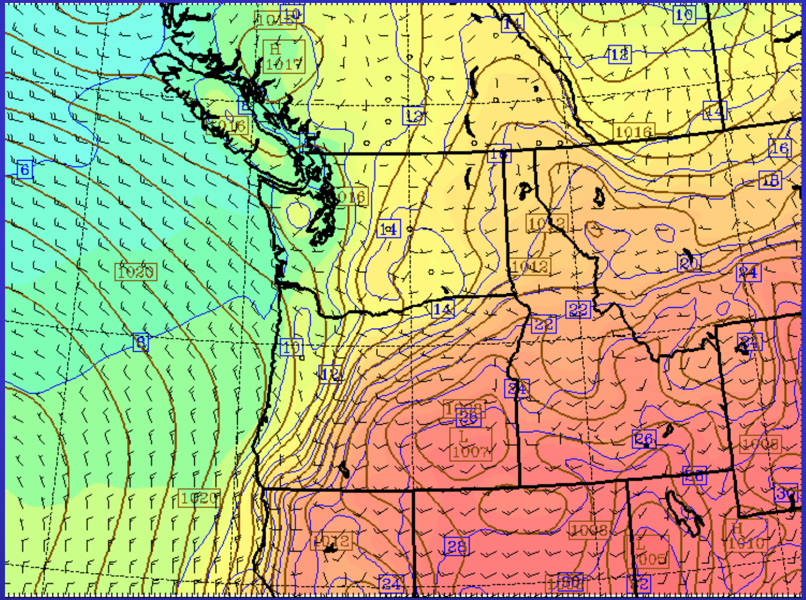
Determining the Local Implications of Global Warming Using a High-Resolution Mesoscale Model



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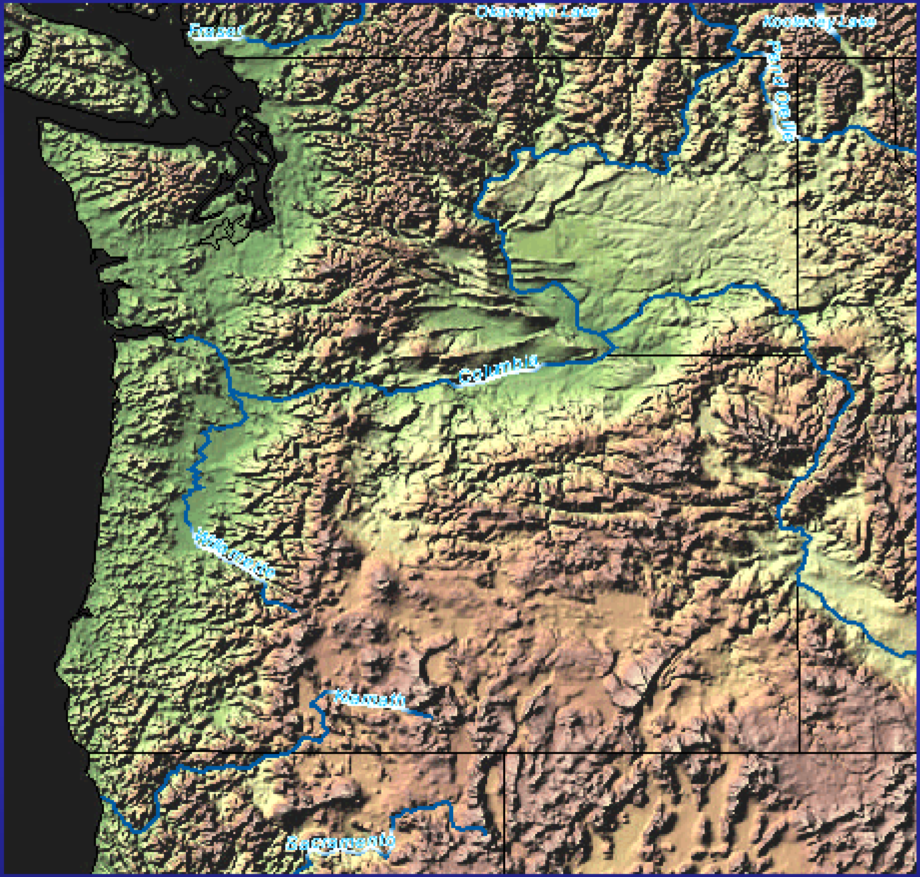
Goals

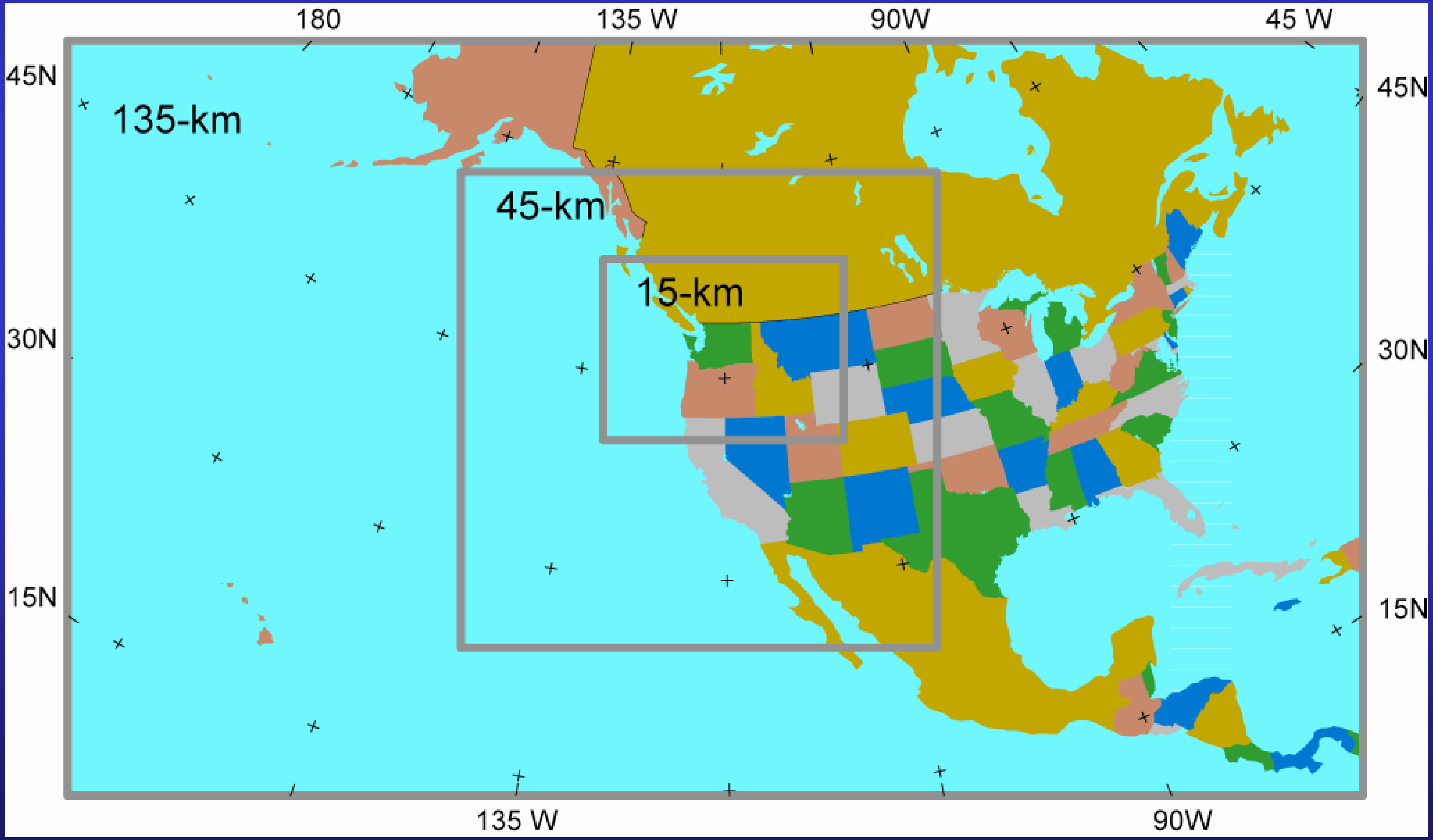
- To develop a system for high-resolution, extended-period regional climate prediction using the combination of a mesoscale model (MM5 now-later WRF) and a GCM
- Using this system to determine regional implications over the Northwest (and eventually elsewhere) of global climate change. Are there any mesoscale surprises?

- In the Pacific Northwest, the complex terrain and land-water contrasts have a large impact on mesoscale circulations.
- Comprehensive experiments and real-time simulations show that 15-km or smaller grid spacing is required.



