Annual Report
Hydrospheric Atmospheric Research Center (HyARC)
Nagoya University

2012

Contents

Foreword

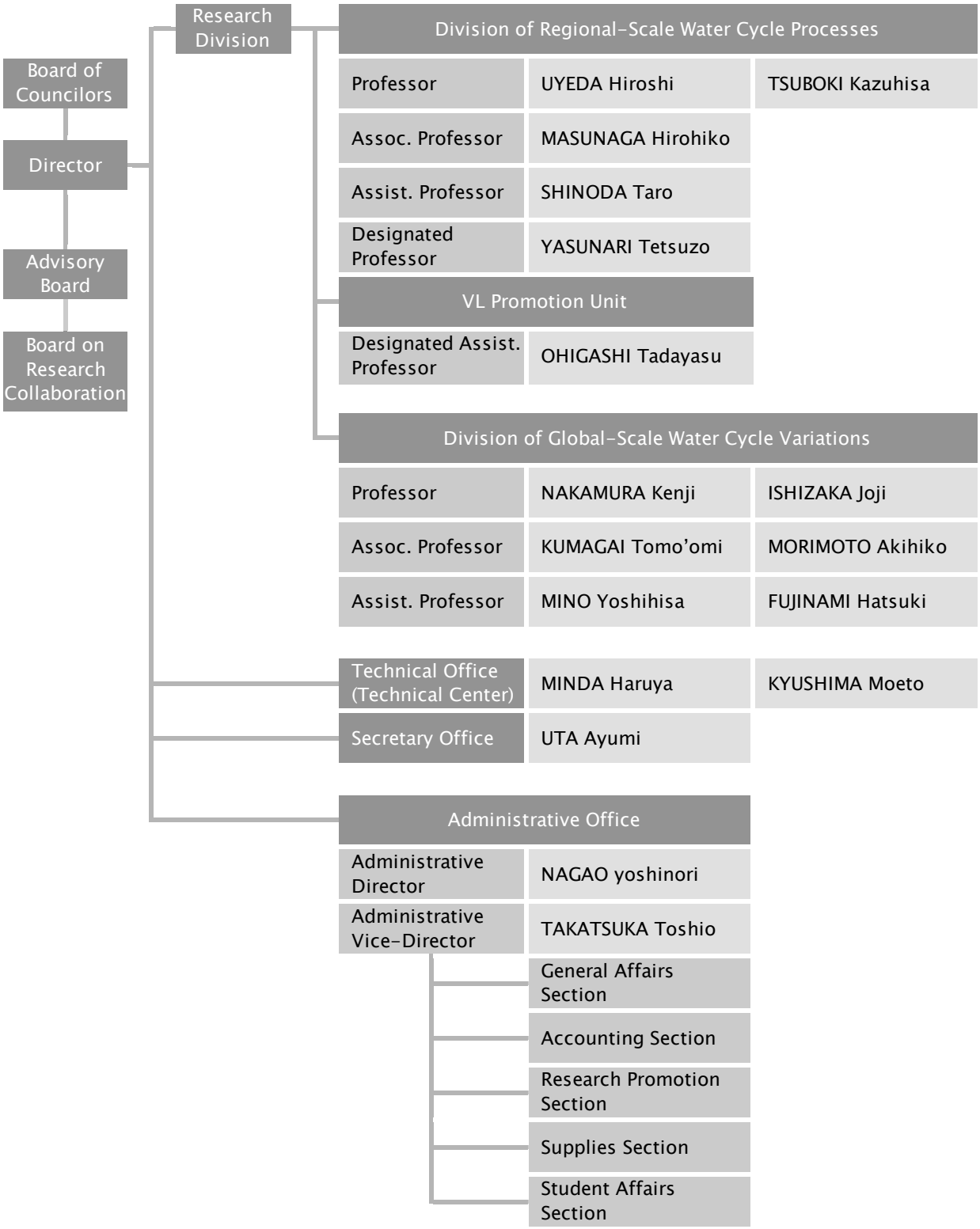
HyARC functions as an inter-university collaborative system, which is in many ways unique in the world. To ensure its research activity, HyARC was accredited as a Joint Usage/Research Center in April 2010 by the Ministry of Education, Culture, Sports, Science, and Technology, Japan. The University Project supported a virtual laboratory for diagnosing the earth's climate system. HyARC has also collaborated with numerous institutions such as the Research Institute of Humanity and Nature (RIHN) and the National Institute of Information and Communication Technology (NICT). In the university, HyARC supports the Study Consortium for Earth-Life Interactive System (SELIS) which is a cross-cutting virtual organization in Nagoya University.

As shown in this report, research activity at HyARC is maintained at high level, and many good results have been published. Three new big project proposals have been accepted: Development of a coupled ocean-atmosphere non-hydrostatic model for typhoon research, Eco-climate system in Northeastern Eurasia and Southeast Asian tropics: impacts of global climate change, and Development of a method to comprehend and predict wind conditions required for offshore wind-power generation. The first one is an extension of the typhoon simulation in the future global warming era. The second one is also related to the interaction between forest and climate. The third one is a study on the potential of off-shore wind power generation. Related to the third one, a new endowed research division "Management of Offshore Wind Power" will start at the beginning of the next fiscal year. This new division could be one of the trials to contribute to society with scientific results in HyARC.

While selecting projects and activities, HyARC considers the project's feasibility, its significance, and the collaboration requirements. Although HyARC has only 10 permanent staff members (four professors, three associate professors, and three assistant professors), it supports many postdoctoral candidates in active research. In addition, HyARC has accepted graduate students in the Department of Environmental Studies. Three students got doctorate titles and six students got masters titles. As part of the UNESCO International Hydrology Program (IHP), HyARC has hosted training courses supported by the Japan Trust Fund with a theme of "Precipitation measurement from space and its applications".

Nakamura Kenji
Director
Hydrospheric Atmospheric Research Center

Staff and Organization



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Research Program

Development of remote sensing technology for atmosphere and ocean observations

The Okinawa Subtropical Environment Remote-Sensing Center, an observation facility in Okinawa, Japan, was established by the National Institute of Information and Communication Technology (NICT). These facilities offer the use of full polarimetric Doppler radar (COBRA), 400 MHz wind profiler radar, Doppler sodar, disdrometers, rain gauges, and ocean radars. In 2005, an interuniversity collaboration was formed between NICT, Okinawa, and the Hydrospheric Atmospheric Research Center at Nagoya University, Japan (HyARC). Based on the results of collaboration studies, last fiscal year, the project has re-started with a new title as "Development of remote sensing technology for atmosphere and ocean observations" recognizing the demand of new techniques for the atmosphere and ocean remote sensing.

