Using the CESM Large Ensemble to project future changes in the distribution and impacts of eastern North American snowstorms

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Northeastern snowstorms

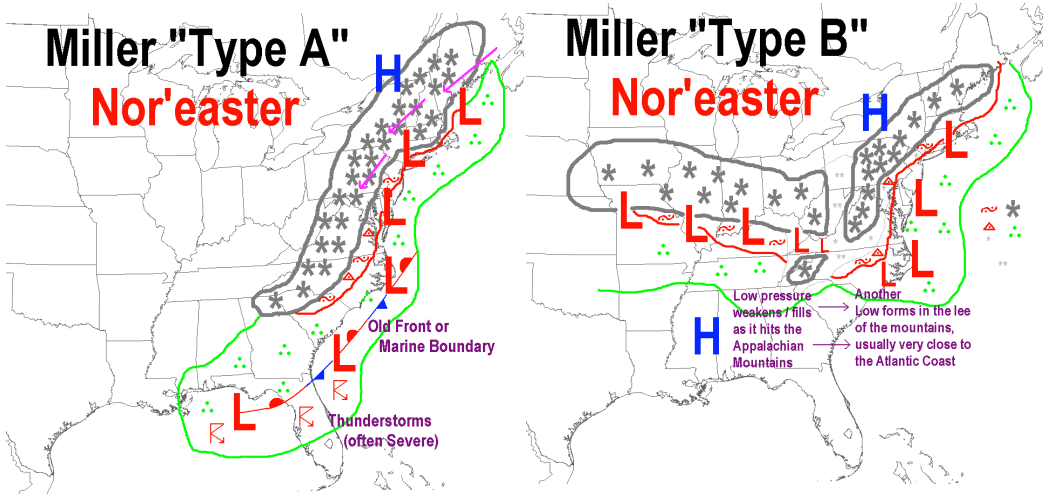
- The eastern United States is vulnerable to impacts from extratropical cyclones (ETCs) during winter months
  - Heavy precipitation
  - High winds
  - Coastal flooding
- Impacts amplified by proximity of population centers such as Boston, New York City, Philadelphia, Baltimore, and Washington D.C. to ETC tracks
- Potential for
  - Risks to health and welfare
  - Massive transportation disruption
  - Lost spending/productivity
  - Widespread power outages
  - Structural damage
- Blizzard of 2016 (#Jonas) - **$2.5 billion to $3 billion** economic impact (Moody's)

Downtown Boston, 2015, Boston Globe

Logan Airport, 2015, AP Photo

What types of storms?

- Intense snowfall associated with two storm pathways
- Miller “A” storm forms in Gulf, tracks up East Coast
- Miller “B” storm initiated by transfer of energy from continental low to coastal baroclinic zone
- **Heavy snowfall (in almost all cases) associated with NE’ward moving surface low along coast**

