

# Solar Eclipse Through Ham Radio: *What the Bands Revealed*

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Philip J. S. Gladstone<sup>6</sup>, Cameron M. Cushing\*, McKenzie Denton<sup>7,\*</sup>, Gwyn Grffiths\*,  
Edward Efchak\*, Gary Mikitin\*, H. Ward Silver\*, the HamSCI Community

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<sup>3</sup>The University of Alabama, Tuscaloosa, AL

<sup>5</sup>Montclair State University, Montclair, NJ

<sup>7</sup>Old Dominion University, VA

<sup>2</sup>The University of Scranton, Scranton, PA

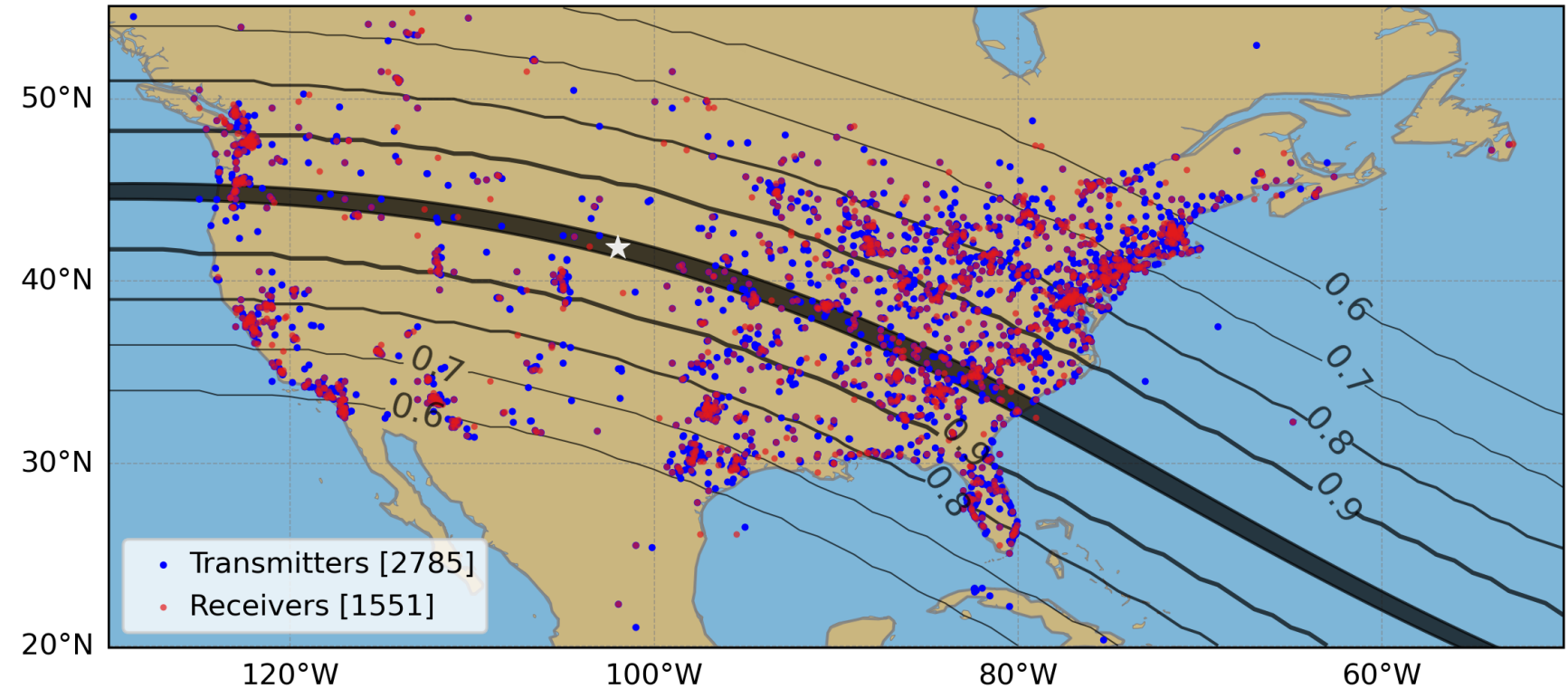
<sup>4</sup>Syntek Technologies, Fairfax, VA

<sup>6</sup>PSKReporter, Carlisle, MA;

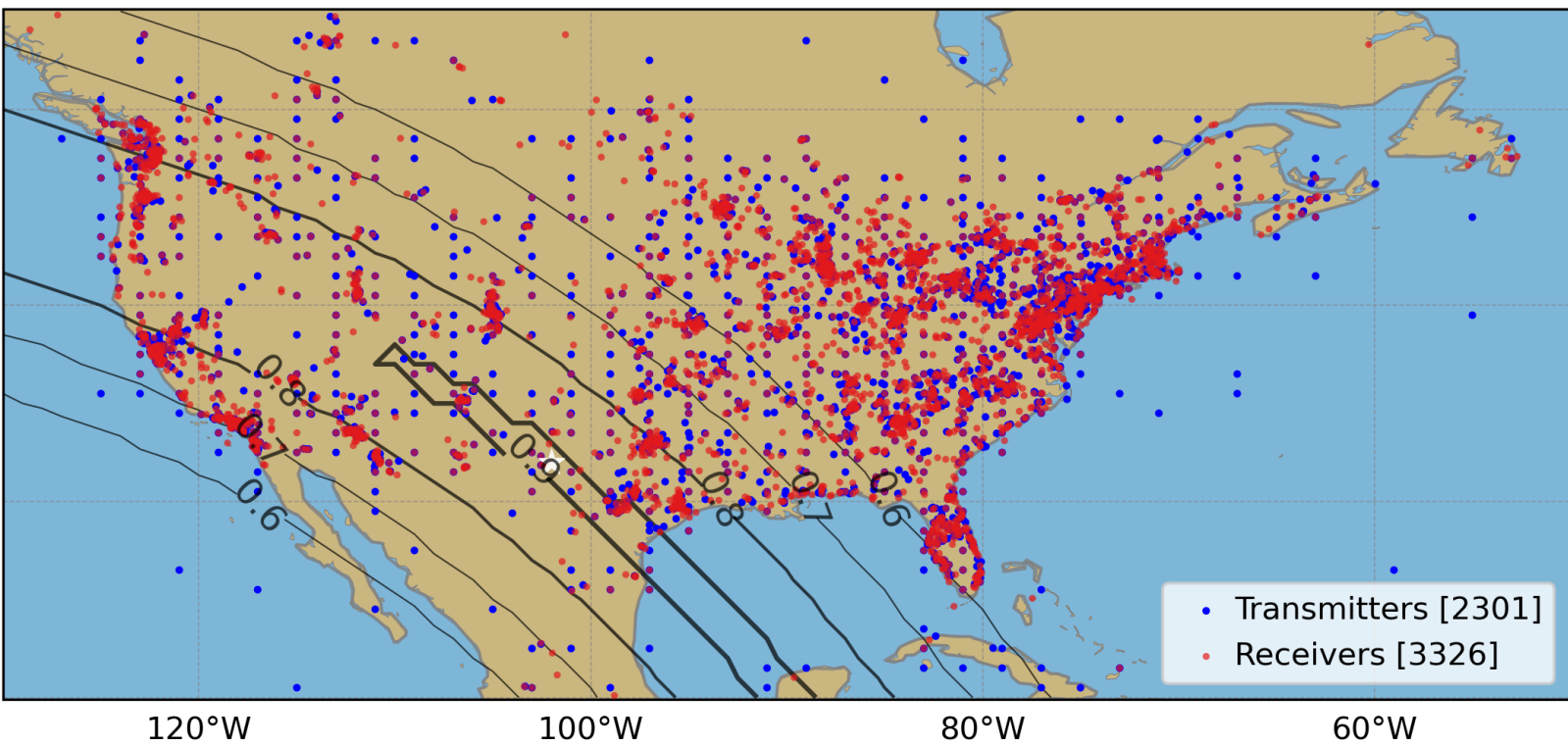
\*HamSCI Community Volunteer, Scranton, PA

# Solar Eclipses Through Ham Radio: CONUS

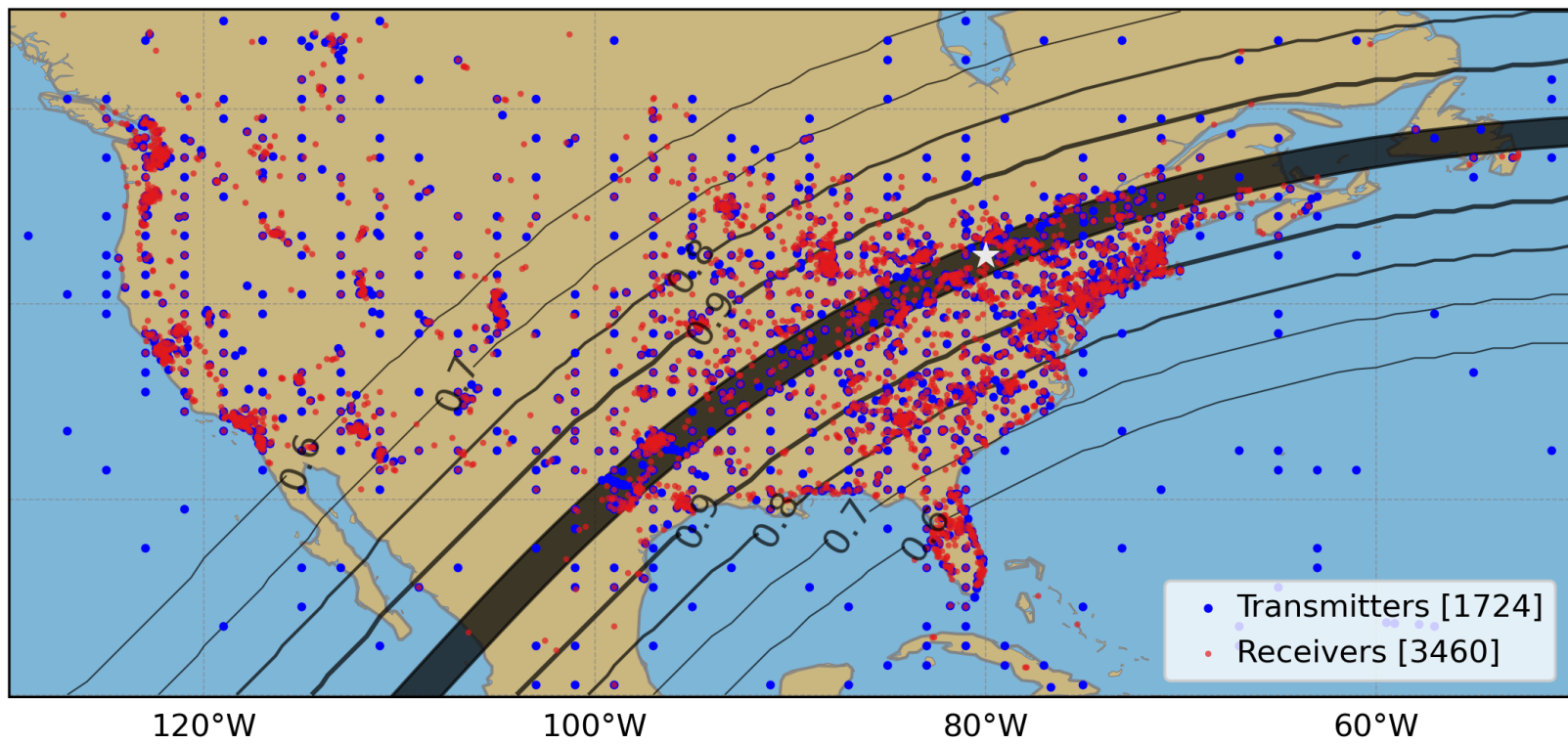
**Total Solar Eclipse  
August 21, 2017**



**Annular Solar Eclipse  
October 14, 2023**



**Total Solar Eclipse  
April 08, 2024**



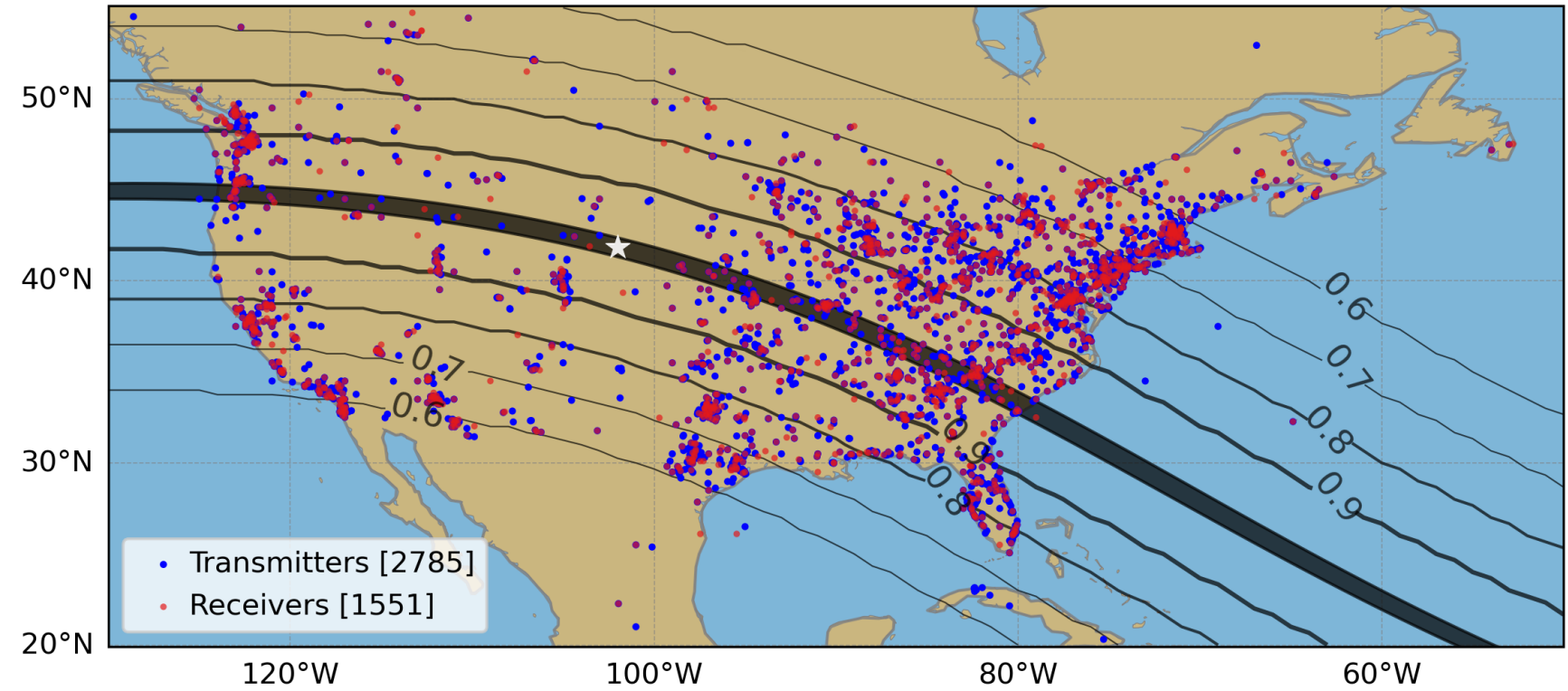
*Table: Number of spots on the eclipse day*

CONUS	~2 million	~45 million	~56 million
RBN	7%	< 1%	< 1%
WSPNet	39%	7%	8%
PSKReporter	54%	93%	92%
<b>WorldWide</b>	<b>~4 million</b>	<b>~166 million</b>	<b>~156 million</b>

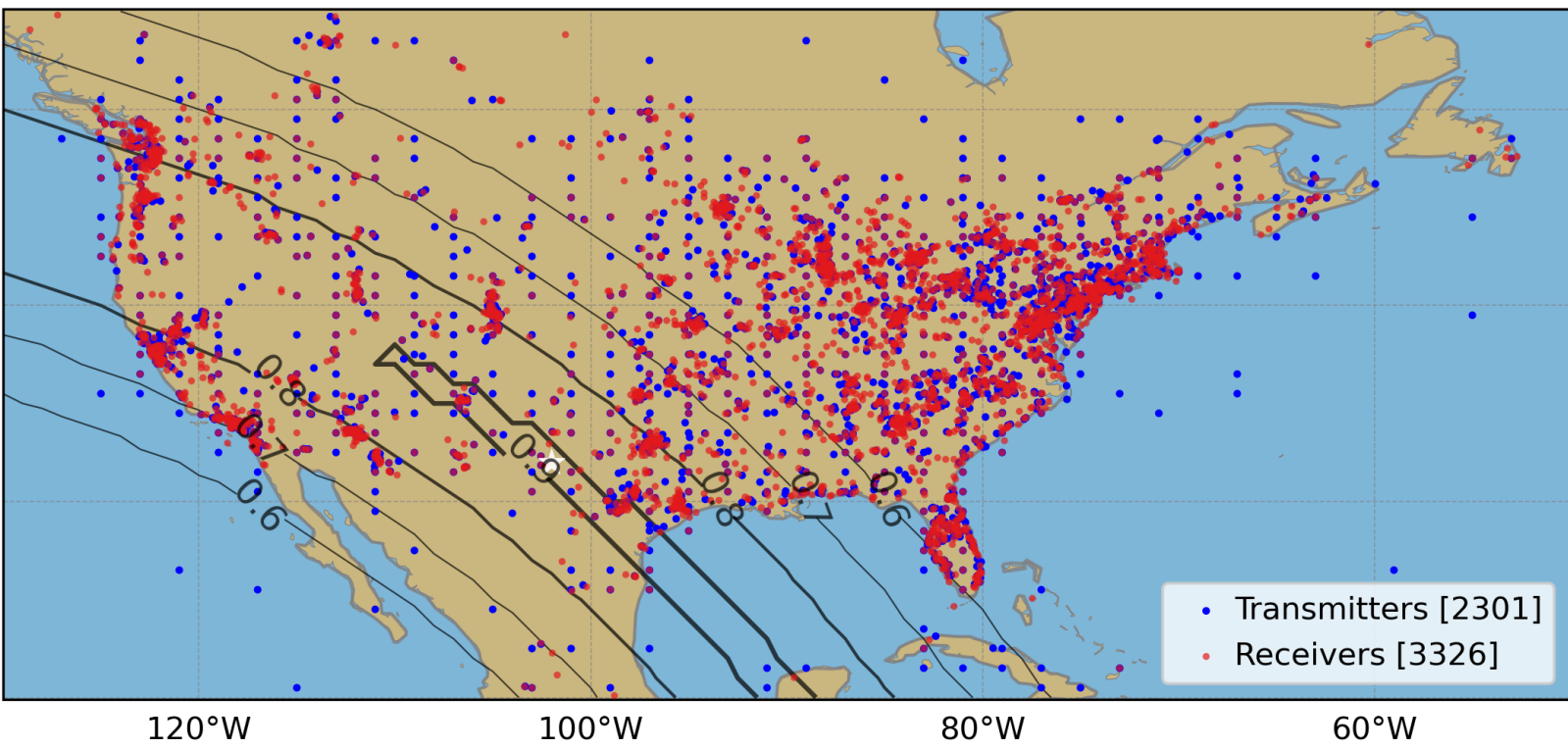
(Ham Radio RBN, WSPR, PSKReporter Datasets Available at *Madrigal database at Millstone*)

# Solar Eclipses Through Ham Radio: CONUS

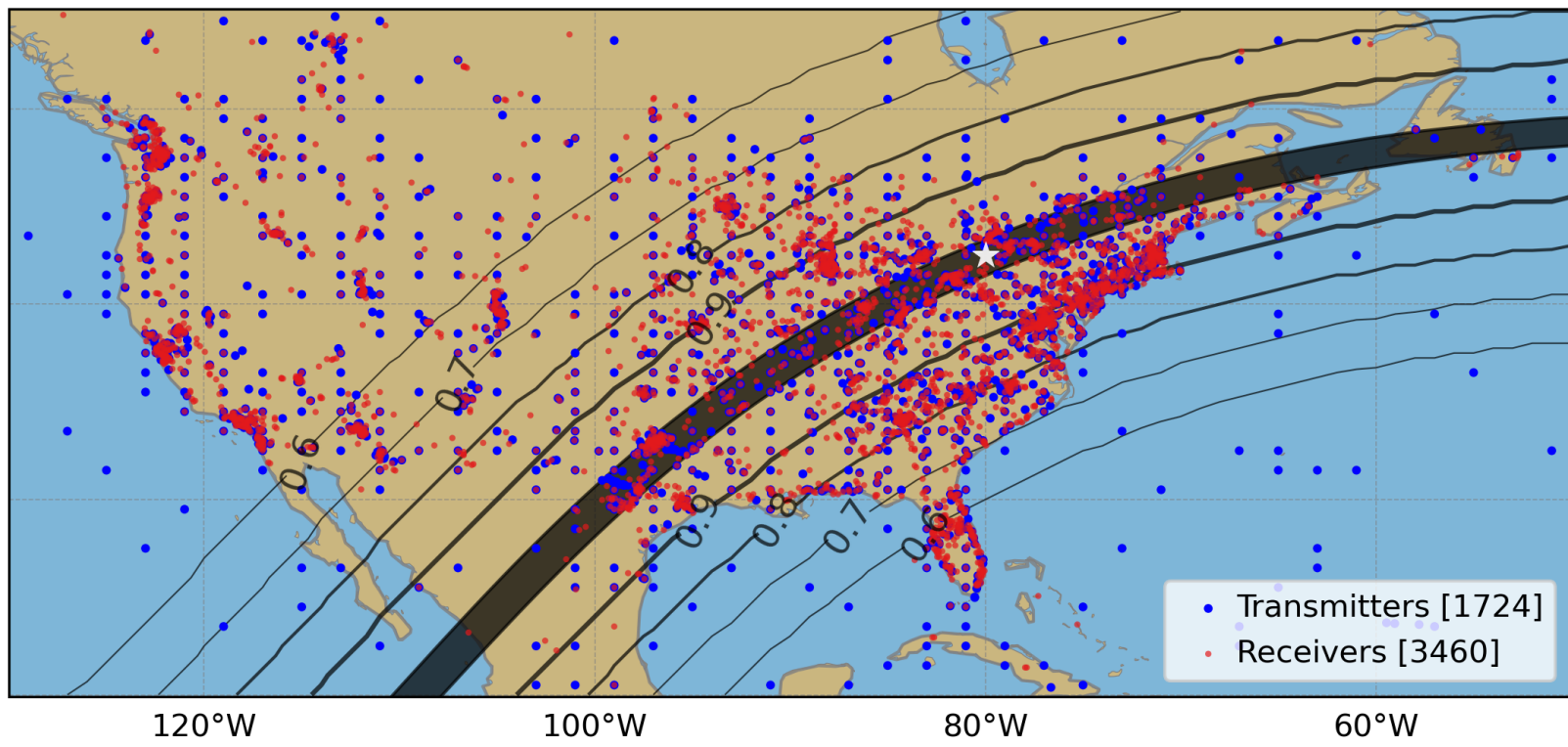
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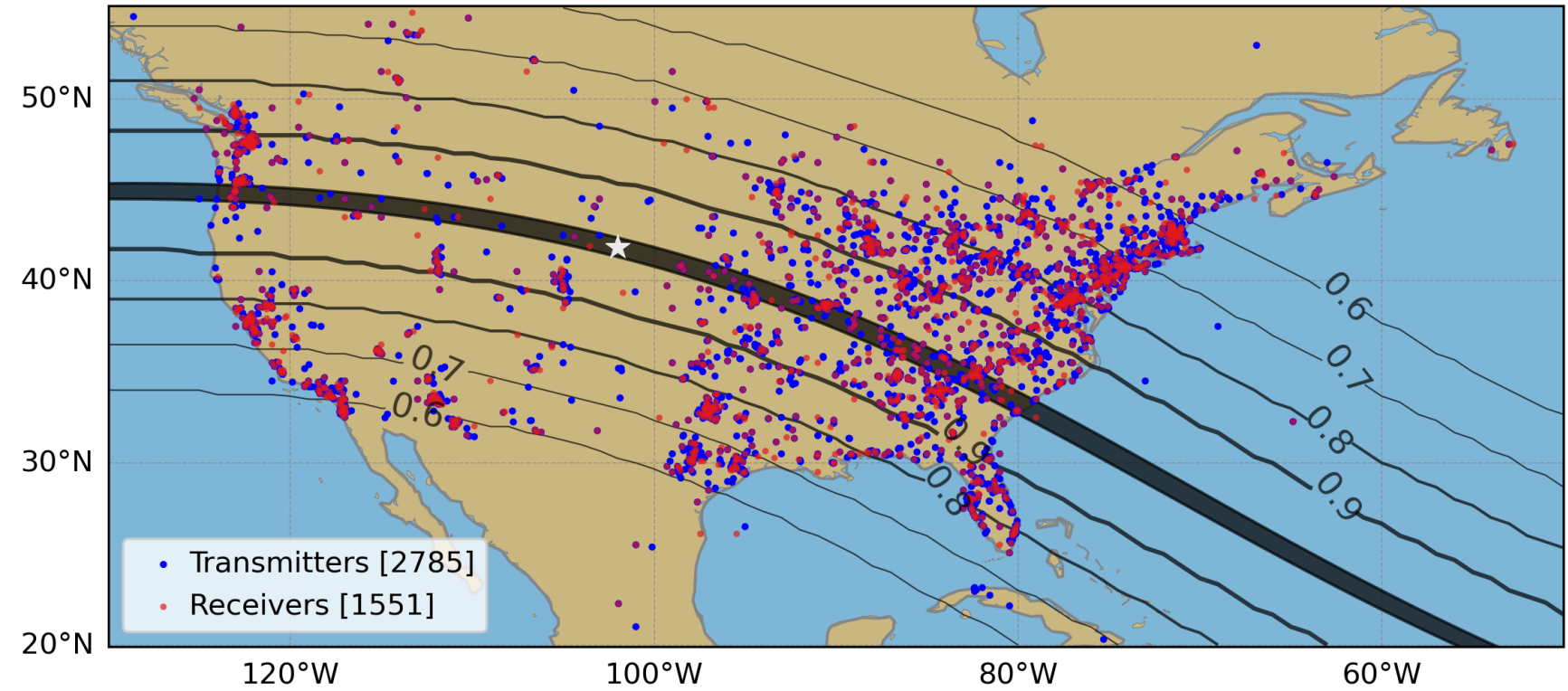


