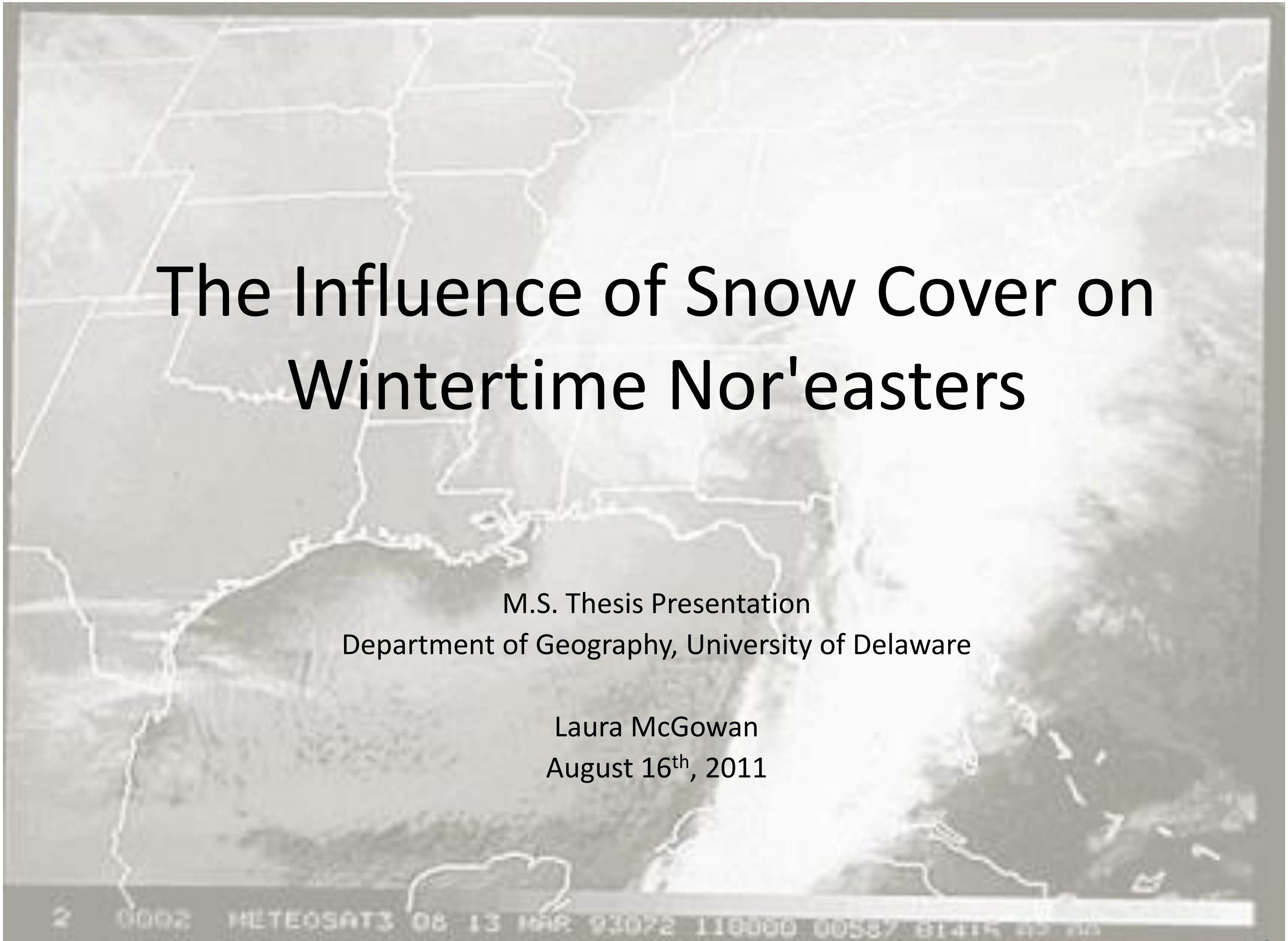

The Influence of Snow Cover on Wintertime Nor'easters

M.S. Thesis Presentation

Department of Geography, University of Delaware

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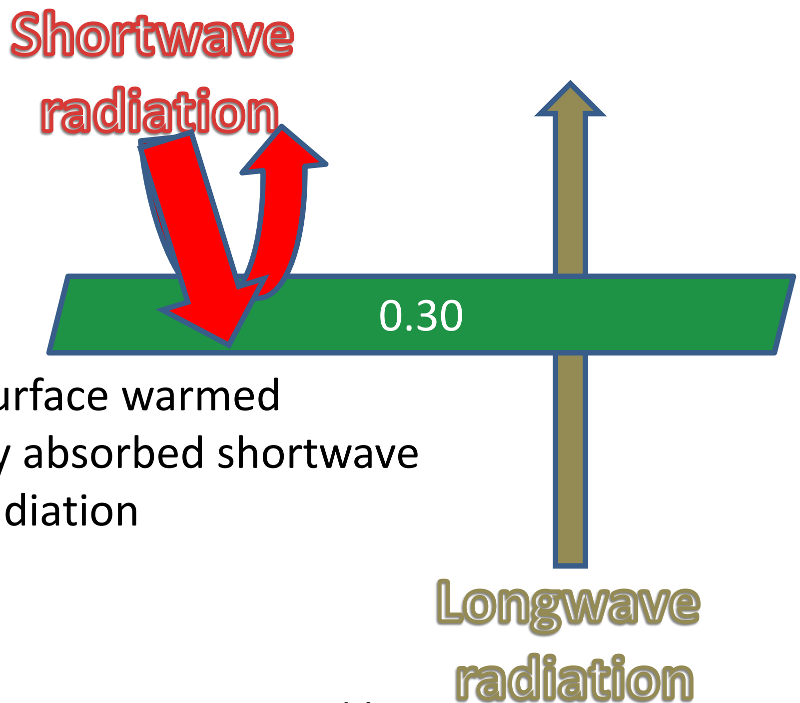
Introduction:
Snow cover and Energy Budget

- In terms of albedo, the addition or removal of snow is the most notable change that can be made to a landcover (Kung et al. 1964).
  - In the mid-latitudes, the north to south winter albedo profile changes significantly due to snow cover with albedo values varying from 0.20 to 0.80
- The surface albedo forcing is thought to be of the same magnitude as the forcing from anthropogenic aerosols, green house gases, and solar variation (Pielke et al. 2002)

