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Net water vapour exchange over a mixed needle and broad-leaved forest in Changbai Mountain during autumn

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Water vapour and CO2 fluxes were measured by the eddy-covariance technique above a mixed needle and broad-leaved forest with affiliated meteorological measurements in Changbai Mountain as part of China´s FLUX projects since late August in 2002. Net water vapour exchange and environmental control over the forest were examined from September 1 to October 31 in 2002. To quantify the seasonal dynamics, the transition period was separated into leafed, leaf falling and leafless stages according to the development of leaf area. The results showed that (a) seasonal variation of water vapour exchange was mainly controlled by net radiation (Rn) which could account for 78.5%, 63.4% and 56.6% for leafed, leaf falling and leafless stages, respectively, while other environmental factors´ effects varied evidently; (b) magnitude of water vapour flux decreased remarkably during autumn and daily mean of water vapour exchange was 24.2 mg m-2 s-1 (100%), 14.8 mg m-2 s-1 (61.2%) and 10.3 mg m-2 s-1 (42.6%) for leafed, leaf falling and leafless stage, respectively; and (c) the budget of water vapour exchange during autumn was estimated to be 87.1 kg H20 m-2, with a mean of 1427.2 g H20 d-1 varying markedly from 3104.0 to 227.5 g H20 m-2 d-1.

Net water vapour exchange over a mixed needle and broad-leaved forest in Changbai Mountain during autumn WEN Xuefa1, YU Guirui1, SUN Xiaomin1, LI Qingkang1, REN Chuanyou1, HAN Shijie2 (1. Inst. of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China; 2. Institute of Applied Ecology, CAS, Shenyang 110016, China) 1 Introduction The elucidation of the circulation of carbon, water and other greenhouse gases and their budgets in various land ecosystems is an important task (Baldocchi et al., 2001). The response of vegetation to the environment is a key global change issue that scientists are investigating by means of measurements and models on short and long-time scales (Law et al., 2002), especially for the seasonal transition periods (Kellomaki and Wang, 1999; Barford et al., 2001). Direct and long-term measurement of canopy-scale carbon dioxide and water vapour fluxes are needed over various ecosystems to inform us about their seasonal variation and magnitude. Canopy-scale carbon dioxide and water vapour are also needed to quantify the effect of environmental and physiological forcing factors on these fluxes and to provide data for the testing of ecosystem carbon and water balance models (Greco and Baldocchi, 1996). However, direct long-term measurements of canopy-scale carbon dioxide and water vapour fluxes have recently become possible (Baldocchi et al., 1988; Wofsy et al., 1993). Most notable are the studies made in Harvard Forest (Wofsy et al., 1993; Goulden et al., 1996) started in 1990, at Oak Ridge (Greco and Baldocchi, 1996), and during the BOREAS project (Goulden et al., 1997; Jarvis et al., 1997). With the establishment of an international network, FLUXNET (Valentini et al., 2000; Baldocchi et al., 2001), we now have available a large body of data on terrestrial ecosystem exchange of mass and energy that are integrated at the stand level, with accompanying meteorological and biological measurements (Berbiger et al., 2001; Pilegaard et al., 2001). However, relatively few long-term studies of water vapour and CO2 fluxes by the eddy-covariance technique have been made until now in China (Zhu et al., 2001; Zhang et al., 2002). In this paper, the subdata set collected from September 1 to October 31 in 2002 was chosen for this study and we mainly focus on (a) relationship between water vapour flux and environmental variables and (b) variation and magnitude of water vapour exchange during autumn in Changbai Mountain, Northeast China. 2 Materials and methods 2.1 Site description The site (42o24´0 9´´ N, 128o05´45´´E, elevation 738 m) is located near Erdaobaihe town of Jilin province. It is placed in an about 200-year needle and broad-leaved forest with an average tree height of 26 m and is mainly made up of Korean pine (Pinus koriaensis), Tuan linden (Tilia amurensis), Mongolian oak (Quercus mongolica), Manchurian ash (Fraxinus mandshurica) and

