Absolute calibration and investigation of ageing of the AERA Radio Detector

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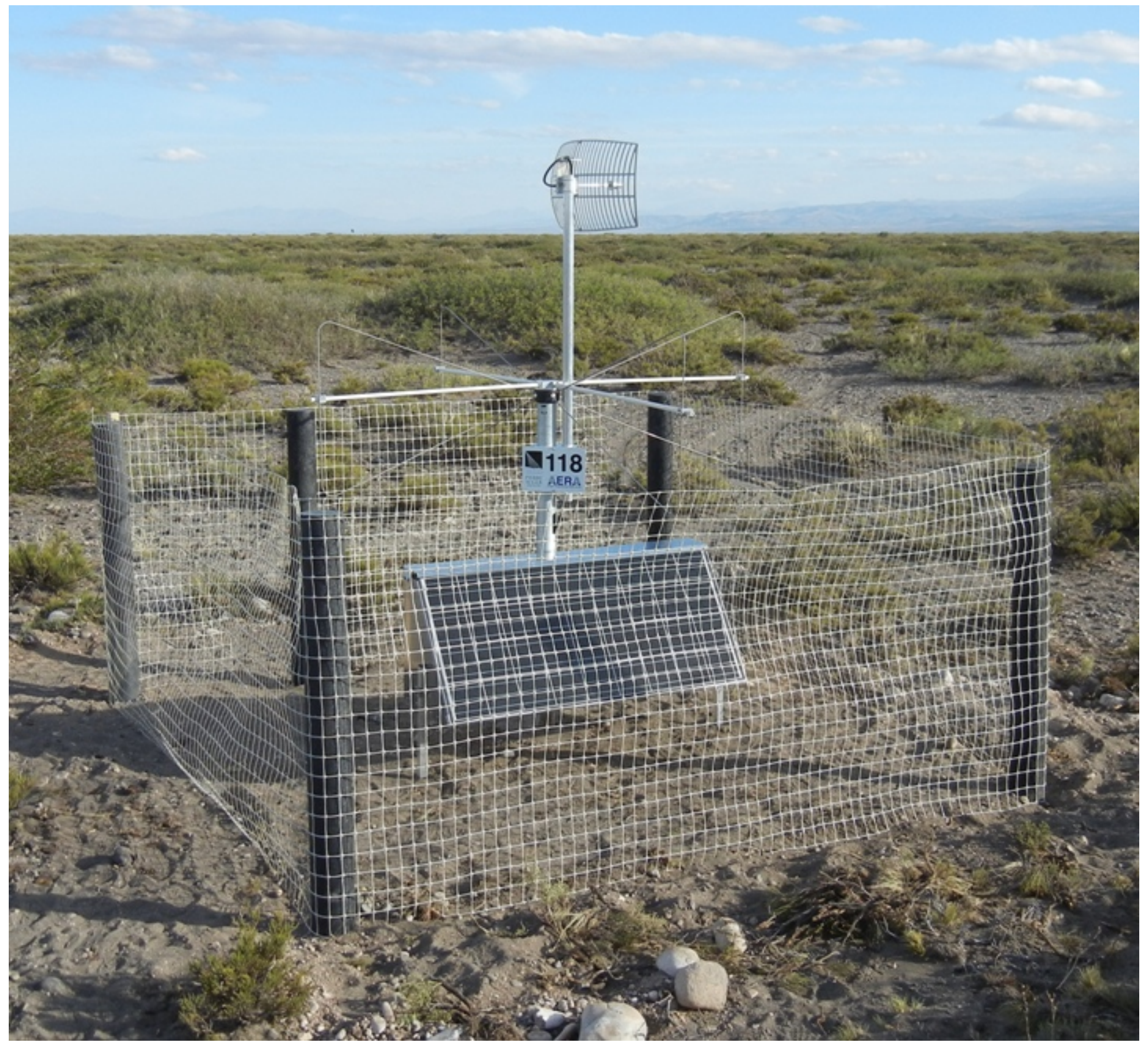
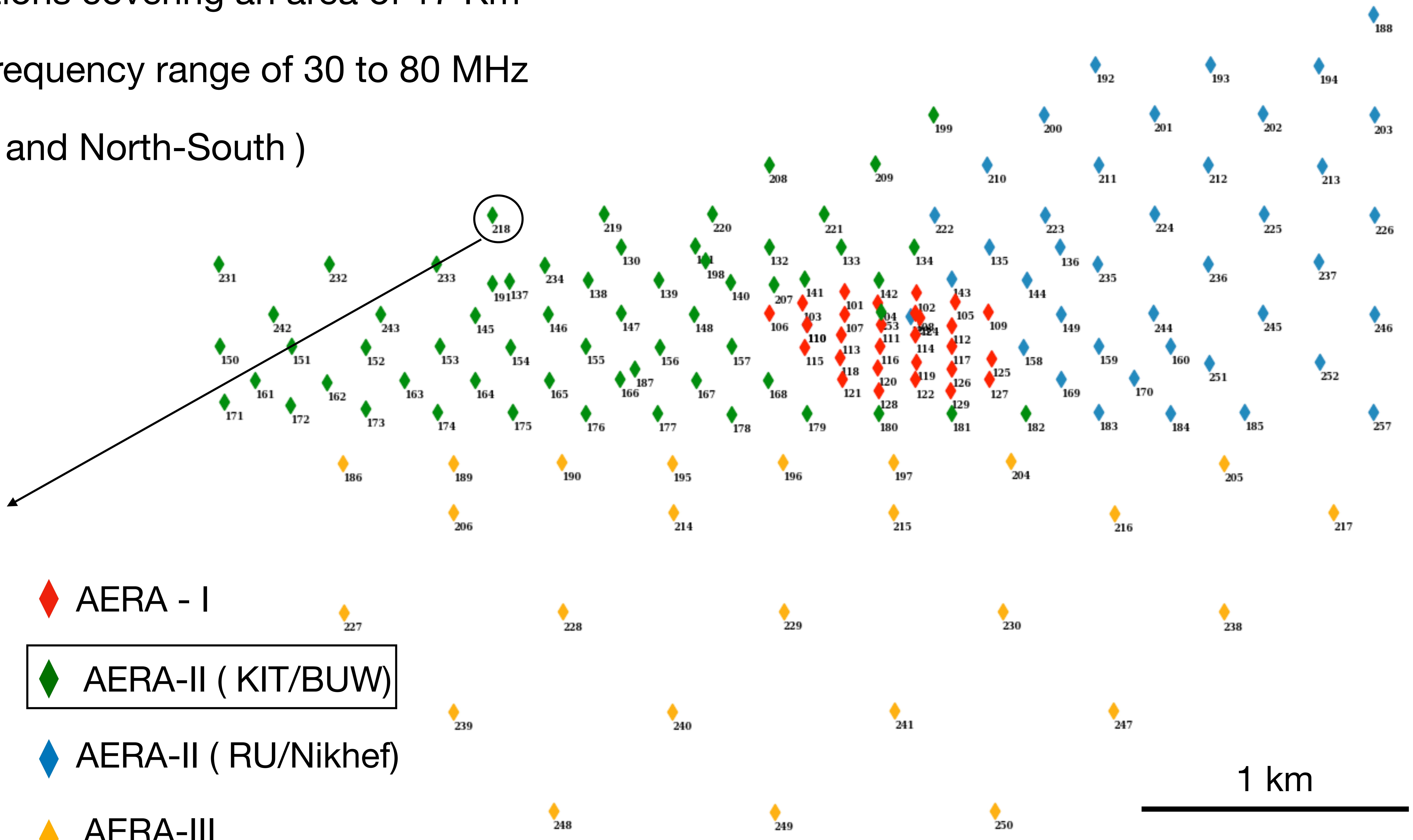
ARENA - June 2022

AERA - Auger Engineering Radio Array

- 153 Autonomous radio stations covering an area of 17 Km^2
- Antennas sensitive in the frequency range of 30 to 80 MHz
- 2 polarizations (East-West and North-South)

Butterfly antennas



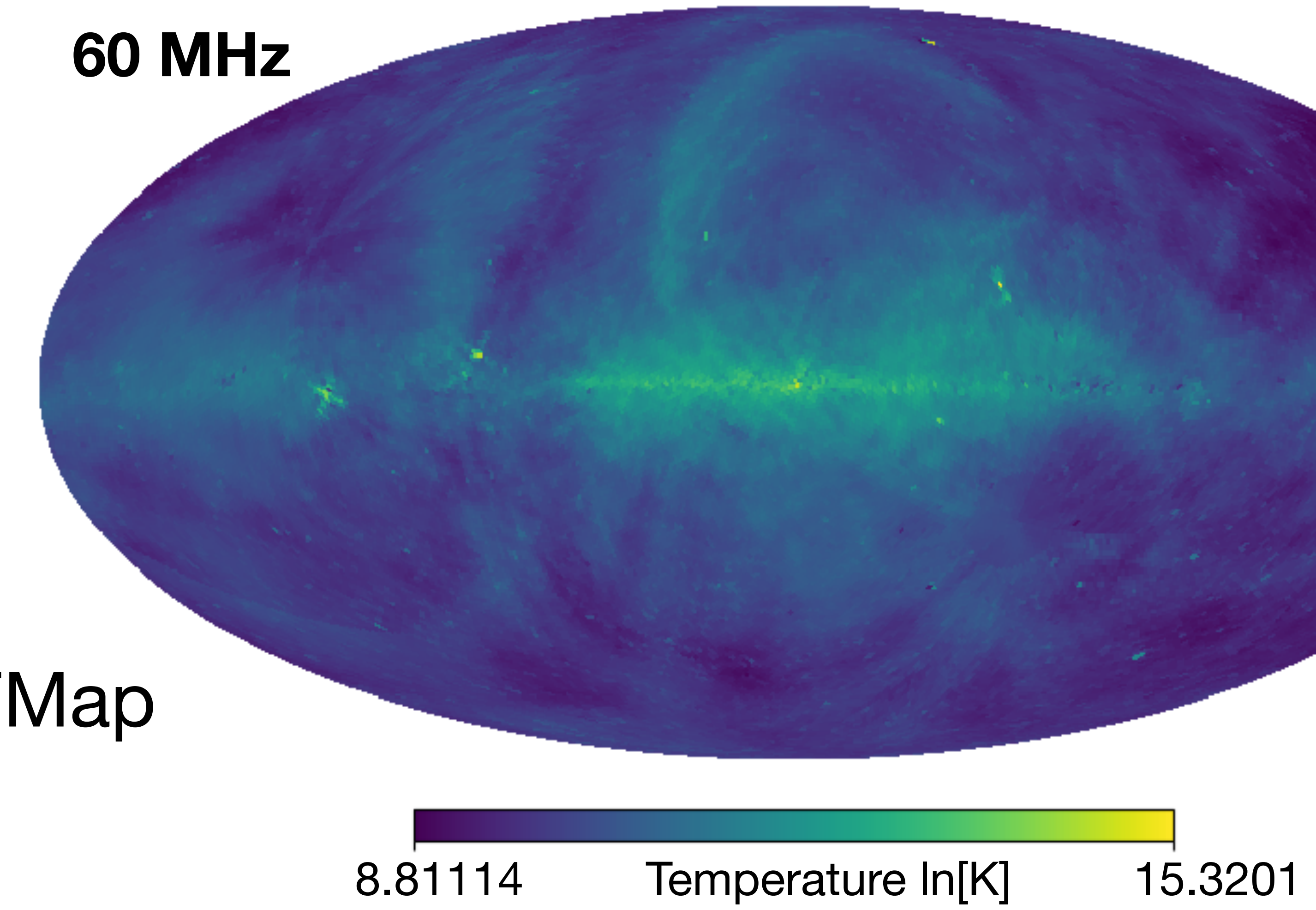


Galactic calibration: Radio sky model

$P_{sky}(t, \nu)$

60 MHz

$T_{sky}(\nu)$



By LFMap

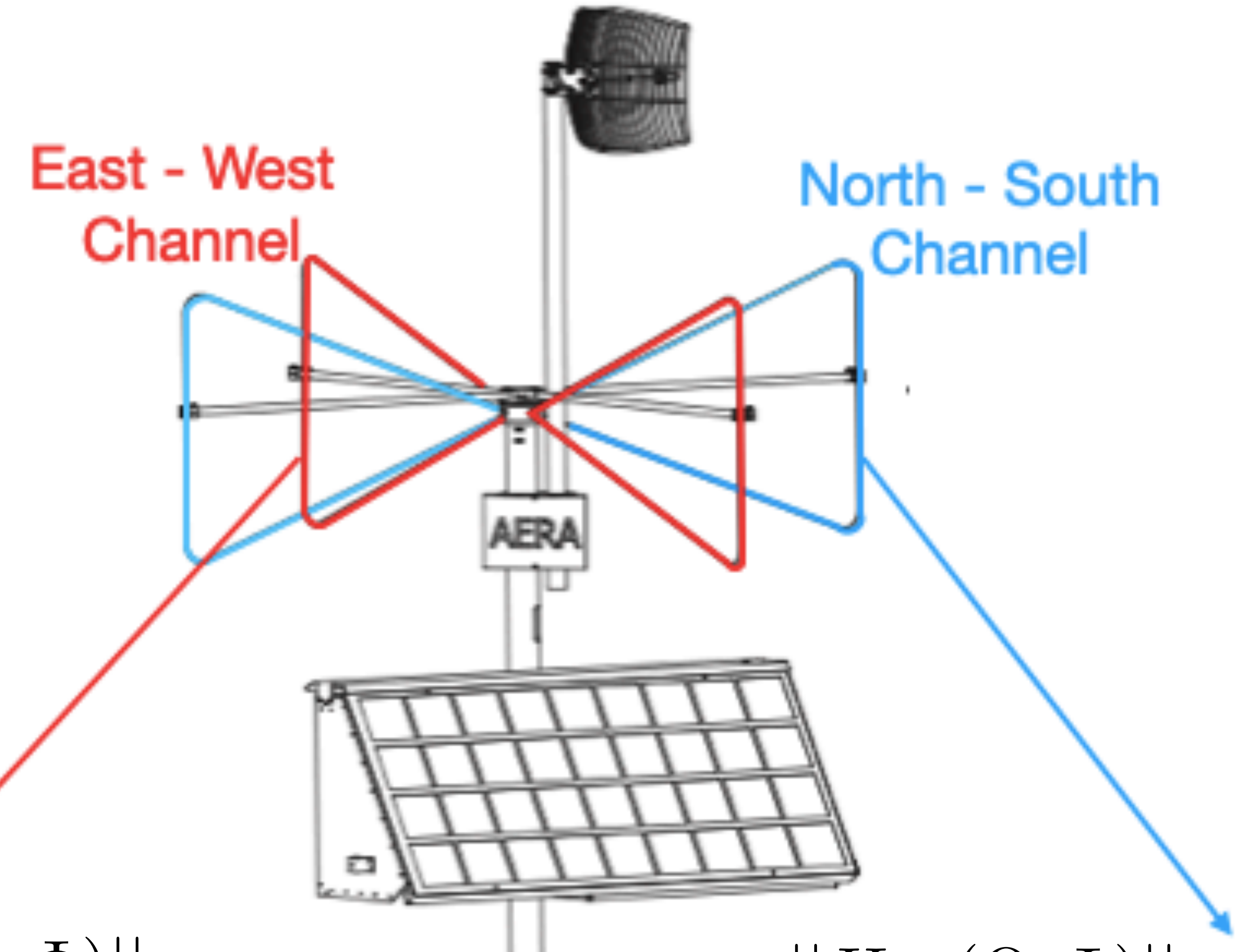
$$B(\nu, \alpha, \delta) = \frac{2K_b\nu^2}{c^2} T_{sky}(\nu, \alpha, \delta)$$

$$I_{\Omega,\nu}(\alpha, \delta) = B_\nu(\alpha, \delta)||H_{i,\nu}(\alpha, \delta)||^2$$

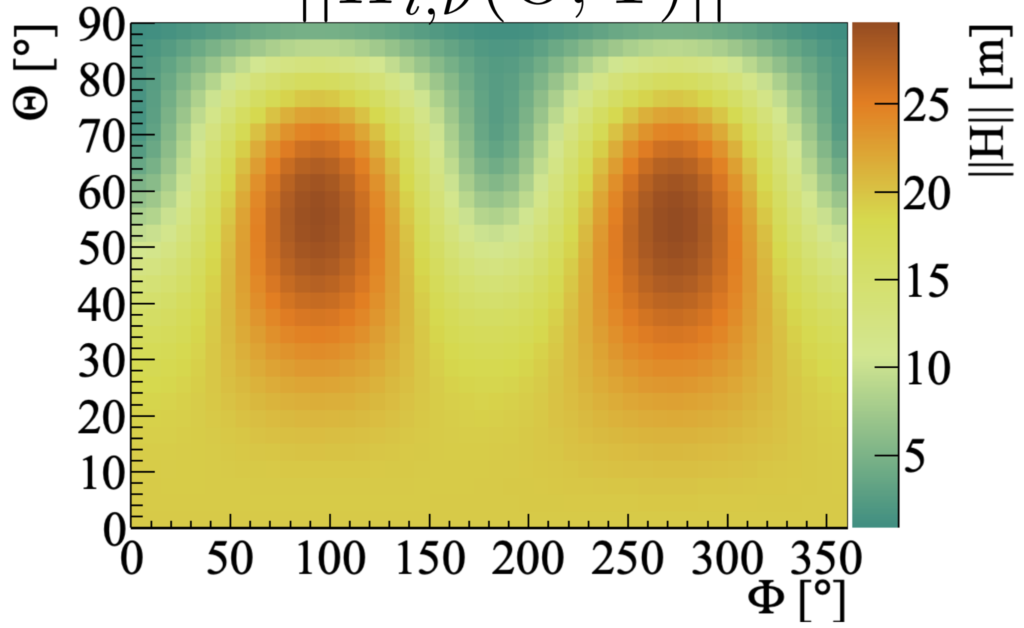
$$P_{sky}(t, \nu) = \frac{1}{2}\frac{Z_0}{Z_L}\int_\Omega I_{\Omega,\nu}(\alpha, \delta)d\Omega$$

$$P_{model}(t, \nu) = P_{sky}(t, \nu)G_{ant}(\nu)G_{RCU}(\nu)\, S(\nu) + N_{tot}(\nu)$$

