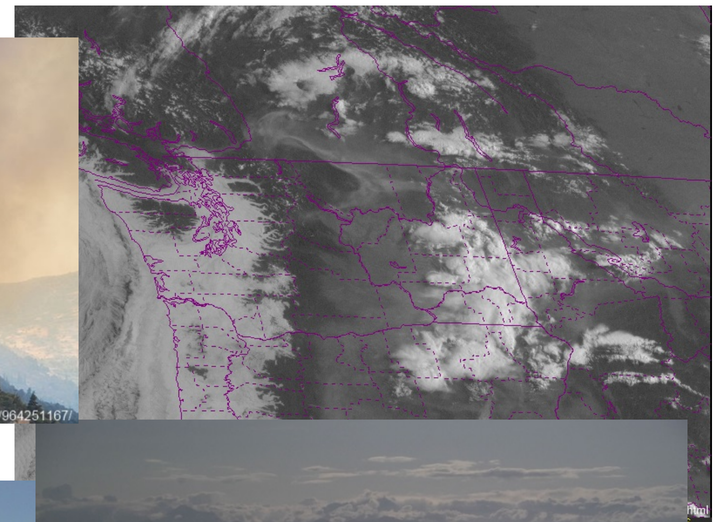
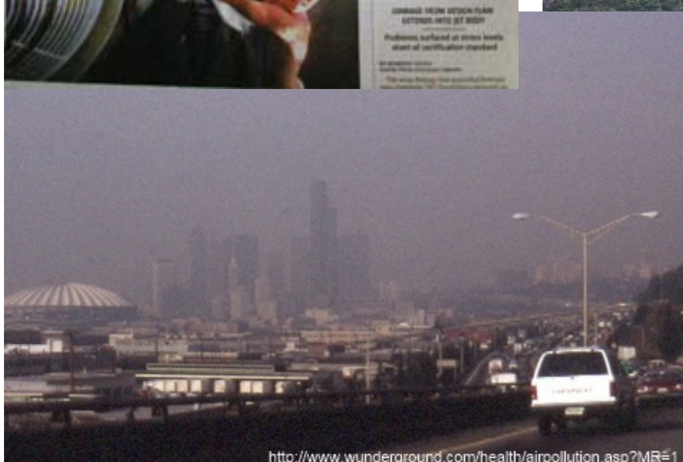
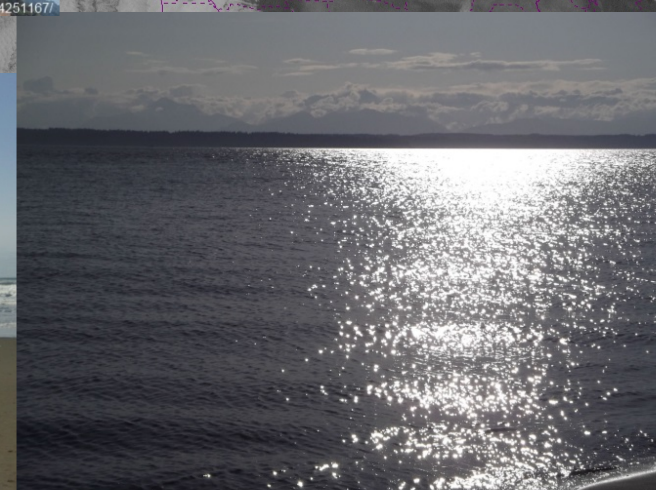
Changes in Pacific Northwest Heat Waves under Anthropogenic Global Warming

By Matt Brewer and Cliff Mass







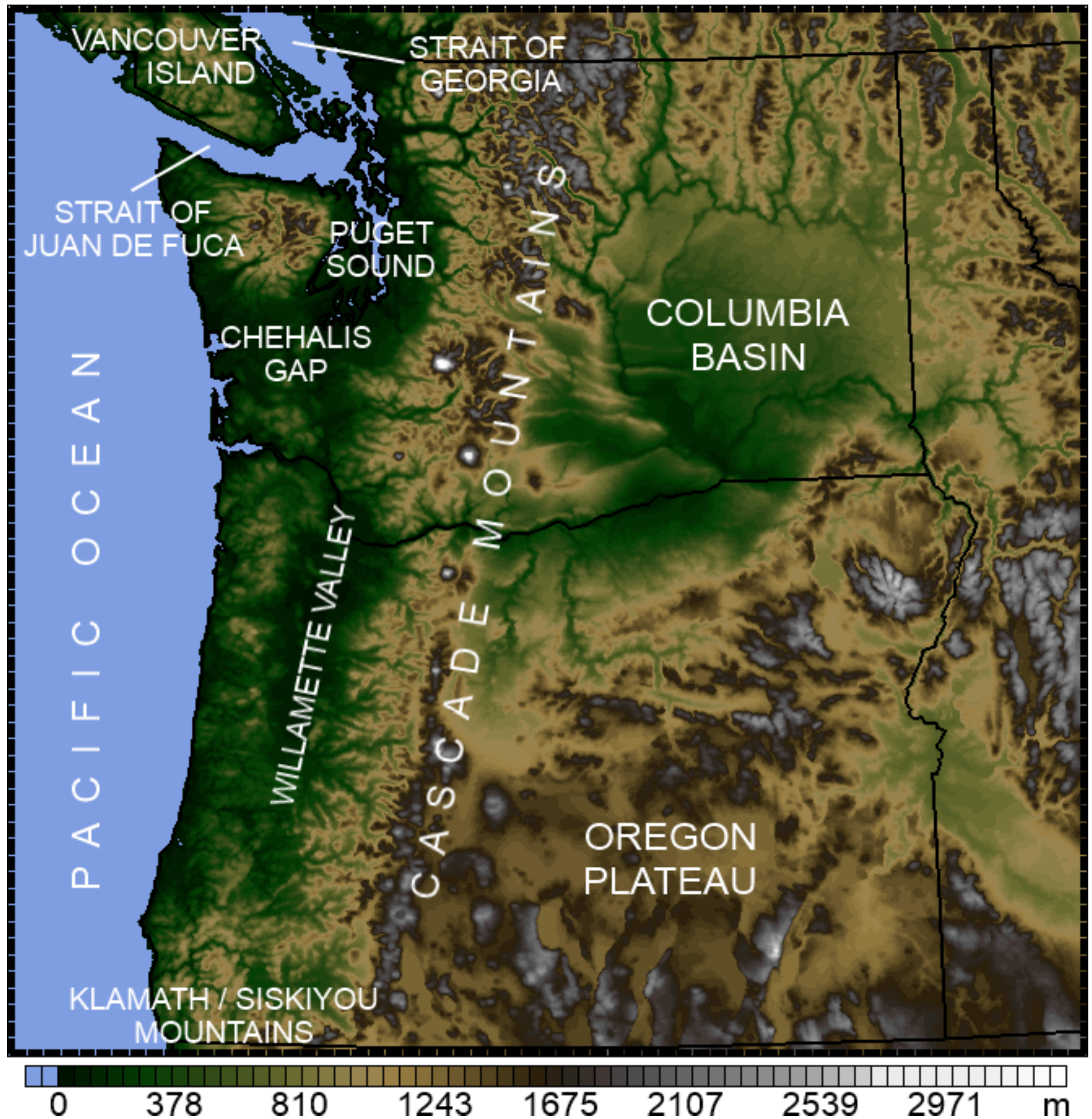
How Will PNW Heat Waves Change?

It's complicated…

- -Complex terrain
- -Vastly different microclimates
- -Land/Sea contrasts

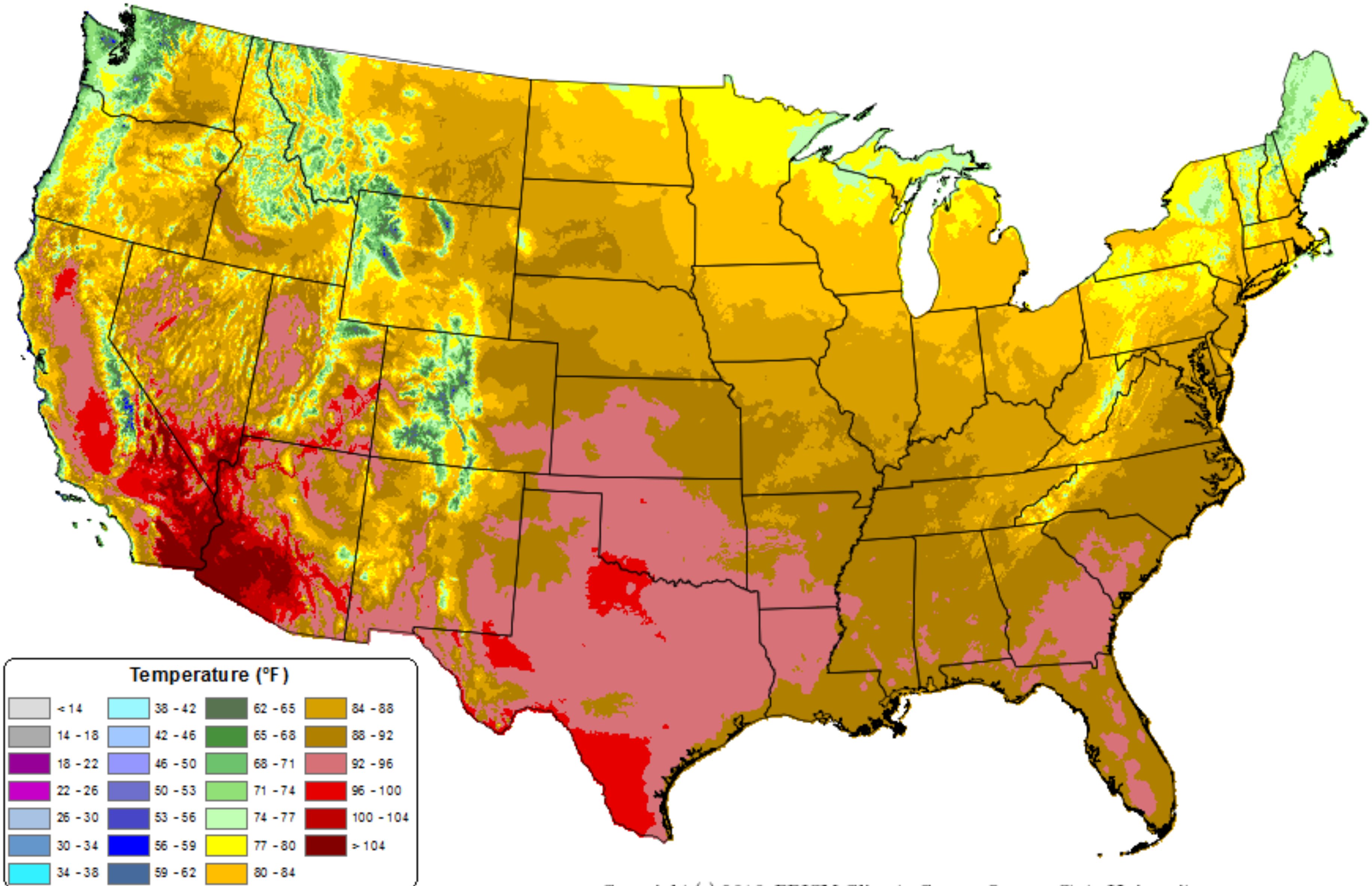
What are we looking for?

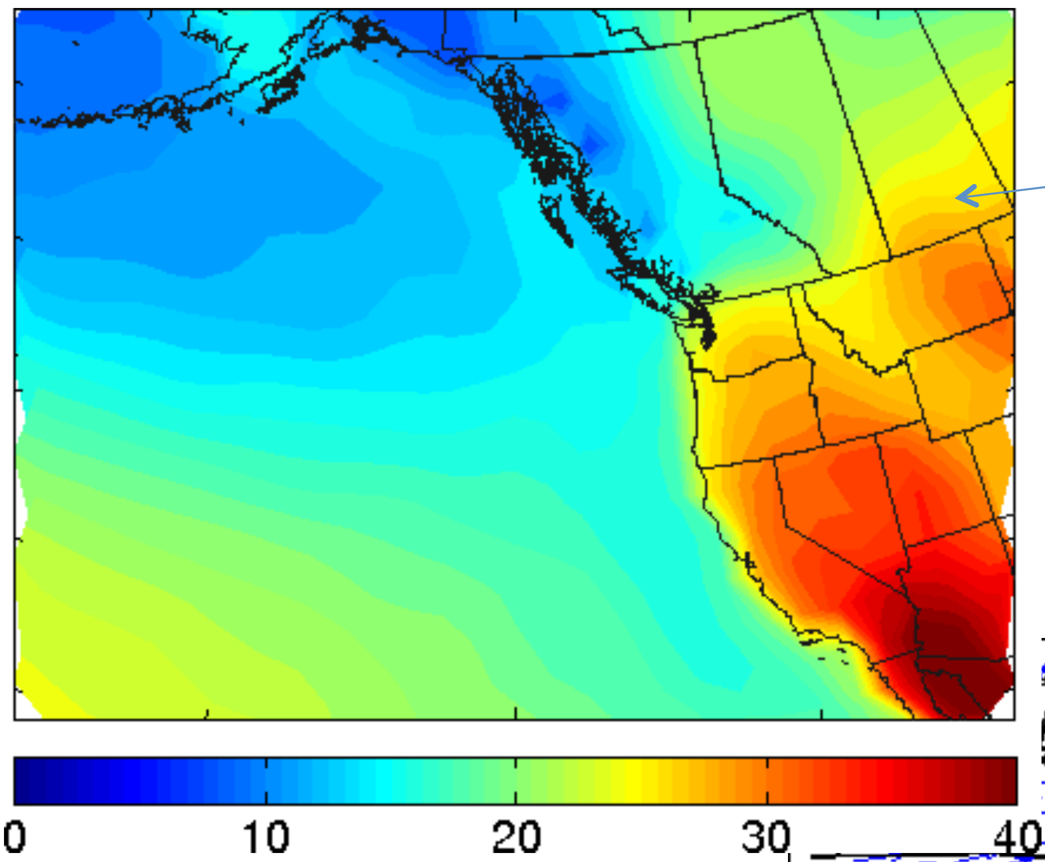
- -How will the mean state change?
- -How will the weather conditions that bring about heat waves change?



30-yr Normal Max Temperature: July

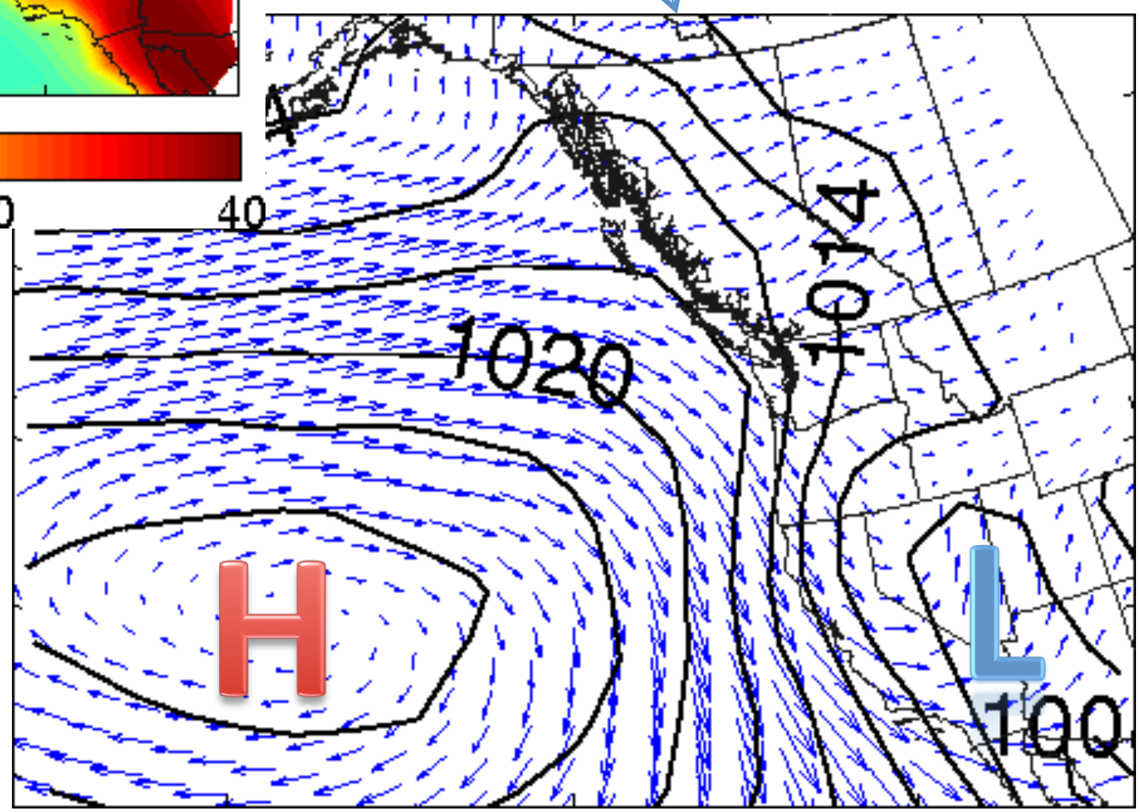
Period: 1981-2010





Average daily max 2-m temp (^oC)

Average SLP (mb) and wind (vectors)



