Decadal variability of the North American monsoon duration and its potential causes

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Previous studies on decadal variation of the NAMS:

- PDO and ENSO influence NAMS interannual and decadal variability (Higgins et al., 1999; Higgins and Shi, 2000; Castro et al., 2001).
- PDO, AMO, and AO influence NAMS decadal variability (McCabe, 2004; Hu and Feng, 2008, 2010).

Our question:

- ***Has NAMS seasonality changed on decadal scale? If so, what might cause such a change?***
- Grantz et al. 2007: Significant delay in the beginning, peak, and closing stages of the monsoon over the SW US during the period 1948-2004.

Datasets

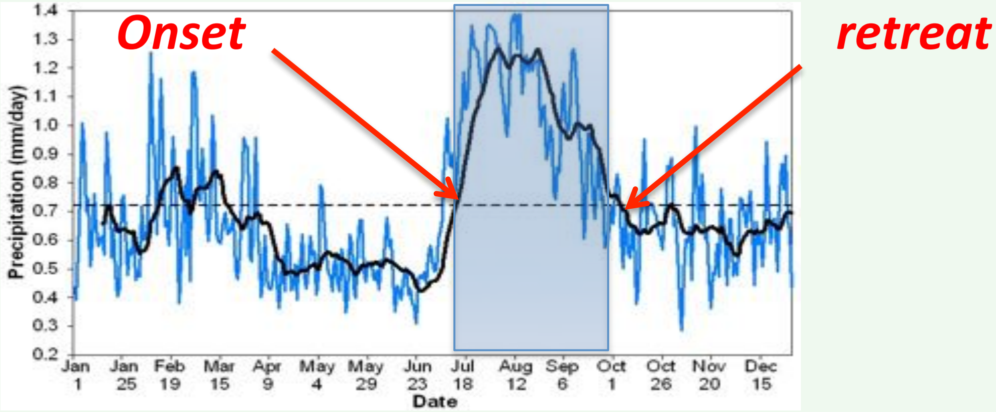
- **NOAA CPC daily rainfall data:** 1° gridded daily rainfall during 1948-2009; Higgins et al. (1999, 2000).

- **Reynolds SST:** 2.5° gridded monthly SST during 1948-2009; Reynolds (1998).

- **NCEP/NCAR Reanalysis:** 2.5° gridded daily data during 1948-2009; Kalnay et al. (1996).

Methods:

- **Monsoon onset and retreat:**
  - Onset/retreat: The first pentad when pentad rain rate is above/below the annual mean during 5 out 8 pentads; Li and Fu (2004).

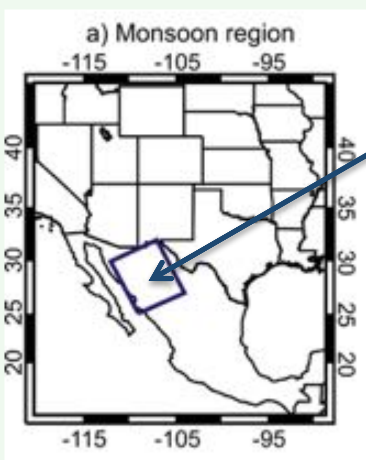


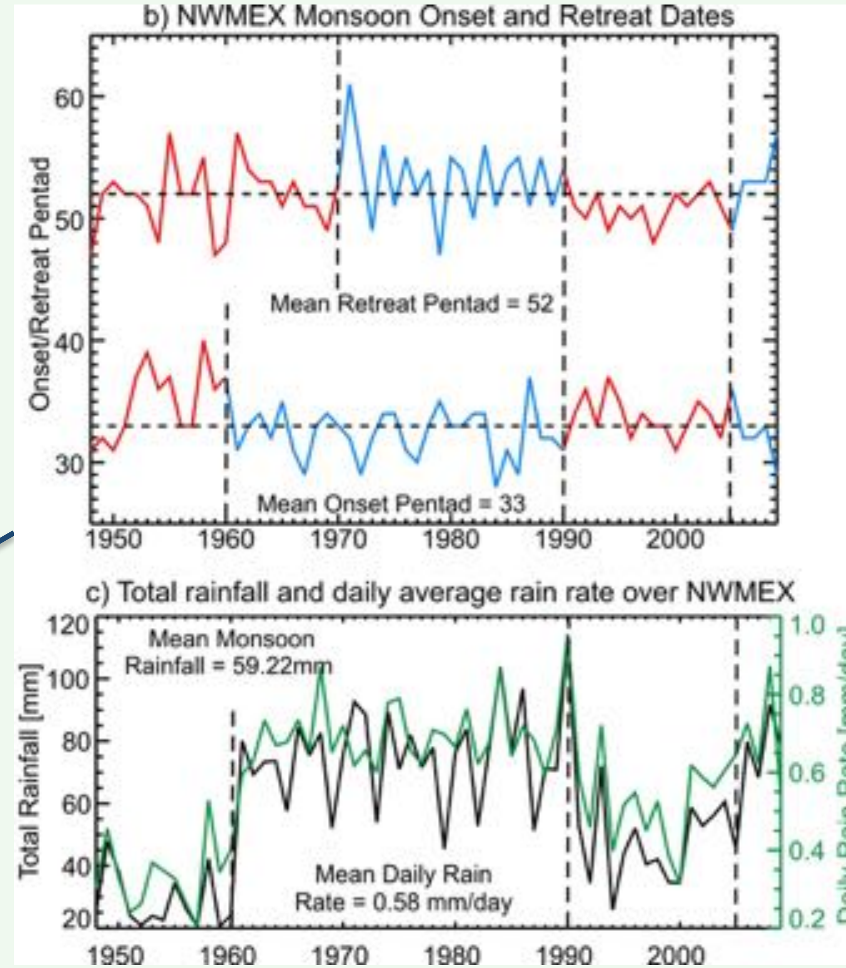
  - Early NAMS retreat: before Sept. 5; Late NAMS retreat: after Sept. 25; Gutzler (2004).
- **Objective identification of regime change:** Rodionov (2004), Rodionov and Overland (2005).

Decadal variation of the North American Monsoon (NAM) seasonality

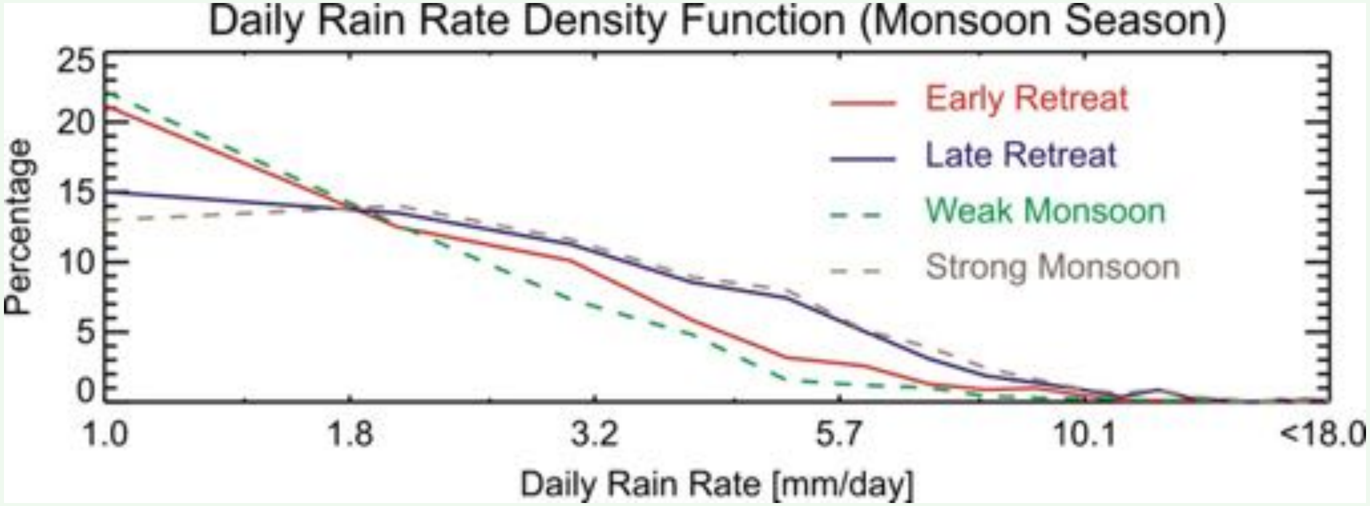
- ***Dry monsoon regime: late onset, early retreat and lower rainrate (1948-1960/70, 1991-2005);***