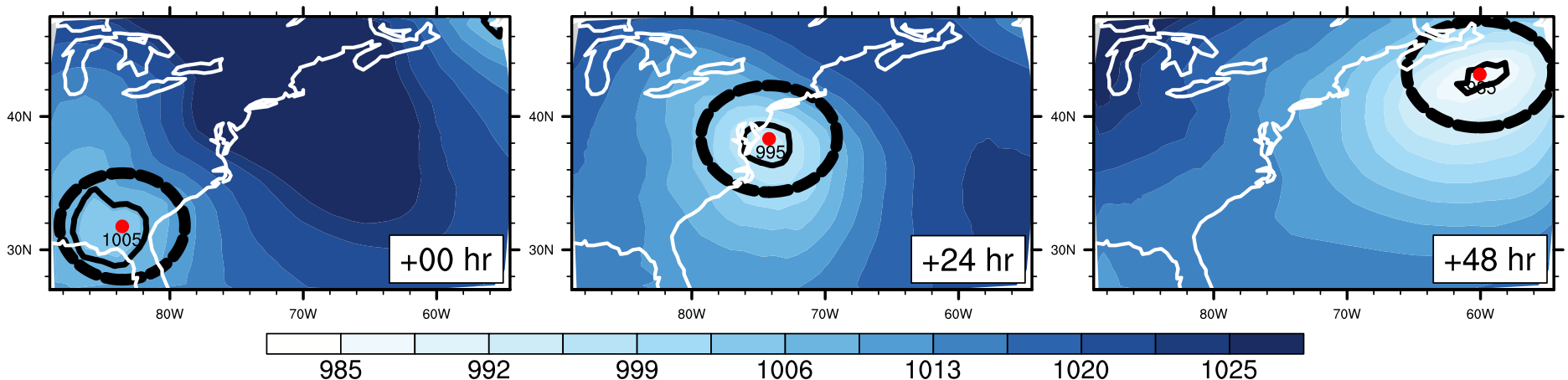


National Weather Service

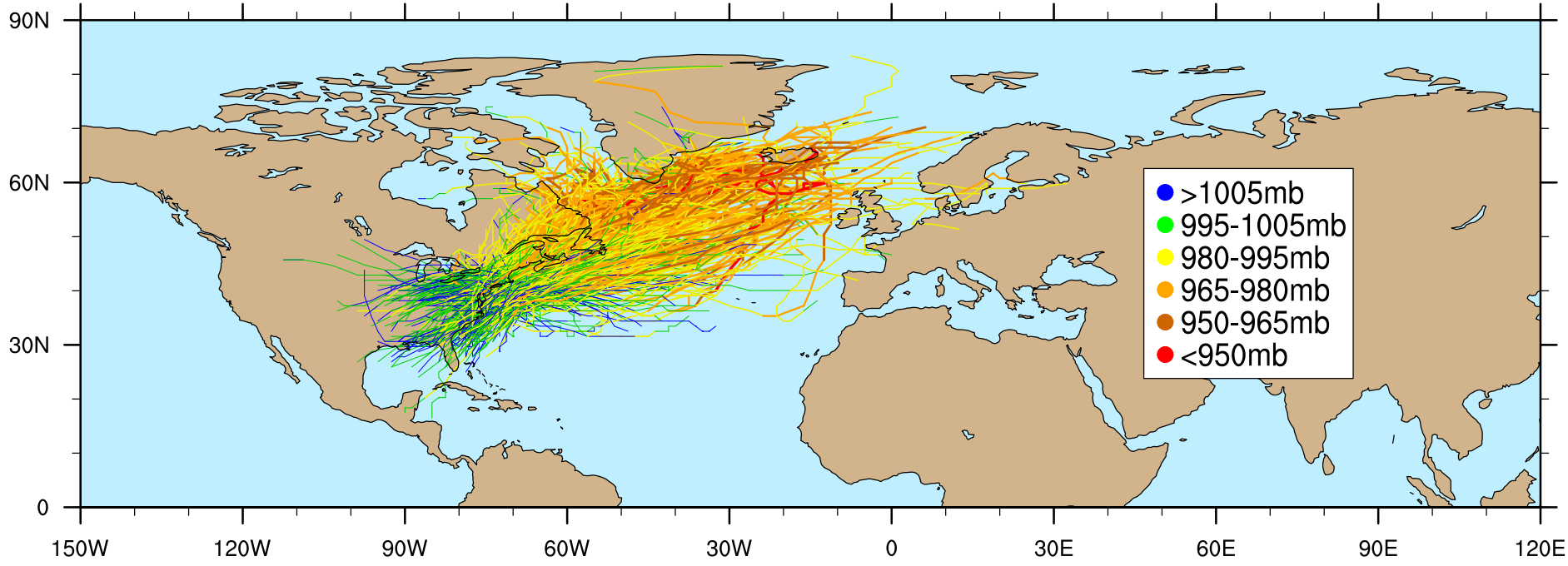
NOAA-NASA GOES 8 Jan 2016 15Z

Tracking storms

- Here, ETCs are discretely tracked using an automated, objective, algorithm
- TempestExtremes (C++, flexible codebase for tracking features on unstructured grids, **https://github.com/paullric/tempestextremes**, Ullrich *et al.*, in prep.)
  1. Storm must occur between October 1st and April 31st
  2. Local minimum in sea level pressure (SLP) must exist, surrounded by closed contour of at least 2 hPa within 4° ➔ defines cyclone center
  3. Storm must pass within 5° of 41°N, 73°W
     - At closest pass to 41°N, 73°W, storm heading must be between due north and due east (inclusive)
  4. Storm must persist for at least 36 consecutive hours



