XXIX$^{th}$ URSI General Assembly

August 14, 2008 • Chicago, IL, USA

# Challenges of Ionogram Autoscaling

## Lessons Learned from ARTIST-5 Evaluation


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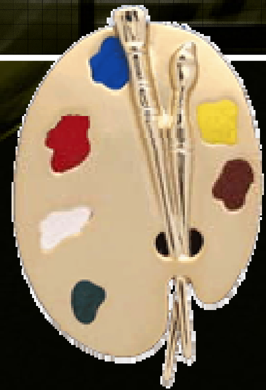


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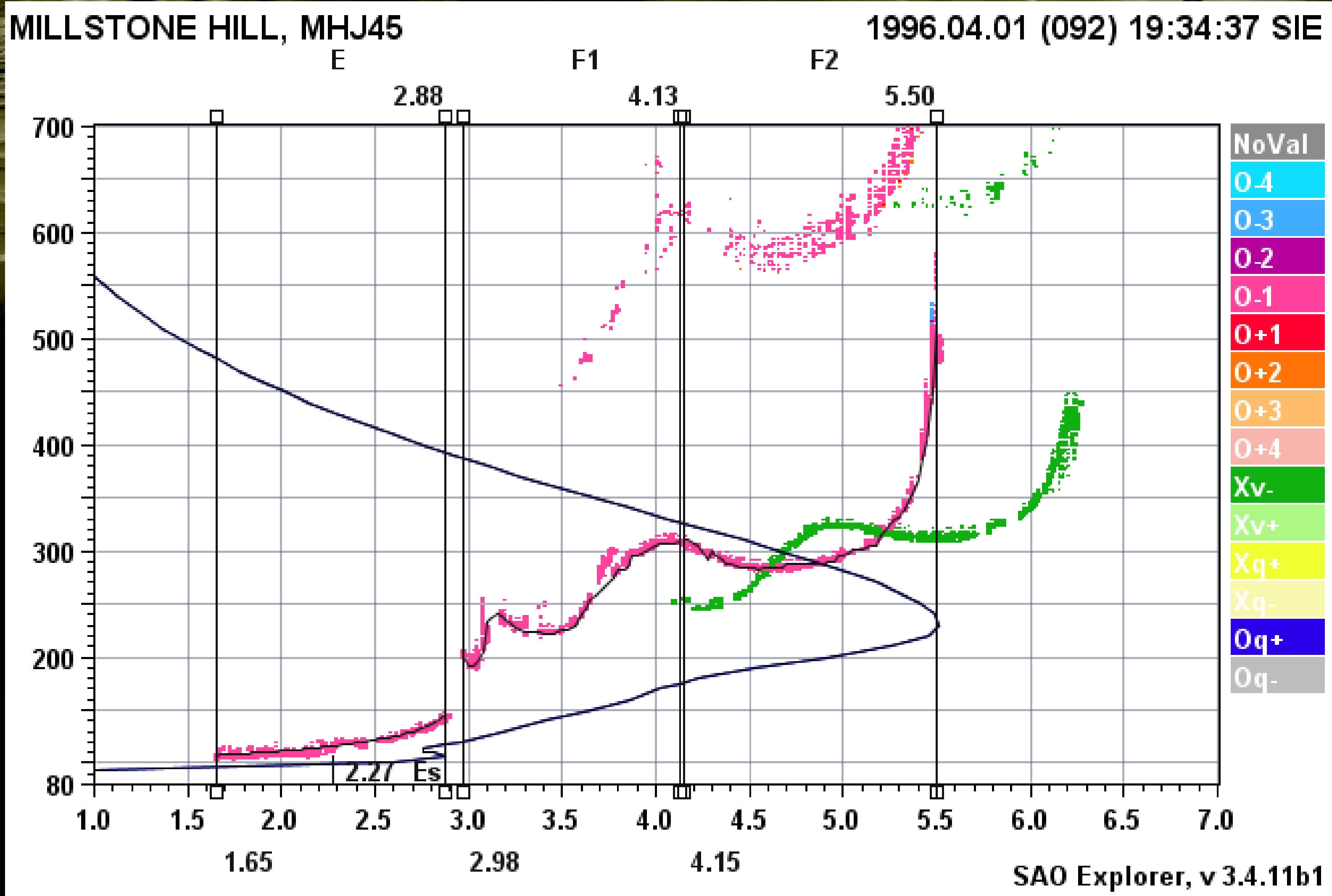
Center for Atmospheric Research

