Model Resolution sensitivity of ENSO Teleconnections to Precipitation Extremes

Salil Mahajan, Qi Tang, Noel Keen, Luke van Roekel, Chris Golaz

Oak Ridge National Laboratory

Lawrence Livermore National Laboratory

Los Alamos National Laboratory

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)

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

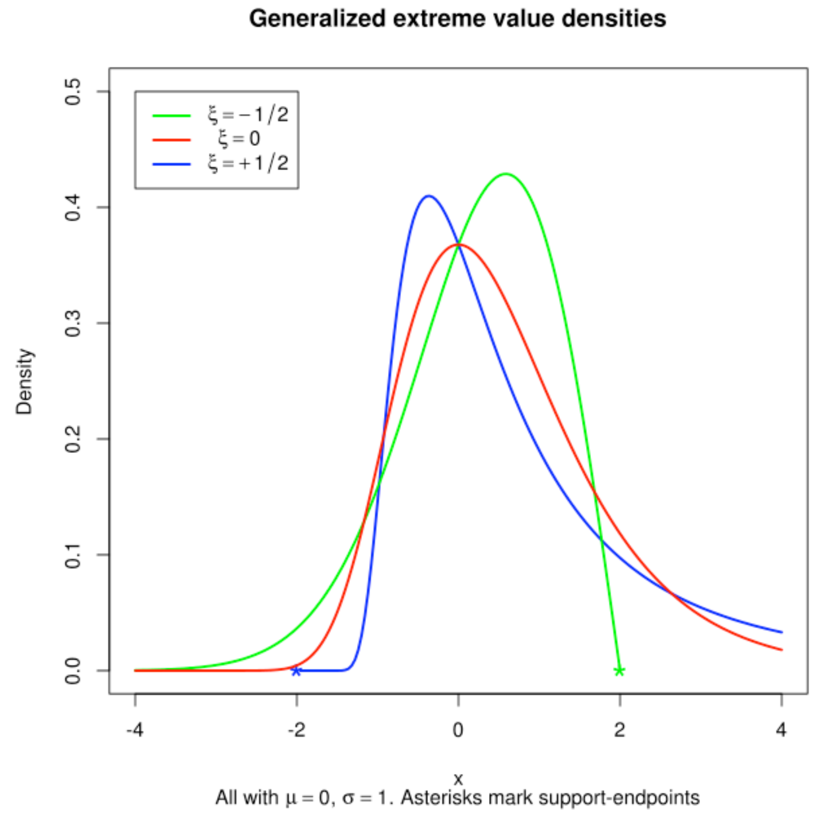
where μ, σ and ξ represent the location, scale and shape parameter respectively.

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

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

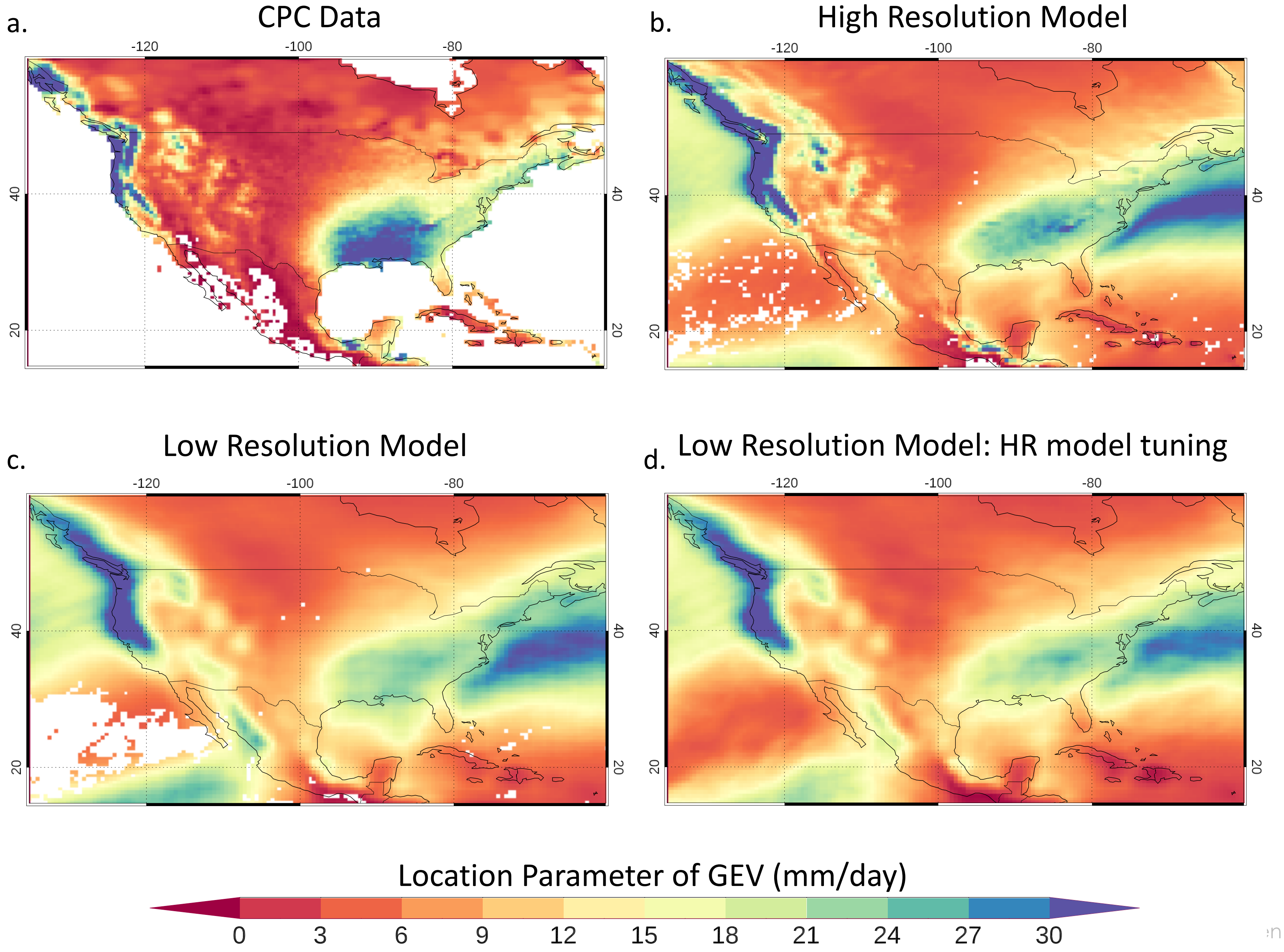
- Here, monthly maximum of daily precipitation in NDJF season
- Parameters estimated using Maximum Likelihood:
    - Maximizes the probability of the occurrence of the fitting data
    - Parameters ~ multivariate normal distribution
    - Return periods can be easily derived
- Non-stationarity in parameters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

