

# VARIABILITY OF HAWAIIAN WINTER RAINFALL DURING LA NIÑA EVENTS

Pao-Shin Chu

Department of Atmospheric Sciences  
School of Ocean and Earth Science and Technology  
University of Hawaii-Manoa

and

C. O'Conner, P.-C. Hsu, and K. Kodama

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# HRI (Hawaii Rainfall Index)

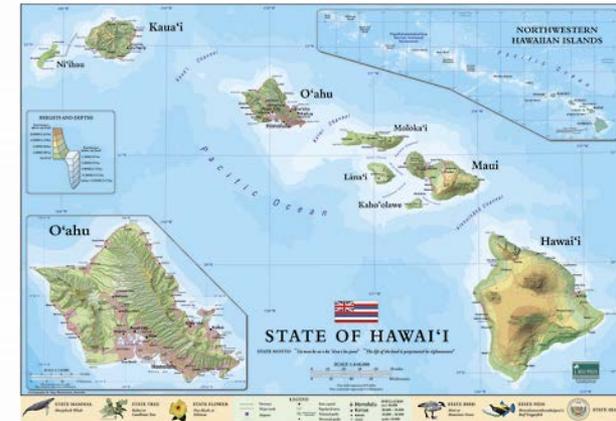
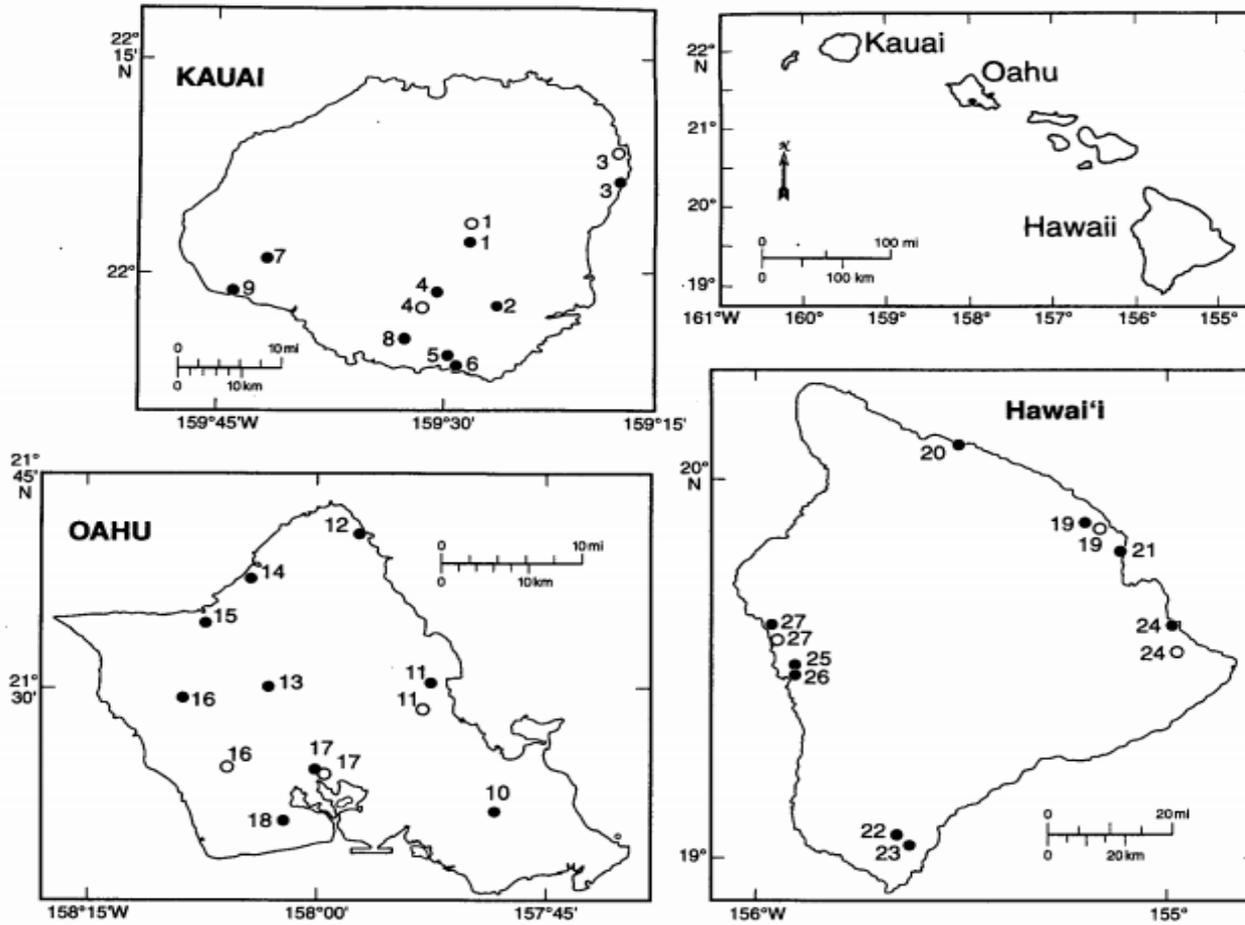
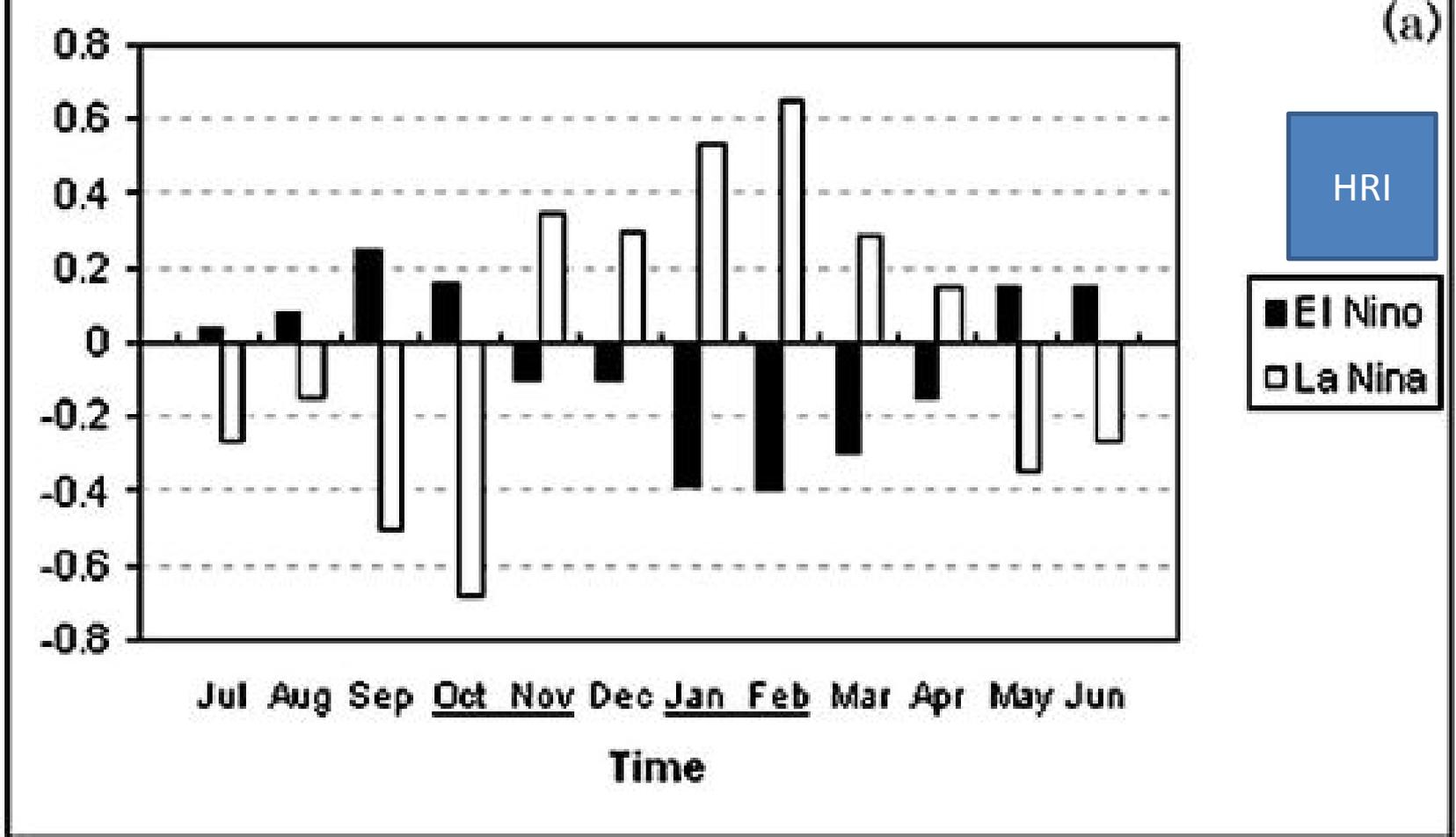