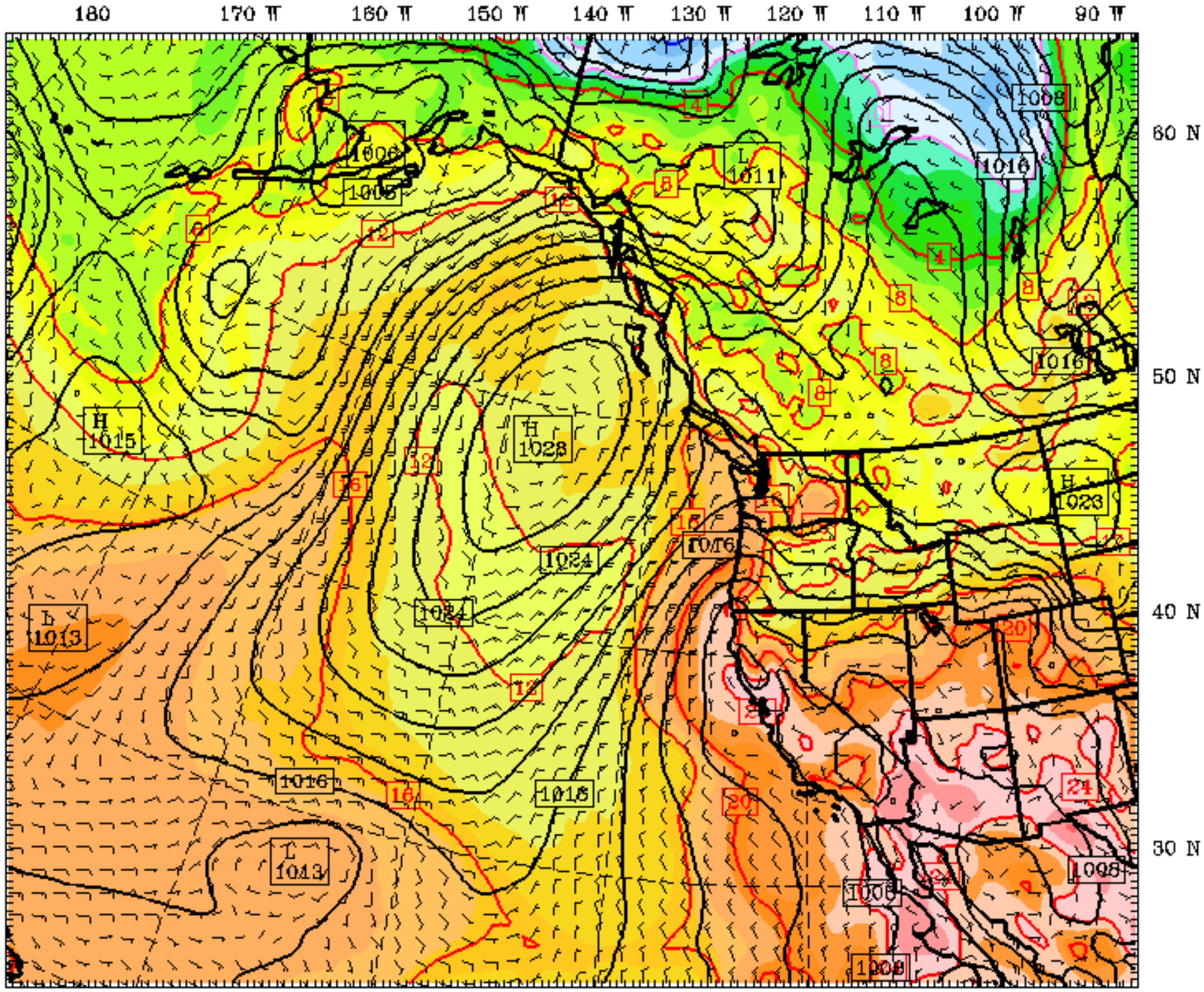
Data from NCEP Reanalysis for 1970-1999 (Jul-Aug only)

PNW Heat Waves

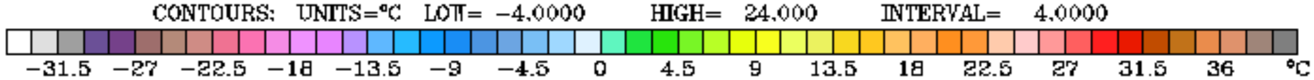
- Western OR & WA get heat waves when high pressure builds in the interior, associated with a ridge aloft.
- Higher pressure inland drives offshore (easterly) flow.
- This gives us our big heat waves because...
  - Downslope flow and adiabatic warming on the western slopes of Cascades & Coastal Mts.
  - Subsidence from downslope flow suppresses clouds.
  - Offshore flow keeps marine air offshore.
- Discusses in Mass et al. 1986, Brewer et al. 2012

UW WRF-GFS 36km Domain
Fcst: 24 h
Temperature at 925 mb (°C)
Sea Level Pressure (hPa)
Wind at 10m (full barb = 10kts)

Init: 12 UTC Thu 04 Sep 14
Valid: 12 UTC Fri 05 Sep 14 (05 PDT Fri 05 Sep 14)



CONTOURS: UNITS=hPa LOW= 1006.0 HIGH= 1028.0 INTERVAL= 2.0000
CONTOURS: UNITS=°C LOW= -4.0000 HIGH= 24.000 INTERVAL= 4.0000



Model Info: V3.5 SAS Sch YSU PBL Thompson Noah LSM 36 km, 37 levels, 216 sec
LW: RRTM SW: RRTMG DIFF: simple KM: 2D Smagor

Data

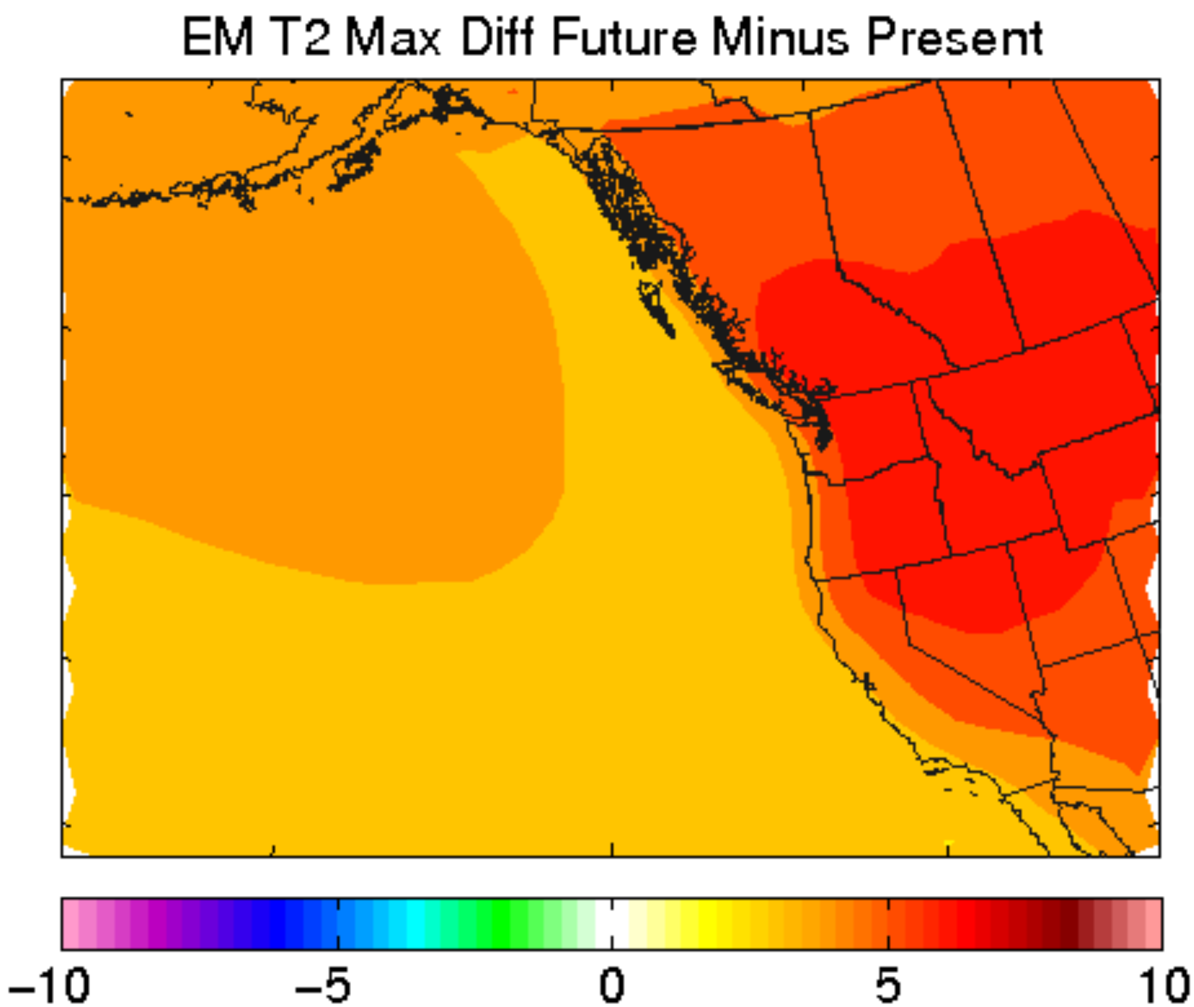
- CMIP5 (Coupled Model Intercomparison Project) GCMs
  - Historical & RCP 8.5 runs (ensemble #1 when available).
  - Important: GCMs do not account for regional terrain influences on weather.
    - Rain Shadows, convergence zones, orographic precip, snow-albedo feedbacks, etc.
- Regional Climate Models (Downscaled CMIP3 runs)
  - Run a high-resolution model with initial and boundary conditions prescribed by GCMs.
  - The WRF V3.1 model was run at 36- & 12-km resolution in a domain centered over Pacific NW with initial/boundary conditions from:
    - NCEP/NCAR Reanalysis (1950-2010)
    - Max Plank Institute ECHAM5 & NCAR CCSM3
      - 1970-2000 from 20th century control run
      - 2000-2070 A1B scenario

For all these runs, model output is 6 hourly (00,06,12 and 18 UTC)

Changes in the Mean State: T (°C)

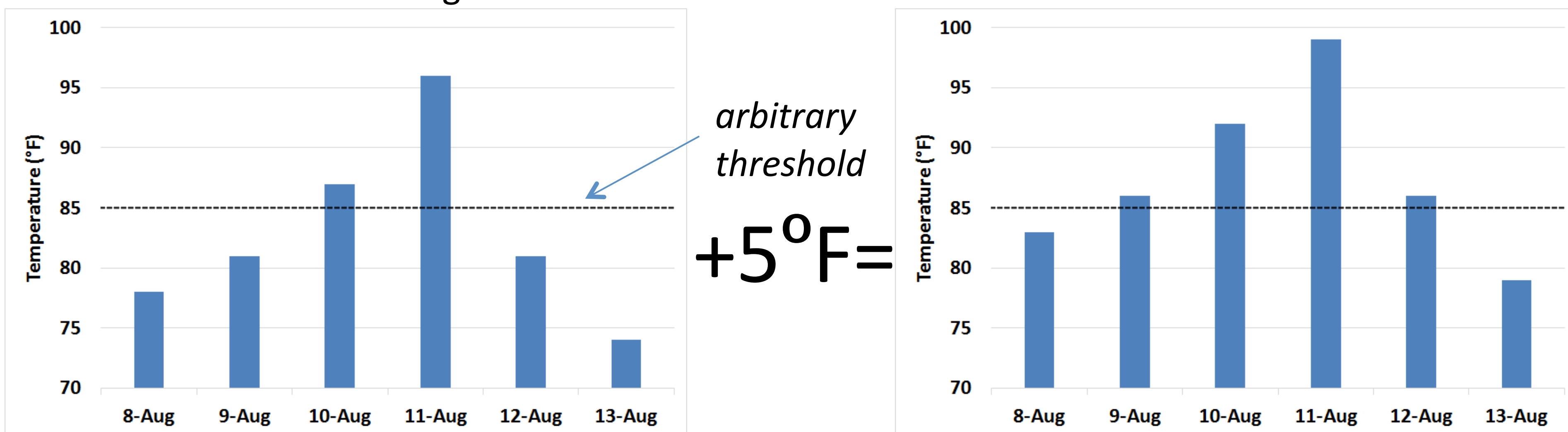
-Future (2070-2099) minus present (1970-1999) daily max 2-m temp from CMIP5 GCM ensemble mean.

-Only Jul & Aug



Future Heatwaves... given a change in the mean state

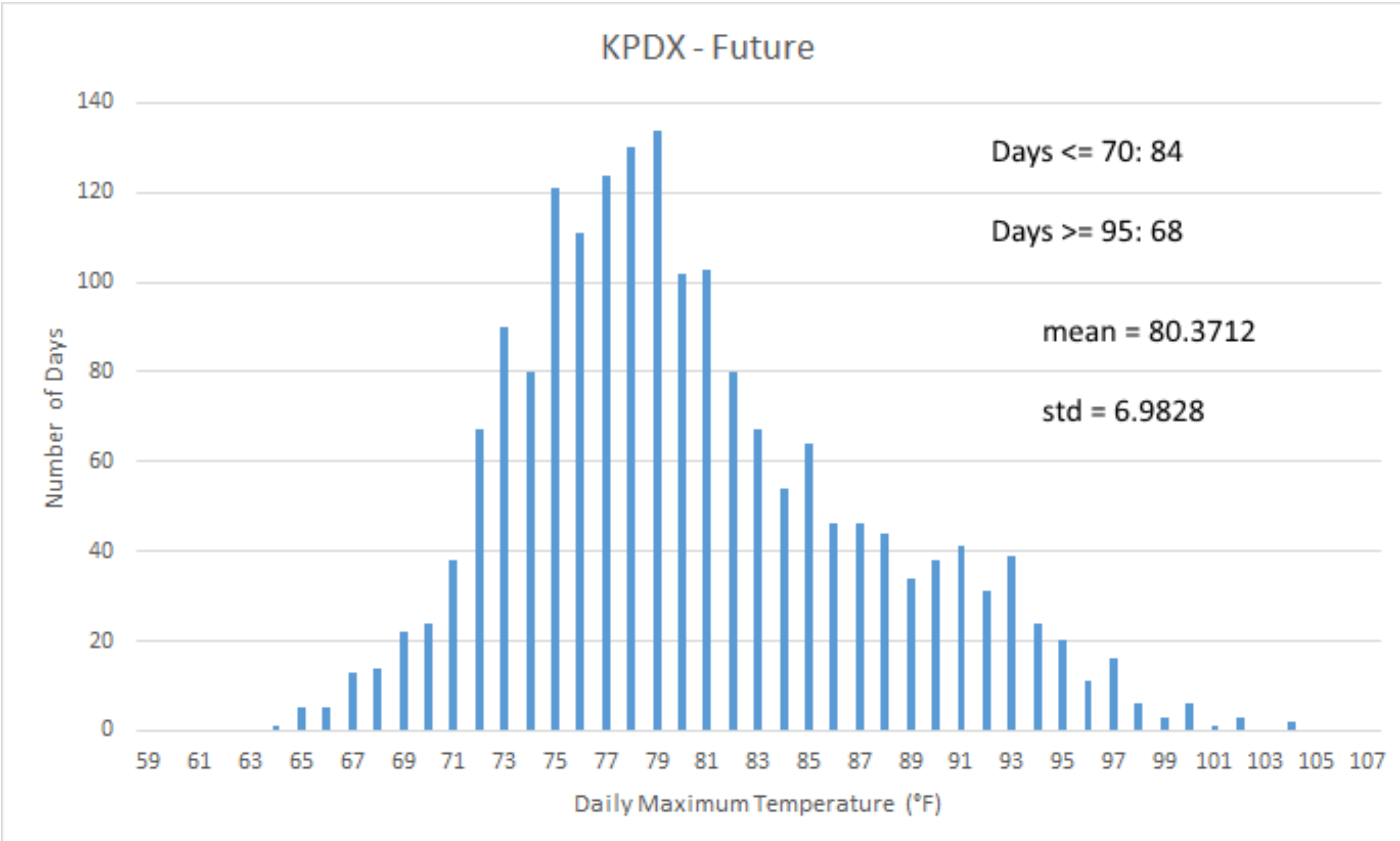
A heatwave back in Aug at KSEA



- Can we project future heat wave frequency, intensity, and duration by increasing the contemporary temperature distribution by the expected change in the mean temperature?
  - This assumes no change to the shape of the temperature distribution under AGW.

KPDX 2-m Temp (°F) Distribution

From downscaled 12-km CCSM3 run



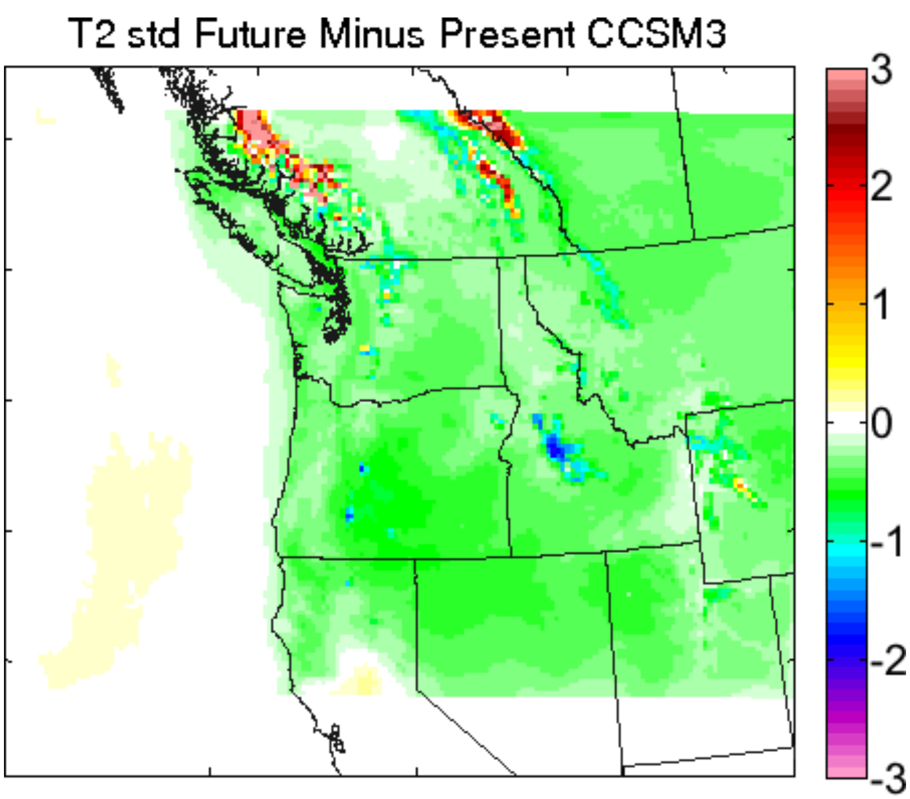
1970-1999 Mean: 76.12° F

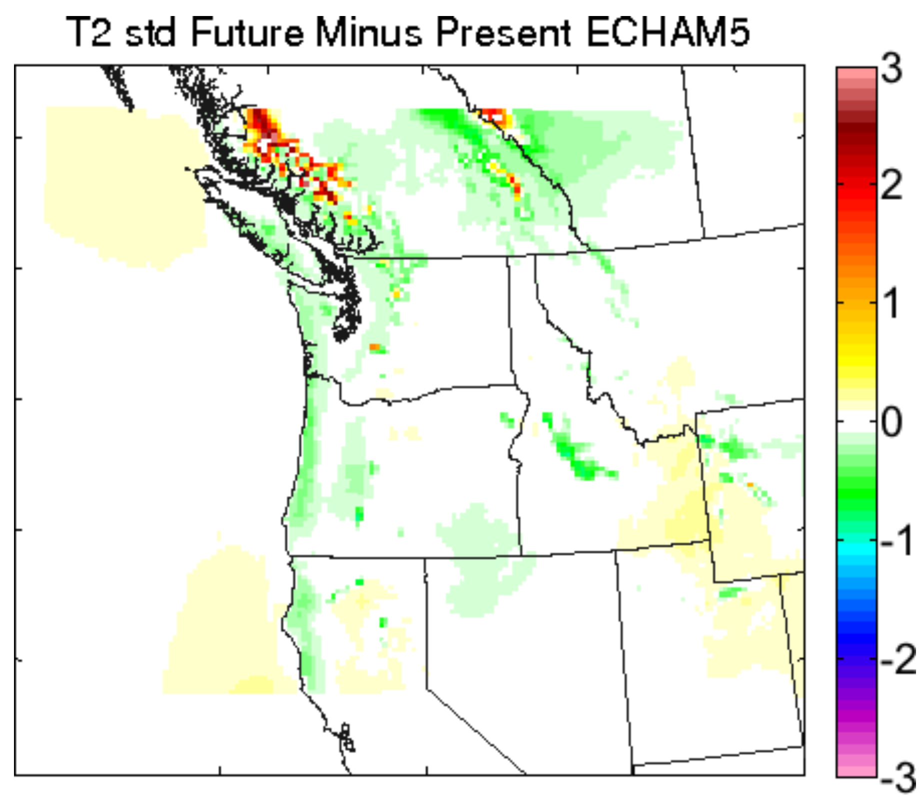
2040-2069 Mean: 80.37° F

Difference: 4.25° F

2-m T (^oC) Standard Deviations

Future (2040-2069)
Present (1970-1999)