Introduction:
Snow cover and Energy Budget

Normal Conditions

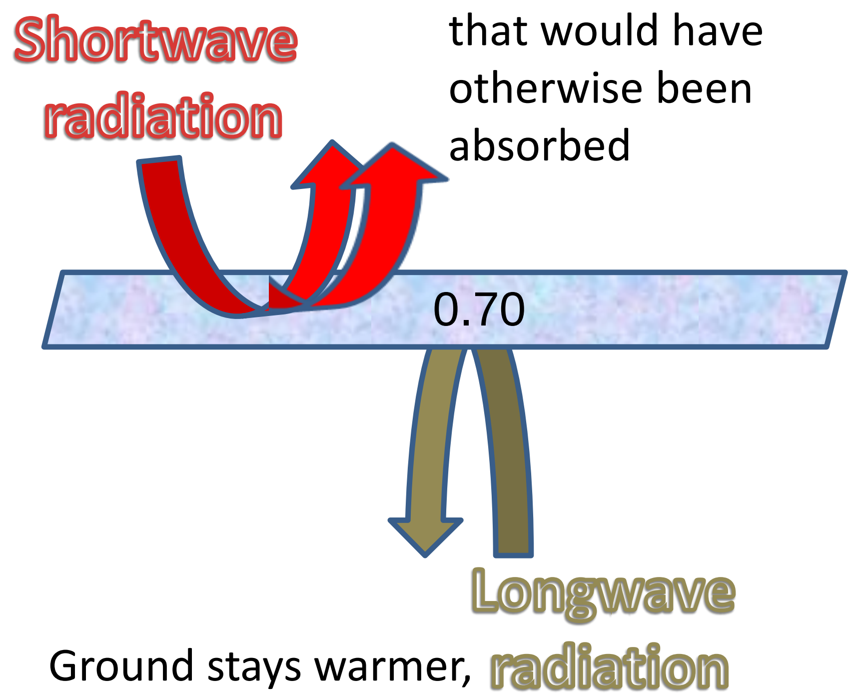


Surface warmed
by absorbed shortwave
radiation

Ground loses
heat to
atmosphere above

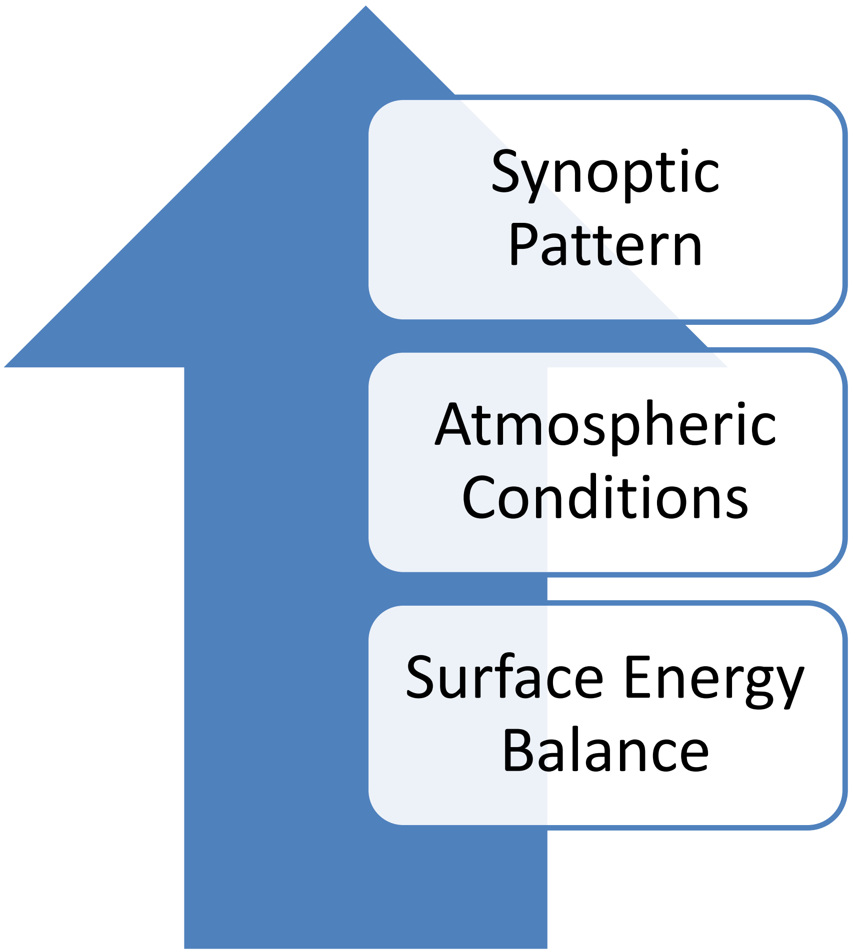
Snowpack Conditions

Surface loses shortwave
that would have
otherwise been
absorbed



Ground stays warmer,
no longer losing heat to
atmosphere above

Introduction:
The impact of snow cover



- Changes starting at the surface then working toward synoptic pattern changes
- Surface energy budget is directly influenced by the overlying snow cover
  - Increased albedo decreasing shortwave radiation
  - Insulating effects decreasing outgoing longwave radiation
- Surface energy budget changes cause changes in atmosphere conditions that have the potential to alter a Nor'easter

Introduction: Synoptic scale

Weakened cyclone

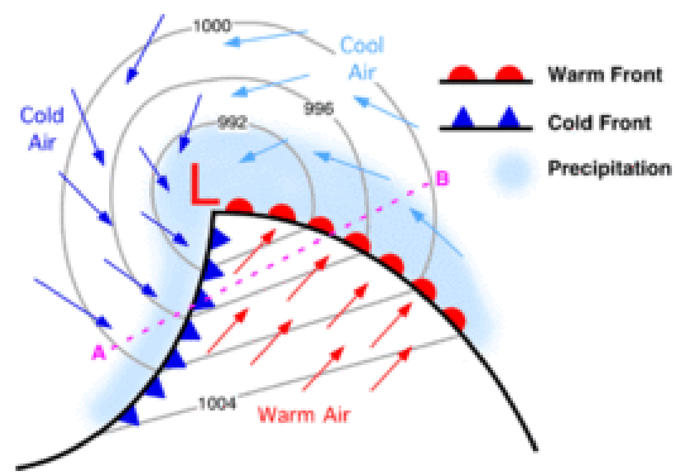
↑

Increase stability, decreased precipitation

↑

Decrease in absorbed shortwave radiation, decrease temperature and sensible heat flux

