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Planning and flying research flights during the suborbital airborne field campaigns ARCSIX and PACE-PAX

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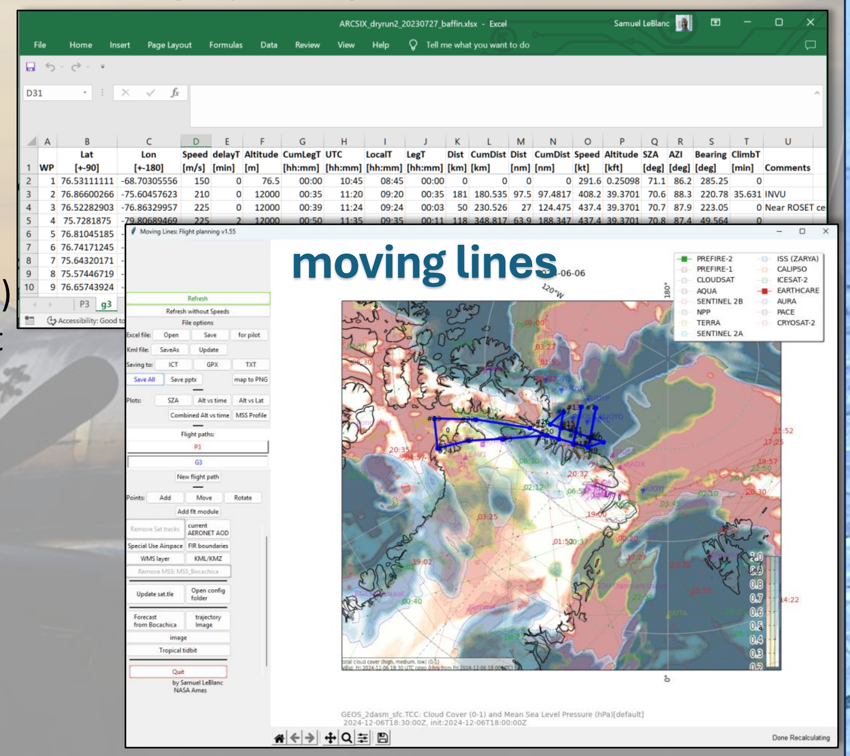
Abstract

- Airborne research and observations continue to be a part of a robust and resilient Earth Science Division program as defined in NASA's decadal survey. As part of this, planning of the suborbital research flights involves much thought, time and effort to translate scientific sampling objectives to aircraft waypoints. We present the planning process and tools that have been used in 2 field campaigns operated by NASA in 2024; ARCSIX and PACE-PAX.

Combined these campaigns include different guiding principles, different regions, and 5 different aircraft. To enable more efficient science operations using distributed observations, we have developed an efficient tool for flight planning, which achieved numerous science objectives.

Moving Lines – Software tool

Moving Lines research flight planning tool is an open-source software that bridges the gap between science goals and flight operations. This gap-bridging enabled the scientists to react to quickly varying forecasts (especially in the Arctic) and convert sampling strategies into flight plans that are easier for pilots to ingest and file during both PACE-PAX and ARCSIX. Such planning also enabled more efficient coordination between multiple aircraft – NASA's P3, G-III, and Spec's Learjet for ARCSIX; and the NASA ER-2 and NPS (Naval Postgraduate School) Twin Otter for PACE-PAX, in addition to coincident satellite and in-water observations



Numerous advances has been implemented for ARCSIX and PACE-PAX, notably change in map projection for arctic mission, ingestion of model forecast fields (mostly from GEOS-FP), update in satellite ground track prediction, file formats and savings for easier pilot use, multi-aircraft coordination figures, and waypoint naming conventions.

	Moving Lines (ML)
Clickable map interface	Python based
Aircraft speed and performance	Parameterization based on previous campaigns (updated for ER-2 during PACE-PAX)
View and solar angles	For sampling with specific geometries like principal plane
Multi-aircraft platform flights	Ease of establishing coordination points and time on targets
Satellite track prediction	Based on TLE (Two-line element) – easier updating for PACE-PAX and ARCSIX (PACE + EarthCARE)
Flight modules	Developed for different sampling strategies moveable, and rotatable
Pilot-ready outputs	Foreflight, UFP, Honeywell (ER2 specific new in PACE-PAX)
Waypoint Spreadsheet	Local using Excel
Generalized figures and WMS overlays	For importing satellite imagery and model outputs and exporting to google earth
Model forecast map overlay	New for ARCSIX, based on server-side loading (ARC's bocachica)
Model forecast profiles along flight path	New for ARCSIX
Aircraft waypoint naming	New for ARCSIX and PACE-PAX

moving lines is open source built on python

LeBlanc, samuelleblanc/fp: Moving Lines: formatting support for pilots files with ER2 specific work (v1.55). Zenodo., 2024, https://doi.org/10.5281/zenodo.13901732

