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Diagnosing Permafrost in (CMIP5) Climate Models

Andrew G. Slater and David M. Lawrence

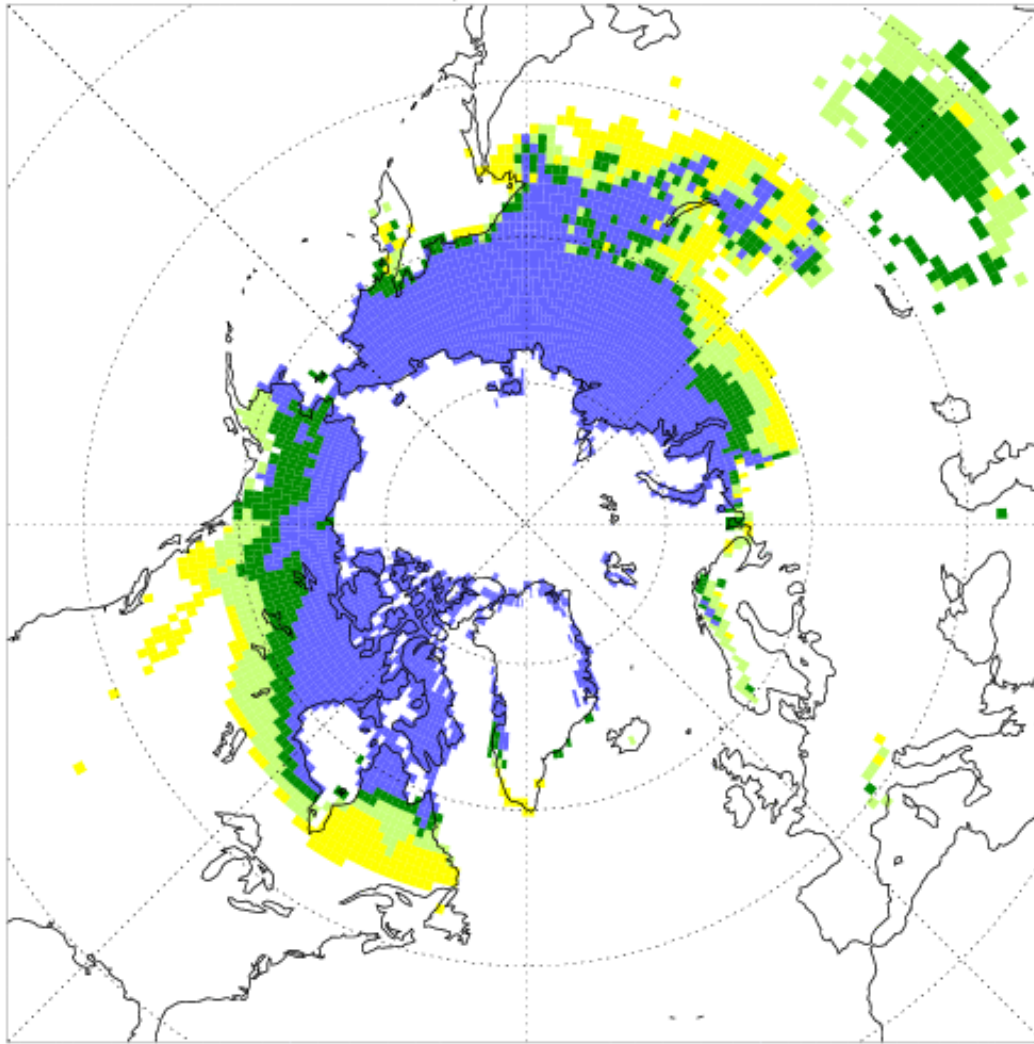


Best Performance by a LSM in a CMIP5 ...

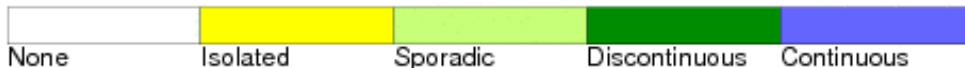


- **BCC-CSM1 ***
- **CanESM2 ***
- **CCSM4 ***
- **CNRM-CM5**
- **CSIRO-Mk3.6**
- **GFDL-ESM2M ***
- **GISS-E2-H/R ***
- **HadCM3**
- **HadGEM2-ES/-CC ***
- **INMC4 ***
- **MIROC5/-ESM ***
- **MPI-ESM-LR ***
- **MRI-CGCM3 ***
- **NorESM1-M***
- **ACCESS-1**
- **IPSL**

