### Ionogram

**Trace Extraction**
- **foF2**: 5.49
- **foF1**: 4.86
- **foF1p**: 4.56
- **foE**: 2.96
- **foEp**: 3.23
- **fxI**: 6.20
- **foEs**: 2.95

<table>
<thead>
<tr>
<th>MUF</th>
<th>18.70</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>3.415</td>
</tr>
<tr>
<td>D</td>
<td>3000</td>
</tr>
</tbody>
</table>

| h°F  | 185   |
| h°F2 | 285   |
| h°E  | 98    |
| h°Es | 98    |

| zmF2 | 227   |
| zmF1 | 196   |
| zmE  | 106   |
| yF2  | 67    |
| yF1  | 40    |
| yE   | 30    |

**C-level**: 1

### Trace Interpretation
- **foF2**: 5.49 MHz
- **foF1**: 4.86 MHz
- **foE**: 2.96 MHz
- **fxF2**: 6.20 MHz
- **h°F**: 185 km
- **h°F2**: 285 km
- **h°E**: 98 km
- **h°Es**: 98 km
- **zmF2**: 227 km
- **zmF1**: 196 km
- **zmE**: 106 km
- **yF2**: 67 km
- **yF1**: 40 km
- **yE**: 30 km

**Vertical Height, km**

**Frequency, MHz**

**MILLSTONE HILL, MHJ45**

**1996.04.01 (092) 19:34:37**
Outline

• Review of ARTIST-5 innovations
• 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)
• Where do we go from here
ARTIST Family

BISA (1981)  Bottomside Ionogram Scaling Algorithm, Cyber 71 and CDC 6600
ARTIST (1982)  Automatic Real Time Ionogram Scaler with True Height calculation, standalone unit based on Intel 8086 chip
ARTIST- II (1986) based on PC
ARTIST- III (1991)  upgrade to ARTIST-II for Digisonde 256
SARTIST (1991)  stand-alone version of ARTIST-III for DPS
ARTIST- 4.5 (2004)  Analysis of data in true height domain (trace gaps and truncation)
ARTIST- 5 (2002)  Fortran → Java, I/O and graphics unified with SAO-X, DIDB technology for testing, other improvements
ARTIST-5 Innovations

ANNAE
© 1993-2007
Artificial Neural Network pre-Attentive Eye

PACIFIC
Program for Autoscaling of Conventional Ionograms with Flexible Interpretation Control

© 2007

A45
1 km
Extraction of Traces

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

Rotor interaction
(co-circular model)

Initial state of NN  Final state of NN

Hopfield Feed-back ANN

Honda ASIMO
PACIFIC

- 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 Extraction

IONOGRAM thresholded

Classic edgel detection

“Dual” A45 edgel detection

1 km
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
  - Not removed by multi-hop analysis
  - Dourbes Digisonde 4D is prone to this
- Ionograms taken during spread F conditions shall be processed differently
Ionogram Optimization for ARTIST-5

• Use smallest frequency step possible under measurement time restrictions
• Use Precision Ranging mode
  – Subject to PR quality verification
• 5 km may be better than 2.5 km
• Reliable polarization tagging is important
  – Special considerations apply for equatorial locations
ARTIST Quality Assessment

- Autoscaling Confidence Level (ACL)
  - Detect severe errors to disqualify such ionograms

- Uncertainty of autoscaled ionograms
  - Bounds for characteristics
  - Boundaries on Ne profile
  - Components of uncertainty:
    - Autoscaling errors: statistics of manual vs autoscaled
    - Profile inversion uncertainty: compare NHPC to POLAN, add difference to the uncertainty
ARTIST 5 Confidence Score

- Determined automatically by inspecting both individual steps of interpretation process and its outcome for anomalies
- Confidence Score ranges from 0 to 100
- Starting score is 100
- Confidence score is lowered each time a quality criterion is violated
- If final score gets below 50, the scaling is flagged as low confidence
- **Do not use low-confidence autoscaled data for IRI validation/verification**
  - ARTIST Flag #10 in SAO and SAO.XML records
Error vs Uncertainty

Error bars vs Uncertainty bounds

**ERROR BAR**
- **Error**: difference between ARTIST value and the true value known from manual scaling
- Error histograms can be built and used to derive the error bars

**UNCERTAINTY BOUNDS**
- **Uncertainty**: expected difference between ARTIST value and unknown true value
- The error bar from previous statistical analysis is attributed to ARTIST value as uncertainty bound

**PRECISION**
- Repeating value in multiple takes
Error Bar → Uncertainty Bounds

• For example, foF2:
  – Manual vs. automatic comparison produces the ERROR BAR for foF2
  – Then, when ARTIST scales a new ionogram, foF2 value is attributed the UNCERTAINTY BAR
ARTIST 5 foF2 scaling, all records

Pruhonice DPS-4, 20675 ionograms (100%)

ARTIST underscales foF2

ARTIST overshoots foF2

-0.45 MHz

+0.15 MHz

95%
Automatic 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

**ALL**

**ARTIST 5 foF2 scaling, all records**

Pruhonice DPS-4, 20675 ionograms (100%)

- Lower bound = -0.45 MHz

**QC**

**ARTIST 5 foF2 scaling, quiet and confident category**

Pruhonice DPS-4, 16712 ionograms (81%)

- Lower bound = -0.3 MHz
Typical ARTIST-5 Error Bars
Digisonde 4D, mid-latitude station

<table>
<thead>
<tr>
<th>Parameter</th>
<th>% ionograms with perfect match to manual value</th>
<th>Error bounds encompassing 95% of all cases (2σ)</th>
<th>High ARTIST confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>QC</td>
<td>MC</td>
<td>HC</td>
</tr>
<tr>
<td>foF2</td>
<td>69%</td>
<td>60%</td>
<td>52%</td>
</tr>
<tr>
<td>foF1</td>
<td>46%</td>
<td>31%</td>
<td>-</td>
</tr>
<tr>
<td>foE</td>
<td>40%</td>
<td>20%</td>
<td>-</td>
</tr>
</tbody>
</table>
Future Work

• ARTIST 5.1
  – Baseline construction
  – E-F transition area
  – Clustering in spread F conditions
• ARTIST 6
  – Attention-driven techniques
    • Based on a model of expected traces
    • Fitting a joint set of O, X, and 2\textsuperscript{nd} hop traces
  – Added contribution from a medium scale wave-like irregularity
  – Multi-scale analysis instead of Spread-F detector