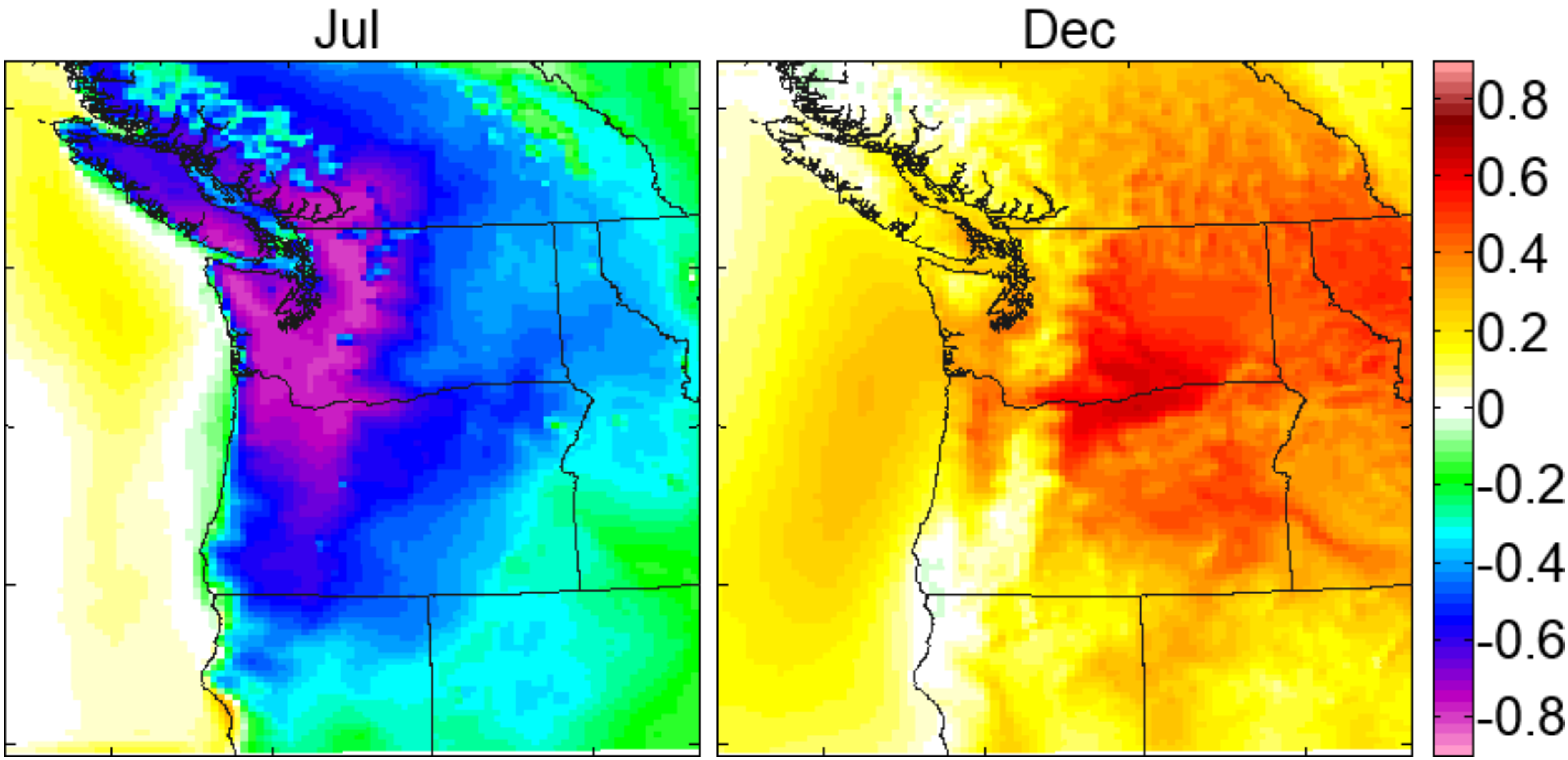
Changes in Offshore Flow Events (OFEs)

- How will the conditions that bring about heat waves change under AGW?
- The Plan:
  - Define an OFE.
  - Create a climatology of past and future OFEs using the downscaled NCEP and GCM WRF runs.
  - Look for changes in intensity, frequency, and duration of OFEs under AGW.

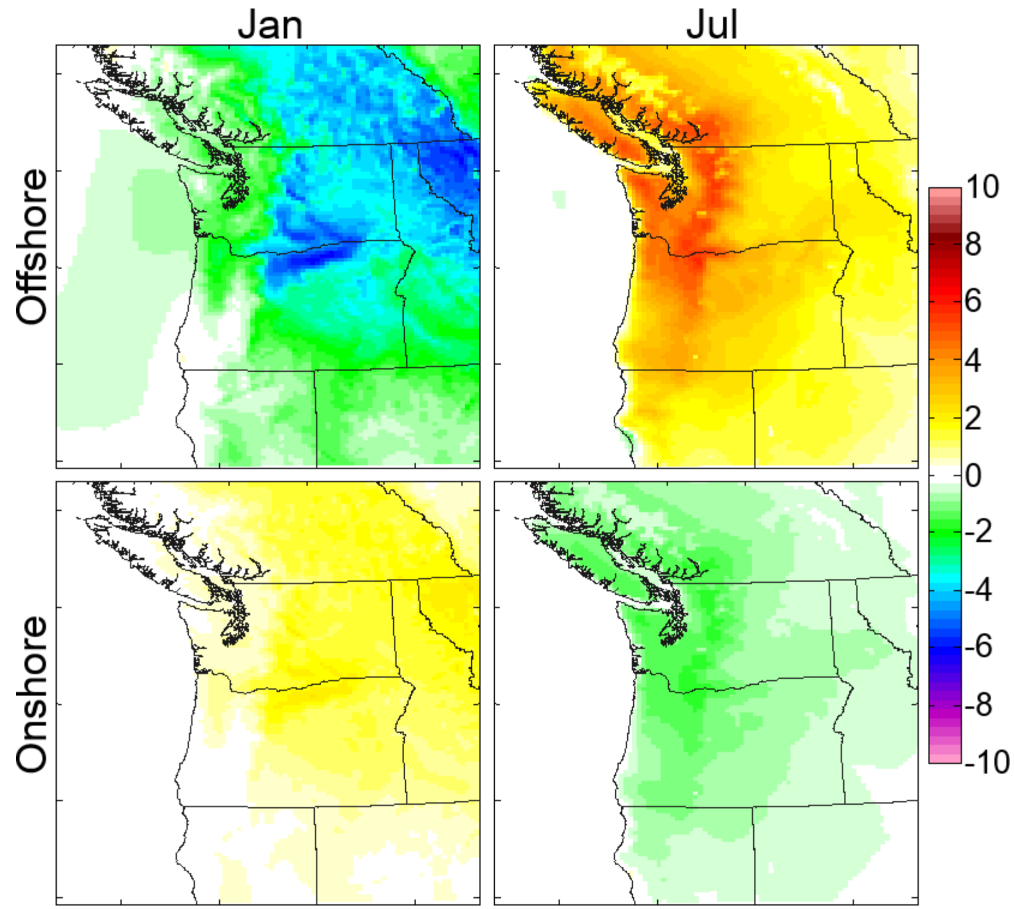
Offshore Flow Definition

- Every 6 hours, the U-wind average is found of all grid points along the Cascade crest in Oregon and Washington at 850mb.
  - For clarity, we'll call this average of the U-wind along the crest the UW-index.
- The 12-hour average UW-index is found for 00,06,12z (nighttime) and 12,18,00z (daytime).
- A string of one or more 12-hour periods with negative UW-index is considered an offshore flow event.

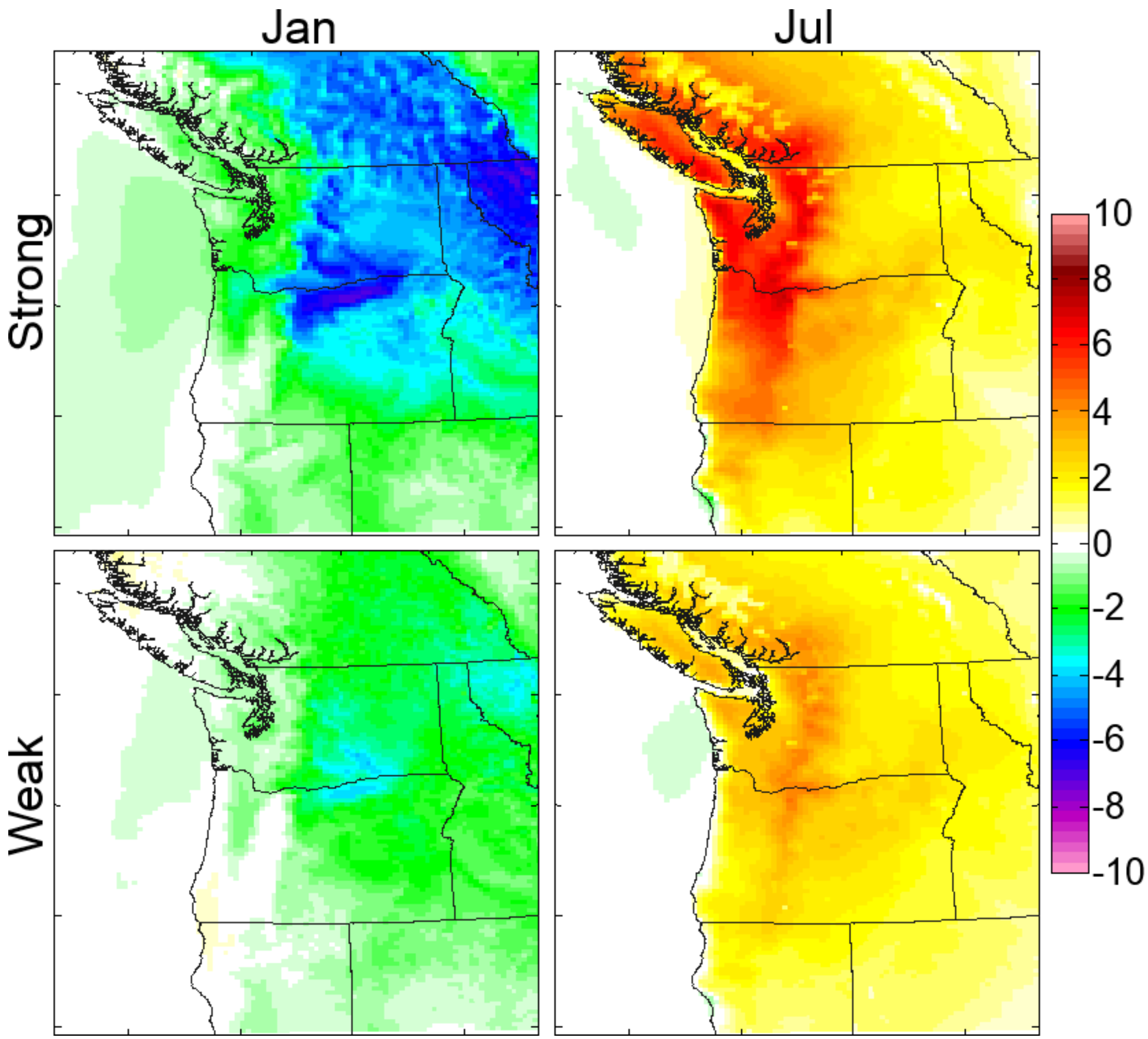
What is the correlation between daytime offshore flow and 2-m daily max T?



- Using downscaled NCEP Reanalysis WRF runs (1950-2010)…
- Composites of temp (°C) departures from normal at 00 UTC for daytime offshore & onshore flow.



- For 10% warmest days at KPDX for Jul-Aug 1980-2009, 171/186 days were associated with an offshore flow event.
- Other 15 days had offshore flow at 12z, but stronger onshore flow at 00z, so UW-index was positive.

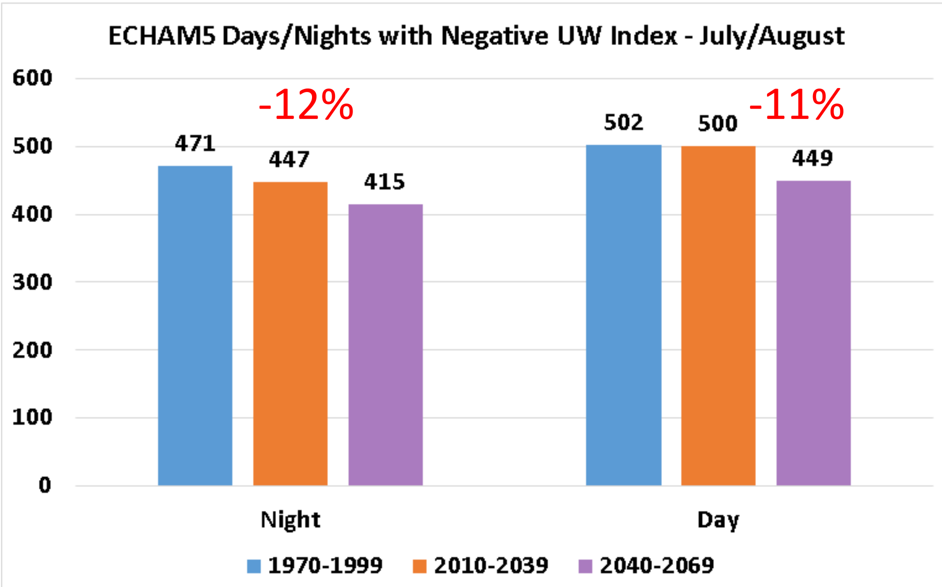


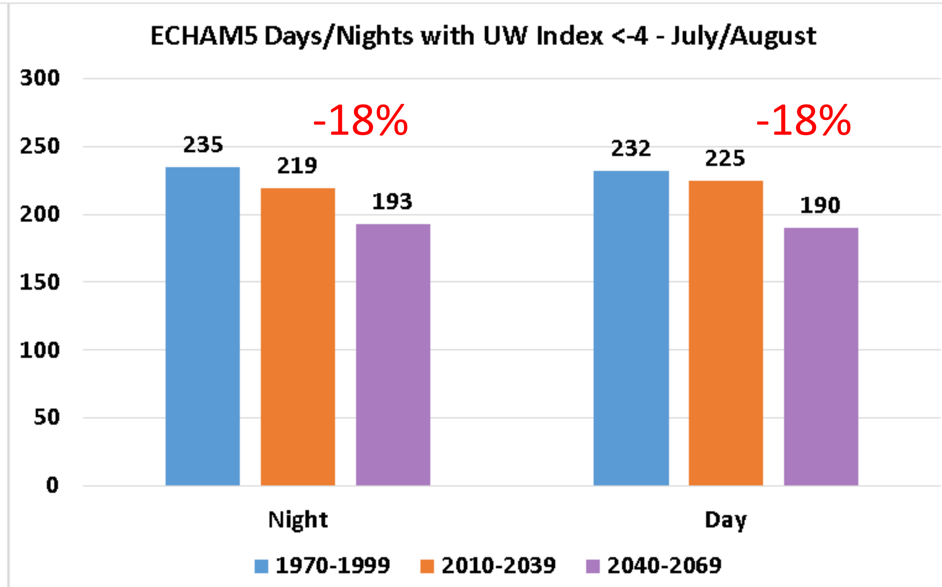
Composites of temp (°C) departures from normal at 00 UTC for daytime strong and weak offshore flow.

