

Model Resolution sensitivity of ENSO Teleconnections to Precipitation Extremes

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Motivation

- Global high-resolution ESMs:
 - Resolve more fine-scale features, e.g. orographic lifting, coastlines, mesoscale eddies, etc.
 - Improve mean, variability, MJO, tropical cyclones, atmospheric blocking, jet streams, tropical and extra-tropical cyclones, teleconnections [e.g. *Delworth et al. 2012*, *Kinter et al. 2013*, *Mahajan et al. 2018*, etc.]
- High-resolution models simulate stronger extremes [e.g. *Wehner et al. 2014*, *Johnson et al. 2016*, *Li et al., 2016*]:
 - Global ESMs allow studying extremes in context of their large-scale environment as compared to RGCMS.
- Evaluate teleconnections of ENSO to precipitation extremes:
 - US winter precipitation, when convective precipitation is subdued
 - Use Generalized Extreme Value (GEV) theory
 - Plausible mechanisms

Model and Data

- E3SM v1 High-Resolution water cycle 1950 control simulation (Caldwell et al. 2019):
 - ne120 Years 26-123 (98 yrs, HR)
- E3SM v1 Low-Resolution DECK Historical Simulation (Golaz et al. 2018):
 - ne30 (4 members) coupled run, 1979-2014 (LR)
- NOAA CPC gauge-based daily precipitation data (0.5x0.5) [Xie et al. 2007]
- MERRA2 Reanalysis (0.5x0.675) [Rienecker et al. 2011]

Generalized Extreme Value (GEV)

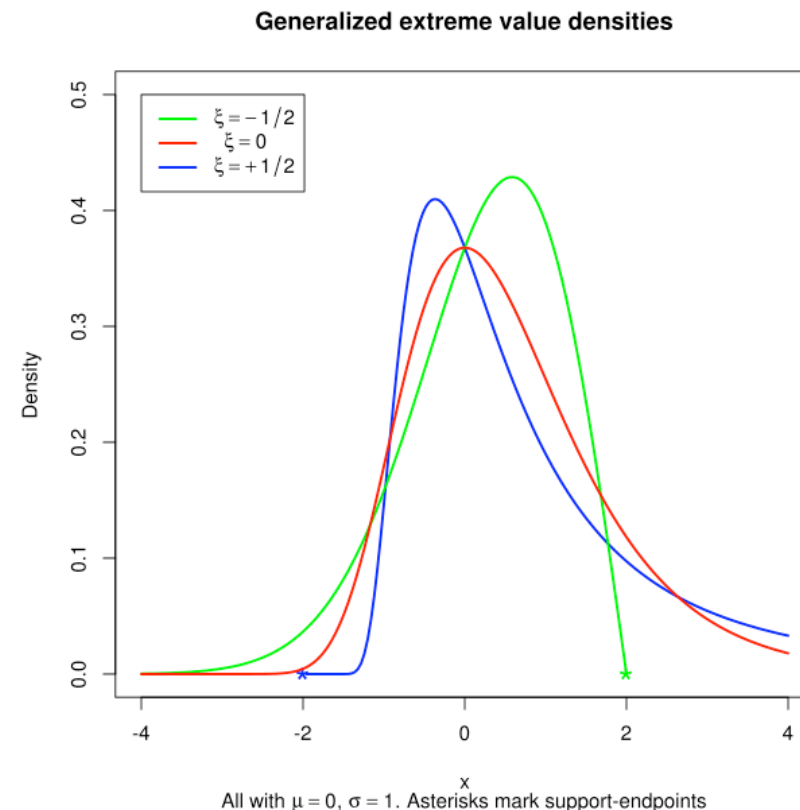
$$G(z) = \exp \left\{ - \left[1 + \xi \left(\frac{z - \mu}{\sigma} \right) \right]^{-1/\xi} \right\}$$

where μ , σ and ξ represent the location, scale and shape parameter respectively.

defined on:

$$z : 1 + \xi(z - \mu)/\sigma > 0$$

- **Extreme Value Theory:** Linearly normalized values of the **max./min. of a process** belong to **GEV** irrespective of the distribution of the population
- **Analogous to central limit theorem:** sample means belong to normal distribution



Source: Wikipedia - <http://en.wikipedia.org/wiki/File:GevDensity.svg#/media/File:GevDensity.svg>

GEV

$$G(z) = \exp \left\{ - \left[1 + \xi \left(\frac{z - \mu}{\sigma} \right) \right]^{-1/\xi} \right\}$$

