No.	

Collaborative Research based on MU Radar and Equatorial Atmosphere Radar
Research Institute for Sustainable Humanosphere (RISH), Kyoto University

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Cooperative Researcher(s) Name, Affiliation, Position	Prof. Dale Lawrence (University of Colorado) Prof. H. Hashiguchi (RISH, Kyoto University) Dr. M. Yabuki (RISH, Kyoto University) Mr. A. Doddi (University of Colorado) Dr T. Mixa(University of Colorado) Dr. H. Luce (MIO)				
Contact Person in RISH (Name, Position)	Dr. H. Hashiguchi, Professor, RISH				
Title of project	Shigaraki UAV Radar Experiment (ShUREX 2020)	A MUR Troposphere/Stratosphere		☐ New proposal X Continued	

1. Goal of the project (if continued project, include reason to continue)

During the ShUREX 2015, 2016 and 2017 campaigns, specially equipped University of Colorado DataHawk UAVs were flown near and over the MU radar to collect data in the atmospheric column up to about 4 km altitude. An IMET radiosonde was also mounted on the UAV, along with high frequency response (800 Hz) cold wire and pitot tube sensors, enabling collection of data that was then used to extract information on turbulence in the atmospheric column in the vicinity of the radar. The autonomous UAV was commanded to sample interesting atmospheric structures detected by the radar in near-real time. The resulting dataset has been used to extract the TKE dissipation rate, C_T^2 and C_n^2 profiles and compare them with radar returns to better understand atmospheric processes and radar observations.

While earlier ShUREX campaigns were highly successful (see cited publications, especially the one on Atmospheric Structures in PEPS), more work still remains. We took the time between 2017 campaign and now to finalize analysis techniques and thoroughly analyze the data collected during the three campaigns. Twelve papers have been published in reputable journals. Still there is more work to be done. During the interim, DataHawk UAV has been deployed in numerous campaigns in US (ISAARA, IDEAL etc.) and therefore the launching, tracking and real-time displays have been improved to such an extent that the launch-time crashes are rare and no constant antenna adjustment is needed. As such, we are now able to concentrate more on science aspects, instead of engineering. We also have perfected a technique to extract winds from UAV data, a task that was quite hard. We can also fly more than one UAV at a time.

We were unable to sample thoroughly the highly random Kelvin-Helmholtz instability (KHI) event. Nor were we able to map the evolution of a Mid-level Cloud-base Convection (MCT) event. We did not properly sample the convective boundary layer (CBL). We did not launch enough radiosondes to supplement UAV data. In ShUREX 2020, we intend to remedy these shortcomings.

We expect to collect a rich collocated radar/UAV dataset from which we can explore dynamical processes involved in evolution and decay of CBL and MCT. To explore these structures and to catch the highly transient MCT events, we need again a 3 to 4-week campaign, with the earlier part focusing on MCT, and the later part on CBL. We also need to launch sondes at hourly intervals during the two IOPs, one on CBL and another on MCT.

2. Observation plan

The plan is to conduct a roughly three-week campaign from June 1st to June 24th, with UAVs bungee-launched using a launch mechanism from the adjacent field. The UAVs will be flown upwind and over the MU radar. We will focus on CBL and MCT sampling. Analysis of earlier ShUREX data has taught us a lot about these processes and we now know exactly what we need to do to obtain comprehensive data on these atmospheric structures. As mentioned in the published papers, there are still many unresolved science issues related to these structures and we hope to resolve them through the ShUREX 2020 campaign. We hope to sample the evolution of the CBL from dawn to dusk when forecasts indicate a clear sunny day, using concurrent UAV and sonde flights every hour. We will use small balloons to make sure they burst just above 12 km height so we can launch more frequently, using both Meisei and Vaisala sondes. We will also make better use of LQ7 radar and lidars at the observatory. The main reason is that these can add significant scientific information on CBLs. As for MCT, if it occurs during daylight and within reachable altitude, we will fly UAVs to sample it. However, if MCT is too high or occurs at night, we will use sondes to sample it at hopefully hourly intervals. When neither MCT nor CBL exploration is feasible, we will focus on "S&L" structures. Overall, the goal is to thoroughly sample these features so that their dynamics can be better understood, and adequate data collected to numerically model them with good fidelity.

An exciting development has taken place. Prof. Lawrence has been able to deploy his high-resolution sensor suite on a balloon and test the feasibility of obtaining turbulence data. The idea is to attach the Pitot tube and Cold Wire rigidly to the underside of the balloon, fly the balloon to a pre-determined altitude and then command the balloon to descend at about 2 m/s by venting appropriate amount of gas in the balloon so that turbulence data can be obtained without contamination from balloon wake. We will try to deploy this system during ShUREX2020, if it can be made ready in time.