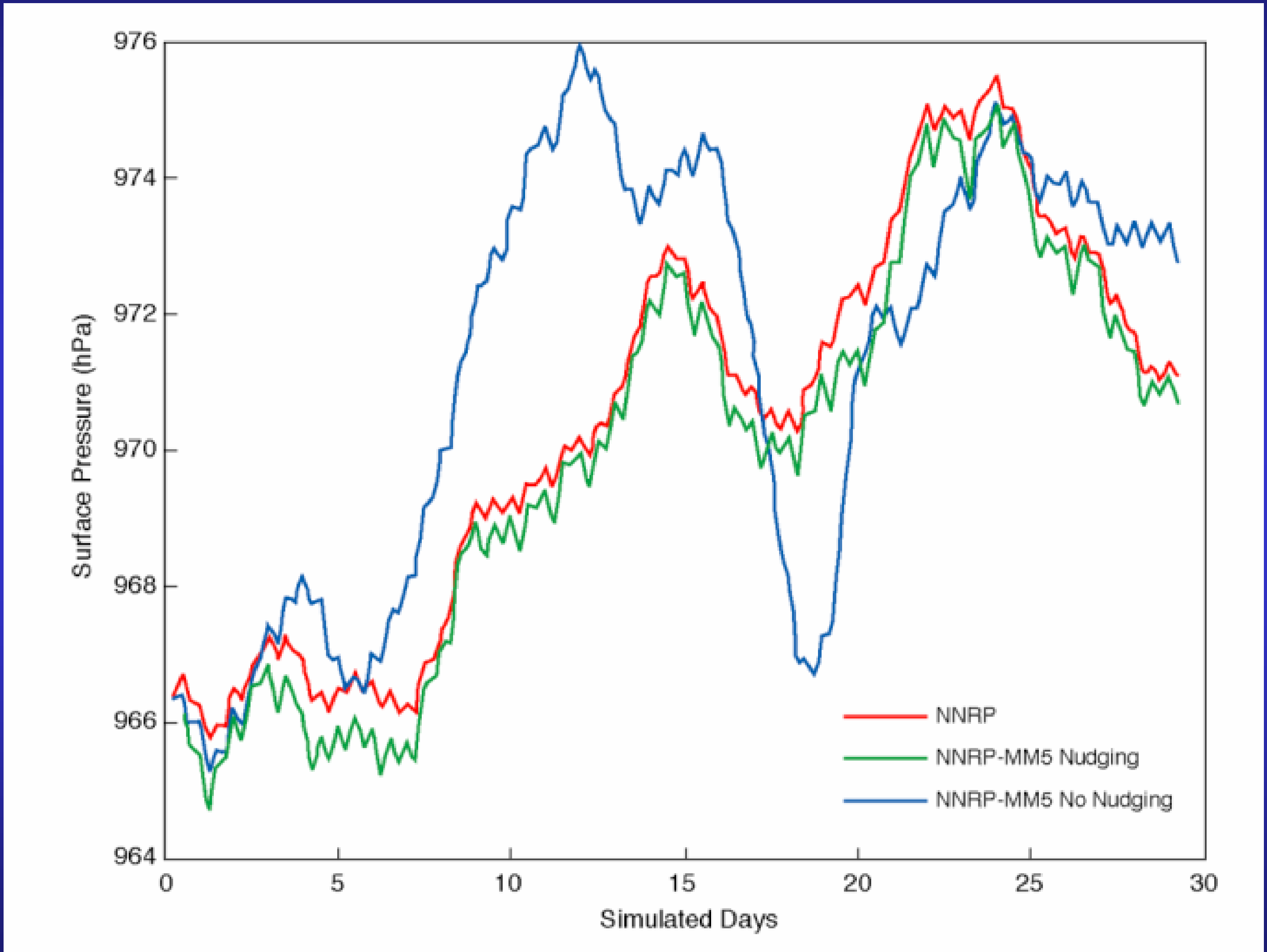
MM5 Model Nesting

- 135, 45, 15 km MM5 domains
- 135 km nested within ECHAM-5 GCM output



Problems

MM5 does not conserve mass over extended periods.



Experiment Using the NCAR-NCEP Reanalysis (NNRP)

Problems

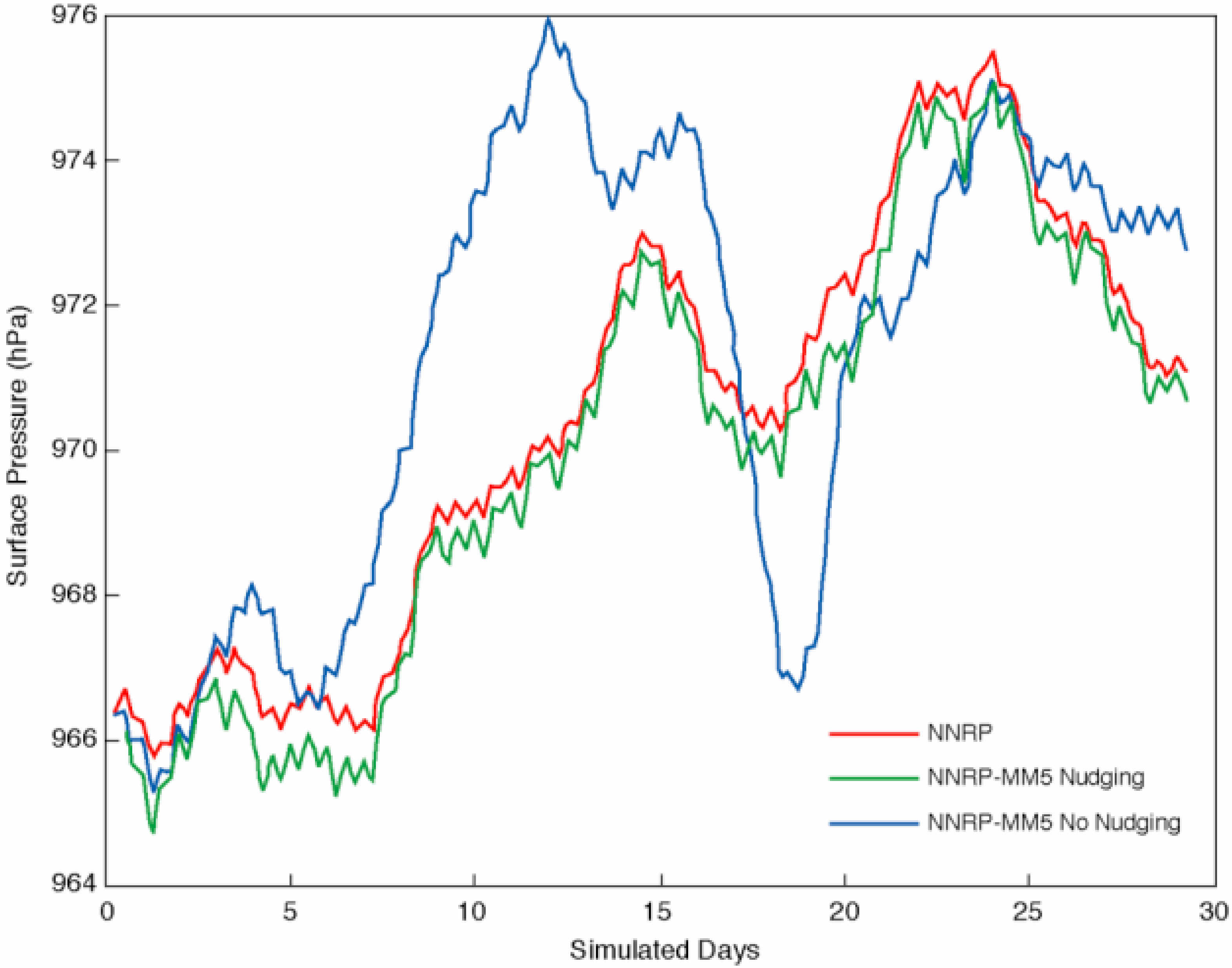
- Global model output is only available with coarse time resolution (6-hr at best), thus a problem getting features realistically through the boundaries.
- MM5 synoptic solution tends to drift from parent GCM.
- Would prefer to have continuous runs rather than with frequent restarts.

The Solution

Analysis nudging!

Nudging

- We ran analysis nudging on the outer (135 km) domain, pushing the solution towards the GCM.
- Stopped mass loss problem
- Solved boundary problem (if features don’t get through boundary well, nudging fixes them)
- Allows long-term runs with no restarts.



976
974
972
970
968
966
964
Surface Pressure (hPa)
0
5
10
15
20
25
30
Simulated Days
NNRP
NNRP-MM5 Nudging
NNRP-MM5 No Nudging

Deep Soil Temperature

- One cannot use default deep soil temperature in extended climate change simulations for obvious reasons.
- To better represent the soil temperature profile in the MM5, we have implemented a parameterization to specify the 3-m depth lower boundary soil temperature for the NOAH LSM.

Deep Soil Temperature

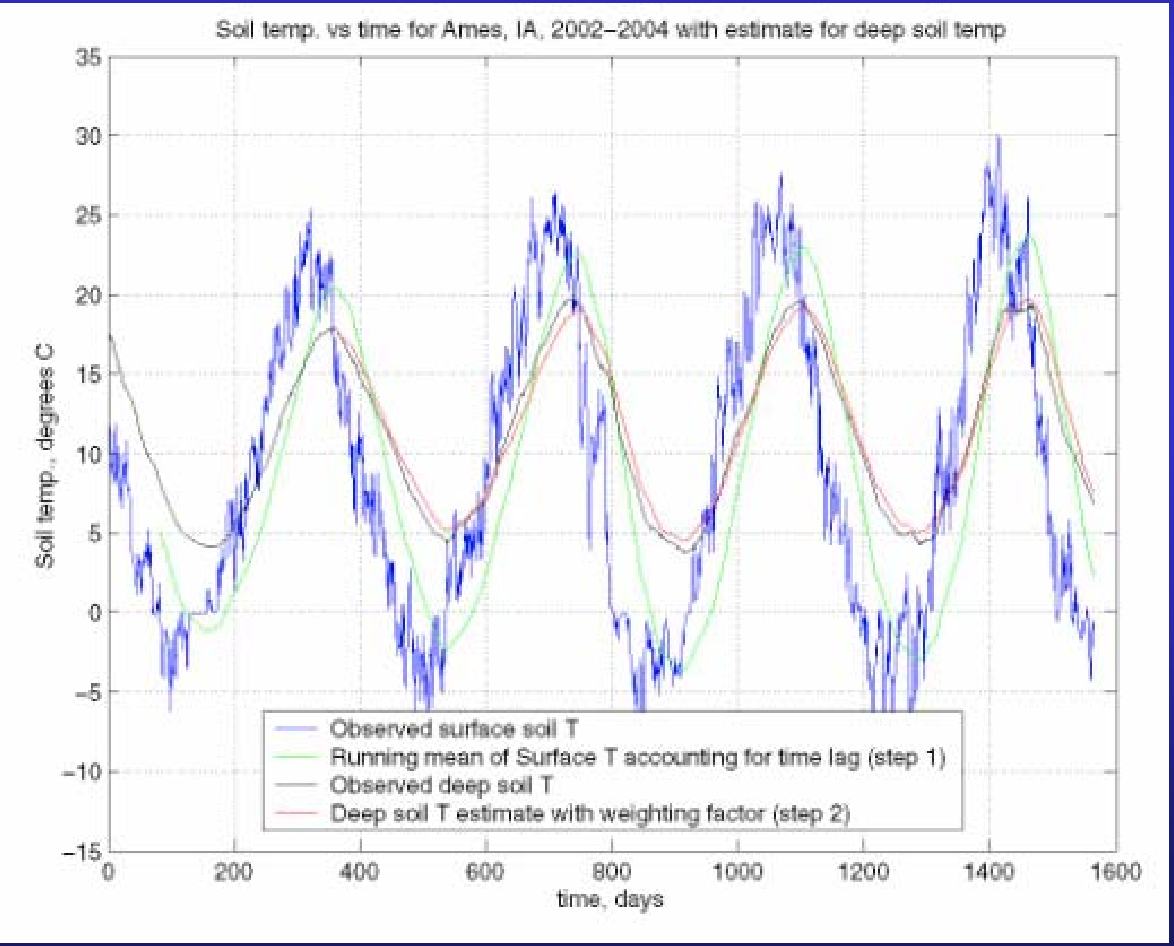
- The soil temperature at depth follows the variations in the surface skin temperature, but with a phase lag and attenuation that depends on depth.
- Our method takes simple weighted average of the skin temperature over a previous period, with the weighting adjusted to yield the desired attenuation and phase lag.

