Spectral Bidirectional Reflectance of Antarctic Snow

Measurements and Parameterisation

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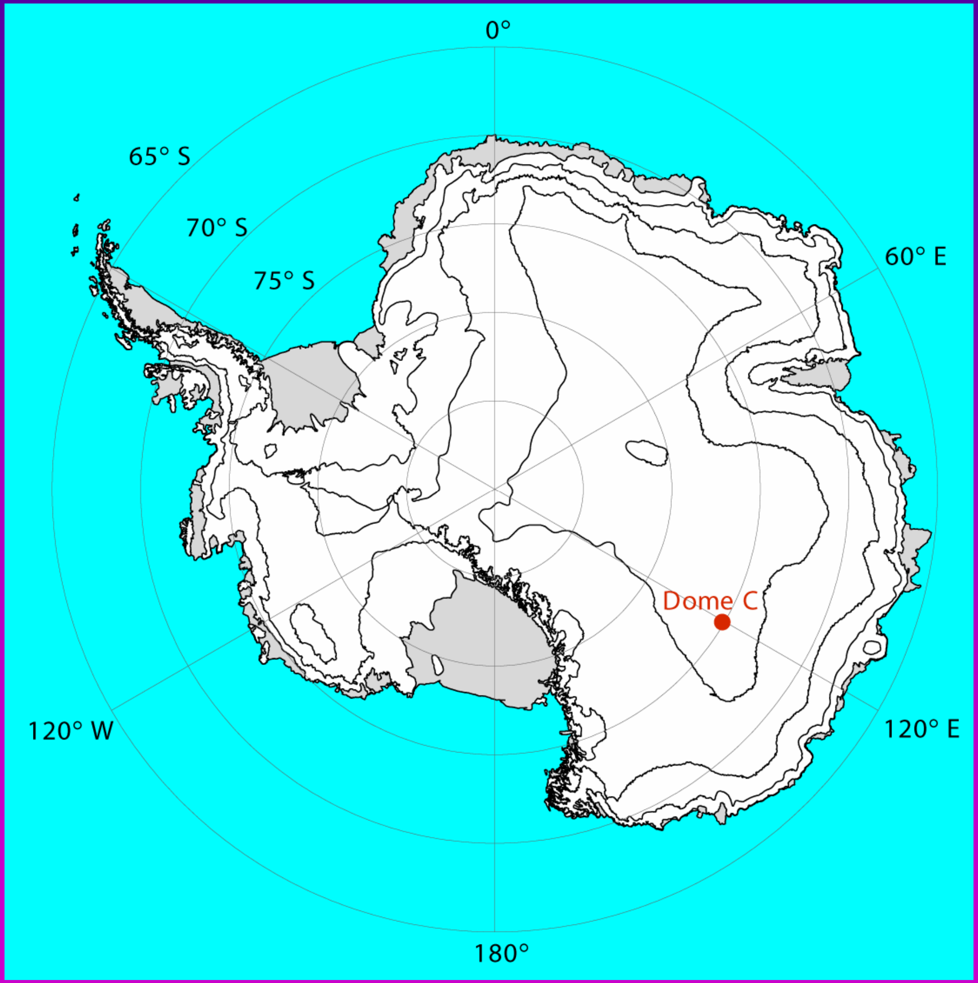
Location

- Dome C
  75°S, 123°E, 3250 m
- Very small surface slope results in light winds and small surface roughness
- Cold, fine-grained snow all year
- Similar surface to most of East Antarctic Plateau above 3000 m

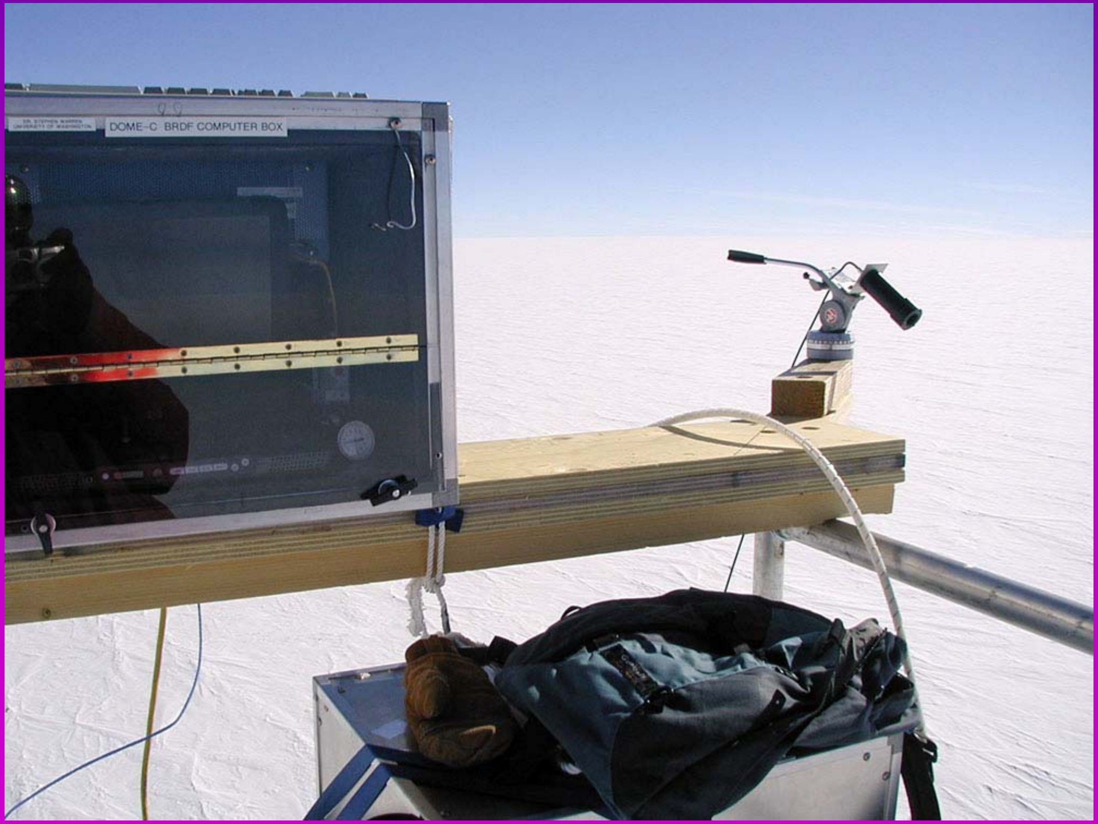


Motivation

- Surface reflectance data from Dome C are representative of a large, temporally-stable, and spatially-homogeneous area
- For these reasons, this region has been used as a satellite calibration target
- Remote sensing products for Antarctica, including satellite cloud detection, will benefit from a better model of the surface reflectance properties

Instrumentation

- Analytical Spectral Devices FieldSpec Pro JR 350 to 2500 nm with 3- to 30-nm resolution

