NASA's NURTURE Field Campaign: High-Resolution Observations of the Atmospheric Dynamics Resulting in High-Impact Weather

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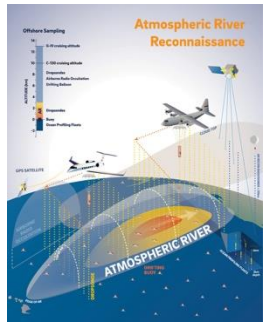
And on behalf of the Science and Instrument Team

North Atlantic Waveguide, Dry Intrusion and Downstream Impact Campaign



NURTURE
NORTH AMERICAN UPSTREAM FEATURE-RESOLVING AND TROPOPAUSE UNCERTAINTY RECON EXPERIMENT

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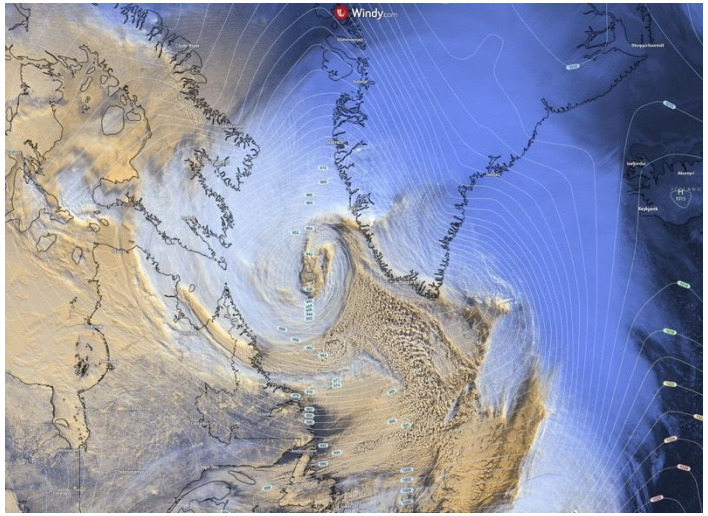
Why Do We Care? High-Impact Weather

High-impact weather (HIW) events have significant socioeconomic costs and pose direct threats to national security (e.g., destabilizing supply chains and damaging infrastructure).



- ***Medium-to-extended*** forecast lead times continue to pose a challenge for state-of-the-art numerical weather prediction (NWP) models.
- These challenges can be attributed to the multiscale interactions of physical processes.
- The predictability of HIW is linked to accurate depictions of the jet streams.
- Improved sampling and understanding of jets streams and precursor mesoscale structures are needed to improve ***medium-to-extended range forecasts***.

Pre-Groundhog Day North American Bomb Cyclone

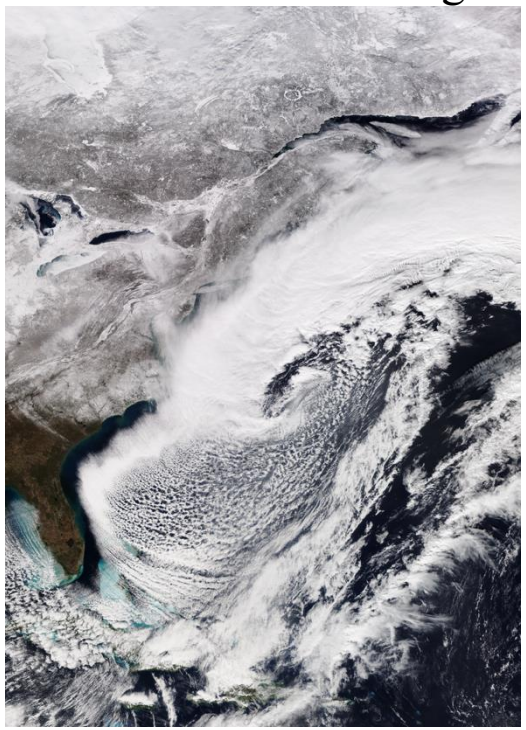
- Impacted southeastern U.S. Jan. 30 – Feb. 2, 2026

- **$13–$15 Billion in total damage** and economic loss to the U.S.
  - Heavy snow, wind damage, travel disruptions, business closures, extensive crop damage

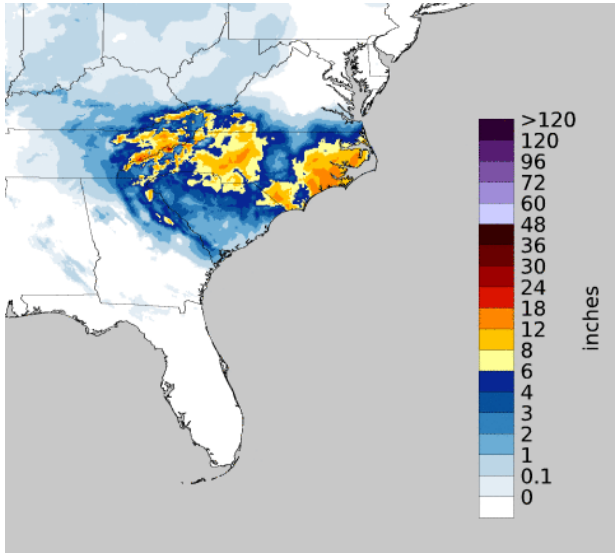
- Associated with a TPV that formed from a potential vorticity (PV) filament just west of Goose Bay on Jan. 26

- ***NURTURE 2026 sampled the precursor TPV with 3 research flights from near when it formed (Jan. 26 / RF2), strengthening (Jan. 27 / RF3), and weakening (Feb. 1 /RF5)***
  - TPV went out of range Jan. 28 – Jan. 31
  - Sampled it again on Feb. 1 / RF5 when it came back into range over the North Atlantic

Visible Satellite Image



Snowfall amounts



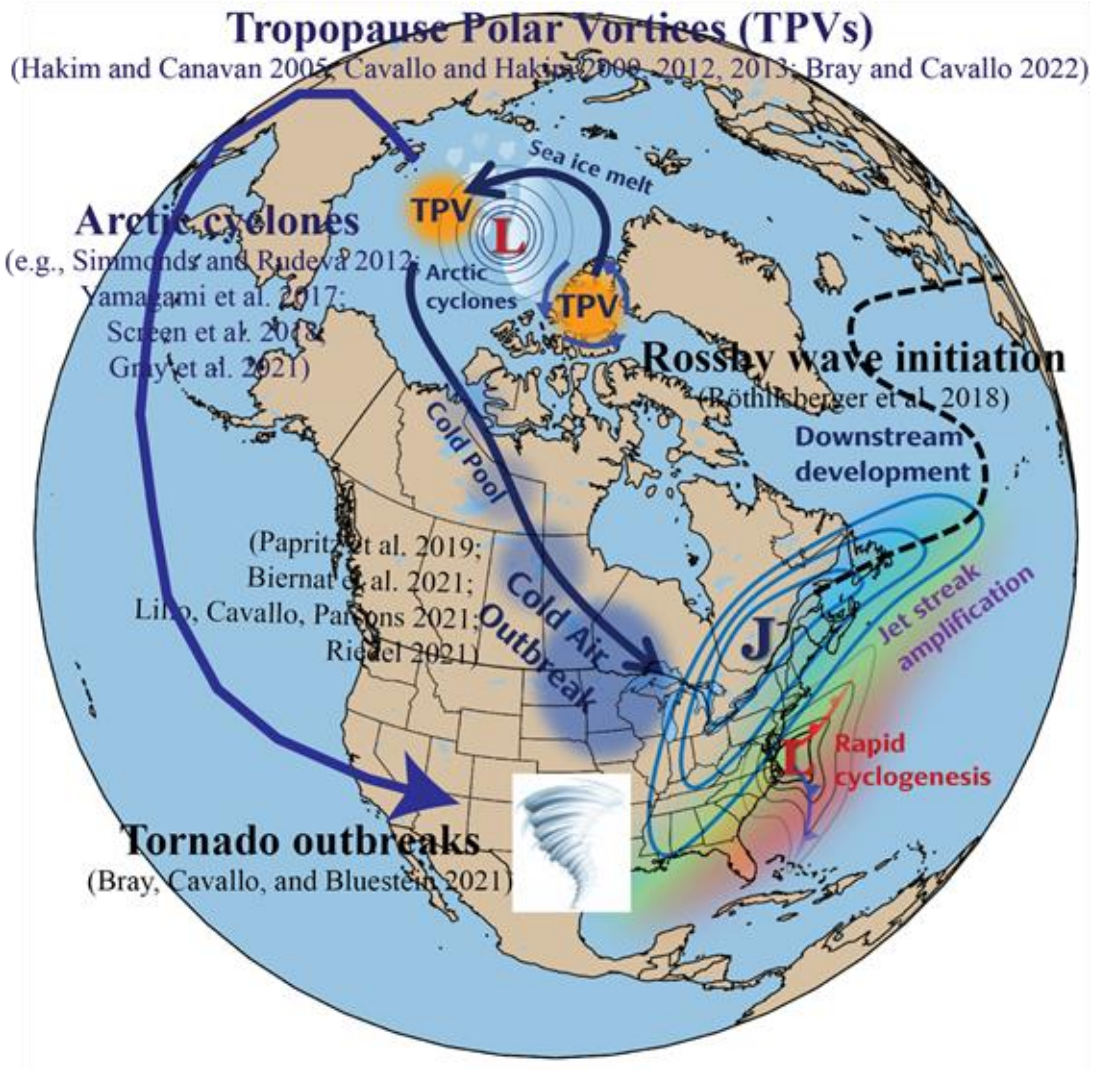
Precursors to High Impact Weather (HIW)

- NURTURE aims to collect high-resolution observations of antecedent tropopause structure and near-jet environment that lead to HIW.
- What antecedent dynamics will we target?
  - ➢ Tropopause Polar Vortices (TPVs)
  - ➢ Dynamics supporting jet superpositions
  - ➢ Mesoscale stratosphere-troposphere interactions
  - ➢ Diabatic processes (e.g., upscale growth of PV anomalies, cloud-radiative feedback, turbulent generation of PV near jets)
- Operations are occurring in two phases:

✓ Phase 1: NASA Langley G-3 based out of Goose Bay (Winter 2026)

➢ Phase 2: NASA Boeing 777 (Winter 2027)

- ➢ Long-range and substantial payload capacity to study multiscale processes
- ➢ This is the very first mission for the NASA 777!



What is a TPV?