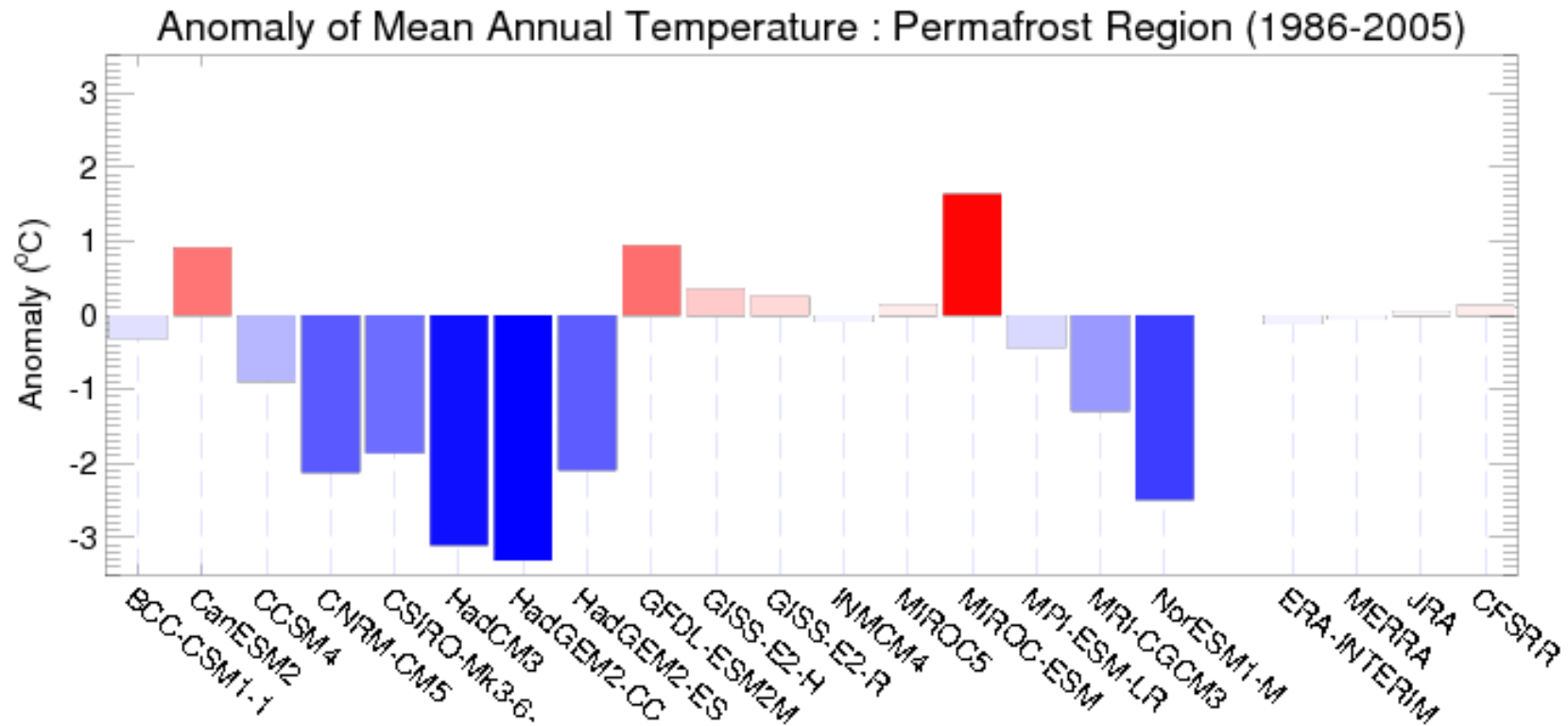
IPA Map of Permafrost



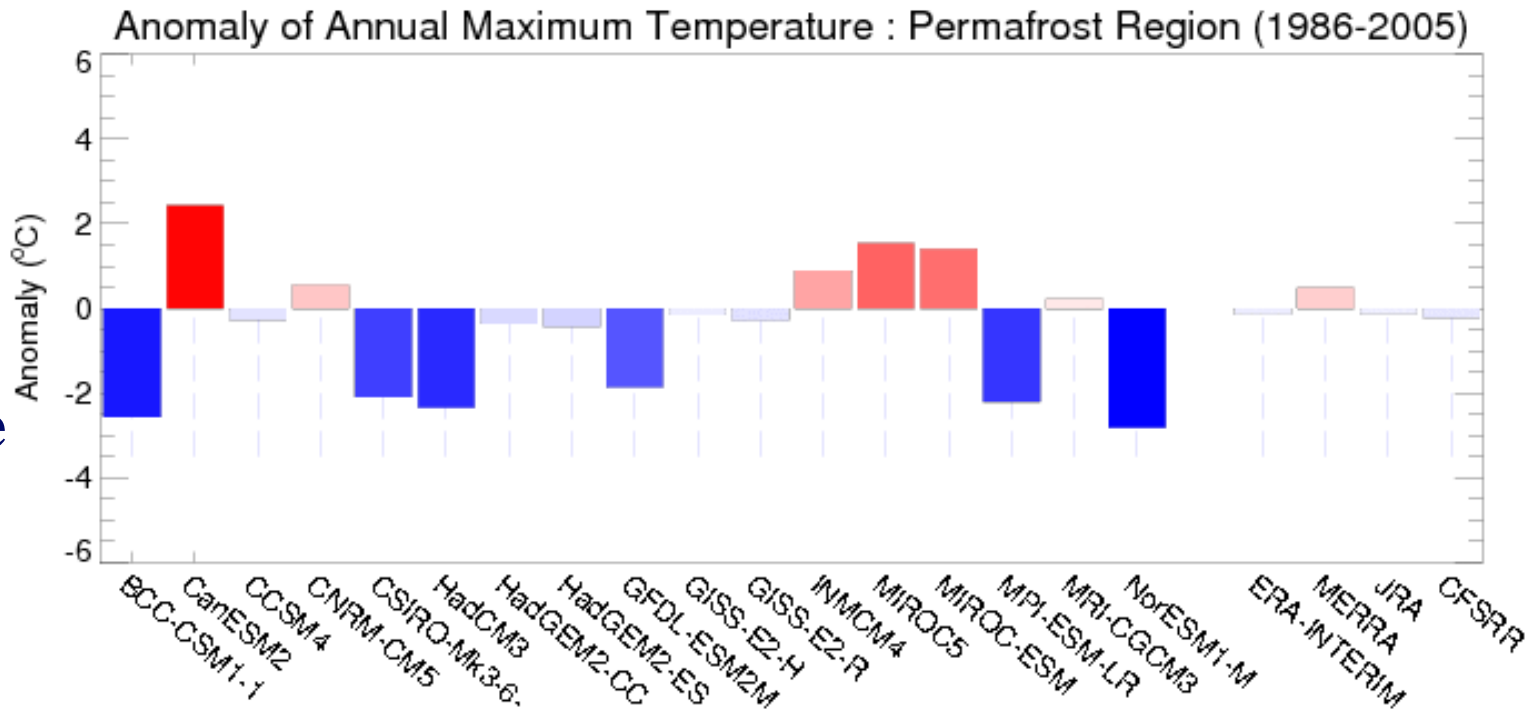
- Data: 1960's to 1993
- $\sim 16 \times 10^6$ km² on CCSM4
 - (Discont + Cont)



