2025 RPPR Interim Progress Report

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Title: Fatima: Fog and turbulence interactions in the marine atmosphere

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Major Goals:

In the long term, Fatima project seeks transformative leaps in fundamental knowledge as well as in prediction and detection capabilities of fog. The project particularly focuses on marine fog, on which significant knowledge gaps and data paucity exist and current and emerging applications abound. In particular, the emphasis is on Marine Sea Fog that forms over shallow seas and shelves. Coastal Ice Fog is also of interest, and will be addressed in a scaled down study to be conducted in the Northern Slopes of Alaska (NSA) Atmospheric Radiation Measurement (ARM) site. The approach is multi-faceted, and includes theoretical analysis, process studies via novel high-resolution numerical and laboratory simulations, extensive field measurements, and numerical weather prediction (NWP) modeling. Fatima draws expertise from a multidisciplinary group of researchers covering a scale continuum of fifteen decades from large weather systems (synoptic) to fog droplets of micrometer scales that spawn on aerosols of nanoscales (microphysical).

The overall goals are to: (i) deploy leading-edge instrumentation and novel measurements techniques in field campaigns to probe from synoptic to microphysical scales, including the capture of (smallest) scales of atmospheric turbulence where momentum, temperature and moisture fluctuations dissipate and, together with [bio] physicochemical properties of aerosols, control the droplet growth; (ii) conduct theoretical and numerical analyses that push the frontiers of multi-phase turbulence, especially nonlinear interactions between fog droplets and turbulence (and ice crystals in the case of Ice Fog); (iii) elicit earth-surface processes that dictate fog genesis and undergird vivid differences between fog and low-level clouds; (iv) identify deficiencies of fog microphysical parameterizations in NWP models and suggest/implement improvements; and (v) understand, exploit and model fog and turbulence impacts on optical propagation. Different participants focus on specific aspects that form the building blocks for prediction of fog life cycle in the overall framework of multiscale-flow (synoptic to turbulence cascade), microphysical (dissipating turbulence, drops), [bio]physicochemical (aerosols and transformations) and thermodynamic (radiation, heat exchange) processes. As the program developed, biophysical interactions also became an area of interest, contributed by collaborators.

The project included two one-month field campaigns at Grand Banks (Fatima-GB, 2022) and Yellow Sea (Fatima-YS, 2023), which are two non-polar global summer fog maxima contributed by different fog formation mechanisms. Both campaigns were successfully completed, utilizing densely instrumented research vessels and fixed operational platforms of Fatima international partners. The vessels included (i) Atlantic Condor, operated in collaboration with MEOPAR (Marine Environmental Observation, Prediction and Response), a Canadian National Network of Strategic Science, after converting this deep-sea supply vessel to a research vessel (R/V), (ii) R/V Onnuri of the Korea Institute of Ocean Science and Technology (KIOST), (iii) R/V Gisang 1 of the Korea Meteorological Agency (KMA), and (iv) Research Aircraft Nara of KMA and National Institute of Meteorological Services (NIMS). The fixed platforms included: (i) the Sable Island (SI) in the outer Canadian Atlantic Shelf, (ii) Korea Ocean Research Stations

(KORS) in the Yellow Sea, in the EEZ of the Republic of Korea (ROK), and (iii) Hibernia Oil Platform in North Atlantic operated by Wood plc. The Ice Fog campaign (Fatima-IF) is to be conducted at NSA during 15 November to 6 December 2025. Multitude of point, profiling and remote sensors pooled from Fatima participants were or will be deployed for measurements across fog-relevant space-time scales.

University of Notre Dame (UND) with H.J.S. Fernando as the PI (and senior personnel D. Richter and I. Gultepe) leads the project with Co-PIs from the Naval Postgraduate School (NPS, PI: Qing Wang), University of California, San Diego and Scripps Institution of Oceanography (UCSD, PI: Clive Dorman); University of Utah (UU, PI: Eric Pardyjak) and University of Minnesota (UM, PI: Lian Shen). A large number of US and international collaborators funded through non-MURI sources participate in the Fatima multidisciplinary endeavor. They are listed in the project website (https://efmlab.nd.edu/research/Fatima/).

UND Goals: (i) Develop and deploy leading edge instrumentation to capture synoptic to dissipative (Kolmogorov and Obukhov-Corrsin) scales to study nonlinear cascading of properties; (ii) Develop a theoretical modeling framework for fog-turbulence interactions; (iii) Identify new mechanisms underpinning fog life cycles, and (iv) Construct physics-based parameterizations. The main numerical tools are the WRF mesoscale model and a Lagrangian Cloud Model (LCM) coupled with Large Eddy Simulations (WRF-LES or LES-LCM).

UCSD Goals: To lead the climatological analysis component across the entire project, in particular, studies on how synoptic scales drive fog formation through cascading of momentum, temperature and water vapor inhomogeneities. Together with Naval Research Laboratory (NRL), UCSD play a leading role in providing forecasting support for Fatima field campaigns. The UCSD PI also provides climatological underpinning for data analyses of different groups.

NPS Goals: (i) Understand physical and terrestrial processes affecting fog evolution, and (ii) Identify microphysical and turbulence parameters affecting optical attenuation to develop more effective parameterizations of attenuation and scintillation of optical signals through fog. The first goal seeks innovative and extensive field deployments and in-depth analyses of observational data in synergy with complementary observations obtained by other Fatima collaborators. The second goal addresses the impacts of fog on important applications such as high-energy lasers and free-space optical communications due to beam attenuation and scatter.

UM Goals: To address how ocean surface processes, including sea surface temperature (SST), momentum flux, and sensible and latent heat fluxes, along with coastal and island land topography, collectively influence marine fog. This is a research topic that is stymied by the paucity of high-resolution data and [numerical and theoretical] analysis. UM Group tackles this question using large-eddy simulations (LES), where a Lagrangian cloud model (LCM) along with LES is used to simulate fog, with evaporation and condensation fog droplets modeled according to Kohler theory. A radiation model is developed to account for long-wave and short- wave radiation effects on the evolution of marine fog. Additionally, the impacts of large-scale dynamics (LSD) are included by incorporating the advective and subsidence terms into the LES governing equations.

UU Goals: To oversee and coordinate extensive instrumentation of Sable Island (SI) during Fatima-GB, data cataloging, and multi-investigator analysis. In the Fatima-YS, they deployed in-house developed liquid water content (LWC) measuring instruments. UU group emphasizes on understanding of the roles of radiative heating and cooling, low-level cloud dynamics, droplet thermodynamics, vertical profiles of microphysical parameters, dissipative processes, and infrared beam propagation through fog.

Accomplishments:

UND: Major activities included: (i) Continued analysis of data from Fatima-GB and Fatima-YS; (ii) Mesoscale-LES simulations of IOPs; (iii) Preparation of archival journal articles; (iv) Completion of a BAMS paper that garnered kudos from the referees, cover page of the July 2025 BAMS Issue and an AMS news release (Fig. 1); (v) Convening of an ONR-Global funded workshop on Marine Atmospheric Boundary Layer (MBL) in Seoul, ROK (Fig. 2); (vi) Submittal of DOE-ARM and ONR proposals to support Fatima Ice Fog (Fatima-IF) campaign in the North Slope of Alaska Site (15 Nov. to 6 Dec., 2025).

UND conducted WRF-LES with nested downscaling to 50m (Fig. 3), with focus on evening transition during IOP-9. At SI, three distinct layers were identified (Fig. 4): IBL over land, MBL advected toward SI, and an outer subsidence inversion layer (OSL) – all consistent with observations. A stable interfacial layer (IL) on SI separated IBL from MBL (Fig. 4a,c), and IL stability increased during evening transition. Continued decrease of temperature increased RH of IBL and MBL (Fig. 4 b,d), and [weak] mixing in IL led to a low-level cloud (LLC) that entrained downward to form fog. Fig. 5 shows the evolution of LWC and TKE in a vertical cross-section. During the day (1800 UTC), warming of moist air advected over SI forms an LWC-deficit plume in the IBL. During evening transition, MBL penetrates into the SI and forms a thin LLC below the IL (1930 UTC).

A LES-LCM model investigated competition between sulfate (land-based) and salt (produced locally) aerosols, which affects macroscopic properties of fog; Fig. 6. Antecedent to Fatima-IF, inclusion of ice in the LES-LCM is being pursued.

NPS: (i) Organized the 4th Fatima Annual Review (Fig. 7); (ii) Analyzed the association of fog events with synoptic/mesoscale variability and temporal variations of low-level moisture and winds (Fig. 8); (iii) Identified fog-layer top from all SI soundings, and contrasted its variability with synoptic forcing from mid-atmospheric thermodynamic variability; (iv) Studied thermodynamic and turbulence variability within the fog layer, including identification of fog layer top, lowest cloud layer top and base, and pertinent correlations (Fig. 9); (v) Continued evaluation of C-CAMS as a captive method for future ship-based deployments; (vi) Improved visibility parameterizations using C-CAMS, D-CAMS and SI data taken during fog events, and their comparison with previous studies in North Atlantic; (viii) Quantified deep-water wave breaking using optical and infrared video remote sensing of ocean surface, with breaking identified using whitecap fraction that is a function of wind forcing and sea state.

With regard to (vi), Fig. 10 shows original data from six fog/mist RVEs using different color markers (precipitation excluded) and the binned-averaged median MOR and LWC relationship (golden thick line). Although individual data points show significant scatter, the binned median curves for various events show similar variability. This suggests plausibility of a robust fit to seemingly scattered data. The fitted relationship only for the six events (thick green line) and for all data (thick black line) are in Fig. 10a; the two differ mainly at low LWC. Fig. 10b shows a comparison of MOR-LWC relationship from SI data with other studies in North Atlantic. The difference was found to be within observational uncertainties.

UU: Studied impacts of hydrometeors on electromagnetic (EM) wave propagation as well as the role of fine-scale turbulence on fog microphysical processes. In addition, UU made contributions to the technology development component of the Fatima Project.

With regard to EM propagation, to determine microphysical parameters of ~ 1 km scale using two-wavelength scintillometry, reduced order representations of droplet-size distributions (DSDs) are needed. Substantial progress was made in this regard by using high-quality datasets obtained during Fatima-GB, CFOG and other campaigns, including a short campaign with NPS near Monterey Bay in January 2024 to test horizontal extinction at infrared and microwave wavelengths. In unison, how inter-campaign variability as well as instrument limitations impact DSD could be quantified.

The differences and similarities of DSDs from all campaigns are more easily visualized via mathematical moments of the DSD (see Fig. 11). When median moments and variance bounds are plotted as a function of visibility, something exciting emerged. The zeroth moment of the total number concentration (Fig. 11a) shows both significant intra- and inter-campaign variability. For higher moments, the spread of data significantly decreases. The first moment (Fig. 11b) still shows variability but with a significant decrease in the inter-campaign variability, meaning that the first moment may be a better candidate for normalizations vis-a-vis. the zeroth moment! Thus, the models and predictions could greatly improve if fog microphysics community adopts higher moments as a primary metric.

As for turbulence-microphysics nexus, the hypothesis was that classical Kolmogorov theory breaks down in fog, viz., the energy spectrum deviates from favored E(k) ~ k**(-b), b = 5/3. The exponent b is related to the Hurst exponent H (Fig. 12 caption), allowing studies based on the first-order structure function. Measured H for disparate meteorological regimes (e.g., fog, mist etc.) were scrutinized, and some impacts of weather regimes on H were noted (Fig. 12). When comparing H based on temperature with stability (z/L), a relationship emerged, wherein H was nearly invariant of the weather regime (Fig. 13).

With regard to the technology development, UU group continued development of a low-cost hot-wire LWC system with two complementary probes: Wind-Sensitive Probe (WSP) and Fog-Sensitive Probe (FSP), with their own intrinsic advantages. During Fatima-GB, both probes were tested, and WSP's LWC agreed with the standard DMT FM120 (Fig. 14a) during fog periods delineated by FD70 sensor (Fig. 14b).

UM: The LES–LSD coupling framework developed at UM was used to investigate a YS fog event. In this study, bulk cloud microphysics (BCM) was incorporated, resulting in the LSD–LES–BCM (LLB) coupling. Fig 15 shows a snapshot from an animation illustrating the evolution of stratus clouds over the YS, simulated by the LLB system. Field observations, ERA5 reanalysis and COAMPS simulations were utilized to derive both the initial conditions for LES and the large-scale dynamics (LSD) forcing terms. The LLB system was applied to simulate the stratus-lowering marine fog observed on 3 July 2023 (IOP5) during Fatima-YS campaign, which was successfully reproduced. Observations indicated that fog formation began at 2100 UTC, which was accurately captured in the simulation. The temporal evolution of liquid water specific humidity (q_l) is presented in Fig. 16. A detailed analysis of this case was conducted to investigate the role of various physical and microphysical processes in controlling stratus lowering and fog development.