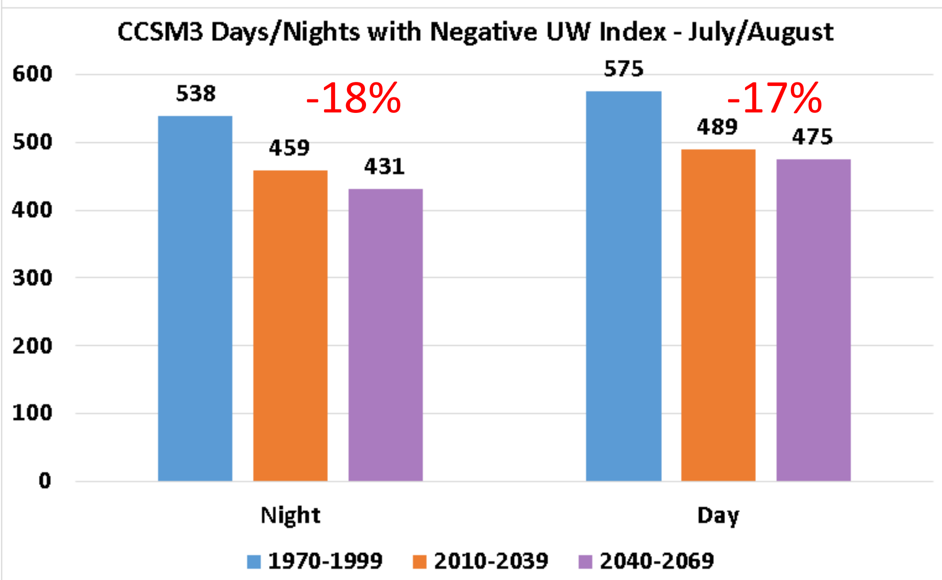
Strong = UW-index less than -4 m/s

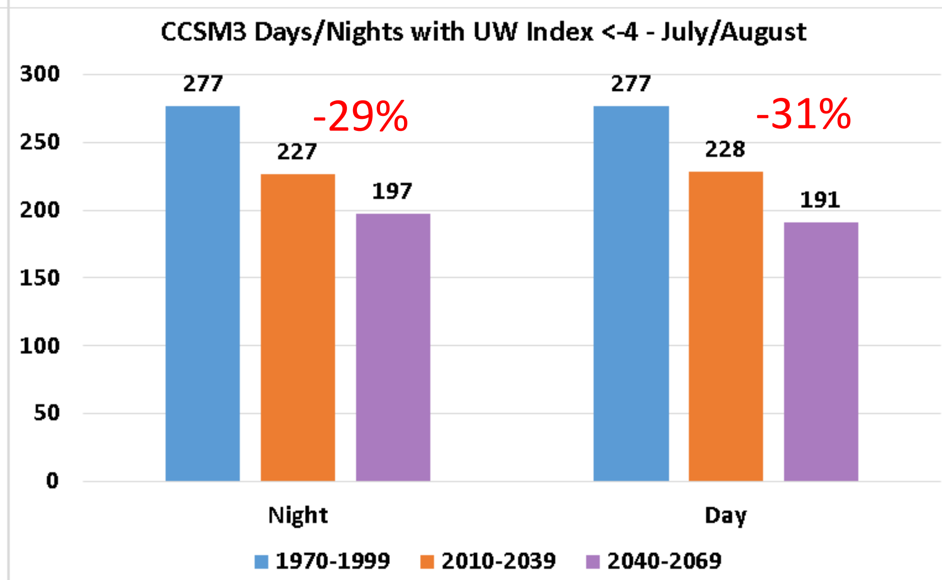
Weak = Between 0 and -4 m/s

Future Offshore Flow

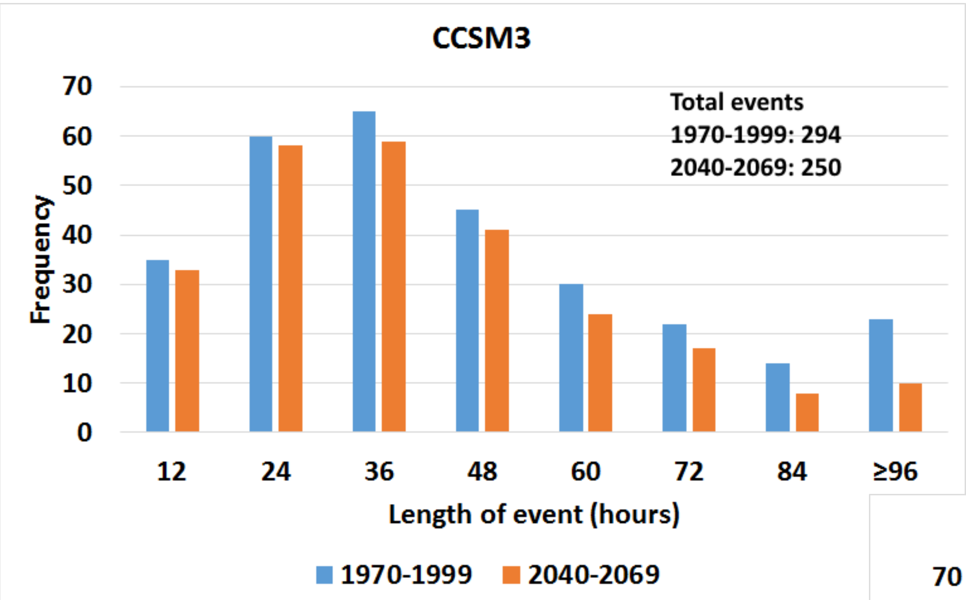


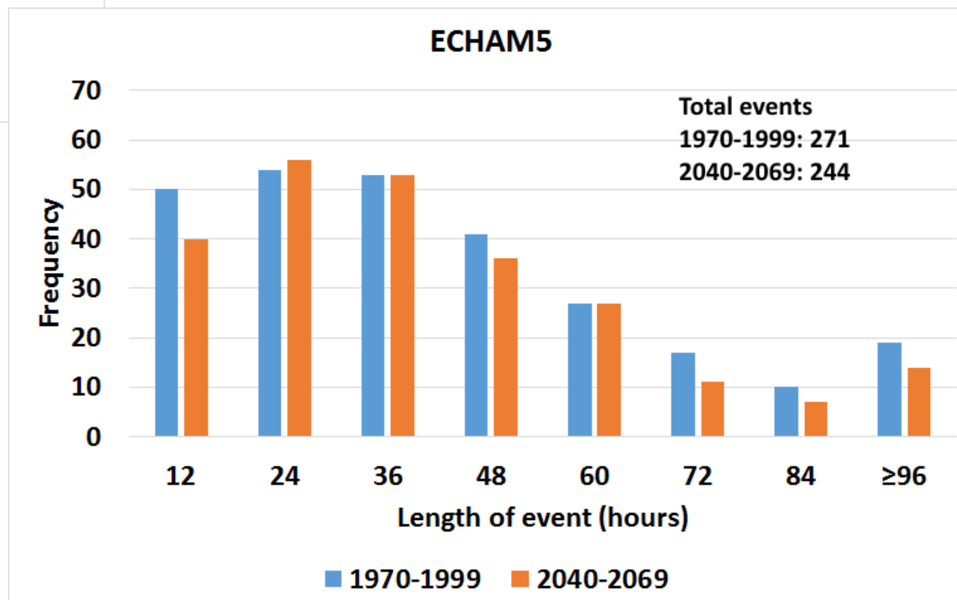






Future Offshore Flow Events





Big Questions Remain…

- Are these results robust?
  - More downscaled runs are needed!
  - Can GCMs simulate these events?
- Why would there be fewer offshore flow events in the future?
  - Could be a mesoscale effect.
    - Stronger onshore flow?
  - Could be larger synoptic scale changes.
    - Position & intensity of storm track, duration and strength of ridges, etc.

A Summery Summary!

- GCMs suggest an enhanced temperature gradient along the coast, which could work against PNW heatwaves.
- An OFE was defined, and offshore flow was found to have a strong relationship to temp in W. WA.
- One of the two downscaled CMIP3 runs (CCSM3) suggests substantial change to the temperature distribution over our region.
- Both downscaled runs suggest a decline in the frequency and duration of OFEs.

Questions?

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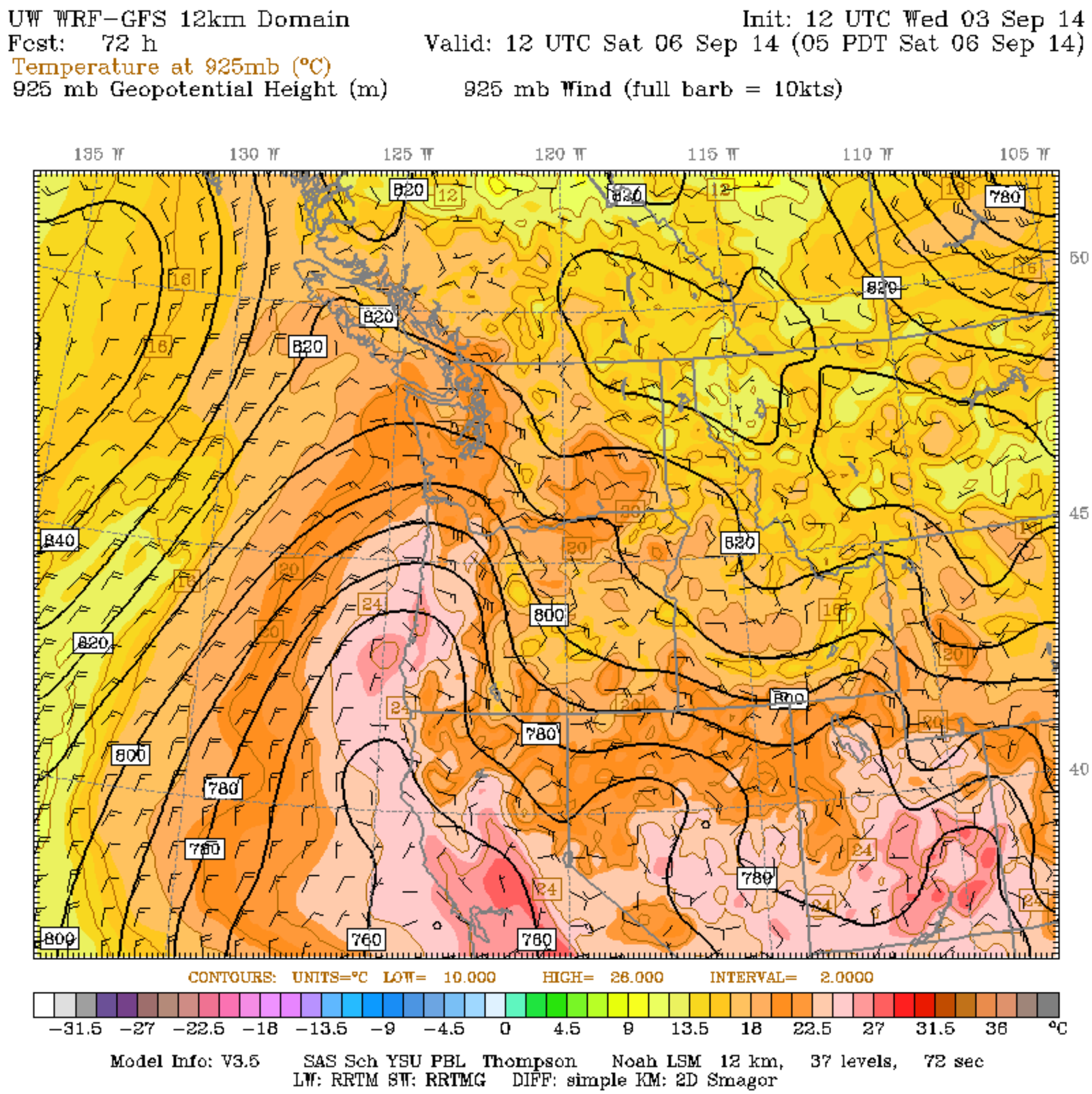
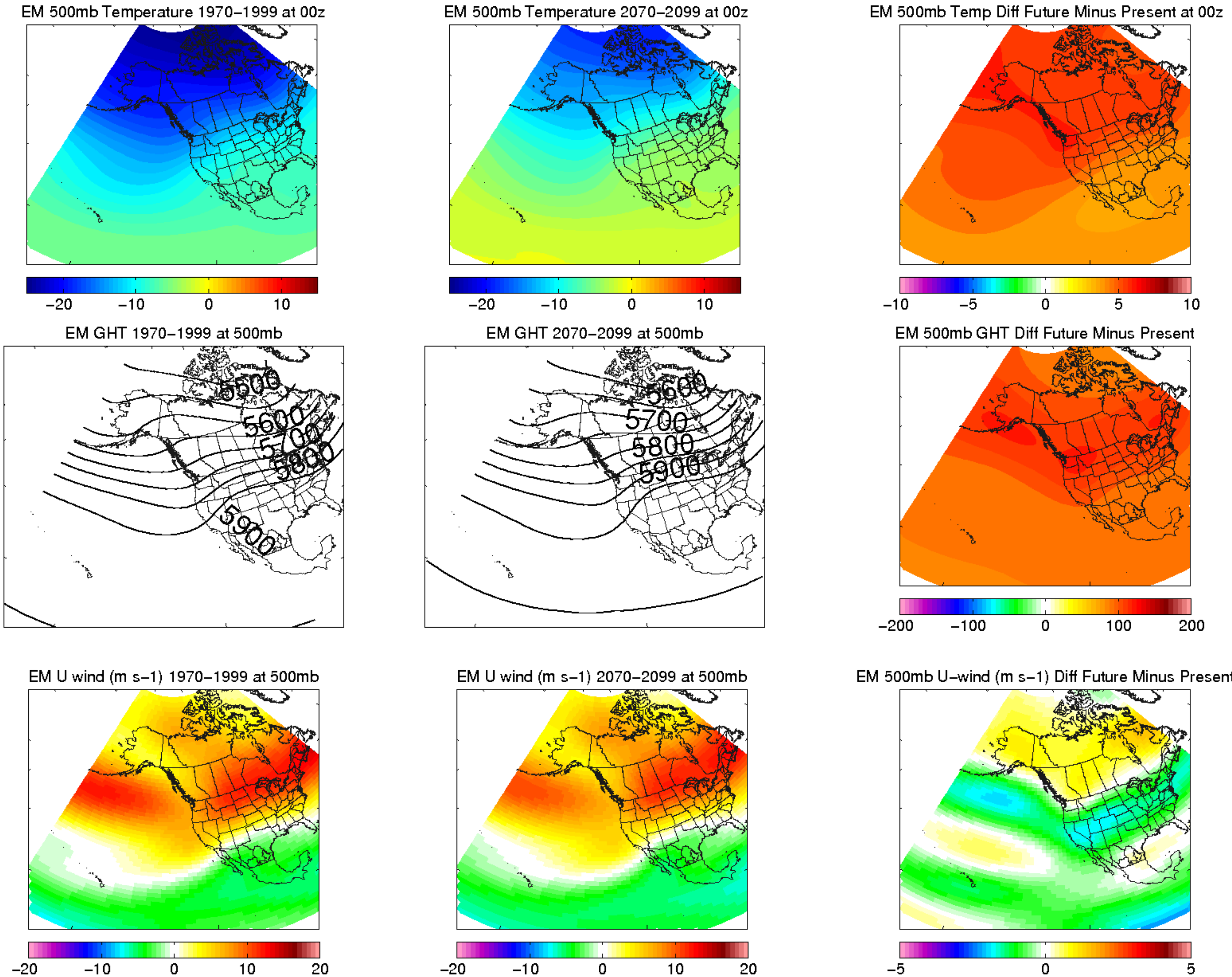
Last Saturday…



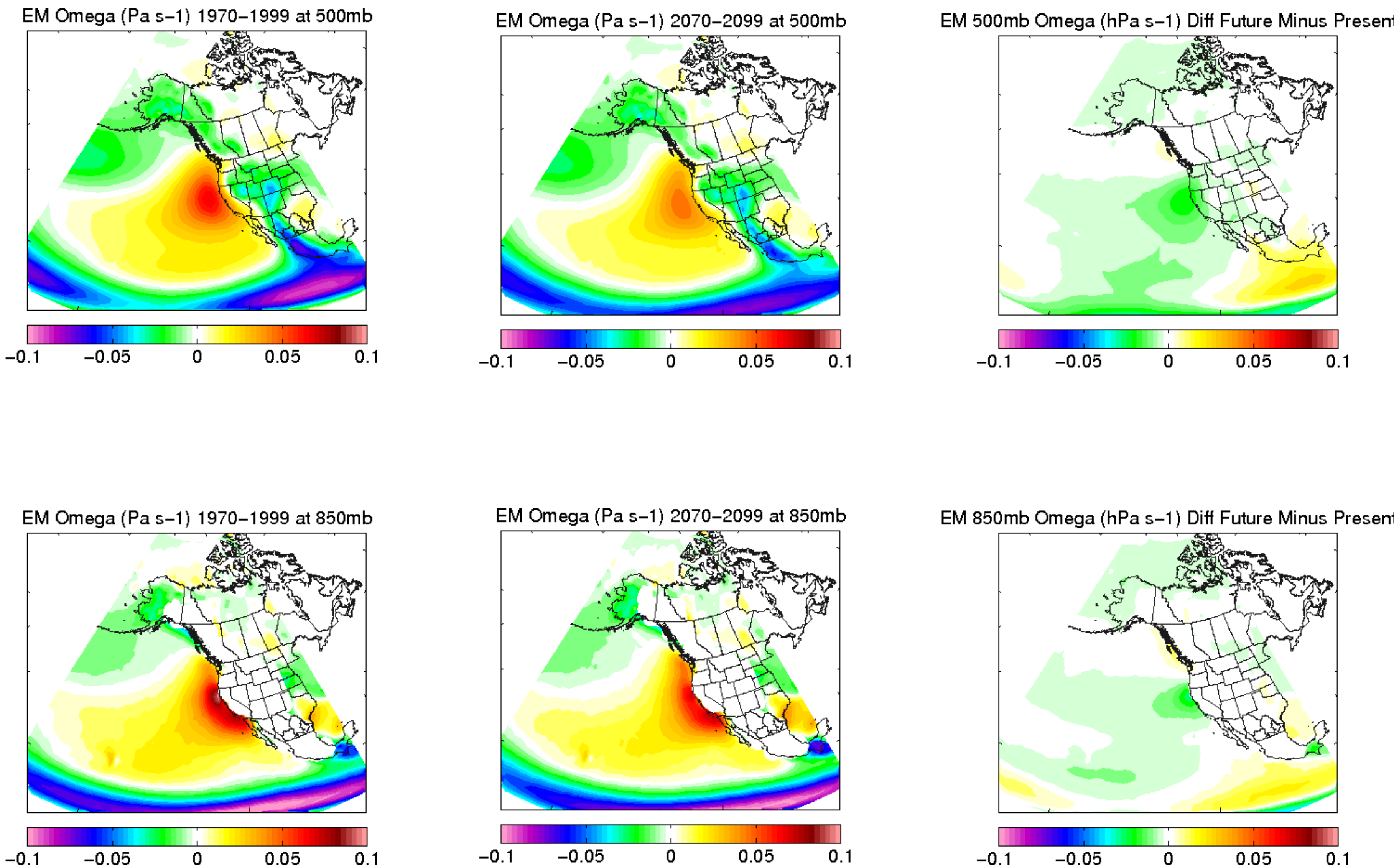
- These conditions bring us our major heatwaves
  - Mass et al. 1986
  - Brewer et al. 2012
  - Bumbaco et al. 2013

