Permafrost in JULES

Rutger Dankers, Eleanor Burke, Jennifer Price

JULES meeting, 12 January 2011

Met Office

A world melting from the top down

Despite years of speculation, little can be said for sure about the future of the Arctic's permafrost. But that's no grounds for complacency, reports **Gabrielle Walker**.

Some of Phil Camill's trees are drunk. Once, the black spruce trees on the plots of woodland that he monitors in northern Manitoba stood as straight and honest as pilgrims. Now an ever-increasing number of them loll about leaning like lager louts. The decline is not in the moral standards of Canadian vegetation, but in the shifting ground beneath their roots. Once it was all hard, solid permafrost. Now much of it has thawed into a soggy sponge that no longer provides a steady footing for the trees. Some contrive to grow at screwball angles; others have drowned and been replaced by floating mats of mosses or sedges. "It is really easy to tell when the permafrost has gone," says Camill. "The vegetation changes right before your eyes."

Camill, an ecologist from Carleton College in Northfield, Minnesota, has used those changes to trace the rate at which the permafrost is disappearing. In their desperate attempts to buttress themselves upright, his leaning spruces put on extra wood on the downslope side of their trunks. Counting the asymmetrical tree rings that result and measuring the distance of each tree from the current boundary of the permafrost gives a measure of the pace of change. The results are shocking. An average warming across his sites of 1.3 °C since 1970 has brought with it a trebling of the thaw rate. In some places the permafrost's perimeter is retreating by 30 centimetres a year[1]. If this trend continues, Camill estimates that no permafrost will be left in any of his five sites by the end of the century.

Thawed-out permafrost has already undermined buildings, highways and other infrastructure from Alaska to Siberia. The damage is one of the most visible effects of warming temperatures on human activities. But the effects on natural systems are to some extent more worrying. Buildings can be rebuilt, asphalt relaid and agricultural practices changed through adaptation, given the right policies and priorities (see page 716). But changes in the vegetation and, crucially, in the soils of the frozen northern landscapes might not be so easy to cope with. The soils of the Arctic are crammed with organic matter — a frozen reservoir of beautifully preserved roots, leaves and other raw material that may contain as much carbon as the whole atmosphere. They are quite unlike soils from more temperate regions, which are mostly made up of the parts that the bacteria cannot digest. "We are unplugging the refrigerator in the far north," says Camill. "Everything that is preserved there is going to start to rot."

For decades environmentalists have worried about the possibility of this great putrefaction. It has become perhaps the most cited example of the biogeochemical feedback that could drastically worsen the effects of anthropogenic climate change. The idea is that humans increase levels of carbon dioxide in the atmosphere, w
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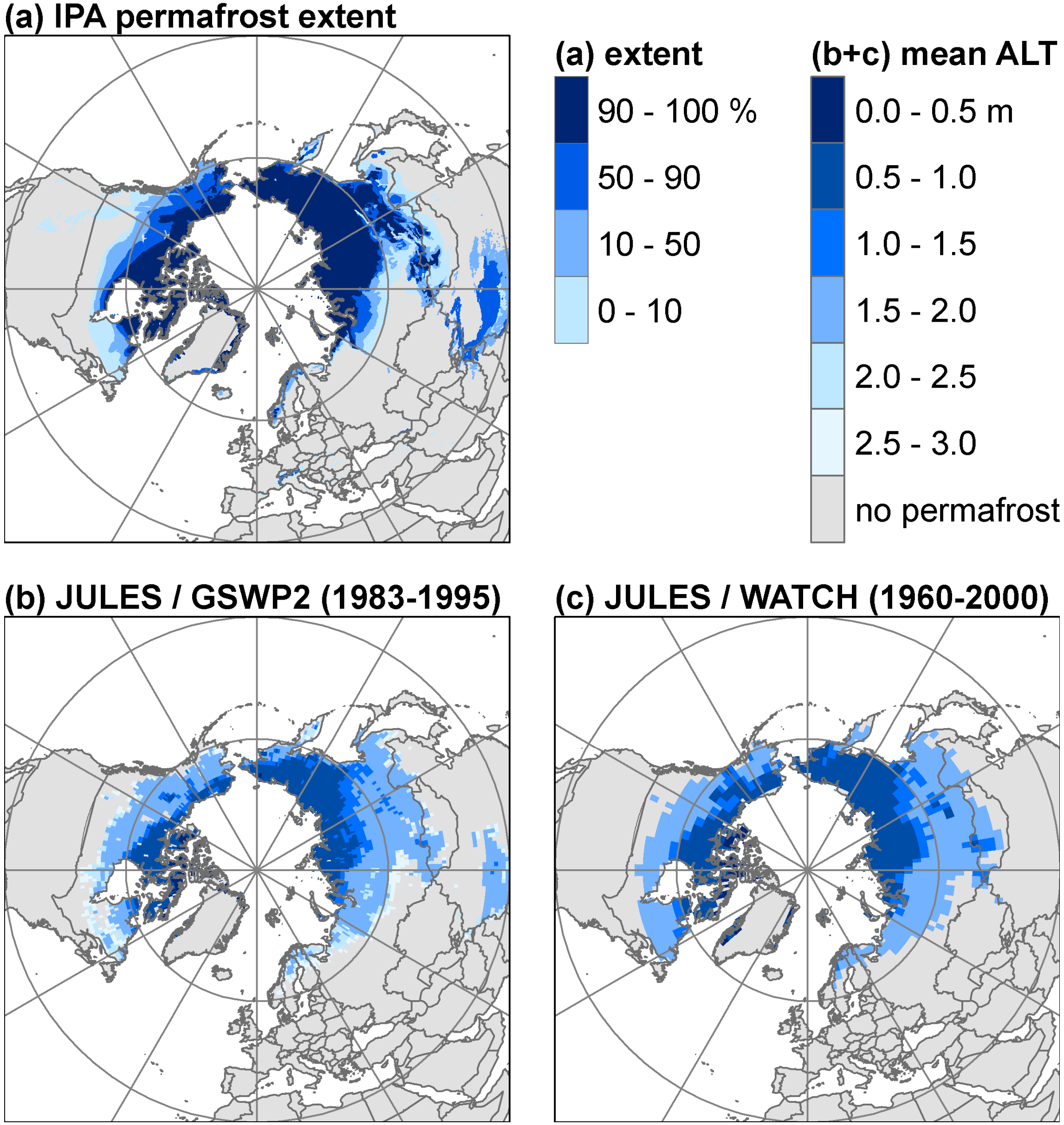
> **"We are unplugging the refrigerator in the far north. Everything that is preserved there is going to start to rot."**
> — Phil Camill

Permafrost in JULES

- Evaluating JULES for simulating large-scale permafrost characteristics
- NH grid runs, standard setup:
  - GSWP2: 1983-1995, 1×1 degree
  - WATCH: 1958-2000, 2×2 degree

Spatial extent



Spatial extent

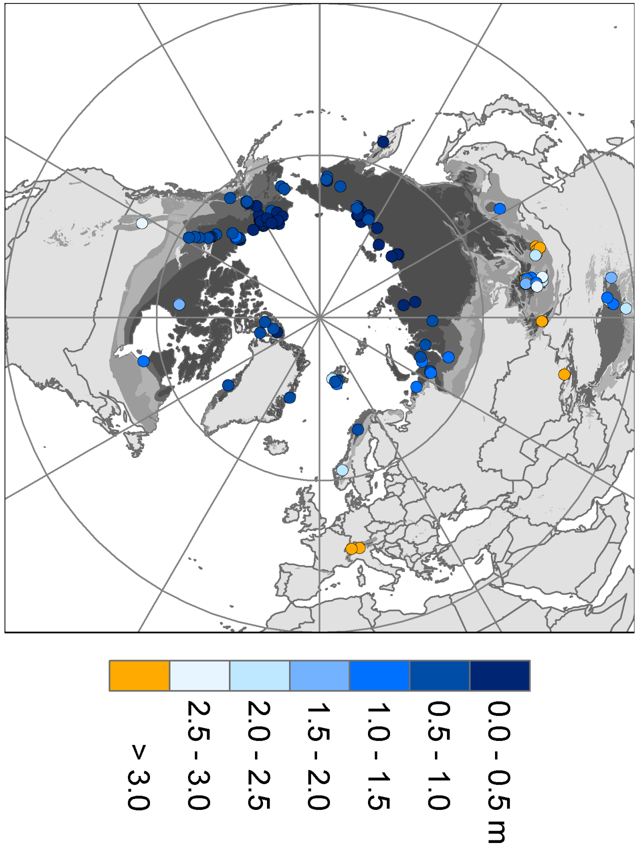
Table 4: Cross-tabulation of permafrost extent classes in the IPA permafrost map (Brown et al., 1998) and JULES mean ALT classes in the GSWP2 run (1983–1995). Values are in million km^2.

