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Improvements on f_0F_1 estimation at polar regions

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ROMA TRE UNIVERSITÀ DEGLI STUDI

Istituto Nazionale di Geofisica e Vulcanologia

Outline

- ✓ AUSPICIO project
- ✓ Data set
- ✓ Behaviour of the f_0F_1 DuCharme and Petrie formulation
- ✓ Correction proposal to the f_0F_1 formulation
- ✓ Some interesting ionograms

AUSPICIO project

Automatic **S**caling of **P**olar **I**onograms and **C**ooperative **I**onospheric **O**bservations

✓ PNRA funded project

✓ carried out by INGV and ICTP

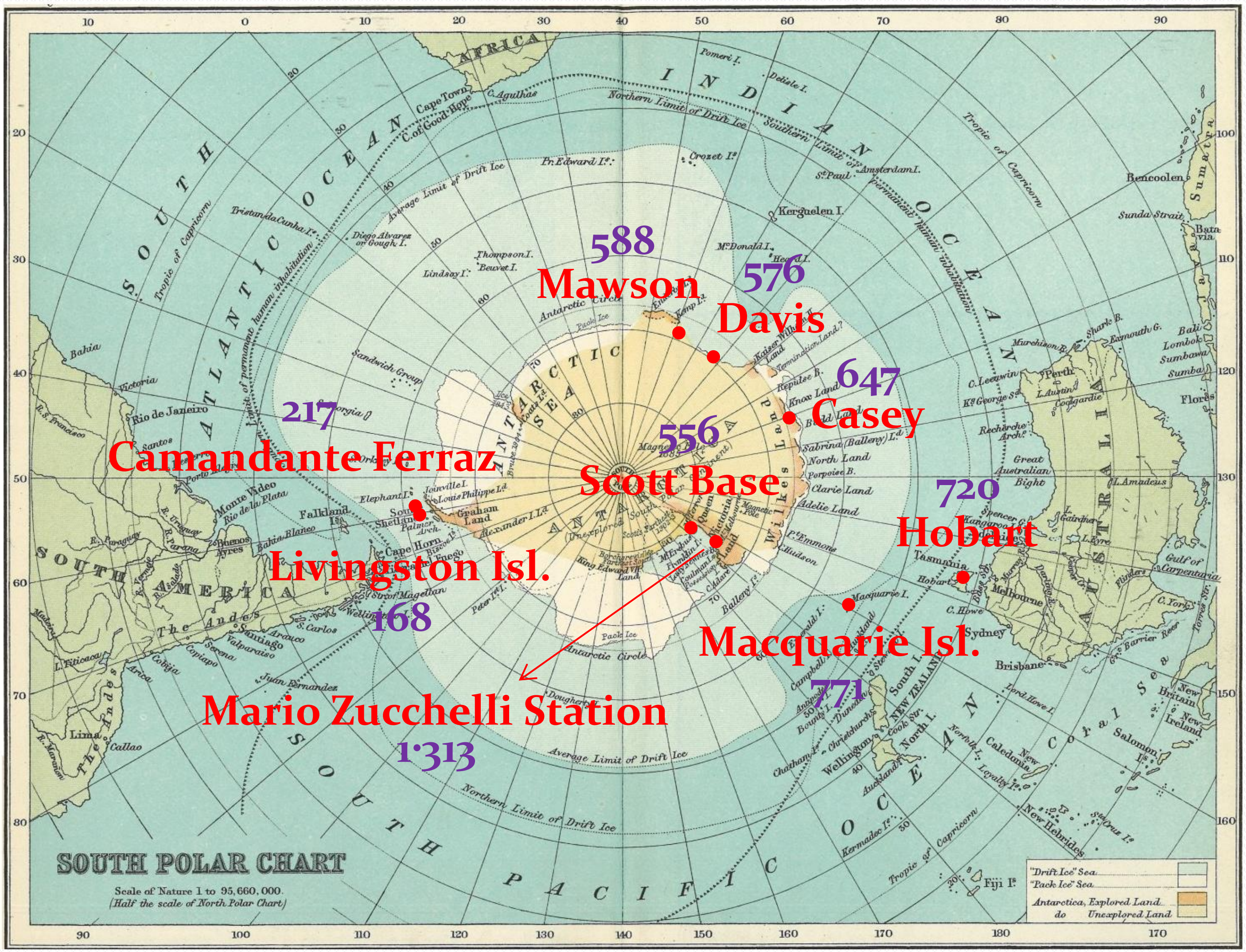
Task ➡ improvements to Autoscala for application in polar regions

