Plasmaspheric electron densities and whistler propagation paths

János LICHTENBERGER[1], Csaba FERENCZ[1], Dániel HAMAR[1], Péter STEINBACH[2], Dan GOLDEN[3], Umran INAN[3], Morris COHEN[3] and Craig RODGER[3]

(1)Space Research Group, Department of Geophysics and Space Sciences, Eötvös University, Hungary

(3)Stanford University, Stanford, USA

(2)Research Group for Geology, Geophysics and Space Sciences of HAS, Budapest, Hungary

(4)Department of Physics, University of Otago, Dunedin, New Zealand

Plasmasphere: why is it important?

Space Weather

- Radiation Belts dynamics: wave-particle interactions

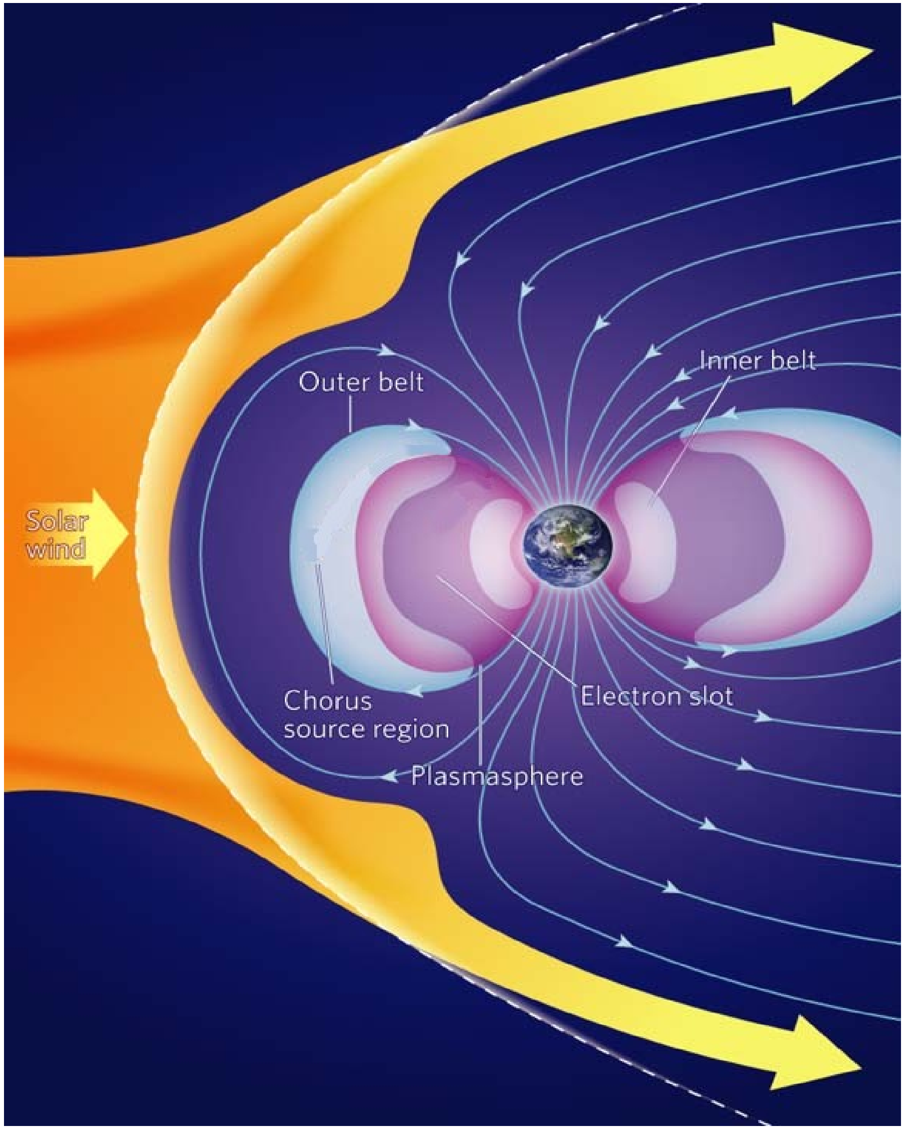
  - chorus

  - hiss

take place in/at
plasmasphere/plasmapause

→ we need a model

of the plasmasphere /plasmapause location



Automatic Whistler Detector and Analyzer (AWDA) system [Lichtenberger et al., *JGR*, 2008]:

Whistlers are searched in the broad-band VLF signal without human interaction

Automatic whistler analysis yields plasma and propagation parameters → electron density distribution → *Space Weather*

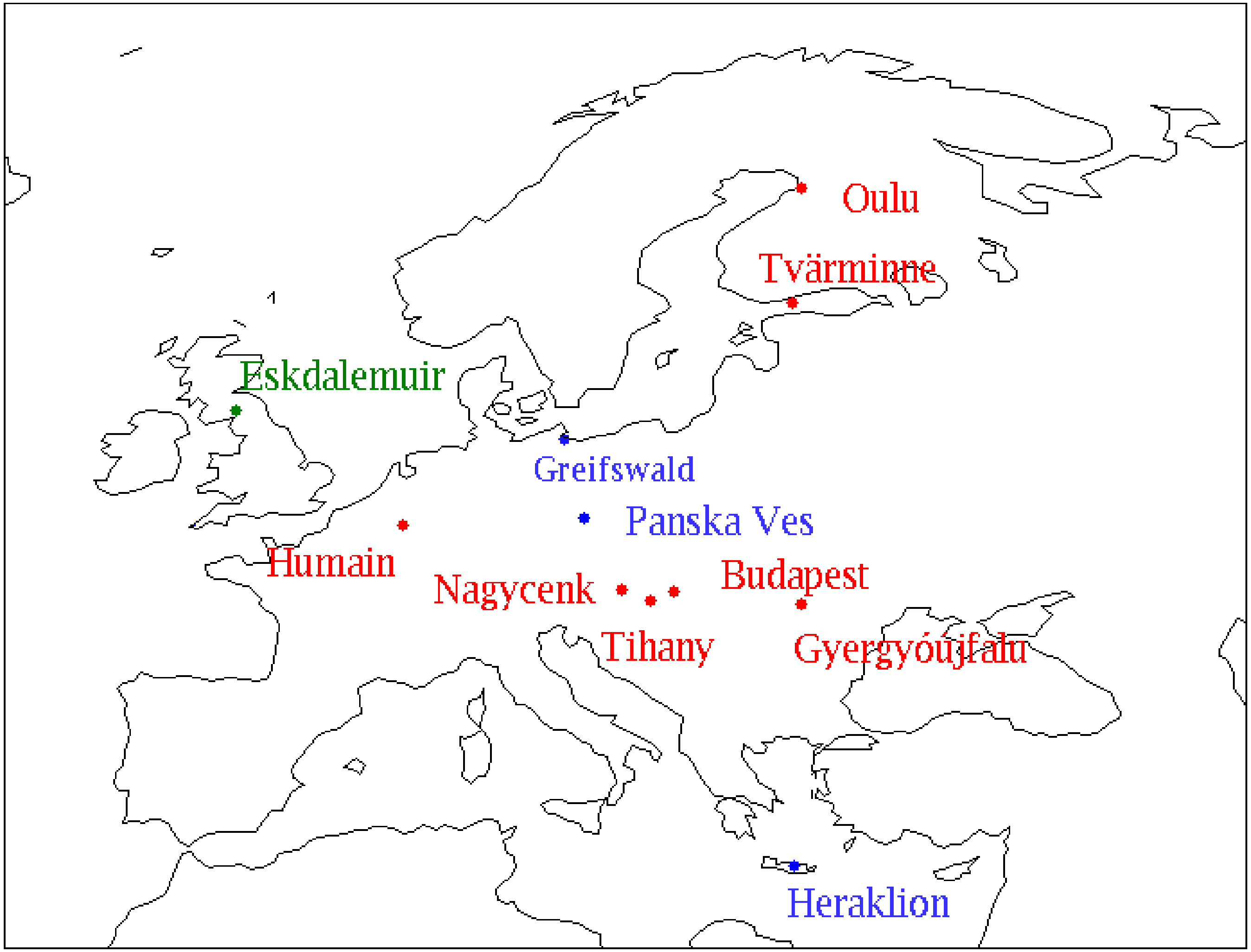
AWDANet

Extending network of AWDA systems covering low-, mid- and high (magnetic) latitudes since 2002 including conjugate locations

