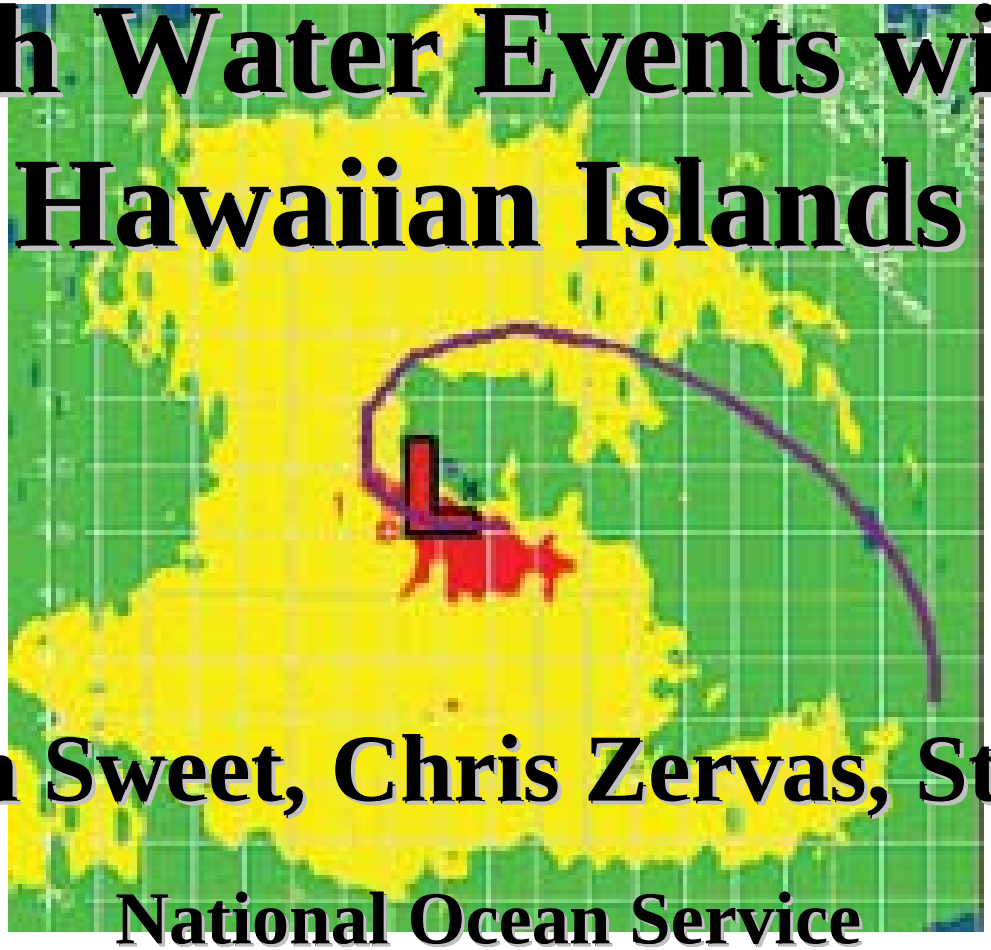
Seasonal Variability of Non-tidal and High Water Events within the Hawaiian Islands