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



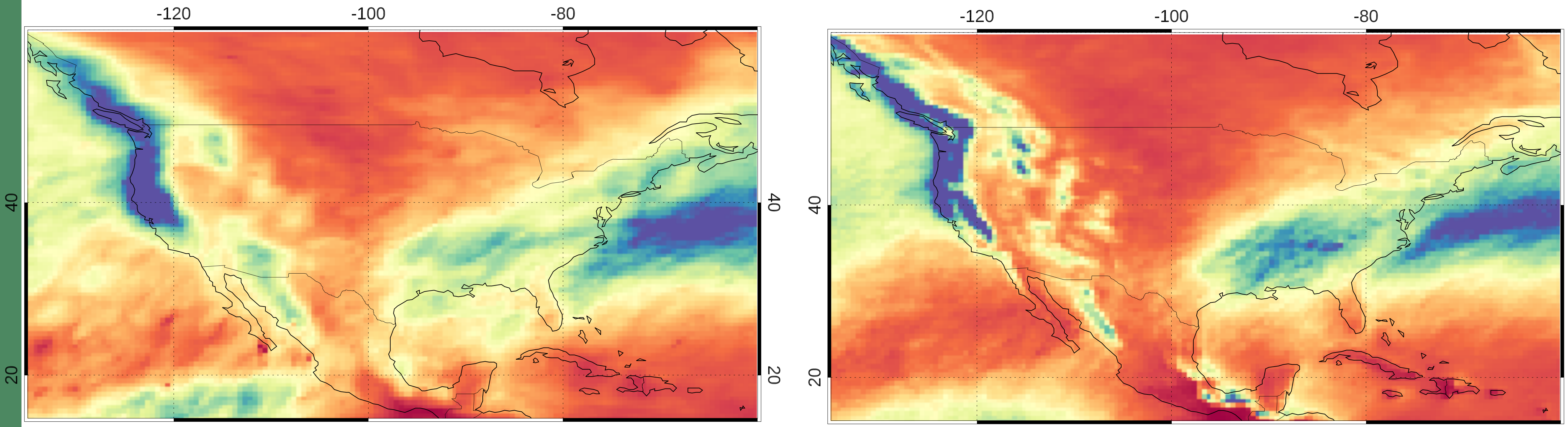
Extremes: HR and LR

Return Period levels (*R*) can be computing by inverting ***G(z):***

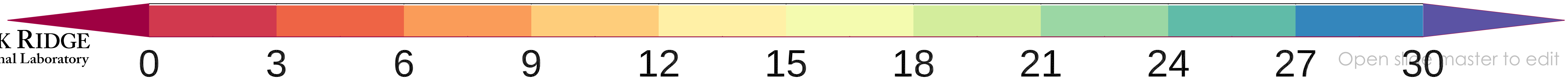
$$R(\tau) = \mu + \frac{\sigma}{\xi}(-log(1 - 1/\tau)^{-\xi} - 1)$$

LR E3SMv1 H1

HR E3SMv1



20 yr Return Period Level (mm/day)

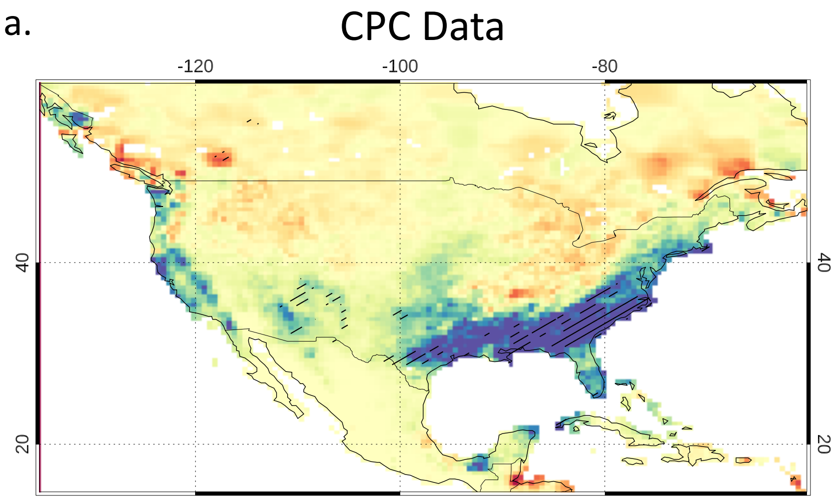


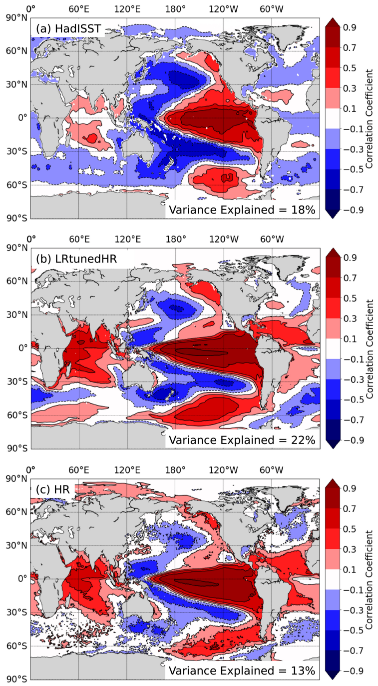
Oak Ridge National Laboratory

ENSO Teleconnections

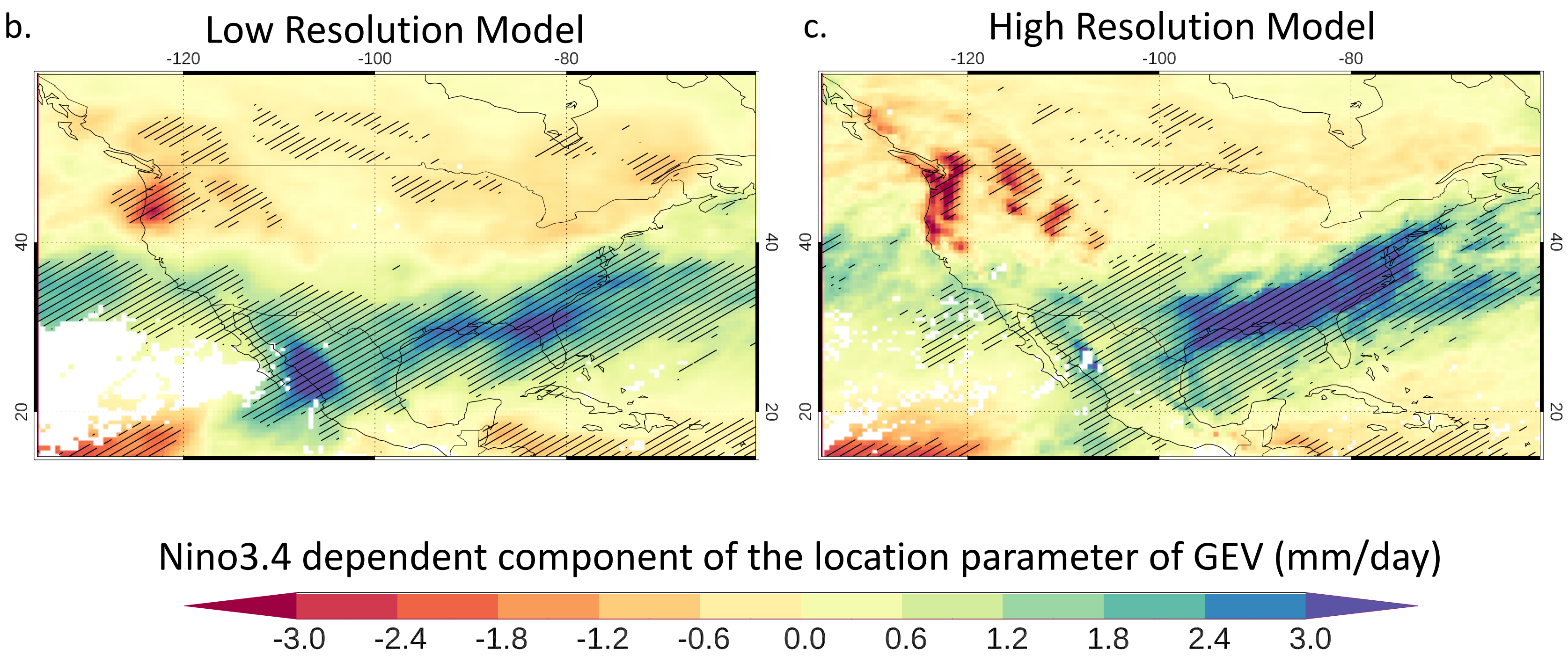
$G(\mu, \sigma, \xi) \qquad \mu = \mu_0 + \boxed{\alpha}t$

