

Science of ARCSIX: Cloud Processes, Regimes, and Evolution

Presenter: Patrick C. Taylor, NASA Langley Research Center

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Writing Team: Sebastian Schmidt, Patrick Taylor, Linette Boisvert-McPartland, Anthony Bucholtz, Gregory Cesana, Paul DeMott, Ann Fridlind, Ralph Kahn, Nathan Kurtz, Greg McFarquhar, Richard Moore, Chelsea Parker, Jens Redemann, Michal Segal-Rozenhaimer, Amy Solomon, Rachel Tilling, Lauren Zamora, Paquita Zuidema

Additional Science Advisors: David Bromwich, Mitch Bushuk, Richard Cullather, Graham Feingold, Seiji Kato, Jennifer Kay, Samuel LeBlanc, Tristan L'Ecuyer, Peter Pilewskie, Joseph Sedlar, Matthew Shupe, Bill Smith Jr., Manfred Wendisch

Program Managers: Hal Maring, Thorsten Markus

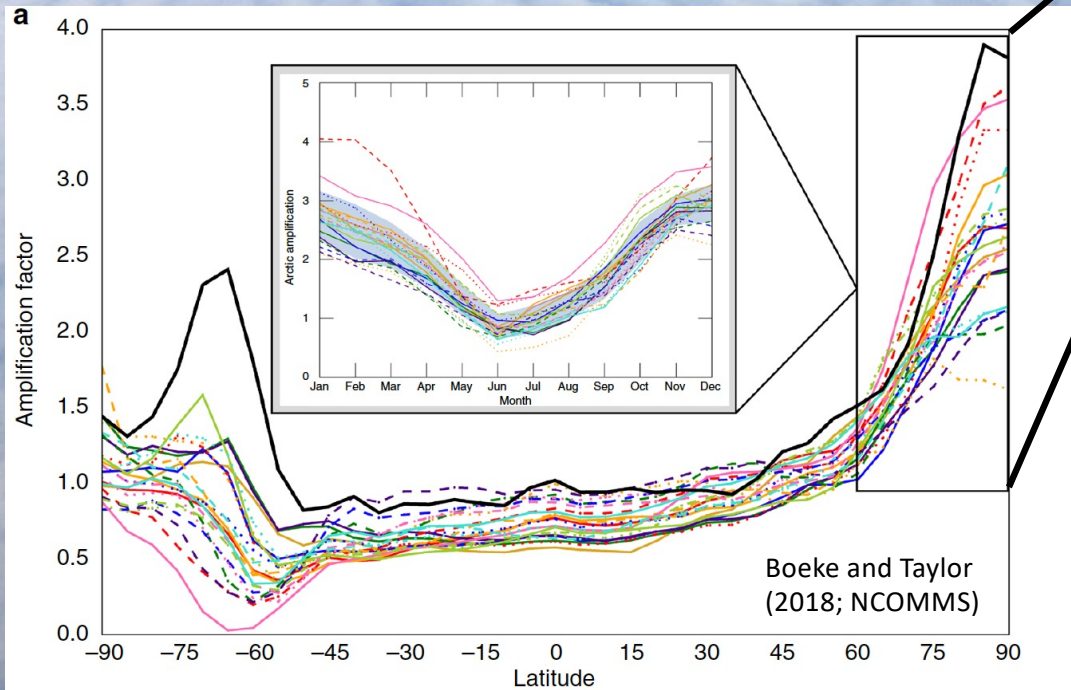
ARCSIX is...

An airborne investigation planned for late spring/early summer in Northern Greenland and Svalbard driven by the need to:

- 1. Understand how coupling between radiative processes and sea ice properties influence summer sea ice melt;**
- 2. Understand processes controlling the predominant Arctic cloud regimes and their properties; and**
- 3. Improve our ability to monitor Arctic cloud, radiation, and sea ice properties and processes from space.**

The overarching goal of ARCSIX is to 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.