The soil temperature at any depth is then the weighted average of these two values,

$$T_{soil} = \alpha \langle T_{skin} \rangle_{365} + (1-\alpha)\langle T_{skin} \rangle_{n},$$

where α and n are a function of depth and tuned to produce the desired attenuation and phase lag for the depth of interest. For 3-m depth, we use the published observed values of 30% attenuation and 70 days lag (Baxter, 1997) to obtain α=0.6 and n = 140 days.

- Red-our estimate
- Black-observed



Other Issue: Crazy Cold Waves Over Western North America

- The ECHAM-5 and other GCMs produce excessive cold waves west of the Rockies
- In fact, the ECHAM-5 appears to be one of the better ones in this regard.
- A possible cause is lack of resolution that prevents sufficient blocking by the Rockies, so cold continental air from the interior washes over the West Coast.

Russia
Arctic Ocean
Bering Sea
Beaufort Sea
Greenland
Reykjavik
Baffin Bay
Anchorage
Godthab
Gulf of Alaska
Labrador Sea
Hudson Bay
Canada
Ottawa
Saint Paul
Detroit
Chicago
New York
Philadelphia
Washington
Atlantic Ocean
Los Angeles
United States
Pacific Ocean
Houston
Gulf of Mexico
Nassau
Havana
Cuba
Monterrey
Mexico
North America
National Capitals
Guadalajara
Mexico City
Port-au-prince
Santo Domingo
Kingston
Caribbean Sea
Guatemala City
San Salvador
Tegucigalpa
Managua
San Jose
Panama City
Caracas

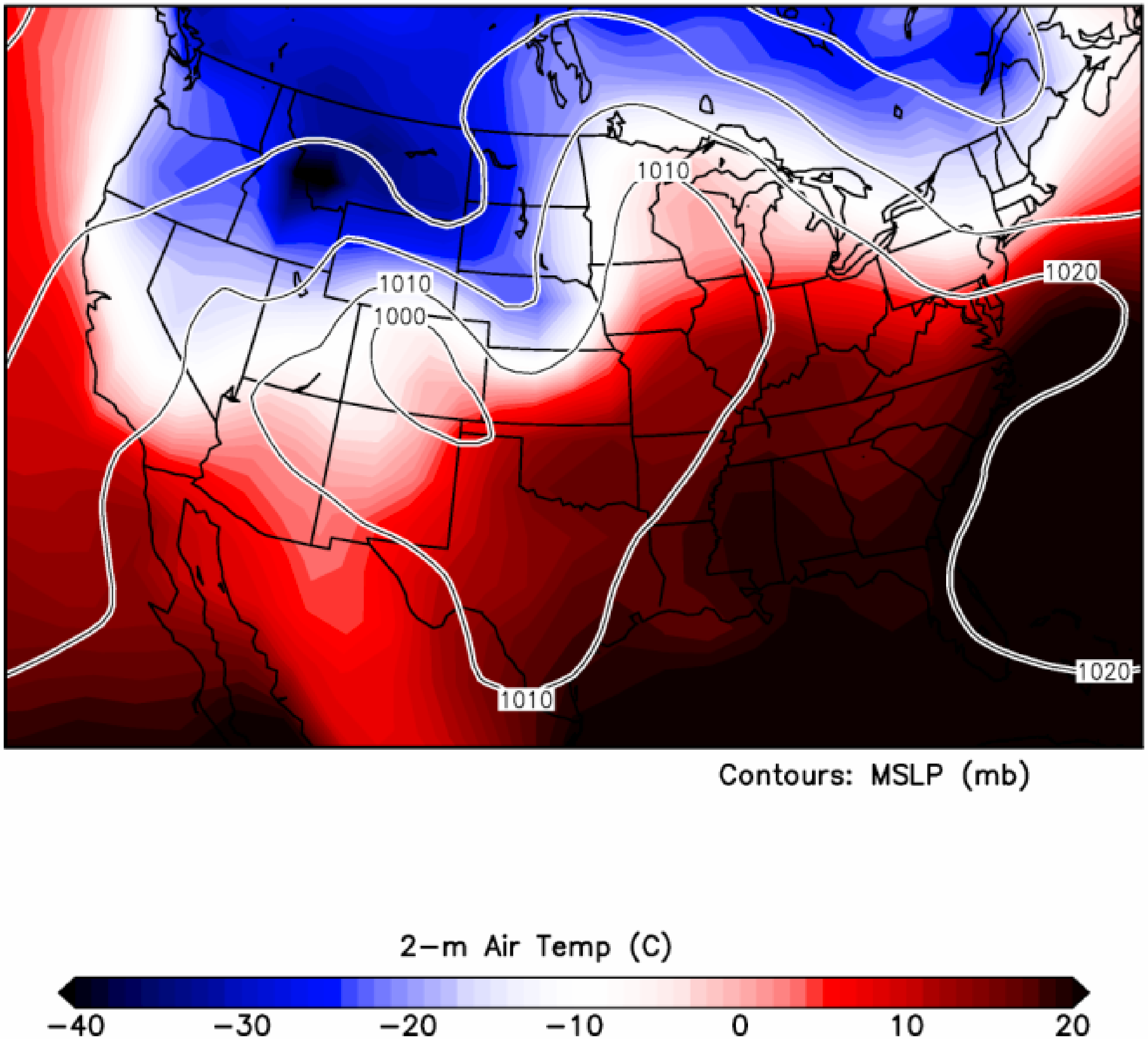
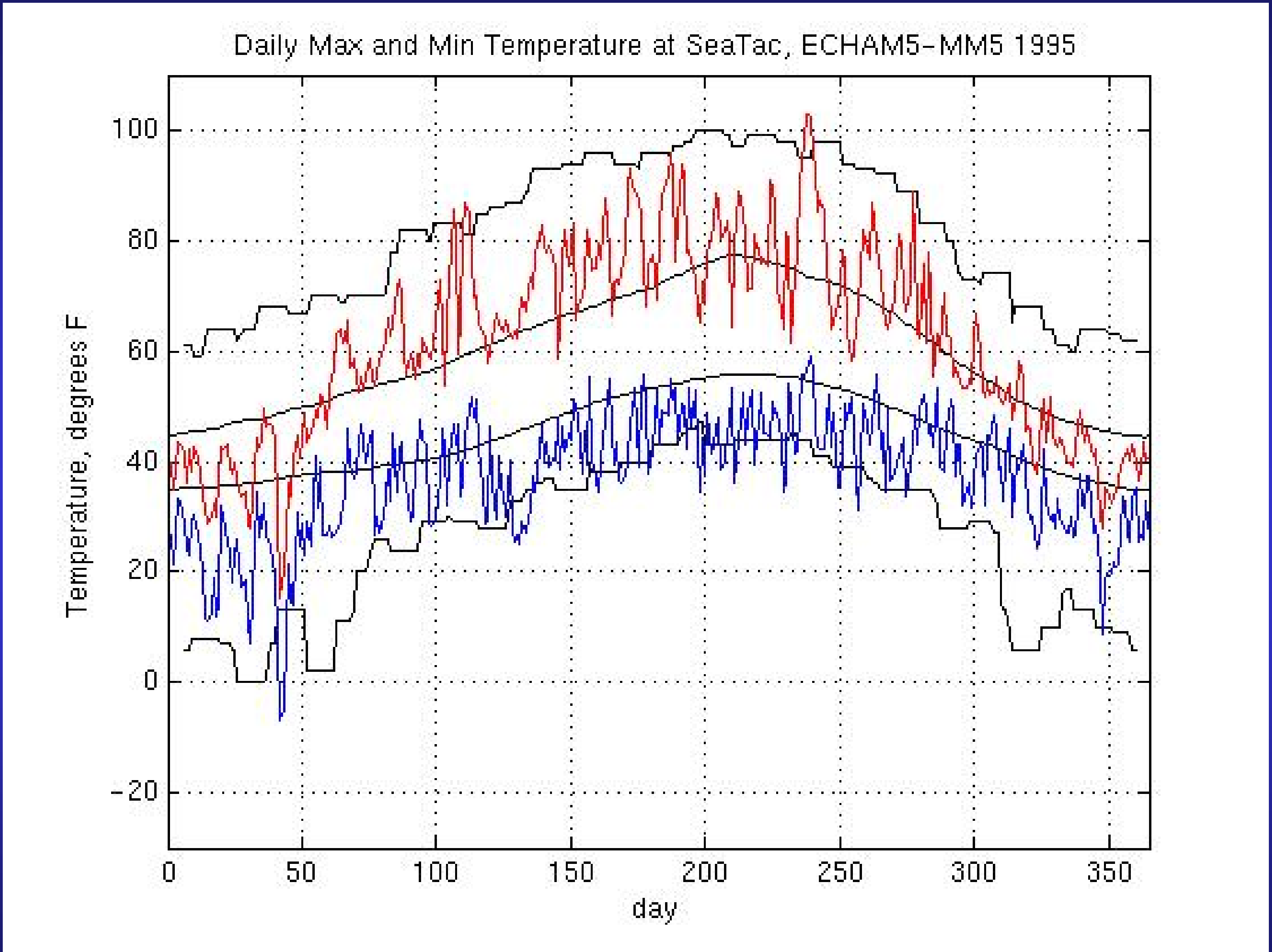


Fig 6. Cold outbreak in ECHAM5 global climate simulation for 12 UTC 21 Feb 1999. Shading indicates 2-m air temperature; white contour lines indicate sea-level pressure in mb.



Daily Max and Min Temperature at SeaTac, ECHAM5-MM5 1995
Temperature, degrees F
100
80
60
40
20
0
-20
0
50
100
150
200
250
300
350
day

Fixing this Problem

- Nudging actually works against the regional model fixing this problem since 135 km domain is nudged.
- Some improvement made by un-nudged 45-km domain.
- Experimenting with larger 45-km domain to address this.
- Bottom line: The driving GCM can have significant problems that must be addressed to secure useful regional simulations.