# Ionogram Autoscaling

DANGER
MACHINE-HARD PROBLEM



# 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

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**© 1993-2007**

**A**rtificial
**N**eural
**N**etwork
**A**lgorithm

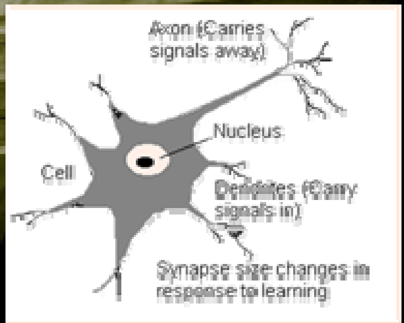

**© 1985-1993, 2006-2008**

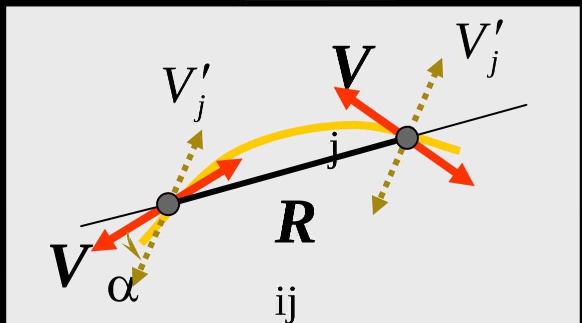
**P**rogram for
**A**utoscaling of
**C**onventional
**I**onograms with
**F**lexible
**I**nterpretation
**C**ontrol


**© 2007**

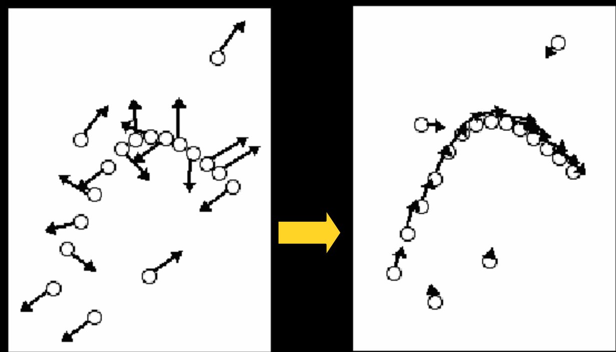

# ANNA: Extraction of traces

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

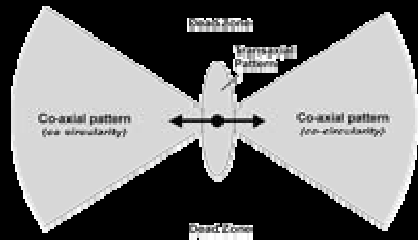


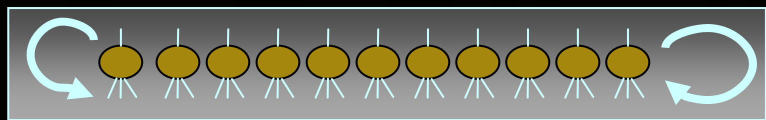




Rotor interaction
(co-circular model)



Initial state of NN    Final state of NN



Hopfield Recurrent ANN

Honda ASIMO

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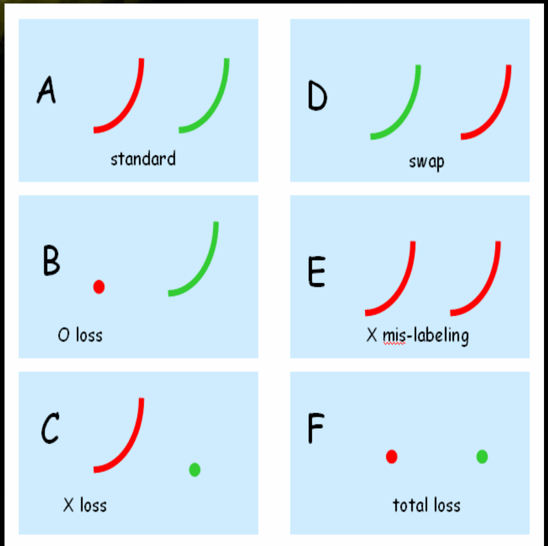
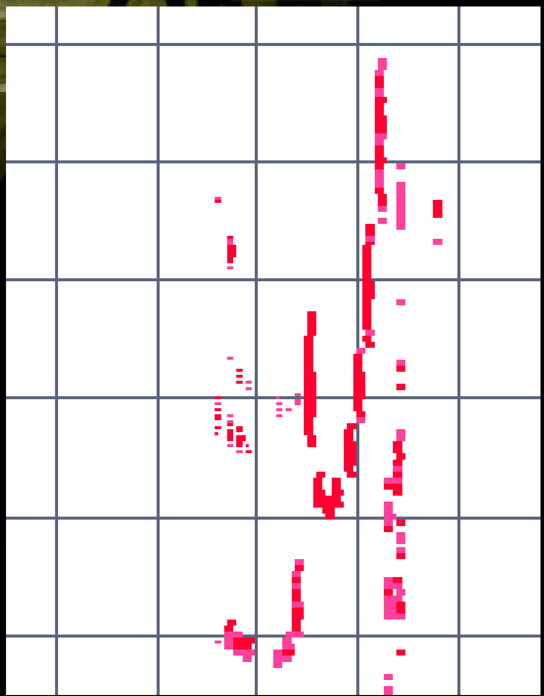
# PACIFIC



