SAND2015-8591C

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Global Infrasound Network Detection and Association

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Overview

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- ITW 2014:
  - Arrowsmith, Blom and Marcillo introduced end-to-end infrasound processing scheme (Adaptive F detector [AFD] + Graph-based Infrasound Associator + Bayesian event locator) for detecting large events with low FAR
  - Jones & Arrowsmith reported on initial results applied to ~1 year of IMS data
- This year:
  - Compare results to IDC processing results over multiple years
  - Adapt algorithms to detect smaller events (low SNR signals, detected at fewer arrays)
  - Test updated algorithms on smaller events
- Reference:
  - Arrowsmith et al., Geophys. J. Int., 200, 1411-1422 (2015) - focused on large events (detected at > 5 arrays)

Detection Results: 3 years of IMS data

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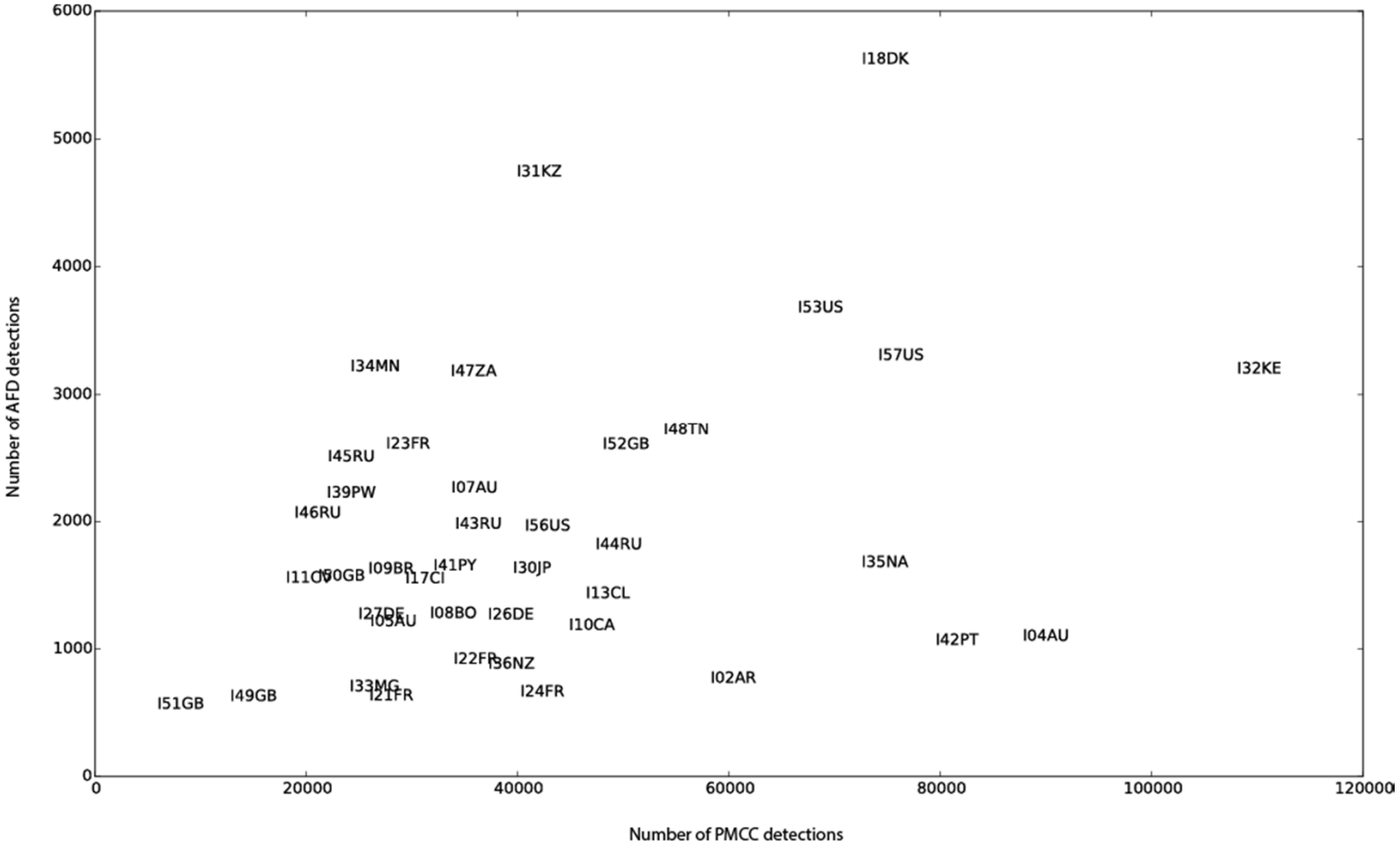
Average # of detections per year in 2011, 2012, and 2013



PMCC finds an order of magnitude more detections than AFD on average

Detection Results: 3 years of IMS data

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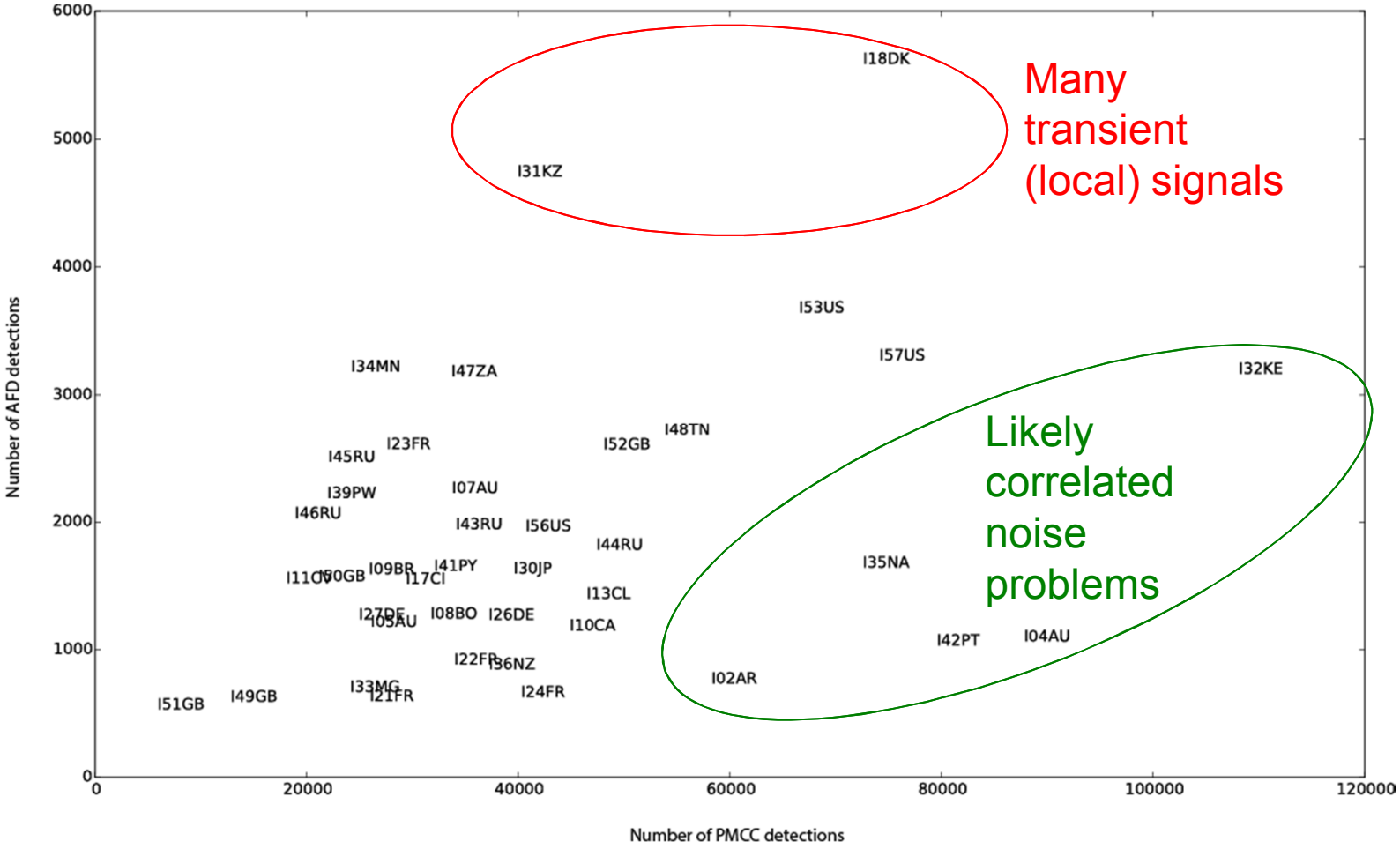
Average # of detections per year in 2011, 2012, and 2013



