国際化推進共同研究概要

No. 1

19EA-1

タ イ ト ル: Dynamical mechanisms of stratospheric control on the tropical troposphere and ocean

研究代表者: UEYAMA, Rei

所内世話人: 江口 菜穂

研究概要:

ここ 30 年間で北半球夏季に南東太平洋の水温の低下がみられ、それは赤道をまたぐ南西風の強化、すなわち対流圏内の南北循環場(Hadley 循環;HD 循環)が北側へシフトしたことに起因することがわかった。さらに HD 循環の強化が、近年の温室効果気体の増加による成層圏の寒冷化によって変調をきたした成層圏の南北循環場(Brewer-Dobson 循環)と関係することが示唆された。今回、衛星観測から導出された雲頂高度データを用いて、熱帯対流圏界面遷移層 (TTL; Tropical Tropopause Layer) に陥入する背の高い積雲対流の雲頂高度が、ここ 10 年間で、特にアフリカ大陸からアジア域の夏季にかけて北進していることを観測的に明らかにした。極端に深い積雲対流の増加は、二酸化炭素濃度の増加による地表面の温暖化と、熱帯成層圏の冷却による熱帯対流圏界面の静的安定性の低下の相乗効果によって強制されると推測される。

Dynamical Mechanisms of Stratospheric Control on the Tropical Troposphere and Ocean

Rei Ueyama (NASA Ames Research Center)

I. Abstract

Cooling of the equatorial southeastern Pacific Ocean occurred since the mid-to-late 1990s in association with enhanced cross-equatorial southerlies, which were associated with a strengthening of the deep ascending branch of the boreal summer Hadley circulation over land extending into the stratosphere. The center of anomalous convective activity moved southward to the equatorial Indian Ocean–Maritime Continent region from boreal summer to winter following the seasonal march, which strengthened the surface easterlies over the equatorial central Pacific. Accordingly, ocean surface cooling expanded over the equatorial central Pacific. Analyses of satellite-derived convective cloud top occurrences (Pfister et al., 2020) suggest that the fundamental cause of the recent decadal change in the tropical troposphere and the ocean is a poleward shift of convective activity that resulted from a strengthening of extreme deep convection penetrating into the tropical tropopause layer (Fig. 1), particularly over the African and Asian continents and adjacent oceans. We conjecture that the increase in extreme deep convection is forced by a combination of land surface warming due to increased CO_2 and a reduction of static stability in the tropical tropopause layer due to tropical stratospheric cooling.

II. Introduction

Changes in the tropical circulation from the mid to late 1990s included (*i*) a slowdown, or hiatus, of global warming associated with a decrease in the tropical eastern Pacific sea surface temperature (SST), (*ii*) the advancement of the onset of the Asian summer monsoon, and (*iii*) an increase in precipitation in western Africa over the Sahel and in southern Africa during the austral summer. In addition to these large-scale circulation changes, mesoscale phenomena such as an increase in Mesoscale Convective Systems over the Sahel were also reported. Each of these elements should be investigated independently in great detail, as well as their relationships to each other and their roles in global climate change. Without the latter, we will be unable to see the 'big picture'. The goal of this study was to provide a framework for assembling these diverse pieces of the climate-change puzzle by investigating the connection between the atmosphere, including the stratosphere, and ocean in the tropics.

Global observational studies using various satellite datasets have given us substantial insight on the statistical distribution of the altitudes of deep convection, including radar from TRMM and GPM, convective overshoot using IR satellite data, microwave from AMSU-B, IR brightness temperatures, space-borne cloud radar from CloudSat, and space-based lidar from CALIOP. Here we make use of global constellation of geostationary weather satellites to estimate the heights of convective cloud tops globally every three hours.

III. Method/Data

We analyzed a variety of datasets including JRA55 reanalysis, outgoing longwave radiation derived from High Resolution Infrared Radiation Sounder, Global Precipitation Climatology Project precipitation, COBE-1 gridded SST, and tropical overshooting clouds derived from brightness temperature differences measured by three high-frequency channels of the Advanced Microwave Sensing Unit module B or the Microwave Humidity Sensor.

Preliminary analyses of satellite-derived convective cloud top altitudes (Pfister et al, 2020) were also used to corroborate the tropical convective overshooting cloud data. Our approach for calculating the convective cloud top altitudes is based on the assumption that rainfall, screened with a proper threshold, can define the area where convection is occurring. These rainfall data, coupled with the infrared satellite information, can then define both the regions where the mass-transporting convective cores occur, and their altitude.

IV. Results

The eastern equatorial Pacific Ocean in the southern hemisphere cooled since the mid 1990s in association with a strengthening of cross-equatorial southerlies near the surface. We showed that this was likely induced by a northward shift and strengthening of convective activity around the climatological deep ascending branch of the Hadley circulation during boreal summer over the African–Asian sector. Additionally, we found that variations in convective activity and SST are related to vertical velocity near the tropopause (Fig. 1).

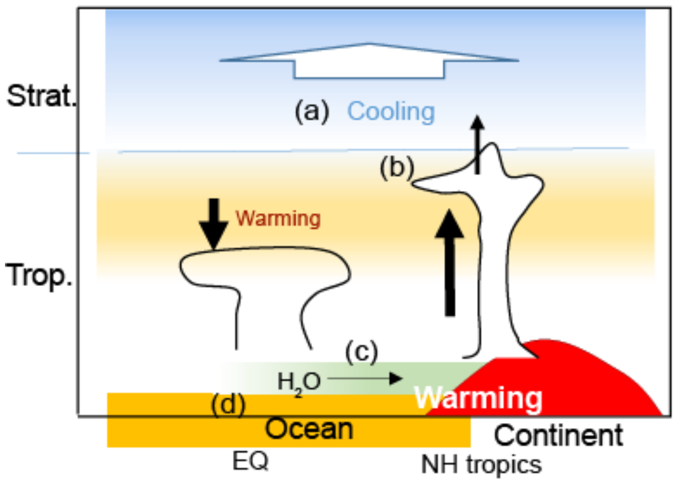

Figure 1: A schematic of the recent changes in the tropics: Lower stratospheric cooling from increased tropical upwelling (a) supports a deepening of extreme convection over the heated continental regions (b). Extreme deep convection over land enhances cross-equatorial near-surface winds over the ocean (c) which further fuels convection through moisture transport and lowers the sea surface temperature from summer to autumn (d).

It is difficult to demonstrate a causal relationship among variables having large trends. Nevertheless, time lags introduced in selected variables from summer to autumn suggest that the aforementioned processes are related. Current global models have difficulty simulating the effect of extreme deep convection on the TTL. Suitably designed numerical experiments using global models with improved convective parameterizations will be needed to add further support to these ideas.

V. Discussion/Summary

We hypothesize that recent tropical circulation changes originate primarily from a strengthening of deep convective activity over the continents and their vicinity in the summer hemisphere, particularly over the African–Asian sector. Stratospheric variation has generally been treated as a problem separate from recent surface climate change, but the results of this study demonstrate that stratospheric changes should be examined together with tropospheric changes. Further investigation is needed to determine whether the stratosphere is merely passively responding to the tropospheric warming or playing an active role in the tropospheric circulation change.

To better understand the details of the stratosphere–troposphere coupling process, we will investigate the coupling process as depicted in convective overshooting and cloud top data (Pfister et al., 2020) in a future study. Specifically, the 0.25° longitude/latitude resolution, 3-hourly cloud top data will be useful for illustrating the time evolution of deep convective activity over a given region in response to stratospheric forcing. As illustrated in Figure 2, enhanced upwelling and subsequent cooling of the tropical lower stratosphere support deep convective activity over land (via a reduction in static stability in the tropical tropopause layer), most notably over tropical Africa. This is consistent with previous findings that show that dynamically-induced tropical stratospheric cooling can trigger deep convective activity in the troposphere (e.g., Eguchi et al., 2015; Kodera et al., 2015; Eguchi et al., 2016).

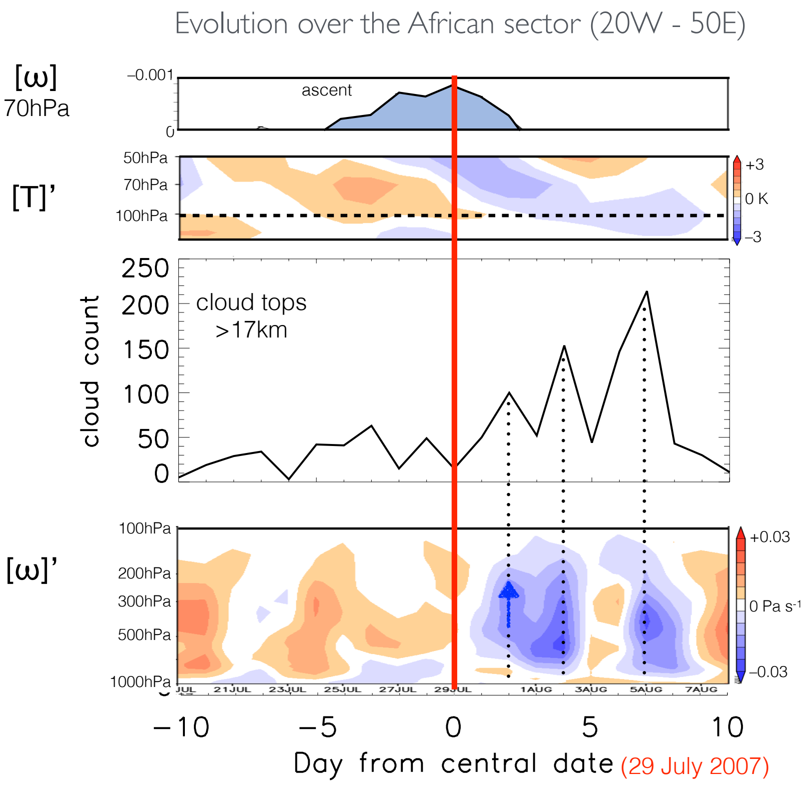

Figure 2: Evolution of (from top to bottom) pressure vertical velocity at 70 hPa, tropical mean temperature anomaly in the TTL, occurrence of convective cloud tops above 17km, and pressure vertical velocity anomalies in the troposphere over the tropical African sector.

VI. References

- Eguchi, N., Kodera, K., and Nasuno, T.: A global non-hydrostatic model study of a downward coupling through the tropical tropopause layer during a stratospheric sudden warming, *Atmos. Chem. Phys.*, *15*, 297-304, 2015.
- Eguchi, N., Kodera, K., Funatsu, B. M., Takashima, H., and Ueyama, R.: Rapid convective transport of tropospheric air into the tropical lower stratosphere during the 2010 sudden stratospheric warming, *SOLA*, *12A*, 13-17, 2016.
- Kodera, K., Funatsu, B. M., Claud, C., and Eguchi, N.: The role of convective overshooting clouds in tropical stratosphere-troposphere dynamical coupling, *Atmos. Chem. Phys.*, *15*, 6767-6774, 2015.
- Pfister, L., Ueyama, R., Jensen, E., and Schoeberl, M.: A method for obtaining high frequency, global, IR-based convective cloud tops for studies of the tropical tropopause layer, in preparation, 2020.

VII. List of Publications and Selected Presentations

- Kodera, K., N. Eguchi, R. Ueyama, Y. Kuroda, C. Kobayashi, B. M. Funatsu, and C. Claud (2019), Implications of tropical lower stratospheric cooling in recent trends in tropical circulation and deep convective activity, *Atmos. Chem. Phys. Discuss.*, *19,* doi:10.5194/acp-19-2655-2019.
- Kodera, K., N. Eguchi, R. Ueyama, B. M. Funatsu, and C. Claud (2019), Influence of tropical lower stratospheric cooling on extreme deep convective activity and tropical cyclones, *AOGS 16th Annual Meeting*, 28 Jul – 2 Aug, Singapore. (oral)
- Ueyama, R., and E. Jensen (2019), Impacts of deep convection on clouds and water vapor in the UTLS, *American Geophysical Union Fall Meeting 2019*, 9-13 Dec, San Francisco, USA. (oral, invited)
- Kodera, K., N. Eguchi, R. Ueyama, L. Pfister, B. M. Funatsu, and C. Claud (2019), Role of extreme deep convection over land on recent tropical change, *American Geophysical Union Fall Meeting 2019*, 9-13 Dec, San Francisco, USA. (oral)
- Eguchi, N., and K, Kodera (2019), Influence of stratospheric dynamics on deep convection and equatorial waves, *American Geophysical Union Fall Meeting 2019*, 9-13 Dec, San Francisco, USA. (poster)
- Ueyama, R., E. Jensen, M. Krämer, L. Pfister, and M. Schoeberl (2020), Impact of convectively-detrained ice crystals on the humidity of the tropical tropopause layer during boreal winter, *100th American Meteorological Society Annual Meeting and Middle Atmosphere One-Day Symposium,* Boston, USA. (poster)

VIII. Research meeting and discussion

Participants: Rei Ueyama, Nawo Eguchi, Kunihiko Kodera
Date: 11 December 2019
Location: AGU Fall Meeting 2019
Discussion topics:

- Possible stratospheric forcing of deep convection and precipitation over the Sahel region in July 2010
- Asian Summer Monsoon Chemical and Climate Impact Project (ACCLIP): science goals, flight scenarios, forecast products including

SPRINTARS aerosol product, and usage of the airborne measurements for our research

IX. Additional information

Rei Ueyama was on maternity leave during this award period from September through December 2019. The results reported here are based on work that was primarily completed before and after the leave period.

X. Members

Rei Ueyama	NASA Ames Research Center
Nawo Eguchi	RIAM, Kyushu University
Kunihiko Kodera	Meteorological Research Institute

No. 2　　　　　　　　国際化推進共同研究概要

19EA-2

タイトル：　　Model inter-comparison study of long-range chemical transport model to have a better understanding of PM2.5 issue over East Asia

研究代表者：　Zifa WANG

所内世話人：　鵜野　伊津志

実施期間：　　新型肺炎による渡航制限で予定していた来日は中止された

概要：

共同利用経費での来日は出来なかったが、2014 年から 2019 年にかけての中国-韓国-日本の PM2.5 の濃度変化についての観測データの解析とモデル結果の整理を行い越境汚染の硫酸塩から硝酸塩へのパラダイム・シフトに関して成果を取りまとめて、英文学術雑誌に投稿した。この研究の事前の会合を 2019 年６月２８日中国大連で半日間の中国と日本の大気汚染に関する研究会として開催した。また 2020 年１月１４日から２４日まで中国大気物理研の Li Jie 教授が中国側の経費で来日し応用力学研で共同研究を行った。

No. 2

19EA-2

タイトル：　Model inter-comparison study of long-range chemical transport model to have a better understanding of PM2.5 issue over East Asia

研究代表者：　Zifa WANG　（中国科学院大気物理研究所）

共同研究の目的

　本共同研究では、中国華北平原から北京にかけて観測される高濃度の PM2.5 汚染とその韓国・日本域への越境影響について、野外観測結果の解析と複数の化学輸送モデル(NAQPMS, CMAQ, GEOS-CHEM など)を用いた相互比較実験を進めている。

　中国と福岡での最新のエアロゾルの観測装置、ライダーなどを駆使したデータの蓄積を独自に行い、同時に、中国・韓国・台湾・日本・アメリカ合衆国の研究者が進めているアジア域の化学輸送モデル相互比較実験(MICS-Asia)への参画を通じて、PM2.5 大気汚染のモデルの問題点とその改良を進め、化学輸送モデルの精緻化を目指す。

共同研究の成果

　最近の $PM_{2.5}$ 濃度の減少は、中国国内でも明らかで北京では 2013 年から 2019 年にかけて年平均濃度は 102 μg/m^3 から 43 μg/m^3 と 58%も減少している。また、福岡でも 2014 年の 18.4 μg/m^3 から 2019 年で 13.8 μg/m^3 と減少している。中国では SO_2 の減少率が最大で、NOx 減少率はその 1/3 程度、NH_3 排出量の経年変動はこれらに対して少ない。このため従来は $(NH_4)_2SO_4$ の形成に使われた NH_3 が余剰になり、NH_4NO_3 の生成量が増加すると考えられる。従って、越境輸送される $PM_{2.5}$ の組成の変化が懸念され、風下域に沈着する S/N 成分の比が変化し、海洋・陸上生態系への影響も危惧される。以上の観点から、観測データの解析とモデル結果の整理を行い越境汚染の硫酸塩から硝酸塩へのパラダイム・シフトに関して成果を取りまとめて、英文学術雑誌に投稿した。

No. 3

国際化推進共同研究概要

19EA-3

タイトル：　　Turbulent mixing in the Kuroshio Current off Taiwan

研究代表者：　　JAN, Sen

所内世話人：　　遠藤　貴洋

概要：国際化推進共同研究 19EA-3「Turbulent mixing in the Kuroshio Current off Taiwan」は、昨年度に引き続き、共同研究・研究集会ともに計画通りに実施された。今年度の共同研究の成果をもとに、国際誌への投稿論文 2 編を執筆中で、国際学会では 3 件の発表が行われた。また研究集会には、海外から 8 名、日本から 14 名と昨年度を上回る参加者があり、黒潮が海山を乗り越えることで生じる強い乱流混合の時空間変動の解明を進めていく上で、有意義な国際研究集会となった。Discussion session にて、次年度もこの共同研究を続けていくことで合意がなされ、その具体的な計画を議論した。

Report on 2019 RIAM International Joint Research Project

Turbulent mixing in the Kuroshio current off Taiwan

JAN, Sen (Institute of Oceanography, National Taiwan University)

Objective

Turbulent mixing in the ocean controls transport of heat, freshwater, dissolved gasses, and pollutants. Turbulent mixing is also of crucial importance for ocean biology, from determining the flow field for the smallest plankton to setting large-scale gradients of nutrient availability. Recent observations suggest that the interaction of large-scale, low-frequency geostrophic currents with steep topography produces a rich sub-mesoscale and mesoscale vorticity field, which initiates a cascade of energy down to small scales and turbulence. The Kuroshio off Taiwan is the very region where such processes are highly expected, especially over the I-Lan Ridge between Taiwan and Yonaguni Island, Japan (Figure 1). This joint research project aims to quantify the turbulent dissipation and associated nutrient transport in the Kuroshio current over the I-Lan Ridge.

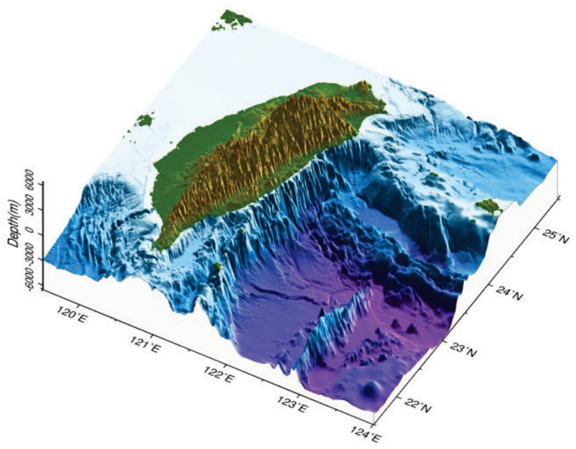

Figure 1. Bird's-eye view of bathymetry around the I-Lan Ridge. The Kuroshio current flows over the ridge to enter the East China Sea.

Research Plan

(1) Carry out the tow-yo microstructure measurements along transects across and downstream of the I-Lan Ridge
(2) Organize an international research workshop in the end of the fiscal year, where the observed results will be shared and discussed

The members involved in this collaborative research and their roles are:

- JAN, Sen (NTU, Professor): Representative person
- YANG, Yiing Jang (NTU, Associate Professor): Analysis of the mooring data
- CHANG, Ming-Huei (NTU, Associate Professor): Analysis of the VMP-500 data
- CHEN, Jia-Lin (National Cheng Kung University, Assistant Professor): Numerical modelling using OpenFOAM
- LIU, Chih-Lun (NTU, Research Assistant): Numerical modelling using MITgcm
- GUO, Xinyu (Ehime University, Professor): Numerical modelling using POM
- NAGAI, Takeyoshi (Tokyo University of Marine Science and Technology, Assistant Professor): Analysis of the tow-yo microstructure profiler data
- MATSUNO, Takeshi (RIAM, Emeritus Professor): Analysis of the TurboMAP data
- SENJYU, Tomoharu (RIAM, Associate Professor): Analysis of the mooring data

- ENDOH, Takahiro (RIAM, Associate Professor): In charge of the collaborative research
- TSUTSUMI, Eisuke (The University of Tokyo, Project Assistant Professor): Numerical modelling using MITgcm

Summary of collaborative research

(1) Field experiment

The field experiment was carried out over the I-Lan Ridge off Taiwan using R/V Legend on July 1-5, 2019. In addition to Dr. Matsuno of RIAM, Dr. Nagai of Tokyo University of Marine Science and Technology and his students joined the cruise to handle the tow-yo microstructure profiler. We carried out the microstructure measurements along four transects across the I-Lan Ridge. The ship moved northward twice along each transect to cover both the high and low tide periods.

Based on this field experiment, we are currently writing two articles on flow instability and turbulent mixing around sill in the I-Lan Ridge as well as its influence on nutrient transport of the Kuroshio current. The international conference presentations related to this project are:

1. CHEN, Jia-Lin, et al., Dynamics and variability of topography-induced shear instabilities in western boundary currents, Ocean Sciences Meeting 2020, San Diego, USA, February 16-21, 2020.
2. MATSUNO, Takeshi, et al., Intensified vertical mixing around various sea mounts along the Kuroshio and its contribution to the ecosystem, Ocean Sciences Meeting 2020, San Diego, USA, February 16-21, 2020.
3. ENDOH, Takahiro, et al., Trapped core formed within second-mode nonlinear internal waves over the shelf break of the East China Sea, Ocean Sciences Meeting 2020, San Diego, USA, February 16-21, 2020.

(2) International research workshop

In order to share and discuss the observed results, "Workshop on turbulent mixing in the Kuroshio current over the topography" was held at RIAM on February 1, 2020. Eight overseas researchers and students as well as 14 Japanese researchers attended this workshop.

The research budget provided for this international joint research project has been used to support the travel expenses of the following three speakers:

- YANG, Yiing Jang (NTU, Associate Professor)
- CHANG, Ming-Huei (NTU, Associate Professor)
- CHEN, Jia-Lin (National Cheng Kung University, Assistant Professor),

and the following two attendees:

- ZHU, Siteng (Toyama University, Doctoral Student)
- JIE, Gao (Ehime University, Master's Student).

Figure 2. Dr. Yiing Jang Yang of NTU presenting the results of the mooring observations over and around the I-Lan ridge.

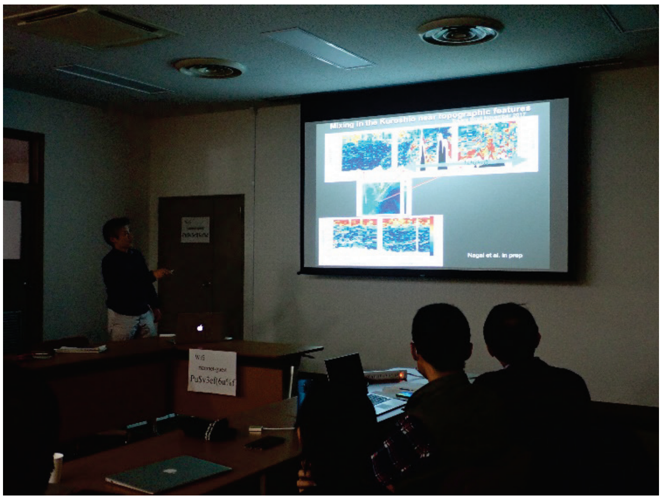

Figure 3. Dr. Takeyoshi Nagai of Tokyo University of Marine Science and Technology presenting the results of the tow-yo microstructure measurements.

In the discussion session of this workshop, we agreed to continue our collaborative research in the next fiscal year, and then discuss the possibility to submit a paper introducing this joint program to the journal such as *Oceanography* or *Frontiers in Marine Science*.

The program of the workshop is shown below.

