2026 RPPR Interim Progress Report

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Principal Investigator:

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Title: Escalated Deployments at Fatima Ice Fog Campaign

Submitter Email: fernando.10@nd.edu **Submitted By:** Dr. Harindra J. Fernando

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Major Goals:

This project concerned escalated funding for the Fog and turbulence interactions in the marine atmosphere (Fatima) MURI project of the US Office of Naval Research (Grant N00014-25-1-2525) to enhance instrument deployments in its third [and final] field campaign dealing with Ice Fog (IF). Following the initiation of Fatima in 2021, many collaborators from national and international academic institutions and research laboratories have joined the project with alternative funding mechanisms. The first two Fatima field campaigns were focused on marine [liquid droplet] fog, conducted in Grand Banks (northern Atlantic Ocean) and Yellow Sea (off the South Korean coast). The third Ice Fog Campaign (Fatima-IF), which is the focus here, became more expansive than what was originally anticipated, and was joined by additional participants in its field and numerical components. The escalated funding through this grant provided resources for the augmentation of Fatima-IF with additional instrumentation, personnel and scope.

IF is defined as a condition in the lower atmospheric boundary layer where the visibility (meteorological optical range) drops below 1 km due to deposition of water vapor from the environment on ice nuclei or by freezing of small, supercooled droplets. IF is also associated with mixed-phase stratiform clouds carrying supercooled droplets and ice crystals characterized by low-level inversions. IF is conceivably the least understood type of fog, given the measurement and logistical difficulties of working in harsh frigid environments and intricacies of physicochemical processes involved in IF formation. Nonetheless, IF has crucial applications in high-latitude navigation (e.g., in the new Arctic), electromagnetic communications as well as in emerging arenas of directed energy and hypersonic flight.

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The Fatima-IF was conducted in the North Slope of Alaska (NSA) Atmospheric Observatory of the US Department of Energy's (DOE) Atmospheric Radiation Measurement (ARM) Program (Fig. 1) during 15 November to 06 December 2025. The central NSA site at Utqiaġvik (formally Barrow) is permanently equipped with extensive atmospheric measurement capabilities and has hosted numerous high-latitude field campaigns. It also supports a nearby measurement site known as 'Extended Facilities.' The scientific goal of Fatima-IF was to establish nexus of IF microphysics and turbulence in the environs of NSA site, including capturing the effects of nearby Arctic Ocean on IF formation. Specifically, Fatima-IF intended to study (i) nucleation and ice crystal formation during IF events in the presence of low boundary-layer clouds, and the role of turbulence thereof, (ii) how air-sea fluxes impact coastal ice-fog formation, (iii) microphysical parameterizations for IF, including the efficacy of existing parameterizations, and (iv) vertical profiles of IF microphysical properties, which are essentially unavailable hitherto, in the context of formation and dissipation mechanisms of IF, and (iv) improved methods for parameterizing IF processes in Numerical Weather Prediction (NWP) models. Several hypotheses related to the roles of inversion layer, surface turbulence, cloud-top convection and bio-chemo-physical properties of aerosols have been proposed and are to be tested. The comprehensive array of high-end instrumentation at NSA augmented by guest-provided [novel] instrumentation offered unique observational opportunities during Fatima-IF.

The participants included Fatima-MURI institutions (University of Notre Dame UND, Naval Postgraduate School NPS, University of Utah UU and Scripps Institution of Oceanography/University of California San Diego, SIO/UCSD) and collaborators (Air Force Institute of Technology AFIT, Ontario Tech University OTU, Pacific Northwest National Laboratory PNNL, University of Alaska UA, and University of Albany ALB. They augmented NSA instrument arsenal with a set of Guest Instruments.

Fig.1 shows a site map and Fig. 2 a close-up site photo of the site (see the attached pdf file). The host at Utqiaġvik was the DOE site operator, the Sandia National Laboratory (SNL). The partnership with Naval Research Laboratory (NRL) provided daily NWP simulations using the COAMPS model, which together with climatological forecasting by Fatima PIs, guided the campaign and selection of Intense Operating Periods (IOPs). As with two preceding Fatima campaigns, high resolution large-eddy simulations were conducted in support of data analyses and interpretation. Quality controlled/assured data were deposited and made available in the ARM User Facility and Fatima database for the benefit of scientific community at large: https://idata.svcs.arm.gov/share?user=theisen&view_id=4affa44d-a2fe-4381-857f-5958a5032e07

Accomplishments:

The visiting Fatima-IF team started guest-instrument deployment about week prior to the campaign (Figs. 3, 4); it consisted of Marilyn Dunbar (AFIT), Carl Schmitt (UA), Rob Reed (UND), Matthis Chabert d'Hieres (UND), Orson Hyde (UND), Ben Bishop (SNL), Todd Houchens (SNL), Valerie Sparks (SNL), Carlos Ruiz (SNL), Dennis DeSmet (SNL) and Andrew Glen (SNL). A contract with Utquiagvik Inupiat Corporation (IUC), an Alaska Native Village Corporation in Utqiaġvik, provided local logistics. Instrumentation included:

UND: CL61 Ceilometer; FD70 Visibility Sensor; 3D Sonic Anemometer (Young); Optical Disdrometer
OUT: Gondola Platform equipped with BCP and CDP; FM 120; GCIP; CRN Radiation Sensor; 2xWXT systems
UU: OPCN3; Liquid Water Content (LWC) probe
AFIT: Cloud Ice Nucleation Characterization System (CINCS); Labs Optical Extinction Analyzer 1065 nm; Optical Extinction Analyzer 460 nm; Optical Extinction Analyzer 520 nm; Purple Air Flex II Air Quality Monitor
UA: VIPS – Video Particle Imaging Spectrometer
ALB: mSEMS
PNNL: STAC – Size and Time-resolved Aerosol Collector for ice nuclei chemical composition and spectra, global (total) and diffuse irradiance and DNI (Direct Normal Irradiance) calculations (0.1-0.5 microns/1Hz)
SNL: MA200 (five wavelength aethalometer); AE-51 (single wavelength aethalometer); SMPS (1 – 50 nm); POPS (140 nm to 3 μm); TSI CPC 3007 (10 nm to >1.0 μm); Heated inlet and 370 lpm pump; And Dryers for all of the above (except the STAC). Also, NSA performed 4 radiosonde launches a day (00z,06z,12z,18z).
ARM: MAWS – Automatic Weather System; ACSM – Aerosol Chemical Speciation Monitor; ASI – All Sky Imager; AOS – Aerosol Observing System; SONDE – Balloon Born Sounding System (NSA performs 4 launches a day (00z,06z,12z,18z); CEILPBLHT – Boundary Layer Height with Ceilometer; CEIL – Ceilometer; DL – Scanning Doppler Lidar; ECOR – Eddy Correlation Flux Measurement System; Micro pulsed Lidar, MWRP – Profiling Microwave Radiometer; Nephelometer; SonicWind ultrasonic wind sensor; METWXT – WXT system; Site camera – every 5 minutes (IR enabled); INS ice nucleation spectrometer for INP measurements – conducting measurements since May every 6 days as a part of the baseline ARM measurements this past May. Thus, we will also have cumulative immersion mode INP spectra from roughly -30 to 0 degC throughout the campaign.

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The campaign period crossed into the polar nights of Arctic-Circle, encountering twilights and aurora borealis (Fig. 5). The site was spectacular, with dramatic ice, floes and intermittent open water, latter providing moisture to the site under favorable wind direction (Fig. 6). Although most instruments operated continuously, labor-intensive systems such as STAC, VIPS, and CINCS operated only during IOPs. IOPs were called during [virtual] weather briefings conducted during 15 November to 5 December 2025 daily at 04:00 pm Utquiagvik time 4:00 pm (UTC-9; PST 5:00 pm; and EST 8:00 pm). The forecasting team was led by Sasa Gabersek, Clive Dorman, Ismail Gultepe, Peter Taylor, Carl Schmitt and Eric Pardyjak, typically with ~ 10 participants. For guidance, NRL used COAMPS® operational mesoscale model at 1 km resolution with Global Forecast System (GFS) model output used for initial and boundary conditions. Model initializations were at 48, 24 and 12 hrs. ahead, and forecasts were hourly. Horizontal maps and vertical profiles based on soundings from the Post-Will Rogers Memorial Airport (BRW, 2/day), NSA (4/day) and surrounding WMO stations were examined. Also used were GFS (resolution 0.25o) and CAPS Canadian Model (1 km) outputs, GOES Satellite Imagery, Weather Radar, RAOB and NOAA HYSPLIT back-trajectories and commercial forecasting products. The IOPs so selected are given in Table 1 (attached pdf).

The common proxy for water-droplet fog, visibility < 1 km, was generally employed for IF identification. Fatima-IF group discussions emphasized the need for a more rigorous definition for mixed phase and ice fogs but at present visibility < 1 km is used as a criterion for IF. PWD22 and the FD70 identified low-visibility events, which were verified using a Lorex continuous-capture video camera. To differentiate fog from precipitation or blowing snow, additional criteria were used: zero precipitation and low wind speeds (≤5 m s^(-1)), respectively. IF occurs under numerous thermodynamic conditions, for example, low air temperature (≤-10 °C for heterogeneous freezing) and high ice-based relative humidity (RH_i>100 %). Fig. 7 shows time series of selected meteorological data. Although PWD22 and FD70 registered different fog intensities, both yielded identical fog-occurrence periods.

