The Algorithm for Prediction of HIWC Areas (ALPHA): Version 2.0

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Presentation Overview

- ALPHA Objectives, Context, History
- ALPHA v2.0 Development
- ALPHA v2.0 Performance

HIWC Nowcasting Research at NCAR

Sponsored by FAA; Performed by NCAR and collaborators

HIWC Science Plan Objective E3: Development of Tools to Nowcast the High-IWC Environment

Overarching Objective

- Produce a high-resolution, frequently-updated field of calibrated HIWC probability

Specific Task Areas

- Establish the feasibility and demonstrate the skill of a HIWC nowcasting tool
  - Operate experimental product in support of field campaigns
  - Refine product using in situ aircraft observations
- Explore a potential path to operations for product
- Engage prospective users to assist with requirements definition and skill assessment

ALPHA 3-Input v1.0: Deployed in Field Campaigns

Satellite

Find highest, coldest, thickest clouds from Total Water Path, Cloud Top Height and Cloud Top Temperature – *2D field*

Total Satellite Interest

Model

Find deep cloud layer, heavy precipitation, high condensate, updrafts, temperature below -15°C – *3D field*

Total Model Interest

3D Radar Mosaic

Find active updrafts, high reflectivity in column along with heights of 10 and 30 dBz echo tops – *2D field*

Total Radar Interest

Calculate Total HIWC Interest

If Total Satellite Interest is > 0

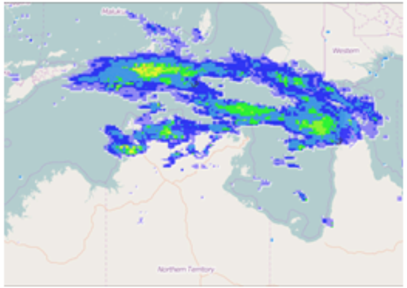
Model 3D Temperature Interest * [45% Total Satellite Interest + 10% Total Model Interest + 45% Total Radar Interest]

= **Total HIWC Interest**

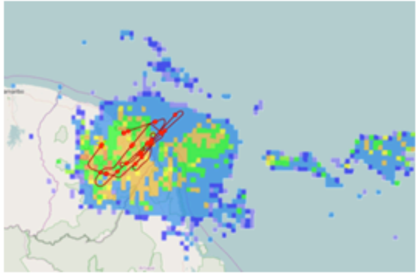
Regional Implementations of ALPHA v1.0

- ACCESS model, MTSat, BOM ground based radar
- 2014 field campaign; now running in "playback" mode for data analysis

Darwin

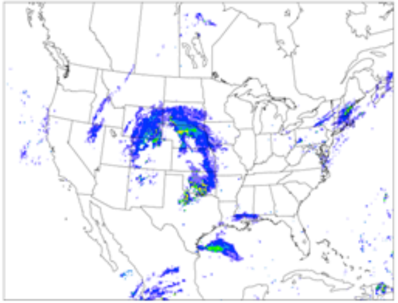


Cayenne



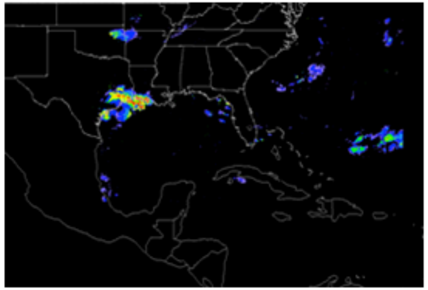
- WRF model, GOES, MSG
- 2015 field campaign; now running in "playback" mode for data analysis

CONUS



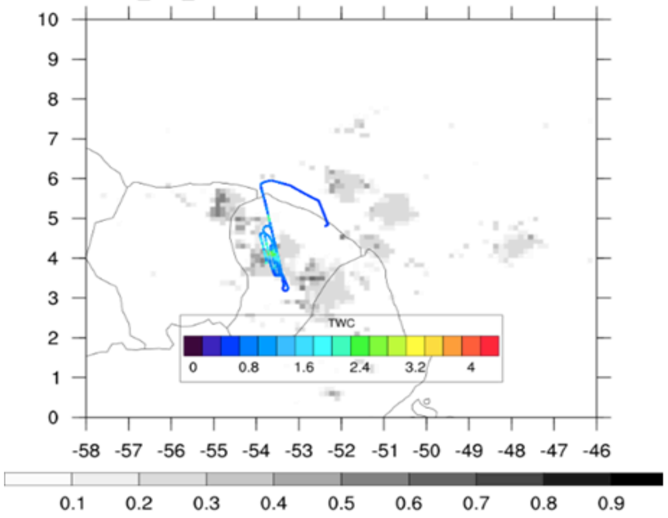
- WRF model, GOES, NEXRAD
- Real-time operation
- Experimental products shared with select users

