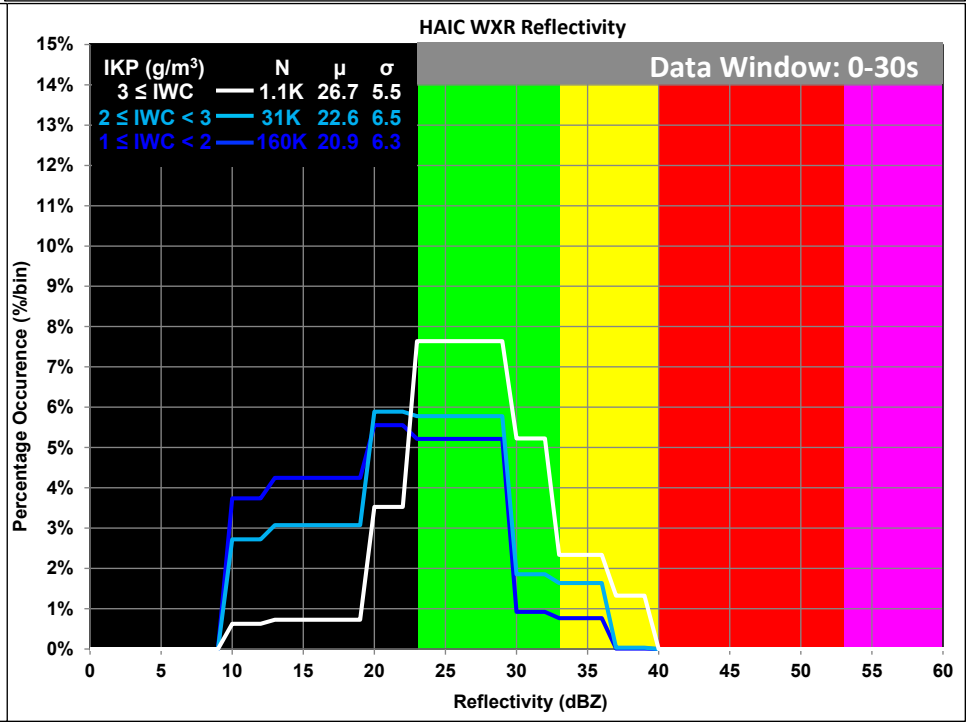

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 234 29.0 4.9
2 ≤ IWC < 3 8.9K 26.4 7.1
1 ≤ IWC < 2 107K 19.5 5.7
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

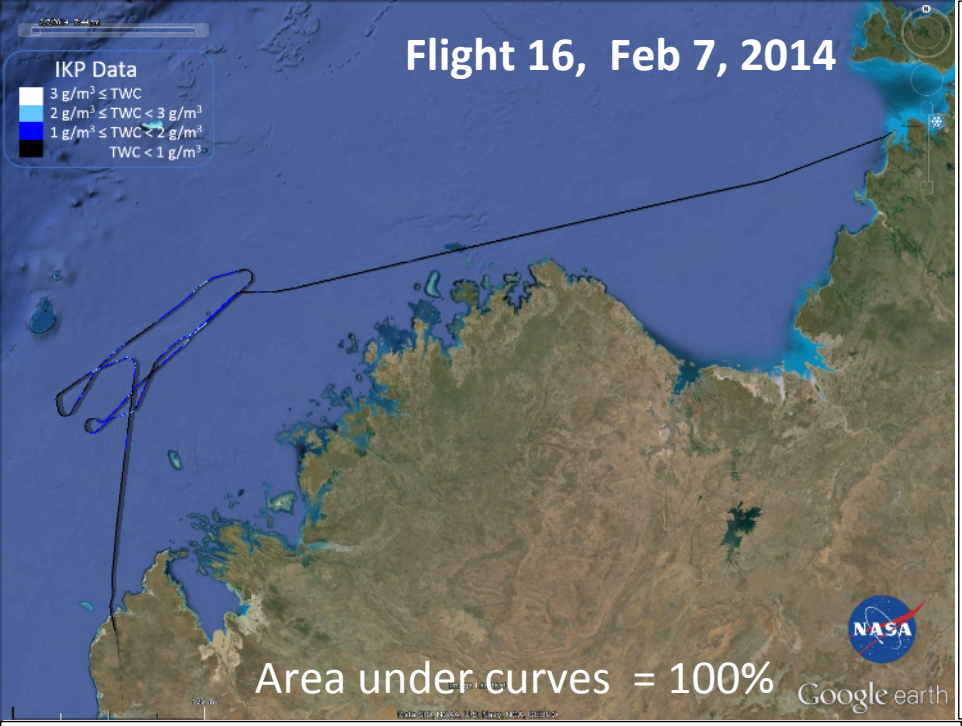

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 92 28.9 4.9
2 ≤ IWC < 3 5.5K 25.9 7.0
1 ≤ IWC < 2 68K 19.7 5.9
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

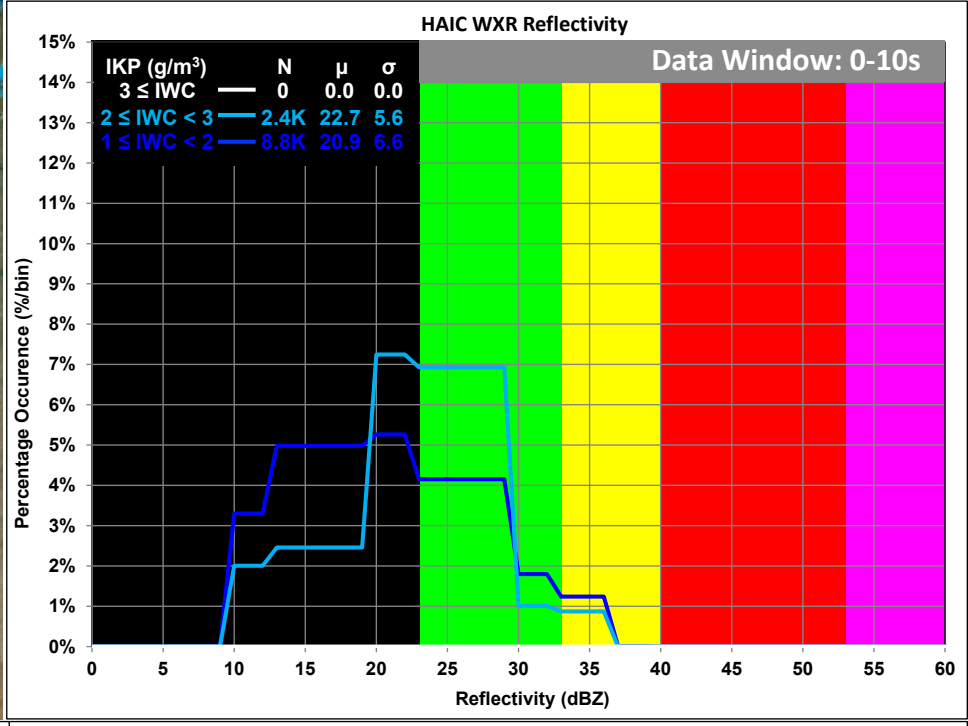

Flight 15, Feb 5, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
Google earth

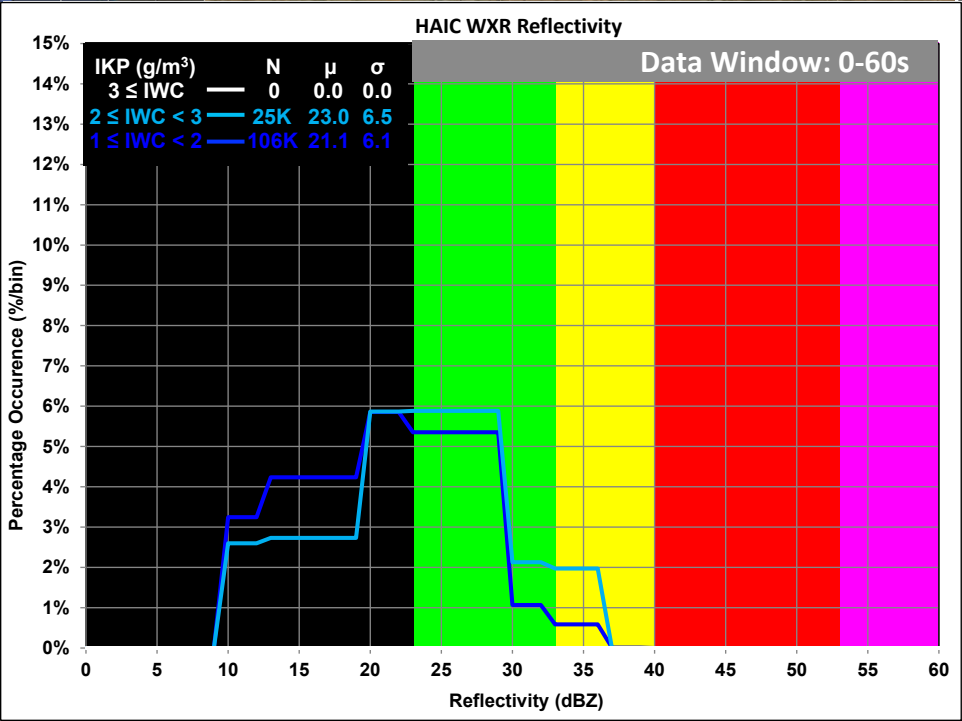

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 189 29.6 5.8
2 ≤ IWC < 3 5.5K 22.5 6.0
1 ≤ IWC < 2 27K 21.0 6.3
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

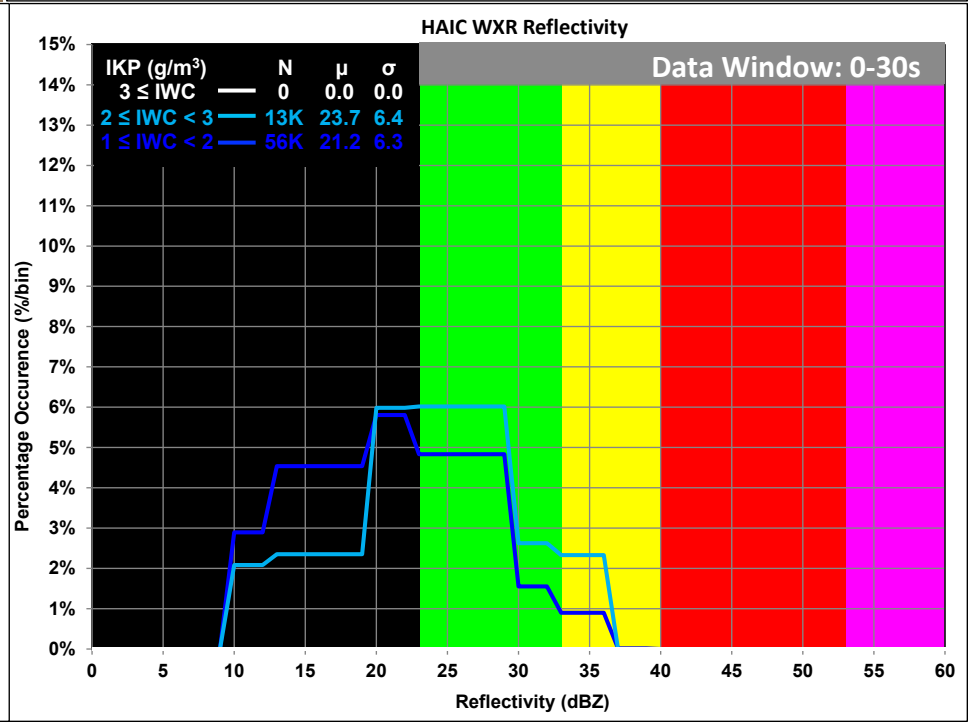

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 1.9K 26.7 5.2
2 ≤ IWC < 3 57K 23.1 6.4
1 ≤ IWC < 2 284K 20.9 6.1
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

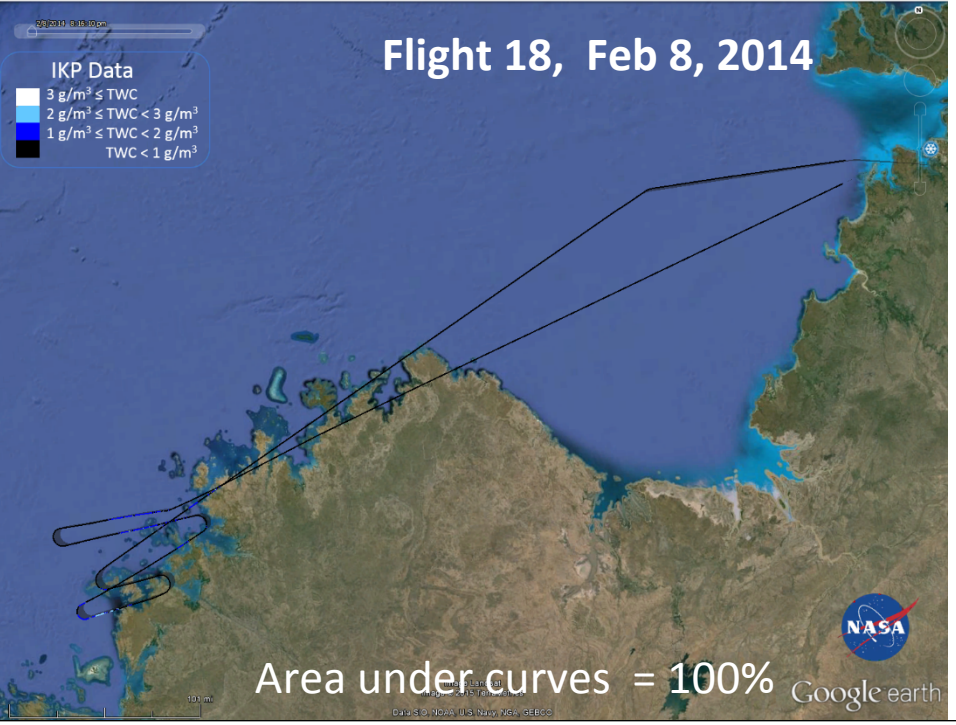

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 1.1K 26.7 5.5
2 ≤ IWC < 3 31K 22.6 6.5
1 ≤ IWC < 2 160K 20.9 6.3
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

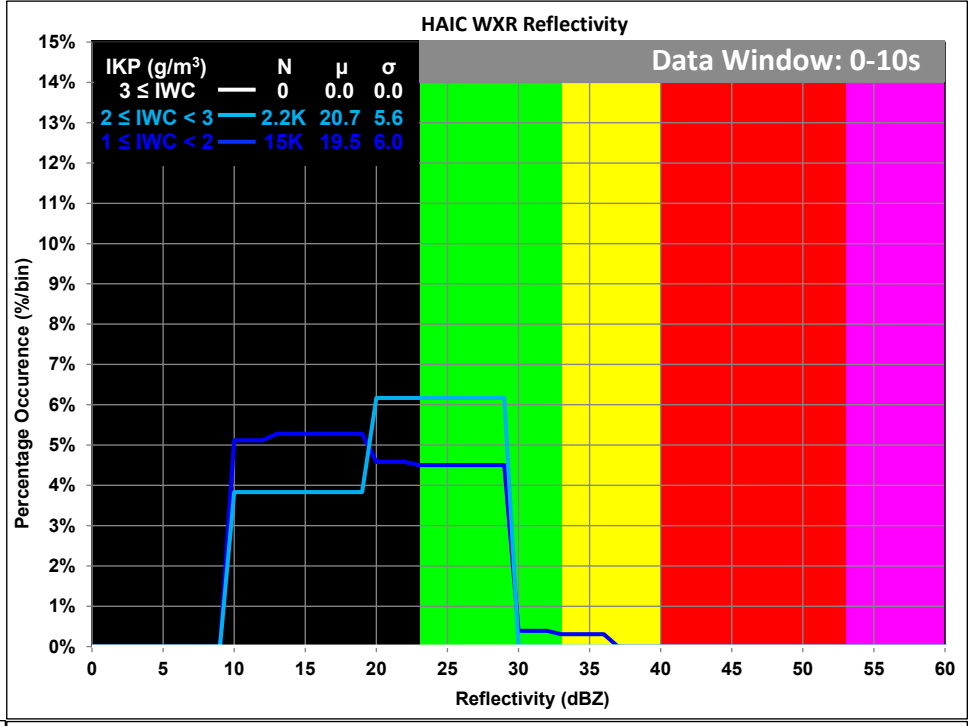

Flight 16, Feb 7, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
Google earth