Mono maple (Acer mimo). Stand density is 560 stems ha-1. Peak leaf area index is about 6 m2 m-2 in late July. The terrain is flat and there is at least a homogeneous fetch of 500-2000 m for all directions. The annual mean air temperature was 3.6oC and annual mean precipitation was 713 mm observed about 1 km away from east to the site (1982-2000). 2.2 Measurement and instrumentation The experiment was started on August 24, 2002 and has continued to collect data since then. Eddy covariance fluxes were measured at a height of 40 m (14 m above the canopy). Wind speed and temperature fluctuations were measured with a three dimensional sonic anemometer (Model CSAT-3, Campbell Scientific) mounted on a 62 m observation tower. CO2 and water vapour density fluctuations were measured by a CO2/H2O open-path analyzers (Model LI-7500, Licor Inc.). Data were recorded by a CR5000 datalogger (Model CR5000, Campbell Scientific) and then block-averaged to 10 Hz for analysis and archiving. To minimize flow distortion the sensors were mounted on 3 m long booms directed southwest so that instruments faced the dominant wind direction (southeast). Additional meteorological measurements were also undertaken. Radiation measurements were made at 32.0 m using a four-component net radiometer (Model CNR-1, Kipp and Zonen) and a pyranometer (Model CM11, Kipp & Zonen) and photosynthetically active radiation (PAR) with a quantum sensor (LI190SB, Licor Inc.). Moreover, photosynthetically active radiation (PAR) under the forest was measured at 2 m by five quantum sensors bars (LQS70-10, Apogee Inc.). Temperature and relative humidity sensors (Model HMP45C, Vaisala Inc.) were mounted in ventilated mounts (Model 41002, RM Young, Inc.) at seven levels (2.5, 16, 22, 26, 32, 50 and 60 m). Two soil heat flux plates (Model HFP01_L, Hukseflux Inc.) were buried at 5 cm below the soil surface in different microenvironments. Soil temperatures were measured at five depths (1, 5, 20, 50 and 100 cm) by thermometers (105T and 107-L, Campbell Scientific). Soil water contents were measured with three TDR probes (Model CS615-L, Campbell Scientific) at depths of 5, 20 and 50 cm. Rainfall was measured by rain gauge (Model 52203, RM Young, Inc.). Data were recorded by three CR10X (Model CR10XTD, Campbell Scientific) and a CR23X (Model CR23XTD, Campbell Scientific) with a 25-channel solid state multiplexer (Model AM25T, Campbell Scientific) datalogger respectively. 2.3 Data processing The eddy covariance technique was used to estimate the flux of water vapour between forest and the atmosphere. Our measurement system produced the above-canopy eddy fluxes of latent heat at 30-min intervals. Correction was made to latent heat flux for the water vapour density effect (Webb et al., 1980). And affiliated meteorological measurements were also averaged at 30-min intervals for analysis. The water vapour flux (latent heat flux) is defined: E = ■ + ■■dz (1) where the first term on right-hand side is the eddy flux for water vapour, and the second term is the storage below the height of observation (zr). Here we ignored the horizontal and vertical advection effects because the terrain is flat and the fetch is large enough (Lee, 1998; Baldcchi et al., 2000; Lee and Hu, 2002). We also noted that Equation (1) provided the theoretical framework that is being used by a majority of the FLUXNET community (Wofsy et al., 1993; Black et al., 1996; Aubinet et al., 2000). The quality checking procedure described by Aubinet et al. (2000) was found too restrictive and did not allow continuous accumulation. As for water vapour flux, we limited ourselves to removing spurious values when their cause was clearly identified and, at night, where problems frequently occurred, to checking that the 30 min energy balance gap was not too different from zero (namely not greater than 100 Wm-2 in absolute value). The problems were, in most cases, related to rainfall or water condensation, which affected both sensible and latent heat fluxes (Berbiger et al., 2001). The spurious data were eliminated, and the remaining data are 78.2% (21.8% gap). The short gaps (due to data transfer and rainfall) of up to 1-2 h were filled by interpolation. The longer gaps were filled by relationship of linear regression between latent heat fluxes (LE) and net radiation (Rn) and a better empirical relationship (Berbigier et al., 2001) as follows (Figure 1): LE = 0.253Rn + 23.82, R2 = 0.713*** (2) 3 Results and discussion 3.1 Meteorological conditions During the autumn-winter transition from September 1 to October 31 in this study, the overall mean of air temperature (at 32 m) was 9.6 oC and the daily mean of air temperature was variable with a range of -7.9 to 17.1 oC. In contrary to air temperature, soil temperature at 1 cm depth had a smaller amplitude ranging from 2.5 to 16.4 oC with a mean of 9.8 oC (Figure 2A). Soil water content (5 cm depth) ranged from 0.25 to 0.44 m3 m-3, experiencing a slight drought without evident effect on water vapour exchange because of higher values still remaining (Figure 2B) and soil water content was closely related to precipitation. Sum of precipitation during autumn was 68.9 mm. Air saturation deficit was also variable with a daily mean decreasing from 1.59 to 0.21 kpa (Figure 2C). Net radiation varied significantly from 12.6 to -0.7 MJ m-2 d-1, and decreased gradually during autumn (Figure 2D). 3.2 Seasonal dynamics We did not collect the leaf area index data during this study. However, LAI must play an important role on water vapour exchange of the forest during autumn (Kellomaki and Wang, 1999; Barford et al., 2001). To quantify the seasonal changes of the LAI, we made use of light intercept indicating the seasonal trend of LAI (Blaken et al., 2001). The graph indicated that leaves fall since about September 24, 2002 and cleared away around October 4, 2002 (Figure 3). Thus, we separated the transition period into three stages, that is, leafed stage (September 1-24), leaf falling stage (September 25-October 4) and leafless stag