FIG. 1. Map of the major Hawaiian Islands and the locations of rainfall stations used in this study. Station numbers are the same as listed in Table 1. An open circle indicates a new station.

Standardized anomalies

(a)

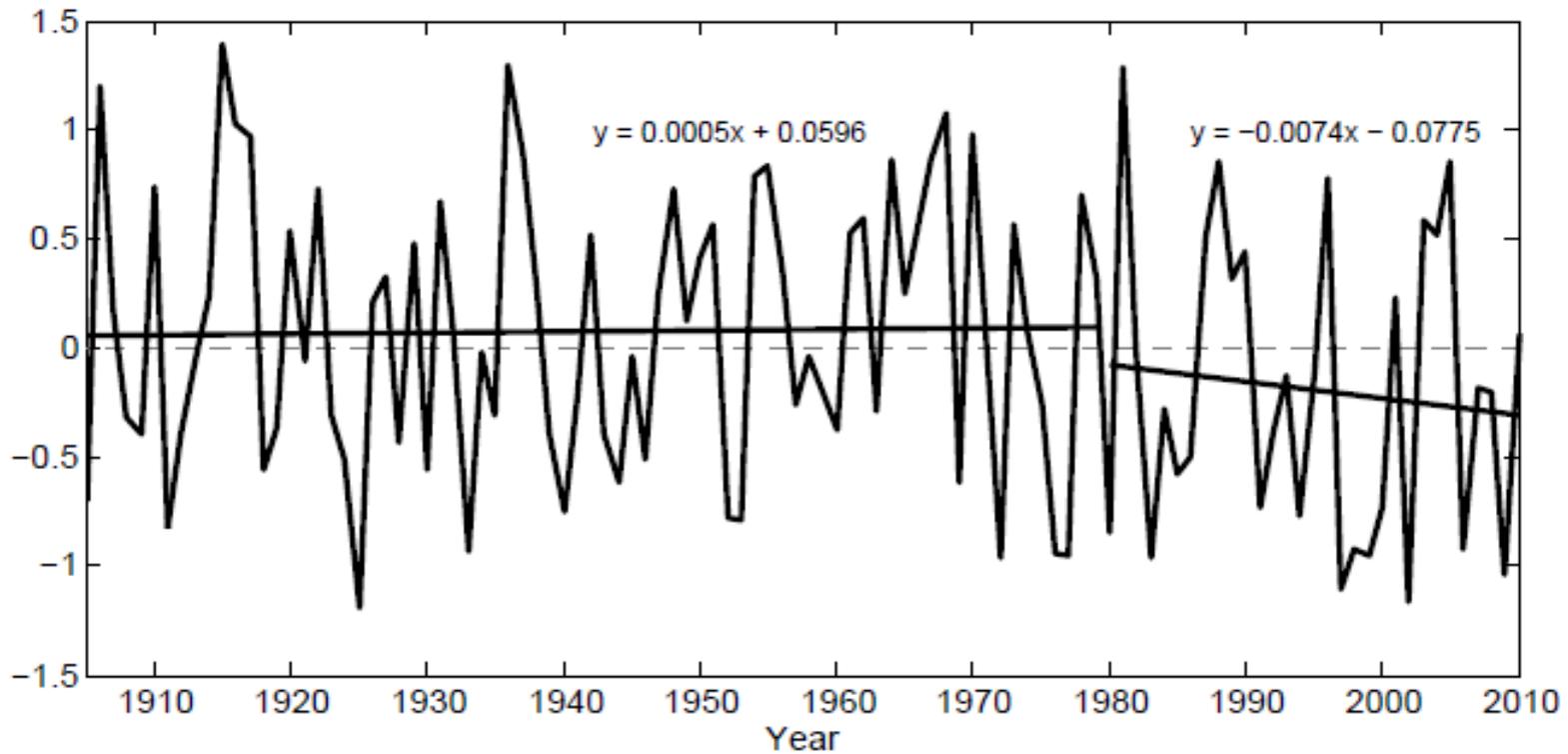


El Niño (La Niña) occurs if a 5-mo running mean of SST anomalies in Niño 3.4 region exceeds  $0.4^{\circ}\text{C}$  ( $-0.4^{\circ}\text{C}$ ) for at least 6 consecutive months