- ***Wet monsoon regime: early onset, late retreat and higher rainrate (1961/71/-1990, 2006-2009)***





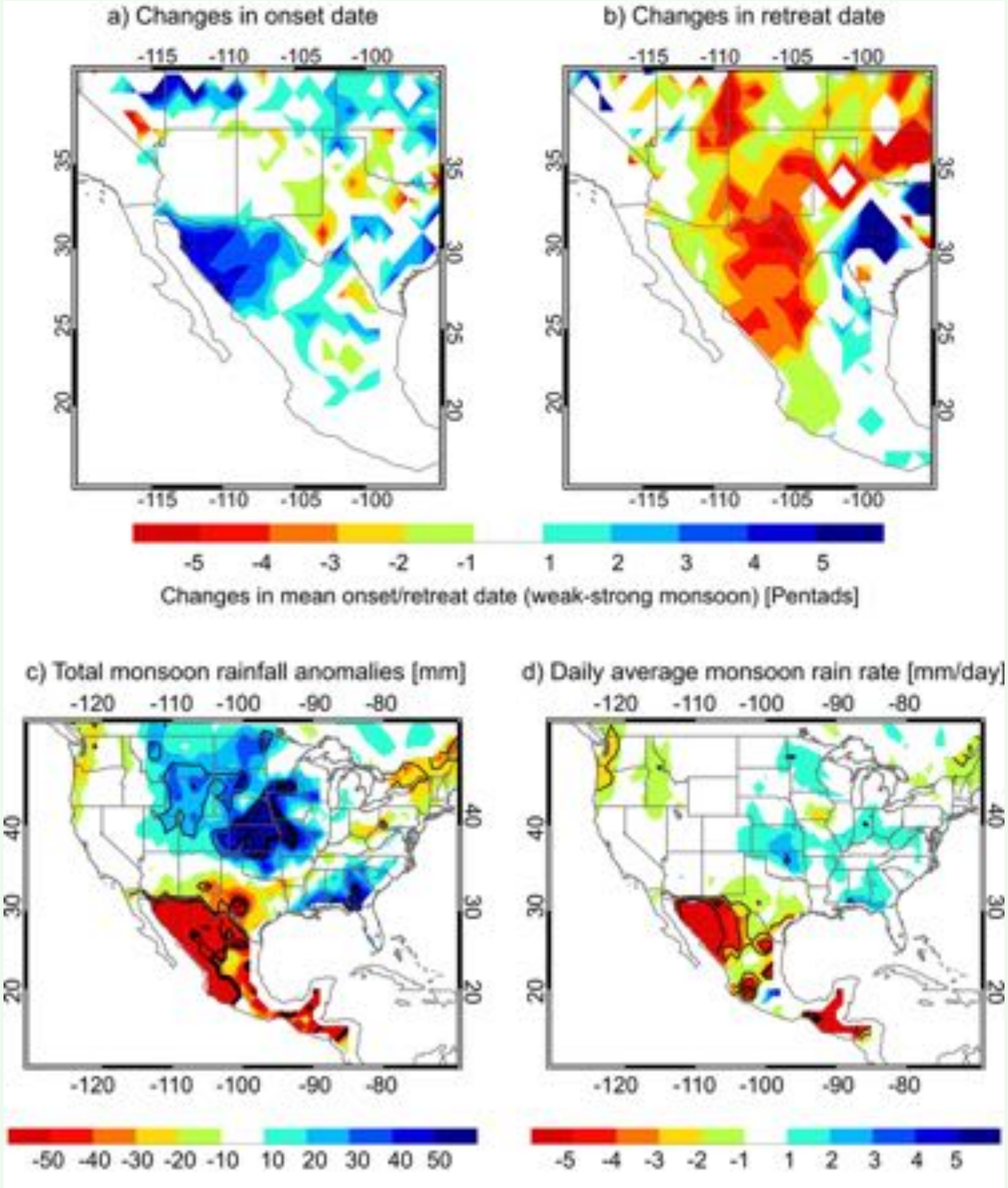
Distribution of daily rain rate



Early Retreat vs. Late Retreat: $P=1.3 \times 10^{-4}$
Weak Monsoon vs. Strong Monsoon: P=0.015

- **Distributions are statistically different at 5% significance level (Two-sample Smirnov-Kolmogorov test).**

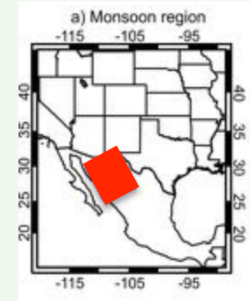
- **Early retreats and weak monsoons: Reduced frequency of rainfall events, mainly of medium intensity (5 mm/day), with perhaps an increased frequency of weaker rainfall events.**



A shorter NAMS season (late onset, earlier retreat) is linked to a weaker monsoons (lower rain rate and total rainfall).