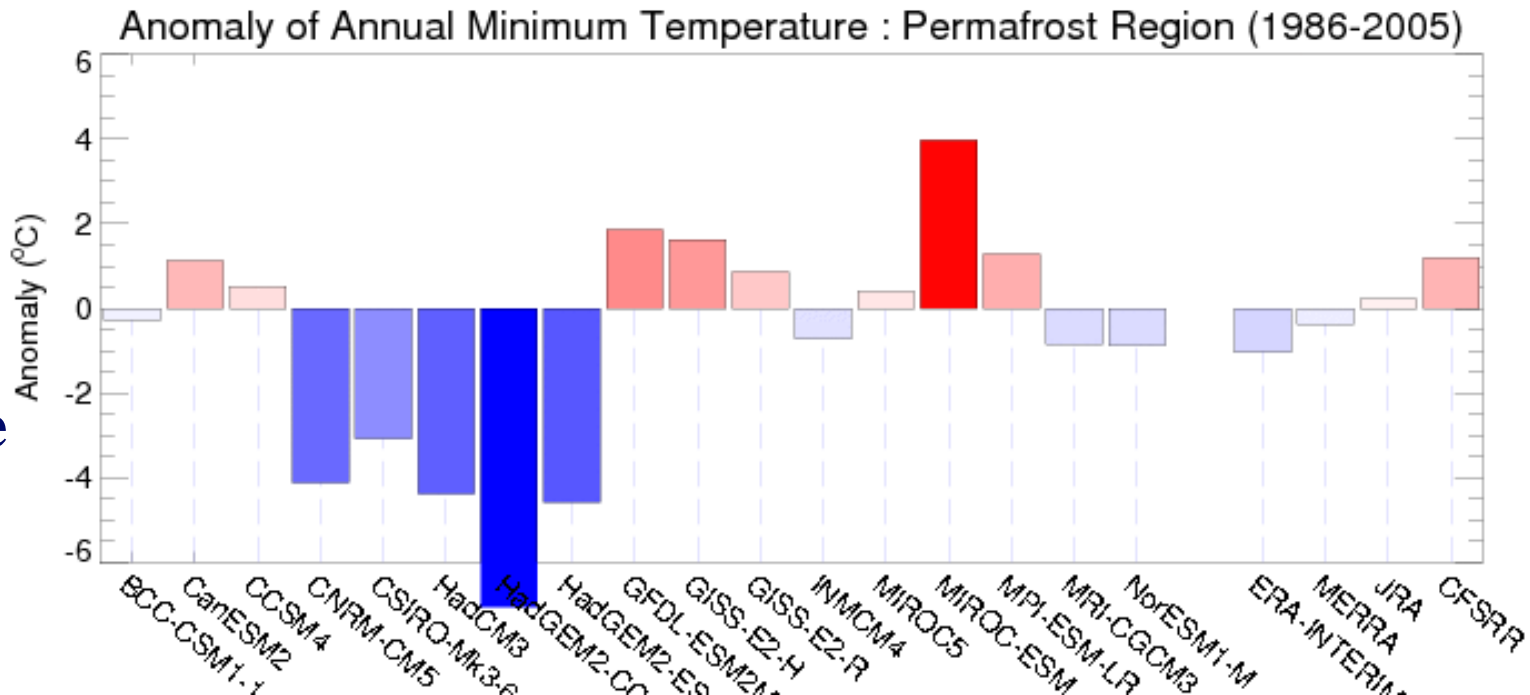
Mean Annual Temperature vs. Reanalysis



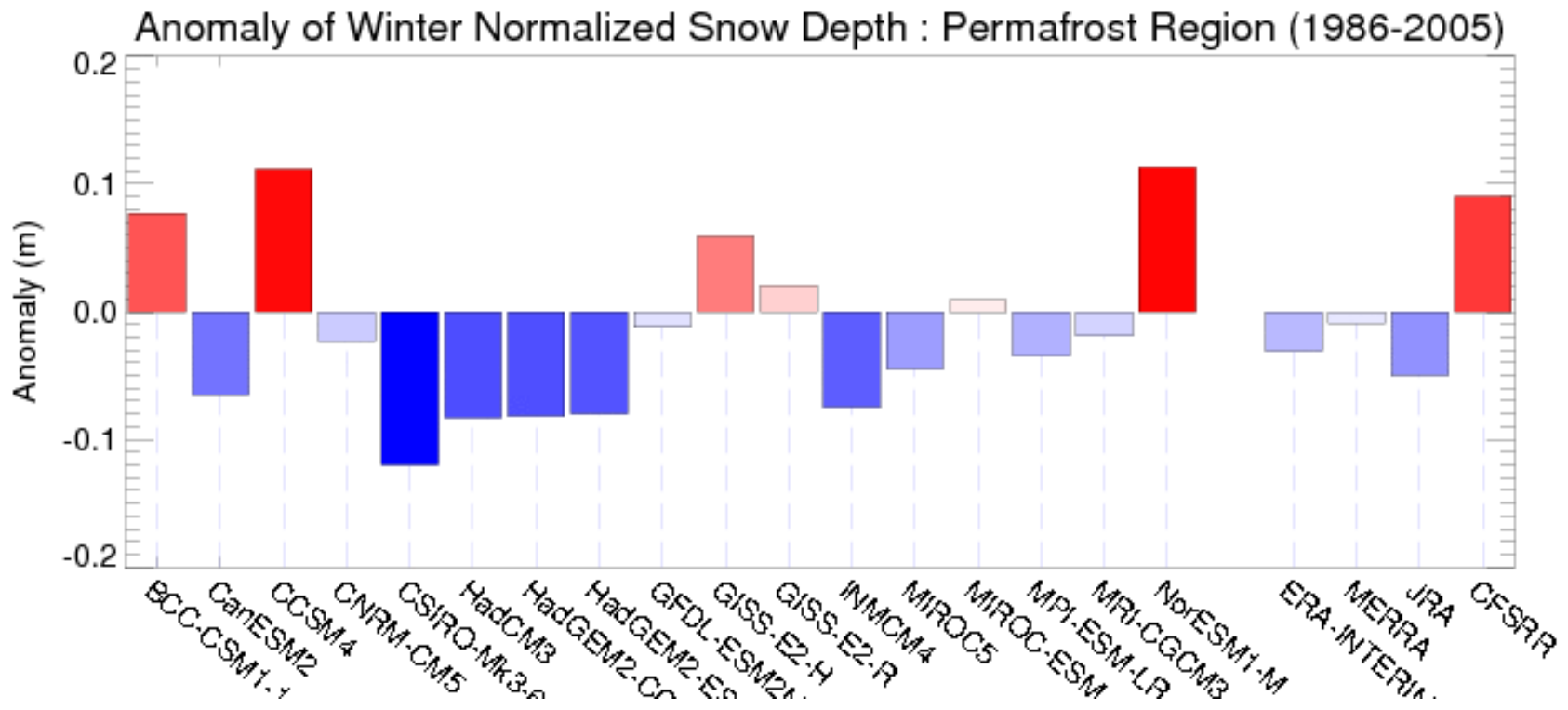
Annual Maximum Temperature



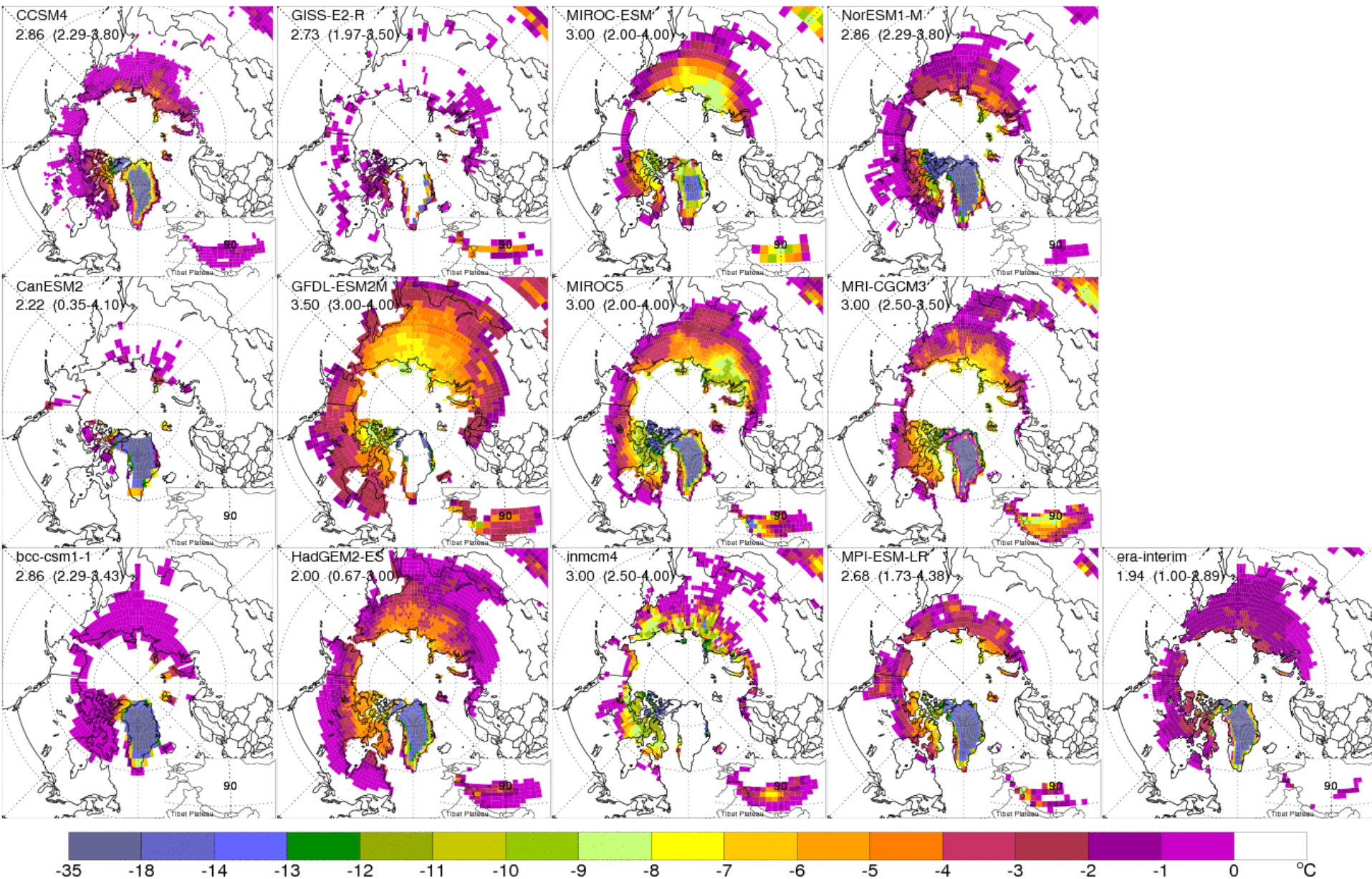
Annual Minimum Temperature



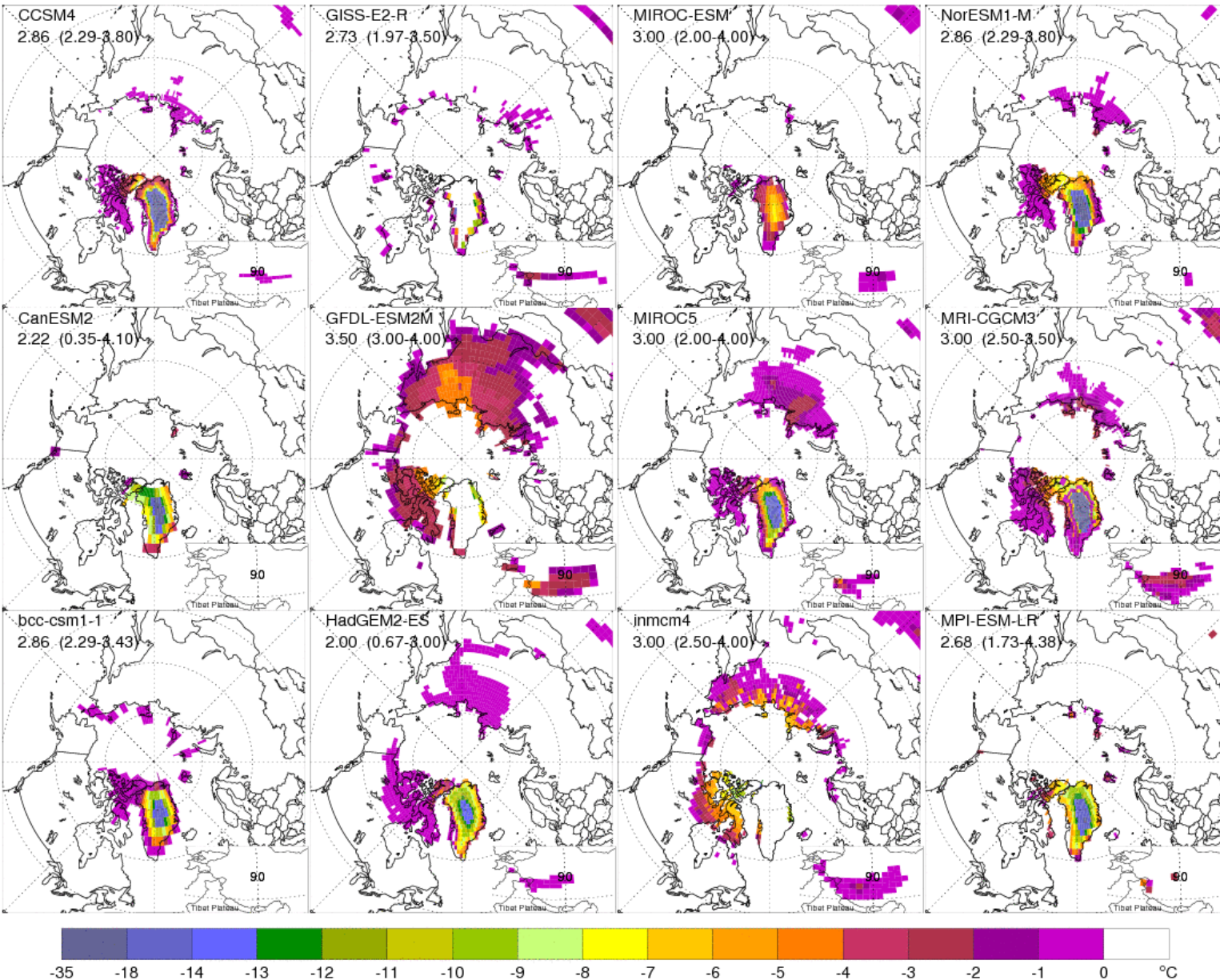
Winter Normalized Snow Depth vs. Reanalysis



