# DISPEC

## Scientific exploitation of space Data for improved Ionospheric SPECification

### Scientific Data Application 2 and 3

# MUF Sensitivity Study for DISPEC Demo

Ivan Galkin (Borealis Global Designs)

2025 IRI CCBW Team 7

DISPEC science team

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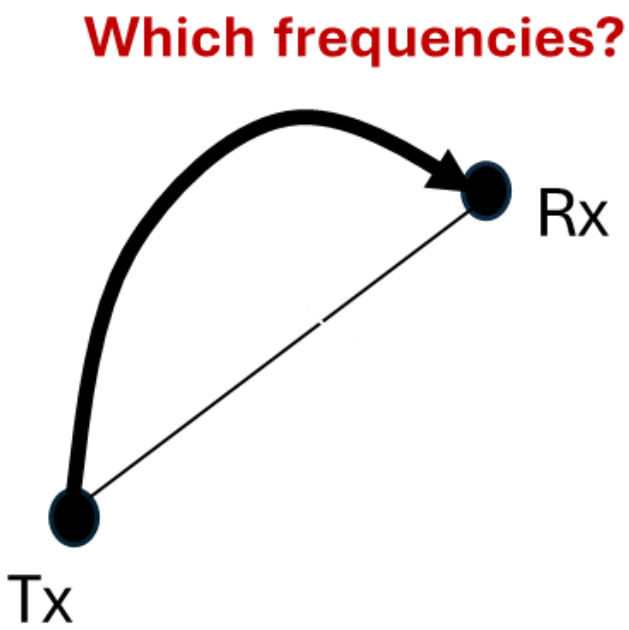
# Motivation

## SDA2: Modelling Trans-ionospheric Radio Signal Propagation
## SDA3: Specification of Slab Thickness Anomalies

- **Monitoring Most Usable Frequencies (MUF) for various applications**
  - HF communications for civil aviation
    - MUF Depressions: 25% = yellow alert, 50% = red alert
- **Relevance to DISPEC**
  - The MUF task is applicable to both SDA2 and SDA3
  - SDA2: Raytracing through ionosphere
    - Raytracing works for MUF(D) nicely
      - Any D, not only 3000 km (current PECASUS approach)
      - And specific radiolink orientation (bearing angle), unlike MUF(3000) computation
  - Test different techniques for specifying underlying ionosphere
    - Which one gives the best EDP quality for raytracing
  - Sensitivity study of the ionospheric properties on MUF computation
    - [Q]: Which real-time sensors are sufficient to determine MUF anomalies?
      - Ionosonde (8 parameters of EDP+raytracing) and GNSS receivers (% depression)

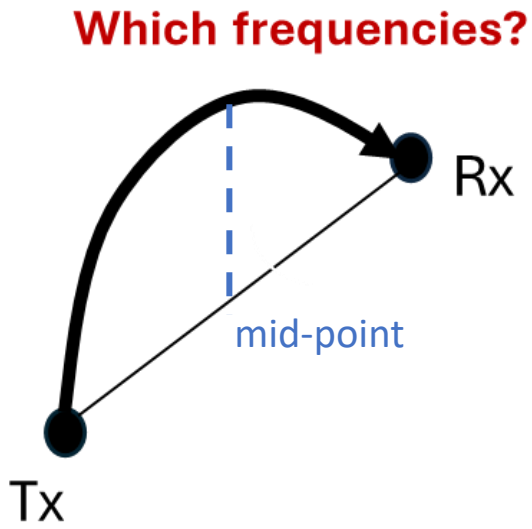


# Status of SDA-2/3 demonstrator

## SDA2: Modelling Trans-ionospheric Radio Signal Propagation
## SDA3: Specification of Slab Thickness Anomalies

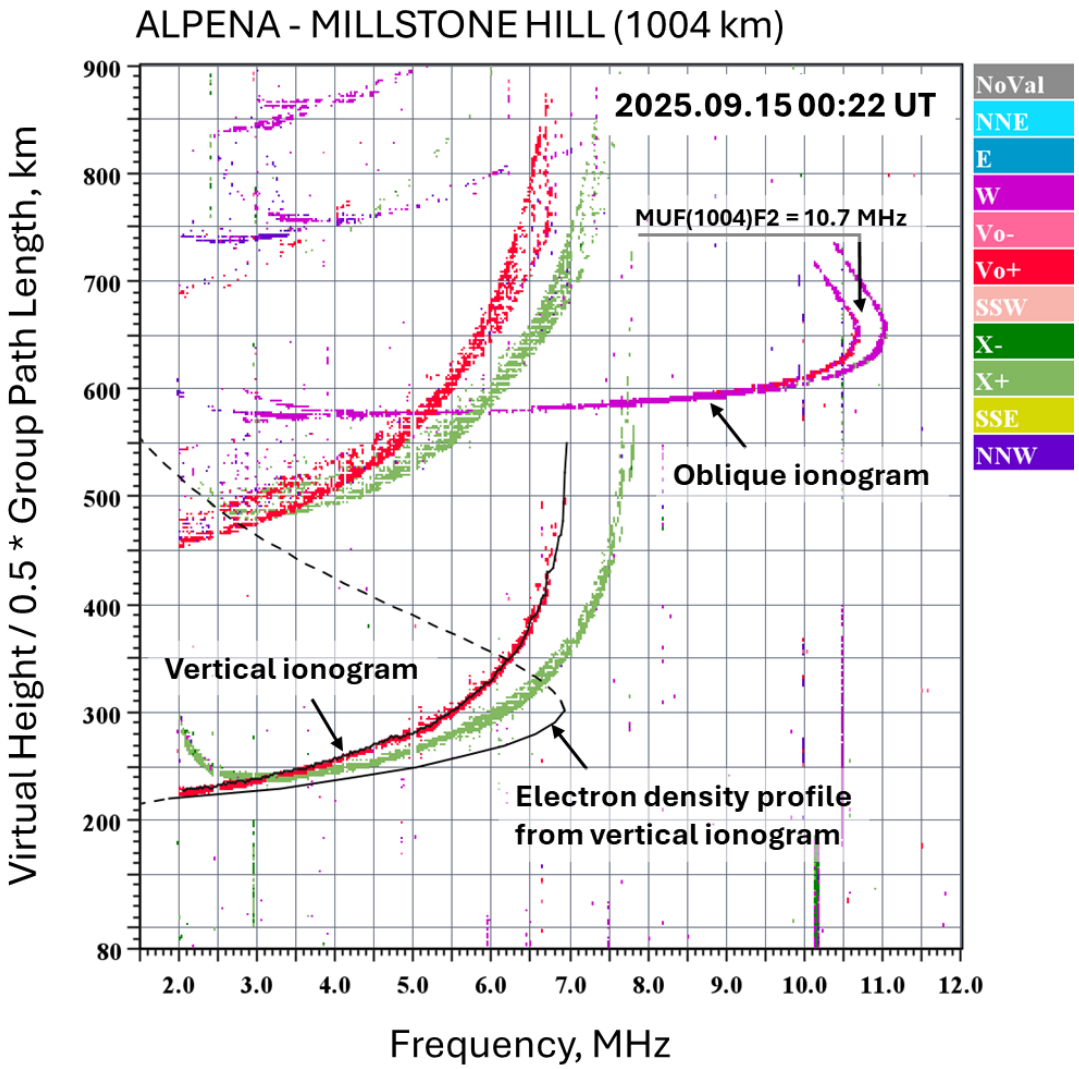
- SDA2 Demonstrator presentation is later today by Vincent Fabbro (WP5)
- This presentation includes several software components being prepared for the Demonstrator:
  - Models
    - IRI-2020, September 2025 version (FORTRAN)
    - IRTAM (public portal with API – https://giro.uml.edu)
    - RayTRIX-CQP raytracer for oblique ionogram synthesis (C++, public API almost done)
  - Observational data for validation: ionosondes
    - ARTIST-5 for VI ionograms (public portal with API – https://giro.uml.edu)
    - LOIAS for OI ionograms (public API in progress)
  - Interactive visualization
    - GAMBIT Explorer for global map displays and data export (app download)
    - Ionograms
      - SAO Explorer with NHPC for VI ionogram editing (app download)
      - ObliX interactive tool for OI ionogram editing (app in progress)
- Integration of these components is based on a standard data format
  - IRI-2020 output to RayTRIX-CQP input
  - RayTRIX-CQP output to plotting software

