A Warming Greenland Ice Sheet: Temperature Uncertainties in Low (1.5 °C) and High (RCP 8.5) Warming Worlds (Getting at Future Surface Melting)

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EARTH AND ENVIRONMENTAL SCIENCE

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Motivation

- Future warming & ice-sheet surface melting!
  - Identifying atmospheric drivers of melting
  - Making predictions with uncertainties

- Society has choices about future emissions
  - What does “high” warming look like?
  - How about “low” warming? Worth trying for?

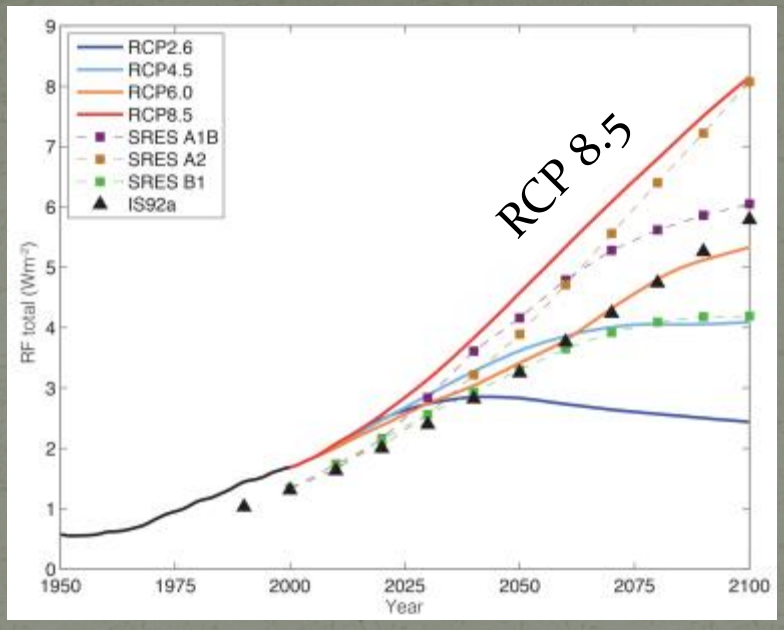
Specific Questions

- How do a reanalysis and GCM compare to observations?
- What does the GCM predict for two future warming scenarios ("High", "Low")?
- How does Polar WRF change these conclusions?
- What does future surface melting look like?

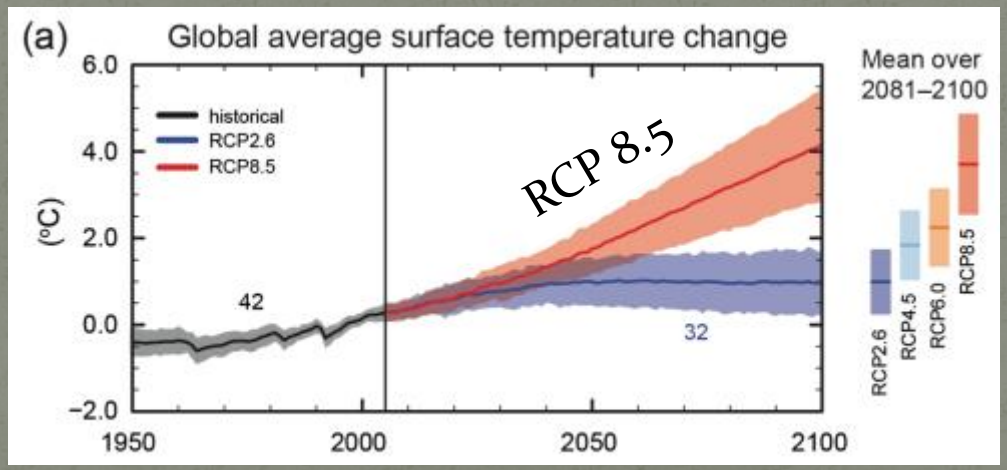
"High" Warming Scenario: RCP 8.5

van Vurren et al 2011, Climatic Change, 10.1007/s10584-011-0148-z

Nice primer on the RCPs



Radiative Forcing Trajectories



Global Average Temperatures

http://www.ipcc.ch/report/graphics

CESM Large Ensemble (LE), 2014

- NCAR project to look at internal model variability via small perturbations of the initial atmospheric state
- 30+ ensemble members, 1920-2100
  - Historical (1981-2000; 1996-2005)
  - RCP 8.5 (2081-2100; 2071-2080)

CESM LE fine print:

- CESM1(CAM5) Large Ensemble Community Project and supercomputing resources provided by NSF/CISL/Yellowstone.
- Kay, J. E., et al, The Community Earth System Model (CESM) Large Ensemble Project: A Community Resource for Studying Climate Change in the Presence of Internal Climate Variability, Bulletin of the American Meteorological Society, doi: 10.1175/BAMS-D-13-00255.1, 2014.

2015 Paris Climate Agreement

The Paris Agreement's central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius.

http://unfccc.int/paris_agreement/items/9485.php

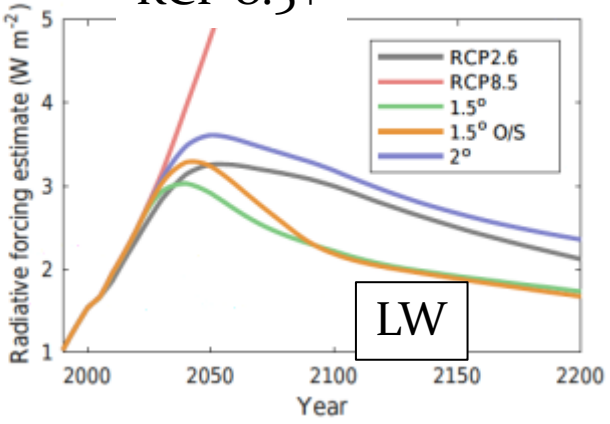
Hawkins et al, BAMS, 2017: may have hit +1° in 2015

CESM Low Warming (LW) Ensemble

- Sanderson et al 2017
  - Use simple climate emulator to find emissions parameters satisfying a given target temperature
  - Produce new concentration pathways, run full GCM
  - Eleven ensemble members, 2006-2100

