Improvements on $f_0F_1$ estimation at polar regions

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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 Scaling of Polar Ionograms and Cooperative Ionospheric Observations

✓ 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:

<table>
<thead>
<tr>
<th>Location</th>
<th>Geographic Coordinates</th>
<th>Ionosonde</th>
<th>Manager</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hobart</td>
<td>42.2 °S, 147.3 °E</td>
<td>CADI</td>
<td>SWS</td>
<td>Australia</td>
</tr>
<tr>
<td>Macquarie Island</td>
<td>54.5 °S, 159.0 °E</td>
<td>CADI</td>
<td>SWS</td>
<td>Australia</td>
</tr>
<tr>
<td>Livingston Island</td>
<td>62.7 °S, 299.6 °E</td>
<td>AIS-INGV</td>
<td>Universitat Ramon Lull</td>
<td>Spain</td>
</tr>
<tr>
<td>Estação Antártica</td>
<td>62.1°S, 58.4°W</td>
<td>CADI</td>
<td>INPE</td>
<td>Brazil</td>
</tr>
<tr>
<td>Comandante Ferraz</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Casey</td>
<td>66.3 °S, 110.50 °E</td>
<td>CADI</td>
<td>SWS</td>
<td>Australia</td>
</tr>
<tr>
<td>Mawson</td>
<td>67.6 °S, 62.9 °E</td>
<td>CADI</td>
<td>SWS</td>
<td>Australia</td>
</tr>
<tr>
<td>Davis</td>
<td>68.6 °S, 78.0 °E</td>
<td>Digisonde</td>
<td>Antarctic Division</td>
<td>Australia</td>
</tr>
<tr>
<td>Base Mario Zucchelli</td>
<td>74.7°S, 164.1°E</td>
<td>AIS-INGV</td>
<td>INGV</td>
<td>Italy</td>
</tr>
<tr>
<td>Scott Base</td>
<td>77.8 °S, 166.8 °E</td>
<td>IPS-42</td>
<td>SWS</td>
<td>Australia</td>
</tr>
</tbody>
</table>
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)
$f_0F_1$ DuCharme formulation behaviour

- $f_0F_1$ manually scaled (reliable values) \(\rightarrow f_0F_1^{\text{obs}}\)
- DuCharme and Petrie $f_0F_1$ \(\rightarrow f_0F_1^{\text{DC}}\)

Comparison for:
- all data
- stations separately

\[
\text{RMSD} = \sqrt{\frac{\sum_{i=1}^{n}(d^{(i)})^2}{n}} \quad \text{with} \quad d^{(i)} \equiv \Delta f_0F_1^{(i)} = f_0F_1^{\text{DC}(i)} - f_0F_1^{\text{obs}(i)}
\]

✓ histograms with classes defined by $d$ intervals of 0.05 MHz
\[ d \leq -1.00 \text{ MHz} \]

DuCharme underestimation

\[ d > 0.85 \text{ MHz} \]

DuCharme overestimation

\[ f_{0}F_{1}^{\text{DC}} < f_{0}F_{1}^{\text{obs}} \]

\[ f_{0}F_{1}^{\text{DC}} > f_{0}F_{1}^{\text{obs}} \]

\[ d_{\text{mean}} = -0.22 \text{ MHz} \]

\[ RMSD = 0.35 \]

\[ n = 476 \]

2001: high solar activity

2009: low solar activity

\[ -0.40 \text{ MHz} < d \leq 0.35 \text{ MHz} \]

\[ 14: \]

<table>
<thead>
<tr>
<th>Class</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( d \leq -1.00 \text{ MHz} )</td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>(-0.05 \text{ MHz} &lt; d \leq 0.00 \text{ MHz} )</td>
</tr>
<tr>
<td>22</td>
<td>(0.00 \text{ MHz} &lt; d \leq 0.05 \text{ MHz} )</td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>( d &gt; 0.85 \text{ MHz} )</td>
</tr>
</tbody>
</table>

\( f_{0}F_{1}^{\text{DC}} < f_{0}F_{1}^{\text{obs}} \)

\( f_{0}F_{1}^{\text{DC}} > f_{0}F_{1}^{\text{obs}} \)

incomplete database
• Stations separately

Livingston Isl.

