Relationship Between Snow Extent and Mid-Latitude Cyclone Centers From NARR Objectively Derived Storm Position and Snow Cover

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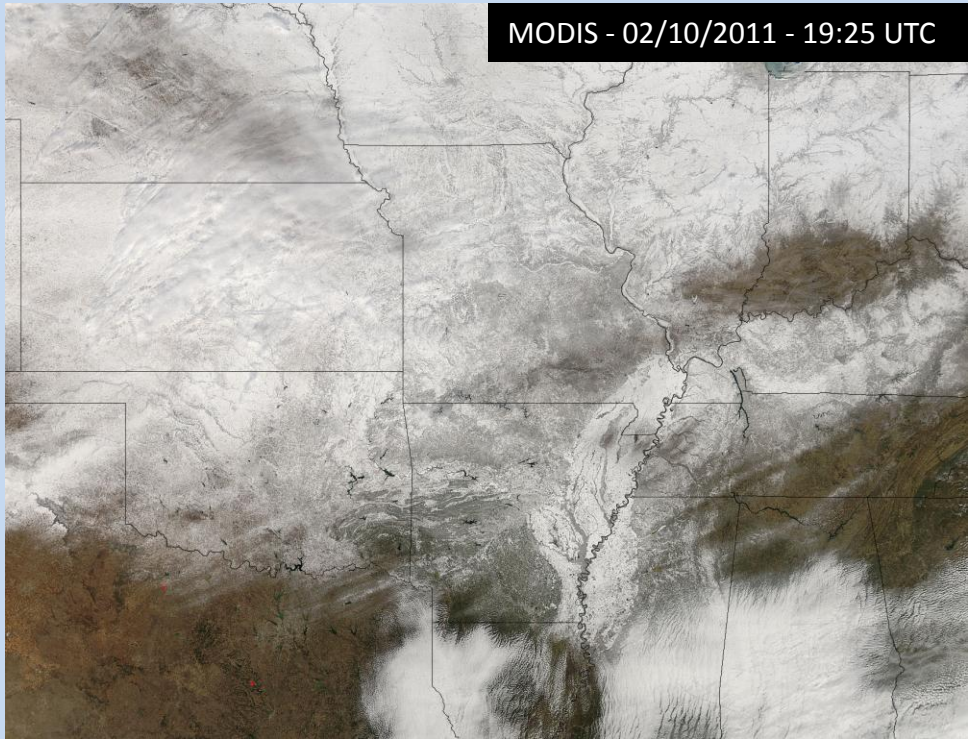
AOS Department Seminar
April 11th, 2012

Outline

1. **Introduction**
2. Data / Methods
   - Snow Cover Extent Algorithm
   - MLC Identification and Tracking
3. Results / Discussion
   - Relationship between snow cover and MLCs
   - Low-level Baroclinicity
4. Conclusions
   - Role in poleward shift of storm tracks?

Snow Cover Impacts

- High albedo reflects more solar radiation
  - Cooler temperature
- Infrared Blackbody
  - Cooler temperature at night
- Insulation
  - Low thermal conductivity



Why do we care?

- “General features include a **poleward shift** in storm track location, increased storm intensity, but a decrease in total storm numbers” - IPCC (2007)
- “The baroclinic zone is a lot of times the place where storms will track. Repeated storm tracks will continue to move the snow cover slightly southward.” - Eric Sorensen - WREX

Snow Cover Influence on MLCs

- Namias (1962) postulated feedback cycle

1. General circulation favored southern snow extent
2. Air masses cooled by anomalous snow cover
3. Increased low-level temperature contrast
4. MLCs feed off of enhanced low-level baroclinicity
5. MLCs aided in injecting future air masses further southward

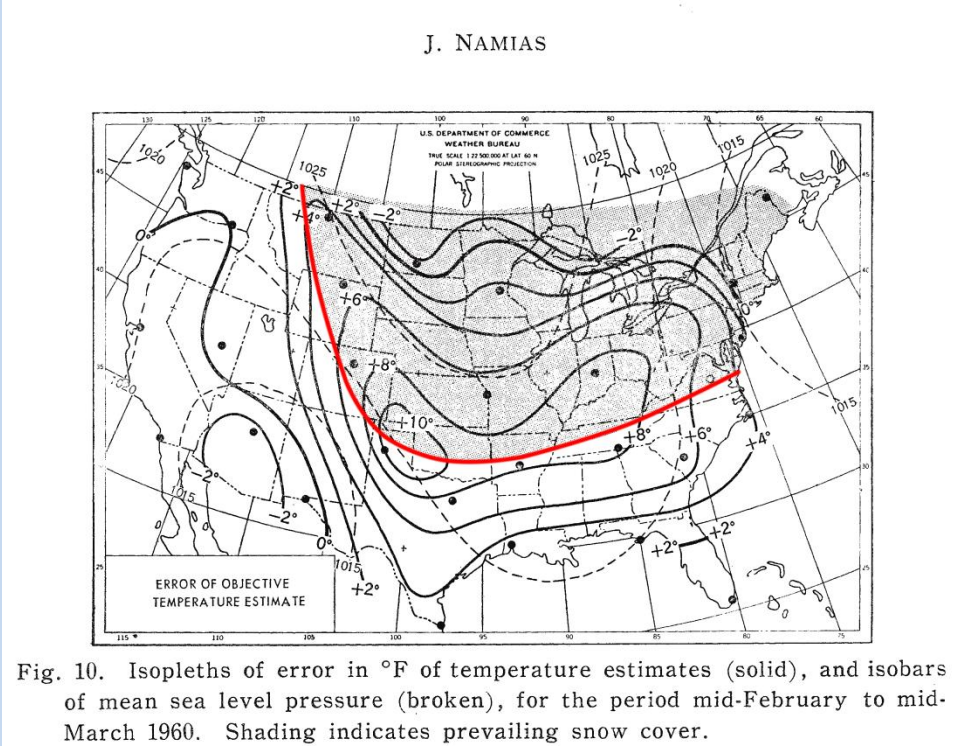
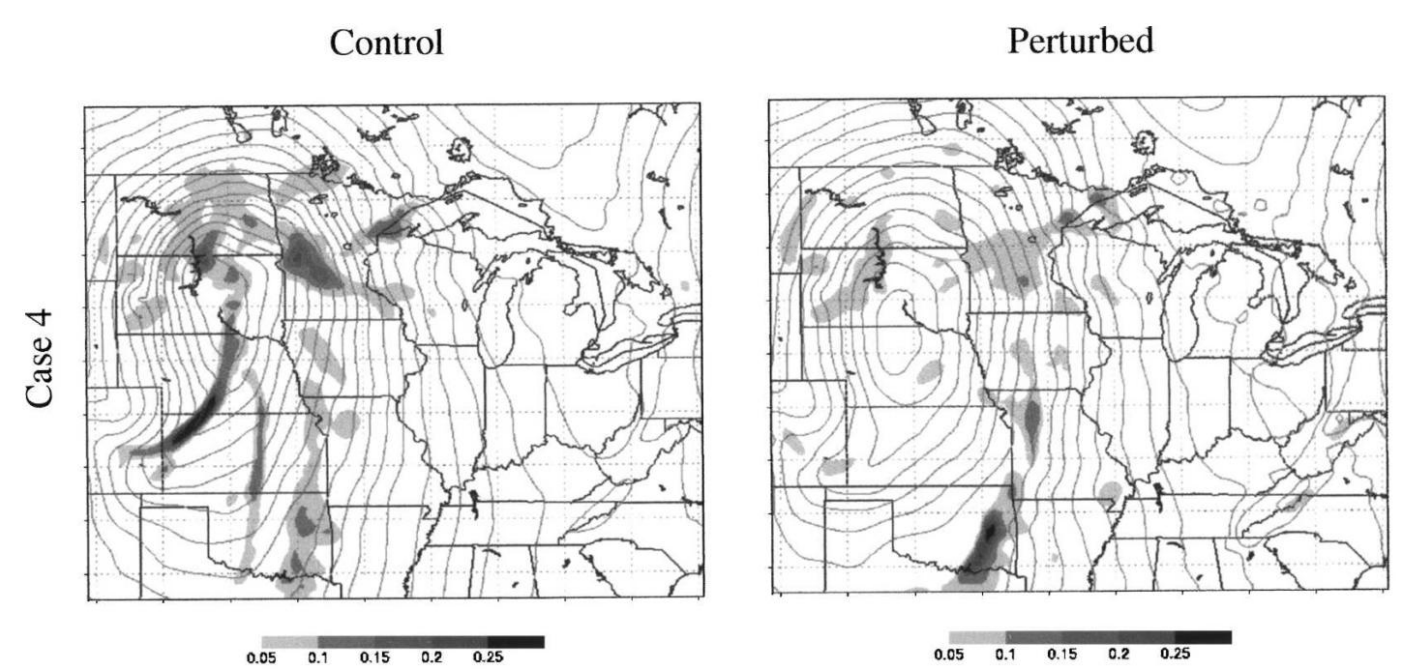


Fig. 10. Isopleths of error in °F of temperature estimates (solid), and isobars of mean sea level pressure (broken), for the period mid-February to mid-March 1960. Shading indicates prevailing snow cover.

Snow Cover Influence on MLCs

- Elguindi et al. (2005) ran model simulations of MLC with modified snow cover
- Control versus Expansive Snow Cover
  - No significant change in MLC trajectories
  - MLCs weakened with increased snow cover



Questions

- How well is the NARR able to represent snow cover extent and mid-latitude cyclone trajectories?
- Is there a relationship between preexisting snow cover extent and mid-latitude cyclone trajectories?
- Is there a region of enhanced baroclinicity near the snow extent edge?

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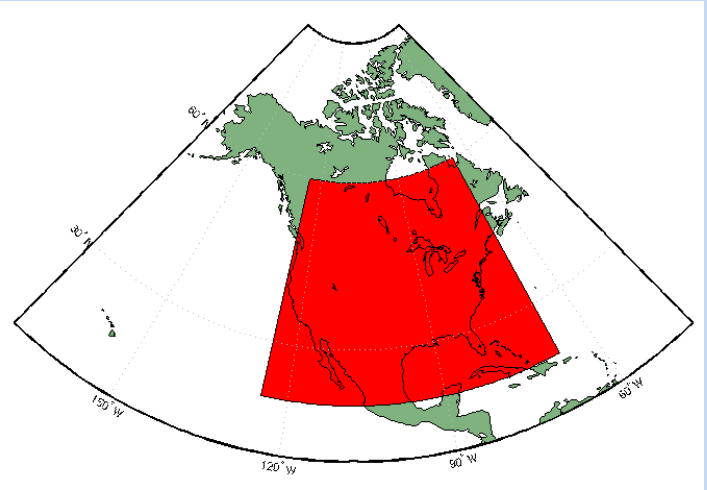
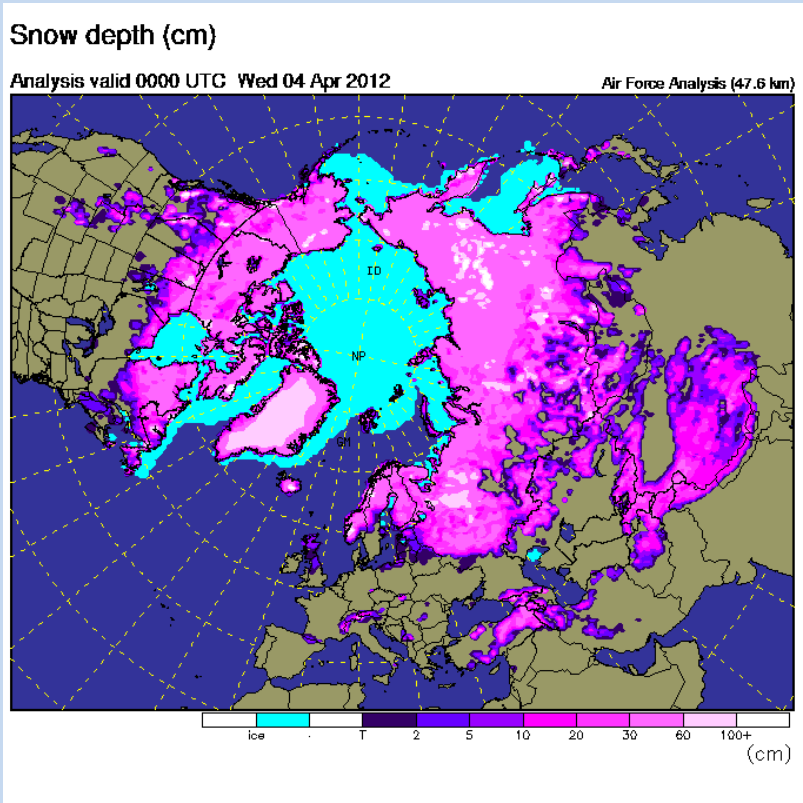
NARR

- Regional reanalysis at 32 km grid spacing
- Snow water equivalent updated at 0000 UTC using SNODEP (Air Force Weather Agency)
  - Station Observations
  - Satellite Retrievals
  - Manual Interpretation





