The Algorithm for the Prediction of HIWC Areas (ALPHA)

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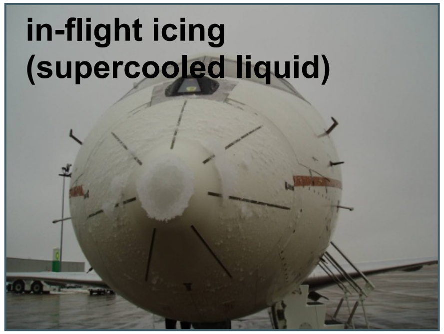
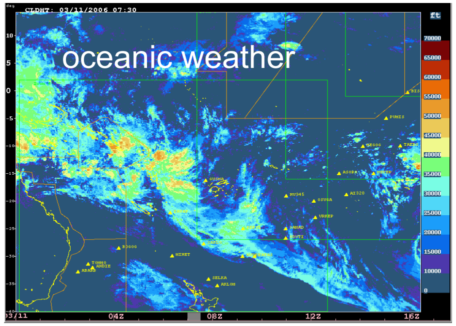
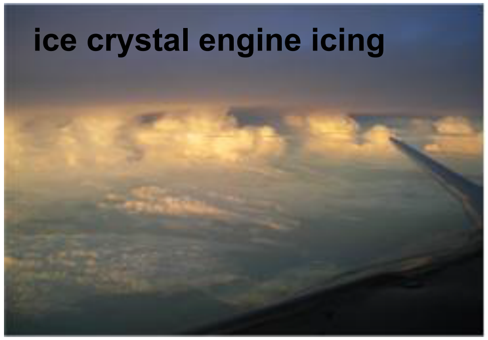
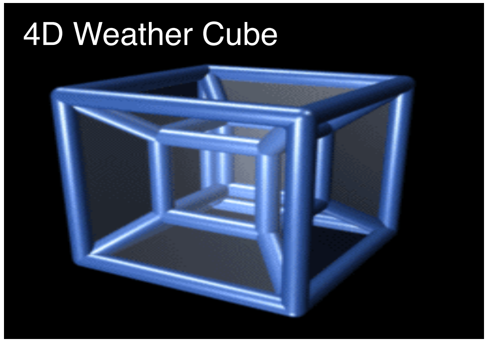
NCAR is sponsored by the U.S. National Science Foundation