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ARCSIX - Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment

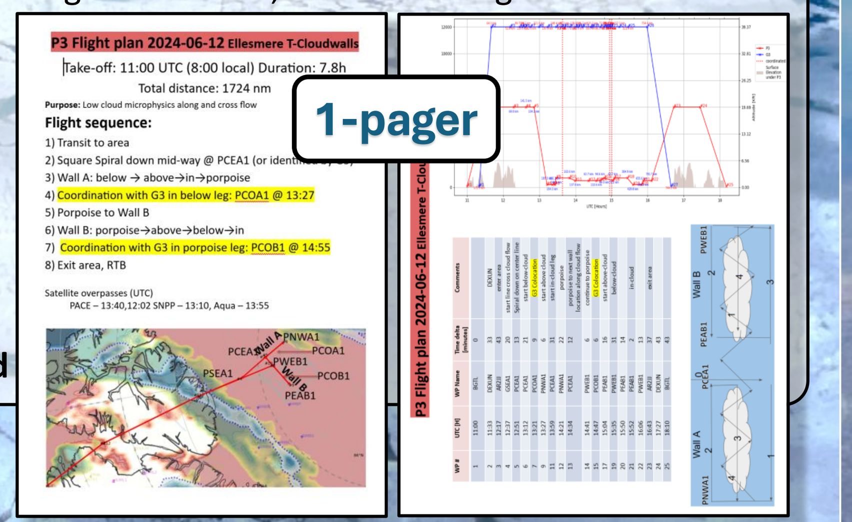
Arctic (based in Pituffik - Thule, Greenland) in May-June (1st deployment), and July-August (2nd) 2024
NASA P-3 (radiation + in situ + remote sensing), NASA G-III (remote sensing),
Spec inc. Learjet (cloud in situ), and NASA C-130 (logistical support)

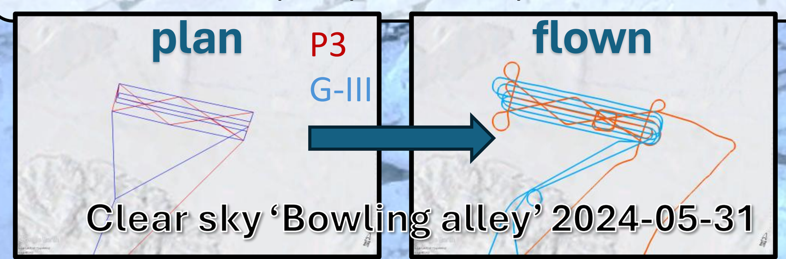
Goal : Quantify the contributions of surface properties, clouds, aerosol particles, and precipitation to the **Arctic summer surface radiation budget** and sea ice melt during the early melt season.

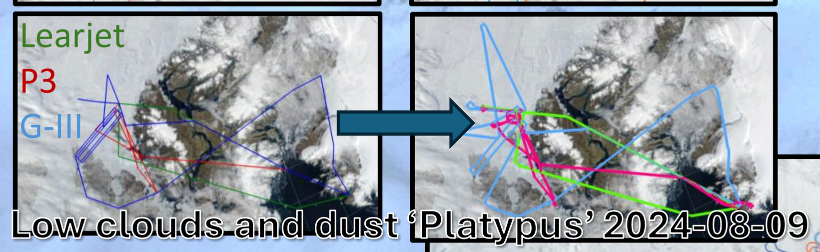
Main science objectives related to radiation, cloud life cycle, sea ice, and remote sensing.