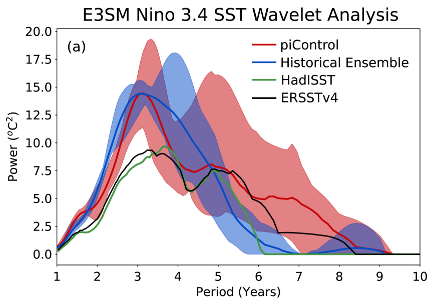
t: Nino3.4 index





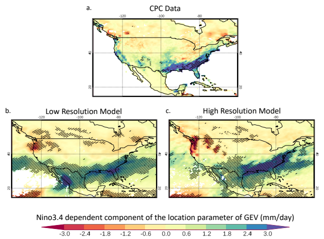
Caldwell et al., 2019



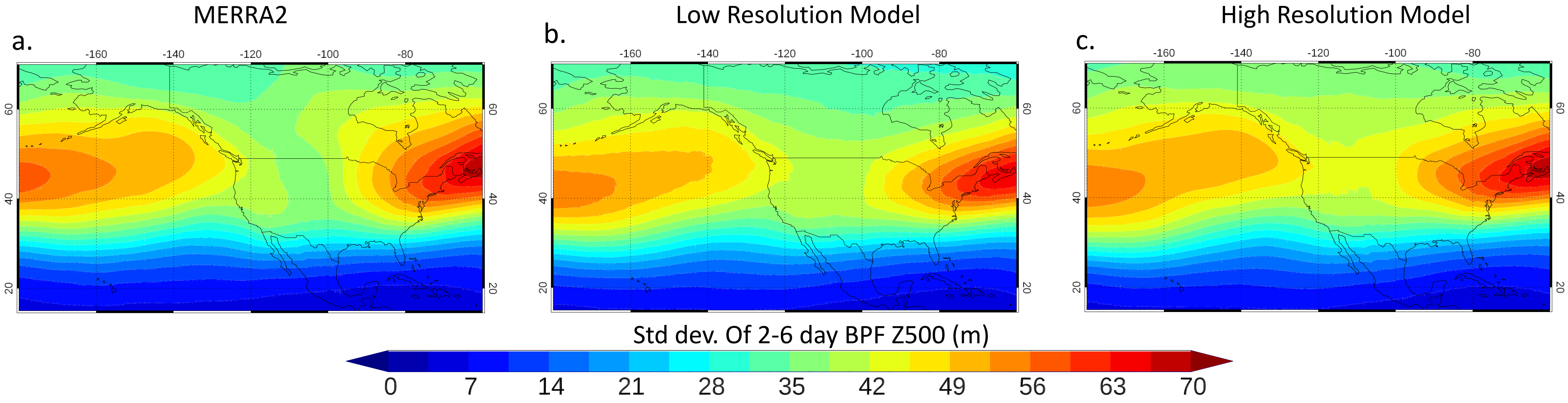


Golaz et al. 2019

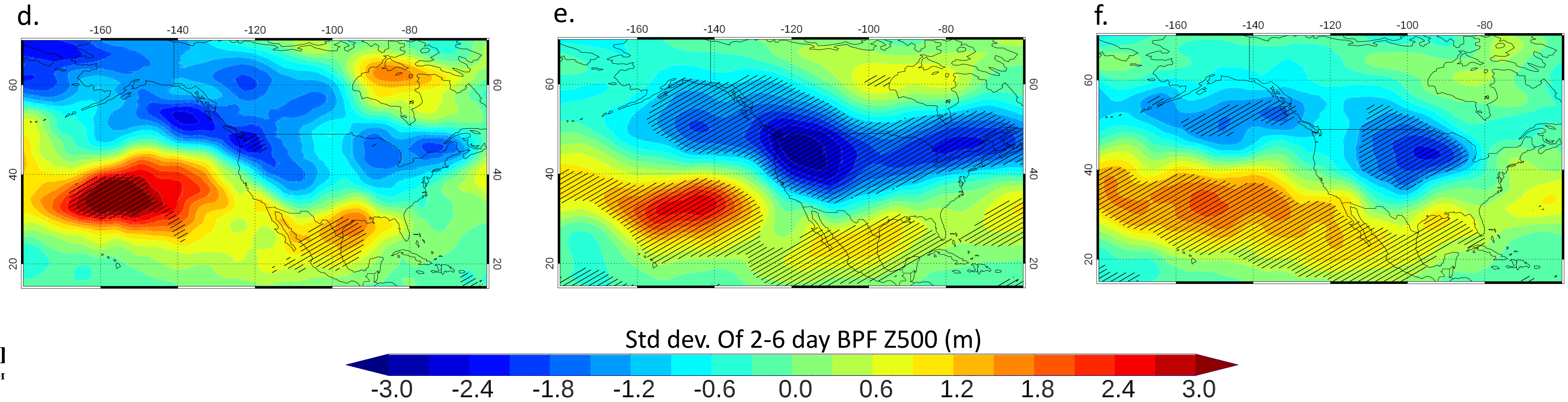
Storm track Activity



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

