Speaker Introduction

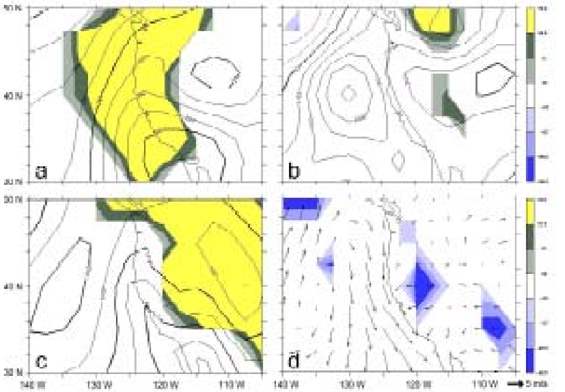
- University of California, Davis
  - Professor of Climate Dynamics
  - Since 01/1982

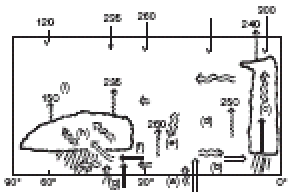
- Father of twins
  - Teenagers!
- Businessman
  - Owner of Rich Fields Farm (Pistachios, other crops)

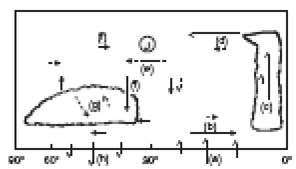
- Too many hobbies…

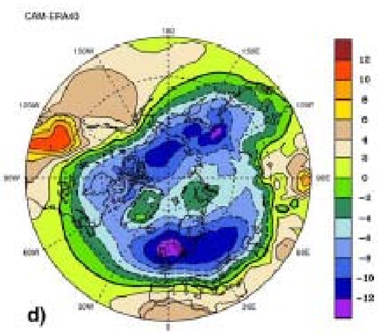
Research Interests

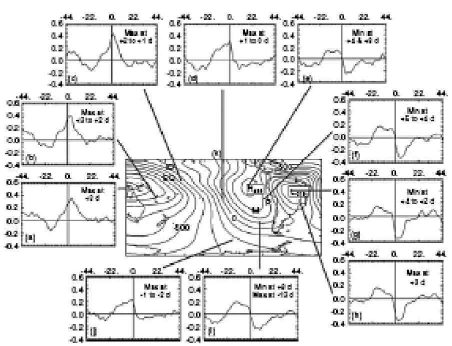
- Extraordinary weather & extreme statistics
  - Grotjahn & Faure (2008), Grotjahn (2010a[*], 2010b)
- General circulation
  - Grotjahn (1993[*], 2002a, 2002b, 2007, 2008, 2011[*])
- Climate model bias
  - Pan etal (2009), Grotjahn etal (2010a, 2010b)
- Subtropical Highs
  - Grotjahn (2004), Grotjahn & Osman (2007)
- Theoretical dynamics
  - Grotjahn 1994a, 1994b, 2003, 2005, & >20 more)

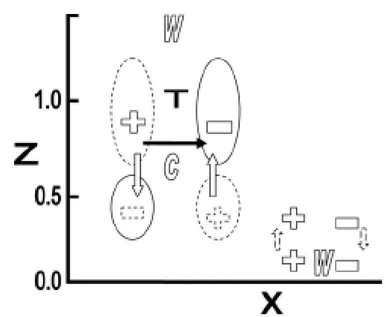












* Denotes book

California Hottest and Coldest Days: Their Large-scale Weather Patterns, Extreme Statistics, Downscaling, and Further Questions

Richard Grotjahn
Atmospheric Science Program

Dept. of LAWR, UCD, Davis, CA, USA

Outline of Talk:

- **1. California Central Valley (CV) Geography**

- **2. CV Coldest Days Upper Air Obs.**
  - Misleading monthly means (Florida, December 1983)
  - CV composites
  - Large scale air mass displacements create Large scale patterns

- **3. CV Hottest Days Upper Air Obs.**
  - Misleading monthly means (California, July 1991)
  - CV composites
  - Large scale air mass displacements create Large scale patterns

- **4. Upper Air Downscale Link to Surface Obs.**
  - A prototype downscale analysis/hindcast scheme
    - How it works
    - How well it does
  - Possible climate model applications

- **5. Conclusions & Questions (statistical, dynamical)**

© AP

1. California Geography

- Will make application to California Central Valley (CV)
- CV extreme events.
  - Most only last a few days
  - Can have big impact upon crops infrastructure, people.
  - Might not show up on monthly means.
- Though ephemeral, they can be important for climate.

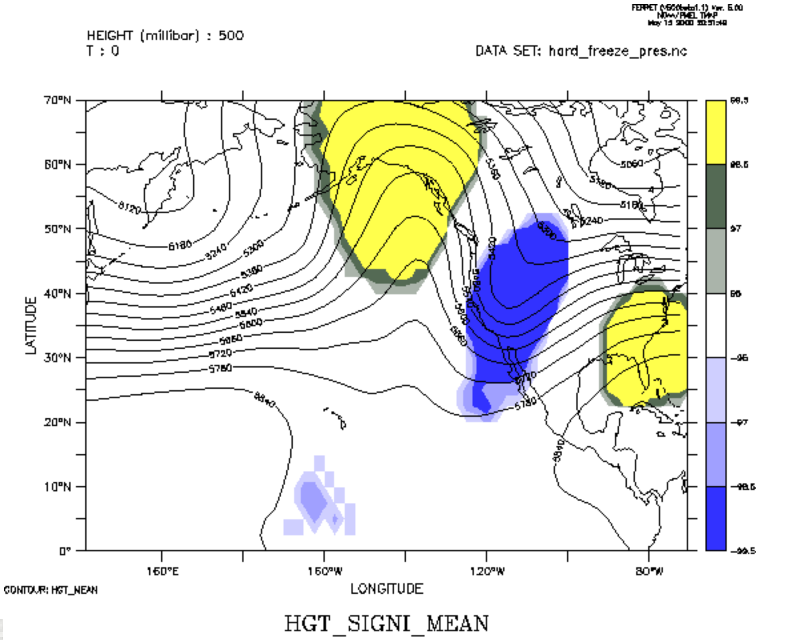
Extreme Weather Patterns

- 1. CV Coldest Days Upper Air Obs.

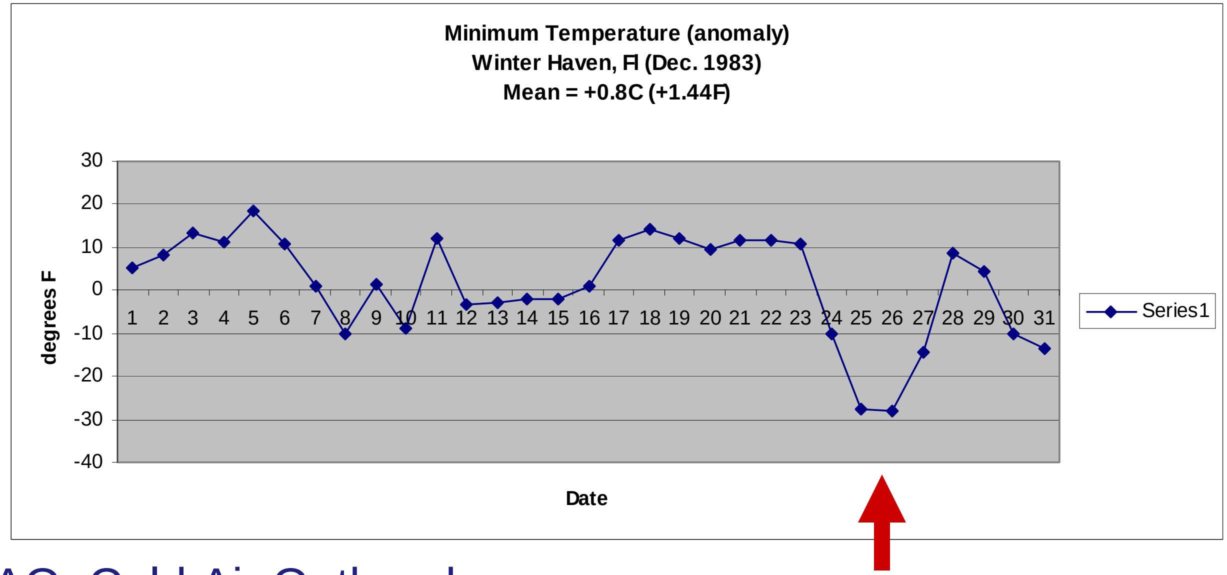
- 2. CV Hottest Days Upper Air Obs.

2. CAO: cold air outbreak

- Cold air outbreak (CAO)
  - Winter
  - Associated with:
    - Freeze damage to subtropical crops (citrus, avocado, etc.)
- Large scale pattern
  - Broad ridge over Alaska
  - Weak ridge over SE USA
  - NNE flow aloft
  - Jet and lower level flow from Arctic stays over land, so little airmass modification.



Example 1: Dec. 1983 CAO



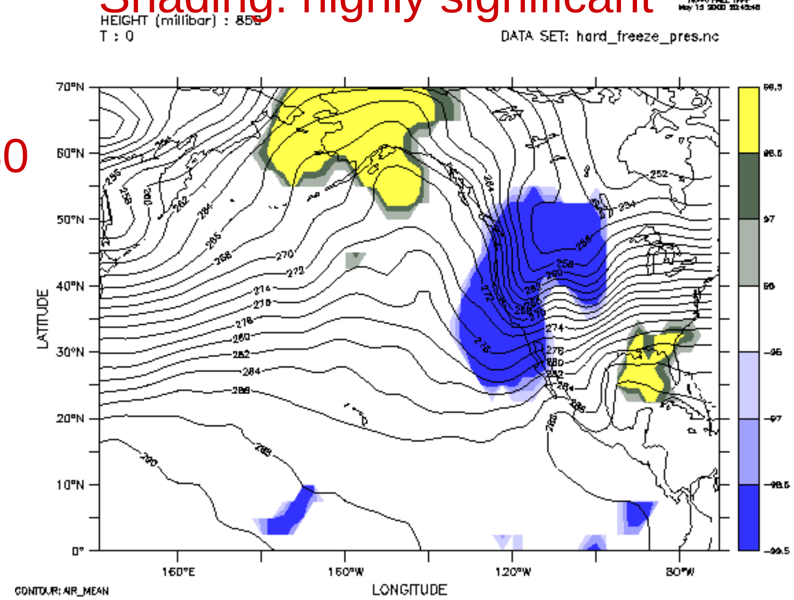
- CAO: Cold Air Outbreak
- One of the coldest outbreaks on record for SE U.S.
- In **Florida**, >80% of the juicing oranges were spoiled; more than half the citrus trees were killed.
- **Winter Haven, Florida** is heart of citrus growing region:
- Daily anomaly temperatures show the 4 day deep freeze
- Rest of month was generally above average.
- The mean for the month? Above normal! +0.8C (+1.44 F)
- So **an above normal December wiped out the crop**.
- Conclusion: **The monthly mean misses this important event!**

CV CAOs upper structure

- Example target composites from cold air outbreaks (onsets) affecting Ca CV.
  - T at 850 hPa
  - Z at 500 hPa
- Composites: very large scale pattern.
  - Highly significant <1%; >99% levels over large areas.
  - Yellow means: grid pt value highest 1%
  - Blue means: grid pt value lowest 1%
  - Grotjahn & Faure, WAF, 2008
  - More posted on web, including lead-up