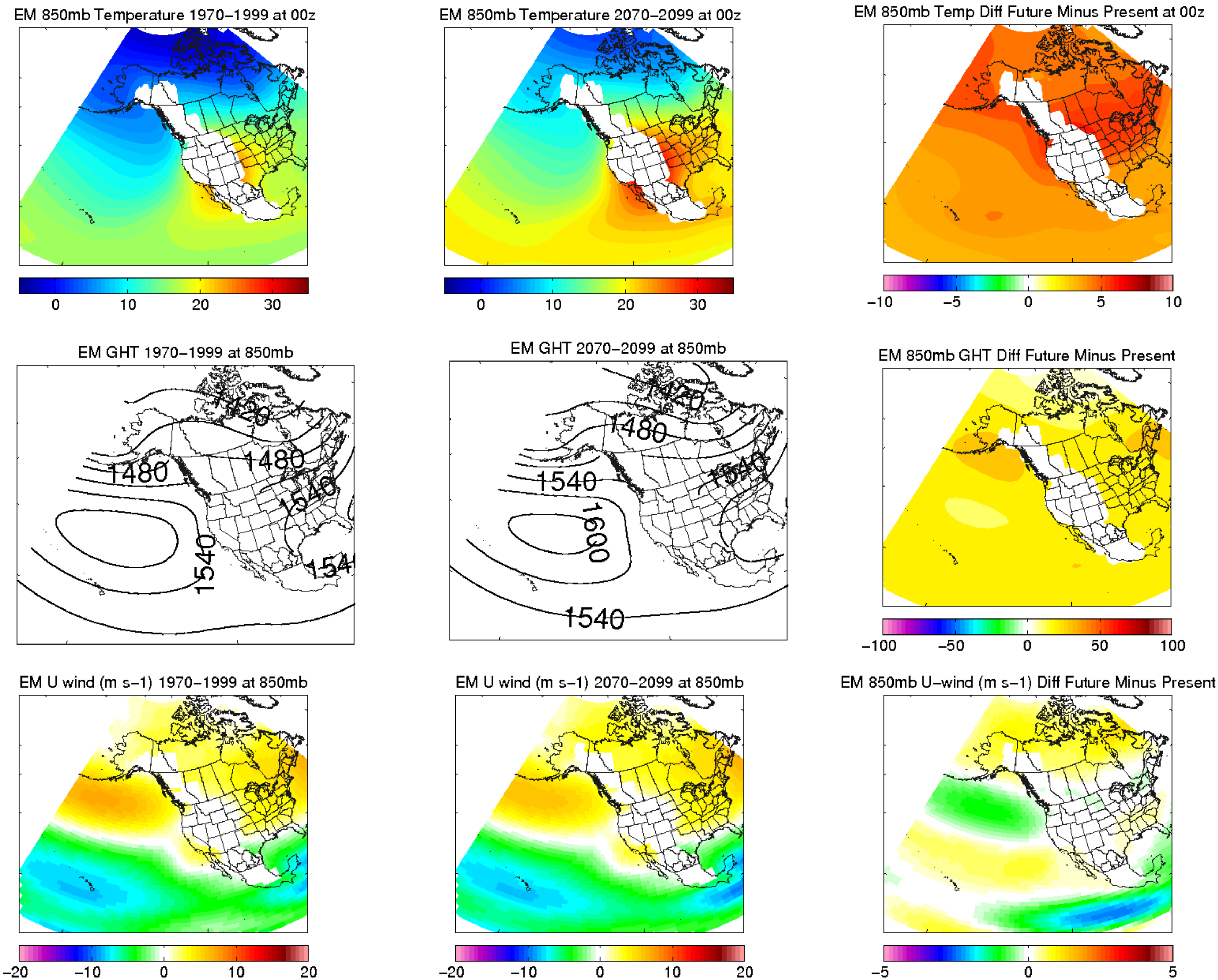
Data

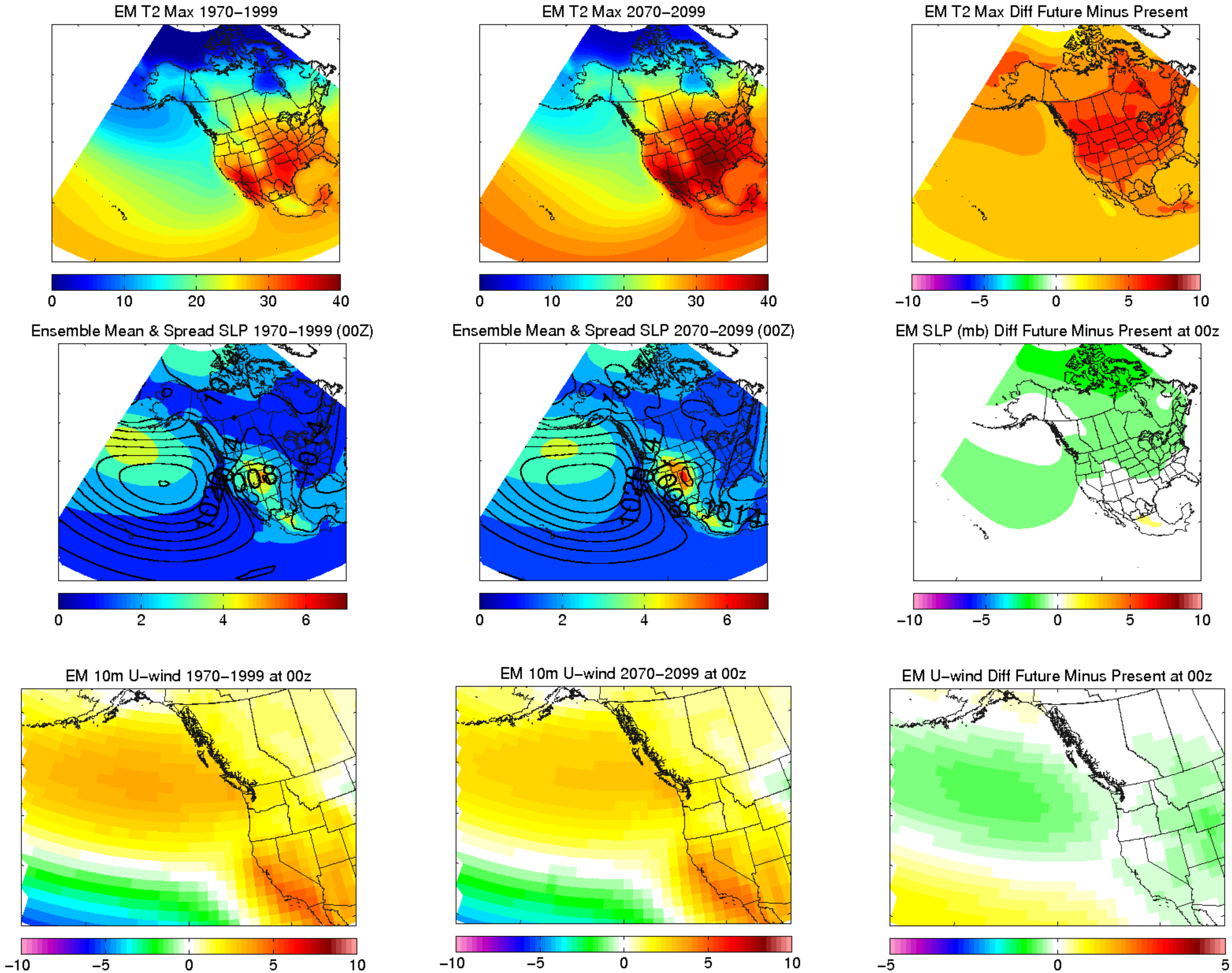
- The WRF V3.1 model was run at 36- & 12-km resolution in a domain centered over Pacific NW with initial/boundary conditions prescribed by:
  - Max Plank Institute ECHAM5 (1970-2070) IPCC AR4
    - 1970-2000 from 20th century control run
    - 2000-2070 A1B scenario
  - NCAR CCSM3 (1970-2070) IPCC AR4
    - 1970-2000 from 20th century control run
    - 2000-2070 A1B scenario
- For all runs, output is 6-hourly (00, 06, 12, and 18z).
- Model Physics: Thompson Microphysics, Kain-Fritsch Cumulus Parameterization, YSU PBL, RRTM Dhudia Radiation, Noah LSM.


EM 500mb Temperature 1970–1999 at 00z
–20
–10
0
10
EM 500mb Temperature 2070–2099 at 00z
–20
–10
0
10
EM 500mb Temp Diff Future Minus Present at 00z
–10
–5
0
5
10
EM GHT 1970–1999 at 500mb
5500
5600
5700
5800
5900
EM GHT 2070–2099 at 500mb
5600
5700
5800
5900
EM 500mb GHT Diff Future Minus Present
–200
–100
0
100
200
EM U wind (m s–1) 1970–1999 at 500mb
–20
–10
0
10
20
EM U wind (m s–1) 2070–2099 at 500mb
–20
–10
0
10
20
EM 500mb U–wind (m s–1) Diff Future Minus Present
–5
0
5

Vertical Motion (Positive is down)

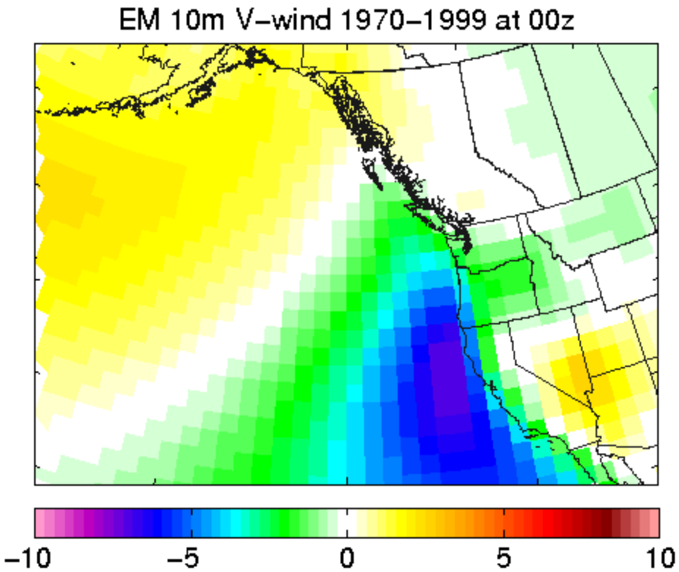


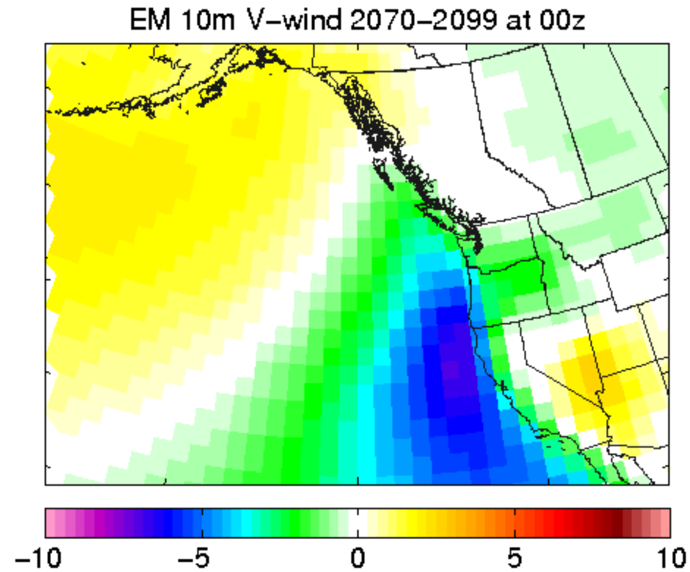

EM 850mb Temperature 1970–1999 at 00z
EM 850mb Temperature 2070–2099 at 00z
EM 850mb Temp Diff Future Minus Present at 00z
0
10
20
30
–10
–5
0
5
10
EM GHT 1970–1999 at 850mb
EM GHT 2070–2099 at 850mb
EM 850mb GHT Diff Future Minus Present
1420
1480
1540
1600
–100
–50
0
50
100
EM U wind (m s–1) 1970–1999 at 850mb
EM U wind (m s–1) 2070–2099 at 850mb
EM 850mb U–wind (m s–1) Diff Future Minus Present
–20
–10
0
10
20
–5
0
5

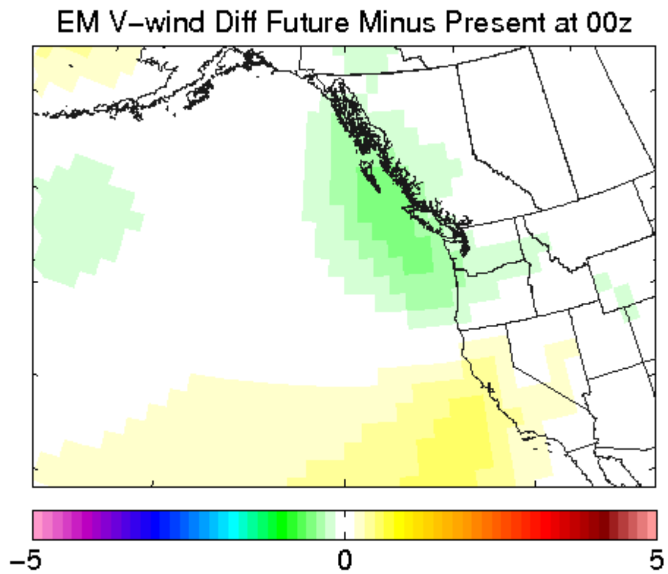


EM T2 Max 1970–1999
0 10 20 30 40
EM T2 Max 2070–2099
0 10 20 30 40
EM T2 Max Diff Future Minus Present
–10 –5 0 5 10
Ensemble Mean & Spread SLP 1970–1999 (00Z)
0 2 4 6
Ensemble Mean & Spread SLP 2070–2099 (00Z)
0 2 4 6
EM SLP (mb) Diff Future Minus Present at 00z
–10 –5 0 5 10
EM 10m U–wind 1970–1999 at 00z
–10 –5 0 5 10
EM 10m U–wind 2070–2099 at 00z
–10 –5 0 5 10
EM U–wind Diff Future Minus Present at 00z
–5 0 5

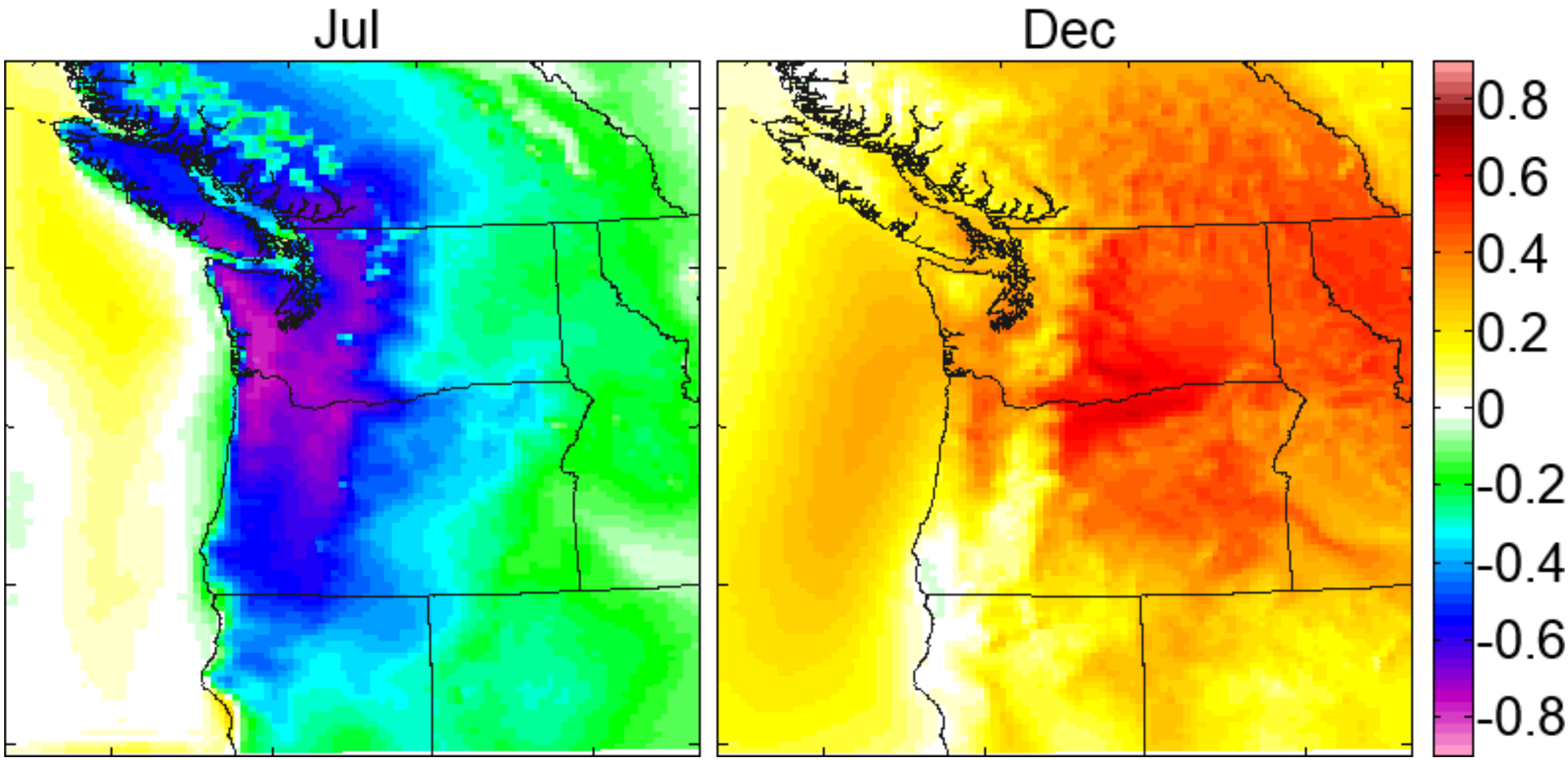
10m V-wind


EM 10m V−wind 1970−1999 at 00z
−10
−5
0
5
10

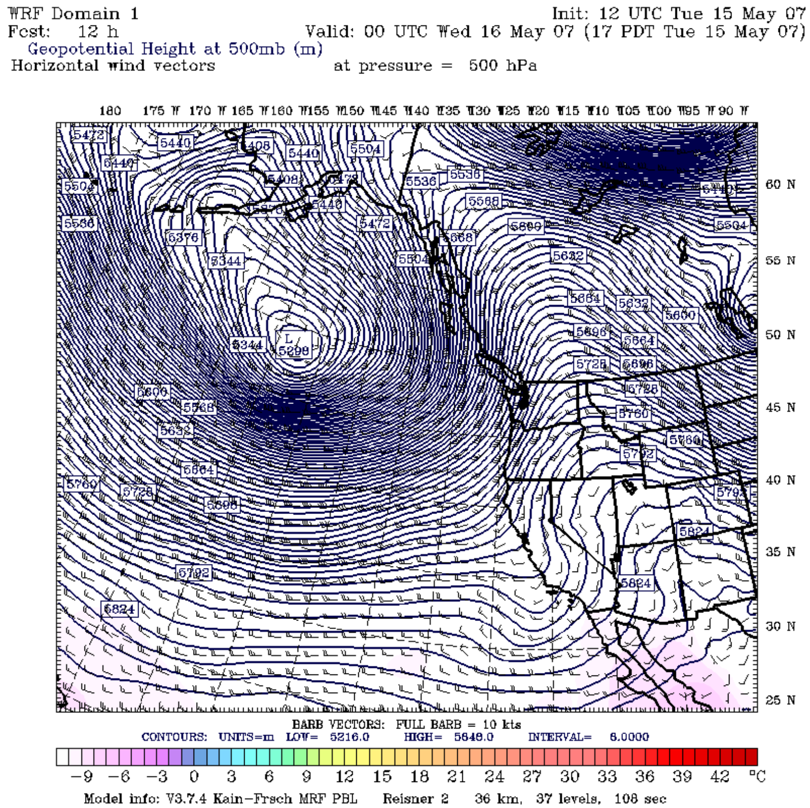

EM 10m V−wind 2070−2099 at 00z
−10
−5
0
5
10

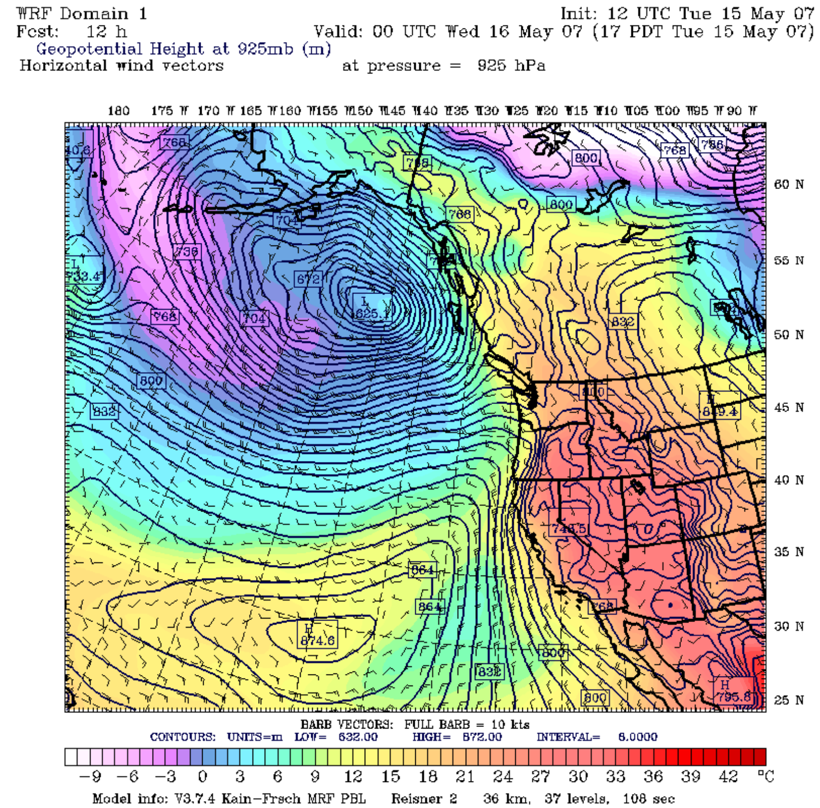

EM V−wind Diff Future Minus Present at 00z
−5
0
5

What is the correlation between UW index (00z) and temp (00z)?

