Evidence of HF multi-hop propagation in Antarctica

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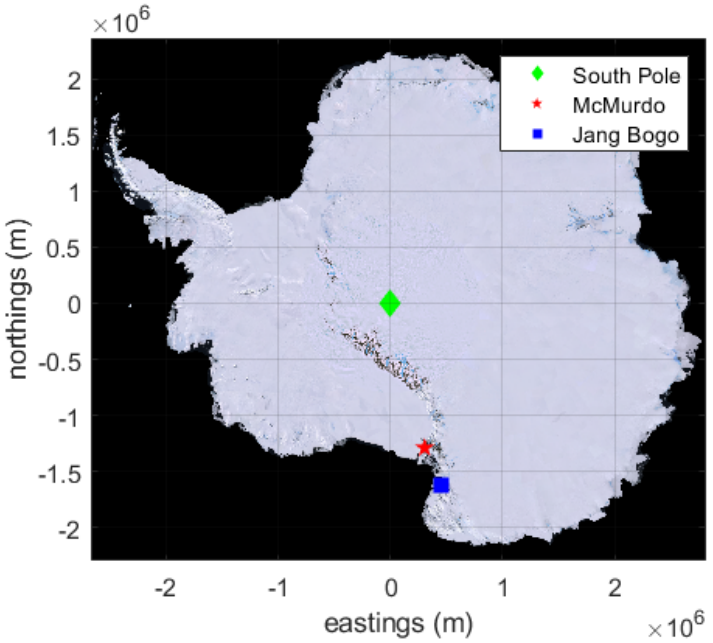
Key Points

- Group range measurements for a High Frequency (HF; 3 - 30 MHz) radio link between the McMurdo and South Pole stations in Antarctica are analyzed.
- Raytracing simulation results for this link are compared with the data.
- Evidence of a multi-hop propagation modes between the stations is observed in the data and corroborated with the modeling.
- Simulations indicate that ground reflections from the Transantarctic Mountains support the multi-hop modes.
  - This is contrary to prevailing wisdom that “HF multi-hop propagation modes do not occur in Antarctica”.

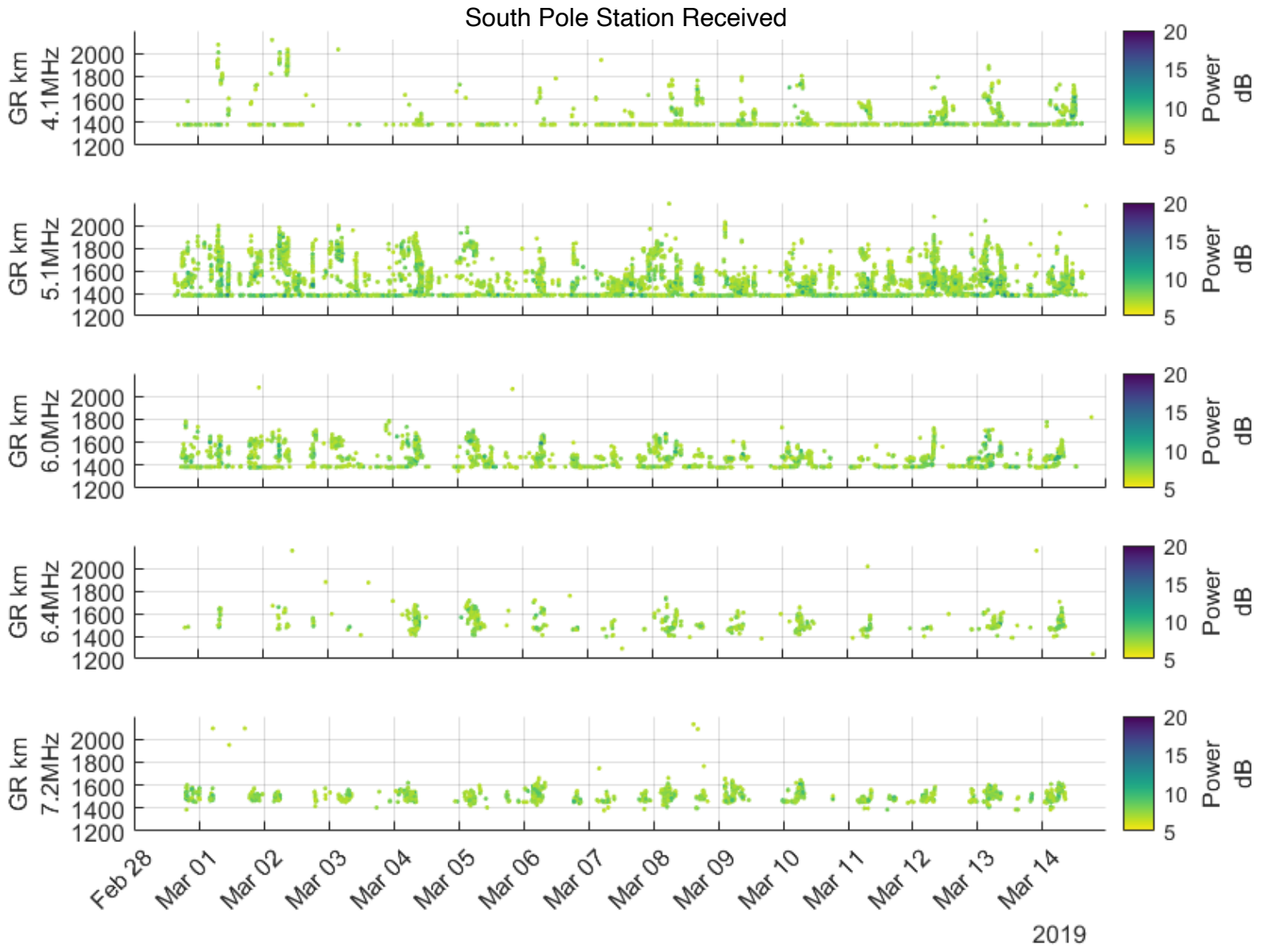
- "Low cost" HF oblique ionosonde installed by Chartier (Chartier et al., 2020).
- Data was collected between 2/28/2019 - 3/15/2019.
- Chartier et al. (2020) reported:
  - Stable E-layer.
  - NmF2 validated well against VIPIR ionosonde at Jan Bono station.
  - Sporadic "spread F".

