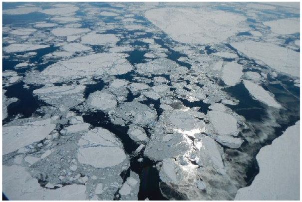
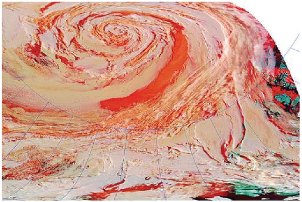
Upcoming atmospheric observations and science: A new airborne mission to improve Arctic atmosphere and sea ice predictability

Steven Cavallo[1]

Arctic System Change Workshop
10 April 2018

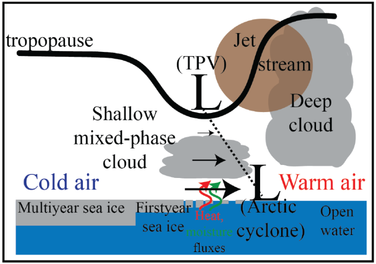


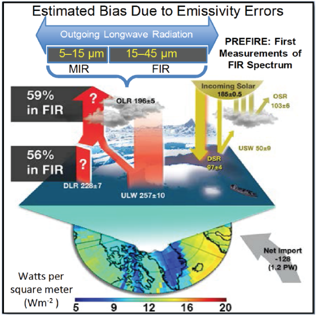


[1] University of Oklahoma, School of Meteorology, Norman, OK

Observations to improve knowledge of Arctic processes

New *aircraft* observations aimed to improve atmospheric and sea ice dynamics ⟷ New *satellite* observations aimed to improve surface radiation budget

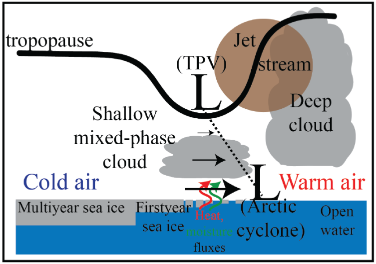




- TPVs ⟷ Arctic cyclones ⟷ Sea ice (THINICE; Cavallo)
- Surface thermal radiation ⟷ Sea ice/ice sheets ⟷ Water vapor/clouds (PREFIRE; L'Ecuyer)

Observations to improve knowledge of Arctic processes

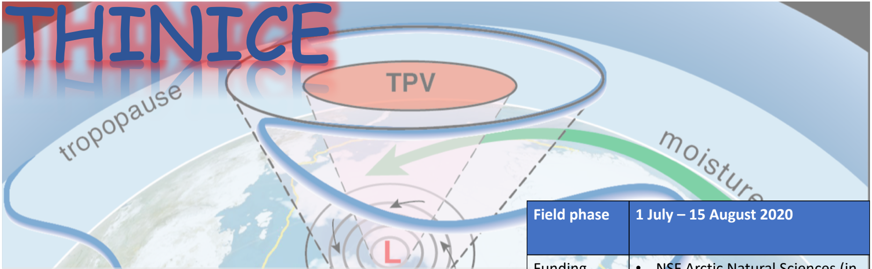
New ***aircraft*** observations aimed to improve atmospheric and sea ice dynamics



Scientific Goals:

1. ***Advance*** knowledge of pan-Arctic atmospheric processes and the coupling of these processes with underlying sea surface and sea ice in summer,
2. ***Develop*** observing strategies to better document and understand rapid changes in the Arctic on daily to monthly timescales,
3. ***Collect*** measurements that will provide the framework necessary to evaluate and advance reanalyses and weather and climate system models