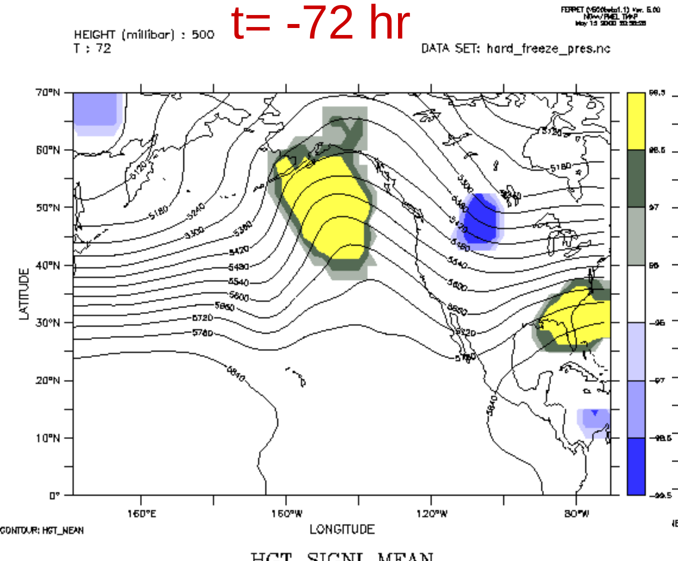
Shading: highly significant

T 850

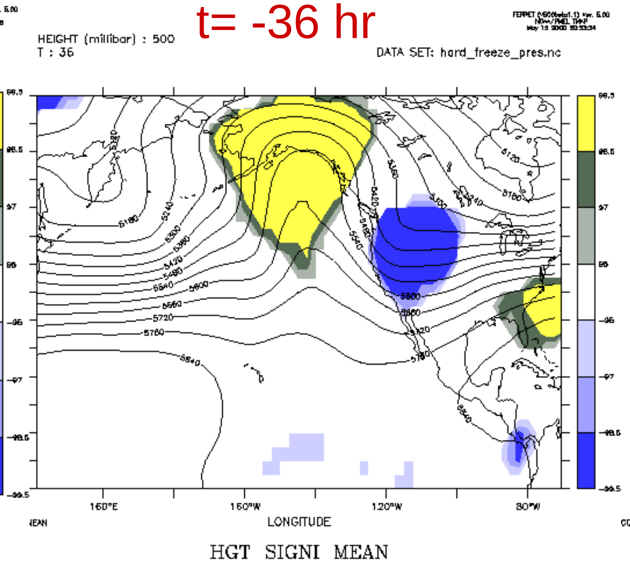


Z 500

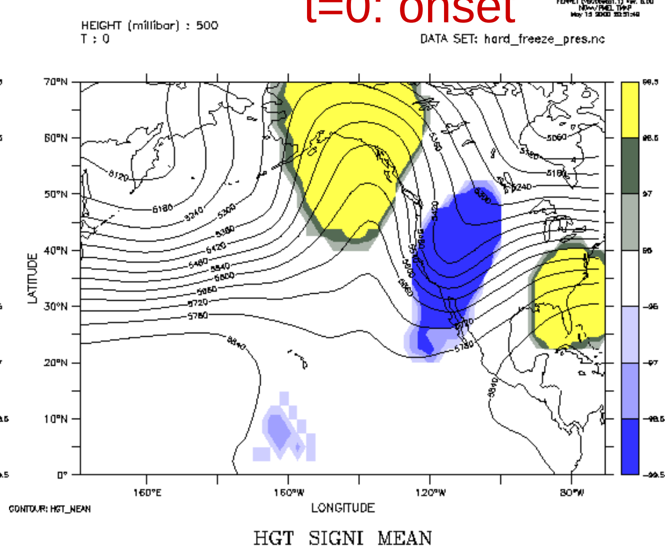
t= -72 hr



t= -36 hr



t=0: onset



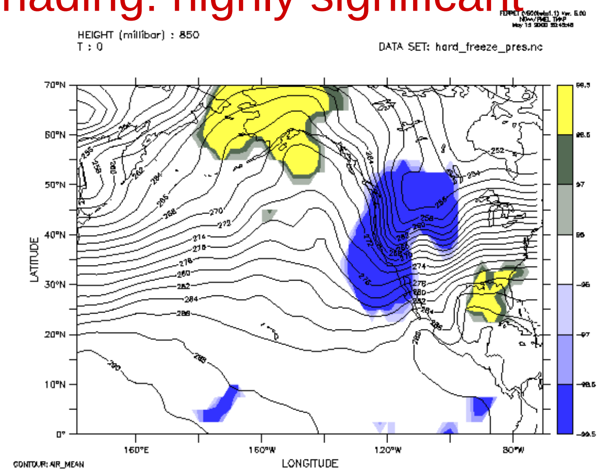
http://atm.ucdavis.edu/~grotjahn/EWEs/hard_freeze/hard_freeze.htm

Some Statistics Notes:

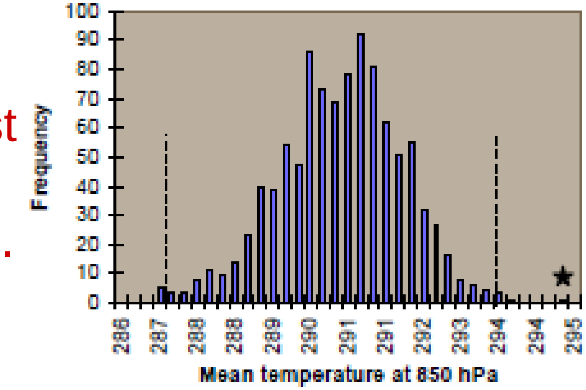
- Define target ensemble from key dates
  - Target ensemble from onset of coldest dates
  - T at 850 hPa composite shown at onset.
- Variations:
  - Times before onset as well.
  - Anomaly data = raw data minus long term daily mean (LTDM) for each grid pt.
- Bootstrap resampling (with replacement) Compare target ensemble to random ensembles of the same size
  - Draw ‘random’ dates, form 1000 composites of such ‘random’ ensembles
  - Random ensembles define a distribution for each grid pt.
  - Yellow means: grid pt value highest 10 of the 1000 ‘random’ composite values
  - Blue means: grid pt value of target ensemble composite is in lowest 10
  - Highest 10 is highest 1% of values, etc.
- Other considerations
  - Compare same time of day (diurnal cycle)
  - Aggregate adjacent grid points (regional significance – for similar features phase-shifted)
  - Test consistency as well (std deviation of target ensemble members vs same for random ensembles; subjective comparison of the members; and ‘sign counts’.)
  - Global statistical assessment of the map (how many pts are signif. Vs the number expected by chance)

Shading: highly significant

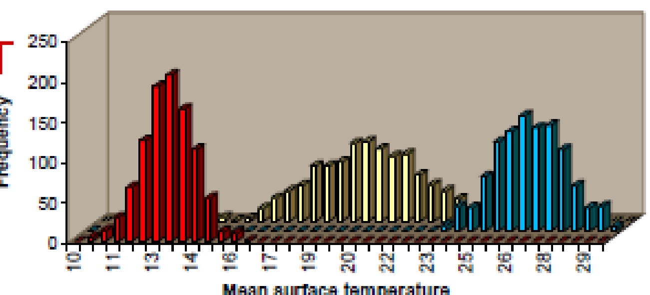
T 850



Hottest Days Distrib.



12GMT
0GMT
mixed



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

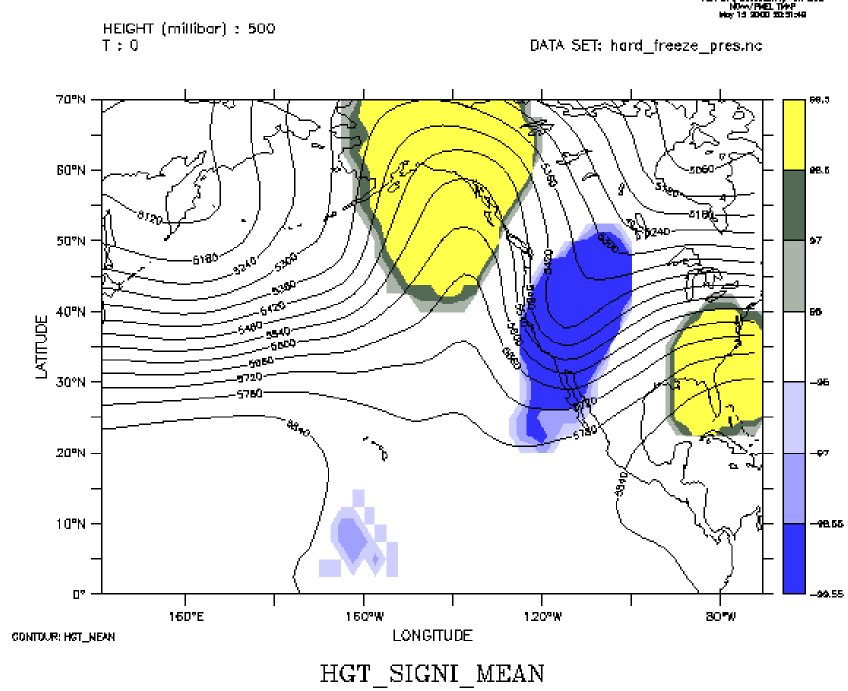
Coldest days: time sequence

- Z 500 hPa
  - 60hr-0hr

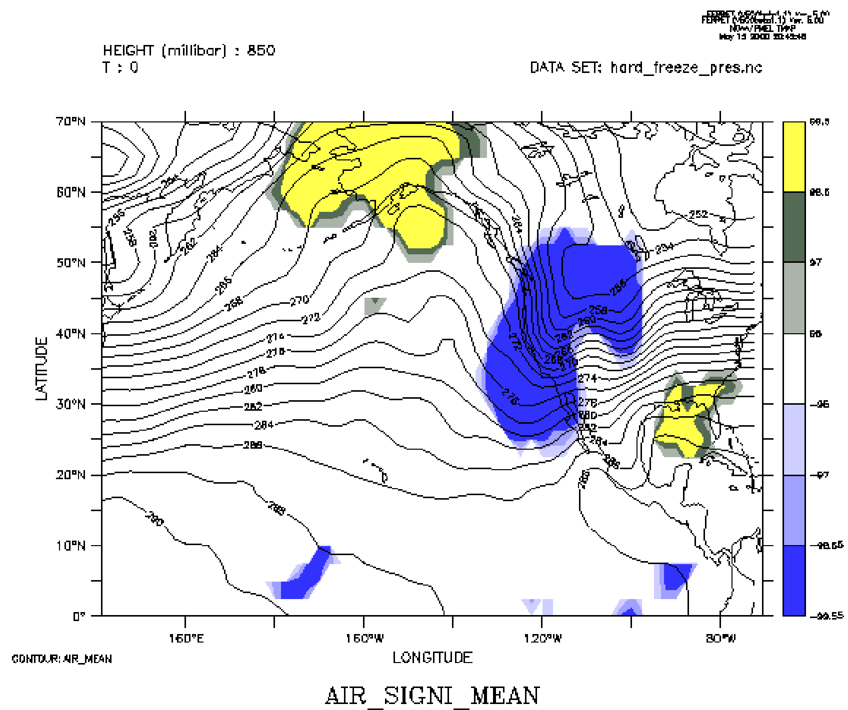
- T 850 hPa
  - 60hr-0hr

Coldest days:

- Z 500 hPa
  - – 60hr-0hr



- T 850 hPa
  - – 60hr-0hr



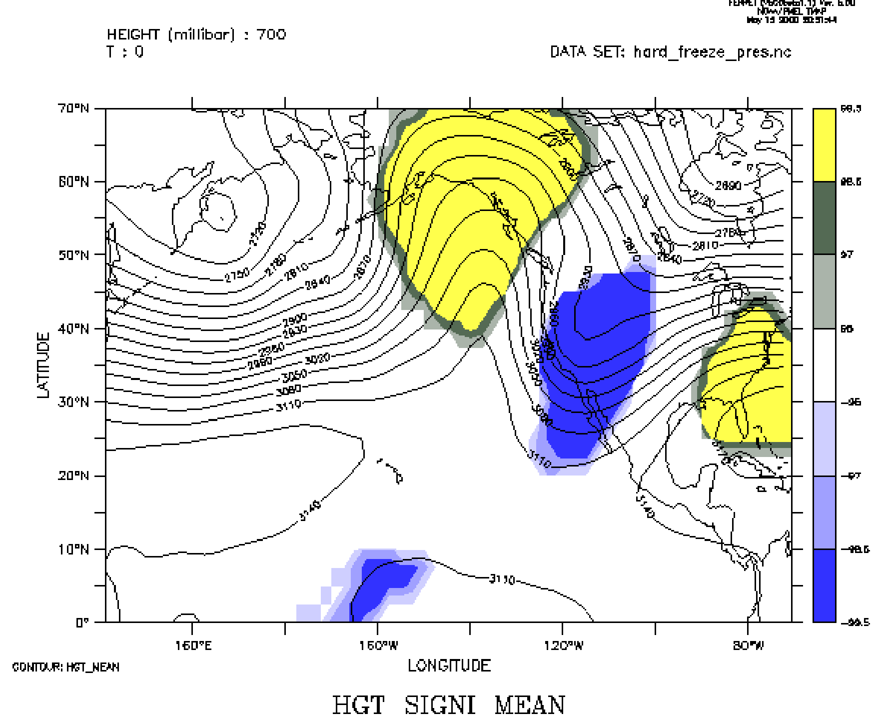
Coldest days: time sequence

- Z 300 hPa
  - 60hr-0hr

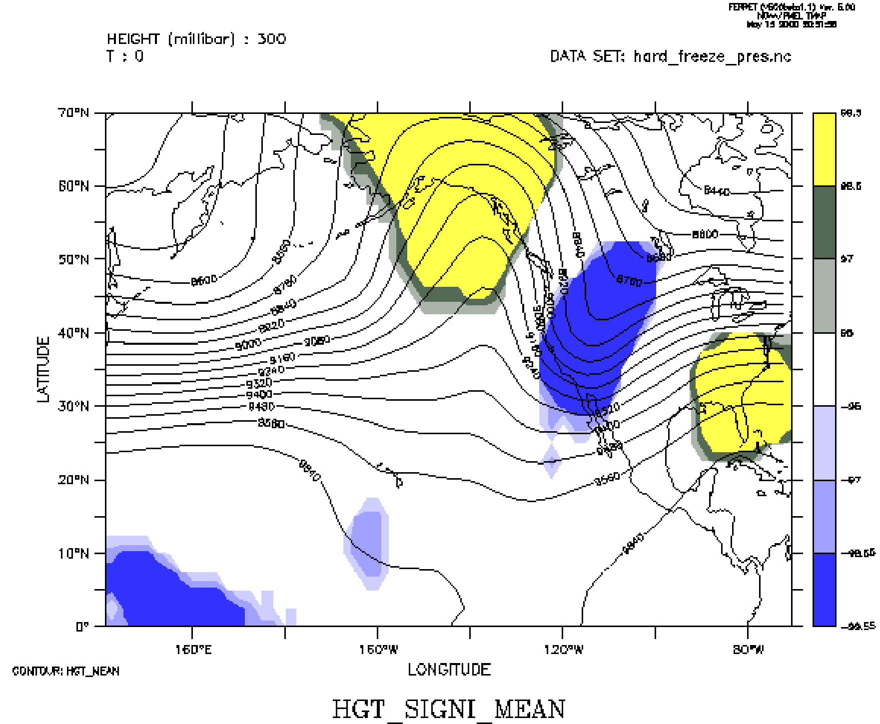
- Z 700 hPa
  - 60hr-0hr

Coldest days:

- Z 300 hPa
  - 60hr-0hr

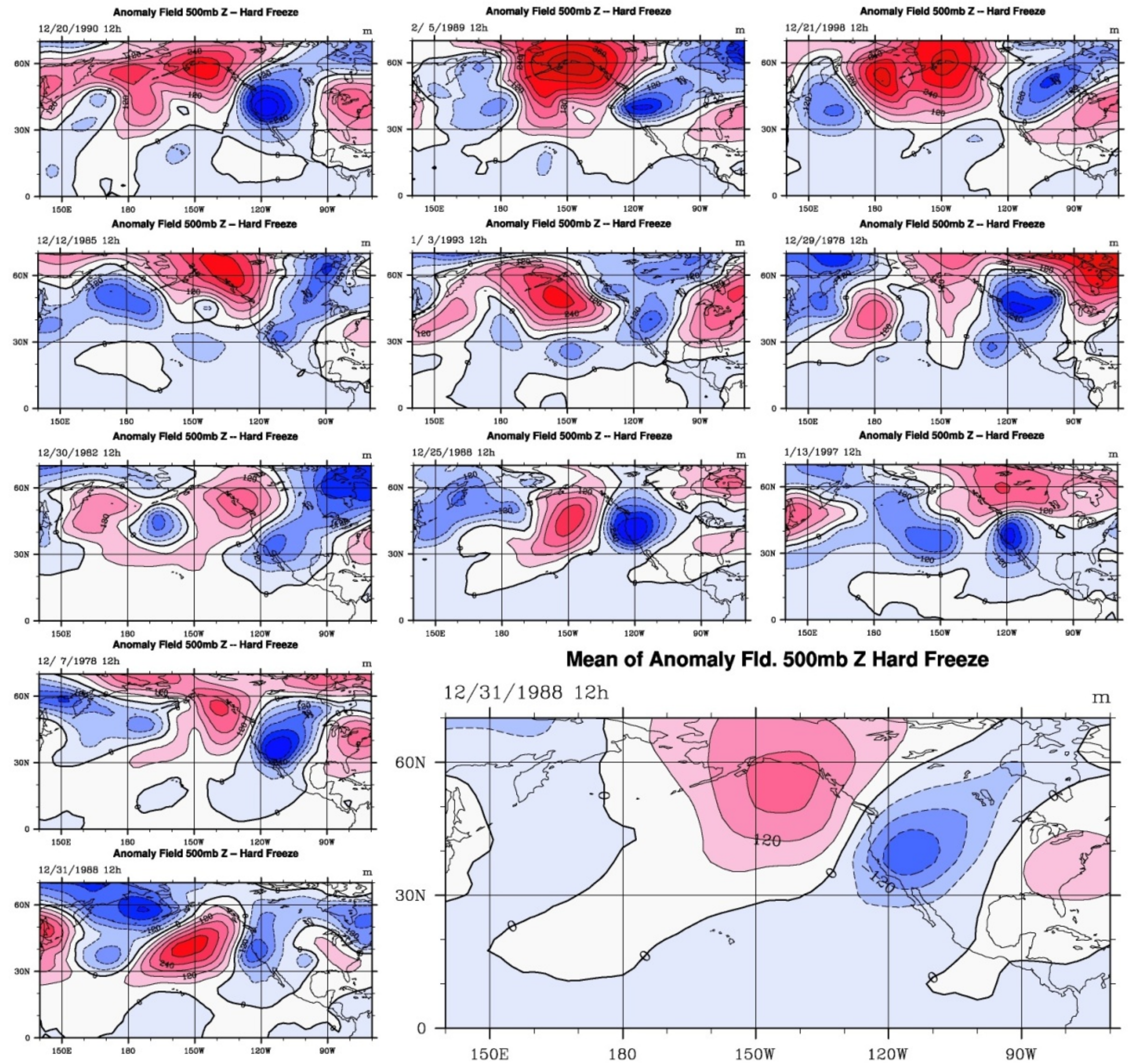


- Z 700 hPa
  - 60hr-0hr



3 parts of the pattern are very consistent

- Parts consistent for all occurrences of extreme events
  - The anomaly Z field has:
  - trough centered over CA & Great Basin (11 of 11).
  - Ridge over or near Alaska (11)
  - Ridge (sometimes weak) over SE USA. (10 of 11)
  - Z500 anomaly shown for the top 11 events. 1979-2006 average of the 11 events (large fig.)
  - Circulation advects cold air over continent – avoids moving airmass over ocean
- BTW: even with global warming, such a circulation brings freezes



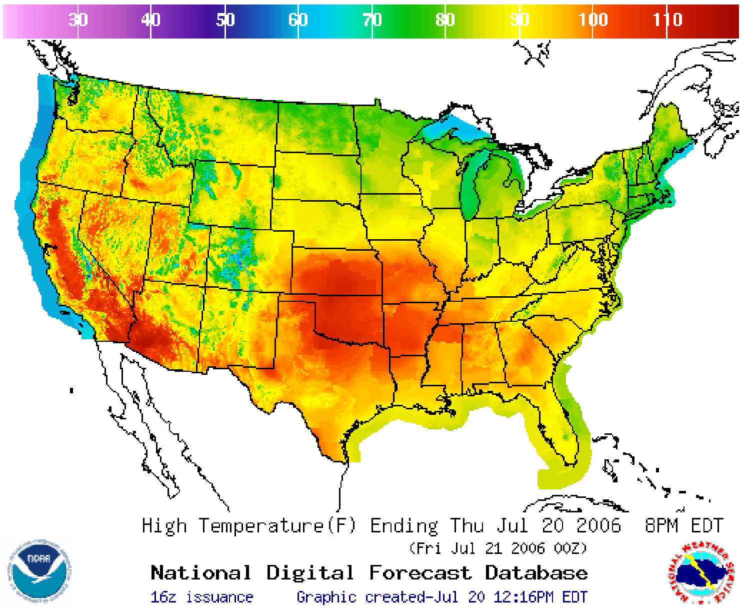
Top 11 cases

Ensemble ave.