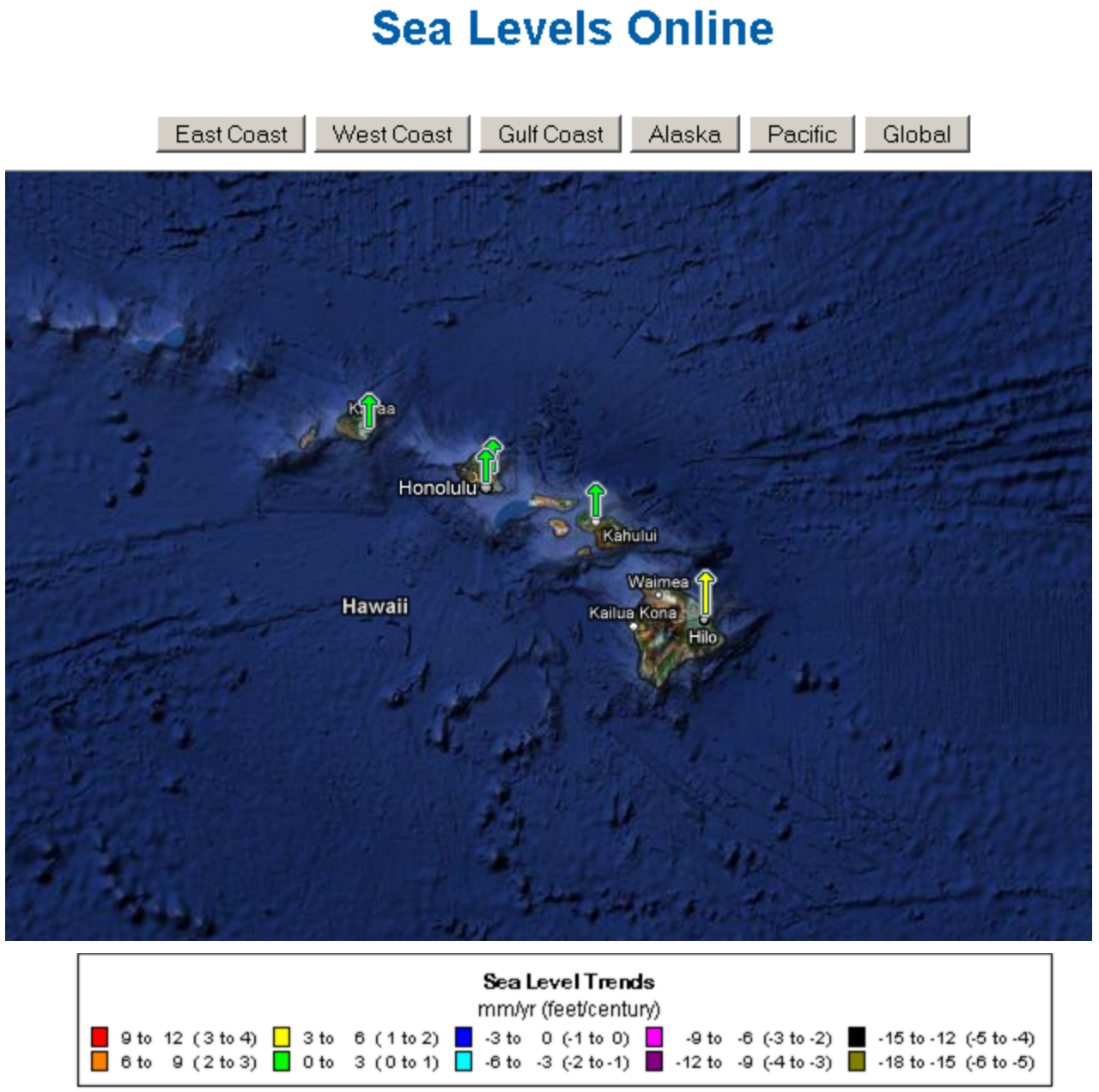


William Sweet, Chris Zervas, Steve Gill

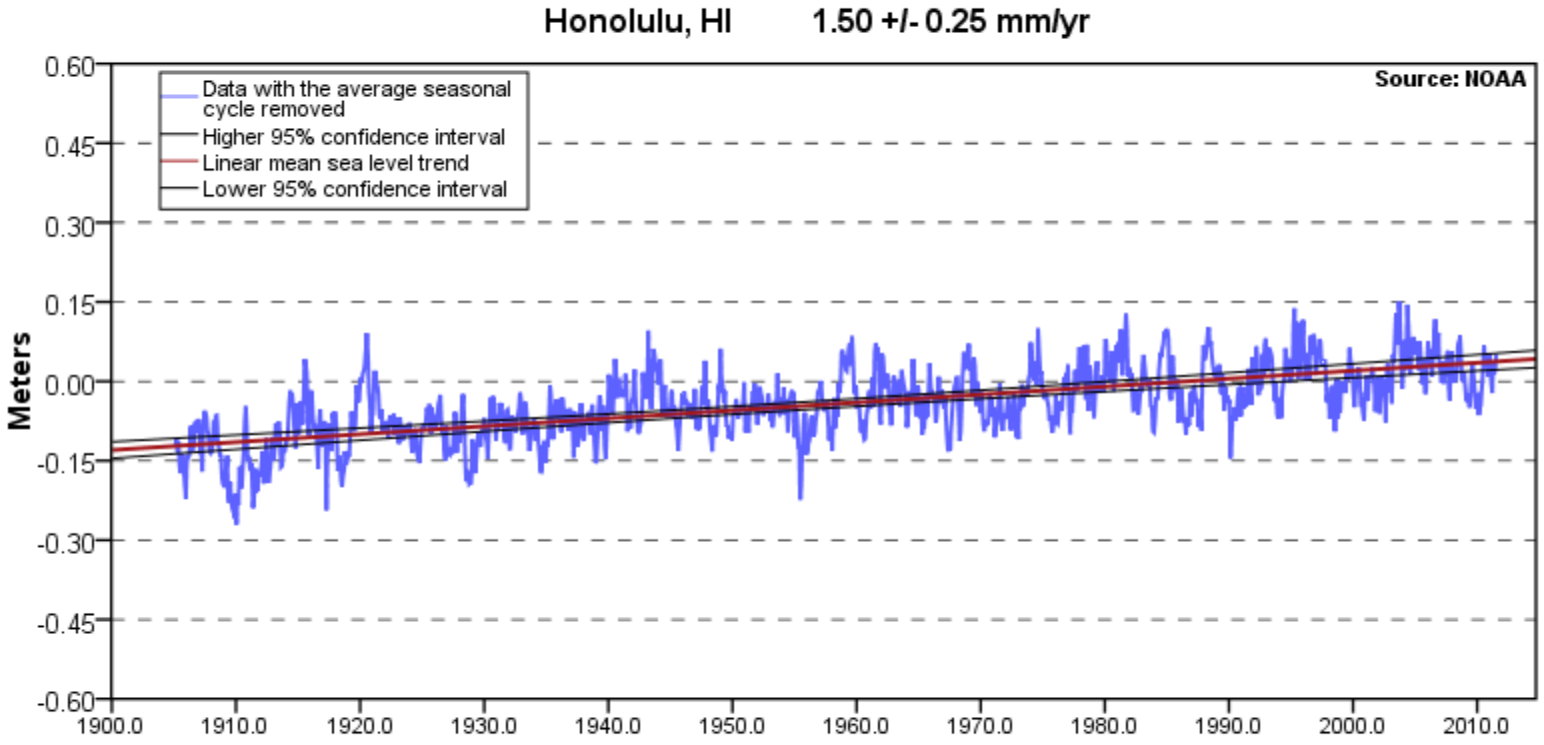
National Ocean Service

National Oceanic and Atmospheric Administration

NOAA tracks long-term changes to relative sea level



Mean Sea Level Trend
1612340 Honolulu, Hawaii



The mean sea level trend is 1.50 millimeters/year with a 95% confidence interval of +/- 0.25 mm/yr based on monthly mean sea level data from 1905 to 2006 which is equivalent to a change of 0.49 feet in 100 years.

Long-term SL change has primarily driven changes in extreme, short-term variability

(Menendez and Woodworth, 2010).

It’s important to recognize patterns of this variability and its related physical forcing to suppose possible future conditions.

This presentation:

1.Climatology of daily and hourly extreme (99%) levels: observations, tidal predictions and non-tidal residuals

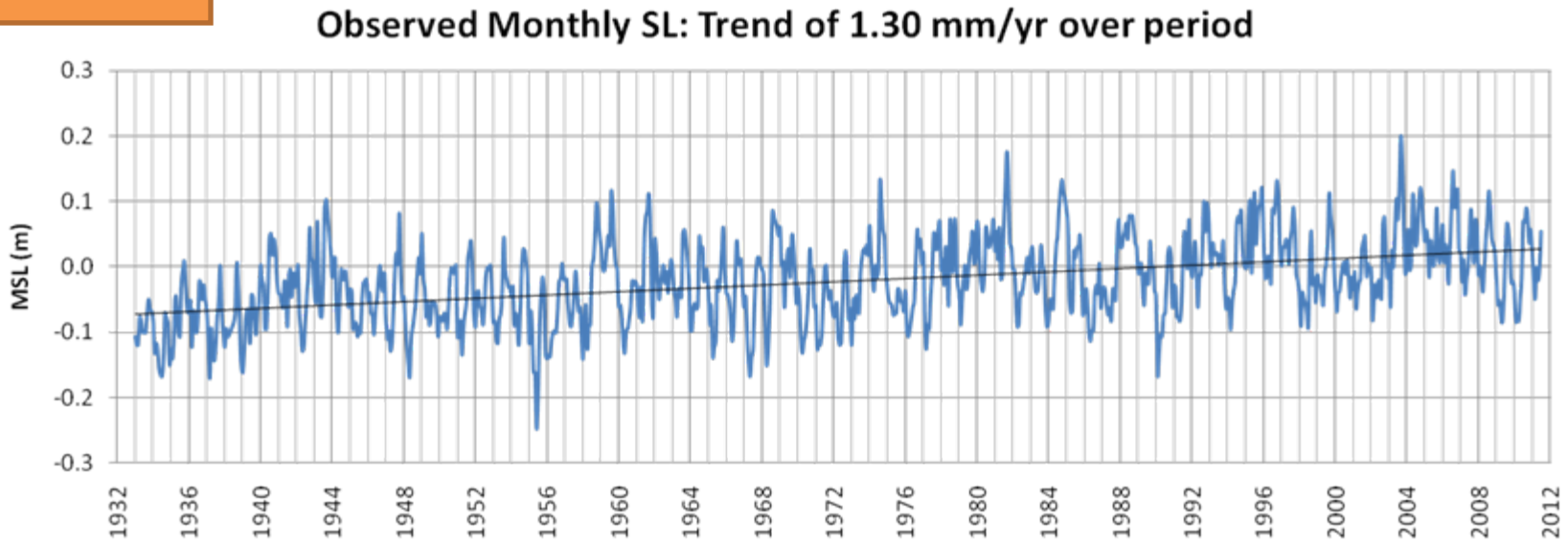
2. Physical forcing and climatic patterns associated with the climatologies

