WSR-88D Chaff Detection and Characterization

James M. Kurdzo

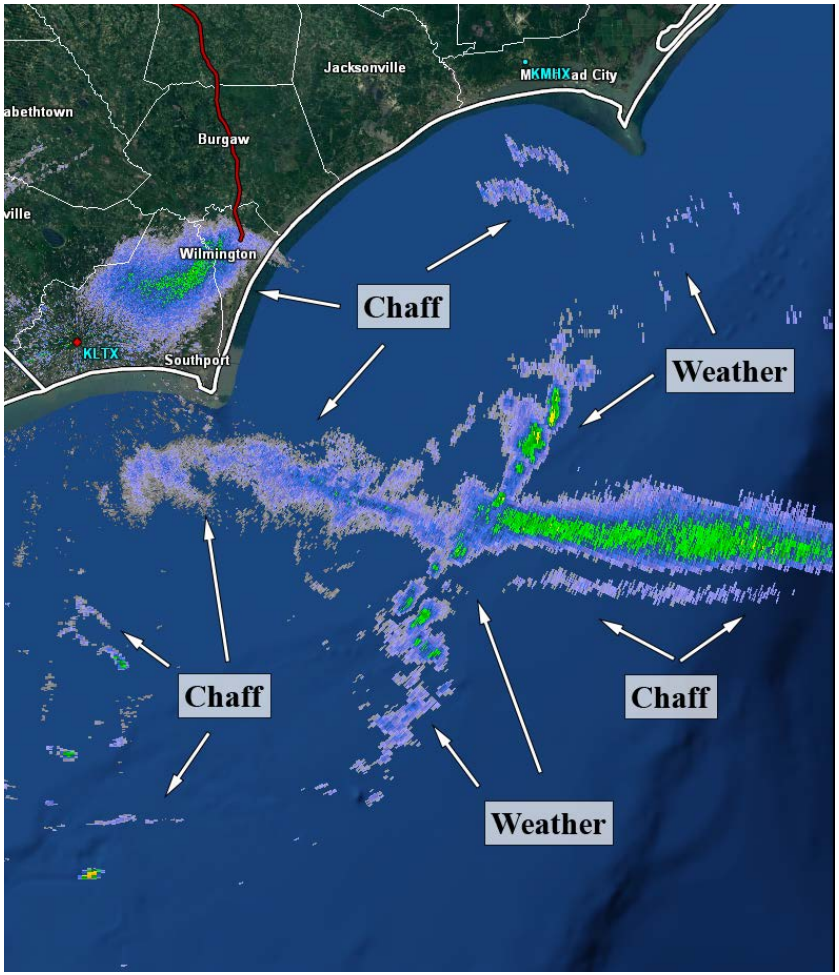
16 February 2017

LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

This material is based upon work supported by the Federal Aviation Administration under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Federal Aviation Administration.

Chaff and Weather Radar

- **False weather returns cause issues for radar users**
- **Co-existence of chaff and weather is particularly problematic**
- **Chaff "clouds" may be undesirable to fly through**
- **Mixed cases can be discerned via Z_{DR}, Φ_{DP}, and ρ_{HV}**
- **Flight controllers don't have access to polarimetric estimates**



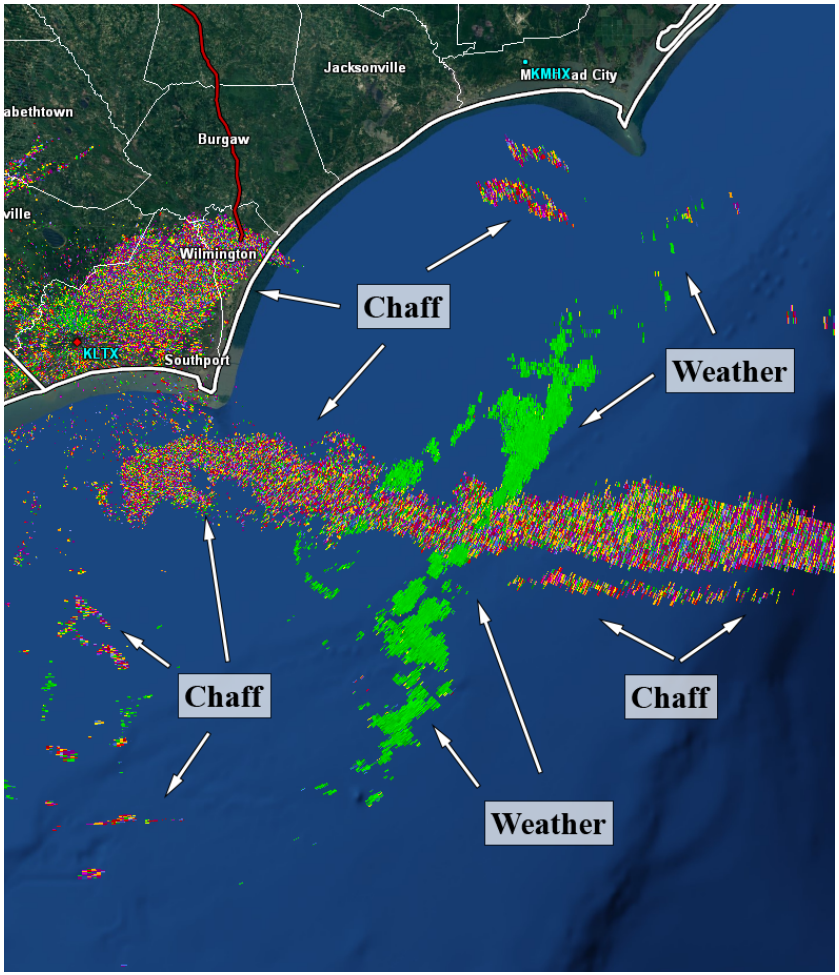
Reflectivity Factor (Z)

Z_{DR} = Differential Reflectivity
Φ_{DP} = Differential Phase
ρ_{HV} = Correlation Coefficient

Chaff and Weather Radar

- **False weather returns cause issues for radar users**
- **Co-existence of chaff and weather is particularly problematic**
- **Chaff "clouds" may be undesirable to fly through**
- **Mixed cases can be discerned via Z_{DR}, Φ_{DP}, and ρ_{HV}**
- **Flight controllers don't have access to polarimetric estimates**

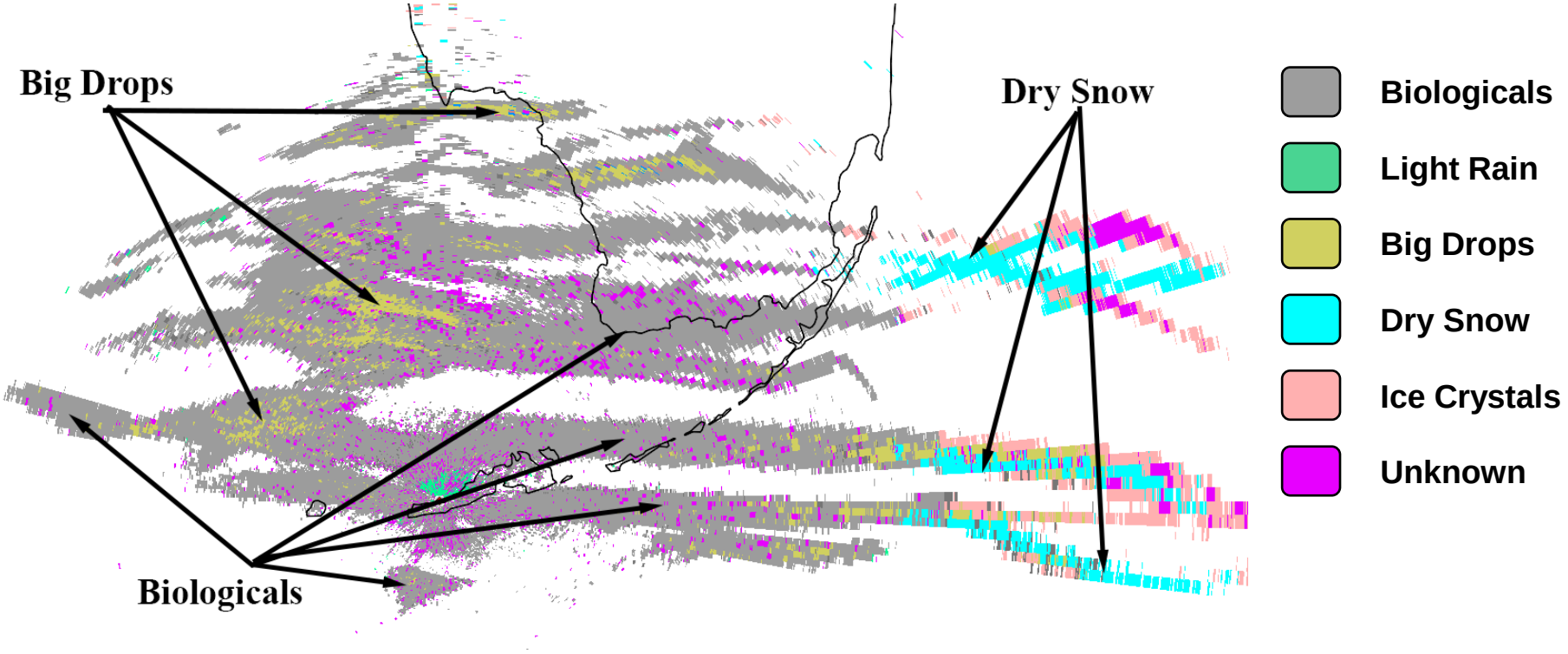
Effective chaff detection is a useful and desired tool



Differential Phase (Φ_{DP})