Chu and Chen, 2005



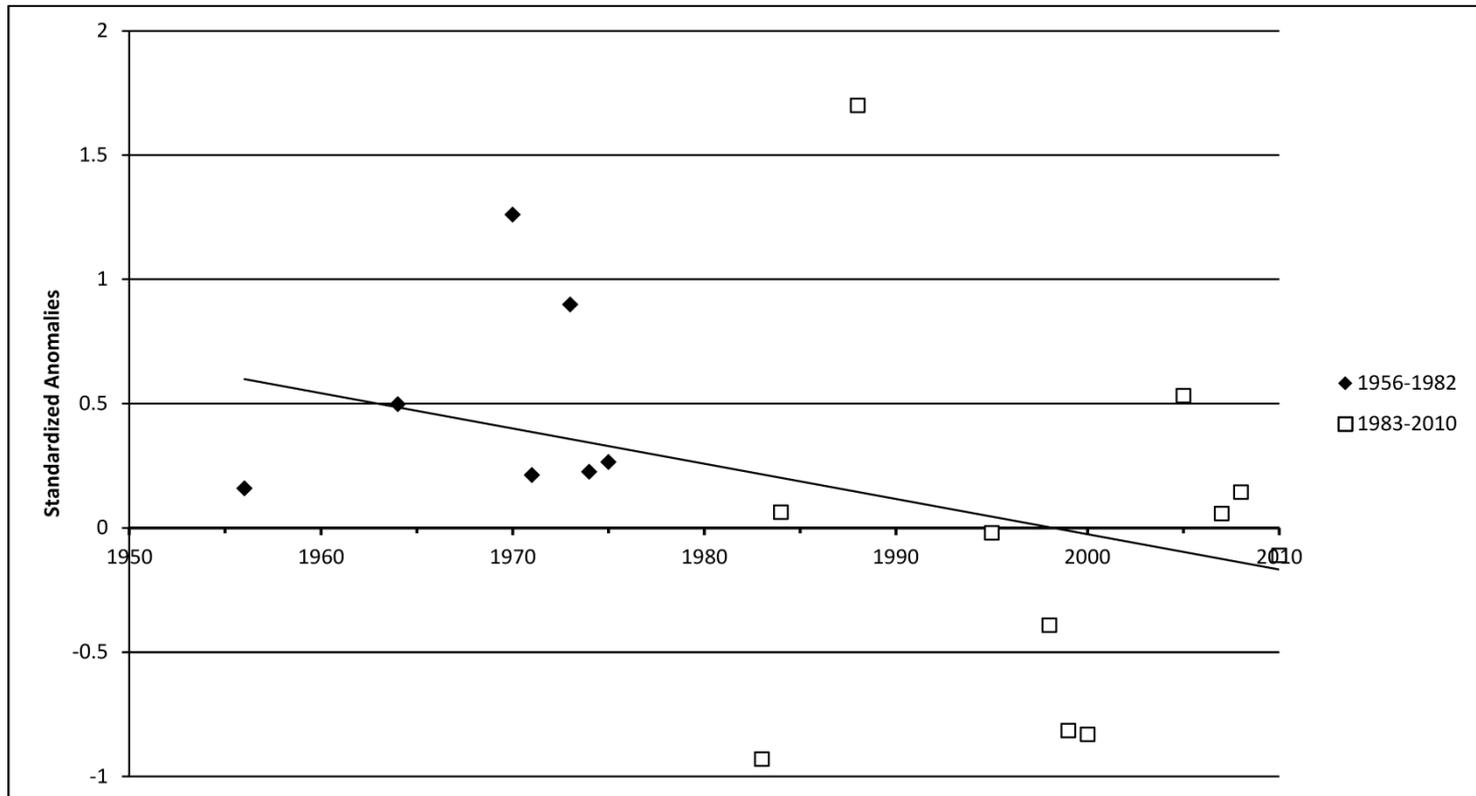
Time series of HRI Anomalies



# Why rainfall in Hawaii has decreased since the early 1980s?

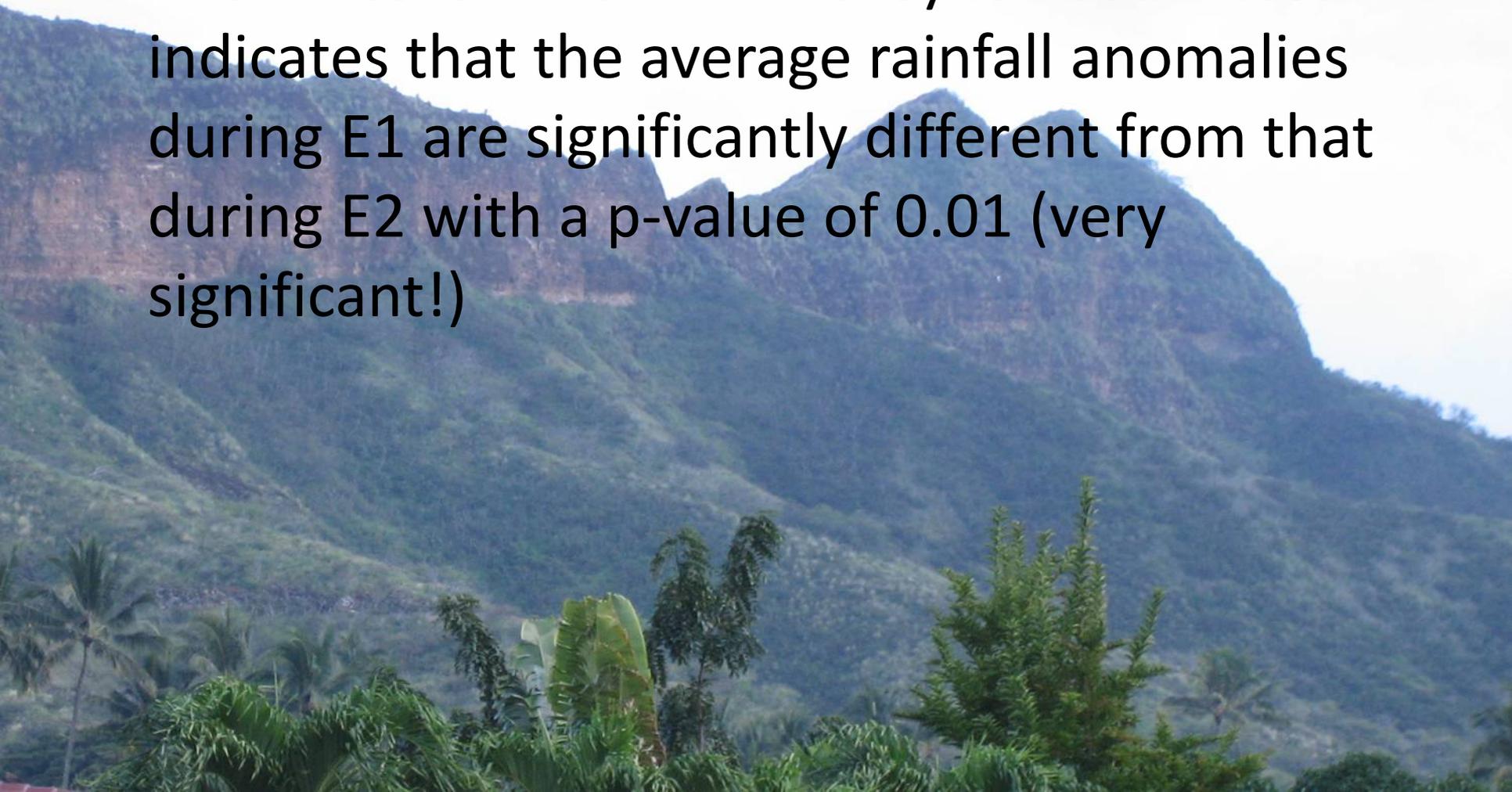
- 50 stations with complete rainfall records for 1956-2010
- NWS-Honolulu Office
- Oceanic Nino Index (ONI) – NOAA/Climate Prediction Center
- El Nino (**La Nina**) event: 3-mo running mean of SSTs in the Nino3.4 region greater (**less**) than 0.5C (**-0.5C**) for five consecutive, overlapping seasons (e.g., JFM, FMA,...)
- NCEP/NCAR reanalysis 1 for circulation study

Standardized rainfall anomalies during wet season (NDJFMA). La Niña events during epoch 1 (1956-1982) and epoch 2 (1983-2010) are marked by black diamonds and white squares, respectively. Note the drying trend indicated by the trend line.



Based on Pettitt-Mann-Whitney change-point test, the most likely shift occurs in 1983 (p-value = 0.06)

- The data series is then partitioned into 2 epochs: 1956-1982 as the first epoch (E1) and 1983-2010 as the second epoch (E2).
- The Wilcoxon-Mann-Whitney rank sum test indicates that the average rainfall anomalies during E1 are significantly different from that during E2 with a p-value of 0.01 (very significant!)