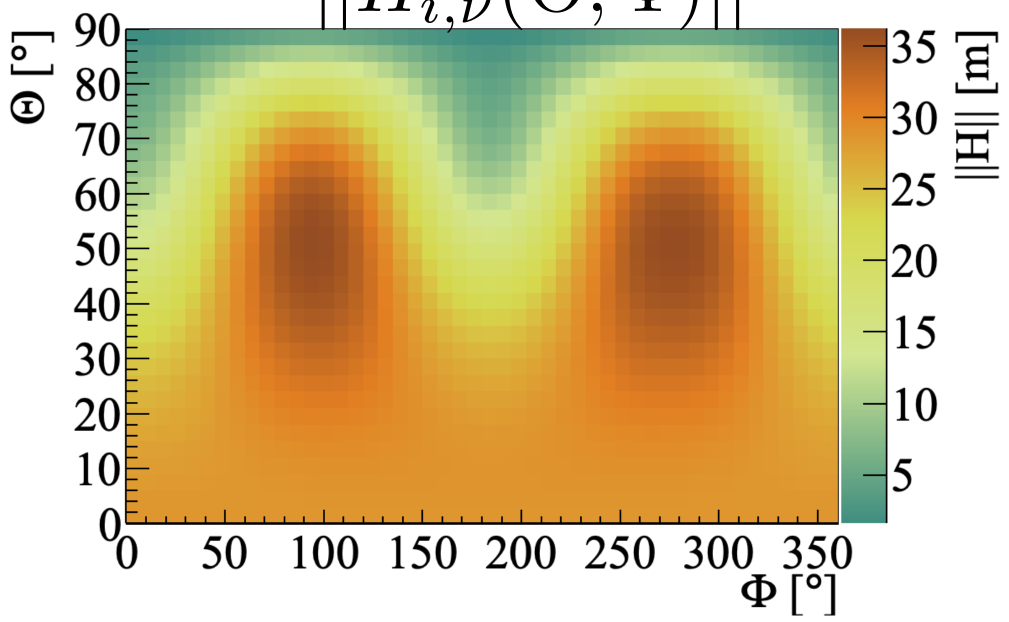
Antenna directional response



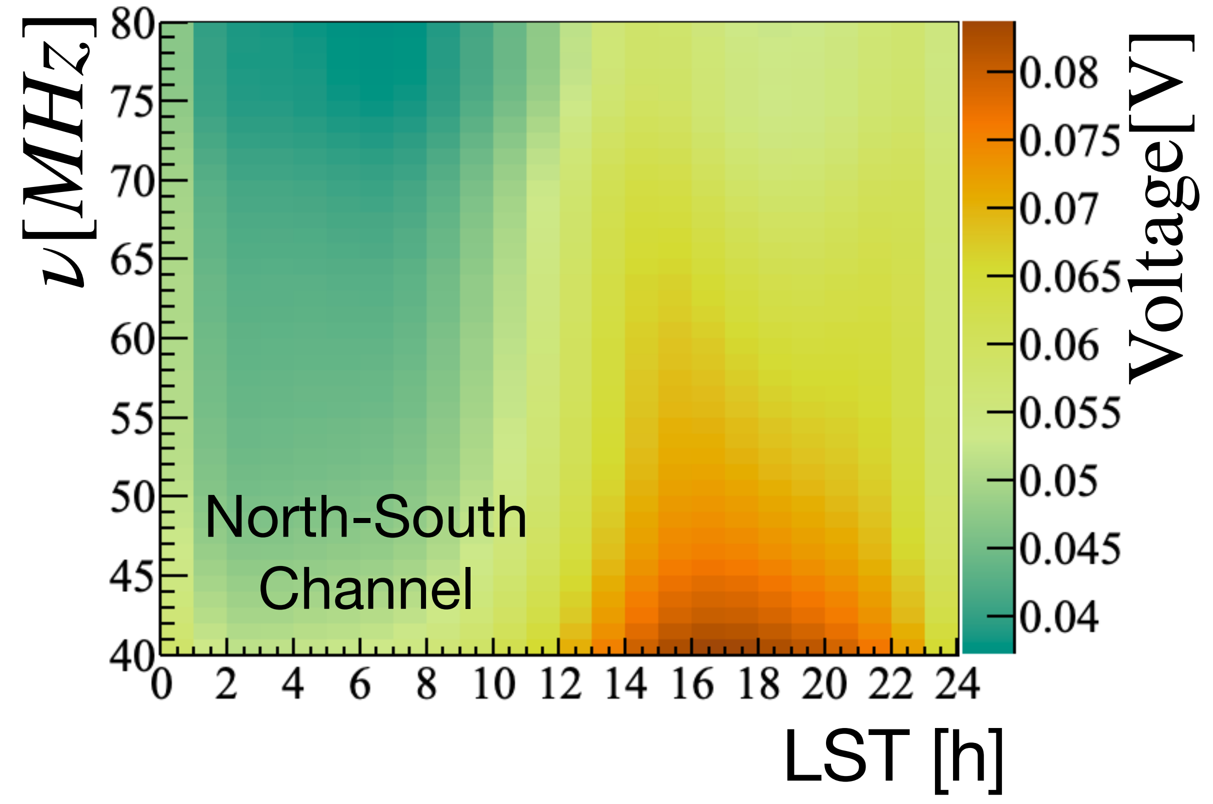
$||H_{i,\nu}(\Theta, \Phi)||$



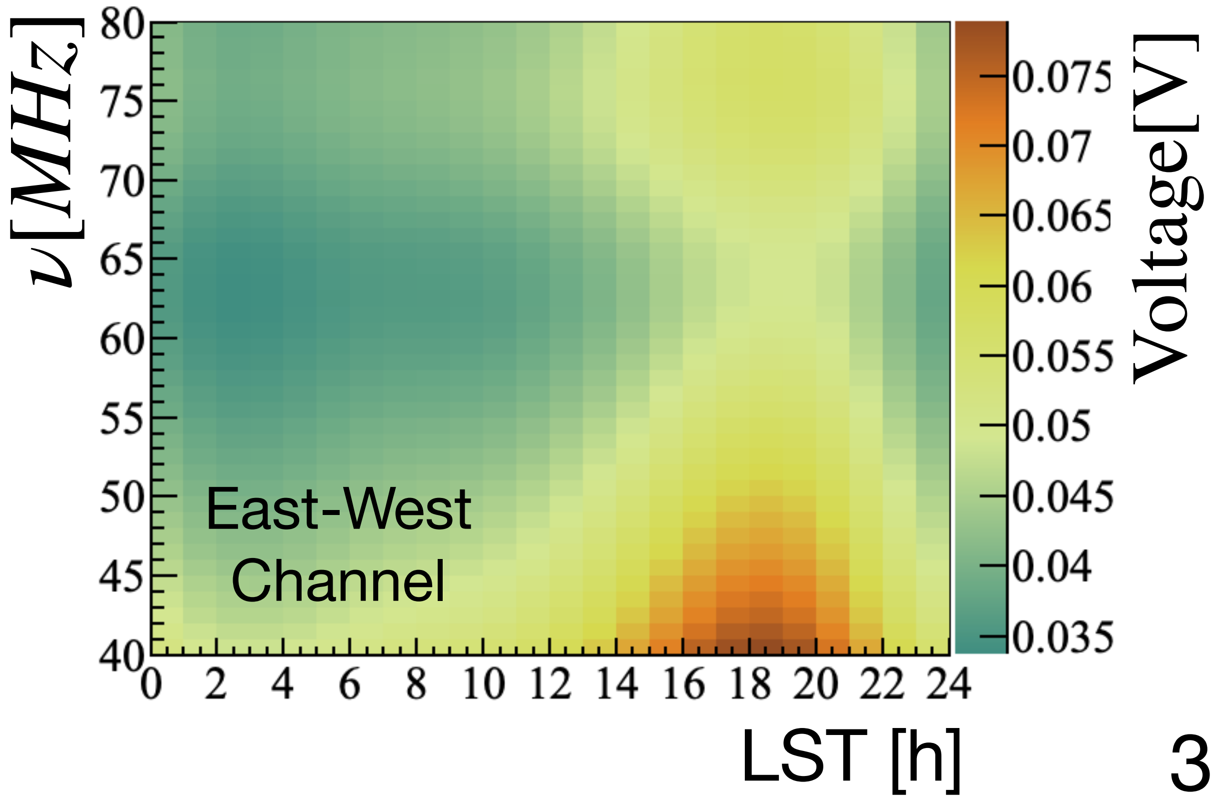
$||H_{i,\nu}(\Theta, \Phi)||$



$U_{sky}(t, \nu)$

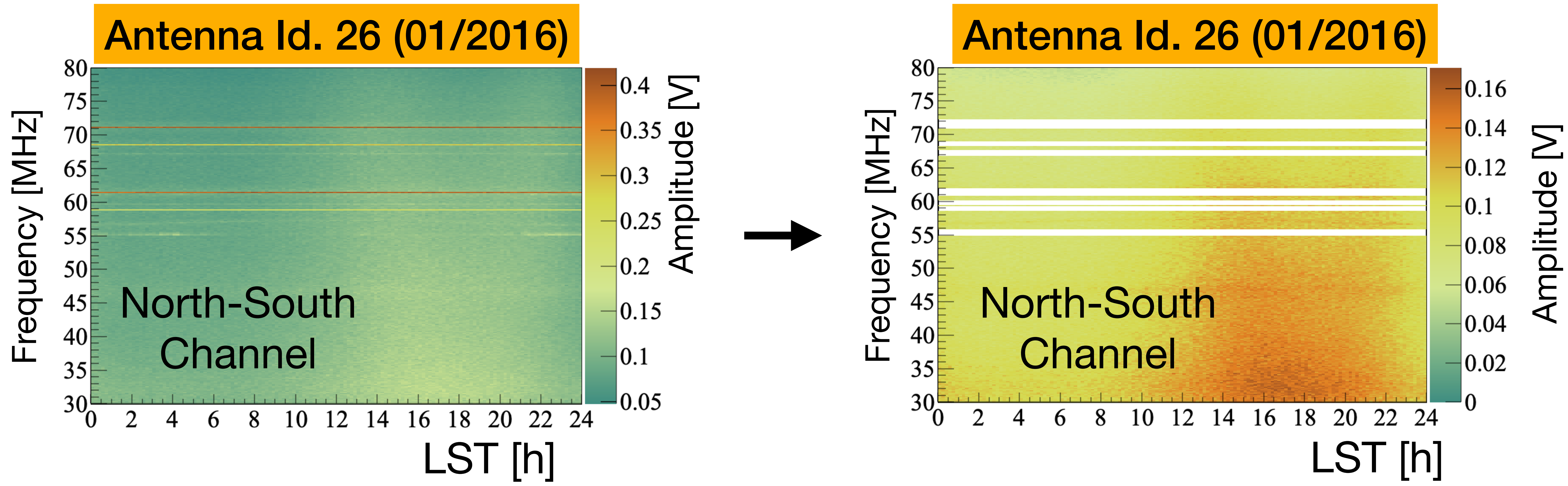


$U_{sky}(t, \nu)$



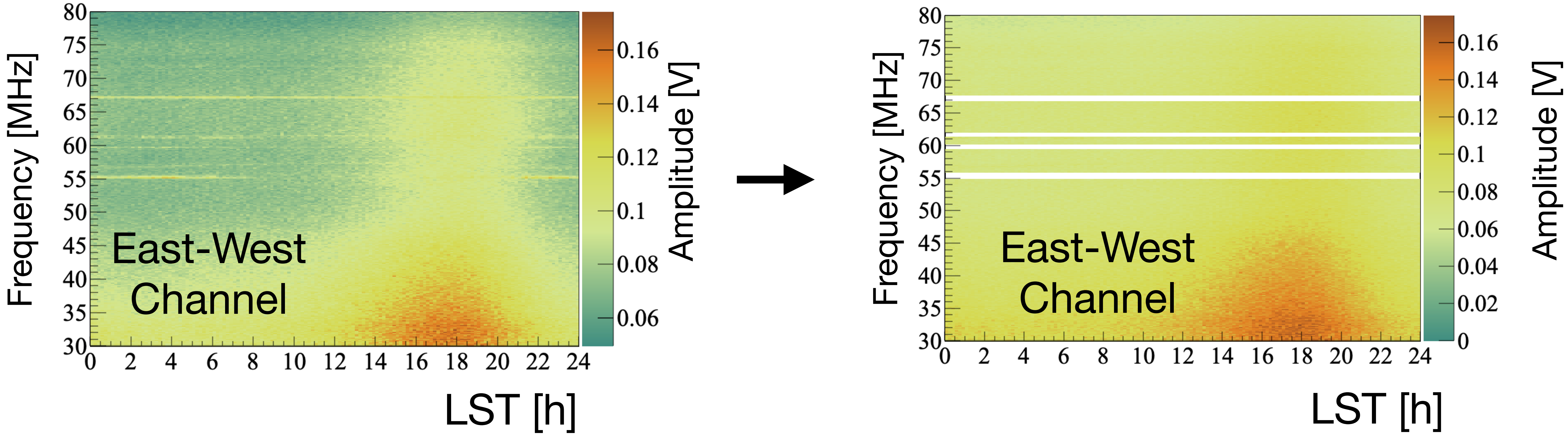
Narrowband RFI and Broadband RFI

- We use 52 butterfly antennas (externally triggered setup)



Narrowband RFI removal

- We identify and remove narrowband RFI



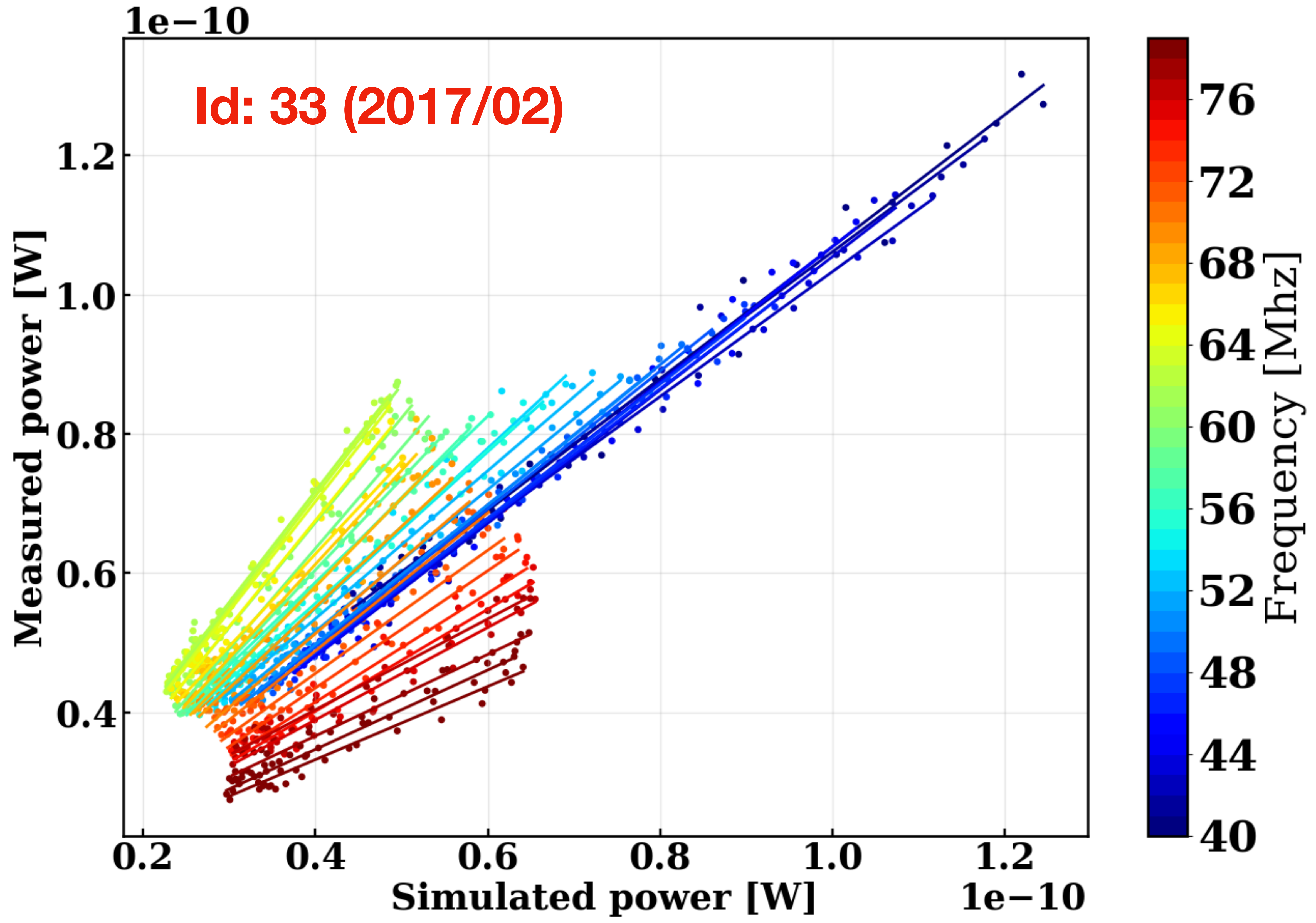
Broadband RFI removal

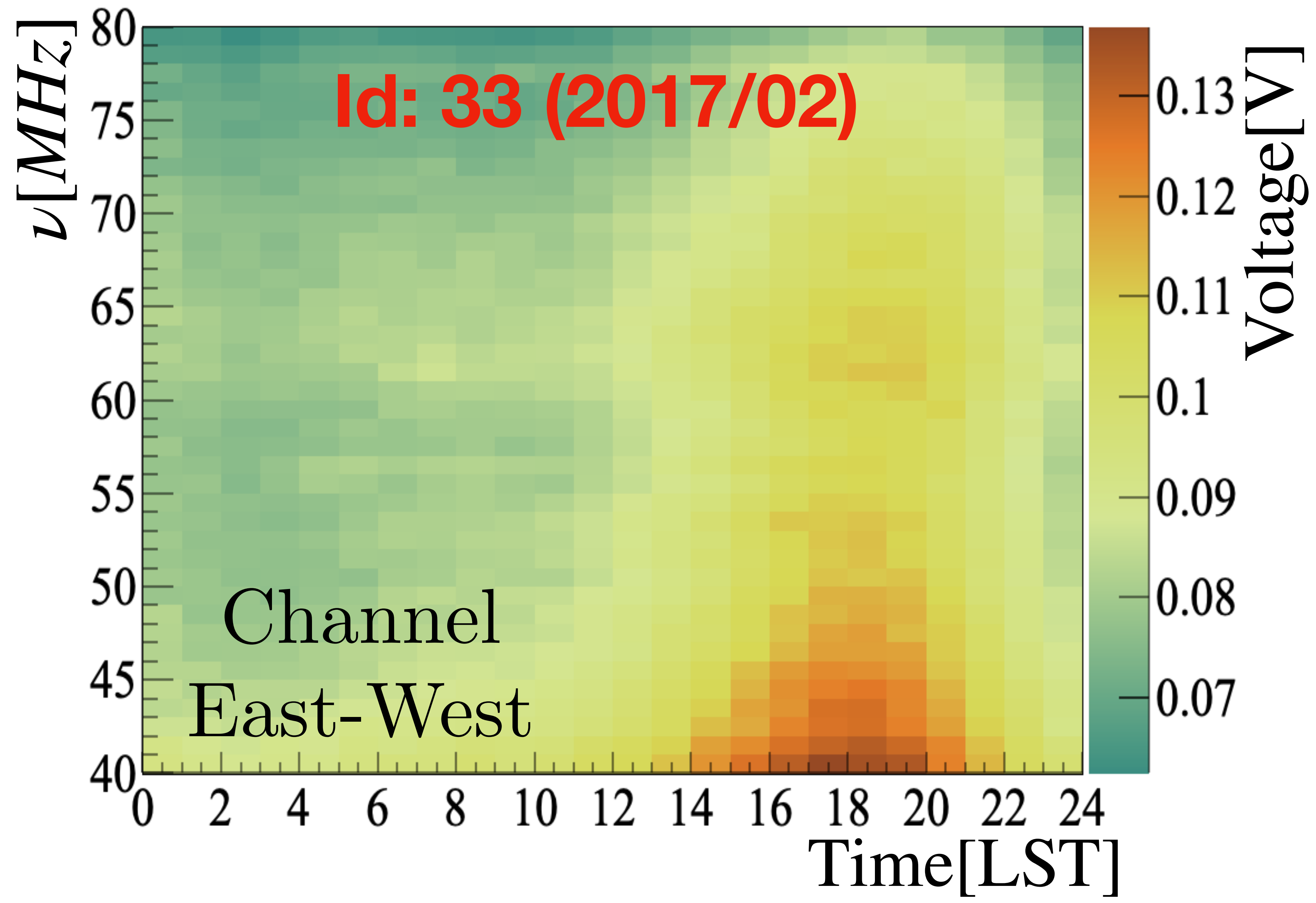
- We use a LST-dependent threshold approach
- Threshold as a function of the LST is determined for each antenna, month and channel

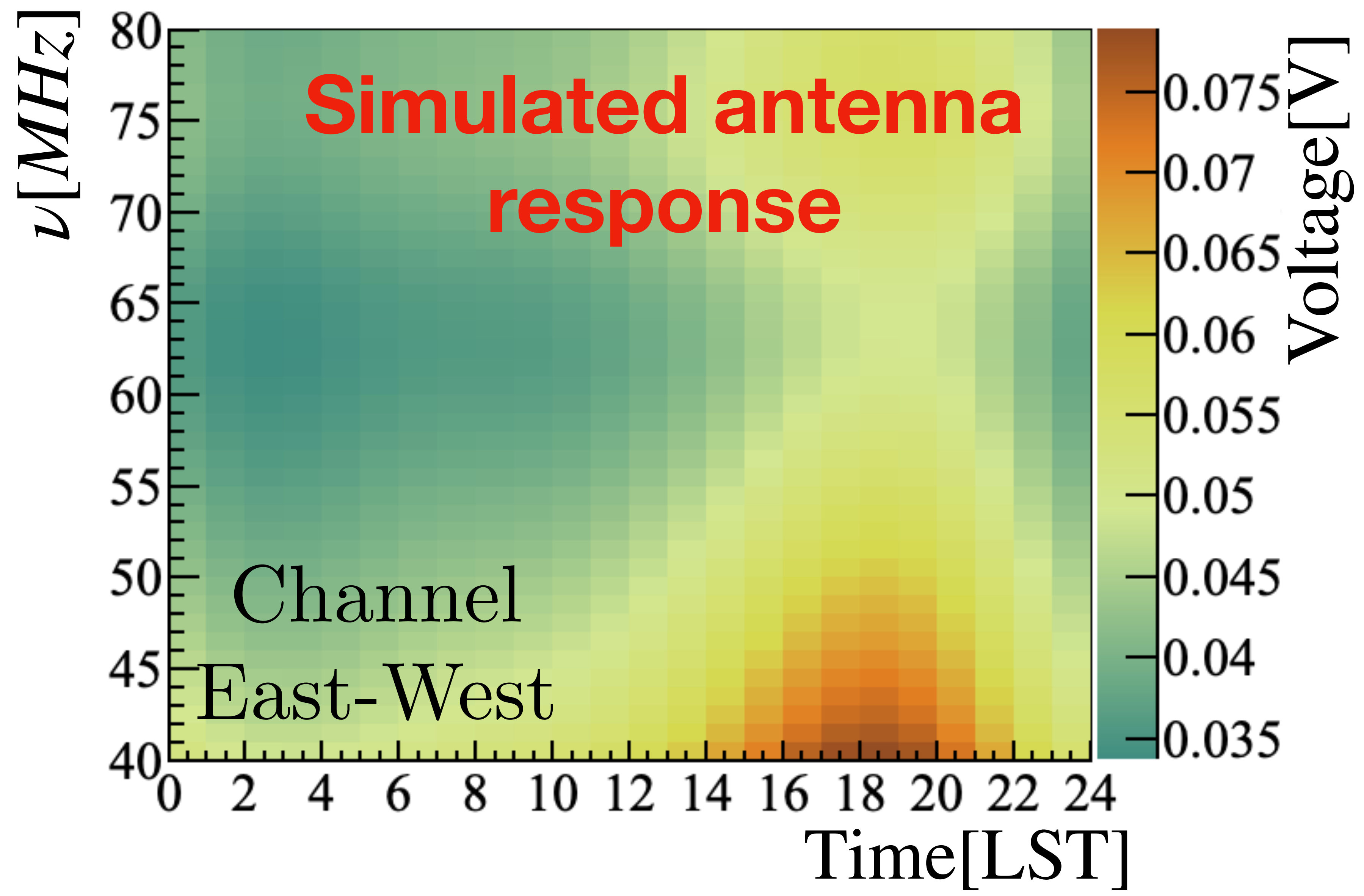
Study of C_0 as a function of the time

$$P_{model}(t,\nu) = P_{sky}(t,\nu) G_{ant}(\nu) G_{RCU}(\nu)\, S(\nu) + N_{tot}(\nu)$$