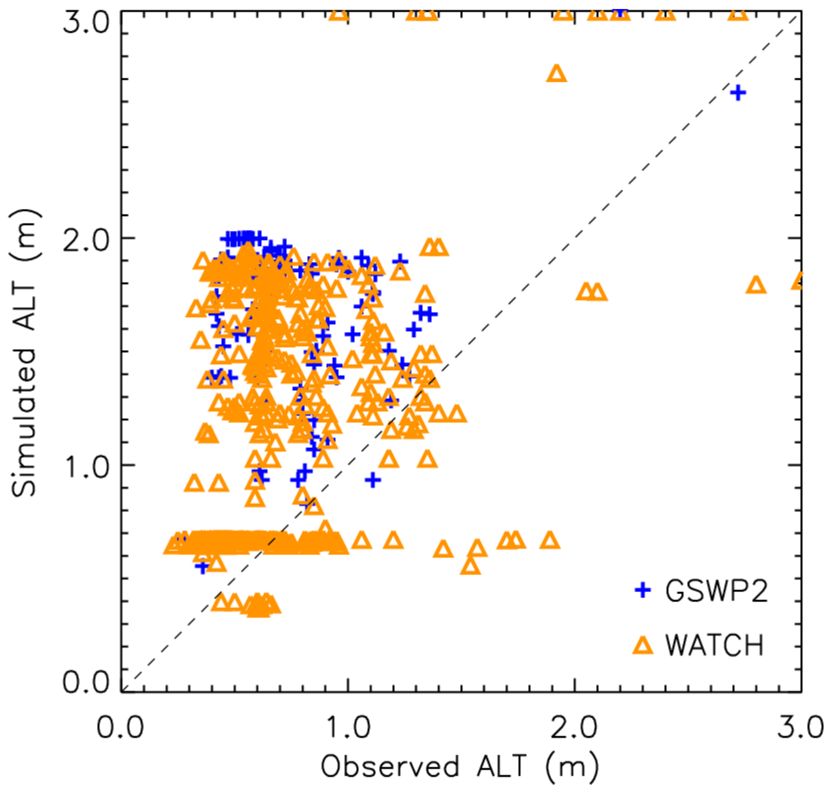
IPA extent	JULES mean ALT (cm)							
	< 50	< 100	< 150	< 200	< 250	< 300	no permafr.	**total**
no permafrost	0.22	0.72	0.80	1.54	2.00	3.05		
isolated	0.00	0.00	0.01	1.41	1.85	2.37	1.41	**3.78**
sporadic	0.00	0.00	0.01	2.49	2.87	3.17	0.69	**3.87**
discontinuous	0.00	0.01	0.17	3.42	3.64	3.72	0.46	**4.19**
continuous	0.36	4.99	6.92	9.70	9.79	9.84	0.01	**9.86**
total	**0.59**	**5.73**	**7.92**	**18.56**	**20.16**	**22.16**	**2.58**	**21.69**
discontinuous + continuous	*0.36*	*5.01*	*7.10*	*13.12*	*13.43*	*13.57*	*0.48*	*14.04*
isolated + sporadic	*0.00*	*0.00*	*0.02*	*3.90*	*4.73*	*5.55*	*2.10*	*7.65*
isolated + sporadic + no permafr.	*0.22*	*0.72*	*0.82*	*5.44*	*6.73*	*8.60*	*2.10*	

- JULES captures ~97% of area underlain with discontinuous and continuous permafrost
- … but overestimates total extent:
  - 25% is isolated/sporadic permafrost in IPA map
  - 14% has no permafrost in IPA map

Active Layer Thickness

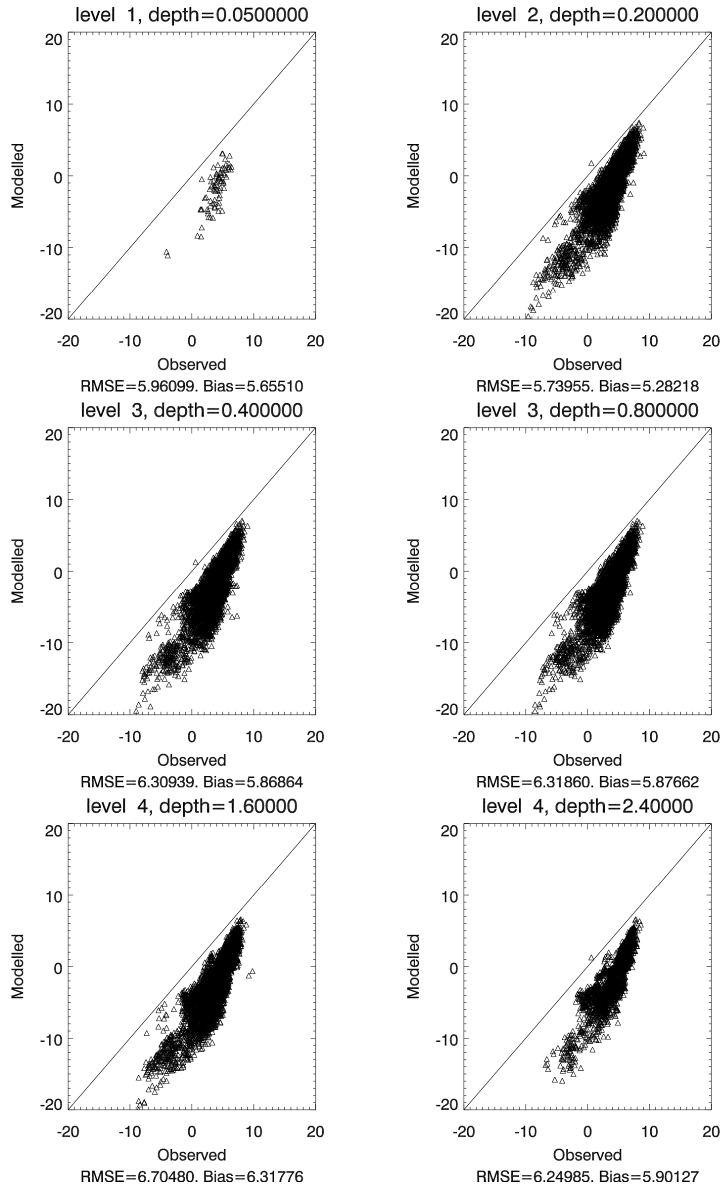
- Observed end-of-season thaw depth at CALM sites
  - Since 1990, i.e. limited overlap with model runs:
  - GSWP2: until 1995, WATCH: until 2000





Soil Temperatures

- Mean annual soil temperature
- Observations at Russian meteorological stations
- Simulations from WATCH run (1958-2000)



