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Real Time Monitoring and Simulation System (RTMASS) for Tak Flux Measurement Site, Thailand

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태국 Tak 플럭스 관측소의 실시간 자료 감시 및 모사 시스템 (Real Time Monitoring and Simulation System, RTMASS)

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ABSTRACT

The Tak flux measurement (TFM) site, one of the sites of Korean Flux Network (KoFlux) which is an infrastructure of AsiaFlux, is constructed at a northwest of Thailand. The eddy covariance technique is used for measuring energy, water and carbon dioxide (CO_2) fluxes, and a real time monitoring and simulation system (RTMASS) developed for data acquisition and processing. The RTMASS is the core structure of the KoFlux-data information system (KoFlux-DIS) and consisted of a remote and a local system. Data acquisition and transmission, and data storage, processing and publishing are functions of those systems, respectively. As primary results about the characteristics of mean flow and turbulence analysis, TFM is a proper site to measure and analyze the various fluxes and those budgets on tropical deciduous forest.

Key words : **eddy covariance technique, KoFlux, RTMASS, Tak flux measurement site(TFM site)**

I. INTRODUCTION

Determination of the amount and distribution of carbon sequestered or released by terrestrial ecosystems is essential to understanding the global carbon cycle. In this study, long-term and tower-based eddy covariance measurements of carbon, water and energy fluxes are fundamental techniques. Water and carbon flow are monitored by local scientific organizations which are members of the FLUXNET (http://www-eosdis.ornl.gov /FLUXNET/index.html). Every site has an individual system for flux measurement, data acquisition, and quality control. They are mainly divided into two types according to measurement methods of the partial pressure of carbon dioxide (CO_2) and water vapor (H_2O), open and closed path flux measurement systems. Each measurement system is reported by AmeriFlux (Baldocchi, 2003) and EuroFlux (Aubinet *et al.*, 2000). While the Korean flux network (KoFlux), an infrastructure of AsiaFlux, was launched on January 2002, its instrumentation and data information system is uncleared.

In terms of data management (acquisition, quality control, and gap filling), several reports are available for assessment of high quality data (Vickers and Mahrt, 1996; Foken and Wichura, 1996; Webb *et al.*, 1980; Falge *et al.*, 2001). Theoretical guidance for implementing the eddy covariance technique is provided by Baldocchi

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et al. (2003) and Paw U *et al.* (2000). It is important that all of these methods are applied to measurements and data processing in order to determine various fluxes using the eddy covariance technique. Instrumentation and data processing methods need to be unified and arranged in KoFlux. This technique is easy to use by colleagues studying water and carbon dynamics (e.g. ecologists and hydrologists).

While the flux measurement site should be located where little anthropogenic perturbation occurs, the general service of cable telecommunication and electronic power is usually unavailable because of distance from the service areas. Accordingly, it is difficult to maintain stability of the power supply for data acquisition.

The main purpose of this paper is to construct a prototype of KoFlux data information system (KoFlux-DIS) which is an infrastructure for a real time monitoring and simulation system (RTMASS) incorporating comprehensive data management of tower flux measurements. Finally, the temporal and spatial variability of mean flow and turbulence characteristics over the experimental site are also described to prove instrumentation accuracy and site importance.

II. SITE INFORMATION

The experimental site (latitude: 16°56'N, longitude: 99°25'E), named Tak flux measurement (TFM) site, is located about 20 km east of Tak and 50 km west of Sukhothai in the northwest part of Thailand. The TFM site is essentially a flat area of about 100 km^2 and 130 m higher than sea level. The fetch is more than 10 km with gently undulating hills with about 20 m differences in height. The climate of the experimental area is divided into wet and dry seasons as a part of the Southeast Asia Monsoon region. The onsets of the wet and dry seasons are in May and October, and the mean temperatures of each season are about 27°C and 31°C, respectively. The total annual precipitation is about 1200 mm.

The zonobiome of TFM site is the humido-arid tropical summer-rain region with deciduous forests by Walter classification (1994). Vegetation type is a mixed wet-deciduous forest with trees 20-25 m tall (e.g., *Tectona*, *Shorea* and *Dipterocarpus*) (Ruangpanit, 1995) and a sparse covering of grass with about 4.0 leaf area index. However a secondary forest matures on the fallow patches within about 10-20 years, due to exploitation by the population for shifting cultivation (Ogawa *et al.*, 1971). According to our recent survey, the vegetation consists of 70% 10-15 m tall deciduous trees with 3-5 LAI, and 30% agricultural area cultivating rice, corn and tobacco.

III. EXPERIMENTAL DESIGN

3.1. Site selection

The TFM site was selected considering the criteria for site selection of flux measurement towers using eddy covariance method:

1. Installing level of the eddy covariance system above the canopy should be approximately one-hundredth of fetch length, and outside of roughness sublayer.
2. The surface condition was considered in selecting the location of the tower: main wind direction for sonic anemometer facing and faster mean wind velocity than 1 m s^{-1} for data quality control.
3. Land surface condition was considered in selecting the study area: homogeneity of land surface for eliminating the complexity of footprint analysis and non-slop condition for mean vertical stream and advection flow equal to zero.
4. Locating the study site far from any anthropogenic disturbance area to avoid artificial effects.

3.2. Instrumentation

The eddy covariance technique to measure the sensible and latent heat, and the carbon dioxide (CO_2) fluxes is used at the TFM site, Thailand. In applying the technique, two sets of KoFlux prototype instruments (Table 1), consisting of three dimensional sonic anemometers (CSAT3, Campbell Scientific, Inc.) to measure wind velocity fluctuation and an open path CO_2/H_2O gas analyzer (LI7500, LI-COR, Inc.) to measure vapor pressure and CO_2 fluctuation. They are mounted at the end of booms located at 30 m and 100 m levels attached to a 120 m climbing tower. The boom is able to fold for sensor maintenance and extends 2 m beyond obstacles. The length is 2 times longer than lateral dimension of tower to minimize wind flow distortion. Leveling of CSAT3 is carried out before the boom is opened and LI7500 is tilted 20 degrees to the north to prevent a radiation effect.