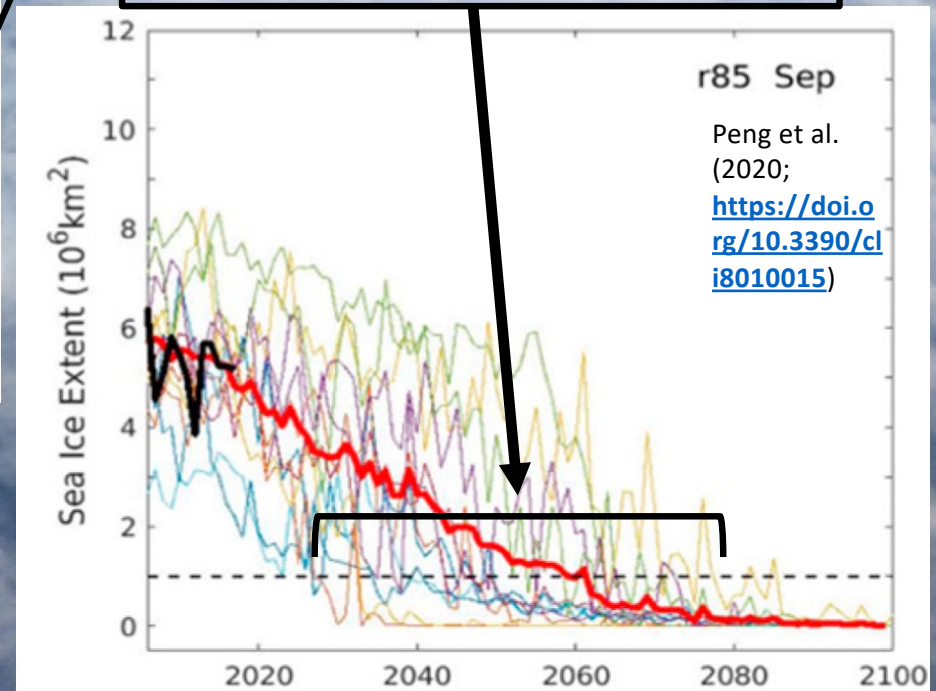
Why ARCSIX?



Considering a +3 K global temperature increase the range of Arctic warming is from 6 to 12K

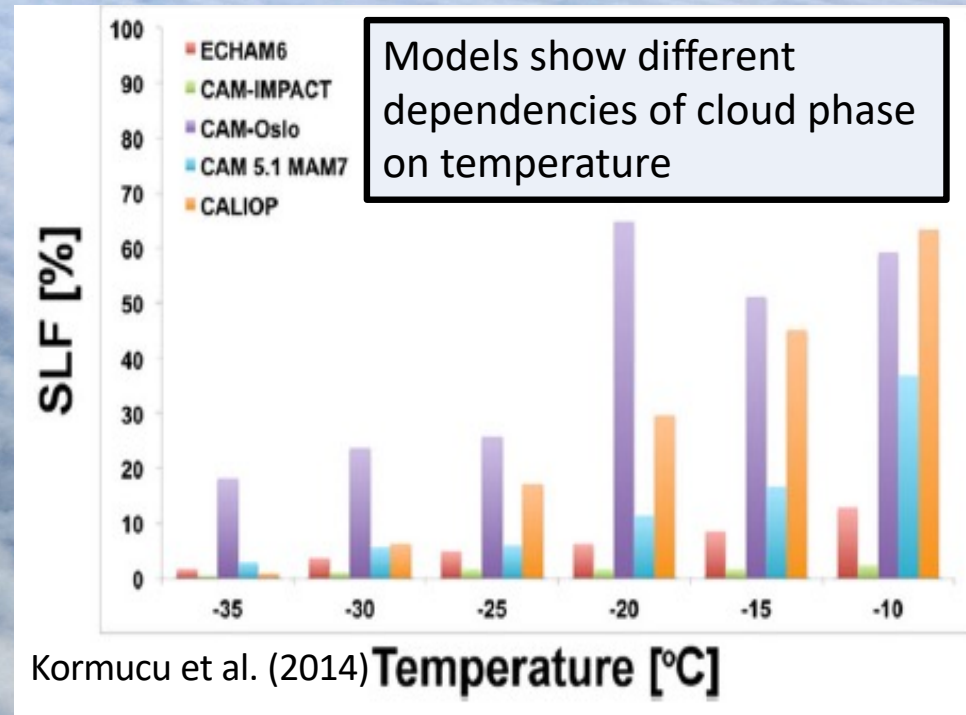
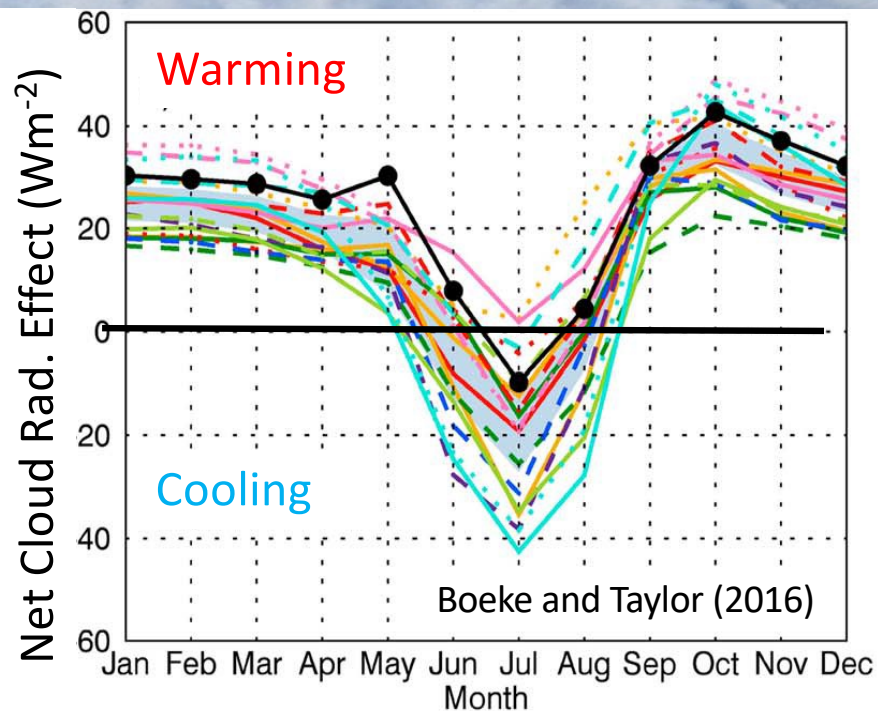
~50 year spread in the timing of the first ice free Arctic summer