Observations to improve knowledge of Arctic processes: THINICE

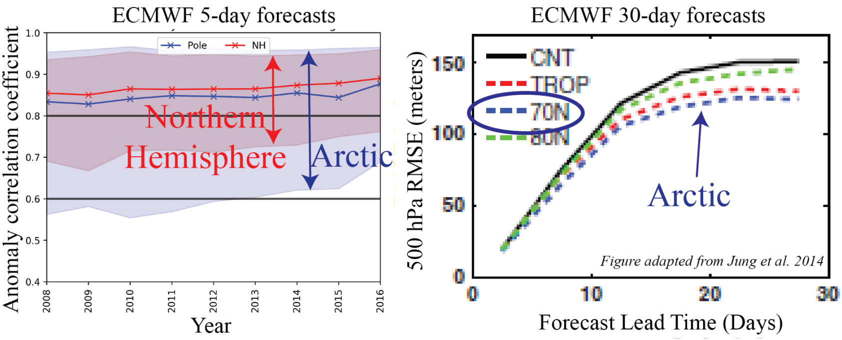


Core Science Steering Committee:

Steven Cavallo (PI), University of Oklahoma
David Parsons (Co-PI), University of Oklahoma
Cecilia Bitz, University of Washington
Steven Businger, University of Hawaii
James Doyle, Naval Research Laboratory

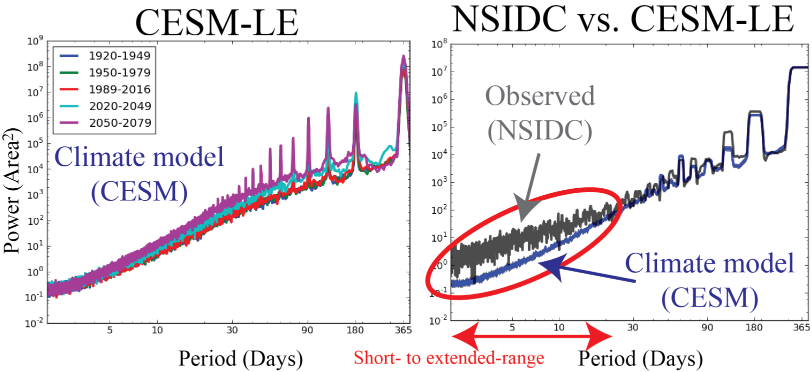
Field phase	1 July – 15 August 2020
Funding	• NSF Arctic Natural Sciences (in review) • ONR (5-year DRI: Overcoming the Barrier to Extended Range Prediction over the Arctic)
Partners	11 Universities + NCAR + NRL + NOAA + NASA+ NCEP + ECMWF
International coordination	NERC (UK)/NSF (with NERC as lead agency), Year of Polar Prediction (YOPP), MOSAiC

Forecast skill in the Arctic



- Global atmospheric prediction is most sensitive to unknown Arctic processes at extended forecast range (e.g., Jung et al. 2014).
- More forecast “drop-outs” in Arctic in comparison to Northern Hemisphere.
- Key polar processes have not been identified, and are therefore not well-represented in models.

What time scales do changes in sea ice vary?



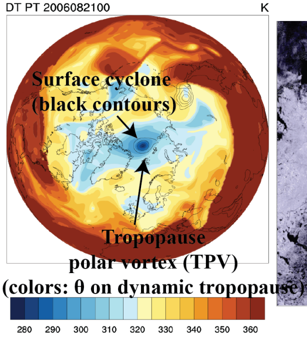
- Observed sea ice extent variability at "weather" time scales is not accounted for in sophisticated climate models.
  $\rightarrow$ Future projections from climate models do not account for sea ice loss from weather processes.

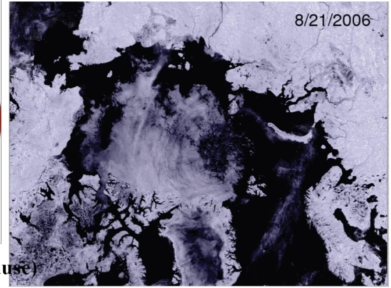
Do weather processes have an impact on sea ice?