Soil Temperatures

- Monthly soil temperatures
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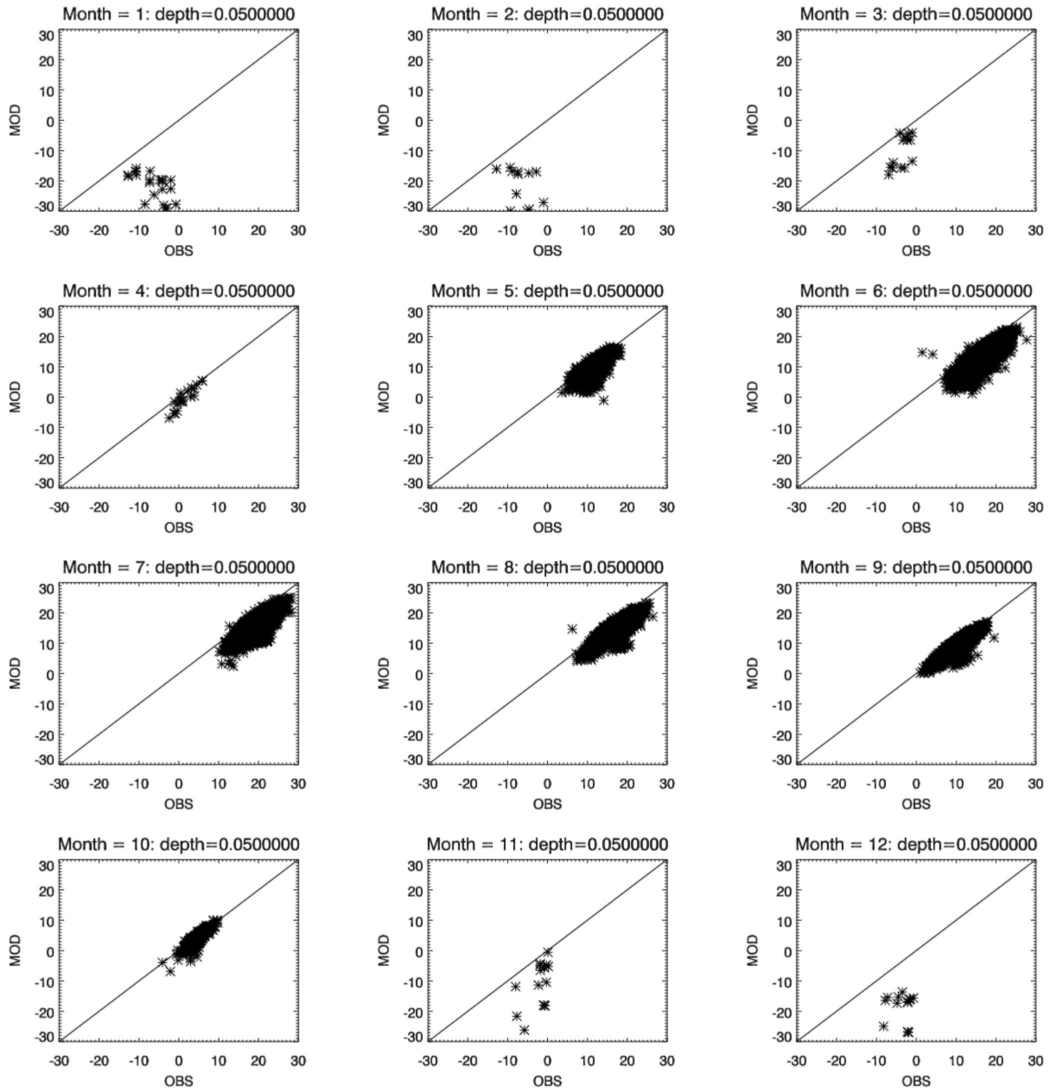
- Simulations from WATCH run (1958-2000)
- **Top soil (0-10 cm)**



Soil Temperatures

- Monthly soil temperatures
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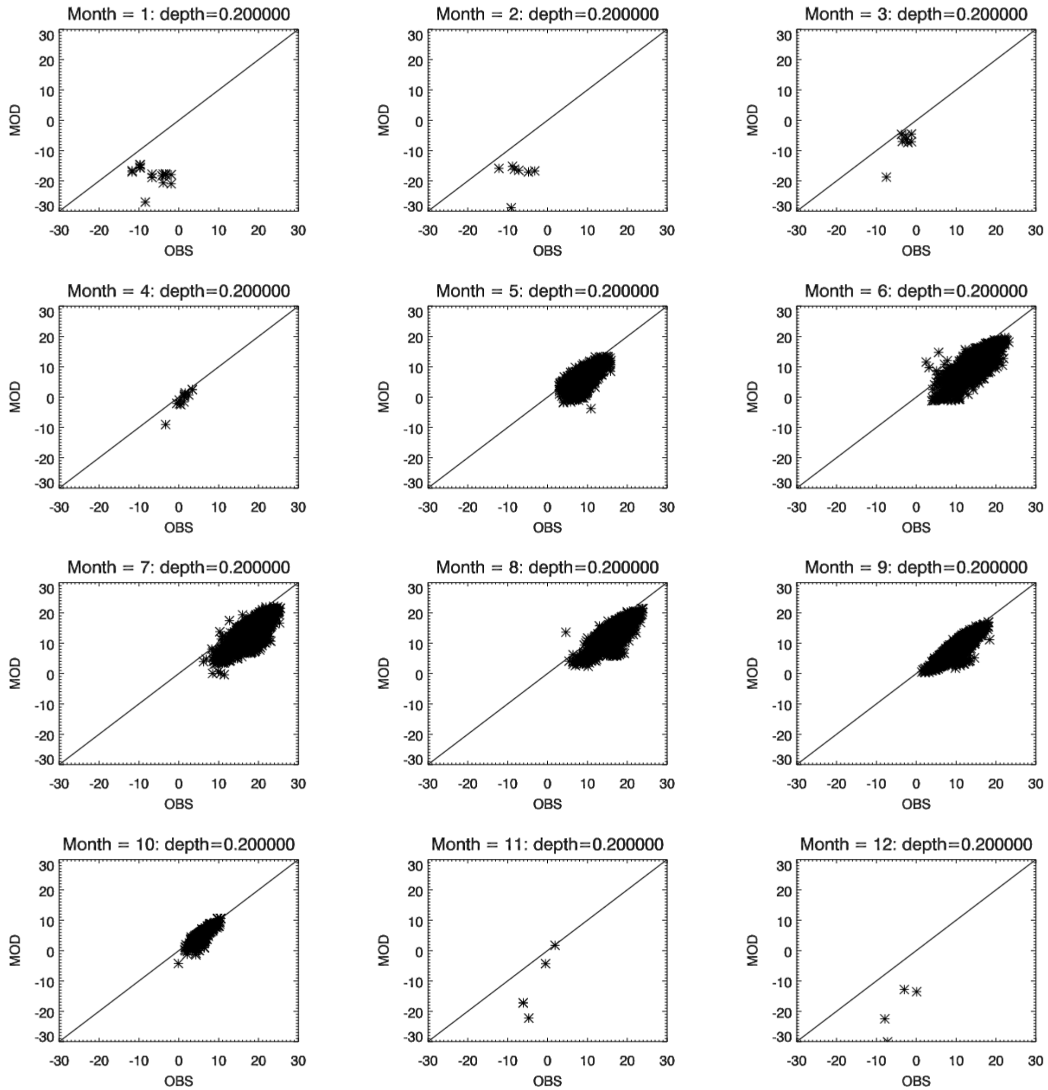
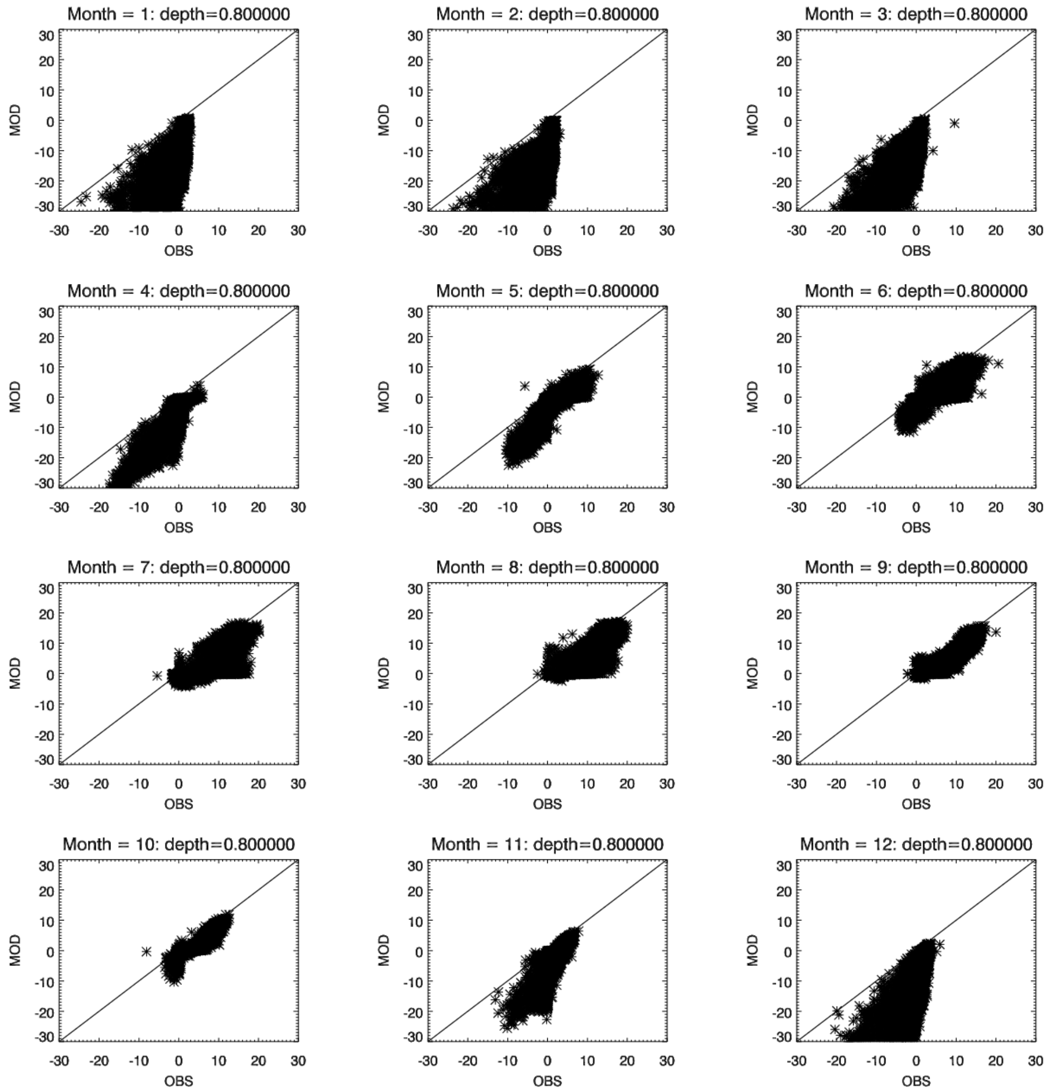
- Simulations from WATCH run (1958-2000)
- **Sub soil (10-35 cm)**