UCSD: Addressed the critical question of how unsaturated stable layers become saturated and remain stable, which occurred in almost all SI fog cases. A moist, stratified MBL was converted into a series of fog-laden mixing layers separated by sharper interfaces. According to Fernando et al. (2023, Environmental Fluid Mechanics, 23), this occurs during turbulent mixing in a stable MBL when a local bulk Richardson number is greater than a critical value. In general, several mechanisms may drive turbulence in such cases: generated via shear, thermal instability or weak convergence and lifting in the surface boundary layer in cyclonic settings. The narrow layers in the MBL have continually fluctuating local Richardson numbers, mostly greater than the critical value, thus fostering fog-laden stable layers, similar to those observed in almost all SI soundings.

Training Opportunities:

The project offered in-depth training opportunities for early career scientists, post-docs, graduate and undergraduate students, and technical staff. The graduate students were directly trained under the PIs, and many had opportunities to plan and participate in either/or Fatima-GB and Fatima-YS campaigns. Some will be involved in the forthcoming Fatima-IF campaign. Through participation in the field campaigns, they receive experience in instrument deployment and data analyses. Post-docs and graduate students worked with their academic advisors in writing archival papers. Early career scientists had an opportunity to work with their senior mentors as well as supervise graduate and undergraduate students; this synergy worked efficiently during the project. Undergraduate engineering student Kristen Mohan received a Slatt fellowship from the Notre Dame Energy Center to work on marine wind forecasting, who, together with another UND engineering undergraduate, Aadhithya Balaji, presented posters at the Notre Dame undergraduate research conference held in August 2025.

In addition, in 2025, UU began a weekly video conference meeting in which PIs, postdocs, and students are involved. It facilitates sharing of data and ideas at this critical juncture of the project. This is an important opportunity for students and postdocs to present to experts in the project and get constructive feedback. Unsurprisingly, many new ideas conducive for collaboration and journal papers are emerging during these meetings.

Since the first two Fatima campaigns were international, trainees had opportunities to travel to destinations abroad and interact with host-country scientists. Many of the trainees participated and presented in national and international workshops and conferences. Student were given opportunity to seek internships with partners. PhD Student Anne Dowling (UND) was a Research Intern at KIOST for a month (June, 2025), augmenting the two-month internship in 2024, where she worked with the Fatima-YS ROK Chief Scientist Dr. Seok Lee and prepared two journal papers; these will be a part of her PhD thesis. All three leading KIOST scientists, KI Chang, J-H Lee and Seok Lee in Fatima participated in the fourth-year review held at NPS during 20-21 February, 2025. Collaboration was maintained with DOD personnel on identifying science needs and transitioning project outcomes to applications. The trainees had an opportunity to interact with DOD laboratories.The following are a list of participants that benefited from training opportunities:

Early Career Scientists (5): Jesus Ruiz-Plancarte (NPS), David Ortiz-Suslow (NPS), Ryan Yamaguchi (NPS), Francesco Barbano (UU, University of Bologna), Dhiraj Singh (UU)

Post-Doctoral Fellows (5): Baban Nagare (UND), Sen Wang (UND), Han Liu (UM), Alexei Perelet (UU), Karli Rees (UU)

Graduate Students (10): Anne Dowling (UND, PhD), Matthis Chabert D’Hières (UND, PhD), Kee Horng (Rolf) Seh (UND, MS)
Matthew Huckins (UU, PhD), Anup Barve (UM, PhD), Leyla Salehpoor (York University, PhD), Gianina Massa (Dalhousie University, PhD), Shubham Mittal (UM, PhD), Sai Chaitanya Gembali (UM, PhD), LCDR. Dantaun Bernstein (MS, NPS).

Undergraduate Students (5): Dominick Russo (UND), Darius Colangelo (UND), Kristen Mohan (UND, Aadhithya Balaji (UND), Carson Ledesma (UU)

Technical Staff (2): Scott Coppersmith (UND), Orson Hyde (UND)

Results Dissemination:

This section contains archival journal papers that were published, submitted, or in revision during the reporting period as well as refereed book chapters. Conference presentations, Invited Talks, Special Fatima Sessions Organized, Special Journal Issues Organized, and Popular Press and News Articles are given the Uploaded Attachment (Figures and Dissemination Information):

2025 Publications

1. Bardoel, S.L., Cheng, S., Chamorro, L., and Fernando, H.J.S., Gravity Currents past Thin Two-Dimensional Obstacles, Journal of Fluid Mechanics, Volume 1012, A15, 10 June 2025. DOI: https://doi.org/10.1017/jfm.2025.412.
2. Barve A, Gultepe I, Fernando H, Wang Q, and Shen L; Large-Eddy Simulation with Lagrangian Cloud Modeling and Large-Scale Dynamics (L3) for Studying the Marine Fog Lifecycle. Quarterly Journal of the Royal Meteorological Society, Online Version of Record before inclusion in an issue, e5022, 2025. https://doi.org/10.1002/qj.5022.

3. Dimitrova, R.N., , Fernando, H.J.S., Silver, S.,, Bardoel, S.L., Dorman, C.E., Koračin, D., Vladimirov, E., and Giani, P., Study of a Mixing Fog Event using WRF-LES Numerical Simulations, Quarterly Journal of the Royal Meteorological Society, Volume151, Issue768 Part A, e4928, 2025. , https://doi.org/10.1002/qj.4928
4. Formby-Fernandez, A., Lenain, L., Pizzo, N, Dorman,C and Xie S-P., "Spatial and temporal structure of the fog life cycle over Atlantic Canada and the Grand Banks" Quarterly Journal of Royal Meteorological Society, Volume151, Issue 769, April 2025, Part B, e4953, 2025. https://doi.org/10.1002/qj.4953.
5. Fernando, H.J.S., Dorman, C.E., Pardyjak, E., Shen, L., Wang, Q., Creegan, E., Gaberšek, S., Gultepe, I., Hoch, S.W., Lenain, L., Richter, D.H., Chang, R., VandenBoer, T., Bardoel, S., Barve, A., Blomquist, B., Bullock, T., Chen, Z., Colosi, L., Coppersmith, R.S., Crawford, I., Crilley, L.R., Dimitrova, R., Dowling, A., Eleuterio, D., Fiorino, S., Gallagher, M., Gapp, N., Giacosa, G., Grachev, A., Grare, L., Hintz, T., Hocut, C., Huang, K.Y., Hyde, O., Keefer, K., Ortiz-Suslow, D., Perelet, A., Perrie, W., Ruiz-Plancarte, J., Salehpoor, L., Singh, D., Statom, N., Taylor, P., Wang, S. and Yamaguchi, R. Fatima-GB: Searching Clarity within Marine Fog. Bulletin of the American Meteorological Society, Vol 106 (6), E971–E1016, 2025. https://doi.org/10.1175/BAMS-D-23-0050.1.
6. Gaberšek, S., Gapp, N., Bardoel, S., Fernando, H.J.S., Ruiz-Plancarte, J., Ortiz-Suslow, D., Wang, Q., Pardyjak, E., Hoch, S., Gultepe, I., Dorman, C., Creegan, E., and Taylor, P., Fog clearing in the lee of an isolated, flat island: A fog shadow, Quarterly Journal of the Royal Meteorological Society. Published online before inclusion in an issue, 2025. https://doi.org/10.1002/qj.5057.
7. Ortiz-Suslow, David G., J. Ruiz-Plancarte, R.Yamaguchi, J. Kalogiros. H. J. Fernando, E. Creegan, E. Pardyjak, S. Gaberšek, I. Gultepe, and Q. Wang 2024: A case study of boundary layer development downstream of a small, remote island, Quarterly Journal of the Royal Meteorological Society, 151(768), e4929. 2025. https://doi.org/10.1002/qj.4929
8. Landolt, S.D., Jacobson, D., Gultepe, I., Underwood, W., Gaydos, A., DiVito, S., Mohling, H.T. and Bierbaum, A.M., Misreporting of Freezing Fog during Snowfall Conditions in US METAR Observations. Journal of Applied Meteorology and Climatology, 64(7), 705-716, 2025.
9. Dorman, C., Kim, J-H., Koracin, D., Dimitrova, R., and Fernando, H.J.S., Interaction of Land and Sea Processes Conductive to Fog over Nova Scotia under a Ridge on 8 September 2021, Quarterly Journal of the Royal Meteorological Society, Revision submitted. (QJ-24-0174).
10. Dorman, C., Koracin, D., Gultepe, I., Hoch, S., Ruis-Plancarte, J., Wang, Q. and Fernando, H.J.S., The role of the synoptic scale conditions in driving fog and mist during the FATIMA July 2022 Sable Island Field Program, Quarterly Journal of the Royal Meteorological Society, Revision submitted.
11. Giacosa, G., Robinson, L., Ortiz-Suslow, D., Yamaguchi, R., Creegan, E., Gauvin-Bourdon, P., Sahelpoo, L., VandenBoer, T. Wang, Q., Fernando, H.J.S., and Chang, R., Microphysics and interactions of aerosols and fog on the Northwest Atlantic Ocean, Quarterly Journal of the Royal Meteorological Society, Revision Submitted (QJ-25-0014).
12. Grachev, A., Fernando, H.J.S., Bardoel S.L., Randall, R.M., Hocut, C.M., Creegan, E., and Leo, L.S., Structure-Function Parameters over Different Surface Footprints in Coastal Zones, Boundary Layer Meteorology, In revision.
13. Lee, Jae-yong, Chan, Kyung-Il, Kim, Kyung Man, Gultepe, Ismail, Fernando, Harindra J.S. Evolution of Sea Fog Based on Meteorological and Oceanographic Observations during FATIMA Yellow Sea Campaign, Quarterly Journal of the Royal Meteorological Society, In Revision (QJ-25-0008).
14. Kim, Jeonghoe, Kim, Jung-Hoon, Dorman, C. and Fernando, H.J.S., Numerical Simulation of a sea fog event over Eastern Yellow Sea with a transition of air-sea temperature difference, Quarterly Journal of the Royal Meteorological Society, Revision Submitted (QJ-24-0176).
15. Lee, S., Gultepe, I., Fernando, H.J.S. Gaberšek, S., Lenain, L., Wang, Q., Pardyjak, E., Creegan, E.D., Dorman, C., Lozovatsky, I., Ortiz-Suslow, D.G., Ruiz-Plancarte, J., Yamaguchi, R., Gultepe, E., Hoch, S., Perelet, A., Singh, D., Cha, J-W., Shen, L., Barve, A., Dowling, A., Wang, S., Giacosa, G., Grare, L., Taylor, P., Chen, Z., Chang, R. Y.-W., Teeloku, P., Gapp, N., Lee, S.-W., Jeong, J-M., Kim, H-J., Jeong, J-Y., Heo, K-Y., Kim, M., Park, M-S., Oh, K-H., Park, J-S., Jeon, D-C., Song, K-M., Kim, J-Y., Jung, D., Chang, K.I., Lee, J.-H., Kim, K.M., Yu, D., Yum, S-C., Heymsfield, A.J., Agelin-Chaab, M., Goo, T-Y., Ryu, D-G., 2025: A review of FATIMA Yellow Sea field campaign research Quarterly Journal of the Royal Meteorological Society, Revision Submitted (QJ-24-0380).
16. Rowe, K., J. Ruiz-Plancarte, Yamaguchi, R.T., D. G., Ortiz-Suslow, E. Pardyjak, I. Gultepe, H. J. Fernando, and Q. Wang, 2025: Characteristics of summertime marine fog observed from a small remote island, Quart. J. Roy. Meteor. Soc., in Revision. (QJ-25-0015)
17. alehpoor, Leyla, Crilley, Leigh R., Giacosa, Gianina, Chang, Rachel Y.W., Ortiz-Suslow, David G., Wang, Qing, Creegan, Edward, Fernando, Harindra J.S., and VandenBoer, Trevor C., Microphysical chemistry of fog-aerosol interactions over the Northwest Atlantic Ocean during Fatima-2022. Quarterly Journal of the Royal Meteorological Society, Revision Resubmitted.