The synchronous device for measurement (SDM) signal from the CSAT3 control box is connected to the LI7500 SDM signal outlet in the control box. To minimize the influence of high pass filtering of turbulence (Moore, 1986; Massman, 2000; Aubinet *et al.*,

Table 1. The list of KoFlux prototype instruments

Sub site number*	Location	Instrument	Type (Inc.)	Measurement	Unit
11fx and 13fx	At 100 m and 30 m on tower	Three dimensional sonic anemometer	CSAT3 (Campbell scientific)	Wind velocity (u) Wind velocity (v) Wind velocity (w) Temperature	$m\ s^{-1}$ $m\ s^{-1}$ $m\ s^{-1}$ °C
		Open path CO_2/H_2O gas analyzer	LI75000 (LI-COR)	CO_2 concentration H_2O concentration Atmospheric pressure	Mg g mb
11sl and 13sl		Net radiometer	CNR1, (Kipp & Zonen)	Downward short- wave radiation Downward long- wave radiation Upward short-wave radiation Upward long-wave radiation	$W\ m^{-2}$ $W\ m^{-2}$ $W\ m^{-2}$ $W\ m^{-2}$
		Humidity and temperature probe	HMP45A (Vaisala)	Humidity Temperature	% °C
21sl	Herb site	Soil heat flux plate	HFT3 (Campbell scientific)	Soil heat flux	$W\ m^{-2}$
22sl	Forest site	Soil temperature sensor	TCAV (Campbell scientific)	Soil temperature	°C
23sl	Herb and forest site	Soil humidity sensor	CS615 (Campbell scientific)	Soil moisture	–
24sl	Herb site	Rain gage	TE525MM (Campbell scientific)	precipitation	mm $10\ min^{-1}$
25sl	In station	Thermocouple	–	Soil temperature	°C

*Abbreviation of sub site number refer to section 3.4.3

2000), wind velocity and mass fluctuation data from two set of fast response sensors are recorded every 0.1 second by the measurement and control system (CR5000, Campbell Scientific, Inc.) with a 2G byte micro drive device for primary data acquisition. The CR5000 is located at 60 m because of having same SDM cable length from two LI7500 control boxes from 30 and 100 m.

Net radiation is measured by a net radiometer (CNR1, Kipp & Zonen Inc.) with CM3 pyranometers and CG3 pyrgeometers mounted facing both up and downward to measure solar radiation and far infrared radiation. Mean temperature and relative humidity ware observed by humidity and temperature probes (HMP45A, Vaisala Inc.) in the ventilated system. The CNR1 and HMP45A are installed in the same way for fast response sensors on tower. These slow response data are observed every 30 second and are calculated and recorded every 30 minutes averaging data by measurement and control module (CR10X, Campbell Scientific, Inc.). Fundamentally, the micrometeorological instruments are installed on the southwest-facing side of the tower.

Soil heat flux plates (HFT3, Campbell Scientific, Inc.) and soil temperature and humidity sensors (TCAV and CS615, Campbell Scientific, Inc.) are installed underground in two types of vegetation (grassland and forest) for measuring soil heat flux.

3.3. Power supply system

Fig. 1 shows the electronic power supply system at the experimental site. Batteries securing the stability of electrical power for instruments, and uninterruptible

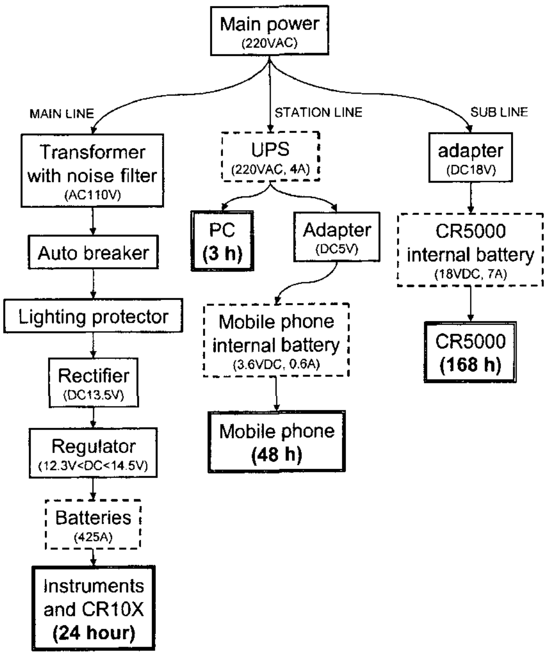

Fig. 1. Flow chart of the power supply system of Tak flux measurement station, Thailand. The dashed box means power storage devices and the double box indicates final device including instruments. The general and bold characters in parentheses are the changed voltage by transformer or adapter and the available operating time of instruments or device respectively.

power supply (UPS) for personal computer and mobile phone are installed on each electronic line in Tak flux measurement site. The battery system located on the end of the main line and located in the CR5000 of sub line have an operational capacity during 24 hours (about 800 W h^{-1}) for all instruments and at lest 1 week more (about 120 W h^{-1}) for logger operation, respectively. The UPS system is mounted on a station line to access continuity of personal computer operating for 3 hours duration (900 W h^{-1}) because electric current is cut off frequently due to main power outages.

A transformer with nose filter for high quality of power and a lightning protector for safety of various meteorological instruments are installed on the main power supply line. The sub line for charging the CR5000 battery is independent from the main and station line for safety of data acquisition.

3.4. Data management

The RTMASS is the core structure of KoFlux-DIS and consists of the remote system and the local system. Data acquisition and transmission are functions of the remote system and data storage, processing and publishing are the functions of the local system (Kim *et al.*, 2002).

3.4.1. Acquisition

Two types of data acquisition sequences are used for the fast and slow response instruments, respectively. One sequence is for fluctuation data from CSAT3 (*u*, *v*, *w*, *T*) and LI7500 (CO_2 and H_2O concentration). The raw data (r-data) at 0.1 second observation rate from fast response sensors are saved on a micro drive installed in the CR5000. These data are transmitted via a fiber optics device to the remote server by serial port 1 per 1 hour and saved to a temporary file on the hard disk drive. The sequence is controlled by PC9000 software provided by Campbell Scientific Inc. The other sequence is for average data (a-data) from various slow response sensors installed in 7 subsites (Table 1). One subsite consists of one CR10X with MD9 multidrop interfaces (Campbell Scientific Inc.) for data acquisition. At a subsite, the 10-minute a-data, calculated by measurement each 10 seconds is recorded on the CR10X internal memory. At the same time, all a-data on the memories of the CR10X at each subsite flow each 1 hour to serial port 2 of the remote server through a coaxial cable connected in series. The schedule to append an a-data file included in 42 record lines (6 times * 7 sub sites) to the hard disk drive in a personal computer is set up using PC208W software provided by Campbell Scientific Inc.

