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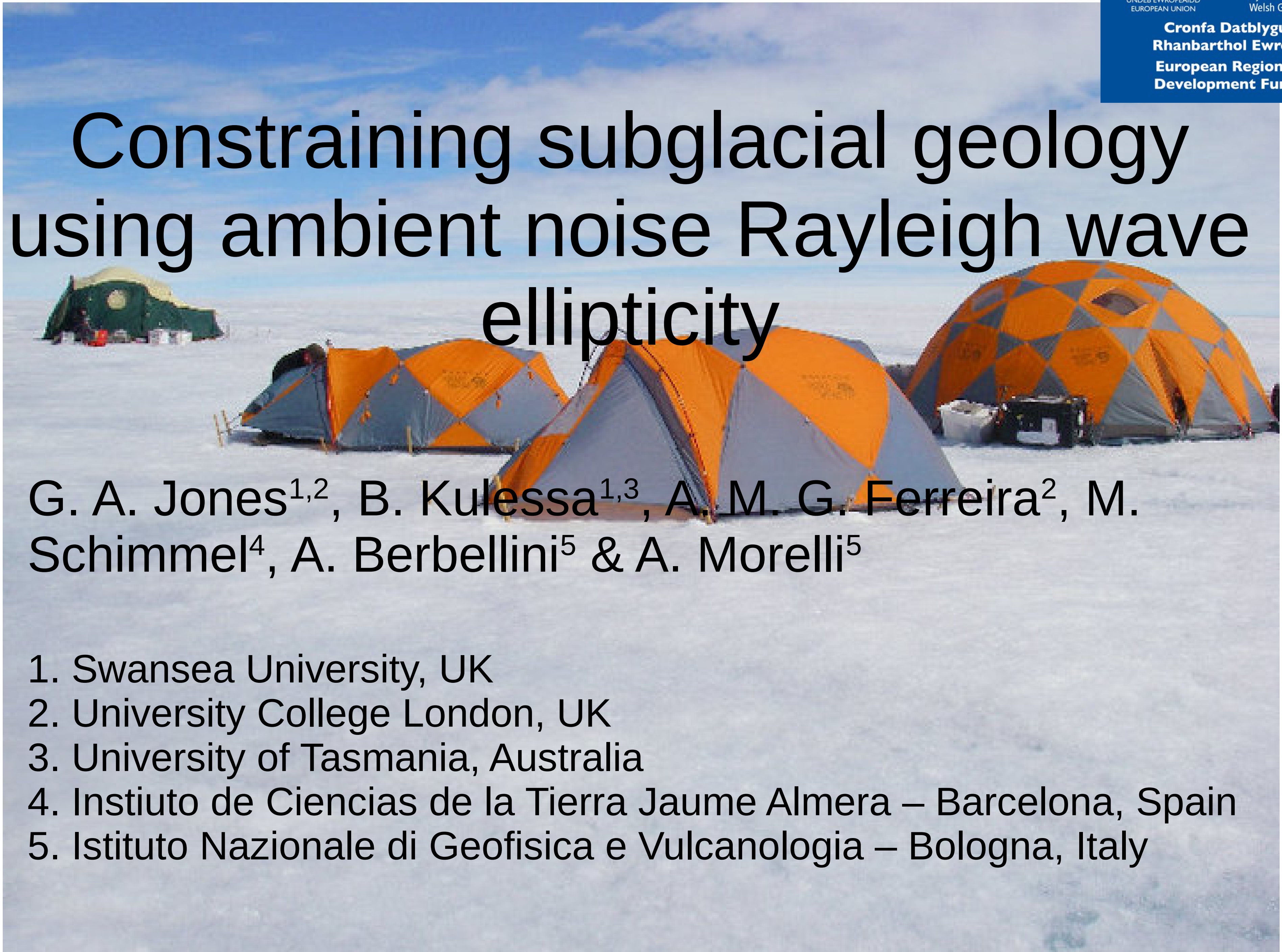

Constraining subglacial geology using ambient noise Rayleigh wave ellipticity

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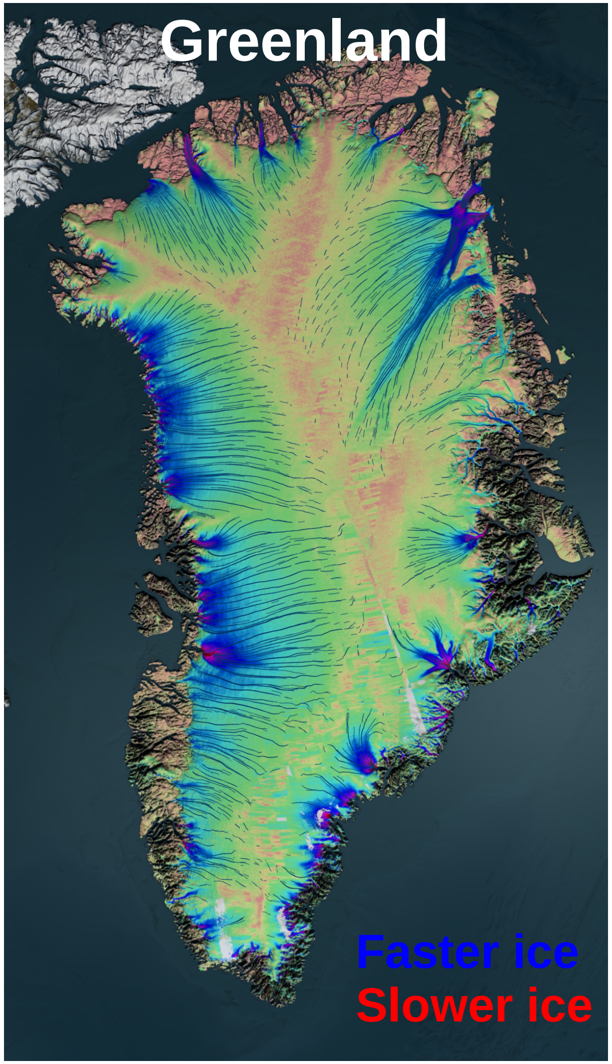
Geological controls on ice flow

