Airborne and satellite remote sensing of the infrared water vapour continuum

Met Office

Stuart M. Newman

The CAVIAR project

CAVIAR (Continuum Absorption by Visible and Infrared Radiation and its Atmospheric Relevance) is a NERC-funded consortium of UK universities and research institutes. Its aims are to improve understanding of the water vapour continuum absorption through field and laboratory measurements and theoretical calculations.

According to the CKD definition (Clough et al., 1989) the continuum is defined as absorption unexplained by the superposition of many pressure- and Doppler-broadened lines. The continuum is partitioned into that due to collisions of H_2O molecules with foreign gases (the "foreign continuum") and that due to H_2O–H_2O interactions (the "self continuum"). Fig. 1 shows how these continuum terms vary spectrally for the CKD (more recently MT_CKD) model.

Laboratory measurements at the Rutherford Appleton Laboratory Molecular Spectroscopy Facility (RAL MSF) have been used to obtain new continuum strengths across a wide spectral range. As Fig 1 shows, these CAVIAR coefficients are larger than MT_CKD for many of relatively transparent window regions.

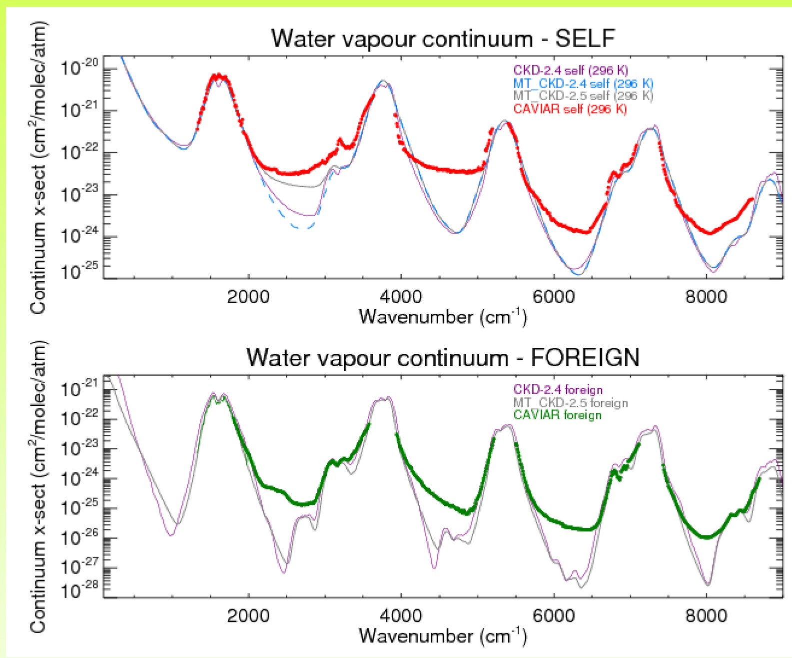

Fig. 1 Spectral dependence of the water vapour continuum. Top: self continuum component (absorption cross-section); bottom: foreign continuum component. The continuum strength is shown (see legend) for CKD-2.4 (released 2000), MT_CKD-2.4 (2009) and MT_CKD-2.5 (2010) models (the latter two are identical for the foreign continuum). Also plotted is the continuum strength derived by Ptashnik et al. (2011a, 2012) from RAL MSF laboratory measurements for CAVIAR.

Self continuum near 4 μm

The self continuum in the range 2400-3000 cm^{-1} (4.2-3.3 μm) has undergone a drastic revision in the most recent version 2.5 of MT_CKD, Fig. 2 (a), to bring the continuum strength into agreement with field datasets (Mlawer et al., 2012). The new MT_CKD-2.5 coefficients are between 4.8 and 7.4 times larger than in MT_CKD-2.4. CAVIAR laboratory-derived continuum coefficients are slightly larger still.