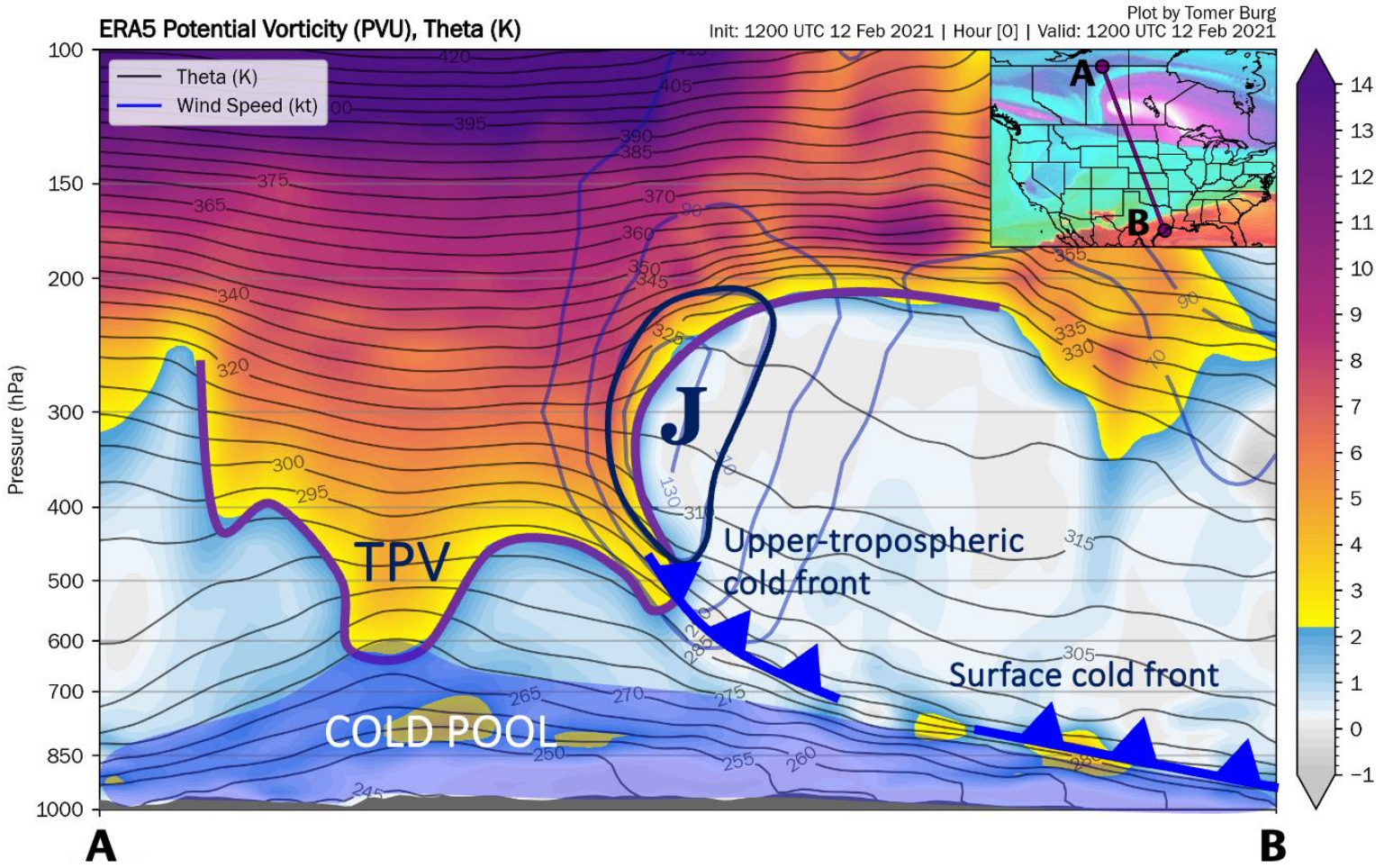
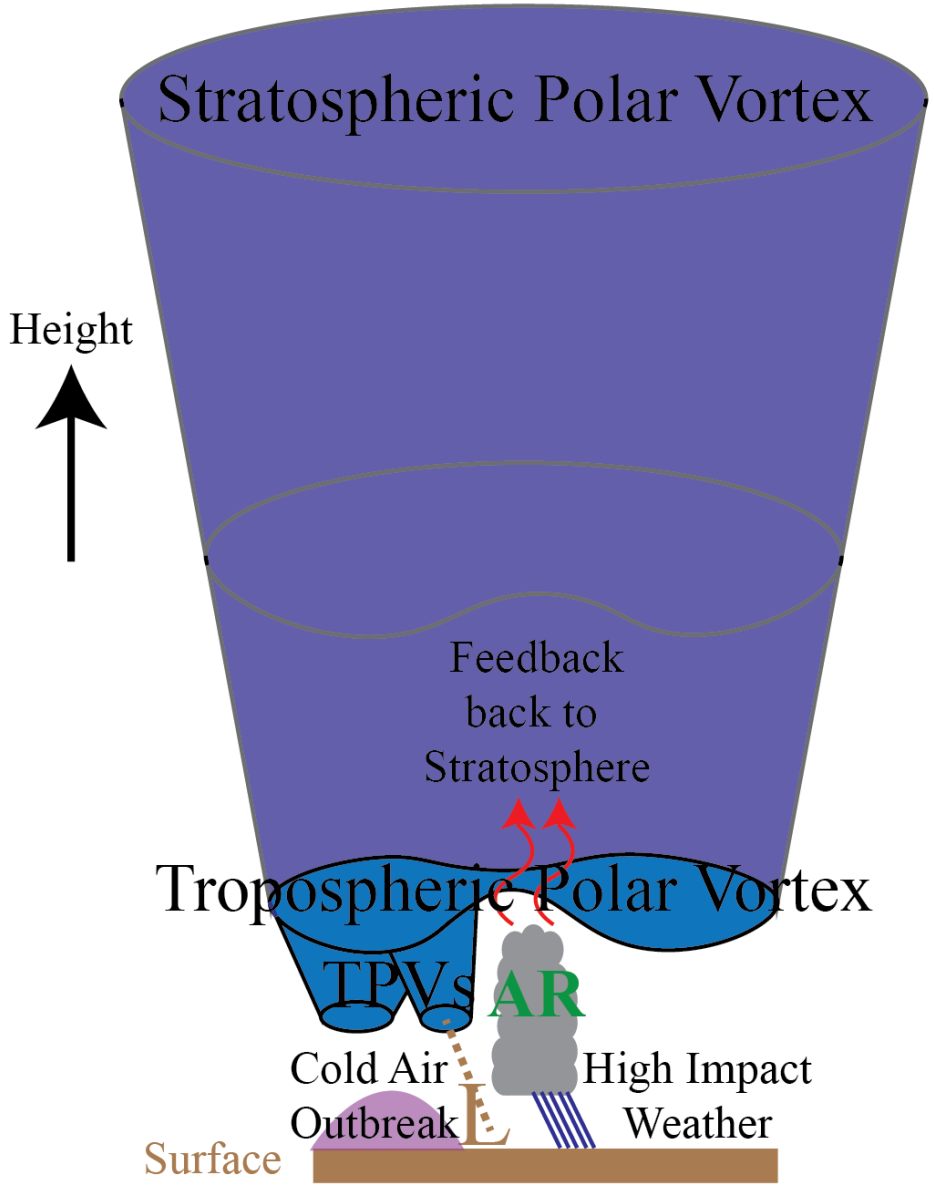


Image credit: Tomer Burg

Tropopause Polar Vortices (TPVs):

- ***Sub-synoptic spatial scale*** coherent vortices with average radii ~400 km (Cavallo and Hakim 2012),
- Are among the ***longest-lived features in the atmosphere***, with lifetimes of up to several months (Bray and Cavallo 2022),
- Are **precursors to surface cyclones** (Bray and Cavallo 2026),
- Intensify diabatically due to the longwave radiative response from ***moisture anomalies*** in the vortex core (Cavallo and Hakim 2013).

Multiscale Processes and Feedbacks



- NURTURE is applying a multiscale approach to observe feedbacks between the surface, boundary layer, upper troposphere, and lower stratosphere

- How do the scales break down from: planetary-scale stratospheric polar vortex → large-scale tropospheric polar vortex → TPVs → boundary layer → surface

- ***Impacts include:***
  - ***Destructive surface cyclones***
  - ***Extreme cold air outbreaks***
  - ***Heavy precipitation and flooding***

NURTURE 2026 Overview

19 Research Flights

110 Research Flight Hours

118 Dropsondes

H2O DIAL/HSRL,

CloudCube Radar,

Dropsondes,

Airborne Occultation,

NASDAT, Trace Gas functioning on all 19 flights (except ozone was down on RF9, RF10, RF11)

4 EarthCARE Satellite underpasses (RF8, RF9, RF12, RF14)

3 Arctic Weather Satellite underpasses (RF7, RF10, RF17)

1 Coordinated mission with NAWDIC (RF12)

Simultaneous EarthCARE overpass and sampling of remnant TPV south of Newfoundland. Feature led to an AR landfall in western Europe

G3 flew at 28,000 ft, DLR HALO flew at 43,000 ft

Science Questions Addressed

1.1: What are the diabatic and kinematic processes governing the development and maintenance of TPVs?

✓ 14 missions

1.2: How does jet stream amplification occur in the presence of TPVs, and what are the implications for downstream HIW?

✓ 5 missions

2.1 How does moisture impact the diabatic processes important for determining the three-dimensional structure in the upper troposphere and lower stratosphere (UTLS) in the vicinity of TPVs and the polar jet stream?

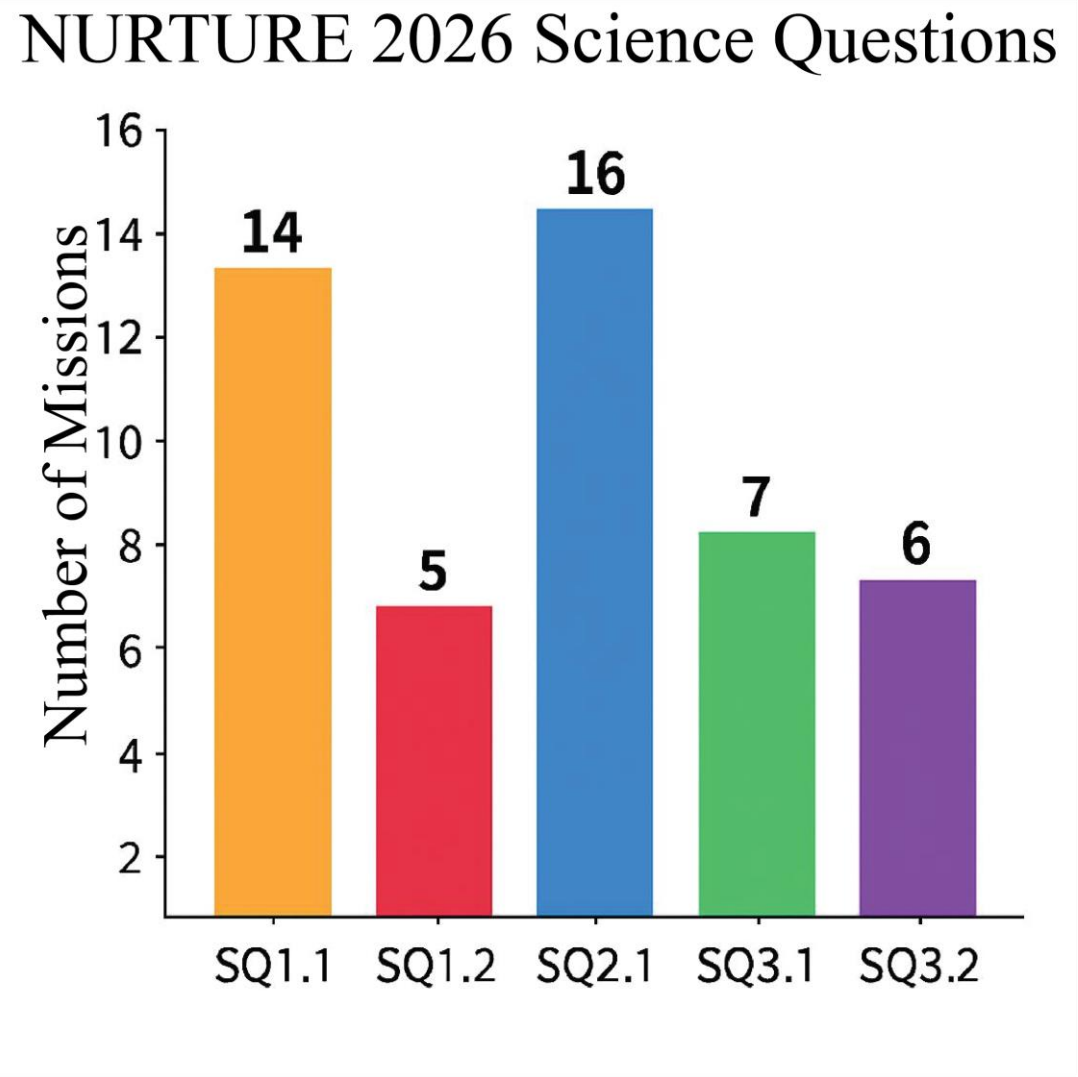
✓ 16 missions

3.1: How do processes related to TPVs generate cold continental airmasses and lead to cold air outbreaks?