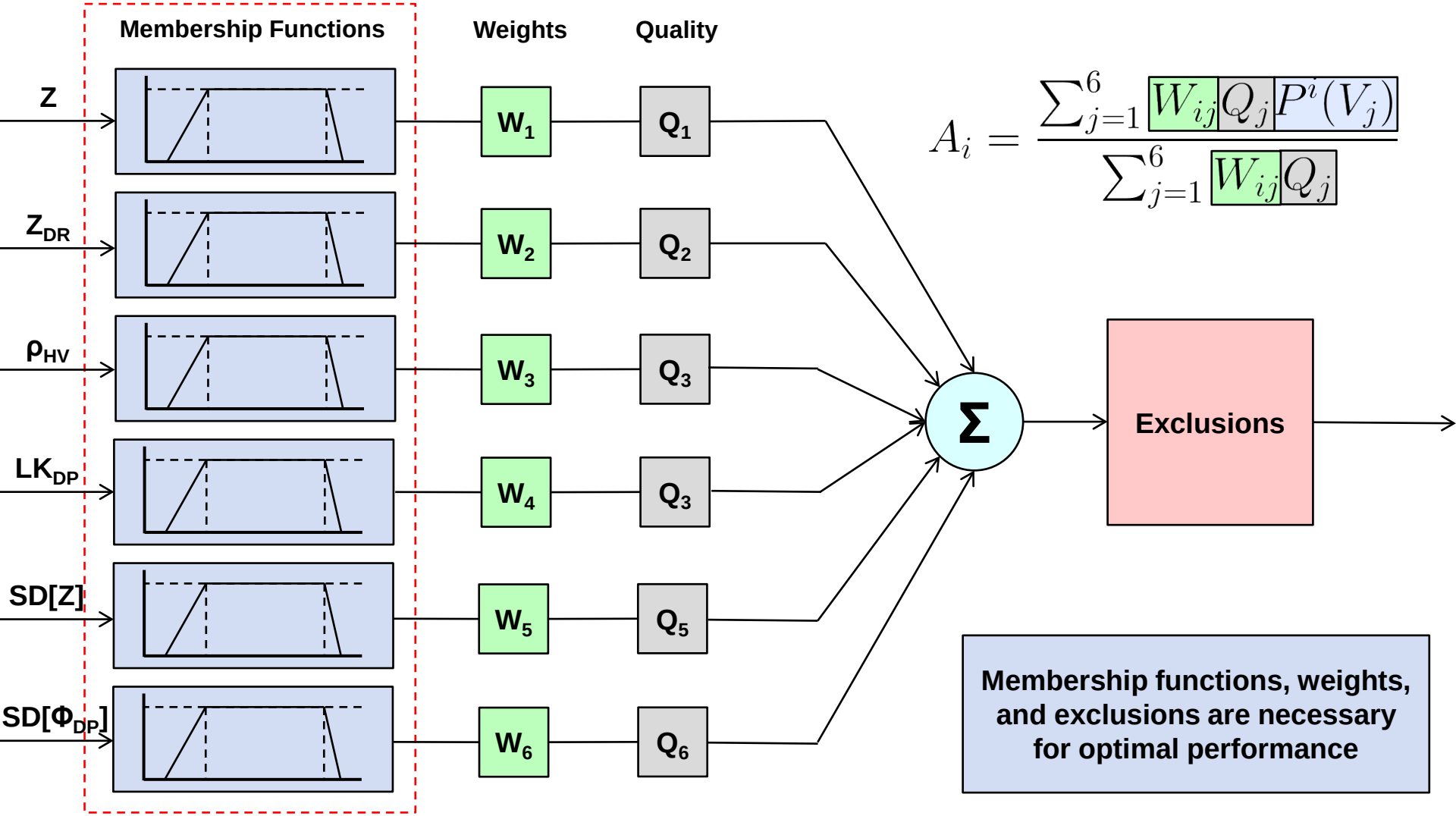
Z_{DR} = Differential Reflectivity
Φ_{DP} = Differential Phase
ρ_{HV} = Correlation Coefficient

