IFFExO (Ice Fog Field Experiment at Oliktok Point)

Introduction

The PIs (Fernando & Gultepe) were granted a two-week intensive field campaign on Ice Fog IF (IFFExO) at the Oliktok Point ARM site (AMF3) in Alaska (https://www.arm.gov/research/campaigns/amf2020iffexo). It was scheduled for 22 March to 5 April, 2020, postponed due to COVID restrictions, but was successfully conducted during 9-21 November, 2020 thanks to openhanded support of the ARM personnel. The IFFExO campaign included: (i) Wind and large-scale turbulence measurements using Doppler lidar; (iii) Ice Water Content (IWC) and integrated water vapor path measurements from a Radiometrics microwave radiometer (MWR); (iv) Vertical profiling by in-situ sensors mounted on a tethered balloon system (TBS) supported by AMF3, augmented by a number of guest user-provided instruments for aerosol microphysics; and (v) Instruments for surface energy budget, meteorology and turbulence. The novelty of IFFExO was the simultaneous measurement of dynamic, thermodynamic, microphysical and physicochemical properties and their spectral characteristics akin to IF, allowing the reckoning of possible natural and anthropogenic aerosol contributions.

IFFExO Design

Considering the critical roles of surface processes, advection/subsidence and mixed-phase and Ice Nuclei (IN) processes in the IF formation and the paucity of lower Atmospheric Boundary Layer (ABL) data during IF events, IFFExO was designed for simultaneous measurements of microphysical, thermodynamic, mass flow/turbulence and chemical parameters as well as subsidence/advection in the ABL at AMF3. Multi-faceted support from the ARM Program was crucial, given logistical difficulties of working in the Arctic. Aircraft data are untenable in the ABL under low visibility conditions, and UAV technologies are still nascent for polar deployments. As such, so far only a handful of field campaigns have been conducted on IF, two notable ones being DOE's ISDAC and FRAM that collected only limited microphysical and aerosol observations without any vertical profiles – and IFFExO rose up to the challenge. Before the full campaign, a pilot test was successfully conducted during 13-15 February 2020 at the ARM Southern Great Plans site (SGP) site to fine-tune selected instruments, evaluate performance of a novel platform of the shape of a Gondola that carry microphysical instruments suspended on a TBS for profiling and test data transmission and storage.

Pilot Experiment

During Pilot, the Gondola with CDP and BCP probes were tested on TBS (See Fig. 1a and Table 1 for acronyms). Tests were performed under both calm and strong turbulence/wind-shear conditions covering a range of stability (stable, unstable and neutral) and cloud conditions. Experience with instrument operation, TBS flight planning as well as synergy established between ARM and guest scientists during Pilot helped successful execution of IFFExO later.

IFFExO Field Campaign

IFFExO provided data for four IF cases and two low-level mixed phase clouds. While the campaign 10-21 November (11 days) was shorter than the PIs' originally requested, propitiously, IF events occurred for ~ 30% of the time (Fig. 1b,c), each lasting ~ 2 - 5 hrs. The extensive suite of leading-edge instruments deployed in IFFExO are listed in Table 1. The flight operational periods with all instruments deployed were defined as the Intense Operational Period (IOPs). The instrument ensemble consisted of three groups: (i) AMF3 surface in-situ instruments; (ii) TBS based platforms, including guest platforms such as Gondola, VIPS and CDMS (Fig. 1 a,b); and (iii) AMF3 remote sensors. Standard satellite products also provided IOP guidance.

The instrument-laden TBS operated in profiling and loitering (tower) modes. In the former, continuous upward traverses to ~ 1 km altitude took ~ 60 min (Fig. 1d,e). Tests with constant altitude (loitering) flight legs took ~ 2 hrs. with 3-20 min loitering at each altitude depending on the weather and flight objectives; ten altitudes from 10 m up to 1 km with ~100-200 m intervals were used. Flights were suspended during blowing snow and winds > 15 m s^{-1} that posed danger. Table 2 shows a summary of campaign conditions (with acronyms). Careful flight planning enabled us to obtain time-height cross sections of meteorological and microphysical variables. Using the measurements of surface-based instruments and remote sensing platforms, it is possible to calculate the surface turbulent heat and moisture fluxes, nucleation parameterizations, vertical profiles of 3D air velocity and turbulence, temperature *T*, (specific) humidity, droplet and ice-crystal physical and optical properties, and cloud physical and optical heights (see: examples in Figs. 2 and 3, preliminary data).

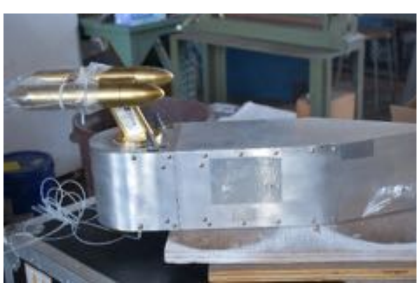

Fig. 1a: The Gondola platform of the University of Ontario Institute of Technology (UOIT)

Fig. 1b: Gondola and CDMS in fog with iced ropes at 04:44 during Flight 2 of IFFExO on Nov 13.