- Namias (1985): snow cover inhibits the formation of clouds and precipitation
- Elguindi et al. (2005): In the Midwest, weakened temperature and moisture gradients across fronts, weakened cyclone
    - warm sector experiences greater cooling

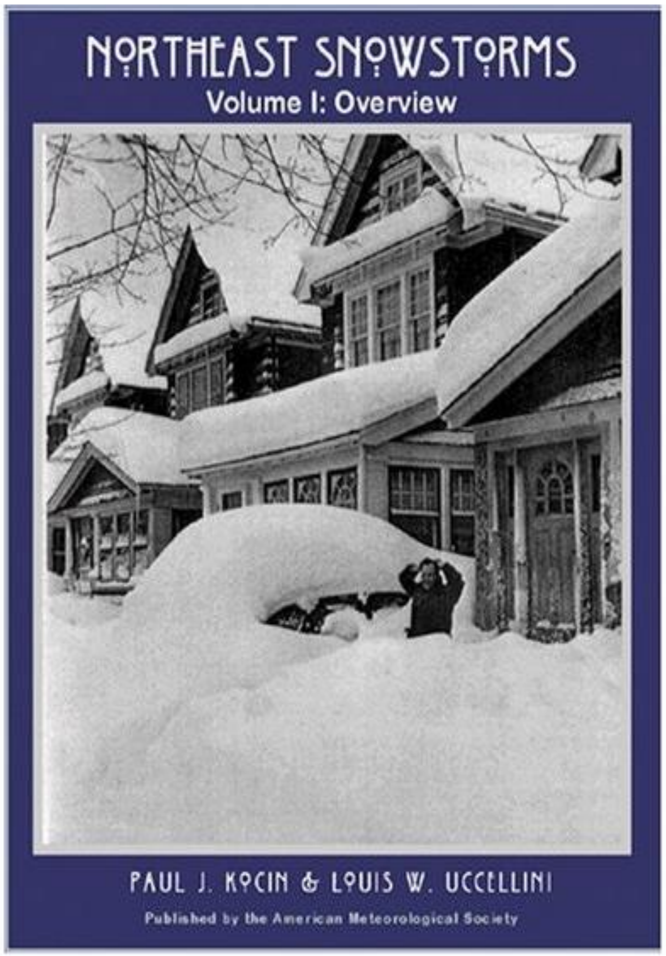


Introduction: Study Area

Northeast United States

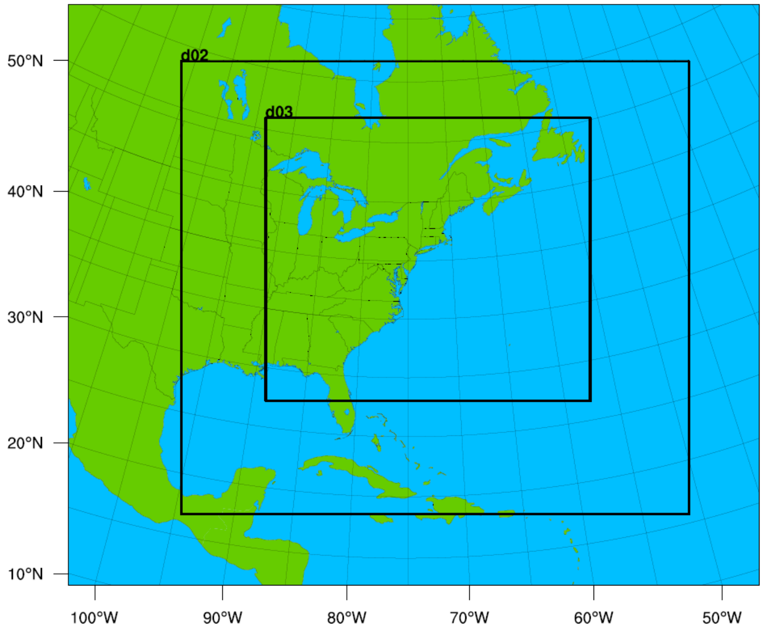
- Only place nor’easters occur due in part to unique topography
  - Cold air damming East of Appalachians
  - Concave coastlines of North Carolina and New England promoting cyclogenisis (Kocin and Ucellini 2004)
  - Thermal contrast of land and ocean
- Close to 20% of US population (55 million)
  - On avg. 35 million people affected by a nor’easter
- Few studies investigating snow packs in the northeast
- Unique characteristics of northeast and nor’easter