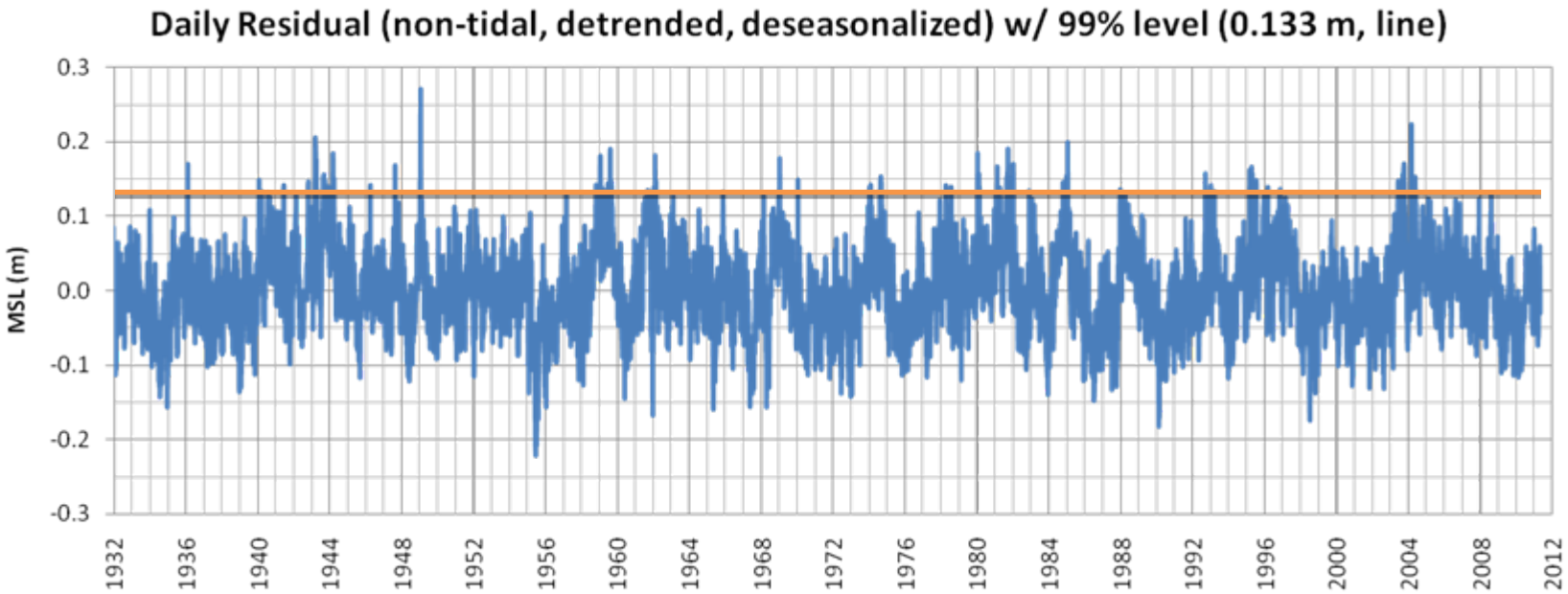
3. High resolution ‘snapshots’ of notable examples

4. Tide-gauge calibration of near-shore wave-buoy record to provide an estimate of wave climatology

5. Comparison of records to ‘storm damage reports’

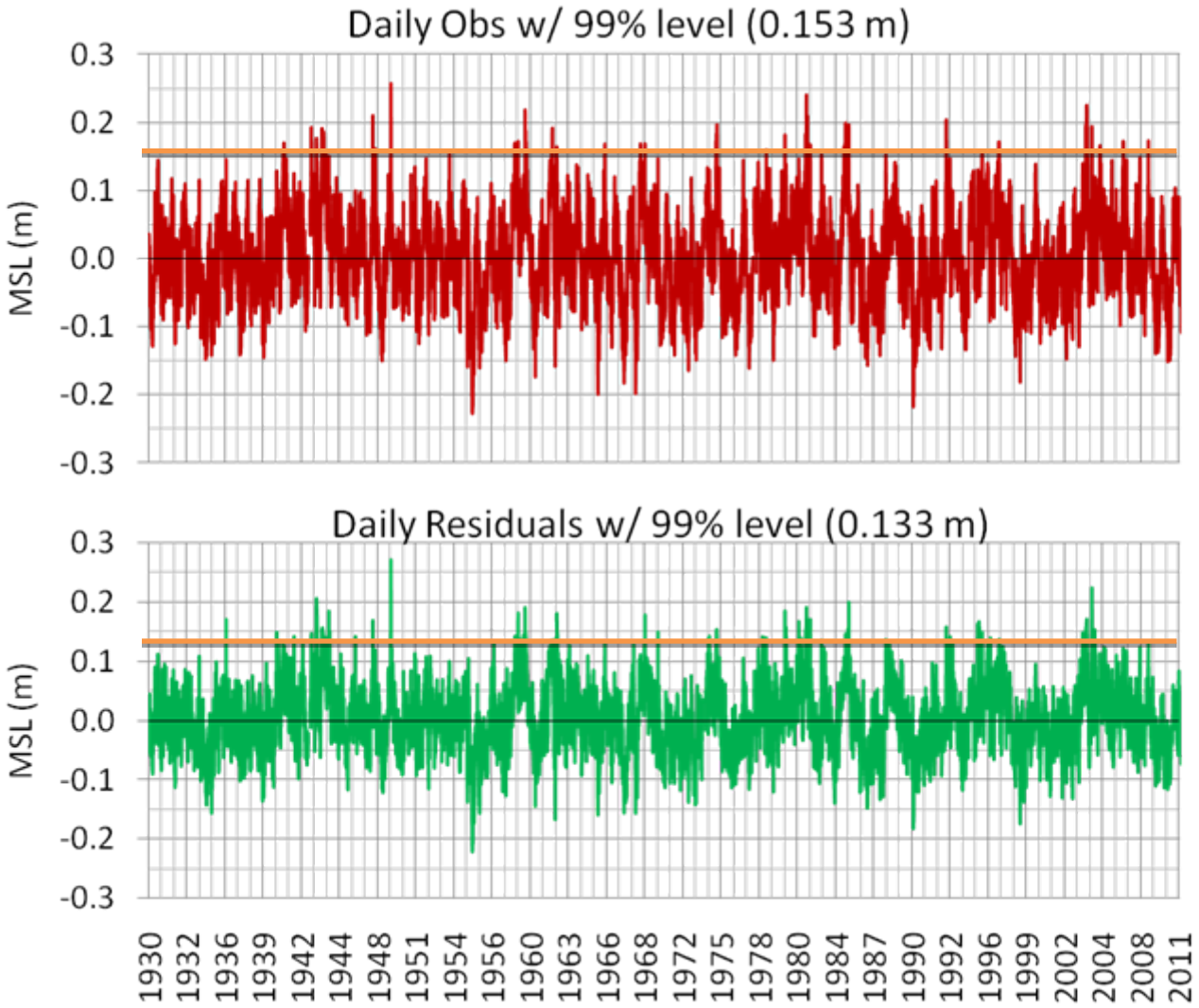
Honolulu


Observed Monthly SL: Trend of 1.30 mm/yr over period
MSL (m)
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
1932
1936
1940
1944
1948
1952
1956
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
2004
2008
2012