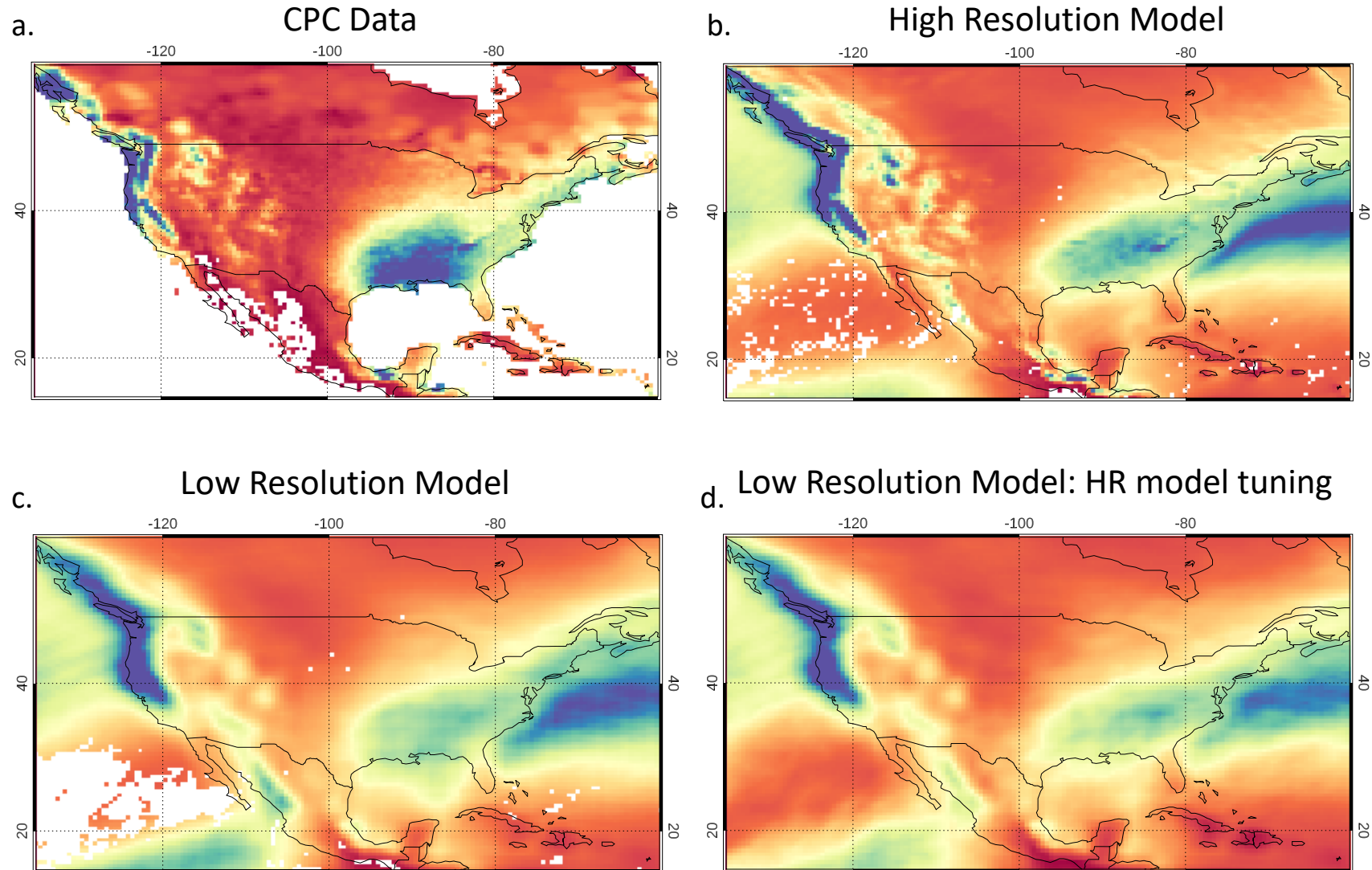
- Here, monthly maximum of daily precipitation in NDJF season
- Parameters estimated using **Maximum Likelihood**:
 - Maximizes the probability of the occurrence of the fitting data
 - Parameters ~ multivariate **normal distribution**
 - Return periods can be easily derived
- **Non-stationarity** in parameters can be introduced, e.g.:

$$\mu = \mu_0 + \alpha t$$

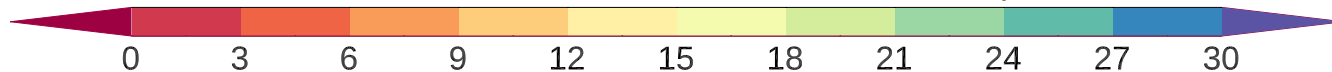
where, t , is a covariate index, like time, Nino3.4, etc.

Extremes: CPC Data and E3SM v1 HR and LR Simulations

$$G(\mu, \sigma, \xi)$$



Location Parameter of GEV (mm/day)

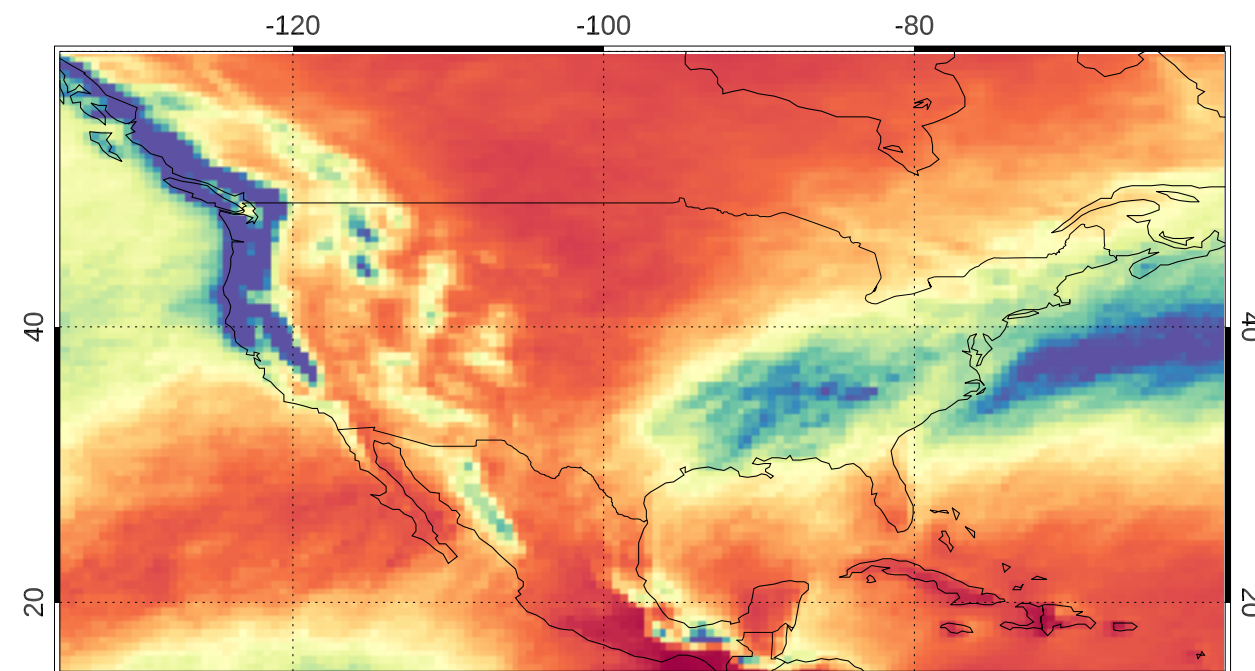
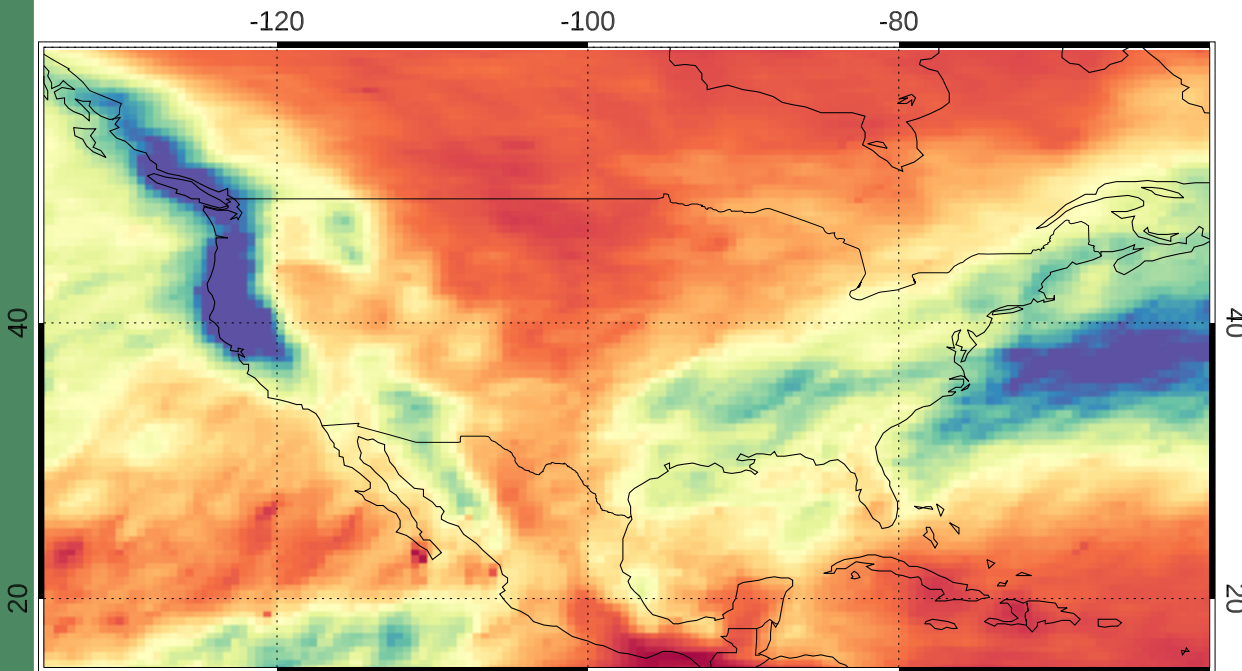