- Independent linear fit for each frequency band







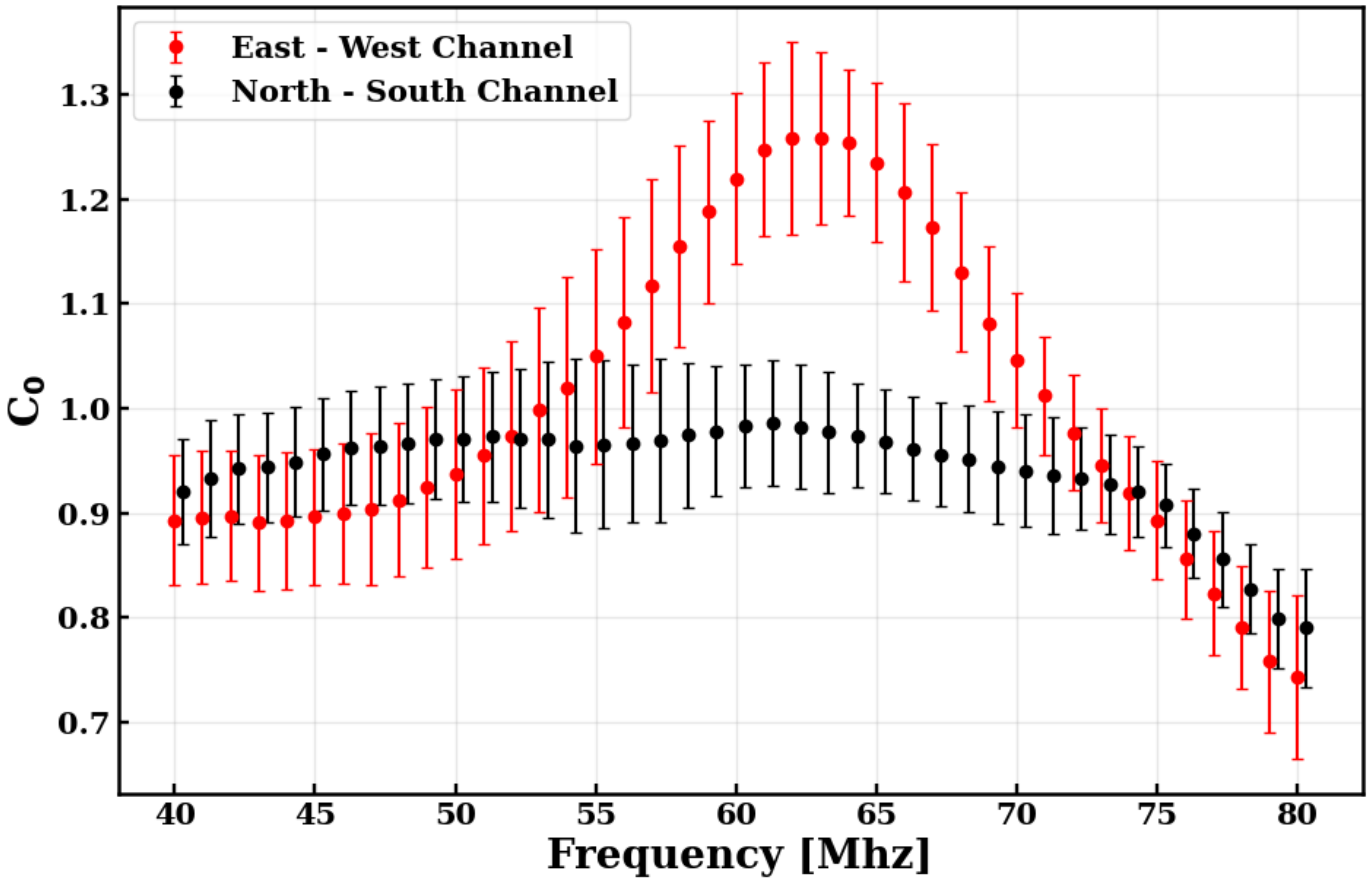
Study of C_0 as a function of the time

→ Perform a fit for each antenna (and channel) in a monthly basis from 2014 to 2020

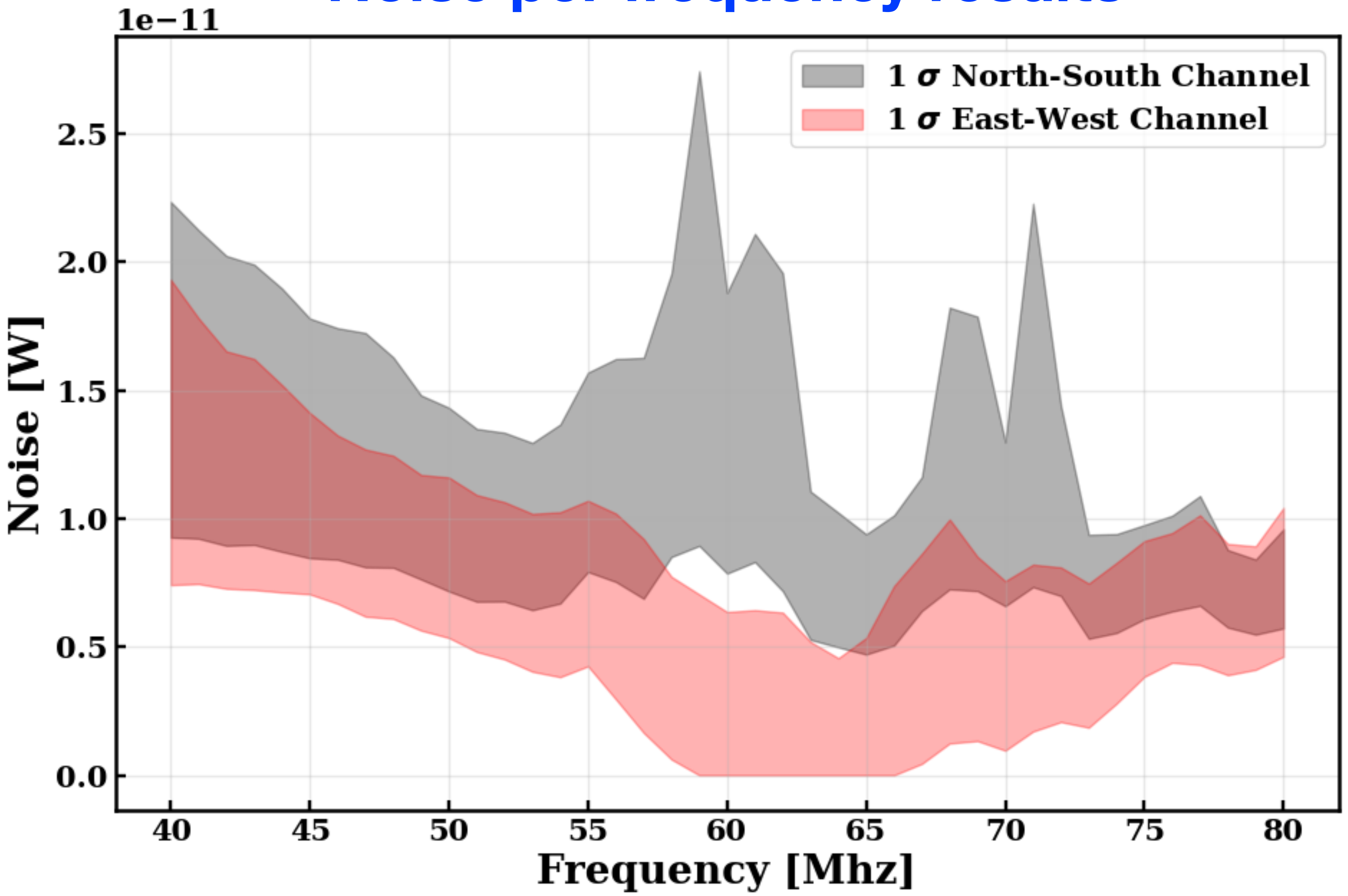
$$P_{model}(t,\nu) = P_{sky}(t,\nu)G_{ant}(\nu)G_{RCU}(\nu)S(\nu) + N_{tot}(\nu)$$

$$C_0 = \sqrt{S}$$

C_0 per frequency factor results



Noise per frequency results

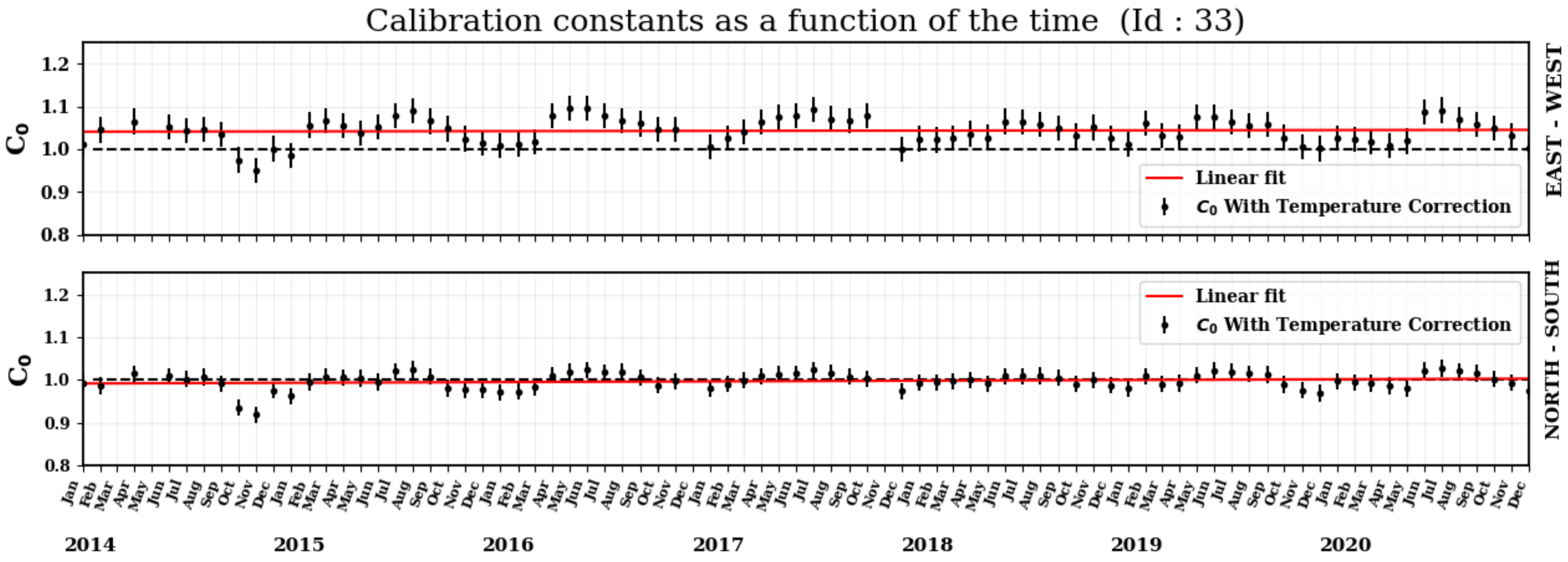


Distributions considering all antennas and months

Study of C_0 as a function of the time

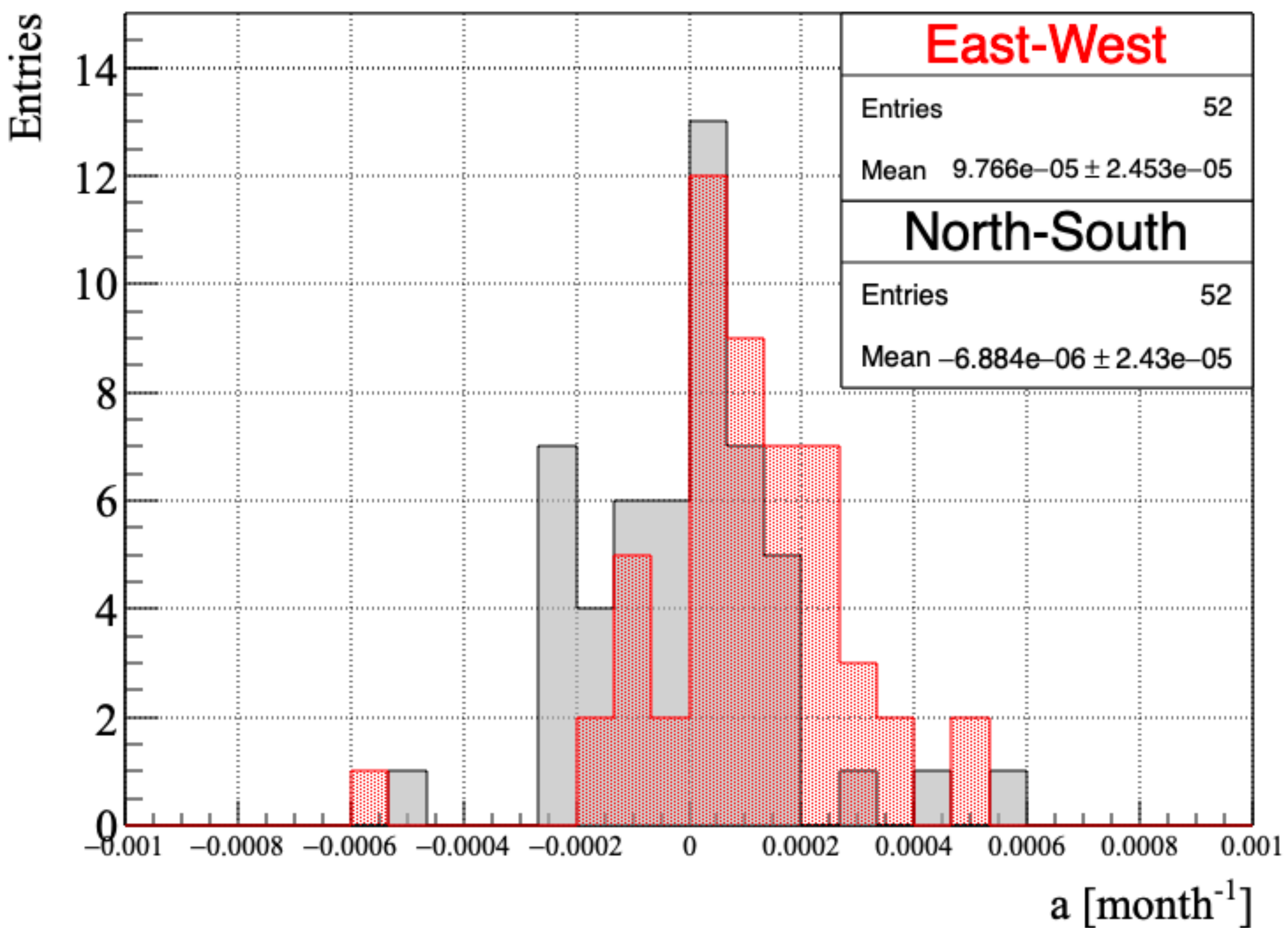
- For each antenna and month, C_0 is given by $\langle C_0(\nu) \rangle$

➞ Perform a linear fit to check for possible ageing factor $C_0(t) = at + b$



Study of C_0 as a function of the time

→ Perform a linear fit to check for possible ageing factor $C_0(t) = at + b$

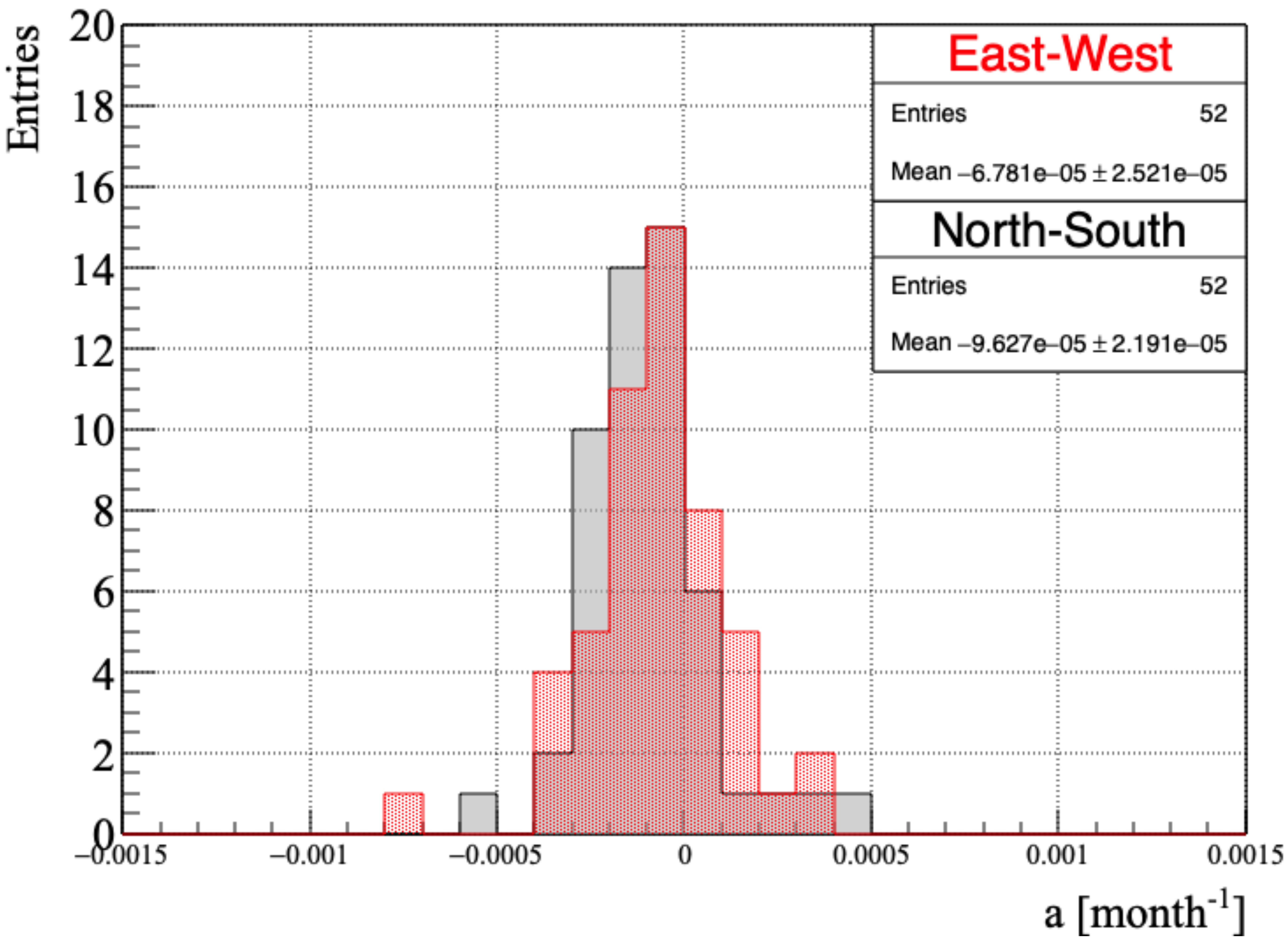


% per decade East-West Channel
1.17 ± 0.29 %
% per decade North-south Channel
-0.08 ± 0.29 %

Study of C_0 as a function of the time

Perform a linear fit to check for possible ageing factor $C_0(t) = at + b$

Removing points strongly fluctuated to smaller C_0 from 2014



% per decade East-West Channel
-0.80 ± 0.30 %
% per decade North-south Channel
-1.10 ± 0.26 %

Conclusions

- We studied the behavior of the AERA stations calibration constants as a function of time from 2014 to 2020.
- Very small ageing effect (if exist) over nearly a decade.

