Western North American extreme heat, associated large scale synoptic-dynamics, and performance by a climate model.

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Or:

US West Coast Hot Spell Patterns Observed and in Climate models

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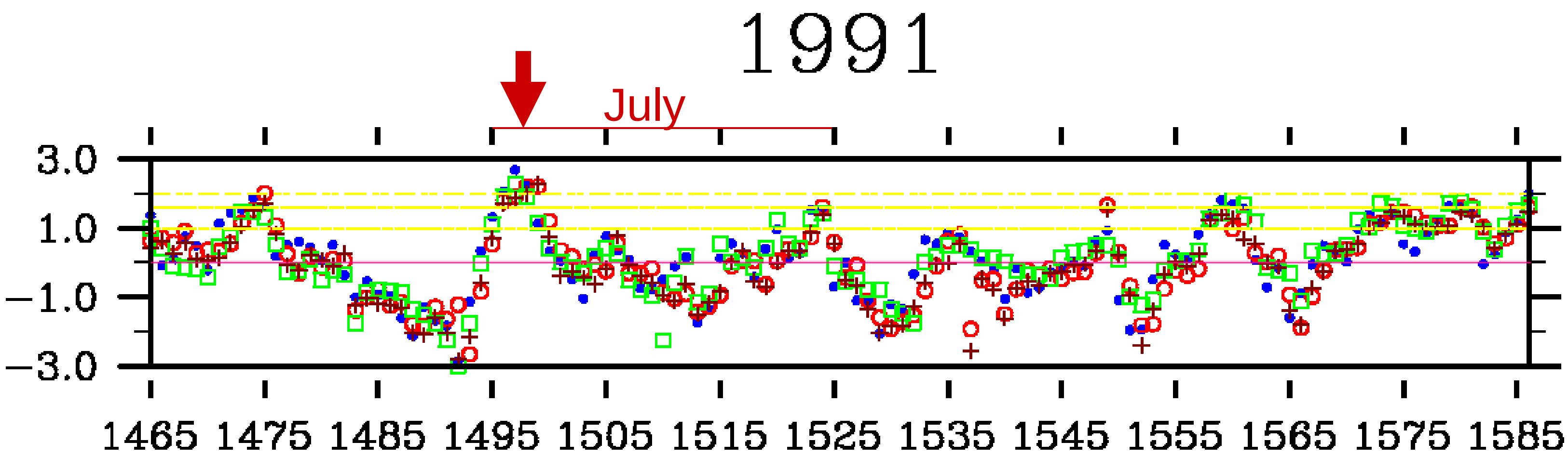
Outline

1. Some climate extremes are weather events
2. Temperature extremes involve air mass shifts
3. California Heat waves: upper air large scale meteorological patterns (LSMPs) synoptics & some dynamics
4. Are LSMPs predictive of surface heat?
5. Are LSMPs simulated in climate model?
6. Summary and other considerations

1 of 5
Climate extremes are weather events

Monthly means miss extremes: Jul. 1991 CV Ta_max



Daily anomaly maximum temperatures at 4 CV stations June-Sept. 1991
Normalized by each station's STD. Pink line is LTDM.

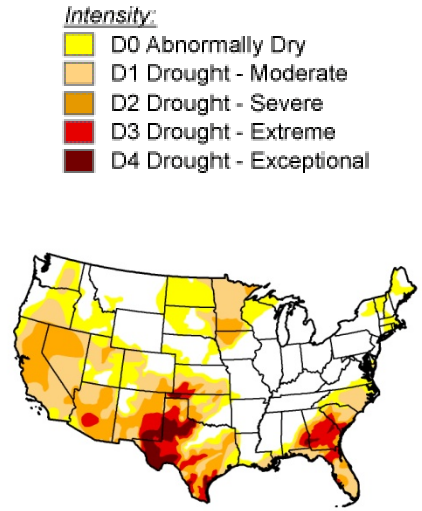
- One of the hottest anomalies in at least 30 years (>2.6 STD).
- Daily anomaly temperatures show 3-4 days of extreme heat
- Rest of month was generally below average.
- The mean for the month? -0.2 STD (Standard deviations). Below normal!

- **A cooler than normal July had one of state's hottest heat waves**
- Conclusion: **The monthly mean misses this important event!**

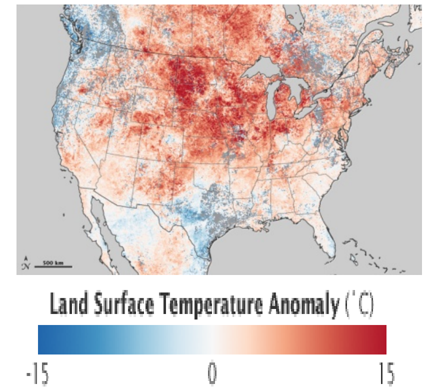
2 of 5
Temperature extremes involve air mass shifts

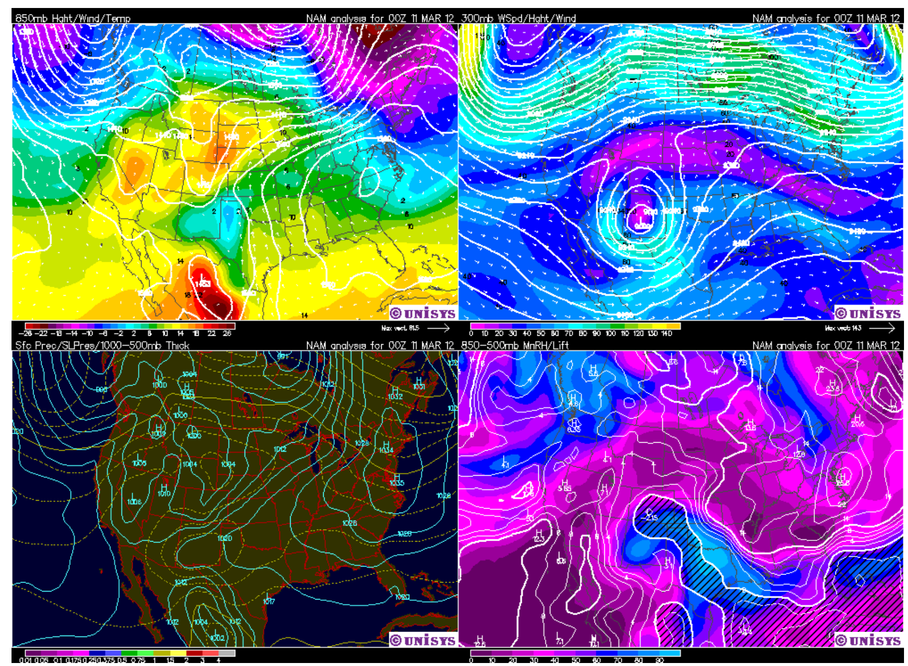
2012 US heat waves & drought

- Longer term drought punctuated by multiple extreme heat events
  - 13-19March (1,054 records; pic 8-15 March: anomalies vs 2000-11 ave)
  - Other periods in June, July, later? (major fires, 29 June derecho blackout)
- March event sequence: 11th



Figs from NOAA, NASA Unisys





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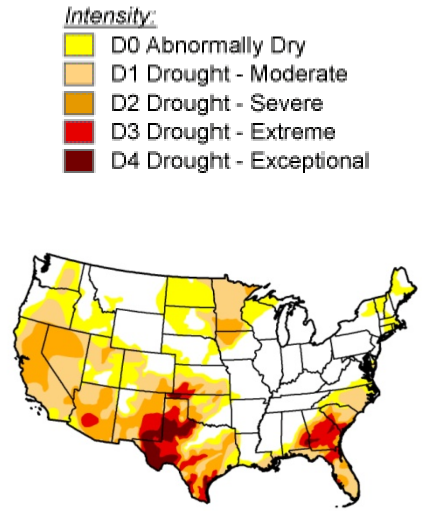

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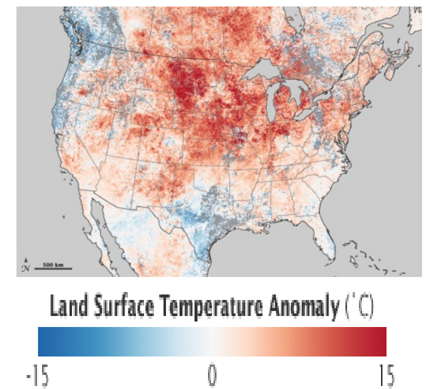
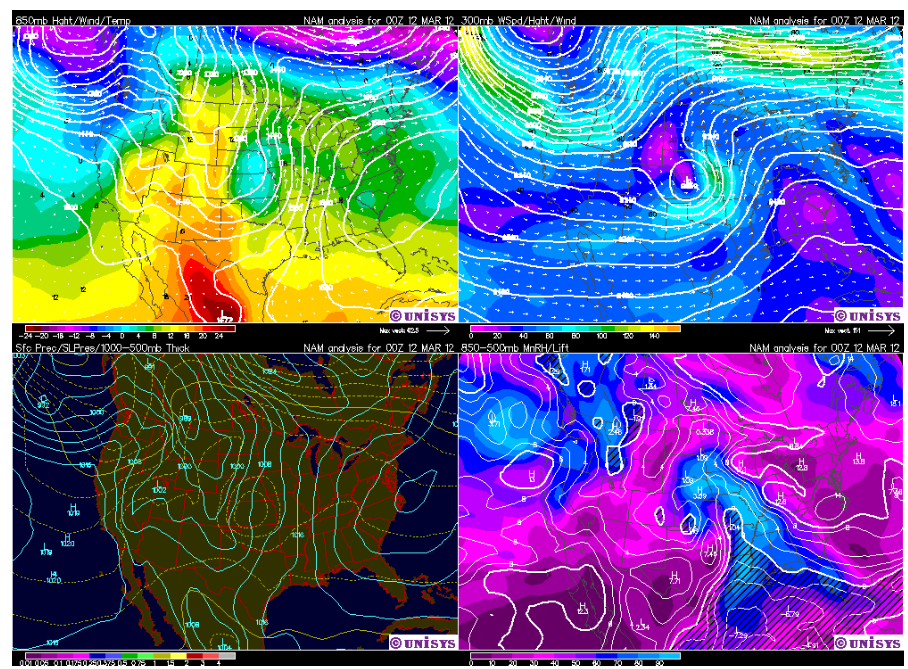
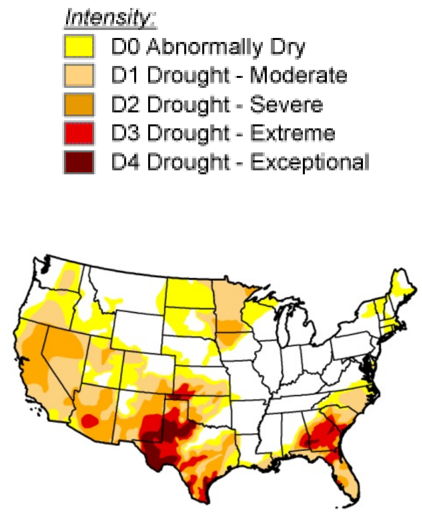




2012 US heat waves & drought



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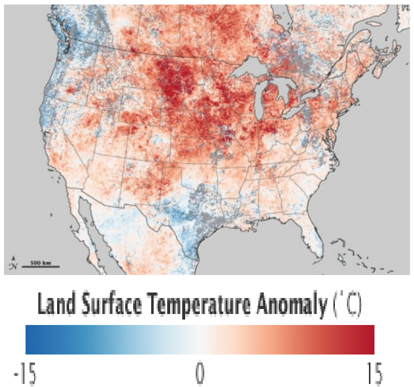

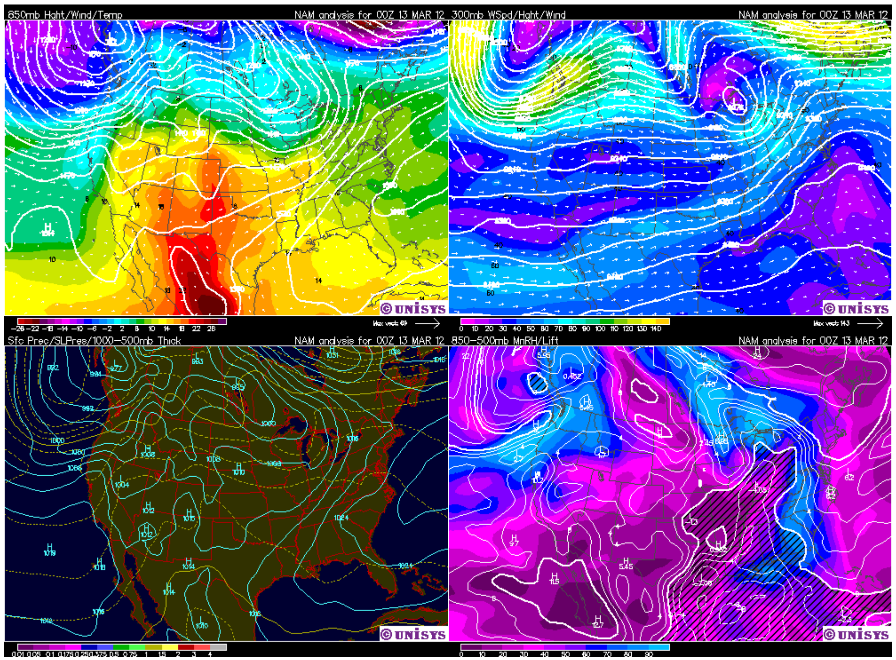

2012 US heat waves & drought

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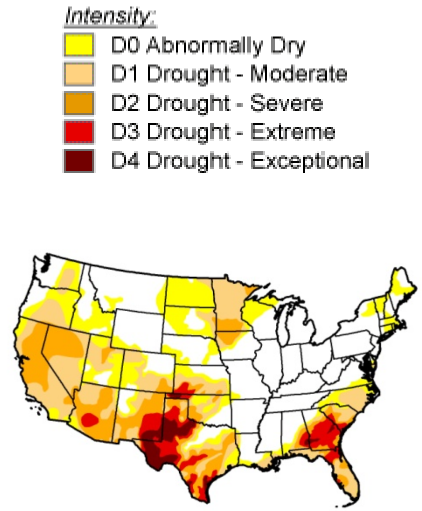