Methods: Case Selection



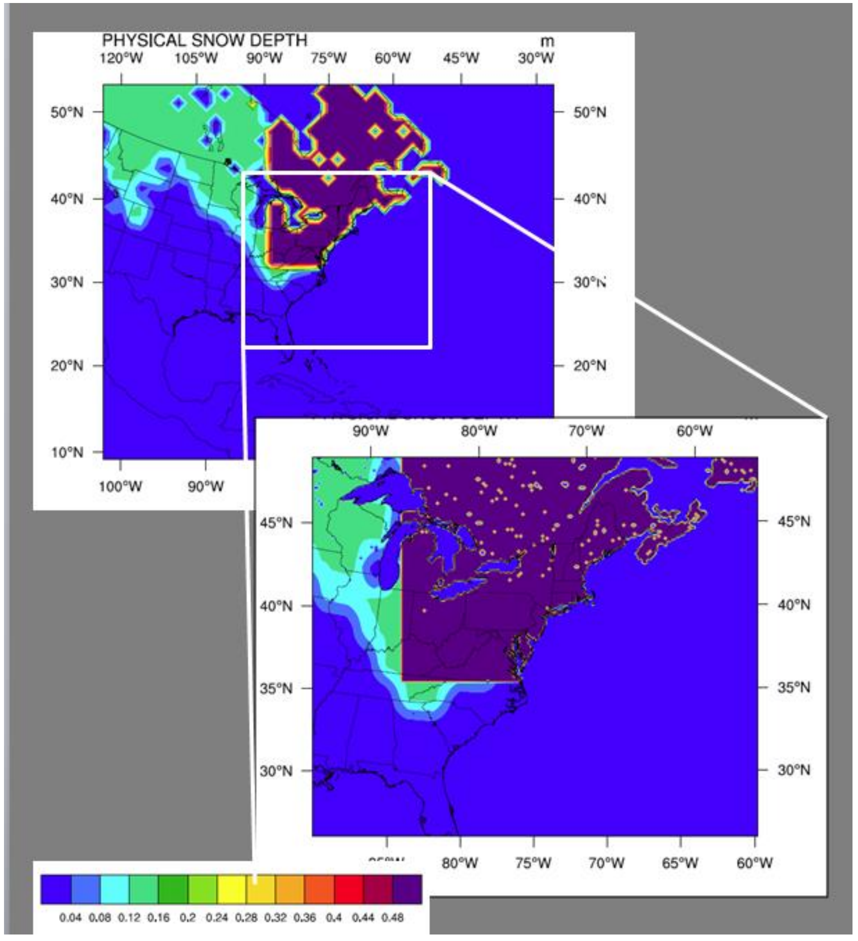
- Computing power limited the number of cases that could be studied
- Case Selection based on Nor'easters in Northeast Snowstorms Volume II
  - Classic nor'easter
  - No secondary low pressure development (Kocin and Ucellini 2004):
  - No center jumps
  - Cases span several seasons to make sure simulations were not seasonally biased
  - Narrowed down to 5 out of 30 cases
- Final Cases
  - 8-10, February 1969
  - 25-28, December 1969
  - 18-20, February 1972
  - 12-14, March 1993
  - 24-26, January 2000

Methods: WRF-ARW Version 3.1.1



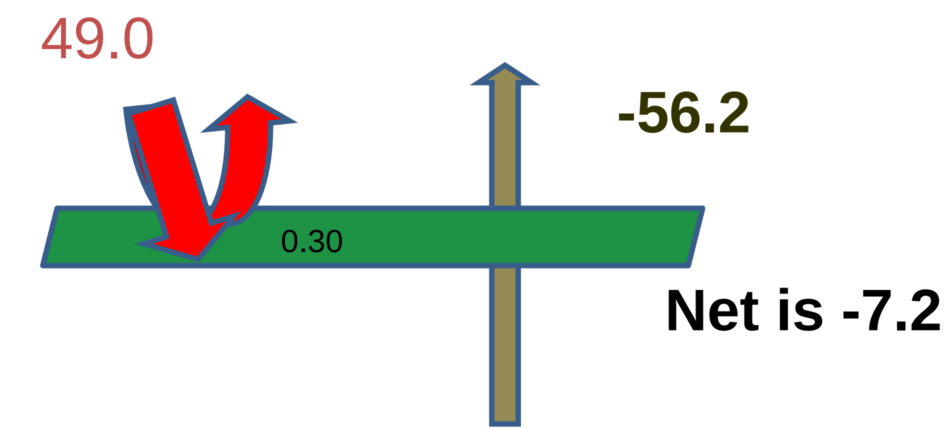
- Triple nested domains
- 3:1 ratio between domains
  - Inner domain 15 x 15 km
  - Second 45 x 45 km
  - Third 135 x 135 km
- Feedback between nests
- Initialize simulation 24 hrs before event
  - Total run time: 4 days, 12 hrs
    - 12 hrs spin up
    - 12 hrs for cyclogensis
- Input data
  - USGS
  - NCEP reanalysis

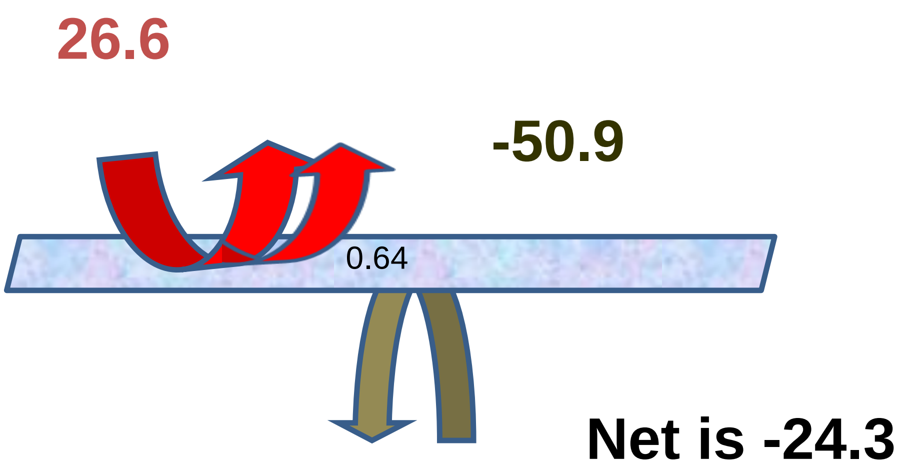
Methods: Simulations



- **Minimize snow cover dependence on atmospheric conditions**
- Control run void of all snow at initialization
- Snowpack run
- 50 cm depth so that during the 4.5 day the simulation the snowpack
  - Maintains a high albedo
  - Remains intact and homogeneous (even with melt)
  - 15 cm which is the height below which albedo of snow changes with depth (Kung et al. 1964; Robinson and Kukla 1985)
- Decreases or eliminate the flux from the soil