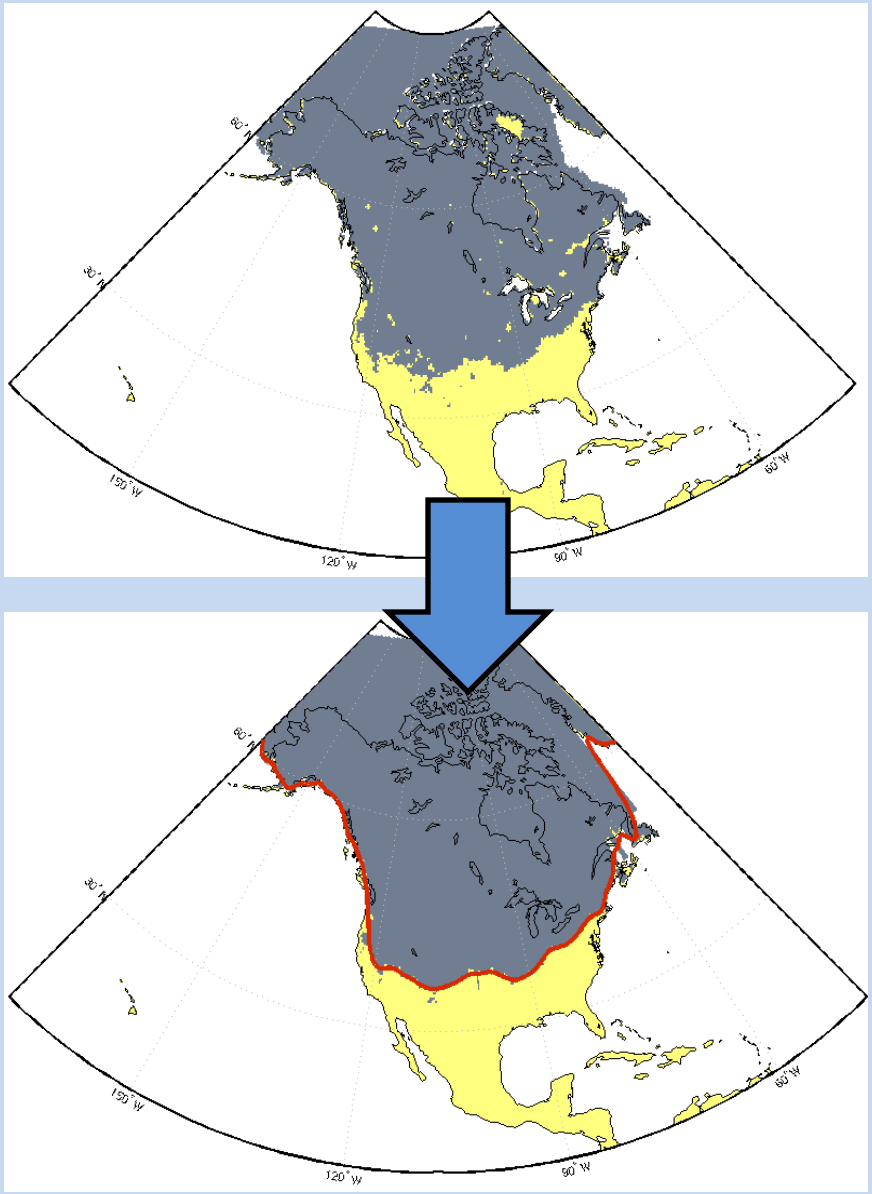
Snow Extent

1. Gaps filled in 0000 UTC NARR categorical snow presence

2. Linearly interpolated to 0.25° grid

3. For each longitude, find 2.5° of consecutive snow cover from south to north

4. Smooth snow extent with 2.5° filter

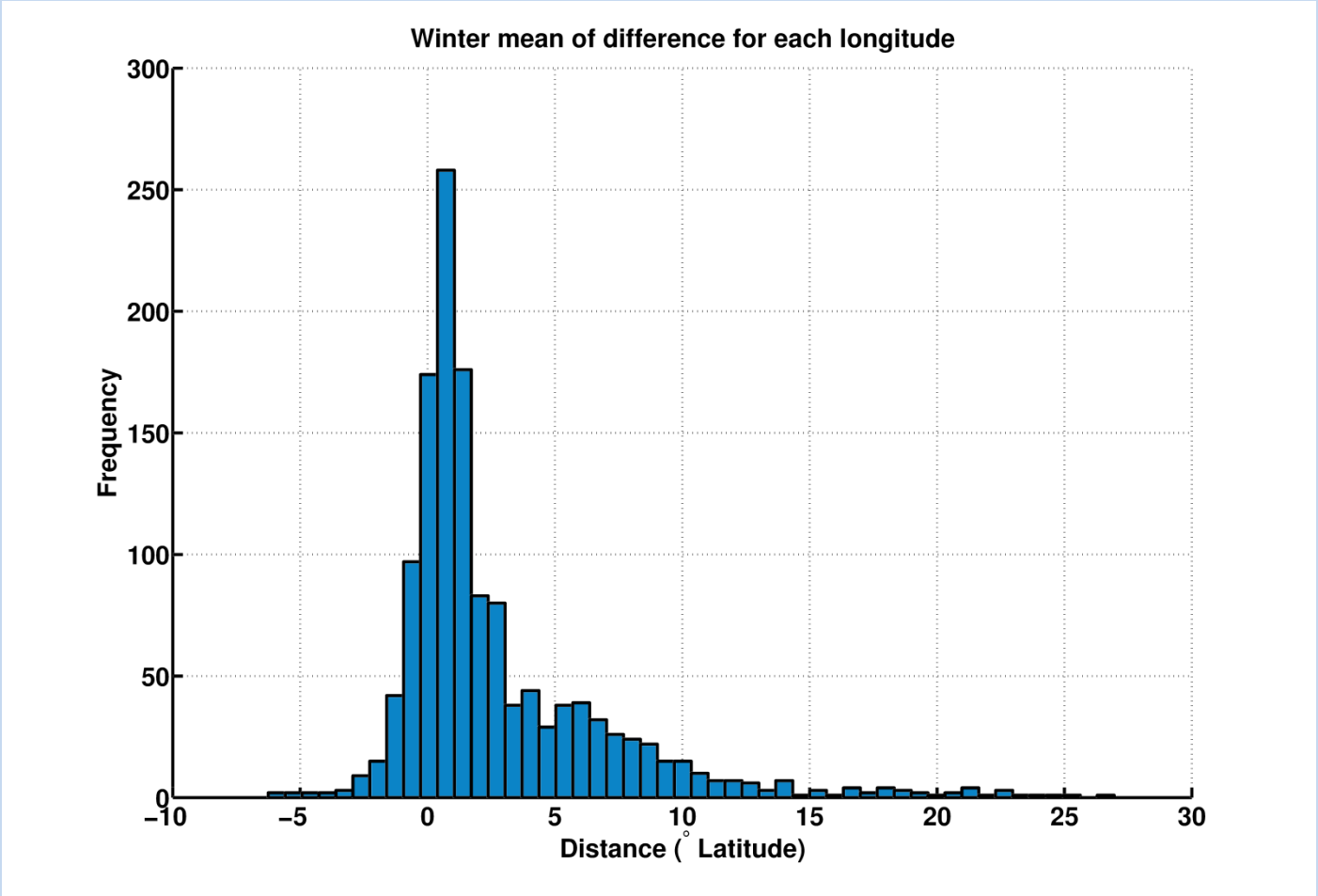


SNODAS

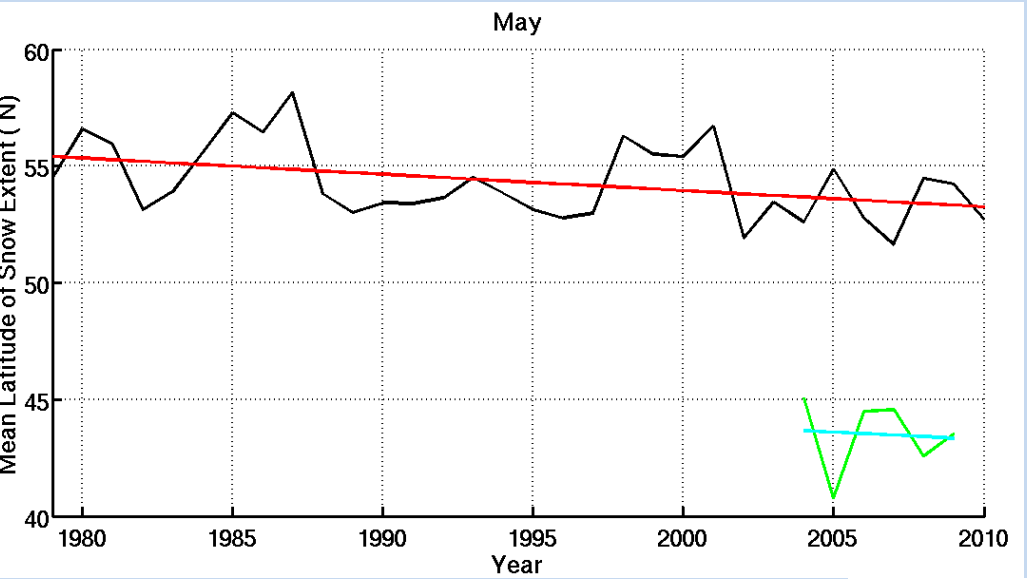
- Modeling and data assimilation framework
- 1 hr temporal and 1 km grid spacing
- Incorporates:
  - Quality controlled and downscaled numerical weather prediction output
  - Snow pack model
  - Data assimilation scheme
- 2004-2009

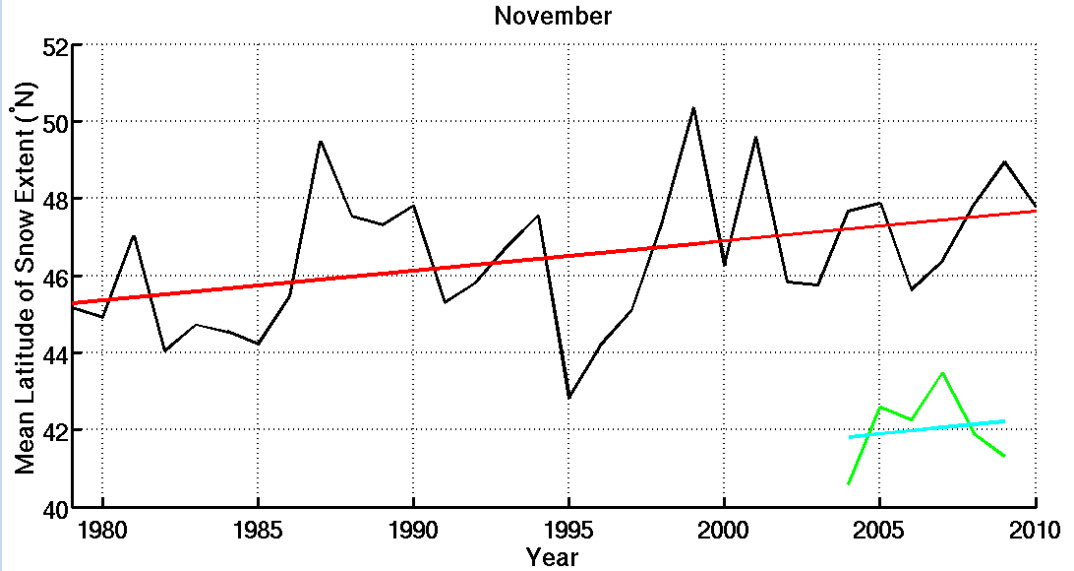
Full details in Barrett (2003)

NARR - SNODAS


Winter mean of difference for each longitude
Frequency
300
250
200
150
100
50
0
−10
−5
0
5
10
15
20
25
30
Distance (° Latitude)

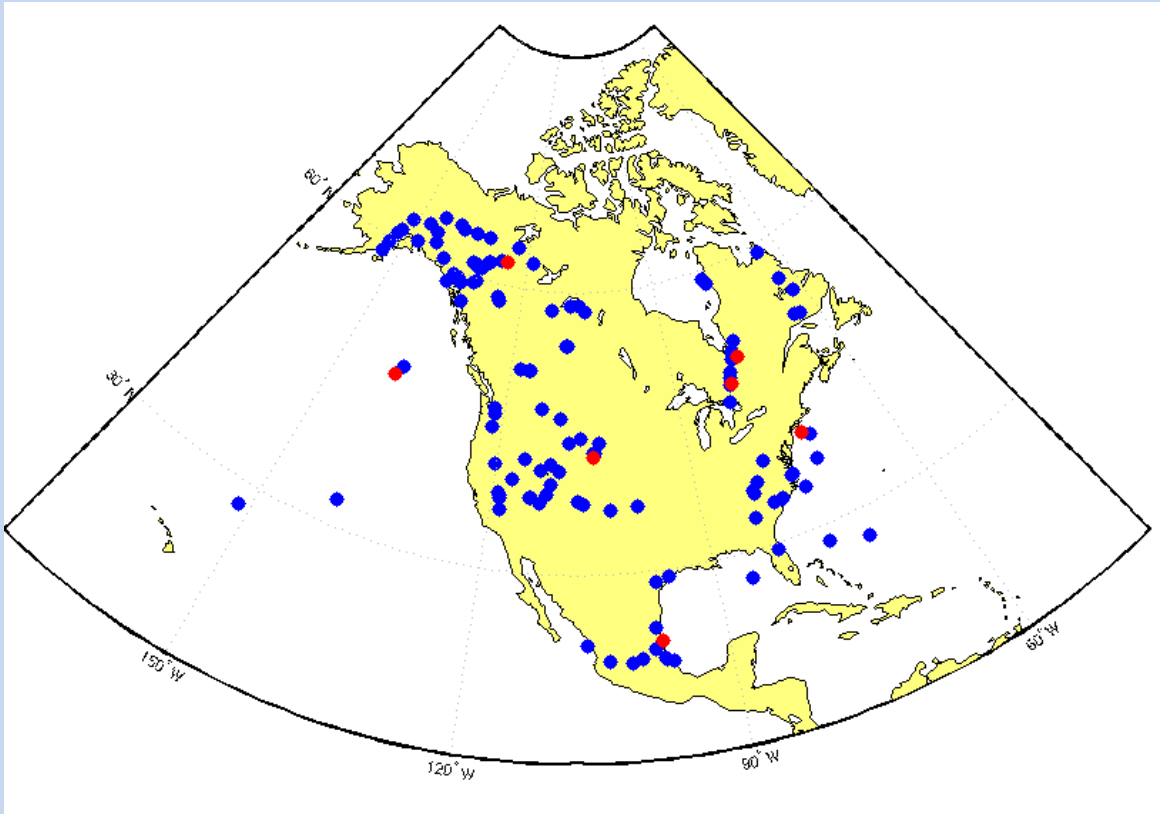
Snow Cover Trends





MLC Identification

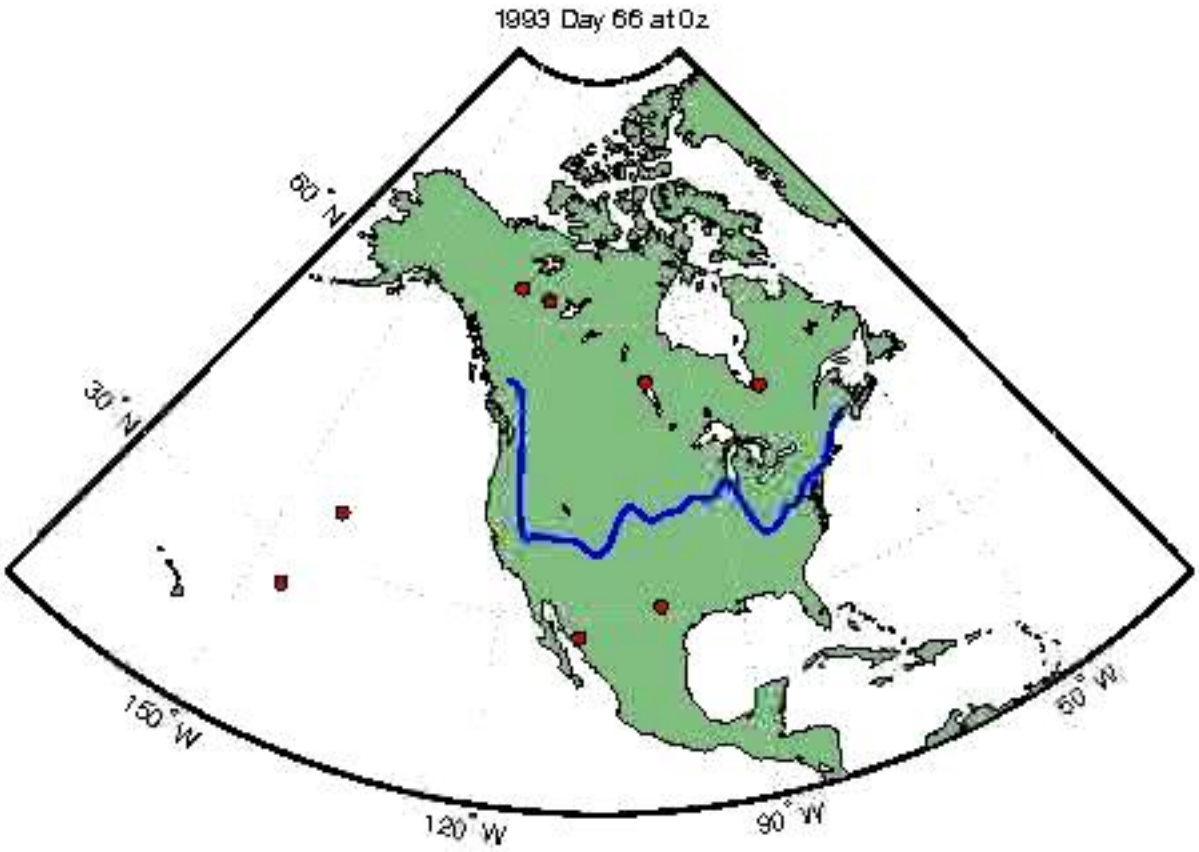
- Pressure minima located at fine (0.25°) and coarse (2.5°) resolution
- Coarse minimum moved to nearest fine minimum



