Department of Global Resources

The mission of the Department of Global Resources is expressed by 2 broad global environmental research goals: to assess the agro-ecological impacts of unusual climatic variations and global warming, and to develop adaptive technical and policy measures to reduce any adverse impacts by clarifying climate-change mechanisms and by monitoring and modeling. These missions are the concern of 2 research groups— the Agro-Meteorology Group and the Ecosystems Group— and 3 teams— the Greenhouse Gas Emission Team, the Food Production Prediction Team, and the Ecosystem Gas Exchange Team.

Research projects are initiated in domains such as 1) prediction of food production under global environmental variability; 2) elucidation of the impacts of global climate change on agro-ecosystems; 3) estimation of greenhouse gas emissions from agricultural activities and development of measures that can be used to minimize emissions; 4) determination of the effects of human activity, especially the flow of carbon and nitrogen; 5) development of techniques for remote sensing and multivariate statistical analysis; and 6) assessment of changes in rural land use.

Some of our research projects are involving in the Global Warming Research Initiative and Water Resources Research Initiative, which are managed under the Council for Science and Technology Policy. The goal of our projects is to formulate an adaptable scenario of greenhouse gas emissions that will help stabilize climate change within a range that is compatible with human civilization.

1) Agro-Meteorology Group

The mission of the Agro-Meteorology Group is to clarify predictions of the impacts on agricultural ecosystems of climate change and elevated atmospheric CO_2 levels and of the resulting atmospheric changes in such ecosystems. The Agro-Meteorology Group consists of 3 units: 1) Climate Resources Unit; 2) Atmospheric Impacts Unit; and 3) Air Quality Conservation Unit.

The research aim of the **Climate Resources Unit** is to develop monitoring techniques for evaluating the effects of climate change and elevated CO_2 on agricultural water resources, and to develop methods for predicting these changes. The research objective of the **Atmospheric Impacts Unit** is to develop models for predicting the effects of elevated atmospheric CO_2 on agricultural ecosystems by analysis of the results of free air CO_2 enrichment (FACE) experiments. The research of the **Air Quality Conservation Unit** is focused on clarifying the processes of emission, diffusion, and deposition of air components such as trace gases, pollens, and dust in agricultural ecosystems.

In FY 2004, the following research was conducted by the 3 units: 1) investigation and prediction of spatio-temporal change in agricultural water resources; 2) development of a dynamic water model for evaluating agricultural water quality on a regional scale; 3) impact assessment of climate change from the viewpoint of agricultural production management; 4) modeling of spatial and temporal dynamics of the soil carbon budget; 5) prediction of the impacts of atmospheric CO_2 increase on crop production and water use; 6) process-based modeling of agricultural ecosystems under rising temperatures and increasing atmospheric CO_2 concentrations; 7) investigation of the impact of increasing atmospheric CO_2 on heat stress in crop plants; 8) modeling and simulation of canopy microclimate and fluid dynamics for developing open-air warming systems; 8) determination of the developmental and morphological responses of rice to elevated atmospheric CO_2 concentrations; 9) development of a system for estimating and testing cultivar coefficients of rice development models utilizing existing data; 10) modeling and estimation of the emission and diffusion processes controlling air quality in agro-ecosystems; 10) examination of the relationship between ground surface conditions and aeolian dust events; 11) assessment of the effects of temporal and spatial variations in the bio-meteorological environment on alpine grassland ecosystems; 12) assessment of the climate mitigation function of agricultural land; and 13) a feasibility study on the linkage of regional climate change with intra-seasonal and inter-annual variations in the concentrations of ozone and its precursors over Japan.

Twenty-two original research papers were published in international and domestic journals in FY 2004. The 21st Meteorology Workshop, entitled “Aeolian dust (kosa) problem and agricultural activity”, was organized by the Air Quality Conservation Unit and held at NIAES on 3 March 2005. Dr. Mingyuan Du, a senior researcher in the Air Quality Conservation Unit, won the progress award of the Japanese Association for Arid Land Studies for his outstanding research on climate and human activity in the arid areas of China, with a particular focus on the Taklamakan Desert.

Topic 1: CO_2, CH_4, and N_2O fluxes from soybean and barley double-cropping in relation to tillage in Japan

Human activity is leading to the atmosphere emission of vast quantities of greenhouse gases and is thus making global warming a reality. If we are to prevent global warming, we will need to control the emission of these greenhouse gases. In terms of carbon equivalents (the sum of emissions of each type of greenhouse gas multiplied by the gas's global warming potential (using factors of 1 for CO_2, 21 for CH_4 and 310 for N_2O)), the total amount of greenhouse gases emitted by the agricultural sector as a proportion of that from all sectors in Japan in FY 2001 was 2.6%; thus, the contribution of the agricultural sector is low. However, the agricultural sector emits high proportions of the total amount of CH_4 (67%; enteric fermentation 33% and rice cultivation 29%) and the total amount of N_2O (57%; manure management 34% and agricultural soil 23%) (National GHGs Inventory Report of Japan 2003, Ministry of the Environment of Japan, 2003). Therefore, the agriculture sector needs to reduce its emissions of CH_4 and N_2O.

Upland fields emit large volumes of N_2O and absorb small amounts of CH_4. Agricultural soils also emit CO_2, and soil CO_2 emissions are strongly dependent on plant and soil microbial activity, which in turn are influenced by temperature. N_2O and CO_2 emissions from upland soils are responsive to management, including appropriate selection of crop species, tillage, and application of fertilizers and manure. CO_2 emission due to soil respiration is often stimulated by tillage. On the other hand, no-tillage cultivation may increase N_2O emissions because of the likelihood of the soil being maintained in a wet condition and becoming anaerobic. Although the number of studies of greenhouse gas emissions from agricultural fields is increasing, there is still only limited research into the reduction of emissions by improvement of farming management.

No-tillage cultivation (Photo 1) is of interest as a farming management technique for greenhouse gas emission reduction. Tillage cultivation accelerates carbon oxidation of organic residue in soil by increasing soil aeration, and it accelerates soil erosion by increasing exposure to wind and rain. In contrast, no-tillage cultivation can reduce water and wind erosion, conserve soil moisture, and reduce fuel costs. About 37% of the land farmed in the United States is now managed by the use of conservational tillage systems, including no-tillage. However, because Japan has a mild and humid climate that allows thick weed growth, plowing (conventional tillage) is yet usually conducted as a control technique for weed.