3.4.2. Transmission

The saved a-data on the hard disk drive in the remote site personal computer at Tak flux measurement site are moved to a local server at Yonsei University using locally developed software as a batch file moving on the Microsoft operating system (Appendix 1). The software is able to make the original directory system (line 67-141) and to select three transmission types such as SCP (secure copy in secure shell service), FTP (file transfer protocol) and mailing system on internet (line 143-151). The procedure for data transmission is as follows:

① Target file which is a-data file compression to ZIP file (line 200-235)
② Dialing to internet provider using mobile phone (line 237-254)
③ Sending ZIP file to database server (line 257-

297): If sending is successful target file is deleted and ZIP file is moved to storage directory and goes to finish stage

④ Error treatment when various types of problem occur (line 300-364): ZIP file is deleted and go to finish stage

⑤ Finish stage for dial cut and exit program (line 372-389)

The batch file is automatically executed four times per day. The result of every procedure is written in the log file and success or errors can be determined by the software.

3.4.3. Storage

All data from the remote sites are stored in a local server located in Yonsei University as Data Archive Naming Structure (DANS):

<Basic>

A. Site ID: MT (Mixed forest, Thailand), granted by KoFlux
B. Group ID
  11fx: 100m eddy covariance system
  13fx: 30m eddy covariance system
  11sl: 100m slow response measurements
  13sl: 30m slow response measurements
  21sl: ground station #1
  22sl: ground station #2
  23sl: ground station #3
  24sl: ground station #4
C. Date/Time ID
  yy: 2-digit year information
  mm: 2-digit month information
  dd: 2-digit date information
  HH: 2-digit hour information
  MM: 2-digit minute information

<File>

A. Raw data:
  Fast response measurements
    Data interval: 10Hz measured data
    Merge period: every 30minutes
    Format: Site ID+Group ID+yymmdd.HHMM
  Slow response measurements
    Data interval: 10minutes averaged data (1/30Hz measured)
    Merge period: every 1day
    Format : Site ID+Group ID+yymm.dd
B. Averaged data
  Fast and Slow response measurements
    Data interval: 30minutes averaged data
    Merge period: every 1day
    Format : dd.Site+IDGroup+IDyymm
C. Example
  30m eddy covariance system, 2003/04/09 11:30:00.0 ~ 11:59:59.9
    MT13fx030409.1130
  ground station #2, 2003/04/09 00:00 ~ 23:59
    MT22sl0304.09
  100m eddy covariance system 2003/04/09 averaged data
    09.MT11fx0304
  ground station #4, 2003/04/09 averaged data
    09.MT24sl0304

<Directory>

A. Raw data
  ./Site_ID/raw/Group_ID/yy/mm/dd
B. Averaged data
  ./Site_ID/avg/Group_ID/yy/mm

3.4.4. Processing

Two methods are available to reduce the influence of low pass filtering of the turbulence to a minimum (Moore, 1986; Massman, 2000; Aubinet *et al.*, 2000). One is to remove the arithmetic mean as determined with a digital recursive filter (McMillen, 1988), and the other is to detrend signals before computing fluctuations from the mean (Foken and Wichura, 1995). The Foken and Wichura (1995) method is applied to averaging to compute the flux covariance and the sampling duration in our data processing.

Classical application of the eddy covariance method involves mathematical rotation of the wind coordinate system to force vertical wind velocity to zero. This rotation enables on to calculate flux covariances that are orthogonal to the mean streamlines flowing over the landscape (McMillen, 1988; Foken and Wichura, 1995). Wilcza (2001) algorithms are applied in our sonic anemometer tilt correction.

In principle, changes in molar density can occur by adding molecules to or removing them from a controlled volume or by changing the size of the controlled volume, as is done when pressure, temperature and humidity change in the atmosphere. Mean vertical velocity is then computed on the basis of temperature and humidity density fluctuations using the Webb-Pearman-Leuning (1980) algorithm.

IV. RESULT AND DISCUSSION

4.1. RTMASS: Real-time monitoring and simulation system

The 30 minute average data (a-data) including basic meteorological measurements, temperature and water content of soil, and various fluxes are available on web site (http://koflux.net/site/egat/egat_frame.htm, Figure 2).

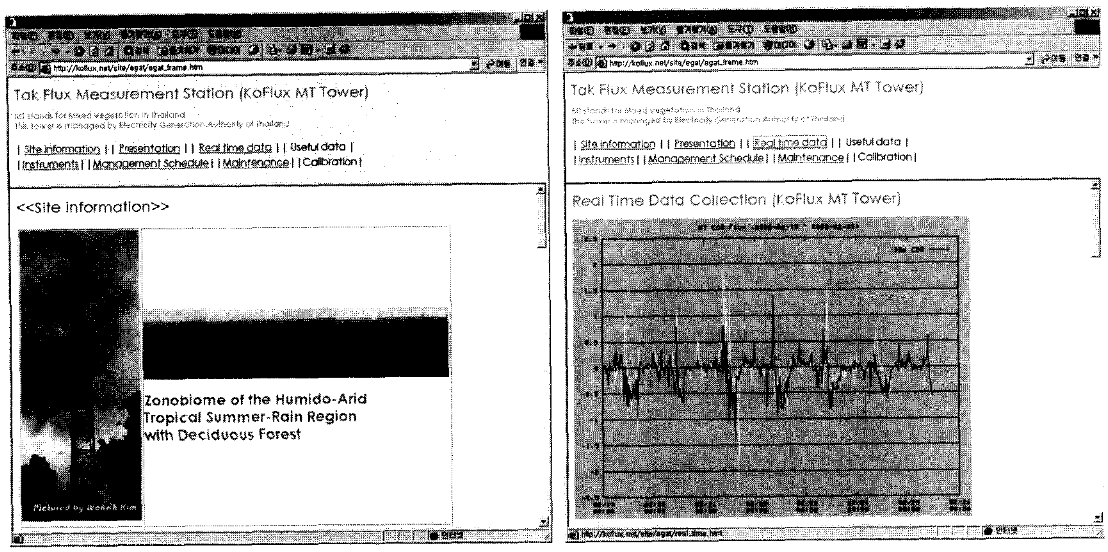

Fig. 2. The webpages for data information system of the Tak Flux measurement site.

The data for the last week are published, and renewal is accomplished 4 times per day. The achieved ratios of slow and fast response data using RTMASS until March 2003 are 85% and 70%, respectively. They are reasonable values with respect to data acquisition because typical data coverage ranges between 65% and 75% for general field studies (Falge *et al.*, 2001)

This data information system (DIS) is a successful and useful method for not only management of instruments status, power supply and system stability at remote sites, but also real-time monitoring of ecological, micrometeorological and hydrological data trend at local sites. While one of the major parts of the RTMASS is function of simulation using a land surface model or dynamic global vegetation model for predicting no measurements and gap filling, in this paper we do not comment on that system.

