国際化推進共同研究概要

NO.1

18EA-1

タ イ ト ル:　Improvements to GPM/TRMM/CloudSat/EarthCare Ice Water Content and Snowfall Rate Algorithms and Results

研究代表者:　HEYMSFIELD, Andrew, Joel

所内世話人:　岡本　創

研究概要:

全球降水観測計画（GPM 計画）の主衛星に搭載されている Ku バンドと Ka バンドの二周波降水レーダ(DPR)、熱帯降雨観測計画(TRMM 計画)に搭載された降雨レーダ(PR)、CloudSat 衛星に搭載された 94GHz 雲レーダ(W バンド)、2021 年度に打ち上げ予定の日欧共同衛星計画 EarthCARE に搭載予定の 94GHz ドップラー雲レーダを想定し、これらの観測データに相当する航空搭載の W, Ka,Ku バンドレーダによって得られたデータを用いて、上記衛星に適用可能な氷雲と降雪の解析アルゴリズムの検証を試みた。

18EA-1：Improvements to GPM/TRMM/CloudSat/EarthCare Ice Water Content and Snowfall Rate Algorithms and Results

Dr. Andrew Joel Heymsfield, University Corporation for Atmospheric Research/National Center for Atmospheric Research.

The synergy of cloud radar with lidar to retrieve the vertical microphysical is described in a paper by Okamoto et al. 2000, 2003, Delanoe and Hogan in 2008, Deng et al., 2010, Okamoto et al., 2010, Sato and Okamoto 2011. In the ice/snow retrieval, an important source of error is linked to errors associated with the assumed or retrieved ice particle size distribution (PSD), and in the ice particle mass-size relationship. PSDs in ice clouds are highly variable, but can be estimated with better fidelity than earlier studies using the air temperature and cloud formation mechanism as constraints. The mass-size relation can be estimated from airborne probes that measure the ice water content (IWC) directly. However, these data have not been adequately incorporated into the retrieval algorithms. The typical assumption is that the mass-size relationship follows the “Brown and Francis” mass size relationship, which has been shown in recent studies to have the potential to lead to appreciable error in the retrieved ice water content. Furthermore, and of in need of significant updating/evaluation, is the assumed particle radar backscatter cross-sections. A particular particle shape must be assumed for most of the models, but it has been shown that most ice/snow particles are irregularly shaped. Given the uncertainties above and the virtual absence of direct in-situ measurements combined with multi-wavelength radar data to assess these uncertainties, a direct means of both evaluating and improving the retrieval algorithms is needed.

We first analyzed backscattering coefficient estimated by the discrete dipole approximation (DDA) at W and Ka band and estimate dual frequency ratio (DFR: or often called dual wavelength ratio; DWR). The DDA results showed that the DWR values strongly depends on the particle shape, orientation and phase.

The most direct method to improve ice water content retrieval is to use PSD measurements from in-cloud aircraft probes to measure IWC and to estimate the snowfall rate, and then to relate these to radar measurements at Ku, Ka, and W bands from an above-cloud research aircraft when the in-cloud and over-flying aircraft are nearly collocated spatially and temporally. With this method, we propose to use data from the GPM-funded Cold Season Precipitation Experiment (GCPEX) in 2012 and the 2015 Olympic Mountain Experiment (OLYMPEX) field programs.

The primary collocation dataset is from the OLYMPEX field campaign conducted in the vicinity of the Olympic Peninsula in Washington state. During OLYMPEX, the University of North Dakota (UND) Cessna Citation flew 20 missions, spanning the in-cloud temperature range of –32° to 9°C. On board the Citation, the microphysical datasets—PSD and particle shape (habit) information—were acquired from three instruments. Doppler radar measurements are available for many thousands of collocations from this field experiment.

The in-situ dataset was complemented by overflights from the NASA DC-8 aircraft, containing the Third Generation Airborne Precipitation Radar (APR-3), a triple-frequency (Ku, Ka, and W bands, 13, 35, and 94 GHz, respectively) Doppler, dual-polarization radar system, downward pointing.

The second dataset, GCPEX, was collected over and near the Ontario, Canada, Environment Canada Centre for Atmospheric Research Experiments (CARE) site in January-February 2012. The data set collected is similar.

We modified cloud particles algorithm used to discriminate ice and snow particles from bins containing hydrometeor particles for CloudSat data for the analysis of data obtained by the airborne W band radar. The algorithm is based on radar reflectivity factor and temperature. It is found that the rain or snow detected regions by the algorithm showed good consistency with the results obtained by airborne-Ku and Ka band radar. Using these unprecedented data sets, we plan to use the collocated data sets to evaluate the current EarthCare retrieval algorithms and to improve them.

国際化推進共同研究概要

NO.2

18EA-2

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

研究概要:

今年度の国際化推進共同研究「Turbulent mixing in the Kuroshio Current off Taiwan」に関して、共同研究・研究集会ともに計画通り実施した。共同研究の成果については、国際誌への投稿論文 5 編を執筆中で、国際学会では 3 件の発表があった。研究集会には、外国から 5 名、日本から 10 名の参加者があり、これまであまり注目されることのなかった、黒潮が海山を乗り越えることで生じる強い乱流混合研究の端緒として、有意義な国際研究集会となった。Discussion session では、次年度もこの共同研究を続けていくことで合意し、具体的な計画について議論がなされた。

Report on 2018 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.

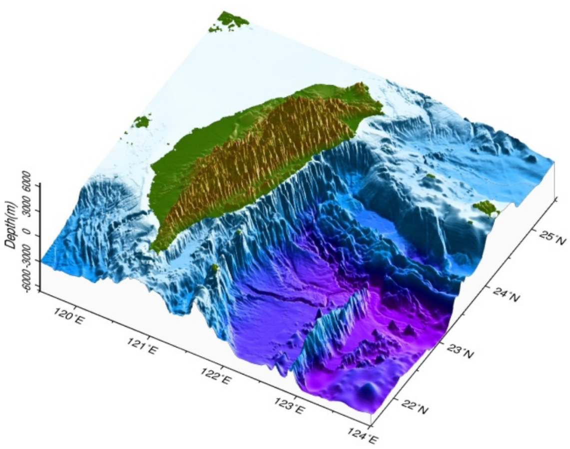


Figure 1. Bird's-eye view of bathymetry around the I-Lan Ridge. The Kuroshio current flows over the ridge to enter the East China Sea.

Research Plan

(1) Carry out the field experiment over the I-Lan Ridge in May using two R/Vs, Ocean Researcher I and II (OR1 and OR2).
- Researchers of RIAM join the OR1 cruise to deploy their microstructure profiler, TurboMAP.
- Researchers of National Taiwan University (NTU) deploy moorings and our microstructure profiler, VMP-500, using OR2.

(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
- GUO, Xinyu (Ehime University, Professor): Numerical modelling
- MATSUNO, Takeshi (RIAM, 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 (RIAM, Postdoctoral Fellow): Analysis of the TurboMAP data

Summary of collaborative research

(1) Field experiment

The field experiment was carried out over the I-Lan Ridge off Taiwan using two R/Vs, Ocean Researcher I and II (OR1 and OR2) on May 14-17 and May 11-15, 2018, respectively. Using OR2, we deployed four moorings (Figure 2) and carried out the microstructure measurements with our microstructure profiler, VMP-500. The RIAM researchers joined the OR1 cruise to carry out the microstructure measurements simultaneously (Figure 3) with their microstructure profiler, TurboMAP, and then recovered the moorings deployed by OR2.

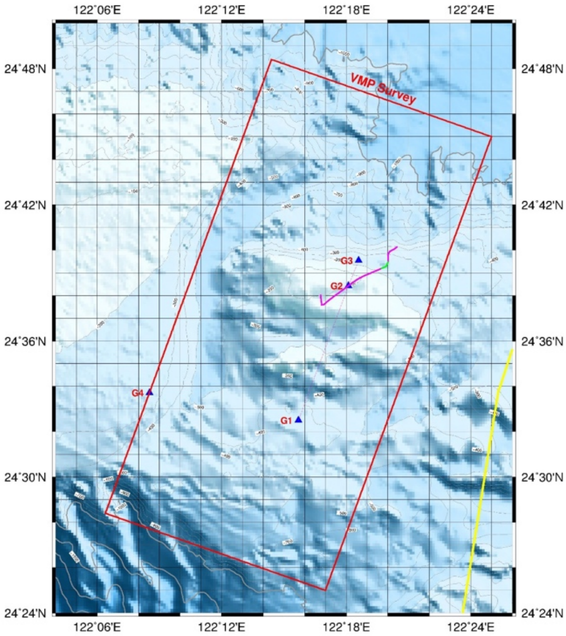


Figure 2. Bottom topography around the I-Lan Ridge. Mooring positions are indicated by blue triangles.

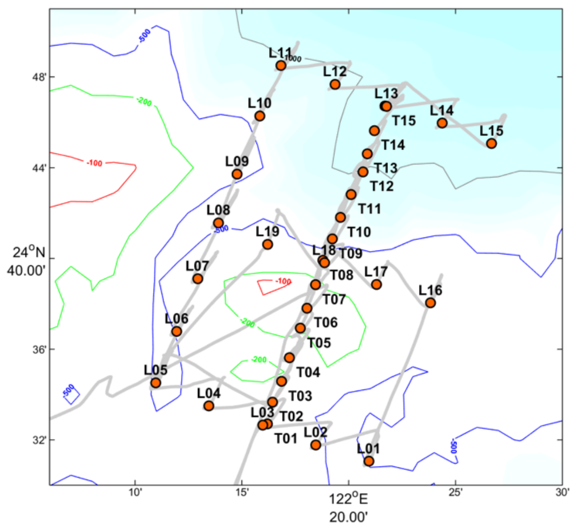


Figure 3. Bottom topography of the Chicken Claw seamount, the shallowest sill of the I-Lan Ridge (around G2 and G3 in Figure 2). Red circles indicate the positions where the TurboMAP was deployed.

Based on this field experiment, we are currently writing five 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, Dynamics and variability of topography-induced shear instabilities in western boundary currents, 20th Pacific Asian Marginal Seas (PAMS 2019) meeting, Kaohsiung, Taiwan, March 19-22, 2019.
2. CHANG, Ming-Huei, Observations of small-scale processes and turbulent mixing generated by Kuroshio flowing over a sill, 20th Pacific Asian Marginal Seas (PAMS 2019) meeting, Kaohsiung, Taiwan, March 19-22, 2019.
3. ENDOH, Takahiro, Observations of nonlinear internal waves over the shelf break of the East China Sea, 20th Pacific Asian Marginal Seas (PAMS 2019) meeting, Kaohsiung, Taiwan, March 19-22, 2019.

(2) International research workshop

In order to share and discuss the observed results, "Workshop on turbulent mixing in the Kuroshio current off Taiwan" was held at RIAM on January 24, 2019. Five overseas researchers as well as ten 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 four speakers:

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

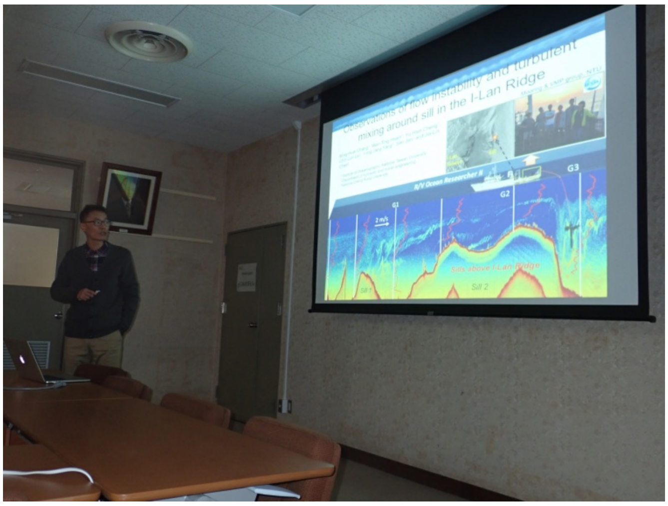


Figure 4. Dr. Ming-Huei Chang of NTU presenting the results observed with OR2.

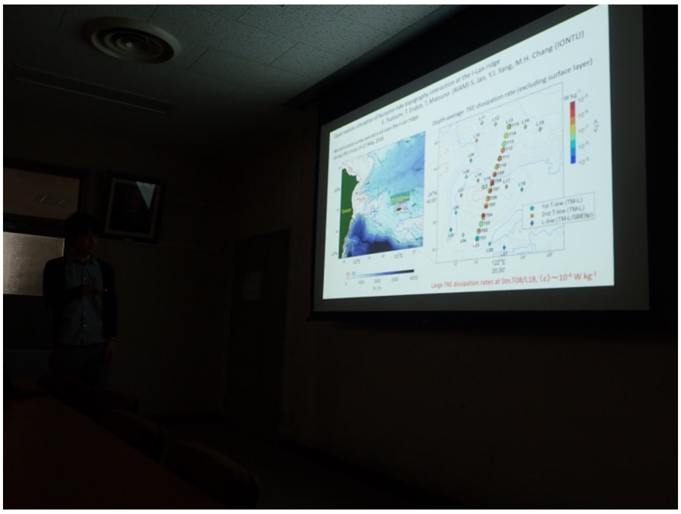


Figure 5. Dr. Eisuke Tsutsumi of RIAM showing the results observed with OR1.

In the discussion session of this workshop, we agreed to continue our collaborative research in the next fiscal year, and then decided to carry out the state-of-the-art tow-yo microstructure measurements over the I-Lan Ridge during the OR2 cruise scheduled in July, 2019, to clarify the downstream extent of the strong turbulence generated at the I-Lan Ridge.

The program of the workshop is shown below.

Workshop on turbulent mixing in the Kuroshio current off Taiwan

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

Date: January 24, 2019

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 a plan for the research cruise in July

Time Table:

10:30 Takahiro Endoh: Opening remarks

10:40 Sen Jan: Characteristic of turbulence in the Kuroshio upstream of I-Lan Ridge

11:10 Yiing Jang Yang: Observations of internal solitary waves on the I-Lan Ridge in the center of Kuroshio

11:40 Ming-Huei Chang: Observations of flow instability and turbulent mixing around sill in the I-Lan Ridge (see Figure 4)

12:10-13:30 Lunch time

13:30 Takeyoshi Nagai: Large energy sink through submesoscale instability caused by the Kuroshio flowing over seamounts in the Tokara Strait revealed by tow-yo microscale turbulence measurements

14:00 Jia-Lin Chen: Flow dynamics and variability over sharply sloping topography in the I-Lan Ridge

14:30-14:50 Coffee break

14:50 Chih-Lun Liu: A preliminary 2D simulation of a flow over the sill above I-Lan Ridge

15:20 Eisuke Tsutsumi: Quasi-realistic numerical simulations of Kuroshio-tide-topography interaction at I-Lan ridge (see Figure 5)

15:50 Discussion

17:00 Takahiro Endoh: Closing remarks

国際化推進共同研究概要

NO.3

18EA-3

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:　WANG, Zifa

所内世話人:　鵜野　伊津志

研究概要:

2014 年から 2018 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った。また、同期間に Prof. Zifa Wang 教授の研究室の博士研究員４名の中国側の経費で来日し、半日間の中国と日本の大気汚染に関する研究会を開催した。

No. 18EA-3

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）

<u>共同研究の目的</u>

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。

<u>共同研究の成果</u>

今年度は、2014 年から 2018 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進めている。福岡の年平均 PM2.5 濃度と北京の年平均 PM2.5 濃度には非常に高い相関が見られ、越境輸送の影響が評価できた。中国では SO_2 の発生量が２０１２年頃にピークに比較して 1/4 程度に減少している。NO_x の発生量もピークに 20%程度減少している。これに対して、NH_3 の濃度は微増で、大気中の S と N のバランスが変化している。バランスの変化の影響がどの程度風下の範囲まで影響しているかについて、今後解析を進め論文として投稿する予定になっている。

国際化推進共同研究概要

NO.4

18EA-5

タ イ ト ル:　Computationally-Intensive Modeling of the Climate System

研究代表者:　SCHNEIDER, Niklas

所内世話人:　木田　新一郎

研究概要:

平成 31 年 2 月 28 日—3 月 1 日に国際研究集会を開催した. 2 名による招待講演に加え、27 の口頭発表と 19 のポスター発表が行われた. 計 53 名の参加者のうち 11 名が海外(アメリカ、中国、台湾)、12 名が大学院生であり、若手が座長となって議論がリードされた. 初日の国立台湾大学の Shih-Nan Chen 准教授、上海交通大学の Lei Zhou 准教授による招待講演では、河川プリュームに代表される沿岸流の傾圧不安定についての考察、そしてインド洋における季節内振動についての新しい解析結果が紹介され、その後のセッションでは高解像度の数値モデルを活用した気候システムについて活発な議論が行われた.

Computationally-Intensive Modeling of the Climate System

University of Hawaii at Manoa. Niklas Schneider

1. Aim

The ocean is filled with eddies and fronts with length scales of kilometers to tens of kilometers. Recent studies strongly suggest that these small-scale processes affect basin-scale ocean circulation, climate, and biogeochemical cycles. Investigations of these processes require high-spatial resolution numerical models of the ocean and the coupled ocean-atmosphere system that cover ocean basins or the globe, and at the same time, resolve eddies and front. Mesoscale and sub-mesoscale processes also play a dominant role on the variability near coasts and in marginal seas. In this research project, we aim to understand the basic dynamics of the scale-interactions and their representation in numerical models. RIAM has a long history of observational and theoretical studies of the coastal and marginal seas of the western North Pacific and the Kuroshio, and of air-sea interaction occurring in the marginal seas. Through this joint research, we aim to utilize the high-resolution numerical models to explore how these regional-scale processes interact with the global-scale.

2. Research Plan

The goal of the workshop is to understand the interactions of eddy, region, and basin-scales, using a semi-global high-resolution numerical model. The workshop will bring together national and international experts on high-resolution modeling of the ocean, atmosphere, and climate, and will discuss recent research results using computationally intensive numerical modeling. Topics will include validation and improvements of the simulations. sub-mesoscale process and its temporal-spatial properties and interaction with the large scale; ensemble experiments to understand internal ocean variability and climate variabilities such as ENSO and Indian Ocean Dipole; the impact of small-scale processes on biogeochemistry cycle and biology; air-sea interaction along western boundary currents and its impact on the mid-latitude atmosphere; mixing on the continental slope; marginal seas-open ocean interactions through narrow straits. Scientists at RIAM will become acquainted with global circulation models and learn their strengths. We expect the discussions from the workshop to deepen understanding of scale-interaction in ocean and climate and improve model forecasts.

3. Workshop

Title: 4th Workshop on Computationally-Intensive Modeling of the Climate System and 9th OFES International Workshop

Date: 2019, February 28, 13:00 – March 1, 17:30

Place: C-cube, 3F Room 303, Chikushi Campus, Kyushu University

Program (see the file attached for details)

[Oral]

Invited Presentations

1. Shih-Nan Chen: On the stability of buoyant coastal currents: A view from the Eady model of baroclinic

instability

2. Lei Zhou: Spreading of the South Pacific Tropical Water and Antarctic Intermediate Water over the maritime continent

Session 1: Air-Sea interaction

1. Kelvin Richards: Ocean response to atmospheric variability over the Indo-Pacific warm pool: a case for high vertical resolution
2. H. Annamalai: Modeling Asian monsoon precipitation climatology: Representation of air-sea interactions over the tropical Indian Ocean
3. Bunmei Taguchi: Kuroshio Extension and Gulf Stream's influences on the variability of near-surface baroclinicity and the associated atmospheric fields
4. Tomoki Tozuka: A metric for surface heat flux effect on horizontal SST gradients and its application to OFES
5. Niklas Schneider: Scale-dependence of observed equivalent neutral wind response to ocean-mesoscale sea surface temperatures
6. Hyodae Seo: Coupled ocean-atmosphere interaction mediated by SST and surface current: Distinctive impacts and scale dependence

Session 2: Model Development

7. Takeshi Enomoto: RAHOTS: Radial basis functions Along Helix On The Sphere
8. Qingyang Song: A 4D variational scheme for nearshore wave model

Session 3: Climate Variability

9. Takeshi Doi: Westerly Wind Burst (WWB)/Easterly Wind Surge (EWS)-like stochastic forcing and the effects on ENSO prediction by the SINTEX-F system
10. Tomomichi Ogata: Mid-latitude source of the ENSO-spread in SINTEX-F ensemble predictions
11. Marvin Xiang Ce Seow: Analyzing atmospheric processes behind the South China sea winter cold tongue using model outputs
12. Shoichiro Kido: Anatomy of the Indian Ocean Dipole using a regional ocean model
13. Ayako Yamamoto: On the emergence of Atlantic Multidecadal SST signal: A key role of the mixed layer depth variability driven by North Atlantic Oscillation

Session 4: Western Pacific and Marginal Seas

14. Yoshi N. Sasaki: Sea surface temperature trend in the East China Sea during the 20th century simulated by a regional ocean model
15. Youfang Yan: A north-south contrast of subsurface salinity anomalies in the northwestern Pacific from
16. 2002-2013
17. Kunihiro Aoki: 80-member ensemble forecast of Kuroshio in JCOPE
18. Shun Ohishi: An LETKF-based ocean reanalysis for the Asia-Oceania region using Himawari-8 SSTs and SMOS/SMAP SSS
19. Haejin Kim: Long-term simulation of physical and biogeochemical compartments using DREAMS2

Session 5: Ocean Dynamics

20. Bo Qiu: Seasonality in transition scale from balanced to unbalanced motions in the world ocean
21. Hidenori Aiki: The life-cycle of annual waves in the Pacific Ocean as identified by a seamless diagnosis for

the energy flux

22. Hung Wei Chou: Improvement and dynamics of barotropic water exchange between the Sea of Okhotsk and Pacific by tidal forcing in OGCM

Session 6: New Version of OFES (OFES2)

23. Hideharu Sasaki: An increase of the Indonesian Throughflow by internal tidal mixing in a high-resolution quasi-global ocean simulation
24. M. Riza Iskandar: Evaluation of the water mass inside Indonesian Seas from OFES2 through lagrangian analysis
25. Shinichiro Kida: The fate of surface freshwater entering the Indonesian Seas
26. Ingo Richter: Revisiting the generation mechanism of Benguela Niños using OFES2 output
27. Masami Nonaka: Wind-driven and intrinsic interannual-to-decadal variability in the Kuroshio Extension

[Poster (presenter)]

1. Takeshi Doi: Impacts of temperature measurements from sea turtles on seasonal prediction around the Arafura Sea
2. Ryo Furue: How deterministic are the deep zonal jets?
3. Yasuhiro Hoshiba: Effects of suspended sediment matter by high riverine discharge on surface river plume and vertical estuary circulation: a simulation study for the Tango Bay, Japan
4. Ryo Kobayashi: Generation mechanisms of the Benguela Niño with a focus on local amplification
5. Nobumasa Komori: Experimental Seasonal Climate Prediction using CFES−Preliminary Results−
6. Kunio Kutsuwada: Verification for subsurface oceanic structure in OFES outputs driven by different wind data sets (NCEP/NCAR and QSCAT) in the tropical Pacific Ocean
7. Zimeng Li: The life-cycle of annual waves in the Indian Ocean as identified by a seamless diagnosis for the energy flux
8. Cong Liu: Subtropical mode water (STMW) in meso- and submeso-scale model
9. Tianran Liu: Estimation of ocean thermal energy potential in the Aguni Basin
10. Ryusuke Masunaga: Seasonality and regional characteristics of sea-surface wind responses to mesoscale SST features
11. Takuro Matsuta: Generation and dissipation of meso-scale eddies in the southern Indian ocean
12. Toru Miyama: Role of river discharges from the Kamchatka Peninsula in the Okhotsk Sea
13. Kazumichi Murata: Mechanisms of reemergence in the North Pacific revealed by mixed layer heat budget analysis
14. Shun Ohishi: Salinity frontogenesis/frontolysis in the northeastern subtropical Pacific region
15. Hyodae Seo: A new framework for near-surface wind convergence over the Kuroshio Extension and Gulf Stream in wintertime: The role of atmospheric fronts
16. Qingyang Song: Seasonal energy analysis for baroclinic waves in equatorial Atlantic through a diagnostic scheme for energy flux
17. Katsumi Takayama: Effect of altimeter data assimilation on the ecosystem distributions of the DREAMS2
18. Sashiko Yoshida: An interior pathway of Fukushima tracer across the KE

3. Summary of the workshop

The workshop had 53 attendants in total with 11 scientists from three countries (U.S.A.(7), China(3), and Taiwan (1)). There were also many attendants domestically, from RIAM (8) and from other universities and research agencies in Japan (23) including 12 graduate students. The workshop was led by young scientists and postdocs, who chaired the oral presentation, with many questions and discussion raised during the workshop over the two days (see below for the summary of each session). The workshop ended successfully, and the next workshop was decided to be held in about two years.

[Invited Speakers]

Two speakers, Associate Prof. Shih-Nan Chen of National Taiwan University and Associate Prof. Lei Zhou of Shanghai Jiao Tong University, were invited to the workshop who introduced new insights and directions for future scientific questions and modeling developments. Dr. Shih-Nan Chen presented a theoretical study related to coastal buoyant plume and how classic baroclinic instability framework is affected by the presence of bottom drag. Dr. Lei Zhou presented a modeling study related to the intrusion of South Pacific subsurface water (e.g. AAIW) to the Indonesian Seas through the Halmahera Sea and the Torres Strait. He also introduced a new index, the Central Indian Ocean mode, that shows the leading mode of the intraseasonal variability of the Indian Ocean. He also showed how a high-spatiotemporal model product like OFES could be used for examining the intraseasonal signal in the ocean.

[Oral session] 27 oral presentations were given. The topics covered various spatiotemporal scale phenomena in the Atlantic, Pacific, and the Indian Ocean. Six sessions were organized, air-sea interaction (Chair: A. Yamamoto), model development (Chair K. Aoki), western Pacific and marginal seas (chair: R. Masunaga), climate variability (chair: Q. Song), ocean dynamics (Chair: S. Kido), and work related to new version of OFES (OFES2) (Chair: S. Ohishi).

[Poster session] 19 poster presentations were given twice during the workshop and for a total of about two hours (2/28 14:10-15:00 and 3/1 14:30-15:30). Many of the posters were presented by the graduate students and young postdocs. The poster session provided ample time and opportunity for them to receive suggestions for their on-going research work from many scientists attending the workshop.

4. Participants

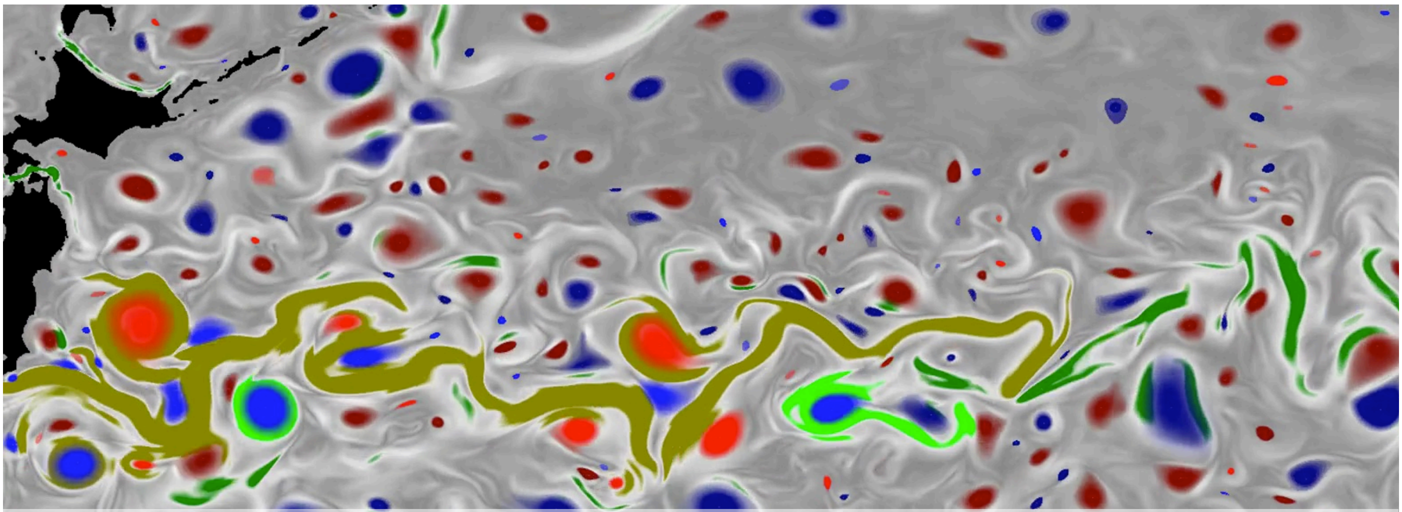
Total of 51 (see the list attached)

5. Publications

None

6. Members

Representative	University of Hawaii	Professor	Niklas Schneider
Co-researcher	JAMSTEC	Senior Scientist	Masami Nonaka
Co-researcher	JAMSTEC	Senior Scientist	Hideharu Sasaki
Co-researcher	University of Hawaii	Professor	Kelvin Richards
Co-researcher	University of Hawaii	Professor	Bo Qiu
Co-researcher	University of Hawaii	Senior Researcher	H. Annamalai
Co-researcher	Nagoya University	Associate Professor	Hidenori Aiki
Co-researcher	The University of Tokyo	Associate Professor	Tomoki Tozuka
Co-researcher	RIAM	Associate Professor	Takahiro Endo
Co-researcher	RIAM	Professor	Naoki Hirose
RIAM attendant	RIAM	Associate Professor	Shinichiro Kida



4th International Joint Workshop on Computationally-Intensive Modeling of the Climate System and 9th OFES International Workshop

February 28 – March 1, 2019
C-Cube Chikushi Campus, Kyushu University , Fukuoka, Japan

Conveners:

Hideharu Sasaki (APL, JAMSTEC)
Shinichiro Kida (RIAM, Kyushu University)
Niklas Schneider (IPRC, University of Hawaii)
Yukio Masumoto (The University of Tokyo)

Support:

This meeting is supported by the joint research program of Research Institute for Applied Mechanics (RIAM), Kyushu University

Schedule

February 28, Thursday

12:30-13:00: Registration
13:00-13:10: Opening Remarks

Invited Presentations (Chair: S. Kida)

13:10-13:40: *On the stability of buoyant coastal currents: A view from the Eady model of baroclinic instability*
Shih-Nan Chen (National Taiwan Univ.), C.-J. Chen (National Taiwan Univ.)