Upper-tropospheric disturbances induce surface cyclones

Strong surface cyclones $\rightarrow$ strong surface wind

More open water $\rightarrow$ increased fetch, wave amplitude, ice fracturing (Collins et al. 2015), failure (Asplin et al. 2014)

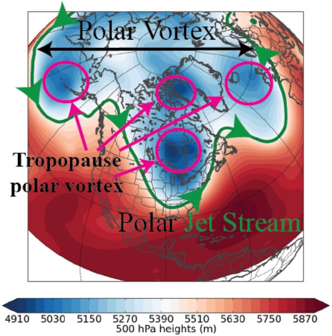




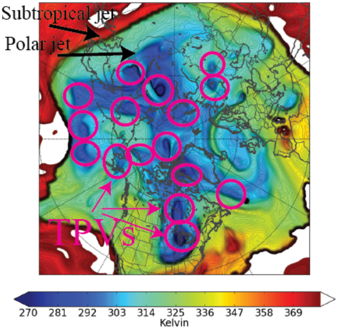
Representing the Arctic atmosphere is a multiscale problem

TPVs are important precursors, and can sometimes exist **months** before the formation of a surface cyclone.

500 hPa geopotential heights



Potential temperature (θ) on dynamic tropopause



A consequence of reduced horizontal scales in Arctic atmosphere:

Waves are dominant in tropics and middle latitudes, whereas **vortices dominate in high latitudes**.

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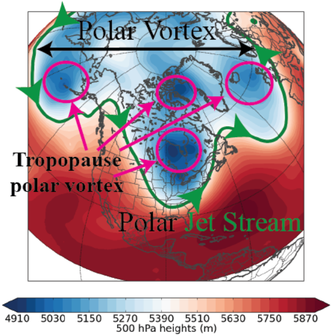

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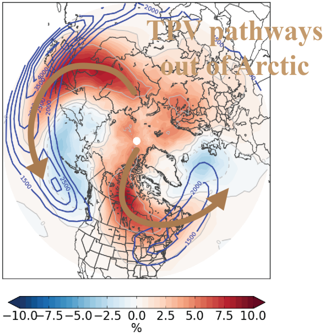

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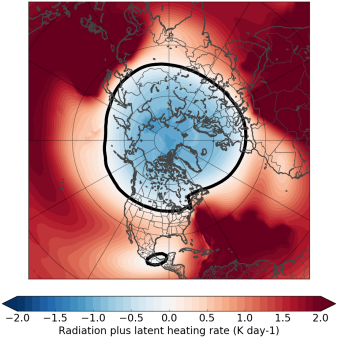
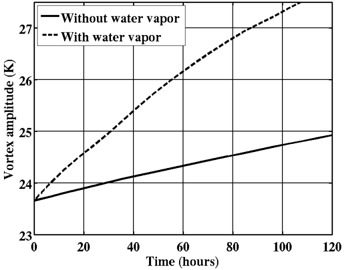
Tropopause polar vortices (TPVs)

Physical processes dominated by radiation and water vapor

Radiation + Latent heating climatology



Idealized modeling experiment of a TPV with and without water vapor



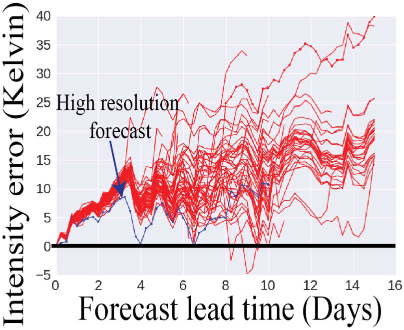
See also Cavallo and Hakim 2012,2013

Details in water vapor are important in order to accurately represent processes, but water vapor is only sparsely observed in upper troposphere and lower stratosphere

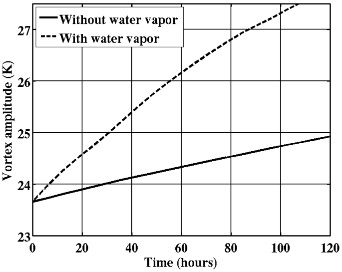
Tropopause polar vortices (TPVs)