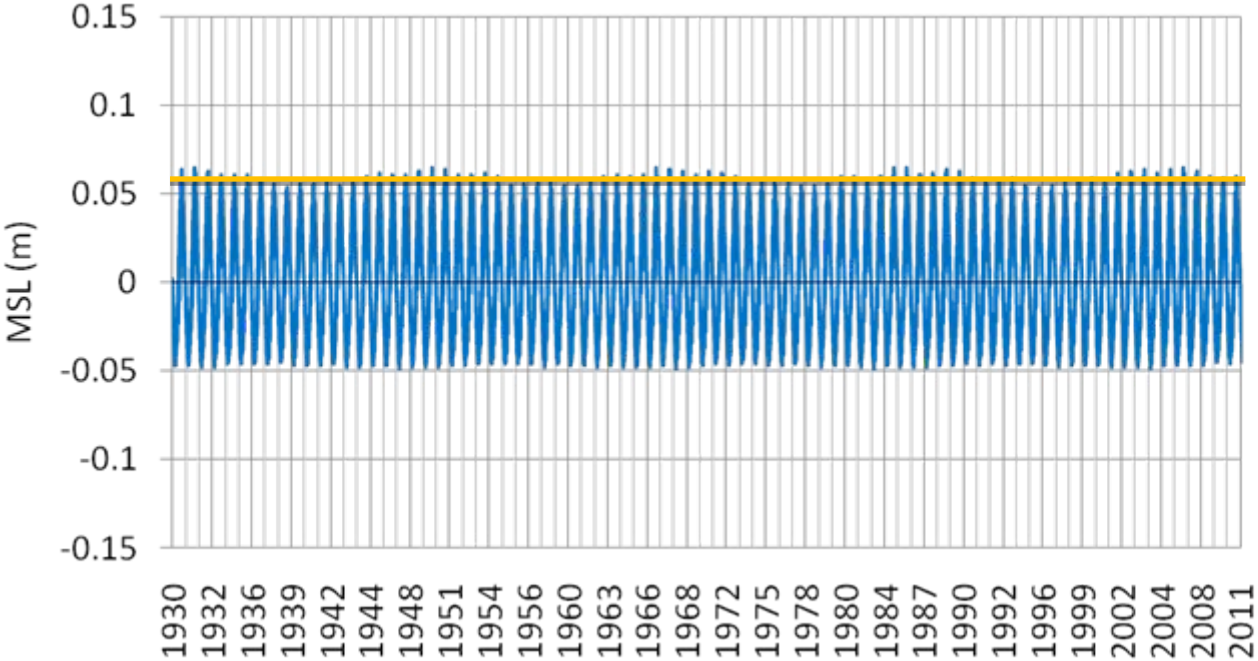

Daily Residual (non-tidal, detrended, deseasonalized) w/ 99% level (0.133 m, line)
MSL (m)
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
1932
1936
1940
1944
1948
1952
1956
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
2004
2008
2012

Daily mean observations are highly correlated to daily residuals (r^2=0.77)

Most of observation w/out semi/diurnal tide is residual

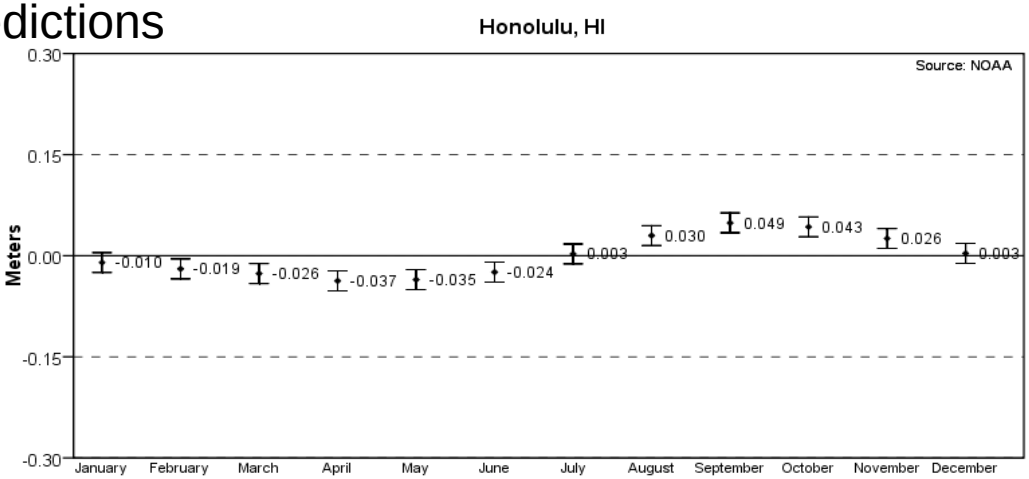


Honolulu Daily Mean Tide w/ 99% level (0.057 m)