Refereed Book Chapters:

Gultepe, I., Fernando, H.J.S., and C. Dorman, Fog Observations and Forecasting. In: Encyclopedia of Atmospheric Sciences, Third Edition, Chapter 1013. Elsevier Publishing, In Press, Encyclopedia of Atmospheric Sciences (Second Edition), Editor(s): Gerald R. North, John Pyle, Fuqing Zhang, Academic Press, Pages 180e188, 2025. ISBN 9780123822253, https://doi.org/10.1016/B978-0-12-382225-3.00152-3.

Plans Next Period:

The Fatima group will continue to analyze field data from Fatima-YS and Fatima-GB, and will conduct planned Fatima-IF (15 November – 6 December, 2025) campaign and data analysis. They will continue with: LES-LCM as well as high resolution mesoscale and research grade (COAMPS, WRF and WRF-LES) simulations; carry out process studies; create knowledge on Fog and Turbulence Interactions and disseminate findings via journal and conference papers, and conference and workshop presentations; train graduate students, post-doctoral fellows and early career scientists; and pursue avenues for extension of Fatima research beyond the project, leveraging on extensive collaborations established during the project. Some undergraduate research participation is also expected. A special emphasis will be placed on STEM education and training.

UND: Complete the Fatima-IF campaign in NSA ARM Site, Utquiagvik, Alaska, including data analysis; Complete archival papers that are in revision, and submit several new manuscripts for publications; Conduct special sessions at the AGU-2025 and AMS-2026 annual meetings; Attract new papers for the Special AMS Collection of Fatima Papers from collaborators; Complete the PhD theses of Anne Dowling (Advisor – Fernando) and MS thesis of Rolf Seh (Advisor – Richter); conduct an in-depth analysis on radiation and height dependence of fog microphysics using FATIMA-GB measurements made by the UU tethered balloon group (Richter); Continuing to configure the LES-LCM framework for ice microphysics in support of FATIMA-IF via an undergraduate and a new MS student (Richter).

NPS: Complete the C-CAMS performance analyses paper on validating crane-based measurements as a general sampling methodology for near-surface altitude-dependent measurements for a broad range of variables, including mean wind, thermodynamics, turbulence fluxes, fog and aerosol size distribution, and other relevant parameters; Complete SI data analyses on variability of fog microphysics and turbulence at fog patch edges as fog events advected over SI; Analyze visibility as a function of fog microphysics using the C-CAMS/D-CAMS measurements from both Fatima-YS and the Fatima-GB campaigns to include the vertical variability of fog/visibility; Complete a thesis on diagnosing wave breaking through visible image analyses; Conduct final clean-up of NPS data and documentation to be archived for future users. Results from the first three will be submitted to the Fatima special issue of AMS journals.

UCSD: Organize and submit a manuscript on channelized flow in the NW Atlantic and its relationship to marine fog; Handle the AMS Special Collection of Fatima Papers as the Lead Guest Editor; and present research at the AMS-2026 and AGU-2025 Annual Meetings. The UCSD PI will continue to work on several collaborative research papers involving multiscale interactions during fog formation, especially the role of turbulence and other sub mesoscale processes. Close collaboration with Darko Koracin (University of Split, Croatia) will continue, who plans to visit ND in 2026 to collaborate with UCSD and UND PIs.

UM: A manuscript summarizing a detailed investigation into physical and microphysical processes governing stratus fog formation and lowering is currently in preparation, and will be submitted to the AMS Special Issue on Fatima. UM will also carry out comprehensive simulations of ice fog, an endeavor that they will lead and foster among Fatima numerical modeling investigators. UM work will include the development of new parameterizations specific to ice fog formation and evolution, which will be evaluated using simulations and observational data of the upcoming Fatima-IF campaign.

UU: Participate in the Ice-Fog field campaign and data analysis; continuing analysis of data from Fatima-GB and Fatima-YS; complete peer-reviewed journal papers and disseminating results via conferences; continued development of the LWC probe systems; continue to host weekly virtual meetings.

Honors and Awards:

Dr. David Richter (UND) was awarded the Notre Dame Frank M. Freimann Collegiate Professorship

Dr. HJS Fernando was presented the 2025 “Springer-Nature Publishing Editor of Distinction Award” for his role as the Editor-in-Chief of the Journal of Environmental Fluid Mechanics.

Dr. Gultepe was rated as a top scholar by ScholarGPS rankings in the areas of Geophysics, Aviation, and Meteorology (i.e., performance in the top 0.5% of all scholars worldwide).
It is based on the publication record, impact of work, and notable quality of scholarly contributions

Dr. Gultepe was awarded with a Certificate of Editorial Excellence by Pure and Applied Geophysics by Springer Inc. in recognition his outstanding contributions and dedication to the journal.

Technology Transfer:

Several technology development efforts have been attempted, and new technologies are being prototyped during Fatima field studies. University of Utah continue to develop and test a low-cost hot-wire LWC system with two types of probes: Wind-Sensitive Probe (WSP) that measures turbulence and can support LWC inference but requires co-located temperature, mean wind speed, and relative humidity inputs and the Fog-Sensitive Probe (FSP) that operates independently to retrieve LWC directly and also reports the mean wind speed; see Figure 14.
A highlight of the project is the close collaboration with DOD Laboratories, which included:

(i) Naval Research Laboratory, Monterey (Sasa Gabersek, who was the lead forecaster of the Fatima-YS and Fatima-GB campaigns, and possibly will be at the Fatima-IF campaign at NSA in November-December 2025). NRL used coupled atmosphere-ocean COAMPS model at 1 km resolution and different initialization times to guide IOP predictions; Model-data intercomparisons are being used to identify model deficiencies and remedy them by developing new parameterizations). In addition, COAMPS is being used in certain process studies.

(ii) Army Research Laboratory, White Sands Missile Range, New Mexico (Ed Creegan, Andrey Grachev, Chris Hocut). Creegan was the Chief Scientists of both Fatima cruises, and was the lead person in the effort of converting the deep-sea supply vessel Atlantic Condor to a research vessel. Grachev and Hocut are conducting research on optical turbulence in fog environments based on turbulence measurements in Fatima field campaigns. A joint journal paper between ARL and UND was submitted recently (and now under revision) on structure function parameters over different coastal footprints.

(iii) Airforce Institute of Technology AFIT (Steve Fiorino and Kevin Keefer) deployed novel instruments in Fatima-GB to capture fine bio aerosols, in particular, the presence of P Syringae in marine aerosols. The results were promising. AFIT will deploy a suite of instruments at Fatima-IF campaign, and the AFIT post-doctoral fellow, Dr. Marilyn Dunbar, is one of the three participants who will spend the entire campaign period at NSA.

(iv) NPS closely works with the Naval Air Warfare Center Weapon Division (NAWCWD), Physics Division, to transition the measurement techniques used/developed in Fatima to support US Navy high energy laser (HEL) weapon testing.

(v) Discussions are underway with Naval Surface Warfare Center (NSWC) Crane Division in Indiana (Dr. Kevin Goodman) to study the effects of fog on hypersonic transport. Several meetings were held to identify ‘elusive’ technical issues that underlie this research area.

Participants:

- Lian Shen (Co PD/PI) - 1 month(s)
- David Richter (Co-Investigator) - 1 month(s)
- Francesco Barbano (Faculty) - 1 month(s)
- Dhiraj Singh (Faculty) - 1 month(s)
- Sen Wang (Postdoctoral (scholar, fellow or other postdoctoral position)) - 1 month(s)
- Leila Salehpoor (Graduate Student (research assistant)) - 1 month(s)
- Gianina Massa (Graduate Student (research assistant)) - 1 month(s)
- LCDR. Dantaum Bernstein (Graduate Student (research assistant)) - 1 month(s)
- Harindra Fernando (Co PD/PI) - 2 month(s)
- Qing Wang (Co PD/PI) - 2 month(s)
- Clive Dorman (Co PD/PI) - 2 month(s)
- Eric Pardyjak (Co PD/PI) - 2 month(s)
- Darko Koracin (Faculty) - 2 month(s)
- David Ortiz-Suslow (Faculty) - 2 month(s)
- Han Liu (Postdoctoral (scholar, fellow or other postdoctoral position)) - 2 month(s)
- Baban Nagare (Postdoctoral (scholar, fellow or other postdoctoral position)) - 2 month(s)
- Matthis D'Hieres (Graduate Student (research assistant)) - 2 month(s)

- Matthew Huckins (Graduate Student (research assistant)) - 2 month(s)
- Gultepe Ismail (Co-Investigator) - 3 month(s)
- Reneta Dimitrova (Faculty) - 3 month(s)
- Jesus Ruiz-Plancarte (Faculty) - 3 month(s)
- Ryan Yamaguchi (Faculty) - 3 month(s)
- Alexei Perelet (Postdoctoral (scholar, fellow or other postdoctoral position)) - 3 month(s)
- Sai Gembali (Graduate Student (research assistant)) - 3 month(s)
- Dominick Russo (Undergraduate Student) - 3 month(s)
- Darius Colangelo (Undergraduate Student) - 3 month(s)
- Kristin Mohan (Undergraduate Student) - 3 month(s)
- Aadhithya Balagi (Undergraduate Student) - 3 month(s)
- Carson Ledesma (Undergraduate Student) - 3 month(s)
- Schubham Mittal (Graduate Student (research assistant)) - 5 month(s)
- Karli Rees (Postdoctoral (scholar, fellow or other postdoctoral position)) - 6 month(s)
- Anup Barve (Graduate Student (research assistant)) - 8 month(s)
- Anne Dowling (Graduate Student (research assistant)) - 12 month(s)
- Anne Dowling (Graduate Student (research assistant)) - 12 month(s)
- Kee Horg (Rolf) Seh (Graduate Student (research assistant)) - 12 month(s)

Partners:

No partners found.

Other Collaborators:

Airforce Institute of Technology AFIT (Steve Fiorino, Kevin Keefer) [USA]
Argonne National Laboratory (Virendra Ghate) [USA]
Army Research Laboratory (Ed Creegan, Andrey Grachev, Chris Hocut) [USA]
Bedford Institute of Oceanography, Canada (William Perrie) [Canada]
Dalhousie University, Canada (Rachel Chang) [Canada]
Korea Institute of Ocean Science and Technology KIOST, ROK (Jae Hak Lee, Myun-Sook Park, Ki-Young Heo; Seok Lee, ROK PI for 2023 Campaign) [ROK]
Pacific Northwest National Laboratory (Raghu Krishnamurthy) [USA]
*Pacific Northwest National Laboratory (Swarup China) [USA]
*Sandia National Laboratory (Darielle Dexheimer and Andrew Glen) [USA]
*University of Alaska (Carl Schmitt) [USA]
*University of Albany (Jie Zhang) [USA]
University of California, Davis (Adele Igel) [USA]
University of California, San Diego and Scripps (Luc Lenain) [USA]
University of Manchester, UK (Martin Gallagher) [United Kingdom]
University of Ontario Institute of Technology (Ismail Gultepe) [Canada]
Wood Infrastructure Solutions (Wood IS), Canada (Terry Bullock) [Canada]
Yonsei University, ROK (Seong Soon Yum) [ROK]
York University, Canada (Peter Taylor; Trevor VandenBoer; George Isaac) [Canada]
Naval Research Laboratory, Monterey (Saša Gaberšek) [USA]
Seoul National University (Jung-Hoon Kim) [ROK]
Geosystems Corporation (KI Chang, Jae Hak Lee) [ROK]
Korea Meteorological Administration KMA (Chulkyu Lee) [ROK]
National Institute of Meteorological Services NIMS, ROK (Joo Woo Cha, Yong H. Lee) [ROK]
Southern Illinois University (Eren Gultepe) [USA]
(*New 2025 collaborations for the ice-fog project)

Figures: This document contains figures and extra dissemination information.

