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mechanisms. A recent global study has detected a subtle increase in RH in northern peatlands over the last four decades¹⁷ (Supplementary Fig. 1), suggesting that the actual water vapor (AVP) increases at approximately the same rate as the saturation water vapor (SVP) (RH = f(AVP, SVP)). This may be due to the unique surface characteristics of the water-rich environment and the high moss cover in the northern peatlands, which supplies sufficient atmospheric water to meet the increasing water demand caused by high VPD¹⁸ and to maintain the atmospheric water balance. If RH remains unchanged,

warmi(S00033.66661(s)0(u)9999923(n)13.6lo000076(m)19(one)-345(w)999694(i)18.8ma000152(ic)32..80000305(h)20.59999961(e)-165.600038(r

Vegetation responses to rising VPD caused b concurrent warming and decreasing RH in global nonpeatland regions

Increasing VPD caused by concurrent warming and decreasing RH led to a stronger suppression impact on GPP in global nonpeatland regions. Ta (mean \pm 1 se, 0.027 \pm 0.003 °C yr⁻¹, p < 0.001) and VPD (0.018 \pm 0.001 hPa yr⁻¹, p < 0.001) increased significantly during 1982–2018, but RH ($-0.027 \pm 0.005\%$ yr⁻¹, p < 0.001) decreased

significantly in global nonpeatland regions (Fig. 3a–c). From 1982 to 2018, ~60% of the global nonpeatland regions showed an increasing VPD trend with significantly increasing Ta and significantly declining RH (p < 0.05, Supplementary Fig. 4). When the detrended Ta, radiation,

-58.2% with a significant negative correla-Supplementary Fig. 5). The regional mean ged from -0.16 to -0.21 for the three satellite-3d). The spatial coverage of significantly negative was 40% higher and the regional mean PCOR_{GPP vs. VPD} er in the global nonpeatland regions than those in the peatlands (Fig. 3d).

further assess the robustness of the divergent drivers and acts of increasing VPD, the global nonpeatland regions were divied into nonhumid regions (AI < 0.65) and humid regions (AI \ge 0.65) based on the aridity index (AI, Methods)³¹. From 1982 to 2018, changes in the temporal trends of Ta, RH, and VPD in the nonhumid regions and the humid regions were consistent with those in the entire nonpeatland region (Supplementary Figs. 4, 6). The PCOR analyses, when the detrended Ta, radiation, wind speed, and precipitation were considered, showed that the spatial coverage of significantly negative PCOR_{GPP vs. VPD} were 59.5% higher (mean of the three satellite-derived GPP) in the nonhumid regions and 25.4% greater in the humid regions, respectively (p < 0.05, Supplementary Figs. 5, 6), than those in the northern peatlands. In addition, a lower regional mean PCOR_{GPP vs. VPD} from three satellite-derived GPP was observed in the nonhumid regions (-0.32) and the humid regions (-0.14) compared to the northern peatlands (0.06) (Supplementary Figs. 5, 6).

The VPD effects based on satellite-derived GPP in the northern peatlands and the global nonpeatland regions were validated by comparison against results with 113 eddy covariance flux towers. Observational data showed that detrended VPD was significantly negatively correlated with detrended GPP at 1 out of 18 (5.6%) eddy covariance flux towers in the northern peatlands and 43 out of 95 (45.3%) towers in global nonpeatland regions, respectively (p < 0.05,

Fig. 3d). Grouping the 95 eddy covariance flux towers into the nonhumid regions (33 towers) and the humid regions (62 towers) further confirmed a greater VPD suppression impact in the global nonpeatland regions compared to the northern peatlands, with a significantly negative PCOR_{GPP vs. VPD} of 63.6% and 35.5% in the nonhumid regions and the humid regions, respectively (Supplementary Fig. 6). In addition, according to the latitude, longitude, and time span in 113 eddy covariance flux towers, we found that the symbols (±) of the satellitederived PCORGPP vs. VPD agreed with 76.4% (mean value from three satellite-derived GPP) of the eddy covariance flux towers (Supplementary Fig. 7, Methods). In addition, the satellite-derived PCOR_{GPP vs.} $_{\mbox{\scriptsize VPD}}$ was positively correlated with eddy covariance $\mbox{\scriptsize PCOR}_{\mbox{\scriptsize GPP}}$ vs. $_{\mbox{\scriptsize VPD}}$ with *r* values ranging from 0.51 to 0.58 (p < 0.05, Supplementary Fig. 7). In summary, the field-scale and grid-scale observations consistently suggested that the prevailing viewpoint derived from the global nonpeatland regions may overestimate the VPD suppression impact in the northern peatlands.

Mechanisms for the divergent VPD effects

Six plant traits and environmental factors were used to understand the causes of the contrasting VPD effects. Soil hydraulic properties were

H₂O lower and 0.22 higher than the global nonpeatland regions, respectively (mean ± 1 se, 1.23 ± 0.01 vs. 1.84 ± 0.01 g C kPa^{0.5} kg⁻¹ H₂O, 0.13 ± 0.01 vs. -0.09 ± 0.006) (Fig. 4c). Overall, plants in the northern peatlands tended to adopt an "open" water-use strategy with lower uWUE and higher PCOR_{Et vs. VPD} in response to increasing VPD, leading to a weaker suppressive impact on vegetation growth compared to the global nonpeatland regions.