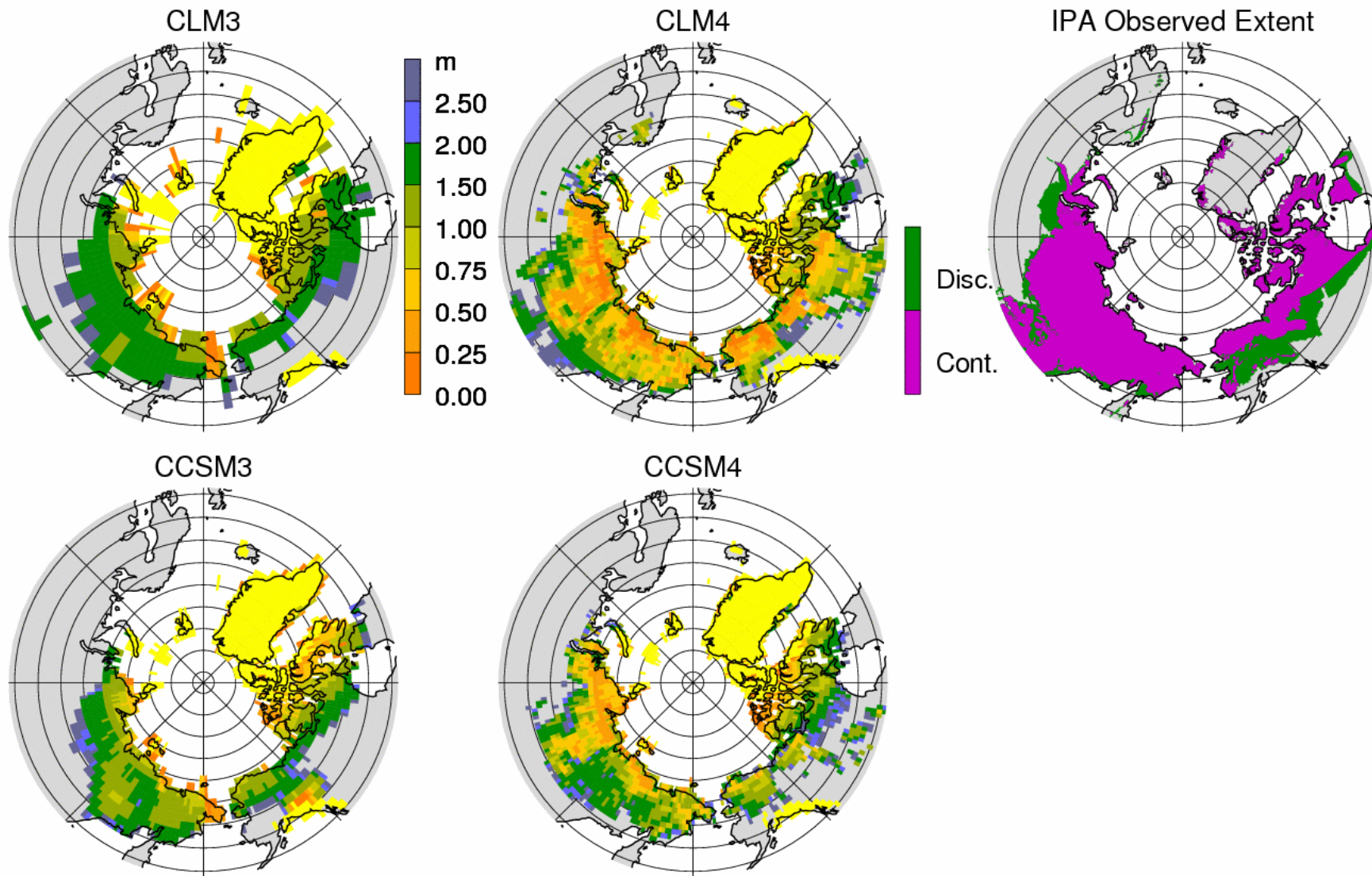
Maximum Soil Temp at ~3.5m, 2000



Maximum Soil Temp at ~3.5m, 2097 (RCP8.5)