Current HCA Output for Chaff

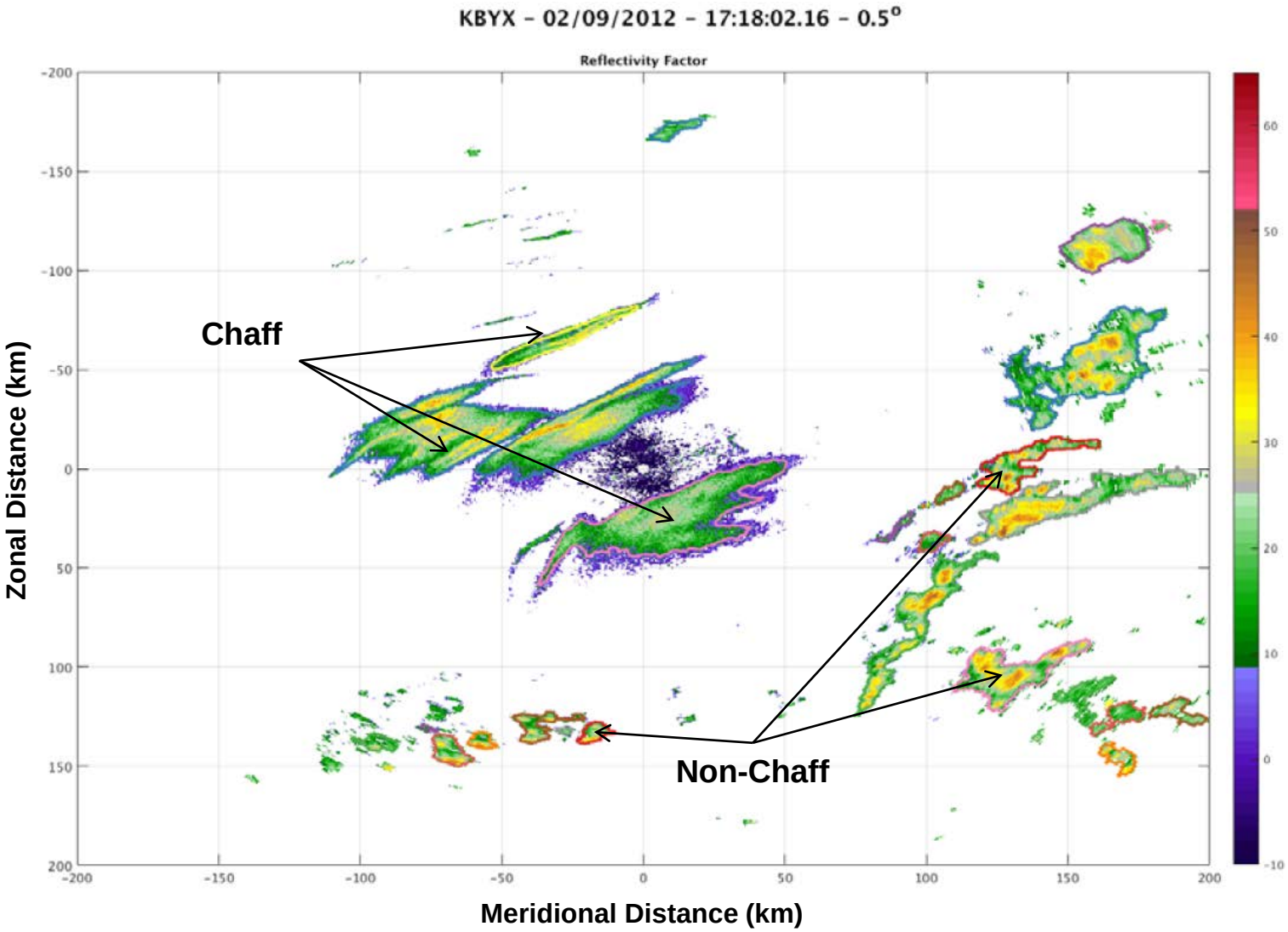


HCA output from the 12 February 2016 chaff event

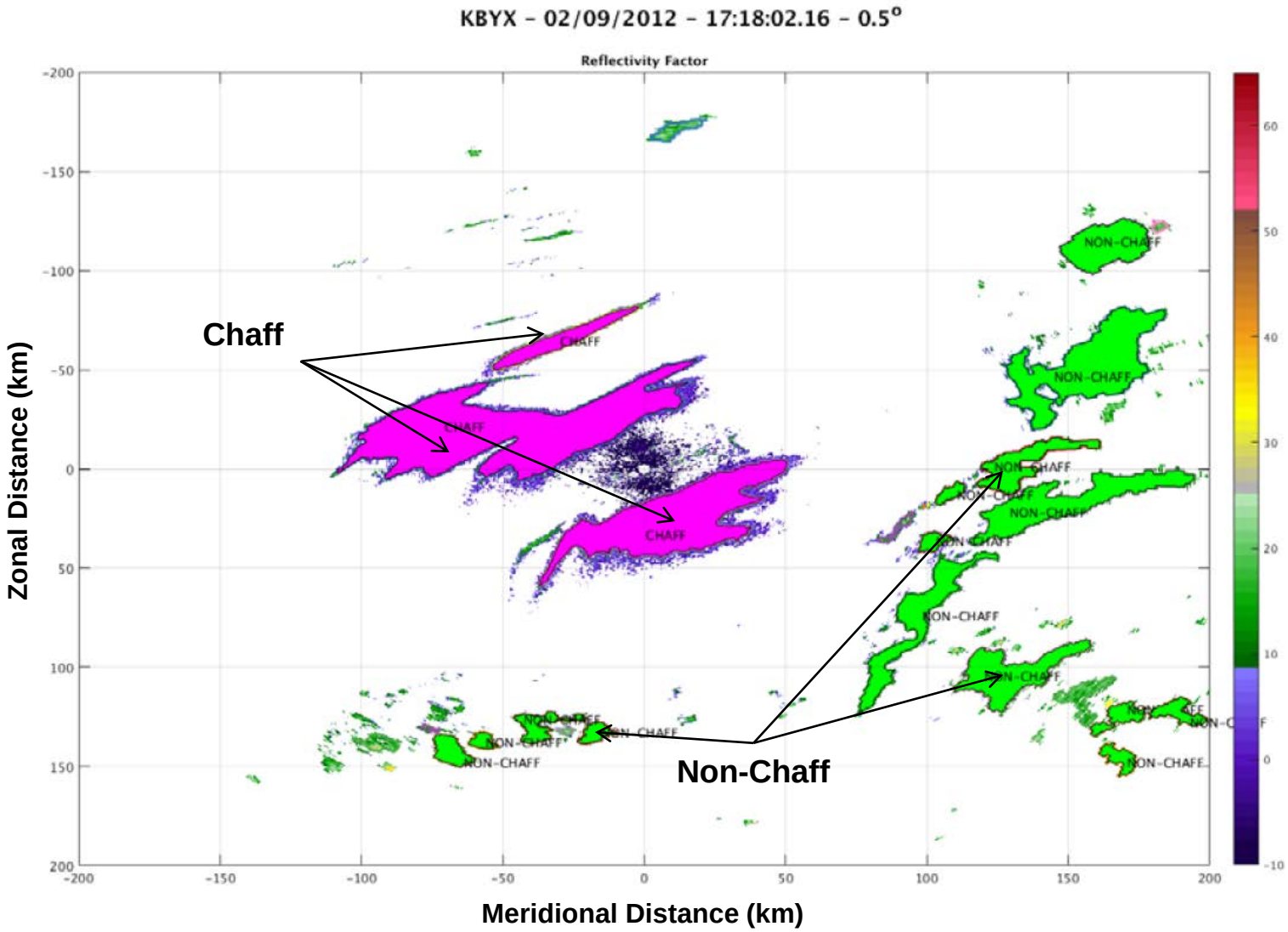
HCA Fuzzy Logic Approach



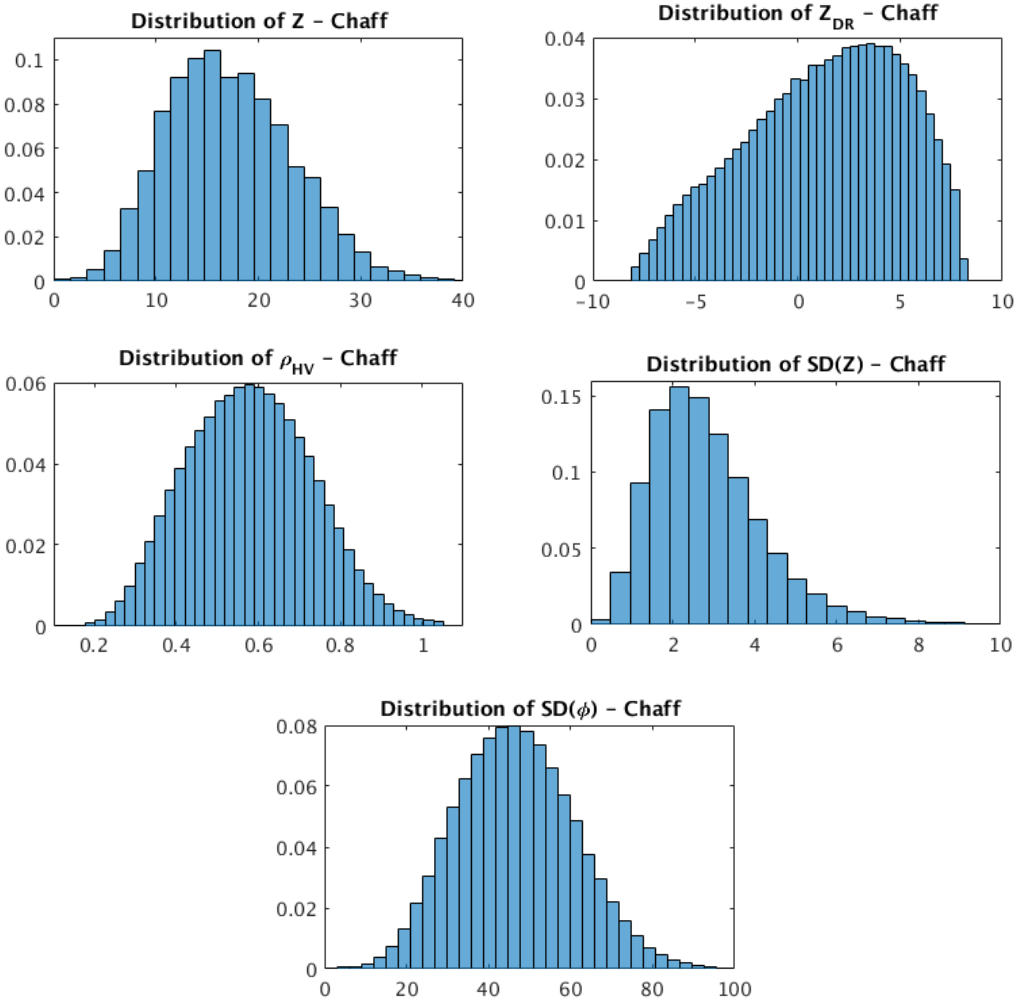
Human Truthing of Chaff Events



Human Truthing of Chaff Events

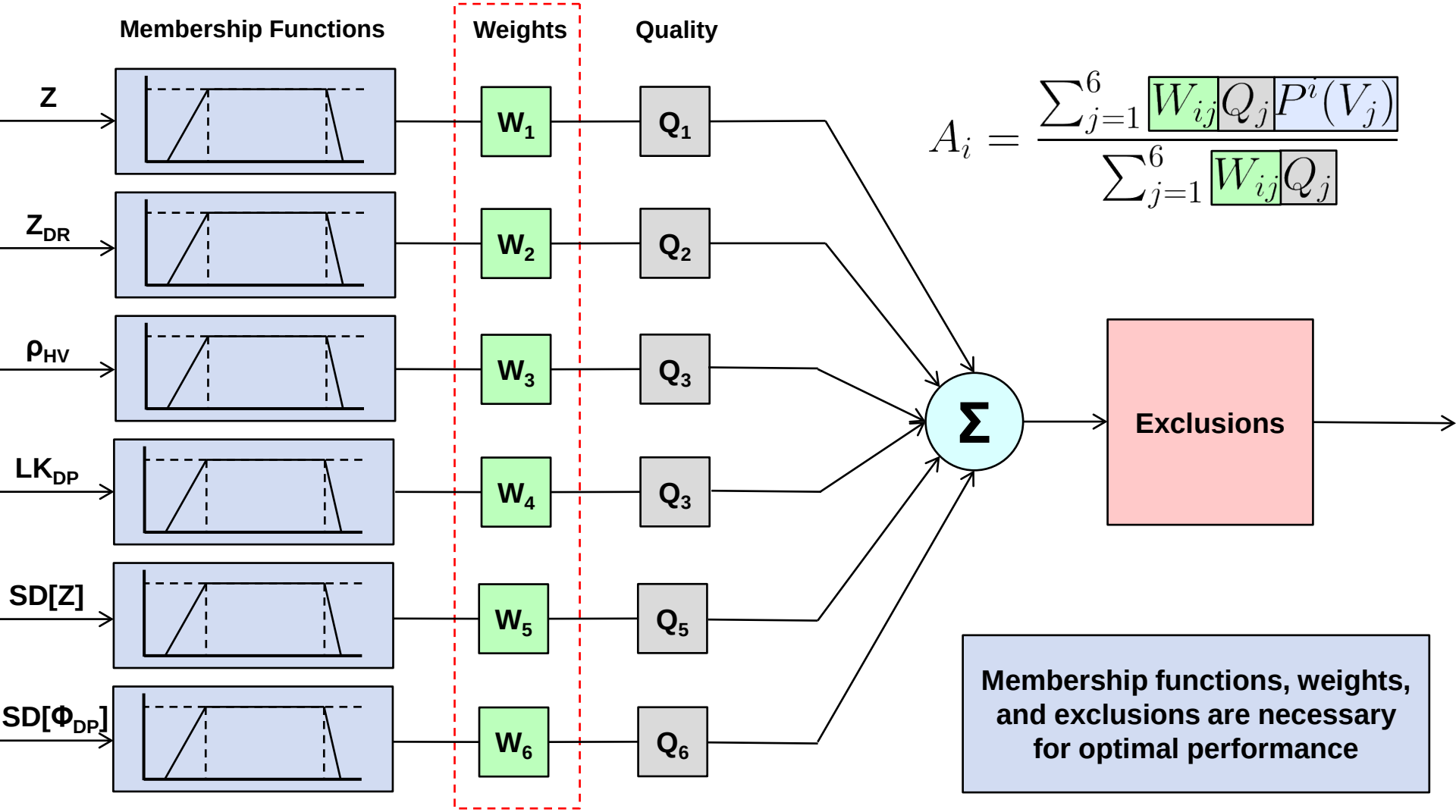


Membership Functions From Human Truthing



Number of Cases: 75

