Radiative contribution to the North-American cold air outbreaks in a Lagrangian perspective

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Motivation

- Polar continental air masses may travel to mid-latitudes and result in cold air outbreaks

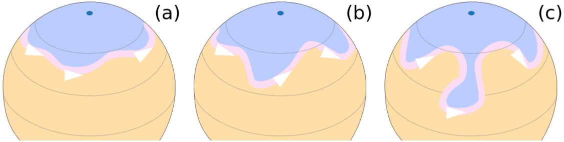
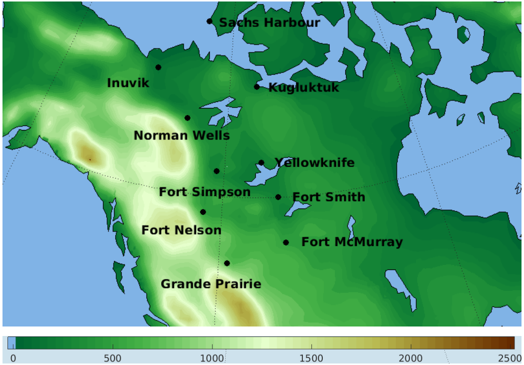


Figure: Meanders of the northern hemisphere's jet stream developing (a, b) and detaching a "drop" of cold air (c); orange: warmer masses of air; pink: jet stream [Wikipedia]

- Dominant mechanism: Longwave cooling during the polar night over land
- Shallow formation of cold air in a single-column model (Wexler 1936)
- Deeper process and importance of clouds (Curry 1983)
- Observations: not necessarily shallow (Turner and Gyakum 2011)

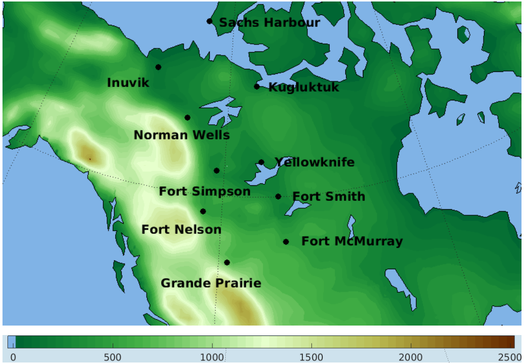
Objectives

1. identify events of cold air mass formation over northwest Canada
2. study shallow vs. deep formation mechanisms
3. quantify the radiative contribution
   - in a Eulerian frame
   - in a Lagrangian frame



Data and tools

- European Centre for Medium-Range Weather Forecasts (ECMWF) interim reanalysis (ERA-Interim) 1979-2016
  - daily/six-hourly data
  - ten stations
- Rapid Radiative Transfer Model (RRTMG, Mlawer et al. 1997)
- LAGRANTO trajectory model (Wernli & Davies 1997, Sprenger & Wernli 2015)



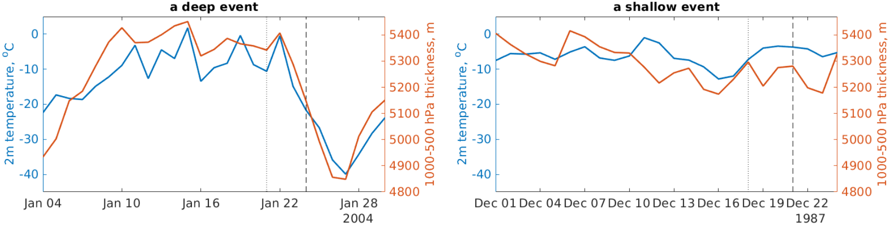
Methodology

Cold event: minimum daily surface temperature below **1 standard deviation** for at least **3 days** over at least **5 stations**. – 42 events

$\mathbf{c}$ = correlation between 1000-500 hPa thickness and 2m temperature during the event and 20 days prior.