# MUF Sensitivity Study Approach



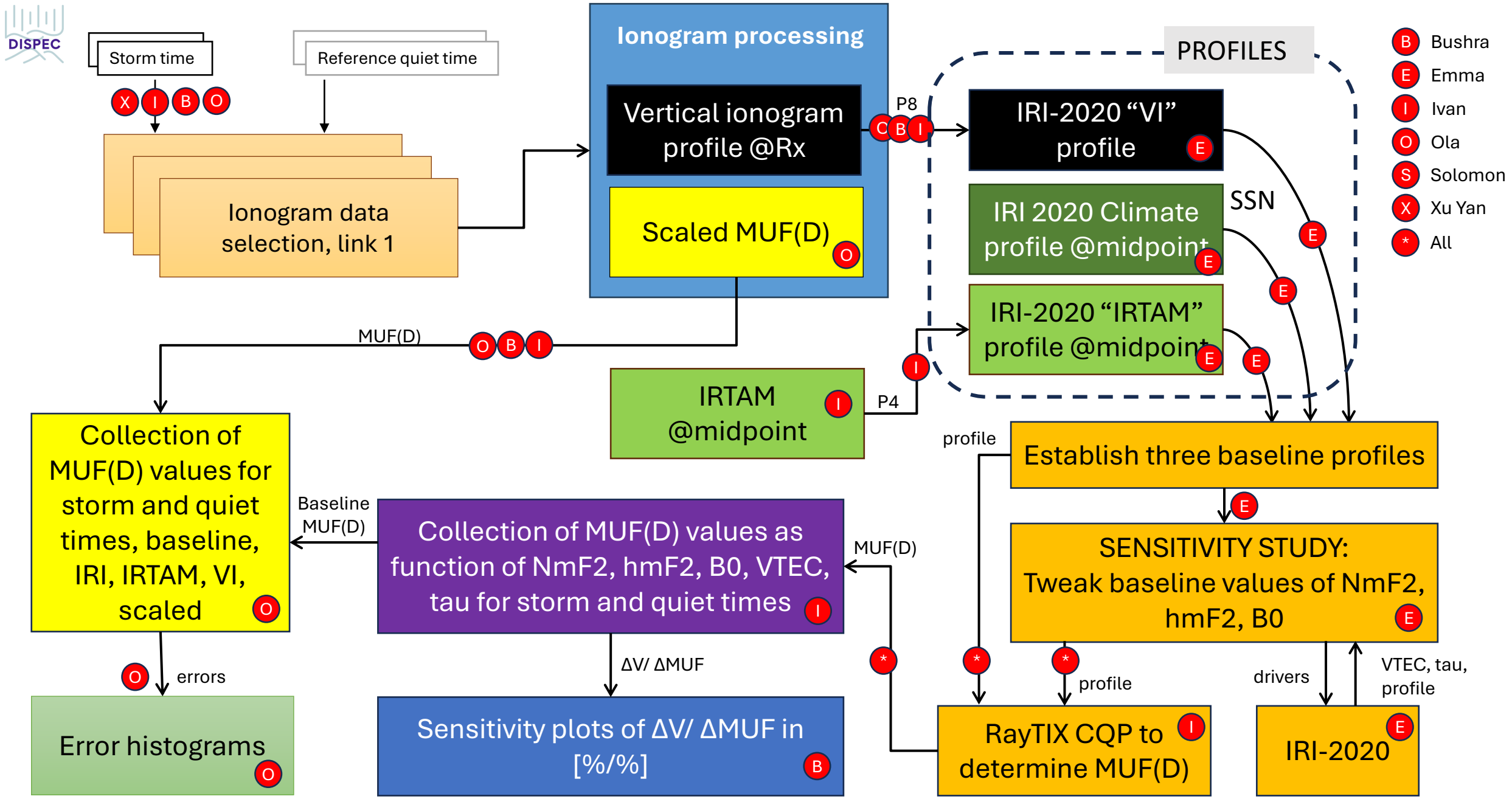

- Use VI+OI ionograms as the ground truth relevance
  - Shorter radiolinks with reliable 1-hop propagation
    - Only mid-point ionosphere is needed for RayTRIX-CQP
- Select storm and quiet reference days for analysis
- Use three different ways to compute mid-point ionosphere
  - (1) VI ionogram at the Rx site
    - That would be 300-500 km away from the midpoint
  - (2) IRI climate
  - (3) IRTAM weather (assimilation of only ionosonde data)
- Raytrace HF signals at all frequencies to obtain MUF(c)
- Two types of analysis:
  - **Validation of MUF(c)** to the ground truth MUF(o) – which mid-point specs are best?
  - **Sensitivity study:** which observables are needed to monitor MUF anomalies
    - foF2, hmF2, B0, VTEC, and tau (slab thickness)