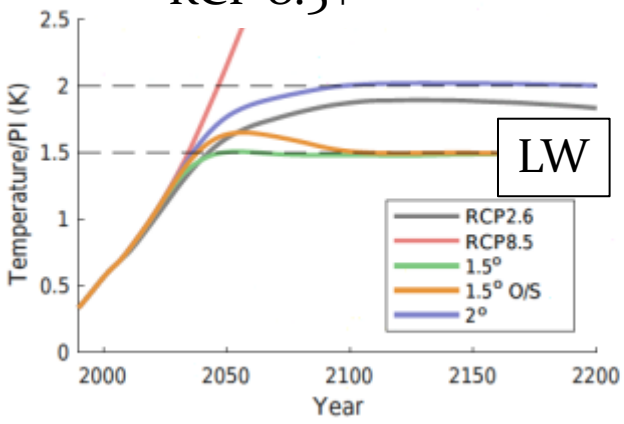
Radiative Forcing Trajectories

RCP 8.5↑



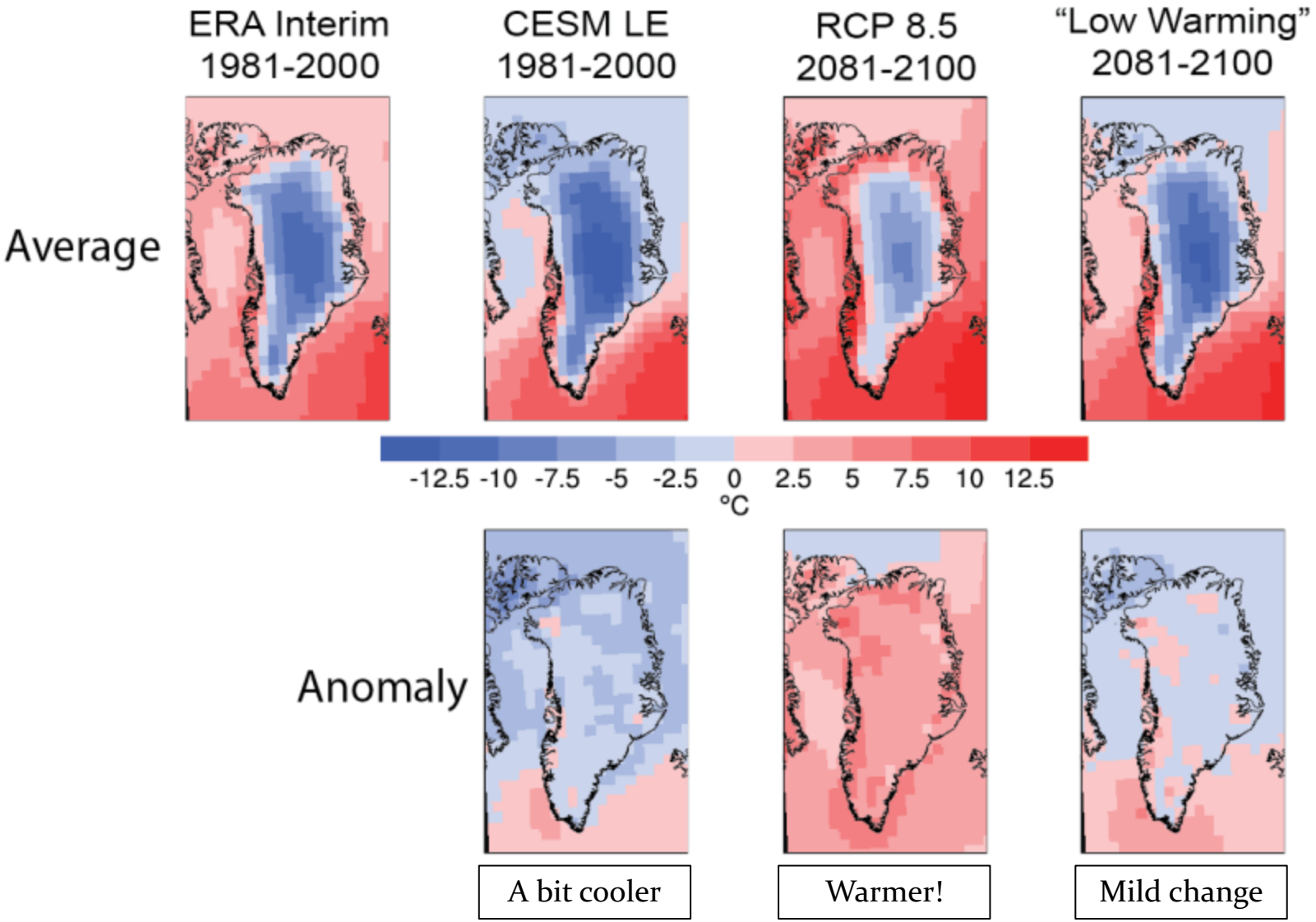
Global Average Temperatures

RCP 8.5↑



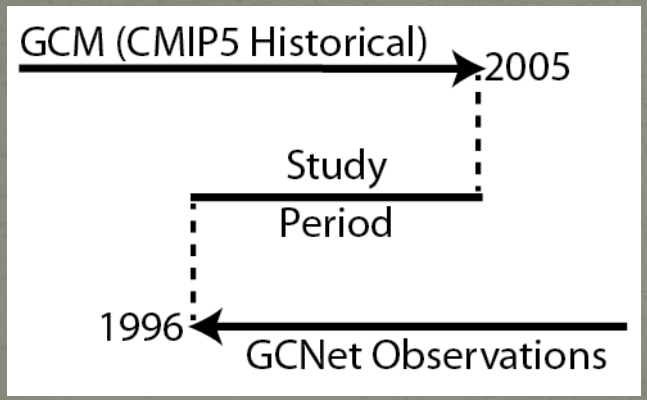
CESM Ensembles vs ERA Interim

July Daily Average Near-surface Temperature



Model Skill Testing: GCNet AWS Sites

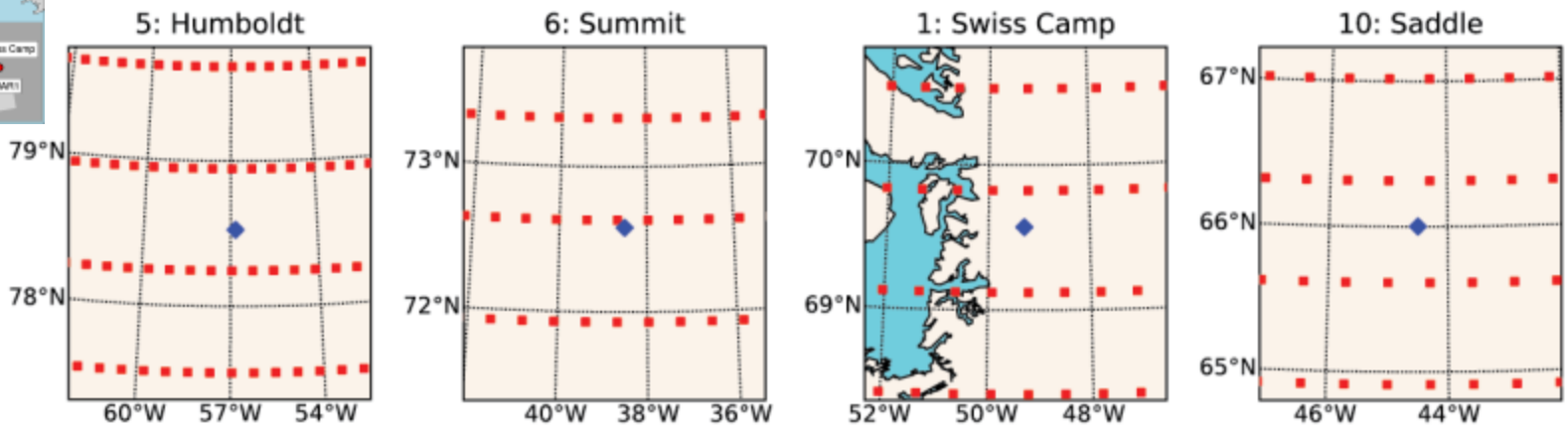
- 23 stations all time (1996 to present)
- 11 with > 50% data for the 1996-2005 decade



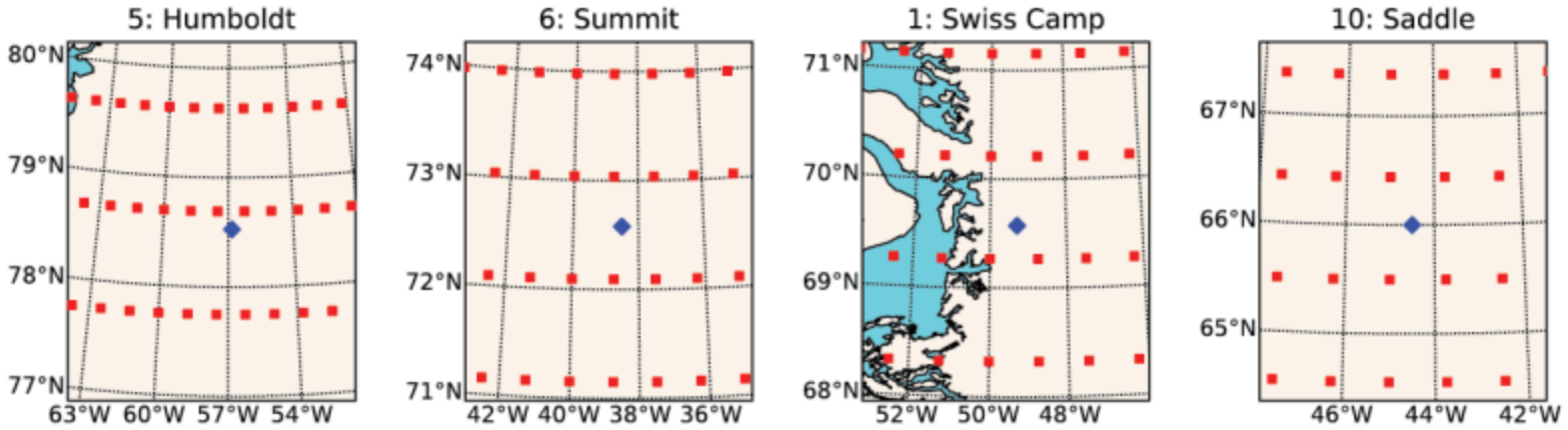
http://cires1.colorado.edu/science/groups/steffen//gcnet/