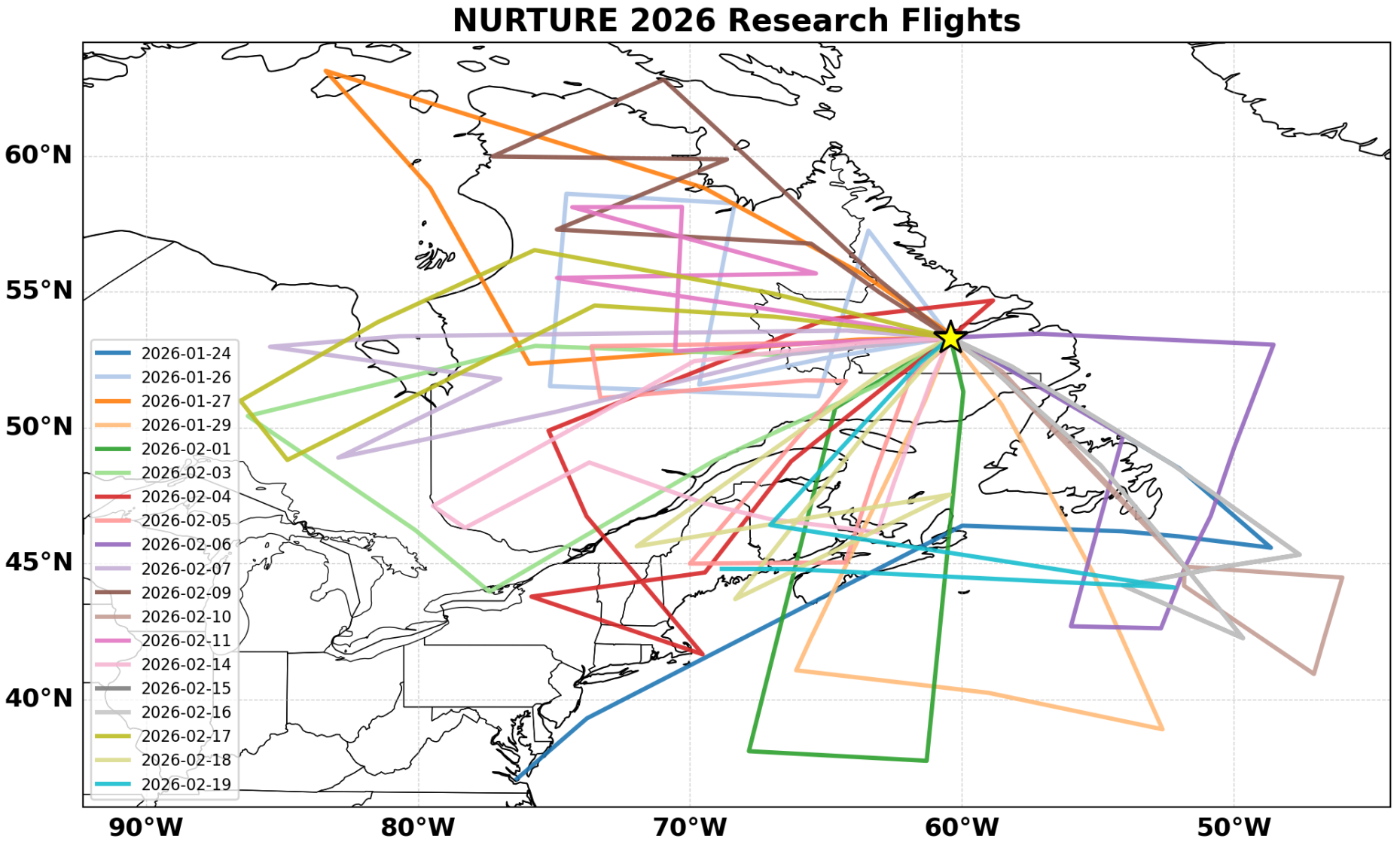
✓ 7 missions

3.2: How do cold continental air masses evolve over maritime regions and feed back to UTLS structure?

✓ 6 missions



NURTURE 2026 Research Flights



Map courtesy of Stephen Nicholls

Summary of Research Flights

Date	Research Flight	Mission Name	Impacts	TPV Transects	Operational Status
24-Jan	RF1	Transit TPV	Winter Storm Fern (North America)	1	
25-Jan					Hard down
26-Jan	RF2	PV Filament		3 (filament)	
27-Jan	RF3			1	
28-Jan					Weather down
29-Jan	RF4	PV Filament A	Sampled by NAWDIC on 31 January (IOP9 "Nenagh")	1	
30-Jan			North American Bomb Cyclone		Weather down
31-Jan					Hard down
1-Feb	RF5	PV Filament B		1	
2-Feb					Weather down
3-Feb	RF6	TPV West		1	
4-Feb	RF7			1	
5-Feb	RF8	PV Streamer		2	
6-Feb	RF9			2	
7-Feb	RF10	NAWDIC TPV		4	
8-Feb					Hard down
9-Feb	RF11	Northern Quebec TPV		4	
10-Feb	RF12	NAWDIC TPV		1	
11-Feb	RF13	Northern Quebec TPV		4	
12-Feb					Weather down
13-Feb					Hard down
14-Feb	RF14	Northern Quebec TPV	Winter Olympics Snowstorm	2	
15-Feb	RF15			3	
16-Feb	RF16			2	
17-Feb	RF17	James Bay TPV		1	
18-Feb	RF18			2	
19-Feb	RF19		UK Cyclone	2	
20-Feb			959-hPa low south of Greenland		
			Total TPV transects	35	

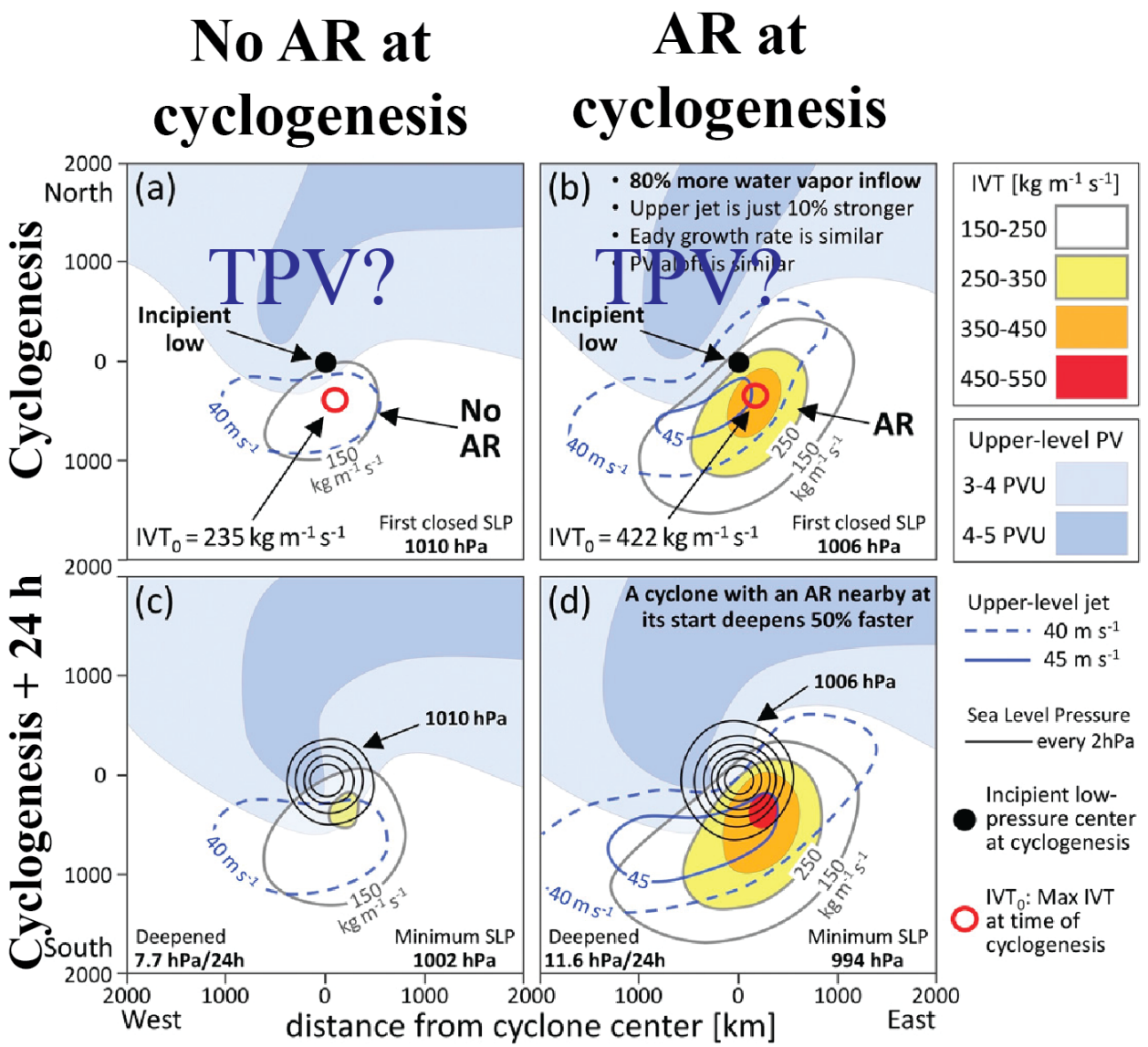
Atmospheric Rivers (ARs) and TPVs

- ARs are associated with surface cyclones
- But, ARs can be present before a surface cyclone develops