...But our models are inadequate to inform society.



Why ARCSIX?

...model uncertainty stems from errors in the representation of clouds.

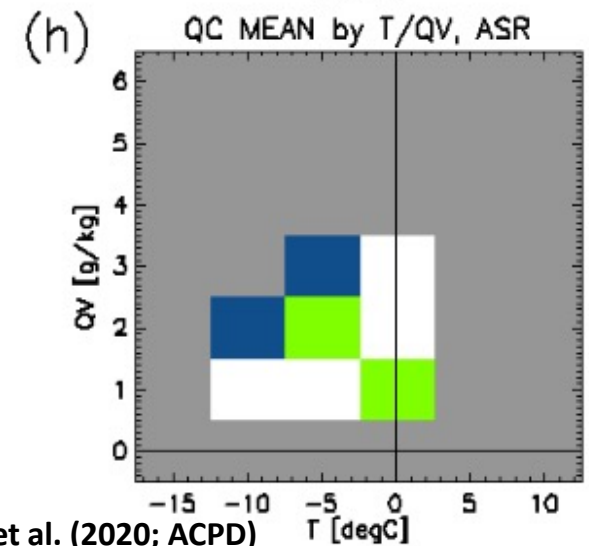
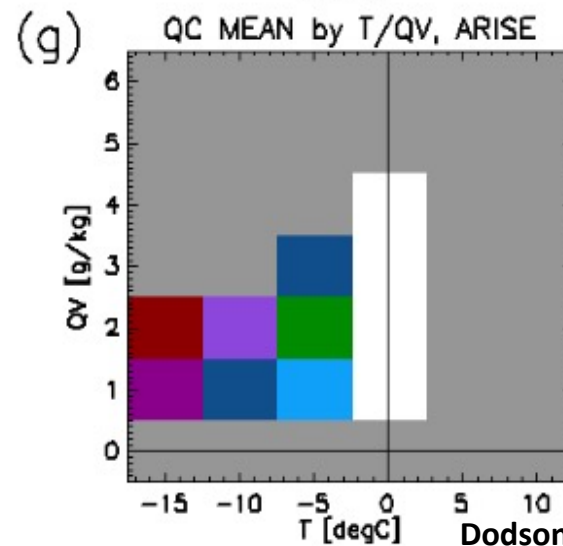
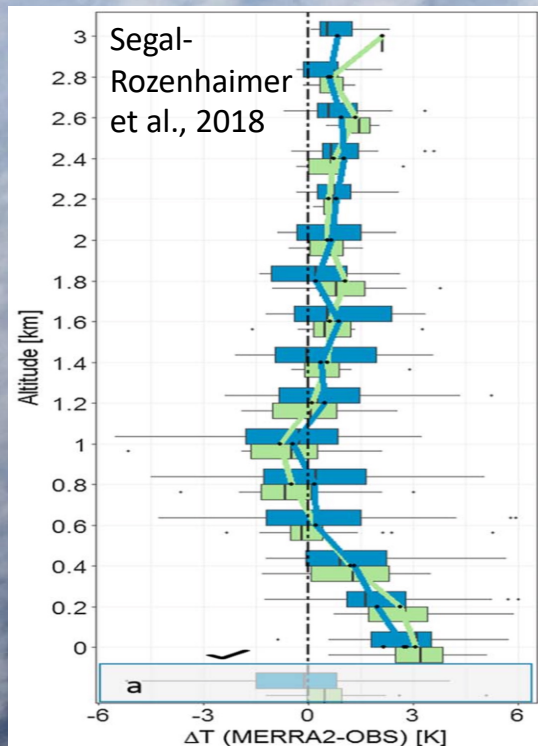