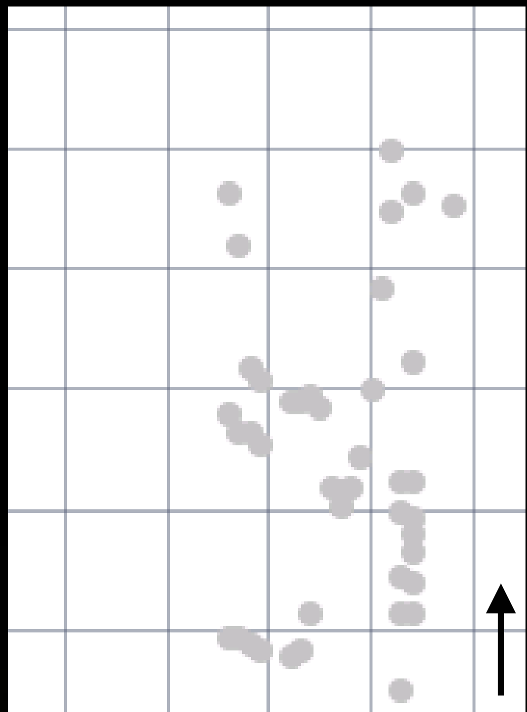

- Seeks trace segments pointing up
- Considers 6 configurations A-F
- Fits O- and X-cusps independently and refits if they do not match
- Allows down-grading to ionograms without polarization tagging or with swapped polarizations
  - ✓ Learmonth, Australia
  - ✓ Jicamarca, Peru