- 30-year composites in the North Pacific show that there is an upper-level trough preceding the development of ARs and surface cyclones

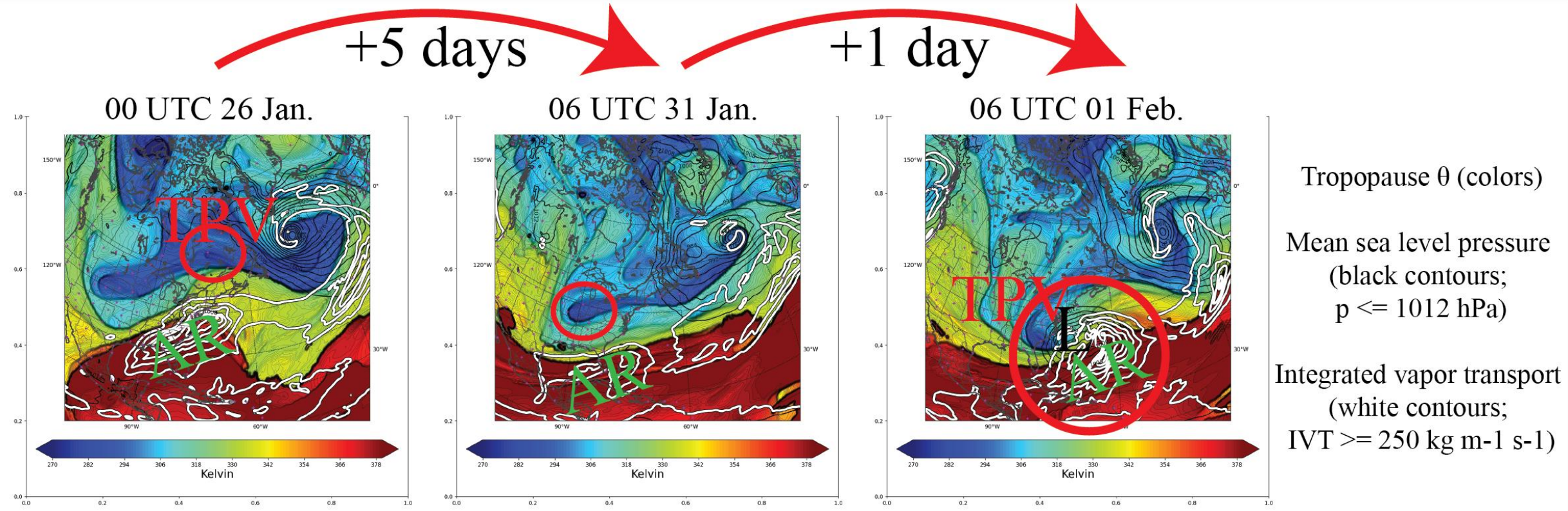
- Are TPVs in the preceding upper-level trough?

➢ If so, then TPVs could lend additional predictability to ARs



Adapted from Figure 15 of Zhang and Ralph (2021)

Atmospheric Rivers (ARs) and TPVs

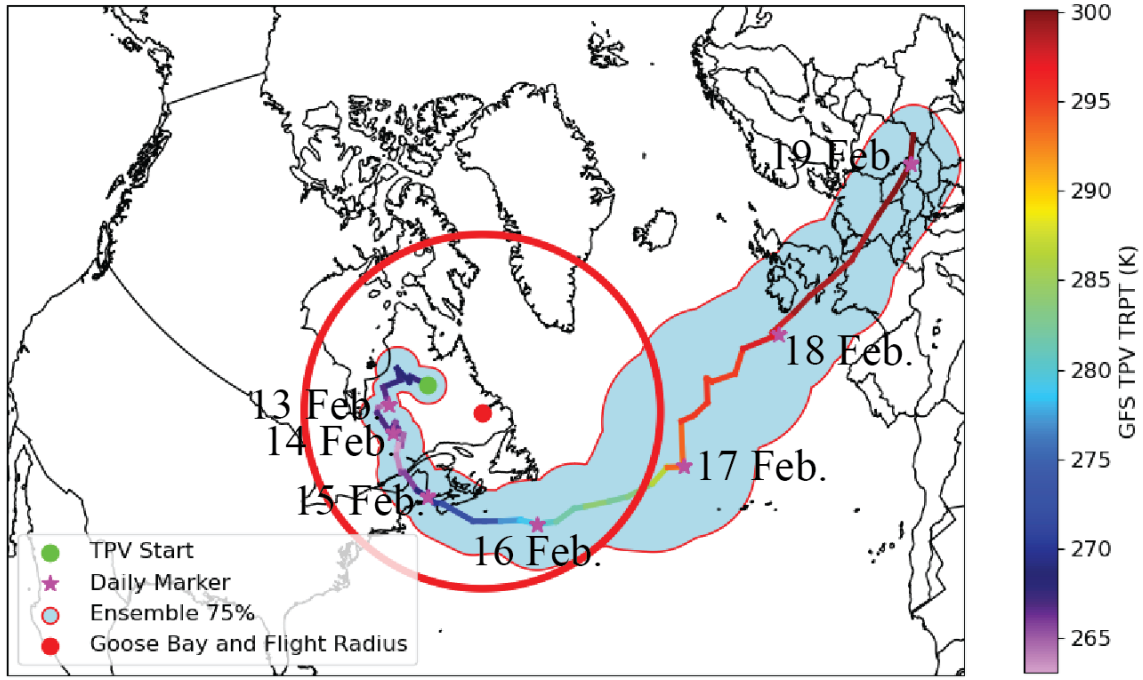


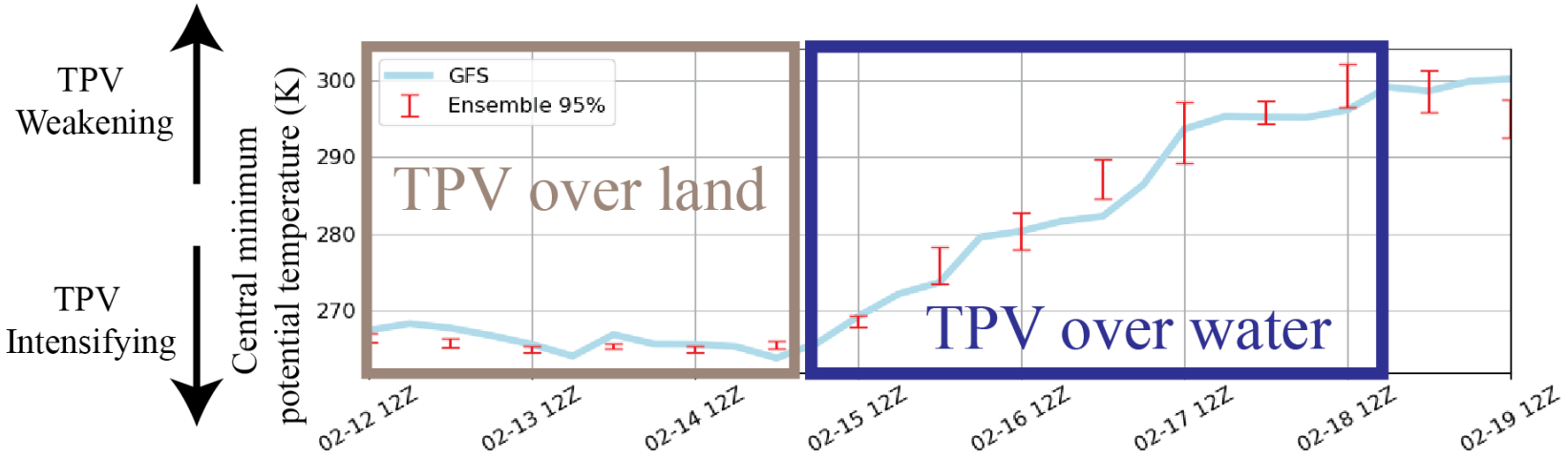
- TPV developing near Hudson Bay
- Sampled by NURTURE in Research Flight 2

- TPV moving equatorward toward antecedent AR

- Surface cyclone forms as TPV moves over antecedent AR

Observations of the Lifecycles of TPVs

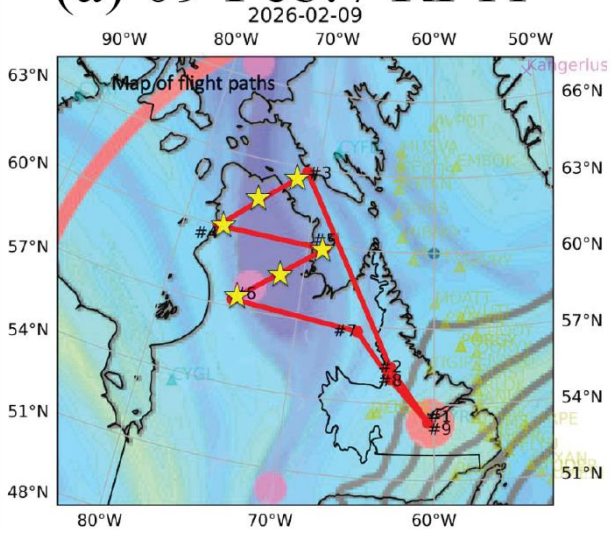




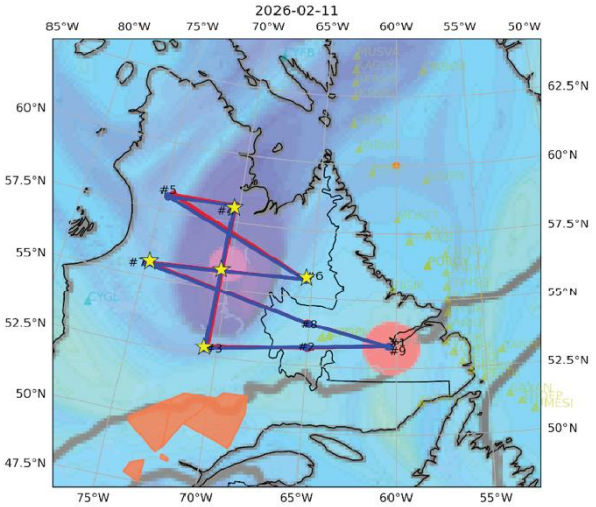
- Ensemble forecasts from GEFS produce reasonable 5-day forecast
  - Forecasts had trouble with its speed after exiting land until forecasts initialized 12 February
- When TPV was over land, it was intensifying
- When TPV was over water, it was weakening
- Sampled TPV Feb. 9, 11, 14, 15, and 16

Northern Quebec TPV aka “Football TPV”

