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養成技術者の研究・研修成果等

１．養成技術者氏名：　王　輝民

２．養成カリキュラム名：　　森林における CO_2 吸収能の測定技術

３．養成カリキュラムの達成状況

渦相関法による森林生態系のCO2吸収能の測定は現在最も精度の高い手法とされている。しかし、この方法は簡単ではなく、専門な技術訓練が必要である。平成13年からの３年間、NEDOフェローとして、私はCO2フラックス観測用の気象測器や赤外分析計等の計測理論、使用方法、メンテナンス、データ回収プログラムの作成、データ品質の管理、解析など幅広い知識や技能を学んだ。その結果、２つの成果を得ることが出来た：１）苫小牧フラックス観測サイトのデータを用いて、カラマツ林CO2吸収能の季節変化、環境要因の影響、及び年間炭素収支について明らかにし、国際誌に発表した。２）収得した観測技術の応用として、2001年中国東北部老山で新たなフラックス観測サイトを設営し、2002年からCO2フラックスの観測を開始した。このサイトでは現在も観測を続けており、観測結果は現在分析中である。更に、各サイト毎に観測したデータから地域的なCO2吸収能を推定するため、国立環境研究所のリモートセンシング研究グループと共同研究し、リモートセンシングデータと森林 CO_2 フラックスとの関係の研究を進めている。様々な植生指標を用いてCO2フラックスの季節変化を分析した結果、GEMIならびにDVIの変化傾向とよく一致することがわかった。以上、本養成カリキュラムでの４つの目標についてすべて達成することができた。

４．成果（Ａ４版３枚程度）

１）. Set up a new flux observation site-- Laoshan site

Since my work in AIST as a NEDO fellow in June 2001, I was mainly responsible for the preparation of field CO_2/H_2O flux observation in northeast China (Laoshan site). I studied the working principle, operation, calibration and maintenance methods of various kinds of meteorological instruments. Several computer programs have also been created for driving data loggers to record the observed meteorological data automatically. In September 2001, I went to China with two scientists in AIST, and set up some meteorological instruments on a tower of 20 m high with the helps from Chinese cooperators.

After several months of careful preparation, a closed path flux observation system had been successfully installed at the Laoshan site in May 2002, and more meteorological instruments had been set up. Presently, we are measuring CO_2/H_2O, energy and also momentum fluxes; simultaneously meteorological items, such as air temperature, air humidity, air pressure, precipitation, short wave and long wave incident and canopy reflected radiations, net radiation, photosynthetically active radiation (PAR), canopy transmitted PAR, soil temperature, soil water content, and soil heat flux. In May 2003, a set of sap flow sensor was newly set up at Laoshan site to evaluate the forest transpiration. The observation system in Laoshan site is shown in Fig. 1.