Comparison of AFD and PMCC bulletins can distinguish arrays with many detections from coherent noise from arrays with numerous impulsive signals

Detection Results: 3 years of IMS data

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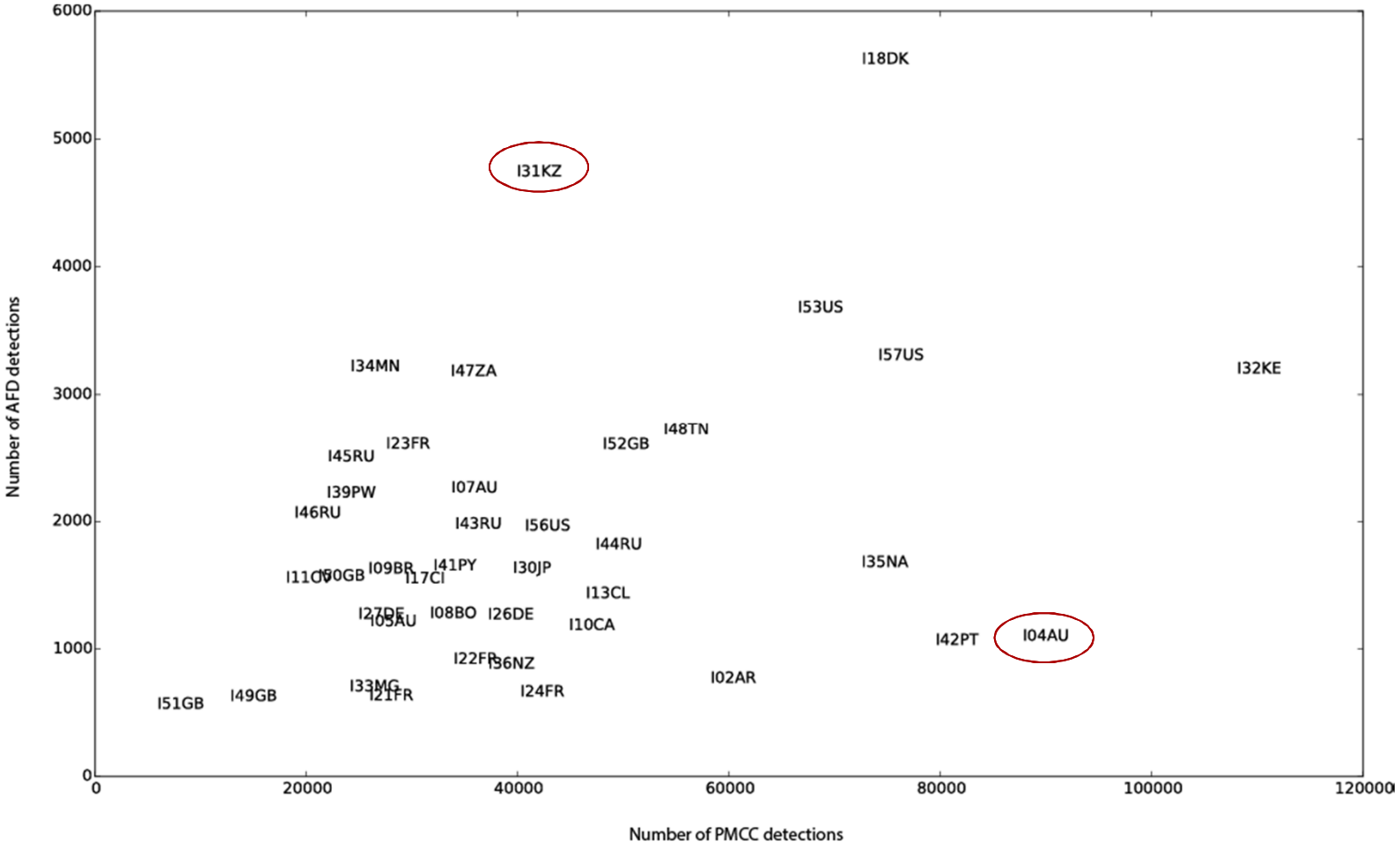
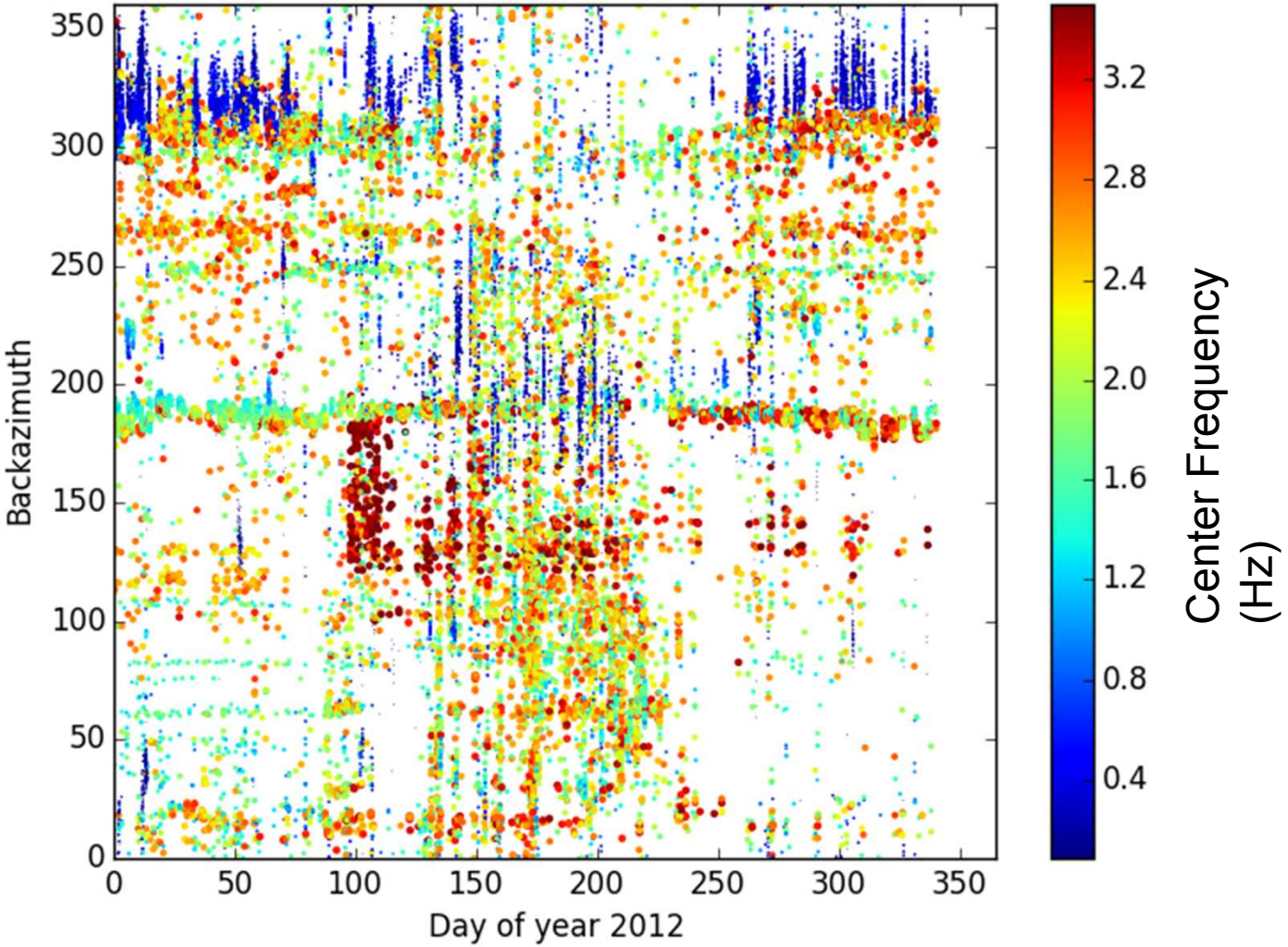
Average # of detections per year in 2011, 2012, and 2013