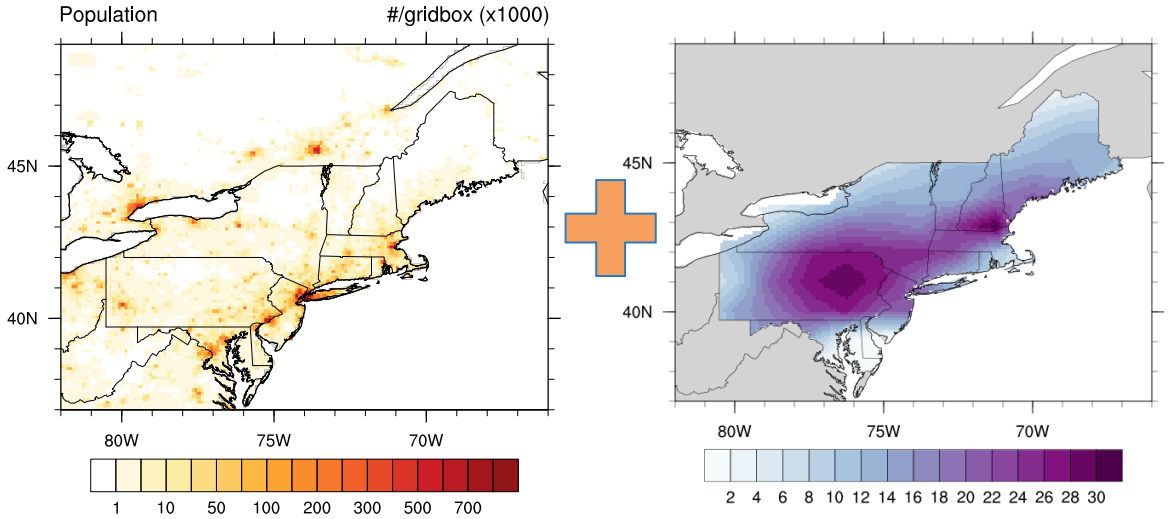
Sample storm trajectories



LENS members #2-9, 1990-2005

Regional Snowfall Index (RSI)

- Individual storms are then classified using **Regional Snowfall Index** (**RSI**) (Squires *et al.*, BAMS, 2014)
  - RSI -> collocation of magnitude/spatial extent of snowfall AND population density = impact
  - Snowfall integrated along ETC trajectory (out to a radius of 20° from cyclone center) for duration of event
  - Snowfall is conservatively mapped to 0.1° population density grid
    - Population grid held fixed!



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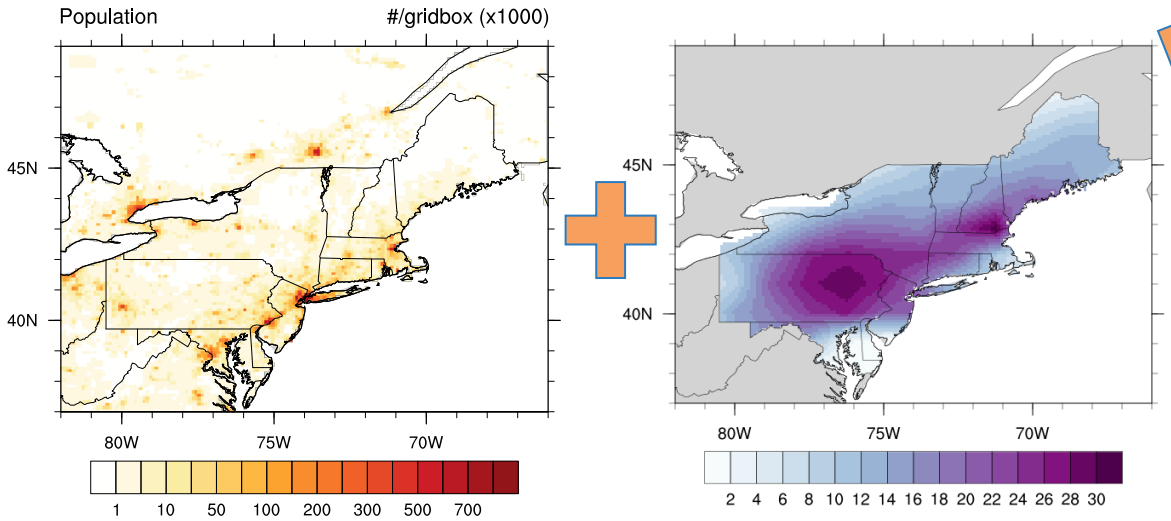