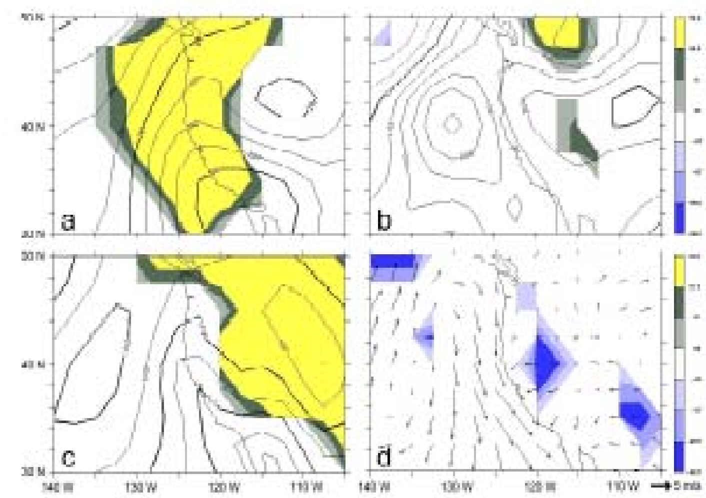
Example: Z anomaly @ 500 hPa

3. Hottest Days:

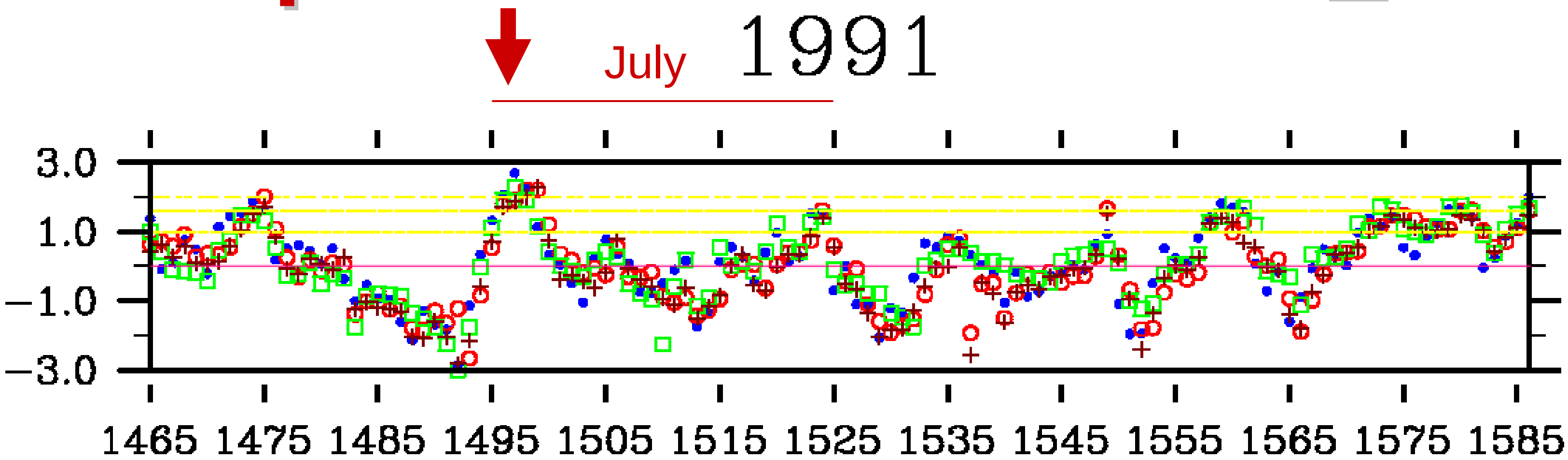
- Hottest Days
  - Summer
  - Associated with:
    - Excessive power demand
    - Poor AQ
    - Mortality



- Large scale pattern
  - Ridge-trough-ridge in Pacific
  - Lower tropospheric T maximum (anomaly) just offshore
    - ‘Themal low’ offshore: offshore and downslope (weak) winds (P<800mb)
    - Creates low level strong inversion
    - Elevated T in lower atmosphere
    - Solar heating of shallow bndy layer



Example 2: Jul. 1991 CV Ta_max



Daily anomaly temperatures at 4 CV stations June-Sept. 1991

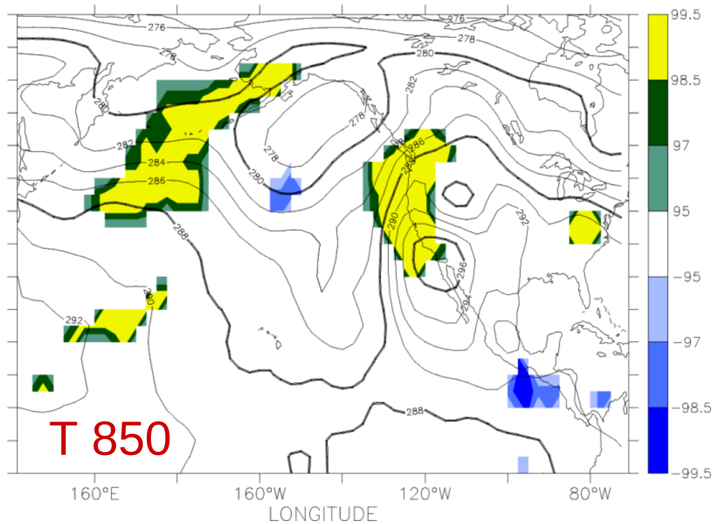
Normalized by each station's STD. Pink line is LTDM.

- **CV HW: California Central Valley Heat Wave**
- The hottest outbreak in at least 30 years.
- Daily anomaly temperatures show 4 days of extreme heat
- Rest of month was generally below average.
- The mean for the month? -0.2 STD (Standard deviations). Below normal!

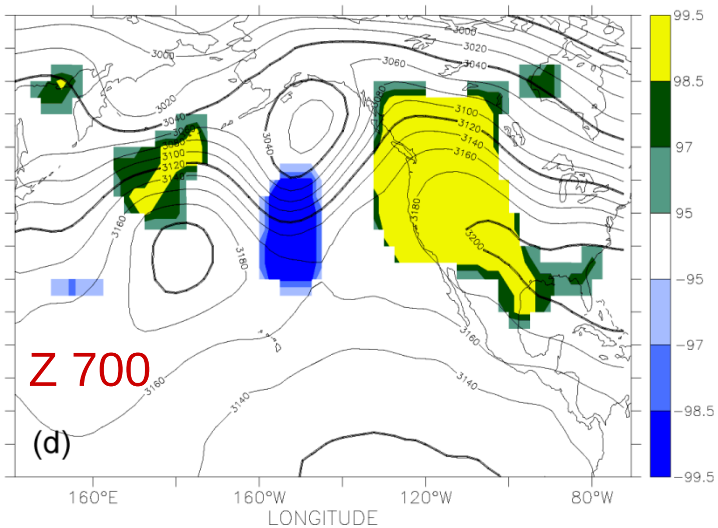
- **A cooler than normal July had the state's hottest heat wave.**
- Conclusion: **The monthly mean misses this important event!**

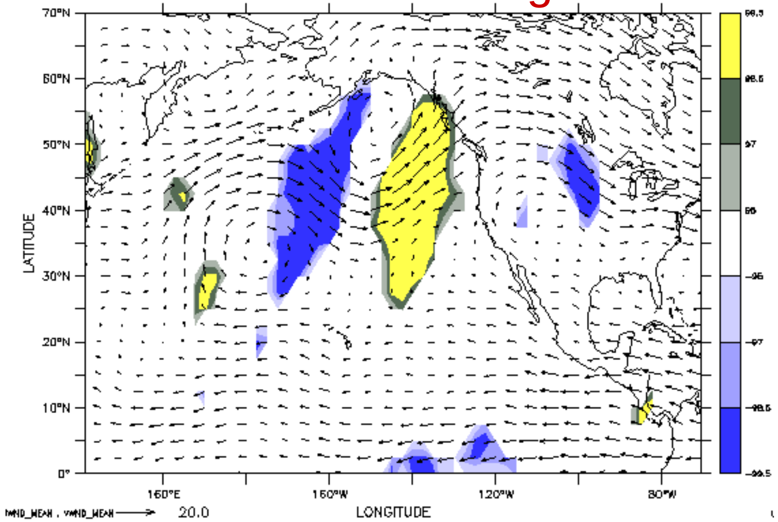
CV Hottest days upper structure

- Example target composites from severe heat waves (onsets) affecting Ca CV.
  - T at 850 hPa
  - V at 700 hPa
  - Z at 700 hPa
- Conclusion: very large scale pattern.
  - Highly significant >99% level
  - Grotjahn & Faure, WAF, 2008
  - More posted on web, including lead-up
- Synoptic situation.
  - Large airmass displacements, including upstream
  - Suppressed thermals, offshore thermal low + offshore flow (P<800 hPa),



Shading: V 700





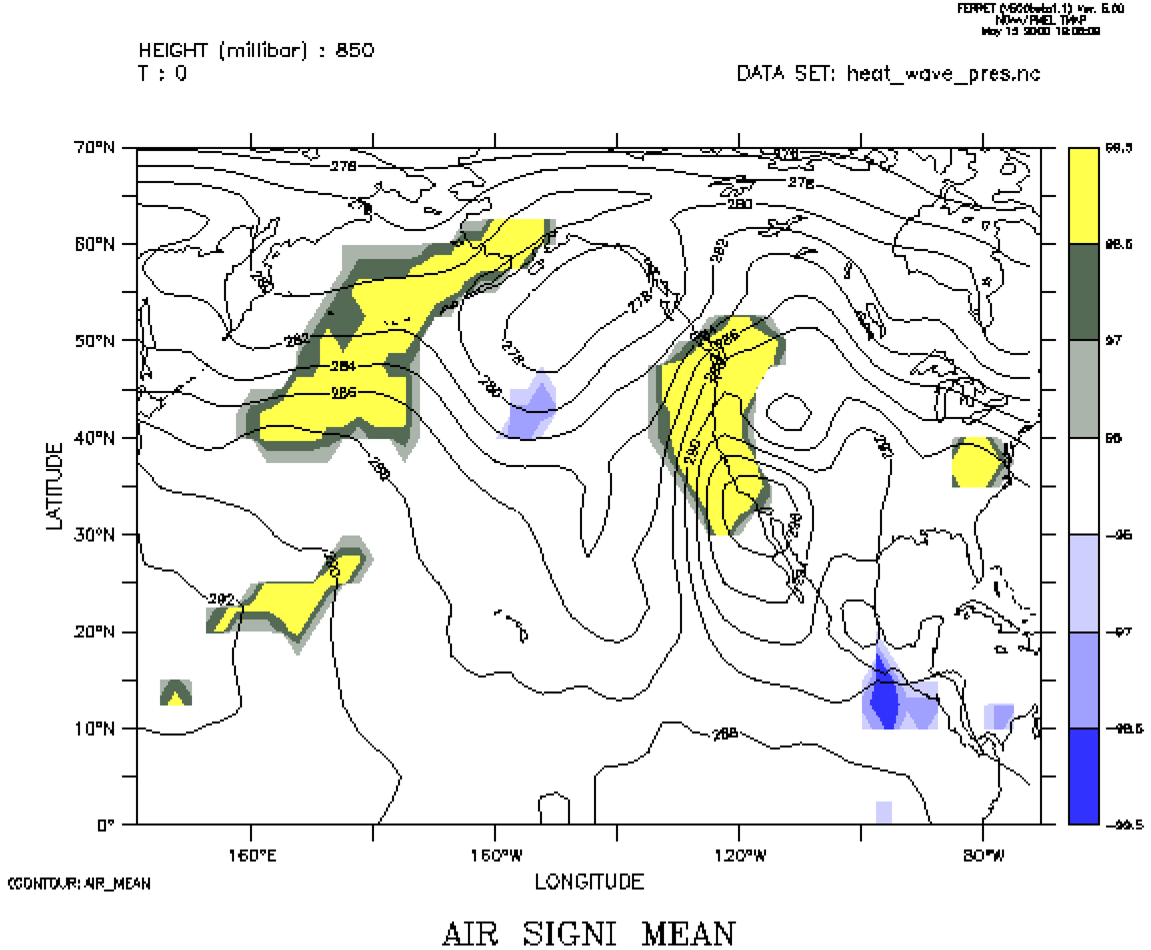
http://atm.ucdavis.edu/~grotjahn/EWEs/heat_wave/heat_wave.htm

Hottest days sequence:

- T 850 hPa
  - 60hr-0hr

Hottest days:

- T 850 hPa
  - 60hr-0hr



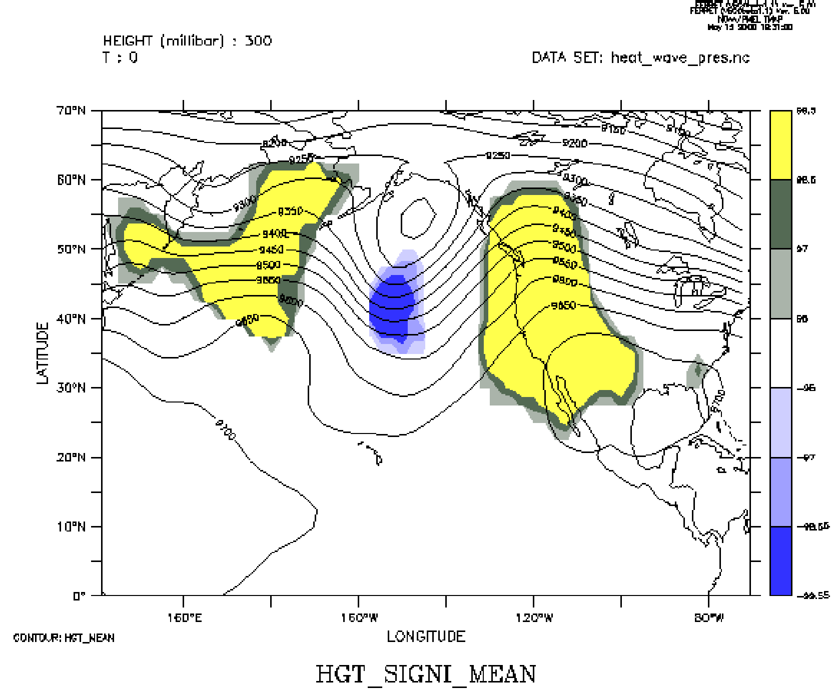
Hottest days:

- Z 300 hPa
  - 36hr-0hr

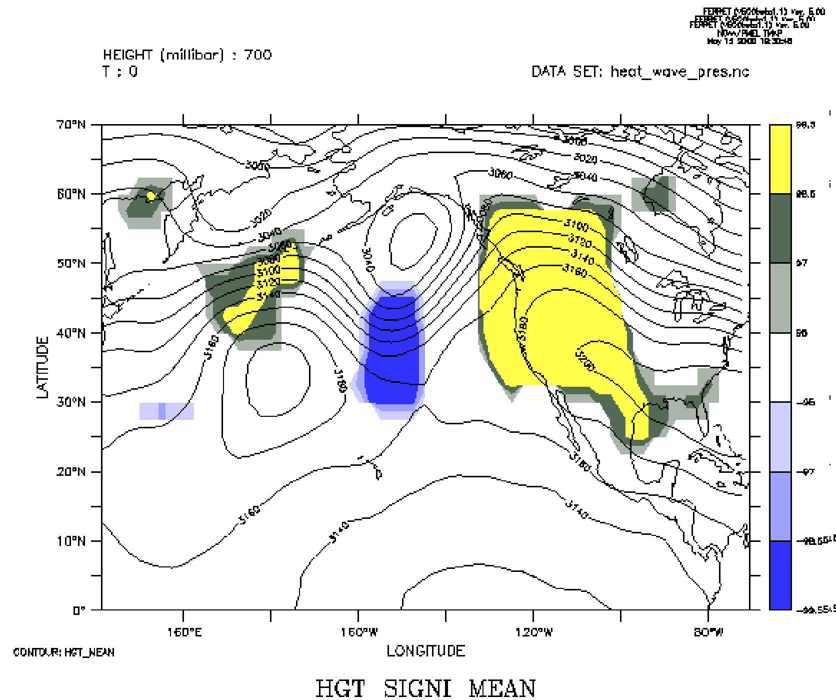
- Z 700 hPa
  - 36hr-0hr

Hottest days:

- Z 300 hPa
  - 36hr-0hr

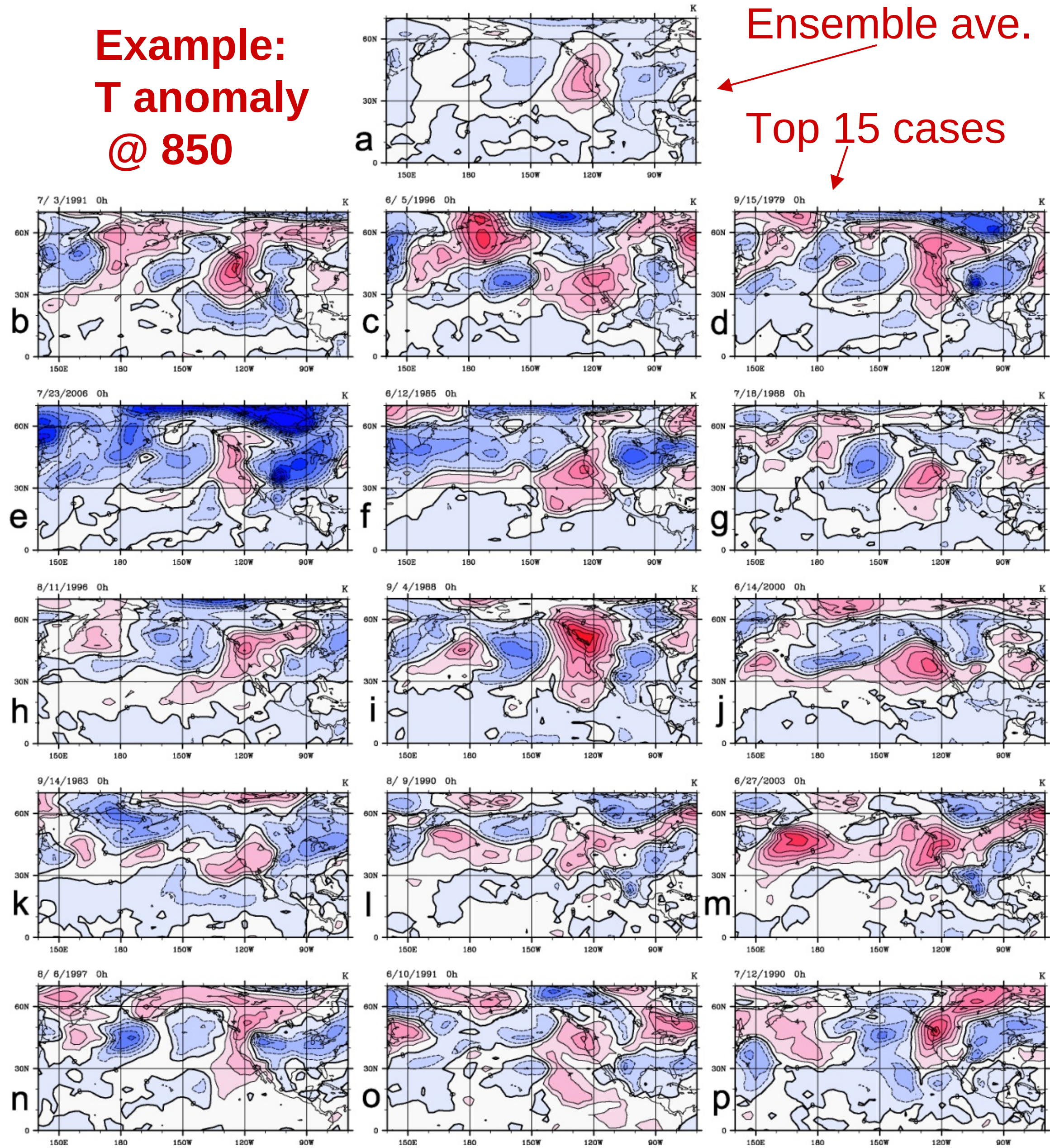


- Z 700 hPa
  - 36hr-0hr



Very Significant Pattern has Consistencies

- Parts consistent for all occurrences of extreme 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).
- Hence Z ridge near coast. So…
  - So upper level sinking over CV and to the East
  - Downslope easterlies too
  - Adiabatic warming traps low level heating
- **Locally, the circulation has features that optimize the high temperatures**.
- So: Worst **freezes** and hottest heat waves have highly significant & consistent areas.

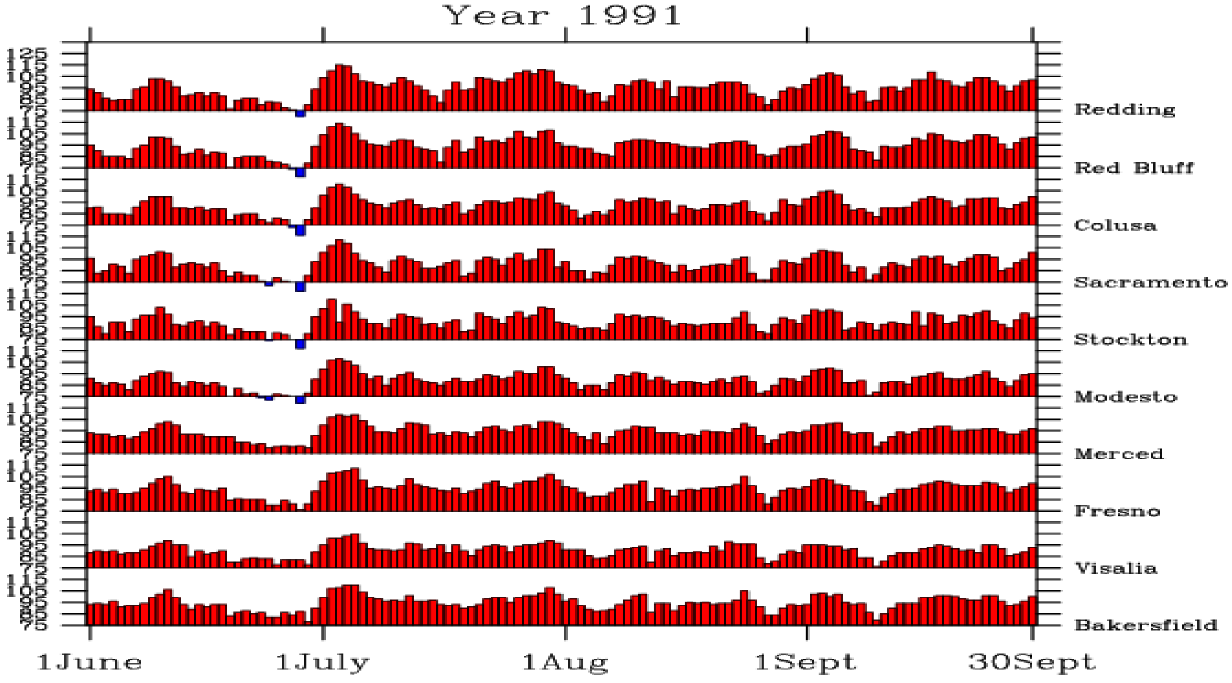


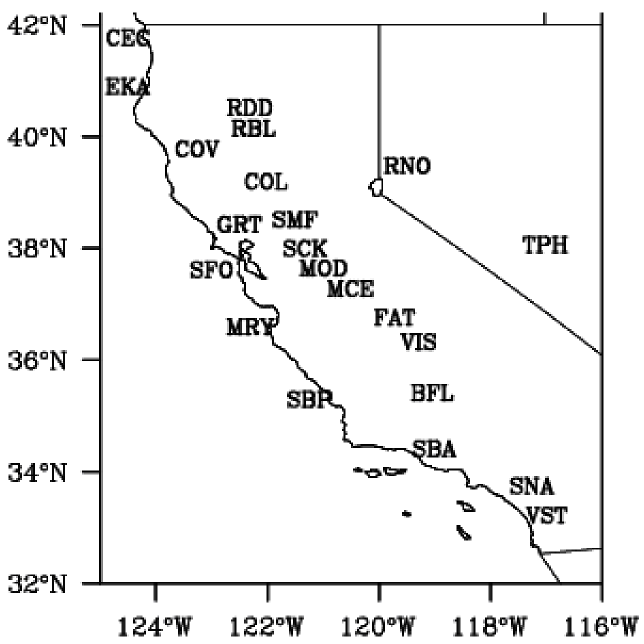
CV hottest days (obs.)