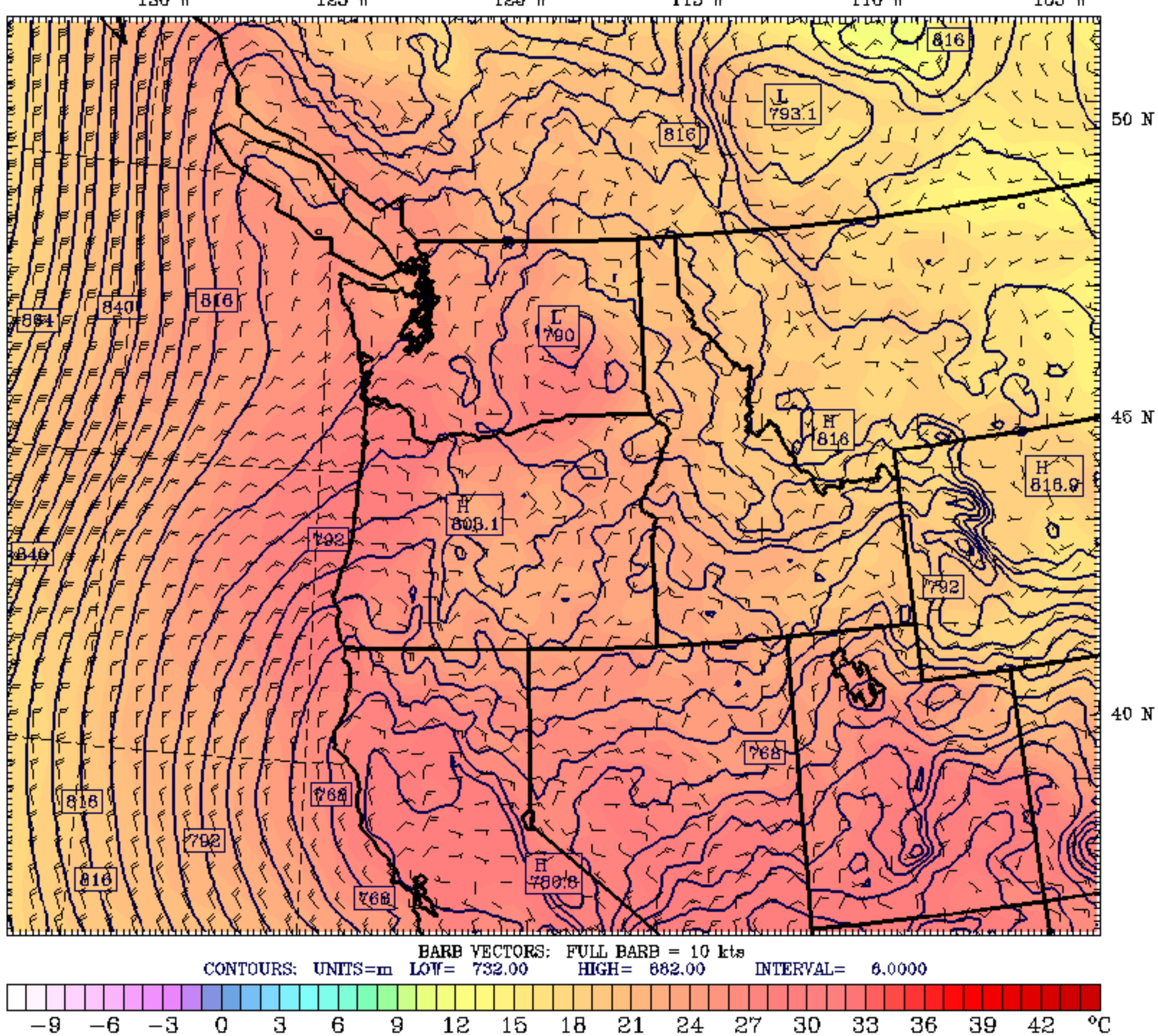


Offshore Flow/WCTT Event: May 13-16 2007



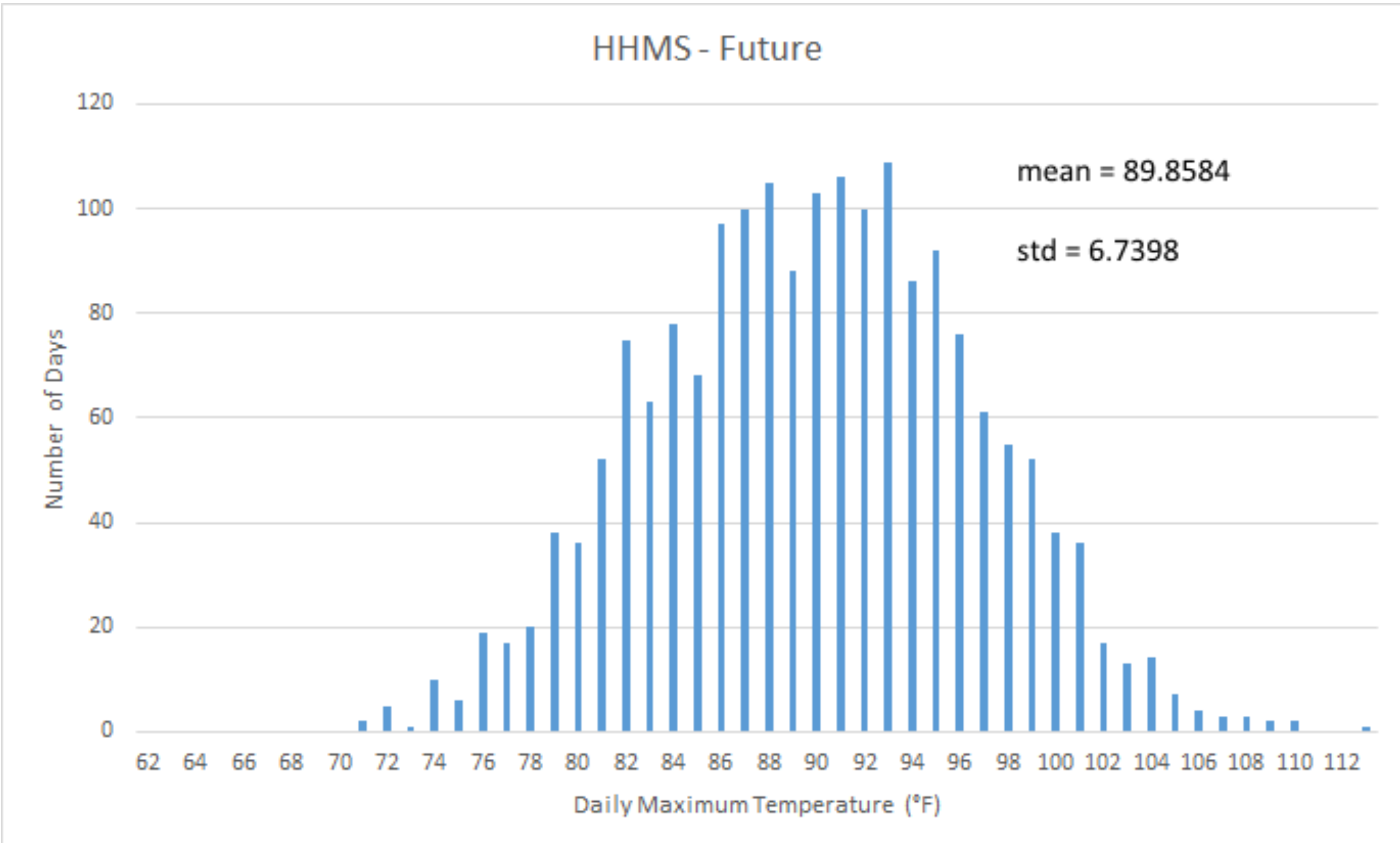


WRF Domain 2 Init: 00 UTC Tue 28 Jul 09
Fcst: 12 h Valid: 12 UTC Tue 28 Jul 09 (05 PDT Tue 28 Jul 09)
Geopotential Height at 925mb (m)
Horizontal wind vectors at pressure = 925 hPa



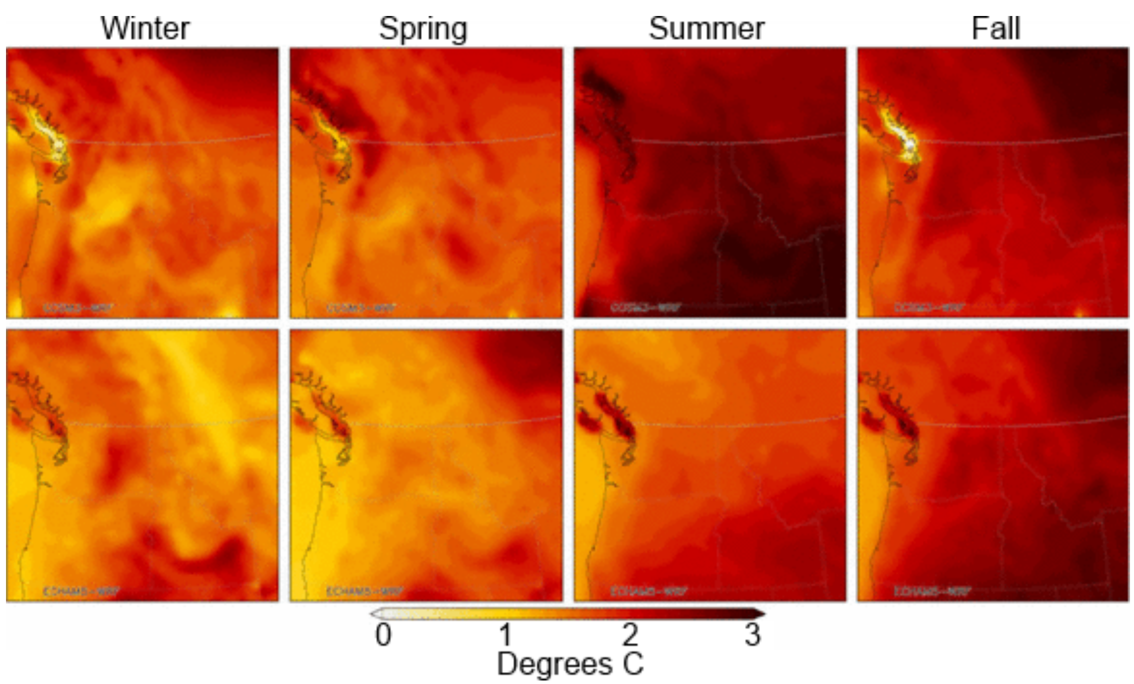
HHMS 2m Temp (°F) Distribution

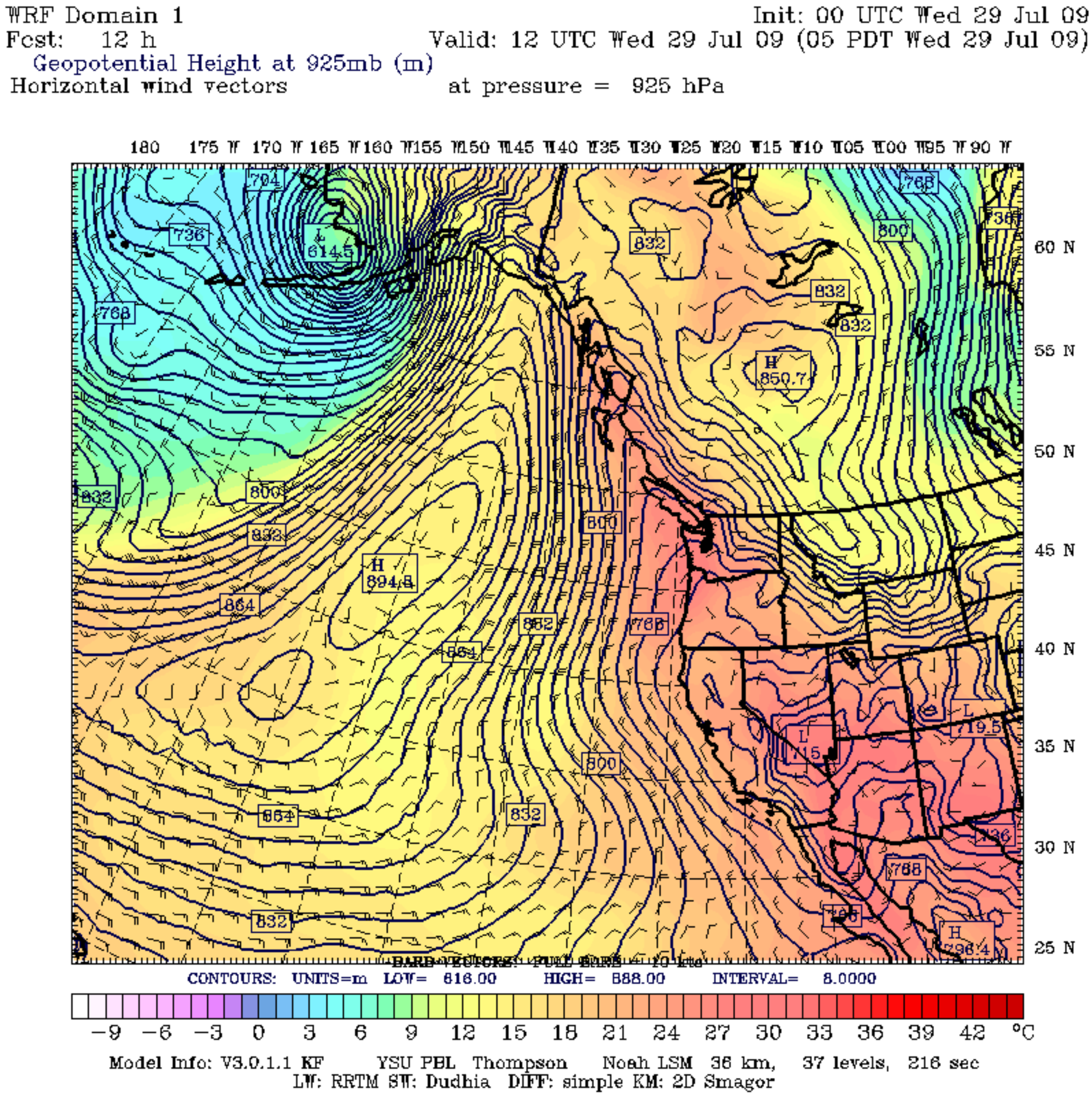
From downscaled CCSM3 run



Future Projections

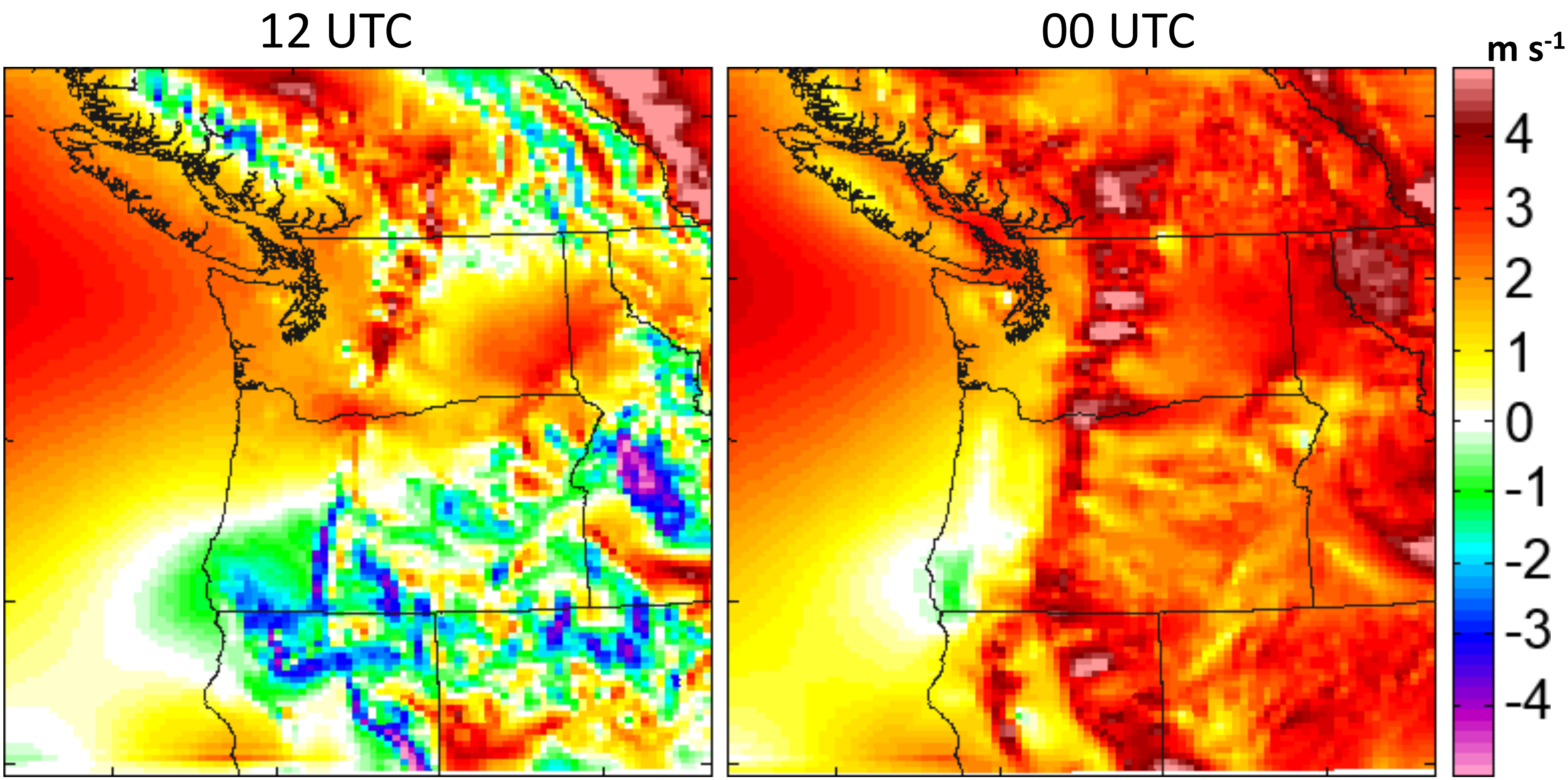
- Salathé et al. 2010 used two 100-yr regional climate runs using the WRF model, forced by 2 GCMs (ECMWF5,CCSM3).