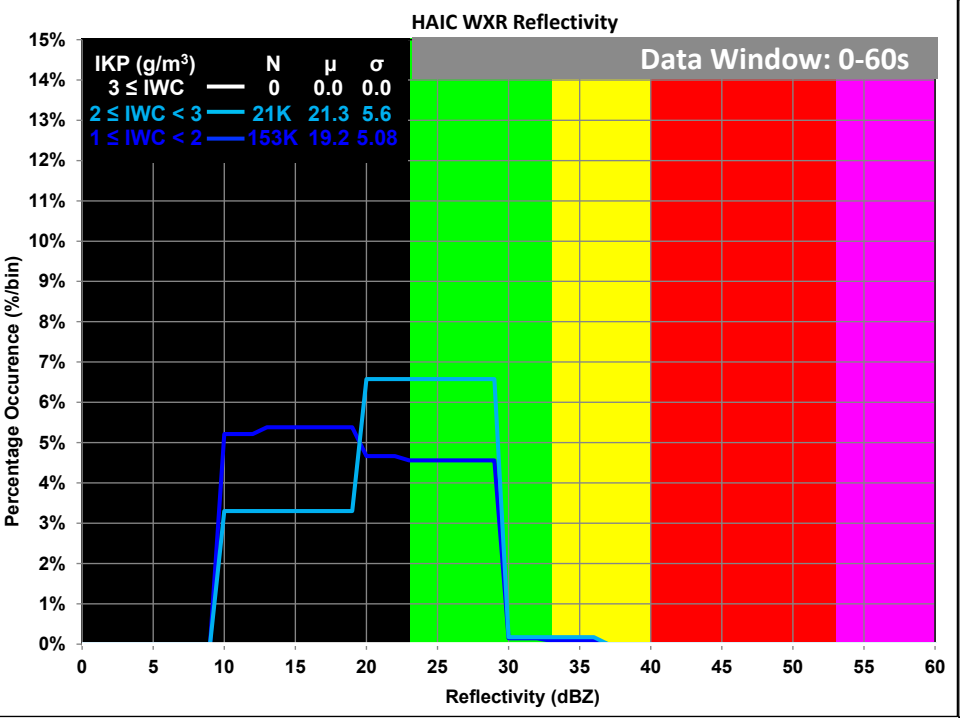

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 2.4K 22.7 5.6
1 ≤ IWC < 2 8.8K 20.9 6.6
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

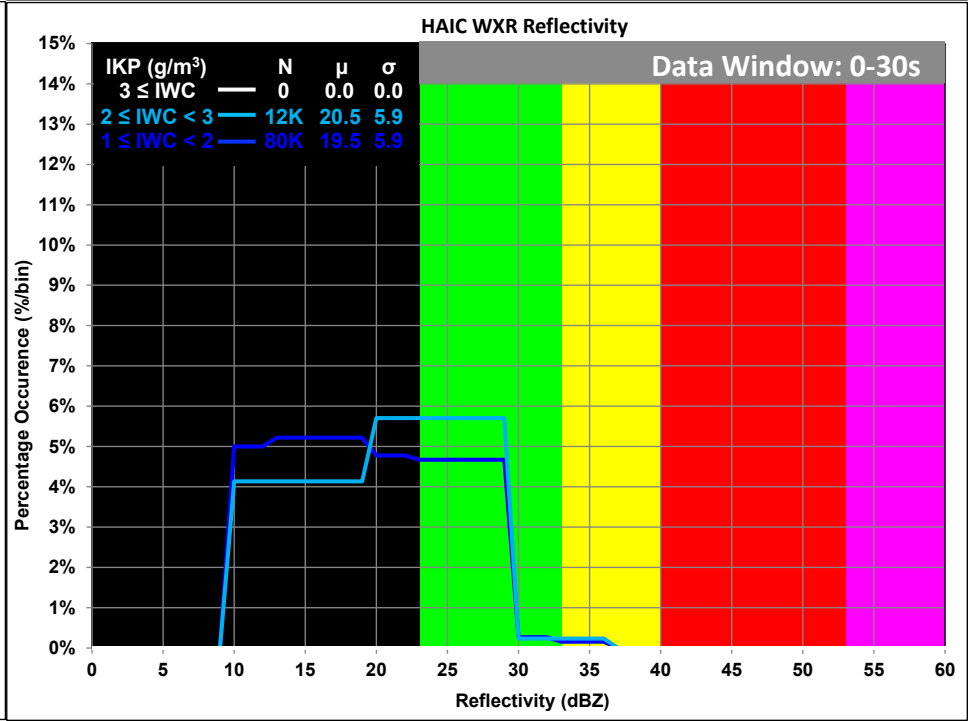

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 25K 23.0 6.5
1 ≤ IWC < 2 106K 21.1 6.1
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

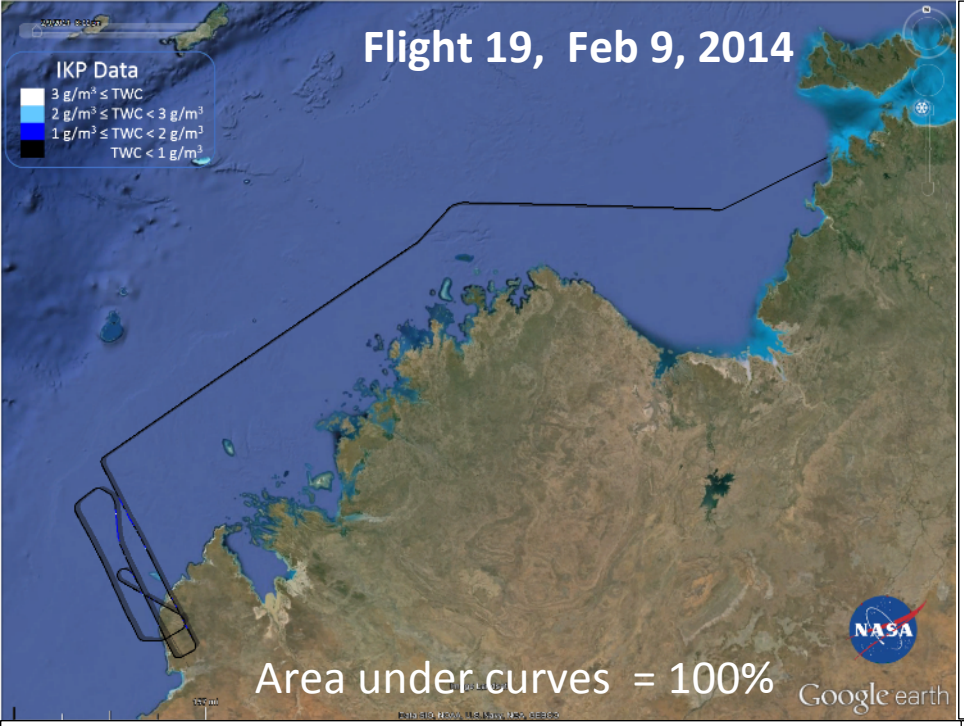

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 13K 23.7 6.4
1 ≤ IWC < 2 56K 21.2 6.3
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

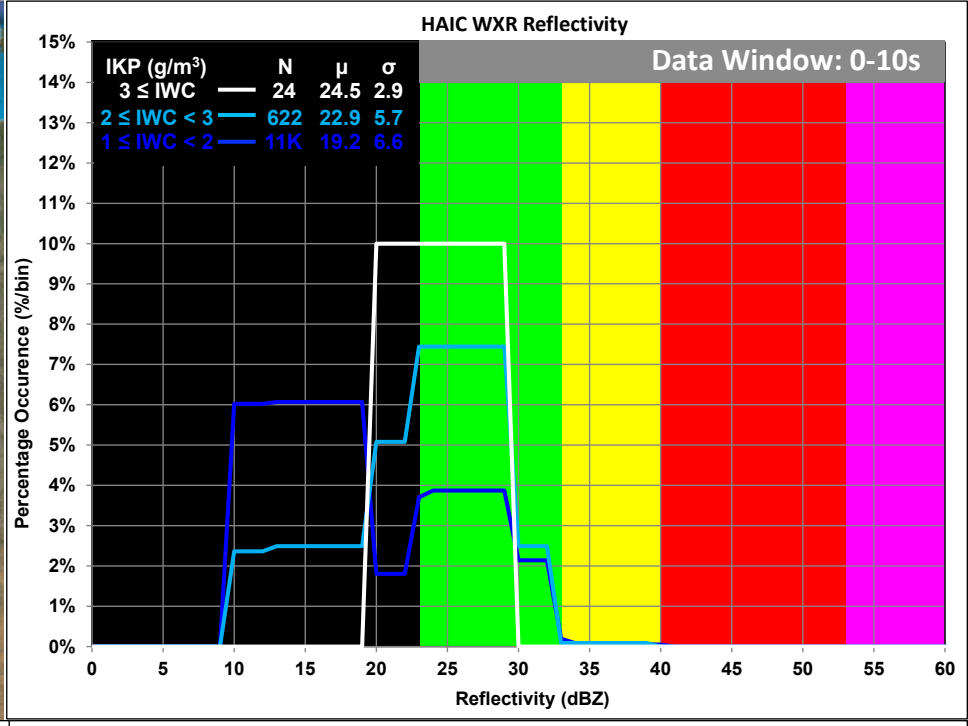

Flight 18, Feb 8, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
Google earth

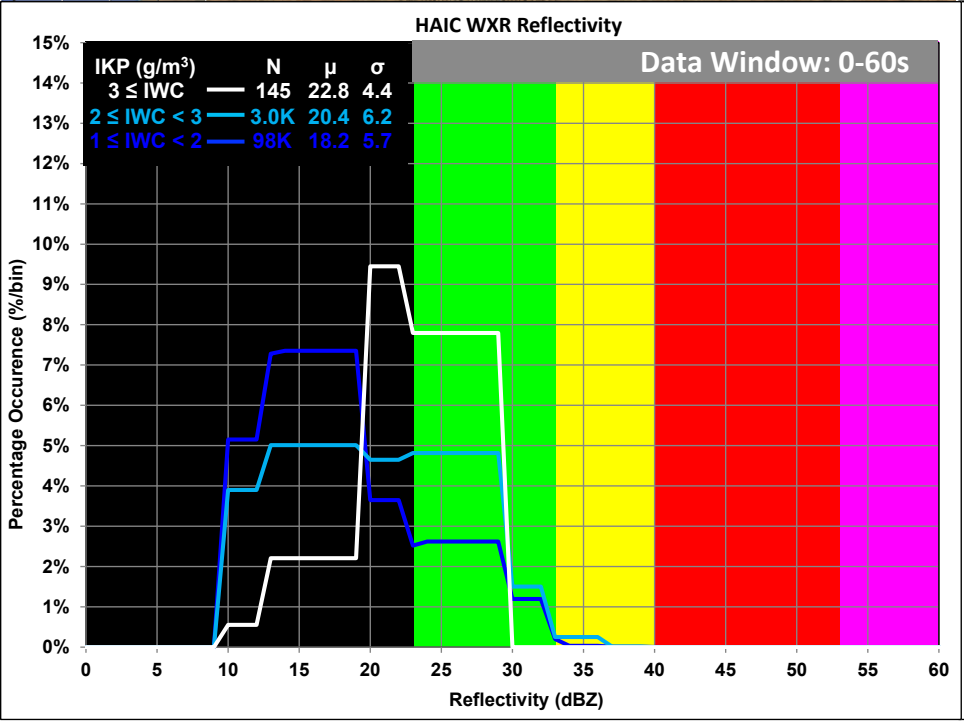

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 2.2K 20.7 5.6
1 ≤ IWC < 2 15K 19.5 6.0
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

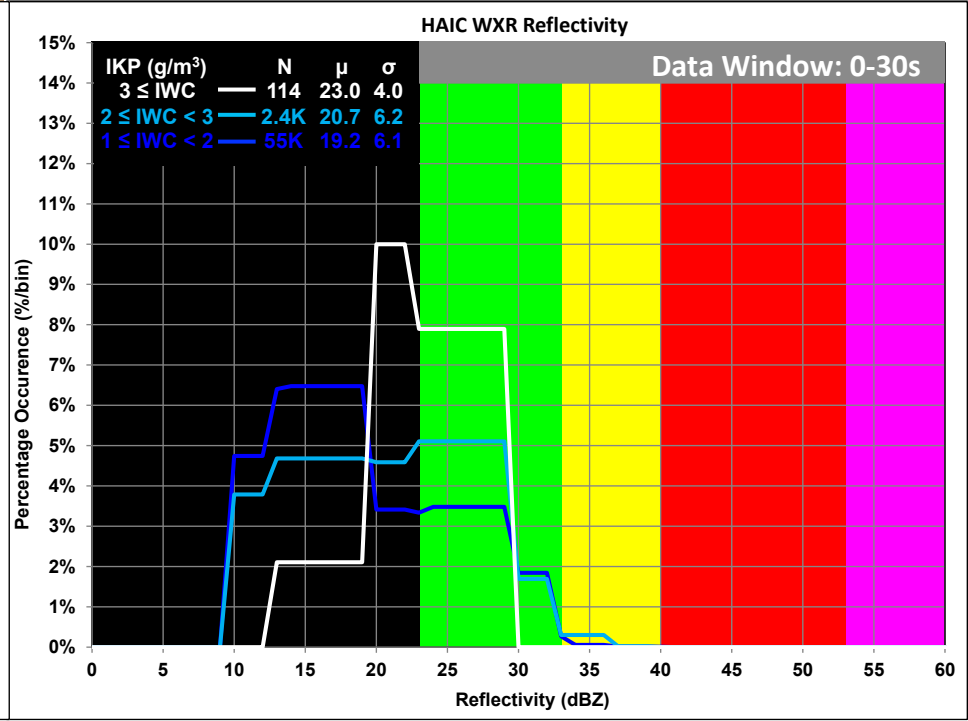

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 21K 21.3 5.6
1 ≤ IWC < 2 153K 19.2 5.08
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

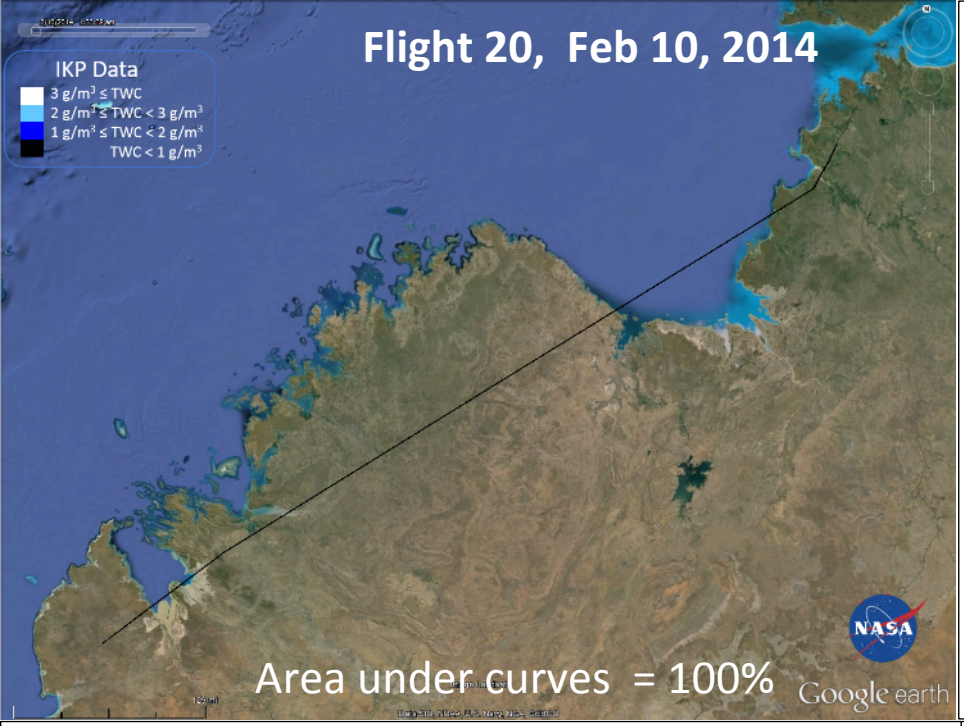

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 12K 20.5 5.9
1 ≤ IWC < 2 80K 19.5 5.9
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