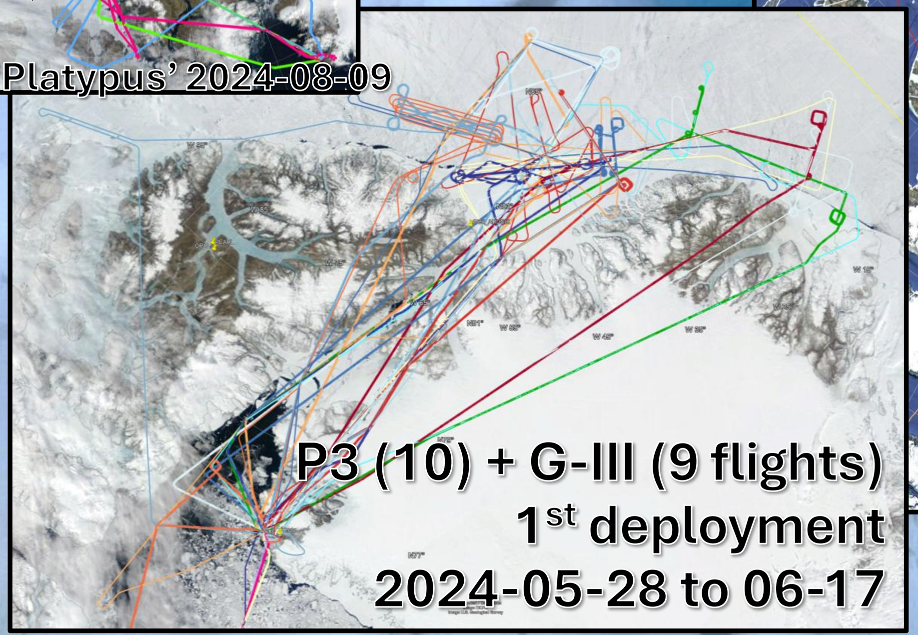
Flight planning lessons learned:

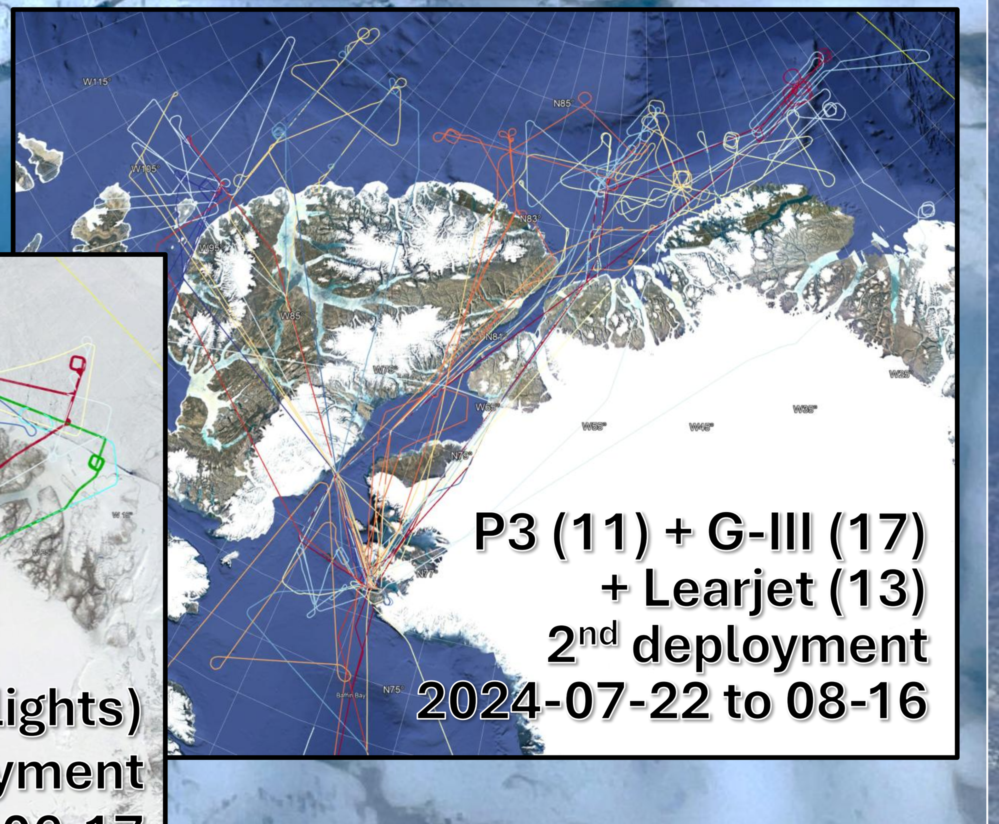
- Coordinated flight segments between the multiple aircraft are very useful for obtaining a full understanding of cloud, aerosol, radiation, and surface properties. This coordination needs to be carefully planned.
- Arctic conditions vary with best forecasting achieved through combination of multiple weather models and satellite nowcasting.
- Multiple flight plan options needs to be refined for each flight day for responding to changes in forecast and achieving coordination.
- Numerous iterations and revisions of flight plans are required for including multiple options and diverse science options:
  flight plan concepts →draft → refinement and timing → quality assurance → same day selection and modifications
- Planned potential options for changes makes in-flight decision and direction from the ground easier, while ensuring that needed observation goals are met.
- One-pager printed and distributed prior to flight for each platform was essential for exchanging information between flight planning team and operational ground mission science and flight scientist to establish common language, waypoints, and important timing.
- Map projection matters therefore good software tools are needed
- For these complex plans and quick turnaround – **flight planning team was needed**











