Challenges of Ionogram Autoscaling

Lessons Learned from ARTIST-5 Evaluation

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Ionogram Autoscaling

MILLSTONE HILL, MHJ45

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SAO Explorer, v 3.4.11b1
Outline

> **Challenges of Automatic Ionogram Scaling:**
  ✓ A. Make less errors
  ✓ B. Detect significant errors by post-analysis to disqualify such data
  ✓ C. Characterize uncertainty of ionogram-derived data due to autoscaling errors

> **Autoscaling Confidence Level (ACL)**
  ✓ Prevent low confidence data from assimilation

> **ARTIST-5 Uncertainty Study**
  ✓ Error Bounds for Characteristics
  ✓ Error Boundaries for Electron Density Profile (EDP)
A. Make Less Autoscaling Errors

> Solutions vary among different ionosonde providers

> Solutions are specific to autoscaling software design
  ✓ Computer Vision approach
  ✓ Signal Processing approach
    • Phase-aware techniques
  ✓ Ne Profile Morphing approach

> ARTIST-5 released May 2007
  ✓ Improved performance
  ✓ Improvements qualified by manual vs. auto studies
    • Using ~250,000 manually scaled ionograms in Lowell DIDBase
Lessons Learned

> ARTIST needs to operate during periods of degraded hardware capability
  ✓ Polarization tagging
  ✓ Directional analysis
  ✓ Precision ranging
  ✓ Signal to noise ratio
  ✓ Non-optimal measurement settings
    • Frequency resolution
    • Range coverage

> Warranted additional effort directed at computer vision techniques
  ✓ Good “background” model
ARTIST-5 Innovations

ANNA

© 1993-2007

Artificial Neural Network Algorithm

PACIFIC


Program for Autoscaling of Conventional Ionograms with Flexible Interpretation Control

© 2007

A45

1 km
ANNA: Extraction of traces

- Original design: 1993-1994
- Bio-plausible additions: 2003-2004
- New clustering algorithm: 2007

Rotor interaction (co-circular model)

Hopfield Recurrent ANN

Honda ASIMO
Seeks trace segments pointing up
Considers 6 configurations A-F
Fits O- and X-cusps independently and refits if they do not match
Allows down-grading to ionograms without polarization tagging or with swapped polarizations

✓ Learmonth, Australia
✓ Jicamarca, Peru
A45: Edgel detection

IONOGRAM thresholded

Classic edgel detection

A45 edgel detection
ARTIST-5 Lessons learned

> Accurate foF2 cusp processing is most important
  ✓ Careful with cusp extrapolation above last trace point

> Imperfections in trace extraction are not important
  ✓ Small effect on Ne density profile

> NHPC Profile inversion works as trace gap interpolator
ARTIST-5: Lessons learned (2)

> Short steep high traces are most difficult
  ✓ Summer
  ✓ Low solar activity
  ✓ Storm time / F3 layer

> Second hop traces are difficult
  ✓ from sporadic E layer
  ✓ stronger than 1st hop trace

> Ionograms taken during spread F conditions shall be processed differently
B. Detect Significant Errors

> Detect significant autoscaling errors to avoid their assimilation
  ✓ Describe remaining minor errors statistically
    • Error bars for characteristics
    • Error boundaries for EDP

> History of error detection by post-analysis:
  ✓ USAF QUALSCAN © 1986-2008
  ✓ ADEP “Merit check” © 1990-1992
  ✓ ARTIST-4 C-Level © 1994-1995
  ✓ JORN Australia Quality Control
  ✓ ARTIST 5 © 2006-2008
ARTIST-5 Confidence Score

> Determined automatically by inspecting both interpretation process and its outcome for anomalies
> Confidence Score ranges from 0 to 100
> Starting score is 100
  ✓ Lower starting score for ionograms with spread F
> Confidence score is lowered each time a quality criterion is violated
> If final score gets below 50, the scaling is flagged as low confidence
AFWA DISS data for GAIM

> 14 DISS digisondes, 17 contributing digisondes send their data to AFWA GAIM for assimilation

> ARTIST-5 software upgrade in progress for digisondes to avert low confidence data from assimilation
C. Characterize Uncertainty

> Probability that true value lies within the uncertainty bounds placed around given value
  ✓ $\sigma$, $2\sigma$, $3\sigma$, 80%, 90%, 95% probability

> Frequently called “Error Bar”

> Multiple sources of uncertainty:
  ✓ Autoscaling errors
  ✓ Model assumptions
  ✓ Equipment and processing bias
  ✓ HF propagation factors
Error Bounds and Error Boundaries