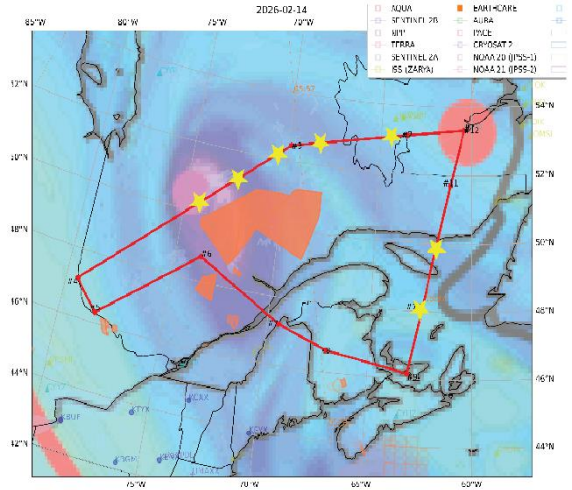
(a) 09 Feb. / RF11



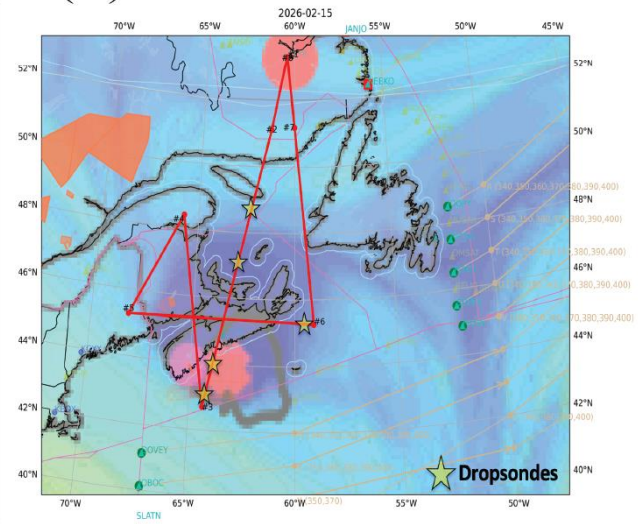
(b) 11 Feb. / RF13



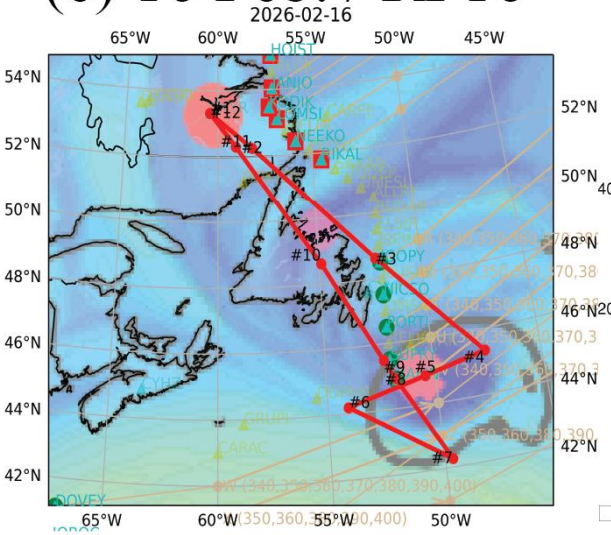
(c) 14 Feb. / RF14



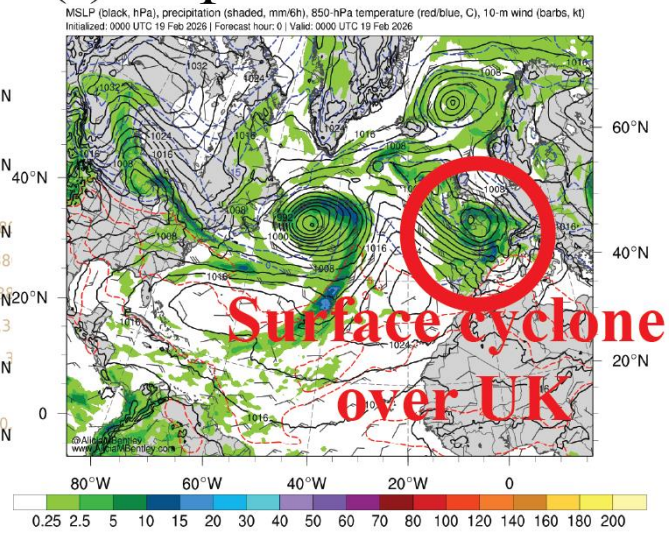
(d) 15 Feb. / RF15



(e) 16 Feb. / RF16

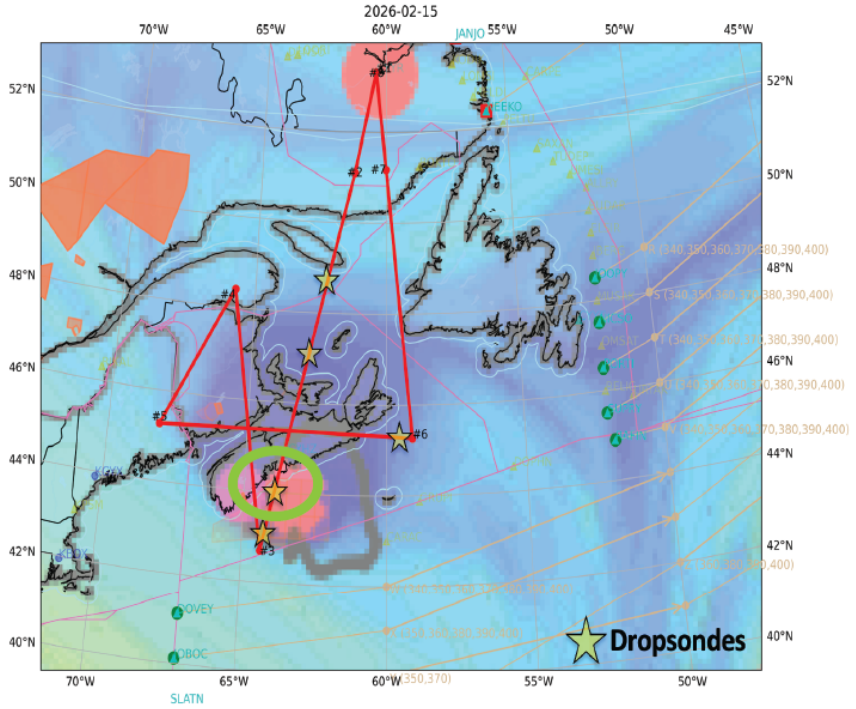


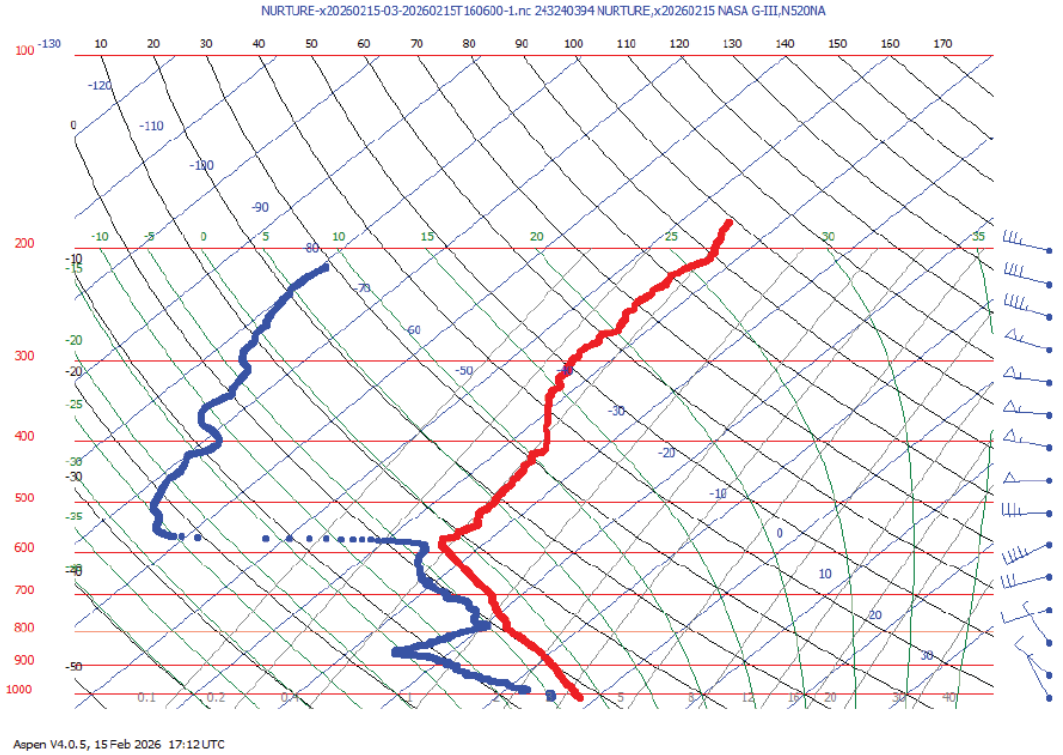
(f) Impact on 19 Feb.



Northern Quebec TPV aka “Football TPV”

