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CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

Towards real-time association of infrasound events using full-wave modeling

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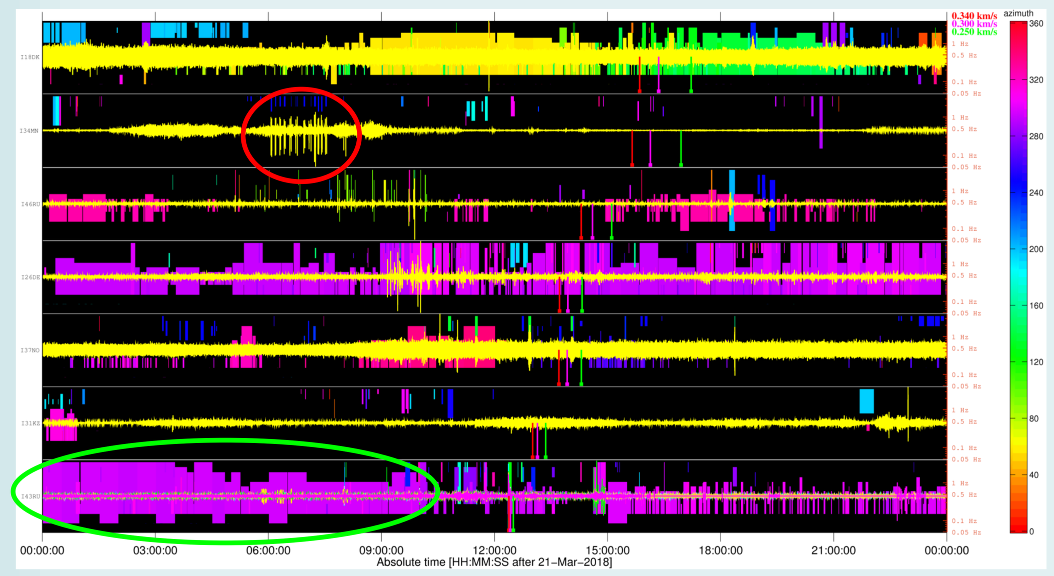
T3.5-P79

1. DIFFICULTIES TO ASSOCIATE INFRASOUND EVENTS



24h analysis of 7 IMS infrasound stations' records with PMCC detector [4], March 21, 2018.

- Local recurrent event (red circle)
- Microbarom (green circle)

Limitations due to the **processing of dataflow** from IMS stations:

- Local wind noise can interfere with infrasound detections;
- Sources of infrasound include events and phenomena that are not of interest for the CTBTO:
  - Anthropogenic sources: local, repetitive events;
  - Natural, continuous sources, e.g., microbaroms;
- Detections errors.

Limitations due to the **model/method** employed for the association:

- Uniform sound speed approximation → a large criterion must be used to associate events → a large false alarm rate is obtained;
- Empirical/statistical model → important physical aspects of event detection may be neglected → some associated phases can be confused with nuisance phases of human or natural origin.

2. BAYESIAN STRATEGY WITH A FULL-WAVE PROPAGATION MODEL

- Evaluation of **the conditional probability** of association scenarios:

$$P(S \mid D, W, A, P)$$

FLOWS
Fast Low-Order Wave Simulation

Association Scenario: Number of events and event characteristics:
- Coordinates: LAT, LON
- Time of emission
- Energy range

PMCC Detections and the associated characteristics:
- Trace velocity
- Azimuth
- RMS Amplitude

Wind Noise: Random model for each station

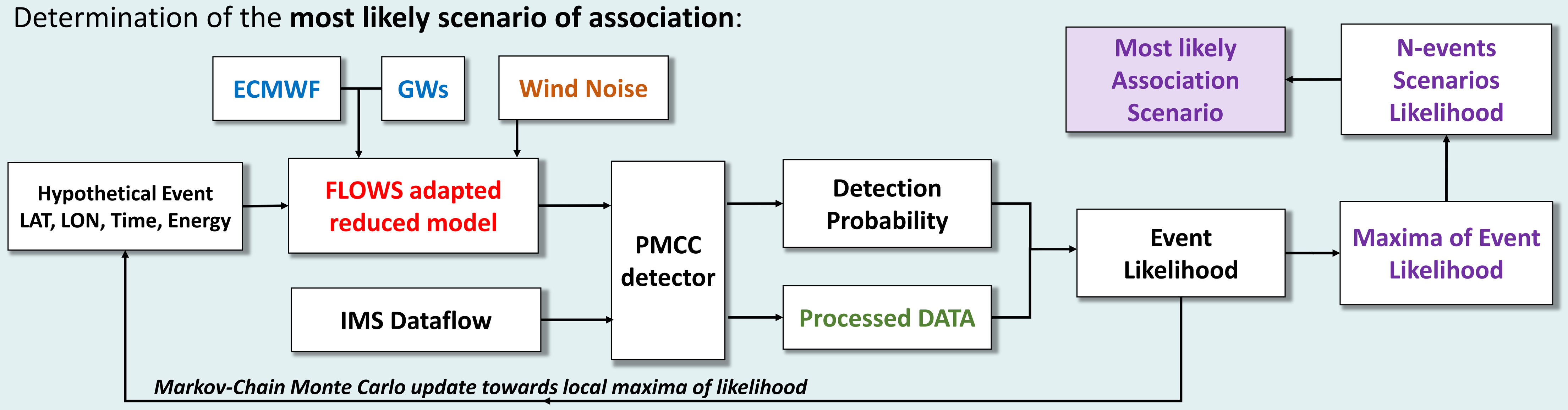
Atmospheric model: ECMWF data + parametric random deviation, e.g., Gravity Waves, see T1.1-P17