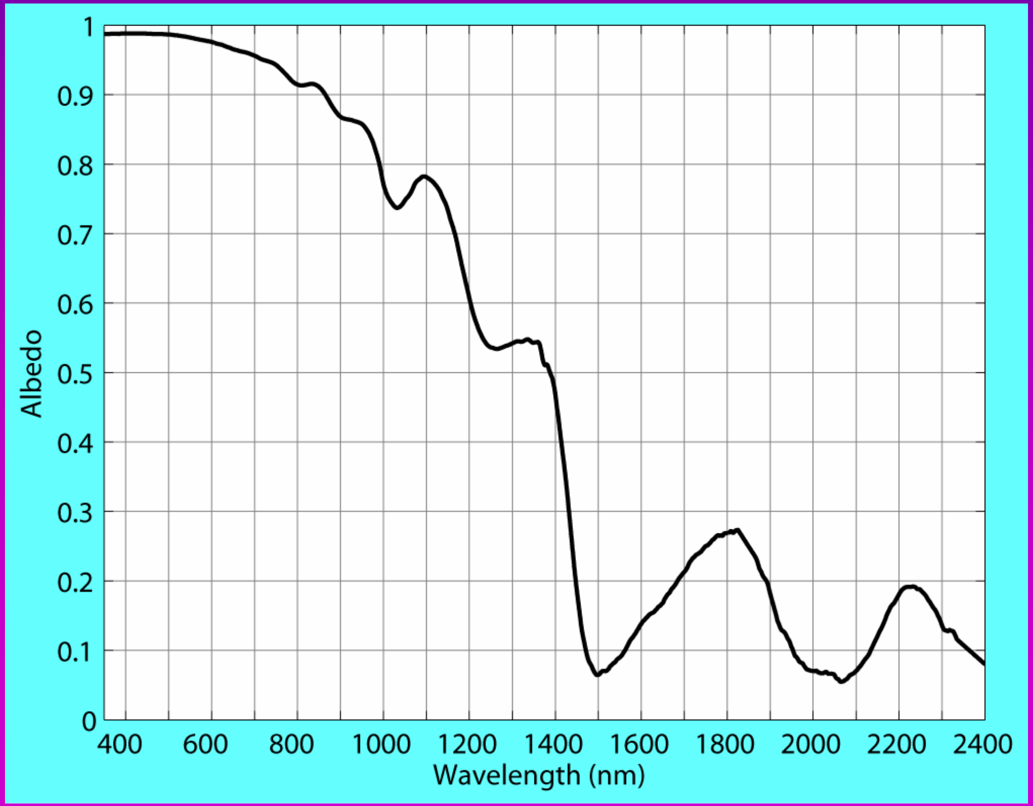


Measurement Technique

- All observations were made from 32 m above the surface to ensure a representative measurement footprint

Albedo of Snow

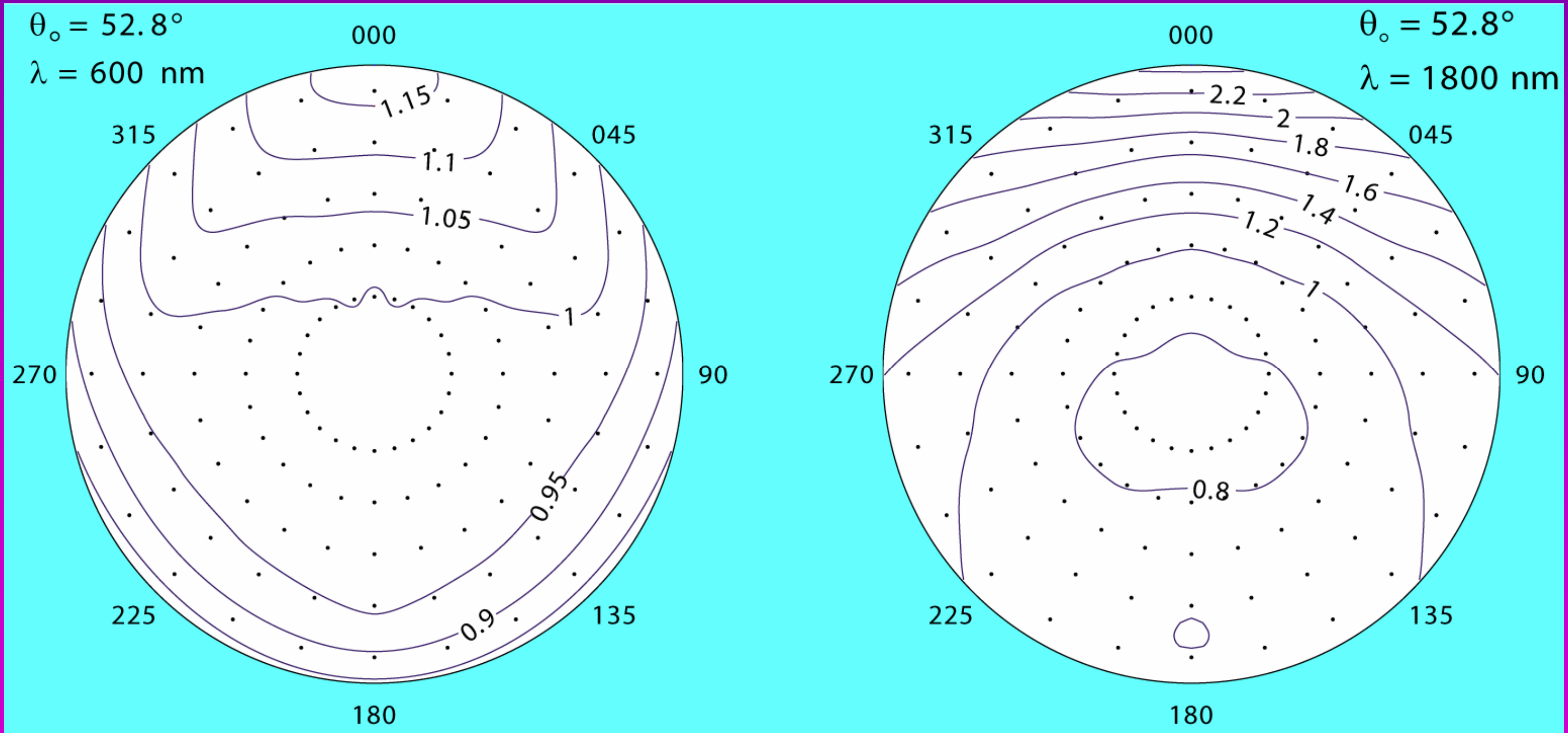
- High in the UV, visible, and NIR to about 1000 nm, low and more variable beyond that
- The BRDF of the snow is similar at all wavelengths with the same albedo



Data ~ High Sun

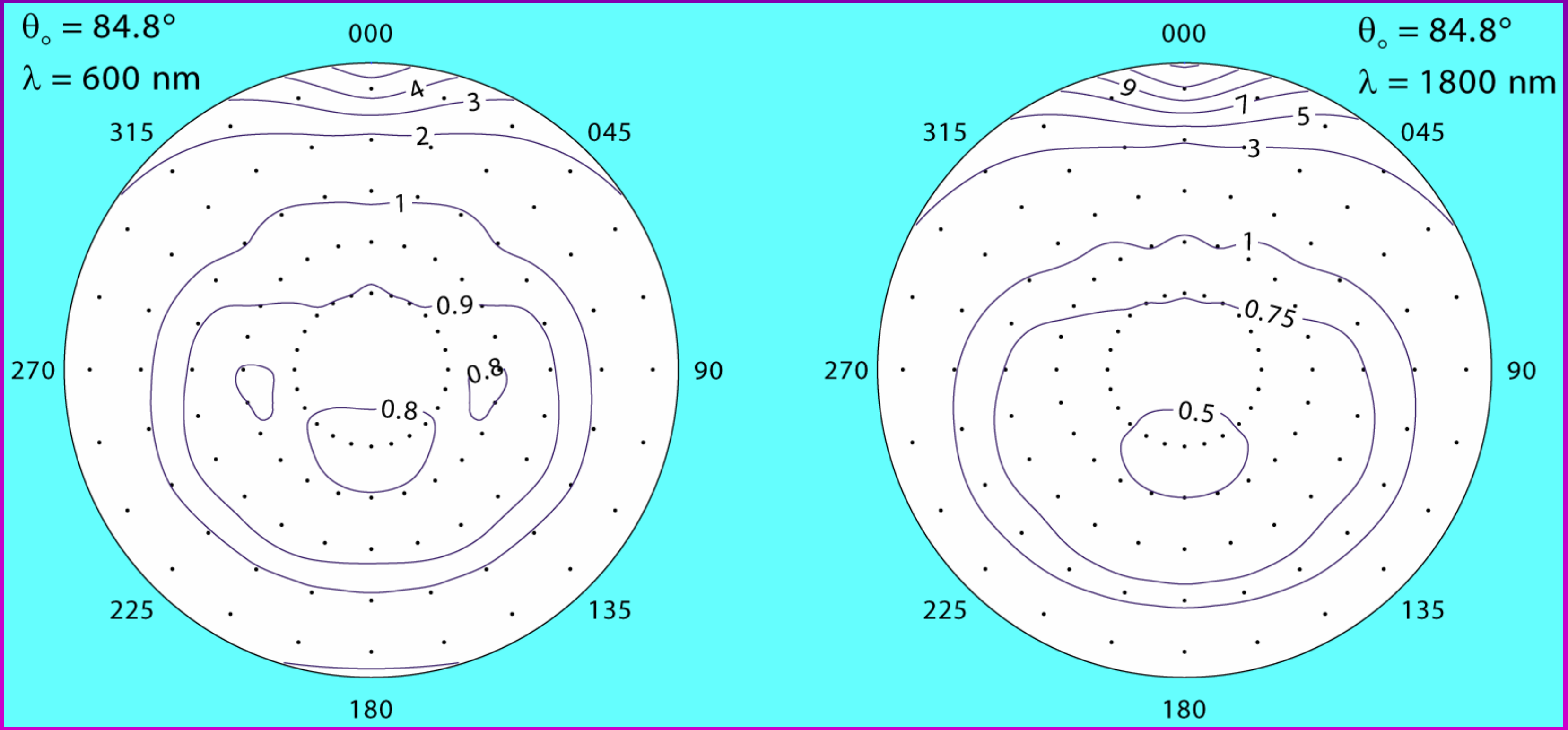
- Anisotropic reflectance factor (R)