In practice, the accuracy of summing short-term eddy flux measurements on daily, seasonal and annual time scales depends upon a set of random and systematic bias errors that are associated with measurements, sampling and theoretical issues relating to the application of the eddy covariance technique to non-ideal conditions. Also, gaps in long-term data records will inevitably occur as sensors break down, are being calibrated, or when measurements over range the data acquisition system. Typical data coverage over the course of a year ranges between 65% and 75% for a large number of field studies. Consequently, the footprint model (Schmid, 2003) and gap filling method (Falge *et al.*, 2001) should be also considered for solving a question with respect to land surface heterogeneity and discontinuity of data in RTMASS. Finally, comparisons between annual estimates of net ecosystem carbon exchange using eddy covariance measurements and traditional ecological methods should be carried out to assess bias errors.

4.2. Mean flow and turbulence characteristics

Because mean wind speed less then 1 m s^{-1} was only 2% and mean wind directions from the tower was 13% during the experimental period (Fig. 3), the data loss according to tower shadow and low wind velocity is less significant for evaluation of the flux. A difference of wind direction between 30 m and 100 m level is fundamentally invisible.

It is often assumed that mean wind streamline conforms to large-scale topography and that the vertical axis is normal to the local terrain (Lee, 1998, Paw U *et al.*, 2000, Baldocchi *et al.*, 2000). This is used to justify coordinate rotation to force the mean vertical velocity to zero, in the absence of a non-zero mean vertical velocity due to larger-scale flow convergence or divergence. Using 0.5 hour data, the mean wind direction is found with the horizontal wind components u and v, and then a tilt angle is found by rotating about the mean cross-wind direction to where the average vertical velocity w becomes zero. The influence of the tower is not observed at the 100 m levels (Fig. 4). Fig.

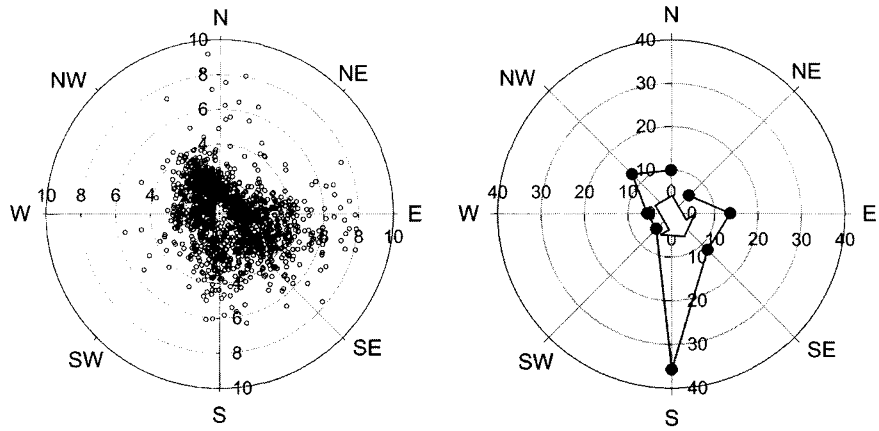

Fig. 3. Mean wind speed in each direction (left panel) and frequency distribution of upwind direction (right panel) at 100 m level. The measurement period was from 25 July to 29 August and, the arrow at the center of the right panel indicates the face of the sensors.

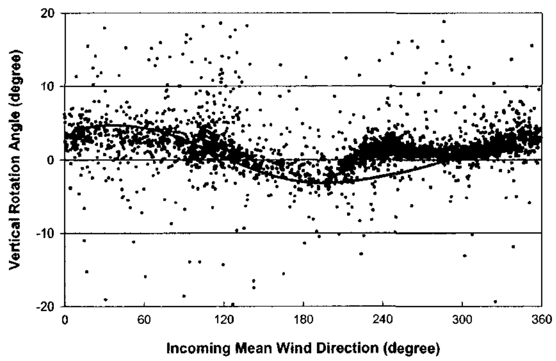

Fig. 4. Long-term vertical rotation angle versus incoming mean wind direction at 100 m level.

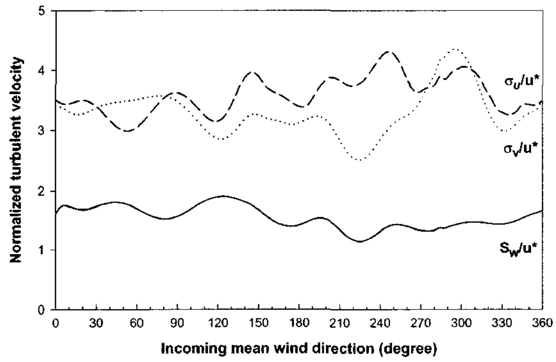

Fig. 5. Distribution of the ratio of standard deviations of velocity components to friction velocity versus incoming mean wind direction at 100 m level.

4 also shows the vertical rotation angle versus the incoming mean wind direction at 100 m after rotating the wind flows due to coordinate system aligned with the local mean streamlines, and that is a single sinusoidal function of wind direction as shown by Golden *et al.* (1996) and Baldocchi *et al.* (2000) which would be expected if the large-scale terrain has a uniform slope though is not agreeable from 200° clockwise to 300°.

Standard deviations of normalized velocity change little and have values close to those in neutral conditions with respect to upwind directions. Large variations are also not shown downwind of the tower according to the distortion of the flow field (Fig. 5, from 285° clockwise to 345°).

The Monin-Obukhov similarity relation is useful for a quality test of eddy covariance measurements. This test gives us the information about site and instrumentation through analyzing turbulence characteristics developed according to the similarity theory of turbulent fluctuations. In diurnal data, the agreement between measured values and theoretical prediction is satisfying. The agreement of vertical velocity variance with theoretical predictions suggests that no additional mechanical turbulence due to obstacles or instrumental distortion perturbed our measurements. This suggests that, despite the site heterogeneity, our measurements are valid and representative of the site (Fig. 6). However it is necessary to consider the heterogeneity effect of terrain to various fluxes at the TFM site because topography and spatial changes in surface roughness, CO_2 source and sink strengths

