CLARREO related activities in the UK - update

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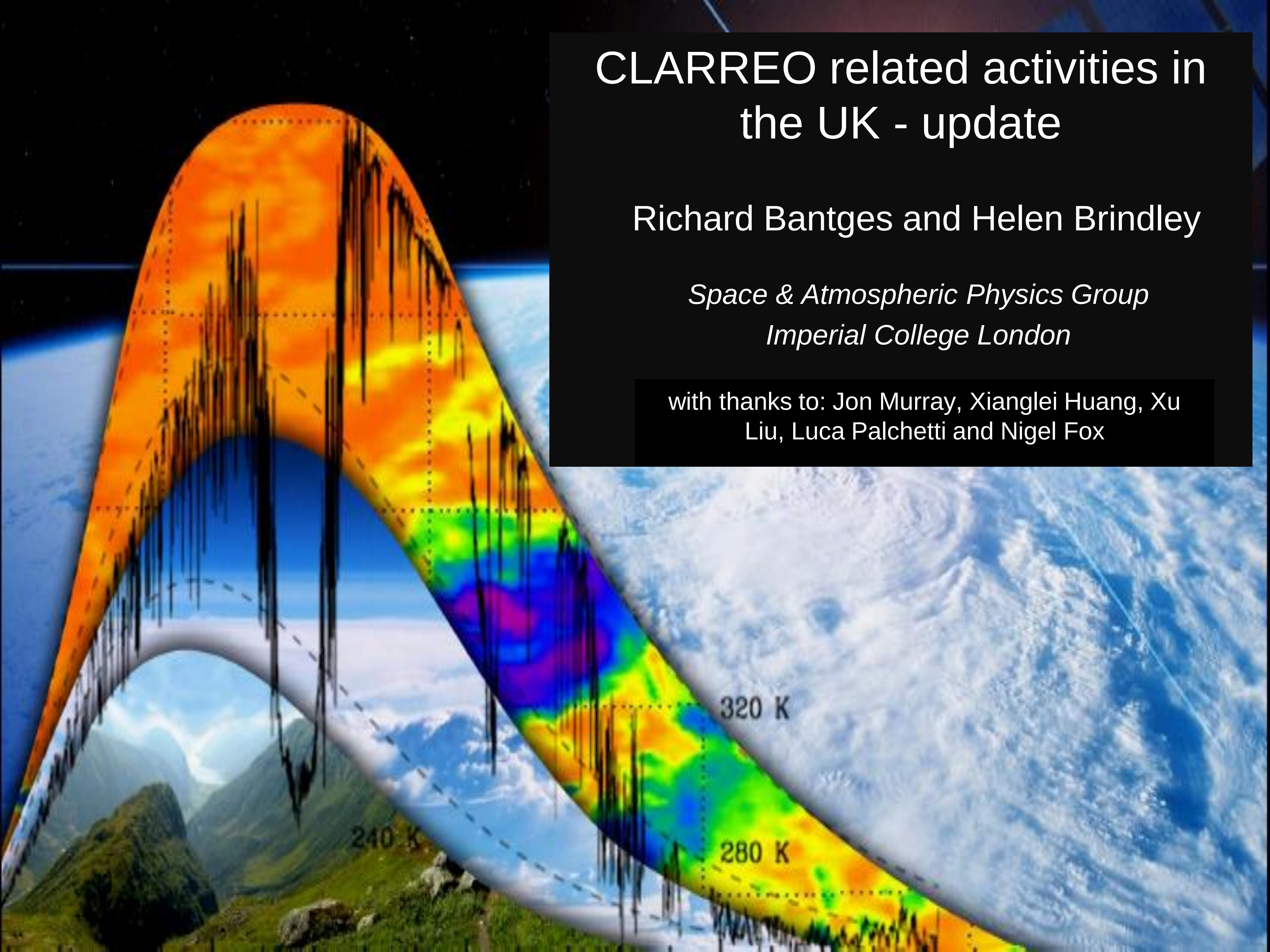
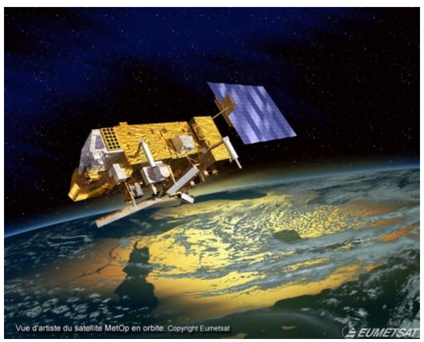
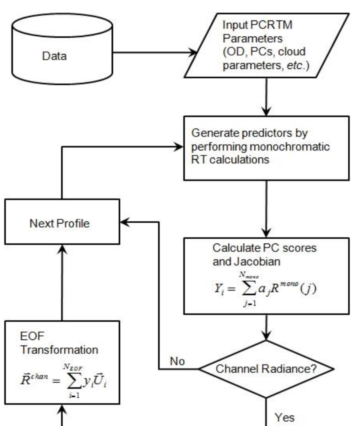
with thanks to: Jon Murray, Xianglei Huang, Xu Liu, Luca Palchetti and Nigel Fox

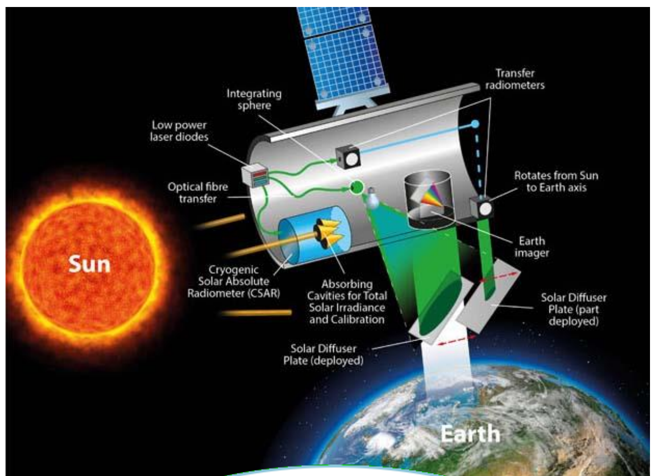


Outline

- Spectral signatures
- Preparation for ESA EE-9: TRUTHS and FORUM
- Estimating ice surface emissivity in the far infra-red and the ICE-IMPACT project

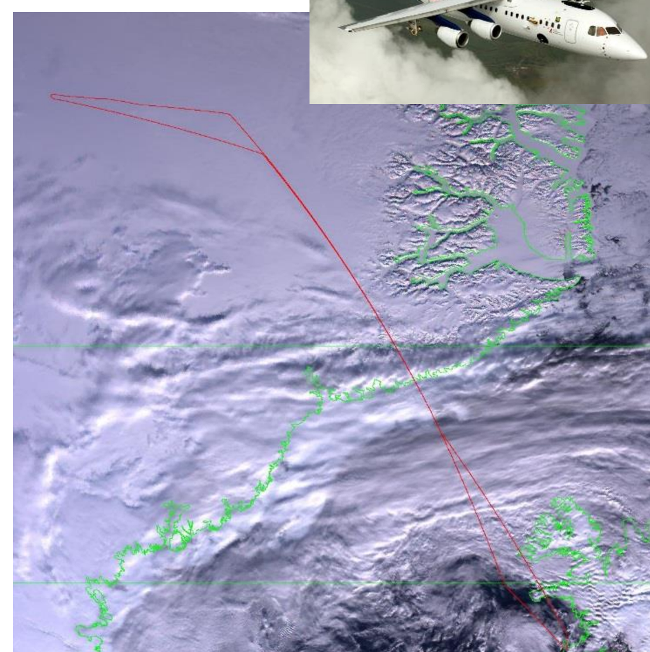






Far-infrared-Outgoing-Radiation Understanding and Monitoring

forum



Spectral signatures – 2 strands

1. Interannual variability on range of spatial scales from IASI

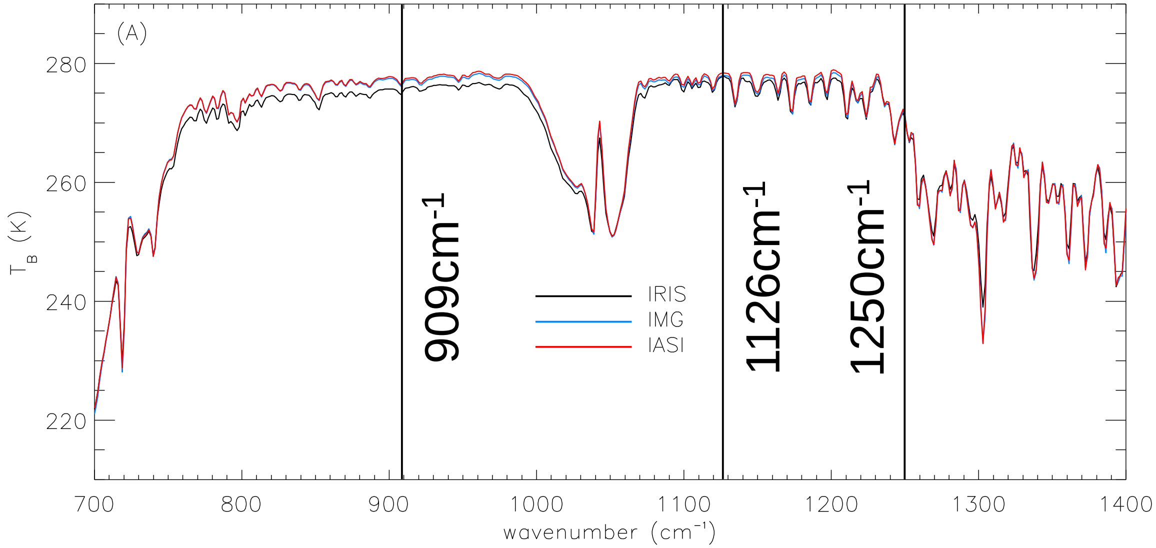
   Spectral signatures of Earth's climate variability over 5 year from IASI, Brindley et al., J. Clim, 2015.