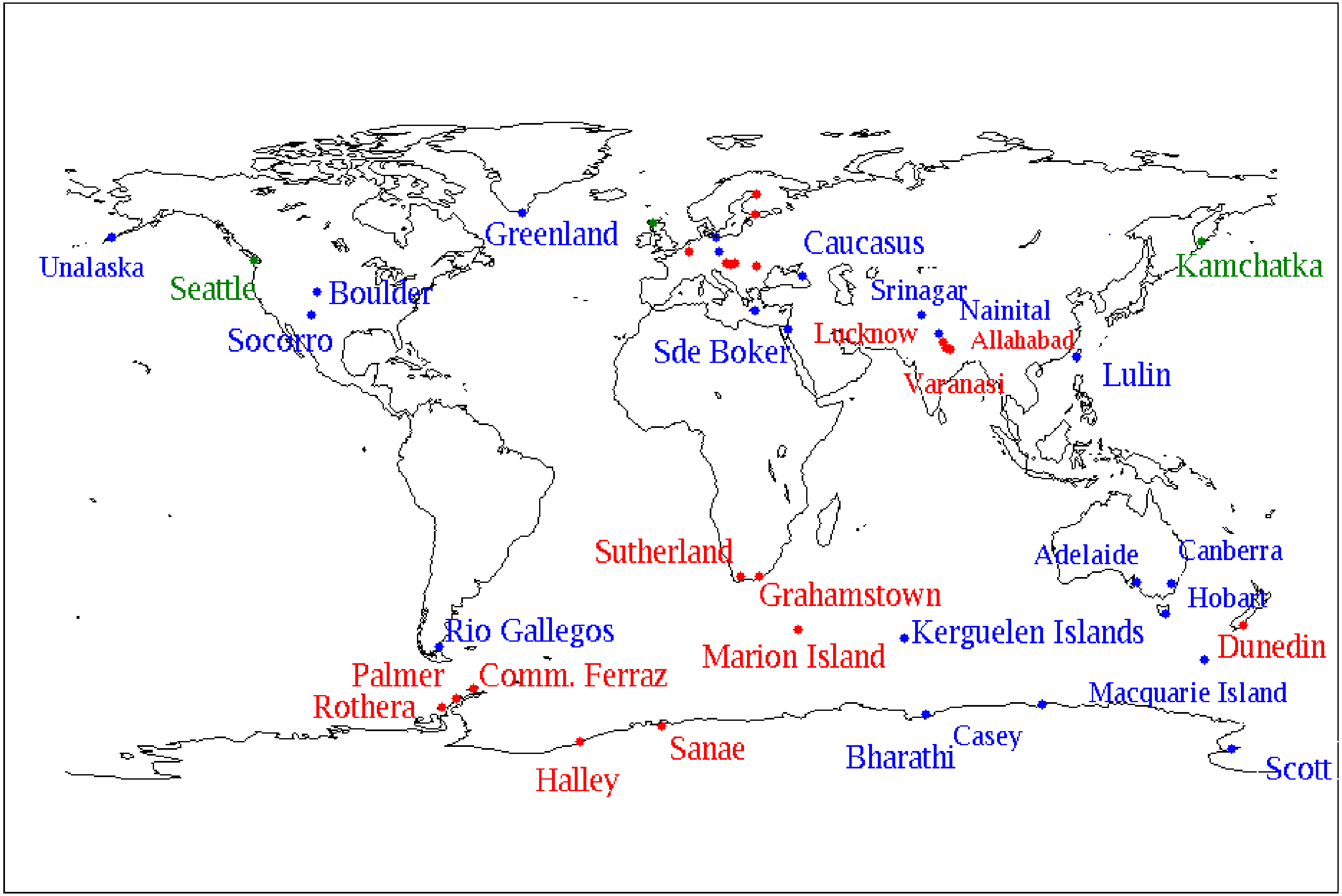
~50 000-10 000 000 traces/year/station

Real time operation is in *experimental* phase

AWDANet -Europe



AWDANet - World

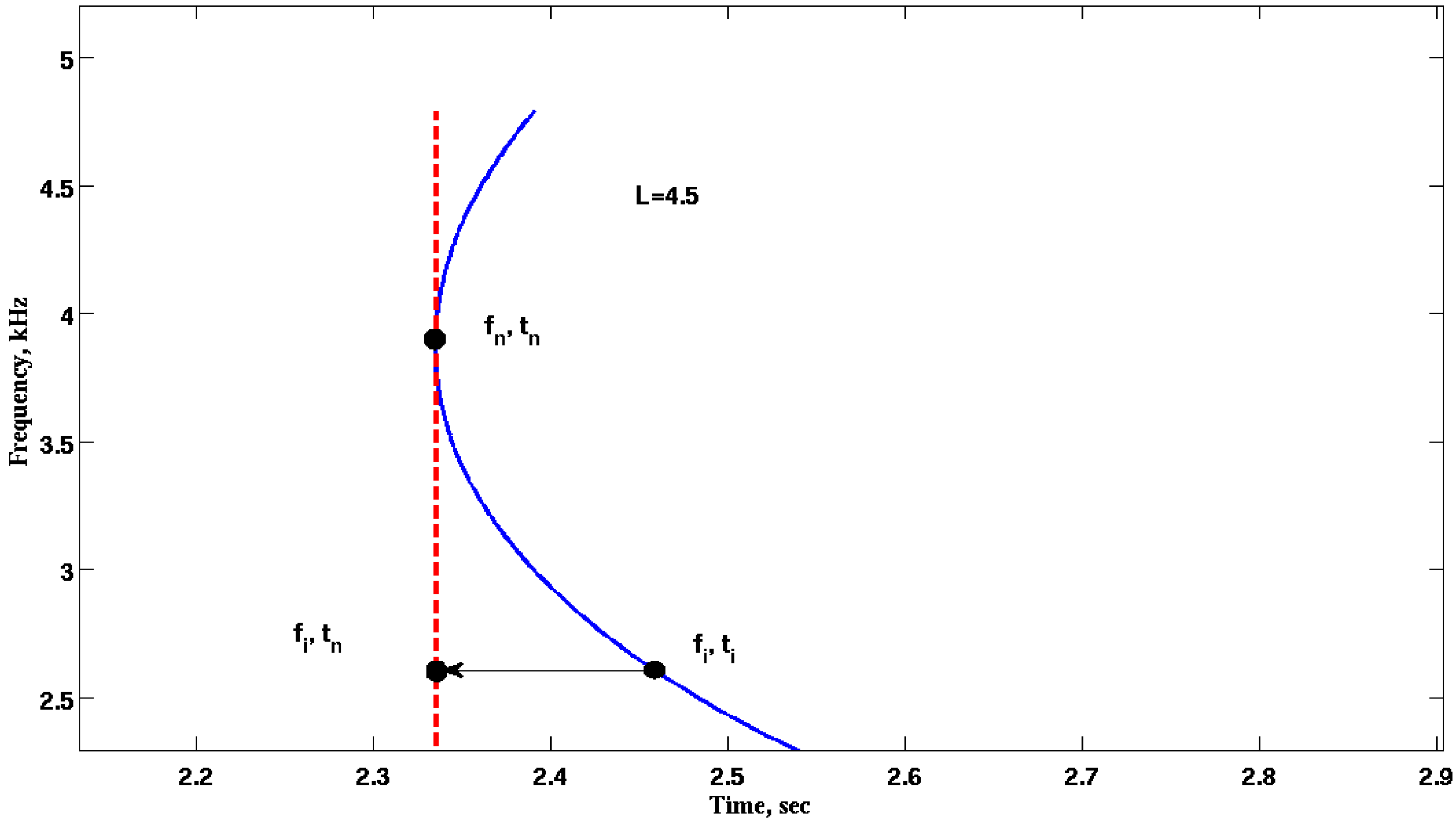


A new *whistler inversion* method

+

Virtual (whistler) Trace Transformation

[Lichtenberger, *JGR*, 2009]

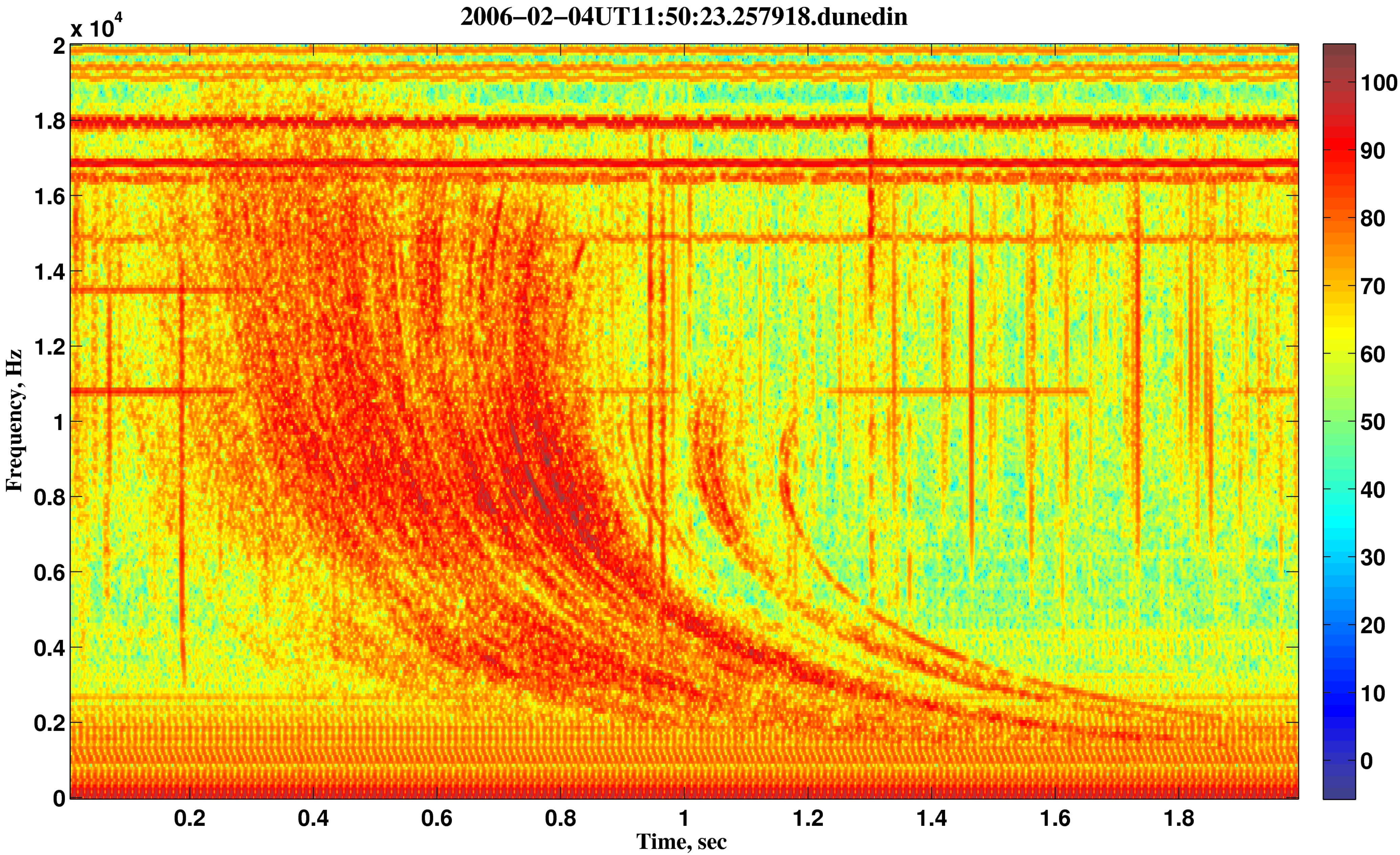


Multiple path whistler group model:

- A new, simplified equatorial electron density profile is introduced in a meridional section of the plasmasphere:

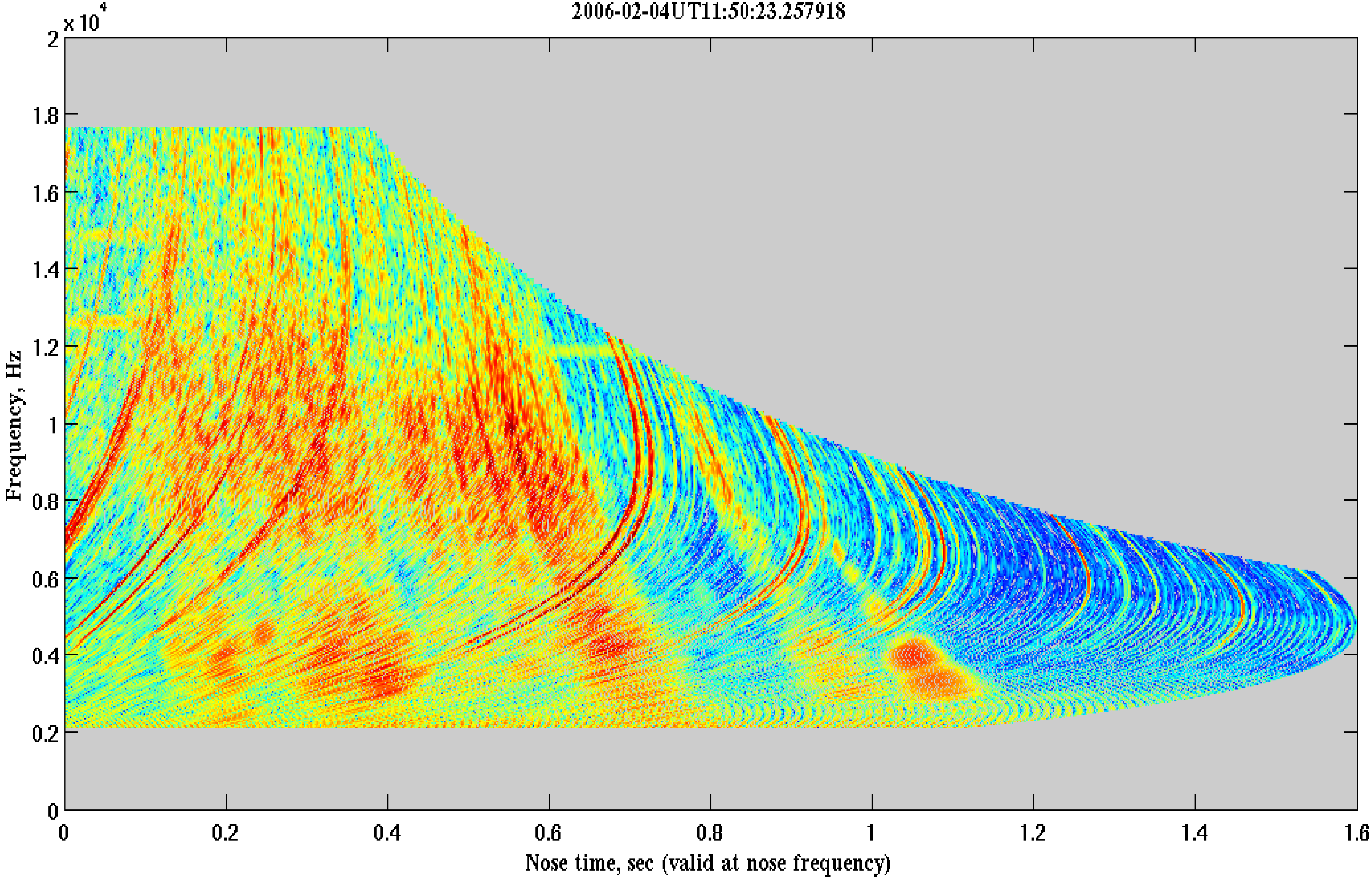
$$\log_{10} n_{eq} = A + B \cdot L$$

- *A* and *B* are constants for a MP group, but may vary to time and place.
- This approximation is valid between ~ 2 < L < min (8, L_{pp}), where L_{pp} is the location of plasmapause.
- Taking a pair of *(A,B)*, the electron density in magnetic equator decreases monotonically. In principle, a whistler can propagate along each field line described by an *L* in this range with corresponding n_{eq} forming a ***virtual whistler continuum***. Of course, in reality only a few whistlers of that continuum may be real.

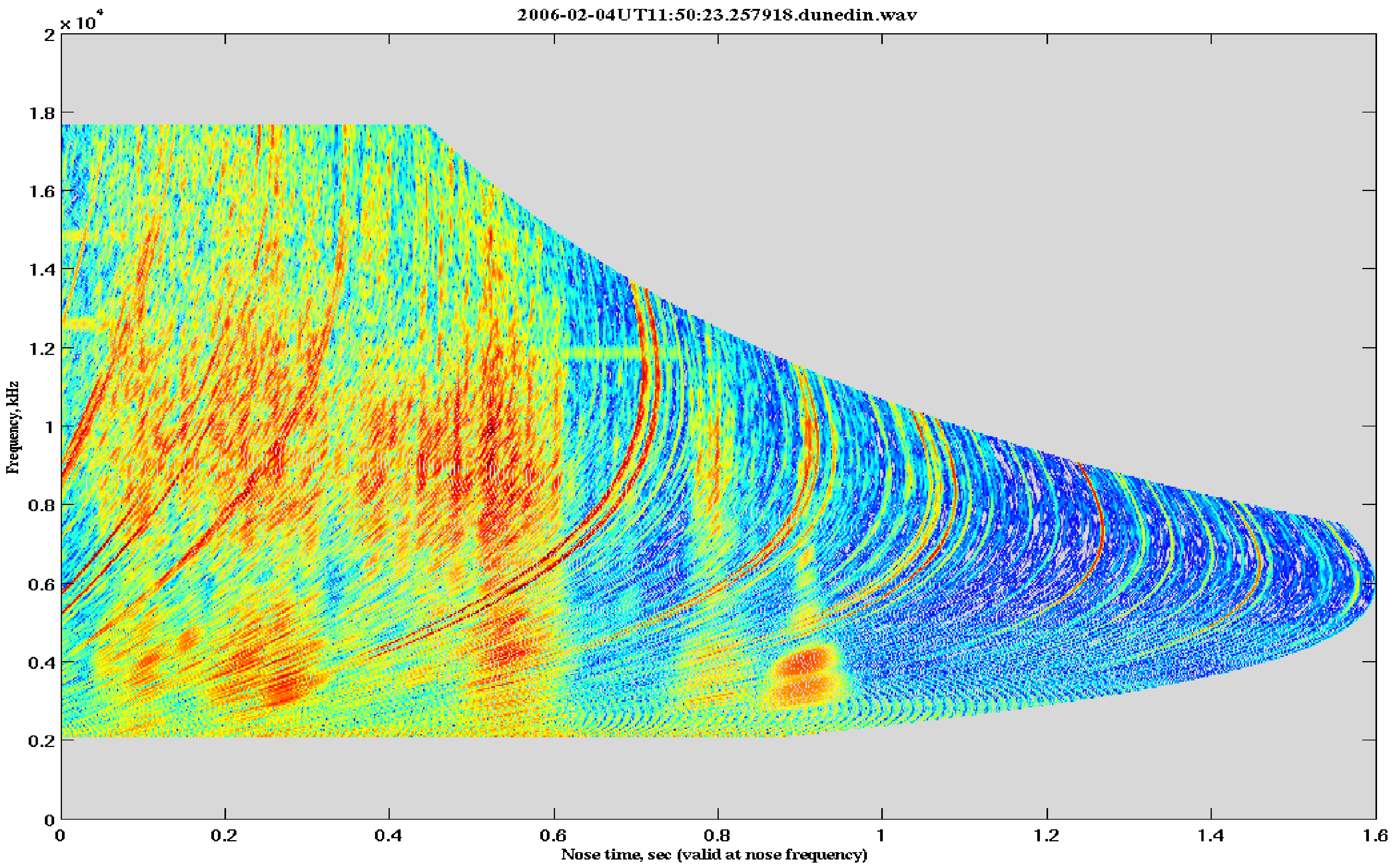


2006−02−04UT11:50:23.257918.dunedin
x 10^4
Frequency, Hz
Time, sec
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
10
20
30
40
50
60
70
80
90
100