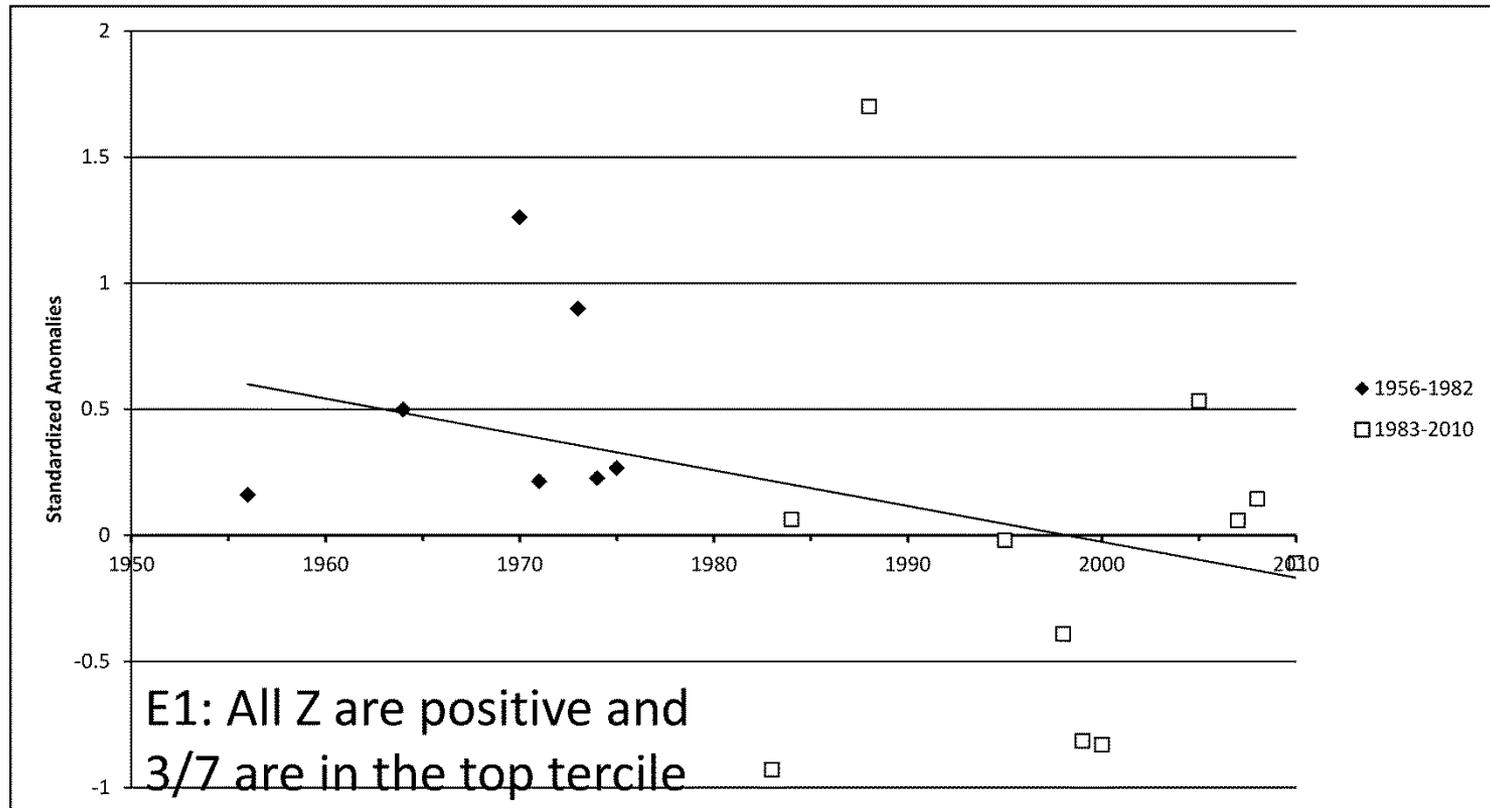
- Rainfall trend for El Niño years is downward and trend for Neutral years (not fallen into El Niño and La Niña groups) is upward, but none of them are statistically significant
- Downward trend in HRI since the early 1980s appears to be caused mainly by decreasing rainfall during La Nina events



- Rainfall anomalies in La Nina years are categorized as either drier than normal ( $Z < -0.43$ ), wetter than normal ( $Z > 0.43$ ), or near normal (between  $-0.43$  and  $+0.43$ ), where  $Z$  is the standardized rainfall anomalies.
- This tercile categorization (i.e., top, middle, bottom) has been commonly used in operational centers.



Standardized rainfall anomalies. La Niña events during epoch 1 (1956-1982) and epoch 2 (1983-2010) are marked by black diamonds and white squares, respectively. Note the drying trend indicated by the trend line.

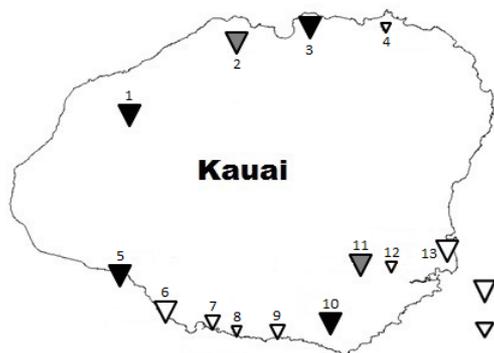


(wetter than normal)

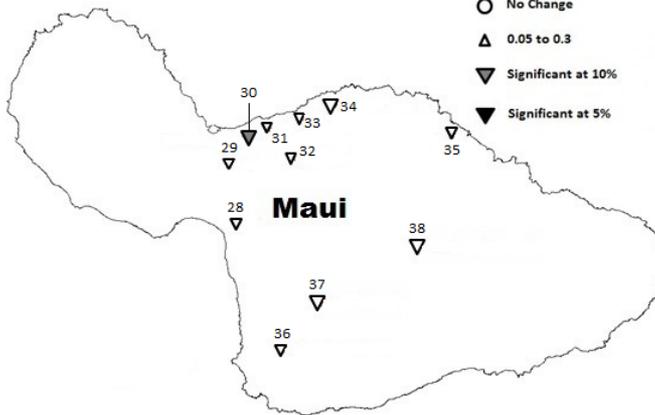
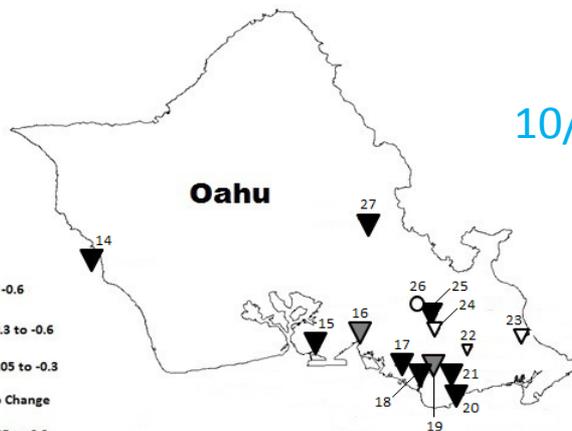
E2: only 2/11 are in the top tercile;

Epochal (E2-E1) difference in standardized rainfall anomalies during the La Nina wet season in Hawaii. Nonparametric rank sum test significance is indicated by shading, black (grey) shading representing significant change between epochs at the 5% (10%) level.