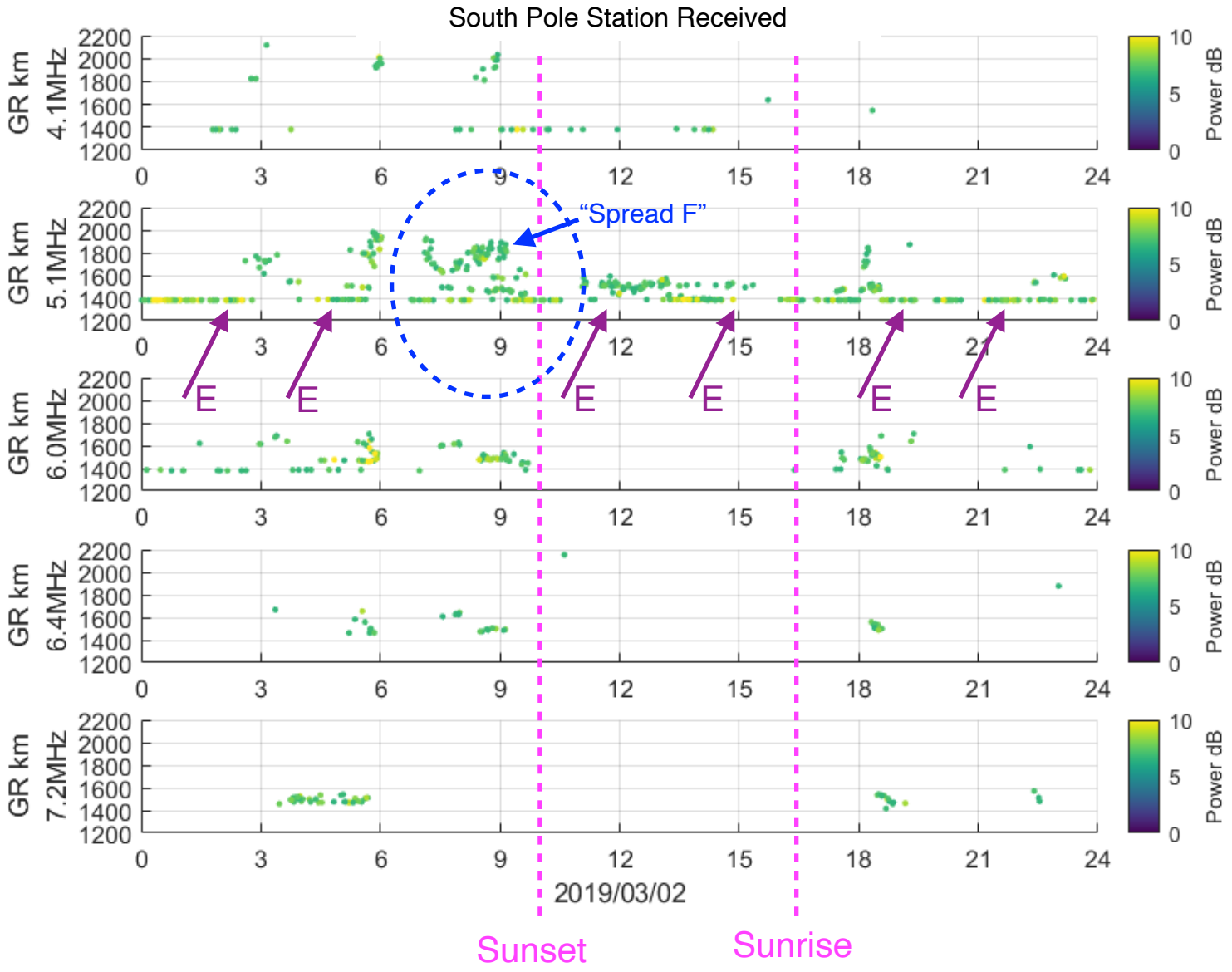


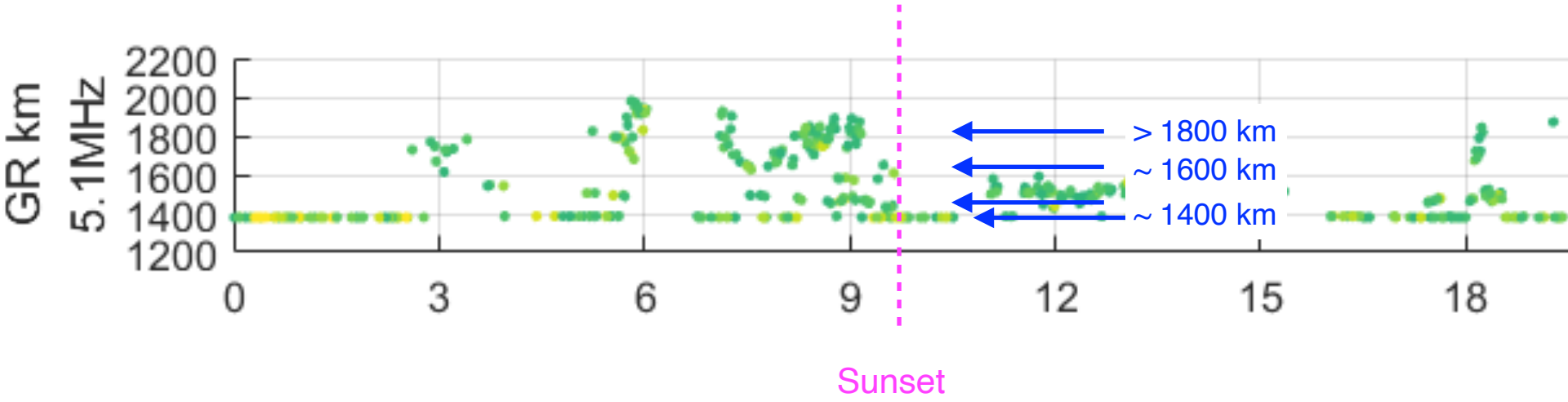
Instrument parameter	Value
Bandwidth	50 kHz (10× oversampled, followed by integration and decimation)
Gaussian phase encoding	1000 bauds, each 20 µs in length
Frequency hopping	12 frequencies (see Table 2) each minute, 5 s dwell
Range	6000 at 6 km resolution
Virtual height	1000 at < 15 km (E layer), < 7 km (F layer)
Doppler	1000 at 11.5 m s^{-1} (for 2.6 MHz) down to 1042 at 4.2 (for 7.2 MHz)
Integration period	5 s (using 12 frequencies each minute)
Data budget	6.31 TB yr^{-1} raw IQ (50 kHz sc16), approx. 1 GB yr^{-1} retrieved parameters
Power budget	Approx. 150 W at the transmitter, 30 W at the receiver