- Conclusions (from observed heat waves)
  - Short events (with long-term consequences) may not show up in time means
  - Onset Pattern understandable from basic synoptics
  - (How each pattern forms is another set of questions!)
  - Temperature and wind related extremes have large scale
    - Heat waves (also severe freezes, and diablos) result from large displacements of air masses
- How to use this information? Data mining of climate models output.
  - Need events with large scale.
  - The large scale patterns can be resolved by medium resolution (e.g. T42) climate models.
- Test link between circulation & event with pilot project

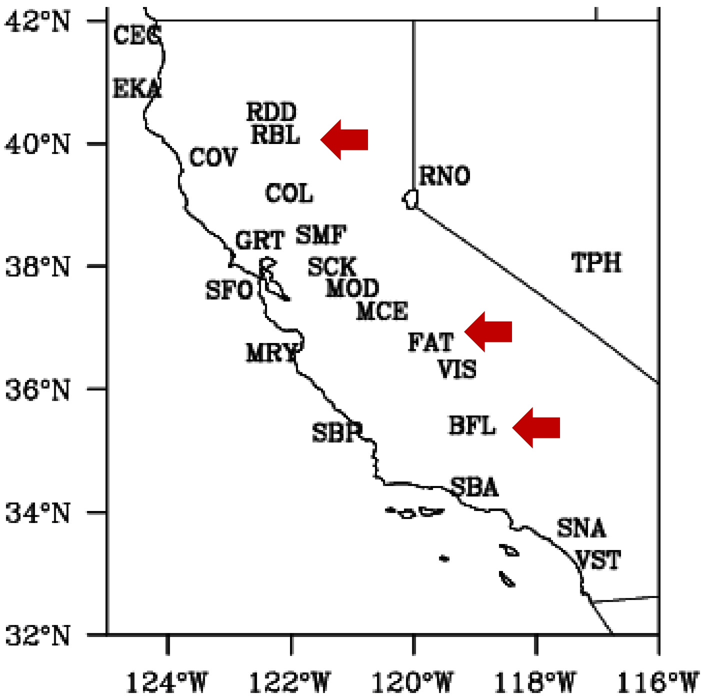
4. Pilot Project (background)

- T at CV stations fairly similar
- Correlations with Sacramento range, N to S:
  - 0.83 (RDD), 0.87 (RBL) to 0.83 (FAT), 0.86 (BFL)
  - N half of CV sfc T changes often lead S half by up to a day
- July 1991 event (worst in SMF July 2-4)
  - A very weak sea breeze can interrupts event (Stockton)
- CV max T coherent if avoid stations near the delta





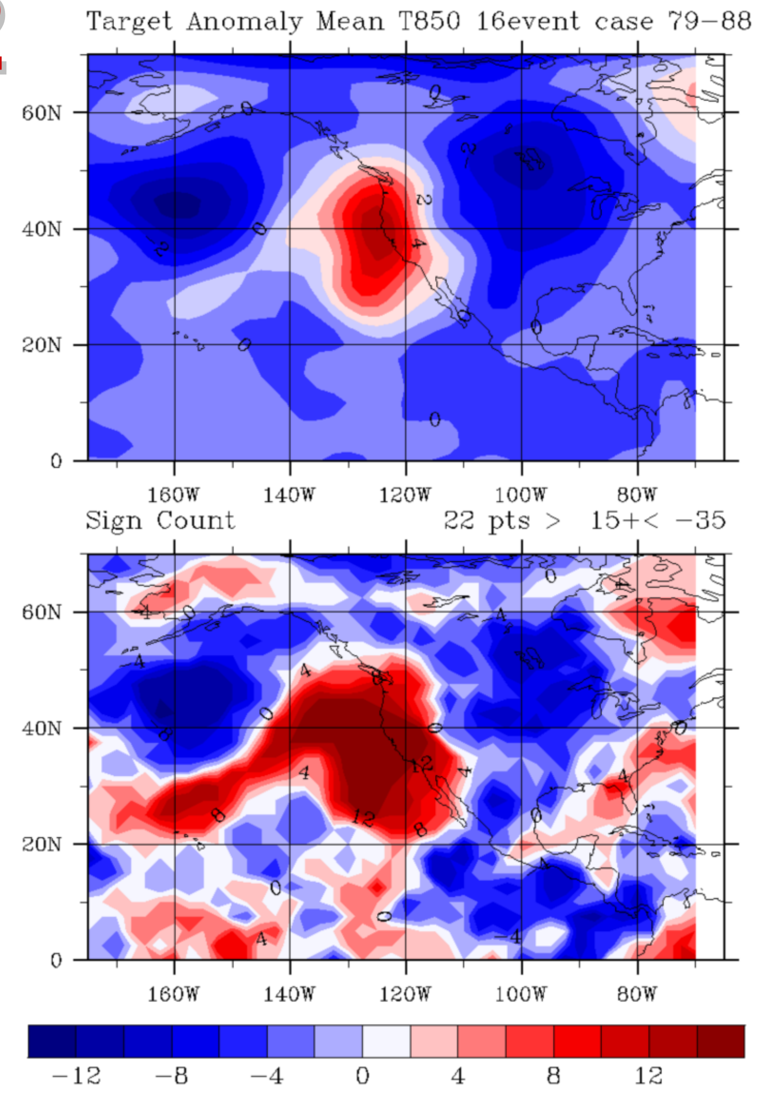
Pilot Project, part 1



- Purpose: Test if one can find extreme surface events from large scale upper air data.
- First find obs. 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
  - 33 **'target dates'** of extreme heat were found when (max-Ta) / (std dev.) >1.6 at all 3 stations.
- Make daily anomaly fields from NCEP/DOE AMIP data: 2.5x2.5 grid.
- 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)
- Then…..

Pilot Project, part 2

- As before, use bootstrap to identify significant areas
- Identify areas of consistent sign in anomaly field using ‘sign counts’.
- Sign count is sum of +1 for >0, -1 for <0 at a grid point for all 16 target ensemble members. So, +16 means all 16 members had positive sign at that grid point.

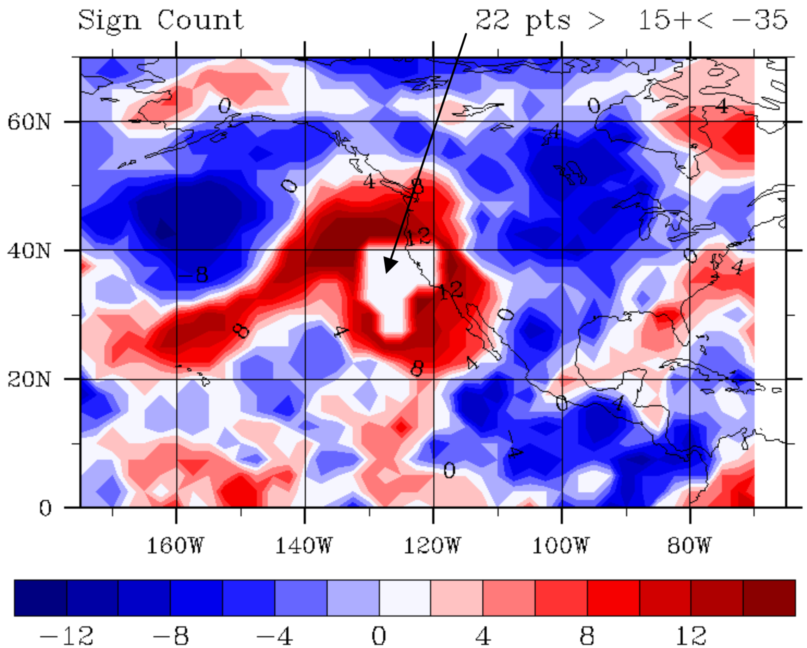


- Index based on an average of the 16 worst days at select points…

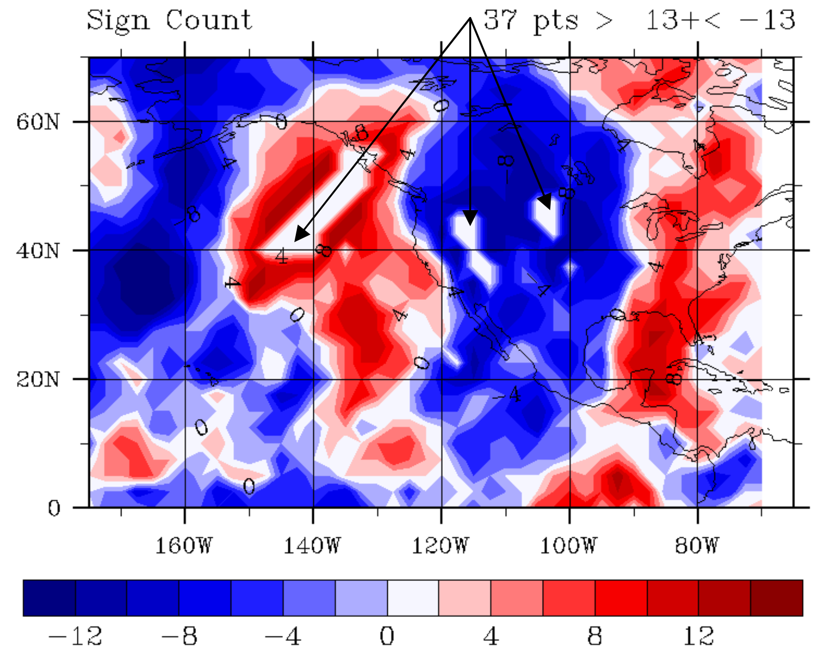
Example: Target composite and sign counts for 16 events. T850 hot consistently at & 10º ***west*** of CV

Pilot Project, part 3

- Use grid pts in select (ad hoc) regions
  - Near CV (to reduce sensitivity to large scale wavelength)
  - Only those highly consistent between extreme events (high sign counts)
  - Indicated by ‘holes’ on this slide



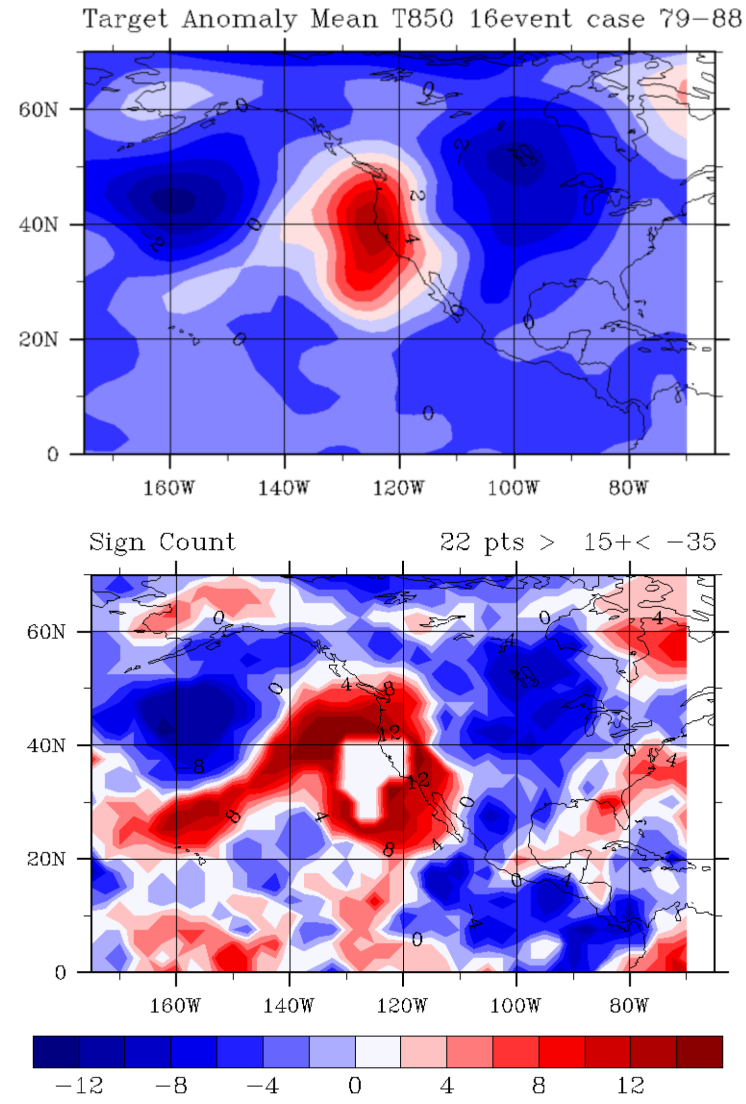
Example: sign counts for 16 events. T850 hot consistently over and 10º ***west*** of CV