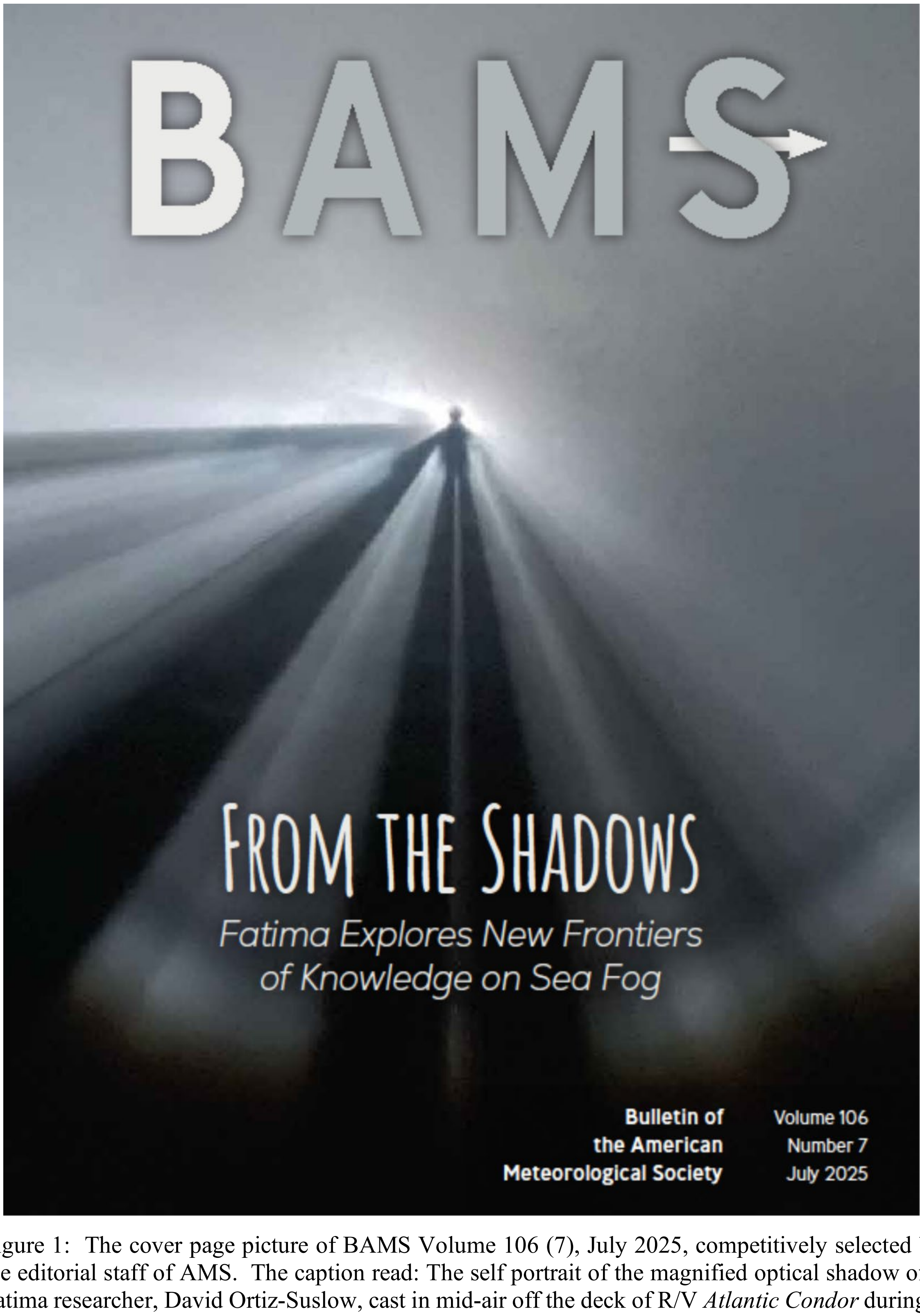


Figure 1: The cover page picture of BAMS Volume 106 (7), July 2025, competitively selected by the editorial staff of AMS. The caption read: The self portrait of the magnified optical shadow of a Fatima researcher, David Ortiz-Suslow, cast in mid-air off the deck of R/V *Atlantic Condor* during a Fatima-GB dense fog event. Upon releasing a radiosonde from the deck, Ortiz-Suslow noticed his mightily enhanced shadow, much similar to a Brocken Spectre (German: Brockengespenst) adorned by halo-like rings known as Glory (Heiligenschein), created by the refraction and backscatter of sunlight by fog droplets.

Figure 2: Attendees of the Marine Atmospheric Boundary Layer over East China/Yellow Seas (MARBLES) Workshop in Seoul, Republic of Korea (ROK), 25-26 June 2025 (https://efmlab.nd.edu/conferences/). The purpose was to discuss enhanced collaborative opportunities beyond the Fatima-YS study. The participants were from ROK, Taiwan, Japan, US and Europe. It was organized by the Geosystems Research Corporation (ROK, Lead), University of Notre Dame, Korea Institute of Ocean Science and Technology (KIOST), Naval Postgraduate School, Korea Hydrographic Office (KHOA) and Korea National Meteorological Services (NIMS) under the aegis of the Fatima Project.

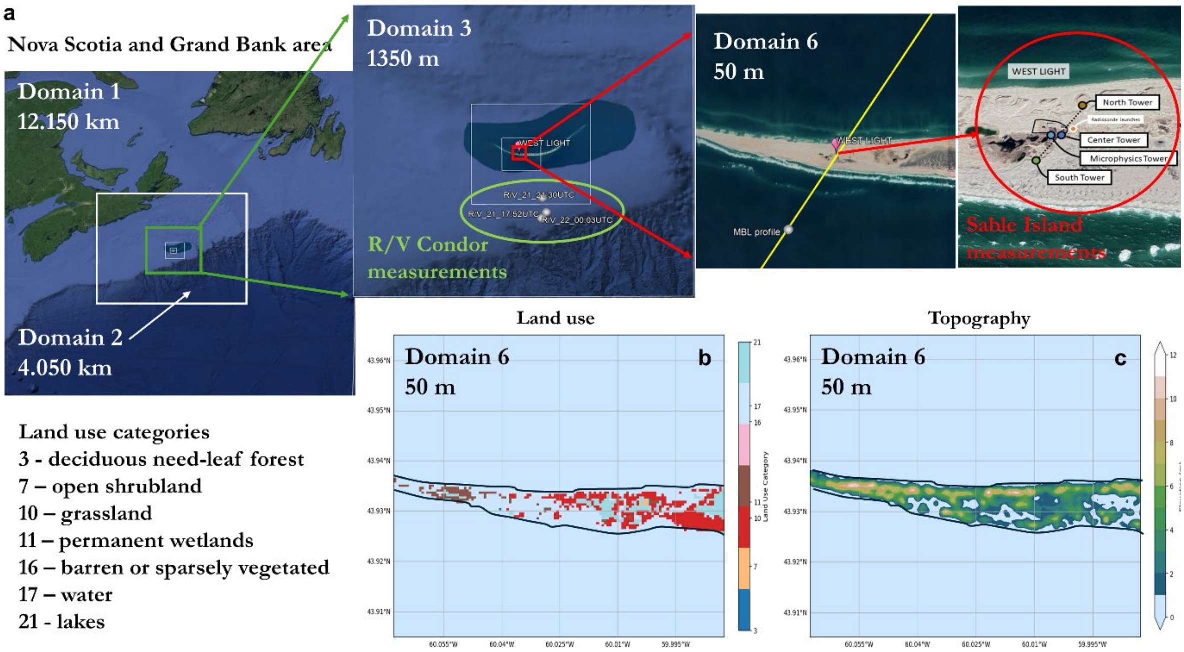


Figure 3: Domains 1, 3 and 6 used for WRF-LES simulations of Fatima-GB IOP-9 over Sable Island (SI): (a) with the instrumented land site (red circle) on SI and R/V Condor traverse region (green circle) in the insets; (b) MODIS land-use categories for domain 6; (c) modified topography for domain 6. The yellow line (domain 6 in (a)) is a section along the main wind direction through the West Light station and a wave-glider location, with locations of vertical profiles over the ocean (MBL profile, grey dot) and SI (West Light).

The case study described in the text concerned IOP-9 (21-22 July 2022). WRF-LES (version 3.9.1) model with option for resolving larger-scale turbulence was downscaled to 50 m in the domains shown above in (a). For all domains,106 vertical levels were used, with more levels (20) in the lowest 500 m, the first level being at 15 m agl. Initial and boundary conditions were from the six-hourly NCEP Final Operational Model Global Tropospheric Analyses. 4D data assimilation was used for the outermost domain, sea surface temperatures were from ERA5 Copernicus Archives, model initialization was at 21 July 2022 at 0000 UTC, and model run continued for 30 hours, with first 18 hours reserved for spin-up. Results were rigorously evaluated using in-situ measurements at SI and R/V Condor.

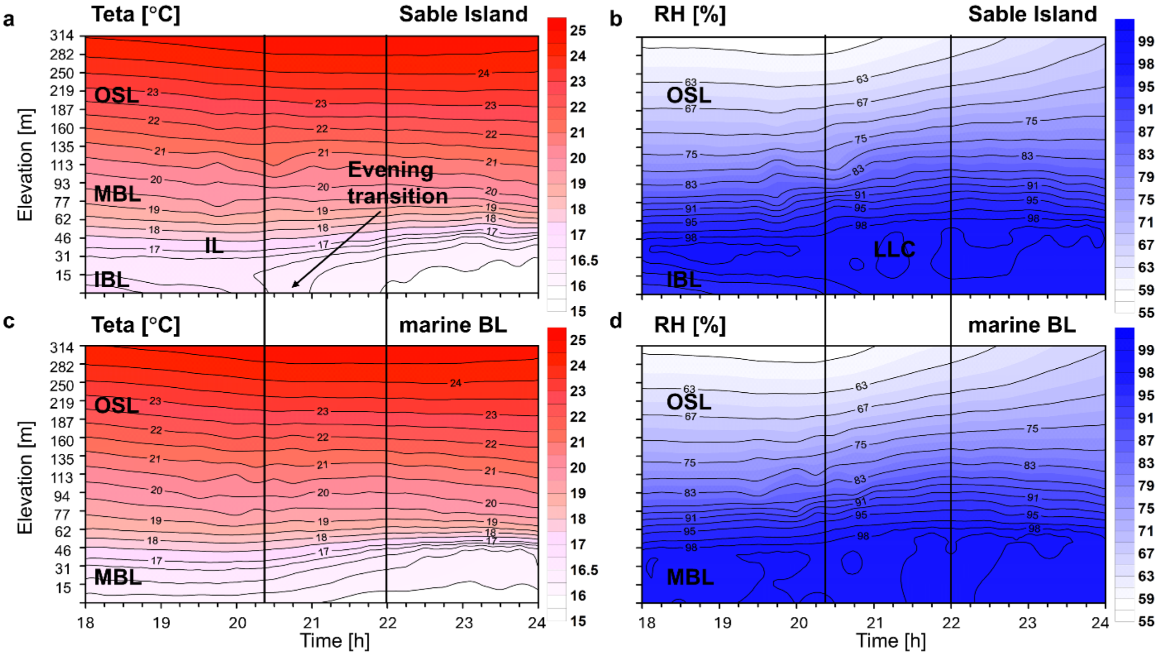


Figure 4: Time evolution of vertical profiles at Sable Island SI (a, b) and over the ocean at about 2.4 km upstream of the land where a wave glider was located (c, d). The potential temperature (Teta) and relative humidity (RH) are shown from WRF-LES simulations.