Frequency (MHz)	No. of echoes received
7.2	2234
6.4	1189
6.0	3474
5.1	21 517
4.4	0
4.1	2129
3.7	0
3.4	0
3.2	0
3.0	0
2.8	0
2.6	0

Tables from Chartier et al. (2020)

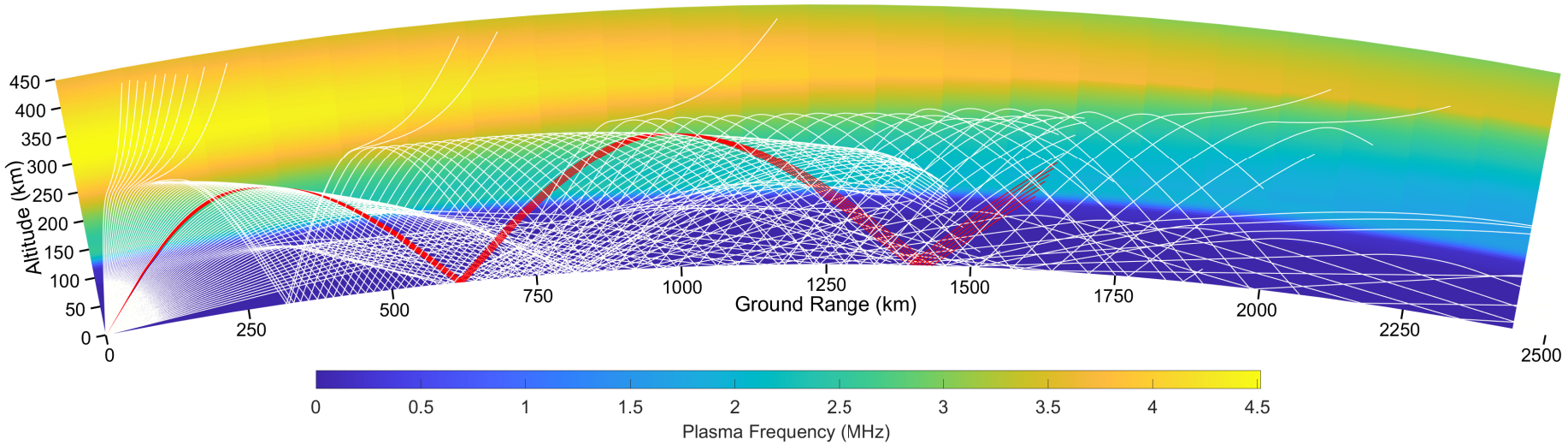

South Pole Station Received
GR km
4.1MHz
5.1MHz
6.0MHz
6.4MHz
7.2MHz
2000
1800
1600
1400
1200
Power
dB
20
15
10
5
Feb 28
Mar 01
Mar 02
Mar 03
Mar 04
Mar 05
Mar 06
Mar 07
Mar 08
Mar 09
Mar 10
Mar 11
Mar 12
Mar 13
Mar 14
2019


South Pole Station Received
GR km
4.1MHz
5.1MHz
6.0MHz
6.4MHz
7.2MHz
2200
2000
1800
1600
1400
1200
0
3
6
9
12
15
18
21
24
Power dB
10
5
0
"Spread F"
E
2019/03/02
Sunset
Sunrise



