

Radar Detection of High Concentrations of Ice Particles

Probabilistic Performance Assessment

RTCA SC-230 WG-10

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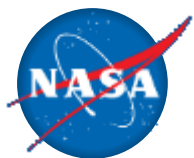


Sponsors:

- Federal Aviation Administration
- NASA Aeronautics Research Mission Directorate, Advanced Air Vehicles Program

Collaborative Partners:

- Federal Aviation Administration
- National Center for Atmospheric Research
- Honeywell
- Boeing



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LANGLEY RESEARCH CENTER

Aeronautics Research Mission Directorate
Advanced Air Vehicles Program
Advanced Air Transport Technologies Project
Advanced Icing Radar Element
– HIWC Flight Campaign

Agenda

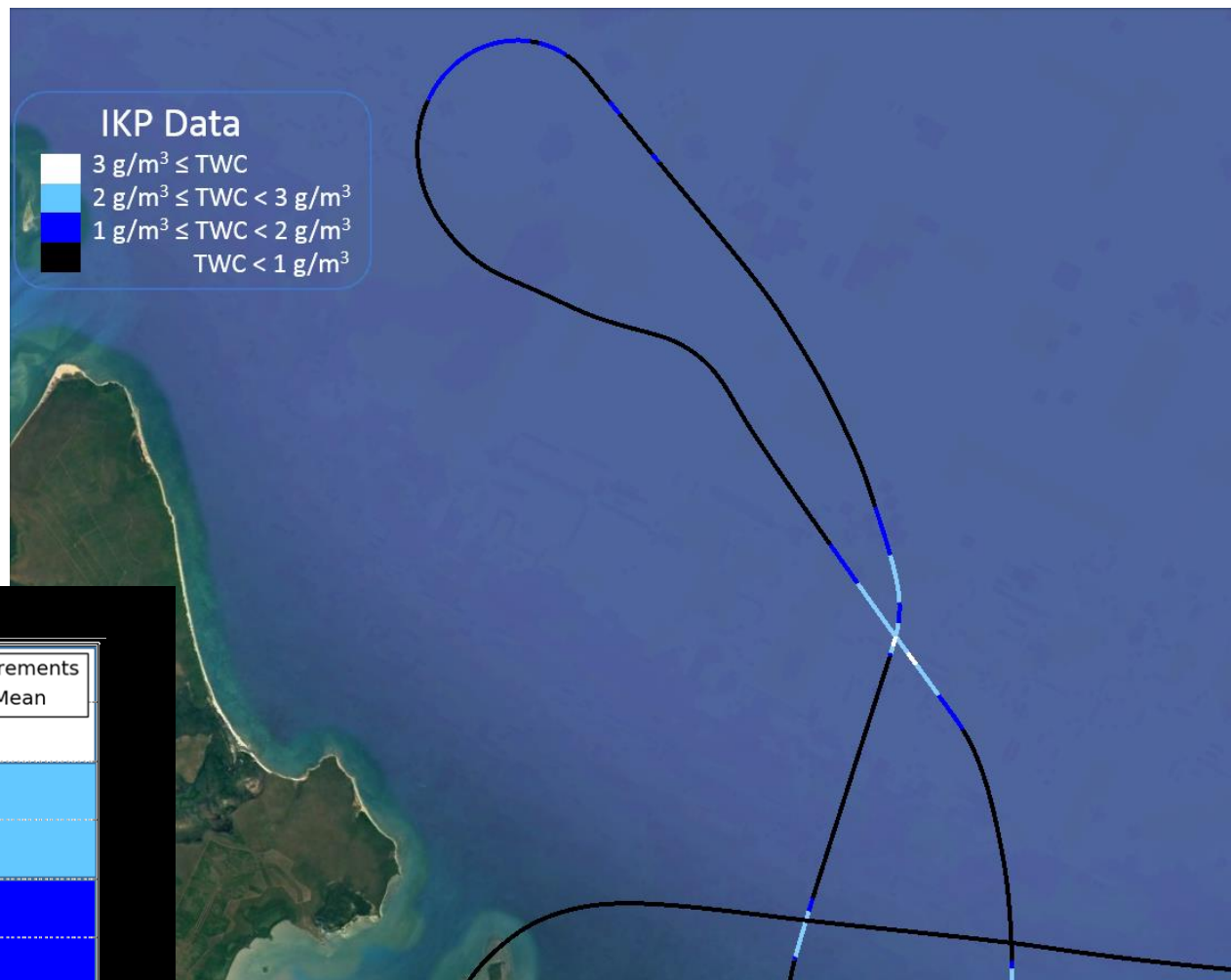
- Correlation of remote radar measurements to in-situ probe measurements
- Swerling Algorithm Description
 - Radar predicted ice water content (RIWC)
- Comparison of RIWC to IWC
 - As measured by the IKP
- Performance goals
- Definition of probabilities
- Performance assessment
 - Fixed and variable thresholds
 - Tight definition of alert level and relaxed margins
- Discussion