$$R(\theta_\circ,\lambda,\theta,\phi)=\frac{\pi\, I(\theta_\circ,\lambda,\theta,\phi)}{\iint\limits_{2\pi} I(\theta_\circ,\lambda,\theta,\phi)\cos\theta\sin\theta\,\mathrm{d}\omega}=\frac{\pi}{\alpha}\,\mathrm{BRDF}$$



Data ~ Low Sun

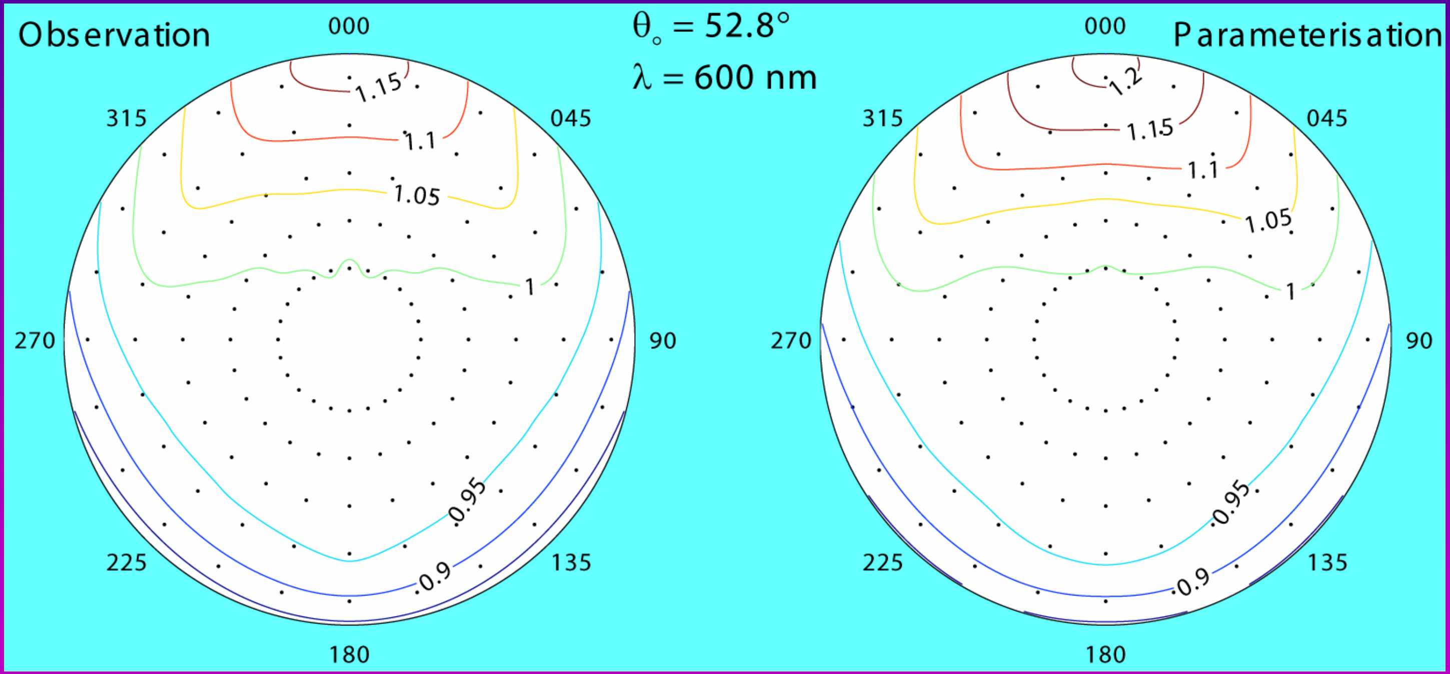
- More anisotropic with low albedo and large solar zenith angle



Parameterisation

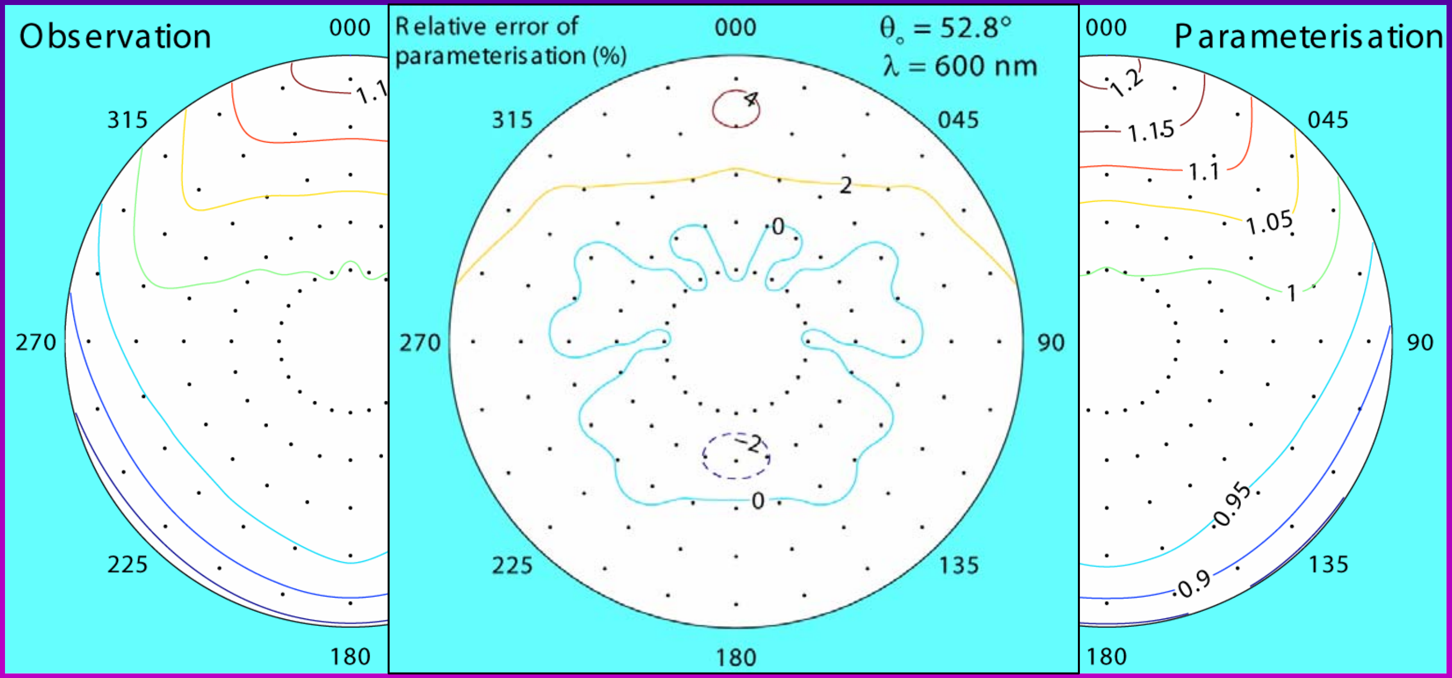
- Use our spectral observations at 96 solar zenith angles to develop simple parameterisations to calculate $R(\theta_o,\lambda,\theta,\phi)$
- The parameterisations use the empirical orthogonal functions (EOFs) of the data matrix as their basis functions
- The coefficients to linearly combine the EOFs were fit to simple functions of θ_o and either λ (UV, VIS, NIR) or α ($\lambda \geq 950$ nm)