AWS vs Model Grids

ERAI



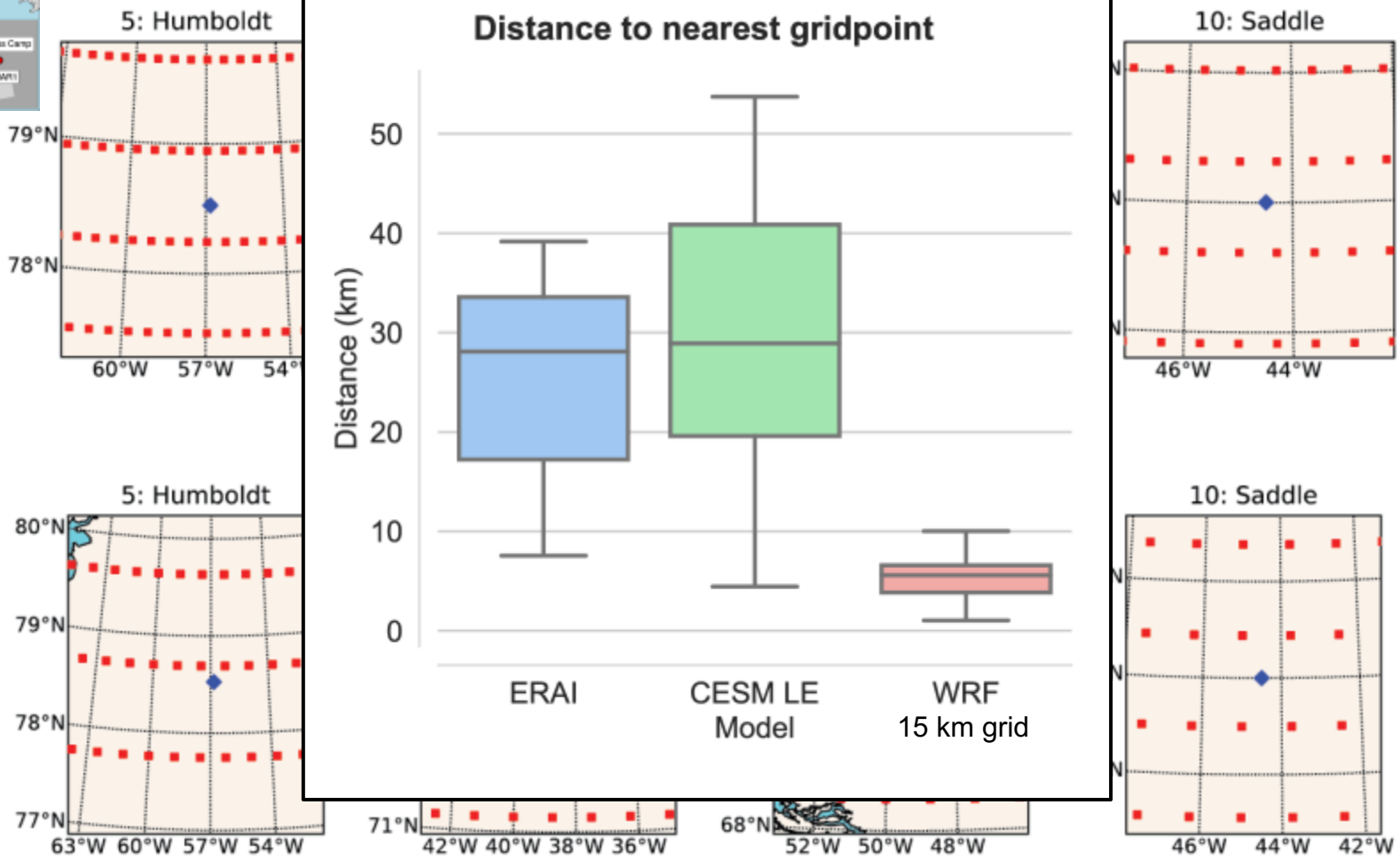
CESM

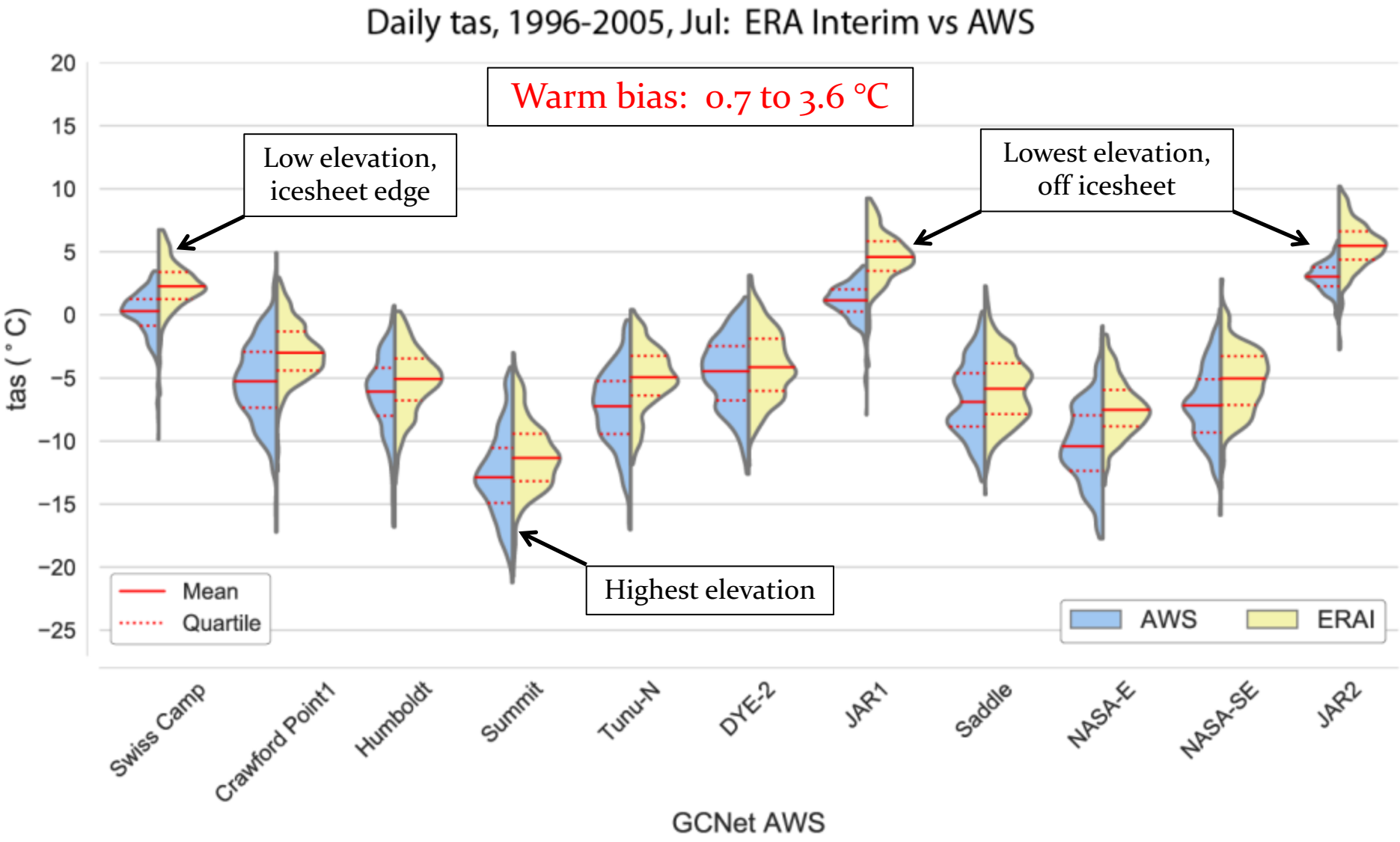


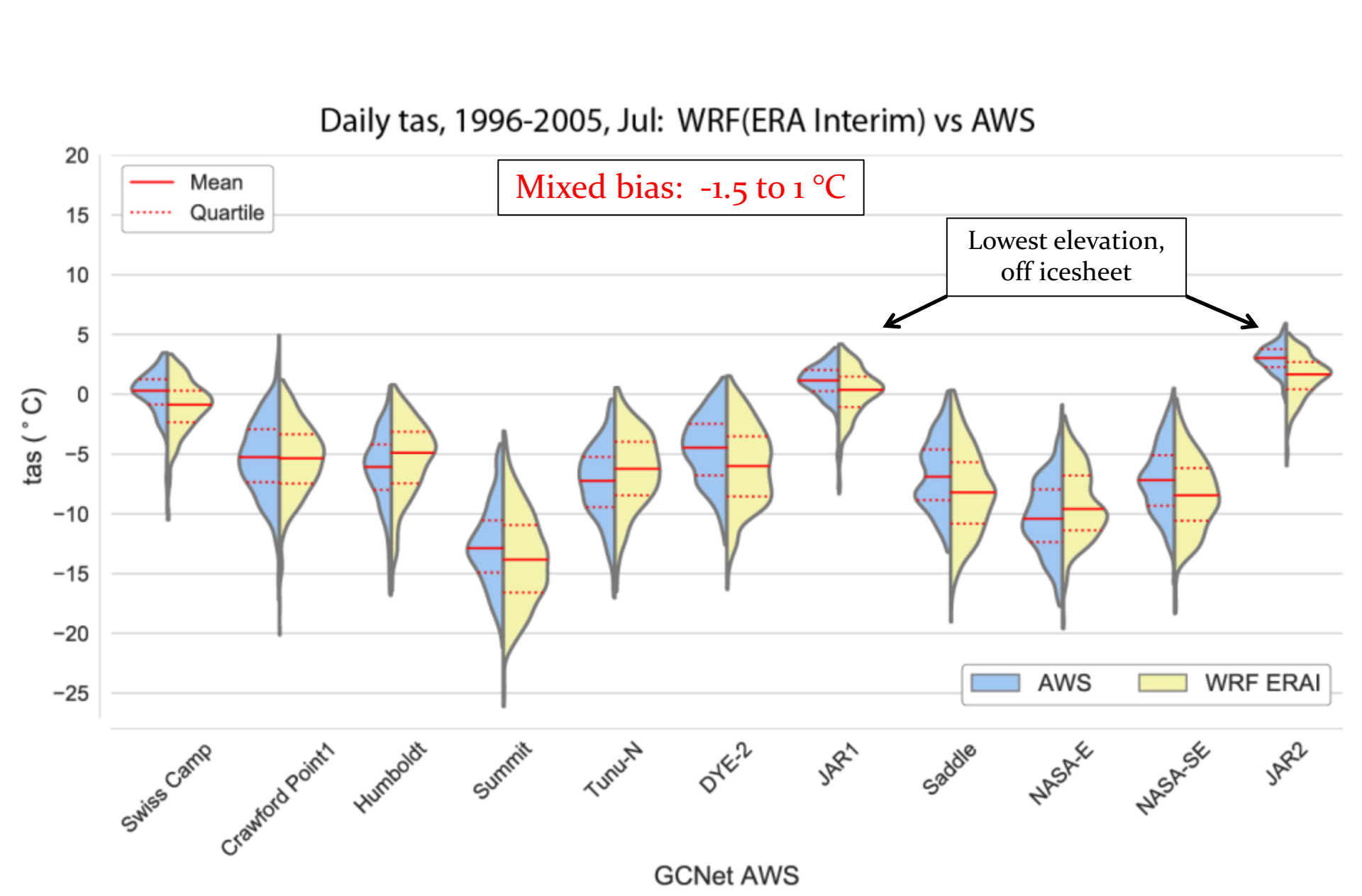
AWS vs Model Grids

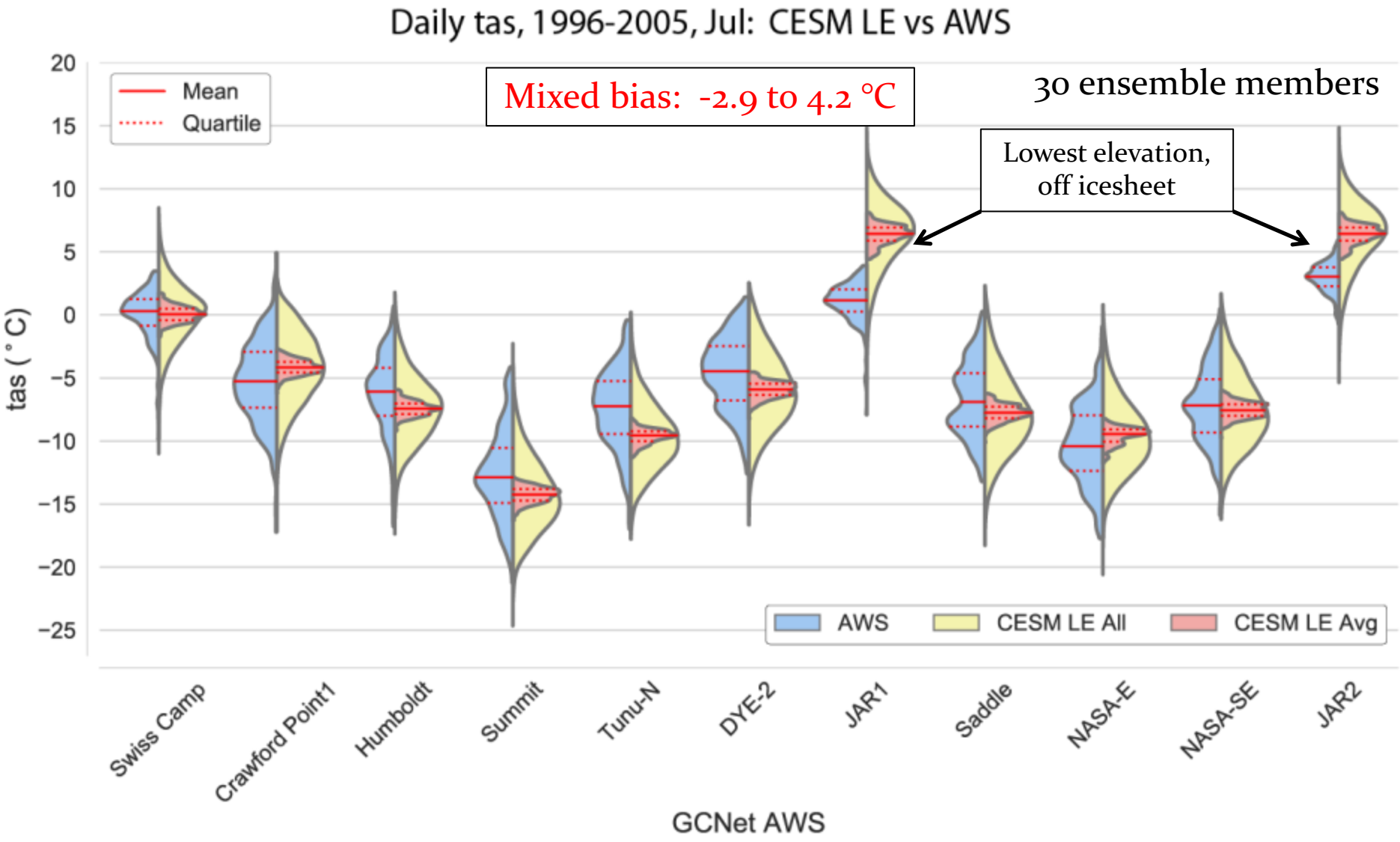
ERAI

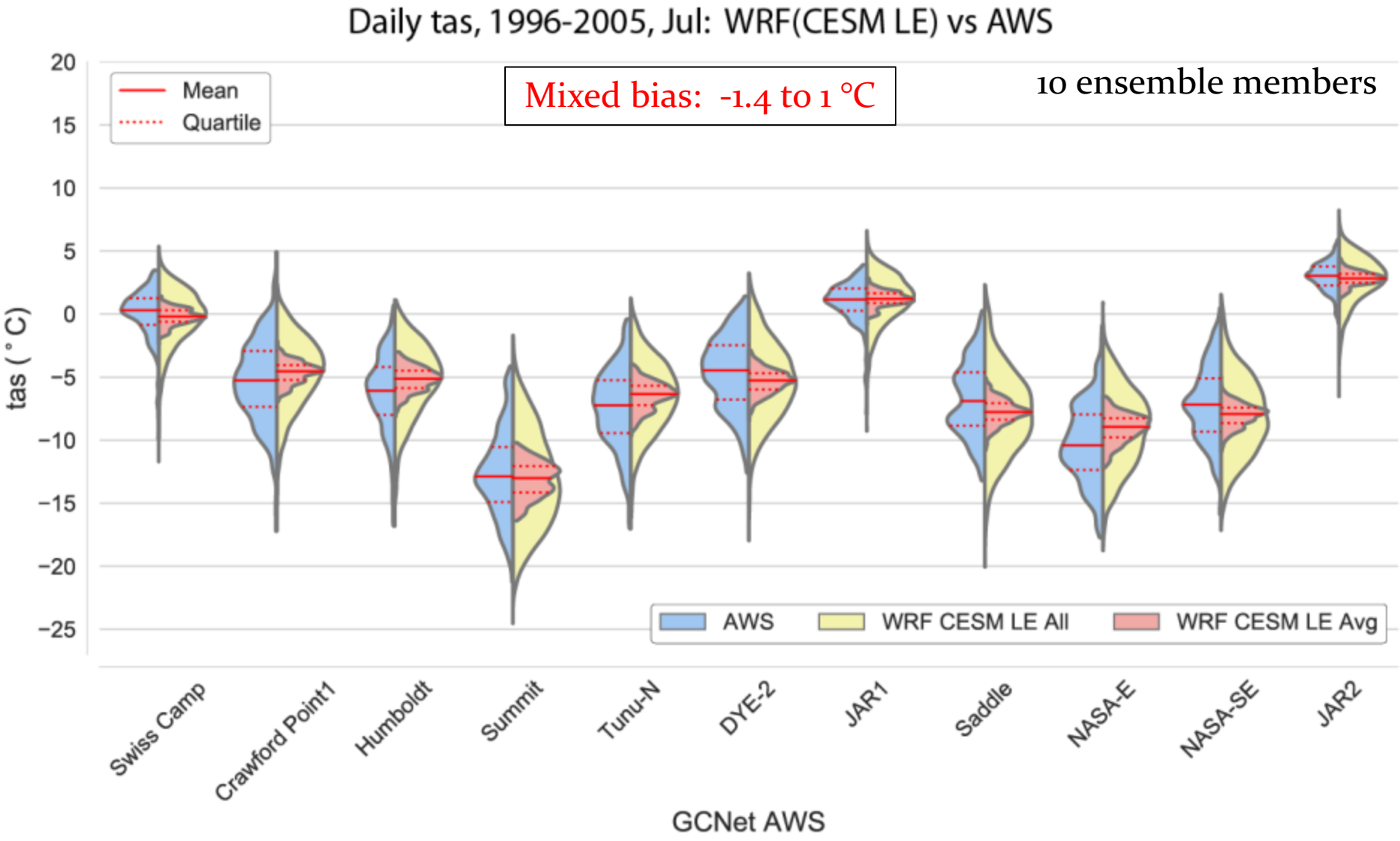
CESM




Daily tas, 1996-2005, Jul: ERA Interim vs AWS