… using ionogram samples provided by international institutions:

Location	Geographic Coordinates	Ionosonde	Manager	Country
Hobart	42.2 °S, 147.3 °E	CADI	SWS	Australia
Macquarie Island	54.5 °S, 159.0°E	CADI	SWS	Australia
Livingston Island	62.7 °S, 299.6 °E	AIS-INGV	Universitat Ramon Lull	Spain
Estação Antártica Comandante Ferraz	62.1°S, 58.4°W	CADI	INPE	Brazil
Casey	66.3 °S, 110.50 °E	CADI	SWS	Australia
Mawson	67.6 °S, 62.9°E	CADI	SWS	Australia
Davis	68.6 °S, 78.0 °E	Digisonde	Antarctic Division	Australia
Base Mario Zucchelli	74.7°S, 164.1°E	AIS-INGV	INGV	Italy
Scott Base	77.8 °S, 166.8 °E	IPS-42	SWS	Australia

Data set

- ✓ Total ionograms: 5·556 from 2001 to 2014
- ✓ Solar activity
  - high ($R_{12} > 100$): 2001
  - low ($R_{12} < 5$): 2009
  - medium (eg: 2003 for MZS)



$f_o\mathrm{F}_1$ DuCharme formulation behaviour

- $f_o\mathrm{F}_1$ manually scaled (reliable values) $\longrightarrow$ $f_o\mathrm{F}_1{}^{\mathrm{obs}}$
- DuCharme and Petrie $f_o\mathrm{F}_1$ $\longrightarrow$ $f_o\mathrm{F}_1{}^{\mathrm{DC}}$

Comparison for:

- all data
- stations separately

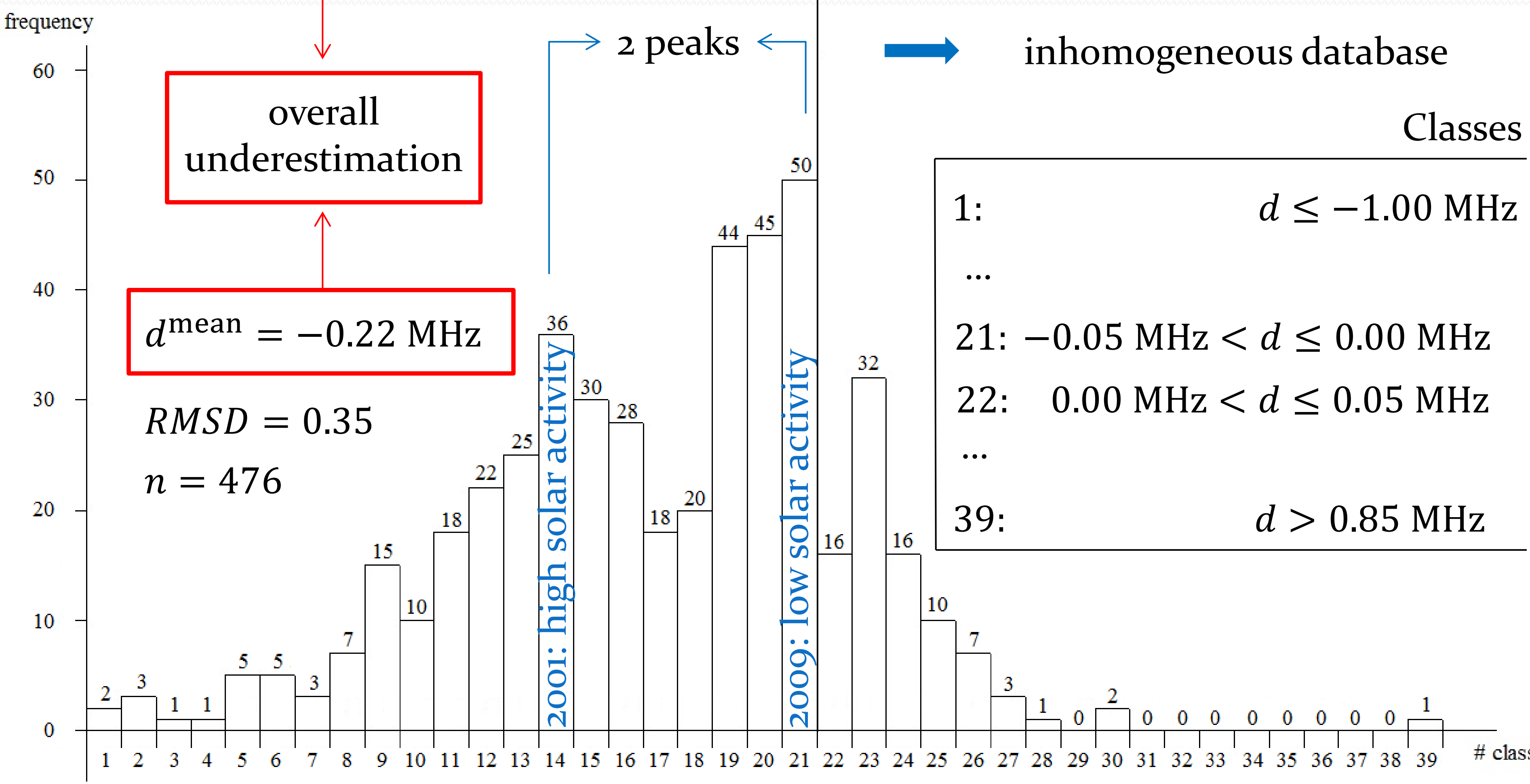
✓ $RMSD = \sqrt{\frac{\sum_{i=1}^{n}\left(d^{(i)}\right)^2}{n}}$ with $d^{(i)} \equiv \Delta f_o\mathrm{F}_1{}^{(i)} = f_o\mathrm{F}_1{}^{\mathrm{DC}(i)} - f_o\mathrm{F}_1{}^{\mathrm{obs}(i)}$