In this report, two fog events are discussed: 30 November (e5) and 06 December (e8). Both cases exhibited visibility < 1 km for more than two hours, but their dynamics differ. In e5, winds were northerly (HYSPLIT trajectories) and fairly humid, given sea ice cover is not yet well consolidated (observed via Sea Ice Radar and Sea Ice Camera). Throughout the day, multiple cloud layers covered the site (radar reflectivity), giving rise to precipitation during 1300-1600 UTC (Radar), with a pause of rain from 1600 to 2100 UTC, whence a stable layer appeared below 150 m (Lidar, tower, radiosondes) and visibility dropped below 1 km during ~ 1700-2000 UTC (i.e., fog). During the pause, large particles in the range 360 microns to 22 mm (Disdrometer) and 110 microns to 7 mm (FD70) disappeared. Simultaneously, droplets in the range 2-50 microns appeared (FM100). Also observed during fog (Fig. 8) was a RHw ~ 90-95%, RHi ~ 102%, air temperature T ~ -10 degC (PWD22), and a shallow layer of fog (Fig. 9; radar). Suspended ice crystals were evident from video images (Fig. 10).

Considering all, we hypothesize that hydrometeor evolution following rain provided apt conditions for IF formation within one hour of the rain pause. Large hydrometeors (360 microns to 22 mm) settle first, abetted by low wind speed, followed by liquid fog droplets (2 to 50 microns). The settling of latter is further retarded by development of stable stratification near the ground, causing accumulation of droplets conducive for supercooling (Figs. 7, 8). Interestingly, environmental conditions (RHw ~ 90-95%, T ~ -10 degC) became just sufficient for supercooled water droplets in unsaturated environment to coexist with nucleating ice particles, activating the Wegener–Bergeron–Findeisen (WBF) microphysical mechanism, thus generating ice particles at the expense of water-droplet evaporation that produce vapor that desublimate on ice crystals. The critical conditions maintained during this process is noteworthy: maintaining RHw just sufficient for RHi to be supersaturated at the environmental temperature. The droplets disappeared at the end of the IF event, being fully consumed by IF formation.

In the second event e8 (06 December), low visibility appeared during 18:00 - 20:00 UTC, mostly teetering around 1 km. A gradual change of wind direction from SE (120-190deg) to SW (210-270 deg) occurred with wind speed dropping to around 2-3 m/s until 18:00 UTC and temperature falling from -31 degC at 17:25 UTC to -33 degC at 18:00 UTC, just enough to cause slight supersaturation (reckoned from the RHi/T/RHw plots). No moisture source exists in these wind sectors, and hence the appearance of IF at 18:00 UTC is conceivably due to supersaturation and T dropping to -33 degC at that time, just sufficient for deposition. While no water droplets were present, FM100 showed a noisy signal with ~ 10-micron sized particles. The event with shifting wind direction to northerly, first with notable fluctuations of low winds and then increasing beyond 5 m/s. An increase of T to ~ -30 degC followed with the environment becoming unsaturated relative to RHi.

Training Opportunities:

A graduate student from UND (Matthis Chabert d'Hieres) and a post-doctoral fellow from AFIT (Marilyn Dunbar) took part in the Fatima-IF campaign. The grad student was trained to operate instruments, data processing, handle campaign logistics, while interacting with a host of collaborators from several national laboratories and participating universities. The grad student also received training to conduct research in frigid environments, which is a challenging endeavor.

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Results Dissemination:

WEBSITES:
Fatima: https://efmlab.nd.edu/research/Fatima/
Fatima-IF: https://efmlab.nd.edu/research/fatima-ice-fog/

NEWS ARTICLES:
These are available on the field experiment and related IF matters of the Fatima project, which include:

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

ARM Alaska Data to Help Researchers Cut Through Ice Fog [FATIMA team studies the microphysics of this phenomenon and how turbulence affects it] by Katie Dorsey (ARM-DOE Program);
https://www.arm.gov/news/facility/post/107162

Cracking the Code of Arctic Ice Fog During the Polar Night: Notre Dame's Atmospheric Research Initiative, https://efmlab.nd.edu/news/cracking-the-code-of-arctic-ice-fog-during-the-polar-night-notre-dames-atmospheric-research-initiative/, (2025 December)

Shedding Light on Ice Fog in the Darkness of Polar Night, https://engineering.nd.edu/news/shedding-light-on-ice-fog-in-the-darkness-of-polar-night/, (2025 December)

RELEVANT PAPERS BY THE FATIMA GROUP:
Barve, A., Gultepe, I., Fernando, H.J.S., and Shen, L., 2026: Investigating ice fog over the North Slope of Alaska using large-eddy simulation with bulk cloud modeling and large-scale dynamics. In preparation for Quarterly Journal of the Royal Meteorological Society
Rees, K. N., I. Gultepe, S. Hoch, A. Perelet, and E.R. Pardyjak, Departure from classical 3D turbulence in fog: A case study from the Fatima field campaign, Physical Research Letters, Submitted