Shallow event: has a station involved with $\mathbf{c} < 0.4$. – 8 events

Deep event: has a station involved with $\mathbf{c} > 0.9$. – 8 events



Thermodynamic budget

Eulerian frame

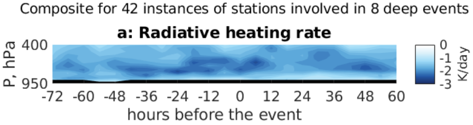
$$\frac{\partial T}{\partial t} = -\vec{v}\cdot\nabla T + \omega\left(\frac{\alpha}{c_p} - \frac{\partial T}{\partial p}\right) + \underbrace{\frac{1}{c_p}\frac{dq_{LH}}{dt}}_{\text{latent heat (residual)}} + \underbrace{\frac{1}{c_p}\frac{dq_{RAD}}{dt}}_{\text{radiative heating rate (explicitly with RRTMG)}}$$

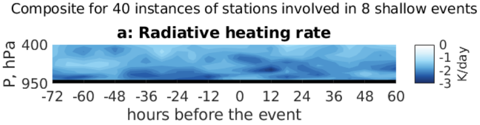
Hereafter:

Computed temperature change = horizontal term + vertical term + radiation term

Observed temperature change $= \frac{T(t+\Delta t)-T(t)}{\Delta t}$, $\Delta t = 6\text{h}$

Thermodynamic budget





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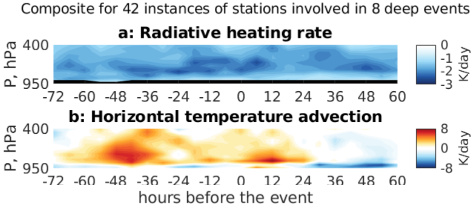

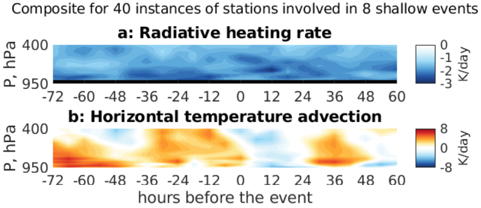

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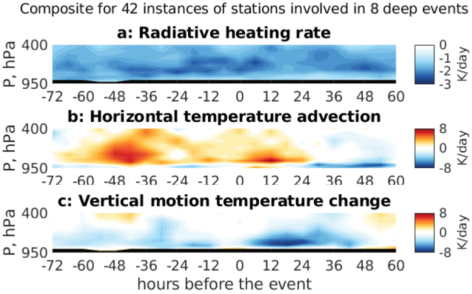

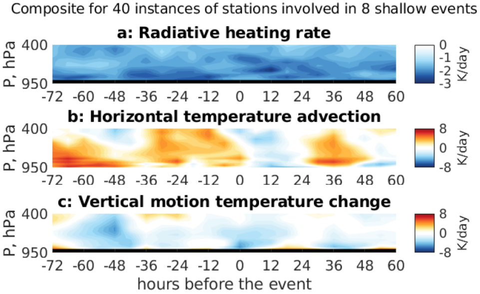

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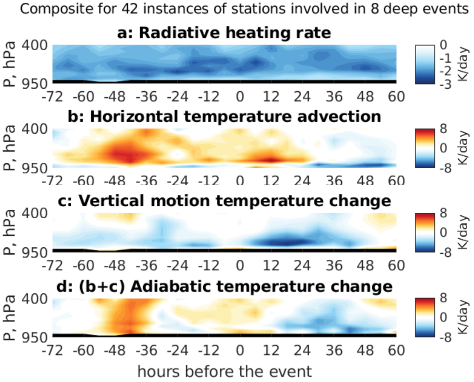

