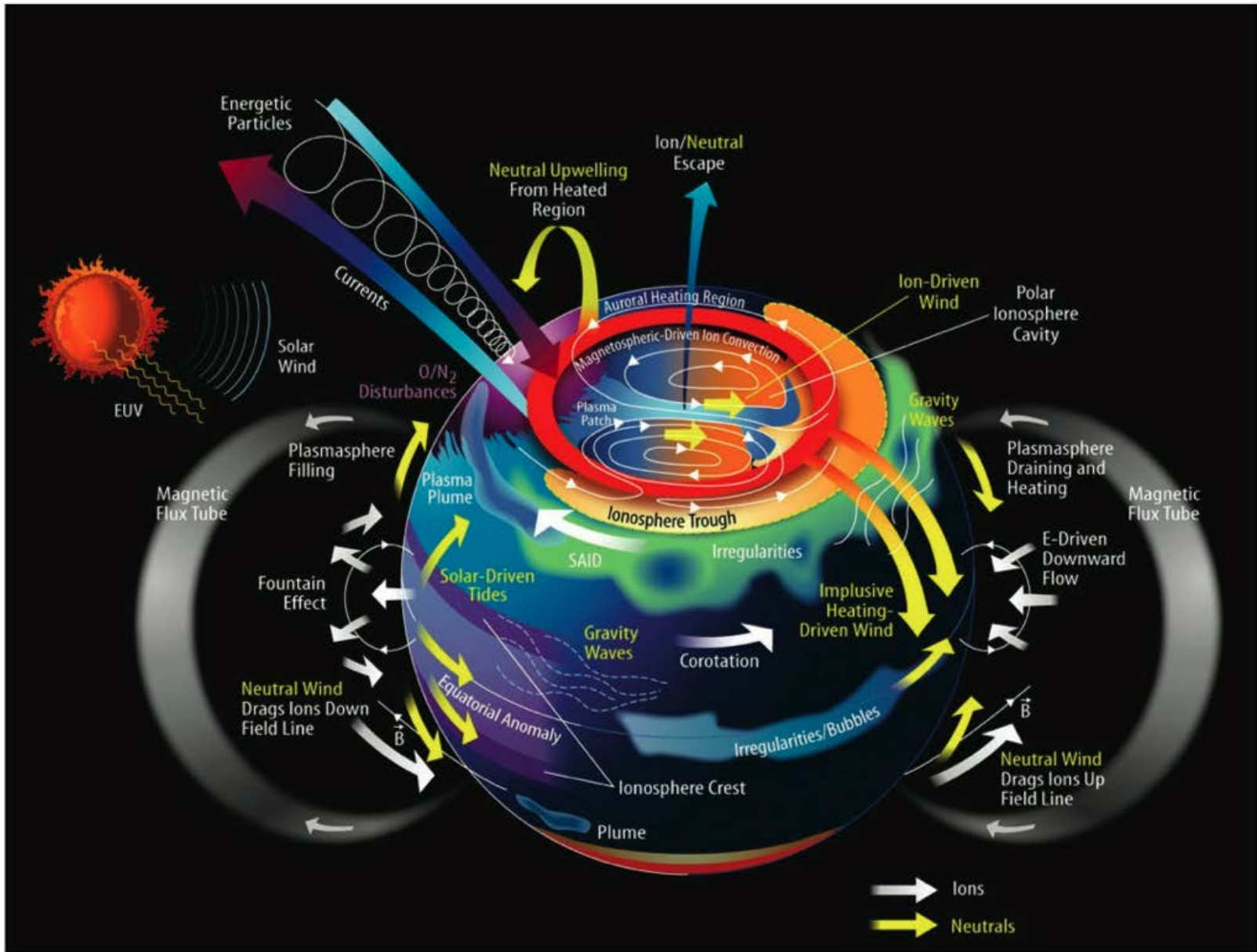


Polar radio science in solar-terrestrial physics

G. W. Perry
Center for Solar-Terrestrial Research
Physics Department

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Polar Radio Science “Fireside Chat”