# A45: Edgel detection

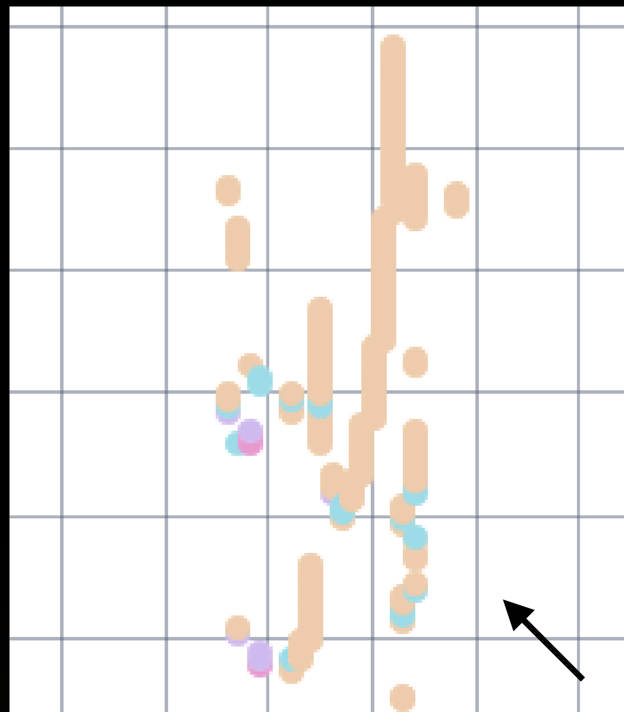




IONOGRAM
thresholded

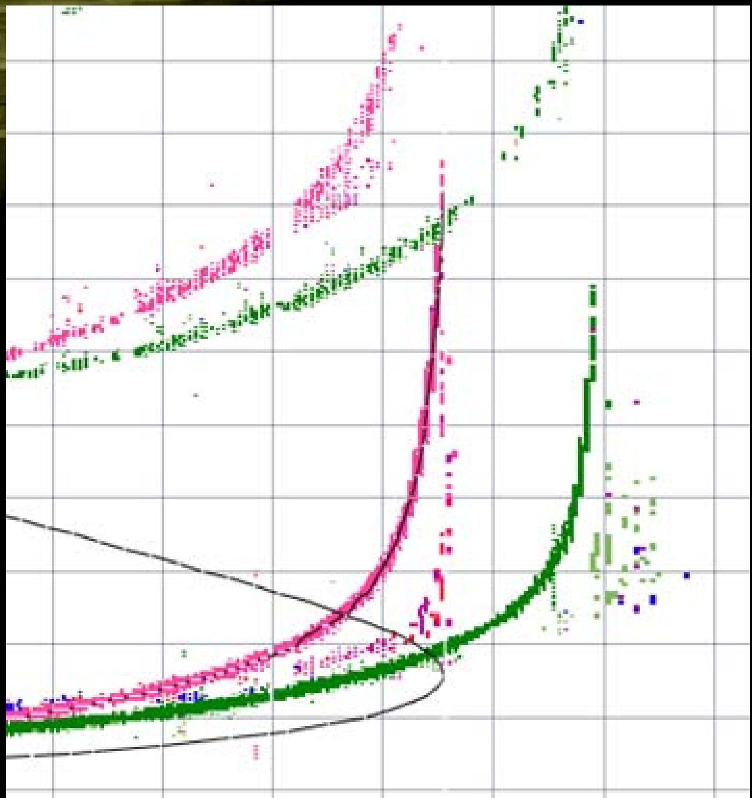


Classic edgel detection



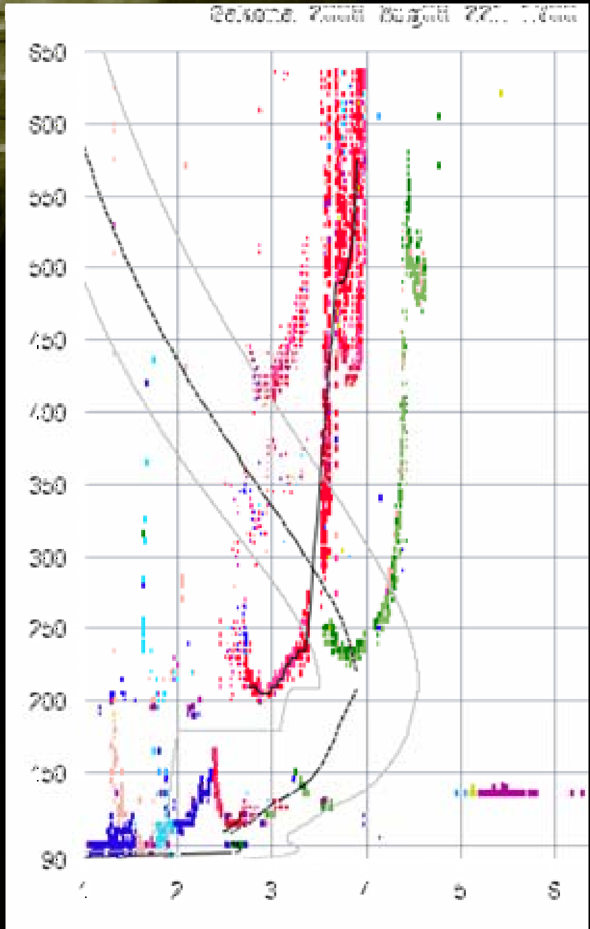
A45 edgel detection

# ARTIST-5 Lessons learned

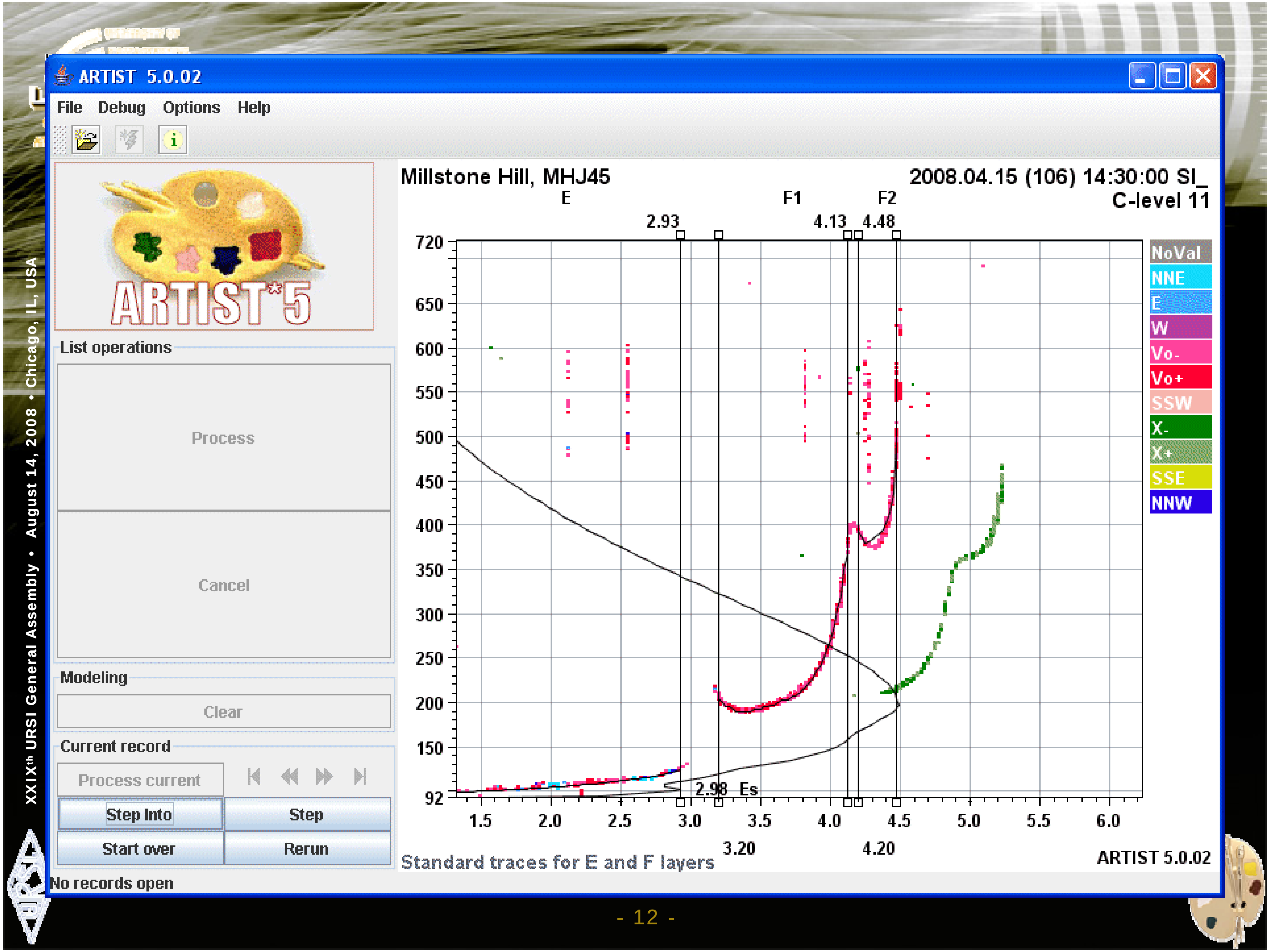


- > **Accurate foF2 cusp processing is most important**
  - ✓ Careful with cusp extrapolation above last trace point
- > **Imperfections in trace extraction are not important**
  - ✓ Small effect on Ne density profile
- > **NHPC Profile inversion works as trace gap interpolator**

# 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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ARTIST 5.0.02
File
Debug
Options
Help
ARTIST*5
List operations
Process
Cancel
Modeling
Clear
Current record
Process current
Step Into
Step
Start over
Rerun
No records open
Millstone Hill, MHJ45
2008.04.15 (106) 14:30:00 SI_
C-level 11
E
F1
F2
2.93
4.13
4.48
720
650
600
550
500
450
400
350
300
250
200
150
92
2.98 Es
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
3.20
4.20
NoVal
NNE
E
W
Vo-
Vo+
SSW
X-
X+
SSE
NNW
Standard traces for E and F layers
ARTIST 5.0.02

# 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
  - ✓ σ, 2σ, 3σ, 80%, 90%, 95% probability
- Frequently called "Error Bar"
- Multiple sources of uncertainty:
  - ✓ Autoscaling errors
  - ✓ Model assumptions
  - ✓ Equipment and processing bias
  - ✓ HF propagation factors