- Basal slip is a major control on ice flow and a major unknown in ice sheet models
- Hypothesised that sedimentary layers lubricate the base of the ice sheet facilitating ice flow
- Radar surveys provide limited information about basal properties and geology
- Focussed field campaigns are conducted during the summer
- Passive seismic methods allow for deep probing of the Earth's crust and once deployed provide year round recording

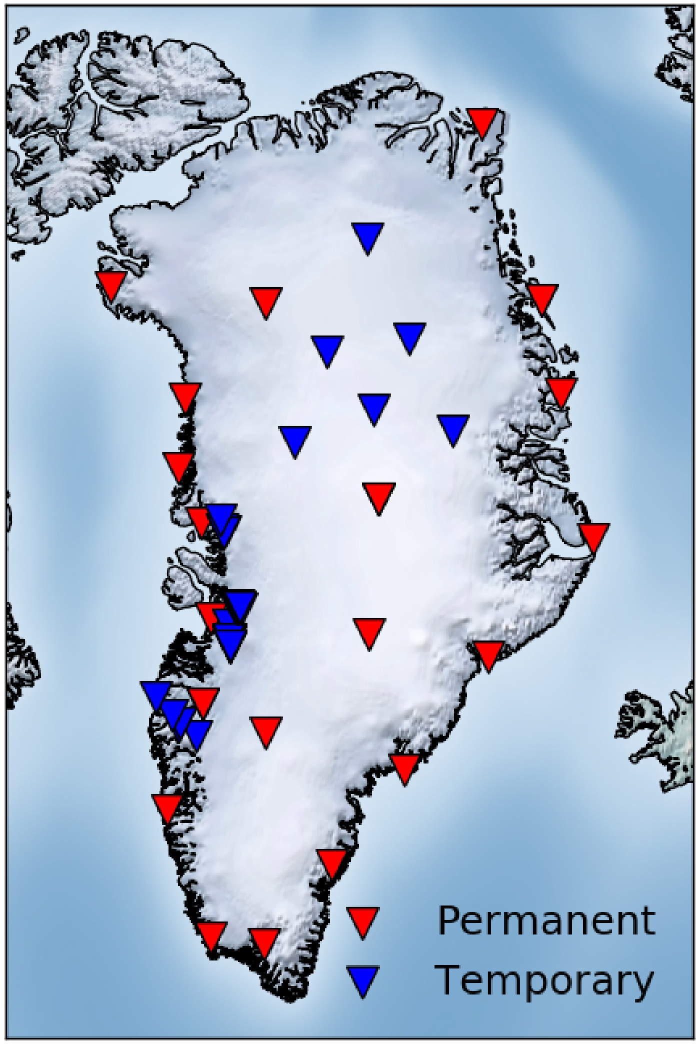
Goal: To quantify the relationship between the ice flow and subsurface geology