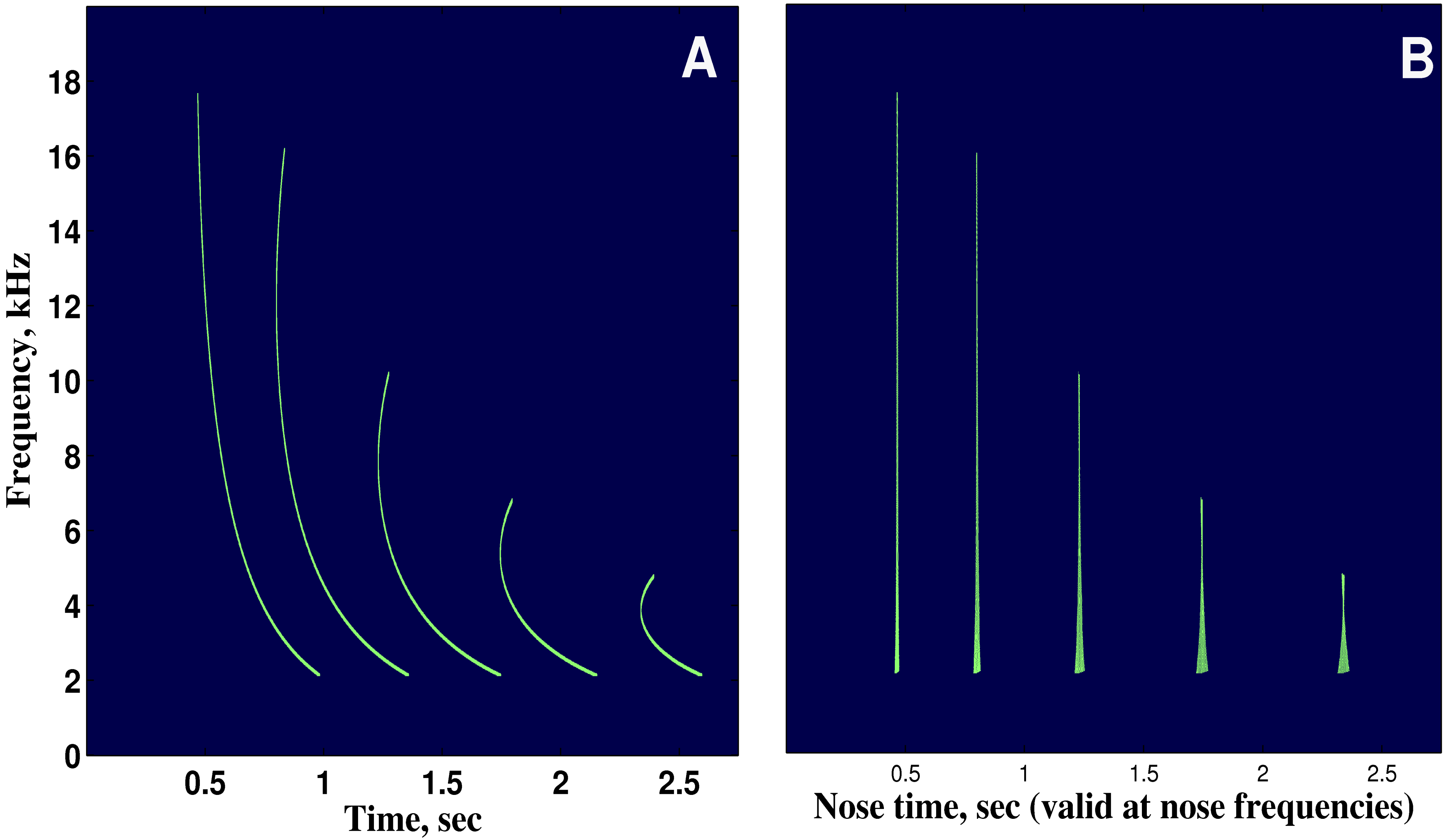
VTT –unmatched parameters



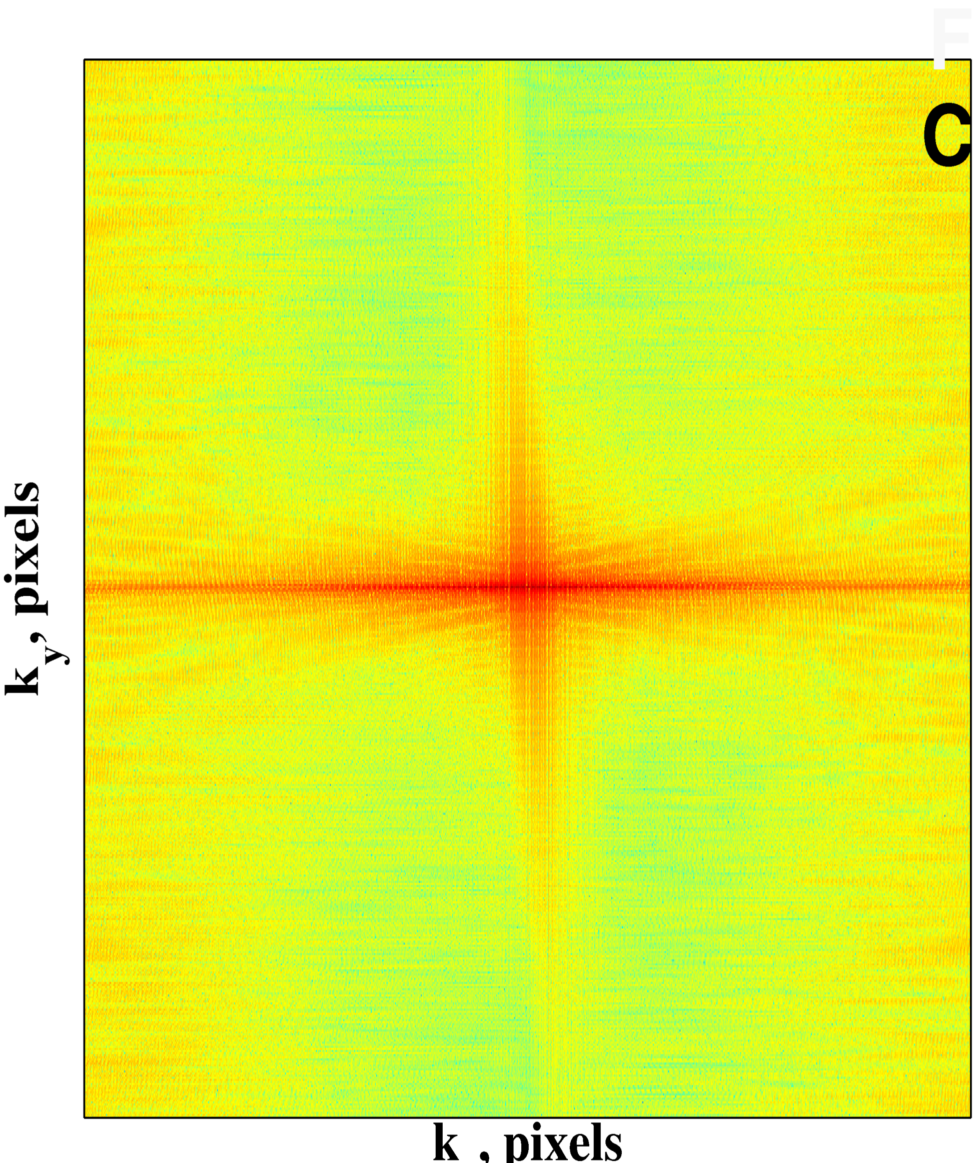
VTT –matched parameters

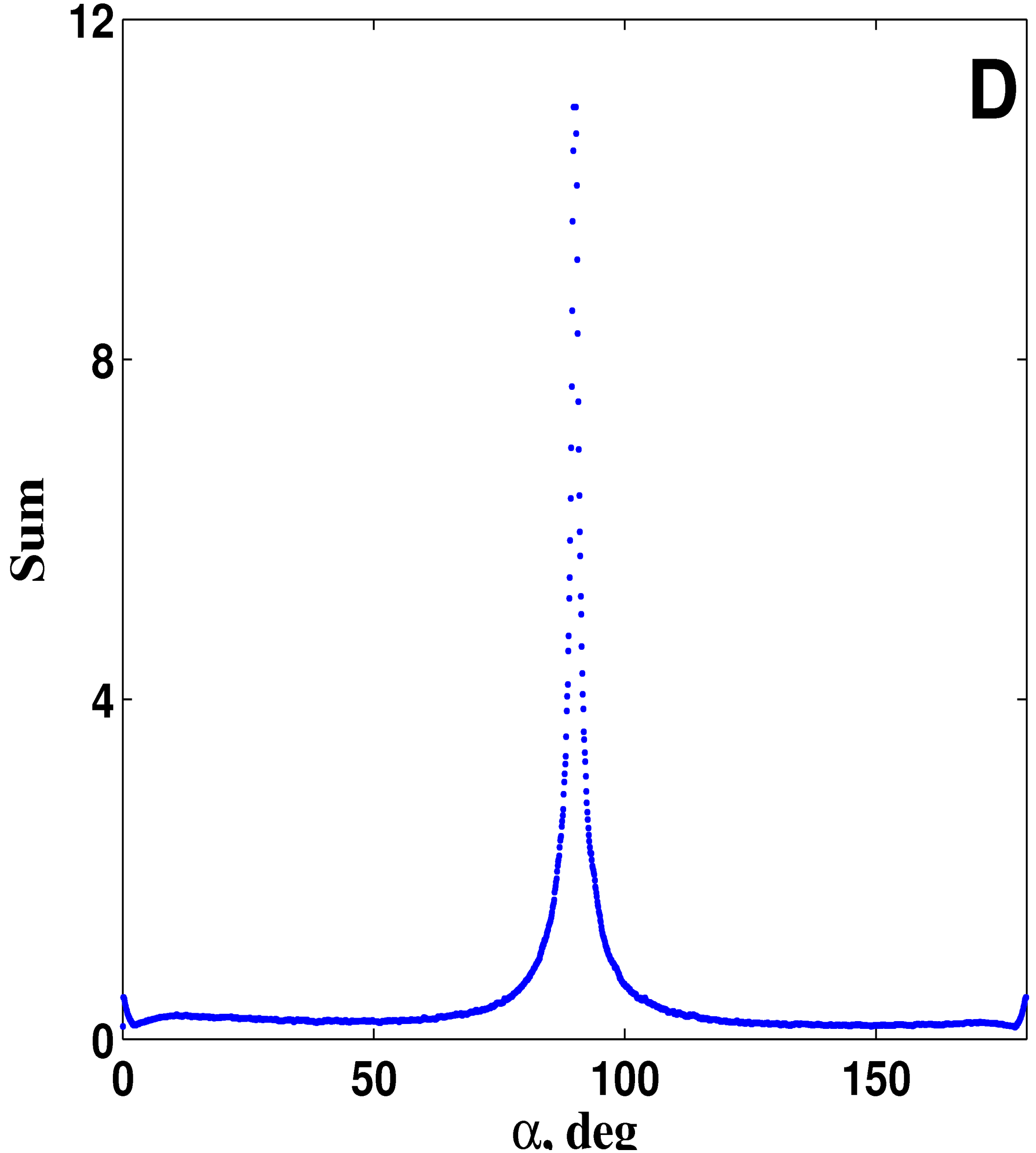


VTT –applied to model MP group

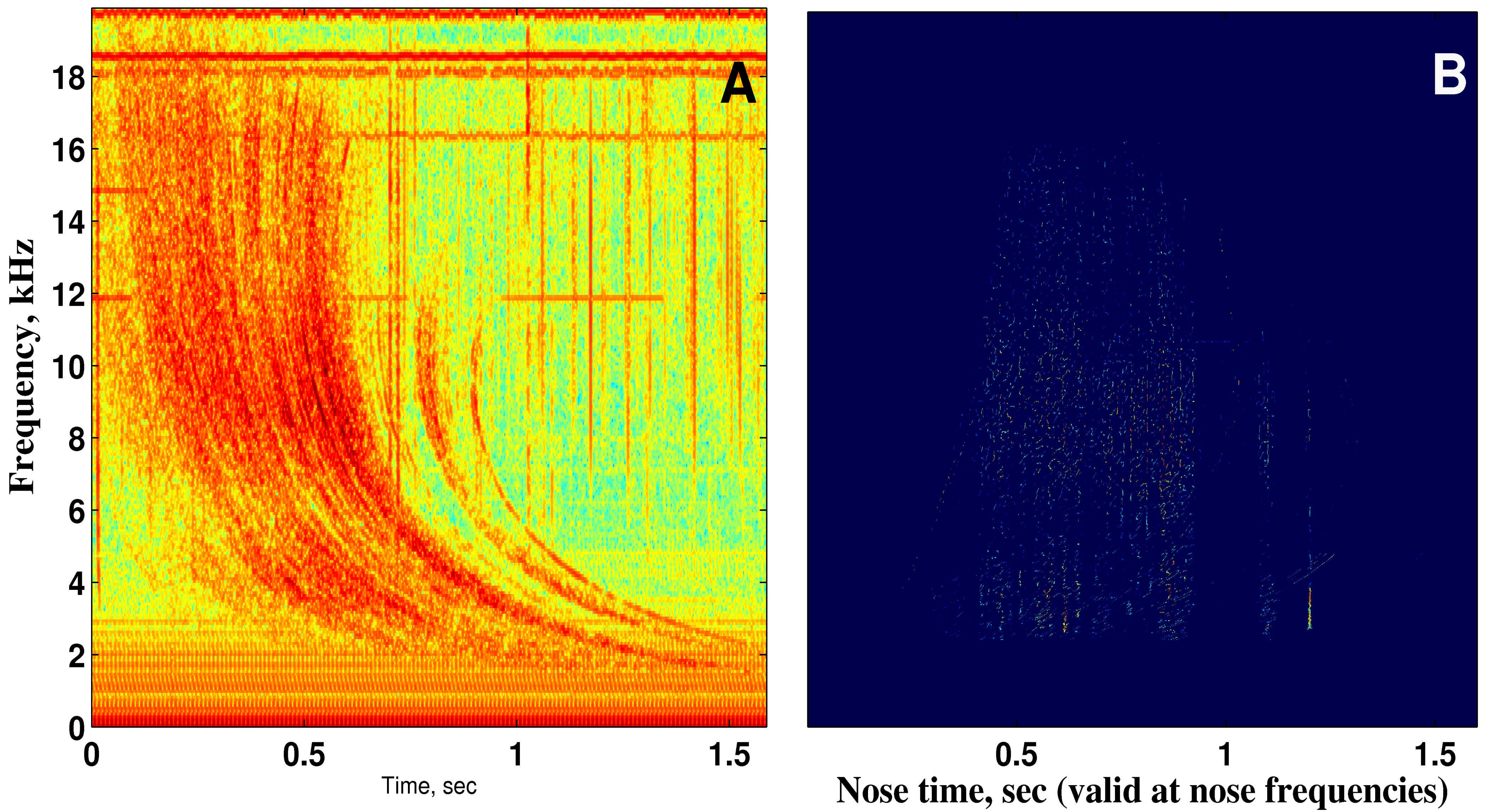


2D FFT of VTT and the "sharpness" plot–applied to model MP group

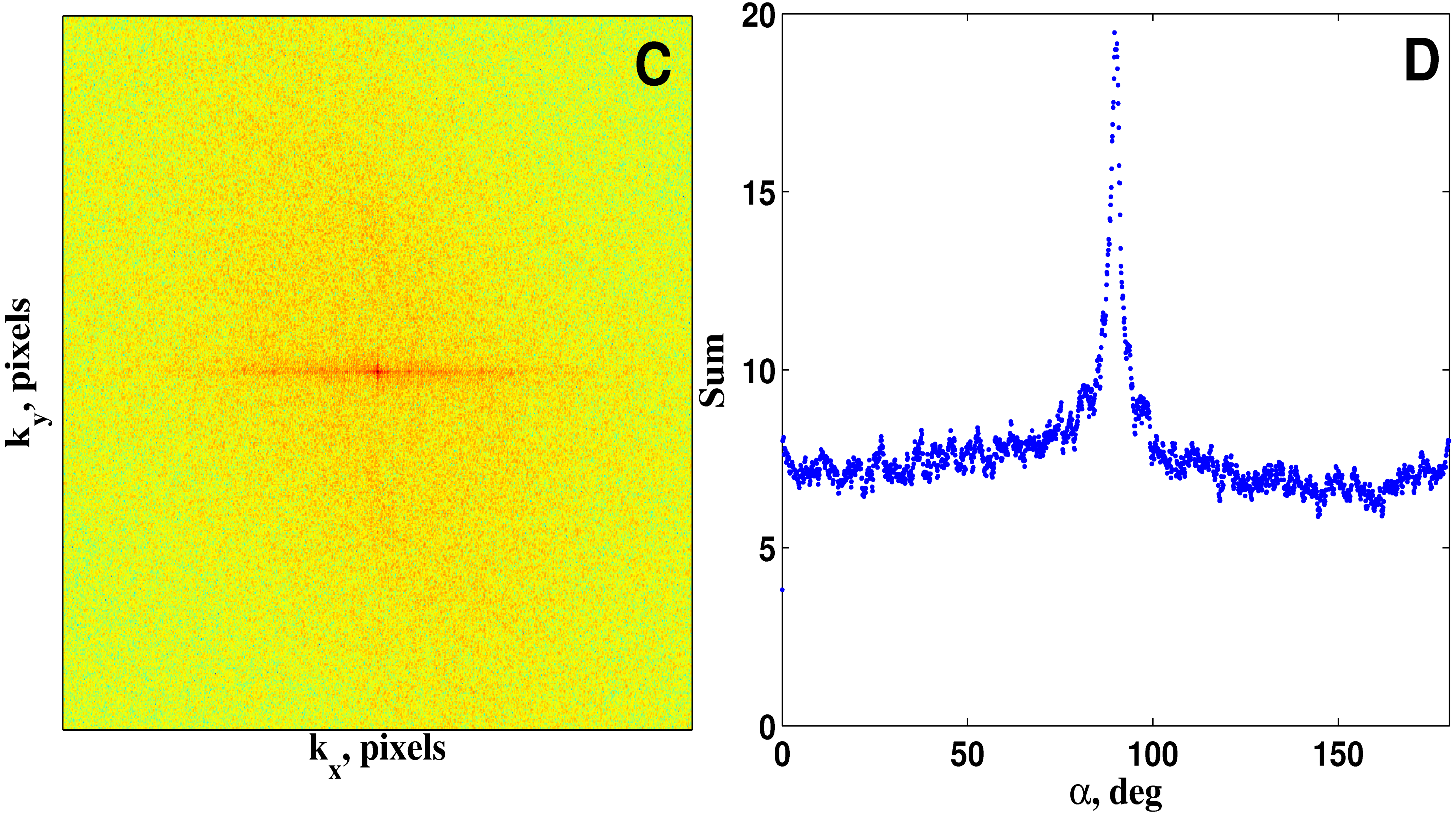




VTT –applied to real MP group



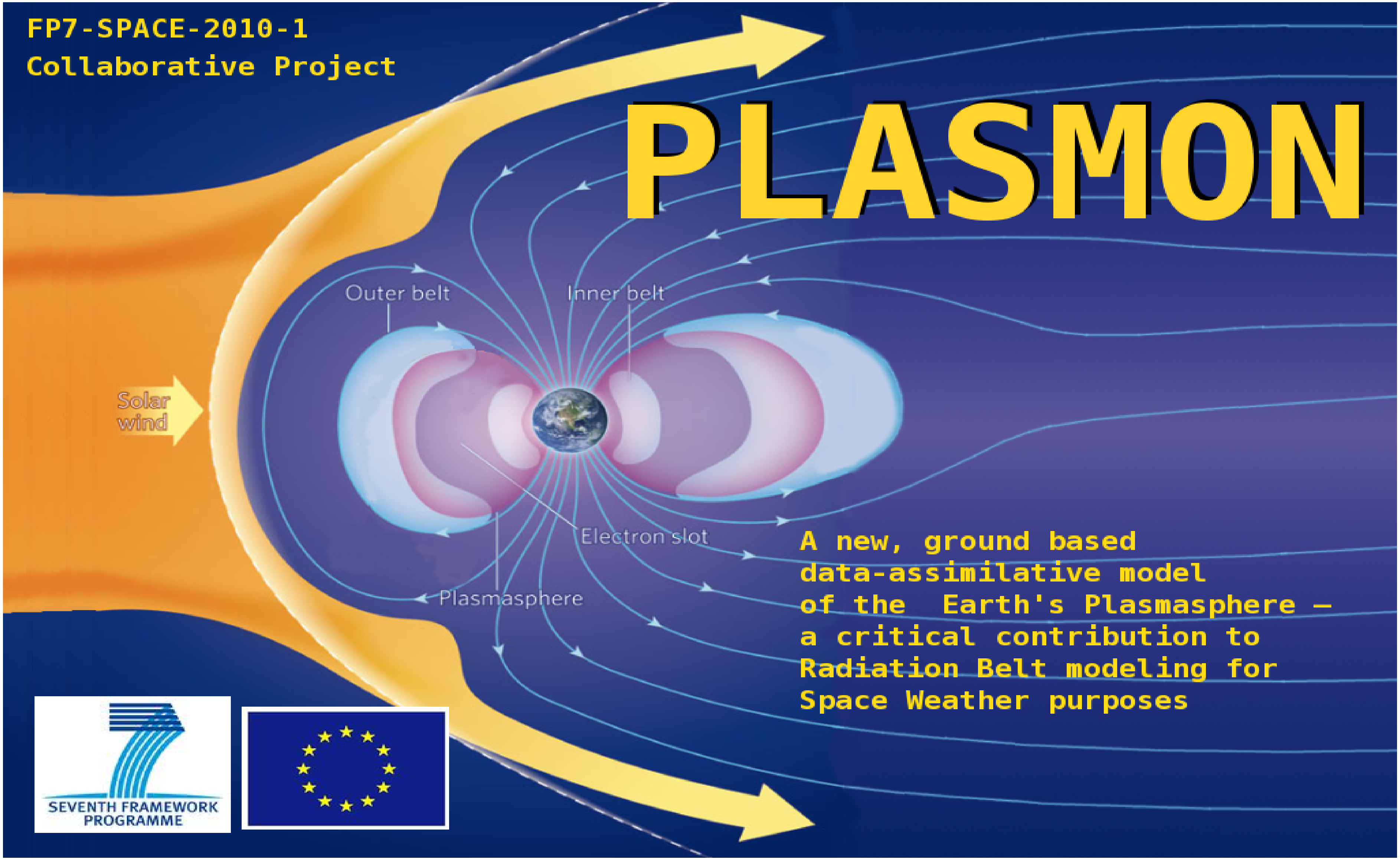
2D FFT of VTT and the "sharpness" plot–applied to real MP group



Implementation of AWA algorithm
[Lichtenberger et al., *JGR*, 2009]

1. Application of VTT to the spectrogram matrix with an initial set of *(dt,A,B)* parameter triplet.
2. Computation of 2D FFT of VTT image.
3. Calculation of sharpness plot for the 2D FFT image and p_{max}, $|\alpha - 90|$ and w from it. The sharpness plot is used as an objective function in the optimiziation procedure
4. Iterate steps 1-3 while tuning the *(dt,A,B)* triplet to simultaneously maximize p_{max} while minimize $|\alpha - 90|$ and w.

- An AWA run on an MP group takes *4.5-5 hours* on a single CPU → PC cluster (100 threads) : 5-15 min
- 10-15 density data per hour as an input for a plasmasphere model
- GPU computing → ~1000 times speed up



http://plasmon.elte.hu

Objectives