Results:
Energy Sink

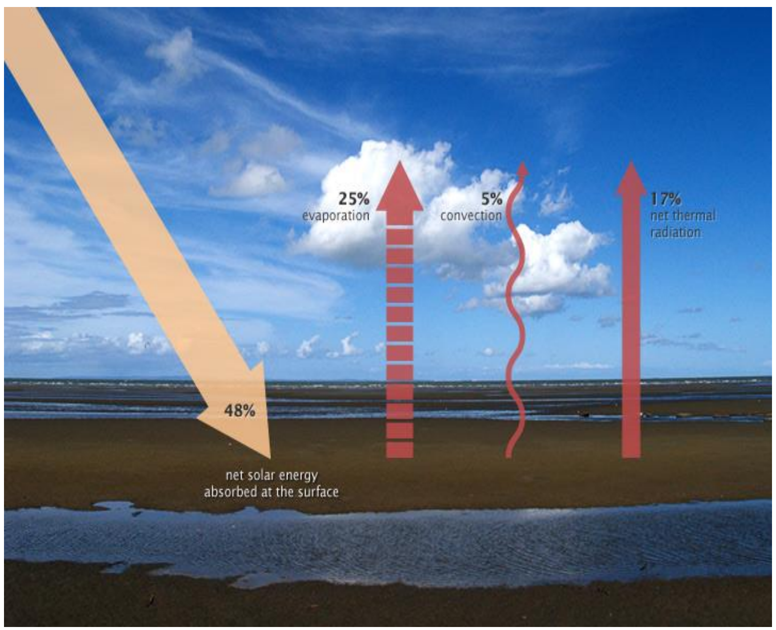




- Albedo, α
  - Snowpack average albedo 0.64 is approximately twice snow-free so a diff of 0.30
  - Reported albedo increase due to snow cover range from 0.24 to 0.56 (Kung et al. 1964, Robinson and Kukla 1985, Cohen and Rind 1991, Klingaman et al. 2008, Baker et al. 1992)
- Shortwave Net
  - Agrees with others (Baker et al. 1992;Cohen and Rind 1992)
- Net longwave radiation
  - decreased by -3.9 W m^{-2}
  - Similar to Baker et al. (1992)

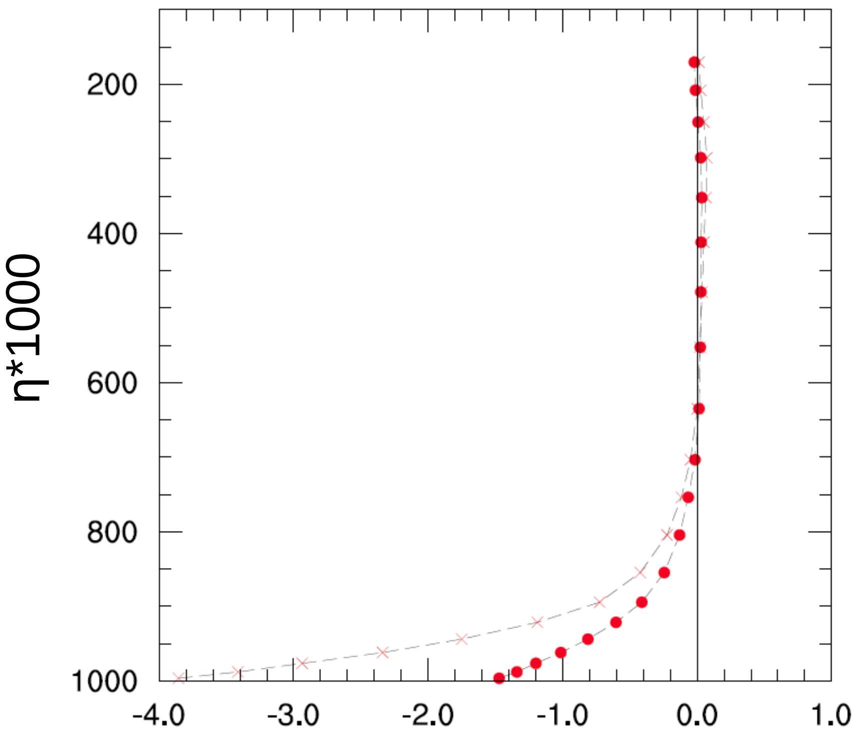
Results:
Net Surface Energy

ΔNet SW + Δ Net LW + Δ SH + Δ LH = Δ Net surface Energy
(-22.4) + (5.3) + (-21.0) + (-2.8) = -40.9 W m^{-2}



- Shortwave radiation and sensible heat largest energy loss
  - Followed by latent heat flux
  - Longwave radiation has a slight gain
    - Snow close to being a black body to longwave radiation
- Baker et al. (1992)
  - Net radiation decrease in snow of 45 W m^{-2} for 10 cm or greater snowpack versus snow-free conditions

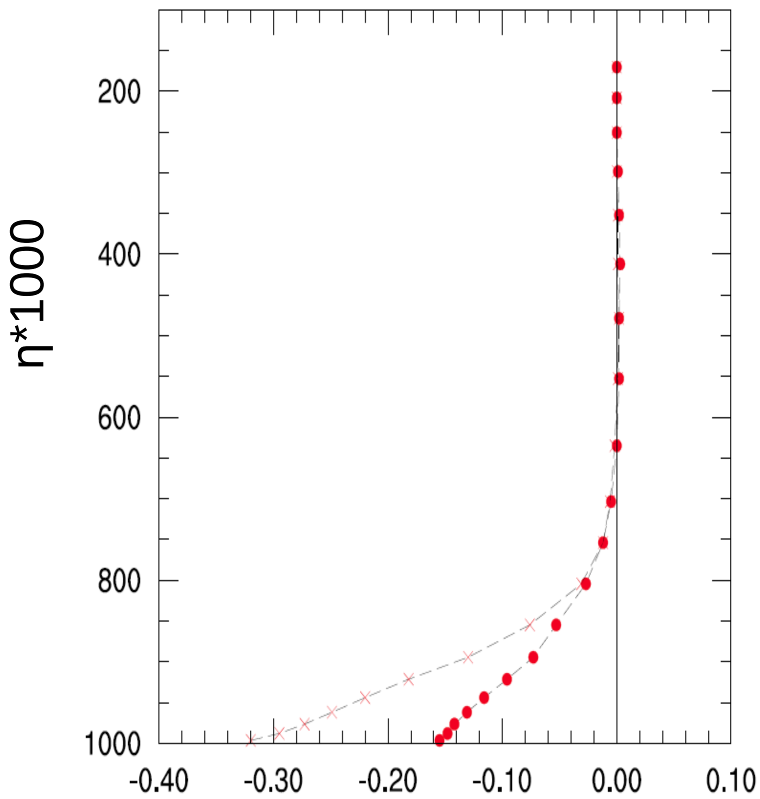
Results: Temperature



Δ 2 m T (°C) (dashed Northeast, solid Atlantic)