2. Multi-decadal changes in the Earth's OLR
   - Differences in Earth's global mean all-sky OLR between 1970, 1997 and 2012
   - Differences evaluated to determine robustness of multi-decadal signals

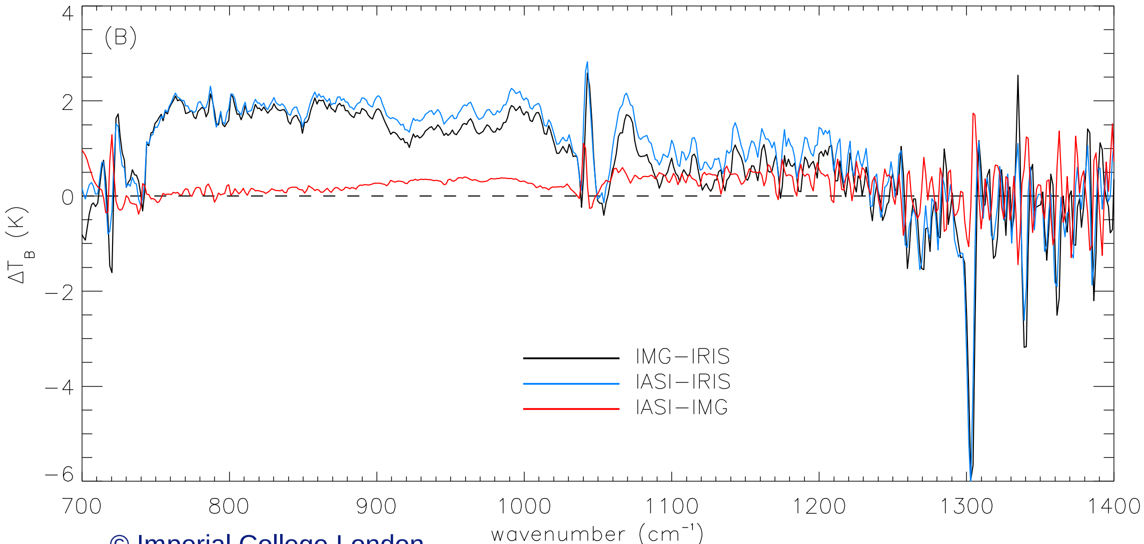
   On the detection of robust multi-decadal changes in the Earth's Outgoing Longwave Radiation spectrum, Bantges et al., J. Clim, (accepted).

Observations – spectral differences (all-sky)

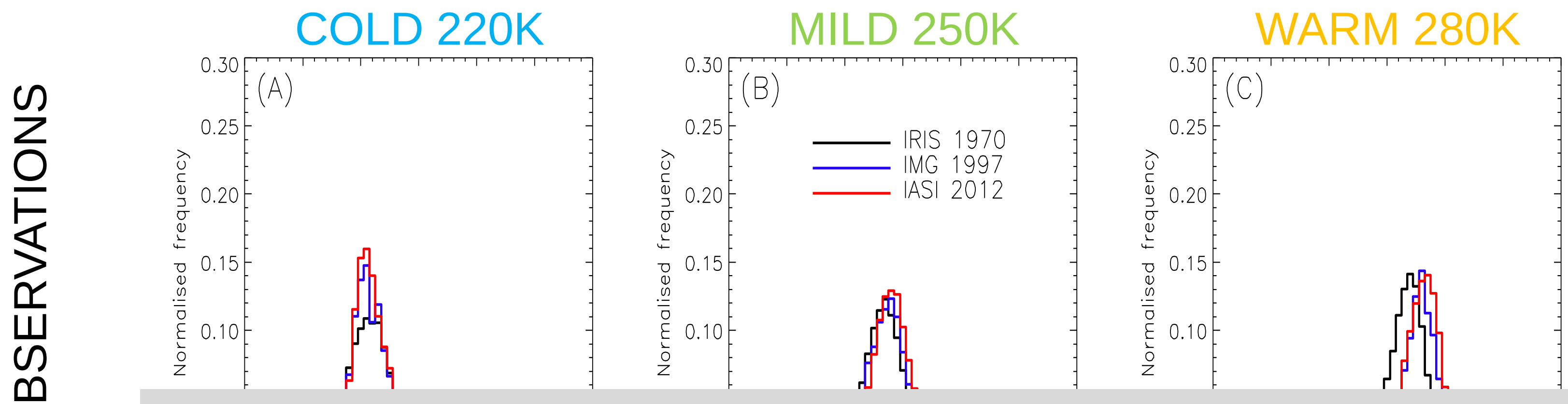
Global mean (AMJ)



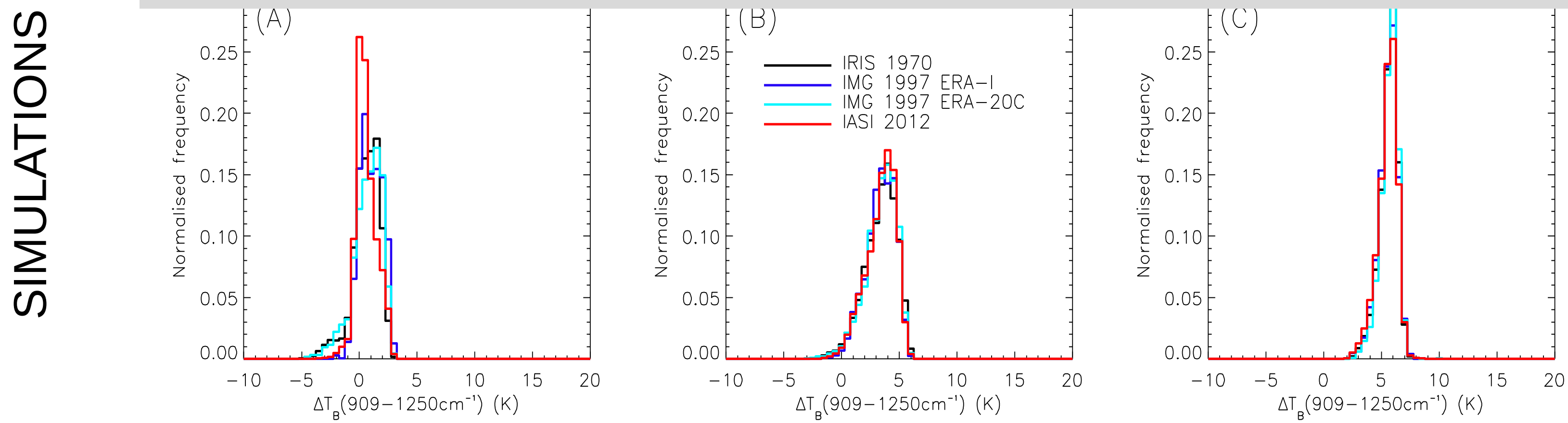
Global mean differences (AMJ)



PDF distributions of observations and simulations ΔT_B (909cm^{-1} – 1250cm^{-1})



Our recommendation: IRIS data are not used as a reference point for ***quantitative*** assessment of long-term changes in the Earth's spectrally resolved OLR.