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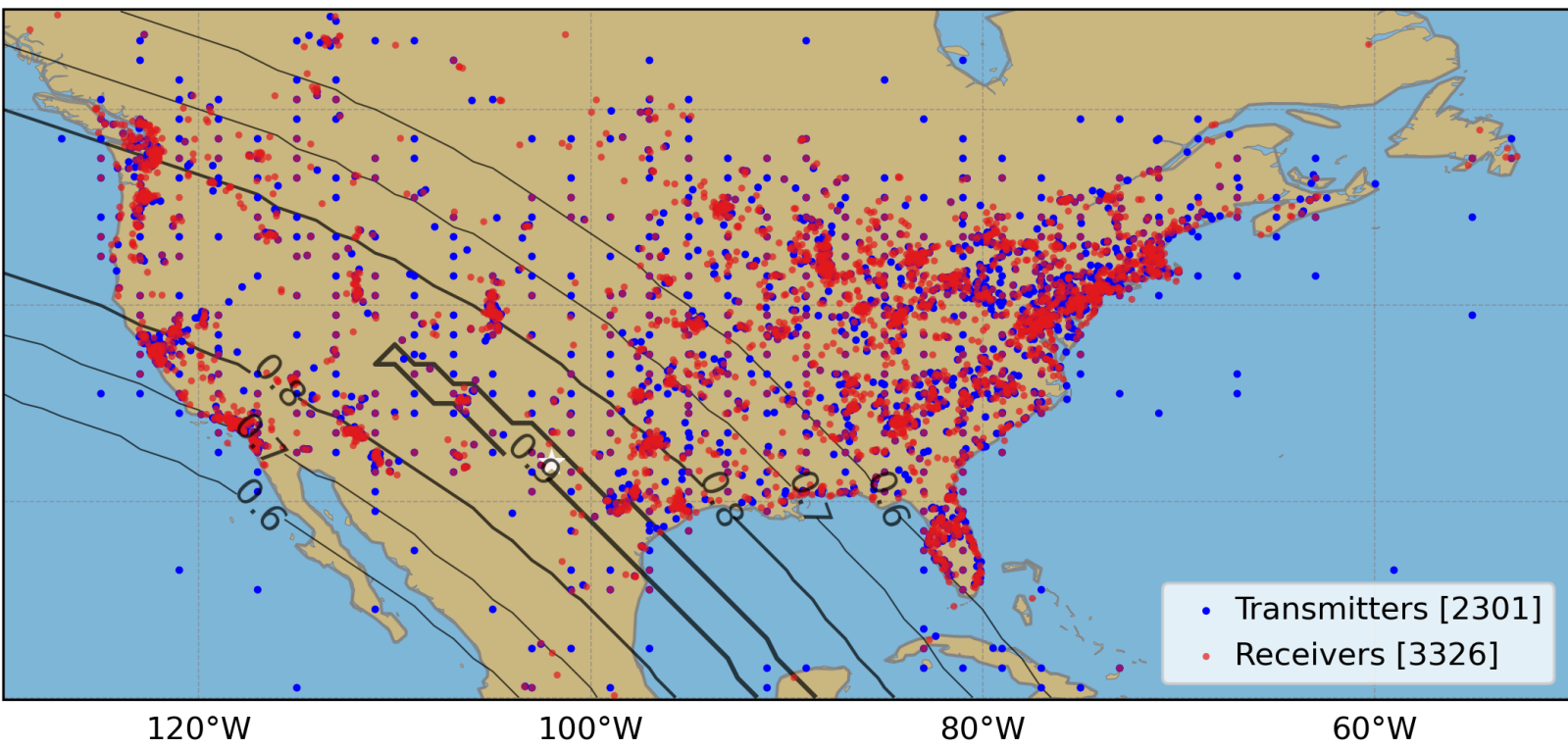
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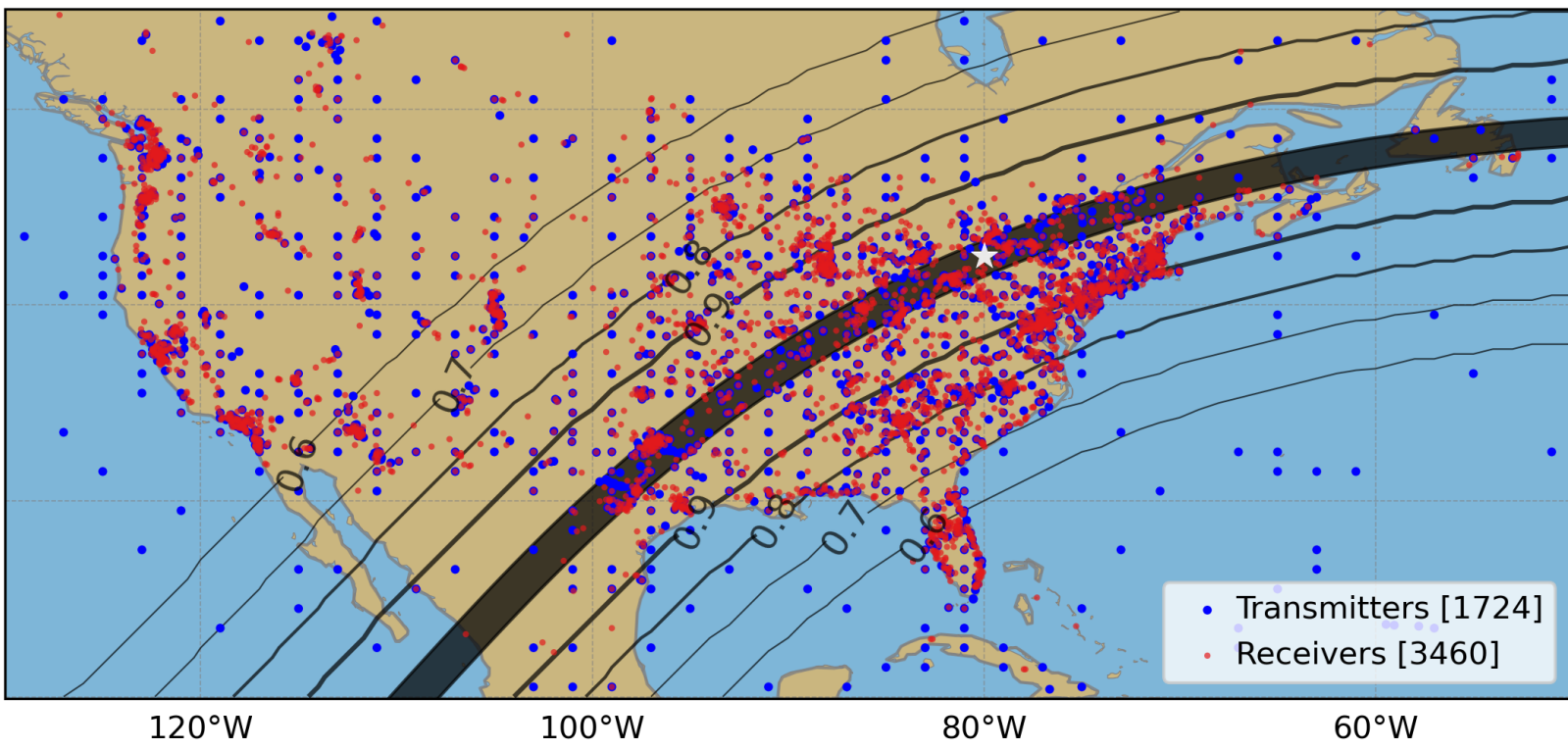
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# Solar Eclipses Through **\*Ham\*** Radio



WIKU-Great Woods Center for the Arts, Columbia



W9RWG - EM69tb



W3USR



<https://hamsci.org/>



WP3R



N6REL



KO4GQT



AI5MM (At totality)

Annular Solar Eclipse  
October 14, 2023: **Saturday**

Total Solar Eclipse  
April 08, 2024: **Monday**

# Solar Eclipses Through **\*Ham\*** Radio



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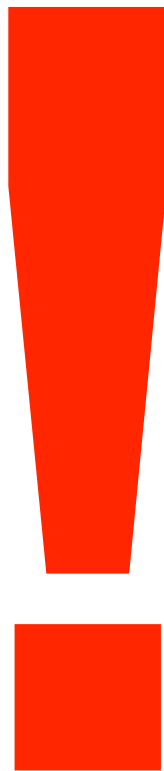
KO4GQT



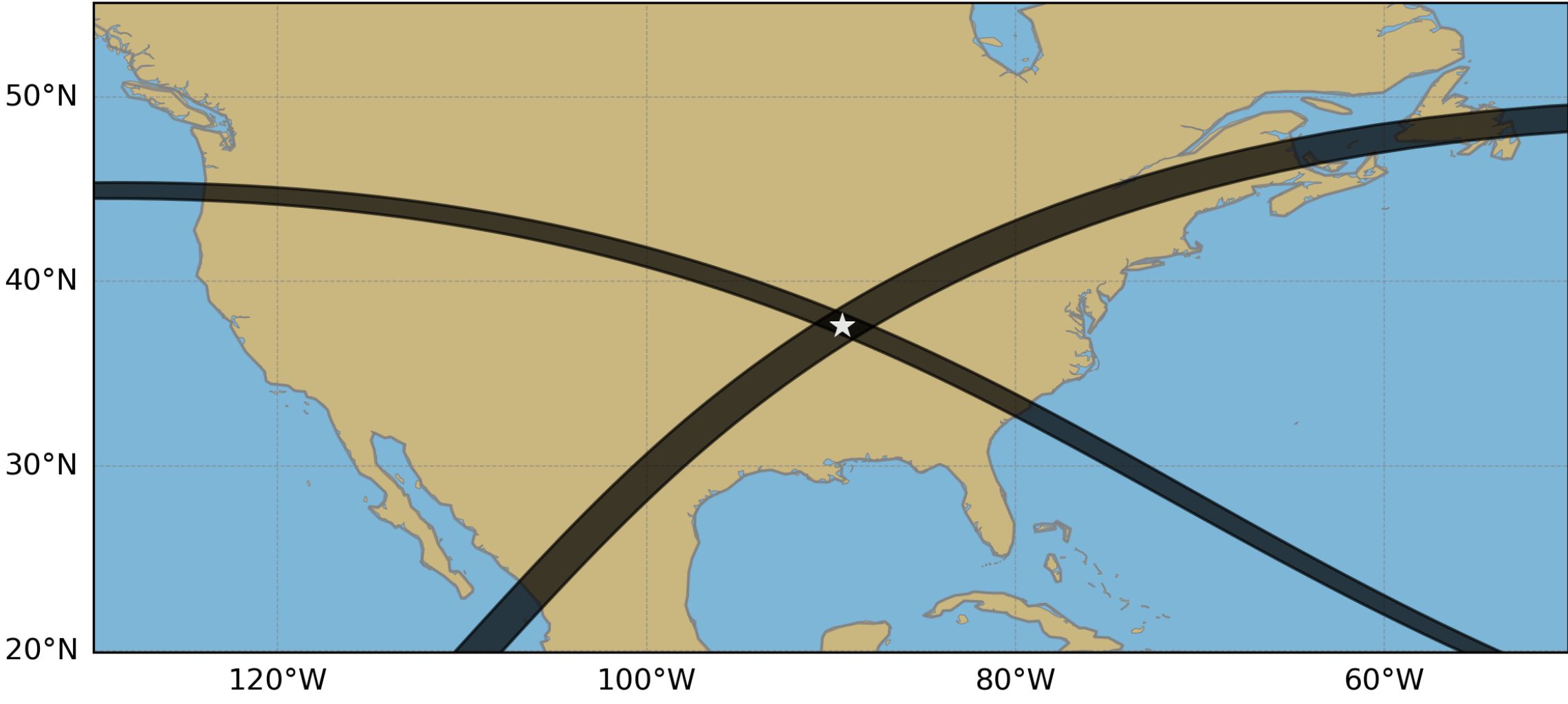
AI5MM (At totality)

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October 14, 2023: **Saturday**

Total Solar Eclipse  
April 08, 2024: **Monday**



# Total Solar Eclipse 2017 v/s 2024: CONUS Links

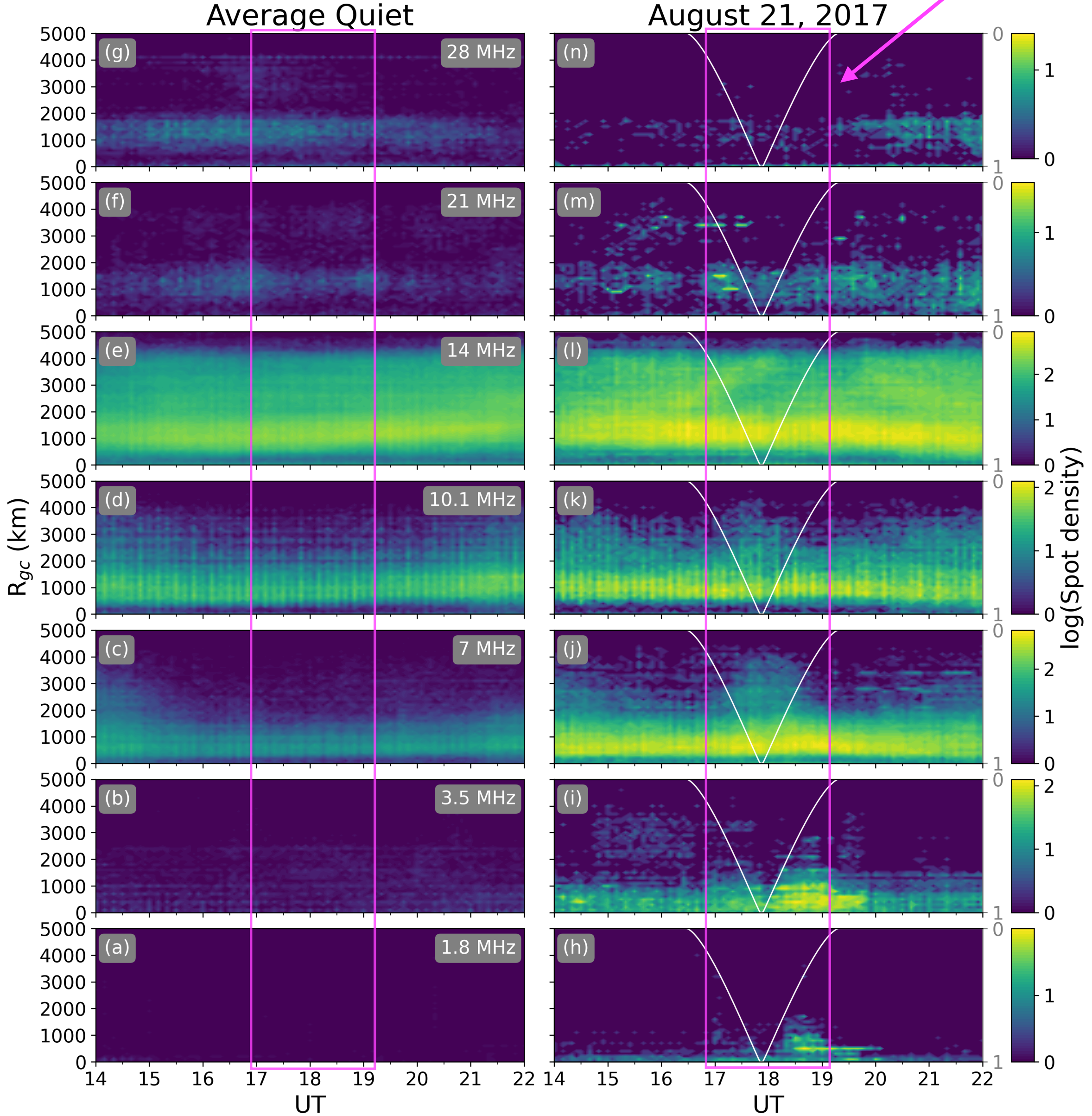
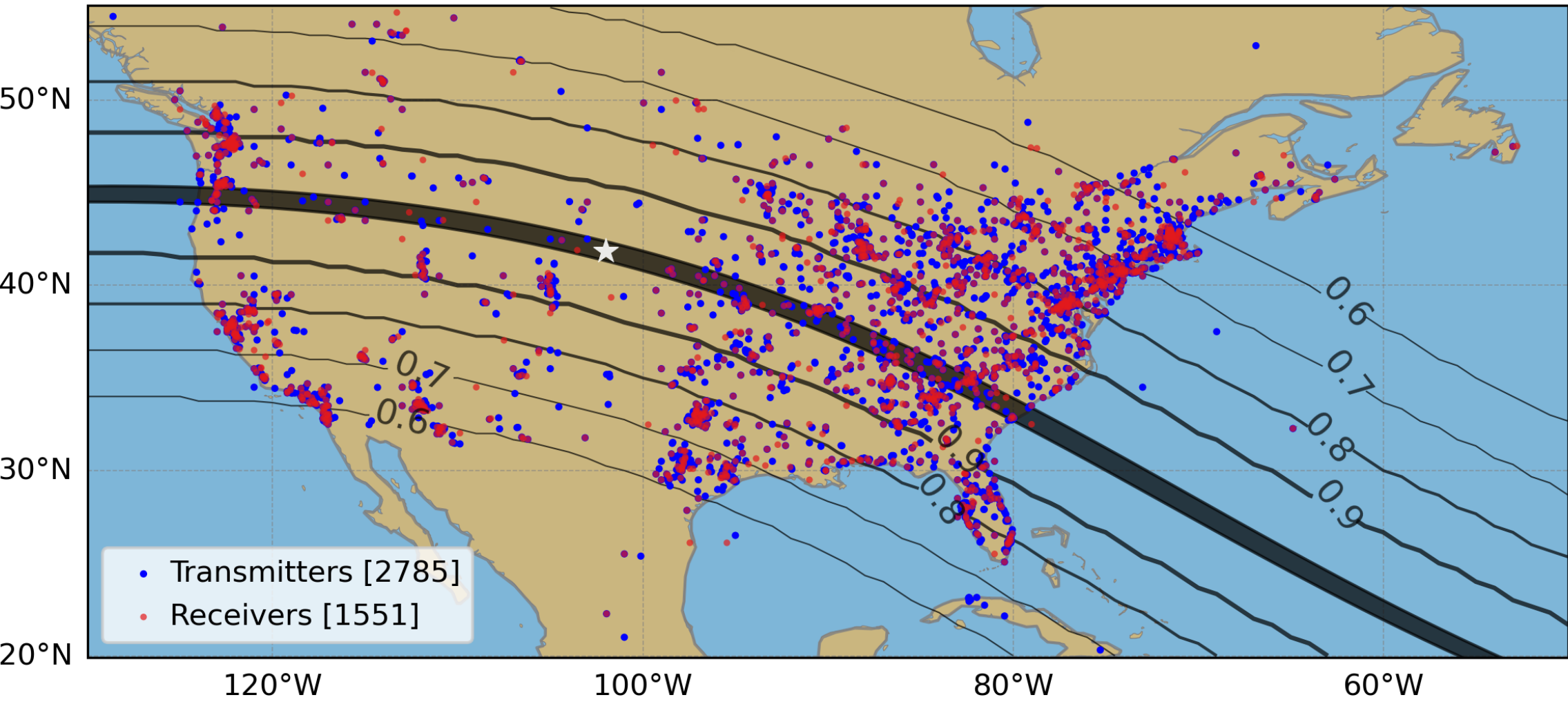


## Interval over CONUS

	Eclipse-17	Eclipse-24
UT :	~17 - 19	~18-20
LT :	~ 09 - 13:30	~11 - 16:30

# Total Solar Eclipse: August 21, 2017

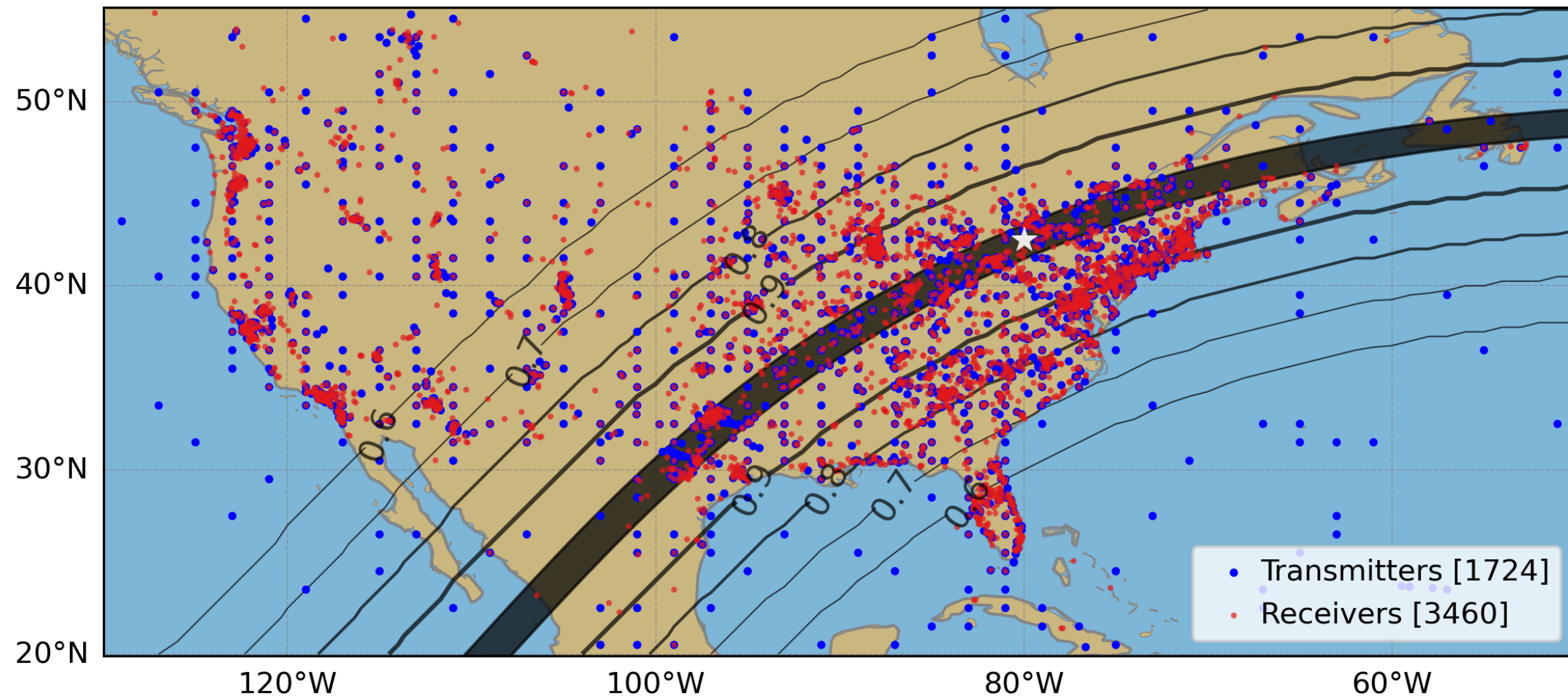
*Eclipse interval over CONUS*



- Eclipse effects observed on multiple frequency bands
- Enhanced propagation during eclipse, suggests a reduction in D-region absorption

# Total Solar Eclipse: April 08, 2024

*Eclipse interval over CONUS*



## 21 - 28 MHz:

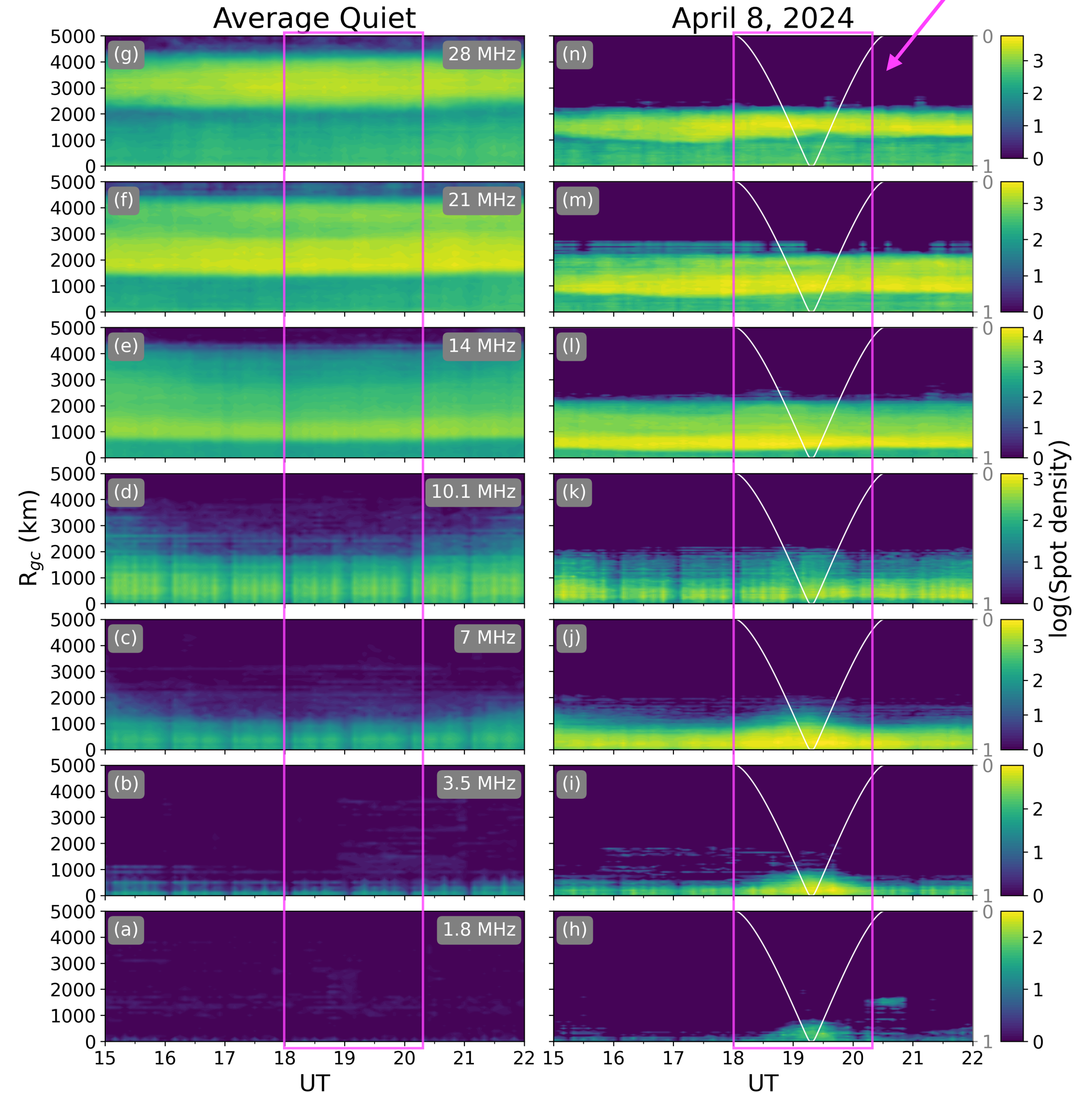
- appears to increase the range of communication, but delayed response