- Avg. two-meter temperature depression is -4.4°C in the Northeast
  - Within range of others (Baker et al. 1992, Ellis et al. 1998, Klingamen et al 2008, Walsh et al 1988, Cohen and Rind 1992)
- Only difference in Atlantic is in the Coastal Waters
- The pattern of lower temperatures over the Northeast persists until approximately η*1000 = 900 when average maps above this height show patterns dissolving.
  - Avg. temperature difference decreases by 0.5°C per η-level over Northeast
  - Therefore a low-level effect
  - Agrees with (Cohen and Rind 1991, Walland and Simmond 1996)

Results:
Atmospheric moisture

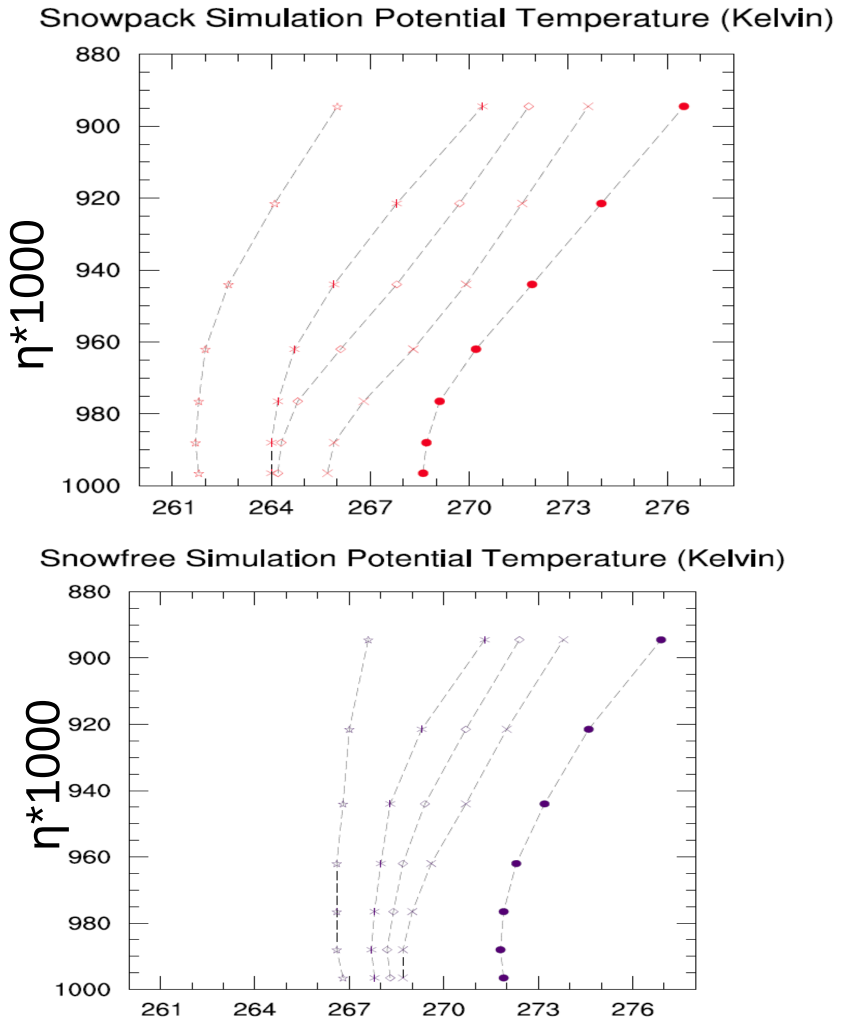


Δ Vapor Mix Ratio (kg kg $^{-1}$) (dashed Northeast, solid Atlantic)

Water vapor mixing ratio

- Snowpack simulation has a lower water vapor mixing ratio over the northeast landmass and both higher and lower over the ocean
- Also see it is a low-level effect and that the trend breaks down by η*1000=750

Results: Stability



Temperature over the Northeast (Kelvin)

- Comparing potential temperature of individual cases at noon
- The potential temperature profile is an indication of stability
  - more positive slopes of the profiles indicate stability and less probability of convection and turbulence
  - Noon best to support turbulence and convection
- Snowpack run is more stable
  - Agrees with others (Cohen and Rind 1991, Namias 1985, Elguinidi 2005)
- Cooler temperature creates more stable conditions because air as not buoyant and does not want to rise

Results: Pressure

Snowpack- snow-free	
Average Surface Pressure	1 mb
Local Maximum Surface	6.1 mb
Central Low Pressure	0.6 mb
Central Low Pressure Max	3.9 mb