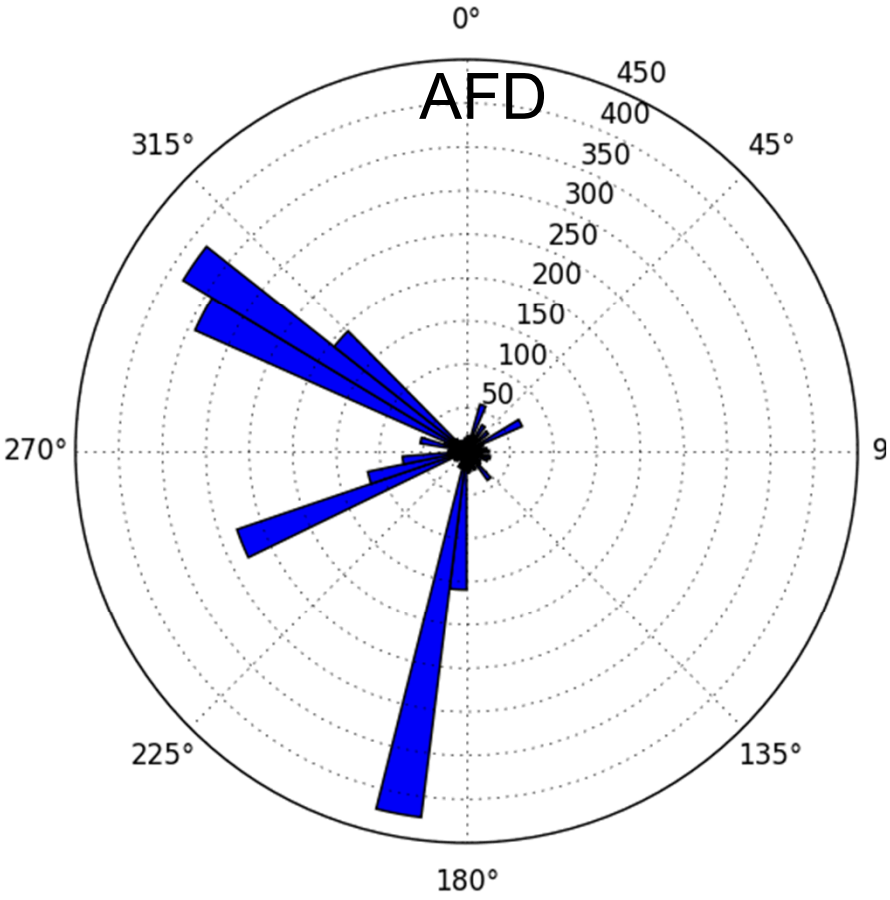
We will take an in-depth look at I31KZ and I04AU

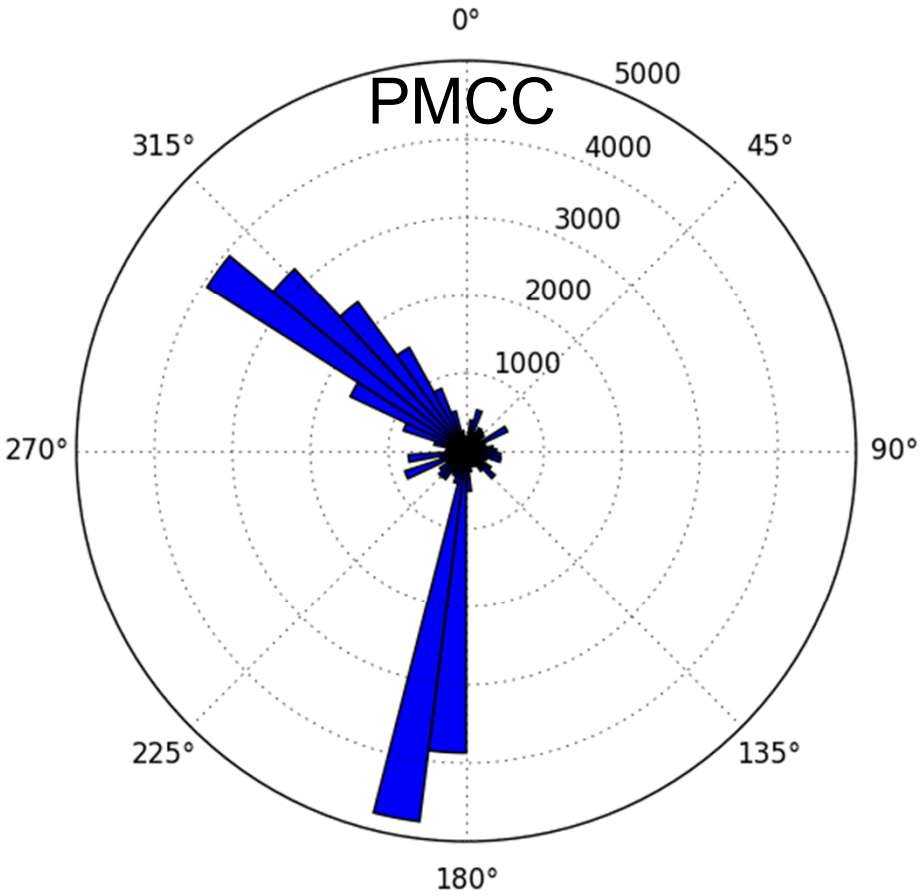
PMCC results for I31KZ



Sizes of points denote bandwidth

Detection Results: Azimuthal distributions at I31KZ





- Similar trend of distributions from AFD and PMCC
- About 1 order of magnitude fewer AFD detections