To examine whether no-tillage cultivation of upland fields mitigates greenhouse gas emissions from agriculture, we measured seasonal changes in CO_2, CH_4, and N_2O emissions under conventional tillage and no-tillage

Photo 1 Soil respiration chamber placed among soybeans under no-tillage cultivation.

over a whole year (13 May 2002 to 13 May 2003) at Tsukuba, Japan, which has a temperate climate. The soil respiration rate increased with increasing soil temperature (Fig. 1). The annual soil respiration rate was 2845 ± 967 g CO_2 m^{-2} y^{-1} in the conventional tillage plot and 2198 ± 656 g CO_2 m^{-2} y^{-1} in the no-tillage plot; the annual soil respiration rate under no-tillage conditions thus showed a 23% decrease compared with that under conventional tillage, but the difference was not significant. When organic matter was incorporated into the soil of the conventional tillage plot by plowing in the crop residue after harvest, the soil respiration rate and N_2O flux increased rapidly (Fig. 2). The majority of the difference between the conventional tillage and no-tillage plots in terms of annual soil respiration rate (647 g CO_2 m^{-2} y^{-1}) was accounted for by the difference in the rate during

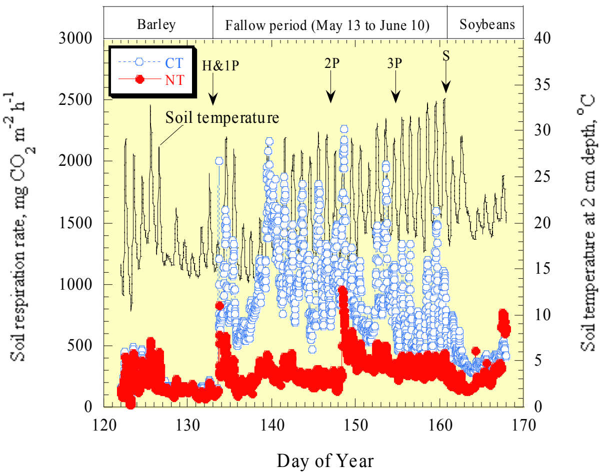

Fig. 1 Daily changes in soil respiration rate over 50 days (2 May to 16 June 2002) during barley growing, harvesting (H), and 3 plowings (1P to 3P) and during sowing (S) of soybeans, with data on soil temperature at a depth of 2 cm. CT: conventional tillage; NT: no-tillage; FA: fertilizer application.

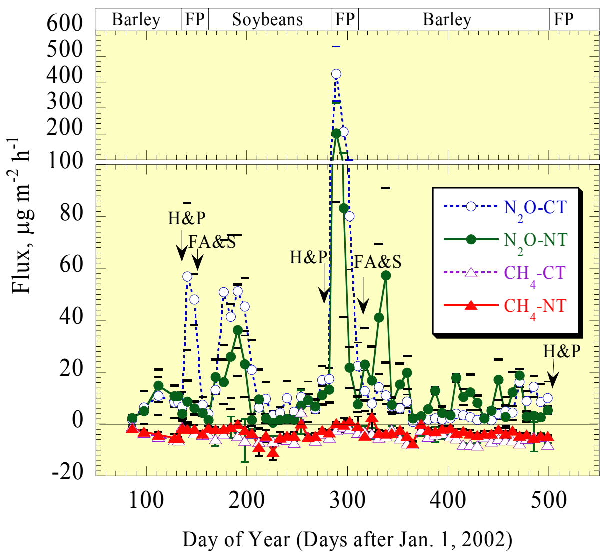

Fig. 2 Seasonal changes in CH_4 and N_2O fluxes over the whole year from conventional tillage and no-tillage plots under a double-cropping agro-ecosystem. CT: conventional tillage; NT: no-tillage; H: harvesting; P: plowing; FA: fertilizer application; S: sowing. The horizontal bars above each symbol represent standard deviations.

fallow periods (444 g CO_2 m^{-2} per period). Comparison of total greenhouse gas emissions in terms of carbon equivalents from soybean and barley double-cropping using conventional tillage and no-tillage showed that a reduction in carbon emission by 183 g carbon m^{-2} y^{-1} was possibly by the use of no-tillage cultivation. These results clearly show that no-tillage cultivation is one of the most promising strategies for the mitigation of greenhouse gas emissions by the agricultural sector. (I. Nouchi)

Topic 2: Rice yield enhancement by CO_2 elevation is negatively correlated with acceleration of heading: results from 5 years of chamber studies

Varying degrees of rice (*Oryza sativa* L.) yield enhancement by elevation of CO_2 concentration ([CO_2]) have often been reported. To identify the reasons behind this variation in yield enhancement by CO_2 elevation, we analyzed the results of experiments conducted in 6 naturally sunlit controlled-environment chambers over 5 years (1998–2002). Rice plants (cv. Nipponbare) were grown season-long under ambient (354–383/397–448 µmol mol^{-1}; day/night) and elevated (670–721/702–780 µmol mol^{-1}) [CO_2], using 3 chambers for each experiment. Air temperatures inside the chambers were controlled at outside levels. Relative humidity was kept at 77% to 80%. Total nitrogen application was 8 g m^{-2} in 1998 and 1999 and 12 g m^{-2} in 2000–2002. In 2001 we added to each chamber 2 subplots in which the timing of topdressing was different.

Leaf area index (LAI) at the heading stage was largely influenced by total N applied, but the effect of elevated [CO_2] was not significant, although LAI was reduced by elevated [CO_2] in 3 of the 5 years. Final total dry weight was significantly increased (by 8.0% to 18.7%) by elevated [CO_2] in all 5 years. Enhancement of final total dry weight by elevated [CO_2] at each N level was similar across years. Interestingly, the enhancement ratio was not altered when the timing of topdressing was changed with the same total N application in 2001, although topdressing at the heading stage increased total dry weight more than at the panicle initiation stage under both [CO_2] treatments. Days to heading were significantly shortened by elevated [CO_2] by 2.6 to 8.0 days. Grain yield was significantly increased by elevated [CO_2] to varying degrees, ranging from 4.1% to 22.4%, but the relationship between grain yield and final total dry weight enhancement was not clear. In contrast, a strong negative relationship was found between grain yield enhancement and reduction in number of days to heading under elevated [CO_2] (Fig. 3). These results suggest that the degree of acceleration of plant development can have a marked impact on rice yield responsiveness to elevated [CO_2]. (H. Sakai)