✓ histograms with classes defined by d intervals of 0.05 MHz

• All data

$f_oF_1^{\,DC} < f_oF_1^{\,obs}$ — DuCharme underestimation

$f_oF_1^{\,DC} > f_oF_1^{\,obs}$ — DuCharme overestimation



overall underestimation

$d^{\text{mean}} = -0.22$ MHz

$RMSD = 0.35$

$n = 476$

inhomogeneous database

Classes

1: $d \le -1.00$ MHz

…

21: $-0.05\text{ MHz} < d \le 0.00$ MHz

22: $0.00\text{ MHz} < d \le 0.05$ MHz

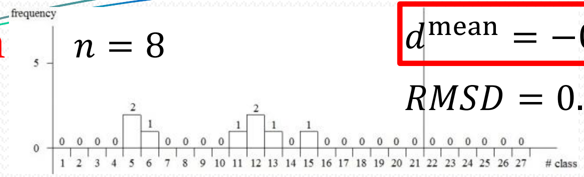
…

39: $d > 0.85$ MHz

14: $-0.40\text{MHz} < d \le 0.35$ MHz

- Stations separately

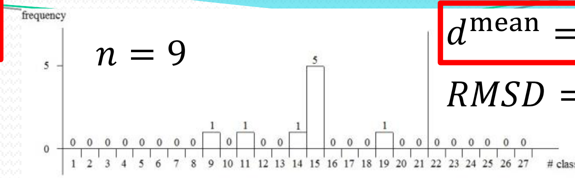
Livingston Isl.