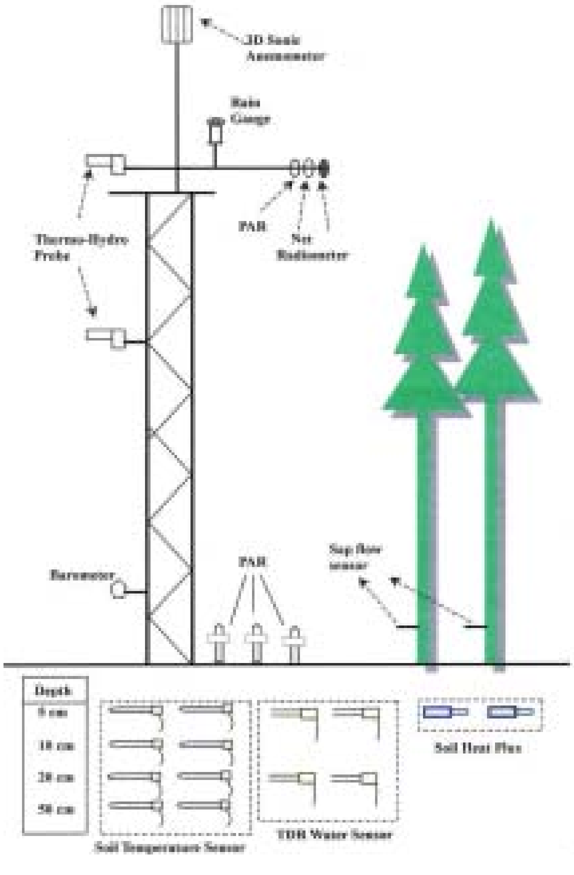

Fig. 1. A rough sketch of Laoshan flux observation site

To analyze the large amount of obtained flux data, I have created a data processing program to calculate, calibrate and analyze the eddy flux data for Laoshan site with the help of colleagues in our research group. At present, I am responding to the maintenance of instruments and also flux data analysis of Laoshan site.

2) **Analysis of CO_2 flux data obtained at Tomakomai site (please reference the attached paper)**

Terrestrial ecosystems are expected to affect the climate changing process by uptake atmospheric CO_2 via photosynthesis. Temperate and boreal forest awarded particular attention because they comprise almost 50% of the world forest and thought to be a major carbon sink (Tans et al, 1990, Baldocchi and Vogel, 1996). Larch forests are dominant vegetation types in boreal region in Eurasian continent, and are considered to take essential role on mitigating the climate warming (Gower and Richards, 1990). To better understand the characteristics of carbon exchange between larch forest and atmosphere at present state so as to evaluate the carbon sequestration ability of the important biome, we carried out a long-term flux monitoring study using eddy covariance technology in a larch forest in Tomakomai (42 44'N, 141 31'E), northern Japan. As a part of my training course for the NEDO Fellow in AIST, I made an analysis, using flux data observed at Tomakomai site in 2001, on the seasonal variation of CO_2 flux, and assessed the CO_2 assimilation ability of the Larch forest during the whole growing season. The negative (positive) flux value indicates that the forest ecosystem absorbs (releases) CO_2 and H_2O. The results indicated that the larch forest at Tomakomai site is a strong carbon sink.

Seasonal and diurnal variation of net CO_2 exchange

The daily Net Ecosystem Exchange (NEE: the residual between ecosystem photosynthesis and the respiration) between the larch forest and atmosphere is strongly varied with season. Before the foliation from January to April, the larch forest acted as a small carbon source (small plus value). With the foliation in May, the forest rapidly switched from carbon source to sink and reached the maximum uptake ability to 10.5 $\mu mol/m^2/s$ at the day 160, and then gradually decreased with time. With the yellowing and senanscing of leaf and the defoliation of larch forest, the forest changed to CO_2 sources again by the end of October (day 301). This variation pattern of CO_2 exchange is rather similar to that of the deciduous boreal aspen forest reported by Chen et al (1999).

The CO_2 assimilation ability of the larch forest also clearly varied with diurnal time. Within a day, the larch forest released CO_2 into the atmosphere during the night and assimilated atmospheric CO_2 in the daytime in the growing season. However, the net CO_2 assimilation of the forest ecosystem did not appear soon after the sunrise, but with a time delay ranged from 1 to 2 hours; this might be the reason that the photosynthetic efficiency is too weak to compensate the forest respiration due to the weak radiation and the relatively low temperature in the early morning. With the increasing radiation and temperature, the photosynthesis rises and reached maximum CO_2 assimilation ability within 2 hours before the noon for all the growing season. After then, the net CO_2 assimilation decreased and became smaller than the forest respiration before the sunset, as a result, the larch forest turned to a carbon source again.

The larch forest clearly showed a seasonal variation on CO_2 assimilation ability. The forest presented the highest uptake rate in summer (June, July and August), and peaked in June as high as ca. 25 $\mu mol/m^2/s$. While the CO_2 assimilation rates were very low in May and October. In May, the larch leafs had not been fully expanded, the low photosynthetic leaf area are considered to be the most important reason, while the yellowing and senescence of the forest foliage and defoliation should be responsible for the low CO_2 uptake rate in October.