PMCC results for I04AU

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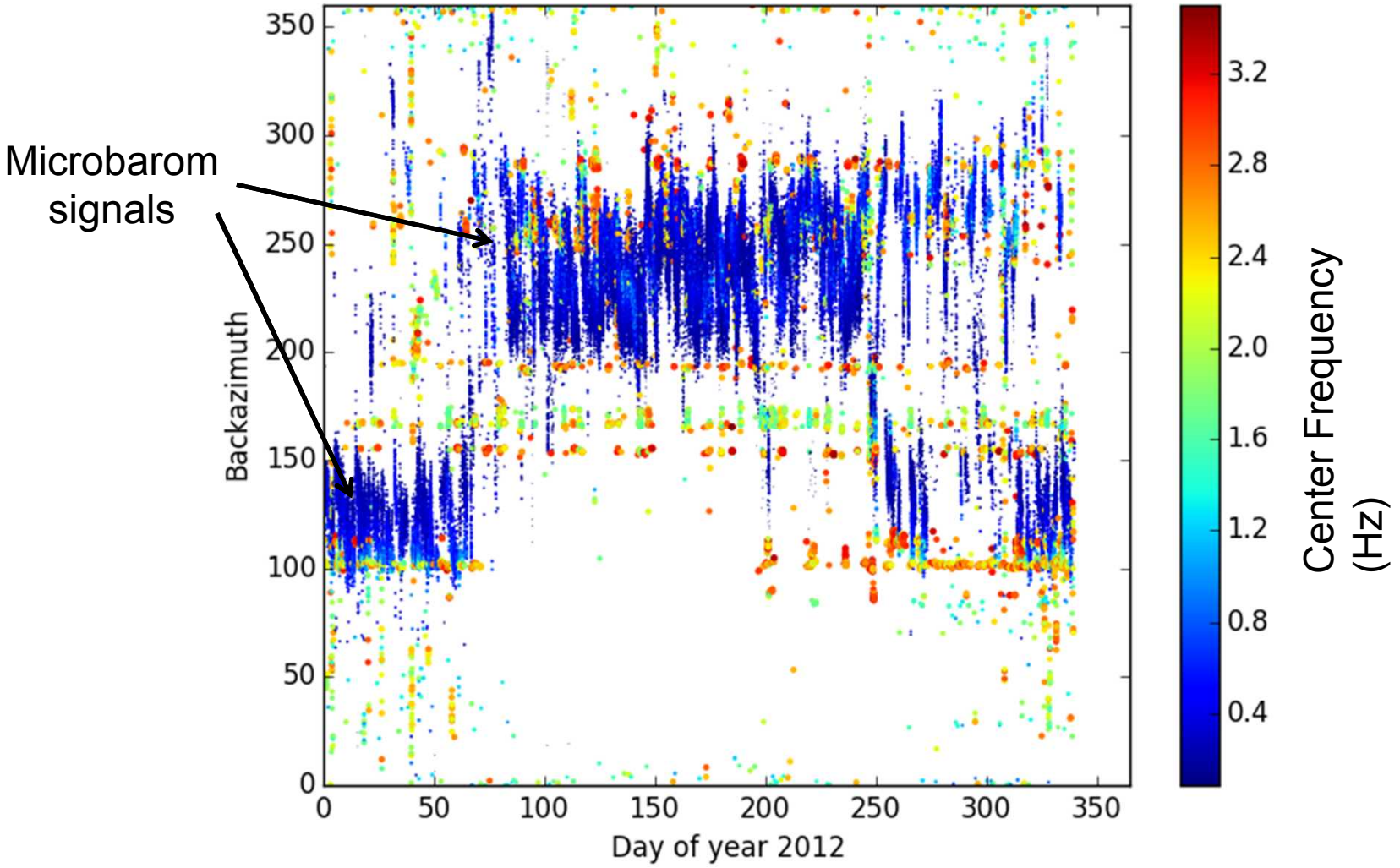
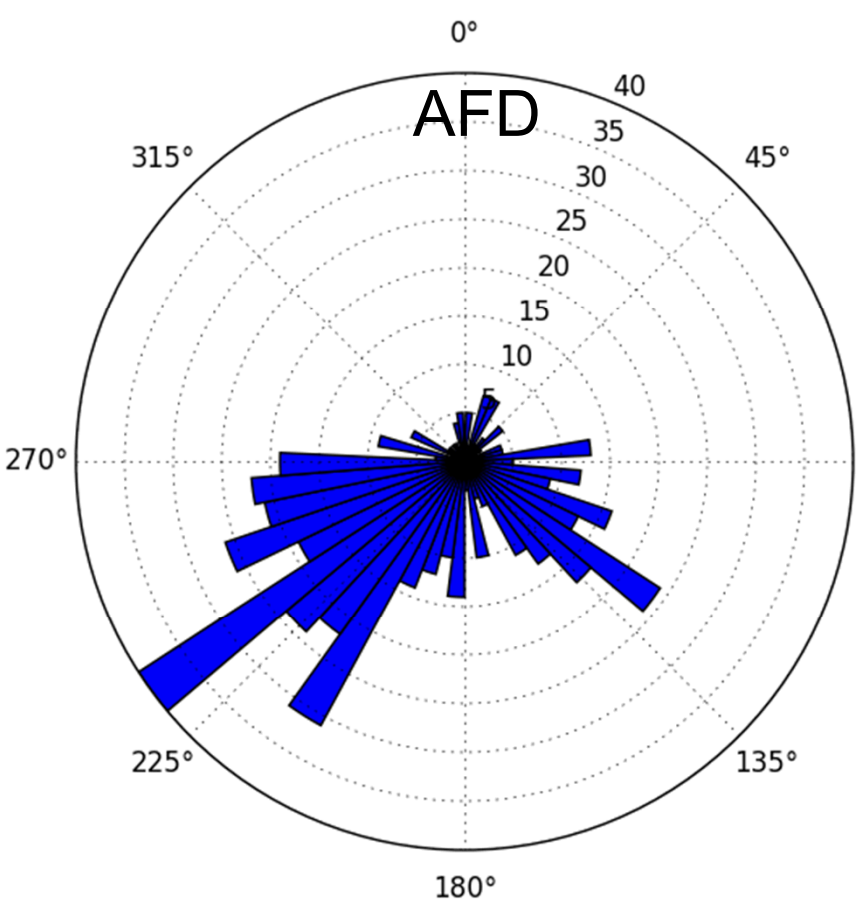
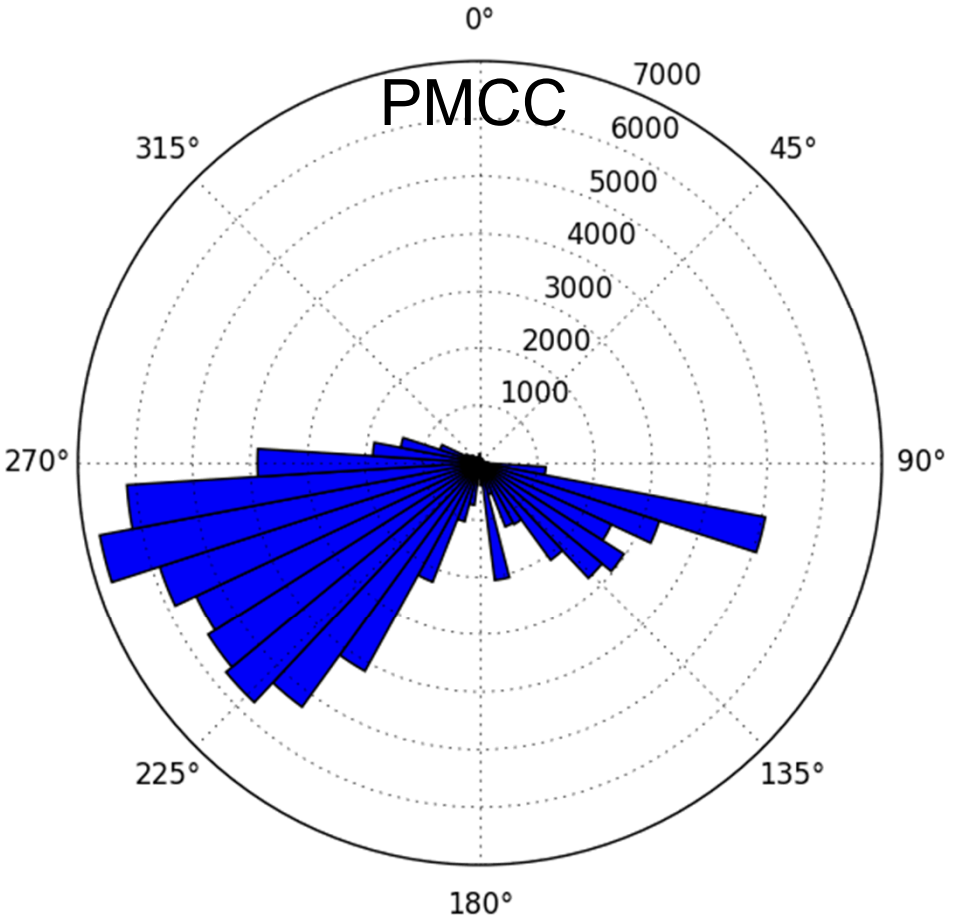


Sizes of points denote bandwidth

Detection Results: Azimuthal distributions at I04AU





- Similar trend of distributions from AFD and PMCC
- About 2 orders of magnitude fewer AFD detections
- AFD is detecting a smaller fraction of microbarom signals as compared with transient signals → Validates concept but are we still removing real signals?