## 10 & 14 MHz:

- eclipse impact not clearly visible in this figure

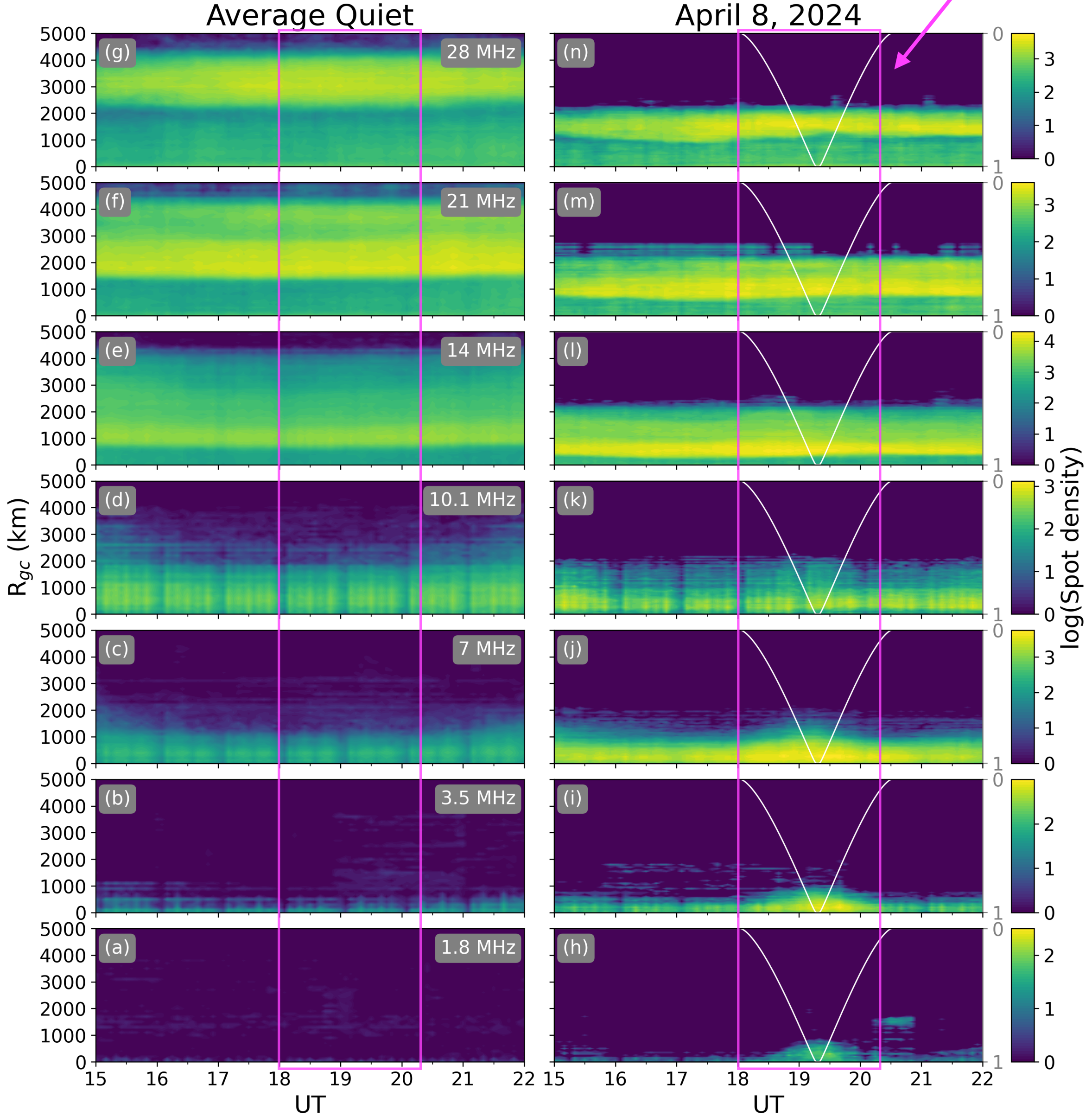
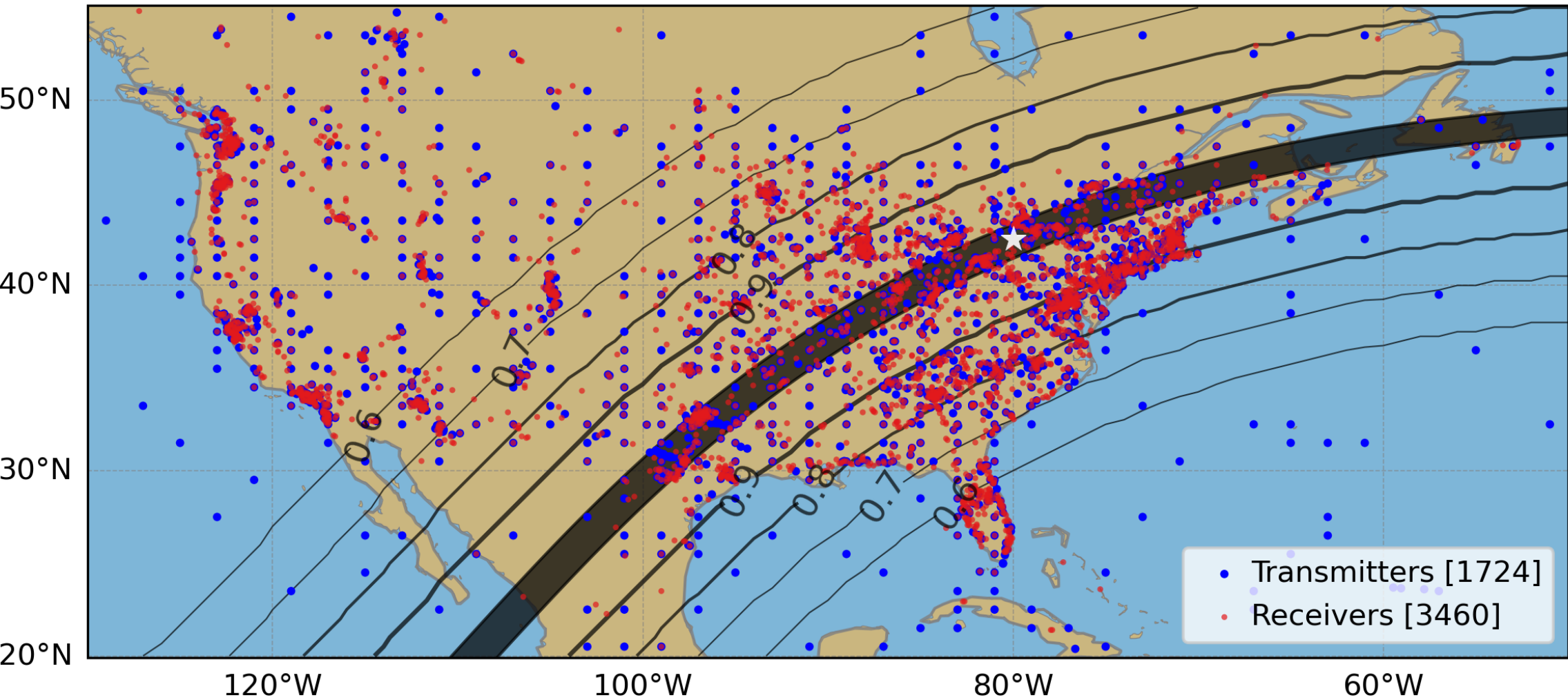
## 1.8 - 7 MHz:

- asymmetric response
- increase in range of communications



# Total Solar Eclipse: April 08, 2024

*Eclipse interval over CONUS*



## 21 - 28 MHz:

- **appears** to increase the range of communication, but delayed response

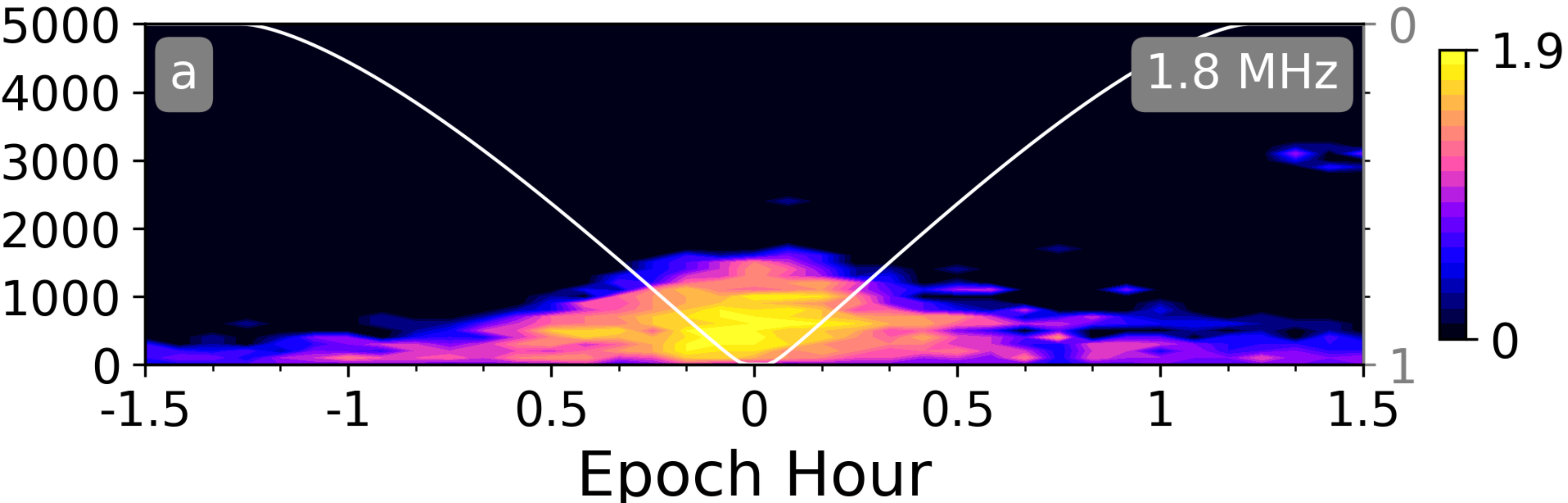
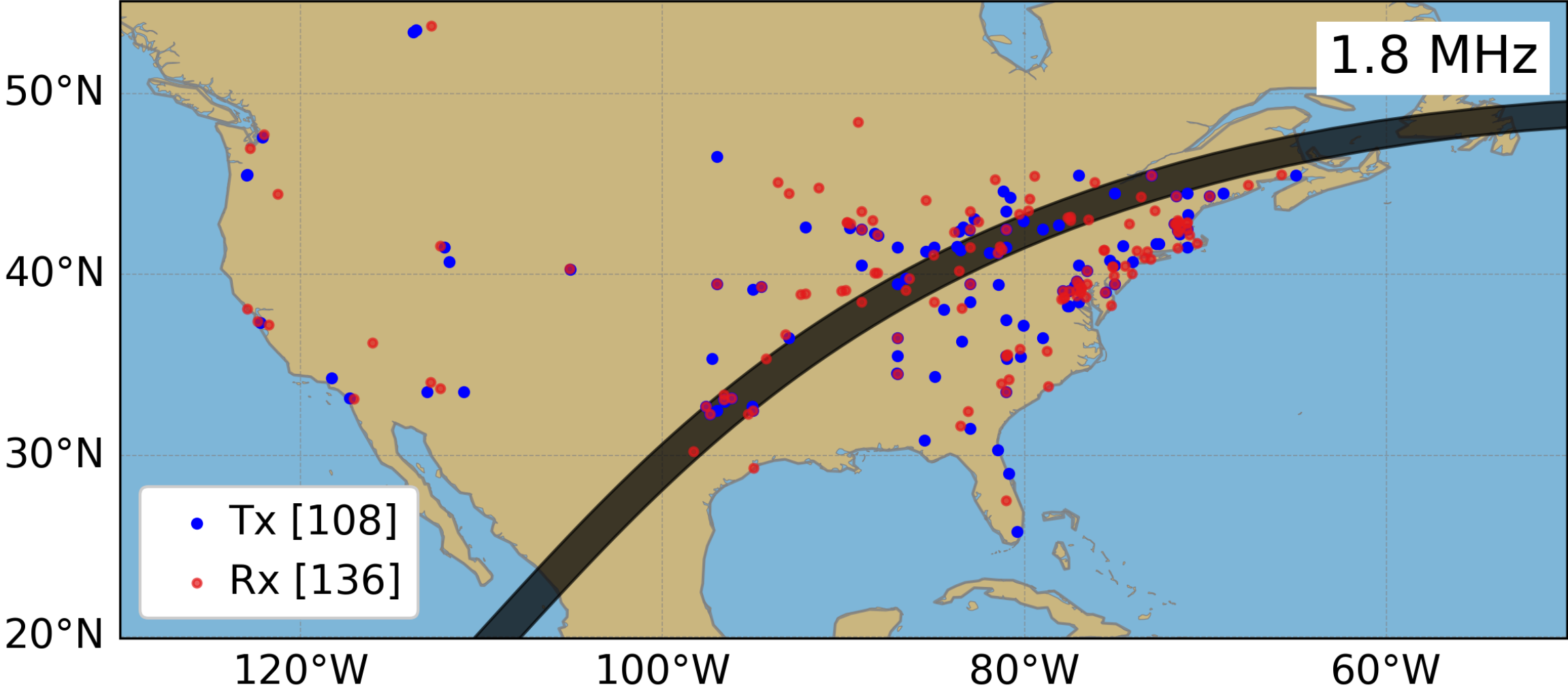
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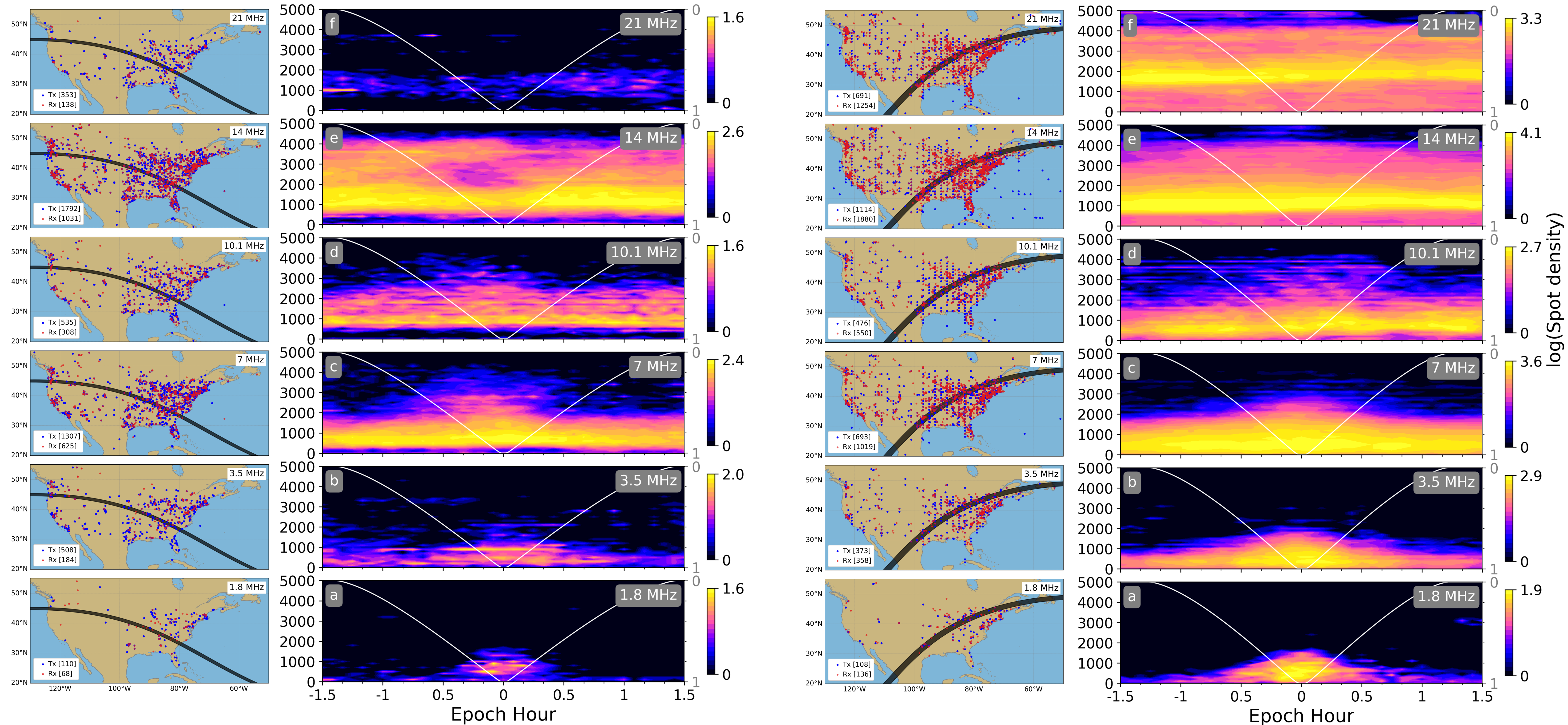
# Epoch Analysis:



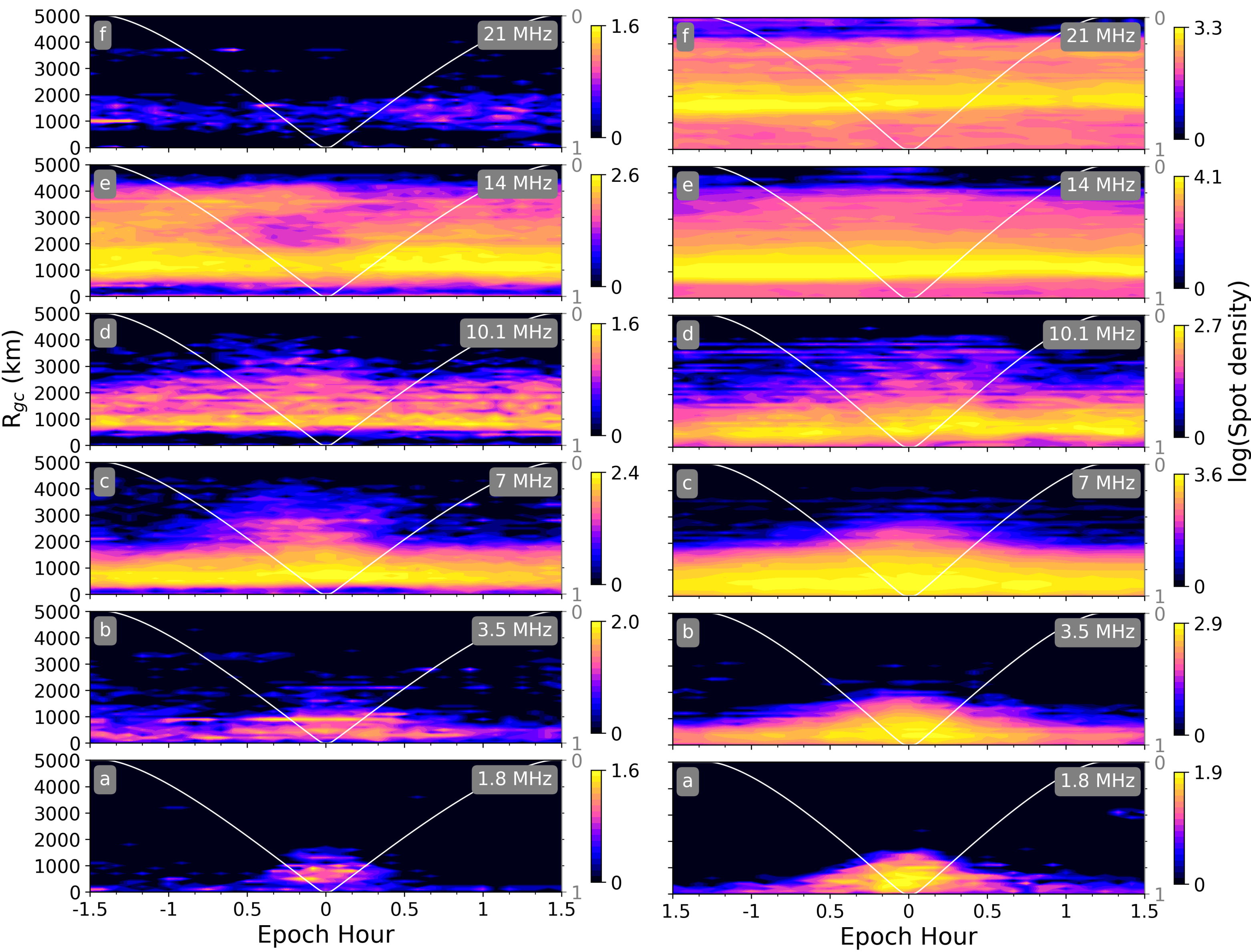
# Epoch Analysis: 2017

v/s

# 2024



# Epoch Analysis: 2017 v/s 2024



**21 - 28 MHz (15 - 10 m):**

Eclipse-17  
*Contacts:* bite out/a few  
*Response:* symmetric

Eclipse-24  
 increased range  
 delayed

**14 MHz (20 m):**

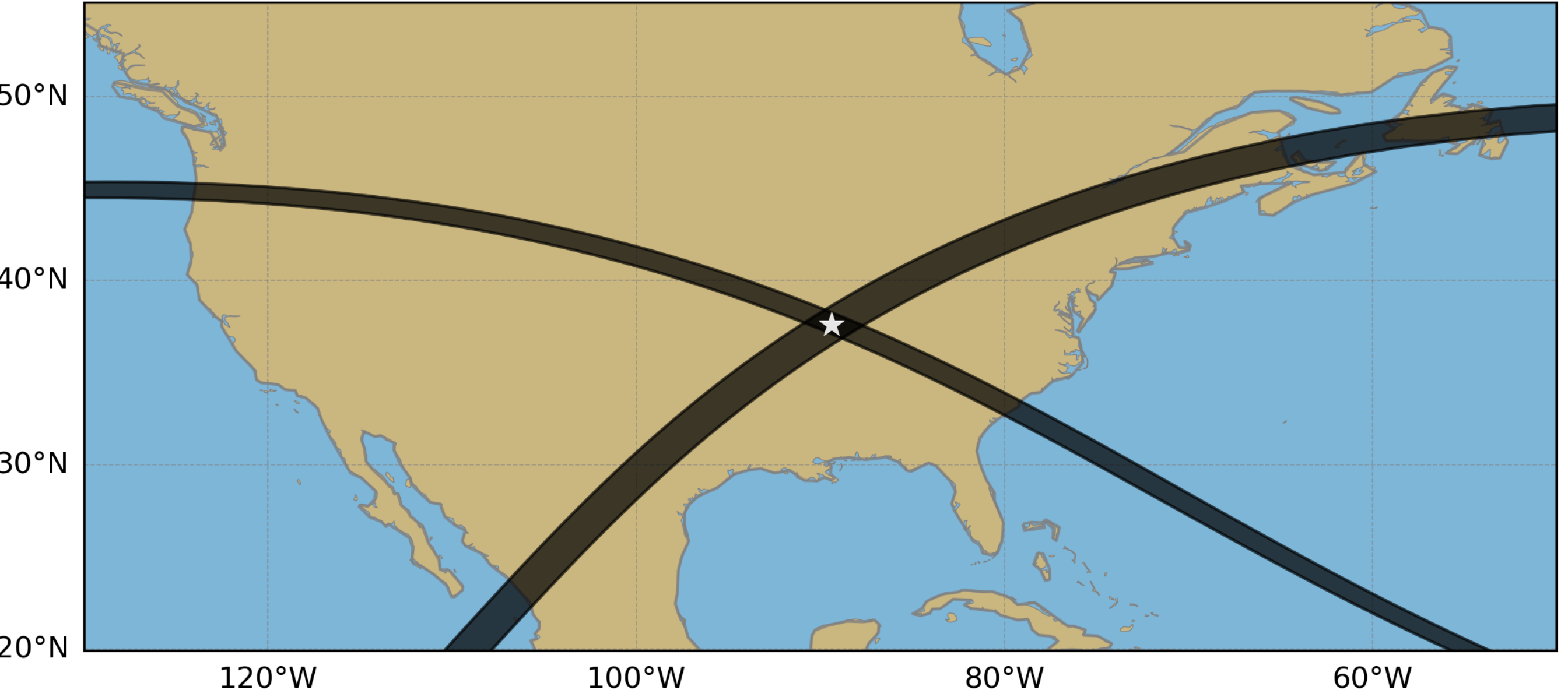
Eclipse-17  
*Contacts:* bite out/lesser  
*Response:* symmetric

Eclipse-24  
 increased range  
 delayed

**1.8 - 10 MHz (160 - 30 m):**

- increase in range of communication
- symmetric response to eclipse

# Eclipse: 2017 v/s 2024



- 14 - 28 MHz (20 - 10 m):**
- 2017: bite out, 2024: connected with increased range
  - **different responses in 2017 and 2024**

- 1.8 - 10 MHz (160 - 30 m):**
- similar responses in 2017 and 2024
  - increase in range of communication

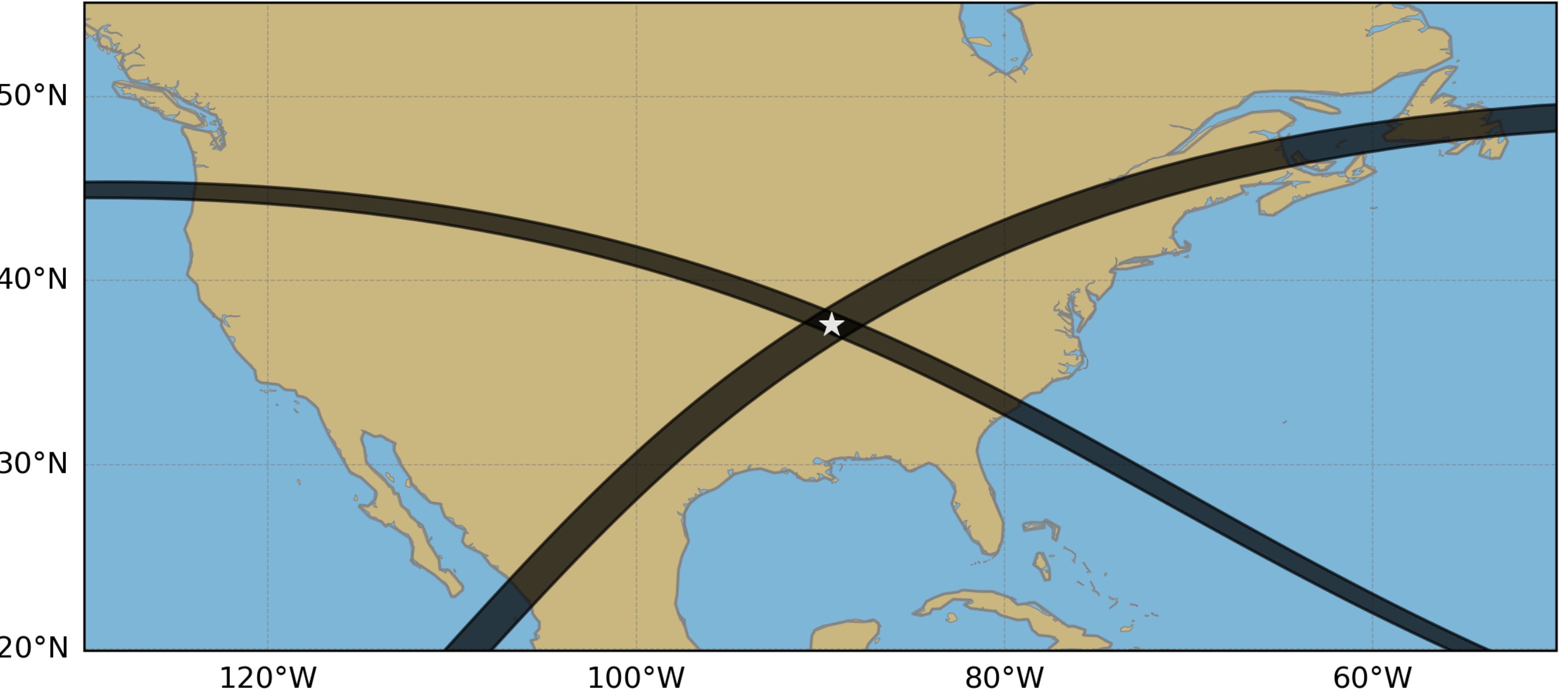
*2017 & 2024 common location: ~37.5°N, 89.5°W*

## Interval over CONUS

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Totality path data from <https://eclipse.gsfc.nasa.gov/eclipse.html>