Other MM5 Model Details

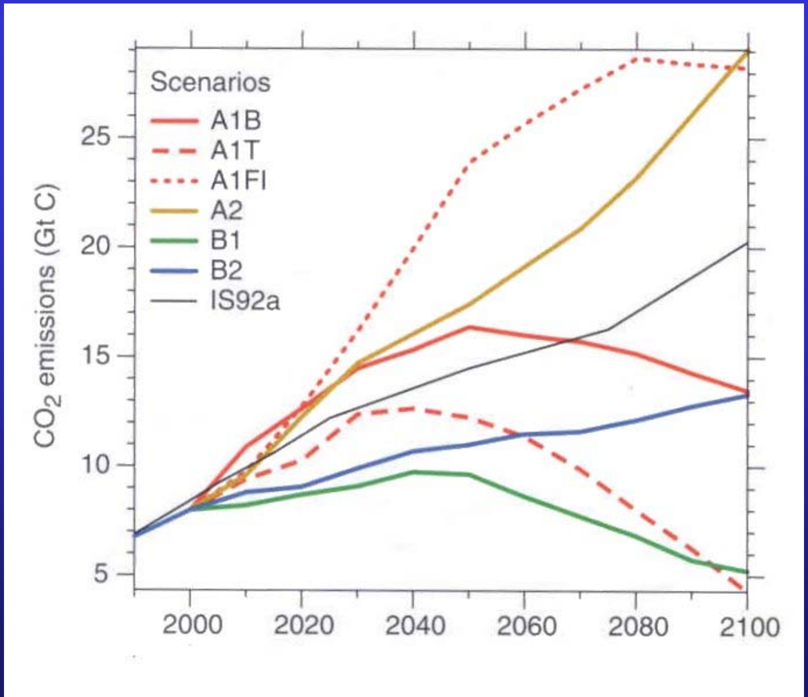
- CCM2 radiation scheme
- Kain-Fritsch convective parameterization
- Simple-ice cloud microphysics
- NOAH Land Surface Model

Regional Modeling

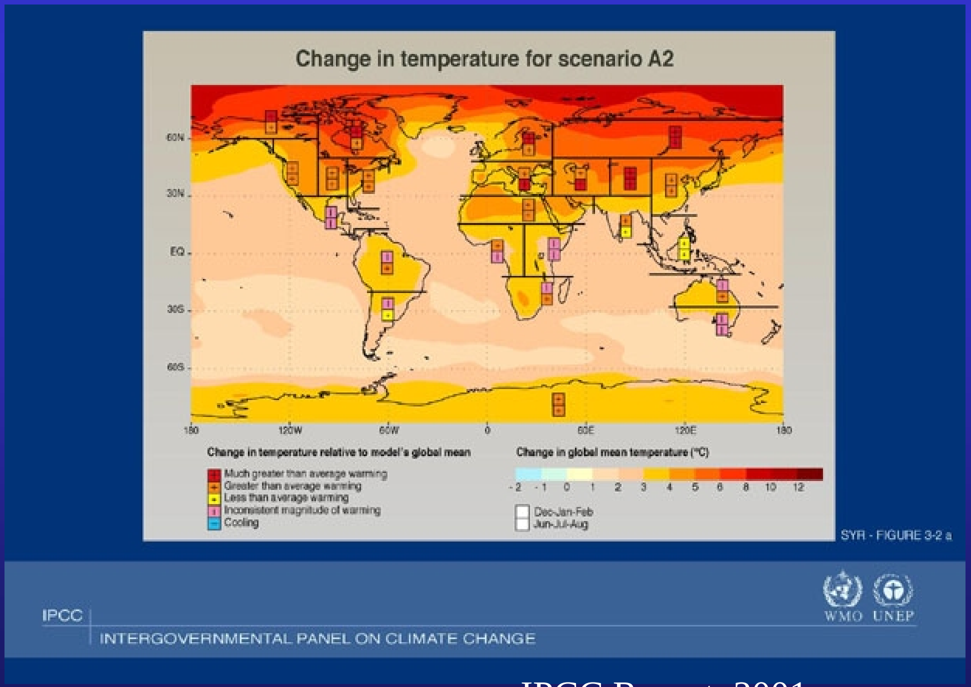
- Ran this configuration over several ten-year periods:
- 1990-2000-to see how well the system is working
- 2020-2030, 2045-2055, 2090-2100
- Completed on Linux clusters-took several weeks each.

Used the ECHAM-5 GCM

- European ECHAM model with resolution roughly equivalent to having grid points spaced ~ 150 km apart.
- IPCC climate change scenario A2 -- aggressive CO_2 increase (doubling by 2050)