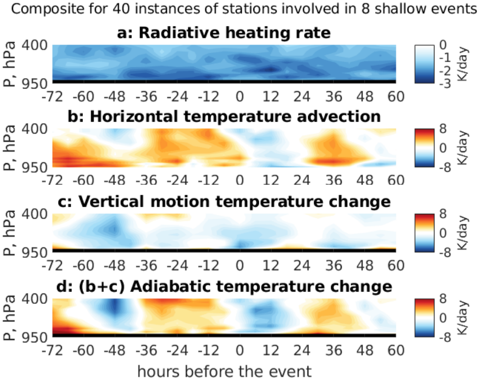

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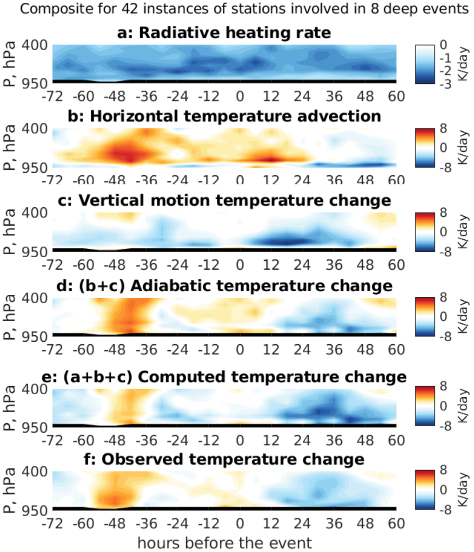
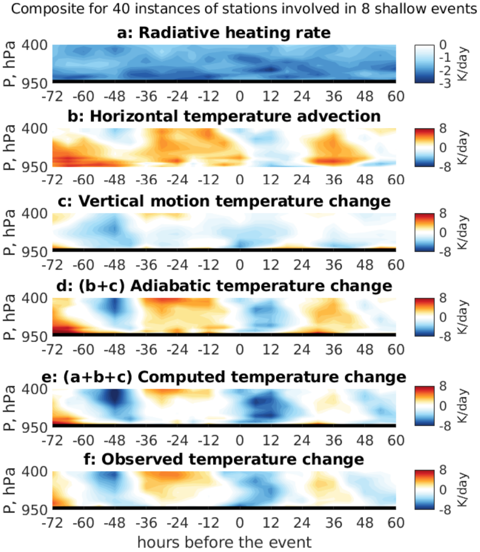
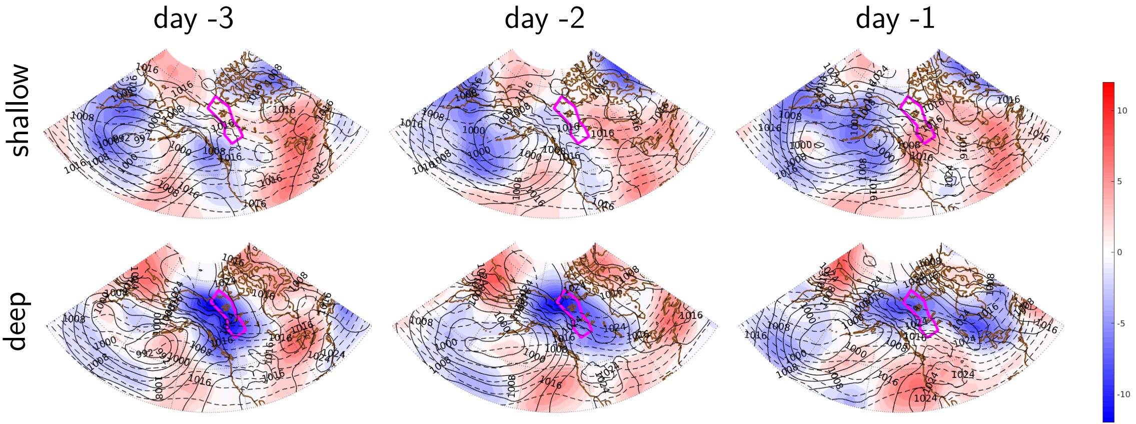




Synoptic composites

Dashed: 1000-500 hPa thickness, solid: SLP (hPa), shaded: 1000-500 hPa thickness anomaly (dam)