- **Regular longitudinally-resolved measurements plasmaspheric electron and mass densities and hence monitor the changing composition of the plasmasphere, one of the properties which determines wave growth in wave-particle interactions in the Radiation Belts**

- **To develop a data assimilative model of the plasmasphere using. Even dense measurements only sample the plasmasphere at limited resolution in both space and time. Yet determining the effect of wave-particle interactions on the Radiation Belts require a continuous map of the plasma density in both time and space. In order to provide such a complete map it becomes necessary to interpolate between measurements, again in both time and space with data assimilation schemes to combine plasmaspheric measurements with a numerical physics-based plasmasphere model. The two data assimilation schemes which we are pursuing are Ensemble Kalman filtering and particle filtering.**

- **To monitor the occurrence and properties of Relativistic Electron Precipitation, tying the time-resolved loss of relativistic electrons to the dynamic plasmasphere observations. Our approach will primarily use ground-based networks of observing stations, operating in the ULF and VLF ranges, deployed on a worldwide level**

Workpackages and methology

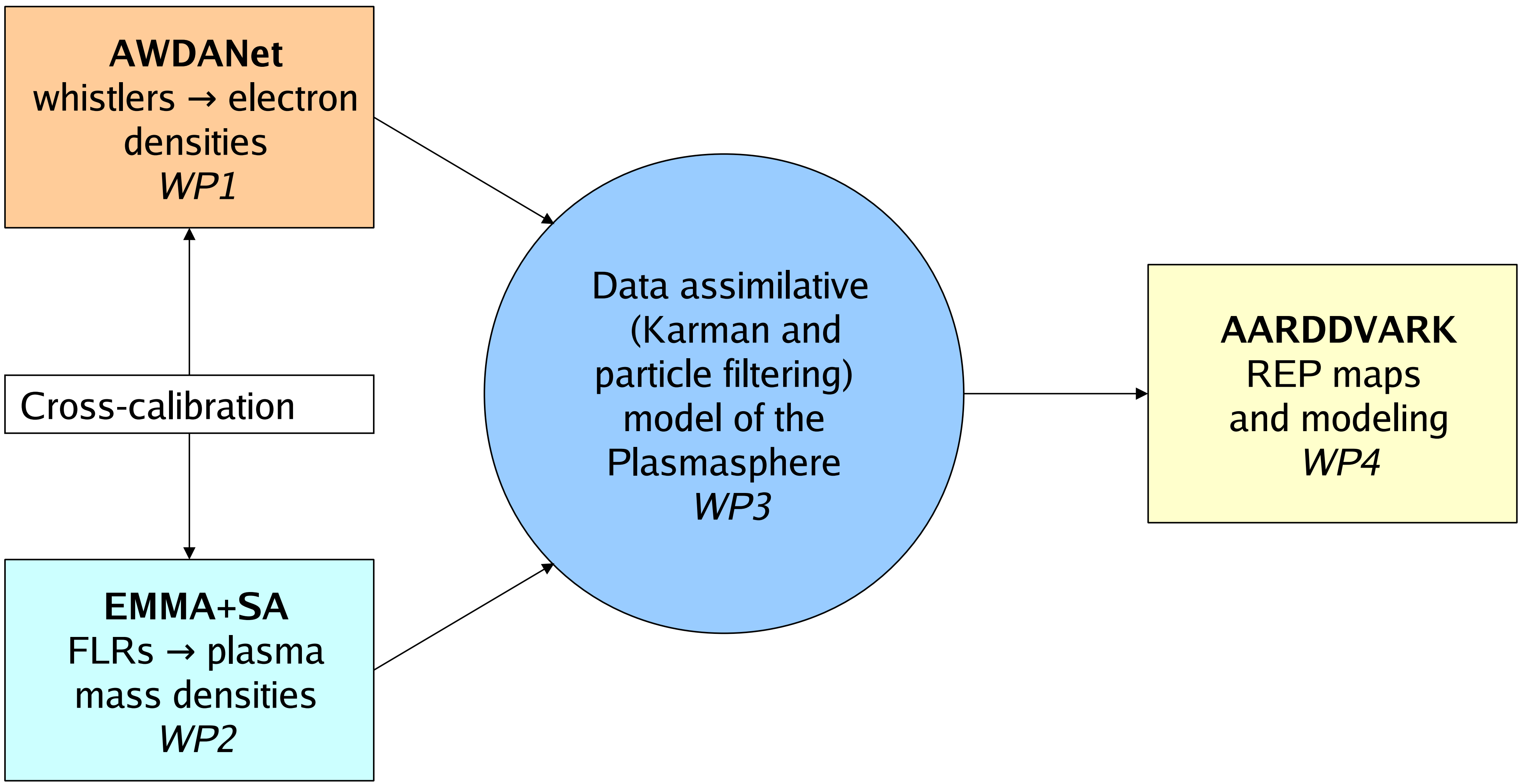
***WP1*: Automatic retrieval of equatorial electron densities and density profiles by Automatic Whistler detector and Analyzer Network (AWDANet)**