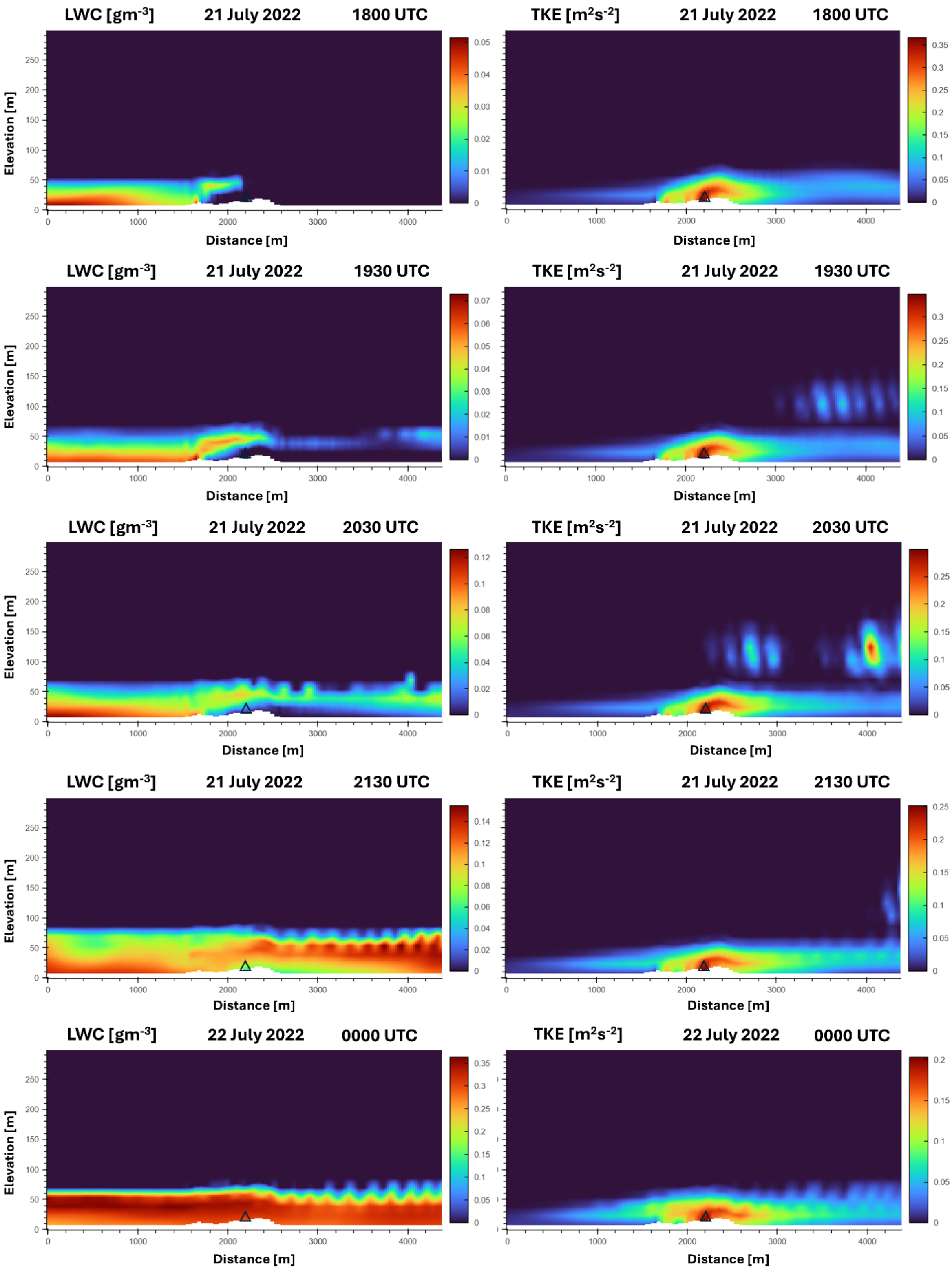


Figure 5: Computed vertical cross-sections of liquid water content (LWC) and turbulent kinetic energy (TKE) along the yellow line (drawn along the wind direction) in Fig. 3a, showing times corresponding to different stages of fog formation. The black triangle indicates the SI observation station used for comparisons with WRF-LES. Note the scale differences between plots.

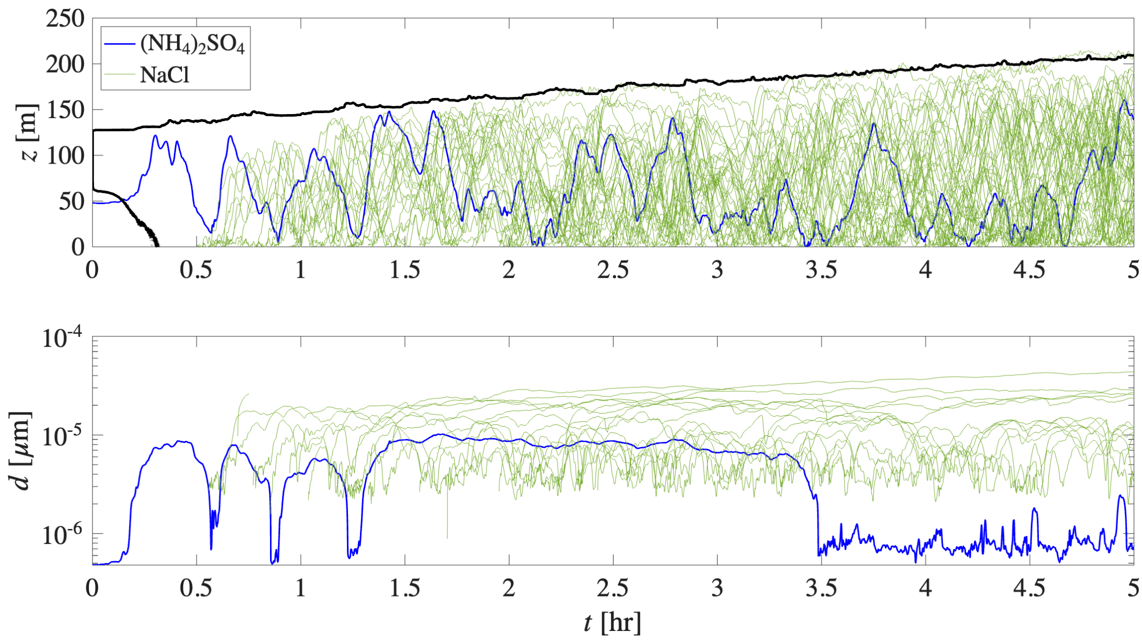


Figure 6: UND LES-LCM model simulations for IOP-10 of the Fatima-GB campaign. Top panel: black outline shows fog extent, while blue and green lines show representative trajectories of sulfate and salt aerosols as they traverse fog. Lower panel shows the radius evolution of the selected droplets, highlighting the distinct difference in hygroscopicity on droplet growth.

Figure 7: Attendees at the 4th Annual Review meeting of the Fatima Project, held 20-21 February, 2025 at NPS in Monterey. Presentations at the meeting can be found in: https://efmlab.nd.edu/research/fatima/workshops-meetings/.

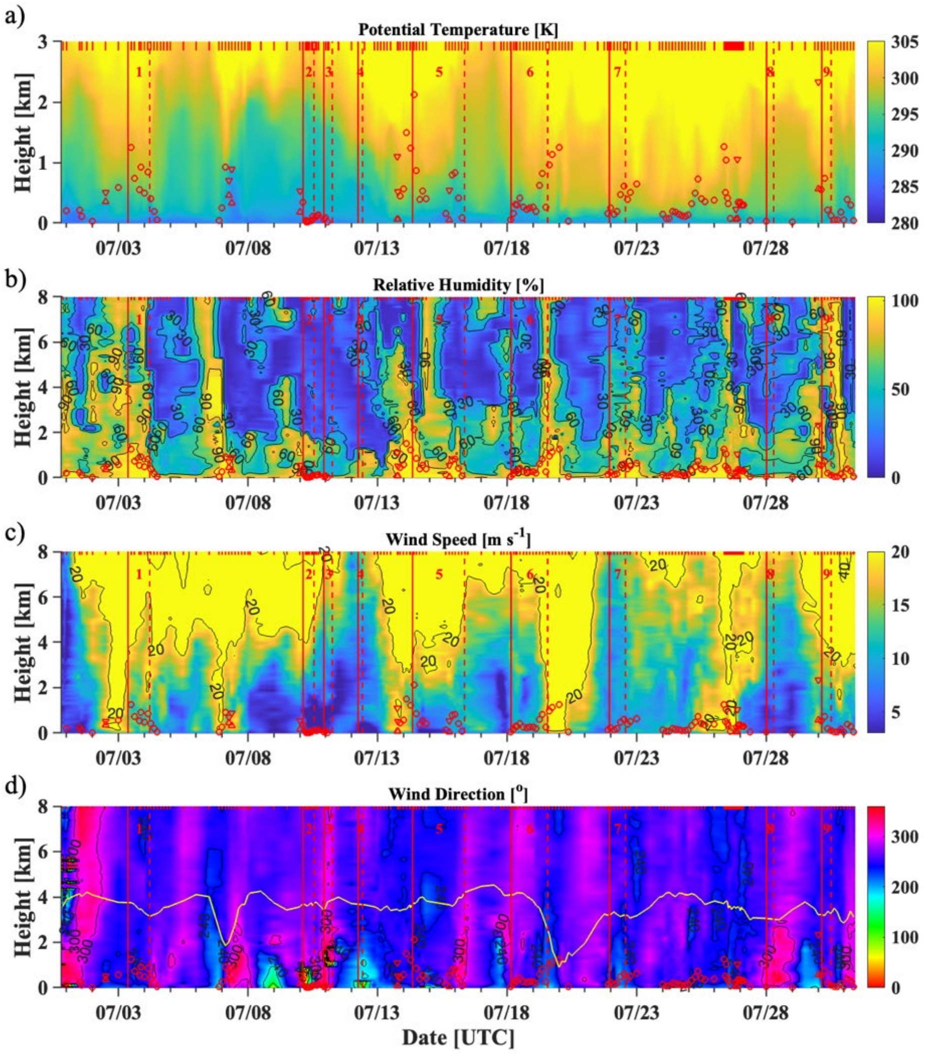
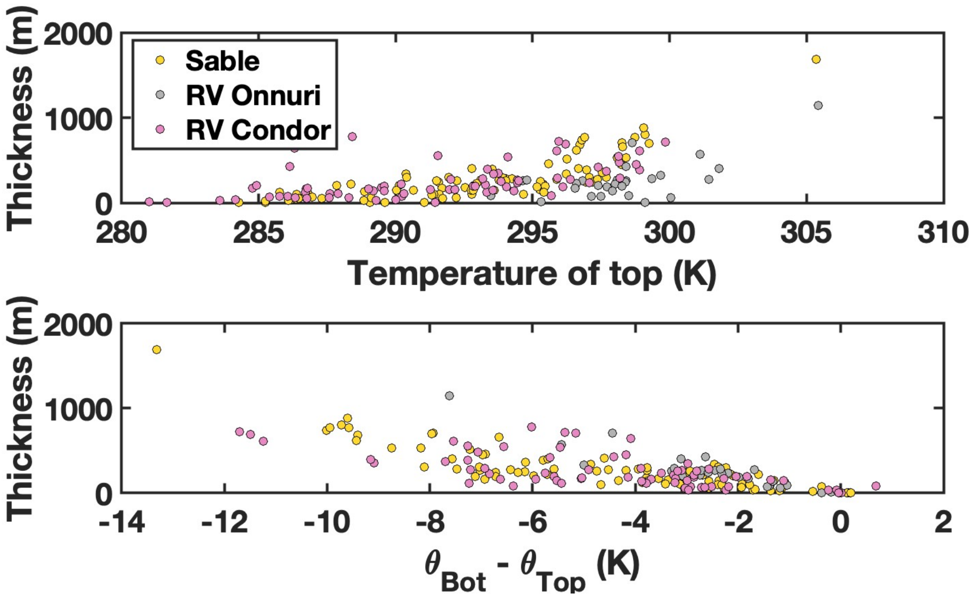


Figure 8: SI radiosonde sounding data of (a) potential temperature, (b) relative humidity, (c) wind speed, and (d) wind direction. The short magenta lines at the top of each subplot delineate the time of each radiosonde launch. The red circles denote the fog layer top, while the red downward and upward triangles denote the low-level cloud top and base, respectively, identified from the individual soundings. The long vertical solid and dashed red lines denote the start and end of each identified Reduced-Visibility Event (RVE), marked by event numbers 1-9. In (d), the variation of surface pressure obtained from the soundings is shown (yellow solid line). The values shown on the left axis were the scaled pressure deviation from 950 mb calculated by (Ps − 950)/6 – 7 (mb).

Note the passage of frontal systems every several days, indicated by the arrival of low-pressure systems. Two most prominent systems were centered at about 03:00 July 7 and 00:00 July 20, 2022. There were also a few weaker systems during the IOPs. Post-frontal high pressure was generally weaker, but identifiable (Fig. 8d). Expectedly, the low-pressure systems were accompanied by a deep moist layer (convective clouds, Fig. 8b) and enhanced wind (Fig. 8c) about 1 day ahead of the lowest surface pressure. The deep moisture layers were followed by a period of dry spell extending to above 2-3 km above the surface when the low-pressure systems recovered and followed by weak high-pressure systems. Under the high-pressure forcing, strong mesoscale variability could be discerned, particularly in the water vapor and wind fields in the mid atmosphere and a persistent saturated layer near the surface. This thin saturated air is a result of warm and moist boundary layer air advected from the warmer Gulf Stream located to the south. The fog events after the frontal passages were normally shallow in contrast to deep fog/cloud layer during the frontal passage. Strong low-level wind associated with frontal passage and the weaker wind under the influence of post-frontal atmosphere are evident (Fig. 8c). The co-existence of fog and high-wind conditions, a unique feature of the North Atlantic fog, is confirmed by this data (Fig. 8c).



(a) Figure 9: (a) Fog-top potential temperature; (b) Surface (Fog-bottom) and fog-top potential temperature difference as a function of fog thickness from all FATIMA sounding measurements.