# Eclipse: 2017 v/s 2024



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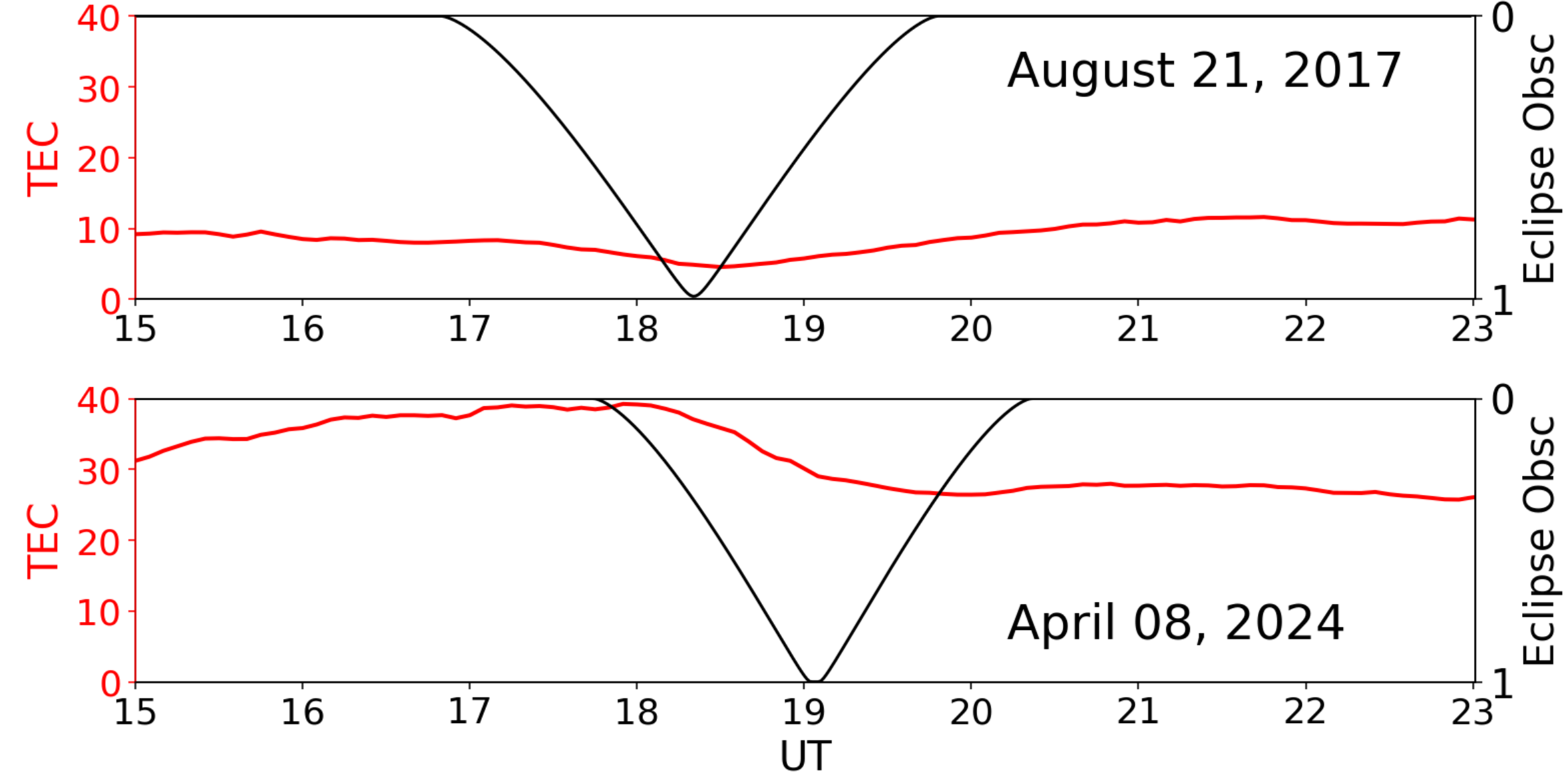
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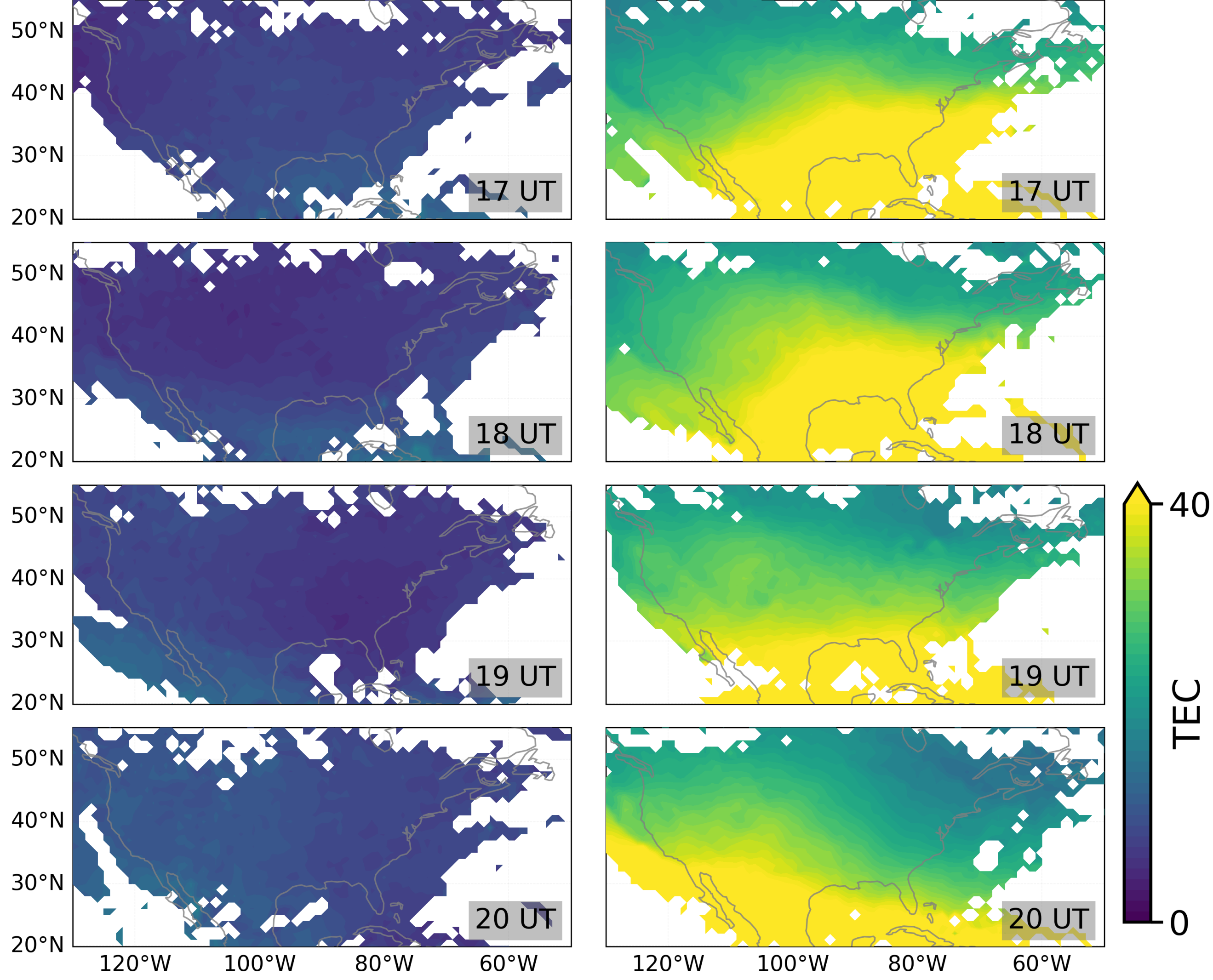
TEC at the common location: 37.5°N, 89.5°W



# Eclipse: 2017 v/s 2024

August, 21 2017

April, 08 2024



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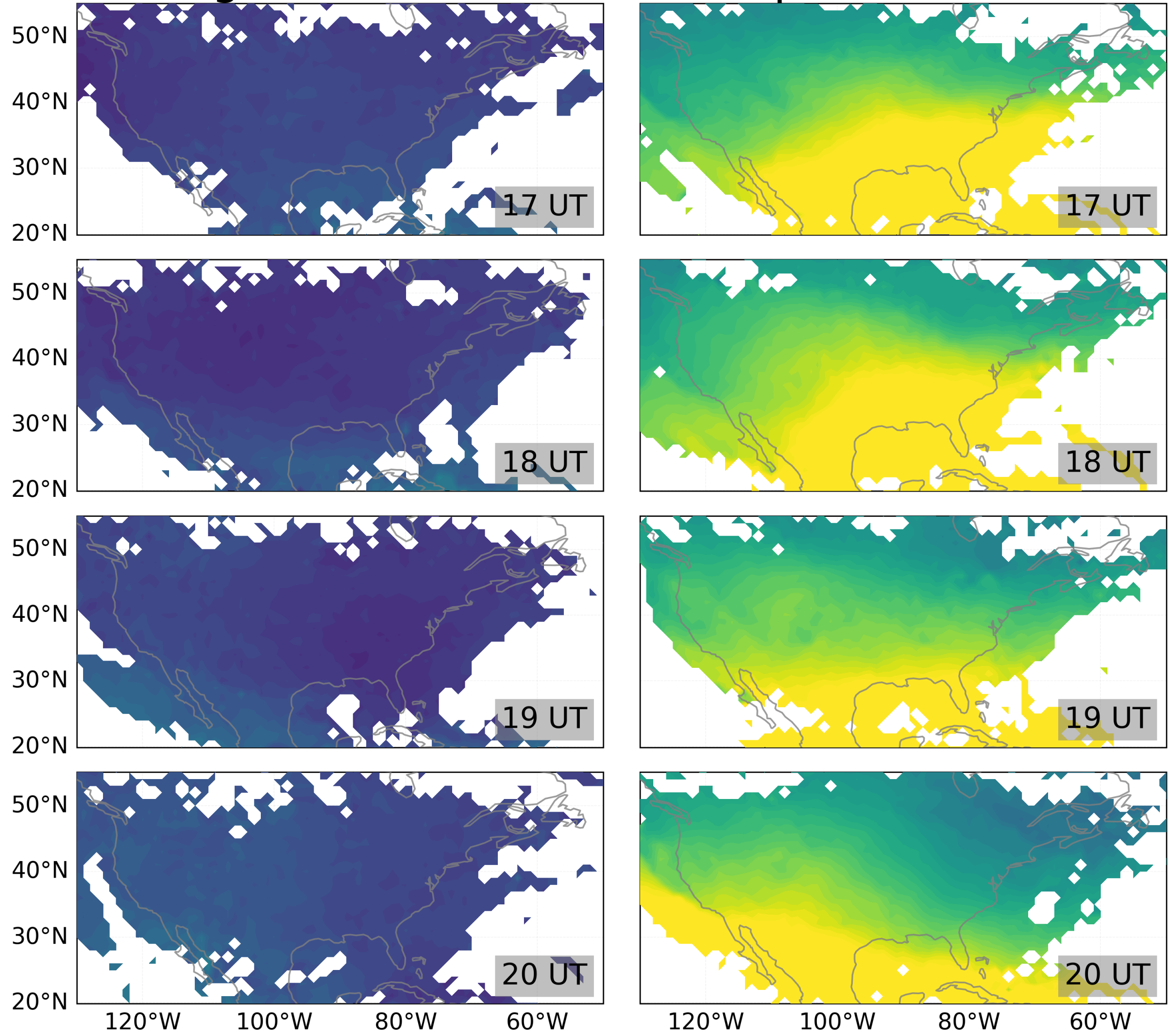
- similar responses
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(Data source: Madrigal database at Millstone)

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August, 21 2017

April, 08 2024



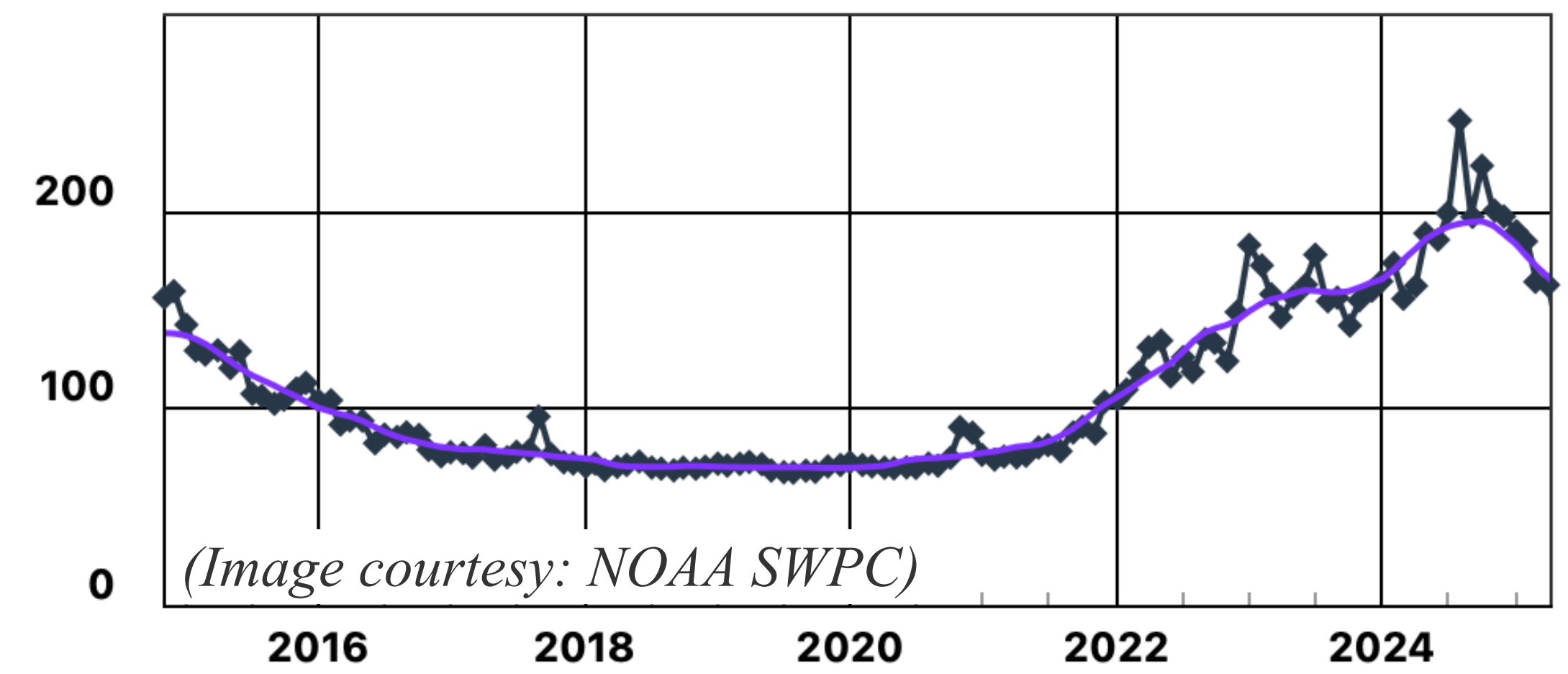
### 14 - 28 MHz (20 - 10 m):

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- **different responses in 2017 and 2024:**
  - primarily, due to differences in solar flux levels or SSN
  - denser ionosphere in 2024: 14-28 MHz waves also bend/reflect back towards the Earth

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- similar responses
- increase in range of communication

Solar Cycle F10.7cm Radio Flux Progression



# Summary#1: CONUS Total Solar Eclipse 2017 v/s 2024

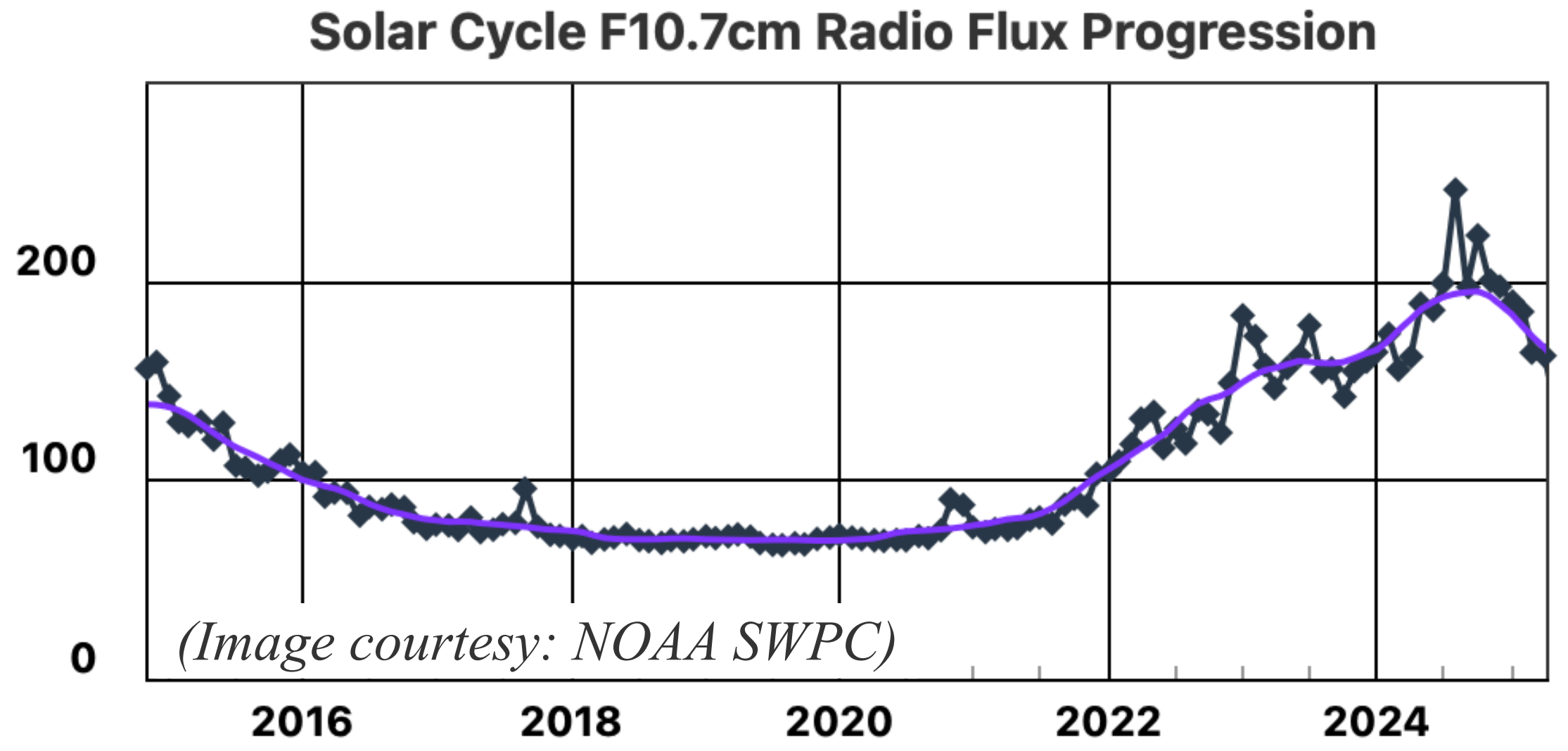
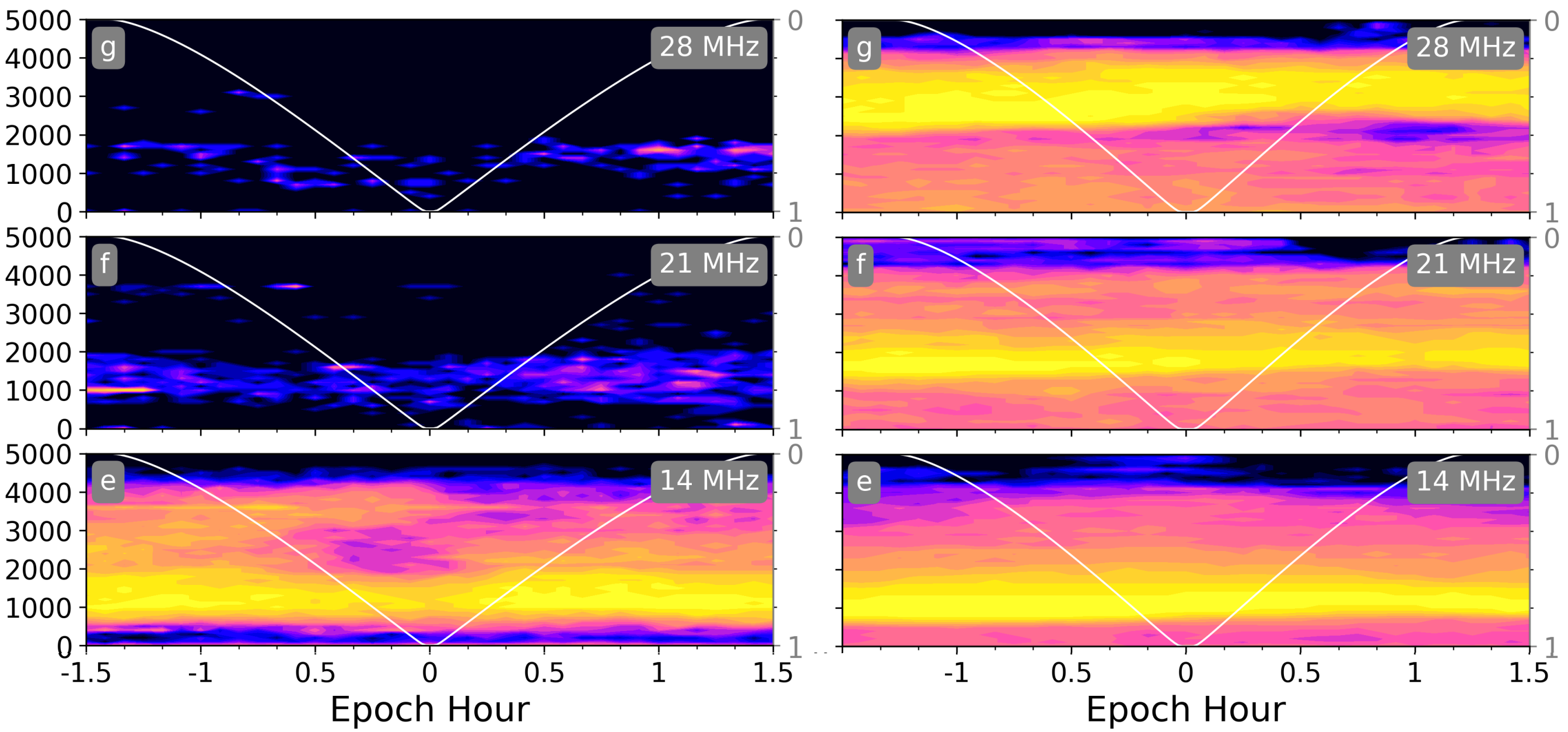
# Summary#1: CONUS Total Solar Eclipse 2017 v/s 2024

## 14 - 28 MHz (20 - 10 m):

- 2017: bite out, 2024: connected with increased range
- *different responses in 2017 and 2024: primarily, due to differences in solar flux levels/ sunspot numbers*
  - *denser ionosphere in 2024: 14-28 MHz waves also bend/ reflect back towards the Earth (ground-to-ground links)*

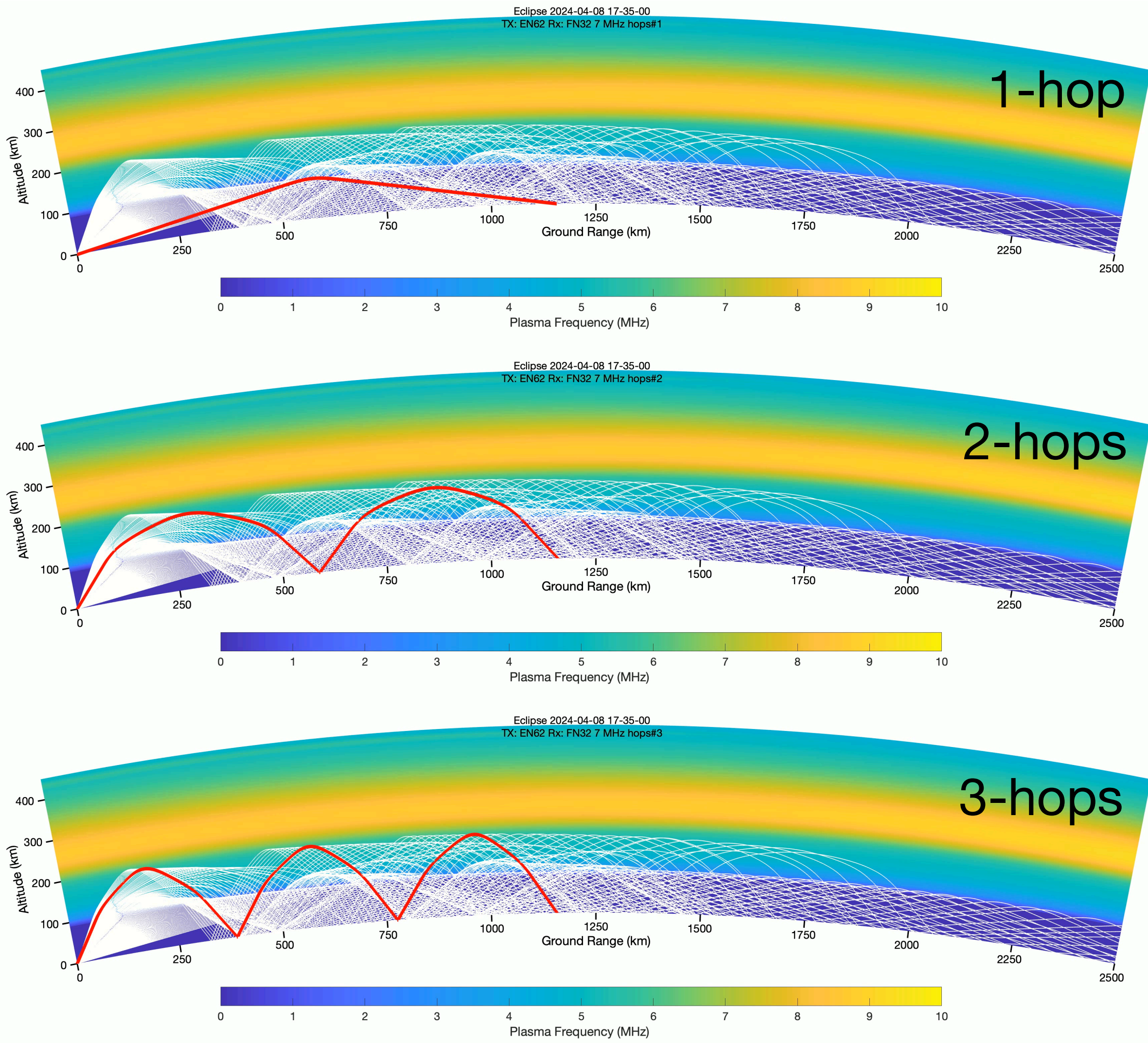
## 1.8 - 10 MHz (160 - 30 m):

- similar responses in 2017 & 2024: increase in range of communication
- changes symmetric to the eclipse obscurations levels
  - *lower altitude ionosphere (D, E, F1 regions) respond quickly to eclipse*