While MU radar (if CBL is higher than ~ 1.3 km), LQ7 radar, UAVs and sondes will be used to sample CBL, it would be helpful if Dr. Yabuki can get the new UV lidar working in time so we can also make continuous measurements of humidity and temperature. Measurements of fluxes near the ground would also be desirable. Prof. Kantha will discuss these issues with RISH scientists when he joins RISH mid-January 2020.

Dr. Luce, in collaboration with RISH scientists, will be responsible for the MU and LQ7 radar components. Dr. Yabuki will be in charge of lidar component. Professors Kantha and Lawrence will be responsible for the UAV and sonde components and will be assisted by one of their students. In the absence of Prof. Wilson, we really need a RISH student to help with intense sonde launches during IOPs. All the PIs will participate in data analysis/synthesis and technical publications.

3. MU Radar (MUR) usage

	X Tr./St.		
Observation Mode:	☐ Standard	☐ Me. Standard	☐ Meteor Wind
	☐ Iono. Standard	☐ E-Region FAI	☐ F-Region FAI
	☐ RASS	X Interferom.	☐ Others (Fill in their summary under '8')

Expected Period: Month: ( ) hours (Except Standard Mode)

Equatorial Atmosphere Radar (EAR) usage

Observation Mode:	☐ Tr./St. Standard	☐ FAI Standard	☐ Interferometry
	☐ RASS		☐ Others (Fill in their summary under '8')

Expected Period: Month: ( ) hours (Except Standard Mode)

4. Number of Radiosondes: As many Meisei or Vaisala sondes as permitted by MUR funding

5. Other facilities

☐ Ionosonde x Surface weather instrument ☐ Raingauge ☐ Network

☐ Meteor radar x Boundary layer radar LQ7 x Others(UV lidar, Raman Lidar?)

6. Planned schedule of visit to the site

ShUREX 2020 campaign will start on June 1st and end on June 24th. This will provide the required time to set up UAV operations for the site, acquire about 3 weeks of data (accounting for inclement weather) on evolution of the atmospheric structures of interest. To save money, the radar will be put to "sleep" on rainy or very windy days during which UAVs cannot be flown.

7. Expected outcome (if continued project, also describe the results already obtained)

Earlier ShUREX campaigns yielded some data on the atmospheric structures we were able to probe and resulted in many publications, and presentations at the MST15/EISCAT18 meeting at NIPR, Tokyo. The datasets have highlighted the need for more comprehensive data on these structures, especially MCT and CBL. The proposed campaign will help probe these atmospheric structures more completely and better understand the evolution of these structures.

(Publications if continued project)

1. Luce, H., L. Kantha, H. Hashiguchi, A. Doddi, D. Lawrence and M. Yabuki, 2020. On the relationship between YKE dissipation rate and the temperature structure function parameter in the convective boundary layer. *J. Atmos. Sci., under revision*.
2. Luce, H., D. Lawrence, H. Hashiguchi and L. Kantha, 2019. Estimation of turbulence parameters in the lower troposphere from ShUREX (2016-2017) UAV data. *Atmosphere,* 10, 384. doi:10.3390/atmos10070384
3. Kantha, L., H. Luce, H. Hashiguchi and A. Doddi, 2019. Atmospheric structures in the troposphere as revealed by high resolution backscatter images from MU radar operating in range-imaging mode. *Prog. Earth Planet. Sci.* 6:32, https://doi.org/10.1186/s40645-019-0274-1
4. Kantha, L., H. Luce and H. Hashiguchi, 2019. Mid-level cloud-base turbulence: radar observations and models. *J. Geophys. Res. Atmos.* 124. https://doi.org/10.1029/2018JD029479.
5. Luce, H., L. Kantha, H. Hashiguchi, D. Lawrence and A. Doddi, 2018. Turbulence kinetic energy dissipation rates estimated from concurrent UAV and MU radar measurements. *Earth Planets Space,* 70-207 (MST Radar Special Issue). DOI:10.1186/s40623-018-0979-1
6. Kantha, L., H. Luce and H. Hashiguchi, 2018. On a numerical model for extracting TKE dissipation rate from VHF radar spectral width. *Earth Planets Space,* 70-205 (MST Radar Special Issue). DOI:10.1186/s40623-018-0957-7
7. Kantha, L. and H. Luce, 2018. Mixing coefficient in stably stratified fluids. *J. Phys. Oceanogr.*, 48, 2649-2665. DOI: 10.1175/JPO-D-18-0139.1
8. Luce, H., L. Kantha, M. Yabuki, and H. Hashiguchi, 2018. Atmospheric Kelvin-Helmholtz billows captured by the MU radar, lidars and a fish-eye camera, *Earth Planets Space*, 70:162. https://doi.org/10.1186/s40623-018-0935-0
9. Luce, H., L. Kantha, H. Hashiguchi, D. Lawrence, T. Mixa, M. Yabuki, and T. Tsuda, 2018. Vertical structure of the lower atmosphere derived from MU radar, unmanned aerial vehicle and balloon measurements during ShUREX 2015, *Prog. Earth Planet. Sci.*, 5:29, DOI 10.1186/s40645-018-0187-4
10. Luce, H., H. Hashiguchi, L. Kantha, D. Lawrence, T. Tsuda, T. Mixa and M. Yabuki, 2018. On the performance of