$n = 8$

$d^{mean} = -0.60$ MHz

$RMSD = 0.61$



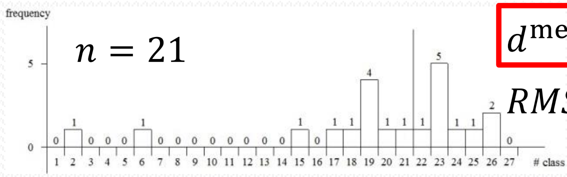
$n = 9$

$d^{mean} = -0.37$ MHz

$RMSD = 0.39$

Com. Ferraz

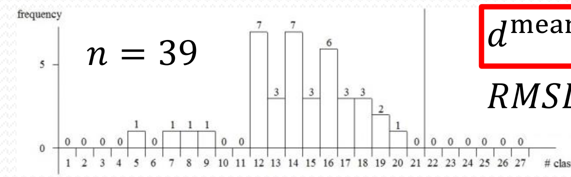
Casey



$n = 21$

$d^{mean} = -0.10$ MHz

$RMSD = 0.31$



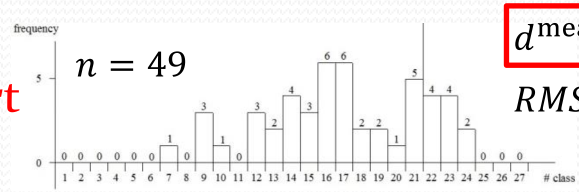
$n = 39$

$d^{mean} = -0.36$ MHz

$RMSD = 0.40$

Davies

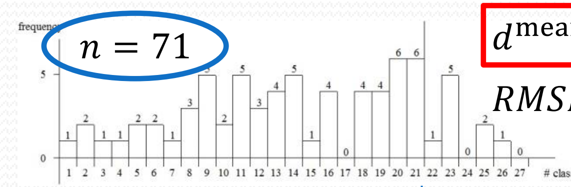
Hobart



$n = 49$

$d^{mean} = -0.22$ MHz

$RMSD = 0.31$



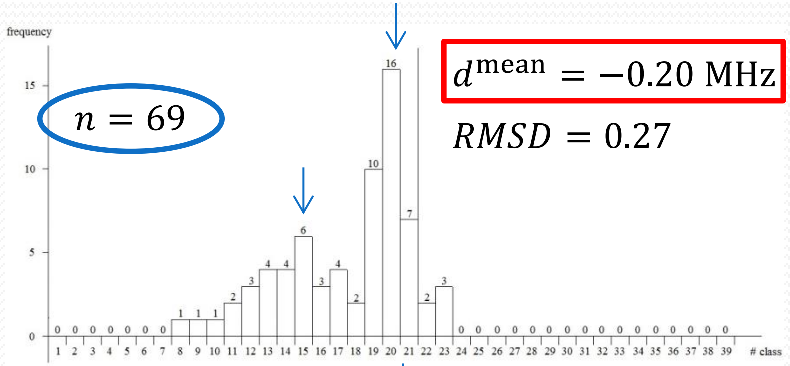
$n = 71$

$d^{mean} = -0.35$ MHz

$RMSD = 0.48$

Scott Base

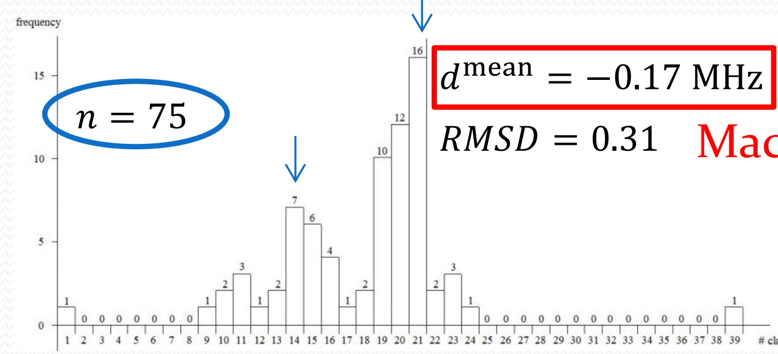
Mawson



$n = 69$

$d^{mean} = -0.20$ MHz

$RMSD = 0.27$



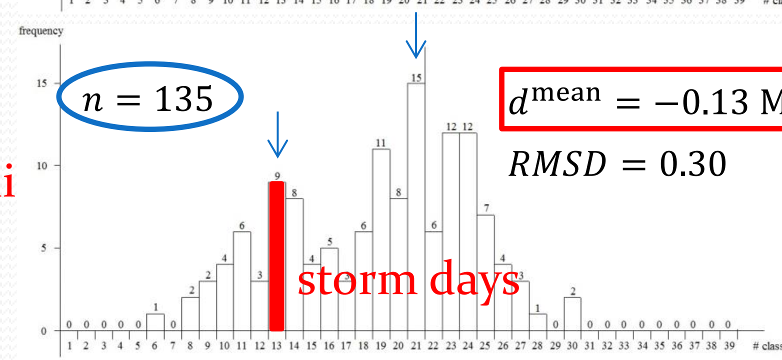
$n = 75$

$d^{mean} = -0.17$ MHz

$RMSD = 0.31$

Macquarie Isl.