•Focus on changes of NAM retreats

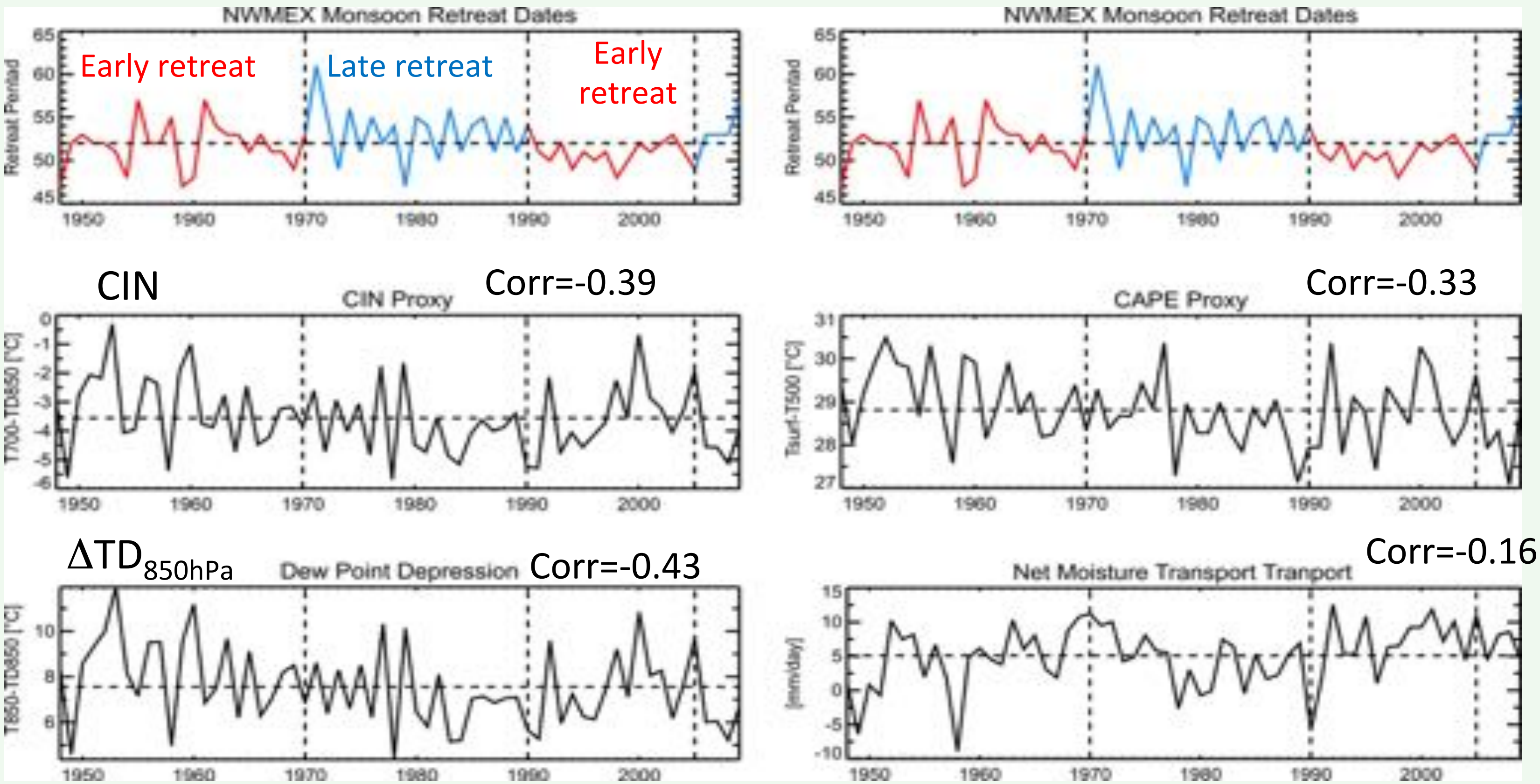
Early retreats appear to be more correlated with an increase of thermodynamic stability, than with a reduction of moisture transport.



CAPE proxy=T_{850hPa}-T_{500hPa}
CIN proxy= T_{700hPa}-TD_{850hPa}

(Myoung & Nielsen-Gammon 2010 J. Climate)

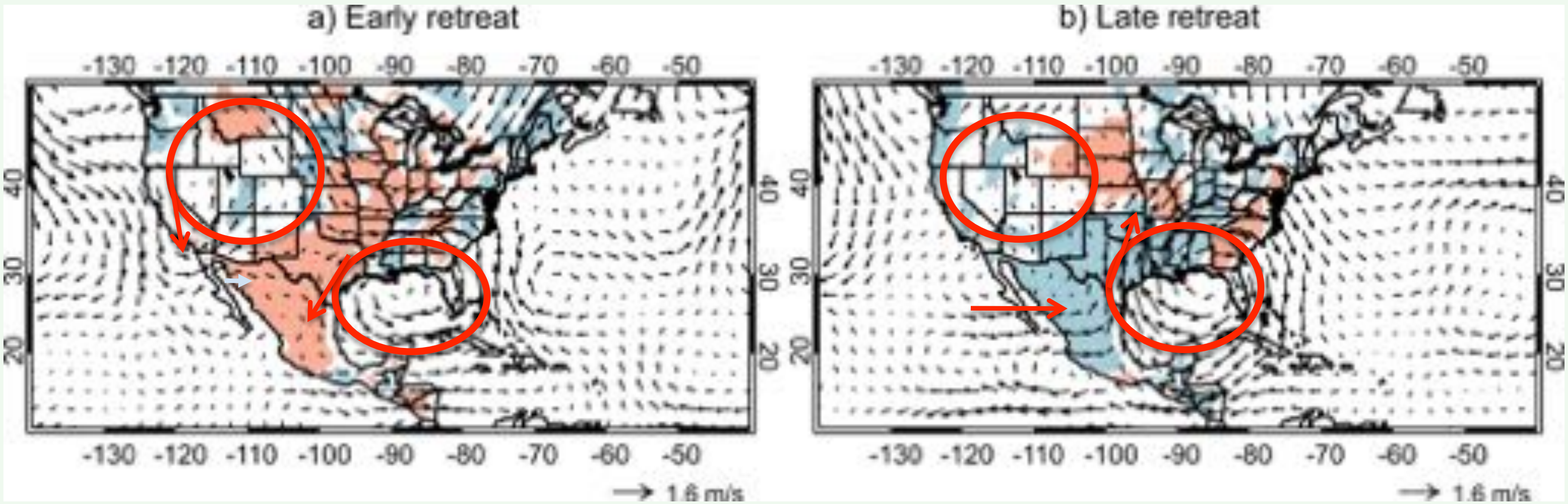
September Composites



Early retreats are associated with:

- An anomalous cyclonic low-level flow over the Gulf of Mexico and an anomalous anticyclonic flow over Baja California
- An increase of rainfall over SE US

850 hPa circulation anomalies composites for early and late retreats (Sept. 1948-2009)

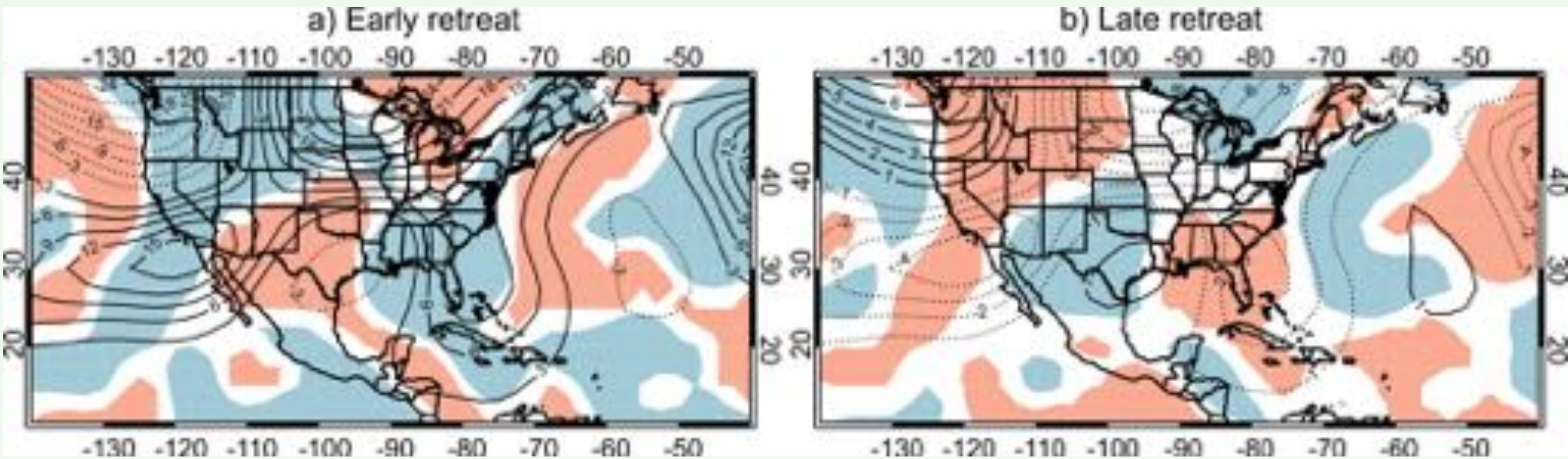


Blue shades: positive rain rate anomalies

Red shades: negative rain rate anomalies

- ***Early retreats are associated with anomalous upper level divergence and an increase of 200 hPa geopotential height over SE US, an decrease of 200 hPa geopotential height over SW US and N. Mexico.***