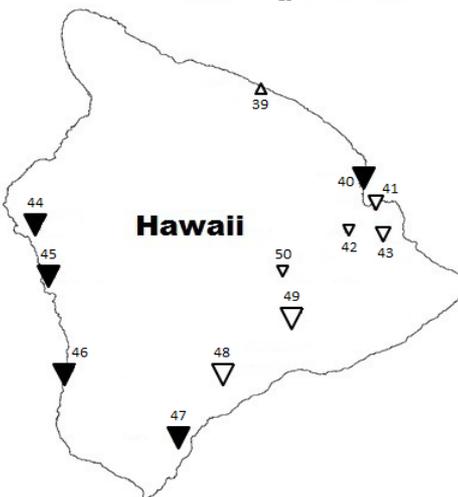
6/13



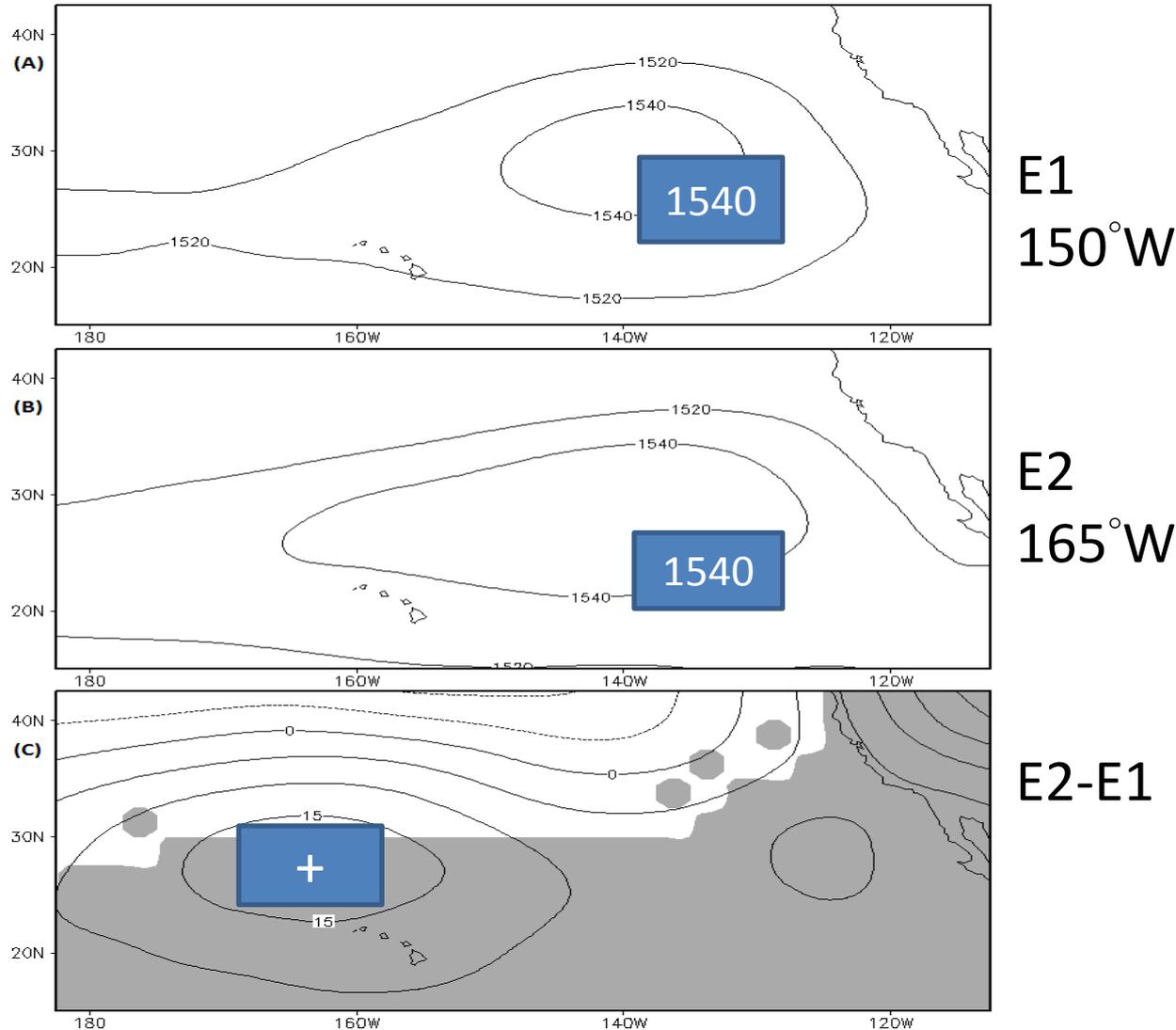
10/14



5/12

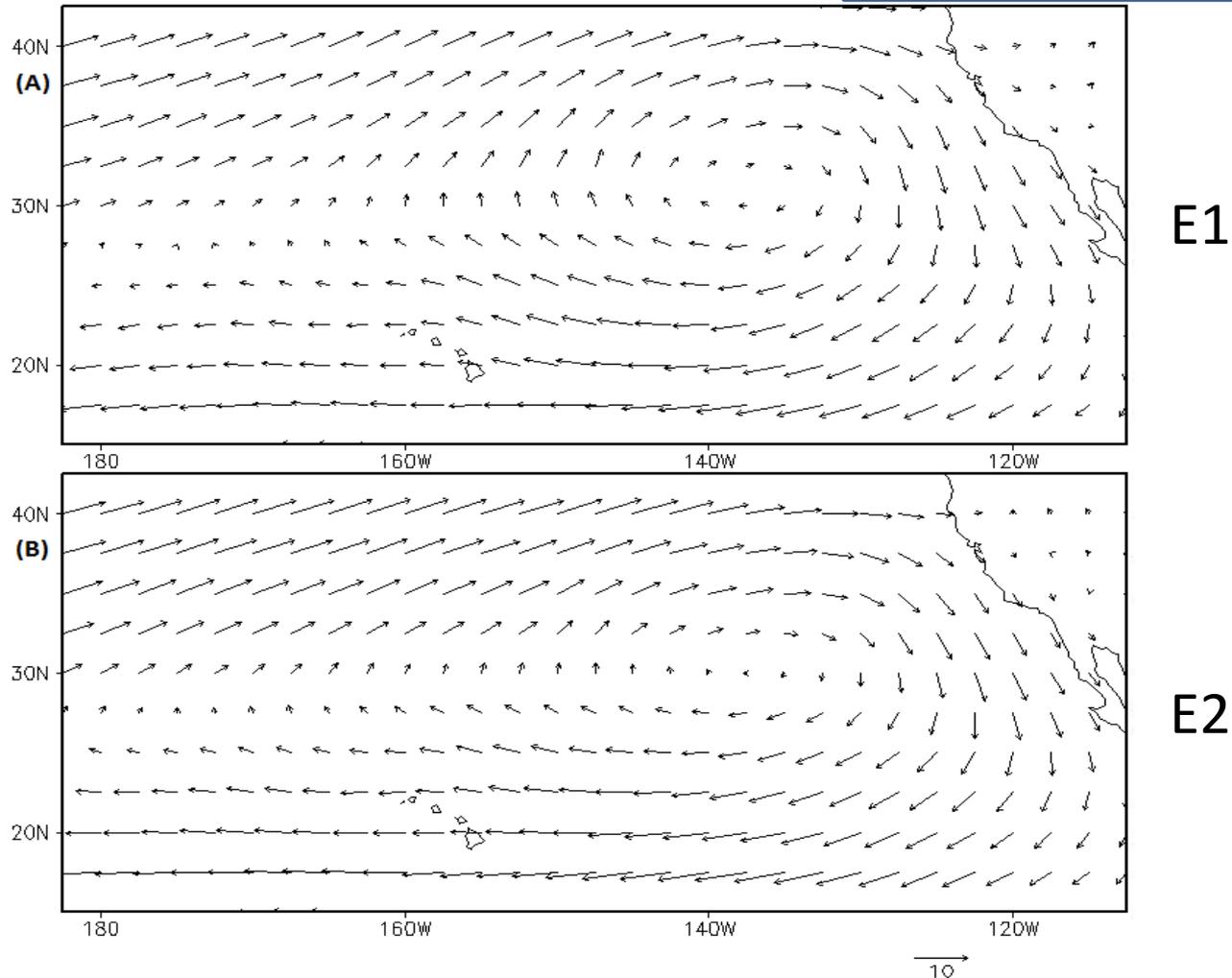


Seasonal mean geopotential height (m) in lower troposphere (850 hPa) during La Niña wet seasons. In (c), the grey shaded area is where the null hypothesis was rejected at the 5% level. Solid (dashed) contours denote positive (negative) value.