Soil Temperatures

- Monthly soil temperatures
- Observations at Russian meteorological stations
- Simulations from WATCH run (1958-2000)
- **Deep soil (35-100 cm)**



Soil Temperatures

- Monthly soil temperatures
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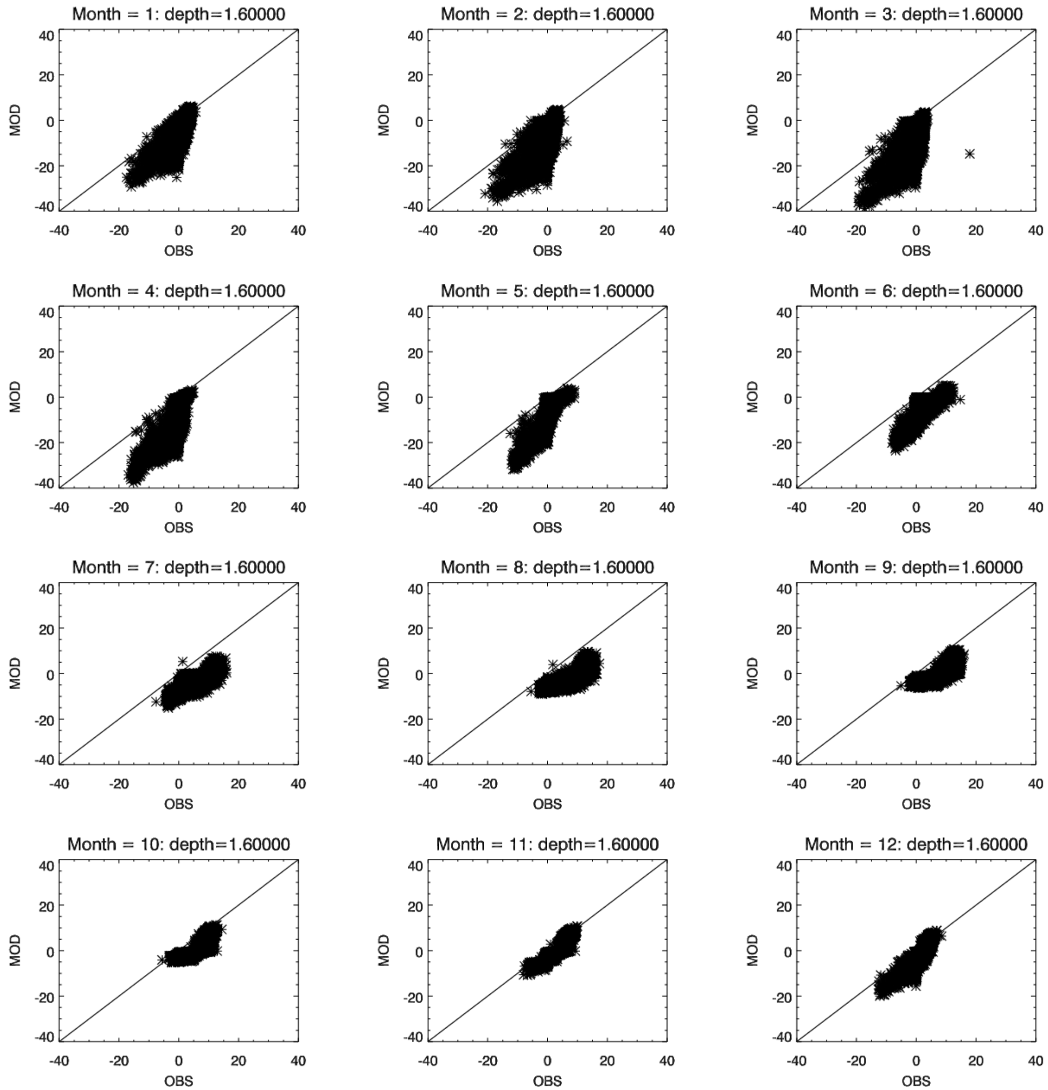
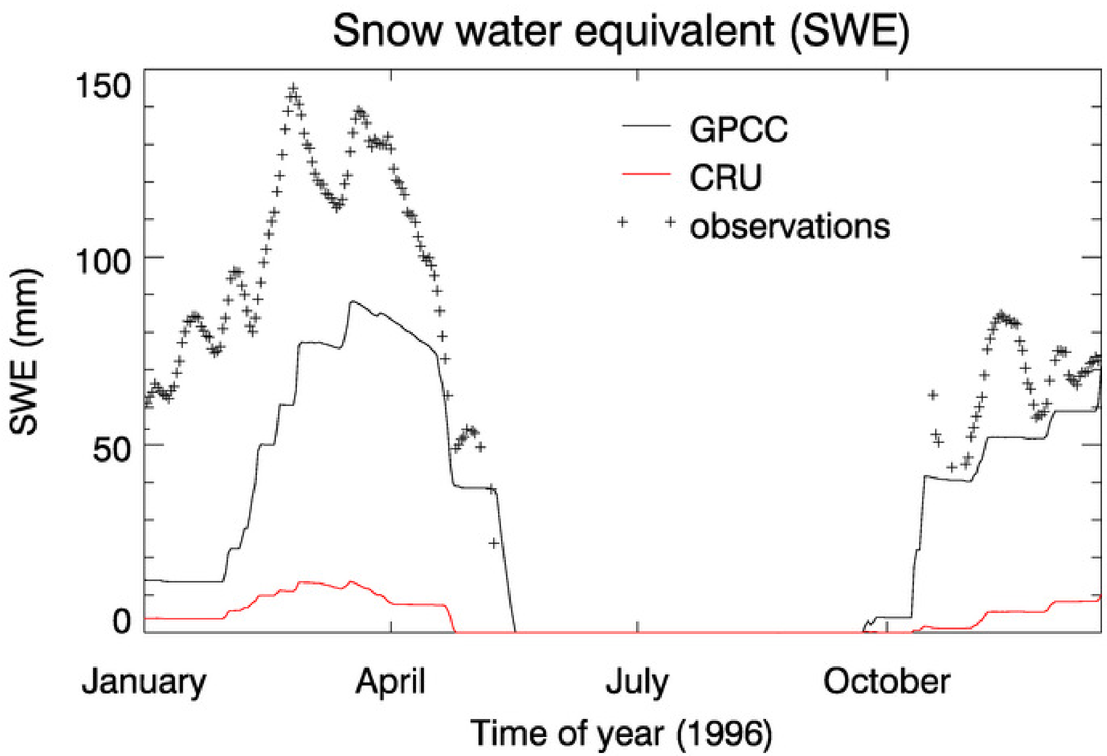
- **Deep soil (100-300 cm)**



Why cold bias?