Warm bias: 0.7 to 3.6 °C
Low elevation, icesheet edge
Lowest elevation, off icesheet
Highest elevation
tas (°C)
20
15
10
5
0
−5
−10
−15
−20
−25
Mean
Quartile
AWS
ERAI
Swiss Camp
Crawford Point1
Humboldt
Summit
Tunu-N
DYE-2
JAR1
Saddle
NASA-E
NASA-SE
JAR2
GCNet AWS

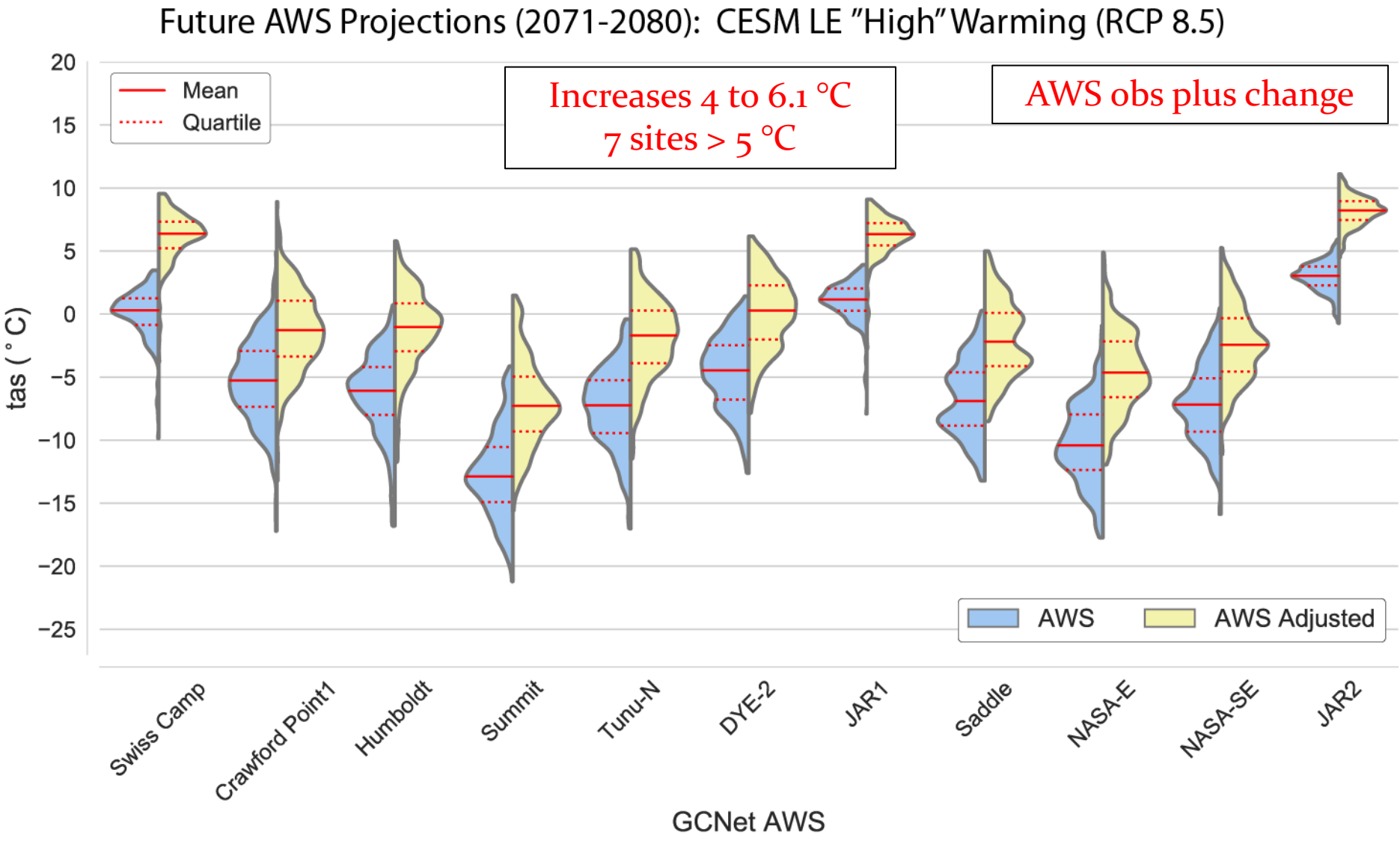

Daily tas, 1996-2005, Jul: WRF(ERA Interim) vs AWS
Mean
Quartile
Mixed bias: -1.5 to 1 °C
Lowest elevation, off icesheet
AWS
WRF ERAI
tas (°C)
20
15
10
5
0
−5
−10
−15
−20
−25
Swiss Camp
Crawford Point1
Humboldt
Summit
Tunu-N
DYE-2
JAR1
Saddle
NASA-E
NASA-SE
JAR2
GCNet AWS