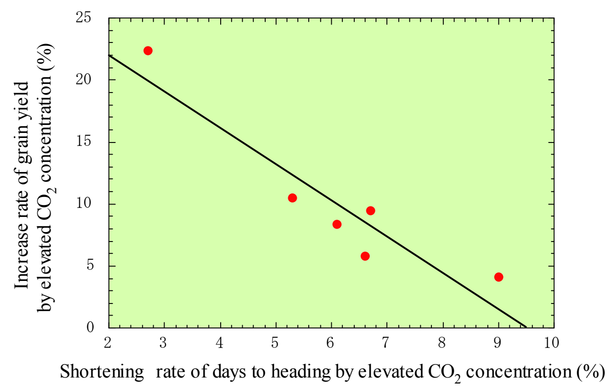

Fig. 3 Relationship between change in rate (%) of grain yield and change in rate of reduction (%) in number of days to heading under elevated CO_2 concentration over 5 years (1998–2002).

2) Ecosystems Group

The Ecosystems Group consists of five units and carries out both practical and fundamental research. The **Agro-Ecological Sensing Unit** is developing remote sensing and modeling methods for monitoring plant and environmental dynamics in agricultural and natural ecosystems on the basis of optical and electromagnetic measurements ranging from leaf scale to regional scale. The **Statistics Unit** is developing novel statistical methodologies for sampling, classifying, and analyzing agro-environmental data. The **Material Ecocycling Unit** is studying nitrogen and nutrient flows in agro-ecosystems to evaluate the relationship between anthropogenic activities and material cycles in Japan and East Asia. The **Ecological Management Unit** is studying historical changes in the spatial structure of rural ecosystems and the conservation and management of the wildlife that inhabits environments of the Kanto District. The **Remote Sensing Unit** is determining the environmental characteristics that can be observed at a regional scale through satellite imaging systems such as multi-band and multi-polarization SAR (Synthetic Aperture Radar) and MODIS (Moderate Resolution Imaging Spectroradiometer) (see Topic). In FY 2004, we conducted 12 research projects funded by MAFF (Ministry of Agriculture, Forestry and Fisheries) and the Ministry of the Environment. Our researchers attended 9 international meetings related to anthropology, ecology, remote sensing, and statistics. The researchers also made 10 overseas trips—to Canada, China, Laos, Vietnam, France, and Thailand—for fieldwork, cooperative projects, and research exchange. Domestically, we made a total of 36 presentations at academic meetings on statistics, remote sensing, geography, environmental sciences, and anthropology.

***Topic:* An accurate technique for detecting planted rice paddy fields using spaceborne radar and geographic information system (GIS)**

Every year the Japanese Government collects about 40 000 nationwide survey samples to determine the distribution of planted rice paddies. Because this requires a massive amount of fieldwork, the government has been looking for a low-cost and fast alternative. Remote sensing techniques, and especially spaceborne radar techniques, fit for this request well.

Synthetic aperture radar (SAR) is a kind of imaging radar that images the strength of radar waves backscattered from the ground surface. As the radar microwave has a longer wavelength than visible light and can penetrate cloud, SAR can acquire cloud-free images independent of weather conditions. This ability is vital for the use of SAR in gathering data on rice.

In SAR imagery, the surface of open water appears dark, because most of the radar wave is reflected, as by a mirror, and only a little is scattered back to the sensor. On the other hand, vegetated surfaces appear bright, because leaves and stems scatter radar waves more isotropically, and stronger scatter returns to the sensor (Fig. 1, top).

On the basis of these features, it is possible to detect planted rice paddies by comparing the SAR images acquired in the rice transplanting and growing seasons. In accordance with the government policy of reducing the rice acreage, some paddy fields are kept unplanted but inundated for weed control. Such fields are distinguishable from planted fields (Fig. 1).

However, the detection performance of SAR drops for paddy fields located on mountainous region because the image position is often not correct. It is caused by the principle of SAR. To reduce misclassification, such areas, which are considered unusable for rice cultivation, are masked out of the satellite-derived distribution. The mask covering these areas is created from 1:25 000 digital maps by image processing and GIS manipulation. Because these digital maps are available for the whole territory of Japan, we can create a mask for any region of interest in a uniform manner (Fig. 2).

The distribution of the planted area on the Saga Plain

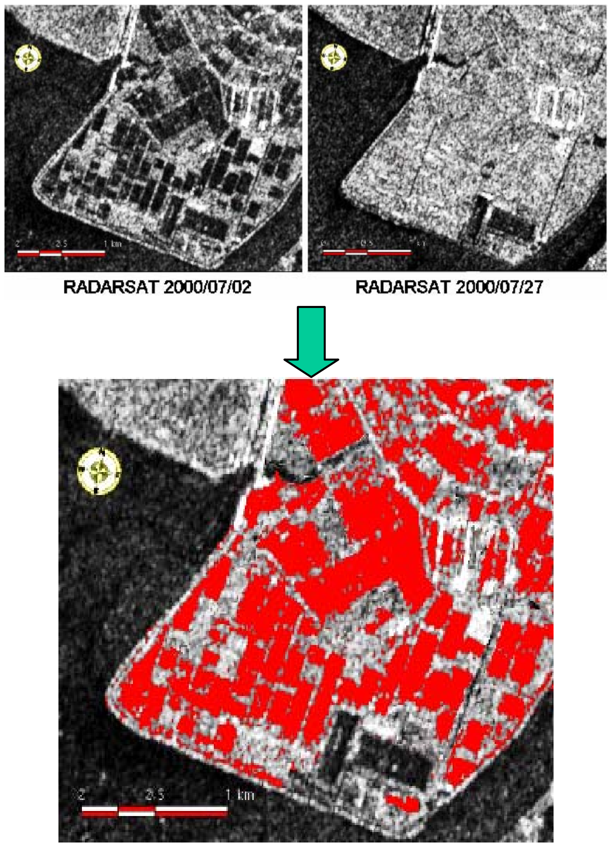

Fig. 1 Detection of planted rice paddy fields on the Saga Plain using SAR images. Specular reflection from water in the transplanting season shows up as dark areas, and large backscatter values from rice vegetation in the growing season appear bright. Unplanted rice fields kept inundated for weed control are found to the lower right of the images.

was determined by using RADARSAT C-band (wavelength 6 cm) images acquired on 2 July and 27 July 2000, and the total area was compared with that determined by the conventional statistical survey procedure. The total area determined by using the SAR technique was 102% of that obtained by the conventional procedure. The RMSE of the area of 26 municipalities on the plain was 85 ha (Fig. 3). A comparison of the same area in 2001 gave equivalent results of 101.5% and 54 ha.