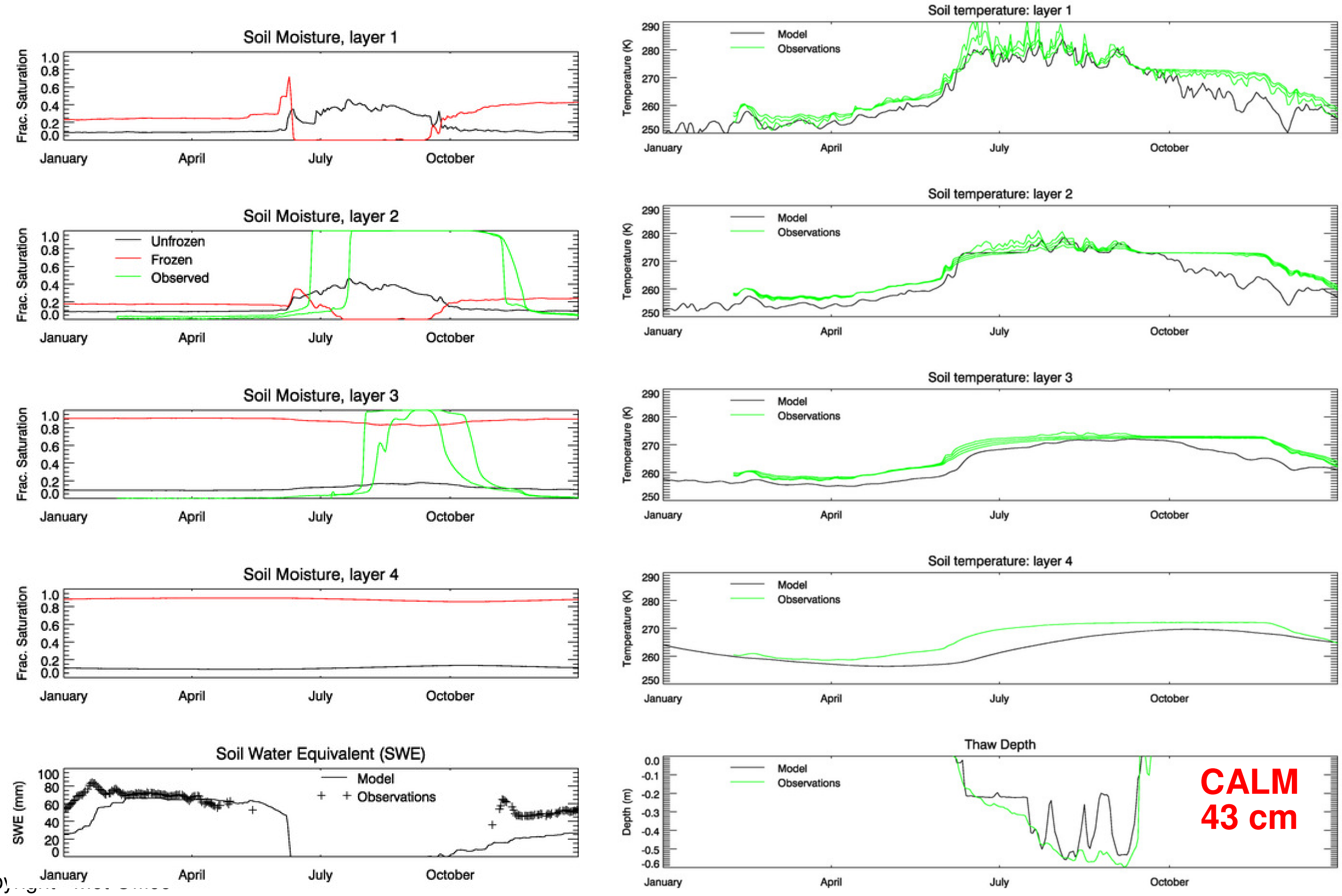
1. Uncertainties in precipitation input
   → snow thickness

- Bonanza Creek, 1996



Why cold bias?

2. Soil moisture dynamics / runoff



Atqasuk, 2000

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- Evaluating JULES for simulating large-scale permafrost characteristics
- NH grid runs, standard setup:
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- Modifying JULES for simulating permafrost under climate change
  - Modified soil parameters for organic soils
  - Represent deep permafrost 'heat sink'

Organic soil parameters

- Final soil parameters linear combination of mineral and organic soil parameters *according to organic fraction*
- Similar approach as in e.g. CLM (Lawrence & Slater, 2008)

Tarnocai et al. (2009) top soil (0-30 cm) SOC

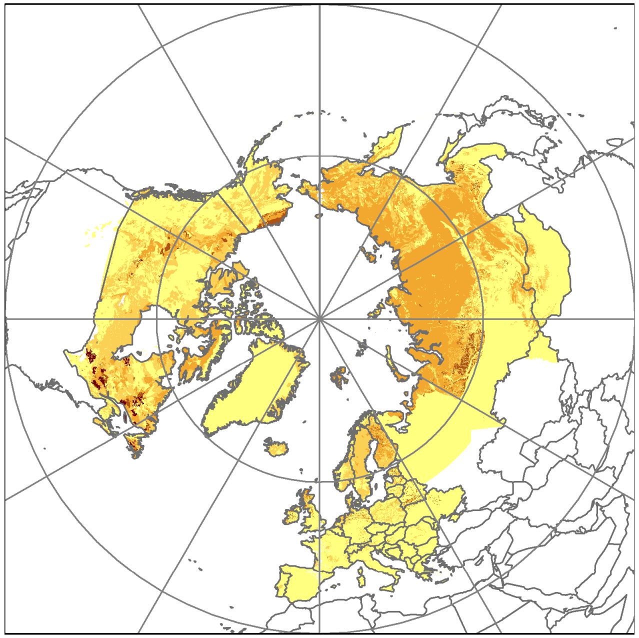


Table 2: Parameters for organic soil used in the SOC experiment. For explanation of the parameters and units, see Table 1.