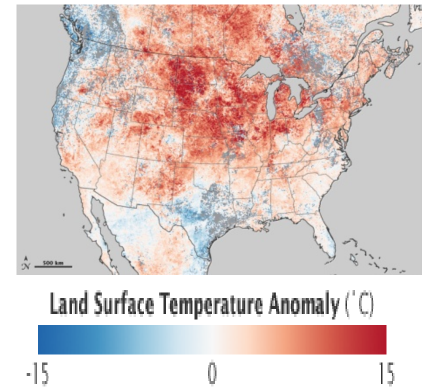

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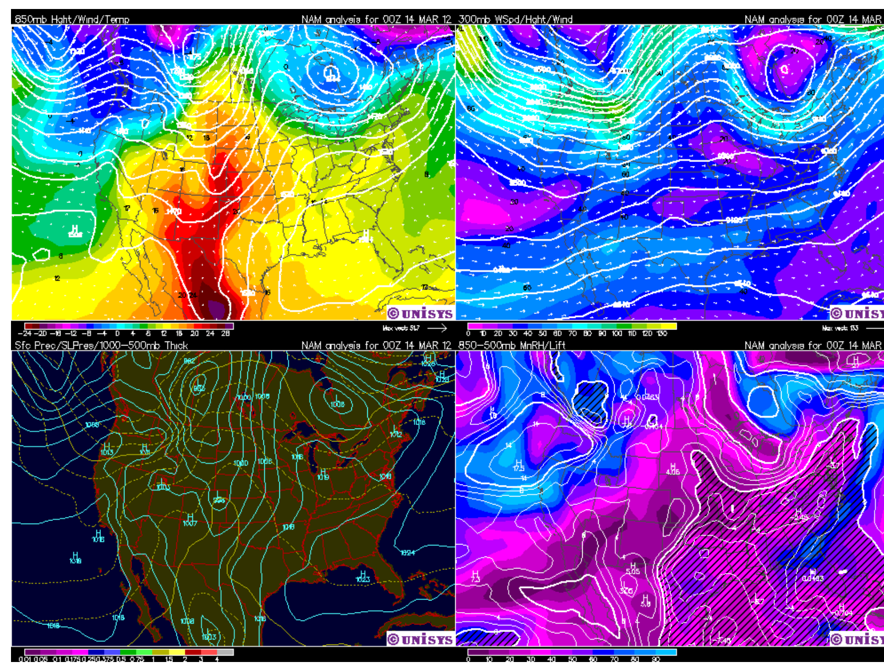

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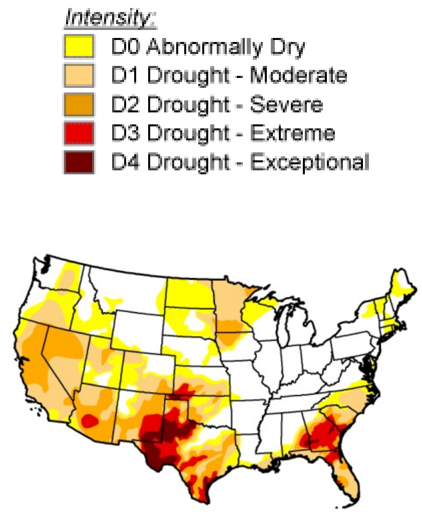
- March event sequence: 15th



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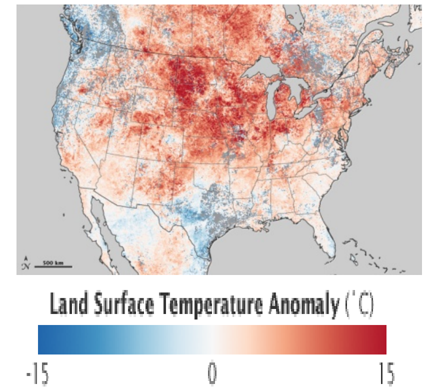
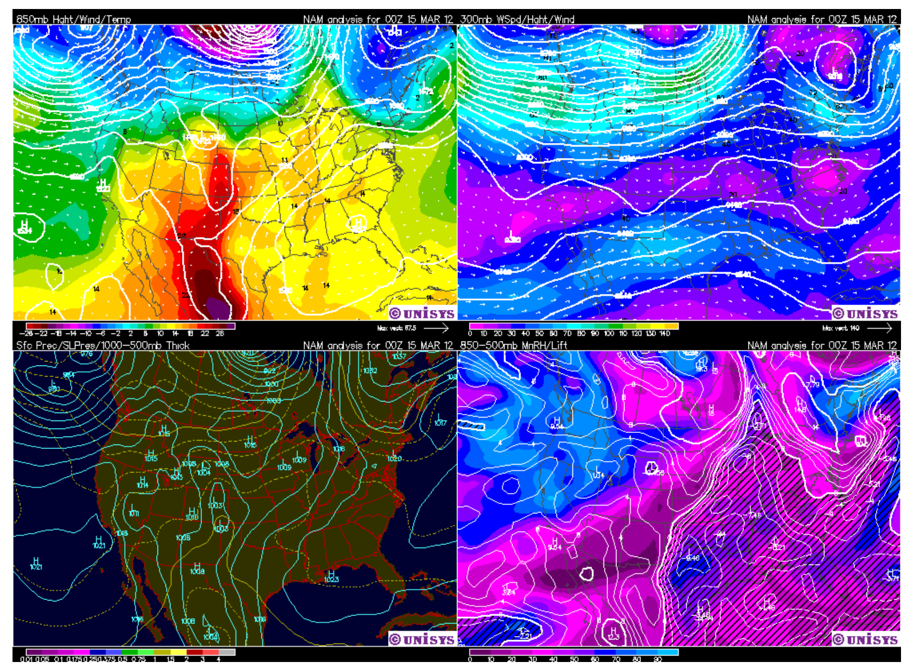
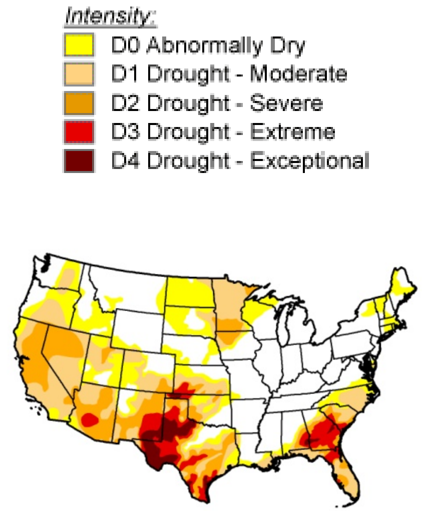




2012 US heat waves & drought



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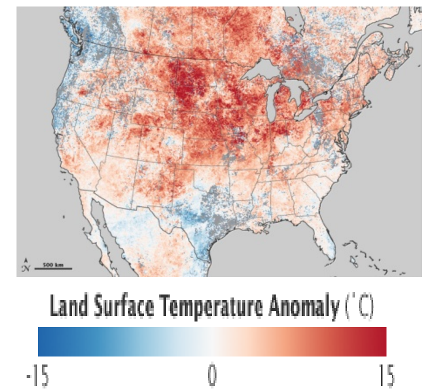

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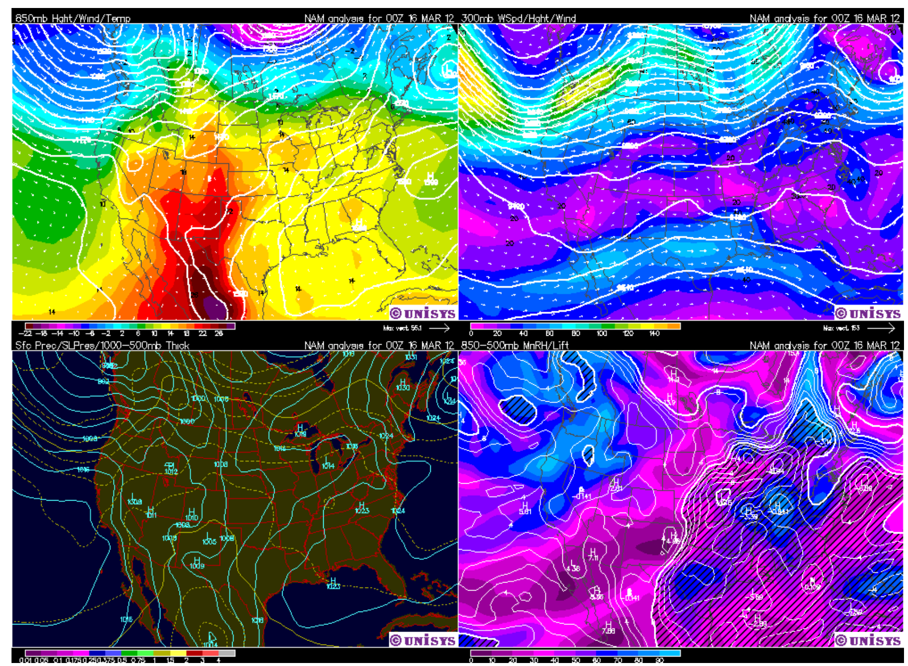
- March event sequence: 16th



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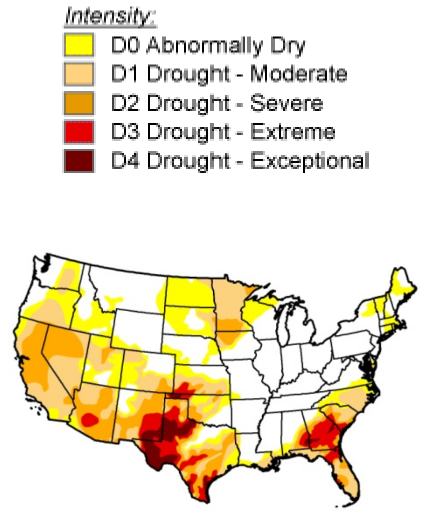

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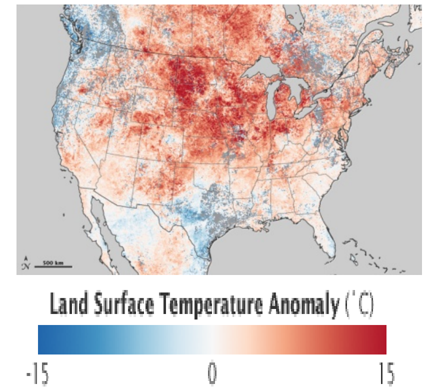

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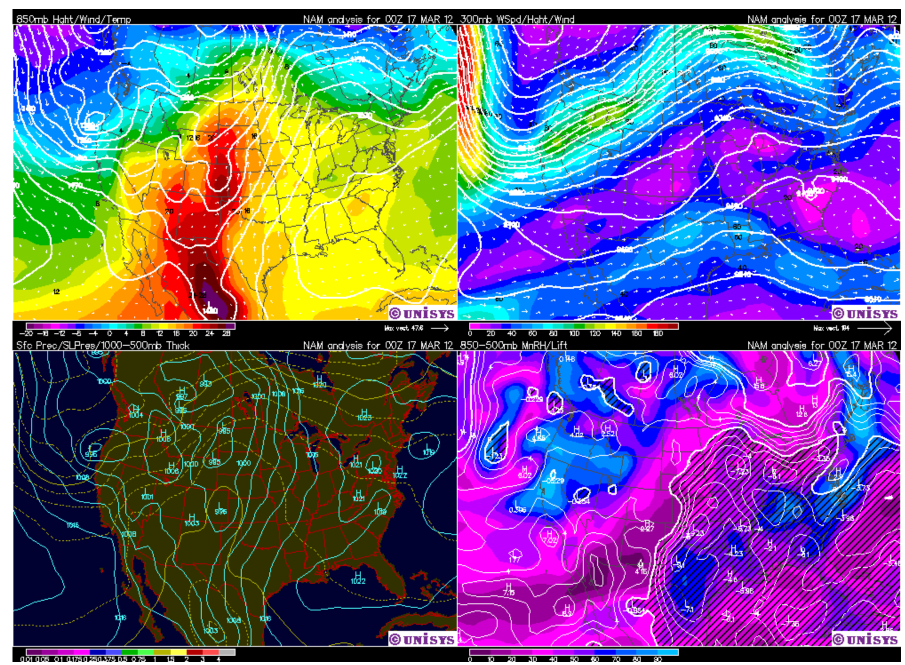

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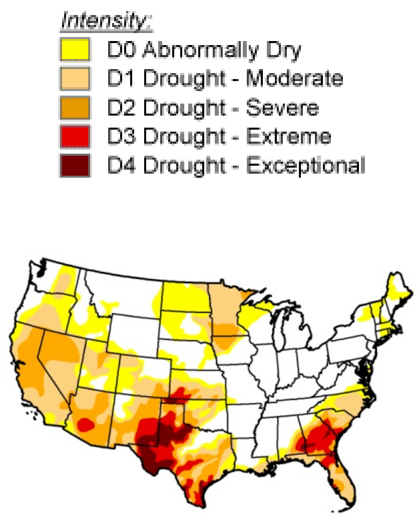