Aviation Weather Research Areas at NCAR

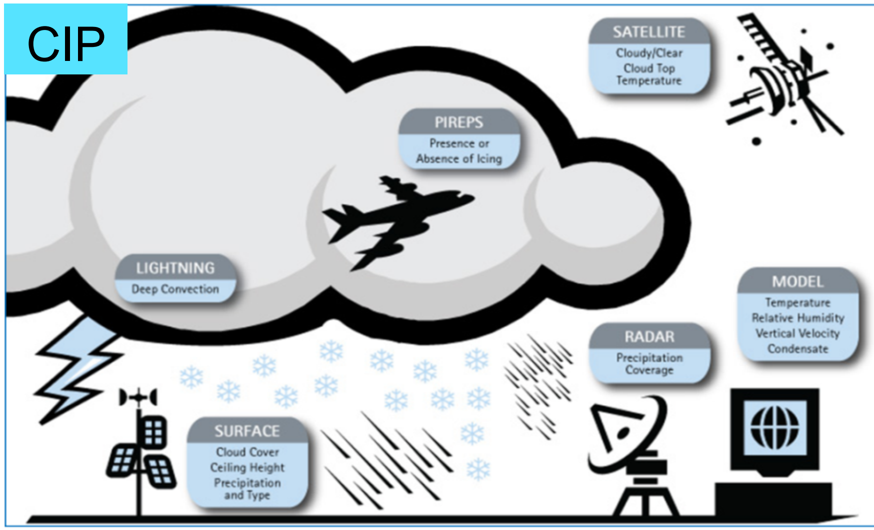


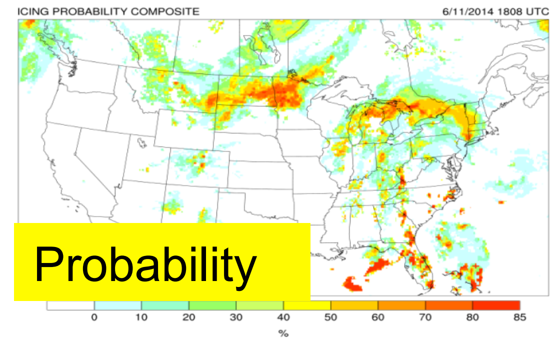


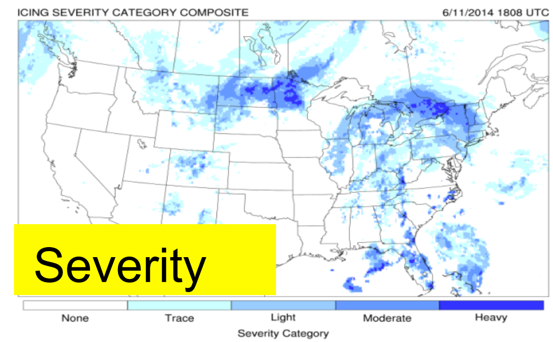


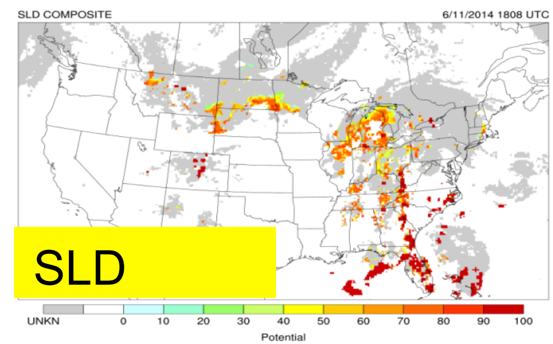


Current Icing Product
Forecast Icing Product





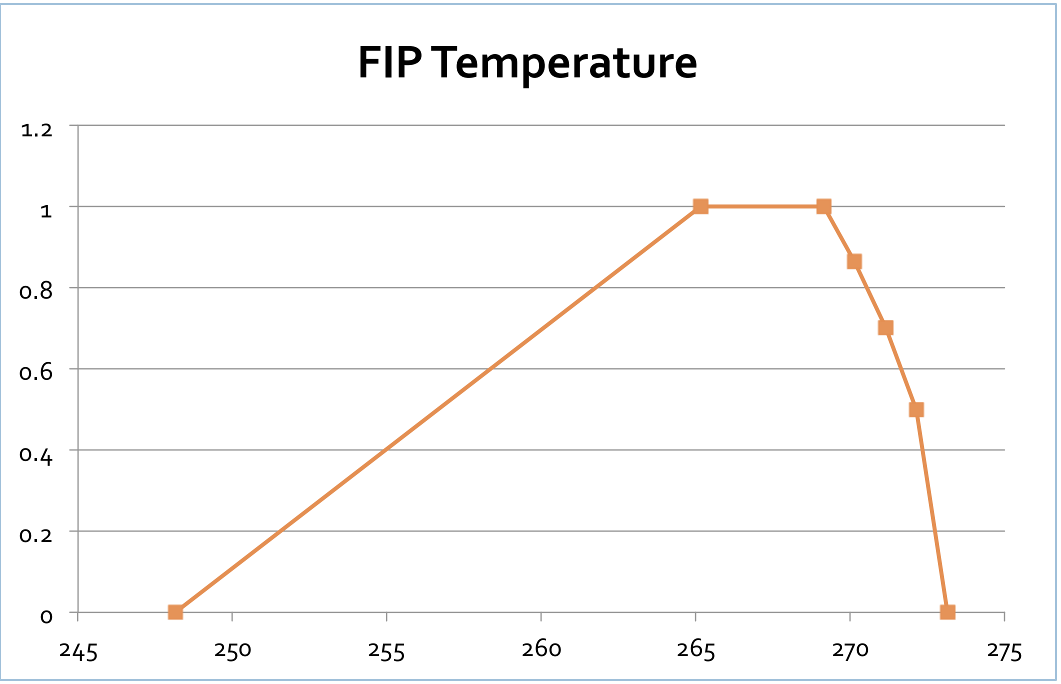




In-Flight Icing Products
Use of Artificial Intelligence Methods

- *Fuzzy-logic membership functions are applied to icing-related fields to create interest maps, which are situationally combined to estimate icing potential*
- *Rather than applying hard thresholds, this approach allows for uncertainties evident in the datasets and mimics the gradual transition from icing to non-icing environments associated with each field*

Temperature Membership Function used in Forecast Icing Product



~ 33 different functions used in the Forecast Icing Product

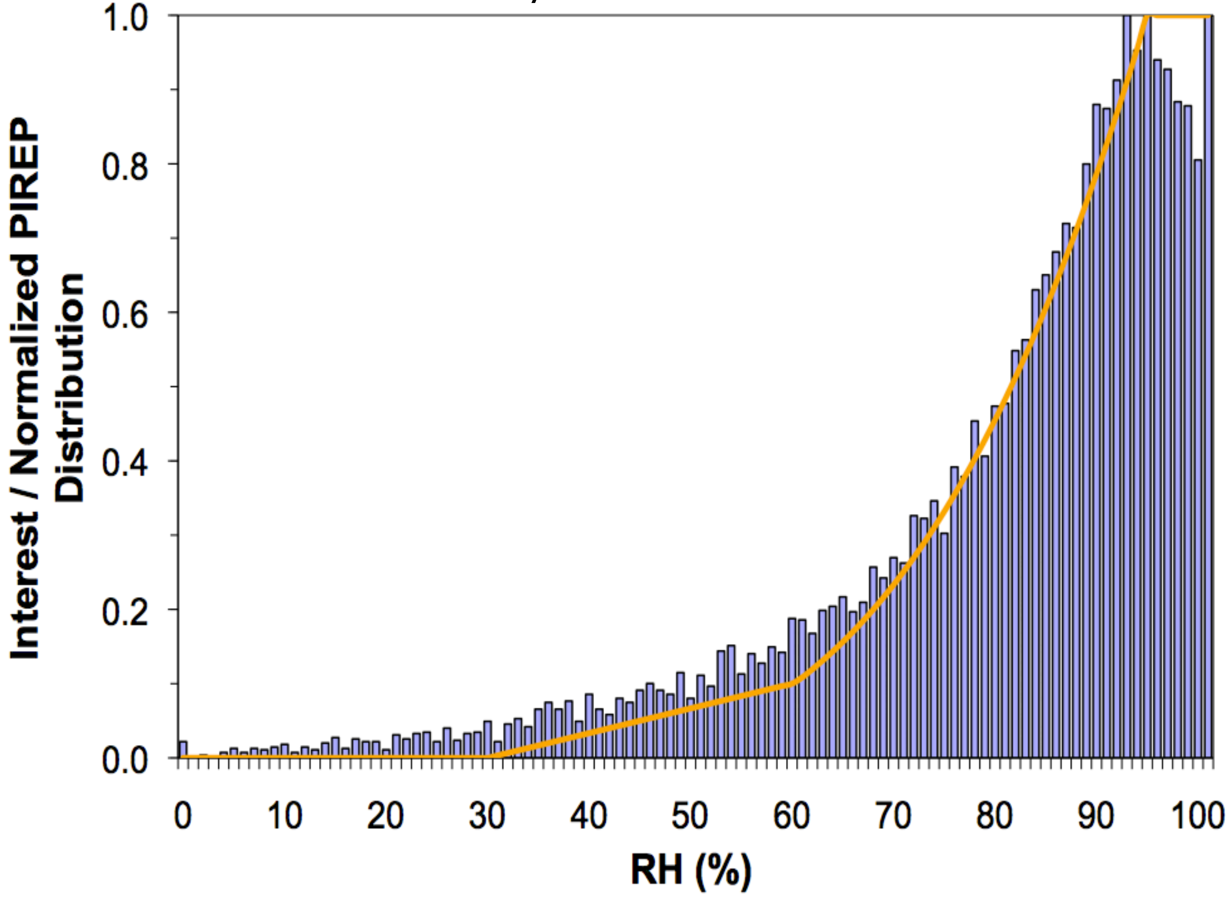
- This membership function assigns 0 to all temperatures < 248.15 K, rises to 1.0 for temperatures between 265.15 K and 270.15 K, then drops quickly back to 0.0 as temperatures warm toward 273.15 K.

- A "fuzzy set" permits intermediate degrees of membership (instead of either in/out of the set).

- If not for the fuzzy set method, any temperature outside of the range 265.15 K to 270.15 K would be assigned 0, but we know icing *can* happen at temperatures outside that range.