Probe Measurements

Probe measurements collected at 1 Hz, spaced along flight path

5-sec running mean applied to probe measurements to reduce variability

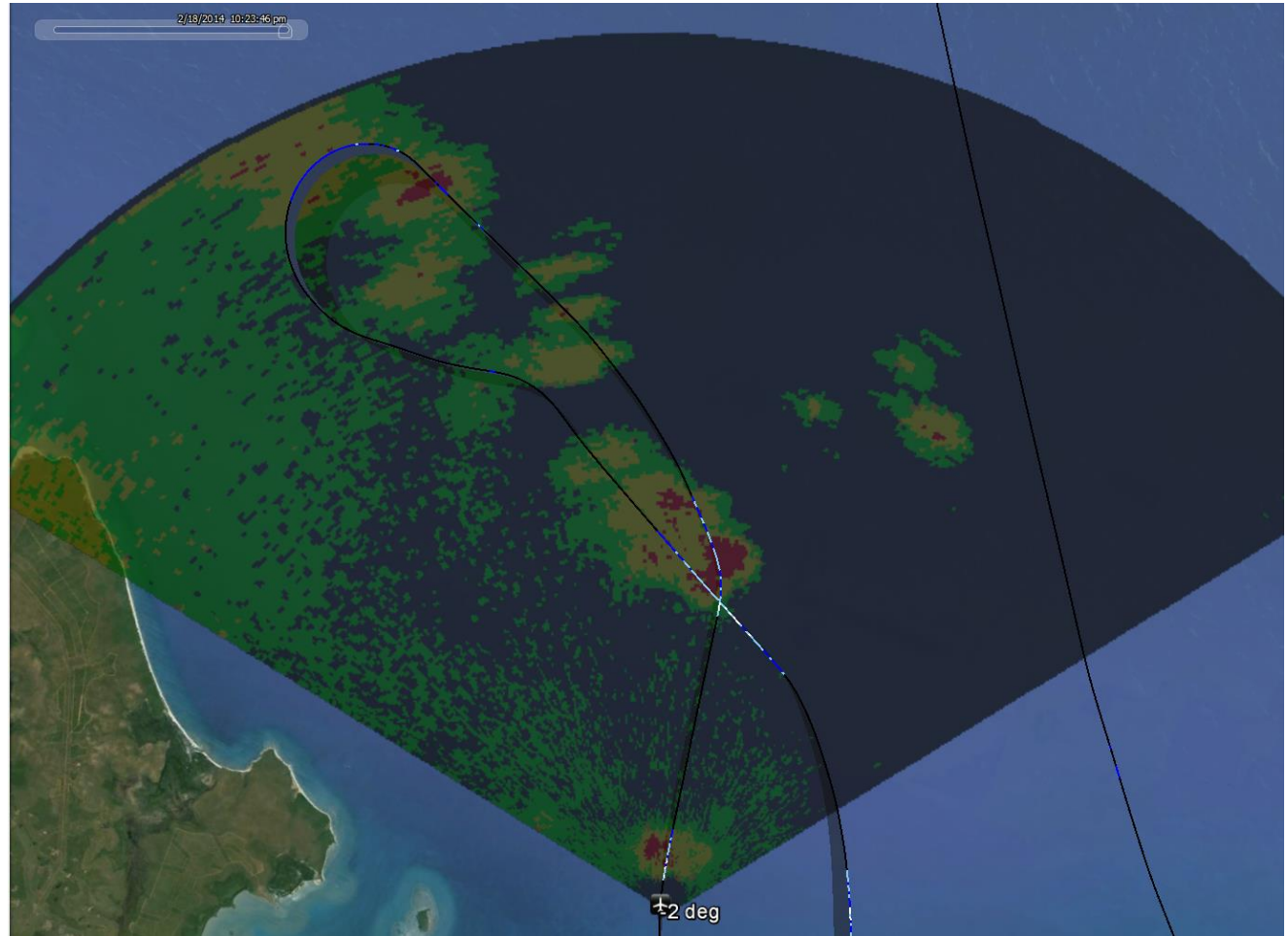




Measurement Correlation

Spatial and temporal correlation of probe measurements and weather radar measurements

For a given aircraft position, all subsequent positions (i.e. future probe measurements) are known

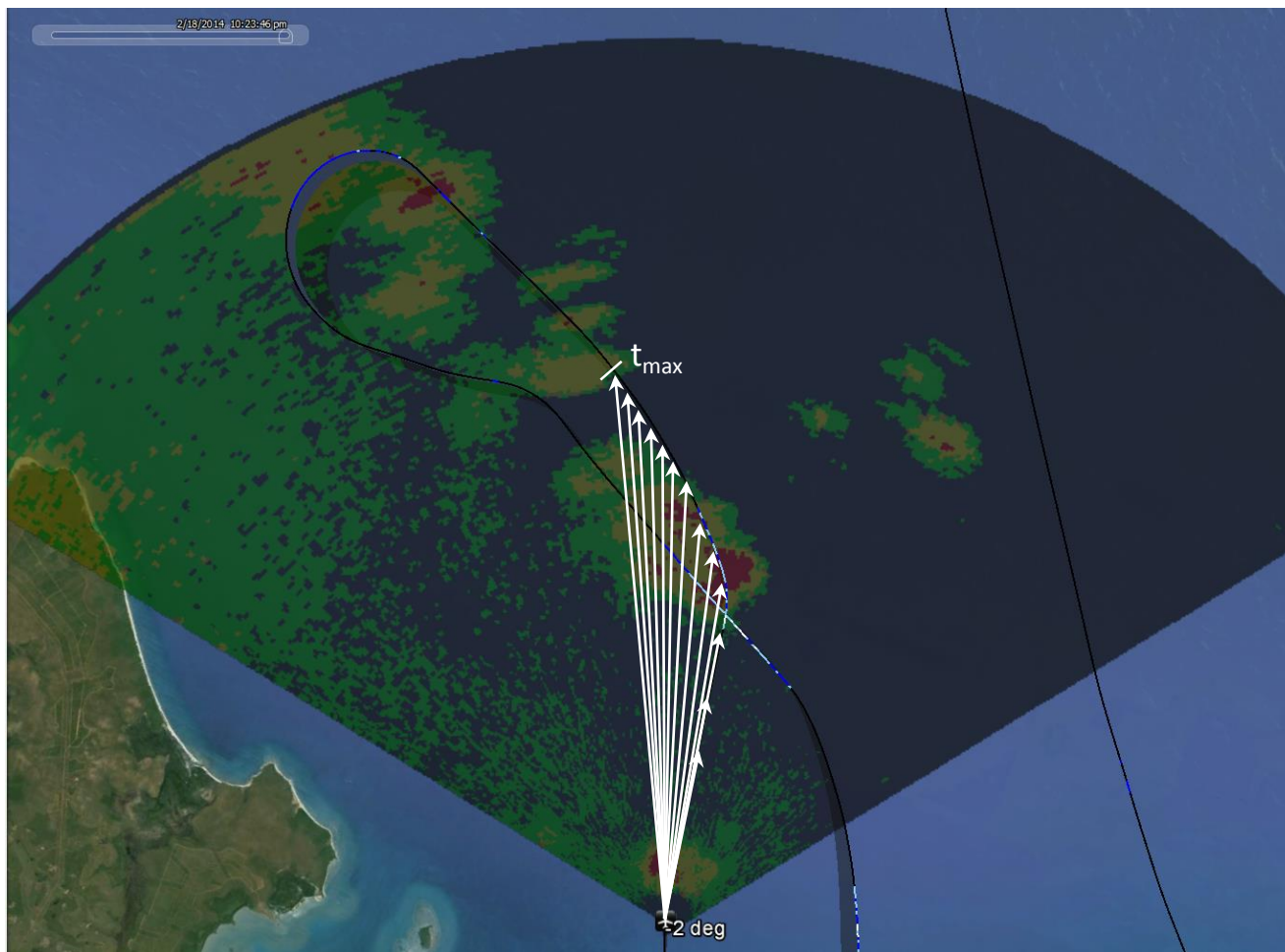




Measurement Correlation

Compute line-of-sight vector from aircraft position to all subsequent probe measurement positions