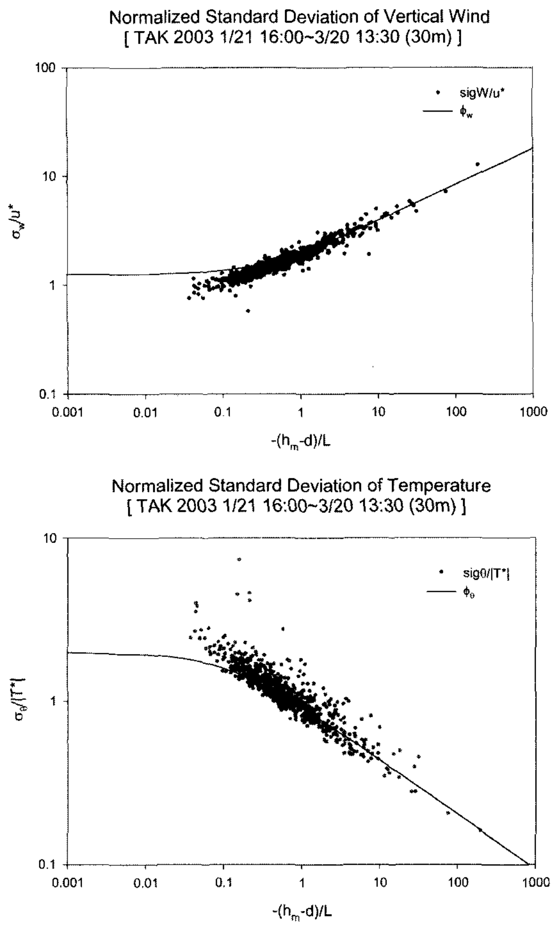

Fig. 6. The normalized standard deviations of temperature, σ_T/T_* and wind speed, σ_w/u_* versus stability, z/L.

produce spatial variations in the scalar concentration and wind velocity fields that may not be accommodated by this one-dimensional advection equation (Finnigan, 1999).

V. CONCLUSION

At present, annual water and carbon budgets over the land surface produced by eddy covariance measurements are most trustworthy though they are made over non-ideal site. Many colleagues efforts have minimized measurement error, generalizing the limitation of theory and developing a data processing technique. The Real Time Monitoring And Simulation System (RTMASS) based on the above results, which is Korean Flux Network-Data Information System (KoFlux-DIS), was constructed on technical aspects. Basically, because a monitoring is fundamental and a considerable step toward resolution of micrometeorological scientific issues, the installation of flux measurement system at Tak, Thailand is valuable. The constructed RTMASS on Tak flux measurement (TFM) site automatically gives valuable information for management of instrument status and real time monitoring of remote site data. The analysis of mean flow and turbulence characteristics over the TFM experimental site also prove the accuracy of instrumentation and importance of TFM site, while minimizing problems in terms of the non-ideal site and the introduction of the gap filling method and the land surface model into RTMASS are needed. Additionally, we also need to partition water and carbon fluxes into its components (transpiration, interception loss and evaporation on water and net primary productivity and respirations on carbon) so field data generated by eddy covariance study sites can be used to validate products developed by biogeochemical models and remote sensing indices (Running *et al.*, 1999). Confidence in long-term carbon flux measurements is limited by the multiple constraints to describe the annual sums. To reach this objective, more collaborative studies among scientists working with the eddy covariance method, dynamic global vegetation models, measuring the respiration method, and soil and biomass inventories will be needed.

적 요

태국 북서부의 Tak 지방에 KoFlux(Korean Flux Network) 연구의 일환으로서 플럭스 관측소(Tak flux measurement, TFM site)가 설립되었다. 이곳에서 이산화탄소와 물, 그리고 에너지 플럭스를 관측하기 위해 와공분산시스템(eddy covariance system)을 적용하였으며 관측된 자료는 실시간 자료 감시 및 모사 시스템(Real time monitoring and simulation system, RTMASS)을 이용하여 처리되어 전송된다. RTMASS는 KoFlux-DIS(Data information system)의 핵심 구조이고 원격지 시스템과 중앙 시스템으로 나누어지며 자료의 수집 및 전송, 자료의 저장 및 처리가 본 시스템의 주된 기능이다. 난류특성과 미기상학적인 분석 자료에 따르면, TFM 관측소는 열대 낙엽수림에 대한 다양한 플럭스 및 에너지 수지를 관측하고 분석하는데 적합하다고 할 수 있다.

REFERENCES

Aubinet, M., A. Grelle, A. Ibrom, Ü. Rannik, J. Moncrieff, T. Foken, A. S. Kowalski, P. H. Martin, P. Berbigier, Ch. Bernhofer, R. Clement, J. Elbers, A. Granier, T. Grünwald, K. Morgenstern, K. Pilegaard, C. Rebmann, W. Snijders, R. Valentini and T. Besala, 2000: Estimates of the annual net carbon and water exchange of European forests: the EUROFLUX methodology. *Advances in Ecological Research*, **30**, 113-175.

Baldocchi D. D., 2003: Assessing the eddy covariance technique for evaluating the carbon balance of ecosystems. *Global Change Biology*, in press.

Baldocchi, D. D., J. J. Finnigan, K. Wilson, K.T. Paw U and E. Falge, 2000: On measuring net ecosystem carbon exchange over tall vegetation on complex terrain. *Boundary-Layer Meteorology*, in press.

Baldocchi, D. D., B. B. Hicks and T. P. Meyers, 1988: Measuring biosphere-atmosphere exchanges of biologically related gases with micrometeorological methods. *Ecology*, **69**, 1331-1340.

Falge E., D. D. Baldocchi, R. Olson, P. Anthoni, M. Aubinet, C. Bernhofer, G. Burba, R. Ceulemans, R. Clement, H. Dolman, A. Granier, P. Gross, T. Grunwald, D. Hollinger, N. Jensen, G. Katul, P. Keronen, A. Kowalski, C. T Lai, B. E. Law, T. Meyers, J. Moncrieff, E. Moors, J. W. Munger, K. Pilegaard, U. Rannik, C. Rebmann, A. Suyker, J. Tenhunen, K. Tu, S. Verma, T. Vesala, K. Wilson and S. Wofsy, 2001: Gap filling strategies for defensible annual sums of net ecosystem exchange. *Agriculture and Forest Meteorology*, **107**, 43-69.

Finnigan, J. J., 1999: A comment on the paper by Lee (1988): On micrometeorological observations of surface-air exchange over tall vegetation, *Agriculture and Forest Meteorology*, **97**, 55-64.

Foken, T. H. and B. Wichura, 1995: Tools for quality assessment of surface-based flux measurement. *Agriculture and Forest Meteorology*, **78**, 83-105.

Golden, M. L., J. W. Munger, S. M. Fan, B. C. Daube and S. C. Wofsy, 1996: Measurements of carbon sequestration by long-term eddy covariance: methods and a critical evaluation of accuracy. *Global Change Biology*, **2**, 169-182.