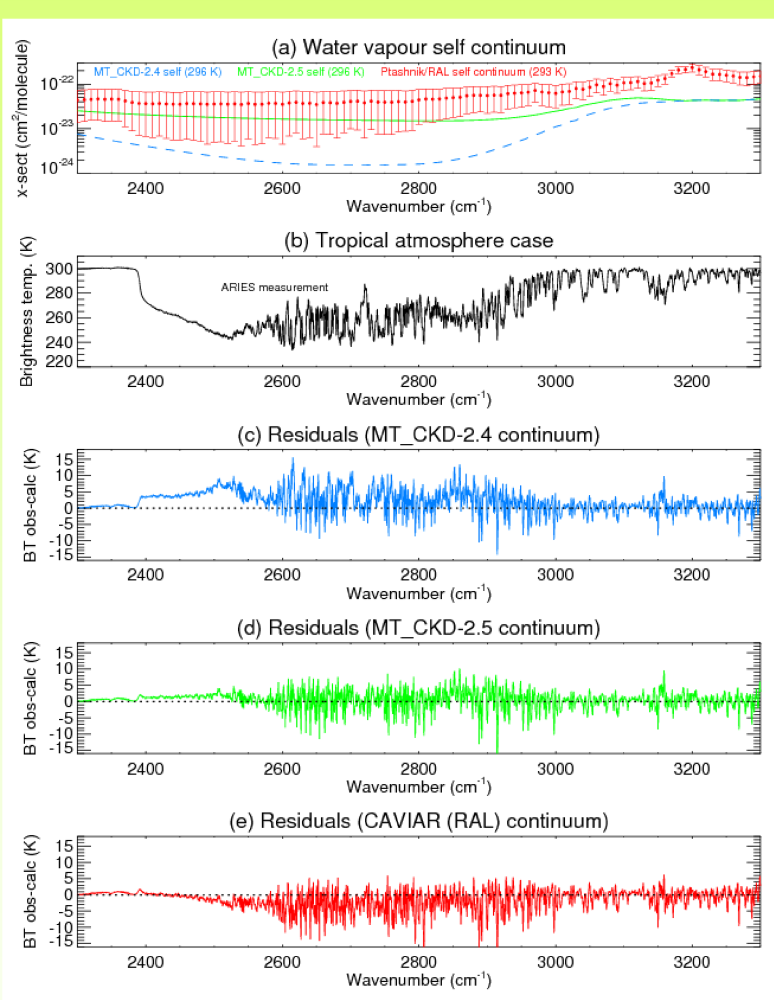

Fig. 2 (a) Water vapour self continuum cross-section, at a reference temperature of 296 K, for the MT CKD formulation versions 2.4 (dashed line) and 2.5 (solid line) together with values derived from RAL MSF laboratory data (data points with error bars). (b) ARIES upward-looking brightness temperatures from low altitude recorded during the MOTH-Tropic campaign. (c-e) Residual differences (obs−calc) between ARIES and LBLRTM brightness temperatures where the modelled continuum strength is adopted from MT CKD-2.4, MT CKD-2.5 and CAVIAR (RAL) respectively. LBLRTM is used for the simulations.

The Atmospheric Research Interferometer Evaluation System (ARIES) is flown on the FAAM BAe 146 research aircraft. It measures infrared spectra at 1 cm^{-1} resolution. Fig. 2 (b) shows a downwelling brightness temperature spectrum in a tropical atmosphere. By comparing line-by-line simulations (initialised with atmospheric profile information from aircraft dropsondes) with the observations different models of the water vapour continuum can be tested for validation.

Using the MT_CKD version 2.4 continuum in LBLRTM results in residual differences of 5 K or more near 2500 cm^{-1}, Fig. 2 (c). This is beyond the expected range of error associated with atmospheric profile uncertainties. With MT_CKD-2.5, Fig. 2 (d), and the new CAVIAR continuum, Fig. 2 (e), the residuals are reduced to a few K at most near 2500 cm^{-1}. Given the size of experimental errors in the laboratory data in Fig. 2 (a), MT_CKD-2.5 is considered as validated over the 2400-2600 cm^{-1} range.

The conceptual basis of the self continuum is still the subject of controversy. Whereas the CKD definition implies that non-Lorentzian contributions to the far wings of lines are a primary cause, new laboratory data suggest the role of dimers cannot be discounted. (Dimers are weakly bound complexes involving pairs of H_2O molecules.) A number of observed spectral features in the continuum are not modelled by MT_CKD, but are in accord with the predictions of dimer theory (Ptashnik et al., 2011b). The discrepancy between CAVIAR and MT_CKD continuum coefficients in window regions (Fig. 1) may be explained by a dimer contribution at atmospheric temperatures and pressures (Ptashnik et al., 2011a).