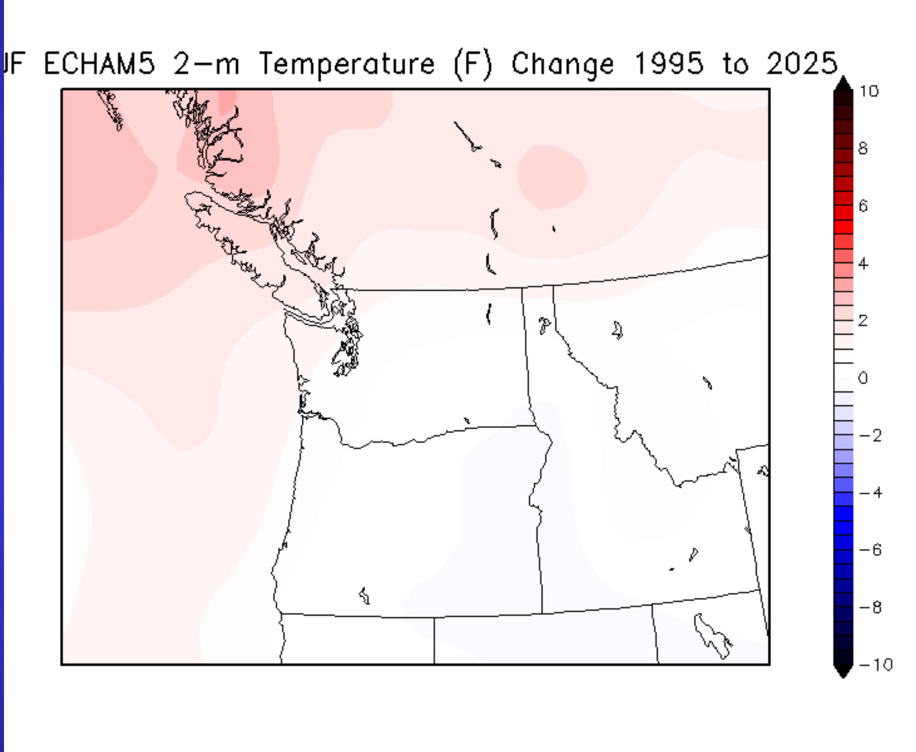


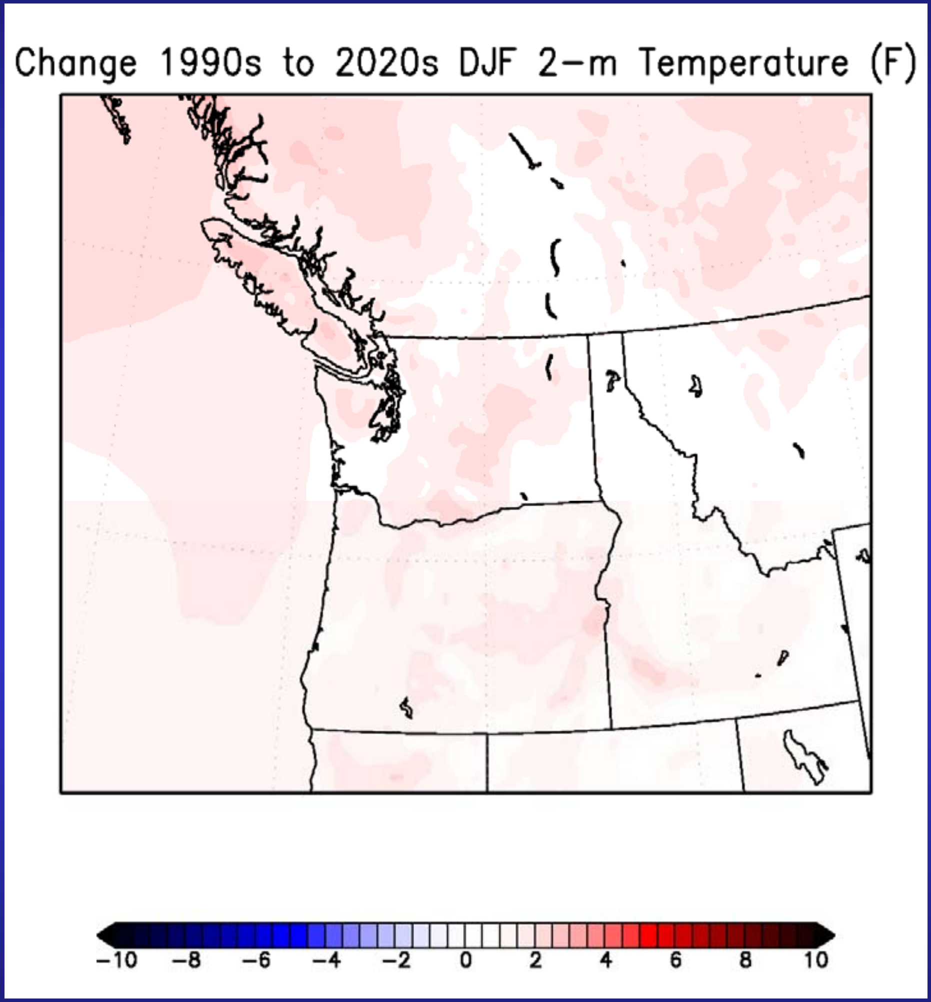
IPCC Report, 2001

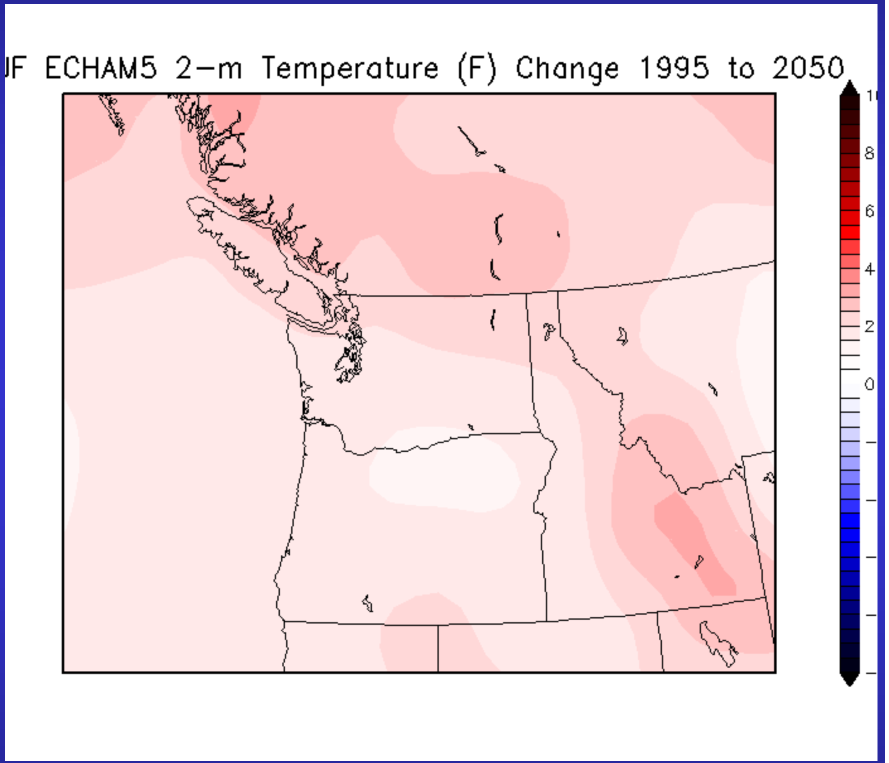


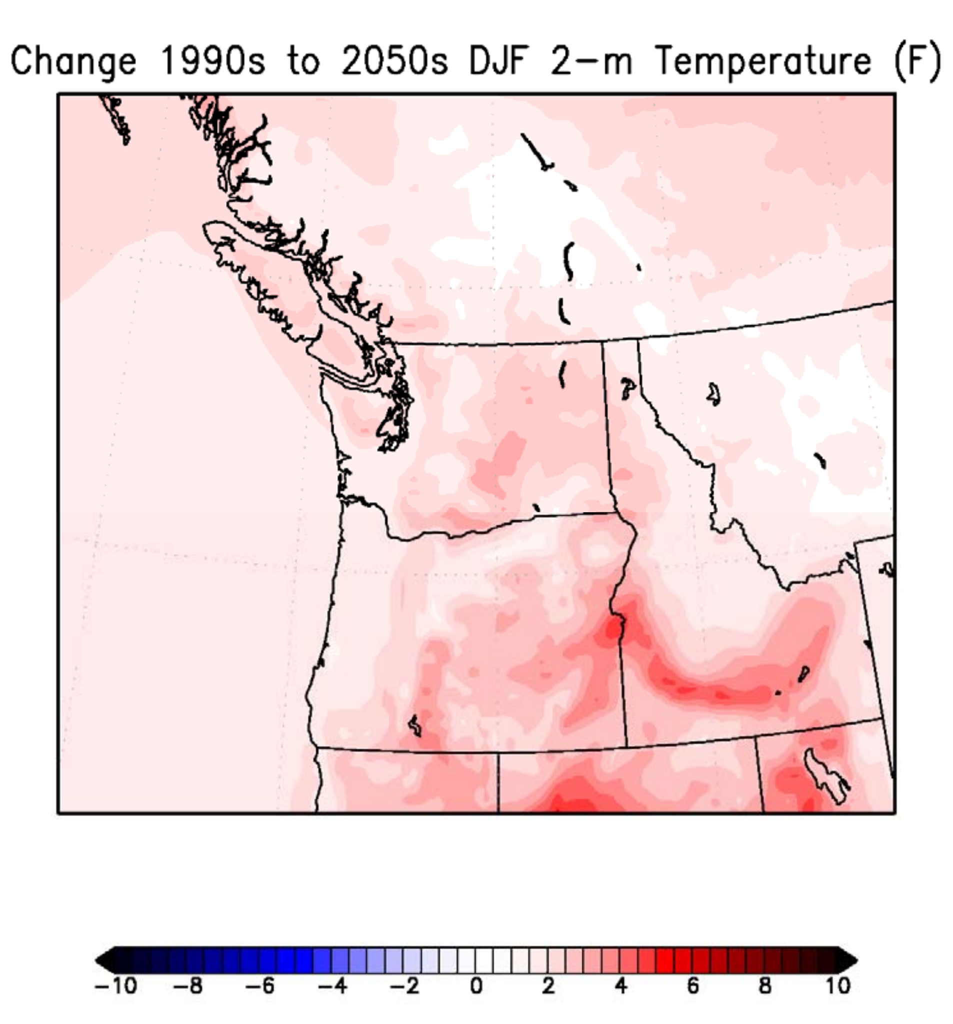
IPCC Report, 2001

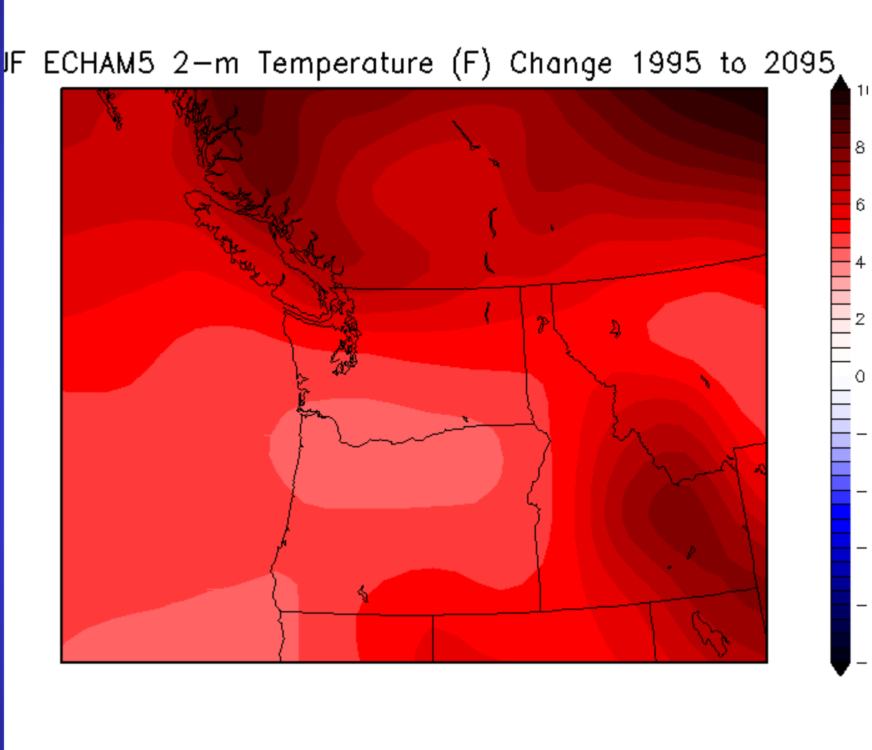
Some Results

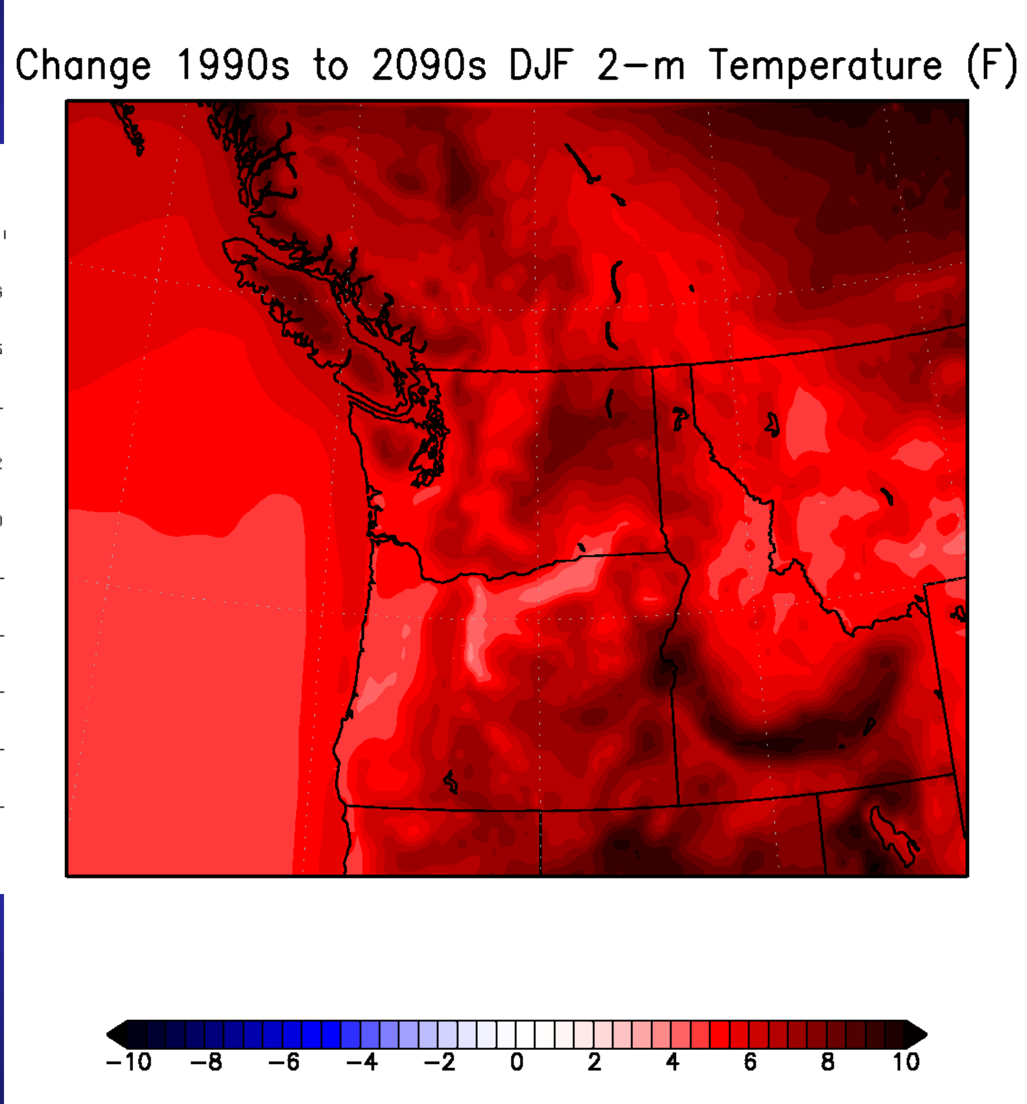

JF ECHAM5 2–m Temperature (F) Change 1995 to 2025
10
8
6
4
2
0
–2
–4
–6
–8
–10


Change 1990s to 2020s DJF 2–m Temperature (F)
–10
–8
–6
–4
–2
0
2
4
6
8
10


JF ECHAM5 2–m Temperature (F) Change 1995 to 2050
8
6
4
2
0

