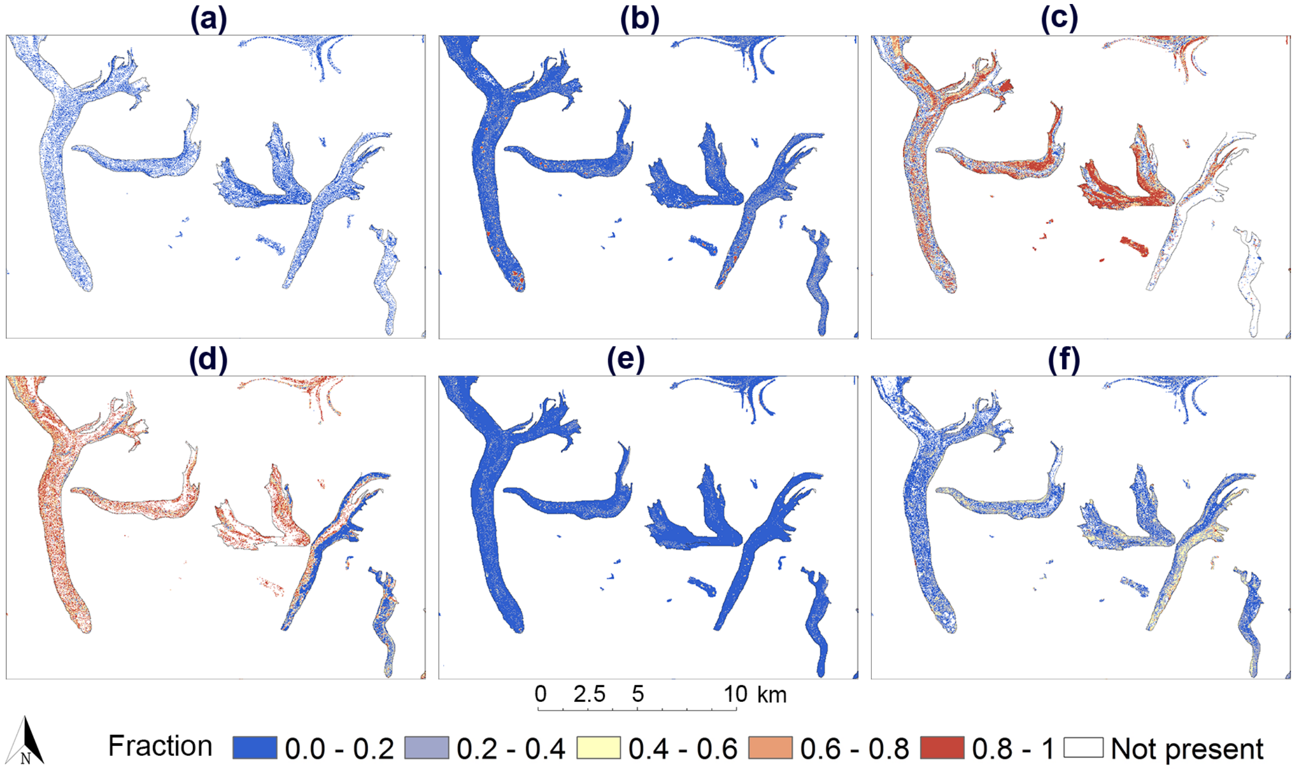

Figure 5. Fractional maps obtained from the LMM routine for a subset of the Khumbu area. Colour bars show the percentage covered by each type of material on a pixel-by-pixel basis: **(a)** clean ice; **(b)** turbid water; **(c)** dark debris; **(d)** light debris; **(e)** clouds; **(f)** dry vegetation.

from SPOT7 data for the same date as the Landsat. LMM underestimated the pond area by 0.05 km^2 (19 %), which is within the uncertainty range (21 %) reported for the ponds in the Langtang area by Steiner et al. (2019).

Visually, the spectrally unmixed pond pixels correspond well with the validation dataset, although there is a difference in the representation of the pond surfaces due to the spatial resolution (30 m Landsat vs. 2 m Pléiades) (Fig. 6). For Lhotse Glacier, the supraglacial pond area was slightly underestimated compared to Pléiades (Table 5) as can be seen on Fig. 6. This is perhaps due to the predominance of darker debris type on this glacier, some of which was confused with water, as shown by the accuracy metrics (Table 2). Similarly, in the Lahaul–Spiti region, locations of the supraglacial ponds correspond well between LMM and PlanetScope on Bara Shigri Glacier (Fig. 6c), but the small ponds are not identified using the water threshold of 0.5, which assumes that more than 50 % of the pixel area is covered by water.

3.4 Application to regional non-glacier lake databases

While supraglacial ponds are the focus of this study, we mention that LMMs can also be parameterized to map other lakes, by masking the debris-covered glacier areas and replacing the turbid water endmember with the clear water endmember, which has a lower spectral signature (Fig. 4a). This is beyond the purpose of this study, but we provide an illustration of such an output for the terminus of Ngozumpa Glacier (Fig. 7). We present the ponds and lakes on the debris cover and outside it for comparison with two existing glacial lake databases constructed from the same year (2015 Landsat): the HMA v.1 lake dataset, derived using a normalized difference water index (Shugar et al., 2020), and HI-MAG constructed using a modified NDWI and manual corrections (Chen et al., 2021). A comparison with other global databases such as the Global Surface Water dataset (Pekel et al., 2016) was not undertaken here, as this has already been shown to underestimate the water occurrence over most of the Himalaya by Chen et al. (2021). With regards to HMA v.1 and HI-MAG datasets, Fig. 7 shows that the lake outlines obtained from spectral unmixing for the supra-glacier ponds at the terminus of Ngozumpa Glacier and the Gokyo Lakes outside the glaciers are outperforming both of the existing databases in this area. Our lake extents are consistent with the HMA v.1 lake extents outside debris cover (Fig. 7), and the surface area estimates agree quite well; for example, we calculated a difference of 5 % in the summed pond area over the three Gokyo Lakes (1.15 km^2 in our estimates vs. 1.09 km^2 in HMA v.1). The slight underestimate in the latter is due to simplification of the raster edges in the vector conversion process, visible in the lake extents. With regards to supraglacial ponds, for example Spillway Lake at