The Japan Aerospace Exploration Agency (JAXA) has developed a new dual Ka-band radar system for ground validation of the Global Precipitation Measuring Mission (GPM). As one of the atmosphere observations, rain observation experiment with this radar was conducted in NICT Okinawa with collaboration of JAXA, and the data were analyzed. For the ocean observation, preliminary study of a new flexible ocean radar idea has been developed. The new radar may be used for the Tsushima Current observation.

Research on Coast Circulation, Biological Production and Material Transport with Remote Sensing

Coastal area is between land and open ocean, and high biological production, active circulation and material transport are maintained by freshwater input with materials from land, including human origin, and by physical variations affected by topography. Because it is difficult to access to oceanic area, unlike on land, observation by remote sensing is very important. However, satellite sensors covering and resolving typical time and spatial scales in coastal area are limited, and remote sensing of coastal area is not fully operational because many technical problems still remain.

Scientists in Hydrospheric-Atmospheric Research Center have conducted research on development of remote sensing data and analysis of the data in coastal area, such as development of verification system of primary production, estimation and behavior of chlorophyll and suspended maters in East China Sea, red tide in Japanese coastal area, circulation in the East China Sea using sea surface topography and HF radar data. Japan Aerospace Exploration Agency (JAXA) is proposing new ocean color and sea surface topography sensors, and it is expecting that activities of remote sensing user community for coastal environment will be expanded.

Research program, “Research on Coast Circulation, Biological Production and Material Transport with Remote Sensing”, has been started from 2011, and five collaborative research programs were accepted and conducted following for 2012.

- Standard products of ocean color sensor, MODIS, for remote sensing reflectance and chlorophyll-a were verified in Biwa Lake.
- Use of S-GLI, which is the coming ocean color sensor, of JAXA was discussed. Atmospheric correction and in-water algorithm for Ise Bay was developed.

- 9th Korea-Japan Workshop on Ocean Color Remote Sensing was held with 6th Program of the East Asian Cooperative Experiments (PEACE) Ocean Science workshop. Collaboration of research of ocean color and oceanography of east Asian marginal seas was discussed with researchers from Japan, Korea, Taiwan, Russia, and Malaysia.

- Sea surface height was measured directly between Fukuoka and Busan by Interference Real-Time Kinematic GPS on a ferryboat, and short term variation with 20-30km eddy shape probably caused by tide was observed.

- Horizontally two dimensional high resolution tidal model for East Asian marginal sea was developed, and accuracy of semi-diurnal cycle variation was improved with data assimilation.

Laboratory for Cloud and Precipitation Climatology

A Satellite Study of Tropical Moist Convection and Environmental Variability: A Moisture and Thermal Budget Analysis

The thermodynamic variability associated with moist convection over tropical oceans is analyzed by making use of a variety of satellite sensors including radars (TRMM PR and CloudSat CPR), an infrared and microwave sounder unit (Aqua AIRS/AMSU suite), and microwave radiometer (Aqua AMSR-E) and scatterometer (QuikSCAT SeaWinds) aboard different platforms. Satellite measurements of atmospheric parameters including air temperature, water vapor, cumulus cloud cover, and surface wind are composited with respect to the temporal lead or lag from TRMM detected convection to obtain statistically continuous time series on hourly to daily time scales. AIRS observed temperature and humidity profiles, representing cloud-cleared sounding, are combined with semi-theoretical estimates of in-cloud temperature and humidity to construct the large-scale mean field. Those measurements are ingested to the moisture and thermal budget equations integrated vertically over each layer separated by cloud base. This strategy makes it possible to evaluate the free-tropospheric (FT) convergence of moisture and dry static energy and their vertical flux at cloud base from satellite observations alone. The main findings include: 1) Vertical moisture transport at cloud base is the dominant source of FT moistening prior to isolated cumulus development while overwhelmed by horizontal moisture convergence for highly organized systems (Fig. 1); 2) FT diabatic heating is largely offset on an instantaneous basis; and 3) FT moistening by convective eddies amounts to a half of the total cloud-base moisture flux in the background state, while large-scale mean updrafts modulate the variability of cloud-base flux when highly organized systems develop (Fig. 2). The known correlation between congestus clouds and FT moisture before deep convection may be accounted for by large-scale mean moisture updraft rather than congestus eddy moistening.

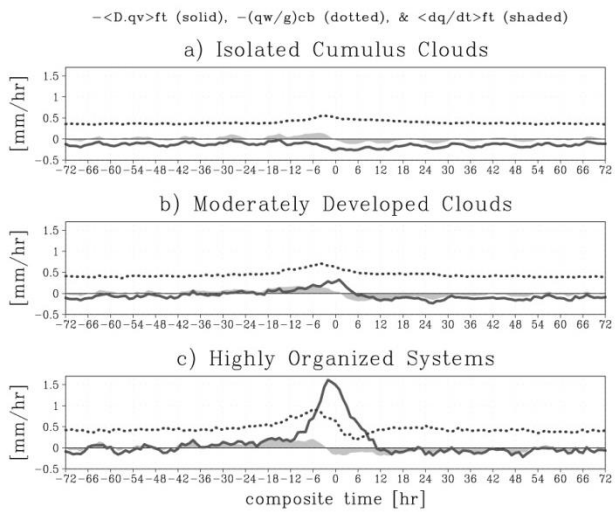

Fig. 1 : Free-tropospheric (FT) moisture budget: FT horizontal moisture convergence (solid), vertical moisture flux at cloud base (dotted), and FT moisture tendency (shaded).

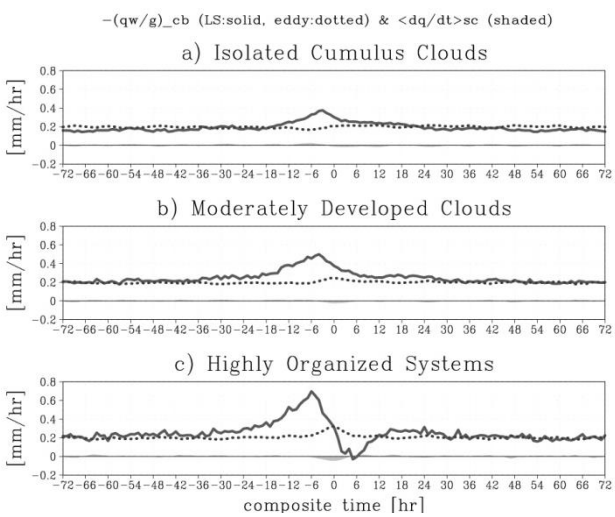

Fig. 2 : Sub-cloud layer (SC) moisture budget: large-scale mean moisture updraft at cloud base (solid), eddy moisture updraft at cloud base (dotted), and SC moisture tendency (shaded).