RSI value

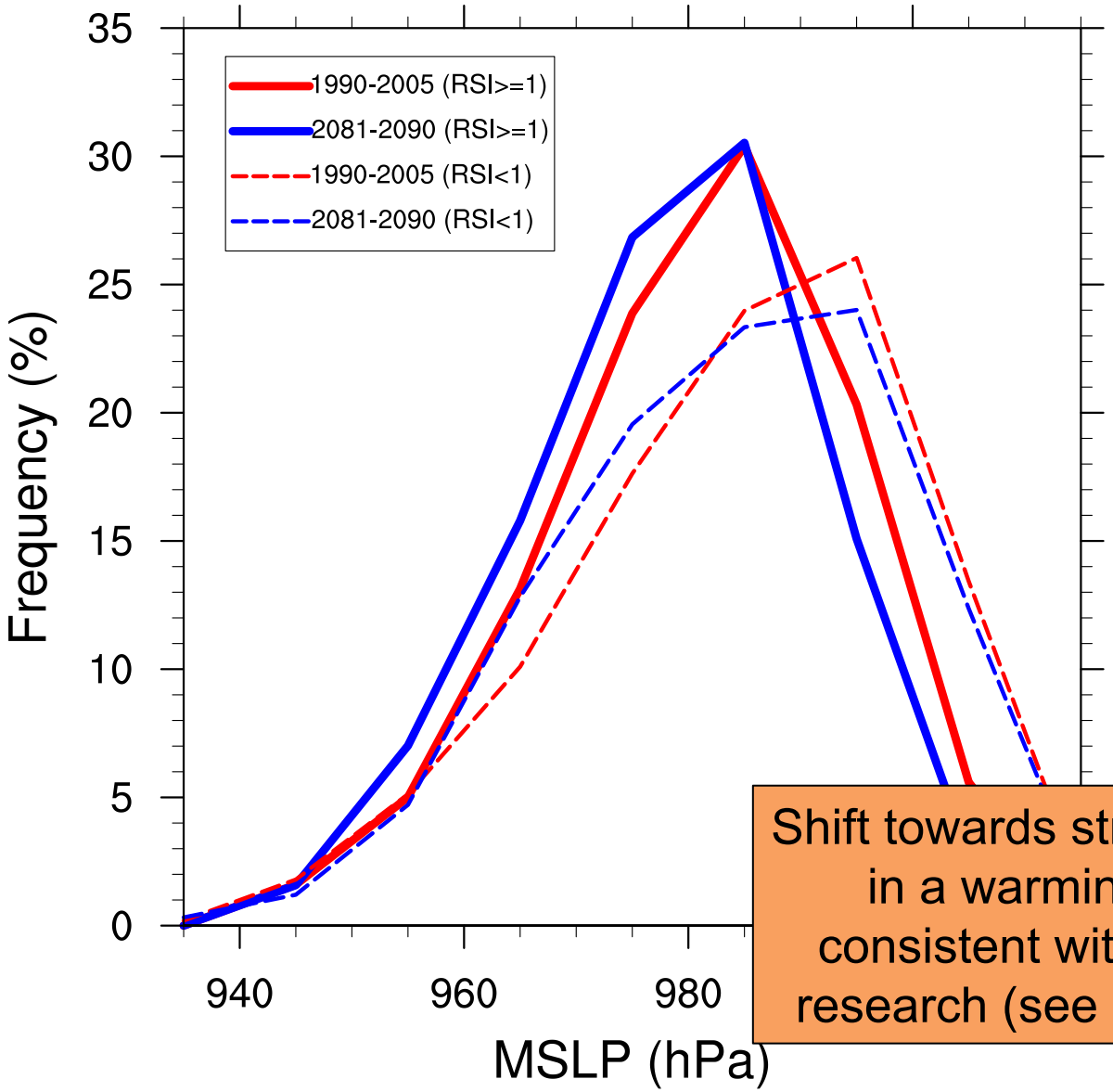
23.9

CAT.	RSI VALUE	IMPACT	RETURN (YRS)
1	1–3	Notable	1
2	3–6	Significant	2
3	6–10	Major	8
4	10–18	Crippling	13
5	18.0+	Extreme	30

LENS application

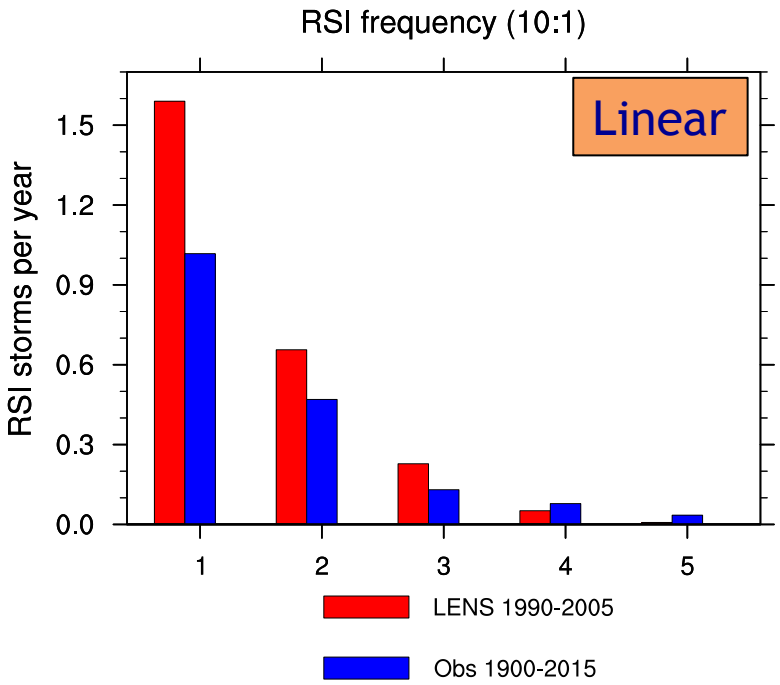
- Need to use 6-hourly/daily data files
  - 1990-2005
  - 2026-2035
  - 2081-2090
- Produces ~320-500 years of analysis over 32 members
- Snowfall determined by internal model classification (**PRECSC + PRECSL**)
- Uniform 10:1 snowfall:liquid ratio assumed
  - Consistent hydrological impact

