

Response to RC1

Thank you very much for your insightful comments on our work. We have responded to them turn-by-turn below. In the responses, we abbreviate the submitted version as 'SV' and the revised version we are now finalising as 'RV'.

Main Comment

This is a useful suggestion that can help to focus the paper. In the RV, we focus the study more clearly on PREFIRE validation, using FINESSE to constrain the input atmospheric profile as much as possible.

We have thus taken the following approach to the points addressed here. We begin by investigating FINESSE radiances using the in-situ data as is. We adjust the profile first to amend the water vapour bias (scaling radiosonde water vapour to match the ERA5 column). We then address the biases in the centre of the 15 μm CO₂ band by reducing the temperature of the whole profile by 0.86K; it was found that a whole-profile adjustment was helpful to not only reduce the bias in band centre but also reduce residuals in the band wings. An independent analysis of ERA5 simulated versus FINESSE radiances under clear conditions sampled throughout the WHAFFERS campaign shows no persistent bias in one direction or another across the CO₂ band centre. Therefore, we do not think the feature here is instrument related and consider it justified to scale the atmospheric temperature profile in the RV.

When turning to PREFIRE, we include the GOES surface temperature in Methods as our primary skin temperature source rather than ERA5, and use our 'best-case' profile from FINESSE, thus only having one profile to compare to PREFIRE observations instead of the current 4. We also add an uncertainty estimate from our humidity and temperature constraints.

Minor Comments:

Title: We acknowledge that it is possible to read the title in its first revision as overstated and accept this change for the RV.

L73-74:

The PWV values for the profiles used are recorded as text in Fig. 3, and we have added a pointer to this in the main body of the text in RV (L177 SV). We have highlighted in the RV that each radiosonde launched in the campaign measured PWV < 0.6cm, meaning semi-transparent conditions in all cases even after accounting for the presumed dry bias of the radiosonde.

L90: We have expanded the acronyms and provided references where relevant in the RV.

L117: The word "valid" intended to indicate PREFIRE spectra that have passed the quality control checks; this has been clarified in RV.

L118: Measurements were not generally taken at nighttime during the campaign due to the working hours of the group; FINESSE requires manual supervision during operation. We have noted this in RV.

L123-124:

We find that the variability (standard deviation) in spectra over the averaging window is equal to the NESR (see Fig. RC1-1, top left panel), indicating that no statistically significant change in the scene is observed over this time. Over broader time windows, the effect of changes in temperature, humidity, and cloud cover becomes visible (Fig. RC1-1). A clarification that variability matches the NESR has been added to RV.

