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Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms

Project Implementation Plan
October 07, 2019

IMPACTS EVS-3 Project Implementation Plan
Signature page

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1.0 Science Objectives

1.1 Background

Winter snowstorms are frequent on the Eastern Seaboard, where a large percentage of the US population lives, and cause major disruptions to transportation, commerce, and public safety. Snowfall within these storms is frequently organized in banded structures that are poorly understood and poorly predicted by current numerical models. The Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) flies a complementary suite of remote-sensing and in-situ instruments in three 6-week deployments on the NASA ER-2 and P-3 aircraft to provide observations critical to understanding the mechanisms of snowband formation, organization, and evolution. IMPACTS also examines how the microphysical characteristics and likely growth mechanisms of snow particles vary across snowbands. These measurements will improve snowfall remote sensing interpretation and modeling to significantly advance predictive capabilities.

The IMPACTS fundamental science objectives are to:

- **Characterize** the spatial and temporal scales and structures of snowbands in Northeast US winter storms,
- **Understand** the dynamical, thermodynamical and microphysical processes that produce the observed structures, and
- **Apply** this understanding of the structures and underlying processes to improve remote sensing and modeling of snowfall.

These objectives are relevant to NASA's vision and mission, and address the first goal of the NASA Strategic Plan, to "Understand the Sun, Earth, Solar System and Universe" and to "Expand human knowledge through new scientific discovery". IMPACTS further addresses the third core context of this strategic goal of "Safeguarding and Improving Life on Earth" and to "provide data for applications for operational use by first responders, weather forecasters, and others". By increasing our understanding of snowband structures and applying this understanding to improving numerical weather forecasts of snowfall and the remote sensing of snow, IMPACTS addresses the NASA Strategic Plan and the NASA Weather Focus Area's research objective to "enable improved predictive capability for weather and extreme weather events".

IMPACTS is also relevant to several NASA missions, such as the Global Precipitation Measurement (GPM) and CloudSat missions and addresses the National Academy's recommendation for a designated program focused on clouds, convection, and precipitation. A key GPM objective is to detect and measure falling snow at the surface over a wide range of snowfall intensities. Interpretation of, retrieval from, and validation of GPM Dual-frequency Precipitation Radar (DPR) and GPM Microwave Imager (GMI) data for all ranges of snowfall intensity requires an understanding of the relationships between snowstorm vertical reflectivity structure, particle characteristics, and passive microwave brightness temperatures. IMPACTS will provide essential data about these relationships for determining GMI and DPR sensitivity thresholds to falling-snow detection and measurement that will improve GPM snow estimates and reduce their uncertainty. The Clouds, Convection, and Precipitation (CCP) Targeted Observable Designated-program recommendation by the National Academies as part of the 2017 NASA Earth Science Decadal Survey seeks to address how we can better understand and predict coupled cloud and precipitation variability and change. IMPACTS' multi-sensor active and passive measurements along with in-situ microphysical measurements helps to inform the development of future satellite missions for measuring clouds and precipitation from space.

IMPACTS is the first mission with a full suite of modern instrumentation to specifically focus on disruptive East Coast US snowfall and winter storms. The IMPACTS remote-sensing and in-situ measurements of the spatial and temporal scales and structures of snowbands in Northeast US winter storms and the understanding gained through the analysis of these measurements is relevant to a broad spectrum of beneficiaries and stakeholders. IMPACTS will benefit not only the scientists directly involved, but the modeling and remote sensing communities, the weather forecast community (both government and private enterprises), and the transportation, commerce and public safety sectors. The knowledge gained through the understanding of the multi-scale processes leading to snowband structures in Northeast US winter storms is applicable to understanding snow processes in storms worldwide, making IMPACTS beneficial to those concerned with winter storms across the globe.

2.0 Level I Science Requirements

As stated in the previous section, the IMPACTS fundamental science objectives are to: 1) characterize the spatial and temporal scales and structures of snowbands in Northeast US winter cyclones; 2) understand the dynamical and microphysical processes that produce the observed structures; and 3) apply the understanding of the structures and underlying processes to improve remote sensing and modeling of snowfall. These fundamental science objectives are designed to address the following science questions:

a) What are the vertical and horizontal structures and scales of the bands and how do these structures evolve with the development of the cyclone?
b) How do patterns of vertical motion (updrafts) relate to snowband structure and what dynamical and thermodynamical processes (frontogenesis, shear instability, conditional or symmetric instability, gravity waves) determine the initiation, size, evolution and longevity of these vertical motions?
c) To what extent is enhanced reflectivity in bands related to increased snow water content versus changes in particle characteristics due to aggregation or riming without a significant change in snow water content?
d) What are the microphysical properties of the bands (particle geometry, degree of riming, ice water content, cloud liquid water, etc.) and how can this information be used in conjunction with simultaneous measurements of passive and active remote sensing instruments to improve remote sensing from space and numerical modeling of snowfall?

2.1 Baseline and Threshold Science Requirements

To meet the three fundamental science objectives and the four science questions listed above, the Baseline and Threshold science requirements address four general categories: design/scope of the deployment, type of data to be collected, analysis objectives, and data archival and publication. The two tables below provide the detailed Level 1 science requirements. These requirements and how they relate to the science objectives and questions above at the baseline level is summarized in Table 2.1 and at the threshold level in Table 2.2. These requirements are then related to the Science Traceability Matrix (STM), which is presented in Table 2.3.

The Baseline investigation meets all IMPACTS science objectives and the Threshold investigation meets these objectives but the measurements are made with limited fidelity. For the Threshold investigation, limited fidelity is defined as measurements (1) collected at lower spatial and temporal resolution as compared to measurements collected for the baseline investigation; (2) subject to greater uncertainties; (3) using fewer instruments so that the full range of measurements are not made (for particle sizes, this would mean not measuring the full range of particle sizes from cloud-sized particles to precipitation-sized particles; for remote sensing instruments, this would mean having only high-frequency or low-frequency radars; or fewer passive microwave radiometer frequencies measured); or (4) obtained from external sources such as high-resolution model output, operational rawinsonde ascents, or state variables (temperature, winds) available from commercial aircraft. Another distinction between threshold and baseline is through how the information required to meet a particular requirement is obtained. For all the baseline requirements, the information is measured by IMPACTS instruments. However, for some of the threshold requirements, the information is determined from sources outside of the IMPACTS observations. To make this distinction clear, we use the word '**Measure**' or '**Determine**' in the particular requirement.

In Tables 2.1 and 2.2, there are two columns: **Requirement** and **Measurement**. The Measurement column details how that particular requirement is met, either through particular measurements made by specific instruments or the delivery of certain products, such as submitted manuscripts. The Mission is met at Baseline when all the measurements made for the six required events of science requirement (b) are at baseline. In the same manner, the mission is met at Threshold when all the measurements made for the three required events of science requirement (b) are at threshold.

Table 2.1: Summary of Baseline Mission Requirements organized into four categories: design/scope of the deployment (blue), type of data to be collected (green), analysis objectives (orange), and data publication and archival (purple). The physical quantity to be measured is listed in bold in the measurement column.

Baseline Mission Requirements	
Requirement	**Measurement**
(a) Conduct **three multi-week deployments** to measure precipitation structures in mid-latitude winter cyclones within the winter months of 2020-2022 with **two aircraft** (one high-altitude and one *in-situ* aircraft) and with ground-based measurements (Addresses science objectives 1 – 3 and science questions a – d)	All measurements as listed below in baseline requirements c-h
(b) Sample **6 or more events** over the course of the entire mission (single or multi-day events, ideally 2 events per deployment) with **one** event an **east coast cyclone** (Addresses science objectives 1 – 3 and science questions a – d).	All measurements as listed below in baseline requirements c-d, f-g for all storms, and include requirements e and h for the east coast cyclone.
(c) Measure the detailed 2-D structure of clouds and precipitation with active and passive remote sensing instruments to diagnose the width, depth and evolution of snowbands. (Addresses science objectives 1 – 3 and science questions a – d, see STM 'Horizontal and vertical structure' rows).	***Precipitation Horizontal structure*****:** CoSMIR and AMPR, or EXRAD ***Precipitation vertical structure low frequency radar**:* EXRAD or HIWRAP Ku-band ***Precipitation vertical structure high frequency radar:*** CRS or HIWRAP Ka-band ***Cloud vertical structure:*** CRS or CPL
(d) Measure the vertical and horizontal air motions that are associated with the observed precipitation structures to deduce dynamical features. (Addresses science	***Vertical storm air motions:*** CRS, HIWRAP ***Horizontal storm air motions:*** EXRAD

objectives 2 – 3 and science questions b, d, see STM ‘Storm dynamics’ rows).	
(e) Measure the vertical thermodynamic environment near snow bands at an observational frequency of every 6 hours or less for the duration of an operational period covering the time before, during and after the aircraft flights to diagnose regions and/or layers of conditional or symmetric instability. (Addresses science objectives 2 – 3 and science questions b, d, see STM ‘Storm thermodynamics’ rows).	***Temperature and Humidity profiles:*** Mobile rawinsondes and dropsondes (AVAPS)
(f) Measure the cloud and microphysical properties of snowbands, sampling particles ranging from cloud to precipitation sizes. (Addresses science objectives 2 – 3 and science questions c, d, see STM ‘*In-situ* microphysical properties’ rows).	For each physical quantity listed below, need at least **two** instruments capable of measuring these quantities (see STM for specific instruments): ***Ice water content, Liquid water content***, ***Cloud PSDs***, ***Precipitation PSDs, Particle phase/shape***
(g) Measure the microscale thermodynamic conditions and air motions representing the environment of the precipitation and cloud particles. (Addresses science objectives 2 – 3 and science questions b – d, see STM ‘*In-situ* particle environment’ rows).	***Air motions, temperature and humidity at flight level***: TAMMS
(h) Measure the detailed 3-D structure and temporal evolution of clouds and precipitation from ground-based remote sensing instruments located on Long Island, for storms that occur in the northeastern US (addresses science objective 1, and science question a).	Of the ground-based instruments on Long Island, at least one radar (scanning or profiling) and one lidar must be operational (see section 3.2.5 of IIP for full description of all instrumentation at Stony Brook)
(i) Use the baseline observations to analyze the variability of the structure, evolution and intensity of snowbands for a variety of mid-latitude wintertime storms and relate these snowband structures to dynamical features and the detailed thermodynamic environment (addresses science objective 1 – 2, and science questions a – c).	Submit at least one manuscript on snowband structure and/or dynamical features by end of funding.
(j) Relate microphysical properties to remote sensing observations in order to address algorithm assumptions and shortcomings to improve snowfall retrievals from space (addresses science objective 3, and science question d).	Submit at least one manuscript on remote sensing applications by end of funding.
(k) Compare measured microphysical properties to model microphysical schemes to improve model forecasts of snow (addresses science objective 3, and science question d).	Submit at least one manuscript on microphysical schemes by end of funding.
(l) Produce standard science data products and associated metadata from all instruments described in the IMPACTS Data Management Plan within the timeframes identified in Table 8.2-1 of Section 8 below. All terms and conditions of the transfer of the	Transfer data products to the DAAC as detailed in section 8.

data products to the GHRC DAAC are documented in the IMPACTS Data Management Plan.	
(m) Give scientific presentations and submit publications on results obtained through the analyses listed above in (i) – (k) each year starting with the year following the first deployment.	Give presentations and submit manuscrips as detailed in section 9.

Table 2.2: Summary of Threshold Mission Requirements organized into four categories: design/scope of the deployment (blue), type of data to be collected (green), analysis objectives (orange), and data publication and archival (purple). The physical quantity to be measured is listed in bold in the measurement column.

Threshold Requirements	
Requirement	**Measurement**
(a) Conduct at least **two multi-week deployments** that can occur sometime within the winter months of the years 2020-2022 to measure precipitation structures in mid-latitude winter cyclones. At least **one deployment must have two aircraft** (one high-altitude and one *in-situ* aircraft). (Addresses science objectives 1 – 3 and science questions a – d)	All measurements as listed below in threshold requirements c-h
(b) Sample 3 or more events over the course of the entire mission (single or multi-day events) (Addresses science objectives 1 – 3 and science questions a – d).	All measurements as listed below in threshold requirements c-h
(c) Measure the 2-D structure of precipitation using active and passive remote sensing instruments to diagnose the width and depth of snowbands. (Addresses science objectives 1 – 3 and science questions a – d, see STM 'Horizontal and vertical structure' rows).	***Precipitation horizontal structure:*** CoSMIR or AMPR or EXRAD ***Precipitation vertical structure:*** EXRAD, or HIWRAP
(d) Determine vertical air motions from a nadir scanning radar on a high-altitude aircraft and horizontal air motions from models or external sources. (Addresses science objectives 2 – 3 and science questions b, d, see STM 'Storm dynamics' rows).	***Vertical storm air motions:*** CRS or HIWRAP ***Horizontal storm air motions:*** models or external sources
(e) Determine vertical thermodynamic environment from external sources at an observational frequency of every 12 hours. (Addresses science objectives 2 – 3 and science questions b, d, See STM 'Storm thermodynamics' rows).	***Temperature and Humidity profiles:*** Obtained from operational soundings.
(f) Measure the microphysical properties of snowbands, focusing on precipitation size particles. (Addresses science objectives 2 – 3 and science questions c, d, see STM '*In-situ* microphysical properties' rows).	For each physical quantity listed below, need at least **one** instruments capable of measuring that quantity (see STM for specific instruments): ***Ice water content, Liquid water content**, **Precipitation PSDs, Particle phase/shape***
(g) Determine the microscale thermodynamic conditions and air motions. (Addresses science objectives 2 – 3 and science questions b – d, see STM '*In-situ* particle environment' rows).	***Air motions, temperature and humidity at flight level***: from models or external sources

(h) Determine the 3-D structure and temporal evolution of clouds and precipitation for observed storms that occur in the northeastern US (addresses science objective 1 and science questions a).	Use operational surface meteorological observations and the National Weather Service operational radars.
(i) Use the observations collected under threshold investigation to analyze the variability of the structure, evolution and intensity of snowbands for a few mid-latitude wintertime storms and relate these snowband structures to dynamical features and the detailed thermodynamic environment (addresses science objective 1 – 2, and science questions a – c).	Submit at least one manuscript on snowband structure and/or dynamical features by end of funding
(j) Use the observations collected under threshold investigation to relate microphysical properties and remote sensing observations to address algorithm assumptions and shortcomings to improve snowfall retrievals from space (addresses science objective 3 and science question d).	Submit at least one manuscript on remote sensing applications by end of funding.
(k) Use the observations collected under threshold investigation to compare measured microphysical properties to model microphysical schemes to improve model forecasts of snow (addresses science objective 3 and science question d).	Submit at least one manuscript on microphysical schemes by end of funding.
(l) Produce standard science data products and associated metadata from all instruments described in the IMPACTS Data Management Plan within the timesframes identified in Table 8.2-1 of Section 8 below. All terms and conditions of the transfer of the data products to the GHRC DAAC are documented in the IMPACTS Data Management Plan.	Transfer data products to the DAAC as detailed in section 8.
(m) Give scientific presentations and submit publications on results obtained through the analyses listed above in (i) – (k) each year starting with the year following the first deployment.	Give presentations and submit manuscrips as detailed in section 9.

2.2 Science Traceability Matrix

The IMPACTS Science Objectives lead to the specific set of requirements in the STM (Table 2.3). The STM shows the flow from the science goals and objectives to the specific set of required physical parameters, observables and instrument performance characteristics, the latter requirements based on recommendations by Bennartz et al. (2011) or based on the IMPACTS team's experience with observational research related to winter storms (IMPROVE, PLOWS), GPM validation campaigns (IPHEx, OLYMPEX), and HS3. The relationships between the level 1 science requirements and the STM are detailed in Tables 2.1 and 2.2 above.

Table 2.3 The Science Traceability Matrix (STM) maps individual scientific measurement requirements into functional requirements. Cloud microphysical measurements on the P-3 contain important redundancy that allows for checks on measurement consistency among the different probes. Only one of the microphysical sensors listed is required for each of the microphysical observables to meet the Threshold Investigation.

Science Goal	Science Objectives	Science Measurement Requirements: Measurement Objectives	Science Measurement Requirements: Physical Parameters	Science Measurement Requirements: Observables	Required Instrument Performance [spatial resolution (H/V), accuracy, sensitivity]	Instruments	Projected Instrument Performance [spatial resolution (H/V), accuracy, sensitivity]	Investigation Requirements
(1) Improve understand-ing of the formation, evolution, air motions, and snow-particle growth mechanisms of high-impact snowbands	**(O1) Characterize** the spatial and temporal scales and structures of snowbands in Northeast US winter storms	**Horizontal and Vertical Structure**						High-altitude (>50 kft) aircraft, 8 h flight duration, for remote sensing
		Measure the detailed 3-D structure of clouds and precipitation to diagnose the depth and width of bands, and their associated structures (Addresses Obj. 1 - 3)	Precipitation horizontal structure*	Radiometric brightness temperatures with sensitivity to precipitation ice (land/ocean), liquid (ocean)	5 km (H), 2 K	COSMIR (50-183 GHz), AMPR (10-85 GHz)	1 km (H), 1 K	
				Raw and calibrated returned power (dB), weak attenuation	2 km (H)/250 m (V), 2 dBZ, sensitivity -10 dBZ	EXRAD (X band)	1 km (H), 1 dBZ, sensitivity -15 (-8) dBZ at nadir (scanning)	
			Precipitation vertical structure*	Raw and calibrated returned power (dB), multi- frequency for advanced retrievals	2 km (H)/250 m (V), 2 dBZ, sensitivity -10 dBZ	EXRAD, HIWRAP (Ku, Ka bands)	EXRAD (see above); HIWRAP: 1 km (H)/250 m (V), 1 dBZ, sensitivity -12 (-10) dBZ for Ka (Ku)	
			Cloud vertical structure*	Raw and calibrated returned power (dB), sensitivity for clouds	2 km (H)/250 m (V), 2 dBZ, sensitivity -20 dBZ	CRS (W band)	1 km (H)/250 m (V), 1 dBZ, sensitivity -30 dBZ	
				Lidar attenuated backscatter profiles, detection of thin clouds and liquid water near cloud top	2 km (H)/250 m (V), 25%	CPL	0.2 km (H)/30 m (V), 10-15%	
	(O2) Understand the dynamical, thermodynamical, and microphysical processes that create the observed structures	**Storm Dynamics**						Low- to mid-level (5-28 kft) cloud-penetrating aircraft, with de-icing capability, 8 h flight duration, for in-situ measurements
		Measure the vertical and horizontal air motions that produce the observed precipitation structures (Obj. 2 & 3)	Storm air motions	Vertical air motion derived from nadir Doppler velocities	2 km (H)/250 m (V), 1 m s-1	CRS, HIWRAP	1 km (H)/250 m (V), 1 m s-1	
				Horizontal air motion derived from scanning Doppler radar	2 km (H)/250 m (V), 1 m s-1	EXRAD	1 km (H)/250 m (V), 1 m s-1	
(2) Enable improved space-based measurement and prediction of snow within winter storms		**Storm thermodynamics**						
		Measure the vertical thermo- dynamic environment near bands to diagnose regions of conditional or symmetric instability (Obj. 2 & 3)	Temperature	Temperature profiles	50 m (V), 3 hourly	Mobile rawinsonde/ dropsonde	20 m (V), 3 hourly	
			Humidity	Humidity profiles	50 m (V), 3 hourly	Mobile rawinsonde/ dropsonde	20 m (V), 3 hourly	
		***In-situ* microphysical properties**						
		Measure the cloud microphysical properties of snowbands (Obj 2 & 3)	Cloud microphysical properties	Ice water content	100 m (H), 0.1 g m-3	Nevzorov, HVPS-3, 2D-S, WISPER	100 m, 0.05 g m-3	
	(O3) Apply this understanding of the structures and underlying processes to improve remote sensing and modeling of snowfall			Liquid water content	100 m (H), 0.1 g m-3	CDP, CAPS, Nevzorov, King, Hawkeye, RICE	100 m, 0.02 g m-3	
				Cloud droplet size distribution	100 m (H), 5 cm-3	CDP, CAPS, 2D-S, Hawkeye	100 m, 1 cm-3	
				Precipitation particle size distribution	100 m (H), 5 liter -1	2D-S, HVPS-3, Hawkeye	100 m, 1 liter -1	Campaigns in the January to early March timeframe
				Particle phase/shape	100 m (H), NA	CAPS, 2D-S, HVPS-3, Hawkeye	100 m, NA	
		***In-situ* particle environment**						
		Measure the microscale thermodynamic conditions and air motions representing the environment of precipitation and cloud particles (Obj 2 & 3)	Air motions	Vertical air motion *in-situ* time series	100 m, NA	TAMMS in-situ measurement system	0.5 m, NA	
				Horizontal air motion *in-situ* time series	100 m, 1 m s-1		0.5 m, 0.5 m s-1	
			Temperature	Temperature *in-situ* time series	100 m, 0.5 K		0.5 m, 0.2 K	
			Humidity	Humidity *in-situ* time series	100m, 10%		0.5 m, 4%	

*Precipitation and cloud structure are defined in terms of variations of passive microwave brightness temperatures, radar reflectivity, and lidar attenuated backscatter

3.0 Technical Approach

3.1 Mission Concept

As described in Section 2, mission requirements are driven by the need for above-storm sampling (ER-2) and in-storm penetrations for in-situ microphysical and state parameters (P-3). The P-3 serves as IMPACTS' in-situ platform for identifying microphysical particle characteristics, the local environment of the particles, and vertical thermodynamic and kinematic profiles from dropsondes. The ER-2 aircraft will serve as an advanced cloud and precipitation remote-sensing platform capable of simulating satellite sensors, but with much higher spatial and temporal resolution, with measurement capabilities. Combining the remote sensing with in-situ microphysics is critical to improving snowfall retrieval algorithms.

The IMPACTS regions of interest (ROI) are shown in Figure 3.1. The primary ROI is the East Coast sector; however, recognizing the variability of winter weather and that this East Coast sector may experience periods of low snowstorm activity, we also include a secondary ROI in the Midwest. While orographic and oceanic influences will differ between the two regions, banded structures are observed in both regions and the mechanisms for band formation and evolution are likely very similar. Intensive operations periods (IOP) will cover six weeks in January and February 2020-2022, with a target of up to 10-12 research flights per deployment to sample about six to eight events, each consisting of flights covering a single or multi-day storm event. The down time between storm events will be used for data processing, flight planning, and writing daily science summaries.

The P-3 will deploy from Wallops Flight Facility (WFF), its home base, minimizing costs and logistical issues. To minimize the impact of adverse winter weather on operations, the ER-2 will be based out of Hunter Army Airfield (AAF) (KSVN) in 2020, and tentatively Warner Robins (WR) Air Force Base (AFB) for 2021 and 2022. This change from basing entirely out of WR was necessitated due to lack of hangar availability in 2020. Both ER-2 sites allow for a minimum of three hours on-station time in the ROIs. From an analysis of 20 years of hourly data by the IMPACTS team, both ER-2 sites have very few periods (<4% of the time) where the ER-2 take-off and landing conditions are out of limits. The P-3 is far less impacted by weather. However, WFF may close when significant snowfall occurs. Snow occurs at WFF on average ~5 days per year, including ~2.5 days/year with snowfall greater than 1 inch. In anticipation of occasional WFF closure due to snow, the P-3 can redeploy to alternative sites, such as the Glenn Research Center (GRC), Langley Research Center (LaRC), WR, Hunter AAF, and return once WFF reopens. Such redeployments are only executed due to weather-related impacts to aircraft operations, not for science, and are not expected to occur more than three times per deployment. The appropriate costs to cover these redeployments will be taken from project reserves if necessary.

By focusing on the Northeast US, IMPACTS takes advantage of pre-existing National Oceanic and Atmospheric Administration (NOAA) observing infrastructure, including rawinsonde and WSR-88D Doppler radar sites (Figure 3.2). These radars provide valuable information on the horizontal structure and movement of snowbands, but generally lack the vertical resolution and sensitivity needed to analyze the vertical structure of the storms and diagnose the horizontal and vertical air motions within the snowbands; hence, the need for aircraft observations. The WSR-88D radars are critical during flight operations for targeting snowbands. NWS rawinsondes are routinely launched every 12 hours, with supplemental rawinsondes at six-hour intervals during major weather events as determined by the NOAA Weather Prediction Center (WPC); NWS staffing issues prevent more frequent ascents. The WPC director, Dr. David Novak, is an IMPACTS collaborator and will facilitate coordination between NWS and IMPACTS operations. IMPACTS will use data from subsets of rawinsonde sites (depending on flight location) (Figure 3.2) across the study region to examine the wind and thermodynamic (static stability) features related to the bands and will use all of the data for data assimilation for WRF model analyses.