ESA Earth Explorer-9 Call

- 120 M€ Cost at Completion (covering all industrial development costs for the space segment and mission specific ground segment)

- Missions must demonstrate TRL >=5; SRL >=4

- Must fit ESA's Earth Observation Science Strategy (ESA SP-1329/1) and Living Planet Programme: Scientific Achievements and Future Challenges (ESA SP-1329/2)

- Open to European and Canadian scientists but can involve other international partners

- Letters of Intent submitted by 1st February 2016 (31 proposing teams)

- Proposer workshop: 8th March 2016 (well attended 29/31, feedback)

- Deadline for full proposals: 24th June 2016 (Launch 2023/4 time-frame)

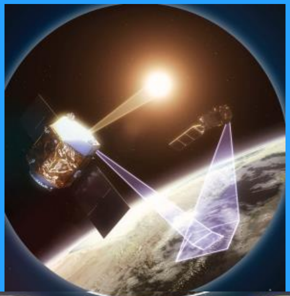
EE9 Proposals – TRUTHS & FORUM

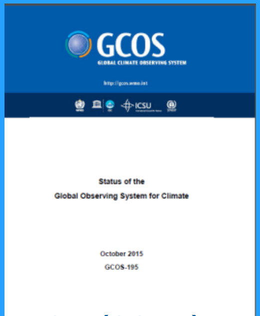
SURREY SATELLITE TECHNOLOGY LTD · OIP Sensor Systems · TELESPAZIO VEGA UNITED KINGDOM · NPL National Physical Laboratory · Centre for Carbon Measurement · Selex ES A Finmeccanica Company · Imperial College London · RAL Space · AIRBUS DEFENCE & SPACE · PML Plymouth Marine Laboratory · pmod wrc

TRUTHS (Traceable Radiometry Underpinning Terrestrial and Helio-Studies): Establishing a climate & calibration observing system in space

'A new paradigm for Earth observation'

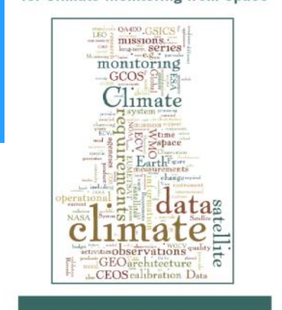
Dr Nigel Fox
(on behalf of TRUTHS team)





195 (2015)

"TRUTHS has important potential contributions to make both directly through well-calibrated measurements and indirectly through facilitating inter-calibration of the data from other platforms" GCOS 2015



CEOS/CGMS/WMO (2013)

"….a dedicated mission flying an SI traceable calibration reference standard would be an important element of a future architecture (see CLARREO and TRUTHS)."

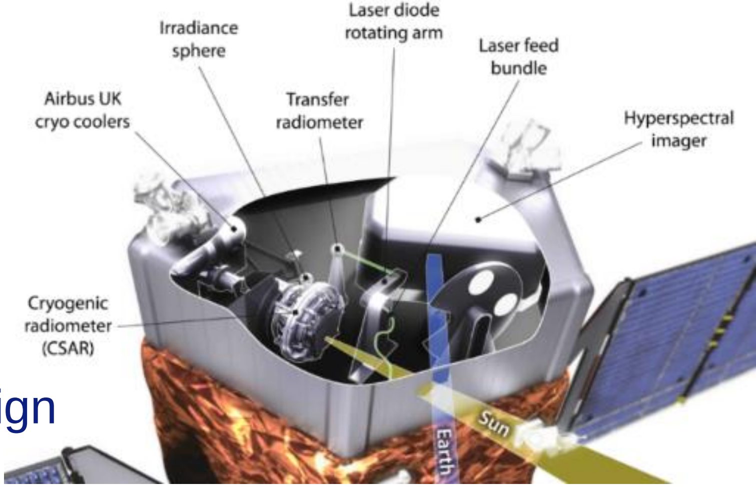
TRUTHS:

A small satellite mission, to establish 'foundational' data sets of Level 1 spectrally resolved (Ir)radiance (solar reflective) of unprecedented (~10X improvement) SI traceable accuracy to enable:

- A robust reference to improve Fundamental Climate Data Records
- An observational benchmark from which to monitor change (including mitigation) and test climate model forecasts in shortest possible time
- Upgrade in performance of Earth Observing system through reference in-orbit calibration leading to an integrated interoperable global -observing system- ESA contribution to CEOS/GEO/GCOS
- SI anchor to address debate on impact of solar irradiance on atmosphere /climate

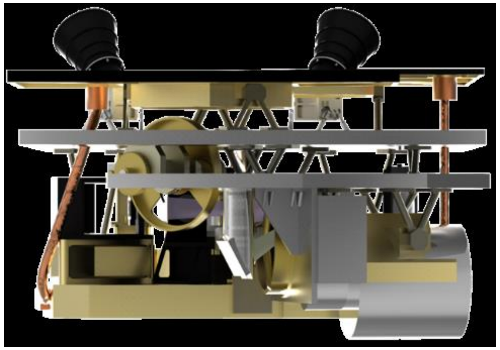
Level 1 products	Mission Characteristics				
	Spectral range nm	Bandwidth nm	Uncertainty %	SNR @ typical levels	GSD m
Earth spectral radiance/global & spectrally complete	320 – 2350	<5 for <1000m <10 for >1000m	0.3	~300 (Vis-NIR) >2000 (blue)	50 250
Solar Spectral Irradiance (SSI)	~300 – 2350	1 (<400) 5 (<1000) 10 (<2350)	0.3	>300	N/A
Total Solar Irradiance (TSI)	Total	200-30000	<0.02	<500	N/A

TRUTHS: Progress since EE8

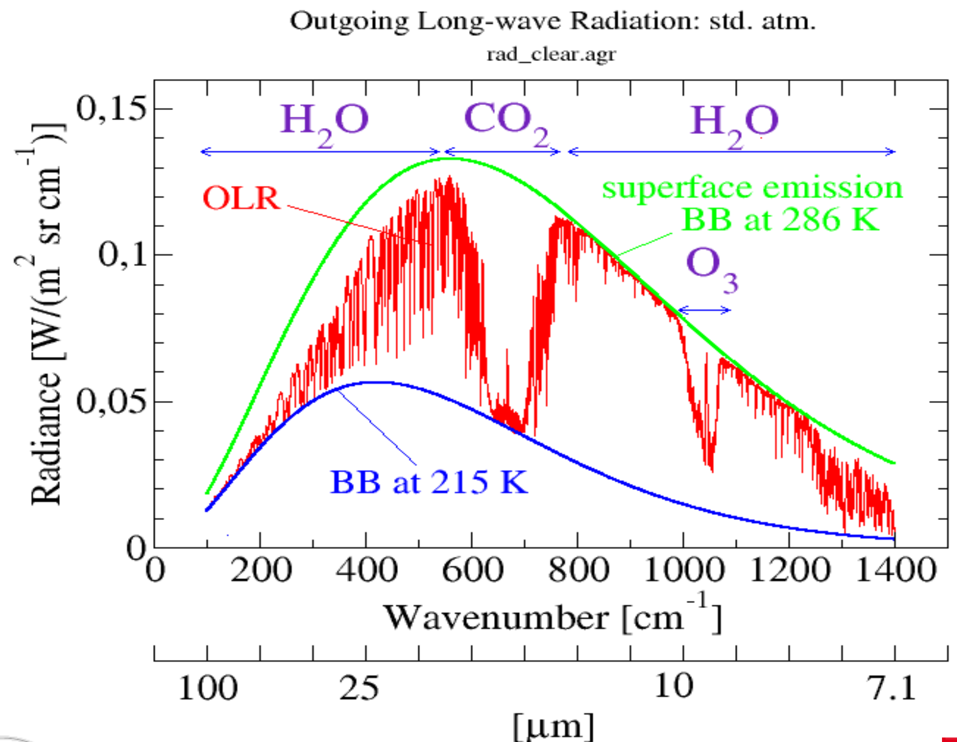


- **Mission undergone significant national funded studies/prototyping to de-risk**
  - Optimisation & simplification of instrument design (e.g. from 5 to 2 instruments)
  - First space designed CSAR built & tested (2010): Anticipated performance demonstrated (now @ PMO Davos)
  - Upgraded design of CSAR (smaller, 50%<mass) (2016)
  - Fully coupled to Airbus HPSC space cooler (upgraded S3)
  - Cal system bread-boarded in lab, full end-to-end vac test by end of 2016 (TRL 5)
  - Imager design/analysis confirms space readiness

- **Platform integration (Airbus & SSTL evaluated)**
  - Agile small platform – (payload ~150 kg, av. orb. power 300 W)
  - On-board Data handling & downlink evaluated
  - L1 Ground segment utilise relatively mature systems



Far-infrared-Outgoing-Radiation Understanding and Monitoring



Far-infrared-Outgoing-Radiation Understanding and Monitoring
forum

INO-CNR
NATIONAL INSTITUTE OF OPTICS

Imperial College London

University of Reading

Met Office

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

THE UNIVERSITY of EDINBURGH

Consiglio Nazionale delle Ricerche
Istituto di Biometeorologia

IFAC

CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

ISAC

UPMC SORBONNE UNIVERSITÉS

GOBIERNO DE ESPAÑA MINISTERIO DE DEFENSA
INTA

FINMECCANICA

ETH zürich

IRF

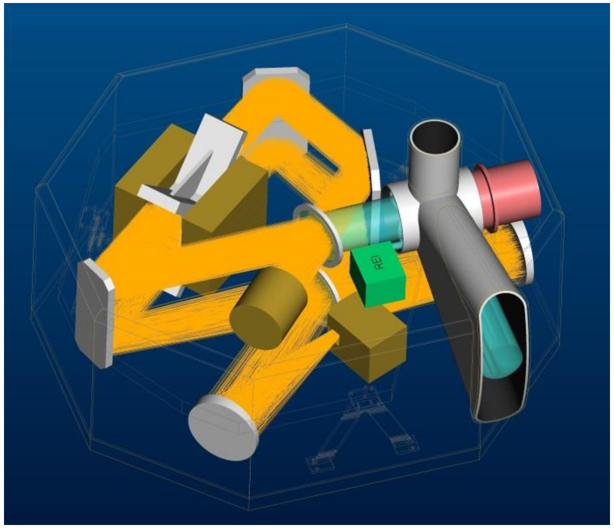
Science and mission objectives

"Provide an improved understanding of the climate system with the development of powerful monitoring techniques for informing climate policy decisions."

