Figure 8. Ratios of $r_{e3.7}$ to $r_{e2.1}$ for a MODIS snapshot scene from the Southeast Pacific stratocumulus region from 16th June, 2015. Left: using uncorrected $r_e$ values. Right: using $r_e$ values that have been corrected using the parameterizations for $g_r$ (for both $r_{e3.7}$ and $r_{e2.1}$). A ratio of one is expected for the plot on the right if the relative differences between $r_{e3.7}$ and $r_{e2.1}$ are caused by vertical stratification alone and if the parameterization is correctly predicting the relative differences.

Region#1 for the 2.1 µm retrieval, assuming perfect initial agreement. This indicates that another N$\text{d}$ bias may have been operating in order to give the good observed agreement.

The MODIS retrieval uses reflectances from both a visible and a shortwave infra-red (SWIR) wavelength channel with the former being primarily determined by $\tau$ and the latter by $r_e$. However, a bi-spectral retrieval is used and so there is also some sensitivity of the retrieved $\tau$ to the SWIR reflectance, which will be representative of the $r_e$ below cloud top due to the vertical penetration effect. This, combined with the fact that the MODIS forward retrieval model assumes a vertically uniform cloud, will result in the retrieved $\tau$ being biased relative to the real value (assuming the real cloud has an adiabatic profile). Figure 10 shows the difference between the retrieved and model profile $\tau$; the bias is negative and smaller in magnitude than 5% for the 3.7 µm retrieval. They are slightly larger for the 2.1 µm retrieval, but still lower in magnitude than 5%, except at $r_e \lessapprox 7$ µm.

Although it should be noted that some of this bias may be due to other causes related to the inconsistencies between the vertically uniform and adiabatic models, rather than the $r_e$ vertical penetration bias. Since the retrieved N$\text{d}$ is proportional to the square root of $\tau$, this will lead to small N$\text{d}$ biases. Biases in LWP will be similar to those in $\tau$ since LWP is proportional to $5\tau$, but $r_e$ biases are still likely to dominate (e.g., see Fig. 1). Thus, we have not pursued this further.

In this paper we have only considered retrievals over the ocean, although retrievals over land for $\tau$ and $r_e$ are available for MODIS. MODIS surface albedo uncertainties are likely to be much higher over land than over the oceans (King et al., 2004; Rosenfeld et al., 2004; Bréon and Doutriaux-Boucher, 2005) since the surface albedo is much more variable over land.