Extremes: HR and LR

Return Period levels (R) can be computed by inverting $\mathbf{G}(\mathbf{z})$:
$$R(\tau) = \mu + \frac{\sigma}{\xi} \left(-\log(1 - 1/\tau)^{-\xi} - 1 \right)$$

LR E3SMv1 H1

HR E3SMv1

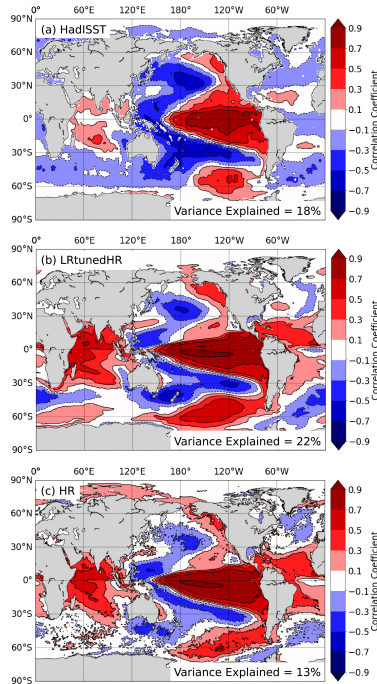


20 yr Return Period Level (mm/day)

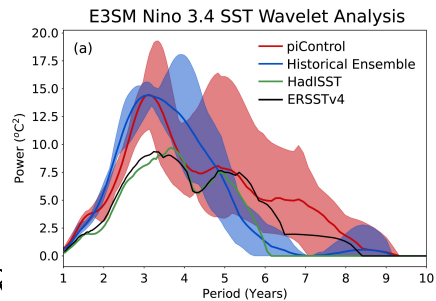
ENSO Teleconnections

$$G(\mu, \sigma, \xi) \quad \mu = \mu_0 + \alpha t$$

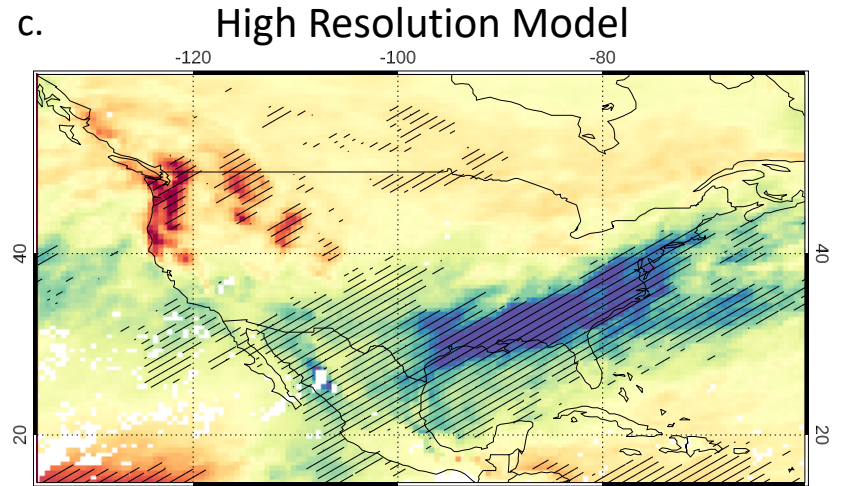
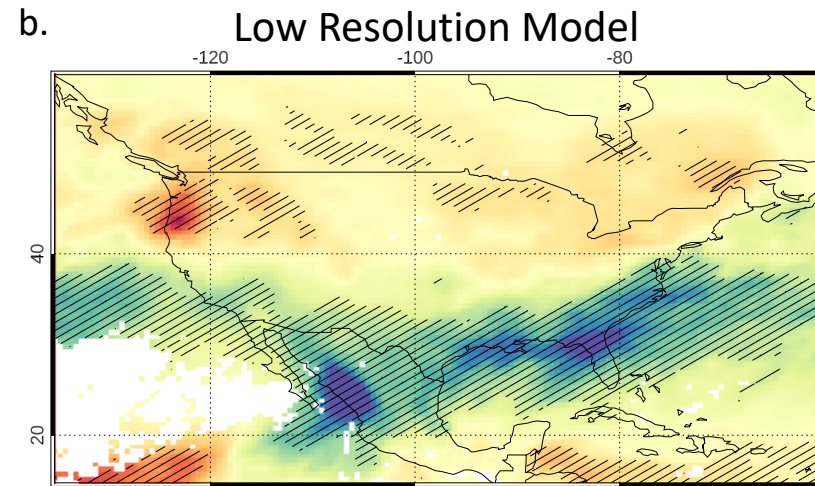
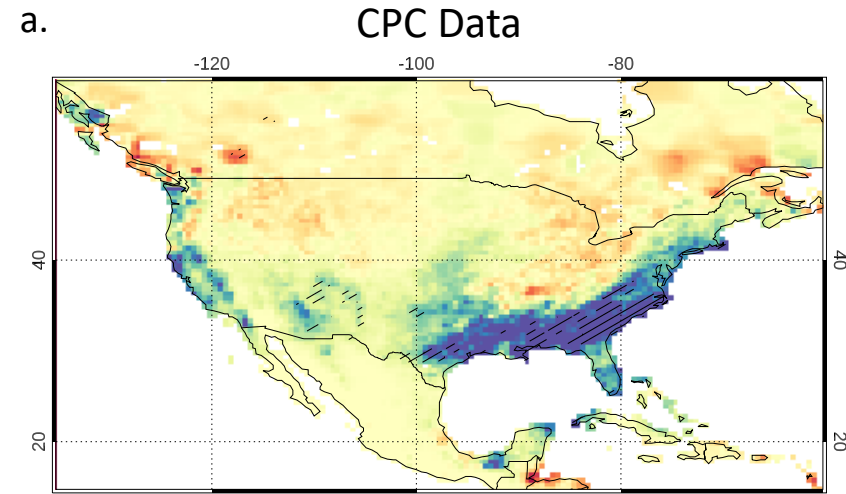
t : Nino3.4 index