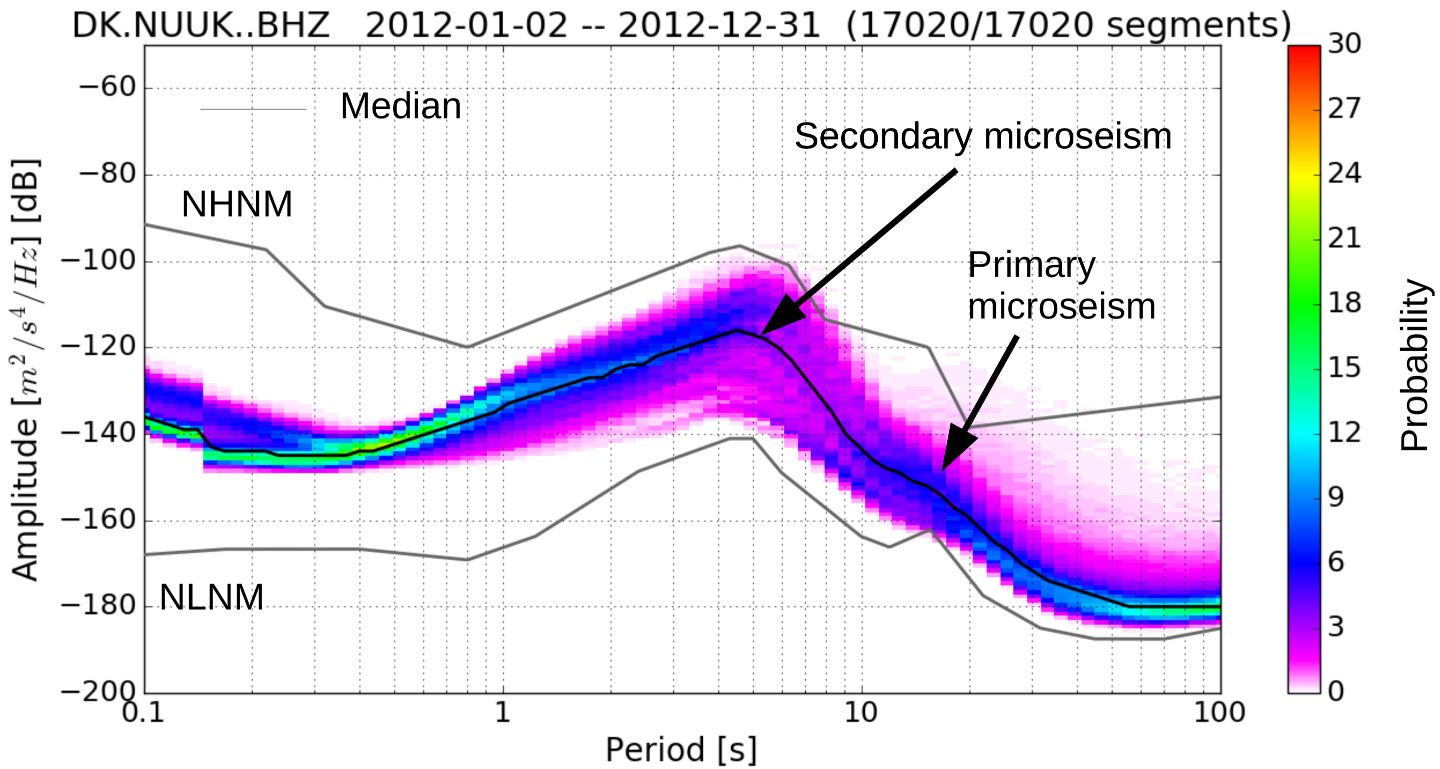
https://svs.gsfc.nasa.gov/3962

Greenland seismic network

- 26 permanent seismic stations deployed since 1970s
- Network of permanent seismic stations known as the Greenland Ice Sheet Monitoring Network – GLISN
- Over 100 temporary stations deployed
  - 47 deployed for over 12 months



Seismic ambient noise



- Background noise of the Earth varies spatially and temporally
- Short period noise typically dominated by human activities
- Primary microseisms are generated by wave-coastline interaction with a peak at ~14s