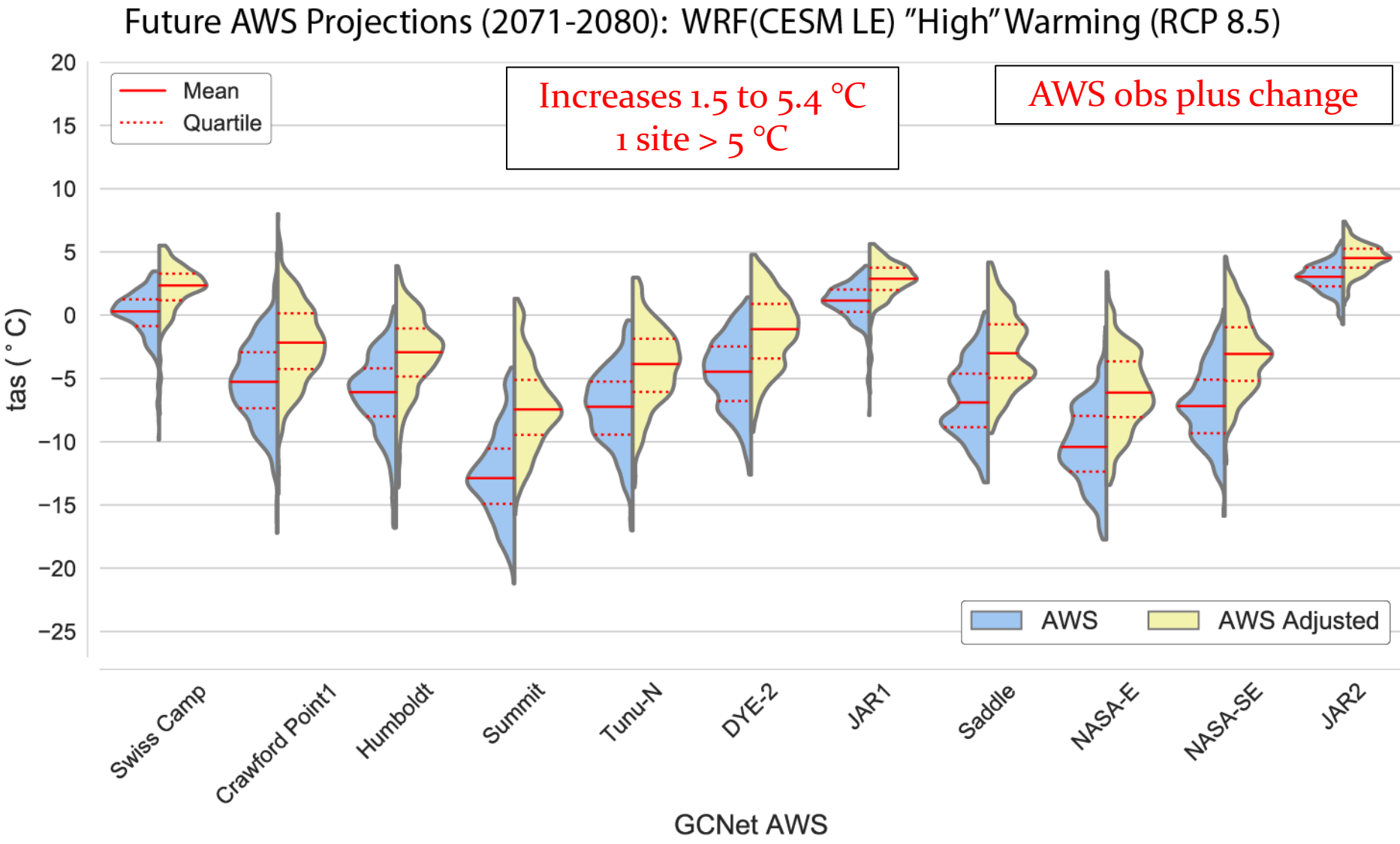

Daily tas, 1996-2005, Jul: CESM LE vs AWS
Mixed bias: -2.9 to 4.2 °C
30 ensemble members
Lowest elevation, off icesheet
Mean
Quartile
tas (°C)
20
15
10
5
0
−5
−10
−15
−20
−25
AWS
CESM LE All
CESM LE Avg
Swiss Camp
Crawford Point1
Humboldt
Summit
Tunu-N
DYE-2
JAR1
Saddle
NASA-E
NASA-SE
JAR2
GCNet AWS

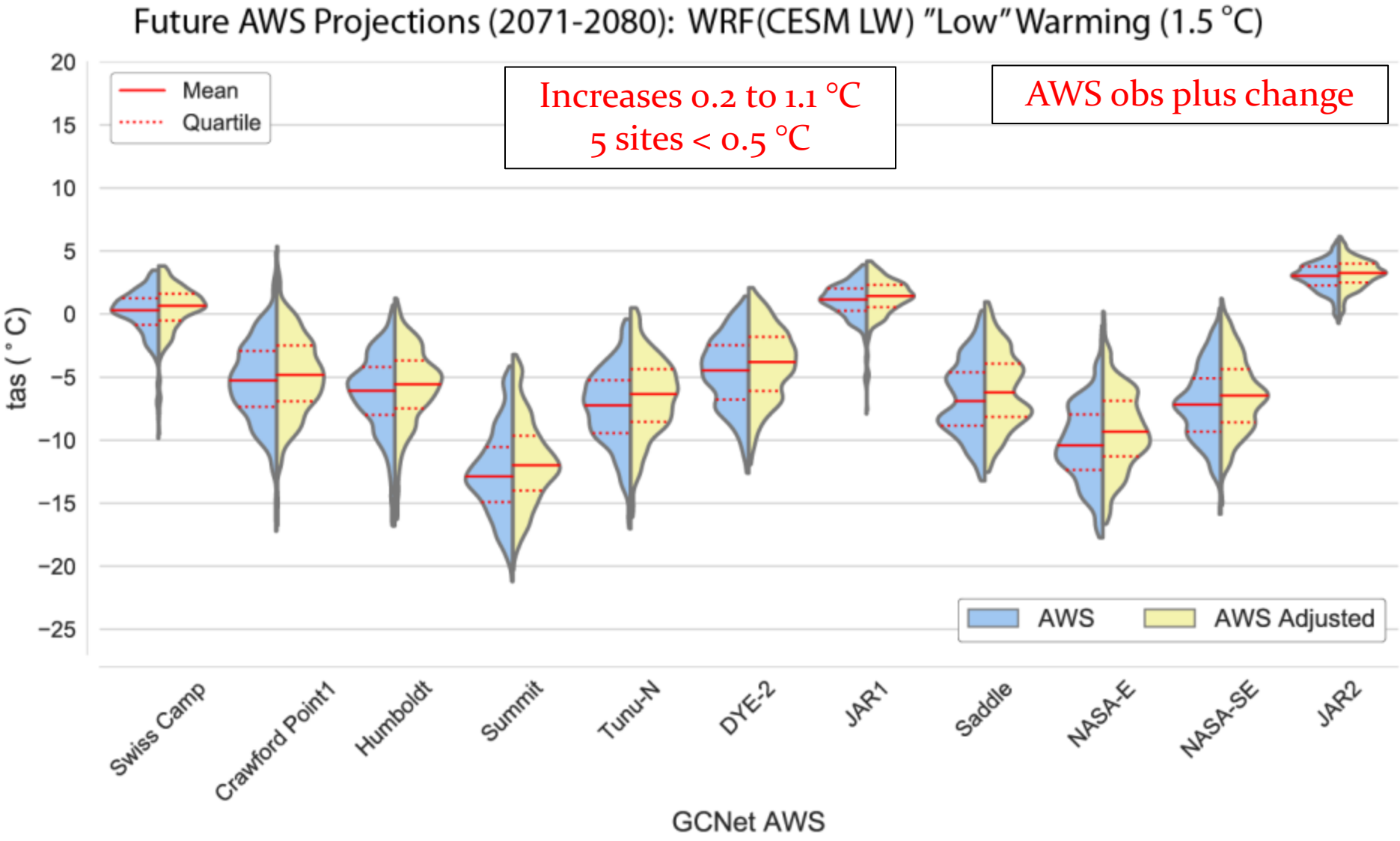

Daily tas, 1996-2005, Jul: WRF(CESM LE) vs AWS
Mixed bias: -1.4 to 1 °C
10 ensemble members
Mean
Quartile
tas (°C)
20
15
10
5
0
−5
−10
−15
−20
−25
AWS
WRF CESM LE All
WRF CESM LE Avg
Swiss Camp
Crawford Point1
Humboldt
Summit
Tunu-N
DYE-2
JAR1
Saddle
NASA-E
NASA-SE
JAR2
GCNet AWS