200 hPa circulation anomalies composites for early and late retreats (Sept. 1948-2009)



Blue shades: UT divergence

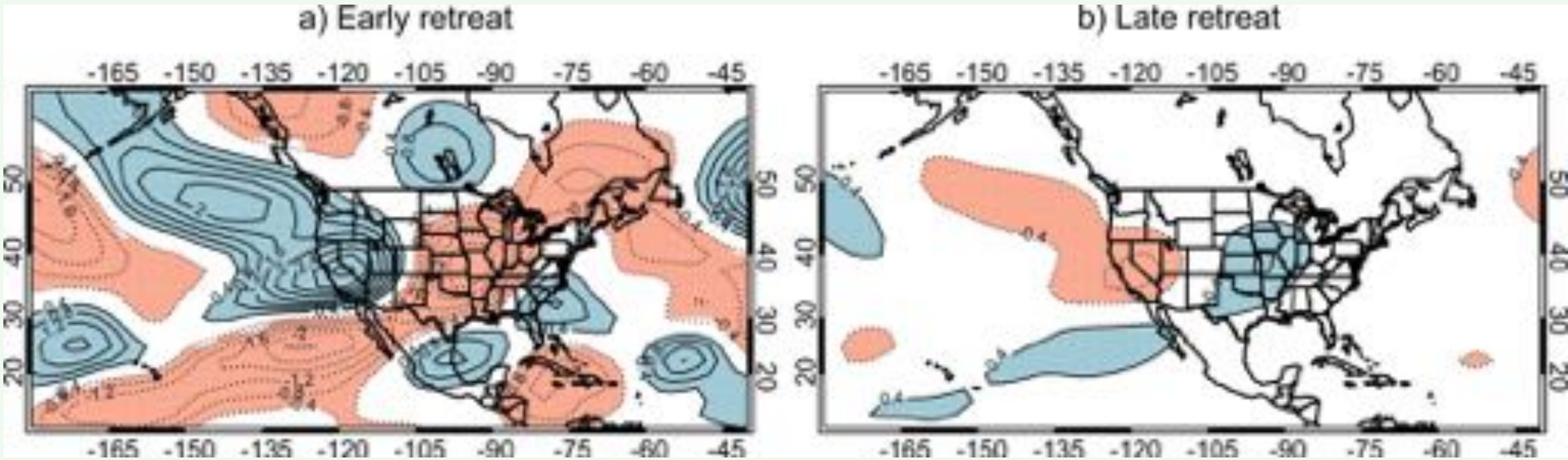
Red shades: UT convergence

Solid contours: positive hgt200 anomalies [m]

Dotted contours: negative hgt200 anomalies [m]

- ***Early retreats are also associated with a NW displacement of the jets over W. North America.***

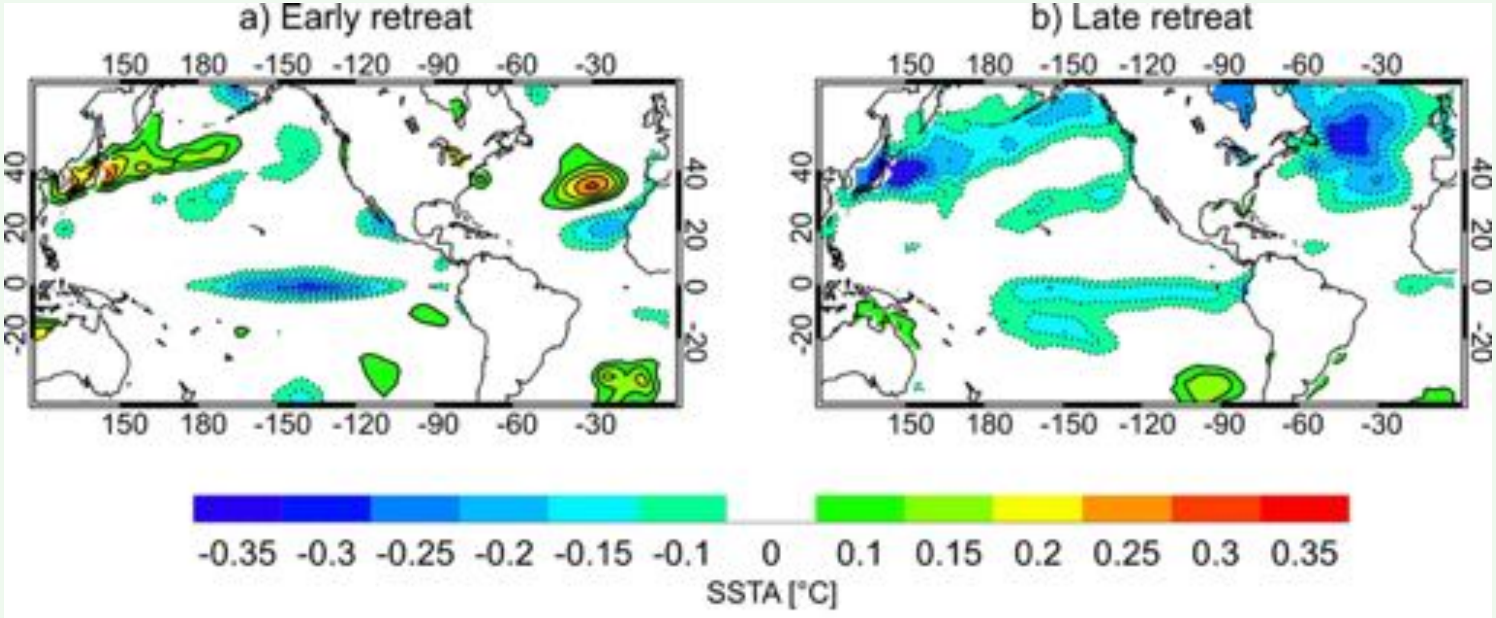
200 hPa zonal wind anomalies composites for early and late retreats (Sept. 1948-2009)

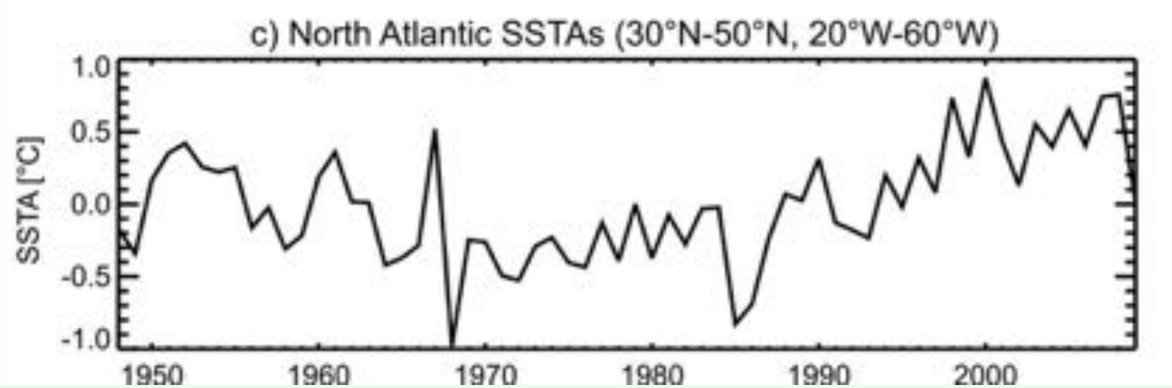


Blue shades/solid contours: Positive u200 anomalies [m/s]
Red shades/dotted contours: Negative u200 anomalies [m/s]

How are NAM early retreats connected to SSTA?