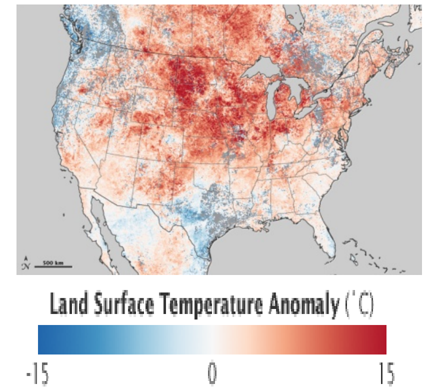

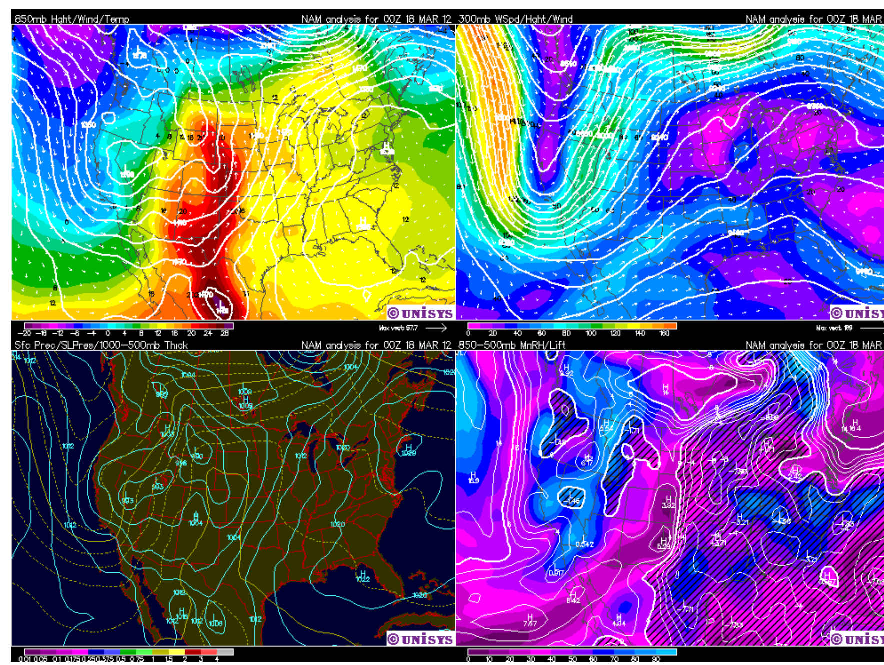

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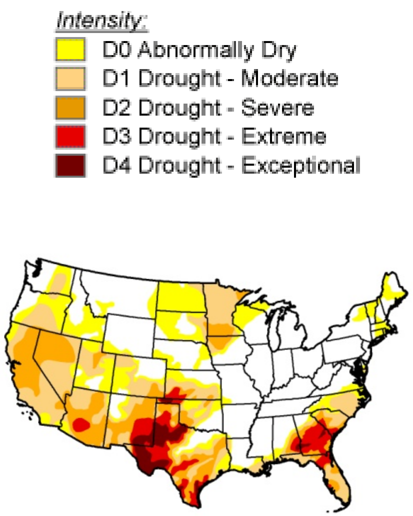
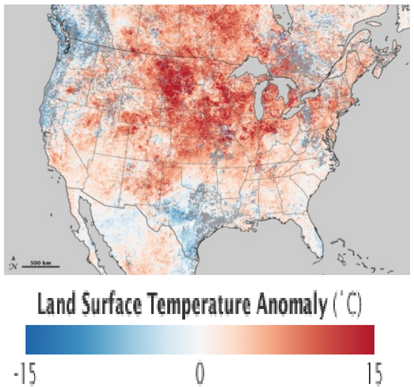
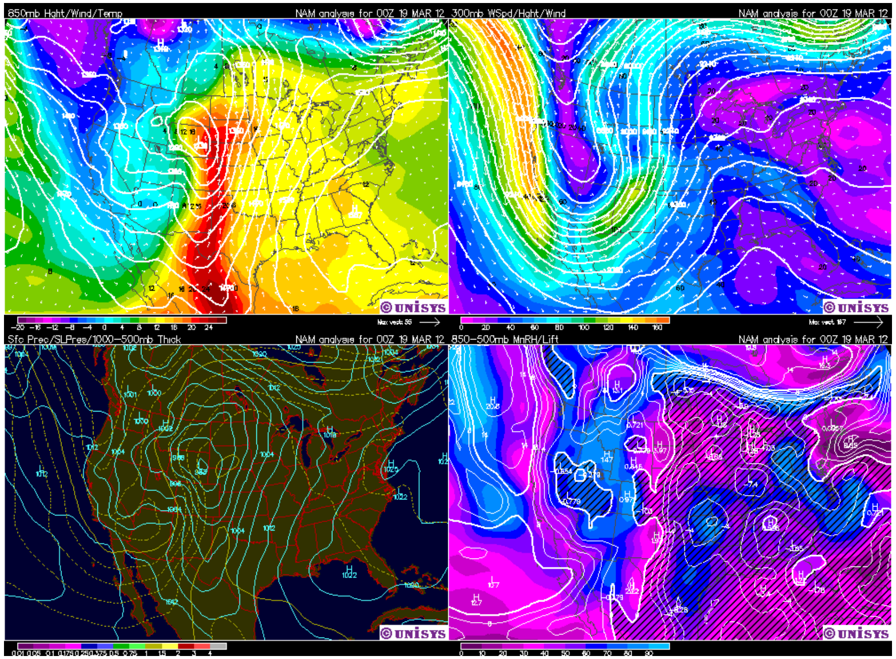
- March event sequence: 19th

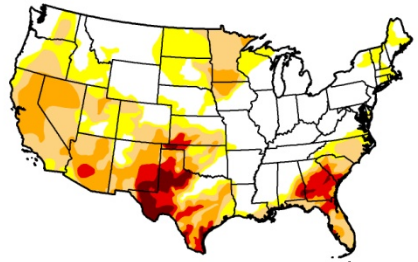




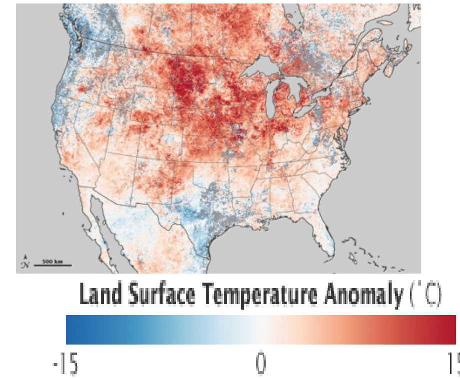


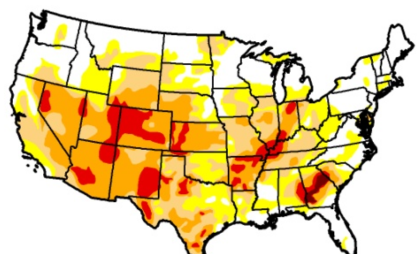
2012 US heat waves & drought

- March event
  - advection of airmass out of SW
  - Northernmost extent ahead of frontal system
- What's happened since?
  - Drought has become more widespread as have the summer heat waves.
- Next speaker has more on connection to soil moisture

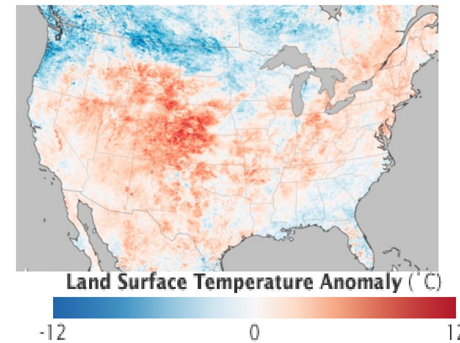


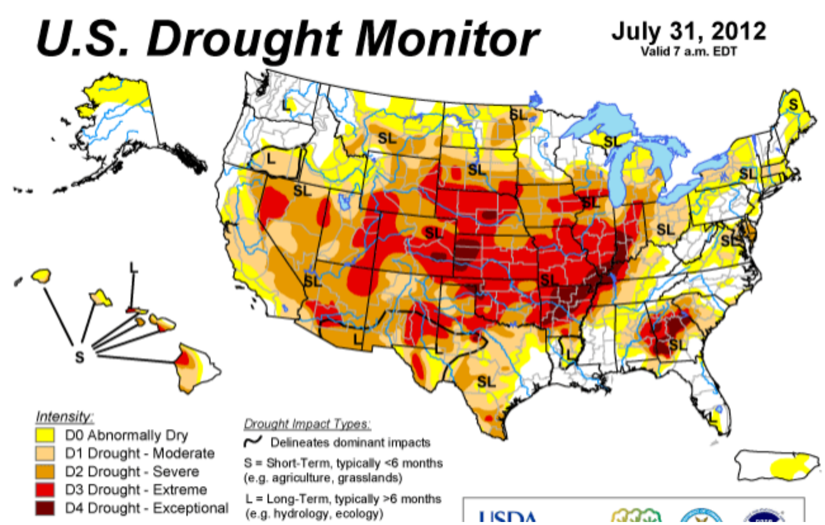
13-19 March





20-26 June



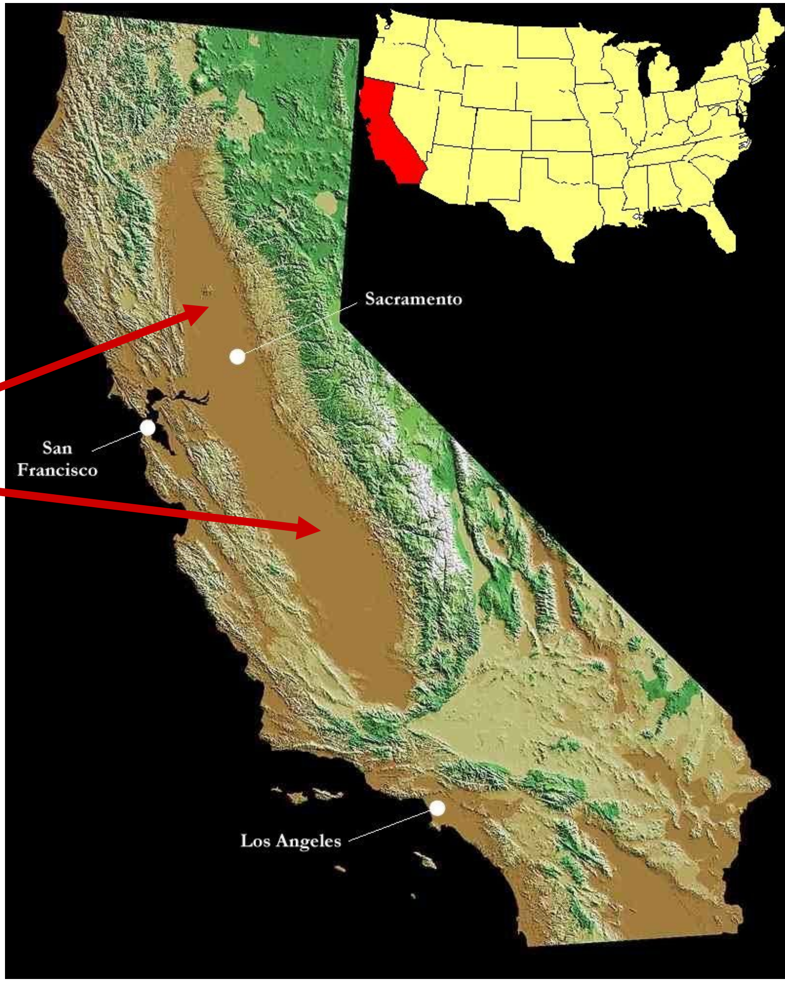


Figs from NOAA, NASA

California Heat waves: upper air large scale meteorological patterns (LSMPs) synoptics & some dynamics

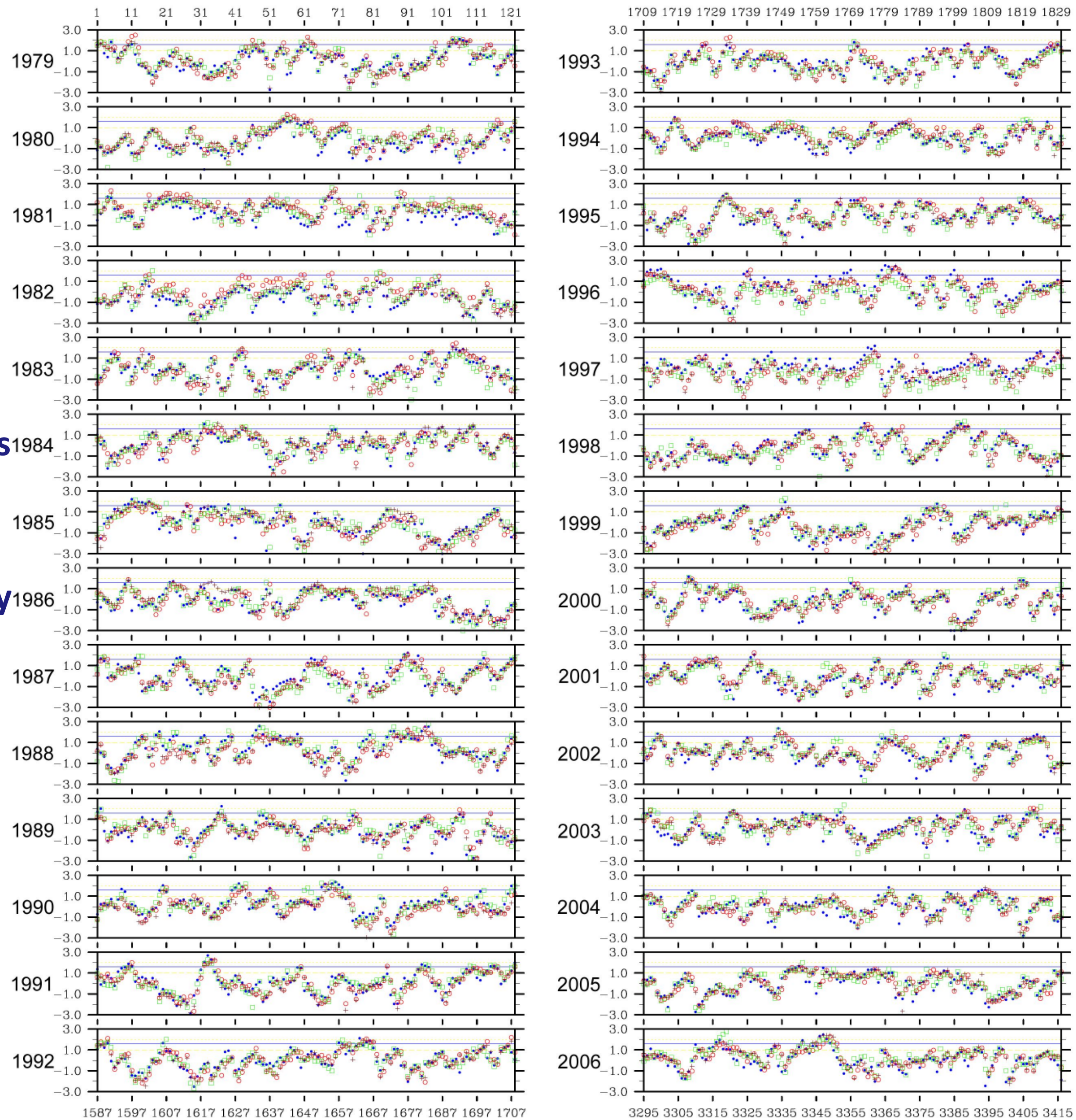
California hot spells overview

- Soil moisture typically not a factor in California
  - has annual drought; little or precipitation during summer months.
  - Central Valley heavily irrigated
  - Link between hot spells and synoptics is (likely) stronger than in central & eastern US.
- Most extreme hot spells last a few days