RELEVANT CONFERENCE PRESENTATIONS BY THE FATIMA GROUP:
1. 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.
2. Hoch, S.W., Pardyjak, E.R., Perelet, E.O., Rees, K., Gultepe, I., Oncley, S.P., Hallar, A.G., Pu, Z., and Brown, W.O.J., The Heat Budget of the Near-Surface Atmosphere under Varying Cold-Fog Conditions (paper # 553), 105th AMS Annual Meeting, from January 12 -16, New Orleans, 2025.
3. Singh, K.D., Pardyjak, E., Gultepe, I., Perelet, A.O., Grare, L., Lenain, L., and Hoch, S.W., Investigation of a Low-Cost Hot-Wire Liquid Water Content Probe for Dense Fog Measurements (paper #554), 105th AMS Annual Meeting, from January 12 - 16, New Orleans, 2025.
4. Pardyjak, E., Dorman, C., Fernando, H.J.S., and Koracin, D., Observations and Modeling of Marine Fog Processes Poster, Paper # A210, AGU2025 Annual Meeting in New Orleans, Louisiana, 15-19 December 2025.
5. Rees, K., Pardyjak, E., Gultepe, I., Hoch, S., and Perelet, A., Dimensional Turbulence in Marine Fog: Observed Transitions Between 2D and 3D Regimes During the FATIMA Field Campaign, Paper # A21O-2204, AGU2025 Annual Meeting in New Orleans, Louisiana, 15-19 December 2025.
6. Gultepe, I., Fernando, H.J.S., Pardyjak, E., Wang, Q., Hoch, S., Perelet, A.O., Lee, S., Gabersek, S., Shen, L., Barve, A., Ortiz-Suslow, D.G., Ruiz-Plancarte, J., Yamaguchi, R., and Chang, K.I., Marine Fog Microphysics and Dynamics during the FATIMA GB and YS Campaigns, Paper # A21O-2207, AGU2025 Annual Meeting in New Orleans, Louisiana, 15-19 December 2025.
7. Fernando, H.J.S. and Fatima-IF team, Fatima Ice-Fog Field Work, SA3NDBAR - Sensing in-situ, Aerosols, Arctic, Air-sea interaction, NWP, and atmospheric Dynamics Basic and Applied Research, Naval Postgraduate School, 8 - 12 December 2025.
8. Pardyjak, E., and Fatima Team, A Review of Recent Fatima Findings, SA3NDBAR - Sensing in-situ, Aerosols, Arctic, Air-sea interaction, NWP, and atmospheric Dynamics Basic and Applied Research, Naval Postgraduate School, 8 - 12 December 2025.
9. Singh, D. K., C. Ledesma, I. Gultepe, A. O. Perelet, S. Hoch, and Pardyjak, E.R., AI-enabled, cost-effective measurement of fog liquid water content and wind speed. Paper# A21O-2201, AGU Fall Meeting 2025, New Orleans, LA, 2025.
10. Perelet, A.O., I. Gultepe, S. Hoch, Pardyjak, E., An updated relation between Liquid Water Content and Visibility for foggy conditions across a variety of fog types, AGU Fall Meeting, 15-19 New Orleans, A21O-2202, 2025.
11. Gultepe, I., Fernando, H.J.S., Pardyjak, E., Dexheimer, D., Sparks, V., Hoch, S., Perelet, A., Shen, L., Barve, A., China, S., Dunbar, M.N., Nagare, B., Chabert d'Hieres, and Glen, A., Ice Fog Observations During Fatima-IF and IFFExO Field Campaigns at NSA, 2026 ARM/ASR Joint User Facility and PI Meeting (Virtual), July 21-23 2026

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12. Fernando, H.J.S., FATIMA: Fog And Turbulence Interactions in the Marine Atmosphere, Invited Paper, Optica's 2026 Propagation Through and Characterization of Atmospheric and Oceanic Phenomena (pcAOP) Topical Meeting, Maastricht, Netherlands, July 12-17, 2026.

Plans Next Period:

(i) Submit an overview article of the Fatima-IF campaign for publication in a journal such as the Bulletin of the American Meteorological Society.
(ii) Continue processing campaign data to address the hypotheses proposed, specifically focusing on the IOP periods.
(iii) Complete a journal article based on the work of Mr. Matthis Chabert d'Hieres
(iv) Presenting the work at national and international conferences.

Honors and Awards:

(i) PI Fernando received the Springer-Nature Publishing Editor of Distinction Award 2025
(ii) PI Fernando delivered the Invited Keynote Address at the Sixteenth (16) International Conference on Hydrodynamics, April 14-18, Macau Institute of Technology 2026 – an International Association of Hydro-environment Engineering and Research (IAHR) Conference.
(iii) PI Fernando delivered an Invited Lecture on Fog and Ice Fog at the Seventy Eighth (78) American Physical Society, Fluid Dynamics Meeting, Houston, TX, November 23-25, 2025.