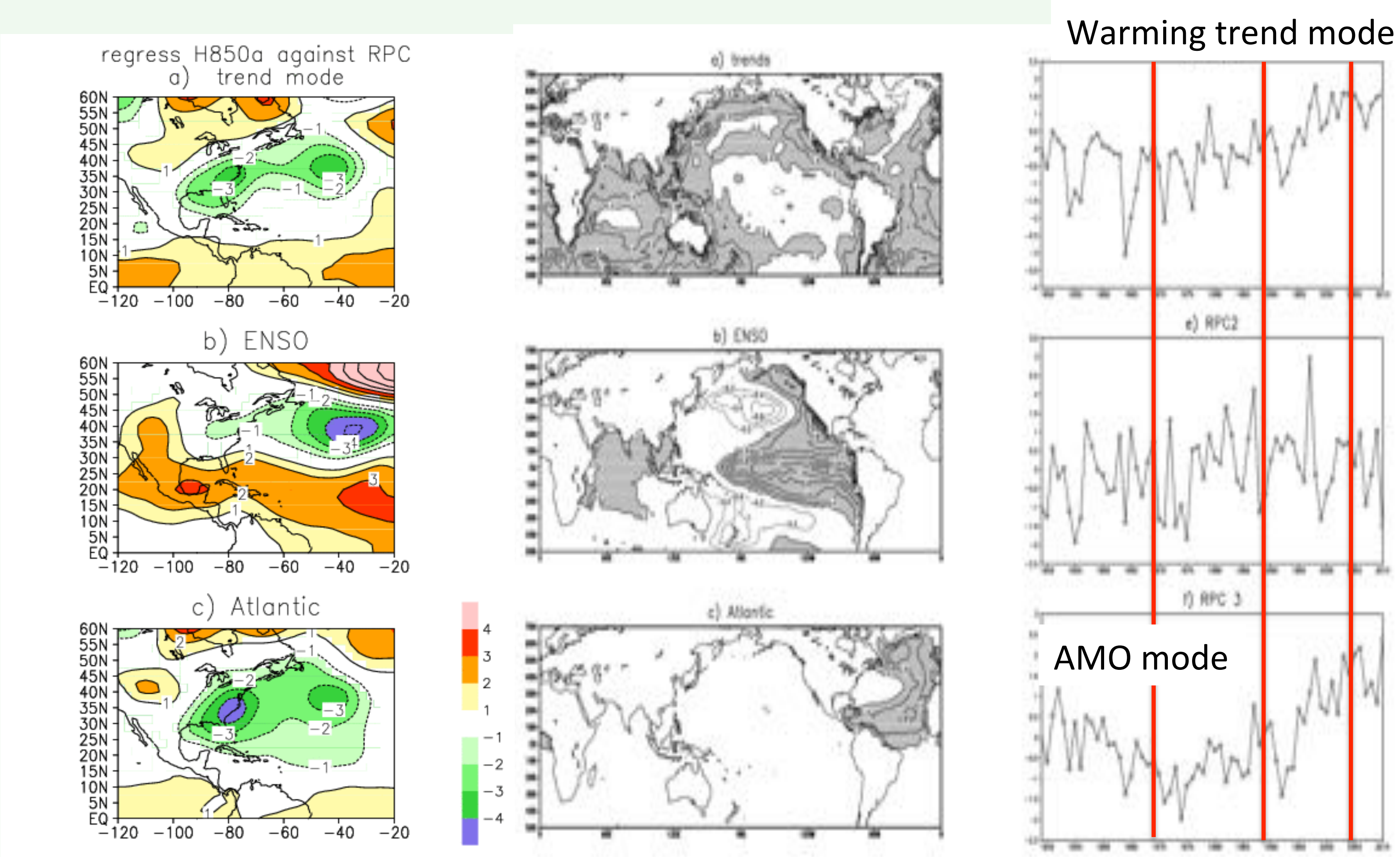
September SSTA composites for early and late retreats (1948-2009)





The change of NAMS retreats appears to be linked mainly to Atlantic SSTAs.

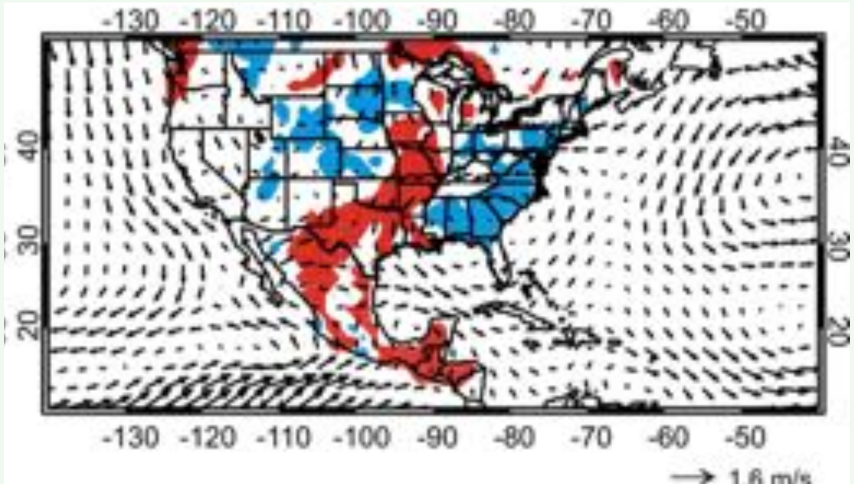
The anomalous circulation pattern associated with early retreats appears to be linked to Atlantic SSTA variability and warming trends.



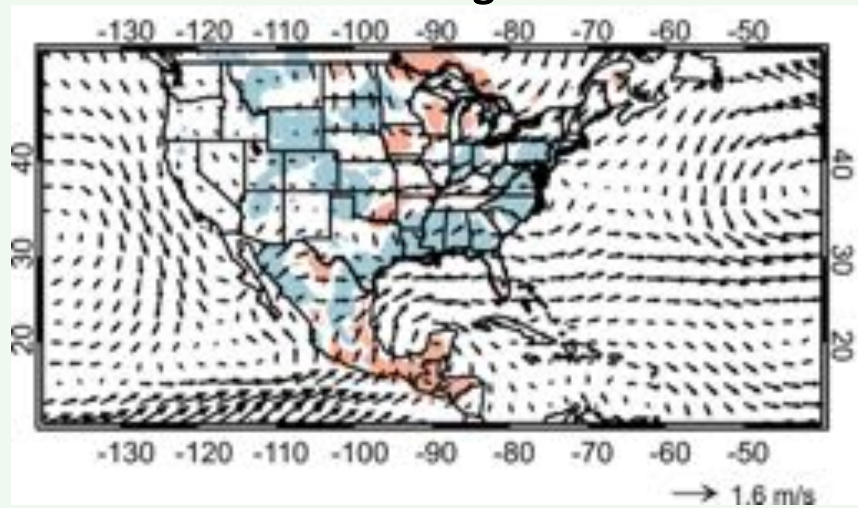
- ***AMO and warming SST modes cannot adequately explain the anomalous cyclonic circulation over the Gulf of Mexico associated with NAM early retreats***