PACE-PAX - Plankton, Aerosol, Cloud, ocean Ecosystem Postlaunch Airborne eXperiment

California (based at Edwards Air Force Base and Marina, CA) in September 2024
NASA ER-2 (remote sensing + PACE-like instrumentation), NPS CIRPAS Twin-Otter (in situ),
NOAA R/V Shearwater (in-water sampling and ocean optics), R/V Blissfully (in-water)

Objectives: **To validate PACE + EarthCARE observations**

1. Validate new satellite data products
2. Provide sufficient validation data for narrow swath observations
3. Validate radiometric and polarimetric properties
4. Target specific processes or phenomena.

These objectives are combined in a Validation Traceability Matrix (VTM).

Flight planning lessons learned:

- ER-2 sampling is best achieved by planning flight segments that extend ahead and past a target. Multiple overpasses are good for ensuring good measurements and to sample evolution.
- 'Timing trombones' are useful for ensuring timed coordination between multiple aircraft, satellite, and research vessels.
- Airspace corridors offshore California can easily be restricted for Navy use, even at ER-2 altitudes.
- Twin Otter in situ measurements of aerosol benefit from spirals for its vertical information and long level legs for potentially broadening types of aerosol (e.g., dust in California central valley).
- Twin Otter cloud sampling is achieved through porpoising through cloud vertical extent.
- To better manage coordination between airborne and Research Vessels sampling, the aircraft plan should have multiple overpasses at different distance from coast at intervals of more than 1 hour, for which the R/V can select the best coordination point given sea state.

- 13 NASA ER-2 science flights, totaling 80.9 flight hours (out of 84 allotted)
- 17 CIRPAS Twin Otter science flights, totaling 60 flight hours (out of 60 allotted)
- 15 day trips of the R/V Shearwater
- 9 day trips of the R/V Blissfully

Validation Traceability Matrix

Validation objectives	ID	Measurement objectives	Importance, w	Required time (hours)	Total observed (hours)	Objective success	Remaining score
1. Validate new retrieval properties	a	Land surface parameters	8	2.0	3.0	0.994	0.1
	b	Ocean radiometric parameters	10	8.0	18.0	0.999	0.0
	c	Aerosol parameters over the ocean	12	8.0	20.5	0.998	0.0
	d	Aerosol parameters over land	12	8.0	22.0	1.000	0.0
	e	Cloud parameters	12	8.0	7.8	0.930	0.8
	f	Ocean surface parameters	1	8.0	1.5	0.354	0.6
3. Validate in a narrow swath	a	Aerosol parameters over the ocean (PACE)	10	8.0	3.0	0.556	4.4
	b	Aerosol parameters over land (PACE)	10	8.0	7.0	0.751	2.5
	c	Cloud parameters (PACE)	5	2.0	2.5	0.918	0.4
	d	Aerosol parameters (EarthCARE)	8	4.0	5.5	0.956	0.4
	e	Cloud parameters (EarthCARE)	8	4.0	2.5	0.632	2.9
4. Validate radiometric and polarimetric properties	a	Validate large reflectances	6	2.0	1.0	0.972	0.2
	b	Validate large reflectances with high polarization	6	2.0	1.5	0.826	1.0
	c	Validate large reflectances with low polarization	6	2.0	2.5	0.982	0.1
	d	Overfly vicarious calibration sites	6	4.0	0.0	0.268	4.4
6. Focus on specific processes or phenomena	a	High aerosol loads over land	4	2.0	0.5	1.000	0.0
	b	High aerosol loads over ocean	4	2.0	0.0	0.393	2.4
	c	Multiple aerosol layers	1	2.0	0.0	1.000	0.0
	d	Aerosol under thin cirrus	2	2.0	3.5	0.826	0.3
	e	Aerosol above liquid phase cloud	4	2.0	0.0	0.826	0.7
	f	Broken clouds with complex structure	4	2.0	3.0	0.895	0.4
	g	Dust aerosols over ocean	4	2.0	0.0	0.430	2.3
	h	Aerosol and ocean parameters over turbid waters	2	2.0	2.3	0.932	0.1
	i	Aerosol and ocean parameters over biologically productive waters	4	2.0	5.3	0.994	0.0
	k	Smoke aerosols over ocean	1	2.0	0.0	0.713	0.3
		total:	150	98	112.8	0.835	

PACE-PAX overall objectives satisfied: **0.835**