# Total Solar Eclipse 2024: Raytracing/ Modeling

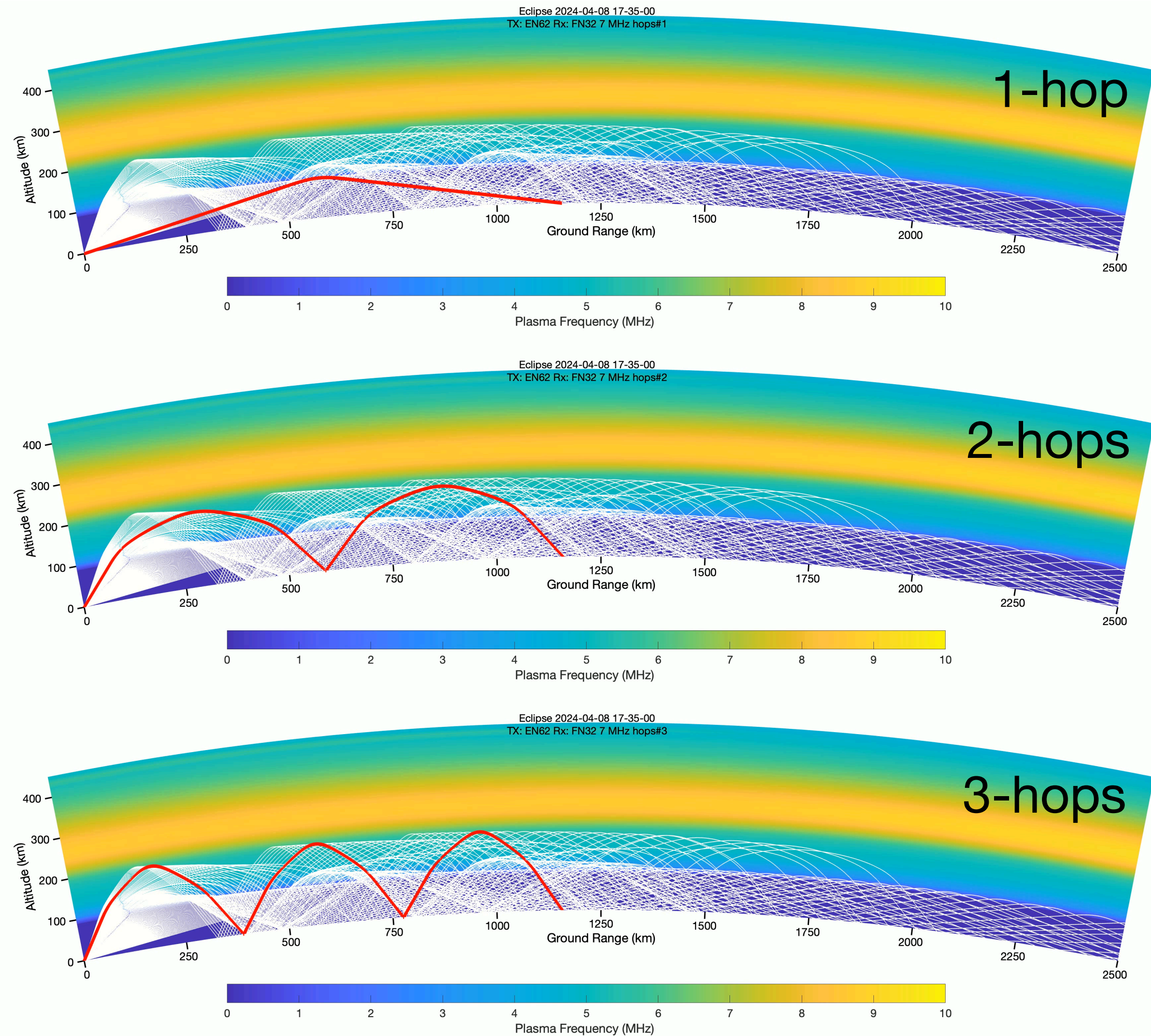
# Total Solar Eclipse 2024: Raytracing/ Modeling



- **Raytrace: PHaRLAP**  
*(Provision of High-frequency Ray tracing Laboratory for Propagation studies)*

**Fig:** Example ray-trace from a fixed Tx to a fixed Rx

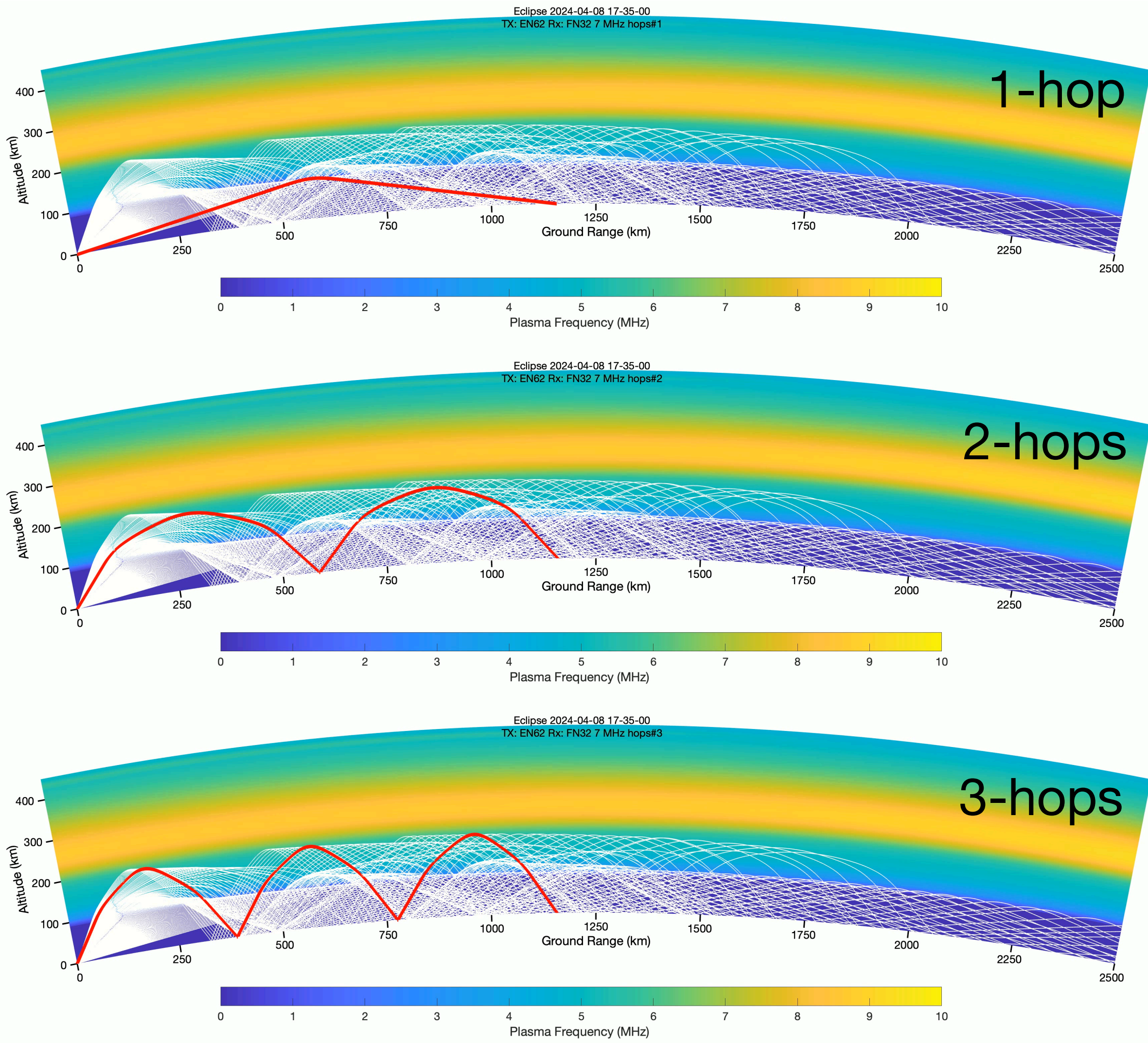
# Total Solar Eclipse 2024: Raytracing/ Modeling



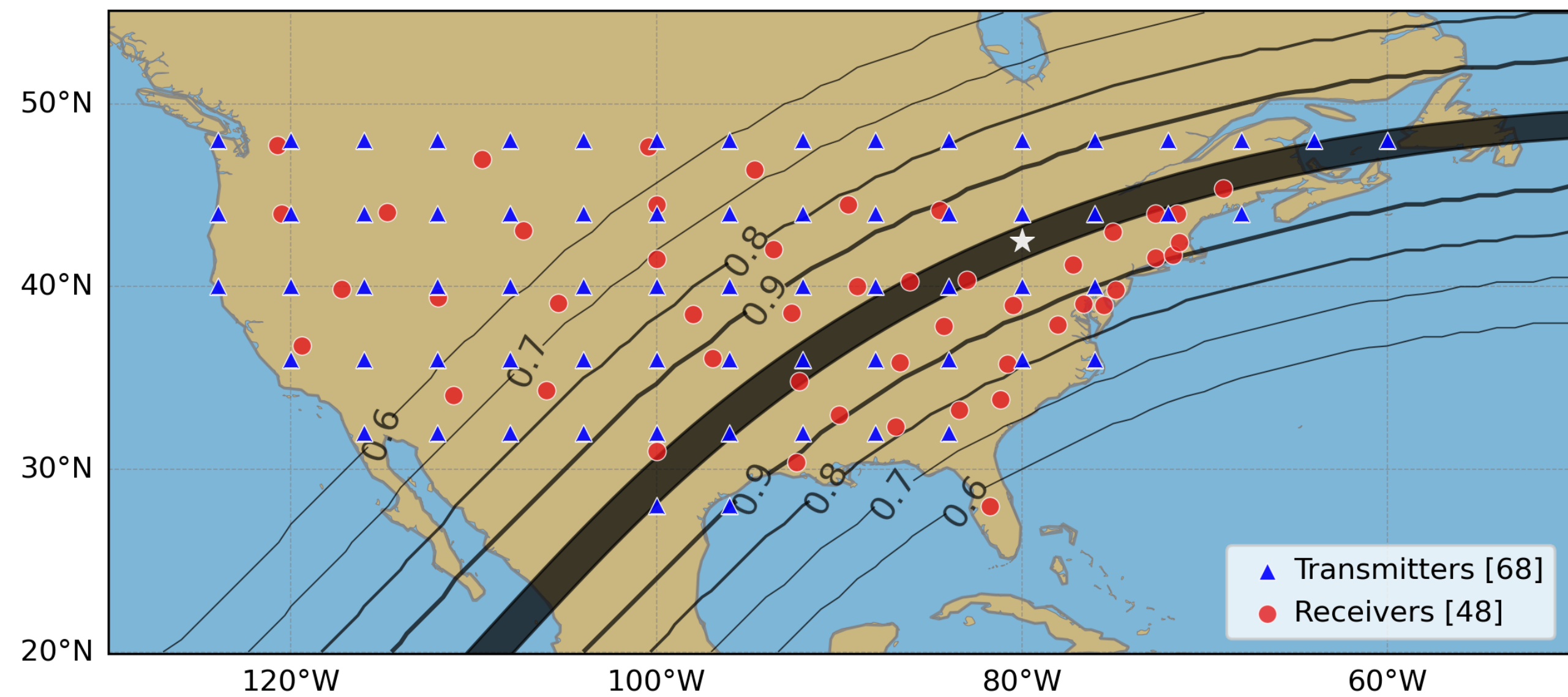
- **Raytrace: PHaRLAP**  
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- **Ionosphere: SAMI3 and SAMI3/WACCMX**  
(*SAMI3 is a physics based 3D model of Ionosphere*)

**Fig:** Example ray-trace from a fixed Tx to a fixed Rx

# Total Solar Eclipse 2024: Raytracing/ Modeling



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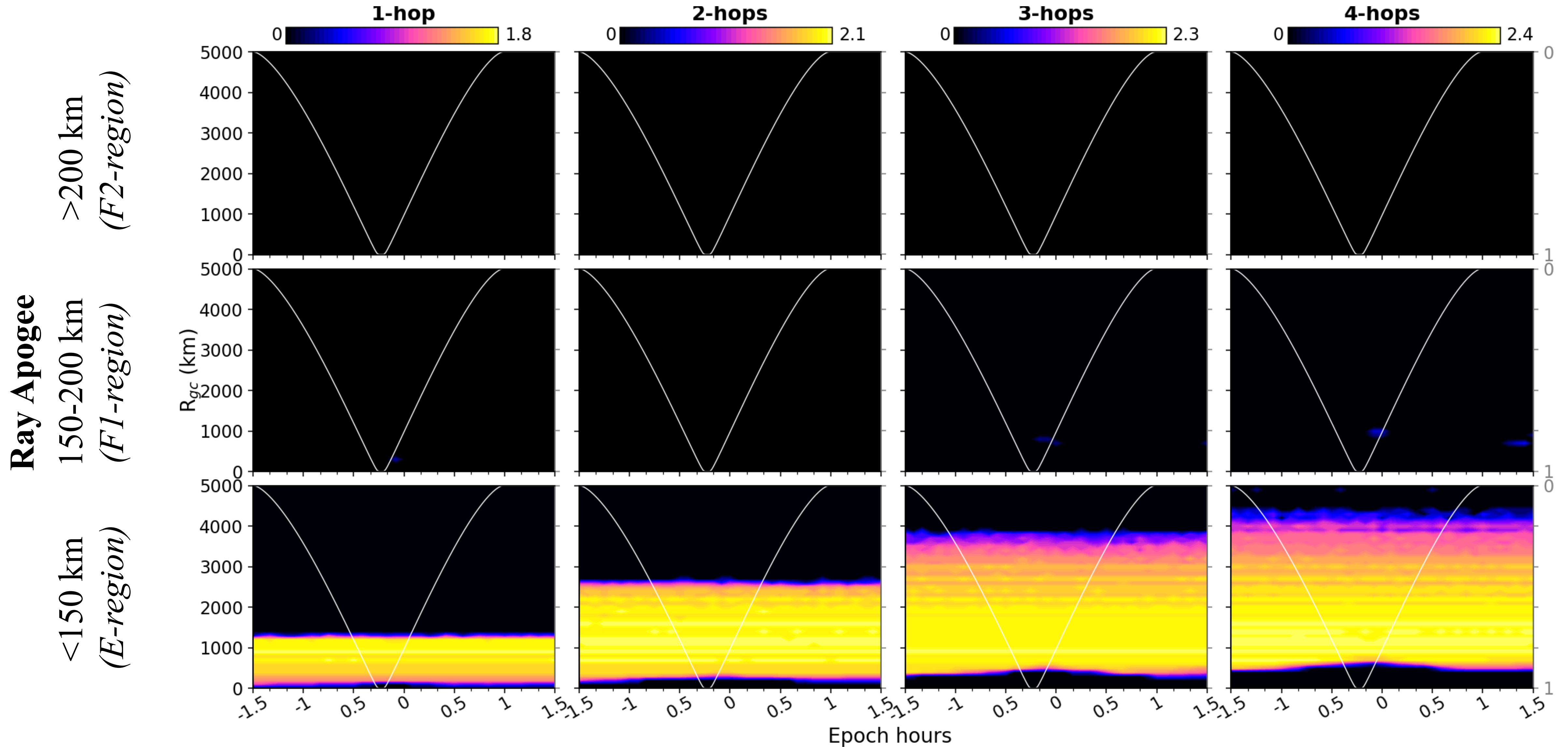


**Fig:** Example ray-trace from a fixed Tx to a fixed Rx

**Fig:** Grid of Tx and Rx stations used for raytracing

# Eclipse 2024 Raytracing: 3.5 MHz

Ionosphere:  
SAMI3

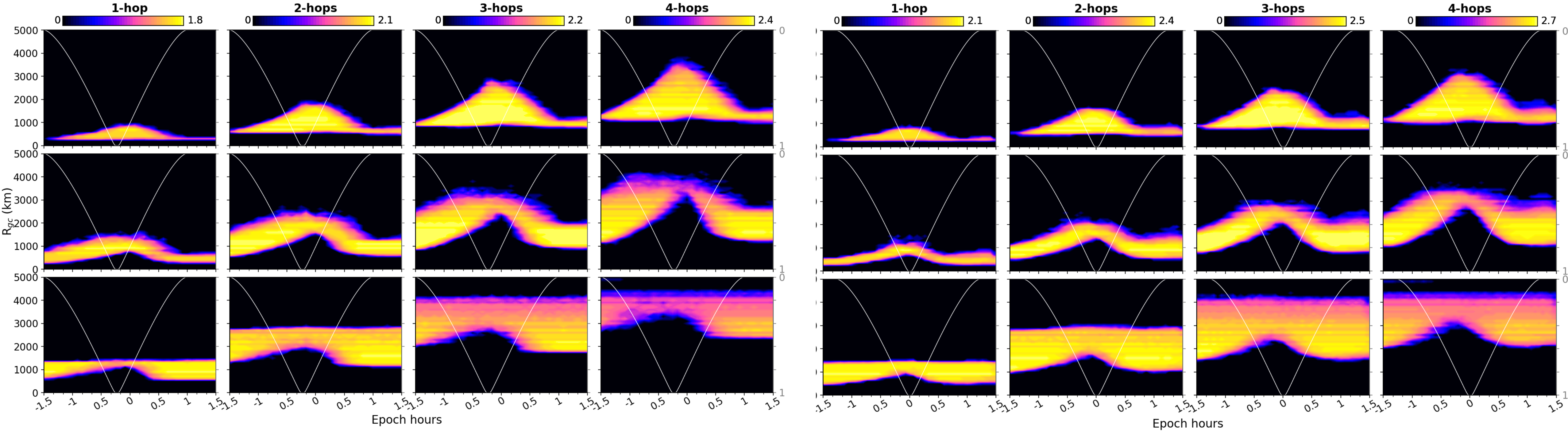


# Eclipse 2024 Raytracing: 7 MHz

Ionosphere:

SAMI3

SAMI3/WACCMX



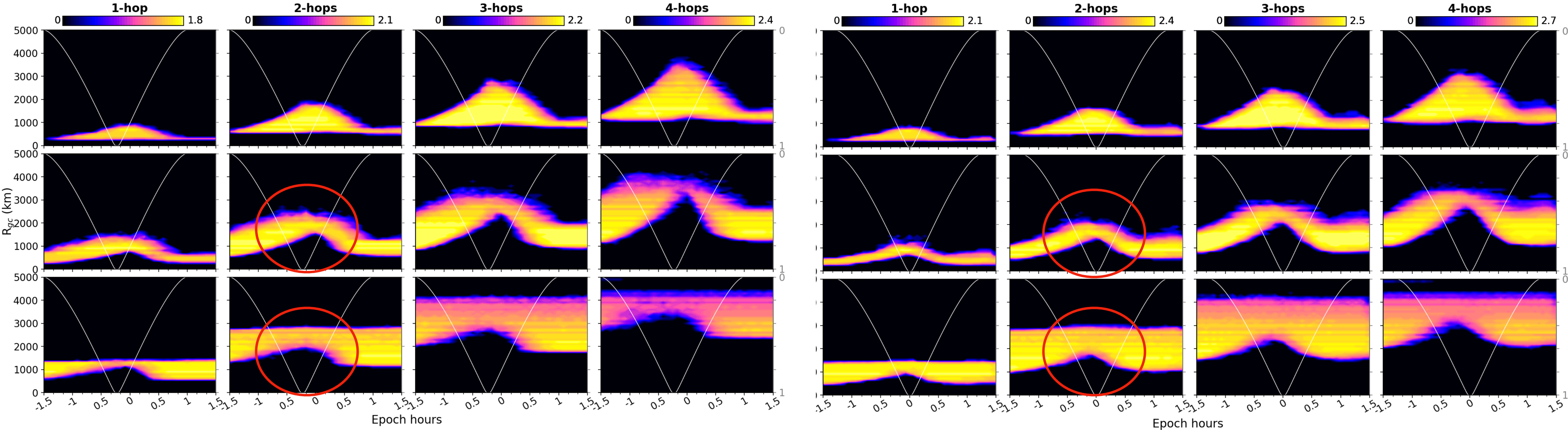
- Both models give broadly similar results

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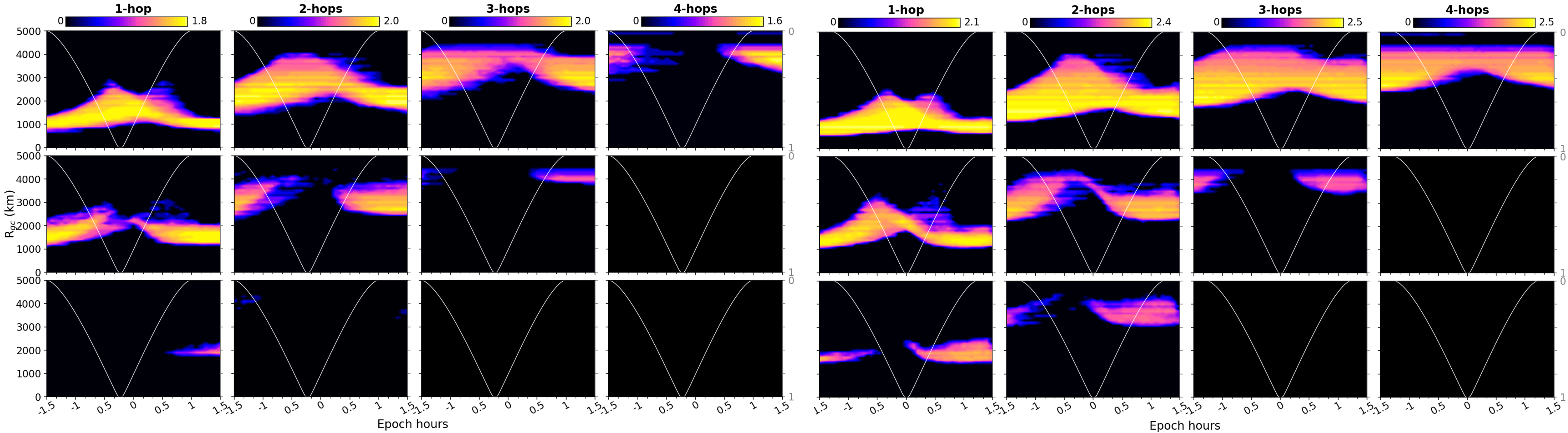
- Both models give broadly similar results
- SAMI3/WACCMX appears to drive more symmetric increase in range of HF communication

# Eclipse 2024 Raytracing: 14 MHz

**Ionosphere:**

**SAMI3**

**SAMI3/WACCMX**



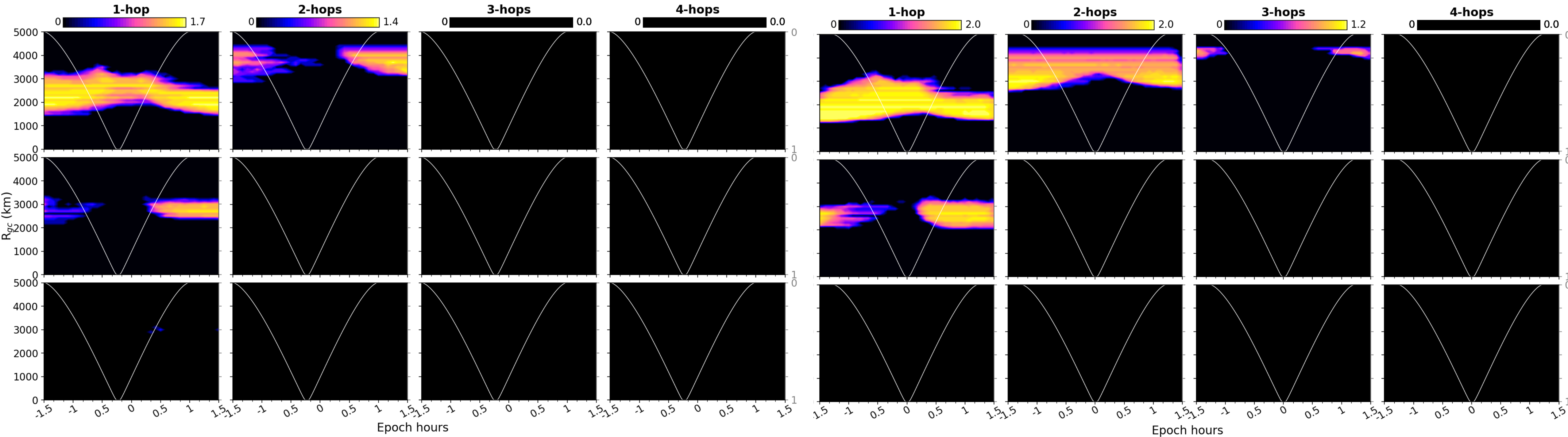
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# Eclipse 2024 Raytracing: 21 MHz

**Ionosphere:**

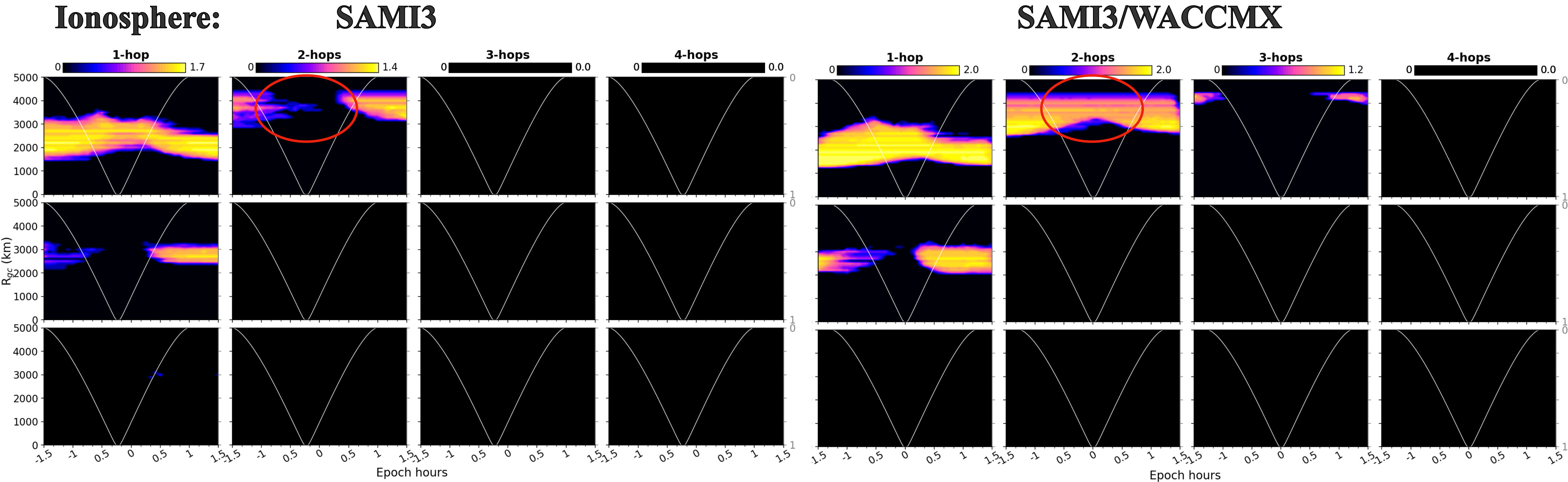
**SAMI3**

**SAMI3/WACCMX**



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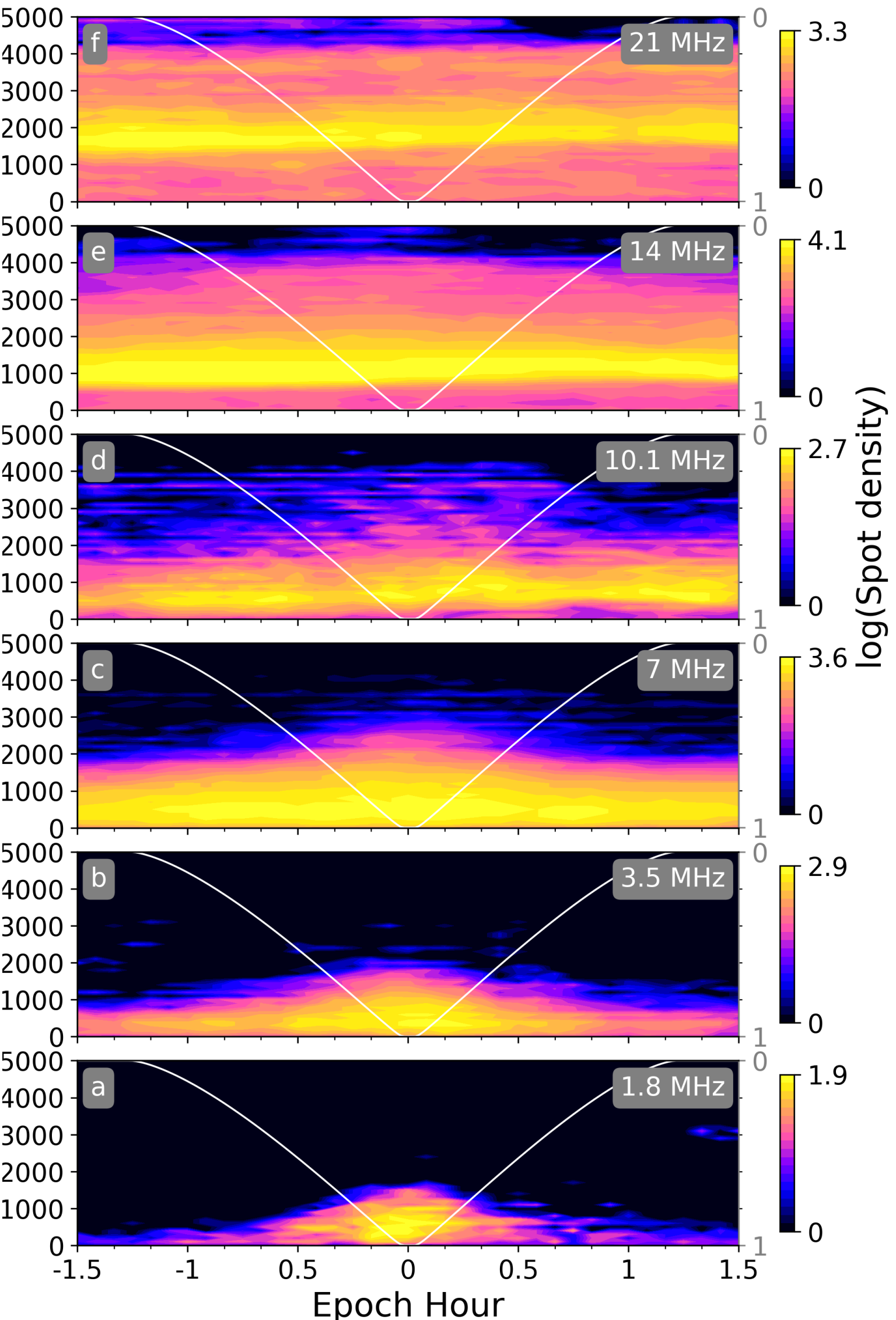
# Eclipse 2024 Raytracing: 21 MHz