Example: sign counts for 16 events. V700 anomaly consistently 10º ***west*** of normal location

Pilot Project, part 4

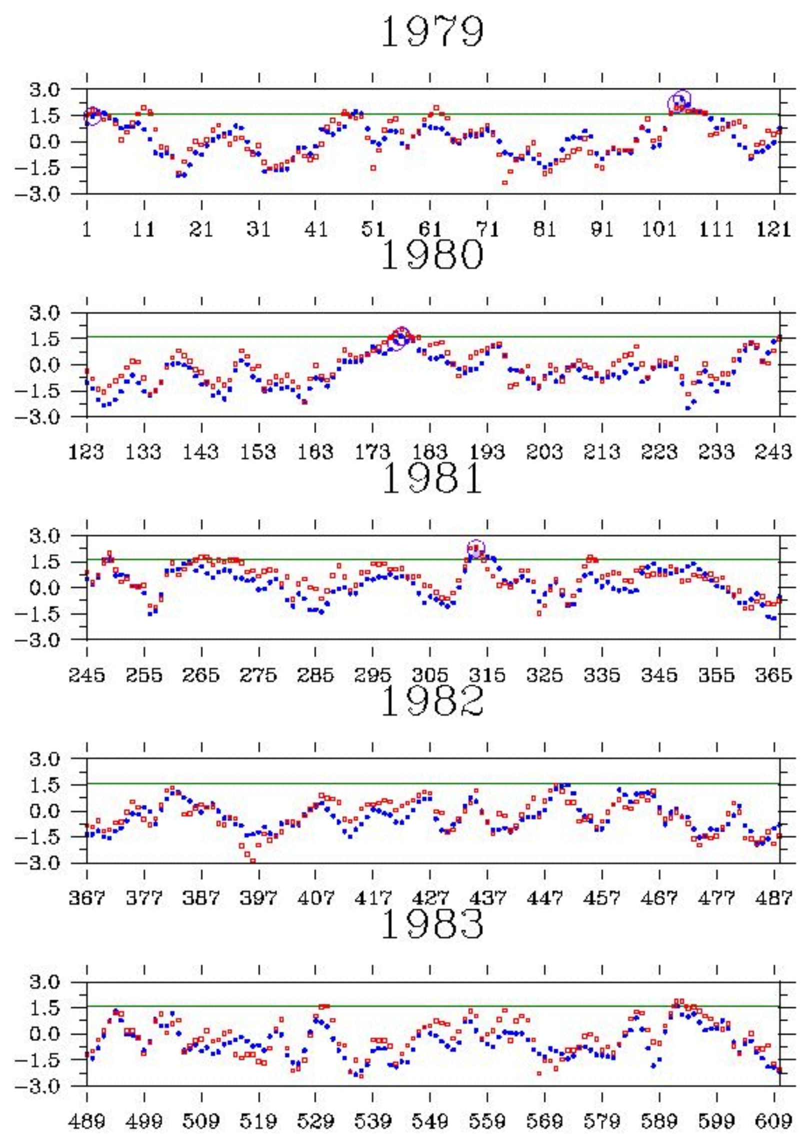
- **‘daily circulation index’**
  - Project (or correlate, or etc.) highly consistent areas of select target composites (or leading extreme EOF) with same areas in daily data.
  - Projections from more than one variable are combined to get an overall ‘daily circulation index’ for the date.
  - Index shown next combines T850 and V700 anomaly data. Goal is to hit most number of target dates
- Index based on an average of the 16 worst days at select points from the 1979-88 pd…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

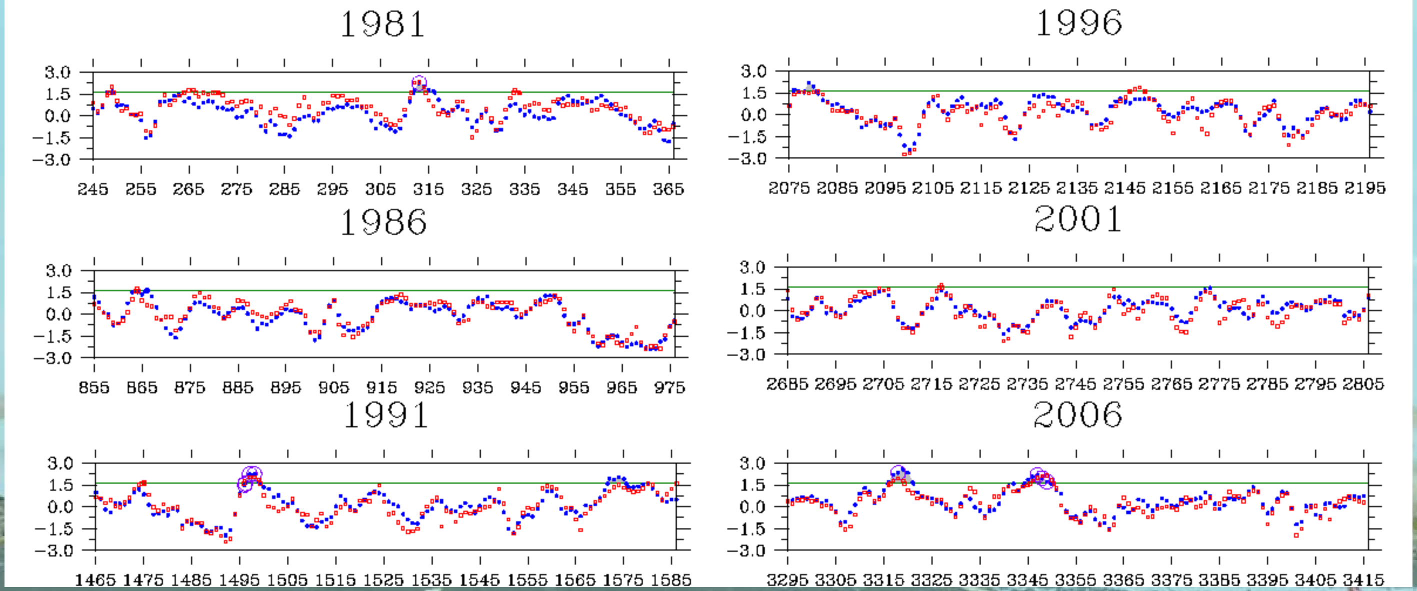
- Index based on similarity of daily pattern to pattern from 16 extremely hot days from first 10 years (1979-88):
  - Plots compare index & obs. max T for **ALL** 3416 days of the **28 year** period(!)
- Animation of time series
  - **Observed anomaly (red)**
  - **Circulation index (blue)**
  - **Extreme event dates (circles)**
- Performance (capturing extremes)
  - Highest 33 values of **index match 16 of the 33 (48%) highest 1%** events.
  - 14 of remaining 17 values of index are top 2% of obs. Events
  - Skill similar outside training period
- Surprise! 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)
- **Picks up many extreme surface events. Even outside period.**



Future Work: Climate Model Applications

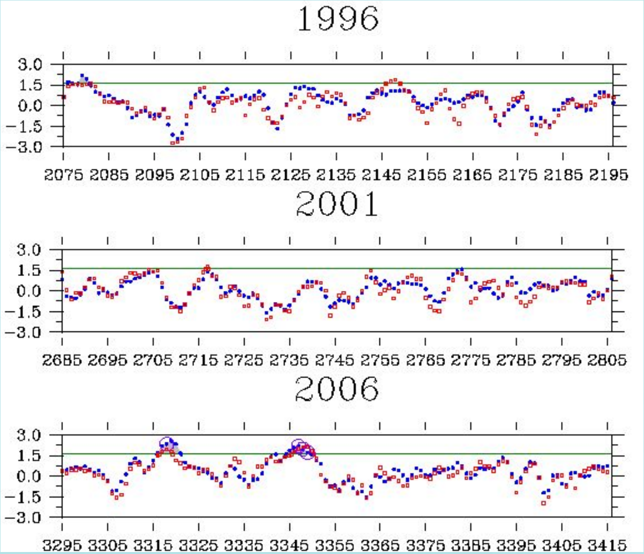
Climate Model Applications, part 1

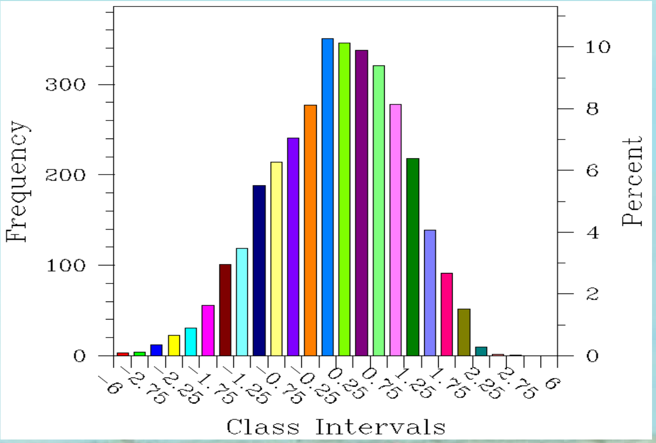
- Apply ‘daily circulation index’ idea to AMIP climate model output
  - Correlate highly significant areas of observed target composites with corresponding areas in daily simulation data (historical, AMIP runs).
  - Combine correlations from more than one variable to get an overall ‘daily circulation index’ for the simulated date.
- Study & adjust the daily indices found for historical simulations
  - Compare the climate model distribution with the observed distribution
    - Gives **model variability bias** information, including extreme hottest days
    - Apply extreme statistical analysis to the peak values.
  - Could rescale index based on the model variability to bring it in line with the observed variability and study relative change: historical to future climate.
  - Assess impact of non-optimal data levels (for study of limited archived output)