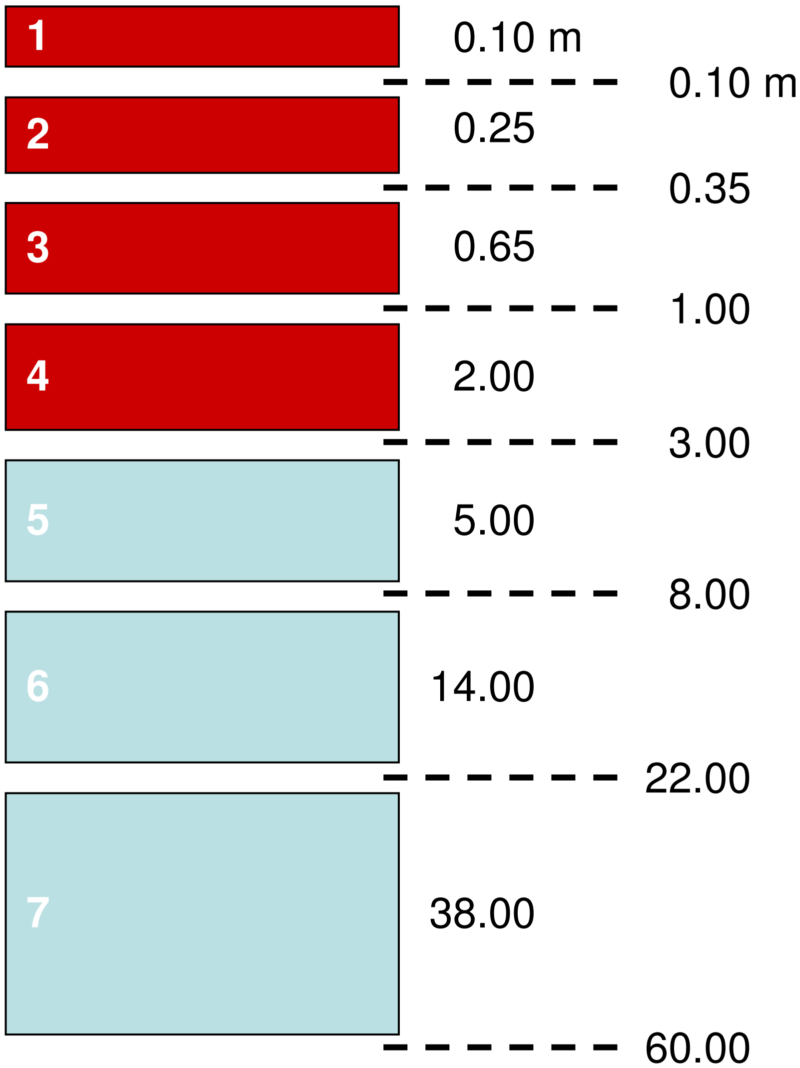
Parameter	Top layer 0–10 cm	Layer 2 10–35 cm	Layer 3 35–100 cm	Source
b	2.7	6.1	12.0	Letts et al. (2000)
Ψ_s	0.0103	0.0102	0.0101	Letts et al. (2000)
K_s	0.28	0.002	0.0001	Letts et al. (2000)
θ_s	0.93	0.88	0.83	Letts et al. (2000)
θ_c	0.11	0.34	0.51	[a]
θ_w	0.03	0.18	0.37	[a]
c	0.58E+06	0.58E+06	0.58E+06	Oke (1987)[b]
λ	0.06	0.06	0.06	Oke (1987)[b]

[a] estimated following Cosby et al. (1984)
[b] based on Van Wijk and De Vries (1963)

Source: C. Tarnocai et al., 'Soil organic carbon pools in the northern circumpolar permafrost region', GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 23, GB2023, doi:10.1029/2008GB003327, 2009

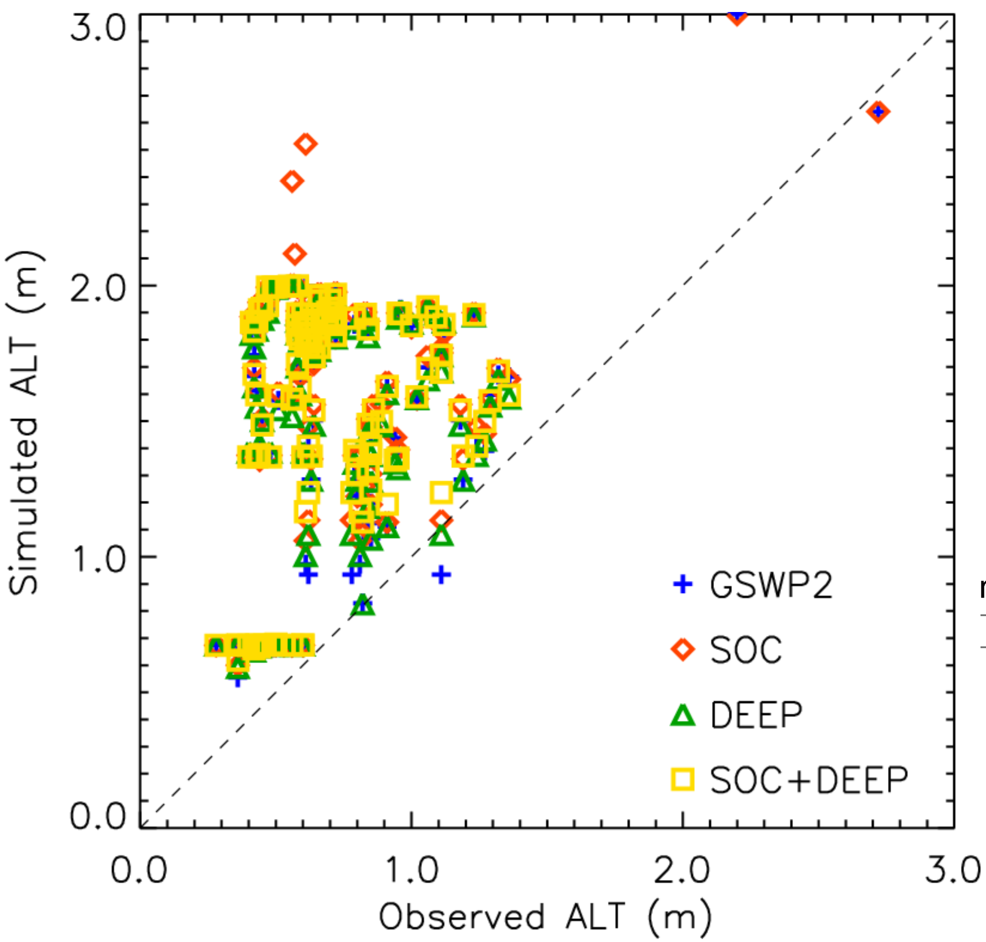
Deep permafrost

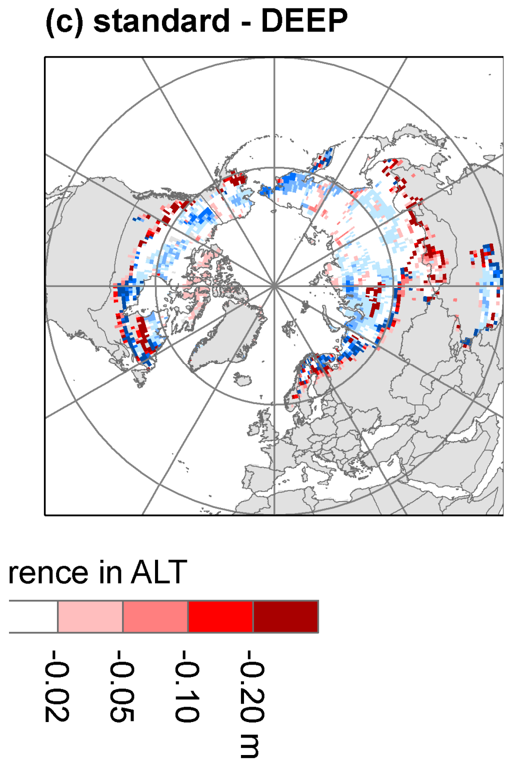
- Aim is not a realistic simulation of deeper soil temperatures
  - Lack of information on sub-surface variability
- Rather, provide additional heat sink for response of upper soil layers to warming



Impact on ALT

- Relatively small impact on ALT in GSWP2 run





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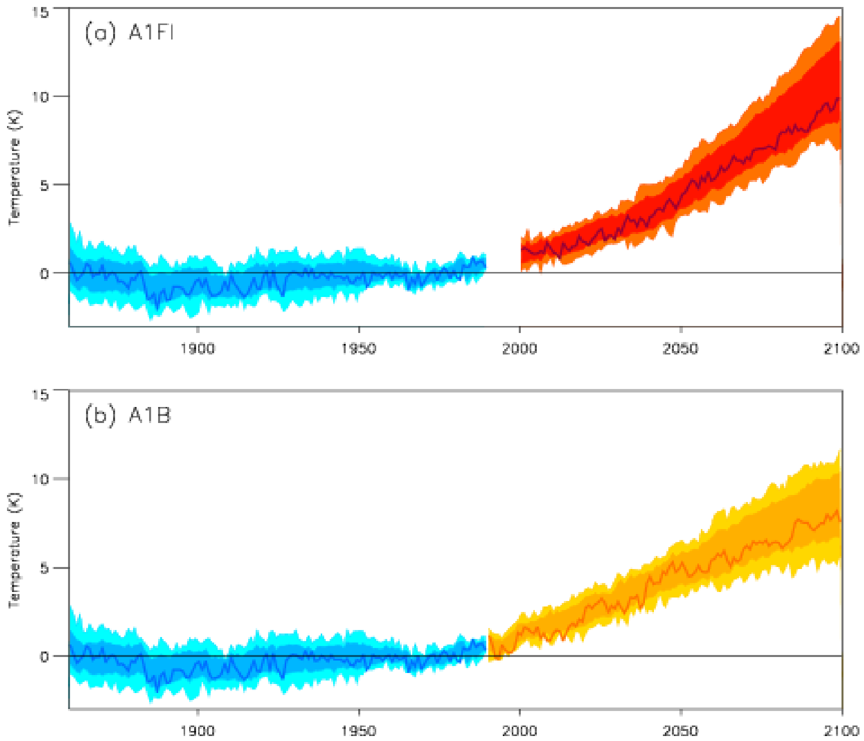
- Future climate runs