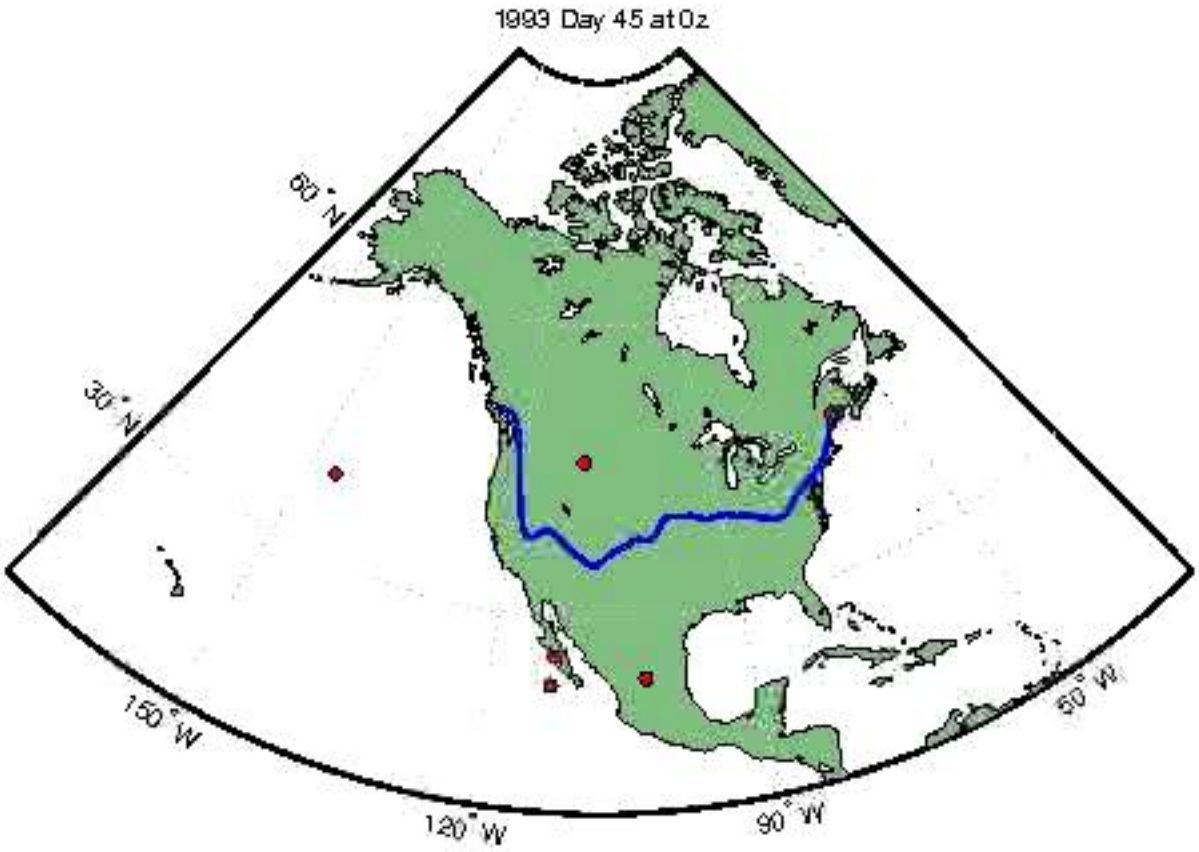
MLC Tracking

- Nearest centers within 400 km are linked at three hour time steps
- Center must move in six hours
- Center may not backtrack
- Center allowed to disappear for one time step

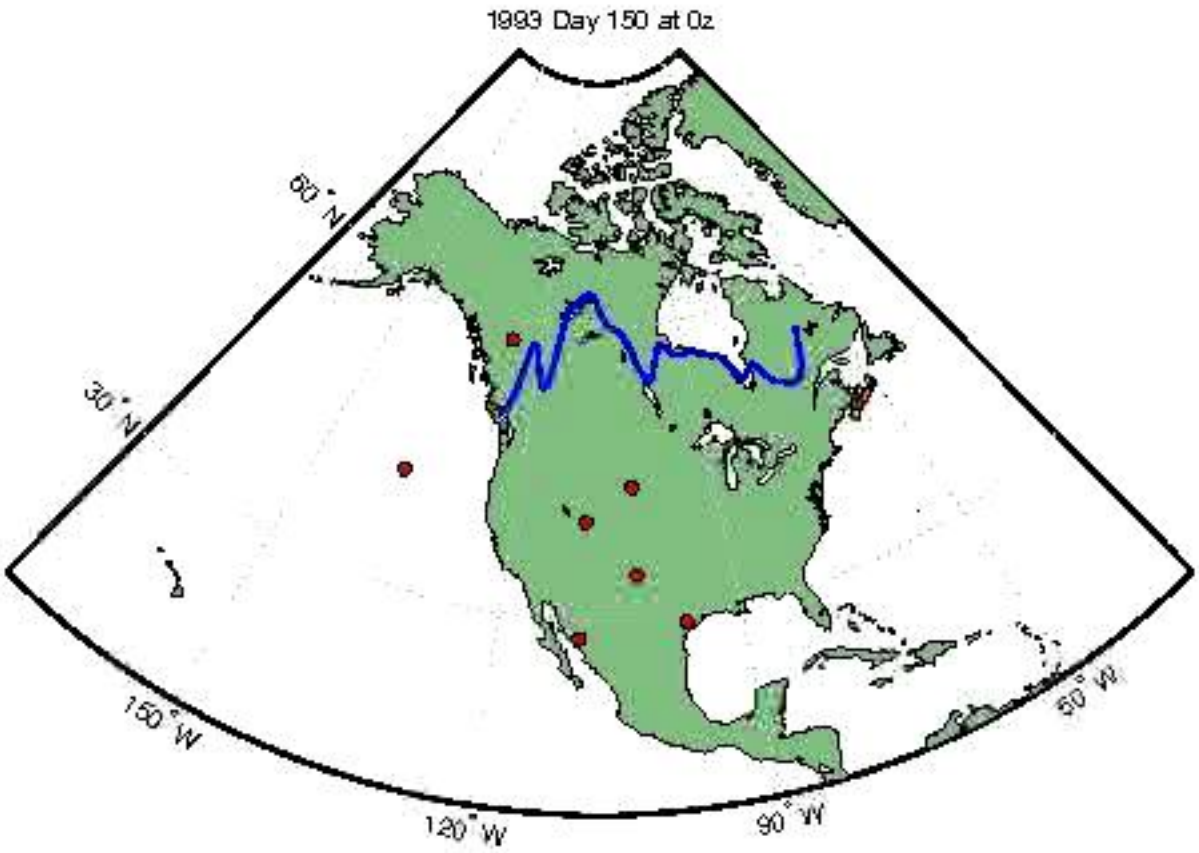
Blizzard of 1993



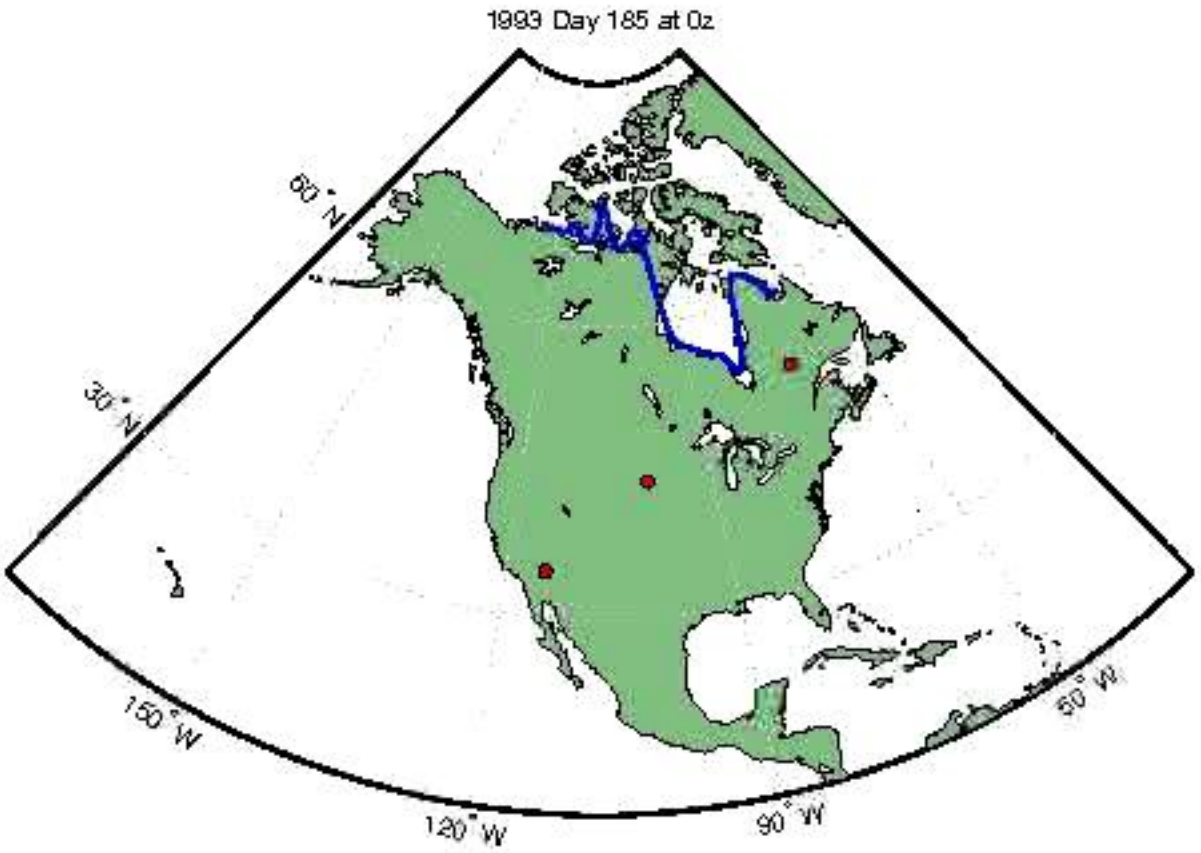
Snow Cover & MLCs



Mountains



Northern Boundary



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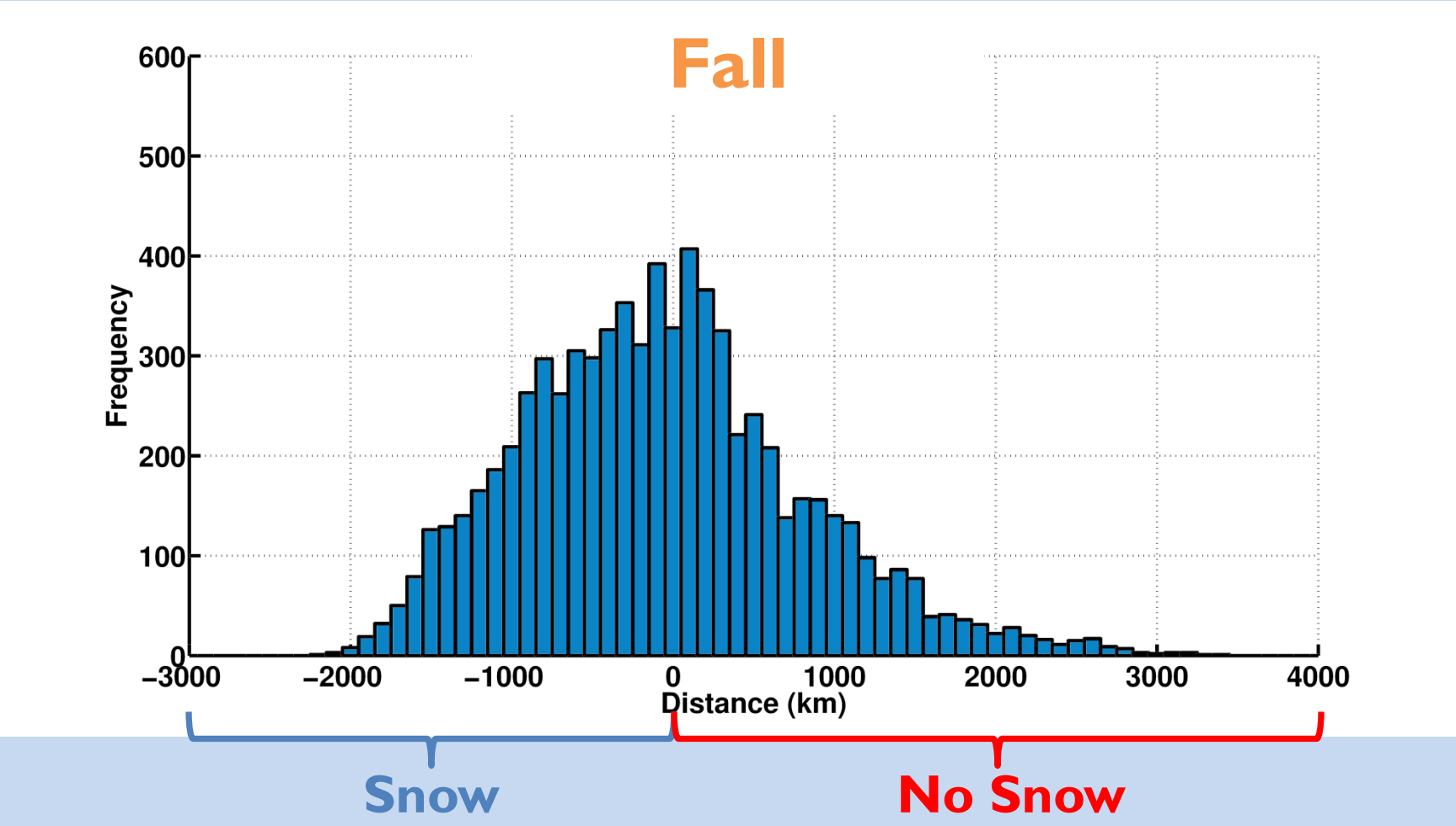
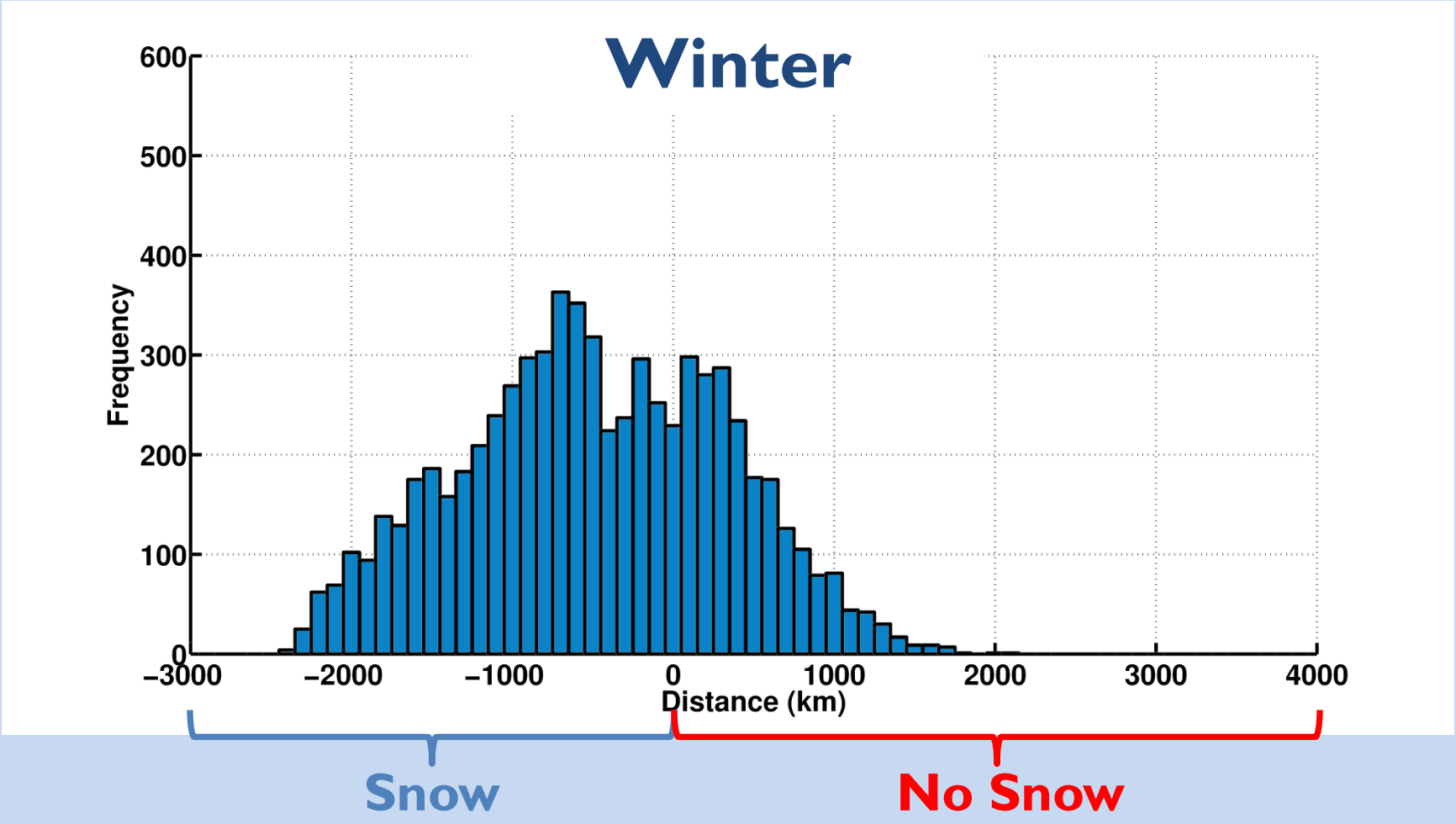
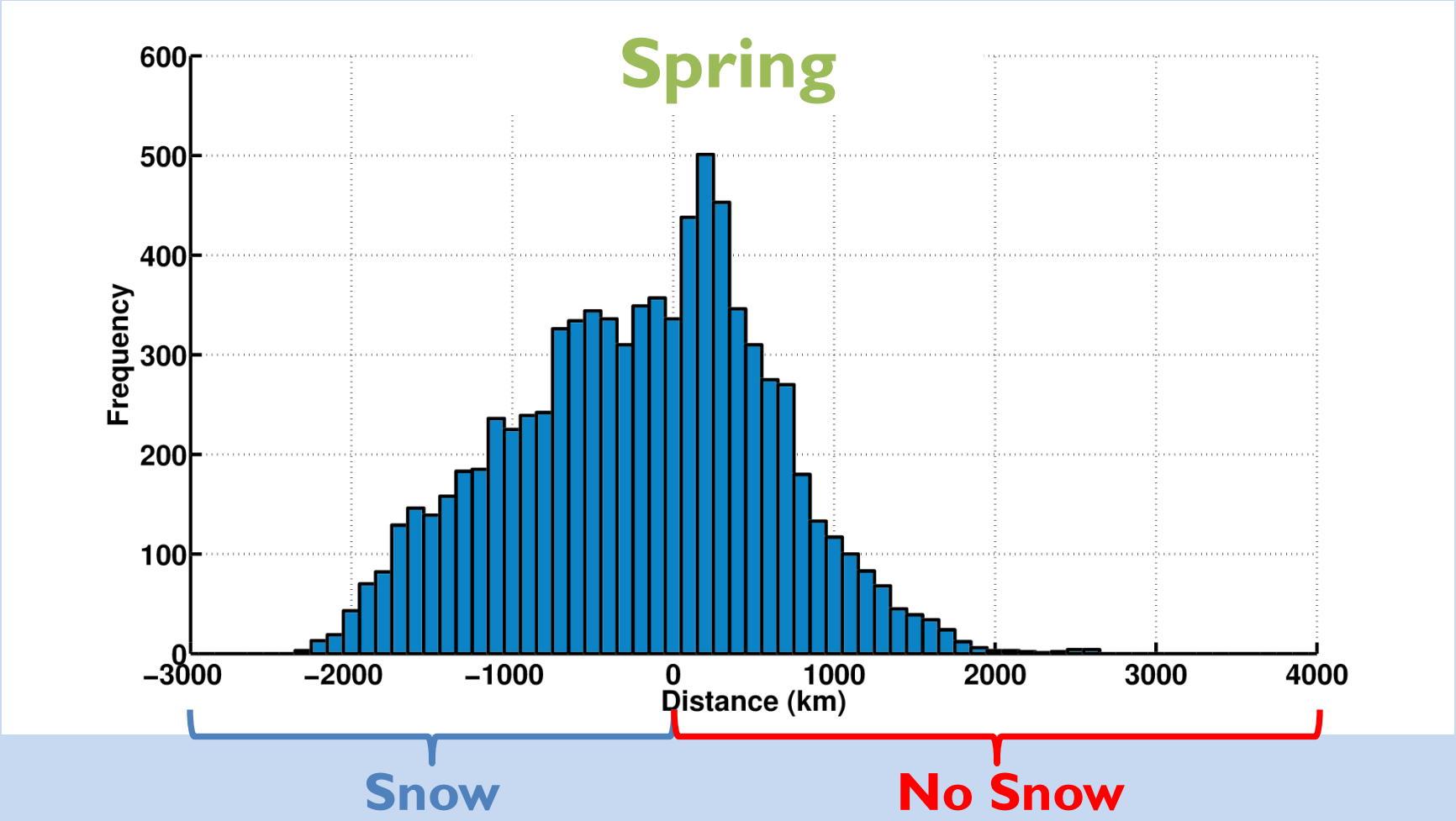
MLC Distance from Snow Extent