Workshop on turbulent mixing in the Kuroshio current over the topography

Place: Conference room at 2nd floor, RIAM, Kyushu University

Date: February 1, 2020

Purpose:

1) Share and discuss the analyzed results of the observations and numerical simulations of turbulent mixing processes in the Kuroshio current
2) Define the outline of several manuscripts
3) Discuss the future direction of our research cruise

Time Table:

10:30 Takahiro Endoh (RIAM, Kyushu University): Opening remarks

10:35 Sen Jan (IO, National Taiwan University): Seasonality of mixing in the Kuroshio east of Taiwan

11:05 Ming-Huei Chang (IONTU): Recent observations of small-scale processes above I-Lan Ridge

11:35 Eisuke Tsutsumi (AORI, The University of Tokyo): Strong turbulent mixing induced by Kuroshio-topography interaction and its tidal modulation at the I-Lan Ridge: observation and numerical simulation

12:05-13:30 Lunch time

13:30 Yiing Jang Yang (IONTU): Results of mooring observations on the I-Lan Ridge

14:00 Jia-Lin Chen (National Cheng Kung University): Instability waves forced by unsteady shear flow in stratified ocean

14:30 Takeyoshi Nagai (Tokyo University of Marine Science and Technology): Three-dimensional mapping of turbulent dissipation rates in the Kuroshio near I-Lan Ridge and in Tokara Strait

15:00-15:15 Coffee break

15:15 Jie Gao (CMES, Ehime University): Motion and commotion due to a seamount in the Kuroshio and their effects on nutrient transport

15:45 Xinyu Guo (CMES, Ehime University): Temporal variations of nutrient concentration east of Taiwan

16:15 Discussion (Chairman: Xinyu Guo)

16:45 Takahiro Endoh: Closing remarks

国際化推進共同研究概要

No. 4

19EA-4

タ イ ト ル: Cloud-radiation and Climate feedbacks / Satellite multi-sensor cloud and aerosol observations

研究代表者: WANG, Zhien

所内世話人: 佐藤 可織

研究概要: 国際化推進共同研究 19EA-4 では, 2019 年 11 月 25 日-11 月 27 日の期間に九州大学筑紫キャンパスにおいて第 8 回 EarthCARE 国際サイエンスワークショップを宇宙航空研究開発機構(JAXA), 欧州宇宙機関(ESA), 情報通信研究機構(NICT), 大気物理統合解析センター(CIRAP), 九州大学, 応用力学研究所と共催した。国際ワークショップでは 5 件の基調講演の他, 一般口頭発表とポスターセッションが行われ, EarthCARE, Aeolus, CloudSat, CALIPSO, MODIS, CERES, GPM, GCOM, Himawari など衛星コミュニティ, DYAMOND など高解像度モデリング・コミュニティ, GCM 気候変動研究コミュニティ, 数値予報モデル・データ同化コミュニティなど, 国内外から約 100 名の専門家が参加し, 活発な議論が行われた。

Cloud-radiation and Climate feedbacks / Satellite multi-sensor cloud and aerosol observations

Zhien Wang (University of Colorado, Boulder)

Objective

Aerosol and cloud play a critical role in regulating earth energy balance; however, they are still poorly understood and represented in weather and climate models. To advance our climate models to reliably predict future climate changes, improved understanding of aerosol, cloud, and their interactions from observations are needed. Satellite multi-sensor observations are essential to characterize aerosol and cloud globally and to better understand related processes. Measurements from current CloudSat and CALIPSO satellites together with other A-train satellites and future EarthCARE satellite offer new opportunities to advance our understanding of cloud and aerosol. Both laboratories have developed multiple multi-sensor algorithms to utilize these new data. The international research workshop on using CloudSat and CALISPO satellite data will prepare us to more efficiently use EarthCARE data for cutting-edge atmospheric research.

Summary of the International Research Workshop

8th International EarthCARE Science Workshop

The Earth Clouds, Aerosol and Radiation Explorer (EarthCARE) is a joint European/Japanese (ESA/JAXA/NICT) mission. 94GHz-Doppler cloud profiling radar, high spectral resolution lidar operated at 355nm, multi spectral imager and broad band radiometer will be employed. The combination of these instruments will provide three-dimensional distribution of clouds with vertical motion, aerosols, and precipitation and their radiative characteristics. The eighth international EarthCARE workshop was held in Fukuoka from 25–27 November 2019, following the seventh international EarthCARE Science Workshop held in Bonn in June 2018. The workshop was a great success, and provided an excellent opportunity to address grand challenges in Earth science related to clouds, aerosols, radiation, cloud feedback, precipitation, climate change predictions, numerical weather predictions, and extreme events. Around 100 experts from science communities of EarthCARE, Aeolus, CloudSat, CALIPSO, MODIS, CERES, GPM, GCOM, Himawari, high resolution global modeling (such as the DYAMOND Initiative), GCM, NWP, Assimilations, climate change predictions and modeling extreme weather events participated the workshop. Presentations were given in the following sessions:

(1) Keynote lectures 1-5
(2) Observations and process studies 1-6
(3) Modeling and Assimilation 1-5
(4) Radiation
(5) Current status of EarthCARE 1-2

Outcome of the workshop

The workshop gave rise to fruitful discussions on:

・Requirements for future water-cycle observations
・Assimilation of EarthCARE data for improving weather forecast

- Energy balance: observational and climate modeling study
- Latest results from high-resolution model inter-comparison studies on cloud and precipitation
- Current status and problems in climate modeling of aerosols and clouds - Development of accurate prognostic cloud physics schemes using EarthCARE data
- Challenges focusing on precipitation and mixed phase cloud retrievals/ Multi-sensor synergy for studying aerosol impacts on mixed-phase cloud properties, temperature dependency of mixed-phase cloud properties, and for model evaluations.
- Future precipitation changes/ Process studies on the formation of warm rain and heavy precipitation.
- Development of new observation systems for: cloud and aerosols studies, satellite calibration.
- ACCP, the NASA's satellite initiative for aerosols, clouds convection and precipitation.

Workshop Chairs:

Hajime Okamoto (Kyushu University, Japan)
Anthony Illingworth (University of Reading, UK)
Riko Oki (JAXA, Japan)
Tobias Wehr (ESA/ESTEC, The Netherlands)

Workshop Science Committee:

Zhien Wang (University of Colorado Boulder, US)
Deborah Vane (JPL, US))
Dave Winker (NASA Langley, US)
Seiji Kato (NASA Langley, US)
Masaki Satoh (University of Tokyo, Japan)
Kentaroh Suzuki (University of Tokyo, Japan)
Tomoaki Nishizawa (NIES, Japan)
Takashi Nakajima (Tokai University, Japan)
Kaori Sato (Kyushu University, Japan)
Takuji Kubota (JAXA, Japan)
Chikako Takahashi (JAXA, Japan)
Yuji Ohno (NICT, Japan)
Teruyuki Nakajima (JAXA, Japan)
Nobuhiro Takahashi (Nagoya University, Japan)
Ulla Wandinger (TROPOS, Germany)
Luca Baldini (CNR ISAC, Italy)
Alessandro Battaglia (University of Leicester, UK)
Helene Chepfer (LMD/IPSL, France)
Nicolas Clerbaux (RMIB, Belgium)
Jason Cole (Environment Canada)
Julien Delanoë (LATMOS, France)
David Donovan (KNMI, The Netherlands)
Jürgen Fischer (Free University of Berlin, Germany)
Silke Gross (DLR, Germany)
Robin Hogan (ECMWF, UK)
Rob Koopman (ESA/ESTEC, The Netherlands)
Pavlos Kollias (Stony Brook University, US)
Riko Oki (JAXA),
Tobias Wehr (ESA/ESTEC, The Netherlands)
Anthony Illingworth (University of Reading, UK)
Hajime Okamoto (Kyushu University)

International support:

JAXA, ESA, NICT, The Center for Integrated Research on Atmospheric Physics (CIRAP), Kyushu University, and Research Institute for Applied Mechanics (RIAM).

Workshop Agenda：

8th International EarthCARE science workshop

25 November 2019 (Monday)

TIME	TITLE	Speaker
12:00	Registration	
13:00	Welcome	Chair: Hajime Okamoto
13:05	Welcome by RIAM	Director Kazuaki Hanada
13:15	Opening Remarks from ESA	Alain Lefebvre
13:25	Opening Remarks from JAXA	Teruyuki Nakajima
	Keynote 1	**Chair: Hajime Okamoto**
13:35	**Scientific Background of Grand Plan for Space-based Water Cycle Observations at JAXA**	**Toshiki Iwasaki**
	Current status of EarthCARE 1	**Chair: Hajime Okamoto**
14:05	Satellite, Project overview and Programmatics	Alain Lefebvre
14:25	CPR status	Eiichi Tomita
	Modeling and Assimilation 1	**Chair: Hajime Okamoto**
14:35	EUREC4A campaign set-up, radar-lidar and in-situ measurements in trade-cumulus clouds	Sandrine Bony (Julien Delanoë)
14:50	Toward better representation of aerosols and clouds in climate models: Current status and problems to be addressed	Toshihiko Takemura
15:05	**Poster**	
	Keynote 2	**Chair: Anthony Illingworth**
16:05	**Aeolus Status**	**Tommaso Parrinello**
	Modeling and Assimilation 2	**Chair: Anthony Illingworth**
16:35	Potential of EarthCARE for improving weather forecasts via direct assimilation of radar reflectivity and lidar backscatter	Marta Janiskova (Mark Fielding)
16:50	Differing impacts of absorbing and scattering aerosols on global energy budget: A climate modeling study	Kentaroh Suzuki
	Observations and Process studies 1	**Chair: Anthony Illingworth**
17:05	Validation of Aeolus aerosol and cloud products with ground-based lidar observations at different locations in the northern and southern hemispheres	Ulla Wandinger
17:20	A Mechanism for the Maintenance of Sharp Tropical Margins	Hirohiko Masunaga
17:35	5-year results of the Global Precipitation Measurement (GPM) mission in Japan	Takuji Kubota
17:50	PSC climatology based on CALIOP measurements from 2006-2019	Michael Pitts (Hajime Okamoto)
18:00	**Discussion of first day**	**Anthony Illingworth, Hajime Okamoto**
18:30	**End of first day**	

26 November 2019 (Tuesday)

	Current status of EarthCARE 2	Chairs: Robin Hogan
9:00	Data Products developed in Europe and Canada	Michael Eisinger
9:10	Data Products developed in Japan	Riko Oki
	Keynote 3	**Chair: Robin Hogan**
9:20	**Energy balance, radiative heating rate in the atmosphere, and entropy production**	**Seiji Kato**
	Observations and process studies 2	**Chairs: Robin Hogan**
9:50	A new rainfall rate algorithm for EarthCARE with independently validated accuracy	Anthony Illingworth
10:05	Algorithms to retrieve optical and microphysical properties of aerosol, cloud, and precipitation from ATLID, MSI, and CPR measurements	Tomoaki Nishizawa
10:20	ATLID L2a Extinction Backscatter and Depolarization Profile Algorithms	Dave Donovan
10:35	Doppler calibration of EarthCARE Cloud Profiling Radar using JMA Wind Profiler Network (WINDAS)	Yuichi Ohno
10:50	**Poster**	
	Modeling and Assimilations 3	**Chairs: Kentaroh Suzuki**
11:20	NICAM results of the project DYAMOND for global storm-resolving model intercomparison	Masaki Satoh
11:35	A New Perspective for Future Precipitation Change from Intense Extratropical Cyclones	Chihiro Kodama (Tatsuya Seiki)
	Observations and process studies 3	**Chairs: Kentaroh Suzuki**
11:50	Aerosol-cloud target classification using combined airborne lidar and radar measurements	Eleni Marinou
12:05	Calibration and Validation of EarthCARE's Cloud Profiling Radar Data Products	Ousmane O. Sy
12:20	Relationship of Dust Load and Cloud Phase Partitioning over High Latitudes Using CALIPSO Products	Kazuaki Kawamoto
12:35	LUNCH and Group Photo	
	Keynote 4	**Chairs: Ulla Wandinger**
13:35	**Mixed-phase cloud macrophysical and microphysical properties from A-train Satellites**	**Zhien Wang**
	Observations and process studies 4	**Chairs: Ulla Wandinger**
14:05	The contributions of passive, integrated and physical constraints to synergistic retrievals of cloud and precipitation from EarthCARE	Shannon Mason (Robin Hogan)
14:20	Development Status of Ground-based W-band Cloud Radars for Calibration and Validation of EarthCARE/CPR	Hiroaki Horie
14:35	A-CARE: Improving EarthCARE aerosol classification by combining lidar and airborne in-situ aerosol measurements	Moritz Haarig
14:50	Continuous measurement of particle backscatter and extinction profiles with a 355-nm high-spectral-resolution lidar	Yoshitaka Jin
15:05	Feature Mask determination using UV lidar data	Gerd-Jan van Zadelhoff
15:20	A radar-only combined radar-radiometer precipitation algorithm	Kaya Kanemaru
15:35	**Poster**	
	Observations and process studies 5	**Chairs: Tomoaki Nishizawa**

16:00	Heaviest rainfall and tallest storms: Their weak linkage and related large-scale environments	Atsushi Hamada
16:15	Bridging CALIPSO and Earth-CARE for Cloud Science: the difference of wavelength issue studied from IPRAL ground-based lidar	Marjolaine Chiriaco
16:30	Insight into growth and decay processes of liquid cloud inferred from a combined analysis of CloudSat and geostationary satellites	Akira Yamauchi
16:45	EarthCARE's Multi-Spectral Imager aerosol stand-alone product	Nicole Docter (Jurgen Fischer)
17:00	Methodology of early phase validation for EarthCARE MSI cloud products, lessons learned from GCOM-C SGLI	Takashi Y. Nakajima
	Radiation	**Chairs: Tomoaki Nishizawa**
17:15	The EarthCARE BBR BM-RAD product	Nicolas Clerbaux
17:30	Methodology and results on estimating radiative fluxes for the EarthCARE BBR instrument	Carlos Domenech (Nicolas Clerbaux)
	Discussion of the Second day	**Robin Hogan, Kentaroh Suzuki, Ulla Wandinger, Tomoaki Nishizawa**
17:45	**End of second day**	
19:00	**Workshop Dinner**	

27 November (Wednesday)

	Keynote 5	**Chairs: Masaki Satoh**
9:00	**ACCP: the emerging NASA vision for the future**	**David Winker**
	Modeling and Assimilations 5	**Chairs: Masaki Satoh**
9:30	Cloud observation in the Tokyo metropolitan area using scanning Ka-band radars	Tadayasu Ohigashi
9:45	Modeling of snow precipitation interaction with a 3D lidar scanner	Gilles Roy
10:00	Reconciling a compensating error between precipitation process constraint and energy budget requirement	Takuro Michibata
10:15	Global aerosol simulations with a cloud-system resolving model	Daisuke Goto
10:30	**Poster**	
	Observations and process studies 6	**Chairs: Dave Donovan**
11:00	In situ observation of cloud droplet size distribution from Tokyo Skytree	Ryohei Misumi
11:15	Spatial and seasonal variability of clouds over the South-West Indian Ocean based on the DARDAR products	Hélène Vérèmes
11:30	Characteristics of ice clouds over mountain regions detected by CALIPSO and CloudSat satellite observations	Tatsuya Seiki
11:45	Narrowing down assumptions of ice crystal shape in radar-lidar retrievals using solar radiance measurements	Florian Ewald
12:00	On the use of a multi-wavelength high spectral resolution airborne lidar to study the sensitivity of extinction and lidar ratio retrievals to lidar measurement techniques	Quitterie Cazenave
12:15	**Discussion of 3rd day**	**Masaki Sato, Dave Donovan**
12:25	**End of Workshop**	
12:30	**Lab Tour (Optional)**	

Poster Exhibition

Poster Number	Poster Title	Author
P1	EarthCARE Flight Segment Status	Michael Eisinger
P2	EarthCARE Ground Processor Development Status	Michael Eisinger
P3	Status of the optical instruments payload on ESA's EarthCARE mission (1)	Kotska Wallace
P4	Status of the optical instruments payload on ESA's EarthCARE mission (2)	Kotska Wallace
P5	Status of the optical instruments payload on ESA's EarthCARE mission (3)	Kotska Wallace
P6	JAXA A-train Products Towards Synergistic Study for EarthCARE	Yuichiro Hagihara
P7	Evaluation of Simulated EarthCARE Doppler Velocity with NICAM	Yuichiro Hagihara
P8	Observation of Atmospheric Dynamics from Spaceborne radars: Added value of Doppler capability and sequence of "Z-only" observations	Ousmane O. Sy
P9	Creation of EarthCARE simulated data sets for algorithm development and testing.	Dave P. Donovan
P10	JAXA EarthCARE algorithm development using the Joint-Simulator (Joint Simulator for Satellite Sensors)	Chikako Takahashi
P11	The benefit of airborne measurements for EarthCARE preparation	Silke Gross
P12	Cloud and aerosol optical properties observed by the airborne and ground-based lidars	Eiji Oikawa
P13	Experimental validation of D parameter model for droplet sizing using off-axis lidar measurements	Gilles Roy
P14	ESA-EVE polarization lidar: A novel mobile reference system for Cal/Val activities	Peristera Paschou
P15	Validation of the EarthCARE Mission	Rob Koopman
P16	Recent development and application of Joint Simulator for Satellite Sensors	Tempei Hashino
P17	The EarthCARE Multi Spectral Imager cloud products	Anja Hünerbein (Vasileios Tzallas)
P18	Development and Validation of the 4-sensor algorithm for radiative fluxes	Akira Yamauchi
P19	Evaluation of cloud vertical structures and their radiative effect in MIROC using CloudSat/CALIPSO satellite observations	Kosuke Yamamoto
P20	Monte Carlo simulator (McRALI) for three dimensional cloudy atmosphere remote sensing with high spectral resolution lidar and Doppler radar	Alain Alkasem
P21	Ground-based remote sensing of heterogeneous clouds using sky-view camera and three-dimensionalradiative transfer model	Rei Kudo
P22	RadSnowExp: Multi-Sensor, Multi-Platform Study of Arctic and Mid-Latitude Storms	Mengistu Wolde
P23	Precipitation characteristics in coastal area of Alaska revealed from GPM DPR and CloudSat CPR	Shunsuke Aoki
P24	Cloud structure and microphysics associated with polar lows over the Nordic Seas based on the DARDAR satellite products	Constantino Listowski (Julien Delanoë)
P25	Supercooled liquid water, ice and mixed-phase in Antarctic clouds, using the DARDAR satellite products	Constantino Listowski (Julien Delanoë)
P26	An Impact of microphysics schemes on the evaluation method using CALIPSO	Woosub Roh
P27	Identification of Particle Growth Processes in Marine Low Clouds Using Spatial Variances of Imager-Derived Cloud Parameters	Takashi M. Nagao
P28	CADDIWA : An airborne campaign to investigate aerosol-radiation-cloud interactions in the tropics with a multi-(space)mission perspective	Cyrille Flamant (Julien Delanoë)
P29	Common Retrieval of Atmospheric Aerosol Properties for geostationary and polar-orbital Satellite Imaging Sensors	Mayumi Yoshida
P30	How EarthCARE AC-TC products will be useful for studying regional cloud and aerosol coverage	Irbah Abadnour
P31	Remote Sensing of aerosol optical properties in the coastal areas	Kazuma Aoki
P32	Profiling of aerosols and clouds in Reunion Island (21°S, 55.5°E)	Hélène Vérèmes
P33	Cirrus clouds detected by GOSAT TANSO-FTS	Nawo Eguchi
P34	Estimation and assimilation of cloud water content over land and its verification using satellite-based passive and active microwave observations	Rie SETO

国際化推進共同研究概要

No. 5

19EA-5

タ イ ト ル:　Japan-Korea Oceanography Seminar on Regional Oceanography and Atmospheric Sciences

研究代表者:　NOH, Yign

所内世話人:　広瀬　直毅

研究概要:

本共同研究の代表者である Noh 教授（延世大学校）と所内世話人である広瀬教授（九大応力研）がコンビーナーとなり、2020 年 1 月 20 日～21 日に宮崎県宮崎市内の会議施設にて、47 名が参加し、日韓海洋研究セミナー “The 16th Japan-Korea Joint Seminar on Ocean Science” を開催した。

Report

2020 年 1 月 20 日～21 日に宮崎県宮崎市のホテル・フェニックスシーガイアリゾート コテージ・ヒムカにて、日韓海洋研究セミナー “The 16th Japan-Korea Joint Seminar on Ocean Science” を開催した。

47 名が参加し、全 36 件の講演を、年齢の若い順に発表してもらった。プログラムは、添付の通りである。

全講演を通じて活発に質疑応答が交わされた。トップバッターの申教授（公州大学校）・金研究員（KIOST）は、定年退職のため招待者として講演を行った。学生の拙い発表の後に、博士研究員や教員がお手本を見せる意図で年齢順にしたが、コンビーナーの狙いとは逆に、学生の発表自体は、発表練習も積んで英語も流暢という印象を受けた。若者ほど質疑応答には戸惑う傾向にあり、学生（および若手研究者）の英語コミュニケーションの経験機会を提供する当セミナーの存在意義は相変わらずである。

日本と韓国の海洋学者と若い学生が集い、東アジア縁辺海の研究成果をワークショップで発表することで研究内容の意見交換及び国際交流を増進させることができた。特に若い大学院生を育てる良い機会で、大学院の学生が英語で発表及び質疑応答をすることで国際的な感覚を身に付けることも出来た。

2 日目後半には、研究発表を元に、今後の共同研究に関する討議、特にアイデア交換を行った。CREAMS プロジェクトに代表されるように、応用力学研究所は長年、東アジア縁辺海の海洋研究をリードしている。そこで東アジア海洋の研究を活発に行っており、地理的にも日韓の接点となる九州大学応用力学研究所が、いわば「日韓海洋学会」の中核を担ってきた。今後は、日本海洋学会と韓国海洋学会の共催として当セミナー継続する可能性を探る。特に対馬海峡の観測データや東アジア縁辺海データ同化モデルの解析値を活用することによって、日韓の領域的な海洋学の発展が望まれ、さらには環境問題や大気海洋相互作用まで波及効果があった。

尹教授と承教授の協力で始まった日韓セミナーも既に 16 回目を迎えたが、相変わらず活気にあふれている。特に今回は韓国側からの参加者が多く、世代交代が進んでいる印象を受けた。日本側もまだ少数だが若く元気な大学院生がすこしずつ増えている。

The 16th Japan-Korea Joint Seminar on Ocean Sciences

Conveners: Yign NOH (Yonsei University)
Naoki HIROSE (Research Institute for Applied Mechanics, Kyushu University)
Hong-Ryeol SHIN (Kongju University)
Venue: Phoenix Seagaia Resort Cottage HIMUKA (Miyazaki Prefecture in Japan)
Date: January 20-21, 2020

[Monday, January 20th]

08:45 Opening Address (Naoki HIROSE)

----------- Morning session ----------

08:50-09:20 Hong-Ryeol SHIN (Kongju University)
(invited) *Physical Characteristics and Classification of the Ulleung Warm Eddy*

09:20-09:30 Sung-Hyun CHO, Jae-Hong MOON (Jeju University)
Decadal variability of the Kuroshio intensity in the East China Sea and its connection with the climate variability

09:30-09:40 Taro MOTOSHIMA, Tianran LIU, Naoki HIROSE (Kyushu University)
Global ocean modeling for thermal energy estimation

09:40-09:50 Daichi TAKATORI, Tomoharu SENJYU (Kyushu University)
Analysis of the current data recorded with a moored buoy in Tokara Strait

09:50-10:00 Takuya HIROOKA and Takahiro ENDOH (Kyushu University)
Estimates of vertical eddy diffusivity in the bottom boundary layer from microstructure measurements

10:00-10:10 Hyun-Jun JANG, Jae-Hong MOON (Jeju University)
Long term variation of volume transport in the Korea Straits and variation of heat contents in the East Sea

10:10-10:20 Miho YOSHITAKE, Atsuhiko ISOBE (Kyushu University)

Numerical experiment on vertical motion of microplastics with both physical and biological processes

10:20-10:30 Hiromi MATSUURA, Katsuto UEHARA, Shinichiro KIDA (Kyushu University)
Decreasing trend of M2 tidal amplitude observed along northwestern Kyushu

10:30～10:45 Break

10:45-11:00 Ingwon KIM, Hong-Ryeol SHIN (Kongju University), Cheol-Ho KIM (KIOST)
Warm and Cold eddies in the southwestern East Sea (Japan Sea)

11:00-11:15 Subin KIM, Jae-Hong MOON (Jeju University)
Influence of sea surface cooling due to the Yellow Sea Bottom Cold Water on weather conditions around Korean Peninsula

11:15-11:30 Keidai MASAKI, Ning ZHAO, Naoki HIROSE (Kyushu University)
Effect of sea surface temperature on torrential rain that occurred in Tsushima on September 1, 2015

11:30-11:45 Yuxiang QIAO, Hirohiko NAKAMURA, Ayako NISHINA and Shin-ichiro KAKO (Kagoshima University)
Interannual-decadal velocity variations over the Kuroshio Extension and Kuroshio system

11:45-12:00 Young Min PARK (GeoSystem)
Development of a red-tide forecasting system

12:00～14:00 Lunch

----------- Afternoon session ----------

<u>14:00-14:30 Cheol-Ho KIM (KIOST)</u>

(invited) *Projection of future sea level change in the East Asian Regional Seas*

14:30-14:50 Akie SAKAI, Tomoharu SENJYU (Kyushu University)
Near-inertial Internal Waves in the Japan/East Sea

14:50-15:10 Sang-Chul CHA, Jae-Hong MOON (Jeju University)
Temporal evolution of global mean sea level rise

15:10-15:30 Joseph BASCONCILLO, Il-Ju MOON (Jeju University)
Increased typhoons affecting Korea and Japan in a changing climate

15:30-15:50 Yeonju CHOI, Yign NOH (Yonsei University)
The comparison of the convective boundary layer in the atmosphere and the ocean at different latitudes

15:50-16:10 Ji-Seok HONG, Jae-Hong MOON (Jeju University)
A weakly coupled data assimilation for short-term prediction of severe weather

16:10-16:30 Byeong-Jun LIM, You-Soon CHANG (Kongju University)
Analysis of extreme sea level change around the East China Seas including Korea

16:30～16:50 Break
16:50-17:10 Il-Ju MOON, Youjung OH (Jeju University)
(invited) *Effects of recurvature and eye size on typhoon-induced ocean waves*

17:10-17:30 Haejin KIM, Naoki HIROSE, Katsumi TAKAYAMA (Kyushu University)
Biological effects on the long-term decrease in dissolved oxygen concentration in the East/Japan Sea

17:30-17:50 Daehyuk KIM, Hong-Ryeol SHIN (Kongju University), Cheol-Ho KIM (KIOST), Naoki HIROSE (Kyushu University)
Characteristics of the East Sea (Japan Sea) circulation depending on surface heat flux and its effect on Branching of the Tsushima Warm Current