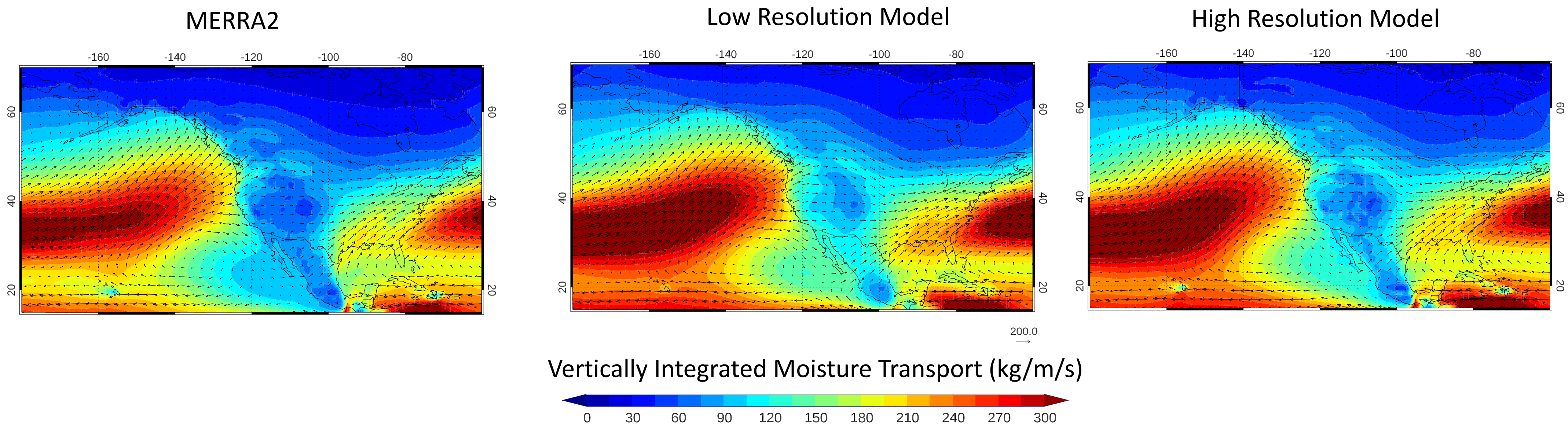


ENSO Impact on Storm Tracks



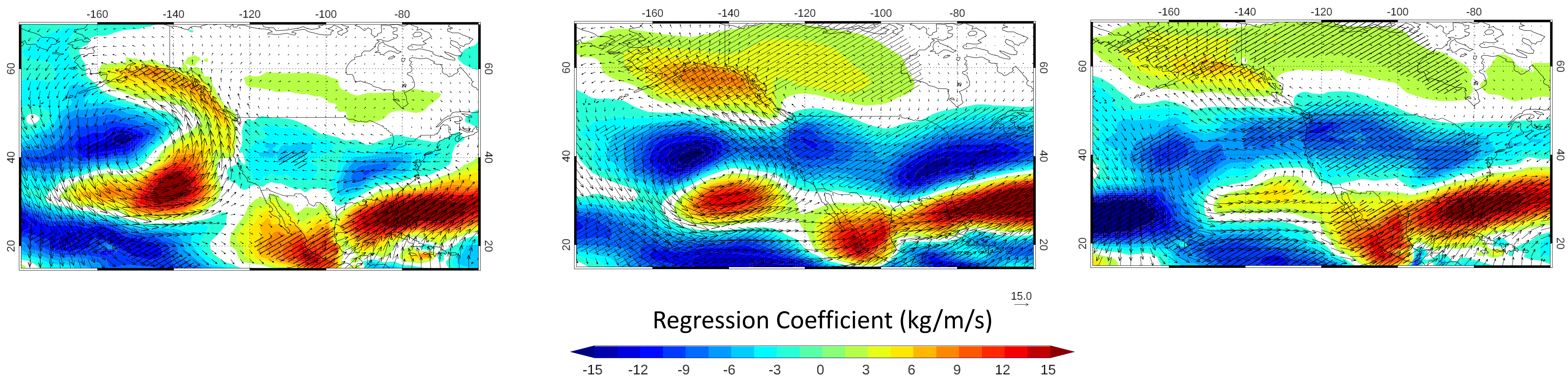
Moisture Transport

Winter Season: Mean Moisture Transport



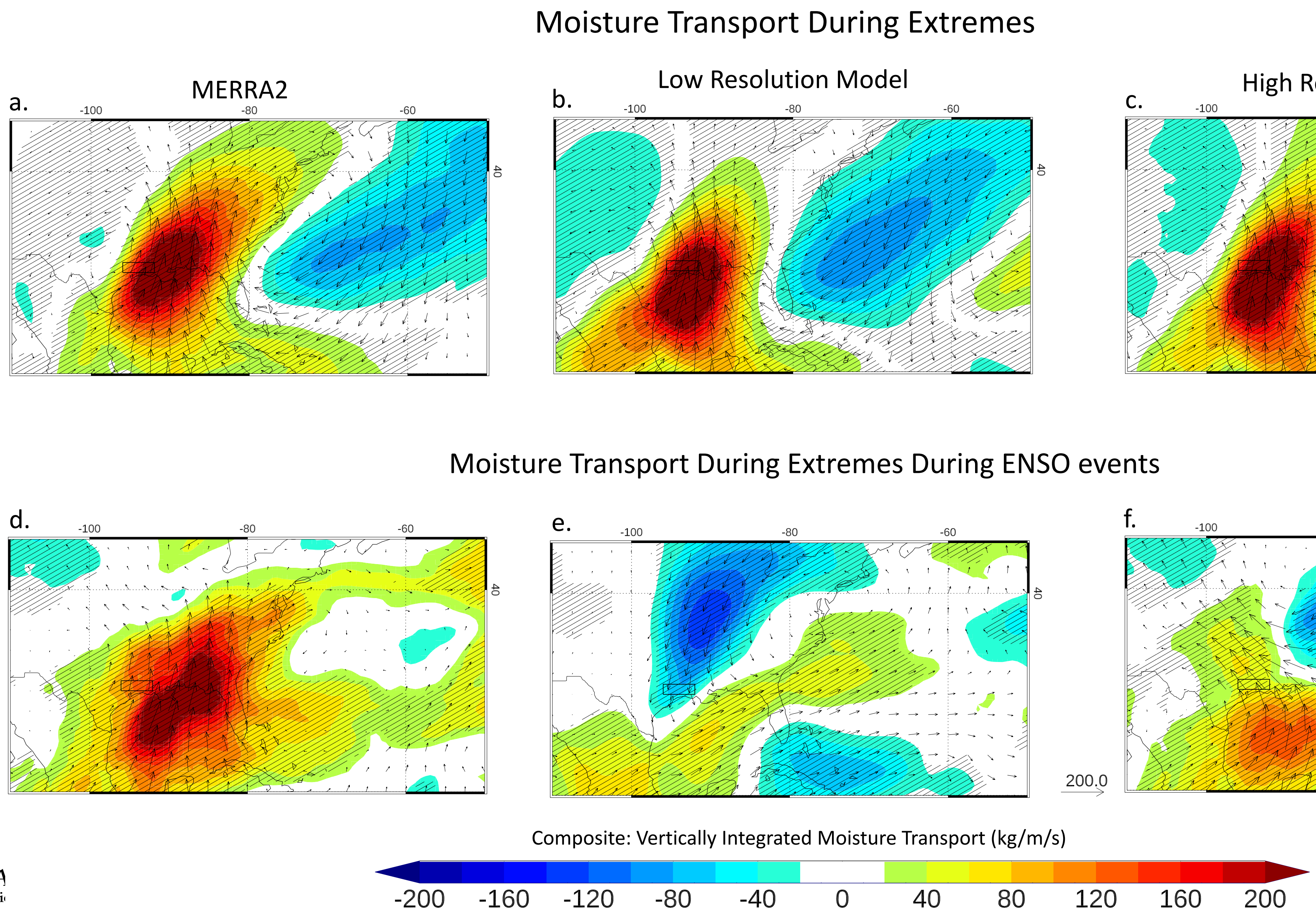
Vertically Integrated Moisture Transport (kg/m/s)