Mario Zucchelli Station



$n = 135$

$d^{mean} = -0.13$ MHz

$RMSD = 0.30$

✓ DuCharme underestimation in all stations

✓ inhomogeneous database

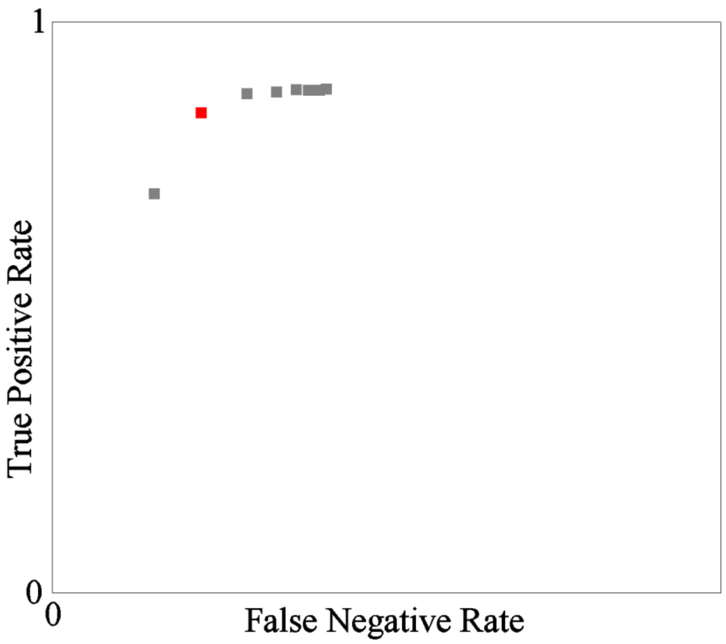
f_oF_1 DuCharme formulation correction

✓ Where?

- particular station at polar regions ⟶ improved version of Autoscala
- performance of a procedure for detecting spread-F (poster presentation, C. Scotto, A. Ippolito)

➡ Macquarie Island

Receiver Operating Characteristic (ROC) curve method



f_0F_1 DuCharme formulation correction

- ✓ How? original DuCharme and Petrie formulation (1973):

$$f_0F_1^{DC} = f_s \cdot \cos^\eta \chi$$

with

$$\eta = 0.093 + 0.0046 \cdot |\lambda| - 0.000054 \cdot |\lambda|^2 + 0.0003 \cdot R_{12}$$