Reference: Masunaga, H., 2013: A Satellite Study of Tropical Moist Convection and Environmental Variability: A Moisture and Thermal Budget Analysis, *J. Atmos. Sci*., in press.

A Satellite Study of the Relationship between Sea Surface Temperature and Column Water Vapor over Tropical and Subtropical Oceans

The known characteristics of the relationship between sea surface temperature (SST) and column water vapor (CWV) are reevaluated with recent satellite observations over tropical and subtropical oceans. Satellite data acquired by the Aqua AMSR-E, AIRS/ AMSU suite, the TRMM PR, and the QuikSCAT SeaWinds are analyzed together for 7 years from October 2002 to September 2009. CWV is decomposed into surface relative humidity (RH_0), presumably coupled closely to SST, and the water vapor scale height (Hv) as an index of vertical moisture gradient between the boundary layer and the free troposphere. Surface relative humidity is climatologically homogeneous across tropical and subtropical oceans, while the dependence of CWV on SST varies from one region to another (Fig. 3). SST mainly accounts for the variation of CWV with the water vapor scale height, which is virtually invariant over subtropical oceans. On the other hand, over tropical oceans, the variability of CWV is explained not only by SST but also by a systematic change of the water vapor scale height. The regional contrast between tropical and subtropical oceans is discussed in the context of the regional moisture budget including vertical moisture transport through convection.

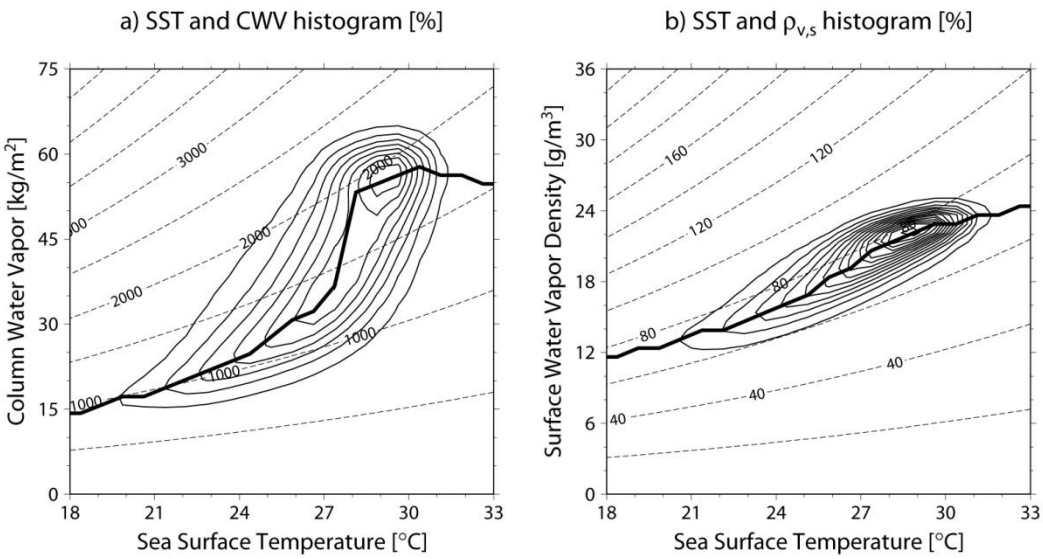

Fig. 3 : a) The joint probability density function of SST and CWV (solid line) and $RH_0 \times Hv$ predicted theoretically (m; dash line). Contour interval is 0.1 %. Thick line shows the maximum occurrence for each SST. b) As a), but SST and surface water vapor density ($\rho_{v,s}$) and predicted RH_0 (%).

Reference: Kanemaru, K. and H. Masunaga, 2013: A Satellite Study of the Relationship between Sea Surface Temperature and Column Water Vapor over Tropical and Subtropical Oceans, *J. Climate*, in press.

Laboratory of Satellite Meteorology

Dual Ka-band radar experiment for GPM DPR algorithm development

A dual Ka-band radar system has been developed by the Japan Aerospace Exploration Agency (JAXA) for the GPM DPR algorithm development. The dual Ka-radar system which consists of two identical Ka-band radars can measure both the specific attenuation (k) and the equivalent radar reflectivity (Ze) at Ka-band. Those parameters are important particularly for snow measurement.

Observations using the dual Ka-radar system were performed in Okinawa Island, in Tsukuba, over the slope of Mt. Fuji, and in Nagaoka, Japan during JFY2011. Along with the data analysis, new observation at Sapporo aiming to the snow measurement has started in 2012.

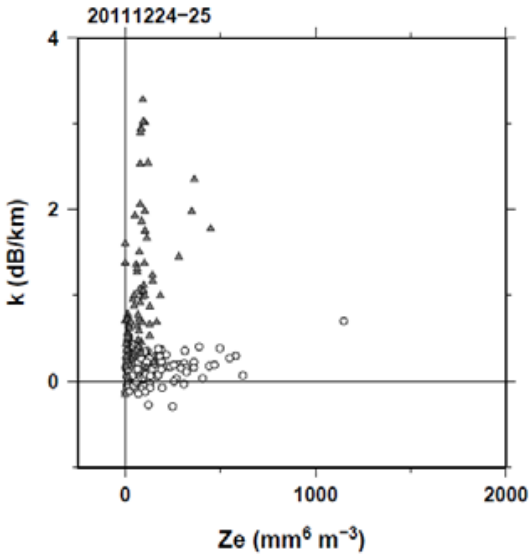

Fig. 1 : k-Ze relationship obtained in snow observation at Nagaoka. Circle: wet snow, and triangle: dry snow.