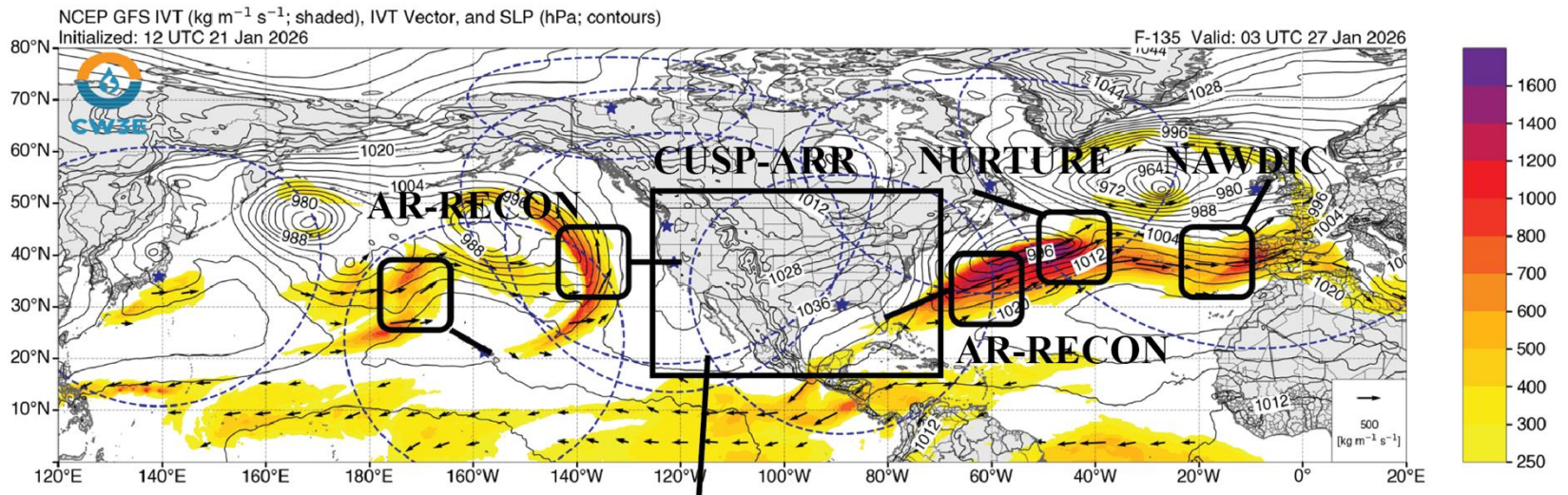
RF15: 15 February 2026

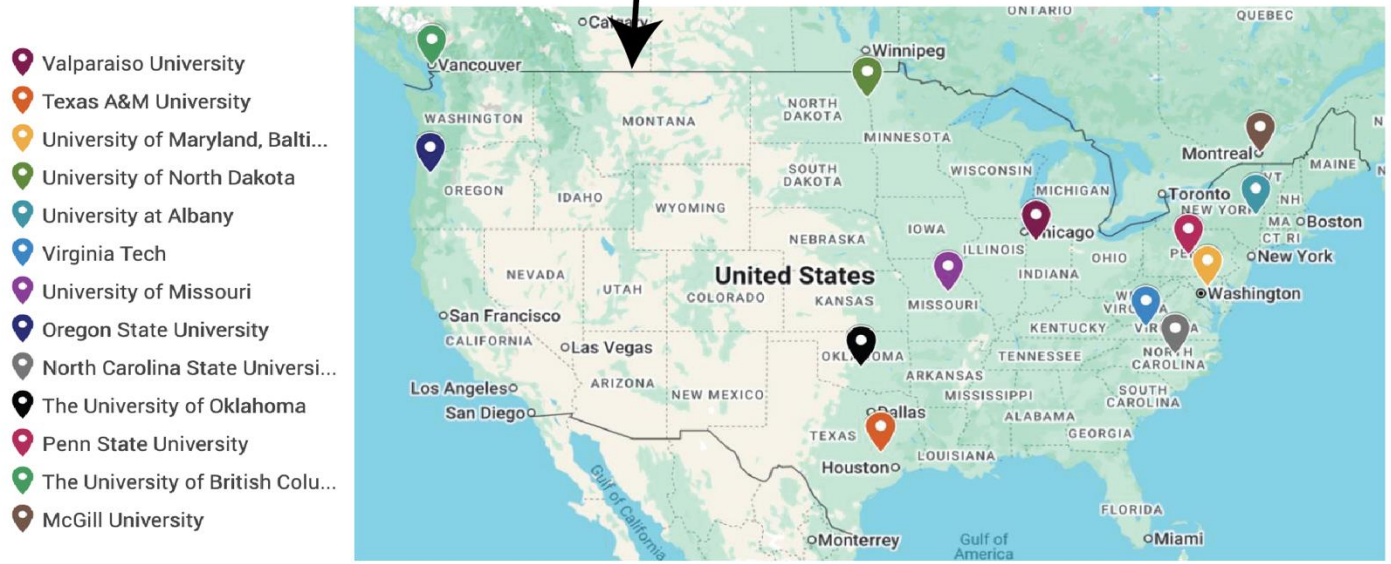




- Sounding just to the south of TPV center
- Tropopause height ~580 hPa
- Deep mixed layer from surface to tropopause

Partnerships to Provide Worldwide Observations





NURTURE (us!)

- G3 flights from Goose Bay, Canada

Atmospheric River Reconnaissance (AR-RECON)

- C130 flights from CA and HI
- GIV flights from FL and OR

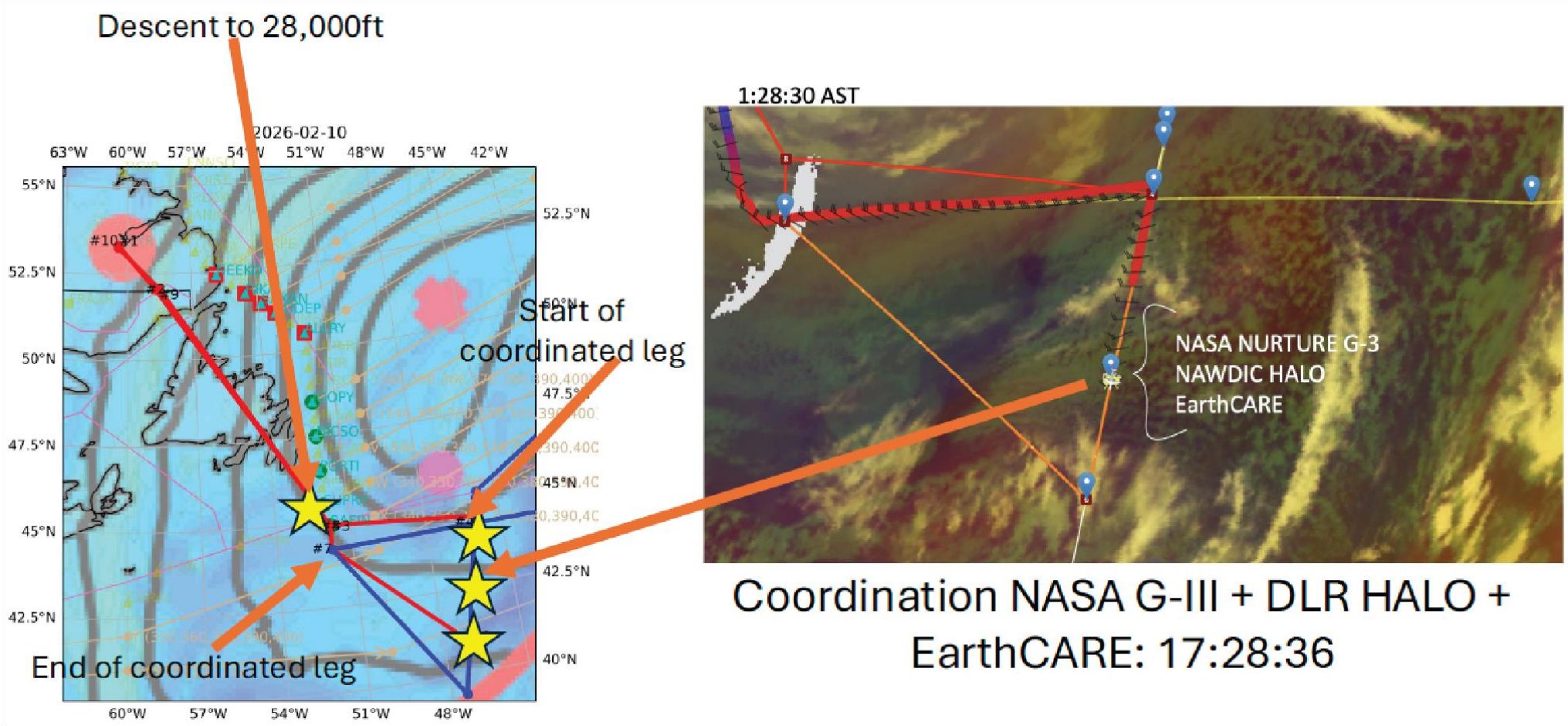
North Atlantic Waveguide, Dry Intrusion, and Downstream Impact Campaign (NAWDIC)

- German GV and French ATR42 flights from Shannon, Ireland

Coordinated University Sounding Program for Atmospheric River Reconnaissance (CUSP-ARR)

- Special radiosonde launches from 13 universities in U.S. and Canada (up to 4x/day)

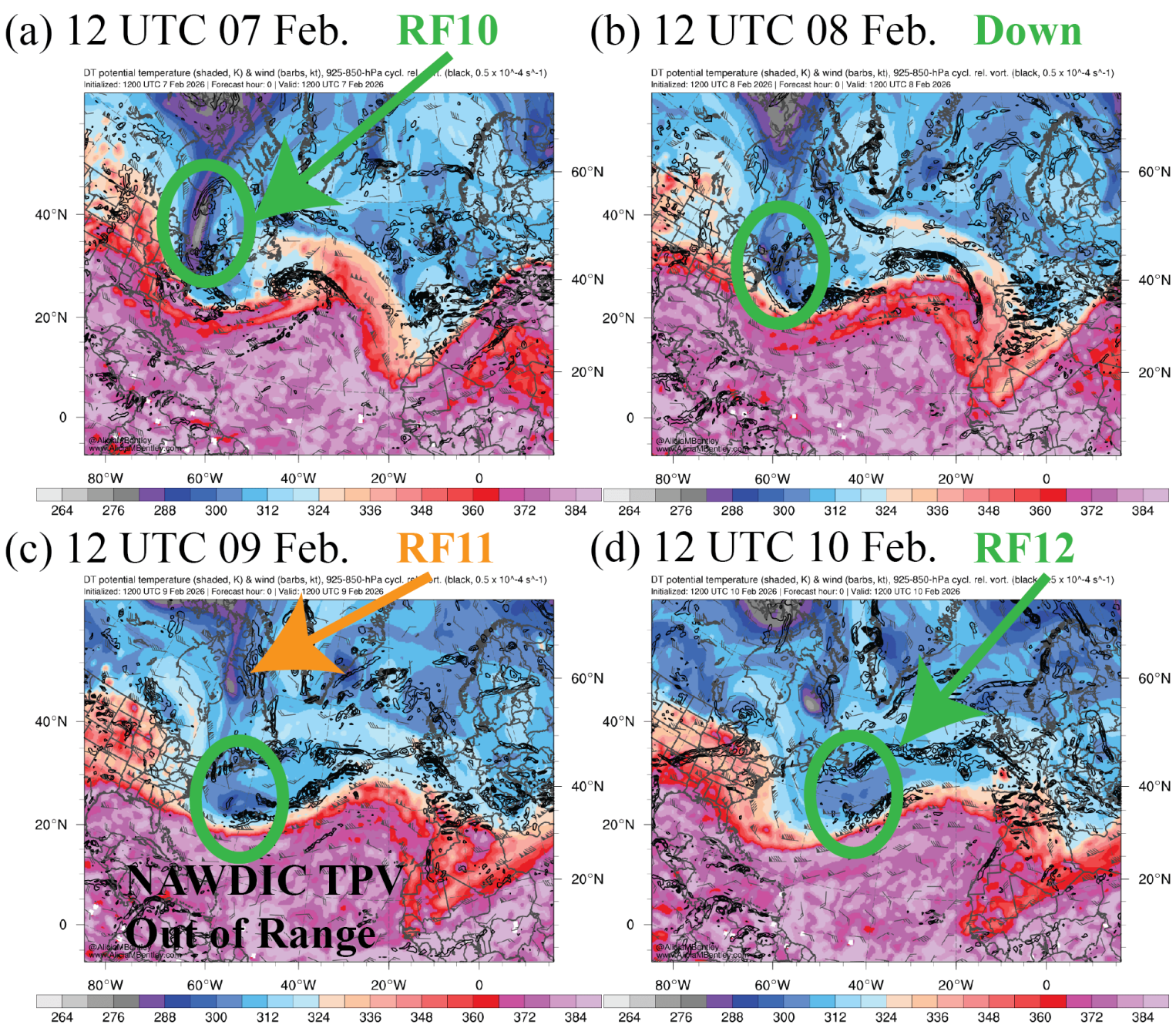
NAWDIC Collaboration



(Left): NASA NURTURE G-III flight (red) and DLR NAWDIC HALO (blue) for RF12 on 10 February 2026.

(Right) A zoomed-in view of the NURTURE and NAWDIC flight paths during the simultaneous observing leg. The yellow stars in the left panel indicate the locations of dropsonde releases from NURTURE. Also shown in the right panel is the simultaneous overpass of the EarthCARE satellite.