***WP2*: Retrieval of equatorial plasma mass densities by European quasi-Meridional Magnetometer Array (EMMA) magnetometer arrays and cross-calibration of whistler and Field Line Resonance method**

***WP3*: Data assimilative modeling of the Earth's plasmasphere**

***WP4*: Modeling REP losses from the radiation belts using the Antarctic-Arctic Radiation- belt (Dynamic) Deposition – VLF Atmospheric Research Konsortia (AARDDVARK) network**

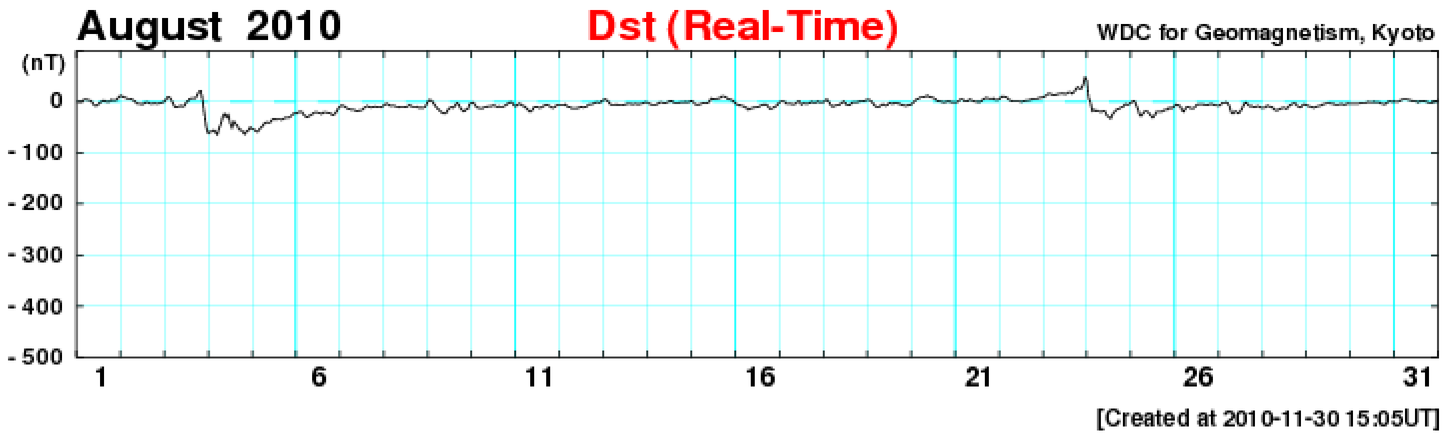
PLASMON structure



Case study: double SSC on 3-4 Aug 2010

82 events processed between 1-8 August 2010.

Whistlers recorded in Dunedin (New Zealand)



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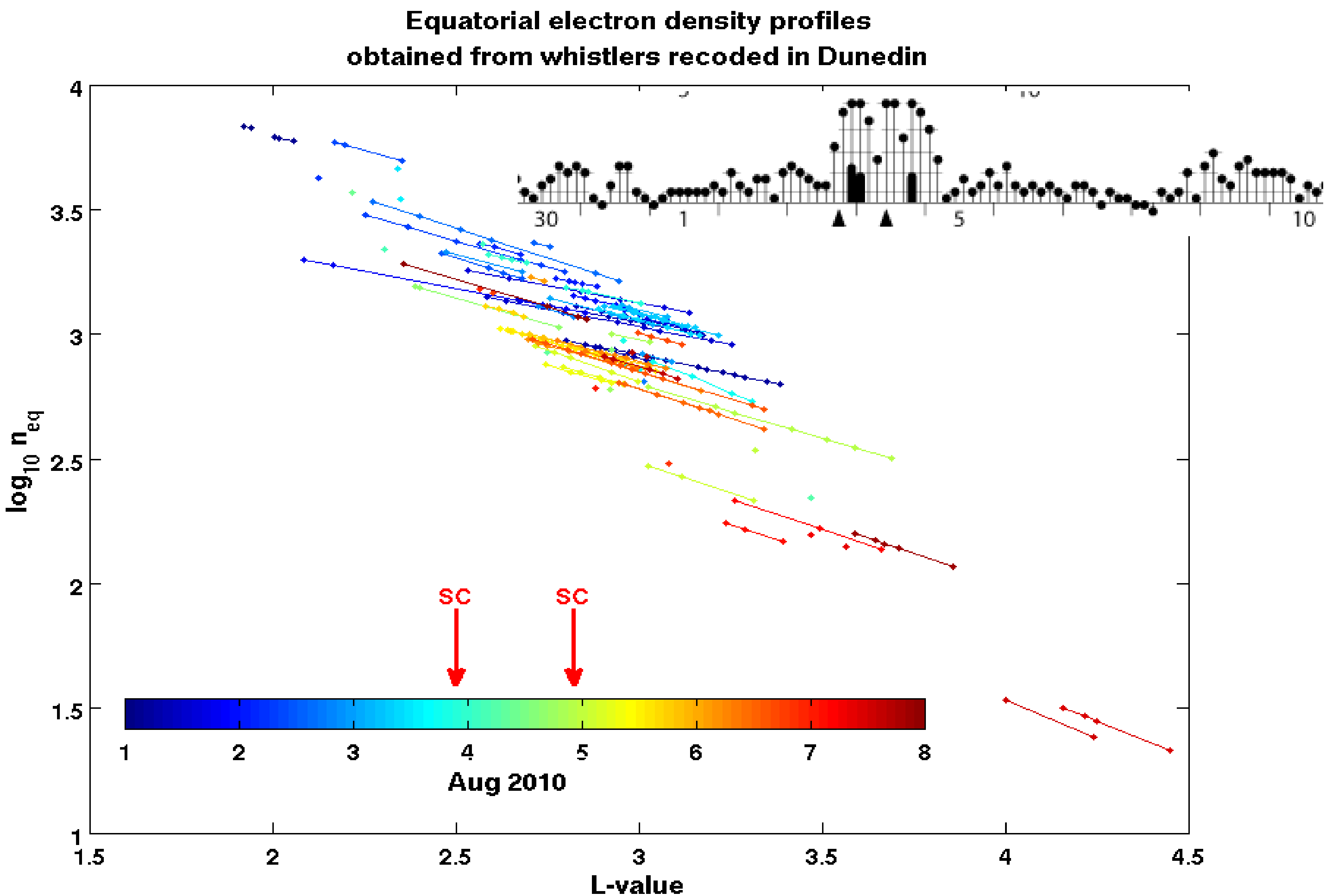

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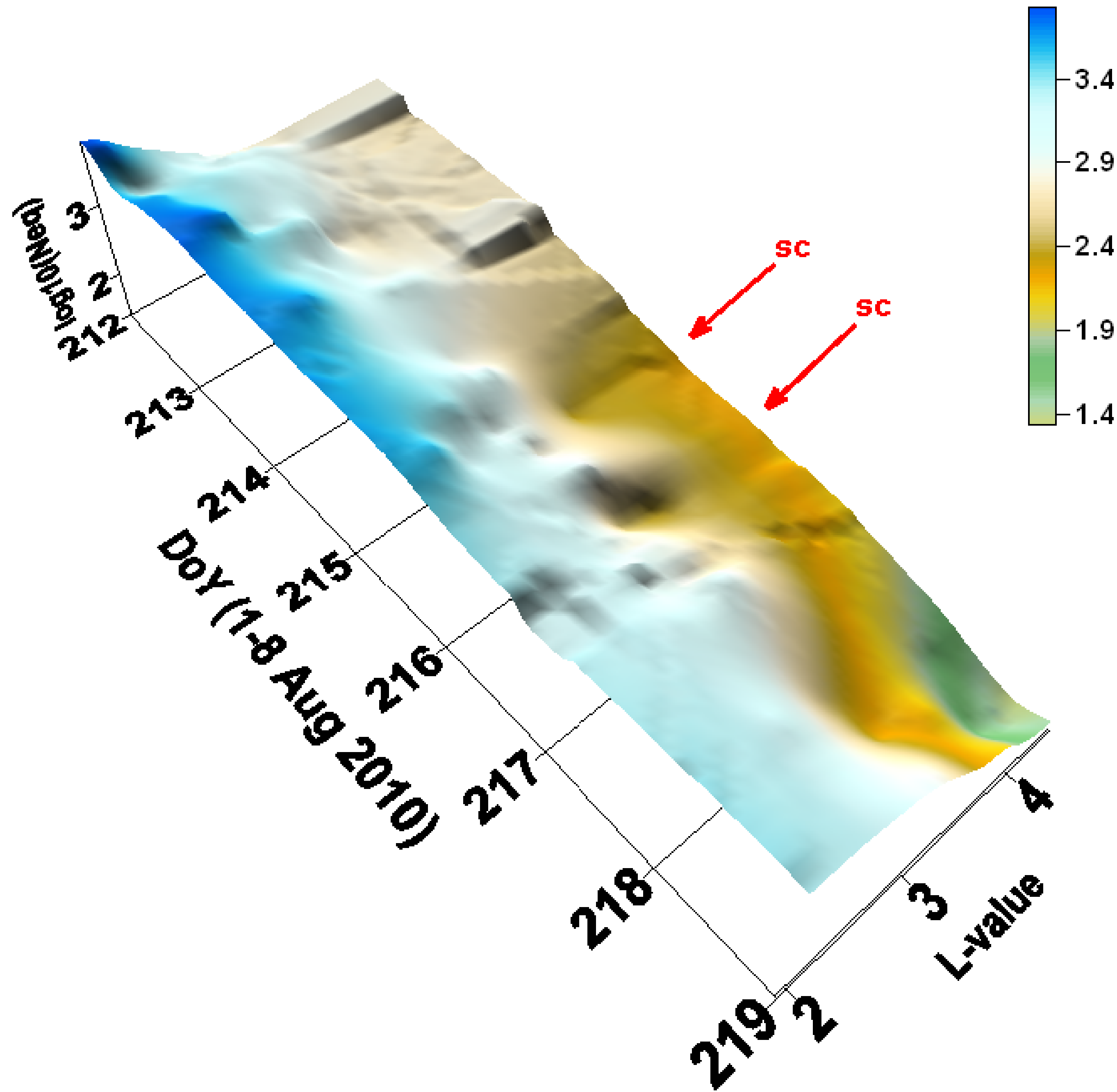
double SSC on 3-4 Aug 2010



I. European-African *meridian*

[Lichtenberger et al., *JGR*, 2008, Collier et al., *JGR,* 2009]

1. Whistler data from *AWDANet* station at Tihany, Hungary

2. Global lightning data form *WWLLN [*Dowden et al., *IEEE Antennas & Prop.,* 2008]: efficacy 5-20%

- statistical approach, correlation of whistler events with lightnings in a window [$T_{whistler}$-1 min, $T_{whistler}$]

3. Six years (Feb 2002-Feb 2008), ~600,000 whistler events => 3°x3° correlation map

I. European-African *meridian*

[Lichtenberger et al., *JGR*, 2008, Collier et al., *JGR*, 2009]