- Secondary microseisms are generated by non-linear interaction of ocean waves with a peak at ~7s

Rayleigh wave ellipticity

- Ellipticity is the ratio of horizontal to vertical displacement of a Rayleigh wave
- Ellipticity measurements shown to be sensitive to earth structure
- Produces 1D depth profiles of v_p v_s and density
- Method applicable to both earthquake and ambient noise data
- Resolution is frequency dependent
  - ambient noise essential in constraining shallow crust

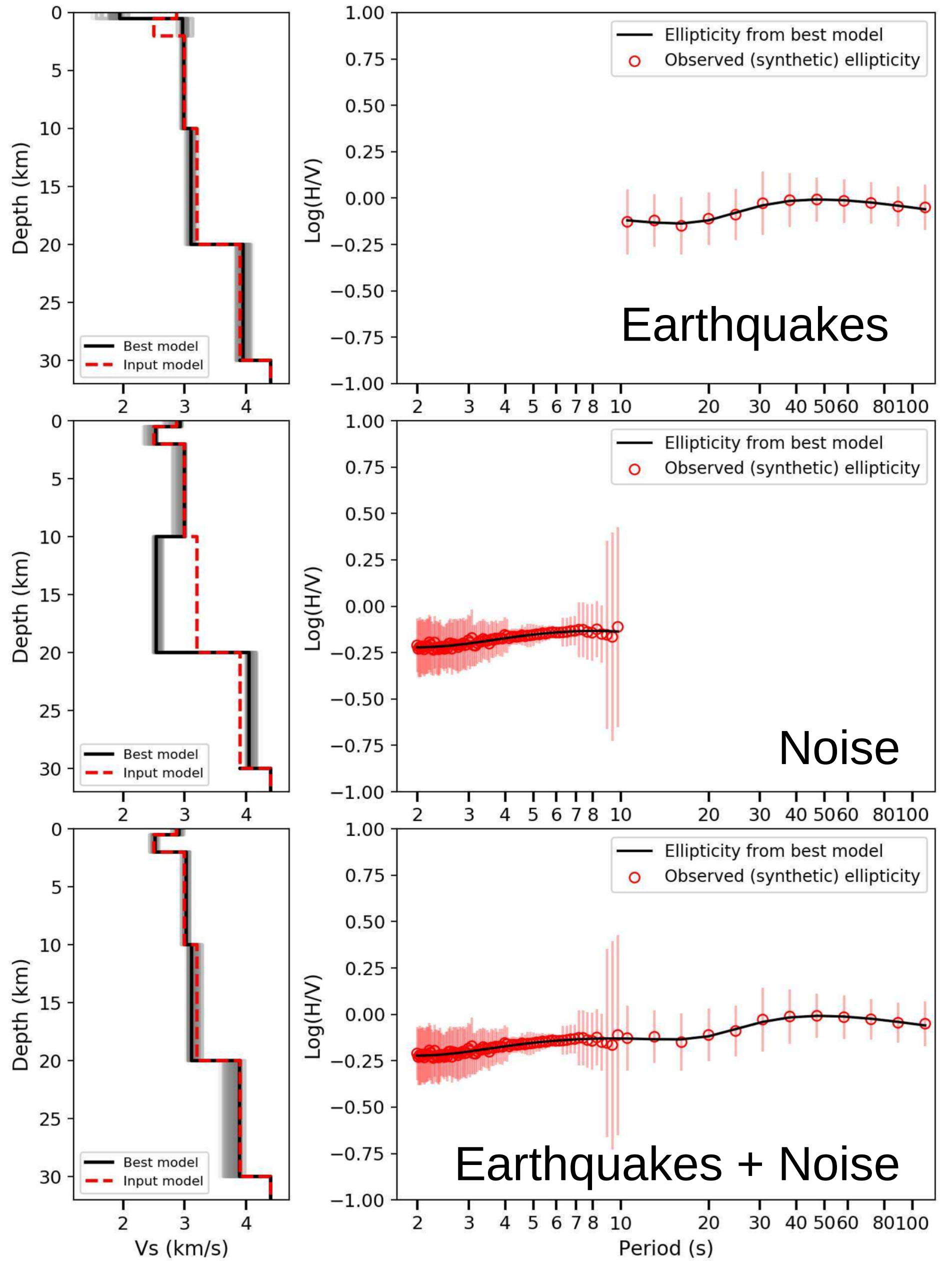
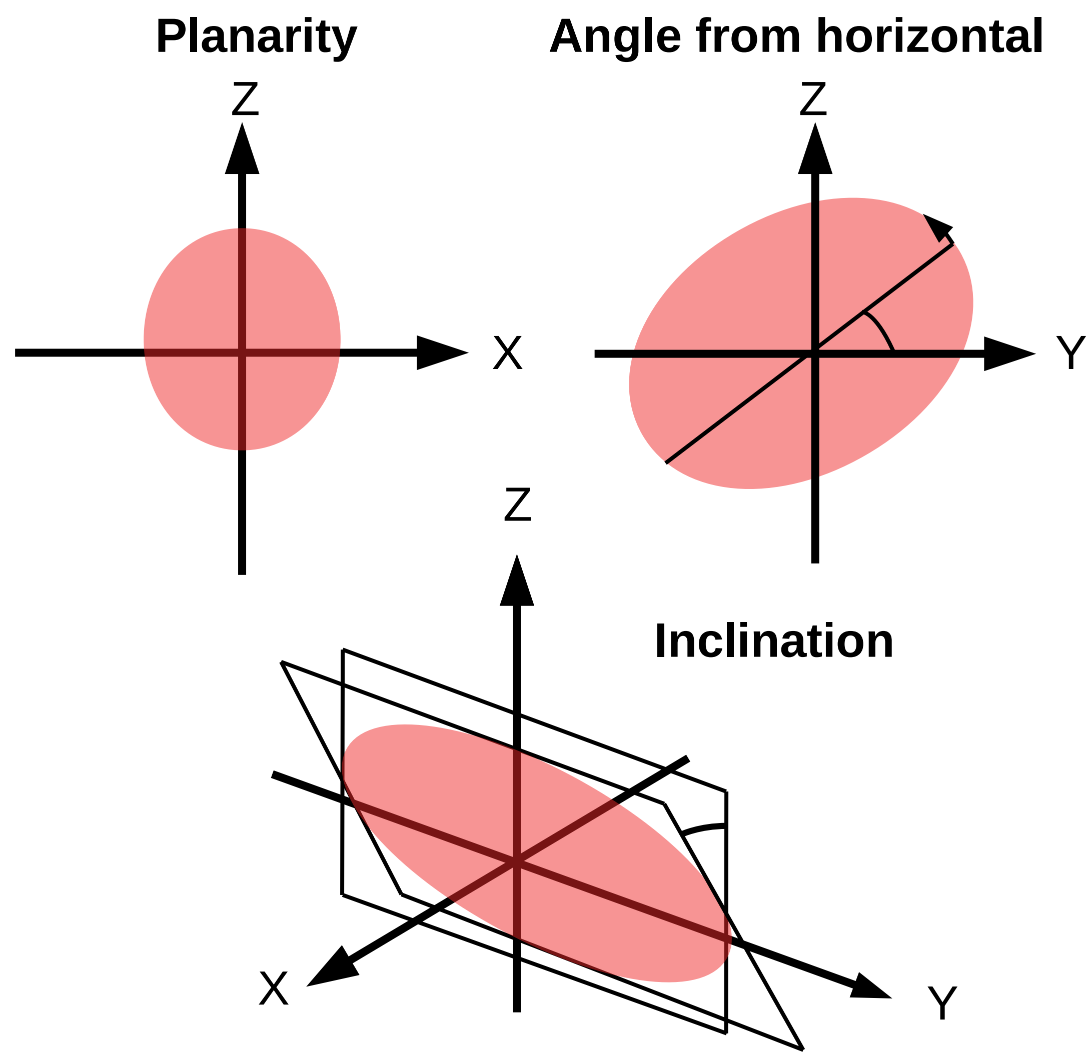