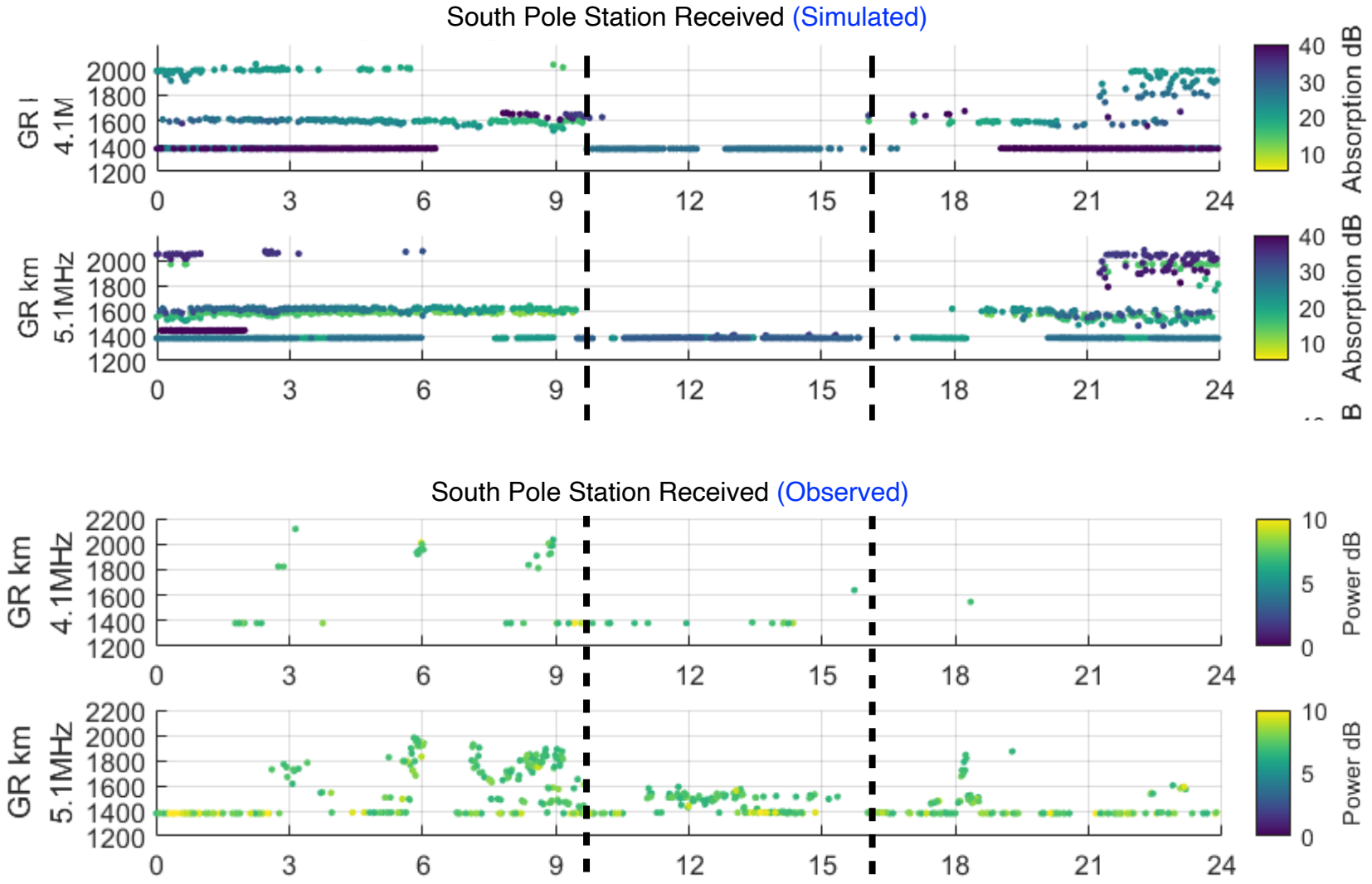
Key Observations

- A close inspection of the data prior to sunrise reveals 3 - 4 discrete bands of group range values.
  - 1-hop E-, 2-hop E-, 1-hop F-, and 2-hop F-layer reflections.
- Similar signatures often seen prior to Sunset over two weeks of data.
- Next, we use ray trace simulations to help narrow down what group ranges we should expect for the McMurdo to South Pole Station link.