ENSO Impact on Moisture Transport



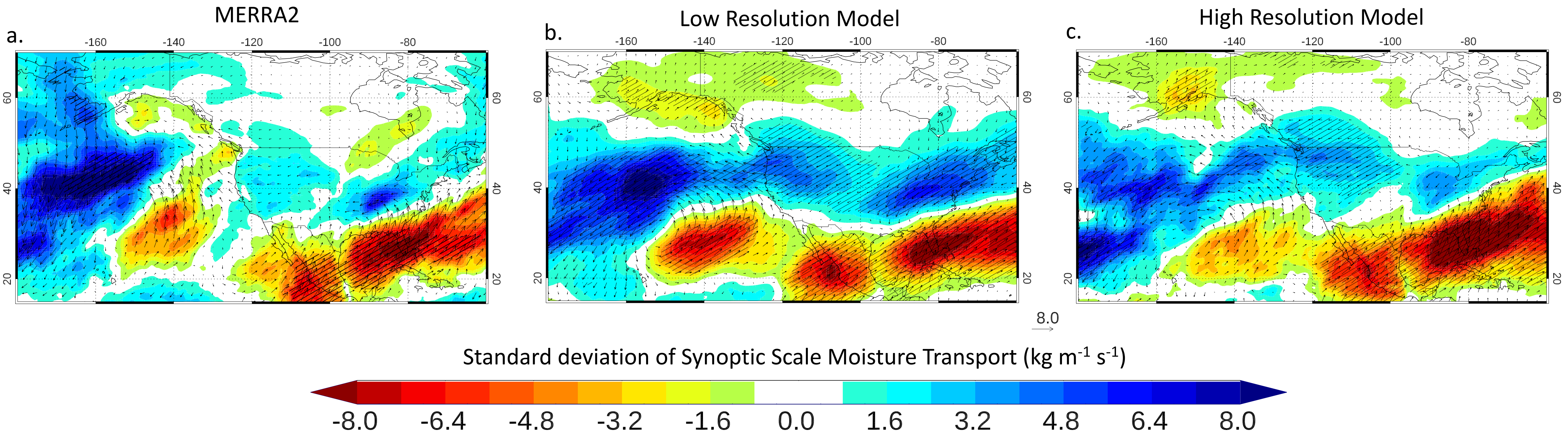
Regression Coefficient (kg/m/s)

Moisture Transport During Extremes



Moisture Transport: Synoptic variability

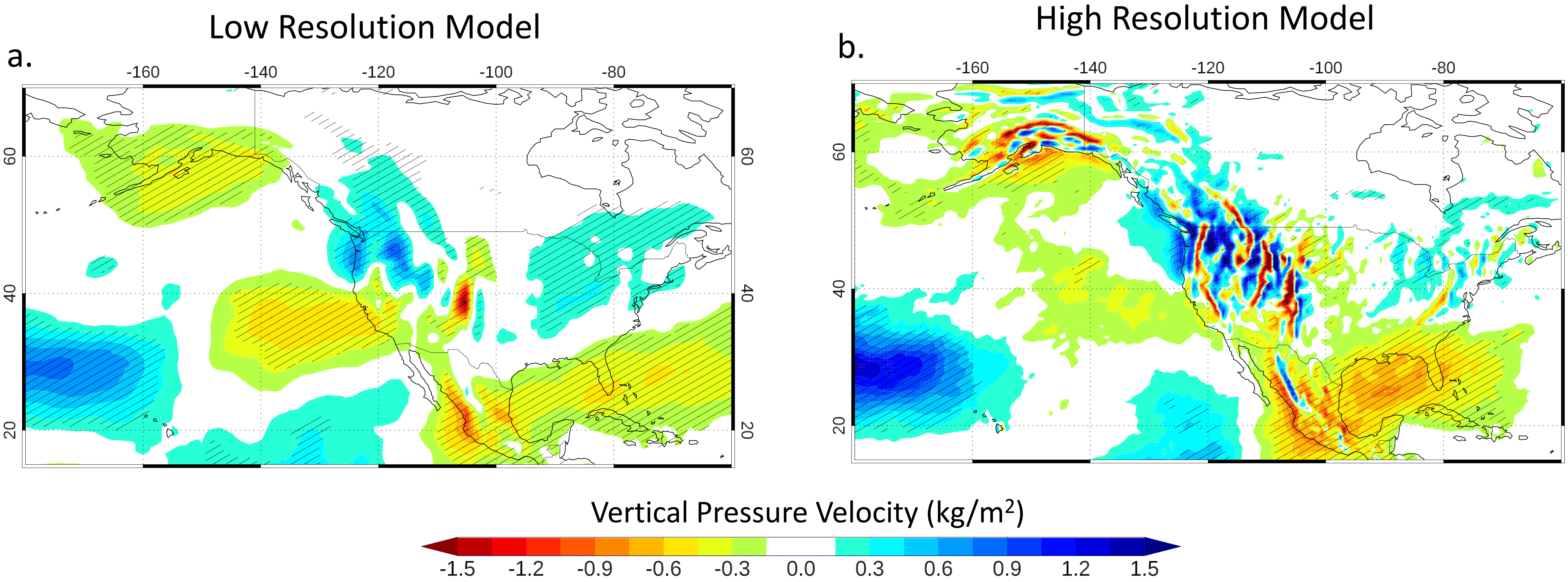
Regression: Synoptic Scale (10-day high-pass filtered) std. dev. of Moisture Transport on Nino 3.4 Index