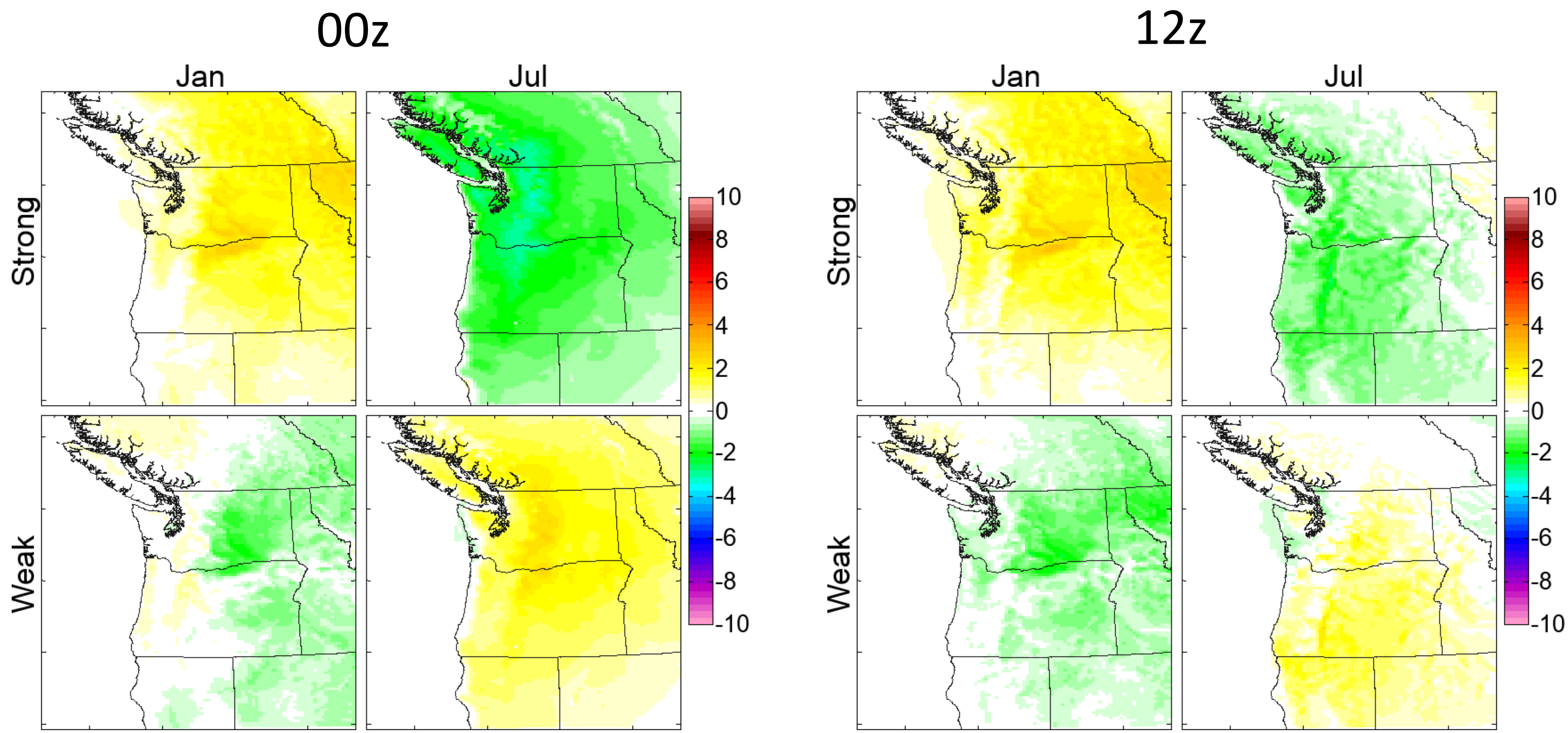

WRF Domain 1
Fcst: 12 h
Init: 00 UTC Wed 29 Jul 09
Valid: 12 UTC Wed 29 Jul 09 (05 PDT Wed 29 Jul 09)
Geopotential Height at 925mb (m)
Horizontal wind vectors
at pressure = 925 hPa
180 175 W 170 W 165 W 160 W 155 W 150 W 145 W 140 W 135 W 130 W 125 W 120 W 115 W 110 W 105 W 100 W 95 W 90 W
60 N
55 N
50 N
45 N
40 N
35 N
30 N
25 N
CONTOURS: UNITS=m LOW= 616.00 HIGH= 888.00 INTERVAL= 8.0000
−9 −6 −3 0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 °C
Model Info: V3.0.1.1 KF YSU PBL Thompson Noah LSM 36 km, 37 levels, 216 sec
LW: RRTM SW: Dudhia DIFF: simple KM: 2D Smagor

Average U-wind at 850 mb

-From 12-km UW WRF runs
-Composites from Jul-Aug 2009-2011



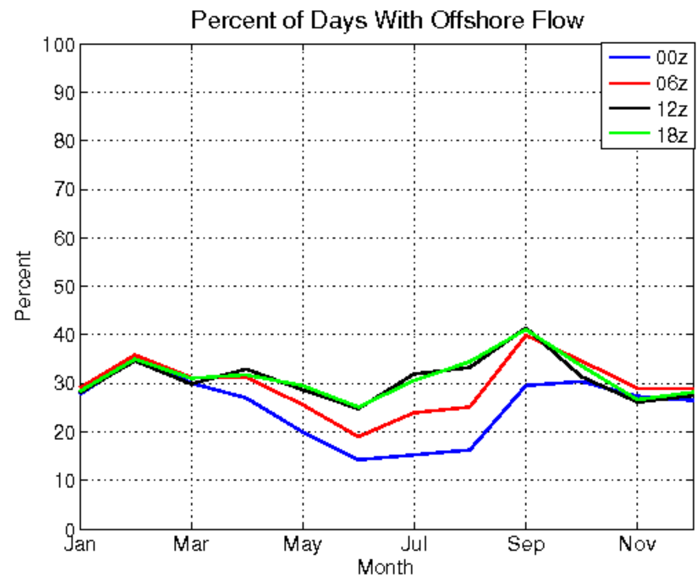
T (°C) Composites of Onshore Flow

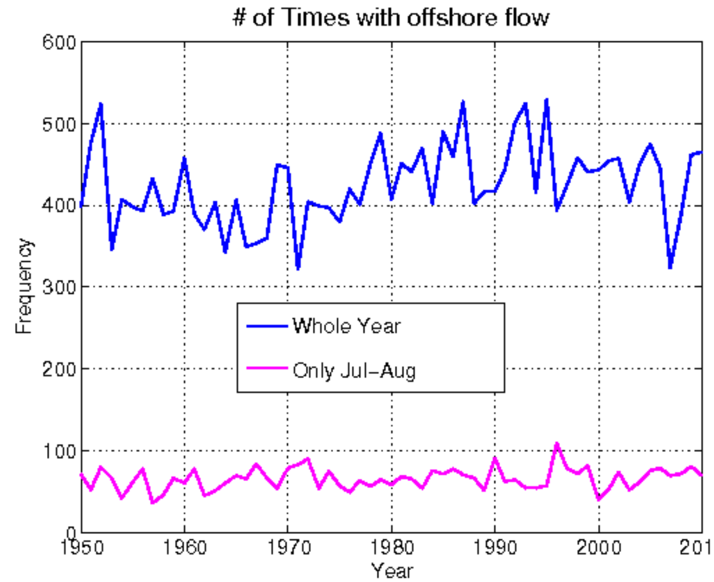


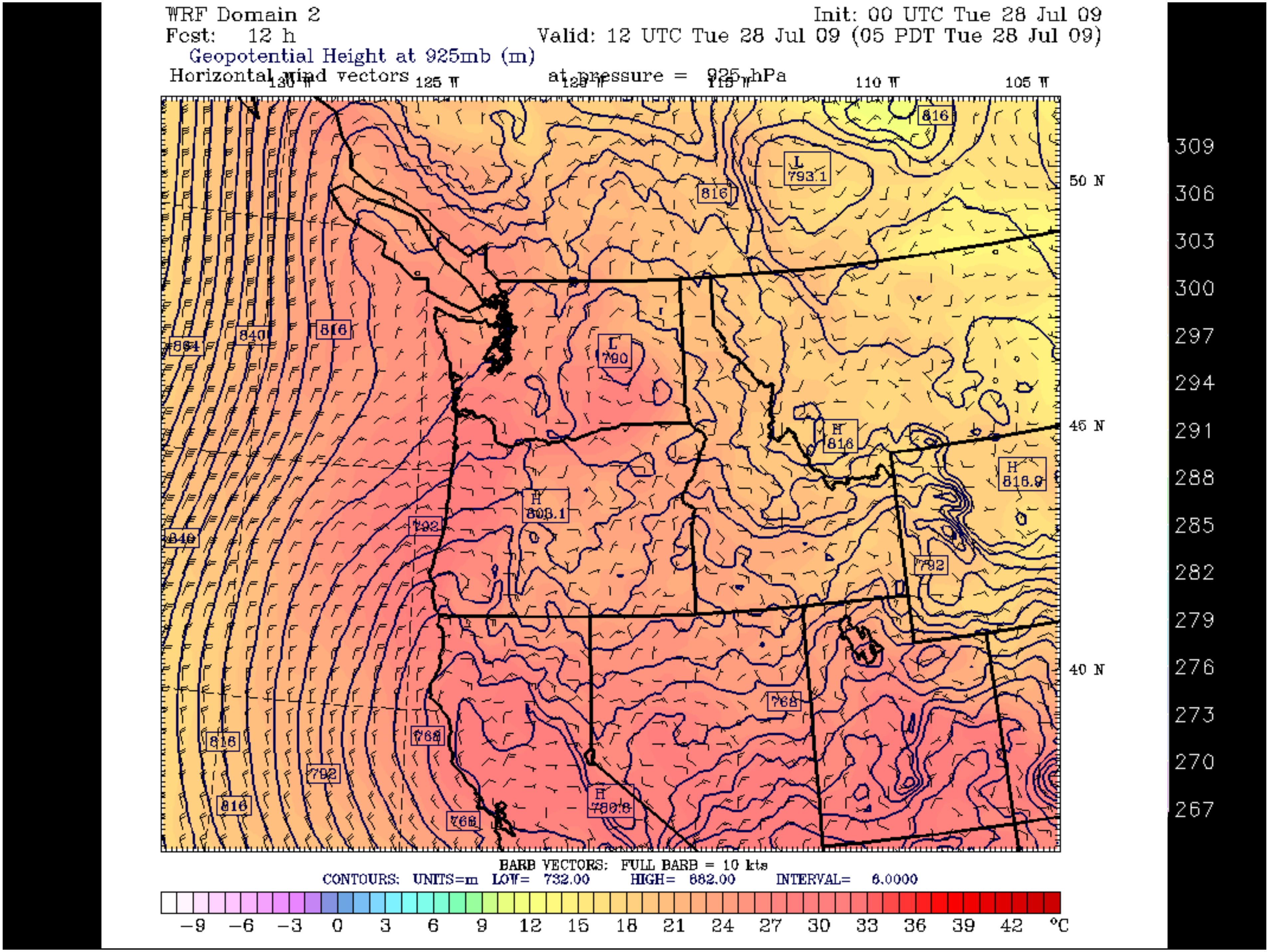
Strong = greater than 3 m/s Weak = less than or equal to 3 m/s

Offshore Flow Definition

- Every 6 hours, the U-wind average is taken of all grid points at 850 hPa along the Cascade crest in Oregon and Washington.
  - Grid points are ignored along the crest when the terrain is above 850 hPa.
- This information will be used to define an event later on.

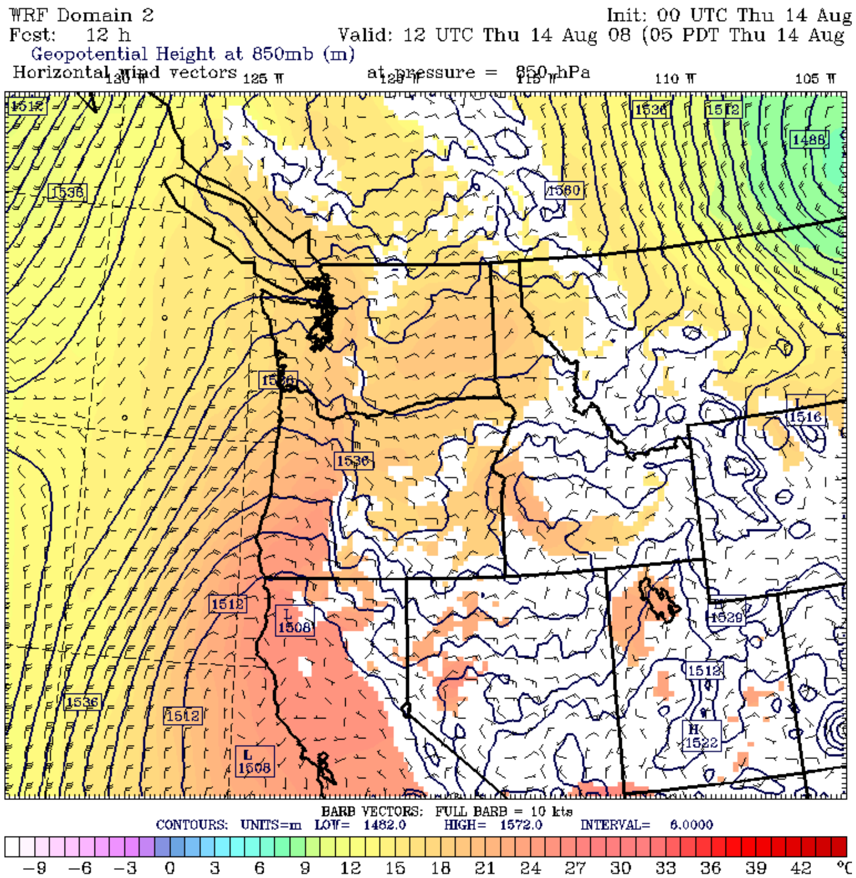


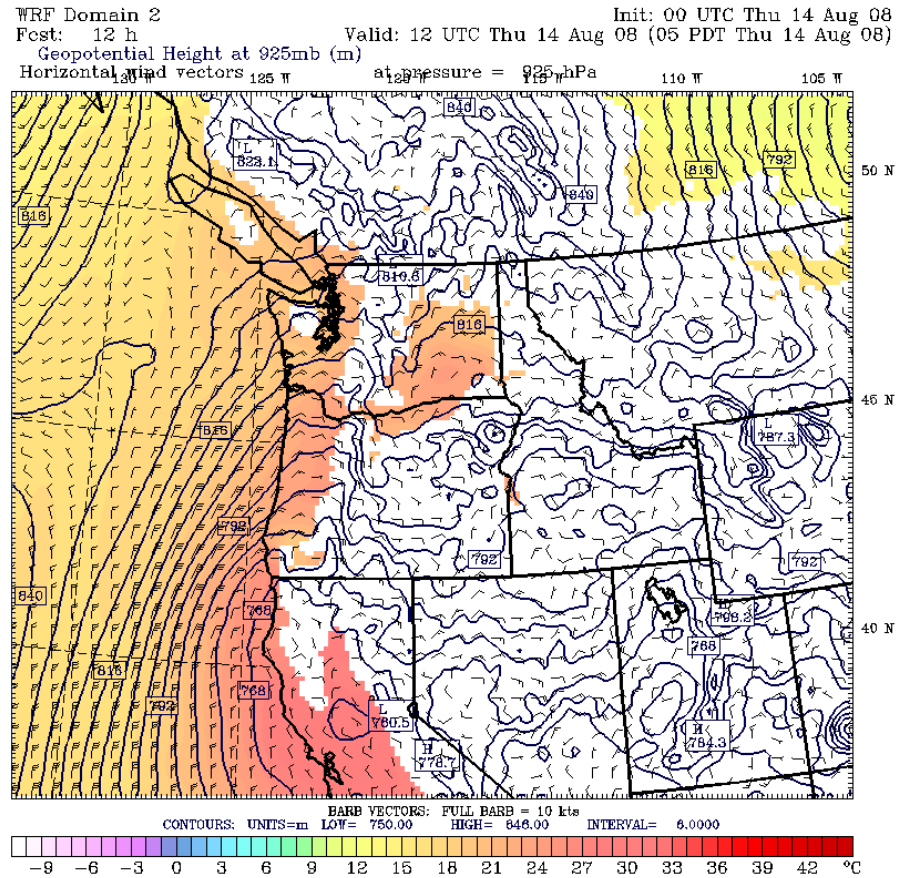


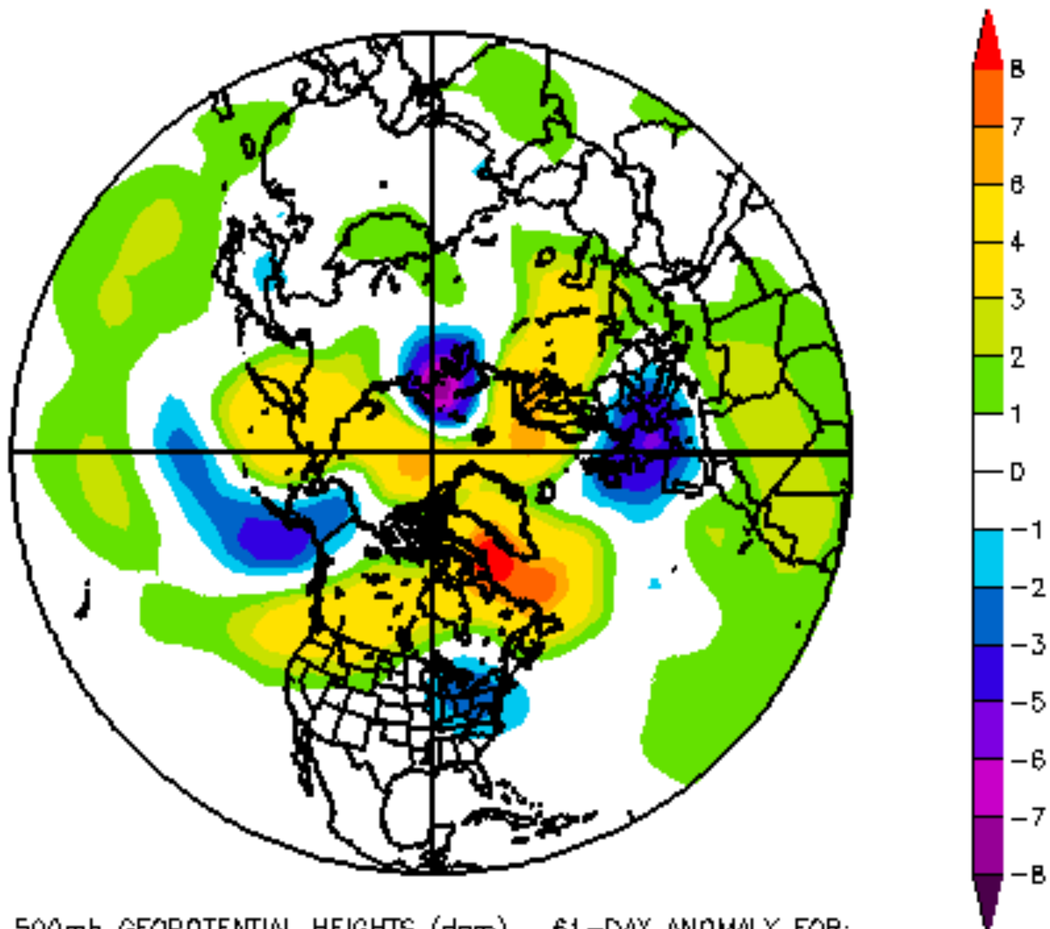


WRF Domain 2
Fcst: 12 h
Init: 00 UTC Tue 28 Jul 09
Valid: 12 UTC Tue 28 Jul 09 (05 PDT Tue 28 Jul 09)
Geopotential Height at 925mb (m)
Horizontal wind vectors at pressure = 925 hPa
130 W
125 W
120 W
115 W
110 W
105 W
50 N
45 N
40 N
L 793.1
L 790
H 816
H 816.9
H 808.1
H 780.8
BARB VECTORS: FULL BARB = 10 kts
CONTOURS: UNITS=m LOW= 732.00 HIGH= 882.00 INTERVAL= 6.0000
−9 −6 −3 0 3 6 9 12 15 18 21 24 27 30 33 36 39 42 °C
309
306
303
300
297
294
291
288
285
282
279
276
273
270
267

Offshore flow where? What level?