13:40-14:10: *Spreading of the South Pacific Tropical Water and Antarctic Intermediate Water over the maritime continent*
Lei Zhou (Shanghai Jiao Tong Univ.)

14:10-15:00 Poster Session

Session 1: Air-Sea Interaction (Chair: A. Yamamoto)

15:00-15:15: *Ocean response to atmospheric variability over the Indo-Pacific warm pool: a case for high vertical resolution*
Kelvin Richards (IPRC, Univ. Hawaii)

15:15-15:30: *Modeling Asian monsoon precipitation climatology: Representation of air-sea interactions over the tropical Indian Ocean*
Hariharasubramanian Annamalai (IPRC, Univ. of Hawaii), B. Taguchi (RCAST, Univ. of Tokyo), F. Hanf (IPRC, Univ. of Hawaii), J. P. McCreary (IPRC, Univ. of Hawaii)

15:30-15:45: *Kuroshio Extension and Gulf Stream's influences on the variability of near-surface baroclinicity and the associated atmospheric fields*
Bunmei Taguchi (RCAST, Univ. of Tokyo), K. Nishii (Mie Univ.), H. Nakamura (RCAST, Univ. of Tokyo)

15:45-16:00: *A metric for surface heat flux effect on horizontal SST gradients and its application to OFES*
Tomoki Tozuka (Univ. of Tokyo), S. Ohishi (ISEE, Nagoya Univ.), M. F. Cronin (PMEL, NOAA)

16:00-16:15 Break

(Chair: K. Aoki)

16:15-16:30: *Scale-dependence of observed equivalent neutral wind response to ocean-mesoscale sea surface temperatures*
Niklas Schneider (IPRC, Univ. of Hawaii)

16:30-16:45: *Coupled ocean-atmosphere interaction mediated by SST and surface current: Distinctive impacts and scale dependence*
Hyodae Seo (WHOI)

Session 2: Model Development

16:45-17:00: *RAHOTS: Radial basis functions Along Helix On The Sphere*
Takeshi Enomoto (DPRI, Kyoto Univ.)

17:00-17:15: *A 4D variational scheme for nearshore wave model*
Qingyang Song(ISEE, Nagoya Univ.), R. Mayerle (FTZ/CRL, CAU)

17:15 End of First Day

March 1, Friday

Session 3: Climate Variability (Chair: R. Masunaga)

9:30-9:45: *Westerly Wind Burst (WWB)/Easterly Wind Surge (EWS)-like stochastic forcing and the effects on ENSO prediction by the SINTEX-F system*
Takeshi Doi (APL, JAMSTEC), S. K. Behera (APL, JAMSTEC), T. Yamagata (APL, JAMSTEC)

9:45-10:00: *Mid-latitude source of the ENSO-spread in SINTEX-F ensemble predictions*
Tomomichi Ogata (APL, JAMSTEC), T. Doi (APL, JAMSTEC), Y. Morioka (APL, JAMSTEC), S. Behera (APL, JAMSTEC)

10:00-10:15: *Analyzing atmospheric processes behind the South China sea winter cold tongue using model outputs*
Marvin Xiang Ce Seow (Univ. of Tokyo), T. Tozuka (Univ. of Tokyo), Y. Morioka (APL/JAMSTEC)

10:15-10:30: *Anatomy of the Indian Ocean Dipole using a regional ocean model*
Shoichiro Kido (Univ. of Tokyo), T. Tozuka (Univ. of Tokyo), W. Han (Univ. of Colorado Boulder)

10:30-10:45: *On the emergence of Atlantic Multidecadal SST signal: A key role of the mixed layer depth variability driven by North Atlantic Oscillation*
Ayako Yamamoto (APL, JAMSTEC), Hiroaki Tatebe (JAMSTEC) , M. Nonaka (APL, JAMSTEC)

10:45-11:00 Coffee Break

Session 4: Western Pacific and Marginal Seas (Chair: Q. Song)

11:00-11:15: *Sea surface temperature trend in the East China Sea during the 20th century simulated by a regional ocean model*
Yoshi N. Sasaki (Hokkaido Univ.), C. Umeda (Hokkaido Univ.)

11:15-11:30: *A north-south contrast of subsurface salinity anomalies in the northwestern Pacific from 2002-2013*
Youfang Yan (SCSIO, CAS), L. Svendsen (Univ. of Bergen, BCCR), C. Wang (SCSIO, CAS), N. Keenlyside (Univ. of Bergen, BCCR), D. Xu (SOA)

11:30-11:45: *80-member ensemble forecast of Kuroshio in JCOPE*
Kunihiro Aoki (APL, JAMSTEC), Y. Miyazawa (APL, JAMSTEC), T. Hihara (APL, JAMSTEC)

11:45-12:00: *An LETKF-based ocean reanalysis for the Asia-Oceania region using Himawari-8 SSTs and SMOS/SMAP SSS*
Shun Ohishi (ISEE, Nagoya Univ.), T. Hihara (APL, JAMSTEC), H. Aiki (ISEE, Nagoya Univ.), J. Ishizaka (ISEE, Nagoya Univ.), Y. Miyazawa (APL, JAMSTEC), M. Kachi (EORC, JAXA)

12:00-12:15: *Long-term simulation of physical and biogeochemical compartments using DREAMS2*
Haejin Kim (RIAM, Kyushu Univ.), K. Takayama (RIAM, Kyushu Univ.) , N. Hirose (RIAM, Kyushu Univ.)

12:15-13:30 Lunch Break

Session 5: Ocean Dynamics (Chair: S. Kido)

13:30-13:45: *Seasonality in transition scale from balanced to unbalanced motions in the world ocean*
Bo Qiu (Univ. of Hawaii), S. Chen (Univ. of Hawaii), P. Klein (JPL, Caltech), J. Wang (JPL, Caltech), H. Torres (JPL, Caltech), L.-L. Fu (JPL, Caltech), D. Menemenlis (JPL, Caltech)

13:45-14:00: *The life-cycle of annual waves in the Pacific Ocean as identified by a seamless diagnosis for the energy flux*
Hidenori Aiki (ISSE, Nagoya Univ.), T. Shimura (Nagoya Univ.)

14:00-14:15: *Improvement and dynamics of barotropic water exchange between the Sea of Okhotsk and Pacific by tidal forcing in OGCM*
Hung Wei Chou (ILTS, Hokkaido Univ.), H. Mitsudera (ILTS, Hokkaido Univ.), K. Yamazaki (ILTS, Hokkaido Univ.), H. Nishikawa (ILTS, Hokkaido Univ.)

14:15-14:30 Photo Session
14:30-15:30 Poster Session

Session 6: New Version of OFES (OFES2) (Chair: S. Ohishi)

15:30-15:45: *An increase of the Indonesian Throughflow by internal tidal mixing in a high-resolution quasi-global ocean simulation*
Hideharu Sasaki (APL, JAMSTEC), S. Kida (RIAM, Kyushu Univ.), R. Furue (APL, JAMSTEC), M. Nonaka (APL, JAMSTEC) , Y. Masumoto (Univ. of Tokyo)

15:45-16:00: *Evaluation of the water mass inside Indonesian Seas from OFES2 through lagrangian analysis*
M Riza Iskandar (Tohoku Univ.), T. Suga (Tohoku Univ.), H. Sasaki (APL/JAMSTEC), Y. Jia (IPRC, Univ. of Hawaii), K. Richards (IPRC, Univ. of Hawaii)

16:00-16:15: *The fate of surface freshwater entering the Indonesian Seas*
Shinichiro Kida (RIAM, Kyushu Univ.), K. Richards (IPRC, Univ. of Hawaii), H. Sasaki(APL, JAMSTEC)

16:15-16:30: *Revisiting the generation mechanism of Benguela Niños using OFES2 output*
Ingo Richter (APL, JAMSTEC)

16:30-16:45: *Wind-driven and intrinsic interannual-to-decadal variability in the Kuroshio Extension*
Masami Nonaka (APL, JAMSTEC), H. Sasaki (APL, JAMSTEC), B. Taguchi (RCAST Univ. of Tokyo), N. Schneider (IPRC, Univ. of Hawaii)

16:45-17:00 Closing Remarks
17:00 Adjourn

Poster Presentations

Impacts of temperature measurements from sea turtles on seasonal prediction around the Arafura Sea
Takeshi Doi (APL, JAMSTEC), A. Storto (CMRE), T. Fukuoka (AORI, Univ. of Tokyo), H. Suganuma (ELNA), K. Sato (AORI, Univ. of Tokyo)

How deterministic are the deep zonal jets?
Ryo Furue (APL, JAMSTEC), M. Nonaka (APL, JAMSTEC), H. Sasaki (APL, JAMSTEC)

Effects of suspended sediment matter by high riverine discharge on surface river plume and vertical estuary circulation: a simulation study for the Tango Bay, Japan
Yasuhiro Hoshiba (AORI, Univ. of Tokyo), Y. Matsumura (AORI, Univ. of Tokyo), H. Hasumi (AORI, Univ. of Tokyo), S. Itoh (AORI, Univ. of Tokyo), S. Nakada (NIES)

Generation mechanisms of the Benguela Niño with a focus on local amplification
Ryo Kobayashi (Univ. of Tokyo), T. Tozuka (Univ. of Tokyo)

Experimental Seasonal Climate Prediction using CFES —Preliminary Results—
Nobumasa Komori (APL, JAMSTEC), B. Taguchi (RCAST, Univ. of Tokyo), A. Kuwano-Yoshida (DPRI, Kyoto Univ.), T. Doi (APL, JAMSTEC), M. Nonaka (APL, JAMSTEC)

Verification for subsurface oceanic structure in OFES outputs driven by different wind data sets (NCEP/NCAR and QSCAT) in the tropical Pacific Ocean
Hiroshige Fukunaga (Tokai Univ.), **Kunio Kutsuwada (Tokai Univ., *presenter)** , A. Kakiuchi (Tokai Univ.) , H. Sasaki (APL, JAMSTEC), Y. Sasaki (RCGC, JAMSTEC)

The life-cycle of annual waves in the Indian Ocean as identified by a seamless diagnosis for the energy flux
Zimeng Li (Nagoya Univ.), H. Aiki (ISEE, Nagoya Univ.)

Subtropical mode water (STMW) in meso- and submeso-scale model
Fuli Yuan (Zhejiang Univ. Zhoushan), **Cong Liu (Zhejiang Univ. Zhoushan, *presenter),** P. Li (Zhejiang Univ. Zhoushan), H. Sasaki (APL/JAMSTEC)

Estimation of ocean thermal energy potential in the Aguni Basin
Tianran Liu (RIAM, Kyushu Univ.), B. Wang (RIAM, Kyushu Univ.), N. Hirose (RIAM, Kyushu Univ.)

Seasonality and regional characteristics of sea-surface wind responses to mesoscale SST features
Ryusuke Masunaga (IPRC, Univ. of Hawaii), N. Schneider (IPRC, Univ. of Hawaii)

Generation and dissipation of meso-scale eddies in the southern Indian ocean
Takuro Matsuta (Univ. of Tokyo), Y. Masumoto (Univ. of Tokyo)

Role of river discharges from the Kamchatka Peninsula in the Okhotsk Sea
Toru Miyama (APL, JAMSTEC), H. Misudera (ILTS, Hokkaido Univ.)

Mechanisms of reemergence in the North Pacific revealed by mixed layer heat budget analysis
Kazumichi Murata (Univ. of Tokyo), S. Kido (Univ. of Tokyo), T. Tozuka (Univ. of Tokyo)

Salinity frontogenesis/frontolysis in the northeastern subtropical Pacific region
Shun Ohishi (ISEE, Nagoya Univ.), S. Katsura (AORI, Univ. of Tokyo), H. Aiki (ISEE, Nagoya Univ.)

A new framework for near-surface wind convergence over the Kuroshio Extension and Gulf Stream in wintertime: The role of atmospheric fronts
Rhys Parfitt (Florida State Univ.), **Hyodae Seo (WHOI, *presenter)**

Seasonal energy analysis for baroclinic waves in equatorial Atlantic through a diagnostic scheme for energy flux
Qingyang Song (ISEE, Nagoya Univ.), H. Aiki (ISEE, Nagoya Univ.)

Effect of altimeter data assimilation on the ecosystem distributions of the DREAMS2
Katsumi Takayama (RIAM, Kyushu Univ.), N. Hirose (RIAM, Kyushu Univ.)

An interior pathway of Fukushima tracer across the KE
Ella Cedarholm (Univ. of New Hampshire), I. Rypina (WHOI), A. Macdonald (WHOI), **Sachiko Yoshida (WHOI, *presenter)**

Information

Homepage of the Meeting

http://www.jamstec.go.jp/apl/ofes_ws9/

Information for Oral Presentations

Each presentation is allocated 15 minutes (12 minutes for presentation and 3 minutes for discussion). The presenters can use their own lap top computers, although Windows and Mac computers are prepared.

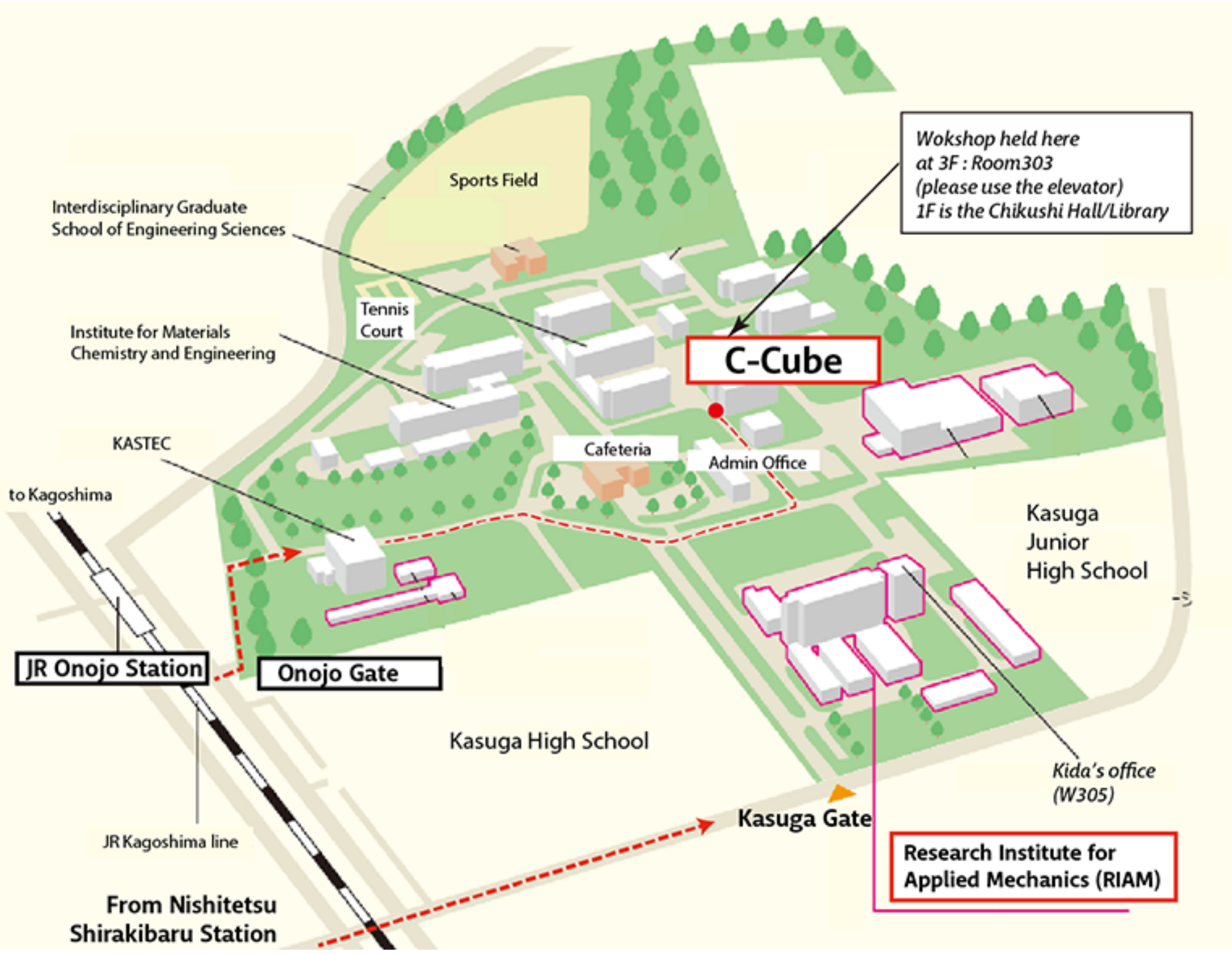
Information for Poster Presentations

The board size for each poster presentation is W82 (cm) x H168 (cm).

Access to Chikushi Campus of Kyushu University

https://www.riam.kyushu-u.ac.jp/en/center/access-e.html

Campus Map



Name	Affiliation	Status
Shih-Nan Chen	National Taiwan U	Associate Prof
Lei Zhou	Shanghai Jiao Tong U	Associate Prof
Niklas Schneider	University of Hawaii/IPRC	Prof
Kelvin Richards	University of Hawaii/IPRC	Prof
Bo Qiu	University of Hawaii	Prof
H. Annamalai	University of Hawaii/IPRC	Senior Scientist
Ryusuke Masunaga	University of Hawaii/IPRC	Postdoc
Liu Cong	Zhejiang University	Postdoc
Youfang Yan	State Key Laboratory of Tropical Oceanography	Associate Prof
Hyodae Seo	Woods Hole Oceanographic Institution	Senior Scientist
Sachiko Yoshida	Woods Hole Oceanographic Institution	Research Specialist
Hideharu Sasaki	JAMSTEC/APL	Senior Scientist
Masami Nonaka	JAMSTEC/APL	Senior Scientist
Toru Miyama	JAMSTEC/APL	Senior Scientist
Tomomichi Ogata	JAMSTEC/APL	Scientist
Ingo Richter	JAMSTEC/APL	Senior Scientist
Ayako Yamamoto	JAMSTEC/APL	Postdoc
Takeshi Doi	JAMSTEC/APL	Scientist
Kunihiro Aoki	JAMSTEC/APL	Scientist
Nobumasa Komori	JAMSTEC/APL	Senior Research Scientist
Ryo Furue	JAMSTEC/APL	Senior Scientist
Yukio Masumoto	The University of Tokyo	Prof
Ryo Kobayashi	The University of Tokyo	Masters Course
Tomoki Tozuka	The University of Tokyo	Associate Prof
Yasuhiro Hoshiba	The University of Tokyo	Postdoc
Takuro Matsuda	The University of Tokyo	Doctors Course
Kazumichi Murata	The University of Tokyo	Masters Course
Marvin Xian Ce Seow	The University of Tokyo	Doctors Course
Bunmei Taguchi	The University of Tokyo	Associate Prof
Shoichiro Kido	The University of Tokyo	Doctors Course
Yuji Kashino	National Fisheries University	Prof
Hung-Wei Chou	Hokkaido University	Doctors Course
Yoshinori Sasaki	Hokkaido University	Associate Prof
Takeshi Enomoto	Kyoto University	Associate Prof
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Shun Ohishi	Nagoya University	Postdoc
Kunio Kutsuwada	Tokai University	Prof
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Shunsuke Okada	Tohoku University	Masters Course
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Shinichiro Kida	Kyushu University	Associate Prof
Yuichi Iwanaka	Kyushu University	Postdoc
Kaoru Ichikawa	Kyushu University	Associate Prof
Ning Zhao	Kyushu University	Postdoc
Natsumi Tanuma	The University of Tokyo	Masters Course

NO.5

国際化推進共同研究概要

18EA-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:

日本海南西部に位置する大和海盆には、Sta. PM5 と呼ばれる最も頻繁に観測されてきた測点がある。この測点での既往観測資料から、日本海深層での水温上昇と溶存酸素量の減少が明らかにされてきたが、流況に関する情報は皆無であった。そこで Sta. PM5 に流速計を係留し、1年間の長期測流を行ったところ、この測点では大和海盆内の反時計回り循環の一部と考えられる順圧的な南下流が卓越していることが明らかとなった。

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

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

Introduction

The Japan/East Sea is a semi-closed marginal sea in the northwestern North Pacific surrounded by the Japanese islands and Korean Peninsula. It has been reported that the Japan/East Sea shows long-term trends of warming and decreasing concentration of dissolved oxygen in the abyssal layers. The warming of deep waters indicates a structural change of the Japan/East Sea. However, relationship between the observed changes in the water mass structure and flow condition in the deep layer is unknown. Therefore, we have been carried out deep flow observations and hydrographic observations in the Yamato Basin in the southeastern part of Japan/East Sea.

Observations

The direct current observations using moored acoustic current meters of RIAM, Kyushu University were carried out at Sta. PM5 (37° 42.0'N, 134° 42.0'E) in the Yamato Basin, as well hydrographic observations with CTD (Fig. 1). Although Sta. PM5 is the most frequently observed hydrographic station in the Japan/East Sea by the Japan Meteorological Agency, flow conditions at this station were unknown because of no current observations in the past. We installed three current meters at 930, 1720, and 2450 m to investigate vertical structure of the deep flow field. The deployment and recovery of the current meters were conducted by T/V Nagasaki Maru of Nagasaki University in October 2017 and October, 2018, respectively.

Results and Discussion

The stick diagrams of flows at Sta. PM5 are shown in Fig. 2. Southward flows were prevailing throughout the layers. In fact, the mean flows at 930, 1720, and 2450 m directed to 178.1, 162.7, and 162.8°T, respectively. This southward flow seems to be part of the cyclonic circulation in the Yamato Basin. Temporal variations of the flows were very similar among the layers, showing a barotropic nature. However, flows at 930 m were somewhat weaker than those in the lower layers; the speeds of mean flow at 930, 1720, 2450 m for the observation period were 1.55, 2.20, and 2.18 cm/s, respectively.

A gradual warming and decreasing of dissolved oxygen concentration have been reported in the abyssal layers of Sta. PM5 since the 1970s by the Japan Meteorological Agency. To clarify the relationship between the long-term changes in water characteristics and flow conditions at Sta. PM5, we need continuous observations.

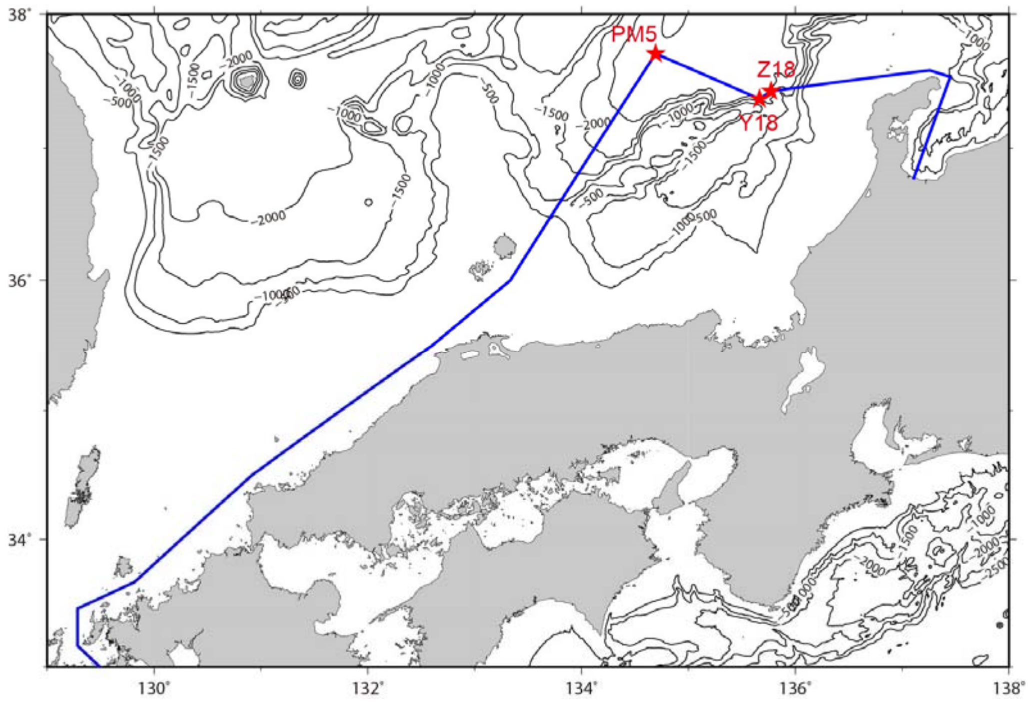

Fig. 1 Map of observation site in October 2018

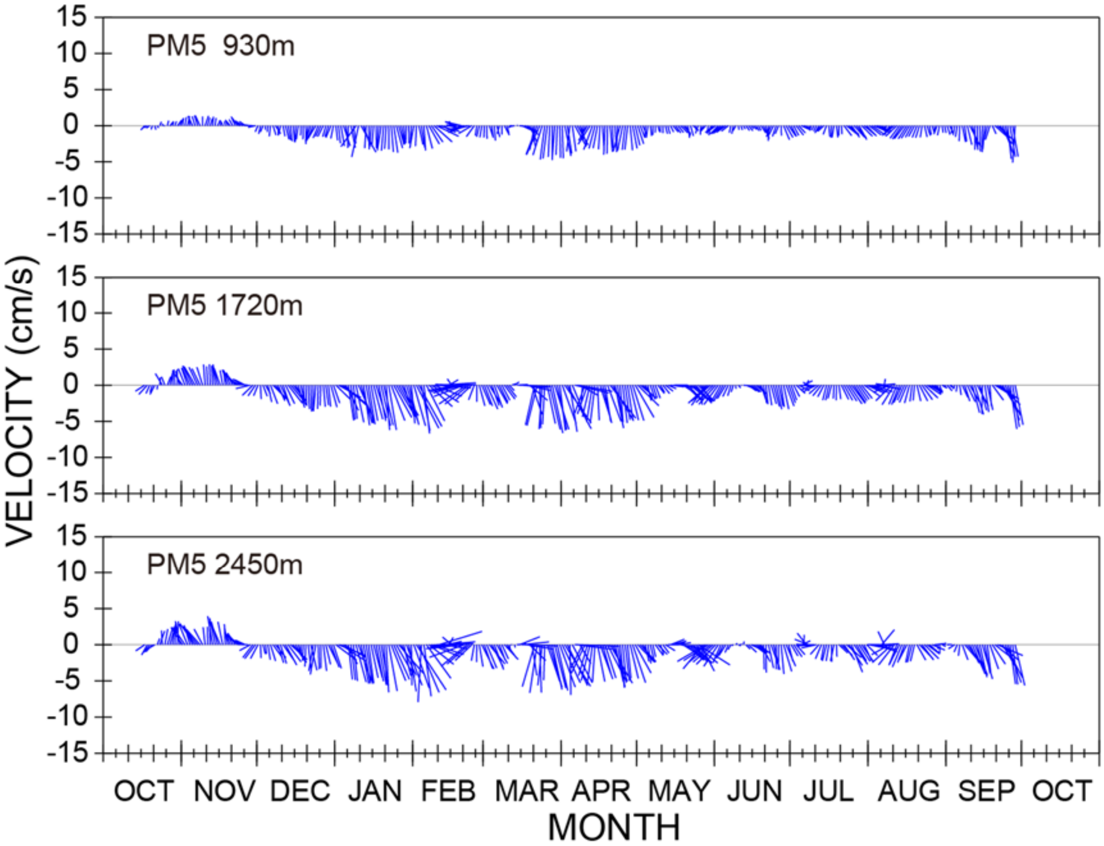

Fig. 2 Stick diagrams of flows at Sta. Y.