Find extreme anomaly T: ‘target’ dates

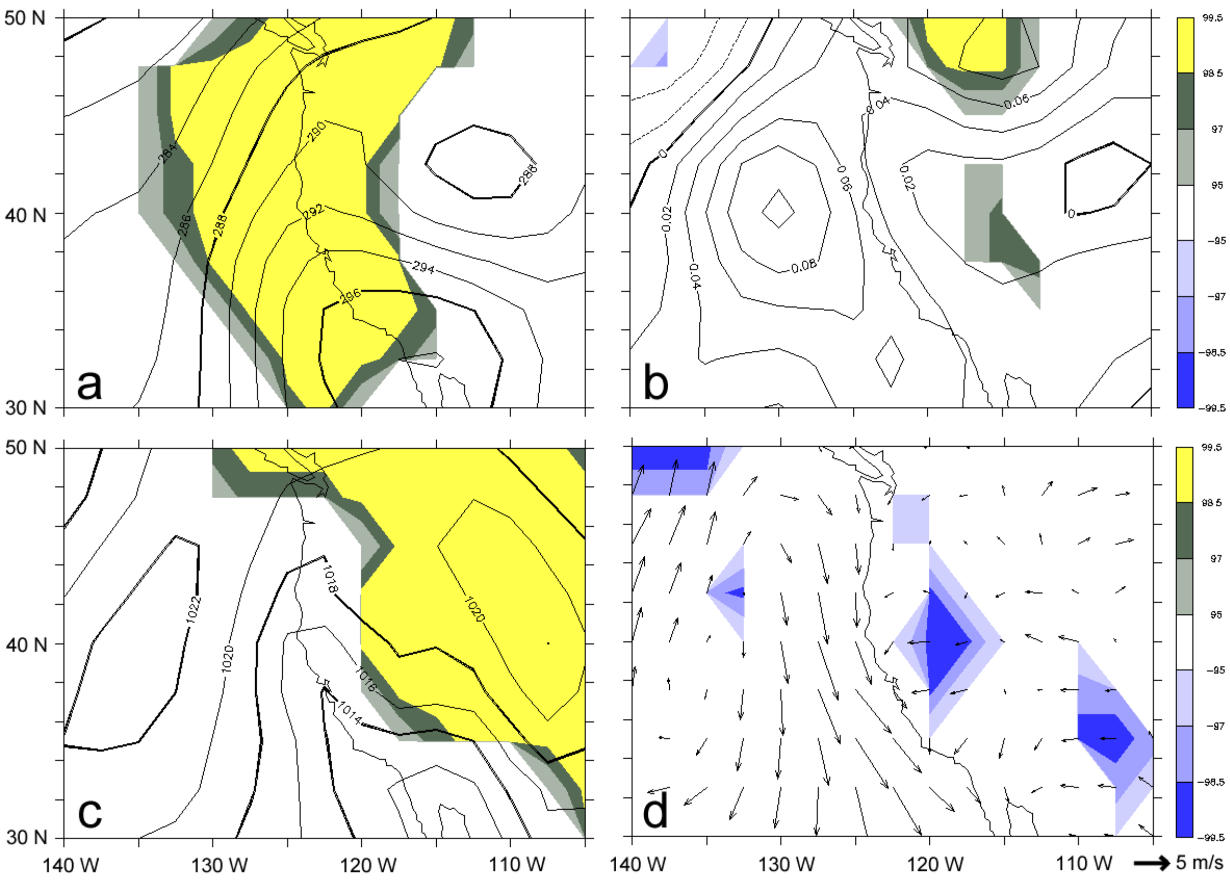
June-September normalized max T anomalies @ 4 stations



- Time series:
  - Daily max temperatures at 4 CV stations
  - Daily anomalies normalized by each station’s long term daily standard deviation
  - 28 years (3416 dates)
- Define target ensemble dates for hot spells
  - Each station’s value must exceed 1.6
  - 33 dates selected (1%)

<u>Local</u>, hot spell synoptic pattern

- "Local" pattern:
  - Lower tropospheric T maximum (anomaly) just offshore (a)
    - 'Themal low' (c) at or offshore:
    - Sea breeze opposed
    - downslope (weak) winds (P<800mb) (d)
    - Sinking (b) elevates T in lower atmosphere
    - Lowers subsidence inversion
    - Solar heating shallow boundary layer



Shading is highest (yellow) or lowest (bule) 1.5%

a. T @ 850hPa,
b. b. dp/dt @ 700hPa
c. SLP
d. Wind @ 850 (shading applies to u component)

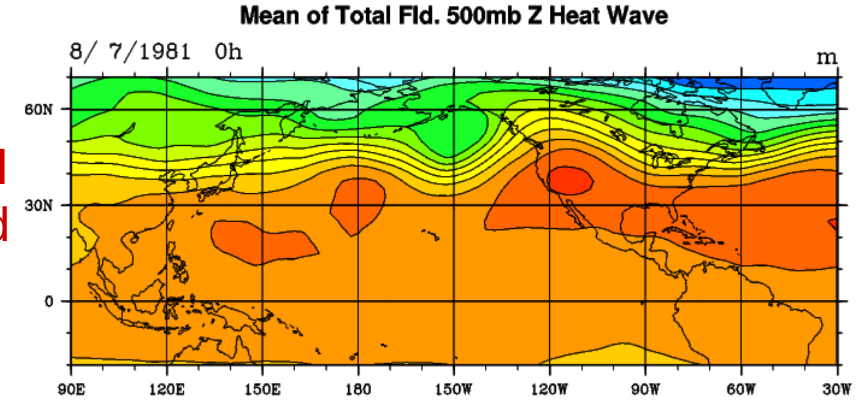
Target composites

- Define target ensemble from target dates of extreme hot days (anomaly) over CV.

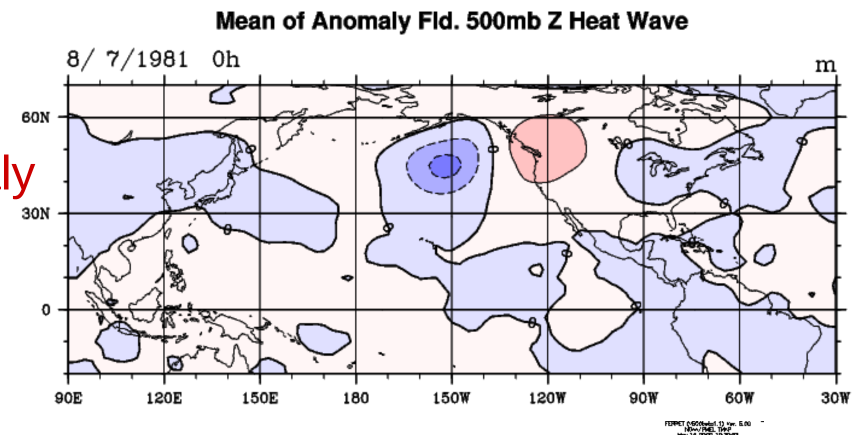
- Example: Z @ 500 mb:
  - Ensemble mean (top)
  - Ensemble mean of daily anomalies (in training pd)
  - Significant areas identified via comparison to random ensembles

- Multiple fields tested

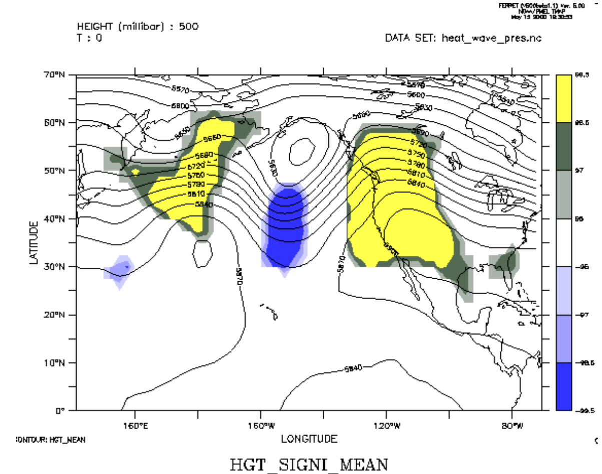
Total Field Z_{500}



Anomaly Field Z_{500}



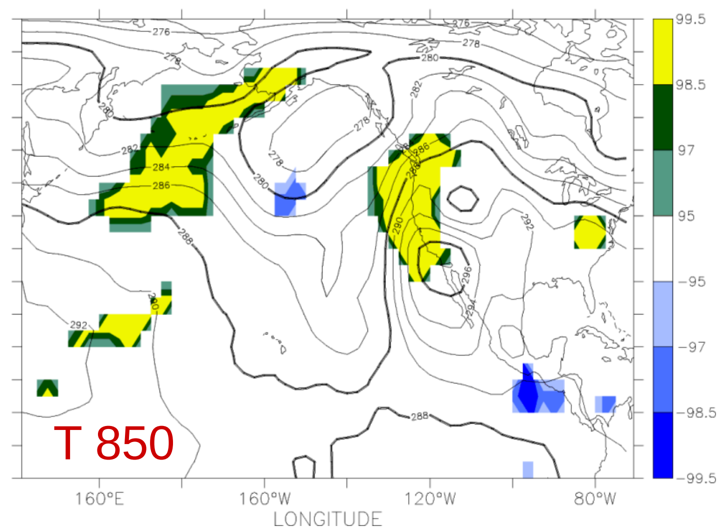
Shading: highly significant



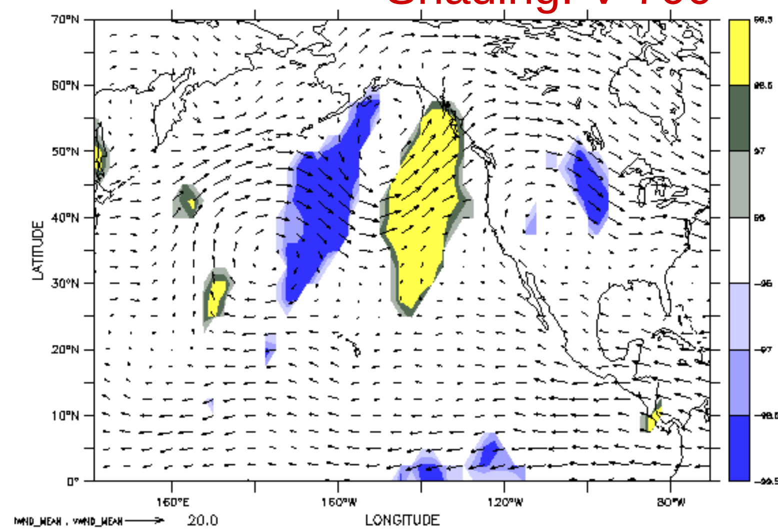
http://atm.ucdavis.edu/~grotjahn/EWEs/

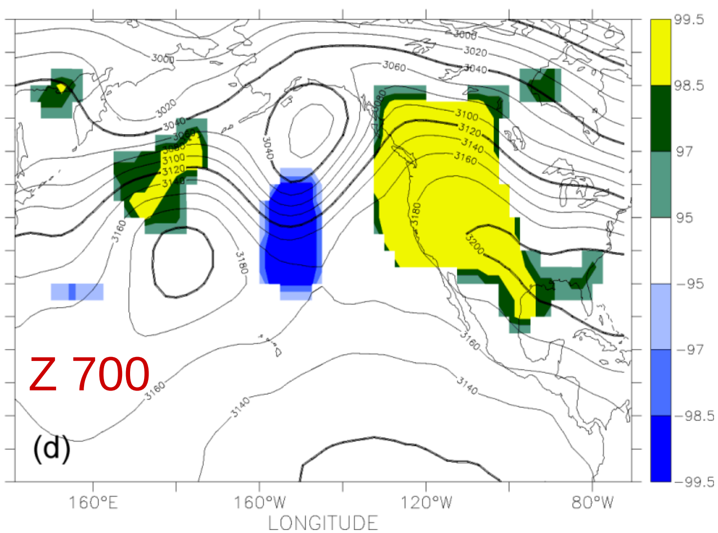
CV Hottest days upper structure

- Example target ensemble means from target dates (hot spells onsets).
  - T at 850 hPa
  - V at 700 hPa
  - Z at 700 hPa
- Conclusion: very large scale pattern.
  - Highly significant >99% level (shaded)
  - Grotjahn & Faure, WAF, 2008
  - More posted on web, including lead-up
- Synoptic situation.
  - Large airmass displacements, upstream and downstream, with corresponding height anomalies.