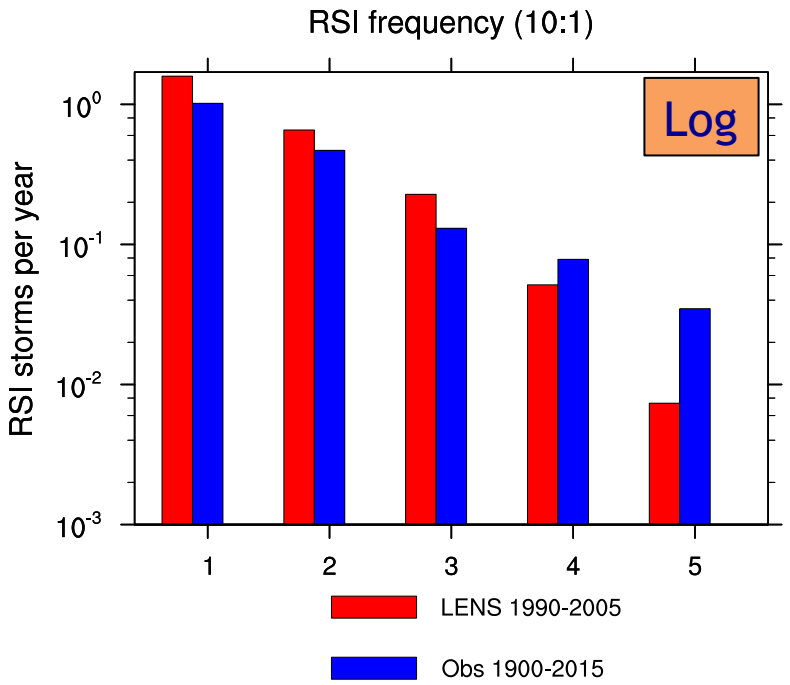
Changes in storm intensity



Shift towards stronger ETCs in a warming world, consistent with previous research (see Colle 2015)