NO.6

国際化推進共同研究概要

18EA-7

タ イ ト ル:　Development of a framework to achieve excellence in urban atmospheric research

研究代表者:　ROTH, Matthias

所内世話人:　鵜野　伊津志

研究概要:
シンガポール と日本の都市間の「都市気象ー汚染」の共同研究の可能性について議論を行った。シンガポールは熱帯に位置した島国で周辺環境が温帯の日本と大きくことなりなかなか共通の課題の発案には至らなかった。しかし、議論の結果、都市気象・気候とPM２５の関係などは可能性があることが示された。つまり、ヒートアイランドの強度 ΔTu-r と ΔPM2.5u-r の相関をみている。
論文がいくつかあり、領域気象モデルWRF-Chem などを用いて理想化した計算設定（300m格子程度の高解像度の格子設定）で都市気象とPM濃度の関係を色々なシナリオを設定して、汚染ー気象のフィードバックの影響も含めて今後検討することとなった。

No.18EA-7

タイトル：　Development of a framework to achieve excellence in urban atmospheric research

研究代表者：　Prof. Matthias ROTH

所内世話人：　鵜野　伊津志

共同研究の目的

Project has two main aims:

(1) Describe NUS’s strategy to become one of the top universities in the world and the best in Asia (QS World University Rankings) with a specific focus on the Department of Geography and its Urban Climate Lab.
(2) Explore avenues to strengthen RIAM’s research agenda and capabilities in urban atmospheric research through exchanges and collaborative research projects

共同研究の成果

初年度は実現可能性の議論を中心に行ったので、特筆するような大きな成果はまだ出ていない。今後の色々な研究予算を使って、研究可能性を議論することとなった。

国際化推進共同研究概要

NO.7

18EA-8

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:

人工衛星および客観解析データを用いて、過去 30 年間の熱帯から中緯度における成層圏・対流圏循環場の長期変動の統計解析を行った。ENSO に伴う長期変動以外に 2000 年以降の成層圏の南北循環場の強化に因ると思われる、特に北半球夏季アジアモンスーン域の局所的ハドレー循環の強化がみられ、それが結果的に対流圏内の循環場を変調させ、南東太平洋の水温低下をもたらしていたことが示された。

Dynamical Mechanisms of Stratospheric Control on the Tropical Troposphere and Ocean

Rei Ueyama (NASA Ames Research Center)

I. Abstract

Large changes in tropical circulation from the mid-to-late 1990s to the present, particularly those related to the summer monsoon and cooling of the sea surface in the equatorial eastern Pacific, are noted. Cooling of the equatorial southeastern Pacific Ocean occurred 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. From boreal summer to winter, the center of anomalous convective activity moved southward to the equatorial Indian Ocean–Maritime Continent region following the seasonal march, which strengthened the surface easterlies over the equatorial central Pacific. Accordingly, ocean surface cooling expanded over the equatorial central Pacific. We 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

Large changes in tropical circulation occurred from the mid to late 1990s. These include (*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. The goal of this study is 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.

III. Method/Data

Datasets used in this study include 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.

IV. Results

Since the mid 1990s, equatorial ocean in the southern hemisphere has cooled in association with a strengthening of cross-equatorial southerlies near the surface. This was 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. We show that variations in convective activity and SST are related to vertical velocity near the tropopause (Fig. 1).

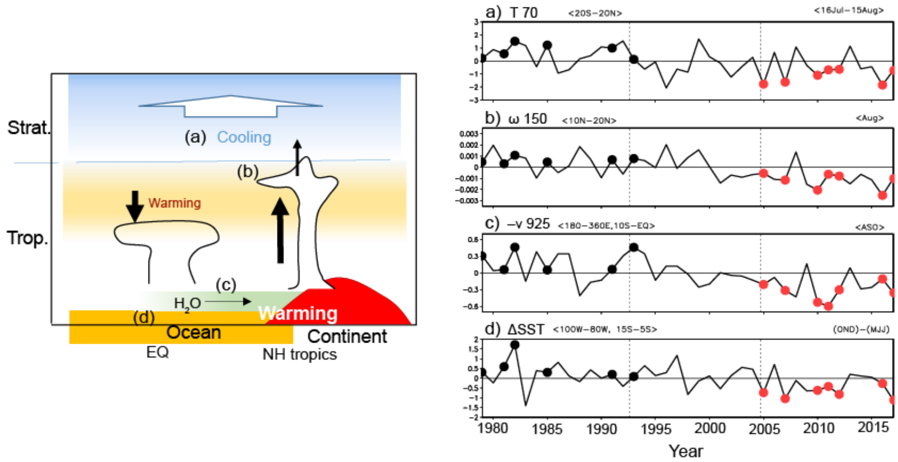

Figure 1: (left) Schematic of recent changes in the tropics, in which the labels (a) to (c) indicate the location of the variable shown in the right panels; (right) time series of four key variables as departures from climatology: (a) lower stratospheric temperature, (b) upwelling in the TTL, (c) cross-equatorial near-surface winds, and (d) time tendency of SST from summer to autumn. Black and red dots indicate years when the four variables are of the same polarity (positive and negative, respectively).

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., 2019) in a future study.

VI. References

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 TTL, in preparation, 2019.

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.*, in review.
- Kodera, K., N. Eguchi, R. Ueyama, Y. Kuroda and C. Kobayashi (2018), Impact of tropical lower stratospheric cooling on recent trends in tropical circulation through modulation of deep convective activity, *AOGS 15th Annual Meeting*, 3-8 June, Honolulu, USA. (oral)
- Kodera, K., R. Ueyama, B.M. Funatsu, N. Eguchi, L. Phister, C. Claud and T. Nasuno (2018), Impact of the tropical lower stratospheric cooling on deep convective activity during a Boreal summer monsoon, *SPARC General Assembly*, 1-5 Oct. 2018, Miyakomesse, Kyoto, Japan. (poster, international)
- Kodera, K., N. Eguchi, R. Ueyama, Y. Kuroda, B. Funatsu, C. Kobayashi, and C. Claud (2019), Role of tropical lower stratospheric cooling on recent tropical tropospheric change, *99th American Meteorological Society Annual Meeting,* Phoenix, USA. (oral)

VIII. Research workshops and seminar
RIAM seminar at Kyushu University
February 5-7, 2018
Title of seminar: "Modeling and (Aircraft) Observations of the Tropical Tropopause Layer"

IX. Member

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

国際化推進共同研究概要

NO.8

18EA-9

タ イ ト ル:　Simulation of light backscattering by ice crystals using the physical-optics approximation for interpretation of the data obtained by the high spectral resolution lidar

研究代表者:　BOROVOY, ANATOLY, GEORGIEVICH

所内世話人:　岡本　創

研究概要:

物理光学(Physical Optics)を非球形形状の氷粒子に適用し、衛星と地上のライダ観測に対応した鉛直から0度、3度と5度の傾斜角の場合に関して、ライダ後方散乱について理論的に解析を行った。六角柱形状の氷粒子で、波長は355nm, 532nmと1064nmに関して、80ミクロンから500ミクロンのサイズ分布を考慮し、水平面に偏って配向している粒子や3次元空間でランダムに配向している場合を考慮した。偏光解消度、ライダ比、そしてカラー比に関して調べた結果、いずれも考えた形状では地上ライダ観測でえられた値を説明できないことがわかった。他の粒子形状を考慮する必要があると判明した。

No. 9_ISEA-9. Simulation of light backscattering by ice crystals using the physical-optics approximation for interpretation of the data obtained by the high spectral resolution lidar

Institute of Atmospheric Optics, Rus. Acad. Sci., Prof. A.G. Borovoy

Aim:

Development and approbation of the methods for retrieving the microphysical characteristics of cirrus clouds from the data of the ground-based and space-borne lidars.
Importance of the task is provided by the fact that a number of satellite instruments are studying the cirrus clouds at optical and microwave wavelengths. Also, the cirrus clouds are investigated by numerous ground-based lidar stations whose data are combined in various lidar nets. However, the accuracy of retrieving the optical and microphysical characteristics of the clouds obtained from these measurements does not satisfy to the demands of the numerical models of the Earth radiative balance. Moreover, the existing theoretical methods for retrieving such microphysical characteristics from remote sensing instruments, as a rule, are not consistent with each other. There are two reasons of the theoretical discrepancies. First, accuracy of the theoretical methods used is not clarified completely. Second, shapes of the ice crystals in cirrus are theoretically assumed as pristine ones while the direct in-situ measurements show their complicated shapes like aggregates. In 2018, we have calculated the backscattering Mueller matrixes for a typical ice aggregate consisting of 8 hexagonal columns that was presented at P. Yang et al. [J. Atmos. Sci. 2013. V. 70. P. 330-347].

Method:

The problem of light scattering by nonspherical particles is a complicated problem of the mathematical physics. The problem of light scattering by ice crystal of cirrus clouds was solved earlier in the approximation of geometric optics where the wave properties of light were ignored (ray-tracing algorithm, K.N. Liou, USA; A. Macke, Germany). In the current literature concerning the optical characteristics of cirrus clouds, the predominant role belongs to the large team of American authors where the central role plays Prof. Ping Yang. These co-author's team has a huge scientific productivity. They publish in average one paper in high-rating journals for every 1 - 2 months. In these papers, the calculation algorithm developed by Ping Yang and called as IGOM (improved geometric-optics method) is used. In this algorithm, the wave properties of light is taken into account approximately. Some modification of IGOM was made later by Masuda in Japan [Masuda K. et al., Papers Meteorol. Geophys. v. 63, 15, 2012].

In particular, Prof. Ping Yang with co-authors for several last years published three papers where the light backscattering by ice crystals was calculated by his IGOM (improved geometric-optics method) algorithm: [J. Quant. Spectrosc. Radiat. Transfer v. 79-80, 1139, 2003; J. Quant. Spectrosc. Radiat. Transfer v. 100, 91, 2006; J. Geophys. Res. v. 114, D00H008, 2009]. And only in his recent papers of 2015-2016 [Opt. Express v. 23, 11995, 2015; Opt. Express v. 24, 620, 2016] he concluded that his algorithm IGOM is not applicable to calculate the light backscattering in cirrus clouds.

At present, the physical-optics method seems to be most acceptable for calculation of light backscattering by ice crystals of cirrus clouds. This method was proposed by us in 2003 [J. Opt. Soc. Am. v. 20A, 2071, 2003] and then it was finalized as a reliably operating computer algorithm [Borovoi A., Konoshonkin A., Kustova N., Opt. Lett, v. 38, 2881, 2013]. The advantages of this method is, first, simple physical interpretation of all computation procedures and, second, a possibility to fulfill the calculations by use of the personal computers instead of supercomputers. It is interesting to note that Prof. Ping Yang (USA) with co-authors had come to the same method only in 2011 that was published in the paper [J. Quant. Spectrosc. Radiat. Transfer v.112, 1492, 2011]. However, these authors had not refined this method to the available algorithms and they don't use this method at present, as far as we know. The reason of this was that they came to developments of two exact methods demanding to use supercomputers. The first method called PSTD is the improved FDTD method that is discussed in the papers [1) J. Quant. Spectrosc. Radiat. Transfer v. 113, 1728, 2012; 2) Opt. Express v. 20, 16763, 2012; 3) J. Quant. Spectrosc. Radiat. Transfer v. 129, 169, 2013; 4) Opt. Express v. 22, 23620, 2014]. The second method is called the invariant imbedding T-matrix method (II-TM), it is described in the papers [J. Quant. Spectrosc. Radiat. Transfer v. 116, 169, 2013] и [J. Quant. Spectrosc. Radiat. Transfer v. 138, 17, 2014].

Simulations in 2018

We used the physical-optics method for calculating the backscatter Mueller matrix and the backscatter ratios for a typical ice aggregate consisting of 8 hexagonal columns that was presented at P. Yang et al. [J. Atmos. Sci. 2013. V. 70. P. 330-347]. The input parameters were as following:
wavelengths: 0.355, 0.532 and 1.064 micrometers;
size distribution: Gamma distribution over maximal dimension (only for random orientation), modal size varies from 80 to 500 microns.
crystal shapes: 4 different shapes with the maximal dimension: 200, 300, 450 and 670 microns
crystal orientations: quasi-horizontal orientation with arbitrary effective crystal tilts up to the random orientation;
lidar tilts: 0, 3 and 5 degrees about the vertical direction.

Results:

The backscattering Mueller matrixes as well as the backscatter ratios have been presented in our data bank at ftp://ftp.iao.ru/pub/GWDT/Physical_optics/Backscattering/for_DWD_2017/.
We have seen that the backscatter ratios (lidar, depolarization and color ratios) reveal strong dependence on shape and size for the aggregates consisting of regular hexagonal columns. Since the obtained magnitudes of the backscatter ratios do not demonstrate the coincidence with the experimental data, we conclude that the crystal shapes used further for calculations should be the crystals of irregular shapes like aggregates of the irregular constituents.

Publications:

ftp://ftp.iao.ru/pub/GWDT/Physical_optics/Backscattering/for_DWD_2017/
Data bank of the Mueller scattering matrixes for ice crystals of cirrus clouds

国際化推進共同研究概要

NO.9

18NU-1

タ イ ト ル:　Equilibrium Control & Test of ECH heating of plasma generated by transient CHI on QUEST

研究代表者:　NELSON, Brian, A

所内世話人:　花田　和明

研究概要:

本案件は新設計電極による CHI プラズマ立ち上げを目的とする。QUEST では電極から離れたポロイダル磁場(PF)コイル配置、コイル電源の電流制御の遅さ、トロイダル磁場の上限が CHI によるプラズマ形成の妨げになっている。本年度、プラズマを拡大及び中心部へ移動させるため、センタースタックの上部コイル PF4-1 と下部コイル PF4-3 を使用した配位、及び同じく PF4-1 と容器上下コイル PF35-1 を使用した配位を試みた。トロイダル電流は持続したが完全な電極からの切り離しはされなかった。本実験データに基づき改善案(電極と内側容器壁間での放電、高出力 ECH 前加熱の実施、ガス導入部の改善、及び PF コイル電源の構築)が検討された。

Equilibrium Control & Test of ECH heating of plasma generated by transient CHI on QUEST [·]

2 January 2019

R. Raman[1], K. Kuroda[2], K. Hanada[2], H. Canbin[2], M. Ono[3], B.A. Nelson[1], E. Hatem[2], T. Onchi[2], M. Hasegawa[2], M. Nagata[4], O. Mitarai[5], T.R. Jarboe[1]

[1] University of Washington, Seattle, WA, USA

[2] Kyushu University, Kyushu, Japan

[3] Princeton Plasma Physics Laboratory, Princeton, NJ, USA

[4] University of Hyogo, Himeji, Japan

[5] Institute for Advanced Fusion and Plasma Education, Japan

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.

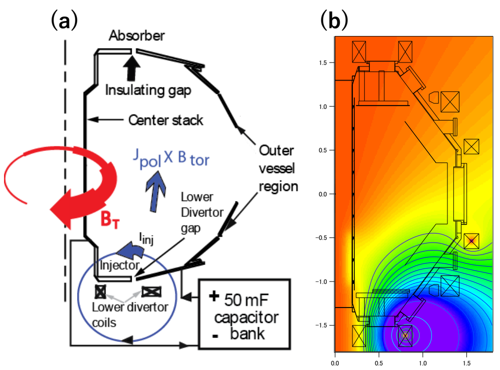

Figure 1: (a) Layout of the transient CHI startup systems in NSTX. The blue circle is the poloidal injector flux produced by the lower divertor coils. This connects the two lower divertor plates, which are insulated. Gas is injected in the region below the divertor gap. On NSTX typically a 5 to 15mF 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.

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.

[·] 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.

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 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. In order to develop viable transient CHI scenarios for QUEST, NSTX-U researchers R. Raman, B. Nelson (Univ. of Washington) and M. Ono (PPPL) visited Kyushu University in Japan December 3-14 to perform coaxial helicity injection (CHI) experiments and to discuss future CHI improvements on QUEST.

In support of these improvements, experiments were conducted in two different configurations aimed at elongating and moving the plasma column towards the center stack. In both configurations, toroidal current persistence was seen after the injector current was reduced to zero, but the CHI discharge appeared not yet fully detached from the electrode plate. Results from these studies will be used to improve the Power Supply-PF coil combinations for the next experiment that will aim at biasing the high voltage electrode plate with respect to the inboard center stack. This new configuration could further reduce the injector flux footprint width, leading to an easier detachment of the CHI plasma from the electrode plate. In addition, this configuration utilizes higher toroidal field region for CHI which could result in a higher current amplification factor and possibly higher toroidal current. During all these experiments, the CHI system and the QUEST system operated reliably without issues.

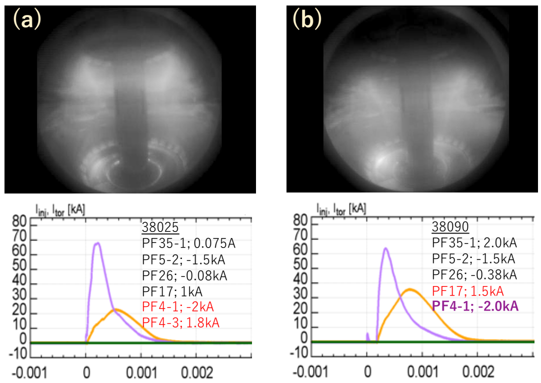

Figure 3: (a) In the top part of the discharge the plasma column has been moved away from the outer wall (which was an issue during the 2017 campaign) and moved closer to the center stack because of the pulling action of the PF4-1 coil. (b) Discharge with good current persistence in the second PF coil configuration. Note that the CHI generated toroidal current is persisting after the injector current is zero.

The two configurations differed in the choice of the power supply / PF coil configuration, and this was necessary due to the limited number of power supplies that were available to power the PF coils. In the first configuration the PF4-3 coil was used in a plasma pushing configuration to bring the oppositely directed flux footprints closer together to force reconnection, while simultaneously pulling the elongated plasma towards the center stack using the PF4-1 coil that was used in the pulling configuration. This configuration was motivated by recent TSC simulations (Fig. 2) that suggested that this configuration should be capable of generating closed flux surfaces. While the PF4-1 coil was indeed successful in elongating the plasma (Fig. 3 (a)), it was found that increasing the current in the PF4-3 coil to the needed levels caused the injector flux footprint to decrease (which is good), but at the low levels of toroidal field in QUEST, there was insufficient injector current to extend the plasma into the vessel.

In the second configuration, the power supply that was used to power PF4-3 coil was used to power the PF5-1 and PF3-1 coils in a plasma pushing configuration to achieve a similar result. In this configuration also, the PF4-1 coil was successful in elongating the plasma and pulling it towards the center stack, and the resulting plasma exhibited better current persistence, as shown in Fig. 3 (b) (i.e., the CHI generated toroidal current remained after the injector current was turned off); however, here too the current in the PF5-1 coil could not be increased to a high enough level. In addition, in this configuration, numerous other scans were conducted to better understand the role of the PF26 and PF17 coils in changing the injector flux footprint width. It was found that under some conditions that used high currents in PF5-1 and oppositely directed currents in PF6, the CHI injector electrode was prone to increased spurious arcing. These results are being studied in detail to better understand the conditions that generate these undesirable arcs. Results from both these configurations were however quite helpful in proving a path forward to assessing improvements to the CHI system on QUEST, as described below. First, it was decided that CHI on QUEST must be tested in a configuration in which the CHI electrode would be biased with respect to the inner center-stack electrode. This has the advantage that, because of the smaller radius where CHI is applied, the toroidal field in that location effectively doubles (compared to the present low-field side location). Second, it was decided that efforts must be made to initiate CHI solely by relying on the pre-fill gas used to initiate an ECH plasma on QUEST, and to increase the ECH power to much higher levels to facilitate CHI plasma breakdown. It was also considered that the ECH alone may not be adequate to establish breakdown, and the CHI gas system may be needed. At present, the CHI gas valves are outside the vacuum vessel, which considerably slows down their response time thus requiring the injection of much larger amounts of gas than is desirable for a transient CHI plasma. Efforts will be made before the next CHI campaign to move these valves inside the vessel so that they can be attached directly to the gas injector location on the electrode plate and dispensing with the long narrow tube that is presently used. In addition, because of the limited number of slow time response power supplies, we are also studying the possibility of building two low-cost capacitor-based, short-pulse, fast power supplies that could be used to power the main PF5-2 injector coil and an additional flux shaping coil (PF2 or PF5-1 or PF4-3).

In summary, the CHI hardware on QUEST has been working well allowing for very productive experimental campaigns. The short-term challenges related to forcing detachment of the CHI plasma from the electrodes will be overcome with some of the near-term planned improvements.

国際化推進共同研究概要

NO.10

18NU-2

タ イ ト ル:　　Investigation of rotation reversal near resonance layer in an EC heated/driven plasma

研究代表者:　　MISHRA, KISHORE, KANTI

所内世話人:　　出射　浩

研究概要:

電子サイクロトロン加熱・電流駆動プラズマにて、共鳴層近くでのプラズマ回転の反転を調べる。電子サイクロトロン加熱・電流駆動は、プラズマに回転トルクを与えないが、自発的に回転を始めることが、幾つかの装置実験で確認されている。QUEST でも電子サイクロトロン加熱・電流駆動プラズマにて自発回転が観測されているが、回転機構は十分に解明されていない。

電子サイクロトロン電流駆動は、第一義的にはプラズマに運動量を与えることはない。電流駆動機構は運動量励起の観点で、回転機構と類似する側面を持つ。電流駆動は、加熱された電子の衝突頻度が下がることを利用するため、回転一方向(例えば時計回り方向)に運動している電子を選択的に加熱することが有効である。捕捉電子の外側軌道、内側軌道のいずれかで共鳴層加熱されるかも重要となる。いずれにしても、一方向に運動している電子の選択加熱が問題となる。

QUEST では一方向に運動している電子の選択加熱を可能とする入射アンテナシステム・偏波器システムを開発しており、今回、一方向に運動している電子の選択加熱に基づく電流駆動に成功した。

A short report on, “Investigation of rotation reversal near resonance layer in EC heated/driven plasma”

By Kishore Mishra
Institute for Plasma Research, Gandhinagar, India, 382 428

Background and Motivation:
It is well known that plasma rotation stabilizes magneto hydro dynamics (MHD) instabilities particularly low m,n modes, locked islands, and island growth towards periphery. Torque to rotate plasma in toroidal direction can be given externally by neutral beam injection or resonant magnetic perturbation. However, at high beam energy and density like the conditions to be prevailed in ITER or DEMO reactors, externally momentum driven rotation may not be significant. Spontaneous rotation with radio frequency (RF) heating on the other hand has been observed in many tokamaks and is intrinsic in nature without any external torque injection. The mechanism of the RF induced intrinsic rotation and the ways to control it has not been understood adequately. Therefore, mechanism of spontaneous rotation after RF heating is an important topic to understand.

A focusing beam mirror system is employed to focus the EC beam near 2nd harmonic resonance layer and it could be steered to inject various N|| in to the plasma. The profiles of field intensity along the toroidal direction is shown in figure-1.

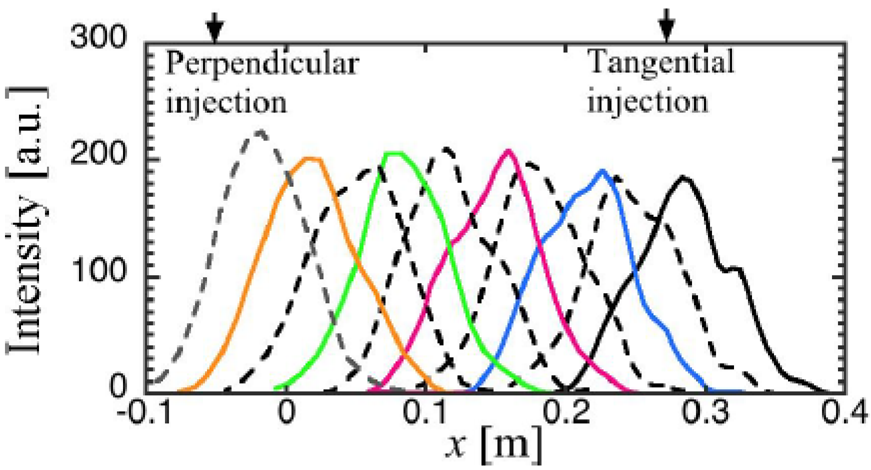

Figure- 1: Field intensity profiles of focused EC beam along toroidal direction for different mirror position injecting various N|| in the plasma. While perpendicular injection has a symmetric profile, the tangential injections have a minor deformation due to different planes of reflection at higher steered angles.

In QUEST spherical tokamak, plasma current is non-inductively started up and driven by Electron Cyclotron Waves (ECW). Spontaneous rotation of such ECW driven plasma has been observed with the help of Doppler spectroscopy and Mach probe measurements. Recent experiment with 28 GHz-ECW shows that plasma current I_p > 80 kA, could be driven with

ECWs alone. A 230 kW 28 GHz injection at N|| = 0.78 at 2nd EC resonance layer location produces a plasma current up to 80 kA fully non-inductively. This created a stable fully non-inductive target plasma for further study on effect of ECR layer in rotation reversal in QUEST.

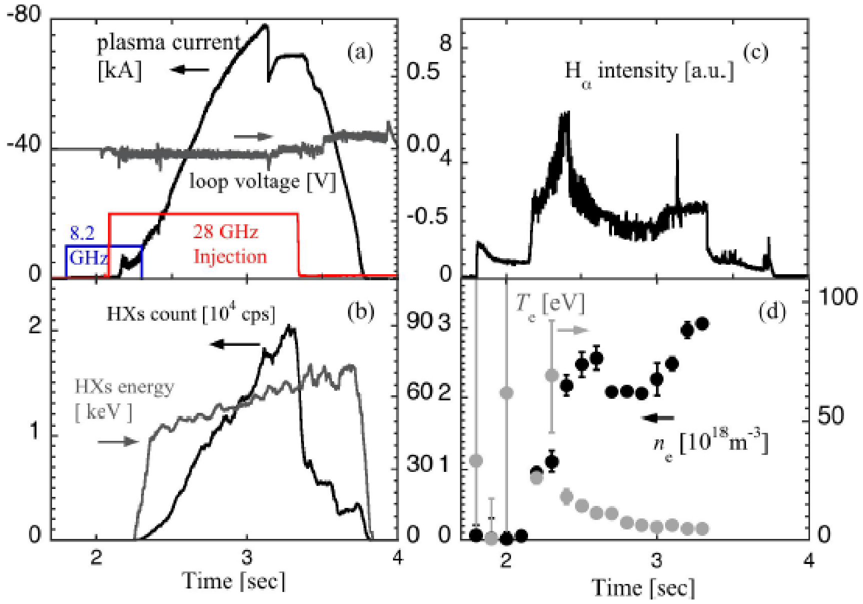

Figure- 2: Time traces of plasma current at zero loop voltage shows the fully non-inductive nature of the plasma current drive with initial assistance of 8.2 GHz EC preionization and principal 28 GHz focused EC beam to generate current. Resulting high energy non-thermal electrons generated due to EC interaction is shown by HXR counts and energy. Thermal temperature part is measured by Thomson Scattering diagnostics.

Acknowledgements:

This research is carried out under international joint research grant from Research Institute for Applied Mechanics, Kyushu University. The author gratefully acknowledges active support and guidance of RIAM collaborators Prof Hiroshi Idei, Prof. Hideki Zushi, Dr. Takumi Onchi and fruitful discussions with Dr. Santanu Banerjee. Part of this research is with a collaboration with Prof. Shikama of Kyoto University, Kyoto.