Impose time limit to eliminate far-future measurements

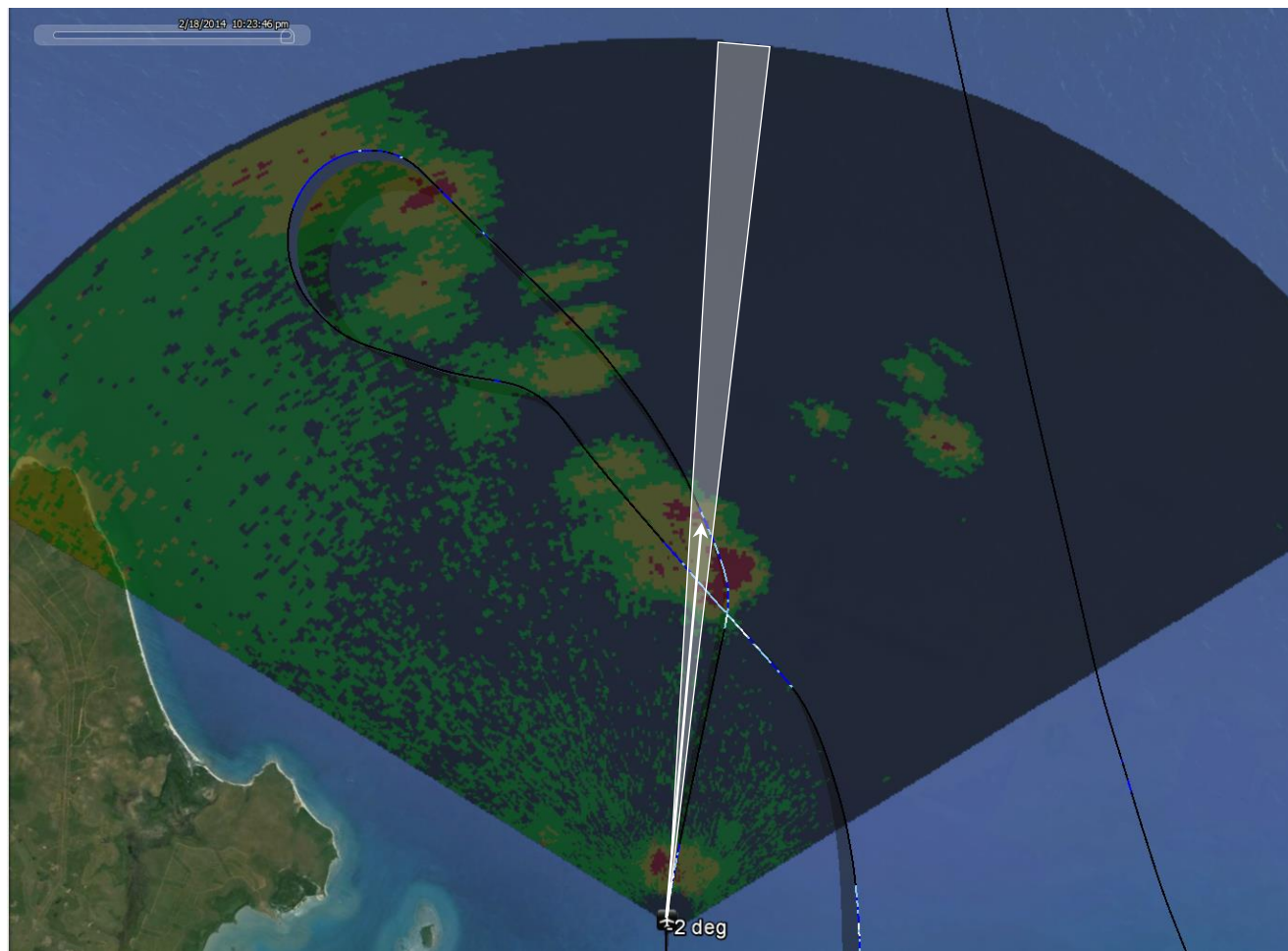




Measurement Correlation

Eliminate probe measurement positions where line-of-sight vector falls outside of radar beam

Compound angle between line-of-sight vector and radar pointing vector < 3 dB beam width





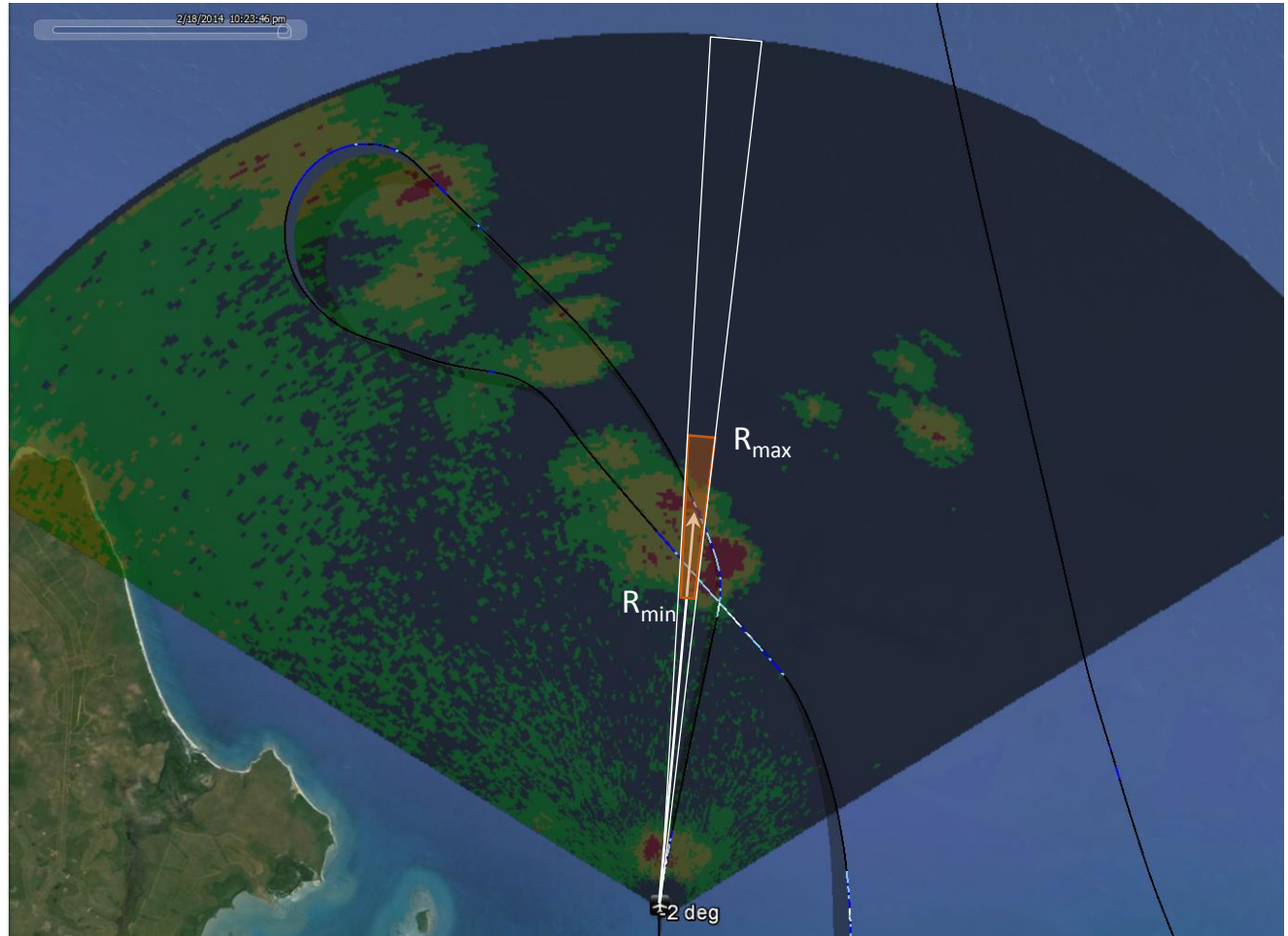
Measurement Correlation

Eliminate probe measurement positions where range falls outside of pre-defined range window

Tabulate remaining candidate radar measurements

Repeat for all radar measurement frames

Measurements correlated at ranges of 0, 12.5, 25, 50NM with 12km range window



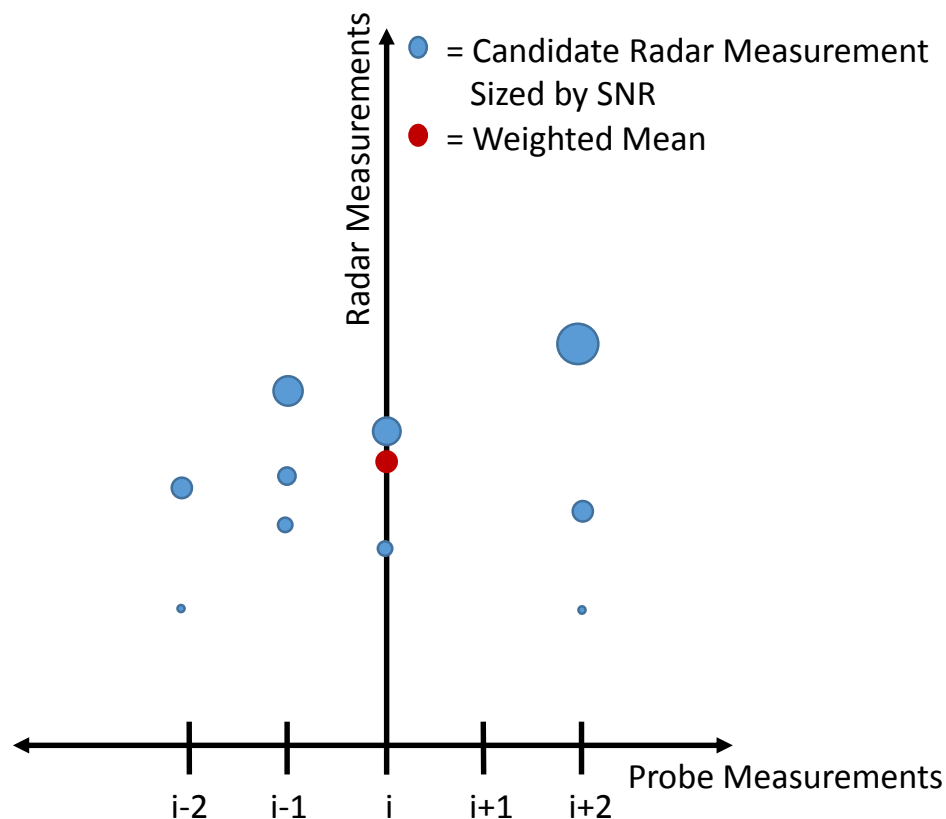


SNR Weighted Mean

Smooth tabulated candidate radar measurements over flight track window

Weighted mean of all candidate radar measurements near a given probe measurement position