- Both models give broadly similar results
- SAMI3: no links for  $R_{gc} > \sim 3000$  km around the totality
- SAMI3/WACCMX:  $R_{gc} > \sim 3000$  connected links even around totality

# Eclipse 2024 Ham Radio Observations & HF Raytracing

## Ham Radio Observations

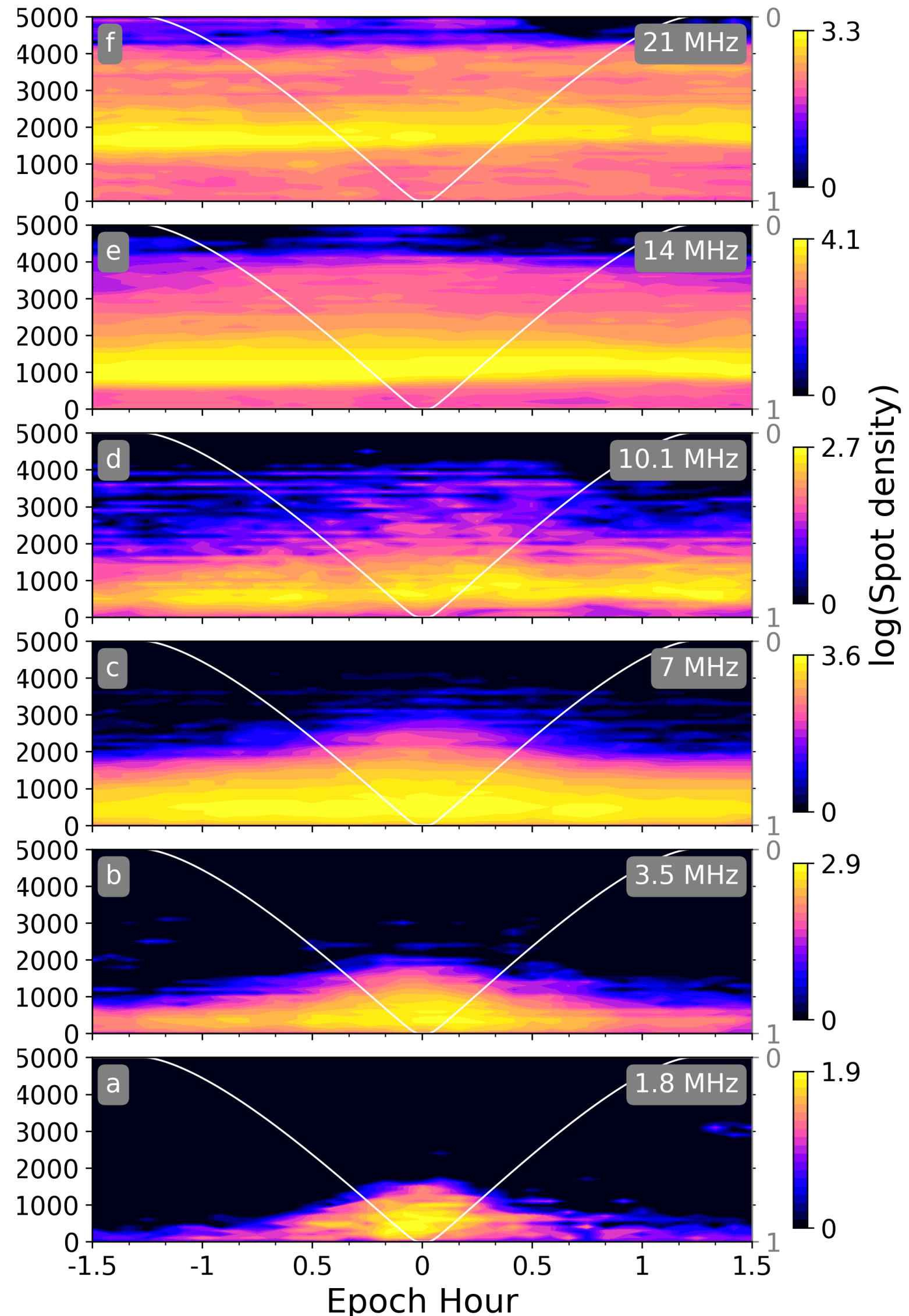


## Raytracing/Modeling results

- In general, SAMI3 and WACCMX/SAMI3 give similar results for ground-to-ground HF links
- 7 MHz: SAMI3/WACCMX appears to drive more symmetric increase in the range of HF communication — *better consistency with data*
- 21 MHz: around totality, the  $R_{gc} > \sim 3000$  links not seen in SAMI3 but still connected in WACCMX/SAMI3 — *observations show continued HF contacts*

# Eclipse 2024: CONUS Observations & Raytracing

## Ham Radio Observations



## Raytracing/Modeling results

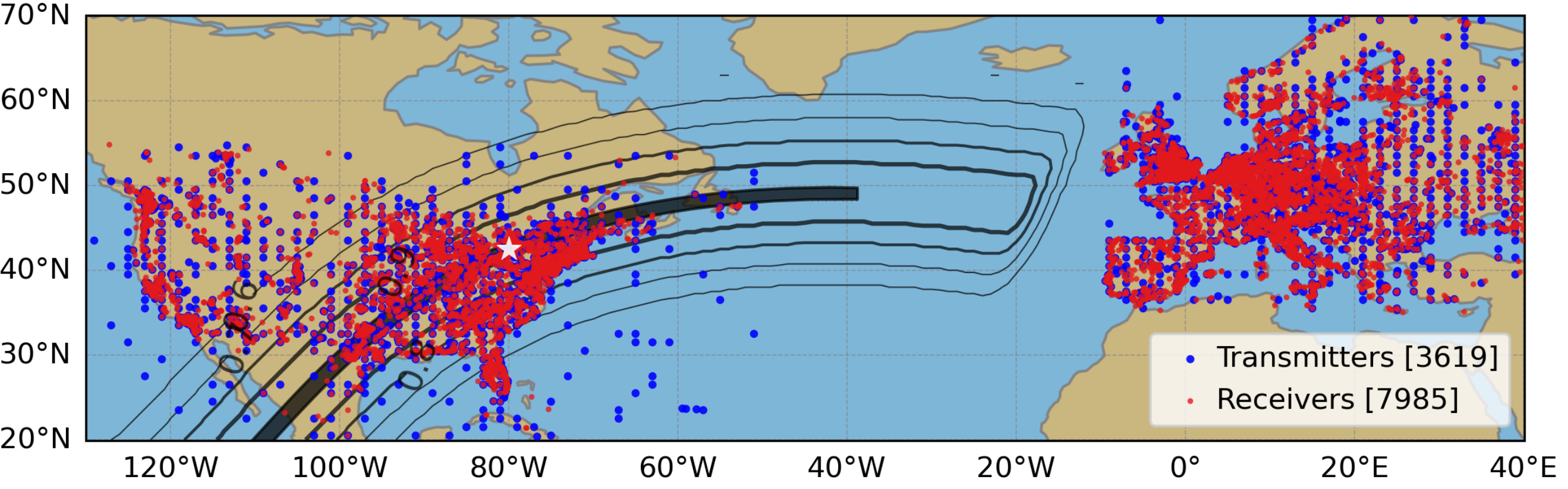
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## Summary#2:

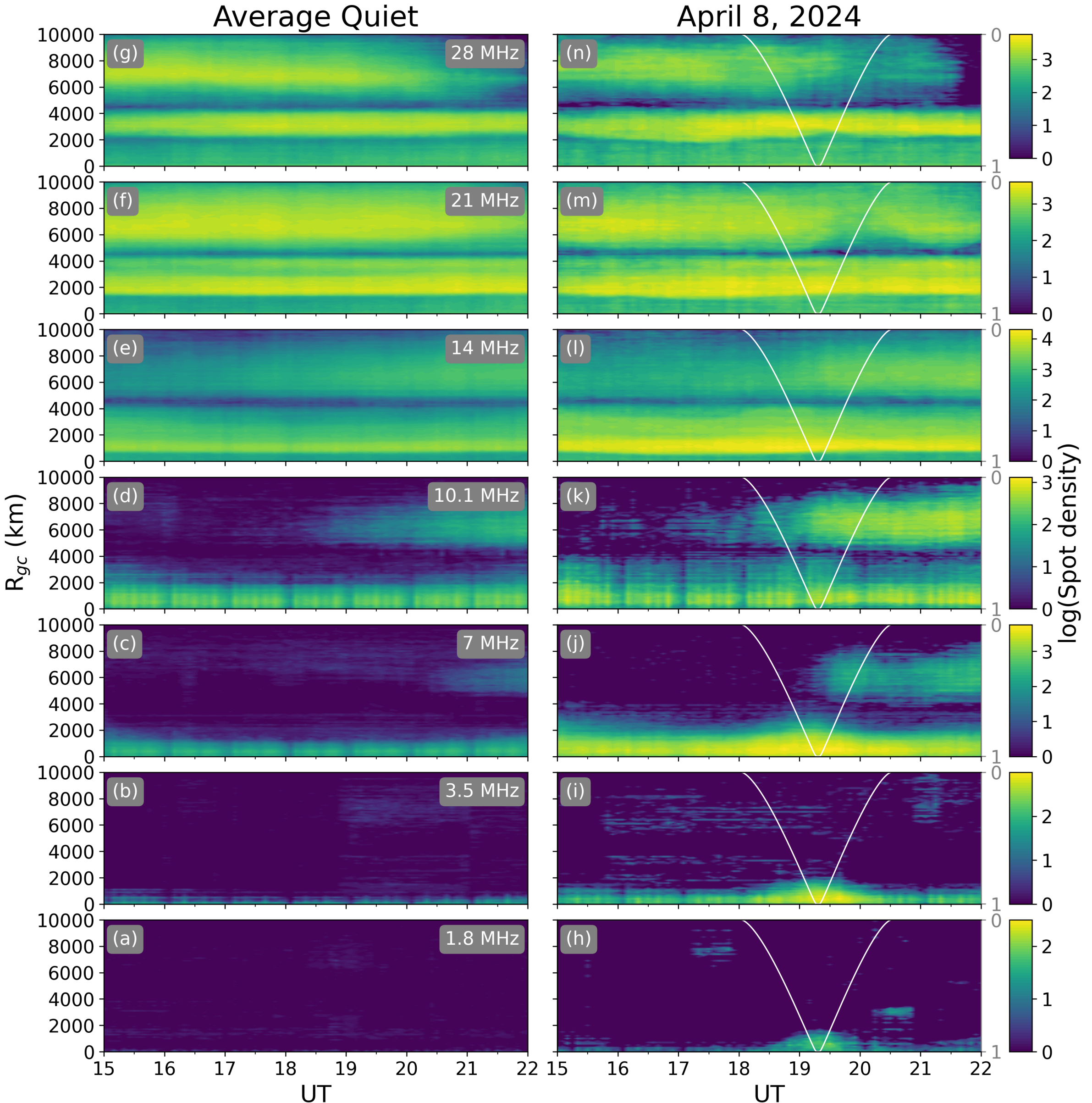
**SAMI3/WACCMX ionosphere based HF raytracing show better consistency with Ham Radio observations over CONUS**

# Eclipse 2024...

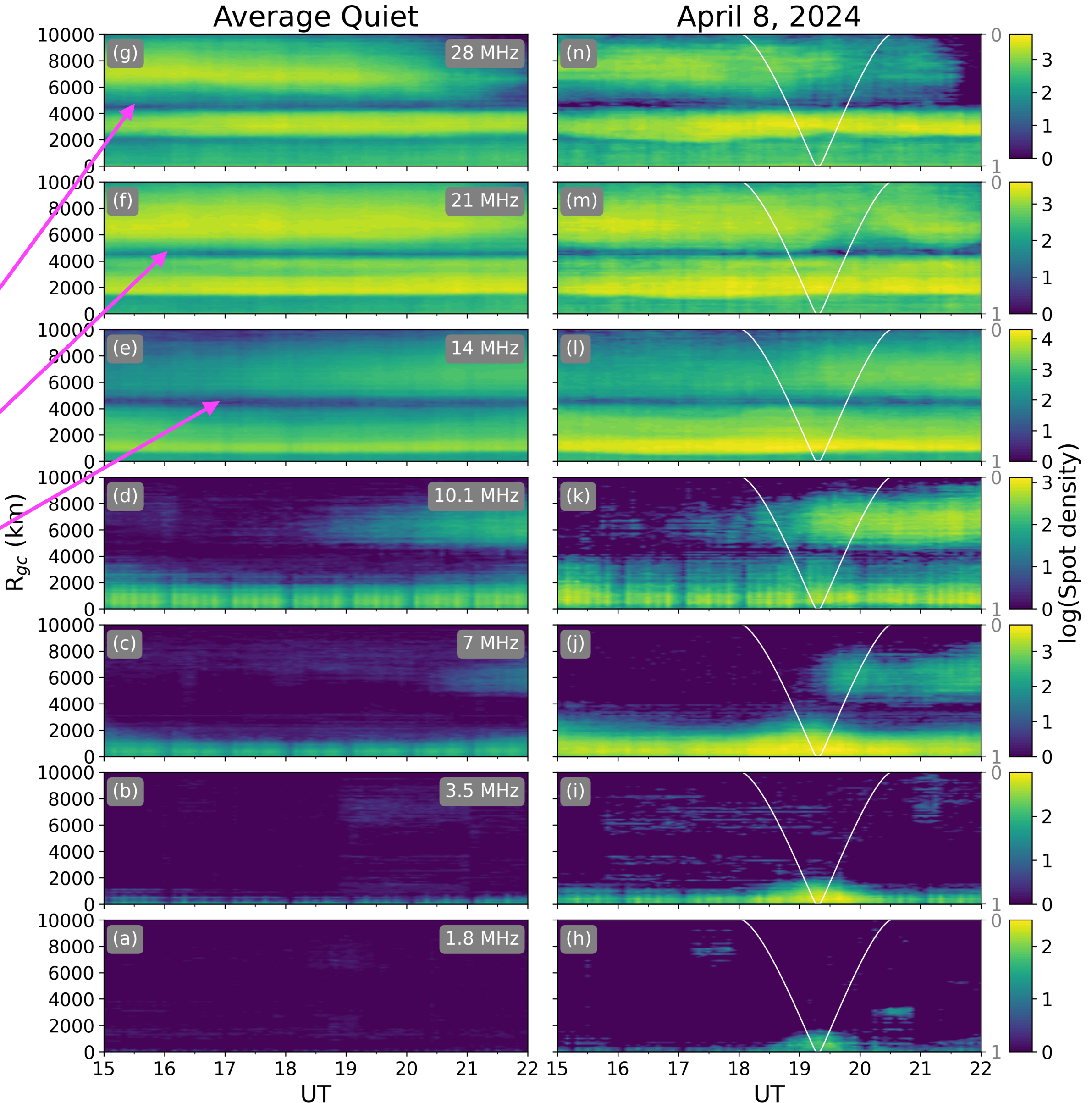
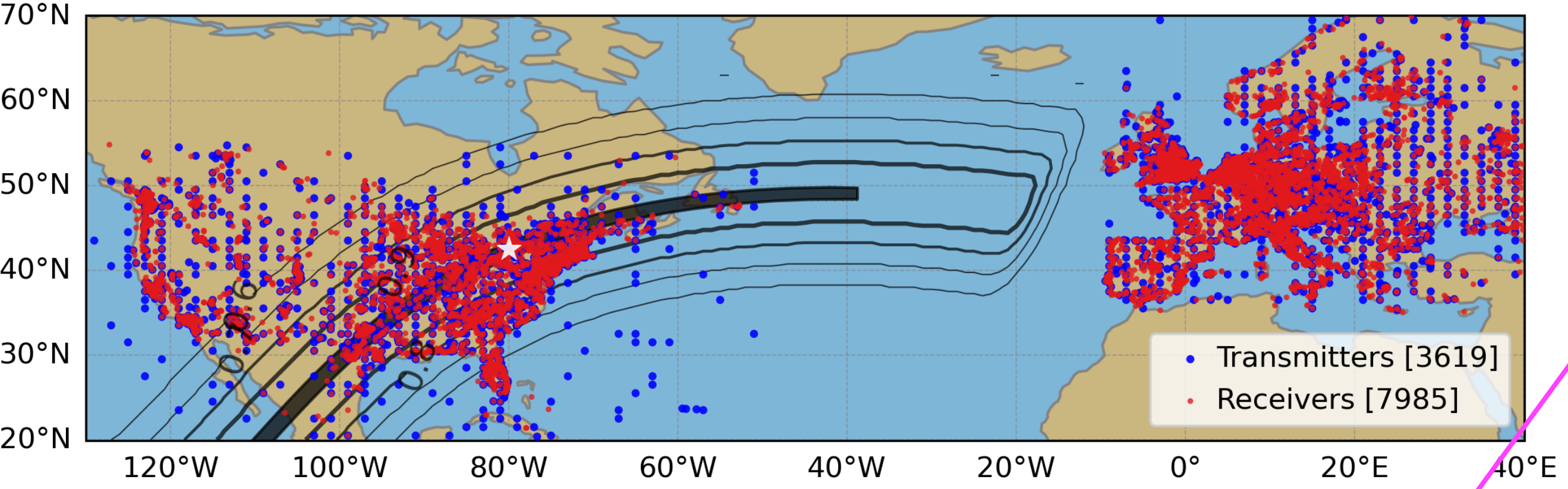
# Eclipse 2024: Worldwide Ham Radio Data



Most Ham stations are across CONUS and Europe



# Eclipse 2024: Worldwide Ham Radio Data



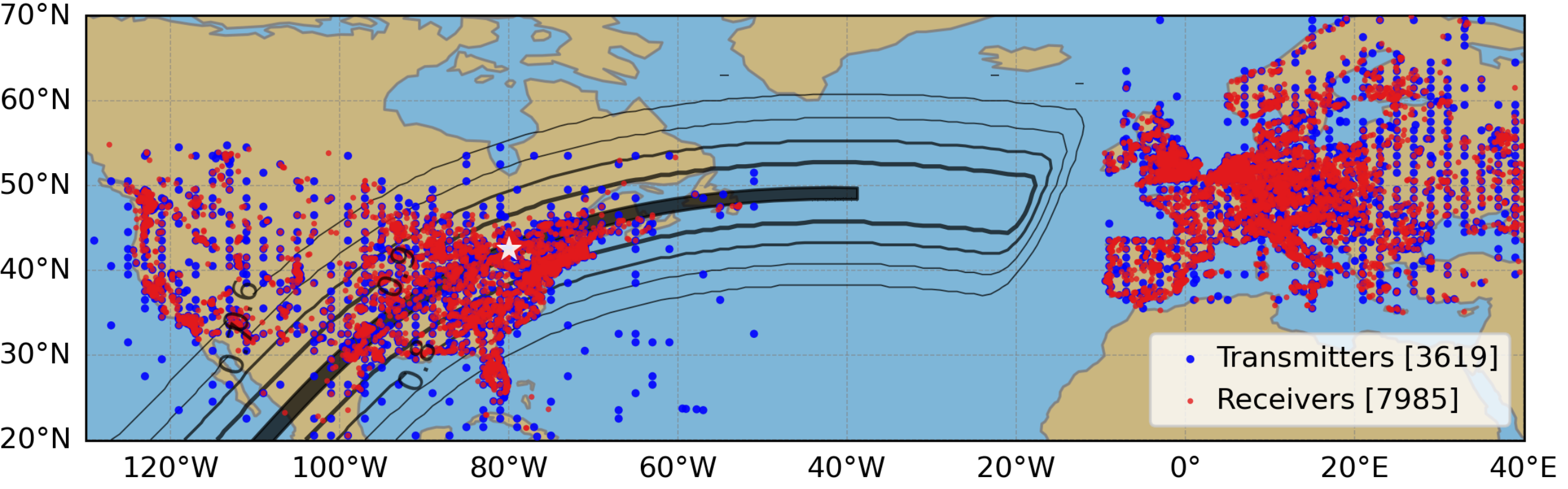
Most Ham stations are across CONUS and Europe

Continues drop in spot density at  $R_{gc} \sim 4,500$  km

$R_{gc} < \sim 4,500$  km: CONUS links

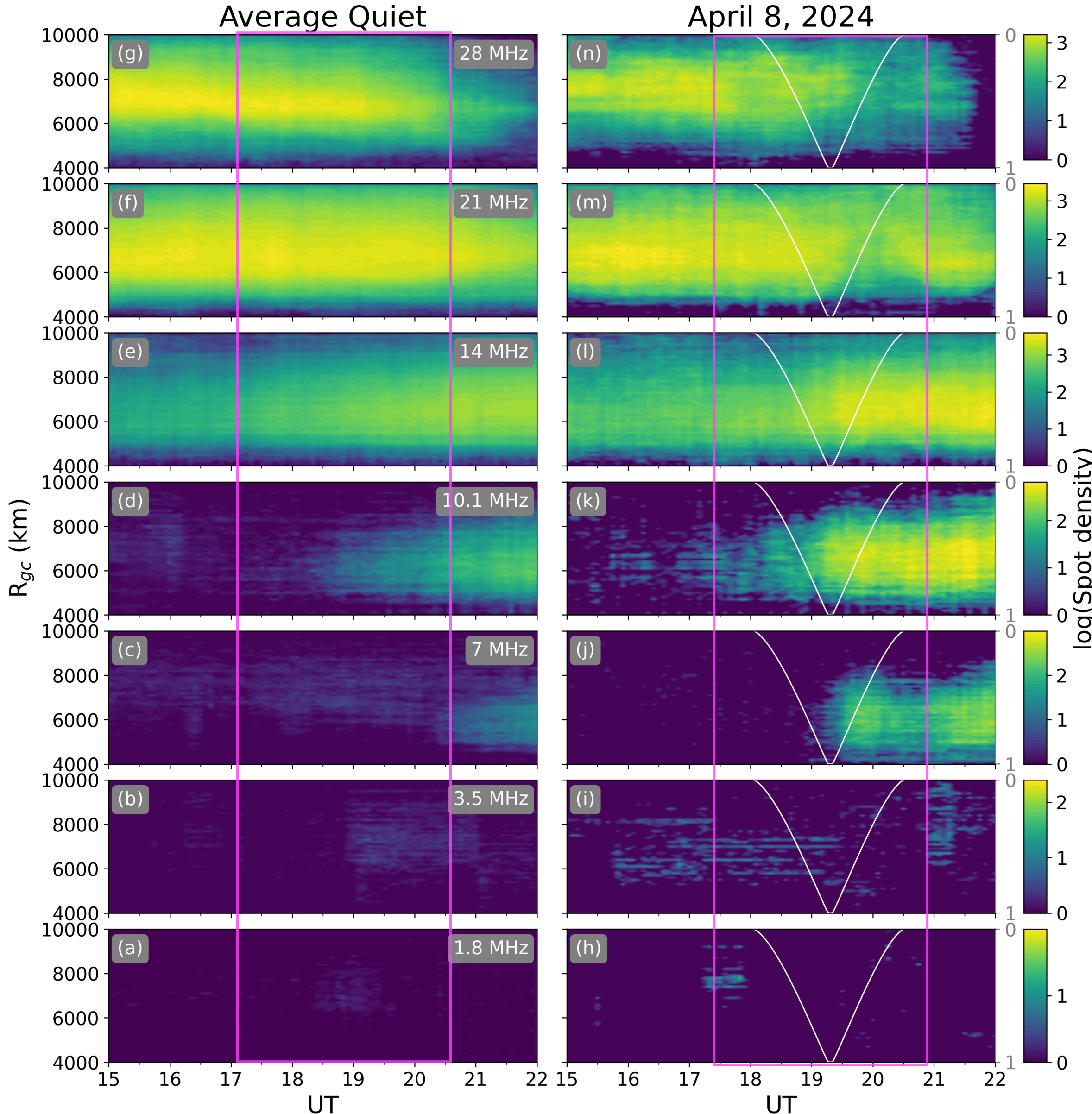
$R_{gc} > \sim 4,500$  km: Transatlantic links

# Eclipse 2024: Transatlantic Links



## Effects around totality

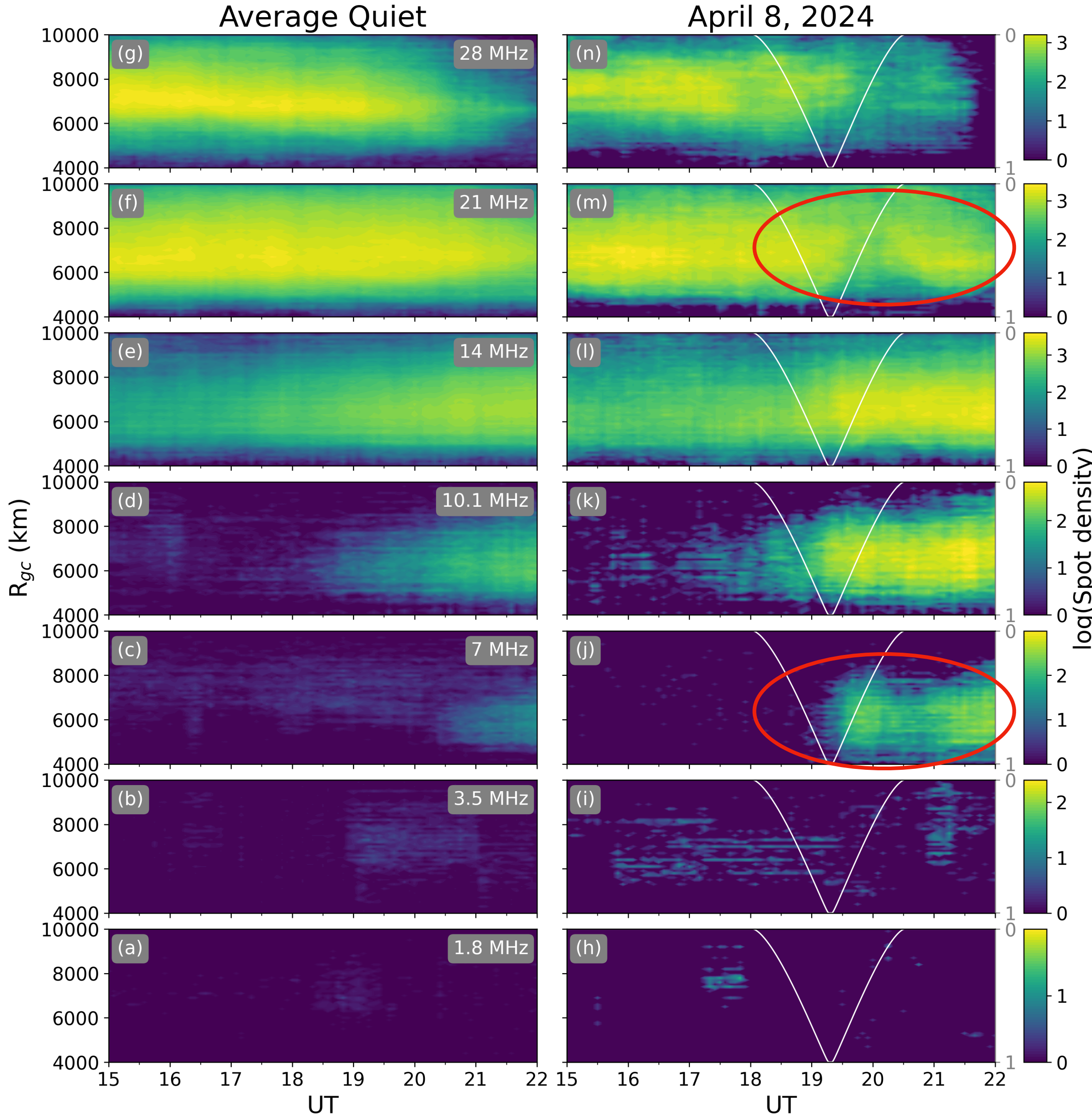
- 21 MHz: drop in number of contacts
- 14 MHz: increase in number of contacts
- 10 MHz: opens up earlier
- 7 MHz: opens up earlier, fades out, connects again
- 1.8, 3 MHz: not clear, only a few contacts