Climate Model Applications part 2

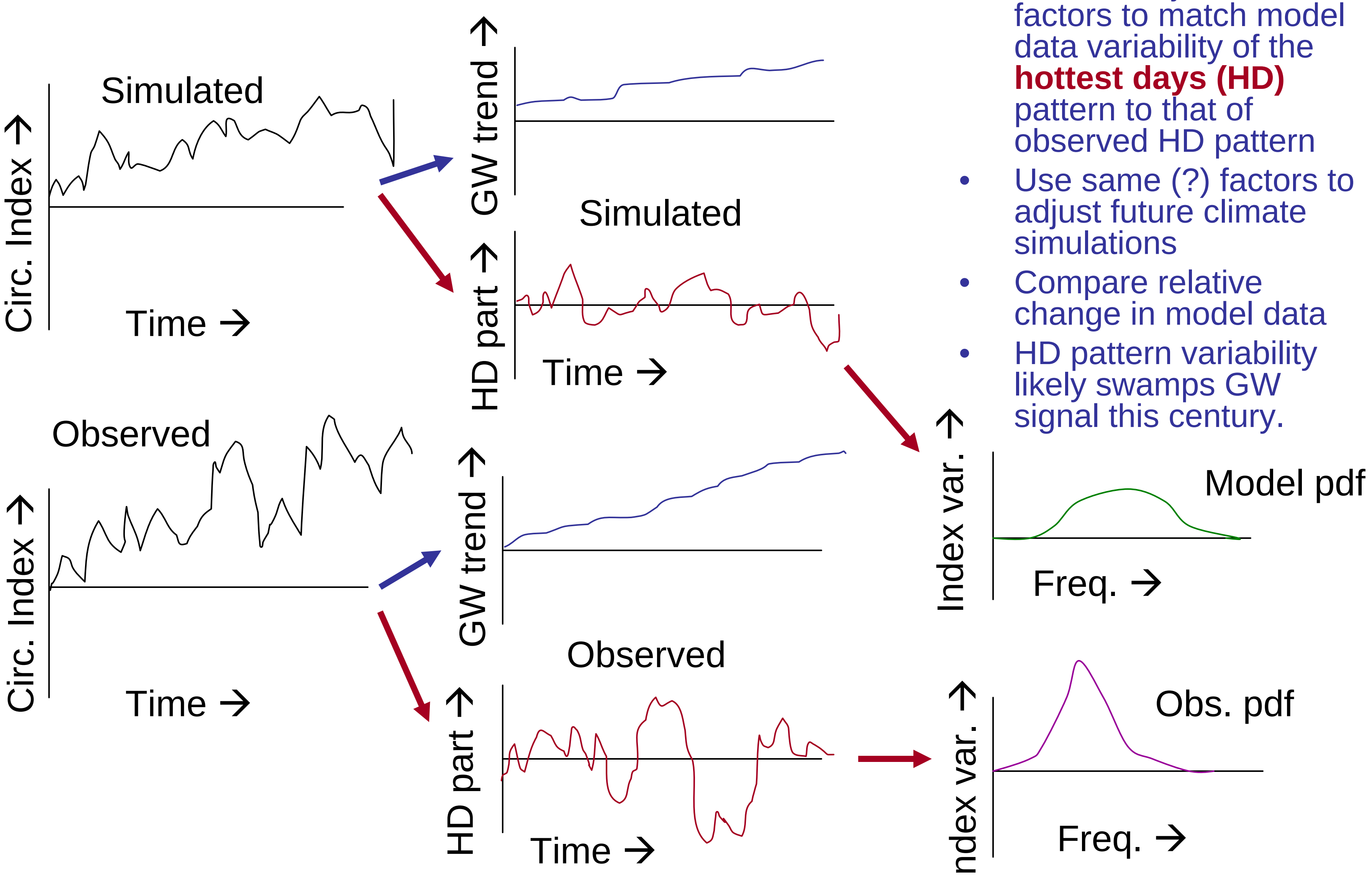
- Calculate ‘daily circulation index’ from climate model output for future scenarios.
- Compare circulation index **statistics** from historical simulations to those from future climate simulations.
  - Apply **extreme statistical analysis** to the peak values. (GPD, PP, GEV, etc.)
  - Presumably **‘global warming’ increases max-T**. T850 anomaly is primary predictor, so use historical definition of mean T850 & historical threshold to study heat waves due to the general warming.
  - How might future **variability** change? (also: duration, frequency, intensity compared with the historical threshold)
  - **Can separate general warming from change in future variability.**



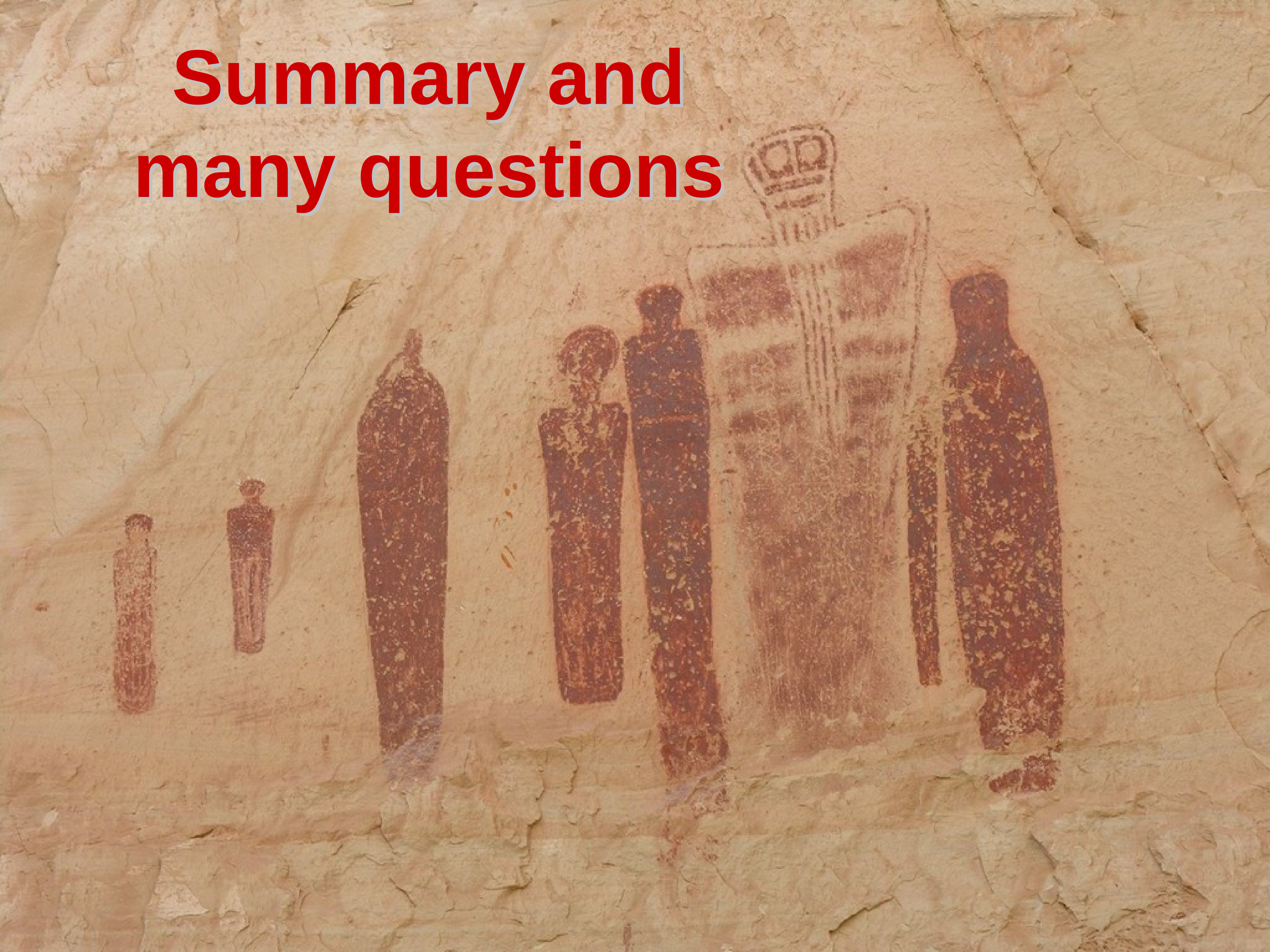


Rescale GCM Simulations

- Deduce adjustment factors to match model data variability of the **hottest days (HD)** pattern to that of observed HD pattern
- Use same (?) factors to adjust future climate simulations
- Compare relative change in model data
- HD pattern variability likely swamps GW signal this century.



Summary and many questions



5. Summary & future work

- CV extraordinary events
  - 2 types: CAO, hottest days
  - Short term events can have big impact,
  - Might not be captured by monthly means
  - All have large scale patterns, some parts very consistent and significant

- Pilot project of California Central Valley heat waves
  - Example composites shown (many more on web)
  - Developed index based on similarity between daily patterns & composites
  - Index picks up most extreme, rare hot events
  - Index picks up variability (hot, cold, near normal pattern)

- Future issues (Discussion topics):
  - Improving the statistics
  - Illuminating the dynamics
  - Applications: evaluate climate model ability to develop the relevant extreme patterns (historical simulations); separating long term warming trend from variability change; assess IPCC scenarios

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

Discussion Topics…

- **CV extraordinary events extreme statistics questions:**
  1. For thresholds: a fixed value or a running mean when using anomaly values?
  2. Can one automate or objectify the process of choosing optimal combinations of predictors when the goal is to catch extreme events (and not necessarily fit the whole time series).
  3. K-means clustering or composites (or versus extreme EOFs)?
  4. How to composite earlier times before event onset given phase separation?
  5. How best to characterize extreme event occurrence in climate model output?
  6. How to quantify the uncertainty when capturing 1/2 or 3/4 of the extreme events?
  7. Can model historical variability bias be applied to future climate simulations? If so, does it depend on the variable?
  8. Can the pattern matching be improved?

- **What dynamics create the large scale patterns of CV extreme events?**
  1. Start with a global picture (e.g. stream function anomaly) to identify upstream links (e.g. maybe there's a tropical link? – but see statistics question 7)
  2. To visualize movements, Hovmuller diagrams of…? V? Followed by estimates of group speed and perhaps a type of mode?
  3. PV on isentropic surfaces, PV streamers or PV coherent structures. What about PV anomaly relative to the 'environs'?
  4. Ray tracing (composite time mean flow; linear q-g group vel. components)
  5. Wave activity flux vectors (about a running mean? 30 day?) for each individual event, then composite those vectors?
  6. Evaluate terms in the height tendency eqn.
  7. Compare with climate indices (e.g. ENSO)
  8. Is winter easier to diagnose than summer?

Matières de discussion…

- **Yahoo.com babelfish translation: (traduction non exacte !)**
- **Questions extrêmes de statistiques d'événements extraordinaires de cv :**
  1. Pour des seuils : une valeur fixe ou un moyen courant en employant des valeurs d'anomalie ?
  2. Peut on automatiser ou objectify le processus de choisir des combinaisons optimales des facteurs prédictifs quand le but est d'attraper des événements extrêmes (et adapter pas nécessairement la série de temps plein).
  3. K-signifie le groupement ou les composés (ou contre EOFs extrême) ?
  4. Comment au composé des périodes plus tôt avant séparation de phase donnée par début d'événement?
  5. Comment mieux caractériser l'occurrence extrême d'événement dans le rendement de modèle de climat?
  6. Comment mesurer l'incertitude en capturant 1/2 ou 3/4 des événements extrêmes ?
  7. Peut modeler la polarisation historique de variabilité être appliqué à de futures simulations de climat ? Si oui, dépend-il de la variable?
  8. La configuration avec un modèle peut-elle être améliorée ?

- **Quelle dynamique crée les modèles de large échelle des événements d'extrémité de cv ?**
  1. Hiver il est-il plus facile diagnostiquer que l'été ?
  2. Commencez par une image globale (par exemple anomalie de fonction de jet) à identifier des liens ascendants (par exemple il y a peut-être un lien tropical ?)
  3. Pour visualiser des mouvements, diagrammes de Hovmuller de… ? V ? Suivi des évaluations de vitesse de groupe et peut-être d'un type de mode ?
  4. Picovolte sur les surfaces isentropiques, les flammes de picovolte ou les structures logiques de picovolte. Que diriez-vous de l'anomalie de picovolte relativement à l'environs'? de `
  5. Évaluez les limites dans l'eqn de tendance de taille .
  6. Vecteurs de flux d'activité de vague (au sujet d'un moyen fonctionnant ? jour 30 ?) pour chaque événement individuel, puis composé ces vecteurs ?

The End

Thank you for your attention

Questions?