Courtesy of the NSF

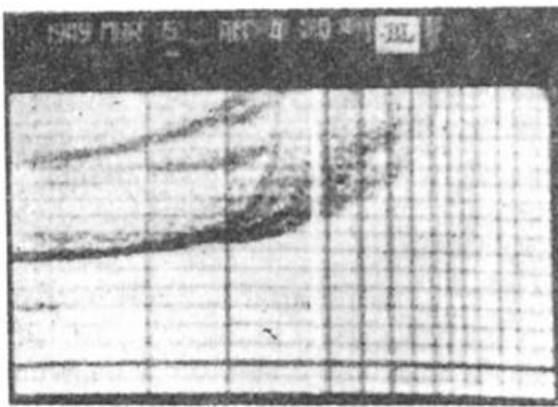


FIG. 7

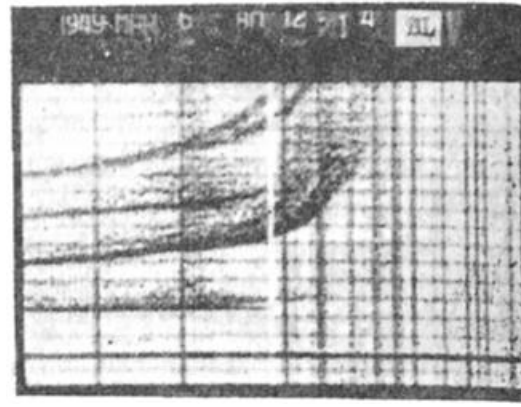
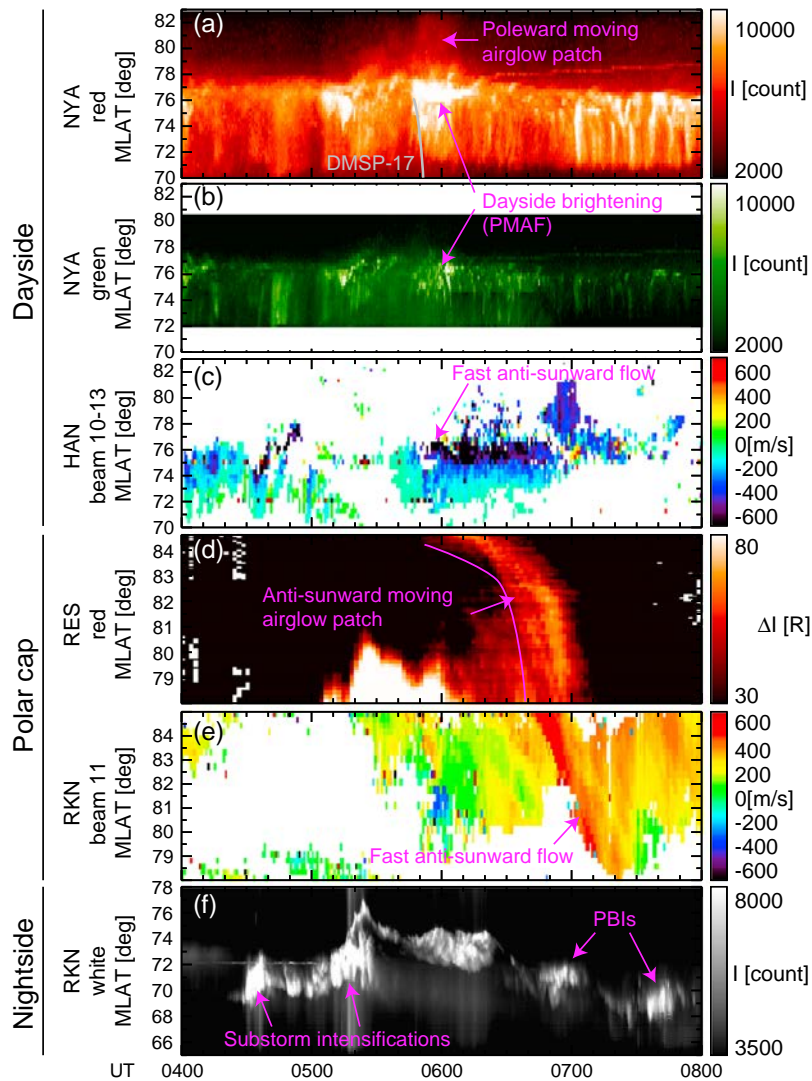