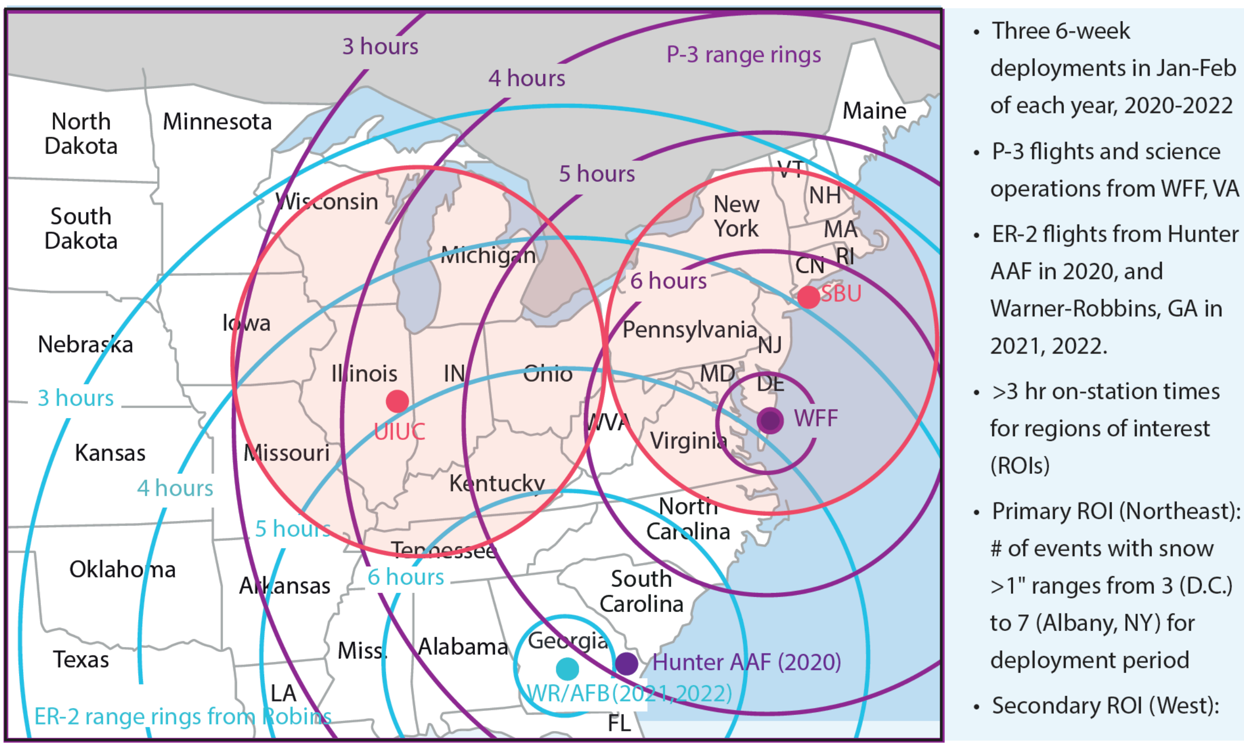


Figure 3.1: IMPACTS' Main ROIs. The two main ROIs are the heavily-populated East Coast and Midwest (red circles). Range rings (P-3 purple, ER-2 turquoise) show on-station time for each of the aircraft. ER-2 range rings are from WR AFB; these will be displaced slightly eastward for Hunter AAF in 2020. Highest priority is given to the East Coast region, where IMPACTS can take advantage of the SBU ground facility (see section 3.2.5).

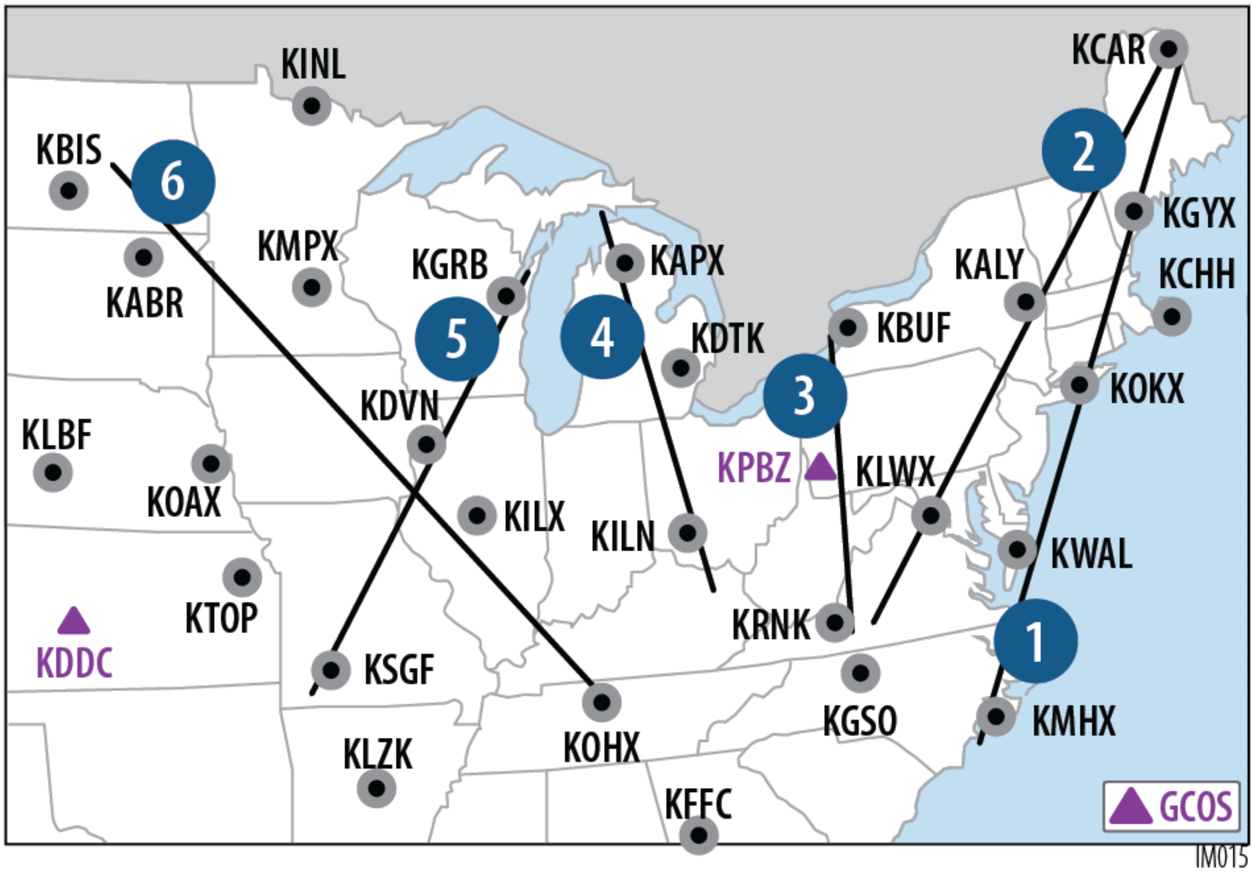


Figure 3.2 Rawinsonde Ascents. IMPACTS will use rawinsonde ascents at selected NWS upper-air sites (located at small gray dots with station IDs provided) to construct vertical cross sections (examples shown by lines and labeled by numbers in blue larger dots) of environmental conditions near flight legs.

3.2 IMPACTS Aircraft, Instruments, and Ground Measurements

3.2.1 P-3 System

For IMPACTS, the P-3 carries a suite of microphysical probes, flight level meteorological data, and a dropsonde system (Figure 3.3, Table 3.1). These instruments provide in-situ measurements to meet the science requirements. All instruments are high technology readiness level (TRL) of TRL8 or greater and have flown in numerous field campaigns. A deficiency in many past microphysical datasets was the lack of in-situ observations necessary to constrain estimates of total ice content— IMPACTS' Water Isotope System for Precipitation and Entrainment Research (WISPER) and Nevzorov instruments provide this critical constraint. WISPER measures the total condensed water content and Nevzorov measures the liquid/ice water content. Supercooled liquid water is expected to be an important driver for particle growth, and the Rosemont icing probe (RICE) provides measurement of supercooled water. After selection, the superior Particle Habit Imaging and Polar Scattering probe (PHIPS) has been added for the first year instead of the Cloud Droplet Probe (CDP) since it became available for one year after proposal award and it provides additional science capability (see further description of the probes below).

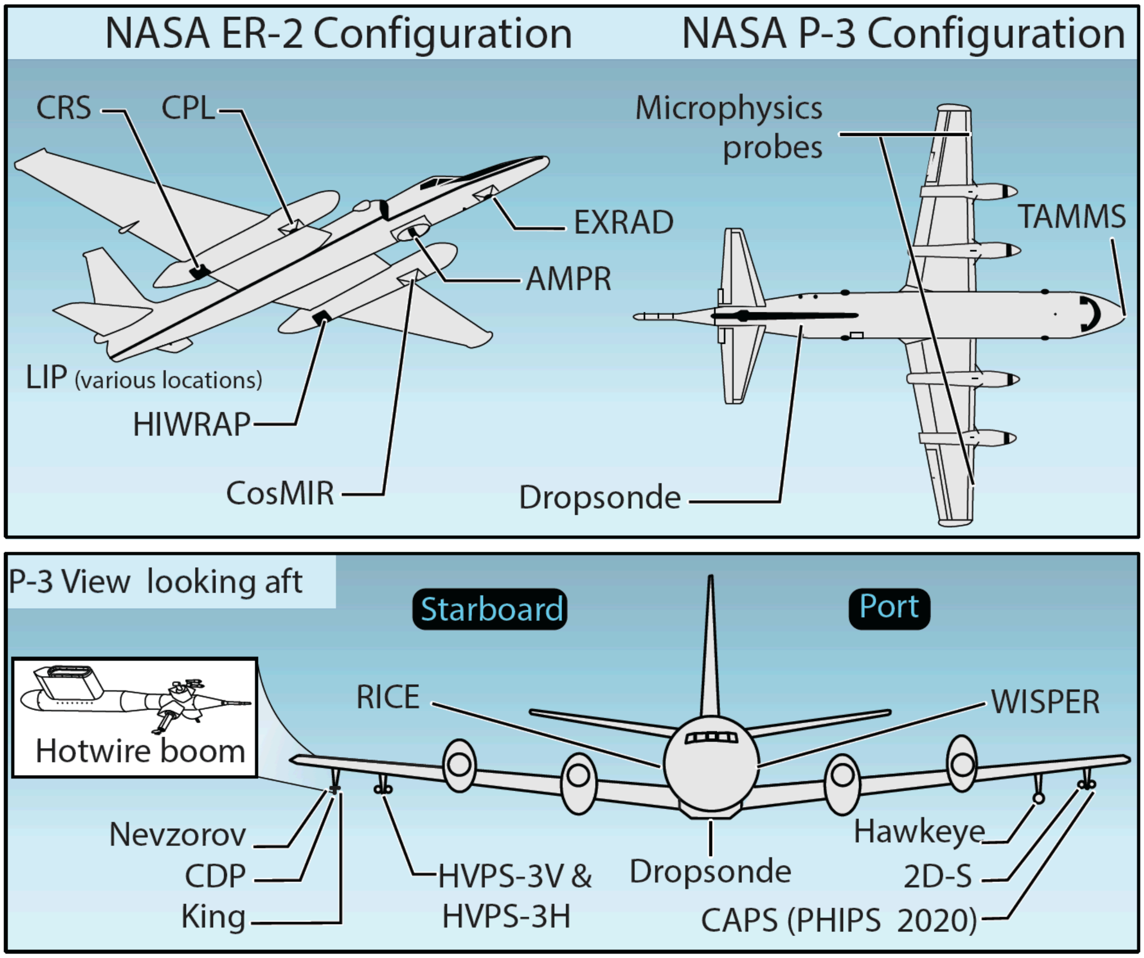


Figure 3.3: P-3 and ER-2 Instrumentation Configuration. The ER-2 and P-3 accommodate the proposed IMPACTS instruments with ample margin. All of the ER-2 instruments and many of the P-3 instruments have flown previously in similar configurations on the NASA P-3. PHIPS will only fly in 2020.

Table 3.1: IMPACTS P-3 Microphysics Probes

Instrument	Measurement	Size Range
DMT Cloud, Aerosol and Precipitation Spectrometer (CAPS)	Aerosol, Cloud Droplets, Droplet and Ice Particle Size Distributions, Liquid Water Content	0.53-50 μm (CAS) 50 μm to > 1 mm (CIP), 0 to 3 g m^{-3} (Hot-Wire)
DMT Cloud-Droplet Probe (CDP)	Droplet, Ice Particle Size Distributions, Estimated Liquid Water Content	2-50 μm
SPEC 2D-S Probe (2D-S)	Droplet, Ice Particle Size Distributions	Nominally 10 μm to 3 mm
SPEC High Volume Particle Spectrometer (HVPS-3V) Probe	Droplet, Ice Particle Size Distributions (HVPS-3 in vertical orientation)	150 μm to 10 cm
SPEC High Volume Particle Spectrometer (HVPS-3H) Probe	Droplet, Ice Particle Size Distributions (HVPS-3 in horizontal orientation)	150 μm to 10 cm
King Probe	Liquid Water Content	0.01-2 g m^{-3} in cloud droplet sizes 2-30 μm
Nevzorov Probe	Liquid/Ice Water Content	Nominally 0.01-2 g m^{-3}
Rosemount Icing Probe (RICE)	Presence & approx. amount of supercooled liquid water	>0.01 g m^{-3}
Water Isotope System for Precipitation and Entrainment Research (CVI Probe + Water Isotope Probe) (WISPER)	Total Condensed (Liquid/Ice) Water Content, Water Isotopes	0.01-2 g m^{-3}
Hawkeye	Droplet, Ice Particle Size Distribution	HCDP (1.5-50 μm), 2D-S1 (10-1280 μm), 2D-S2 (50-6400 μm), CPI (2.3-2300 μm)
Particle Habit Imaging and Polar Scattering (PHIPS) (2020)	Particle imaging, shape, orientation, particle size distribution	(10-1000 μm) stereo microscopy (10-1000 μm) polar nephelometer

Table 3.2: Wallops estimates for IMPACTS P-3 payload weight, power and margins.

IMPACTS Payload	Weight (lbs)	Power (Watts)
AVAPS	137	600
Nevzorov Probe	12	684
Hawkeye	150	2,510
RICE	10	385
TAMMS	450	750
CAPS, CDP, King, HVPS-3, 2DS	339	3,590
WISPER	307	710
Misc. (racks, seats, etc.)	1,812.5	N/A
Total Inst.	**3,217.5**	**9,229**
Capacity	**14,700**	**89,840**
Margin	**75.9%**	**88.7%**

Margin = [Aircraft Capability - (Payload Current Best Estimate) (1 + Uncertainty)]/Aircraft Capability. Uncertainty = 10%.

Advanced Vertical Atmospheric Profiling System (AVAPS): The National Center for Atmospheric Research (NCAR) AVAPS dropsonde system measures high-resolution vertical profiles of ambient temperature, pressure, humidity, and wind speed and direction. Measurements are taken by a parachuted dropsonde that transmits data back to the P-3. The AVAPS processes the data in real time and displays and archives the data. AVAPS and the drop tube have been installed and tested on the P-3 in preparation for the 2019 CAMP2Ex field campaign.

Microphysics Probes: The IMPACTS team based its selection of microphysics probes (Table 3.1) on experience with previous microphysical campaigns and the science requirements in the baseline and threshold level 1 science requirements (Table 2.2) and the STM (Table 2.1). The IMPACTS microphysical team has worked extensively with all of the selected probes, and has built existing state-of-the-art software to process their data. The Cloud-Droplet Probe (CDP) and Cloud, Aerosol and Precipitation Spectrometer (CAPS) are used to measure the size distributions of cloud water droplets. CAPS consists of a Cloud and Aerosol Spectrometer (CAS), Cloud Imaging Probe (CIP), and a hot wire probe for measuring liquid water content (LWC). For cloud droplets and larger ice particles, IMPACTS relies on the 2D-S and High Volume Precipitation Sampler-3 Vertical (HVPS-3V) probes, which combined yield size distributions and particle shapes in the range of ~10 µm to ~10 cm. A second HVPS-3H is oriented orthogonal with the first and is used to measure particle shape (the “V” or “H” suffix on the standard HVPS-3 denotes vertical or horizontal orientation). Two orthogonally oriented HVPS-3 probes were used successfully in OLYMPEX to measure particle canting angles to improve ice particle scattering assumptions for radar retrievals. The Hawkeye is a relatively new 4 in 1 (cloud particle imagery, CPI, 2D-S [10 micron resolution], 2D-S [50 micron], and fast cloud droplet probe, FCDP) cloud probe developed under a NASA Goddard Space Flight Center (GSFC) Small Business Innovation Research (SBIR) Phase II and IIe with SPEC Inc. Hawkeye has flown on the SPEC Lear Jet and during the ATTREX Earth Venture Global Hawk mission. CAMP2Ex will be its first deployment on the P-3. Hawkeye largely provides redundancy for the other cloud probes being flown on the P-3 (Table 3.1). Cloud liquid content for drop sizes ~2 to 30 μm is measured with a King Probe and a hot wire on the CAPS probe. In liquid-only regions, the CDP, CAPS, and imaging-probe size distributions can be integrated to yield the LWC. WISPER contains the Counter Virtual Impactor (CVI) that provides high-accuracy measurements of total liquid and ice contents. The CVI portion of WISPER is similar to NCAR's CVI except that it has additional heaters to help vaporize ice in higher ice water content (IWC) regions. For these extreme conditions, there is some loss of time resolution in the data but the data quality is still high. These high ice or water cases are still being evaluated for accuracy. Imaging probe data will also be used in the high ice situations. IMPACTS also includes RICE to detect the occurrence and amount of supercooled water. All P-3 microphysics instruments (Table 3.1) have flight heritage, are high TRL (8 or higher), and meet IMPACTS requirements. All cloud particle instruments, other than the cloud droplet component of the CAPS and Hawkeye, have open-path geometry, resulting in fewer particle sampling problems based on extensive analysis of prior measurements. Particle measuring probes including CDP, CAPS, and 2D-S have anti-shattering tips to mitigate artifacts generated by particle splashing, breakup, and deformation. Hawkeye has an inlet tube to reduce shattering. The removal of shattered particles is accomplished using algorithms based on particle inter-arrival time (Field et al., 2006).

Turbulent wind measurement system (TAMMS): Measures 3D winds along with fast-response measurements of humidity and temperature at the P-3 flight level. It includes fast-response flow-angle and temperature sensors, an inertial navigation system (INS), a PC-based data acquisition system, and a flight management system (FMS) to provide the aircraft's position, speed, and attitude. The flow-angle system includes five flush-mounted pressure ports installed in a cruciform pattern in the aircraft radome to provide angle-of-attack (vertically aligned ports) and side-slip (horizontally-aligned ports) measurements [Brown et al., 1983]. Corresponding fast-response (20-Hz), high-precision pressure transducers are placed as close as possible to the pressure ports to minimize delays and errors. Three-dimensional winds are computed from the full air motion equations [Lenschow, 1986]. Derived measurements of the 3D wind components, temperature, and moisture are archived at 20-Hz resolution. TAMMS does not have heaters and therefore the five small ports on the radome may occasionally ice up and stop providing measurements. The backup for the TAMMS horizontal winds is to use two existing P-3 Rosemount 0858Y probes (for angle of attack and sideslip). These probes will provide a less accurate measurement, but will meet the baseline science requirements; they have heaters that will be implemented during IMPACTS for melting ice accumulation.

Particle Habit Imaging and Polar Scattering (PHIPS): This is an experimental instrument developed for the German HALO aircraft. It provides stereo imaging of individual cloud particles and the simultaneous measurement of the polar scattering function of the same particle. PHIPS uses an automated particle event triggering system that ensures that only those particles are captured which are located in the field of view - depth of field volume of the microscope unit. Structural details like hollow crystals, crystals with inclusions, and crystals with stepped surfaces could be resolved by PHIPS. It enables habit classification and information on particle orientation. It has been operated on the HALO and NCAR G-V aircraft. It will only be flown in the 2020 flights due to its availability. This probe is a collaborative effort (see section 13.2).

P-3 Payload Communications

At least one mission scientist will fly with the P-3 to provide directions to in-flight crew, particularly in the event of a lost link between the P-3 and the aircraft coordinator (AC) on the ground. The on-board mission scientist will communicate with team members at the MOC via X-Chat, and Inmarsat will provide a low data rate, basic toolset for the mission scientist on the P-3. The AC (Jan Nystrom) will provide flight changes to the P-3 pilots as necessary.

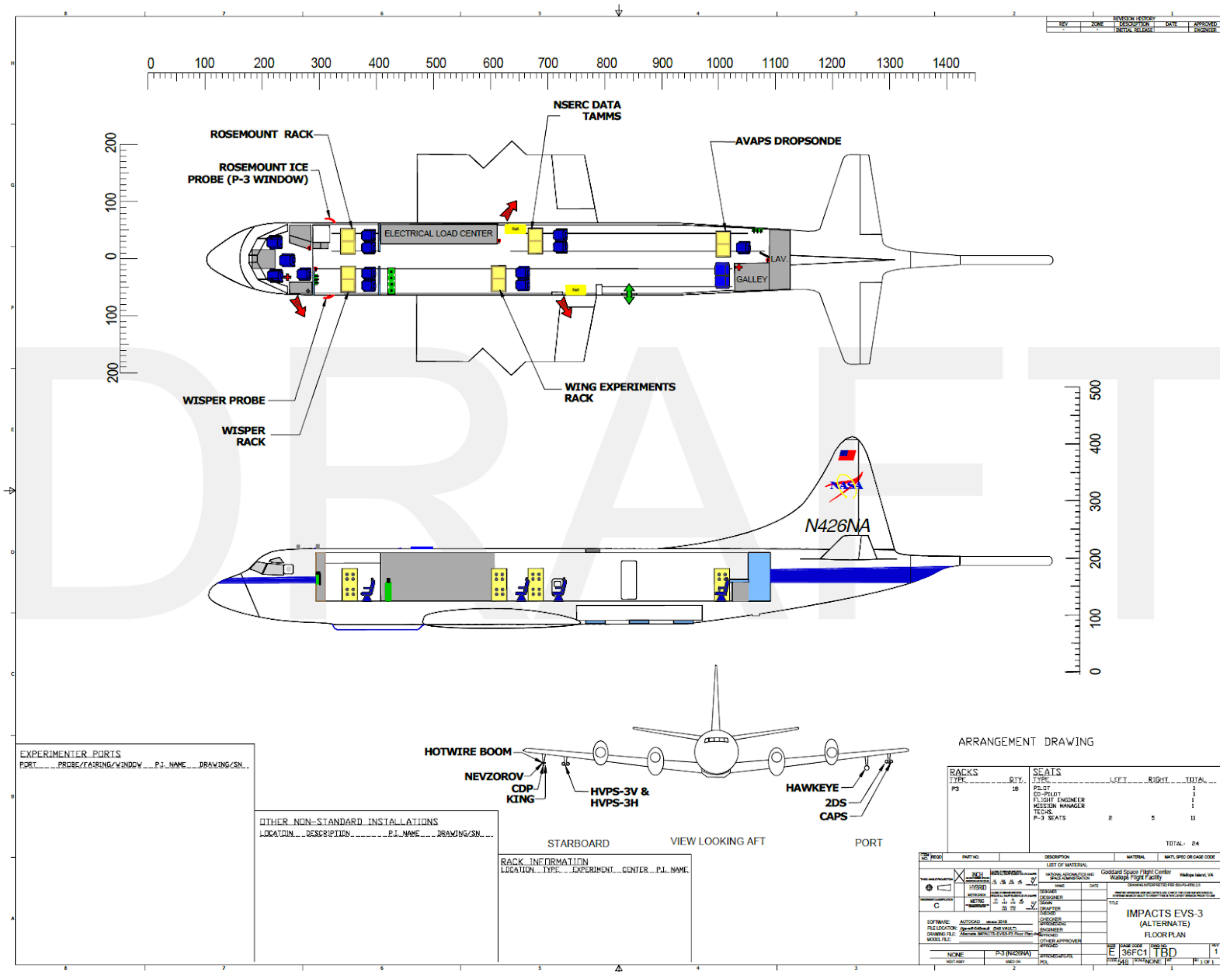


Figure 3.4: P-3 Payload Floor Plan & Wing-Mounted Probes .

P-3 instrument locations are shown in Figure 3.3 and 3.4 and the Wallops estimates for weight and margin are provided in Table 3.2. The P-3 will have plenty of margin with the IMPACTS payload.

3.2.2 ER-2 System

The ER-2 will carry a suite of radars, microwave radiometers, and a lidar (Figure 3.3 and Table 3.3). CoSMIR and AMPR together provide the range of frequencies spanning GPM microwave imager (GMI) measurements. These together will be used to document snowband horizontal structure as well as provide horizontal context for the vertical profiling and narrow swath radar measurements. The range of radar frequencies spans high sensitivity wavelengths (W- and Ka-band), as well as wavelengths with relative insensitivity to attenuation in heavy snowfall (Ku-band) and rainfall (X-band). Nadir profiling with W-, Ka-, and Ku-band radars provides high horizontal- and vertical-resolution profiles of reflectivity and Doppler velocity for multifrequency radar and combined radar-radiometer retrievals of snow particle characteristics, as well as vertical motion determination to assess the dynamics associated with snowbands and generating cells. The conically scanning X-band radar allows retrieval of 3D horizontal and vertical motions in a swath surrounding the nadir curtains to examine snowband dynamics. The lidar provides the highest possible sensitivity for thin clouds and enables detection of supercooled liquid water in generating cells near cloud tops.