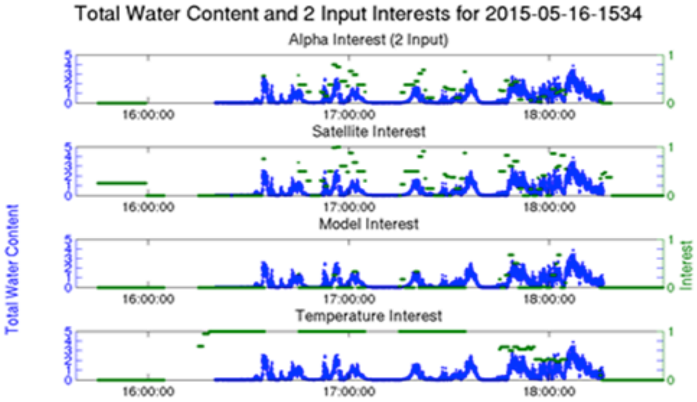
Florida



- WRF model, GOES, NEXRAD
- 2015 field campaign

Evaluation of ALPHA v1.0





HIWC Field Campaigns

- Darwin, Australia (Jan-Feb 2014)
- Cayenne, French Guyana (May 2015)
- Ft Lauderdale, Florida (Aug 2015)

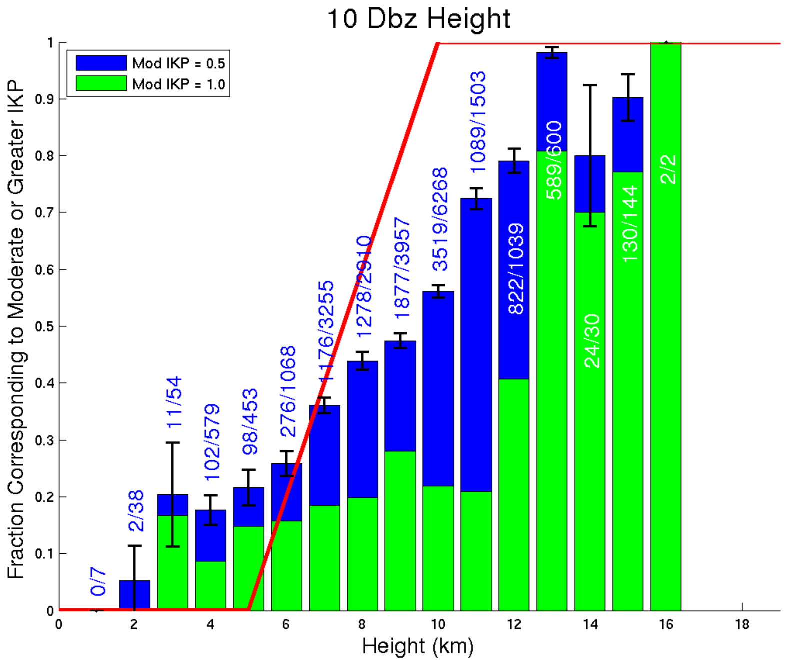
Measurements Analyzed

- Isokinetic Probe – in situ ice water content (IWC)
- RASTA Cloud Radar – remote retrievals of IWC above/below aircraft

Applied for ALPHA v1.0 Performance Assessment

- IWC from IKP2
- Darwin and Cayenne flights
- Florida data reserved for independent evaluation of ALPHA v2.0