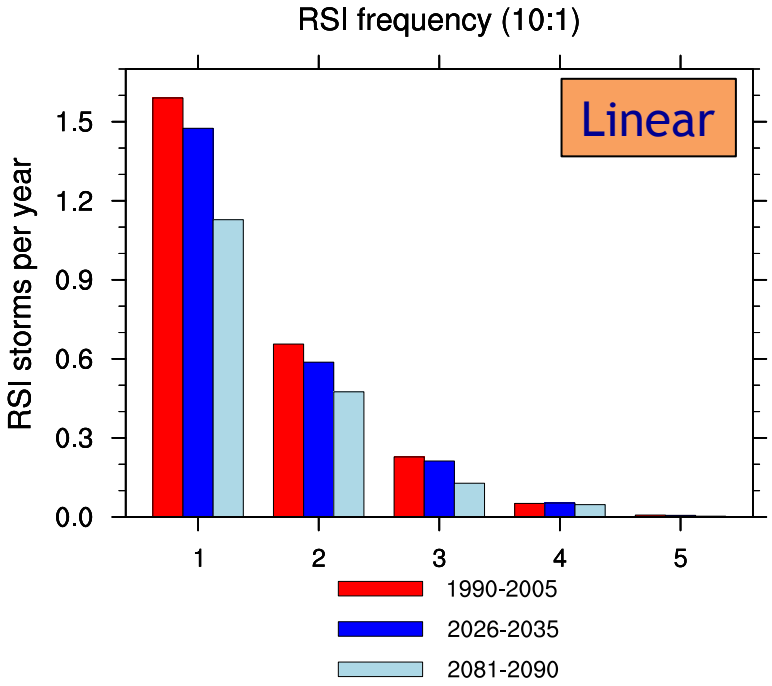
LENS compared to observations

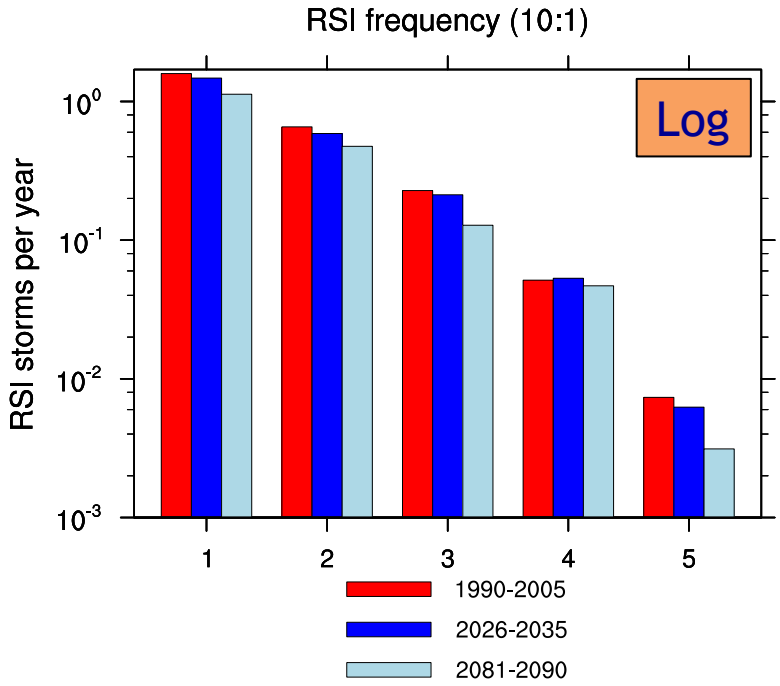




- General profile reproducibility
- LENS produces too many storms at “weak” end of the spectrum; too few at “stronger” end
- Could be resolution signature? (more on that later)

Future changes using LENS





- Across the board decrease when comparing historical with 2026-2035
- More significant decreases by 2081-2090

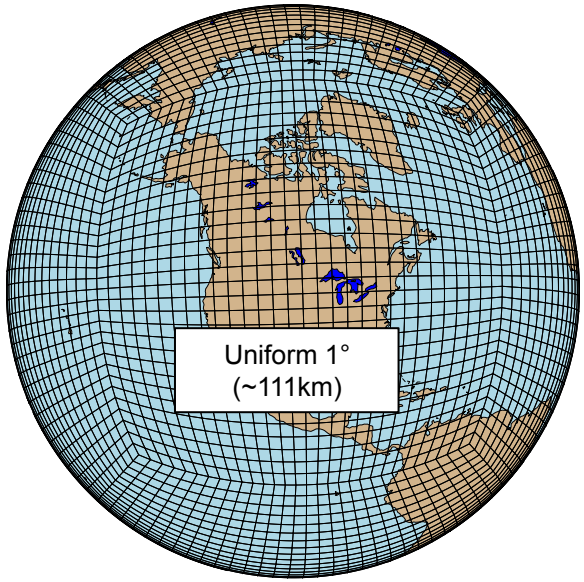
Change in annual frequency

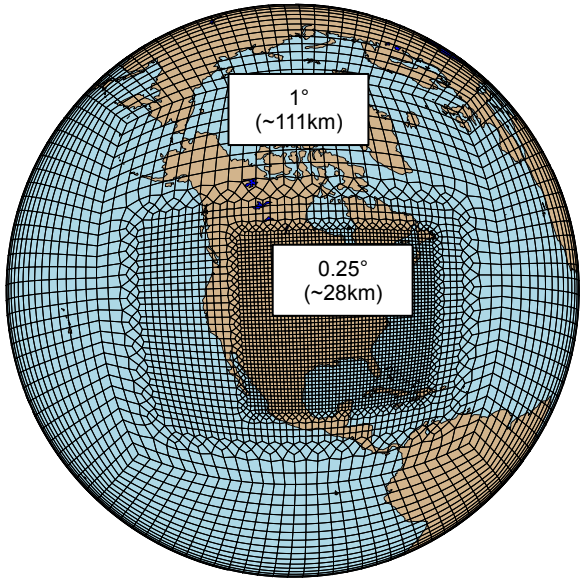
CAT	1990-2005	2026-2035	2081-2100
1	0	-7%	-29%
2	0	-10%	-28%
3	0	-7%	-44%
4	0	3%	-9%
5	0	-15%	-58%