# Ground Truth




**Ionogram Selection for Manual Scaling**

- Radiolinks:
  - (EU) El Arenosillo to Roquetes
  - (SA) Hermanus to Grahamstown
  - (US) Alpena to Millstone Hill
- Storm Days:
  - 2025-04-16 G3
  - 2025-09-15 G3
- Quiet Days:
  - 2025-04-10
  - 2025-09-20


DISPEC
Storm time
Reference quiet time
X I B O
Ionogram data selection, link 1
Ionogram processing
Vertical ionogram profile @Rx
Scaled MUF(D)
O
P8
C B I
PROFILES
IRI-2020 "VI" profile
E
IRI 2020 Climate profile @midpoint
SSN
IRI-2020 "IRTAM" profile @midpoint
B Bushra
E Emma
I Ivan
O Ola
S Solomon
X Xu Yan
* All
MUF(D)
O B I
IRTAM @midpoint
P4
Collection of MUF(D) values for storm and quiet times, baseline, IRI, IRTAM, VI, scaled
Baseline MUF(D)
Collection of MUF(D) values as function of NmF2, hmF2, B0, VTEC, tau for storm and quiet times
MUF(D)
profile
Establish three baseline profiles
SENSITIVITY STUDY: Tweak baseline values of NmF2, hmF2, B0
errors
Error histograms
ΔV/ ΔMUF
Sensitivity plots of ΔV/ ΔMUF in [%/%]
RayTIX CQP to determine MUF(D)
drivers
VTEC, tau, profile
IRI-2020

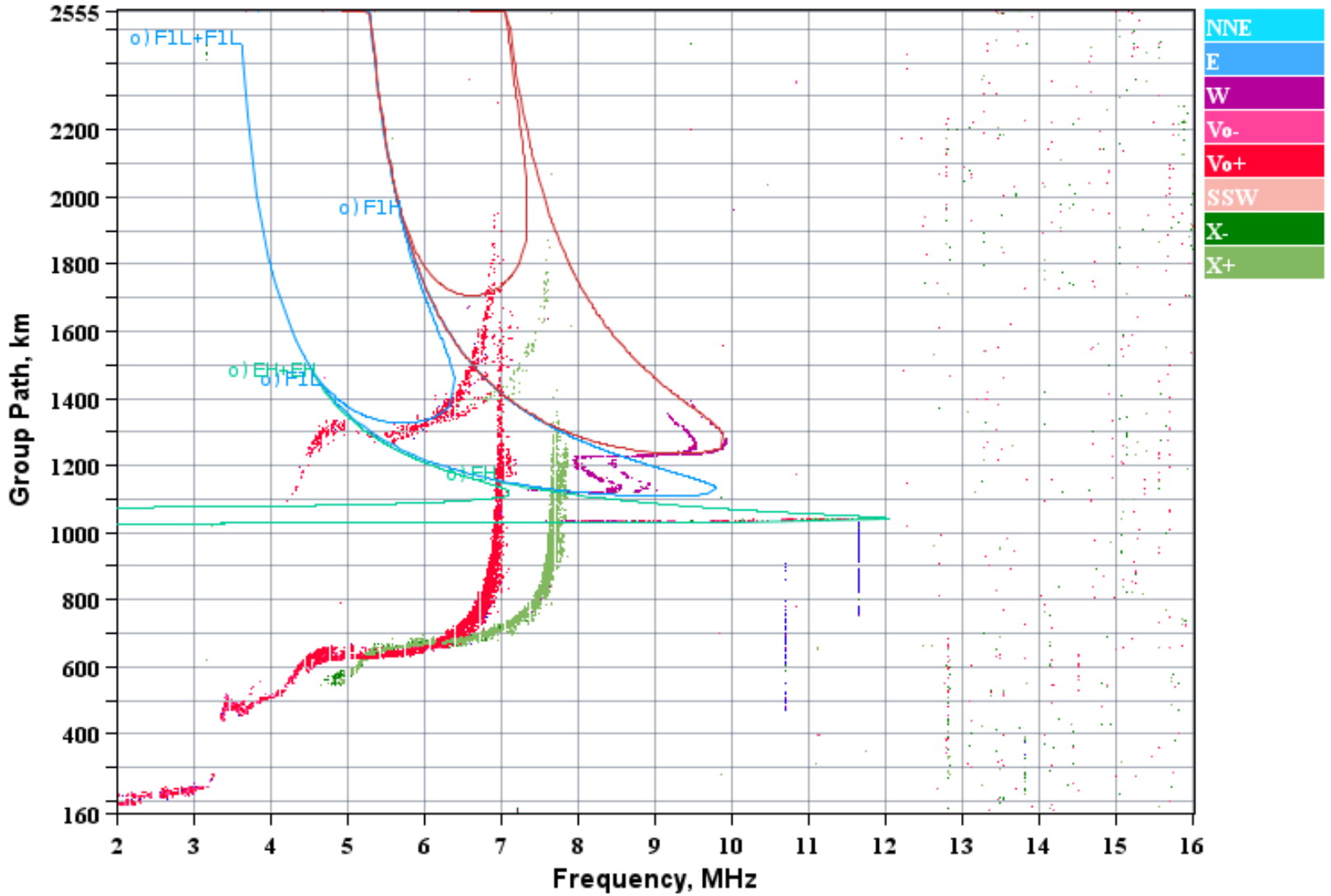
Lowell GIRO Data Center

Station YYYY DAY DDD HHMMSS P1 FFS S AXN PPS IGA PS
Millstone Hill 2025 Sep15 258 134500 RSF 1 712 100 03+ 33