For IMPACTS, ER-2 flights will be up to 8 hours in duration, similar to the 2015 OLYMPEX/RADEX campaign. Instruments are prepared and installed for flight prior to a 2-hour 'hands off' period before takeoff. ER-2 pilots are limited to a 12-hour duty day, with 12 hours minimum between duty periods. An 8-hour flight with crews reporting three hours before takeoff can approach the crew limit with weather delays. For this reason good planning for flight days is needed – efficient preparation enables 8-hour flights on consecutive days (with takeoff stagger), if conditions dictate. In general, IMPACTS may fly two 8-hour flights on consecutive days for a storm event and then stand down until the next storm event.

Table 3.3: The IMPACTS ER-2 payload weight, and size constraints, accommodation and performance specifications.

Instrument	Total Mass (lbs)	Total Volume (ft)	Power (Avg/Peak)		Provider/ Organization	Sensor/Probe Payload Area
			DC (W)	AC (W)		
Remote Sensing Aircraft (ER-2)						
CRS	200	9.5	420/560	1750/230	Li/GSFC	Aft superpod
HIWRAP	256	6	760/1000	460/600	Li/GSFC	Midbody superpod
EXRAD	217	5	560/720	920/1500	Li/GSFC	Nose
CosMIR	194	8.7	420/500	N/A	Kroodsma/GSFC	Forward superpod
AMPR	264	2.6	140/400	200/550	Lang/MSFC	Q-bay
CPL	227	5.3	700/980	230/230	McGill/GSFC	Forward superpod
Total Instr.	**1358**	**37.1**	**3000/3440**	**1985/2880**		
Capacity	**2600**		**10,000**	**30,000**		
Margin	**52.5%**		**72%**	**99%**		

Margin = [Aircraft Capability - (Payload Current Best Estimate) (1 + Uncertainty)]/Aircraft Capability. Uncertainty = 10%

3.2.3 ER-2 Aircraft Remote Sensing Instruments

The ER-2 payload (Table 3.3) consists of mature instruments with high TRL that have flown in numerous field campaigns and readily meet IMPACTS science requirements (Section 2.0). None of these instruments require modification for IMPACTS. All of the instruments have previously flown in numerous field campaigns and on different aircraft in addition to the ER-2 (Table 3.5).

Advanced Microwave Precipitation Radiometer (AMPR): AMPR is a downward looking, 8-channel, multi-frequency, cross-track scanning microwave instrument that measures the polarimetric brightness temperatures of geophysical phenomena like clouds and precipitation, as well as the land and ocean surfaces [e.g., Battaglia et al., 2016; Leppert and Cecil, 2015]. AMPR scans a 90° field of view centered on aircraft nadir using a rotating splash plate. The instrument polarization basis rotates with respect to that of the scene as a function of scan angle. The recent ability to deconvolve the pure vertical (V) and pure horizontal (H) brightness temperatures in a scene enabled development of improved passive microwave retrievals of cloud, precipitation, and ocean wind properties.

Cloud Physics Lidar (CPL): CPL is a multi-wavelength elastic backscatter lidar that enables a comprehensive analysis of radiative and optical properties of clouds and aerosols [McGill et al., 2002]. CPL data have been used for cloud properties analysis [McGill et al., 2003; McGill et al., 2004] and validation of satellite retrievals [McGill et al., 2007; Hlavka et al., 2012]. CPL measures the total (aerosol plus Rayleigh) attenuated backscatter as a function of altitude at each wavelength. Additional cloud and aerosol properties include the particle depolarization ratio for phase discrimination, lidar ratio, extinction coefficient, optical depth, and backscatter color ratio. Final CPL data product accuracy depends upon the number of laser pulses averaged and the aerosol loading of the atmosphere. Data products are provided as 1-second averages, corresponding to ~200-m (30-m) horizontal (vertical) resolution.

Cloud Radar System (CRS): CRS is a W-band Doppler radar that provides highly sensitive nadir-pointing measurements of reflectivity and Doppler velocity from clouds and light precipitation [Li et al., 2005]. It has been used for science process studies, multi-frequency algorithm development (GPM, ACE, CaPPM) [e.g., Battaglia et al., 2016], and CloudSat calibration using the ocean normalized radar cross section (NRCS) [Li et al., 2005]. CRS measures the backscattered power, Doppler velocity, spectral width, and linear depolarization ratio (LDR) from precipitation and clouds. The Doppler information provides air vertical velocity with a particle fall speed assumption. The current CRS utilizes a solid state transmitter and pulse compression for improved reliability and performance.

Conical Scanning Millimeter-wave Imaging Radiometer (CoSMIR): CoSMIR is an airborne, 9-channel millimeter-wave total-power radiometer originally developed for calibration/validation of the Special Sensor Microwave Imager/Sounder, a conical scanning radiometer for the Defense Meteorological Satellite Project F-series satellites [Wang et al., 2007]. All CoSMIR receivers and radiometer electronics are housed in a small cylindrical scan head that is rotated by a two-axis gimbaled mechanism capable of generating a wide variety of scan profiles. Radiometric signals from each channel are sampled at 0.01 sec intervals. These signals and housekeeping data are fed to the main computer in an external electronics box.

ER-2 X-Band Doppler Radar (EXRAD): EXRAD is a high sensitivity X-band Doppler radar with fixed nadir and conical/cross-track scanning beams that first flew in 2012. It measures 3D cloud/precipitation structure, horizontal wind vectors, and ocean surface winds through scatterometry. EXRAD's low frequency provides greater penetration than IMPACTS' higher-frequency radars. The conical-scanning beam with variable elevation angle is nominally tilted ~30° off nadir, providing a ~25-km wide swath on the surface. The nadir beam provides a high-resolution nadir curtain similar to its highly successful predecessor, ER-2 Doppler Radar (EDOP) [Heymsfield et al., 1996], while the conical-scanning beam is used for horizontal wind retrievals and to provide reflectivity structure over the swath. EXRAD is a conventional high-power radar employing advanced digital signal processing. Real-time data will be provided from the nadir beam during flight.

High-altitude Imaging Wind and Rain Airborne Profiler (HIWRAP): HIWRAP is a dual-frequency (Ku- and Ka-band), dual-beam (30° and 40° incidence angles), conically scanning radar originally designed for the Global Hawk platform, first flown in 2010, and reconfigured in 2011 for nadir-only operation in an ER-2 superpod during MC3E [Li et al., 2016, Heymsfield et al., 2013]. It has been used for hurricane and convection studies, and most recently for winter storms during OLYMPEX [Houze et al., 2017]. The ER-2 configuration measures reflectivity, Doppler velocity, spectral width, and LDR using a single lens-type antenna. HIWRAP uses solid state transmitters and pulse compression.

ER-2 Margins (weight, volume, power): The IMPACTS science instruments payload (Table 3.2.1-1) of HIWRAP, CRS, EXRAD, CosMIR, and CPL have all flown in their ER-2 zones in the past and meet all location-specific mass/volume/power limitations. The payload has similarities to what flew in both IPHEx (2014) and OLYMPEX (2015). During IPHEx, CRS and CoSMIR flew in the right superpod, and HIWRAP flew in the left superpod; CPL did not fly during IPHEx. For OLYMPEX, CRS and HIWRAP flew in the left superpod and CPL flew in the right superpod. For IMPACTS, CRS and CPL will fly in the right superpod, and CoSMIR and HIWRAP will fly in the left superpod. This latter change will necessitate adjusting the positions of a few of the HIWRAP boxes. EXRAD will use a new scan motor that is heavier than the previous one. Weight/ balance and moment arm analysis by the ER-2 payload engineer is in process. A structural analysis is currently underway for EXRAD since it has flown before but there was never a formal structural analysis performed on this radar nose built in 1970.

ER-2 Payload Communications: Most ER-2 instruments (CPL, AMPR, HIWRAP, CRS, and EXRAD) have used lower data rate Iridium to transfer housekeeping data and limited science data to the ground in real-time. Several ER-2 instruments (CPL, AMPR, CRS) have also used higher data rate Inmarsat to downlink instrument data for "quick looks". CPL, EXRAD, and HIWRAP have downlinked data over Inmarsat on the Global Hawk. For IMPACTS, all the ER-2 instruments including CoSMIR will be capable of sending real-time instrument status and data for quick look displays generated on the ground, and then displayed in NASA Mission Tools Suite (MTS) (https://mts.nasa.gov), developed by the NASA Ames Exploration Technology Directorate. Appropriate funds have been budgeted for Inmarsat for providing a minimum level of data from instruments.

3.2.4 Instrument Development Approach and Technical Readiness Level

Maturity and heritage information for the IMPACTS P-3 and ER-2 instruments are shown in Tables 3.4 and 3.5 respectively. All ER-2 instruments have flown previously, are TRL 9 and do not require integration development. The IMPACTS ER-2 instruments have flown together in previous campaigns and there are no known weight, balance, or power issues. Instrument installations for the ER-2 and P-3 will occur at the aircrafts' home facilities.

The P-3 wing probes have all flown previously on either the NASA P-3 (WISPER, King, 2D-S, HVPS-3) or on other aircraft; they are all high TRL (8 or 9). AVAPS has been installed and tested on the P-3 in preparation for CAMP2Ex, and Hawkeye will be installed and test flown in July 2019 also for CAMP2Ex. One difference for AVAPS/dropsondes during IMPACTS is that the NCAR mini-dropsonde used on the Global Hawk during HS3 and SHOUT will be used instead of the Vaisala RD-43 dropsonde for CAMP2Ex. The mini-dropsonde has slightly better performance than the RD-43 and it is smaller and lighter; both dropsonde types were successfully tested on the P-3. Two "extended" wing pylons will be flown during CAMP2Ex and also for IMPACTS for possibly better particle sampling performance; only one of the extended pylons was flown during ORACLES. A new installation is in progress for a "hot-wire boom", a custom pylon loaned from NASA GRC that was originally designed for hot-wire probes but in IMPACTS it will carry the Nevzorov, CDP, and King probes (Figure 3.3). It has its own wind speed transducer to improve liquid and ice measurement accuracy. The RICE probe will be mounted on the right P-3 fuselage window and WISPER will install on the left window. If there are any issues with installing the GRC hot-wire boom, the Nevzorov would be moved to a P-3 window, and the King and CDP would remain in separate Particle Measuring Systems (PMS) canisters on the wing.

PHIPS was added to the payload (only for 2020 deployment) after proposal selection and it has flown previously on the NCAR G-V and HALO aircraft. It installs in a standard P-3 PMS canister. The second HVPS-3 and the RICE probe are newly purchased from their manufacturers, and they are copies of existing probes. Based on discussions with WFF, payload power, weight, and size are not an issue; new wiring harnesses are in progress to accommodate the IMPACTS wing probes.

Table 3.4: Maturity and heritage of IMPACTS P-3 instruments.

Instrument	Measurement Requirements	Source	TRL	Key Aspects	Prior Campaigns
AVAPS	Vertical profiling	NCAR	8	Over ocean only	2, 3, 4, 5, 6, 7, 8
Microphysics Probes except Hawkeye and PHIPS	*In-situ* cloud & precipitation particle characteristics	UND, OSU	8/9	Wing mounted, fuselage mounted, fast response, high time resolution	1, 4, 6, 7, 9, 10, 16
Hawkeye	*Cloud particle characteristics*	GSFC	8	Wing mounted	17, 18, 19, 20
PHIPS	*Cloud particle characteristics*	KIT	8	Wing mounted	21, 22, 23, 24, 25
TAMMS	*In-situ* T, p, RH, 3-D winds	LaRC	9	Fast response, high time resolution	11, 12, 13, 14, 15, 16
Key: 1 GCPEX, 2 GRIP, 3 HS3, 4 OLYMPEX, 5 EPOCH, 6 CAMEX-3, 7 CAMEX-4, 8 SHOUT, 9 IPHEX, 10, MC3E, 11 ABLE 3A, 12 ABLE 3B, 13 PEM Tropics A, 14 PEM Tropics B, 15 TRACE-P/ACE-Asia, 16 ORACLES, 17 ATTREX, 18 SPEC Lear Flights, 19 Ice-T, 20 SEAC4RS, 21 ARISTO 2016 (NSF C130), 22 ARISTO 2017 (NSF GV), 23, ACLOUD 2017 (DC3), 24 SOCRATES (NSF GV), 25 CapeEx2019 (UND, Citation II)					

Table 3.5: Maturity and heritage of IMPACTS ER-2 instruments

Instrument	Measurement Frequencies	Source	TRL	Key Aspects	Prior Campaigns	Satellite References
AMPR	10.7, 19.35, 37.1, 85.5 GHz	MSFC	9	Cross-track Scan	2, 5, 6, 9, 10, 11	TRMM, GPM
CosMIR	50.3 (H), 52.6 (H), 89 (H & V), 165.5 (H & V), 183.3±1, 183.3±3, and 183.3±7 GHz (183 all H)	GSFC	9	Cross-track Scan	1, 2, 6, 12	SSMIS, TRMM GPM
CPL	Lidar backscatter at 355, 532, 1064 nm, depolarization	GSFC	9	Nadir, depolarization ratio	4, 5, 6, 7, 13	Calipso, CATS
CRS	94 GHz co/cross-pol. reflectivity and Doppler	GSFC	9	Nadir, LDR	2, 5, 6, 7, 12	CloudSat
EXRAD	9.6 GHz co-pol reflectivity and Doppler	GSFC	9	Nadir & Conical Scan	2, 5, 6, 8	
HIWRAP	35.5/13.5 GHz co/cross-pol. reflectivity and Doppler	GSFC	9	Nadir, LDR	2, 3, 4, 5, 6,12	TRMM, GPM
Key: 1 GCPEX, 2 IPHEX, 3 GRIP, 4 HS3, 5 RADEX, 6 OLYMPEX, 7 GLM Cal/val, 8 EPOCH, 9 CAMEX-3, 10 CAMEX-4, 11 TCSP, 12 MC3E, 13 ATTREX						

Aircraft-supplied navigation data: The navigation data meets the requirements of the instruments. All ER-2 and P-3 instruments capture navigation and time code information provided at 1 Hz from the aircraft in Interagency Working Group (IWG1) format (Webster and Freudinger, https://www.eol.ucar.edu/raf/Software/iwgadts/33_ISRSE_IWGADTS.pdf). This IWG1 data has standard Global Positioning System (GPS) location accuracy of ~4 meters. In addition, EXRAD, HIWRAP, and CRS on the ER-2 and TAMMS on the P-3 have their own dedicated inertial navigation systems that produce higher data rates and accuracy than the aircraft-provided data. The ER-2 radar navigation systems are capable of 5-cm accuracy with post-processing after a flight.

3.2.5 Ground Measurements

SBU Fixed Radar Site: IMPACTS will take advantage of an existing, well-instrumented ground site at SBU (https://you.stonybrook.edu/radar/). This facility includes a Ka-band (35 GHz) scanning polarimetric radar, two profiling radars operating at W band (94 GHz) and Ku band (14 GHz), a profiling microwave radiometer that provides measurements of integrated water vapor and liquid water path, a scanning Doppler lidar that provides information about the heights of supercooled liquid water layers and kinematic measurements (i.e., vertical air motion, horizontal wind profile), and a ceilometer. Measurements from a Parsivel disdrometer and a Multi-Angle Snow Camera are also available. The SBU radar facility is ideally situated 21 km away from the S-band KOKX WSR-88D radar in Upton, NY, which provides large-scale context for the precipitation events and polarimetric information over the site.

SBU Mobile Truck Facility: Stony Brook has a mobile weather truck that will be deployed to locations determined by mission scientists preferably across Long Island from New York City to Montauk along the south or north Shore. If road safety permits and with enough forecast warning, it can also operate from New Jersey, Connecticut and Massachusetts. This truck will act as a platform to launch rawinsondes, will provide continuous profiling observations of clouds and precipitation using radar and lidar, will provide surface observations from a meteorological station and a Parsivel 2 Disdrometer, and conduct volumetric scans with a dual-polarization phased array radar. The mobile sounding system uses graw radiosondes (http://www.graw.de/products/radio-sondes/dfm-09/). The portable scanning Doppler Lidar is capable of providing winds under all-weather conditions with a maximum range of 10-12 km, and the dual-polarization phased-array radar operates at X band, providing ±45° azimuth scan, 30° elevation scan, and an operational range of 40 km. The SBU ground instrument lead (Kollias) will visit potential sites for the mobile remote sensing facilities for initial set up, as well as identify any specific hazards associated with ground operations. Based upon this hazard assessment, daily work plans and/or training sessions will be developed to mitigate any hazards. Mobile rawinsondes can be deployed on short notice (within 2 days) from most locations with minimal hazard risk. Training will be provided by SBU and UIUC for rawinsonde operators.

University of Illinois Mobile Rawinsonde Unit: The University of Illinois will deploy a mobile rawinsonde unit and it will also be placed strategically prior to the onset of an event, and launch sondes every 3 hours throughout the event. The rawinsonde system is manufactured by International Met Systems (iMet) and is capable of measurements to well above the tropopause within 45-60 min after launch. A laptop computer is used to process the radiosonde data in real time. Although the iMet system offers data quality control (QC) during initial processing, additional QC is performed at the completion of each field campaign.

New York (NY) State Mesonet: NY maintains a mesonet of 126 surface weather stations (standard meteorological variables plus snow depth), and 17 sites with profiling lidars (up to 3 km) and microwave radiometers (temperature, humidity up to 10 km). In addition, 20 sites provide snow water equivalent measurements. Data will be made available to IMPACTS through a procurement with State University of NY at Albany, which has responsibility for the mesonet.

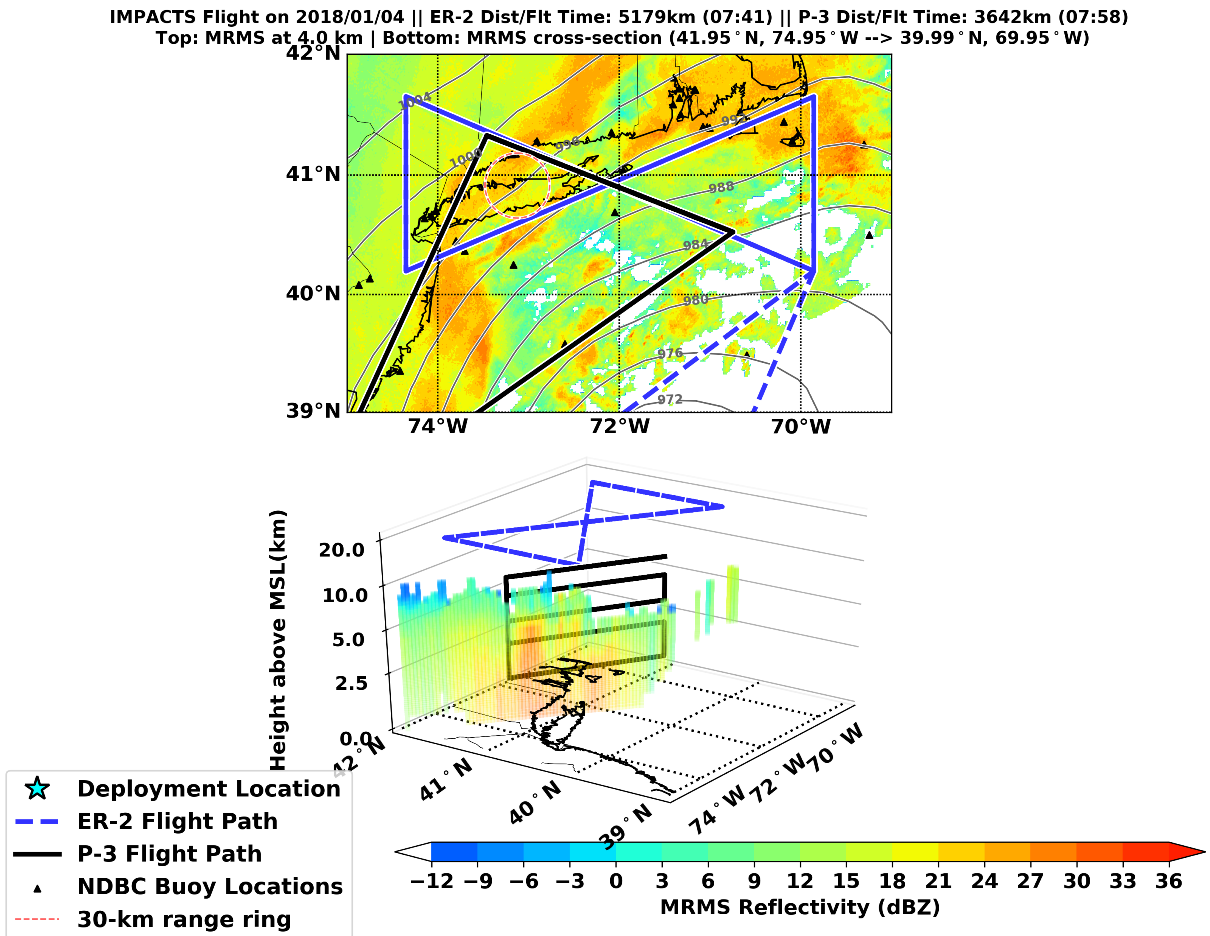
3.3 Flight Planning

Routine Flight Plans: IMPACTS uses a "playbook" of flight modules/patterns to plan each flight. These flight modules include concise descriptions of the requirements to achieve each of the IMPACTS science objectives. These requirements include the critical instruments, key observables, the observational conditions (i.e., location of storm, horizontal extent of the storm, types of clouds, winds, etc.), specific flight patterns to provide the required measurements, the duration of the flight patterns, any coordination between the aircraft or with satellite overpasses, and possible risks (i.e., air traffic, no fly zones, etc.). The purpose of the flight modules is to illustrate which objectives can reasonably be combined in a given research flight. To keep track of which science objectives were targeted and how often appropriate observational opportunities were present in prior flights, IMPACTS uses scorecards during the field deployment. These scorecards summarize flight outcomes, facilitate flight planning for successive flights, and reflect the accumulated situational knowledge of the observational environment. The flight module and scorecard concepts were successfully used in the recent OLYMPEX and prior NASA airborne experiments, where many flight modules were developed by the IMPACTS PI and IMPACTS science team members.

The flight tracks modules/patterns are separated into four categories: (1) large-scale sampling of Northeast snowstorms to achieve mission requirements b, c and g (Table 2.2), (2) small-scale sampling of thermodynamic processes to achieve mission requirements d and f, (3) cloud microphysics sampling to achieve mission requirement e, and (4) Midwest snowstorms (all mission requirements). The two aircraft will fly in an approximately vertically stacked, coordinated pattern (Figure 3.5), with flight legs generally orthogonal to the snowband orientation and the P-3 will sample different vertical levels to capture the temperature dependence of the microphysics and the origins of the snow. Flight legs will be timed so that the aircraft are vertically aligned at the center of the legs, with increasing temporal offsets at the beginning and end (up to 5 min for 200 nmi legs). Since the cruise speed of the ER-2 is faster than that of the P-3, its flight legs will be longer to compensate for the differing air speeds. The team has discussed and agreed upon flight strategies with the P-3 pilots and will establish initial positions away from busy air corridors and work with local air traffic controllers to position at appropriate flight levels that avoid approach and departure corridors. Attaining desired flight levels may entail shifting flight tracks horizontally to avoid major air corridors, and the large lengths of snowbands allow flexibility in making such adjustments.

An example flight plan for large-scale sampling of Northeast snowstorms (category 1 above) is shown in Figure 3.5. In this example, the ER-2 (blue line) flies a large bowtie pattern across the northeast (NE) and northwest (NW) quadrants of the low-pressure system. The P-3 (solid black line) flies various altitudes along one of the lines of the ER-2 bowtie pattern. The goal of this module is to document the radar reflectivity and vertical velocity associated with the snowband structures in the NE sector of the storm near the warm front and in the NW sector of the storm associated with the comma head/occluded front. As part of the transit to the storm for any of the IMPACTS flight modules, the ER-2 can fly a straight and level leg over buoys (black triangles) in the Atlantic Ocean, under clear-sky conditions, if possible, for calibration of the AMPR, CoSMIR, CRS, EXRAD, and HIWRAP instruments.