Technology Transfer:

Nothing to Report

Participants:

- Ismail Gultepe (Consultant) - 1 month(s)
- Harindra Fernando (PD/PI) - 1 month(s)
- Baban Nagare (Postdoctoral (scholar, fellow or other postdoctoral position)) - 3 month(s)
- Scott Coppersmith (Other Professional) - 3 month(s)
- Jay Hyde (Technician) - 3 month(s)
- Matthis Chabert d'Hieres (Graduate Student (research assistant)) - 12 month(s)

Partners:

No partners found.

Other Collaborators:

As listed in this report, a group of collaborators from the FATIMA MURI Project, academic institutions and ARM Program were involved in the project.

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Figures File:

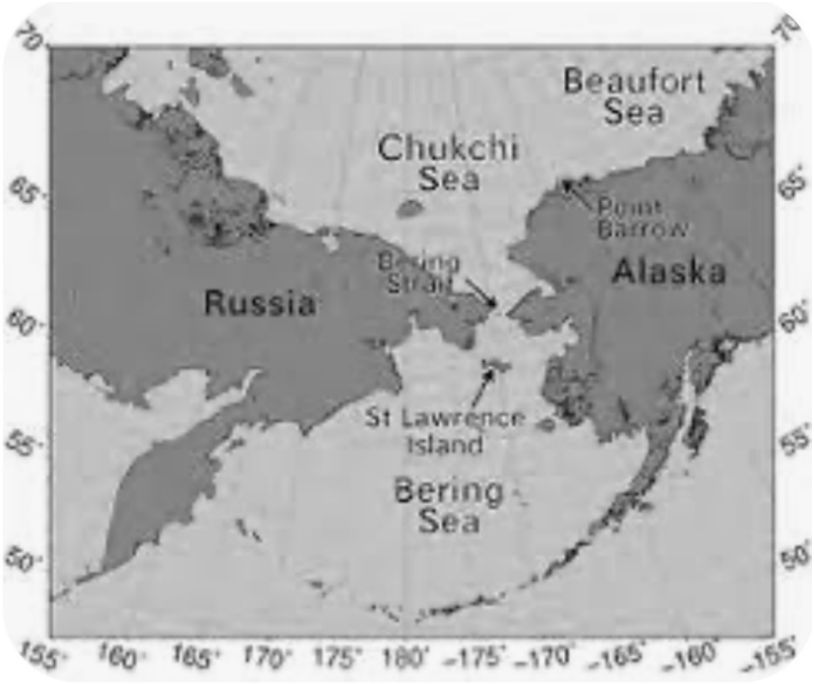


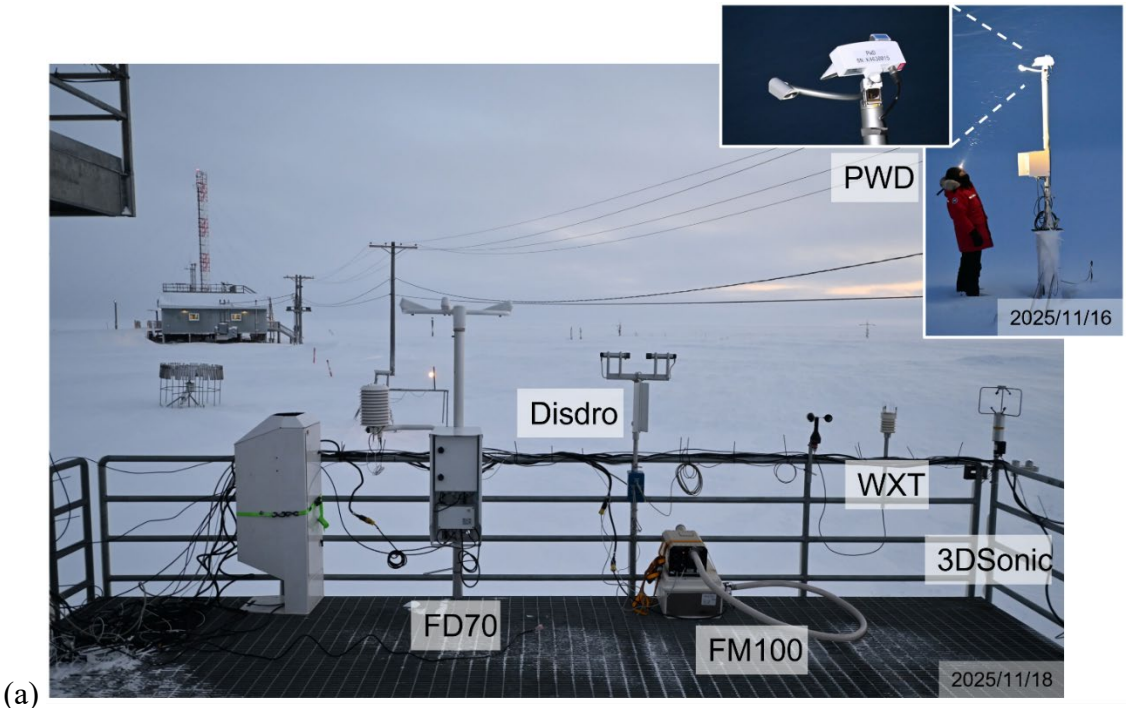
Figure 1: Map of Fatima-IF campaign location. The ocean north of Utqiaġvik (formerly Barrow**)** is part of the Arctic Ocean, the Beaufort Sea to the east and the Chukchi Sea to the west. The Arctic Circle is about 300 miles to the south. Point Barrow, the northernmost point of US on the Arctic coast is about 9 miles northeast of Utqiaġvik, and is the boundary between Chukchi and Beaufort Seas.