Shading: V 700

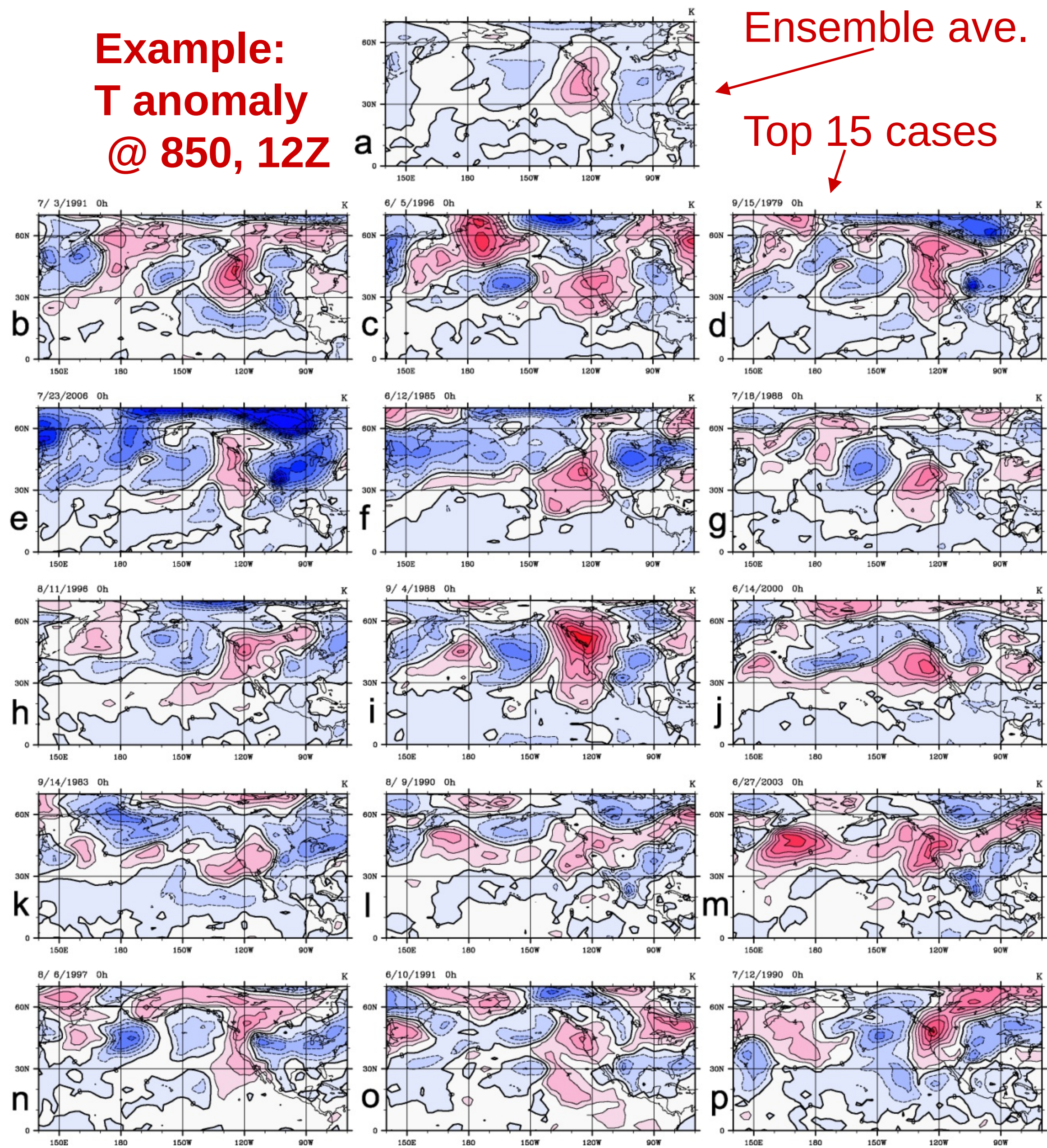




http://atm.ucdavis.edu/~grotjahn/EWEs/heat_wave/heat_wave.htm

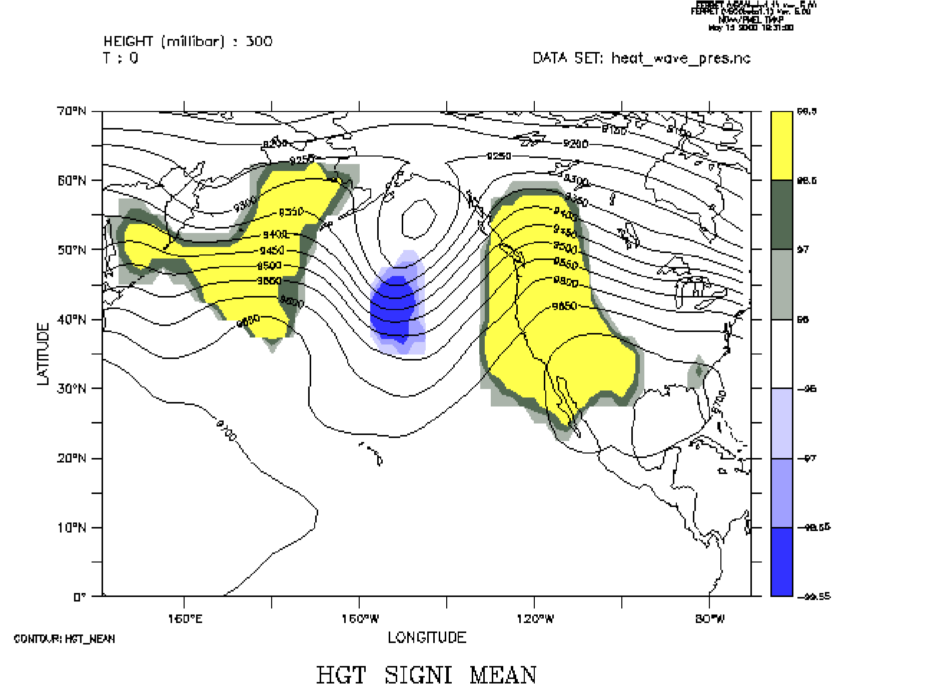
Significance vs consistency

- Significance does not guarantee consistency!
- But parts of pattern are consistent for all dates of extreme heat events
  - In every case the strongest anomaly T is centered at or near west coast.
  - T850 shown for the top 15 events (b-p). 1979-2006 average of the 15 events (a).



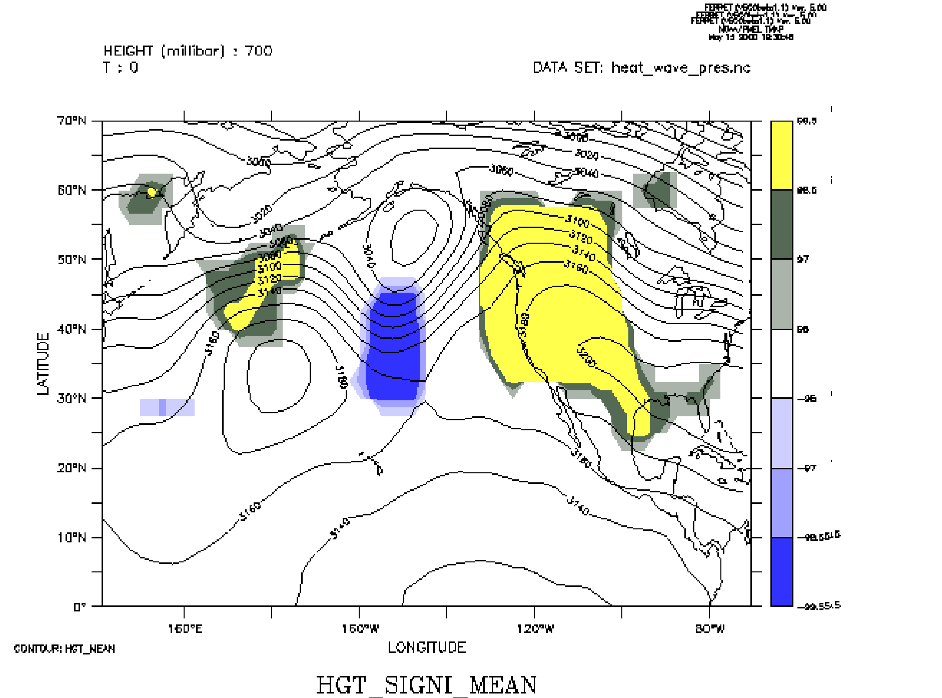
Hottest days: time sequences

- Z 300 hPa
  36hr-0hr



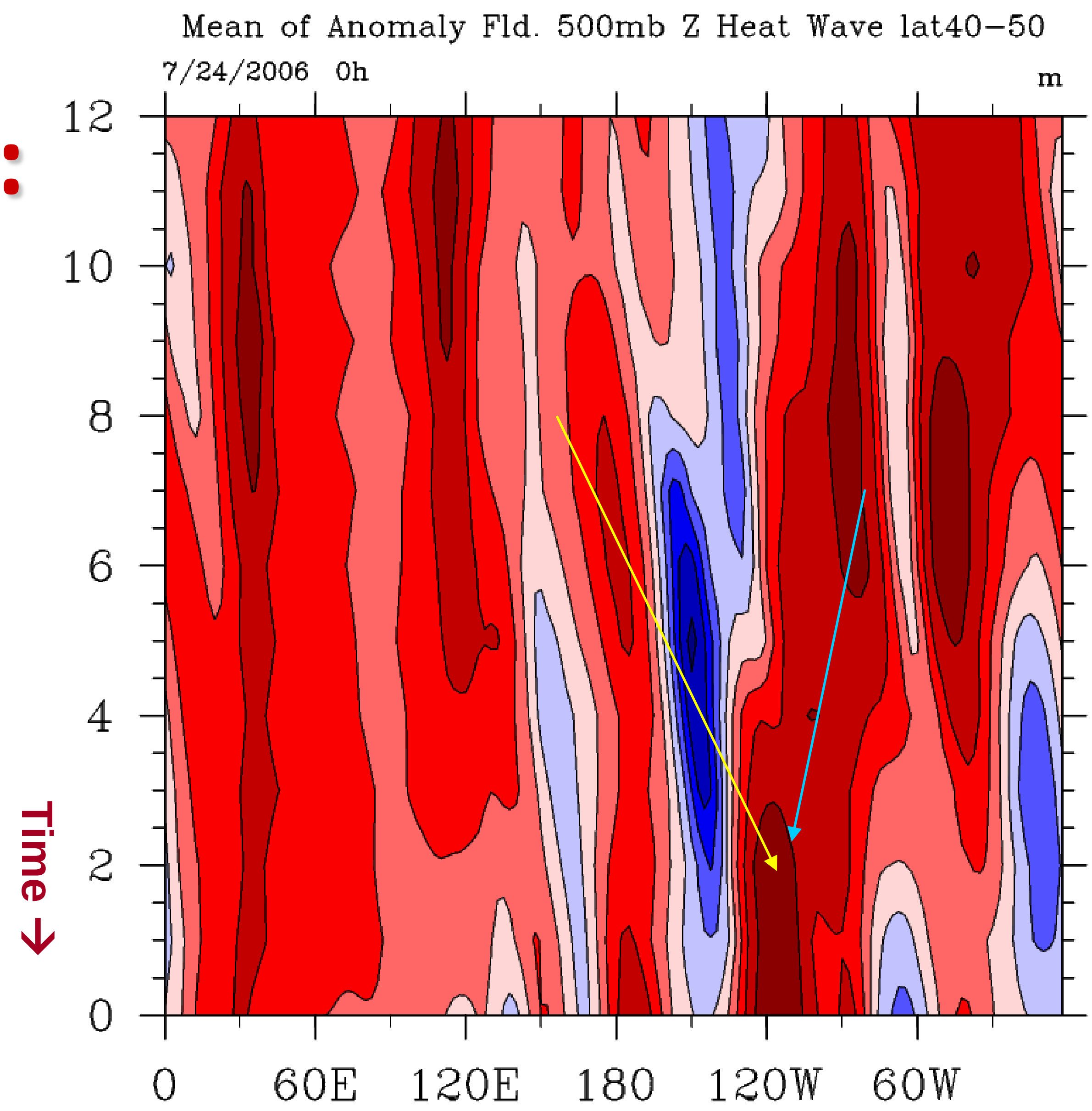
- (Equivalent barotropic pattern)

