Some issues in near-infrared radiative transfer

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Particular thanks to Jon Elsey (Univ of Reading), Igor Ptashnik (IAO, Tomsk) and Tom Gardiner and Marc Coleman (National Physical Laboratory)

Workshop on Radiation in the Next Generation of Weather Models, ECMWF May 2018
I’ll cover three clear/clean sky issues in the near-IR

- The solar spectral irradiance
- The water vapour continuum
- The role of methane near-IR bands
Modern (global and annual averaged) Earth energy budget

Stephens et al. (2012), Nature Geoscience 10.1038/NGEO1580
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A surprising uncertainty!

• The wavelength-integrated total solar irradiance is believed to be known with an uncertainty of less than 0.5% (e.g. Kopp and Lean 2011)

• But how well do we know the spectrally-resolved irradiance?

• Implications for total solar irradiance?

• A controversy largely played out in the solar physics literature
The near-IR Extraterrestrial Solar Spectrum (NIR ESS)

- ESS are readily available, even if not at the highest spectral resolution (so that many solar lines are not resolved). OK?
- Not really. SORCE SSI is adjusted downwards (by 8%) to agree with ATLAS3 (see soon!) at $\lambda > 1.5 \mu m$.
- TSIS launched late 2017. Results pending

Menang et al 2013, JGR 10.1002/jgrd.50425

lasp.colorado.edu/lisird/sorce/sorce_ssi/
SOLSPEC

• Grating spectrometer, covering (about) 0.17 to 3.1 μm at about 0.5 nm resolution (around 20 cm⁻¹)

• First flew on Spacelab I in 1983


• Also flew on European EUREKA mission in 1994 (but called SOSP)

• Then installed on International Space Station in 2008 with updated electronics and optics
Thuillier et al. (2014) showed that “new” (2008) NIR ESS measurements were 7% lower than ATLAS-3 at >1.5 µm.

Lower values were consistent with e.g. Sciamachy.
Bolsée et al. (2014) showed ground-based measurements. Theirs and ours (Menang et al. 2013) were also broadly consistent with the lower values derived by SOLAR2.

But then ...
• SOLAR2 was based on ISS “first light” from measurements in April 2008 “to avoid ageing effects”

• Thullier et al. (2015) “Increase of solar signal (with time) ... (has) no clear explanation ... most likely due to some temperature effect and/or outgassing of the instrument”

• They concluded that the ESS was closer to original ATLAS3 (Solar1) spectrum and evidence supporting the lower SOLAR2 ESS was flawed

Thullier et al. (Sol Phys 2015)
Not every one agreed

Comment on the Article by Thuillier et al. “The Infrared Solar Spectrum Measured by the SOLSPEC Spectrometer onboard the International Space Station”

Invited Review

M. Weber

Comments to the Article by Thuillier et al. “The Infrared Solar Spectrum Measured by the SOLSPEC Spectrometer Onboard the International Space Station” on the Interpretation of Ground-based Measurements at the Izaña Site

D. Bolsée¹ · N. Pereira¹ · E. Cuevas² · R. García² · A. Redondas²
Ground-based sun-pointing FTS measurements

- Calibration traceable to a primary standard cryogenic radiometer
- Field campaign in UK in 2008
- Recent work by Jon Elsey (GRL, 2017) builds on Menang et al. (JGR, 2013) with a more detailed error budget
Field campaign results

- Direct modelling of surface spectral irradiance *inconsistent* with observed irradiances using the *higher* SOLSPEC ESS
- Discrepancy is outside known instrumental, spectroscopic or atmospheric state uncertainties
- Updated Langley analysis shows good agreement with the SOLAR2 ESS, and so supports the *lower* value

Elsey et al. 2017 GRL
10.1002/2017GL073902
Newer SOLSPEC analysis

- Newer analysis of Solspec “confirms” ATLAS-3 is an overestimate by 8% in near-IR
- Good agreement with independent SCIAMACHY ESS.
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Between the water bands … the water vapour continuum

- Leading importance in the 10 μm window – long history of measurements; potentially important in other windows
- No settled scientific cause – not today’s subject
- Very few measurements prior to 2000 in 1.6 and 2.1 μm near-infrared windows. Today there are still just a few
- Those that do exist do not agree well near room temperature, and none extend to lower temperatures
- Most models use CKD/MT-CKD self and foreign continuum
All comparisons with MT_CKD-2.5
Latest version is 3.2
UK CAVIAR (Continuum Absorption at Visible and Infrared wavelengths and its Atmospheric Relevance) project (2006-2011) – indicated that widely-used continuum models are too weak. But most confident lab observations have necessarily been made at high temperature.
Few measurements near room temperature – main ones are from 3 groups: CAVIAR, Tomsk and Grenoble – and the degree of agreement can be very poor ... especially in the core of the 1.6 µm window at room temperature.

CAVIAR/Tomsk – uses Fourier Transform Spectrometry with large gas cells – large uncertainties at room temperature, but much better at elevated temperatures.