Water vapour ν_2 band

The H_2O ν_2 band in the range 1300-2000 cm^{-1} (7.7-5.0 μm) is important for the remote sensing of humidity, e.g. from the Infrared Atmospheric Sounding Interferometer (IASI).

Fig. 3 (a) shows how continuum coefficients measured in the laboratory compare with MT_CKD-2.5. The experimental data (measured at 296 K) suggest a somewhat weaker continuum than MT_CKD.

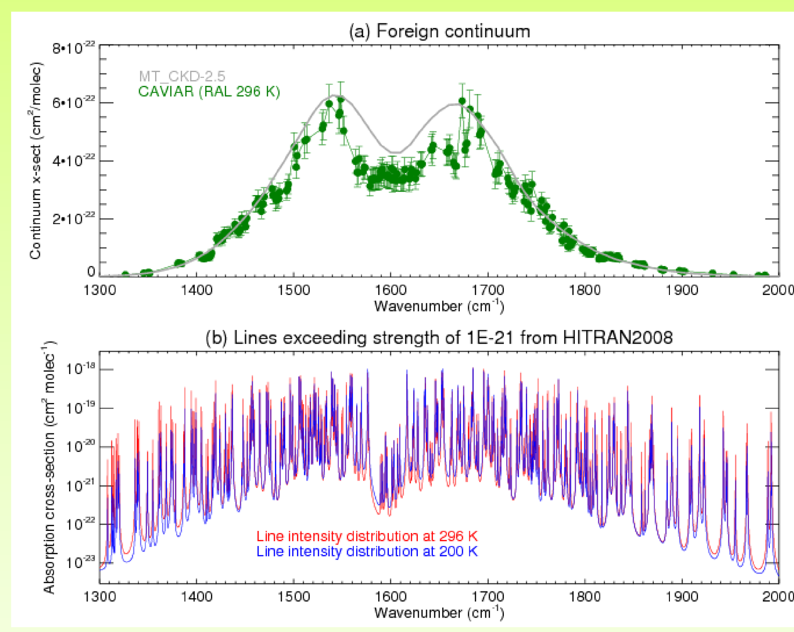

Fig. 3 (a) MT_CKD version 2.5 foreign continuum and CAVIAR laboratory coefficients. (b) Distribution of water line intensities at 296 K and 200 K.

Other studies (e.g. Rowe and Walden (2009) in Antarctica) have found evidence that the foreign continuum may exhibit a temperature dependence. As Fig. 3 (b) shows, the Boltzmann distribution of H_2O line intensities changes with temperature. This offers a mechanism for how continuum coefficients may display a *T*-dependence. CAVIAR foreign continuum data at 296 K have been adjusted for *T*-dependence based on the behaviour in Fig. 3 (b).

Data sets such as the Joint Airborne IASI Validation Experiment (JAIVEx) can be used to test the proposed continuum model. Fig. 4 shows a clear sky night-time case over the Gulf of Mexico. For continuum-sensitive channels the root mean square (rms) residuals are reduced from 0.98 K to 0.52 K using the CAVIAR coefficients.

To gauge the potential impact on operational NWP a global set of 1788 clear sky IASI observations were selected (Fig. 5).