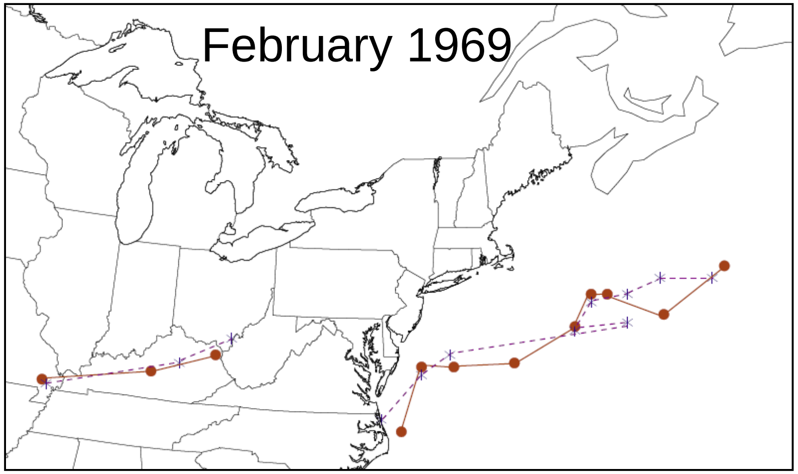
<u>Surface pressure</u>

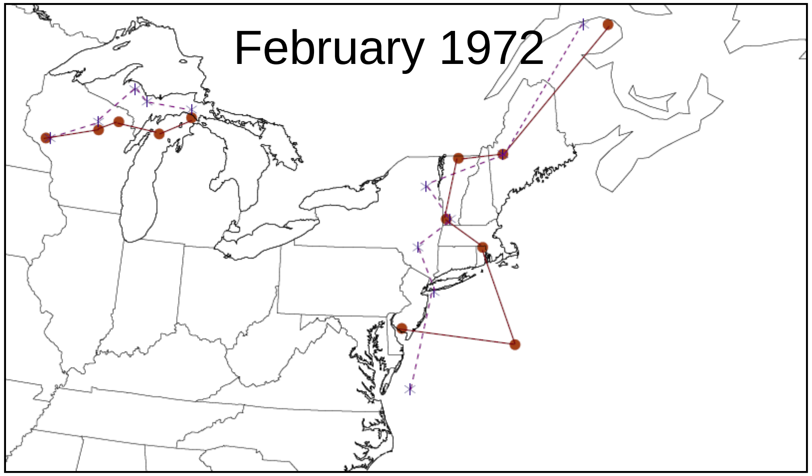
- Trend is consistent over time
- Differences decrease with height similar to temperature
- Others found increase in surface pressure for increased snow up to 5 mb (Spar 1973, Walsh and Ross 1988, Walland and Simmond 1996)
  - Also found low-level effect

<u>Central Low Pressure</u>

- Increase not consistent over time
- Elguindi et al. (2005) found average central low pressure decreased by 4 mb ranging from 0.4 to 10.0 mb
  - Noted that the difference not sizeable but importance, because surface energy fluxes are not the primary driving forces of continental wintertime cyclones

Results: Trajectory





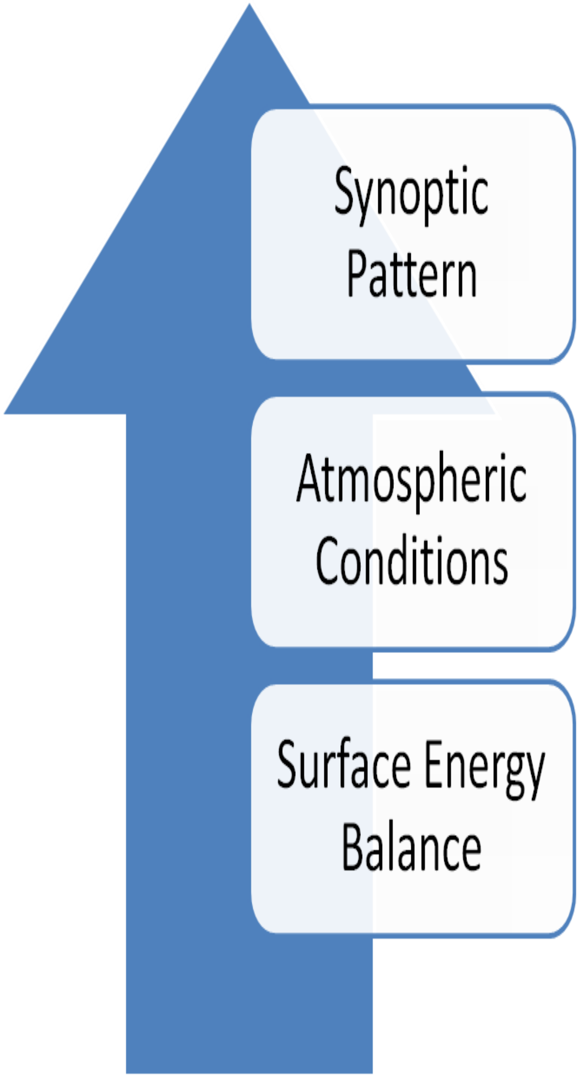
- Three of the five simulations' trajectories, based on the position of the lowest low, were more or less identical
  - December 1969
  - March 1993
  - January 2000
- February cases did have some changes but the changes did not exhibit any strong pattern
  - Solid is snowpack simulation
  - Dashed is snow-free

Results: Precipitation

- 2.8% gain in total precipitation
- 40% decrease in convective precipitation as a percent of total precipitation was approximately due to increased stability
  - Elguindi et al. (2005) none of the convective precipitation over snowpack because of increased stability and decreased convergence
- Slight increase in integrated cloud depth but not significant
- Increases could be from increased baroclinicity between ocean and land
  - Cold land next to warm ocean is now colder
  - Namias hypothesized this would increase precipitation

Convective precipitation (% Total precipitation)	
Snowpack	15.9
Snow free	25.5

Results



- Synoptic Pattern changes
  - Average central low pressure weaker not temporally consistent
  - Decreased convective precip, increase in total precipitation and clouds
- Lower atmospheric changes
  - Decreased temperature and moisture flux
  - Increased pressure and stability
- Surface energy budget changes
  - Albedo is 2x higher
  - Loss of net shortwave radiation and sensible heat flux