# Eclipse 2024: Transatlantic Links

## Effects around totality

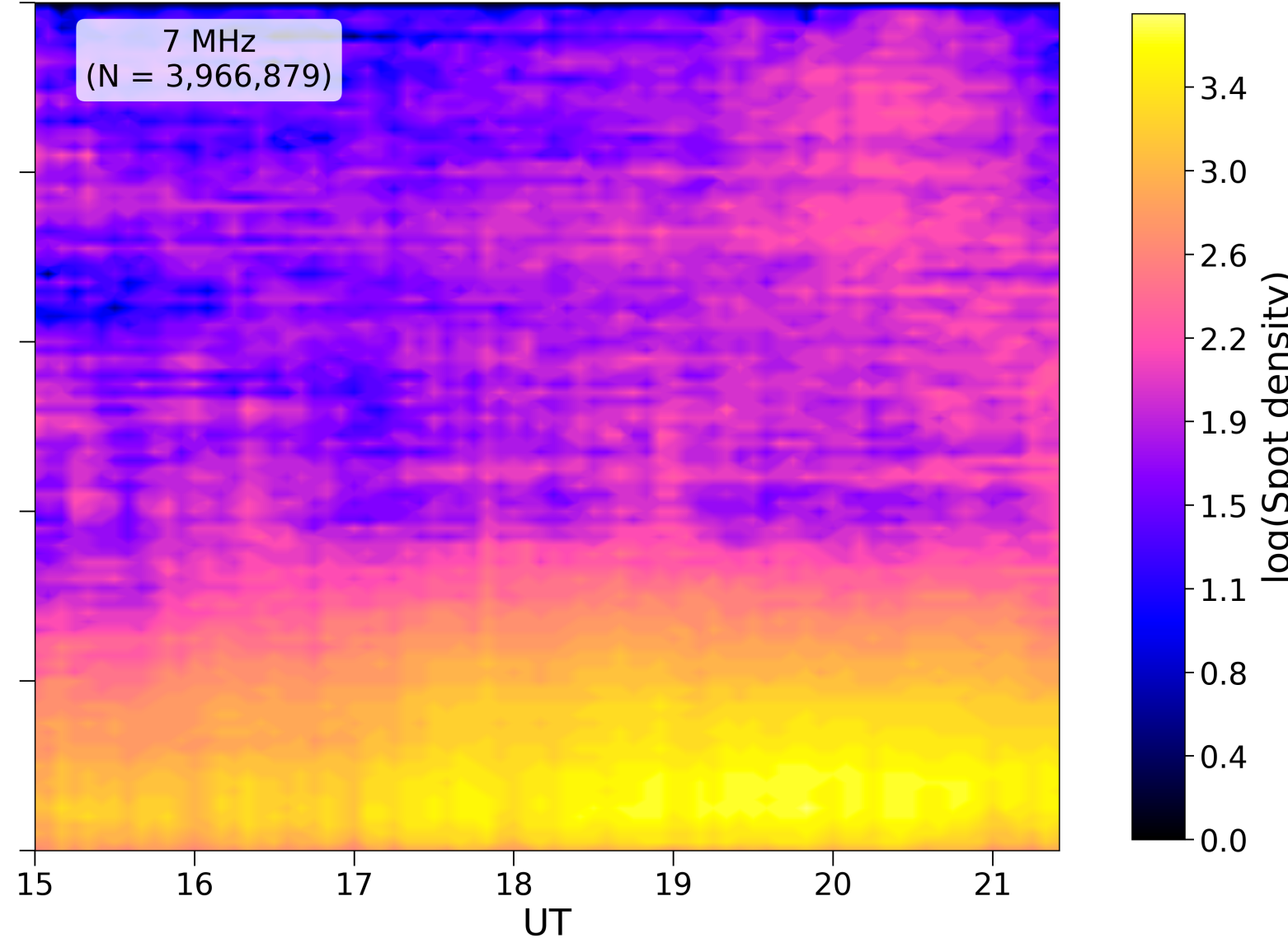
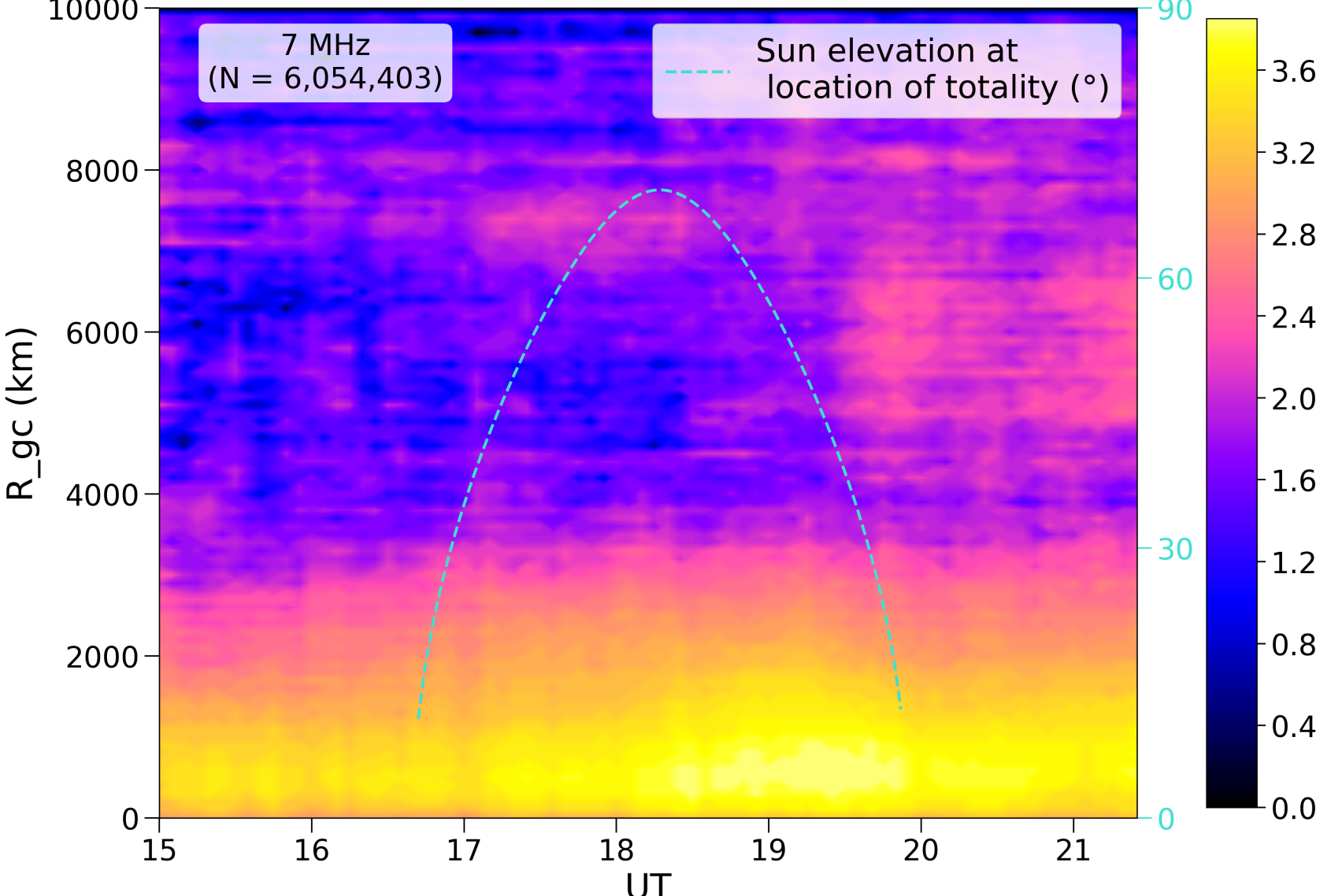
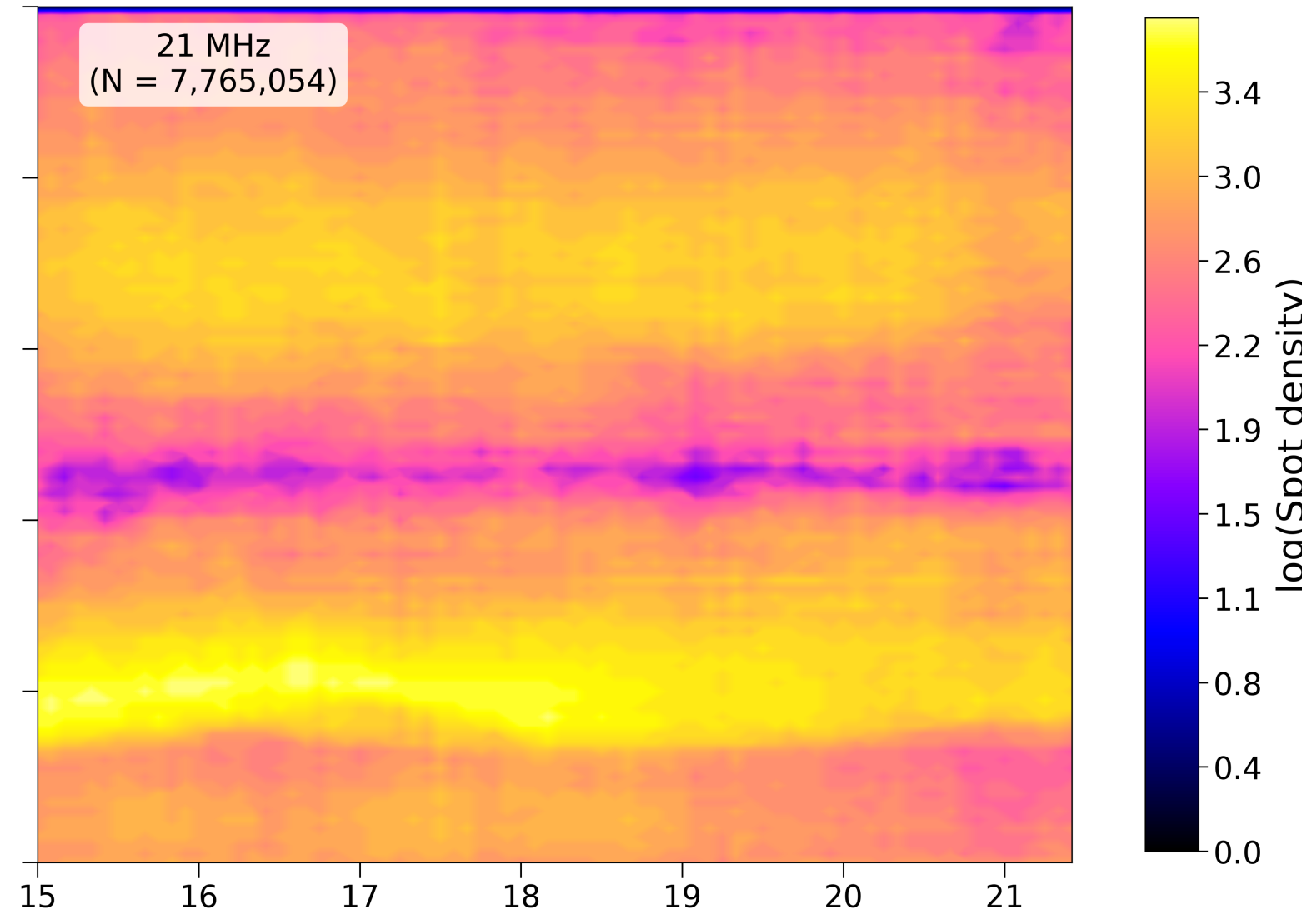
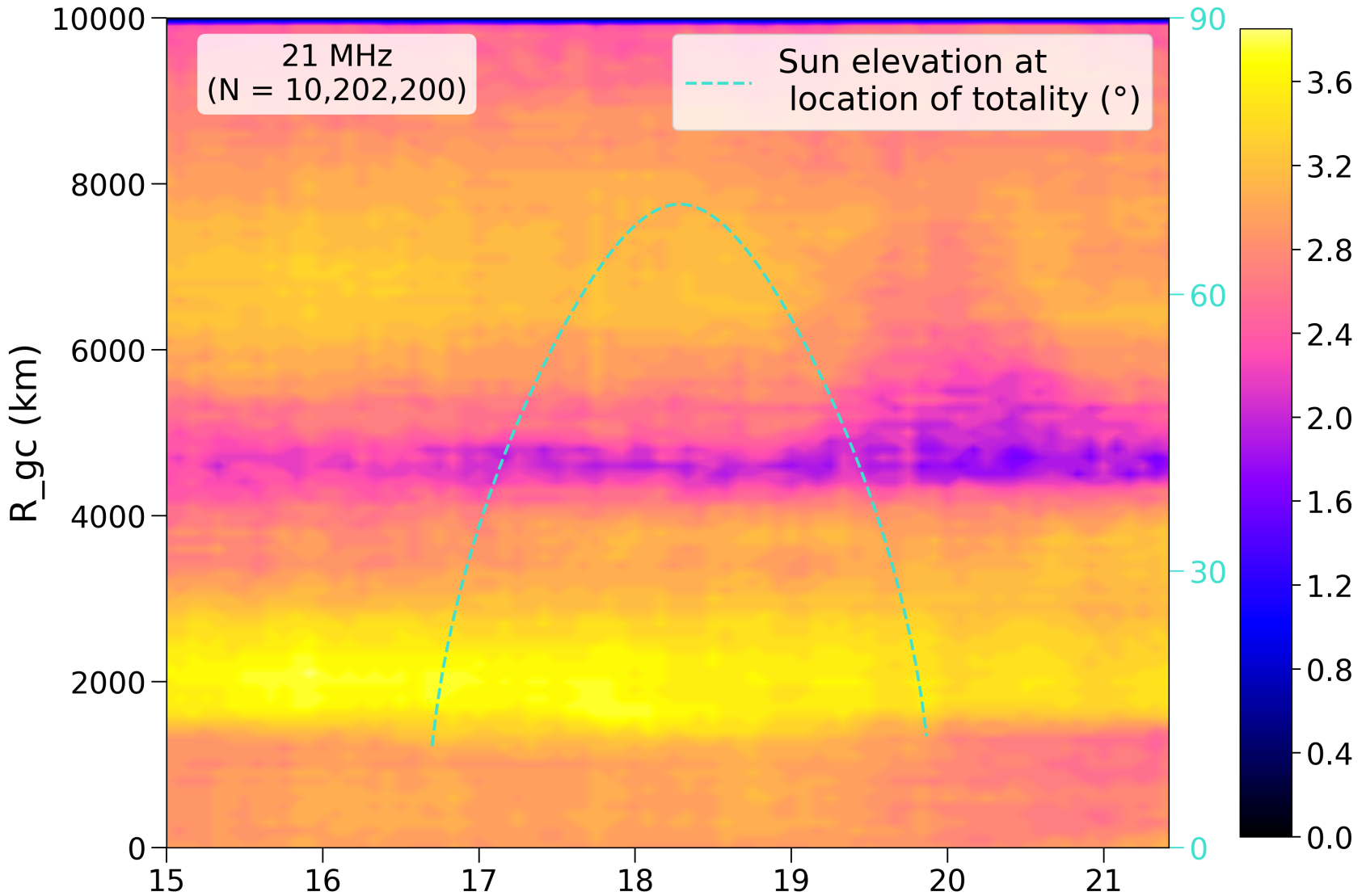
- 21 MHz: drop in number of contacts, response at the end phase of eclipse (~19:30 UT) !
- 7 MHz: opens up earlier, fades out, connects again



# Eclipse 2024: Continually Operated Tx-Rx Links

Eclipse (April 8, 2024)

No-eclipse (April 9, 2024)



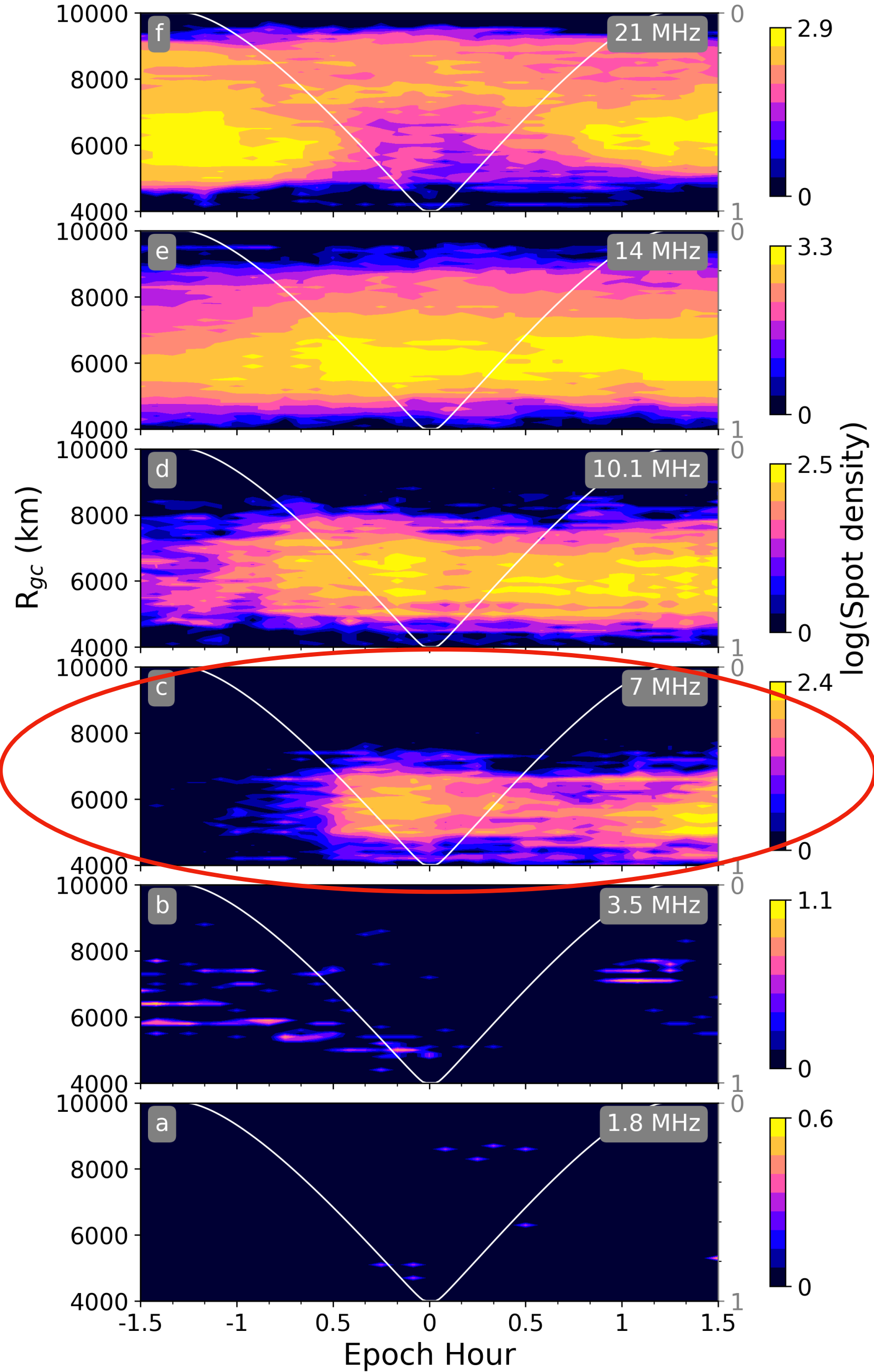
Changes in Transatlantic links (> ~4,500 km)

- appeared after 19:30 UT not during the entire eclipse interval
- 7 MHz: opens up earlier, fades out, connects again ??

Fig: spots density with continually operated Tx and Rx stations only

# Epoch Analysis: Transatlantic Links

- 21 MHz: eclipse related response, symmetric to obscuration levels
- **7 MHz: opens up due to eclipse, fades out, opens up again ?**