- Station: Livingston Isl.
- Number of observations: \( n = 8 \)
- Mean difference: \( d^\text{mean} = -0.60 \text{ MHz} \)
- RMSD: 0.61

Casey

- Station: Casey
- Number of observations: \( n = 21 \)
- Mean difference: \( d^\text{mean} = -0.10 \text{ MHz} \)
- RMSD: 0.31

Hobart

- Station: Hobart
- Number of observations: \( n = 49 \)
- Mean difference: \( d^\text{mean} = -0.22 \text{ MHz} \)
- RMSD: 0.31

Mawson

- Station: Mawson
- Number of observations: \( n = 69 \)
- Mean difference: \( d^\text{mean} = -0.20 \text{ MHz} \)
- RMSD: 0.27

Davies

- Station: Davies
- Number of observations: \( n = 71 \)
- Mean difference: \( d^\text{mean} = -0.35 \text{ MHz} \)
- RMSD: 0.48

Scott Base

- Station: Scott Base
- Number of observations: \( n = 75 \)
- Mean difference: \( d^\text{mean} = -0.17 \text{ MHz} \)
- RMSD: 0.31

Macquarie Isl.

- Station: Macquarie Isl.
- Number of observations: \( n = 135 \)
- Mean difference: \( d^\text{mean} = -0.13 \text{ MHz} \)
- RMSD: 0.30

- DuCharme underestimation in all stations
- Inhomogeneous database
\[ f_{0}F_1 \] DuCharme formulation correction

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

- Macquarie Island

Receiver Operating Characteristic (ROC) curve method

![ROC Curve](image)
The DuCharme formulation correction

How?

original DuCharme and Petrie formulation (1973):

\[ f_0 F_1^{DC} = f_s \cdot \cos^n \chi \]

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

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

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

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

\[ \lambda_{[Mac]} = -59.6 \]

\[ a_{1[base]} = 0.17534 \]

\[ b_{[base]} = 4.2694206 \]

\[ a_{2[base]} = 0.0003 \]

\[ c_{[base]} = 5.1866032 \]
$f_0 F_1$ DuCharme formulation correction

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

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

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

$$f_{0F_1}^{\text{new}}[\text{Mac}] = f_s[\text{Mac}](b^*, c^*) \cdot \cos^{\eta_{\text{Mac}}}(a_1^*, a_2^*) \chi$$

with

$$f_s[\text{Mac}] = b^* + [(c^* - b^*) \cdot (R_{12}/100)]$$

$$\eta_{\text{Mac}} = a_1^* + a_2^* \cdot R_{12}$$
\[ RMD = 0.31 \]
\[ d^{mean} = -0.17 \text{ MHz} \]
\[ n = 75 \]

Single peak

Classes

1: \[ d \leq -1.00 \text{ MHz} \]

... 

14: \[ -0.40 \text{ MHz} < d \leq 0.35 \text{ MHz} \]

... 

21: \[ -0.05 \text{ MHz} < d \leq 0.00 \text{ MHz} \]

22: \[ 0.00 \text{ MHz} < d \leq 0.05 \text{ MHz} \]

... 

39: \[ d > 0.85 \text{ MHz} \]
Conclusions

✓ Polar ionograms data set analysis

✓ Comparison between \( f_0 F_1^{\text{obs}} \) and \( f_0 F_1^{\text{DC}} \)

✓ \( f_0 F_1^{\text{DC}} \) underestimates \( f_0 F_1^{\text{obs}} \), especially for high solar activity

✓ Correction proposal for \( f_0 F_1 \) estimation at Macquarie Island

✓ Good behaviour of \( f_0 F_1^{\text{new}}_{\text{[Mac]}} \)

✓ 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

- 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
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• Universitat Ramon Lull (Spain) for providing the ionograms at Livingstone Island
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