Membership Function Development Relative Humidity

Normalized Distribution of Icing Pilot Reports vs. Relative Humidity



Membership functions are also derived from field observations, cloud physics principles, and human forecasting techniques

Application of Icing Product Methodology to HIWC Nowcasting

- Existing CIP/FIP infrastructure exploited for development of HIWC diagnostic product → Algorithm for the Prediction of HIWC Areas (ALPHA)
- Process more challenging due to limited observations and understanding of icing crystal icing processes
- Initial membership functions based on (few) engine events plus statistics published by Mason and Grzych (ALPHA v1.0)
- Field campaigns provided more information; evaluation and upgrades in progress (ALPHA 2.0)

Algorithm for the Prediction of HIWC Areas (ALPHA)

- Uses operationally available data as input
- Applies fuzzy logic to blend input data to maximize strengths and minimize weaknesses of each data set
  - Membership functions characterize the relationship of each variable to the possibility of HIWC conditions
  - Blend data with adjustable weighting factors
- Provides a 3-dimensional estimate of HIWC likelihood
  - 0: minimum interest, no HIWC likely
  - 1: maximum interest, high likelihood of HIWC
  - Currently uncalibrated

Value of Available Datasets for Indicating HIWC Conditions

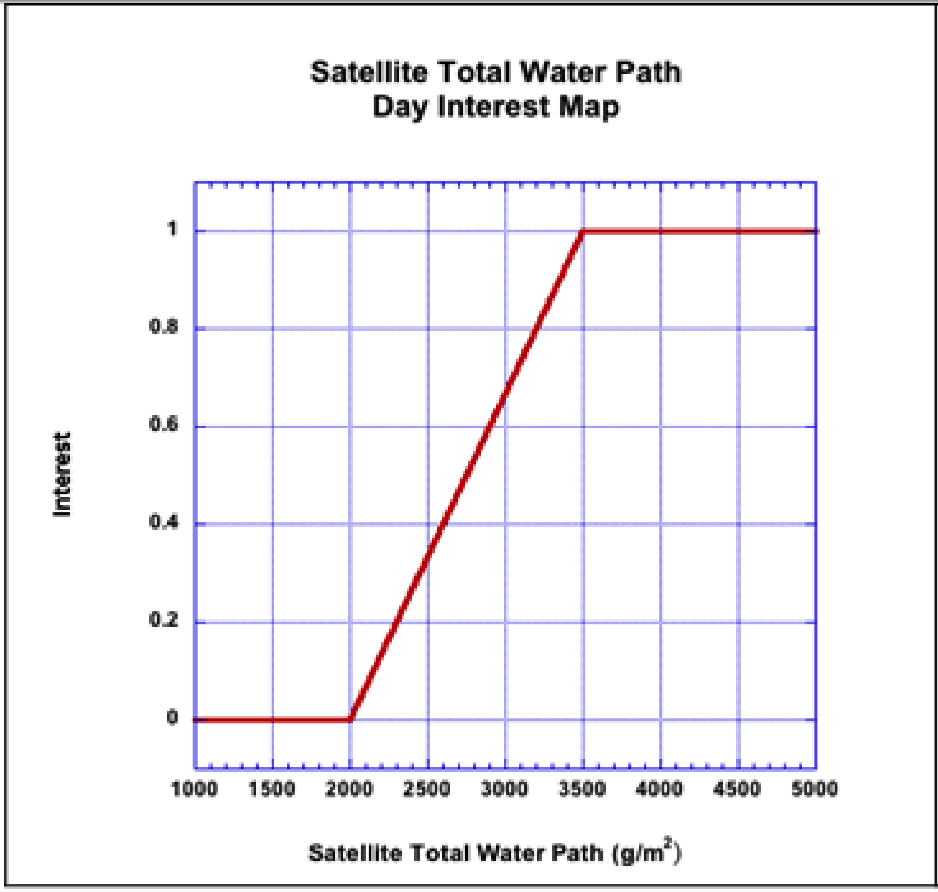
	Satellite (vis/IR)	NWP Model (operational)	Radar (groundbased)
Strengths	Global Availability Moderate spatial resolution	Global Availability 3-Dimensional Forecasting capability	High spatial resolution 3-Dimensional
Weaknesses	2-Dimensional (cloud top)	Limited ability to capture convective processes	Regional availability

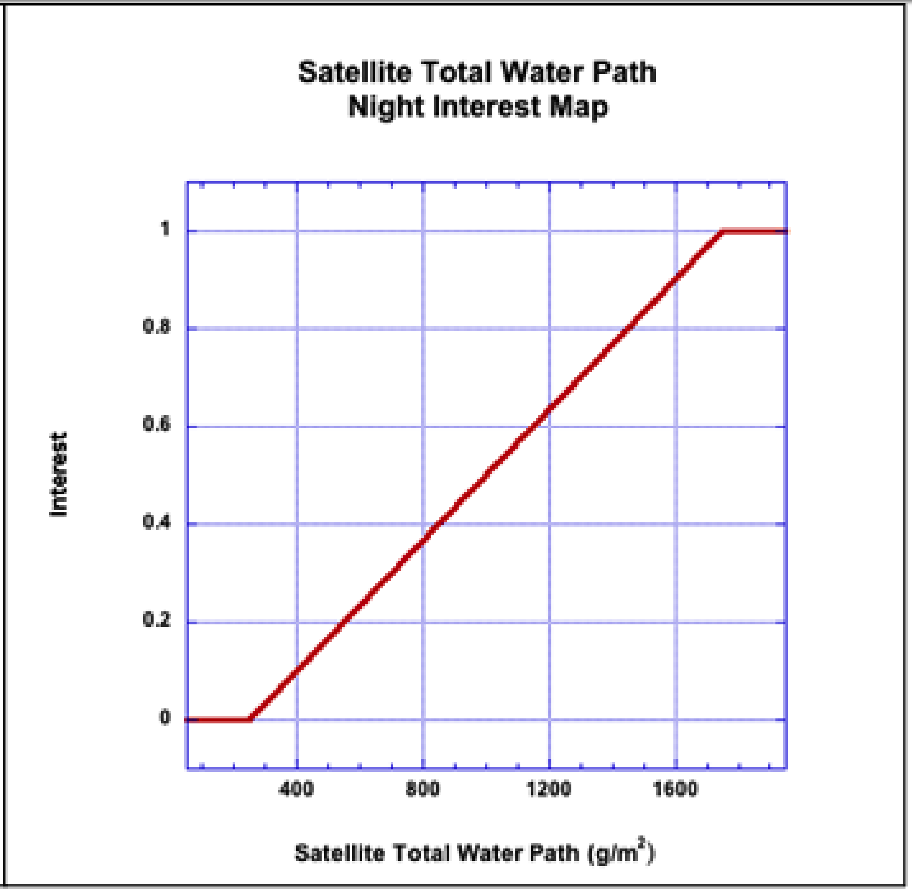
Fields Currently Used in ALPHA

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
	Total Water Path	
	Vertical Velocity**	
	Tropopause Height	