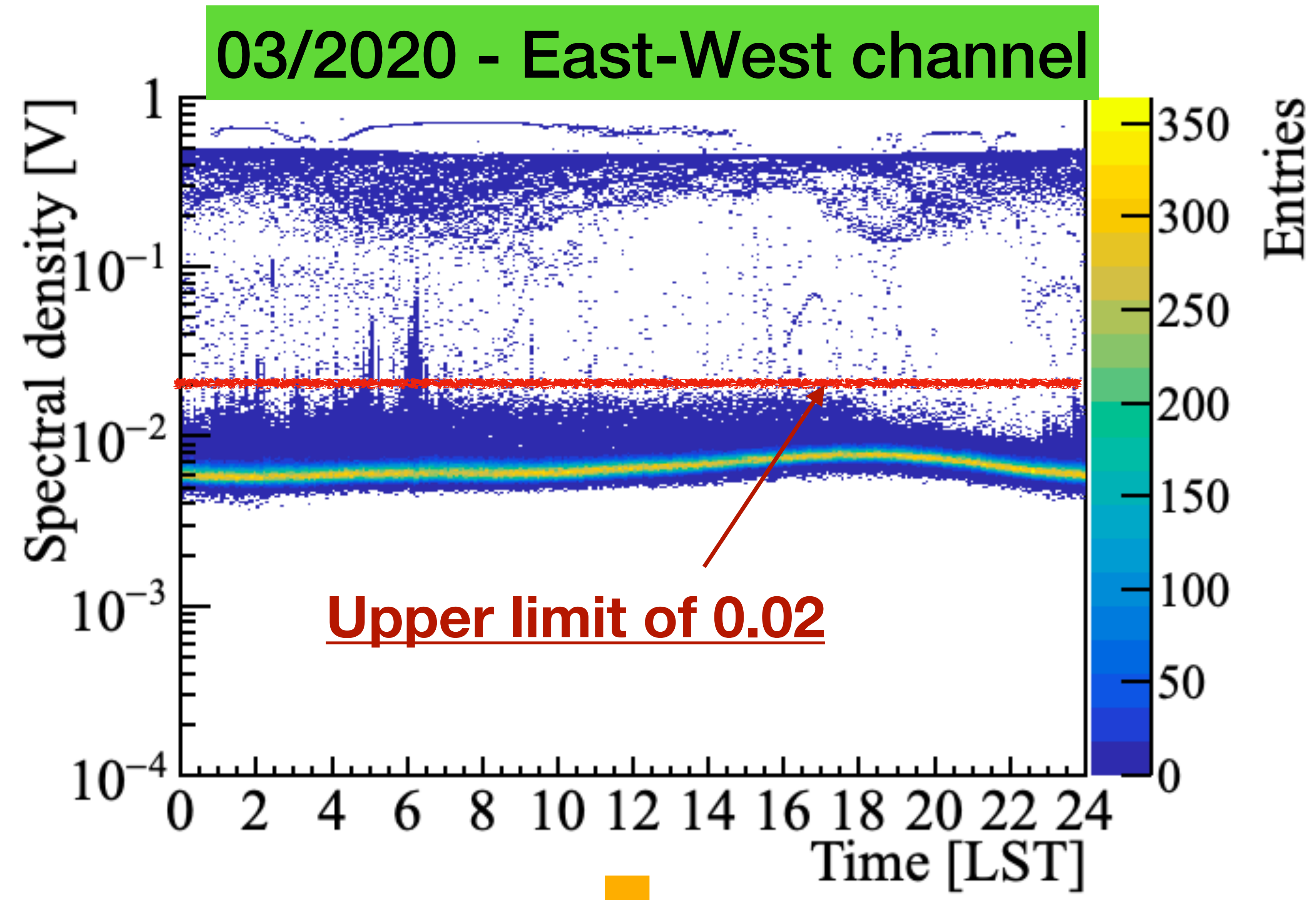
→ Radio detectors could help to monitor possible ageing effects of other detector systems during long-term operations

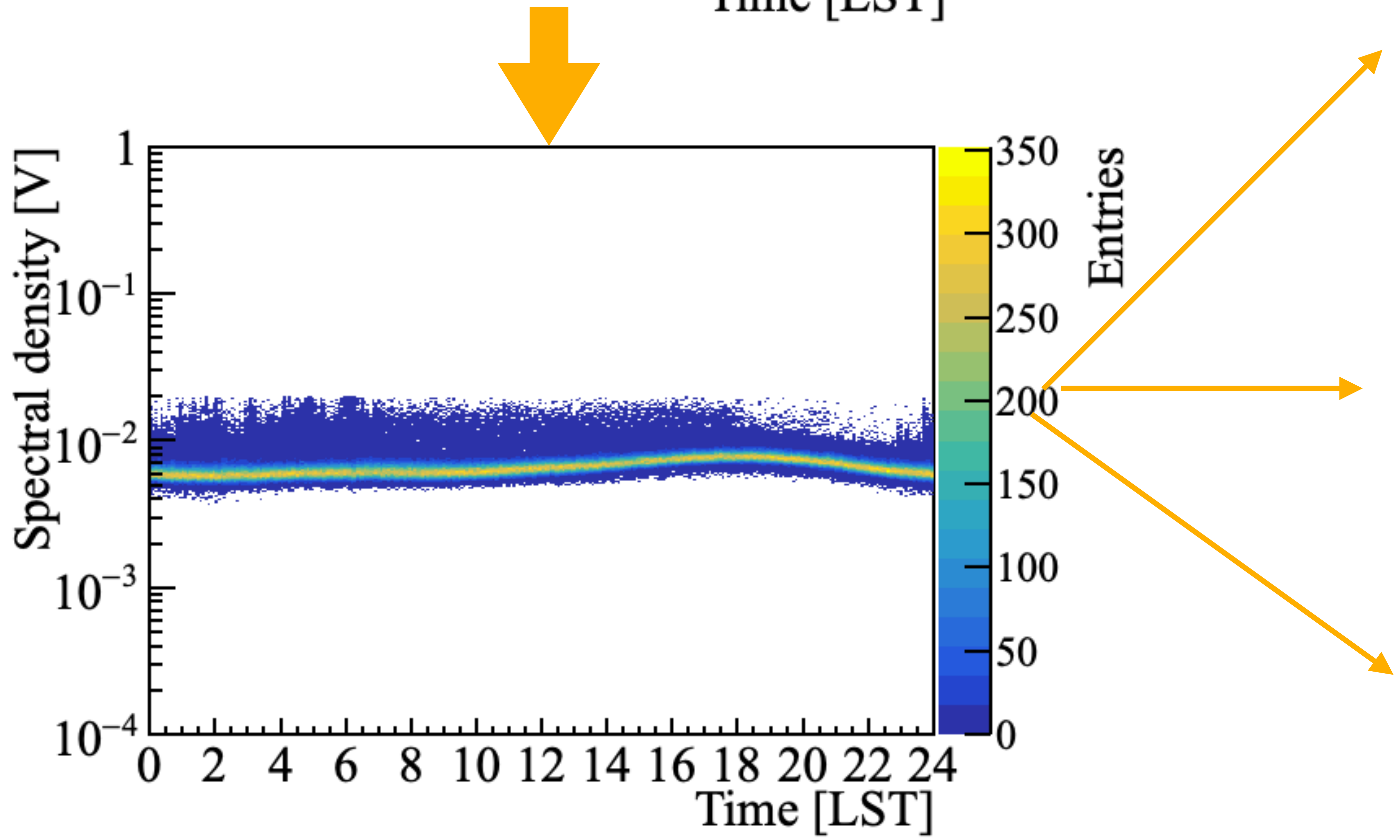
→ Very important for determining an absolute energy scale

Backup

Broadband RFI

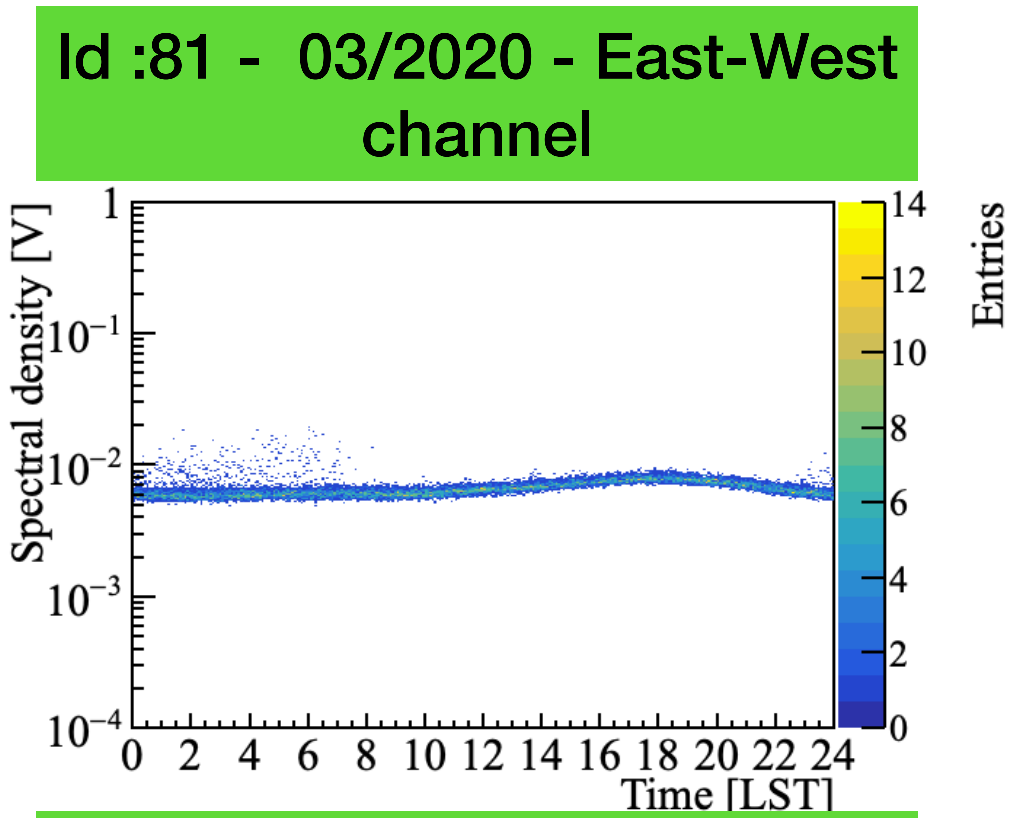
Procedure pipeline

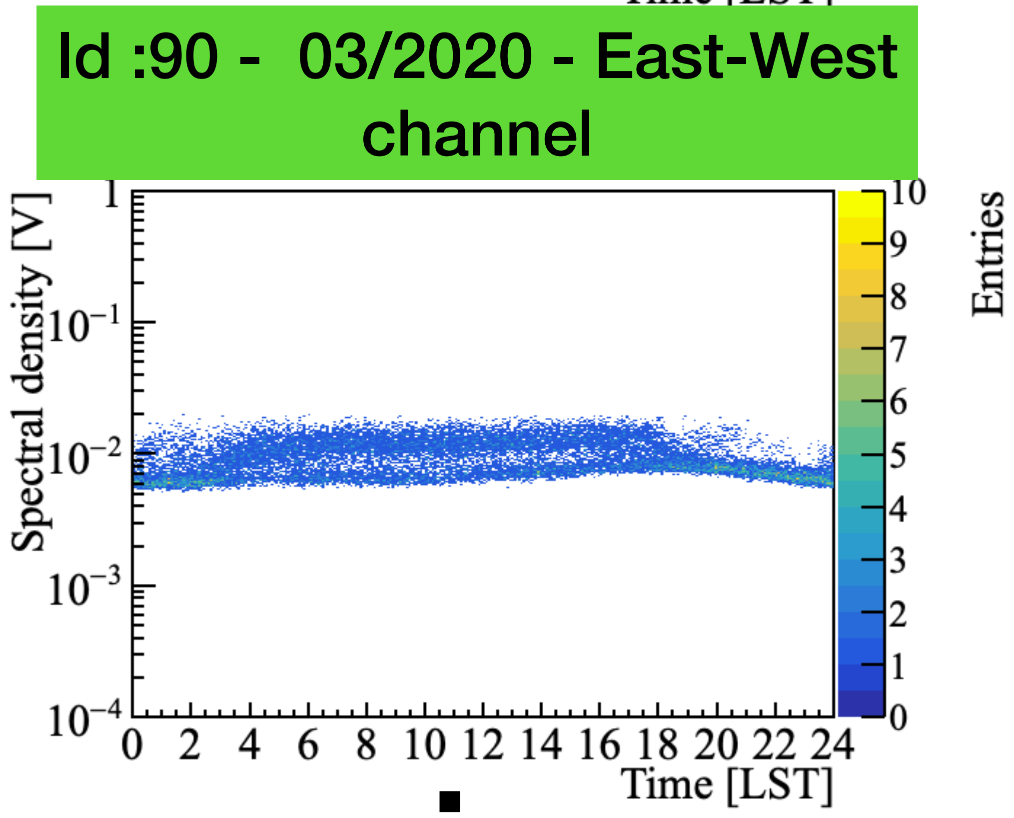




1. First, from the spectral density of all the antennas together, we reject signals larger than 0.02 V to avoid too high noise in our next steps/analyses.

2. We get the spectral density of each antenna and then we discretize the LST in 180 bins.

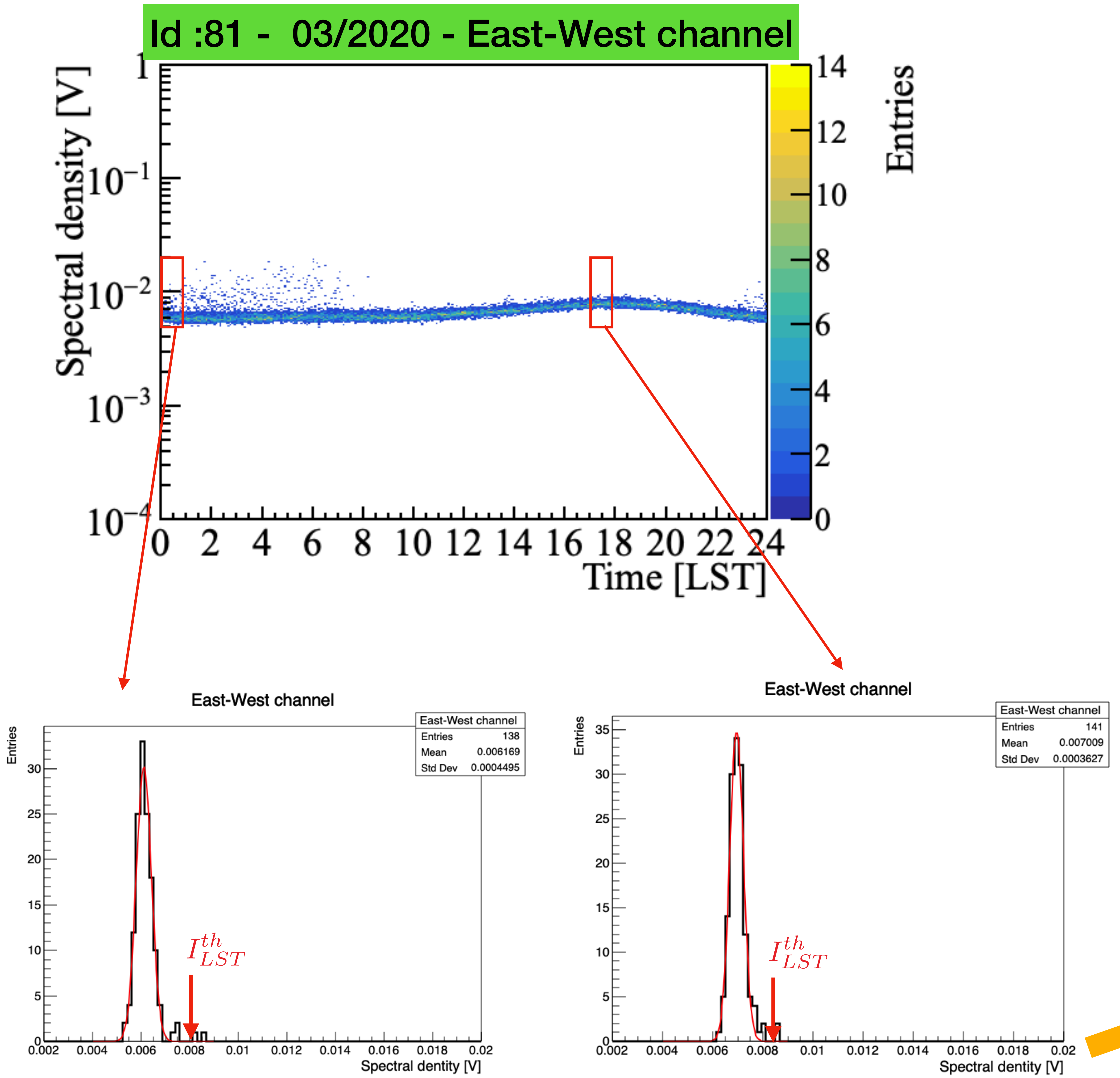




⋮

Broadband RFI

Procedure pipeline



3. We do a gaussian fit for the signal within each LST bin

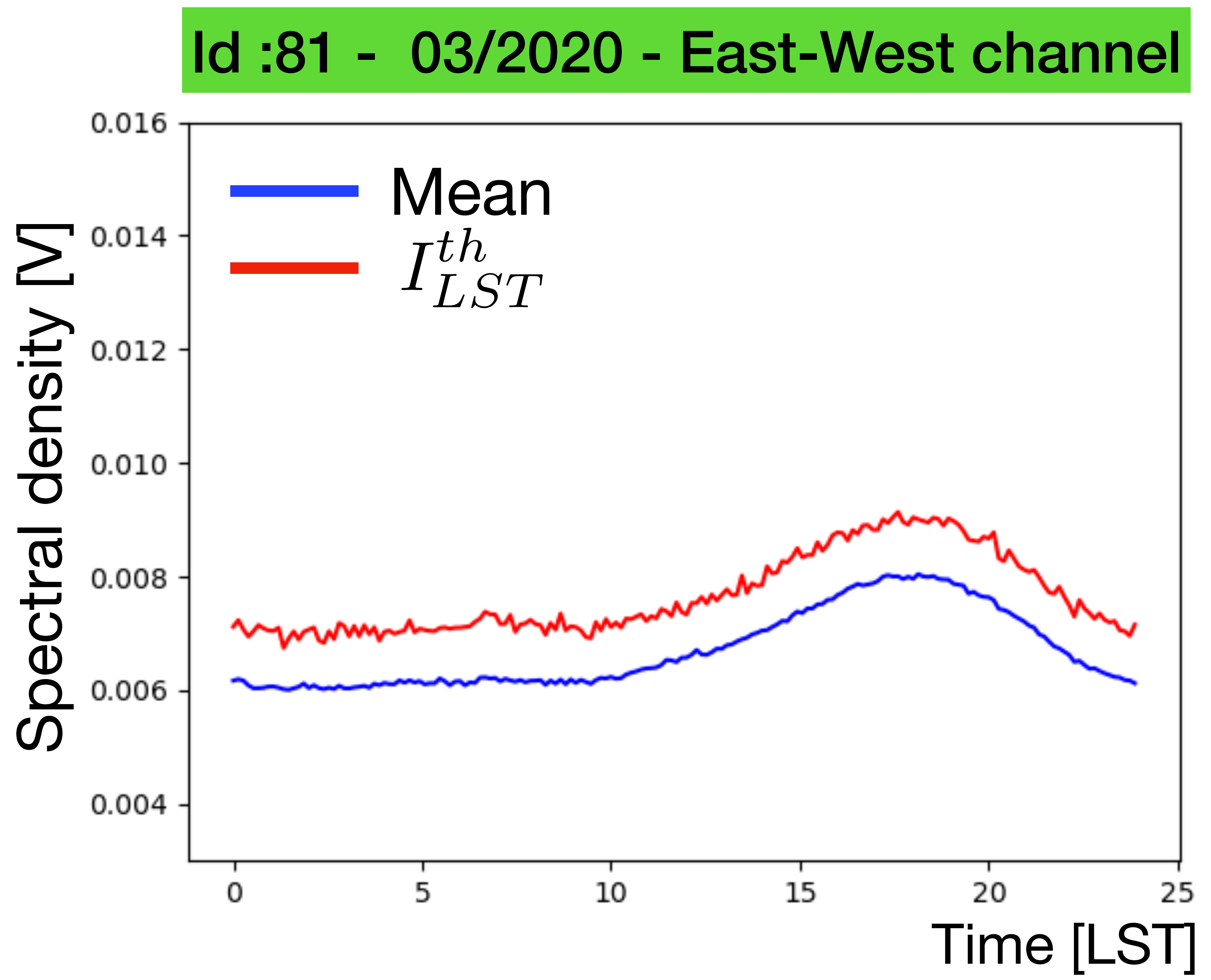
4. The threshold is defined according to the equation

$$\int_{-\infty}^{I_{LST}^{th}} G(I;\bar{I},\sigma_I)dI = 0.9973$$

Gaussian function

5. This procedure is repeated for all antennas and for both channels

...