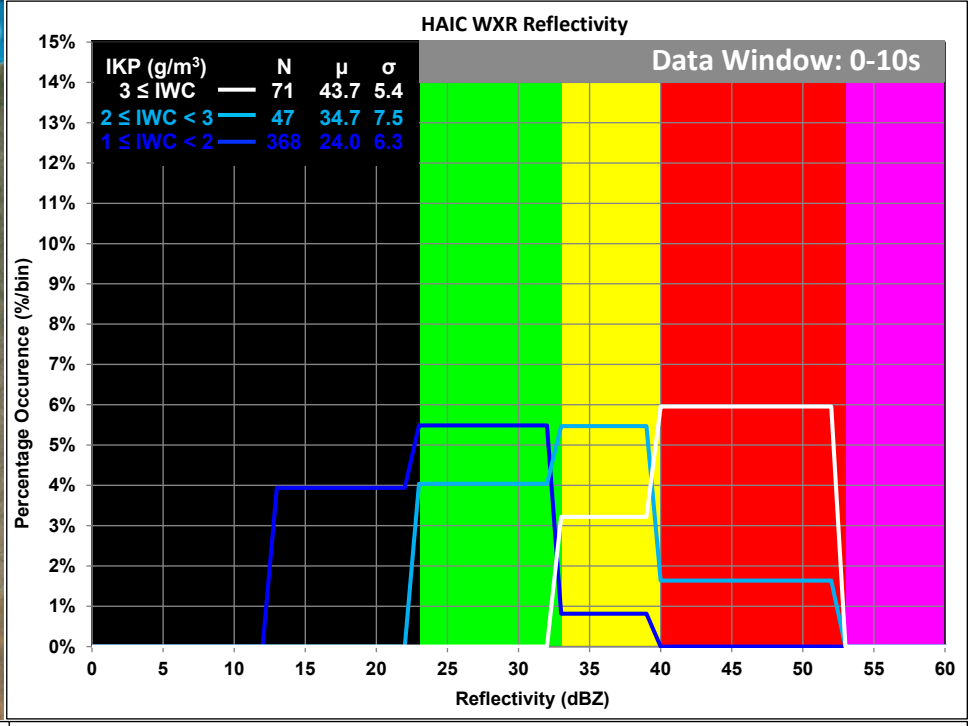

Flight 19, Feb 9, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
NASA
Google earth

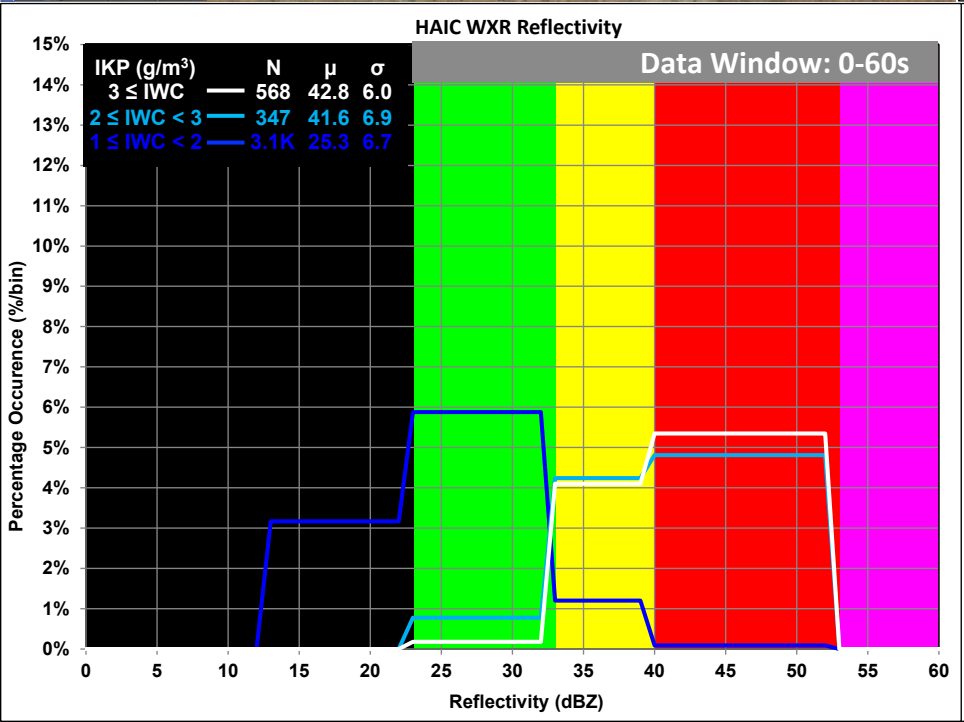

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 24 24.5 2.9
2 ≤ IWC < 3 622 22.9 5.7
1 ≤ IWC < 2 11K 19.2 6.6
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

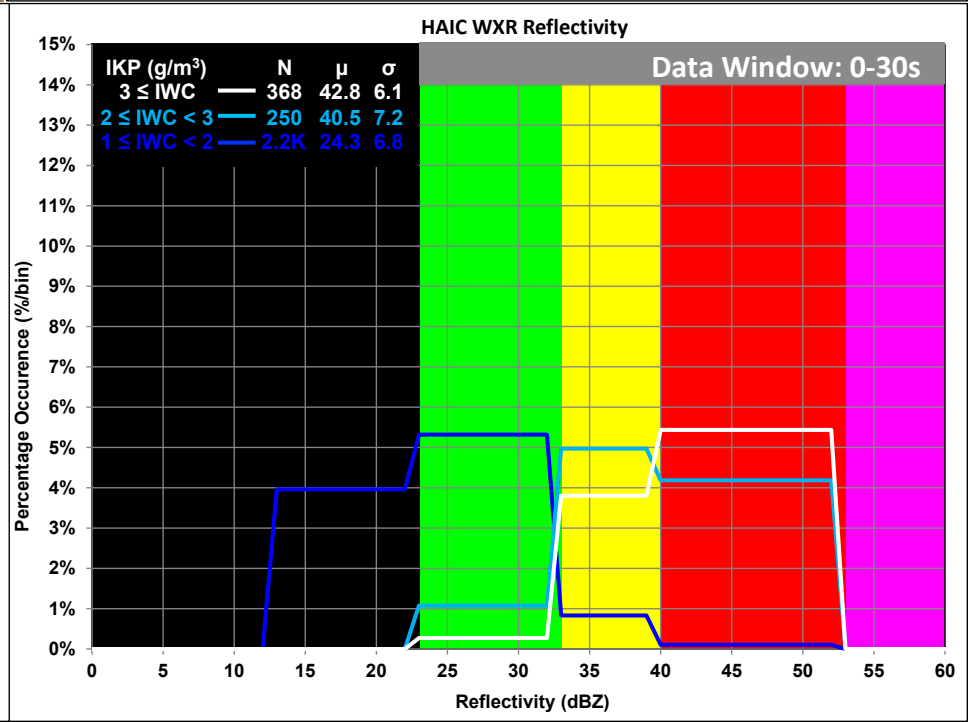

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 145 22.8 4.4
2 ≤ IWC < 3 3.0K 20.4 6.2
1 ≤ IWC < 2 98K 18.2 5.7
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

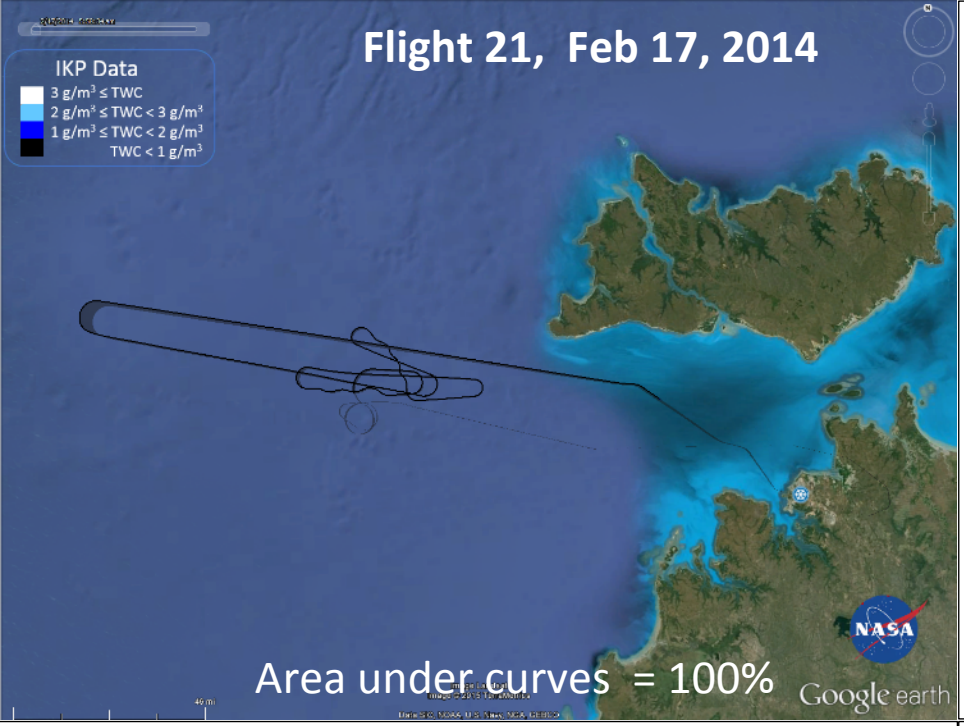

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 114 23.0 4.0
2 ≤ IWC < 3 2.4K 20.7 6.2
1 ≤ IWC < 2 55K 19.2 6.1
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

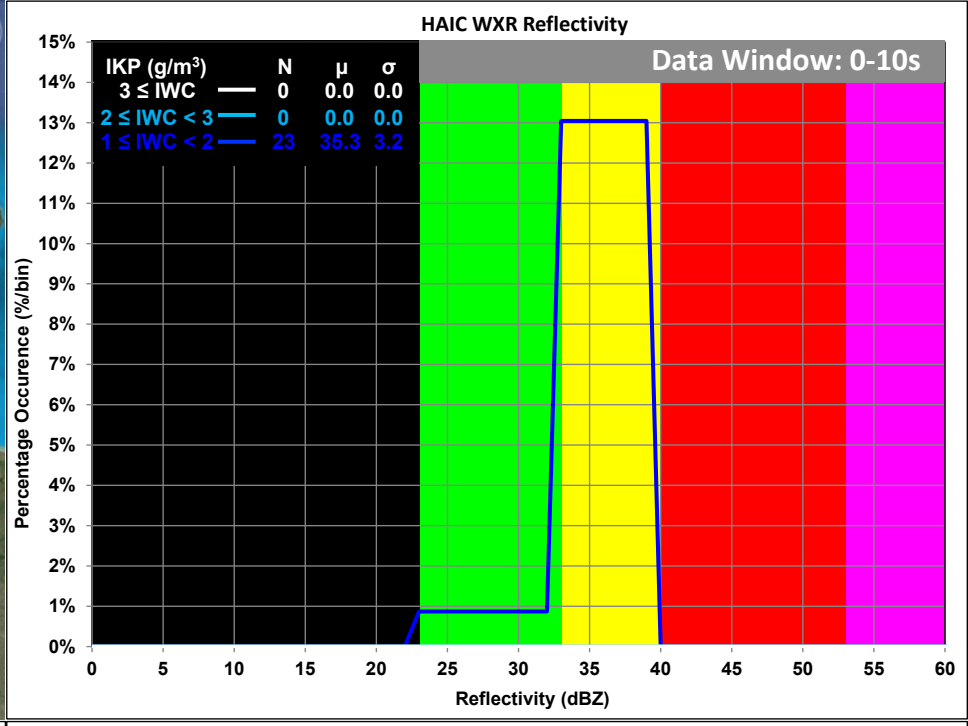

Flight 20, Feb 10, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
NASA
Google earth

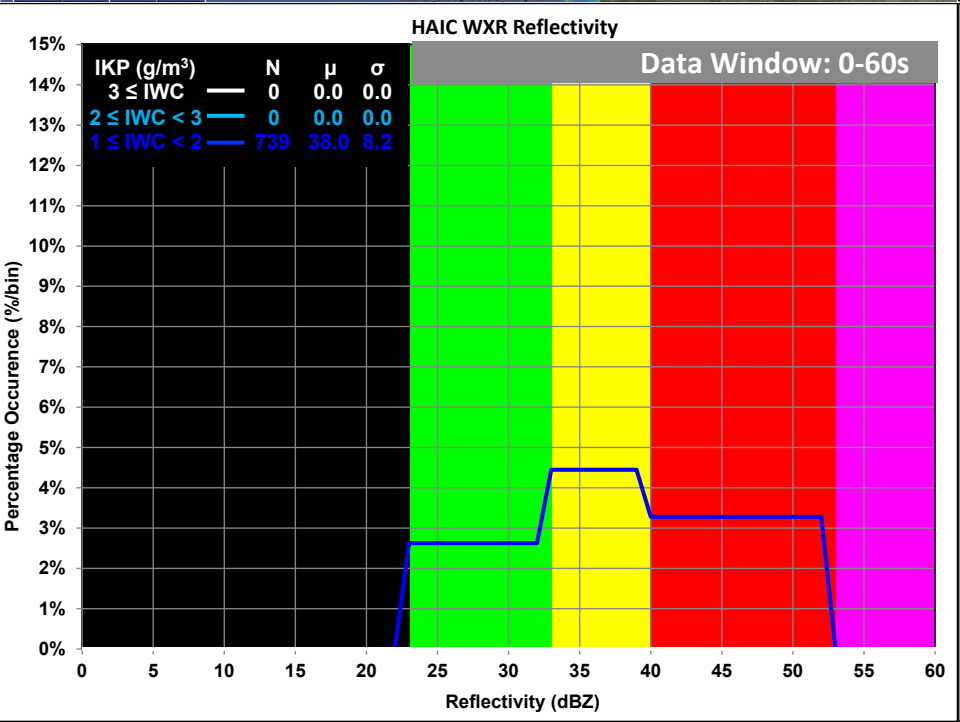

HAIC WXR Reflectivity
Data Window: 0-10s
IKP (g/m³) N μ σ
3 ≤ IWC 71 43.7 5.4
2 ≤ IWC < 3 47 34.7 7.5
1 ≤ IWC < 2 368 24.0 6.3
Percentage Occurence (%/bin)
Reflectivity (dBZ)

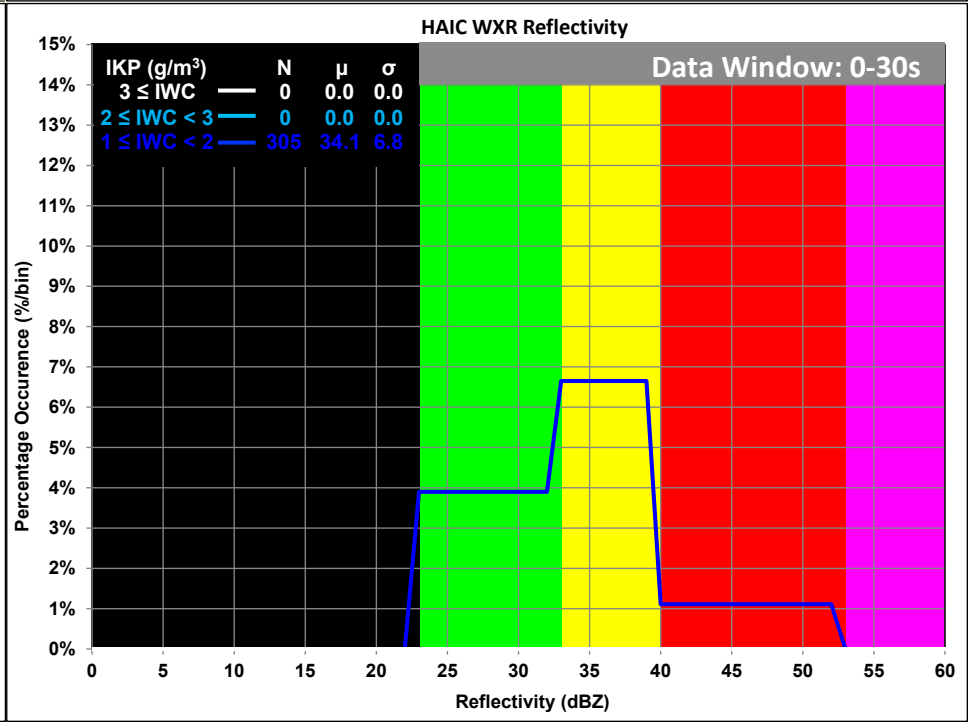

HAIC WXR Reflectivity
Data Window: 0-60s
IKP (g/m³) N μ σ
3 ≤ IWC 568 42.8 6.0
2 ≤ IWC < 3 347 41.6 6.9
1 ≤ IWC < 2 3.1K 25.3 6.7
Percentage Occurence (%/bin)
Reflectivity (dBZ)