Fig. 6: Berbellini et al., 2019, *GJI* 1817-1830, doi:10.1093/gji/ggy512

Rayleigh wave data extraction

- Ambient noise consists of multiple seismic phases
- Signals are detected based on the characteristic particle motion of Rayleigh waves

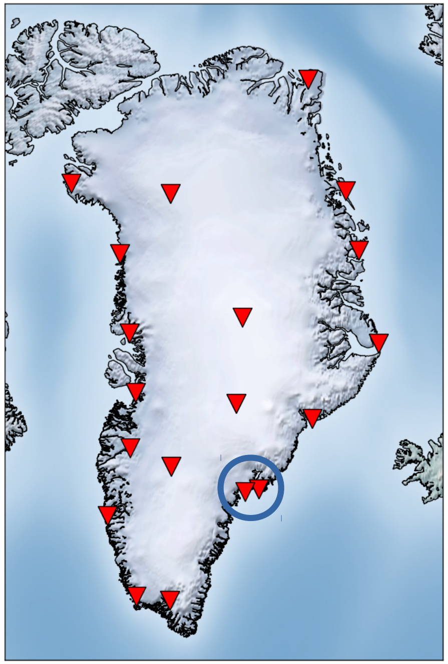
Rayleigh wave polarisation attributes



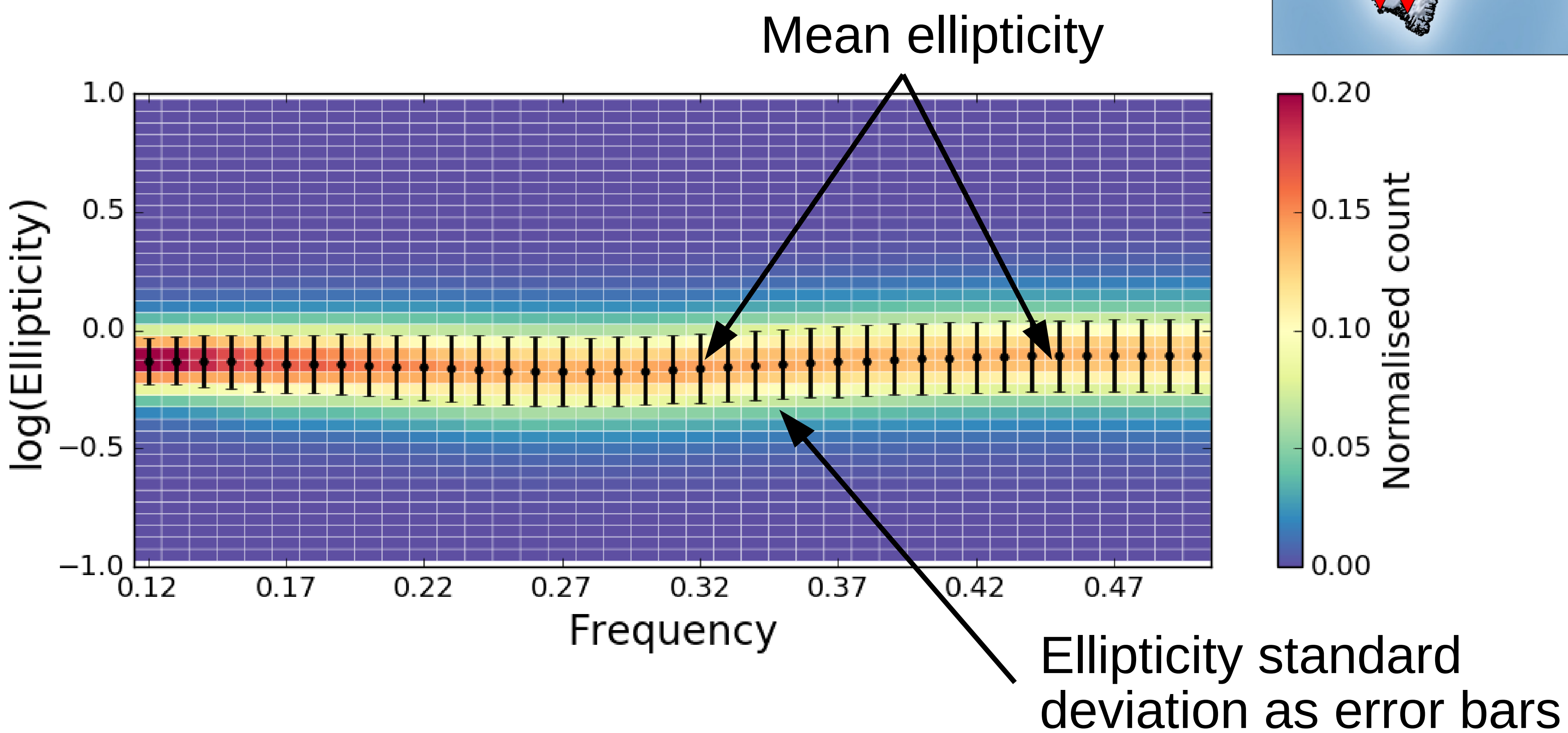
Data extraction workflow

1. Frequency dependent data windowing
2. Time-freq. transform of data
3. Eigen decomposition
4. Polarisation attributes and QC

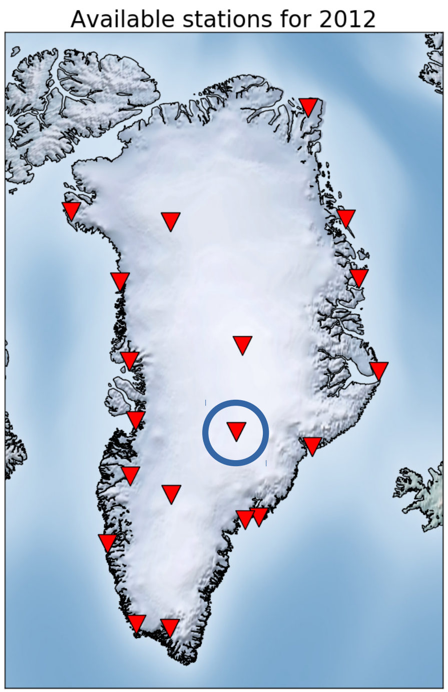
Ellipticity measurements – Off-ice



- Ellipticity measurements give a log-normal distribution
- The mean and standard deviation of these can be estimated and used in the inversion