Physical processes dominated by radiation and water vapor

TIGGE intensity error of TPVs



Idealized modeling experiment of a TPV with and without water vapor



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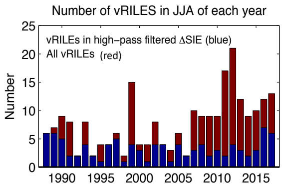
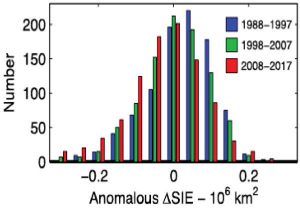
Observations to improve knowledge of Arctic processes: THINICE





- Arctic sea ice can undergo large-scale Very Rapid Ice Loss Events (vRILEs) on time-scales of days, and predictability is low. ***A fundamental understanding of the processes at these short time scales (i.e., "Weather scales") that impact sea ice is lacking.***

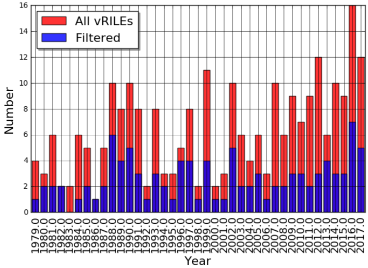
- vRILEs are increasing in frequency over time, and may contribute to up to half of the total summer ice loss.

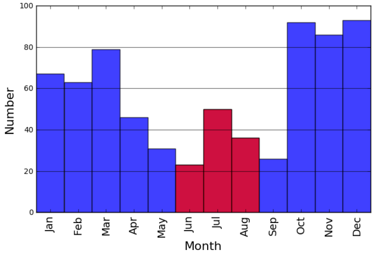
- Arctic cyclones have strong correlations with vRILEs, such as "The Great Arctic Cyclone of 2012"

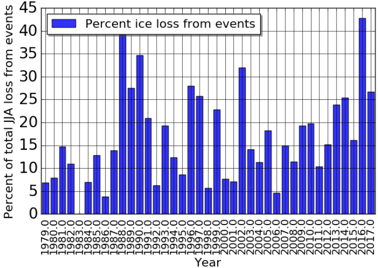
- There have ***never before been measurements*** to quantify the **feedbacks between Rossby wave breaks, Tropopause Polar Vortices (TPVS), Arctic cyclones, and sea ice**:
  - How thin does sea ice need to be for atmospheric wind to impact it?
  - Are ocean waves generated during cyclone events when ice is fractured, and does this accelerate ice loss?
  - What are the uncertainties in the tropopause disturbance precursors of Arctic cyclones (i.e., TPVs), and how does this impact the prediction of Arctic cyclones?

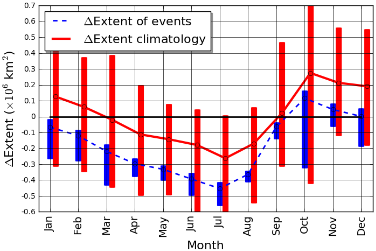
Very Rapid Sea Ice Loss Events (vRILEs)

Composites of top 5% rapid sea ice loss events





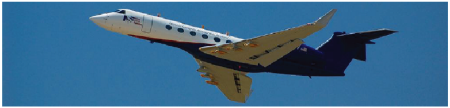




NSF/ONR THINICE Program

- Key platforms: NCAR G-V, Satellite Obs. (w/ YOPP, MOSAiC, other programs)
- G-V Base Possibilities: Longyearbyen, Norway; Thule Air Base, Greenland; Prudhoe Bay, AK; Kiruna, Sweden, Bodø, Norway
- Possible G-V Instrument Payload:
  - ➔ Flight-level parameters including temperature, humidity, wind, turbulence, cloud and precipitation probes
  - ➔ Microwave Temperature Profiler (MTP)
  - ➔ AVAPS dropsondes
  - ➔ HIAPER W-Band Cloud Radar (HCR)
  - ➔ High Spectral Resolution Lidar (HSRL)
  - ➔ Fast Ozone, GISMOS occultation sensing system, Kipp and Zonen CGR4 pyrgeometers, gust probes

NSF/NCAR G-V



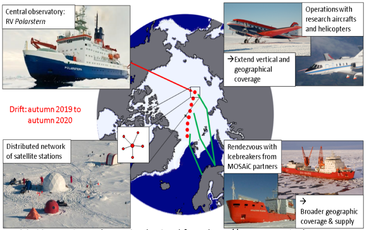
THINICE collaborations with YOPP, MOSAiC

- THINICE will contribute to the goal of **NSF's Navigating the New Arctic "10 Big Ideas for Future Investments"** through efforts to obtain Arctic observations enabling discovery and simulation of the key processes within the Arctic system.