The main results are the k-Ze relationships. For the rain, reasonable k-Ze relationship has been obtained. The feasibility of total attenuation in melting layer has been studied. Different k-Ze relationships have been obtained in snow observations. Figure 1 shows two examples of the k-Ze relationships obtained in the experiment in Nagaoka. One is for rain and the other is for wet snow. Compared with rain, wet snow shows large specific attenuation. Using the difference in radar echoes due to the path length difference between vertical and slant paths, total attenuation in the melting layer can be estimated. The result shows that estimated attenuation is twice or three times larger of the ground-measured rain rates.

Study of the life cycle of tropical cloud and precipitation systems using MTSAT-1R and TRMM data

Observation data from the Multi-functional Transport Satellite (MTSAT)-1R and the Tropical Rainfall Measuring Mission (TRMM) satellite are analyzed to show statistical view of the cloud life cycle, including the change of vertical structure of rainfall, over the Maritime Continent and a part of the tropical western Pacific. The analysis focuses on the isolated cold cloud systems, which can be considered as fundamental self-organized cloud systems. After identifying temporally connected isolated cold cloud systems by a cloud tracking procedure, spatiotemporally synchronized TRMM observations with the cloud systems were searched and various statistics were computed.

Long-lived systems show similar evolution with mesoscale convective systems (MCS), that is, the echo top develops followed by the maximum of cloud and rain areas with decrease of the fraction of convective rain. The short-lived systems show generally weak rainrates and do not have the expansion of cloud and rain areas. The precipitation radar (PR) onboard TRMM detects different evolution from that of the microwave radiometer.

Vertical profiles of the latent heat release reflect the evolution of the precipitation systems. Convective systems show heating in all layers, but the stratiform systems show heating only in upper layers. The height of the maximum heating moves upward from about 4 km to 8 km as the precipitation system evolves. The stratiform system does not show significant change of heating profile, but the area fraction stratiform rain increases resulting in the total heating profile changes.

Precipitation characteristics in mountainous region

Precipitation characteristics and circulation, specifically focusing on its relationship with elevation, are examined over mountainous regions utilizing the Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR) data, the Japanese 25-year reanalysis (JRA-25), and the Global 30 Arc-Second Elevation Data Set (GTOPO30). The rainfall-elevation relationship in the central Himalayan region for pre-monsoon and monsoon seasons is analyzed using the 11-year (1998-2008) TRMM PR data of spatial resolution 0.1 x 0.1 degrees. Variability of precipitation characteristics is also studied for Himalayan active and break periods. The TRMM product 3B42 is used for identification of active and break periods. The results indicate a large-scale relationship between rainfall and elevation during both seasons. The investigation reveals a relatively large amount of rainfall over higher elevations during pre-monsoon season. During summer monsoon, there appear well-known double peaks of rainfall over the southern slope of the Himalayas. The first peak appears along the Sub-Himalayas, while the second one appears along the Lesser Himalayas. The former rainfall peak is attributed to fewer heavy rainfall events, and the latter to frequent but weak rainfall (Fig. 2). It is suggested that the atmosphere is insufficiently moist to trigger convections during the pre-monsoon season, and sufficiently moist during summer monsoon season. The convections over the Sub-Himalayas may moisten the middle layer, and the water vapor in the atmosphere condenses due to forced lifting along the slope forming the second peak rain band. Total rain amount is primarily determined by the frequency of rain. The rain-conditioned rain rate along the slope monotonically decreases with elevation. This shows that the precipitation occurs due to forced lifting. In addition, the results show that seasonal variation of rainfall is rather similar to the variation of rainfall characteristics observed during active and break periods.

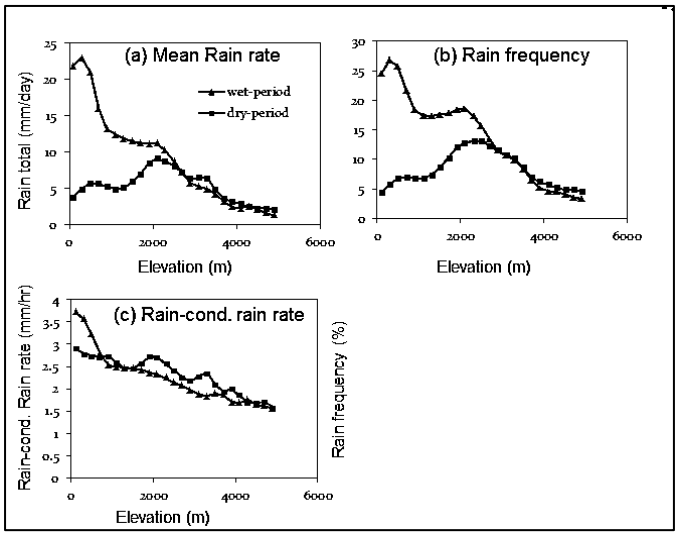

Fig. 2 : Precipitation characteristics with ground elevation. Rectangle: March - May, triangle: June - August。(a): mean rain rate, (b): rain frequency, and (c): rain conditioned rain rate.

Dry air intrusion in Okinawa area

The Okinawa Islands locates in the subtropics, and sometimes disturbances by westerly waves cause dry air intrusions. Radiosonde observation data at Okinawa in August 2002 and June 2004 are analyzed to investigate dry air intrusions. Data also used are sounding data, JRA-25 and ERA-Interim reanalysis datasets, GMS-5 andGOES-9 geosynchronous meteorological satellite datasets, and Hysplit Trajectory Model data.

The dry air is produced by extratropical disturbances, and is transported to the Okinawa area. Subsidence at Okinawa is weak and is not the primary cause of the dry air. Results of a global non-hydrostatic numerical model (NICAM) are analyzed, and it is found that the Okinawa cases are rather rare cases in which north wind due to westerly waves causes the dry intrusion.

Differences in phytoplankton light absorption between the Tsushima Strait and East China Sea: Possible influence of Changjiang Discharge

Phytoplankton light absorption is a major factor in determining the optical properties of waters, and it has been widely investigated in the oceanic and coastal regions in the past few decades. The East China Sea (ECS) receives enormous amounts of freshwater containing very high concentrations of nitrogen from Changjiang River in summer. Waters from the ECS as well as the Kuroshio form waters in the Tsushima Strait (TS). It is suggested that freshwater significantly change optical properties of the area, while its impact on phytoplankton light absorption is rarely known.

We hypothesize that the Changjiang freshwater may cause distinct phytoplankton absorption in the ECS. To verify this hypothesis, the variability in phytoplankton absorption of surface and subsurface chlorophyll a maximum (SCM) samples were analyzed in the TS and ECS, and the differences among these regions were characterized. Furthermore, to understand the variations and differences of phytoplankton absorption, changes in the phytoplankton size structure derived from HPLC pigments data, packaging effect and pigment composition were studied.