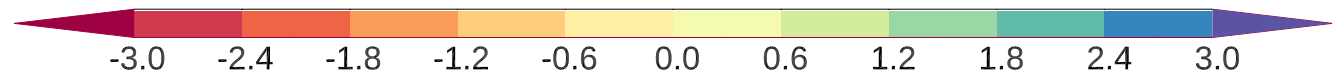
Caldwell et al., 2019



Golaz et al. 2019

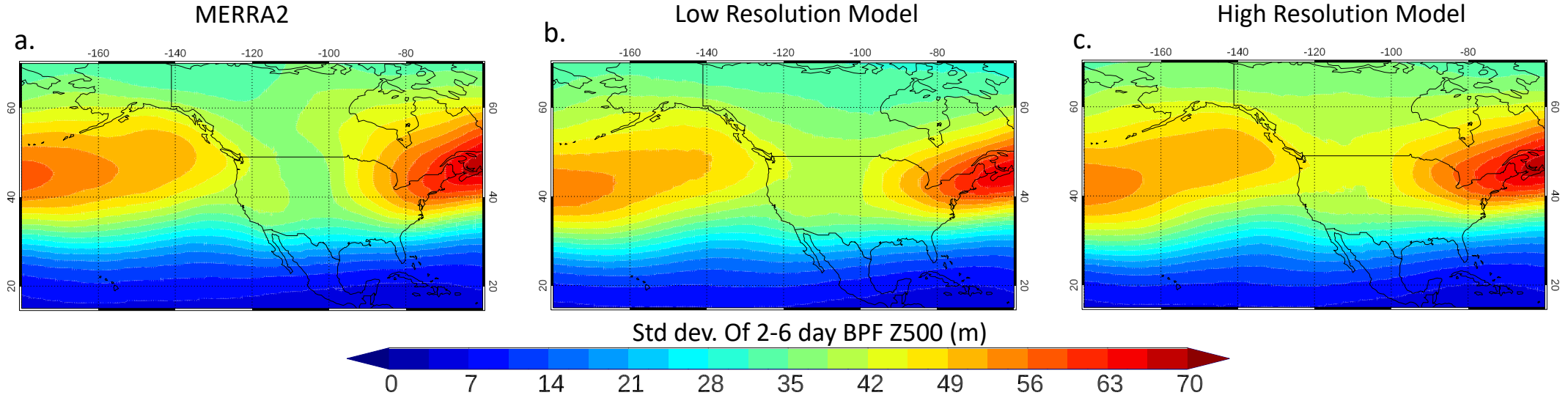


Nino3.4 dependent component of the location parameter of GEV (mm/day)