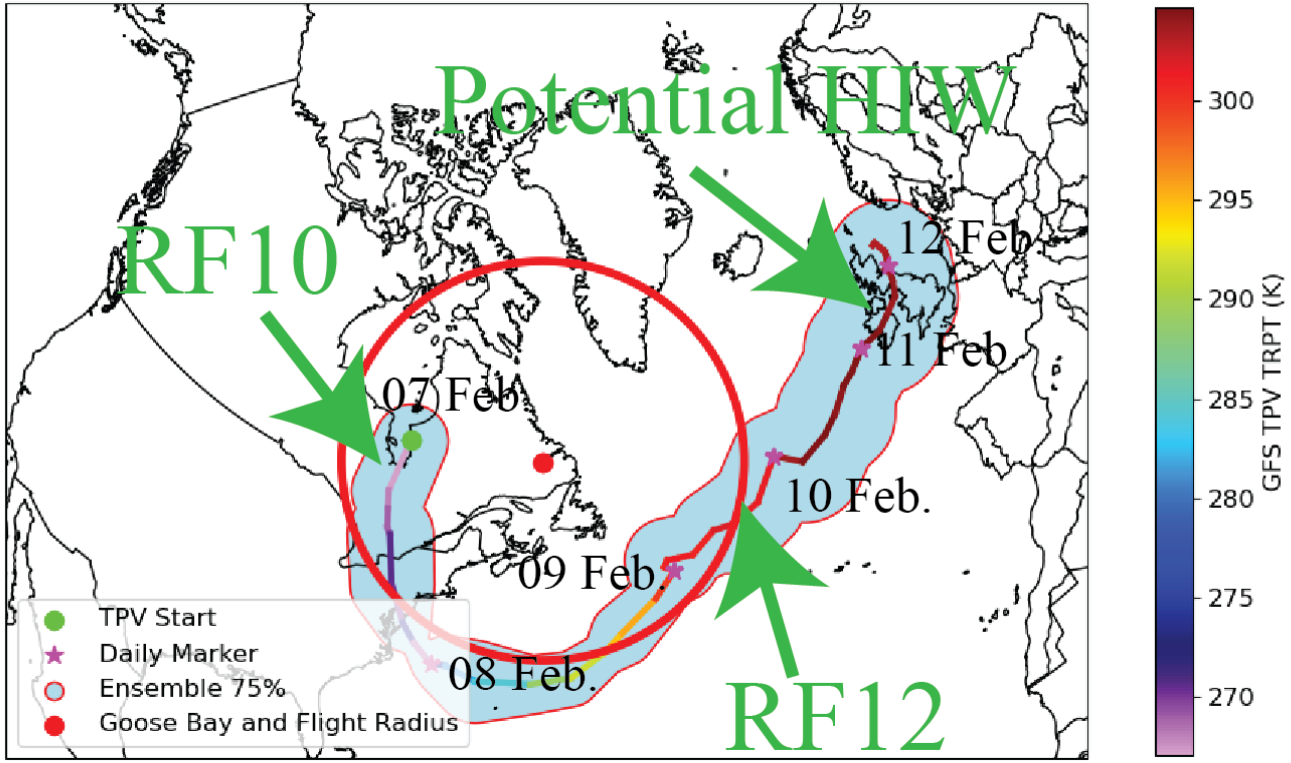
NAWDIC Collaboration (RF10, RF12)



NAWDIC Collaboration

(a) TPV Ensemble Forecast

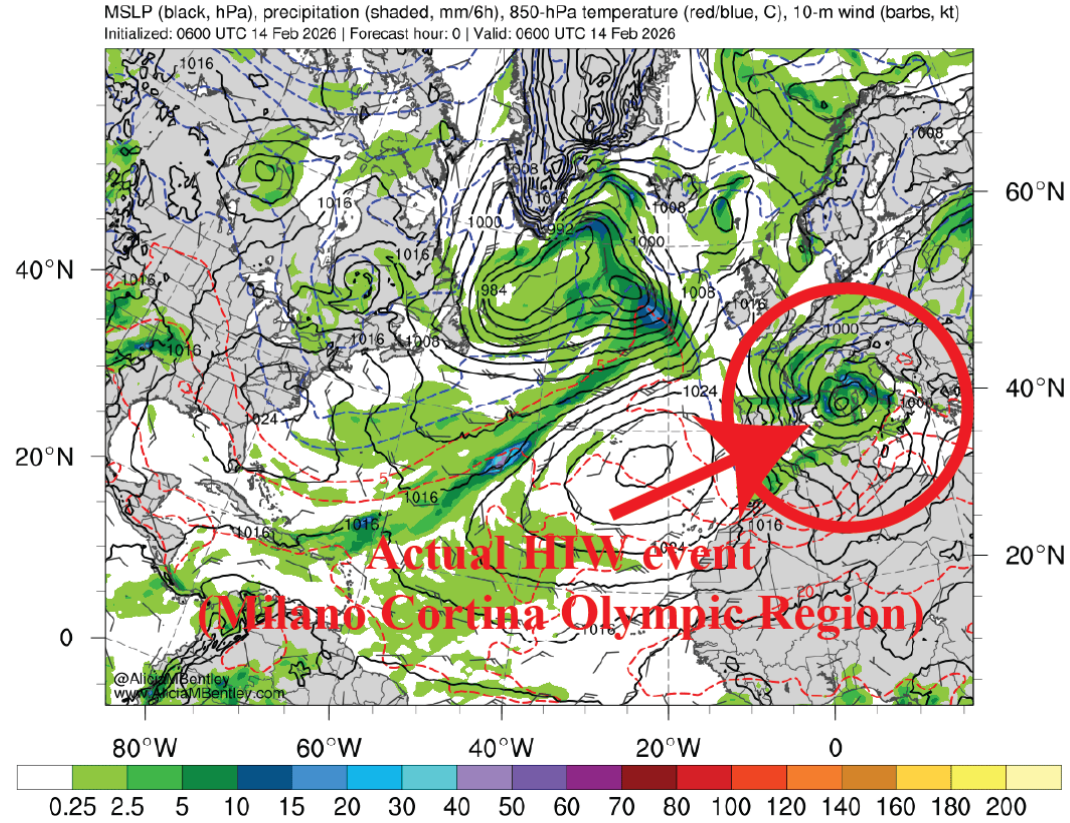
GEFS: Initialized 00 UTC 07 Feb.



(a) 75% TPV track envelope (blue shading) with central minimum potential temperature value of the TPV (colors; units = Kelvin)

(b) GFS Analysis

06 UTC 14 Feb.



(b) Mean sea level pressure (black contours; units = hPa), precipitation (shaded; units = mm/6h), 850-hPa temperature (red/blue contours; units = degrees Celsius), 10-meter wind barbs (units = knots)

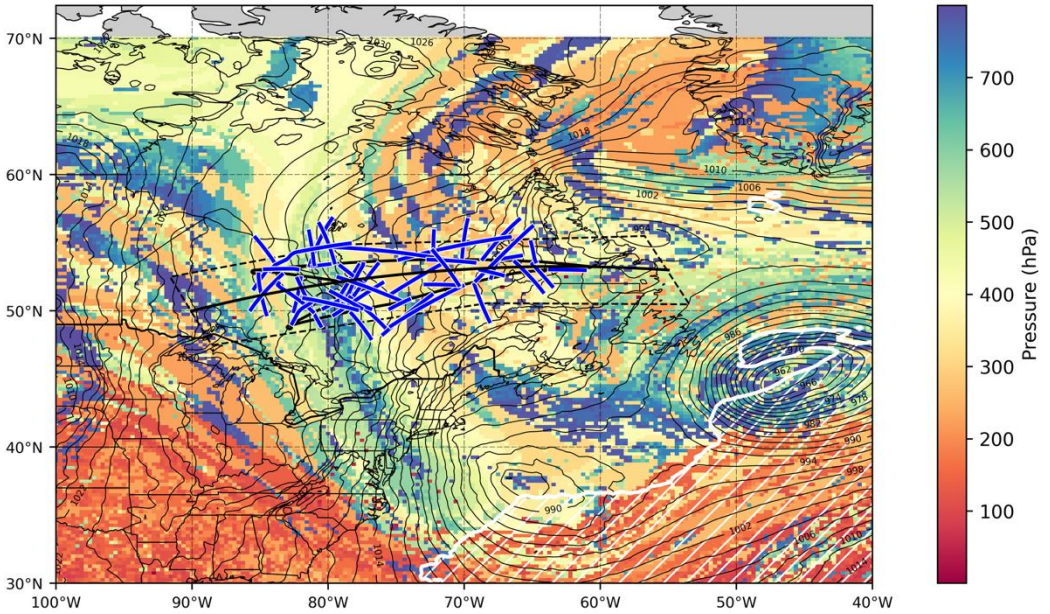
NAWDIC Collaboration: RF10

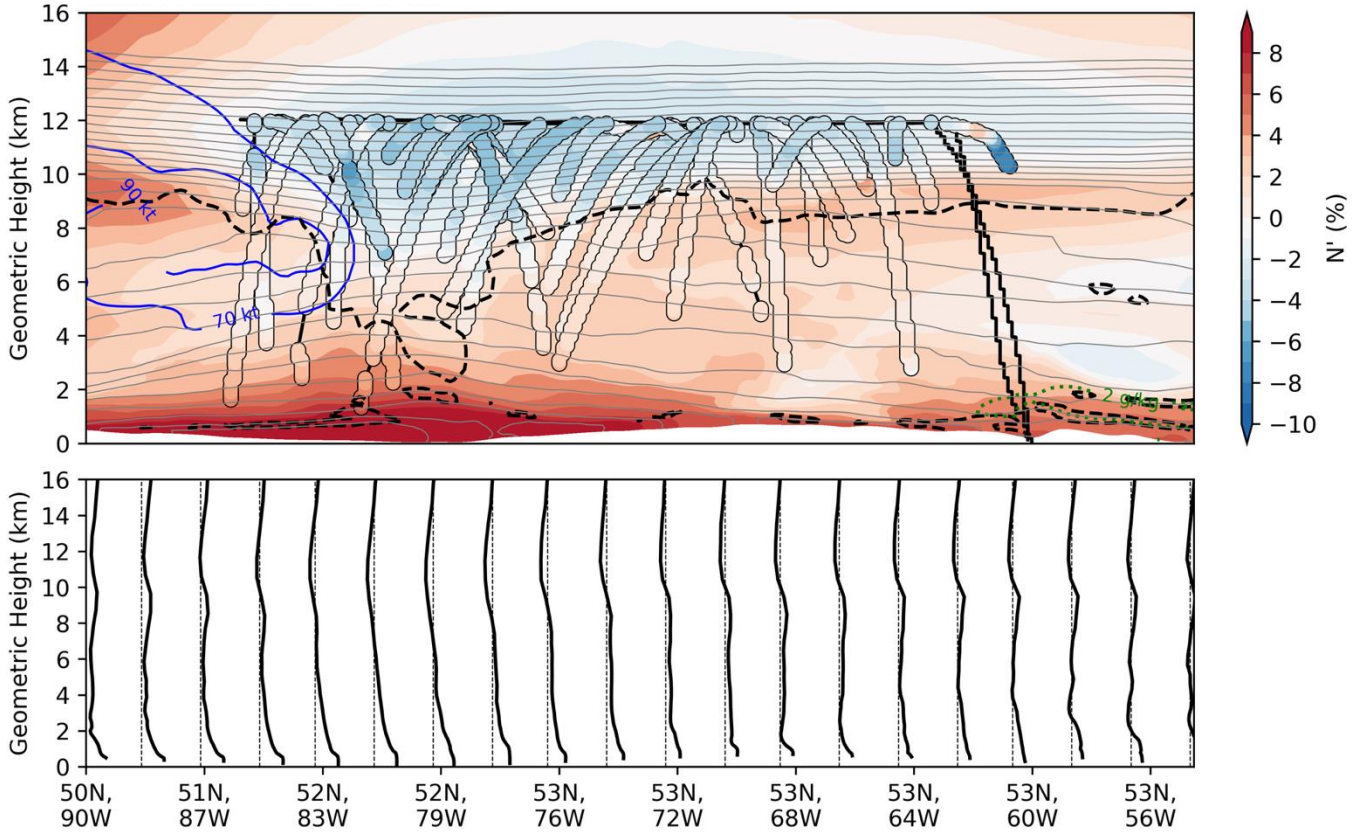
Airborne Radio Occultation

Dynamic tropopause pressure (shading)
Flight path (black lines)
ARO profiles (blue lines; 47 profiles)