Evaluation of Individual Input Variables



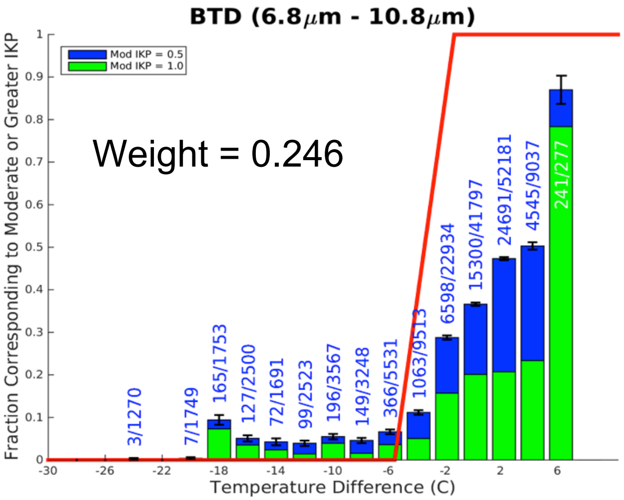
- Histogram shows max altitude of radar reflectivity exceeding 10 dBz vs. fraction of observations with moderate or greater (MOG) ice water content (IWC)
- Blue (green) bars indicate the fraction of field observations where ice water content exceeded 0.5 g/m^3 (1.0 g/m^3)
- Black bars indicate the 95% confidence interval for the "true" fraction of MOG IWC
- Ratios represent the number of HIWC observations over the number of total radar observations in a category
- Red line indicates the original membership function used in ALPHA v1.0

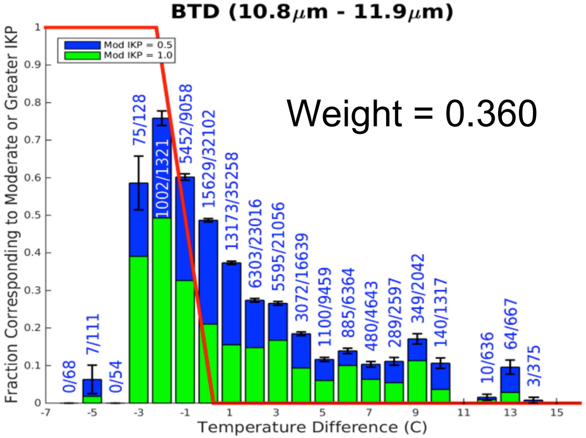
Input Variables Considered for Use in ALPHA

Satellite	NWP Model	Groundbased Radar
Effective Cloud Top Temperature	Temperature	Maximum Reflectivity in Column
Effective Cloud Top Height	Surface Precipitation	Maximum Height of 30 dBz Reflectivity
Total Water Path	Total Condensate	Maximum Height of 10 dBz Reflectivity
Optical Depth	Total Water Path	Vertically Integrated Liquid
Brightness Temperature Difference (6.7 – 10.8 um)	Vertical Velocity	Volume Averaged Height Integrated Reflectivity
Brightness Temperature Difference (10.8 -12 um)	Tropopause Height	Precipitation Ice Mass
	Convective Available Potential Energy, Convective Inhibition	
	Divergence/Convergence	
	Vorticity	

New Variable Example: Brightness Temperature Differences

- Given high weight in ALPHA 2.0 satellite interests
  - Over 60% combined
- Water vapor minus infrared (right)
  - Indicates moist stratosphere
  - Associated with overshooting tops
- Two different infrared channels (below)





Schmetz, J., S. A. Tjemkes, M. Gube, and L. Van De Berg. "Monitoring Deep Convection and Convective Overshooting with Meteosat." *Adv. Space Res.* 19.3 (1997): 433-441.

Objective Re-Design of the ALPHA Fuzzy Logic Algorithms Using Field Campaign Data

- Fuzzy logic methodology allows for adjustment of multiple parameters in the algorithms including:
  - Input variables used
  - Shape of membership function for each variable
  - Weight given to each variable in the blending process

- Optimization of parameter set
  - Need a performance metric that defines “optimal”
  - Apply machine learning tool to our data set
  - Many iterations later, we have a new algorithm

Machine Learning Tool and Performance Metrics

- Particle Swarm Optimization
  - Simultaneously tunes membership functions and weights for all input variables
  - Optimize values of each parameter