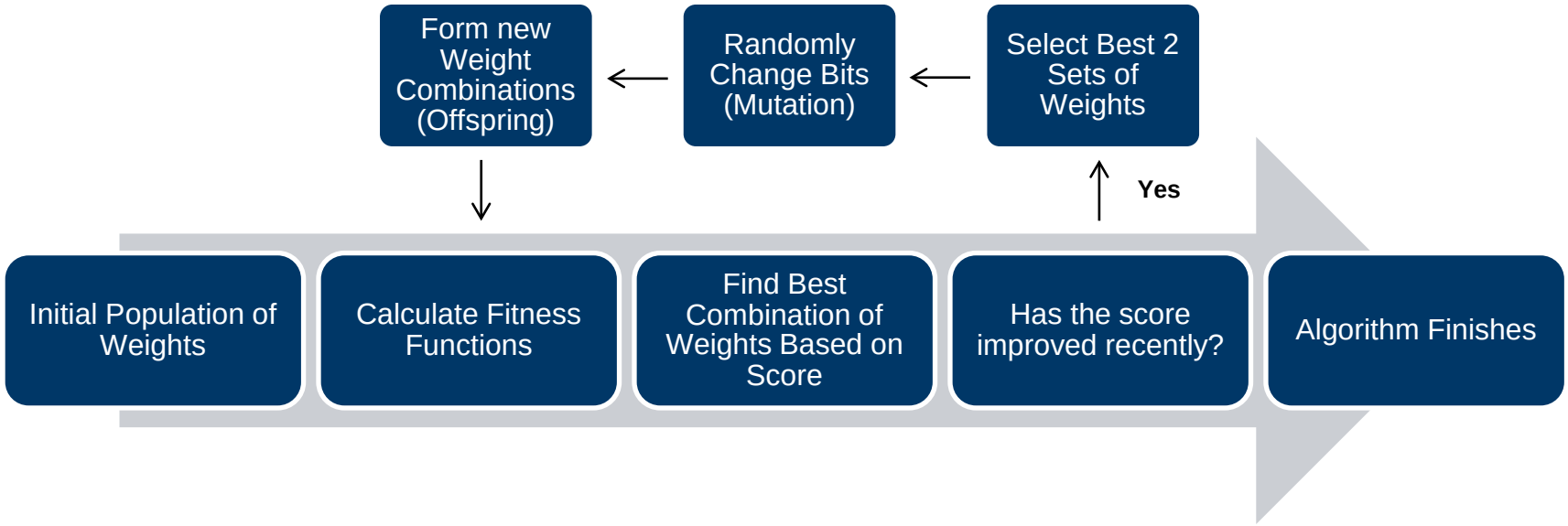
HCA Fuzzy Logic Approach



Optimization of Weights

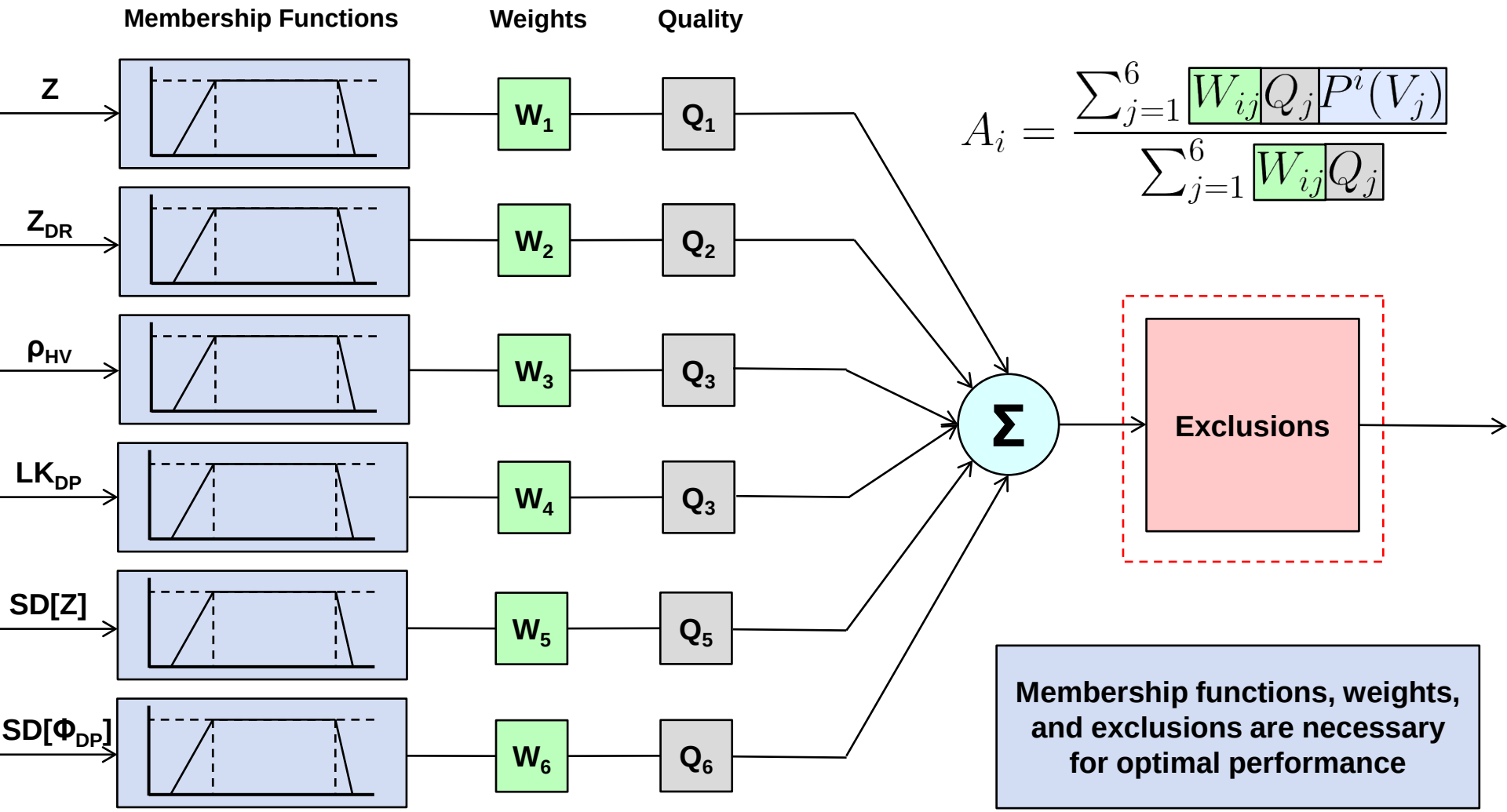
- **Provide initial weights to optimization framework**
- **Add additional thresholds as needed**
- **Optimize with a genetic algorithm**
- **Use human-truthed and weather data to maximize POD and minimize PFA**

A genetic algorithm fits the type and scale of the problem well enough to provide viable output