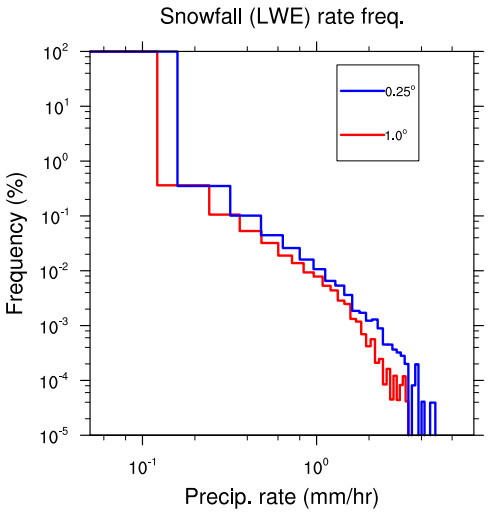
Going forward…

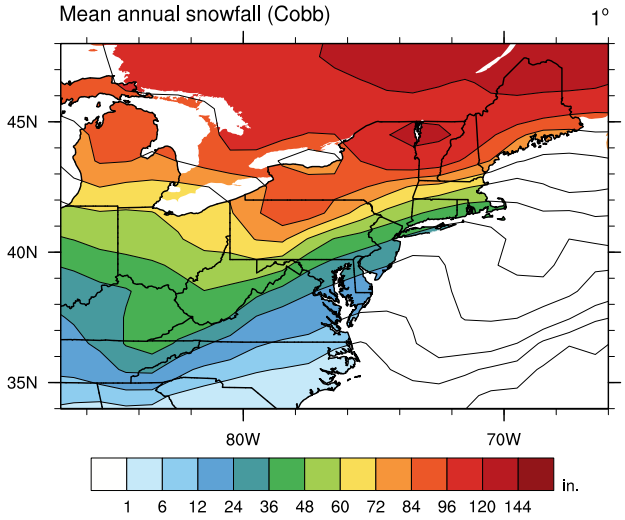
- Resolution
- Precipitation typing
- Pseudo-prognostic snowfall ratios