- Performance Metric
  - Correlation between IWC (IKP2) and ALPHA interest

- Details discussed in subsequent presentations

ALPHA 2.0: Satellite Interest

Input Variable	Changes	Membership Function	Weight
Cloud Top Temp	Replaced Tropo – CTT; lower weight	CTT < -76.3C → interest = 1 CTT > -71.3 C → interest = 0	0.097
Tropopause Height - Cloud Top Height	Includes lower clouds; lower weight	Trop - CTZ < 1.90 km → interest = 1 Trop – CTZ > 9.40 km → interest = 0	0.085
BTD (6.8– 10.8)	Added to algorithm	BTD < -5.68 C → interest = 0 BTD >-1.49 C → interest = 1	0.246
BTD (10.8 – 11.9)	Added to algorithm	BTD <-2.24 C → interest = 1 BTD > 0.22 C → interest = 0	0.360
Optical Depth	Replaced Total Water Path; lower weight	Opt < 37.52 → interest = 0 Opt > 111.67→ interest = 1	0.213

ALPHA 2.0: Radar Interest

Input Variable*	Changes	Membership Function	Weight
10 dBz Height	Eliminate low heights; larger weight	Height < 9.72 km → interest = 0 Height > 12.63 km → interest = 1	0.675
Max Reflectivity in Column**	Include smaller values; lower weight	Max Ref < 15.40 dBz → interest = 0 Max Ref > 16.95 dBz → interest = 1	0.224
VAHIRR	Added to algorithm	VAHIRR < 0.01 → interest = 0 VAHIRR > 18.22 → interest = 1	0.101

Removed: 30 dBz Height

* All radar inputs are now calculated after the bright band is removed from the reflectivity profile (Thanks Cathy for doing this and providing the new VAHIRR field!)

** We looked at the max reflectivity above 2km, but the results were not significantly different

ALPHA 2.0: Model Interest

Input Variable	Changes	Membership Function	Weight
Surface Wind Curl/sin(latitude)**	Added to algorithm	Curl < 0.202e-3 → interest = 0 Curl > 1.408e-3 → interest = 1	0.079
Surface Wind Divergence	Added to algorithm	Div < -2.288e-4 → interest = 0 Div > -0.614e-4 → interest = 1	0.054
Vertical Velocity	Change from Pa/s to m/s, lower weight	Vel < 0.070 m/s → interest = 0 Vel > 0.700 m/s → interest = 1	0.083
Total Condensate	Include lower values, higher weight	Cond < -0.005 → interest = 0 Cond > 0.015 → interest = 1	0.784

Removed: Total Water Path, Precipitation

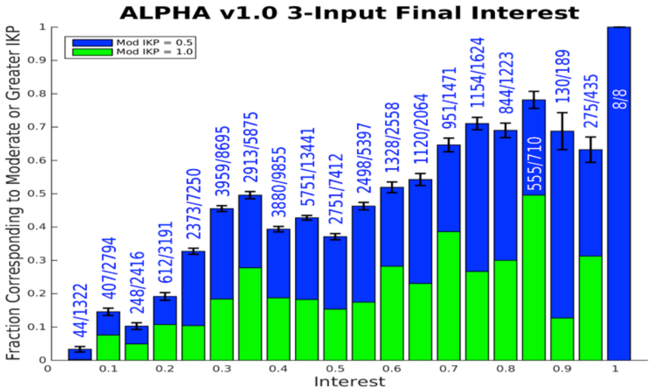
** The surface curl field is divided by the sine of the latitude to account for the latitude dependence of the Coriolis force. This way, all locations can use the same membership function.