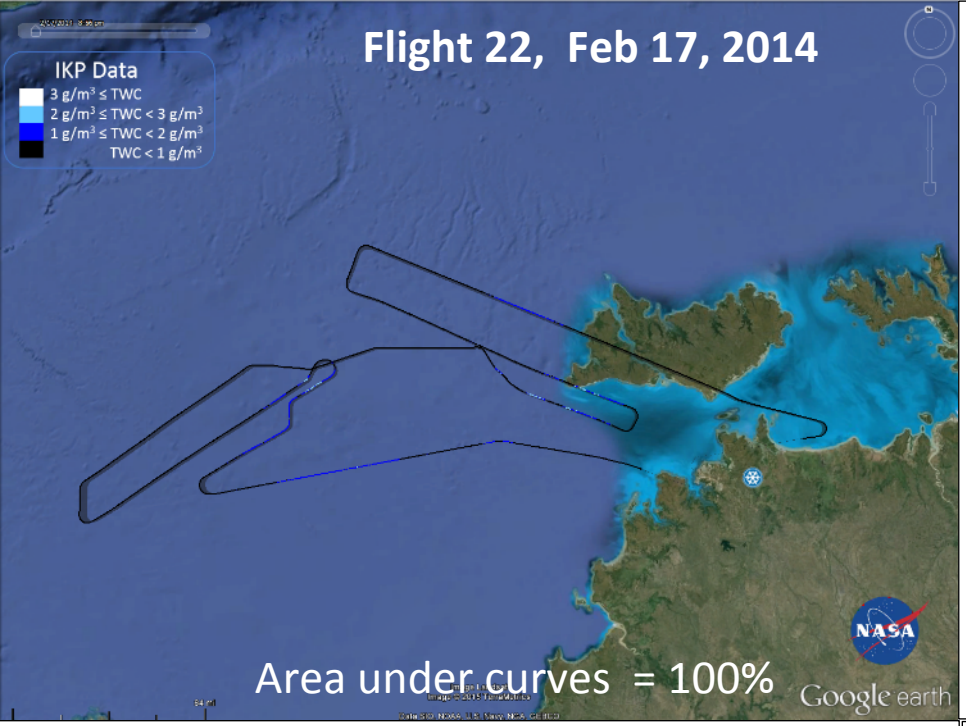

HAIC WXR Reflectivity
Data Window: 0-30s
IKP (g/m³) N μ σ
3 ≤ IWC 368 42.8 6.1
2 ≤ IWC < 3 250 40.5 7.2
1 ≤ IWC < 2 2.2K 24.3 6.8
Percentage Occurence (%/bin)
Reflectivity (dBZ)

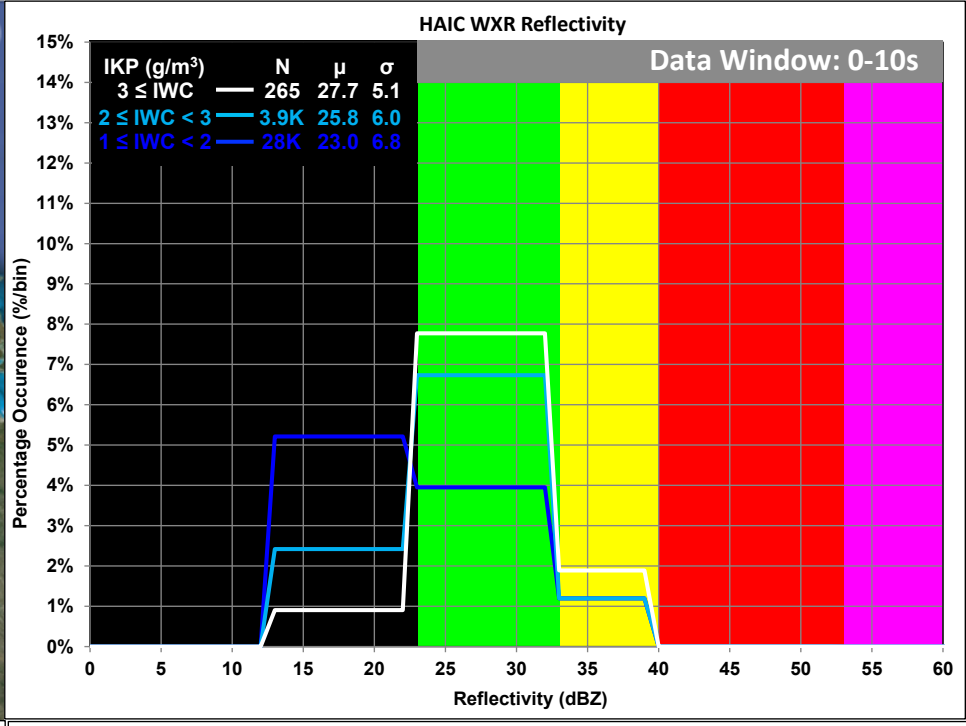

Flight 21, Feb 17, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
Google earth

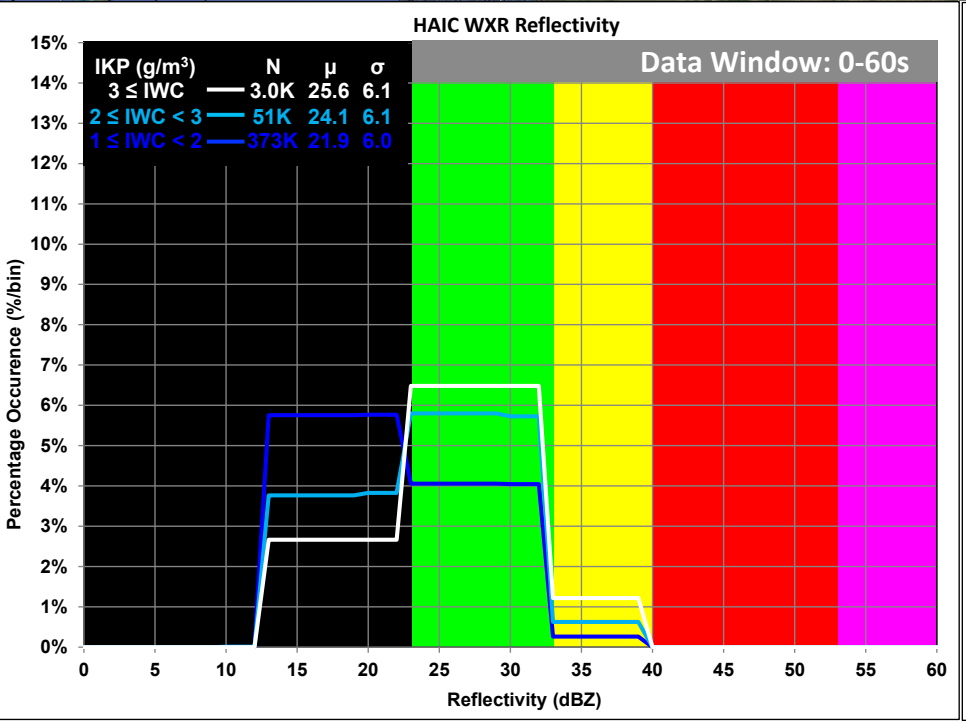

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 0 0.0 0.0
1 ≤ IWC < 2 23 35.3 3.2
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

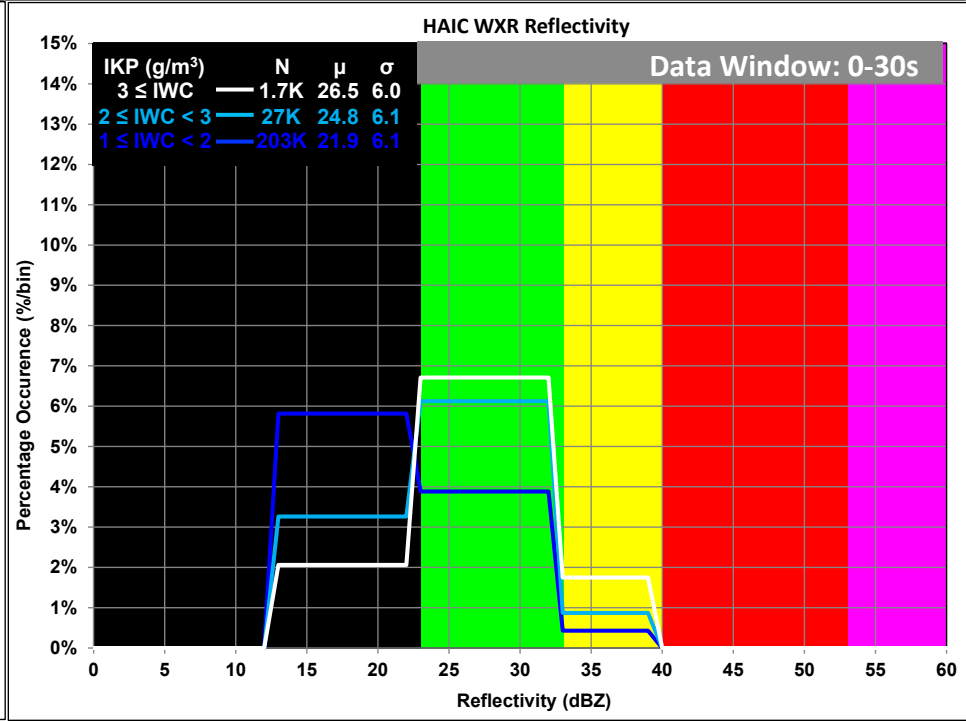

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 0 0.0 0.0
1 ≤ IWC < 2 739 38.0 8.2
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

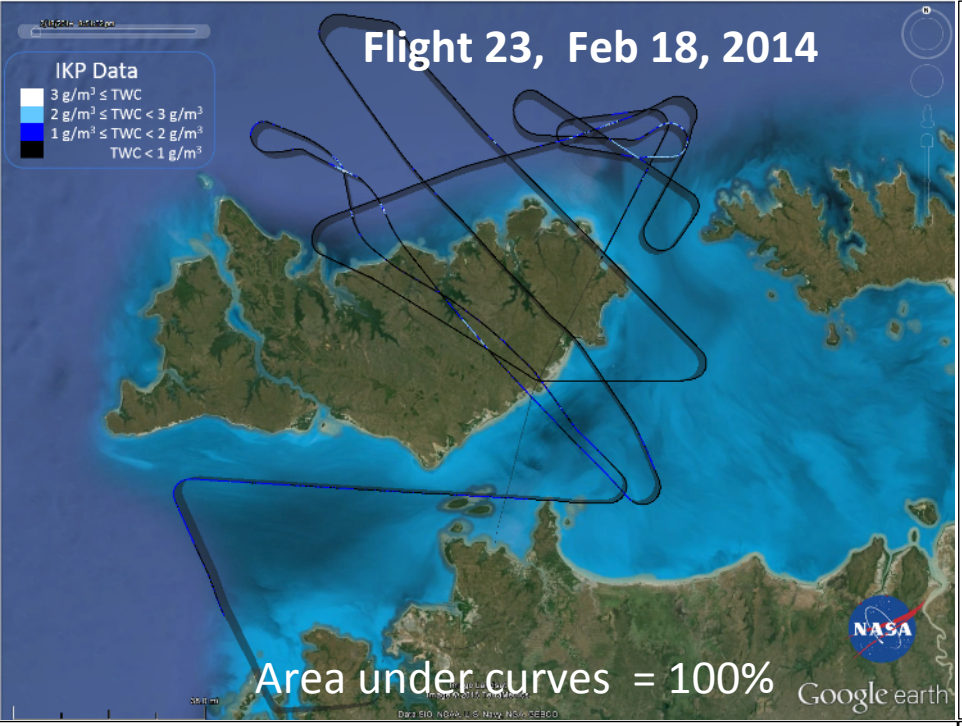

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 0 0.0 0.0
2 ≤ IWC < 3 0 0.0 0.0
1 ≤ IWC < 2 305 34.1 6.8
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

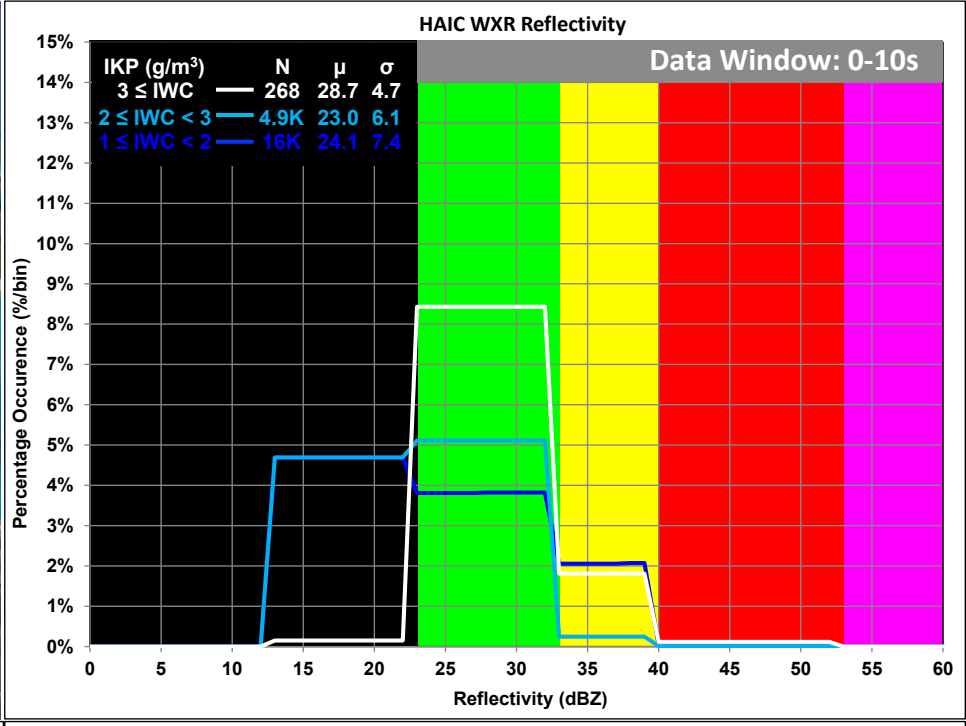

Flight 22, Feb 17, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
Google earth

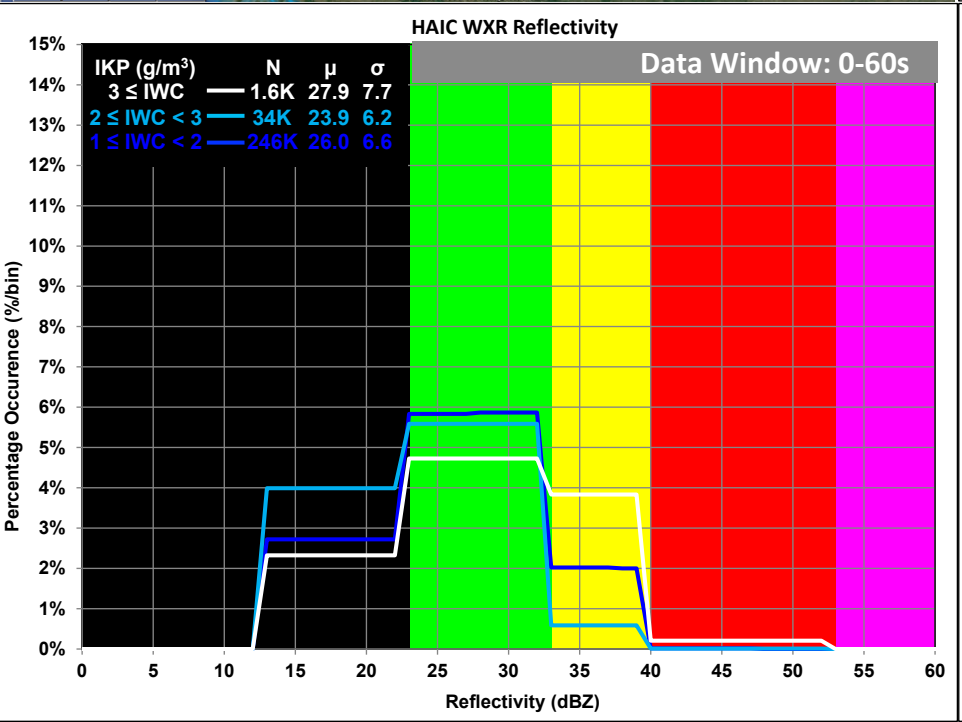

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 265 27.7 5.1
2 ≤ IWC < 3 3.9K 25.8 6.0
1 ≤ IWC < 2 28K 23.0 6.8
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