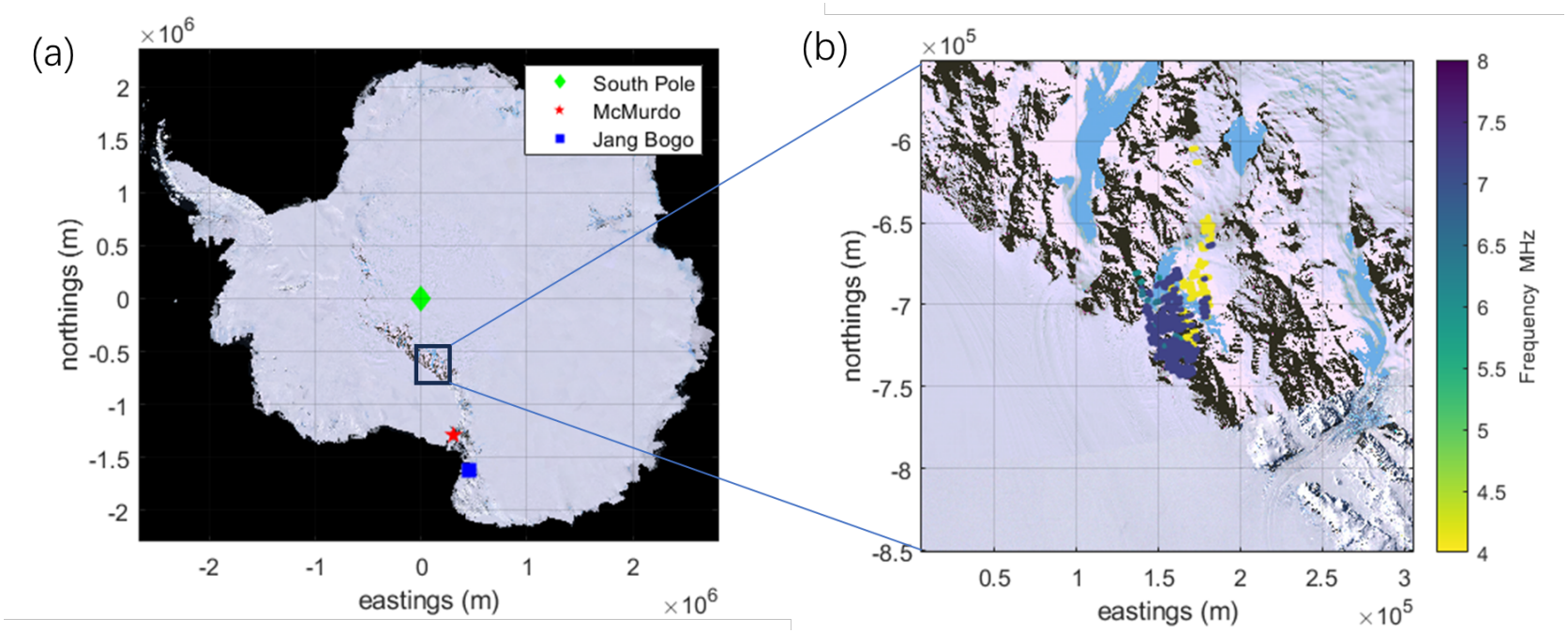
HF Ray tracing

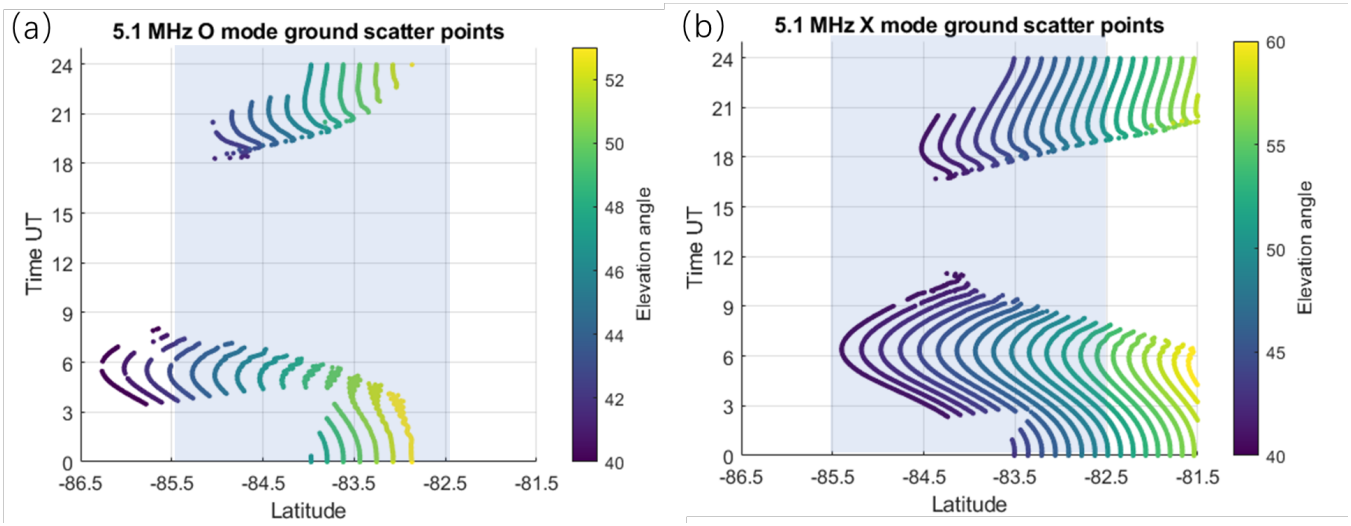
- 3D numerical ray trace simulations performed using PHaRLAP.
- IRI ionosphere and IGRF magnetic field used.
  - Temporal variability in IRI introduced by driving IRI function call with Jang Bogo VIPIR data.
- Simulated rays which landed within 3 km of receiver were considered “captured”.
- Earth treated as perfect conductor.