FIG. 8

F-REGION OBLIQUE TRACES

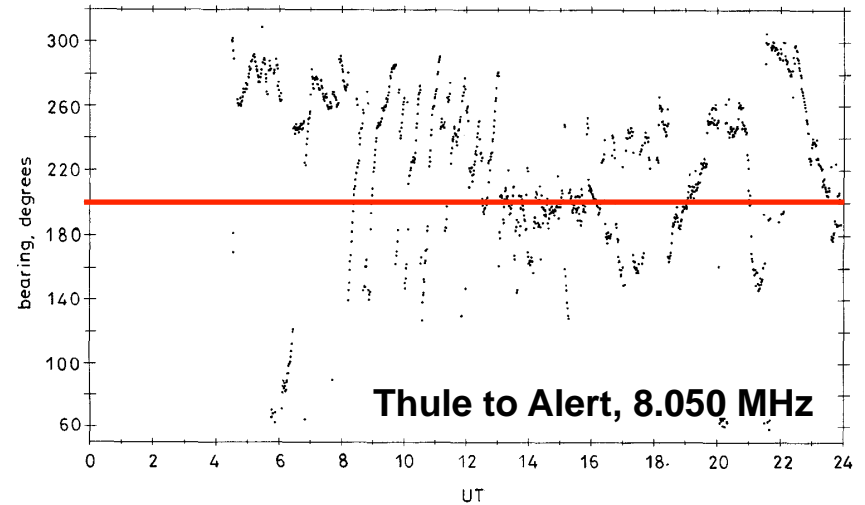
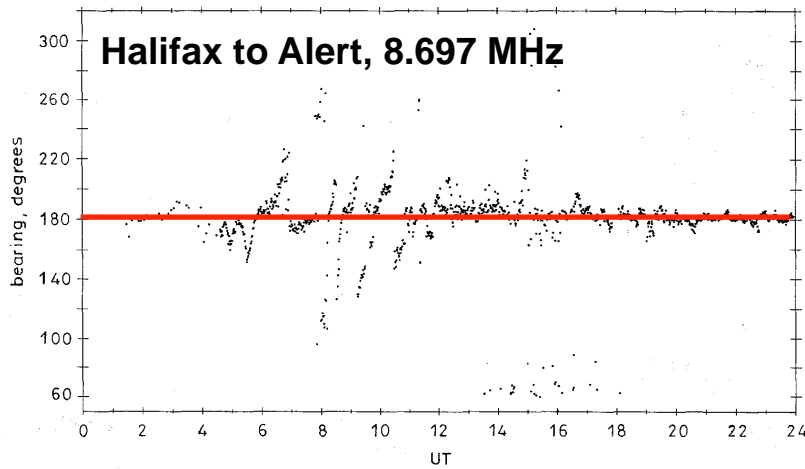
From: Meek, J. H. (1949). Sporadic ionization at high latitudes. *Journal of Geophysical Research*, 54(4), 339–345. <https://doi.org/10.1029/JZ054i004p00339>

- We've known for a while that plasma structuring in the polar-cap ionosphere is fundamentally different compared to lower latitudes.
- The polar ionosphere is very structured - especially in the F region.
 - *“On some sequences of records, it is possible to pick out series of traces which appear first at great virtual heights, usually about twice the height of the normal F-region trace, and on successive sweeps decrease in height to the level of the F-region trace and then rise at about the same rate. These we may consider to be horizontally moving clouds of ionization passing over the recording station.” Meek, 1949*
- Plasma transport plays an important role.
 - Winter F-region chemical recombination of O⁺ is slow (several hours).
 - Cross-field diffusion time scale is even slower.
 - Large scale irregularities (>10 km scale size) can be transported around the polar-cap region.