e (October 5-31) in order to quantity the environmental factors´ role during the seasonal transition. Daily mean trends of water vapour exchange (latent heat flux) for leafed, leaf falling and leafless stages were presented in Figure 4. Student t-pairs test showed that water vapour exchange varied significantly at 0.01 levels for different stages. In order to determine the effects of environmental factors of net radiation (Rn), air temperature (Ta), soil temperature (Ts), soil water content (Sw), air saturation deficient (VPD) and precipitation (P) on the water vapour exchange (latent heat flux), we made analysis among them by multiple stepwise regression method for leafed, leaf falling and leafless stages, respectively. The regression results showed that the influence degrees of environmental variables on water vapour exchange (latent heat exchange) as follows: Rn>Ts>VPD>Sw during the leafed stage; Rn>Ta>VPD>Sw during the leaf falling stage and Rn>Sw>P>VPD>Ts>Ta during the leafless stage. Moreover, student t-pairs test also showed that all variables decreased significantly at 0.01 levels except for net radiation at 0.05 levels during the autumn-winter transitions. Seasonal variations in incident sunlight, leaf area index, temperature, precipitation and soil moisture are expected to exert control on the net transfer of water vapour between the vegetation and the atmosphere because these variables control transpiration (Greco and Balldcchi, 1996). Leaf area determines the amount of available transpiring material. The amount of absorbed sunlight establishes an upper limit for canopy evaporation (Greco and Balldcchi, 1996). Those described above were indicated that water vapour exchange was mainly controlled by net radiation and leaf area and other factors´ action varied remarkable during the autumn-winter transition. The linear regression between latent heat fluxes (LE) and net radiation (Rn) showed the net radiation could account for 78.5, 63.4 and 56.6% of water vapour flux for leafed, leaf falling and leafless stages in our study, respectively. 3.3 Net water vapour exchange with the atmosphere The daily mean trends of water vapour exchange (latent heat flux) among leafed, leaf falling and leafless stages varied significantly (Figure 4). Daily mean of water vapour exchange was 24.2 mg m-2 s-1 (with a range of 1.5-73.8 mg m-2 s-1), 14.8 mg m-2 s-1 (0.8-50.0 mg m-2 s-1) and 10.3 mg m-2 s-1 (1.7-31.6 mg m-2 s-1) for leafed, leaf falling and leafless stages. Furthermore, daily sums trend of water vapour exchange (latent heat flux) during autumn varied from 3104.0 to 227.5 g H2O m-2 d-1 with a mean of 1427.2 g H2O d-1 (Figure 5). Our calculated results indicated that net water vapour exchange during autumn was 87.1 kg H2O m-2 (i.e., 87.1 mm). As we know that precipitation was 68.9 mm at the same time (Figure 2B). Thus, during the measurement of this study the water balance of this forest was -18.2 mm, with a mean of -0.3 mm d-1. The phenomena were also common at annual scale (Law et al., 2002) and a positive water balance was observed only at Flakaliden, Sweden (FL) an Manitoba, Canada (NB), both of which are boreal coniferous forests (Lindroth et al., 1998; Goulden et al., 1998). 3 Conclusion Water vapour exchange was mainly controlled by net radiation and leaf area, and the roles of other environmental factors varied remarkably during autumn. Net radiation could account for 78.5, 63.4 and 56.6% for leafed, leaf falling and leafless stages respectively. Daily mean of water vapour exchange was 24.2 mg m-2 s-1 (with a range of 1.5-73.8 mg m-2 s-1), 14.8 mg m-2 s-1 (0.8-50.0 mg m-2 s-1) and 10.3 mg m-2 s-1 (1.7-31.6 mg m-2 s-1) for leafed, leaf falling and leafless stages, respectively. The budget of water vapour exchange from September 1 to October 31 was estimated to be 87.1 kg H2O m-2, with a mean of 1427.2 g H2O d-1 ranging from 227.5 to 3104.0 g H2O m-2 s-1. It is remarkable that we need the continuation of long-term water vapour and CO2 fluxes measurement, at numerous sites, to obtain a sufficiently large pool of data to assess interannual and intra-annual variation in water vapour and CO2 fluxes with better certainty, environmental and physiological forcing factors on water vapour and CO2 fluxes and test of ecosystem water and carbon balance models.

关键词： eddy-covariance; net water vapour exchange; latent heat flux