Kim, J., W. Kim, B.-L. Lee, K.-H. Kim, K.-R. Kim, M.-Y. Kim, B.-Y. Lee, D.-W. Lee, G.-W. Lee, J.-T. Lee, J.-H. Lim, J.-H. Oh, J.-H. Lim, J.-H. Oh, E.-W. Park, J.-S. Shim, J.-I. Yun and C.-S. Rho, 2002: KoFlux: A New Tool to Study the Biosphere-Atmosphere Interactions in Asia. *Ecology of Korea*, D. Lee (Ed.), VIII INTECOL International Congress of Ecology Local Organizing Committee, 215-229.

Lee, X., 1998: On micrometeorological observations of surface-air exchange over tall vegetation. *Agricultural and Forest Meteorology*, **91**, 39-49.

Massman, W. J., 2000: A simple method for estimating frequency response corrections for eddy covariance systems. *Agricultural and Forest Meteorology*, **104**, 185-198.

McMillen, R. T., 1988: Eddy correlation technique with extended applicability to nonsimple terrain. *Boundary-Layer Meteorology*, **43**, 231-245.

Moore, C. J., 1986: Frequency response corrections for eddy covariance systems. *Boundary-Layer Meteorology*, **37**, 17-35.

Ogawa, H., K. Yoda, Kirot, 1971: A preliminary survey of the vegetation of Thailand. *Nature life SE Asia*, **1**, 21-157.

Paw U. K., D. D. Baldocchi, T. P. Meyers and K. B. Wilson, 2000: Correction of eddy covariance measurements incorporating both advective effects and density fluxes. *Boundary-Layer Meteorology*, **97**, 487-511.

Ruangpanit, N., 1995: Tropical seasonal forests in monsoon Asia: With emphasis on continental southeast Asia. *Vegetatio*, **121**, 31-40.

Schmid, H. P., 2003: Footprint modeling for vegetation atmosphere exchange studies: A reviews and perspective. *Agricultural and Forest Meteorology*, in press.

Twine, E. K., G. Pearman and R. Leuning, 1980: Correction of flux measurements for density effects due to heat and water vapor transfer. *Q. J. Roy. Meteorol. Soc*, **106**, 85-100.

Vickers, D. and L. Mahrt, 1996: Quality control and flux sampling problems for tower and aircraft data. *Journal of Atmospheric and Oceanic Technology*, **14**, 512-526.

Walter, H., 1994: Vegetation of the earth and ecological systems of the geo-biosphere (3rd ed.). Springer-Verlag, 318pp.

Webb, E. K., G. Pearman and R. Leuning, 1980: Correction of flux measurements for density effects due to heat and water vapor transfer, *Quart. J. R. Met. Soc.*, **106**, 85-100.

Wilczak, J. M., S. P. Oncley and S. A. Stage, 2001: Sonic anemometer tilt correction algorithms. *Boundary-Layer Meteorology*, **99**, 127-150.

Wilson, K., A. Goldstein, E. Falge, M. Aubinet, D. Baldocchi, P. Berbigier, C. Bernhofer, R. Ceulemans, H. Dolman, C. Field, A. Grelle, A. Ibrom, B. E. Law, A. Kowalski, T. Meyers, J. Moncrieff, R. Monson, W. Oechel, J. Tenhunen, R. Valentini and S. Verma, 2002: Energy balance closure at FLUXNET sites. *Agricultural and Forest Meteorology*, **113**, 223-243.

Yi, C., K. J. Davis, P. S. Bakwin, B. W. Berger and L. C. Marr, 2000: Influence of advection on measurements of the net ecosystem-atmosphere exchange of CO_2 from a very tall tower, *Journal of Geophysical Research*, **105**, 9991-9999.