500mb GEOPOTENTIAL HEIGHTS (dam) 61-DAY ANOMALY FOR:
Tue JUL 01 2014 - Sat AUG 30 2014

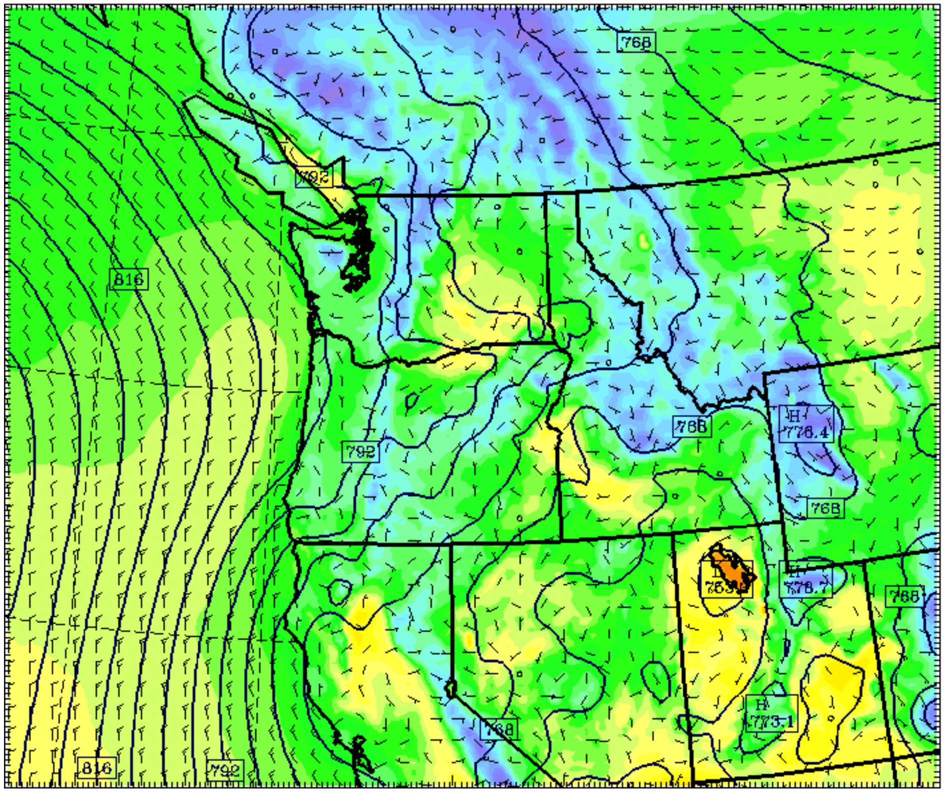
NCEP OPERATIONAL DATASET

WRF 12-km Composites

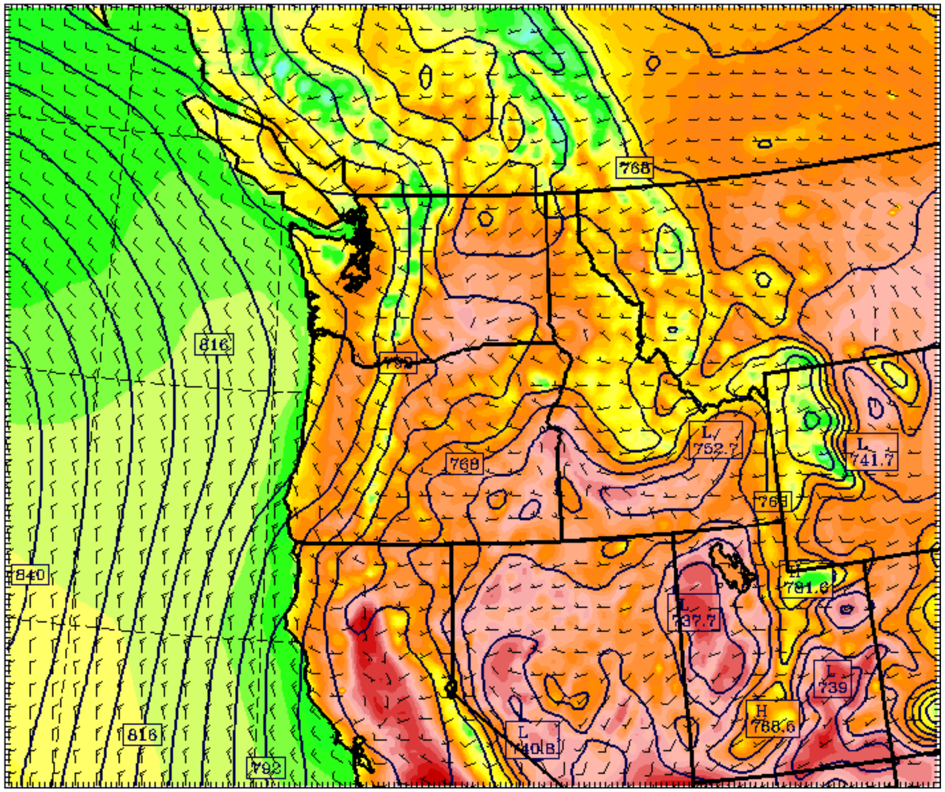
925mb GHT and 2-m Temp and 10-m Wind

Jul-Aug 2009-2011

1200 UTC

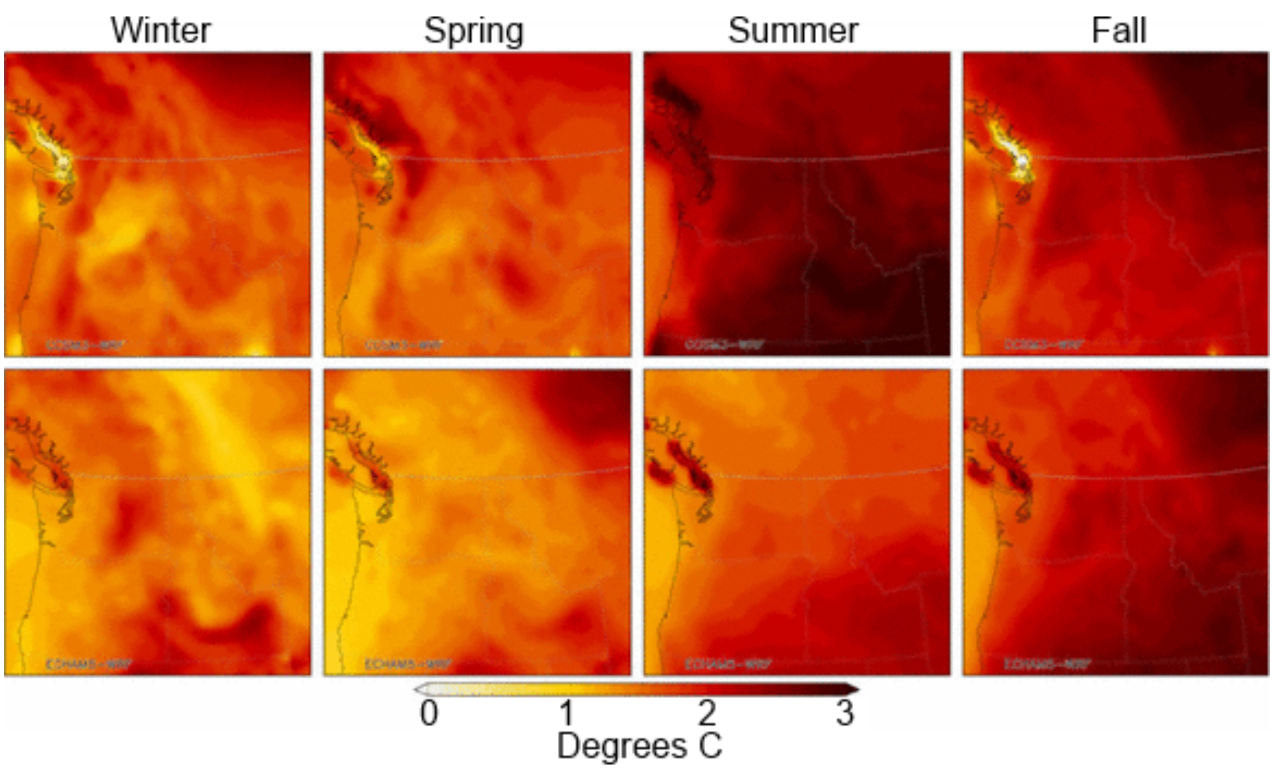


0000 UTC



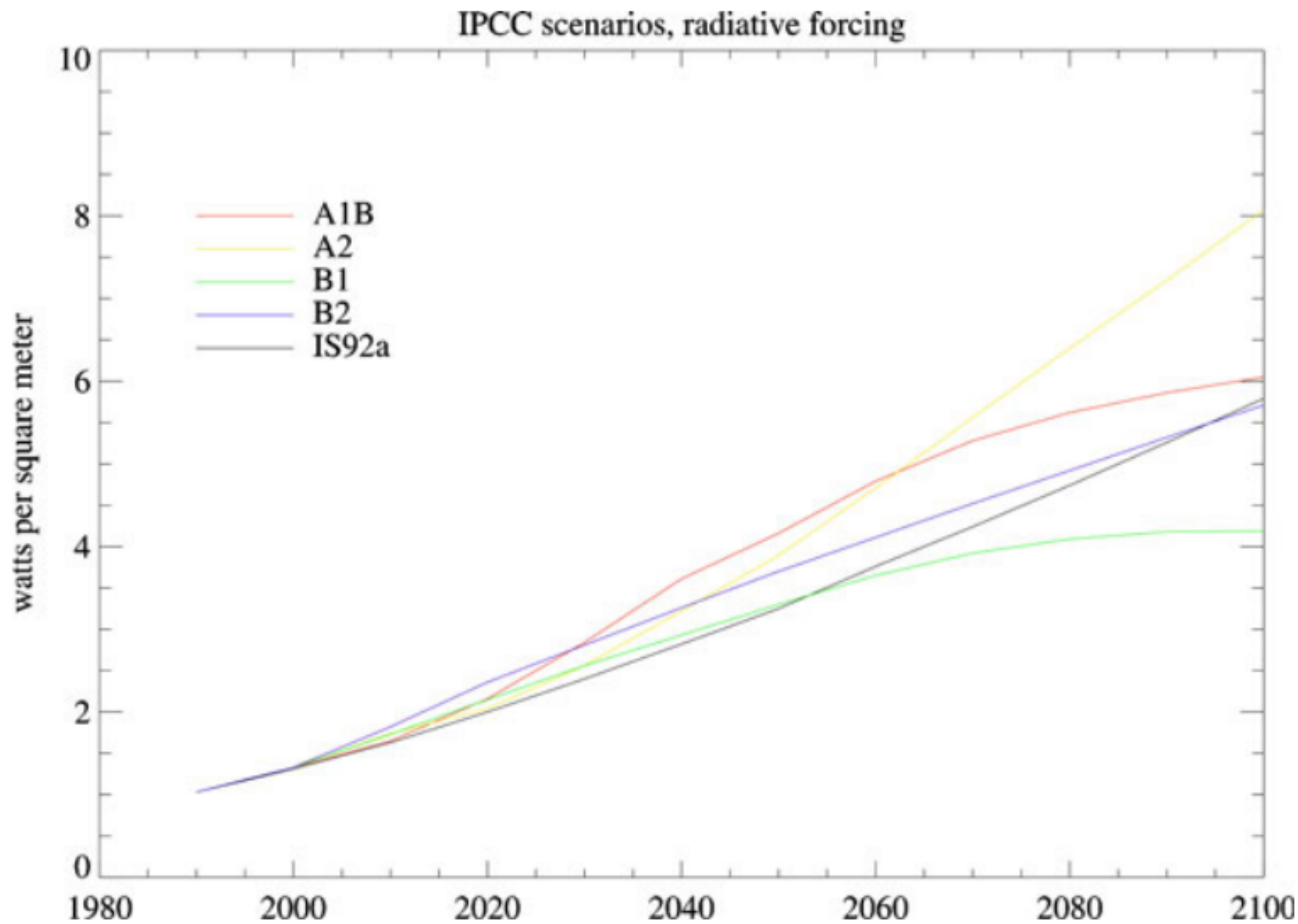
Downscaled runs – seasonal composites

- Salathé et al. 2010 used the ECHAM3 and CCSM3 downscaled climate runs.
  - Change in temp from 1970-1999 to 2030-2059.



CCSM3

ECHAM5

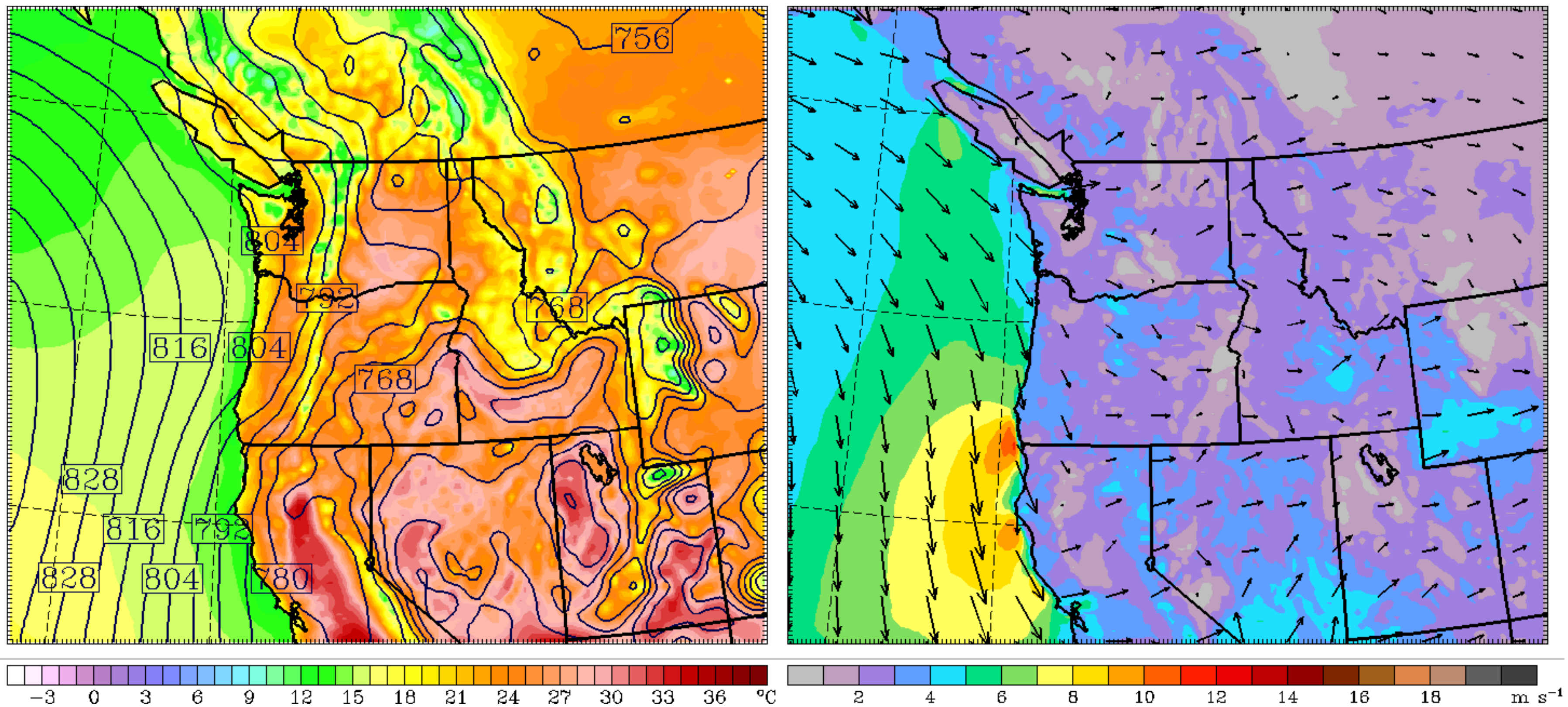


Globally averaged radiative forcing by greenhouse gases and sulfate aerosols, for four of the six illustrative scenarios plus the older IS92a scenario, from IPCC (2001) Appendix II.3.

WRF 12-km Composites

925mb GHT and 2-m Temp (left) and 10-m Wind (right)
Jul-Aug 2009-2011

1700 LDT



The mechanics of Heatwaves

- How will thermal trough/offshore flow events change under AGW?
  - Important questions to address:
    - Will events more/less frequent?
    - Will events be longer/shorter?
    - Will offshore flow be stronger/weaker?
    - Will heat waves associated with events be longer/ shorter and more/less intense?
      - In order to completely understand how Pacific Northwest heat waves will evolve under AGW, we must understand how the synoptic conditions that bring them about will evolve.