Fig. 1c: Light snow before the IF event on Nov 17 (shown in Fig. 1d)

(d)

(e)

Fig. 1d: Gondola laser in IF during Flight 2 with instruments along the tetherline on Nov 17; **Fig. 1e**: Deployment during IFFExO on Nov 18, 2020 (Pictures 1b-e by: Dr. Darielle Dexheimer, Sandia NL)

IFFExO Data

The data from platforms in Table 1 are being inspected and quality controlled. Both CDP and BCP sensors on Gondola cover IF crystal size range 1 - 75 μm. Alongside these sensors were a VIPS and an icing sensor that provided particle phase and size spectra up to 1 mm. Using measurements of aerosol spectra at 16 channels (0.3 to 10 μm; POPS), aerosol composition and spectra (0.1-0.5 µm at 1Hz; STAC; also see below) and CCN concentration (<1 μm down to 20 nm; OPC) and TBI impactor (aerosol composition), it will be possible to obtain a variety of microphysical characteristics. The vertical structure of microphysical properties measured via TBS profiling as well as surface measurements yielded a unique data set on IF and low clouds as well as surface heat and moisture budgets.

Table 1: List of instruments and/or platforms at IFFExO and other information

Platform	Instrument	Measurements	Make	Notes
ARM-TBS	CPC (Cloud Particle Counter)	CCN	TSI	>25 nm & <1 µm [estimated measurement uncertainty:±10%]
	TRAPS (Time-Resolved Aerosol Particle Sampler)	IN chemical composition	CSU	1 nm-10 µm, 30 min averages (±30%)
(New – Prototype)	STAC (Size and Time-resolved Aerosol Collector	IN chemical composition & spectra	PNNL	0.1-0.5µm & 1Hz (±20%)
	POPS, Printed Optical Particle Spectrometer	Ice Nuclei 0.14-3 µm ASD.	Handix	>0.3 µm (±10%)
	VIPS, Video Ice Particle Sampler	Droplet or ice crystal spectra and images	Nat. Sys. Res.	10-2000 µm (±50% at 10 µm)
	CDMS (Cloud Droplet Measurement System)	Droplet spectra	MesaPhotonics	10-1000 µm (±10%)
	TBI (Tethered Balloon Impactor)	Aerosol composition	TSI	0.25,0.5,1.0,2.5 µm (±20%)
	3-D Sonic Anemometer	(x,y,z) wind vectors	Young	Not for icing (±8%)
	SLD (supercooled Liquid Droplet) Sondes	Supercooled LWC	Anasphere	Entire size range (±15%)
	iMet XQ2 UAV Sensor	Meteorology	InterMet	At the TBS (±10%)
	DTS (Distributed Temperature Sensing)	Distributed T sensing system	Silixa	T at 0.5 m scales (±5%)
UOIT-Gondola	CDP (Cloud Droplet Probe)	Droplet/ice spectra	DMT	(1-50 µm); 1 Hz; (±10%)
(For TBS)	BCP (Backscatter Cloud Probe)	Droplet/ice spectra	DMT	(5-75 µm); 1 Hz; Cloud icing and SLD (±20%)
ARM-AMF3	MWR (Microwave Radiometer)	T, LWP and IWVP	Radiometrics	3 channels, not profiling (±20%)
	Halo Doppler Lidar	Doppler wind velocity	Metek	For ice fog and clouds (±10%)
	Ka-band radar	Radar reflectivity (Z) and Cloud properties	Metek	Profiling (±10%)
	Nepholemeter	Aerosol extinction parameter	TSI	(±10%)
	Ceilometer	Cloud base and ceiling, backscattering	Vaisala	For vertical aerosol backscatter and visibility (±10%)
	PSAP (Particle Soot Absorbing Photometer)	absorption	DMT	(±20%)
	UHSAS (Ultra High Sensitive Aerosol Spectro.)	Aerosols size distribution	DMT	<0.5 µm, spectral ASD (±10%)
	(PNNL) Aerosol Impactor	Aerosol composition	AOS	0.25-2.5 µm (±10%)
	LPM (Laser Precipitation Monitor); disdrometer	Snow spectra and type; hydrometeors	Metek	100 µm -1 cm (±30%)
	Sunphotometer	Optical thickness	Cimel Elect.	For aerosols and haze (±10%)
	SRS (Snow Ranging Sensor)	Snow depth	Metek	(±20%)
	MET tower	Met measurements		(various)
	DTS, fiber optic distributed temp sensing	T profile measured at 0.25 m intervals	ARM	30-60 sec profiles (±5%)
	AMC (Ameriflux Measurement Component System)	Upwelling and Downwelling radiative fluxes	AMC Labs	(±10%)
	MAWS (Met Automatic Wx station)	Met measurements	Metek	Radiosonde profiles (±10%)

Table 2: Observed and predicted conditions during IFFExO. Some days were dedicated for instrument testing and intercomparison. Reduced Vis days/conditions are highlighted. IF - ice fog; FFG - freezing fog; FG – fog; LSN, BSN - Blowing, Light snow; HPS - high pressure system; LPS - low pressure system; ICG – icing; HICG: high icing; MICG - Moderate icing; LICG - low icing; CLR - clear weather.