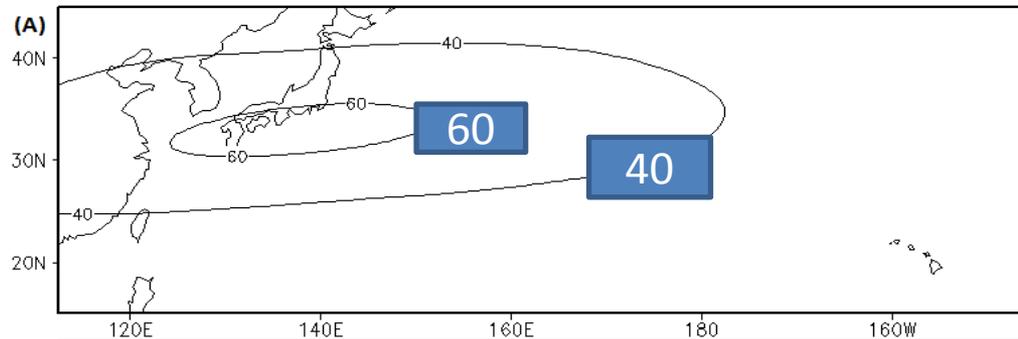
Seasonal mean wind ( $m s^{-1}$ ) at 925 hPa during La Niña wet seasons. (a) Epoch 1 (1956-1982). (b) Epoch 2 (1983-2010).

Lower troposphere

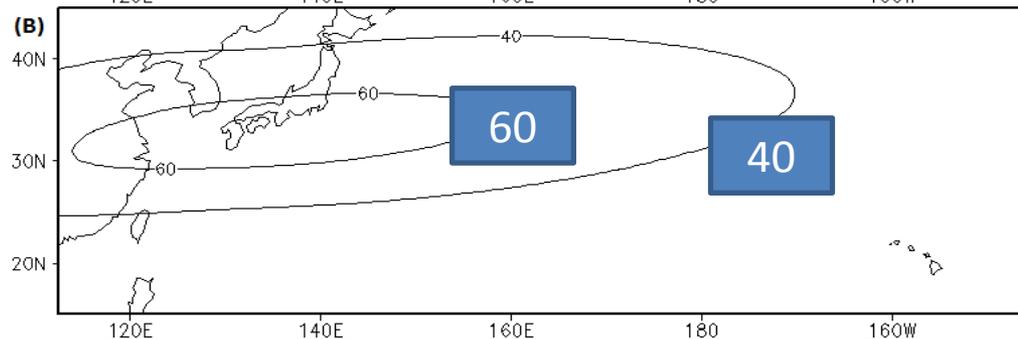


Seasonal mean zonal wind ( $ms^{-1}$ ) at 200 hPa during the La Niña wet seasons. The grey shaded area is where the null hypothesis of the rank sum test was rejected at the 5% level. Solid (dashed) contours in (c) denote westerly (easterly) direction.

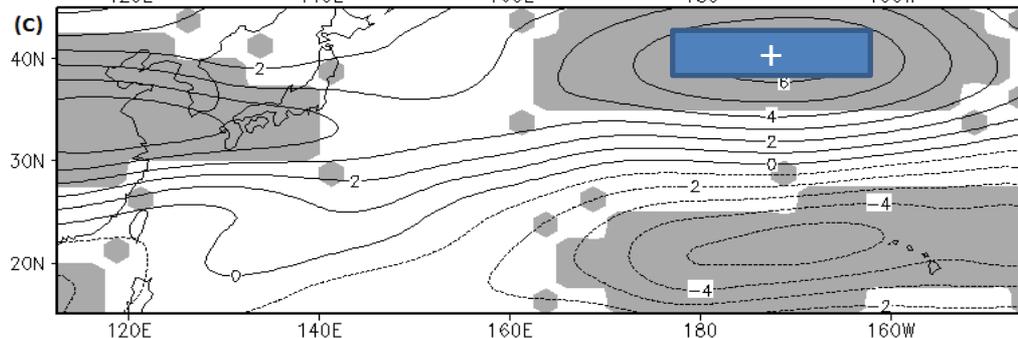
Upper  
troposphere



E1  
178W



E2  
170W



E2-E1

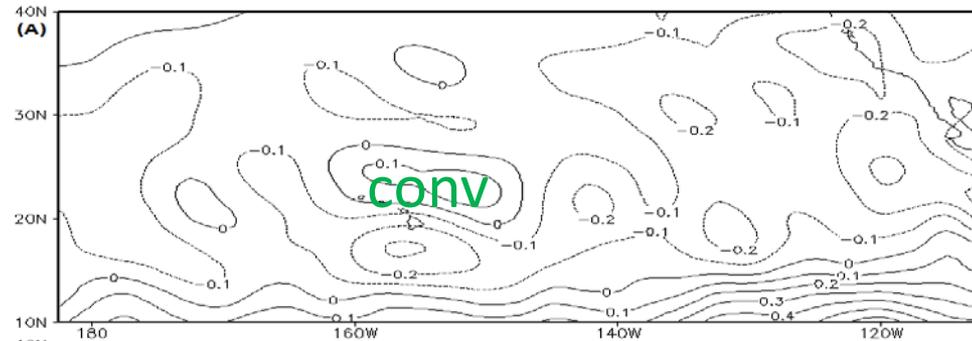
# Moisture Transport Analysis

$$\Delta \langle -\nabla \cdot (qV) \rangle = \Delta \langle -q(\nabla \cdot V) \rangle + \Delta \langle -V \cdot (\nabla q) \rangle,$$

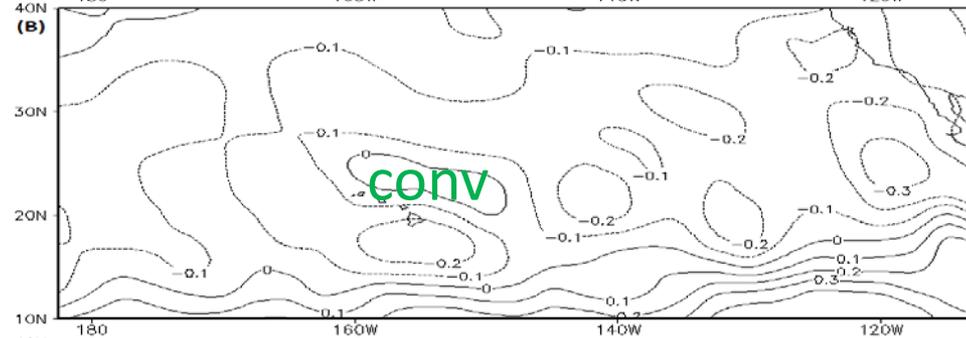
where  $q$  is specific humidity ( $\text{kg}[\text{kg}^{-1}]$ ),  $V$  is the horizontal vector wind,  $\langle \rangle$  indicates a vertical integration from 1000 to 300 hPa, and  $\nabla$  is the horizontal gradient operator. The operator  $\Delta$  represents the difference between epoch 2 and epoch 1 (E2 minus E1).

The first term on the right hand side of this equation indicates the effect of **moisture convergence**, while the second term is the contribution of horizontal **moisture advection** to the difference of **moisture flux** between the two epochs.