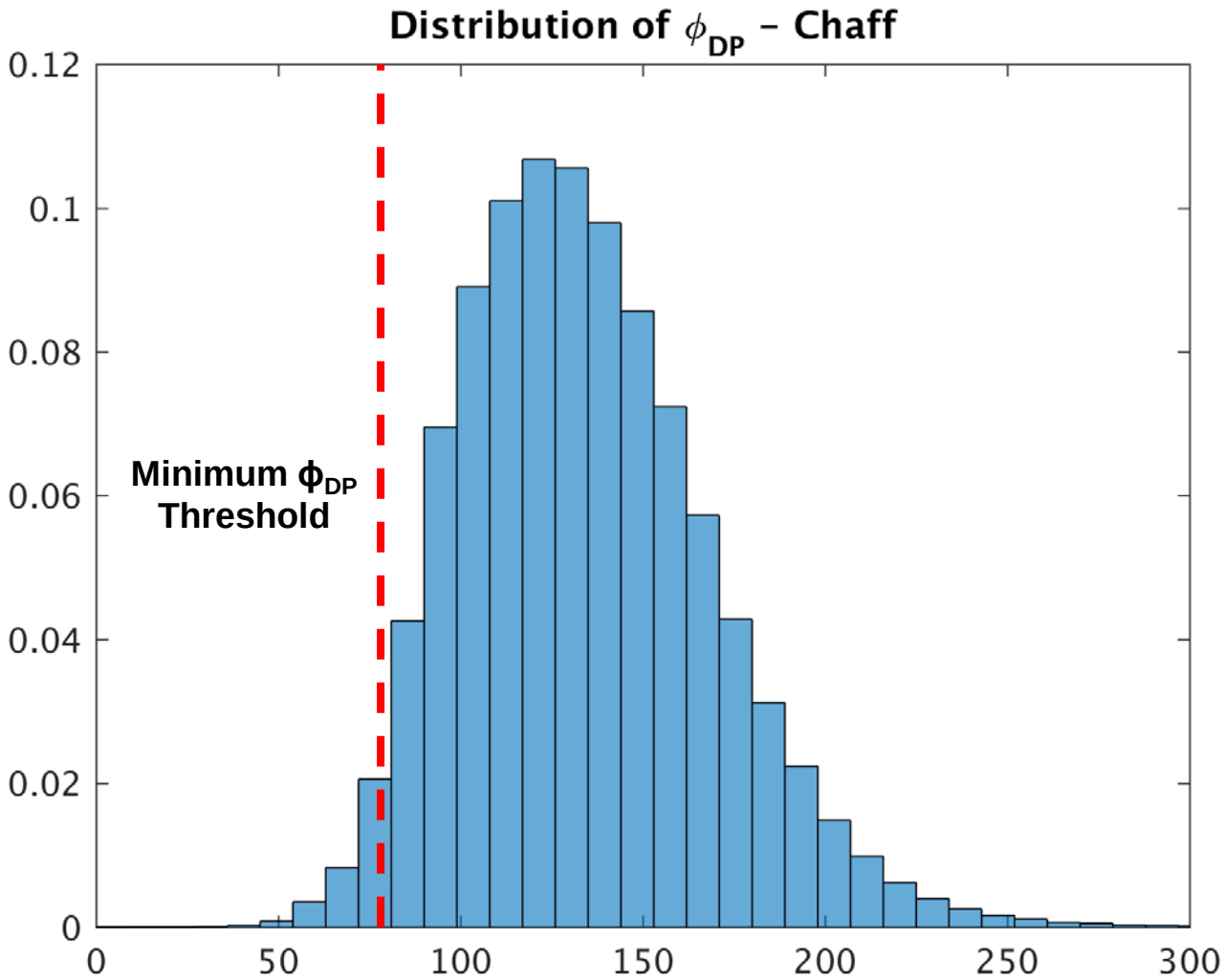


POD = Probability of Detection
PFA = Probability of False Alarm

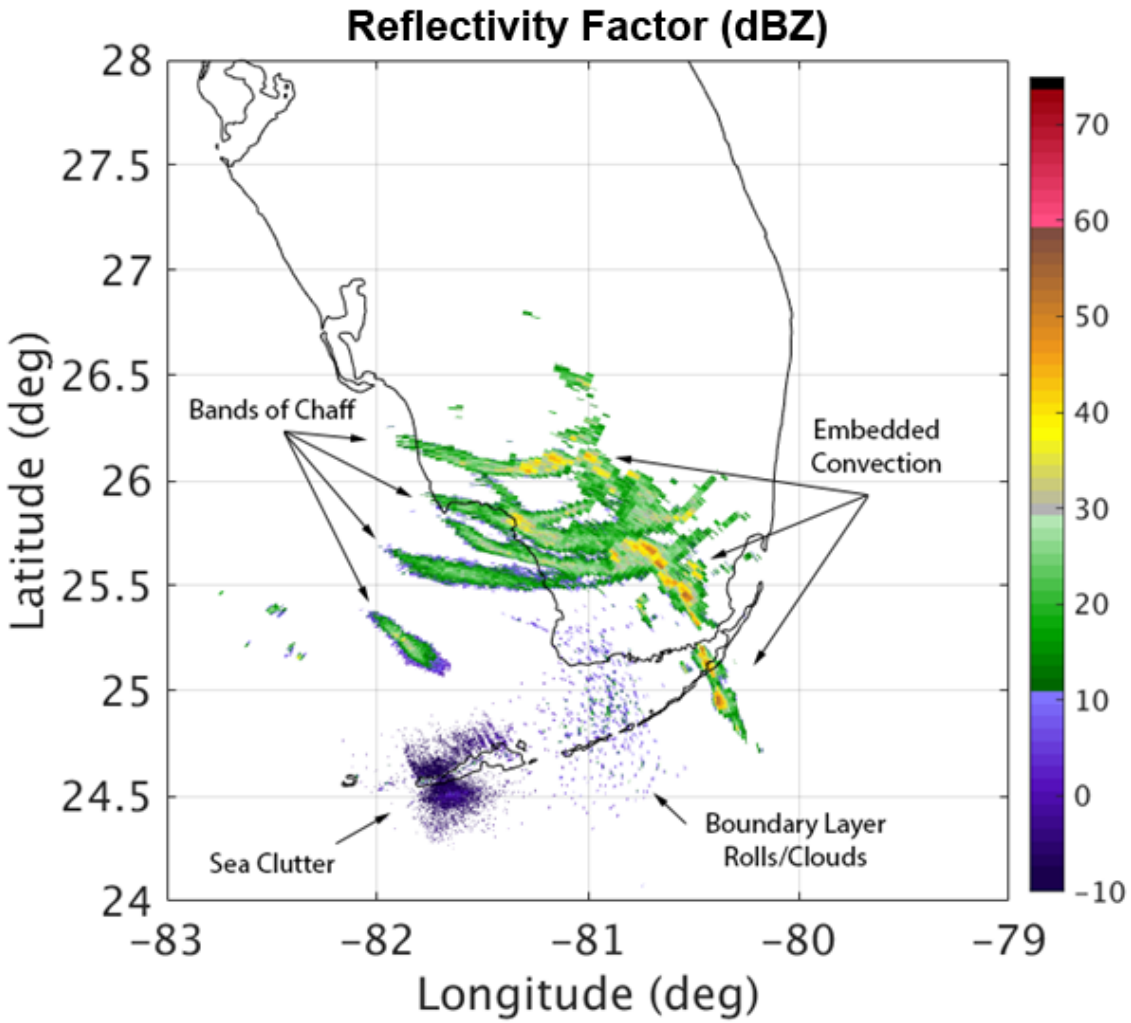
HCA Fuzzy Logic Approach



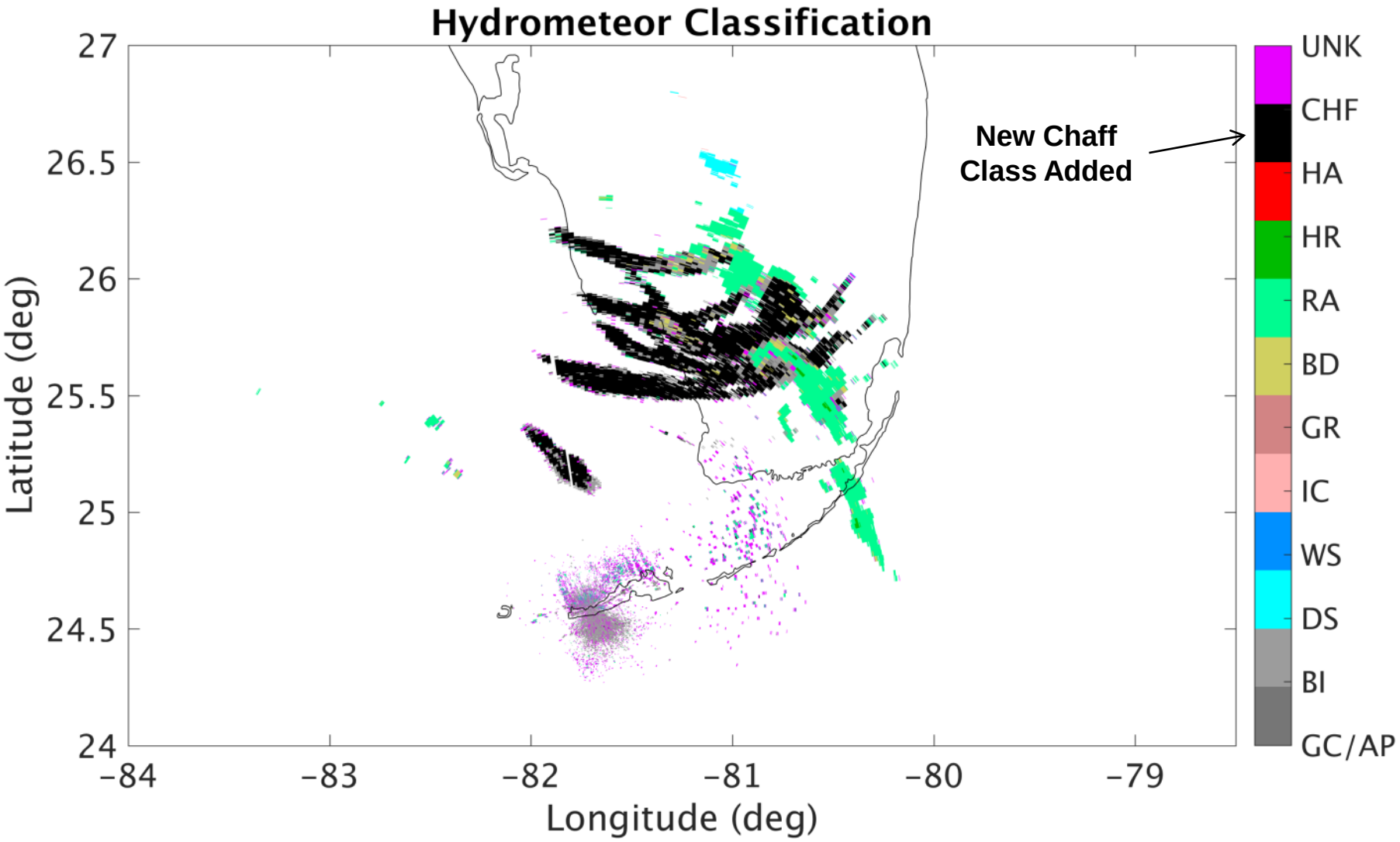
Distribution of Differential Phase in Chaff