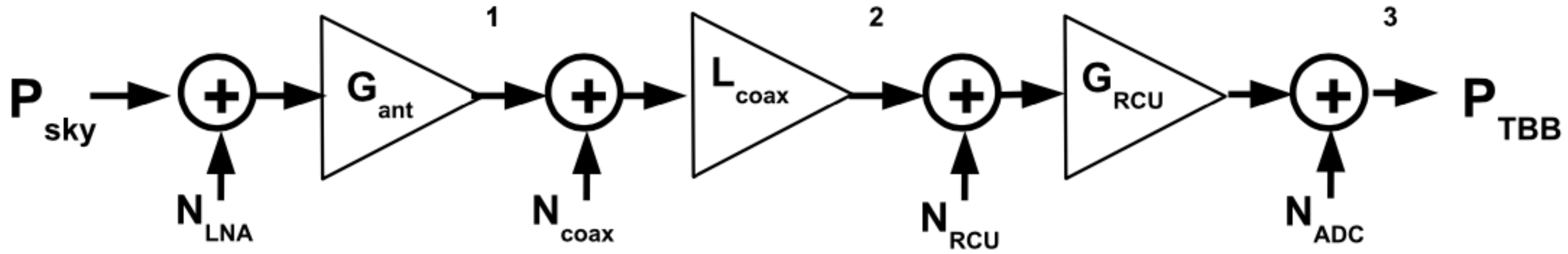


Galactic calibration: Nf model approach

Introduced by T.Fodran PoS (ICRC2021) 270

- Inspired in LOFAR calibration approach + frequency-dependent noise

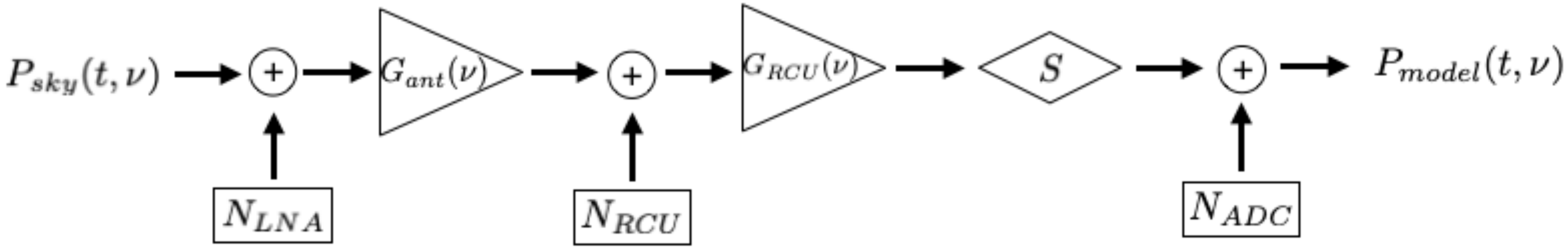
- **LOFAR approach:** Electronic noise enters in the system at various stages of the signal chain



$$P_{model}(t,\nu) = [(P_{sky}(t,\nu) + N_{LNA})G_{ant}(\nu)A(\nu)L_{coax}(\nu) + N_{RCU}]G_{RCU}(\nu)S + N_{ADC}$$

Astroparticle Physics Vol. 111, September 2019, pages 1-11

- Accounting for the AERA antenna model



$$P_{model}(t,\nu) = P_{sky}(t,\nu)G_{ant}(\nu)G_{RCU}(\nu)S + N_{LNA}G_{ant}(\nu)G_{RCU}(\nu)S + N_{RCU}G_{RCU}S + N_{ADC}$$

$\rightarrow N_{sys}(\nu)$

We can combine these terms into one single frequency-dependent term

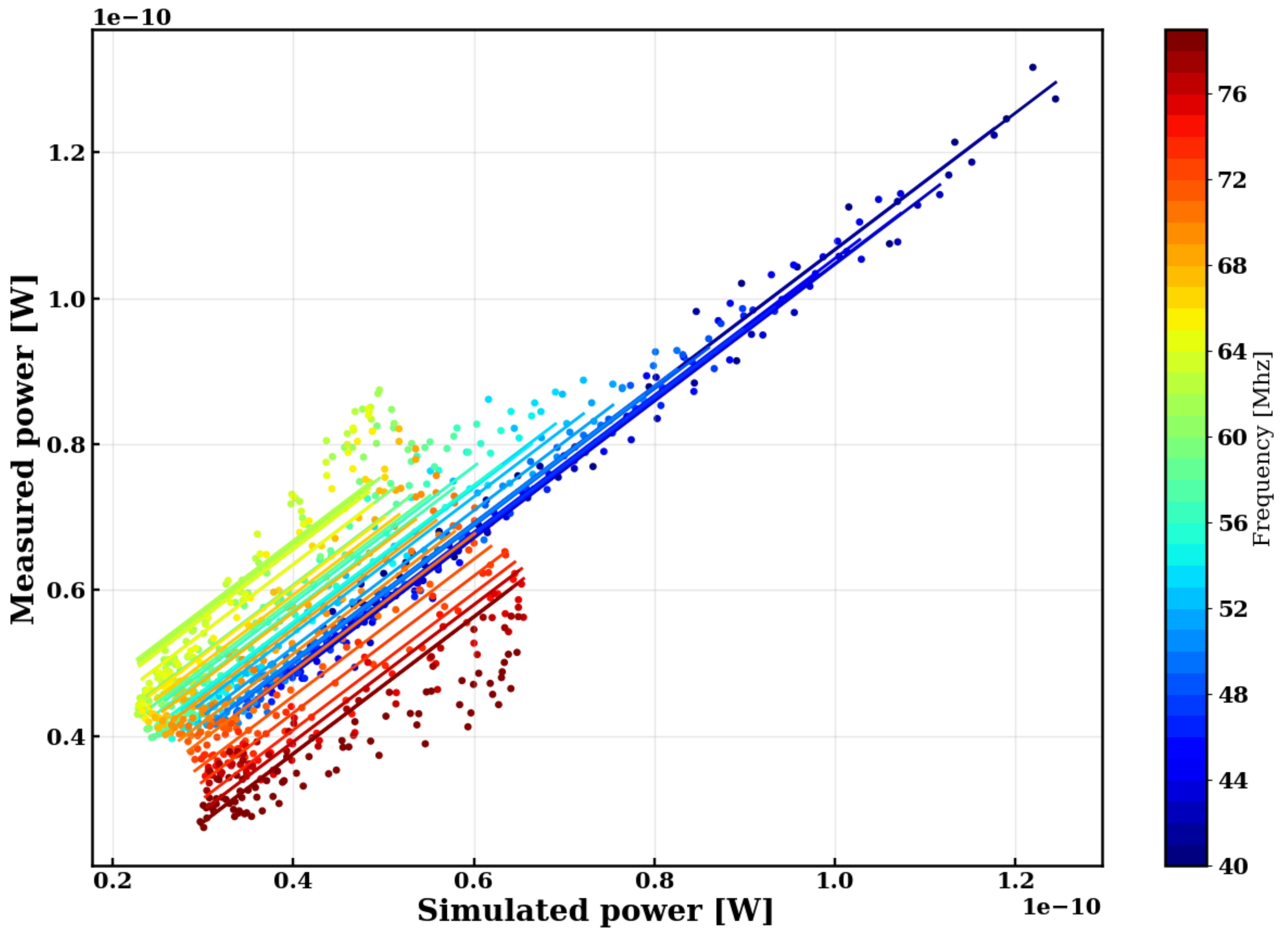
- Considering a possible external noise $N_{ext}(\nu)$

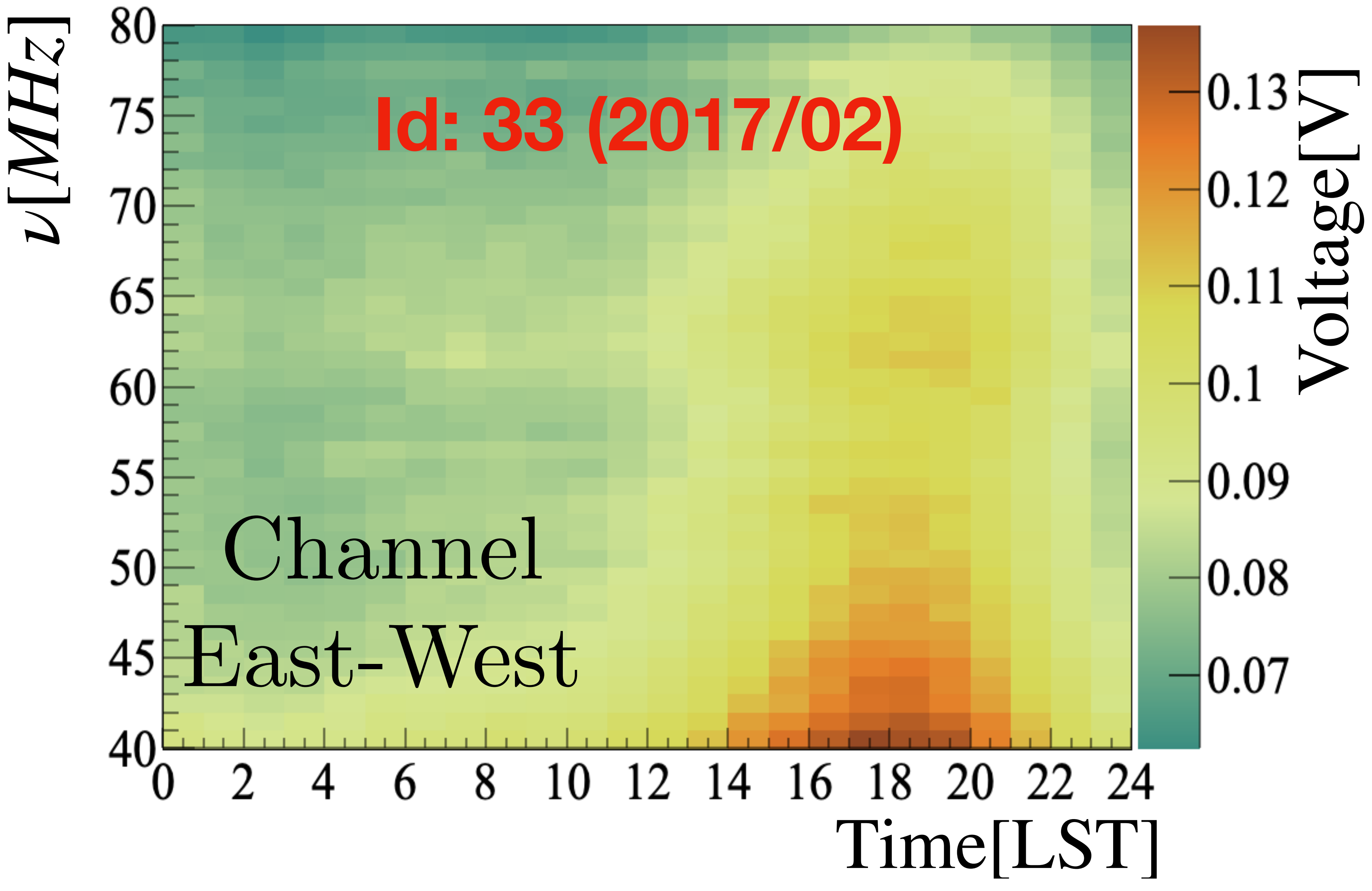
So, $N_{tot}(\nu) = N_{ext}(\nu) + N_{sys}(\nu)$

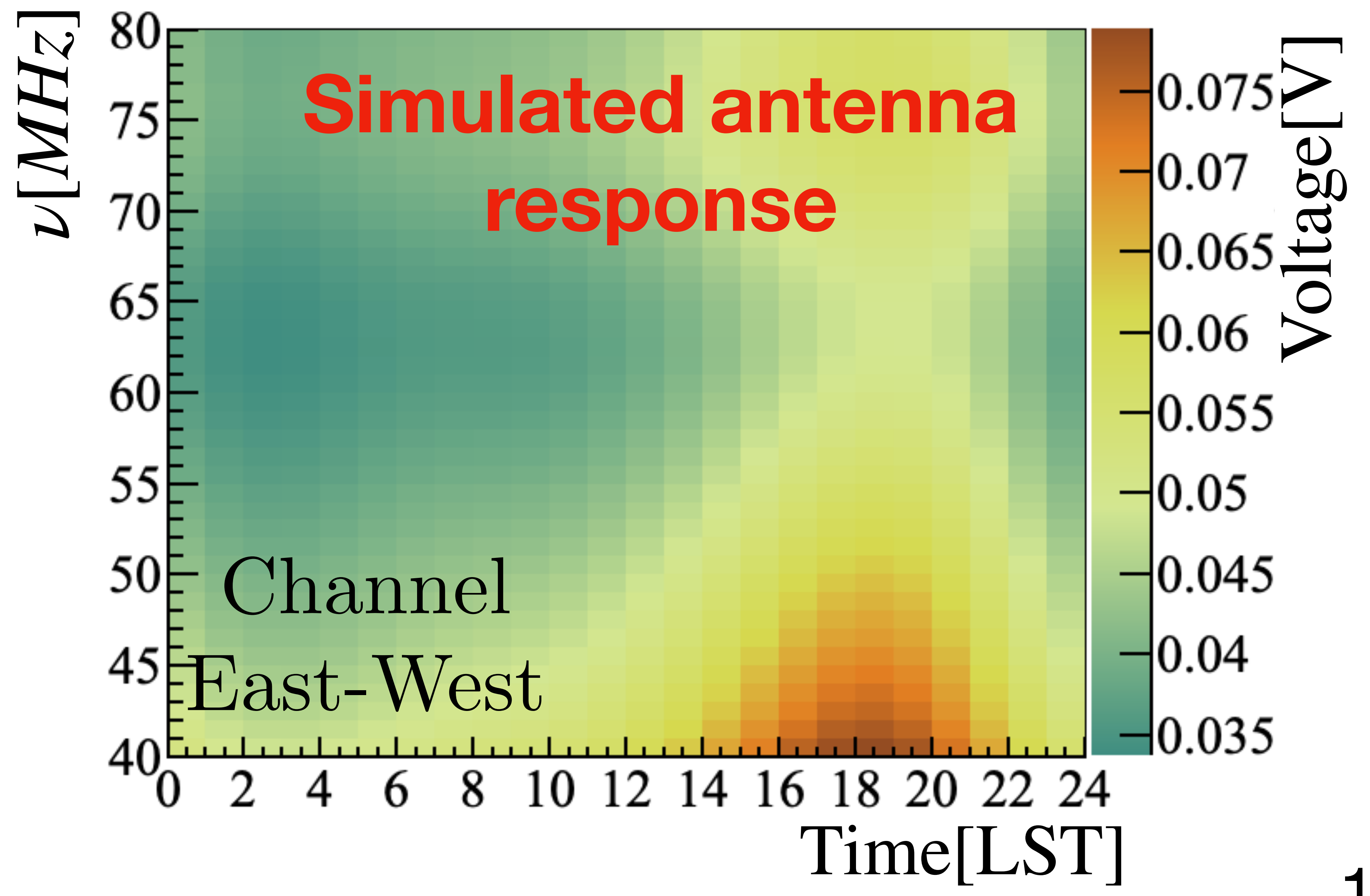
$$\boxed{P_{model}(t,\nu) = P_{sky}(t,\nu)G_{ant}(\nu)G_{RCU}(\nu)S + N_{tot}(\nu)}$$

Study of C_0 as a function of the time

$$P_{model}(t,\nu) = P_{sky}(t,\nu)G_{ant}(\nu)G_{RCU}(\nu)S + N_{tot}(\nu)$$

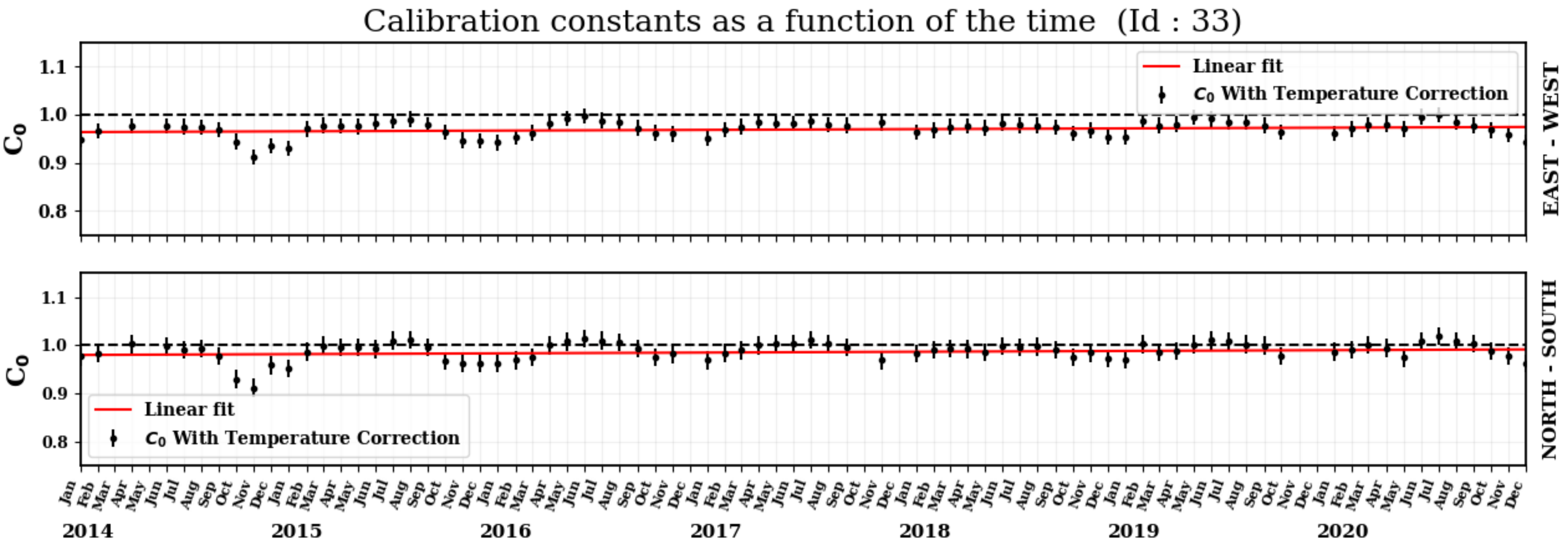






Study of C_0 as a function of the time

- Linear fit of all points to check ageing effect $C_0(t) = at + b$



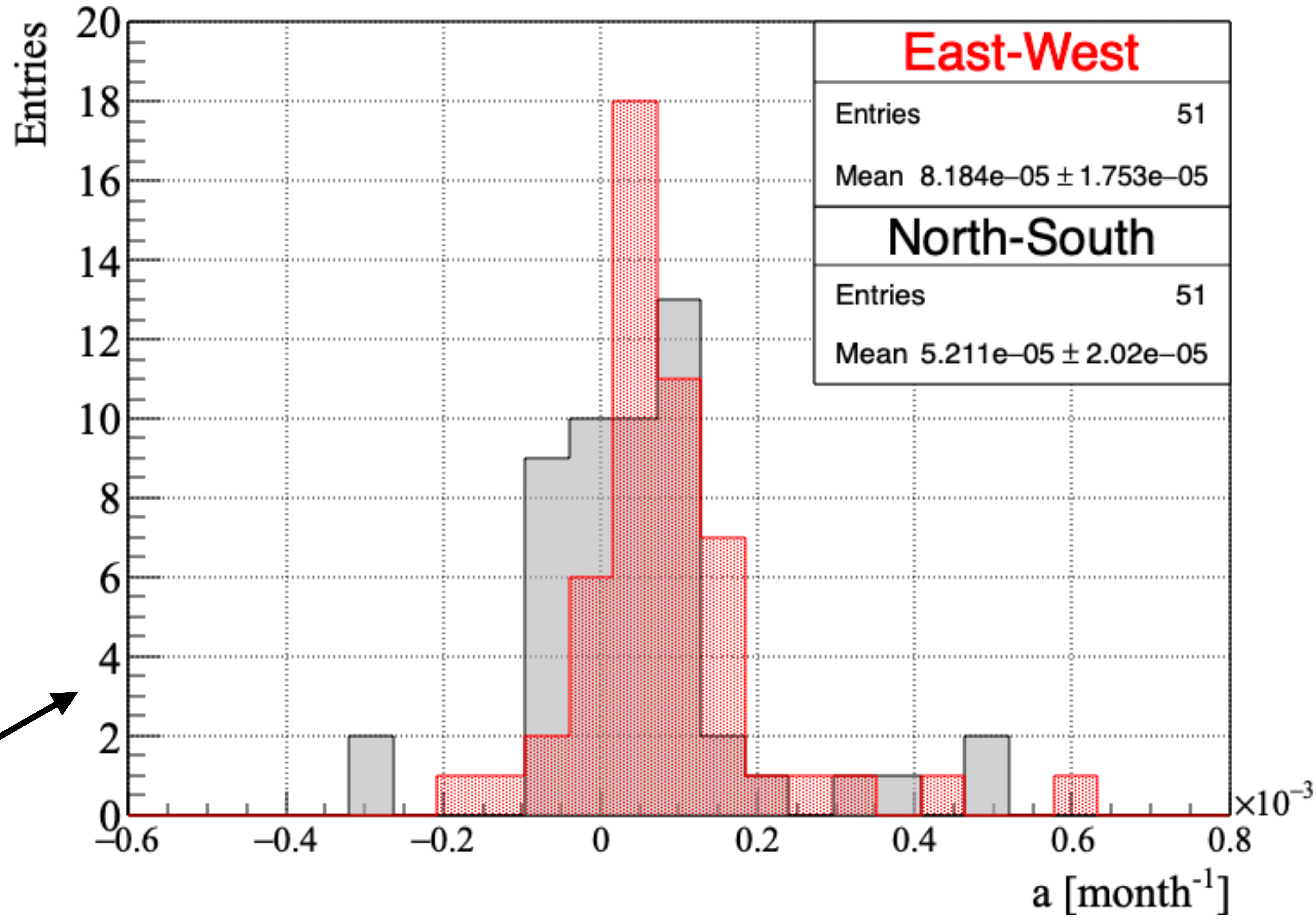
Study of C_0 as a function of the time

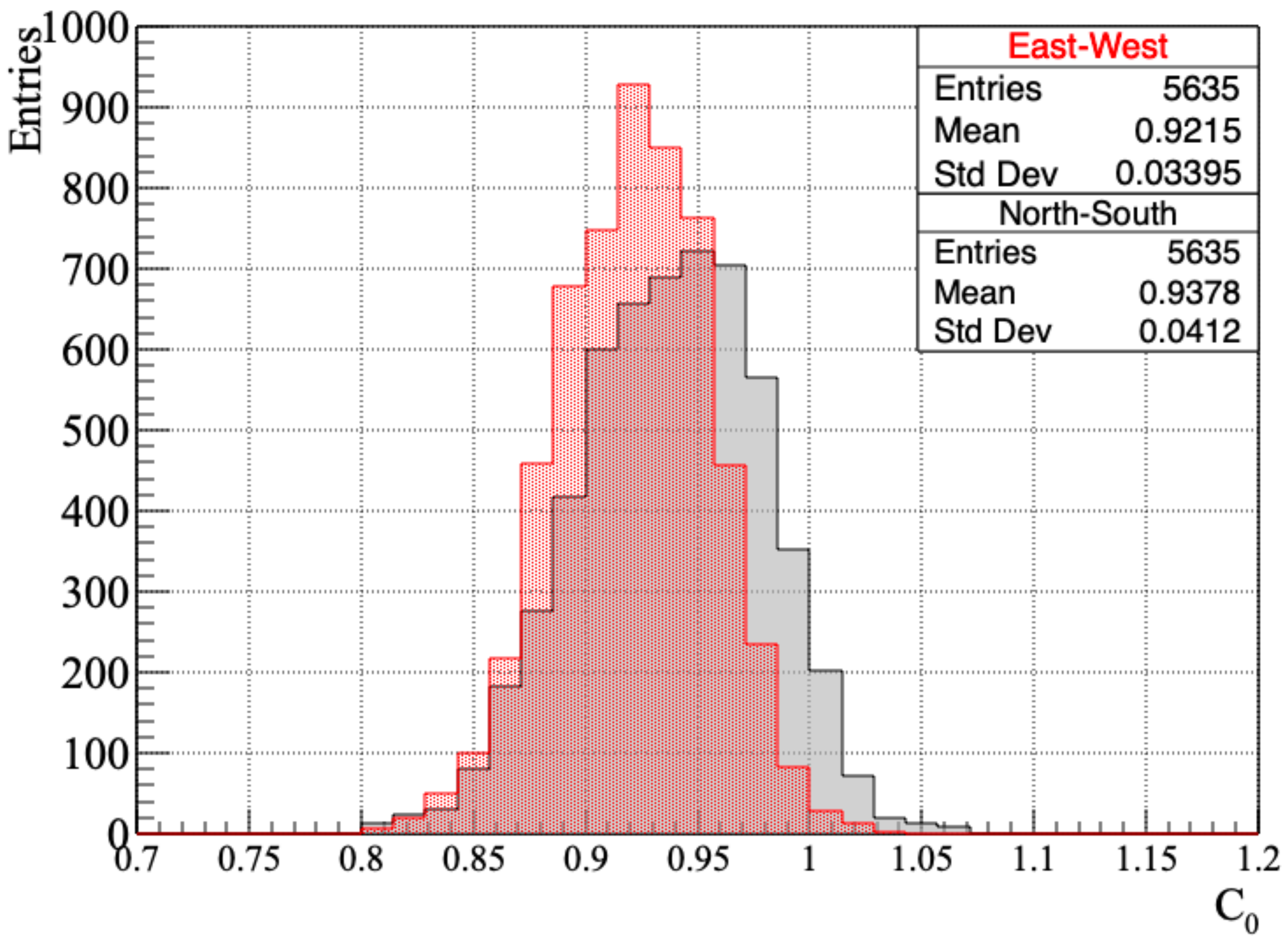
$$P_{model}(t,\nu) = P_{sky}(t,\nu)G_{ant}(\nu)G_{RCU}(\nu)S + N_{tot}(\nu)$$