the range imaging technique estimated using unmanned aerial vehicles during the ShUREX 2015 campaign. *IEEE Trans. Geosci. Remote Sensing*, 56, 2033-2042, DOI 10.1109/TGRS.2017.2772351.

11. Kantha, L., D. Lawrence, H. Luce, H. Hashiguchi, T. Tsuda, R. Wilson, T. Mixa and M. Yabuki, 2017. Shigaraki UAV-Radar Experiment (ShUREX): Overview of the campaign with some preliminary results. *Prog. Earth Planet. Sci.*, 4:19, DOI 10.1186/s40645-017-0133-x
 Correction: https://doi.org/10.1186/s40645-018-0210-9
12. Luce, H., L. Kantha, H. Hashiguchi, D. Lawrence, M. Yabuki, T. Tsuda and T. Mixa, 2017. Comparisons between high-resolution profiles of squared refractive index gradient M^2 measured by the Middle and Upper Atmosphere Radar and unmanned aerial vehicles (UAVs) during the Shigaraki UAV-Radar Experiment 2015 campaign. *Ann. Geophys.*, 35, 423-441.

8. Remarks (Details of what is described in 3)

MUR will be operated in range imaging (FII) mode:

- 5 equally spaced frequencies from 46.0 to 47.0 MHz.
- 3 *or* 8 beams.
  - 3 beams: (0,0) x 5 / (0,10) x 5 / (90,10) x 5
  - 8 beams: (0,0) x 5 / (0,10) x 5 / (90,10) x 5 / (45,10), (135,10), (180,10), (270,10), (315,10)

  Drawbacks: reduced time resolution and sensitivity. *Advantages*: More combinations for wind estimates and information on horizontal homogeneity of vertical and horizontal winds.
- Number of receiving channels: 1 (the total array also used for transmission)
- Pulse coding: 16 or 8-bit optimal code (subpulse duration=1 μs)
- Number of coherent integrations (Ncoh): 32 or 16
- Number of FFT points (NFFT):128-512 (arbitrary, no gap between the records)
- Number of gates: 128 (from 1.05 km in the parameter file)

Note 1: The proposed configuration includes the standard observational mode. It means that the dataset can be analyzed at the standard range resolution (i.e. 150 m) for other scientific purposes which do not need improved range resolution. The weaker sensitivity (due to the small number of coherent integrations) is partly compensated by the improved detectability (5 additional incoherent integrations with respect to the standard mode can be applied due to the use of 5 frequencies).

Note 2: The configuration should provide data with a sufficient sensitivity in the range of observations expected for UAV (4-5 km). The application of FII in three directions will provide more (accurate) information on echo aspect sensitivity, better Cn2 estimates (from oblique beams), and *potentially* high resolution wind (and shear) estimates to be compared with estimates from UAV (evaluation of the range imaging technique for retrieving HR winds from a VHF radar has still to be done).

9. Financial support (Fill in type, title, and P.I. of research budget related to this proposal)

As before, we plan to bring 5 UAVs and we need funds to transport them to and from Japan. We also need enough helium for 40 (if possible) Meisei/Vaisala sondes. The NSF application for funds for ShUREX 2020 by Profs. Kantha and Lawrence was unfortunately declined. However, international travel expenses for Dr. Lawrence and a student will still be borne by Dr. Lawrence. Internal travel and subsistence expenses for participants are requested from RISH MUR funding.

Prof. Kantha will be at RISH from January 16th to July 15th as a Visiting Professor, a period that encompasses the ShUREX 2020 campaign. He plans to continue working on ShUREX-related matters. He also expects to make presentations at May JpGU/AGU meeting in Makuhari Messe in Chiba.