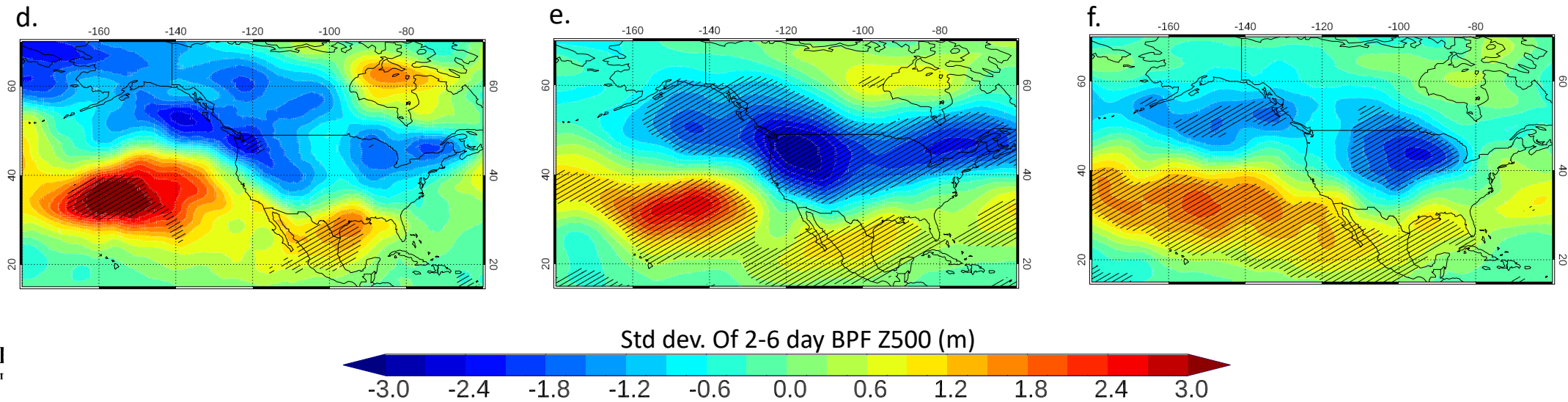


Storm track Activity

Storm Tracks: Std dev. Of 2-6 day BPF Z500

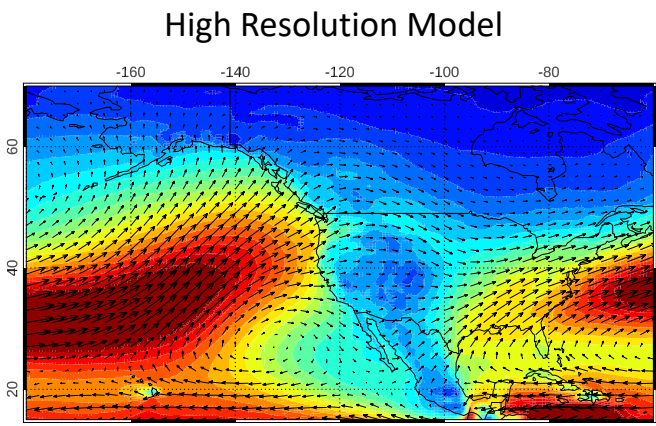
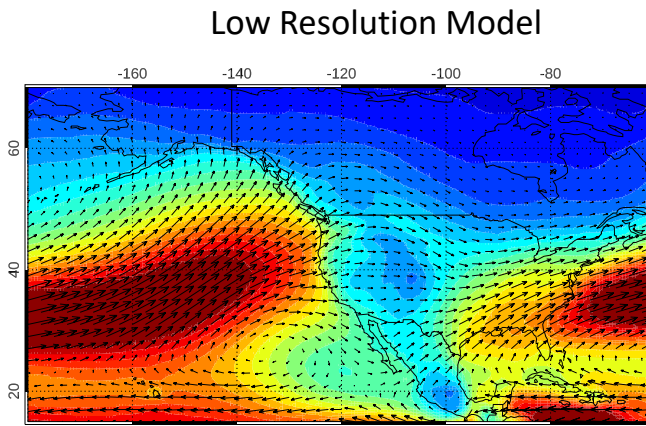
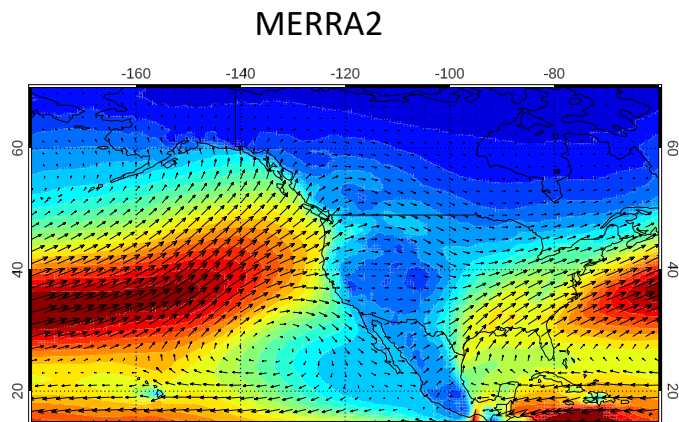


ENSO Impact on Storm Tracks

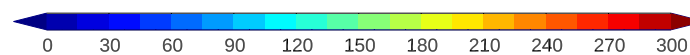


Moisture Transport

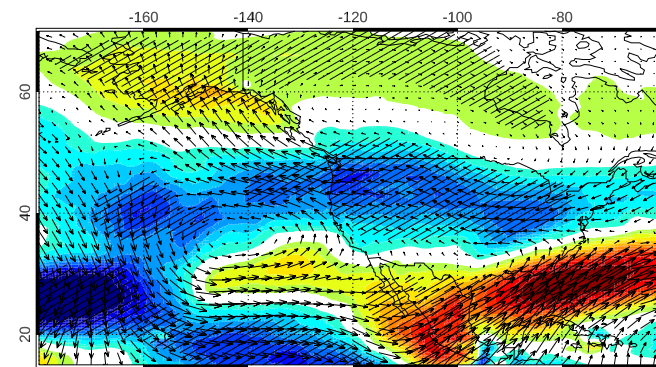
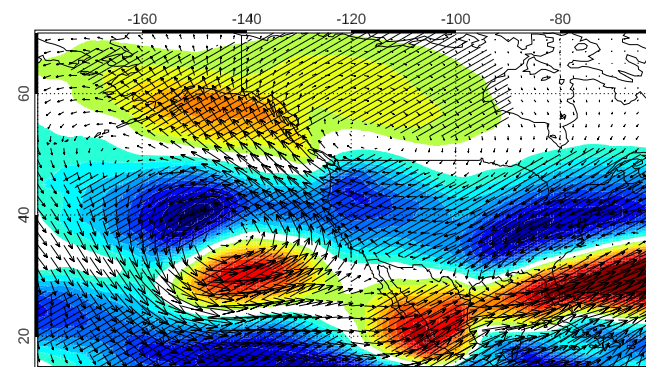
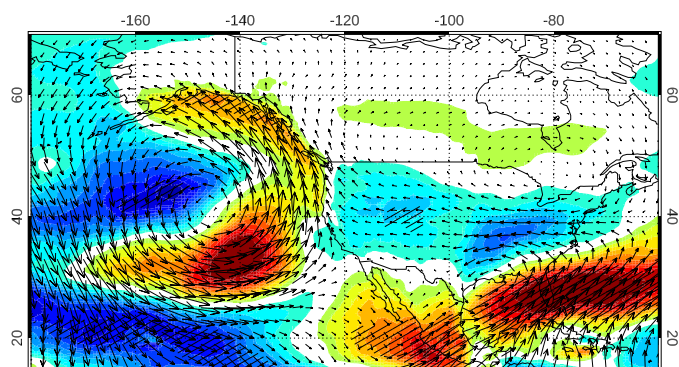
Winter Season: Mean Moisture Transport



Vertically Integrated Moisture Transport (kg/m/s)



ENSO Impact on Moisture Transport

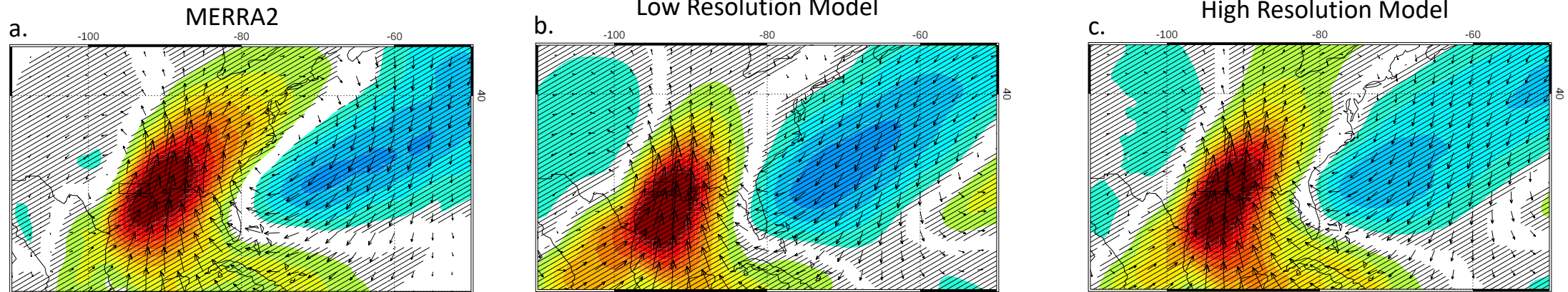


Regression Coefficient (kg/m/s)