$$f_s = f_0 + [(f_{100} - f_0) \cdot (R_{12}/100)]$$

where

$$f_0 = 4.350 + 0.0058 \cdot |\lambda| - 0.000120 \cdot |\lambda|^2$$

$$f_{100} = 5.348 + 0.0110 \cdot |\lambda| - 0.000230 \cdot |\lambda|^2$$

1. Definition of the parameters a_1, a_2, b, c /

$$\eta_{[Mac]} = a_1 + a_2 \cdot R_{12}$$

$$f_{0[Mac]} = b$$

$$f_{100[Mac]} = c$$

$\lambda_{[Mac]} = -59.6$ →

$a_{1[base]} = 0.17534$

$a_{2[base]} = 0.0003$

$b_{[base]} = 4.2694206$

$c_{[base]} = 5.1866032$

$f_o F_1$ DuCharme formulation correction

2. Variation a_1, a_2, b, c $\longrightarrow$ $RMSD$ minimization

$\Rightarrow$

$a_1* = 0.166573$ $\quad b* = 4.312114$ $\quad RMSD^{\min} = 0.22$

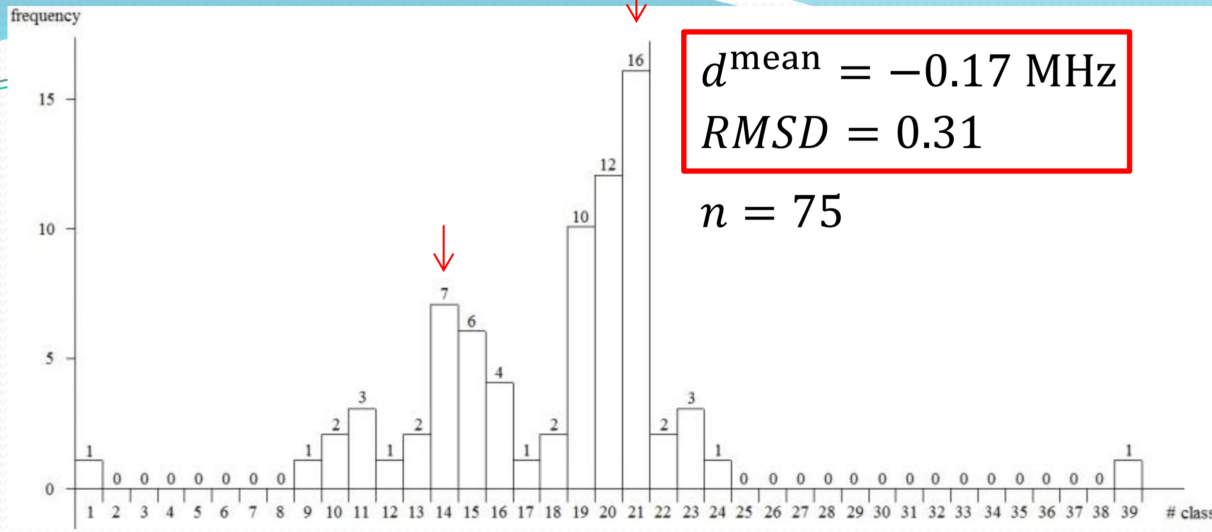
$a_2{}^* = 0.0027$ $\quad c^* = 5.4978$

$$f_o F_{1[\mathrm{Mac}]}^{\mathrm{new}} = f_{s[\mathrm{Mac}]}(b^*, c^*) \cdot \cos^{\eta_{[\mathrm{Mac}]}(a_1{}^*, a_2{}^*)} \chi$$

with $\quad f_{s[\mathrm{Mac}]} = b^* + [(c^* - b^*) \cdot (R_{12}/100)]$

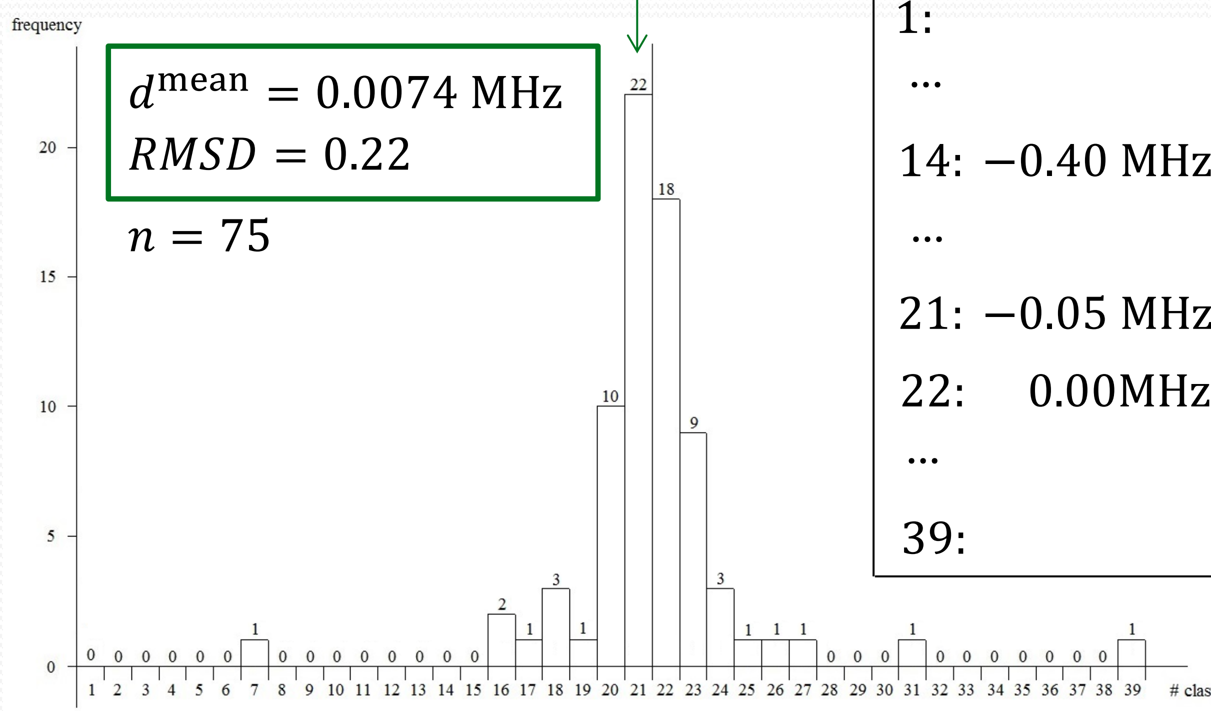
$$\eta_{[\mathrm{Mac}]} = a_1* + a_2* \cdot R_{12}$$