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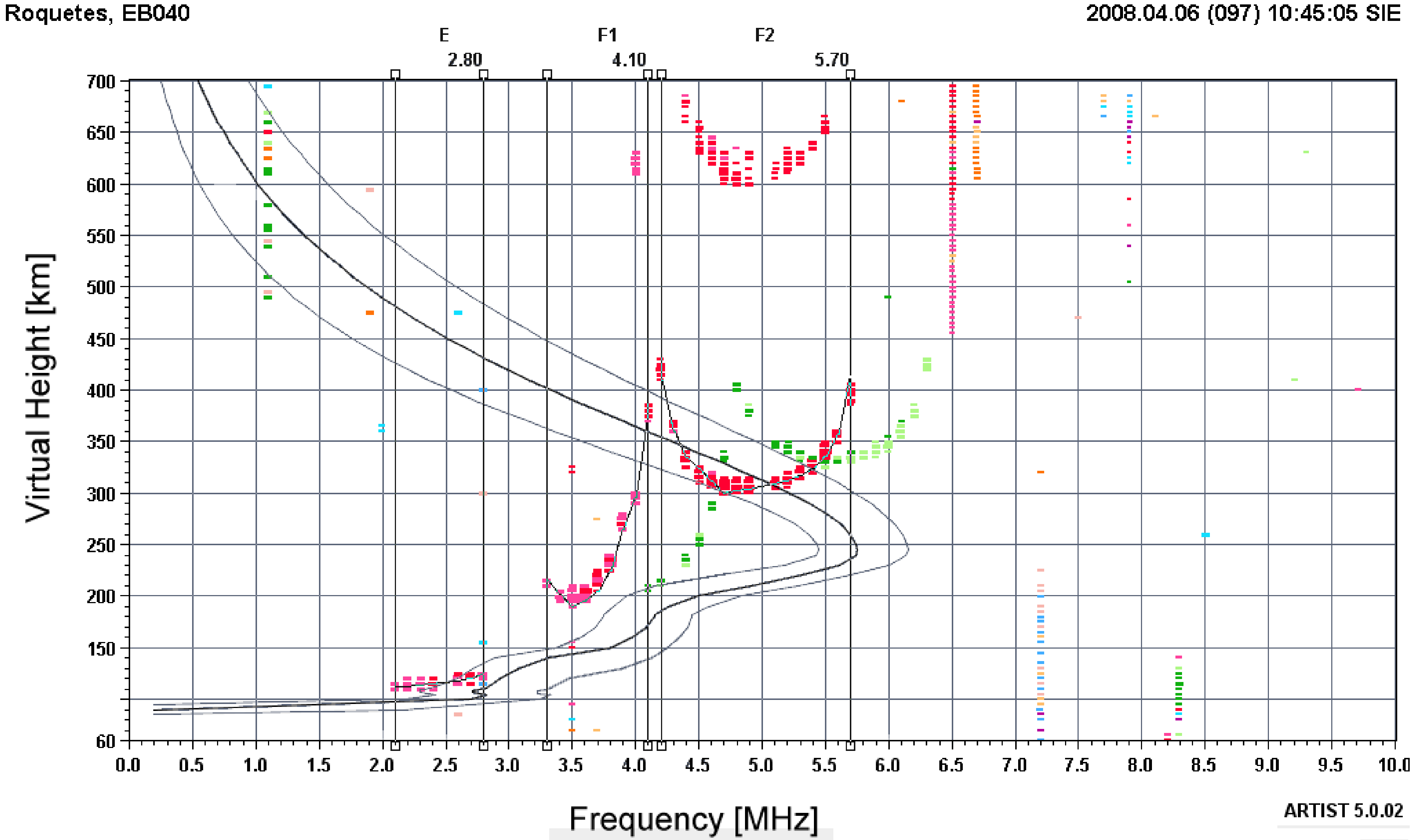