GEOS Refractivity Anomaly (N’; background shading)
ARO Refractivity Anomaly (N’; circle shadings)
Wind speed (blue contours); Potential temperature (black contours); Dynamic Tropopause (dashed black contour)

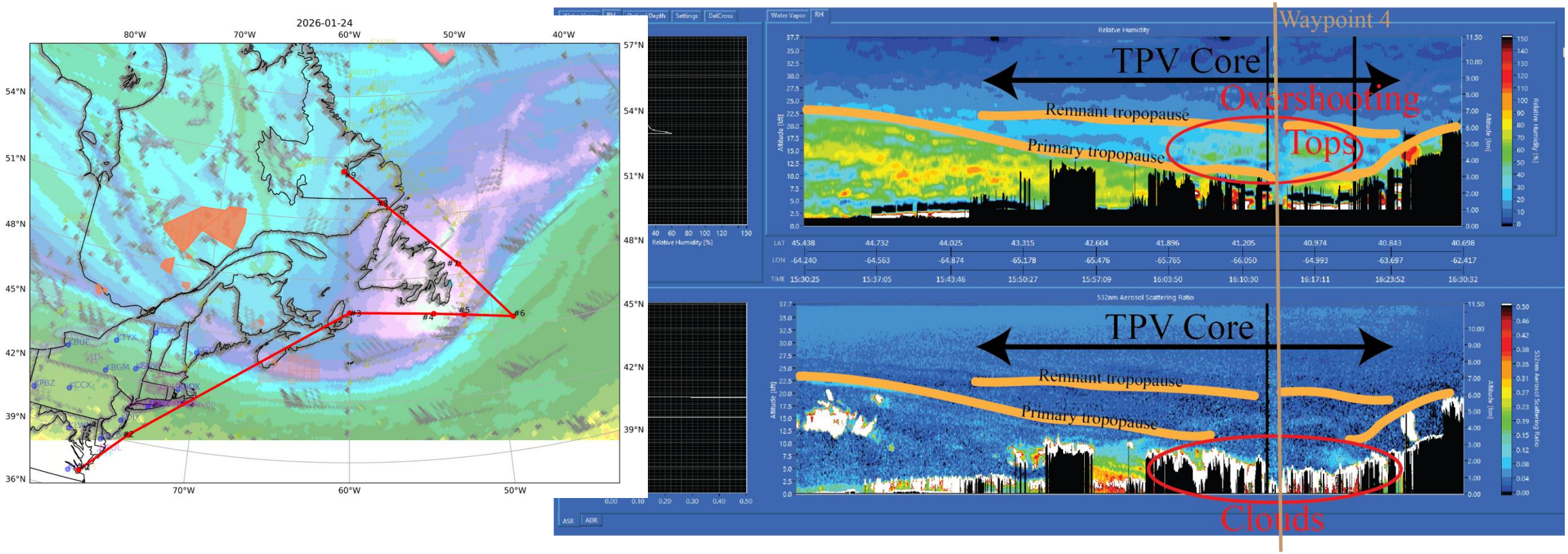
18 UTC 07 February 2026





Images courtesy of Noah Barton

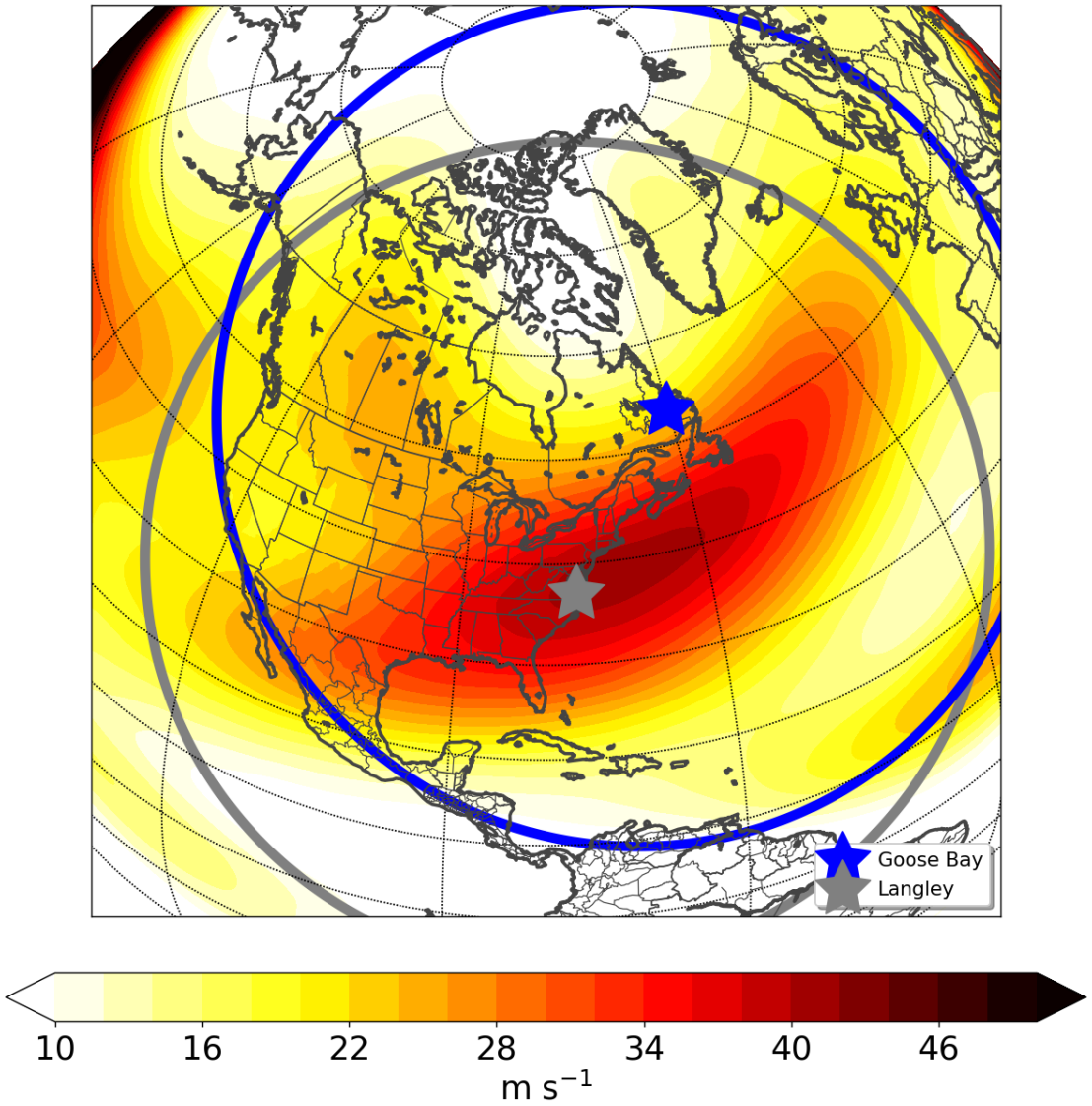
Overshooting Tops in TPVs



- TPV core sampled between waypoints 3 and 5 (1545–1621 UTC)
- Sharp vertical moisture gradient ~3 km near waypoint 4
- Weak vertical moisture gradient ~6 km
- Lidar attenuation below 3 km indicates cloud cover (supported by CloudCube radar)
- ***Moisture overshooting primary tropopause in TPV core!***

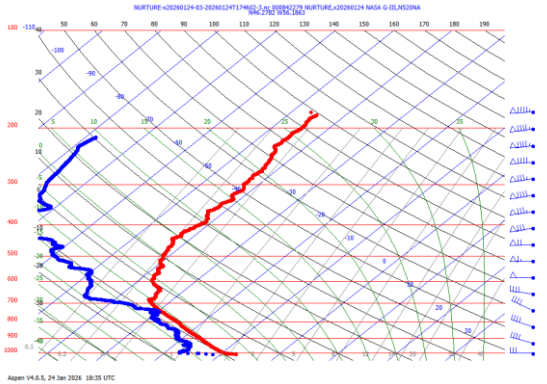
NURTURE Phase 2: 15 January – 1 March 2027

- Planned to occur for 6 weeks using the ***NASA 777*** starting 15 Jan. 2027 (Blue: Also on G3 in 2026).
- Payload:
  - HALO
  - ARO (Airborne Radio Occultation)
  - AVAPS (Advanced Vertical Atmospheric Profiling System / Dropsondes)
  - Trace Gases
  - HSRL-2
  - APR3 (Airborne 3rd Generation Precipitation Radar)
  - G-Band Radar
  - AWP (Airborne Wind Profiler)
  - VIPR (Vapor in-cloud Profiling Radar)
  - MBARS (Microwave Barometer Radar and Sounder)
  - CoSSIR (Sub-mm Wavelength Radiometer)
  - COSMIR (Connical Scanning Millimeter Wave-imaging Radiometer)
  - S-HIS (Scanning Resolution High-Resolution Interferometer Sounder)
  - BBR (Broadband Radiometer)
  - DLH (Diode Layer Hygrometer)
  - TAMMS (Turbulent Air Motion Measurement System)
  - NSRC (Aircraft Data System)



Colors: Mean jet-stream wind speeds during the winter
Rings: Science ranges of 777 from Goose Bay (blue) and Langley (Gray)

Summary and Future



- NURTURE Phase 1 consisted of 19 research flights, 110 flight hours, 118 dropsondes over a 4-week period from 24 January–19 February 20, 2026
  - TPVs sampled at various stages of their lifecycles
  - Marine cold air outbreaks, polar lows, jet streams, “overshooting” convection into lower stratosphere

- Phase 2 will occur over a 6-week period from 15 January – 1 March 2027 with ~120 flight hours and ~400 dropsondes on the ***NASA 777.***