The accuracy and stability of this technique are therefore sufficient for it to be used as an alternative to the procedure currently used to determine the area of paddies planted to rice in Japan. (N. Ishitsuka, H. Ohno and T. Sakamoto)

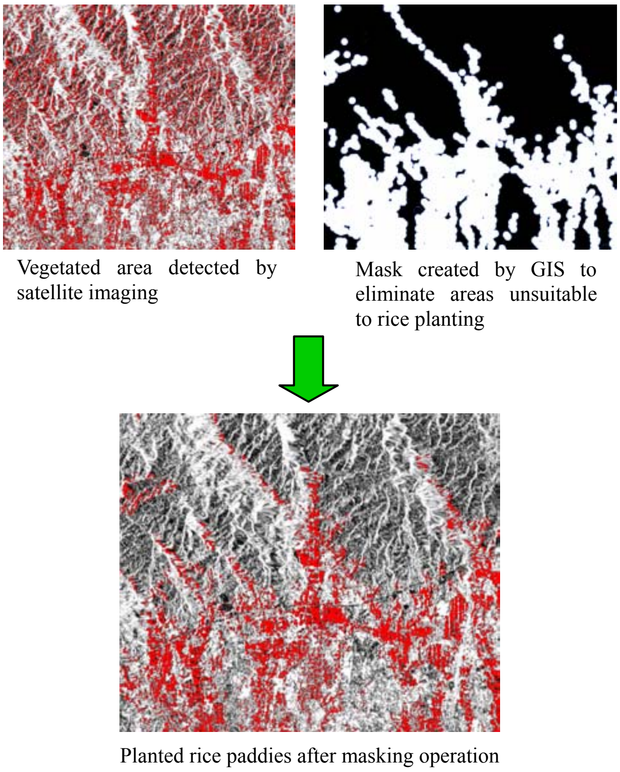

Fig. 2 Mask processing of GIS data. To reduce misclassification, a mask covering areas where rice is never cultivated is applied to detect planted rice paddy fields on satellite images.

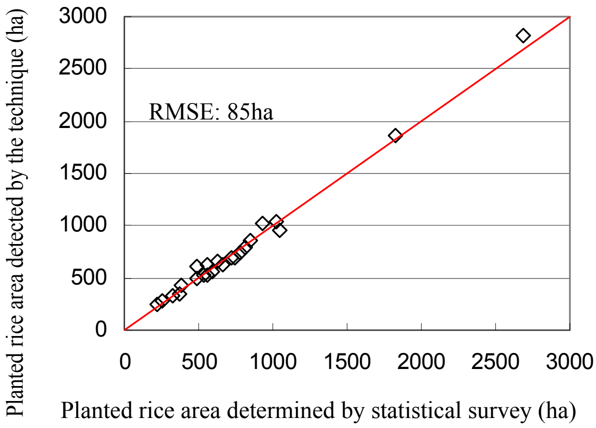

Fig. 3 Comparison of the area of rice paddies planted on the Saga Plain in 2000, as determined by the SAR technique and by the current statistical technique.

3) Greenhouse Gas Emission Team

Considerable attention has been paid in recent years to the likelihood of significant changes in world climate owing to the presence of increased atmospheric concentrations of greenhouse gases (GHGs). GHGs, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), can absorb thermal radiation from the surface of the earth and thus contribute to the warming of the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) has reported that concentrations of atmospheric GHGs and their radiative forcing have continued to increase as a result of various human activities.

Agriculture contributes to over 20% of global anthropogenic GHG emissions. In particular, 55% to 60% and 65% to 80% of total emissions of CH_4 and N_2O, respectively, are derived from agricultural sources. These GHGs are emitted to the atmosphere as a result of accelerated turnover of carbon and nitrogen in agricultural soils and the surrounding environment through increased input of chemical and organic fertilizers and other agro-materials. This increased input also results in increased emission of nitrogen oxide (NO) and ammonia (NH_3), which are precursors of acid rain, and in pollution of rivers and groundwater by leaching of nitrogen and carbon components. Land-use change and burning of plant biomass increase emissions of CO_2, CH_4, N_2O, and other trace gases such as carbon monoxide (CO), hydrogen (H_2), and halocarbons.

The Greenhouse Gas Emission Team studies emission and absorption of these environmentally important gases in association with different land uses and agricultural management. The activities of the team are based on field measurements of GHG exchange, laboratory experiments, data interpretation, and modeling. The goals of the team are 1) to quantify and model the processes of GHG emission and absorption (mechanism); 2) to estimate the rates of GHG emission and absorption (inventory); and 3) to develop promising and feasible technologies that reduce GHG emissions (mitigation) (Fig. 1). The studies have been developed to address scientifically and socially important questions related to the environmental impacts of agriculture.

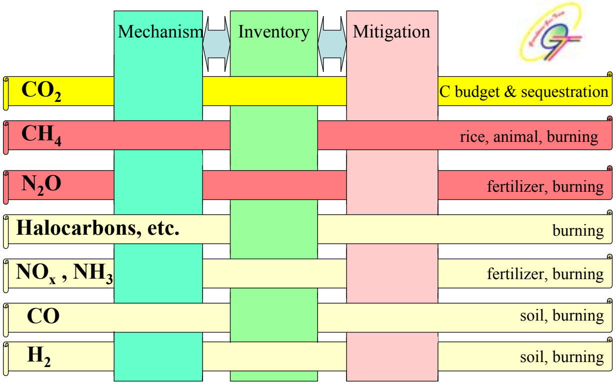

Fig. 1 Research targets of the Greenhouse Gas Team.

Photo Overview of furnace used for biomass burning experiments.

***Topic:* Laboratory combustion experiment for estimation of greenhouse gas emissions from biomass burning**

Biomass burning is known as one of the major sources of emission of greenhouse gases (e.g. CH_4, N_2O, CO_2) from agro-ecosystems. The emission factors of greenhouse gases from biomass combustion have large uncertainties, as they are controlled by several kinds of combustion parameters such as water content, density and porosity of combusted materials, environmental humidity, and fire temperature. Using a closed-shell type combustion furnace (see photo), we simulated the factors controlling greenhouse gas emissions from several types of biomass combustion.