- **Provide the first global observations of the spectrally resolved Earth's OLR in the FIR (100-1600cm^{-1})**
  - Key component of the ERB: Up to 30% (clear sky) to 50% (cloudy) of the OLR emitted to space in FIR (global mean)
- **Improve the quality of water vapour retrievals in UTLS**
  - Key to understanding water vapour feedback in climate
  - Enhance NWP / forecasting
  - Inform tropospheric / stratospheric exchange of water vapour (TTL)
- **Provide unique information of cirrus cloud properties**
  - Ice cloud microphysics & bulk properties
  - Consistency with other spectral regions (mid-IR and visible)
- **Enable retrieval of ice / snow surface emissivity in FIR**
  - Key for understanding climate change in polar regions: recent work suggests important ice-emissivity feedback mechanism

Mission characteristics and implementation

- Single FTS instrument – based on heritage REFIR-PAD (TRL 5)
- Nadir viewing, ground pixel 10km, 250km along track sampling
- 3 year mission lifetime – resolve seasonal & inter-annual variability
- Low earth orbit – polar / near-polar sun-synchronous, designed to maximise coincidences with complementary observations from existing/future missions.
- Investigating option to fly in convoy with IASI-NG (METOP-SG)



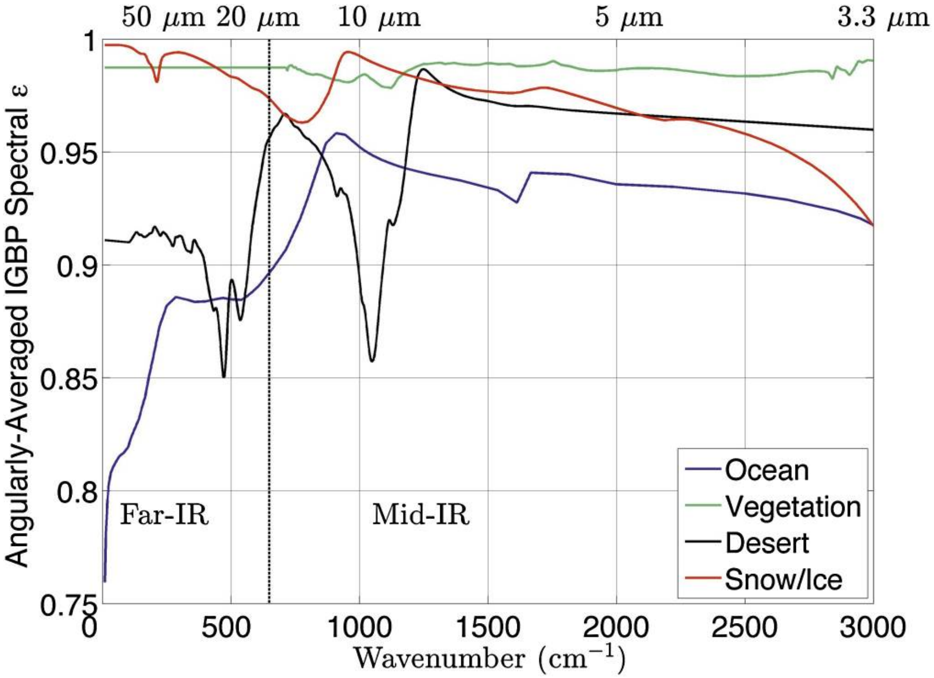
<u>FTS Specifications</u> (provisional)

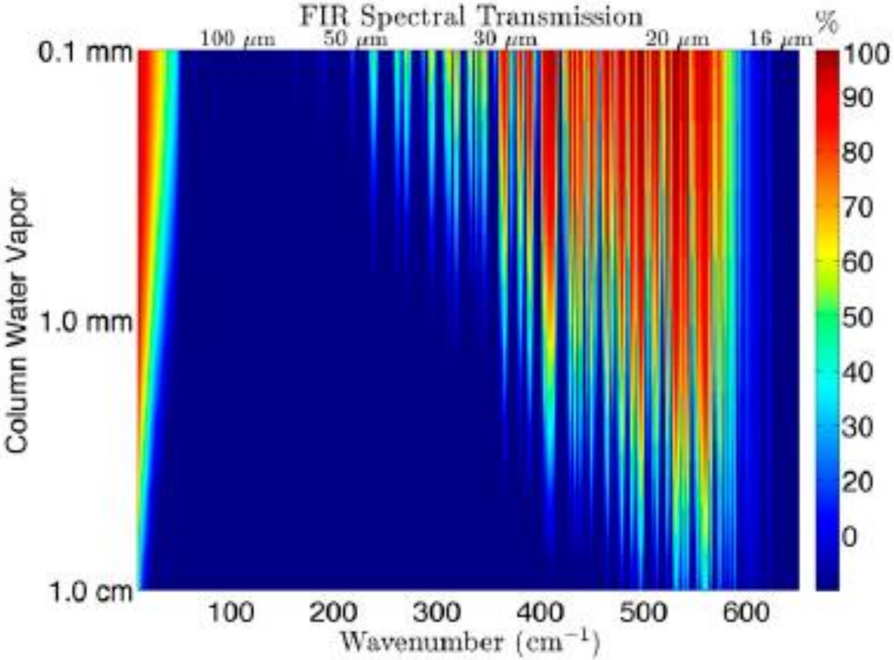
- 14 uncooled pyroelectrics (D* ≈10^9 cm√Hz/W)
- Sampling rate = 1.25 kHz
- Acquisition time = 32 s
- Weight = 70 kg
- Power = 40 W
- T_{BB} abs. cal. = 100 mK
- Spectral range: 100-1600cm^{-1} with 0.5 cm^{-1} average resolution (±2.5cm OPD)
- Max^m resolving power R_{max}=2500
- Radiometric accuracy: <0.1K
- NESR 0.2 $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$

Estimating FIR surface emissivity over Greenland from the Tropospheric Airborne Fourier Transform Spectrometer (TAFTS)

Estimating FIR surface emissivity over Greenland from TAFTS

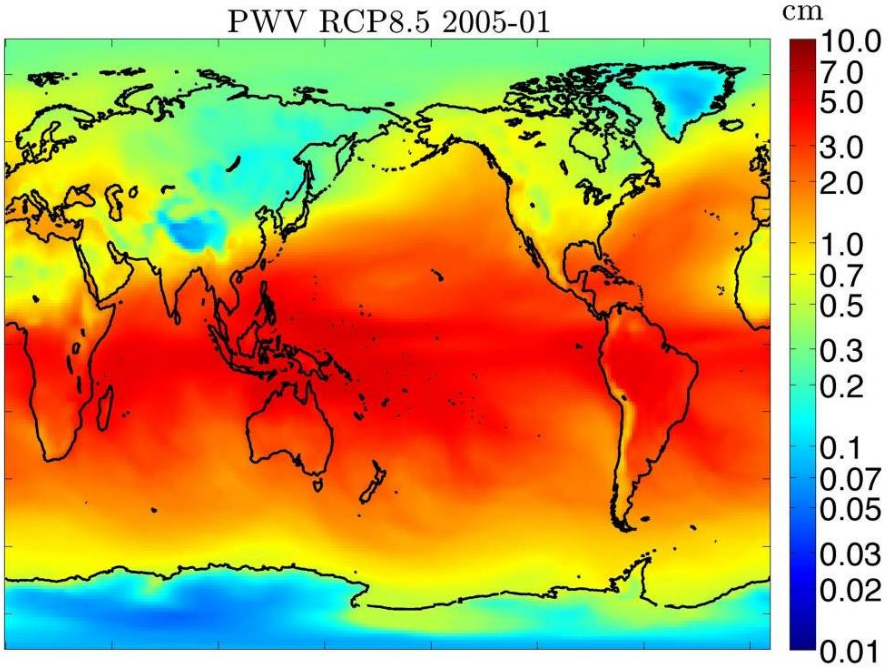
- Motivated by Feldman *et al*., PNAS, 2014
- Identified an 'ice-emissivity' feedback related to differences between FIR sea-ice and ocean emissivity