Roquettes, EB040

Error Bounds and Error Boundaries
ARTIST $f_0F2$ scaling, all records

Pruhonice DPS-4, 20675 ionograms (100%)

ARTIST underscales $f_0F2$

$-0.45 \text{ MHz}$

95%

ARTIST overshoots $f_0F2$

$+0.15 \text{ MHz}$
Automatic Spread-F Detection

All ionograms

Error bounds

Moderate spread

No spread

Heavy spread

Error bounds 1

Error bounds 2

Error bounds 3
Ionogram Classification

- Qualification is tailored to each digisonde station individually

- THREE CLASSES:
  - Quiet ionosphere (no spread)
  - Moderately disturbed ionosphere
  - Heavily disturbed ionosphere

- TWO SUB-CLASSES in each class based on Autoscaling Confidence Level (ACL)
  - Confidently scaled ionograms (ACL=1)
  - Not confidently scaled ionograms (ACL=0)
    - Only confident (ACL=1) records are sent to assimilation
Quiet-Confident Category

ARTIST 5 foF2 scaling, all records

ALL

Průhonice DPS-4, 20675 ionograms (100%)

Percent

Error, MHz

ARTIST underscales foF2

ARTIST overshifts foF2

-0.45 MHz

+0.15 MHz

95%

Lower bound = -0.45 MHz

ARTIST 5 foF2 scaling, quiet and confident category

QC

Průhonice DPS-4, 16712 ionograms (81%)

Percent

Error, MHz

ARTIST underscales foF2

ARTIST overshifts foF2

-0.3 MHz

+0.15 MHz

95%

Lower bound = -0.3 MHz
Comparison Results for foF2

<table>
<thead>
<tr>
<th>Location</th>
<th>System</th>
<th>ARTIST version</th>
<th>Total manual ionograms</th>
<th>ACL=1 percentage of all ionograms</th>
<th>Lower bound foF2 MHz</th>
<th>Upper bound foF2 MHz</th>
<th>Unscalable ionograms % of all ionograms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boulder, CO</td>
<td>DISS</td>
<td>4.5</td>
<td>47,261</td>
<td>82 %</td>
<td>-0.3</td>
<td>+0.3</td>
<td>8 %</td>
</tr>
<tr>
<td>Vandenberg</td>
<td>DISS</td>
<td>4</td>
<td>4,660</td>
<td>78 %</td>
<td>-0.7</td>
<td>+0.7</td>
<td>4 %</td>
</tr>
<tr>
<td>Dyess</td>
<td>DISS</td>
<td>4</td>
<td>6,881</td>
<td>87 %</td>
<td>-2.4</td>
<td>+1.0</td>
<td>3 %</td>
</tr>
<tr>
<td>Dyess</td>
<td>DISS</td>
<td>5</td>
<td>6,881</td>
<td>90 %</td>
<td>-0.3</td>
<td>+0.5</td>
<td>3 %</td>
</tr>
<tr>
<td>Roquetes</td>
<td>D-256</td>
<td>5</td>
<td>125,046</td>
<td>85 %</td>
<td>-0.3</td>
<td>+0.4</td>
<td>5 %</td>
</tr>
<tr>
<td>Grahamstown</td>
<td>DPS-4</td>
<td>5</td>
<td>5,251</td>
<td>85 %</td>
<td>-0.1</td>
<td>+0.2</td>
<td>1 %</td>
</tr>
<tr>
<td>Pruhonice</td>
<td>DPS-4</td>
<td>5</td>
<td>20,675</td>
<td>88 %</td>
<td>-0.15</td>
<td>+0.35</td>
<td>3 %</td>
</tr>
<tr>
<td>Gakona, AK</td>
<td>DPS-4</td>
<td>5</td>
<td>11,109</td>
<td>48 %</td>
<td>-0.25</td>
<td>+0.6</td>
<td>13 %</td>
</tr>
</tbody>
</table>

TABLE 3: ARTIST foF2 validation results. Error bounds are given at 95% probability level for ionograms in quiet & confident category.
Summary

> Major campaign of ARTIST testing has been conducted using ¼ million manually scaled ionograms

> Error bounds are determined, enabling proper assimilation of ARTIST data
  ✓ foF2, foF1, foE
  ✓ Electron density profile

> ARTIST Confidence Level (ACL) is important and effective tool for quality control
  ✓ Low confidence data shall not be assimilated
  ✓ ~15% of data can be removed because of ACL

> UMASS Lowell developed tools and process data to aid further ARTIST development
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  - Inigo Blanco

**FREE ACCESS TO MANUALLY SCALED IONOGRAMS in DI DBASE**