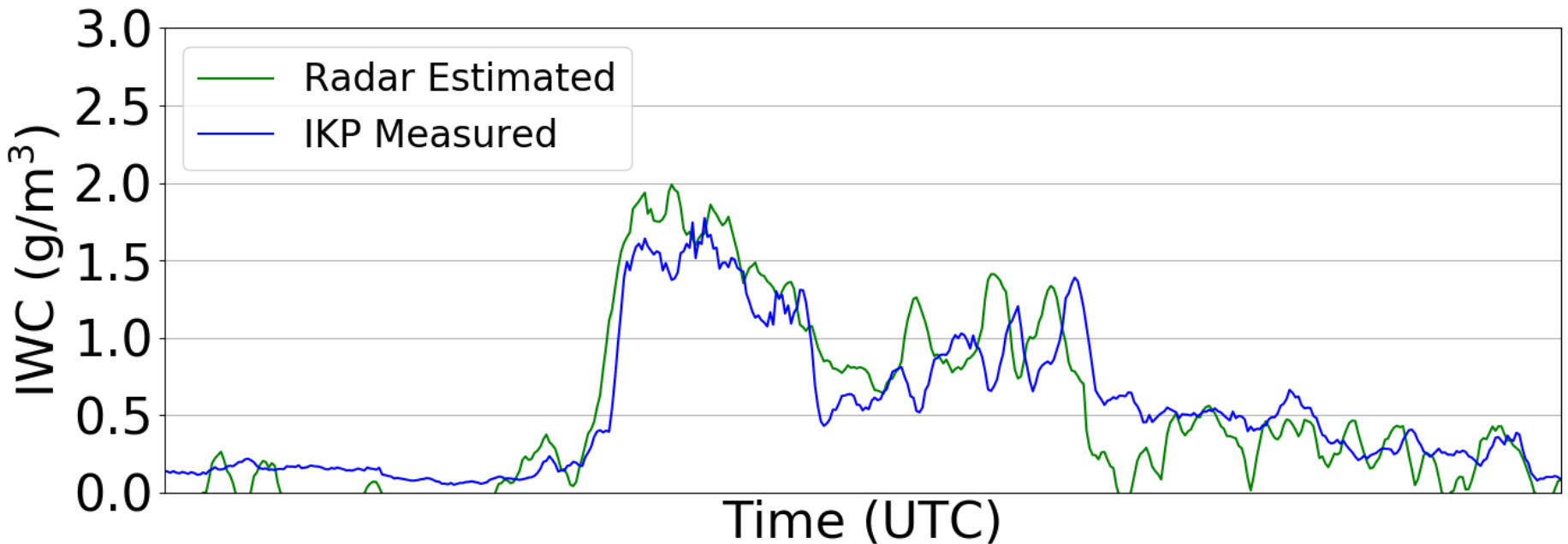
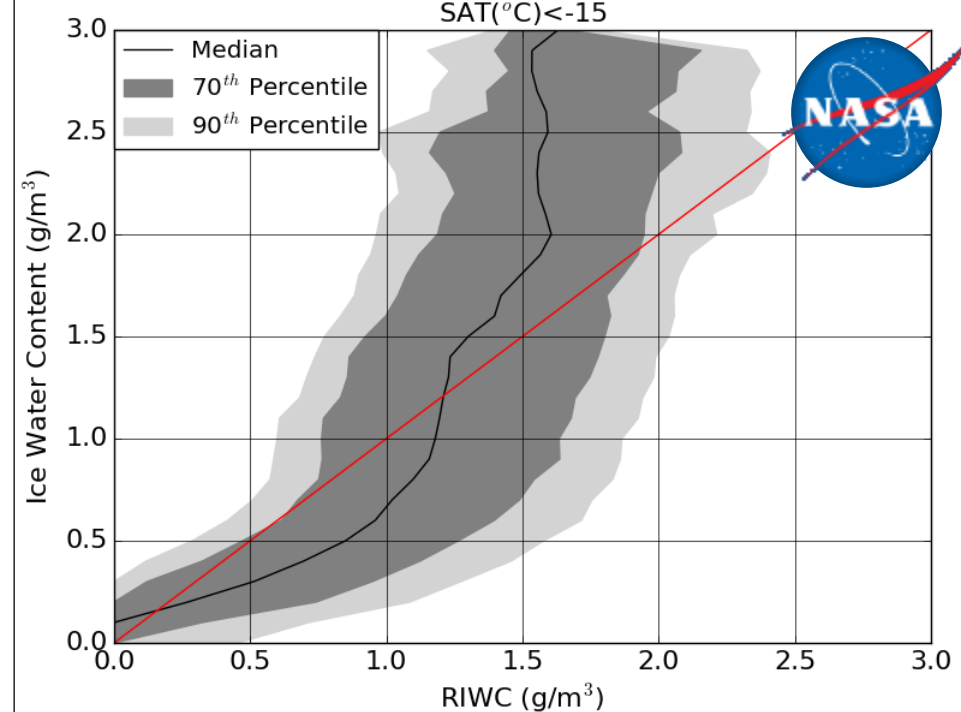
Results in one radar measurement per probe measurement