Publication and presentation

1. H. Idei, T. Onchi, T. Kariya, T.I. Tsujimura, S. Kubo, S. Kobayashi, M. Sakaguchi, T. Imai, M. Hasegawa, K. Nakamura, K. Mishra, M. Fukuyama, M. Yunoki, S. Kojima, O. Watanabe, K. Kuroda, K. Hanada, Y. Nagashima, A. Ejiri, N. Matsumoto, M. Ono, A. Higashijima, T. Nagata, S. Shimabukoro, Y. Takase, A. Fukuyama, S. Murakami, 28-GHz ECHCD system with beam focusing launcher on the QUEST spherical tokamak, **Fusion Engineering Design**, January, 2019

国際化推進共同研究概要

NO.11

18NU-3

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

研究代表者:　Carsten Lechte, Hanno

所内世話人:　出射　浩

研究概要:

国際熱核融合実験炉（ ITER ）実験では、プラズマパラメータ分布の詳細な細部制御により、燃焼プラズマを閉じ込めることが重要である。電子サイクロトロン加熱・電流駆動では、局所的にプラズマ電流を駆動することで不安定性（磁気島）を抑制することが期待されている。磁気島は kHz～10 kHz 程度の周期でプラズマ断面を回転する。磁気島の回転に併せて局所電子サイクロトロン加熱・電流駆動することで高効率な抑制が可能となる。現在、kHz～10 kHz で入射位置を変えるスイッチ素子が開発中である。本共同研究で低電力試験を実施し、さらに高電力試験準備を進めた。スイッチング素子を用いて伝送モードの純度が上がることも期待される。

Report of collaboration between RIAM and IGVP in FY2018 High- and low-power tests of the MQIV diplexer for ITER with automatic tuning at RIAM and QST

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. It will be tested at QST (Naka) in March of FY2018 at high power (400 kW) and relatively short pulse lengths of 0.1 s. Our technical partners at TNO in the Netherlands designed and built a fast mechanical tuning control unit for the device that is also vacuum-compatible. It uses feedback to nail 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. It was tested if the control can follow the frequency chirp of the gyrotron after switch-on. This chirp is much larger than the resonance width for output into the resonant channel. However, the limited pulse length did not include the full chirp. Furthermore, the switching between outputs without changing the gyrotron frequency from its optimum power configuration was tested. It is planned to expand these tests with longer pulses, pending the availability of a second long-pulse dummy load at QST.

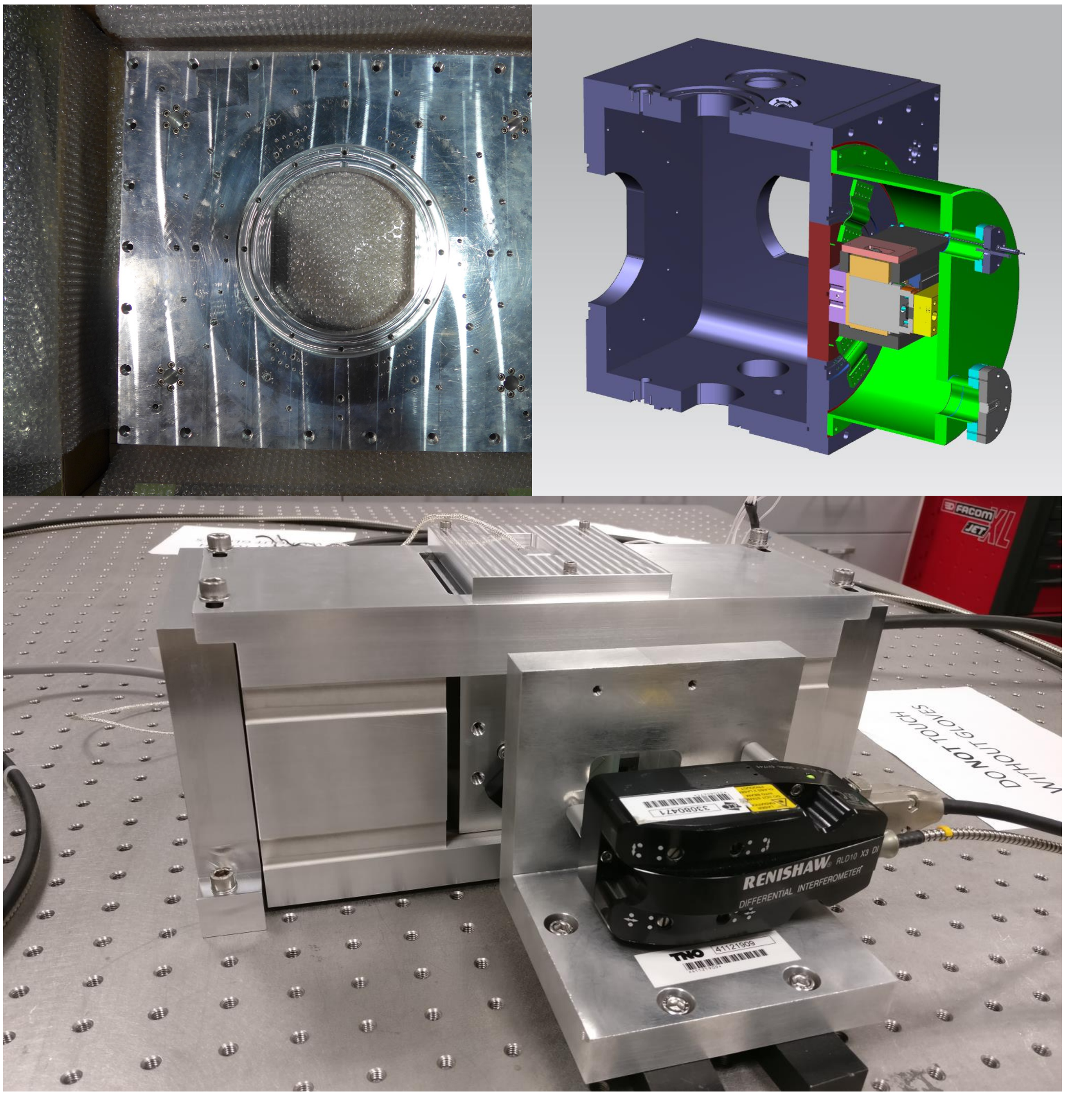

Fig 1: new diplexer lid and automatic mirror drive from TNO, NL and its integration into the diplexer system.

In this year, a new tuning system was developed by our Dutch partners at TNO. Previously, mechanical tuning was achieved manually by moving one of the resonator mirrors. The resonance curve is shown in Fig. 2.

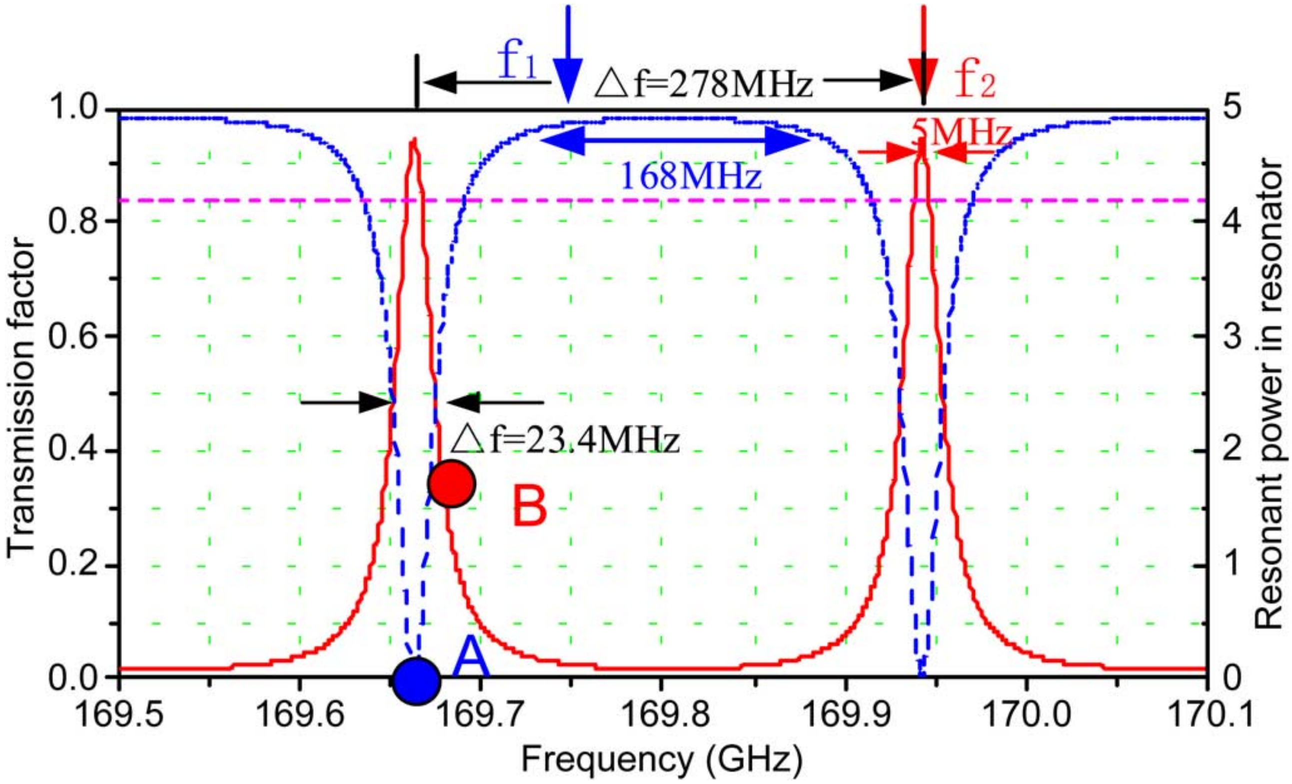

Fig. 2: diplexer resonance curve.

The resonance curve is only valid for a fixed resonator lenght. The resonance peaks shift when the length is changed, either from thermal expansion or from deliberate tuning by movement of a mirror. With this tuning, the resonances can be shift so that any frequency can be sent either to the resonant or non-resonant output port. The new automatic system uses power monitoring signals to adjust the resonator size until the input beam is coming out of the desired output port. In particular, if the input frequency changes (due to thermal expansion in the gyrotron cavity after switch-on), the system compensates for this.

国際化推進共同研究概要

NO.12

18NU-4

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:

電子サイクロトロン（EC）・電子バーンシュタイン波（ECW）加熱・電流駆動につき、GENRAY 光線追跡コードをインストールし、他の光線追跡コードとのベンチマークを実施した。QUEST で観測されているEC加熱・電流駆動時の高速電子をバルク電子とともに考慮し、入射ビームの吸収を評価、比較した。高速電子の吸収解析は、相対論的に扱う必要がある。異なるコードで同様な結果が得られる場合、異なる結果が得られる場合があり、いくつか必要なコード修正、条件修正項目が明らかとなった。

Collaboration Report

N. Bertelli

Princeton Plasma Physics Laboratory

1. Initial benchmark between four ray-tracing code has been performed
    a. GENRAY from R. Harvey
    b. TRAVIS from Maruschenko
    c. RT-4 from M. Ono
    d. TASK-WR from Fukuyama

    The ray trajectories are relatively in good agreement (Fig. 1). GENRAY and TRAVIS are also in good agreement in terms of power deposition (Fig. 2). Moreover, a stronger absorption in the X-mode with respect to the O-mode is also found (Fig. 2). On the other hand, TASK-WR results show a significantly smaller absorption with respect to GENRAY and RT-4. However, all codes show a significant 3rd and 4th harmonic absorptions observed at high temperature of the energetic electron population (Fig. 3 and 4).

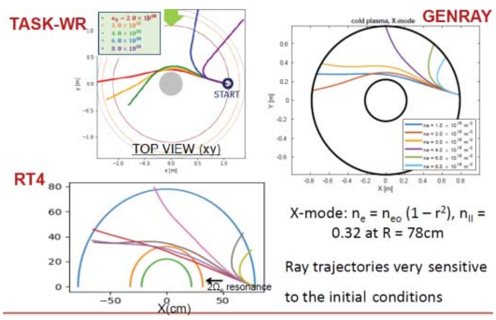

Figure 1. Ray trajectories calculated by TASK-WR, GENRAY, and RT-4

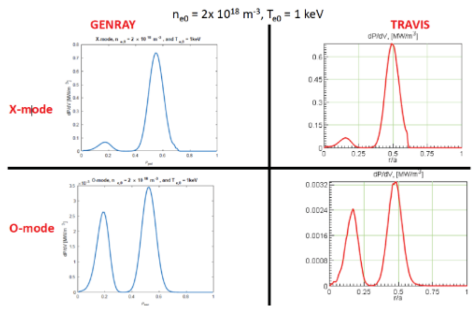

Figure 2. Power deposition profiles evaluated by GENRAY and TRAVIS for both X- and O-mode.

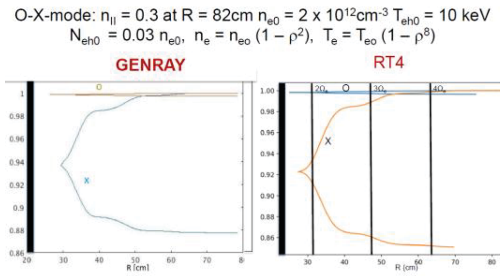

Figure 3. Power absorption along the ray trajectory calculated GENRAY and RT-4.

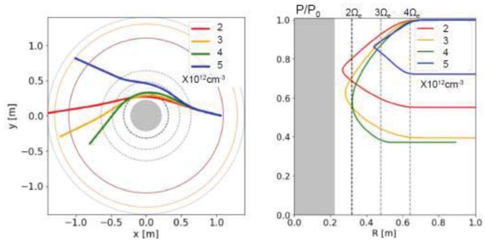

Figure 4. Ray trajectories and power absorption by evaluated by TASK-WR.

2. Fokker-Planck simulations have been performed by using CQL3D for TST-2 machine. The starting simulation was provided by H. Yamazaki, and N. Tsujii. The purpose of these simulations was to make use of the soft/hard X-ray synthetic diagnostic implemented in CQL3D in order to support the future installation of the soft X-ray diagnostic on TST-2 machine.

    a. Detector position is specified in the namelist input to be at a given position in the x-z-plane (i.e., the y = 0 plane)
    b. The X-ray detector view cord direction is specified by two angles (polar and azimuthal)
    c. The user can specify several independent sightlines.

In our simulation we used 61 cords with 1 degree step on Y=0 plane. We developed a 3D post-processing, which could help the SXR diagnostic setting (Fig. 5).
We found the SXR energy flux as a function of the photon energy (between 2 and 40 keV)- see Fig. 6.
The peak of the SXR energy flux is found off-axis corresponding to the location of the LH current drive profile evaluated by CQL3D (see Fig. 7).

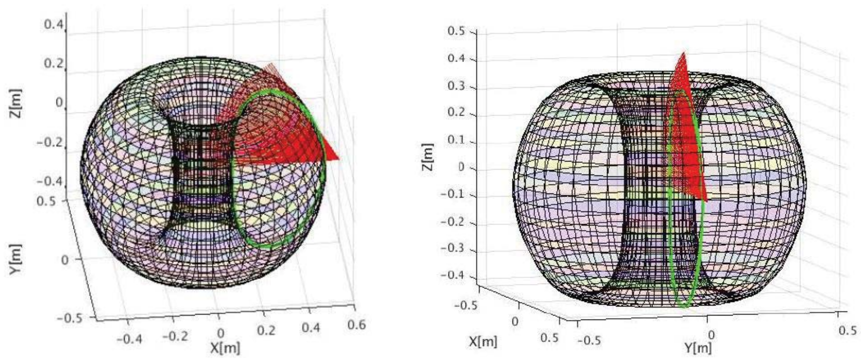

Figure 5. View cords used here to estimate the SXR flux in TST-2

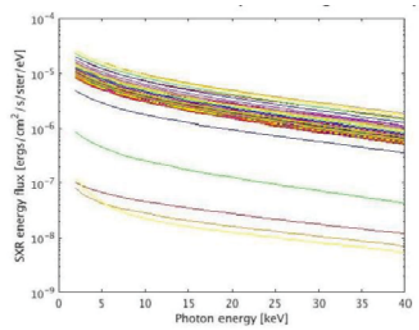

Figure 6. SXR energy flux as a function of the photon energy evaluated by the CQL3D code.

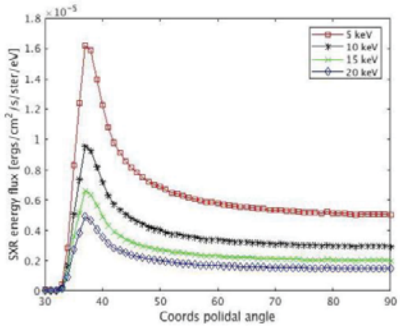

Figure 7. SXR energy flux as a function of cords poloidal angle.

3. A description of the recent extension of the ray tracing code TRAVIS to include a bi-Maxwellian distribution has been presented. Such code capability will be essential for further studies in QUEST and for continuing in the benchmark activity.

4. I gave a presentation on the High Harmonic Fast Wave full wave simulations in NSTX-U by the AORSA code to the QUEST team.

5. In collaboration with Prof. Idei we installed, built and test the ray tracing code GENRAY on a QUEST computer for future work.

COLLABORATION with QUEST

Tasks:

1) Continue the benchmark activity between ray tracing code (in collaboration with H. Idei and M. Ono and Fukuyama)
    a. Maxwellian distribution
    b. Bi-Maxwellian distribution
    c. Try to understand the discrepancies between TASK-WR and GENRAY/RT-4
2) Continue work on GENRAY/CQL3D simulations in collaboration with Idei-sensei
    a. More realistic data (?)
    b. Different dispersion relations
    c. Consider also the SXR/HXR synthetic diagnostic in CQL3D

国際化推進共同研究概要

NO.13

18NU-5

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:

球状トカマク配位は、トカマク放電で通常用いられる誘導加熱用、センターソレノイドコイルを設置するスペースを十分にとることが難しく、高周波を用いた非誘導プラズマ立ち上げ研究が精力的に展開されている。QUEST での定常プラズマによるプラズマー壁相互作用の研究では、高周波を用いたプラズマ電流駆動が不可欠である。開催されたワークショップでは、球状トカマクでの高周波を用いた非誘導プラズマ電流立ち上げ・電流駆動実験・理論解析について米国より3名の研究者、国内から6名の研究者が講演をし、議論された。

7th Workshop Agenda, RIAM 2019

31 January AM

10:00 -10:10

Masayuki Ono / Kazuaki Hanada

WS purpose and agenda

10:10 - 11:00

Kazuaki Hanada

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

11:00 - 11:10

Coffee Break

11:10 - 11:50

Yuichi Takase

LH antenna development and plasma start-up experiment on TST-2

11:50 - 12:20

Y. Ko

Wave polarization and distribution measurement in TST-2 LH-driven plasmas

12:20 - 13:20 **Lunch**

31 January PM

13:20- 14:00

Hitoshi Tanaka

Present status of EBW experiment in LATE

14:00 - 14:40

Masayuki Ono

NSTX-U Start-up Program and Modeling of the QUEST 28 GHZ Plasma Start-up Experiment

14:40 – 14:50

Coffee Break

14:50 - 15:30

Luis F. Delgado-Aparicio

High resolution soft x-ray camera for QUEST and TST-2

15:30 - 16:10

Nicola Bertelli

Initial benchmark of ray-tracing codes and Fokker-Planck simulations in QUEST plasma

16:10 – 16:50

Atsushi Fukuyama

Modeling of EC waves in tokamak plasmas using the TASK code

16:50 - **Group Photo & QUEST Machine Tour**

1 February AM

9:30 - 9:50

Martin Peng

Plans and status of a new ST experiment at the ENN, EST50

9:50 - 10:30

Kengoh Kuroda

CHI Experiments in QUEST

10:30 - 11:10

Sadayoshi Murakami

Modeling of toroidal torque by ECH and toroidal rotation measurement in QUEST

11:10 - 11:50

Shin Kubo

System design of sub-THz collective scattering measurement for electron Bernstein wave detection

11:50 – 14:00 **Lunch**

1 February PM (Drafting of proposals for experiments, diagnosis, and analysis)

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

16:30 - Masayuki Ono

Summary

Workshop on Plasma start-up and sustainment in spherical tokamak configuration by RF

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

Y. Takase
LH antenna development and plasma start-up experiment on TST-2

The capacitively-coupled combline (CCC) antenna, which can excite the LHW with high directionality efficiently with simple feeding and low reflectivity, was developed on TST-2. It was found that the antenna-plasma coupling should be moderate to excite the optimum $n_{||}$ spectrum. A variety of codes is used to model the antenna characteristics, wave excitation, propagation, and current drive. It is shown that the antenna-plasma coupling should be moderate to maintain the optimum parallel wavenumber spectrum. Successful plasma start-up and Ip ramp-up to > 25 kA have been demonstrated on TST-2. It is shown experimentally that higher Ip can be achieved with top launch (compared to outboard launch), which is in agreement with theoretical expectation that the top-launch LHW undergoes rapid upshift in parallel index of refraction $n_{||}$ and strong single-pass damping. Bottom launch can be simulated with top launch with reversed toroidal field Bt. Since the $n_{||}$ downshift occurs initially for bottom launch, poor current drive was expected, but experimentally even higher Ip than top launch was achieved. This result can be explained by further acceleration of energetic electrons to higher velocities by the downshifted $n_{||}$ LHW, after thermal electrons are accelerated by the upshifted $n_{||}$ LHW after reflection from the cut-off layer in the plasma edge region. The driven Ip was found to increase almost linearly with Bt because of improved accessibility. It also increases with top limiter height, because of larger plasma cross section. The top-launch antenna was modified to allow more space for the plasma. A circuit model based on LTspice was developed to study parameter dependences efficiently. This was useful for developing a procedure for tuning the CCC antenna for proper passband characteristics and minimizing reflection.

Y. Ko
Wave polarization and distribution measurement in TST-2 LH-driven plasmas

Wave measurements were performed on TST-2 using RF magnetic probes for three different modes of LHW excitation: outboard-launch, top-launch, and simulated bottom-launch. Experimental data are partially consistent with numerical calculation results of wave propagation and polarization. To resolve this discrepancy and for more quantitative comparison, upgrade of the RFMP system for higher spatial coverage is planned.

H. Tanaka
Present status of EBW experiment in LATE

Over dense ST plasmas with more than 7 times the plasma cutoff density are produced non-inductively with EBW mode-converted via O-X-B scheme in the LATE device. EBW is excited in the 1st propagation band and the fundamental EC resonance layer is located near the magnetic axis. High energy tail electrons with energy up to ~100 keV carry the plasma current and pressure. The bulk electrons are confined in LCFS with q0 ~ 8 and qa~ 60. In such a plasma, Sawtooth-like density oscillations in the plasma core are observed, which are synchronized with poloidal field decrement. It means the loss of high energy electrons during the crash. A part of the bulk plasma is ejected across LCFS and reaches the vacuum vessel walls along and across the magnetic field. High frequency oscillations in the Alfven eigen modes range of frequnecy appear during the crash. Preliminary potential measurement by HIBP shows that the potential increases during the crash and recover after it, which indicates the temporary loss of electrons.

M. Ono
NSTX-U Start-up Program and Modeling of the QUEST 28 GHZ Plasma Start-up Experiment

Starting tokamak without ohmic solenoid is one of the most important goals for the worldwide ST program. NSTX-U plans to test the solenoid-free electron cyclotron heating (ECH) start-up in the future and the QUEST ECH solenoid-free start-up experiment utilizing the 28 GHz gyrotron at 2nd harmonic frequency appears to be quite promising with its remarkably high efficiency achieving record start-up current values [1]. To better understand the QUEST experimental results, PPPL initiated a modeling effort in collaboration with the QUEST group [2]. Improved modeling should also help develop better predictive capability for future ST and tokamak-based reactors. An ST/tokamak start-up modeling 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. Initially, 2^{nd} harmonic electron cyclotron heating takes place with multi-pass ECH absorption as the single-pass absorption is relatively small at low temperature. The current generated in this stage is purely pressure driven since the launched wave phase and polarization information is likely lost quickly. 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. Once the closed field configuration is formed, highly focused QUEST 28 GHZ beam could heat the minority ~ 1% hot component to~ 1 keV range even with a single-pass absorption. 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. The entire start-up process is therefore a self-amplifying non-linear problem where a very rapid spontaneous plasma current rise can be expected. Once the plasma temperature becomes sufficiently high ~ 1 keV, the electron cyclotron current drive (ECCD) becomes significant. An important point to note is that two-component distribution (hot minority and colder bulk) is highly advantageous for hot electrons generation for efficient ECCD. Once heated to ~ 10 keV, the hot component could be sustained even with the subsequent density rise to 3-4 x $10^{12}cm^{-3}$. With the planned NSTX-U x-ray camera on QUEST, the behavior of hot electron population can be measured to support the modeling. The QUEST 28 GHz ECH start-up appears to scale well to higher field experiments including NSTX-U and ST-40.

[1] H. Idei, et al., IAEA 2018.
[2] M. Ono et al., APS-DPP 2018.

Work supported by US DOE Contract DE-AC02-09CH11466

Luis F. Delgado-Aparicio
High resolution soft x-ray camera for QUEST and TST-2

Nicola Bertelli
Initial benchmark of ray-tracing codes and Fokker-Planck simulations in QUEST plasma

The ray trajectories are relatively in good agreement. GENRAY and TRAVIS are also in good agreement in terms of power deposition assuming an energetic electron population. Moreover, a stronger absorption in the X-mode with respect to the O-mode is also found. On the other hand, TASK-WR results show a significantly smaller absorption with respect to GENRAY and RT- 4. However, all codes show a significant 3rd and 4th harmonic absorptions observed at high temperature of the energetic electron population.

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Detector position is specified in the namelist input to be at a given position in the x-z- plane (i.e., the y = 0 plane) The X-ray detector view cord direction is specified by two angles (polar and azimuthal) The user can specify several independent sightlines.

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A description of the recent extension of the ray tracing code TRAVIS to include a bi-Maxwellian distribution, has been presented. Such code capability will be essential for further studies in QUEST and for continuing in the benchmark activity.

COLLABORATION with QUEST Tasks:

1) Continue the benchmark activity between ray tracing code

(in collaboration with H. Idei and M. Ono and Fukuyama)
Maxwellian distribution
Bi-Maxwellian distribution
Try to understand the discrepancies between TASK-WR and GENRAY/RT-4
2) Continue work on GENRAY/CQL3D simulations in collaboration with Idei
More realistic data
Different dispersion relations
Consider also the SXR/HXR synthetic diagnostic in CQL3D

16:10 – 16:50
A. Fukuyama
Modeling of EC waves in tokamak plasmas using the TASK code
The integrated tokamak modeling code TASK is still under development for analyzing wave behavior and transport phenomena in toroidal plasmas. For EC wave physics, the component WR is used for ray and beam tracing analysis, and WM and WF2D are used for full wave analysis with cold plasma approximation. Kinetic full wave analysis of O-X-B
mode conversion was carried out by 1D component W1. Extension to 2D configuration is under way. Analysis of energetic electron generation by the Forker-Planck component FP is also planned.

M. Peng
Plans and status of a new ST experiment at the ENN, EST50

K. Kuroda
CHI Experiments in QUEST
CHI on a new design electrode configuration is developing on QUEST, that make easier introducing the system to a reactor. On the 4th experiment, CHI evolution for closing flux was investigated on two field configurations. Measurement data will be beneficial to find out the CHI evolution mechanism and necessary conditions for closing flux. We plan to do improvement gas injector system and attempt of high field side inject configuration on the 5th experiment. On the experiment, reducing generation of strong arcs, increasing temperature, lowering injector current for expanding flux with narrow footprint and Increasing current multiplication are expected.

S Murakami
Modeling of toroidal torque by ECH and toroidal rotation measurement in QUEST
We have studied the toroidal flow generation by ECH assuming the crucial roles of the supra-thermal electrons in non-axisymmetric toroidal plasmas.The JxB and collisional toques by ECH are evaluated using GNET code in the non-axisymmetric tokamaks. We have found significant torques by ECH due to the toroidal ripples and RMPs. The experimental measurements of the toroidal rotation have been started and comparisons with the simulation results in QUEST will be presented at the next workshop 2020.

S. Kubo
System design of sub-THz collective scattering measurement for electron Bernstein wave detection
It is necessary to drive steady state toroidal current by electron Bernstein wave (EBW) in QUEST. For the well-controlled and well-optimized current drive and heating, documentation of the EBW is important. Direct detection of EBW by the scattering of sub-THz wave due to the excited electron Bernstein wave clarifies the physics of EBW mode conversion, propagation, and absorption. The sub-THz wave at 400 GHz gyrotron developed at Univ. Fukui can be used for the scattering source and planned to be installed before Autumn 2019. The design of the scattering measurement system is progressed. To get rid of the limitation of the accessible port, corrugated plates on the center post are under design. Steering mirror system will be installed in one of horizontal ports and probing /scattered beam are injected/received as a -1st diffracted beam at the corrugated plates on the center post. The design method uses the idea of quasi-optical grating concept which is extended from quasi-optical mirror design method.