To make a closed-shell combustion system in which the inside air pressure and humidity were controllable and the total volume of gas flow was measurable, we customized a commercially available furnace. The furnace was equipped with an electric igniter with nichrome wire and stainless steel ports for supplying fresh air and extracting smoke gases. An electronic balance was installed inside the furnace and connected to a PC to measure the transition of biomass weight during combustion. Atmospheric pressure was maintained inside the furnace by using a 5-L pressure-compensating plastic bag. Fresh air (synthesized by mixing pure O_2 and N_2) from gas cylinders was supplied at flow rate (0.5 to 1.0 L/min). A gas-tight syringe for use as a water-injection port was added to the fresh-air supply line to adjust the humidity.

Various parameters of biomass sample and combustion conditions are shown in Table 1, together with

Table 1 Parameters of biomass samples and combustion conditions, and measured emission factors of CO_2, CO, and CH_4.

Biomass sample	Water Content (g/g)	Humidity (%)	Porosity (cm^3/cm^3)	Density (g/cm^3)	MCE	Fire Temp. (°C)	Weight (g dm)	Carbon content (g)	†Ef-CO_2 (x10)	‡Ef-CO ($x10^2$)	¶Ef-CH_4 ($x10^4$)	*GCR (gC/gC)
Abies sachalinensis	0.00	0.20	0.11	0.98	0.973	852	3.20	1.58	9.05	1.57	5.34	0.514
Abies sachalinensis	0.30	0.20	0.11	0.98	0.984	897	2.23	1.10	14.96	1.57	3.97	1.094
Abies sachalinensis	0.30	0.60	0.11	0.98	0.985	901	2.46	1.22	10.32	1.02	2.83	0.750
Acer pictum	0.00	0.20	0.48	1.66	0.972	847	2.70	1.27	4.30	0.78	3.79	0.257
Betula ermanii	0.00	0.20	0.49	1.80	0.973	850	3.30	1.65	2.65	0.64	3.54	0.151
Betula ermanii	0.30	0.20	0.49	1.80	0.987	913	2.92	1.46	4.02	0.33	0.79	0.289
Betula ermanii	0.30	0.60	0.49	1.80	0.984	897	3.08	1.54	10.15	1.06	2.54	0.731
Kalopanax pictus	0.00	0.20	0.54	1.86	0.965	817	3.00	1.35	10.75	2.44	9.25	0.676
Kalopanax pictus	0.30	0.20	0.54	1.86	0.978	872	2.23	1.01	1.31	0.19	0.36	0.105
Kalopanax pictus	0.30	0.60	0.54	1.86	0.977	867	2.31	1.04	15.40	2.31	11.32	1.243
Picea glehnii Mast.	0.00	0.20	0.37	1.51	0.977	869	4.10	1.89	7.36	1.09	2.46	0.446

†Ef-CO_2: emission factor for CO_2
‡Ef-CO: emission factor for CO
¶Ef-CH_4: emission factor for CH_4
*GCR: Gas Conversion Ratio

measured emission factors for CO_2, CO, and CH_4. There was a negative correlation between sample density and porosity, with a slope value of 2.03 ($R^2 > 0.99$), indicating that heavier wood materials in this experimental series had lower porosities. The dry weight of each sample was measured after keeping the sample in a desiccator with silica gel for 1 week.

Emission factors were calculated by dividing the weight of the emitted gas by the dry weight of the biomass sample. The gas conversion ratio (GCR) was calculated by dividing the total weight of CO_2, CO, and CH_4 by the dry weight of the biomass sample. Modified combustion efficiency (MCE), as defined in Eq. 1 (Yokelson et al., 1997), was used to estimate the average combustion temperature, which is difficult to measure directly owing to wide variation, even in a single combustion run.

$$MCE = dCO_2 / (dCO_2 + dCO) \quad \text{(Eq. 1)}$$

where dCO_2 and dCO represent the increases in concentrations of CO_2 and CO, respectively, in fire smoke compared with those in the ambient atmosphere. The range of GCR was 0.105 to 1.243, with an average value of 0.569. GCR and the gas emission factors had no clear relationship in any of the tree species tested. Differences in the physical parameters of the samples, such as porosity, density, and water content, could not explain the differences in MCE, gas emission factors, or GCR. However, MCE and the emission factor of CH_4 were negatively correlated, with a slope value of –308 ($R^2 = 0.47$), indicating that emission of CH_4 from biomass burning is controlled by combustion temperature. (K. Yagi, S. Sudo, H. Akiyama, and S. Nishimura)

Reference

Yokelson, R. J., Suscott, R., Ward, D. E., Readon, J. and Griffith, D. W. T., Emission from smoldering combustion of biomass measured by open-path Fourier transform infrared spectroscopy, *J. Geophys. Res., 102,* 18865-18877 (1997).

4) Food Production Prediction Team

The mission of the Food Production Prediction Team is to assess both the impact of global environmental change on food production and the effectiveness of technologies designed to mitigate adverse environmental changes in meeting food production targets. Our major research domains are assessment of the impact of global warming on agriculture; monitoring and modeling of environment changes in agricultural ecosystems; development of regional climate change scenarios; and assessment of the variability of climate systems in Asian monsoon countries. This year, a total of 12 researchers on the team went abroad for field surveys or presentations at international conferences, and they hosted 2 guest scientists from overseas.

In total the team has 7 activities. A new activity was initiated in FY 2004: Development of a technique to comprehensively evaluate the influence of global warming on agriculture, forestry, and fisheries. One activity was completed in FY 2004: Development of a technique for risk assessment in agro-ecosystems in light of the variability and regionality of factors that can influence these systems.

The remaining 5 activities are: 1) Development of advanced techniques for projecting future climate change by using ocean–atmosphere coupled global climate models (GCM) and statistical methods; 2) Prediction of the impacts of climate change on food supplies; 3) Prediction of agricultural productivity change, incorporating responses to global warming; 4) Evaluation of the influence of environmental change on the organic carbon content and nitrogen supply capability of soils; and 5) Evaluation of the vulnerability of agriculture by using soil, vegetation, and hydrology analyses.