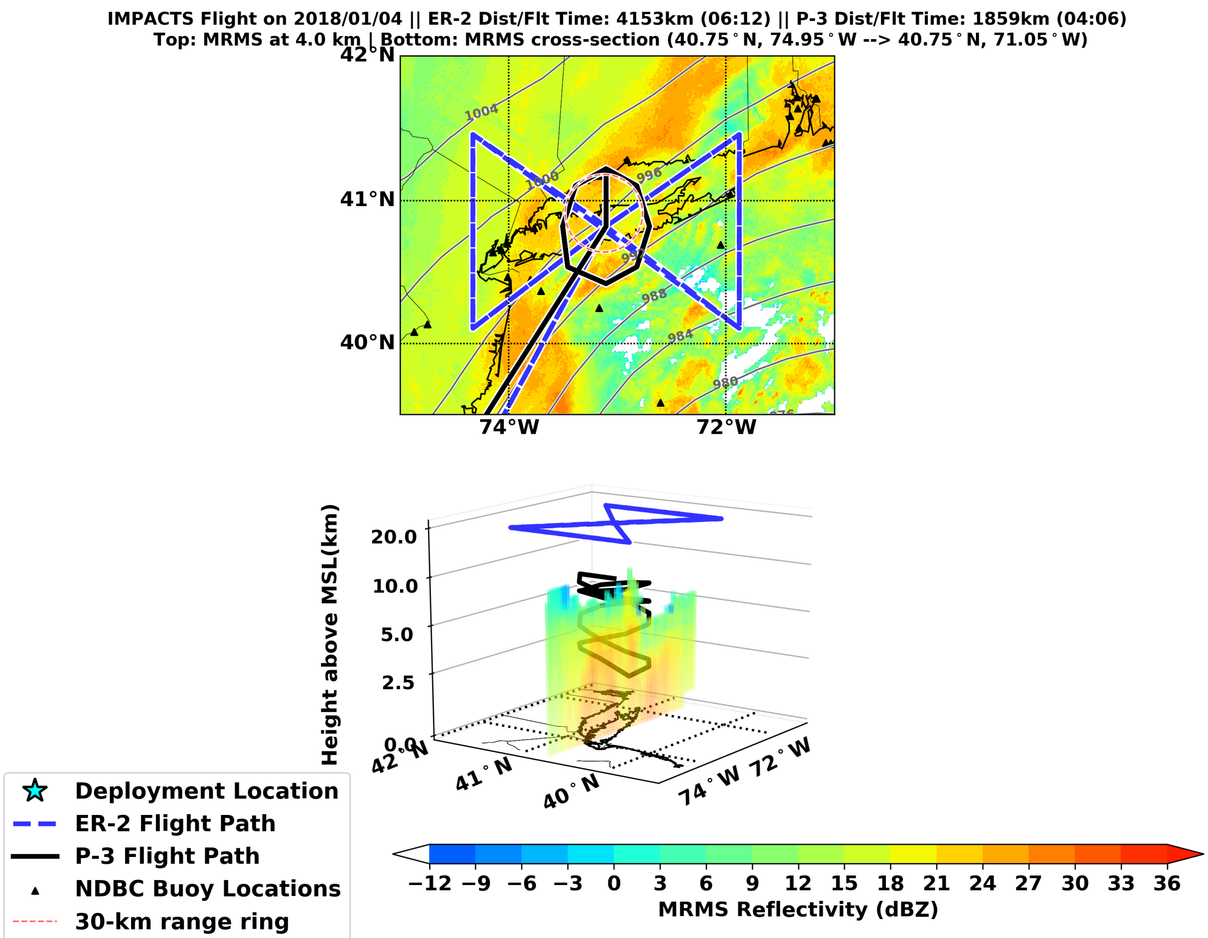
Figure 3.5: Sample IMPACTS flight plan.



Sample IMPACTS flight plan for a previous winter storm on 4 January 2018 that includes modules for investigating the area near the center of the low-pressure system, examining the NE and NW sectors of the system, and obtaining calibration data for the radars and radiometers. The storm's radar reflectivity is shown using the MRMS dataset.

A flight plan for small-scale sampling of thermodynamic processes (category 2) within Northeast snowstorms is shown in Figure 3.6. The ER-2 (blue line) flies a tight bowtie pattern in the NW sector of the low-pressure system, while the P-3 (black line) flies a spiral pattern at the center of the ER-2 bowtie. Ideally, the center of the ER-2 bowtie and P-3 spiral is a mobile rawinsonde site or NOAA rawinsonde site to provide thermodynamic profiles over land. Dropsondes will be released over the ocean from near maximum altitude, which is ~7 km at the beginning of the flight and possibly ~8.5 km at the end of the flight pattern. The goal of this flight is to determine the relationships between snow bands and the small-scale thermodynamic processes such as elevated convection.

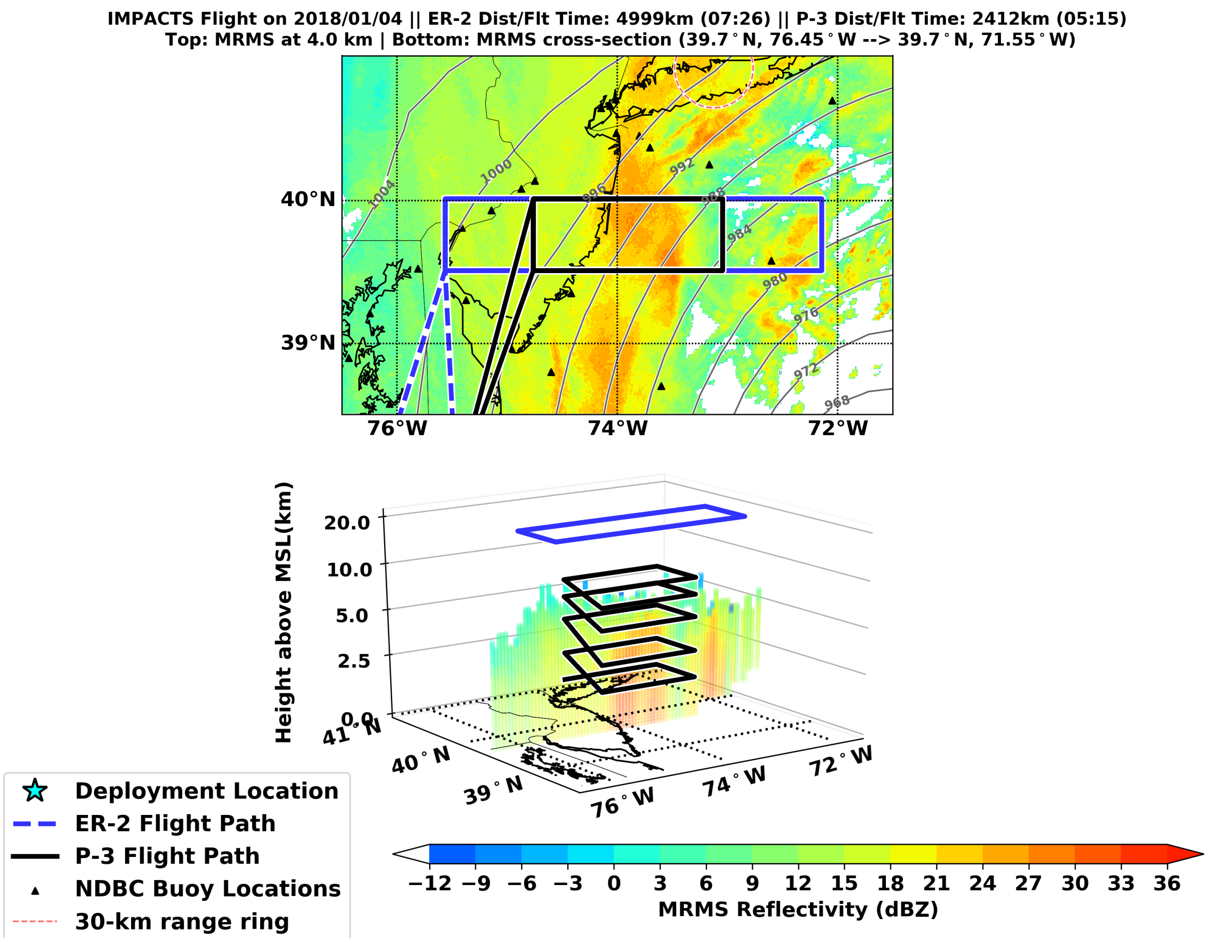
Figure 3.6: Coordinated ER-2 and P-3 Flight Patterns.



This example plan can be used to investigate the small-scale thermodynamic processes that create elevated convection.

Racetrack patterns, such as the ones shown in Figure 3.7, will be used to determine the variability of particle microphysical characteristics within winter storms and their relationships with key radar and passive microwave structures (category 3). The purpose of racetracks is to get frequently repeated measurements across an evolving band to describe band evolution and/or overfly the ground-based radar sites. The ER-2 flies at cruise altitude while the P-3 flies several vertical stacks. Growth by riming is more dependent on the size of the water drops rather than temperature, which may not require P-3 flights at specific altitudes. Ice nucleation often occurs at much colder temperatures, typically above the maximum flight altitude (7-8.5 km depending on fuel load) of the P-3, so it will not be a focus of IMPACTS. Consequently, P-3 flight levels will target altitudes (identified from NWS rawinsondes) with mean temperatures near -5, -10, -15, and -20°C, recognizing that there will be temperature gradients along these flight legs. The -5°C level may at times be below the minimum flight altitude [>~1 km during Instrument Flight Rules (IFR) conditions], while all other temperature levels are usually well below maximum flight altitude (-20°C typically below 6 km).

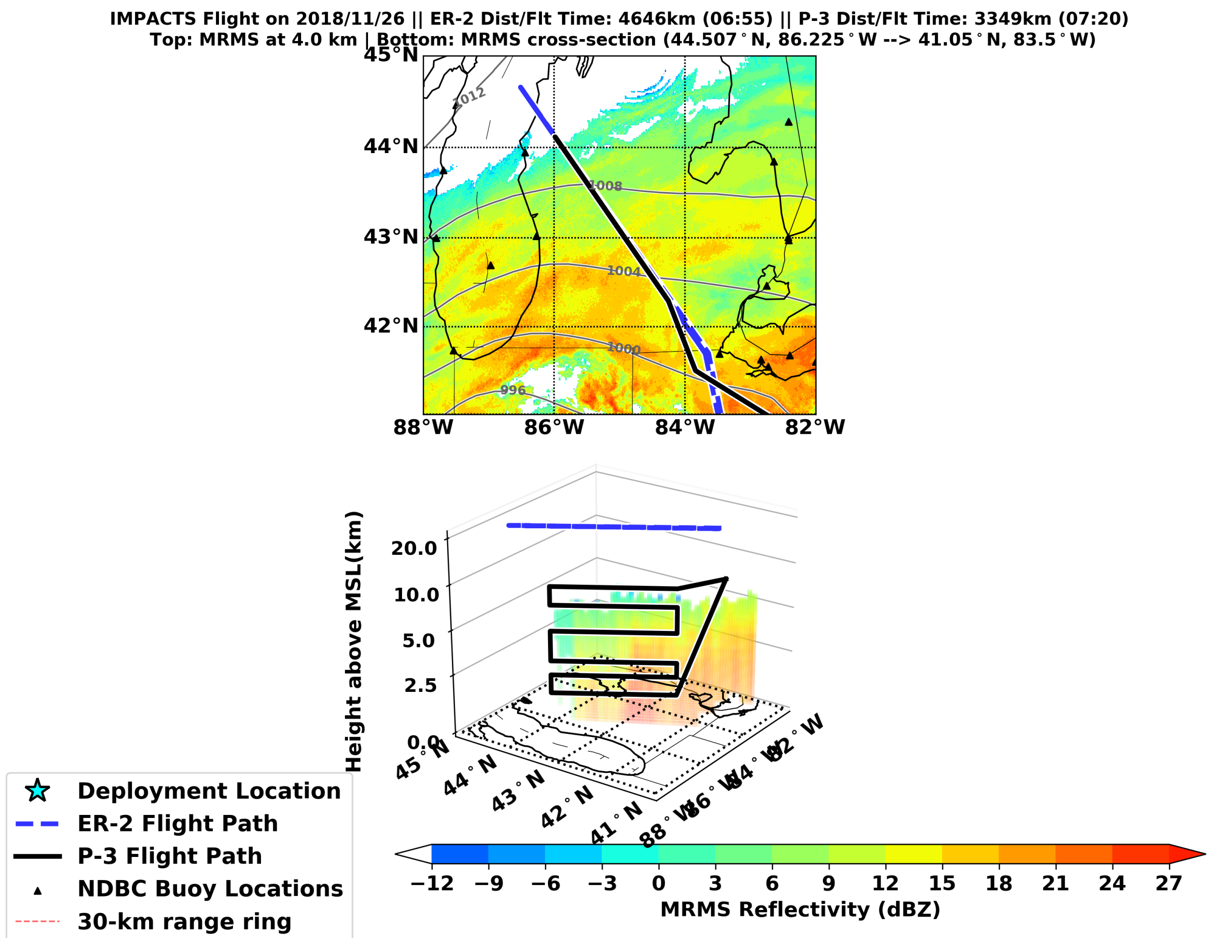
Figure 3.7: Example of a Racetrack Pattern.



To achieve the project's microphysics objectives, IMPACTS will primarily use racetrack patterns (as shown here) or straight lines to measure the evolution of snow bands and cloud microphysical properties.

The primary region of operations will be the Eastern Seaboard of the US (~35-48°N, ~80-65°W) where storms typically undergo cyclogenesis, allowing IMPACTS to sample banded structures as they initiate along the coast and over the ocean and move northward. This region averages 3-4 significant cyclones per month. In the event that the large-scale flow suppresses cyclone development over the East Coast, IMPACTS will operate in a secondary region, the US upper Midwest (~35-48°N, ~90-80°W). This region averages 2-3 significant cyclones per month. Dynamical and thermodynamical processes in baroclinic systems are nearly universal, and snowband structures in the Midwest (e.g., Grim et al., 2007; Rauber et al. 2014) are generally similar to those in the Northeast (e.g., Novak et al., 2008, 2010; Rauber et al., 2017), so that flight plans and findings in the two regions are transferable. Figure 3.8 shows an example flight plan, using a straight line pattern, in the Midwest region to relate precipitation processes to microphysical properties, vertical motions, and snowband structure.

Figure 3.8 Example Flight Pattern in the Midwest US, secondary ROI.



Aircraft Coordination: Coordination and guidance of aircraft in flight is facilitated by use of the Mission Tool Suite (MTS) that enables real-time tracking of aircraft, comparison of actually flown tracks to the original flight plans, and simultaneous visualization of geo-stationary satellite imagery, radar products, model predictions, and satellite overpass tracks for in-flight guidance of the aircraft. This guidance is performed from the ground by a team comprised of the PI, a mission scientist, a platform scientist, (a scientist who has intimate knowledge of a specific flight plan and authority to change the flight plan after take-off), and the navigator for each of the aircraft in flight. This paradigm has worked well in the recent multi-aircraft operations of the OLYMPEX and ORACLES campaigns.

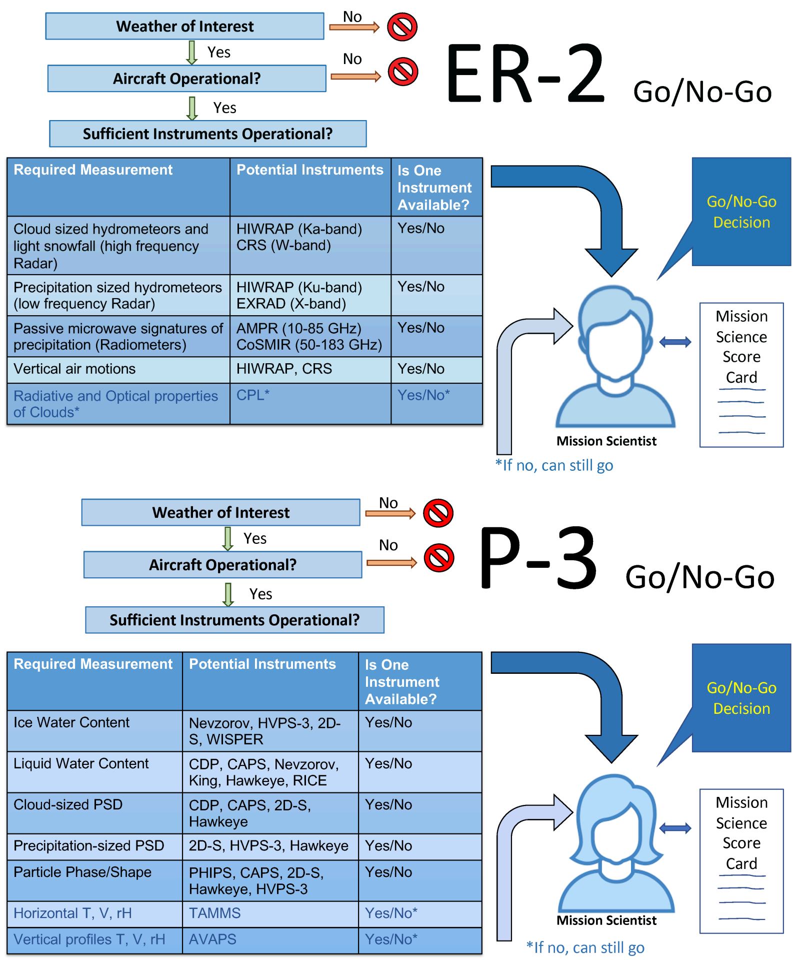
When both aircraft deploy, careful coordination of platforms is crucial to ensure safety and to gather the needed coincident and collocated data since cloud and precipitation properties can vary significantly over a few kilometers or minutes. The IMPACTS team is experienced in performing such coordination, and the Earth Science Projects Office (ESPO) at NASA Ames has facilitated such missions in dozens of campaigns. Pre-flight coordination is aided by a pre-coordinated document of all pilot contact information and aircraft communication frequencies. Mr. Jan Nystrom, former ER-2 pilot and our Aircraft Coordinator (AC), will be based at WFF in the IMPACTS Ops Center to help the Mission Scientists with coordination between the two aircraft and to communicate directly with the P-3 and ER-2 pilots during flight.

3.4 Mission Operations

The IMPACTS Mission Operations Center (MOC) will consist of an Operations Director, 4 Mission Scientists (one for each aircraft and two general roles), an Aircraft Coordinator, a Project Manager, Aircraft Mission Managers, a Ground Director, and several forecasters. On a nominal 1 flight per 2-day schedule, this staffing allows the planning of a future target of opportunity flight during a flight day. Daily briefings are conducted to review the meteorological forecasts, evaluate aircraft and instrument status, and identify targets for potential flights 48 hours in advance. To facilitate these meetings among multiple participation sites, some as much as 3 hours apart, ESPO ensures that the necessary communications equipment is in place (internet, WebEx, phones) and firewall issues are resolved to enable broadcast from the central operations site at WFF to remote participants. The daily weather briefings are provided by the forecasting team at WFF, supported remotely by weather forecasts provided by the National Weather Service and high-resolution model output created at Stony Brook University. Satellite imagery and ground-based radar imagery are shared electronically through the field catalog (see Section 8.2) or through MTS. The forecasting team provides the short- and long-term forecasts that are critical for flight planning.

At T-36 hours before takeoff, flight modules are selected to address the science goals of the next flight, as discussed in Section 3.3. A planning meeting between the Operations Director, Platform/Mission Scientists, pilots and project management is held to resolve any coordination and communication issues and to ensure flight objectives and flight plans are understood. Mission Scientists work with the aircraft pilots/management to ensure flight plans are filed with applicable aviation authorities. Mission success is further ensured by designation of a Platform Scientist for each aircraft to collect, prioritize and oversee platform-specific scientific goals. This timeline provides ample planning time for the aircraft crews and allows the science team to adjust flight plans in response to changing observational conditions up to 3 hours before takeoff. Table 3.4-1 summarizes the daily flight planning procedure.

At T-3 hours before takeoff, a Go/No-Go decision is made based on the weather of interest, aircraft status, and whether there are sufficient instruments operational to make the required measurements (see Figure 3.4-1 for a graphical representation of this decision for each aircraft). While plans for each flight are preset at T-3 hours before takeoff, real-time adjustments to aircraft altitudes and flight lines (within the predetermined airspace) can be made based on the changing weather patterns, through coordination between the Mission Scientist, Aircraft Coordinator, and FAA.



Required Measurement	Potential Instruments	Is One Instrument Available?
Cloud sized hydrometeors and light snowfall (high frequency Radar)	HIWRAP (Ka-band) CRS (W-band)	Yes/No
Precipitation sized hydrometeors (low frequency Radar)	HIWRAP (Ku-band) EXRAD (X-band)	Yes/No
Passive microwave signatures of precipitation (Radiometers)	AMPR (10-85 GHz) CoSMIR (50-183 GHz)	Yes/No
Vertical air motions	HIWRAP, CRS	Yes/No
Radiative and Optical properties of Clouds*	CPL*	Yes/No*

Required Measurement	Potential Instruments	Is One Instrument Available?
Ice Water Content	Nevzorov, HVPS-3, 2D-S, WISPER	Yes/No
Liquid Water Content	CDP, CAPS, Nevzorov, King, Hawkeye, RICE	Yes/No
Cloud-sized PSD	CDP, CAPS, 2D-S, Hawkeye	Yes/No
Precipitation-sized PSD	2D-S, HVPS-3, Hawkeye	Yes/No
Particle Phase/Shape	PHIPS, CAPS, 2D-S, Hawkeye, HVPS-3	Yes/No
Horizontal T, V, rH	TAMMS	Yes/No*
Vertical profiles T, V, rH	AVAPS	Yes/No*

Figure 3.9 Go/No-Go decision for the ER-2 and P-3 aircraft based on instrument availability. As long as one instrument is available for each required measurement, the science objectives can be met. Instruments listed in blue are not required to meet the science objectives at threshold level.

Table 3.6: IMPACTS Flight Planning Schedule Relative to Aircraft Takeoff

Time Relative to Takeoff	Action
T-48 Hours	Weather briefing and initial target identification from model output and satellite imagery
T-36 Hours	Preliminary flight plans submitted to aircraft teams
T-24 Hours	Updates to weather and target status
T-18 Hours	Modifications to flight plans submitted to aircraft teams
T-3 Hours	Final weather briefing and target update with aircraft teams; GO/NO GO decision instrument operational status update
Post-Landing	Pilot debrief; Instrument team access; Produce flight scorecards

Two potential issues arose in early proposal planning: (1) the ability of the P-3 to conduct in-storm flights in busy US air corridors, including near New York City, and (2) aircraft icing. In December 2017, the IMPACTS Deputy PIs met with the P-3 pilots (including the aviation safety officer) at WFF, who confirmed neither issue poses a significant problem for science operations. For flights over the US, keeping adequate distance from major airports allows the P-3 to establish initial flight positions from which subsequent repositioning of flight tracks can be accomplished. Given that snow- bands can be hundreds of km in length, establishing a flight line normal to the bands with sufficient distance from major airports is readily achievable. In the case of flights over the SBU site on Long Island, NY, the pilots suggested that altitude blocks can be determined that avoid arrival and departure corridors. The P-3 flight crews plan to brief the Federal Aviation Administration (FAA) months in advance to explain IMPACTS' mission goals and finalize flight procedures. The P-3 team has successfully conducted similar planning for DISCOVER-AQ.

During the IMPACTS mission, the P-3 will operate in winter storms that may periodically support supercooled liquid water and airframe icing conditions; however, based upon the pilots' extensive experience, icing is not expected to be a major issue in regions of active snowfall, as snow particles typically grow at the expense of cloud liquid water. The P-3 aircraft is an all-weather aircraft, equipped with de-icing capabilities in the wings, tail, and engines. If significant icing occurs, pilots can bring the aircraft to a level above or outside the clouds and use heaters to melt the ice, or move southward to above-freezing temperatures and then return to science operations. The NOAA P-3 has operated in similar conditions, including during West Coast winter storms for IMPROVE (2001) in which occasional icing conditions were likely exacerbated by uplift over the much steeper West Coast topography. The UND Citation and DC-8 used for OLYMPEX and GCPEX, and NSF/NCAR C-130 used for PLOWS, have safely flown in similar circumstances.

3.5 Science Team

The IMPACTS team includes experienced individuals from a wide range of institutions (Table 3.7) including multiple NASA centers (GSFC, WFF, MSFC, LaRC, AFRC, ARC), multiple universities, and NCAR. A collaboration between IMPACTS and NOAA/NWS has also been established (see letters of collaboration in Appendix B). The Science Team has a wealth of field program experience, including aircraft, logistics, instruments, and science.

Table 3.7. IMPACTS Science Leads and Co-I's, ER-2 Co-Is, P-3 Co-I's, and Collaborators.