CMIP5 models show varied representations of the warming and cooling effects of clouds on the Arctic surface energy budget.

Why ARCSIX?

...model uncertainty stems from errors in the thermodynamic state of the lower Arctic atmosphere.

Probability distributions of lower tropospheric temperature and humidity in reanalysis diverge from airborne observations...



...as a result there are also large differences in cloud condensate (Dodson et al. 2020).

Overarching Objective

Quantify the contributions of clouds, aerosols, and precipitation to the Arctic summer surface radiation budget and sea-ice melt

SQ1: RADIATION

What is the impact of the predominant summertime Arctic cloud types on the radiative surface energy budget?

1.1: What is the relative contribution of thin low-level clouds and synoptically-forced multi-layer cloud systems to the surface radiative energy budget and its spatio-temporal variability?

1.2: How does the surface reflectance change with melt and precipitation events? How does surface variability affect the cloud radiative effect and surface fluxes?

1.3: What are the dominant error sources for state-of-the-art clear-, cloudy-, and all-sky estimates of surface radiative flux?

SQ3: SEA ICE

What is the **two-way** relationship between surface radiation, clouds, precipitation, surface properties and the seasonal evolution of sea ice?

3.1: How does the evolution of sea ice properties (topography, thickness, and surface characteristics) affect clouds, advected air masses, and near surface temperature and humidity structures?

3.2: What is the combined impact of initial surface conditions and changing atmospheric forcings (radiation, clouds, precipitation, etc) on the evolution of sea ice throughout the melt season?

SQ2: CLOUD LIFE CYCLE

What processes control the evolution and maintenance of the predominant cloud regimes in the summertime Arctic?

2.1: How do key parameters such as liquid/ice water path, cloud particle size distribution, thermodynamic structure, CCN/INP, and precipitation rate influence low cloud evolution?

2.2: How do initially cloudy or clear air masses evolve as they move poleward from midlatitudes and interact with changing surface conditions?

2.3: How do clouds evolve in response to local and remote aerosol sources?