Application to 10 events

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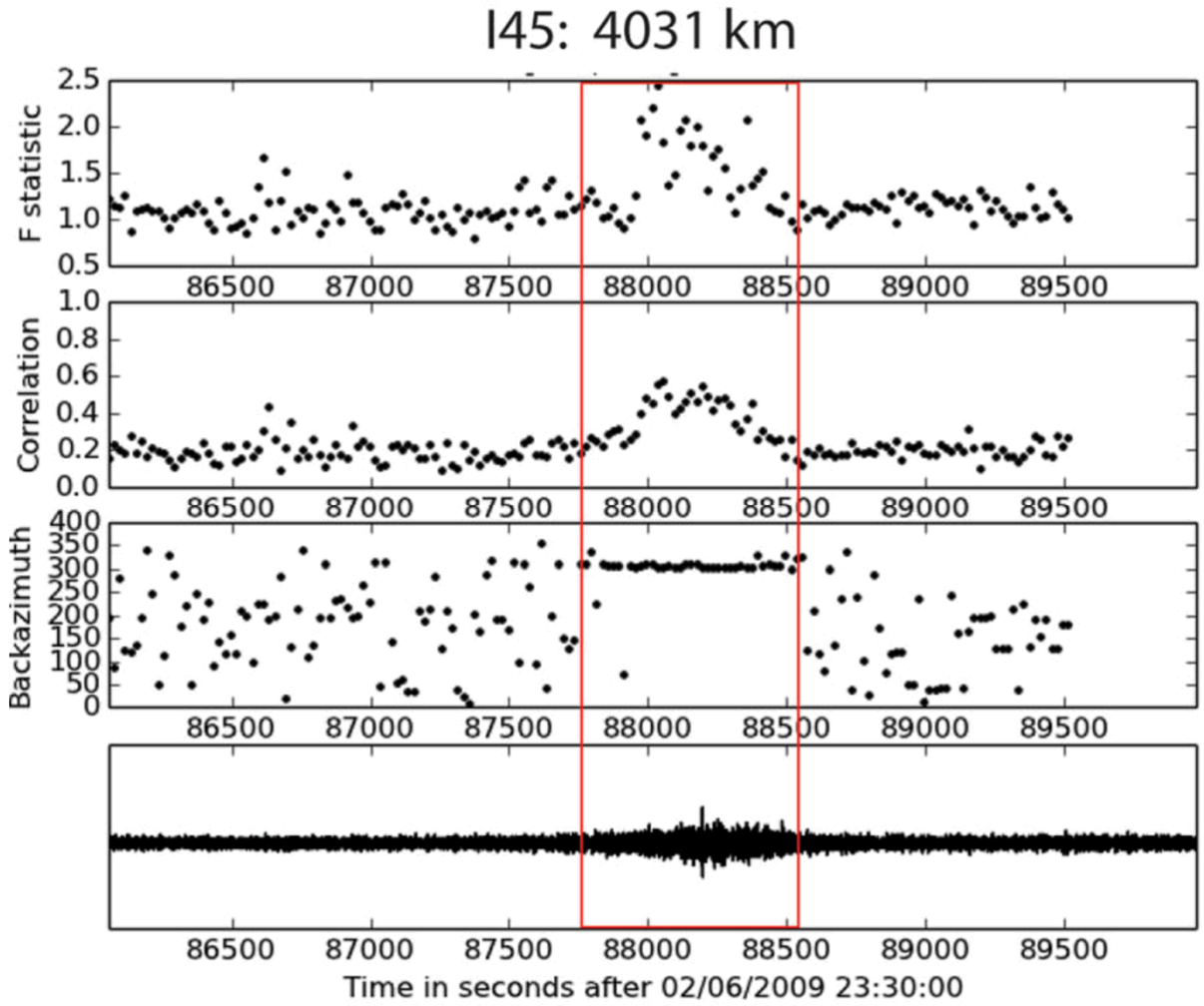
A comparison between automated results and large events in the REB suggests three events are missed by the automatic methods

Event #	Date	Latitude	Longitude	Description	# Associated detections in REB	# Associated detections in this study
1	02/07/2009	56.0779	76.7068	Russian mining explosion?	6	Not associated
2	10/08/2009	−4.2261	121.1155	Large bolide near Sulawesi	14	6
3	12/26/2010	40.0244	156.9966	Large bolide over North Pacific	11	8
4	04/18/2011	0.831	−126.5921	Large bolide over Central Pacific?	8	6
5	05/21/2011	64.688	−17.368	Eruption of Grimsvotn, Iceland	6	Not associated
6	05/05/2012	76.7401	−10.5816	Bolide east of Greenland?	8	4
7	10/22/2012	51.7055	117.1126	Russian mining explosion?	6	Not associated
8	02/15/2013	54.0563	61.8062	Large bolide over Chelyabinsk, Russia	17	5
9	10/18/2013	56.1074	160.9198	Eruption of Klyuchevsky, Kamchatka	6	7
10*	02/13/2014	−8.5353	109.7683	Eruption of Kelud, Indonesia	13	13

Events from REB detected at > 5 arrays

Why were 3 events missed?



Example missed signal

- Missed detections of low-coherence signals
- Green (2015) shows that coherence degrades with range due to multipathing

Combining detectors to detect low-coherence signals without clutter

- Different detectors might exploit different signal properties (e.g., coherence, duration, bandwidth)
- How can we combine detections from different detectors?
  - Logical
    - Doesn't fully exploit the combined effects of two detectors

$$d_1 > d_1^{\text{thres}} \text{ OR } d_2 > d_2^{\text{thres}}$$

$$d_1 > d_1^{\text{thres}} \text{ AND } d_2 > d_2^{\text{thres}}$$

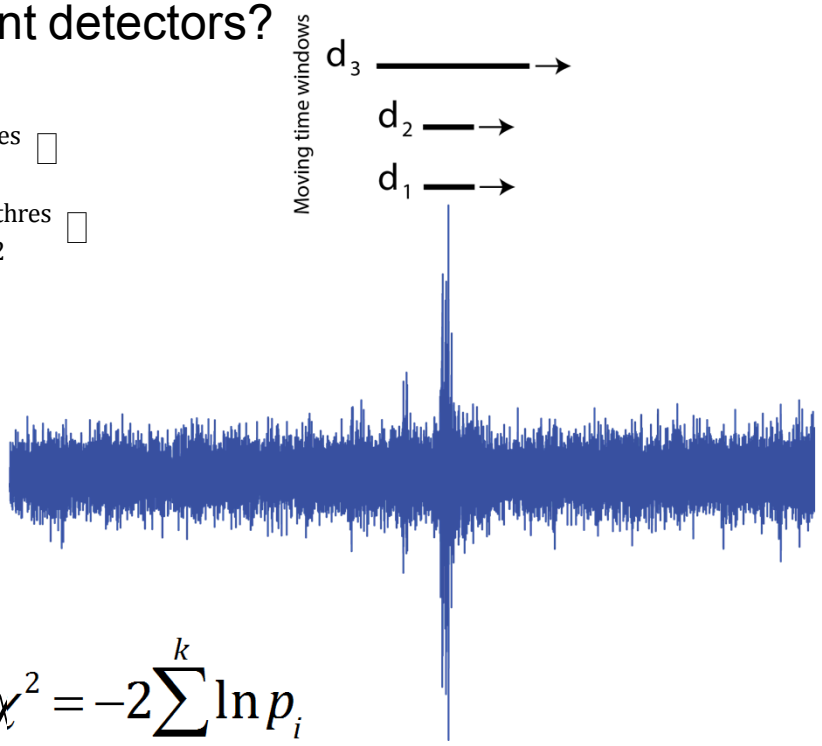
  - Arithmetic
    - Doesn't use noise distribution information

$$\sum_{i=1}^{k} w_i d_i > \text{thres}$$

  - Fishers Combined Probability Test
    - Uses distributional properties of H0
    - requires a probability model

$$p_i = \int_{d_i}^{\infty} p\left(\mathrm{x}; H_0\right) \qquad \chi^2 = -2\sum_{i=1}^{k} \ln p_i$$

  - …



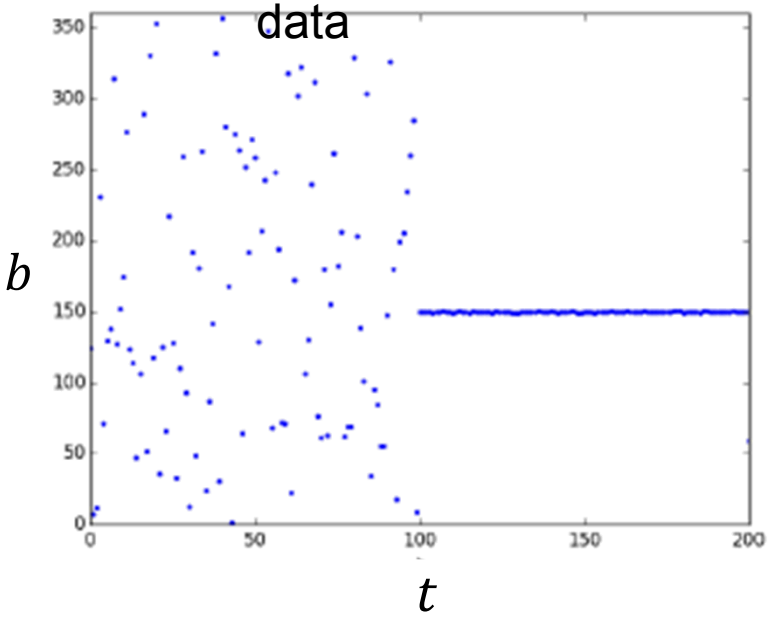
Detectors should ideally exploit different signal characteristics