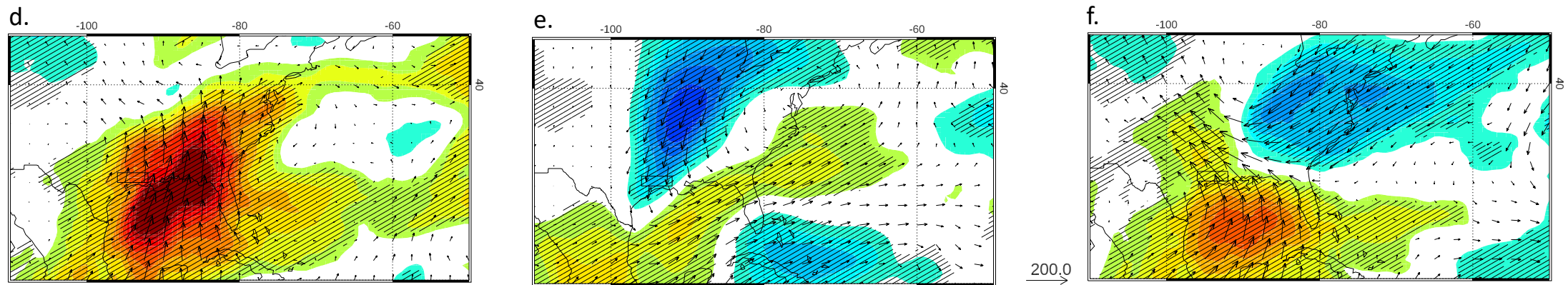


Moisture Transport During Extremes

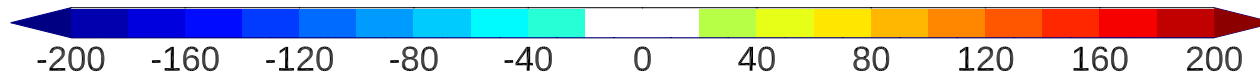
Moisture Transport During Extremes



Moisture Transport During Extremes During ENSO events

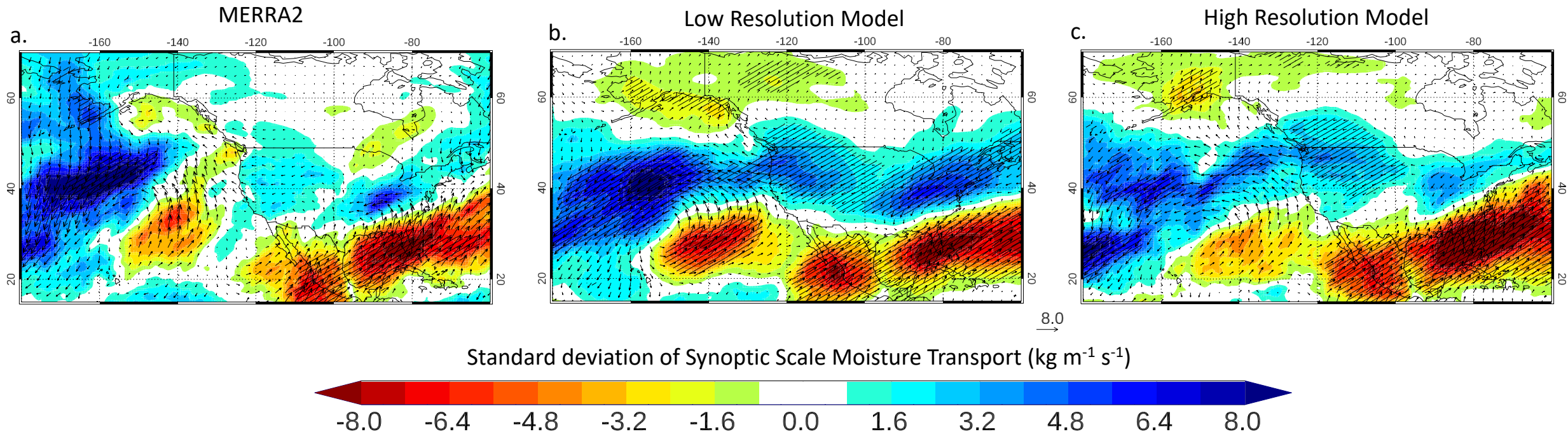


Composite: Vertically Integrated Moisture Transport (kg/m/s)



Moisture Transport: Synoptic variability

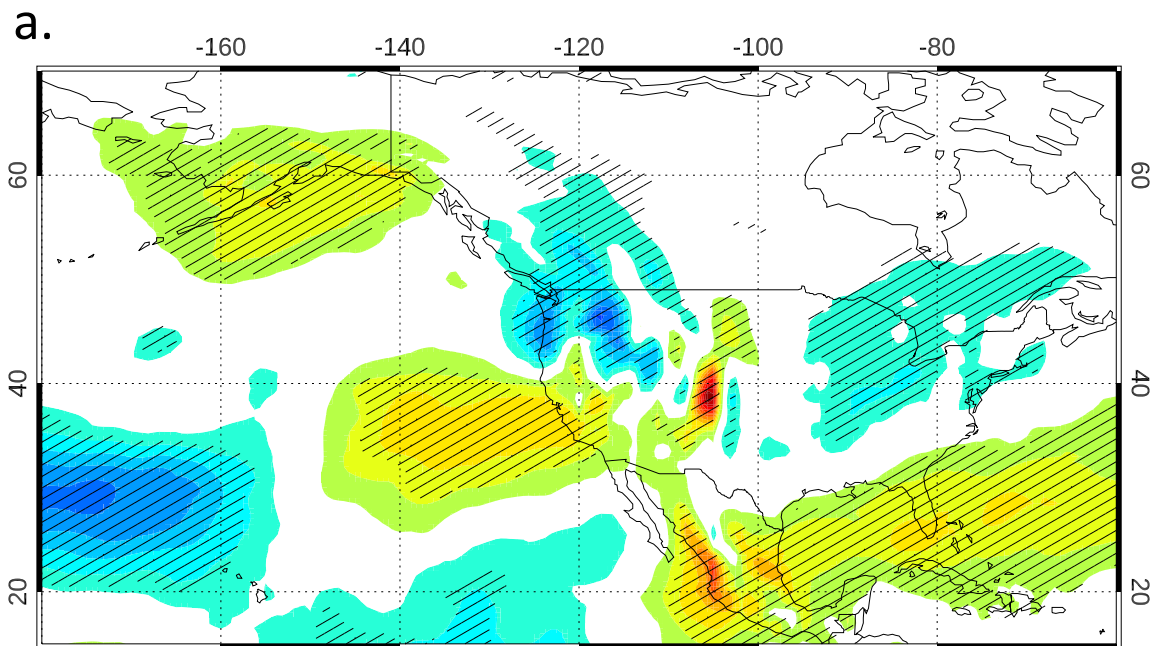
Regression: Synoptic Scale (10-day high-pass filtered) std. dev. of Moisture Transport on Nino 3.4 Index