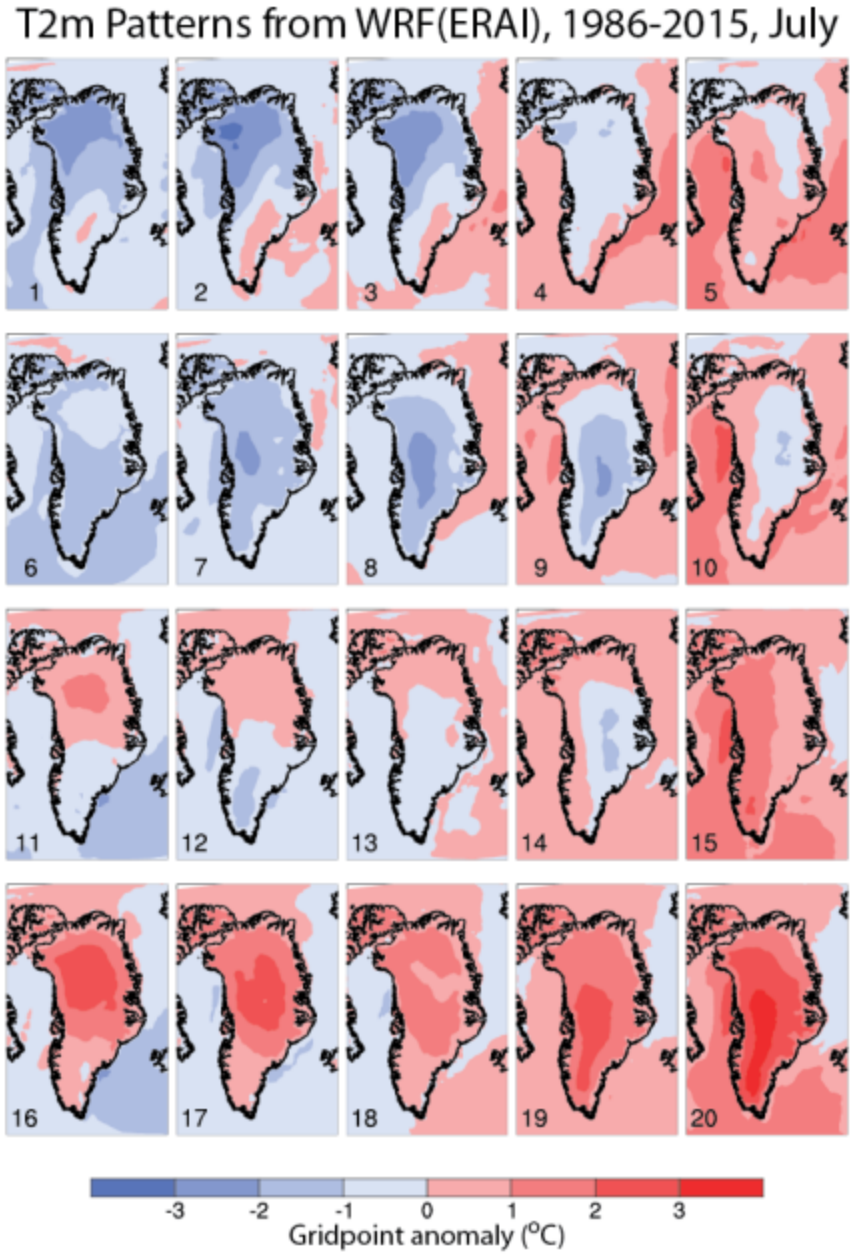
Applying this to the future

- Ideal: Translate point results to spatially resolved
  - Average across AWS, apply one number?
  - Interpolate stations across domain?
  - Something “more empirical”?
- Short-term: add future change to AWS mean

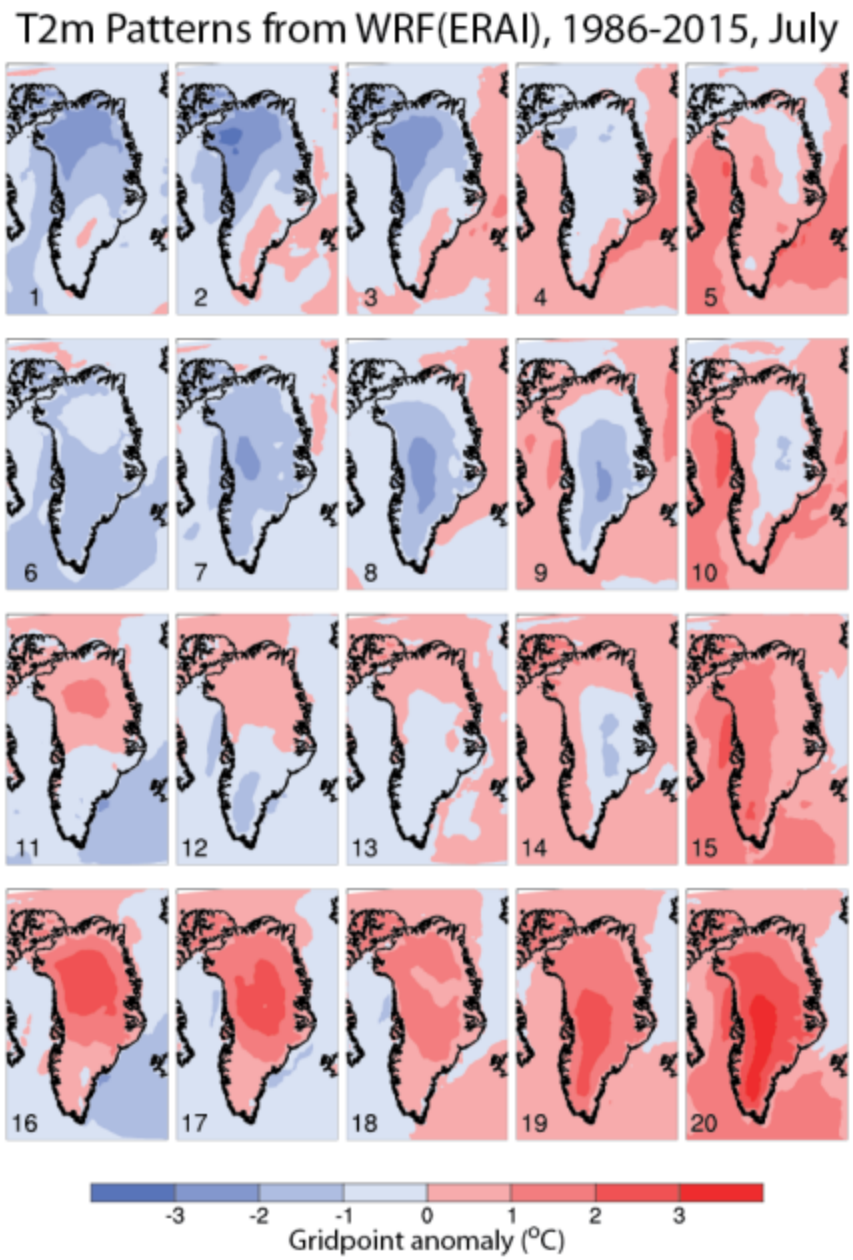

Future AWS Projections (2071-2080): CESM LE "High" Warming (RCP 8.5)
Increases 4 to 6.1 °C
7 sites > 5 °C
AWS obs plus change
Mean
Quartile
AWS
AWS Adjusted
tas (° C)
20
15
10
5
0
−5
−10
−15
−20
−25
Swiss Camp
Crawford Point1
Humboldt
Summit
Tunu-N
DYE-2
JAR1
Saddle
NASA-E
NASA-SE
JAR2
GCNet AWS