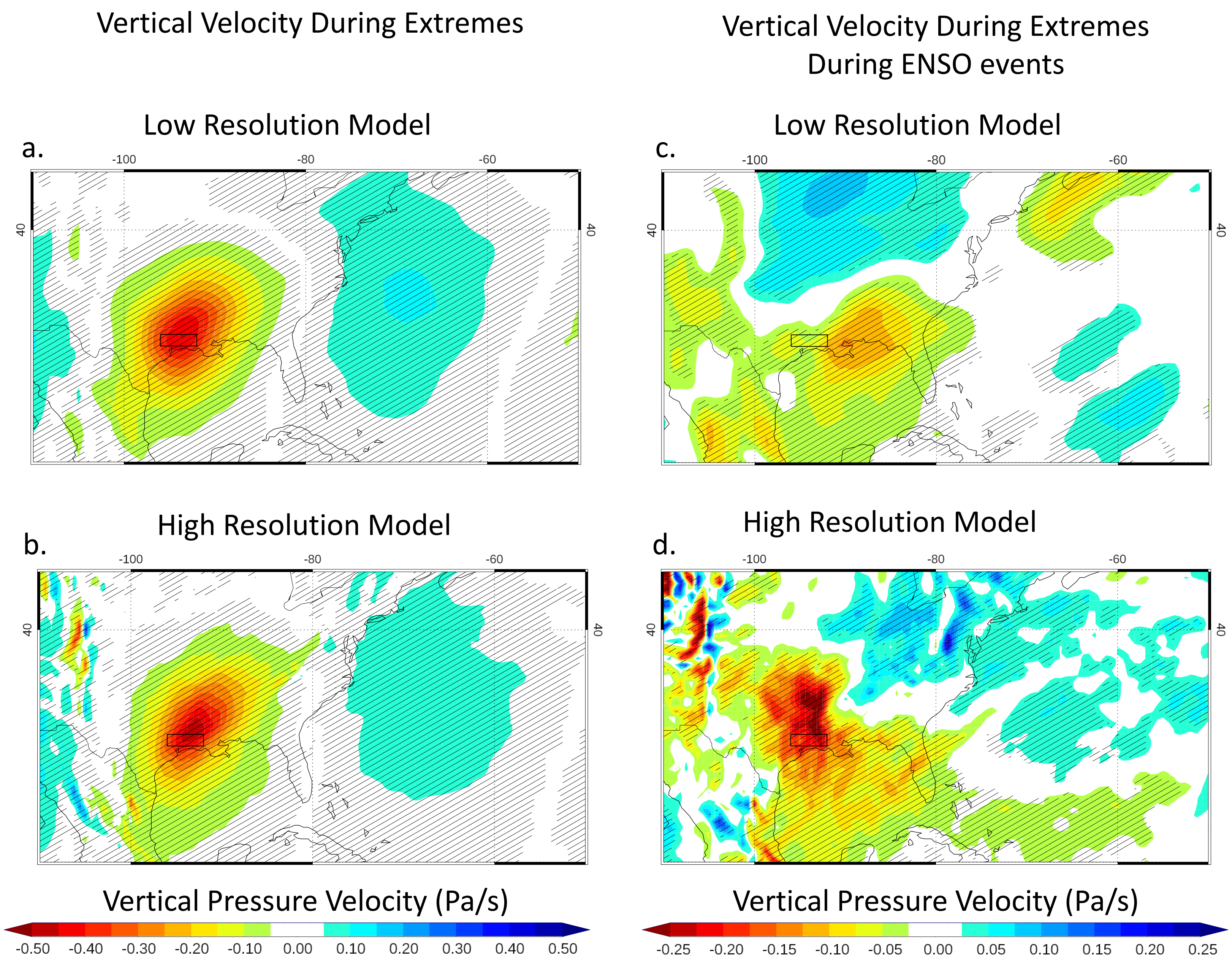
OAK RIDGE
National Laboratory

Vertical Mass Flux

Regression: Vertical velocity at 500 hpa on Nino 3.4 Index

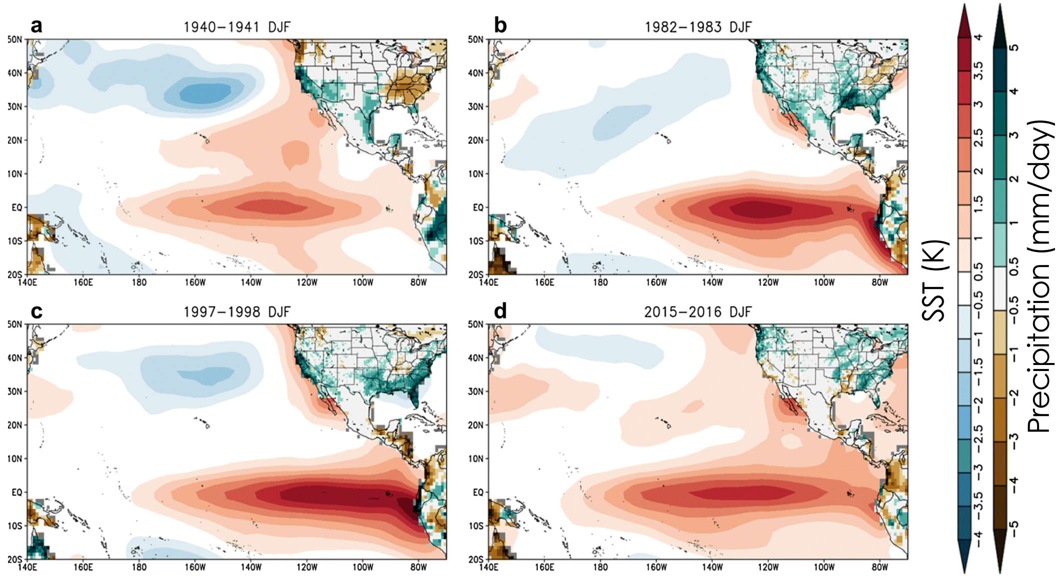


Vertical Mass Flux During Extremes



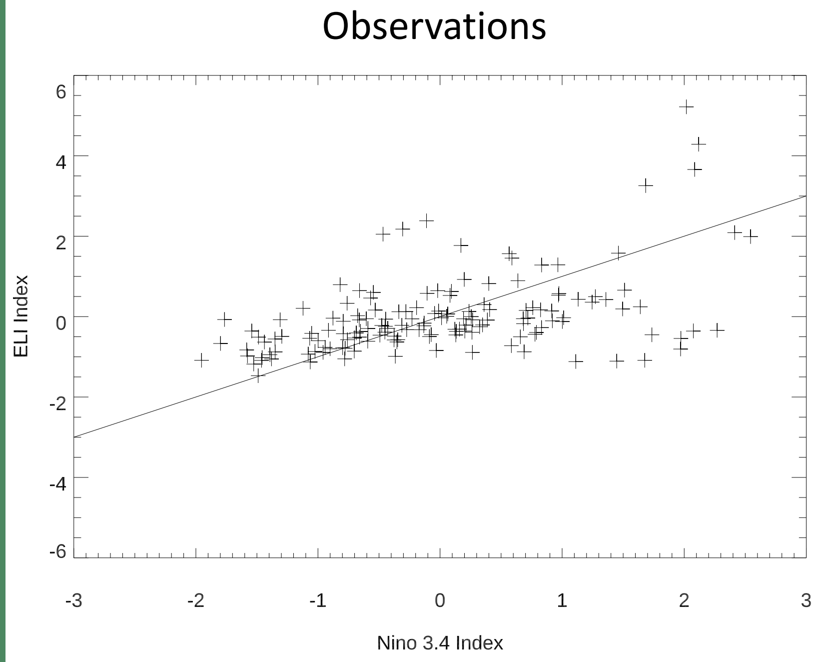
ENSO Diversity: ELI Index

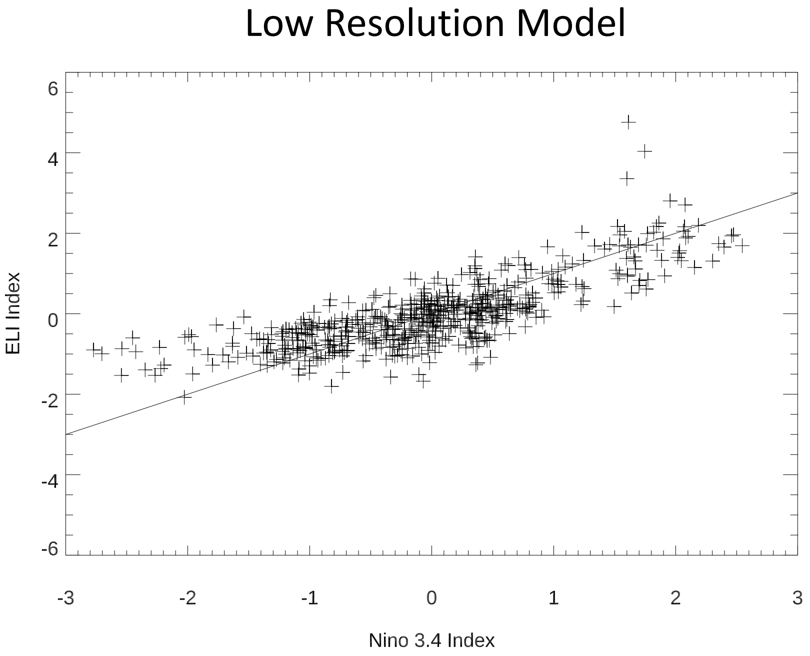
ENSO Longitutidinal Index (ELI):
Average of longitudes over the tropical Pacific where SST > mean SST of global tropics