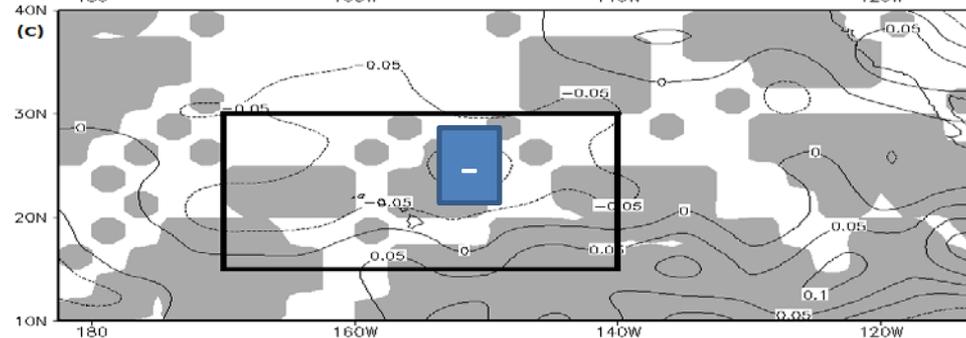
Moisture flux convergence during La Niña wet seasons. **Solid (dotted) contours denote moisture convergence (divergence)**. (c) Solid (dotted) contours denote where difference in seasonal mean moisture flux is positive (negative).



E1



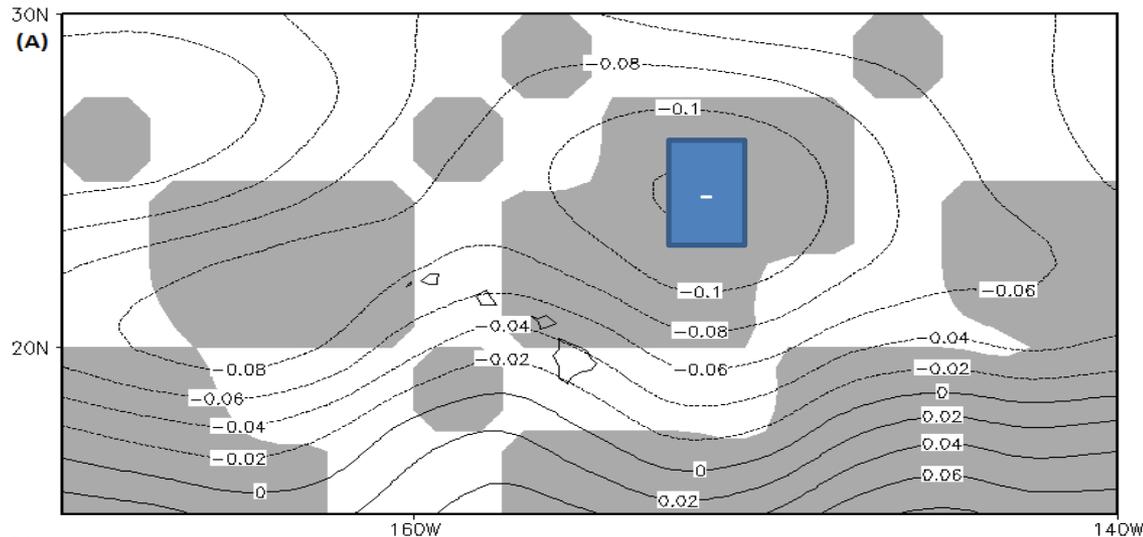
E2



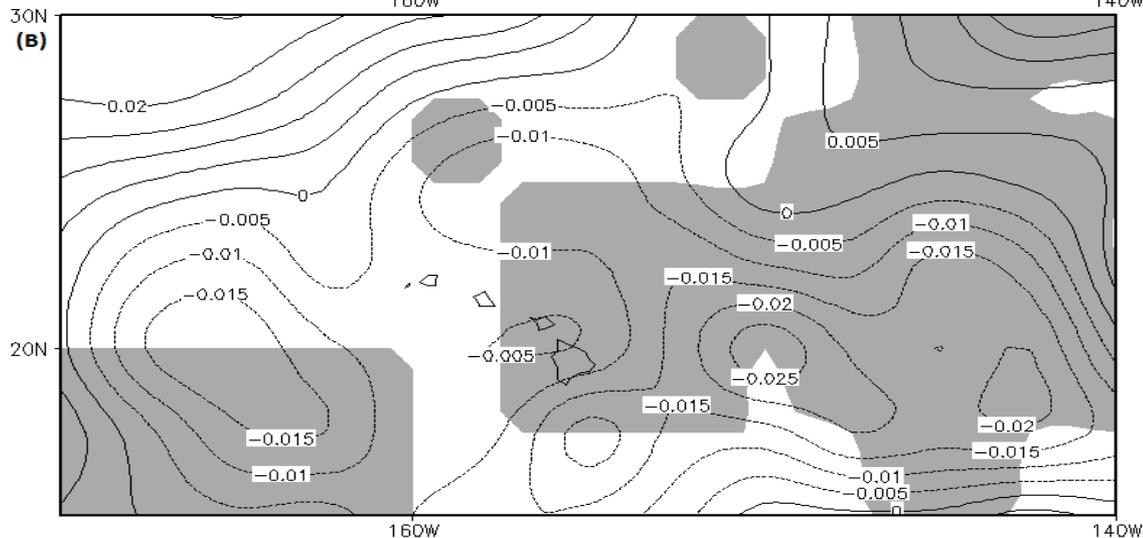
E2-E1

The domain of this analysis is depicted by the bold black box previously. The grey shaded area is where the null hypothesis was rejected at the 5% level.

Difference in  
moisture  
convergence



Difference in  
moisture  
advection



E2 - E1

- Because the **moisture convergence** is modulated by both the circulation and moisture variations, it is worthwhile to further examine the relative roles of **dynamic** and **thermodynamic** processes via the following equation

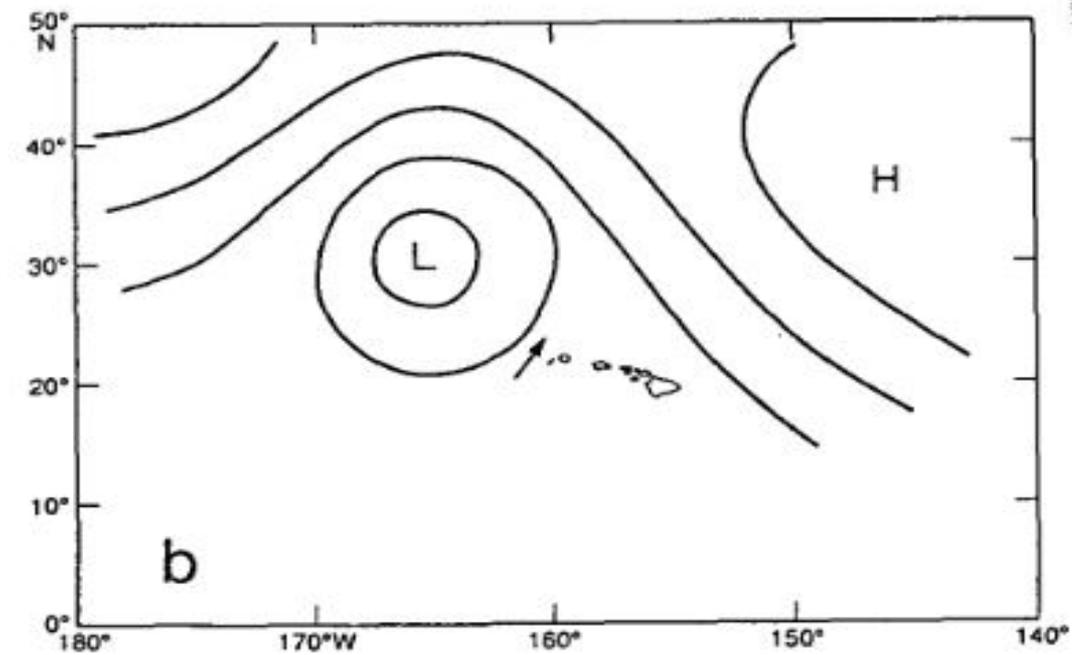
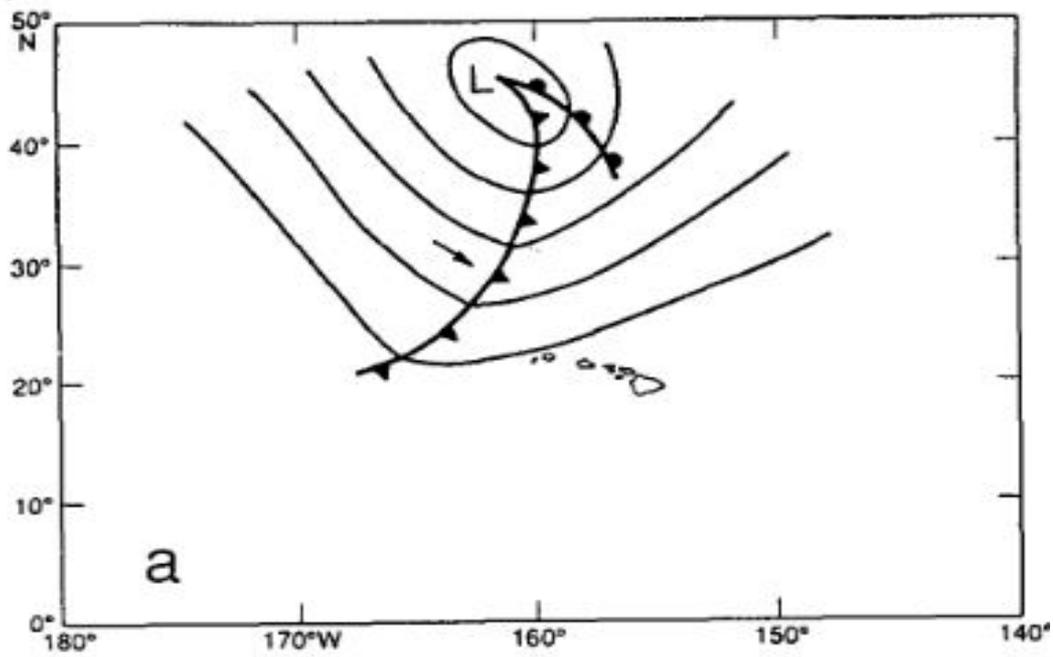
$$-\Delta\langle q * D \rangle = -\langle q * \Delta D \rangle - \langle \Delta q * D \rangle - \langle \Delta q * \Delta D \rangle,$$