Composites rainfall and 850 hPa wind anomalies (Sept. 1948-2009)

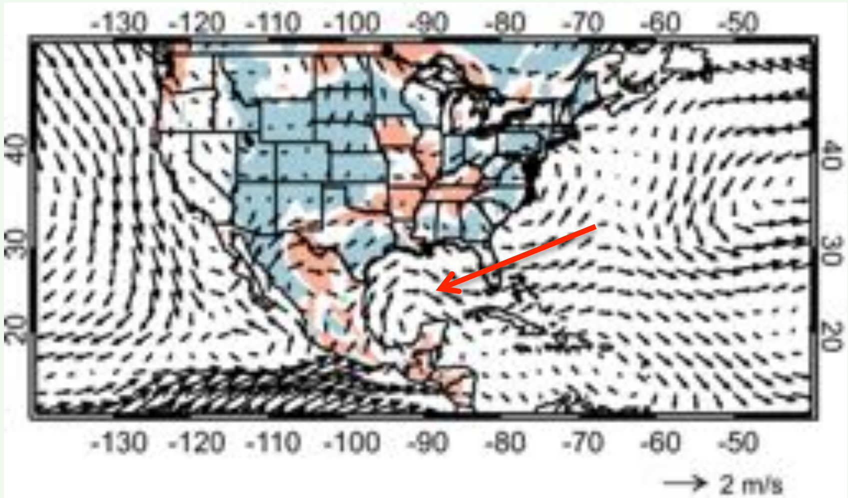
AMO mode



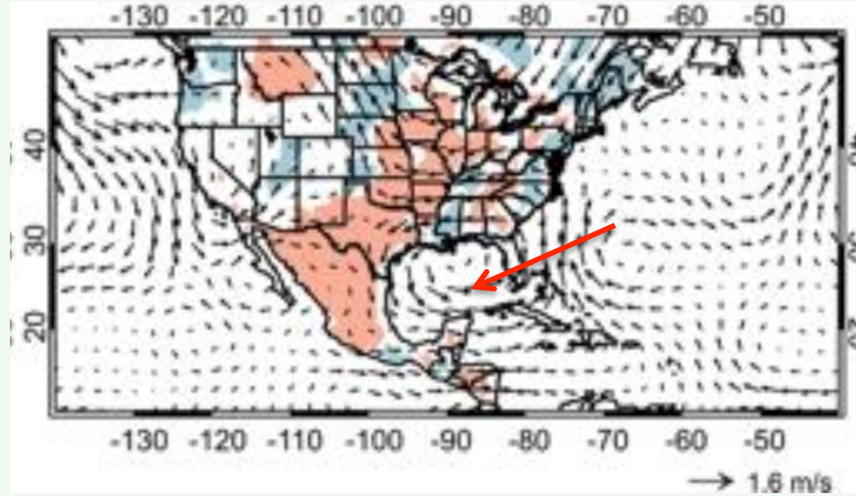
Warming mode



Warming + AMO

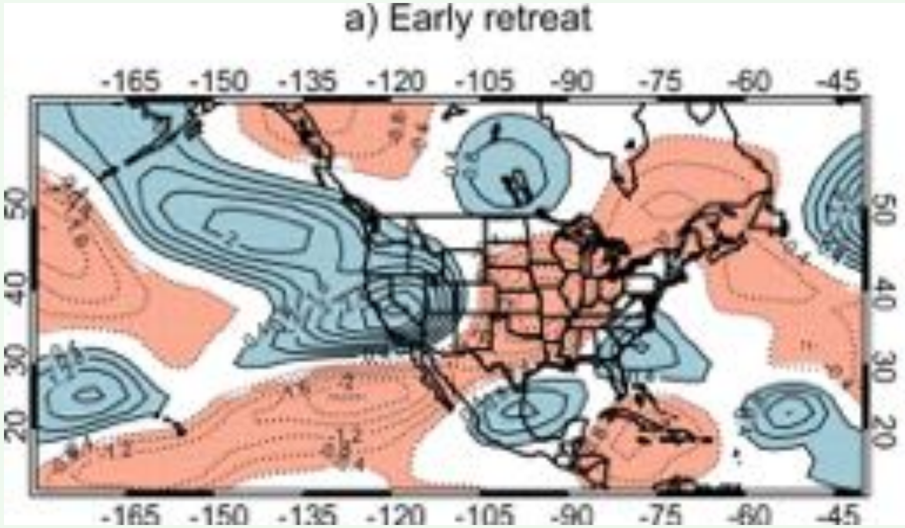


Early NAMS retreat



Blue shades: Positive rain rate anomalies

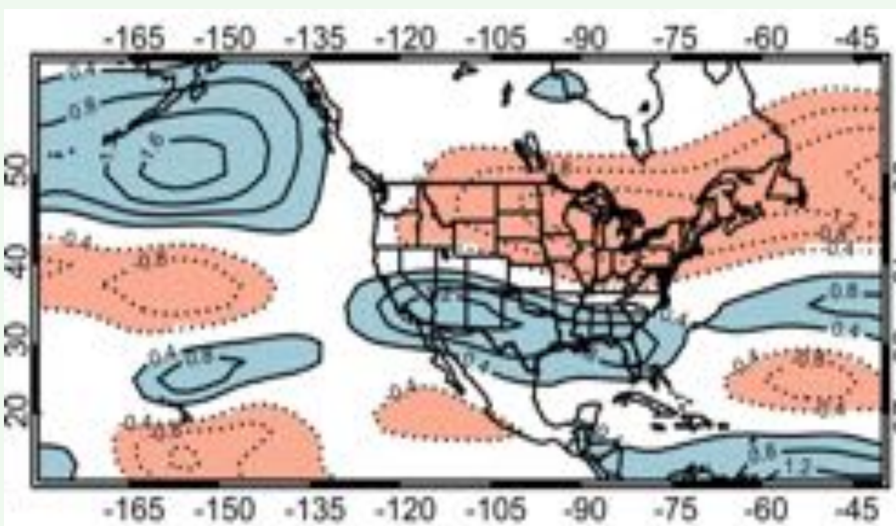
Red shades: negative rain rate anomalies

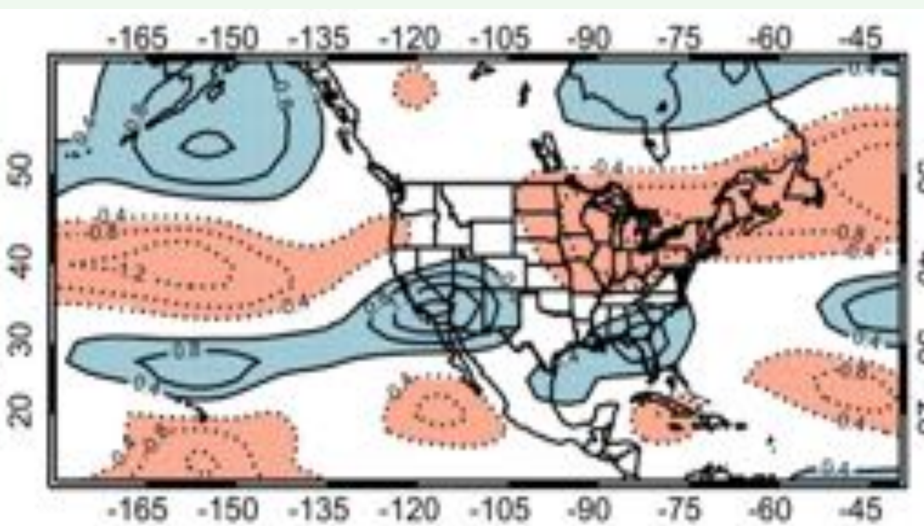


The warming and AMO modes cannot explain NW shift of jets associated with early NAM retreats over W. North America.