- The parameter we are focusing on here is group range.

- The multi-hop propagation mode is supported in the simulations by a perfectly conducting ground.
- Ice is highly absorptive at HF frequencies (Fujita et al., 2000), so **if we are indeed observing multi-hop propagation modes in the McMurdo to South Pole HF link, how are they supported?**
  - Answer: the foot points of the multi-hop mode are coincident with the Transantarctic Mountain range.





- A closer look at the movement of the foot points of the multi-hop modes shows that they sweep across the latitude of the Transantarctic mountains.
  - The greatest overlap occurs in the evening and morning.
- A sensitivity analysis was preformed to ensure that no other “realistic” ionosphere profile could reproduce the group-ranges observed by the McMurdo to South Pole HF link.

NJIT Update: Antarctic Network

Palmer, McMurdo and South Pole

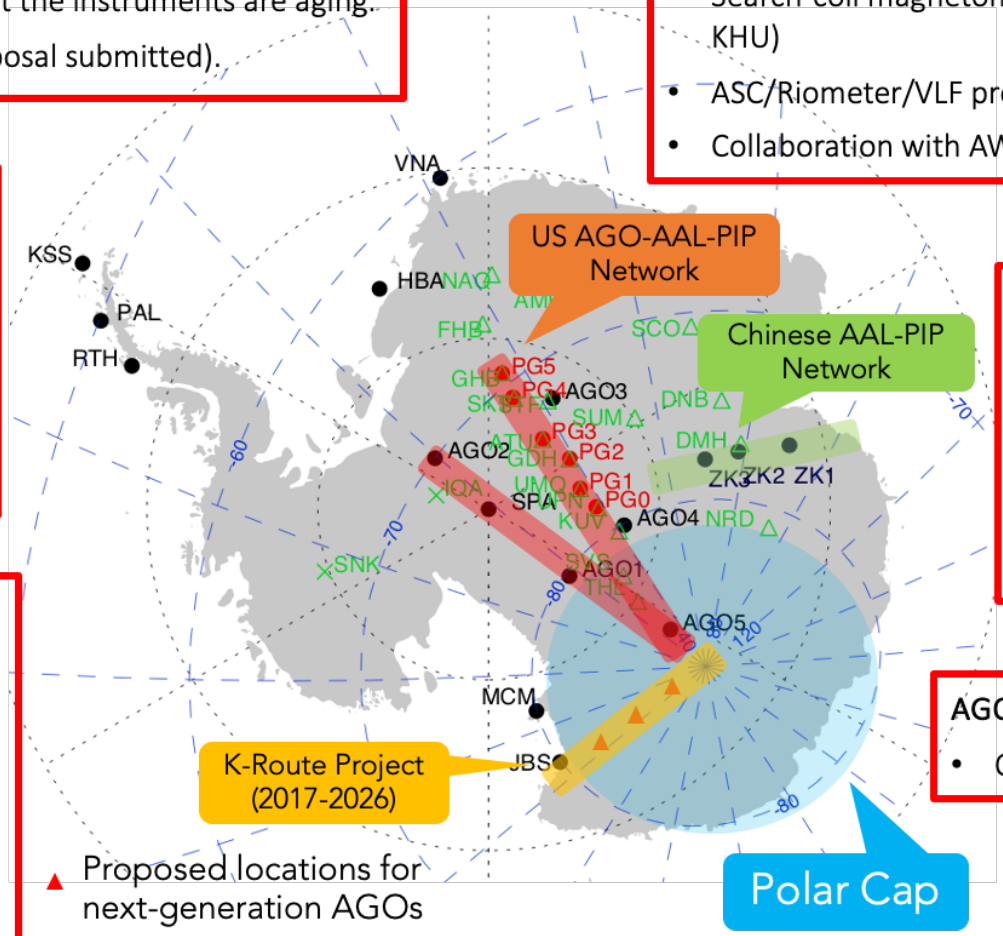
- Normal operation but the instruments are aging.
- Needs upgrade (proposal submitted).