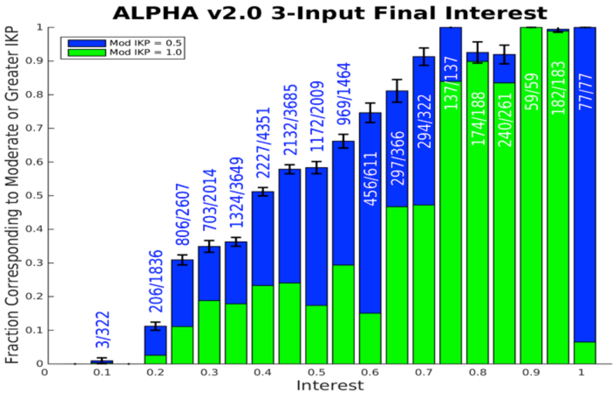
ALPHA 2.0 Algorithm: Blending

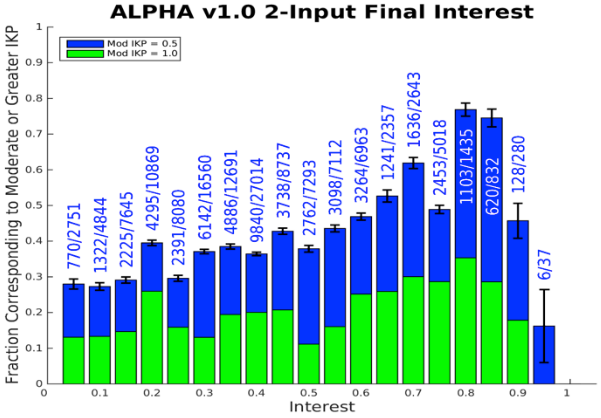
Product	Changes	Satellite Weight	Radar Weight	Model Weight**
2-Input ALPHA	Slightly higher model weight	0.734	------	0.266
3-Input ALPHA	Higher radar and model weight, lower satellite weight	0.339	0.486	0.175

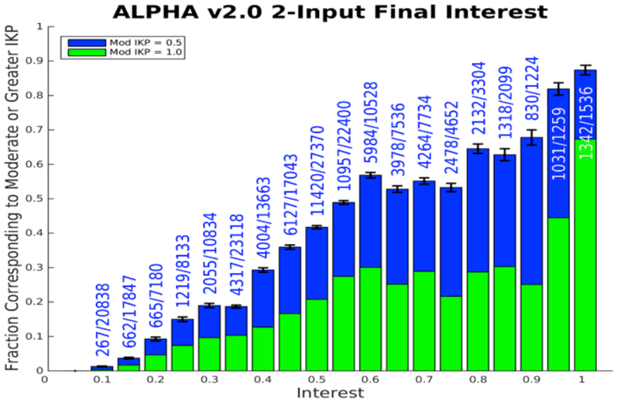
** Model interest was only allowed to increase the final interest. If it would have decreased the interest, it was omitted and the interest was computed from the remaining available fields. We found this method improved the overall correlation between IWC and final interest