CLM4 : Offline vs Coupled



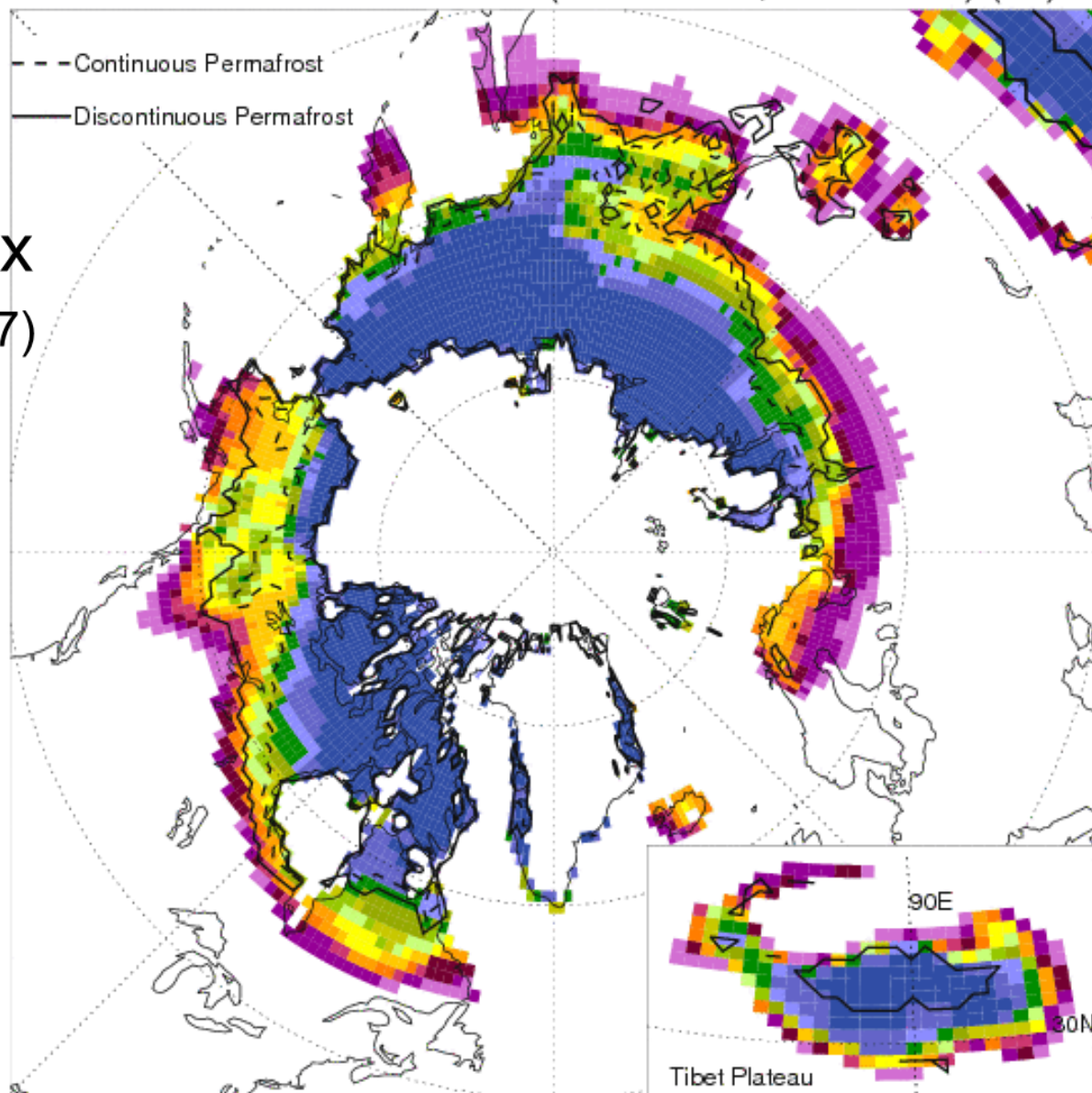
Indirect Measure

• Surface Frost Index

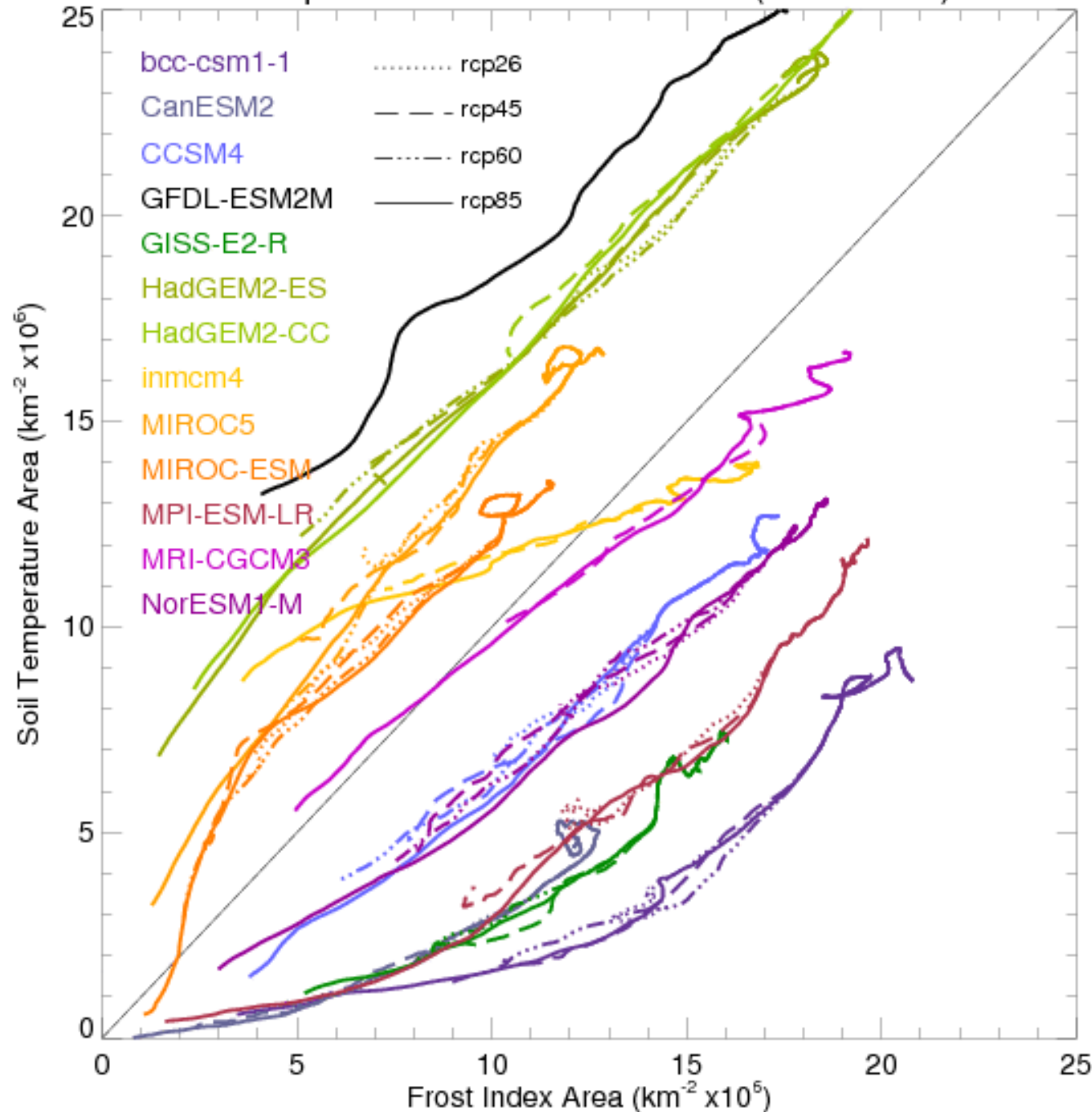
- Nelson & Outcalt (1987)
- Climate Only
- Steady-State
- Empirical Estimate

$$SFI = \frac{\sqrt{DDF^*}}{\sqrt{DDF^*} + \sqrt{DDT}}$$

No. Models with Permafrost (Frost Index, Year:2000) (16)



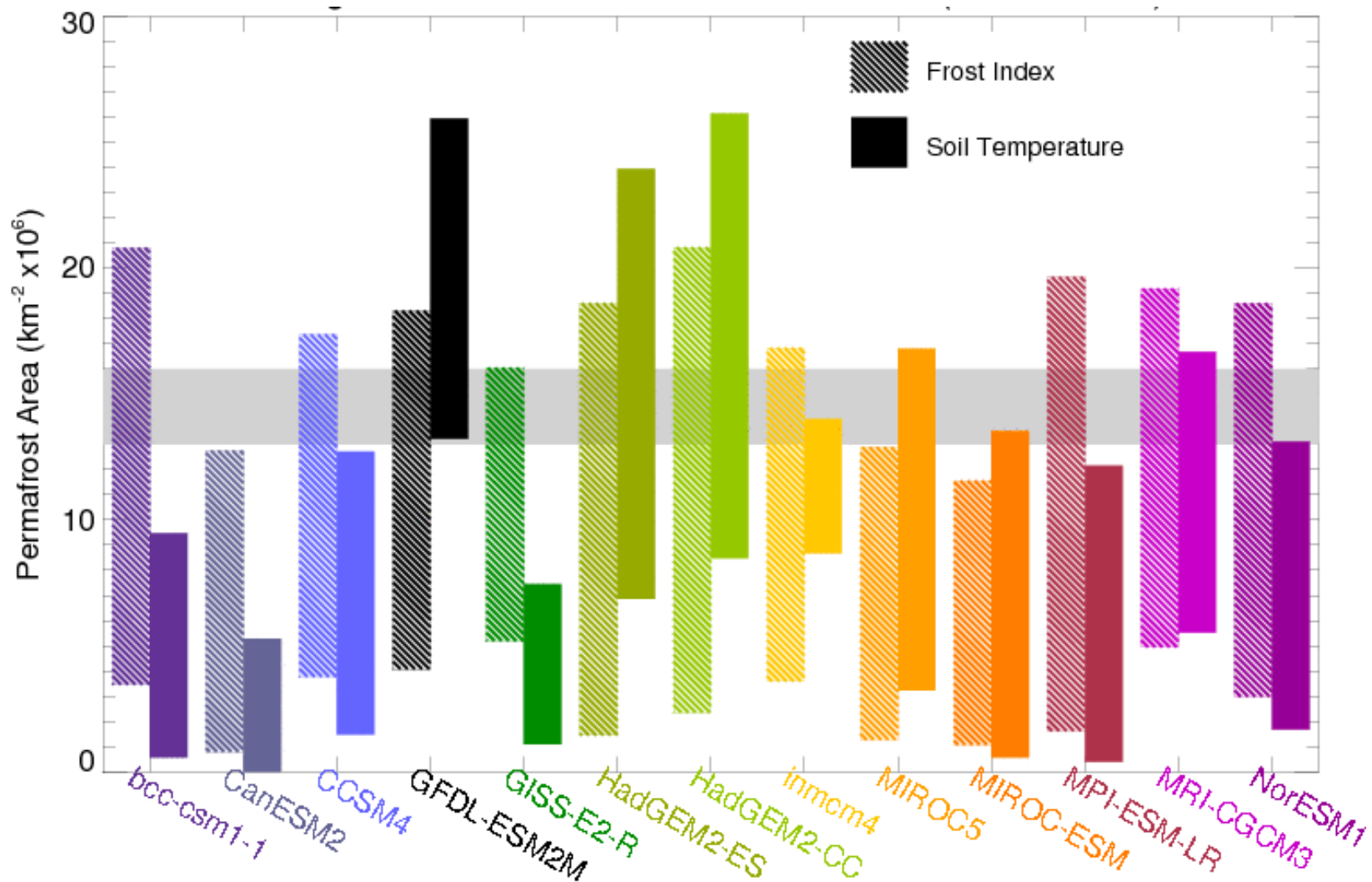
Comparison of Permafrost Area (1900-2099)