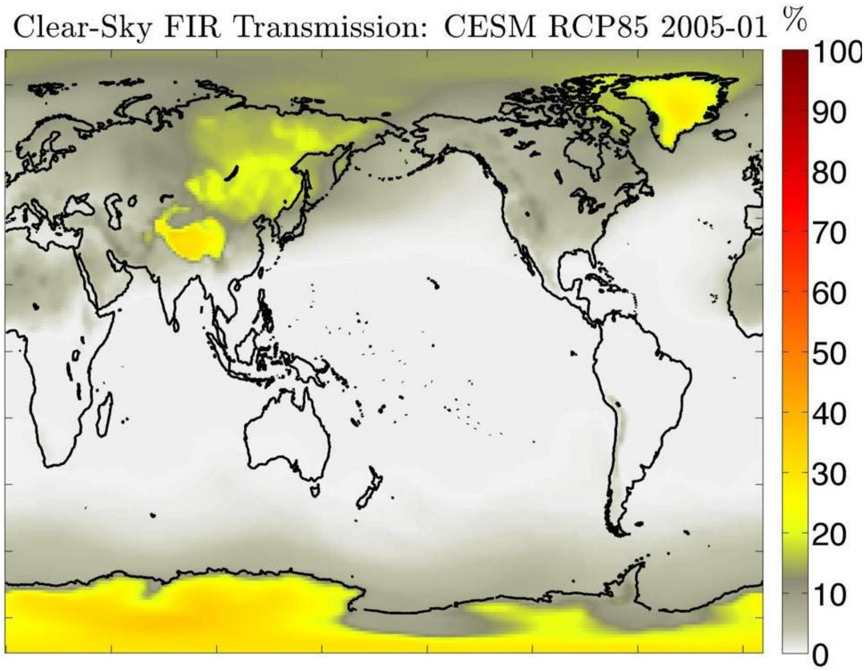




Estimating FIR surface emissivity over Greenland from TAFTS

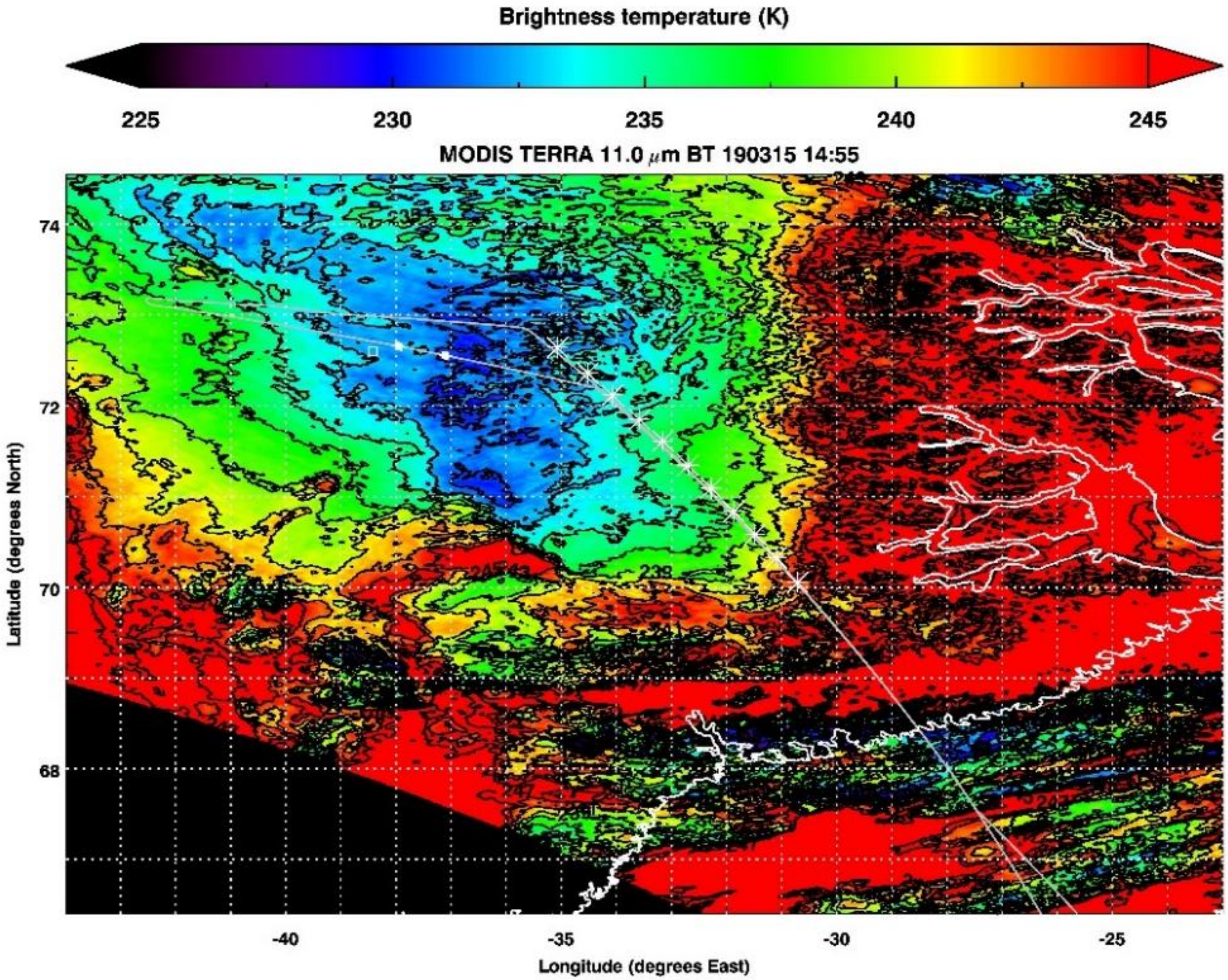
- Motivated by Feldman *et al*., PNAS, 2014
- Identified an ‘ice-emissivity’ feedback related to differences between FIR sea-ice and ocean emissivity
- More rapid Arctic sea-ice loss and enhanced surface warming under RCP8.5 change scenario when FIR surface emissivities set to realistic values





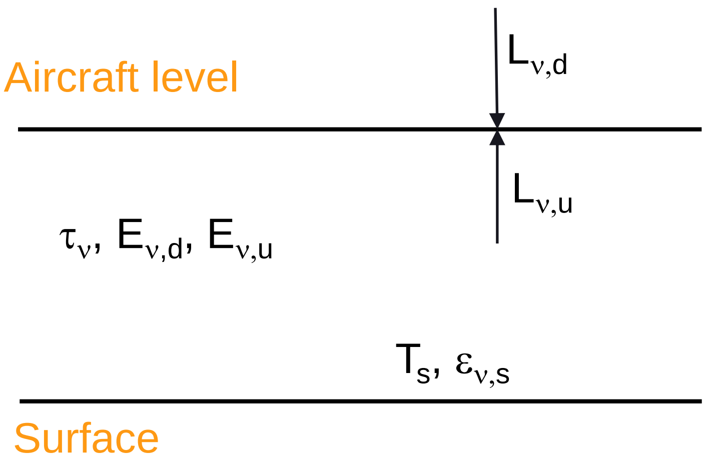
TAFTS Flight Track

- 2 Flights of Opportunity over Greenland during CIRRCREX campaign (March 2015)
- Focus on B898, 19/03/15



Theoretical Methodology

1: Specular reflectance



$$L_{v,u} = \varepsilon_{v,s} B_v(T_s)\tau_v + E_{v,u} + (1 - \varepsilon_{v,s})(L_{v,d}\tau_v^2 + E_{v,d}\tau_v)$$