Propagation model: Low-order reduced models from the **FLOWS** platform [2].

- Random atmosphere is decomposed over distinct scales.
- Different reduced models are produced with FLOWS to solve each atmospheric scale [2].
- Models are selected and combined following a **BMA** framework [3].

For each hypothetical scenario of events, FLOWS computes the **probability distribution of detection** on each IMS station, given the wind noise and ECMWF atmospheric data, and using a full-wave propagation model.

- Determination of the **most likely scenario of association**:



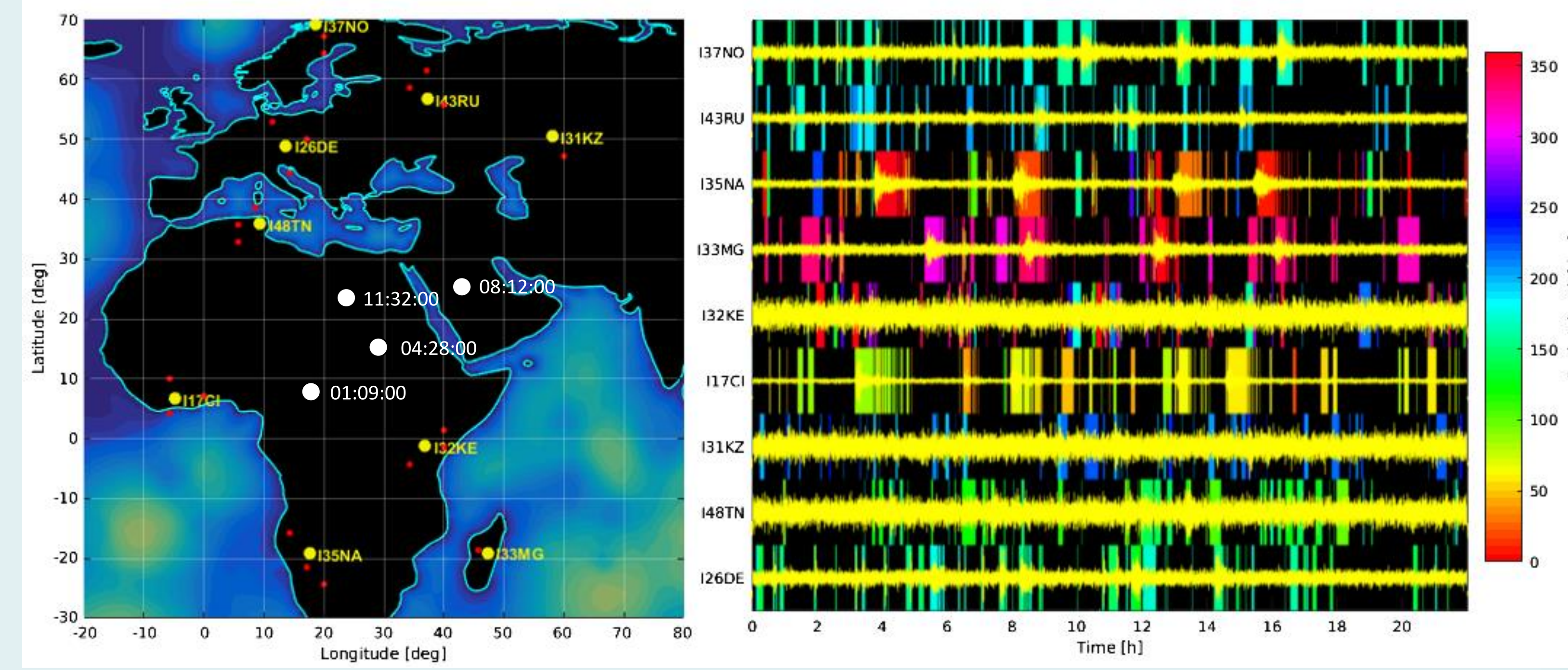
Ordered local maxima of likelihood are obtained with multi-MCMC [5,6], and provide event candidates for each scenario (N events).
The approach is based on the independence hypothesis of detections [1] and the MLE approximation (Maximum Likelihood Estimation).