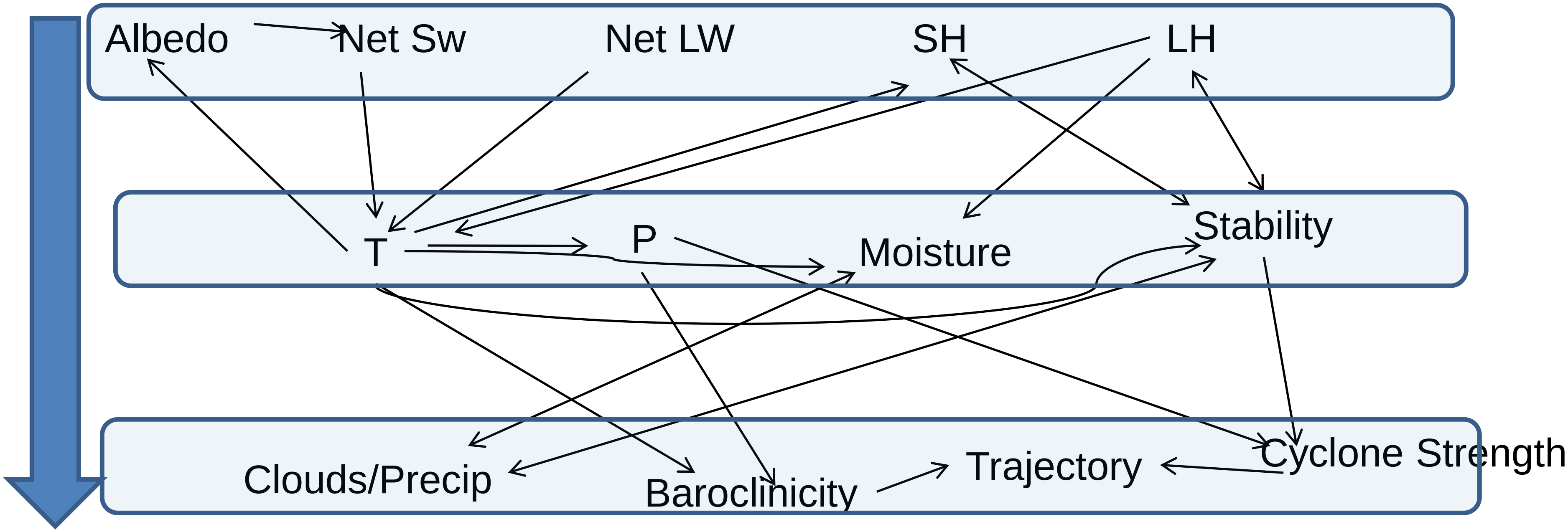
Results

- Results not as strong as mid-west, Elguindi
  - Only slight indication of changes to nor’easter
    - Decrease in central low pressure and was not consistent
    - Less convective precipitation but more total precipitation
  - Tracks were more or less the same
- Strong energy forcing do materialize into lower atmosphere changes
  - Temperature, pressure, moisture, stability
- Lower atmosphere changes however did not alter synoptic scale phenomena significantly

Conclusion

- Clear and strong modification to surface energy balance that change lower atmospheric conditions but do not create clear synoptic changes and therefore changes in the Nor'easter
  - Ocean acts as control?
    - Upper-level dynamics that control the cyclone formation over the Atlantic are not influenced by lower-level changes
    - Upper level dynamics determined by existing geographic controls including the ocean

Conclusion: Synergistic effects

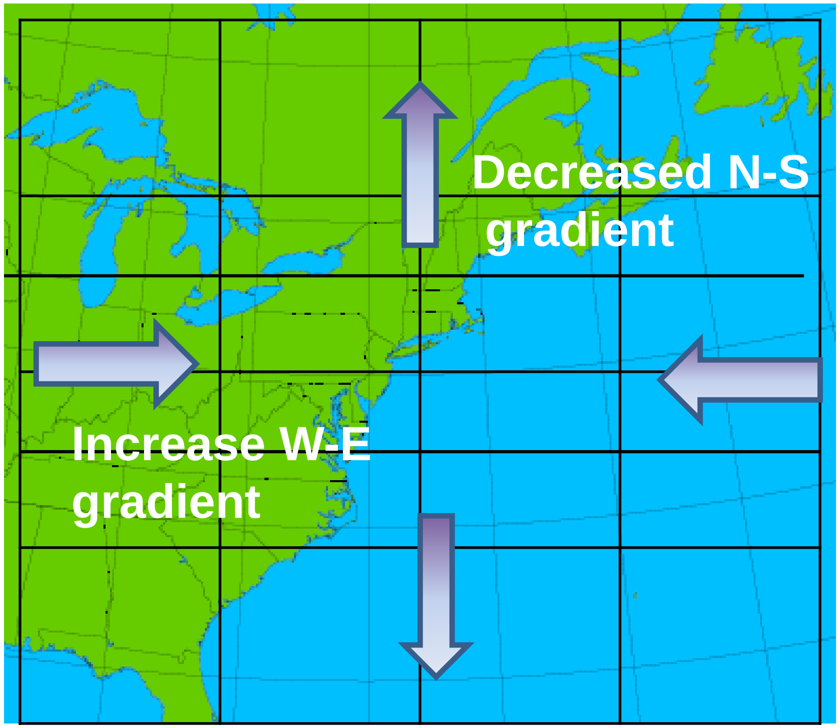


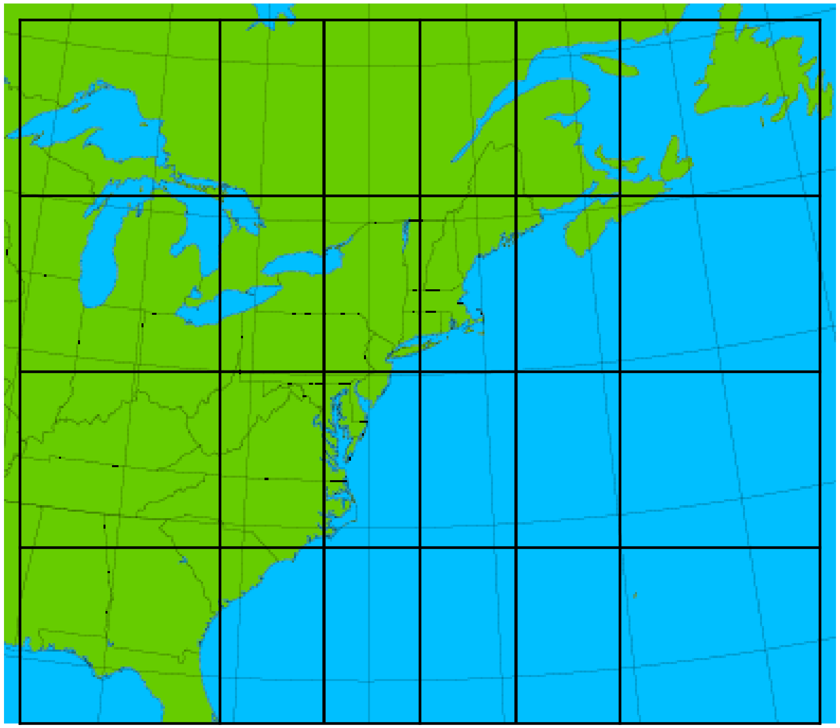
Synergistic effects, positive, and negative feedbacks.

Conclusion: Baroclinicity

- Increased West-East baroclinicity
  - Cold land next to warm ocean is now colder
- Decreased North-South baroclinicity
  - Extensive snow extent decreases north-south albedo profile and therefore temperature gradient
- Increasing West-East gradient and decreasing North-South gradient could balance each other making the net baroclinicity change close to zero

Conclusion: Baroclinicity





Results is the effect of snow is balance out and final pattern is similar to the original