Topic: **Modified Rothamsted carbon model for paddy soils**

Soil organic matter (SOM) turnover models are very effective at simulating changes in the SOM content caused by different agricultural management systems or by climate change. However, most existing models cannot be successfully applied to paddy soils because they were developed for upland soils. SOM dynamics in paddy soils differ considerably from those in upland soils, because paddy soils are waterlogged (and therefore anaerobic) during the rice-growing period. SOM decomposition is thereby slowed, resulting in higher soil organic carbon (SOC) levels in paddy fields than in upland soils.

Paddy fields play very important roles in both food production and environmental issues in Asia. Consequently, changes in the SOC levels in paddy soils contribute markedly to changes in the calculation of CO_2 emissions from soils, as well as to changes in calculations of total national soil productivity. Therefore, an SOM model that can accurately simulate the SOC turnover in paddy soils needs to be constructed.

Of the existing SOM models, the Denitrification–Decomposition (DNDC) model has been applied to paddy soils. The good performance of the decomposition submodel of the DNDC model has been verified for long-term SOC decomposition in paddy soils as well as for upland soils. However, careful tuning of crop growth parameters is required for better simulation. The detailed information on farming management required for input parameters is often difficult to obtain, especially in long-term experiments.

On the other hand, the structure of the Rothamsted carbon (RothC) model is simpler than those of the many other SOM models published, and the few input parameters it requires can be easily obtained. Therefore, it has the advantage of having been tested with existing data sets and being applicable over a wide area. Although this model was developed for use in non-waterlogged soils, as were most other existing models, it is possible to modify it for application to paddy soils. If this rather simple model were to be modified thus, it would be very useful for estimating carbon loss from soils, as well as for planning suitable organic matter management in paddy soils, not only on a plot scale but also on regional or national scales.

The objectives of this study were 1) to apply the RothC for long-term experiments on Japanese paddy soils and 2) to modify the model to accurately simulate changes in SOC content with time in paddy soils.

We selected 5 sites for long-term (16- to 22-year) experiments with the application of the model to paddy soils. The soil types were as follows: Gley Soils in Akita and Shimane, Gray Lowland Soils in Toyama and Mie, and Yellow Soil in Oita. Gray Lowland Soils, Gley Soils, and Yellow Soils constitute 38%, 27%, and 6%, respectively, of the total area of paddy soils in Japan.

In modeling each set of experimental data, we fixed the initial SOC content to that measured at the beginning of each experiment and then simulated the changes in SOC content with time for each management system.

Two statistical indices were employed to evaluate model performance: the root mean square error (RMSE), which represents the degree of coincidence; and the mean difference (M), which is a measure of model bias (positive values indicate consistent undercalculation of measured data, and vice versa).

It was obvious that RothC consistently underestimated the SOC content of all 9 plots (5 NPK plots and 4 NPK + straw plots) at the 5 sites. We expected this result, because RothC was developed for simulating SOC dynamics in non-waterlogged soils. Underestimation may have occurred mainly because of the slow decomposition rate of organic matter during the rice-growing period, when soils are submerged and subjected to anaerobic conditions. Decomposition of organic matter is severely inhibited under these conditions, and fermentation becomes the main form of transformation, with a markedly restricted oxygen supply.

However, in paddy soils, decomposition of organic matter might be inhibited not only during the submergence period but also throughout the remainder of the year. Fungi are the major agents that decompose coarse organic debris in upland soils. Fungi display a remarkable ability to break down the skeletal components of plant debris, such as cellulose and lignin, which normally do not decompose easily. Conversely, under the submerged conditions of paddy soils, aerobic microorganisms such as fungi cannot grow well, and thriving anaerobic microorganisms, such as bacteria, generally cannot decompose these skeletal components. This difference in the composition of microorganisms between upland soils and paddy soils may account for the difference in decomposition rates of organic matter assuming that this difference in microorganism population persists when the paddy soil dries out.

Taking into account these possible differences in decomposition rate between upland soils and paddy soils, we decided to separately change the decomposition rates of RothC for the submergence period (summer) and the period without submergence (winter). We ran the model many times with changes in decomposition rates for summer and winter, and we tried to identify the optimum combinations of values of the factors required to change the default decomposition rates. Our aim was to make the modeled SOC contents consistent with the values observed in the 9 plots at the 5 experimental sites.

We then compared the observed and predicted changes in SOC content over time by using our modified model, in which the decomposition rate was changed by 0.2 in summer (the rice-growing period) and by 0.6 in winter (the fallow period or growing period of winter crops) (Fig. 1). In these long-term experiments, the predicted values were clearly much closer to the observed values in all 9 plots at 5 sites than were the predicted values obtained with the original model.

Figure 2 shows the statistics describing the performance of the original and the modified models. RMSE in simulations with changes in decomposition rate was much lower than in simulations with the original model. This supports our assumption that the model performance could be improved by changing the decomposition rates. Similarly, the absolute values of M were much lower in simulations with the modified model, indicating that this model's performance was better than that of the original model.

We conclude that, despite certain limitations, the RothC modified for paddy soils by simple tuning of decomposition rates gave a much better performance than the original model for modeling changes in SOC content over time in Japanese paddy soils under various climatic conditions, types of soil texture, and management systems. This modified model can be used to estimate carbon loss from soils and to plan suitable organic matter management, at least in Japanese paddy soils. It could be useful for paddy soils in other regions, but further testing under other environmental conditions and other management systems might be necessary. (Y. Shirato and H. Toritani)

