Projected changes to California extreme precipitation accumulations from the CESM Large Ensemble

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California floods 2017: accumulations >200 mm

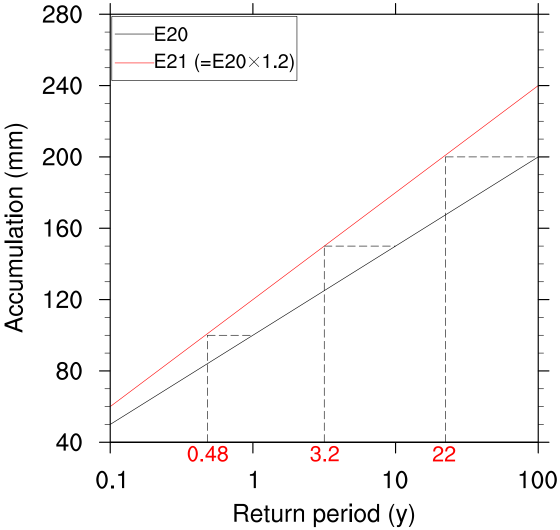



Motivation

- Extreme accumulations (100s of mm) projected to become more frequent in the 21st Century (Dwyer and O'Gorman 2017; Neelin et al. 2017).
- In a warmer climate, greater moisture levels imply greater precipitation intensity, according to Clausius–Clapeyron (Trenberth 1999; Allen and Ingram 2002).
- Dynamical forcing (Pfahl et al. 2017; Chen et al. 2018; Norris et al. 2018) and duration of events (Dwyer and O'Gorman 2017) may offset/enhance thermodynamic changes.

1. How much more frequent will major accumulations, e.g., the 10-year or 100-year events, become in California?
2. How will intensity and duration each change in the future?

Enhanced frequency of large accumulations in a future climate



CESM Large Ensemble

- Coupled atmosphere–ocean model
- Approx 1° grid spacing, 30 vertical levels
- 40 ensemble members for current climate (1990–2005) and late 21st Century (2071–2080)
- RCP8.5 forcing from 2006 onward (approx. 3 K warming by late 21st Century)
- 6-hourly output used to calculate accumulations

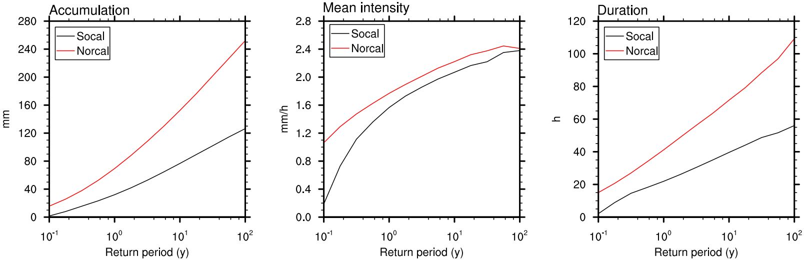
Precipitation accumulations

- Time integration of consecutive precip rates $>$0.5 mm/h: $A = \int_{t_{\text{start}}}^{t_{\text{end}}} P dt$
- Accumulation starts when P first exceeds 0.5 mm/h and ends when P first drops below 0.5 mm/h.
- Accumulation is equal to product of mean intensity and duration: $A = ID$

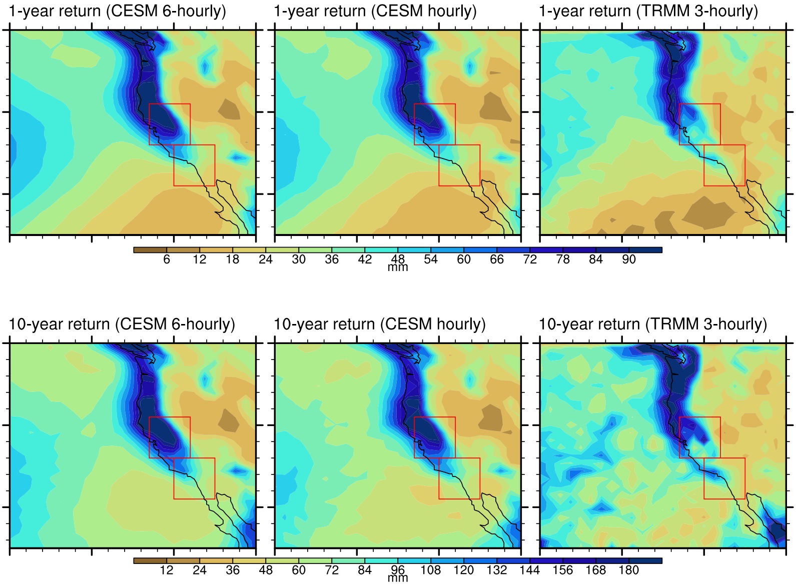
Conditional mean accumulation as function of return period