AL945>MHJ45/1004km

| | |
|---|---|
| MUF | 12.05 |
| LUF | 1.00 |
| MUFoF2 | 9.89 |
| MUFoF2p | N/A |
| MUFxF2 | N/A |
| MUFoF1 | 9.80 |
| MUFoF1p | N/A |
| MUFxF1 | N/A |
| MUFoE | 12.05 |
| MUFoEp | N/A |
| MUFxE | N/A |
| MUFoEs | N/A |
| MUFxEs | N/A |
| pminF2 | 1236 |
| pminF2p | N/A |
| pminF1 | 1109 |
| pminF1p | N/A |
| pminE | 1027 |
| pminEp | N/A |
| pminEs | N/A |

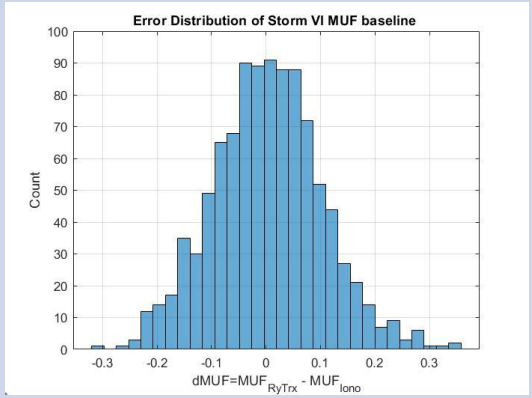
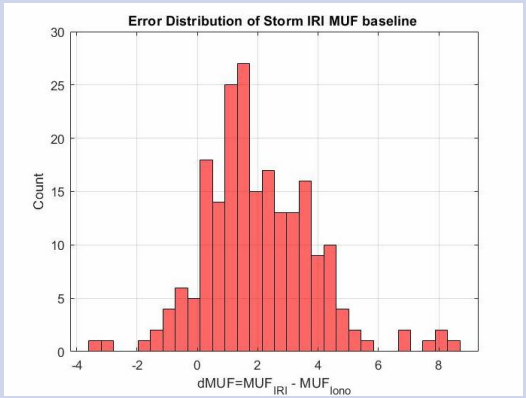
OI Synthesizer:



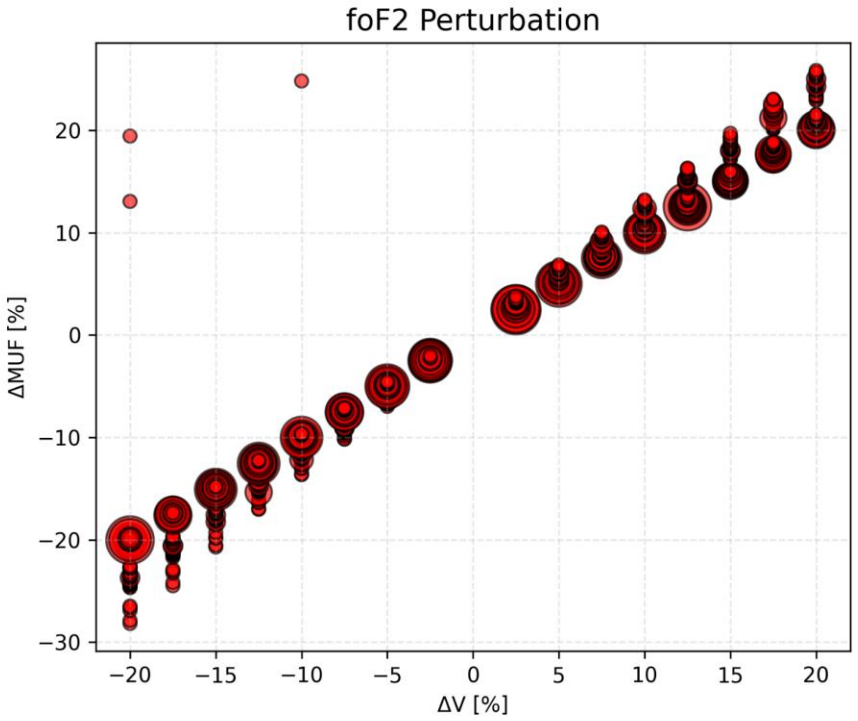

RayTRIX-CQP_IRI-EDP 0.1

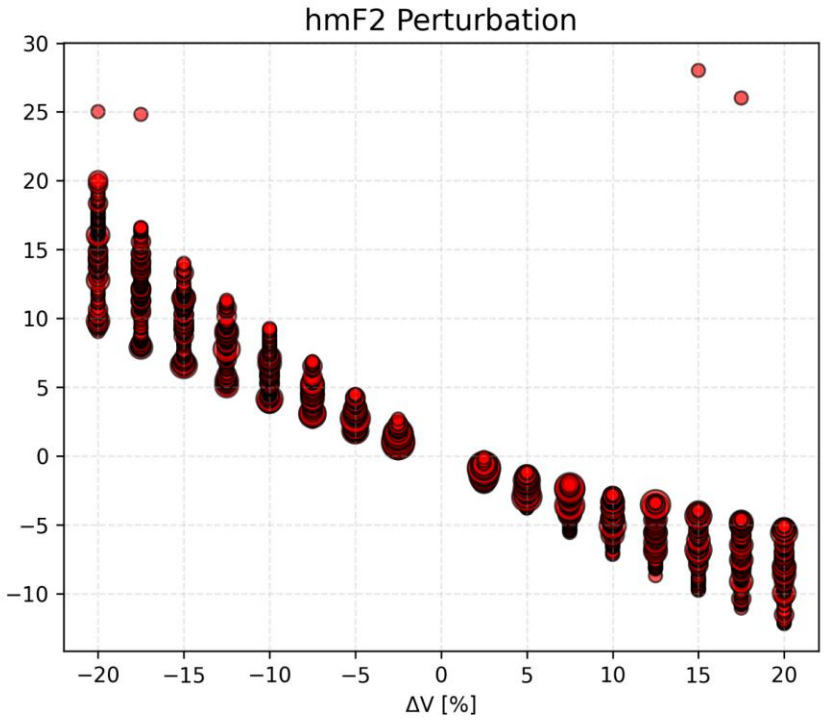
45N:276E > 42N:288E /1004km db mhj45 20250915 134500.rsf / 561fx512h 5 kHz 2.5 km / DPS-4D MHJ45 42