17:50-18:10 You-Hyun BAEK, Il-Ju MOON (Jeju University)
Accuracy of satellite-observed and numerical model-calculated SST around the Korean peninsular

18:10-18:30 Jae-Ho LEE, You-Soon CHANG, Shaoqing ZHANG (Kongju University)
Observation System Simulation Experiment for the JMA serial observation lines in the Northwestern Pacific

18:30-18:50 Tianran LIU, Naoki HIROSE (Kyushu University)
OTEC power potential estimation at the Aguni Basin using a high-resolution ocean model

19:00～ Dinner

[Tuesday, January 21st]

----------- Morning session ----------

<u>08:45-09:05 Jae-Hong MOON, Joonho LEE (Jeju University)</u>
(invited) *Developing the data assimilative operational forecasting model in the north western pacific*

09:05-09:25 Ashley BRERETON, Yign NOH (Yonsei University)
A mechanism for thin phytoplankton layer generation

09:25-09:45 Dong-Hoon KIM, Chaewook LIM, Seung-Buhm WOO (Inha University)
The Deep Learning Prediction of Nino-3.4 SST Anomalies

09:45-10:05 Yohei ONUKI (Kyushu University)
Quasi-local method of wave decomposition in a slowly varying medium

10:05-10:25 Hidekazu TSUJI and Naoki HIROSE (Kyushu University)
Numerical Study of Generation and Propagation of Large Internal Waves in the East China Sea
10:25～10:45 Break

<u>10:45-11:05 Ichiro YASUDA (University of Tokyo)</u>
(invited) *Ocean vertical mixing observation and impact*

<u>11:05-11:25 Yign NOH (Yonsei University)</u>

(invited) *The route to a spring phytoplankton bloom simulated by a Lagrangian plankton model*

11:25-11:45　Takeshi Matsuno (Kyushu University), Eisuke Tsutsumi (University of Tokyo), Tomoharu Senjyu, Takahiro Endoh (Kyushu University), Daisuke Hasegawa (Tohoku National Fisheries Research Institute), Yiing Jang Yang, Sen Jan (National Taiwan University), Hirohiko Nakamura (Kagoshima University), Xinyu Guo (Ehime University), Ichiro Yasuda (University of Tokyo)

(invited) *Vertical mixing intensified around sea mounts in the Kuroshio*

11:45-12:05　Young Ho SEUNG (GeoSystem)

(invited) *A review of the Tsushima Current Dynamics*

12:05-12:25　Tetsuo Yanagi (Kyushu University)

(invited) *Value of Relation in the Japanese Satoumi*

12:25～　General Discussion (Naoki HIROSE)

14:30～17:00　Splitter Meeting

国際化推進共同研究概要

No. 6

19EA-6

タ イ ト ル:　Circulation and Water mass modification in the abyssal Japan/East Sea

研究代表者:　SHIN, Hong-Ryeol

所内世話人:　千手　智晴

研究概要:

　深海における海水の鉛直混合は、海洋の熱塩循環を維持するために必須の現象である。海水混合のエネルギー源としては潮汐と海上風が大きな割合を占めるが、日本海のような半閉鎖的な縁海では潮汐が非常に弱いため、風によって励起される内部波、特に近慣性周期の内部重力波(近慣性内部波)が重要と考えられる。日本海南東部の大和海盆の深層で、2014 年 5 月に行った流速計の係留観測の結果を解析したところ、散発的な近慣性内部波イベントが観測された。イベント期間中の流速変動には、鉛直的にコヒーレントな構造を保ちつつ、深度と共に振幅が増大するという特徴がみられた。このような特徴は、風起源の下向きに伝播する近慣性内部波と、海底で反射された上向きの近慣性内部波が重なり合うことで説明できる。また、一般に深層水の成層は弱いため、流速の底層強化にともなう鉛直シアーは容易に不安定な状況を生じ得ることが明らかとなり、近慣性内部波イベントにともなう深海での鉛直混合の促進が示唆された。この仮説を検証し、精密化するために、2019 年 10 月に大和海盆西部の深海に再び流速計を係留した。これらの流速計は、2020 年 5 月に回収する予定である。

Circulation and water mass modification in the abyssal Japan/East Sea

Hong-Ryeol Shin (Kongju National University)
Tomoharu Senjyu (RIAM, Kyushu University)

Introduction

Vertical mixing in the deep sea is essential for maintaining the oceanic thermohaline circulation. The main sources of energy for abyssal mixing are considered to be tides and wind (Munk and Wunsch 1998). However, the wind contribution is likely to be more in the Japan/East Sea where tidal flows are negligible except in the Tsushima Basin in the southwest. To investigate the behavior of near-inertial internal waves (NIWs) generated by wind in the deep sea, we have been carried out deep flow and hydrographic observations in the southern part of Japan/East Sea. We here report the flow intensification by the superposition of NIWs in the abyssal Yamato Basin in the southeastern Japan/East Sea.

Observations

An acoustic Doppler current profiler (ADCP) and two single-point acoustic current meters were moored at Sta. YB in the eastern Yamato Basin during the periods May 12–23 and October 16–27, 2014 (Fig. 1). In addition, two current meters were deployed at 950 and 1975 m of Sta. YB-S (south of Sta. YB), which were 2.6 km apart, during the period from October 14, 2013 to October 16, 2014. Therefore, we discuss the current records during May 2014. The temporal interval for the measurements at Sta. YB was set to 1 min for all equipment, although the measurement interval for the current meters at Sta. YB-S was set to 30 min. The spatial interval for the ADCP at Sta. YB was set to 4-m bins. The deployment and recovery of the current meters were conducted by T/V Nagasaki Maru of Nagasaki University.

Results and Discussion

An active NIW event occurred below 2475 m in the Yamato Basin during May 12–16, 2014 (Fig. 2). This was followed by the upward propagation of a wave packet from 2475 to 950 m at speeds ranging 0.75–1.39 cm s^{-1}. The near-inertial flows (1.07*f*) during the event exhibited a vertically coherent phase, although their amplitude increased with depth by a factor of 1.5 from 2475 to 2635 m. The observed flow characteristics can be explained by the superposition of downward-propagating NIWs that can be excited by a strong wind event and upward-propagating NIWs that bounced off the seabed. As the stratification in the abyssal Japan/East Sea is very weak, a slight vertical shear by the flow intensification can induce an unstable condition. This suggests the promotion of vertical mixing in the deep sea during significant NIW events.

To confirm the above idea, we redeployed an ADCP and current meters in the bottom layer of the western Yamato Basin in October 2019. These current meters will be recovered in May 2020.

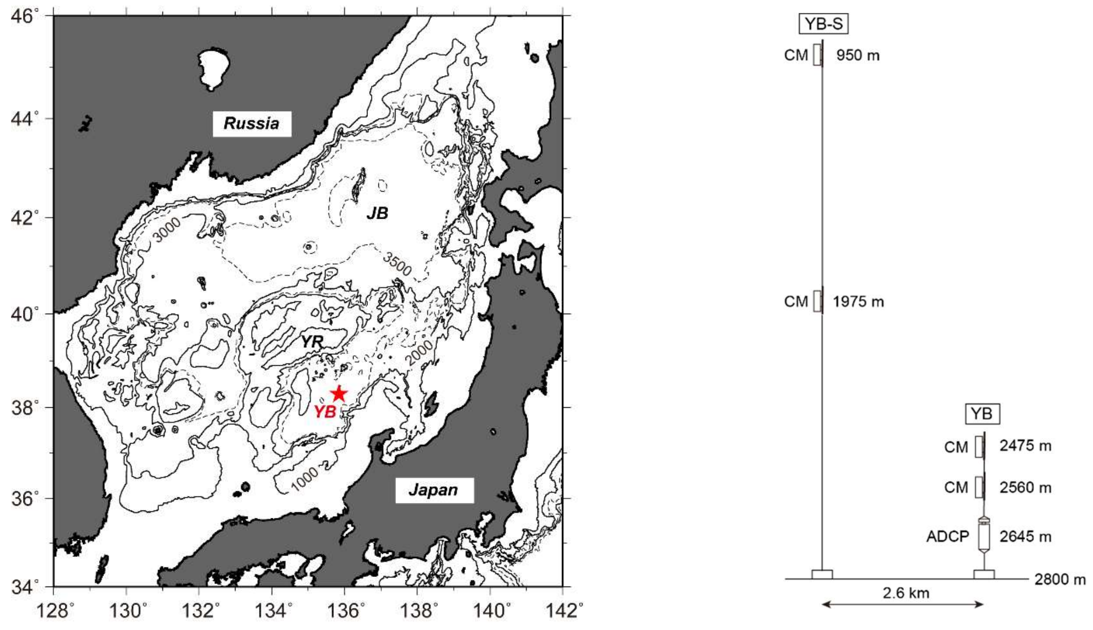

Fig. 1 Location of Sta. YB (left) and schematic of the moorings at Stas. YB and YB-S (right)

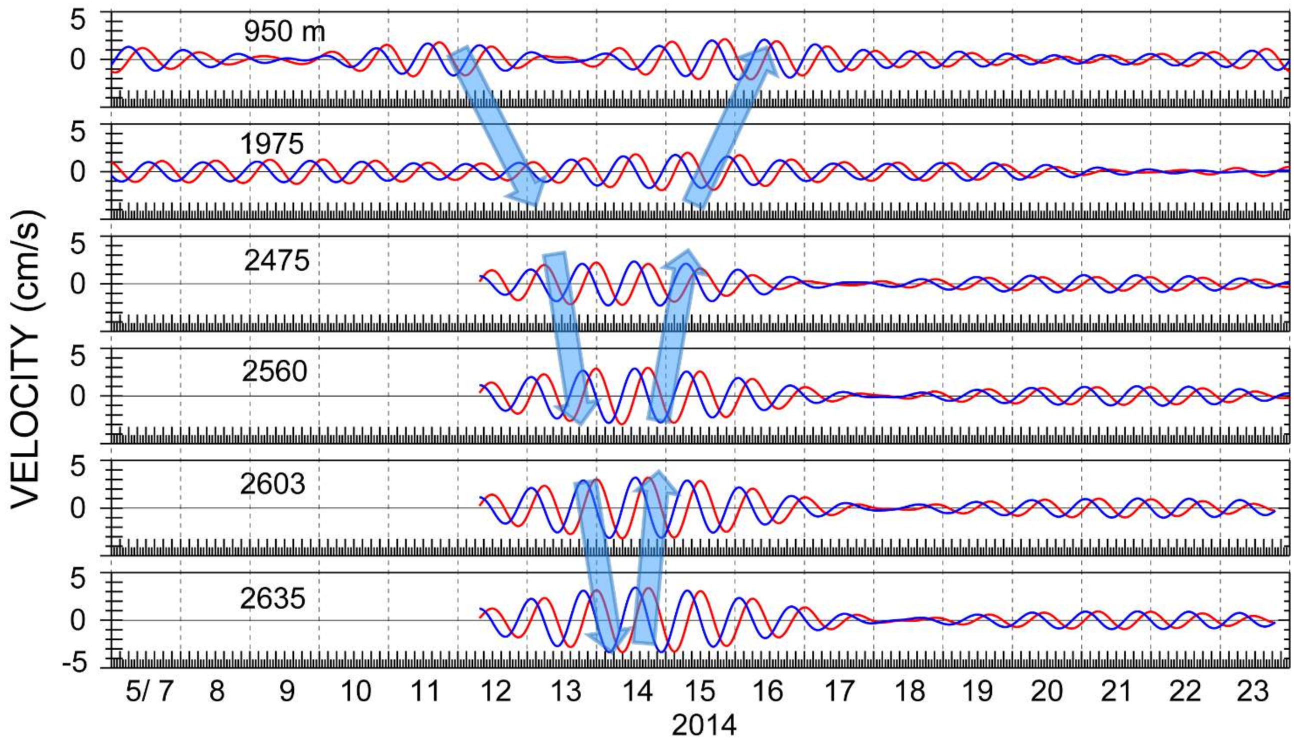

Fig. 2 Time series of inertial component of flows at Stas. YB and YB-S in May 2014. The red and blue lines indicate the zonal and meridional components. Blue arrows indicate conceptual view of the flow intensification due to the superposition of downward- and upward-propagating NIWs.

国際化推進共同研究概要

No. 7

19NU-1

タ イ ト ル:　High-field side transient CHI plasma start-up on QUEST

研究代表者:　NELSON, Brian, A

所内世話人:　花田　和明

研究概要:

同軸ヘリシティ入射(CHI)は経済的な核融合炉を実現させる球状トカマク(ST)装置のためのプラズマ立ち上げ手法として HIT-II や NSTX などで研究されている。QUEST の CHI 実験では軽元素不純物の低減が期待される全面金属壁構造において、SF-FNSF(米国で設計されたデモ炉)に適した新配位電極の開発が行われている。HIT-II や NSTX では容器内側壁と外側壁を連結する入射磁束の磁力線に沿って電流を駆動させる。QUEST では下部ダイバータ板上に絶縁されたトロイダルリング状の電極が設置され、ダイバータ下の PF コイルにより形成される入射磁束はリング状電極(陰極)と外側容器壁(陽極)を連結し、CHI プラズマは電極間にガスを入射して電圧を印加させることで生成される。2019 年度の実験ではリング状電極と中心柱間を連結させることで、HIT-II や NSTX の結果とよく似た CHI プラズマ発展が得られた。

プラズマの平衡制御のために使用される QUEST の PF コイルはリング状電極から離れており、接続されている電源の制御速度は速くない。また現状の QUEST のトロイダル磁場は HIT-II や NSTX の磁場よりも低い。これらの要因は適切な CHI プラズマ発展に不利となる。2019 年度の実験では QUEST の CHI システム改善のための、QUEST における HIT-II、NSTX 配位プラズマ特性の再現性が評価された。これまでのリング状電極と外側容器壁を連結した配位では、非常に高い入射電流に対してトロイダル電流の増倍率は1程度と低く、適切なプラズマ発展(狭い footprint を維持した発展)を得ることが出来なかった。リング状電極と中心柱間を連結させることで、1)入射電流値が大きく減少して電流増倍率が増加、2)プラズマの持続時間がそれまでの数倍に改善、3)プラズマが狭い footprint を維持したまま真空容器内部へ大きく発展するなどの結果が得られた。これらは HIT-II、NSTX 配位プラズマ特性をよく再現している。ただし明確な閉じ込め配位の形成は観測されなかった。

本実験結果により QUEST における HIT-II、NSTX 配位プラズマ特性の再現性が確認された。この結果に基づき、CHI 入射磁束形成のためのコイル増設が計画されている。試

作コイルによる評価を実施後、常設コイルの設計、導入を行う。これによる成果は ST 装置における CHI と ECH の組み合わせ手法の研究及び核融合炉の設計に貢献する。

High-field side transient CHI plasma start-up on QUEST *

2 January 2020

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Introduction

Methods for starting a plasma discharge in a spherical tokamak (ST) without reliance of the center solenoid are essential for the validity of the ST concept. These methods could also simplify and reduce the cost of tokamak-based systems and make them more economical by eliminating components that are not needed during steady-state operation. Coaxial Helicity Injection (CHI) for an ST, first developed on HIT-II at the Univ. of Washington and then further developed on NSTX, is the method for which scaling to larger devices such as reactors is well understood. On QUEST, this method would be further developed using the unique all metal capability of QUEST, which is predicted to reduce low-z impurities. In addition, CHI on QUEST will develop a new configuration that is much more suited to an ST-FNSF.

Basic concept for CHI operation on QUEST

On HIT-II, and on NSTX, CHI is implemented by driving current along externally produced field lines that connect the inner and outer vacuum vessel components in the presence of externally generated toroidal and poloidal magnetic fields. This is qualitatively shown in Fig. 1 (a). On QUEST, as briefly described in Fig. 1 (b), a toroidal ring electrode is mounted on top of the existing lower divertor plate, and the electrode separated from the divertor plate using a toroidal alumina insulator. Magnetic flux generated by the lower divertor coils connects this electrode plate (the cathode) to the outer vessel (the anode). Gas is injected in the gap between these electrodes and a 20-30mF capacitor bank, charged up to 2kV is discharged across these electrodes to generate the CHI plasma. In the recent experiments conducted during 2019, the electrode was biased with respect to the center stack on QUEST as shown in Figure 1(c). This is more like the configurations used on HIT-II and NSTX.

Progress with CHI on QUEST

An area in which the implementation of CHI on QUEST is different from that on NSTX is that the Poloidal Field (PF) coils that are needed for equilibrium control are much farther away from the CHI electrodes and the power supplies that operate these coils have slower current slew rates than the ones

* We acknowledge helpful discussions with Prof. Zushi, Mr. Noda (V-Tech Limited) and Mr. Rogers (Univ. of Washington) and with other members of the QUEST Team.

on NSTX. In addition, the toroidal field capability of QUEST is much lower than that on NSTX. Both these factors have made it more difficult to properly shape the injector flux into a narrow flux foot print condition that is necessary for forcing reconnection to occur in the injector region. To improve the CHI design for QUEST, during 2019 we conducted a test of CHI in a HIT-II/NSTX configuration to first assess if some of the performance features for the HIT-II/NSTX configurations could be reproduced on QUEST. If this is indeed the case, then this would provide the needed information to address the other concern related to the improved positioning of the CHI injector coil with respect to the electrode.

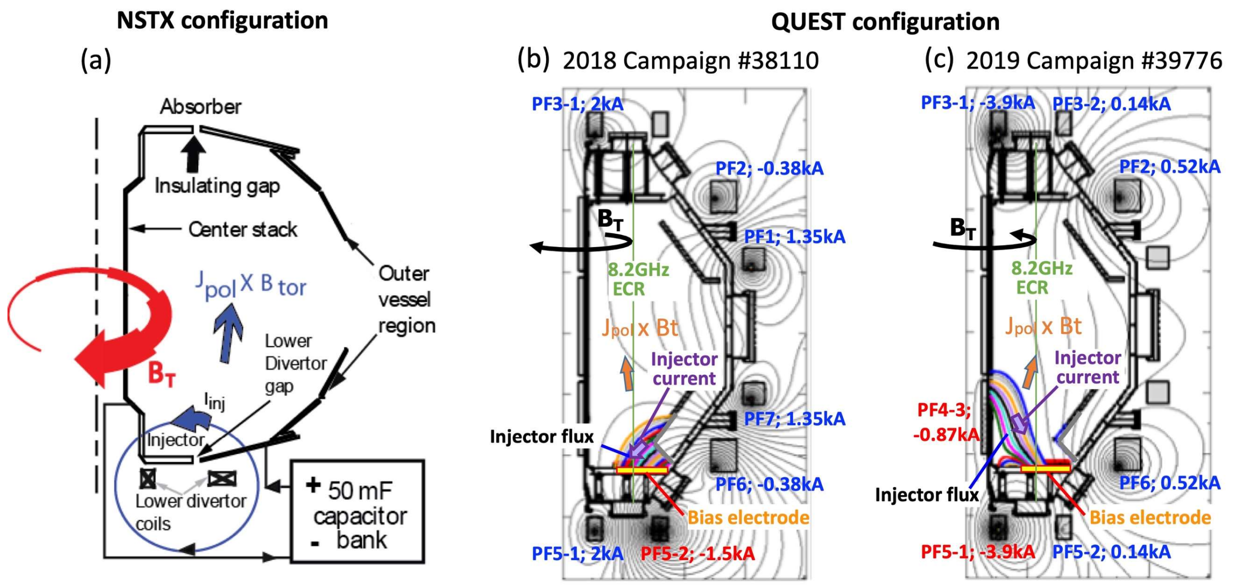

Figure 1: (a) Layout of the transient CHI startup systems in NSTX. The blue circle is the poloidal injector flux produced by the lower divertor coils. This connects the two lower divertor plates, which are insulated. Gas is injected in the region below the divertor gap. On NSTX typically a 5 to 15mF capacitor bank charged up to 1.7kV is used to produce the injector current. (b) Typical vacuum field line configuration for CHI discharge initiation on QUEST. (c) Configuration of the new injector configuration used in the 2019 experiments.

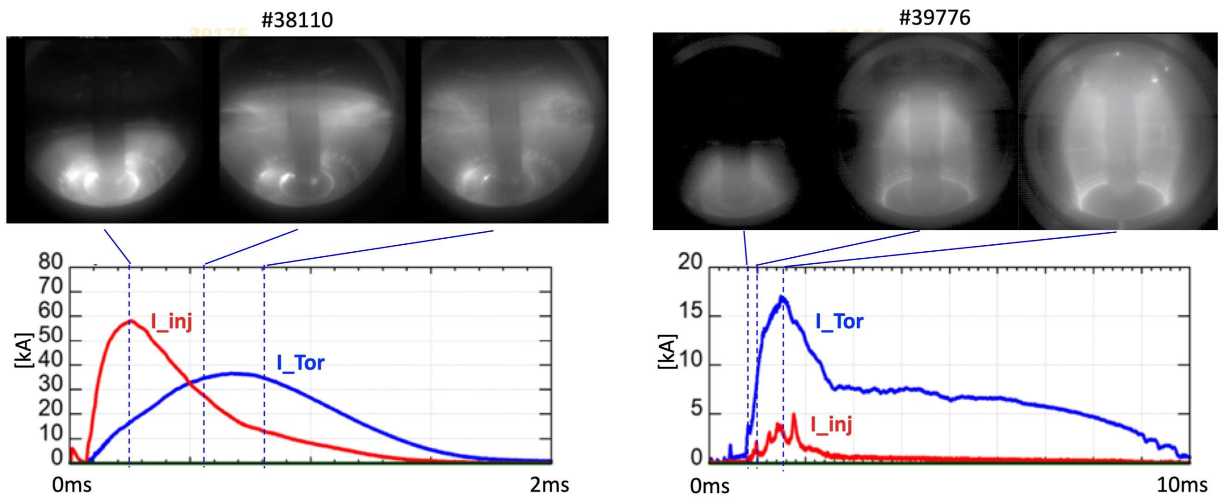

Fig 2: Comparison of transient CHI discharges in the (a) old (bias to outer vessel) configuration and in the (b) new recently conducted experiments in 2019 in which the electrode is biased with respect to the center stack as on HIT-II and NSTX.

Figure 2 shows a comparison of two discharges in which the injector region is different. When the injector flux is formed between the bias electrode and outer vessel wall (the old configuration) [1], the injector current flowing from electrode is very high but the toroidal current is comparable to the injector current showing that the current multiplication ratio is about 1. The flux evolves but its footprint becomes wide. When the injector flux is formed between the bias electrode and inner vessel wall, the injector current is substantially reduced, and the plasma evolves with a narrow footprint configuration to fill the entire height of the vessel (figure 1). In addition, the plasma current pulse duration increases by several times that in the other configuration and the outer leg of the current channel is much clearly defined. The latter result has many similarities to the discharges generated by the conventional electrode on HIT-II and NSTX. References [2,3].

The main results from the new configurations are:

- Injector current drops to very low value, and the current multiplication ratio (toroidal current / injector current) becomes very high, as on NSTX.
- The discharge pulse duration also dramatically improves
- The fast camera images show good resemblance to NSTX CHI plasmas; however, although the injector current becomes very small, closed flux formation cannot be clearly ascertained at this time.

These new experiments, however, are quite promising in that they have been able to reproduce many of the important features seen on HIT-II and NSTX. An important difficulty that remains is that because of the large distance between the divertor coils and electrodes, only a small portion of the coil flux connects the electrodes, and our ability to shape this flux is also very limited. These new results now provide a basis for improving the CHI injector coil location on QUEST. To further test this configuration with an optimally positioned injector coil, a new (temporary) PF coil will be used during the 2020 experiments. The design work for this coil has now been completed, and a new low-cost capacitor bank-based power supply is also now mostly built. The coil will be installed during January 2020. After a successful test during 2020, a new (permanent) CHI coil could be installed on QUEST to support detailed CHI + ECH studies in support of ST and tokamak reactor designs. We also note that, through a collaboration with the University of Washington and PPPL, we are also conducting a conceptual design study of the transient CHI configuration for the 3T ST-40 device in the United Kingdom.

References

[1] Kuroda K et al 2018 Plasma Phys. Contr. Fusion 60 115001.
[2] Raman R et al 2004 Phys. Plasmas 11 2565.
[3] Raman R et al 2011 Phys. Plasmas 18 092504

* We acknowledge helpful discussions with Prof. Zushi, Mr. Noda (V-Tech Limited) and Mr. Rogers (Univ. of Washington) and with other members of the QUEST Team.