Detecting low-coherence signals

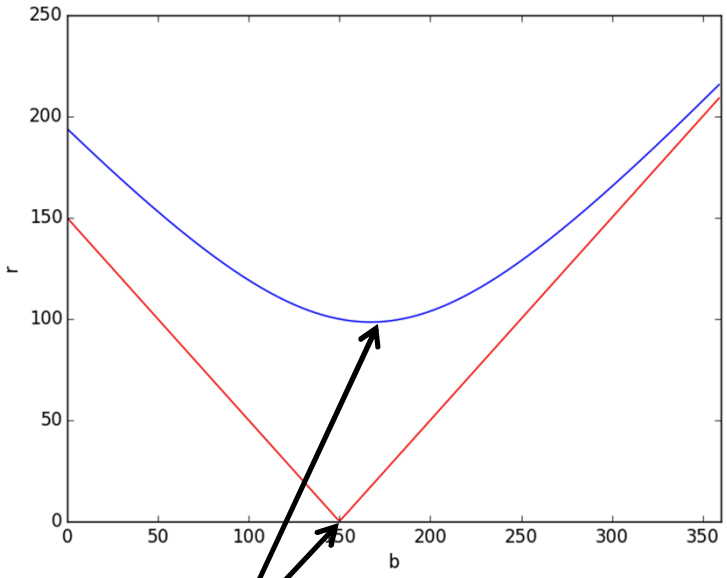
At long distances, we can search for horizontal lines in backazimuth/time space

Model: $y_{pi} = b$

Synthetic data



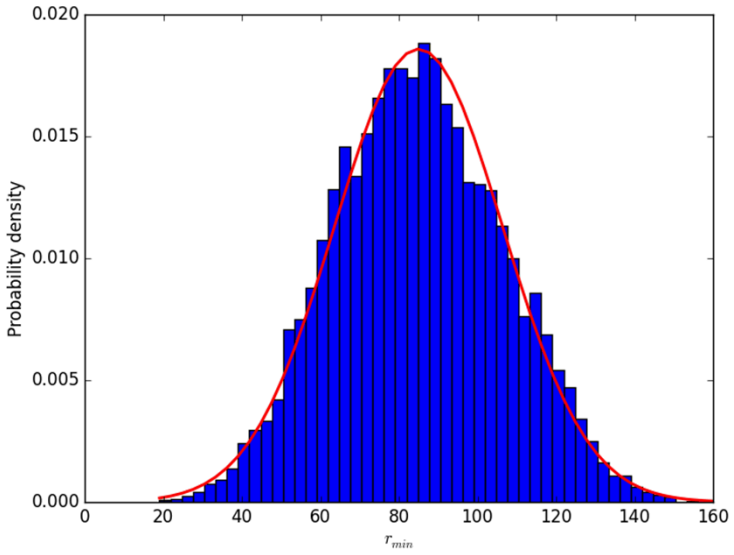
Misfit functions in two 100 s windows



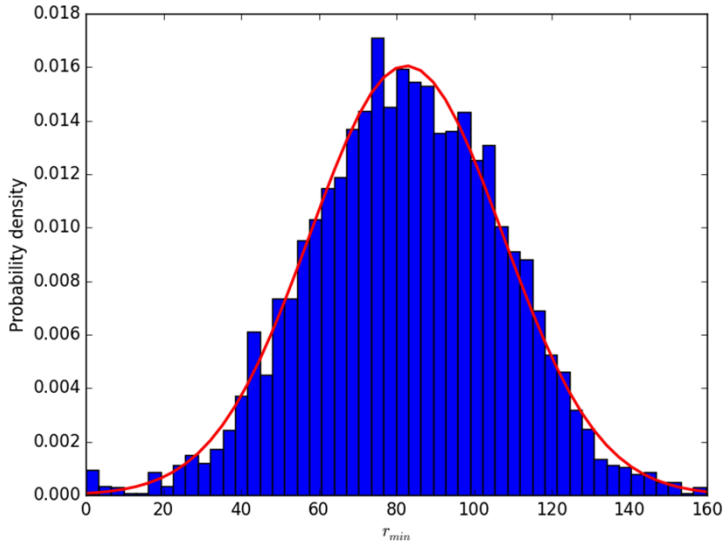
$$r_{\min} = \min\left(\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(b - b_i\right)^2}\right) \quad b \in [0, 360]$$

Detecting consistent azimuths

Distributional properties of $r_{\min} = \min\left(\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(b - b_i\right)^2} \right)$



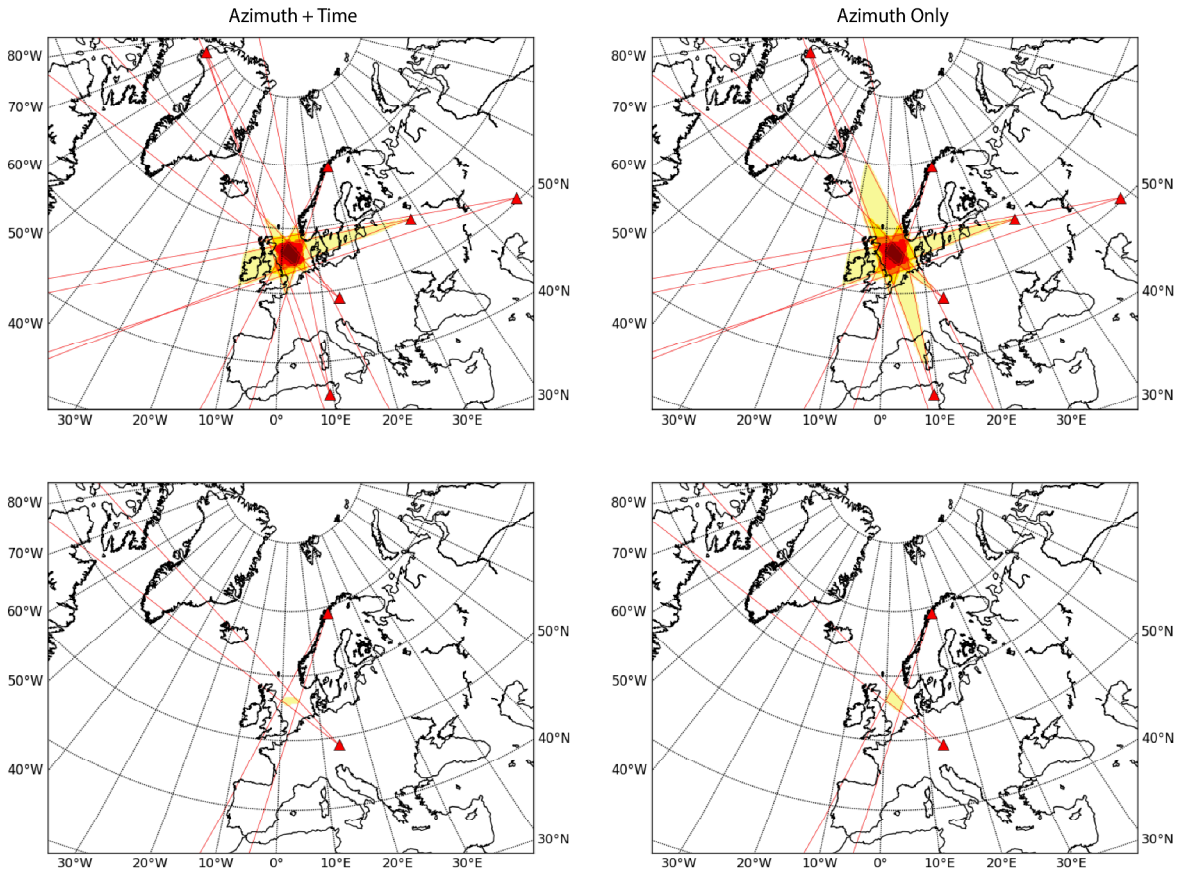
Uniformly distributed noise U[0,360]