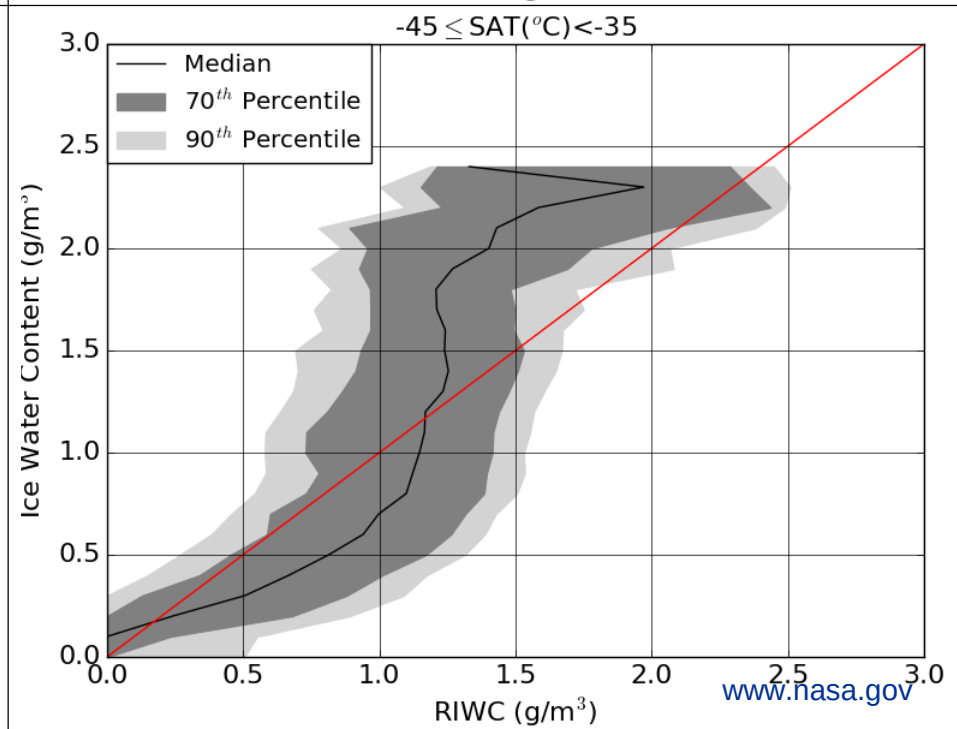
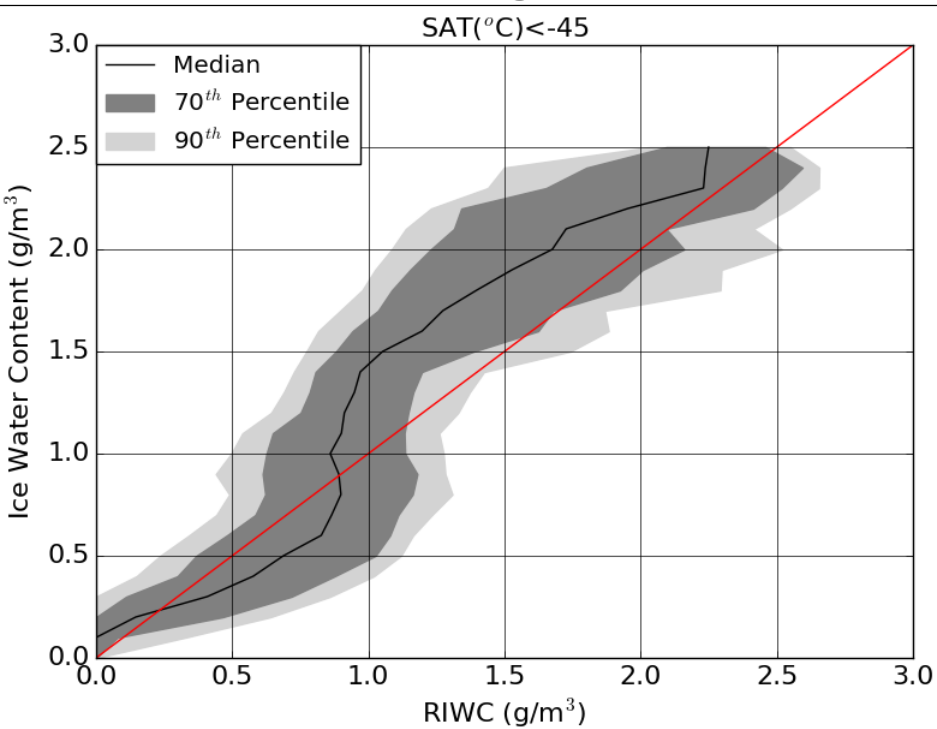
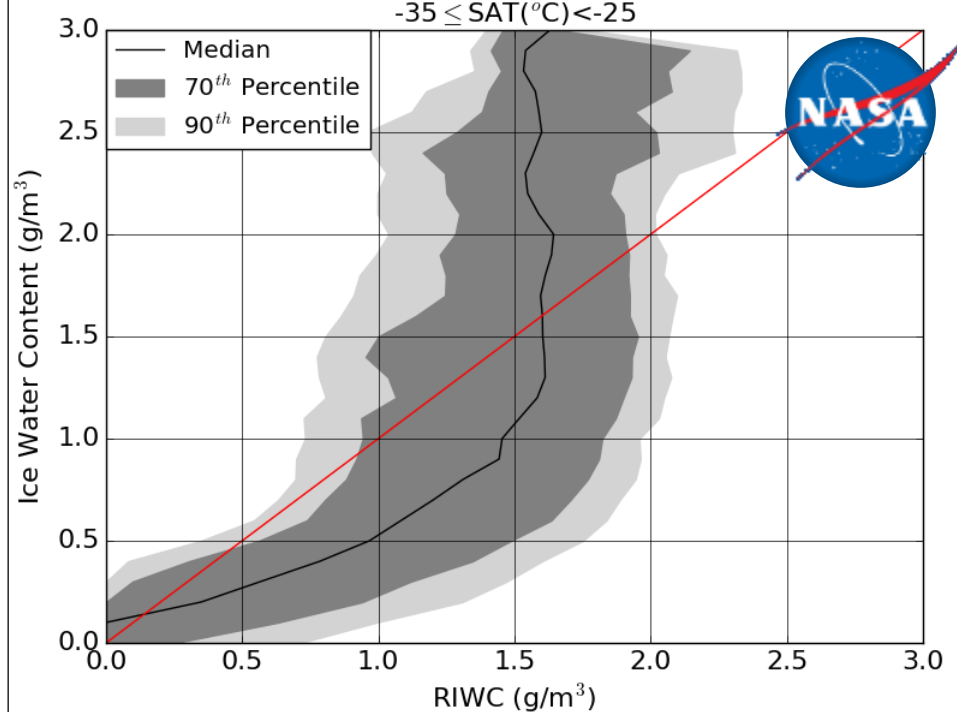
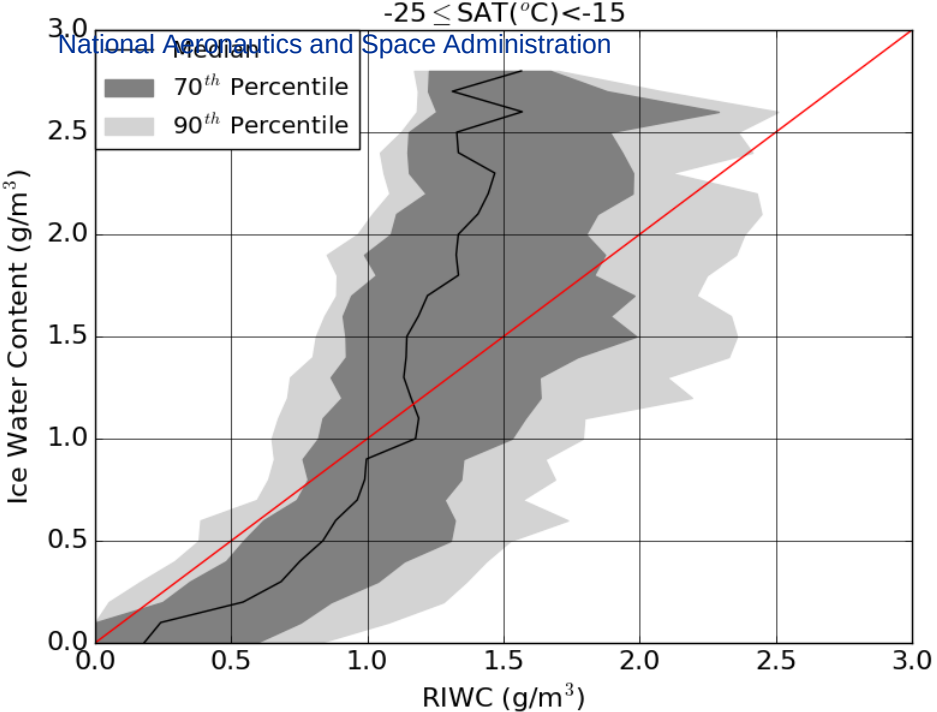