Figure 2: The ARM Northern Slope of Alaska (NSA) Site, taken during Fatima-IF.



Figure 3: Deploying guest instruments at NSA



(a)


(b)

Figure 4: (a) Selected guest instruments at NSA, (b) Frigid conditions create challenges for instrument operations





Figure 5: Last day of Sun was November 18, whereupon sun dips below the horizon for the final time, descending Barrow to pronged continuous darkness (polar night) for 65-67 days. Town experiences period of civil twilight midday, creating a deep blue and purple glow on the horizon as well as (b) occasional glow of Aurora Borealis (northern lights) overhead. (Photo by Valerie Sparks, SNL).





Figure 6: Ice flows in the surrounding oceans as well as channels of ice floes cutting though snow cover with NSA in the background.

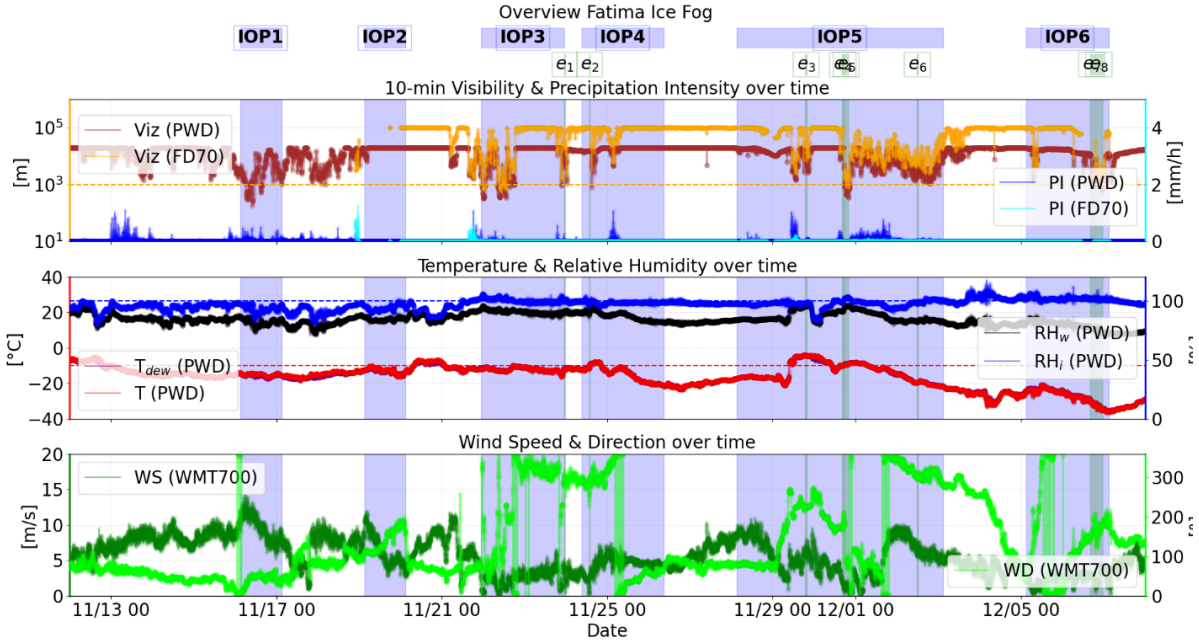


Figure 7: Overview of bulk meteorological measurements during Fatima-IF campaign. The six IOPs are shaded in blue and numbered, and potential IF events based on observations are shaded in green (e_1, e_2…). Data are from PWD22, FD70 and WMT700.