ALPHA v1.0 vs. ALPHA v2.0 for all Darwin and Cayenne Flights

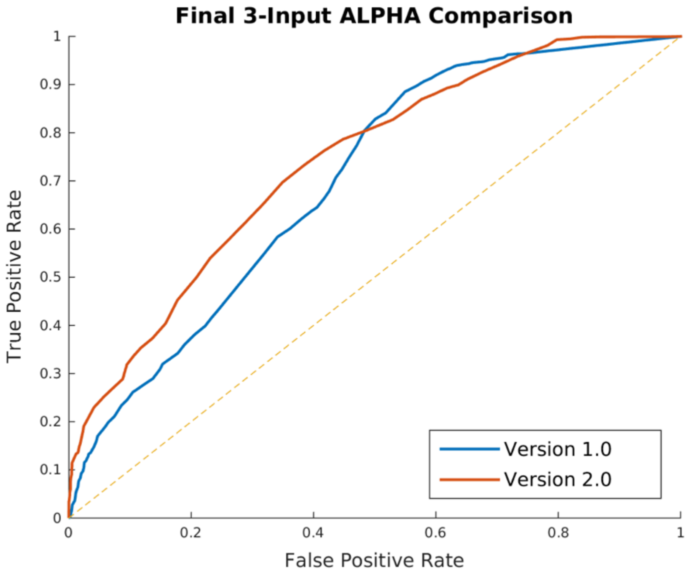


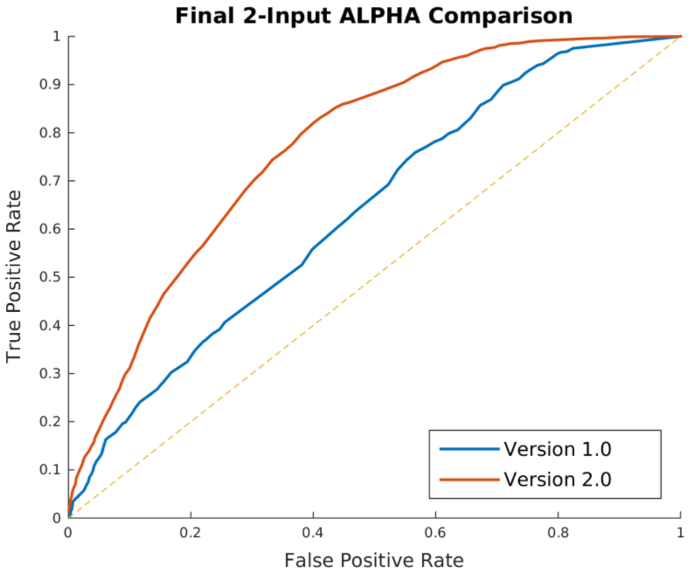






Performance Comparison



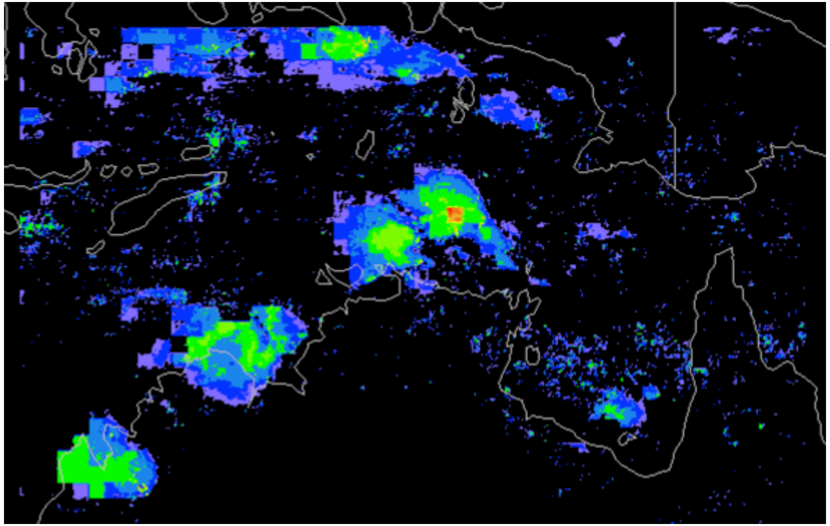


These ROC curves are created by setting a constant HIWC threshold of 0.5 g/m^3 and letting the HIWC interest threshold vary between 0 and 1

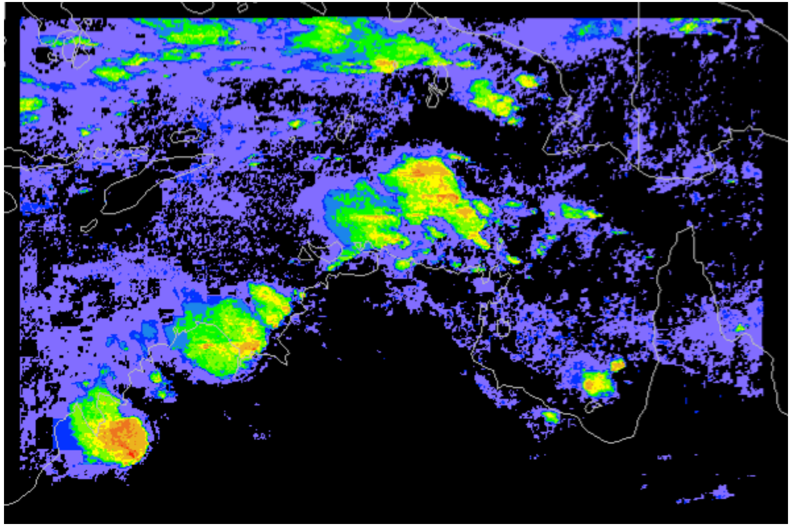
Note: The 3-Input interest has a much smaller sample size than the 2-Input. If we only consider point where both interests are available, the 3-Input performs better than the 2-Input interest.