Future climate runs

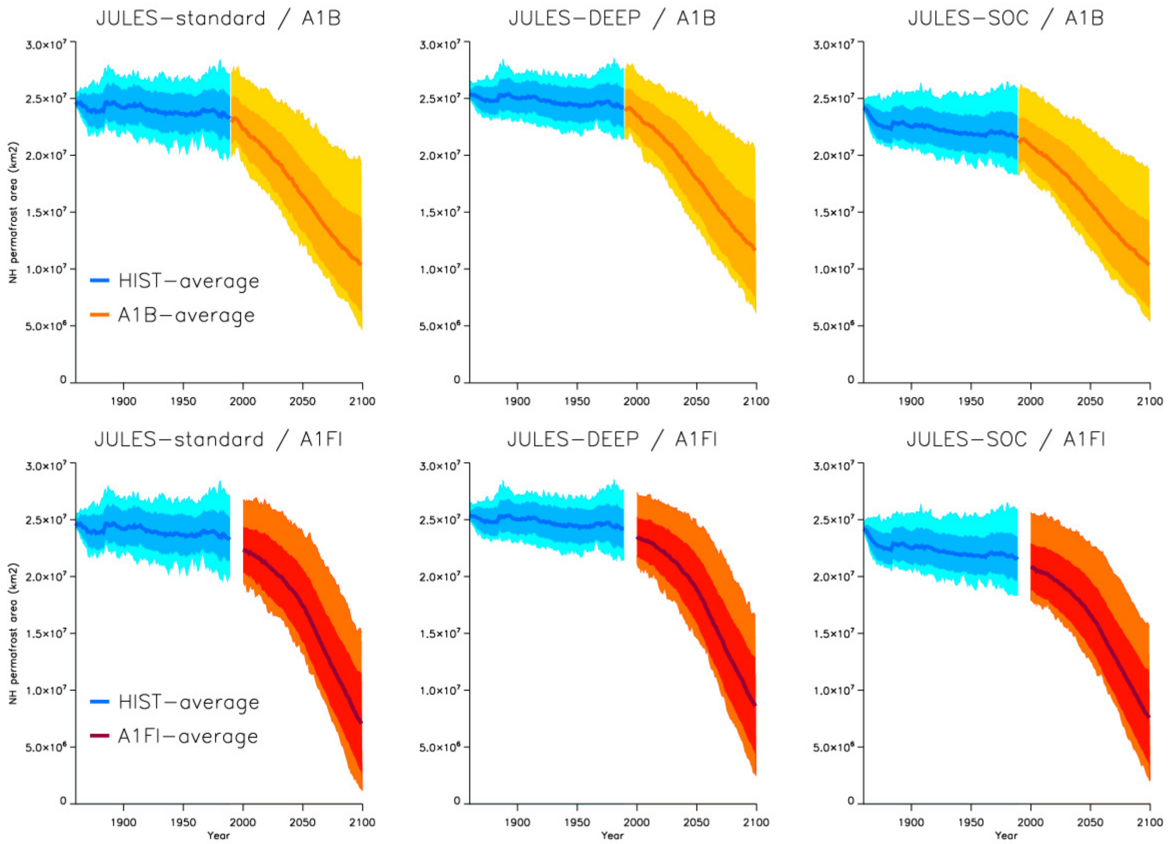
- Driven by probabilistic climate scenarios from HadCM3 QUMP ensemble *(Collins et al., 2010)*
    - 17 member perturbed physics ensemble
    - 2 scenarios (A1B, A1FI), 1860-2100
    - 2.5º x 3.75º grid



Mean annual temperature change north of 60ºN relative to 1960-89

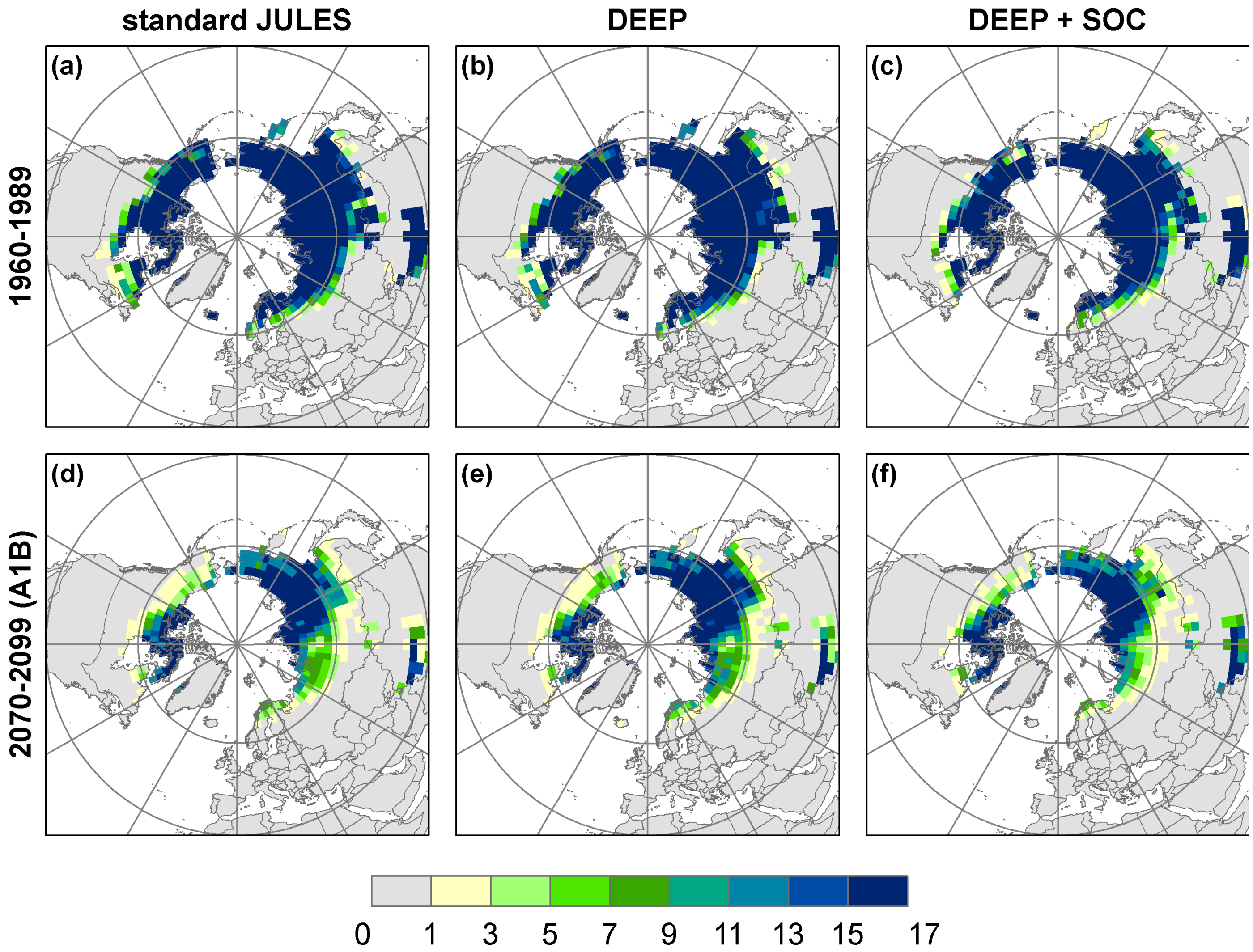
Future climate runs

- Surface permafrost projected to disappear
  - A1B: ~ 45% (20-60%) of current area
  - A1FI: ~ 60% (35-85%)



Future climate runs

- Probability of permafrost occurrence



Some conclusions…

- JULES simulates permafrost where it is known to occur…
- … but appears to overestimate total extent
- Overestimation of observed ALT…
- … but soil temperatures appear to be generally too cold (although least so in summer/autumn)
  - Precip input / snow depth highly uncertain
  - Soil moisture / runoff treatment
  - Very few observations available!