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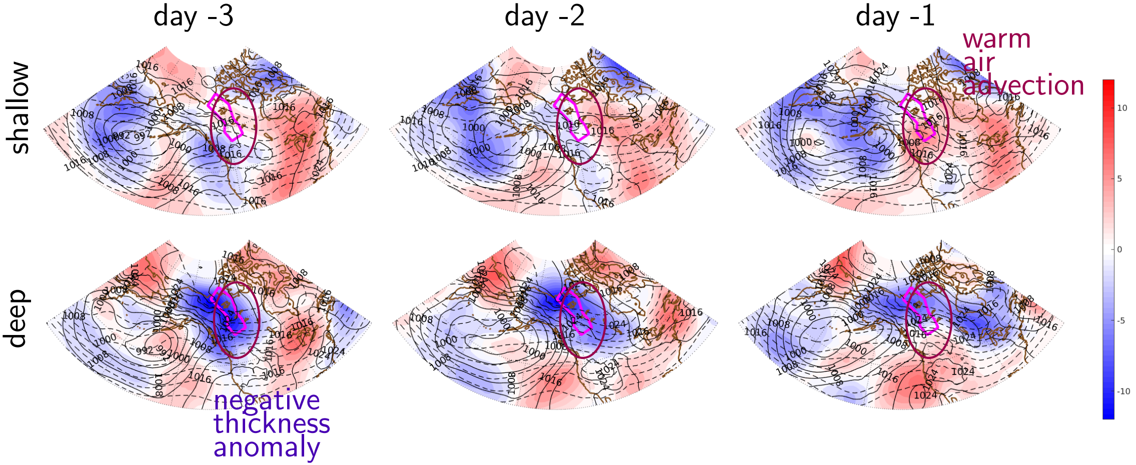

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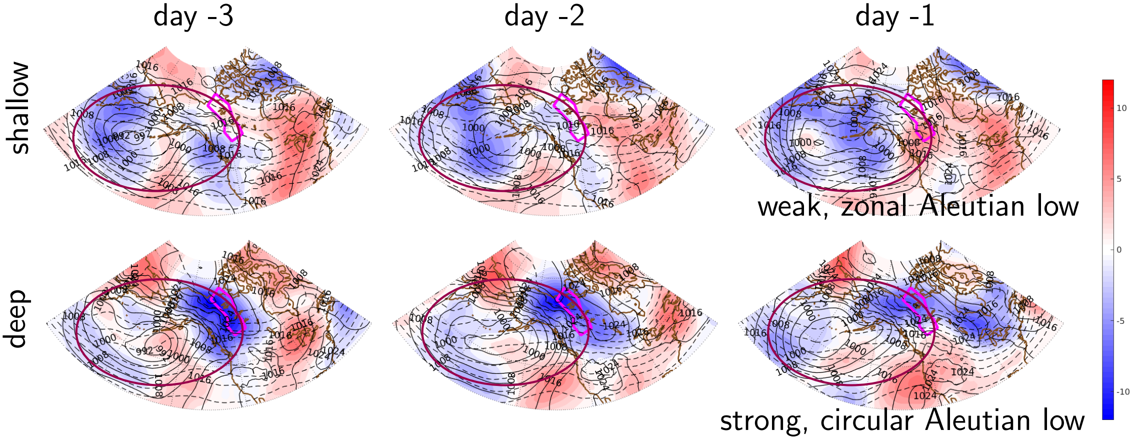

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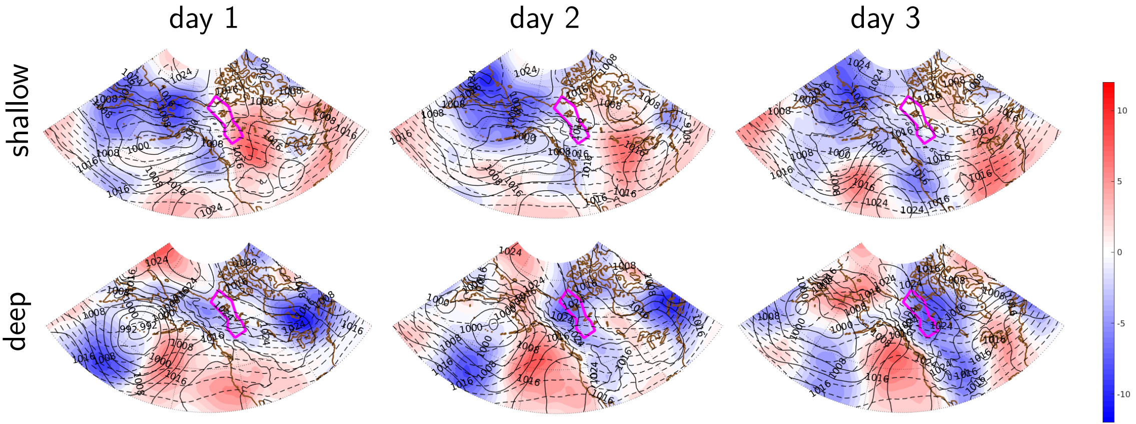