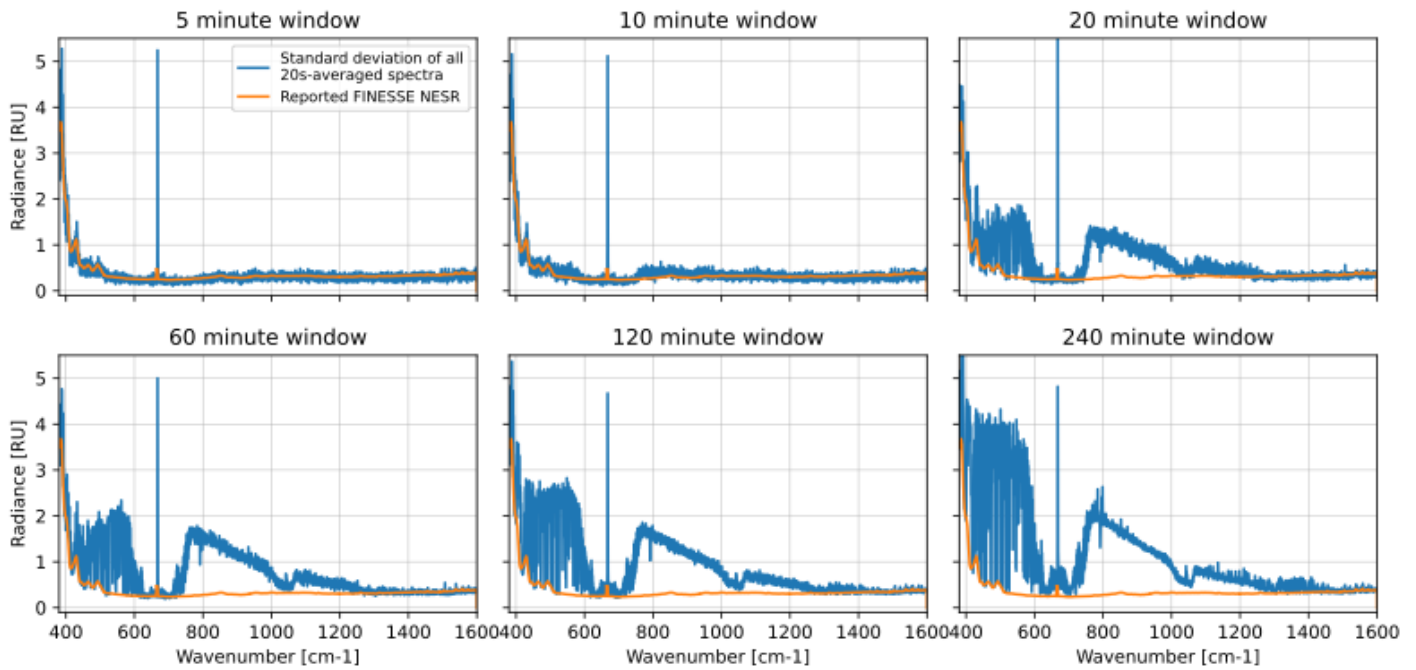


Figure RC1-1: Standard deviation in observed FINESSE radiances, calculated over increasing time windows centred on the PREFIRE overpass. The FINESSE NESR is shown for comparison. 1 RU = 1 mW (m² sr cm⁻¹)⁻¹.

L149-150:

Bias in the meteorological sensors at the Gault site is not of key importance to our study and was mentioned mainly to alert other potential users of the data. Across many measurement days, the 1.5m and 3.5m sensors were consistently warmer than those at other heights (higher, lower, and in between) which we believe to be unphysical. However, to simplify the paper, we have removed this point of discussion in the RV.

L151-154:

We also recognise the importance of the surface emissivity in this study. The inclusion of MODIS imagery in Fig. 2 is intended to show the surface observed by the satellite and demonstrates the extent of the snow cover over what is largely flat land. We used a ‘medium snow’ surface type from the Huang et al. (2016) dataset as a reasonable mid-range estimate and included the spread in snow types in our uncertainty estimate.

For modelled snow surfaces, the effect of varying viewing angles up to 15° (the maximum PREFIRE viewing zenith angle across all scenes) on the surface emissivity was found to be minimal, causing a maximum change in emissivity of only 0.0005. A surface containing some more ‘sheet-like’ ice (e.g. if some snow had thawed and refrozen) could have a different emissivity but there is insufficient data to investigate the actual nature of the surface cover at that time. In Figure RC1-2 (solid lines), we demonstrate that even a 20% change to ice would have only a small impact on observed radiances, or equally a change to a different size of snow.

We note that the current (SV) estimate of forward-modelling uncertainty due to snow crystal size-dependent spread in emissivity is lower than that due to surface temperature by a factor of about 4, and that emissivity uncertainty only impacts (semi-)transparent atmospheric regions (dashed lines, Fig. RC1-2). It appears that the surface emissivity uncertainty is underestimated for some parts of the spectrum, so the estimate of this uncertainty has been modified in RV to reflect the red dot-dash line.

There is a lack of modelled or observational data for the FIR emissivity of the woodland or urban areas included in the PREFIRE FOVs. The Huang et al 2016 dataset indicates that the emissivity of woodland surfaces is not drastically different to snow where the surfaces are observed in the MIR. Unfortunately, we

also do not have PREFIRE retrieved emissivity to compare to for this scene since it is out of the range of operational retrievals (polewards of 60° latitude). We highlight this FIR emissivity data gap in RV.