where  $D$  is divergence ( $s^{-1}$ ). The first term on the right hand side of this equation is associated with the column-integrated circulation change, which can be regarded as a **dynamic** contributor. The second term involves the column-integrated change in water vapor content holding circulation fixed, thus reflecting the **thermodynamic** effect. The third term is a **nonlinear** term that includes the effect of both the column-integrated moisture and circulation changes.

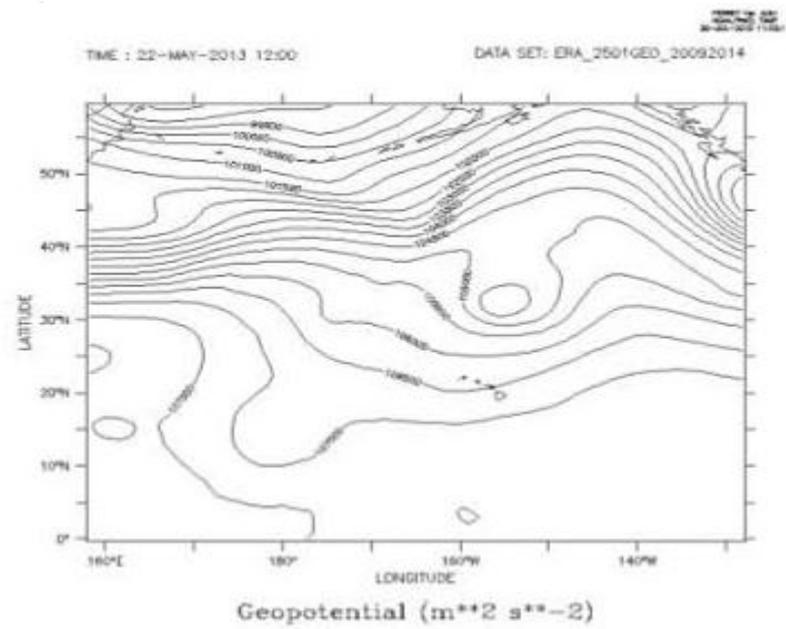
- We decompose the column-integrated moisture convergence term to examine the relative role of the dynamic effect (i.e., circulation change), thermodynamic effect (i.e., water vapor content change) and nonlinear effect (i.e., the combined influence of moisture and circulation).
- The difference in the **dynamic** effect is the primary contributor to the change in moisture transport surrounding Hawaii from E1 to E2.

18.5°-22.5°N  
159.5°-  
154.5°W

La Niña Wet Seasons	Midlatitude Fronts	Kona Lows	Upper-level Lows	Rainfall Anomaly
1956	15	3	2	0.16
1964	18	5	2	0.50
1970	11	6	8	1.26
1971	9	10	3	0.21
1973	17	5	7	0.90
1974	9	4	6	0.23
1975	14	5	6	0.27
1983	11	2	1	-0.93
1984	13	5	4	0.06
1988	14	3	2	1.70
1995	12	4	3	-0.02
1998	8	1	4	-0.39
1999	6	1	4	-0.81
2000	10	1	2	-0.83
2005	8	4	6	0.53
2007	12	3	6	0.06
2008	8	5	5	-0.11
2010	10	4	7	0.14
E1 AVG	13.3	5.4	4.9	0.50
E2 AVG	10.2	3.0	4.0	-0.05
(E2 – E1)	-3.1	-2.4	-0.9	-0.55
E2/E1	0.77 (23%↓)	0.56 (44%↓)	0.82 (18%↓)	-



1  
4  
2



Chu et al., 1993

# Summary

- Historically, Hawaii experienced low rainfall during El Nino events and abundant rainfall during La Nina events.
- A drying trend in Hawaii rainfall during La Nina years is evident. A change-point analysis determined that the shift occurs in 1983, forming 2 epochs (1956-1982 and 1983-2010).
- Tropical SSTs and circulation features in the North Pacific (e.g., Trenberth and Hurrell, 1994) have concurrently changed, thus possibly causing changes in La Nina year rainfall.
- The strengthening, and westward shifting of the eastern North Pacific subtropical high, coupled with the eastward elongation of the subtropical jet stream, are two main influences.

- Moisture transport analysis shows a reduction of moisture flux convergence in the Hawaii region during the second epoch. Changes in the circulation terms (i.e., dynamic effect) are found to be the primary driving force for the difference in moisture convergence surrounding Hawaii from E1 to E2.
- Additionally, a storm track analysis found fewer Kona lows and midlatitude fronts in the vicinity of Hawaii over the last 60 years. Decrease in these kinds of rain-bearing systems contributes mainly to a decline in La Nina rainfall since 1983.

# References

- Chu, P.-S., 1995: Hawaii rainfall anomalies and El Niño. *J. Climate*, 8, 1697-1703.
- Chu, P.-S. and H. Chen, 2005: Interannual and interdecadal rainfall variability in the Hawaiian Islands. *J. Climate*, 18, 4796-4813.
- Chu, P.-S., A.J. Nash, and F. Porter, 1993: Diagnostic studies of two contrasting rainfall episodes in Hawaii: Dry 1981 and wet 1982. *J. Climate*, 6, 1457-1462.
- O'Conner, C., P.-S. Chu, P.-C. Hsu, and K. Kodama, 2015: Variability of Hawaiian winter rainfall during La Nina events since 1956. *J. Climate*, 28, 7809-7823.