3. MULTI-MCMC ALGORITHM APPLIED TO A COMPLEX SCENARIO

- A complex scenario is considered:

- 50+ recurrent, low-energy infrasound emissions, located near 9 IMS stations;
- Continuous natural source: microbarom;
- 4 fictive events of interest (high energy);
- Random wind noise at each station;
- Random, spurious detections added to the PMCC analysis.

→ Goal: associate the correct events using PMCC detections [4] and the full-wave propagation model FLOWS [2].



- IMS infrasound stations
- Recurrent events
- Microbarom source
- High-energy events

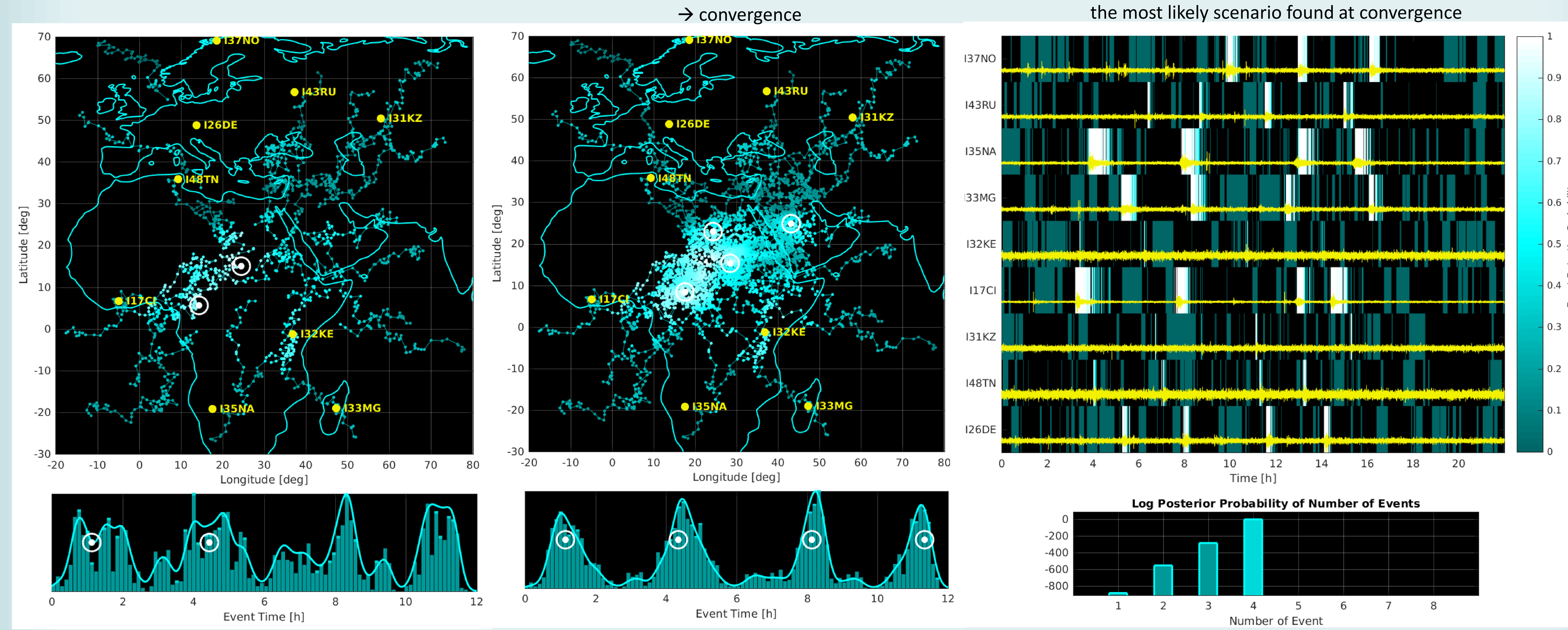
24h PMCC detections issued from the scenario

- 30 parallel Markov chains [5,6] are designed to probe the event space (latitude, longitude, time of emission) in order to retrieve the correct association scenario.

2400 MCMC iterations – 189 600 simulated waveforms

5700 MCMC iterations – 450 300 simulated waveforms → convergence

Probability distribution of detections on 9 IMS stations issued from the most likely scenario found at convergence



The most likely scenario accounts for 4 events of interest

→ **4 events of interest correctly associated;**
→ **Recurrent events and most false detections identified.**

- Results from 20 randomly generated scenarios:

- 94% of false detections correctly identified and excluded (98.5% of anthropogenic/natural events, 90.3% of spurious detections);
- 99% of true detections correctly identified and associated.

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[2] Bertin M., Millet C. and Bouche, D., A low-order reduced model for the long range propagation of infrasound in the atmosphere, *The Journal of the Acoustical Society of America*, **136**, 37, **2014**.
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[5] Gelman A. and Rubin D. B., Inference from iterative simulation using multiple sequences, *Statistical Science*, **7**, 457-511, **1992**.
[6] Hastings W. K., Monte-Carlo sampling method using Markov chains and their applications, *Biometrika*, **57**, 97-109, **1970**.