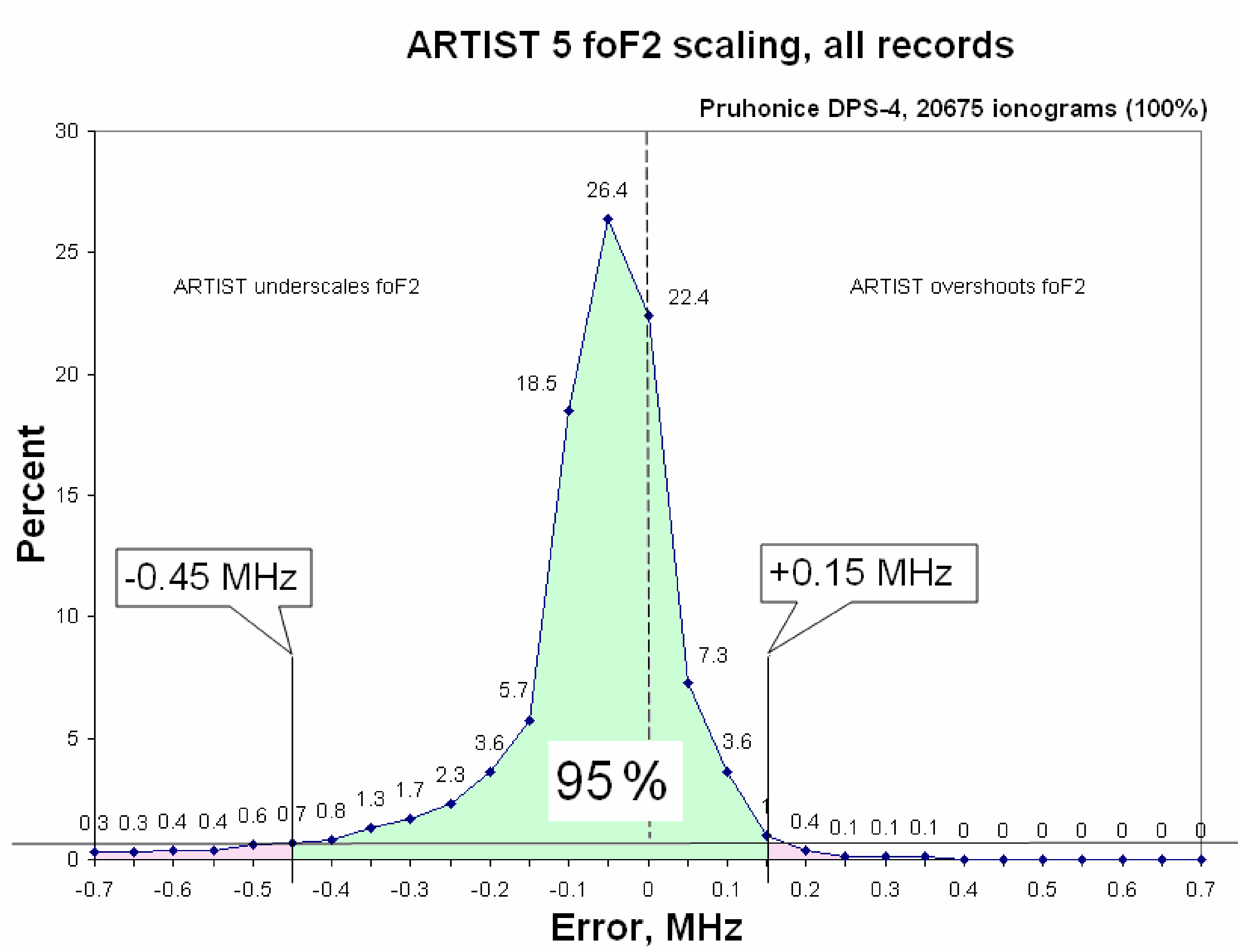
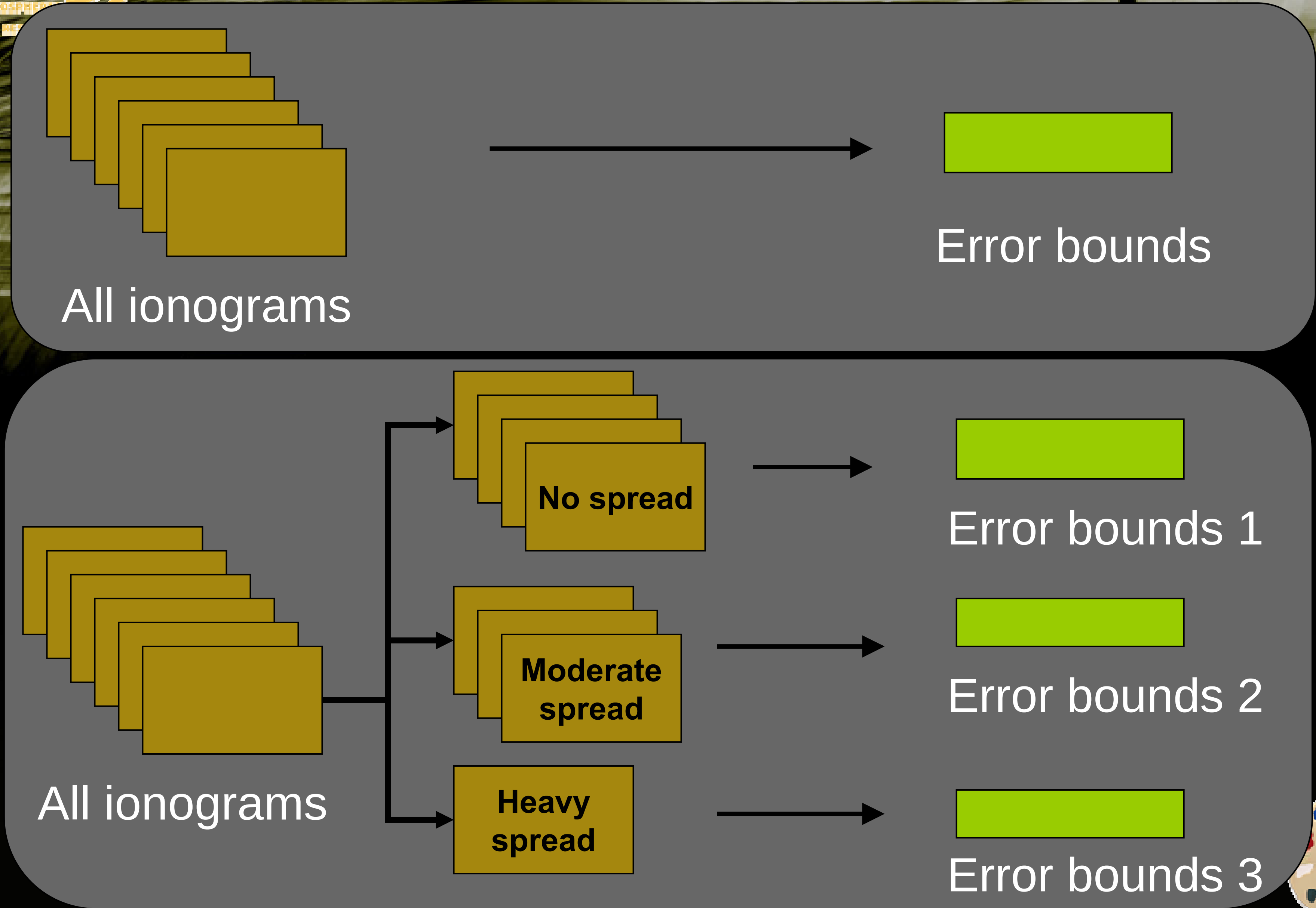
# Error Bounds and Error Boundaries