Similar spatial resolution as IKP measurements

Swerling – Correlation

- Compute Index of Dispersion (I_D) for RRF
 - $I_D = \frac{\sigma^2}{\mu}$
 - Requires radar waveform with sufficient pulses to gather meaningful statistics
- Preliminary IWC estimate
 - $IWC \approx \text{Log}_{10}(I_D)$
 - Based on spatial correlation with measured IWC
- Estimates can be improved with slightly different relationship accounting for SAT



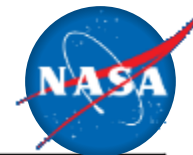




HIWC Detection Performance Goal

- Draft Minimum Operational Performance Standards (MOPS) for ice crystal awareness
 - RTCA SC-230 WG-10
- Moderate alerting level
 - $IWC \geq 1 \text{ g/m}^3$
- Severe alerting level
 - $IWC \geq 3 \text{ g/m}^3$
- Must-detect
 - Probability of detection (P_D) ≥ 0.8
- Missed annunciation
 - Probability of missed detection (P_{MD}) ≤ 0.2
- Must-not-detect
 - Probability of false alarm (P_{FA}) ≤ 0.2

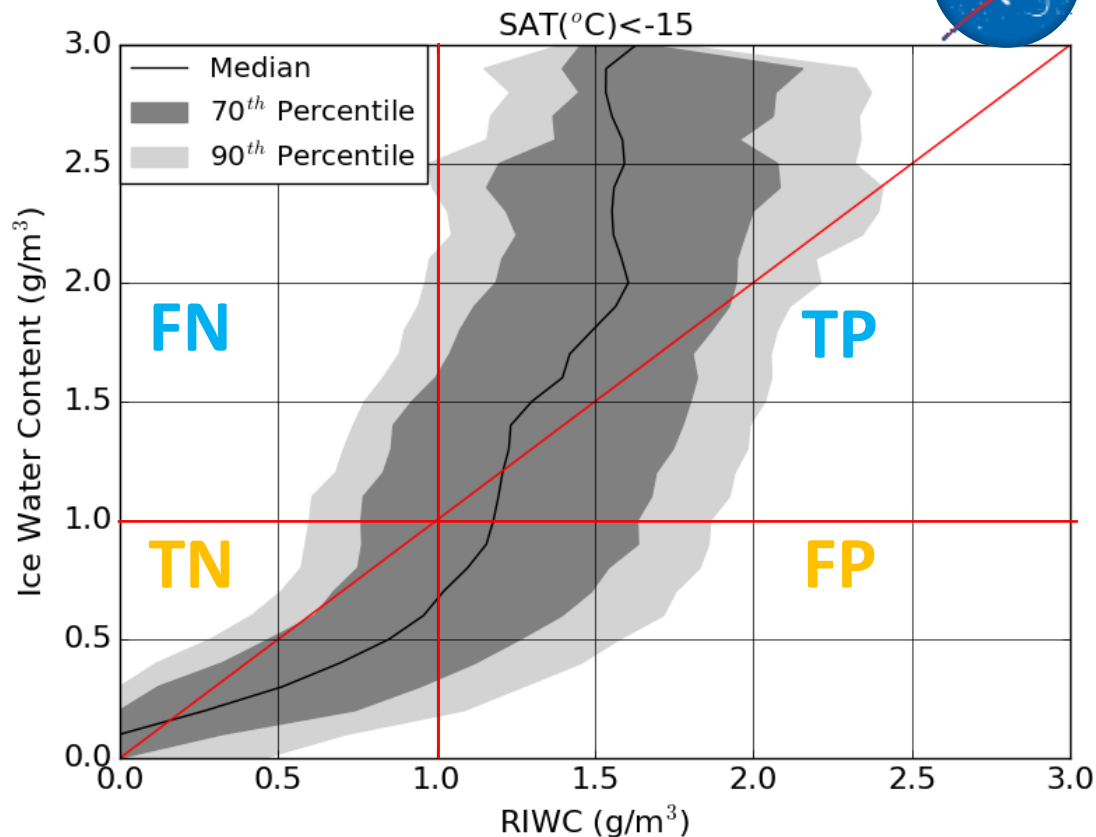
Insufficient data to evaluate severe alerting level



HIWC Detection Confusion Matrix

		Radar Estimated IWC (RIWC)	
		LOW	HIGH
IWC	HIGH	False Negative (miss detection)	True Positive (possible HIWC)
	LOW	True Negative (clear air)	False Positive (false indicator)

$$\text{Accuracy} = (TP + TN) / (TP + TN + FP + FN)$$



True Positive Rate (TPR) = $TP / (TP + FN)$ = $1 - FNR$ = Probability of Detection (P_D) = $P(RIWC > 1 \mid IWC > 1)$

False Negative Rate (FNR) = $FN / (FN + TP)$ = $1 - TPR$ = Probability of Missed Detection (P_{MD})

True Negative Rate (TNR) = $TN / (TN + FP)$ = $1 - FPR$ = Probability of Null (P_N) = $P(RIWC < 1 \mid IWC < 1)$

False Positive Rate (FPR) = $FP / (FP + TN)$ = $1 - TNR$ = Probability of False Alarm (P_{FA})

Positive Predictive Value (PPV) = $TP / (TP + FP)$ = $1 - FDR$ = Hazard Confidence = $P(IWC > 1 \mid RIWC > 1)$

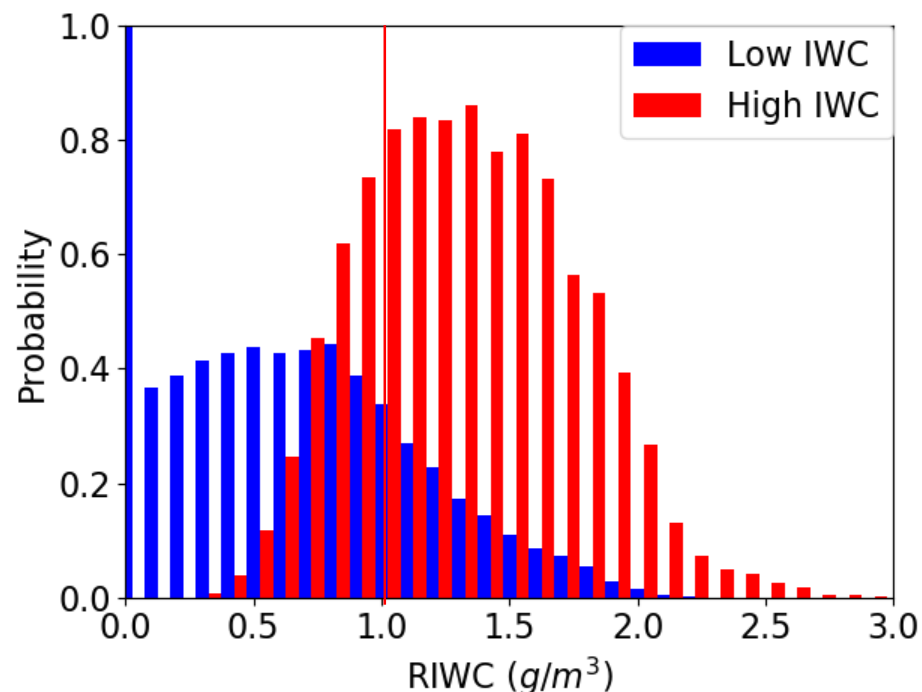
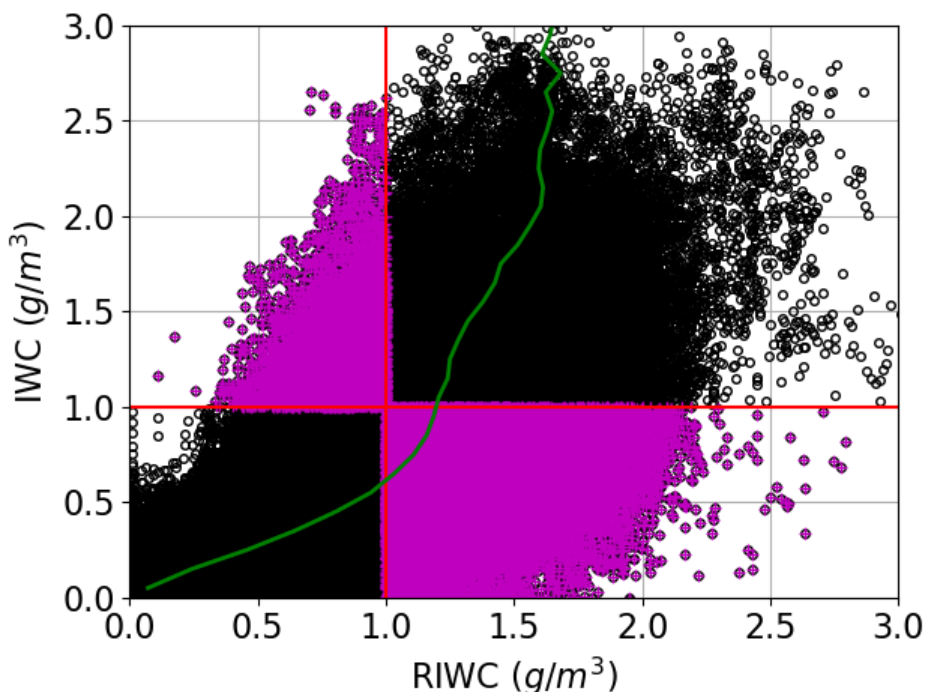
False Discovery Rate (FDR) = $FP / (FP + TP)$ = $1 - PPV$