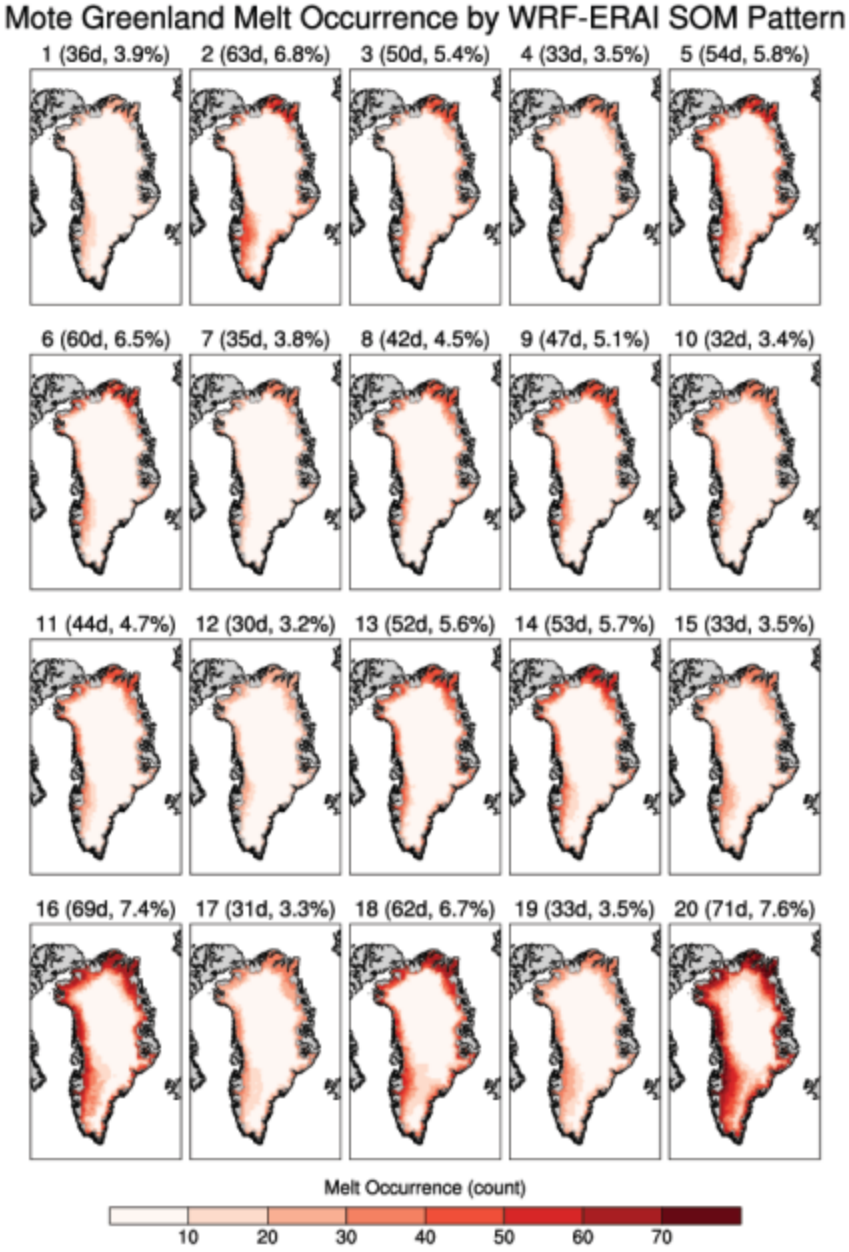

Future AWS Projections (2071-2080): WRF(CESM LE) "High" Warming (RCP 8.5)
Increases 1.5 to 5.4 °C
1 site > 5 °C
AWS obs plus change
Mean
Quartile
AWS
AWS Adjusted
tas (° C)
20
15
10
5
0
−5
−10
−15
−20
−25
Swiss Camp
Crawford Point1
Humboldt
Summit
Tunu-N
DYE-2
JAR1
Saddle
NASA-E
NASA-SE
JAR2
GCNet AWS


Future AWS Projections (2071-2080): WRF(CESM LW) "Low" Warming (1.5 °C)
Increases 0.2 to 1.1 °C
5 sites < 0.5 °C
AWS obs plus change
Mean
Quartile
AWS
AWS Adjusted
tas (°C)
20
15
10
5
0
−5
−10
−15
−20
−25
Swiss Camp
Crawford Point1
Humboldt
Summit
Tunu-N
DYE-2
JAR1
Saddle
NASA-E
NASA-SE
JAR2
GCNet AWS



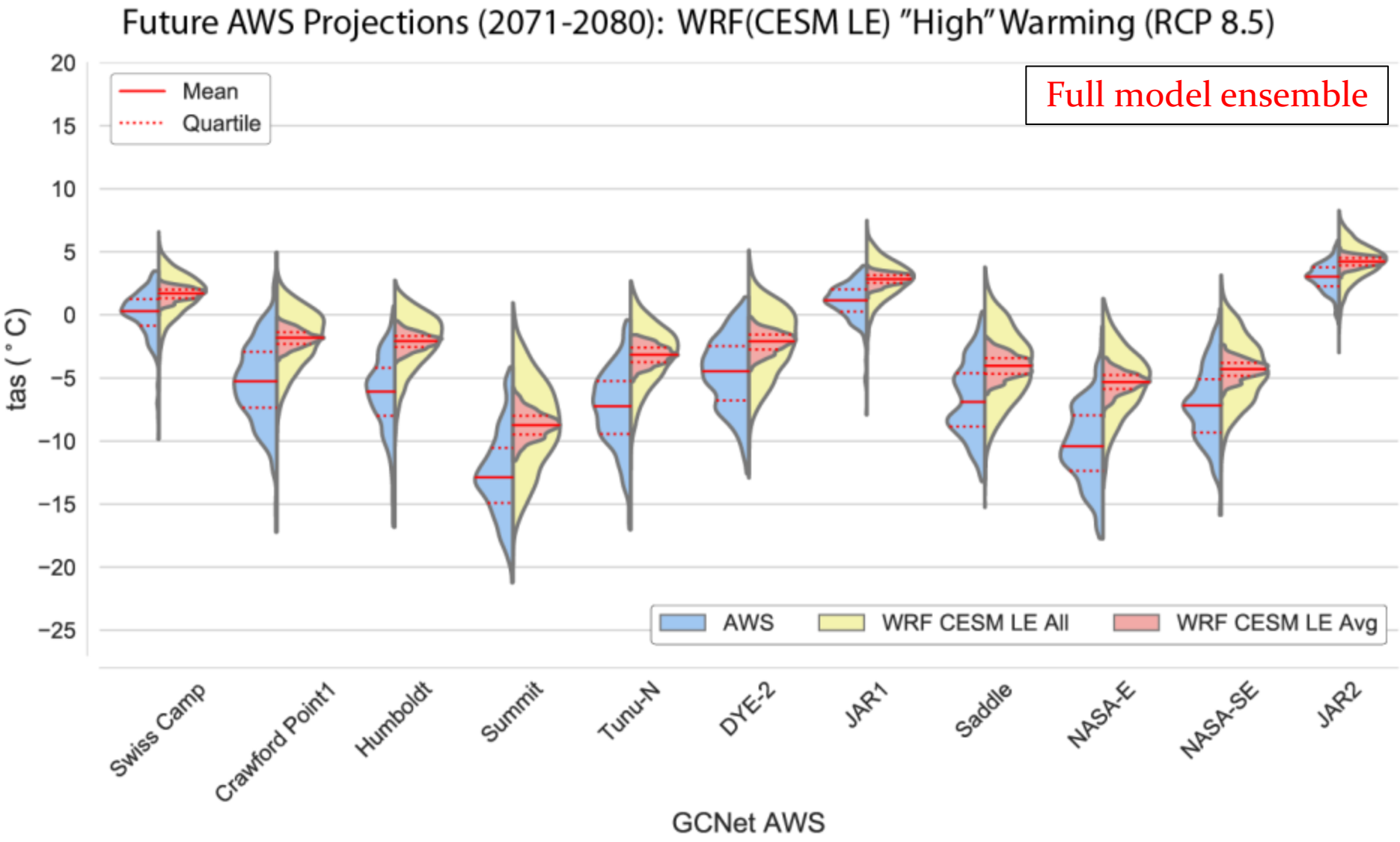
Generalized patterns of temperature variability in a 30-year WRF(ERAI) dataset


T2m Patterns from WRF(ERAI), 1986-2015, July
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
-3
-2
-1
0
1
2
3
Gridpoint anomaly (°C)


Mote Greenland Melt Occurrence by WRF-ERAI SOM Pattern
1 (36d, 3.9%)
2 (63d, 6.8%)
3 (50d, 5.4%)
4 (33d, 3.5%)
5 (54d, 5.8%)
6 (60d, 6.5%)
7 (35d, 3.8%)
8 (42d, 4.5%)
9 (47d, 5.1%)
10 (32d, 3.4%)
11 (44d, 4.7%)
12 (30d, 3.2%)
13 (52d, 5.6%)
14 (53d, 5.7%)
15 (33d, 3.5%)
16 (69d, 7.4%)
17 (31d, 3.3%)
18 (62d, 6.7%)
19 (33d, 3.5%)
20 (71d, 7.6%)
Melt Occurrence (count)
10
20
30
40
50
60
70

Summary

- Skill
  - ERAI is warm, CESM LE is mostly cold
  - WRF helps some/a lot (bias range more zero-centered)
- Future temperatures (relative to 1996-2005)
  - "High" scenario mean increase of 1.5-5.5 °C
  - "Low" scenario almost never exceeds 1 °C in the mean
- In progress/future work
  - Using ensembles to understand uncertainty/distributions
  - Calibrating models to surface melting, predicting future
  - Adding PROMICE AWS dataset


Future AWS Projections (2071-2080): WRF(CESM LE) "High" Warming (RCP 8.5)
Full model ensemble
Mean
Quartile
tas (°C)
20
15
10
5
0
−5
−10
−15
−20
−25
AWS
WRF CESM LE All
WRF CESM LE Avg
Swiss Camp
Crawford Point1
Humboldt
Summit
Tunu-N
DYE-2
JAR1
Saddle
NASA-E
NASA-SE
JAR2
GCNet AWS