Warming mode u200 anomalies

AMO mode u200 anomalies

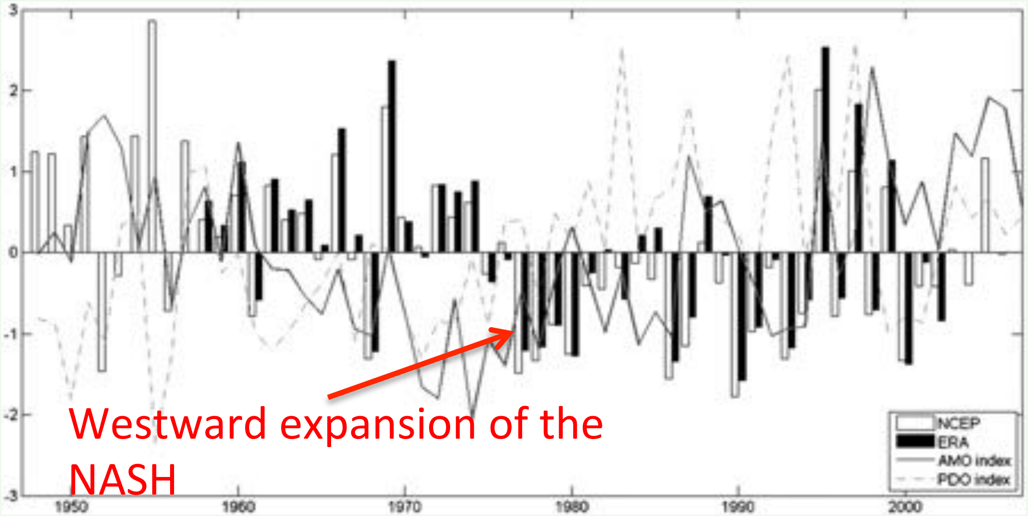


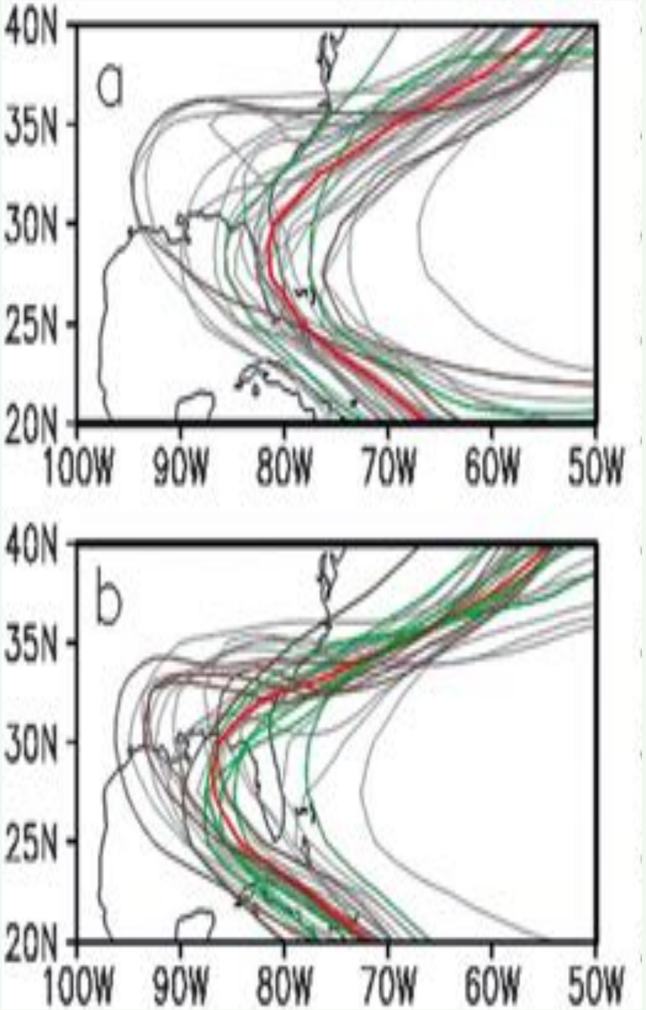


Is there any other cause?

- Li et al. 2010, J. Climate: a westward expansion of NASH since late 1970s.

- ***How would change of NASH influence NAM retreats?***

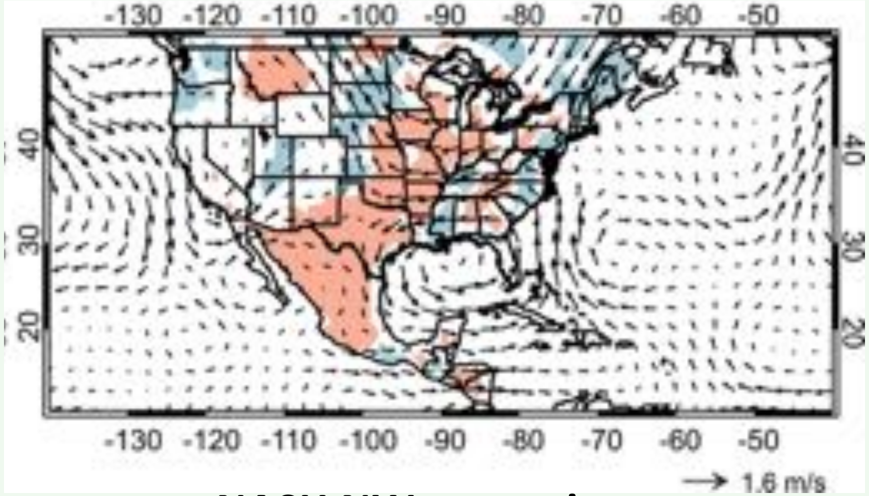




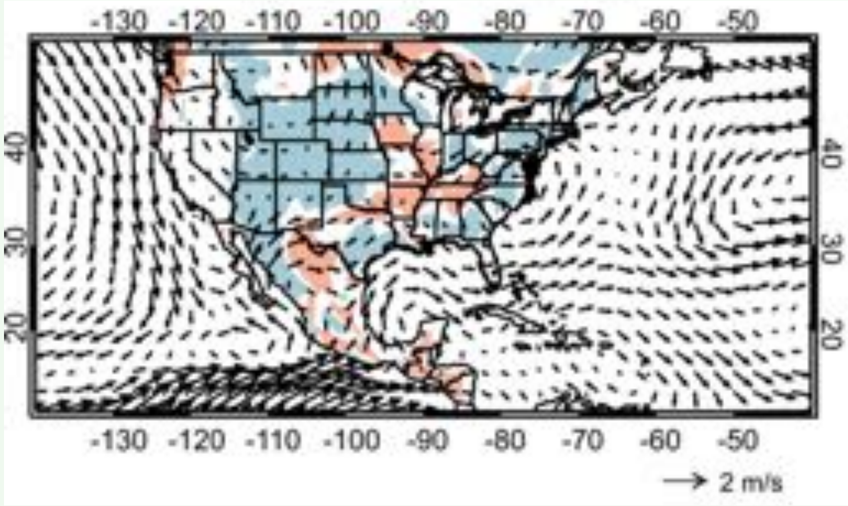
How does NW expansion of the NASH influence NAM retreats?