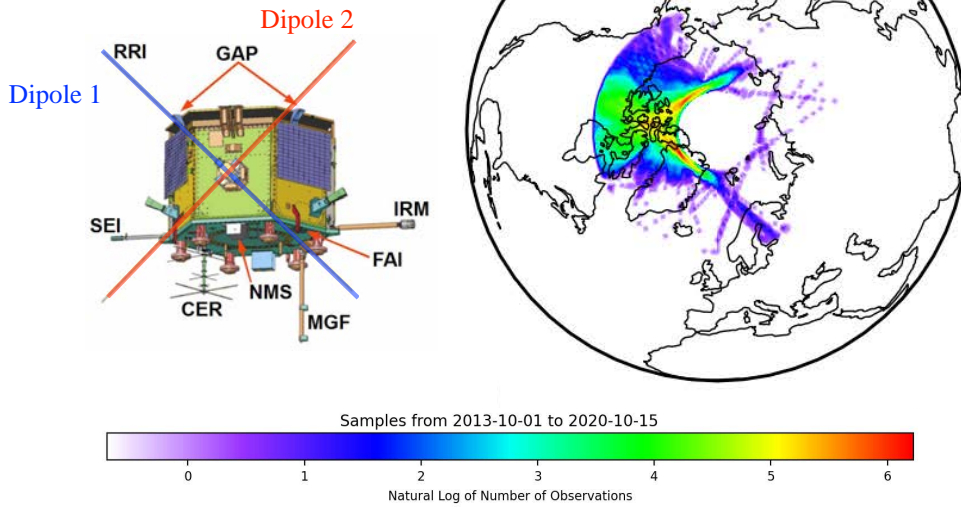
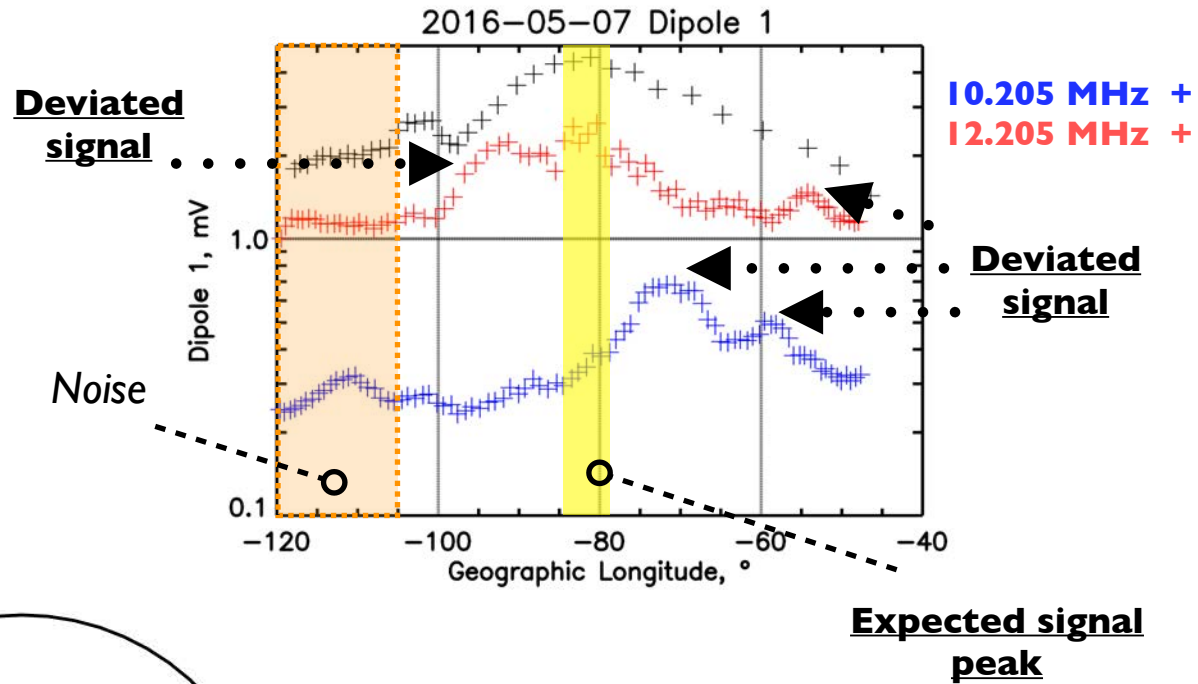
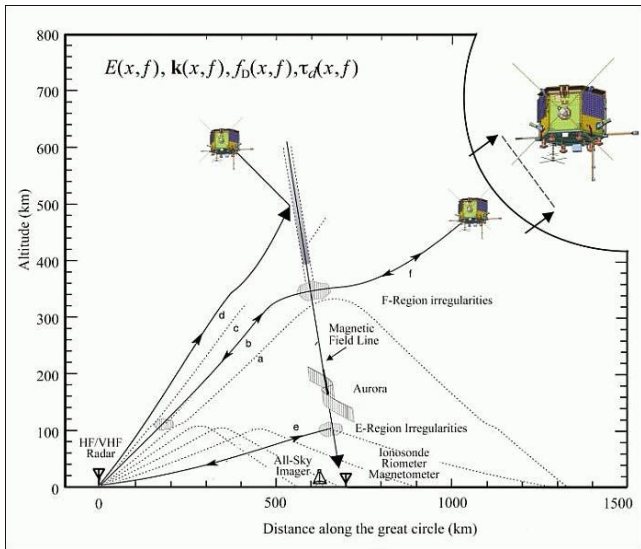
- Over time, our understanding of the region's plasma dynamics and its connection to the magnetosphere-ionosphere-thermosphere (M-I-T) system has improved.
 - Several multi-instrument studies have been exceptionally insightful.
 - SuperDARN HF radars, all sky imagers, incoherent scatter radars at Poker Flat and Resolute Bay (x2), GNSS TEC measurements, etc...
 - Multi-institution collaborations.
- Paradigm shift: large scale irregularities we capture aren't sporadic, boring, fossilized remnants of some bygone geophysical event - they are signatures of ongoing processes.
 - E.g., We now understand that structuring in density and plasma velocity can be a manifestation of magnetic reconnection in the dayside and nightside ionosphere.