MLC Distance from Snow Extent

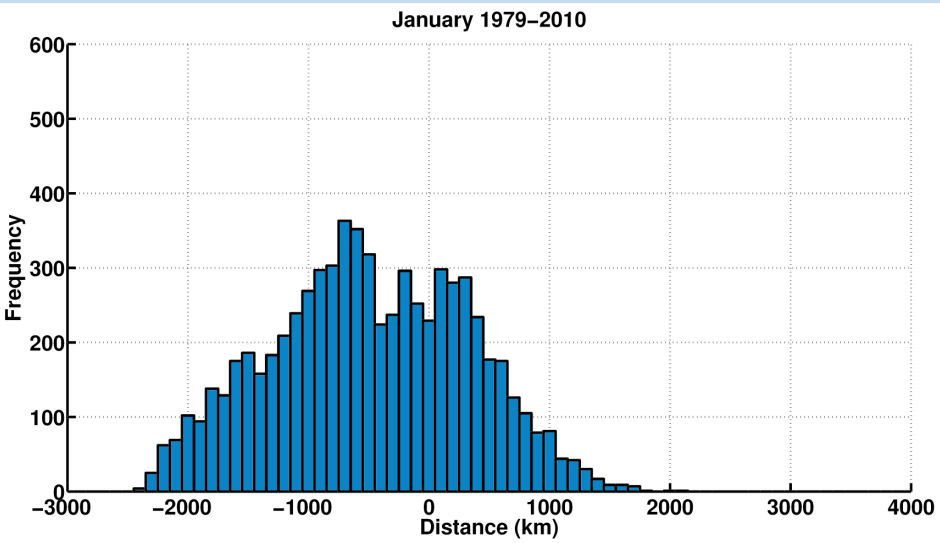


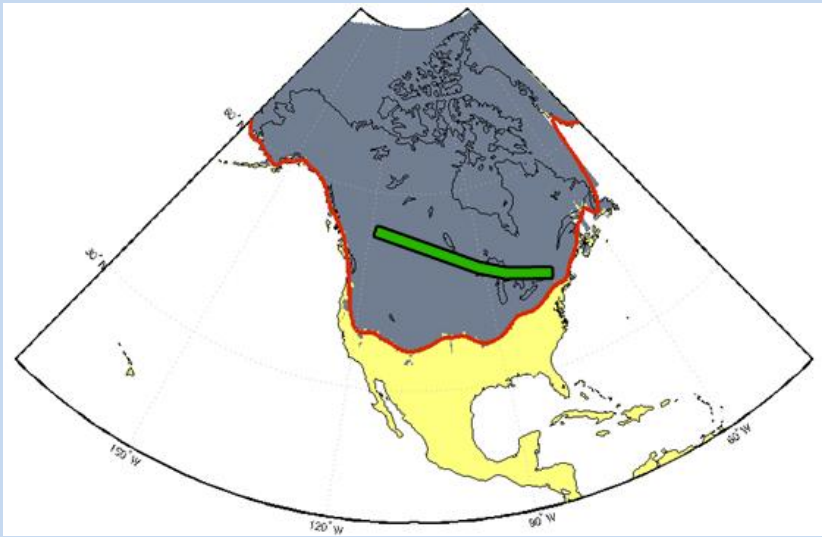
MLC Distance from Snow Extent



Why a Bimodal January?

- Likely caused by Alberta clippers
  - Occur roughly 600-800 km north of typical January snow cover extent
  - Most common in January



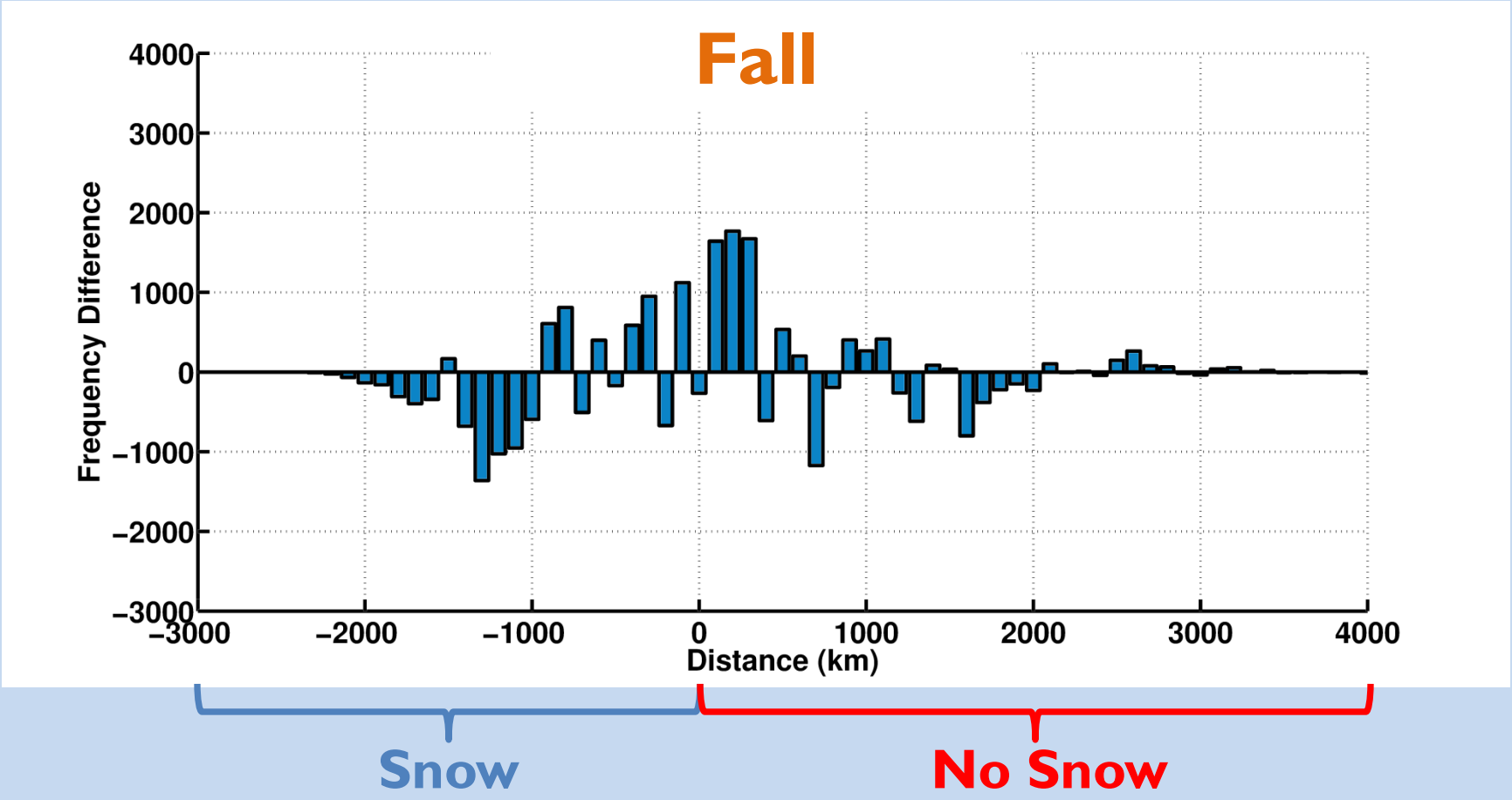


Average Alberta clipper track from Thomas and Martin (2007)

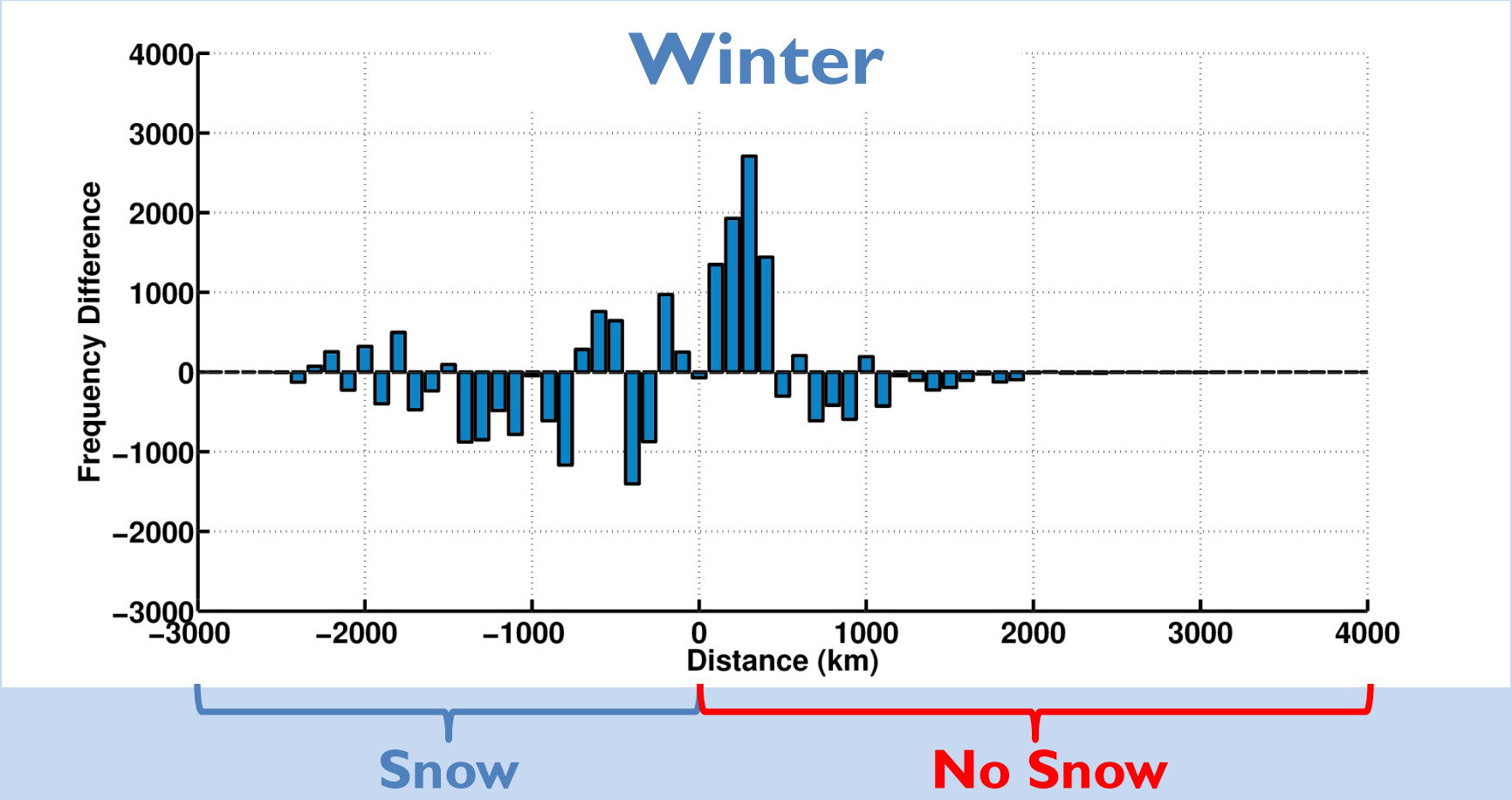
Robustness

- Create distributions from shuffled snow cover
  - Use the other 31 years of snow cover from the same day
- Subtract new distribution from original
- Sum the differences
- Assume that shuffling creates random noise that will cancel when summed
  - Regions of coherent peaks are assumed to be significant