国際化推進共同研究概要

NO.14

18NU-6

タ イ ト ル:　Study of edge turbulence and search for edge coherent modes（ECMs）and their effect on plasma confinement and transport in QUEST

研究代表者:　BANERJEE, SANTANU

所内世話人:　出射　浩

研究概要:

SOL プラズマに類似したプラズマとしてスラブプラズマを生成し、磁場シア、磁力線の接続長の観点で、励起されたプラズマ揺動に関し、解析した。揺動は高速カメラによって観測した。揺動を特長づける統計量の解析後、揺動の周波数解析、分散解析を進めた。磁場シア、磁力線の接続長で揺動特性が変わることを明らかにし、学術論文としてまとめた。

Report on the international joint research for 2018-19.

Topic: Study of edge turbulence and search for edge coherent modes (ECMs) and their effect on plasma confinement and transport in QUEST

Santanu Banerjee
Research Scientist
Department of Applied Science
College of William and Mary
Williamsburg, VA 23187-8795, USA

Previously:
Scientific Officer – E,
Institute for Plasma Research,
Bhat, Gandhinagar 382 428, Gujarat, INDIA

During the tenure of this collaborative research, Intensity fluctuations are investigated using the fast camera imaging technique in the slab annular plasma as a function of magnetic shear and connection length in the spherical tokamak QUEST. Note that here QUEST is operated as a simple magnetized torus with a tight aspect ratio. Slab annular plasmas feature open magnetic field lines and can mimic the tokamak edge-scrape off layer (SOL)-like plasma attributes reasonably well. Three magnetic shear regimes are realized using three poloidal magnetic field (PF) coil pairs. A whole range of connection lengths ($\sim\infty \geq$ Lc $\geq$ 5.5 m) is scanned by varying the PF strength for a given toroidal field for each magnetic shear regime. For the first time a systematic study of the effect of magnetic shear and field line pitch together on edge-SOL-like plasma fluctuations is being reported. Slab plasmas with intermediate magnetic shear are observed to be more susceptible to generate distinct blobs when Lc is reduced by increasing the PF strength. A distinct coherent mode appears only at the lowest magnetic shear slab featuring a deep potential well. Such mode is not apparent at other magnetic shear cases even at the same Lc. Finally, with a combination of PF coil pairs, both the features of intermediate and low magnetic shear slabs are shown to be realizable simultaneously. Significantly stronger blobs are observed with such combination of PF mirror ratios in the presence of a coherent mode. This study may provide better insight into the effect of magnetic configuration in the tokamak edge and SOL turbulence and can help in searching for better tools to control cross-field convective intermittent transport in tokamaks.

Experimental detail

Slab-annular plasmas, intersecting the divertor plates, are initiated with hydrogen and using ECRH at 2.45 GHz continuous wave (CW), and pulsed with 8.2 GHz ECRH. In this pulsed phase, the 8.2 GHz ECRH driven slab plasma dominates. Plasmas extend vertically near the resonance layer R_{res} (~0.24 m) corresponding to the resonant field of B_{t_res} = 293 mT, and diffuse outwards depending on RF power and Bz/Bt. Bz is varied in both curvature and strength by different poloidal field coil combinations (PF17, 26 and 35-12) and coil currents. B_t is kept constant in the experiment. PF strength can be quantified in terms of the pitch distance $\Delta_z = 2\pi R B_z/B_t$, connection length of field lines $L_c = 2\pi R 2b/\Delta_z$ between the two divertor plates and pitch angle $\vartheta = \tan^{-1}(B_z/B_t)$. While referring to L_c, we always specify it at R=0.48 m, which is slightly away from the source plasma and coincide with the ECR 2nd harmonic. This radial location also represents the density gradient region and has been interpreted as the blob generation location earlier. PF curvature can be demonstrated in terms of the magnetic shear

$S_m = \frac{R}{\vartheta}\frac{d\vartheta}{dR}$ and the mirror ratio $\varepsilon = (B_{t\_div}/B_{t\_mid})$. For ε, the field lines starting at the second harmonic layer on the mid-plane, are traced to calculate B_t at the launching (B_{t_mid}) and terminating point on the divertor (B_{t_div}). Three distinct S_m regimes for three PF coil pairs ($S_m \sim$ 1.05 for PF17, ~ 0.85 for PF26, and ~ 0.65 for PF35-12 at ECR 2nd harmonic) are realized. These three coil pairs will be referred, henceforth in the text, as HiMS (PF17 with High S_m), InMS (PF26 with Intermediate S_m) and LoMS (PF35-12 with Low S_m). Corresponding ε are, provides deep (PF35-12), shallow (PF26), and negative (ε <1 for PF17) potential wells, respectively.

Statistical analysis:

Statistical features have been reported in detail earlier for slab annular plasma as well as Ohmic HFS limited plasma, as a result of this collaboration, in QUEST. However, for slab annular plasma generation, 2.45 GHz ECRH was used in the earlier work with only InMS. Here we intend to report the characteristics of slab annular plasma as a function of magnetic shear Sm. The fluctuation amplitude is the highest for the InMS configuration as compared to similar Lc for the LoMS and HiMS configurations. In fact, the fluctuation amplitude grows steadily with the field line pitch for InMS, as reported earlier, and finally distinct blobs start to appear when Lc is ≤10 m. Distinct blobs with intermittent intensity bursts can be seen at Rsf. However, we could not achieve Lc <14.5 m for LoMS or HiMS due to coil current rating and power supply limitations for these coil pairs.

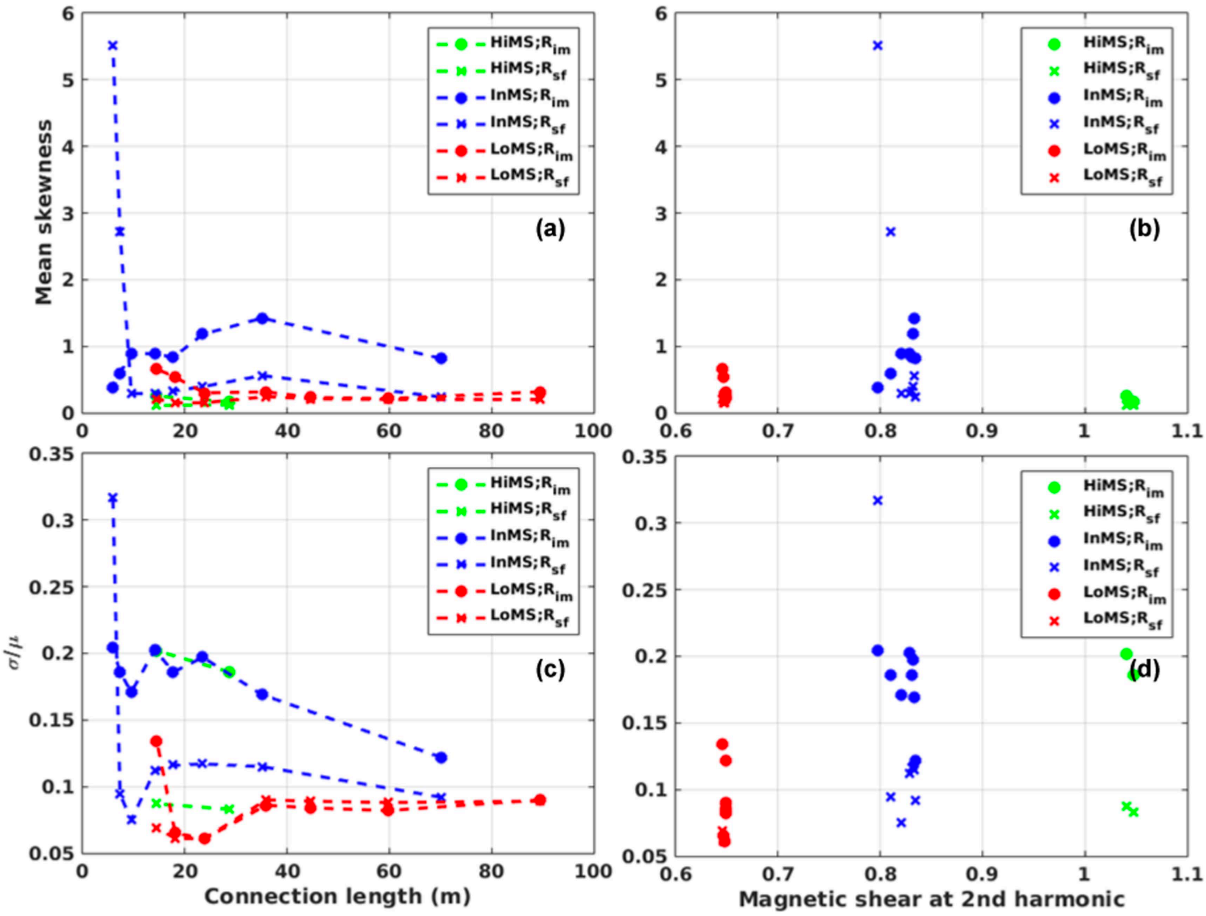


Fig. 1: (a)–(b) s_{mean} for the three coil pairs as a function of L_c and S_m, respectively; (c)–(d) variation of σ/μ similar to (a)–(b).

Intensity fluctuations from each pixel are considered as raw time series signals. PDF p(x) of the time series is characterized by the mean (μ) and variance (σ^2). The higher order moments of the p(x)-like skewness s and kurtosis k characterize the shape of the PDF. These shape factors can be explored to understand the statistics of the fluctuations leading to the physical stochastic principles. Higher skewness indicates the fluctuations to be driven toward intermittency. Figure 1 shows the variation of mean skewness (s_{mean}) at Rim and Rsf, with connection length Lc (a) and magnetic shear Sm (b), respectively. smean is calculated for the skewness at all pixels in the poloidal direction and 3 pixels radially about the central location of a given radial region. smean stays slightly higher for InMS as compared to HiMS and LoMS. smean stays predominantly higher at Rim as compared to Rsf. It is worthwhile to recollect here that Rim is the steep intensity (density) gradient region and is identified as the location of blob generation. smean increases a bit for InMS, at both Rim and Rsf, with decreasing Lc till Lc ~ 35 m and then drops off gradually. As Lc reduces to ~10 m, smean goes down fast at Rim, while shooting off abruptly at Rsf. This is a result of the blobs detached from the main plasma column and traversing through Rsf. Such blobs are now abundant at the Rsf for Lc ≤ 10 m. A similar trend has been seen for σ/μ variation. σ/μ may be treated as the root mean square (rms) fluctuation level, normalized to the mean, for a given time series signal. There is a peculiarity with HiMS in this regard. It can be noted that even if the rms fluctuation level is predominantly higher at Rim, comparable to InMS, yet the PDF continues to remain near-Gaussian all along. Further, it seems that if Lc can be reduced below ~10 m for LoMS, distinct blobs are likely to be observed for this magnetic shear. However, for HiMS, an upward trend is not apparent in smean as Lc is lower. It can be noted again that HiMS is the only coil pair with negative field line curvature and ε<1. At Lc ~ 15–25 m, there seems to be a rather quiet region with both smean and σ/μ tending to achieve a minima for both InMS and LoMS.

Spectral features of fluctuations

A. Fourier analysis

Fig. 2 shows the spectrograms for intensity fluctuations at R_s (a) and R_{im} (b) respectively for LoMS at L_c = 14.5 m. At R_s, this mode appears at ~3.5 kHz and then gets downshifted slightly to ~2.5 kHz at R_{im}. It has been seen that the mode has two radially localized lobes, one strong lobe at ~2 cm around R_{im} and the other relatively weaker lobe at ~10 cm inside R_{im}. Further, this mode has a long poloidal span of ~40 cm.

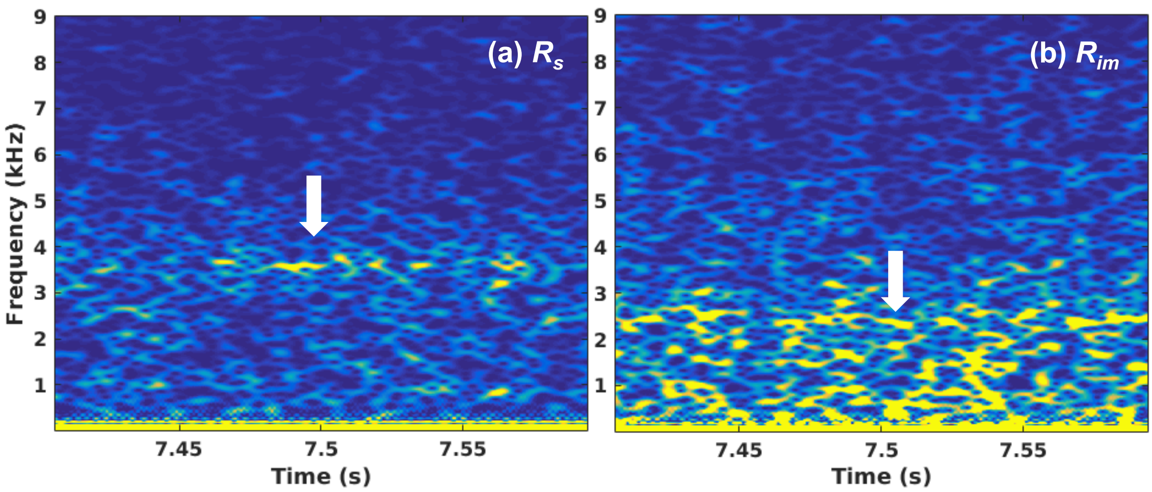


Fig. 2: (a)-(b): spectrograms for 200 ms at R_s and R_{im} respectively; The coherent mode at 3.5 kHz and 2.5 kHz at R_s and R_{im} respectively is shown by white arrows.

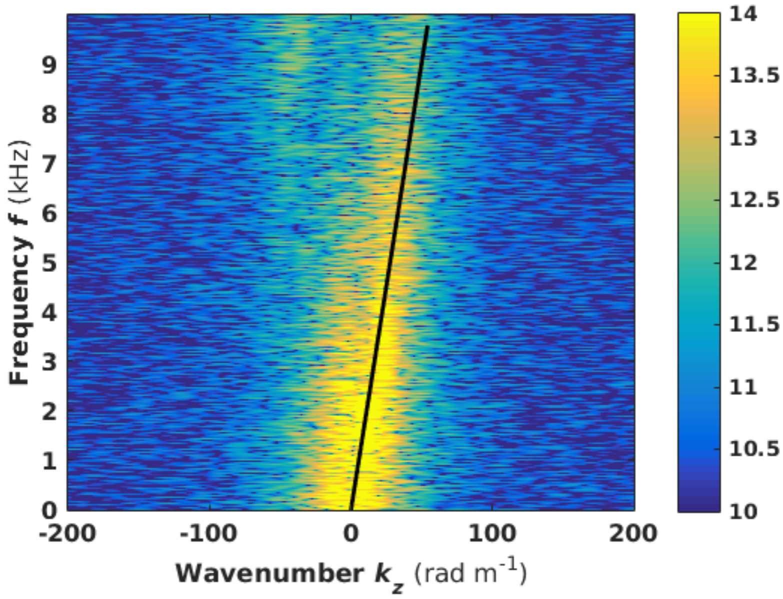


Fig. 3: InMS with L_c=5.9 m; Turbulence characteristics at R_{im} in poloidal wavenumber and frequency (k_z-f) space. $k_z > 0$ corresponds to propagation vertically up, in the IDD. Black solid line represents the linear fit.

B. Wavenumber frequency (kz-f) spectra

A two-dimensional discrete Fourier transform (DFT) estimate of the poloidal wavenumber-frequency (k_z-f) spectra for intensity fluctuations at R_{im} is shown for L_c = 5.9 m in InMS in Fig. 3. The colorbar denotes the magnitude of DFT. All along the radial direction k_z-f spectra shows a single lobe with $k_z > 0$ fluctuations, which means fluctuation (both broadband and the coherent mode) propagation is vertically upward in the ion diamagnetic drift direction (IDD). The measured k_z-f spectra can be fitted by a single linear dispersion relation ($f = v(k)k / 2\pi$) up to moderate range of frequencies such that poloidal $v_{ph} = v_g$ for a broad range, as shown in Fig. 3. The black solid line represents the linear fit and hence poloidal phase velocity v_{ph} can be calculated. For the representative case with InMS and Lc=5.9 m, v_{ph} at R_{im} is 1.1 km s^{-1}. v_{ph} stays in the range of 1±0.1 km s^{-1} for the L_c variation considered in this experiment. However, for LoMS, v_{ph} is 0.5±0.1 km s^{-1}.

Combination of mirror ratios

With all these observations, the next logical step would be to combine the mirror ratios by simultaneous operation of two or more coil pairs. In other words, it is rather obvious to look for solutions where the distinctive features of the individual coil pairs can be combined. The goal is to see if the amplitude or frequency of the blobs, seen in InMS operation, can be altered by introducing the coherent mode seen in LoMS operation. Here we try to maintain the value of Lc for a comparison of the only InMS case with the case with a combination of InMS and LoMS. Figure 4 shows the bursty intensity time series at Rsf for similar Lc in the corresponding cases. In figures 4(a)–(b) Lc is maintained at ~7 m. This is the limiting Lc for detached blob observation. Lc variation within the corresponding cases is within 3%. In figures 4 (c)–(d) Lc is maintained at ~7 m. Brisk blob activity can be seen here. Lc variation is within 7% in these corresponding cases. It can be seen in both the values of Lc, even though the variation in Lc is small enough, the blob strength has increased by ~70%. Figure 4(e) shows the PDF p(x) of the waiting times for blobs at Rsf for Lc = 5.9 m. Fluctuation data from 5 pixels at Rsf, placed at an inter-pixel distance of 2 cm vertically, are stacked to obtain better statistics for blobs. p(x) shows an exponential distribution with the black solid line denoting the exponential fit. Thus, the blob generation process can be interpreted as a Poisson process occurring continuously and independently at a constant average frequency. The fitting parameter λ for p(x) is 4 ms and does not change significantly with the combination of mirror ratios. So, it can be concluded that in the presence of the coherent mode, a feature of the LoMS operation, the InMS blob strengths are increased drastically while the average blob frequency remains unchanged.

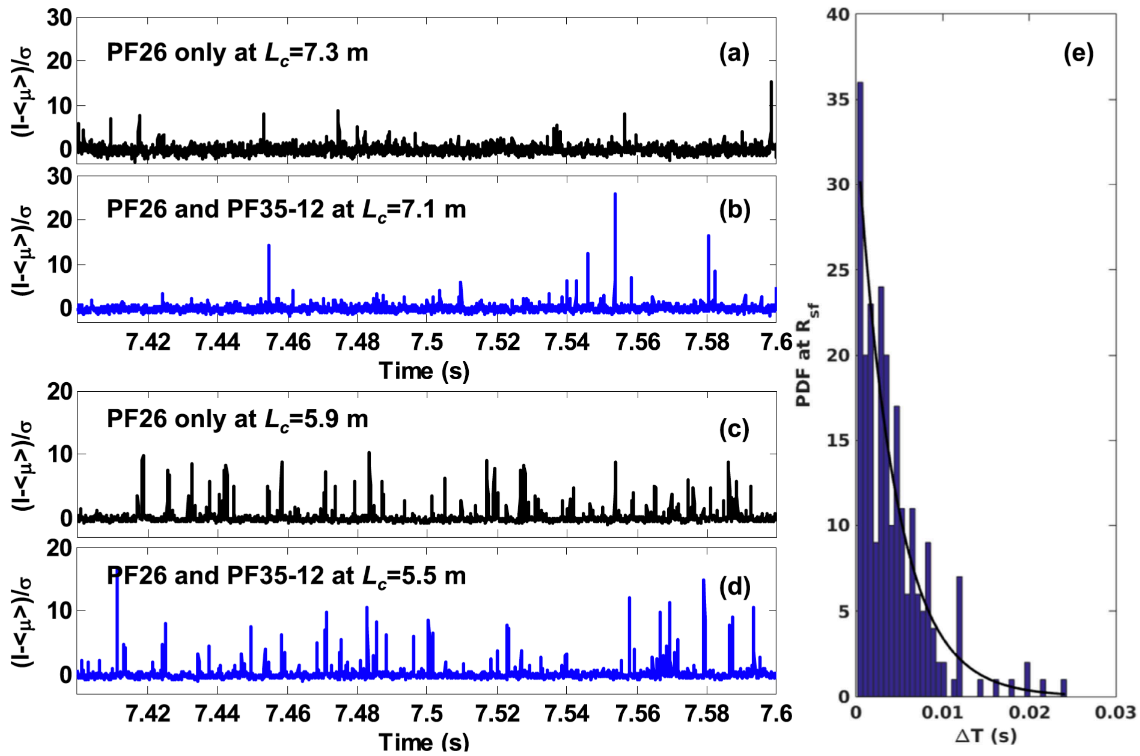


Fig. 4. (a)–(b) Fluctuation of characteristics at Rsf showing blob-dominated transport for Lc ~ 7 m with InMS alone and a combination of InMS and LoMS, respectively; (c)–(d) same for Lc ~ 6 m; (e) PDF of the waiting times for blobs at Rsf for Lc = 5.9 m.

Summary of the analysis done

Fluctuation characteristics are observed to differ considerably with the variation in magnetic shear (S_m). Slab plasmas with intermediate magnetic shear (InMS) are more susceptible to generate blobs with decreasing connection length (L_c). Slabs with low magnetic shear (LoMS) feature triggering of a coherent mode at ~ 3 kHz as L_c is decreased below ~ 18 m. Slabs with high magnetic shear (HiMS) are the most stable and are not likely to generate blobs or coherent modes even at similar L_c as that of their other S_m counterparts. At InMS, fluctuations are dominated by broadband turbulence while, at LoMS, drift wave predominance is observed. Propagation direction of fluctuations remains in the ion diamagnetic drift direction (IDD) similar to tokamak SOL. Propagation velocity is double in case of InMS as compared to LoMS. Finally, when the PF coil pairs for InMS and LoMS cases are combined, considerably stronger blobs with similar average blob frequency are observed in the presence of the coherent mode. Hence, such suitable combination of magnetic shear can be used as a tool to modify the density gradient scale length at the edge, edge turbulence characteristics and thereby control the cross-field convective intermittent transport across the LCFS in tokamaks.

Acknowledgements

I gratefully acknowledge the support of my collaborator Prof. H. Idei. I also acknowledge the help and support offered by Prof. K. Hanada, and all other AFRC staff during the tenure of this collaborative effort. This work was supported by the International Joint Research Program of the Research Institute for Applied Mechanics (RIAM), Kyushu University, JAPAN.

Publications and presentations regarding this collaboration during 2018-19.

Publications:

1. **Santanu Banerjee**, H. Zushi, N. Nishino, K. Hanada, H. Idei, K. Nakamura, M. Hasegawa, A. Fujisawa, Y. Nagashima, K. Mishra, S. Tashima, T. Onchi, A. Kuzmin, and K. Matsuoka, "*Effect of magnetic shear on edge turbulence in SOL-like open field line configuration in QUEST*", Plasma Phys. Control. Fusion **60** (2018) 085014

国際化推進共同研究概要

NO.15

18NU-7

タ イ ト ル:　Develop and improve EFIT code of the plasma equilibrium reconstruction for SSO operation and advanced physical study on QUEST

研究代表者:　QIAN, Jinping

所内世話人:　花田　和明

研究概要:

センターに導入された平衡計算コード EFIT は、波動伝搬コード GENRAY と連動させて実験結果の解析に使用されている。今後はフォッカーフランクコード CQL3D との連動を行う予定であり、EFIT 解析の重要性が高まっている。今年度は28GHzの高周波入射実験の解析を行い、実験結果との整合性を確認した。解析結果については現在論文投稿準備中である。

（様式 11・拠点）

RESEARCH REPORT

Date Feb.20 2019

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) Feb. 12, 2019 (to) Feb. 18, 2019

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 Tuesday 12th Feb. 2019. During this visit, QUEST did not start experiments of this campaign, Hanada, I and Hatem had a talk on the status of QUEST equilibrium reconstruction using EFIT. In some cases, EFIT cannot well converged for with the error of finding plasma boundary.

In the following days, Hatem and I had discussions on how to fix this problem. At the very beginning, Hatem showed that two sets of flux data were poor recently. A temporary solution is using the artificial flux data with the assumption of up-down symmetry, where the poor flux data were replaced with the good flux data. Note that the reason for poor data in the flux loop is not clear. Then we worked together, checking the connection of PF coils & power supply, update EFIT and EFUND, benchmarking FLUX data. Most of the calculated flux loop can match the measurement very well after using the correction of flux data and the new version of EFIT. A comparison of calculated flux loop versus measurement is shown in figure 1. Then, we optimized the flux loop data by switching on and off signal in the input file, together with the fitting weight. An example of EFIT reconstruction is given in figure 2. Meanwhile, a time dependent of stored energy is shown in figure 3. The stored energy reasonably increases with the increase of plasma current (shown in figure 2) during the period from 2.3 to 3s for discharge 35673.

Since QUEST has limited power supply, different discharges may have different coil connections. This will require a different version of EFIT for equilibrium reconstruction. Next, we will think about how to generate a general version which can be used for all of PF connections.

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.

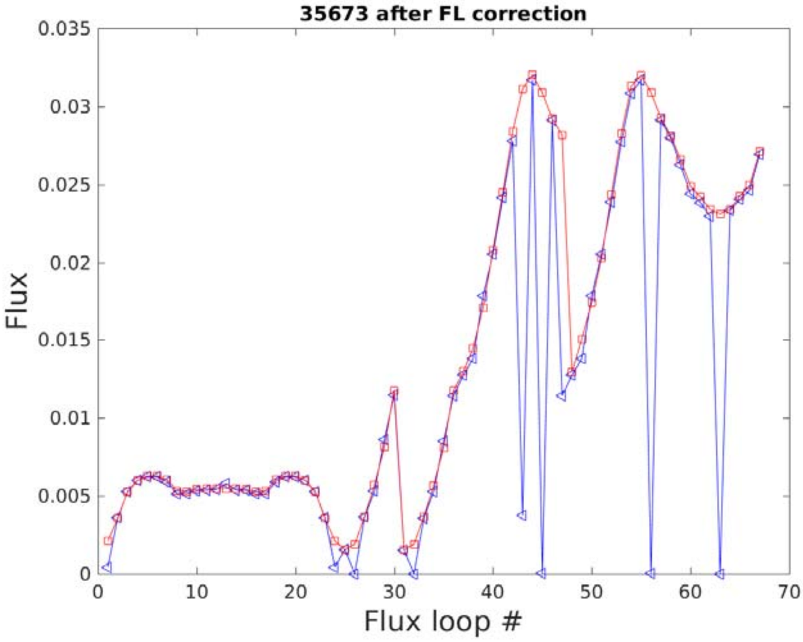


Figure 1, comparison of flux loop data, where red square and blue triangle are corresponding calculation and measurements separately.

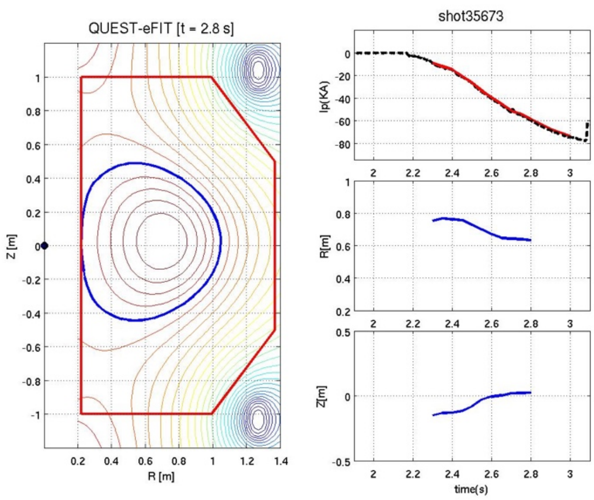


Figure 2. Equilibrium reconstruction with updated EFIT, left: flux contour, right (top to bottom): plasma current , horizontal and vertical positions.