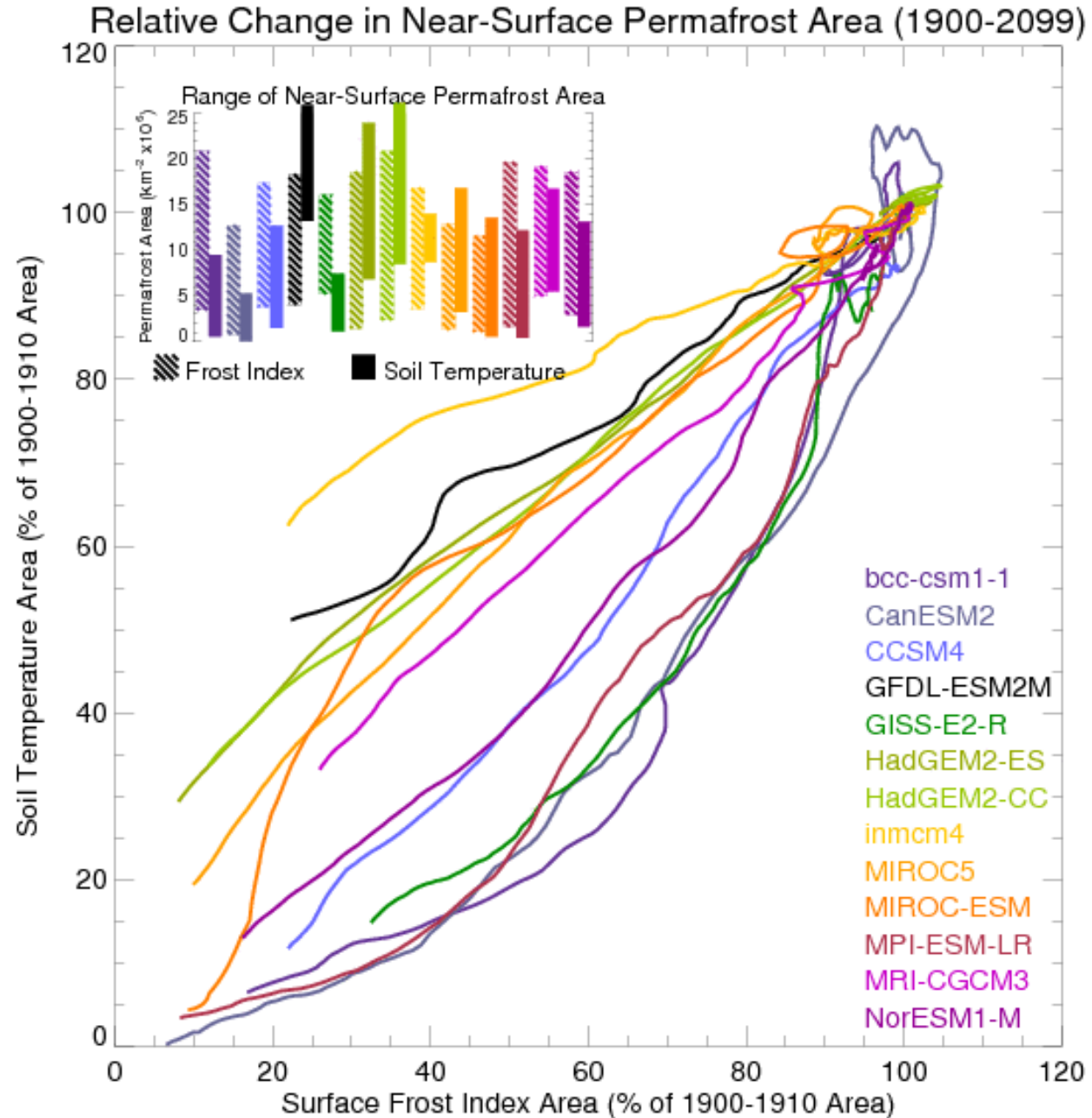
Direct
vs
Indirect
Diagnosis

- Impact of Land Model
- Common result across RCPs

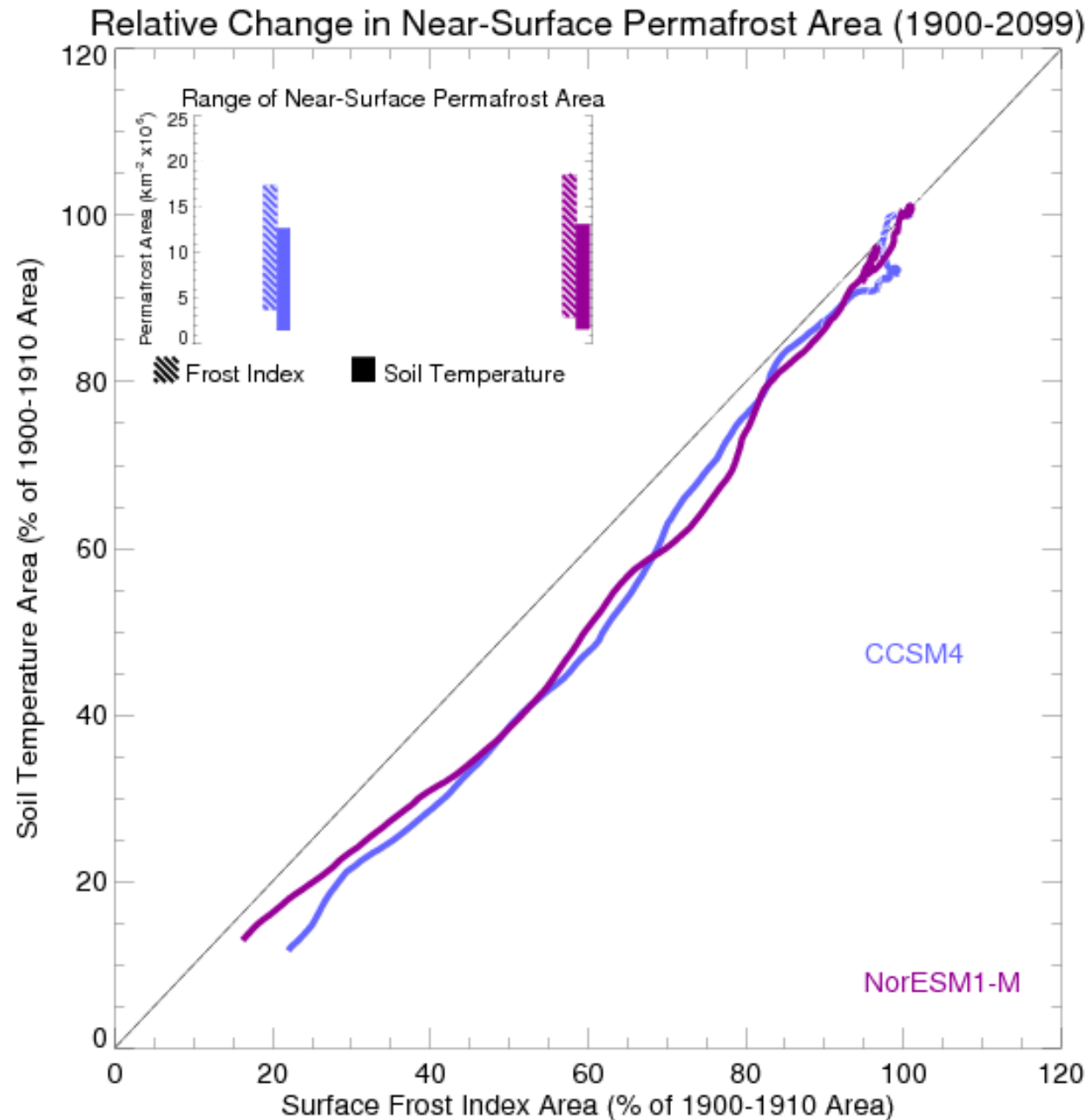
Range of Near-Surface Permafrost Area (1900-2100)