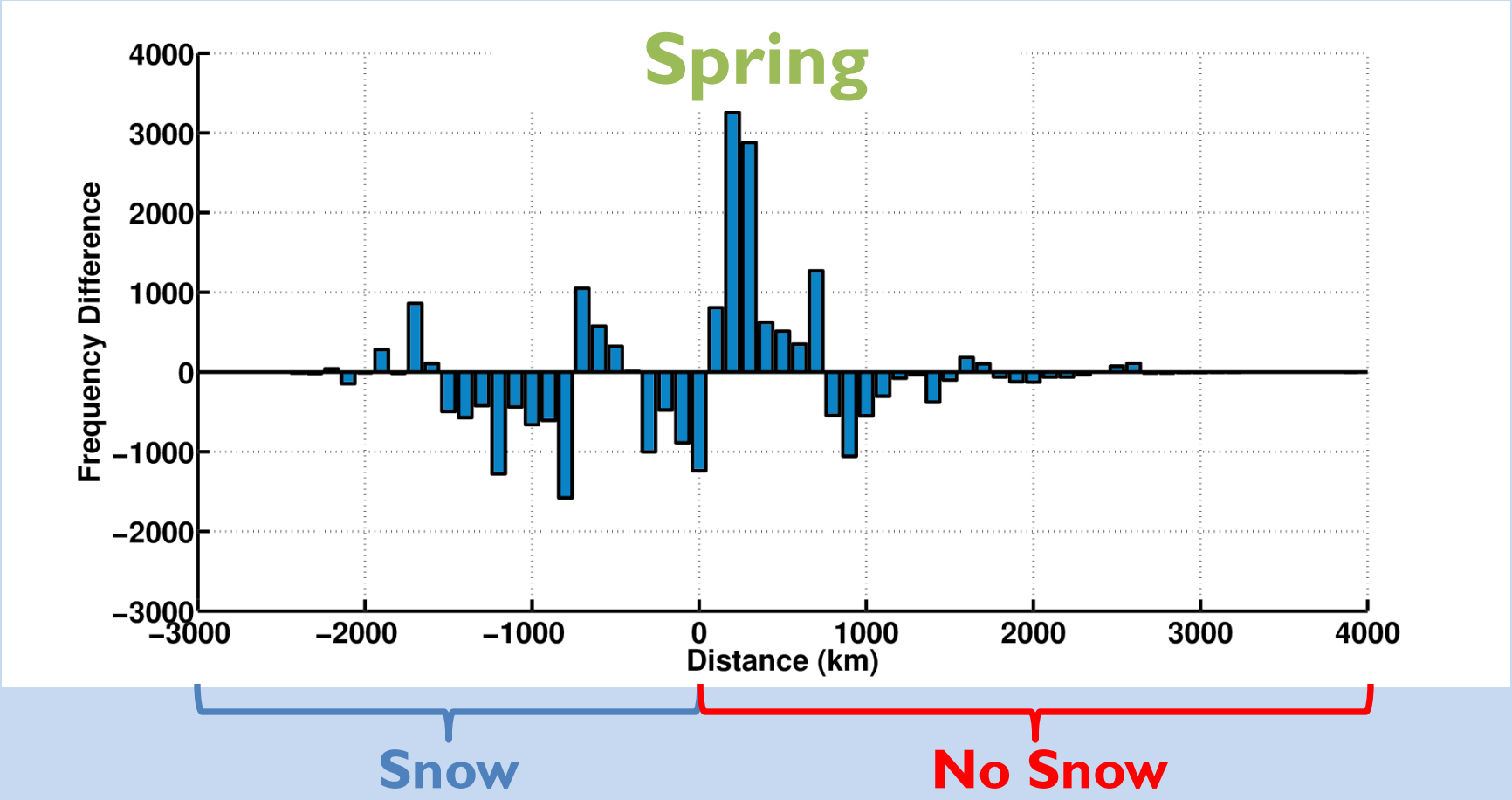
Robustness


Fall
Frequency Difference
4000
3000
2000
1000
0
−1000
−2000
−3000
−3000
−2000
−1000
0
1000
2000
3000
4000
Distance (km)
Snow
No Snow

Robustness


Winter
Frequency Difference
4000
3000
2000
1000
0
−1000
−2000
−3000
−3000
−2000
−1000
0
1000
2000
3000
4000
Distance (km)
Snow
No Snow

Robustness

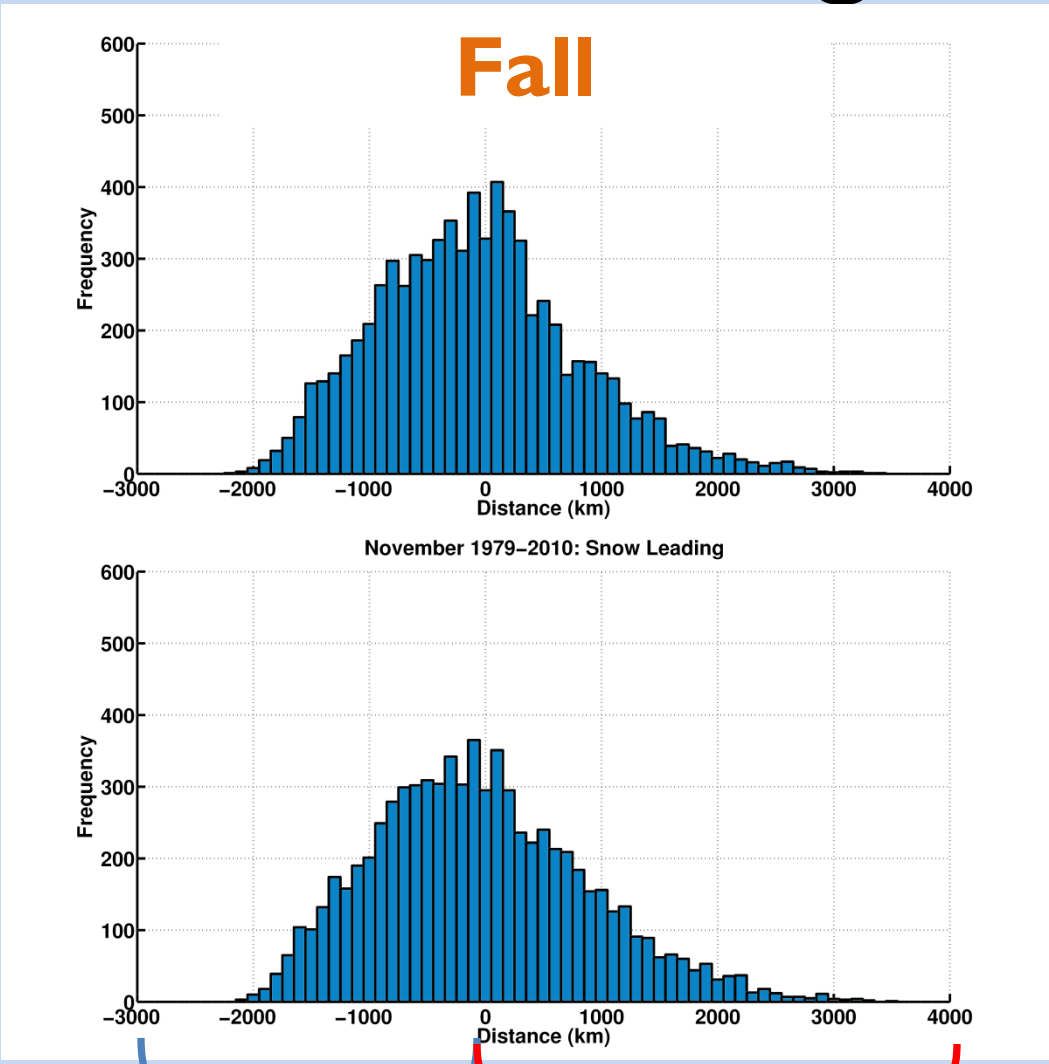

Spring
Frequency Difference
4000
3000
2000
1000
0
−1000
−2000
−3000
−3000
−2000
−1000
0
1000
2000
3000
4000
Distance (km)
Snow
No Snow

Lagged Relationships

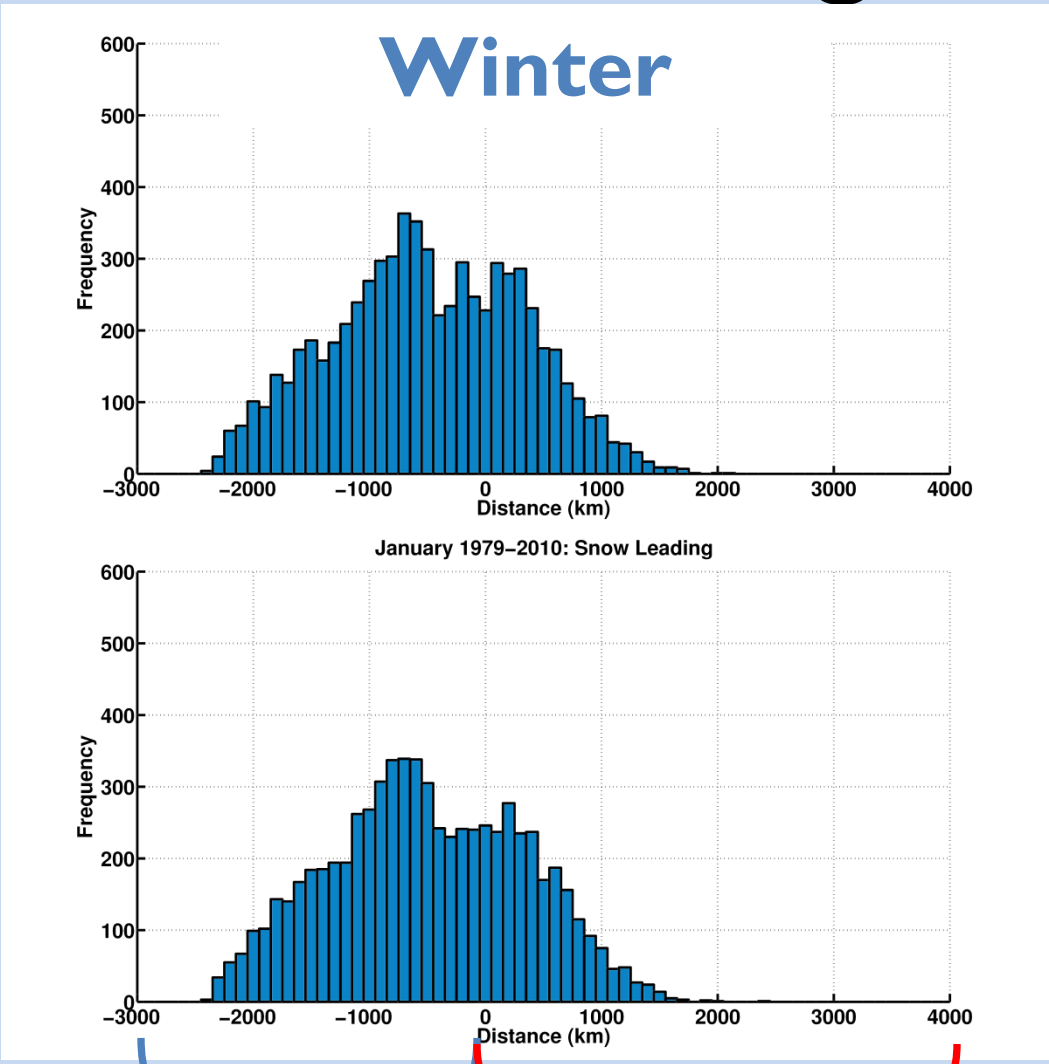
- A relationship between MLCs and snow cover is expected
  - During the winter, MLCs tend to deposit snow on their northern side

- If pre-existing snow cover is driving the relationship, then we expect little change in the distributions