- Z 700 hPa
  36hr-0hr



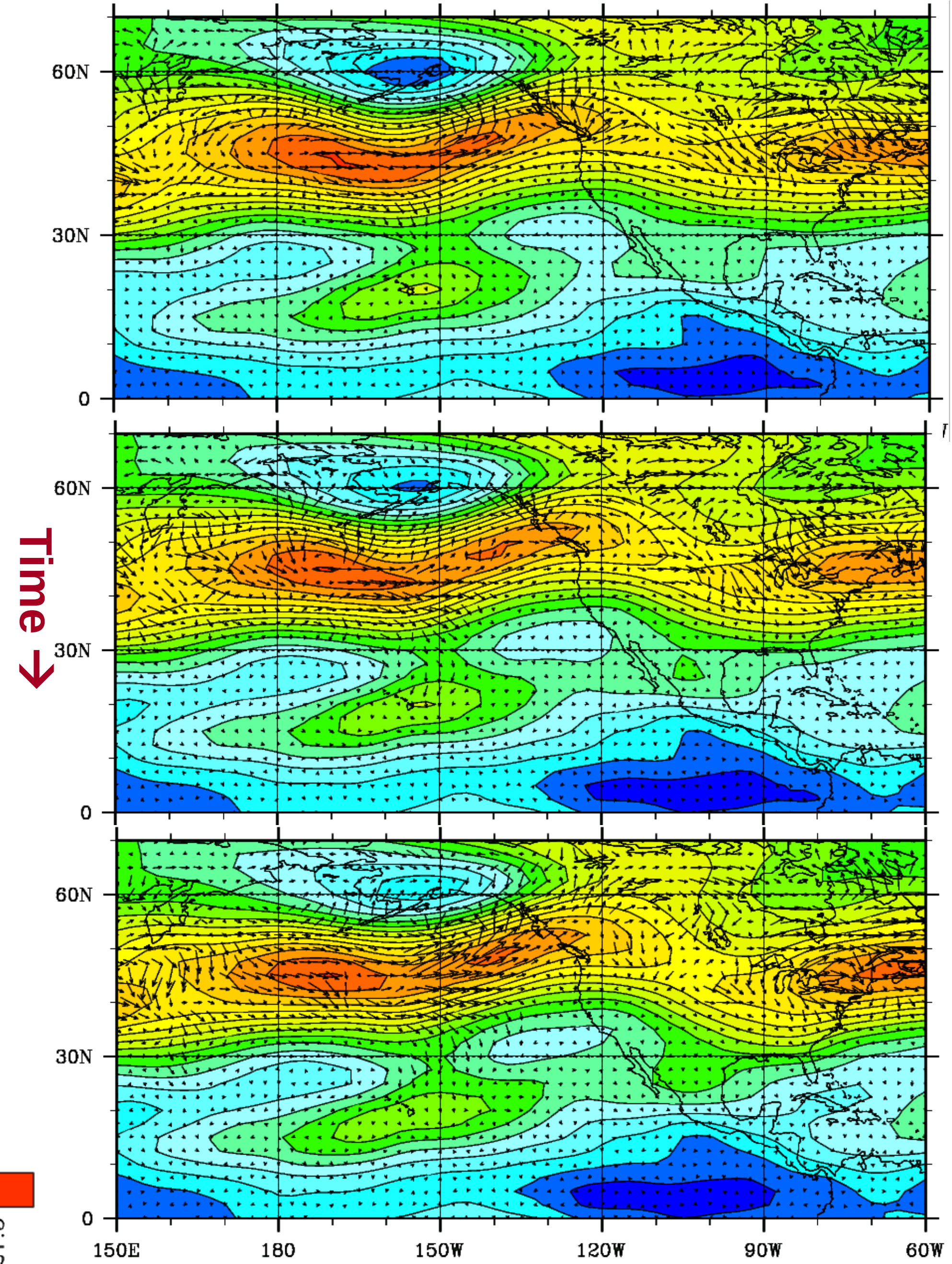
Unfiltered Hovmeuller: (time vs longitude)

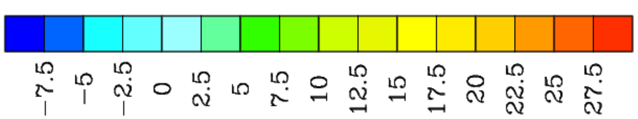
Z 500 hPa: from 6 days before onset (= '12') to onset (= '0')



HF E_u-vectors & LF U

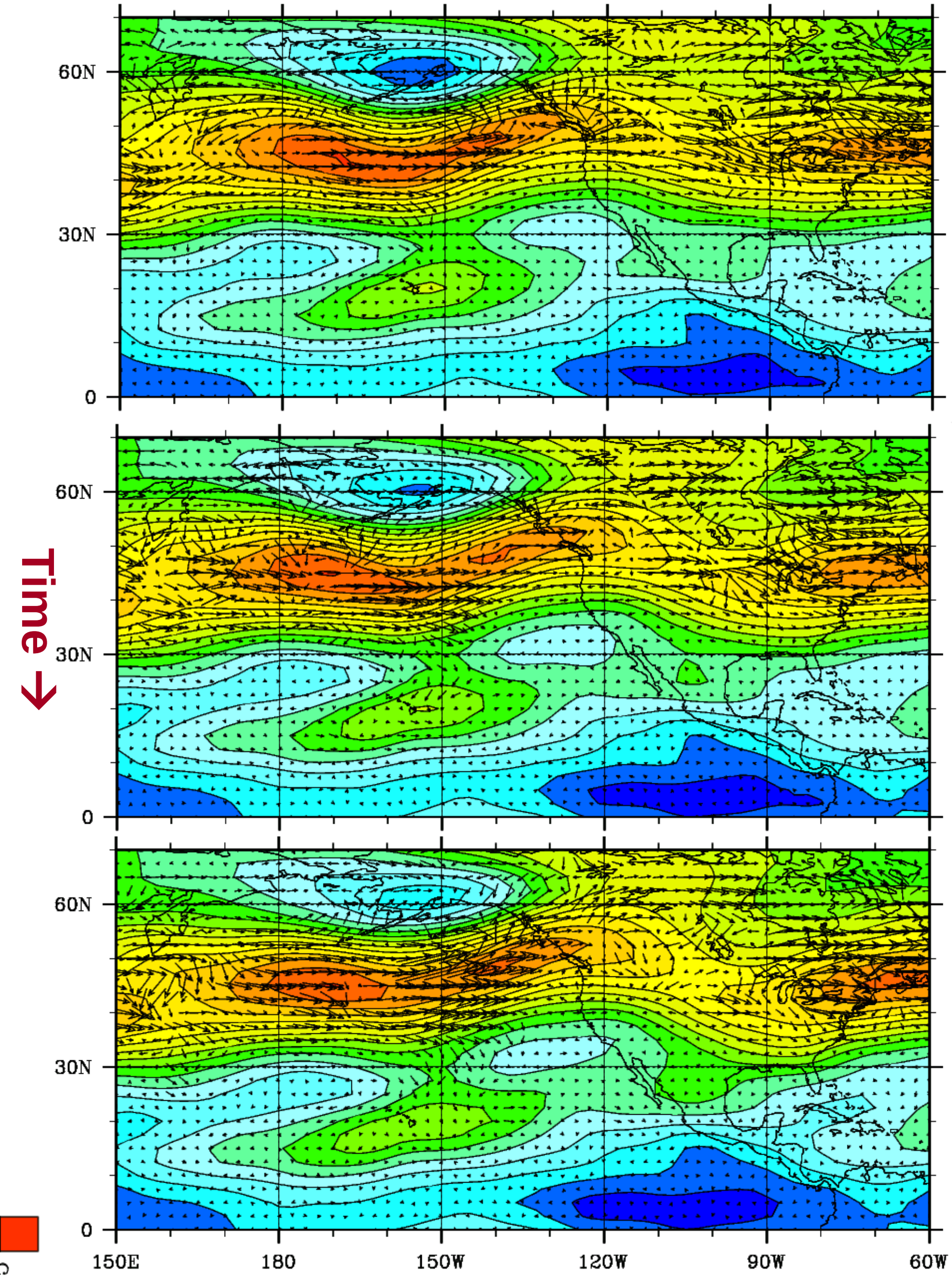
- High freq. E_u vectors vs low freq. wind @ 300hPa
- $E_u = [\ 1/2(v'^2 - u'^2\ ), -u'v'\ ]$
- $DU/Dt - fv^* = \nabla \cdot E_u$
- Ensemble of 23 events
  - (top) 2 days before onset
  - (middle) 1 day before
  - (bottom) hot spell onset
- E_u-vectors convergence (<0) on W & N sides of LF ridge, slows down LF (>7d) U there; ridge building

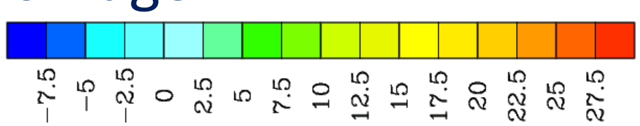




HF E-vectors & LF KE

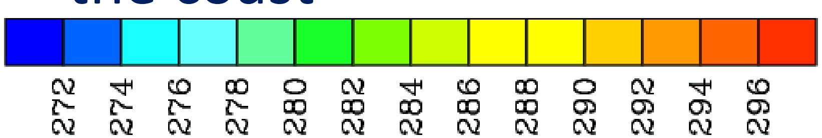
- High freq. E vectors vs kinetic energy @ 300 hPa
- E = [(v'^2-u'^2), -u'v']
- $\int \partial K'/\partial t \, dm \approx \int E \cdot \nabla U dm$
- Ensemble of 23 events
  - (top) 2 days before onset
  - (middle) 1 day before
  - (bottom) hot spell onset
- $E \cdot \nabla U < 0$ is barotropic KE conversion HF to LF
- On N side LF U stronger
- On W side LF V stronger, builds ridge

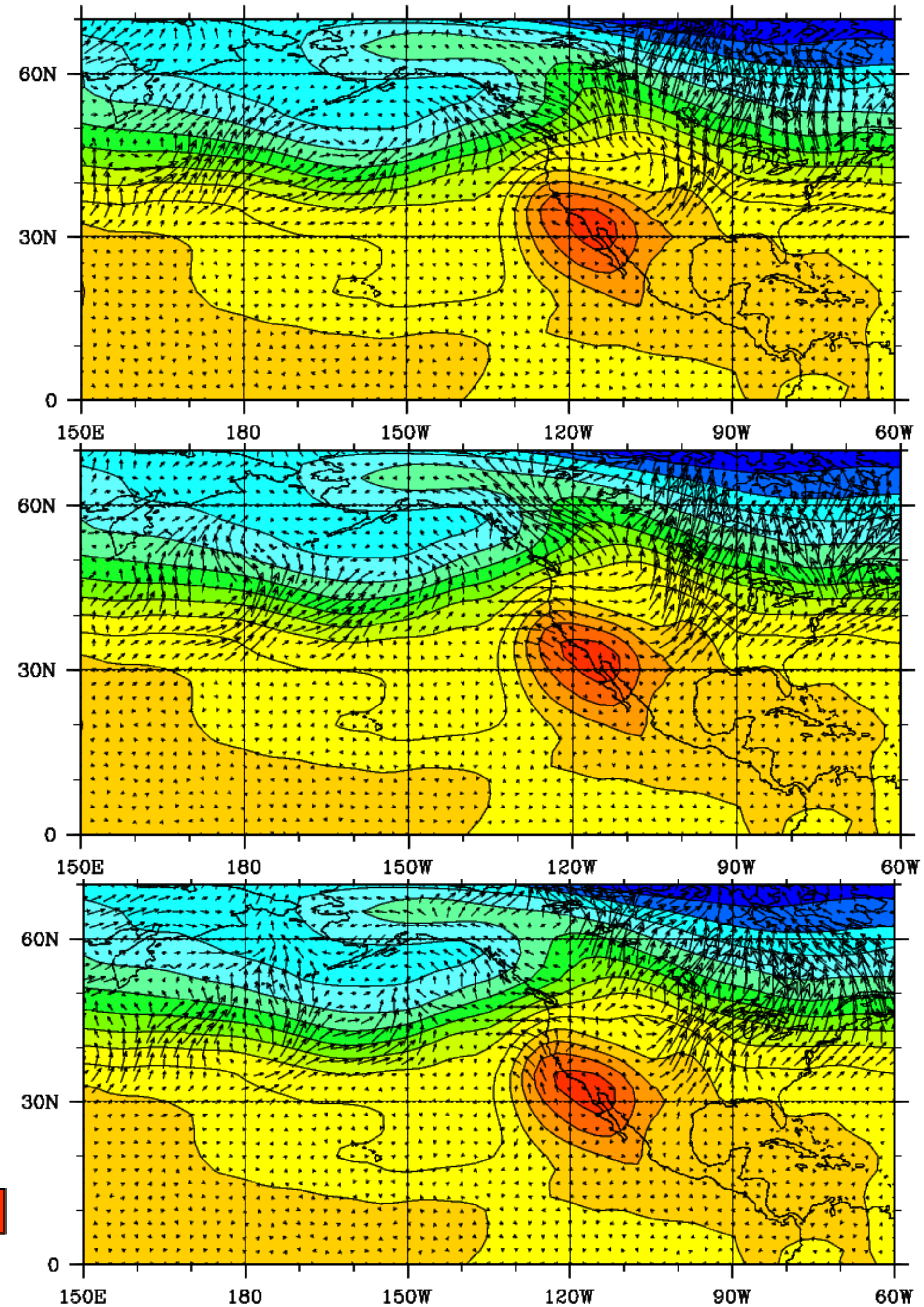




HF Heat Flux & LF T

- HF heat fluxes and LF (>14 days) T @ 850 mb
- Ensemble of 23 events
  - (top) 2 days before onset
  - (middle) 1 day before
  - (bottom) hot spell onset
- Large T anomaly ‘bubble’ in LF pattern. (red area)
- Vectors on NW tip of T ‘bubble’ directed to NW; dragging LF T bubble to the north and west along the coast





4 of 5
Are upper air LSMPs predictive of surface hot spells?