- The **Office of Naval Research** DRI "Overcoming the Barrier to Extended Range Prediction over the Arctic" is only funded for a field phase until September 30, 2020. ***Summer 2020 is the only window for which ONR can collaborate with THINICE***.

- THINICE is endorsed by World Meteorological Organization (WMO)'s World Weather Research Programme (WWRP) **Year of Polar Prediction (YOPP)**, for which its ***final phase is Summer 2020***.
  - Period of intensive observing, modeling, verification, user-engagement and education activities aimed at significantly improving environmental prediction capabilities for the polar regions and beyond on a wide range of timescales.

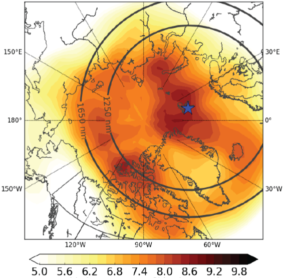
- **MOSAiC** is a component of YOPP aimed at enhancing the understanding of the regional and global consequences of Arctic climate change and sea-ice loss and improving weather and climate predictions.
  - The primary platform of MOSAiC will be the icebreaker *RV Polarstern*, which will drift with the sea ice across the central Arctic ***beginning in October 2019 and exiting the ice by October 2020***.
- Collaboration with **United Kingdom: NERC-NSF** is proposing instrumented Twin Otter research aircraft to provide measurements of the surface and PBL in the Arctic.



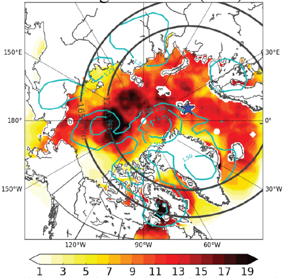
MOSAiC overview schematic obtained from http://www.mosaicobservatory.org/

THINICE airborne field campaign

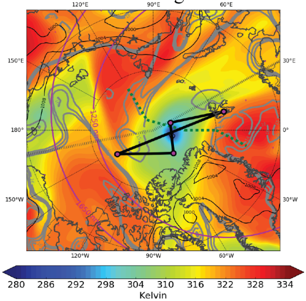
Probability of TPV per day (JJA)



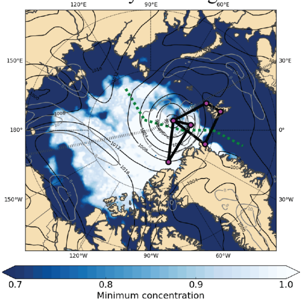
Locations of Arctic cyclones leading to vRILE (JJA)



Possible TPV flight mission



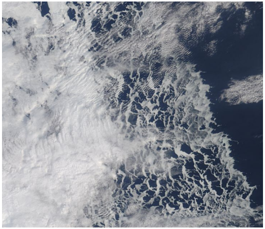
Possible Arctic cyclone flight mission



Summary

- Atmospheric processes at short- to extended- ranges are important in Arctic, yet processes not yet well understood:
  - ➔ Arctic is dominated by small-scale features, such as vortices rather than waves.
  - ➔ Arctic cyclones play important role in sea ice loss.
- High-resolution atmospheric model **and** fully-coupled Earth-system components are needed account for the small-scales and atmosphere/ocean/sea-ice interactions
  - ➔ Targeted observations, data assimilation are crucially needed in order to improve atmospheric models.
- New aircraft observation campaign is planned to obtain measurements that target:
  - ➔ Mesocale structures important for TPV growth and evolution such as moisture and clouds,
  - ➔ Poleward heat and moisture transport from lower latitudes into Arctic cyclones from Rossby waves,
  - ➔ Breakup of sea ice from Arctic cyclones.