IOPs	Airmass origin via HYSPLIT model back-trajectories	IFFExO In-situ Obs.	NWS Obs.	National Weather Service (NWS) Forecast	# of Flights
Nov 10	Arctic Ocean, N	FG & IF	HPS 1031 mb	-16°C; FG & mist	1-flight
Nov 11	Pacific Ocean, SW	No fog	LPS 965 mb	-12°C; FFG & CLR	No flights
Nov 12	Arctic Ocean, NW	No fog	HPS, 1005 mb	-13°C; FFG & LSN	1-flight/2 profiles
Nov 13	Arctic Ocean, N	FFG, IF, FFG &HICG	HPS, 1004 mb	-19°C; FG, mist & LSN	2-flights
Nov 14	Arctic Ocean, NW	No fog	HPS, 1010 mb	-11°C; LSN & FG	Testing/Calibration
Nov 15	Arctic Ocean, NW	LSN-IF	HPS, 1025 mb	-09°C; FFG & LSN	2-flights
Nov 16	Arctic Ocean, SW	LSN	HPS, 1030 mb	-13°C; SN	No flights
Nov 17	Arctic Ocean, NW	*Low Vis*	HPS, 1029 mb	-06°C; FG	Testing (LSN, IF)
Nov 18	Arctic Ocean, N	*Cloudy*	HPS, 1012 mb	-11°C; FFG & cloudy	2-flights
Nov 19	Continental, SW	IF&ICG	HPS, 1008 mb	-14°C; CLR & cloudy	3-flights
Nov 20	Arctic Ocean, E	IF&MICG	HPS, 1012 mb	-15°C; FFG	1-flight, testing
Nov 21	Arctic Ocean, NE	BSN	HPS_1010 mb	-18°C; FFG	End of campaign

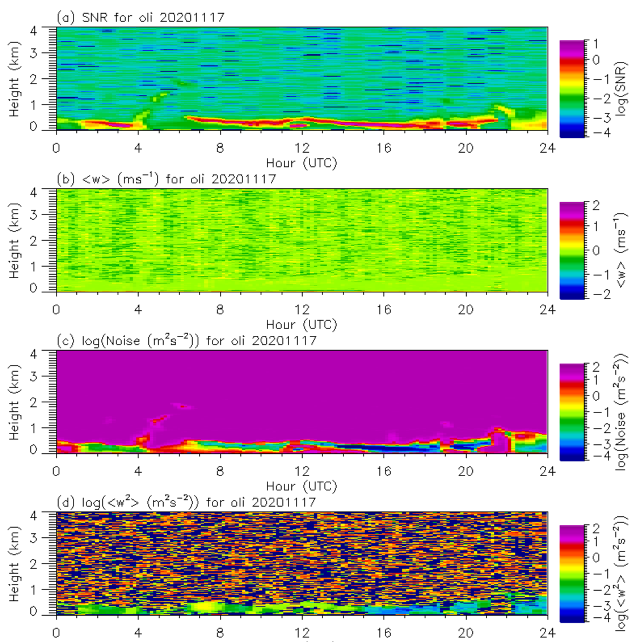

Figure 2: Doppler lidar time-height cross-sections of (a) Signal to noise ratio, (b) 1Hz vertical velocity, (c) 10-min vertical velocity error variance (noise), (d) 10-min vertical velocity variance (without noise correction) on 10 Nov 2020 at AMF3. Courtesy: Dr. Rob Newsom and Dr. Raghu Krishnamurthy (PNNL Lidar Mentors)

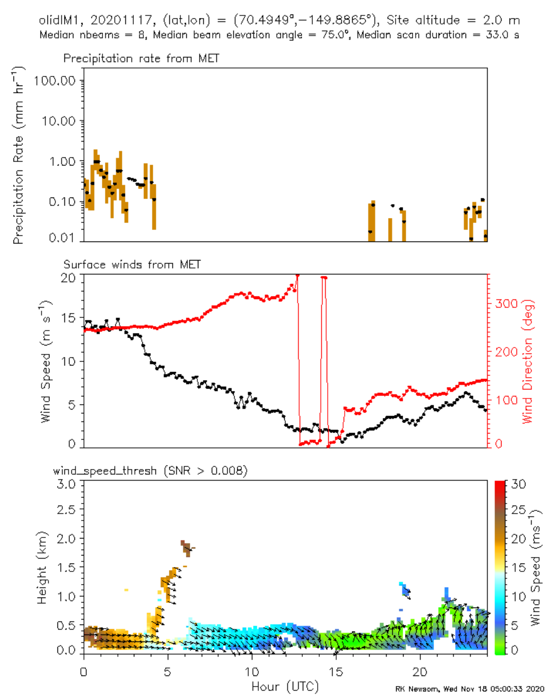

Figure 3: Time series of 10-min averaged (a) precipitation rate, (b) surface wind speed and direction, (c) Doppler lidar profiles of wind speed and direction on 17 November 2020 at AMF3.