Appendix 1. The source code for sendata.bat file

```
REM @echo off

REM
REM senddata.bat : automatic zipping & mail/FTP/scp sending batch
REM

REM description :

REM Requirements :
REM [1]set datetime format as follows:
REM         yyyy/MM/dd for date, HH:mm:ss for time
REM         at [start]-[settings]-[control panel]-[regional settings]-
REM         [regional options*****]-[customize]-[date](and -[time])
REM
REM
REM [2]Dialup profile (set the name of the profile at %dial_account%
on
REM         a line below) at [start]-[settings]-[network***]
REM
REM [3]install following programs and set the path to them in setting
REM       section below.
REM        a) compress program
REM           pkzip.exe
REM        b) transmission program
REM           for e-mail supports
REM            - confirm ISP constract with e-mail support
REM            - install command line e-mail client
REM             blat.exe( http://www.interlog.com/~tcharron/blat.html )
REM                  (run "blat -install smtp_server my_mail_address
how_many_trial" once)
REM           or
REM
REM           for FTP supports
REM            - confirm FTP client(C:¥WINNT¥SYSTEM¥ftp.exe)
REM             (MS Windows 2000/XP includes FTP client basically.)
REM           or
REM
REM           for scp support
REM            - confirm whether the server support ssh or not
REM            - prepare Win32 SSH client
REM pscp.exe( http://www.chiark.greenend.org.uk/~sgtatham/putty/ )
REM            - get Public/Private key and install
RE(http://the.earth.li/~sgtatham/putty/0.53b/puttydoc.txt ) for reference
REM

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REM http://
REM

REM Version History is on the end of this file.

;
;
;

                  :
                  : Environment Settings Change as you like
                  :

                  REM set debug=echo when debug (dryrun) mode
                  REM set dial=echo    when nodial mode
                  REM set method =mail or scp or ftp for each method

REM               set debug=echo
                  set debug=
                  set dial=rasdial
REM               set dial=echo

                  set METHOD=scp

                  REM regional settings

set station_name=MT
set subject_header=
set time_zone=GMT+7:00

                  REM ISP settings
                  REM This promotion will be expired at 19/07/2003

set dial_account=CSInternet TAK
set isp_userid=EA2b0326
set isp_passwd=5m1dJXA*
set blat_how_many_try=1

                  REM target files in full path (can be emtpty)

set target_dir_1=C:¥RTMASS¥data
set target_dir_2=C:¥RTMASS¥work
set target_dir_3=C:¥RTMASS¥sent
set target_dir_4=C:¥RTMASS
set target_dir_5=

set file_1=%target_dir_1%¥slow.dat
set file_2=%target_dir_1%¥fx100m00.dat
set file_3=%target_dir_1%¥fx30m00.dat
set file_4=
set file_5=
set file_6=
set file_7=
set file_8=
set file_9=

                  REM Dummy files in full path (can be empty)

set dummy_1=%target_dir_1%¥SCAN_100.DAT
set dummy_2=%target_dir_1%¥COMP_C00.DAT
set dummy_3=
set dummy_4=
set dummy_5=

                  REM Other directory settings

set archive_file_dir=%target_dir_1%
set work_dir=%target_dir_2%
set sent_dir=%target_dir_3%
set log_dir=%target_dir_2%
set tools_dir=%target_dir_4%

                  REM programs settings

set ZIP=%tools_dir%¥pkzip.exe
set ZIP_UPDATE=%ZIP% -u
set ZIP_LIST=%ZIP% -vb
set MAIL=%tools_dir%¥blat.exe
set scp=%tools_dir%¥pscp.exe

                  REM destinations settings

set mail_addresses=
set ftp_address=134.75.155.67
set scp_address=134.75.155.67

                  REM account settings

set ftp_userid=
set ftp_passwd=
set ftp_target_dir=
set ftp_script=
set scp_userid=rtmass
set private_key=rtmass.PPK
set scp_target_dir=/home/incoming/%station_name%

                  REM enable long-file-name? (1:enabled, 0:disabled)

set supports_lfs=1

                  REM end of user-defined section

                  :
                  : Get today's date/time and set time variables
                  :

set gettime=call :GETTIME
set send_log_day=Sun
set send_log_time=0

call :GETTIME

                  :
                  : File Names
                  :

set target_files=%file_1% %file_2% %file_3% %file_4% %file_5%
%file_6% %file_7% %file_8% %file_9%
set new_target_files=

set archive_file=%archive_file_dir%¥%mmdd%
%station_name%%hour%.zip

set log_file=%log_dir%¥send_log.txt
set ftp_log_file=%log_dir%¥ftp_log.txt
set body_file=%work_dir%¥mail_body.txt

                  :
                  : Start Log and init report status
                  :

call :GETTIME

echo : >> %log_file%
echo : >> %log_file%
echo
=================================================================>> %log_file%
echo %datetime% : Info : starting process >> %log_file%
echo
=================================================================>> %log_file%
echo : >> %log_file%

set status_report=

                  :
                  : Check Source Data Files and Log File
                  :
```

```
set FILE_EXISTANCE=0

echo
------------------------------------------------------------------->> %log_file%
echo %datetime% : Check Original Data Files >> %log_file%
echo
------------------------------------------------------------------->> %log_file%

for %%f in ( %target_files% ) do if EXIST %%f (
call :NEW_FILE_LIST %%f
            ) ELSE (
call :LOG "Warning" "Missing : %%f "
)

if "%day%" == "%send_log_day%" (if "%hour%"== "%send_log_time%"
call :NEW_FILE_LIST %log_file%)

echo : >> %log_file%

if "%FILE_EXISTANCE%" == "0" goto FILE_EXISTANCE_ERROR


            :
            : ZIP
            :

echo
------------------------------------------------------------------->> %log_file%
echo %datetime% : Compress Data Files >> %log_file%
echo
------------------------------------------------------------------->> %log_file%

for %%f in ( %new_target_files% ) do call :ZIP_FILE %%f

if NOT EXIST %archive_file% goto ZIP_NOT_EXIST

call :LOG "Info" "A zipped file %archive_file% was created."

%ZIP_LIST% %archive_file% | findstr -v PK >> %log_file%
echo : >> %log_file%

            :
            : Dial Up!
            :

echo
------------------------------------------------------------------->> %log_file%
echo %datetime% : Dial Up! >> %log_file%
echo
------------------------------------------------------------------->> %log_file%

call :LOG "Info" "Rasdial Dialing up to %dial_account%."

%dial%  /d
%dial% "%dial_account%" %isp_userid% %isp_passwd%

call :LOG "Info" "Rasdial ERRORLEVEL=%ERRORLEVEL%"

echo : >> %log_file%

if not "%ERRORLEVEL%" == "0" goto DIAL_ERROR

            :
            : Sending!
            :

call :%METHOD%

if "%FTP_FAILED%" == "1" goto FTP_ERROR
if "%SCP_FAILED%" == "1" goto SCP_ERROR

:
: Move the sent file to "sent" folder and delete original files
:

echo
------------------------------------------------------------------->> %log_file%
echo %datetime% : Arrangement to end >> %log_file%
echo
------------------------------------------------------------------->> %log_file%

if NOT EXIST %sent_dir% mkdir %sent_dir%

move /y %archive_file% %sent_dir%
call :LOG   "Info" "%archive_file% was moved to %sent_dir."

del %new_target_files%
for %%f in ( %new_target_files% ) do call :LOG   "Info" "%%f was
removed."

            :
            : Remove dummy files
            :

del /q %dummy_1% %dummy_2% %dummy_3% %dummy_4%
%dummy_5%
call :LOG   "Info" "Dummy files were removed."

            :
            : Normal End
            :

echo : >> %log_file%
call :LOG "Info" "All procedures were completed normally. Cheers!"
echo : >> %log_file%

set return_status=0