From: Nishimura, Y., Lyons, L. R., Zou, Y., Oksavik, K., Moen, J. I., Clausen, L. B., ... Lester, M. (2014). Day-night coupling by a localized flow channel visualized by polar cap patch propagation. *Geophysical Research Letters*, 41(11), 3701–3709. <https://doi.org/10.1002/2014GL060301>



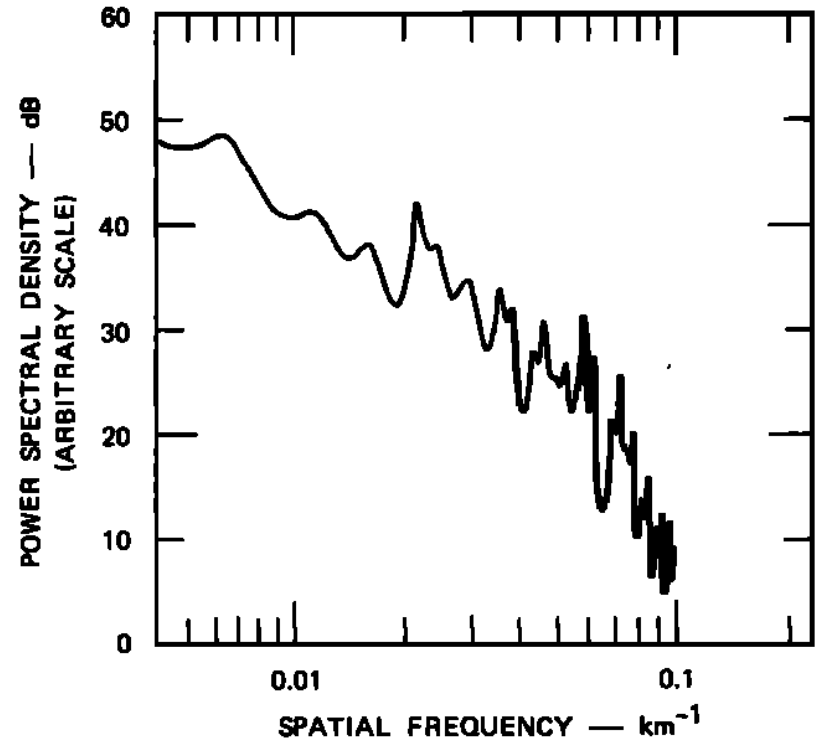
From: Warrington, E. M., Rogers, N. C., & Jones, T. B. (1997). Large HF bearing errors for propagation paths contained within the polar cap. *IEE Proceedings: Microwaves, Antennas and Propagation*, 144(4), 241–249. <https://doi.org/10.1049/ip-map:19971187>

- A highly structured and dynamic ionosphere has important implications.
- Our reliance on radio links in the polar-cap region is *increasing*.
 - Accordingly, so is our vulnerability to space weather.
- Plasma density irregularities and the instability processes they trigger are sources of scintillation in radio links.
 - High Frequency (3-30 MHz) and GNSS systems can be severely affected.
 - Small scale irregularity processes still not well understood; instability mechanisms have not been identified.



- **CASSIOPE** (CAScade, Smallsat and IOnospheric Polar Explorer)
 - Launched September 29, 2013.
 - 1500 x 325 km polar orbit.
- **e-POP** (enhanced Polar Outflow Probe)
 - 8 instruments.
- **RRI** (Radio Receiver Instrument)

- We still do not have a strong understanding of how structured the polar-cap ionosphere really is.
- Models, such as IRI, aren't very good in the polar-cap regions.
 - E-CHAIM is a distinct improvement in the northern polar-cap.
- The transient nature of the polar-cap ionosphere is under-represented by our models.



Irregularity spectrum at 350 km from an elevation scan performed by the Chatanika ISR

From: Kelley, M. C., Vickrey, J. F., Carlson, C. W., & Torbert, R. (1982). On the origin and spatial extent of high-latitude F region irregularities. *Journal of Geophysical Research: Space Physics*, 87(A6), 4469–4475. <https://doi.org/10.1029/JA087iA06p04469>

- Many fundamental questions remain....
- What does the irregularity structure of the polar-cap ionosphere look like, and how is it influence by geomagnetic conditions?
- What role do irregularities that are depletions (rather than enhancements in plasma density) have to play?
- How is HF radio propagation affected by the nature of a highly structured propagation medium?
 - How are our remote sensing techniques affected?
 - E.g., SuperDARN HF radars assume great-circle path propagation to and from the scattering volume. How valid is this, and how does it affect our understanding of the coupled M-I-T system?
- The implications stretch beyond radio science and solar-terrestrial science.
 - Over-the-horizon communications and monitoring.
 - Vitality of GNSS systems.
- The northern arctic is opening up (warming - like we heard a few minutes ago).
 - A reliable communications infrastructure is crucial.
- We can make significant progress on these questions with our existing data sets — we just need to keep digging.