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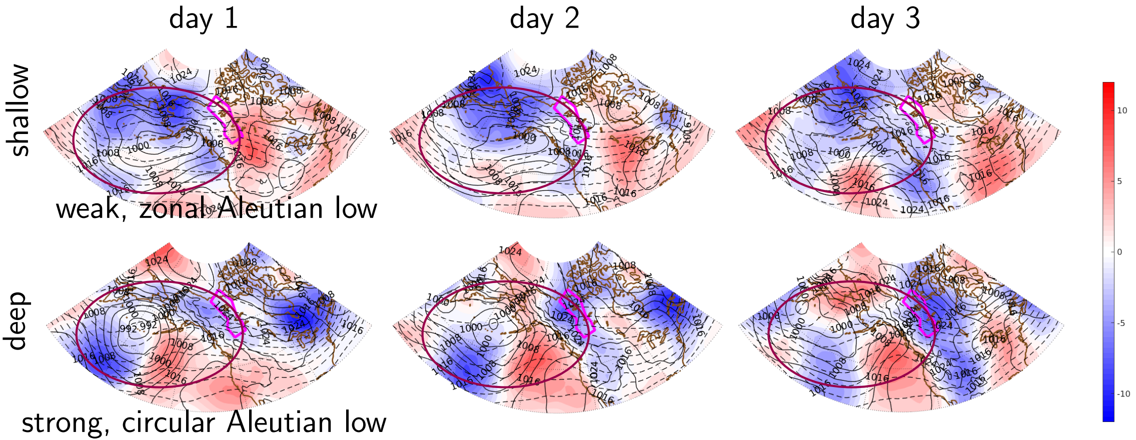

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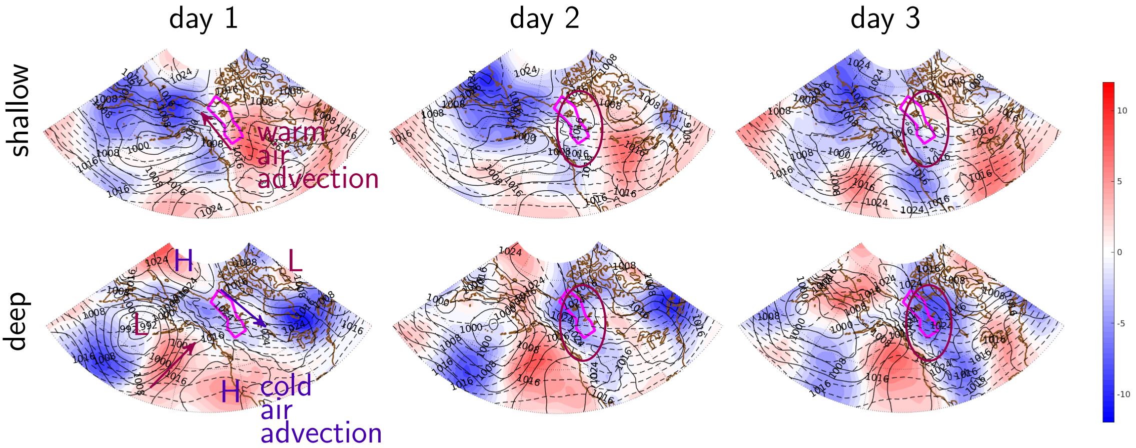
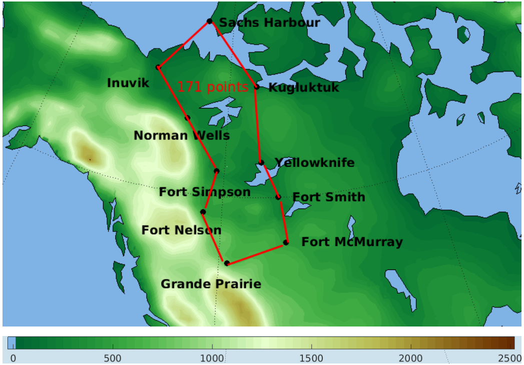