REMOTE SENSING & MODELING OBJECTIVE

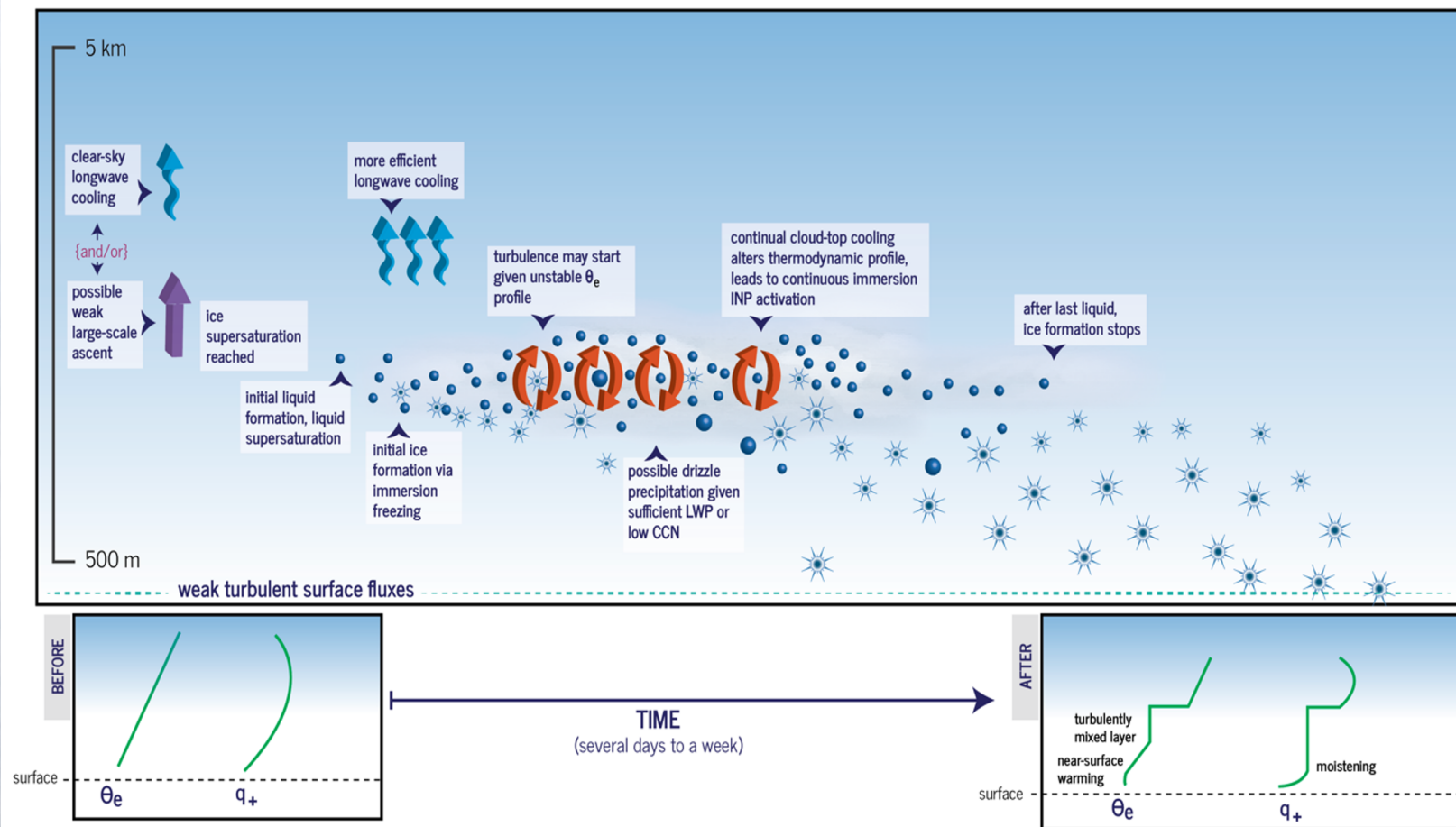
Generalize the aircraft observations of radiation-cloud-aerosol-surface interactions collected regime by regime by putting them in context with satellite observations and models on a range of scales, while validating and improving remote sensing in the Arctic.

clouds
albedo
fluxes

coupling
forcings

regimes
evolution

ARCSIX SQ2: Cloud lifecycle

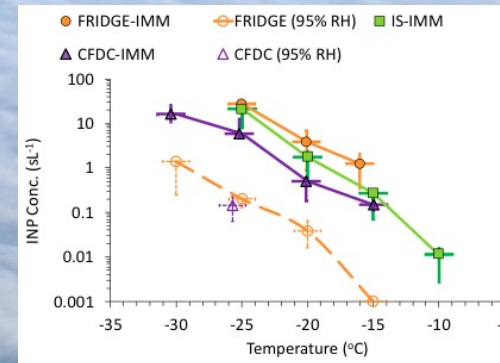


This conceptual picture of the Arctic low cloud lifecycle serves as a key hypothesis and represents a series of understood processes incompletely captured in NWP and climate models.