The total chlorophyll a (Tchla) specific absorption coefficient ($a^*_{ph}(\lambda)$) at 440 nm of TS waters varied inversely with Tchla ($P < 0.01$, $R^2 = 0.708$) (Fig. 1 (a)). Meanwhile, the fitted power law function was comparable with that obtained in the global ocean by Bricaud et al. (1995). However, the ECS waters showed a weak correlation between $a^*_{ph}(440)$ and Tchla. The packaging effect index $Q_a^*(440)$ revealed quite similar variations as the $a^*_{ph}(440)$ (Fig. 1 (b)); meanwhile, absorption of all pigments also showed small but significant changes (data not shown), which confirmed that the packaging effect is the predominant factor in determination of $a^*_{ph}(\lambda)$.

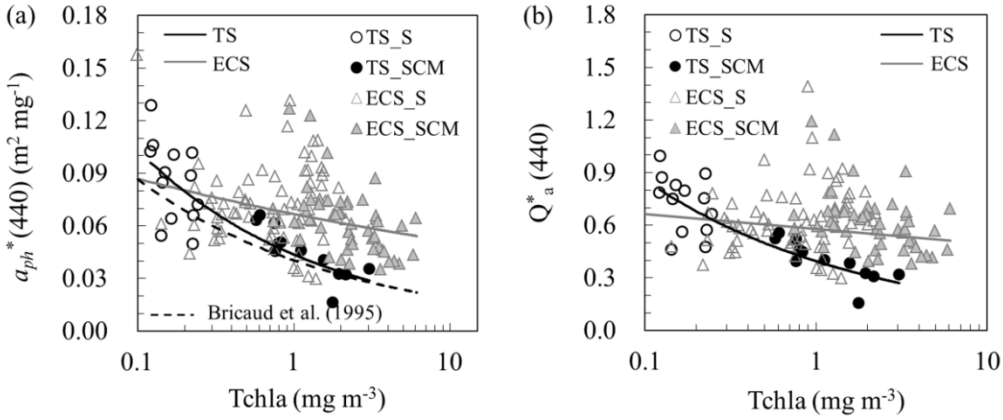

Fig. 1 : Variations of $a^*_{ph}(440)$ (a) and $Q_a^*(440)$ (b) as a function of Tchla in the Tsushima Strait (TS) and East China Sea (ECS). TS_S, TS_SCM, ECS_S and ECS_SCM represent the TS surface, TS SCM, ECS surface and ECS SCM, respectively. Black and gray lines indicate fitting functions in the TS and ECS, respectively. Black dashed line corresponds to the regression of Bricaud et al. (1995).

It is well known that packaging effect is high for large cell but low for small cell. Based on this, the phytoplankton size-fractions could qualitatively explain the variations of $Q_a^*(440)$ (Fig. 2). The TS waters showed typical characteristics of the global ocean that pico-plankton was dominant at low Tchla, nano-plankton at medium Tchla, and micro-plankton at high Tchla, which was highly consistent with those observed by in the global ocean. Such characteristics, however, could not be found in the ECS. These results suggested that the algorithms for size-fractions estimation based on the relationship

between Tchla and size-fraction proposed for the global ocean, could be adaptable in the TS but not in the ECS.

In conclusion, probably due to the influence of Changjiang freshwater, variations in phytoplankton size structure and pigment composition were different between TS and ECS waters, in turn, these differences might cause significantly different phytoplankton absorption. These findings caution against us that we should pay more attention to the applications of the general parameterizations for the global ocean, such as relationships between $a^*_{ph}(\lambda)$ and Tchla affected by phytoplankton size structure as well as the algorithms proposed based on the relationships, in the coastal waters where is significantly influenced by freshwater discharge.

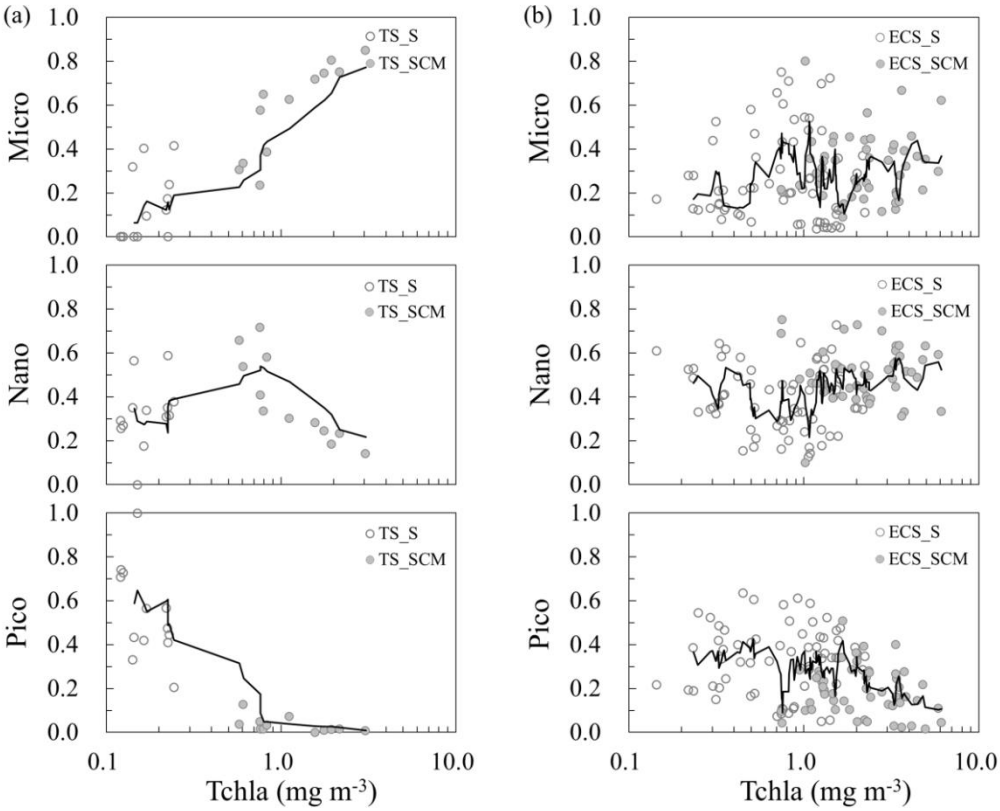

Fig. 2 : Variations of Tchla size-fractions of micro-, nano- and pico-phytoplankton as a function of Tchla for waters from the Tsushima Strait (TS) (a) and East China Sea (ECS) (b). TS_S, TS_SCM, ECS_S and ECS_SCM represent the TS surface, TS SCM, ECS surface and ECS SCM, respectively. Lines represent the 5-point running average.