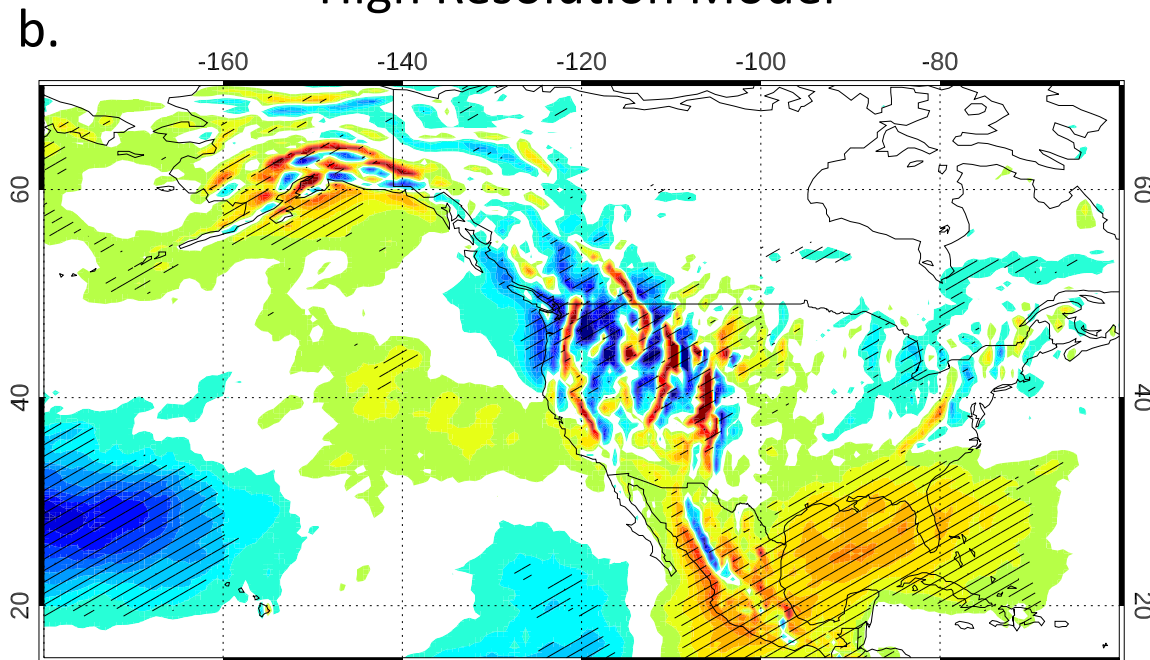
Vertical Mass Flux

Regression: Vertical velocity at 500 hpa on Nino 3.4 Index

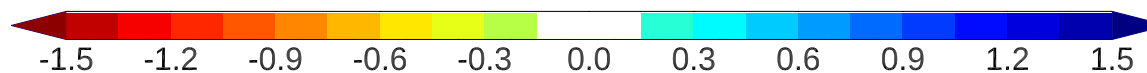
Low Resolution Model



High Resolution Model



Vertical Pressure Velocity (kg/m²)



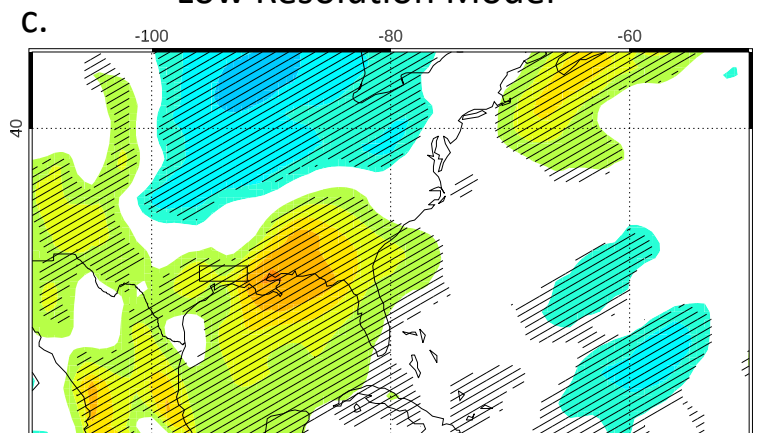
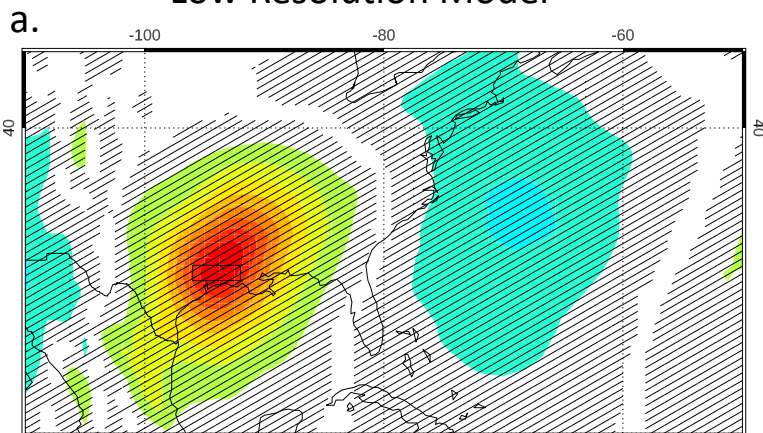
Vertical Mass Flux During Extremes