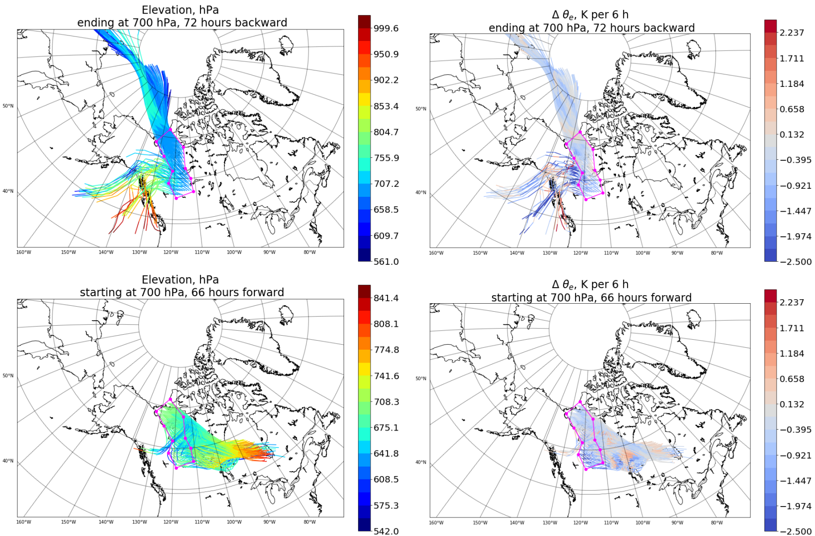
Trajectory analysis

- Start time: 00UTC of the onset day
- Model: LAGRANTO
  on ERA-Interim 6-hourly data
- Duration: 3 days backward/forward
- Starting locations:
  171 gridpoints inside the polygon
- Starting level: 500, 700, 850 hPa
- Tracing:
  - $\Delta\theta_e$ (i.e. diabatic changes)
  - 1000-500 hPa thickness along the trajectory



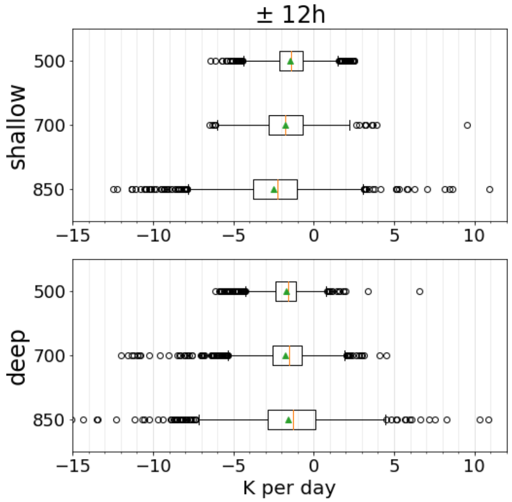
Backward and forward trajectories @700 hPa

A deep case study, 00UTC Jan 24, 2004



Diabatic cooling: Lagrangian frame

Distribution of $\Delta\theta_e$ based on 171 trajectories $\times$ 8 events



Vertical structure:

- less cooling aloft for shallow events (confidence level $> 99\%$)

Possible reasons of $\Delta\theta_e < 0$:

- Physical:
  - radiative cooling
  - convection, evaporation
- Computational:
  - mixing
  - errors

Summary and Future work

- 42 cold events over northwest Canada were identified, including 8 shallow/8 deep.
- For both, warm air advection is present, but its timing is different.
- No negative thickness anomaly before and during shallow events.
- Shallow: weak and zonal Aleutian low, displaced eastward;
  Deep: deep and circular Aleutian low, large-scale deformation zone.
- Instantly, the radiative cooling is less pronounced than the dynamical terms, but is consistently negative and therefore plays an important role on the long timescale.
- Diabatic decrease in θ_e, in part due to radiative cooling.

Future work:

- explicitly compute radiative cooling along trajectories with RRTMG.