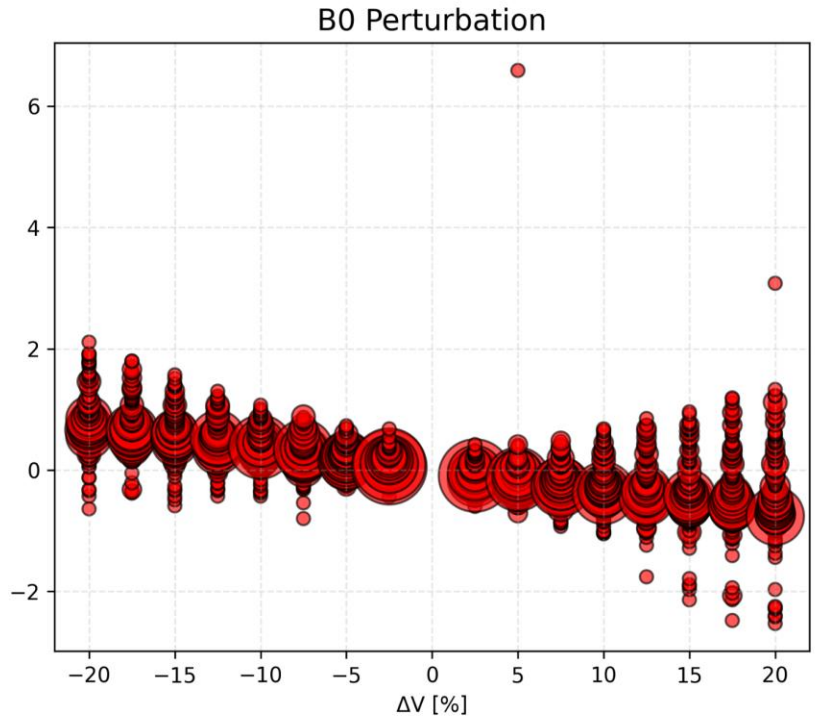
# Error Histograms

| Activity | VI profile at Rx site | IRI quiet time climate | IRTAM weather |
|---|---|---|---|
| **STORM TIME** |  Very good, +/- 0.2 MHz (manual scaling) |  Overestimation of MUF during storms | TBD |
| **QUIET TIME** | TBD | TBD | TBD |