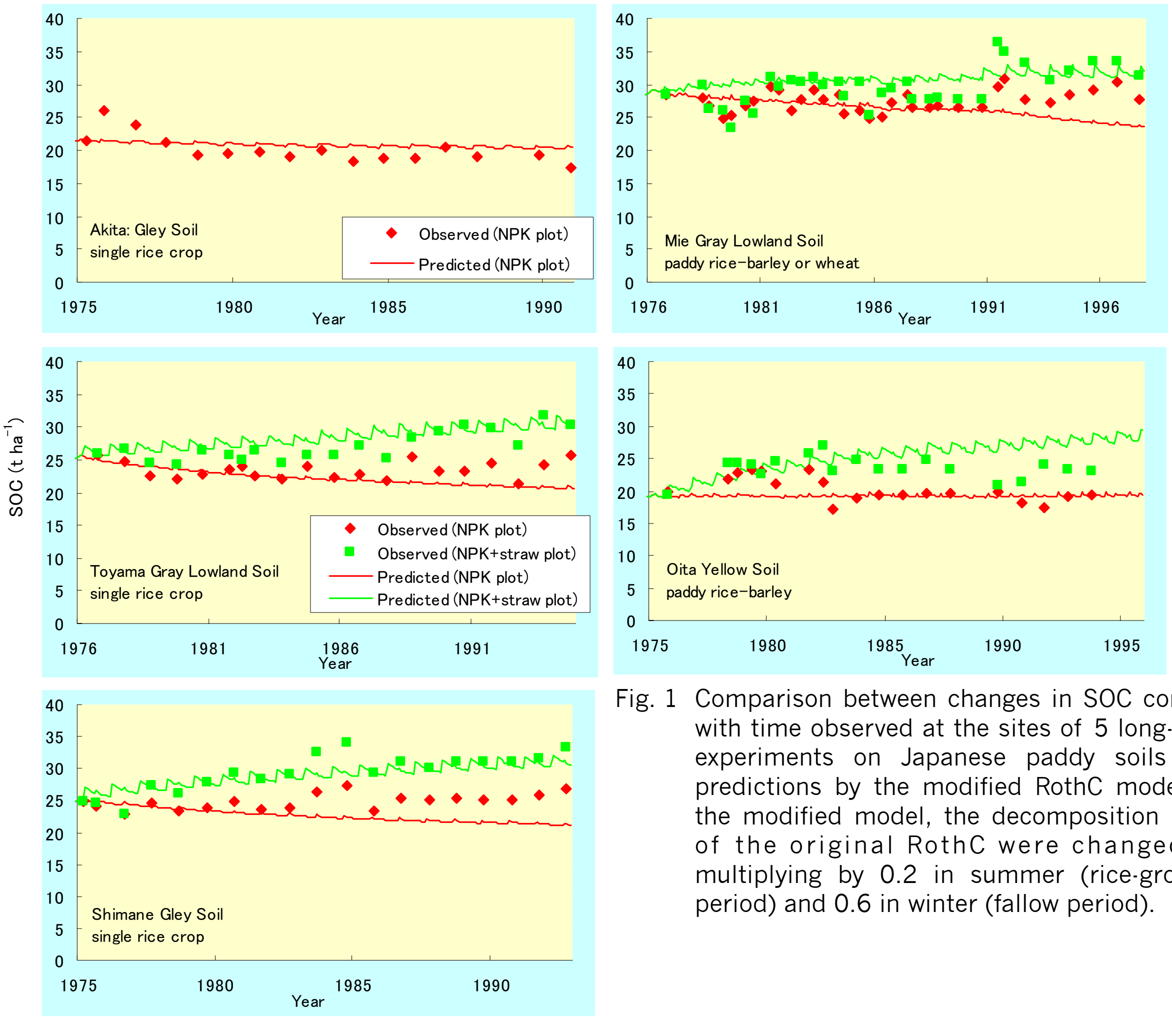

Fig. 1 Comparison between changes in SOC content with time observed at the sites of 5 long-term experiments on Japanese paddy soils and predictions by the modified RothC model. In the modified model, the decomposition rates of the original RothC were changed by multiplying by 0.2 in summer (rice-growing period) and 0.6 in winter (fallow period).

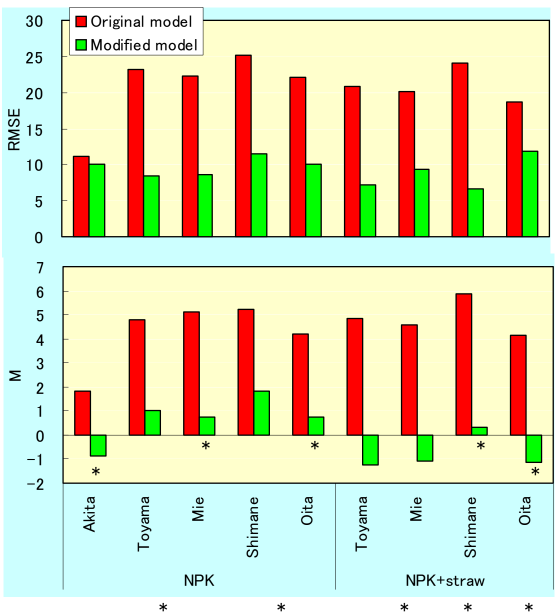

Fig. 2 Statistics describing the performance of the original RothC (red bar) and the modified model (green bar) in simulating 5 long-term experiments on Japanese paddy soils. In the modified model, the decomposition rates of the original RothC were changed by multiplying by 0.2 in summer (rice-growing period) and 0.6 in winter (fallow period). RMSE: root mean square error; M: mean difference; asterisks (*) represent absence of significant bias at $P < 0.025$ in the t-test for M.

5) Ecosystem Gas Exchange Team

To investigate seasonal and inter-annual variations in carbon, water vapor, and energy exchange between agricultural ecosystems and the atmosphere, the Ecosystem Gas Exchange Team conducts long-term observations of gas and energy fluxes at 3 sites: a single-cropping rice paddy field in central Japan, a natural wetland in eastern Hokkaido, Japan, and a wet sedge tundra at Barrow, Alaska. In 2004, our main focus was on the paddy site (Photo 1). Along with making standard measurements of meteorological and ecological variables, we are measuring the flux densities of carbon dioxide (CO_2), methane (CH_4), water vapor, and sensible heat by using the eddy covariance method. Process studies on carbon exchange utilizing stable isotopes are also conducted at the paddy site.

In 2004, the following measurements were added to the paddy site: 1) soil CO_2 flux throughout the year using a dynamic chamber technique; 2) stable isotope composition of CO_2 respired from, and assimilated by, the paddy; and 3) horizontal distribution of spectral reflectance of the canopy, in collaboration with the Agro-Ecological Sensing Unit, NIAES. Meteorological conditions in summer 2004 contrasted with those of the previous summer, and were characterized by the third-highest air temperature since 1946 and more solar radiation than in normal years. Under meteorological conditions favorable to rice growth, net CO_2 uptake by the paddy during the 2004 growing season was 35% greater (140 g C m^{-2} greater) than in the previous summer, and methane emission also increased by 10% (by 2 g C m^{-2}). Comparison of the seasonal CO_2 budget estimated from long-term flux data with the amount of carbon accumulated as rice dry matter indicated that about 25% of the ecosystem respiration originated from the soil, even when the paddy was flooded. The direct measurement of soil CO_2 flux using the chamber technique and the isotopic signature of CO_2 respired from the ecosystem both support the importance of the below-ground contribution to the CO_2 budget of the paddy during the growing period, although further investigations are needed for quantification.