Parameterisation Results



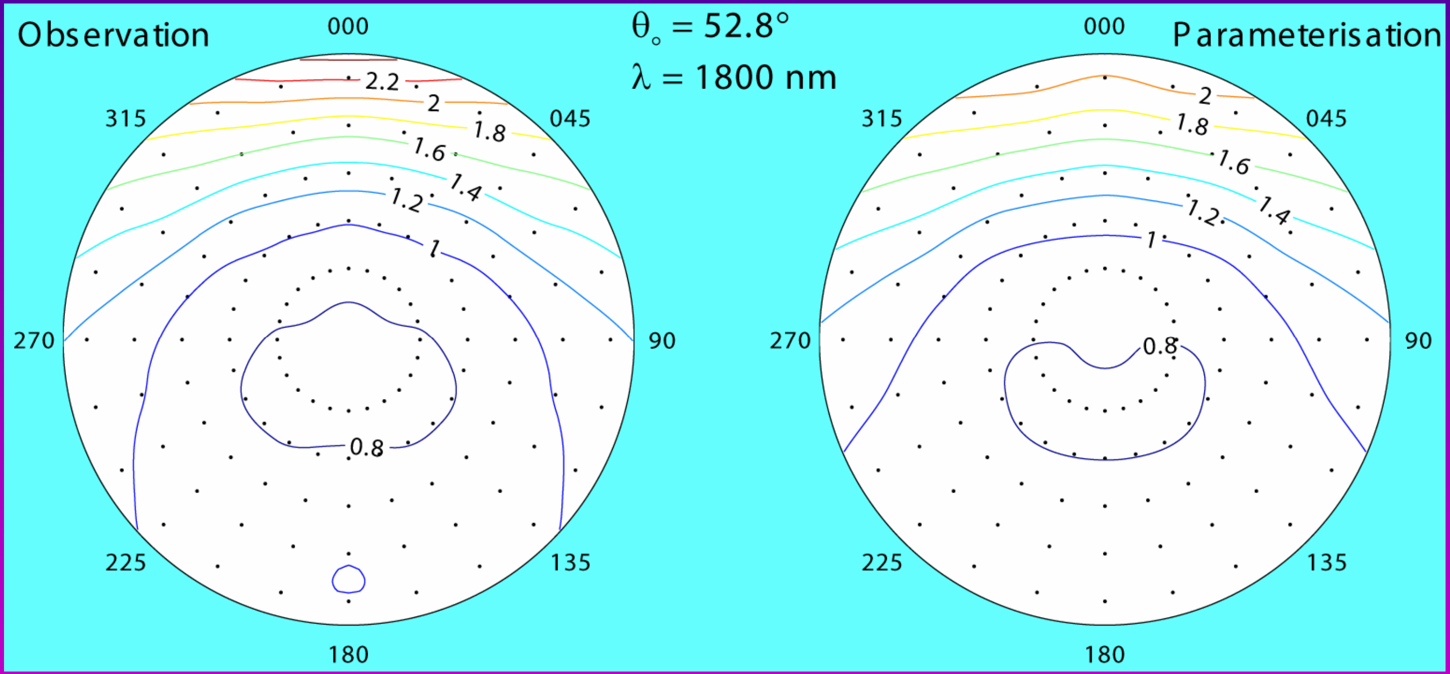
- The parameterisation matches the shape and magnitude of the data quite well

Parameterisation Results



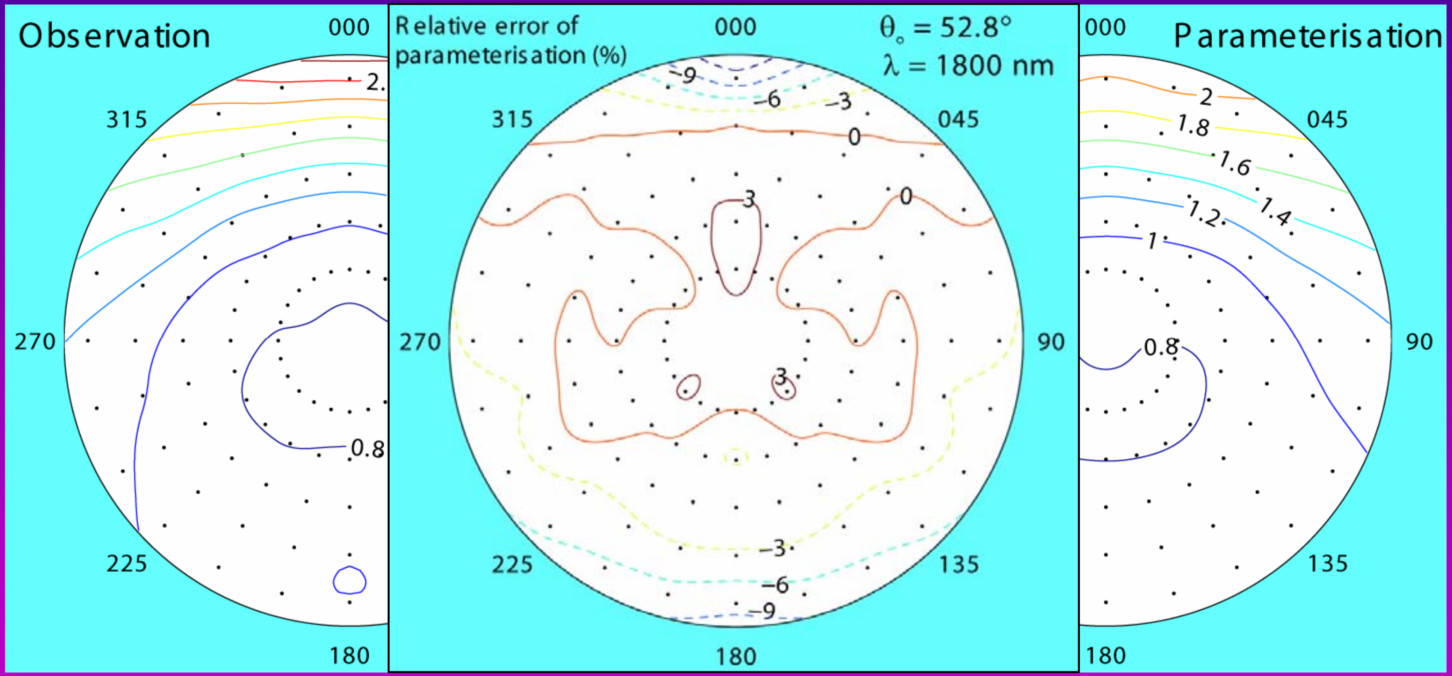
- Errors between the parameterisation and individual observations are not much larger than the expected uncertainties of the data