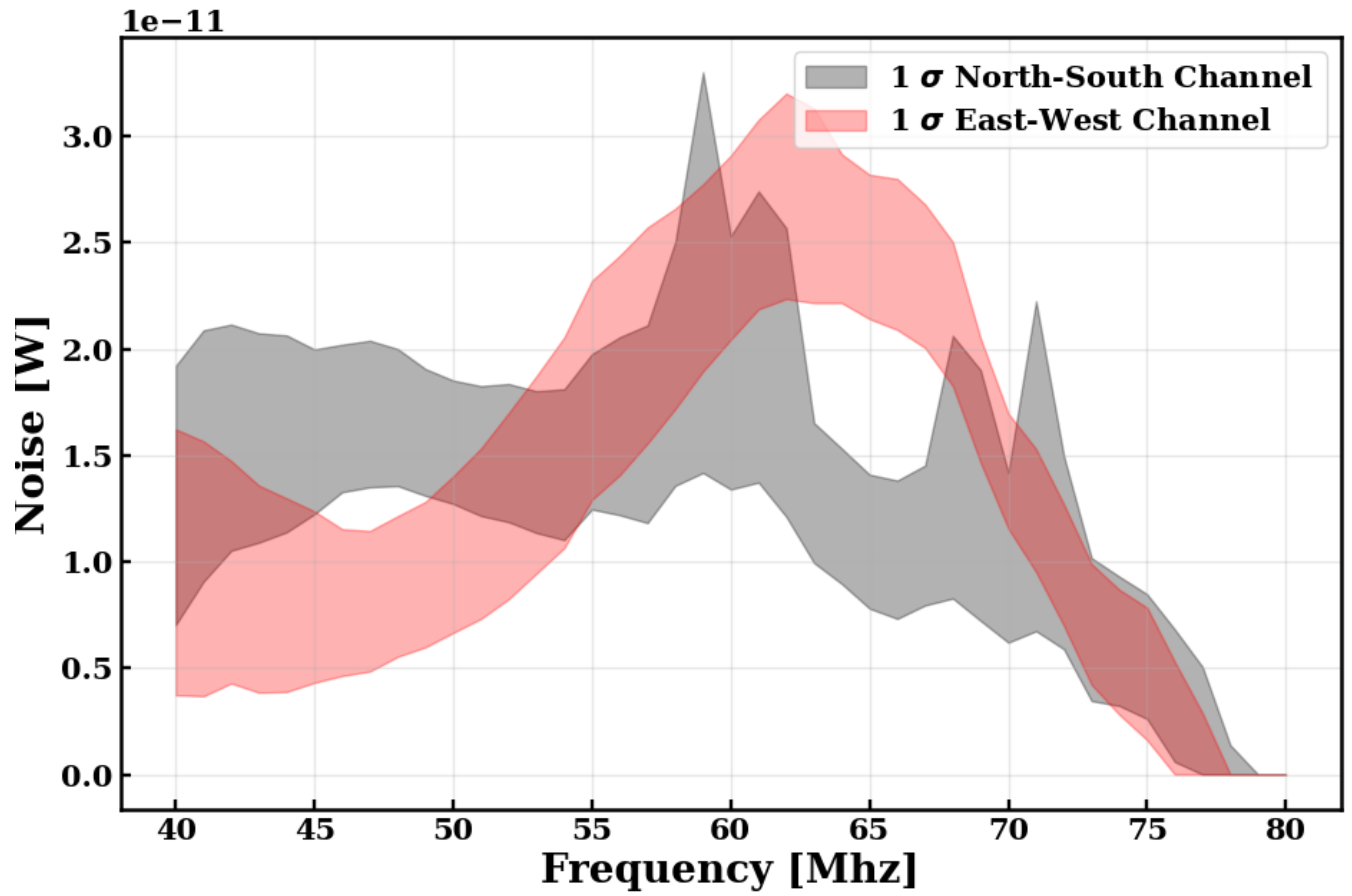
- Linear fit of all points to check ageing effect

$$C_0(t) = at + b$$

- 52 antennas with calibration constants from 2014-2020







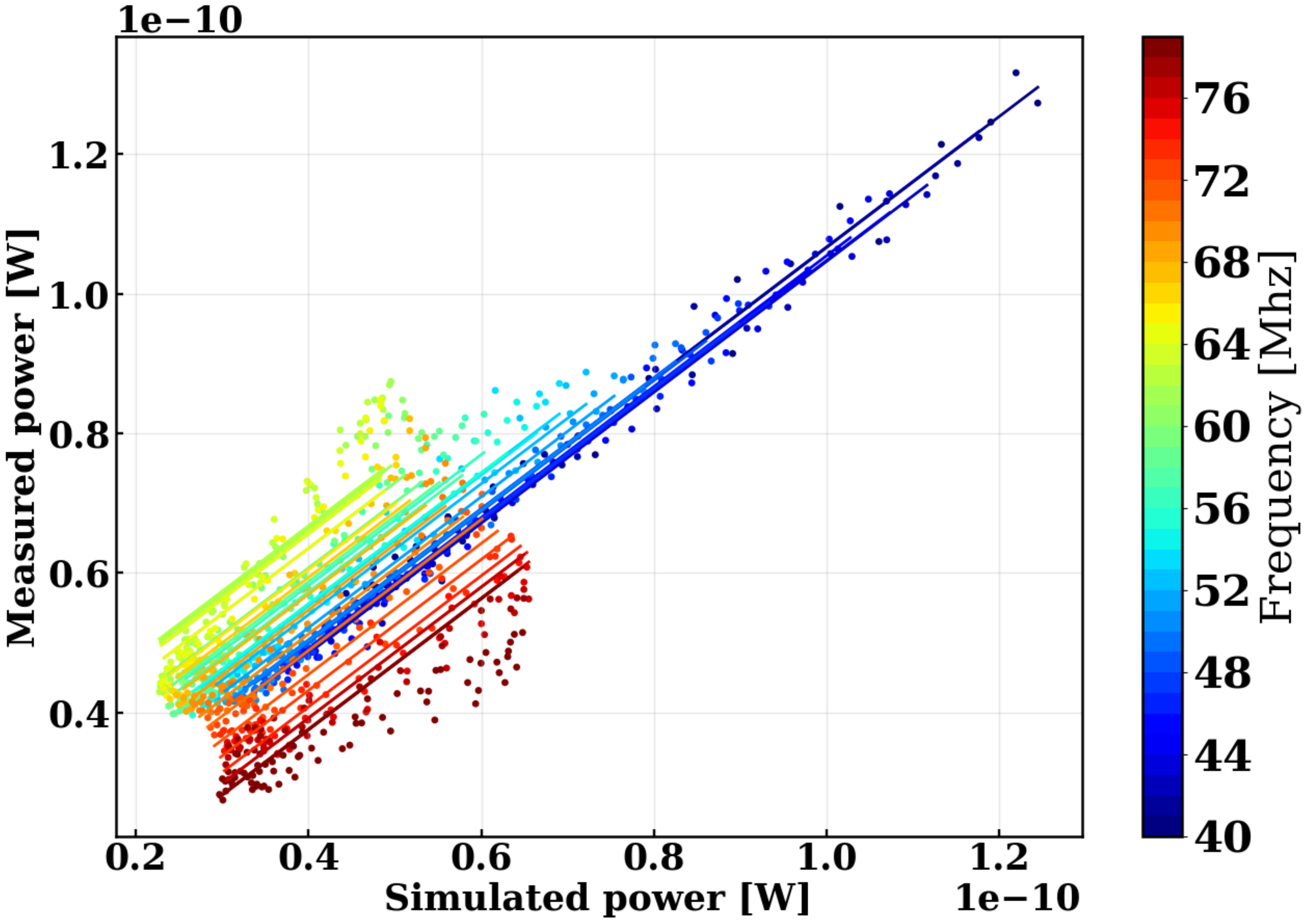
Ageing

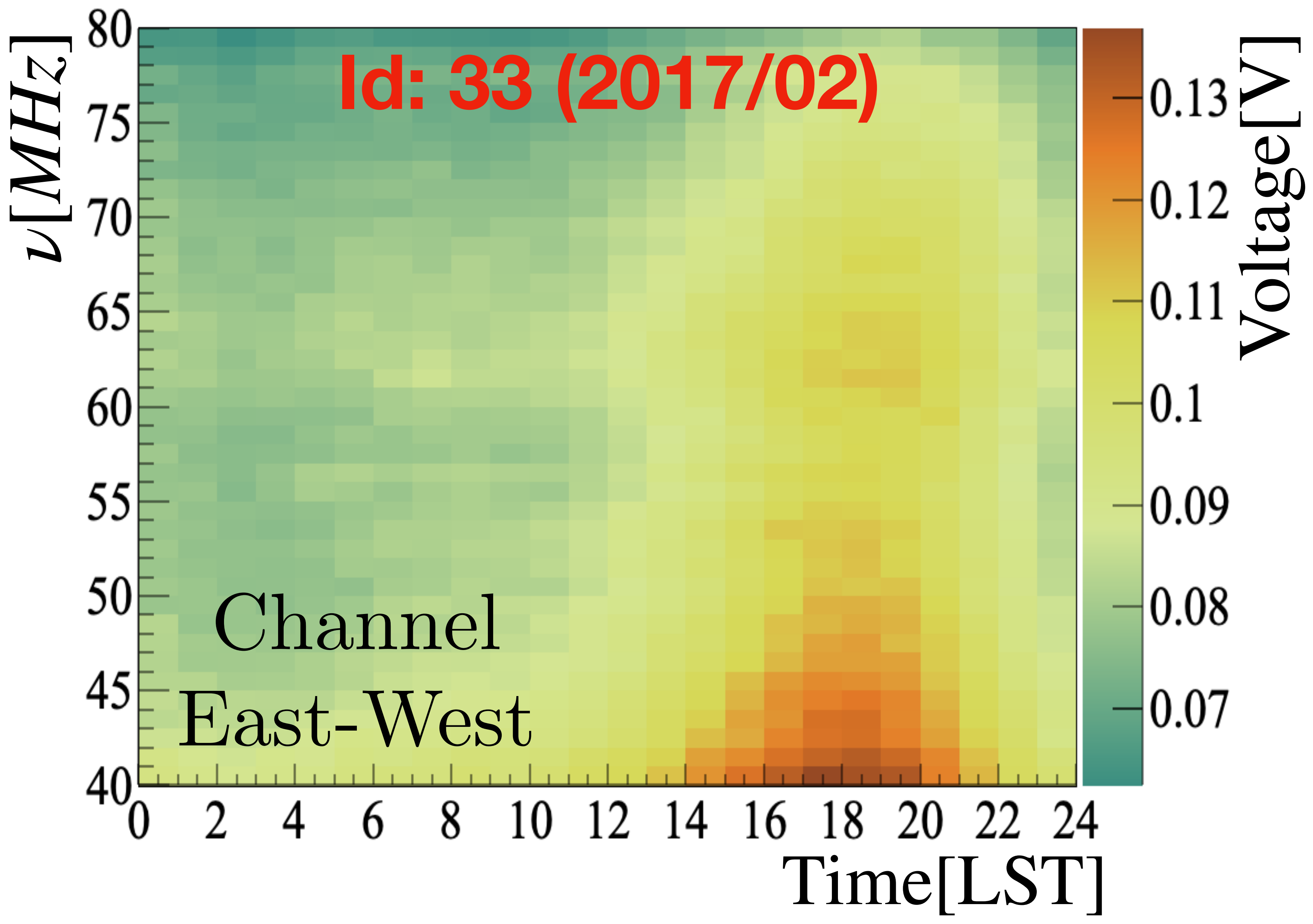
% per decade East-West Channel
0.98 ± 0.20 %
% per decade North-south Channel
0.62 ± 0.24 %