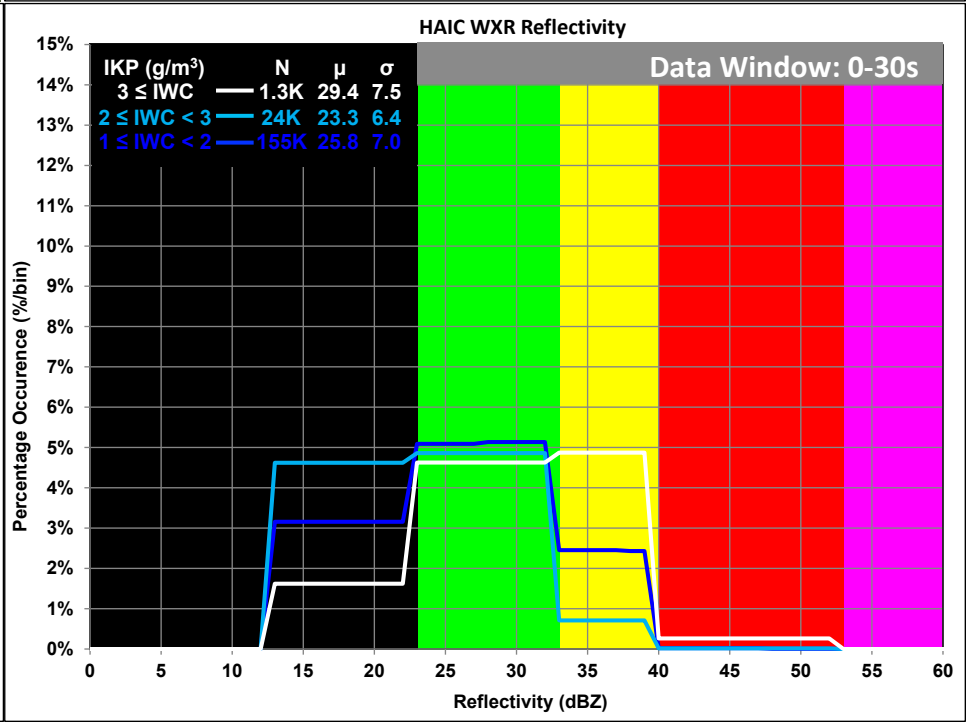

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 3.0K 25.6 6.1
2 ≤ IWC < 3 51K 24.1 6.1
1 ≤ IWC < 2 373K 21.9 6.0
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

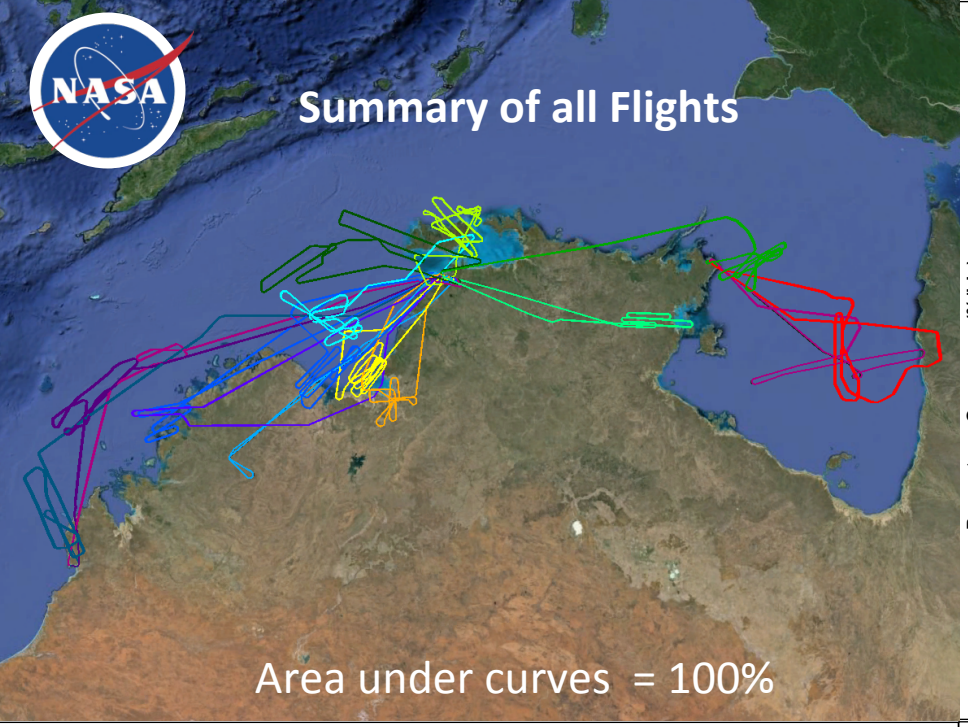

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 1.7K 26.5 6.0
2 ≤ IWC < 3 27K 24.8 6.1
1 ≤ IWC < 2 203K 21.9 6.1
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

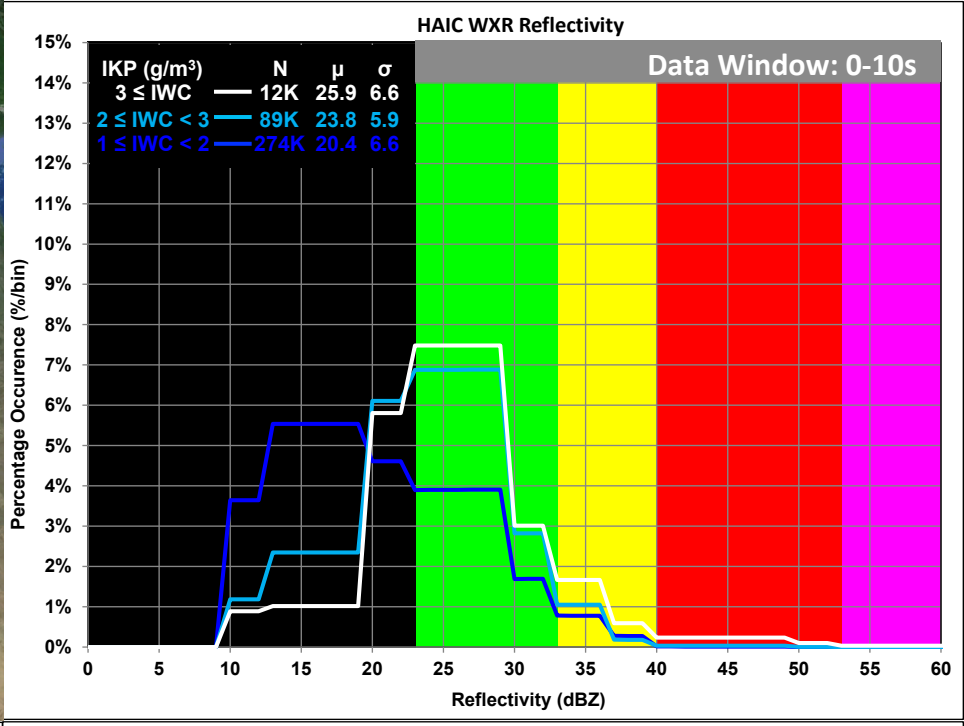

Flight 23, Feb 18, 2014
IKP Data
3 g/m³ ≤ TWC
2 g/m³ ≤ TWC < 3 g/m³
1 g/m³ ≤ TWC < 2 g/m³
TWC < 1 g/m³
Area under curves = 100%
NASA
Google earth

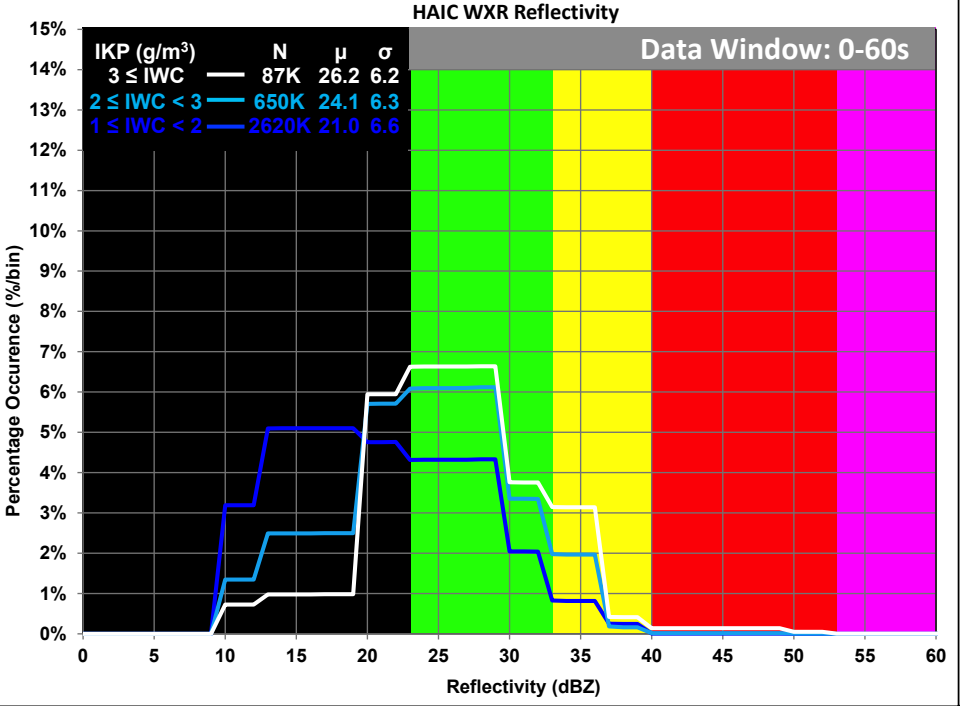

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 268 28.7 4.7
2 ≤ IWC < 3 4.9K 23.0 6.1
1 ≤ IWC < 2 16K 24.1 7.4
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

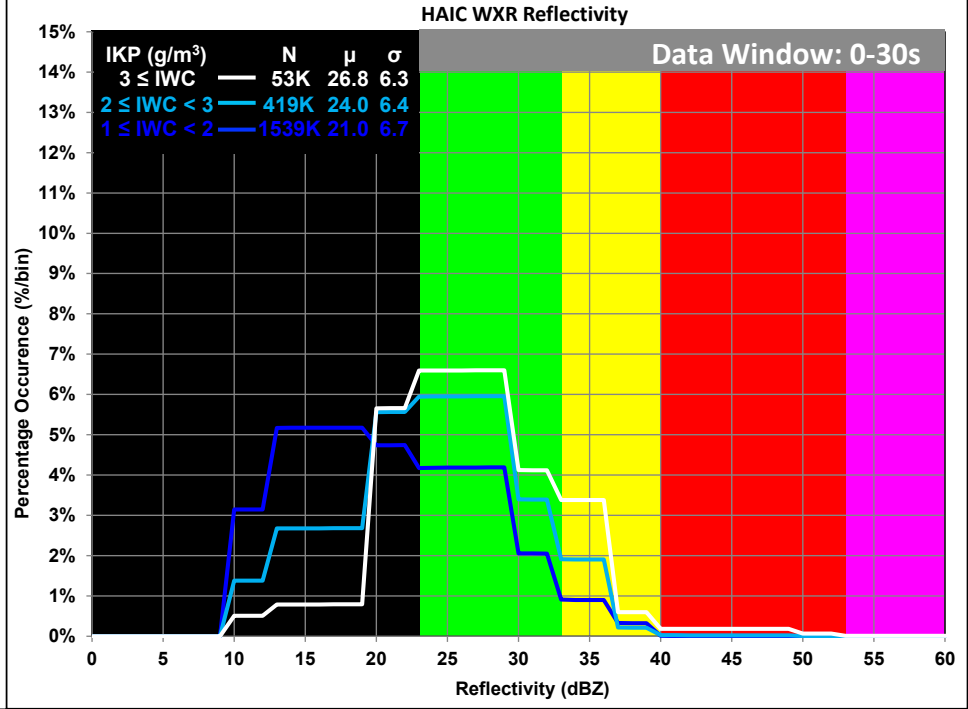

HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 1.6K 27.9 7.7
2 ≤ IWC < 3 34K 23.9 6.2
1 ≤ IWC < 2 246K 26.0 6.6
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)


HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 1.3K 29.4 7.5
2 ≤ IWC < 3 24K 23.3 6.4
1 ≤ IWC < 2 155K 25.8 7.0
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)


Summary of all Flights
Area under curves = 100%


HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 12K 25.9 6.6
2 ≤ IWC < 3 89K 23.8 5.9
1 ≤ IWC < 2 274K 20.4 6.6
Data Window: 0-10s
Percentage Occurence (%/bin)
Reflectivity (dBZ)


HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 87K 26.2 6.2
2 ≤ IWC < 3 650K 24.1 6.3
1 ≤ IWC < 2 2620K 21.0 6.6
Data Window: 0-60s
Percentage Occurence (%/bin)
Reflectivity (dBZ)


HAIC WXR Reflectivity
IKP (g/m³) N μ σ
3 ≤ IWC 53K 26.8 6.3
2 ≤ IWC < 3 419K 24.0 6.4
1 ≤ IWC < 2 1539K 21.0 6.7
Data Window: 0-30s
Percentage Occurence (%/bin)
Reflectivity (dBZ)

BACK-UP CHARTS

INCLUDING:

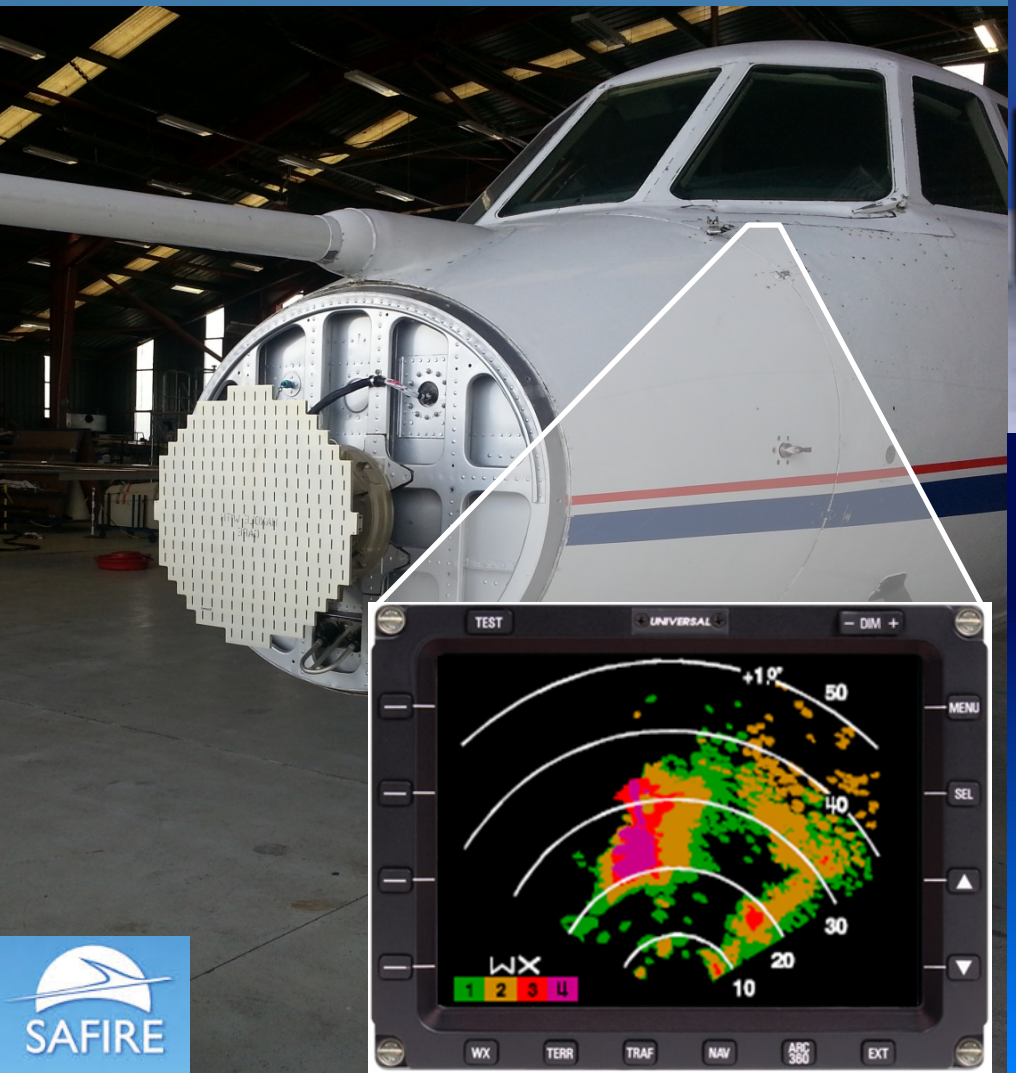
DAY-BY-DAY STATS

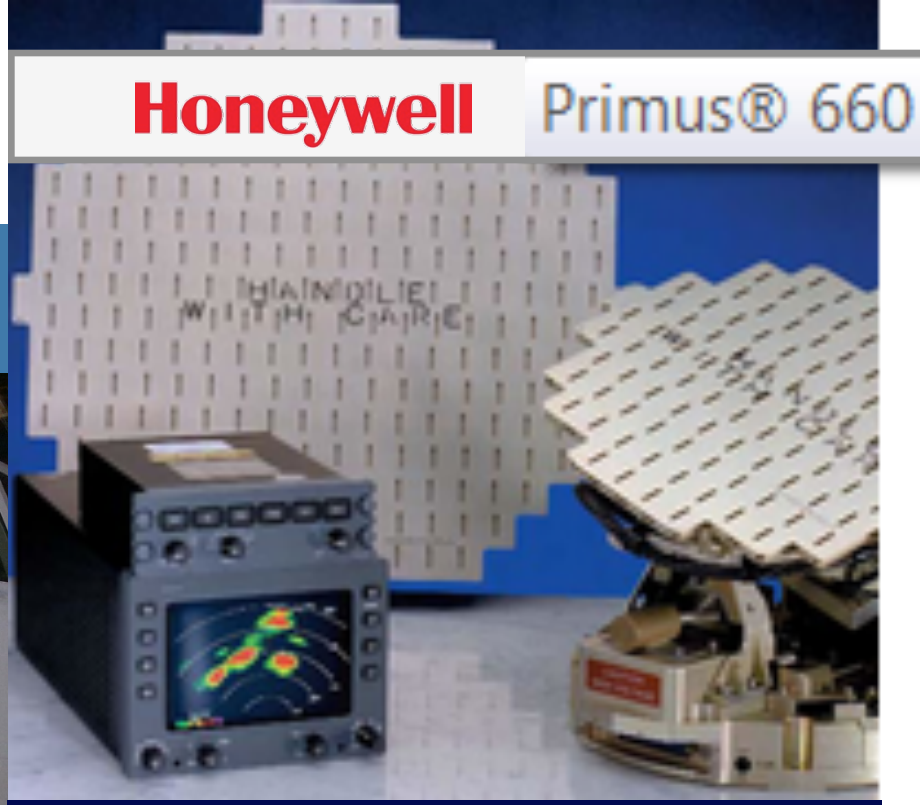
&

CHARTS FROM PREVIOUS (PARIS)
HAIC-HIWC SCIENCE TEAM MEETING

2014 HAIC-HIWC International Field Campaign

Radar Data is Recorded from Display Bus of Honeywell Primus 660 Weather Radar





- Radar data consists of pilot's display only
- 5 color labels:

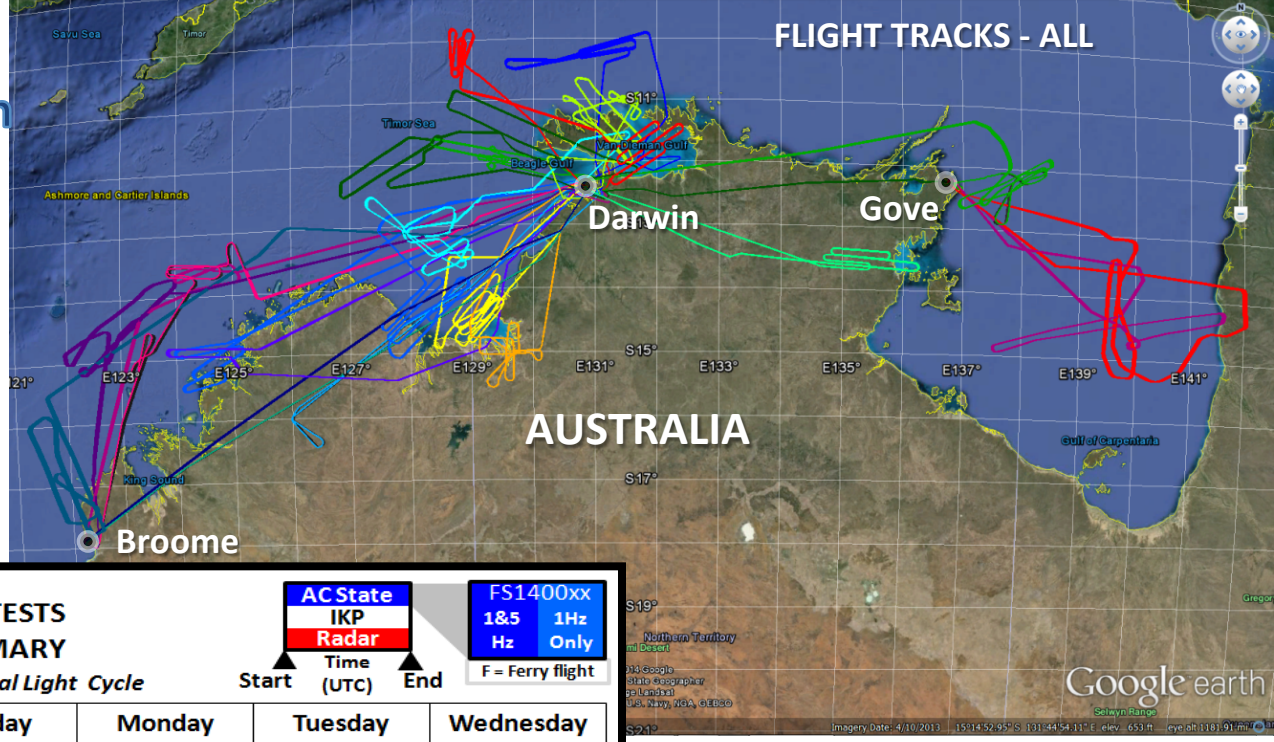
53 ≤	magenta		dBZ
40 ≤	red	< 53	
33 ≤	yellow	< 40	
23 ≤	green	< 33	
	black	< 23	

- Variable Gain
  - +3 to -15 dB
  - CAL setting (0 dB gain with gnd_filter)
- GPS time (1 Hz)
  - Used to synchronize all files

POC: Steven.D.Harrah@NASA.gov

2014 HAIC-HIWC International Field Campaign

- AC Deployed to Darwin
- Darwin Served as Base
- Australian BoM provided:
  - General Met Support
  - Office/Meeting Facilities
  - Gnd Radar (multiple sites)
- Emphasis - oceanic storms



Date Format dd/mm

2014 HAIC FLIGHT TESTS
FLIGHT DATA SUMMARY
UTC Dates/Time but Local Diurnal Light Cycle

AC State: IKP / Radar — Start / End Time (UTC)
FS1400xx: 1&5 Hz / 1Hz Only
F = Ferry flight

Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday
16/01	17/01	18/01	19/01	20/01	21/01	22/01
01, 02	03, 04				05	
23/01	24/01	25/01	26/01	27/01	28/01	29/01
06	07			08	09	10
30/01	31/01	01/02	02/02	03/02	04/02	05/02
11 F			12	13	14	
06/02	07/02	08/02	09/02	10/02	11/02	12/02
15	16, 17 F	18	19	20 F		
13/02	14/02	15/02	16/02	17/02	18/02	19/02
				21, 22	23	

- Over 5 weeks
  (Jan 16 – Feb 19, 2014)
- 20 Flight Days
  (Dawn – Midday)
- Total of 23 flights
  (incl. 3 ferry/cal flights)
- Radar Data
  (sweep recording)
- Aircraft Data
  (1 and 5 Hz)
- IKP Data

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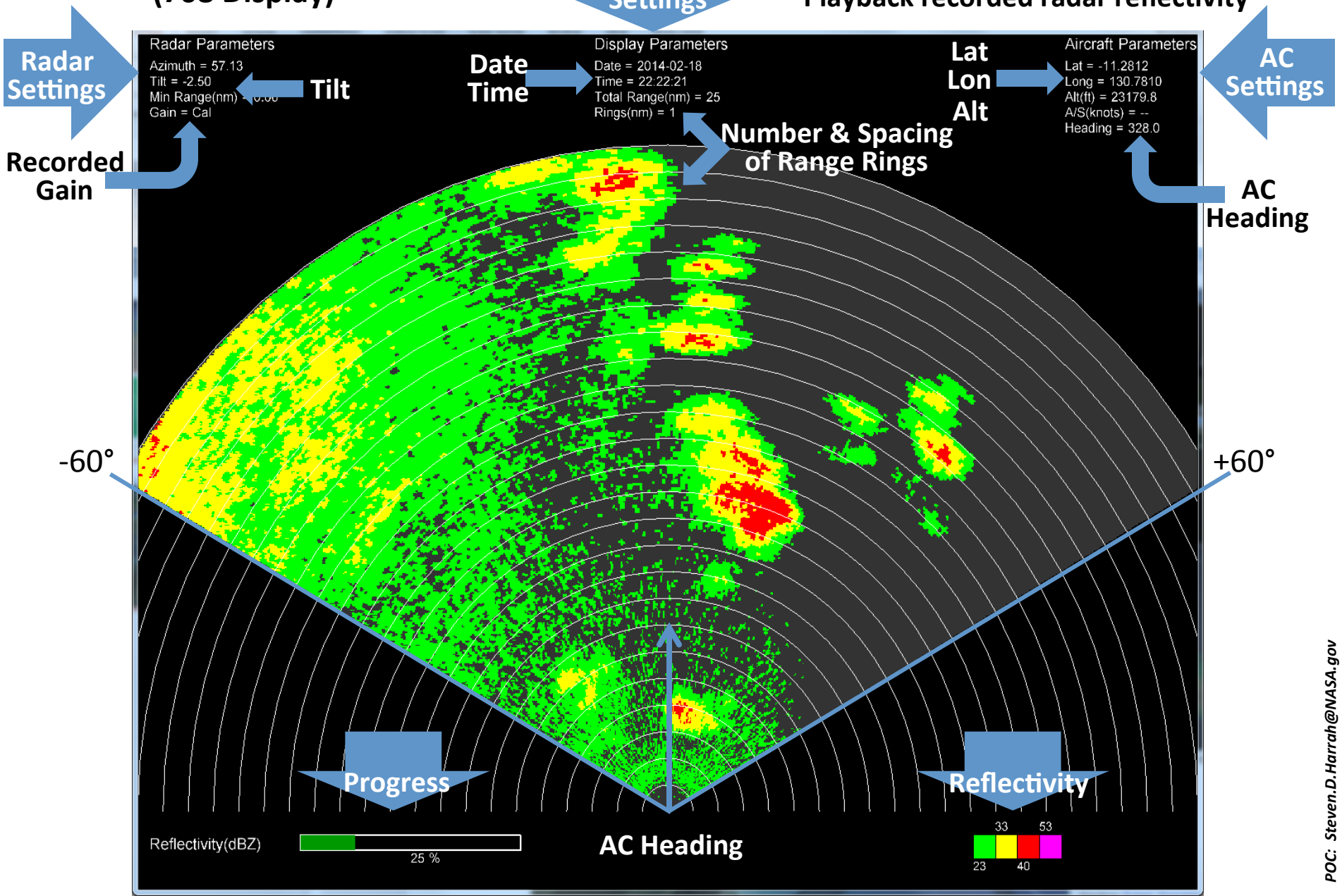
Weather Radar Viewer Application (708 Display)

- Delivered for Flt Ops
- Replicates pilot display
- Playback recorded radar reflectivity



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DATA COLLECTION – SUMMARY

- We have received almost 4GB of Recorded Radar Data – THANK YOU !!!
  Representing ~52.5hrs of flight time (more than 90% of the flight time)
- Missing data (FS140006, 23/01/2014) appears to contain one of the BETTER IKP events
- Recording Color rather than Reflectivity ONLY Limits Precision of Results
  – Limited Scientific Value but Results Do Confirm Pilot Observations (now & past)
- NASA-supplied Radar Visualization Tool enable post-flight review of:
  – pilot observations
  – radar operational procedures
  – some idea of HAIC event characteristics (GOOD DATA BEING COLLECTED)
- Pilot's Use of GAIN did NOT help/hurt Flt Ops or Analyses
  – MAX GAIN is only +3 dB, if this value had been greater then GAIN might have helped
  – Use of MIN GAIN (-15dB), while sizeable, would be counter-productive
  – Radar GAIN Setting was recorded thereby allowing compensation
  – Published GAIN values were confirmed (not assumed)
- Pilot's Use of Tilt Un-Covered Higher Reflectivities Below Flight Altitude
  but questions about ground/sea-clutter must also be considered

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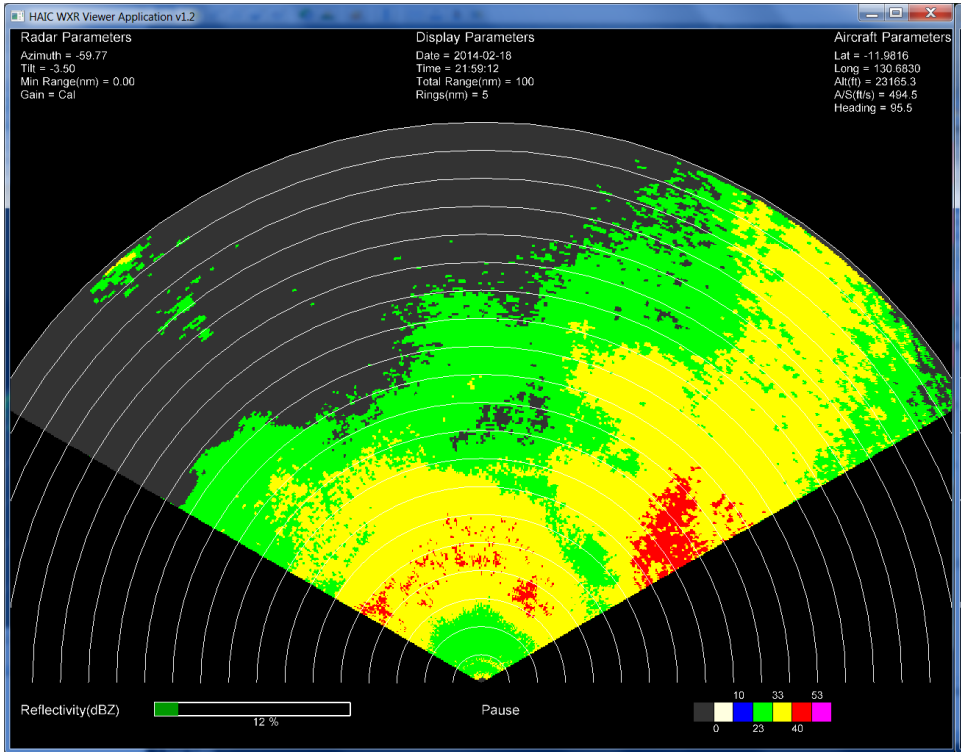
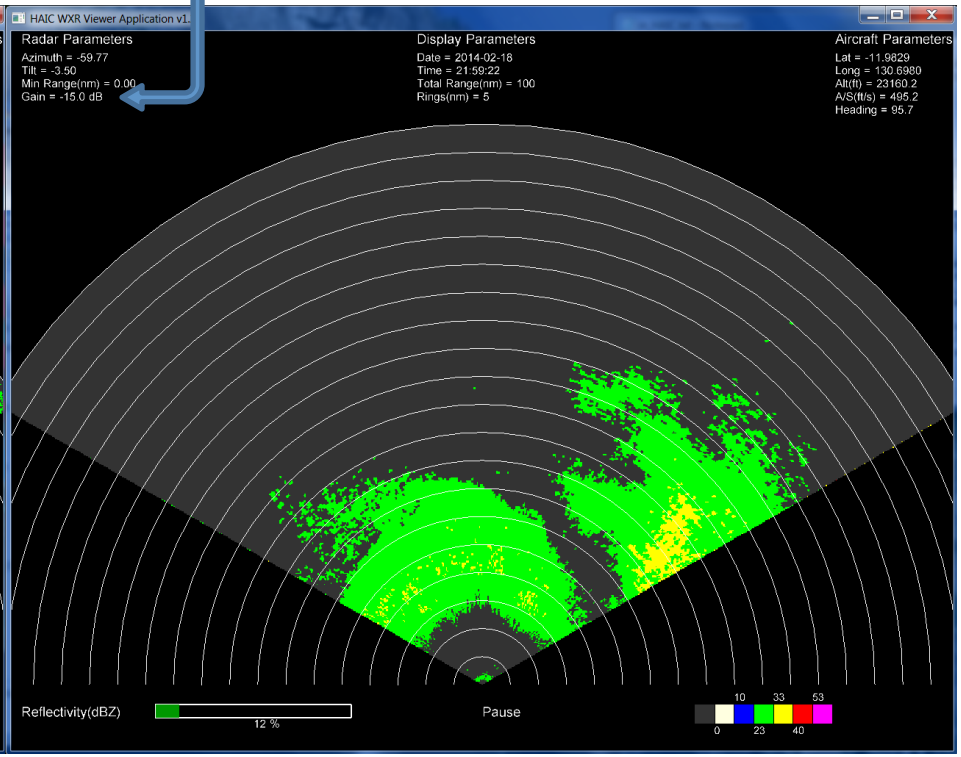
Why care about the GAIN setting?
Difference between CAL and Minimum Gain