1-day interval at I26DE

Updating the association algorithm

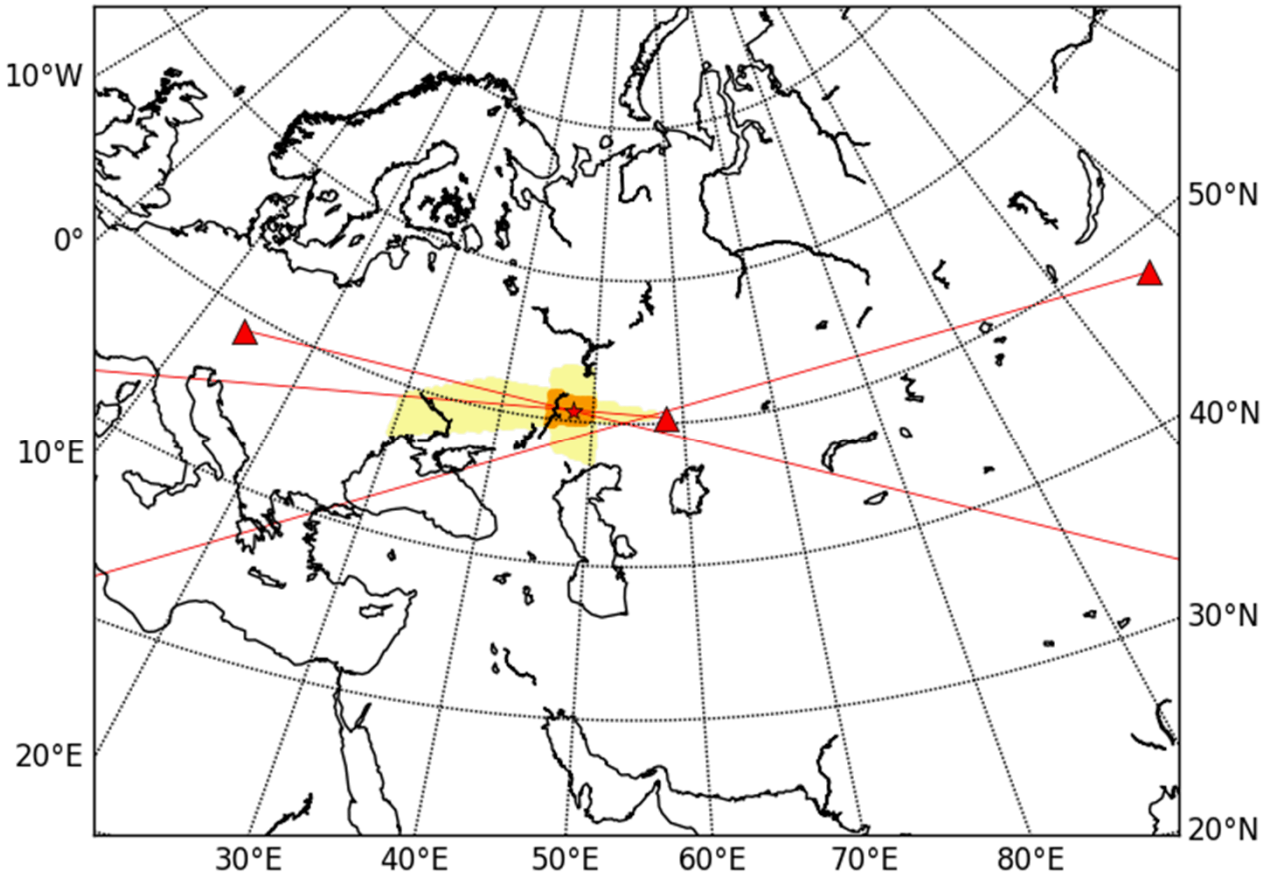
- Arrowsmith et al. (2015) algorithm is optimized for efficiency for the typical number of AFD detections, but does not scale well for an order of magnitude more detections
- An alternate method has been implemented that is equivalent to projecting detections back with specified celerity and azimuthal deviation ranges to generate 2D maps of possible event hypotheses
- Similar to location problem but a pairwise approach + graph-based methods ensure efficiency for handling large numbers of detections



Maps of association fitness for trial 6-array (top) and 2-array (bottom) synthetic events

Moving towards smaller events: An example

- Event near I31 associated with a location generating large numbers of infrasound events in the LEB
- Updated detector and associator found 3-array association that fits with IDC result (red star)
- LEB included a signal at I18 that we don't believe is real
- Next, we drill down to explore the detections…

