Introduction
Vegetation optical depth (VOD) is an indicator of the water content of both woody and leaf components in terrestrial aboveground vegetation biomass that can be derived from passive microwave remote sensing. VOD is distinct from optical vegetation remote sensing data such as the normalized difference vegetation index in that it is: (a) less prone to saturation in dense canopies; (b) sensitive to both photosynthetic and non-photosynthetic biomass; and (c) less affected by atmospheric conditions. Our primary objective was to analyze a recently developed long-term VOD record and investigate how the vegetation water content of various land-cover types responded to environmental changes and human influences from 1988 to 2008.

Data and Methods
We first conducted Mann–Kendall trend tests on global 0.25-degree annual average VOD dataset to identify regions with significant changes over the period 1988–2008. To diagnose the underlying cause of the observed significant changes, patterns for these identified regions were further compared with independent datasets of precipitation, crop production, deforestation and fire occurrence.

Results

Figure 1. (a) Annual average VOD for 1988–2008. Regions probably affected by open water area masked in grey and excluded from the analysis in this study. (b) Biome classes based on University of Maryland scheme.

Figure 2. Areas with significant changes (P<0.05) in annual average VOD for 1988–2008 (Unit: VOD change per year). Nineteen regions selected for further analysis are outlined.

Figure 3. Annual precipitation (mm, bars) and average VOD (line) for 1988–2008 for eight different regions. Also listed is the Spearman correlation coefficient (r) between precipitation and VOD.

Figure 4. (a, b) Magnitude of VOD trends for 1988–2008 over the American tropics and Southeast Asia. (c, d) Deforestation hot spots in 1990s. (e, f) Estimated tropical forest loss rates between 2000–2005.

Figure 5. Annual average VOD and annual production of major crops for five regions. Also shown are the Spearman’s correlation coefficient (r) between VOD and annual production.

Figure 6. Magnitude of VOD trends (1988–2008) over (a) Alaska and western Canada, (b) west Russia and (c) East Russia. (d–f) the average number of fire observations per year (2001–2008) estimated from the MODIS fire product.

Conclusions
Passive microwave remote sensing of VOD can be used to monitor global changes in total aboveground vegetation water content and biomass over grassland, shrubland, croplands, humid tropical forest and boreal forest. This new observational record can help in hydrological, agricultural, ecological and climate change studies, and provides new insights into large-scale vegetation change and its drivers.