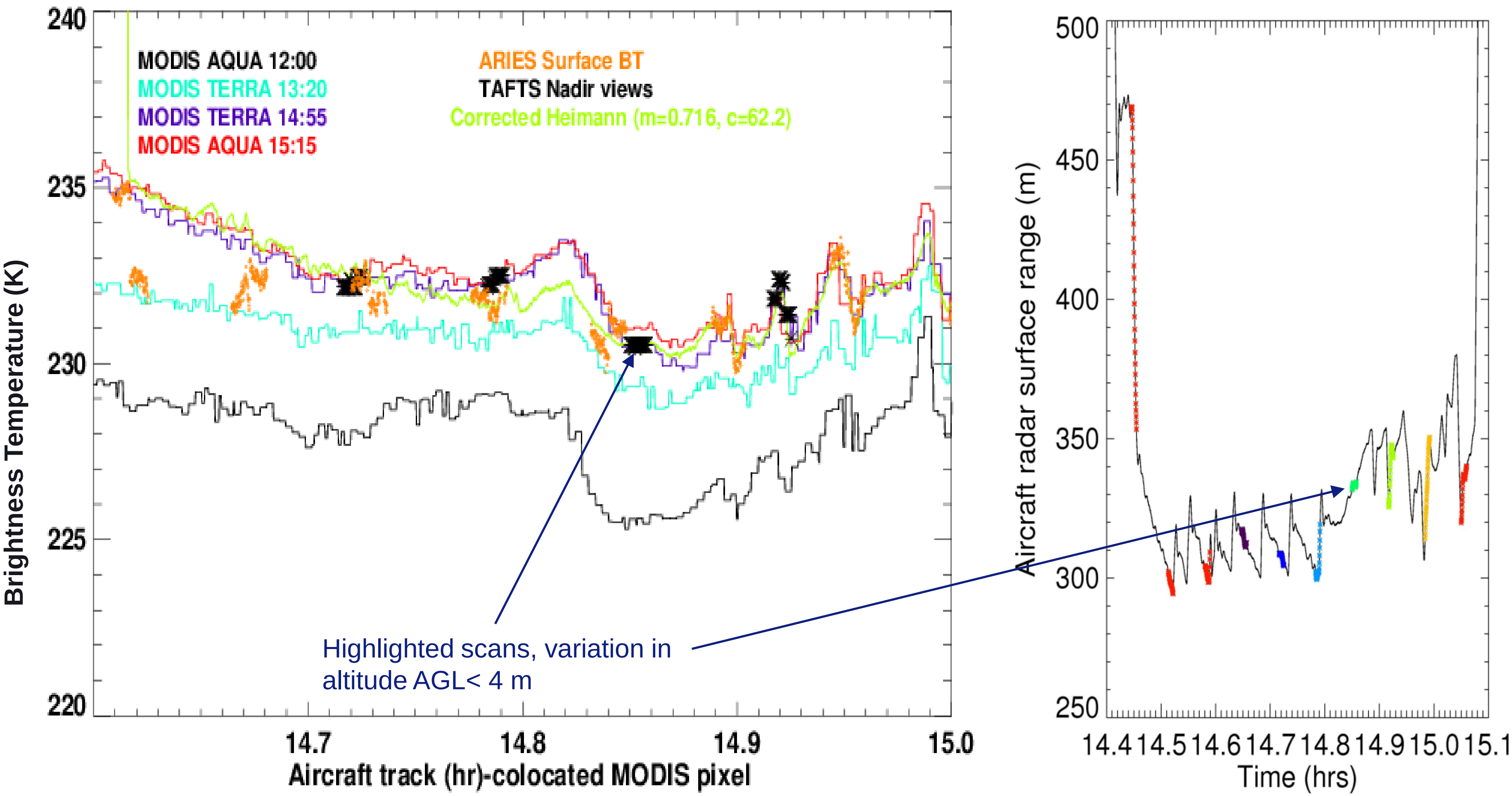
$$\varepsilon_s = \frac{L_{v,u} - \tau_v^2 L_{v,d} - E_{v,d}\tau_v - E_{v,u}}{\tau_v B_v(T_s) - \tau_v^2 L_{v,d} - \tau_v E_{v,d}}$$

2: Lambertian reflectance (approx. following Newman, 2013)

$$\varepsilon_s = \frac{L_{v,u} - \tau_{v,55}\tau_v L_{v,eff} - E_{v,55}\tau_v - E_{v,u}}{\tau_v B_v(T_s) - \tau_{v,55}\tau_v L_{v,eff} - \tau_v E_{v,55}}$$

In both cases need characterisation of surface temperature and layer below aircraft + forward modelling
For 2. also need to simulate downwelling radiance at aircraft

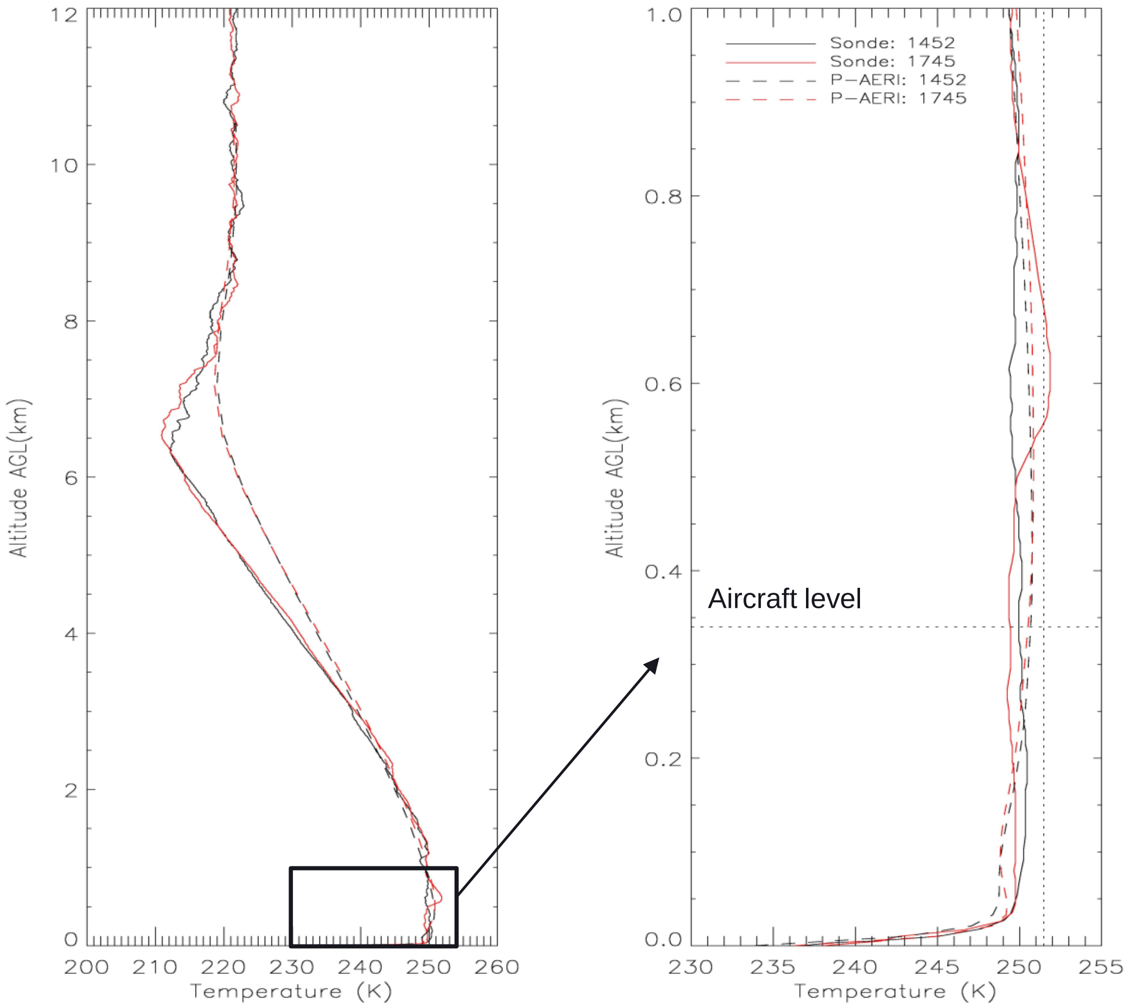
Scene Characterisation: Surface Temperature



Best estimate T_s = 230.5 ± 0.1 K (from UKMO)

Scene Characterisation: Atmospheric Temperature

Biggest issue is below aircraft layer characterisation: no contemporaneous profile information, only measurements at aircraft level