- All 40 members aggregated to give data period of several 100 years.
- Accumulations binned according to return period: obtain the mean accumulation corresponding to the given return period.
- A^e denotes the conditional mean accumulation for the e-year return period.
- Also calculate mean intensity and duration of events for a given return period: $A^e \approx I^e D^e$
- Analysis performed at each grid point for end-of-20th (E20) and end-of-21st (E21) Centuries separately.
- Significant changes at a given return period where 90% bootstrap replications agree on sign.
- Focus on California, i.e., frontal events.

Greater accumulations over Norcal than Socal due to greater duration



Accumulations well represented compared to TRMM 3B42



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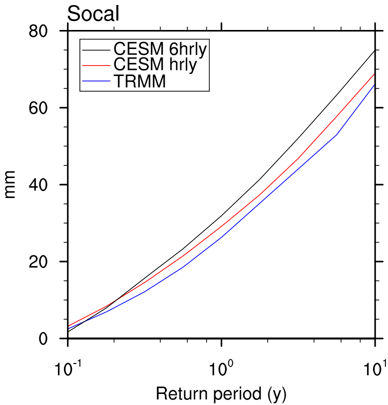
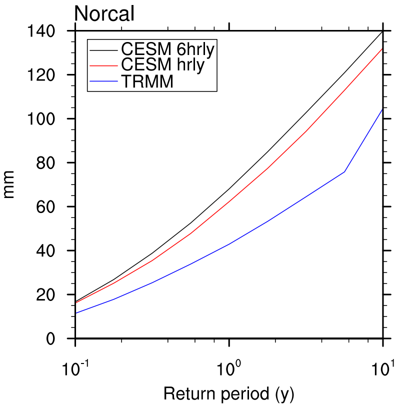
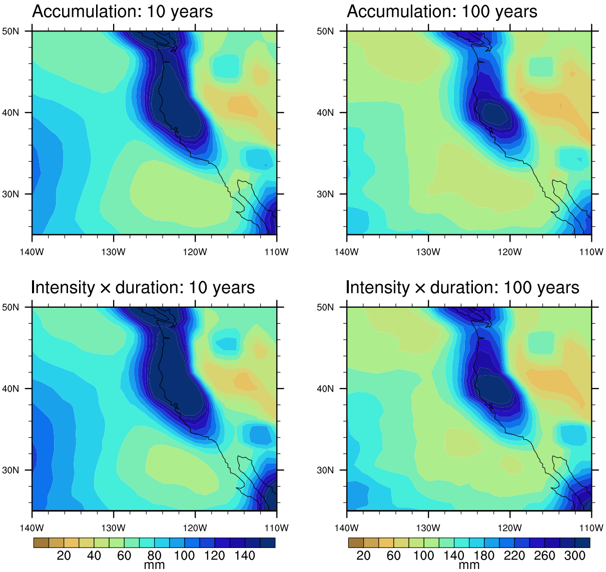
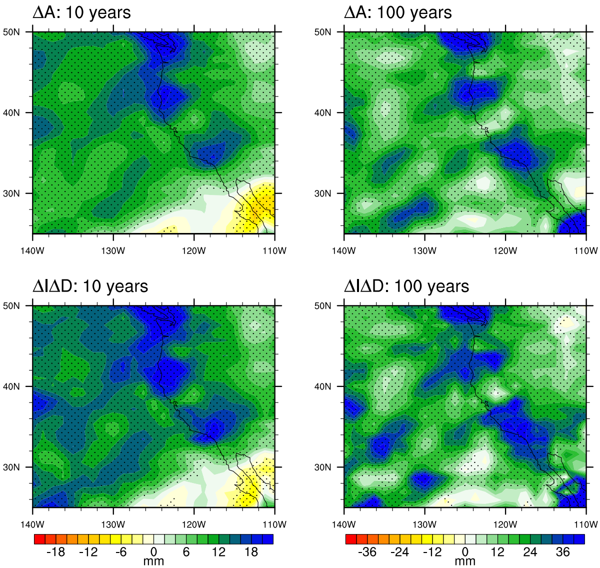