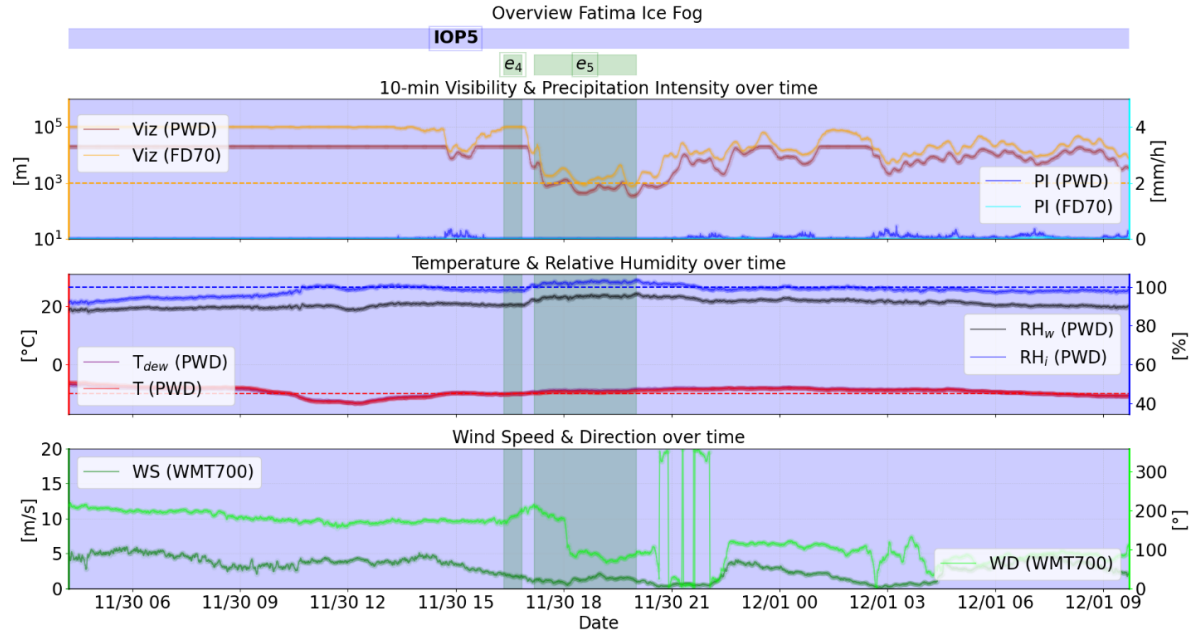


Figure 8: Low visibility, no precipitation, and low wind during e5. The temperature is around $-10°C$, RHi ice reaches 100% threshold during the event, and decreases after the event. Note the sudden switch in wind direction from south to east bringing in a low speed airmass conucieve for fog. Although the visibility is above 1 km for e4, Lorex camara clearly showed IF during e4 period, advocating for a more rigorous definition for IF.

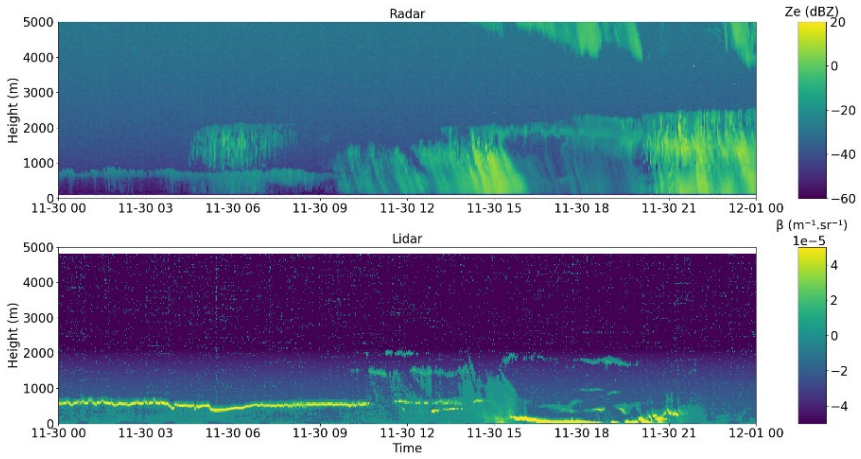


Figure 9: Reflectivity (Radar) and Backscatter (Lidar) during e5. The high reflectivity indicates rain, which faints during the 1600 – 2100 UTC due to pause of rain. At the same time, large backscatter can be seen near the ground, reflecting the presence of a fog layer.

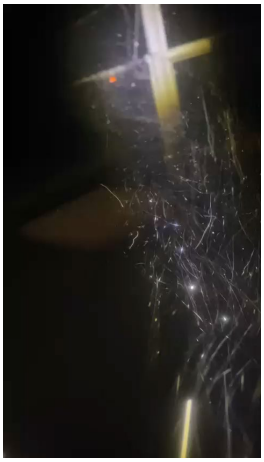


Figure 10: Ice fog was clearly visible in ARM camera, identified using scintillating ice particles during e5