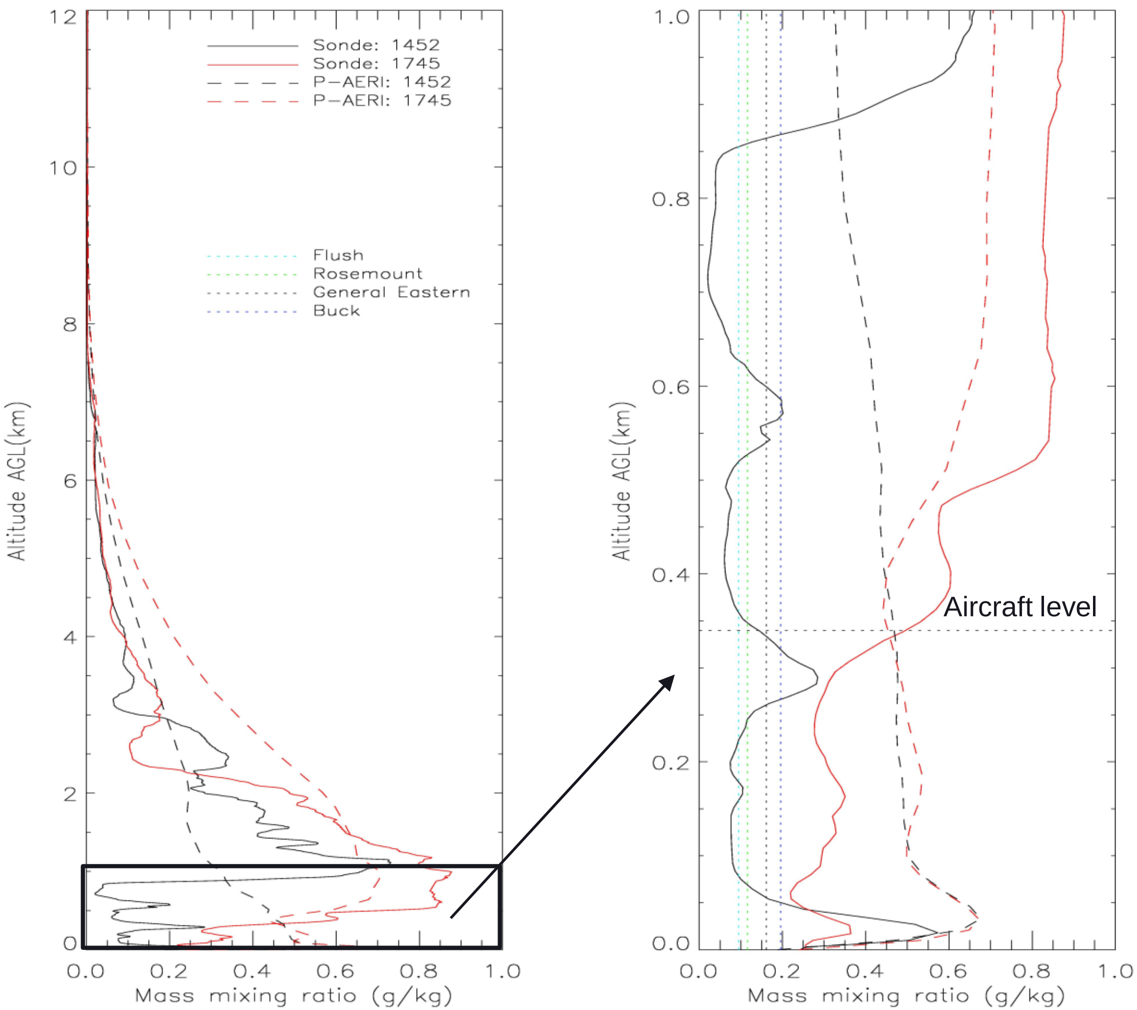
First cut: radiosonde ascent from Summit camp (~50 km distant)

Radiosonde temperature at aircraft level within 2K of de-iced aircraft measurement at time and location of TAFTS scans

Note large near surface T inversion

Scene Characterisation: Atmospheric Humidity

Biggest issue is below aircraft layer characterisation: no contemporaneous profile information, only measurements at aircraft level

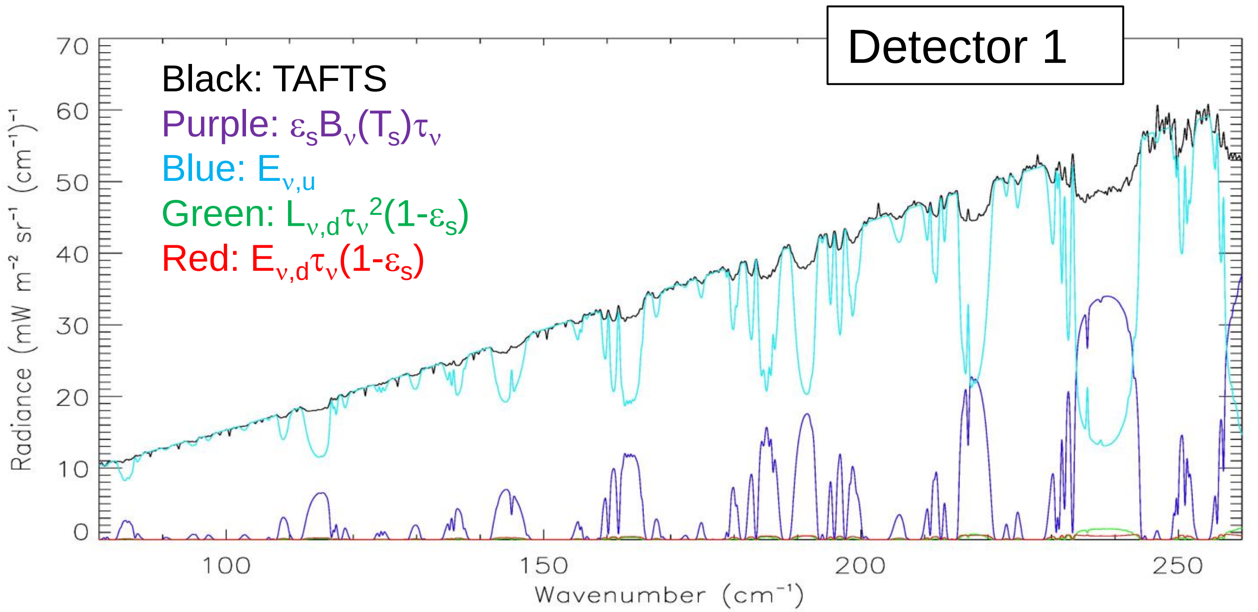


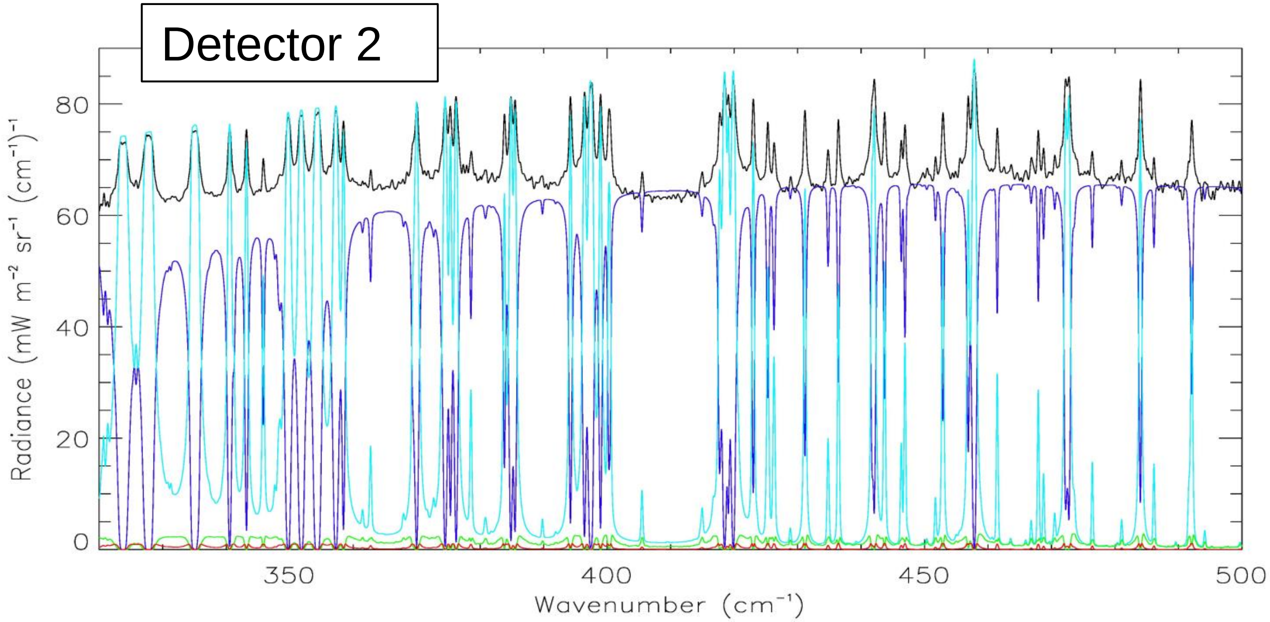
First cut: radiosonde ascent from Summit camp (~50 km distant)

Mixing ratio at aircraft level falls within range measured by aircraft instrumentation

Precipitable water vapour below aircraft < 0.005 mm! (total profile < 0.1 mm)