- **NW expansion of the NASH appears to contribute to the anomalous circulation associated with NAM early retreats.**

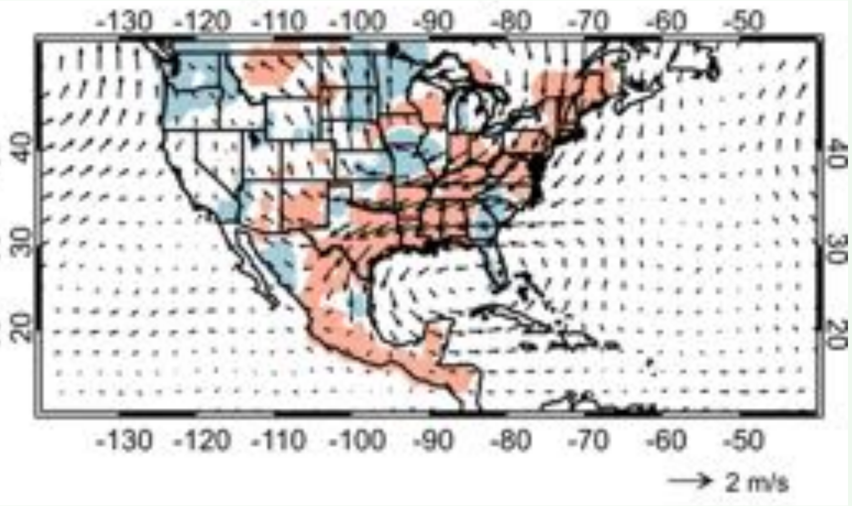
Early NAMS retreat



Warming + AMO

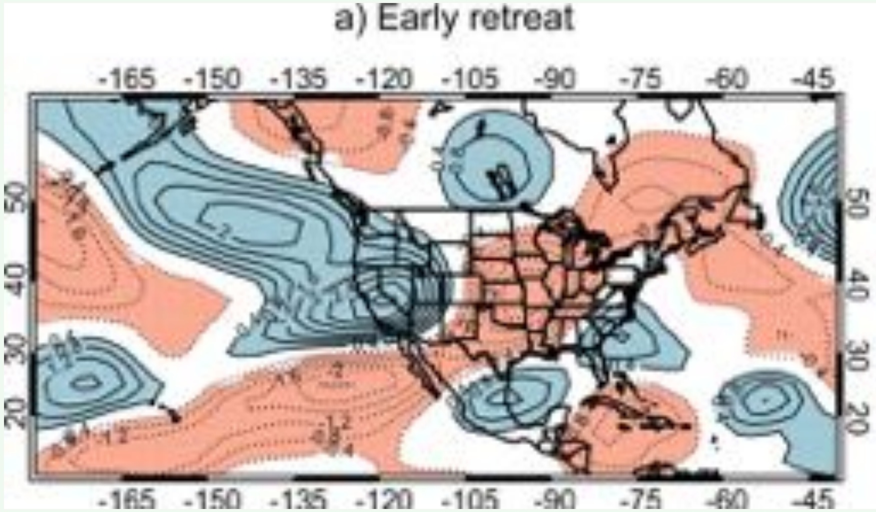


NASH NW expansion

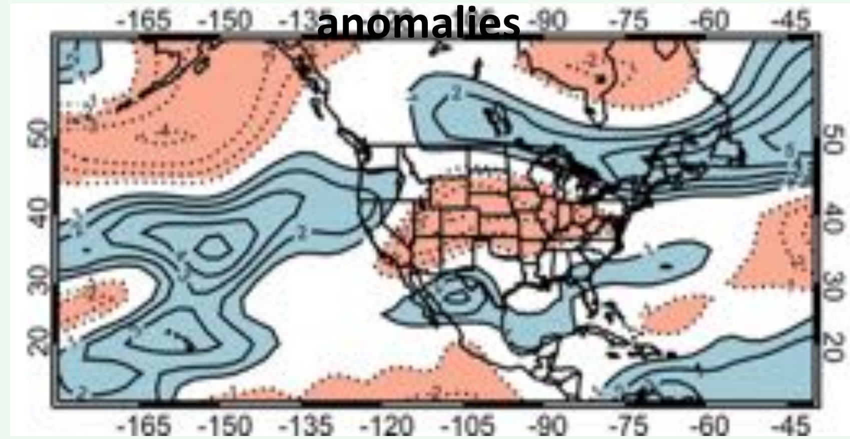


Blue shades: Positive rain rate anomalies   Red shades: negative rain rate anomalies

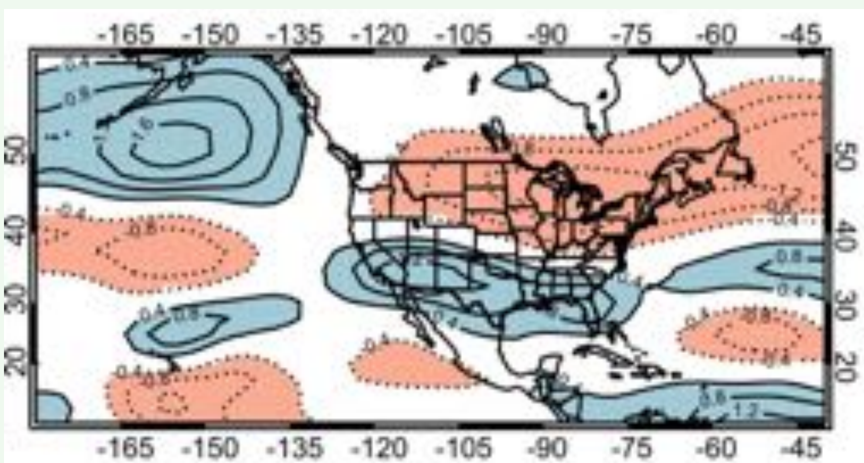
NW displacement of the jets over North America associated with early NAM retreats is probably contributed by NW expansion of NASH, +AMO and warming SST mode.



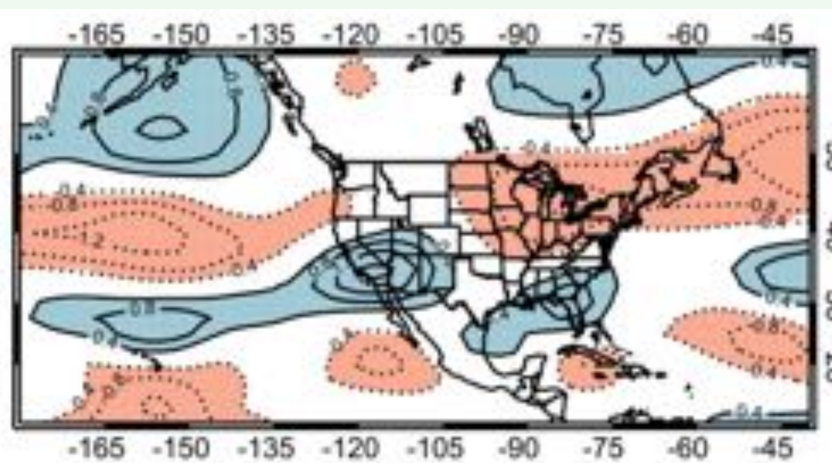
NW NASH expansion u200 anomalies



Warming mode u200 anomalies



AMO mode u200 anomalies



What contributes to the decadal variation of NAM retreats?