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Vertical profile retrievals of marine stratocumulus from passive remote sensing: An assessment of information content and the potential for improved retrievals from hyperspectral measurements

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We present a theoretical study into the information content of solar reflectance measurements at multiple near-infrared wavelengths in the context of deriving a vertical profile of droplet size from marine stratocumulus. Several previous studies have suggested that the variation of droplet absorption with wavelength in the near-infrared results in differing penetration depths of photons at different wavelengths. This suggests that multi-wavelength measurements contain information about the vertical variation of droplet effective radius and several retrieval approaches have been proposed. Recent efforts to reconcile differences in effective radius retrievals, using several near-infrared channels, with observed cloud structure have however been inconclusive.

We employ a Bayesian optimal estimation approach to retrieve a profile of effective radius as a function of optical depth in the cloud. This allows an assessment of the information content of the measurement of reflectance in different regions of the wavelength spectrum and the potential for a new generation of hyperspectral sensors to improve the retrieval. Our results show that using the three absorbing near-infrared channels of the Moderate Resolution Imaging Spectroradiometer (MODIS) centred at 1.6, 2.1 and 3.7 μm a retrieval of droplet size lower in the cloud is highly sensitive to small changes in reflectance. Consequently instrument and modelling errors must be reduced to unrealistically low levels in order to gain a useful uncertainty restraint on droplet size in the lower portions of the cloud. It is therefore likely that any errors in ancillary model parameters such as above cloud water vapour along with biases due to the modelling of the cloud as a plane-parallel layer will significantly affect the retrieval.

By introducing many high spectral resolution wavelength channels, such as those available from hyperspectral sensors, we find that the information content pertaining to all retrieval variables increases significantly. This results in a reduction in the uncertainty estimates on all retrieved quantities. The use of hyperspectral channels also allows measurements of reflected radiance at many wavelengths which experience varying degrees of water vapour absorption. We show that by including above cloud water vapour amount as a variable in the retrieval, the cloud reflectance signal can be effectively separated from vapour absorption thus reducing an important source of uncertainty in passive cloud retrievals.

Finally we test the performance of the hyperspectral retrieval using in situ profiling measurements of droplet size distributions and liquid water content of marine stratocumulus in the South-East pacific region. These profiles were sampled from the UK BAe146 aircraft during the VOCALS campaign in October and November 2008 and are used to generate synthetic measurements on which vertical profile and two-band lookup table retrievals are performed. We find that a hyperspectral profile retrieval represents the droplet size to good accuracy at all levels in the cloud and the resulting total liquid water path retrieval agrees to within 3% for all cases. This is a significant improvement over the two-band lookup table retrieval of liquid water path which displays a high bias as large as 20%.