Note the correlation between fog thickness and the temperature difference between the bottom and the top of the fog layer from all three sounding locations (SI, R/V Condor, and R/V Onnuri). A very consistent temperature gradient is seen. Since local cooling in most of the fog tops was observed, the increase of potential temperature from the surface to the fog layer top must have been imposed by the large/mesoscale environment. As a result, the fog layers are in generally weak in turbulence, although wind shear and fog-top infrared cooling may exist to generate turbulent kinetic energy.

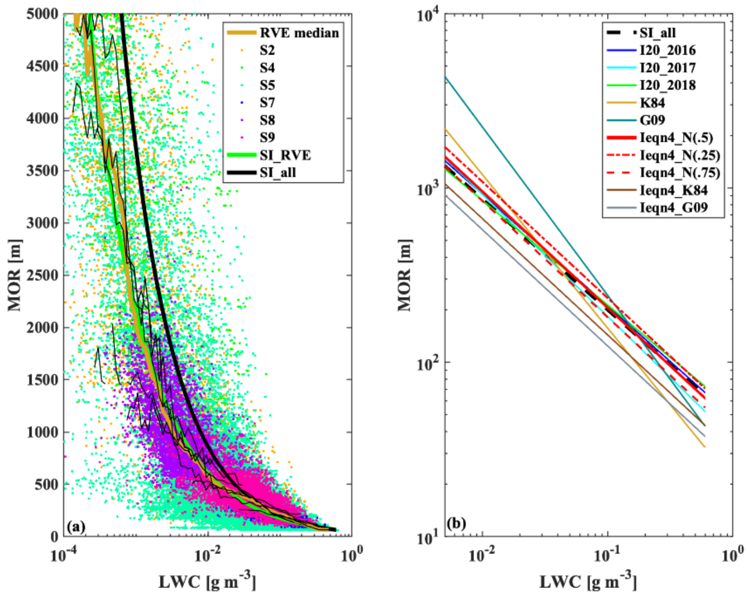


Figure 10: (a) Variations of MOR with LWC for data from each fog/mist Reduced Visibility Events (RVEs, colored dots) and their median curves (thin black lines). Only the fog/mist RVEs are included in this figure. The thick golden line is the median curve for all RVEs included here. The golden, black, and green thick lines represent the median for all RVEs, the fitted line for all data points and for all RVEs. (b) A comparison of Fatima RVE results with measurements from 2016, 2017, and 2018 by Isaac et al. (2020), Kunkel (1984), and Gultepe et al. (2009) shown as ’I2016’, ’I2017’, and ’I2018’, ’K84’, and G09. All legends with ’Ieqn4’ denote the fitted lines using Eq. (4) in Isaac (2020) with measured median (’Ieqn4_N(.5)’), 1st quartile (’Ieqn4_N(.25)’), and 3rd quartile (’Ieqn4_N(.75)’) from this study, and using those from Kunkel (1984, ’Ieqn4_K84’) and Gultepe et al. (2009, ’Ieqn4_G09’).

Note the MOR-LWC relationship from SI data and those of other studies in the North Atlantic in Fig. 10b. While K84 and G09 are measurements from coastal land surface sites, I20 studies were made on a fixed platform over the open ocean. In addition, the results are also compared to a simple theoretical derivation by Isaac et al. (2020) labeled as EIeqn4 with various droplet number concentrations. Fig. 10b shows remarkable consistency between the I20 measurements and SI results when all data were used (line labeled ’SI_all’): SI results sit in between those in I20 from the three seasons. The small differences, hence, can be explained by seasonal variability, despite of differences in the details of the microphysics parameters (likely due to the height differences of the sampling platform). Fig. 10b also is in close agreement with Fatima measurements and the simple theoretical relationship of (Weather and Forecasting, 35(2), 2020). To account for the variability in number concentration, the I20 theoretical relationship was calculated using the first and third quartiles of droplet concentration shown as ‘Ieqn4_N(.25)’ and ‘Ieqn4_N(.75)’, respectively. The differences are within the observational uncertainties, suggesting that this relationship may be used with reasonable accuracy if an approximate number concentration is provided.

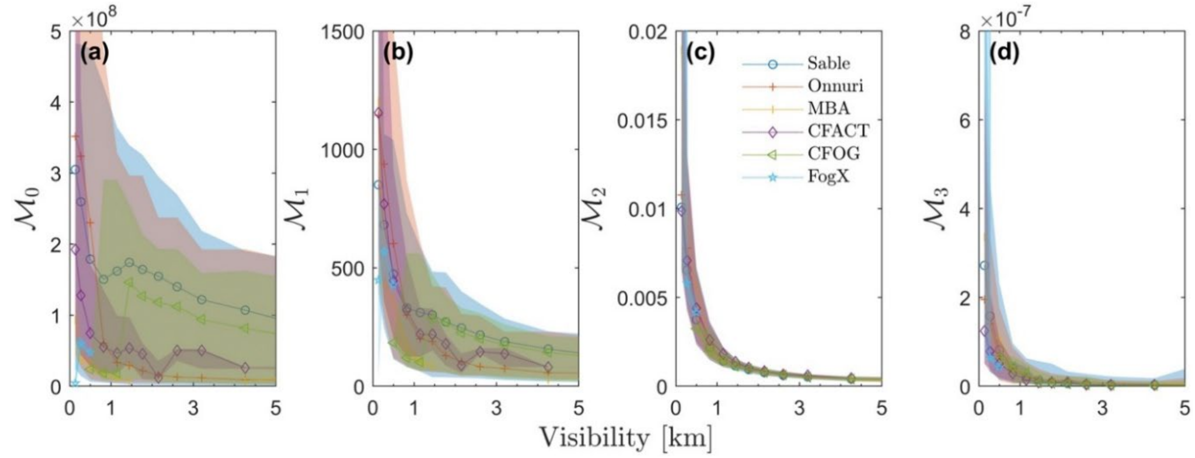


Figure 11: Median values of the first four moments of the droplet-size distribution (DSD) as well as shading that corresponds to the 2σ bounds of data for each of the six campaigns indicated in the inset. Visibility ranges without colored shading indicate that the campaign lacked sufficient data for that visibility range. The X^{th} moment of the DSD is defined as

$$\mathcal{M}_X = \int_0^\infty D^X N_D(D) dD,$$

where D is the droplet diameter and $N_D(D)$ is the measured DSD from optical particle counters (OPCs). These moments have physical meaning with $\mathcal{M}_0 \equiv N_{D,tot}$ (total number concentration), $\mathcal{M}_2 \propto Vis$ (Visibility), and $\mathcal{M}_3 \propto LWC$ (Liquid Water Content).

Note that according to Fig. 11a the zeroth moment of the total number concentration shows both significant intra- and inter-campaign variability. This wide variability points toward total number concentration not being an ideal parameter for parameterizations, although it is used extensively in models and normalization schemes. The wide inter-campaign variability indicates that total number concentration is a poor metric for blanket normalization across different fog types. Part of the variability could also represent instrument limitations. Since it is not possible currently to separate instrument variability from environmental variability, the variability needs to be taken at face value, and high variability is undesirable for predictability. When higher moments are concerned, the spread of the data significantly decreases. The first moment (Fig. 11b) still shows variability but there is a significant decrease in the inter-campaign variability meaning that the first moment may be a better candidate for normalizations in place of the zeroth moment. When second and third moments are considered, a general decrease in both the intra- and inter-campaign variability can be seen. The takeaway is that even with the wide variability of the total number concentration across campaigns, these two critical metrics are not grossly impacted. Thus, the models and predictions could greatly improve if fog microphysics community were to shift to using other moments as a primary metric.

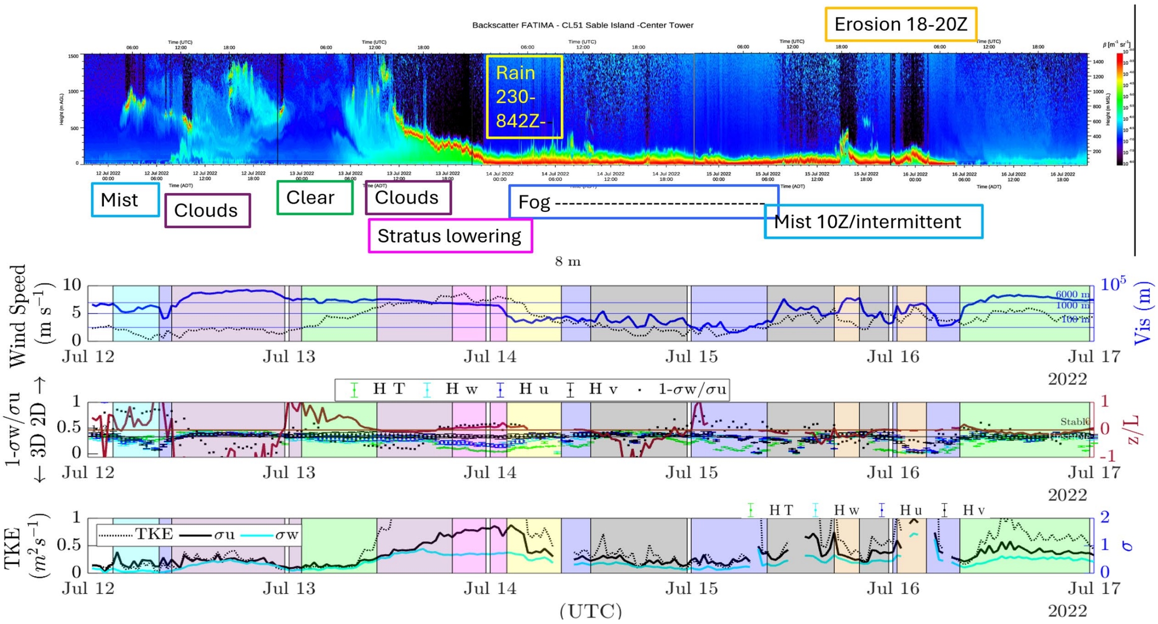


Figure 12: Time series of ceilometer data with weather [regime], wind and turbulence measurements from Fatima-GB for July 12-17, 2022. According to Kolmogorov's theory of 3D isotropic turbulence, $E(k) \sim k^{-b}$, where $b = -5/3$, which is related to Hurst exponent H *as* $b = 2H + 1$ *or* $H = (b-1)/2$. For 3D isotropic turbulence, H=1/3 and for 2D turbulence H=1. This allows for more straightforward measurements using the first-order structure function $S(\ell) = |\Delta\Theta(\ell)| = \langle|\Theta(x+\ell) - \Theta(x)|\rangle \propto \ell^H$, where Θ represents turbulent fluctuation of a meteorological variable (u, v, w, T), obtained by sonic anemometers, and ℓ the separation distance between two measured quantities.

Note that the time-averaged structure function S(ℓ) slopes were used to retrieve H using linear regression. Some impact of weather regimes (defined as mist, fog, precipitation, clear skies, clouds, stratus lowering, and stratus erosion events) were noted on H, and hence H dependence on the nature of turbulence (e.g., 2D versus 3D).

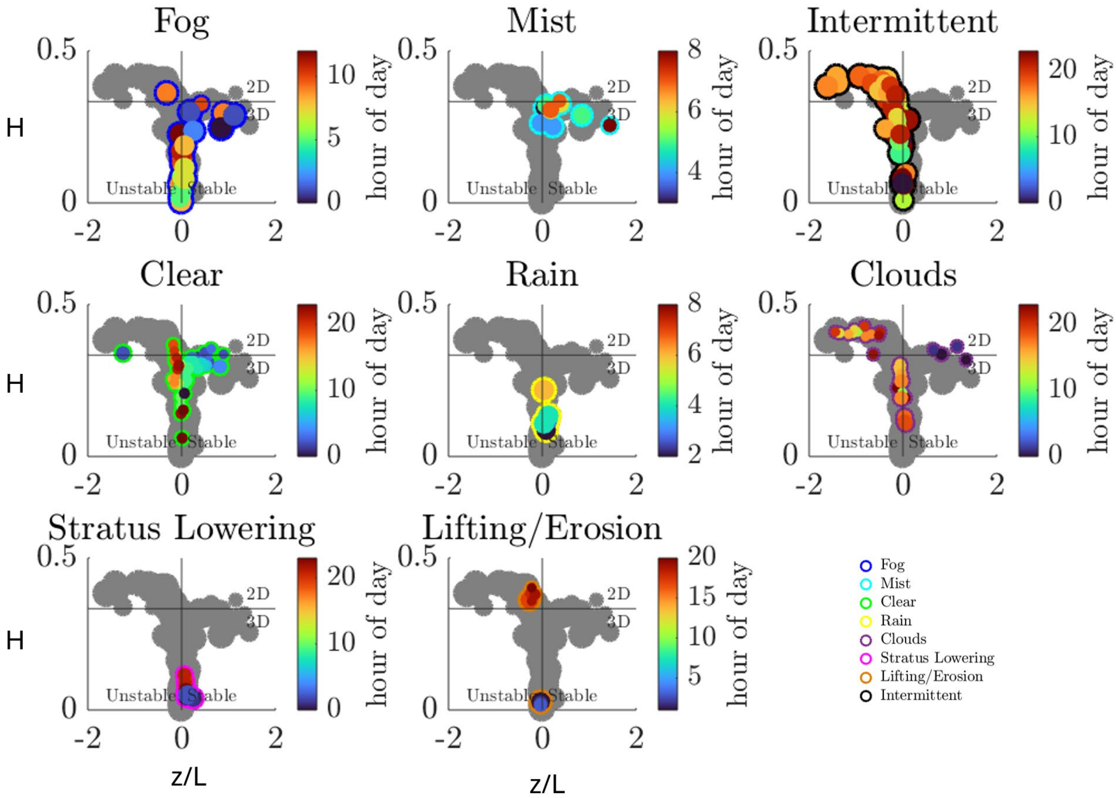


Figure 13: Scaling of the Hurst exponent H as a function of stability z/L for different conditions.