✓ $f_o F_{1[\mathrm{Mac}]}^{\mathrm{DC}}$



single peak

✓ $f_o F_{1[\mathrm{Mac}]}^{\mathrm{new}}$



Classes

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…

14: $-0.40\ \mathrm{MHz} < d \leq 0.35$ MHz

…

21: $-0.05\ \mathrm{MHz} < d \leq 0.00$ MHz

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…

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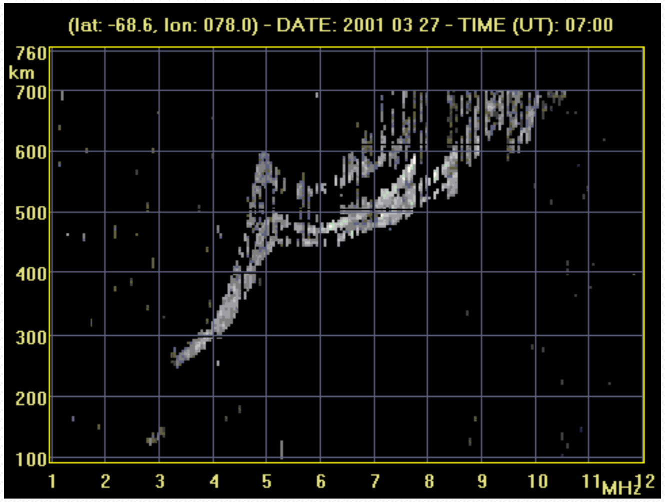
Conclusions

- ✓ Polar ionograms data set analysis
- ✓ Comparison between $f_o F_1{}^{obs}$ and $f_o F_1{}^{DC}$
- ✓ $f_o F_1{}^{DC}$ underestimates $f_o F_1{}^{obs}$, expecially for high solar activity
- ✓ Correction proposal for $f_o F_1$ estimation at Macquarie Island
- ✓ Good behaviour of $f_o F_{1[Mac]}^{new}$
- ✓ Further study
  - wider data set
  - solar activity
  - geomagnetic activity