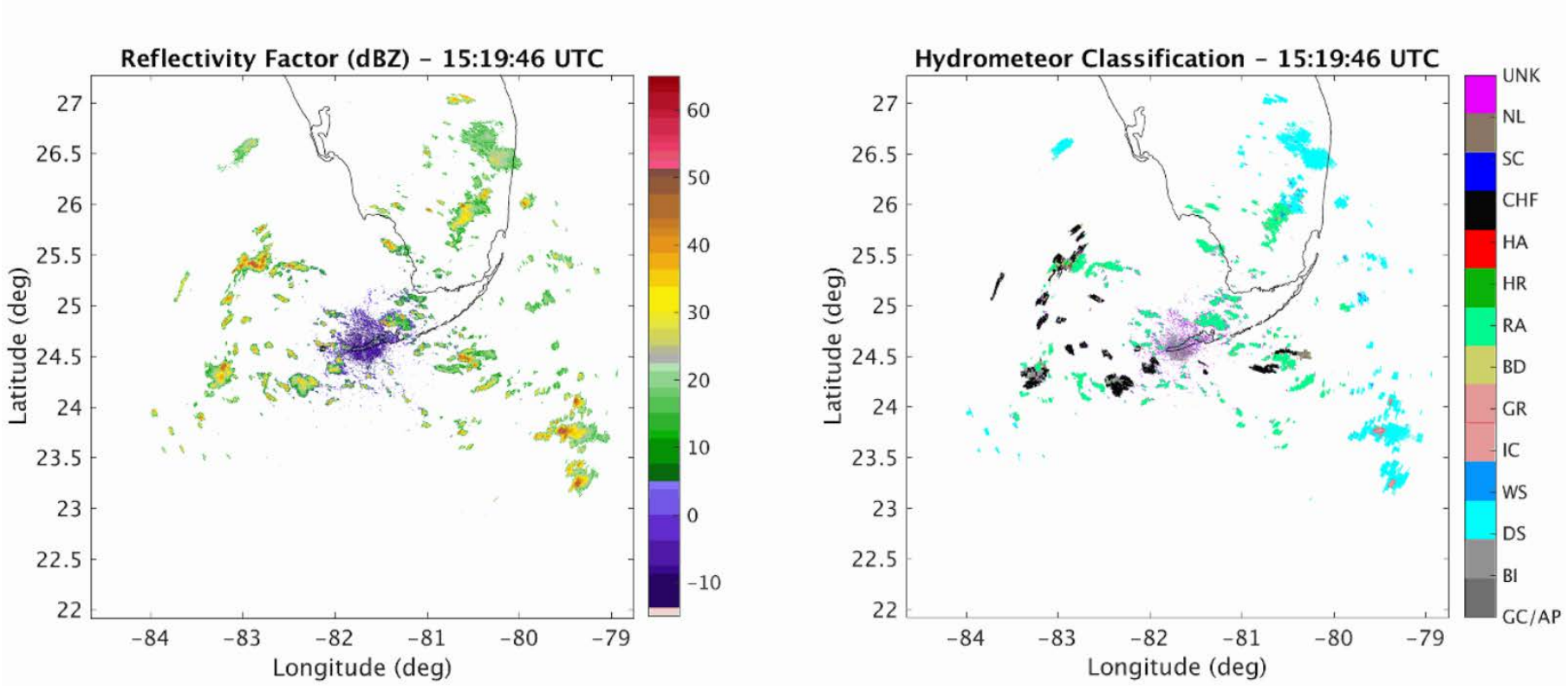
Case Example: 02/23/2016 - KBYX



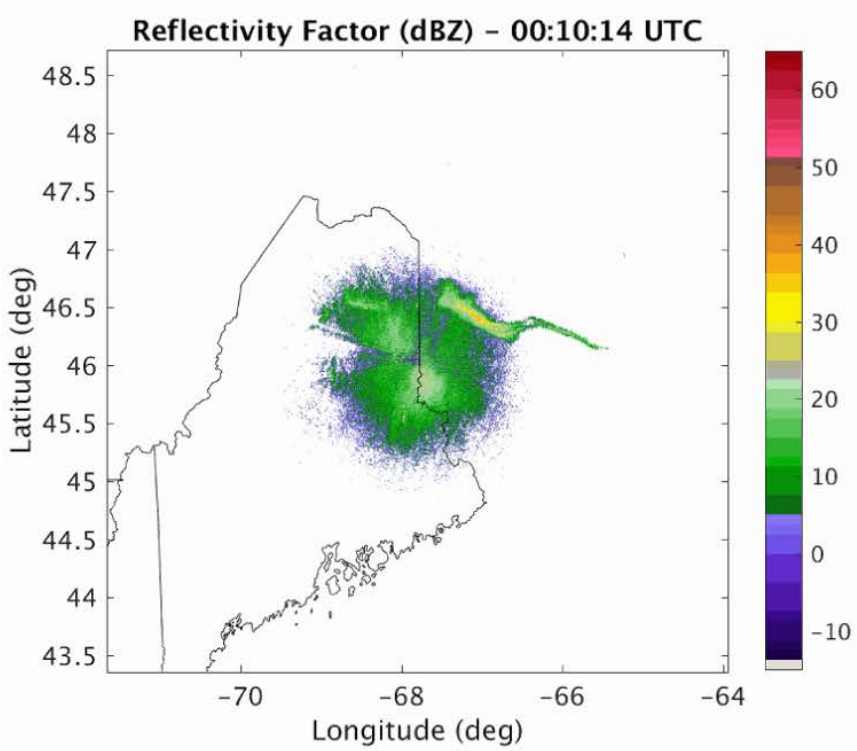
Case Example: 02/23/2016 - KBYX



Case Example: 08/02/2016 - KBYX



Case Example: 08/29/2016 - KCBW



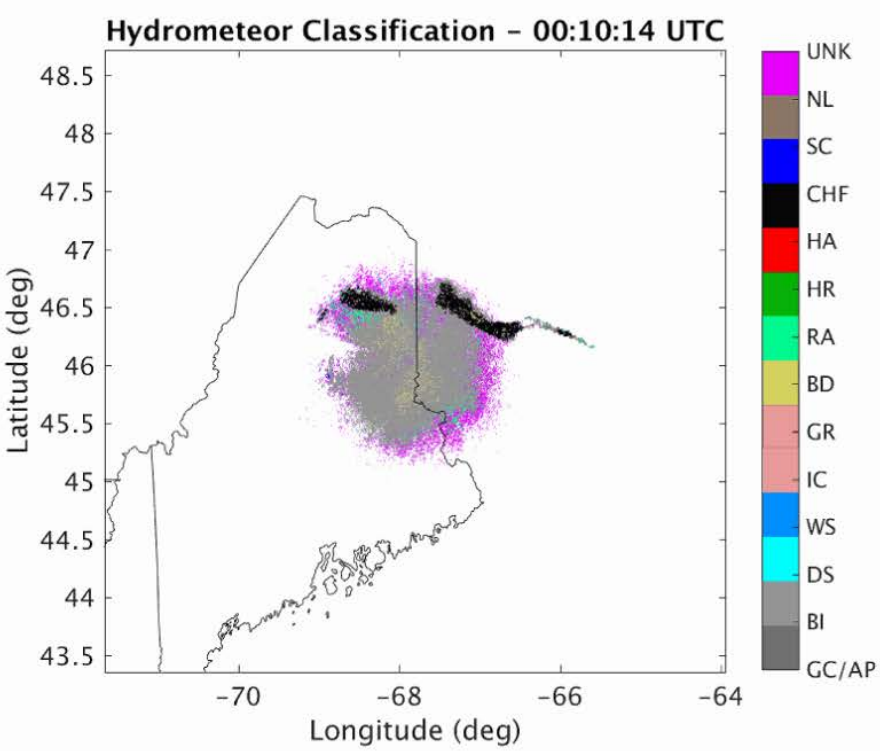
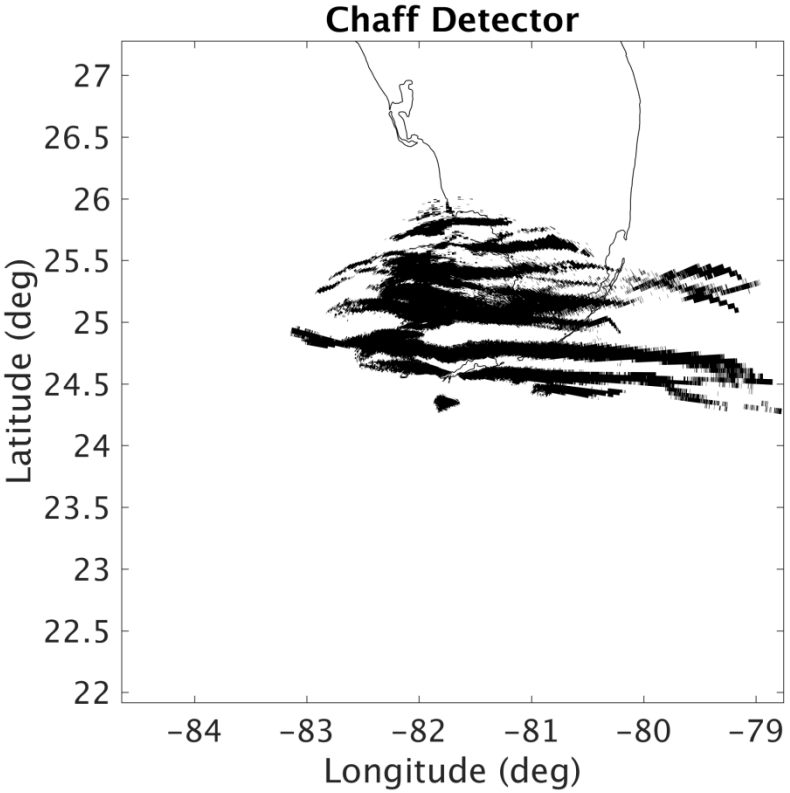


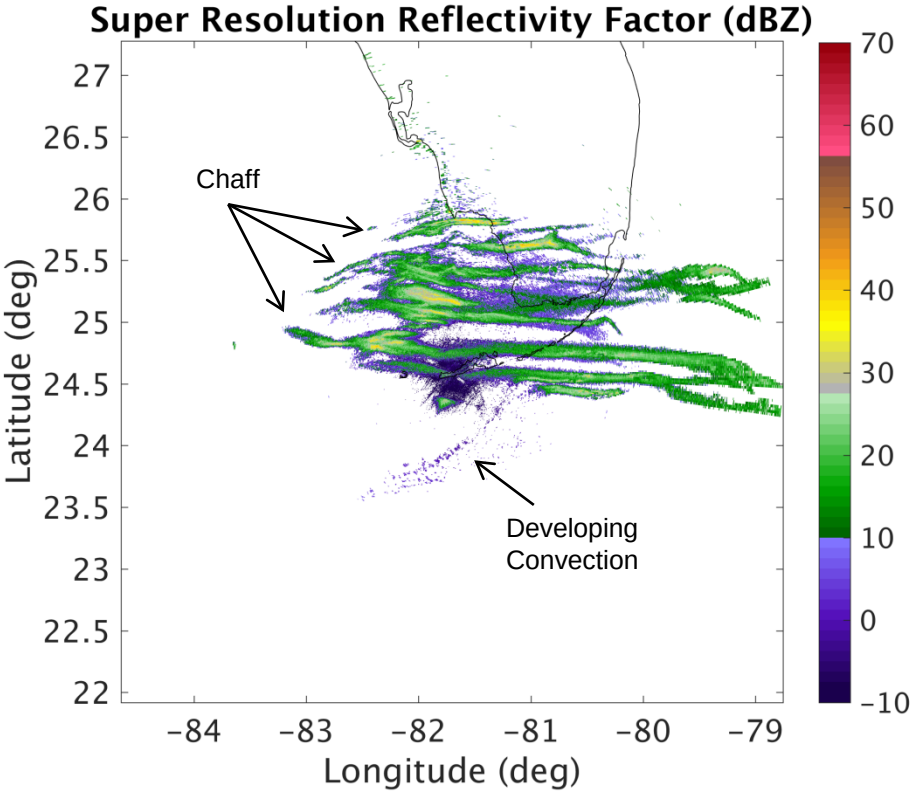
Image Processing Algorithm

- **Desire for a smooth product**
- **Processing consists of 7 steps:**

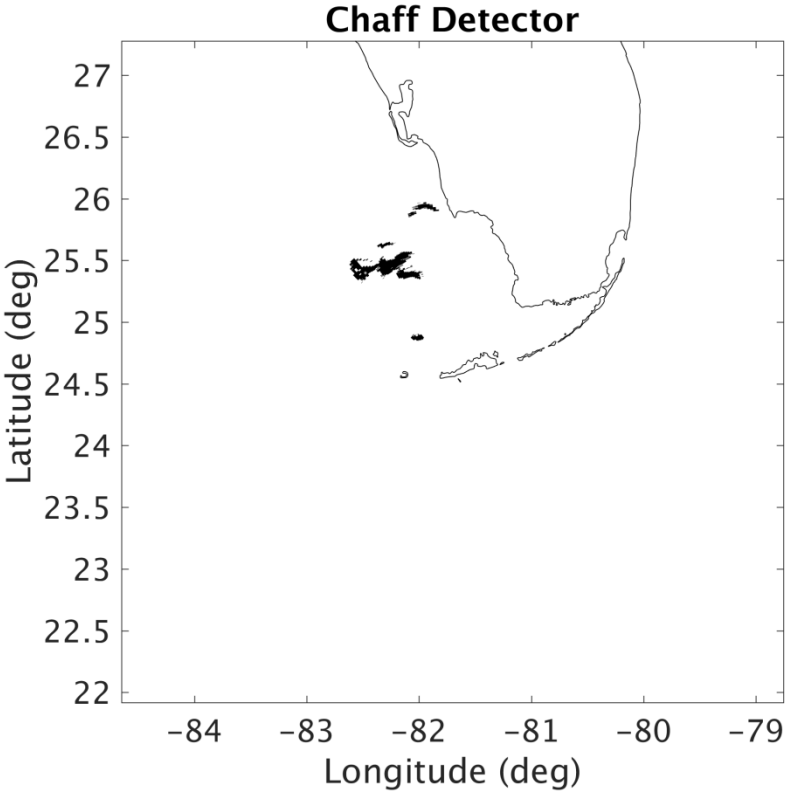
1. **Calculate HCA output including new chaff class**
2. **Separation of chaff and non-chaff**
3. **Median filtering**
4. **Dilation and Closing**
5. **Clustering and Thresholding**
6. **Filtering of Wet Classes**
7. **Dilation and Closing**

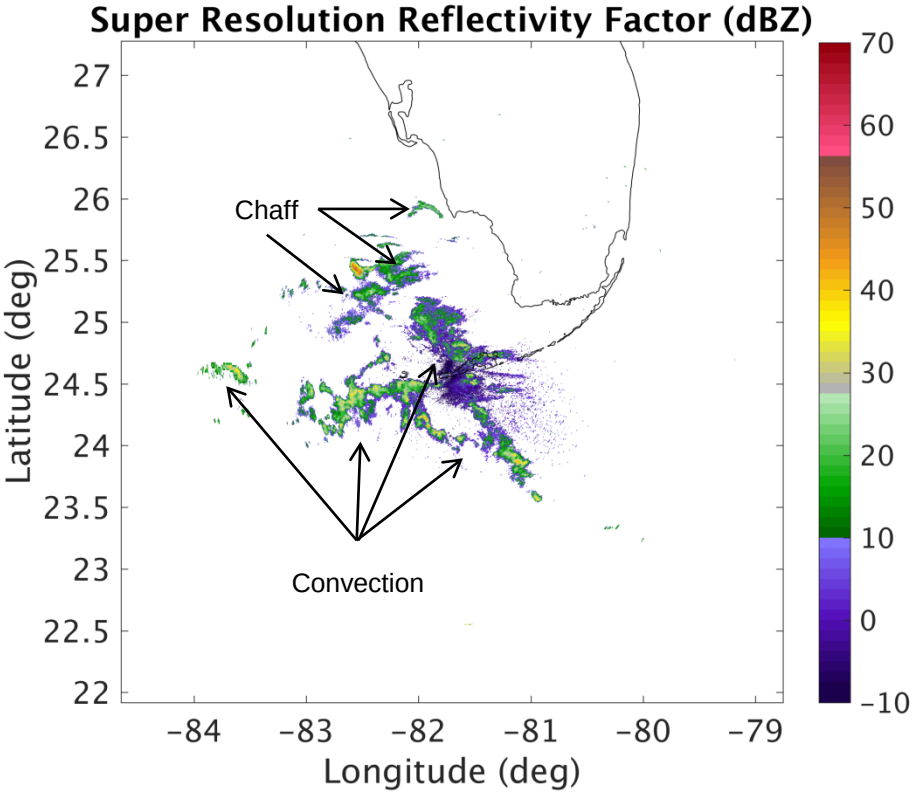
Case Examples – Chaff Detection Algorithm