These two sequential images are of the same scene with the same antenna tilt

Note reduction in reflectivity appearance but GAIN value shows why this is produced





Gain = 0dB (CAL)
Sweep ending at 21:59:12

Gain = -15 dB
Sweep ending at 21:59:22

Counter-Productive for seeing low reflectivity targets

Flight 23 02/18/2014

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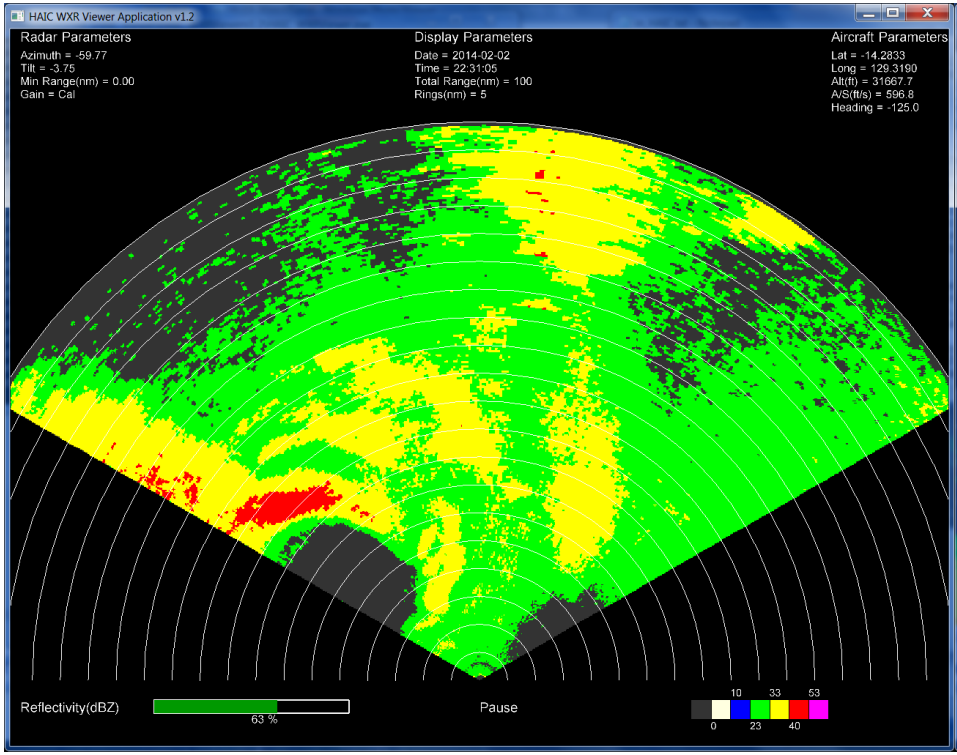
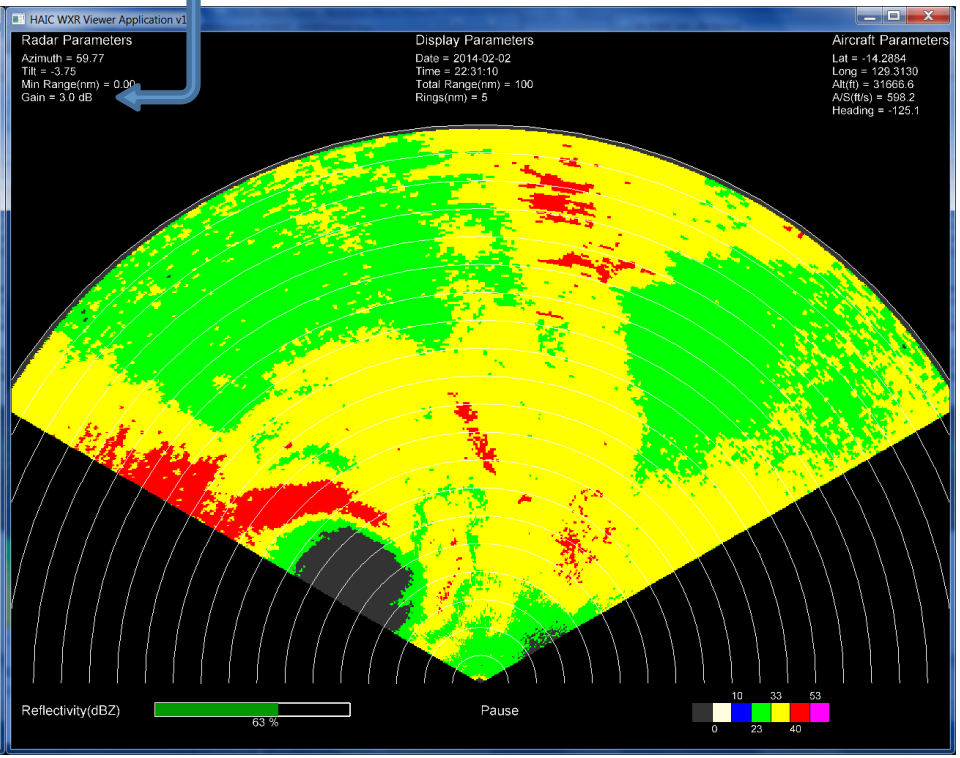
Why care about the GAIN setting?
Difference between CAL and Maximum Gain

These two sequential images are of the same scene with the same antenna tilt

Note small increases in reflectivity appearance but GAIN value shows why this is produced





Gain = 0dB (CAL)
Sweep ending at 22:31:05

Gain = +3 dB
Sweep ending at 22:31:10

Not enough help seeing low-reflectivity targets causes confusion regarding flt ops

Flight 12 02/02/2014

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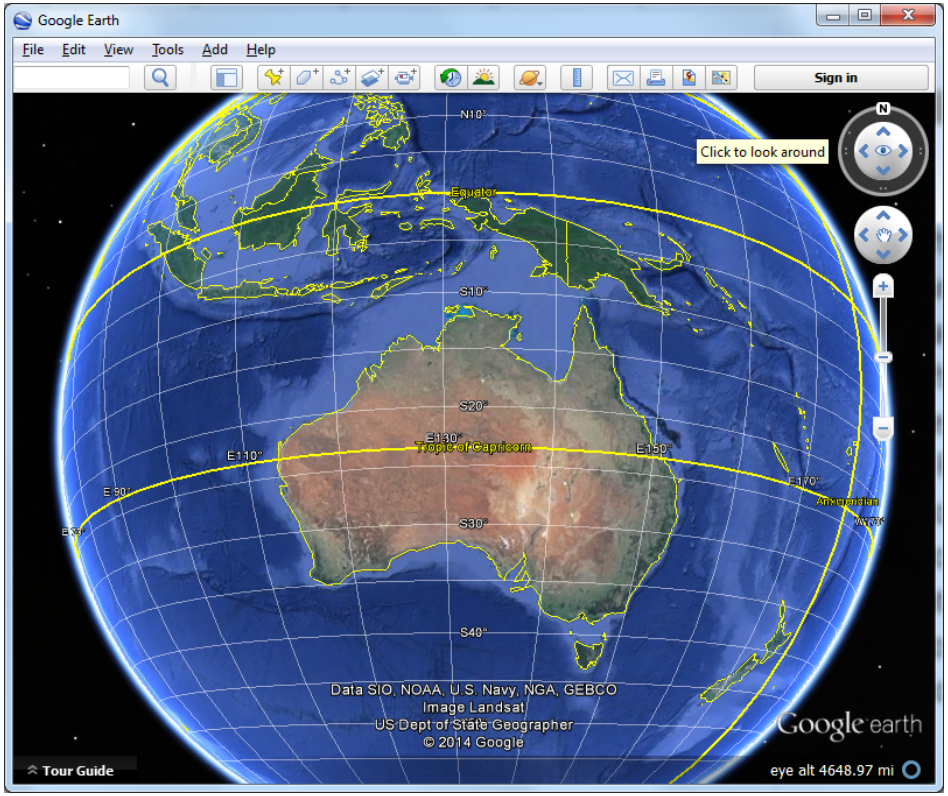
Geospatial Visualization of Flight Data

Utilizing Google®Earth as the Graphics Engine

Data Representations

- Aircraft Flight Path
  - Graphical 4-D Track
  - Latitude, Longitude, Altitude, Time
- Aircraft and Radar Parameters
  - Text-based Pop-up Box
- Radar Reflectivity
  - Color-coded Imagery
  - Position, Orientation, Scale, Time
- IKP Data
  - Total Water Content (TWC)
  - Color-coded 3-D Track



Visualization Engine

Google earth

- Freely Available
- http://www.google.com/earth/
- Abundant Documentation & Tutorials
- Active User & Developer Communities
- External Data Import
  - Via Keyhole Markup Language (KML)
- Feature Rich GUI
  - View Control
- Animation Support
  - Timeline controls

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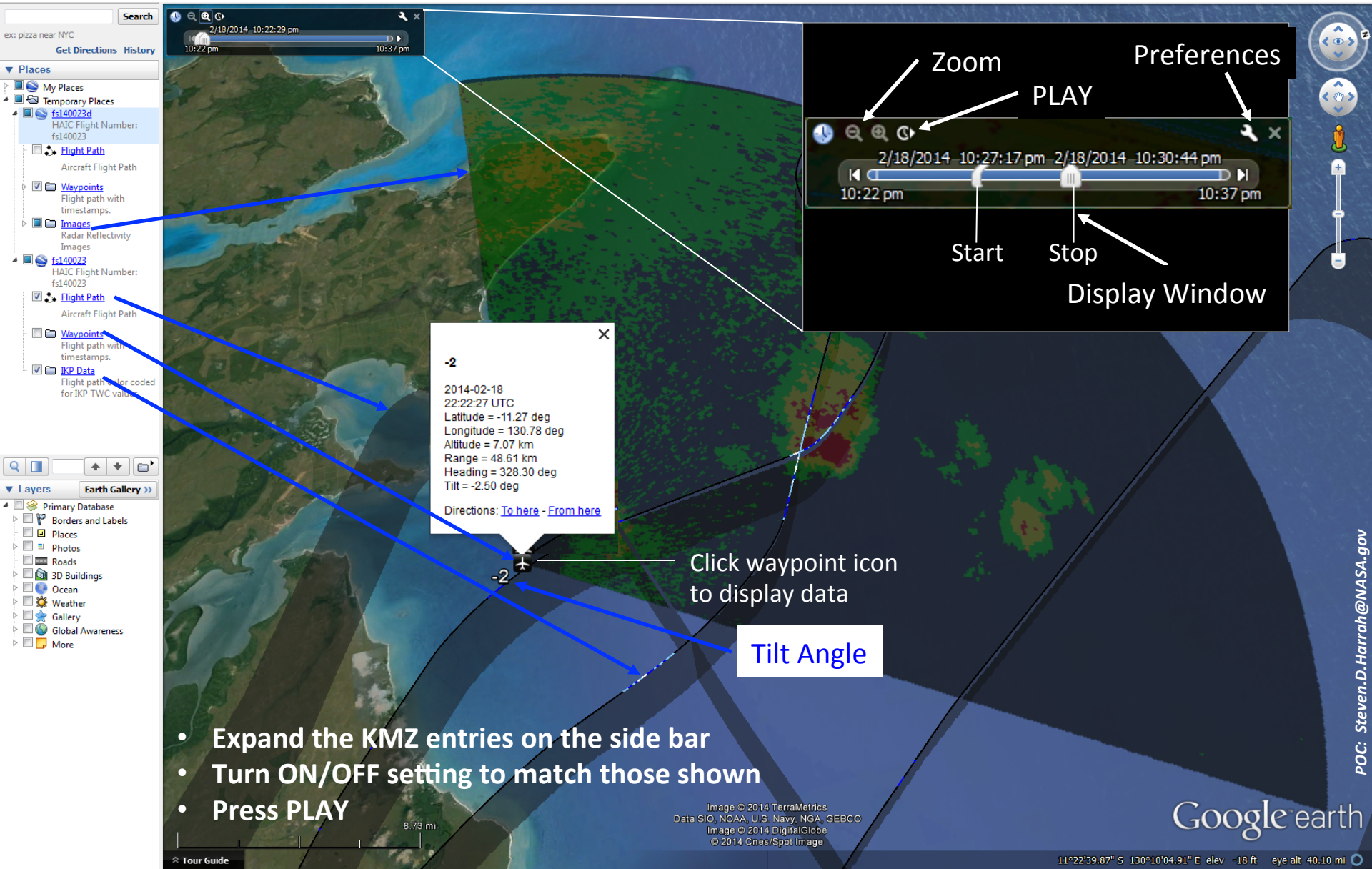
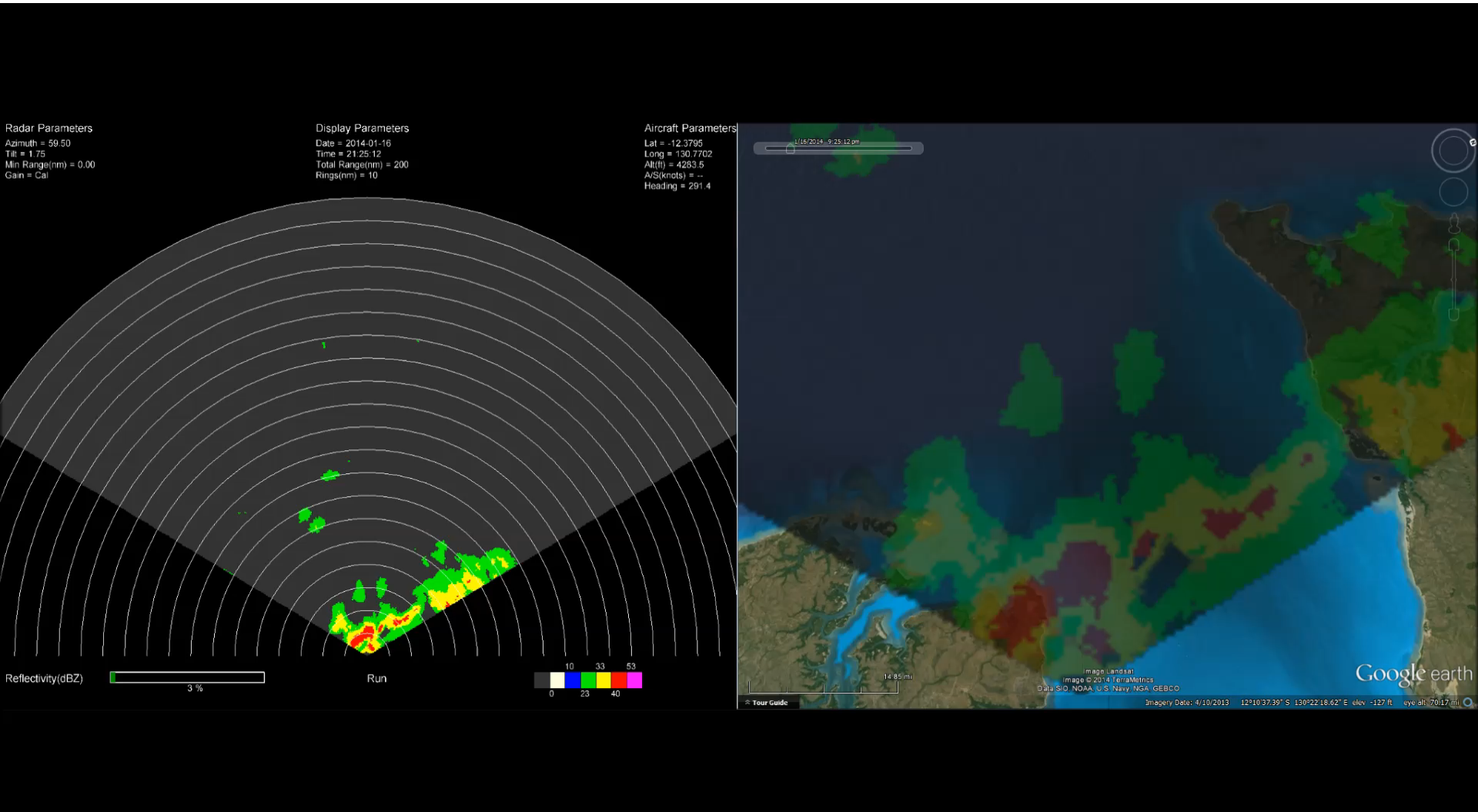
Visualizing aircraft, radar, and IKP data in Google®Earth