ARCSIX SQ2: Clouds

2.1: How do key parameters such as liquid/ice water path, cloud particle size distribution, thermodynamic structure, CCN/INP, and precipitation rate influence low cloud evolution?

regimes



Immersion freezing (“-IMM”) is more effective than deposition ice nucleation at near-saturated (95% RH) conditions.

Key Hypotheses:

- Hypothesis 2.1a: Arctic cloud systems formed and maintained by advection of moisture from lower latitudes, radiative cooling, and (when supercooled) sparse INP.
- Hypothesis 2.1b: Pre-existing water vapor structure determines initial cloud vertical structure, longwave radiation cooling, and turbulence.
- Hypothesis 2.1c: Immersion freezing is responsible for most (>90%) ice formation in clouds warmer than -35°C.

Approach:

- Collect measurements of aerosol and cloud evolution parameters (including liquid and water content, LWP/IWP, cloud liquid and ice particle size distribution, in-cloud turbulence, aerosol size distribution and composition, CCN/INP concentration and composition, INP mode, precipitation, and cloud top radiative fluxes) concurrently with thermodynamic profile information from the surface up to ~5 km to characterize the spatial and temporal variability.
- Perform flights to sample conditions below, in, and above clouds in a range of meteorological regimes to assess the influence of different microphysical processes on cloud properties as a function of atmospheric conditions and cloud life cycle stage.

ARCSIX SQ2: Clouds

2.2: How do initially cloudy or clear air masses evolve as they move poleward from midlatitudes and interact with changing surface conditions?

Key Hypotheses:

- *Hypothesis 2.2a: Air mass transformation is substantially different in initially clear or cloudy airmasses.*
- *Hypothesis 2.2b: >50% of the atmospheric moisture and aerosol enters the study domain episodically.*
- *Hypothesis 2.2c: More than a week is required to transform lower latitude air into Arctic air.*

Approach:

- Characterize the air mass thermodynamic and aerosol properties (temperature and humidity curtains, aerosol size distribution, vertical distribution, and composition), air mass cloud properties (cloud particle size distribution, LWP/IWP), regional cloud distribution (satellite image retrievals), and radiative fluxes.
- Perform Lagrangian flights with two coordinated aircraft to track the coupled evolution of air mass thermodynamic transformation, aerosol and cloud properties, and radiation informed by temperature and moisture advection from data assimilation and satellite imager derived cloud properties.
- Evaluate the moisture and aerosol conditions associated with background and episodic events.

ARCSIX SQ2: Clouds

2.3: How do clouds evolve in response to local and remote aerosol sources?

Key Hypotheses:

- *Hypothesis 2.3a: Substantial local sources of CCN and INP exist over ice-free ocean, not over sea ice covered areas.*
- *Hypothesis 2.3b: Local thermodynamic properties are more important to the episodic transport events to cloud evolution.*

Approach:

- Determine the spatial structure of aerosol properties (size distribution and composition), proxies/gas tracers and CCN/INP concentrations and composition surrounding Arctic clouds, along with cloud droplet/crystal size distributions (by phase) for a range of contrasting aerosol environments (e.g., pristine vs. advection-influenced by dust or pollution), meteorological conditions and surface types, as well as across air mass boundaries.
- Determine cloud responses to CCN and INP vary under different meteorological conditions and validate poorly constrained aerosol models over the region.

Takeaways...(what should I go and tell my neighbor?)

What is ARCSIX? A NASA airborne investigation planned for late spring/early summer 2024 based in Thule, Greenland driven by the need to understand how the coupling between the atmosphere and the surface influence energy flows and ultimately sea ice melt.

Why ARCSIX? The Arctic is a region that is changing fast with implications for natural and human systems within and outside of the Arctic. Collecting and analyzing data that advances our understanding of the factors that influence sea ice loss with enable better projections and decisions, improving our lives.

Questions?

Email: Patrick.c.taylor@nasa.gov