Vertical Velocity During Extremes

Vertical Velocity During Extremes
During ENSO events

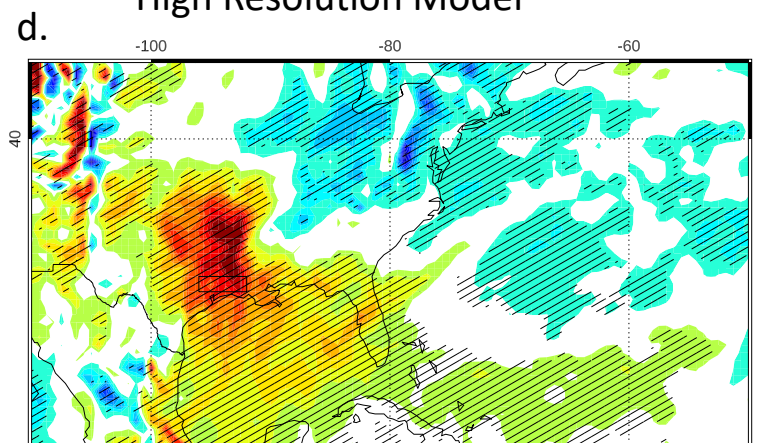
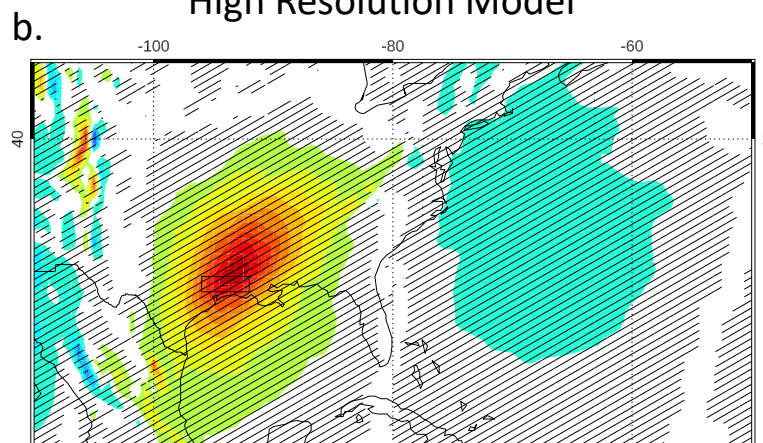
Low Resolution Model

Low Resolution Model



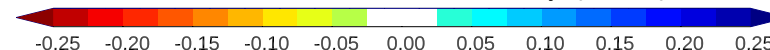
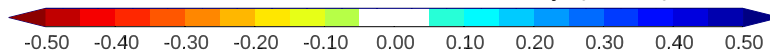
High Resolution Model

High Resolution Model



Vertical Pressure Velocity (Pa/s)

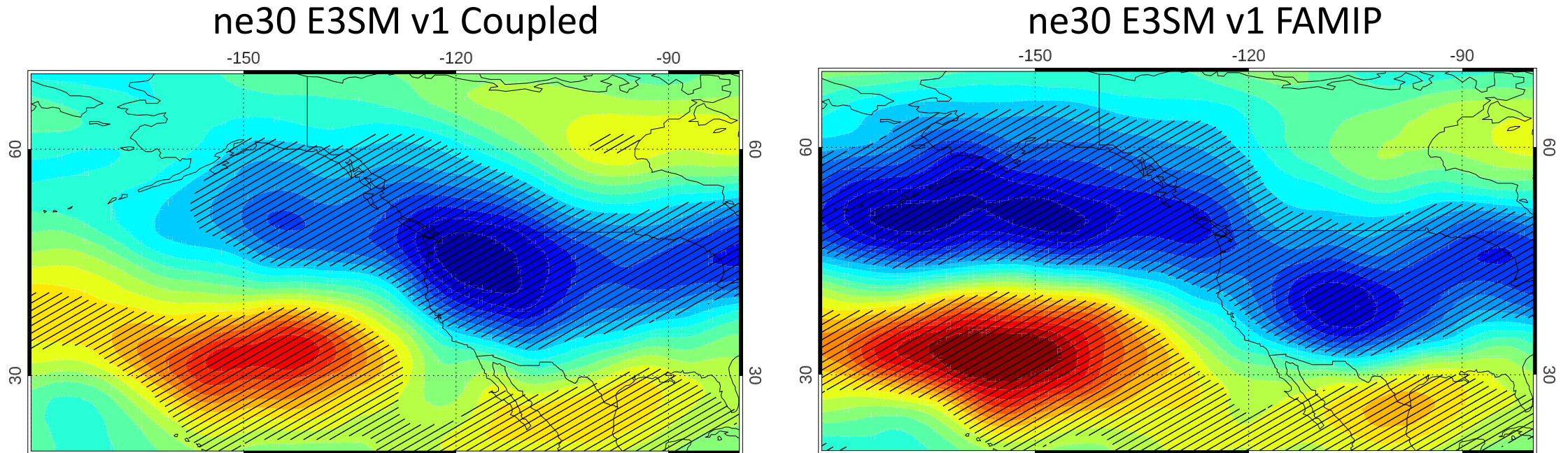
Vertical Pressure Velocity (Pa/s)



Summary

- High resolution (25km) E3SMv1 simulation better captures observed ENSO teleconnections to precipitation extremes over SE USA.
- Both low- and high-res models produce stronger than observed ENSO induced precipitation extremes over Pacific Northwest.
- Strong biases exist in storm track activity (and moisture transport) associated with ENSO in both models yielding stronger extremes response over P-NW.
- Improved SE USA response in high resolution simulation is due to improvement in ENSO induced moisture transport from the Gulf of Mexico and its synoptic variability.
- Plausible mechanism: HR produces stronger uplift in response to El Nino, yielding stronger stable condensation and larger latent heating of the troposphere, pulling in more moisture from the Gulf of Mexico into the SE USA causing extremes.
- Future work:
 - Assess impact of ENSO diversity on results (e.g. Patricola et al. 2020)
 - Role of blocking and atmospheric rivers
 - Future projections, RRM, MMF, aerosols-only and GHG-only runs

ENSO impacts on storm tracks: Coupled vs. Uncoupled



Regression Coefficient: Nino 3.4 index on Std Dev. of 2-6 day BPF Z500 (m)