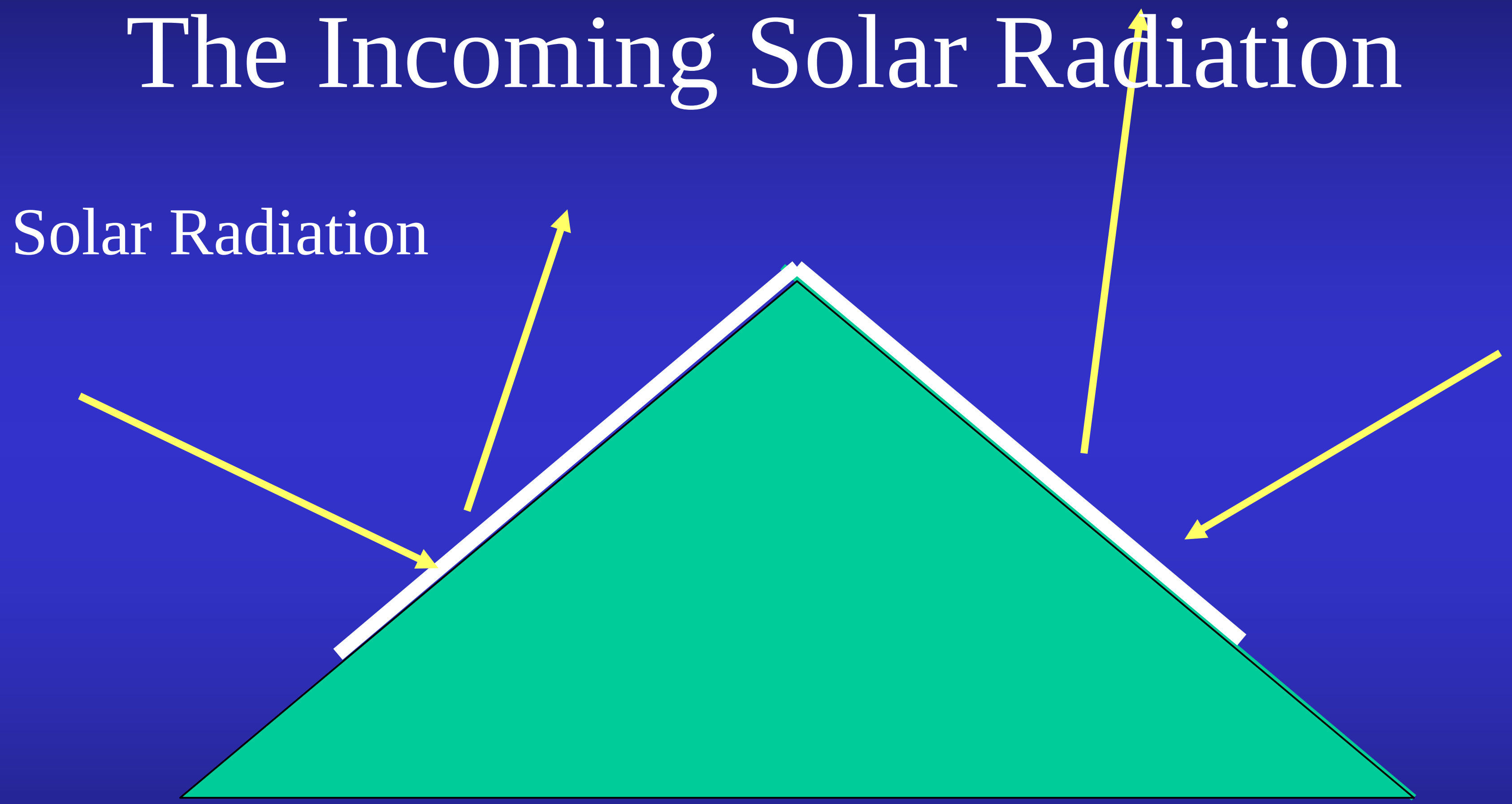

Change 1990s to 2050s DJF 2–m Temperature (F)
–10
–8
–6
–4
–2
0
2
4
6
8
10


JF ECHAM5 2-m Temperature (F) Change 1995 to 2095
8
6
4
2
0


Change 1990s to 2090s DJF 2-m Temperature (F)
-10 -8 -6 -4 -2 0 2 4 6 8 10

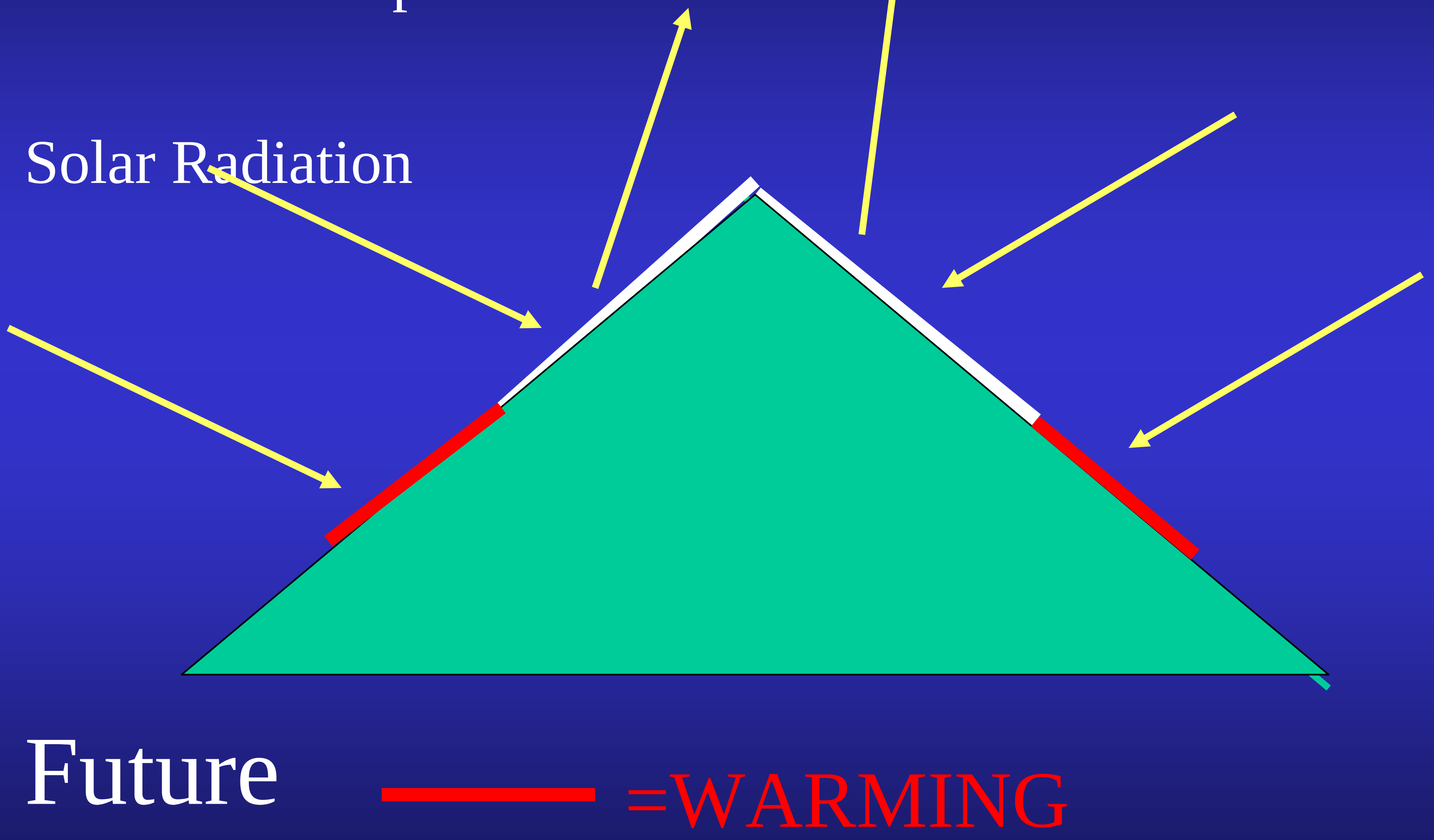
Why banded warming structures?

Snow and Ice Reflect Much of The Incoming Solar Radiation



Now

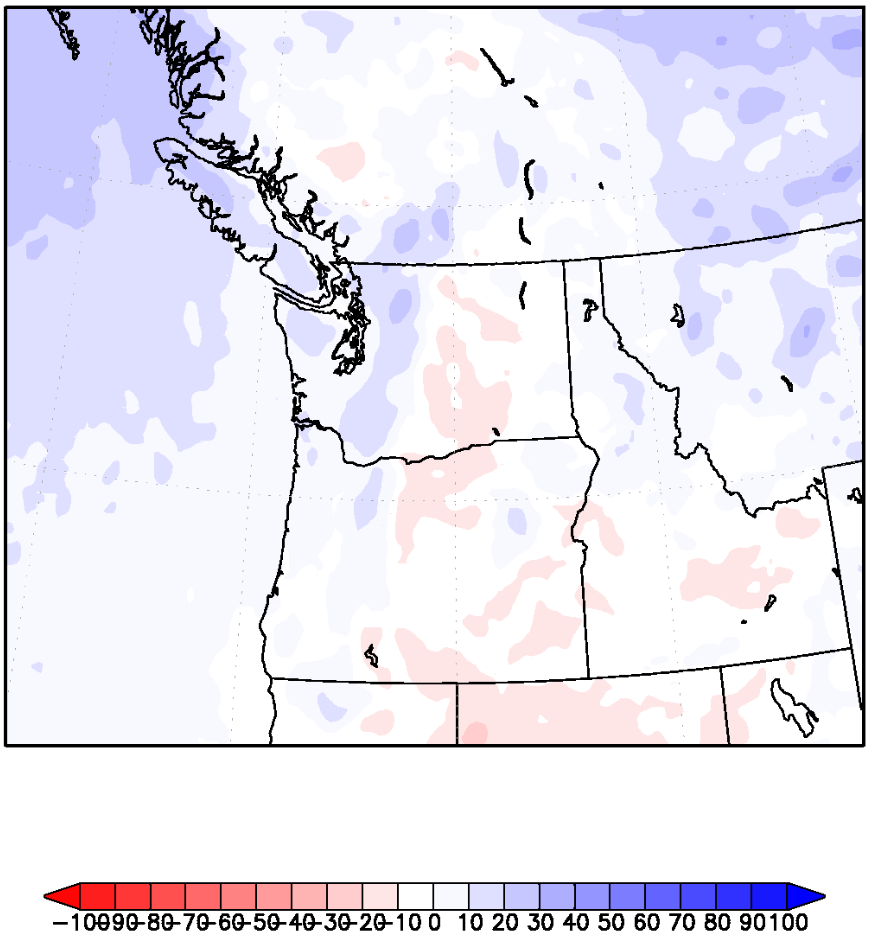
Global Warming Causes Snow level to Rise Resulting In Absorption of Solar Energy on Melted Slopes