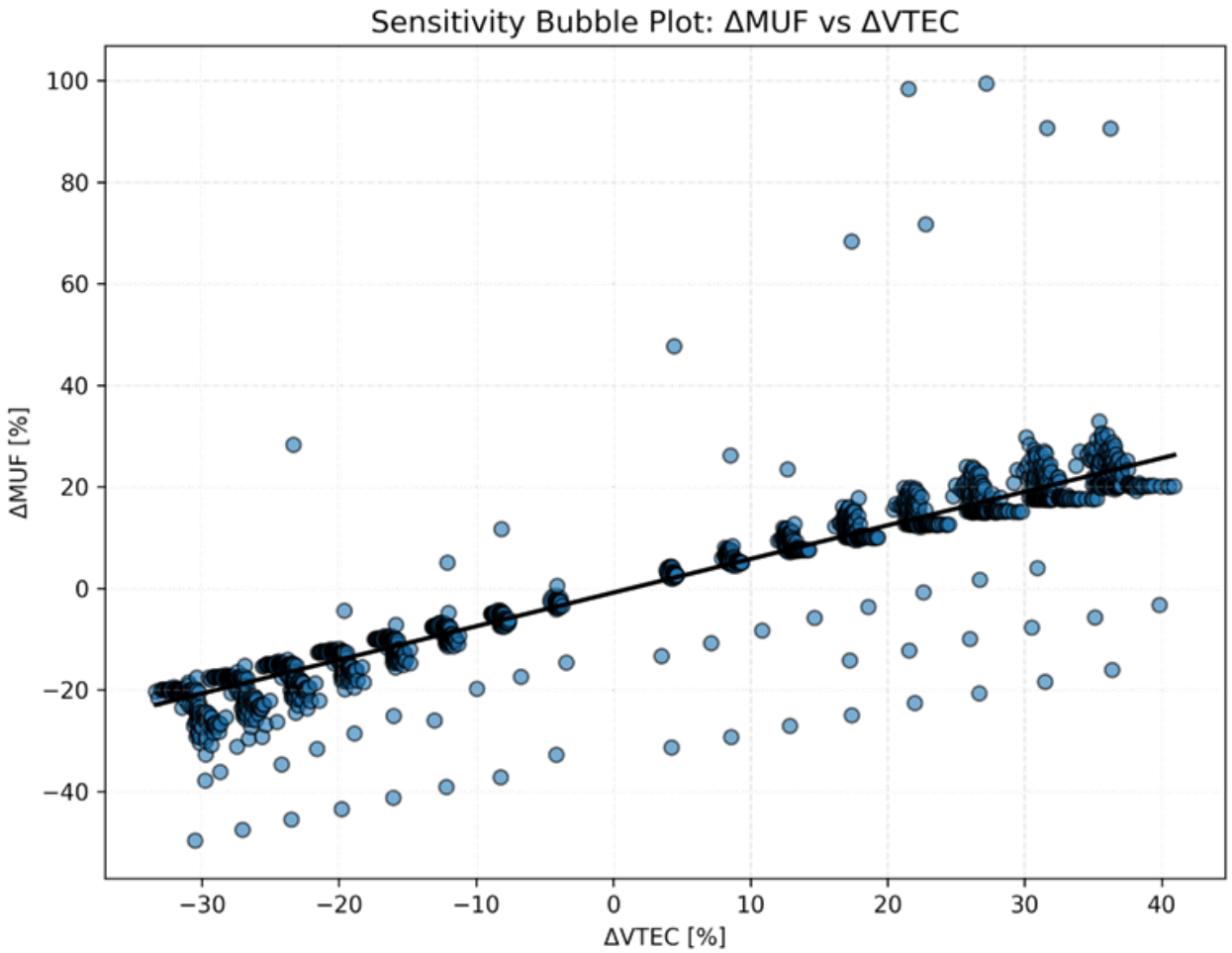
# Sensitivity Study Results, Storm time

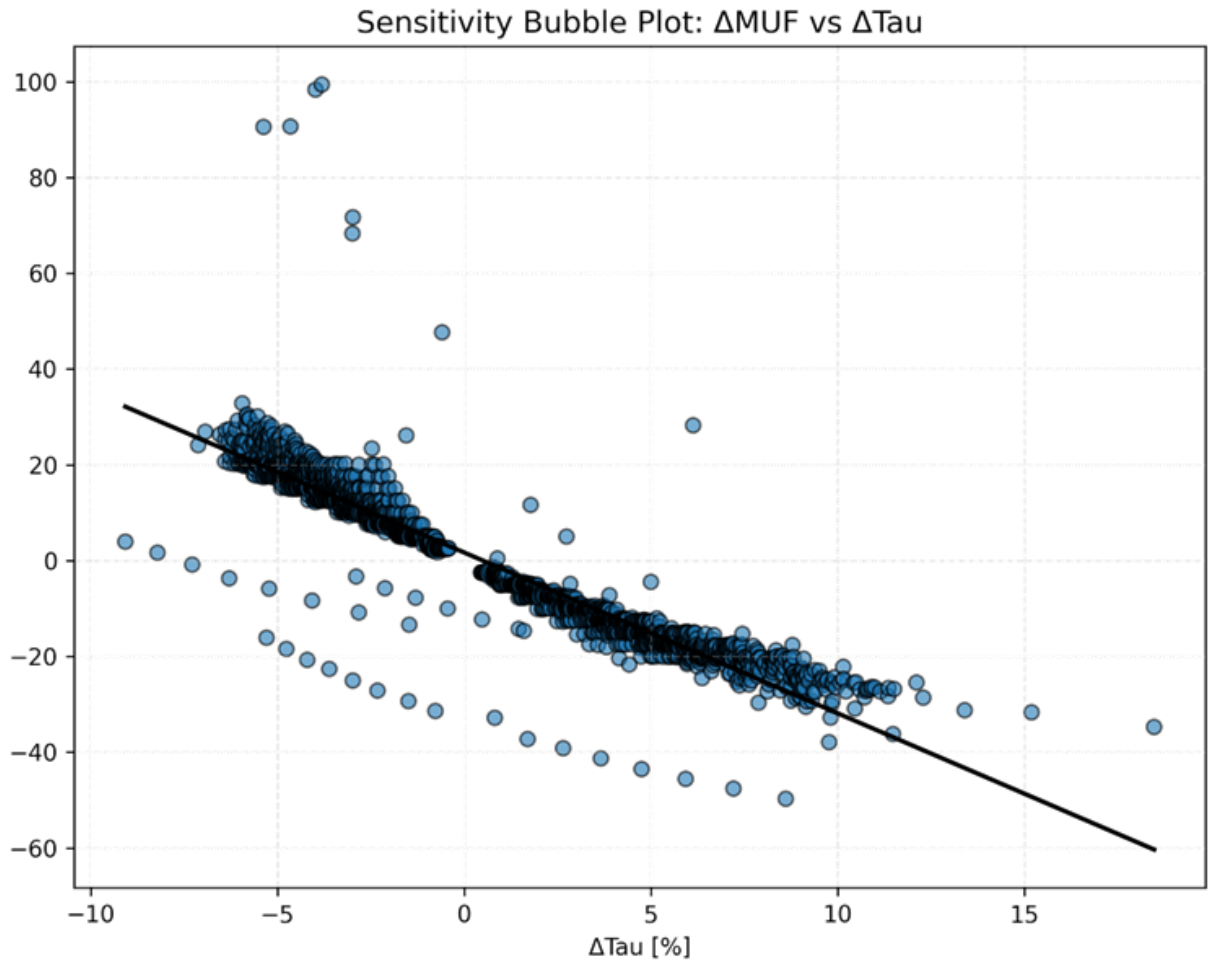


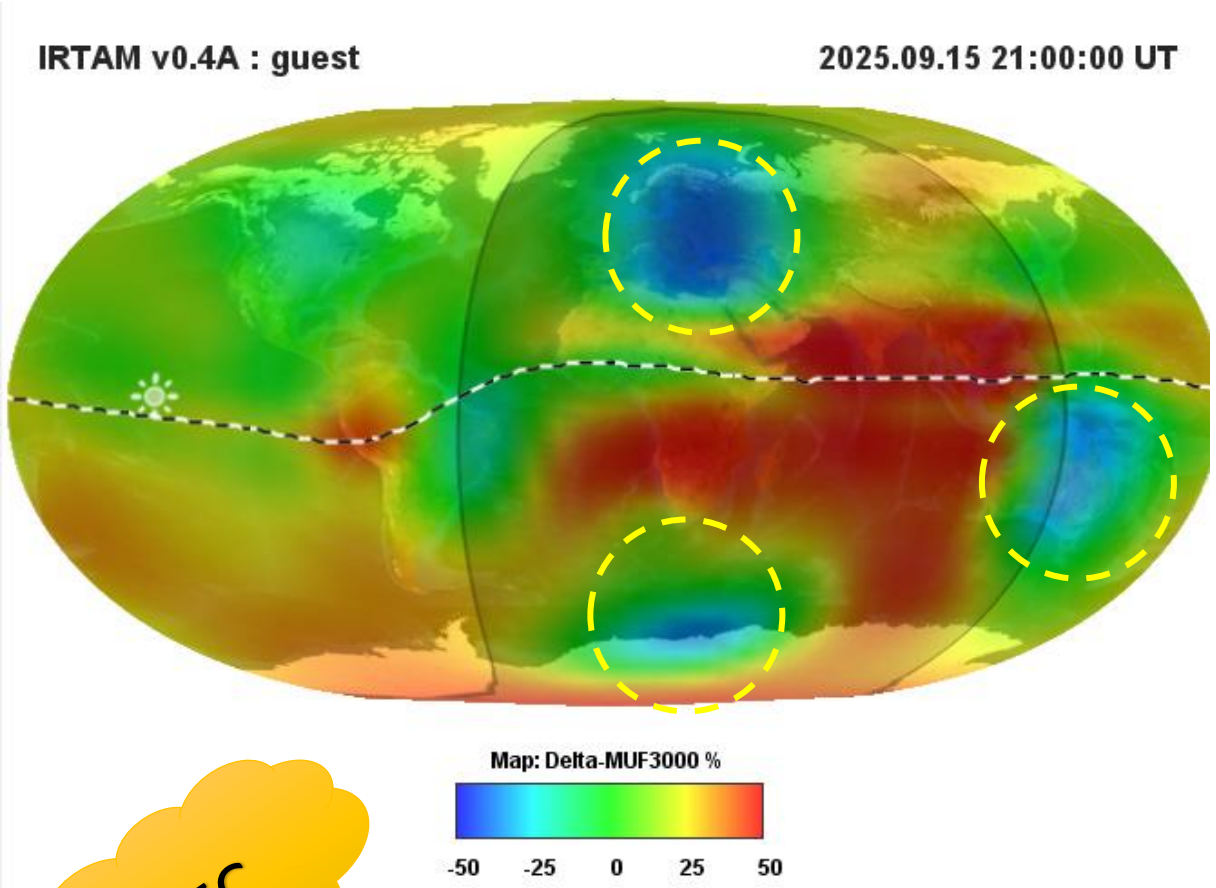