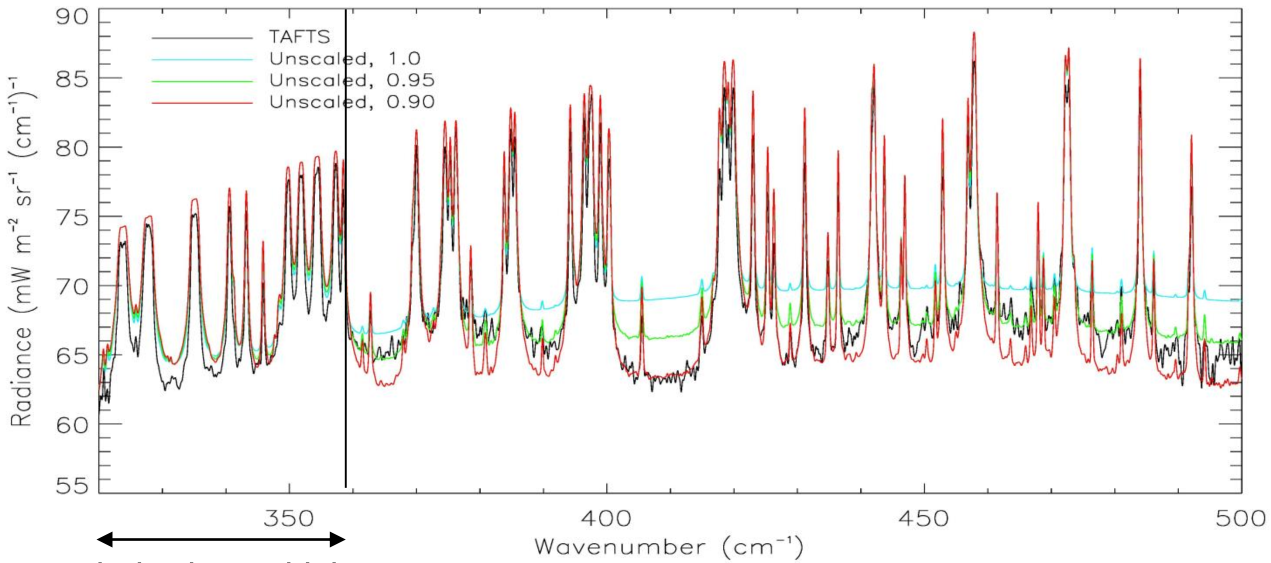
TAFTS spectra and contributing terms





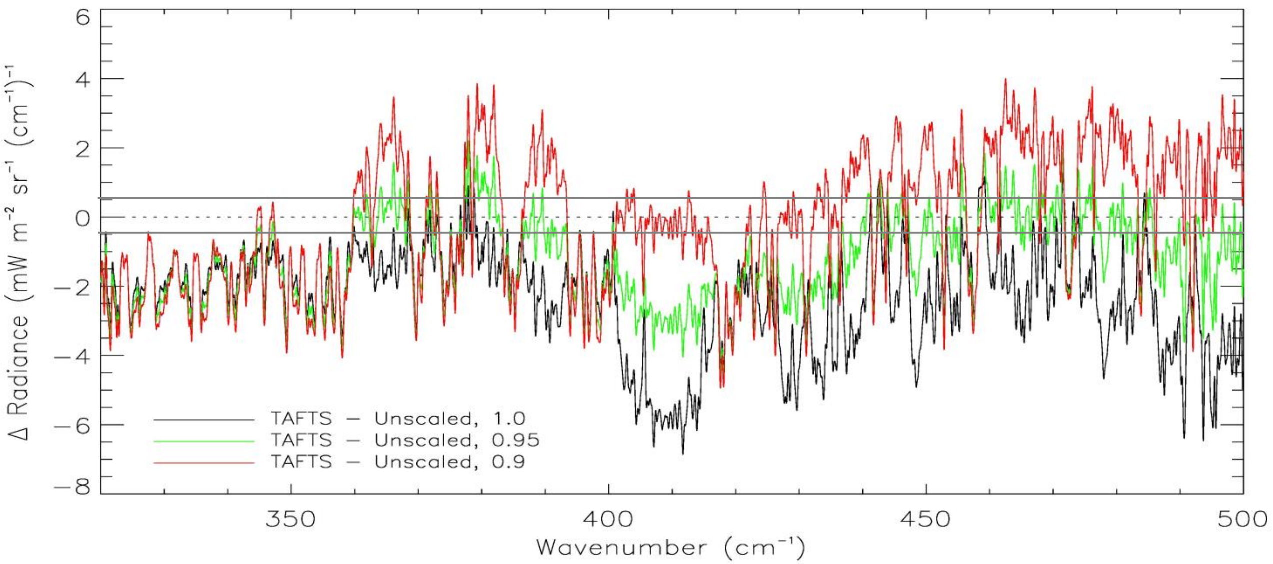
Grey-body ε_s = 0.95 in simulations and specular reflection

Sensitivity to emissivity



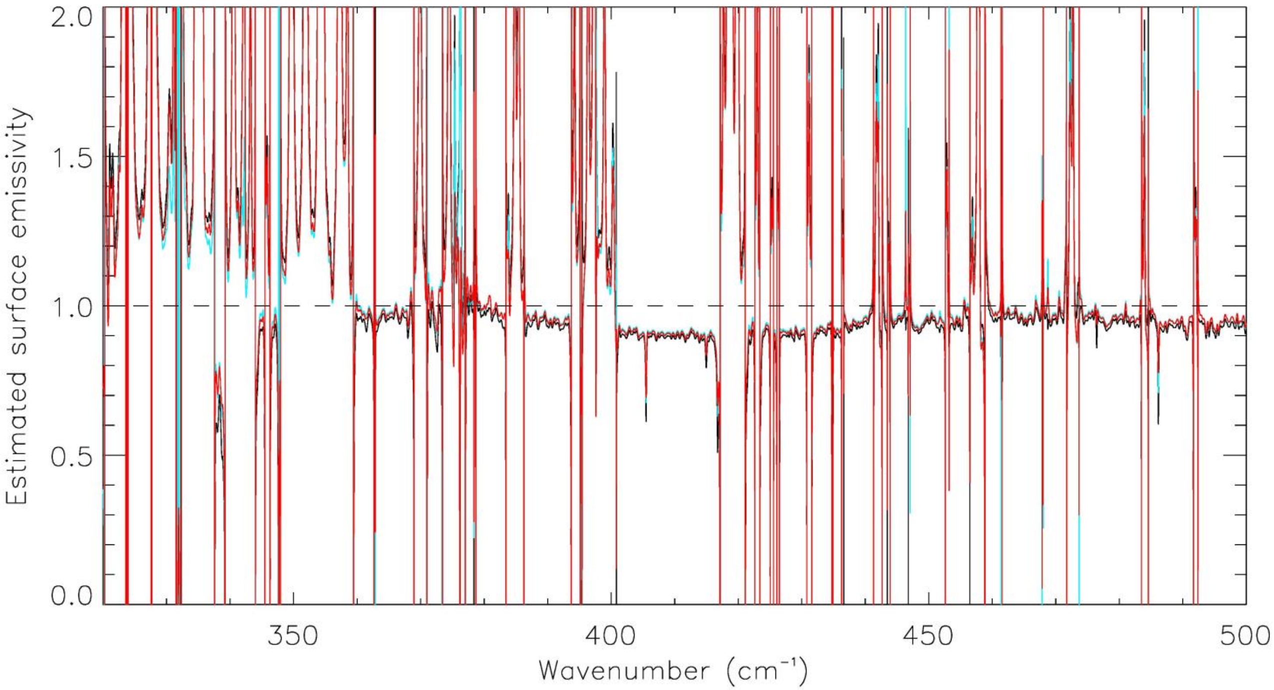
Limited sensitivity

Measured and simulated radiance (varying grey-body ε_s)



Measured – simulated radiance

First estimate (specular - no smoothing)



Black: T_s = 230.5 K
Blue: T_s = 229.5 K
Red: TAFTS noise added (as bias)

NB: Lambertian surface gives marginally lower ε_s for the same conditions

- Significantly lower values than derived by Chen *et al*. (2014) and used in Feldman *et al*. (2014).
- Substantial caveats related to atmospheric layer properties and assumptions in ‘retrieval’ methodology.
- TAFTS observations also need further assessment: aim to exploit additional nadir/zenith views obtained during B898.

International Consortium for the Exploitation of Infrared Measurements of PolAr ClimaTe (ICE-IMPACT)

O1: the derivation of FIR snow and ice surface emissivity from in-situ measurements over the Arctic ice sheet

O2: the delivery of a unique, spectrally-resolved surface downwelling longwave radiation (DLR) database, stratified according to meteorological/cloud regime, designed for satellite retrieval and model evaluation over Antarctica

O3: the delivery of a thoroughly validated, multi-year, ongoing satellite-based record of spectral outgoing longwave radiation (OLR) covering the full infrared spectrum

O4: the application of the tools developed in O1-O3 to evaluate model performance in polar environments with initial focus on the atmospheric components of the UK’s Earth System Model (UKESM) and the US Department of Energy's Community Earth System Model (CESM)