Verification and correction of data of satellite ocean color sensors SeaWiFS and MODIS for long-term analysis of chlorophyll-a in Ise Bay.

Environment of Ise Bay, an inner bay with large volume of freshwater input, became worse since 1970s, and many red tides and anoxic condition has been observed. Recently, nutrient supply was reduced to improve the conditions; however, anoxic water is still observed. Furthermore, decrease of fisheries catch has been worried because of the oligotrophication and climate change. In order to monitor the change of the ecosystem, it is expected to use satellite remote sensing technology to observe phytoplankton biomass, chlorophyll-a (Chl-a). However, abundant suspended and dissolved color materials and smog may influence to the accuracy of the data. It is also pointed out that the one satellite cannot monitor for a long time. In this study, accuracy and continuation of Chl-a data of Ise Bay from

satellite ocean color sensors, SeaWiFS and MODIS/Aqua, was verified, and the satellite Chl-a data was improved.

Chl-a from SeaWiFS and MODIS showed significant positive correlation with *in situ* data but overestimated about 2-fold. The overestimation was large (3.5-fold) when remote sensing reflectance at 412nm (Rr412) was negative. Error of MODIS Rrs was small and large at 547 and 412 nm, respectively. The error of atmospheric correction was large in spring, and Kosa may be one of the causes. Chl-a estimated from *in situ* Rrs was closer to *in situ* Chl-a than satellite Chl-a; however, it was overestimated 2-fold and underestimated 1/2-fold at less and greater than 4 mg m^{-3} of Chl-a, respectively. These results suggested that the error of satellite Chl-a data in Ise Bay was caused by both atmospheric correction, specifically at short wavelength, and in-water algorithm. On the other hand, MODIS Chl-a was larger than SeaWiFS Chl-a for more than 3 mg m^{-3}. The difference between the sensors caused by the difference of wavelength of Rrs used for the in-water algorithm of Chl-a estimation.

From those results, negative Rrs412 was set to zero with fixed Rrs547 or Rw555 with small error, across the line between Rrs412 to Rrs547 or Rrs555. Furthermore, Rrs ratio between the different sensors were corrected by regression, and anther regression model was made between the Rrs ratio and *in situ* Chl-a. The overestimation of satellite Chl-a was corrected to make accurate and consistent data of the sensors.

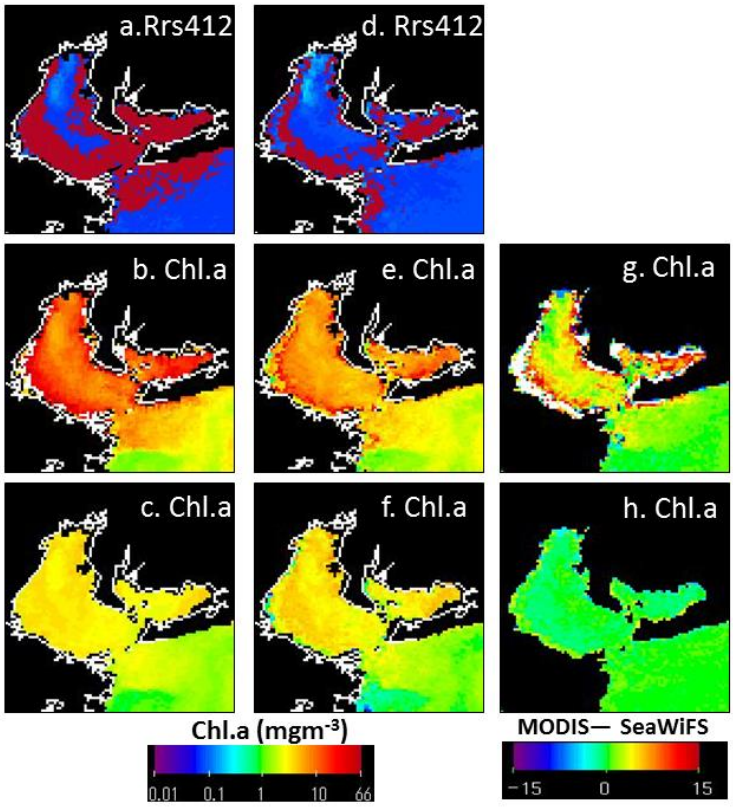

Fig. 3 : MODIS Rrs412 (a), NASA standard Chl-a (b), and corrected Chl-a (c) on April 29, 2004. SeaWiFS Rrs412 (d), NASA standard Chl-a (e), and corrected Chl-a (f). Difference between MODIS and SeaWiFS for standard Chl-a (g) and corrected Chl-a (h).

Seasonal variations in nitrogen isotopic ratio of the sinking particles in the Western North Pacific Subtropical Gyre

A part of the particles produced in the upper ocean by phytoplankton is vertically carried to the deep layer via sinking. This process plays a major role in CO_2 sequestration to the deep sea, is known as the

biological pump. In the subtropical regions that cover 60 percent of the entire oceans, the primary productivity is mainly limited by a supply of nutrients. Then the stable nitrogen isotopic signal (^{15}N) of particulate organic matter can provide insights into factors controlling the efficiency of biological pump in the subtropics since it reflects the trophic condition when the organic matter was formed. Here, we discuss a time-series change in trophic condition at the upper layer of the western north subtropical Pacific by analyzing ^{15}N of the sinking particles collected by the moored sediment traps deployed at 200 and 500 m depth of the station S1 (30°N, 145°E) during February 2010 to July 2011.