When comparing H based on temperature with measured stability (z/L; z being the measurement height and L the Monin-Obukhov length scale), a relationship emerged, which is nearly invariant of the weather regime. Nevertheless, very low values of H were observed, particularly for fog events, suggesting a nearly flat structure function slope. It is hypothesized that lowest H indicate temperature fluctuations becoming more homogeneous during condensation and evaporation.

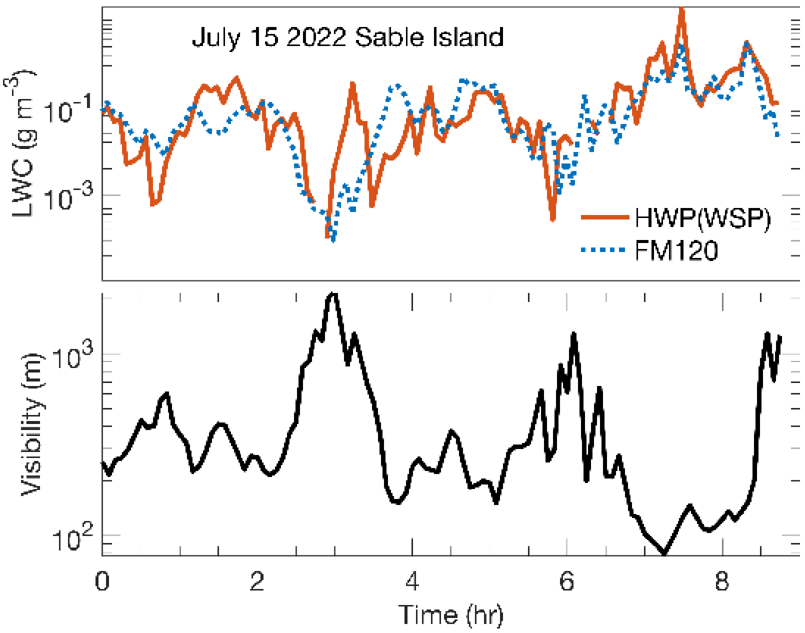


Figure 14: (a) Time series of LWC from the WSP and fog monitor DMT FM120 (1 Hz) on 14 July 2022, at SI. (b) corresponding visibility time series for the same period based on FD70.

Note that UU hot-wire LWC system consisted of two probes. The first is the Wind-Sensitive Probe (WSP) that measures turbulence and supports LWC retrieval, but requires co-located temperature, mean wind speed, and RH inputs. The second, Fog-Sensitive Probe (FSP), operates independently to retrieve LWC directly and also reports mean wind speed (not turbulence). Both were tested during Fatima.

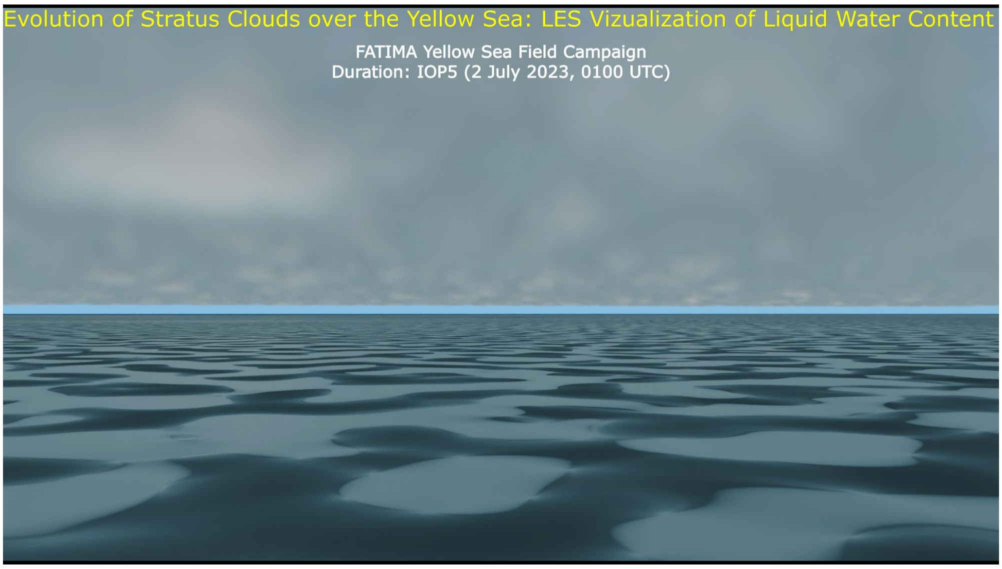


Figure 15: A stratus-lowering marine fog event observed on July 3, 2023 during IOP5 of the Fatima-YS campaign is simulated using Large-Eddy Simulation (LES). Owing to domain size limitations, large-scale dynamics (LSD) are typically poorly represented in traditional LES. To overcome this limitation, this study employs an LES–LSD coupling approach, in which advective and subsidence tendencies from large-scale processes are explicitly incorporated into the LES governing equations. In addition, a two-moment bulk microphysics scheme, which prognoses both the cloud droplet number concentration and cloud water mixing ratio, is implemented to enable a more realistic representation of microphysical processes relevant to fog formation. The coupled model is validated against in situ and remote sensing observations collected during Fatima-YS campaign. The figure shows a representative frame from an animation depicting the evolution of stratus clouds over the YS, illustrating the spatial distribution of LWC.

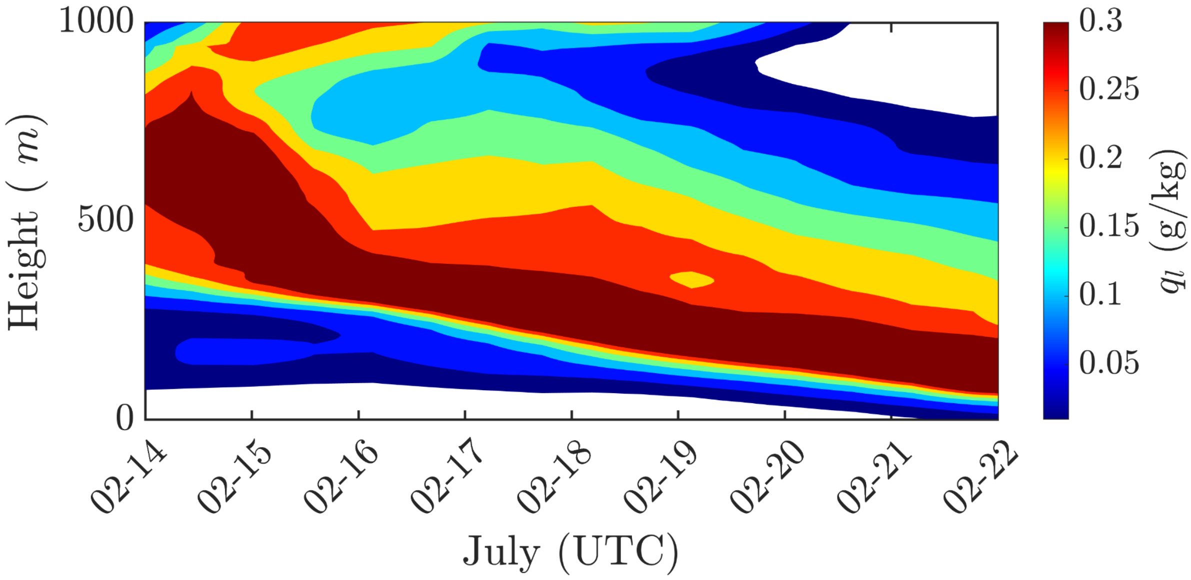


Figure 16: LES-simulated evolution of the stratus cloud during IOP5 of Fatima-YS. Stratus clouds were present at 1400 UTC, with cloud base located around 100 m. The stratus base gradually lowered, eventually forming fog at 2100 UTC. This lowering was primarily attributed to cloud droplet sedimentation, which enhanced evaporation and increased near-surface humidity. The simulated fog formation time (~2100 UTC) was consistent with the observed time.

Extra Dissemination Information:

Conference Presentations:

1. Alexei O. Perelet, S. W. Hoch, I. Gultepe, and E. R. Pardyjak, Gamma Distribution Fits of the Fog Droplet Size Spectrum – Impacts on Integrated Quantities, 555, *AMS Annual Meeting*, Jan 2025.
2. Barve A, Gultepe I, Shen L; Investigation of Stratus-Fog Transitions over Yellow Sea Using Large-Eddy Simulation Coupled with Large-Scale Dynamics and Bulk Cloud Model; Abstract (A51P) presented at AGU24, 11-15 Dec.
3. Chang, R.Y.-W., Croft, B., Giacosa, G., Salehpoor, L., VandenBoer, T.C., Pardyjak, E., Creegan, E.D., and Fernando, H.J.S., A51P-1918 Investigating aerosol microphysics and chemistry in relation to fog during the FATIMA studies. Paper #A102 (A51P-1918), AGU24.
4. Dorman, C.E., Koračin, D., Dimitrova, R.N., Gultepe, I., Hoch, S.W., Ruiz-Plancarte, J., Wang, Q., Perelet, A.O., and Fernando, H.J.S., A Comparison of Properties of a Cyclonic Event Fog and an Anticyclonic Event Fog in July 2022 at Sable Island, Nova Scotia, (paper # 549), 105th AMS Annual Meeting, from January 12-16, New Orleans, 2025.
5. Dorman, C.E., Koračin, D. and Fernando, H.J.S., The Intermittency of Fog During a low Cloud Event on Sable Island on 13-14 July 2022, Paper #A102 (A53V-03), AGU24 Meeting in Washington DC, December 09-13, 2024.