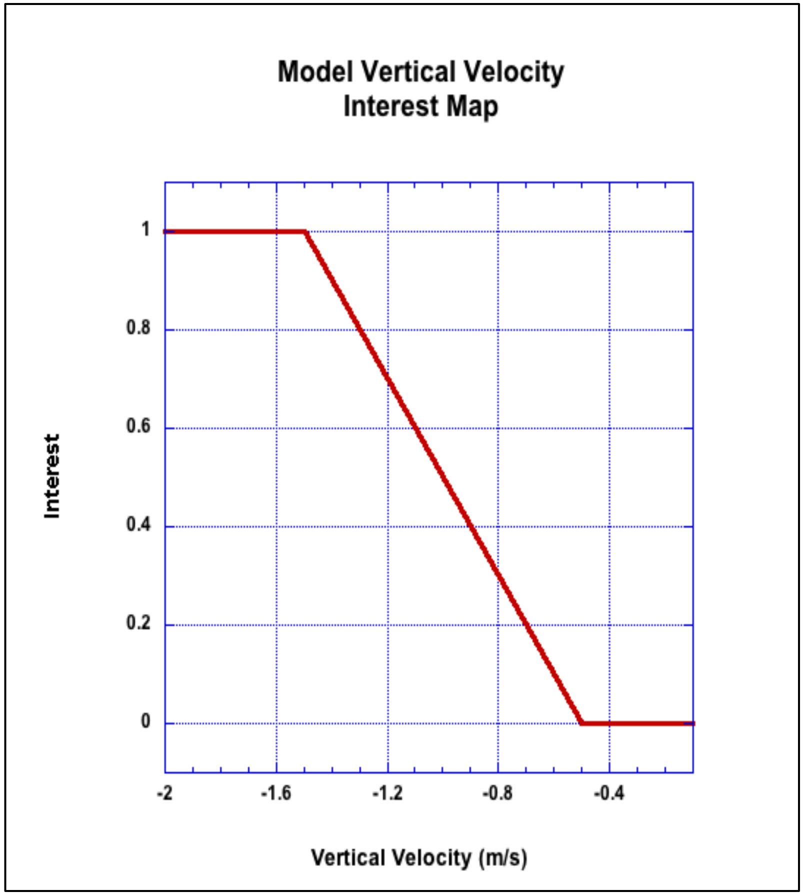
* Products provided by NASA LaRC
** 3-dimensional fields

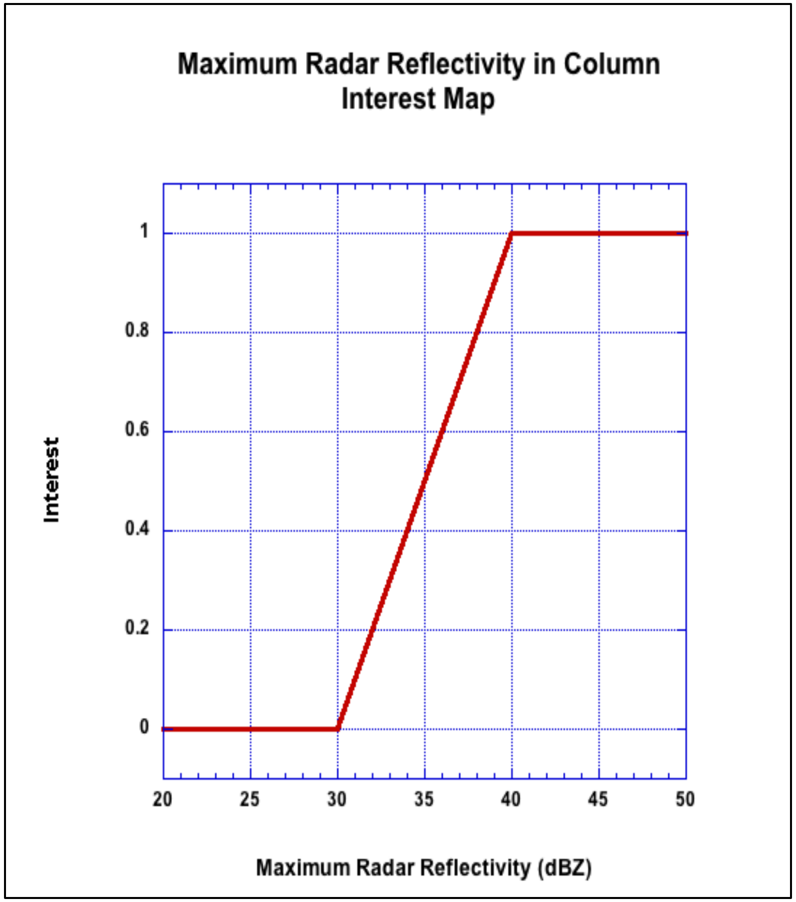
ALPHA Membership Function Example: Satellite TWP





ALPHA Membership Function: Model and Radar Examples





ALPHA 2-Input Algorithm

Satellite

Model

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

Total Satellite Interest

Blend individual fields using algebraic and geometric weighting schemes

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

Total Model Interest

Calculate Total HIWC Interest

If Total Satellite Interest is > 0

Model 3D Temperature Interest * [75% Total Satellite Interest + 25% Total Model Interest]

= **Total HIWC Interest**

ALPHA 3-Input Algorithm

Satellite	Model	3D Radar Mosaic
Find highest, coldest, thickest clouds from Total Water Path, Cloud Top Height and Cloud Top Temperature – *2D field*	Find deep cloud layer, heavy precipitation, high condensate, updrafts, temperature below -15°C – *3D field*	Find active updrafts, high reflectivity in column along with heights of 10 and 30 dBz echo tops – *2D field*
Total Satellite Interest	**Total Model Interest**	**Total Radar Interest**