# HF Raytracing/ Modeling

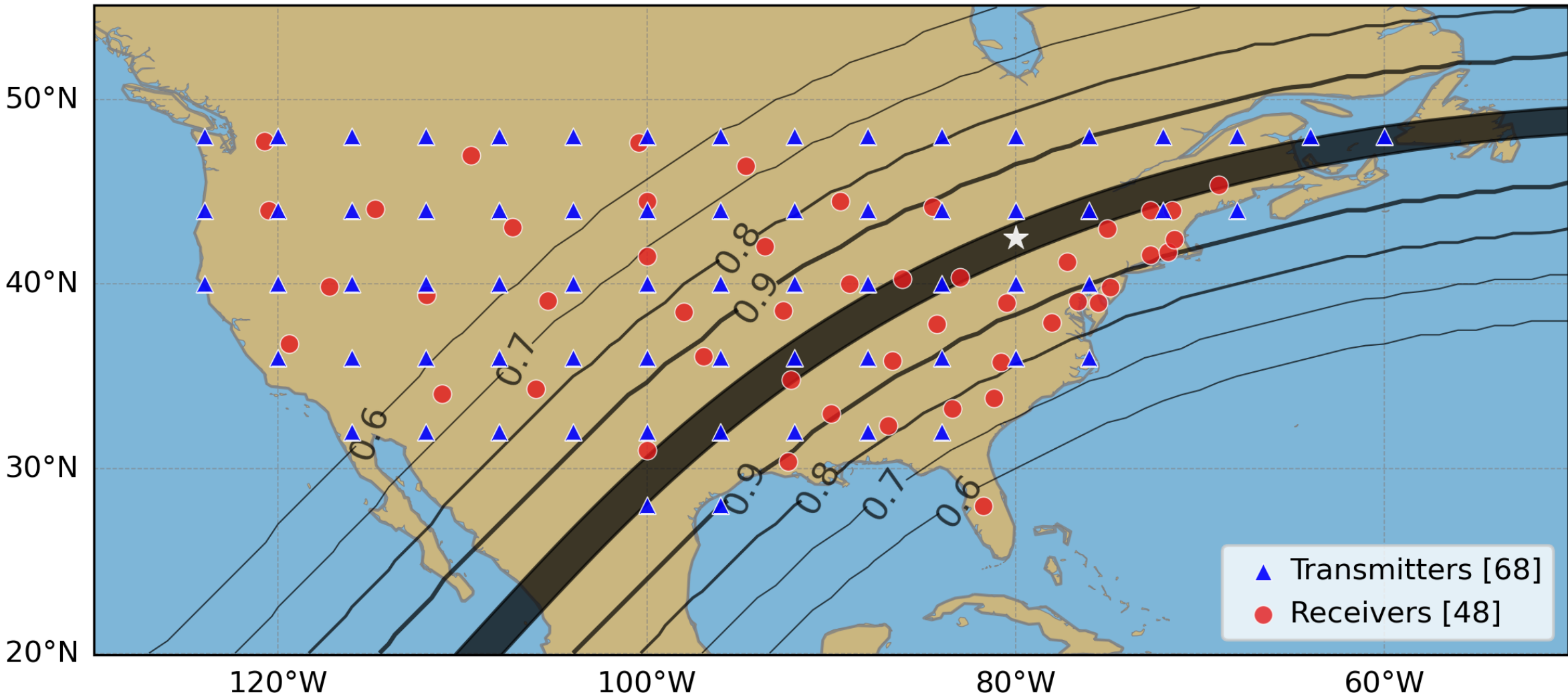


Fig: Tx - Rx grid for CONUS raytracing

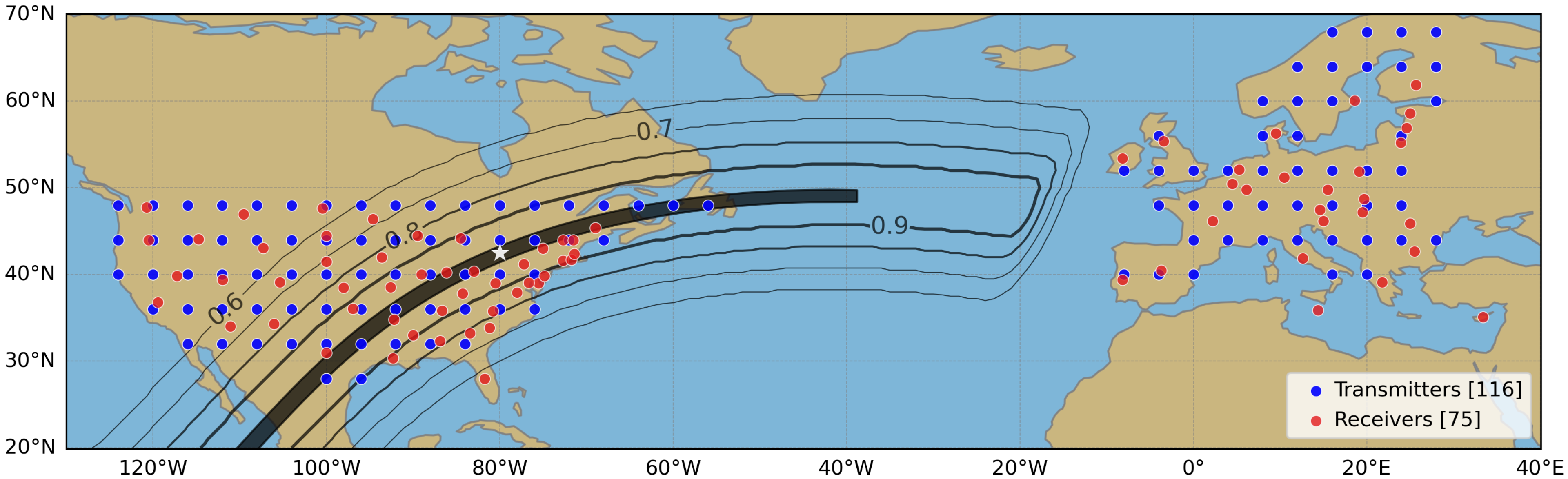
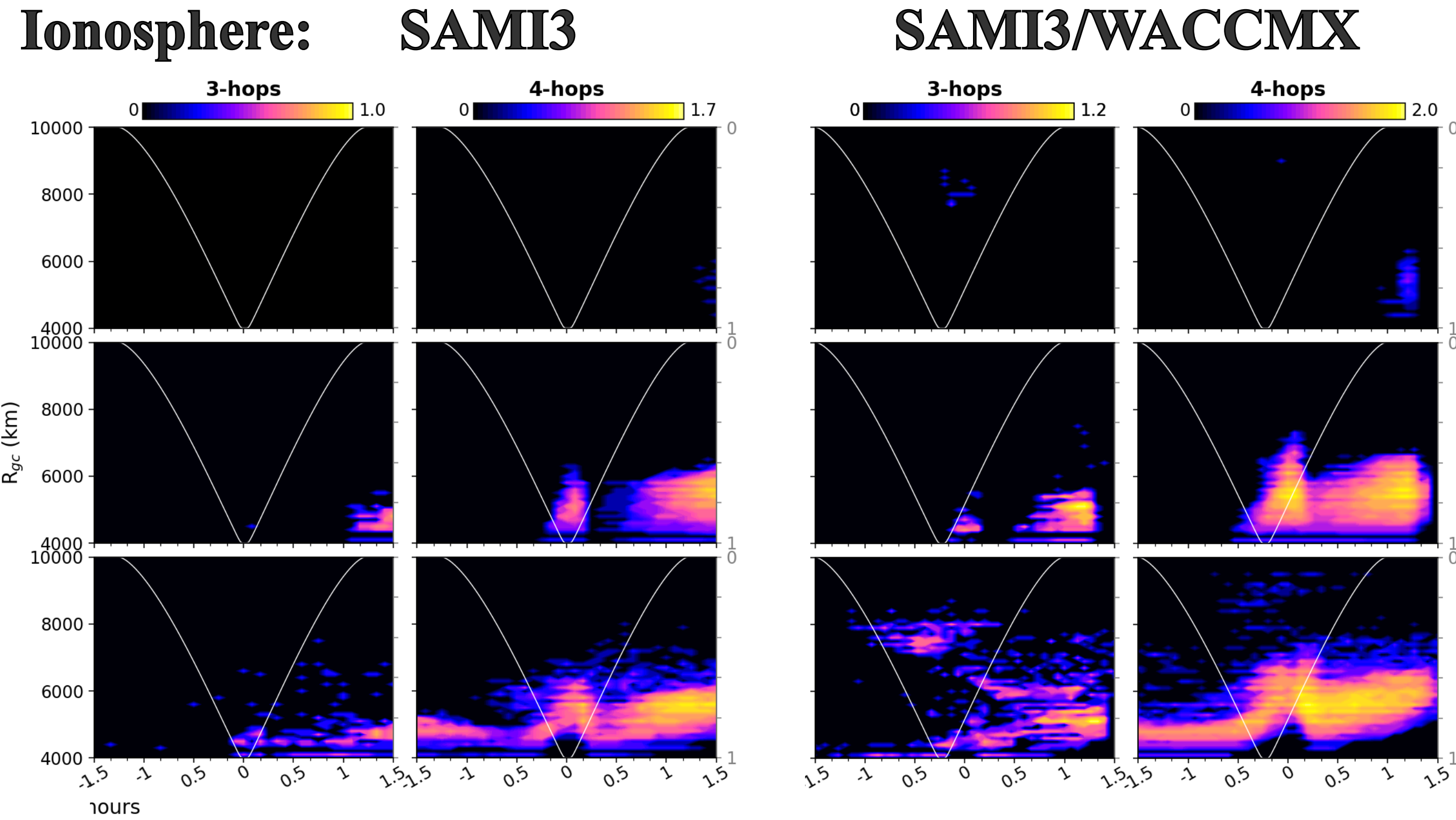
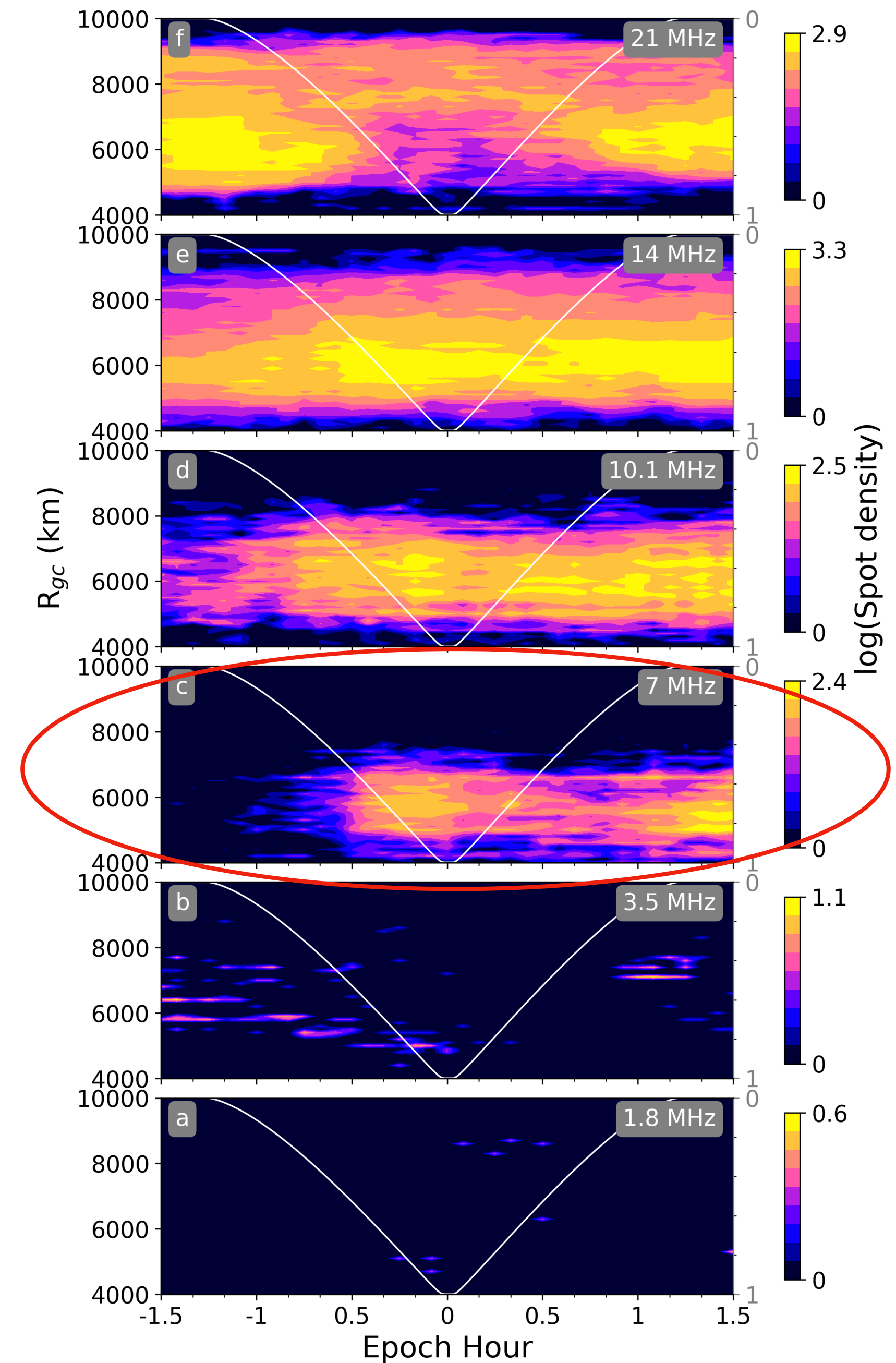


Fig: Tx - Rx grid for Transatlantic raytracing

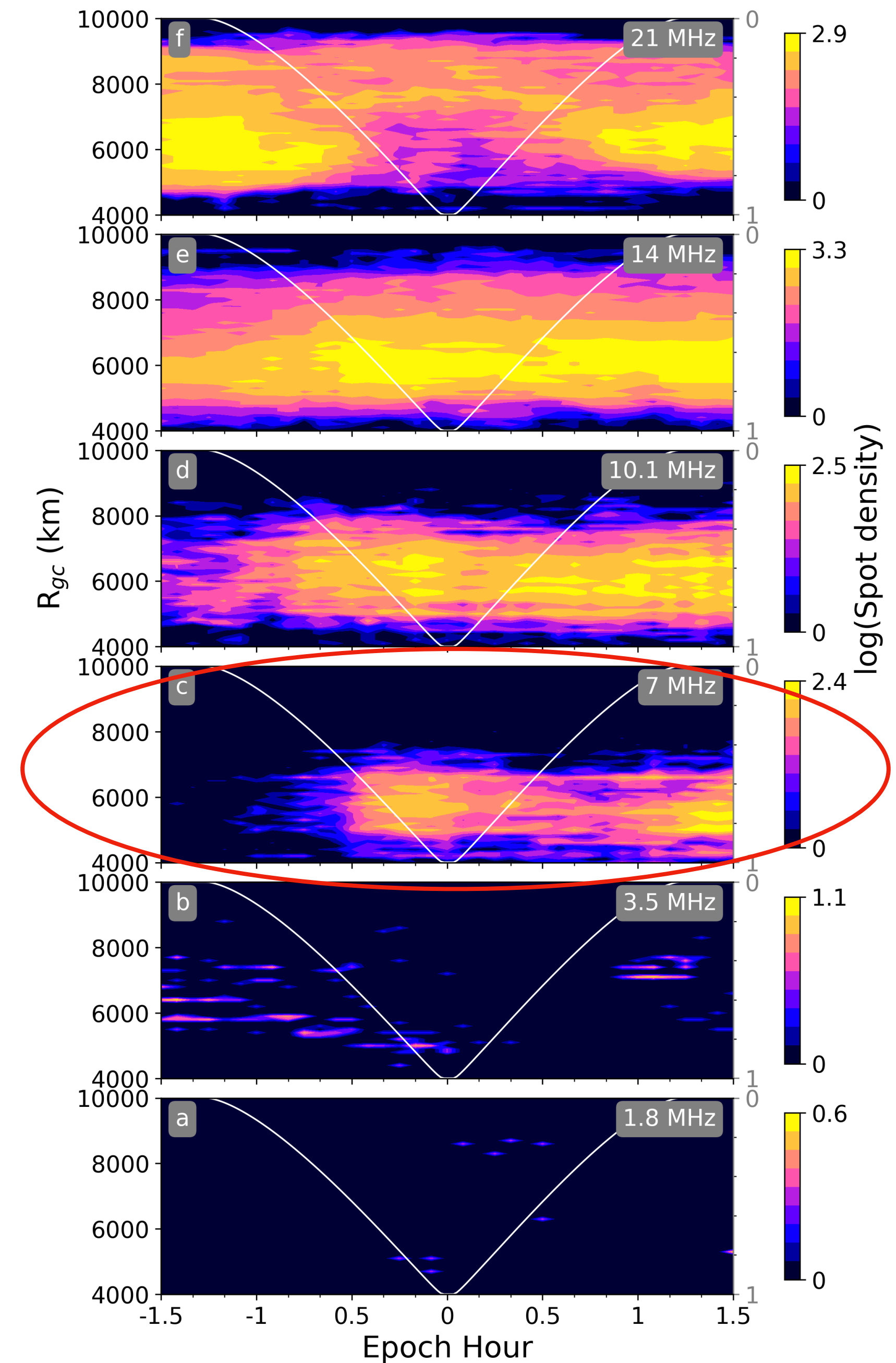
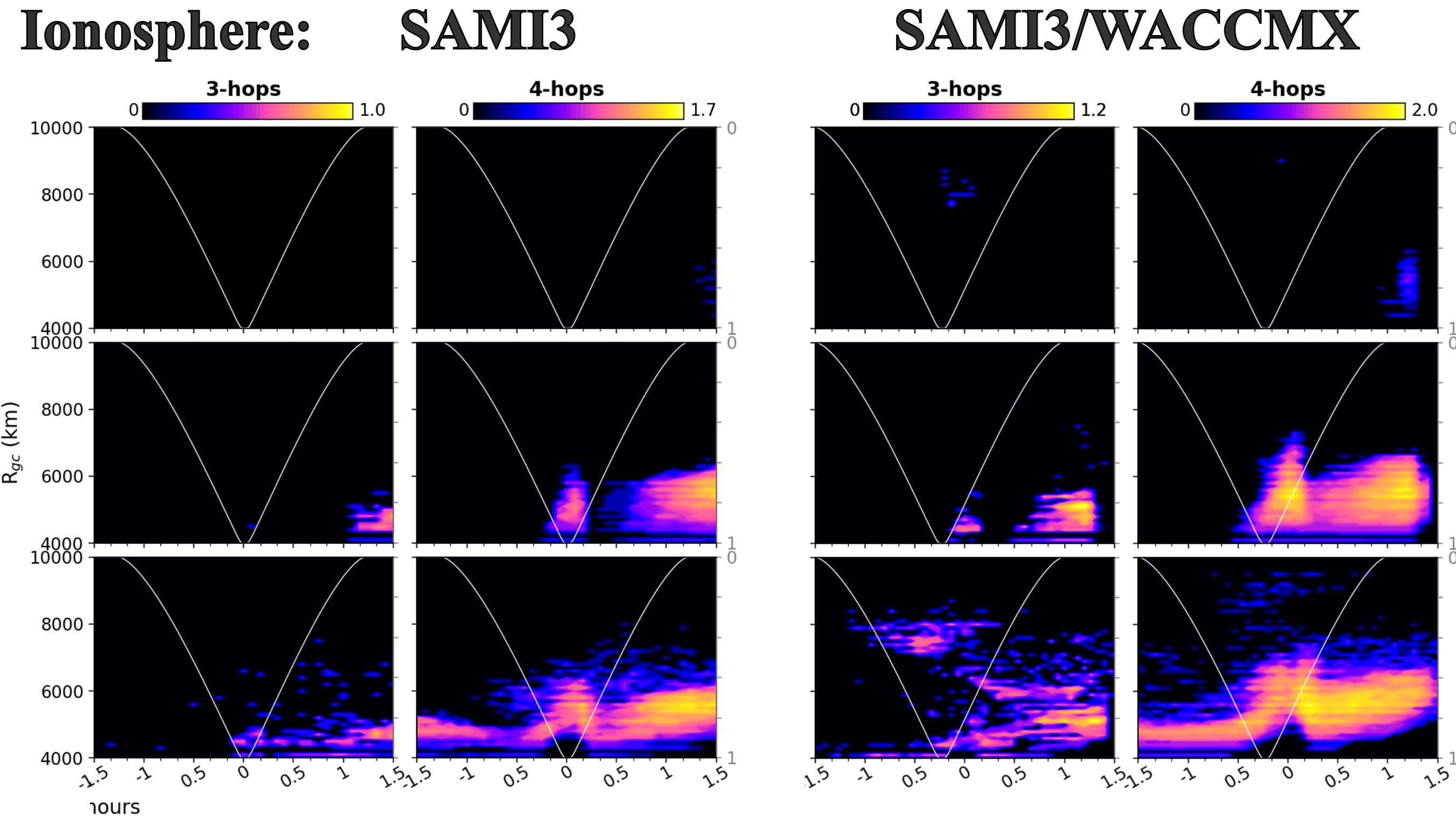
# Data - Model: 7 MHz Transatlantic Links



- in general, both model results are similar
- **after eclipse related opening**
  - stronger drop in SAMI3 based HF links
  - small drop in SAMI3/WACCMX links

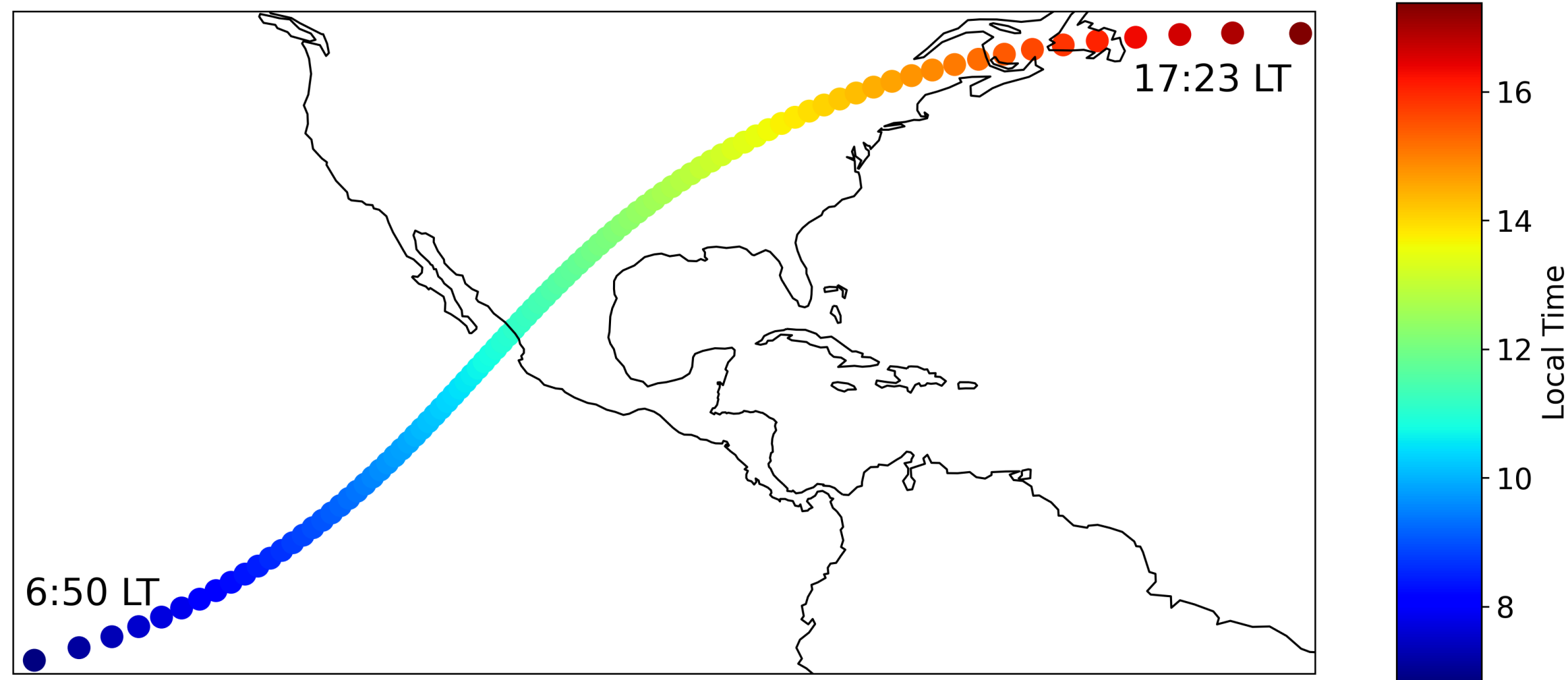


# Data - Model: 7 MHz Transatlantic Links

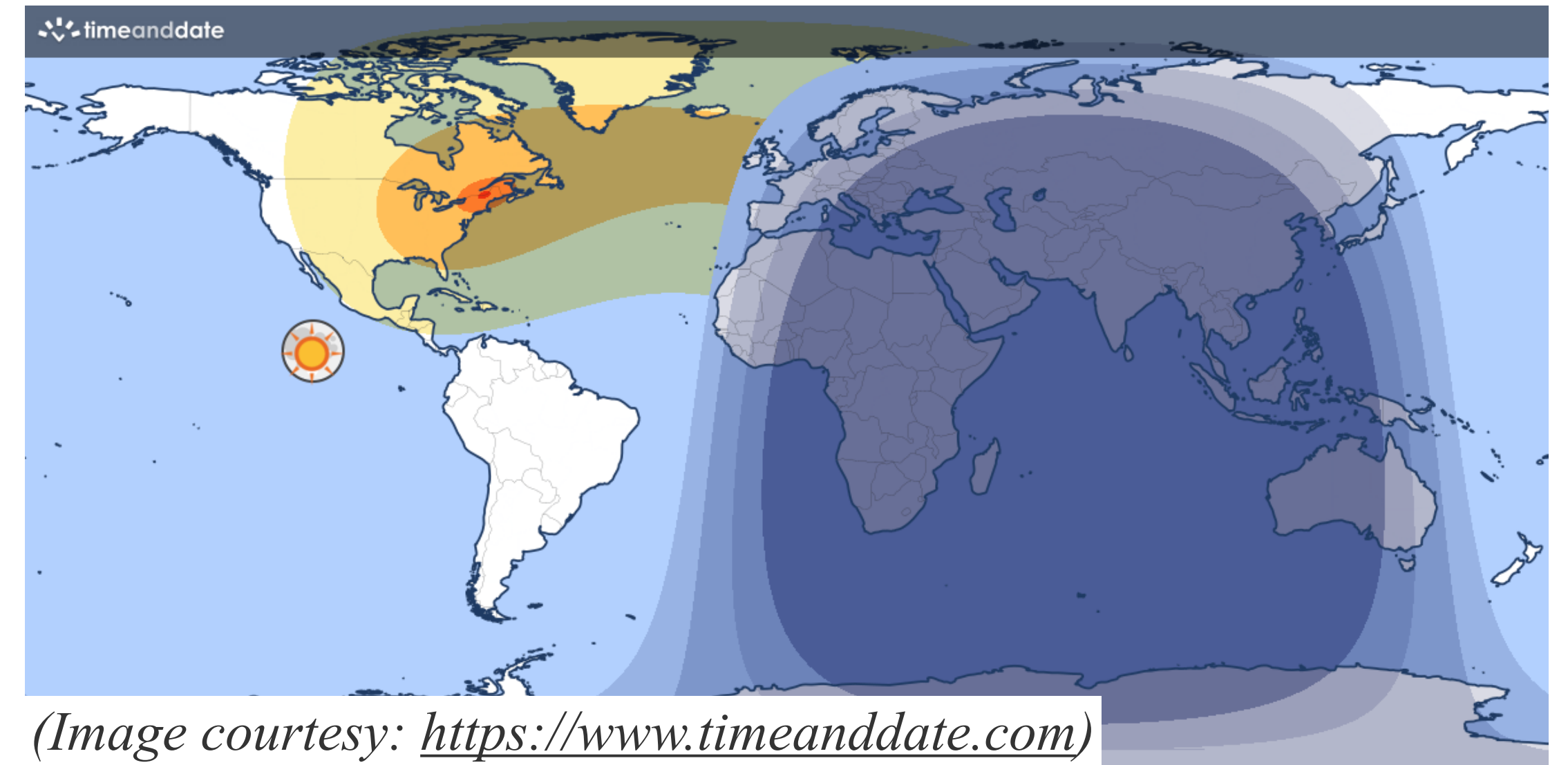


- in general, both model results are similar
- **after eclipse related opening**
  - stronger drop in SAMI3 based HF links
  - small drop in **SAMI3/WACCMX links: better match with data**

# 7 MHz Transatlantic Links



**Fig:** eclipse track with local time



**Fig:** eclipse shadow at 19:30 UT + day-night conditions

- Extended shadow like conditions around 19:30 UT
- **Combined effect of eclipse & sunset terminator**
  - earlier opening: eclipse related
  - lesser contacts in between: end phase of **eclipse + sunset terminator**
  - opening up again: regular evening/nighttime propagation

# Summary#3: Eclipse 2024 Transatlantic HF Links

- **7 MHz band shows the combined effect of eclipse and sunset terminator**
- In general, both SAMI3 and SAMI3/WACCMX driven HF links match with Ham radio observations
- **SAMI3/WACCMX shows better match with the Ham radio observations**

# Some thoughts: SAMI3/WACCMX results match better

- For both CONUS and Transatlantic links SAMI3/WACCMX driven results match better with the Ham observations than SAMI3 model

## Some thoughts why SAMI3/WACCMX performs better

- Ionosphere: common model SAMI3
- Thermosphere: different models
  - MSIS model in SAMI3
  - WACCM in SAMI3/WACCMX
- MSIS: Empirical, global atmospheric model
  - trained on large datasets representing broader trends, less influence/training for transient events - eclipse
- WACCM: Physics-based numerical model
  - solves physics-based equations: no to little preference for broader trend or transient events - eclipse

# Summary

## 1. CONUS Total Solar Eclipse 2017 v/s 2024

- Similar responses 1.8 - 10 MHz
  - increase in range of communication, changes symmetric to the eclipse obscurations levels
  - lower altitude ionosphere (D, E, F1 regions) respond quickly to eclipse, reduced D-region absorption
- Different responses 14 - 28 MHz
  - likely, due to differences in solar flux levels/ sunspot numbers
  - denser ionosphere in 2024 bends/reflects back 14-28 MHz waves towards the Earth (ground-to-ground links)

## 2. Raytracing/Modeling HF Links over CONUS for Eclipse 2024

SAMI3/WACCMX based results match better with Ham Radio observations

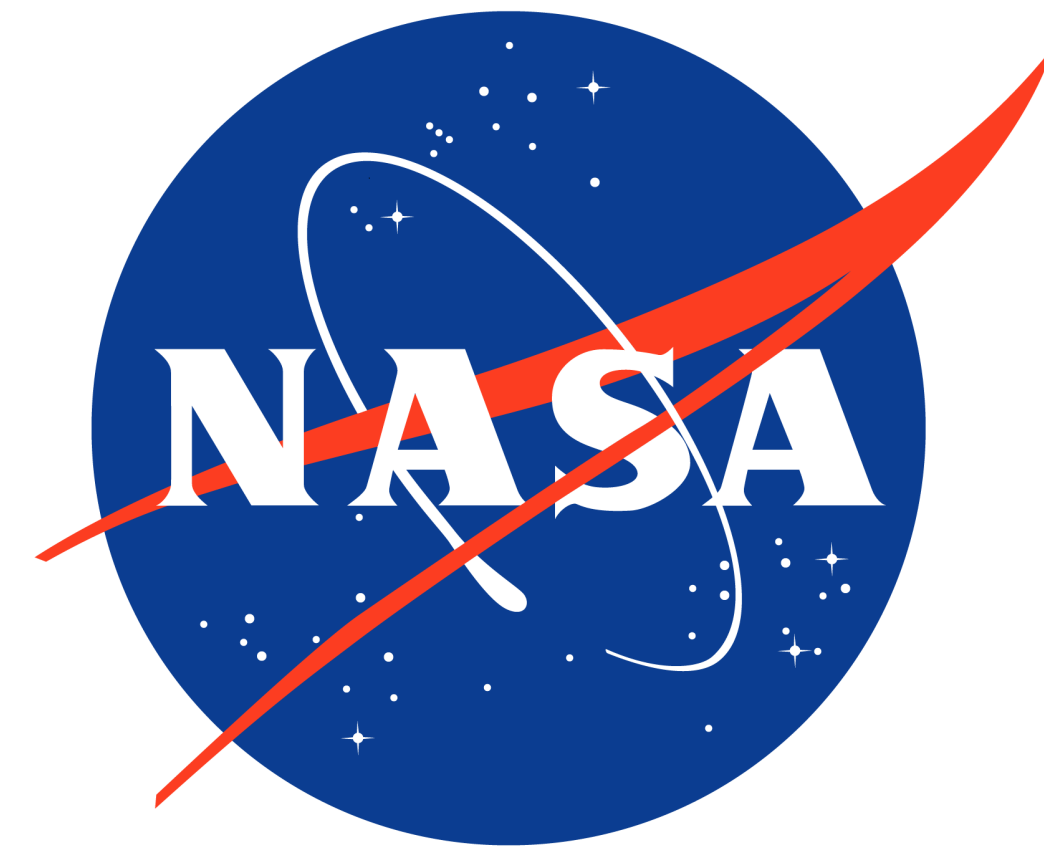
## 3. Transatlantic HF Links during Eclipse 2024

- 7 MHz band shows the combined effect of eclipse & sunset terminator
- SAMI3/WACCMX shows better match with the Ham radio observations
- Probably because of physics based Thermosphere from WACCMX than empirical MSIS model

## Acknowledgements

NASA grant 80NSSC23K1322, NSF grants AGS-2045755, AGS-2230345, AGS-2230346, Ham Radio community

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**Thank you!**