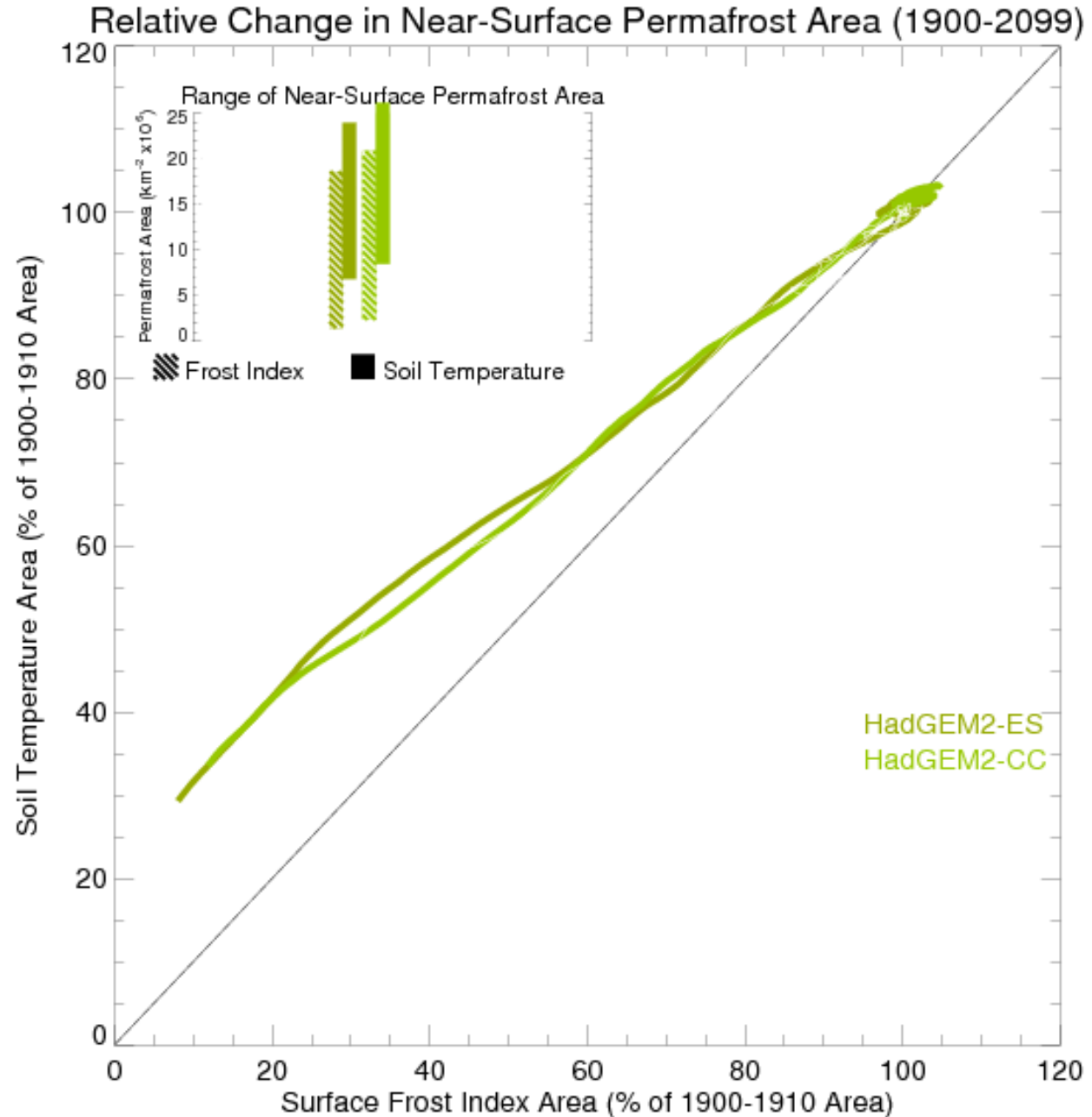
Sensitivity of the Land Model



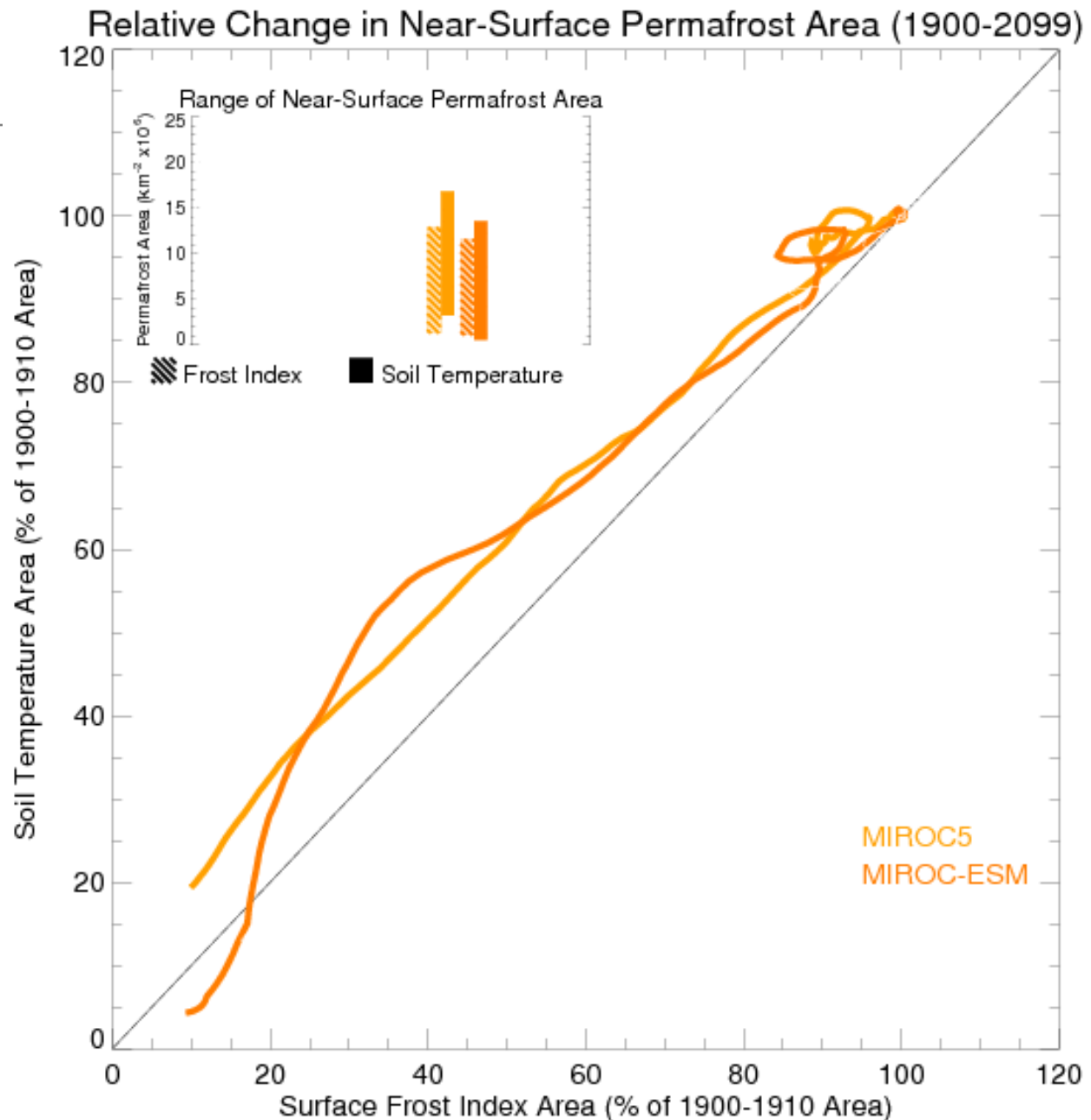
*Same LSM,
different CGCM
(slightly)*



*Same LSM,
different CGCM
(slightly)*

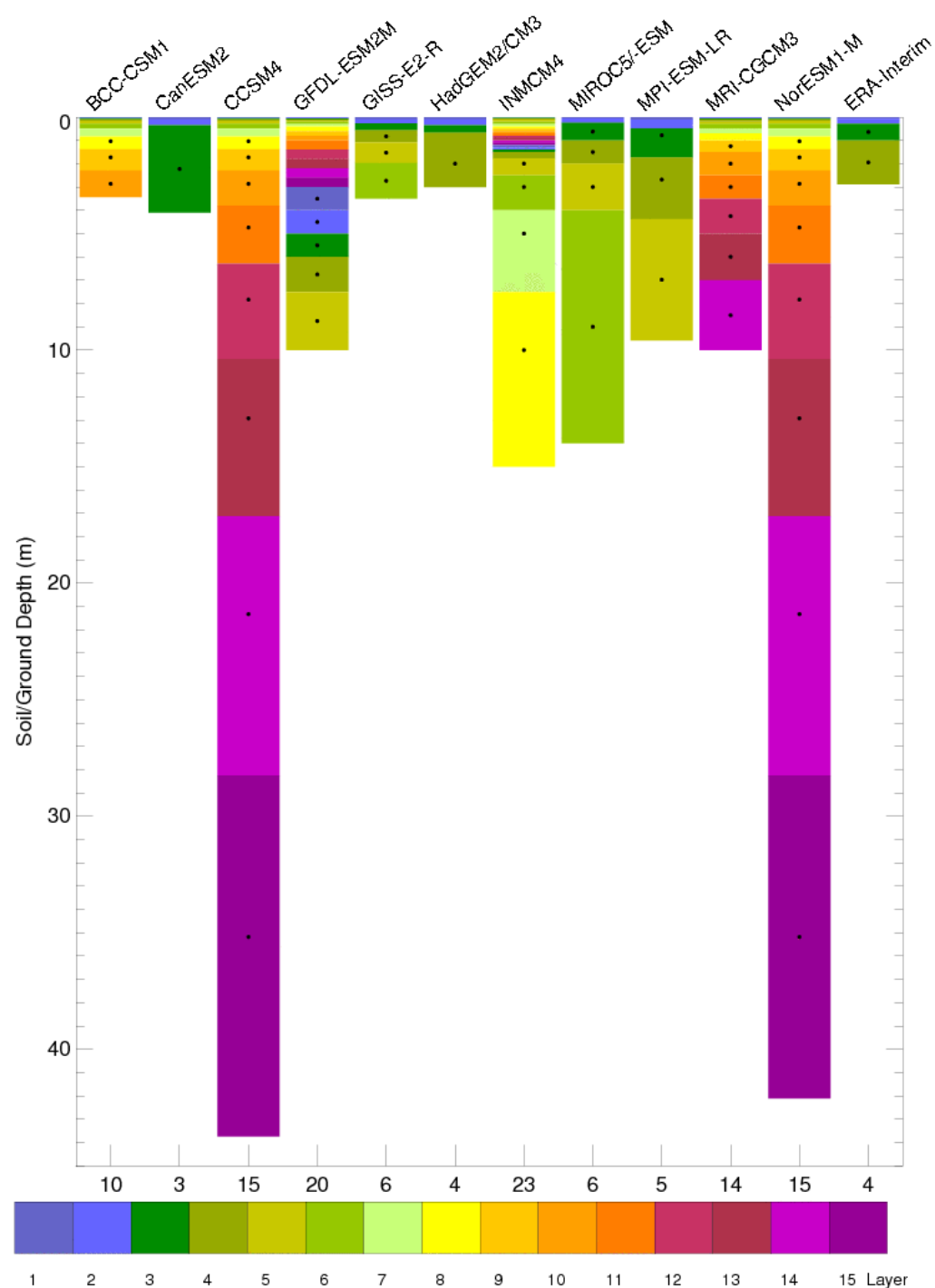


*Same LSM,
different CGCM
(slightly)*



Model Structure?

- Why do LSMs behave differently?
- Structure
 - Soil Columns
 - Surface fractions
 - Snow
 - Land-Atmo coupling
- Parameters
 - Organics?

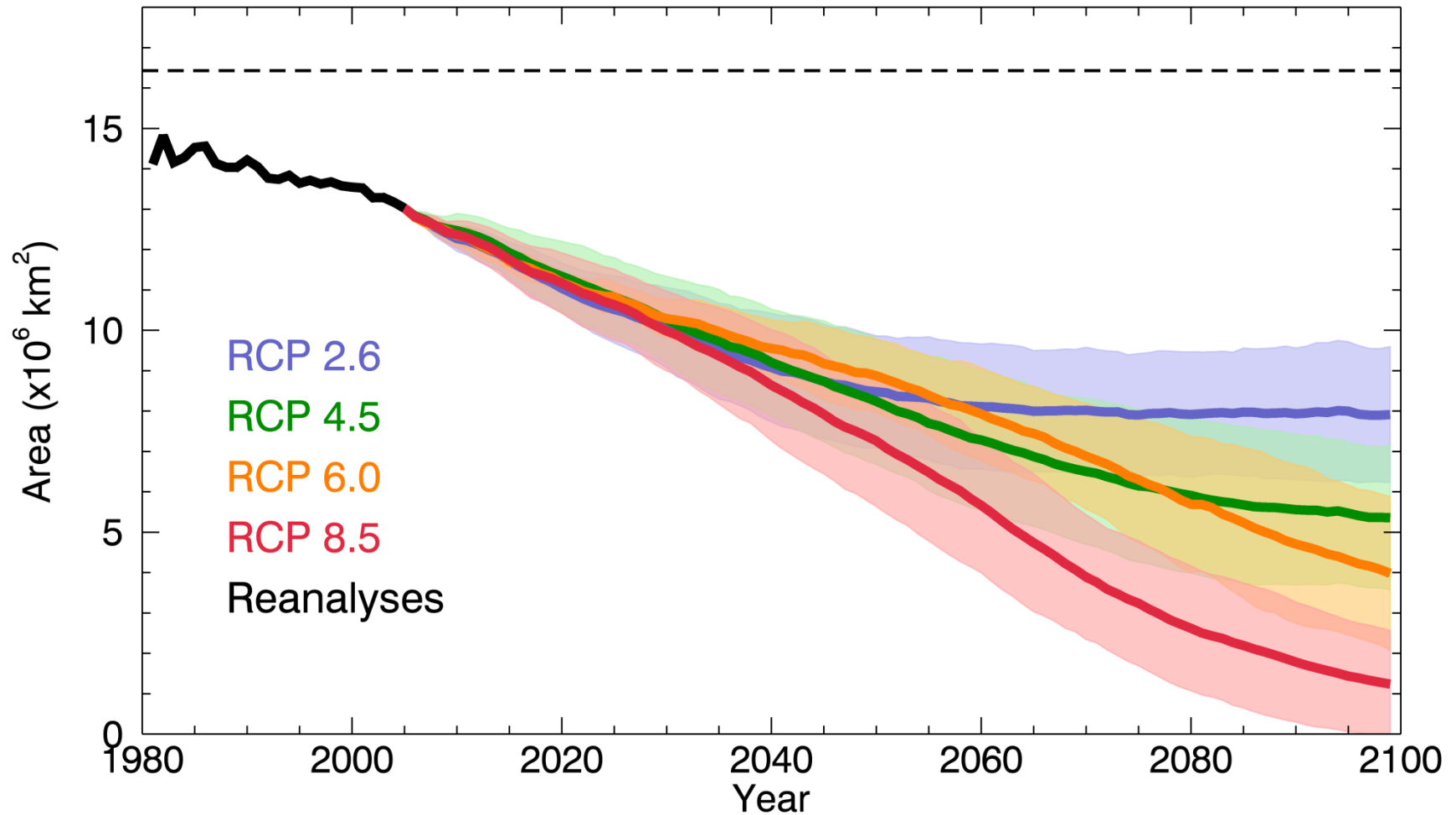


Summary

- Permafrost = f(surface climate, land model)
- Climate biases exist
 - many models cold, low snow (+permafrost)
 - CCSM4 = excess snow (-permafrost)
- Land Models are dramatically different, but
 - Consistent LSM performance in CGCMs
 - Consistent LSM influence in RCP's
- So, what will happen to permafrost?

One Estimate of Change in Permafrost Area

Permafrost Area (via Frost Index, CMIP5 Changes from Present Day)



Conclusions

- Climate warms → Permafrost degrades
- Wide range of results
- Land model plays a significant role
- Need to understand structural of LSMs
 - Assessed “coldness” of LSMs
 - Assessed sensitivity of LSMs
- Questions remain ...