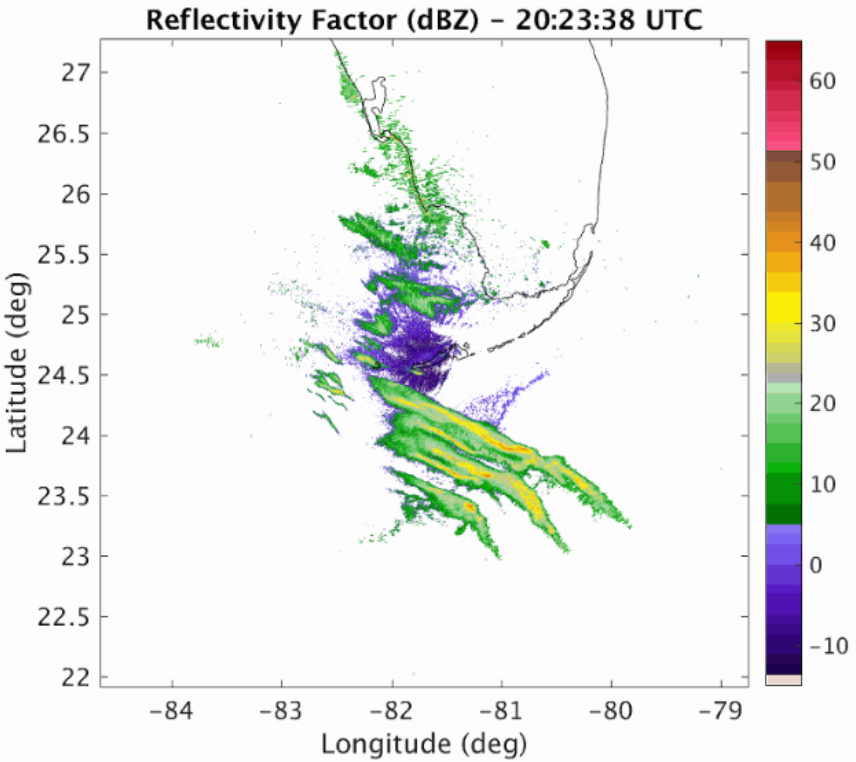


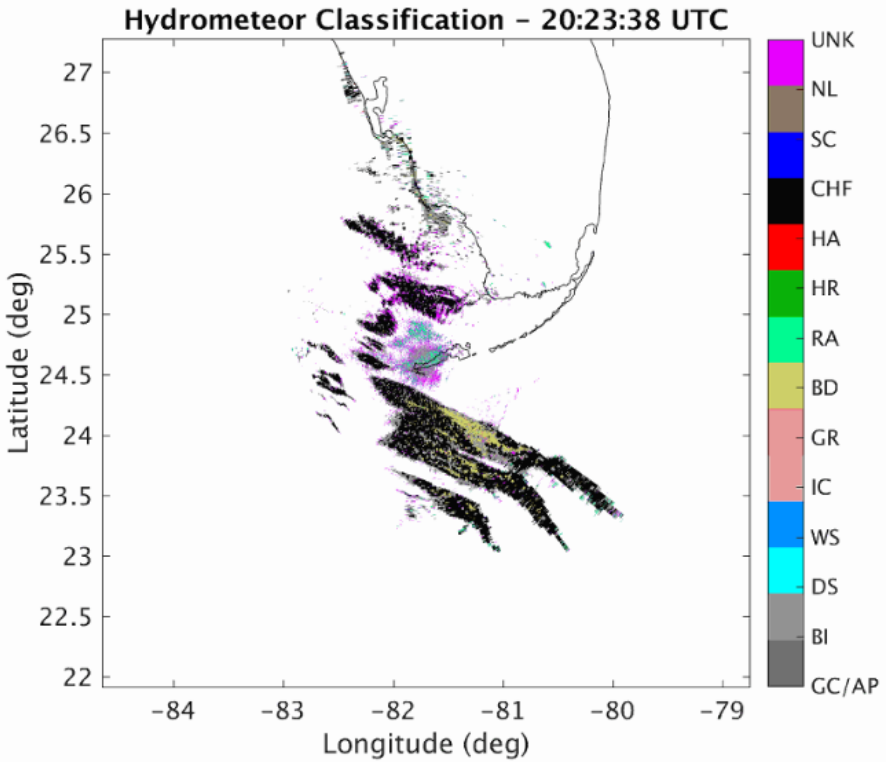
Case Examples – Chaff Detection Algorithm





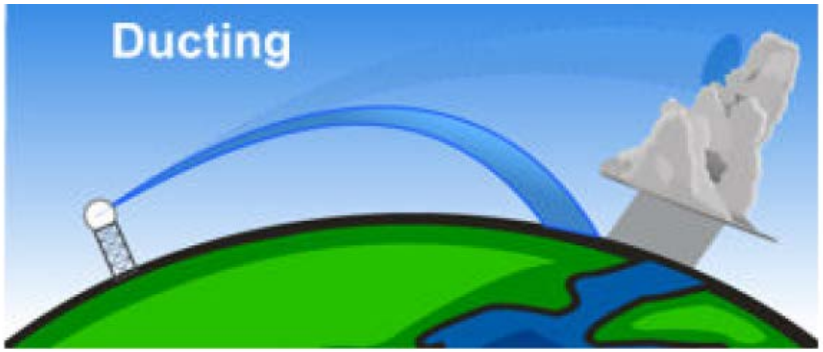
Case Example: 02/18/2016 - KBYX

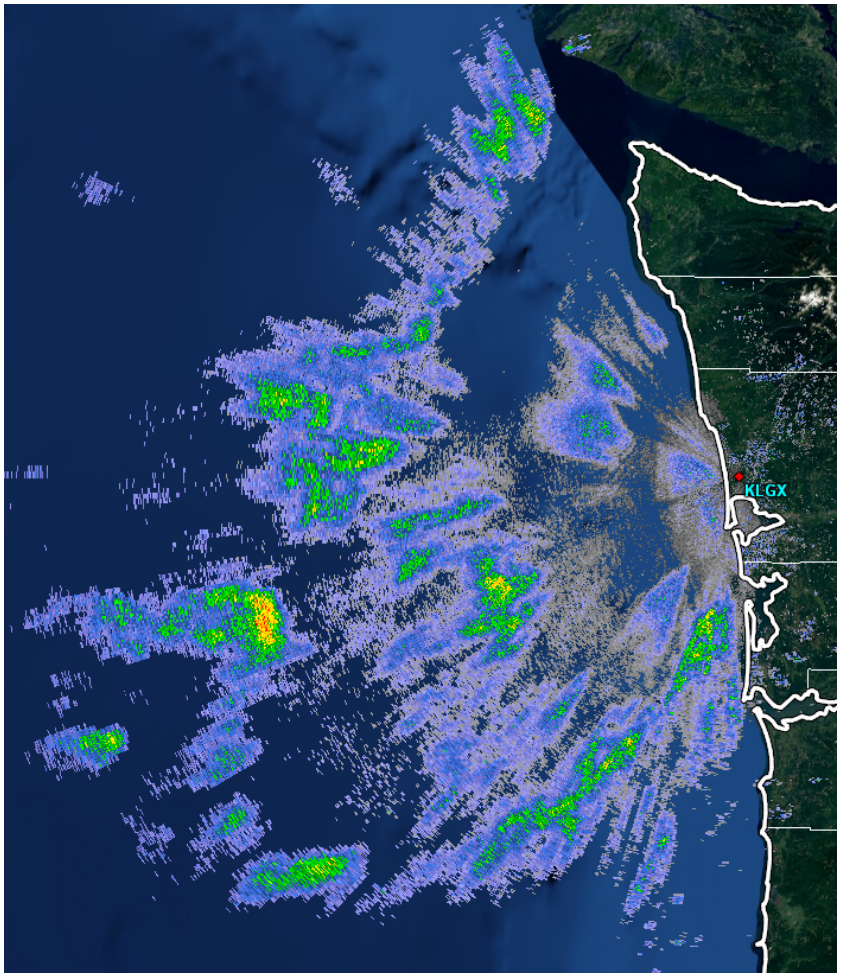




Sea Clutter and Weather Radar

- **A common source of errors for the chaff algorithm**
- **Beam is refracted and returned from waves on water**
- **Motion of waves precludes Doppler filtering**
- **Similar characteristics in the polarimetric fields to chaff**



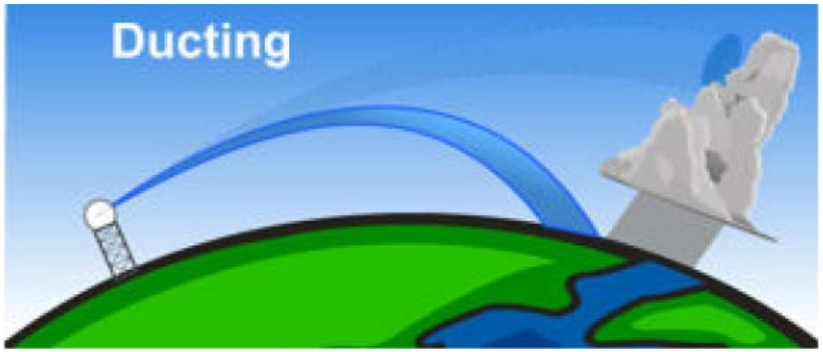


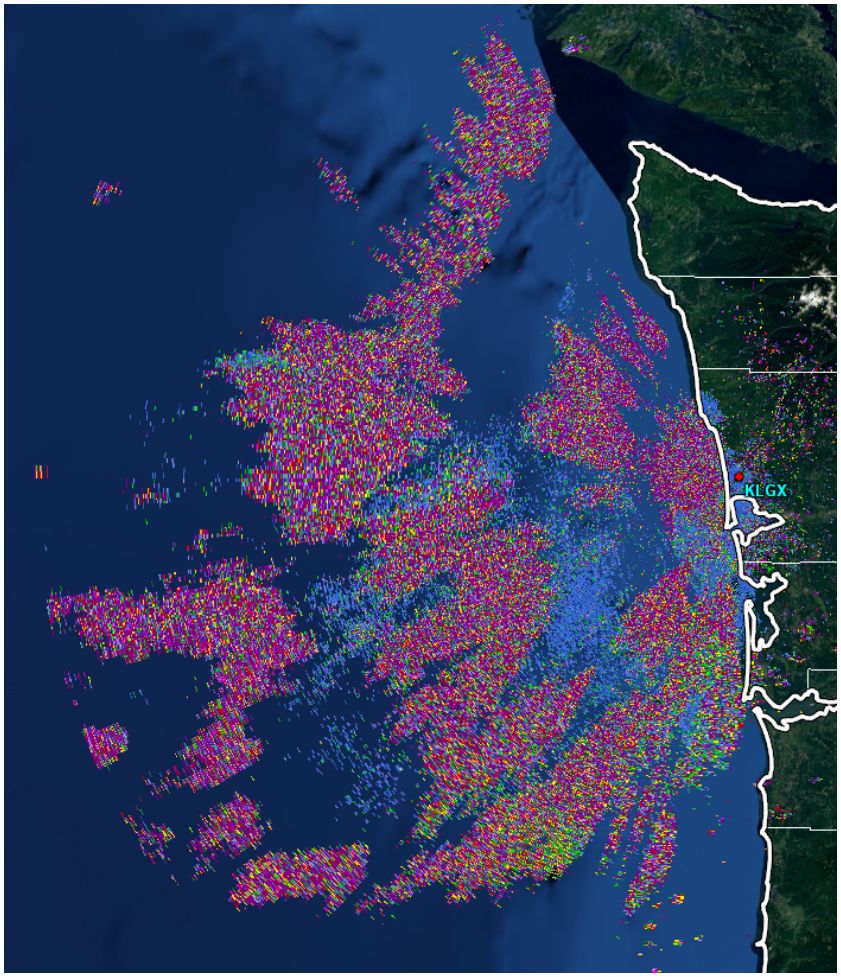
Reflectivity Factor (Z)