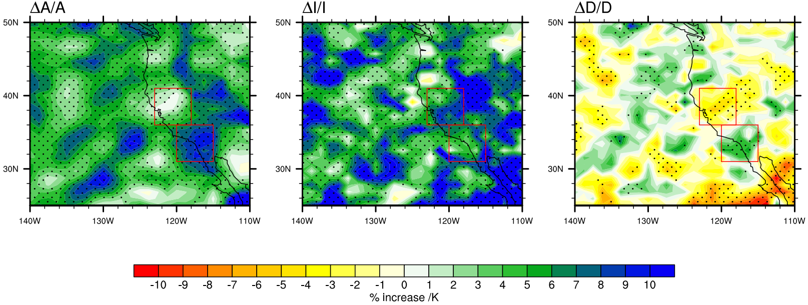
Accumulations approx. equal to product of conditionally averaged duration and intensity



Similarly for projected changes



100-year return: Projected changes to intensity negatively correlated with changes to duration



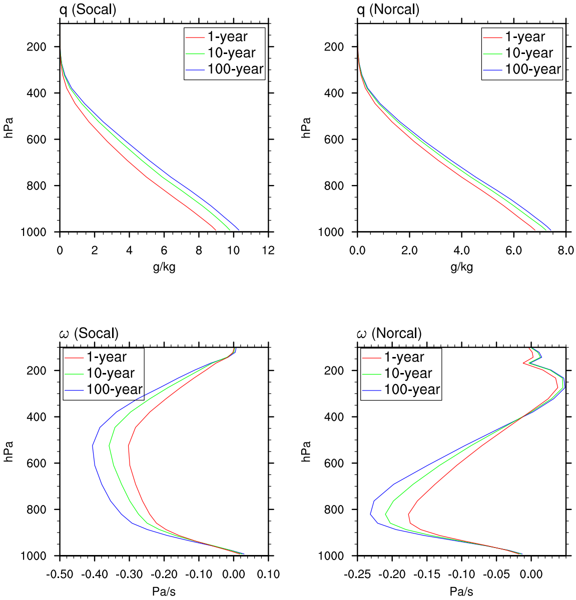
Moisture budget

- For extreme instantaneous precipitation (e.g., 99.9th percentile), precipitation rate is approximately equal to the vertical integral of moisture multiplied by mass convergence (Norris et al. 2018):

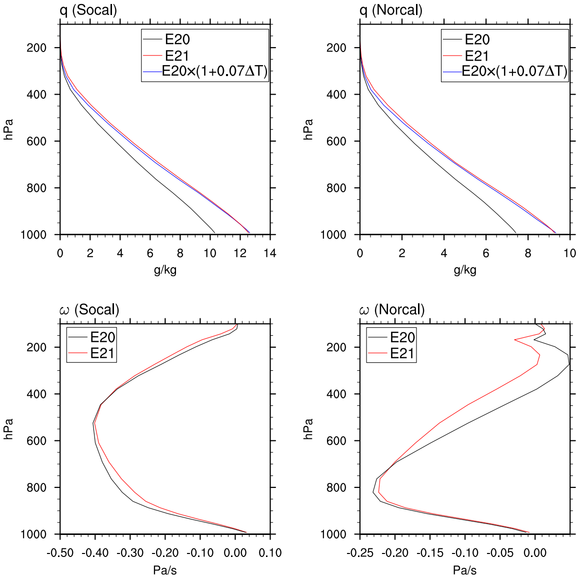
$$P = \sum_k q_k C_k$$

  where q_k is vapor mixing ratio at the kth model level and $C_k = -\frac{1}{g}\nabla \cdot (\mathbf{v}_k dp_k)$ is upward mass transport integrated over the kth model layer.
- Hence to understand the change in intensity of large accumulations, we analyze the changes to the mean q and C profiles.

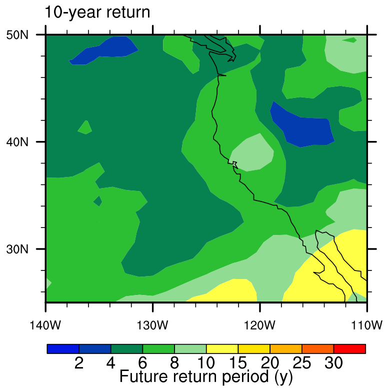
Moisture and convergence both increase with return period



For 100-year return, convergence enhanced over Norcal and weakened over Socal



Over Socal, 100-year return projected to occur approx. every 20 years in late 21st Century



Summary

- Extreme accumulations (100s of mm) projected to become more frequent over California.
- Accumulations are greater over Norcal due to greater duration, but in the future the gap closes in duration of events, hence the gap closes in accumulation size.
- Changes to intensity negatively correlated with changes to duration — increasing duration is associated with weakening dynamical forcing.
- Reduced duration over Norcal leads to lower increases.
- Enhanced duration of large accumulations over Socal leads to particularly large increases — 100-year return becomes 5 times more frequent.
- Other models needed to confirm results.

References

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