Negative Predictive Value (NPV) = $TN / (TN + FN)$ = $1 - FOR$ = Safe Confidence = $P(IWC < 1 \mid RIWC < 1)$

False Omission Rate (FOR) = $FN / (FN + TN)$ = $1 - NPV$

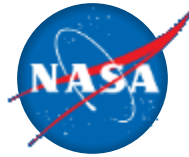


HIWC Detection Algorithm Performance



All temperatures SAT < -15C
Range < 6 Nmi
Fixed thresholds at 1 g/m³

Accuracy	0.84
Probability of Detection (P_D)	0.78
Probability of Missed Detection (P_{MD})	0.22
Probability of False Alarm (P_{FA})	0.15
Hazard Confidence	0.47
Safe Confidence	0.96



HIWC Detection Algorithm Performance

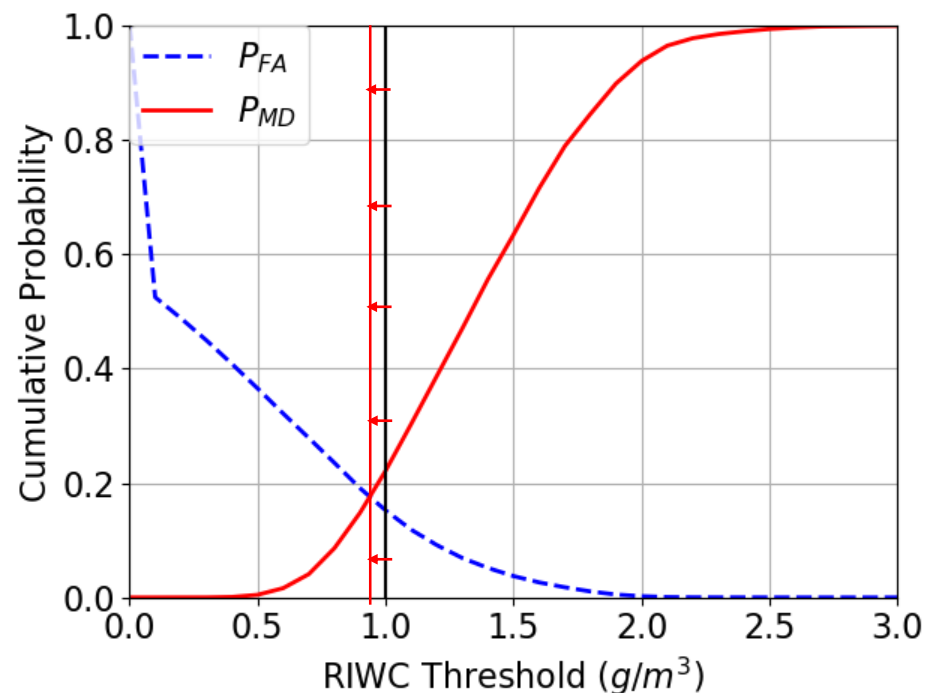
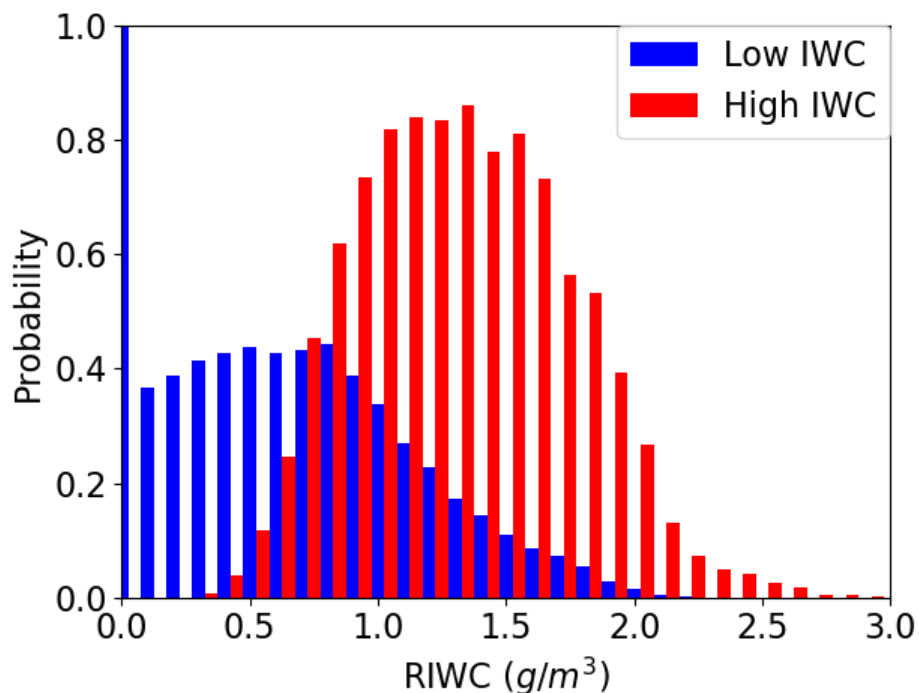
Range < 6 Nmi

Fixed thresholds at 1 g/m³

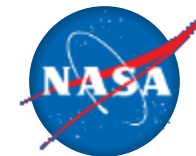
	-15<SAT<-25	-25<SAT<-35	-35<SAT<-45	SAT<-45
Accuracy	0.81	0.75	0.87	0.90
Probability of Detection (P_D)	0.81	0.89	0.75	0.56
Probability of Missed Detection (P_{MD})	0.19	0.11	0.25	0.44
Probability of False Alarm (P_{FA})	0.19	0.28	0.11	0.05
Hazard Confidence	0.49	0.46	0.46	0.57
Safe Confidence	0.95	0.96	0.96	0.94