Effects of environmental factors on CO_2 fluxes

Forest assimilates atmospheric CO_2 via photosynthesis and releases CO_2 via respiration. The balance between photosynthesis and respiration determines whether an ecosystem sequestering or releasing carbon. To analysis the relation of CO_2 efflux and temperature, we selected the windy night flux data with friction velocity (u*) higher than 0.2 m/s following previous studies to reduce the error (Monson et al, 2002), because the net ecosystem exchange (NEE) is the sum of observed CO_2 flux (Fc) and forest storage (Fs); the storage most likely to be significant during the night when the atmosphere is stably stratified and winds are weak (Baldocchi et al., 1997). Our analysis demonstrated that the night respiration of the forest highly correlated with temperature. The Q_{10} (the ratio of the rate of a process at one temperature to that at a temperature 10℃ lower) was estimated to be 3.0. This value is higher than that estimated in boreal larch forest in eastern Siberia (Hollinger et al, 1998), boreal jack pine stand (Baldocchi et al, 1996) and also a temperate deciduous forest stand (Greco and Baldocchi, 1996); there the Q_{10} value was 2.3, 2.6, and 1.6, respectively. This correlation was also used to fill the flux data gaps for leafless season and nighttime in growing season.

Gross Primary Production (GPP: total carbon fixed by vegetation via photosynthesis) is expected to be a function of parameters such as LAI, photosynthesis active radiation (PAR), air temperature, and air humidity. In practice, GPP is usually simply estimated from incident PAR or intercepted PAR using a saturating model expressed as Eq (a) when other parameters were considered to be at the same level (Hollinger et al, 1998, Saigusa et al, 2002; Monson et al, 2002).

$GPP = P_{max} * PAR / (PAR + P_{max}/\alpha)$……………………………………..(a)

Thus, during the daytime in growing season, we have:

$NEE = Re - GPP = - P_{max} * PAR / (PAR + P_{max}/\alpha) + Re$……………………(b)

Here, Re is respiration. P_{max} and α is the maximum level of photosynthetic capacity and the light use efficiency of the canopy level, respectively.

Both P_{max} and α reached their maximum values as high as 42 μmol $CO_2/m^2/s$ and 0.10 μmol CO_2/μmol photons, respectively, in June. After or before then, P_{max} and α gradually declined with time. When in October, the P_{max} and α was decreased to 17.7 μmol $CO_2/m^2/s$ and 0.029 μmol CO_2/μmol photons, respectively. The senescing of foliage and foliation were expected to be responsible for the low P_{max} and α values in autumn season.

Monthly and annual carbon sequestration

Generally, the larch forest acted as a small carbon source during the leafless season (from Nov. to Apr.), which totally released 100 g C/m^2, and strong carbon sink in growing season (from May. to Oct.), which sequestrated 340 g C/m^2. The forest reached the maximum assimilation ability of 186 gC/m^2/mon in June. Totally, the larch forest in Tomakomai flux site was a strong carbon sink, sequestered 240 gC/m^2/yr, which is much higher than that observed in east Siberia by Hollinger et al (1998).

3）. Correlating the field observation flux data with remote sensing indexes

To extend the field observation flux data to a region or continental scale, remote sensing technique is expected to be a useful tool. By cooperation with remote sensing research group, we are trying to correlate the field observed flux data to various remote sensing vegetation indexes. Our preliminary result indicated that the GEMI (Global Environmental Monitoring Index) and DVI (Difference Vegetation Index) are rather better parameters reflecting the seasonal variation of field observed carbon flux. Further studies are in progress.

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５．成果の対外的発表等

（１）論文発表（論文掲載済、または査読済を対象。）

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（３）特許等（出願番号を記載）

なし