国際化推進共同研究概要

No. 8

19NU-2

タ イ ト ル:　Plasma start-up and sustainment in spherical tokamak configuration by RF

研究代表者:　SHEVCHENKO, Vladimir

所内世話人:　出射　浩

研究概要:
Scevchenko さん分

令和2年1月30―31日の 2 日間で国際 WS を開催した。欧州から 1 名、米国から 3 名、国内の学外者が 7 名、別途、共同研究で訪れていた中国の研究者、応研関係者の参加があった。QUEST 実験の最近の進展に加え、国内外実験の進展、新たなシミュレーション解析などが議論された。特に今年度は、新規の ST40 実験での発表があり、他の発表も加え、関連する QUEST での非誘導プラズマ電流立ち上げに関し、共同研究が広く議論された。欧州方から1件、米国から2件、中国から1件、国内で9件の研究成果発表があり、活発な議論があった。

RF-only ST plasma confinement, sustainment,

and interactions with wall materials

Vladimir Shevchenko

A program of the Workshop which was held on 30-31 January 2020 and was as following:

8th Workshop Agenda, RIAM 2020

30 January AM

10:00 -10:10

Vladimir Shevchenko / Kazuaki Hanada

WS purpose and agenda

10:00 - 10:40

Vladimir Shevchenko

ST40: Recent results and ECRH & HTS plans for future

10:40 - 11:20

Kazuaki Hanada

Recent results for steady state operation and plasma current start-up on QUEST （TBD）

11:20 - 12:00

Modification of plasma-facing surface in QUEST due to PWI and development of advanced W wall panel for ultra-long pulse operation

Naoaki Yoshida

31 January PM

12:00 - 13:00

Lunch Time

13:00 - 13:40

Recent results from TST-2

Yuichi Takase

13:40 - 14:10

Peng Yi

Thomson scattering system in TST-2

14:10 - 14:40

James Rice

Detection of Fast Electrons in SOL Plasma Using a Langmuir Probe Diagnostic

14:40 - 14:55

Yongtae Ko

Measurement of LH waves in TST-2

14:55 - 15:15

Coffee Break

15:15 - 15:55

Hitoshi Tanaka

Overview of Recent EBW Experiment in LATE

15:55 - 16:35

Kengo Kuroda

CHI Experiments in QUEST

16:40 - **Group Photo & QUEST Machine Tour**

31 January AM

9:30 - 10:10

X. Gao

Non-inductive current drive experiments on EAST tokamak

10:10 - 10:50

Masayuki Ono

Update on ECH /ECCD modeling

10:50 - 11:30

Nicola Bertelli

3D full wave simulations in NSTX-U plasmas with the recent developed Petra-M code

11:30 - 12:10

Sadayoshi Murakami

MHD equilibrium reproduction by visible light computed tomography in QUEST

12:10 – 14:00

Lunch

31 January PM (Drafting of proposals for experiments, diagnosis, and analysis)

14:00 - **All Suggested focus and output for this joint drafting session**

The presentation summaries are as following:

Vladimir Shevchenko

ST40: Recent results and ECRH & HTS plans for future

In September 2019 there was a short experimental campaign on ST40 after relocation of the machine into the new building. This campaign was conducted to re-confirm operational status of ST40 after re-commissioning. After that several new diagnostics have been installed and commissioned. Solenoid and additional vertical field power supplies were installed and tested. Diagnostic Neutral Beam (DNB) injector has been delivered and partly tested.

In Autumn 2019 installation of the second part of TF power supply was completed and 1 MW 25 keV Heating Neutral Beam (HNB) injector has been tested and installed. These installations were followed by commissioning on ST40 in December 2019 and January 2020. Both beams demonstrated good performance in hydrogen gas. An improved plasma performance has been demonstrated in this second 2019 campaign taking advantage of the plasma sustainment using solenoid and upgraded plasma diagnostics. Some plasma heating and fuelling were observed with HNB injection into plasmas. To date plasma currents achieved in ST40 are above 0.5 MA with the current flattop up to 100 ms. Toroidal fields in excess of 2 T at the major radius of 0.4 m have been delivered on a regular basis. Kiloelectron volt range electron and ion temperatures have been regularly achieved during this campaign. All diagnostics were commissioned and prepared for full scale experiments. Currently, installation of liquid nitrogen cooling for TF and Bv coils is progress. Next experimental campaign is planned after completion of the cooling system.

Further upgrades of ST40 include installation of the 2nd HNB 1 MW 50 keV in Summer followed by commissioning and plasma experiments in Autumn 2020. A dual (140/105 GHz) frequency 1 MW gyrotron is scheduled for delivery and commissioning in Q1 2021.

Another significant activity at Tokamak Energy (TE) is a high temperature superconductor (HTS) magnet development. We believe that HTS technology gives an opportunity to build a compact tokamak-reactor which would allow achievement of plasma parameters close to ignition. A special magnet winding and testing facilities have been built at TE. HTS tapes from several suppliers were tested and compared against requirements for the tokamak-reactor. Using the best tape, a test magnet was developed demonstrating a world record field of 24 T. It was shown that HTS based magnets are resilient to a thermal quench and can withstand internal damages without causing catastrophic degradation. The next step is a development of a full scale HTS toroidal magnetic system DEMO-4 with the target magnetic field of 10 T at a major radius of 0.25 m. This milestone is to be achieved by the end of 2020.

Kazuaki Hanada

Recent results for steady state operation and plasma current start-up on QUEST

• The QUEST project is focusing on plasma start-up with RFCD and steady state operation.

• The 28GHz RF injection system has the capability to regulate both the wave polarization and N//. The system has also the capability to focus RF beam down to 5 cm in radius.

• More than 100kA could be obtained in N//=0.78 X-mode with a little OH provided from the poloidal field increment. According to the RF absorption, the RF is likely to absorb to energetic electrons. Which is useful to drive plasma current.

• Low N//=0.1, X-mode injection could successfully heat up bulk plasma up to 0.5 keV of Te. Single pass absorption of achieved plasma parameters is expected to be approximately 40%, therefore the effective bulk heating could be obtained with a sophisticated neutral control to avoid production of energetic electron.

• High field launch of RF has been tried to effectively excite EBW in the plasma. A new tentative waveguide and antenna was installed for the experiment. The designed value of mode conversion to EBW is 93%. The rest RF is absorbed at the fundamental ECR.

• Higher density and better absorption of RF in HFS launch than those in the LFS launch could be obtained. PDI signal was measured with a movable probe and larger PDI in the HFS launch was measured. This supports to higher mode conversion to EBW.

• To get evidence of EBWCD, TF and PF direction modification has been executed. The plasma reproducibility is insufficient to compare the value of plasma current. The flux loop signals denote the inversion of plasma current direction in the mid-plane, bur need to more confirmation.

• Plasma Breakdown has been investigated with 2nd harmonic ECW. The threshold power was much higher than fundamental ECW predicted by numerical calculation. The connection length dependence was different from fundamental ECW.

• The hot wall plays essential roles in reducing the amount of wall-stored H and facilitating H recycling. Only top hot wall has the capability to water cool down since 2018SS campaign.

• The clear reduction of Ha after water cooling of the top hot wall. This indicates the recycling could be control by wall temperature.

• The cooling down from 473K of only top hot wall with water can extend the plasma duration

• During long duration discharges, neutral compression could be achieved behind the bottom divertor plate. The reason is still unclear, because there are many candidates to make this to-bottom asymmetry. It is a future work.

Naoaki Yoshida

Modification of plasma-facing surface in QUEST due to PWI and development of advanced W wall panel for ultra-long pulse operation

Impurity deposition on the plasma facing surface in QUEST at preset is aggregation of nanocrystals of carbide and metallic oxide and little amount of amorphous carbon. TDS results indicate that its contribution to the retention and thermal desorption of H under plasma discharge is little. In contrast, large amount of H can be retained in hot wall liner APS-W and its thermal desorption continues up to around 1000K. It can be considered that active desorption of H from the APS-W liner causes the termination of long pulse plasma discharges.

For ultra-long pule discharges at higher temperatures (≤773K) we have already started development of advanced W liners, in which retention of H at high temperatures is low enough.

Yuichi Takase

Recent results from TST-2

The capacitively-coupled combline (CCC) antennas for exciting the traveling LHW for Ip start-up and ramp-up were developed. Outboard launch, top-launch, and "bottom-launch" (top-launch with reversed Bt) were compared. The driven current was higher for top-launch than outboard-launch as expected, but the highest driven current was achieved by "bottom-launch", contrary to initial expectation. Thomson scattering measurements show peaked ne profile and hollow Te profile with the highest temperature in the inboard edge region, and equilibrium reconstruction using an extended MHD model shows a hollow j profile. Hard X-ray spectra show higher flux and effective temperature for top-launch compared to outboard-launch, especially in the inboard edge region, consistent with Te and j profiles. A large orbit loss fraction was inferred from the RF power modulation experiment. A combined ray-tracing and Fokker-Planck analysis indicate n|| upshift and strong damping around r/a ~ 0.5 for top-launch. For "bottom-launch", n|| downshifts first, but upshifts after reflection. Once electrons are accelerated to high energies, these electrons can absorb the downshifted n|| LHW and very high energy electrons can be generated. The result of this analysis can explain the experimental results.

An EC-assisted inductive Ip start-up scenarios being developed for JT-60SA on TST-2. The trapped-particle configuration (TPC) with a weak Bv with positive decay index enlarged the operating window for reliable start-up compared to the usual field-null configuration (FNC). Application of EC power extended both the low pressure limit for breakdown and the high pressure limit for burn-through. The TPC was particularly beneficial at low pre-fill pressure and high EC power.

AC Ohmic coil operation is a reliable pre-ionization method. A small inboard coil can be used for pre-ionization. The breakdown voltage is nearly the same as the regular Ohmic coil. Positive and negative triangularities can be obtained using the small inboard coil. Recent results from TST-2

Peng Yi

Thomson scattering system in TST-2

It is useful to find the optimum operational conditions for fusion reactors if the electron temperature and density profile measured by the Thomson scattering measurements, as well as their scaling could be obtained.

In the study, the relation of the electron temperature (Te) and pressure (P) to the electron density (ne), RF power (Pw), toroidal magnetic field (Bt), and plasma current (Ip), for the scenario of D+CW+Top (deuterium, clockwise toroidal field, and top antenna), is obtained by separate fitting for the parameters in the presumed formula. In addition, the comparisons of different scenarios, such as hydrogen (H) and D, top and out antenna, CW and counter-clockwise (CCW), have been conducted to investigate the effects of them on the electron temperature. Compared with the D+CW+Top scenario, the results show the H fuel gas gives rise to higher electron temperature, CCW toroidal field would produce lower electron temperature, and the out antenna results in rough same electron temperature within error bars. On the basis of temperature relaxation time calculation for the TST-2 and the estimation of confinement time, as well as the heating power for bulk electrons and the equivalent heating power calculated by stored energy in the plasmas and confinement time, it is feasible to explain qualitatively the measured results of electron temperature by collisional heating.

In order to observe the temperature anisotropy in the plasmas, the double-optical-pass configuration for Thomson scattering system in TST-2 is also investigated. The effects of displacement of the focal points on the fiber's collection efficiency are estimated, as well as the deviation of the returned beam from the center of laser source, caused by the tilt angle of the distant mirror, is analyzed since the returned beam will pose the laser source in jeopardy. Also, the theoretical calculations of the displacement of returned beam are verified by corresponding measured results, and that indicates the possibility of blocking the returned beam by putting an aperture in front of the lens or the laser source. The optimization of the double-optical-pass configuration will be implemented in the next step.

James Rice

Detection of Fast Electrons in SOL Plasma Using a Langmuir Probe Diagnostic

Electron Energy Distribution Function (EEDF) analysis has been used to confirm the presence of fast electron populations in SOL plasma in TST-2. A full profile of TST-2's SOL plasma is desired for ray-tracing and plasma simulations. To this end, a new Langmuir probe has been installed as a prototype for a full profile of SOL parameters. This prototype has been used to refine the measurement methods used.

Recent results from power modulation experiments show strong alteration to Te and Vfl during RF power. The positive increase to Vfl indicates RF sheath rectification is not the dominant alteration. It is thought that the non-thermal electron energy distribution in TST-2 causes an overestimation of Te. To confirm this, EEDF analysis has been used to confirm the presence of fast electrons in SOL plasma. Preliminary results show low-temperature bulk electrons and a higher energy component at lower density. Further research is required to better classify this fast electron component and identify its effect on measured plasma parameters.

Yongtae Ko

Measurement of LH waves in TST-2

14-ch RF magnetic probe has been developed to detect LH waves (200 MHz). Parametric decay instability corresponding to ion cyclotron quasi-mode were observed in TST-2 LH driven plasma experiments. The interest is what the differences among launching mode, outboard-launch, top (CW) launch and top (CCW) launch. In the experimental results, large peak of PDI associated with ICQM was observed on sideband of the pump-wave frequency in hydrogen plasma with outboard and top (CW) launch case, while disappeared in deuterium plasma with top (CW and CCW) launch case. The fraction of side band power (100 – 199.9 MHz) was dominant (over 100%) in inboard region with the outboard launch and also dominant (over 200 %) in bottom-outboard region with top (CW) launch. However, with top (CCW) case, fraction was suppressed under 80 %, but direct relationship between current drive efficiency and PDI suppression is not realized.

Hitoshi Tanaka

Overview of Recent EBW Experiment in LATE

Microwave at 2.45 GHz is used to start-up and form ST plasmas. In order to excite the EBW via O-X-B mode conversion, three polarizations of microwave such as O-mode-like left-handed elliptically polarized ones and X-mode-like ones are used and compared. Results of effect on bulk electron heating are qualitatively related to the mode conversion rate calculated by the linear theory with the cold resonance absorption model in a slab model.
HIBP measurement have been carried out during the intermittent plasma ejection events which usually appear when the density exceeds several times of the plasma cut off density and the central safety factor becomes about 8. Fast space potential variations are observed during the event, which indicate the local escape of electrons and its recovery.
An electron beam is injected from a cold cathode installed at the bottom port into a ST plasma which is produced non-inductively by EBW. Investigation of synergistic effects of electron beam injection and EBW current drive has begun.

Kengo Kuroda

CHI Experiments in QUEST

CHI current start-up by using simple electrode has been tested in QUEST. Initial result, in which the injector flux forms between electrode and outer wall shows that the reliable gas breakdown is achieved under appropriate conditions and plasma evolves with increasing toroidal current which is dependent on the PF configuration, but keeping a “narrow footprint” is difficult and current multiplication I_tor/I_inj is low, ~1.

In the discharges, in which the injector flux forms between electrode and inner wall high current multiplication, 5~10 and long duration 10~30ms are achieved and plasma evolves to fill vessel with keeping “narrow footprint”.

We plan to improve and further test the second configuration by installing a new (temporary) injector flux coil that is much closer to CHI electrodes.

After verifying good closed flux surface formation a more permanent CHI coil design will be considered to support CHI + ECH studies.

X. Gao

Non-inductive current drive experiments on EAST tokamak

Overview of experimental progress on EAST is presented. Steady-state fully non-inductive scenarios (such as long pulse H mode, high beta-p plasma, and high beta-N plasma et al.) is demonstrated with extension of fusion performance. Regular and low loop voltage start-ups without resistors have been achieved on EAST tokamak in 2019.

Masayuki Ono

Update on ECH /ECCD modelling

The QUEST ECH solenoid-free start-up experiment utilizing the 28 GHz gyrotron at 2nd harmonic frequency has demonstrated remarkable efficiency and achieved record start-up current values [1]. The experiment provides rich opportunities to understand and optimize ECH-based tokamak/ST current start-up and ramp-up concept. Another potentially noteworthy aspect of the QUEST 28 GHz experiment is its very high frequency to toroidal magnetic field ratio, which is 28 GHz/0.25T or 112GHz/1T. The higher frequency enables higher density limit and for reactors with several Tesla toroidal field, this start-up scenario can largely avoid the usual density limit often encountered by ECCD. Conversely this higher harmonic scenario would enable utilization of ECH at lower magnetic field as in the case of many ST experiments. This scenario maybe also attractive for the ECH assisted start up for the initial phase of ITER where the toroidal magnetic field maybe relatively low ~ 2 T. To better understand the QUEST experimental results, we initiated a modelling effort at PPPL. Improved modelling should also help develop better predictive capability for future ST and tokamak-based reactors. An ST/tokamak start-up modelling is a highly coupled non-linear problem as the magnetic field topology evolves dramatically from an open vacuum field configuration to a closed configuration. The plasma temperature evolves from a very cold collisional regime to a very hot collision-less regime. For this task, we developed a grid-based start-up code where plasma parameters, generated plasma currents, and resulting poloidal magnetic fields are evolved from the vacuum fields. The grad-B drift driven current together with the processional currents can then create a closed flux surface configuration and then the bootstrap current in a closed configuration can further enhance the plasma current. The ECH heating efficiency increases with plasma current since the confinement is increased and resulting electron temperature rise would further increase the ECH absorption and plasma currents. Once the plasma temperature becomes sufficiently high ~ 1 keV, a single-pass absorption can rise sufficiently to transition to the ECCD phase. An important point to note is that two-component distribution (hot minority and colder bulk) is highly advantageous for hot electrons to be generated for efficient ECCD as observed in the QUEST start-up experiment. An update of the modelling is given including some benchmarking of RT-4 with Genray at higher temperature range of ~30 keV and also including the effects of particle loss to better simulate the experimental situation.

Nicola Bertelli

3D full wave simulations in NSTX-U plasmas with the recent developed Petra-M code

In this work we present the recently developed tool Petra-M and its current applications. Petra-M code [1] is a state-of-the-art generic electromagnetic simulation tool for modeling RF wave propagation based on MFEM [http://mfem.org], open source scalable C++ finite element method library. Commonly, RF simulation has been often limited to a relatively small volume in front of the antenna, and it involves physics simplification from the actual experimental situation such as stratifying antenna strap structure, flat antenna model and/or treating the antenna front volume as vacuum. This paper, instead, shows the full 3D NSTX-U device geometry including realistic antenna geometry in order to capture the 3D effects and the antenna-plasma interaction in the SOL plasma and, at the same time, the core wave propagation. A scan of the antenna phasing shows a strong interaction between FWs and the SOL plasma for lower antenna phasing, which is consistent with previous NSTX HHFW observations. Furthermore, the effect of the 3D wave field on the fast ion population from NBI beams in NSTX-U is quantified by using the 3D field obtained from the Petra-M simulations in the SPIRAL full-orbit following particle code [2]. Then we show the 3D full wave simulations of a new HHFW 4-straps antenna recently installed by Tri-Alpha Energy on LAPD with an initial comparison with the experimental data. Finally, initial Petra-M simulations on the JET ITER-like antenna, ICRH/LH in WEST machine, and helicon in KSTAR are discussed.

[1] S. Shiraiwa et al., EPJ Web of Conferences 157, 03048 (2017). [2] G. J. Kramer et al., Plasma Phys. Control. Fusion 55, 025013 (2013).

Sadayoshi Murakami

MHD equilibrium reproduction by visible light computed tomography in QUEST

We propose a method for reconstructing image of a poloidal plasma cross section from visible light information in the tangential direction of tokamak. We realize a robust reconstruction method using Laplacian eigenfunction expansion & L1 regularization. The MHD equilibrium is calculated from reconstructed image applying TASK/EQ code. Rotating toroidally the obtained outer flux surface, we obtain a similar image with the measured visible light.

国際化推進共同研究概要

No. 9

19NU-3

タ イ ト ル:　EC and EBW simulations in QUEST plasmas

研究代表者:　BERTELLI, Nicola

所内世話人:　出射 浩

研究概要:
QUEST では、28 GHz 電子サイクロトロン波による非誘導電流立ち上げを行っている。50 keV 程度の高速電子を効率良く生成し、世界最高値を誇る、高プラズマ電流立ち上げに成功している。核融合炉での炉心プラズマ電子温度より、高温度・高エネルギーとなる 50 keV の電子による波動吸収の評価で、如何に相対論的ドップラー効果を取り扱うかが課題となる。「非相対論的電子分布関数の速度微分項の速度空間積分」で評価される誘電率の非エルミート項に、質量が重くなる相対論効果を取り入れた評価と、「相対論的電子分布関数の速度微分項の速度空間積分」を用いた評価が異なる。相対論的電子分布関数を扱った2つのコード間でベンチマーク評価し、良好な一致を得た。非相対論的電子分布関数を用いて質量が重くなる相対論効果を取り入れた評価との差を議論した。

EC and EBW simulation in QUEST

BERTELLI, NICOLA

Non-inductive electron cyclotron (EC) plasma current ramp-up is an attractive start-up method for tokamaks. The non-inductive plasma ramp- up either with or without a small central solenoid (CS) provides distinct advantages in reactor engineering design and in cost considerations when compared with conventional tokamak operations. In a spherical tokamak (ST), the CS flux is small because the center stack area is limited. EBWHCD (electron Bernstein wave heating and current drive) has been discussed as an attractive candidate for fully non-inductive plasma current ramp-up in the STs. The EBWHCD in the O-X-B mode conversion scenario have been explored for steady-state ST operation in QUEST as well as EC heating and current drive (ECHCD).

A 28-GHz ECHCD system with a quasi-optical mirror launcher was developed to provide second harmonic（2 f_{ce}） X-mode EC non-inductive plasma ramp-up in QUEST. In oblique injection with a parallel refractive index $N_{//}$ = 0.75 at the 2 f_{ce} resonance position, high non-inductive plasma-current of ~ 80 kA was efficiently ramp-up with the 28 GHz wave (Fig,1). Hard rays (HXs) were measured at forward tangential viewings for current-carrying energetic electrons in the mid-plane. The HX count with averaged energy of ~ 60 keV increased following the ramp-up in current. It is very likely that the energetic electrons play a key role in generating the plasma current. To consider plasma ramp-up mechanism, the single pass absorption was evaluated with a ray-tracing code. The 3 % of the bulk density was assumed as energetic electron component. Figure 2 shows ray absorption rate along the propagation evaluated with the TASK/WR code [1] in various density cases. The 20-30 % of the incident power would be absorbed as a single pass absorption at higher harmonic resonance (3 f_{ce} and 4 f_{ce}) due to the energetic electrons as well as the 2nd harmonics. As the benchmark, the single pass absorptions with various energetic-temperature electrons were assessed using a couple of ray-tracing codes. A couple of ray tracing codes to were used to evaluated the

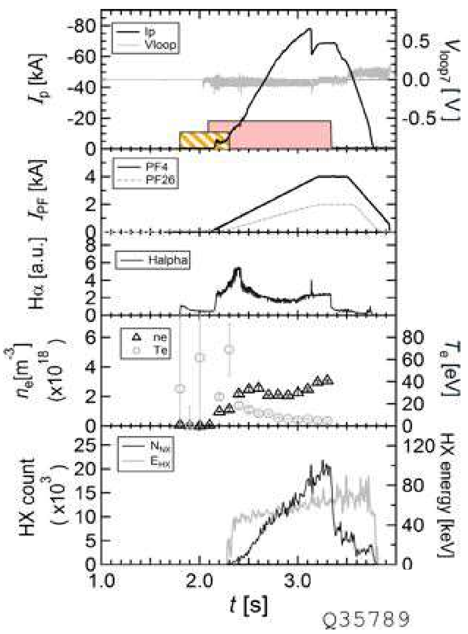

Fig.1: Time evolution of plasma parameters in 28 GHz non-inductive ramped-up plasma.

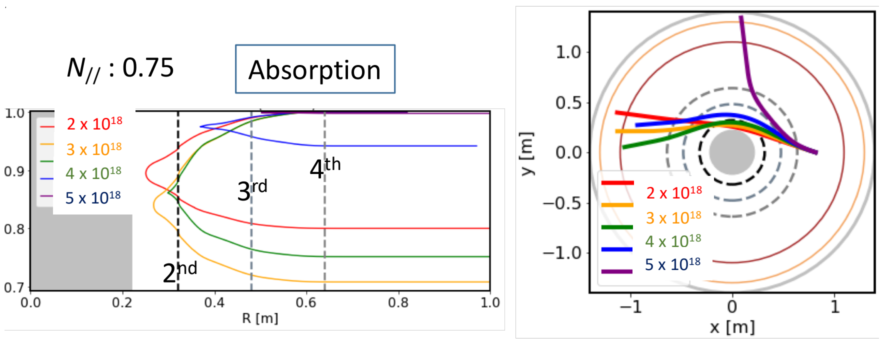

Fig2 : Ray absorption rate along the ray propagation with TASK/WR code.

single pass absorption. Bulk electron temperature and density are 2 x 10^{18} m^{-3} and 30 eV at the center, respectively. Figure 3 shows the evaluated single pass absorption rate as a function of the energetic electron temperature by TASK/WR, RT-4 [2] and GENRAY [3] codes. The 1 % and 3 % energetic electron components were assumed. Evaluated single pass absorption rates match well among three codes up to 30 keV, however, the rate evaluated by RT-4 code become larger than the others with increasing energetic electron temperature beyond 30 keV. The rates by TASK/WR and GENRAY codes coincide together with, even in the highly energetic electron-temperature range. The RT-4 takes the relativistic mass effect into account on electron cyclotron frequency, electron plasma frequency, and so on after taking integral of the distribution-function derivative at velocity in the velocity space within the non-relativistic limit. The other codes take the integral of the derivative with no non-relativistic approximations. The difference among the rates with the three codes is considering on the physics point of view.

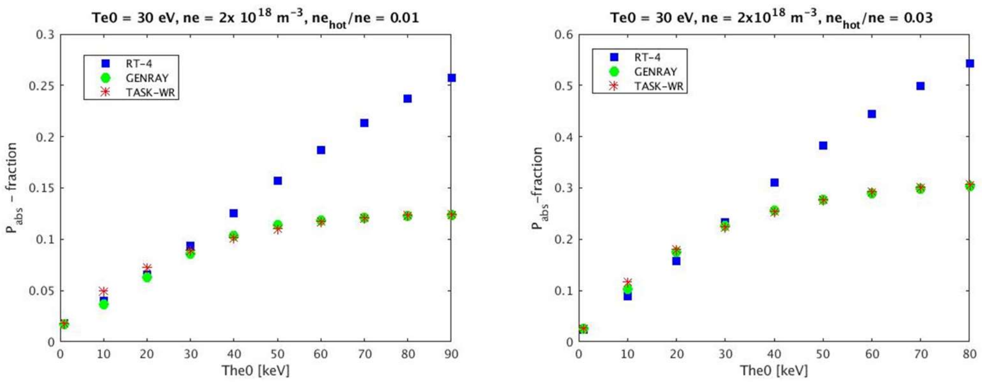

Fig.3: Evaluated single pass absorption rate with1 % and 3 % energetic electron components as a function of the energetic electron temperature by TASK/WR[1], RT-4 [2] and GENRAY [3] codes.