→ generalization at polar regions

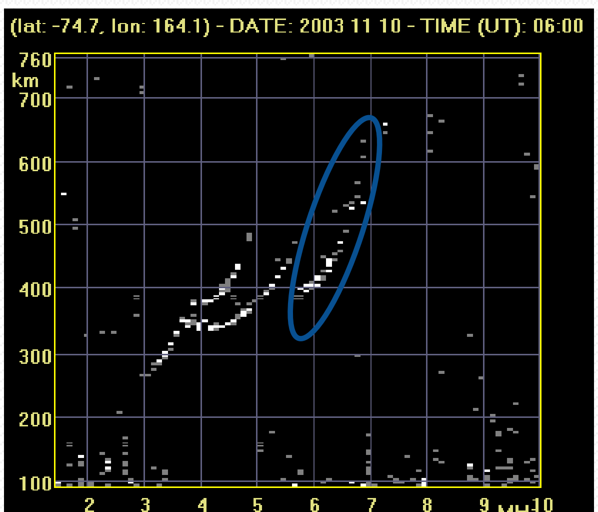
Some interesting ionograms

Davis



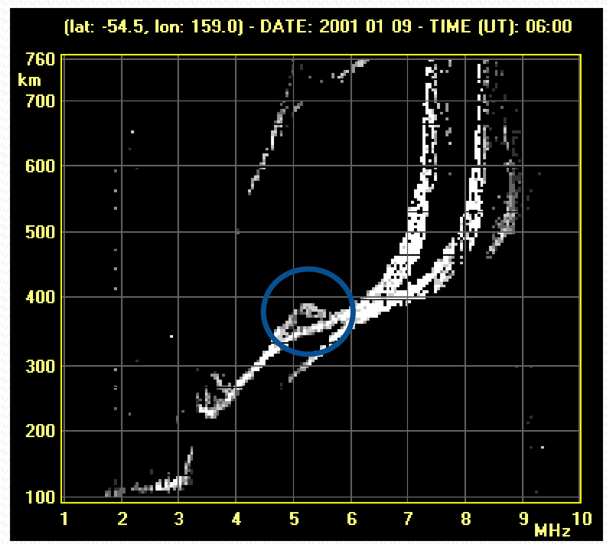
✓ Multiple reflections

Mario Zucchelli Station



✓ Z-ray

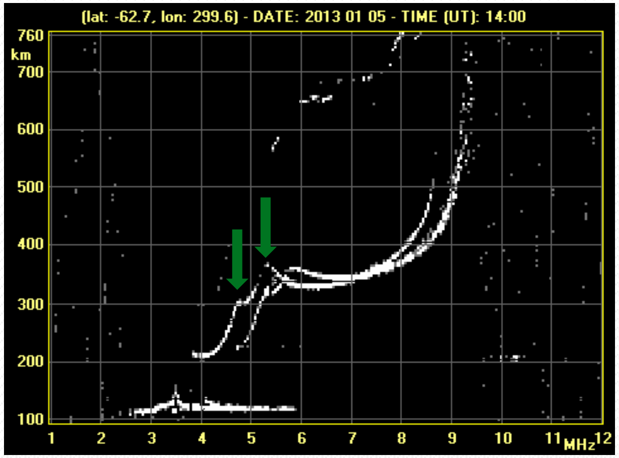
Macquarie Island



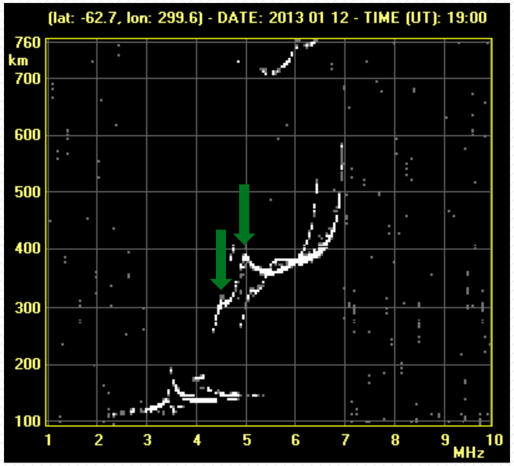
✓ Tilted ionosphere

Some interesting ionograms

Livingston Island

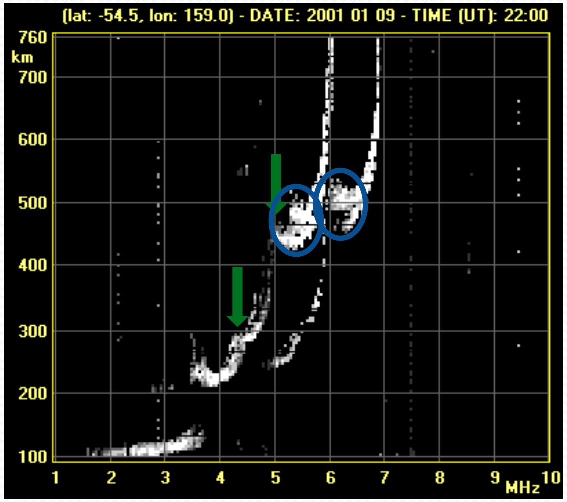


Livingston Island



✓ Double stratification

Macquarie Island



✓ Double stratification
+ tilted ionosphere

Thank you
for your attention

Acknowledgements

- Space Weather Service (SWS, Australia) for providing the ionograms database at Hobart, Macquarie Island, Casey, Mawson, Davis, and Scott Base
- Istituto Nacional de Pesquisas Espaciais (INPE, Brasil) for providing the ionograms at Comandante Ferraz
- Universitat Ramon Lull (Spain) for providing the ionograms at Livingstone Island
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