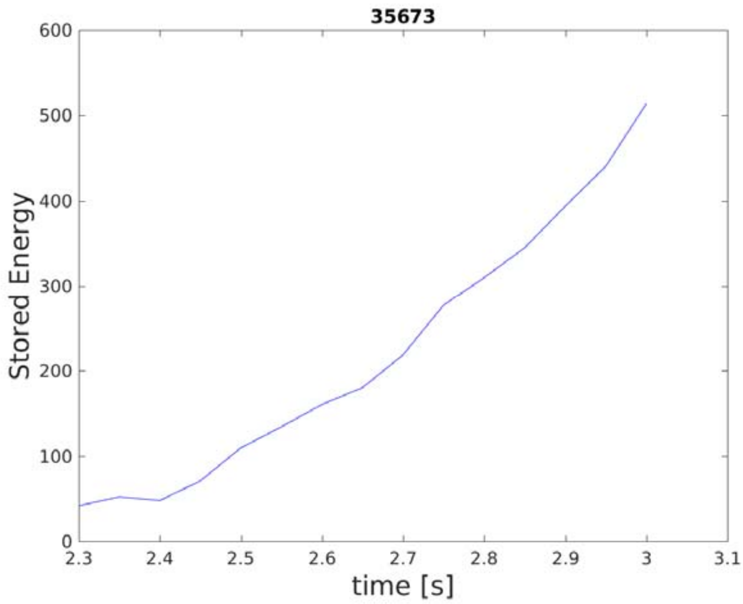


Figure 3, time evolution of stored energy from EFIT

(Signature) J. Qian

(Name in print) Jinping Qian

国際化推進共同研究概要

NO.16

18NU-8

タ イ ト ル:　Joint study of long pulse high beta discharges and related egde turbulence transport in steady state operation (SSO) plasmas on QUEST and EAST

研究代表者:　GAO, Xiang

所内世話人:　花田　和明

研究概要:

今年度は、定常運転実現で重要な課題である粒子リサイクリングに関する情報交換を行った。QUEST で開発された壁モニタリングの手法[1-3]が EAST にも適応できるかを検討するため、典型的な放電での放電後のガス放出のデータを取得し、解析を始めた。この手法が EAST にも適応できるようなら、他の装置への適応も含めて大きく発展する可能性がある。

[1] Hanada, K., Yoshida, N., Honda, T., Wang, Z., Kuzmin, A., Takagi, I., ... Mitarai, O. (2017). Investigation of hydrogen recycling in long-duration discharges and its modification with a hot wall in the spherical tokamak QUEST. Nuclear Fusion, 57(12), [126061]. https://doi.org/10.1088/1741-4326/aa8121

[2] Hanada, K. et al., submitted to Nuclear Materials and Energy

[3] Hanada, K., et al. submitted to Nuclear Fusion

（様式 11・拠点）

RESEARCH REPORT

Date: Feb. 20, 2019

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) Feb. 12, 2019 (to) Feb. 19, 2019

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 addition, turbulence driven transport plays an important role in long pulse high beta plasma with SSO. In QUEST and EAST, limit cycle oscillations (LCO) had been observed in L-LCO-L and L-LCO-H. So joint study of the turbulence transport on QUEST and EAST will provide some key understandings. The combined study will be helpful for understanding the underlying physics of LCO and helpful for obtaining H mode plasma on QUEST. It is benefit for the long pulse high beta discharges of EAST and QUEST.

New results, limit cycle oscillations (LCO), on QUEST and EAST in 2018

On QUEST, A new limit cycle oscillations (LCO) was obtained during Fully non-inductive plasma, shot No. 22069, with RFCD by 28GHZ and 8.2 GHz, as shown in Fig.1.. [C. B. Huang et al., Presentation during this visit]. In this discharge, two 8.2 GHz and 28 GHz electron cyclotron resonance (ECR) system are used on QUEST. 2D-SXR system can see the core of plasma, as well as 2nd and 3rd harmonic layer of 8.2 GHz ECR at Bt_0 = 0.13 T. The LCO can observed during the L-LCO-L transition on QUEST. The LCO can both observed by SXR system and Ha signals, which suggests that the LCO is related with density fluctuations , as shown in Fig.2..

The LCOs also can be observed by multi-channel AXUV measurement. The signals from AXUV, SXR system, Ha system all indicate the LCOs had relations with the density fluctuations and located at around the pedestal area. The store energy of plasma and the turbulence of plasma should have Prey-Predator relations during the LCOs on QUEST. It is similar with the LCOs during the L-LCO-H phase of other devices. That is to say, during this shot, the RF heat power is near to the power threshold of L-H transition of QUEST. Of course, we should find the more clearly evidence, Er fluctuations at around this oscillations, to make sure of our conclusions. If this is can be validated by other diagnostics, we can easily to increase RF heating power with same experimental conditions to achieved H mode Plasmas on QUEST.

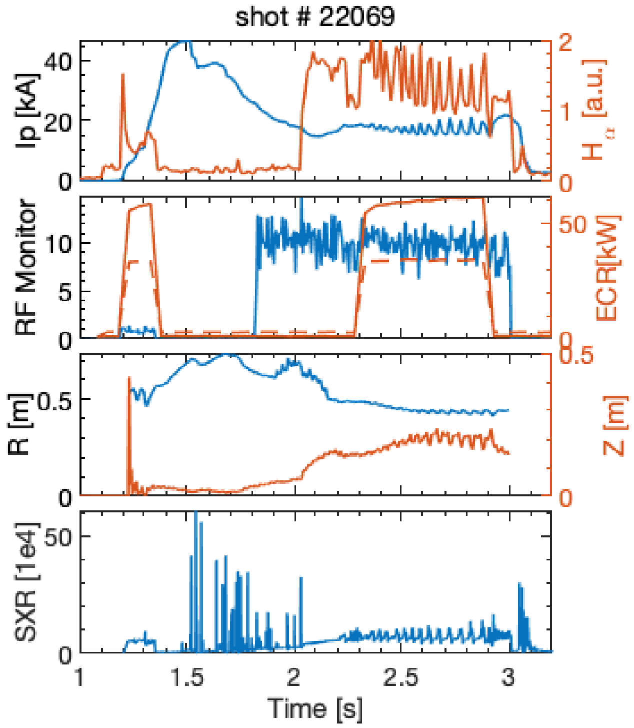


Figure 1 A new limit cycle oscillations (LCO) was obtained during fully non-inductive plasma on QUEST (C. B. Huang et al., Presentation during this visit).

On EAST, limit cycle oscillations (LCO) was also observed during L-LCO-H transitons in many shots, as shown in Fig. 3.. According to the Staebler's model for the low-to-high (L-H) confinement transition, which based on a new paradigm for turbulence suppression by velocity shear. As evidenced, for the first time, by the direct observation of a turbulence radial wave number spectral shift and turbulence structure tilting prior to the L-H transition at tokamak edge by direct probing on EAST. The new mechanism does not require a pretransition overshoot in the turbulent Reynolds stress, shunting turbulence energy to zonal flows for turbulence suppression as demonstrated in the experiment on EAST. The experimental results show that the evolution of pressure gradient near the separatrix for the LCO dynamics. The pressure gradient near the separatrix is proportional to the pressure difference between the inner side of the separatrix and the SOL. It is found in the experiments that a reduction in the SOL pressure significantly contributes to the increment of pressure gradient near the separatrix. This pressure gradient controls the EF, which has been shownto play an important role in the transition physics. An exponential decay in the divertor Dα emission as well as the GPI emission intensity in the SOL are observed during the quiescent period in each dithering cycle, on a time scale of the SOL particle confinement, ~ 500 μs. During the quiescent period, the particle and heat sources in the SOL are significantly reduced, since the cross-field transport is blocked by the flow shear at the plasma edge. The particle and heat in the SOL are therefore gradually exhausted through parallel transport, resulting in the exponential decay. When a turbulent transient enhancement occurs, the accumulated pressure inside the separatrix during the quiescent period is rapidly released by the strong turbulent ejection, which replenishes the SOL with fresh particles and heat, leading to a quick recovery of the SOL pressure.

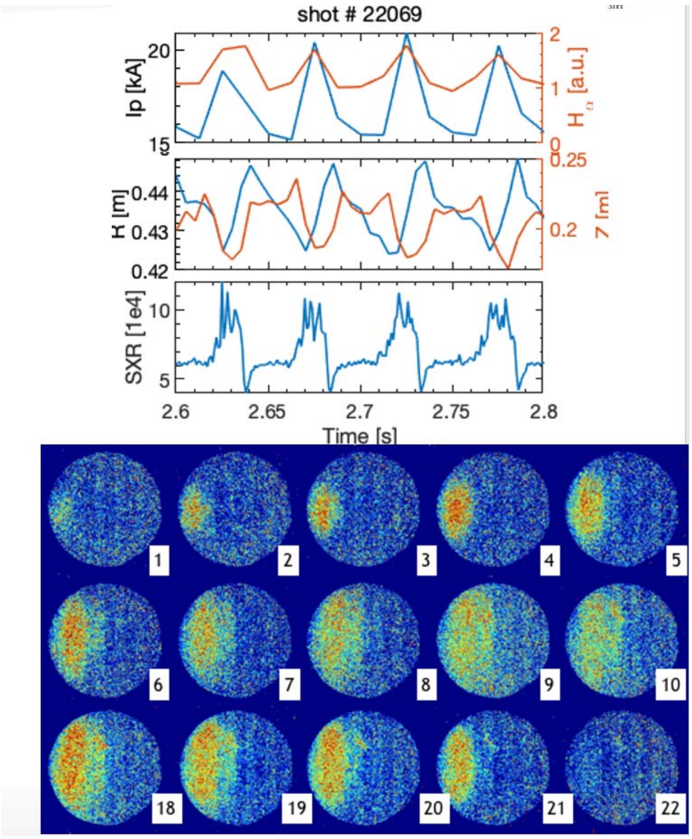


Figure 2 The LCOs were observed by SXR system and Ha signal (Mr. Huang's Presentation).

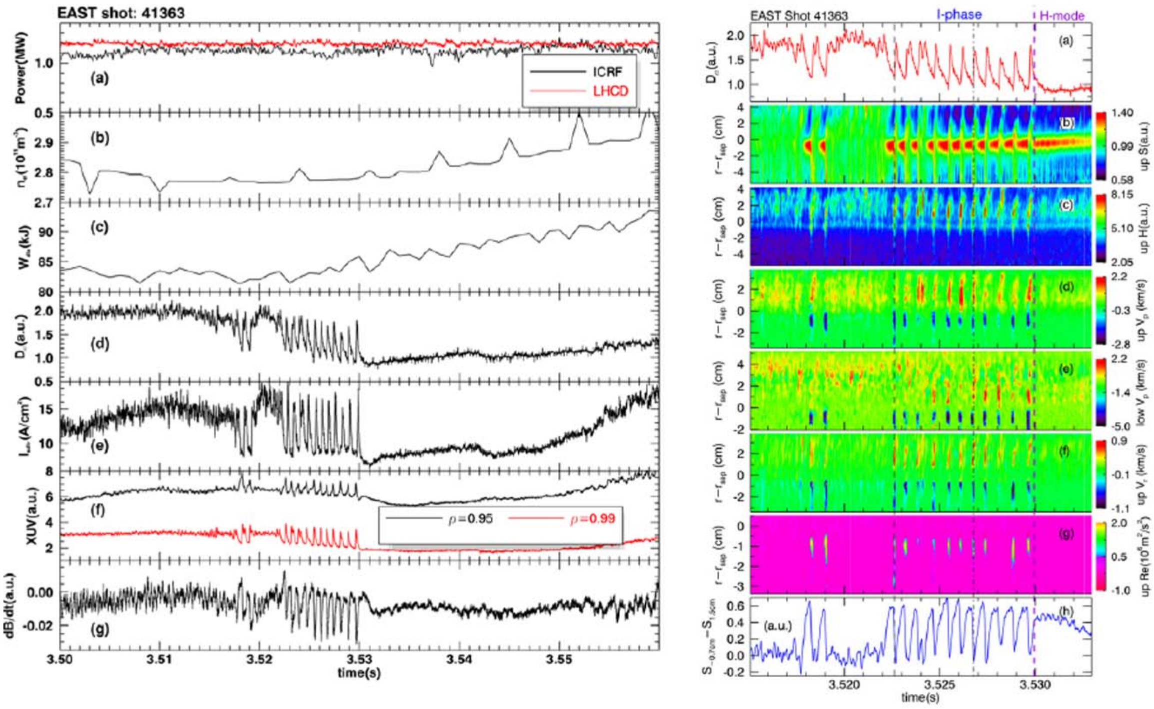


Figure 3 Limit cycle oscillations (LCO) was observed on EAST

Some critical issues still need to be addressed in future work. For example, recent experiments suggest that the ZFs may not play a dominant role in some types of LCOs . On the other hand, supposing the zonal flows really play a significant role in the L–H transition, how to explain the transition power threshold scaling based on the zonal-flow-related microscopic dynamics? To address these questions, experiments need to develop new diagnostics to measure turbulence, density and temperature gradients, and all flow components in the main ion radial force balance equation simultaneously on different device. We will focus on the studying of limit cycle oscillations (LCO) on EAST and QUEST. To understand the underlying physics mechanism of LCO is important for obtaining steady state high performance plasma. The LCO had been found during L-H transitions on EAST and also had been found during L-LCO-L on QUEST. The combined study will be helpful for understanding the underlying physics and obtaining H mode plasma on QUEST. It is benefit for the long pulse high beta discharges of EAST and QUEST.

Discussions

QUEST and EAST are both to develop the scientific basis for achieving a steady state condition. Now here has a new start point for the comparative and joint study on QUEST and EAST, especially in high beta discharges, high performance SSO operation. The joint study results now and in future may shed light on the ITER SSO scenario.

During this visit, several interesting topics are also involved in discussions. Those are "2D-SXR imaging system on QUEST", "Inner null diverter configuration" , "limit cycle oscillations (LCO)" and "Heat transfer interface coupled with turbulence flow by COMSOL" etc. in QUEST and EAST. 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 2018. 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. Ms. Kawamura and Ms. Yamaguchi 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.

Co-Publications in 2018:

[1] X. Gao,…, H.Q.Liu,…,K. Hanada, et al., ITPA-PEP TG meeting, Saint-Paul-lès-Durance, France, Oct.29-31, 2018

(Signature)________________________________

(Name in print) Xiang Gao

国際化推進共同研究概要

NO.17

18NU-9

タ イ ト ル: Joint study of calorimetric measurement of heat load and power balance estimation in steady state operation (SSO) plasmas on QUEST and EAST

研究代表者: LIU, Haiqing

所内世話人: 花田　和明

研究概要:

QUEST で開発されたパワーバランスの解析手法を EAST に適応している。すでに装置の設置は終了し、初期的なデータは論文化[1]されている。今年度は EAST のデータの詳細を解析し、論文を投稿予定である。本手法は、EAST 側で広く受け入れられて、現在 EAST 側で費用を負担して全プラズマ対向壁への熱入力を計測できるように改良されている。

[1] Liu, Y. K., Hamada, N., Hanada, K., Gao, X., Liu, H. Q., Yu, Y. W., ... Li, G. S. (2017). Preliminary study on heat load using calorimetric measurement during long-pulse high-performance discharges on EAST. Plasma Physics and Controlled Fusion, 59(4), [045009]. https://doi.org/10.1088/1361-6587/aa5d88

（様式 11・拠点）

RESEARCH REPORT

Date: Feb. 20, 2019

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

(position) **Professor**

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

Chinese Academy of Sciences

(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) Feb. 12, 2019 (to) Feb. 19, 2019

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 ($10MW/m^2$) is coming to the diverter (vertical heat target) locally from the plasma in the future fusion reactor, the heat load distrubution (power 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. From 2019, 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, and even provide experience for blanket calorimetry to measure plasma reactivity in burning plasma experiment. QUEST device, the temperature measurement has been done to measure water cooled movable limiters and other part PFCs. Although the strong modification of plasma configuration was applied, much of the heat load to the outer vessel was still remained. It means that the heat load is mainly supplied from energetic electrons which are generated by injected RF electric field. The SMITER field line tracing code together with its graphical user interface (GUI) provides a simulation framework for variety of use cases. Its main uses at ITER Organisation are:

- Power deposition mapping for first wall and divertor plasma-facing components
- Input to control algorithms and production of synthetic surface temperatures for diagnostic design.

To compare and combine the experimental results and simulation results by SMITER in both EAST and QUEST device is benefit to understand the head load and power balance issues. The measurement of heat load and researching of power balance in EAST and QUEST will provide crucial support for ITER and CFETR.

Recent progress on QUEST and EAST

On QUEST, the calorimetric measurement had done of direct loss of energetic electrons. Two movable water-cooled limiters made of W were installed to effectively remove the heat load from the energetic electrons. Total heat load on MLs located in LFS is corresponding to 10% (5kW) of the inject RF power (50kW) and approximately constant, selectively heat flows into MLs that is locally protruding plasma side. Additionally, heat load of the MLs is due to the plasma which is strongly dependent on the magnetic field lines structure. Heat load on MLs is not due to the bulk plasma as a result from that the distance between the position of outermost magnetic surface and MLs, greatly accelerated energetic electrons at the resonant layer by RF injected hits the MLs directly.

On EAST, the record longest steady-state H-mode plasma was achieved (#73999 discharge) with a upper single null divertor configuration; it lasted 101.3 s at a plasma current of 0.4 MA, and a confinement enhancement factor H98,y2 of 1.1. Figure 1 shows the evolution of plasma parameters for the discharge. The plasma stored energy and radiated power loss increase gradually after 69 s, at which time a number of events occurred.

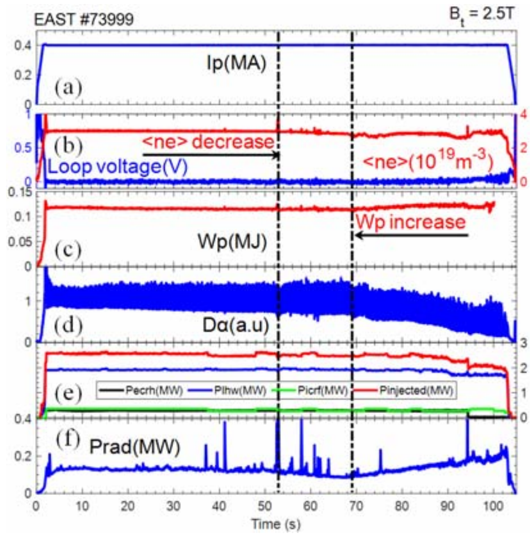


Figure 1. Time evolution of the (a) plasma current Ip, (b) loop voltage and central line averaged density <ne>, (c) plasma stored energy Wp, (d) intensity of the Dα emissions, (e) RF heating power (Pecrh, Plhw, Picrf) and total auxiliary heating power Pinjected, and (f) the radiated power loss Prad.[Y. K. Liu's presentation, this visit]

Figure 2 (a) shows waveforms for the incremental changes in cooling water temperature in the A, C, E modules. As the discharge with the longest steady-state H-mode plasma under the upper single null divertor configuration, the maximum value of the temperature difference in the A module is 9.1°C. It should be noted that the water temperature increment of the A module reached changeless after 28 s, then decreased after 55 s. Then increment speed of temperature difference in the E module increased aaccording to the time evolution of gradient of temperature difference (Figure 2 (b)). This indicates that the heat load distribution on the first wall was significantly changed, which appears to be inseparably linked to the slight variations in the magnetic configuration. Simulated results for water temperature on the A module using the COMSOL multiphysics software coupled with heat transfer in solid and fluid interfaces and the k-ε turbulent flow interface is almost same as the experimental temperature data, despite a 0.7 °C gap during the evolution platform, where a heat load of 119.5 MJ for the simulation is hypothetical in accordance with heat load measured by calorimetry (Figure 2 (a)). The heat load measured by calorimetry diagnostic was 114.5 MJ; the difference is very small, and so the hypothetical heat load on the A module is reasonable. However, the integral heat load utilizing simulated water temperature according to equation (1) is 129.4 MJ. The 9.9 MJ difference reflects the computing process of the COMSOL multiphysics software, and in particular the mesh structure and size. A delayed time of thermal conduction of 26 s is identical between simulation and experimental results. During entire 105 s discharge, equilibrium remained stable, but the lower outer strike point gradually moved, which is considered as the cause of the appearance and disappearance of hot spots. As the lower outer strike point moved to the high field side, more obvious hot spots appeared. This suggests that the tile in this position has a bulge compared with other outer dome tiles for which there were no hot spots. Hot spot distribution was not toroidally uniform, but was localized. That is to say, the main reason of the termination of the long pulse plasma is the water cooling ability of lower graphite divertor is not enough. So the ITER-like tungsten divertor will be installed in the lower divertor in near future.

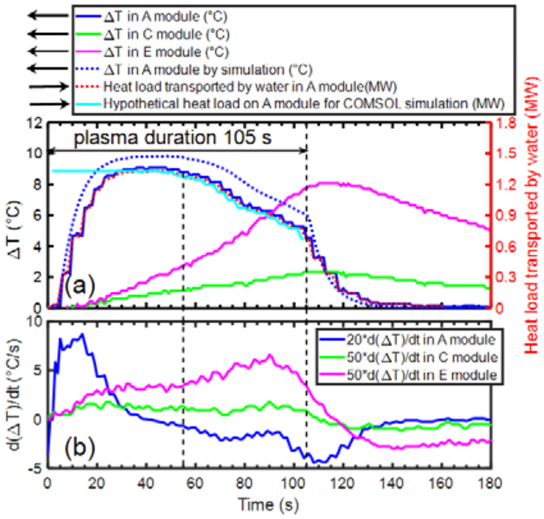


Figure 2. (a) Time evolution of cooling water temperature difference in the A, C, E modules (blue line, green line, and magenta line, respectively), temperature difference simulated by COMSOL (dotted blue line), heat load transported by cooling water in the A module (dotted red line) for the # 73999 discharge, and hypothetical heat load on the A module from COMSOL simulation in accordance with heat load measured by calorimetry (cyan line). (b) the temperature difference gradient of the A, C and E modules (blue line, green line, and magenta line, respectively). [Y. K. Liu's presentation, this visit]

The SMITER field line tracing code together with its graphical user interface (GUI provides a simulation framework for variety of use cases, as shown in Fig.3.. Its main uses at ITER Organisation are:Power deposition mapping for first wall and divertor plasma-facing components; Input to control algorithms and production of synthetic surface temperatures for diagnostic design. It is a good tool to do the power deposition mapping on EAST and QUEST. We also can use the COMSOL to do the head load simulations. Then we can combine the experimental results and simulation results on QUEST and EAST. To investigate the head load, heat transfer, particle balance and so on for steady state operation. The new analysis and new results will provide crucial support for ITER and CFETR in near future.

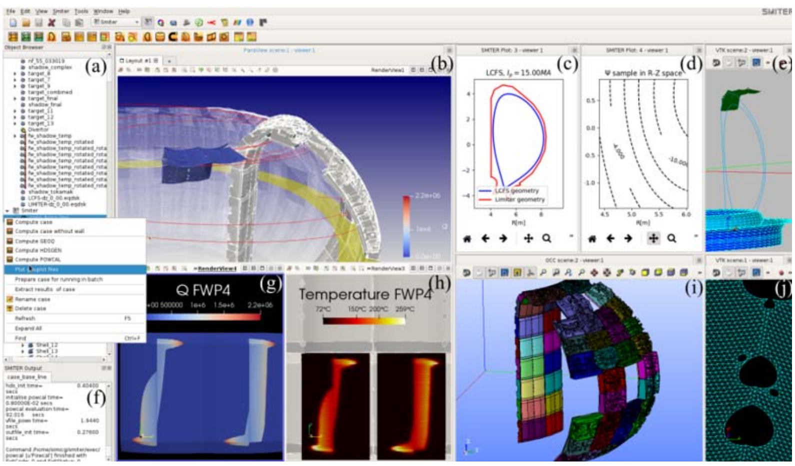


Figure 3. SMITER Graphical user interface for ITER .[Y.K.Liu's presentation during this visit]

Discussions

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.

During this visit, several interesting topics are also involved in discussions. 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 2018. 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. Ms. Kawamura and Ms. Yamaguchi 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.

Co-Publications in 2017:

[1] X. Gao,…, H.Q.Liu,…,K. Hanada, et al., ITPA-PEP TG meeting, Saint-Paul-lès-Durance, France, Oct.29-31, 2018.

Publications which had acknowledged to "the Collaborative Research Program of the Research Institute for Applied Mechanics, Kyushu University" in 2018:

[1] S. X. Wang, H. Q. Liu et al., Nucl. Fusion 58(2018) 112013.
[2] W. M. Li, H.Q.Liu, et al., Journal of Instrumentation 13(2018) C02011.
[3] Z.Y.Zou, H.Q.Liu, et al., Review of scientific instruments, 89 (2018) 013510.

(Signature)____________________________________

(Name in print) Haiqing Liu, Yinxian Jie

国際化推進共同研究概要

NO.18

18NU-10

タ イ ト ル:　Electron Bernstein wave heating with XB mode conversion fron low field side launch

研究代表者:　HWANG, Yong-Seok

所内世話人:　花田　和明

研究概要:

今年度は LFS と HFS 入射の比較実験を実施した。初期実験結果は論文[1]にまとめられているが、当初計画していた本研究を行うことはできなかった。今後は取得したデータの解析を共同で行う予定である。

[1] Plasma and Fusion Research, Rapid communication, Hatem, et al. to be published.

Electron Bernstein wave heating with XB mode conversion from low field side launch

Hwang, Yong-Seok (Seoul National Univ., Korea)

Abstract

Electron Bernstein wave (EBW) heating and current drive is considered as one of the most important tools in Spherical Torus (ST). Over-dense plasmas beyond L cutoff are successfully generated via direct XB mode conversion with low field side (LFS) X mode injection at the very low microwave frequency of 2.45 GHz in the VEST pre-ionization experiments. Mode conversion for over-dense plasmas at higher frequencies with shorter wavelength can be realized only when sufficiently high density gradient at the upper hybrid resonance is provided by any means. This simple scheme is examined at higher heating frequency of 8.2GHz with appropriate magnetic field strengths in QUEST. In the recent QUEST operation with 28GHz ECCD and CHI experiments, plasmas with electron densities of $4-6\times 10^{18}\ \#/m^3$ and electron temperatures of ~100eV are measured with Thomson scattering.[1] For the measured plasma density profile with various peak density values, mode conversion efficiencies are estimated to be as high as 96% when microwave with 8.2 GHz is injected from LFS in X mode. Experimental confirmation will be attempted in the next year's international joint research.

Introduction

We have been working on EBW heating in VEST at Seoul National University. Over-dense plasmas are generated for pre-ionization by applying 2.45 GHz microwave in X mode from LFS via direct XB mode conversion. Efficient penetration and mode conversion with LFS X mode injection are successfully explained with both Budden parameter analysis and numerical simulation with one-dimensional full wave code. [2,3] Even for the frequency of 8.2 GHz equipped in QUEST, possibility of significant XB mode conversion efficiency with LFS injection were proposed by expecting much steeper density gradient near UHR than that of the VEST at the low frequency of 2.45Hz. Recently, high power heating systems such as 28GHz and CHI successfully generate high density plasmas, which may provide sufficient density gradient for efficient mode conversion for the 8.2GHz microwave system. These target plasmas are utilized to get optimal mode conversion efficiency for 8.2GHz EBW heating.

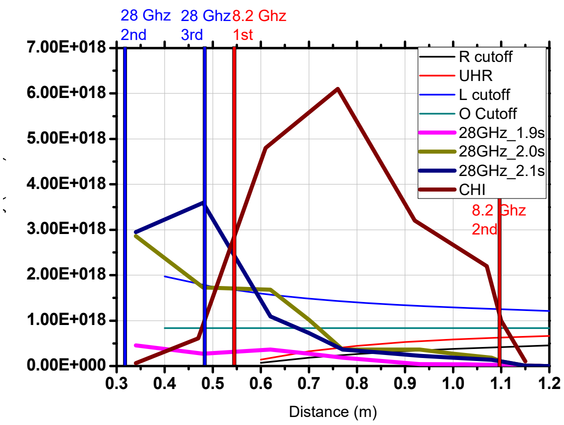
Method

Electron density and temperature profiles are measured with Thomson scattering in QUEST. With the measured profiles, mode conversion efficiencies for the 8.2GHz RF system are estimated with one-dimensional full wave simulation. For higher XB mode conversion efficiency in QUEST with the 8.2 GHz heating system, higher plasma density should be generated for steep density gradient near UHR by providing trapped particle configuration (TPC) with high mirror ratio via better particle confinement.[4] Various combinations of PF coils need to be utilized for appropriate density profiles as well as high peak density with better mirror trapping in high power 28GHz ECCD experiments.

Results

One-dimensional full wave simulation has been performed for the QUEST heating system at the frequency of 8.2 GHz. Recent high density profiles measured with Thomson scattering are utilized as shown in Fig. 1. Once it is mode converted, converted Bernstein wave can meet either second harmonic or fundamental electron cyclotron resonances, providing efficient heating without density cut-off. With the measured plasma density profiles provided in Fig. 1, XB Mode conversion efficiencies are calculated to be from 22% (at 2.0sec) to 29% (at 2.1sec) as shown in Fig. 2, which is believed to be due to low plasma density gradient at UHR layer between 0.7m and 0.8m. Relatively low plasma density in QUEST may be due to the low absorption efficiency of the second harmonic resonance of the 28GHz heating system. Moreover, since the resonance position is very close to the inner wall, density gradient at the UHR layer is still small even with relatively high peak density of 4× 〖10〗 ^18 #/m^3. Trapped particle configurations with high mirror ratios from different sets of poloidal field coils will be attempted to increase plasma density gradient at the UHR layer for higher mode conversion efficiency.