Parameterisation Results



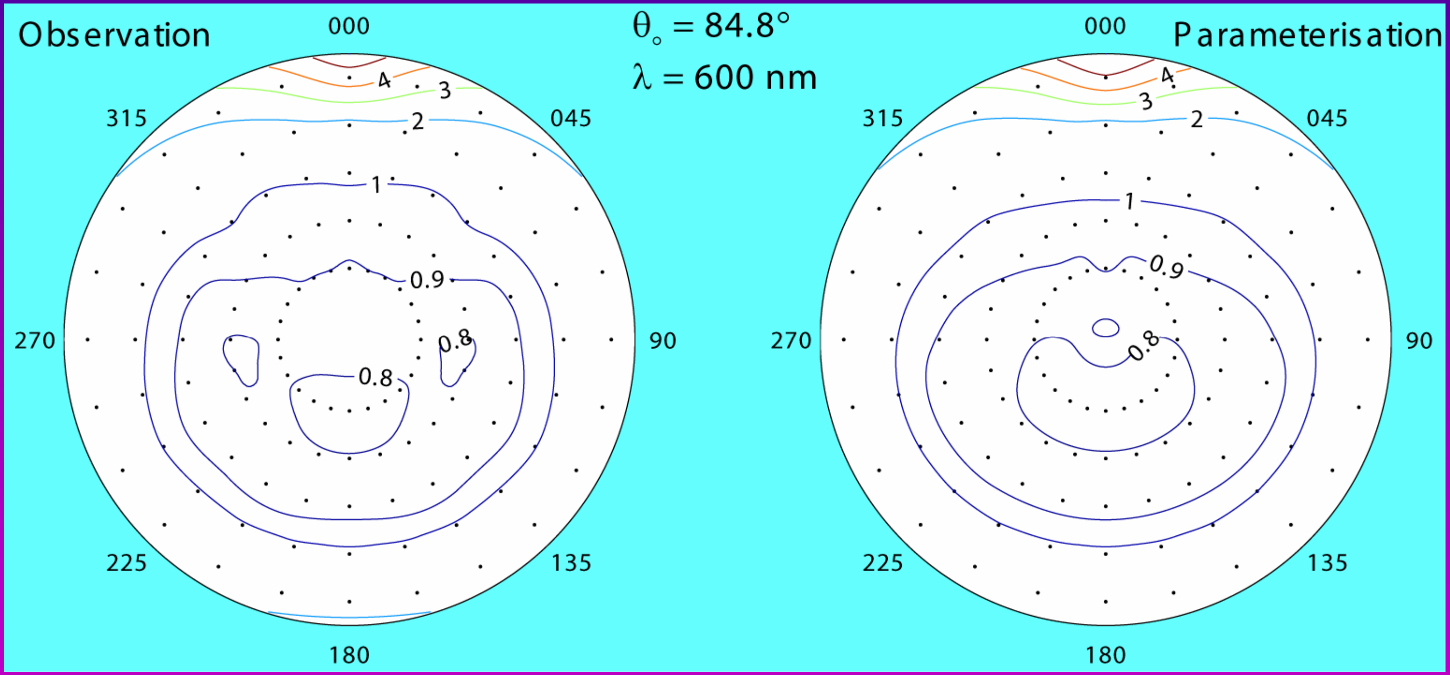
- The parameterisation reproduces the higher anisotropy at wavelengths with moderately low albedo fairly well

Parameterisation Results



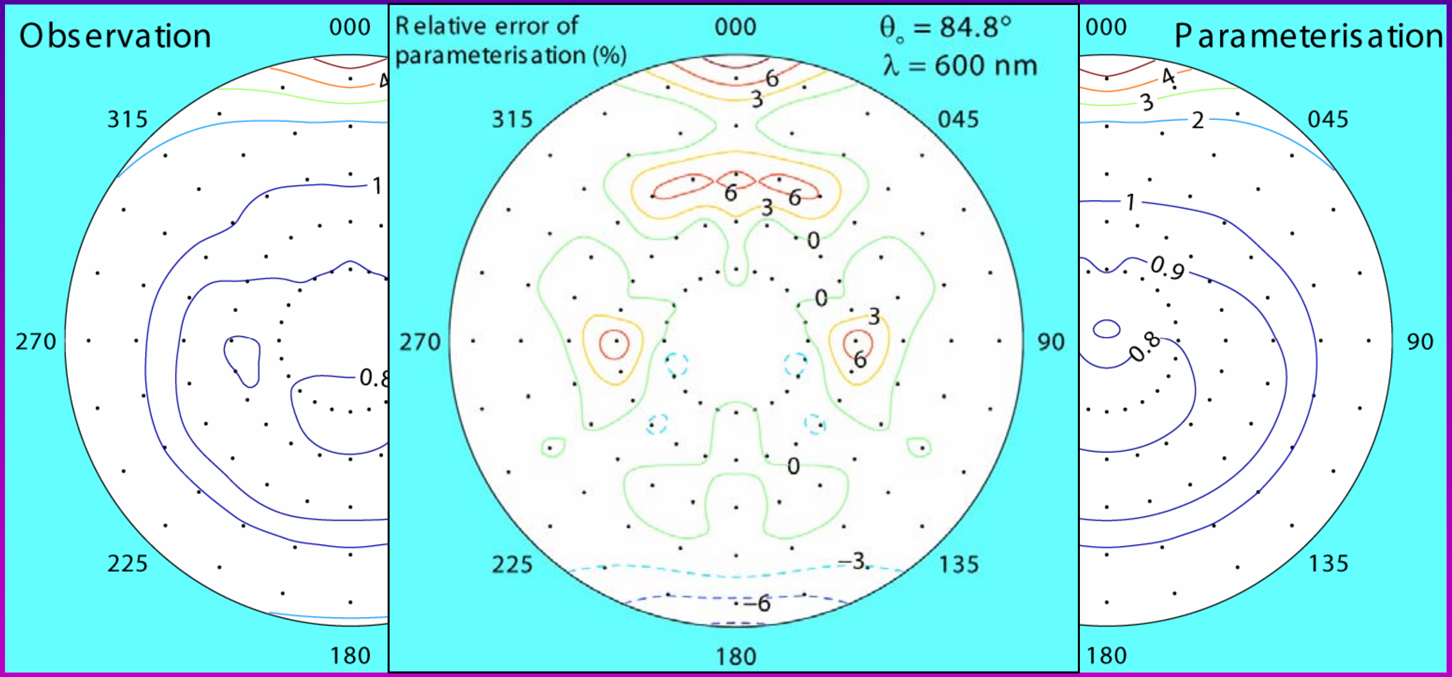
- The largest errors tend to be at large viewing zenith angles–those least likely to be used for remote sensing

Parameterisation Results



- At wavelengths less than 1400 nm the parameterisation works well to solar zeniths angles of 86° (the limit of our data)

Parameterisation Results



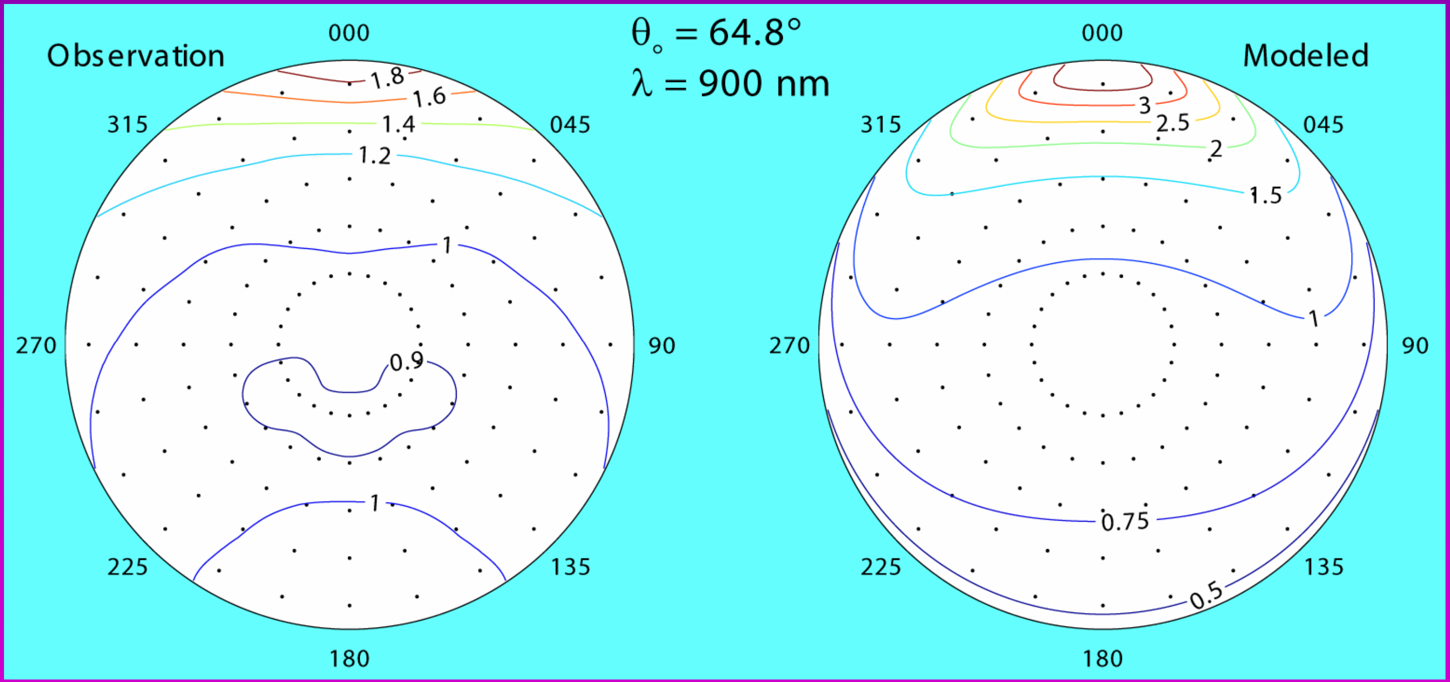
- The error, between the parameterisation and individual observations, and the uncertainty of the data are both larger at large θ_o and low α