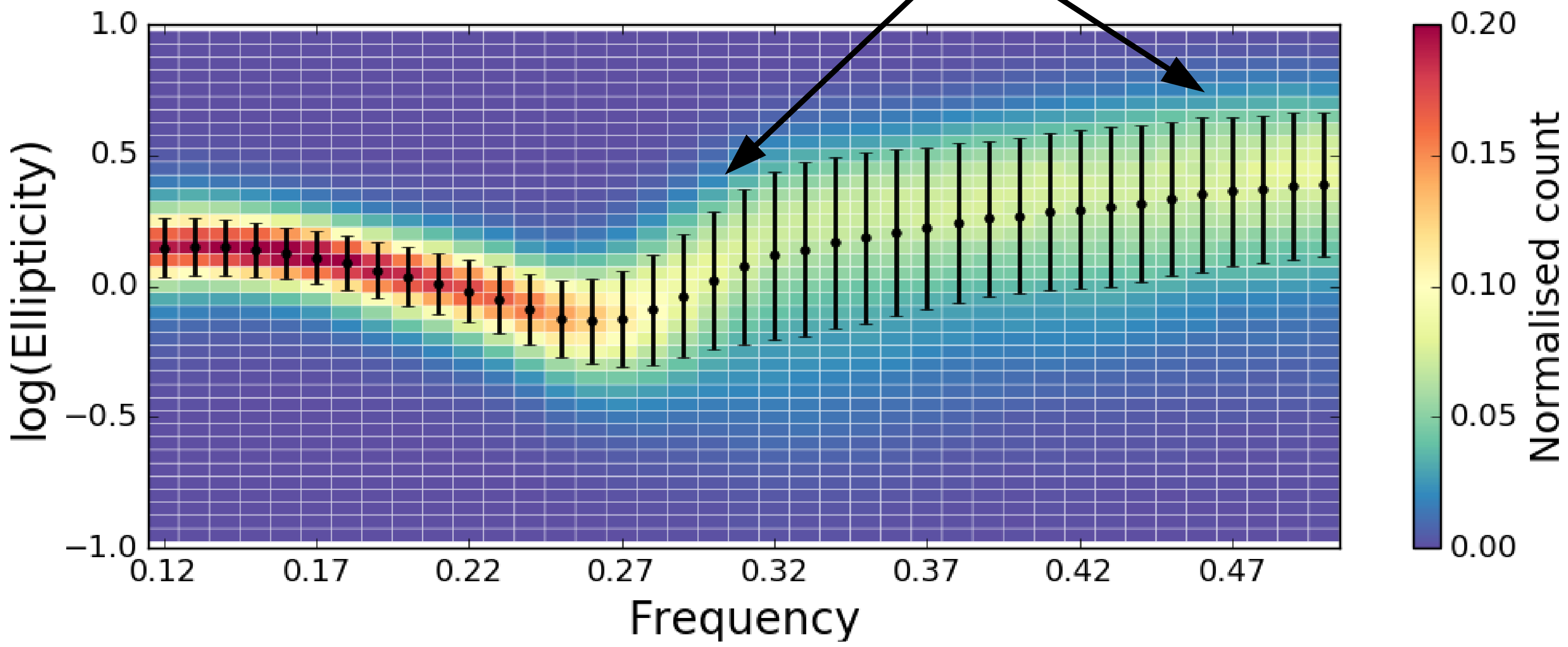


Ellipticity measurements – On-ice



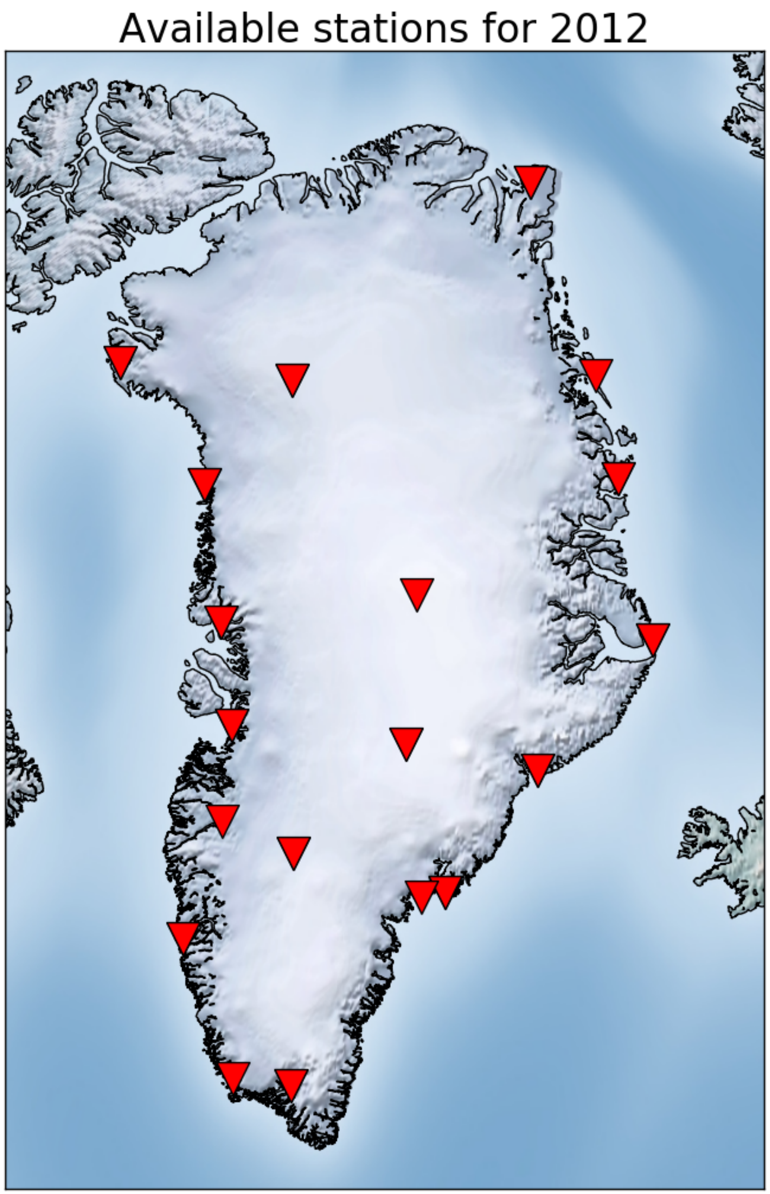
- On-ice stations show greater variability in the ellipticity curve relative to off-ice counterparts