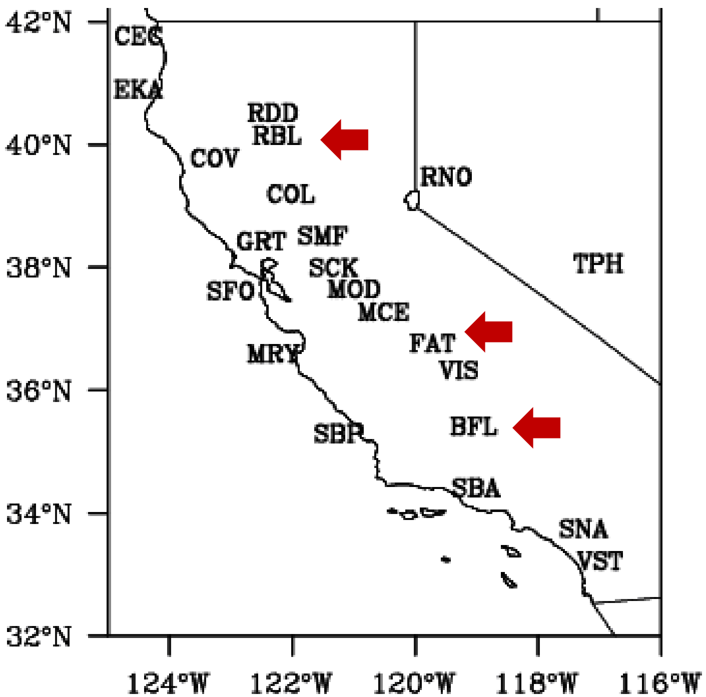
- Test calculation (‘pilot project’) using the large scale upper air pattern for hot spells to predict the rare events at the surface

Pilot Project: identify dates

- Pilot scheme described in Grotjahn, 2011, *Climate Dynamics.*

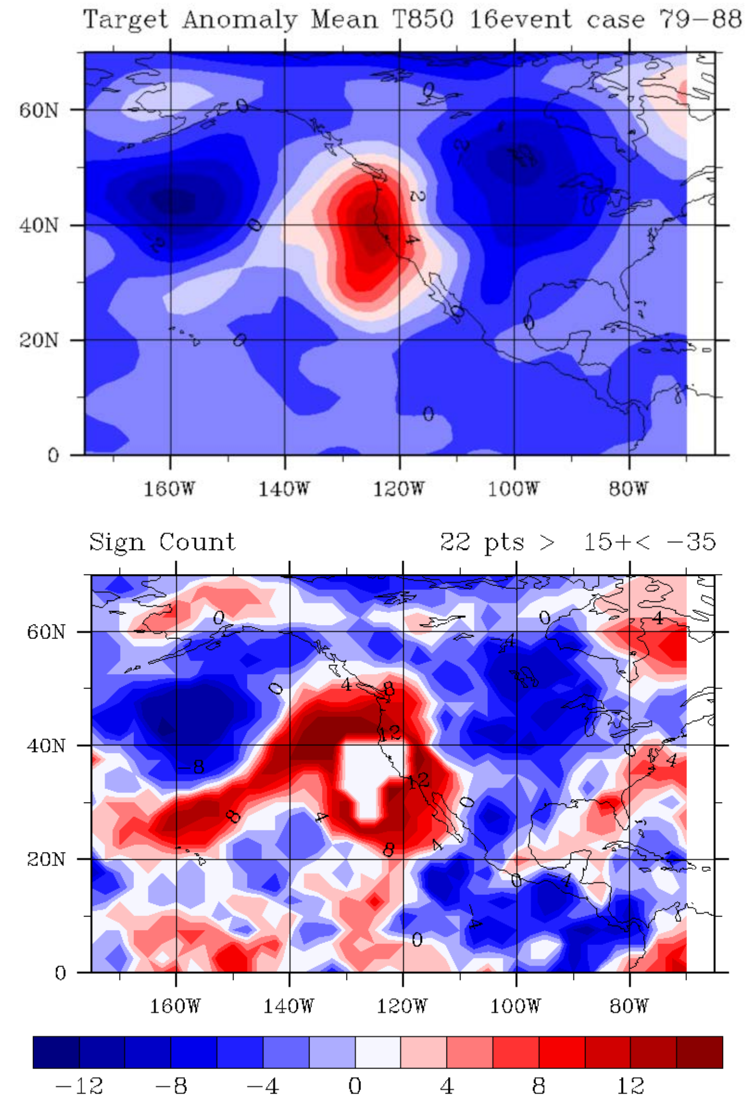
- **Can one find extreme surface events from large scale upper air data?**
- Make **'target composites'** of many variables on the target dates using anomaly gridded data from the **first 10 years** of data (= 16 of the target dates)

- First find dates of obs. extreme events
  - daily anomalies of max-T = **max-Ta** for 28 summers (3416 days) 1979-2006
  - Average 3 stations spaced along the CV, (RBL, FAT, BFL)
  - Choose threshold to find hottest ~1% of max-Ta
  - 16 **'target dates'** of extreme heat found in first 10 years (1979-89) when (max-Ta) / (std dev.) >1.6 at all 3 stations.
- Make daily anomaly fields from NCEP/DOE AMIP data: 2.5x2.5 grid.



Project daily maps onto target ensemble

- Compute **'daily circulation index'**
  - Project daily data onto selected highly consistent area(s) of the target composite (e.g. 'hole' in lower diagram)
  - Combine projections from variables to get an overall 'daily circulation index' for the date.
  - Index shown next combines T850 and V700 anomaly data. Goal is for extreme circulation index values to match the most number of target dates
- Index based on 16 hottest (anomaly) days in CV during 1979-88…
- but applied to 1979-2006



Example: Target composite and sign counts for 16 events. T850 hot consistently at & 10º ***west*** of CV

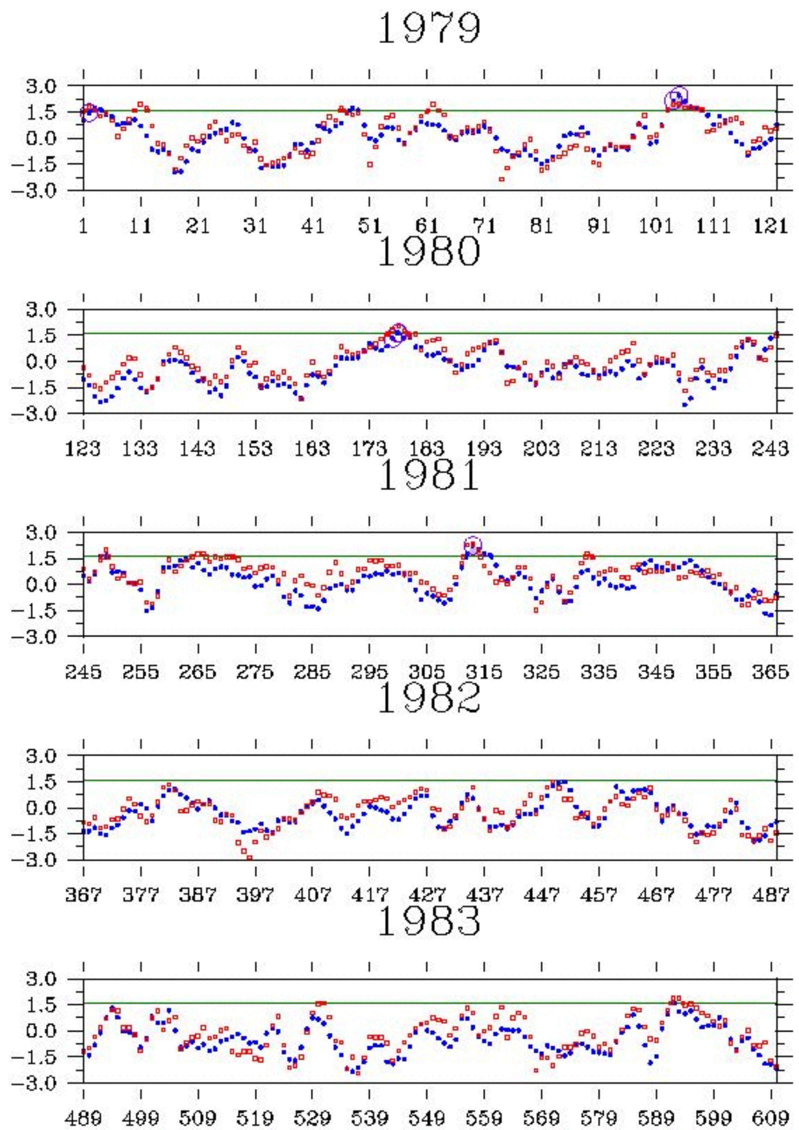
Pilot Project Results: part 1

- Plots compare index & obs. max T for all 3416 days of the 28 year period.
- Time series: June-September
  - Observed anomaly (red)
  - Circulation index (blue)
  - Extreme event dates (blue circles)

- Index picks up cold and near normal events very well, too.
  - Correlation between index and surface obs: 0.84
  - Bias: 0.04 F (index ave.)
  - Mean error: ~3C (comparable to WRF)

- Good ability to capture extremes
  - Highest 33 values of index match 15 of the 33 (46%) highest 1% events.
  - 15 of remaining 18 values of index are top 2% of obs. events

- Skill at finding extreme surface events is same inside & outside training period.



Results Part 2: EVS scores

- Pilot scheme has skill in measures of rare events.
- Rare event contingency table
- Tail fitting
- Scheme better than ‘obvious’ alternative choices.
- 2 predictors superior to 1

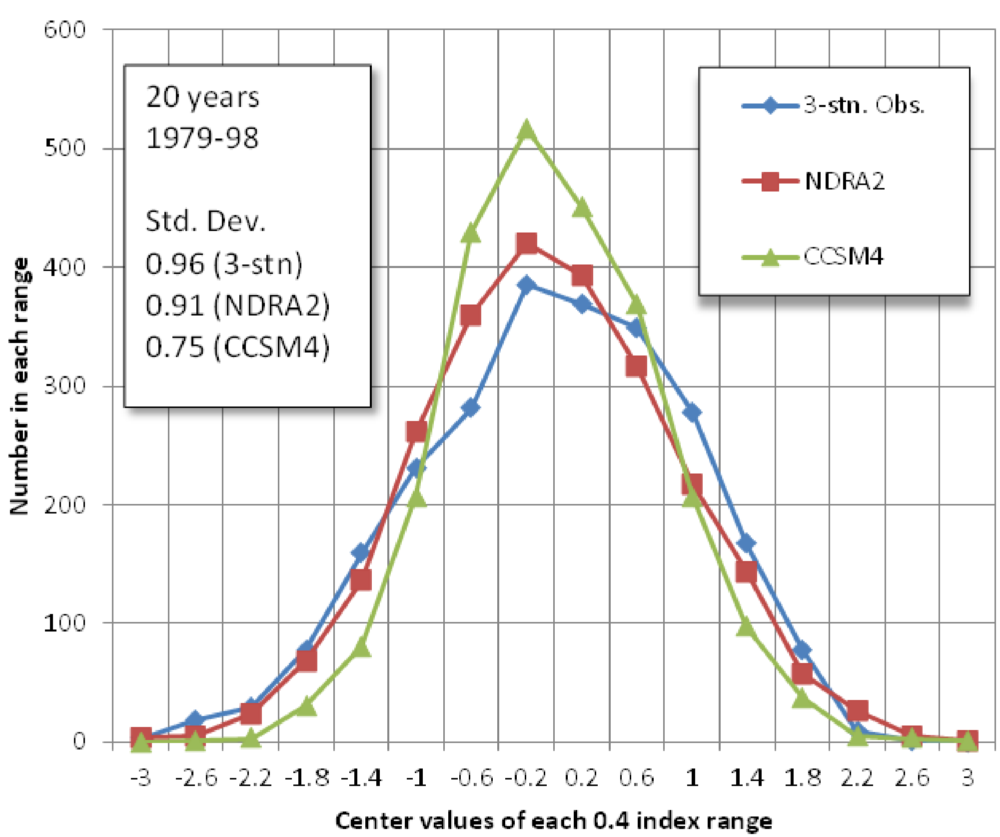
Table 3. Comparisons of skill and fit of extreme values in pilot scheme and alternative predictors
* estimated skill measure if random guesses are used

	Observed 3-station average	Pilot scheme (T850 & V700)	Pilot Scheme (Only T850)	3 CV grid pts: 12 GMT	3 CV grid pts: 0 GMT
Skill in capturing dates of high extreme temperatures					
Dates matching original 33 (1.6 threshold)	33	15	11	10	7
Dates of largest 30 in 3-station average	30	11	10	10	7
POD (Probability Of Detection) *0.0097 if random	–	0.4545	0.3333	0.3030	0.2121
FAR (False Alarm Rate) *0.9903 if random		0.5454	0.6667	0.6969	0.7878
CSI (Critical Success Index) *0.0049 if random		0.2941	0.2000	0.1786	0.1186
EDS (extreme dependency score)	1.0	0.71	0.62	0.59	0.50
Generalized Pareto Distribution fit using top 33 values					
Scale parameter (σ)	0.147	0.205	0.294	0.246	0.251
Shape parameter (ξ)	0.010	0.009	—-0.249	—-0.304	—-0.184
Location (specified)	1.858	2.04	2.35	2.07	2.00

5 of 5
Are upper air LSMPs simulated in a climate model?