Summary of Parameterisations

- We developed six parameterisations for different subsets of the data
- They cover all observed θ_o for wavelengths 350 to 1400 nm and $\theta_o \leq 75°$ for wavelengths 1450 to 2400 nm with $\alpha > 0.15$
- The RMS error for the parameterisations ranges from 2% to 8%

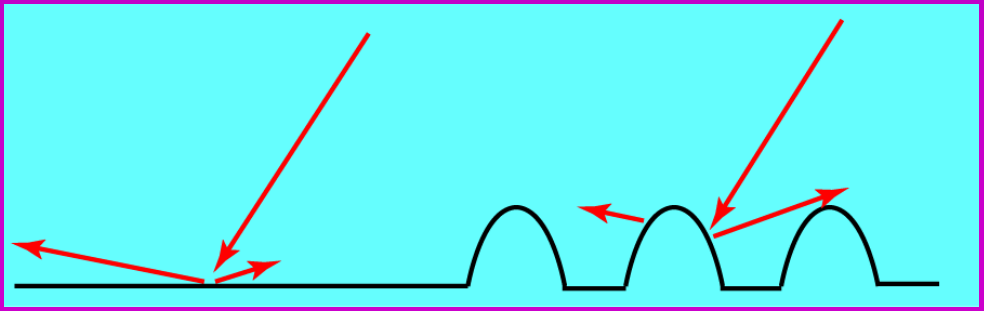
Effect of Surface Roughness

- The observed patterns of *R* differ dramatically from those predicted by radiative transfer models



Effect of Surface Roughness

- The amount of forward-escaping radiation is reduced because the observer facing the sun sees the shaded sides of roughness elements
- The backscatter is increased because the solar zenith angle is effectively reduced for faces of roughness elements that face the sun

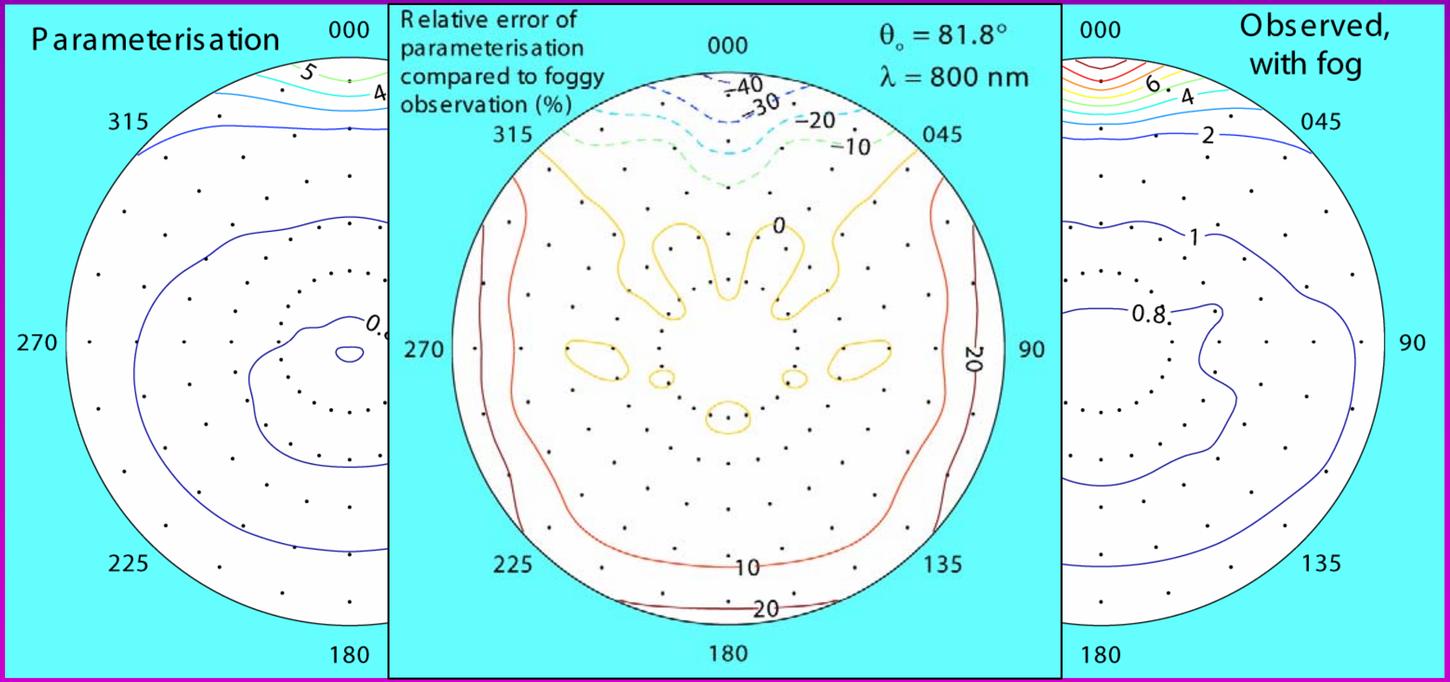


Effect of Cloud

- Some observations were made at times with shallow radiation fog to examine the effect of fog or cloud on the BRDF of snow