The ^{15}N value is similar among particles from 200 and 500 m depth, with the average of 4.2 permil for the experimental period. ^{15}N signal marked a minimum (2.3 permil) during February to March and gradually increased to ~6 permil in Jun (Fig. 4), suggested that nutrients supplied due to winter mixing were gradually consumed by phytoplankton during spring. In July, ^{15}N showed a decline to around 4~5 permil and became stable subsequently, implying that nutrients newly supplied into the euphotic zone in summer. As this process of nitrogen supply, two possibilities are considered: the first is due to a disturbance of upper waters by episodic, cyclonic eddies and the second is a biological fixation of N_2. Another observations on the hydrographic cruise during October 2010 provided the vertical distribution of ^{15}N of nitrate with relatively low values in upper layer (Fig. 5), which suggests that an atmospheric N_2 fixed might contribute to new N input. Also this presumption can account for the fact that the averaged ^{15}N of particles was lower than that of nitrate (5~6 permil) in deep sea (Fig. 5). The summer ^{15}N declines were found in 2010 and 2011, suggesting that such new N inputs to the ecosystem in the upper layer may occur every summer and sustain productivity and organic carbon flux in the oligotrophic subtropical Pacific.

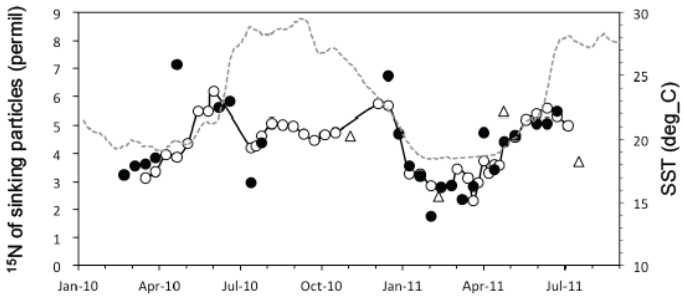

Fig.4 : Temporal changes in ^{15}N of sinking particles at the depth of 200 m (open circle) and 500 m (filled circle) of the station S1, and the satellite-derived sea surface temperature (SST: dashed line) that was 13 days-moving averaged. Triangles indicate the data for ^{15}N of particles collected by the short-term, shallow-layers (100-200 m) sediment traps.

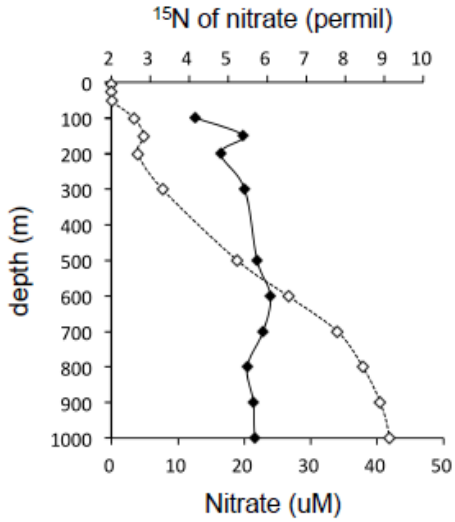

Fig.5 : Vertical distributions of nitrate concentrations (open diamond) and ^{15}N (filled diamond) at the station S1 during October 2010 (Abe and Kaiser, unpublished data).

Loboratory of Bio-Physical Oceanography

Variability in Kuroshio axis in the northeast Taiwan

The Kuroshio flows northward east of Taiwan, then turns to northeastward along shelf sloop in the northeast of Taiwan, and enters into the East China Sea. Since the Kuroshio variations in the northeast of Taiwan strongly relate to water mass formation in the shelf, variation in volume transport of the Tsushima Warm Current, and nutrients supply from Open Ocean to the shelf, many oceanographers have conducted research. Although it is difficult to capture the spatially and temporally variation of Kuroshio based on observation, most of researches were carried out by mooring at a few points, snapshot hydrographic observations, and numerical studies. In the present study, we analyzed the long-term sea surface current data with spatial resolution of 7 km and temporal resolution of 30 min. measured by the Long Range Ocean Radar (LROR) which was installed at Yonaguni and Ishigaki Islands in 2001 by NICT.

In order to derive currents of the Kuroshio from LROR data, tidal currents and wind-driven current were removed. The data were daily averaged and were applied 5 days running mean. We made the Kuroshio axis dataset from the processed current data based on method of Ambe et al. (2004).

Figure 1a shows frequency distribution of the Kuroshio axis position at 10 sections that was calculated from all data for 8 years. It is found that highest frequencies appear near shelf edge and the Kuroshio flows along the shelf sloop with the characteristics of geostrophic current. However, relatively high frequencies were seen in the shelf. This fact suggests that the Kuroshio moves to the shelf frequently. Frequency distribution in summer and winter are shown in Fig. 1a, b. The Kuroshio in summer flowed northeastward stably along the shelf edge as reported by previous studies. On the other hand, according to the previous studies the Kuroshio in winter flows on the shelf. However our result indicated that high frequency of the Kuroshio axis position was not only along the shelf edge but also in the shelf. Namely, it was found that there were 2 modes of the Kuroshio axis position in winter. We analyzed time series of the Kuroshio axis position in winter. Although previous studies suggested that the Kuroshio in winter shifts to the north due to northeast monsoon or sea surface cooling, we could not recognize such the relations between the Kuroshio axis variation and the factors.

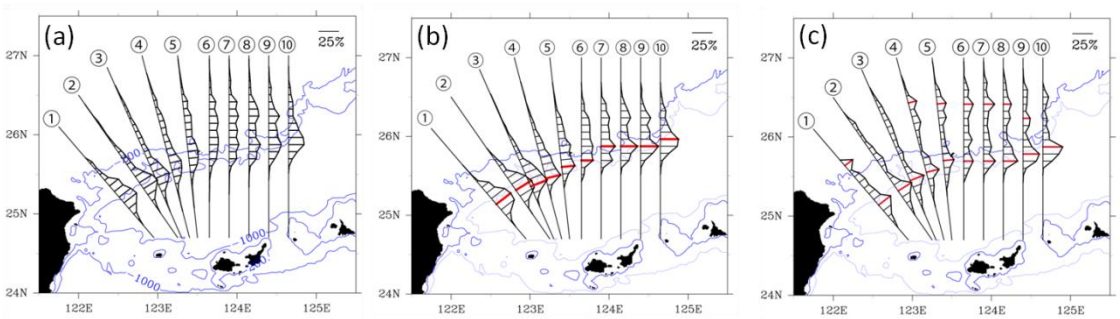

Fig. 1 : Frequency distribution of the Kuroshio axis position (a) for 8 years, (b) in summer (July - August), and (c) in winter (December - February).