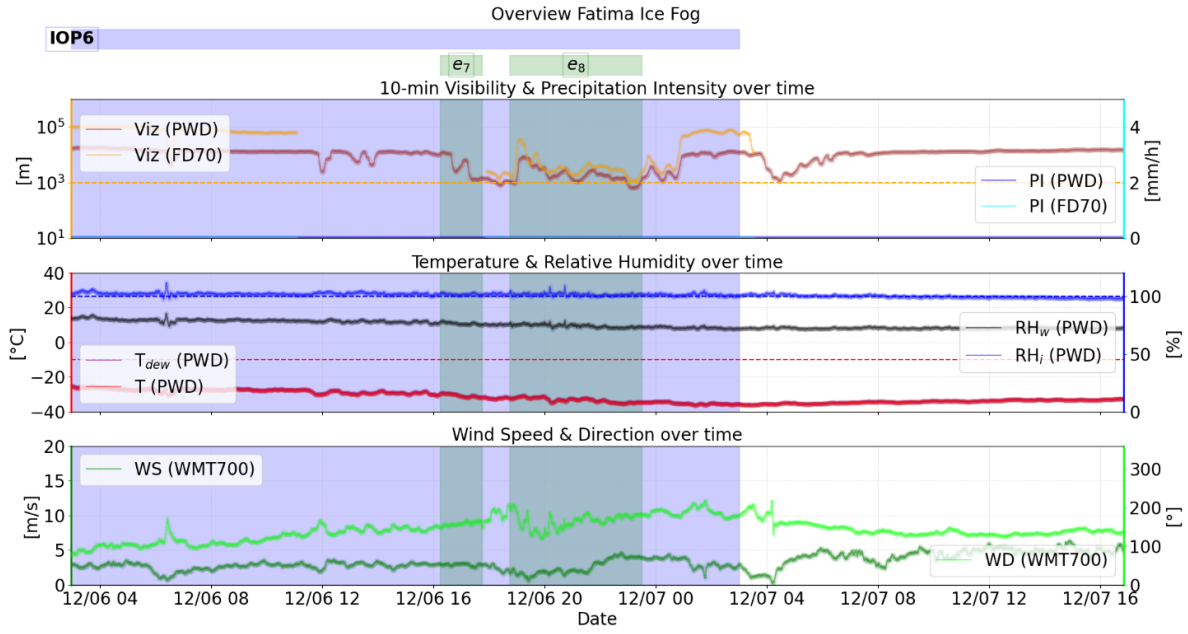


Figure 11: Meteorological conditions during e8. This low visibility event at very low temperature (< -30 °C) maintained just supersaturated RHi as well as subsaturated RHw (~75 %).

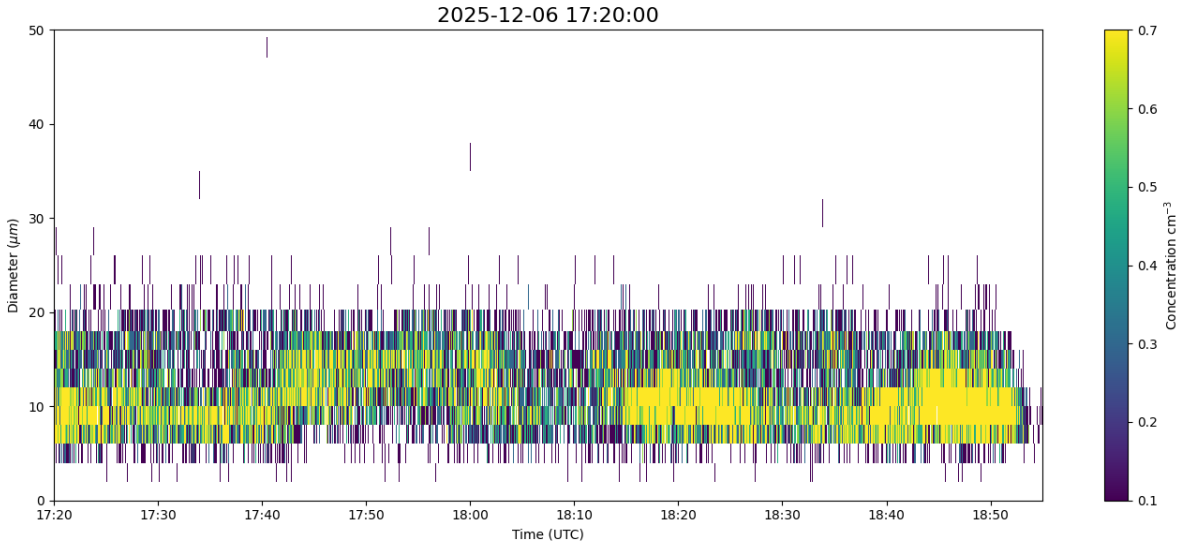


Figure 12: The evolution of droplet diameter as measured by FM100 during e8. While FM100 does not quantitatively capture ice particles accurately, the instrument showed a rough dominant diameter of ~ 10 microns, in the range of IF.

Table 1:

IOP	Start Time	End Time
1	16 Nov, 3 UTC	17 Nov, 3 UTC
2	19 Nov, 3 UTC	20 Nov, 3 UTC
3	21 Nov, 23 UTC	23 Nov, 23 UTC
4	24 Nov 09 UTC	26 Nov, 09 UTC
5	28 Nov, 3 UTC	3 Dec, 3 UTC
6	5 Dec, 3 UTC	7 Dec, 3 UTC