goto FINISH

:=======================================================================
: Errortraps
:

:FILE_EXISTANCE_ERROR

call :LOG "Fatal" "No data files to send"

set return_status=1
goto FINISH

:DIAL_ERROR

call :LOG "Fatal" "Dial Failed to [%dial_account%]"
del %archive_file%

set return_status=2
goto FINISH

:ZIP_NOT_EXIST

call :LOG "Fatal" "zip file was not created for (%new_target_files%)"
set status_report=%status_report% [ZIP_FAILED (possibly some files do
not exist)]

echo This is an ERROR INFO from MT EGAT_TOWER
at %yymmdd% %hhmm% (%time_zone%).  > %body_file%
echo Error Report   : zip was not created for ( %new_target_files% )
>> %body_file%

set subject="%subject_header% (ZIP ERROR) %yymmdd% %hhmm%"

%debug% %MAIL% %body_file% -to %mail_addresses%
-subject %subject% -attach %archive_file%

if NOT "%ERRORLEVEL%"=="0" goto MAIL_ERROR

call :LOG "Info" "An ERROR REPORT MAIL was sent
to %mail_addresses%."

set return_status=3
goto FINISH

:MAIL_ERROR

call :LOG    "Fatal" "Mailing %archive_file% failed
after %blat_how_many_try% trial(s)."

set return_status=4
goto FINISH

:FTP_ERROR

type %ftp_log_file% >> %log_file%
echo : >> %log_file%

call :LOG "Fatal" "FTP failure : %archive_file%
to %ftp_userid%@%ftp_address%"
echo : >> %log_file%

del %ftp_log_file% %archive_file%

set return_status=5
goto FINISH

:SCP_ERROR

echo : >> %log_file%

call :LOG "Fatal" "SCP failure : %archive_file%
to %scp_userid%@%scp_address%"

set return_status=6
goto FINISH

:
:
:=======================================================================

:FINISH
            :
            : Dial cut
            :

echo
------------------------------------------------------------------->> %log_file%
echo %datetime% : Finishing >> %log_file%
echo
------------------------------------------------------------------->> %log_file%

%dial% "%dial_account%" /d
call :LOG "Info" "cutting dial line to [%dial_account%]"

            :
            :exiting
            :

call :LOG "Info" "Process finished at status %return_status%."
echo
===================================================================>> %log_file%
```

```

exit /b %return_status%

REM End of main program

REM ============ Subroutines ==============

                :
                : SCP
                :

:SCP
                REM copy the zipped file to certian SSH server

set SCP_FAILED=0

echo
------------------------------------------------------------------>> %log_file%
echo %datetime% : SCP log >> %log_file%
echo
------------------------------------------------------------------>> %log_file%
echo : >> %log_file%

%scp% -i %private_key% %archive_file% %scp_userid%@
%scp_address% %scp_target_dir% >> %log_file% 2>&1

if NOT "%ERRORLEVEL%" == "0" (
                set SCP_FAILED=1
                ) else (
                echo : >> %log_file%
call :LOG "Info" "SCP success : %archive_file% to %scp_userid%
@%scp_address%"
                echo : >> %log_file%
                )

goto :EOF
REM end of SCP

                :
                : FTP
                :

:FTP

                REM send the zipped file to certain FTP server

set FTP_FAILED=0

echo open %ftp_address%> %ftp_script%
echo %ftp_userid%>> %ftp_script%
echo %ftp_passwd%>> %ftp_script%
echo binary>> %ftp_script%
echo cd %ftp_target_dir%>> %ftp_script%
echo put %archive_file%>> %ftp_script%
echo quit>> %ftp_script%

echo
------------------------------------------------------------------>> %log_file%
echo %datetime% : FTP log >> %log_file%
echo
------------------------------------------------------------------>> %log_file%

FTP -s:%ftp_script% | findstr -v "ftp> %ftp_address% binary 200 220
331">> %ftp_log_file%
del %ftp_script%

findstr 55 %ftp_log_file%
if "%ERRORLEVEL%" == "0" (
                set FTP_FAILED=1
                ) else (
                type %ftp_log_file% >> %log_file%
                del %ftp_log_file%
                echo : >> %log_file%
call :LOG "Info" "FTP success : %archive_file%
to %ftp_userid%@%ftp_address%"
echo : >> %log_file%


goto :EOF
REM end of FTP

                :
                : Mail
                :

:MAIL

                REM notice :
                REM
                REM

if "%status_report%"=="" set status_report=[Normal]

echo These data files are from %station_name% at %datetime%. Enjoy!
> %body_file%
echo Status Report   : %status_report% >> %body_file%
%ZIP_LIST% %archive_file% >> %body_file%

set subject="%subject_header% (senddata
succeeded) %yymmdd% %hhmm%"

%debug% %MAIL% %body_file% -to %mail_addresses% -subject
%subject% -attach %archive_file% -try %blat_how_many_try%
if NOT "%ERRORLEVEL%" == "0" goto MAIL_ERROR

call :LOG "Info" "A mail was sent to %mail_addresses%."

goto :EOF
REM end of MAIL

                :
                : Get time
                :

:GETTIME

REM notice : values in "tokens=" and "delims=" option strongly depend
REM             on the setting of date/time setting. See comments on
REM             the top of this file for detail.

@echo off
for /f "tokens=1" %%i in ('date /t') do set day=%%i
for /f "tokens=2 delims=/ " %%i in ('date /t') do set year=%%i
for /f "tokens=3 delims=/ " %%i in ('date /t') do set month=%%i
for /f "tokens=4 delims=/ " %%i in ('date /t') do set ddate=%%i

set yymmdd=%year%%month%%ddate%
set mmdd=%month%%ddate%

for /f "tokens=1 delims=: " %%i in ('time /t') do set hour=%%i
for /f "tokens=2 delims=: " %%i in ('time /t') do set min=%%i

set hhmm=%hour%:%min%

set datetime=%date% %hhmm%[%time_zone%]

goto :EOF
REM end of GETTIME

:ZIP_FILE
REM usage : call :ZIP_FILE fullpath

set filename=%~f1
%debug% %ZIP_UPDATE% %archive_file% %filename%

if NOT "%ERRORLEVEL%"=="0"   (
call :LOG   "Warning" "zip failed for %filename%."
                ) else (
call :LOG   "Zipped" "%filename%."
                )

goto :EOF
REM end of ZIP_FILE

:LOG
@echo off
REM usage : call :LOG level message_to_be_sent
REM   level is either of Info, Warning or Fatal.
REM   message must be quoted when containg space(s).

call :GETTIME

echo : %~1 : %~2 >> %log_file%

goto :EOF
REM end of LOG

:NEW_FILE_LIST
                set FILE_EXISTANCE=1
                set new_target_files=%~1 %new_target_files%
                call :LOG "Pass" "File %~1 exists."
goto :EOF
REM end of NEW_FILE_LIST

REM Version History (latest to oldest)
REM [0.5.0] 2003/01/16
REM   Changed : Declaration of time variables were changed to
combination
REM               of each tokens
REM               Variable %time_id% was removed.
REM               Archive file name format was changed to
REM               %mmdd%%station_name%%hh%
REM   New Feature : Dummy files remove function was added.
REM                   Puts log file into archive file periodically.
REM
REM [0.4.0] 2002/11/27
REM   New Feature : scp option was added
REM
REM [0.3.0] 2002/11/21
REM   New Feature : FTP option was added
REM
REM [0.2.0] 2002/11/01
REM   Bug fixed : Log message was not correct when ZIP error occured
REM   Changed : no special error mail will be sent when zip failed but
REM        zip file exists.
REM   Improved : contents in zip file are displayed in the mail body.
REM                Files to be sent are now moved to another dir and
REM                a zip is created containing all files in that dir.
REM                (Only when finishing correctly, all files are deleted)
REM   New Feature : if no zip file will not be created, an error mail
REM                will be sent
REM
REM [0.1.1] 2002/10/27
REM   Bug fixed : too long line for pkzip. Now uses "for" loop for zip
REM
REM [0.1.0] 2002/10/26
REM   First Version
```