[1] A. Fukuyama, Fusion Eng. and Design, **146** (2011) 1149.

[2] M. Ono, N., *et al.*, Proc. of the 23rd Topical Conference on Radio Frequency Power in Plasmas (2020).

[3] A. P. Smirnov and R. W. Harvey, *Bull. Am. Phys. Soc.* **40**, (1995) 1837.

No. 10

（様式 11・拠点）

19NU-4

日本語要約

1 月 29 日―2 月 5 日に九州大学応用力学研究所に来所し、QUEST で開催された第８回国際ワークショップに参加し、EAST に関する最新の実験データについて「Non-inductive current drive experiments on EAST tokamak」と題したの報告・議論を行った。高温プラズマの長時間維持は QUEST と EAST（中国科学院プラズマ物理研究所に設置された中国最大のトカマク装置）の共通の主要課題であり、高性能化したプラズマの長時間運転では EAST は世界でトップクラスである。QUEST での粒子バランス研究と EAST の高性能運転の状況を議論し、新たな研究の可能性について議論を行った。本研究課題に関連して中国側から１名の学生が２年間派遣されており、中国科学技術大学で学位を取得した。今後も情報交換を進めるとともに、協力できる研究分野での研究協力や学生交流を続けていくこととした。関連研究では以下の 2 報が出版されており、中国側で 1 報の投稿が行われる予定である。

K. Hanada *et al* 2019 *Nucl. Fusion* **59** 076007

K. Hanada *et al* 2019 Nucl. Materials and Energy **19** pp544-549

（様式 11・拠点）

RESEARCH REPORT

Date: Feb. 12, 2020

Visiting scientists: (name) **Xiang Gao**

(position) **Professor**

(university / institute) **Institute of Plasma Physics, Chinese Academy of Sciences**

Host scientist: (name) **Kazuaki Hanada**

(position) **Professor**

(university / institute) **Kyushu University**

Research period: (from) **Jan. 29, 2020** (to) **Feb. 05, 2020**

Research subject: **Joint study of long pulse high beta discharges and related egde turbulence transport in steady state operation (SSO) plasmas on QUEST and EAST**

Introduction

Steady state operation (SSO) of tokamak plasma is one of the basic requirements for future fusion reactors. Long pulse high beta operation is one of important missions for ITER. Joint study long pulse high beta discharges in SSO plasma research field on QUEST and EAST is strongly supporting ITER experiment from both experience and theory. In this year, the collaboration research focused on the non-inductive current drive steady state operation and plasma current start-up on QUEST and EAST. QUEST project is now focusing on plasma start-up with RFCD and SSO. Steady-state fully non-inductive scenarios is demonstrated with extension of fusion performance on EAST. Regular and low loop voltage start-ups without resistors is also achieved on EAST. The joint research on plasma current start-up and non-inductive current drive is benefit for the SSO high beta discharges of EAST and QUEST. During the stay at QUEST building this year, I and Prof. Hanada both participate in "the 8th international workshop for non-inductive plasma start-up" in Jan. 30-31. I give a presentation of "Non-inductive current drive experiments on EAST tokamak", which introduced the recent results on steady state operation and non-inductive current drive experiments on EAST tokamak. Prof. Hanada give a presentation of "Recent results for steady state operation and plasma current start-up on QUEST", which showed the recent results on SSO and plasma current start-up on QUEST. This report based on the two presentations and discussions on them, to show the new results with the joint research support.

New results on plasma current start-up and non-inductive current drive SSO on QUEST and EAST in 2019

QUEST project is focusing on plasma start-up with RFCD and SSO. QUEST has recently been able to achieve the long duration discharge lasting 1 h 55 min with well-controlled wall temperatures using the hot wall and proper Hα level feedback control. These long duration discharges, lasting more than 1000 s, as shown in Figure 1, have been achieved and reproduced by a full non-inductive electron cyclotron current drive (ECCD) using an 8.2 GHz, 40–50 kW RF source. The plasma current in long duration discharges was relatively low (5 kA–20 kA) and its density was significantly low (~10^{17} m^3). Another 28 GHz, ~360 kW RF heating source is also available in QUEST. A bifurcation of electron energy of dominantly driving plasma current was observed and the bifurcation was triggered by the reduction of fuel neutral in the fully non-inductive plasma current start-up without fundamental EC resonance. The plasma current of more than 90 kA and the density up to 5 x 10^{18} m^{-3} could be obtained with proper polarization, focusing and injection angle of RF. The EC launch from high field side (HFS) is promoting and higher density than plasma cut-off could be obtained in only HFS launch. More than 100kA could be obtained in $N_{//}$ ~ 0.78 X mode with a little OH provided from the poloidal field increment. It was found that high $N_{//}$ ~0.78 RF injection is better to get higher plasma current and the Hard Xray of several 10keV was observed. Low $N_{//}$ ~ 0.1 RF injection is better to get higher elcctron temperature 0.5keV in Te could be obtained. RF absorption with bi-Maxwell denotes that elctron energy selcectivity. Energetic electron could absorb well the RF power in higher $N_{//}$. In QUESE, EBW conversion of HFS injected X modes, a tentative waveguide was installed for the experiment. The effective mode-conversion to electron Bernstein wave (EBW) being free from density limit is expected, indicating leak RF power monitoring. Parmetric decay signal was observed in an inserting probe around the LH frequency in the HFS injection. GENRAY calculation predicts EBWCD direction is decided by the direction of TF and PF. The 2nd harmonic ECW breakdown has been investigated with high power threshold. It was observed higher frequency give higher power threshold.

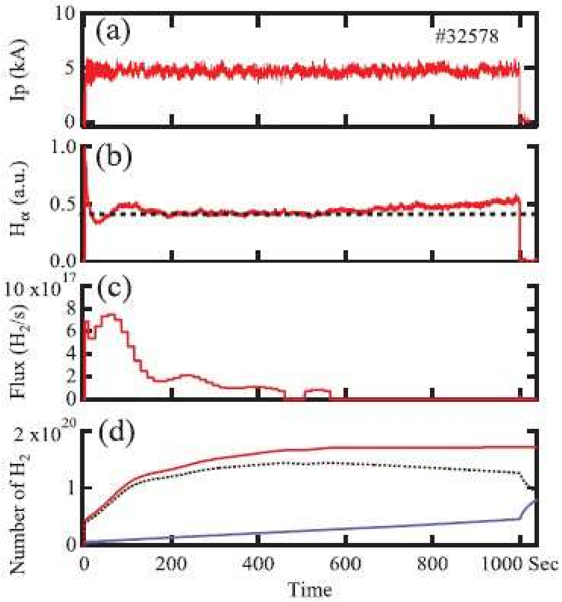

Figure 1 Typical waveforms of a long discharge at TW = 473 K. (a) Plasma current, Ip, (b) intensity of Hα line radiation (red line) and a targeted value (black dashed line), (c) injecting H2 flux into the vessel using the flowmeter, (d) time-integrated supplied H2 tothe vessel (red line), time-integrated evacuated H2 from the vessel(blue line), and calculated wall-stored H converted into H2 (black dotted line). (K. Hanada et al., Presentation during this visit).

A 50kW 8.2GHz RF system and a 150kW 28GHz RF system was for long pulse operation in QUEST. In 2019-2020 campaign experimental set up for SSO, only top hot wall has the capability to water cool down during discharge. The cooling down from with water can extend the plasma duration. The radiation in midplane area was firstly increasing from Ha profiles measurement during long duration discharge(>1000s). Radiation images are similar in both discharge just before the palsma termination. An unbalance wall temperature gives rise to fuel particlce compression behind divertor plates in the bottom. It indicates H recycling is a crucial issue to maintain a burning condition. The additional H_2 supply is assumed as denoted by red solid line in Fig. 2(a). From 2000s to the end of discharge, the additional H_2 supply is linearly increasing up to 2×10^{17} H_2. The evolution of ne can be well reconstructed shown in Fig. 2(c). The evolution of the wall stored H is quite different from the experimental observation, but the experimentally measured wall stored H is just difference between the supplied H_2 and evacuated H_2 and the direct comparison has no meaning. Thus, the model calculation using experimental measurements is useful to understand particle balance quantitatively and a more appropriate wall model should be developed, including for all-metal PFW devices.

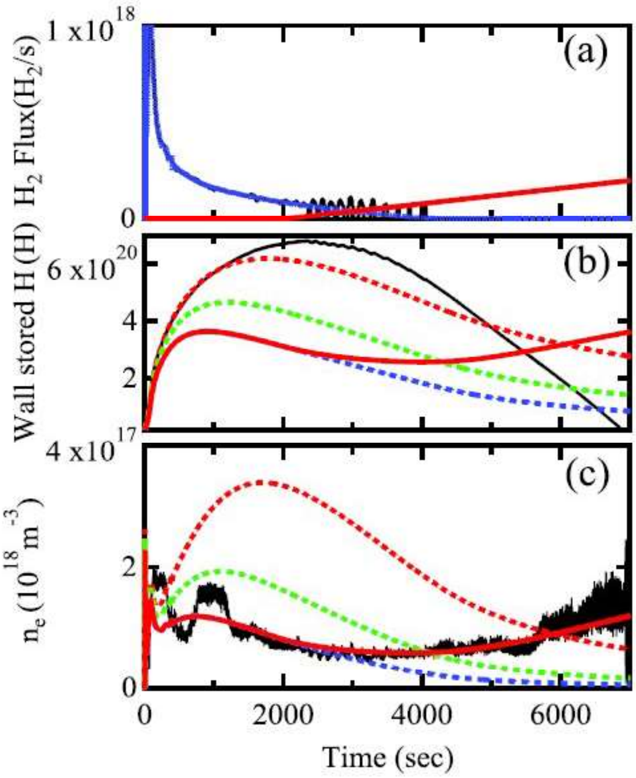

Figure 2 Time evolutions of (a) supplied fuel H2 gas flux in the experiment (black solid line) and fitted curve for the calculation (blue dotted line), (b) wall stored H, and (c) electron density. (K. Hanada et al., Presentation during this visit).

On EAST, demonstration of high performance steady-state H-mode operation with a reactor-like metal wall, a low momentum input, and electron dominated heating scheme is a critical step on the path towards the success of economical fusion energy. Two advanced scenarios on EAST tokamak have been developed. One is the high β_N operation in ELMy H-mode with internal transport barrier, the other is high β_p steady-state operation with pure

RF and RF+NB.

Figure 3 shows an example of the high β_N plasma discharge (*Ip* = 400- 500 kA, B_T = 1.5-1.6 T, q_{95} =3.4 - 4.4) with the ITER-like tungsten divertor. In this high β_N experiment, the plasma density increases up to 5.5×10^{19} m^{-3} (Greenwald factor up to 0.75), and a high β_N of 2.1 has been obtained with a good plasma confinement ($H_{98(y2)}$ = 1.1). The value of β_N reaches above 3×l_i, where l_i is the internal inductance calculated from the equilibrium analysis. By comparing the EAST results with the advanced inductive scenario database from DIII-D, JT-60U, JET and ASDEX-U, the EAST high β_N scenario is still in the heating power limited regime, rather than the MHD limited regime as indicated by the 4×l_i line. This is supported by the fact that no clear NTM has been observed in this scenario.

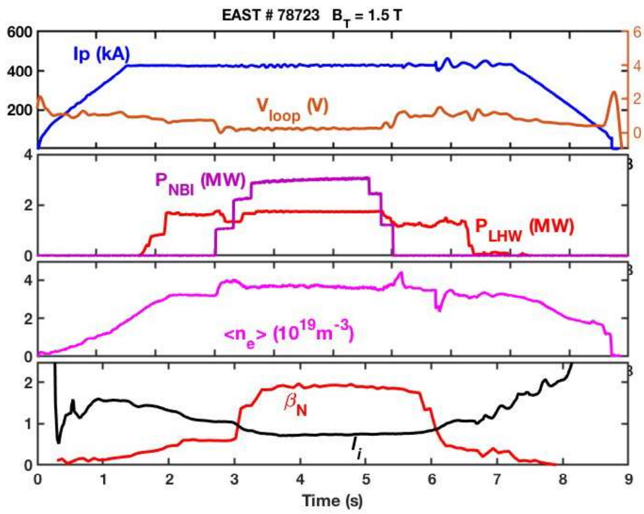

Figure 3 High β_N scenario development for EAST#78723 with β_N >1.9 sustained for 2s. Signals from top to bottom are plasma current (Ip) and loop voltage, LHW power (PLHW) and NBI power (PNBI), the core line averaged density, plasma normalized beta and inductance.(My presentation during this visit)

In these high β_N scenario H-mode plasmas, the internal transport barrier (ITB) has been often observed after step-up of the NBI power. It is rather important to note that the ITB can be obtained on EAST with various different types of plasma current profiles, including monotonic, central flat (q(0)~1) and reversed shear current profiles. The MHD instabilities associated with these different types of current profiles have been studied. It is found that the fishbone mode (*m/n* = 1/1) can be beneficial to sustain the central flat (q(0)~1) q profile, thus a stable ITB can be obtained. The reverse-sheared Alfvén eigenmodes (RSAEs) have been observed in the reverse sheared plasma with a transient ITB formation. Recently, all these three ITB operational regimes have been further extended in the EAST 2018 campaign. The role of the plasma current profile on the formation of the ITB will be further investigated. In particular, the non-inductive current fraction in the central flat (q(0)~1) q profile plasma is larger than 40%. Further investigation of this operation regime might be important for the development of the hybrid scenario for ITER and CFETR.

In the steady-state operation with RF heating only, a first demonstration of >100 s (~250 times the current relaxation time) timescale long-pulse steady-state scenario with good plasma performance (H98y 2 ~ 1.1) and good control of impurity and heat exhaust with the tungsten divertor has been successfully achieved. The zero-loop voltage indicate the truly steady-state condition. A peaked electron temperature profile was observed with a weak ITB at ρ=0.4. Additionally, the extended operation regimes of the steady-state scenario have been obtained (βp ~ 1.9 & βN ~ 1.5 & H98y2 ~ 1.3 of using only RF heating) since 2019. It is shown that the plasma performance is increased with the density and it is confirmed in both modeling result and experiments. Also, the Shafranov shift is shown to play a key role in the suppression of the electron turbulent energy transport in the high bootstrap fraction scenario.

In EAST last experimental compaign, plasma start-up was studied and optimized. Regular and low loop voltage start-ups without resistors is achieved. According to Townsend avalanche theory, a minimum electric field E_{min}(p, L) for breakdown for hydrogen, deuterium or tritium,

$$E_{\min}(V \bullet m^{-1}) = \frac{1.25\times10^4\, p(\mathrm{Torr})}{\ln[510\,p(\mathrm{Torr})L(\mathrm{m})]}$$

Optimization of null field configuration, electric field and gas pressure, under well wall condition, low loop voltage (Vloop~3.1V) startup with LHCD assistant, reliable breakdown could be achieved at E~0.3-1.0V/m. LHCD applied at plasma startup phase can significantly reduce the current ramping rate in PF coils or voltage applied at PF coils, which increases the safety margin of SC magnets and provide larger margin for plasma control. Configuration control during ramp up was done with early X-point formation and heating&CD, li control, VDE control, full Bore starup for ITER startup. Low Vp Startup and Establishment of Negative Ip for Assessment of Counter-NB Fast Ion Loss was obtained. The lowest Vloop ~ 2.1V with LHW@2.45GHz of 600kW， ECRH of 500kW.

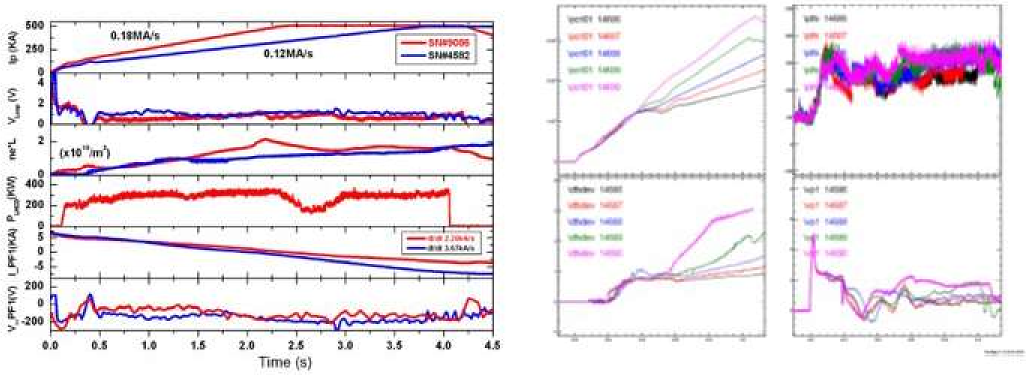

Figure 4 Plasma ramp up w/o LHCD assistant, dIp/dt~0.1MA/s, 0.15MA/s,0.2MA/s,0.3MA/s, 0.4MA/s, li Control.(My presentation during this visit)

Discussions

QUEST and EAST are both to develop the scientific basis for achieving a steady state condition. Research in this year was focused on the non-inductive current drive steady state operation and plasma current start-up on QUEST and EAST. Especially in long pulse discharges with full metal wall. The joint study results now and in future may shed light on the ITER SSO scenario. Based on the fruitful communications, the abundant progress and requirement of future research of this project are expected and deeply joint research is required in future.

Acknowledgement and comments:

Work supported by the international joint research at the Joint Usage of Research Centers for Applied Mechanics for 2019. I would like to thank our host, Professor K. Hanada, who helps a lot during our staying at QUEST and very appreciate the useful discussions and comments. Also RIAM and QUEST staffs and students are thanked for their helpful discussions. Ms. Kawamura and Ms. Urano are thanked for her kindly helps for this visit. We hope that the international joint research at the Joint Usage of Research Centers for Applied Mechanics could continue to enhance China-Japan cooperation on fusion plasma research in the future.

My Co-Publications in 2019-2020:

[1] Y.K. Liu,…,K. Hanada, X. Gao, et al., Plasma Phys. Control. Fusion **62**(2020) 039501.

(Signature)____________________________________

(Name in print) Xiang Gao

No. 11

（様式 11・拠点）

19NU-5

日本語要約

1 月 29 日―2 月 5 日に九州大学応用力学研究所に来所し、QUEST で開催された第８回国際ワークショップに参加し、議論を行った。また、QUEST に設置されている軟 X 線カメラの性能や視野等について調査し、今後の研究の発展の可能性を検討した。議論を行った。QUEST の RF 加熱実験で得られている高βp 配位での平衡の限界について軟 X 線計測で議論することができないか議論を行い、今後の検討課題とした。

RESEARCH REPORT

Date: Feb. 12, 2020

Visiting scientists: (name) **Yinxian Jie**

(position) **Professor**

(university / institute) **Institute of Plasma Physics,**

Chinese Academy of Sciences

Host scientist: (name) **Kazuaki Hanada**

(position) **Professor**

(university / institute) **Kyushu University**

Research period: (from) **Jan. 29, 2020** (to) **Feb. 5, 2020**

Research subject: **Soft x-ray spectra in inboard poloidal field null (IPN) configuration and relevant physical research on QUEST**

This visiting started on Wednesday 29th Jan. 2020，ended on Wednesday 5th Feb. 2020. During this visit, QUEST did not start experiments of this campaign, Prof. Gao, Prof. Liu,Prof. Qian and I attended the 8th workshop , RIAM 2020 on 30th Jan. And 31th Jan. Prof. Gao gived a report “Non-inductive current drive experiment on EAST tokamak”. I read some papers about in inboard poloidal field null (IPN) configuration and Soft x-ray spectra on QUEST.

Soft x-ray spectra system is a very important diagnotic on tokamaks. It is one of the most widely used in measuring the palsma electron tempreture and MHD phenomenons. The whole system needs modification to get more detail date to get the position of IPN and relevant physical research on QUEST.

The mission of QUEST is to develop the scientific basis for achieving a steady state condition at sufficiently high beta (~20%), with high confinement and low collisionality. Operating Tokamak at a high poloidal beta value is usually attactive and this makes the spherical tokamak an interesting choice for future reactors.The maximum achievable βp, however, is limited by a so called equilibrium limit, where an inboard poloidal magnetic field null (IPN) appears at the high field side of the vacuum vessel.Inboard poloidal field null (IPN) configuration in a high Bp dischargin was reported first time on TFTR in 1991. In those discharge the evolution of the poloidal field measured at the midplane on the inboard side of the TFTR vacuum vessel was studied.As Ip was ramped down, and Bp increased, the midplane poloidal field decreased and eventually become negative, indicating that the separatrix had crossed the coil position and moved into the vacuum vessel. The separatrixlimited discharge was sustained until the end of the beam heating phase. In QUEST, such an IPN configuration is easily achieved under a high magnetic mirror ratio and high Bz/Bt values (≈10%) via electron cyclotron (EC) heating and current drive. A soft x-ray spectra system was set up on QUEST and got some primary date.The whole system needs modification to get more detail date to get the position of IPN on QUEST(Fig.1 and Fig.2).

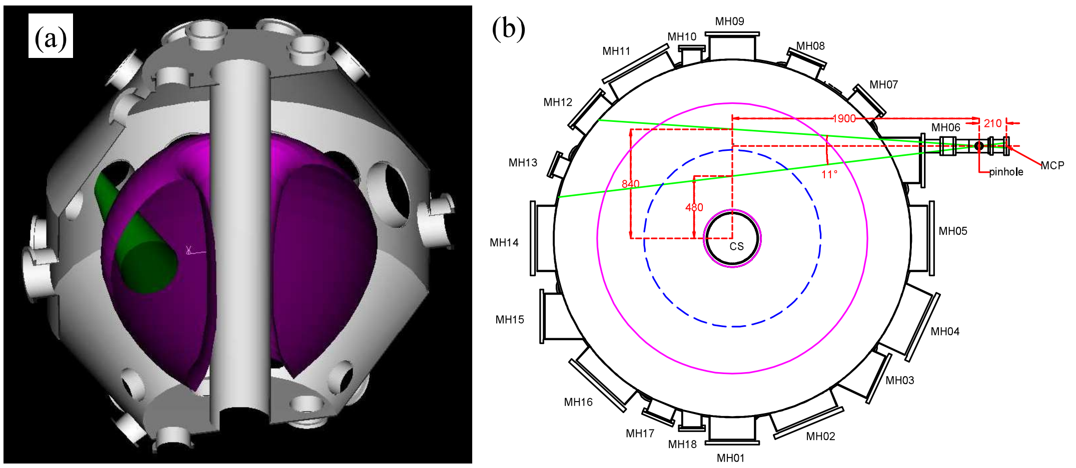

Figure 1. Schematic plot of field of view (shown in green color) of the tangential soft x-ray imaging system on QUEST. (a) 3-Dimensional modeling; (b) bird-view plot of relative location. The major radius of typical QUEST plasma is denoted by the blue dashed circle.

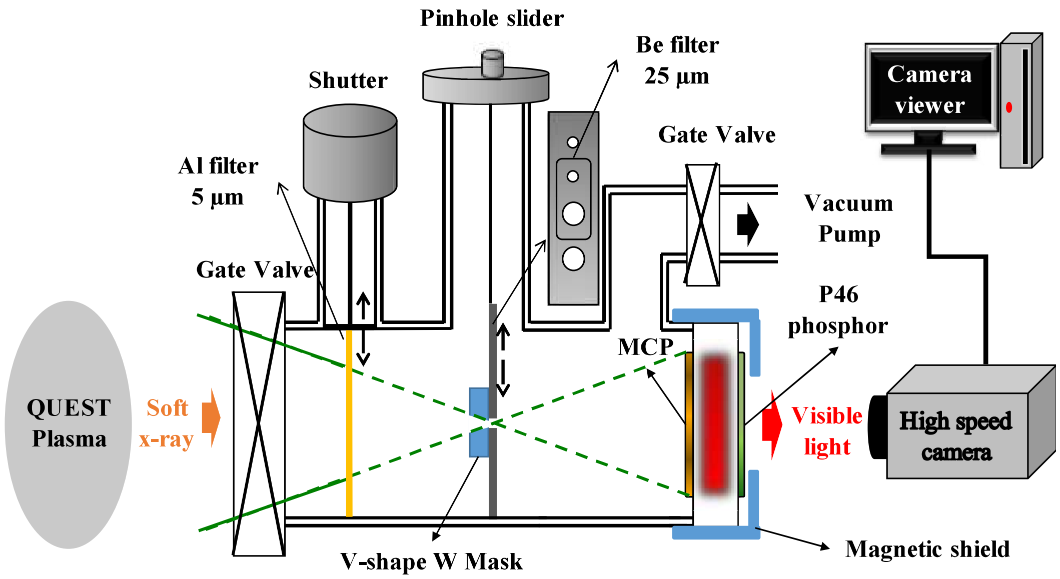

Figure 2. Schematic diagram of the soft x-ray imaging system on QUEST.

Acknowledgement and comments:

The Work supported by the international joint research at the Joint Usage of Research

Centers for Applied Mechanics for 2019. We would like to thank our host, Professor K. Hanada, who helps a lot during our staying at QUEST and very appreciate the useful discussions and comments. It is a good chance for us to join in study in the QUEST. Also QUEST staffs and students are thanked for their helpful discussions.