On the other hand, if the peak density is increased to 6×10^{18} $\#/m^3$ as shown in CHI case, this low efficiency is expected be increased with steep density gradient compared to the profile of the 28GHz heated plasma case. However, the case for CHI looks still much lower mode conversion efficiency even with higher plasma density and density gradient. In this case, XB mode conversion may become low since density gradient becomes too high compared to the optimal mode conversion efficiency.[5] When we reduce the gradient by half or two thirds with artificially reduced peak density, then the conversion efficiency is expected to be increased up to 85% or 96%. These mode conversion efficiencies may be attempted experimentally by adjusting plasma density with different operating pressure at CHI experiments.



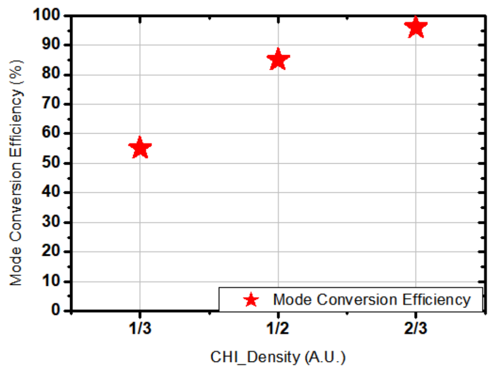


Fig. 1 Various density profiles measured in QUEST Fig. 2 Estimated mode conversion efficiencies for CHI cases with different peak densities for the same density profile

References

[1] Kishore Mishra, H. Zushi, H. Idei, M. Hasegawa, K. Hanada and QUEST team, "High βp plasma formation using off-axis ECCD in Ohmic heated plasma in the spherical tokamak QUEST", EPJ Web of Conferences 87, 02012(2015)
[2] S. H. Kim, H. Y. Lee, J. G. Jo and Y. S. Hwang, "One-dimensional full wave simulation on XB mode conversion in electron cyclotron heating", Phys. Plasmas 21, 062108 (2014)
[3] JongGab Jo, H. Y. Lee, S. C. Kim, S. H. Kim, Y. H. An, and Y. S. Hwang, "Efficient pre-ionization by direct X-B mode conversion in VEST", Phys. Plasmas 24, 012103 (2017)
[4] YoungHwa An, et. als, "Efficient ECH-assisted plasma start-up using trapped particle configuration in the versatile experiment spherical torus", Nucl. Fusion 57, 016001 (2017)
[5] Heinrich Peter Laqua , "Electron Bernstein wave heating and diagnostic", Plasma Phys. Control. Fusion 49, R1–R42 (2007)

国際化推進共同研究概要

NO.19

18RE-2

タ イ ト ル:　Computational and experimental analysis for marine renewable energy development

研究代表者:　WAN, Decheng

所内世話人:　胡　長洪

研究概要:

国際化推進共同研究「Computational and experimental analysis for marine renewable energy development」について今年度は 2 年目で, 共同研究・研究集会とも予定通り実施した。共同研究について、洋上浮体の渦励起運動を高精度予測するための CFD 手法及び水槽実験手法に関する検討であり、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。12 月 8 日～9 日に国際研究集会「International RIAM Symposium on Ocean Renewable Energy Technologies and Related Computational and Experimental Researches」を開催され、外国から7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必要な理論解析方法及び水槽実験方法の高精度化・高効率化に関して有意義な国際研究集会となった。

Report for 2018 RIAM International Joint Research Project

[18RE-2]

Computational and experimental analysis for marine renewable energy development

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. Therefor 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 aims to provide an opportunity for researchers, especially younger researchers in SJTU and RIAM, to exchange their knowhow on development of computational and experimental tools for the purpose.

2. Research Plan

(1) Carry out collaborative research between SJTU and RIAM, in the area of advanced modeling of VIM for various kinds of offshore platforms, most of which are performed by means of model tests in towing tanks or numerical simulations based on Computational Fluid Dynamics (CFD). And the hydrodynamic characteristic of ship in restricted water, including maneuverability, propulsion of propeller.

(2) Evaluate the flow around floating circular cylinders, as a motivation for better understanding the VIM of platforms and to guide the actual design work of offshore platforms. Evaluate the maneuverability of ship based on body force method of propeller.

(3) Organize an international symposium in the end of each fiscal year, in which relative researchers will present and discuss their research results

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)
Guanyu Zhang	SJTU	PhD student	Co-researcher (CFD)
Aiqin Miao	SJTU	PhD student	Co-researcher (CFD)
Zheng Li	SJTU	PhD student	Co-researcher (CFD)
Makoto Sueyoshi	RIAM	Assistant professor	Co-researcher (experiment)
Cheng Liu	RIAM	Posdoc	Co-researcher (CFD)
Changhong Hu	RIAM	Professor	RIAM Attendant

3. Summary of Collaboration Research

In 2018, modern offshore structures are often designed to have deep draft stabilized columns and low gravitational center. These column structures are subject to motions that are induced by the periodical fluctuation forces and vortex shedding when currents velocities exceed a few knots. The CFD simulation of a semisubmersible with multi-columns and squared-pontoon hull configuration is performed using CFD method. To resolve the turbulent wake structures and predict the wake interference between columns and pontoons, a DES turbulence model (SST-DDES) is employed. An unstructured moving grid approach (overset mesh) is adopted to avoid mesh distortion and to support the arbitrary large movements of the hull. Besides, overset mesh is used widely in the simulations of ship, especially for the large movement in the maneuverability and sea-keeping. The maneuverability of ship in restricted channel is very specific since the hydrodynamic performance of ship and propeller will be affected by the wall. Currently, the studies on the maneuverability of ship and propeller in open water are carried out with RANS turbulence model.

International conference papers related to this joint research project in 2018 are listed as follows.

1) Zhenghao Liu, Decheng Wan, Changhong Hu, Numerical Investigation of Regular Waves Interaction with Two Fixed Cylinders in Tandem Arrangement, the ASME 2018 37th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2018, June 17-22, 2018, Madrid, Spain, OMAE2018-78373
2) Yang Huang, Decheng Wan, Changhong Hu, Numerical Study of Wake Interactions between Two Floating Offshore Wind Turbines, the Twenty-eighth (2018) International Ocean and Polar Engineering Conference Sapporo, Japan, June 10-15, 2018, pp.541-548
3) Ping Cheng, Decheng Wan, Changhong Hu, Numerical Simulations of Flows around Floating Offshore Wind Turbine, the Twenty-eighth (2018) International Ocean and Polar Engineering Conference Sapporo, Japan, June 10-15, 2018, pp.414-421
4) Xinze Duan, Ping Cheng, Decheng Wan, Changhong Hu, Numerical Simulations of Wake Flows of Wind Farm with Fourteen Wind Turbines, the Twenty-eighth (2018) International Ocean and Polar Engineering Conference Sapporo, Japan, June 10-15, 2018, pp.519-526
5) Jianhua Wang, Lu Zou, Decheng Wan, Numerical Simulations of Zigzag Maneuver of Free Running Ship in Waves by RANS-Overset Grid Method, Ocean Engineering, 2018, 162: 55-79
6) Weiwen Zhao , Lu Zou , Decheng Wan, Zhiqiang Hu, Numerical Investigation of Vortex-Induced Motions of a Paired-Column Semisubmersible in Currents, Ocean Engineering, 2018, 164: 272–283.
7) Jianhua Wang, Lu Zou, Decheng Wan, Numerical Simulations of Zigzag Maneuver of Free Running Ship in Waves by RANS-Overset Grid Method, Ocean Engineering, 2018, 162: 55-79.

As a main event of this international joint research project, 'International RIAM Symposium on Ocean Renewable Energy Technologies and Related Computational and Experimental Researches' was held on December 8-9, 2018. 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. Jiawei He, PhD Student, Shanghai Jiao Tong University, China
3. Zhen Ren, PhD Student, Shanghai Jiao Tong University, China

The program of the symposium is as follows.

PROGRAM

Date: December 8-9, 2018

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

8 December (Saturday)

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

Session 1

13:10 - 13:50	**Feng Xiao** (Tokyo Institute of Technology) *Invited Lecture* BVD: A New Principle to Design High-Fidelity Numerical Solver for Interfacial Multiphase Flows
13:50 - 14:20	**Mohamed Kamra** (Kyushu University) Error Investigation of UMTHINC Interface Capturing Method
14:20 - 14:50	**Ronit Kurmar** (Tokyo Institute of Technology) THINC-Scaling Method for Interface Capturing
14:50 - 15:20	**Yunxing Zhang**, Kangping Liao, Wenyang Duan (Harbin Engineering University, China)
	Numerical Simulation of Two Phase Flow with Adaptive Mesh Refinement

15:20 - 15:50	Coffee break

Session 2

15:50 - 16:30	**Decheng Wan** (Shanghai Jiao Tong University) *Invited Lecture* Development of Numerical Solver for Complex Flow Interaction of Floating Structure System
16:30 - 17:00	**Takahito Iida** (Osaka University） Particle Simulation for Fluid and Structure Interaction Involving Fracture
17:00 - 17:30	**Peng Jin** (Tokyo Institute of Technology) Multi-moment Finite Volume Method on Varying Domain for Fluid-Structure Interactions
17:30 - 18:00	**Isshiki Hiroshi** (Institute of Numerical Analysis) Curvilinear Coordinates for Numerical Analysis

18:00 - 20:00	Dinner Party

9 December (Sunday)

Session 3

9:20 - 10:00	**Kangping Liao** (Harbin Engineering University, China) *Invited Lecture* Recent Progress of China Numerical Tank Project
10:00 - 10:30	**Zhen Ren**, Decheng Wan (Shanghai Jiao Tong University, China) Numerial Investigation of Hydrodynamic Performance of Propeller in Restricted Channel
10:30 - 11:00	**Jiawei He**, Decheng Wan (Shanghai Jiao Tong University, China) vim-FOAM-SJTU Solver for Vortex-Induced Motions of Cylinder Structures in Currents
11:00 - 11:30	**Hironao Ohnishi**, Hidetsugu Iwashita, Masashi Kashiwagi, Yusuke Ito (Hiroshima University) Visualization of the Unsteady Wave Field on Ship Hull by means of an Advanced EFD Technology
11:30 - 12:00	**Tarek N. Dief** (Kyushu University) Experimental Results of Kite Power System

12:00 - 13:00	Lunch break

Session 4

13:00 - 13:30	**Zhiqiang Hu** (Newcastle University, UK) DARwind, A Program for Dynamic Responses Prediction of Floating Wind Turbine and Its Validation with Basin Model Test
13:30 - 14:00	**Taiki Horiuchi** (Osaka University) Integrated Simulation Method for Floating Offshore Wind Turbines with Mooring
14:00 - 14:30	**Amr Halawa** (Kyushu University) Numerical Studies on Horizontal Axis Wind Turbine Rotor
14:30 - 15:00	**Hongbin Hao**, Qingwei Ma, Kangping Liao, Zhiqun Guo, Xing Zheng (Harbin Engineering University, China） Experimental and Numerical Studies on Floating Offshore Wind Turbine
15:00 - 15:30	**Yusaku Kyozuka**, Daisaku Sakaguchi (Nagasaki University) Makoto Sueyoshi, Changhong Hu (Kyushu University) R&D of a Floating/Submersible Tidal Current Power Generator Applicable in Low Speed Tidal Flow

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

国際化推進共同研究概要

NO.20

18RE-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:
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して、独自で開発した解析コードに対して、九大応研で実施した水槽実験及び上海交通大学で実施した水槽実験に対して数値シミュレーションを行い、解析コードの精度検証と改良を行った。12 月に応研で開催された国際研究集会「International RIAM Symposium on Ocean Renewable Energy Technologies and Related Computational and Experimental Researches」に出席し、共同利用の成果に関する講演を行い、参加者との研究交流を行った。

Report for 2018 RIAM International Joint Research Project

[18RE-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 2018, fruitful collaborative works have been conducted between RIAM Kyushu University and MOST Newcastle University. The outcomes are listed as below.

1) Attendance of RIAM International Symposium on Ocean Renewable Technologies and related Computational and Experimental Researches, at RIAM Kyushu University in Dec 2018.
2) Collaborative research on the development of an innovative method for predicting dynamic responses of floating wind turbine through artificial neural network technology.

1. Participation in RIAM international symposium

An international symposium on ocean renewable technologies was successfully held at RIAM Kyushu University on 8-9th Dec 2018. Professor Zhiqiang Hu attended this symposium and made an academic presentation with topic on 'DARwind, a program for dynamic responses prediction of floating wind turbine and its validation with basin model test'. This presentation introduced the latest research progress of Zhiqiang Hu's team at Newcastle University and Shanghai Jiao Tong University. The DARwind program can be used to do the dynamic responses prediction accurately and effectively during the design stage. In addition, the challenges on basin model testing conduction are also discussed in the symposium. Through this symposium work, Zhiqiang Hu had fruitful discussions with other scholars attending the symposium, and most of all, a fruitful discussion and plan with professor Changhong Hu on the collaboration works and further investigations.

2. Collaboration on floating wind turbine investigation

In the year of 2018, a collaborative research entitled 'Development of a Reliable Method for Dynamic Responses Prediction of Floating Wind Turbines' was initiated, based on the cooperations between Professor Changhong Hu at RIAM, Kyushu University and Professor Zhiqiang Hu at Newcastle University. Some research work has been conducted in 2018, and the project will continue in year 2019. In addition, thanks for the support and collaboration in 2018, Zhiqiang Hu invited Professor Changhong Hu as co-author for a collaborative conference paper submitted to the 11th International Workshop on Ship and Marine Hydrodynamics (IWSH2019), which will be held at TUHH at 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 accepted and will be presented in the workshop.

In year 2019, this research will be developed to a further step. It is aimed use artificial intelligent technology into the methodology in the development for this novel method ensuring offshore wind industry to have reliable predicted results of the dynamic responses of floating wind turbine during the design stage, to a further step. Professor Changhong Hu will continue do his contribution on the CFD calculation validation. Based on the collaboration work, Zhiqiang Hu will submit an application to EPSRC (Engineering and Physical Science Research Council) at United Kingdom, for a project funding. This funding application has 4 universities and 3 industry partners all over the world.

The accepted abstract for IWSH2019 symposium is listed as below.

Title: Software-In-the-Loop method to predict the global dynamic responses of prototype FOWTs by using Artificial Neural Network algorithm

Peng Chen[a], Zhiqiang Hu[a], Changhong Hu[b]

[a] School of Engineering, Newcastle University, Newcastle upon Tyne, NE1 7RU, United Kingdom

[b] Research Institute for Applied Mechanics, Kyushu University, 6-1 Kasuga-koen, Kasuga, Fukuoka 816-8580, Japan

The design of floating wind turbine needs accurate prediction of full-scale global dynamic responses, and it is not reliable if numerical analysis solely used. Conventional basin experimental method can hardly be used directly to predict the global dynamic responses of floating wind turbines accurately, due to the dissimilarity of aerodynamics and hydrodynamics. Therefore, it is necessary to find an accurate, economic and efficient approach. A new method is proposed in this study. Software-in-the-Loop method based on artificial neural network is an iterative aspect of AI algorithms by machine learning, numerical simulation and statistical methods. This paper demonstrates the three core steps including Data processing, Model the Model and Extrapolation, which form the core concept of this method. Initially, datasets, signal processing and selected validation cases were conducted in Data processing from a previews scaled basin model tests. After that, the “Model the Model” section aims to optimize experimental results by artificial neural network. The comparisons of the hydro-aero dynamic responses demonstrated that the proposed method has a satisfactory ability to perform fully coupled simulations based on the numerous experimental data. Finally, the extrapolation will be conducted based on three different basin model tests in terms of “point-to-point”, “line-to-line” thus forming a surface. In conclusion, this proposed method takes advantage of the artificial neural network technology, which brings new solution for the handicaps impeding engineering application of ocean renewable energy harvesting facilities in the future.

Key words: floating offshore wind turbines; Software-in-the-Loop; artificial neural network; basin experiment; numerical simulation.

国際化推進共同研究概要

NO.21

18RE-4

タ イ ト ル:　Thermodynamic stability of nitride semiconductors surfaces includinf phonon properties

研究代表者:　Kempisty, Pawel, Tomasz

所内世話人:　寒川　義裕

研究概要:

本研究は、窒化物半導体の気相成長、特に有機金属気相成長（MOVPE）およびハイドライド気相成長（HVPE）における表面構造および表面反応を理論的に解明することを目的とする。半導体成長表面で起こる種々の物理・化学現象を理解することで、薄膜の結晶性向上や意図しない不純物混入の抑制などに寄与することができる。本研究では、これまで考慮されていなかった格子振動および配位エントロピーの寄与を取り入れて表面構造安定性の解析を行った。これらのエントロピーの寄与を考慮することにより特に高温領域で安定な表面構造の予測精度を向上することができた。

Thermodynamic stability of nitride semiconductors surfaces including phonon properties

Pawel Tomasz Kempisty,
Institute of High Pressure Physics PAS, Sokolowska 29/37, 01-142 Warsaw, Poland

Abstract

The subject of this project was the study of influence of temperature changes on the stability of III-N semiconductor surface structures. An analysis of mechanical and thermodynamic stability was made on the basis of quantum-mechanical calculations from first principles as well as statistical physics and thermodynamics.

The problem to be resolved is the lack of agreement between the results obtained using the existing theoretical description in the literature and the results of observations and measurements, especially in the high temperature range. We hypothesize that this is due to neglecting the contribution originating from surface entropy, both configurational and vibrational (surface thermal vibrations), in the theoretical models and calculations. The temperature dependence in the common models is limited to determining changes of the chemical potential of species in the gas phase. Our research experience shows that under certain physical conditions the entropy term of condensed phase is also an essential factor affecting the thermodynamic stability of the surface. We determined this factor on the basis of first principles phonons calculations.

Introduction

III-nitrides semiconductors are very promising materials that finds application in the next-generation high-power electronic devices because of its thermal conductivity combined with an excellent high-voltage and high-current capacity. For example, recent interests focus on the development of vertical GaN power devices for use in electric vehicles. To realize a high-performance power device, a high-growth-rate and high-purity GaN growth technique are needed. Surface thermodynamics is extremely important for epitaxially grown materials, but unfortunately some information are not straightforwardly accessible in typical growth experiments. Molecular structure of the surfaces can change in function of temperature, what makes it difficult to control the processes of growth and the introduction of specific dopants or avoiding impurities. Therefore, theoretical studies are still needed to improve our knowledge and quantitative description. The purpose of this work is to develop an accurate approach to modeling the true hot surface existing during growth processes.

Method

The essence of the project is a thermodynamic analysis based on data from the first principles calculations. It is an extension of the Prof. Kangawa model which includes the total energy of crystal (and molecular systems) from ab initio calculations and free energy of the vapor phase determined by statistical mechanics. Here we include also the contributions derived from the vibrational motion of the solid and its surface obtained from the phonon calculations. The SIESTA code based on the Density Functional Theory (DFT) within General Gradient Approximation was used to calculate energies of the systems as well as matrices of the interatomic forces constants required for the computation of the phonon band structures. The forces were determined as a result of small displacements of atoms from their equilibrium positions. Then from phonon spectra, using the thermodynamic relations, a number of thermal properties, such as constant volume heat capacity Cv, entropy S and Helmholtz free energy F can be computed as functions of temperature.

The slab model, i.e. supercell with periodic boundary conditions in two dimensions, was used to represent the surface. The typical size of the system for calculating energy was about 64-80 atoms, while for phonon calculations the system was multiplicated in lateral directions by a factor of 3×3.

Results

The primary results are concerned with the calculation of thermal properties of a number of GaN(0001) surfaces with various reconstructions and adsorbates that have been reported so far by other authors. The most important results include determining the zero-point vibrational energy and the change of surface free energy as a function of temperature. These terms are corrections that should be added to standard DFT-based thermodynamics to draw out the solid phase beyond 0K and consider the actual hot surfaces. Example temperature relationships are shown in Fig. 1 and their effect on the phase diagram of the surface in Fig. 2. As can be seen in both figures, temperature-induced changes are significant so they should be included in the thermodynamic model.

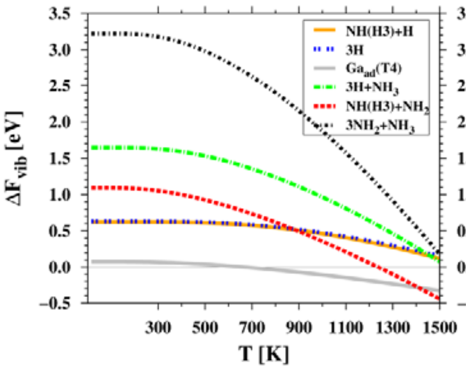


Figure 1. The relative changes of Hemholtz free energy for various GaN(0001) surface as a function of temperature.

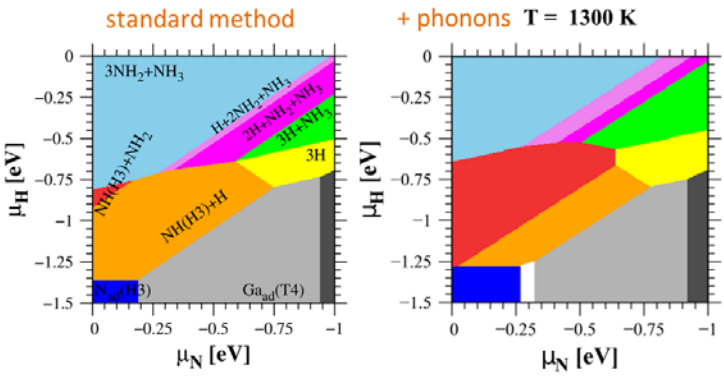


Figure 2. Comparison of phase diagram for GaN(0001) surface prepared without and with phonon contribution.

Conclusion

Within the project we showed that on the basis of first-principles phonon calculations we can determine several temperature-dependent surface properties. These properties, combined with standard DFT calculations, can be used for improving a thermodynamic analysis. This is the next significant step towards the transition from a qualitatively consistent description to a quantitatively consistent description.

Measurable effects of participation in the programme

As part of the project, Dr. Kempisty held a short research stay in Japan during November 11-22, 2018. During this stay, he participated in the International Workshop on Nitride Semiconductors 2018 (IWN 2018) held in Kanazawa on November 11-16, 2018. An oral presentation entitled “Systematic improvement of III-nitrides surface thermodynamics by including first principles phonon calculations” by P. Kempisty and Y. Kangawa was presented at the CR9 Theory & Simulation session. The research concept was also shown in the presentation “First-principles phonon calculations as a method of improving the thermodynamics for III-nitride surfaces” given on the 5th REME International Seminar at RIAM, Kyushu University.

The part of project results have been described in the manuscript entitled “Evolution of the free energy of GaN(0001) surface based on the first-principles phonon calculations”. The manuscript was submitted to the Physical Review B. At this moment, the paper is after first round of reviews. The results was specified as interesting and suitable for publication in the PRB, but considerable revision were recommended. The manuscript will be resubmitted to PRB after the recommended improvements.

Cooperation and joint research based on the subject of the project will be continued.

国際化推進共同研究概要

NO.22

18RE-5

タ イ ト ル:　Mechanical performances of hybrid composites constructed from CFRP and GFRP

研究代表者:　CHOI, Nak-Sam

所内世話人:　新川 和夫

研究概要:

真空含浸法により、炭素繊維とガラス繊維からなるハイブリッド複合材料を試作した。炭素繊維とガラス繊維の含有率を変化させること、また積層順序を変化させることによる破壊強度を評価した。各繊維の含有率また積層順序を変化させることにより、破壊強度が大きく変化することを明らかにした。この結果から、コストパーフォーマンスに優れた複合材料を作製することを可能にした。

Fracture strength of hybrid composites fabricated by vacuum-assisted resin transfer molding

*E.K. Lee [1], K.Yamashita[2], N.S.Choi[1+], and K.Arakawa[3]
[1] Department of Mechanical Engineering, Hanyang Univ., Ansan, Korea
[2] Interdisciplinary Graduate School of Eng & Sci, Kyushu Univ., Fukuoka, Japan
[3] Research Institute for Applied Mechanics, Kyushu Univ., Fukuoka, Japan

Keywords : Hybrid composites, VaRTM, Bending strength, Charpy impact strength

1. Introduction

Carbon fiber reinforced plastic (CFRP) composites have a significant advantage for their application in engineering structures due to their high strength-to-weight ratio. However CFRPs have disadvantage in cost and ductility as compared with metal and glass fibers. Thus, hybrid composites composed of carbon fibers and glass fibers have strong attraction in application to high toughness structures. In this study hybrid composites using carbon fiber cloth and glass fiber cloth are fabricated through a vacuum assisted resin transfer molding (VaRTM) technique [1,2]. Composition ratio of carbon and glass cloths is an important parameter to investigate better bending strength and charpy impact strength for the hybrid composites.

2. Experimental method : Figure 1 shows the VaRTM process to fabricate the hybrid composites which were stacked in a pre-determined order. Unidirectional carbon fiber cloth (15KUD300G, Mitsubishi Rayon) and plain woven glass fiber cloth (ATG25330, Polymer SSP) were used as reinforcing fiber materials to compose the hybrid laminates. Various composition ratios as well as stacking type were adopted. The width and length of the hybrid cloths were 250mm and 250mm, respectively. The number of stacking layers was consistently five. Epoxy resin (Denatite XNR6815, Nagase Chemtech) and hardener (XNH6815) was mixed with a weight ratio of 100: 27. The resin was infused into the dry hybrid cloths in the VaRTM process. The hybrid laminates were cured in the sealed state for 24 hours in room temperature. From the cured plates, specimens for bending test and charpy impact test were extracted using a diamond wheel cutter. Five specimens were tested for each experiment condition.

3. Results and Discussion : Bending strength results were studied according to stacking types. The bending strength increased with an increase of carbon cloth layers. The strength was prominent at the composition ratio of glass and carbon cloths (3:2, specimen C) in comparison to 4:1 (B). Because the bending load induced interlaminar shear fracture rather than compressive or tensile fracture, excellent wettability of carbon fiber cloths should have assisted interlaminar toughness which led to such an increasing bending strength.

Figure 2 shows charpy impact results in accordance with stacking types. Charpy impact values indicate absorbed fracture energy normalized by specimen cross-sectional area. Charpy impact values did not show consistent improvements with increasing carbon cloth layers. However the GF/CF ratio of 3:2 (C) represented the best. This behavior might be because glass fibers have excellent failure strain about 3 times of the carbon fibers. The placement of glass fiber cloth at the skin layer must have endured the high impact stress.

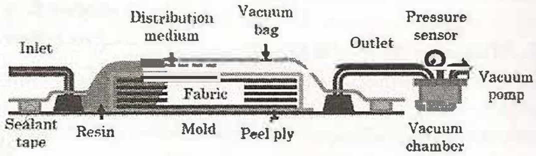


Fig. 1. Schematic VaRTM process

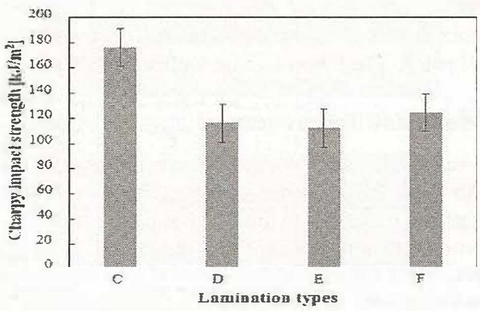


Fig.2 Charpy impact strength characteristics

4. Concluding remark

Hybrid composites fabricated with glass fiber cloth and carbon fiber cloth through the VaRTM were studied. Optimal composition ratio was 3:2 with glass fiber skins. Carbon fabric improved bending strength, while glass fiber cloth as a skin layer brought about excellent charpy impact resistence. The glass and carbont fibers showed different hybrid effects for strong mechanical performances.

References

[1] T Yokozeki et al. VaRTM process of composites using porous mold. *Adv Compos Mater.* 22(2):99-107, 2013.
[2] P Simacek et al. Modeling resin flow and fiber tow saturation induced by distribution media collapse in VARTM. *Compos Sci Tech.* 67(13):2757-2769, 2007.

Acknowledgement
This work was supported by the Collaborative Research Program of Research Institute for Applied Mechanics, Kyushu University.