Team Member	Institution	Role and Duties
Science Management		
Lynn McMurdie	UW	PI; Responsible to NASA for overall mission; mission direction/planning; heads UW project website; Operations Forecasting Lead
Gerald Heymsfield	GSFC	Deputy PI for Science; leads Science Team activities
John Yorks	GSFC	Deputy PI for Data; assists PI in all phases of project, including data management
Scott Braun	GSFC	Science Lead
Science Team		
Ian Adams	GSFC	Co-I; Ice scattering properties, radar multiple scattering, polarimetric forward modeling
Brian Colle	SBU	Co-I; Characterization of snowband structures and dynamics using ground & airborne data, WRF modeling, SBU mobile rawinsonde Lead
Mircea Grecu	GSFC	Co-I; Inverse methods for multi-sensor retrievals, validation with aircraft in-situ data
Stephen Guimond	GSFC	Co-I; EXRAD wind retrievals, experience from previous NASA campaigns, including HS3
Mei Han	GSFC	Co-I; Characterization of snowband structures and microphysics using ground & airborne data, WRF modeling;
Andrew Heymsfield	NCAR	Co-I; Analysis of microphysics data, diagnosis of particle growth regimes, relationships to remote sensing.
Brian Jewett	UIUC	Co-I; WRF modeling and analysis of banded structures, comparison to observations; with Co-I Rauber
Matthew Kumjian	PSU	Co-I; Analysis of data impacts on banded structures in WRF mesoscale analyses
Greg McFarquhar	OU	Co-I; Cloud microphysics analysis and integration with UIUC analysis
Stephen Munchak	GSFC	Co-I; Particle type and cloud liquid water retrievals, surface forward models
David Novak	NOAA/NWS	Collaborator; facilitate access to NOAA data and provide an interface between IMPACTS and operational community
Robert Rauber	UIUC	Co-I; Analysis of relationship between radar-observed banded structures and in-situ cloud microphysics, UIUC Mobile Rawinsonde Lead
Jeff Waldstreicher	NOAA/NWS	Collaborator; interface with local NWS forecasters, coordination of real-time soundings, facilitate seamless exchange of NOAA data
Sandra Yuter	NCSU	Co-I; Analysis of ground & airborne remote sensing and in-situ microphysics, relationship of measurements to dynamical causes of bands

MaMatthew R Kumjian	PSU	Co-I; WRF modeling, data assimilation, simultaneous state and parameter estimation.
Instruments Leads		
Gerald Heymsfield	GSFC	Co-I; EXRAD Instrument Lead
Rachel Kroodsma	GSFC	Co-I; CosMIR Instrument Lead (GPM Project Scientist)
Timothy Lang	MSFC	Co-I; AMPR Instrument Lead
Pavlos Kollias	SBU	Co-I; SBU ground instrument facility lead
Lihua Li	GSFC	Co-I; HIWRAP Instrument Lead
Mathew McGill	GSFC	Co-I; CPL Instrument Lead
Matthew McLinden	GSFC	Co-I; CRS Instrument Lead
David Noone	OSU	Co-I; WISPER Instrument Lead
Michael Poellot	UND	Co-I; Microphysics Probes Lead
Lee Thornhill	LaRC	Co-I; TAMMS Instrument Lead and AVAPS Instrument Lead
Collaborators not funded through IMPACTS		
Vijay Tallapragada	NOAA/NCEP	Coordination with NOAA Winter Storms Program
Peter Black	I.M. Systems	Coordination with NOAA Winter Storms Program
Martin Schnaiter	KIT	Participation in 2020 with P-3 PHIPS instrument
Christopher Schultz	MSFC	Participation with ER-2 LIP instrument
David Wolff	WFF	GPM participation with D3R transportable radar
Karen Kosiba	CSWR	Potential NSF collaboration LANGOSTINO winter storm field program

3.6 Logistics and Deployment Plans

Location: As stated earlier, the IMPACTS Mission Operations Center (MOC) will be based at NASA's Wallops Flight Facility (WFF) which in turn is the main base of operations of the NASA P-3. In the event of a snow closure at WFF, IMPACTS will use a conference room at a local hotel where team members stay as a temporary operations center. IMPACTS experiment requirements dictate the deployment of about 15-20 (mission scientists, forecasters, and instrument support) people to WFF.

The NASA ER-2 aircraft will be based at Hunter AAF in the first deployment in January-February 2020, and Warner Robins in the second and third deployments January-February 2021-2022. We expect up to 10 instruments scientists and up to 10 ER-2 crew members that will support the aircraft during the field phases.

Communications during IMPACTS deployments will follow the successful model of OLYMPEX and other NASA campaigns (e.g., GOES-R validation, IPHEx, MC3E). The MOC at WFF will serve as the center of flight operations. Mission scientists at the MOC will communicate flight changes from the field and the pre-flight plan to the air crews through the Aircraft Coordinator (Jan Nystrom). The mission coordinator typically receives input on desired flight changes from the mission scientists, provides feedback to the scientists about the changes, and then communicates the finalized flight changes directly to the ER-2 pilot and the P-3 flight crew. The flights will be monitored by the mission scientists and mission coordinator using the mission tools suite (MTS), which overlays flight tracks on a variety of satellite, radar and numerical forecast products, displays real-time aircraft datasets, and provides tools for communications (X-Chat), team collaboration, flight planning, file sharing, and documentation. Appropriate funds have been budgeted for downlinking ER-2 and P-3 instrument data. At least one mission scientist will fly with the P-3 to provide directions to in-flight crew, particularly in the event of a lost link between the P-3 and mission coordinator. The on-board mission scientist will communicate with team members at the MOC via X-Chat, and Inmarsat will provide a low data rate, basic toolset for the mission scientist on the P-3.

Staffing: The planned flight tempo will depend on suitable snow storms to meet the science objectives but will average about two flights per week with a total of 10-12 flights with durations of six to eight hours for each aircraft. The likelihood is that there will be flights on a few successive days for a given storm system, and generally at daytime. These are long shifts for the pilot, science and instrument teams, but multiple shifts are not required. IMPACTS personnel at Wallops will stay either on site at NASA lodging, at the Navy lodging nearby, or at hotels in Chincoteague, Virginia. Scientists supporting the MOC will be encouraged to stay at a specific local hotel. In the event of a snow closure at WFF, IMPACTS will use a conference room at the local hotel where team members stay as a temporary operations center.

Transport of Equipment and Supplies: Each instrument team is responsible for shipping their instrument and ancillary equipment to the integration site (AFRC and/or WFF) and back to their institution. ESPO arranges transportation of ER-2 and ER-2 PI equipment to Hunter AAF or WR. For the P-3, the AM determines who and what travels to a temporary P-3 location in the event of significant snow at WFF.

Communications: ESPO uses email listserves to communicate with the project team via email as necessary; white/message boards as well as cellphone apps like (WhatsApp or text) are used as needed. Both aircraft teams hold twice-daily meetings during deployment to assess status and to set plans for the current day and the following days. General deployment plans will be made out to five days ahead. ESPO works with the AMs to ensure aircraft status/plans are disseminated to instrument teams frequently and fully and ensures instrument needs are voiced during aircraft planning discussions. ESPO communicates frequently during deployment to keep team members as current as possible, and keep NASA management up to date. Some of the team members will be located remotely such as the MTS lead, the Data Manager lead, and sometimes mission scientists and forecasters. ESPO compiles and disseminates a communications plan to ensure that all pertinent flight crews have contact info for one another, before, during and after deployment.

Dry Run: ESPO institutes a ‘dry run’ activity for IMPACTS, similar to those in ESPO’s recent missions. The first IMPACTS dry run is scheduled to take place in October 2019 in preparation of the 2020 deployment. Mission and platform scientists, pilots, modelers and forecasters will meet by phone and WebEx to simulate forecasting activities expected during operations. Since October is too early to expect snow events, we will use specific case studies as if they were occurring in real time during the dry run activity. The forecaster will prepare a mock briefing which will include ‘current’ conditions based on observations, radar and satellite imagery, and model forecasts out to two to three days for the event. The mission science team will then discuss possible flight plans, timing of potential flights and discuss uncertainties for the event. Several case studies will be used to bracket a range of possible types of storms that we expect to experience while in the field. The process familiarizes the science staff with items that impact real flight planning – the regional meteorology at the deployment time of year, aircraft limitations, staff fatigue limits (8th day down, crew rest, etc.), FAA coordination time lines, etc. Experience shows this practice time makes actual deployments more efficient.

Integration & Test: Instruments are first weighed to ensure their configuration has not changed, and then are mechanically integrated and connected to electrical and communications interfaces. Aircraft weight and balance are confirmed. Communications testing proceeds first in the hangar, then an outdoor systems test is conducted to ensure payloads and aircraft systems operate nominally. The instrument engineers are responsible for each instrument/aircraft interface and instrument flight safety. AFRC and WFF Airworthiness and Flight Safety Review Boards (AFSRB), each hold a flight or operational readiness review (FRR/ORR) to examine their respective payload arrangement and mission plans prior to flight. Test flights are currently scheduled to take place in December 2019, 2020, 2021 for the P-3 and ER-2. The ER-2 typically flies a short engineering check flight followed by a range flight; P-3 flies a similar pair of flights. Test flights involving first-time payloads or payload combinations are extremely valuable in that they reveal aircraft and payload peculiarities. These operational flights clear the instruments for science flights. After test flights begin, the IMPACTS team conducts a Mission Readiness Review (MRR) for NASA Headquarters (HQ) sponsors. Following a successful MRR, the ER-2 will deploy to Hunter AAF in January 2020 that will have been prepared in advance by ESPO. Site survey visits were completed for the ER-2 for Hunter AAF in June 2019.

4.0 Management Approach

4.1 Management Structure

The Science Team has a wealth of field program experience, including aircraft, logistics, instruments, and science. The IMPACTS management structure (Figure 4.1) will operate in accordance with NPR 7120.8 and provide for project coordination and leadership.

Specific responsibilities of the project leadership team are described below.

The **Principal Investigator (PI: Lynn McMurdie, University of Washington)** has authority over all IMPACTS aspects (mission definition science goals and implementation and key decisions). The PI has decision authority over all financial decision regarding the project. The PI will also assume the role of Operations Director during deployment. In this role, the PI will oversee all aspects of operations, lead planning discussions with mission and aircraft scientists for operations and ensure science objectives are upheld in all operational decisions, and write daily science summaries.

The **Deputy Principal Investigators (DPI: Gerald Heymsfield, NASA Goddard Space Flight Center, DPI: John Yorks, NASA Goddard Space Flight Center)** supports the PI in all aspects of mission development, implementation and reporting. The DPIs fill in for the PI when the latter is unavailable. The DPIs are the primary project interface to GSFC management. The DPIs also have the responsibility to oversee data collection (**DPI-Data: J. Yorks**) and science objectives (**DPI-Science: G. Heymsfield**). The DPIs will also serve as Mission Scientists during deployment. The Mission Scientists responsibilities are to: (1) make decisions for flight operations (flight tracks, dropsondes, timing of missions, etc.) and ground operations (mobile soundings, ground radars), (2) ensure science objectives are met by the current operations plan, (3) track flights during operations and communicate to the scientists on board, and (4) communicate to the aircraft (through Jan Nystrom) any changes to the flight plans.

The **Science Lead (SL: Scott Braun, NASA Goddard Space Flight Center)** supports the PI with leadership of the IMPACTS science team, including review of mission planning and operations for achieving the science objectives, and oversight of science team data analysis and modeling activities.

The **Project Manager (PM: Vidal Salazar, NASA Ames Research Center (ARC))** also supports the PI in all aspects of mission development, implementation and reporting. He works with the PI, the ER-2 Aircraft Manager, P-3 Aircraft Manager, science leadership and all instrument teams in setting the schedule for instrument integration and deployments. He has oversight of schedule and spending plan. The PM is responsible for deployment team staffing, deployment logistics setup, teardown, communications and programmatic reporting; and facilitates facility management and flight coordination.

The **Deputy Project Manager (DPM: Katie Stern, NASA Ames Research Center)** supports the PM in implementing project activity that supports the PI's science decision and priorities. She takes the PMs Role in case the PM is unavailable for meetings, teleconferences and other activities. The DPM is heavily involved in overall mission planning.

The **ER-2 Aircraft Manager (ER-2 AM: Brian Hobbs, NASA Armstrong Flight Research Center)** is responsible for the management of the ER-2 Aircraft system to meet mission requirements. Responsibilities include planning, documentation, verification, implementation, quality assurance and safety efforts. The ER-2 AM provides direction to the ER-2 Mission Manager and ER-2 Instrument Manager. The ER-2 AM also controls the spending plan and schedule for payload integration within the baselined budget, aircraft safety concerns and schedule. The ER-2 AM is the primary project interface to AFRC management.

The **ER-2 Mission Manager (ER-2 MM: Franzesca Becker, NASA Armstrong Flight Research Center)** works closely with the ER-2 AM, PM and ER-2 Instrument Manager (ER-2 IM), overseeing aircraft operations and engineering activity, including configuration management processes and documentation to ensure aircraft system quality and mission success. The ER-2 MM is the primary aircraft interface to the PM.

The **ER-2 Instrument Manager (ER-2 IM: Tyler Latsha, NASA Armstrong Flight Research Center)** is the point of contact for instrument teams on payload engineering and integration. The ER-2 IM is responsible for instrument mechanical and electrical integration, instrument environmental testing, instrument control and communication and safety. The ER-2 IM maintains interface control documents. The ER-2 IM works with the ER-2 MM and ER-2 AM on integration and de-integration schedule and spending plan. The ER-2 IM will also provide input to the PM and ER-2 AM on all aspects of aircraft and payload safety.

The **P-3 Aircraft Manager (P-3 AM: Mike Cropper, NASA GSFC Wallops Flight Facility)** is responsible for the management of the P-3 Aircraft system to meet mission requirements. Responsibilities include planning, documentation, verification, implementation, quality assurance and safety efforts. The P-3 AM provides direction to the P-3 Mission Manager and P-3 Instrument Manager. The P-3 AM also controls the spending plan and schedule for payload integration within the baselined budget, aircraft safety concerns and schedule. The P-3 AM is the primary project interface to GSFC management for P-3 aircraft specific matters.

The **P-3 Mission Manager (P-3 MM: Kelly Griffin, NASA GSFC Wallops Flight Facility)** works closely with the P-3 AM, PM and P-3 Instrument Manager (P-3 IM), overseeing aircraft operations and engineering activity, including configuration management processes and documentation to ensure aircraft system quality and mission success. The P-3 MM is the primary aircraft interface to the PM.

The **P-3 Instrument Manager (P-3 IM: Monica Chance, NASA GSFC Wallops Flight Facility)** is the point of contact for instrument teams on payload engineering and integration. The P-3 IM is responsible for instrument mechanical and electrical integration, instrument environmental testing, instrument control and communication and safety. The P-3 IM maintains interface control documents. The P-3 IM works with the P-3 MM and P-3 AM on integration and de-integration schedule and spending plan. The P-3 IM will also provide input to the PM and P-3 AM on all aspects of aircraft and payload safety.

The **Aircraft Coordinator (AC: Jan Nystrom, BAERI)** assists in flight planning from an aircraft perspective, and is responsible for coordinating the ER-2 and P-3 during flights. The AC is the interface between the Mission scientists and the pilots and will provide desired flight changes directly to the P-3 pilots and the ER-2 ground pilot during flights.

The **Ground Operations Lead (GOL: Bob Rauber, University of Illinois Urbana)** is responsible for coordinating ground base assets (Mobile Rawinsondes, SUNY SB Radars and National Weather Service Radars) coordinating and operational activities.

The **Aircraft Mission Scientists (AMS: Dynamic role to be determined during mission deployment)** participate in decisions and flight planning before flights and ensure instruments are ready for the flight and that the flight plan is optimal for critical instruments. The P-3 Mission Scientists also flies on the P-3 during missions to be back-up mission scientist if communications with ops center goes down.

The **Data Manager (DM: Stacy Brodzik, University of Washington)** is responsible for coordinating data management efforts, data management plan and archiving of the final project data.

The **Forecasting Team Lead (FTL: Dynamic role to be determined during mission deployment)** is responsible for coordinating the forecasting activities and briefings, as well as contributing to flight planning activities.

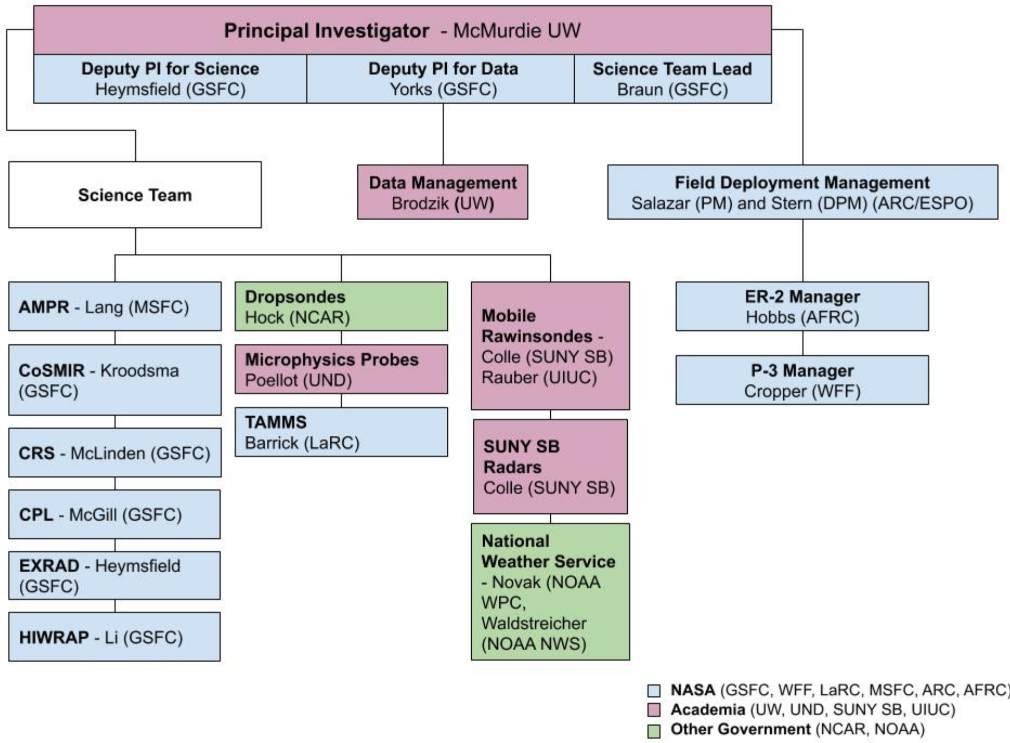


Figure 4.1: IMPACTS organizational structure depicts overall PI responsibility with focus support for platform science and data management.

4.2 Communication and Reporting

IMPACTS PI and PM maintain close communication with each other and with the IMPACTS team to provide leadership and direction, to seek input on decisions regarding project implementation, and to determine and track project milestones so the project is completed within budget and schedule. The team leadership (PI,PM, DPIs, and DPMs) communicates as a group weekly; with the program office twice monthly; and with the science team monthly. There are also monthly aircraft telecons (one for each aircraft, P-3 and ER-2) for the AM and instrument PIs. Science team meeting notes are distributed via the IMPACTS project website. The team makes liberal use of collaboration/ communication tools like meet-me lines, mailing lists, Webex, Skype, Google Documents and features of the drupal-based ESPO IMPACTS site. A face-to-face science meeting is to be held annually to discuss plans for the upcoming deployment, review/present IMPACTS science and discuss lessons learned from the prior deployment in accordance with the requirement of NPR 7120.8 (and Earth Systems Science Pathfinder Program Office (ESSPPO) programmatic guidance) for an annual science review. Additional meetings are established as needed to address specific issues.

Problems and issues are surfaced in any of the aforementioned meetings to the PI/PM or in smaller sub-group voice or electronic communications. Leadership discusses issues at least weekly and establishes focused meetings for discussion and resolution of larger issues. The PI seeks advice from the leadership team but she has final decision authority on all topics, issues, and questions concerning IMPACTS scope, implementation and spending plan.

The PI is also responsible for all documentation, but delegates generously.

The IMPACTS organization is shown in Figure 4.1. Instrument and science team member roles are described in Section 3.5.

The leadership team compiles a monthly status report for ESSPPO and delivers it on the 15th of each month. This project plan documents the baseline and threshold science requirements, technical approach, baseline spending plan and schedule for the mission, related policy/guidance for oversight of IMPACTS; and will serve as a guide for project execution and control. ESPO creates and administers a mission website for broadly applicable project details, including schedule, instrument descriptions, participants and responsibilities, logistics, science goals and results, education and public outreach, lessons learned, and more (https://espo.nasa.gov/IMPACTS).

6.0 Schedule/Milestones

IMPACTS will conduct pre-deployment activities and the Investigation Confirmation Review (ICR) prior to the operations phase. The deployment plan calls for three 6-week field deployments over a three year period. The field deployment phase can be flexible within the months of January-February, providing flexibility to accommodate unanticipated delays or facility access conflicts. Minor adjustments in start and end dates of deployments are also possible without impacting science objectives. If necessary, one deployment could be moved to year five, although completion of all deployments in years two, three, and four is preferred.

The flight planning team will carry out a flight planning exercise (or Dry Run, see section 3.6) on a pre-deployment basis. The dry run is slated to occur in October of 2019 to test science objectives, analysis, forecasting, communications and flight planning procedures. This Dry Run will ensure that data collection, overshooting analysis, forecasts and flight planning activities will be carried out in a timely and efficient manner during the actual deployment phase.

Yearly science team meetings and monthly to quarterly ISRs are scheduled throughout the operational phase, and members of the science team will also attend biennial ESSP Program Forums. IMPACTS Science Meetings will occur within 6 months of each deployment to allow sufficient time to prepare data for final archiving.

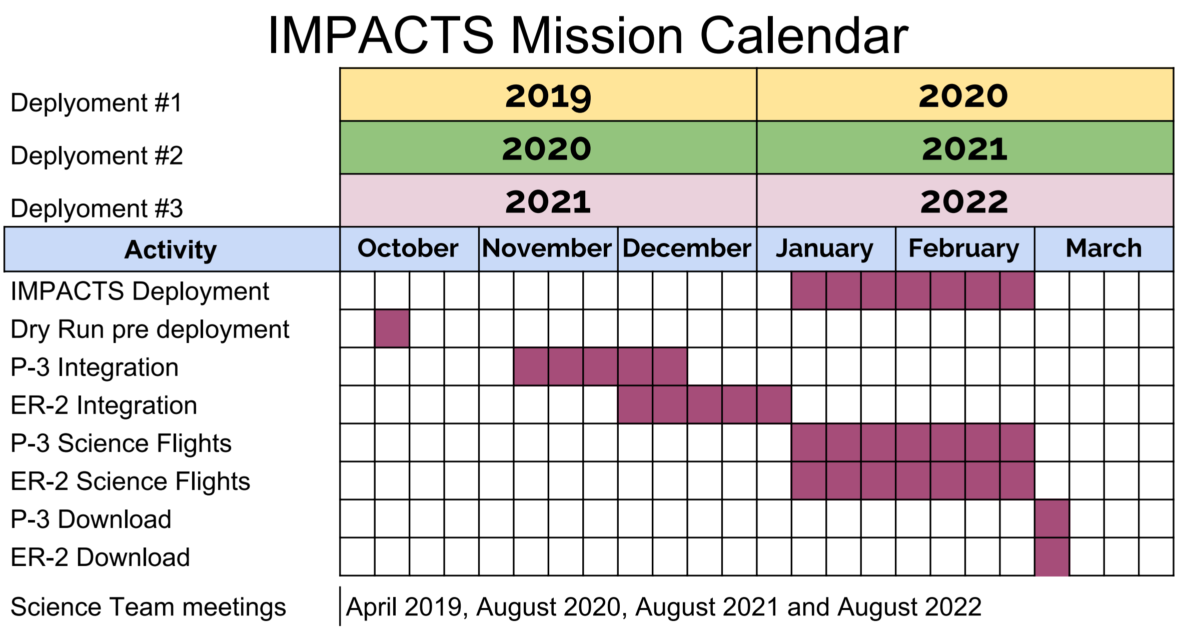


Figure 6.1: IMPACTS Overall Mission Calendar showing a standard deployment calendar year with Science meeting scheduled for the month of August. ICR dates (not shown) is October 2019.

6.1 Field Deployments

There are three science field deployments planned for IMPACTS. For all three, the NASA P-3 will be based out of NASA's Wallops Flight Facility. The ER-2 will be based out of Hunter AAF in Savannah GA for the FY20 deployment while the FY21 and FY22 deployments, are planned to be carried out from Warner Robins.

Both aircraft teams have planned an early integration period starting in early November for the P-3 and early December for the ER-2. Both teams are planning to carry out initial instrument upload and test flights prior to the IMPACTS deployment phase (January - February). The purpose of this early integration is to finalize instrument upload and have enough time to test the entire payload. We anticipate the first two weeks will be devoted to upload and reviews (tech brief and FRR/ORR) for both the P-3 and ER-2, followed by two short test fights and one science-length flight. The operations for the P-3 will take place at Wallops Flight Facility, while the operations for the ER-2 will take place at Palmdale Regional Airport in Palmdale, CA. Upon certification of the payload, the P-3 will be ready to start operations from their home base of operations (Wallops) and the ER-2 will transit to Hunter AAF in Savannah GA or Warner Robins accordingly.
The schedule will repeat for FY21 and FY22.