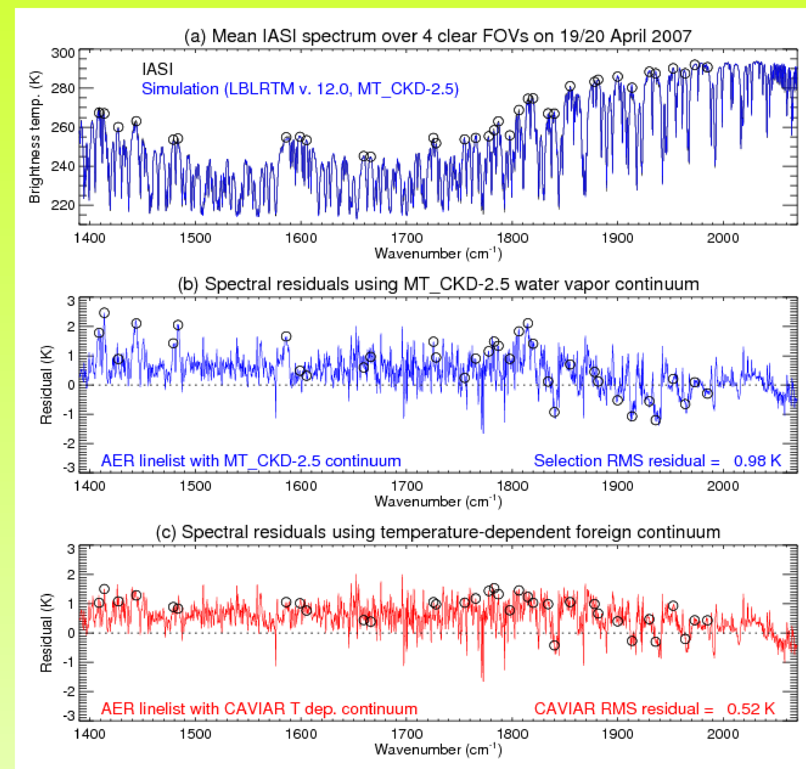

Fig. 4 (a) Mean IASI observation and default simulation. Continuum sensitive channels are circled. (b) Obs-calc residuals with MT_CKD-2.5 continuum. (c) As in (b), but MT_CKD-2.5 has been replaced with *T*-dependent foreign continuum. The stated rms residuals are calculated for the circled channels.

For most of the NWP channel selection the impact is small, although an improved fit to PC reconstructed observations is seen, particularly near 1585 cm^{-1}. The persistent positive bias may be due to an insufficiently large sample size for the data set.

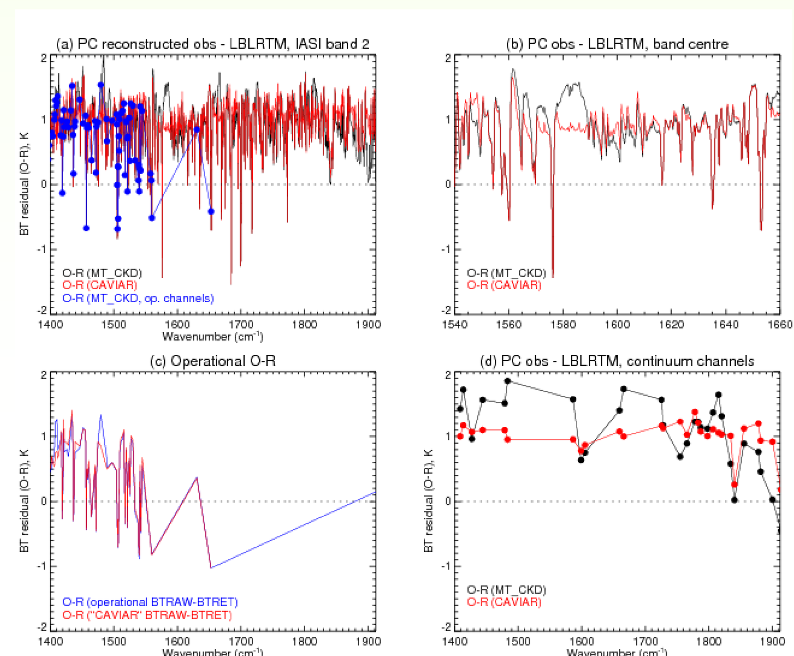

Fig. 5 IASI band 2 observation minus 1d-Var retrieved-profile simulation (O-R) mean residuals. (a) IASI PC-reconstructed obs, LBLRTM simulations incorporating the MT_CKD-2.5 continuum (black) and CAVIAR continuum (red). The subset of channels monitored operationally is also shown in blue. (b) As in (a), zoom of centre of H_2O band. (c) Operational O-R (BTRAW-BTRET) in blue, adjusted values based on CAVIAR-T2 impact in red. (d) As in (a), restricted to continuum sensitive channels..

Summary

The CAVIAR consortium project has resulted in improved measurements of the water vapour continuum. Near 2500 cm^{-1} recent changes in MT_CKD (version 2.5) are found to be in accord with laboratory and field data. A temperature dependent foreign continuum over the 1300-2000 cm^{-1} range improves the fit to IASI observations and may be of benefit in NWP if an expanded channel selection is used.

References

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Met Office FitzRoy Road, Exeter, Devon, EX1 3PB United Kingdom
Tel: 01392 884605 Fax: 01392 885681
Email: stu.newman@metoffice.gov.uk