We further assessed the robustness of the satellite-derived differences in the plant traits between the northern peatlands and the global nonpeatland regions using eddy covariance flux towers. As the proxy for the plant water-use strategy, the uWUE in the northern peatlands was $0.78 \text{ g C } \text{ kPa}^{0.5} \text{ kg}^{-1} \text{ H}_2\text{O}$ lower than that in the global nonpeatland regions (mean $\pm 1 \text{ se}$, $1.10 \pm 0.12 \text{ vs}$. $1.88 \pm 0.10 \text{ g C } \text{ kPa}^{0.5} \text{ kg}^{-1} \text{ H}_2\text{O}$) (Fig. 4c). Compared to the global nonpeatland regions, weak stomatal regulation and an abundant atmospheric water supply in response to increasing VPD in the northern peatlands were also confirmed by the eddy covariance flux datasets. For stomatal activity, a significant negative response of *Gc* to VPD was found in only 5.6% of the eddy covariance flux towers in the northern peatlands (coefficient mean ± 1 se, 0.04 ± 0.08), whereas this percentage increased to 52.6% in the global nonpeatland regions (-0.27 ± 0.04) (p < 0.05, Fig. 4c, Methods). As a proxy for atmospheric water supply with increasing VPD, a significant negative response of evapotranspiration (ET) to VPD

open water⁴⁷. Under the same environmental conditions, our synthesized observations showed that the ET of moss was significantly greater by 0.43 ± 0.14 mm day⁻¹ (mean ± 1 se) than that of vascular plants (p = 0.009, Supplementary Fig. 9). The moss-dominated wet system of the northern peatlands allowed ET and Et to increase with increasing VPD¹⁸. Therefore, a sufficient atmospheric water supply allowed increases in AVP in approximately the same proportion as the SVP, leading to increasing VPD induced by warming alone in the northern peatlands.

A neutral response of vegetation growth to warming-induced increased VPD was observed in the northern peatlands. This is contrary to the prevailing views that increasing VPD induced by the coaction of warming and decreased RH markedly depressed vegetation growth in global nonpeatland regions^{6-10,22,49}. A relatively dry environment in the global nonpeatland regions can limit atmospheric water supply under increasing VPD, disrupting the supply-demand balance of atmospheric water conditions and exacerbating atmospheric water stress²⁷. This can increase the hydraulic burden of plants, limiting their stomatal activity to preventing excessive water loss at the expense of photosynthesis^{16,50}. In contrast, the moss-dominated wet system of the northern peatlands can provide adequate atmospheric water to meet the increased water demand caused by increasing VPD. Even if atmospheric water stress occurs as warming-induced VPD increases, the stress may be below the threshold that leads to stomatal closure, as evidenced by the neutral response of Gc, Et, and GPP to increasing VPD. In this wet soil-air environment, plants adopt an "open" water-use strategy in response to water stress, maximizing carbon uptake by relaxing stomatal regulation^{24,29}. Although an "open" water-use strategy may sacrifice hydraulic security, plants in water-rich environments would benefit more from keeping their stomata open to take up carbon than from conserving water^{29,41}. Multisource datasets consistently demonstrated that plants in the northern peatlands were believed to The warming experiment at the Mohe site was conducted in a peatland in the northern Greater Hinggan Mountains (Tuqiang Forestry Bureau in Mohe city, Heilongjiang Province; 52.93°N, 122.83°E). The peatland is characterized by a humid monsoon climate in a cold temperate zone with a mean annual temperature and precipitation of -3.9 °C and 450 mm, respectively. The growing season lasts for *c*. 120 days, from mid-May to mid-September. Four common native plant species in the plant community are *Sphagnum palustre* (SP), *Vaccinium uliginosum* (VU), *Ledum palustre* The flux tower-based GPP, latent heat flux (LE, W m⁻²), sensible heat flux (H, W m⁻²), and environmental variables of Ta, VPD, precipitation, shortwave radiation, wind speed (m s⁻¹), friction velocity (u₈, unitless), and atmospheric pressure were obtained from the global eddy-covariance flux dataset, FLUXNET2015 (global nonpeatland regions) and FLUXNET-CH₄ Community Product (northern peatlands). Following recent studies on VPD effects, we used GPP estimates based on the nighttime partitioning method (i.e., "GPP_NT_VUT_REF")^{7,20}. We identified and used sites with at least 3 years (more than 15 months) of high-quality data (\geq 75% of good quality data in a month)⁶³. In addition, we removed all cropland towers in the study area to exclude the effects of human activity⁷

and the mean *r* was >0.8 in this study. In the analyses, one of the predictor variables was perturbed by one standard deviation (a value of 1 due to the initial input data normalization), and PCOR_{GPP vs. VPD} was predicted again using the existing random forest model with the pre-

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Author contributions

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Competing interests

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Additional information