Some conclusions…

- Organic soil parameterisation + representation of deep permafrost heat sink
  - Relatively small impact on ALT
  - Counteract each other in many places
  - Slows down response to warming to some extent, but does not change overall pattern
- Future climate simulations suggest general decline in surface permafrost area

The future?

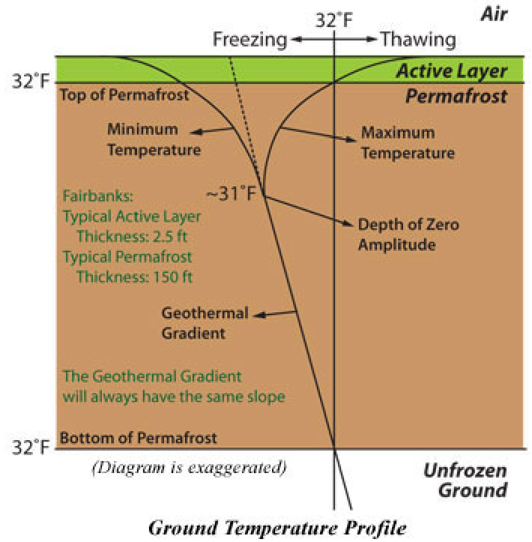
- Better understand cold bias in soil temperature
  - Snow → input issue?
  - Parameter values?
  - Point observations *vs* grid simulation?
- Dynamic soil carbon affecting soil properties?
- Sub-grid variability in soil properties / tiling?
- Higher vertical resolution for better representation of thawing front?
- … ?

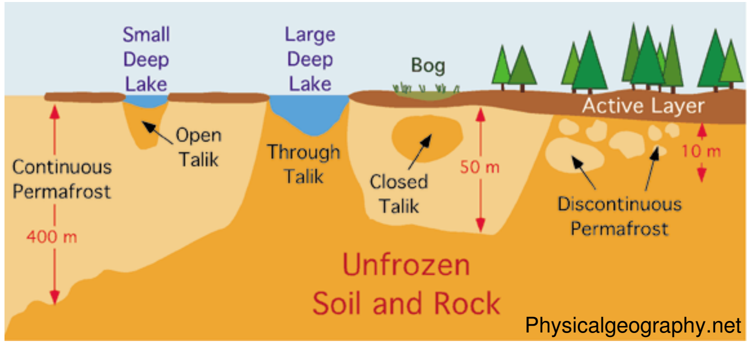
Thanks!

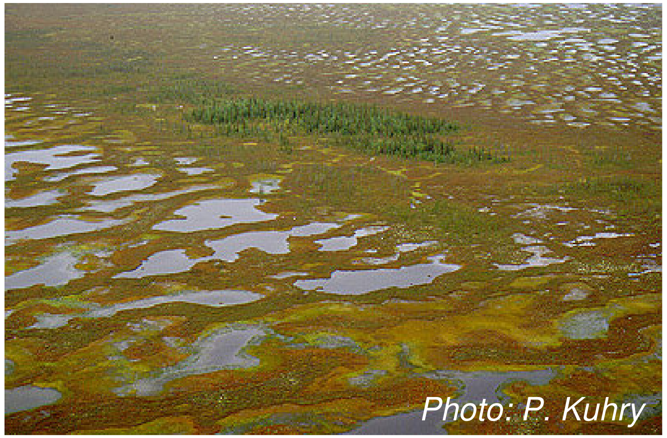
FCO Strategic Programme Fund, Joint DECC/Defra Met Office Hadley Centre Climate Programme, Andy Wiltshire, Doug Clark, Richard Essery, Matt Pryor…

Permafrost???

- By definition, soil that is below 0ºC for two consecutive years or more
- Permafrost layer can be 100s of m deep and 1000s of years old
- Recent estimates of total carbon store: 1672 Gt (Schuur et al., 2008) (i.e. twice atmospheric carbon pool)



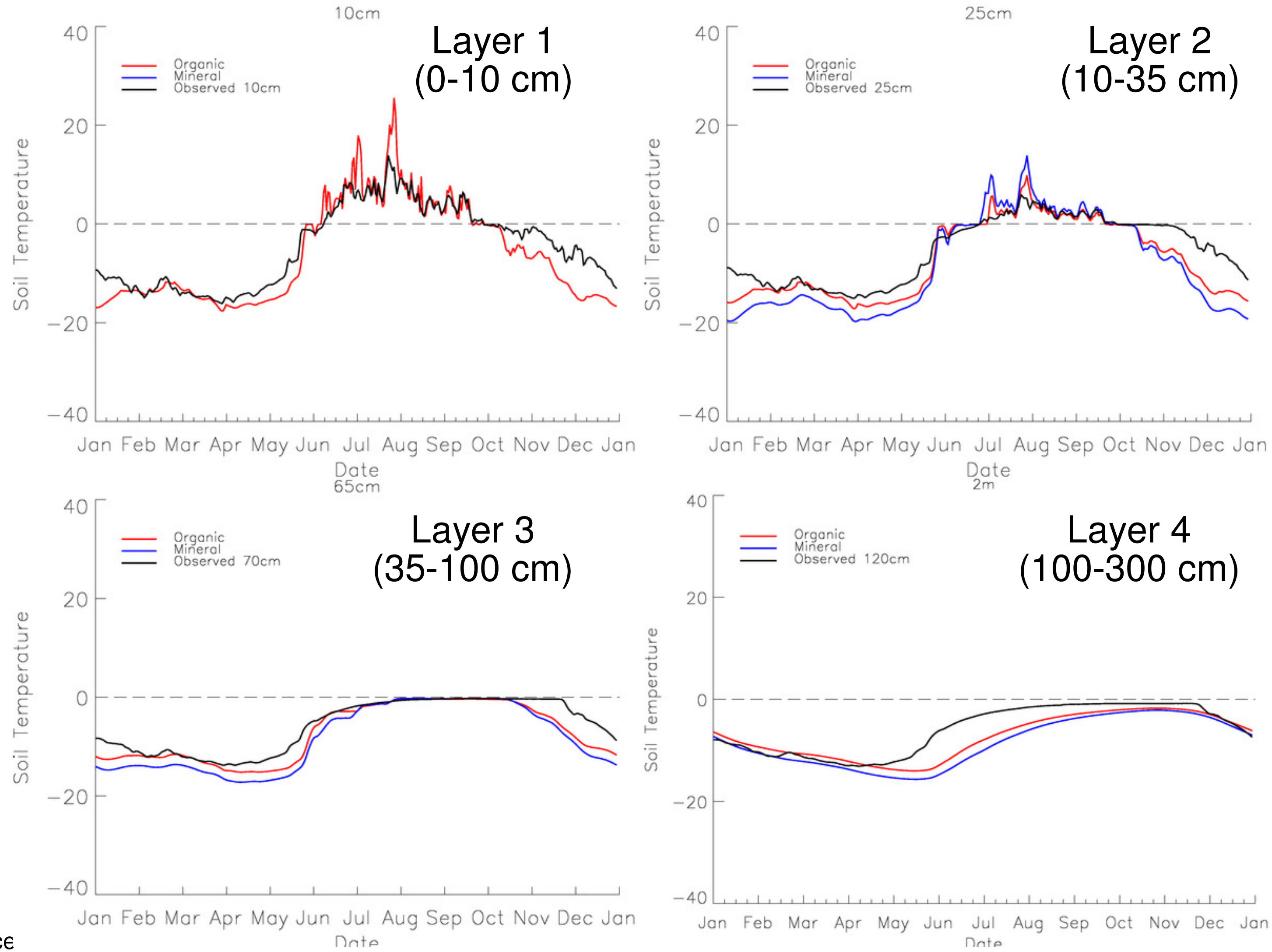




Permafrost in JULES

Met Office

- Point simulation for Atqasuk, Alaska



NB precipitation input corrected for snow undercatch