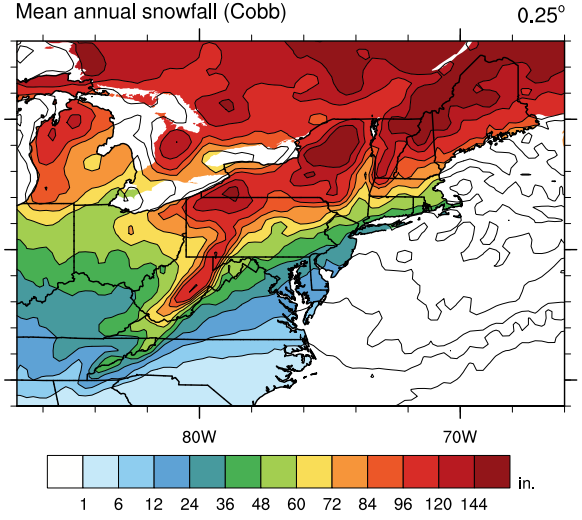
Resolution going forward…

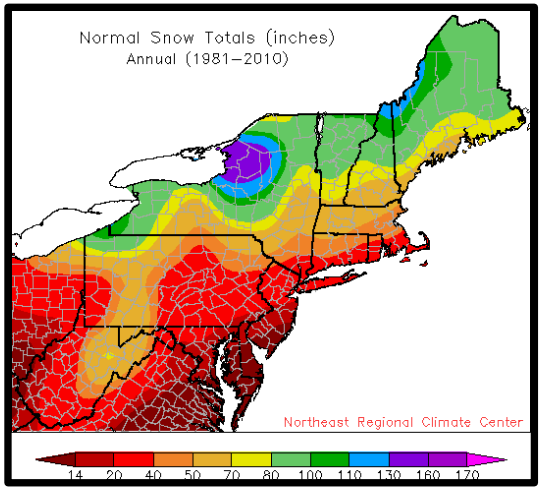






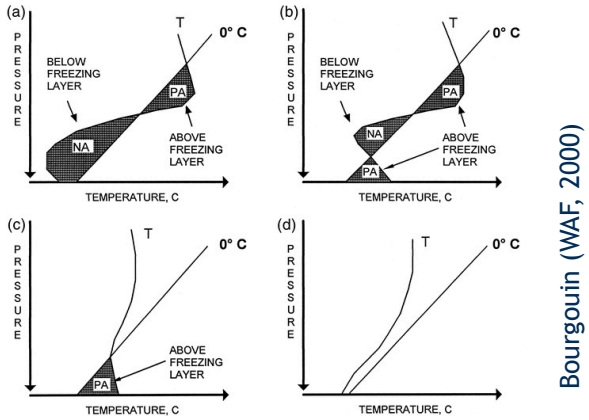




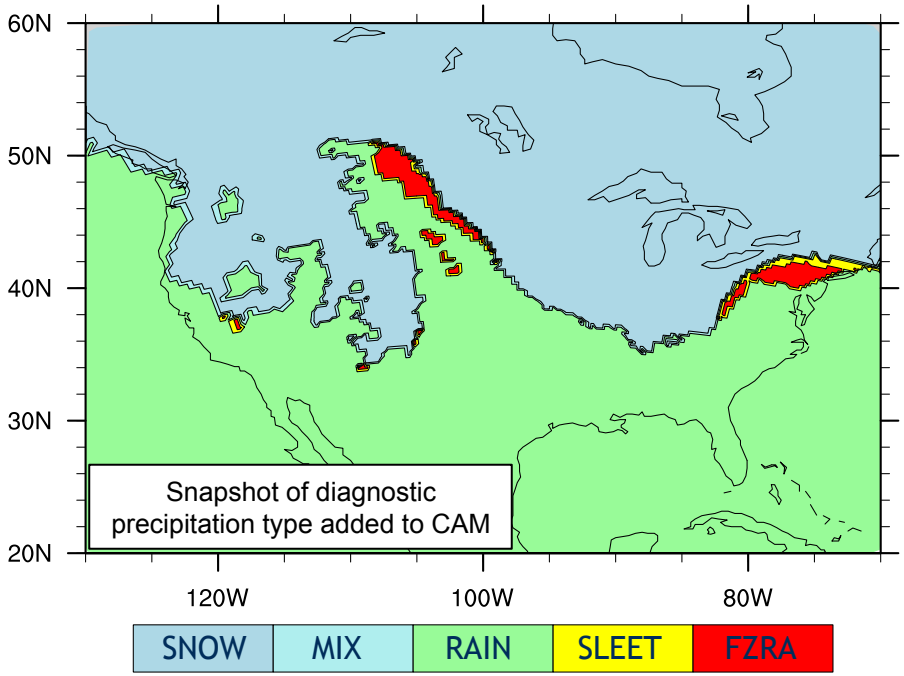


Precipitation typing

- CAM roughly partitions frozen/liquid precip (snow or rain in standard outputs)
- Apply more comprehensive thermal energy criterion to further break down into rain, snow, mix, sleet, freezing rain (Bourgouin, WAF, 2000)
- Needs to be “reverse engineered” for use in LENS

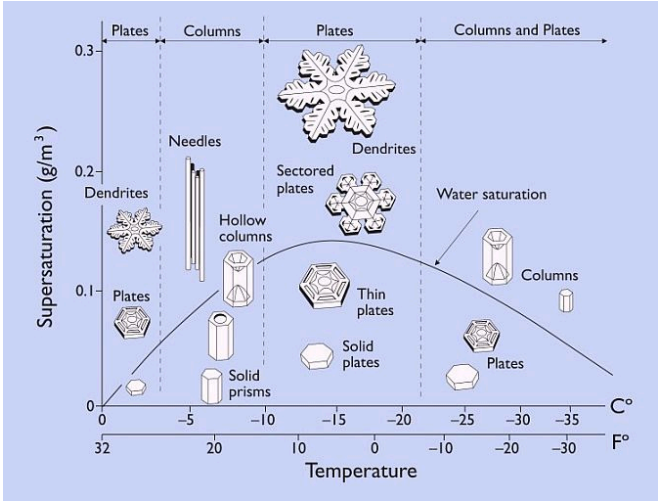


Bourgouin (WAF, 2000)

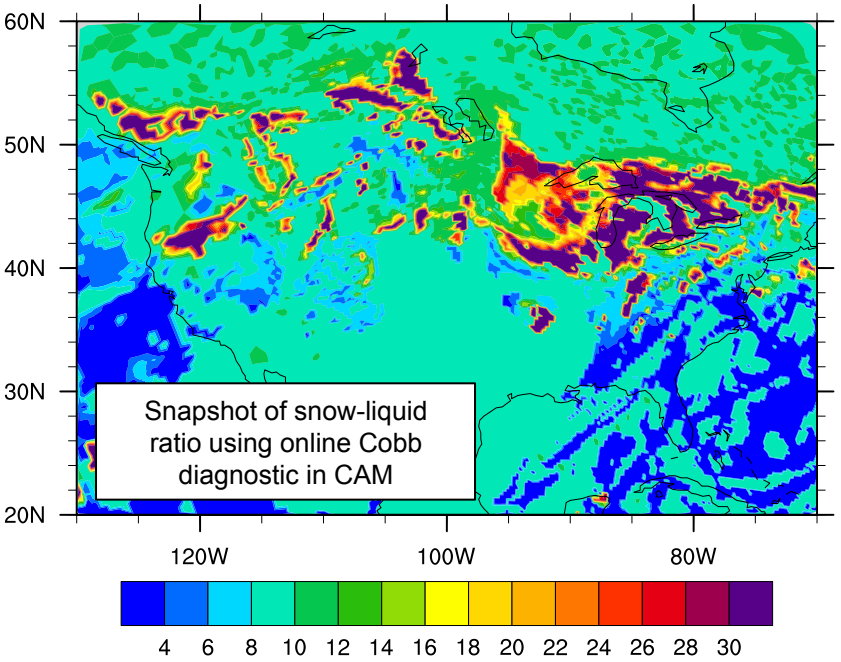


Pseudo-prognostic snowfall ratios

- Snowfall amount depends on dendritic growth zones RH/ vertical velocity collocation
- For snowfall, apply Cobb (2005, AMS) algorithm to diagnose time and spatial dependent snow-to-liquid equivalency ratios
- More “reverse engineering”



Nakaya, 1954



(Very preliminary) conclusions

- Objective tracking algorithm used to find eastern North American coastal cyclones in CESM Large Ensemble dataset
- Application of Regional Snowfall Index (RSI) implies that **CESM produces reasonable climatology of northeastern US snowstorms**
- **ALL classifications of snowstorms** projected to ***decrease*** by end of century
- This **despite shift in frequency** towards **stronger ETCs**