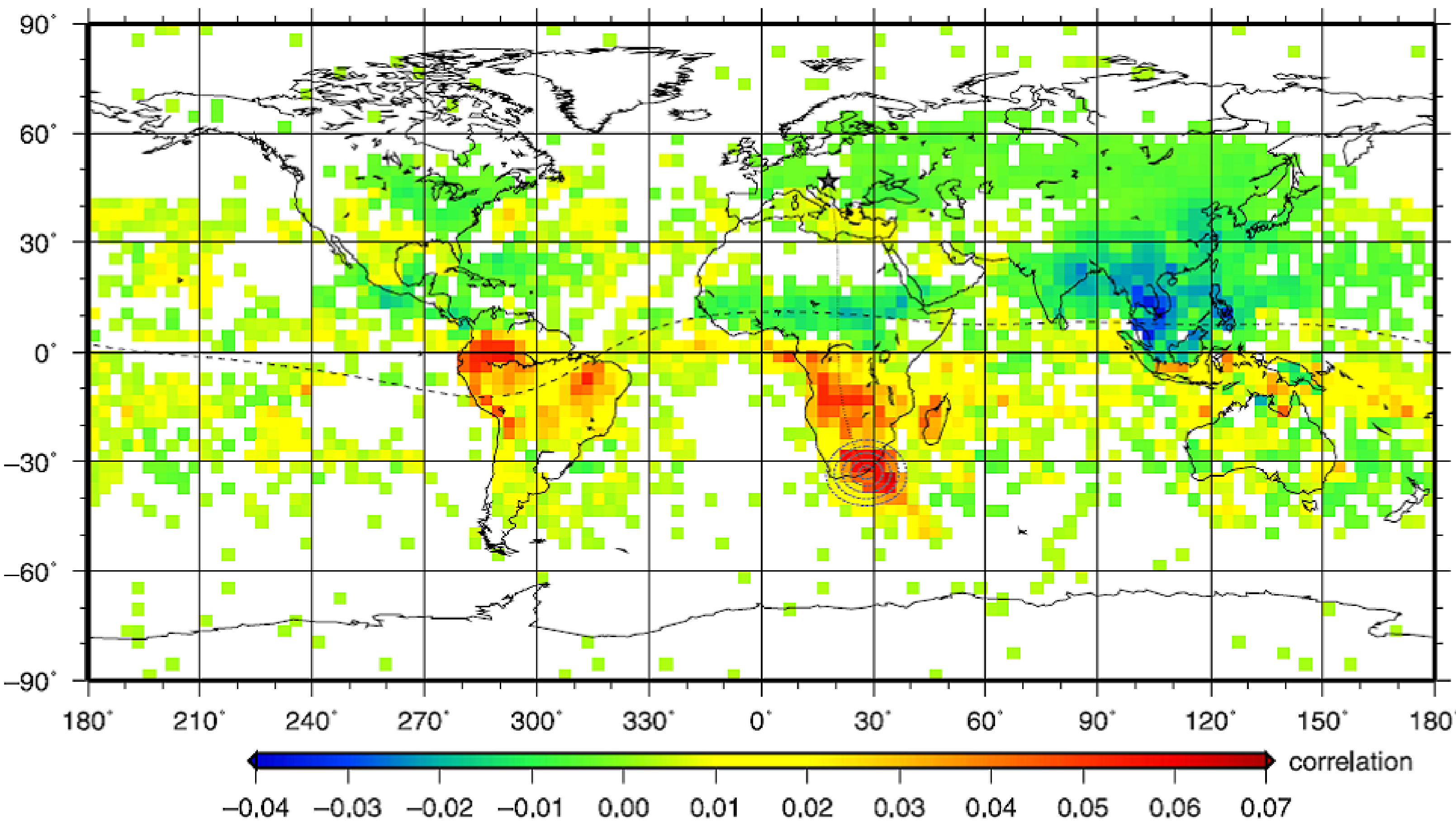
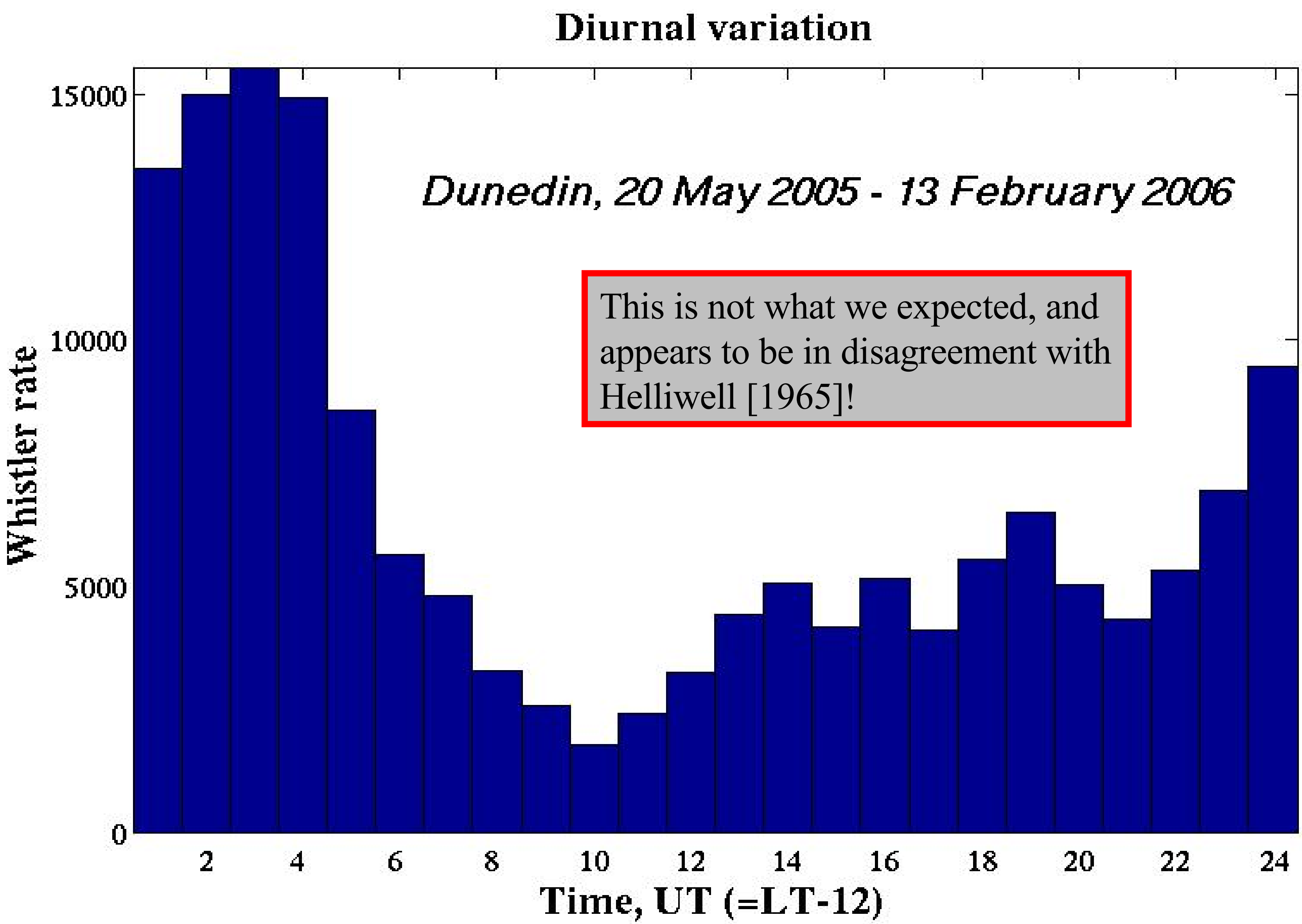


Figure 6. Correlation between whistler observations at Tihany, Hungary, and global lightning strokes for $\Delta t = 1$ min. Data are plotted only in cells for which the correlation is statistically significant. The geomagnetic equator is indicated by the dashed curve. The location of Tihany is reflected by a pentagram. The conjugate point is surrounded by circles at intervals of 200 km up to a distance of 1000 km. The magnetic meridian linking Tihany to the conjugate point is indicated by a dotted curve.

II. Pacific *meridian*

[Rodger et al., *Radio Sci*., 2006; Collier et al., *JGR*, 2010]



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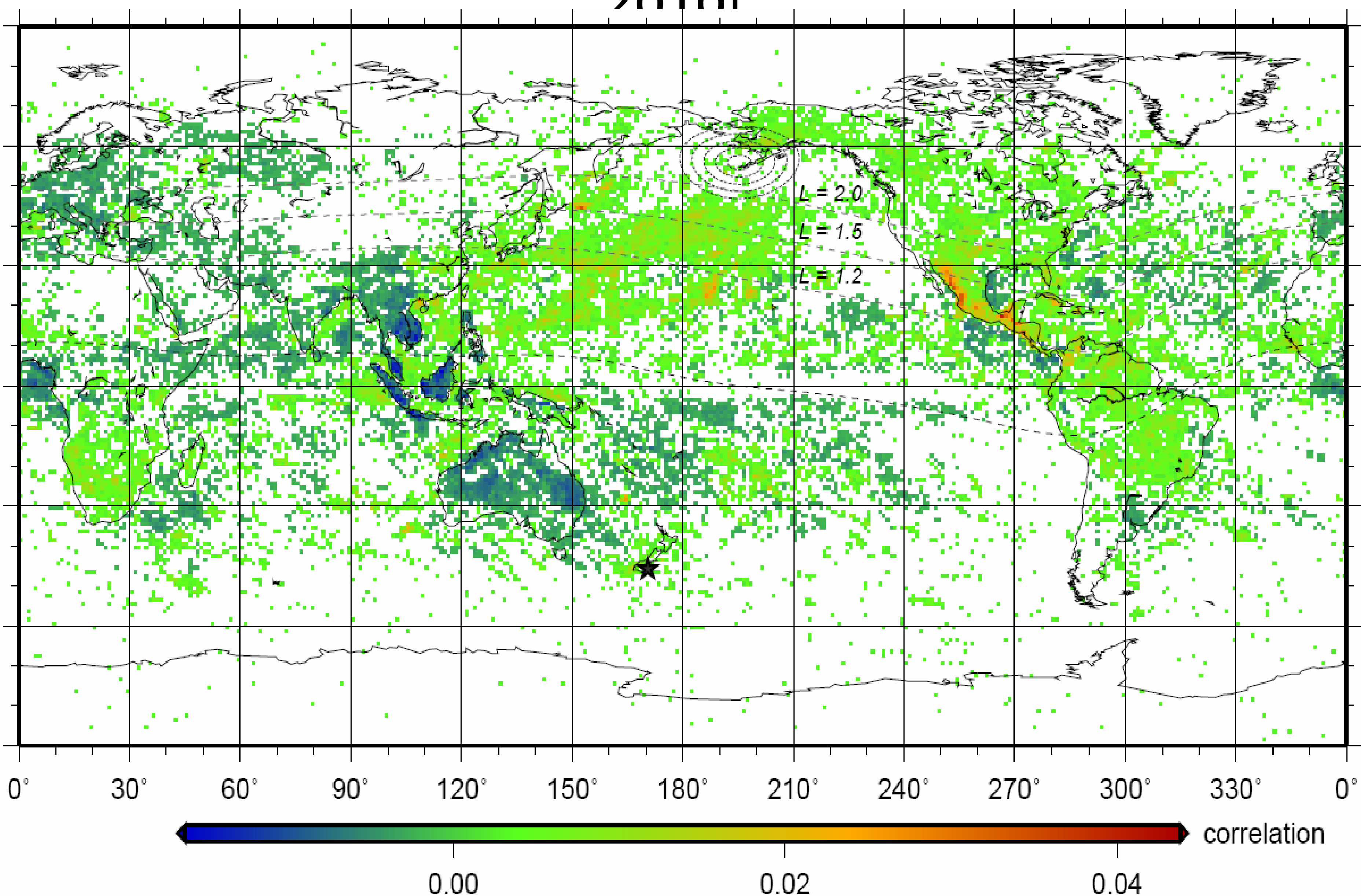
[Rodger et al., *Radio Sci.*, 2006; Collier et al., *JGR*, 2010]

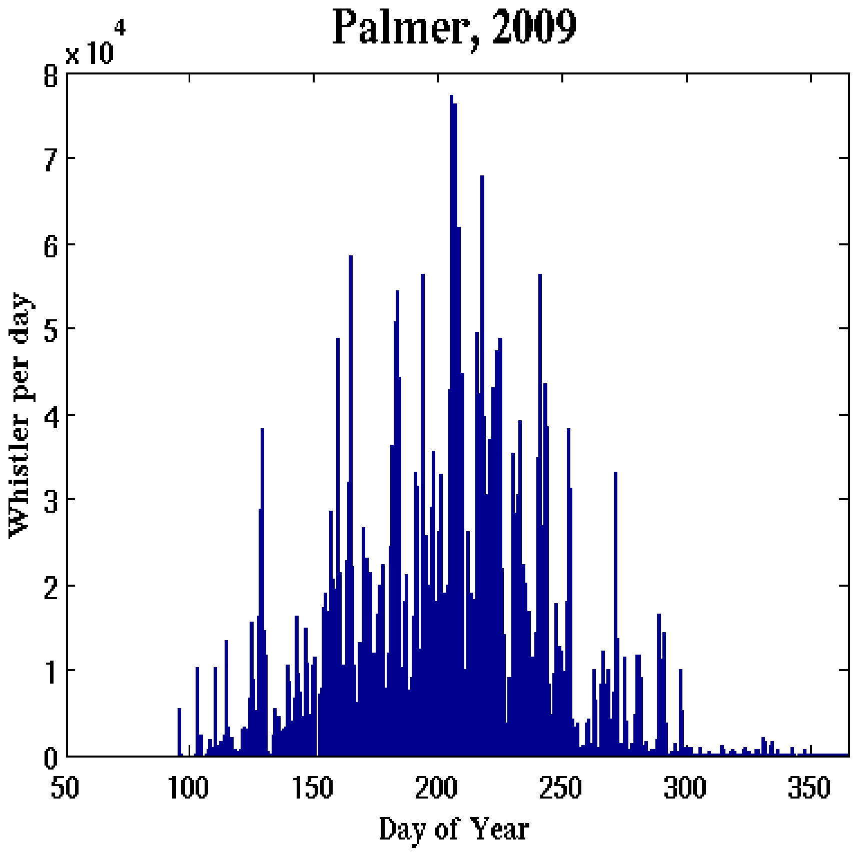


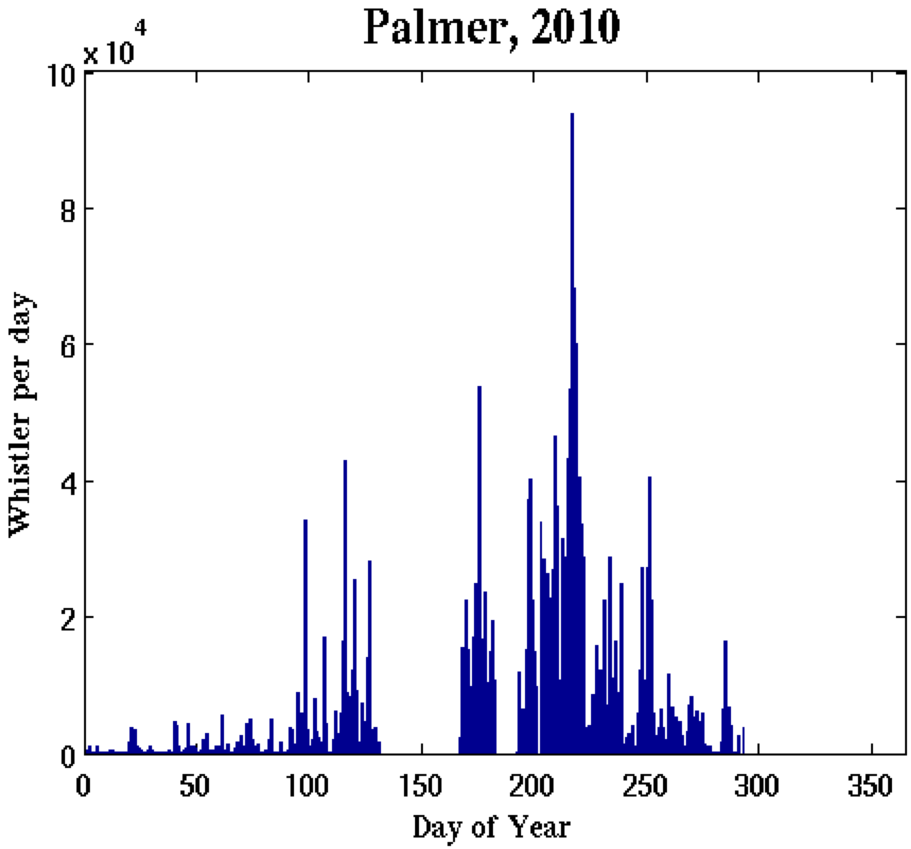
III. American *meridian*

=> A more direct statistical approach:

- correlation of whistler events with lightnings in a window [$T_{whistler}$ - 1500msec, $T_{whistler}$ - 200msec]
- same correlation map on a 1^ox1^o grid

III. American *meridian*





3.8 million events	2.2 million events
11.3 million traces	6.3 million traces

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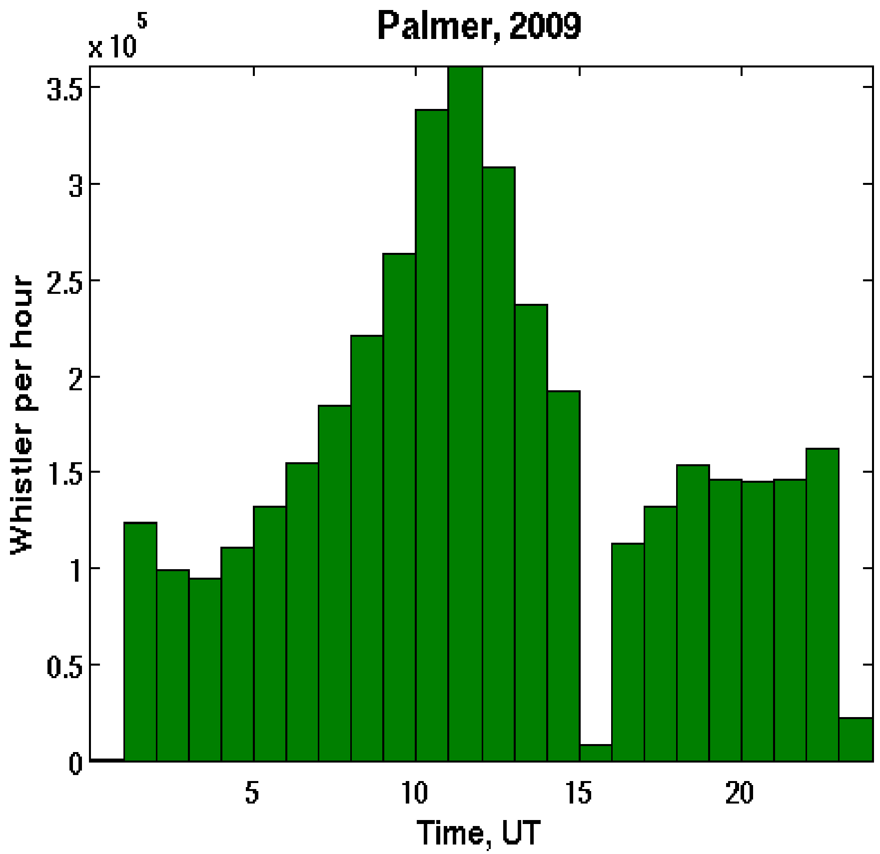

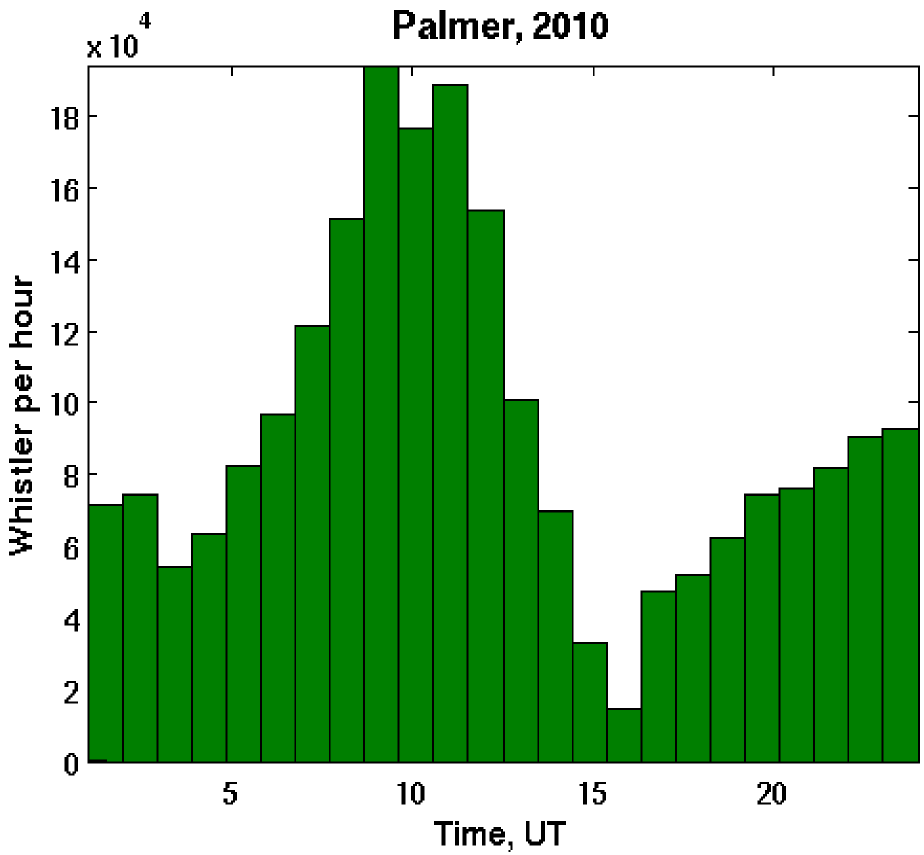

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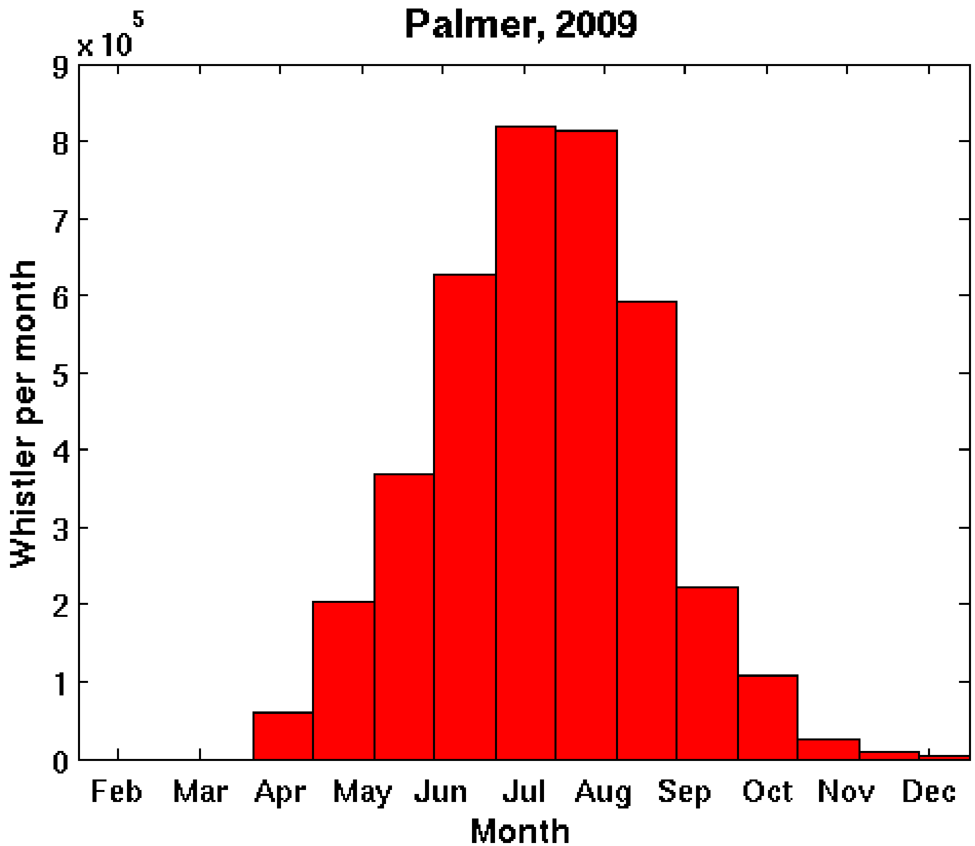

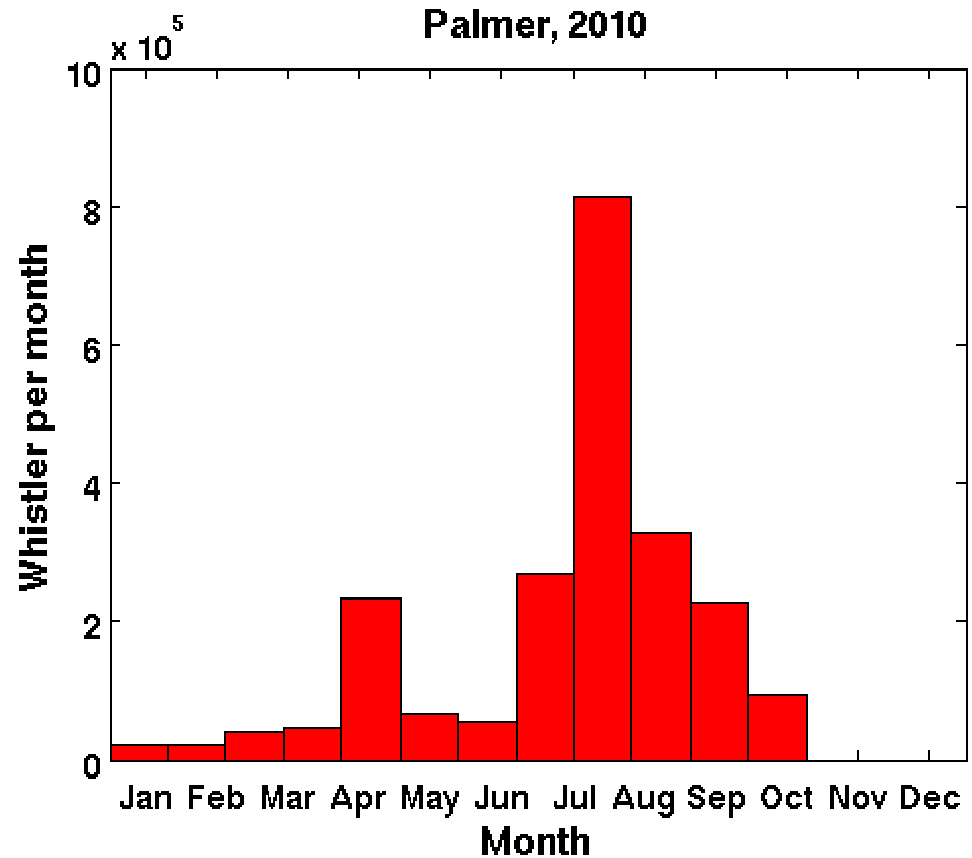

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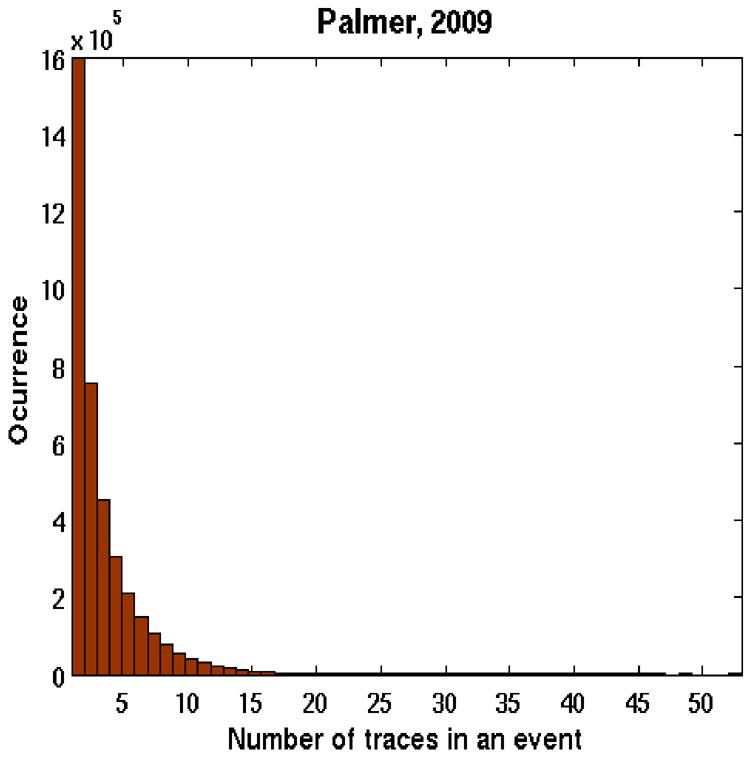