# ARTIST foF2 – Manual foF2



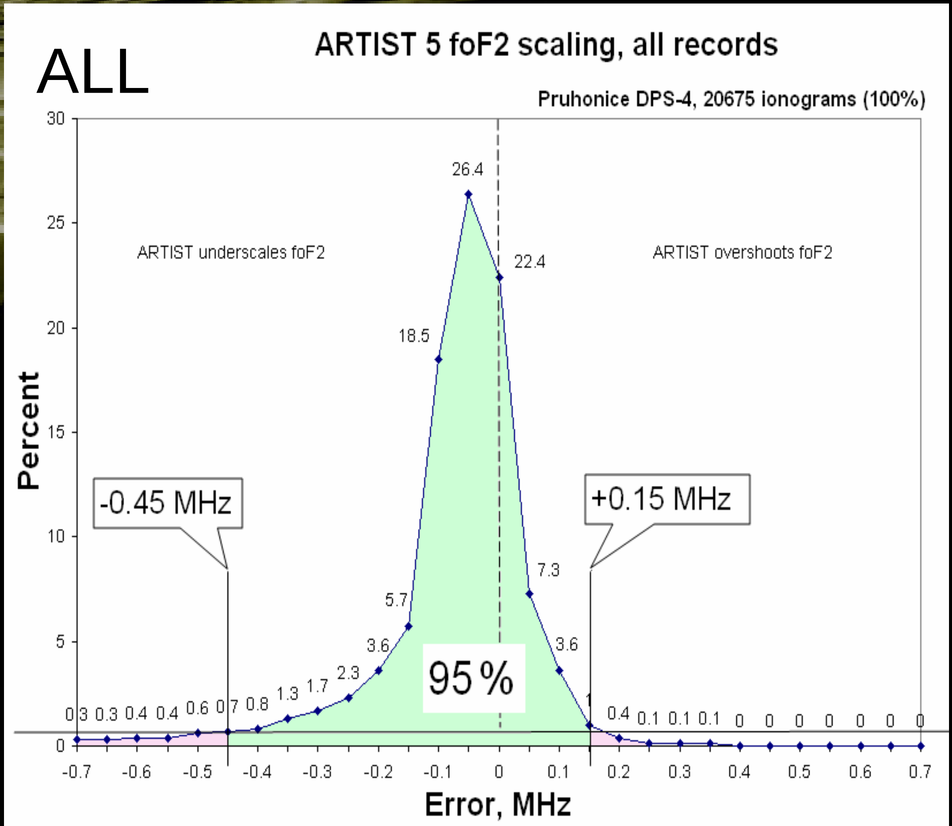
# Automatic Spread-F Detection

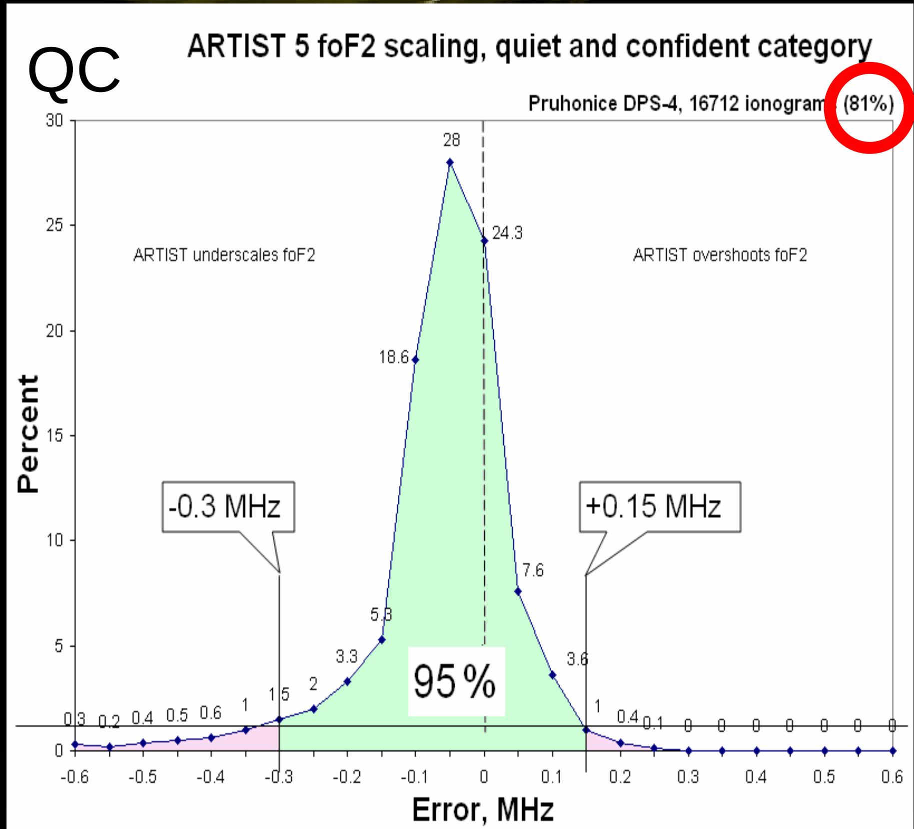


# Ionogram Classification

- 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

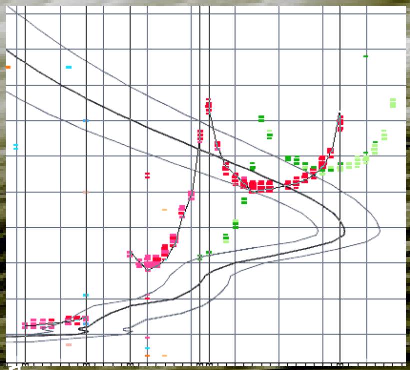
# Quiet-Confident Category




Lower bound = -0.45 MHz

Lower bound = -0.3 MHz



# Comparison Results for foF2

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

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

# 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

# Acknowledgements

> **UMLCAR Scaler Team:**

- ✓ Jason Conway
- ✓ Daniil Khmyrov
- ✓ Keith Sorota
- ✓ Dima Paznukhov
- ✓ Cindy Shugrue
- ✓ Ebrahim Nasser
- ✓ William Kersey

> **International Scaler Team:**

- ✓ David Altadill, *et al*.
- ✓ Dalia Buresova
- ✓ Katy Alazo Cuartas
- ✓ Inigo Blanco

**FREE ACCESS TO MANUALLY SCALED IONOGRAMS in DIDBASE**