(Signature)____________________________________

(Name in print) Yinxian Jie

No. 12

（様式 11・拠点）

19NU-6

日本語要約

1 月 29 日—2 月 5 日に九州大学応用力学研究所に来所し、QUEST で開催された第８回国際ワークショップに参加し、議論を行った。高温プラズマの長時間維持は QUEST と EAST（中国科学院プラズマ物理研究所に設置された中国最大のトカマク装置）の共通の主要課題である。九州大学で開発された冷却水計測に基づく熱バランス計測に必要な機器は、すでに中国側の外部資金により EAST に設置され、結果についての論文が出版されている。国家公水平の枠組みで 2 年間 1 名の研究生が九州大学に滞在し、パワーバランスの計測法や解析法について指導を受け、その内容で中国科学技術大学にて学位を取得した。また、本研究課題にて実施された EAST に関する実験研究で４報の論文が submit され査読中である。また、QUEST 側の論文 1 報が受理されている。今後は QUEST で見出されている粒子バランスとパワーバランスの関係について研究を進めていくこととしている。

K. Hanada *et al* 2019 *Nucl. Fusion* **59** 076007

（様式 11・拠点）

RESEARCH REPORT

Date: Feb. 12, 2020

Visiting scientists: (name) **Haiqing LIU**

(position) **Professor**

(university / institute) **Institute of Plasma Physics,**

Chinese Academy of Sciences

Host scientist: (name) **Kazuaki Hanada**

(position) **Professor**

(university / institute) **Kyushu University**

Research period: (from) **Jan. 29, 2020** (to) **Feb. 05, 2020**

Research subject: Joint study of calorimetric measurement of heat load and power balance estimation in steady state operation (SSO) plasmas on QUEST and EAST

Introduction

Steady state operation (SSO) of magnetic fusion devices is one of the goals for fusion research. As it is predicted that an enormous heat flux (10MW/m2) is coming to the diverter (vertical heat target) locally from the plasma in the future fusion reactor, the heat load distrubution (power balance, particle balance) and its control should be investigated to realize future fusion power plants. Actually, control of contact point of PFCs to plasma has been applied in many long duration discharge devices such as TRIAM-1M, QUEST, EAST

and on which long duration discharges can be successfully obtained. However, the longest plasma is spontaneously terminated and the reason is still unclear. Plasma confinement degeneration during long-pulse discharge could be caused by increment of first wall temperature then boundary recycle enhance. In last year, EAST energy balance results obtained by calorimetry in long-pulse high-performance discharges provide the foundation for the long-pulse operation of ITER and CFETR. QUEST device, the temperature measurement has been done to measure water cooled movable limiters and other part PFCs. The heat load is mainly supplied from energetic electrons which are generated by injected RF electric field. Last year, fuel particle balance on all-metal plasma facing walls has been investigated on QUEST and it was indicated that plasma-facing wall temperature decided by plasma-induced power deposition and cooling capability has siginificant impact on particle balance. This means power balance is tightly connecting to particle balance in long duration discharges. In this year, the collaboration research focused on the power balance investigation in long pulse high performance discharge with ITER-like tungsten divertor on EAST and estimation of fuel particle balance in SSO with hydrogen barrier model on QUEST. This report based on our co-publications and discussions.
During this visit, I also participated in “the 8th international workshop for non-inductive plasma start-up” in Jan. 30-31. Prof. Gao give a presentation of “Non-inductive current drive experiments on EAST tokamak”, which introduced the recent results on steady state operation and non-inductive current drive experiments on EAST tokamak. Prof. Hanada give a presentation of “Recent results for steady state operation and plasma current start-up on QUEST”, which showed the recent results on SSO and plasma current start-up on QUEST. Many interesting talks were also presented in this workshop. I have some helpful discussions with the speakers.

Recent progress on QUEST and EAST

Recently, the fuel particle balance during long duration discharge was investigated in an all-metal plasma facing wall (PFW) through intensive QUEST execution. A simple wall model including the plasma-induced deposition layer that creates hydrogen (H) barriers, called the H barrier model, was established. A simple calculation, based on a combination of H state rate equations and the H barrier model, was applied to real plasma in the early phase of its longest discharge. The model accurately reconstructed the evolutions of electron density and wall-stored H over time, when the values to have difficulty determining experimentally are properly selected. Comparative calculations that used the H barrier and a fully reflective models, predicted significant impacts of wall models on the plasma density time response and value of electron density, indicating that a proper wall model should be developed for all-metal PFW devices. The water cooling of the hot wall was firstly operated and was working well to modify the wall temperature and H recycling, although significant unexpected outgas of argon and nitrogen took place. The calculation also applied to longer phase and it finds that unknown supply of fuel is necessary to be sustainable. This indicates the particle balance model assigned by the experimental data is

useful to understand and importance of developing an appropriate wall model for estimating particle balance.
On EAST, the joint research concentrates on demonstrating steady-state high-performance H-mode operations with ITER-like tungsten divertor. Calorimetry was applied to actively water-cool the plasma facing components (PFCs) by increasing the water temperature for power balance investigation. Considering the energy balance of EAST long-pulse high-performance discharges with upper single null (USN) configuration, thus far, approximately 78% of the injected energy could be accounted for. The method of estimation of heat flux on upper tungsten divertor target with a high time- and spatial-resolved infrared camera has been developed, and the sum of its heat load was found to be significantly consistent with that measured through calorimetry. The record longest steady-state H-mode plasma #73999 was sustained for up to 101.2 s with net injected energy exceeding ~0.25 GJ in the USN configuration. Heat load analysis of this discharge using calorimetric measurement indicates that the modification of heat load distribution was observed and this was induced by a slight change in the magnetic configuration. A significant part of the PFC-deposited energy was delivered by the energetic electrons with large poloidal orbits and their localized power gave rise to hot spots on PFCs. Not all temperature increments in the five cooling water modules reached the saturated state for the 100 s level discharge, which means that 100 s timescales are insufficient as compared to the thermal transport timescale in the targeted PFCs. The magnetic configuration, even with slight variations, and surface structure of the first wall strongly affect the heat load distribution during the long pulse discharges. It is important to mitigate or avoid the hot spots during long pulse discharge operation, because the hot spots lead to unusual local heat flux and subsequent impurity generation, which cause serious damages to the inner structure of PFCs and thus, cannot obtain longer H-mode discharge owing to the local material overheating. A method to quickly estimate the heat flux on tungsten divertor has been developed, and the heat load measured by calorimetry are consistent with that measured by the infrared camera. The divertor has a capability of withstanding 3.3 times the injected power of #73999, which is about 8.3 MW, and this estimation is expected to obtain better plasma with higher injected power in EAST. The split of heat load between the outer and inner divertor target is not near-balance with out: in ratio of ~2: 1 for the longest H-mode discharge.

Discussions

Recent investigation on fuel particle balance on all-metal plasma facing walls indicated that plasma-facing wall temperature decided by plasma-induced power deposition and cooling capability has siginificant impact on particle balance. This means power balance is tightly connecting to particle balance in long duration discharges. Heat load results obtained on EAST in long-pulse high-performance discharges provide the foundation for long-pulse steady-state operation of ITER and CFETR, and provide insights for blanket calorimetry to measure plasma reactivity in burning plasma experiments. In the next step, the lower

graphite divertor will be upgraded into ITER-like actively water cooling tungsten divertor for more effective power handling. Excellent power balance has not been implemented. Gradually narrowing this gap and assessing the uncertainties of contributing terms for power and energy balance will be the focus of future work.
Because measurement of heat load and researching of power balance in EAST and QUEST will provide crucial support for ITER experiments. This subproject was continued to be supported by the National Magnetic Confinement Fusion Program of China with Contract No. 2014GB106002 (Prof. Liu) in the next years. The joint study of QUEST and EAST will push this subproject forward in the next year.
Dr. Yukai LIU had already gotten his PHD degree in 2019 with joint-supervision by Prof. Hanada and Prof. Gao under this international joint research frame. In 2020, we will recommend a new student to apply doctor course in Kyushu university and continue to study the power balance (particle balance) estimation in steady state operation (SSO) plasmas on QUEST and EAST.

Acknowledgement and comments:

Work supported by the international joint research at the Joint Usage of Research Centers for Applied Mechanics for 2019. I would like to thank our host, Professor K. Hanada, who helps a lot during our staying at QUEST and very appreciate the useful discussions and comments. Also RIAM and QUEST staffs and students are thanked for their helpful discussions. Ms. Kawamura and Ms. Urano are thanked for her kindly helps for this visit. We hope that the international joint research at the Joint Usage of Research Centers for Applied Mechanics could continue to enhance China-Japan cooperation on fusion plasma research in the future.

My co-Publications in 2019-2020:

[1] Y.K. Liu,…,K. Hanada, X. Gao, H.Q.Liu et al., Plasma Phys. Control. Fusion **62**(2020) 039501.

My publications which had acknowledged to “the Collaborative Research Program of the Research Institute for Applied Mechanics, Kyushu University” in 2019-2020:

[1] S. X. Wang, H. Q. Liu* et al.,Phys. Plasmas, **26**(2019) 052515.
[2] H. Lian, H.Q.Liu*, et al., Review of scientific instruments, **90** (2019) 053501.

(Signature)________________________________
(Name in print) Haiqing Liu

No. 13

（様式 11・拠点）

19NU-7

日本語要約

1 月 29 日—2 月 5 日に九州大学応用力学研究所に来所し、QUEST で開催された第８回国際ワークショップに参加し、QUEST や EAST に関する平衡計算やそれに基づいた RF 伝搬、吸収に関する解析についての議論を行った。本研究で導入された平衡計算コード EFIT は世界標準の計算コードで、この計算結果に基づいて RF の伝搬や吸収を議論するための GENRAY（米国 PPPL との共同研究）を導入して QUEST の実験結果を議論している。近年、QUEST の平衡計算において計算結果が得られない問題が発生しており、QUEST 側が対応していたが、今回は QUEST で運用されている EFIT をダウンロードして中国側に持ち帰り、問題点をチェックすることとした。QUEST 実験を解析するための重要な計算コードなので、至急の対応が必要である。本研究に関連して QUEST から３報の論文が出版されている。

K. Hanada *et al* 2019 *Nucl. Fusion* **59** 076007

K. Hanada *et al* 2019 Nucl. Materials and Energy **19** pp544-549

H. Idei *et al* 2019 *Nucl. Fusion* **59** 126045

（様式 11・拠点）

RESEARCH REPORT

Date Feb. 20 2020

Visiting scientist: (name) **Jinping Qian**

(position) **Professor**

(university / institute) **Institute of Plasma Physics,**

Chinese Academy of Sciences

Host scientist: (name) **K. Hanada**

(position) **Professor**

(university / institute) **Kyushu University**

Research period: (from) **Jan. 29, 2020** (to) **Feb. 5, 2020**

Research subject: **Develop and improve EFIT code of the plasma equilibrium reconstruction for SSO operation and advanced physical study on QUEST**

The visiting started on Thursday Jan. 29 Feb. 2020, ended Feb. 5, total 4 working days. During this stay at QUEST building this year, I attended "the 8th international workshop for non-inductive plasma start-up" in Jan. 30-31. Prof. Gao gave a presentation of "Non-inductive current drive experiments on EAST tokamak" by introducing the recent results on steady state operation and non-inductive current drive experiments on EAST tokamak. Prof. Hanada gave a presentation of "Recent results for steady state operation and plasma current start-up on QUEST", which focused on the recent SSO and plasma current start-up on QUEST. Privately, we discussed with Prof. Hanada on the status of QUEST equilibrium reconstruction. In some cases, EFIT cannot well converged for with the error of finding plasma boundary. Since Hatem and other students were graduated in the last several years. In the coming 1-2 years, we will help train a Chinese student with the subject on QUEST equilibrium.

In the following 2 days, I have downloaded EFIT files from Linux server and uploaded all files to EAST data-sever. I spent one day and a half to compile the QUEST EFIT on EAST server. Next step, I will work together with the new student, let him familiar with QUEST device and help him run EFIT, which includes checking the connection of PF coils & power supply, update EFIT and EFUND, benchmarking all QUEST FLUX data. We will discuss how to optimize the fitting weights of flux loop data to make QUEST EFIT robust. Meanwhile, we will set up different version of EFIT for equilibrium reconstruction since QUEST has several power supply connections for different scenarios.

As a conclusion to this visit, we of the EAST experiment team warmly thank professor Hanada for welcoming us and showing us QUEST activities and very appreciate the useful discussion and comments between EAST and QUEST.

(Signature) J. Qian

(Name in print) Jinping Qian

国際化推進共同研究概要

No. 14

19NU-8

タ イ ト ル:　　Towards high mode purity in ECRH transmission and launchers fo ITER

研究代表者:　　CARSTEN, Lechite, Hanno

所内世話人:　　出射　浩

研究概要:

ITER に向けた準光学高速伝送路スイッチの開発の高電力試験を行うべく、昨年度、新たなスイッチング機構を欧州側で準備した。日本側は、機構組み込みのための装置改造をした。今年度、新たなスイッチング機構による高電力試験をQST 那珂核融合研究所にて行った。200 kW レベルの電力で、スイッチング素子内のアーキングを回避するために、用いる偏波面制御が必要であった。偏波面制御は、TRIAM-1M 装置で用いられていた偏波器を用いた。偏波器性能は、九州大学で低電力試験にて評価した。高電力試験では、アーキングを低減し、発振周波数のドリフトに応じたスイッチング性能を評価した。

Report of collaboration between RIAM and IGVP in FY2019: High-power tests of the MQIV diplexer for ITER with automatic tuning at QST

Mr. Dr. Carsten Lechte

The MQIV diplexer developed at IGVP is a fast switch, power combiner, and mode filter for 170 GHz using a Fabry-Perot resonator in a compact box design that is vacuum capable and can be directly interfaced with the 63.5 mm ITER ECRH waveguides which are available at QST. Our technical partners at TNO in the Netherlands have designed and built a fast mechanical tuning control unit for the device that is also vacuum-compatible. It uses feedback to fix the output power to either the resonant or the non-resonant output port, compensating for changes in the gyrotron frequency and mechanical expansion of the resonator. The activities of this year have concentrated on proving high-power compatibility and the calibration of the power monitoring sensors at the input and the two outputs of the diplexer.

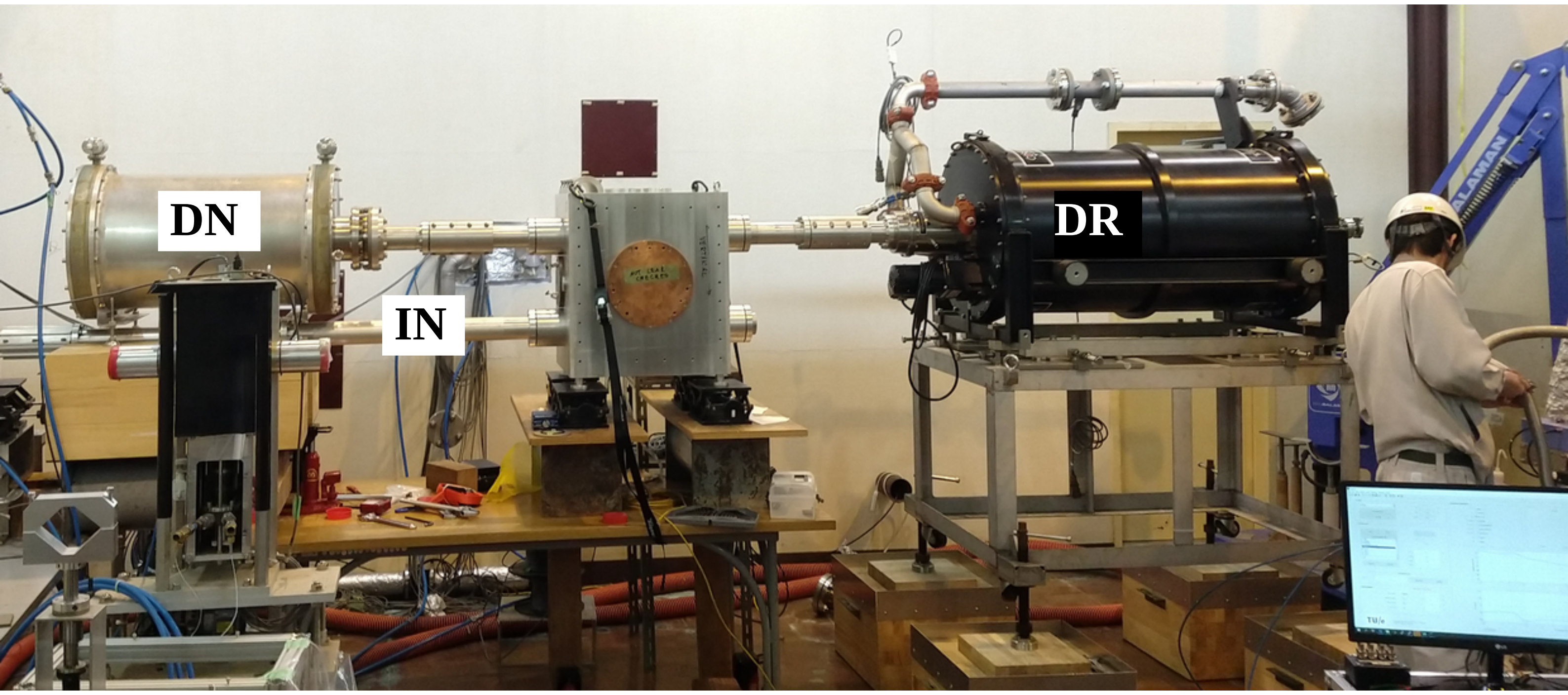

Fig 1: Diplexer integration into the gyrotron test stand at QST. DN and DR are the dummy loads at the non-resonant and the resonant channel, respectively, and IN is the input waveguide.

The tests were started with 10 ms pulses of 100-150 kW at 170 GHz. Occasional arcing was observed but the pulses were completed. The pulse length was then increased to 100 ms in the first week, and 300 ms in the second. The power in the input and the two outputs was monitored via diagnostic gratings on the matching mirrors, which divert a beam of -40 dB of incident power into horn antennas in the diplexer wall. After a vacuum seal and further attenuation, the signal is measured with diodes. This power measurement is not calibrated. It is also very susceptible to stray radiation, i.e. 1 % of stray radiation in the box can drown out the 0.01 % signal. This has only been evident during arcing events.

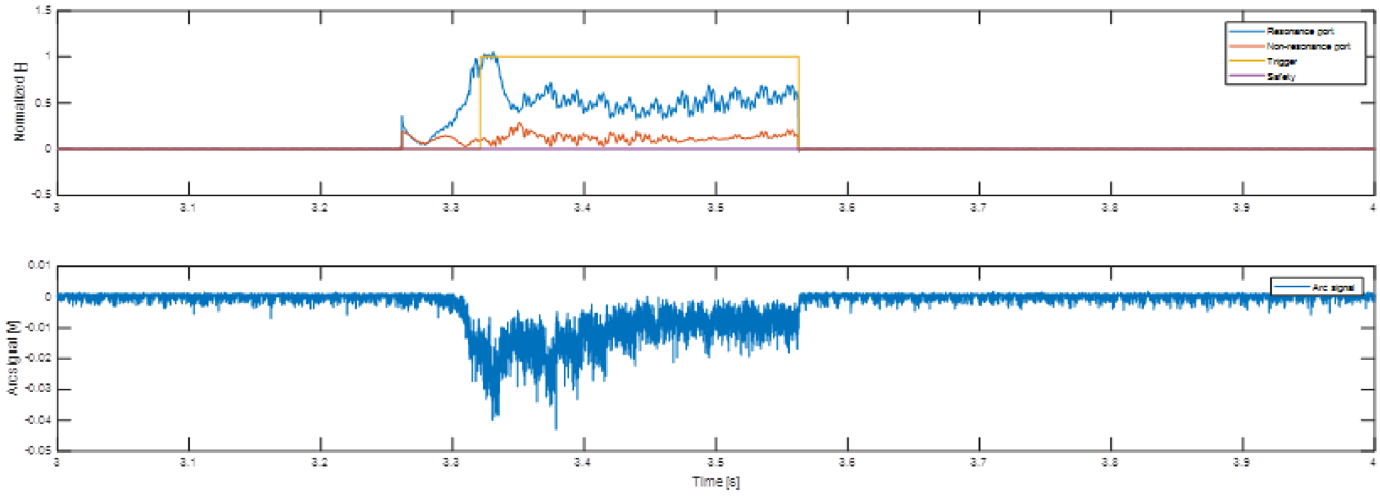

Fig 2: Demonstration of control. The upper graph shows resonant (blue) and non-resonant (red) output power. The lower graph shows arcing events.

The high power switching capability was demonstrated, see figure 2. The tuning mirror's position was controlled so that maximum power would come out of the resonant port. The control was not perfect, because of noise on the power monitor signals, and the continuous arcing activity, which was polluting the power signal. Nevertheless, a clear majority of the power is sent to the resonant output. Furthermore, the control system was able to tune the diplexer according to the changing frequency of the input, albeit the frequency chirp of the gyrotron was moderate in this scenario.

Fig. 3: View of arcs on coupling grating via the observation window.

The following problems were identified during testing: Arcing was happening continuously on the coupling gratings and probably also on the resonator mirrors. In full power operation, such events would necessitate the termination of the pulse, which would make the device unusable. In addition, the stray radiation caused by the arcs was degrading the control test results.
No higher power tests were possible because of the arcing and also because of the time contraints caused by attempts to control the arcing.

For the next test period, a number of mitigation techniques are planned: electropolishing of the problematic mirror surfaces to reduce the arcing, which may be caused by material defects in the surfaces, and the addition of stray radiation absorbers in the box. These will be made from metal plates with a resonant ceramic absorption coating for 170 GHz waves.

国際化推進共同研究概要

No. 15

19RE-1

タイトル: Development of III-Nitride optical devices: a materials perspective

研究代表者： GRZEGORY, IZABELLA, ALICJA

所内世話人： 寒川 義裕

研究概要：

アモノサーマル法およびハライド気相成長法＋アモノサーマル法のハイブリッド手法による窒化ガリウム（GaN）のバルク成長に関する現状を報告した。特に、アモノサーマル法における最近の GaN 成長速度、応力制御技術、純度について概観した。また、高品質バルク GaN 基板上に成長した長寿命レーザーダイオードとそのトンネル接合を含むデバイス構造の優位性について議論した。プラズマ・アシスト分子線エピタキシーを用いることにより水素フリーでの成長が可能となるため、Mg アクセプターの活性化熱処理が不要になるなどデバイス構造のチューニングにおいて優位性があることが示された。

[19RE-1] Development of III-Nitride optical devices: a materials perspective

Izabella Grzegory
Institute of High Pressure Physics Polish Academy of Sciences
Ul. Sokołowska 29/37, 01-142 Warsaw, Poland

The current status of bulk GaN crystallization by Ammono and hybrid HVPE/Ammono methods was reported. Extremely long living LDs and their vertical stacks including tunnel junctions grown by PA MBE was discussed.

GaN substrates with low dislocation density and flat crystallographic planes are highly desirable in III-N technology of both electronic and optoelectronic devices. In latter case dislocations are detrimental as non-radiative recombination centers but also as growth centers disturbing flat crystallization front especially in thick epitaxial structures necessary for vertical integration of LEDs and LDs.

In this joint research the current status of bulk GaN crystallization by basic ammonothermal (Ammono) and hybrid HVPE/Ammono methods was reported and discussed. In particular, recent progress in the growth rate, stress engineering and purity in the ammonothermal process was highlighted.

Very high quality substrates fabricated from the bulk GaN crystals were used for epitaxial growth of quantum structures of LDs and their vertical stacks containing tunnel junctions, by PA MBE. It was shown that extremely long lifetimes of the devices can be achieved due to the use of the near dislocation free GaN substrates.

The PA MBE is particularly useful for growing vertically integrated structures including tunnel p-n junctions since the method is hydrogen free and activation of Mg-acceptors is not necessary. Therefore, perfect 2-fold and 3-fold stacks of full LD structures could be grown straightforward. Corresponding devices will be characterized and their current and potential advantages was discussed.

No.16

国際化推進共同研究概要

19RE-2

タ イ ト ル:　Cold Crucible Czochralski (3C)

研究代表者:　ZAIDAT, Kader

所内世話人:　柿本　浩一

研 究 期 間:　2019 年　6　月　10　日　～　6　月　15　日

概　　要:　シリコン半導体の新規結晶成長法の実現に向けた提案に関して議論を行った。特に局所磁場の発生方法に関して定量的な議論を、数値計算結果を交えて議論した。その結果、従来不可能であった局所磁場の発生が可能であることを見つけた。

Project: Cold Crucible Czochralski

Acronym: 3CZ

Scientific partners: SiMaP France/ RIAM Japan

1) Summary of the visit in 2015 at Kyushu University by Dr K. Zaidat

The goal of the visit was to present the scientific context (bibliography) at the Pr Kakimoto's group in order to discuss on the possibility to decrease the contamination (oxygen and carbon) during the Czochralski (Cz) process.

The visit was very fruitful for the two groups, in fact the Dr Zaidat has presented his idea on the possibility to use cold crucible in order to avoid oxygen during the Cz process. After some presentations on the different relative work on the topic it appears:

That the cold crucible will be a good compromise to avoid the contamination but the difficulty will be to adapt the thermal insulation around the ingot in order to avoid the thermal stress induced by the crucible.

The fluid flow induced inside a cold crucible will be the key parameter to achieve a large ingot with this technic.