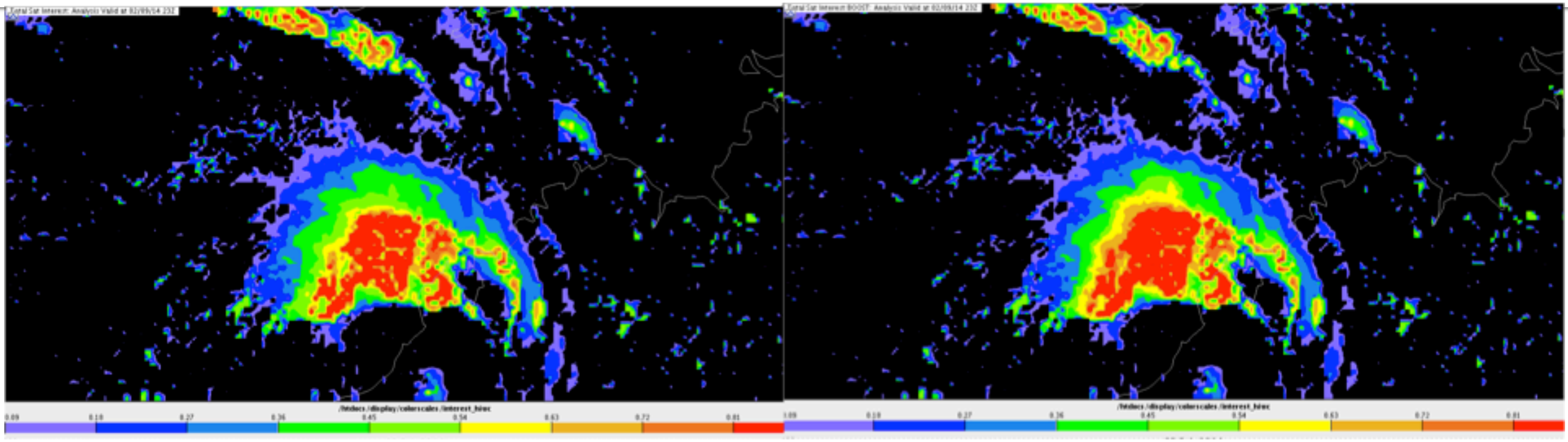
Calculate Total HIWC Interest

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**

Blended Membership Function: Enhanced Cirrus Anvil Algorithm (based on initial observations in Darwin)

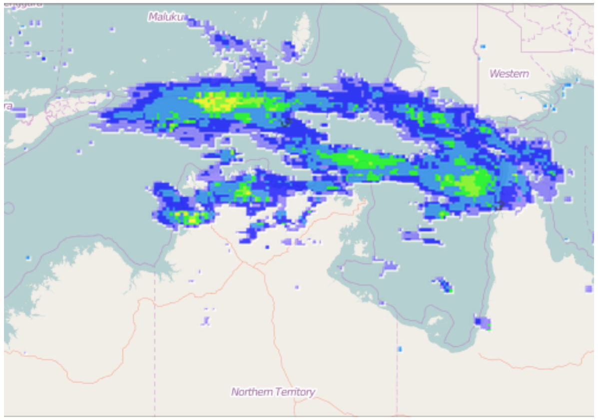


- Identifies large smooth areas of cloud tops close to the tropopause
- Model output determines tropopause height
- Satellite cloud top height is used to determine distance from the tropopause; other satellite products identify features that exceed size threshold
- As distance between cloud top and tropopause decreases for features larger than specified size, interest level is adjusted upward
- Thresholds adjusted for Cayenne version of ALPHA based on observations of HIWC in clouds with larger distances between cloud top and tropopause

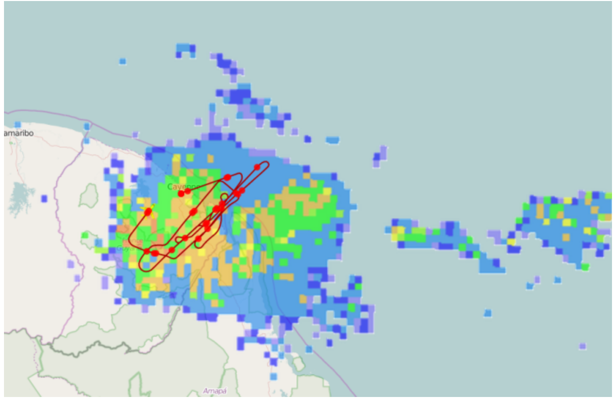
Regional Versions of ALPHA

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

Darwin



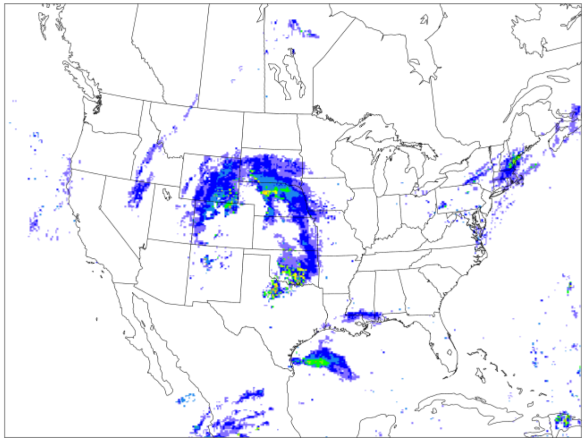
Cayenne



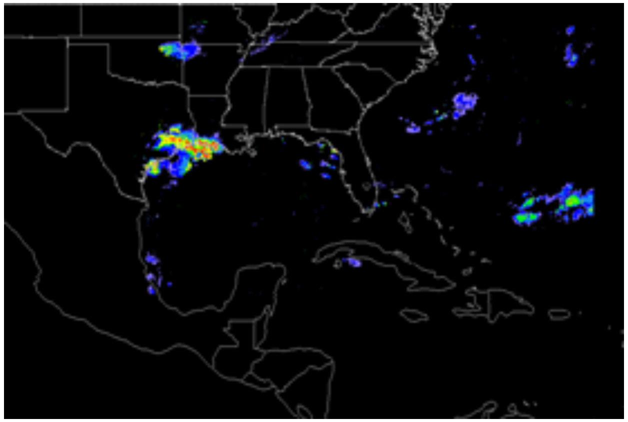
- WRF model, GOES, MSG
- 2015 field campaign; now running in "playback" mode for data analysis