Variable Threshold



	-15<SAT<-25	-25<SAT<-35	-35<SAT<-45	SAT<-45
RIWC Threshold (g/m³)	1.00	1.21	0.86	0.76



Variable Threshold Performance

Variable thresholds chosen to minimize P_{MD} and P_{FA}

	-15<SAT<-25	-25<SAT<-35	-35<SAT<-45	SAT<-45
RIWC Threshold (g/m^3)	1.00	1.21	0.86	0.76
Accuracy	0.81	0.80	0.84	0.88
Probability of Detection (P_D)	0.81	0.80	0.84	0.89
Probability of Missed Detection (P_{MD})	0.19	0.20	0.16	0.11
Probability of False Alarm (P_{FA})	0.19	0.20	0.16	0.11
Hazard Confidence	0.46	0.52	0.40	0.49
Safe Confidence	0.95	0.94	0.98	0.98

Accuracy	0.84
Probability of Detection (P_D)	0.83
Probability of Missed Detection (P_{MD})	0.17
Probability of False Alarm (P_{FA})	0.16
Hazard Confidence	0.47
Safe Confidence	0.97



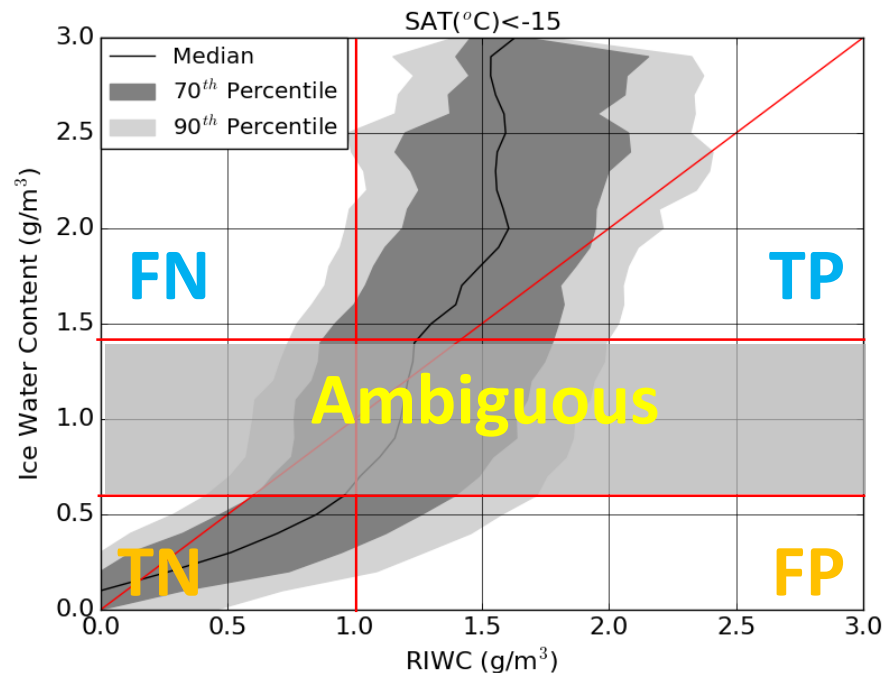
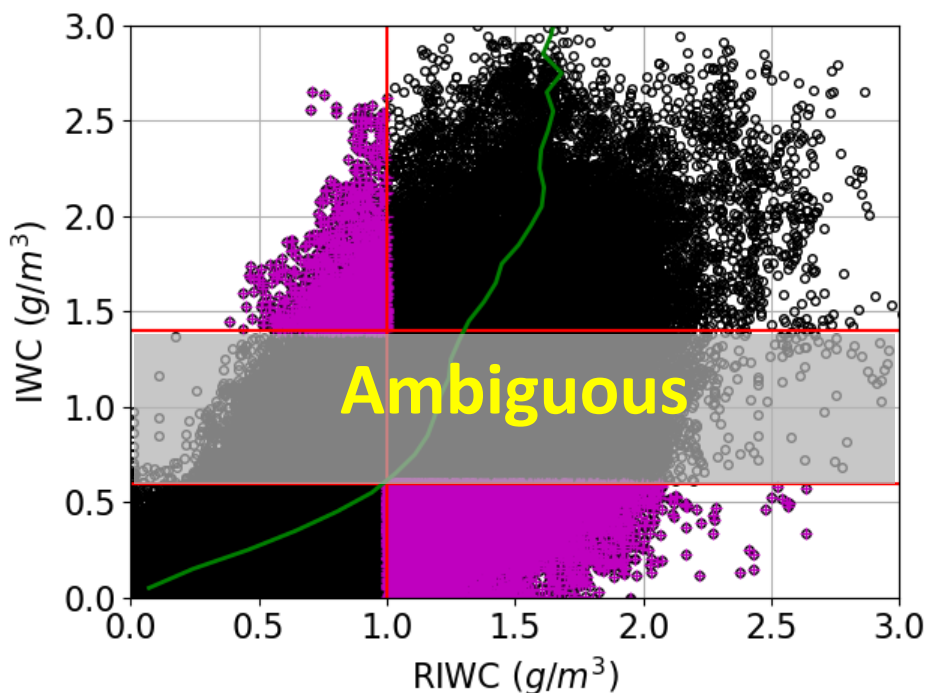
HIWC Detection Performance Goal Revisited

- Must-detect
 - Probability of detection (P_D) ≥ 0.8
 - IWC $\geq 1.4 \text{ g/m}^3$
- Must-not-detect
 - Probability of false alarm (P_{FA}) ≤ 0.2
 - IWC $\leq 0.6 \text{ g/m}^3$

Margins defined around alerting level

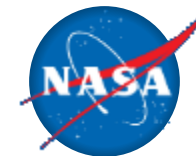


HIWC Detection Algorithm Performance with Margins



All temperatures SAT < -15C
Range < 6 Nmi
Fixed thresholds at 1 g/m^3

Accuracy	0.92
Probability of Detection (P_D)	0.87
Probability of Missed Detection (P_{MD})	0.13
Probability of False Alarm (P_{FA})	0.08
Hazard Confidence	0.53
Safe Confidence	0.99

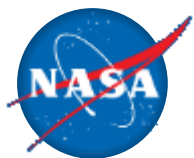


Variable Threshold Performance with Margins

Variable thresholds chosen to minimize P_{MD} and P_{FA}

	-15<SAT<-25	-25<SAT<-35	-35<SAT<-45	SAT<-45
RIWC Threshold (g/m^3)	0.99	1.14	0.84	0.81
Accuracy	0.87	0.87	0.91	0.95
Probability of Detection (P_D)	0.87	0.87	0.91	0.95
Probability of Missed Detection (P_{MD})	0.13	0.13	0.09	0.05
Probability of False Alarm (P_{FA})	0.13	0.13	0.09	0.05
Hazard Confidence	0.55	0.57	0.36	0.57
Safe Confidence	0.97	0.97	0.99	0.99

Accuracy	0.91
Probability of Detection (P_D)	0.90
Probability of Missed Detection (P_{MD})	0.10
Probability of False Alarm (P_{FA})	0.09
Hazard Confidence	0.51
Safe Confidence	0.99



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Summary/Conclusions

- Swerling HIWC detection algorithm predicted RIWC used to assess detection probabilities
- Tight definition of alert level
 - Near performance goal using fixed detection threshold
 - Meets performance goal using temperature depended thresholds
 - Performs best at colder temperatures
- Margins around alert level
 - Meets performance goal using fixed threshold
 - Exceeds performance goal using temperature depended thresholds



Q&A

***ANY REMAINING SLIDES IN THIS BRIEFING
ARE BACKGROUND INFO
BELIEVED AS UNNECESSARY FOR THIS BRIEFING***