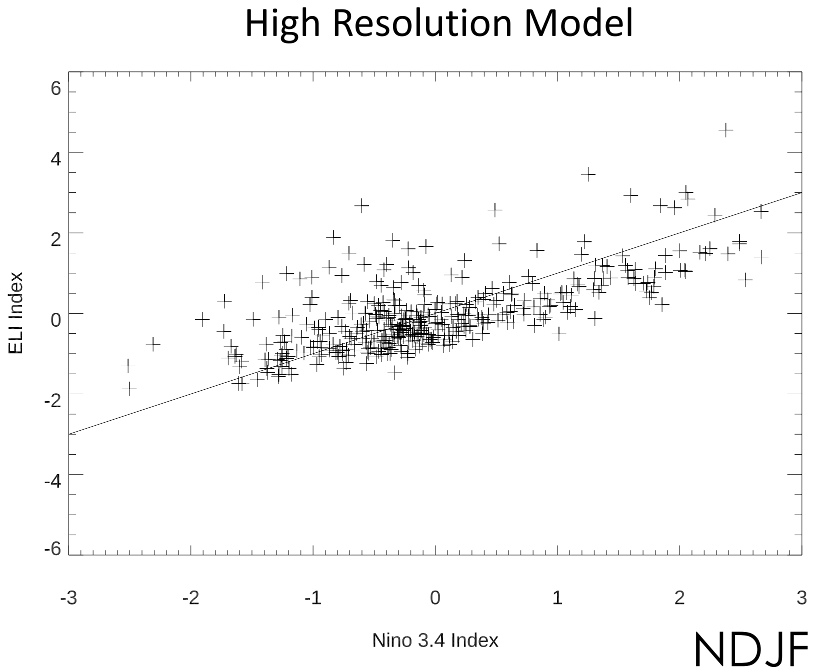


Patricola et al. 2019

Nino3.4 vs. ELI

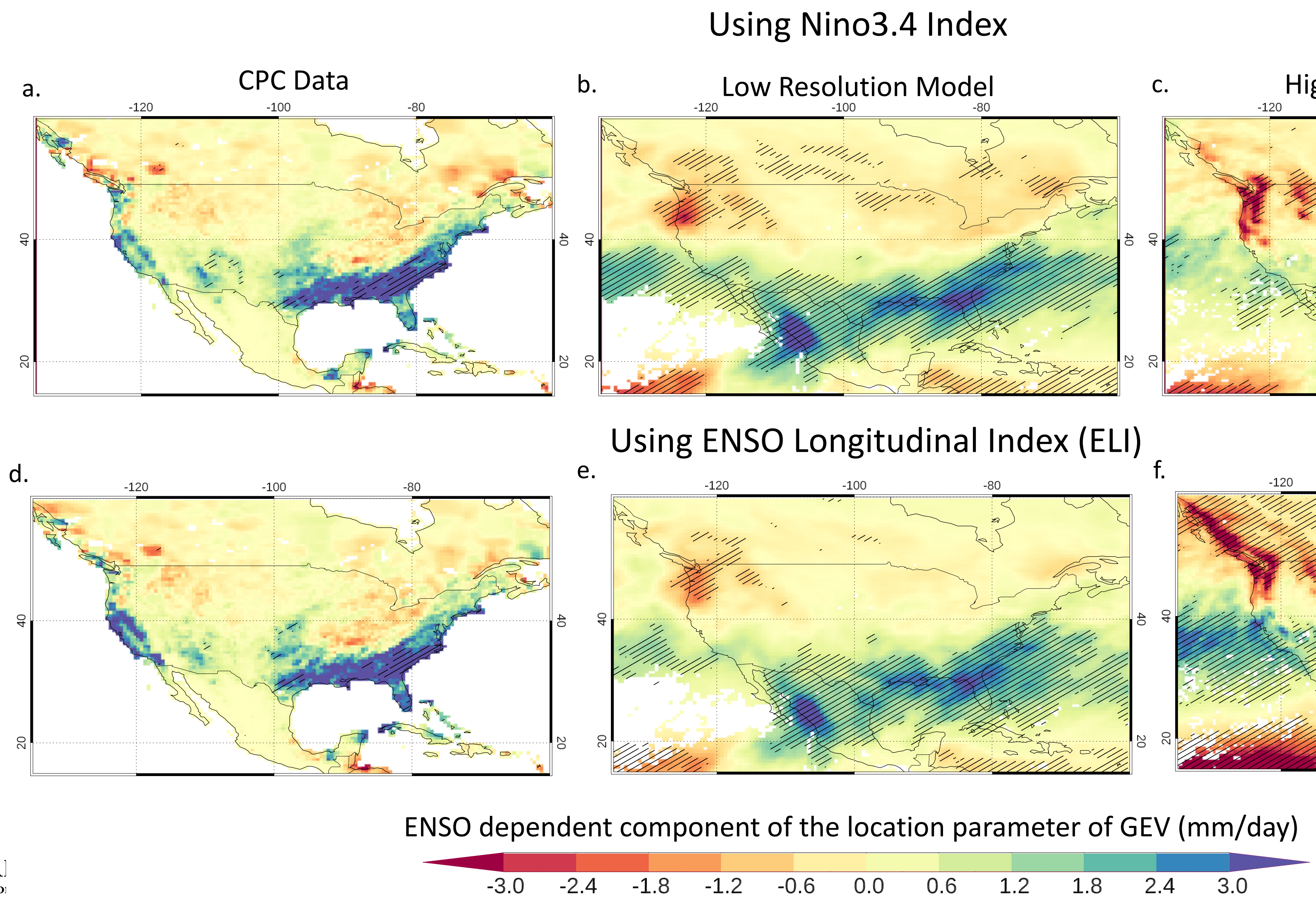




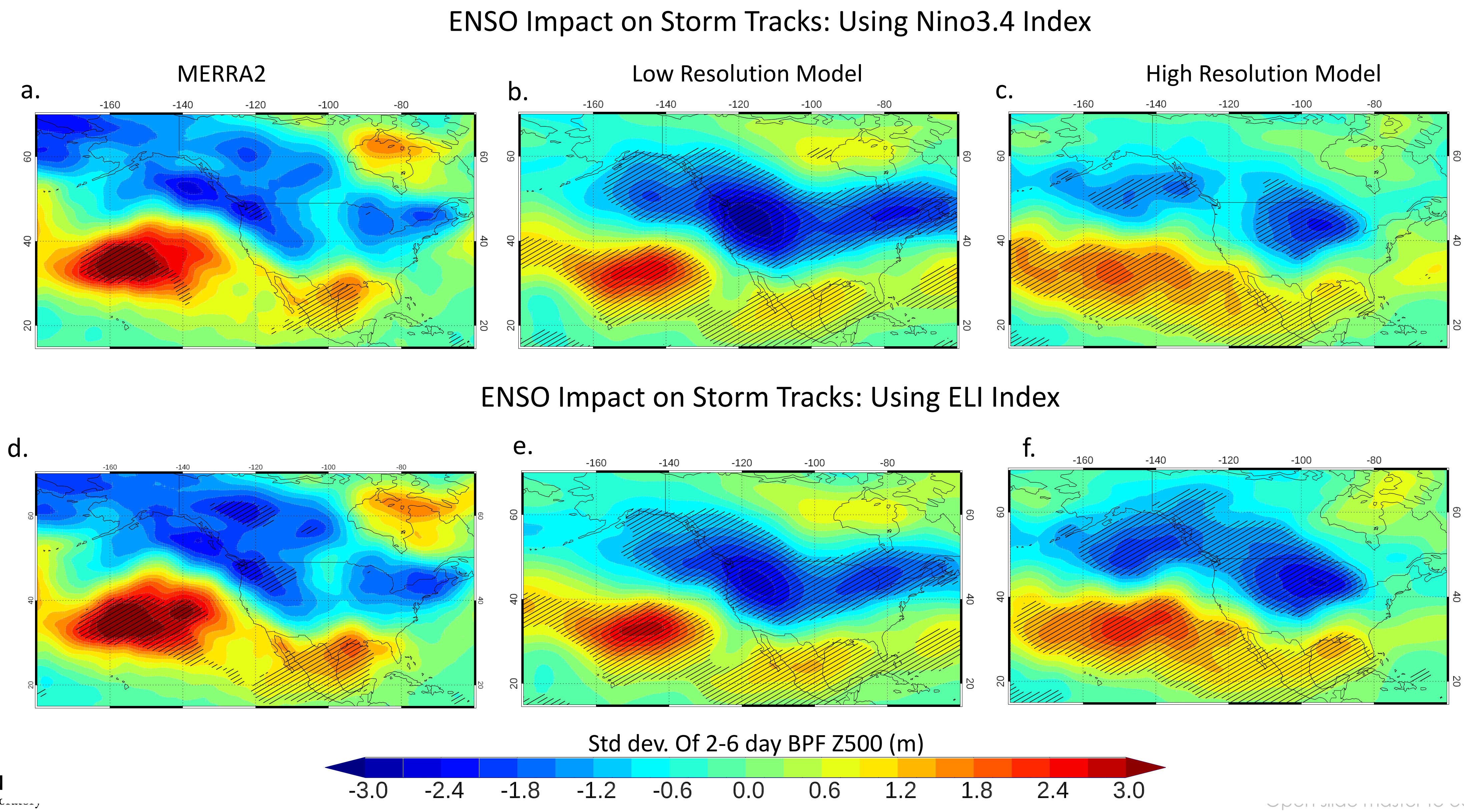


NDJF

ENSO Diversity: Extremes Response



ENSO Diversity: Storm Track Activity

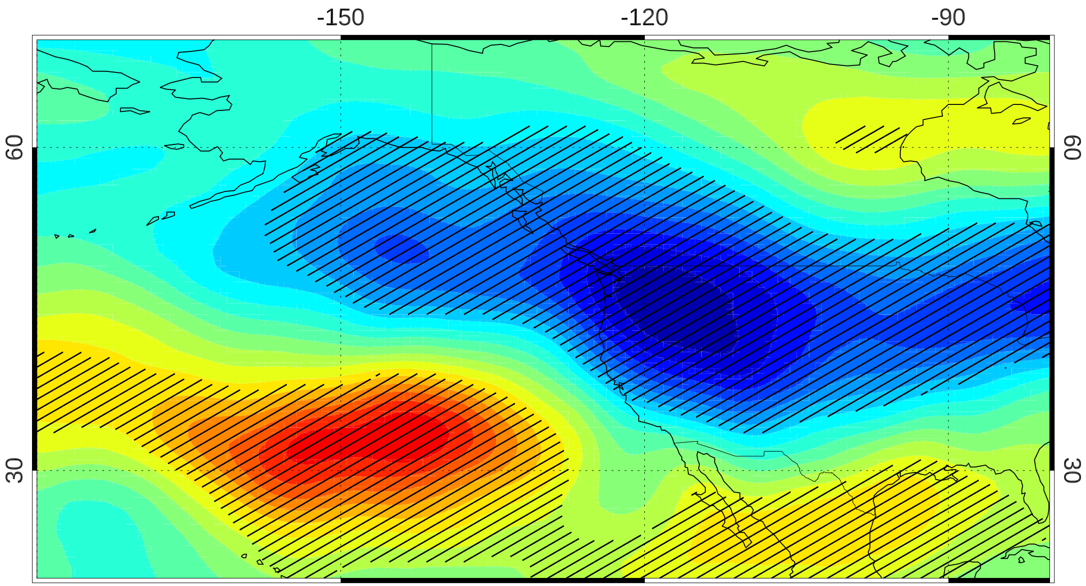


Summary

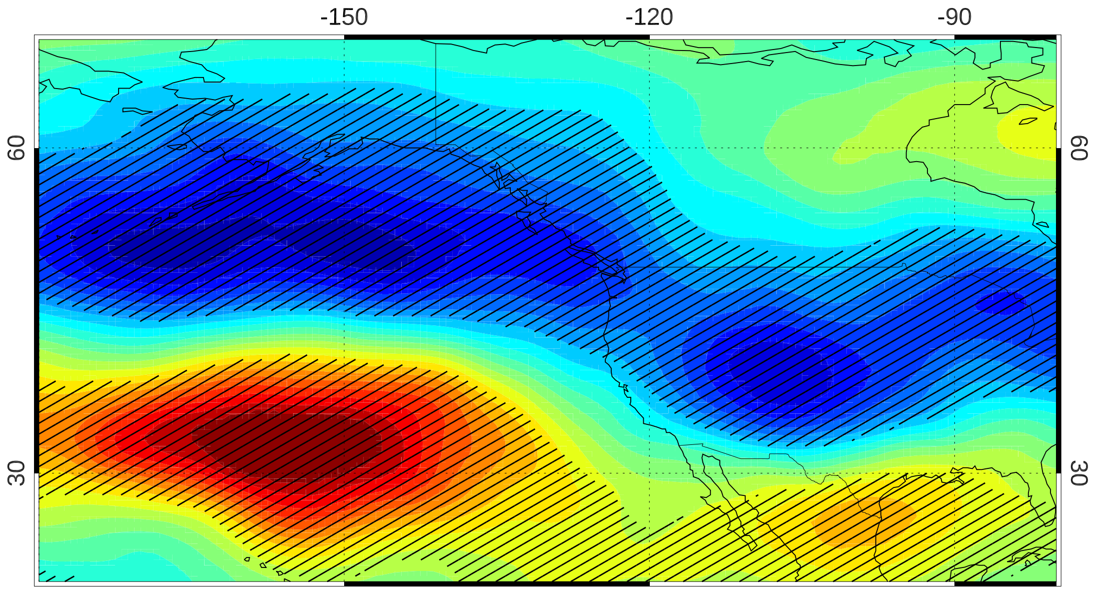
- High resolution (25km) E3SMv1 simulation better captures observed ENSO teleconnections to precipitation extremes over SE USA.
- Both low- and high-res models produce stronger than observed ENSO induced precipitation extremes over Pacific Northwest.
- Strong biases exist in storm track activity and 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

ne30 E3SM v1 Coupled



ne30 E3SM v1 FAMIP



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