Photo 1 The flux site at Mase, near Tsukuba in central Japan, in August. Carbon dioxide exchange between a single-cropping rice paddy field and the atmosphere is continuously monitored at this site.

Our studies are supported by MAFF and MOE (Ministry of the Environment) and are closely linked to AsiaFlux, which operates tower-based sites for the observation of carbon and water vapor exchange between terrestrial ecosystems and the atmosphere in eastern and southeastern Asia as part of the worldwide network FLUXNET. Through the activities of AsiaFlux, we are collaborating with domestic institutions such as Okayama University, the Kyushu-Okinawa Agricultural Research Center, the Forestry and Forest Product Research Institute, the National Institute of Advanced Industrial Science and Technology, and the National Institute for Environmental Studies. We are giving technical support to a new project ,"Establishment of good practices to mitigate greenhouse gas emissions from Japanese grasslands (FY 2004–2006)", organized by the Japan Grassland Agriculture and Forage Seed Association and funded by the Racing and Livestock Association. We are also collaborating with the International Arctic Research Center, San Diego State University, and Bangladesh Agricultural University. We host a post-doctoral fellow funded by MOE, and 4 technical staff members under the Cooperative System for Supporting Priority Research (FY 2000–05), sponsored by the Japan Science and Technology Agency.

***Topic:* A basic program to process eddy covariance data obtained by long-term CO_2 flux measurement**

Eddy covariance is a direct method of measuring the turbulent transport of mass and energy in the atmosphere by using a sonic anemometer and a gas analyzer. The eddy covariance method was first applied successfully to CO_2 flux measurement in about 1980, with an indispensable contribution by Japanese scientists. From the late 1990s, the eddy covariance method has been operationally employed to measure the amounts of CO_2 absorbed by, or emitted from, the world's forests, grasslands, and croplands to accumulate basic data for estimating the CO_2 budget of the global terrestrial ecosystem. In addition, the eddy covariance method has been gradually popularized in various fields as a standard method of measuring gas exchange between plant/soil and the atmosphere.

In the observation of CO_2 flux by the eddy covariance method, fieldwork is now less demanding than before owing to improvements in infrared gas analyzers, but instead the data processing has become demanding. This is first because enormous data sets are accumulated by long-term observation, and second (and more important) because the data processing has become advanced and has become complicated as a result of endeavors to estimate CO_2 exchange as accurately as possible from data obtained under non-ideal conditions. Studies on eddy covariance data processing are still continuing in an effort to solve the remaining problems. The processing of eddy covariance data requires an understanding of micrometeorology. Investigators have to process data in their own ways because the data processing is still under development and depends on site-specific conditions such as topography, meteorology, and vegetation. Lack of data processing programs that can be easily used is a hurdle for investigators who are not familiar with micrometeorology and hinders further popularization of the eddy covariance method.

Under these circumstances, we produced a post-processing program that includes basic processing and the required corrections, such as coordinate rotation, frequency response correction and density correction, and which can be used by investigators who are not specialized in micrometeorology. Along with raw eddy covariance data, users prepare several instructions on data processing and site information, including the configuration of sensors, aerodynamic parameters, and supporting meteorological data. The results of executing the program include not only calculated half-hourly fluxes but also the results of various quality control (QC) tests, random errors, and flux footprints (Fig. 1). These supplementary data are useful for evaluating the reliability of the calculated fluxes, and for rejecting and removing erroneous flux data that have been influenced by instrument malfunction or inadequate meteorological conditions. Users can make practical data sets for further analysis by adding site-specific processing, if needed. Caution has to be exercised to ensure that the program does not cover gap-filling procedures. Although the filling of missing or rejected half-hourly flux data is inevitable in estimating annual CO_2 budgets, it is difficult to incorporate gap filling into general data processing programs because the appropriate gap-filling procedure is highly dependent on site-specific conditions. Incorporation of gap filling into the program is our next challenge. (A. Miyata and M. Mano)

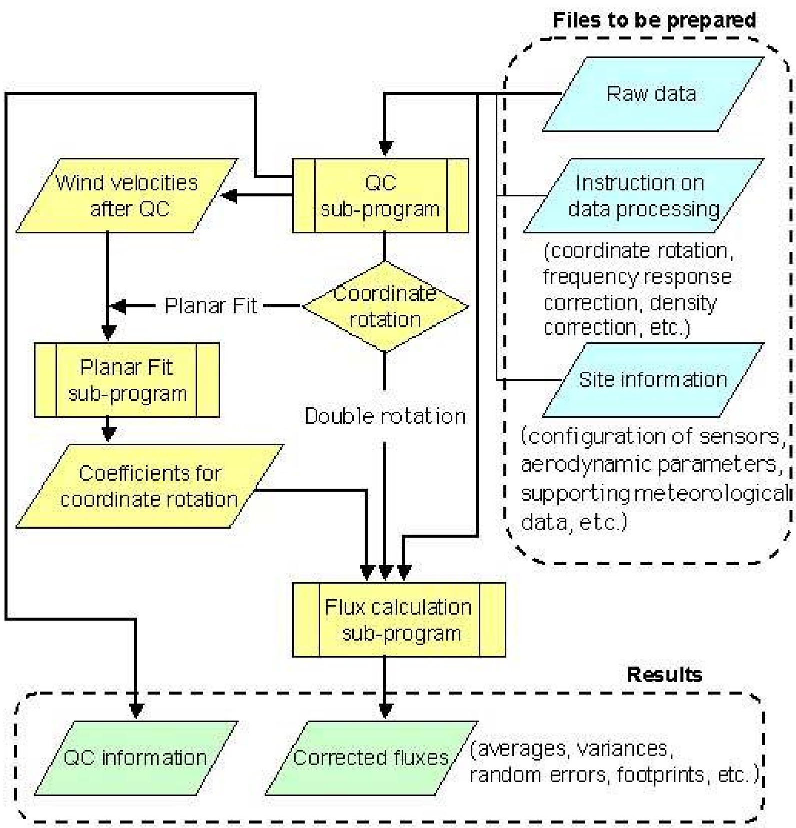

Fig. 1 Schematic diagram of a program developed for post-processing of eddy covariance data obtained by long-term flux measurements.