Flight schedules will be determined during the campaigns based upon real time weather forecasting, and Science Leadership Team working in conjunction with the aircraft (P-3 and ER-2) leadership and operations. It is anticipated that during each deployment there may be several back-to-back flights. These flights will be confirmed with all instrument teams leads and their capability to support the second flight. The P-3 and ER-3 crew chiefs and pilots will make the final decision. IMPACTS will adhere to the following crew rest rules and will coordinate with aircraft managers on a day to day basis, especially for potential back-to-back flights.

Table 6.1: Crew rest guidelines

ER-2 guidelines	P-3 Guidelines
Work Shifts • Maximum of 12-hours per day • Maximum of 60-hours during a 7-day work week **Crew Rest** • 12-hours minimum crew rest from end of all duties • Maximum of 7 consecutive days without at least 1 full day off **Per AFOP-7000.3-006**	**Work Shifts** • 7-days with the 8th day as a down day. The P-3 could adjust to the more restricted ER-2 work shift. • 12 hours on and 12 hours off • 8-hour flights + 2 hour preflight and 2-hour post flight • Up to 16-hour duty day but rest must be 12 hours • Any crew duty day over 12 hours is going to result in a delayed flight the next day.

• Maximum of twelve (12) hours from crew brief to engine shutdown • Twelve (12) hours free of all duty prior to report for flight • Cannot be disturbed during crew rest **General considerations** • Flights longer than 8.0 hours require concurrence of the mission pilot and mobile. • Considerations - adequate crew rest, duties between flights, length, complexity and timing of flights, previous levels of flight activity, takeoff and recovery weather, mission justification, and personal issues. • Pilots flying missions of 9.0 hours or more will be given the following physiological recovery time: • First day after the flight – no duties • Second day after the flight – no pressure suit flights	• Once a day down occurs the clocks are normally reset.

All necessary reviews will be conducted each year prior to the science deployments to ensure that the science, aircraft, logistics and mission planning are ready. In addition, the IMPACTS PI, Deputy PIs and science leadership team, will develop a decision tree to address potential instrument issues involving measurements critical to the IMPACTS Threshold science goals. This decision tree takes into account instrument fault status, contingency day remaining, likelihood of repair, and its potential impact on schedule, to evaluate options and minimize impact on the science goals and overall schedule.

The proposed schedules have been reviewed and approved by GSFC Wallops and AFRC management.

6.2 Instrument Integration and Development

6.2.1 ER-2

The proposed IMPACTS payload has been reviewed by the ER-2 project management and meets the ER-2 payload specifications with substantial positive margins for total weight, power and mass distribution (See section 3.2.3). Additionally, the ER-2 payload integration schedule has been reviewed and is in accordance with AFRC policies to ensure accurate and safe installation. Members of the instrument teams are holding regular meetings with ER-2 management to talk about integration specifications and requirements and to address any integration concerns. None of these instruments require modification for IMPACTS. IMPACTS payloads CPL, CRS, EXRAD, HIWRAP, AMPR, and CoSMIR have all flown in the same zones of the ER-2 aircraft numerous times (Figure 3.3 and Table 3.5). These instruments meet all location-specific mass/volume/power limitations and are easily integrated/removed from the aircraft before/after the mission. Thus, the allotted two weeks of integration time for the ER-2 is very conservative.

6.3.2 P-3

The proposed IMPACTS payload for the NASA P-3 has been reviewed by WFF project management and meets the P-3 payload specification with substantial positive margins for total weight, power and mass distribution (See section 3.2.4). IMPACTS relies on proven instruments to deliver the required science data products. All the in-situ instruments flying on the P-3 are TRL 8 or higher and have flown several missions on the P-3 or similar platforms (Table 3.4). The platform layout and the sampling inlets/view ports needed for the P-3 are shown in Figure 3.3, with additional details provided in Section 3.2.1. Only minor adaptations to mounting arrangements are necessary to integrate the TRL 8 instruments onto the NASA P-3, and most of these adaptations are being executed for the 2019 CAMP2Ex mission (Sep. 2019). Additionally, the P-3 aircraft's dropsonde capabilities (AVAPS) are being upgraded in summer of 2019 in time for CAMP2Ex. The IMPACTS team is tracking P-3 integration efforts during upcoming CAMP2Ex project closely for the cloud probes and AVAPS Dropsondes integration status. If there are any issues with the integration of these instruments on the P-3 for CAMP2Ex, the IMPACTS team has allotted over 5 weeks for P-3 integration, providing schedule reserves to ensure instrument readiness.

8.0 Data and Knowledge Management and Distribution

8.1 Introduction

IMPACTS will adhere to the NASA Earth Science Data Policy (https://science.nasa.gov/earth-science/earth-science-data/data-information-policy/). More specifically, IMPACTS commits to the full and open sharing of scientific data obtained during field campaigns with all users as soon as such data becomes available. Following a post-deployment checkout period (six months), all data, as well as source code for algorithm software, coefficients, and ancillary data used to generate these products, will be delivered to the GHRC DAAC to be made available to the user community. A comprehensive data management plan was developed for IMPACTS to (1) facilitate the implementation of these data principles, (2) maximize the scientific value of the airborne and ground-based observations, and (3) promote collaboration across the various components of the field study. The full details of Data and Knowledge Management and Distribution are contained in a separate Data Management Plan document.

This section of the IIP provides an overview of how the observational data are effectively archived, managed, and shared. This section also addresses the transfer of data for archival at NASA's Global Hydrology Resource Center (GHRC) Distributed Active Archive Center (DAAC). The main goal of the IMPACTS Data Management Plan is to generate high-quality science data, deliver data products in a timely manner, stimulate the interest of the scientific community, and ultimately help achieve the project overall science objectives.

8.2 Data Products and Archival

The IMPACTS data will undergo three stages within the project-lifecycle: in-field data, preliminary data, and final data. The in-field data and browse images are generated during the field deployment and are primarily used to measure progress in achieving the science goals. The preliminary data incorporates possible adjustments due to post-deployment instrument calibration and the quality assurance/quality control (QA/QC) process. The final step of the QA/QC process involves integrated data processing and analysis, which may reveal issues requiring reevaluation of preliminary data products. The final data is intended to be publication-quality and is required to be open to the public. The data submission deadlines are summarized in the table below (Table 8.1).

Table 8.1: IMPACTS data submission deadline timelines.

File Type	Submission Deadline	Access Control
In-Field Data/Images	24-48 hours after each flight	Science Team & Partners
Preliminary QA/QC Data	2-6 months after each campaign	Science Team & Partners
Final Data and Documentation	6 months after deployment completion.	Public at GHRC

The IMPACTS public in-field data and browse images (also called the field catalog) will be archived using a UW-hosted webpage and archive (http://impacts.atmos.washington.edu/), under construction between now and ICR. Browse images of supporting fields, such as satellite imagery, operational NWS radar reflectivity, surface meteorological observations and model forecasts are also supported on this IMPACTS field catalog. During operations, IMPACTS aircraft and ground-based instrument teams will submit browse images to the UW web site while in the field after each flight and during analysis periods. These preliminary images and data products will be submitted by the instrument Pis within 24-48 hours of the flight, either to the IMPACTS field catalog or the instrument's individual website in their native data formats (accessible via links on the IMPACTS web page), similar to the process used by HS3. Exemptions may be granted by the project leadership for certain measurements which require additional data-processing time or when special circumstances occur, e.g., back-to-back flights. The timely submission of in-field data files and browse images is required to assess progress toward mission science goals and to plan subsequent flights. The IMPACTS field catalog will be maintained by UW permanently (beyond the 5-year project lifetime), and ancillary data, such as aircraft flight reports, mission scientist reports, forecaster reports, will be transferred to GHRC.

The preliminary data products, due approximately 2-6 months after each campaign, are primarily used for integrated processing and analysis by the IMPACTS science team and collaborators, which serves as an important step toward finalizing the QA/QC activities and producing final data products. Data will be examined during post-deployment Science Team meetings in August to assess data quality, identify issues, and develop corrective actions, if necessary. As the project progresses, the UW website will serve as a permanent quick-look site that will efficiently guide IMPACTS science team members and the public to preliminary data products. Each instrument PI will be free to distribute his or her own data at any time within the first 6 months from their instrument-specific archive or the IMPACTS field catalog. If any members of the IMPACTS team publicly present data at a conference or in another open forum, that preliminary data will be made publicly available through the IMPACTS field catalog or individual instrument websites.

The final data products and associated documentation (See Section 8.4) will be made available to the public through the GHRC. The IMPACTS data products expected to be archived and their estimated data volumes are detailed in Tables 8.2 through 8.4. Instrument PIs shall submit final data products and documentation as soon as possible, six months after each campaign at latest (no later than September 1), to the GHRC where they are made available to the public. IMPACTS will provide metadata and references along with the data products in the archive. Extensions may be granted by IMPACTS leadership and NASA's Earth Science Data and Information System (ESDIS) for specific data products that require additional QA/QC time due to special circumstances, but the data must be publicly available at GHRC before any publications are submitted. This analysis and archival plan is fully compliant with NASA Earth Science Data Policy. In addition, the IMPACTS website will provide links to in-depth descriptions of the aircraft and instruments, meteorological and forecasting data, summaries of all mission flights, and links to the GHRC.

The data manager will communicate and lead testing with the GHRC in 2020 after data and documentation from the first campaign become available. This test will include a transfer of representative data and ancillary information to prove that the data meets the format, metadata and ancillary information requirements (See Section 8.4), prior to the complete transfer of the final data and documentation. The aircraft flight reports, Mission Scientist reports, Forecaster reports, and aircraft navigation data will all be transferred to the GHRC. The IMPACTS Data Manager will work with the GHRC to ensure the DAAC has access to collect these reports and data from the Field Catalog. Archive and distribution metrics will also be tracked by the Data Manager and the GHRC to ensure all data products have been submitted in accordance with data formats required by NASA (NetCDF, HDF5). As a result of previous NASA field campaigns, the GHRC already has a data transition procedure for nearly all IMPACTS instruments in place (AMPR, CPL, CPR, EXRAD, etc.). It is expected that the same or slightly modified procedure can be employed for other IMPACTS instrument data transitions. Likewise, the GHRC already has an inventory of data from those instruments. Thus, there already exist metadata, instrument documentation and dataset guides for data collected by these instruments during projects such as GRIP and OLYMPEX. The GHRC will work with Instrument Scientists for the remaining instruments (PHIPS, WISPER, TAMMS) to develop a transition plan for their data.

Table 8.2: IMPACTS estimated data volume per deployment for aircraft and ground-based instruments.

Data Products (Type and Platform)	Total Volume
ER-2 Remote Sensing	1.51 TB
P-3 In Situ	0.42 TB
Ground-Based Remote Sensing and Soundings	1.75 TB

Table 8.3: IMPACTS data product information and estimated data volume per deployment for aircraft instruments.

Aircraft Instrument	Data Products (L0, L1, L2)	Level (0,1A,1B,2,3,4)	Size Est for 2020 Campaign
HIWRAP	L0/L1: Vertical profiles of reflectivity, platform-corrected Doppler velocities, linear depolarization ratio. L2: Vertical velocity, precipitation rates, phase, hydrometeor size, various vertical profile characteristics.	1	15GB
CRS	L0/L1: Vertical profiles of reflectivity, platform-corrected Doppler velocities, linear depolarization ratio. L2: Vertical velocity, precipitation rates, phase, hydrometeor size, various vertical profile characteristics.	1	15GB

EXRAD	L0/L1: Vertical and conical-scan profiles of reflectivity, platform-corrected Doppler velocities. L2: Vertical velocity, precipitation rates, phase, hydrometeor size, various vertical profile characteristics; horizontal winds.	1	1.5 TB
AMPR	L0/L1: Brightness temperatures at 10-85 GHz. L2: Precipitation characteristics, path integrated LWC and IWC.	1	550MB
CoSMIR	L0/L1: Brightness temperatures at 50-183 GHz. L2: Precipitation characteristics, path integrated liquid water content (LWC) and ice water content (IWC).	1	240MB
CPL	L0/L1: Vertical profiles of attenuated backscatter, depolarization ratio. L2: Cloud/aerosol layer boundaries, cloud/aerosol optical depth, extinction, depolarization; liquid water detection at cloud top.	1 & 2	17GB
LIP	L0: Static Electric Field time series. L1: Vector electric fields. L2: Calibrated electric fields. L3: Geo-located, calibrated electric fields	0-3	1 GB
Microphysics Probes	L0/L1: Cloud droplet size distributions, effective radius, liquid water content, 2D cloud water and ice particle images, particle size distributions, ice particle mass distributions, particle shape/habit, ice crystal aspect ratio, ice mass content and radar reflectivity approximations, precipitation particle volume distributions, ice mass content, cloud liquid and total condensate 0.01-2 g m-3 for particles < 4 mm, supercooled liquid water measurements in excess of 0.01 g m-3.	1	340GB
TAMMS	Flight level 3D-wind vector, temperature, humidity	1	320MB
Dropsondes (AVAPS)	Vertical profiles of pressure, temperature, relative humidity, and winds	1	80MB
WISPER	L0/L1: Cloud particle concentration, condensate mass, water vapor, water isotopes.	1	500 MB
PHIPS	L0: Raw images, raw light scattering signals; L1: Microphysical properties deduced from the stereo imaging data and the (correlated) angular light scattering functions on a single particle basis. Overviews of the stereo micrographs captured by the imager part of PHIPS. Image panels are given for camera C1 and camera C2 of the stereo imager	1	70 GB
TOTAL	**Aircraft Data Products**	**1-3**	**1.93 TB**

Table 8.4: IMPACTS data product information and estimated data volume per deployment for ground-based instruments.

Ground Instrument	Data Products (L0, L1, L2)	Level (0,1A,1B,2,3,4)	Size Est for 2020 Campaign
Mobile rawinsondes	P, T, wind direction, wind speed, RH	1	1 GB
NOAA rawinsondes	P, T, wind direction, wind speed, RH	1	10 MB
Mobile UIUC x 2	P, T, wind direction, wind speed, RH	1	1 GB
SUNY-SB Mobile Sounding	P, T, wind direction, wind speed, RH	1	1 GB
SUNY Parsivel	PSD, particle velocity, dbz, rain rate	1 & 2	2.8 GB
SUNY Pluvio2	precipitation intensity, total precipitation amount	1	15 MB
WFF Parsivel	DSD, Rain Rate, Concentration, Reflectivity, LWC	1 & 2	100 MB
WFF 2DVD	DSD, Rain Rate, Concentration, Reflectivity, LWC	1 & 2	100 MB
SUNY MRR-PRO	dbz, mdv, Doppler spectra, sw	1 & 2	280 GB
SUNY Ceilometers	backscatter, cloud base height	1 & 2	9 GB
SUNY MRR	dbz, mdv, Doppler spectra, sw	1 & 2	140 GB
SUNY-SB KASPR	dbz, mdv, zdr, phidp, rhohv, rhoxh, ldr, sw, Doppler spectra	1 & 2	800 GB
SUNY-SB ROGER	dbz, mdv, Doppler spectra, sw	1 & 2	120 GB
SUNY-SB MWR	lwp, T, RH, water vapor	1 & 2	0.4 GB
SUNY-SB SKYLER	dbz, mdv, zdr, phidp, sw	1 & 2	20 GB
NPOL	dbz, vr, sw, zdr, phidp, kdp, correlation, rain rate, hydrometeor id	1 & 2	180 GB
D3R	dbz, vr, sw, zdr, phidp, kdp, correlation, rain rate, hydrometeor id	1 & 2	180 GB
TOTAL	**Ground-Based Data Products**	**1 & 2**	**1.75 TB**

8.3 Data Format Requirements

IMPACTS data format requirements are intended to facilitate seamless data exchange among the science team members and partners and to meet the standards for long-term data preservation. The observational data products from in-situ measurements are required to conform to the International Consortium for Atmospheric Research on Transport and Transformation (ICARTT) data format standards. The ICARTT format is now one of the NASA Earth Science Division's approved data system standards (ESDS-RFC-019). A detailed description of the data format protocol can be found at https://earthdata.nasa.gov/standards/icartt-file-format. As required by the ICARTT format protocol, all IMPACTS observational data must be reported with universal time

(UT) for the time record. The files will be named according to the ICARTT convention (see Appendix C). This includes a dataID, selected by the Co-Is, used to identify the data source (e.g., instrument). This dataID is typically an acronym describing the measurement group, measured species, instruments or model, etc. Note that all Co-Is are required to register their “dataIDs” prior to their data submission, regardless of file type. Otherwise, the system will not recognize their files as valid data inputs. As an example, in past studies, “DLH-H2O” was used as a “dataID” for diode laser hygrometer measurements of water vapor data during the MACPEX and ATTREX missions.

All incoming ICARTT format data files will be electronically scanned to ensure compliance with the ICARTT format requirements. The scanning software will provide error messages if deviation from the ICARTT format is detected. Additional assistance will be made available to the science team through the Data Manager to troubleshoot issues in generating and/or submitting ICARTT files.

The IMPACTS remote sensing data and model products may opt to use ICARTT, HDF 5, NetCDF Classic or NetCDF-4/HDF5 File format. More information can be found at: https://earthdata.nasa.gov/user-resources/standards-and-references#ed-standards. This reflects the fact that large datasets are stored more efficiently using a binary format than using an ASCII format, such as ICARTT. To ensure data access to all, links to HDF Group/HDFView (http://www.hdfgroup.org/downloads/) will be provided on the IMPACTS website. As no specific metadata requirements are built into the HDF and NetCDF File Format protocols, IMPACTS Instrument Pis are required to provide the metadata equivalent to the ICARTT format metadata specifications, given in Appendix D. Like the ICARTT files, the HDF and NetCDF files will follow the naming convention given Appendix C. The incoming files will be checked for the naming structure before being placed in the appropriate directory. UT shall also be used for reporting time of the observations. It is also required that the Co-I should clearly indicate the measurement/integration period by labeling the time stamps as start, stop and/or mid time.

8.4 Science Data Guidelines

In order to ensure that data are used and acknowledged fairly and properly, all IMPACTS participants are required to accept the following responsibilities:

- Submit data in ICARTT, HDF or netCDF format no later than the specified deadlines.
- If unexpected events lead to any delay in data submission, the Instrument PI is required to notify the project leadership as soon as issues are known.
- Prior to any presentation at scientific conferences (e.g. American Geophysical Union (AGU) or American Meteorological Society (AMS)), the data (even if preliminary) needs to be publicly available on a website or submitted to the GHRC.
- All aircraft measurements from a common platform should be synchronized to science team pre-agreed time standard.

- Consult with instrument Pis when using their data in conference/data workshop presentations and/or manuscripts.
- Consider inviting instrument Pis of any data used to be co-authors (particularly during post- deployment research phase).
- Instrument Pis shall be available to answer questions about their data after submission and send revised files, if any, to the GHRC. The Data Manager will send revised files and images to the IMPACTS website.
- The IMPACTS Investigation team shall participate in relevant NASA-sponsored data product application workshops (Table 9.1).

The IMPACTS instrument Pis shall provide the GHRC and Data Manager with sufficient documentation for each measurement in the archive. The primary goals of the documentation requirement are to: 1) maintain data reprocessing capability, 2) maintain transparency of the data processing, and 3) facilitate users' understanding and use of data. This documentation contains descriptions of the instrument, primary instrument output data and ancillary data sets for reprocessing. The instrument description document includes the measurement principle, calibration procedures and standards (if applicable), data processing procedure (including software), data validation (if applicable), data revision records, and uncertainties/detection limits. Data and documentation will adhere to NASA Earth Science Data Preservation Content Specification https://earthdata.nasa.gov/standards/preservation-content-spec.

Scientifically relevant data sets from collaborators and data merge products, i.e., aggregated observational data from a common platform or ground site provided on a common time base, will also be archived. The merge data products will be generated by the data manager or science team members for both preliminary data and final airborne data to assist the project analysis effort. Examples of such merged data products include combined radar-radiometer-lidar data that has been synced by time and location, merged cloud probe data from multiple instruments, as well as the combination of cloud probe data with associated atmospheric measurements of the meteorological environment from the TAMMS instrument. These merged products offer a means to readily analyze the covariance of the common platform atmospheric measurements. Special merged data products requested by Co-Is or partners will be accommodated. The preliminary merge files will be generated during the deployment phase and will be updated as data are being revised.

8.5 Acknowledgement Statements

Access to IMPACTS data is not restricted. However, we do ask that data users respect the experiment Co-Is, especially instrument Pis, by contacting them to make sure all Preliminary Data is suitable for publication given the science application of the data user's study. When appropriate, an offer of co-authorship on any publications, presentation, etc., should be made to IMPACTS team members if images and/or data are used (even if they are freely accessed). When any of the IMPACTS data are used in a publication, an acknowledgement statement should be included, recognizing the efforts from the science team and the funding program and agency. An example of such a statement is “We are tremendously grateful to the IMPACTS team that collected a comprehensive in situ and remote sensing dataset, enabling this study. The IMPACTS project was funded by the NASA Earth Venture Suborbital-3 (EVS-3) program under the guidance of Barry Lefer and managed by the Earth System Science Pathfinder (ESSP) Program Office (PO).” The data users are also required to reference IMPACTS’ Digital Object Identifiers (DOI), to be assigned by ESDIS.

8.6 Data Manager

The IMPACTS Data Manager is Stacy Brodzik (srbrodzik@gmail.com). She will create the website for in-field data and browse images (field catalog), as well as monitor the file submission status to the GHRC in accord with the timeline. The data manager will also coordinate the efforts to support implementation of the file formats and collaborative use of data.

9.0 Data Analysis and Publication

Dissemination of scientific results from IMPACTS will be conducted in accordance with NASA Procedural Requirements document, NPR 2200.2C, “Requirements for Documentation, Approval, and Dissemination of NASA Scientific and Technical Information (STI)”. This NPR provides an overview of NASA’s process for approving, publishing, and disseminating the results of NASA’s STI activities. It mandates management and technical review of publications for quality (dependent on the delivery venue); and Document Availability Authorization (DAA) review using the NASA form NF-1676 for NASA-funded and NASA-sponsored research. IMPACTS will utilize internal science team meetings, external conferences, and peer-reviewed manuscripts to publicize data analysis results. The IMPACTS website will host information on recent publications, presentations, as well as links to general interest articles, interviews, video clips, and visualizations related to the project and/or team members, in coordination with the ESSP communications support team.

Internal Science Team Meetings, which are scheduled for August of each post-deployment year, will be used primarily to (1) examine previous deployment flight plans, including successes and shortcomings, instrument performance, and data quality/issues, (2) review sampled cases and initial science results, and map executed science flight mission objectives onto the overall IMPACTS mission objectives, (3) modify deployment operations plans, if needed, for the next deployment to ensure all IMPACTS mission objectives are met, (4) discuss lessons learned from the previous deployment and (5) generate a collegial usage of the data, exchange ideas, and define the nature of publications to follow from each campaign.

External Conferences and Data Workshops will be used to publicize the data products created during the IMPACTS field campaigns and initial data analysis results. External conferences most appropriate to the IMPACTS science are the AGU Fall Meeting, AMS Annual Meeting, AMS Conference on Mesoscale Processes, etc. The IMPACTS team will also create a list of potential collaborators and unfunded data users, who will be invited to open data applications workshops. These data applications workshops will be held in conjunction with August Science Team meetings following each of the deployments in 2020-2022, and/or during the AGU Fall Meeting in those same years. The schedule of the open data workshops is shown in Table 9.1. These open data workshops enable the IMPACTS team to present important information to potential IMPACTS data users for their analysis of the data, such as the data products, data formats, status of data product delivery, and operational information (i.e., flight logs, flight tracks, weather briefings).

Table 9.1: Schedule of IMPACTS open data applications workshops and Mid-Term Review.

Event	Location	Date
Data Workshop 1	Seattle, WA (Second IMPACTS Science Team Meeting)	August 2020
Mid-Term Review	NASA HQ	June 2021
Data Workshop 2	Mountain View, CA (Third IMPACTS Science Team Meeting)	August 2021
Data Workshop 3	Denver, CO (AMS Annual Meeting)	January 2023

Peer-reviewed publications will be submitted by the IMPACTS team to summarize each deployment and key science results ~12 months after deployment completion. The team will submit three deployment summary publications (at different stages of the mission) to three different journals: American Geophysical Union's (AGU) EOS, AGU's Geophysical Research Letters, and the Bulletin of the AMS. The IMPACTS Science Team members, including their affiliation and a brief summary of their specific responsibilities, are given in Table 3.7. Deeper-dive studies by Science Team members will be published in a special IMPACTS collection hosted by the AMS. Team members can publish in any of the AMS journals and indicate that the manuscript is part of the IMPACTS collection. Each Science Team member is expected to publish at least one peer-reviewed publication, totaling at least 20 for the IMPACTS collection. Team members responsible for generating a measurement or data product are offered co-authorship for essential contributions. The IMPACTS field catalog will host a list of all IMPACTS data DOIs, as well as a publication list that includes the publication DOIs.