- Using 4th generation NCAR Community Climate System model (AR5) CCSM4
- ~1 degree FV resolution
- 20 year historical simulation (1979-1998)
- Comparison with surface observations and NCEP/DOE AMIP-II reanalysis (‘NDRA2’)

Comparison Histograms



- 3-stn vs ndra2 vs CCSM4 pilot scheme circulation index.
- CCSM4 std dev too small:
  - 3-stn, NDRA2, CCSM4
  - 1.00, 0.91, 0.67
- CCSM4 skew reversed:
  - 3-stn, NDRA2, CCSM4
  - -0.31, -0.05, +0.28
- Hottest days in model will be too weak, too infrequent
  - Top 1% 9 vs 24 in 20 years
- Coldest days will be missed
- Large scale errors cannot be overcome by an RCM

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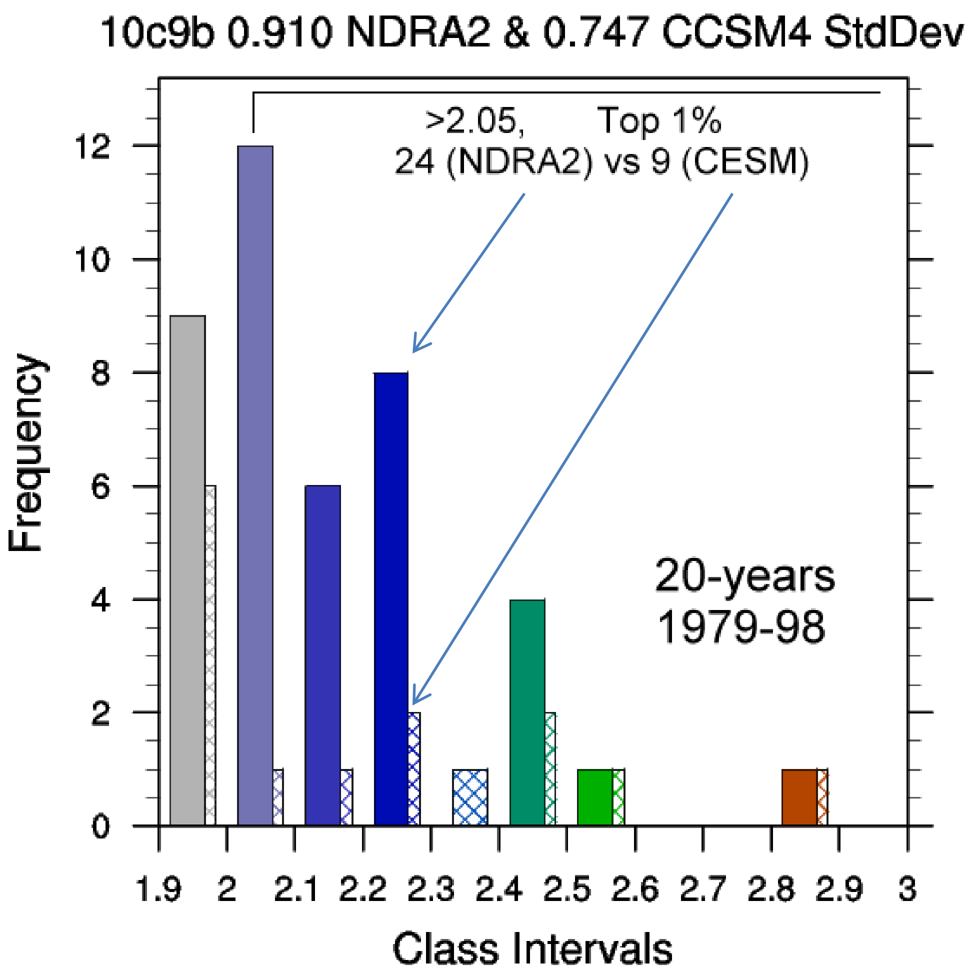

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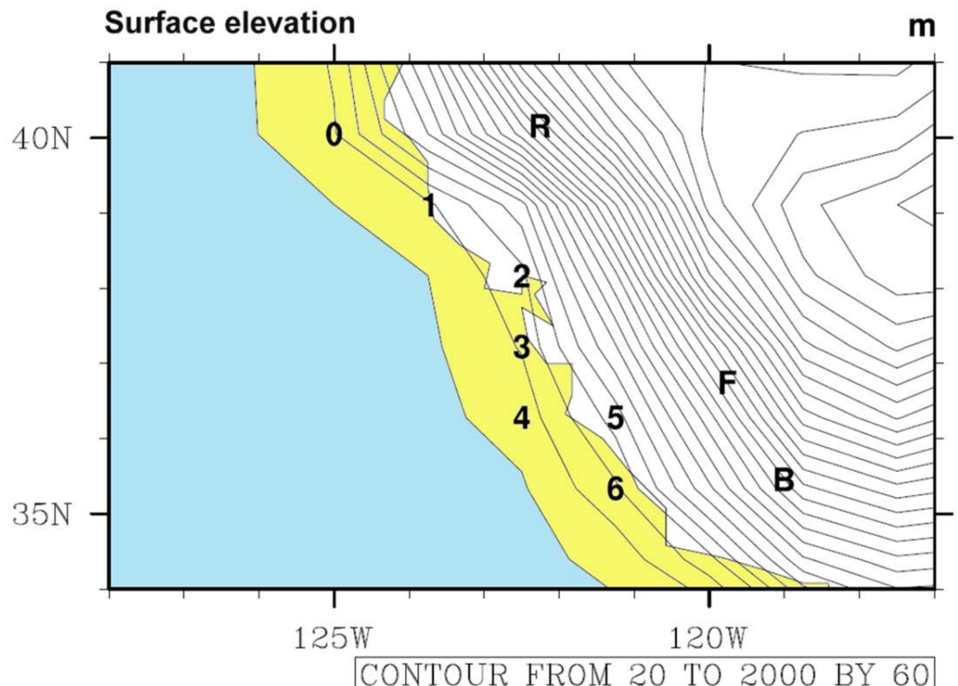
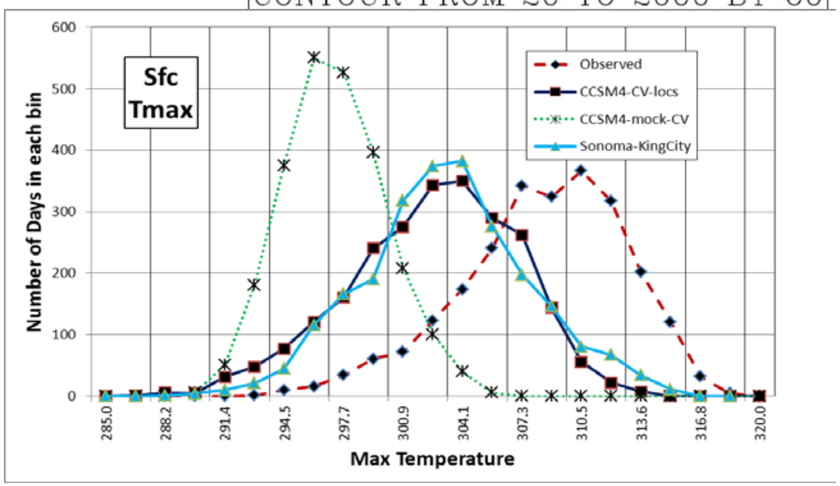
CCSM4: 1° version can't resolve CV

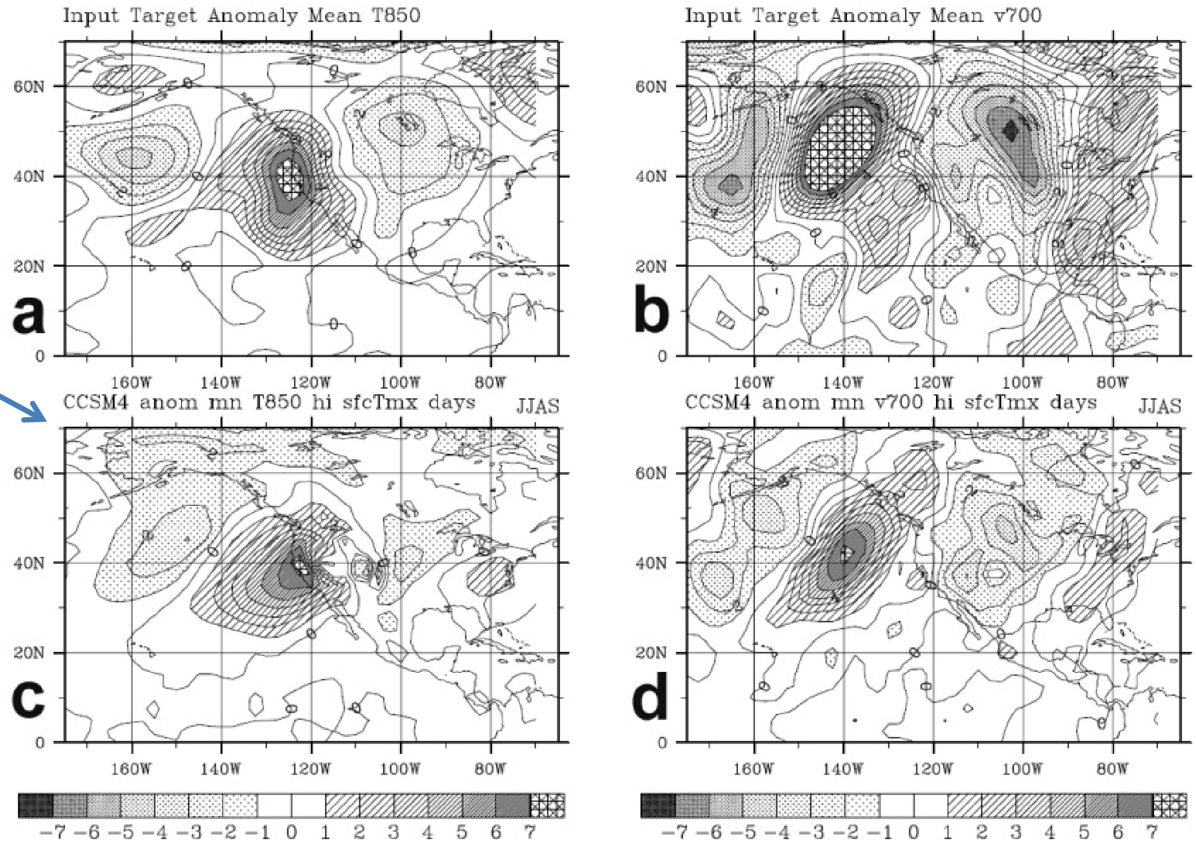
- Ocean above sea level (yellow)
- Illustrative grid points (numbers)
- Central Valley station locations (letters)
- No Central Valley, just broad slope
- Can't match reality in CCSM4: either too much marine or too much elevation
  - Observed CV max T skewed (red)
  - Model points near R,F,B similar skew, just cooler (dark blue)
  - Obs. near pts 2 & 5 (light blue)
  - Model points on coastal plain (green) have different skew, much cooler. Will use these as 'worst case' to find LSMP for high max T in model.





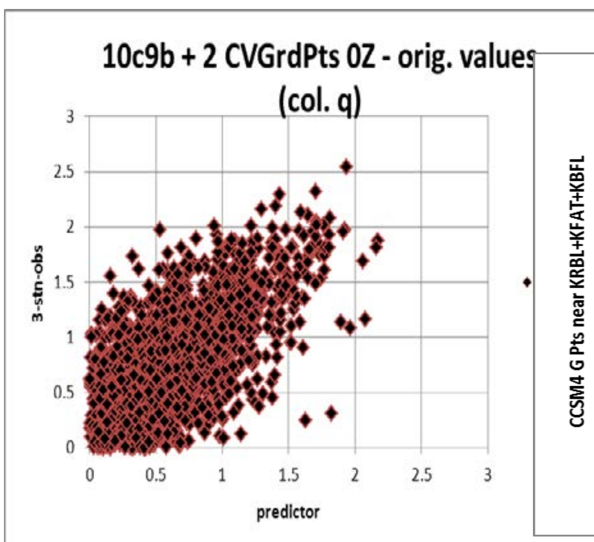
CCSM4: model LSMP for high T_{Sfc}

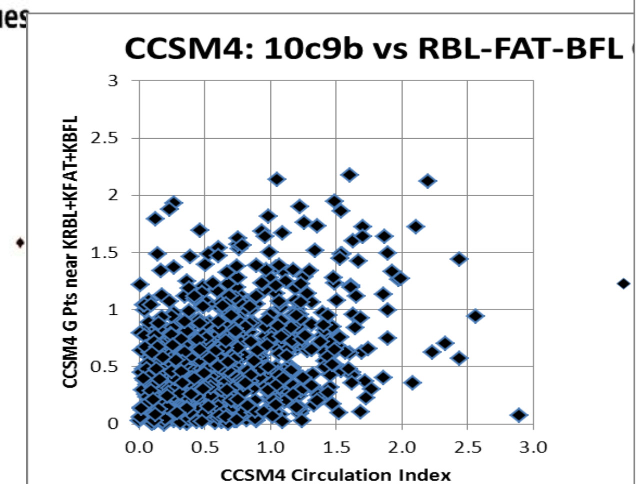
- NDRA2 reanalysis LSMPs (a: T 850 & b: v 700)
- CCSM4 LSMPs using coastal points (c: T 850 & d: v 700)
- Similar patterns for this ‘worst case’, but:
  - max T 850 anomaly onshore in model, offshore in NDRA2
  - Model patterns weaker

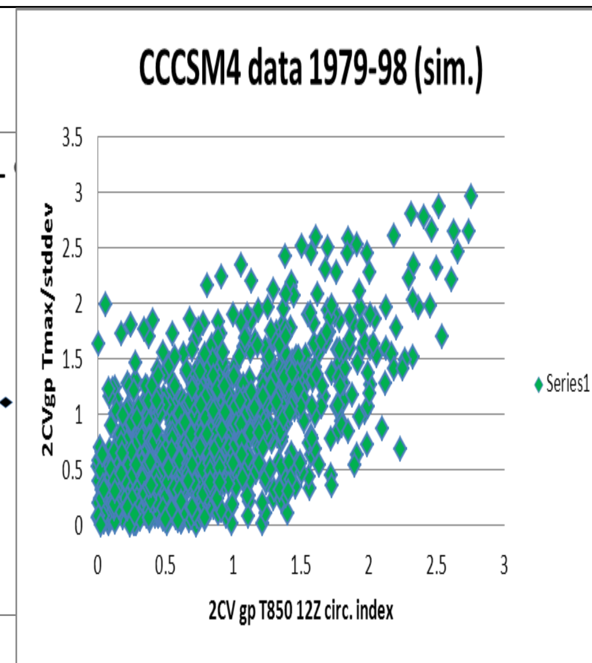


Scatterplots comparison

- Compare circulation index to surface max T in CV area.
- Using the NDRA2 upper air patterns index and observed CV max T has few ‘busts’ (left plot)
- Using the NDRA2 patterns with the CCSM4 surface data at inland station locations is not so predictive (middle plot).
- Using CCSM4 patterns with inland CCSM4 surface data (right plot) is ‘too good’; since close to model surface.







Summary and Other considerations

- Extremes have LSMPs that are resolved by global models; (hot spells shown; also: CAOs, heavy frontal precip.)
- LSMPs are predictive of, and needed for, surface extremes; also needed for proper RCM simulation
- US CLIVAR has its first WG on extremes. WG focus on topic of the extremes & LSMPs. LSMP/extremes workshop 2013.
- Future dynamical analyses include:
  - Better Hovmöller (Ψ, filtering, GC path, chaining, …)
  - Remote connections ('instantaneous' WAF, PV tracking & inversion, EP fluxes,…)
  - More from other studies (E conversions, T & ζ eqn. terms, …)
- Thanks for listening!