Broader distribution of ellipticity measurements at higher frequencies

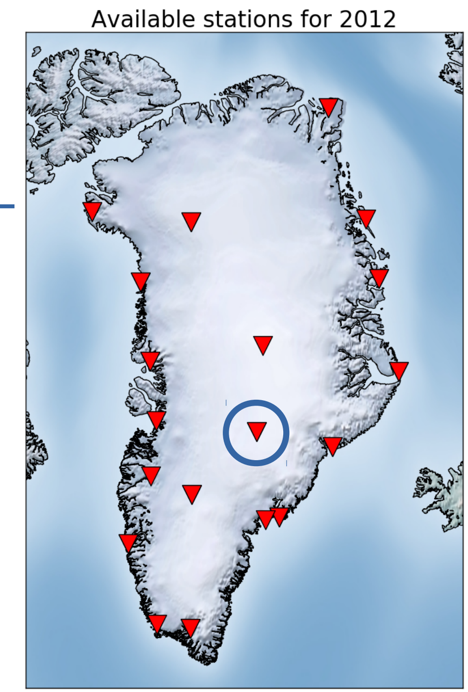


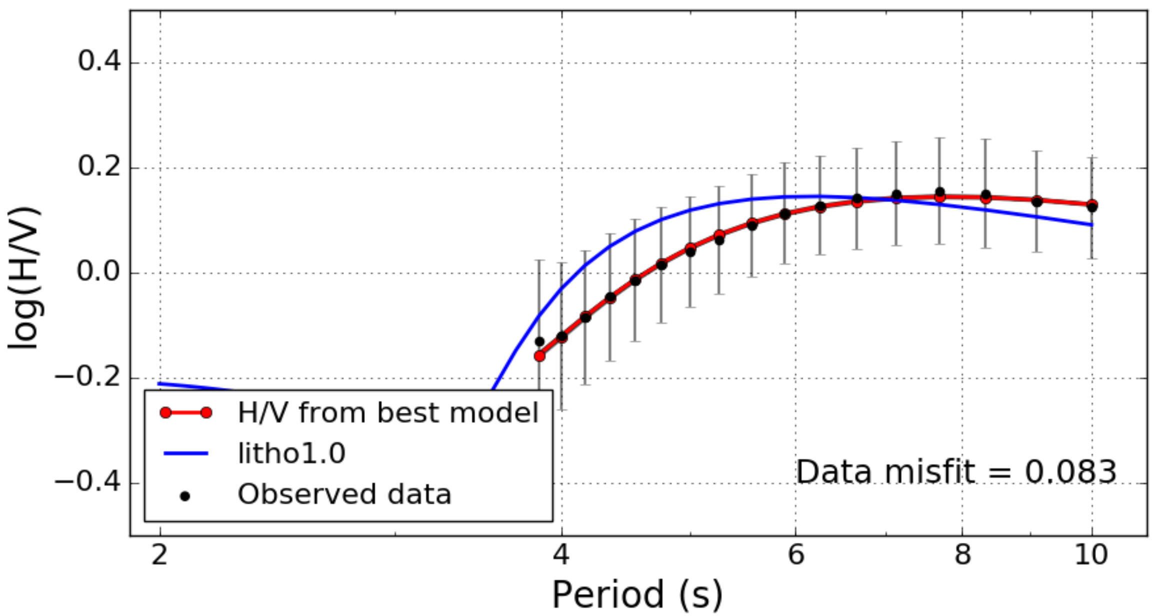
On-ice station inversions

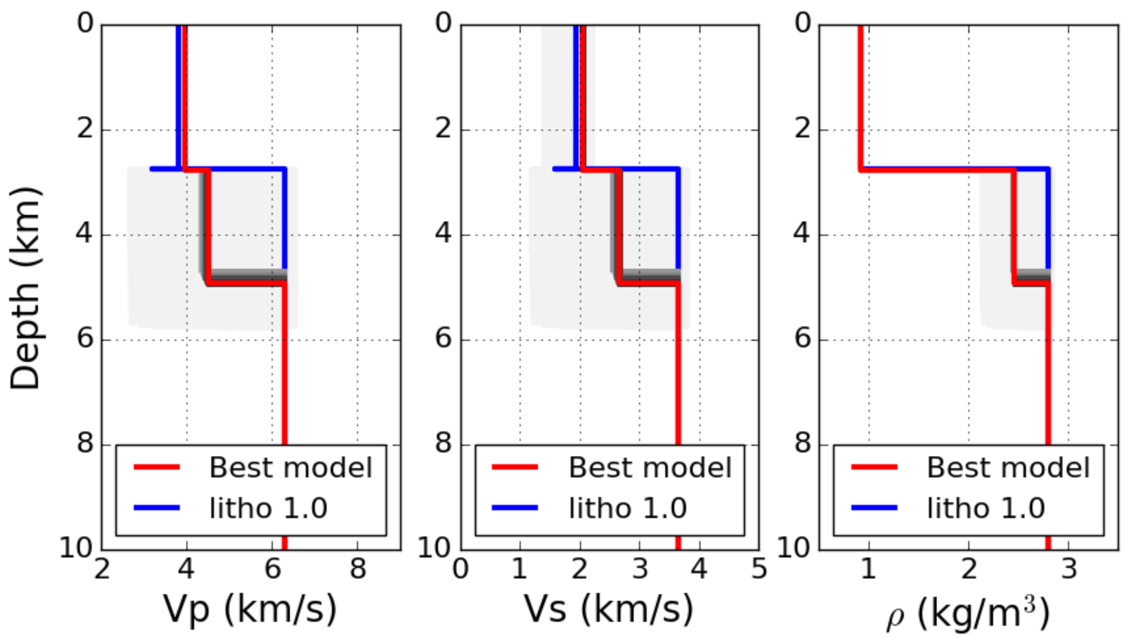
- Ellipticity measurements QC to remove values with errors > 0.2
- Invert for v_s with v_p and density scaled empirically
- Ice depth fixed based on BedMachine v3 bed topography (*Morlighem M. et al., GRL 2017*)
- Ice v_s = 1.4 – 2.2km/s with fixed v_p = 3.96 km/s and ρ = 0.915 kg/m^3
- Single sub ice layer:
  - Depth 0.0 – 3.0km
  - v_s 1.2 – 3.8 km/s
- 2012 data inverted