10.0 Risk Management

10.1 Management Approach for Risk, Schedule, and Cost

IMPACTS will implement a Continuous Risk Management approach in accordance with NPRs 7120.8 and 8000.4 under "NASA Program and Project Management Processes and Requirements" and will adhere to all mandatory flight reviews in accordance with NPR 7900.3. The PM will be responsible for applying standard risk management functions to each assigned risk. The PI and PM will co-chair the Risk Management Board, composed of the PI, DPIs, and PM. The risk board will identify risks, assign a risk manager, and decide when to retire a risk. The PI and DPIs will work with the PM to manage schedule and cost. University grants and interagency agreements will be administered by the ESPO PM and an ESPO Contract Property Manager. Descope plans will be implemented as needed in the event of depletion of reserves, as agreed to by the PI, DPIs, and PM. While the maturity of the instruments greatly reduces schedule risk, the PI and DPIs will work with the FDM and aircraft leads to identify and mitigate risks to scheduled events and milestones.

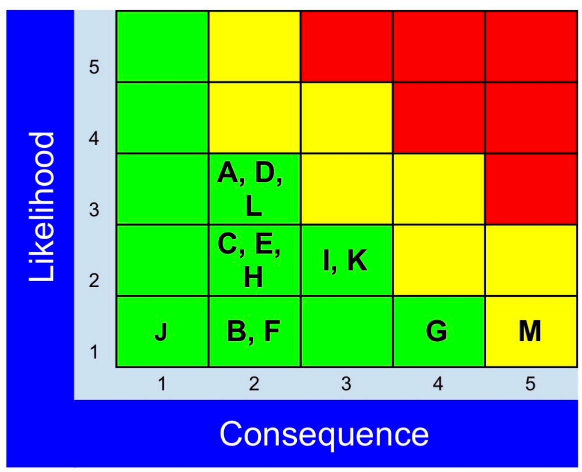


Figure 10.1: IMPACTS Risk Matrix Grid for the risks identified in table 10.1. The letters refer to the risk listed in table 10.1. See description of the likelihood and consequence risk values (1-5) in the caption for table 10.1.

10.2 Science Risk Management

10.2.1 Risks

IMPACTS is a low-risk mission with robust instrument heritage and an experienced team and leadership, including (1) excellent ER-2 and P-3 flight records from the selected deployment sites (home base for the P-3) for numerous previous NASA science missions; (2) high-TRL instruments with proven flight heritage; (3) personnel, including the PI, DPIs, PM, and Co-Is, with decades of airborne experience; (4)

engineering support (GSFC, WFF, AFRC, LaRC, and MSFC) built upon a rich heritage of satellite and airborne experience; and (5) support teams with wide experience in quality management, configuration control, contract negotiations, and contract monitoring.

IMPACTS' risk evaluation approach will use a Consequence-Likelihood-Timeframe scheme under NASA Safety Impact Definitions. Several risks have been specifically identified and targeted for reduction (Table 10.1). IMPACTS has no high-likelihood/high-consequence (category 5/catastrophic) risks. Risks typical to any aircraft field mission (e.g., winds exceeding cross wind limits, instrument failures, aircraft part failures, dropped communications links, IT issues, etc.) are generally resolved through spending plan and schedule reserves**.**

Table 10.1: IMPACTS' Mission Risks.

The risks are well understood and the team has strong mitigation plans in place. Careful planning by the experienced IMPACTS management team will minimize science impact even if a risk is realized. Risks are rated 1-5 in Likelihood (L) and Consequence (C). For example, a catastrophic risk would have a L-5, C-5 Value and will be represented in red in Figure10.1. In the science impact column, the letters refer to the baseline/threshold level 1 science requirements as listed in Table 2.2.

	Example Risks	Background	Response/Mitigation	Science/Cost Impact
A	Difficulty securing a location for the deployment of the ER-2. (L=3, C=2)	Finding a deployment site that can fit the needs of an ER-2 with favorable winter weather conditions can be challenging. Management at some air bases are reluctant to agree to hosting the ER-2 well in advance.	ER-2 can operate in several locations but it might deploy in a new location each year. This can increase mission management time, requirements and cost expenditures.	**Science Impact:** Small impact on science as we will secure a deployment site before mission operations start. No science objectives will be significantly affected. **Cost Impact:** Additional expenses will be incurred due to operational costs such as site survey visits and fuel transportation.
B	Increased costs due to the repositioning and operations of the P-3 due to bad weather at deployment site(s). ER-2 could be diverted for landing due to weather (L=1, C=2)	Inclement weather can increase financial costs due to diverting and/or operating from a different base, i.e. "suit case" flights.	Forecasters will monitor storms continuously even days before an event. Suitcase flights will be planned if weather expected at WFF. Unexpected WFF closures will lead to flight cancellations. Use reserves to mitigate costs.	**Science Impact:** Minimal impact on P-3 or ER-2 due to temporary redeployments. All science requirements can still be met at baseline. **Cost Impact:** Increased cost to support suitcase flights.

C	Plane(s) grounded due to bad weather at a deployment site(s). (L=2, C=2)	Inclement weather can cause deployment site closures. Strong crosswinds (especially for ER-2) can prevent takeoff/landing.	P-3 can temporarily redeploy to alternate sites to avoid bad weather. Snow is rare at Hunter (hence, site selection). High crosswinds at Hunter are rare, and typically short term, and might require shifting takeoff/landing times.	**Science Impact:** Impact on P-3 science (requirements e, f and g) is minimal due to temporary redeployments. On rare occasions, ER-2 may miss a storm of interest if conditions do not permit flight, impacting science requirements c and d for that event.
D	P-3 flight coordination with FAA during winter storm conditions and heavy traffic can lead to non-ideal flight lines. (L=3, C=2)	P-3 operates in busy US flight corridors in instrument-flight rules conditions.	Pre-deployment coordination between WFF pilots and FAA based on lessons learned and successful coordination procedures from previous missions (e.g., Discover-AQ).	**Science Impact:** Air traffic may require flight lines to shift from optimal lines and altitudes. Primary impact is reduced range of atmospheric temperatures (altitudes) sampled. This may bring requirement (f) to threshold if we repeatedly miss ideal flight lines to sample snowbands. It also may impact science requirement (i) by restricting the range of snow events sampled.
E	Aircraft equipment failure for the P-3 and ER-2 that could interrupt mission operations (L=2, C=2)	The P-3 will be deployed in the Philippines before integration for IMPACTS. The ER-2 will be on another mission and this does not leave much time for repairs if any issues should arise.	The flight crews are well experienced in aircraft preparation and maintenance. Aircraft are routinely maintained and checked to ensure safety. Each team comes equipped with spare parts in case there is a need.	**Science Impact:** In the event that there is an equipment failure, the aircraft crew will utilize their spare parts and expertise to get the plane up and running. There might be a few science flight days lost due to maintenance but the winter storm window should be large enough to account for any down days. This affects science requirement (b), and depending on the length of down time, may bring that objective to threshold.
F	NASA P-3 aircraft unavailable during one of the deployment years. (L=1, C=2)	Aircraft could be unavailable due to numerous reasons, which could affect the mission schedule and collection of scientific data.	Might be able to find alternative aircraft for P-3, such as the NOAA P-3, Wyoming King Air, or North Dakota Citation.	**Science Impact:** Can still obtain a subset of cloud microphysics measurements with less accuracy from another aircraft with less range. This affects science requirements d, e, f and g. If the P-3 were unavailable for

				all three years, then requirement a would only be met at threshold. **Cost Impact:** Alternative aircraft costs could be higher or lower than NASA P-3.
G	NASA ER-2 aircraft unavailable during one of the deployment years. (L=1, C=4)	Aircraft could be unavailable due to numerous reasons, which could affect the mission schedule and collection of scientific data.	If ER-2 is unavailable we would consider 2 multi-week deployments instead of 3 deployments or alternative aircraft such as the second ER-2 or the NASA WB-57. Several of the IMPACTS instruments (CPL, CRS, CoSMIR, and HIWRAP) have previously flown on the WB-57. Recently, CPL flew but it was more than 10 years ago when the other instruments flew on the WB-57. There is ample space on the WB-57 for most if not all IMPACTS ER-2 instruments, but significant work would be required to reintegrate them.	**Science Impact:** Can still obtain a subset of remote sensing measurements from another aircraft with less range, affecting science requirements c and d. Ground-based radar systems can also provide suitable measurements so that objective c can be met at threshold for the period without an ER-2. However, the mission would be jeopardized if no high-altitude aircraft were available for all three years. **Cost Impact:** The WB-57 would be the best ER-2 alternative other than for its reduced endurance. Costs and schedule would have to be evaluated for the aircraft and the reintegration.
H	Unable to complete the GRC wing pylon structural interface for wing mounting. (Likelihood=2, Consequence=2)	The pylon mounting to the P-3 wing may not meet structural margins precluding its use.	The pylon would not be used, requiring relocation of the Nevzorov, CDP, and King probes. These probes would be mounted on either the fuselage or on a window with WISPER or RICE.	**Science Impact:** Small impact on science. Intercomparison between probes would be required to assess the relocation. Still able to accomplish baseline requirements for all science objectives. **Cost Impact:** Costs associated with work/fabrication.
I	TAMMS, dropsonde (AVAPS) openings on the P-3 may accumulate ice and not be able to collect data. (L=2, C=3).	Since the instrument openings are not heated, icing conditions could cause sufficient ice buildup and prevent instruments from operating properly.	If early in flight, take the aircraft to warmer altitudes. If late, accept loss of data. Use operational rawinsonde, commercial flight data (ACARS) and ER-2 radar-derived vertical motions.	**Science Impact:** Loss of TAMMS and AVAPS prevents correlation of microphysical properties to exact thermodynamic/wind conditions; instead must be related to secondary sources. At threshold for science requirements (d),

				(e) and (g) on the flight legs where this occurs.
J	Ground-based radar, profilers and lidar systems located on Long Island are unavailable (L=1, C=1)	Ground-based remote sensing instruments could be unavailable due to numerous reasons, such as mechanical issues, lack of operators or excessive snowfall.	Use operational WSR-88D ground based radars to obtain environmental context for the aircraft observations.	**Science Impact:** This affects science objective (h) for storms that occur near Long Island and brings that objective to threshold. Since the other science requirements can be met wherever storms occur, none of the other objectives are impacted and overall risk is low.
K	Mobile rawinsondes launched at three-hourly intervals cannot be achieved. (L=2, C=3)	There could be a variety of issues that prevent rawinsonde launches at desired frequency, such as instrument failure, or inability of crews to get to desired locations or loss of the system entirely.	If there are failures for a particular launch, then data loss is accepted. If the entire system is unavailable, then thermodynamic information will be obtained from other sources, such as operational rawinsonde information or high-resolution models	**Science Impact:** The loss of mobile rawinsonde launches affects requirement (e) and will bring that to threshold.
L	Winter weather often brings about illness. There is a high likelihood that the PIs, aircraft crew, and scientists will become ill during deployment (L=3, C=2)	Work productivity decreases during the winter months as germs are easily transmitted. When working in close proximity such as mission operations, or traveling on flights, there is a high probability of getting sick.	Each team will have back-up personnel that are well-versed in the mission goal and role responsibilities. Scheduling will be such that there is enough overlap with team members in case of illness.	**Science Impact:** If there is no back-up for the key roles, we run the risk of not being able to support the instruments, aircraft, and operations. Scheduling will be created to minimize these risks and to plan for back-ups.
M	No significant winter weather in the study area during the deployment window (L=1, C=5).	The NE US averages 6-14 days with measurable snowfall during January and February, but there is strong variability from year to year.	Each deployment is 6-8 weeks. The probability of not sampling 2 storms during each deployment is very low. Midwest is included as target region to mitigate this risk. We would also fly in storms that have low melting level heights, but may have rain instead of snow at the surface. These storms would also have very similar banded	**Science impact:** If an extremely quiet winter occurs, then the other two winters would need a total of 6 events (average 3 per year) to meet baseline. Otherwise mission requirement (b) would be met at threshold. **Cost Impact:** If we sample storms in the Midwest, there would be only a small cost impact as the target region can be reached from the

			structures to storms with snow reaching the surface.	deployment airfields. Costs would go up if we relocate any aircraft to a different airfield and those extra costs will be taken out of reserves.

10.2.2 Descope Plan

IMPACTS has adequate cost reserves and schedule margins and is of low operational risk due to previous campaign heritage, deployment locations and it's not exposed to the higher costs of international deployments, all of which lessen the likelihood the project will need to exercise descope options. In the unlikely event that descopes become necessary, the primary descope options at the time of IIP are to: (1) descope the AMPR instrument. If the AMPR team is removed from the 2nd and 3rd deployment, the cost savings are approximately $610K. The scientific cost of removing AMPR is to lose low frequency radiometer channels with the biggest impact for observations over the ocean. Our second descope priority is to (2) eliminate support for the SBU facility. Removing the SBU facility for the 2nd and 3rd deployment will give us a cost savings of $890K while losing validation of aircraft measurements, specifically for storms near Long Island, NY. The 3rd option is to (3) descope the CPL instrument, which is operated by GSFC. Removing the CPL instrument from the 2nd and 3rd deployment will give us a savings of approximately $877K but will result in loss of the high sensitivity measurements of thin clouds and liquid water detection at cloud top. Our 4th descope option is to (4) reduce the number of science flight hours for each deployment. Each flight-hour saved from the ER-2 and P-3 will give us a savings of $5K and $4K, respectively. The scientific impact will be the reduced number of cases/events and/or storms sampled. Our last descope option is to (5) reduce the number of flight campaigns from three 6-week campaigns to two 6- or 8-week campaigns. The associated savings will be in the range of $3M and this will severely impact the number of events and the range of storm types sampled. The associated science impacts and cost savings are presented in table 10.2 below. With any of the descope options presented below, threshold can be archived. Table 10.3 shows the science impacts for the different descope options.

Because all of the deployments for IMPACTS will take place at the same time every year (January-February), any decision to enact or consider any of the descoping options will have to be carefully reviewed by the science leadership team. These will be announced at the scheduled August Science Team Meeting in order to take effect at the next fiscal year/deployment.

10.3 Schedule

The team will conduct monthly project status reviews with the ESSP PO until the end of the mission (through 2023). An ICR, mid-term review, and pre-deployment FRR/ORRs and MRRs will be conducted as described in Section 3.6 and shown in Figure 10.2. The pre-deployment phase provides adequate time for establishment of university grants, small instrument procurements, coordination between the science leads and ESPO to prepare for the ICR, creation of project documentation (IIP, DMP), and planning for mission operations, including a dry run of forecasting and operations planning in early October 2019. The GSFC Medical and Environmental Division will conduct an environmental assessment to ensure minimal impact on the environment and compliance with the National Environmental Policy Act.

The post-deployment phase includes up to three months for data calibration and processing, with final quality-controlled data posted to the data archive immediately upon completion. Following the first deployment, data analysis will be ongoing throughout the remainder of the project. The team will submit summaries and initial findings for publication ~12 months after each deployment ends. Science Team members will submit publications throughout the investigation period.

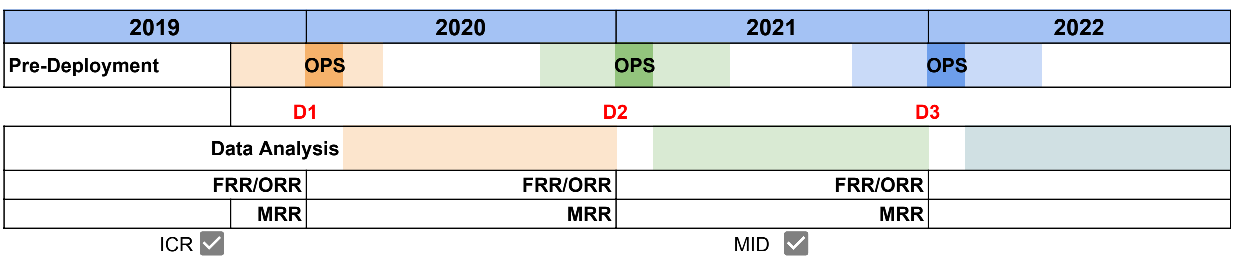


Figure 10.2 Overall Impacts Schedule. The color bars show the time allocated for each deployment (D1, D2 and D3) for instrument upload and download. The intensive observational period is also marked as "OPS" for each deployment. The data analysis effort will start upon competition of the observational period and will last until the next observational period starts. The figure also show the FRR/ORR and MRR reviews required prior to the deployment phase.

11.0 Investigation Evaluation

IMPACTS will incorporate the following reviews as part of its management systems:

11.1 Investigation Confirmation Process

The IMPACTS Confirmation process is completed before the first deployment. It consists of two meetings: the Confirmation Assessment Meeting (CAM) and the Investigation Confirmation Review (ICR). The focus is on investigation concept and requirements – with an emphasis on changes since selection.

For IMPACTS this includes changes to: the ER-2 first year deployment site to Hunter AAF rather than Warner Robins in subsequent years; instrument revisions/additions (PHIPS instead of CDP in first campaign), and spending plan impacts associated with ER-2 basing.

The CAM audience consists of the Earth Systems Science Pathfinder Program Office staff (Program Manager, Mission Manager, Program Executive, Resource Manager, others) and Subject Matter Experts as invited by ESSPPO.

IMPACTS will seek approval and signature from the ICR audience on the project plan, setting a baseline for the mission concept, level 1 requirements, schedule and spending plan. ICR approval authority is NASA's ESD director or delegated authority.

IMPACTS' CAM was held 26 July, 2019, our ICR is scheduled for October 07, 2019, and our midterm review will be held in the summer (sometime in June – August) of 2021.

11.2 Flight Readiness Review (FRR)/Operations Readiness Review (ORR)

An FRR/ORR is held for each aircraft. Those reviews are held at the aircraft home centers in accordance with governing NPDs and NPRs. An FRR/ORR reviews the operational requirements for a specific flight or campaign. A supervisory Flight Operations pilot or other Flight Operations supervisory personnel chairs the meeting and approves the FRR/ORR flight authorization.

Topics covered in the FRR/ORR include: science requirements, flight operations procedures, no/no-go criteria, pilot qualifications, training and flight manuals, aircraft configuration, aircraft maintenance, science payload and operations, status of reviews, special weather conditions, science functional flight test plan, and accident/incident plans.

IMPACTS project and science management will provide information to those reviews and will attend to answer questions.

After the FRR/ORRs, the project will hold a Mission Readiness Review (MRR). Topics covered in the MRR include: flight experiment and science flight requirements, organizational chart, payload status, flight operations procedures, aircraft separation/coordination, communications plan, inter-agency coordination plan, hazardous ground procedures, timeline, roles and responsibilities, science coordination requirements, mishap preparedness, liability coverage, deployment, logistics, public affairs/outreach, mission assurance.

11.3 Project Status Reviews (PSRs)

Status Reviews are held by phone monthly between IMPACTS leadership and the ESSPPO Mission Manager. Recent events, unresolved issues and progress against the plan are discussed. After confirmation, we expect the frequency of these updates to be reduced to bimonthly or quarterly.

11.4 Science Reviews

IMPACTS will hold a face-to-face science review annually for all team members as part of the annual science team meetings. Teams budgeted for this function and will arrange their own travel. The first IMPACTS review was held at Wallops Flight Facility April 16-18, 2019. For budgeting purposes, it was assumed that the subsequent meetings would be held at the University of Washington (2020), and Ames Research Center (2021). Science reviews in later years will likely be in early Fall, approximately nine months after deployment (three months before next), with locations TBD. We will consider other venues for future annual science reviews, with input from the science team.

Pre-first deployment, the focus was on science objectives, instrument capabilities and readiness and deployment planning. After each deployment, data and lessons learned will be discussed as they pertain to project goals.

12.0 Safety and Mission Assurance

NASA aircraft Safety and Mission Assurance are conducted in accordance with procedures outlined in the NPR-7900.3C, Aircraft Operations Management Manual. The first year of the IMPACTS mission, there will be three categories of readiness reviews a, b, c, which are applied to both the ER-2 and P-3 aircraft, rather than just two, a and b, for a single aircraft deployment year:

A. Airworthiness and Flight Readiness (FRR) focuses on the safe integration of the science instruments and aircraft operations from a technical and flight safety perspective. A Technical Brief will be conducted to ensure airworthiness and flight readiness in order to obtain an approved Flight Request. This is the responsibility of the aircraft organization.
B. Operations and Mission Readiness (ORR) focuses on the safe execution of mission and mission assurance. An Operational Readiness Review (ORR) will be conducted to ensure adequate mission planning and mishap response planning has been accomplished. This is the responsibility of the aircraft organization.
C. Mission Readiness Review (MRR) focuses on the operational safety of missions that use multiple aircraft to ensure readiness for transit and deployment operations. A MRR reviews the mission interoperability of multiple aircraft from multiple organizations to ensure mission success for a specific flight event or campaign. Organizations may be at different Centers, other Federal agencies, military services, commercial vendors, or non-NASA aircraft. Prior to conducting an MRR, each aircraft involved in the flight or campaign shall have an approved FRR/ORR. The MRR is the responsibility of the IMPACTS leadership team.

Installation of investigator equipment is documented and reviewed for airworthiness by each aircraft's home NASA center. New instrument PI's consult the ER-2 and P-3 Airborne Laboratory Experimenter Handbooks respectively for general knowledge and safety guidelines.

The Pilot in Command (PIC) has the overall responsibility for the safety, security and proper operation of the aircraft in accordance with NPR 7900.3C Chapter 3.2. Command responsibility includes compliance with all preflight, inflight and post flight requirements. Prior to each flight a planning meeting is held to address the flight's objective, flight line, duration, expected weather and all associated safety and risk issues. The PIC of a NASA aircraft shall ensure that the crew is briefed on the mission plan, safety procedures, and emergency information, including emergency egress.
I
ER-2 radars (CRS, HIWRAP, EXRAD) require licensing and special safety considerations for transmitting. These radars all have operational licenses through NASA Headquarters that works with the National Telecommunications and Information Administration (NTIA), the agency that reviews Radio Frequency (RF) transmissions for government agencies. The operational licenses still require that the Goddard Spectrum Manager is informed with regions that will be flown during a deployment. The radars all have interlocks that prevent them from transmitting on the ground.

The American National Standards Institute (ANSI) requires that all NASA instruments conform to the ANSI standards for eye safety. The specific guidelines and sample calculations are set forth in the documents ANSI-Z136.1 and ANSI-Z136.6. CPL has a robust Laser Safety Plan, used in dozens of previous field campaigns, that provides analysis showing CPL laser transmitter eye safety conforms to ANSI-Z136.1 and ANSI-Z136.6. The important parameter for the CPL operation is the Nominal Ocular Hazard Distance (NOHD), which is the distance from an aperture emitting laser radiation an observer must be to avoid eye damage. According to the ANSI guidelines, at distances greater than the NOHD there is no eye hazard. For CPL, the NOHD is 50,000 ft, so the instrument will not operate the laser if the ER-2 altitude is below that altitude. Given the ER-2 cruise altitude is ~60,000 ft for IMPACTS, the CPL laser will be turned on and off at 50,000 ft during ascent and decent, respectively (about 40 minutes on either end of the flights). The CPL team will complete the FAA Form 7140 (Notice of Proposed Outdoor Laser Operations) and appropriate NASA Amrstrong Laser Safety Forms (User Qualifications, Laser Safety Permit, and Laser Inventory).

12.1 Ground operations

Ground safety is governed by AFRC DPD-8700.1-001, Revision B-1 and WFF 800-PG-8715.5.1. For the SBU mobile sounding facility, a NOTAM is required for rawinsonde releases. SBU will call Lockheed Martin NOTAM service at 1 877 487 6867 when planning to release. There is no advance notice time restriction.

The UIUC Rawinsonde team will follow standard protocol of issuing a NOTAM (Notice to Airmen) in advance of a rawinsonde launch. All launches will be done at sites well removed (at least 5 km) from airports. During any storm, launches will be done from a single site. For safety and comfort, the launches will be done from a hotel parking area. The team will deploy to the hotel prior to the storm when road conditions are safe to travel. The hotel will serve as a residence during the event so that the teams have bathroom facilities, can stay warm, alternate shifts so that they can rest, and have food. After the storm, the teams will remain at the hotel until road conditions are safe to return to the central base hotel that they will reside in when skies are clear and no storms are on the horizon.

12.2 Fire Safety

Wallops N-159, Hunter AAF, and Warner Robins AFB airports comply with ICAO fire and rescue categories 9 and 6 respectively, with water, foam and a number of fire trucks. In order to house a NASA aircraft, NASA requirements state that a hangar must have an automatic foam deluge system of some capacity.

- Airport Rescue & Fire Fighting (ARFF) category is CAT (9)
- Fully fledged ARFF vehicles / equipment
- 15 ARFF personnel on duty (24/7)

12.3 Security

Wallops, Hunter AAF, and Warner Robins AFB are all controlled airfields.