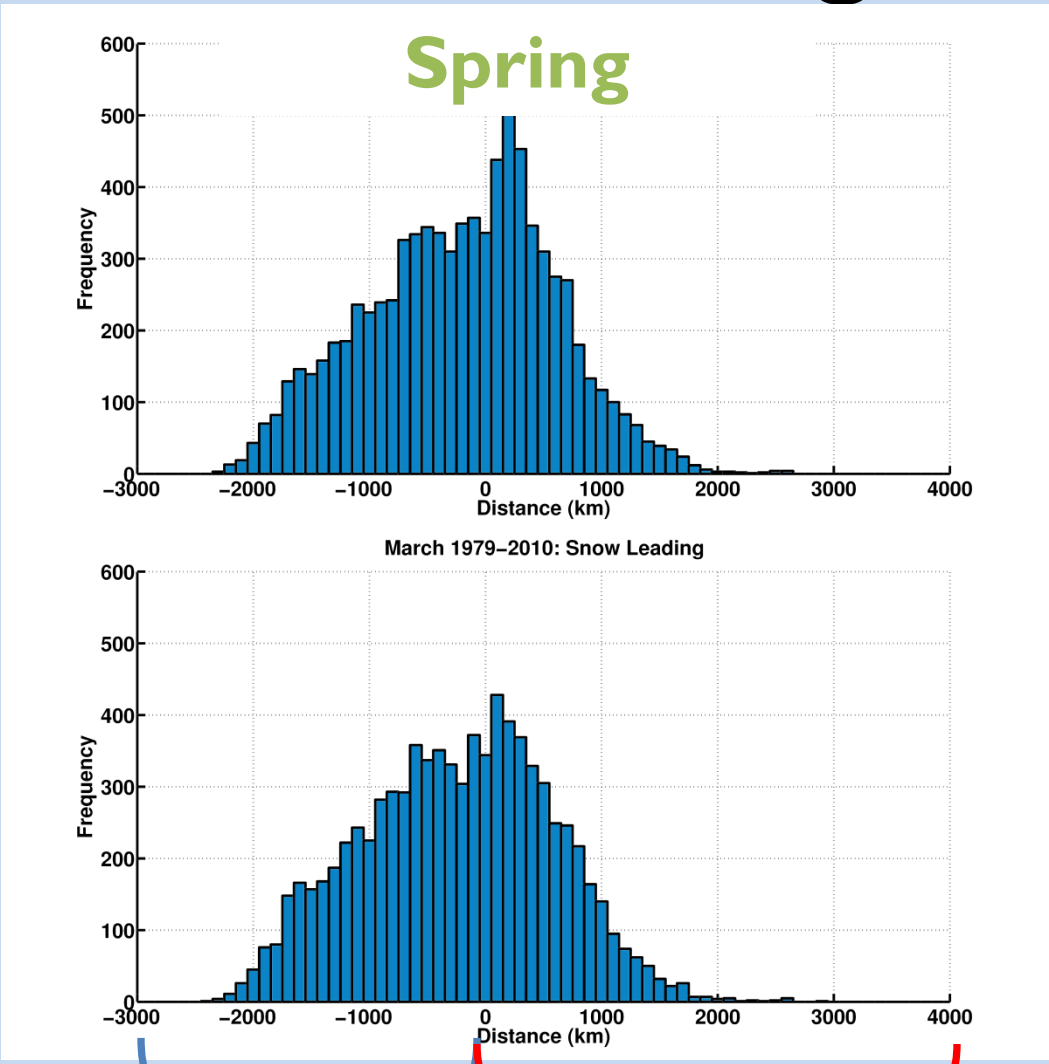
Lagged Relationship
Snow Leading



Lagged Relationship Snow Leading



Lagged Relationship Snow Leading

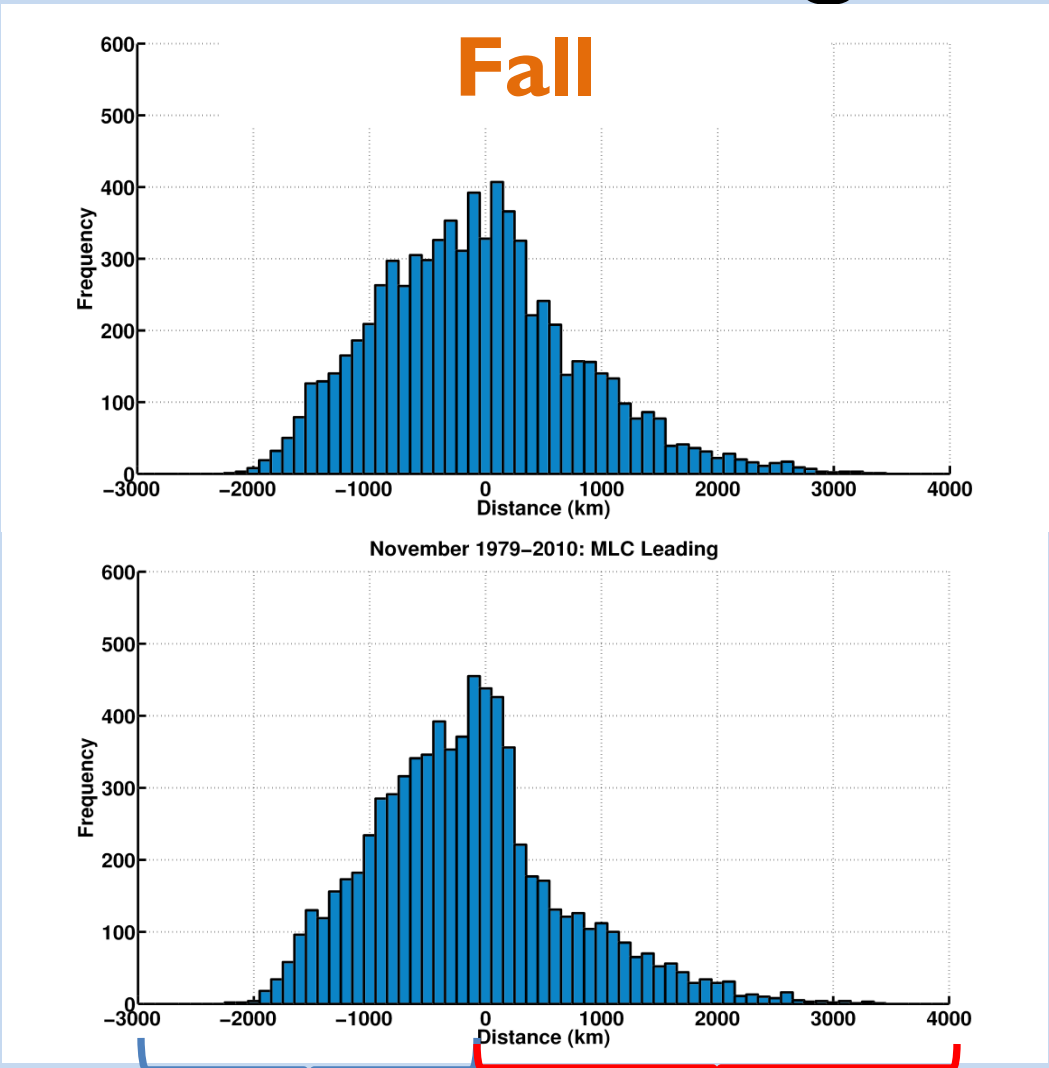


Lagged Relationships

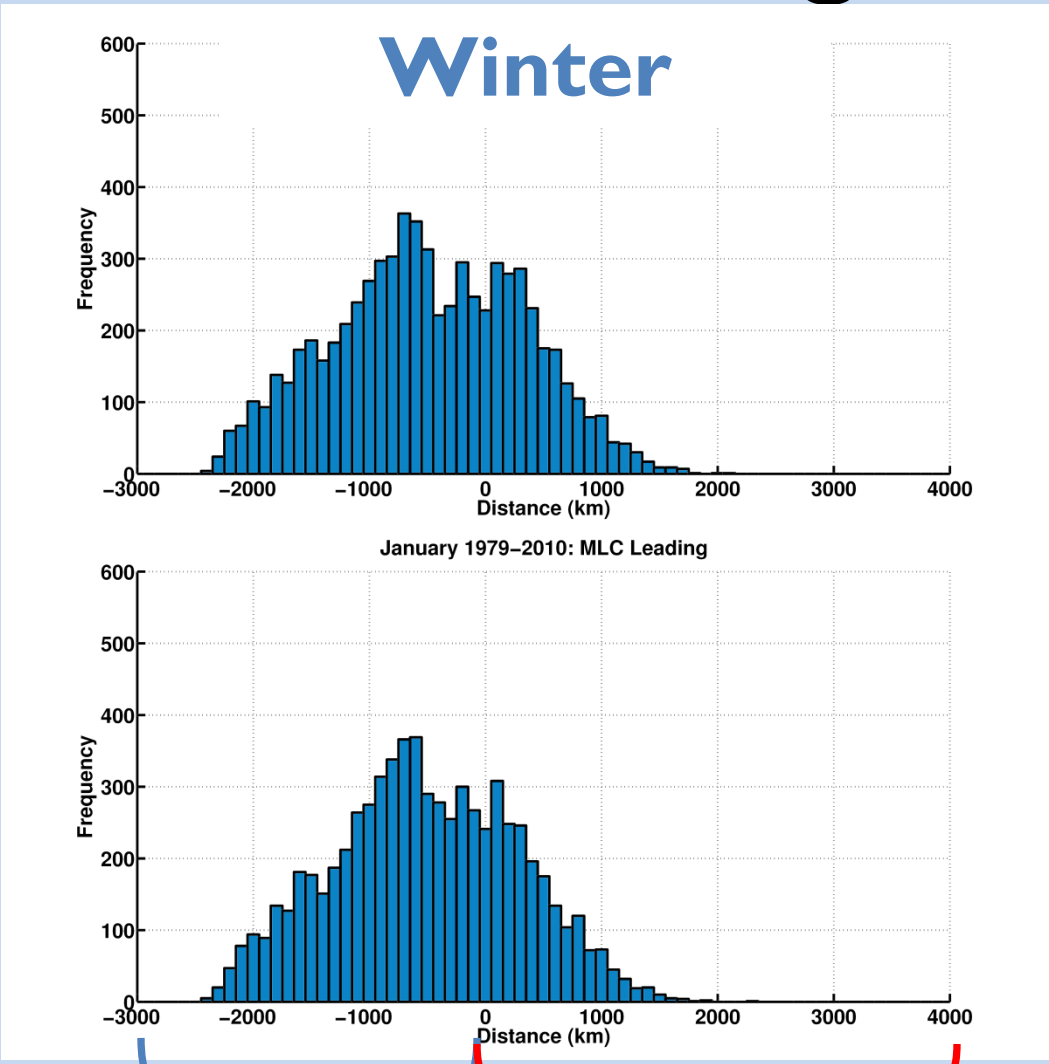
- Little change between no lag and snow leading by two days
  - Inherent lag for some MLC centers because of NARR snow water equivalent update time

- If the MLC is leading the snow cover, then we expect a shift in the distributions to the left

Lagged Relationship
MLC Leading



Lagged Relationship
MLC Leading



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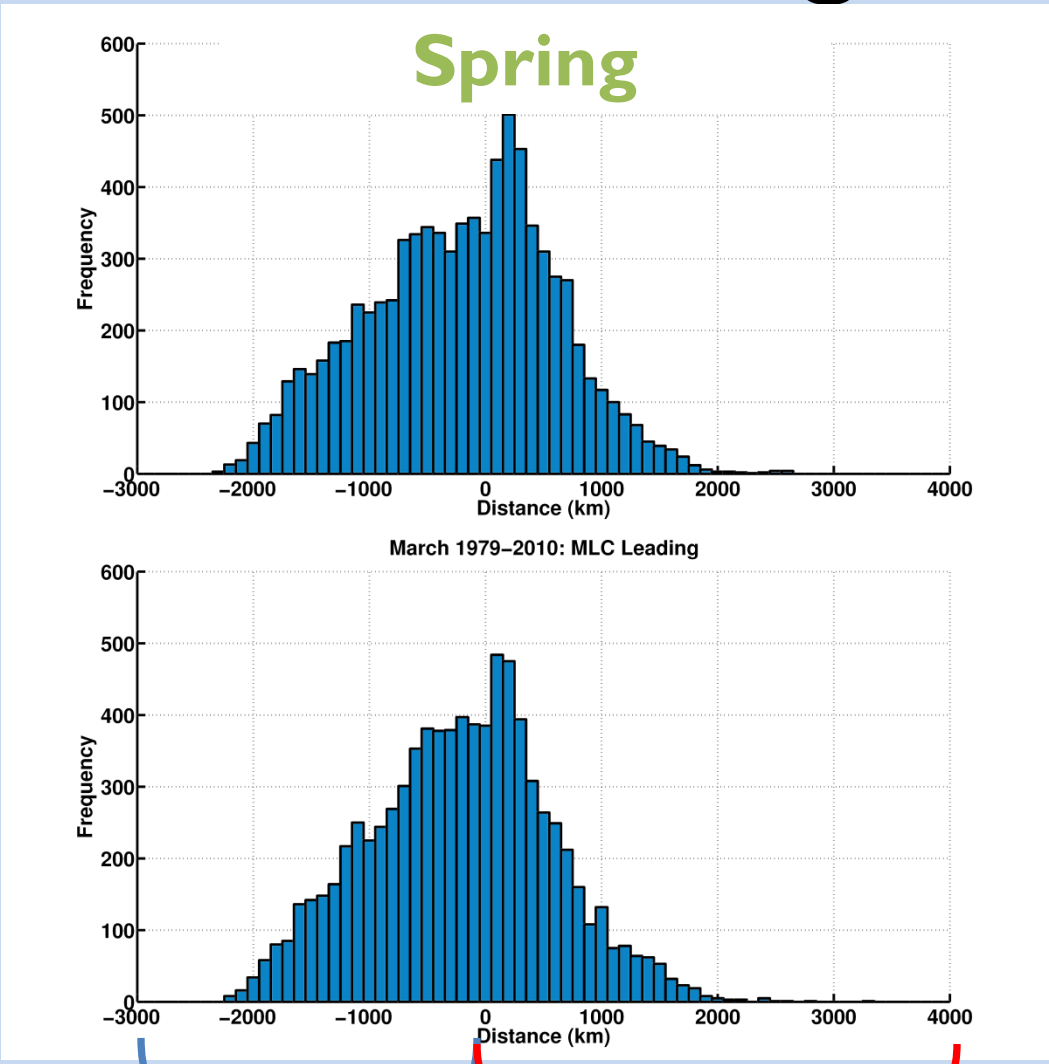
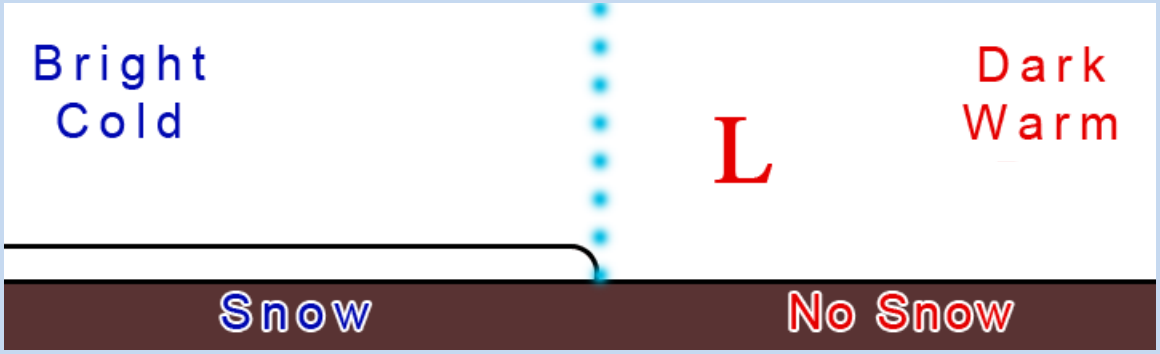
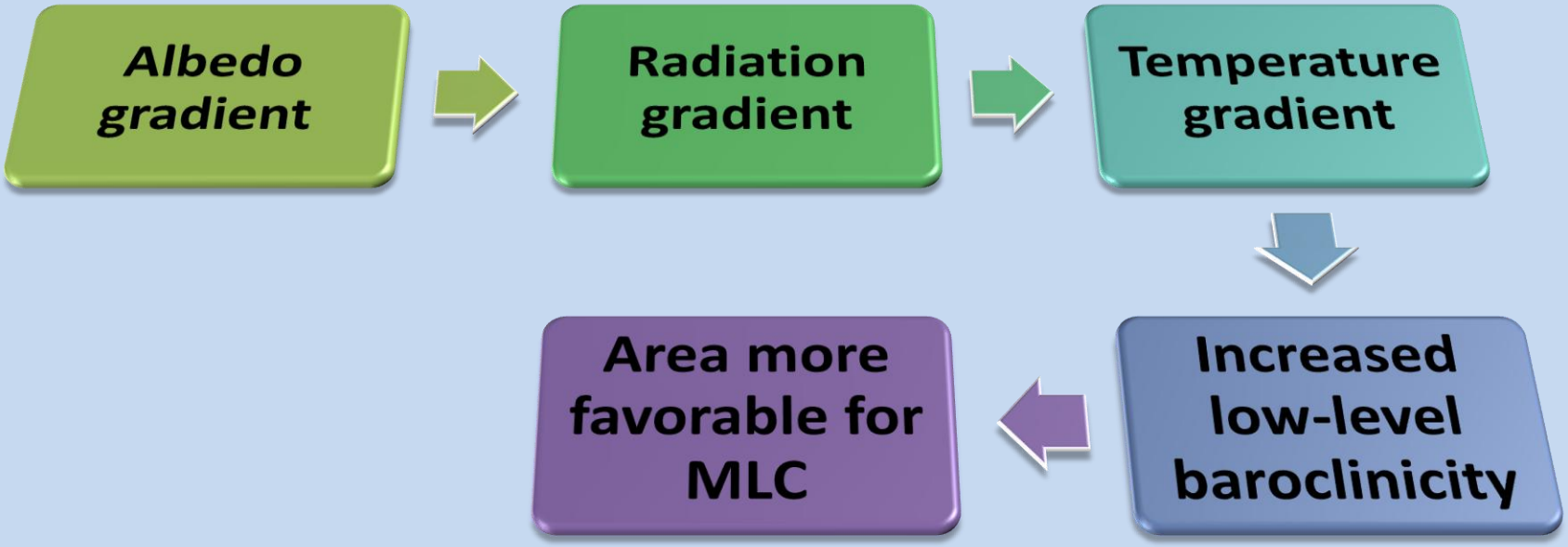
MLC Leading

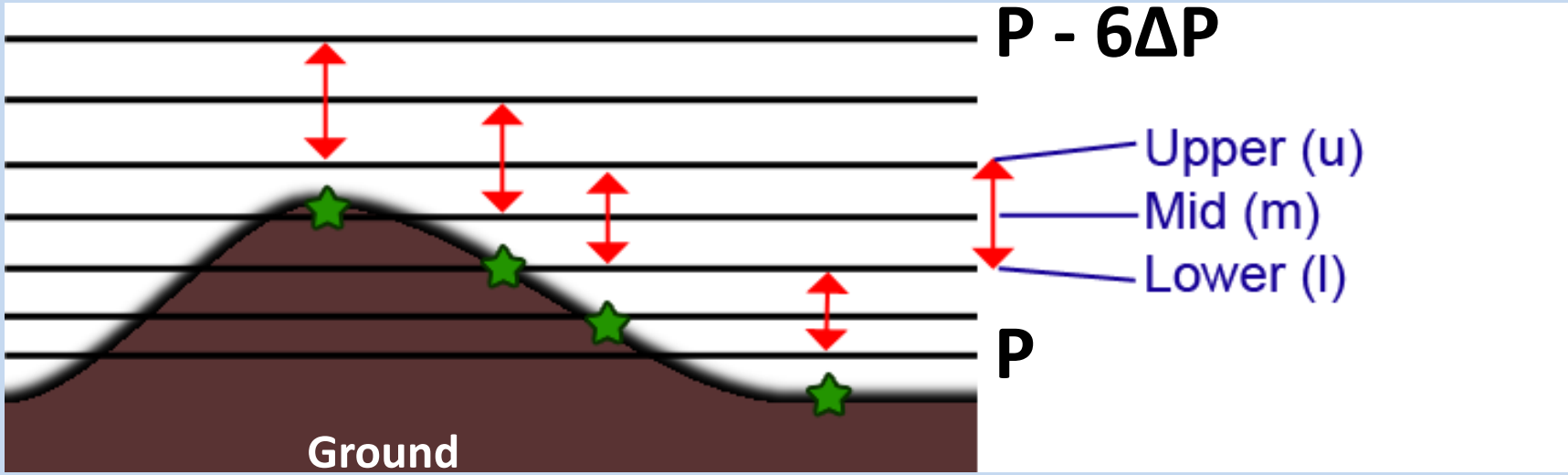


Why is there a relationship?