Neumayer

- Search-coil magnetometer (UNH-NJIT-KHU)
- ASC/Riometer/VLF proposed (Jun 2023)
- Collaboration with AWI/GFZ

King Sejong, Jang Bogo, Rothera, Neumayer and Halley

- UNH-NJIT search-coil magnetometers
- Collaboration with KHU



Automatic Geophysical Observatories (AGO)

- Some stations report good data; some don't.
- *No further USAP logistics support.*

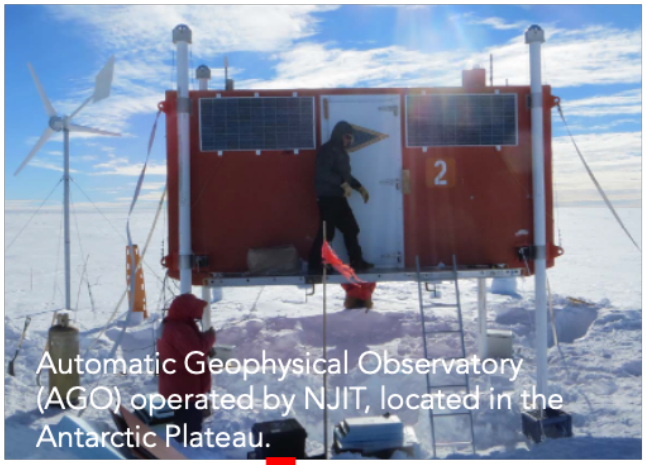
Deep Polar Cap Network

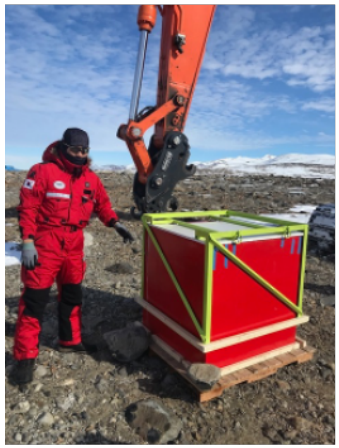
- Autonomous, next-generation AGO
- International collaboration (with KOPRI)
- No logistics cost from US

AGO-AAL-PIP Network

- Collaboration with VT

NJIT Update: Antarctic Instrument Network





Deep polar cap network

- Fluxgate magnetometer
- HF transceiver
- GNSS receiver
- All-sky imager

Summary

- Group range measurements of HF radio link between the McMurdo and South Pole stations in Antarctica were analyzed.
- Evidence of a multi-hop propagation modes between the stations is observed in the data and corroborated with the modeling.
- Ground reflections from the Transantarctic mountains support the multi-hop modes.
- The prevailing wisdom in the Antarctic is that HF multi-hop propagation modes do not exist.
  - This may not be true in cases where the multi-hop foot point are coincident with exposed rock.
- Manuscript (Liu et al., 2024) under review…
- Active international collaborations to deploy automated geophysical observatories.

References

Cervera, M., & Harris, T. (2014). Modeling ionospheric disturbance features in quasi-vertically incident ionograms using 3-d magnetoionic ray tracing and atmospheric gravity waves. *Journal of Geophysical Rsearch: Space Physics*, doi: 10.1002/2013JA019247.

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Extra Slides

- By comparing the observed and simulated group range, we can get an estimate of the propagation modes are their corresponding group ranges.