12.4 Deployment Orientation

PI's will be provided an orientation package prior to arrival at the deployment sites (Wallops and Hunter or Warner Robins) that will include safety information regarding working in and around the aircraft, facilities and laboratory. This will include emergency protocol and information regarding the nearest medical facility, safe driving guidelines, visitor dos and don'ts and general awareness. The general orientation package guideline will be produced based on the final ER-2 and P-3 deployment sites, and will include five main sections:

1. Arrivals and badging info
2. Lab and office info
3. Safety – Lab, ramp, and personal safety
4. Mission Info – Camera use, schedules, and reporting plans
5. Appendices – Maps and hangar layout

IMPACTS will remain compliant with any mandatory training requirements of NASA, US Army, and USAF.

13.0 Relationships to Other Projects and Organizations

13.1 Internal Relationships

Formal relationships with other NASA Centers in regard to the IMPACTS scientific plan and programmatic activities are described throughout this plan. Here, we highlight a few additional relationships not mentioned elsewhere.

Spending Plan: The ARC resource analyst who supports IMPACTS will interface on a regular basis with ESPO and with like-personnel at other participating Centers, namely Langley, Goddard, Marshall, Armstrong and NASA HQ.

Table 13.1: Point of Contacts

Center	Person
Ames	Maricela Davis
Armstrong	Lisa Logan
Goddard	Dianna Adamczyk
Langley	Sandra G. Craft-Kemp
Marshall	Leigh Anderson
HQ, ESSPO	Kristin Price

Travel: Contacts for the LaRC SSAI contract, used to organize/implement travel for non-CS team members are: David McBride, Cassie Lehnardt, Sandra Chellis. SSAI provides periodic contract report.

Ombudsman: The term Ombudsman is a Swedish term that means designated neutral. Many academic institutions, business and government agencies have adopted this function to act as an early warning and listening post for their organizations. The NASA Ombuds Program was established in 2005 as a result of the Columbia accident. The program provides a supplemental channel of communications within NASA to raise issues related to safety, organizational performance and mission success. This program will be available to all IMPACTS participants during integration and deployments in resolution of any issues that arise.

Contact info for all of the above persons is in the NASA Directory, accessible to all those on NASA internal networks.

13.2 External Relationships

IMPACTS will work with the following institutions and their instruments to supplement the observational capabilities of our current payload. None of the additional instrumentation is required to meet baseline/threshold science requirements, but their participation is beneficial and elevates the quality of the science achieved by IMPACTS.

PHIPS: Martin Schnaiter from the Karlsruhe Institute of Technology (KIT), Germany has offered to fly this instrument at no cost for FY20. PHIPS has superior performance to CDP so it will be a valuable contribution to IMPACTS. It is unclear whether PHIPS will be available in subsequent years since it is scheduled to fly on the HALO aircraft after IMPACTS. PHIPS is currently at NCAR since Martin Schnaiter is on a sabbatical there. Integration of PHIPS requires changes in the P-3 wing harness; this harness will accommodate both CDP and PHIPS. Martin Schnaiter will support the instrument and provide data. At the time of the IIP, an international agreement between NASA and KIT is being worked

Lightning Instrument Package (LIP): This package has flown on the ER-2 numerous times and NASA HQ funds are likely but not definite for the 2020 IMPACTS flights. The Marshall Space Flight Center (MSFC) LIP group is interested in corroborating electrical activity that has been observed in winter storms with GOES-R GLM. LIPs inclusion should not have an impact on the IMPACTS ER-2 payload although this will be looked at in more detail.

GPM – D3R: The GPM Ground Validation (GV) program may fund the D3R transportable Ku- and Ka-band scanning radar at the GPM DPR frequencies. D3R would be moved to one site TBD during each deployment period of IMPACTS preferably near a WSR-88D radar or another lower frequency scanning radar such as at SBU.

NOAA Supplemental Rawinsondes: There is a possibility that NOAA NWS may be able to launch supplemental rawinsondes at a 6- or possibly 3-hourly frequency from standard operational stations along the East Coast.

NOAA Winter Storms Program: NOAA has tentative plans to perform flights offshore of the east coast with their instrumented P-3 aircraft. In previous years, their program has been primarily over the western Pacific studying Atmospheric Rivers and other winter events. NOAA is mainly interested in the operational forecasting aspects of winter storms using primarily dropsonde data for the purpose of model improvement through data assimilation. In upcoming years, they plan to have a larger Atlantic component, off the U.S. East Coast. Their program will complement IMPACTS and it would provide valuable offshore radar and thermodynamic data. We will know more on the certainty of their flights in early Fall 2019.

Limited-Area Network of Ground-based Observations of Snowbands and Transition zones In NOr'easters (LANGOSTINO): There is a pending NSF proposal (P.I. Karen Kosiba, Center for Severe Weather Research) with an intensive surface network around Coastal New England (ground base near Plymouth, MA). The period of operation would be January - March 2021, i.e., during the second IMPACTS campaign. They propose 4 Doppler on Wheels (DOW) radars, soundings, mesonet and pod systems, and snow cameras. If this proposal is funded, it would provide valuable supplemental data for IMPACTS.

14.0 Waivers

IMPACTS is a domestic deployment that will follow standard policies. The deployment locations for both the P-3 (Wallops) and ER-2 (Hunter AAF and Warner Robins) follow all government rules and regulations, in addition, the localities are well served by travel options that make crew rotations easy and affordable for the project.

Operationally, IMPACTS does not anticipate any deviations from standard policy and are not requesting operational waivers.

<u>Travel duration waivers:</u> Travel duration beyond 29 days are typically deemed extended TDY (ETDY) by NASA and are assigned a reduced per diem and lodging allowance, consistent with 6 or 12 month leases, with grocery shopping and in-residence meal preparation. Airborne science deployments can exceed 30 days, especially in locations where team member swaps are expensive or for teams who have reduced staff, or when personal emergencies prevent a planned swap. An individual's travel rarely exceeds 60 days, making a long-term lease lodging rate highly unlikely. In addition, lodging accommodations are typically without kitchens, and even with kitchen facilities long work days make meal preparation burdensome. In FY18, approval was received to wave the ETDY rule on all foreign airborne science and astronomy deployments from 30 to 60 days duration. This rule has not been codified for domestic deployments. ESPO and Ames Travel office will work with the other center counterparts to seek an agency wide waiver for domestic deployments in each fiscal year in which IMPACTS deploys.

15.0 Change Log

Changes to the Investigation Implementation Plan should be documented in a change log. To expedite the processing of changes, approval for all changes, other than those related to the Level 1 mission requirements, only require the signatures of the ESSP Program Office and the Principal Investigator. All signatories will be provided a copy of the updated plan. Changes to the Level 1 science requirements require the approval of all the signatories.

Appendix A: Acronyms

- AC: Aircraft Coordinator
- AFB: Air Force Base
- AFRC: Armstrong Flight Research Center
- AFSRB: Airworthiness and Flight Safety Review Boards
- AGU: American Geophysical Union
- AM: Aircraft Manager
- AMPR: Advanced Microwave Precipitation Radiometer
- AMS: Aircraft Mission Scientists
- ARC: Ames Research Center
- AVAPS: Advanced Vertical Atmospheric Profiling System
- CAPS: Cloud, Aerosol and Precipitation Spectrometer
- CAS: Cloud and Aerosol Spectrometer
- CCP: Clouds, Convection, and Precipitation
- CDP: Cloud-Droplet Probe
- CIP: Cloud Imaging Probe
- CoSMIR: Conical Scanning Millimeter-wave Imaging Radiometer
- CPL: Cloud Physics Lidar
- CRS: Cloud Radar System
- CVI: Counter Virtual Impactor
- DAA: Document Availability Authorization
- DAAC: Distributed Active Archive Center
- DPR: Dual-frequency Precipitation Radar
- DOW: Doppler on Wheels
- DM: Data Manager
- DOI: Digital Object Identifiers
- DPI: Deputy Principal Investigator
- ESPO: Earth Science Project Office
- ESSPO: Earth Systems Science Pathfinder Program Office
- EVS: Earth Venture Suborbital
- EXRAD: ER-2 X-Band Doppler Radar
- FAA: Federal Aviation Administration
- FCDP: Fast Cloud Droplet Probe
- FDM: Field Deployment Management
- FMS: Flight Management System
- FRR: Flight Readiness Review
- FTL: Forecasting Team Lead
- GHRC: Global Hydrology Resource Center
- GMI: GPM Microwave Imager
- GOL: Ground Operations Lead
- GPM: Global Precipitation Measurement
- GPS: Global Positioning System
- GRC: Glenn Research Center
- GSFC: Goddard SPace Flight Center
- GV: Ground Validation
- HIWRAP: High-altitude Imaging Wind & Rain Airborne Profiler

- HS3: Hurricane Severe Storms Sentinel
- HVPS-3: High Volume Precipitation Sampler-3
- ICA: Investigation Confirmation Assessment
- ICARTT: International Consortium for Atmospheric Research on Transport and Transformation
- ICR: Investigation Confirmation Review
- IFR: Instrument Flight Rules
- IM: Instrument Manager
- iMET: International Met Systems
- IMPACTS: The Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms
- IMPROVE: Improvement of Microphysical Parameterization through Observational Verification Experiment
- INS: Inertial Navigation System
- IOP: Intensive Operation Periods
- IPHEx: Integrated Precipitation and Hydrology Experiment
- IWC: Ice Water Content
- IWG1: Interagency Working Group
- LANGOSTINO: Limited-Area Network of Ground-based Observations of Snowbands and Transition zones In NOr'easters
- LaRC: Langley Research Center
- LCC: Life Cycle Costs
- LDR: linear Depolarization Ratio
- LIP: Lightning Instrument Package
- LWC: Liquid Water Content
- MM: Mission Manager
- MOC: Mission Operations Center
- MPC: Mission Peculiar Costs
- MSFC: Marshall Space Flight Center
- MTS: Mission Tools Suite
- MRR: Mission Readiness Review
- NASA: National Aeronautics and Space Administration
- NCAR: National Center for Atmospheric Research
- NOAA: National Oceanic and Atmospheric Administration
- NRCS: Normalized Radar Cross Section
- NSF: National Science Foundation
- NSW: National Weather Service
- OLYMPEX: Olympic Mountains Precipitation Experiment
- ORR: Operations Readiness Review
- PHIPS: Particle Habit Imaging and Polar Scattering
- PI: Principal Investigator
- PLOWS: Profiling of Winter Storms
- PM: Project Manager
- PMS: Particle Measuring Systems
- PSR: Project Status Reviews
- QA/QC: Quality Assurance/Quality Control

- RICE: Rosemount Icing Probe
- ROI: Regions of Interest
- SBIR: Small Business Innovation Research
- SBU: Stony Brook University
- SL: Science Lead
- SSAI: Science Systems and Applications, Inc.
- STI: Scientific and Technical Information
- STM: Science Traceability Matrix
- TAMMS: Turbulent Air Motion Measurement System
- TRL: Technology Readiness Level
- WFF: Wallops Flight Facility
- WISPER: Water Isotope System for Precipitation and Entrainment Research
- WPC: Weather Prediction Center
- WR: Warner Robins

Appendix B: IMPACTS Support Letters

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Eastern Region Headquarters
630 Johnson Ave. Suite 202
Bohemia, NY 11716

March 14, 2018

Dr. Lynn McMurdie
Research Associate Professor
Department of Atmospheric Sciences
University of Washington
Box 351640
Seattle, WA 98195

Subject: Letter of Commitment for the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) Earth Venture Suborbital-3 Proposal

Dr. McMurdie,

The Eastern Region of the National Weather Service is pleased to participate in the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) investigation. We are extremely interested in the proposed IMPACTS research and aircraft in situ and remote observations of banded structures in developing cyclones, given precipitation bands dramatically affect snowfall rate and snow gradients, which dramatically impacts road transportation, the national aviation system, and general infrastructure. The 2015 New York City Blizzard is an example of where 50 miles in location can make a tremendous difference in impact. Further, the National Weather Service Winter Weather Service Program has identified snowfall rate as a key programmatic requirement. For example, snowfall rate is critical for airport operations (runway clearing and de-icing ops) and airport restrictions. The observations IMPACTS offers will further our understanding of these features, and ultimately lead to better predictions.

In support of IMPACTS, the Eastern Region is committed to providing:

- Access to local forecast office experts leading up to and during intensive observing period (IOP) days to guide optimal research flights.
- Coordination of additional real-time soundings during IOP days, as NWS resources allow.
- Seamless exchange of operational data between Eastern Region Forecast Offices and IMPACTS.

Jeff Waldstreicher, Deputy Chief of the Eastern Region Scientific Services Division, will serve as point-of-contact for these efforts. Mr. Waldstreicher has extensive research and operational experience with mesoscale precipitation features within extratropical cyclones. Mr. Waldstreicher has led numerous research-to-operations projects within the NWS, including mesoscale band projects.

In conclusion, I assure that the operational coordination support that is necessary for the on-time and within budget delivery of the IMPACTS investigation will be available and committed by the Eastern Region, as specified in the proposal.

Hi Lynn!
Jason

Sincerely,

Jason P. Tuell
Director, NWS Eastern Region

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
National Centers for Environmental Prediction
Weather Prediction Center
5830 University Research Court
College Park, Maryland 20740

March 15, 2018

Dr. Lynn McMurdie
Research Associate Professor
Department of Atmospheric Sciences
University of Washington
Box 351640
Seattle, WA 98195

Subject: Letter of Commitment for the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) Earth Venture Suborbital-3 Proposal

Dr. McMurdie,

The Weather Prediction Center of the National Weather Service is pleased to participate in the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) investigation. We are extremely interested in the proposed IMPACTS research and aircraft in situ and remote observations of banded structures in developing cyclones, given precipitation bands dramatically affect snowfall rate and snow gradients, which dramatically impacts road transportation, the national aviation system, and general infrastructure. The 2015 New York City Blizzard is an example of where 50 miles in location can make a tremendous difference in impact. Further, the National Weather Service Winter Weather Service Program has identified snowfall rate as a key programmatic requirement. For example, snowfall rate is critical for airport operations (runway clearing and de-icing ops) and airport restrictions. The observations IMPACTS offers will further our understanding of these features, and ultimately lead to better predictions.

In support of IMPACTS, the Weather Prediction Center is committed to provide:

- Coordination with IMPACTS scientists and the Winter Weather Desk forecasters and Senior Duty Meteorologists during Intensive Operation Period (IOP) days. This may entail coordination of additional real-time soundings during IOP days as well as the latest operational forecast insight to guide optimal research flights.
- Seamless exchange of operational data between WPC and IMPACTS

I will serve as a point of contact for these efforts. I have extensive research and operational experience with mesoscale precipitation features within extratropical cyclones and have led numerous research-to-operations projects within the NWS, including mesoscale band projects.

In conclusion, I assure that the operational coordination support that is necessary for the on-time and within budget delivery of the IMPACTS investigation will be available and committed by the Weather Prediction Center, as specified in the proposal.

Sincerely,
Dr. David Novak
Director, NOAA/NWS Weather Prediction Center

Appendix C: IMPACTS data file naming convention

dataID_locationID_YYYYMMDD_R#.extension

The only allowed characters are: A-Z a-z 0-9_.- (that is, upper and lower case alphanumeric, underscore, period, and hyphen). The use of the underscore character is restricted by the ICARTT format naming convention and may only be used to separate fields, as shown above. Fields are described as follows:

dataID: an identifier of measured parameter/species, instrument, or model (e.g., O3; NxOy; and PTRMS).

locationID: an identifier of airborne platform or ground station. ER2 and P3 will be the locationIDs used for the ER-2 and P-3 aircraft platforms, respectively.

YYYY: four-digit year

MM: two-digit month

DD: two-digit day (for flight data, the date corresponds to the UT date at takeoff)

R#: data revision number, using numerical values, e.g., R0, R1, R2 ... etc.

Extension: “ict” for ICARTT files; “h5” for HDF 5 files; and, “nc” for NetCDF files.

For example, the filename for the ER-2 CPL measurements made on February, 1, 2020 flight may be: CPL_er2_20200201_R0.h5 (for initial data) or CPL_er2_20200201_R1.h5 (for revised data). Note that mission name (IMPACTS) shall be absent from the filename but included in the header, to comply with the ICARTT File Format Standards V1.1 (see the link in Section 8.4).

Appendix D: Summary of ICARTT format metadata requirements

(also required for HDF 5, NetCDF Classic and NetCDF-4/HDF5 files)

Platform and associated location data: Geographic location and altitude will be embedded as part of the data file or provided via a link to the archival location of the aircraft navigational data.

Data Source Contact Information: phone number, mailing information, and e-mail address shall be given for **the measurement Co-I and one alternate contact**.

Data Information: Clear definition of measured quantities will be given in plain English, avoiding the use of undefined acronyms, along with reporting units and limitation of data use if applicable.

Measurement Description: A simple description of the measurement technique with reference to readme file and relevant journal publication.

Measurement Uncertainty: Overall uncertainty will need to be given as a minimum. Ideally, precision and accuracy will be provided explicitly. The confidence level associated with the reported uncertainties will also need to be specified for the reported uncertainties if it is applicable. The measurement uncertainty can be reported as constants for entire flights or as separate variables. Measurement uncertainty is required by the ICARTT data file format.

Limit of Detection Information: Definition of the upper and lower limits of the instrument or measurement technique (or N/A if not applicable), as well as flag codes for when measurements were outside of those bounds (separate flag codes should be provided for above the upper limit of detection and below the lower limit of detection).

Data Quality Flags: Definition of flag codes for missing data (not reported due to instrument malfunction or calibration) and detection limits.

Data Revision Comments: Provide sufficient discussion about the rationale for data revision. The discussions should focus on highlighting issues, solutions, assumptions, and impact.

Appendix E: References

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Appendix F: Letter Regarding Management Support from NASA Ames

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, CA 94035-1000

September 3, 2019

Reply to Attn of: SG:232-22

Dr. Lynn McMurdie
Department of Atmospheric Sciences
University of Washington
Seattle, WA 98195-1640

Dear Dr. McMurdie:

NASA Ames Research Center is pleased to provide project management support through the Earth Science Project Office (ESPO) for your project entitled "Investigation of Microphysics and Precipitation for Atlantic Coast Threatening Snowstorms" (IMPACTS) which was competitively selected in response to the NASA Research Annoucement Solicitation NNH17ZDA001N-EVS3.

The project management tasks for your mission are well within the scope and capabilities of ESPO and they can accommodate the planned deployment schedule and project deliverables over this five-year project (January 2019 through December 2023). The ESPO Project Manager will be Vidal Salazar, with additional civil servant and cooperative agreement support staff. The effort will also include financial analyst support from our finance organization to aid with grant, agreement, and reporting requirements. The total level of effort required for the duration of this project is approximately 1 FTE and 1 WYE per year for each of five years plus mission peculiar costs for each deployment year for a total of $3.8M.

Ames is committed to provide the workforce and facilities required to successfully execute the work that will be done by ESPO on behalf of the mission.

Sincerely,

Eugene L. Tu
Center Director

Appendix G: Submitted NEPA Enviromental Questionnaire

NEPA Environmental Checklist (Offsite R&D Projects)

Project Name: Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS)
Date of Selection: September 18, 2018
Project Contact: Vidal Salazar, IMPACTS Project Manager
Location: NASA Ames
Phone Number: (650) 605 5313
Project Start Date: January 15, 2020
Description of Project:

The **Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS)** will fly a complementary suite of remote sensing and in-situ instruments for three 6-week deployments on the ER-2 and P-3 aircraft starting in January 2020. IMPACTS will address three specific objectives, providing observations critical to understanding the mechanisms of snowband formation, organization, and evolution. IMPACTS will also examine how the microphysical characteristics and likely growth mechanisms of snow particles vary across snowbands. IMPACTS will improve snowfall remote sensing interpretation and modeling to significantly advance predictive capabilities.

Location of Project: The NASA aircraft will be based at two different locations**,** NASA Wallops Facility (P-3) and Hunter Army Airfield (ER-2).
Nature of Environment:
Administrative Facility Governing Land:
Facility Contact: NASA P-3: Mike Cropper, michael.c.cropper@nasa.gov and Kelly Griffin, kelly.griffin@nasa.gov **NASA ER-2**: Brian Hobbs, brian.l.hobbs@nasa.gov and Franzeska Becker, franzeska.becker@nasa.gov

Facility Environmental Office Contact:
AMES: Estrada, Andres V. (ARC-JQ) andres.v.estrada@nasa.gov
AFRC: Mark Lunsford, mark.n.lunsford@nasa.gov
NASA Wallops: Miller, Shari A. (WFF-2500) <shari.a.miller@nasa.gov>

Environmental Impacts:

"Yes" responses may require the project to prepare an Environmental Assessment or conduct additional studies.

A. Geologic:

	Yes	No	Unknown
a. Change in topography or ground surface relief features?		X	
b. Increased erosion of soils, either on or off site?		X	
c. Change in deposition, siltation, or erosion that may affect adjacent water bodies or wetlands?		X	

Explain all "yes" and "unknown" answers: ____

B. Air:

	Yes	No	Unknown
a. Substantial air emissions or deterioration of ambient air quality?		X	
b. Creation of objectionable odors outside of the facility?		X	
c. Alteration of air movement, moisture, temperature, or any change in climate, locally or regionally?		X	

Explain all "yes" and "unknown" answers: ____

C. Water:

	Yes	No	Unknown
a. Disturbance of groundwater?		X	
b. Changes in absorption rates, drainage patterns, or rate and amount of surface runoff?		X	
c. Alter the course or flow of flood waters?		X	
d. Alteration of the direction or rate of ground water flow?		X	
e. Change in the quantity or quality of ground waters?		X	
f. Changes in total potable water use?		X	
g. Any activity in a floodplain or wetland?		X	

Explain all "yes" and "unknown" answers: ____

D. Cultural Resources:

	Yes	No	Unknown
a. Does the project have adverse effects on existing historic or cultural landmarks?		X	
b. Will the project alter a building that is 50 years or older?		X	
c. Is the project located in an area of suspected or known archaeological resources?		X	

Explain all "yes" and "unknown" answers: ____

E. Biological Resources:

	Yes	No	Unknown
a. Construction/grading/filling within or adjacent to designated wetlands?		X	
b. Reduction of the numbers of any rare, or endangered species?		X	
c. Construction/grading/filling within open space or grasslands areas?		X	
d. Introduction of new species or plants into an area, or impact to normal replenishment of existing species?		X	
e. Construction activities in rare or endangered species habitat?		X	
f. Will the project take place in or have the potential to adversely affect ecologically sensitive areas (e.g. National Park, wilderness areas, biological reserves, recreation or refuge areas, wild or scenic rivers, prime farmlands, landmarks listed on the National Register of Natural Landmarks, etc.)?…..		X	

Explain all "yes" and "unknown" answers: ____

F. Noise:

	Yes	No	Unknown
a. An increase in noise greater than 10% from an existing operation?		X	
b. Exposure of people to severe noise levels (above 80 dBA)?		X	

Explain all "yes" and "unknown" answers:

G. Land Use:

	Yes	No	Unknown
a. Substantial alteration of the present or planned land use?		X	
b. Increase in the rate of use of any natural resource?		X	
c. Substantial increase in energy consumption?		X	
d. Substantial change in total employment levels?		X	

Explain all "yes" and "unknown" answers:

H. Health and Safety:

	Yes	No	Unknown
a. Significant adverse effects on public health or safety?		X	
b. Generation of ionizing or non-ionizing radiation?		X	
c. Generate air emissions?		X	
d. Use of pesticides, including insecticides, herbicides, fungicides or rodenticides?		X	
e. Confined space entry?		X	
f. Risk of exposure to asbestos or lead containing materials?		X	
g. Result in the exposure or disturbance of contaminated soil or ground water?		X	
h. Generate industrial waste water or storm water discharge?		X	
i. Use of Class I ozone depleting substances (CFCs, TCA, halons)?		X	
j. Acquisition, use, or storage of any toxic or hazardous substance?		X	
k. Generation of medical (biohazard), hazardous, toxic, or radiological wastes?		X	
l. Use, disturbance, or disposal of PCBs?		X	
m. Use of toxic gas?		X	

Explain all "yes" and "unknown" answers:

I. Transportation/Circulation:

	Yes	No	Unknown
a. Generation of substantial vehicle trips?		X	
b. Affect existing parking facilities or demand for new parking?		X	
c. Substantial impact upon existing transportation systems?		X	
d. Increase in traffic hazards to motor vehicles, bicyclists, or pedestrians?		X	

Explain all "yes" and "unknown" answers:

J. Services:

	Yes	No	Unknown
a. Affect or result in need for new or altered government-provided fire protection services?		X	
b. Affect or result in need for new or altered government-provided security services?		X	

Explain all "yes" and "unknown" answers:

K. Environmental Justice:

	Yes	No	Unknown
a. Does the project have the potential to create a disproportionate negative impact to low income populations or minority populations?		X	

Explain if answer is "yes" or "unknown":

L. Controversy:

	Yes	No	Unknown
a. Does the project have the potential to generate public controversy?		X	

Explain if answer is "yes" or "unknown":

M. Risk:

	Yes	No	Unknown

a. Does the project have highly uncertain and potentially significant environmental effects or involve unique or unknown environmental risks? ....

	X	

Explain if answer is "yes" or "unknown":