6. Dorman, C.E., Koračin, D., Dimitrova, R.N., Gultepe, I., Hoch, S.W., Ruiz-Plancarte, J., Wang, Q., Perelet, A.O., and Fernando, H.J.S., A Comparison of Properties of a Cyclonic Event Fog and an Anticyclonic Event Fog in July 2022 at Sable Island, Nova Scotia, (paper # 549), 105th AMS Annual Meeting, from January 12-16, New Orleans, 2025.
7. Chand, D., Bianco, L., Adler, B., Smith Jr., W. L., Smith Sr., W. L., DiNorscia, A.., Bodini, N., Letizia, S., Ghate, V.P., Turner, D.D., Fernando, H.J.S., Kirincich, A., Newsom, R., and Krishnamurthy, R., Uncertainty Quantification of Satellite-Based Thermodynamic Soundings across Mid-Atlantic Bight (paper # 794), 105th AMS Annual Meeting, from January 12 -16, New Orleans, 2025.
8. Creegan, E.D., Ortiz-Suslow, D.G., Fernando, H.J.S., Lee, S., and Chang, K.-I.,A53V-07 Fatima Yellow Sea: A Radiosonde Derived Climatology Study. Paper #A102 (A53V-07), AGU24 Meeting in Washington DC, December 09-13.
9. Dowling, A., Lee, S., Oh, K., Lozovatsky, I., Fernando, H.J.S., Ruiz-Plancarte, J., Ortiz-Suslow, D.G., Gabersek, S., and Lee, S.-W., A53V-05 The Exploration of the Effects of Tides on Fog in the Yellow Sea in Summer Paper #A102 (A53V-05), AGU24 Meeting in Washington DC, December 09-13, 2024.
10. Gultepe, I., Fernando, H.J.S., Wang, Q., Pardyjak, E., Hoch, S.W., Perelet, A.O., Wang, S., Creegan, E.D., Lee, S., Chang, K.-I., Lee, J.-H., Cha, J.-W., Kim, H.-J., Shen, L., and Barve, A., Fog microphysics and its parameterizations during FATIMA Marine fog Project. Paper #A102 (A53V-06), AGU24 Meeting in Washington DC, December 09-13, 2024.
11. Gultepe, I., Fernando, H.J.S., Wang, Q., Pardyjak, E., Hoch, S., Perelet, A.E., Shen, L., Creegan, E.D., Lee, S., Chang, K.I., Lee, J.H., Cha, J.W., Barve, A. V., Kim, H., Dorman, C.E., Gabersek, S., Lenain, PL., and Ruiz-Plancarte, J., Marine Fog Research During Fatima Field Campaigns., (paper # 1.1), 105th AMS Annual Meeting, from January 12 -16, New Orleans, 2025.
12. Kim, Hojin, Fernando, H.J.S., Heo, K-Y., Jeong, J-Y., Stable boundary layer characteristics observed during the FATIMA-YS Campaign at the S-ORS and implications for numerical model, Paper AS2.1, AGU General Assembly, Vienna, 27 April–2 May 2025.
13. Fernando, H.J.S., From Fatima to Marbles. Presented at the: Marine Atmospheric Research on Boundary Layers over East China/Yellow Seas (MARBLES), ONR-G Workshop, Oakwood Premier COEX Center, Seoul, Republic of Korea, June 25-26, 2025.
14. Fernando, H.J.S., Dorman, C.E., Pardyjak, E., Creegan, E.D., Hoch, S.W., Lenain, L., Chang, K.-I., Lee, J.-H., Wang, Q., Shen, L., Gabersek, S., Gultepe, I., Richter, D.H., and Lee, S., A53V-01 Fatima Marine-Fog MURI; Vignetting Major Leaps of Knowledge. Paper #A102 (A53V-01), AGU24 Meeting in Washington DC, December 09-13, 2024.
15. Fernando, H.J.S., Marine Atmospheric Boundary Layer: Some Recent Developments. Presented at the: Marine Atmospheric Research on Boundary Layers over East China/Yellow Seas (MARBLES), ONR-G Workshop, Oakwood Premier COEX Center, Seoul, Republic of Korea, June 25-26, 2025.
16. Giacosa, G., Robinson, L., Gauvin-Bourdon, P., Salehpoor, L., Crilley, L., VandenBoer, T.C., Ortiz-Suslow, D.G., Yamaguchi, R., Wang, Q., Creegan, E., Fernando, H.J.S., and Chang, R., Aerosol contribution to fog life cycle during the FATIMA fog study in the Northwest Atlantic Ocean, *Canadian Meteorological and Oceanography Society 58th Congress*, June 3–6, 2025.
17. Koračin, D., Dorman, C.E., and Fernando, H.J.S., Frontal Effects on the Rapid Formation of a Deep Layer of Marine Fog and Cloud in the NW Atlantic (paper #1.2), 105th AMS Annual Meeting, from January 12 -16, New Orleans, 2025.

18. Ruiz-Plancarte, J., R. Yamaguchi, D.G. Ortiz-Suslow, J. Kalogiros, HJS Fernando, and Q. Wang: 2025: Ruiz-Plancarte, J., Yamaguchi, R., Hoch, S.W., Huang, K.Y., Fernando, H.J.S., and Wang, Q., A51P-1921 Surface layer properties and fog processes of Sable Island during FATIMA. Paper #A102 (A51P-1921), AGU24 Meeting in Washington DC, December 09-13, 2024.
19. Mittal S, Bave A., Shen L., Investigating the Impact of Coastal Topography on Temperature for Marine Fog Dynamics Using Large-Eddy Simulations; 2024; *Abstract (ZC26) presented at APS DFD 2024, 24-26 Nov*
20. Overton, C., Salehpoor, L., Chang, R. Y-W., Massa, G., Fernando, H.J., Creegan, E.D., VandenBoer, C.T., Investigating alkylamine content in size-resolved aerosol collected over the Yellow Sea during Fatima 2023, 43rd American Association for Aerosol Research (AAAR) conference in Buffalo, NY. Oct. 13-17, 2025.
21. Richter, D.H., Seh, K.H., Giacosa, G., Chang, R., Salehpoor, L., and VandenBoer, T.C., A51P-1912 Interactions of Marine Aerosols and Turbulence Towards Understanding of Fog Formation in the Marine Boundary Layer. Paper #A102 (A51P-1912), AGU24 Meeting in Washington DC, December 09-13, 2024.
22. Salehpoor, L., Crilley, L.R., Young, C.J., Giacosa, G., Robinson, L., Gauvin-Bourdon, P., Chang, R., Tao, Y., Creegan, E., Fernando, H.J.S., and VandenBoer, T., Characterization of chemical composition in size-resolved marine aerosol during fog formation events over the Northwest Atlantic Ocean during FATIMA 2022, *107th Canadian Chemistry Conference Exhibition(CSC 2024)*, RBC Convention Centre, Winnipeg, Canada., 2024.
23. Singh, E. Dhiraj Kumar, Pardyjak, I. Gultepe, A. O. Perelet, L. Grare, L. Lenain, and S. W. Hoch, Investigation of a Low-Cost Hot-Wire Liquid Water Content Probe for Dense Fog Measurements, 554, 105th AMS Annual Meeting, from January 12-16, New Orleans, 2025.
24. Fernando, H.J.S., Dorman, C., Wang, Q., Pardyjak, E., Shen, L., Creegan, E.D., Gabersek, S., Hoch, S.W., Gultepe, I., Lenain, L., Richter, D.H., Chang, K.I., Lee, S., Lee, J.-H., Fatima Marine-Fog MURI; Vignetting Major Leaps of Knowledge. A53V-01. AGU24 Meeting in Washington DC, December 09-13, 2024.
25. Gultepe, I., Fernando, H.J.S., Wang, Q., Pardyjak, E.P., Hoch, S.W., Perelet, A.O., Wang, S., Creegan, E.D., Lee, S., Chang, K.I., Lee, J-H., Cha, J.W., Kim, H-J., Shen, L., and Barve. A., Fog microphysics and its parameterizations during FATIMA Marine fog Project. A53V-06. AGU24 Meeting in Washington DC, December 09-13, 2024.
26. Lata, N.N., Gultepe, I., Fernando, H.J.S., Dexheimer, D., C. Zezhen, Mei, F., and China, S., Arctic Ice Fog: Unveiling the Role of Aerosol Chemistry, AAAR 42nd Annual Conference, October 21-25, Albuquerque, New Mexico, 2024.
27. VandenBoer, T., Salehpoor, L., Crilley, L., Young, C., Giacosa, G., Gauvin-Bourdon, Chang, R., Creegan, E., and Fernando, H.J.S., -Fog Interactions and Chemical Processing: Insights from the Grand Banks and Sable Island regions during Fatima 2022, AAAR 42nd Annual Conference, October 21-25, Albuquerque, New Mexico, 2024.
28. Wang, S., and Fernando, H.J.S., A53V-08 Large Eddy Simulation of Layered Stratification with Moist Thermodynamics as a Mechanisms for Fog Formation. Paper #A102 (A53V-08), AGU24 Meeting in Washington DC, December 09-13, 2024.
29. Wang, Q., Ortiz-Suslow, D.G., Ruiz-Plancarte, J., Yamaguchi, R., Creegan, E.D., Lee, S., Chang, R., Fernando, H.J.S., and Chang, K.-I., A53V-02 Turbulence and Fog Microphysics Variability over the Yellow Sea. Paper #A102 (A53V-02), AGU24 Meeting in Washington DC, December 09-13, 2024.
30. Wang, Q., B. Darby, R. Yamaguchi, J. Ruiz-Plancarte, J. Kalogiros, R. Hoheisel, T. Hansen, Z. Wang, and D. Ortiz-Suslow, 2025: Air-Sea Interaction in the YS/ECS and Innovative Measurements for Air-Sea Interaction Studies, Presentation at the Workshop

on Marine Atmospheric Research on Boundary Layers over East China/Yellow Seas (MARBLES), 25-26 June 2025, Seoul, S. Korea.

31. Lee, S., Dowling, A., Oh, K.H., Lee, S.W., Lozovatsky, I., Fernando, H.J.S., Ruiz-Plancarte, J., Ortiz-Suslow, D., Gaberšek, S., Kim M.S., Wang, S., Thompson, E., Phadtare, J., *Influences on Tidal Mixing Frontal Intrusion Development in Summertime.* The Korean Society of Oceanography Conference. Busan, Republic of Korea. Poster Presentation. May 08-09 2025.

Invited Talks:

1. Richter, D., "Lagrangian cloud modeling of fog: Do fog droplets actually activate?" presented at the Michigan Technological University Department of Physics seminar series.
2. Dowling, A., "*Tidal Boundary Mixing as a Fog Formation Mechanism,"* Pusan National University, ROK, May 15 2025.
3. Dowling, A., *The Dynamics of Fog Formation along the Edge of a Tidal Mixing Front.* GeoSystems Research Corporation, June 04 2025.
4. Dowling, A, *The Complexities of Fog Formation induced by Tidal Mixing Fronts in the Yellow Sea.* Seoul National University, Seoul, ROK, June 05 2025.
5. Fernando, H.J.S., A Deep Dive into Life Cycle of Marine Fog, University of South Carolina, Department of Civil Engineering (May 29, 2025)

Special Fatima Sessions Organized:

"Fog Life Cycle" Special Session at the AGU Meeting in Washington DC, 9-13 December 2024. (Convenors - Lian Shen (Lead), Trevor VandenBoer, Seok Lee, Jesus Ruiz-Plancarte, Anne Dowling and HJS Fernando)

"Fog and Visibility" Special session on at the American Meteorological Society's Second Symposium on Cloud Physics, January 12 - 16, 2025 in New Orleans, LA (Convenors - I. Gultepe (Lead), A.J. Heymsfield, Seong Soo Yum and HJS Fernando)

"Marine Atmospheric Research on Boundary Layers over East China/Yellow Sea (MARBLES)" (Convenors: KI Chang (Lead), HJS Fernando and Qing Wang), Office of Naval Research Global Workshop on at Oakwood-Premier COEX Center, Seoul, Republic of Korea, June 25-26, 2025.

"Observations and Modeling of Marine Fog Processes" Special Session (A086) at AGU25, New Orleans, LA from 15-19 December 2025. (Convenors - Eric Pardyjak, Clive Dorman, Darko Koracin and HJS Fernando)

"Fog and Visibility" Special Session on at the 26th Conference on Aviation, Range, and Aerospace Meteorology, AMS Meeting 25-29 January, Houston Texas, 2026 (Convenor: Ismail Gultepe, HJS Fernando)

"Fog and Visibility" special session on at the American Meteorological Society's Second Symposium on Cloud Physics to be held January 12 - 16, 2025 in New Orleans, LA (Convenors - I. Gultepe (Lead), A.J. Heymsfield, Seong Soo Yum and HJS Fernando)

Special Journal Issues Organized:

Special Collection of Papers in the Quarterly Journal of the Royal Meteorological Society, "Fatima: Marine Fog and Turbulence" (Eric Pardyjak – Lead Guest Editor with Ismail Gultepe and HJS Fernando) (2023-2025; SI 2023-000388)

Special Collection of Papers in the American Meteorological Society Journals, “Nexus of Fog and Turbulence in Marine Boundary Layer: Outcomes of FATIMA Mega Project” (Clive Dorman – Lead Guest Editor with Ismail Gultepe, Darko Koracin, Ki-Young Heo, David Ortiz-Suslow, Seok Lee, HJS Fernando and Qing Wang, 2025-)

Popular Press and News Articles:

Shadows in the Marine Fog: An Investigation of Mist Opportunity by Aaron Price

(https://weathertwist.substack.com/p/shadows-in-marine-fog?utm_source=post-email-title&publication_id=2108892&post_id=157084658&utm_campaign=email-post-title&isFreemail=true&r=3q3ld7&triedRedirect=true)

Researcher helps examine puzzling Arctic Ocean ice fog (by Rod Boyce,, University of Alaska) https://www.uaf.edu/news/researcher-helps-examine-puzzling-arctic-ocean-ice-fog%20.php