CRDS – Cavity Ringdown Spectroscopy with small gas cells. Inherently more precise. Limited wavenumbers.

See also Lechevallier et al. 10.5194/amt-11-2159-2018 (CRDS at 2.0 and 3.3 µm)
and Richard et al. 10.1016/j.jqsrt.2017.06.037 (CRDS at 2.1 and 4.0 µm)
Temperature dependence as a useful diagnostic of consistency of measurements.

In 2.1 µm window, high-T CAVIAR FTS data appear strongly consistent with the Grenoble CRDS measurements.

Straight line if T dependence is of form exp(D/kT)
Temperature dependence as a useful diagnostic of consistency of measurements.

- In the 1.6 μm window, high-T CAVIAR and CRDS are much less consistent, especially in the centre of the window.
- Why are 1.6 and 2.1 μm windows so different?

CRDS-MT_CKD agreement is really only at room temperature.

Foreign water vapour continuum

- Even fewer measurements in 1.6 and 2.1 μm window – CAVIAR FTS, plus one CRDS measurement
- But expect little temperature dependence and so elevated temperature measurements are more applicable – and constancy exists after self-continuum removed.
- Factor of 2 agreement between FTS and CRDS despite claim by Oyafuso et al. (JQSRT 2017) that CRDS agrees better with MT-CKD.

Impact on atmospheric absorption

Using the CAVIAR continuum increases the global-mean clear-sky atmospheric shortwave absorption by 2% compared to MT-CKD, mostly from 2.1 μm window.

But could be more (e.g. Tomsk 1.6 μm) or could be less (CRDS), if different lab measurements used.

In a warming world, this absorption increases by 12% more using CAVIAR continuum than MT-CKD.

Ptashnik et al. (Phil Trans Roy Soc, 2012)
Rädel et al. (QJRMS, 2015)
Impact on remote sensing

**Clouds:** If CAVIAR continuum is used, it could systematically reduce the retrieved droplet radius at 4900 cm\(^{-1}\) by typically about 1 μm (in 10 μm). Depends on cloud height and location.

Shine et al., Surveys in Geophys, 2012

**CO\(_2\)** Analysis of TCCON (ground-based FTS) in context of OCO-2 (Oyafuso et al. JQSRT 2017) - could not reconcile variation of retrieved CO\(_2\) with air-mass between summer and winter observations. Concluded “unrealistically large multiplicative factors [\(\sim 8x\) in 2.06 μm band and \(\sim 150x\) in 1.6 μm band] for the water vapour continuum were required”. Unrealistically?
The near-IR water vapour continuum: some conclusions

• Significant differences in the room-temperature self-continuum. Generally better agreement at higher temperatures but puzzles about variations between windows
• Too few independent measurements; little overlap in measurement conditions; no lower T measurements; only one set of extensive foreign continuum measurements
• What next? Continued analysis of sun-pointing FTS measurements (Elsey et al. to be presented at HITRAN 2018 and AMS radiation meetings)
• What next? New Reading-RAL project: Advanced Spectroscopy Advanced Spectroscopy for improved characterisation of the near-Infrared water vapour Continuum (ASPIC). Supercontinuum laser sources increase signal and allow increased path length in lab
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Near-IR bands of CH$_4$

Bands are well known but “underrepresented” in GCM radiation schemes.

Collins et al (2006) showed line-by-line codes have positive TOA forcing and negative surface forcing, for an idealised case. GCM codes have zero ...

See also Li et al. (JAS, 2010) for impact on GCM simulations

Collins et al. (JGR 2006)
Near-IR bands of CH$_4$

Radiative forcing of carbon dioxide, methane, and nitrous oxide: A significant revision of the methane radiative forcing

M. Etminan$^1$, G. Myhre$^2$, E. J. Highwood$^4$, and K. P. Shine$^3$

- Etminan et al. line-by-line code calculations indicate methane forcing (and GWP etc) is enhanced by about 15% (6% due to direct absorption, 9% due to stratospheric warming) due to near-IR bands
- Deliciously “rich” structure in forcing – even sign of forcing varies spectrally, depending on strength of band and position relative to main water vapour bands
- Strong dependence on cloudiness (and surface albedo) – enhanced absorption of reflected beam changes sign of forcing

Etminan et al. (GRL 2016)
Near-IR bands of CH$_4$

Some modern GCM codes do include the CH$_4$ near-IR bands, but those we studied do not generate much forcing from them. Handling of overlap with water vapour?? An issue for codes used for both NWP and climate change.

Awaiting an “independent” and enhanced verification of the Etminan et al. results – will be important for IPCC AR6, if they are to adopt an enhanced methane forcing.

Preliminary: Geographical distribution of SW forcing (W m$^{-2}$) using high-spectral resolution version of SOCRATES code for May conditions) relative to pre-industrial

Byrom, Checa-Garcia et al, in prep
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Thank you