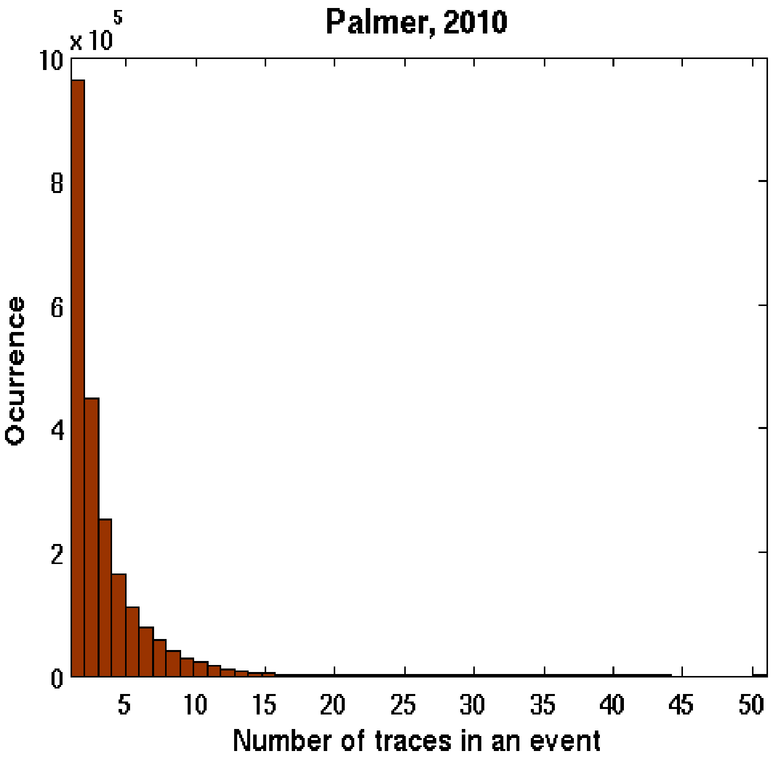

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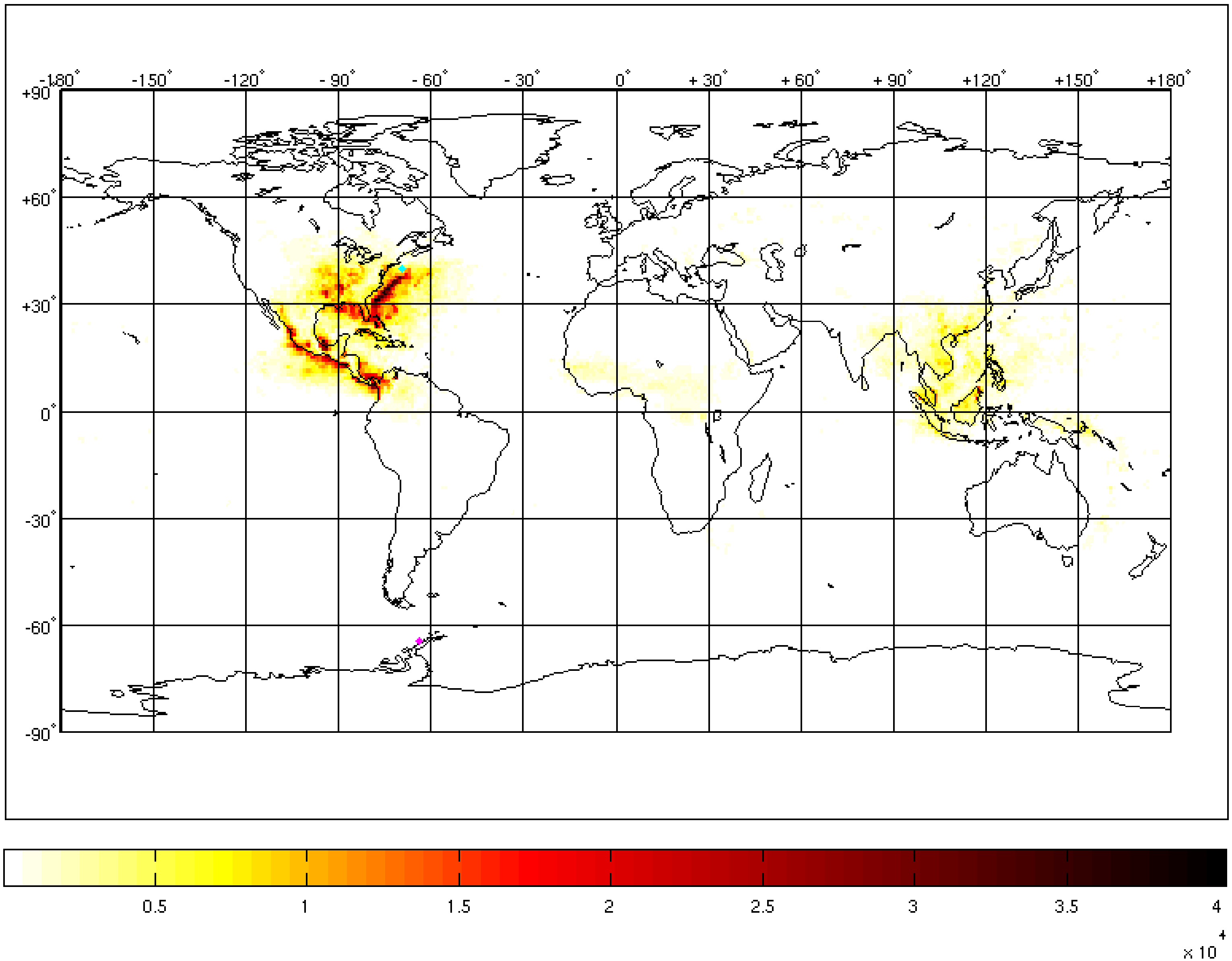
Palmer, 2009



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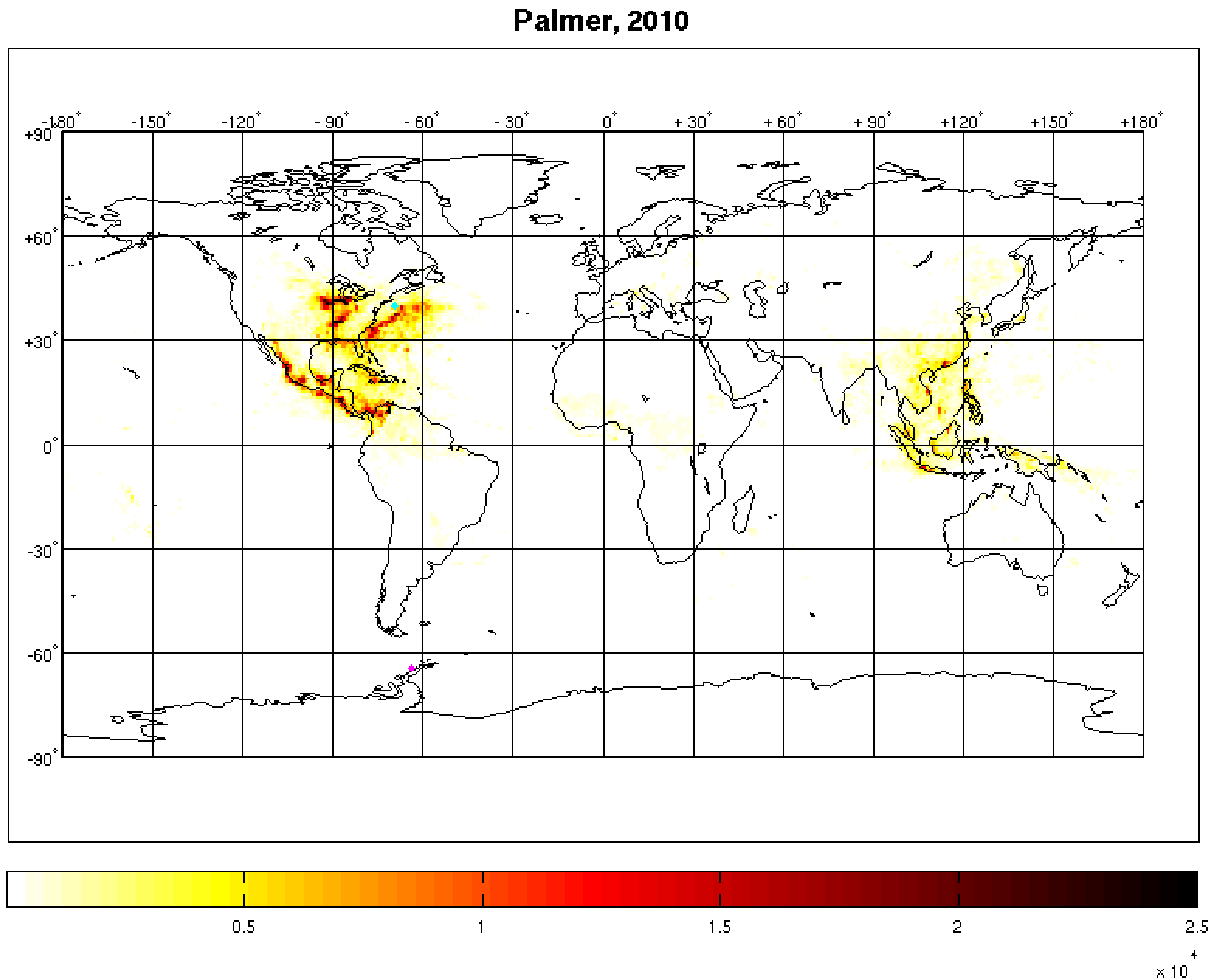

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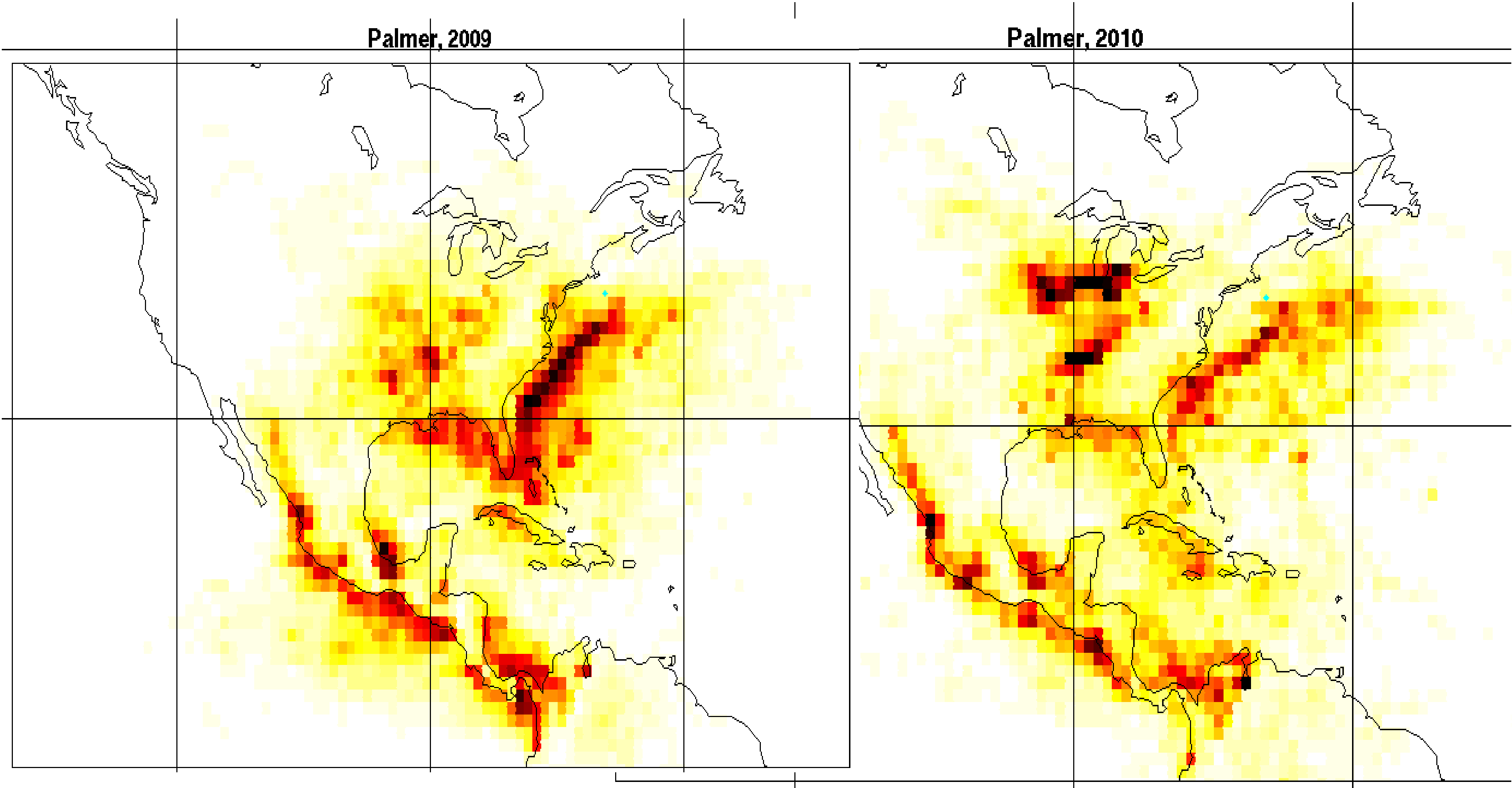

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Conclusions

1. The Automatic Whistler Analyzer algorithm has been implemented
2. An experimental version operates in quasi real-time on a PC cluster with 100 threads/cores.
3. Final solution: GPU cluster
4. Significant differences in whistler sources region over years

The research leading to these results has received funding from the European Union Seventh Framework Programme [FP7/2007-2013] under grant agreement n°263218