According to the Pr Kakimoto, the dislocation density should be decrease (comparing the classical technic) only if the level of carbide and oxygen will be decrease at the same level of the Floating zone.

In conclusion, it was really a pleasure for the two groups to discuss on this critical point especially on the carbide and oxygen contamination. The two groups hope to continue to collaborate on this topic in the future.

2) Summary of the visit in 2016 at Nagoya during the International Conference of Crystal Growth and Epitaxy-2016

After a first visit in 2015 (see resume before), it was identified to find a solution on the control of the fluid flow inside a cold crucible. The two teams have discussed during the ICCGE conference organised by the Pr Kakimoto in order to propose a solution of this technical point.

The SIMAP team will try to add a static magnetic field in order to damped the liquid and decrease the velocity induced by the cold crucible. A first 2D model must be develop in order to understand the interaction between a static magnetic field and the electromagnetic field induced by the cold crucible.

3) Summary of the visit in 2019 at Kyushu University by Kader Zaidat

This visit was the third visit on the same topic.

Pr K. Zaidat has presented the last results on the effect of the magnetic field induced by a Halbach configuration. A long discussion on the adaptation of this kind of structure was discussed for floating zone process.

Pr K. Zaidat has proposed and developed a new model for Halbach configuration study in order to include it in a global model of the Kakimoto's group.

No.17

国際化推進共同研究概要

19RE-3

タ イ ト ル:　Development of a Reliable Method for Dynamic Responses Prediction of Floating Wind Turbines

研究代表者:　HU, Zhiqiang

所内世話人:　胡　長洪

研究概要:

本国際化推進共同研究について今年度は 2 年目で，共同研究を予定通り実施した。特に、浮体式洋上風力発電システム用のセミサブ型浮体の動特性解析に関する機械学習の応用可能性について検討を行った。R2 年 1 月に応研で開催された国際研究集会「International RIAM Symposium on Novel Computational and Experimental Methods for Complicated Fluid-Structure Interactions」に出席し、「A Machine Learning based Software-In-the-Loop method to Predict and Monitor the global dynamic responses of floating wind turbine system」のタイトルで共同利用成果の発表を行い、参加者との研究交流を行った。

Report for 2019 RIAM International Joint Research Project

[19RE-3]

Development of a Reliable Method for Dynamic Responses Prediction of Floating Wind Turbines

Zhiqiang Hu
Marine, Offshore and Subsea Technology, School of Engineering, Newcastle University, UK

During year of 2019, fruitful collaborative works have been conducted between RIAM Kyushu University and Newcastle University. The outcomes are listed as below.

1) Attendance of RIAM International Symposium on Novel Computational and Experimental Methods for Complicated Fluid-Structure Interactions, at RIAM Kyushu University in Jan 2020.
2) Collaborations on the proposal and development of a novel method to use machine-learning technology with theoretical and experimental ways to predict dynamic responses of floating wind turbine. Zhiqiang Hu at Newcastle University has submitted a proposal to EPSRC UK for a funding application, and Professor Changhong Hu has kindly joined the application team. It is expected that EPSRC will make the decision in early 2020.
3) Based on the research in year 2019/20, a collaborative conference paper entitled 'Software-In-the-Loop Method to Predict the Global Dynamic Responses of Full-scale Floating Wind Turbines by Using Artificial Neural Network' has been published on the 11th International Workshop on Ship and Marine Hydrodynamics, at Hamburg Germany, September 22-25, 2019. The paper was presented by Mr. Peng Chen, a PhD student of Zhiqiang Hu at Newcastle University.

1. RIAM international symposium

An international symposium 'Novel Computational and Experimental Methods for Complicated Fluid-Structure Interactions' was successfully held at RIAM Kyushu University on 20-21st Jan 2020. Professor Zhiqiang Hu attended this symposium and made an academic presentation with topic on 'A Machine Learning based Software-In-the-Loop method to Predict and Monitor the global dynamic responses of floating wind turbine system'. This presentation introduced the latest research outcome of Zhiqiang Hu's research team at Newcastle University during year 2019. This research aims to propose a new method, which utilizes Software-in-the-Loop method with machine learning (Artificial Neural Network) approach for FOWT's dynamic responses prediction. With the attendance of this symposium, Zhiqiang Hu has made fruitful discussions with other scholars, and most of all, a fruitful discussion and future plan with professor Changhong Hu to continue and extend the collaborations in the field of artificial intelligence.

2. Collaborative research on AI technology for floating wind turbine

In the year of 2019, a collaborative research aiming to apply AI technology in the FOWT research was developed, based on the cooperation between Professor Changhong Hu at RIAM, Kyushu University and Professor Zhiqiang Hu at Newcastle University. This research will propose a novel method to solve the challenge of satisfying Fr. And Re. at the same time for FOWT. At the moment, this challenge is the obstacle to predict dynamic response of FOWT during the design stage, and wind industry has emphasized this as one of the critical challenges that must be overcome within the next few years. The collaborative research has led to an application to EPSRC UK, and Professor Changhong Hu has provided strong support for the proposal.

In addition, thanks for the support and collaboration in 2019, a collaborative conference paper submitted to the 11th International Workshop on Ship and Marine Hydrodynamics (IWSH2019), Hamburg, Germany. The paper is titled 'Software-In-the-Loop method to predict the global dynamic responses of prototype FOWTs by using Artificial Neural Network algorithm'. This paper has been presented on the ISWH2019.

In year 2020, the research on AI technology with FOWT will be conducted to a further step. This research includes three phases in terms of Numerical modeling, Experimental combination and Real time monitoring. In the first phase, a method combing machine learning (ANN) approach with an in-house programme *DARwind* is proposed. In the second phase, the programme is optimized through correlation analysis based on real-measurement data and basin model data. In last phase, A methodology will be established, including perfecting the scale relationship between the data of basin model test and that of full-scale measurement, the numerical simulation application in design and real-time monitoring, and the risk control in wind farm management. Professor Changhong Hu will continue do his contribution on the CFD calculation validation.

No.18

国際化推進共同研究概要

19RE-4

タ イ ト ル:　Novel computational and experimental approaches to the analysis of complicated fluid-structure interactions

研究代表者:　WAN, Decheng

所内世話人:　胡　長洪

研究概要:

２年間予定されている国際化推進共同研究「Novel computational and experimental approaches to the analysis of complicated fluid-structure interactions」の初年度で，共同研究・研究集会とも予定通り実施した。特に大規模風力発電所における風車間後流干渉を考慮した高精度 LES シミュレーションについて共同研究を実施し、関連の研究成果は５編の国際学会論文を投稿し採択された。R2 年 1 月 20 日～21 日に国際研究集会「International RIAM Symposium on Novel Computational and Experimental Methods for Complicated Fluid-Structure Interactions」が開催され、外国から 11 名、日本から約３０名の参加者があり、海洋再生可能エネルギー開発に重要な研究課題である流体・構造連成解析に関して有意義な国際研究集会となった。

Report for 2019 RIAM International Joint Research Project

[19RE-4]

Novel computational and experimental approaches to the analysis of complicated fluid-structure interactions

Decheng Wan
School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, China

1. Purpose

Marine renewable energy devices are usually installed in a sea area where severe environmental conditions have to be considered. On the other hand, cost control is strictly required for those devices in order to pass economic evaluations. Therefore for successful design of those devices, accurate numerical methods as well as efficient experimental methods are required to evaluate the hydro- and aerodynamic performance of these devices. This joint research project focuses on one of the most important fundamental fluid mechanics problems in marine renewable energy development, the fluid-structure interaction problem. Researchers, especially younger researchers, including but not limited to SJTU and RIAM, are invited to exchange their knowhow on development of computational and experimental tools for the purpose.

2. Research Plan

This joint research project is planned for two years. FY2019 is the first year of the project. The major research topic is the development of novel CFD and experimental methods for analysis of complicated fluid-structure interaction problems in ocean engineering and marine renewable energy developments. CFD codes which are developed in SJTU and RIAM will be compared to the experiments. In the end of 2019, as the main event of this international joint research project, International RIAM Symposium on Novel Computational and Experimental Methods for Complicated Fluid-Structure Interactions will been carried out. Researchers involved in this joint research project will present and discuss their research progresses.

The members involved in this collaborative research are shown in the following table.

Researcher’s Name	Name of University or Institute	Present Status or Grade (graduate students)	Researcher role
Decheng Wan	SJTU	Professor	Representative person (CFD)
Jianhua Wang	SJTU	Assistant Professor	Co-researcher (CFD)
Cheng Liu	SJTU	Associate Professor	Co-researcher (CFD)
Weiwen Zhao	SJTU	PhD student	Co-researcher (CFD)
Guanyu Zhang	SJTU	PhD student	Co-researcher (CFD)
Zheng Li	SJTU	PhD student	Co-researcher (CFD)
Cong Liu	SJTU	PhD student	Co-researcher (CFD)
Mohamed M. Kamra	RIAM	Research Fellow	Co-researcher (CFD)
Makoto Sueyoshi	RIAM	Assistant professor	Co-researcher (experiment)
Changhong Hu	RIAM	Professor	RIAM Attendant

3. Summary of Collaboration Research

In 2019, large-eddy simulations of complex wake flows around large wind farm in real wind environments have been carried. In order to improve the economic performance of wind power generation, the wind turbine is developing towards the direction of floating type and large scale. In the present work, the complex wake flows around large wind farm in real wind environments are investigated. A large eddy simulation and an actuator disk model are applied to simulate the wake field and aerodynamic loads of wind turbines in large wind turbine. The influence of inflow wind speed, surface roughness length and atmosphere boundary layer on the turbine aerodynamics and wake characteristics are discussed in detail. Moreover, the yaw-control optimization for large wind farm based on the particle swarm algorithm is evaluated by LES simulation.

International conference papers related to this joint research project in 2019 are listed as follows.

1) Hao Guo, Jianhua Wang, Decheng Wan, Changhong Hu, Benchmark Computations on Motion Responses and Bow Waves of the Ship in Regular Waves, Proceedings of the Twenty-ninth (2019) International Ocean and Polar Engineering Conference, Honolulu, Hawaii, USA, June 16-21, 2019, pp. 2871-2878
2) Xinwang Liu, Decheng Wan, Gang Chen, Changhong Hu, Wigley Hull Form Optimization with or without Bulbous Bow, Proceedings of the Twenty-ninth (2019) International Ocean and Polar Engineering Conference, Honolulu, Hawaii, USA, June 16-21, 2019, pp. 4486-4493
3) Xu Ning, Yang Huang, Decheng Wan, Changhong Hu, Numerical Study of Wake Interaction and its Effect on Wind Turbine Aerodynamics Based on Actuator Line Model, Proceedings of the Twenty-ninth (2019) International Ocean and Polar Engineering Conference, Honolulu, Hawaii, USA, June 16-21, 2019, pp. 483-490
4) Xu Ning, Decheng Wan, LES Study of Wake Meandering in Different Atmospheric Stabilities and Its Effects on Wind Turbine Aerodynamics, Sustainability, 2019, 11(24), 6939, https://doi.org/10.3390/su11246939
5) Ping Cheng, Yang Huang, Decheng Wan, A numerical model for fully coupled aero-hydrodynamic analysis of floating offshore wind turbine, Ocean Engineering, 2019, 173: 183–196

As a main event of this international joint research project, ‘International Symposium on Novel Computational and Experimental Methods for Complicated Fluid-Structure Interactions’ was held on January 20-21, 2020. On the symposium, overseas scholars are invited to present their recent researches on ocean renewable energy development.

The research budget provided for this international joint research has been used to support part of the travel expenses of the following 5 scholars to attend the symposium.

1. Decheng Wan, Professor, Shanghai Jiao Tong University, China
2. Weiwen Zhao, Assistant Professor, Shanghai Jiao Tong University, China
3. Yuan Zhuang, PhD Student, Shanghai Jiao Tong University, China
4. Ye Li, Professor, Shanghai Jiao Tong University, China
5. Zhiqiang Hu, Professor, Newcastle University, UK

The program of the symposium is as follows.

PROGRAM

Date: January 20-21, 2020

Place: Meeting Room at 2nd Floor, RIAM, Kyushu University

20 January (Monday)

13:00 - 13:10	Opening Address by Changhong Hu

Session 1 *Chair: Changhong Hu*

13:10 - 13:50	**Takayuki Aoki** (Tokyo Institute of Technology) *Invited Lecture* Weakly Compressible Flow Computations for Incompressible Two-phase flows and Fluid-Structure Interactions
13:50 - 14:20	**Mohamed Kamra** (Kyushu University) Development of Unstructured Mesh CFD Code for Fluid-Structure Interactions
14:20 - 14:50	**Weiwen Zhao,** Decheng Wan (Shanghai Jiao Tong University, China) Numerical Investigations of Vortex-Induced Vibration of Flexible Riser under Motions of Floating Platform
14:50 - 15:20	**Seiya Watanabe** (RIAM, Kyushu University)
	Large-scale FSI Simulations for Free-surface Flow Using Lattice Boltzmann Method with Adaptive Mesh Refinement

15:20 - 15:50	Coffee break

Session 2 *Chair: Decheng Wan*

15:50 - 16:30	**Young-Ho Lee** (Korea Maritime & Ocean University, Korea) *Invited Lecture* KMOU Offshore Energy Research Activities and KOREA Strategy on Floating Offshore Wind Development
16:30 - 17:00	**Yuan Zhuang**, Decheng Wan (Shanghai Jiao Tong University, China） Combined Solver HOS and naoe-FOAM-SJTU for Wave-Structure Interactions
17:00 - 17:30	**Takao Fukumoto** (Hiroshima University) Estimation of Hydrodynamic Forces by Integrating Unsteady-Pressure Distribution Measured with FBG Pressure Sensors
17:30 - 18:00	**Kurniawan Waskito**, Masashi Kashiwagi, Hidetsugu Iwashita, Munehiko Hinatsu (Osaka University) Prediction of Nonlinear Wave Loads Using Measured Pressure Distribution on Ship Hull
18:00 - 18:30	**Isshiki Hiroshi** (Institute of Numerical Analysis) Node Generation in Numerical Calculation by Stochastic Sampling – Application to Interpolation of a Function and Solution of Burgers Equation Using Collocation Method

18:00 - 20:00	Dinner Party

21 January (Tuesday)

Session 3 *Chair: Tomoaki Utsunomiya*

9:20 - 10:00	**Ye Li** (Shanghai Jiao Tong University, China) *Invited Lecture* Numerical and Experimental Investigation of Offshore Renewable Energy System
10:00 - 10:30	**Lin Yang,** Q.W. Ma and Kangping Liao (Harbin Engineering University, China) Coupled Aero-Elastic Analysis of a Wind Turbine System using CFD and Finite Element Method
10:30 - 11:00	**Zhiqiang Hu** (Newcastle University, UK) A Machine Learning based Software-In-the-Loop method to Predict and Monitor the global dynamic responses of floating wind turbine system
11:00 - 11:30	**Decheng Wan** (Shanghai Jiao Tong University, China) Large-Eddy Simulations of Complex Wake Flows around Large Wind Farm in Real Wind Environments
11:30 - 12:00	**Tarek Dief,** Mostafa Rushdi, Amr Halawa, Shigeo Yoshida (RIAM, Kyushu University) Hardware-in-the-Loop (HIL) and Experimental Results for the 7 kW Pumping Kite Power System

12:00 - 13:20	Lunch break

Session 4 *Chair: Yingyi Liu*

13:00 - 13:30	**Christopher Vogel** (Oxford University, UK) *Invited Lecture* Multi-Scale Fluid Dynamics in Offshore Renewable Energy
13:30 - 14:00	**Dezhi Ning** (Dalian University of Technology, China) Hydrodynamic Performance of a Dual-Chamber OWC Wave Energy Converter
14:00 - 14:30	**Guojian Chen** (Bureau Veritas Marine China Co., ltd) Windmill R&D progressing in BV
14:30 - 15:00	**Ying Gou** (Dalian University of Technology, China) Vertical Motion Response of a Submerged Body Induced by Internal Solitary Waves
15:00 - 15:30	**Guanghua He** (Harbin Institute of Technology, China) Study on a Wave Energy Converter with eight round Floats

15:30 - 15:40	Closing Address by Decheng Wan

国際化推進共同研究概要

No. 19

19RE-5

タ イ ト ル:　Downwind Turbine Technologies, Model Development and Verification

研究代表者:CHOKANI, Ndaona

所内世話人:吉田　茂雄

研究概要:

タワーの風下側にロータを配置するダウンウィンドロータは，今日の商業風車においてはほとんど見られない. しかし，ロータが若干下方に傾斜していること，タワーとのクリアランスが大きくなること，ヨー方向の空力安定性が優れていることから，複雑地形向け，将来の浮体式洋上風車ならびに超大型風車に適した技術として注目されている. しかし，これまでの風車はほとんどがタワーの風上側にロータを持つアップウィンド風車であり，ダウンウィンド風車の解析法や設計基準は十分ダウンウィンド風車に対応していないものがある. そのような状況に鑑み，本プロジェクトでは，解析モデルの開発を行う.

本研究では，ダウンウィンド風車のモデル開発・評価に関するワークショップを 2 回開催した. 実施した. 主な成果は以下のとおりである.

・空力弾性解析用の 2MW ベースラインモデルを開発した
・ロータ～タワーの干渉に関する各種モデルを開発した.
・暴風待機時のパッシブヨーの特性に関する解析条件を検討した.
・大型化に対するダウンウィンドロータの優位性を検討した.

Downwind Turbine Technologies, Model Development and Verification

Applicant: Ndaona Chokani, Senior Scientist, ETH Zurich
RIAM Attendant: Shigeo Yoshida, Professor

1. OUTLINE OF THE WORKSHOP

1.1 CENER, Pamplona, Spain

(1) Date: 2019/05/13(mon)-14(tue)
(2) Place: CENER (Pamplona, Spain)
(3) Participants:
(CENER) Antonio Ugarte OLARREAGA, Xabier MUNDUATE, Ivan MALLAFRE
(X1 Wind) Alex RAVENTOS, Rocio TORRES
(IWES) Elia DANIELE
(BWC) Sandy BUTTERFIELD
(NREL) Rick DAMIANI
(Hitachi) Yasuo OSONE, Kunihiko TOMIYASU, Soichiro KIYOKI, Nobuo NAMURA
(WEIT) Masataka OWADA
(KU RIAM) Shigeo YOSHIDA

1.2 Hitachi, Hitachinaka, Japan

(1) Date: 2019/10/23(tue)-24(wed)
(2) Place: Hitachi (Hitachinaka, Japan)
(3) Participants:
(NREL) Nick JOHNSON
(IWES) Elia DANIELE
(UTokyo) Atsushi YAMAGUCHI
(Hitachi) Yasuo OSONE, Kunihiko TOMIYASU, Soichiro KIYOKI, Nobuo NAMURA, Yusuke OTAKE, Takumi TADANO
(WEIT) Masataka OWADA
(KU RIAM) Shigeo YOSHIDA

1.3 Outlines of the Task

WP1) Model Development& Verification
- WP1-1) 2MW Baseline Turbine Model
- WP1-2) Tower Shadow
- WP1-3) Nacelle-Rotor Interaction
- WP1-4) Stability & Control
- WP1-5) Complex Terrain

WP2) Design and LCOE Assessment
- WP2-1) Blade Optimization for Downwind Turbines
- WP2-2) Scalability Benefits for Downwind Turbines

WP3 Recommended Practice
- WP3-1) Standards Evaluation for Downwind Turbines
- WP3-2) RP for Downwind Turbines

2. REPORTS

WP1-1) Baseline Model, UTokyo

Aeroelastic models of a 2MW baseline downwind turbine model were defined. Power coefficient to tip speed ratio is shown in Fig 1. The tower was designed to avoid resonace in the opration conditions as shown in Fig 2.

The Bladed and FAST models were delivered to the members to proceed the verification study in each research subject.

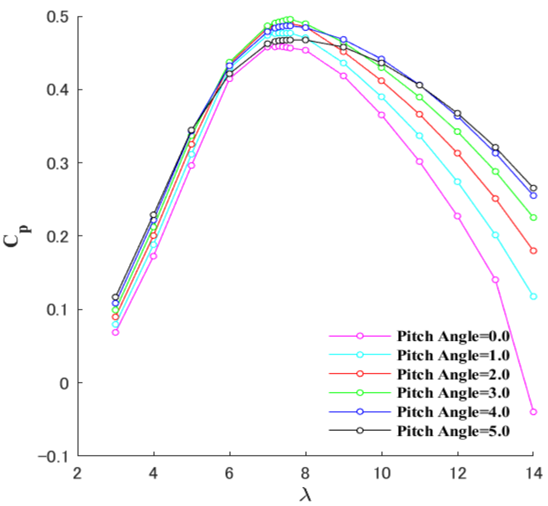

Fig 1 Power coefficient to tip speed ratio

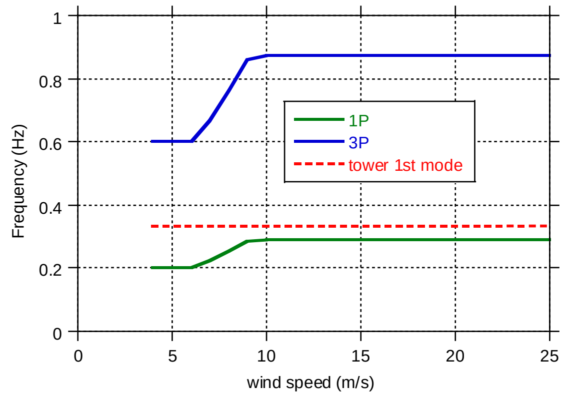

Fig 2 Excitation frequencies and tower 1-st mode bending frequency

WP1-2) Tower Shadow, KU

Some research results on tower shadow modeling of downwind turbines in Blade-Element and Momentum (BEM) method, which was not considered in the former methods were reported.

(1) Tower Variable Load [1]

The variable load model of downwind turbine tower, which was not considered in the previous model, is formulated as below, using lifting-line theory.

$$\Delta C_{dT} = \frac{\pi D_T}{2U_0^{\ 2}}\left(-U_0\frac{du}{dx_T} + r\Omega\frac{dv}{dx_T} - w\frac{dw}{dx_T}\right)$$

It was verified by the CFD of rotor-tower-nacelle configurations at rated and cut-out operating conditions. It shows fairly nice agreement with the CFD in particular out-board section and at low thrust conditions as shown in Fig 3. However, there still be some more room for improvement in inboard sections.

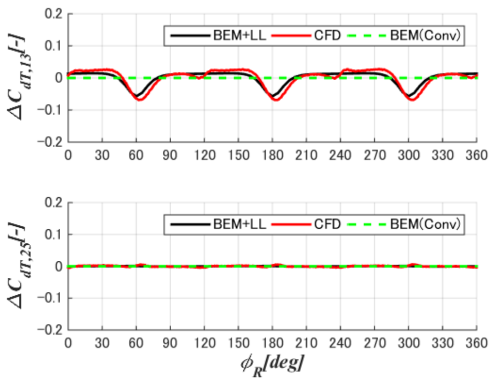

Fig 3 Variable loads of the downwind turbine tower at 100% rotor radius: (T) 13 m/s, (B) 25 m/s

(2) Tower Average Load [2]

And the average tower load model was also introduced based on the momentum theory, which consists with velocity and pressure gradient terms.

$$\begin{aligned}\Delta C_{dTV} &= \Delta C_{dTV} + \Delta C_{dTP} \\ &= -C_{dT0}\left(1-\mu_T^{\ 2}\right) + \frac{\pi}{2}\mu_T\frac{d\mu_T}{d\xi_T}\end{aligned}$$

The model was validated by the wind tunnel test. It shows good agreement with the wind tunnel test data as shown in Fig 4.

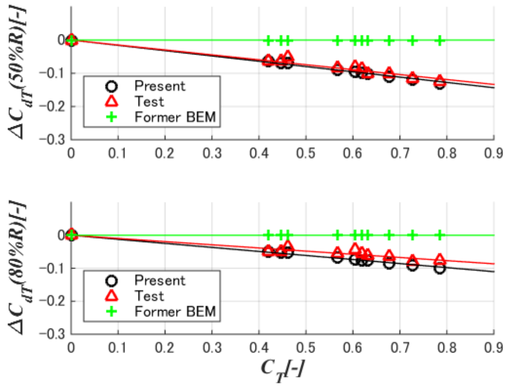

Fig 4 Rotor thrust to tower drag: (T) 13m/s, (B) 25 m/s

(3) Dynamic Blade Load [3]

The dynamic blade load model was reported. This model was developed based on the former study of Munduate [4]. Two points were modified from the reference; 1) application of Moriarty's tower wake model [5] and 2) wake entrance condition. エラー! スイッチの指定が正しくありません。 shows the analysis and experiment results on a 1 m diameter model. Where, UG indicates University Glasgow's former model and KU does present model. The present model was successfully shown the increase in load before the wake entrance was modeled better than the previous work.

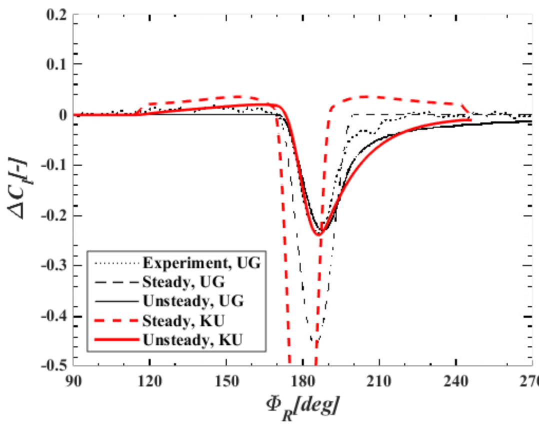

Fig 5 Blade section (75% rotor radius) lift coefficient to rotor azimuth, UG model

The scale effects of the model were investigated. Fig 6 is the simulation results for the similar models. The top, middle and bottom subplots are analysis results with x1 model (1 m rotor diameter), x3 (3 m), and x10 (10m), respectively. Here the tip speeds are set to be identical. As shown in these figures, the variation of the lift coefficients are decreasing as the scale getting larger.