国際化推進共同研究概要

NO.23

18RE-6

タ イ ト ル:　Management of Light impurities in Silicon crystallization for maximized performance

研究代表者:　CHICHIGNOUD, Guy

所内世話人:　西澤　伸一

研究概要:

太陽電池用シリコン製造プロセスから、①原料シリコンの純化プロセス、②シリコン単結晶成長プロセス、を取り上げ、解析を行った。①では、シリコン中の不純物リンの除去条件を化学平衡論を用いて検討し、酸素がシリコン中のリンを安定化させるため、酸素の寄与と蒸発のバランスで最終リン濃度が決定することを示した。また②では、単結晶成長法として Kyropoulos 法を取り上げ、数値解析による装置最適化を行い、特に種結晶周辺の熱流束を制御することで、成長単結晶の形状、品質が向上できることを示している。

Theme : Management of Light impurities in Silicon crystallization for maximized performance

Name & Affiliation : CHICHIGNOUD, Guy. SIMAP/CNRS, France

RIAM attendant : Shin-ichi NISHIZAWA

Report :

Background:

SIMAP is mostly related to the processing of materials for Energy applications, meaning essentially semiconductors from column IV (Si, SiC) and III-V (nitrides) whose elaboration implies high temperature steps.

In this frame we are focusing in developing novel processes to improve material properties, in relation with final properties. I am mainly focused on adapting upstream Silicon processes to get more efficient, cheaper Silicon for Photovoltaics: refining processes (Boron removal with thermal plasma, Phosphorous distillation, segregation of metals), light impurities (C,O) management during crystallization, novel crystallization technics for Silicon. Among investigated technics should be mentioned directional solidification, Czochralski and Kyropoulos methods, solution growth, PVT and CVD. My approach, essentially experimental, extents from Thermodynamics (data acquisition and database strengthening, Thermodynamics calculations) to instrumentation (Optical Emission Spectroscopy, Mass Spectrometry) and Characterizations (XRD, Laue, SEM, EBSD…), to highlight phenomena related to mass and heat transport close to interface(s) defined in a large extent and their consequences on crystallization and final properties (crystalline defects, efficiency…)

Kyushu university has good and great knowledge of crystal growth process and its modeling, and knowledge of relation between material properties and device performance. Under this collaboration, both knowledge of SIMAP and Kyushu univ. will be applied to the management of light impurities during crystallization process of Silicon in relation with crystalline structure and finale performance

Objectives:

The present research project aims at applying competencies from Grenoble University and Kyushu University to further describe and understand the behavior of light impurities during the processing of Silicon, especially through its crystallization and to investigate their influence upon crystalline defects and final properties and performance, with the ultimate objective to optimize process conditions to allow maximized performance of the devices.

In particular the two Universities will contribute by using their elaboration/crystallization pilots and dedicated characterizations technics: model experiments will be planned using academic tools, for instance Electromagnetic levitators coupled with mass spectrometry for chemical analysis, to produce isolated results for one family of impurities; and compared to “real” crystallization experiments where coupled phenomena occur. In addition, numerical simulations can be used to better describe mass transport at the process scale.

Crystalline quality and defects density will be particularly considered in relation with light impurities concentrations during the elaboration process by taking advantage of standard technics for better comparison with literature but also through innovative technics to go beyond classical characterizations. This research project spreads logically over several years and the first year of will be dedicated to feasibility studies and to establishing conditions for further developments based on identified assets.

Current status:

Fig.1 shows the standard c-Si PV chain.

First, we discussed the purification process. In order to reduce phosphor concentration in silicon material, the effect of oxygen on phosphor stability was discussed by using CALPHAD, thermodynamic evaluation. In case of high oxygen partial pressure, eq. high concentration in silicon melt, as increasing the temperature, phosphor concentration decreases because of stabilization effect dominant.　On the other hand, in case of low oxygen concentration, as increasing the temperature, phosphor concentration increasing because of evaporation effect dominant.

Then, we discussed the crystallization process. On this part, we discussed the Kyropoulos Process to grow silicon single crystal.　We analyzed the flow field in silicon melt numerically, and also the effect of heat transfer in seed region was discussed.　By controlling the thermal field by using thermal shield around seed, the grown crystal shape and quality could be improved.

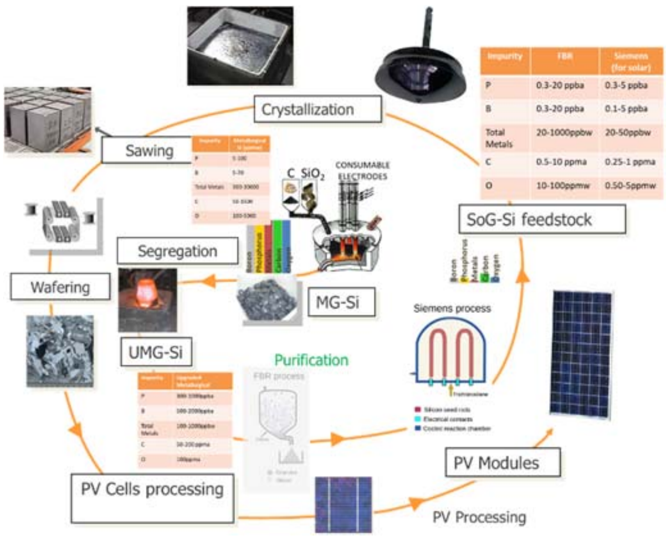


Fig.1 standard c-Si PV chain

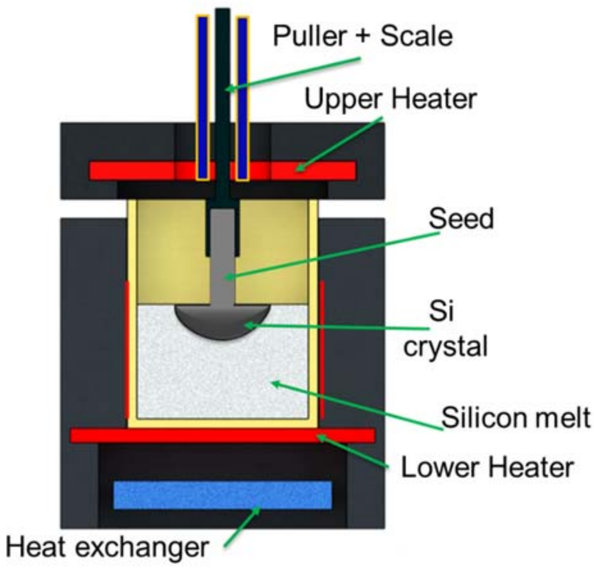


Fig.2 Kyropolus process

Futures

Under the collaboration, we apply the thermodynamic evaluation for common CZ siligon single crystal growth process.

国際化推進共同研究概要

NO.24

18RE-7

タ イ ト ル:　Joint study on the next generation of bidirectional power semiconductor device technologies

研究代表者:　EKKANATH MADATHIL, SANKARA NARAYANAN

所内世話人:　西澤　伸一

研究概要:

まず、パワーデバイス全体の研究開発動向、将来の応用技術への向けた課題を整理した。低耐圧系では、現在主流のシリコンデバイスに加え、シェフィールド大学が提案している分極接合を利用した GaN 集積パワーデバイスの利用が期待される。また、将来のホームグリッド、直流グリッドなどでは、現在使用されている機械式ブレーカにかわる半導体双方向スイッチが期待されており、GaN デバイスは有力な候補である。高耐圧系では、シェフィールド大学が提案しているクラスターIGBT,九州大学が参加し実施ている NEDO プロジェクトで実証が進んでいるスケーリング IGBT のコンセプトを共有化し、新しい IGBT 構造を提案することを計画している。

Theme: Joint study on the next generation of bidirectional power semiconductor device technologies

Name & Affiliation: EKKANATH MADATHIL, SANKARA NARAYANAN.
University of Sheffield, UK

RIAM attendant: Shin-ichi NISHIZAWA

Report:

Background:

Power management of bidirectional flow of energy is emerging as a critical challenge to address the blackouts arising due to grid-connected renewables operating under massively varying loads, such as the charging of electric vehicles and IT infrastructure for managing autonomous vehicles. Higher efficiency and power density converters offer significant system level cost benefits. However, three advances are required:

i) Bi-directional operation: Equal current conduction in both directions facilitating transfer of power to and from the grid to allow storage devices such as stationary car batteries to become point sources of energy to address grid instability.

ii) High operating voltages: ability of converters connected to the local 3-phase grid, which require transistors of 1.2kV and above, and;

iii) Bidirectional Protection: fast reacting technologies to reduce arc flash (fire hazard) in such DC systems.

This project is about knowledge exchange between two world renowned institutions for harnessing the potential of bidirectional power semiconductor switches. This will be achieved via detailed evaluation of semiconductor models in circuit topologies.

Objectives:

This joint project is aimed to evaluate efficient power management solutions for bidirectional flow of energy. This work offers unique opportunity for knowledge exchange, which could result in the proposal of new energy management system including the improved / new power semiconductors. The objectives of this study will have a direct impact on the increase the penetration of renewable energies in the power grid.

Current status:

First, we reviewed the power semiconductor devices today, and future prospects. For low voltage applications, silicon MOSFET has been available, and polarization GaN is a strong candidate for future power management systems. With GaN, systems can be operated at higher frequencies and higher temperatures, higher efficiencies as well as higher power densities than Silicon solution. For high voltage applications, Si-IGBT is improving its performance continuously with 3D scaling rules, as presented by Japanese NEDO Si-IGBT project, in which Kyushu University is involved. The University of Sheffield has followed the results of NEDO project, and has carried out the further simulations. The University of Sheffield has proposed the Clustered IGBT for future advanced power devices. The University of Sheffield and Kyushu University discussed the future common research topics, such as new IGBT devices for higher frequency and higher temperature operations, and material and process impact on IGBT and GaN devices. Because of both sides contribution, such as the concept of Clustered IGBT proposed by the university of Sheffield, and experience of scaling IGBT, super junction MOSFET and knowledge of materials in Kyushu University, the new IGBT structure and characteristics will be investigated numerically, and will be proposed jointly.

Future plan:

The team had applied for JSPS fellowship program on this subjects. And it is accepted in 2019. This will facilitate the team to continue the collaboration research under JSPS short term visiting program.

国際化推進共同研究概要

NO.25

18RE-8

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:

ダウンウィンド風車技術，モデル開発，検証

2019/01/22～23 に，九州大学日本橋サテライトにて，研究集会を開催した．スイス，スペイン，デンマーク，ドイツ，日本から 18 名の参加があり，12 件の発表があった．概要を以下に示す．

1) ベースラインモデル：以降の研究における共通のモデルとして，2MW ダウンウィンド風車の空力弾性モデルを定義した．

2) タワーシャドウモデル：一般的な設計・解析法におけるロータとタワーの空力干渉のモデリング，ならびに，CFD によるトラスタワーとモノポールタワーの比較結果を報告した．

3) ヨー安定性：ヨー安定性に関するダウンウィンド風車の優位性を示した．また，独立ピッチ制御による安定性向上技術を報告した．

4) 騒音：ダウンウィンド風車の大きなリスクである騒音に関して，計測結果や評価方法の研究成果を報告した．

5) ブレード最適化：超大型風車におけるダウンウィンド風車の優位性を評価するため設計方法について紹介した．

Downwind Turbine Technologies, Model Development and Verification

Applicant: Ndaona Chokani, Senior Scientist, ETH Zurich
RIAM Attendant: Shigeo Yoshida, Professor, Research Institute for Applied Mechanics, Kyushu University

1. OUTLINE OF THE WORKSHOP

(1) Date: 2019/01/22(tue) - 23(wed)
(2) Place: Kyushu University Nihonbashi Satellite, Nihonbashi, Tokyo.
(3) Participants:
- ETH Zurich: Ndaona Chokani
- CENER: Xabier Munduate, Ivan Mallafre
- X1Wind: Alex Raventos
- DTU: Gesine Wanke
- Fraunhofer IWES: Elia Daniele
- The University of Tokyo: Atsushi Yamaguchi, Hideki Tachibana
- Hitachi: Yasuo Osone, Takashi Harada, Soichiro Kiyoki, Emi Fujita, Azuma Okuno
- Hitachi Research Institute: Mamoru Kimura, Nobuo Namura
- Wind Energy Institute of Tokyo: Masataka Owada
- Kyushu University: Shigeo Yoshida

2. REPORTS

WP1-1) Yamaguchi, A. (UTokyo), 2 MW Baseline Model

An aeroelastic model of a 2MW baseline downwind turbine (DT) model was defined (Fig 1). The general concept and typical data were introduced. The model will be delivered to the members to proceed the verification study in each research subject.

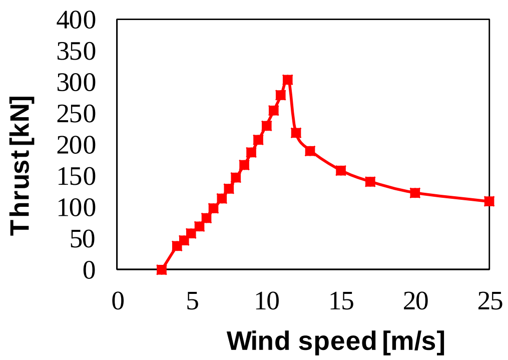


Fig 1 Thrust curve of the model

WP1-2) Yoshida, S. (KU), Tower Load Models of DTs in for BEM [1][2]

Two 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.

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 (Fig 2). However, there still be some more room for improvement in inboard sections.

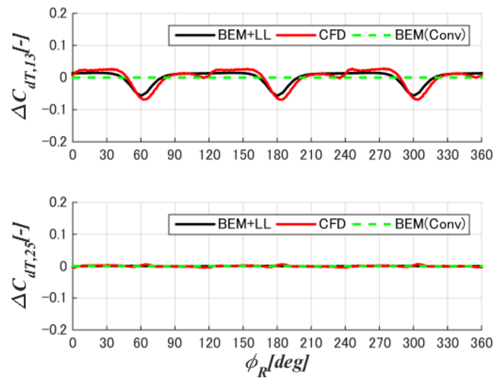


Fig 2 Variable loads of the downwind turbine tower at 100% rotor radius

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

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

The model was validated by the wind tunnel test. It shows good agreement with the wind tunnel test data (Fig 3).

WP1-2) Munduate, X. (CENER), Tower Shadow

CFD was conducted to validate the empirical tower shadow models in BEM. The empirical model showed different characteristics than the CFD; narrower and steeper drops of the load in tower shadow (Fig 4).

Aeroelastic analyses of 10 MW 3-bladed upwind turbine (UT) and 3-/2-bladed DTs were reported. DTs show lower energy production than that of the UTs due to the elastic deformation makes the rotor area to be shrunk (Table 1).

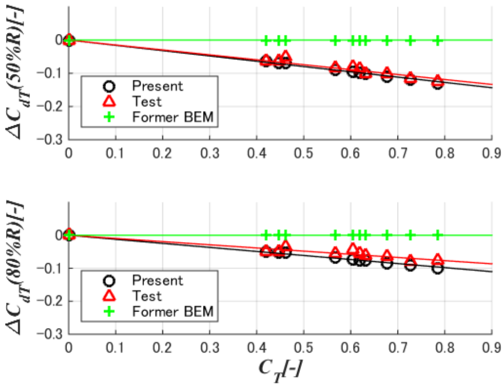


Fig 3 Rotor thrust to tower drag

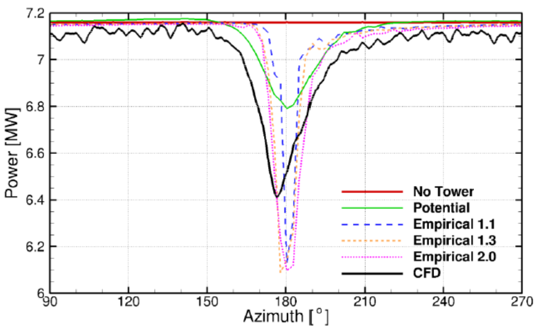


Fig 4 Power fluctuation by tower shadow

Table 1 Aeroelastic simulation results for 10 MW WTs

	Tower impact on AEP (%)
3Bl Upwind	-0.27%
3Bl Downwind	-0.63%
2Bl Downwind	-0.70%
	Configuration impact on AEP (%)
% AEP withTwrShd 3Bdown-3Bup	-0.49%
% AEP withTwrShd 2Bdown-3Bdown	-2.03%
% AEP withTwrShd 2Bdown-3Bup	-2.51%

WP1-2) Daniele. E. (Fraunhofer IWES), Status of FSI for Downwind Turbines at IWES

Fluid-structure interaction analysis for DTss with tubular and truss towers were reported. The truss tower, which was expressed by rectangular columns, showed larger wind speed dissipation behind the tower (Fig 5). 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 (Fig 6).

WP1-2) Raventos, A. (X1 Wind), Development of a Low-cost Weathervaning Solution for WTs

The concept of X1 Wind was introduced. CFD was conducted for the monopole and the truss structure. The wake of the truss shows much smaller wake as compared with the monopole in both of downwind and upwind rotor, indicating lower load impacts on blades (Fig 7, Fig 8).

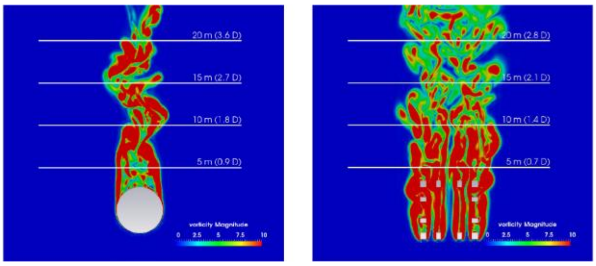


Fig 5 Tower wake behind the tubular and truss towers

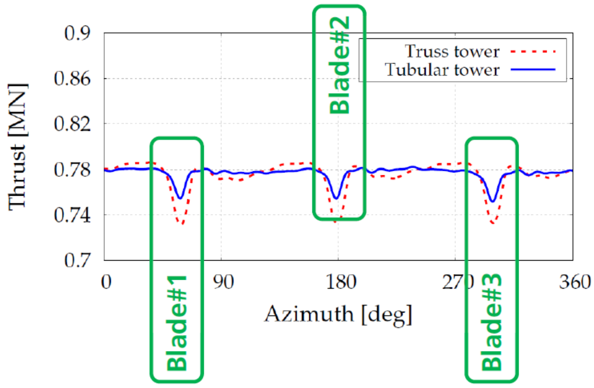


Fig 6 Thrust fluctuation by the towers

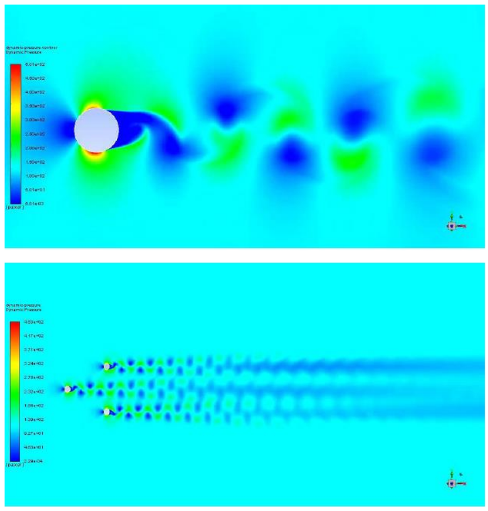


Fig 7 CFD behind a tubular and a truss towers

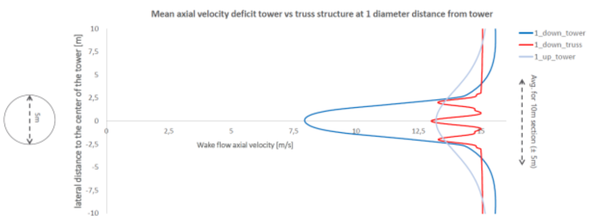


Fig 8 Wind speed distribution behind the towers

WP1-4) Wanke, G. (DTU), Conceptual Research of a Down Wind Turbine – Stability Investigations

The yaw system shares about 1-2% of the capital cost. Passive yaw operating is one of the promising aspects of DTs for further cost reduction. The stability to the coning angle of the blade to operating wind speed was investigated. It shows the yawning is getting more stable for larger rotor coning angle (Fig 9).

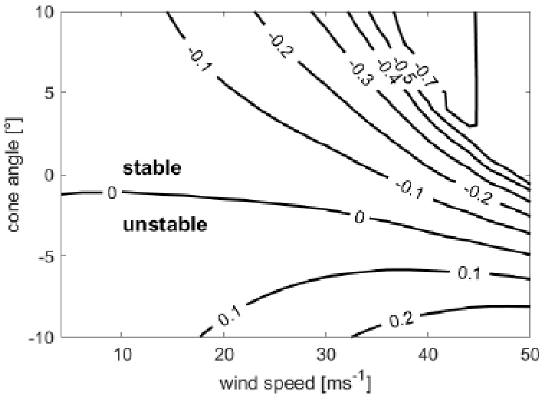


Fig 9 Stability of free yawing

WP1-4) Chokani, N. (ETH Zurich), Enhancing Yaw Stability of DTs Using IPC

The advantage of DTs of yawing stability was shown through the towing tank test. Furthermore, sinusoidal individual pitch control (IPC) was shown to be effective for the yawing stability (Fig 10).

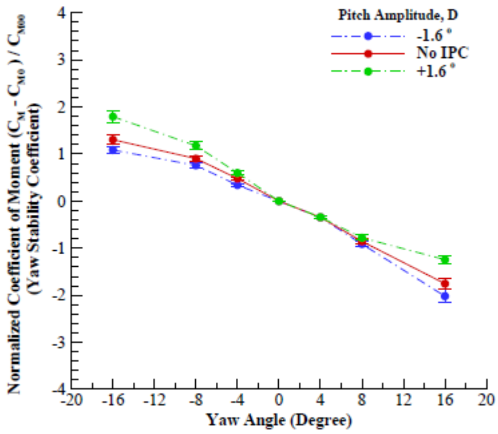


Fig 10 Yaw stability enhanced with IPC

WP1-4) Okuno, A. (Hitachi), Validation of Extreme Loads of Wind Turbine by Measurement Data and Simulation [3]

The extreme loads of a 5.2 MW DT in parked condition in Typhpoon #21 in 2017 were simulated. The results are consistent with the measurement about the loads on the blade and the tower (Fig 11).

WP1-5) Fujita, E. (Hitachi), LiDAR Measurement in Complex Terrain [4]

One of the advantages insisted by DTs is the performance in complex terrain; the negative tilt angle is advantageous for up-flow wind in complex terrain. Measurement by LiDAR was conducted in a wind farm located in a complex terrain.

The measurement of the LiDAR showed good agreement with those by the cup and ultrasonic anemometers. And the inclination and the turbulence of the flow were shown to be largely different on wind direction (22.5 deg each) (Fig 12).

The chanacteristics of DTs in conjunction with the measurement will be analyzed in the future work.

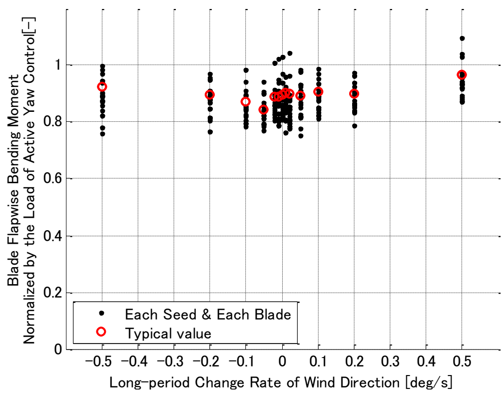


Fig 11 Blade root flapwise bending to wind direction change rate

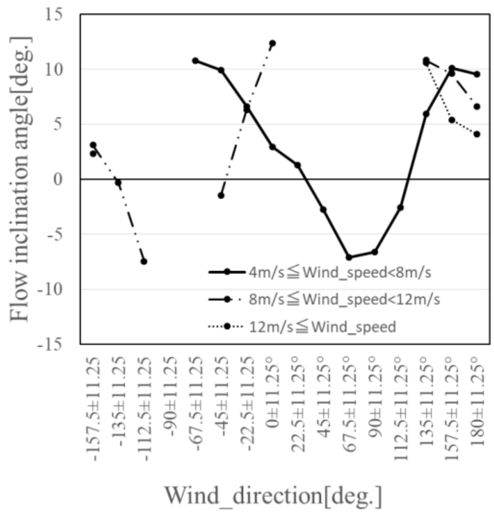


Fig 12 Flow inclination

WP1-6) Tachibana, H. (UTokyo), A Synthetic Research on Wind Turbine Noise in Japan

Noise and infrasound are one of the biggest risks of deployment of DTs. A wide variety of noise researches in Japan are introduced from field measurement (both of DTs and UTs), social survey, and auditory experiment.

Regarding the acoustical characteristics, the frequency components below 20 Hz are not audible/sensible (Fig 13).

And a new method was proposed for the assessment of the and amplitude modulation by the difference between FAST and SLOW measurements (Fig 14).

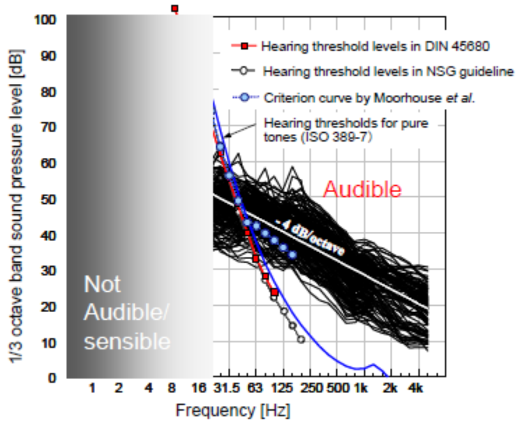


Fig 13 Audibility of the wind turbine noise

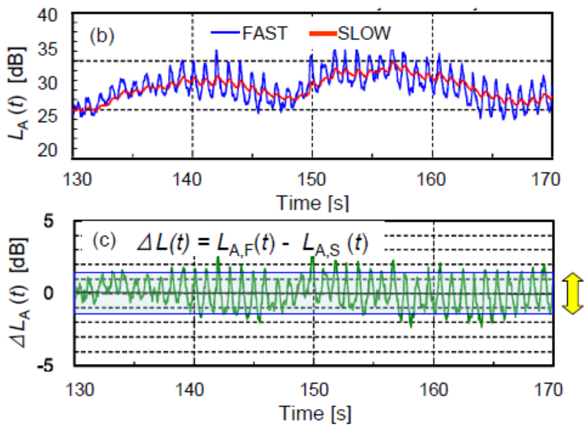


Fig 14 Assessment of the amplitude modulation

WP2-1) Munduate, X. (CENER), Blade Optimization

10 MW 2-bladed UW and DT were optimized using the in-house the design tool MDAO (Multidisciplinary Design, Analysis and Optimization) (Fig 15).

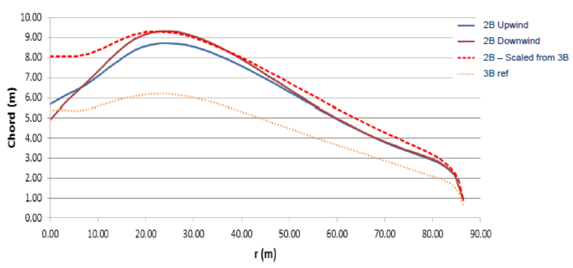


Fig 15 10 MW blades optimized by MDAO

3. CONCLUSION

Wide ranging subjects were discussed about downwind turbine technologies, such as tower shadow, stability, wind characteristics in complex terrain, noise, and blade optimization. Interesting results were found in the mutual comparison.

WP1-1) 2MW Baseline Model

2MW aeroelastic model for Bladed wad developed. It will be delivered for further modeling study in other work packages.

WP1-2) Tower Shadow

CFD around the monopole and the truss structures showed the cross section of the tower strongly affect to the wake profile. Furthermore, the wake wind speed profile was not shown to be enough for the accurate load calculation of downwind turbines using BEM.

WP1-4) Stability and Control

Downwind turbines were shown to be advantageous in yaw stability. Furthermore, individual pitch control was shown to be effective for further stabilization. And extreme load calculation model was validated with the measurement.

WP1-5) Complex Terrains

The LiDAR measurement of wind characteristics in complex terrain indicated the positive wind inclination in complex terrain is advantageous for downwind turbines, which have negative rotor tilt angles.

WP1-6) Noise

Extensive researches on wind turbine noise showed that the low frequency noise of modern downwind turbines, which was problematic in downwind turbine in the history, is a minor problem.

WP2-1) Blade Optimization

Case study of blade optimization by MDAO, the CENER'S in-house multidisciplinary optimization code.

4. REFERNCES

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