Case Study: Jan 23rd 2015, 22:45 UTC

ALPHA 1.0



ALPHA 2.0



ALPHA v2.0: Apply to HIWC Radar Experiment (Florida) Data Set

Work in progress

Preliminary results to be shown in subsequent presentations

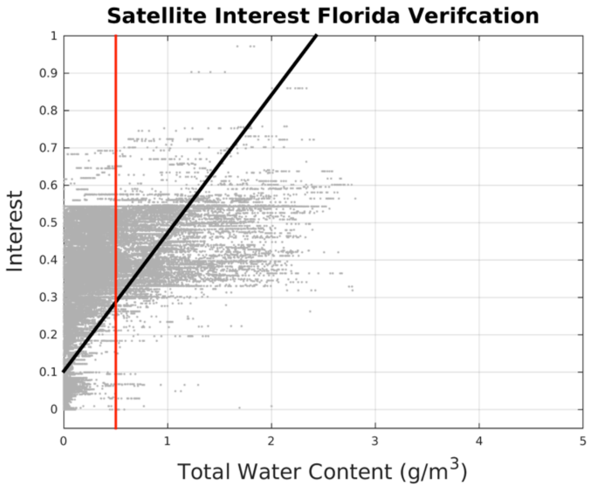
Florida Verification: Satellite

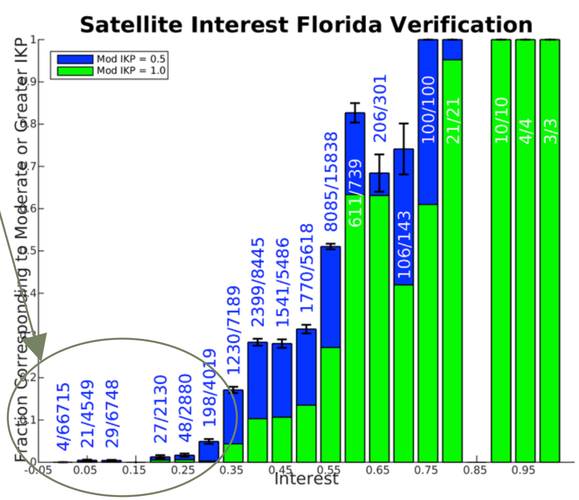
Stronger correlation between interest and IWC than training set (Darwin and Cayenne)

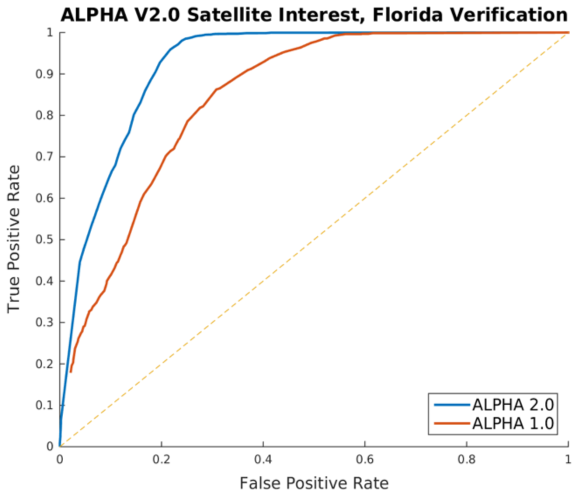
- Florida satellite correlation: 0.6671
- Training set satellite correlation: 0.4394

Few interest values above ~0.55

Very few false negatives







Next Steps with ALPHA v2.0

- Finish comparison of ALPHA product with IKP2 IWC measurements from HIWC-Florida experiment
  - Independent assessment
- Update ALPHA-CONUS real-time product with ALPHA v2.0; implement a version in Australia
- Use ALPHA v2.0 to characterize horizontal variation and time duration of HIWC features in ALPHA products
- Airborne cloud radar (RASTA) IWC retrievals for comparison with ALPHA vertical variation
- Advection of HIWC features using TITAN (Thunderstorm Identification Tracking and Nowcasting)

Planned presentations and publications

AMS ARAM Conference - Jan 2017

1. Haggerty, Rugg, McCabe, Kessinger, Strapp, Potts, Palikonda: Detection of High Ice Water Content (HIWC) conditions: Status of nowcasting tool development for avoidance of ice crystal icing events, submitted.
2. Rugg, Haggerty, McCabe, Kessinger, Strapp, Delanoe: Evaluation of the Algorithm for Prediction of High Ice Water Content Areas (ALPHA): Methods and Results, submitted

AIAA Atmosphere and Space Environment Conference - June 2017

1. Rugg, Haggerty, Palikonda, Potts: High Ice Water Content Conditions around Darwin: Frequency of Occurrence and Duration as Estimated by a Nowcasting Model, submitted.

Journal Articles in Preparation

1. Haggerty and HIWC co-authors: Development and Verification of a Detection Method for High Ice Water Content Regions, planned submission to an AMS journal, early 2017
2. Haggerty, Jensen, and Yost: High Ice Water Content and Airborne Temperature Measurement Anomalies near Tropical Convection, planned submission to an AMS journal, early 2017