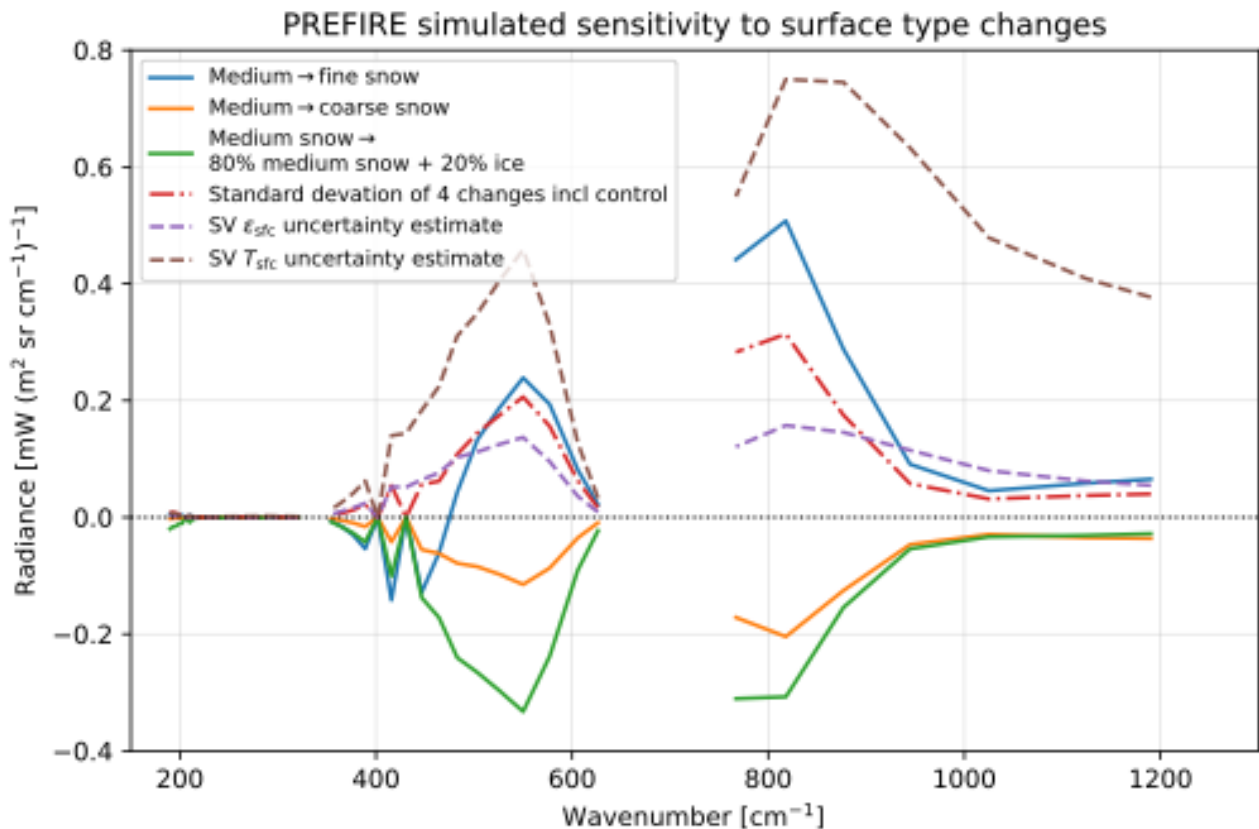


Figure RC1-2: Solid lines: sensitivity of PREFIRE to changes in simulated surface type, represented as offsets from the ‘medium snow’ type used as default in simulations. Dash-dot line: standard deviation of these offsets, including the control (i.e. zero offset). Dashed lines: uncertainty estimates in radiances from the SV, resulting from uncertain surface emissivity and surface temperature.

L155: Ozone concentrations in the study have been taken from ERA5 (see L137, SV).

L205: This was a research radiosonde launch not forming part of any operational observation network and as such it was not assimilated into any reanalysis product such as ERA5.

Figure 5:

Interpretation of the uncertainties in the figure should be guided by the text, but some clarification in the figure keys and caption can help and so we have added this in the RV.

- In (a), calibration uncertainty is the instrument ‘absolute radiometric accuracy’.
- The uncertainties in (b) are reported solely as ‘uncertainty’ in the PREFIRE product, we believe this is equivalent to NESR.
- In (c-f) SV, uncertainties are the dy described in the text §3.3. We believe that the approach taken approximates a 1-sigma deviation in spectral radiance due to a 1-sigma uncertainty in profile input quantities.
- The uncertainties in (g,h) SV indicate the expected range of the radiative uncertainty due to uncertainty in H2O spectral parameters. Spectroscopic uncertainty values represent only an estimate of the effect due to the inexact nature of the source uncertainty values (HITRAN and Mlawer et al 2019) and so we cannot apply an exact statistical label to our derived uncertainty estimates. In the RV we include more in Discussion about this uncertainty and note that there is a need for the spectroscopic community to share experimental uncertainty results or for uncertainties that are shared to be properly utilised and documented in spectroscopic databases.

Figure 6: We have addressed this point in the response to the “Main Comment” above.

L350-351: The wording was perhaps unclear here and has been revised in RV. The evidence to believe this is that all other known sources of uncertainty have been accounted for in the forward modelling part of the closure experiment such that the residuals must, by elimination, be due to deficiencies of the observing system.