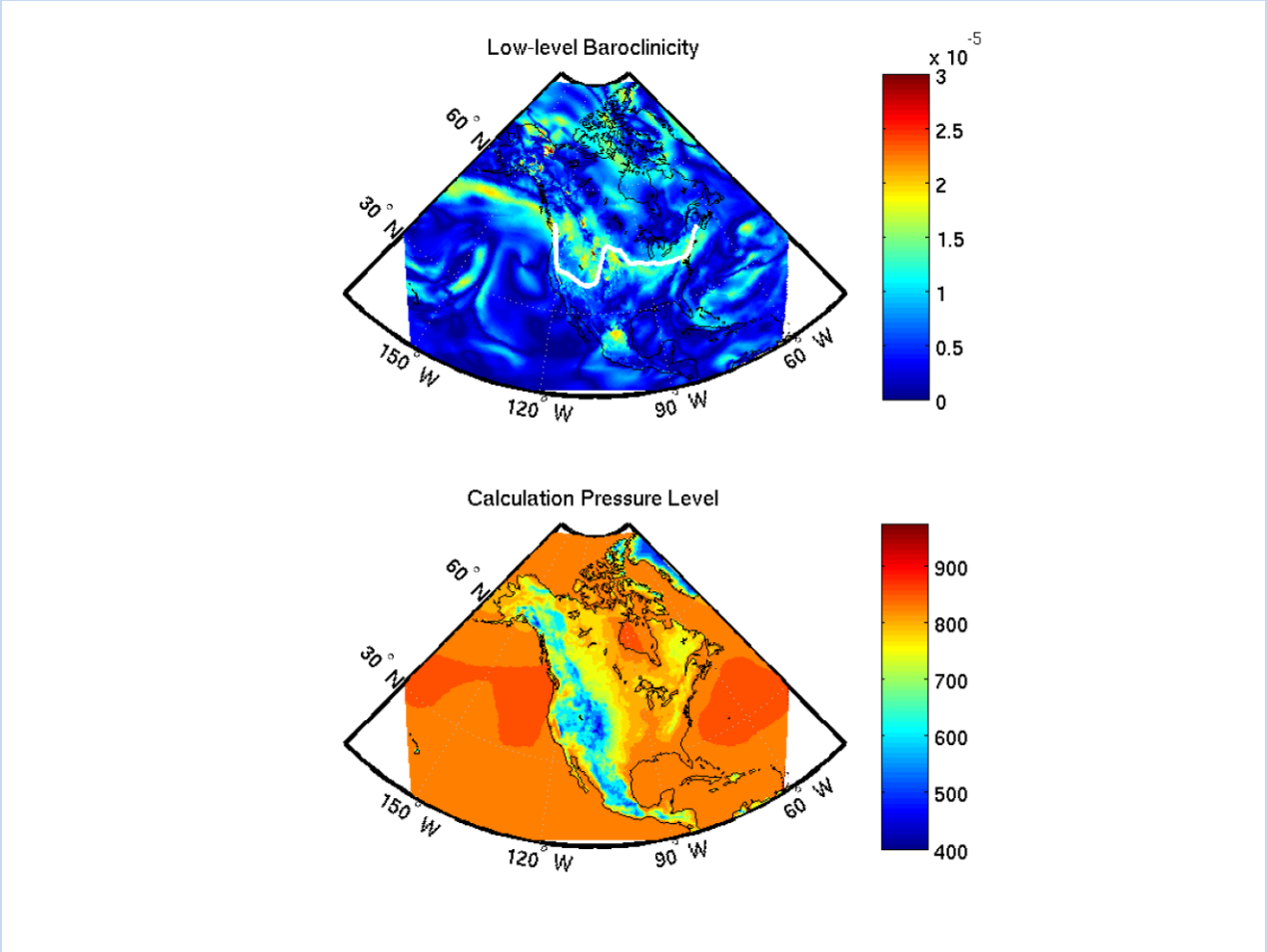
Low-level Baroclinicity



$$\sigma_{BI} = 0.31 \frac{f}{\sqrt{\frac{g}{\Theta_m} \frac{\Theta_u - \Theta_l}{\Phi_u - \Phi_l}}} \left| \frac{V_u - V_l}{\Phi_u - \Phi_l} \right|$$

(based off of Lindzen and Farrell, 1980)

Low-level Baroclinicity



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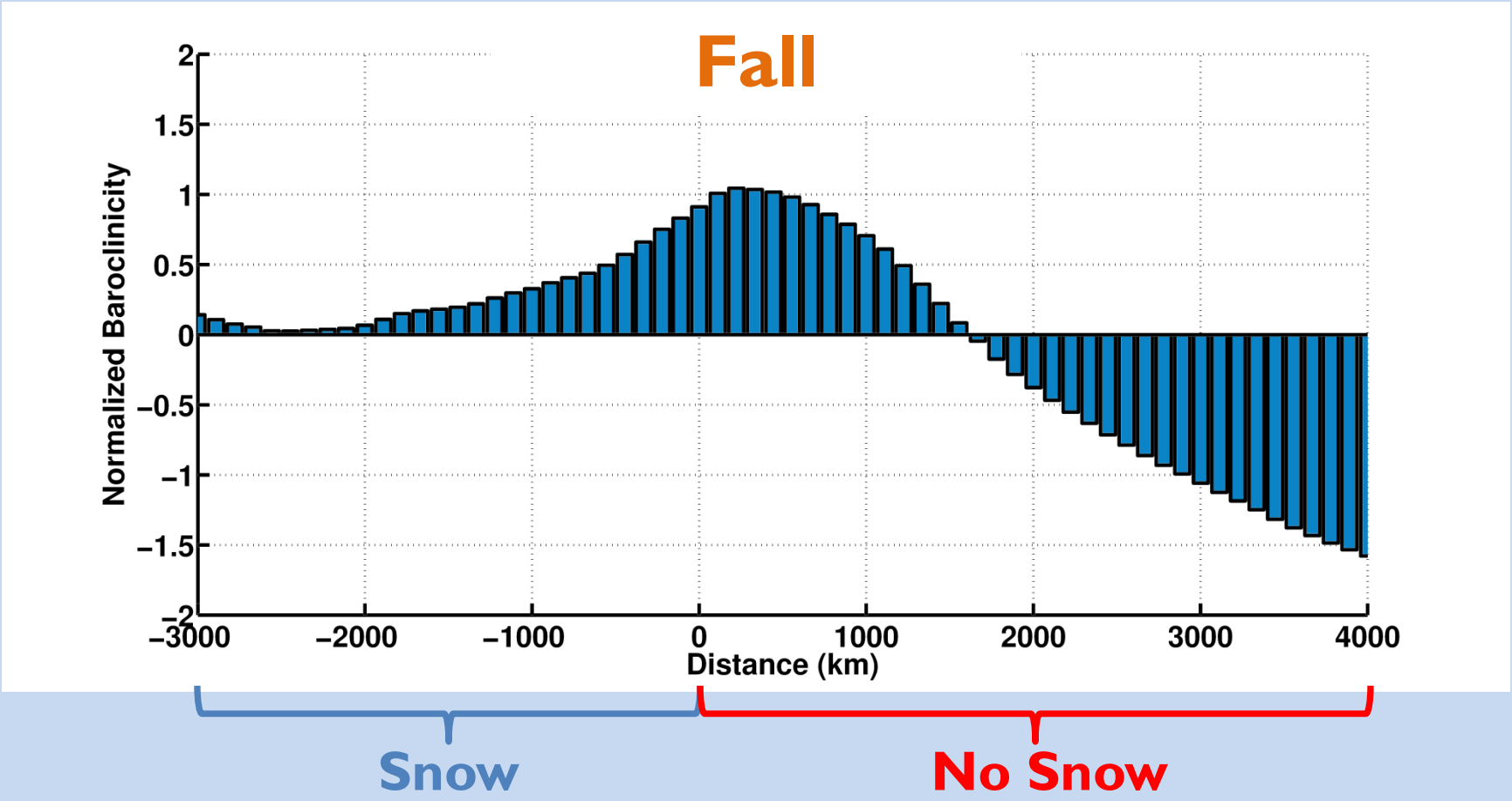
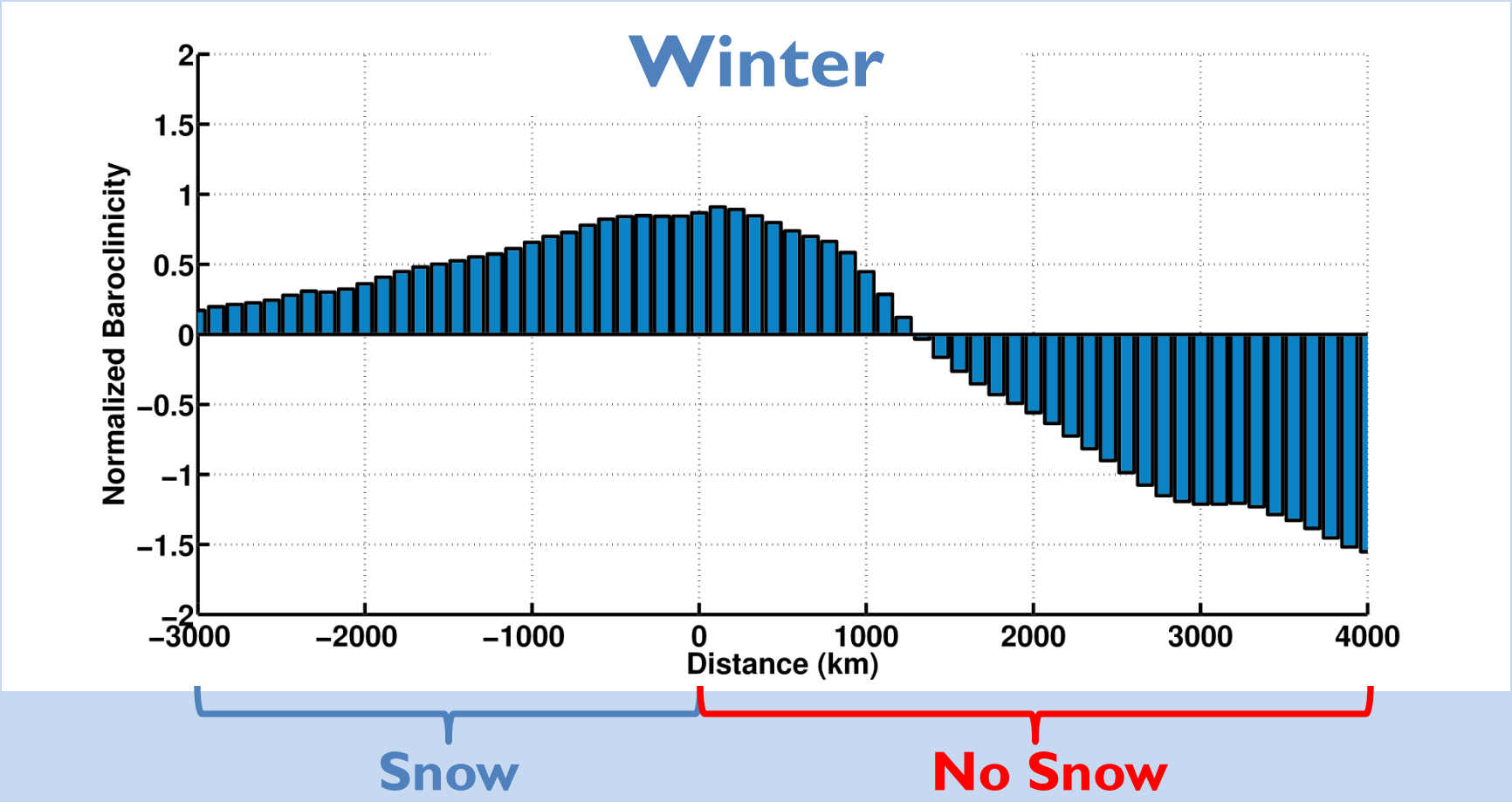
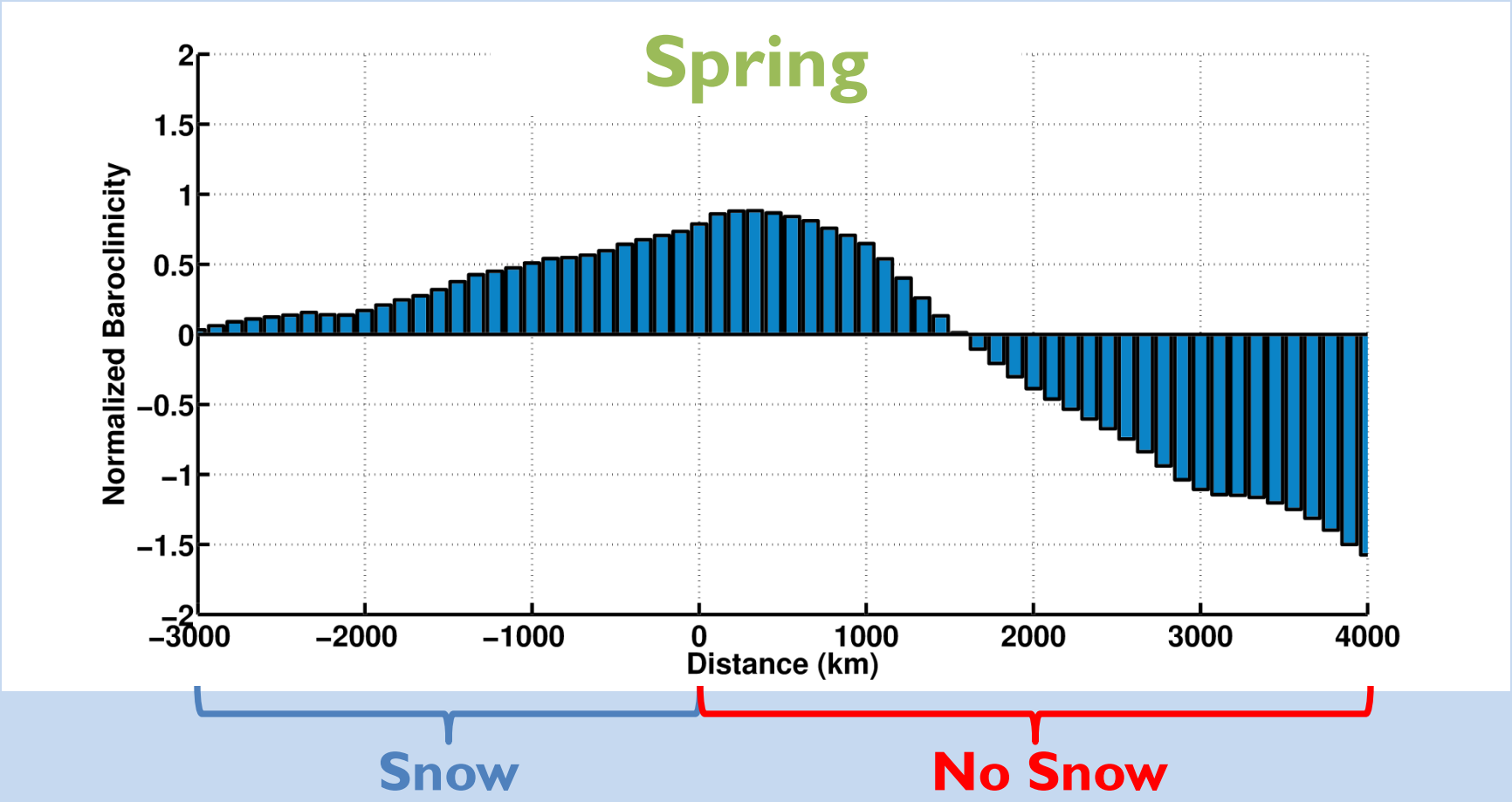