- **Open KMZ files – typically one IKP (whole day) and one (or more) WXR files (each ~15min)**
- **Compress Start-Stop indicators (see detail below) till only one WXR sweep is shown**



Video of side by side comparison of 708 with Google®Earth



- **Google®Earth provides more intuitive presentation**
  - **Pilot changes (radar range, antenna tilt, & aircraft heading)**
  - **Ground clutter identification & feature localization/correlation**

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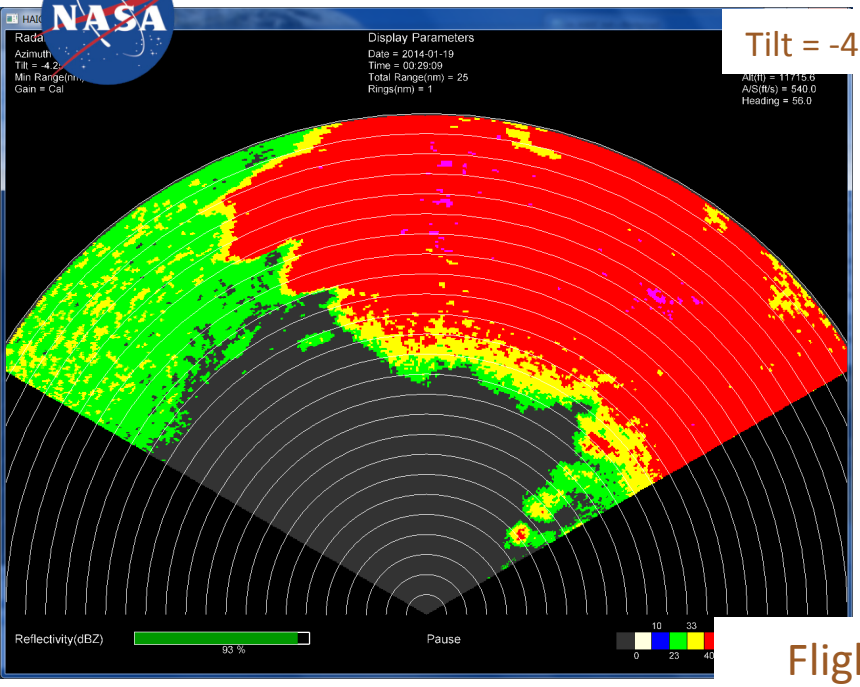
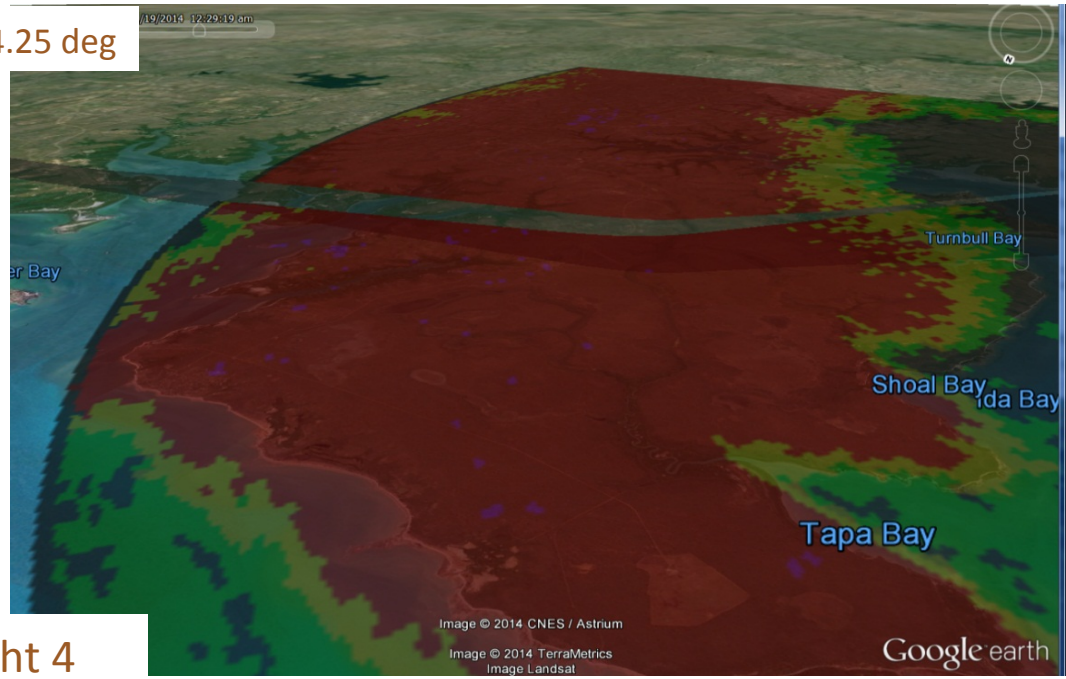
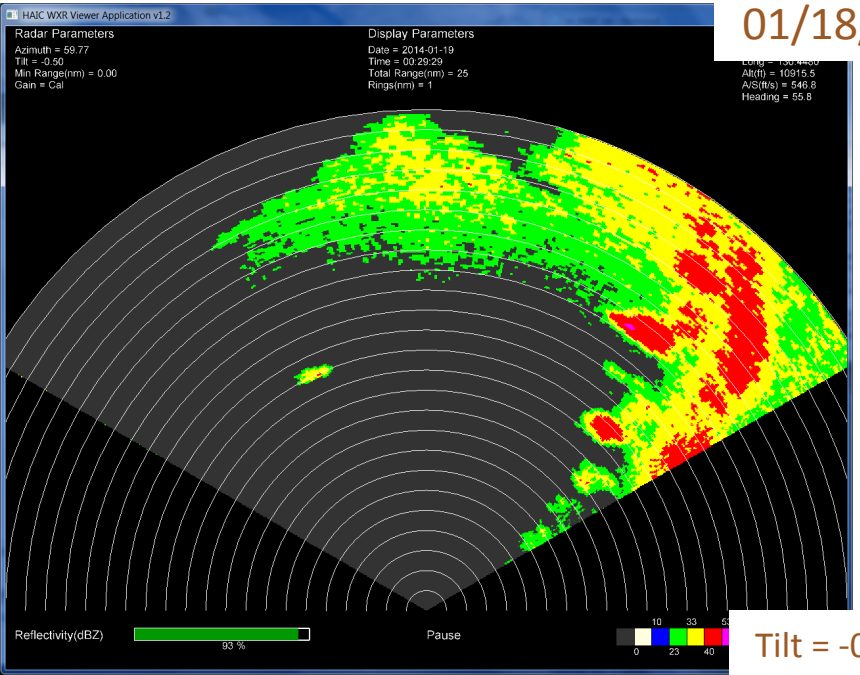
Tilt Change not Gain change comparison with 708 and Google Earth



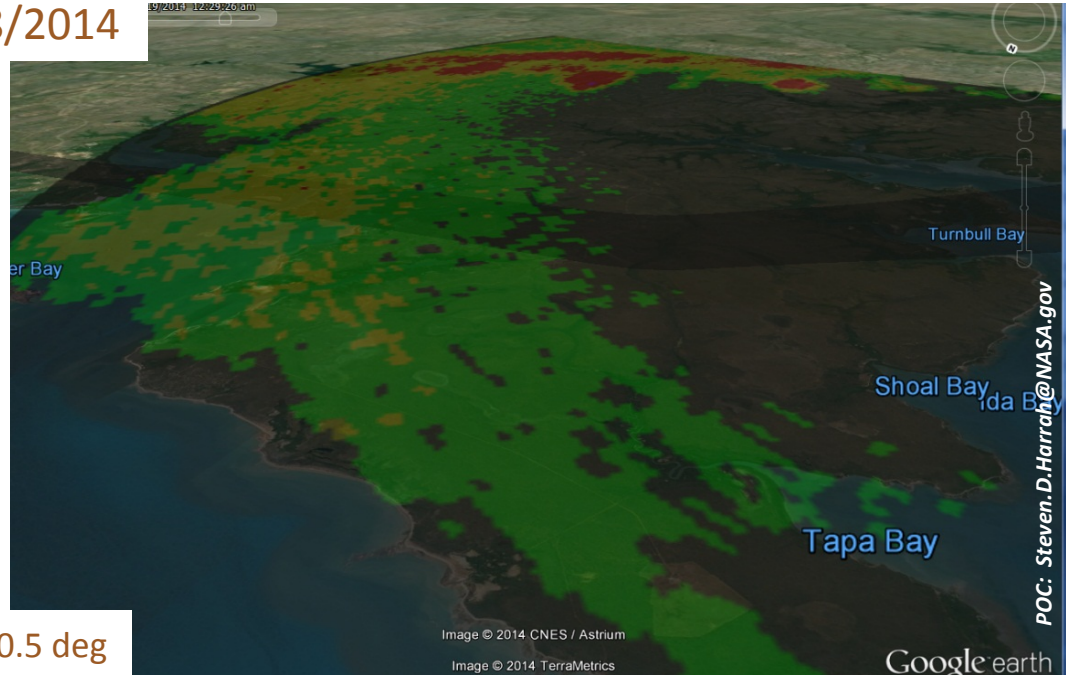
Tilt = -4.25 deg



Flight 4
01/18/2014



Tilt = -0.5 deg



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Event Definitions

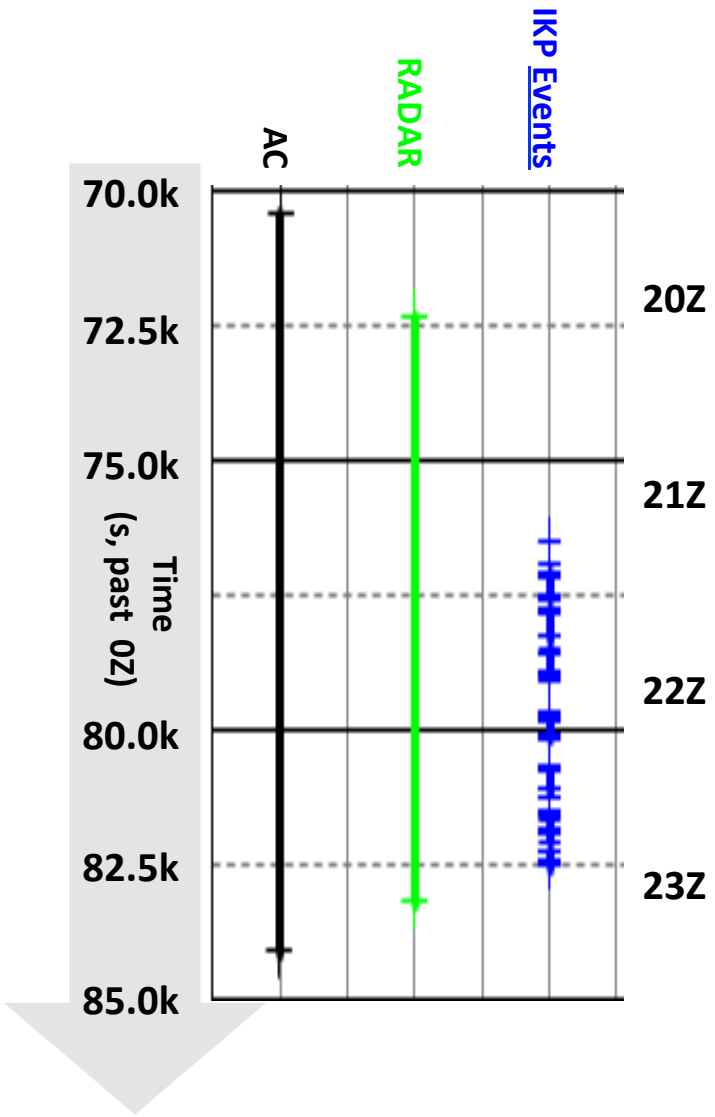
Event duration ≥ 1 second (more than one sample)
Use radar reflectivity to create statistics

IKP Events

- 3 different Levels for events
  - 1 ≤ IKP value < 2
  - 2 ≤ IKP value < 3
  - 3 ≤ IKP value

  } $g \cdot m^{-3}$
- Total # events 788
- No Radar data for 96 events
- Need IKP and Radar data resulting in 692 usable events

Strip Chart
FS140010



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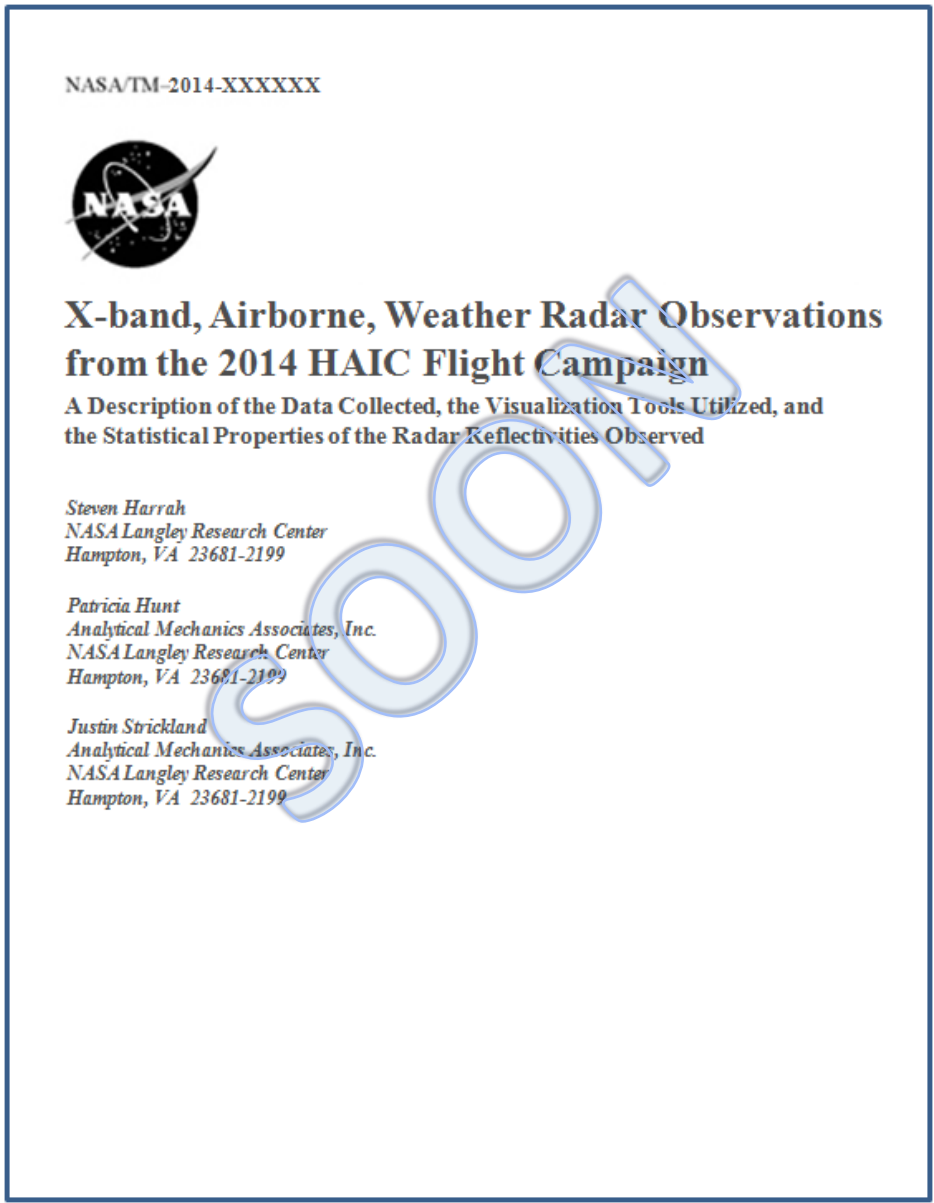
For More Information

- NASA Technical Memorandum has been prepared and will be released soon. This report summarizes these analyses, provides additional results, and discusses more aspects of these analyses/results than could be expressed in this single briefing.

- All KMZ files (viewable in Google®Earth) showing aircraft track, preliminary IKP values, and all the weather radar scans (as seen in flight) are being provided to NCAR for archiving.

- Additional weather radar results will be produced as part of the NASA 2015 HIWC Flight Campaign – August 2015 expected to be conducted in the vicinity of Puerto Rico utilizing the NASA DC-8 aircraft.


NASA/TM-2014-XXXXXX

X-band, Airborne, Weather Radar Observations from the 2014 HAIC Flight Campaign

A Description of the Data Collected, the Visualization Tools Utilized, and the Statistical Properties of the Radar Reflectivities Observed

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