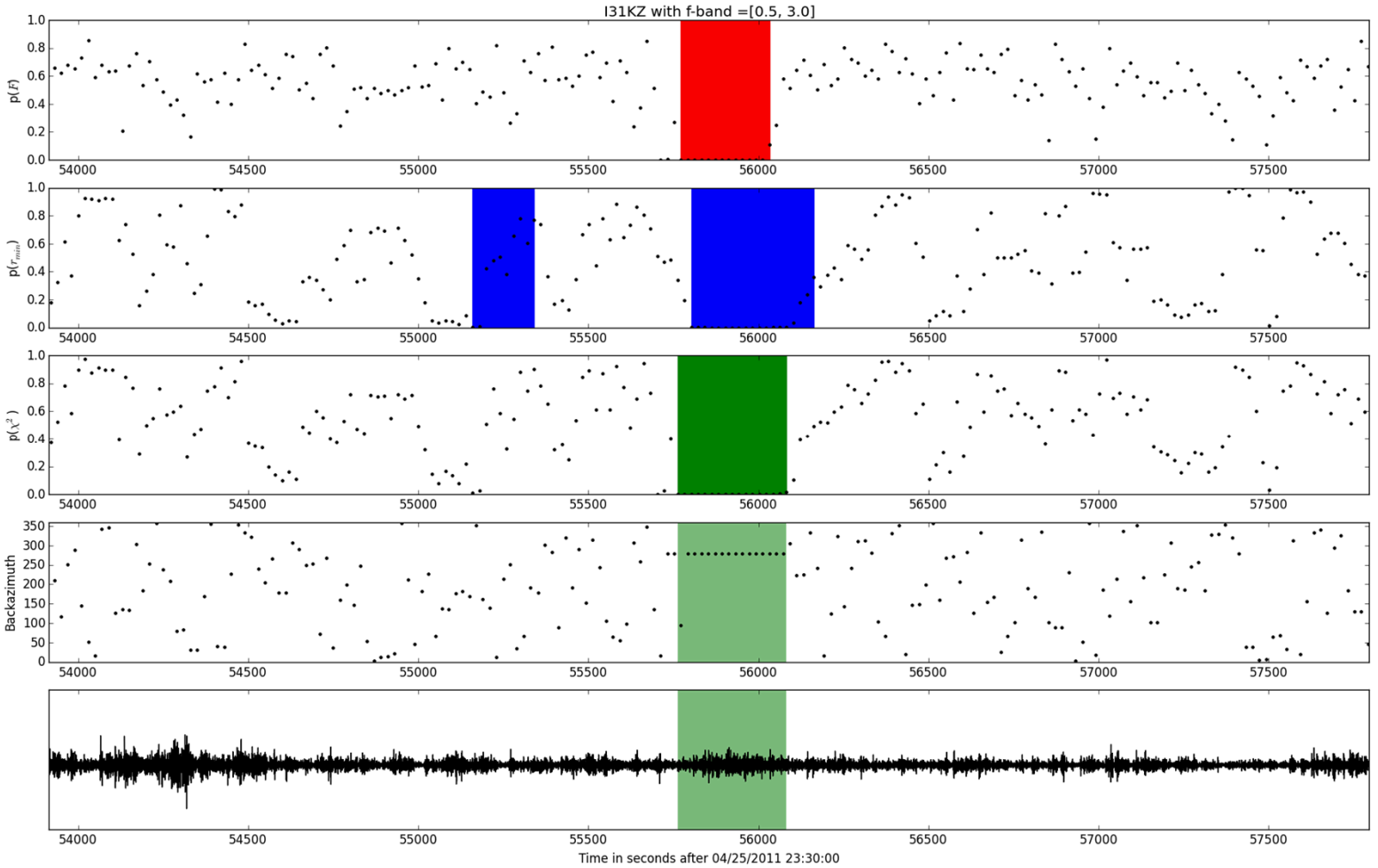


Maps of association fitness for LEB event near I31

Example event at I31

Separate p-values

Combined p-value



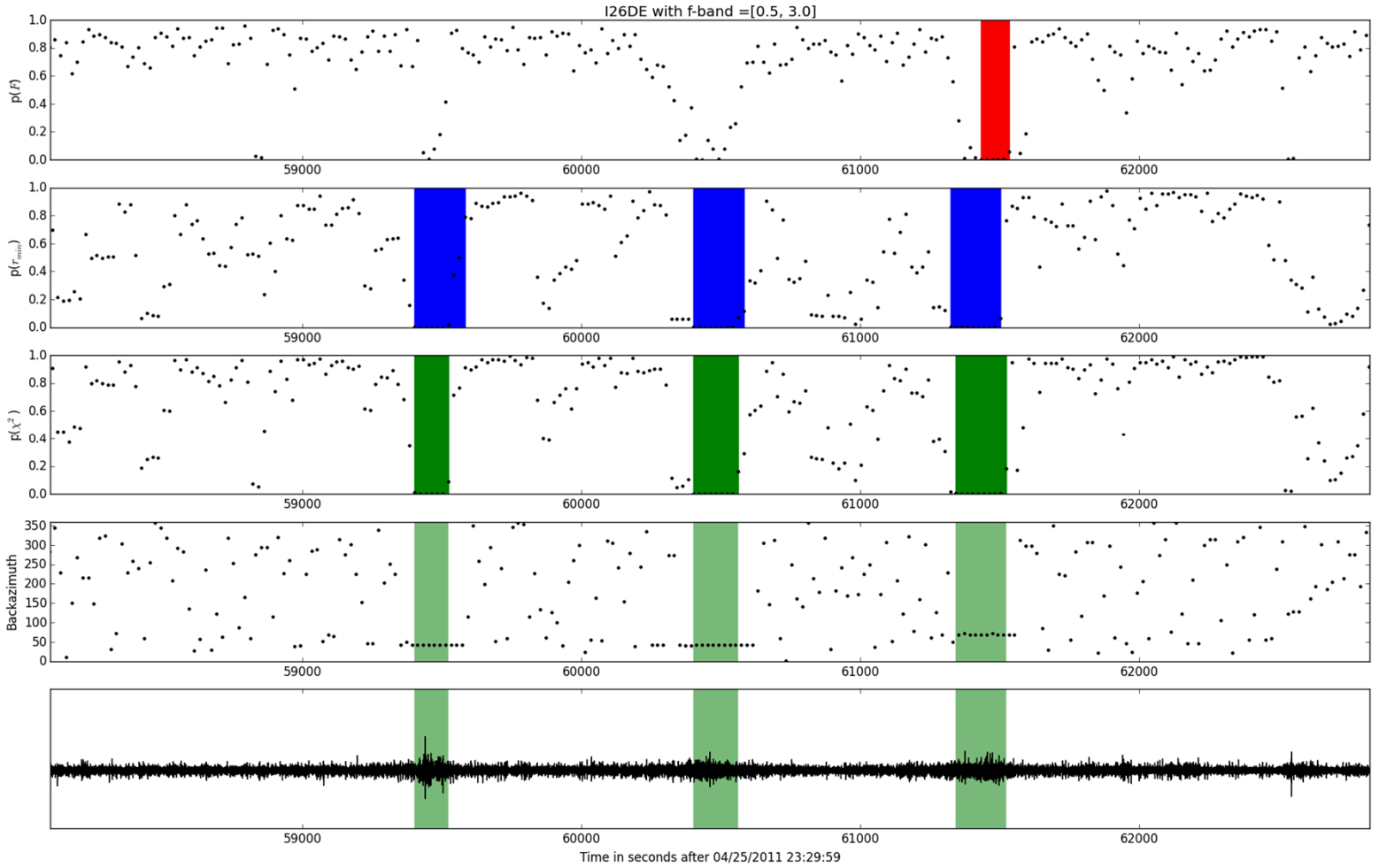
Red – Adaptive F detections
Blue – Line detections
Green – Multivariate detections

Adaptive F and multivariate detectors detect the signal at I31

Example event at I26

Separate p-values

Combined p-value



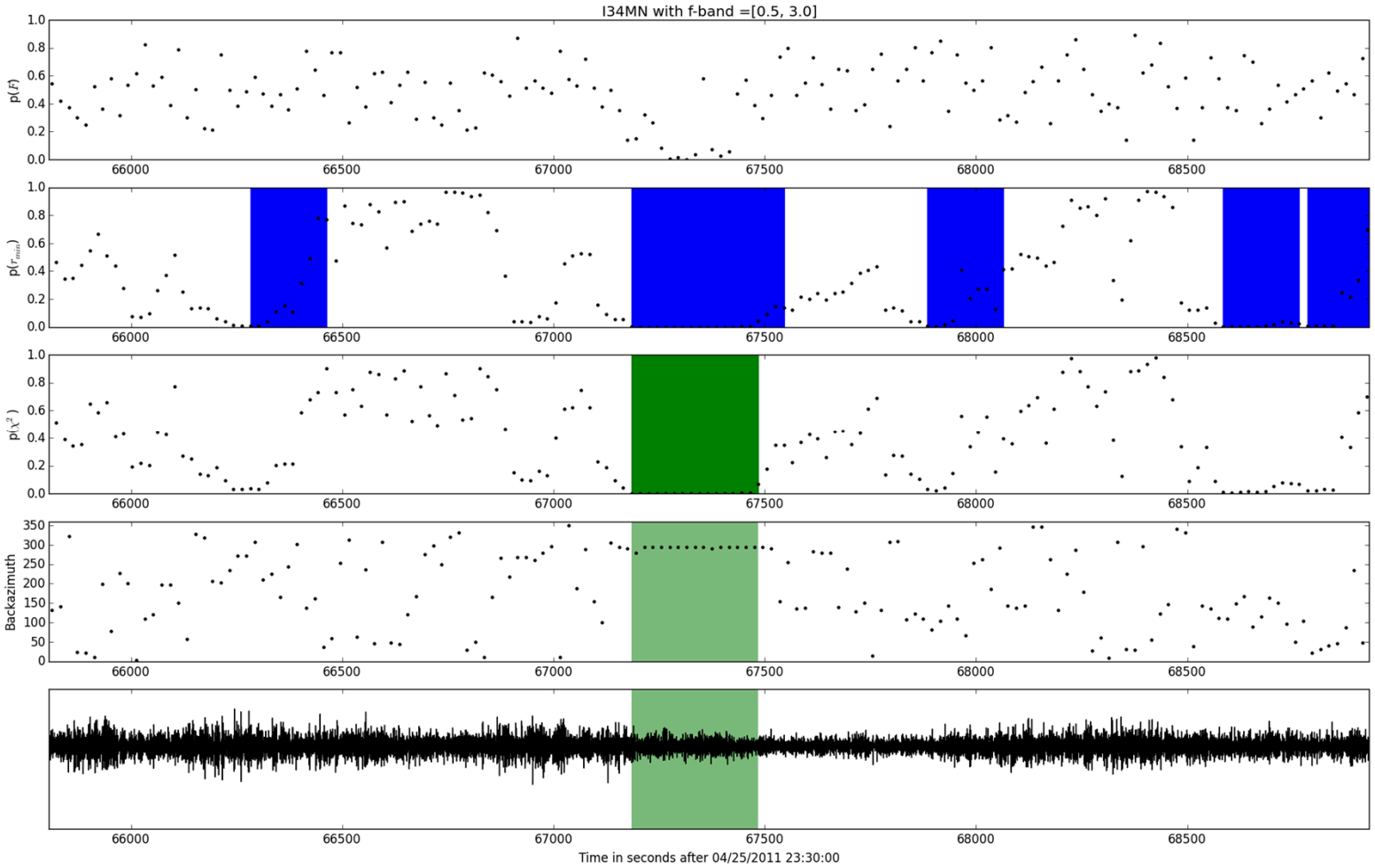
Red – Adaptive F detections
Blue – Line detections
Green – Multivariate detections

AFD and multivariate detectors detect the event at I26, but AFD misses the first two arrivals

Example event at I34

Separate p-values

Combined p-value



Red – Adaptive F detections
Blue – Line detections
Green – Multivariate detections

Only the multivariate detector detects the signal at I34

Conclusions

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- The comparison between AFD and IDC detection bulletins reveals ~1 order of magnitude fewer detections in AFD on average, and ~2 orders of magnitude fewer detections of clutter
- Arrays with numerous coherent noise detections are distinguished from arrays with numerous impulsive sources by comparing PMCC and AFD results
- A limitation with AFD is identified for low-coherence signals, and the concept of multivariate detection is explored to address this
- The multivariate detector gets ~2x as many signals as AFD in initial tests
- A new association method is implemented to handle larger numbers of detections
- We test updated algorithms on an example LEB event from near the Caspian Sea, finding that the multivariate approach is necessary to detect weak events