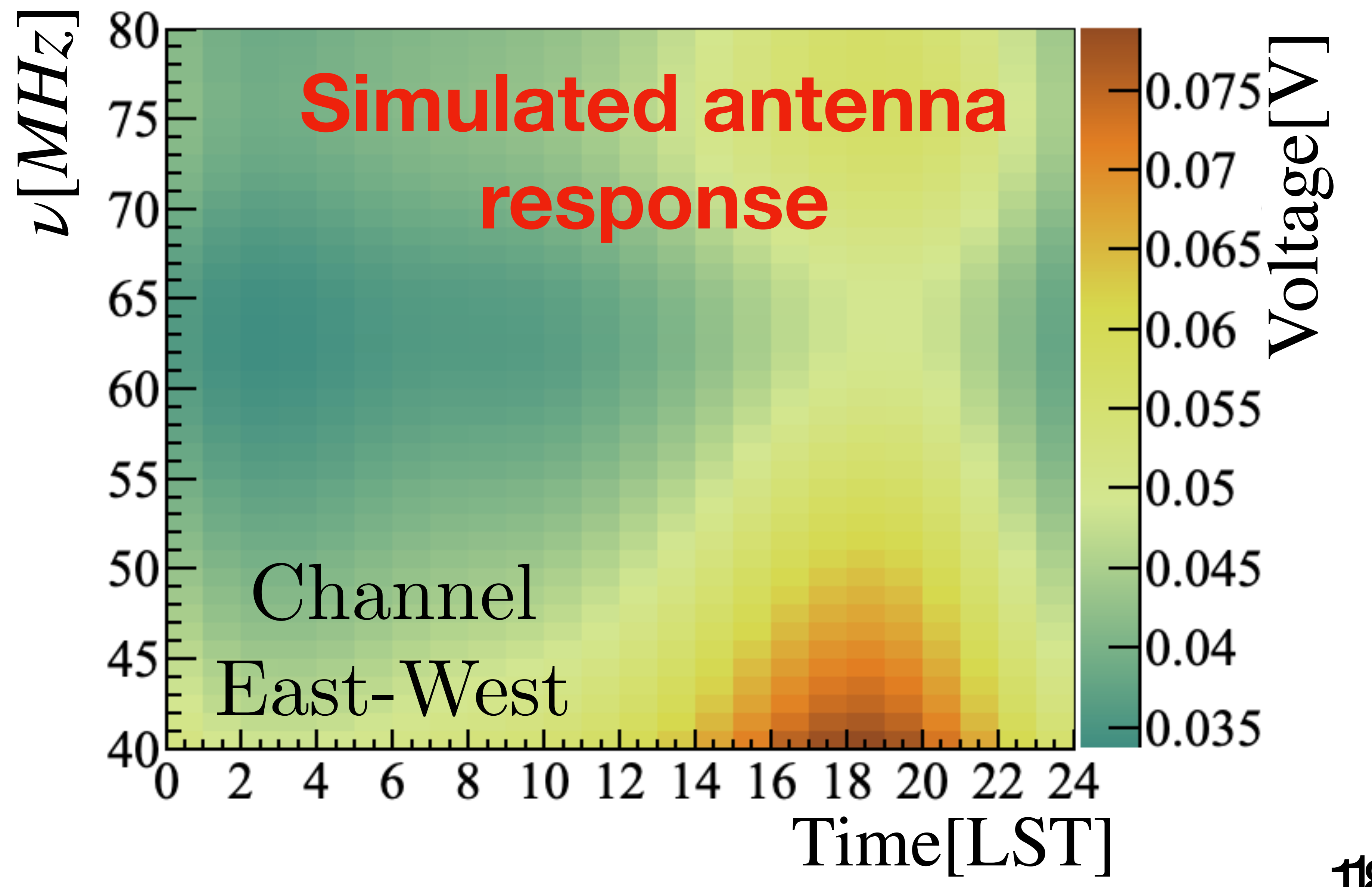
Study of C_0 as a function of the time

$$P_{model}(t,\nu) = P_{sky}(t,\nu)G_{ant}(\nu)G_{RCU}(\nu)S + N_{tot}(\nu)$$

Removing points strongly fluctuated to smaller C_0 from 2014



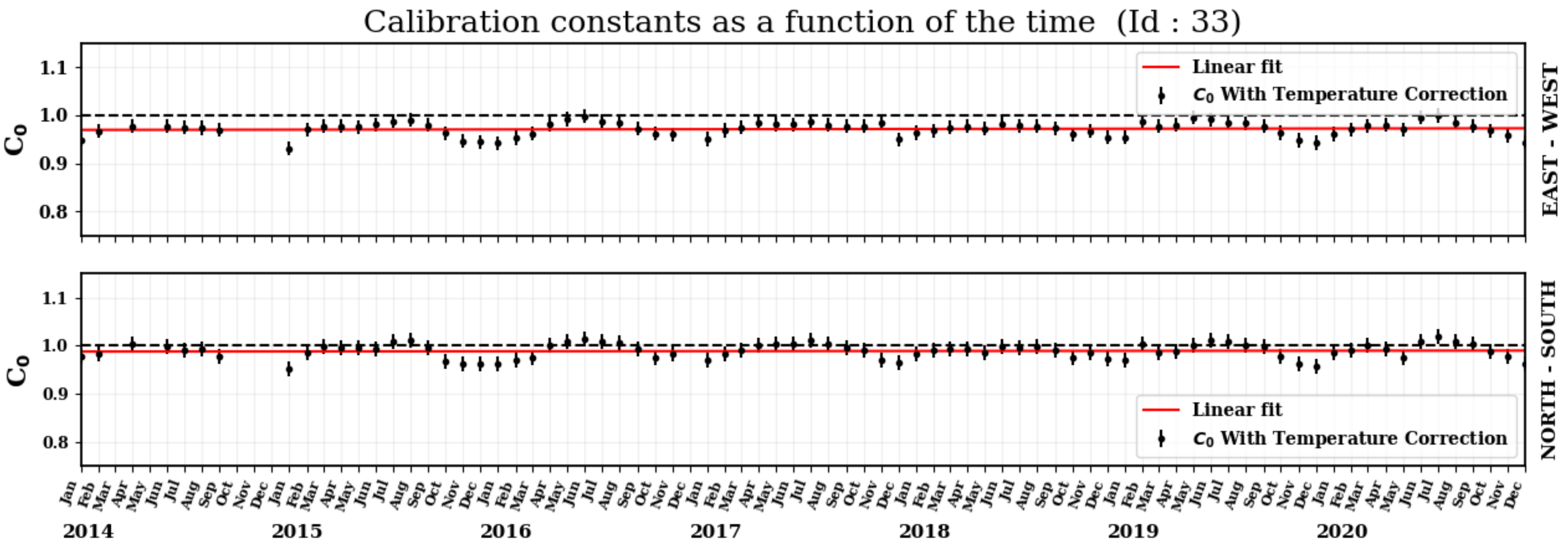




Study of C_0 as a function of the time

Removing points strongly fluctuated to smaller C_0 from 2014

- Linear fit of all points to check ageing effect $C_0(t) = at + b$



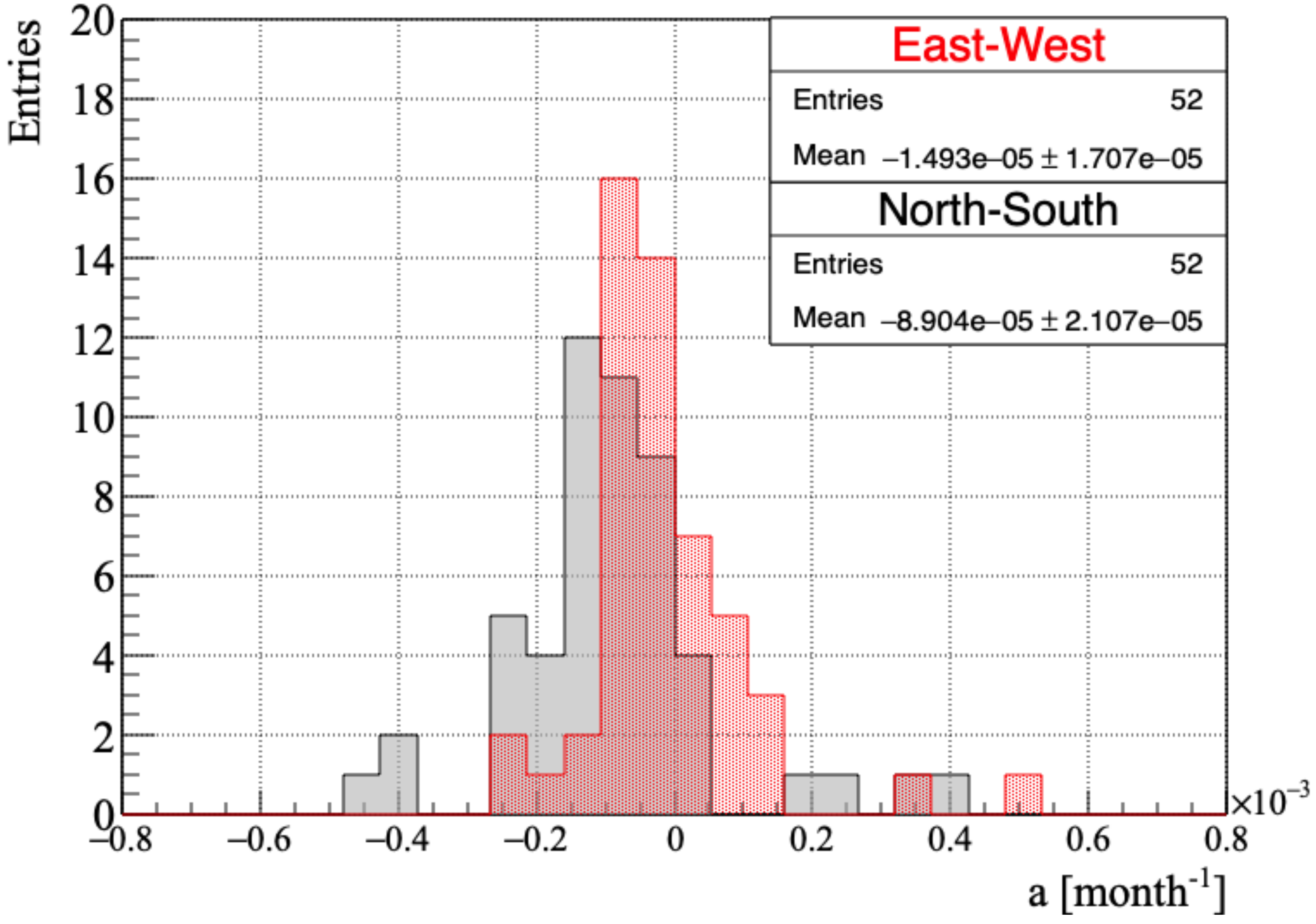
Study of C_0 as a function of the time

$$P_{model}(t,\nu) = P_{sky}(t,\nu)G_{ant}(\nu)G_{RCU}(\nu)S + N_{tot}(\nu)$$

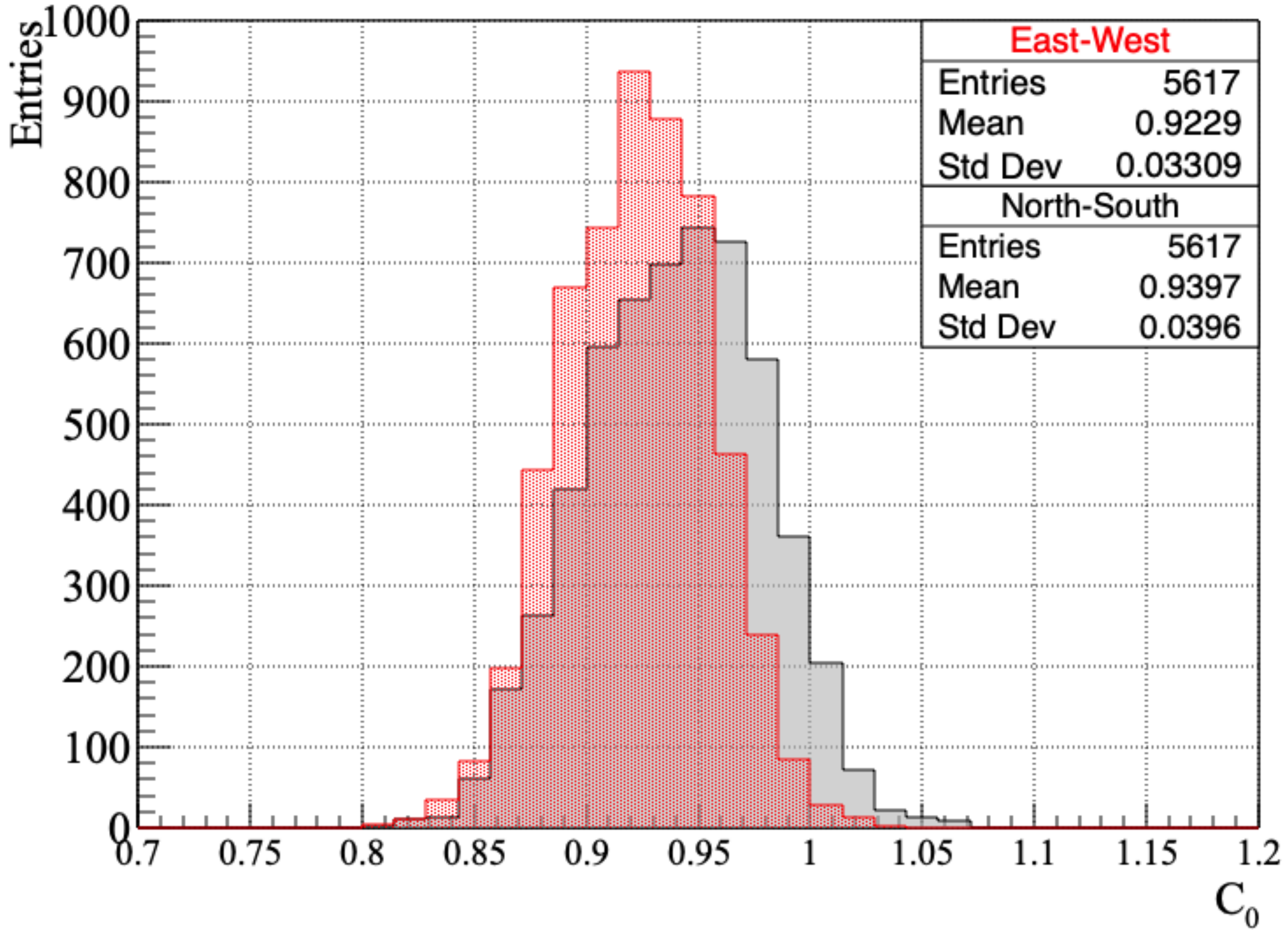
- Linear fit of all points to check ageing effect

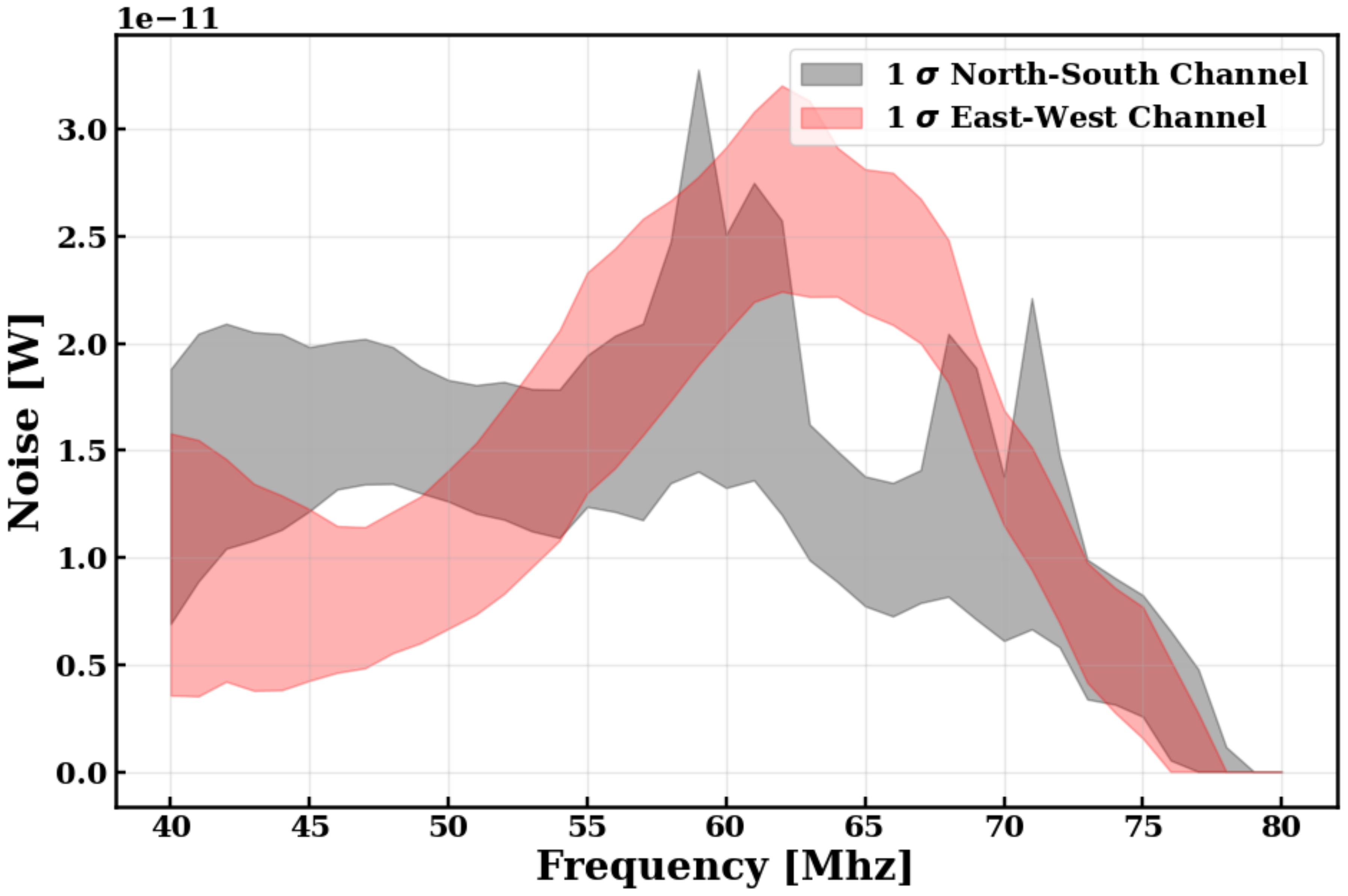
$$C_0(t) = at + b$$

- 52 antennas with calibration constants from 2014-2020



Removing points strongly fluctuated to smaller C_0 from 2014

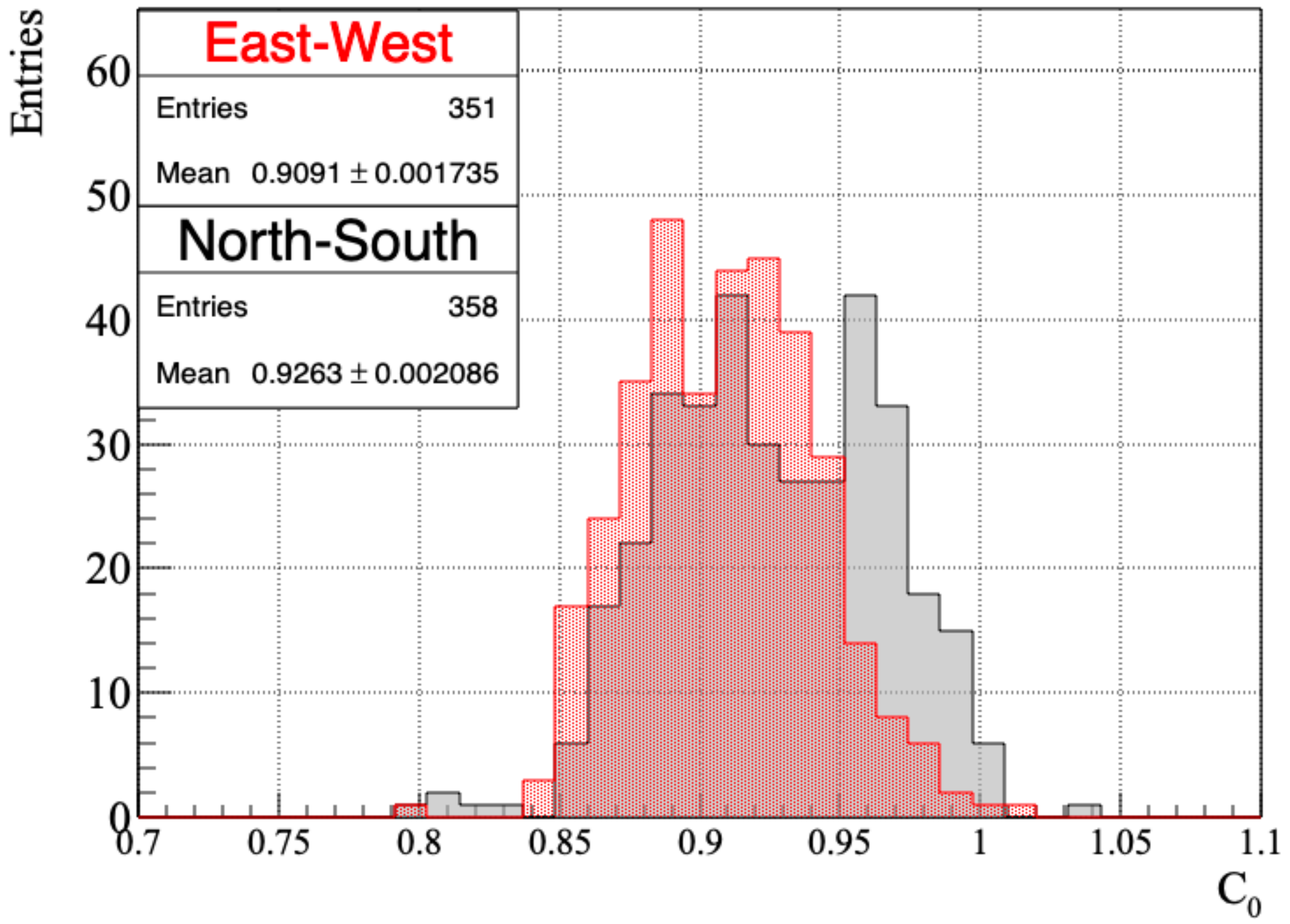




Ageing

% per decade East-West Channel
-0.17 ± 0.20 %
% per decade North-south Channel
-1.07 ± 0.25 %

Study of temperature x C_0

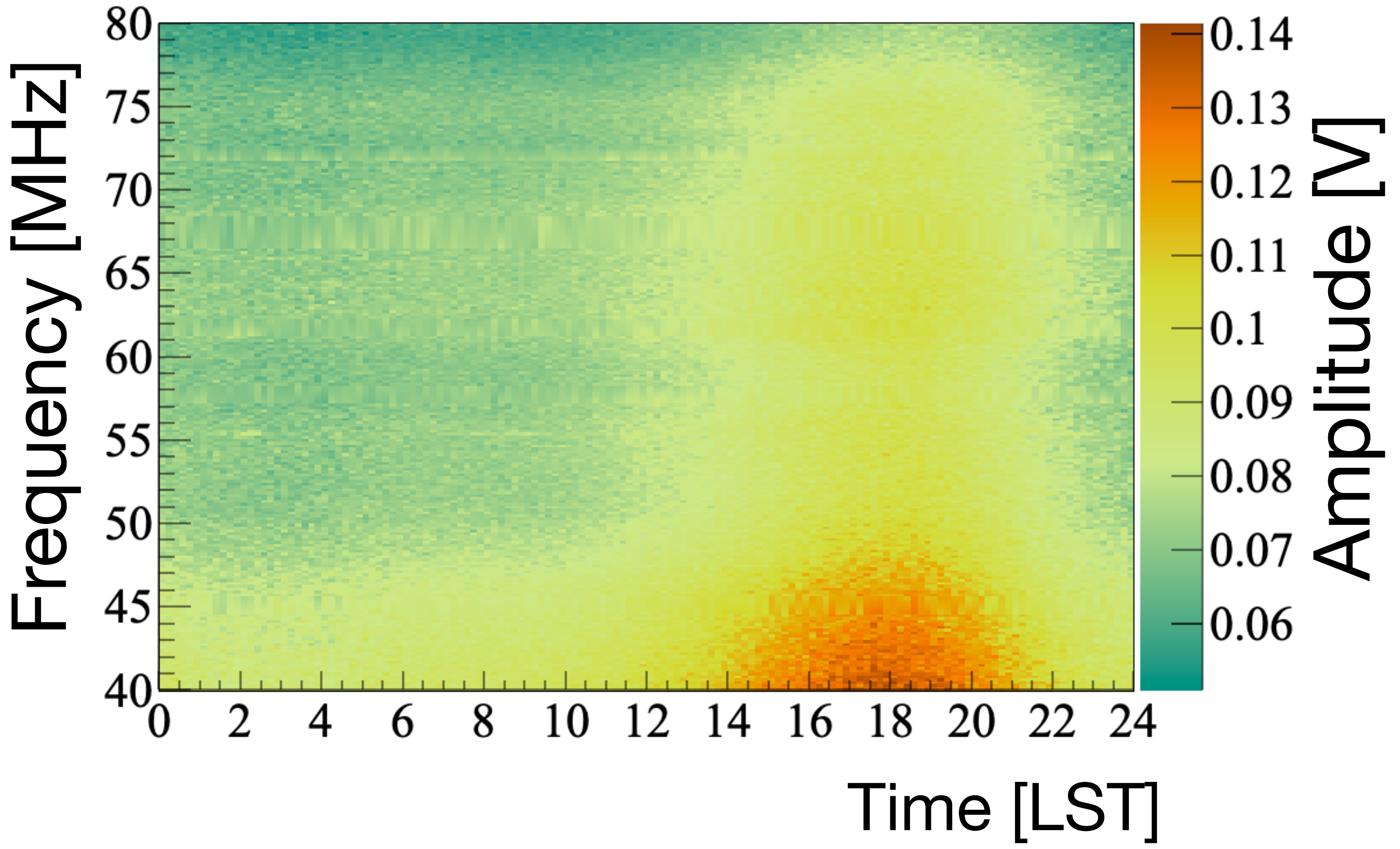


- Spectrum of each antenna obtained considering the whole year of 2019
- Ambient temperature used (CRS)

Procedure

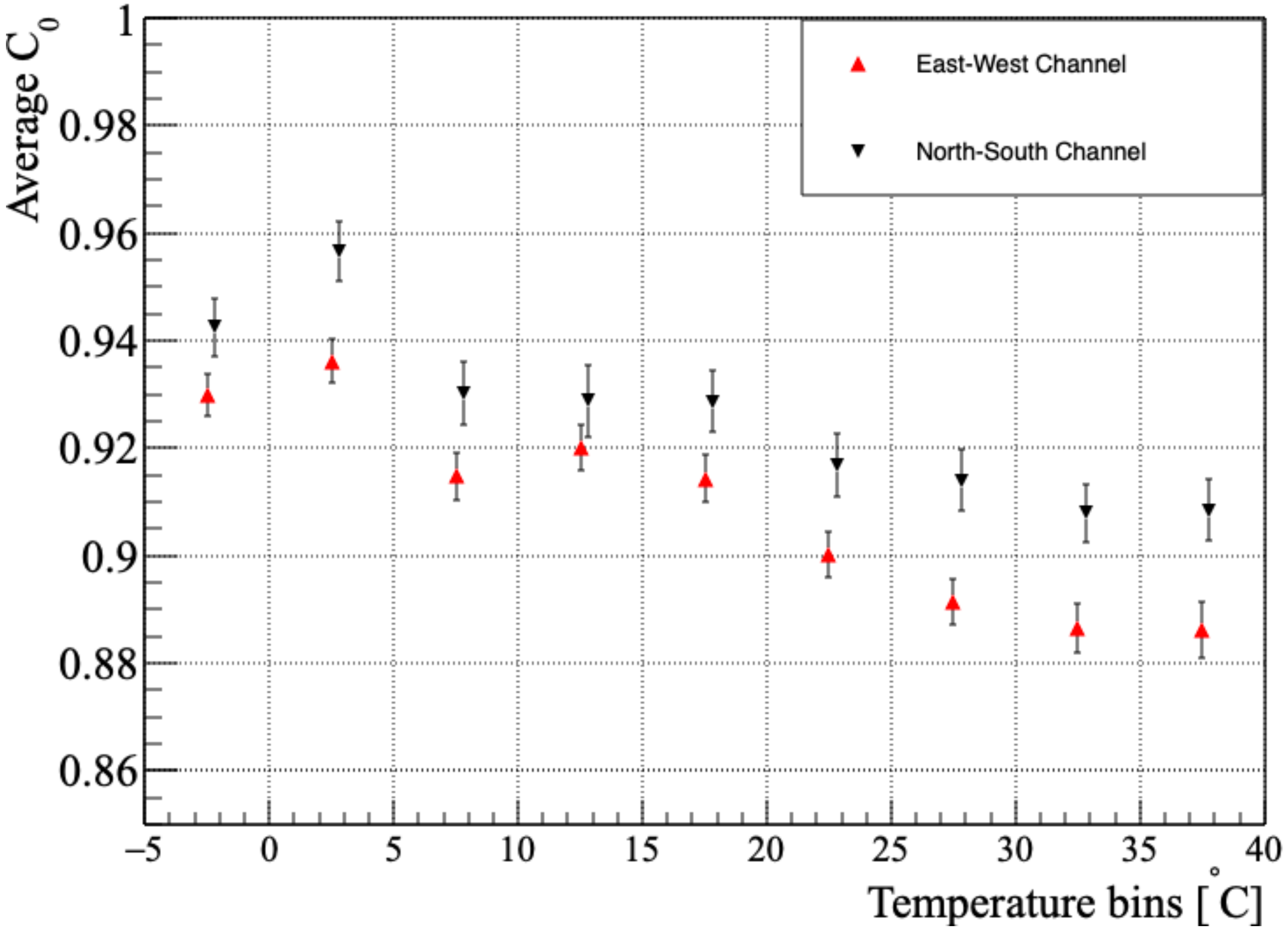
Fix a temperature bin (ex -5 to 0 degree)