QPE = Quantitative Precipitation Estimation

Sea Clutter and Weather Radar

- **A common source of errors for the chaff algorithm**
- **Beam is refracted and returned from waves on water**
- **Motion of waves precludes Doppler filtering**
- **Similar characteristics in the polarimetric fields to chaff**



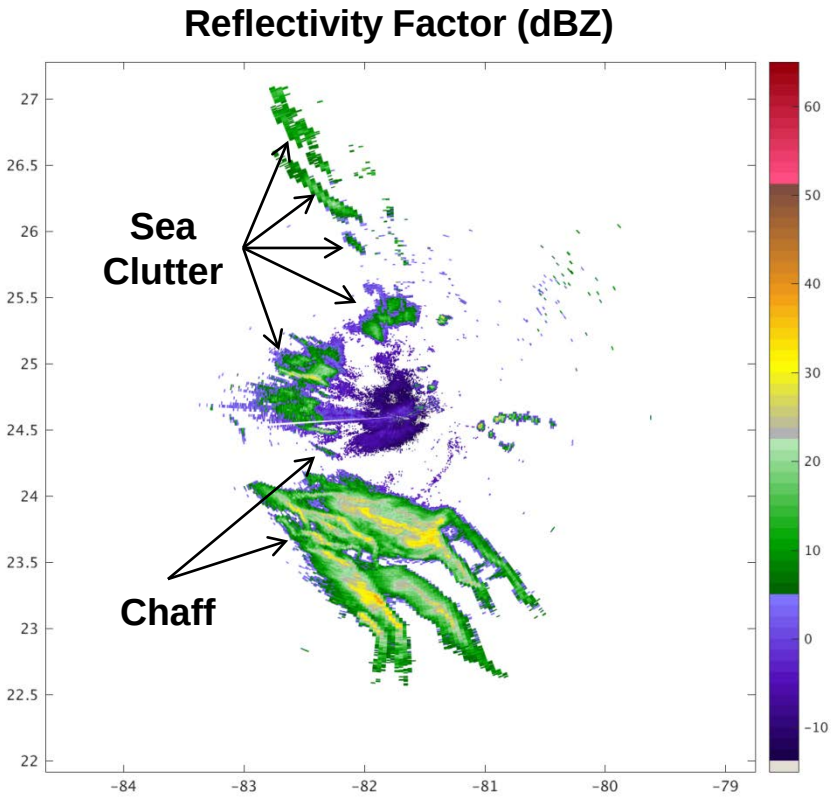


Differential Phase (Φ_{DP})

QPE = Quantitative Precipitation Estimation

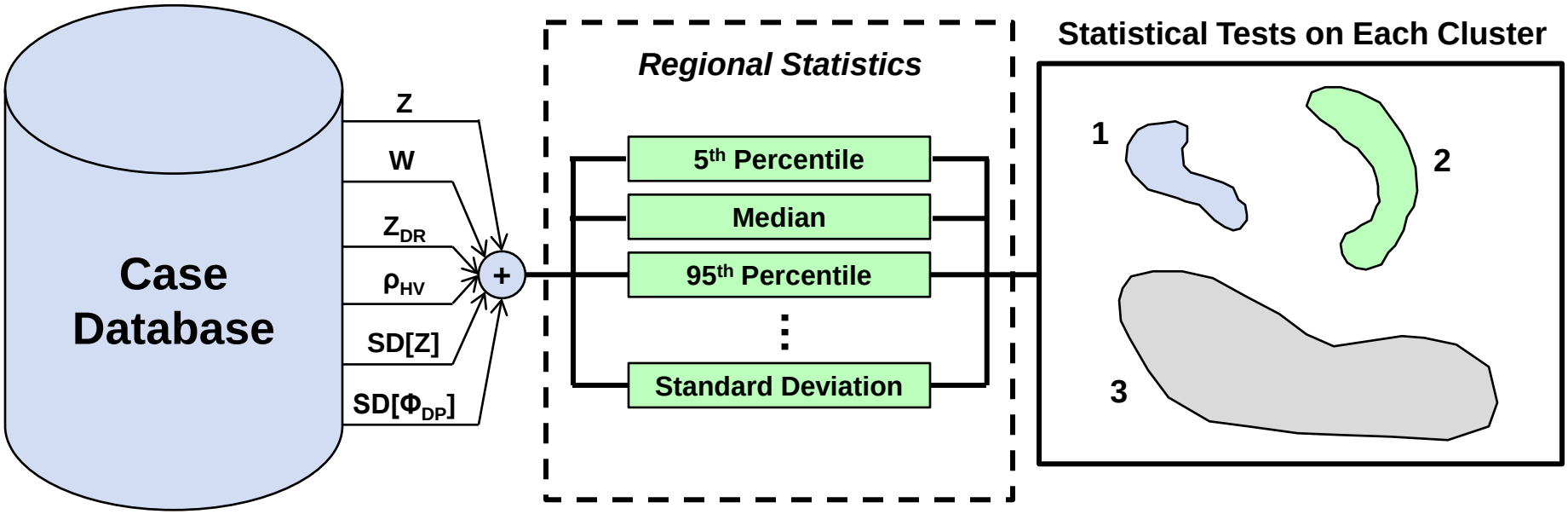
Classification of Sea Clutter

- Utilizes a Support Vector Machine (SVM) – a machine learning technique
- SVM used as an “error-checker”
- Trained with human-truthed sea clutter, chaff, and null cases
- Clusters are classified based on a pre-compiled SVM vector
- Uses regional statistics rather than local statistics
- If confidence of sea clutter is high enough, SVM changes the cell to sea clutter

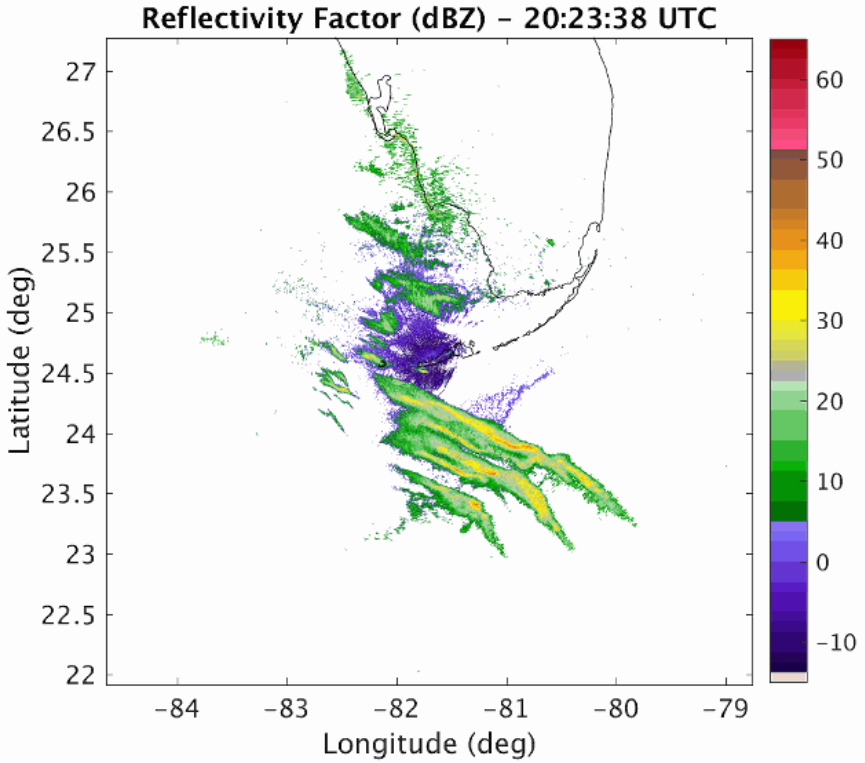


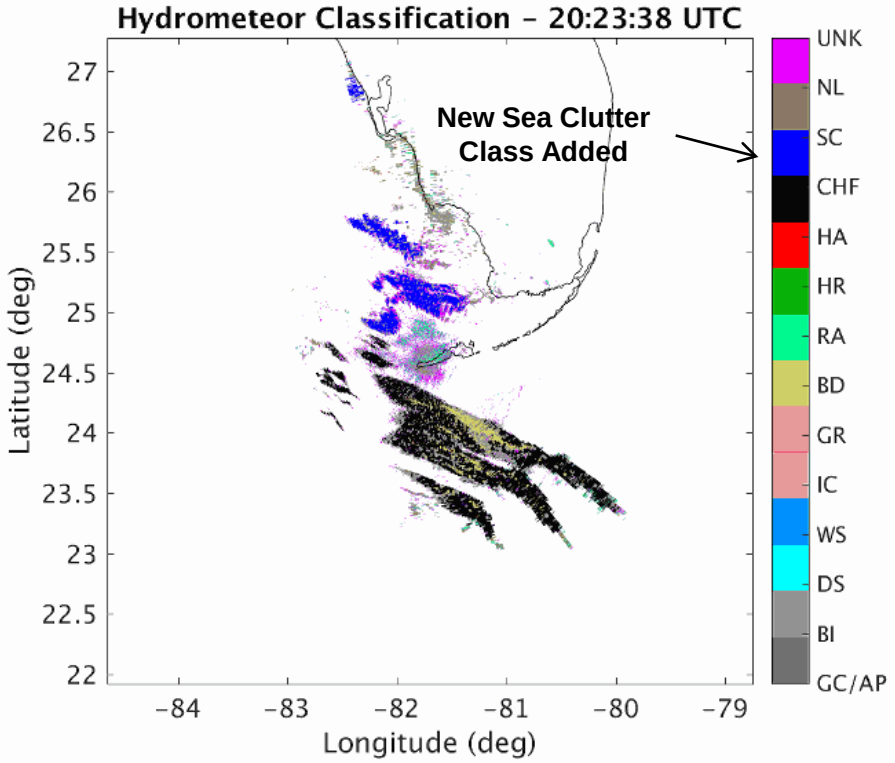
SVM Framework

- Human truth sea clutter cases
- Data are clustered into cells for analysis as a group of pixels
- An SVM framework of cells is used for training
- The SVM output is applied to new cells for classification



Case Example: 02/18/2016 - KBYX





Summary

- **Developed a chaff detector based on a modified HCA and an image processing algorithm**
- **Compiled and analyzed chaff distributions**
- **Optimized new chaff class weights**
- **Applied SVM classification to separate out sea clutter**

Upcoming Work

- **Collection of larger datasets for testing**
- **Calculation of accurate POD/PFA/CSI in various event types**
- **Extensive testing on ORPG datasets**
- **Further refinement of weights and thresholds**

Decisions on Implementation

- **HCA classes**
- **CDA (Chaff Detection Algorithm)**

POD = Probability of Detection
PFA = Probability of False Alarm

CSI = Critical Success Index
ORPG = Open Radar Product Generator
CDA = Chaff Detection Algorithm