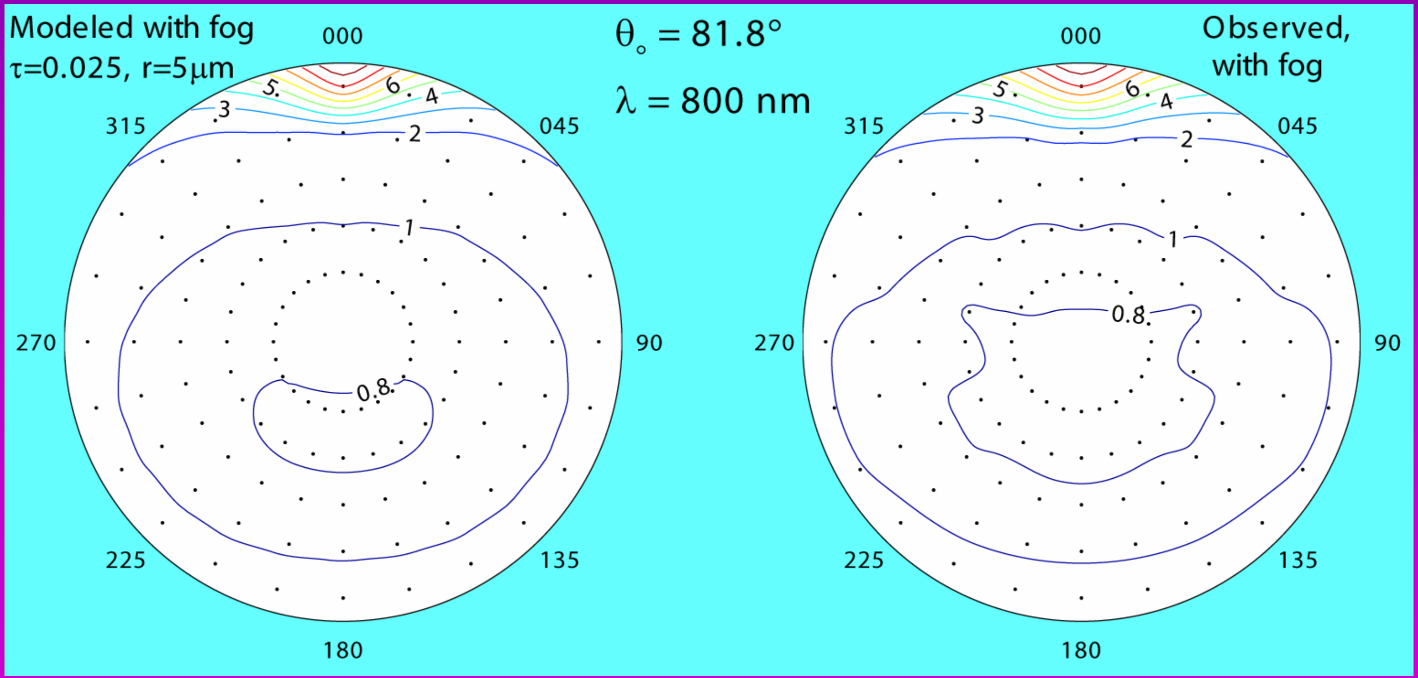
Effect of Cloud

- Cloud over the snow significantly enhances the forward scattering, while slightly reducing the scattering into other directions



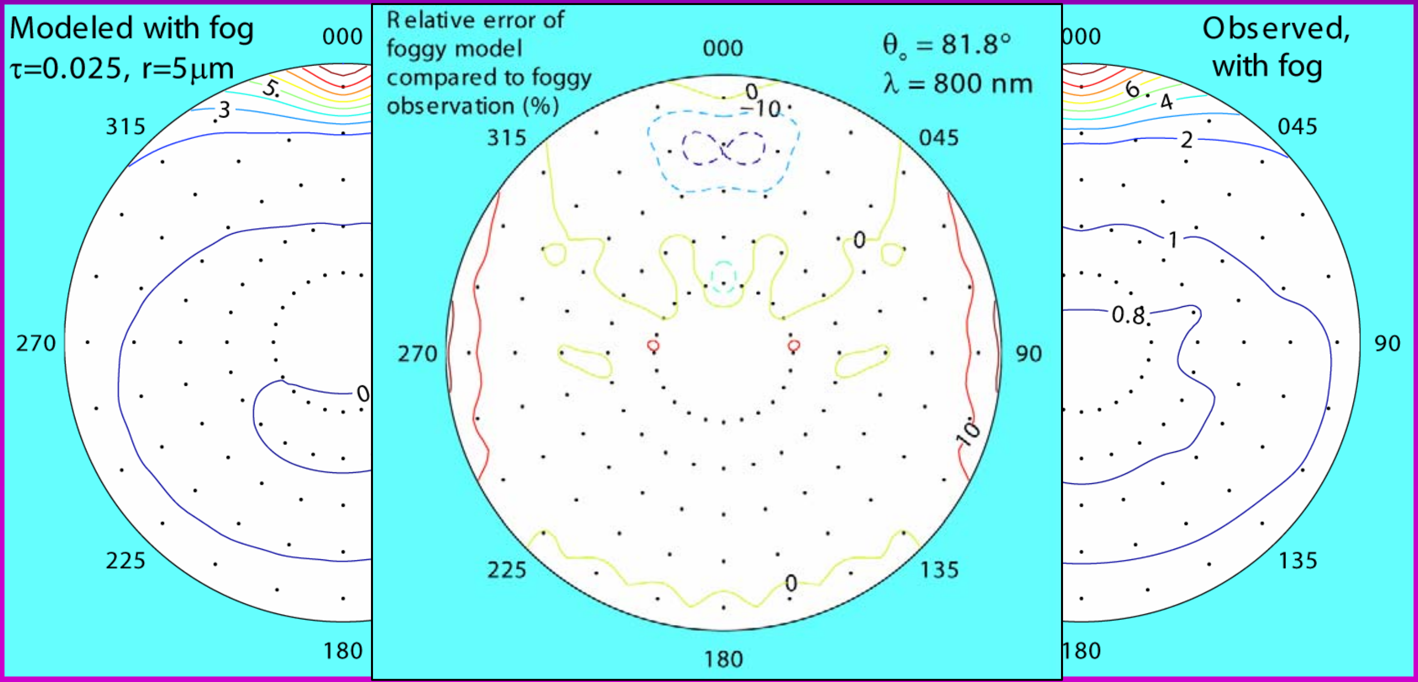
Modelling Cloud Over Snow

- Placing a thin cloud above the parameterised snow surface in DISORT produces output that is much more similar to the observation



Modelling Cloud Over Snow

- The top of the fog is much smoother than the snow surface, so DISORT can adequately model this situation if the snow BRDF is specified



Summary

- An extensive set of directional-reflectance data was collected on the high East Antarctic Plateau
- These data were used to develop a parameterisation for the anisotropic reflectance factor of the snow in this region that is valid over a broad spectral range and at most solar zenith angles encountered in Antarctica

Summary

- The natural surface roughness of the Antarctic snow surface makes the reflected radiation field less anisotropic than that predicted by RT models for a flat snow surface
- Placing a cloud over the snow masks some of this roughness and allows RT models to perform better, especially if the surface BRDF is specified with the parameterisation

Acknowledgements

- Michel Fily at the Laboratoire de Glaciologie et Géophysique de l'Environnement sponsored our work at Dome C
- Logistics were provided by l'Institut Polaire Français Paul Emile Victor, Il Programma Nazionale di Ricerche in Antartide, and the National Science Foundation

Paper has been submitted to JGR Atmospheres.

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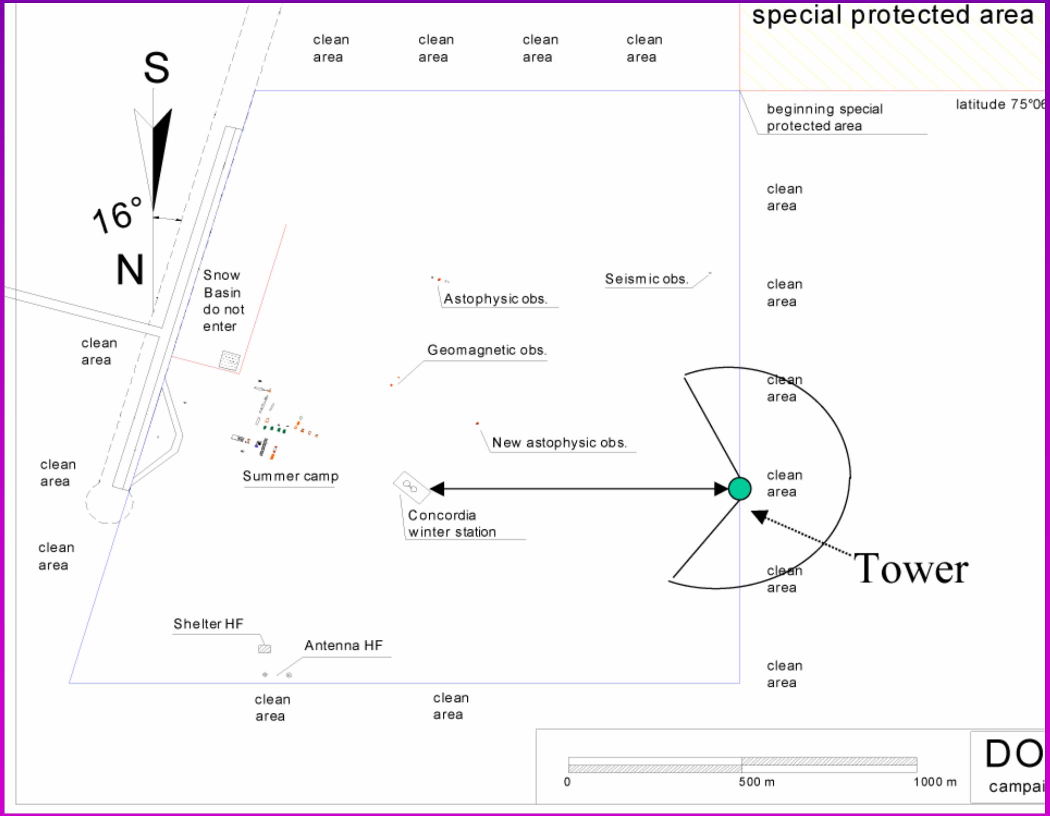
Measurement Technique