In a whole year (2019) it only keeps traces when the temperature is within the temperature bin



Calibration

★ **Temperature correction is used**



Study of Irradiance x C_0

- Spectrum of each antenna obtained considering the whole year of 2020
- Irradiance data used

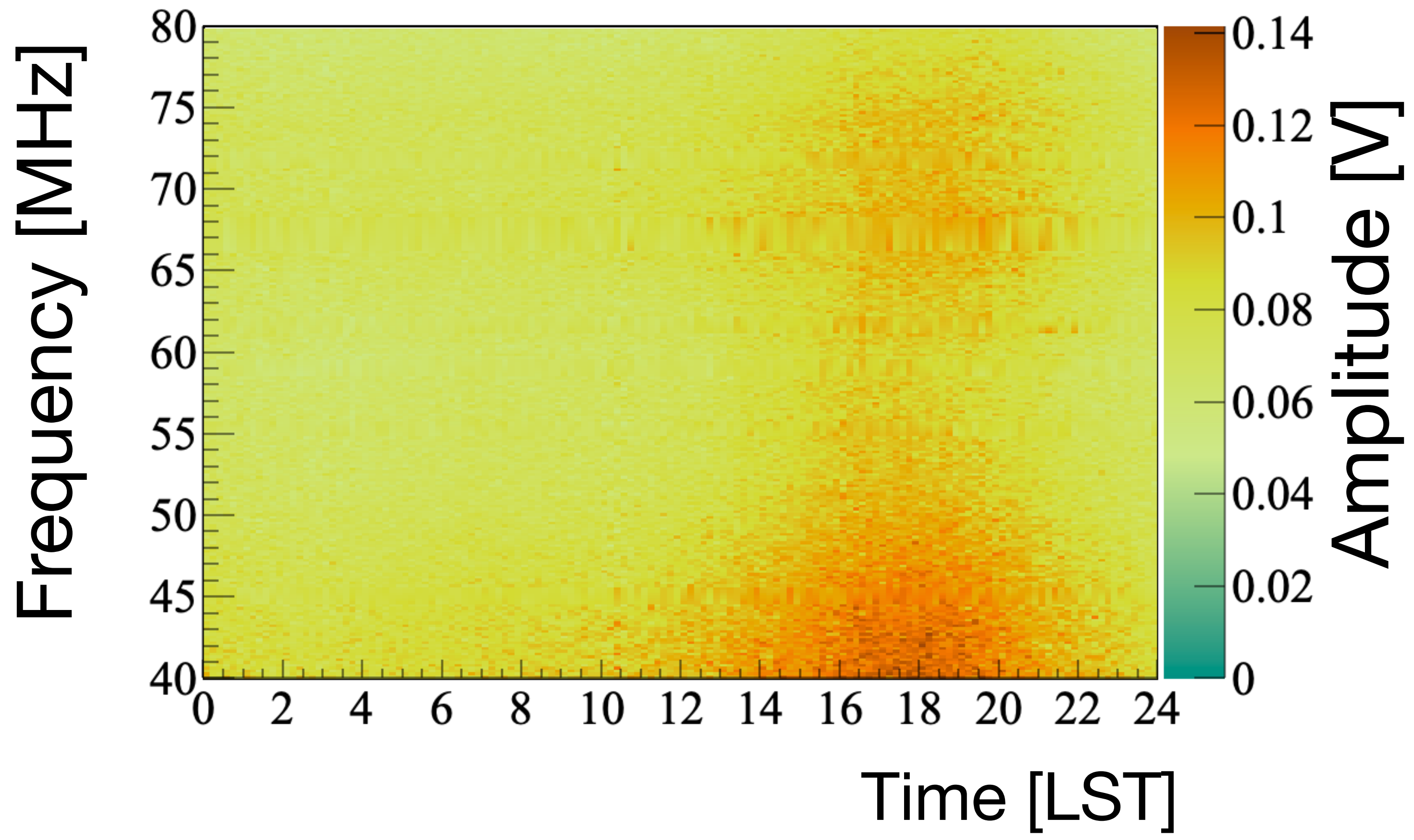
★ **Temperature correction is used**

Procedure

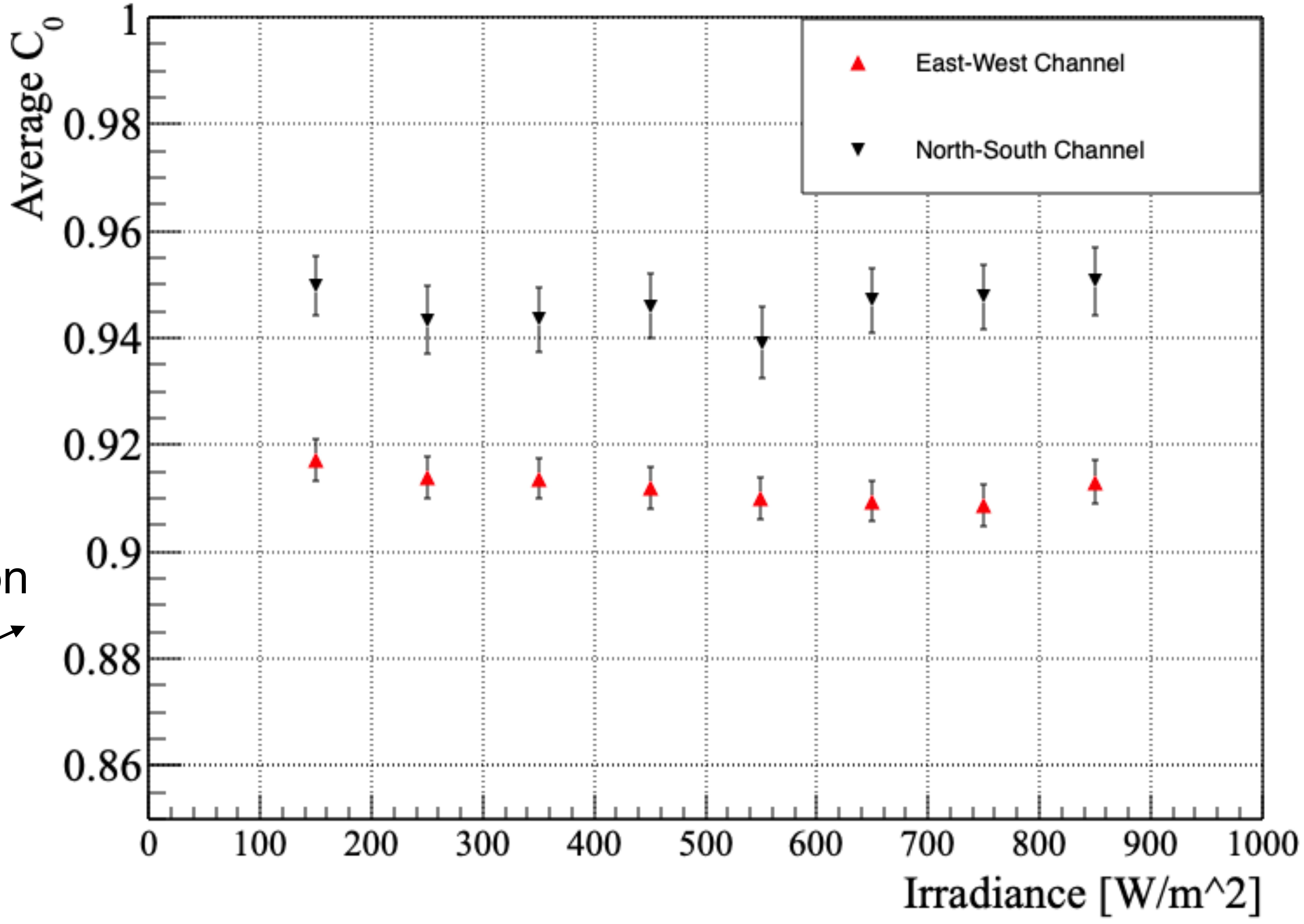
Fix an Irradiance bin (ex 200 to 300 W/m^2)

In a whole year (2020) it only keeps traces when the irradiance is within the irradiance bin

Id:147 - East-West channel

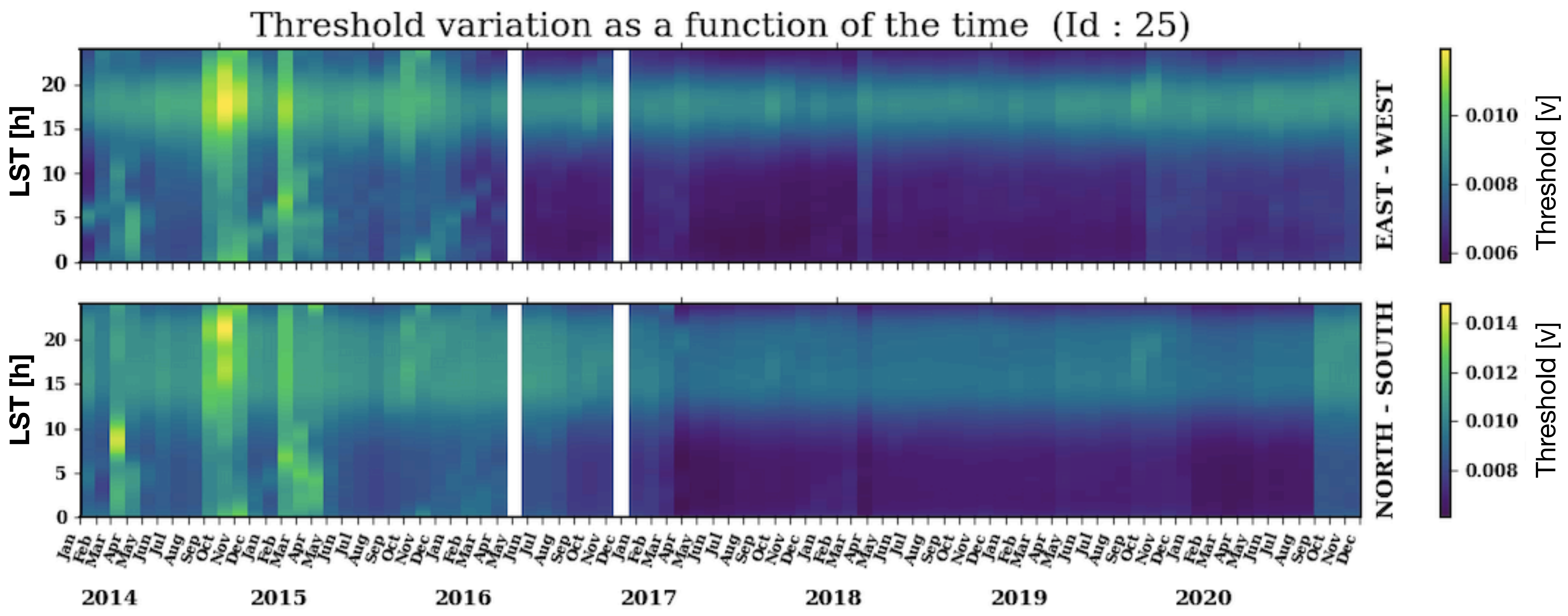


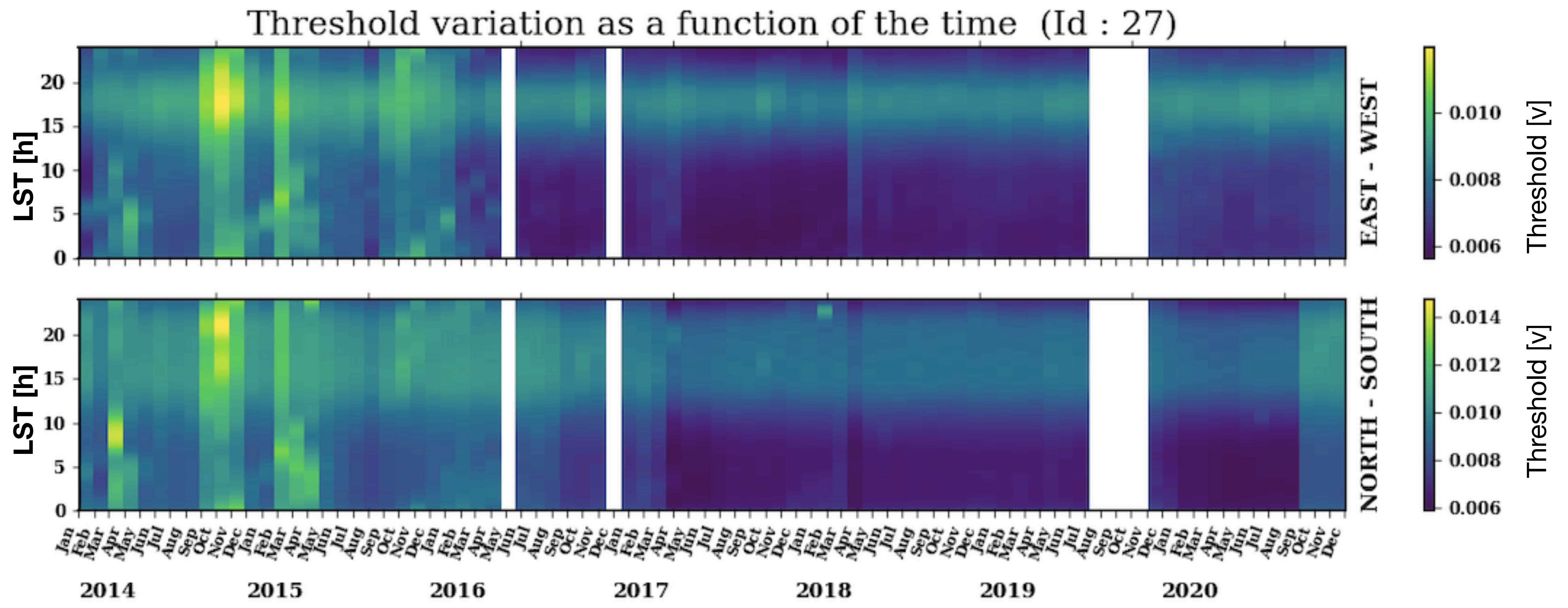
Calibration

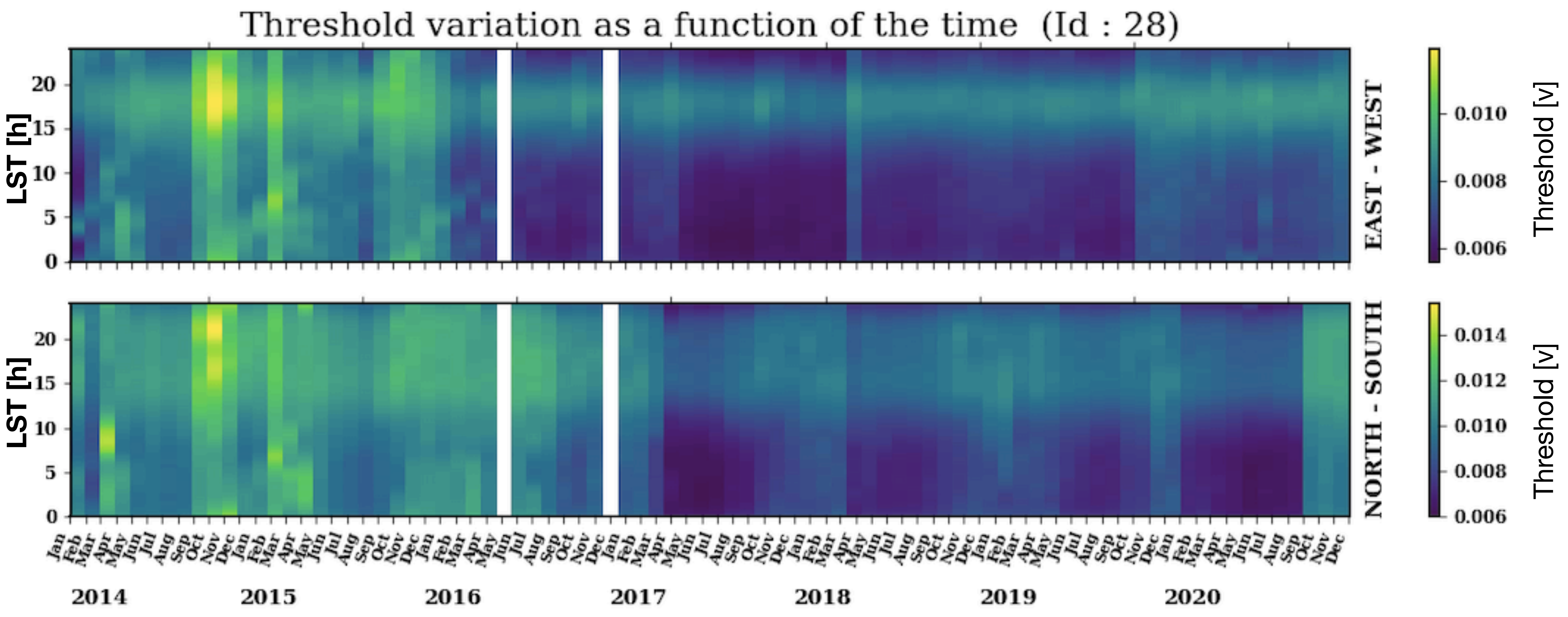


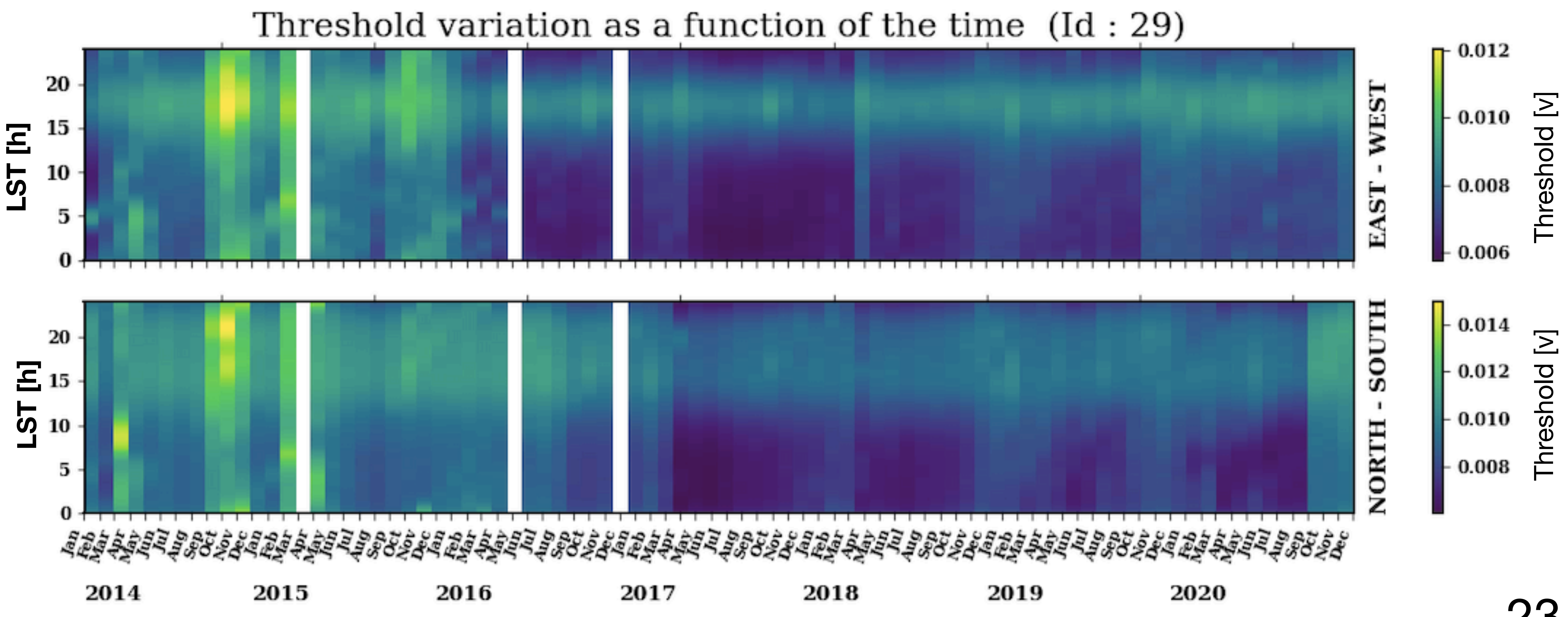
Time-dependent threshold approach

- Threshold as a function of time for each antenna









Time-dependent threshold approach

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