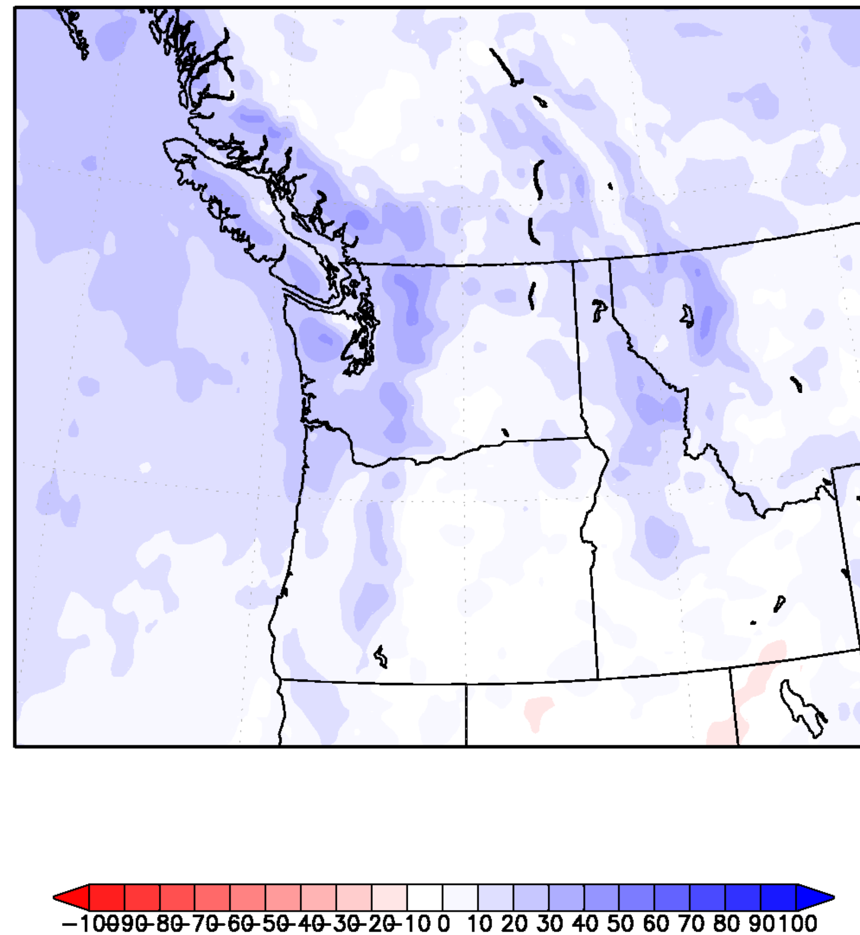
More Low Clouds West of Cascades in Spring Under Global Warming

- Low clouds due to more onshore flow from off the cool, cloud Pacific.
- More low clouds over ocean..why?
- The Montereyization of the western lowlands!

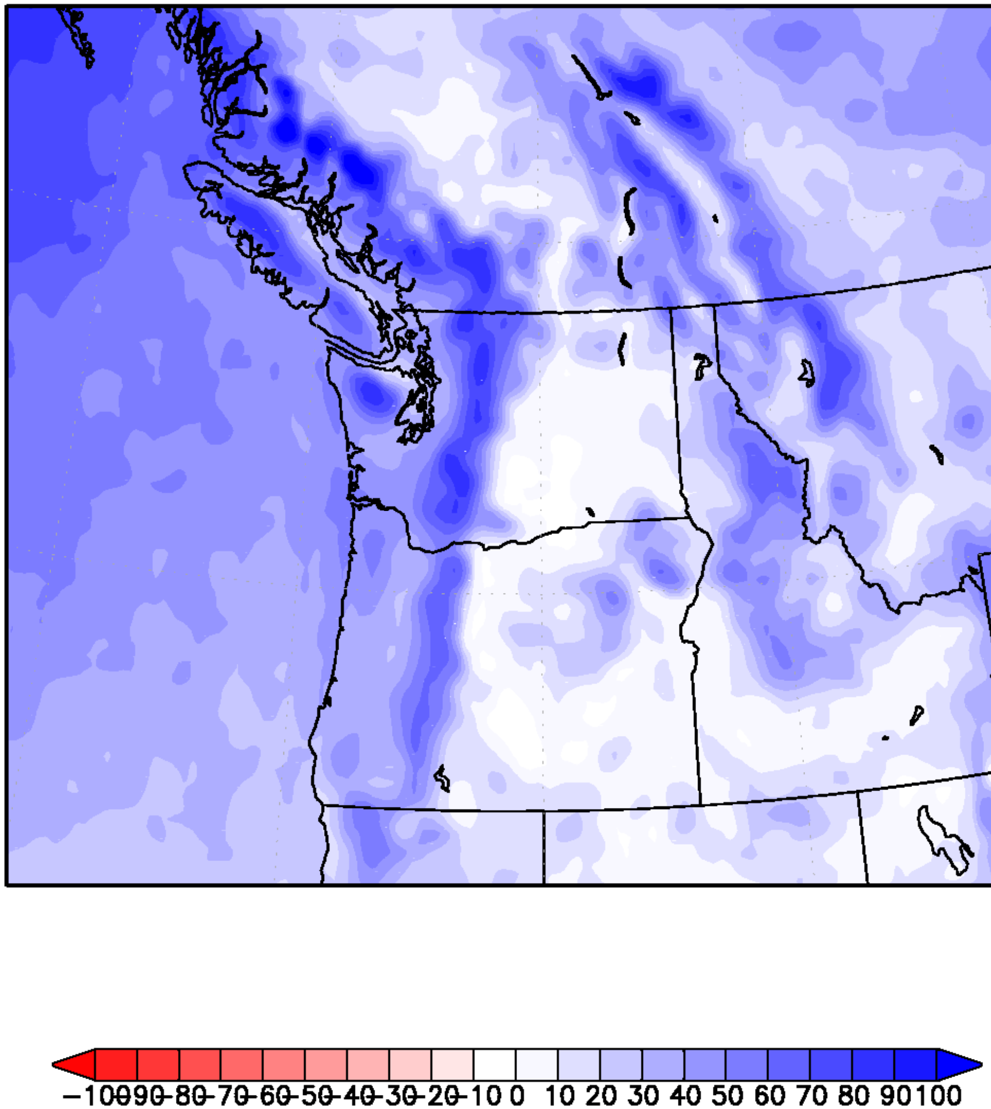
Percent Change 1990s to 2020s MAM Cloud Water



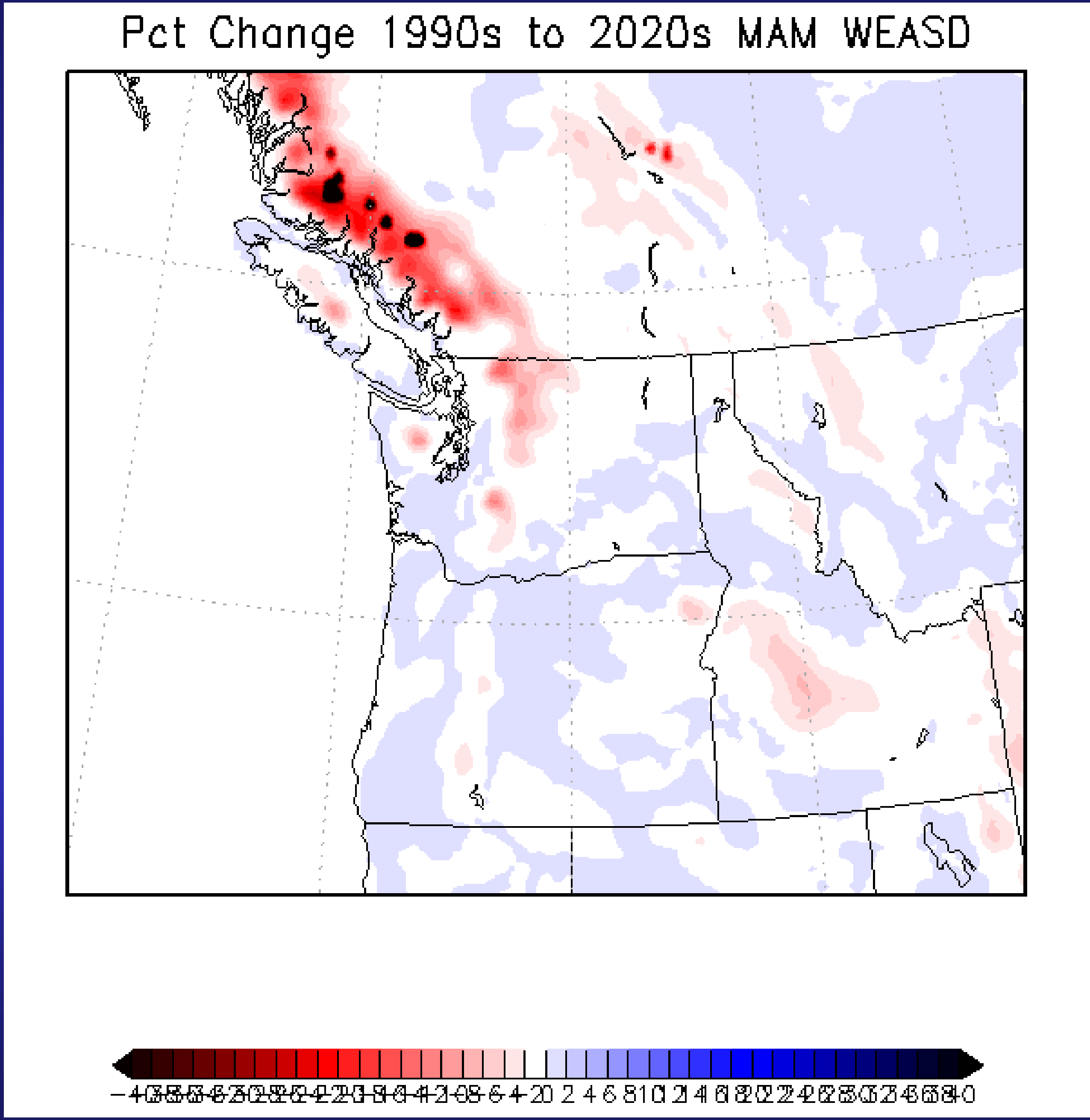
Percent Change 1990s to 2050s MAM Cloud Water