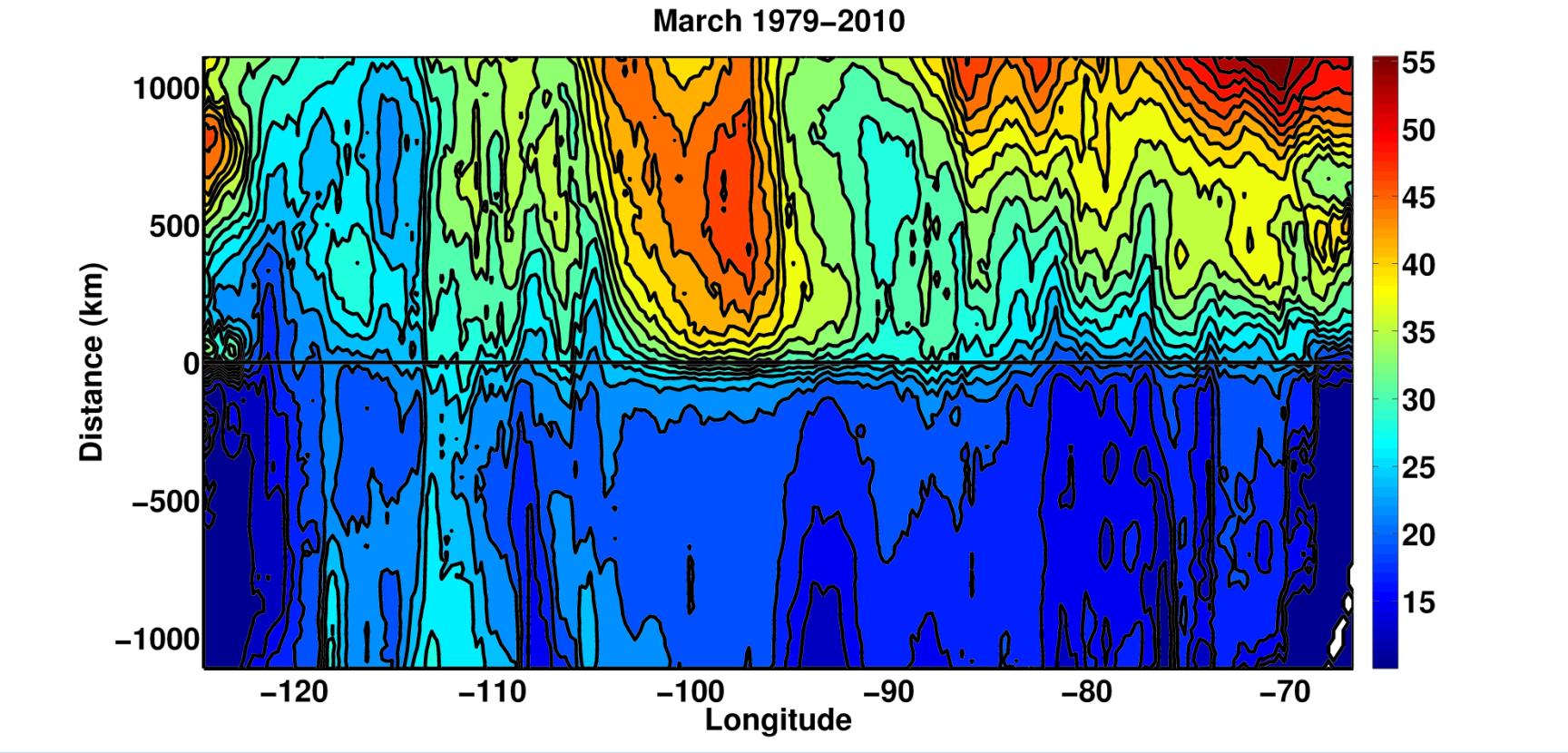
Low-level Baroclinicity



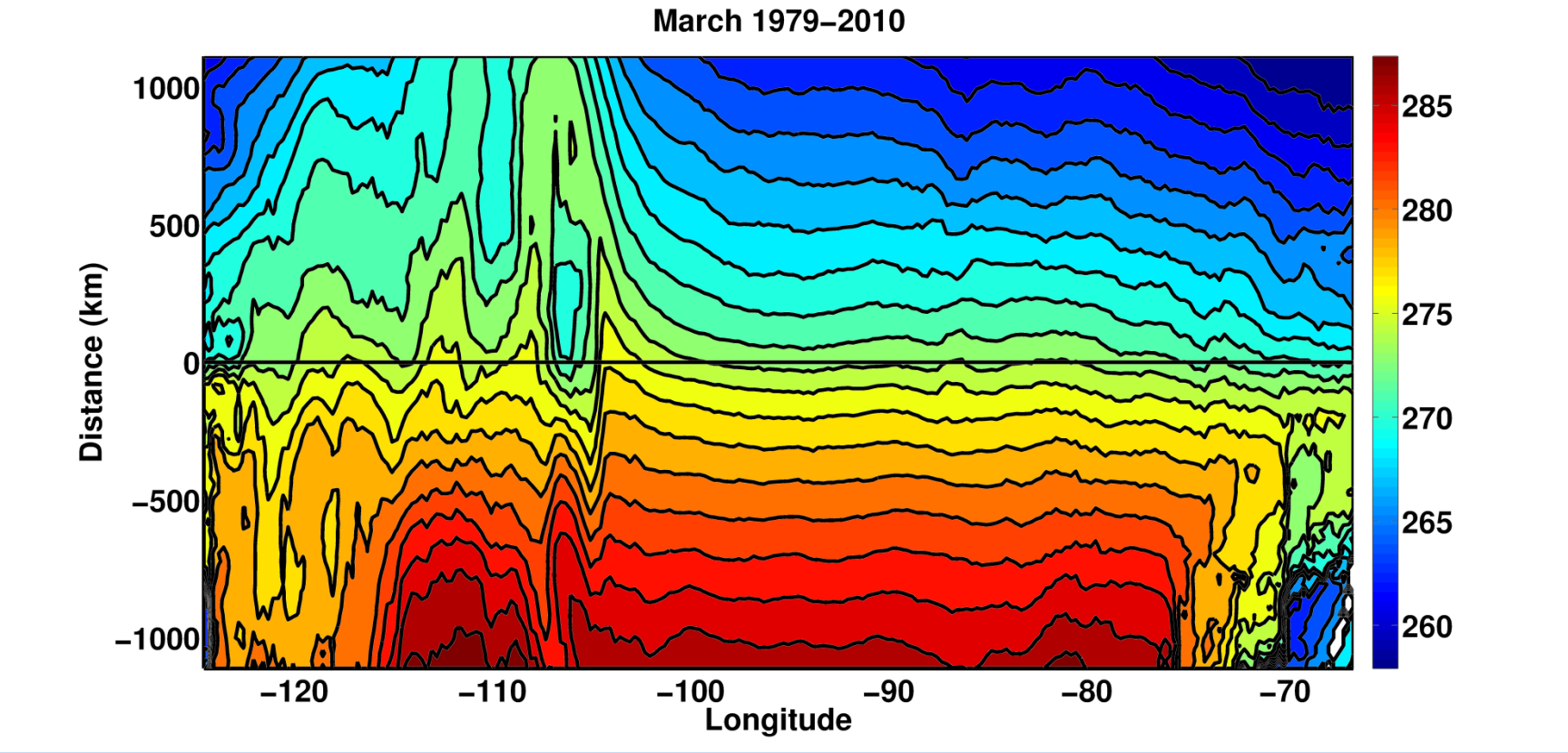
Low-level Baroclinicity



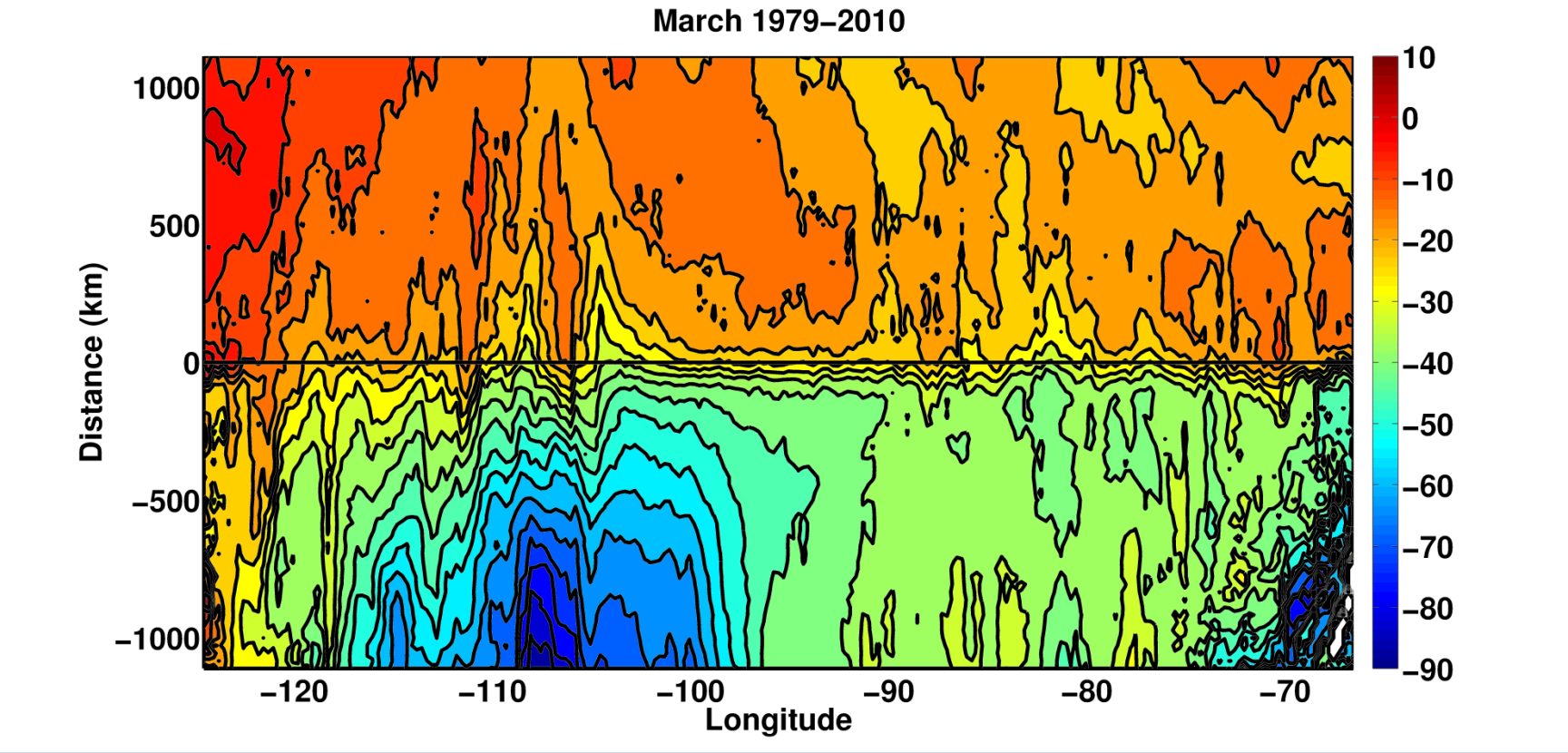
Snow Extent Albedo



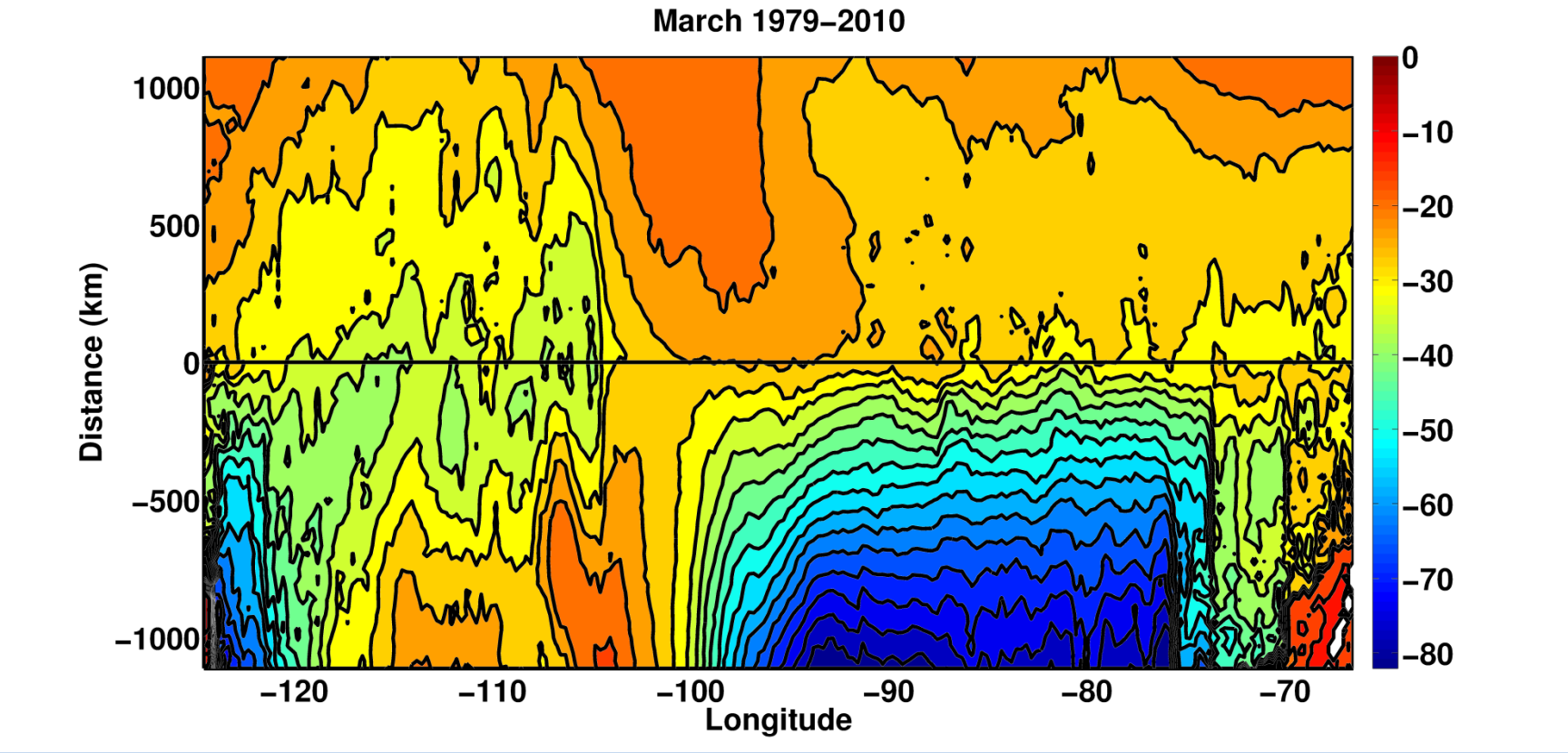
Snow Extent Temperature



Snow Extent Sensible Heat Flux



Snow Extent Latent Heat Flux



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Questions

- How well is the NARR able to represent snow cover extent and mid-latitude cyclone trajectories?

Reasonably well

- Is there a relationship between preexisting snow cover extent and mid-latitude cyclone trajectories?

Yes

- Is there a region of enhanced baroclinicity near the snow extent edge?

Yes

Poleward Shift

- Snow cover extent is expected to decrease with ACC (Brown and Mote, 2009)

- Thus, our relationship suggests snow cover extent will lead MLCs poleward over continents

Poleward Shift

- Observed and forecast poleward shift in storm tracks from ACC, mainly in the North Atlantic and North Pacific (IPCC, 2007; Jiang and Perrie, 2007)

- Increased baroclinicity off the east coast of continents important to oceanic storm track locations (Hoskins and Valdes, 1990)

Poleward Shift

- Ross and Walsh (1986) found that enhanced baroclinicity near coastal boundaries due to increased snow cover is important to MLC trajectories

- The relationship suggests that continental snow cover may play a role in oceanic storm tracks shifting poleward

Future Work

- Why is it the region 50-350 km south of the snow extent?
- Why is MLC frequency confined to a narrow region while low-level baroclinicity has a broad structure?

- Methods
  - Idealized model
  - Case studies with small snow extent perturbations

Take Home Messages

- Enhanced frequency of MLCs in a region 50-350km south of snow extent
  - Stronger relationship during the spring
- Driven by low-level baroclinicity
- May play a role in the poleward shift of storm tracks with ACC

Acknowledgements

- Advisor – Ankur Desai
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