On-ice station inversion results





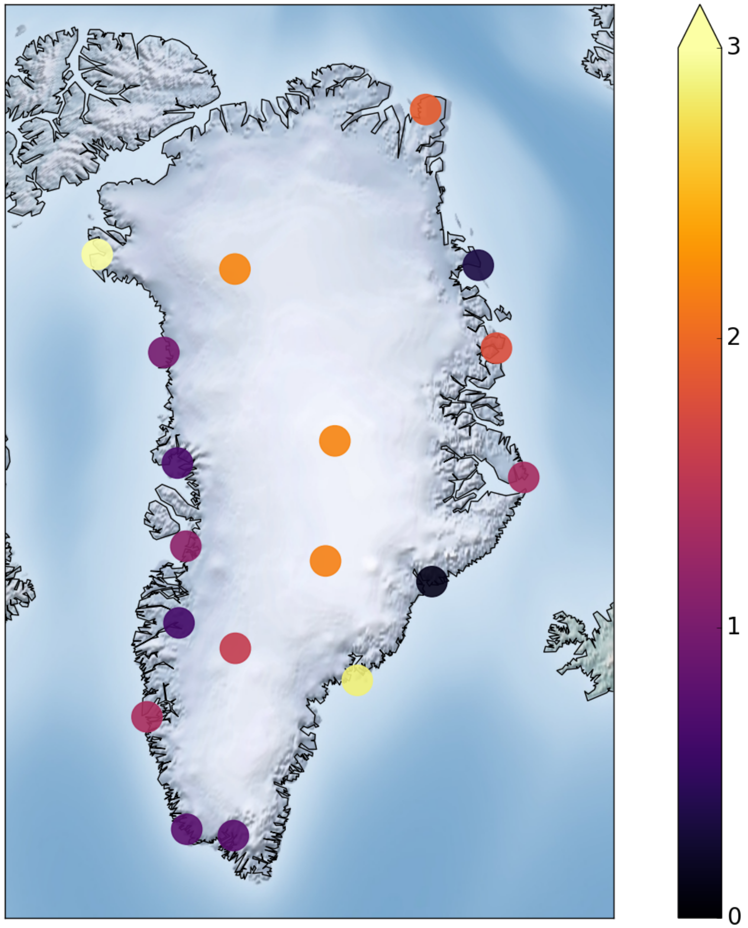


- Inversion results are a better match to data than litho1.0 model

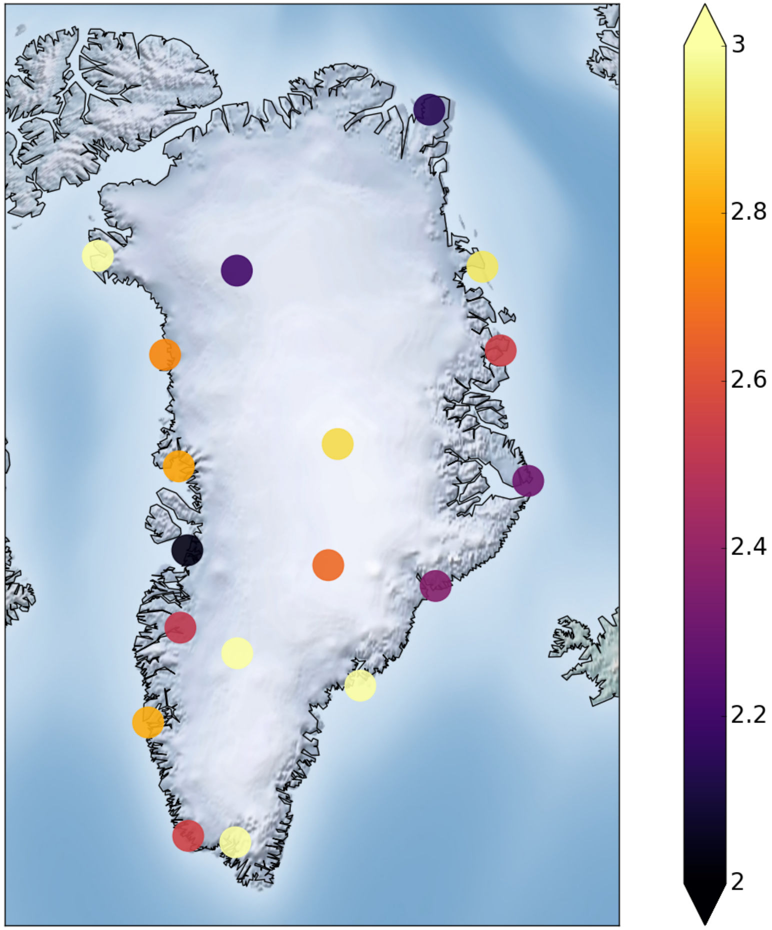
Depth (km)	v_p (km/s)	v_s (km/s)	Density (kg/m³)
2.77	3.96	2.06	0.915
4.93	4.51	2.67	2.46
16.52	6.3	3.65	2.8

Inversion results

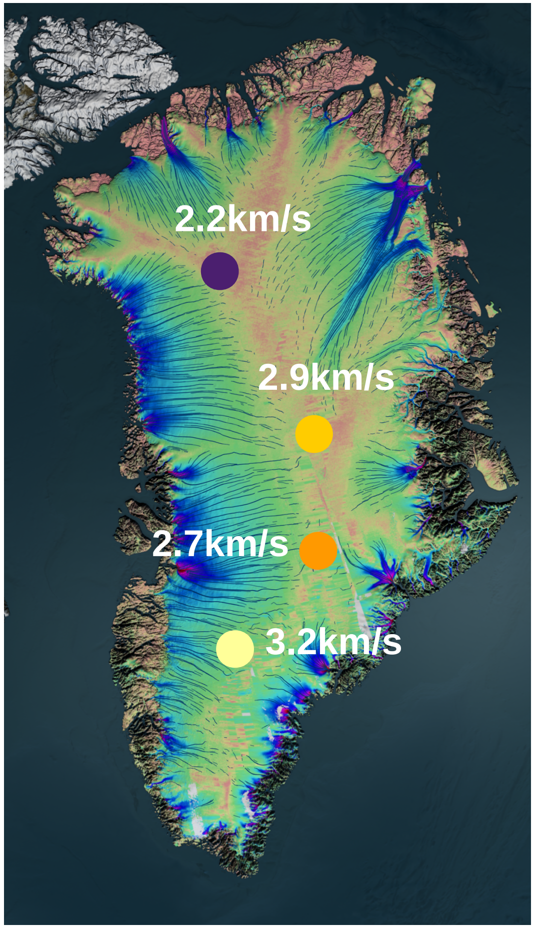
Layer thickness



S-wave velocity



Ice velocity



- 2 – 3km thick layer beneath the ice with v_s 2.2 – 3.2 km/s
- < 1km thick layer off-ice with v_s 2 – 3+ km/s
- Possible sediment at northernmost ice station

Summary

- Extraction of Rayleigh wave ellipticity from the ambient noise using the degree of polarisation method
- On-ice stations display greater variation in ellipticity measurements compared to off-ice stations
- Ice effects the distribution of ellipticity measurements at higher frequencies
- Off-ice stations typically indicate a shallow < 1km thick layer with v_s between 2 – 3+km/s
- On-ice stations indicate the presence of 2 – 3km thick layer with variable v_s between 2.2 km/s to 3.2 km/s
- Spatial differences in on-ice v_s with northernmost station suggesting the presence of sediment