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

United States



Florida-Puerto Rico



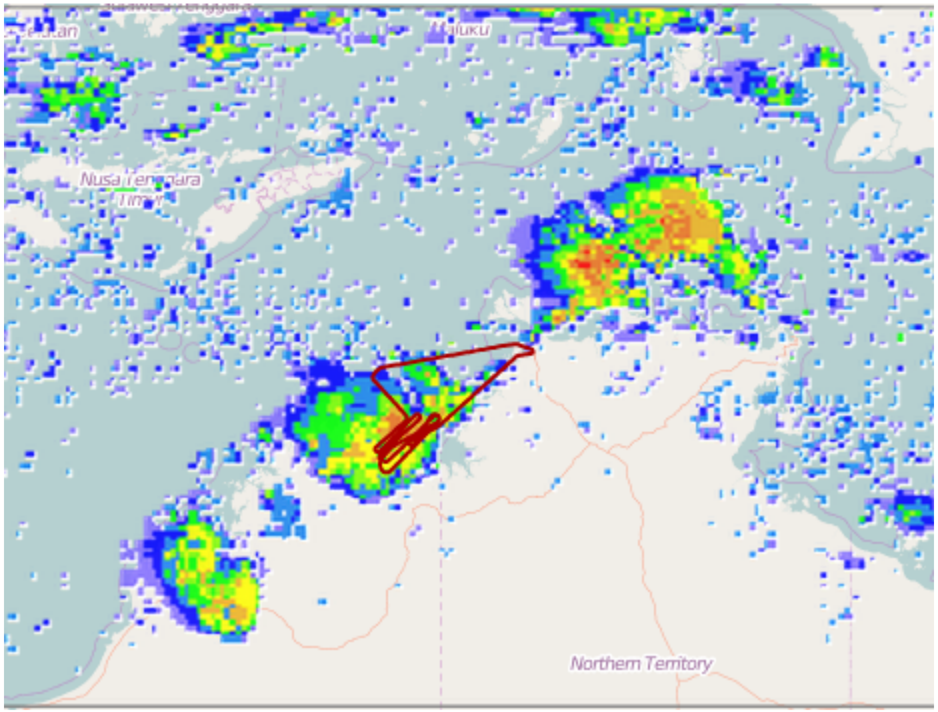
- WRF model, GOES, NEXRAD
- 2015 field campaign

ALPHA Assessment Procedures

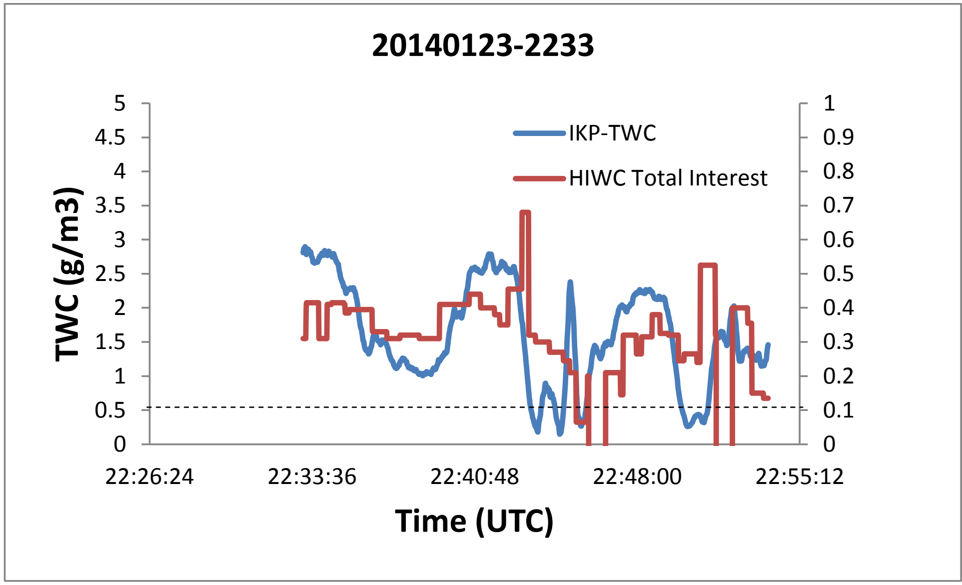
- Ice water content (IWC) from airborne Isokinetic Probe (Darwin and Cayenne flights)
- Extract ALPHA HIWC interest parameter along flight track
- Compare relative trends in time series plots
- Compile probability of detection statistics
- Correlate IWC observations with individual input fields to evaluate and refine membership functions