THINICE: Scientific hypotheses



Hypothesis 1. **Arctic cyclones are primarily responsible for vRILEs through ocean waves, ocean upwelling, and atmospheric stresses exerted on relatively thin ice.**

- ***Objective: Distinguish cyclones that do lead to vRILEs from those where couplings between atmosphere, ocean, and sea ice are inactive at short time scales.***

Hypothesis 2. **Increases in the frequency of vRILEs over time is due to a positive feedback between Arctic cyclones, sea ice becoming thin enough for corresponding atmospheric stresses to have an impact at short time scales, and the dynamical coupling of Arctic cyclones with TPVs.**

- ***Objective: Determine the factors that lead to known systematic biases in TPV intensity, such as clouds and water vapor, that are important for the predictability of Arctic cyclones.***

Hypothesis 3. **The dynamical impact of Rossby waves plays a key role in sea ice loss through both creating favorable conditions for melting in warm anticyclonic vortices that are relatively cloud free and through changes in the polar votex inducing cyclogenesis as TPVs are advected over low-level baroclinic zones.**

- ***Objective: Characterize the 3-dimensional thermodynamic, kinematic and cloud characteristics of the lower latitude air flowing into Arctic cyclones.***

THINICE: Science Traceability

Hypothesis	Required observations	Instruments	G-V deployment strategy
(H1) Arctic cyclones are primarily responsible for vRILEs through ocean waves, ocean upwelling, and atmospheric stresses exerted on relatively thin ice.	Horizontal, vertical distribution of clouds, precipitation and thermodynamic and dynamic variables Turbulent flux of momentum and moisture Daily changes in sea ice state Horizontal movement of sea ice	(NCAR): Heated temperature sensor, dropsondes, VCCEL, LAMS, GPS, MTP, HCR, HSRL, Gust Probe, Lyman-alpha hygrometer, HARP, Kipp & Zonen pyrgeometers Polar Orbiting Earth Satellites (POES)	Cloverleaf or butterfly flight pattern to obtain data from the center of the Arctic cyclone outward to the edge of the Arctic; Upper- and lower-altitude samples; dropsondes deployed to sample low-level jet, elevated or surface-based inversions.
(H2) Increases in the frequency of vRILEs over time is due to a positive feedback between Arctic cyclones, sea ice becoming thin enough for corresponding atmospheric stresses to have an impact at short time scales, and the dynamical coupling of Arctic cyclones with TPVs.	Vertical distribution and in-situ flight level measurements, including radiation Horizontal and vertical distributions of dynamic, thermodynamic, and moisture variables Low-level winds, thermodynamics and cloud fields and surface fluxes	(NCAR): Heated temperature sensor, dropsondes, VCCEL, LAMS, GPS, MTP, HCR, HSRL, Gust Probe, HARP, Fast Ozone, Kipp & Zonen pyrgeometers Polar Orbiting Earth Satellites (POES)	Flights in the lower stratosphere; butterfly flight pattern that transects TPVs from the edge of the vortex and across the TPV through the TPV center; Possible lower-altitude samples to corroborate vertical differences in temperature and moisture; dropsondes deployed to sample vertical profiles across TPVs
(H3) The dynamical impact of Rossby waves plays a key role in sea ice loss through both creating favorable conditions for melting in warm anticyclonic vortices that are relatively cloud free and through regime change inducing cyclogenesis as TPVs are advected over low-level baroclinic zones	Horizontal, vertical distribution of clouds, precipitation and thermodynamic and dynamic variables and turbulence	(NCAR): Heated temperature sensor, dropsondes, VCCEL, LAMS, GPS, MTP, HCR, HSRL, HARP, Fast Ozone, Kipp & Zonen pyrgeometers	Maximum possible altitude; flight legs normal to the warm conveyor belt; Possible lower-altitude upstream samples; dropsonde samples deployed to sample Warm Conveyor Belt (WCB)