- Undisturbed snow over 255° of azimuth
- Two methods to complete patterns:

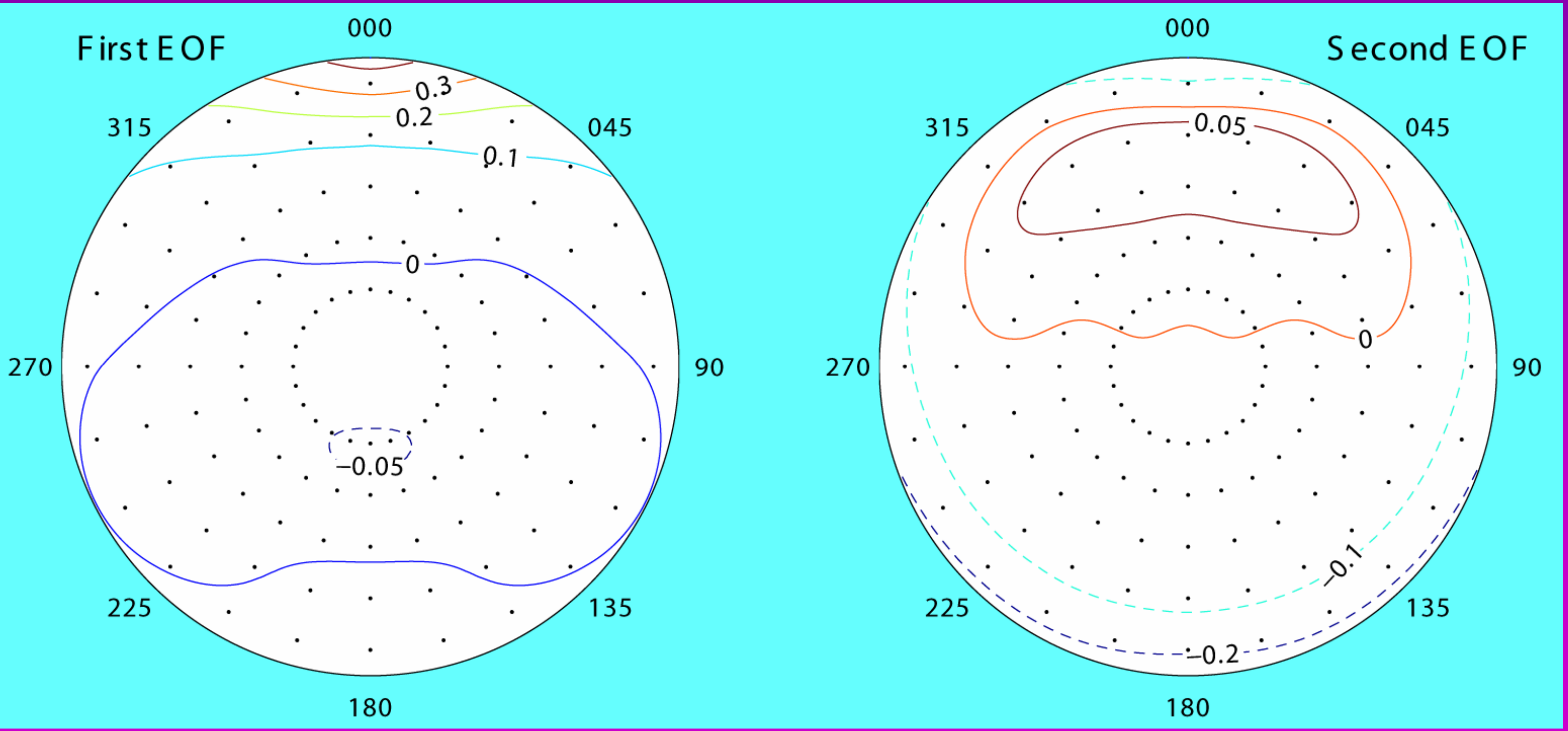
1. Reflect across principal plane

2. Combine two observations



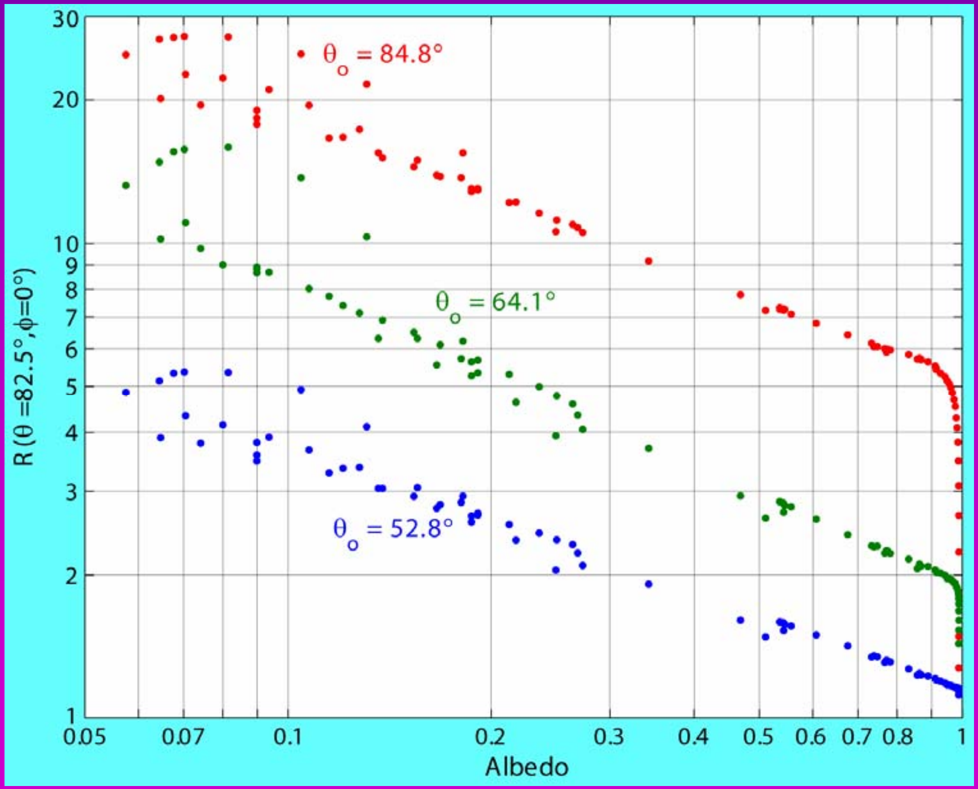
Empirical Orthogonal Functions

- Linear combinations of these two patterns can represent 98% of the variance in the dataset with $\lambda \leq 900$ nm, $\theta_o \leq 75°$



Fitting the Coefficients

- The coefficients to combine the EOFs to correctly represent the data were then parameterised as functions of solar zenith angle and either wavelength or albedo



RMS Error of Parameterisations

Data Included in Parameterisation				RMS Error	
λ (nm)	θ_o	α	θ	All θ	$\theta \leq 52.5°$
350–950	51.6°–75°	n/a	0°–82.5°	2.3%	1.9%
350–950	70°–86.6°	n/a	0°–82.5°	3.7%	3.0%
950–1400	51.6°–75°	0.47–0.86	0°–82.5°	3.5%	2.7%
950–1400	70°–86.6°	0.47–0.86	0°–82.5°	4.1%	3.7%
1450–2400	51.6°–75°	0.15–0.28	0°–52.5°	5.6%	5.6%
1450–2400	51.6°–75°	0.15–0.28	52.5°–82.5°	7.9%	n/a