# Connection of ΔMUF(c) to ΔVTEC(c) and Tau(c)



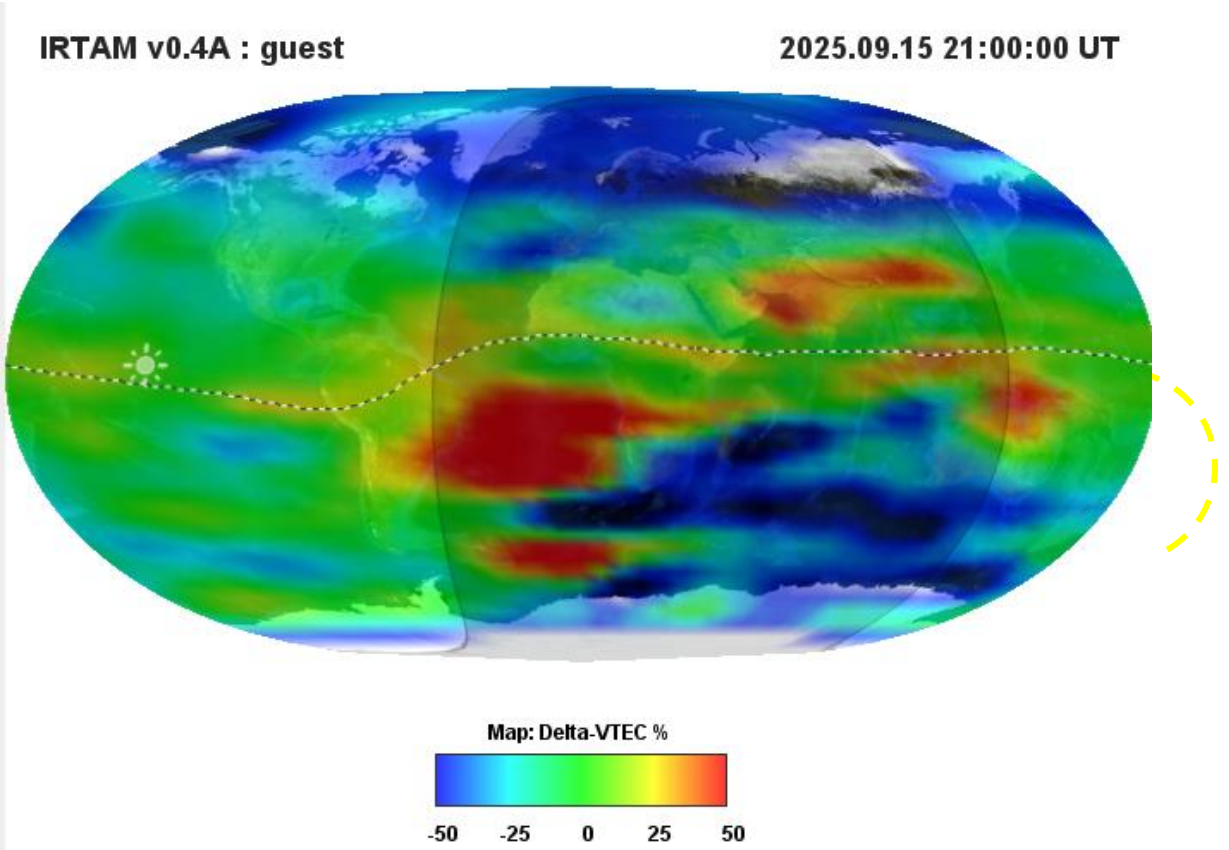
# VTEC(o) is sensitive! But not quite clear match to MUF