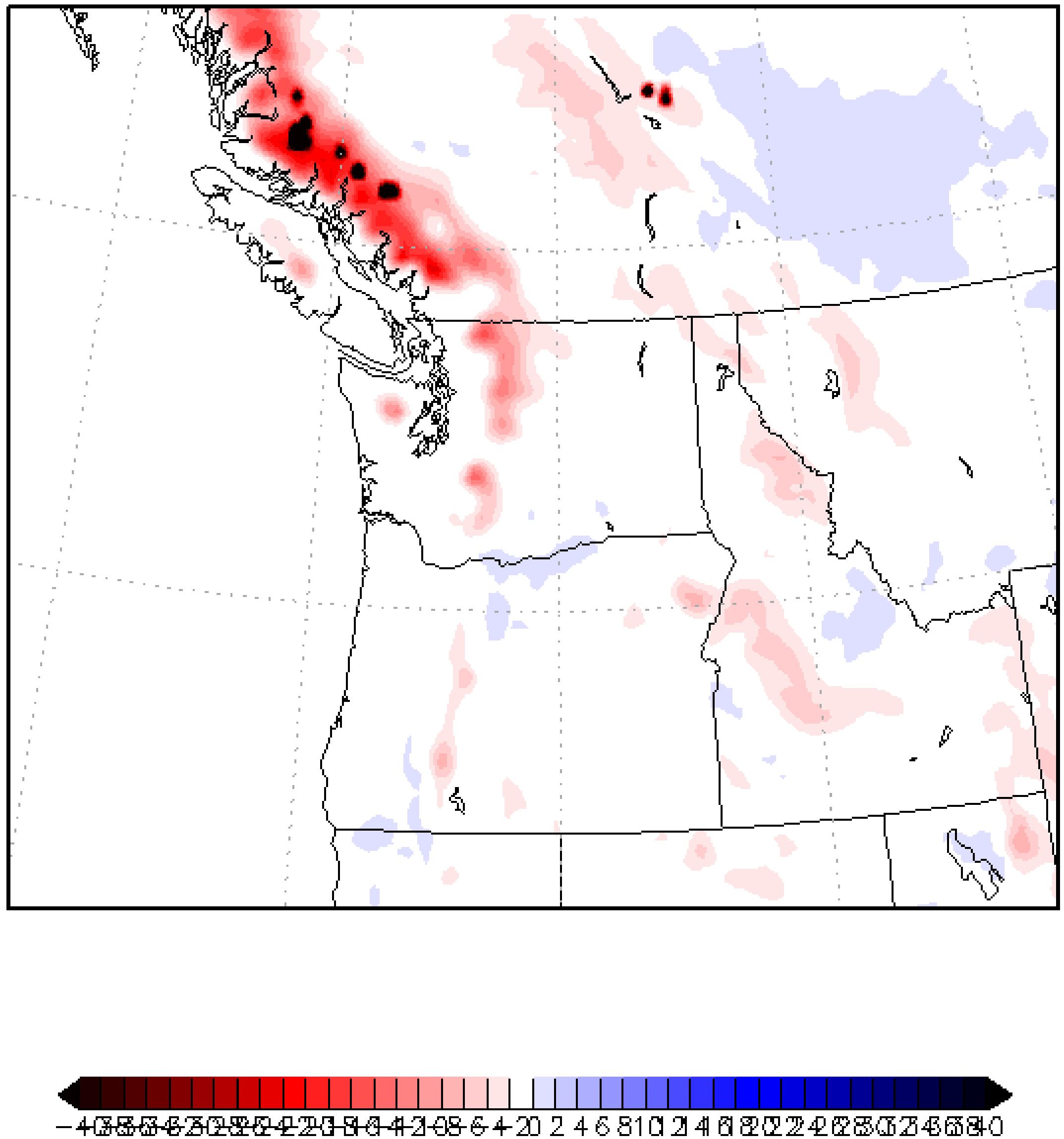
Percent Change 1990s to 2090s MAM Cloud Water

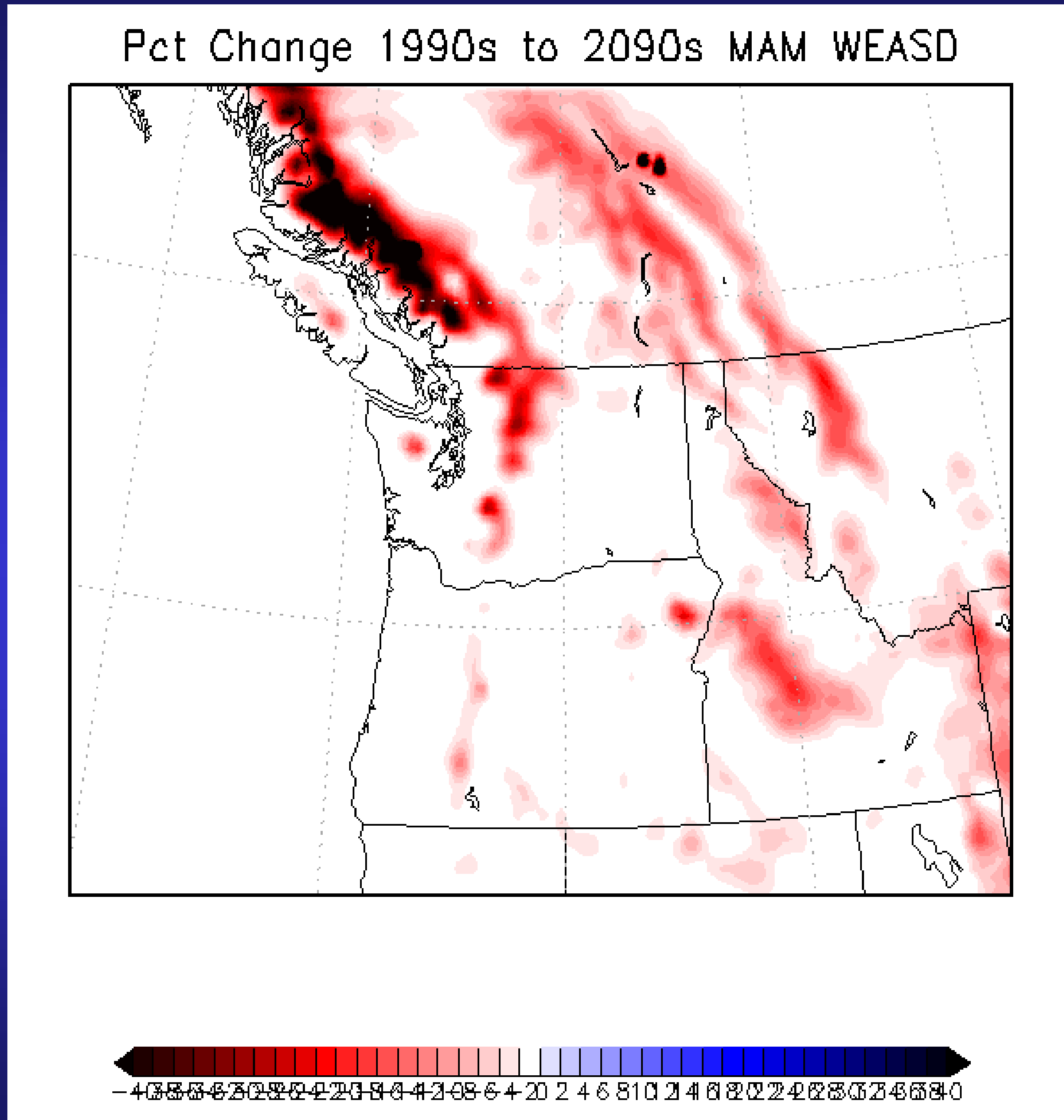


Change in Water Of Snowpack (%)



Pct Change 1990s to 2050s MAM WEASD




Pct Change 1990s to 2090s MAM WEASD

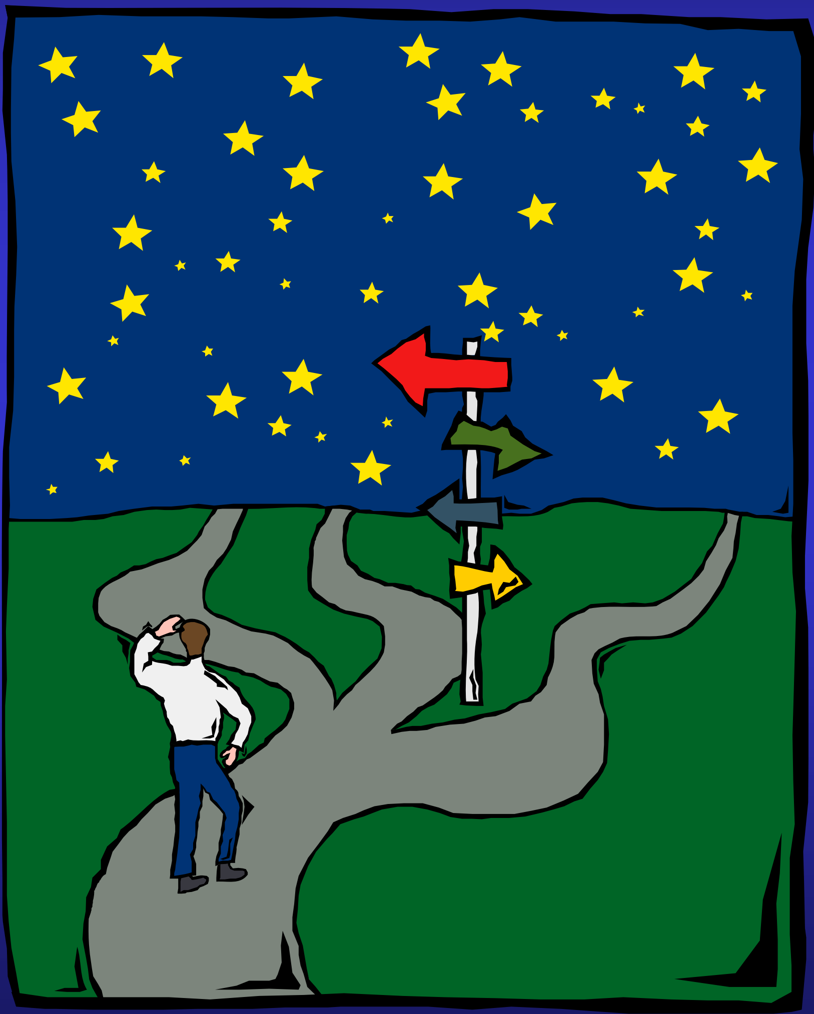
Summary

- The viability of the approach…using high resolution numerical prediction models forced by large-scale general circulation climate models (GCMs)… has been demonstrated.
- Careful evaluation of the GCM output is required…there are deficiencies.
- Although there is general warming over the region for all seasons, the terrain and land water contrasts of the region enhance or weaken the warming in certain areas.

Summary

- Warming is enhanced on the upper windward slopes due to snow melt.
- Springtime warming is lessened west of the Cascade crest due to more low clouds.
- Many more hot days during the summer.
- Precipitation changes are more modest then temperature changes.
- There will be a substantial loss of snowpack, reaching catastrophic decreases by 2090.

The END



Issues

- How can one efficiently complete high-resolution mesoscale runs nested with a global GCM?
- How does one deal with deep soil temperature?
- When we started the project WRF was not ready (lack of nudging, physics inadequacies). WRF 2.2 solves these problems and a next step is to move from MM5 to WRF.