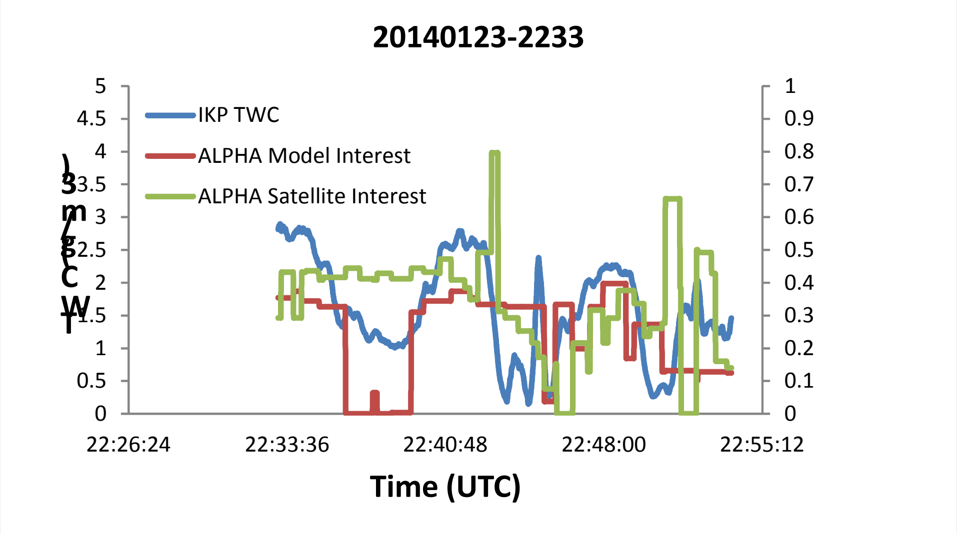
Darwin 20140123 Falcon F06

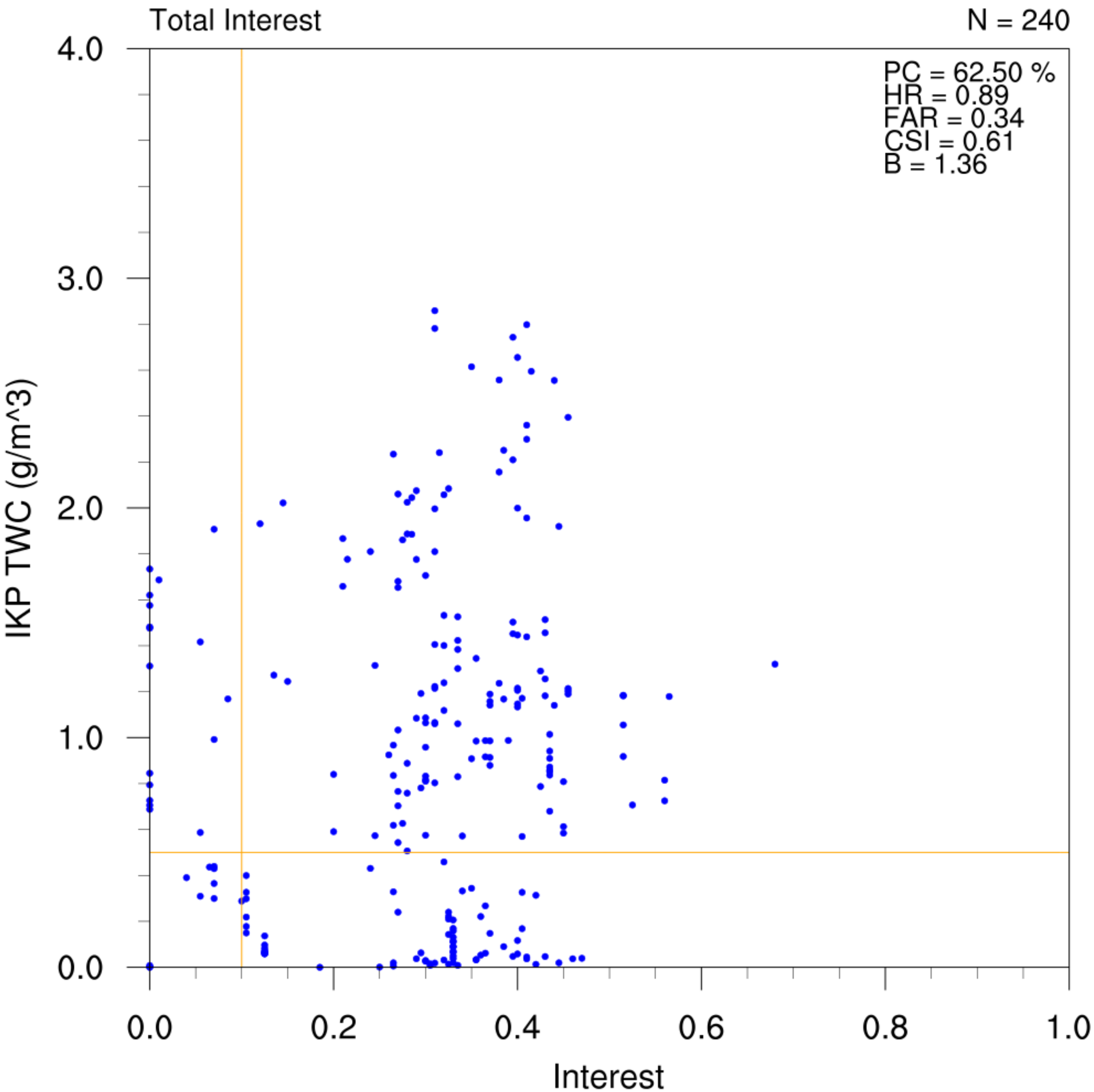
Ice Water Content vs. ALPHA Interest



Level flight segment at 33 kft, -30°C

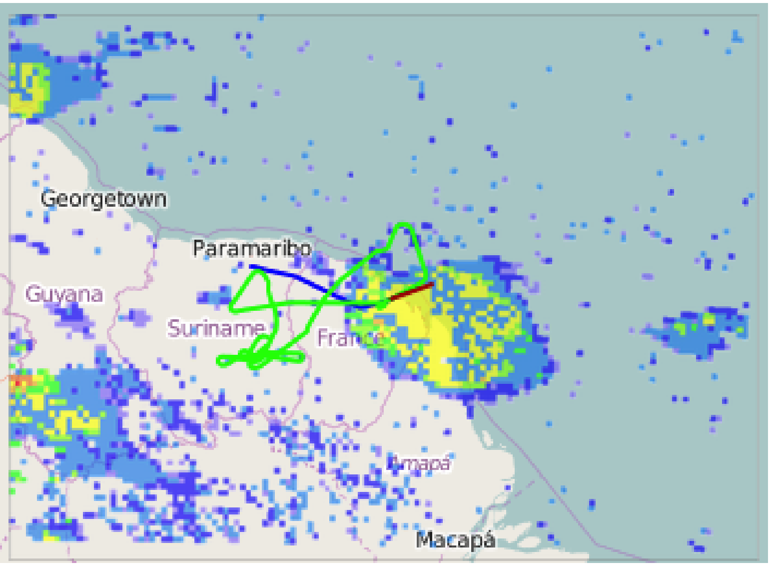




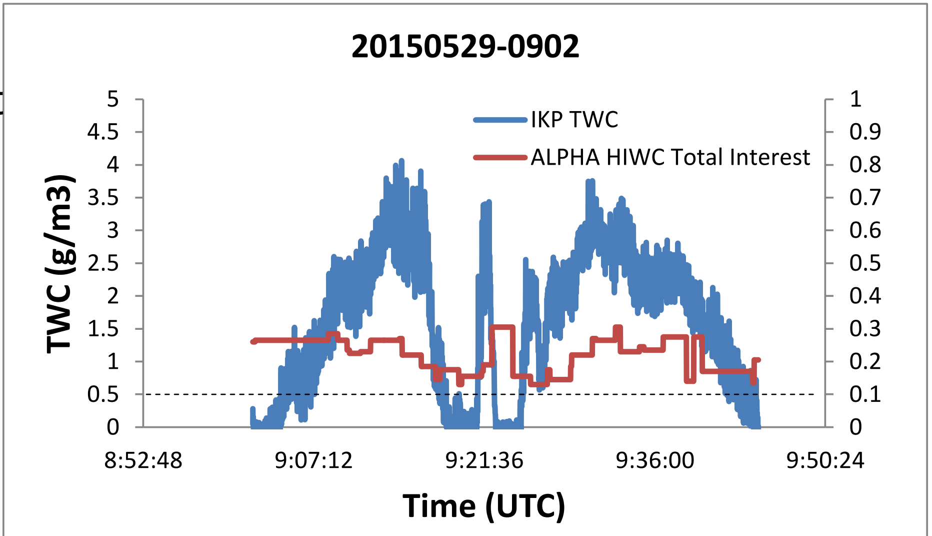


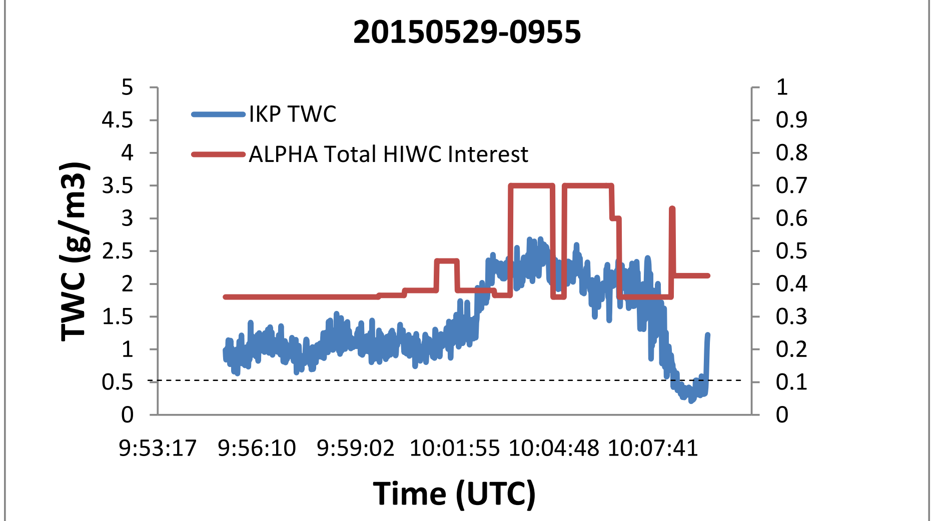
20140123-2233
Percent Correct = 62.5%
Probability of Detection = 89%
False Alarm Rate = 34%

Cayenne 20150529 Falcon F26
Ice Water Content vs. ALPHA Interest



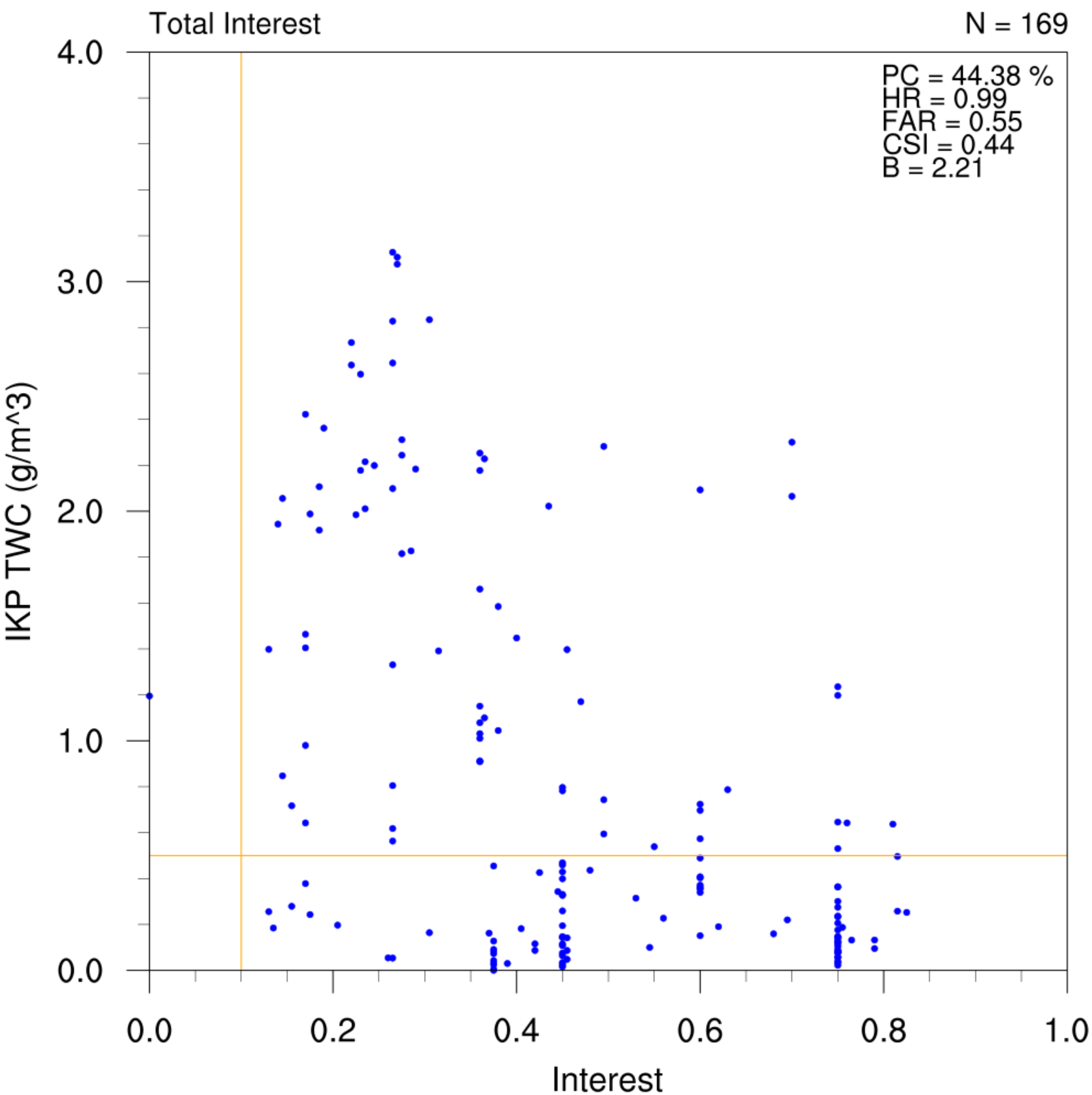
Level segment at -10°C





Level segment at -30°C

Note: preliminary IKP data shown



20150529-0902

Percent Correct = 44%

Probability of Detection = 99%

False Alarm Rate = 55%

Next Steps

- Compile probability of detection (POD) statistics for all flights
  - Darwin – finished
  - Cayenne – recently received IWC data
  - Florida – awaiting IWC data
- Stratify POD results according to altitude/ temperature, day/night, etc.
- Examine variation of each input variable with IWC data; refine membership functions accordingly
  - Darwin – partial results available

Further Data Analysis with ALPHA v2.0

- Airborne cloud radar (RASTA) IWC retrievals for comparison with ALPHA vertical variation
- Characterize horizontal variation and time duration of HIWC features in ALPHA products
- Advection of HIWC features using TITAN (Thunderstorm Identification Tracking and Nowcasting)