No VTEC

MUF Anomaly

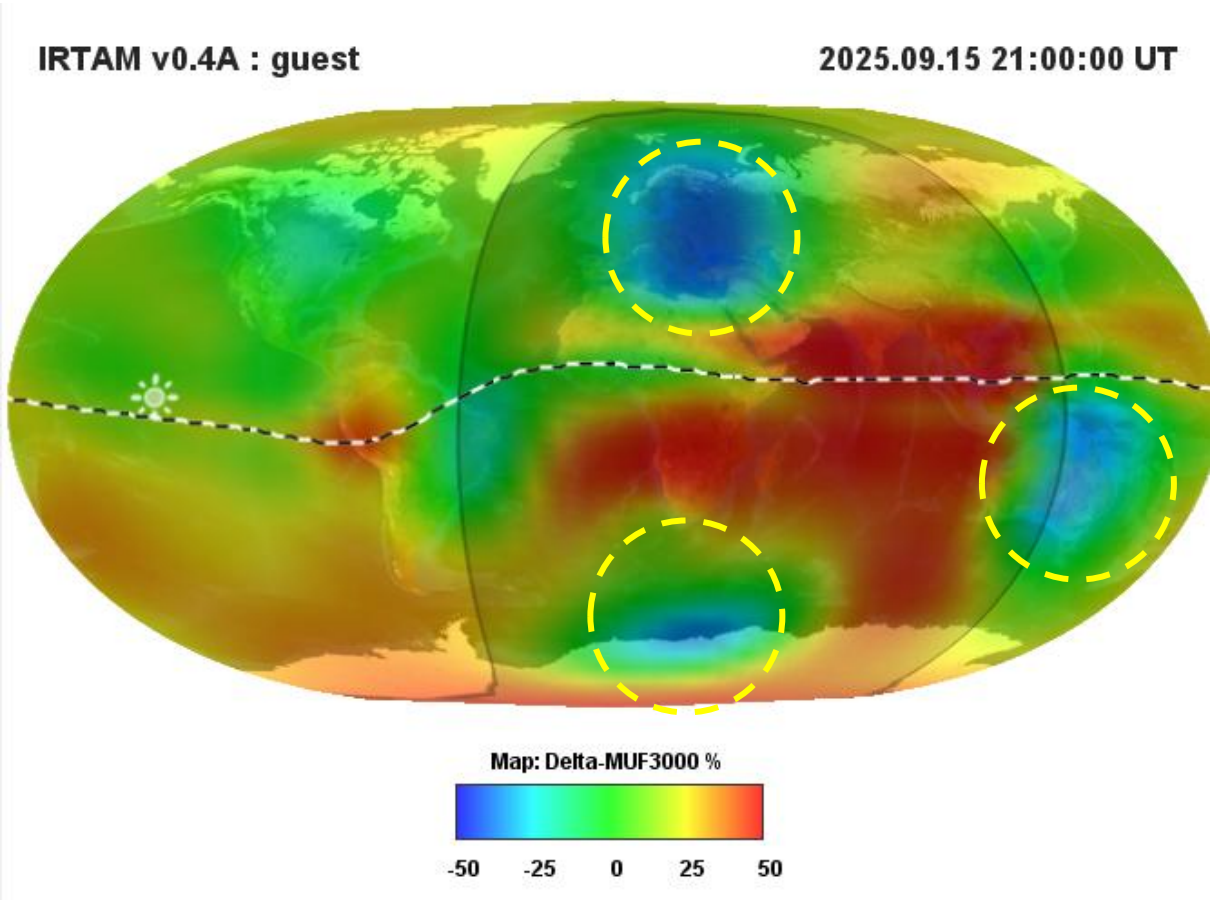
(only bottomside)

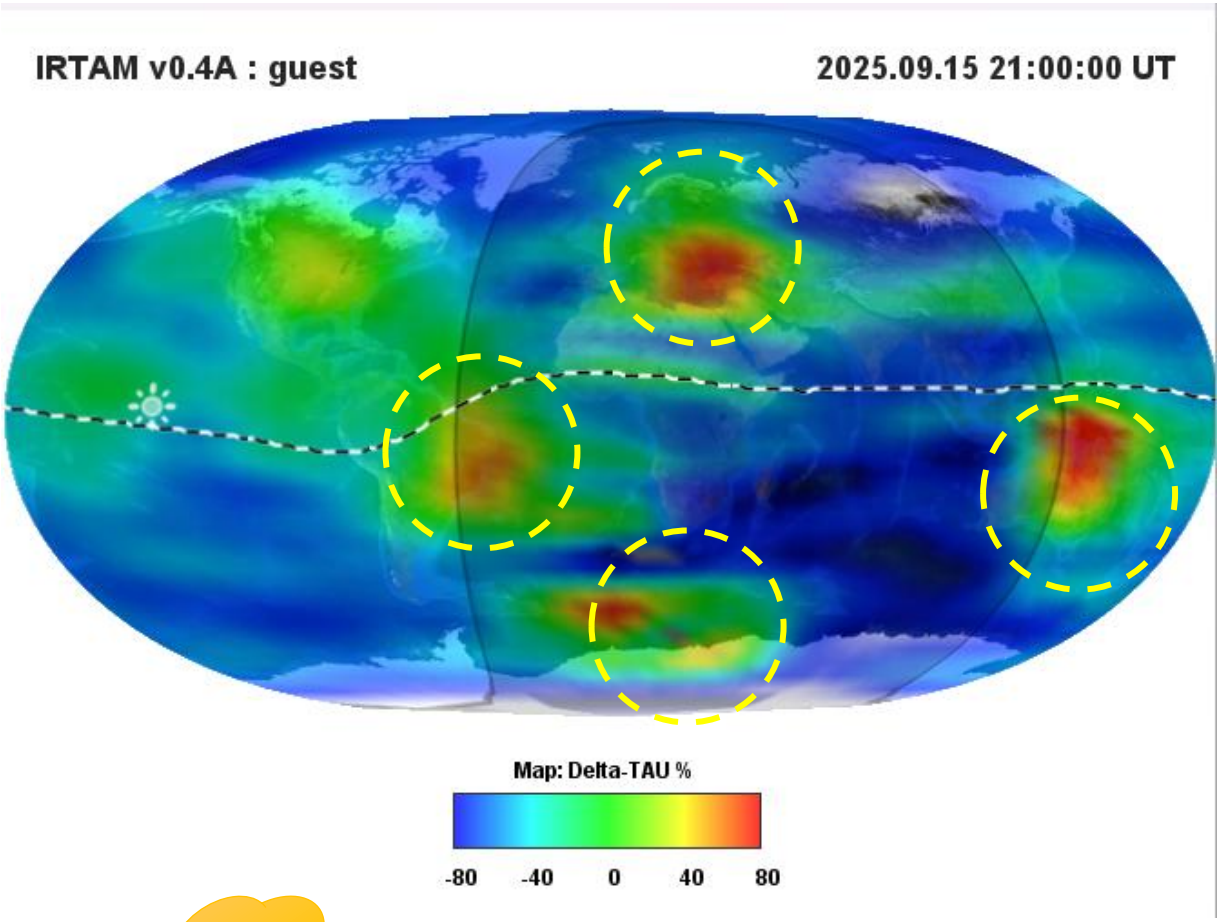



VTEC Anomaly

(with topside/plasmasphere)

# Tau appears to be very sensitive




MUF Anomaly

No MUF computations

Tau Anomaly

# Operational advantages of Tau

- Uses only foF2 (autoscaled) and VTEC
  - But reflects EDP shape modifications, ever so crudely
  - Autoscaled foF2 are more reliable vs hmF2 and MUF
- Two communities (GNSS and GIRO) cooperate nicely
  - https://giro.uml.edu/GAMBIT
    - GAMBIT Explorer includes real-time anomaly maps of NmF2, VTEC, and tau
    - NmF2: GIRO ionosondes
    - VTEC: GIM computations

# Thank you for your attention!

WEB: https://dispec.eu

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