Investigation of air-sea flux and its variation over the Kuroshio Extension region

The Kuroshio Extension region (KE), where is characterized by active air-sea interactions, is one of key regions for better understanding of climate around Japan. Thus, the investigation of air-sea flux and its variation over the KE is an important issue. Recently, many in-situ observations have been conducted in the KE region along with interests of many researchers. This study analyzes a set of in-situ observation data of air-sea flux obtained from the JKEO buoy for air-sea interaction studies. The data set has very

high-temporal resolution (10 minutes interval) and it is expected to better understand of high-frequency variation of air-sea flux. Firstly, we investigated the most dominant air-sea heat flux variability that has time scales of several days. As a result, that variations were accompanied with changes in wind direction because of passages of atmospheric disturbances. Moreover, the contrastive characteristics in the air-sea heat flux variability between the two wind direction regimes were quantitatively clarified (see Fig.2).

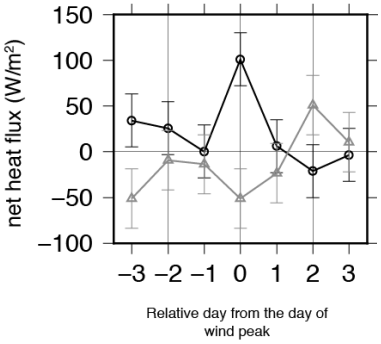

Fig. 2 : Composite time series of upward air-sea net heat flux for two wind regimes: northerly (black) and southerly (gray).

Interannual variation in the third branch of the Tsushima Warm Current path

In order to investigate the Tsushima Warm Current (TWC) paths, we used satellite altimeter and Argos buoy trajectory data to create monthly average sea surface dynamical height (SSDH) and current field data which has a higher spatial-temporal resolution compared to the ship observed data. We focused on the variation of the third branch of the TWC (TBTWC) which flows along the east coast of Korea to the northward. We recognized that TBTWC has not only seasonal variation but also has a large interannual variation especially in summer (Fig. 3).

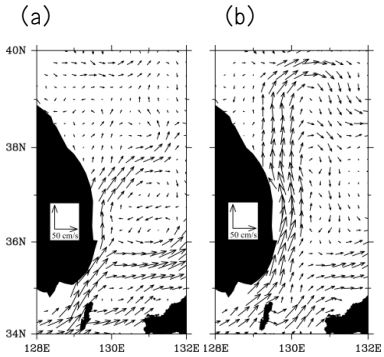

Fig. 3 : TBTWC path pattern in summer:
(a) offshore pattern, July 2000,
(b) northward pattern, July 2009.

To examine the interannual variation of the TBTWC, we applied the empirical orthogonal function (EOF) analysis to the SSDH data. The result shows the first EOF mode explains 11 % of the total variance and has a pattern of current speed variation. In this pattern, the turning point of the TBTWC is constantly around 38˚N. On the other hand, the second EOF mode explains 10 % of the total variance and indicates a large variation pattern of the turning point of the TBTWC (Fig. 4).

We made interannual variation data by reconstructing of the second EOF mode (hereafter EOF monthly data). Then we compared the EOF monthly data to net heat flux over the Japan Sea in winter (average from January to March). As a result, the EOF monthly data in winter or in April through July have high correlation (over 0.6) with the winter net heat flux. Therefore, it is suggested that when winter net heat flux is large (small) over the Japan Sea, TBTWC become offshore (northward) current path pattern.

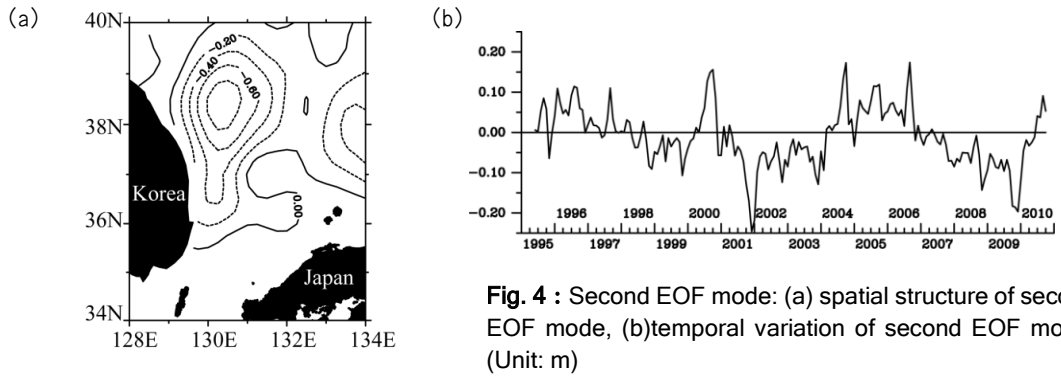

Fig. 4 : Second EOF mode: (a) spatial structure of second EOF mode, (b)temporal variation of second EOF mode. (Unit: m)

List of Publications

*:Staffs, students and research fellows in the HyARC.

1. Akter, N. and K. Tsuboki*
   Numerical simulation of Cyclone Sidr using a cloud-resolving model: Characteristics and formation process of an outer rainband. Monthly Weather Review, 140(3), 789-810, doi:10.1175/2011MWR3643.1, 2012.
2. Fukutomi, Y., K. Masuda and T. Yasunari*
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3. Hirose, M., S. Shimizu, R. Oki, T. Iguchi, D. A. Short and K. Nakamura*
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4. Ichikawa, H., H. Masunaga*, Y. Tsushima and H. Kanzawa
   Reproducibility by climate models of cloud radiative forcing associated with tropical convection. Journal of Climate, 25(4), 1247–1262, doi:10.1175/JCLI-D-11-00114.1, 2012.
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   Seasonality of water and carbon dioxide exchanges at a teak plantation in northern Thailand. Ecohydrology, 6(1), 125–133. DOI:10.1002/eco.284, 2012.
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    Advanced Asian summer monsoon onset in recent decades. Geophysical Research Letters, 39(3), L03803, doi:10.1029/2011GL050540, 2012.
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    Strategies of a Bornean tropical rainforest water use as a function of rainfall regime: isohydric or anisohydric? Plant, Cell & Environment, 35(1), 61-71, doi:10.1111/j.1365-3040.2011.02428.x, 2012.
12. Kumagai, T.* and A. Porporato
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13. Kumagai, T.* and T. Kume
    Influences of diurnal rainfall cycle on CO2 exchange over Bornean tropical rainforests. Ecological Modelling, 246, 91-98, doi:10.1016/j.ecolmodel.2012.07.014, 2012.

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The 2012 Annual Report was published November 2013 by the Hydrospheric Atmospheric Research Center (HyARC) Nagoya University.

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Hydrospheric Atmospheric Research Center, Nagoya University