エラー! 参照元が見つかりません。 is the

anlysis results for the 2 MW baseline model. The top and bottom subplots are at 13 m/s and 25 m/s respectively. The tower shadow effects are still large as compared with the previous figure as the tower diameter is large and the clearance between the rotor and the tower is smaller in the realistic turbine.

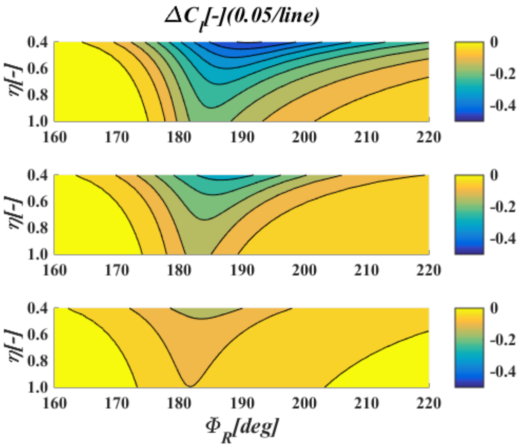

Fig 6 Blade section lift coefficient to rotor azimuth: scale (T) x1, (M) x3, (B) x10, KU model

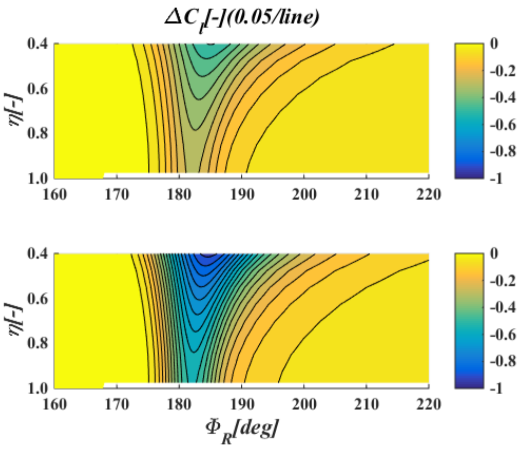

Fig 7 Blade section lift (75% rotor radius) coefficient to rotor azimuth of 2MW DT: (T) 13 ms/, (B) 25 m/s

(4) Influence of Karman Vortex [6]

CFD results for a 0.7 m test model are shown in Fig 8. The top, middle and bottom subplots are those at 60 deg, 180 deg, and 300 deg of rotor azimuth angles, at 75% rotor radius. The blade passes through the vortex at 60 deg and 300 deg, whereas, between vortex at 180 deg of rotor azimuth angles.

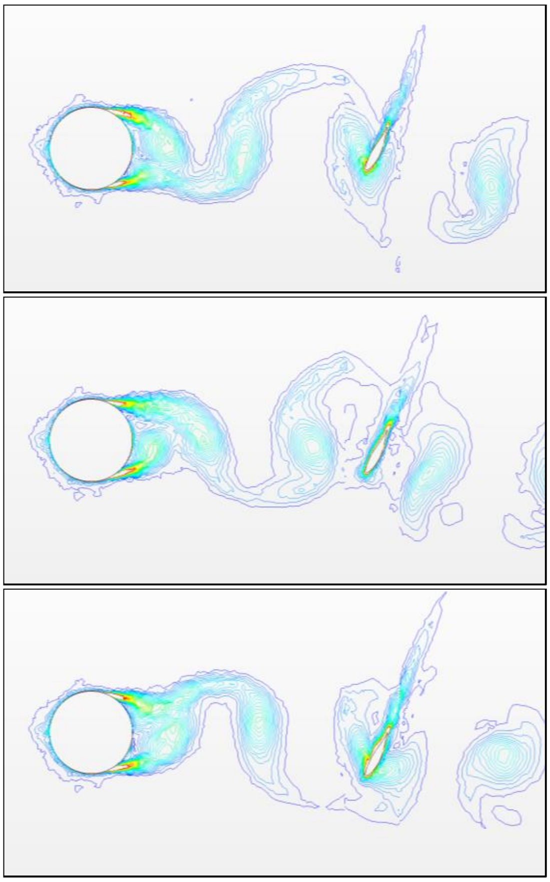

Fig 8 Flow around the tower and the blade (75% rotor radius): azimuth at (T) 60 deg, (M) 180 deg, (B) 300 deg, at 13 m/s

Rotor thrust and torque on 75% radius are shown in Fig 9 and Fig 10. The load fluctuations appear as one of the blades approaches to the tower. Furthermore, the amplitudes are strongly correspondent with the interaction with the vortex behind the tower; the fluctuation tends to be large when the blade passes through the vertex.

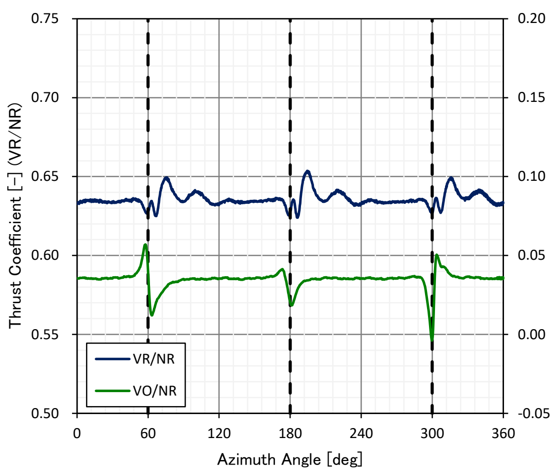

Fig 9 Rotor thrust coefficient (75% rotor radius) to rotor azimuth: (VR) 13 m/s, (VO) 25 m/s

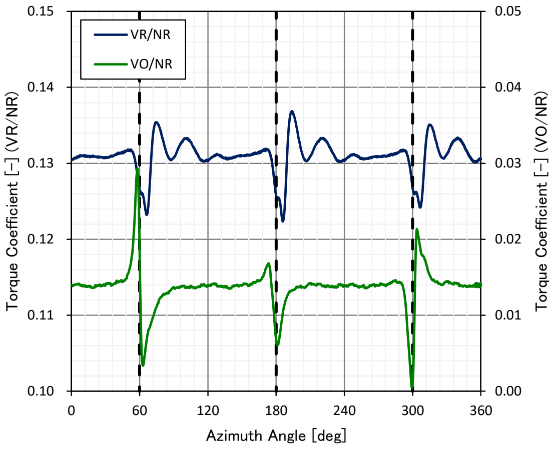

Fig 10 Rotor torque coefficient (75% rotor radius) to rotor azimuth: (VR) 13 m/s, (VO) 25 m/s

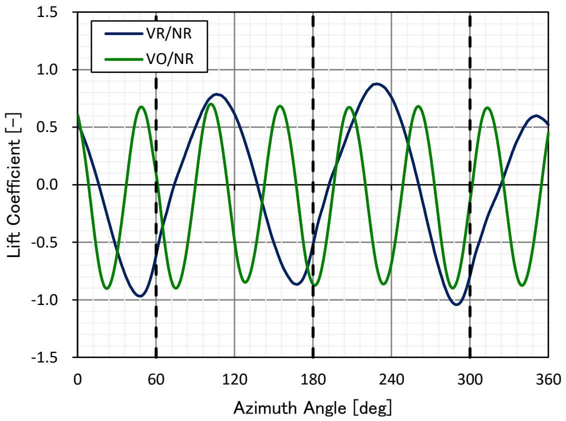

Fig 11 Tower lift coefficient (75% rotor radius) to rotor azimuth: (VR) 13 m/s, (VO) 25 m/s

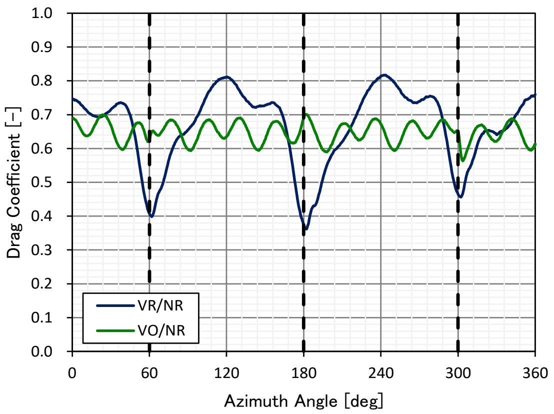

Fig 12 Tower drag coefficient (75% rotor radius) to rotor azimuth: (VR) 13 m/s, (VO) 25 m/s

Tower lift coefficient at 75% rotor radius is shown in Fig 11. It shows the Karman vortex is dominant for the lift unlike the rotor loads. The wind speed around the tower decreases in 13 m/s (rated wind speed) as rotor thrust is larger than at 25 m/s. These differences affect the frequency of the lift.

Tower drag coefficient is shown in エラー! 参照元が見つかりません。. it consists of two components; interaction by blade and Karman vortices. The former is still dominant in 13 m/s, as the thrust is large, but, the component almost disappears in 25 m/s when thrust is almost zero.

WP1-2) Tower Shadow, IWES

Fluid-structure interaction analysis for DTs with tubular and truss towers (square cross section) were reported. The truss tower, which was expressed by rectangular columns, showed larger wind speed dissipation behind the tower as shown in Fig 1. It also shows larger load fluctuation the one of the blades pass through the wake of the tower. It also shows, the excitation in the twist of blade adversely affects the load fluctuation as shown in エラー! 参照元が見つかりません。. This results is different from the next section. The cross section of the truss tower affects the result drastically.

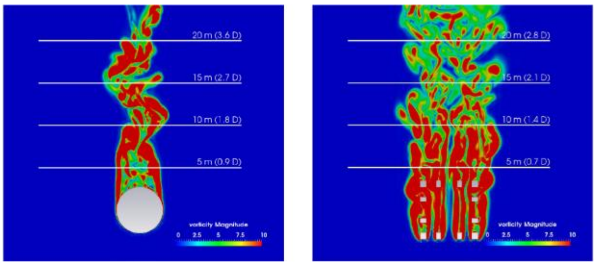

Fig 1 Wakes behind the tubular and truss towers

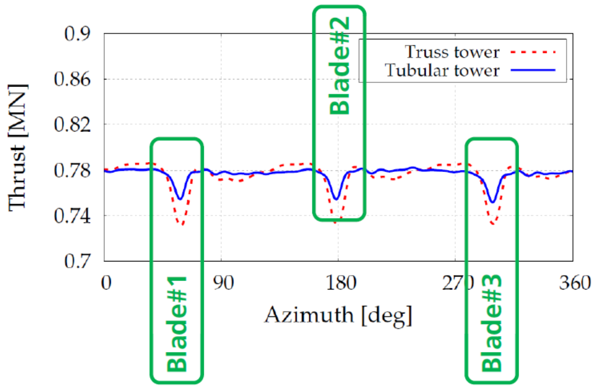

Fig 13 Thrust fluctuation by the towers

WP1-2) Tower Shadow, X1 Wind

The concept of X1 Wind was introduced. CFD was conducted for the monopole and the truss structure (cylindrical cross section). The wake of the truss shows much smaller wake as compared with the tubular tower in both of downwind and upwind rotor (Fig 14, Fig 15). It indicates the truss tower can be effective to reduce the impact loads on blades.

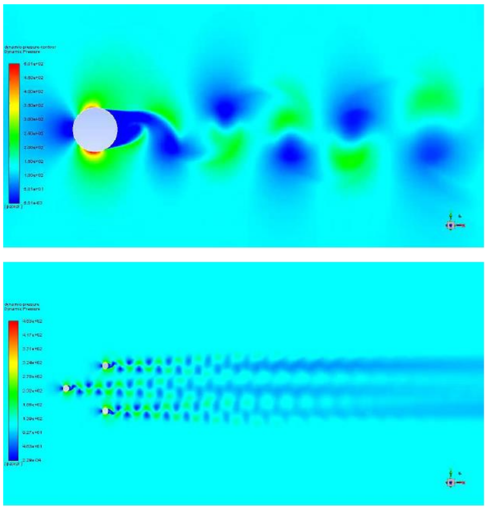

Fig 14 CFD behind a tubular and a truss towers

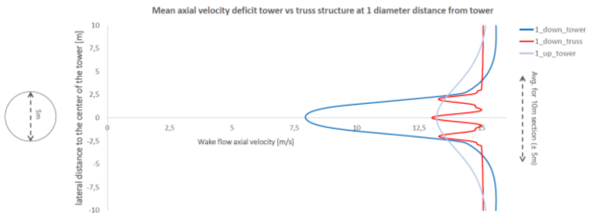

Fig 15 Wind speed distribution behind the towers

WP1-4) Stability, Hitachi [7][8]

The extreme loads of a 5.2 MW DT in parked condition in Typhoon #21 in 2017 were simulated. Yaw angles by the measurement and the analysis are shown in Fig 16. Blade root flapwise bending moment are shown in Fig 17. The results are consistent with the measurement.

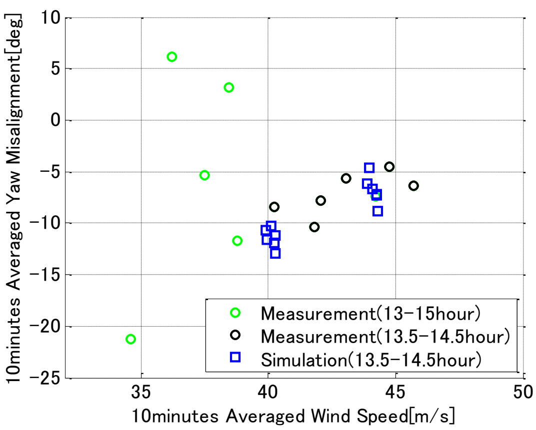

Fig 16 Yaw misalignment to wind speed

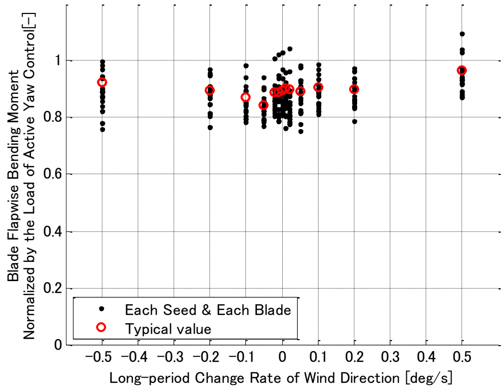

Fig 17 Blade root flapwise bending to wind direction change rate

WP1-5) Complex Terrain, CENER

Outlines of the NEWA-ALEX17 project was introduced by CENER. The test site is shown in Fig 18.

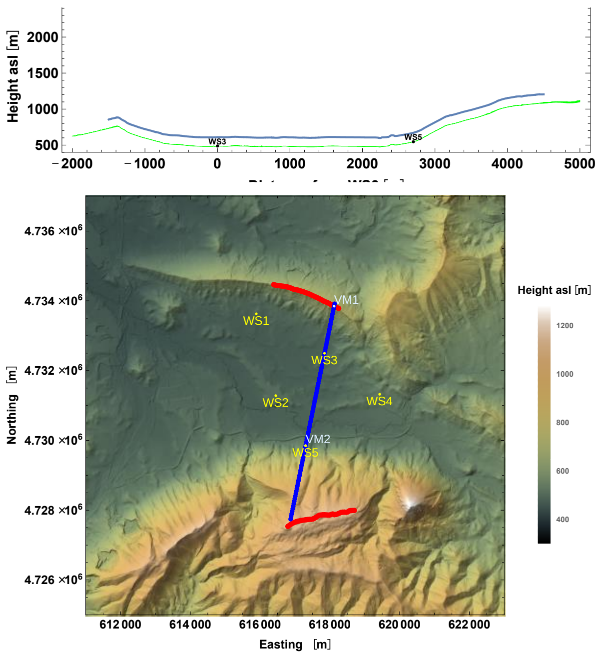

Fig 18 Test site for ALEX17

WP2-1) Blade Optimization, NREL

Baseline 10MW rotor was created in WISDEM/RotorSE.

WP2-2) Blade Optimization, Hitachi

Fatigue calculation and tower shadow model were introduced in this research. Natural frequencies in flap-wise and edgewise are the output of the optimization. Design variables are not optimized for pre-bent blades as present cost is not considered. Less than 5m is recommended due to the manufacturing and transportation. The tower shadow model is too pessimistic. Therefore, the advantage of downwind turbines is underestimation.

WP2-1) Blade Optimization, CENER

The CENER airfoil family was introduced. It was designed for high Reynolds number at high lift coefficient as shown in Fig 19. And it is also designed for insensitivity roughness. It is effective to maintain efficiency, reduce rotor speed at the same AEP level, chord reduction for a slender blade (Fig 20).

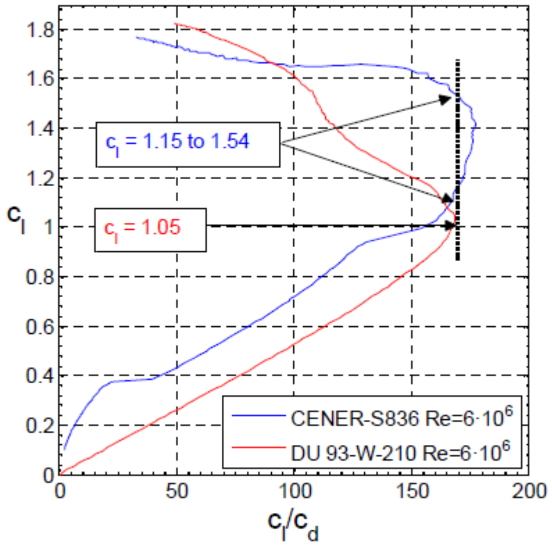

Fig 19 Lift to drag coefficients of DU-W-210 and CENER S836 airfoils

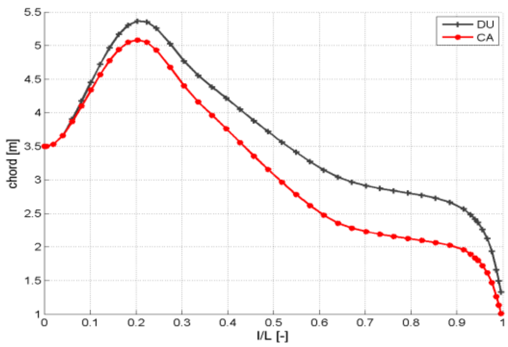

Fig 20 Optimal blade chord length distribution using DU and CENER airfoils

WP2-2 Scalability Benefits, NREL

The scalability benefits of downwind rotor will be demonstrated. The approaches are as below.

- 2MW DWT LCOE Input data
- CAPEX: ORCA, regional cost analyzer
- O&M Cost: ECN’s Offshore O&M Tool

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国際化推進共同研究概要

No. 20

19RE-6

タ イ ト ル:　Coupled aerodynamic and floating platform dynamics

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研究概要:　近海の風力資源が豊富と考えられ、洋上浮体式風車が最適な選択肢。レイノルズ数とフルード数が同じ速度でスケーリングしないため、時間領域の数値法がこの連成問題に非常に適当と考えます。いくつかの適切な修正を加えた翼素運動量理論は、風車の空気力学に最も効果的です。ただし、ピッチ運動をする浮体式風車では、個々のブレードに対し、ピッチ制御が必要と思われ、非定常流れを考慮する必要があります。Vogel と Liu の専門知識を組み合わせて、風車とプラットフォーム間の結合に関するさらなる研究、それらの相互効果および代替の風車制御を検討する予定です。

Floating wind turbines are attractive considering the wind resources in the ocean far offshore. Due to that the Reynolds number and the Froude number do not scale at the same rate, a time-domain numerical method may be much suitable for the coupled problem. The Blade Element Momentum Theory with some appropriate modifications are effective for the wind turbine aerodynamics. However, unsteady inflow needs to be considered for a pitching floating wind turbine for which an individual blade pitch controller may be therefore necessary. Combining the expertise of Vogel and Liu, further work on coupling between wind turbine and platform, their mutual effects and alternative turbine controllers is going to be considered in the future.

Introduction

Cost of installation and the drive to deployment in deeper waters are two of the key factors that are leading to the development of floating offshore wind turbines. A similar process has been occurring in tidal stream energy, where deploying turbines from a floating platform offers improved access for maintenance as the technology develops. The coupled platform motion and turbine dynamics in both cases make this a challenging problem to address, as turbine loads are affected by platform motion and vice versa (van der Veen et al. 2012). It is necessary to resort to analytical or numerical techniques to investigate these problems, as the key non-dimensional parameters for coupled turbine-platform motion, the Reynolds number and the Froude number, do not scale at the same rate. However, analytical and numerical models also have limitations which must be appreciated for the coupled problem.

Although solving floating body problems can be conveniently considered in a frequency domain analysis, only the simplest turbine representations may be investigated through this approach. Real turbines operate in a complex way in response to the prevailing wind, and the additional effect of platform motion on turbine performance is non-linear. Hence, time domain methods are more suitable for investigating coupled turbine-platform dynamics, although appropriate parametrisation of added mass and damping effects is still required.

Methodology

Blade element momentum theory has been widely applied to wind turbine problems as an approach that couples the leading order two-dimensional aerofoil aerodynamics with the overall changes in momentum in the fluid due to the thrust of the turbine. Correction factors are applied in the blade root and tip regions in order to account for departures from the simplified theory. Modifications to the theory are also available to account for the blocked flow environment encountered by tidal stream turbines (Vogel et al. 2018).

The effects of unsteady inflow on blade loading, and consequences for the design and operation of an axial flow turbine are described below.

Results

Below rated flow speed, wind and tidal stream turbines are typically designed to operate at a condition that maximises efficiency corresponding to the largest lift-to-drag ratio (achieved at angle of attack $\alpha*$). Above rated flow speed turbine performance is adjusted to limit power as required. As shown in Fig 1, a change in the inflow conditions (here the rotational speed of the turbine is held constant) results in a change in the magnitude and direction of the incident flow vector at the aerofoil section. As the turbine's tip-speed-ratio is generally between 6–10, the impact of the changes in the magnitude of the flow vector is less significant than that of the changes in the angle of attack. Although only a few degrees, this may significantly affect turbine performance as the turbine may approach, or even go into stall, when the apparent flow speed increases.

The turbines typically respond to changes in incident flow by altering rotational speed or blade pitch angle in order to return to the optimal operating condition (Wu et al. 2018). Changes to rotational speed may be achieved faster than changes in blade pitch angle, whereas the response time of blade pitch adjustments is slower. However, the change in flow experienced by each blade is unlikely to be the same for a pitching floating wind or tidal turbine due to the different positions of the blades, so collective-control (turbine speed or collective pitch control) applied to the whole rotor will not restore the performance of the turbine. Instead, individual blade pitch is likely to be a better solution. Furthermore, individual blade pitch control offers the potential to adjust blade operation as the turbine rotates through a vertical shear profile.

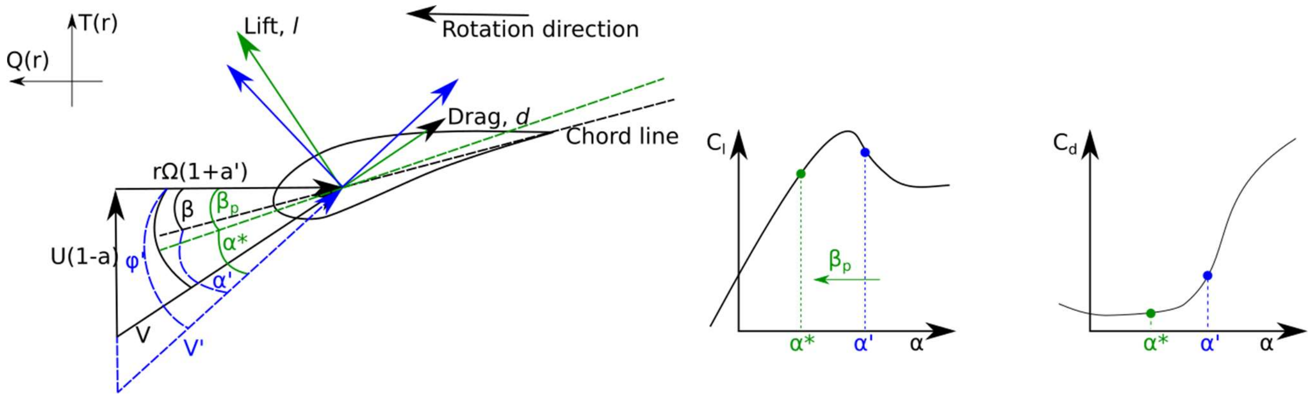

Fig 1: Aerofoil section (left) indicating blade forces and inflow velocity change due to a change in incident flow (shown in blue) and the required blade pitch adjustment (green) to return to optimal operation.

Further work is required to couple turbine performance to platform dynamics in order to explore the feedback that the change in wind turbine operation has on platform motion and loads, and also to investigate whether alternative forms of turbine control compared to fixed-foundation turbines may be helpful for mitigating the unsteady effects on floating wind turbines. This will draw on the experience of Vogel's work in aerodynamics of wind turbines, including the development of wind turbine wakes and subsequent impact on downstream turbines (Vogel & Willden 2020) and Liu's experience in floating body dynamics and floating wind turbines.

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