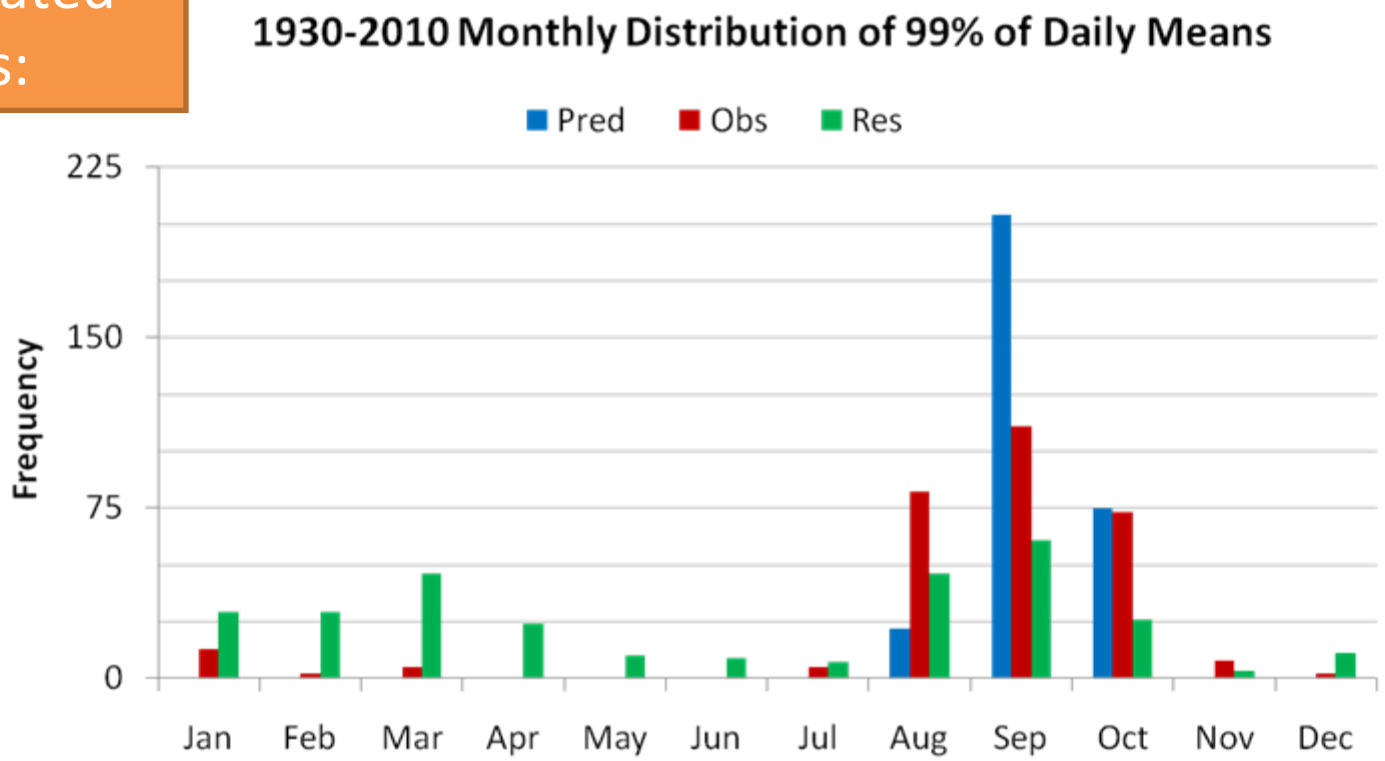
~19 yr
Metonic Cycle

Mean Seasonal Cycle incorporated into Tide Predictions



Daily mean tide highest in fall

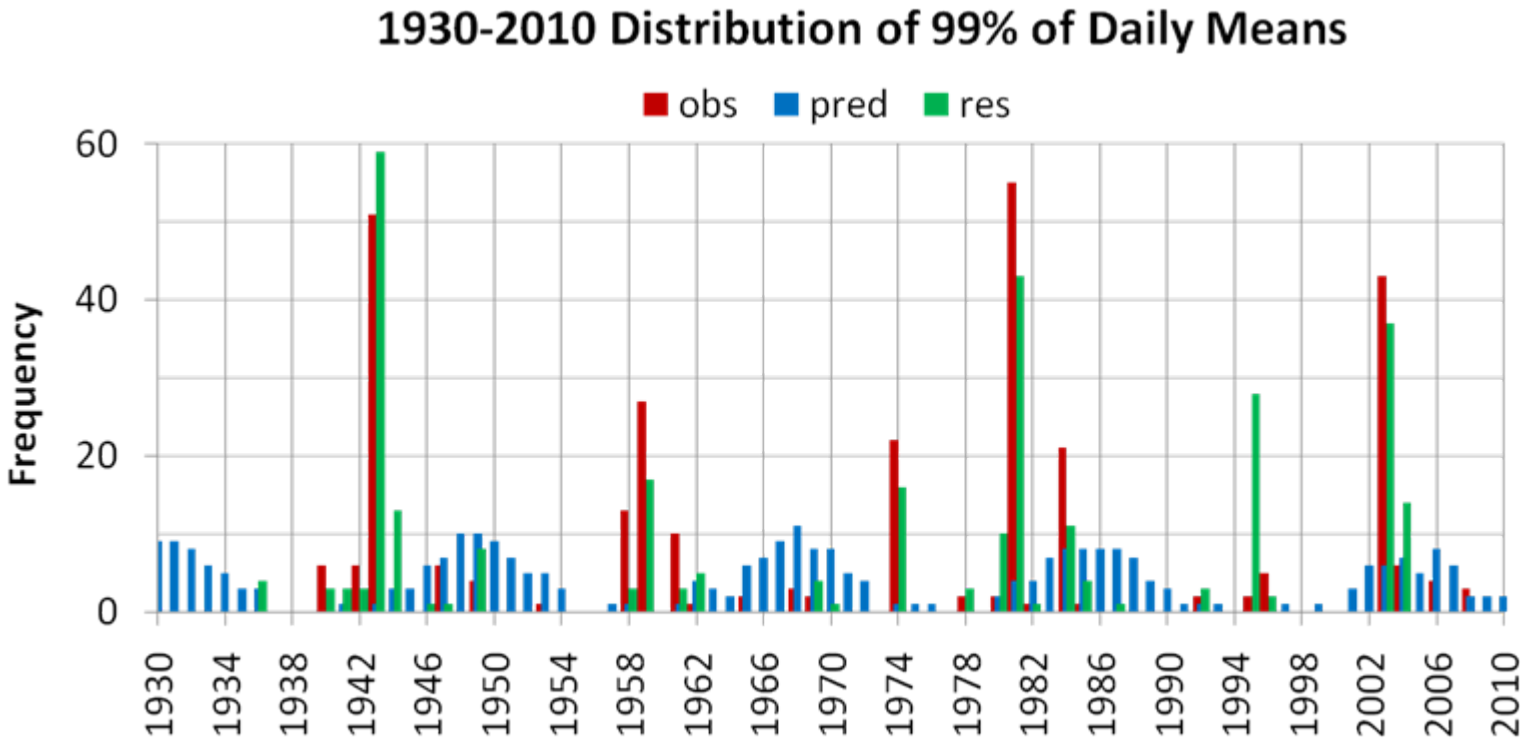
Not separated as “Events:



1. Highest instances of tide in fall (seasonal cycle)

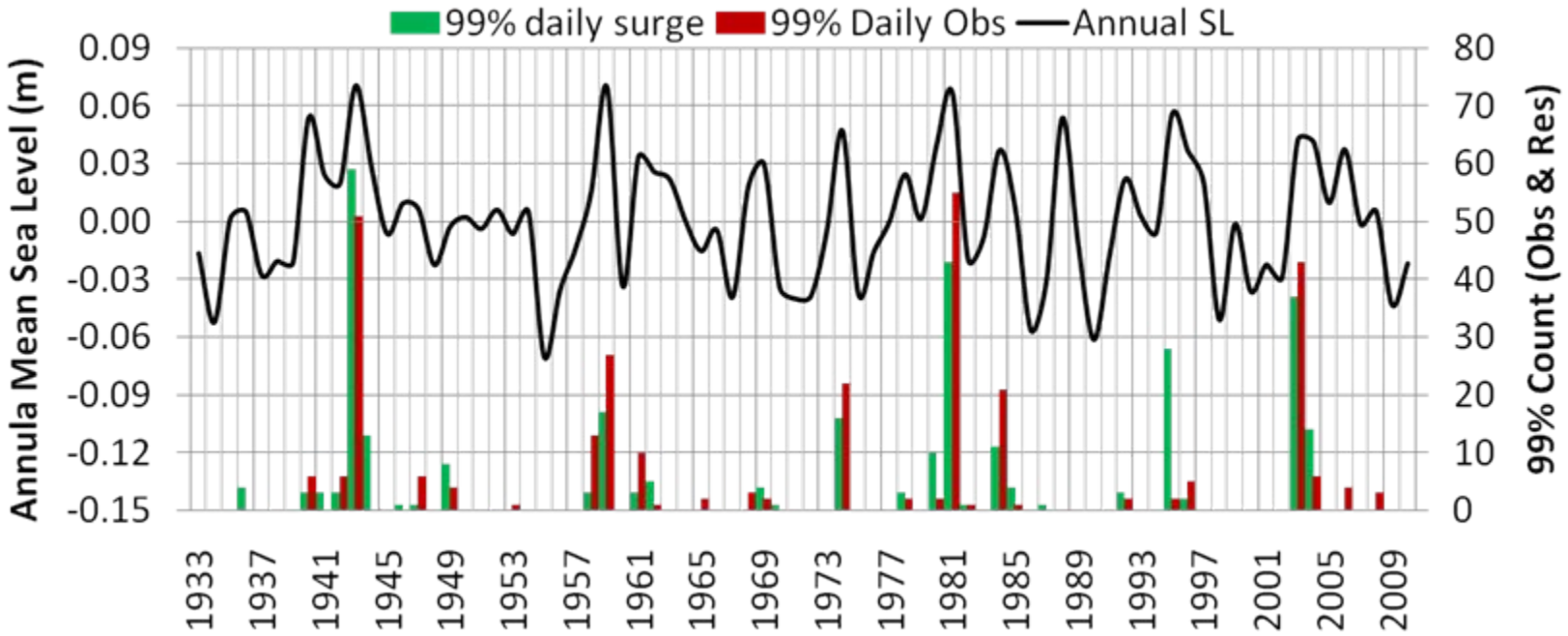
2. High number of observations in fall

3. Residuals high in fall and spring

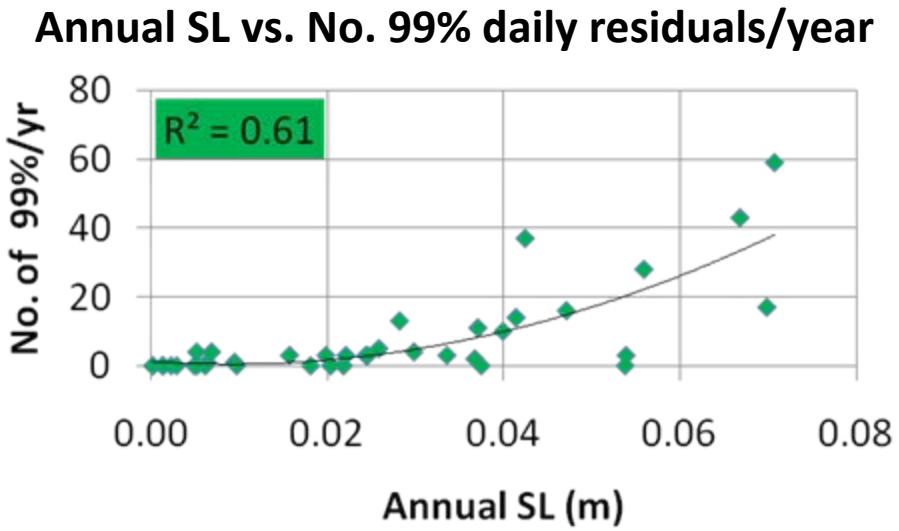


1. Co-variation between Obs/Res

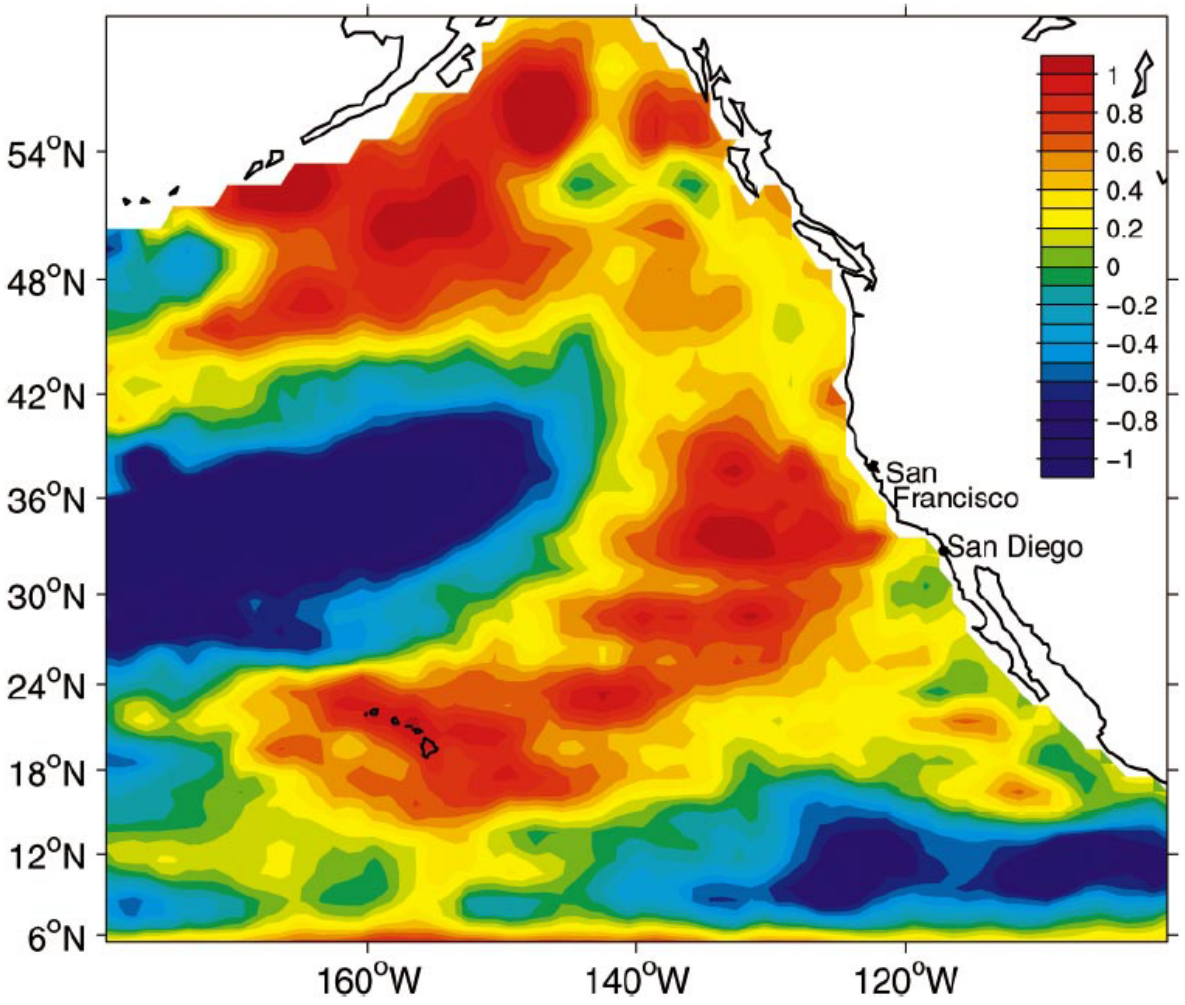
2. Periodicity between clumps of events



Honolulu: Inter-annual variability of SL and 99% Obs/Res instances



Correlation between annual SL and number of days w/ residual at or above 99% levels



Synchronized SSH pattern of ‘horseshoe’ is in response to thermal changes of ~upper 500 m of water column

Regression (zero lag) of annual sea surface height anomaly on Hawaii sea level (EOF Mode 1).

(Fig 3 of Firing et al., 2004; J. of Phys. Ocean)

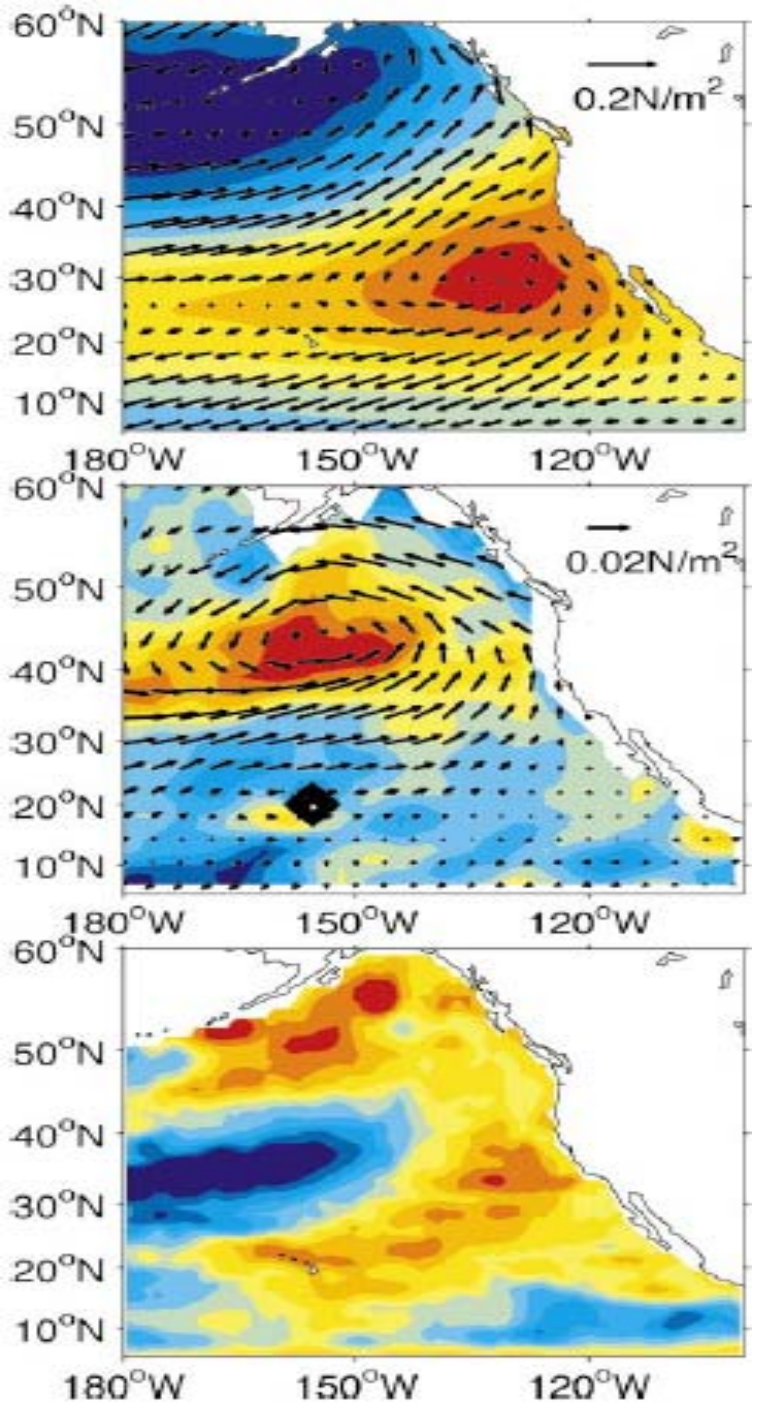
Annual composites for high Hawaii SL:

(top): winter wind stress and sea level pressure
** *deepened Aleutian L* **

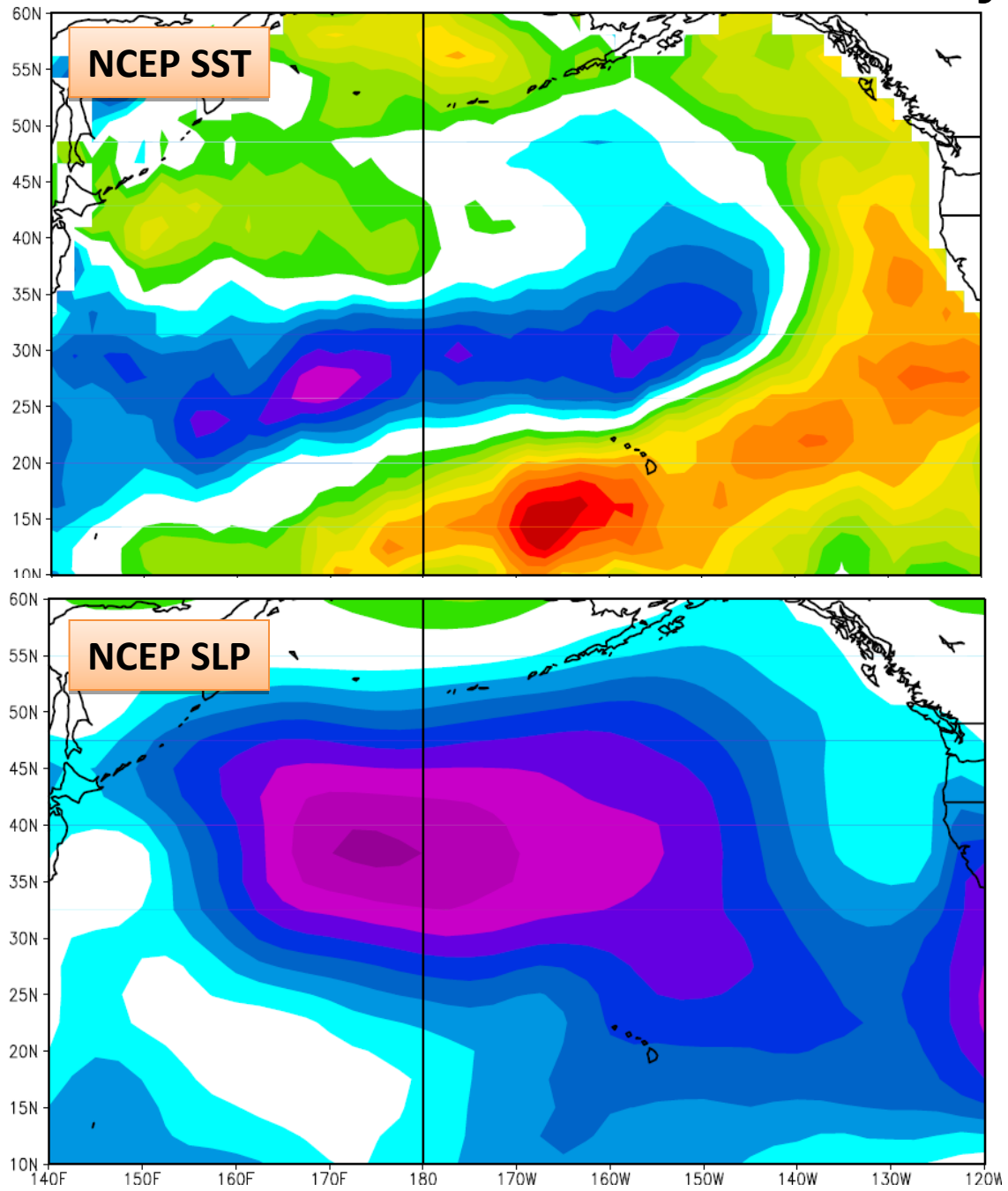
(middle): winter wind stress anomaly and wind stress curl anomaly
** + *wind curl anomaly to north* **

(bottom): SSH
** >*SSH w/in horseshoe* **

(Figure 8, Firing et al., 2004)



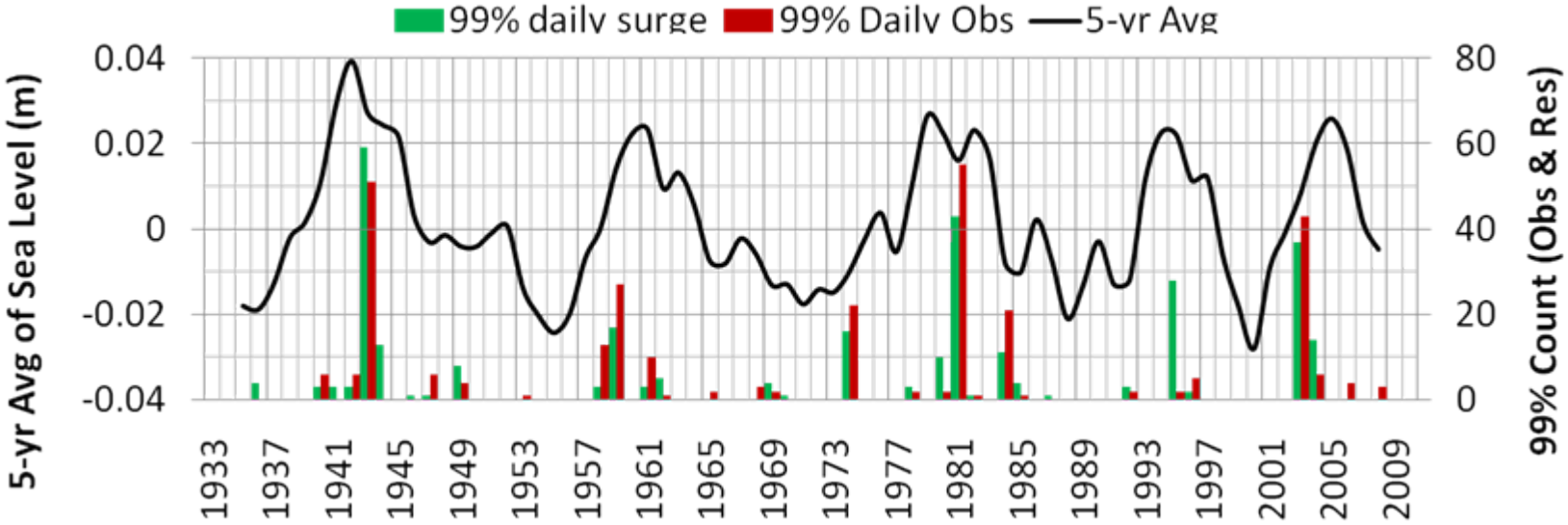
1948-2010 Annual Count of 99% Daily Residuals at Honolulu correlated with:



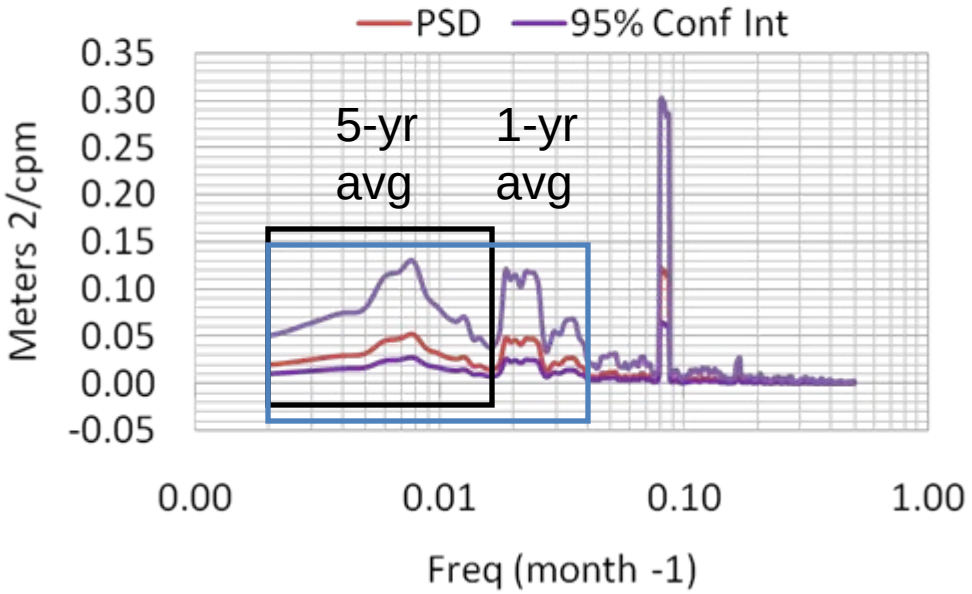
SST
a proxy for dynamic height

SLP

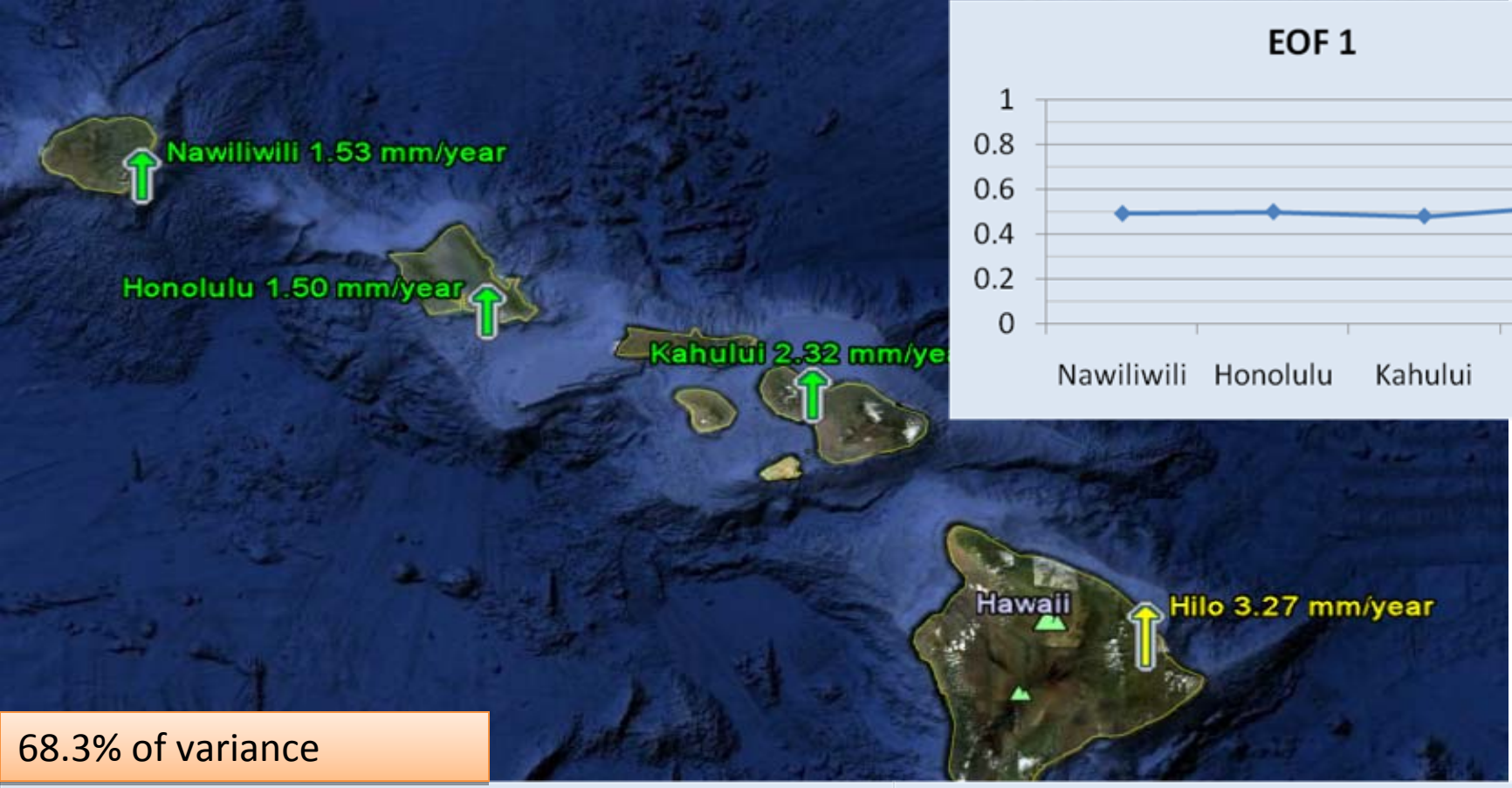
- Aleutian low deepens
- Positive wind curl anomaly
- Counteracting the N. Pacific gyre / Ekman downwelling w/in ‘horseshoe’



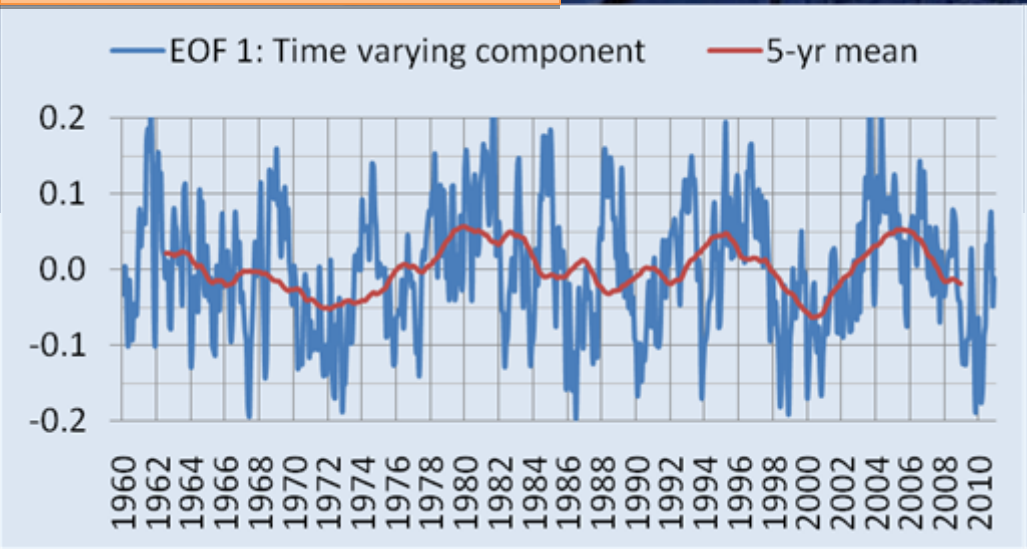
Honolulu Spectral Density of Monthly SL
(detrended w/seasons)

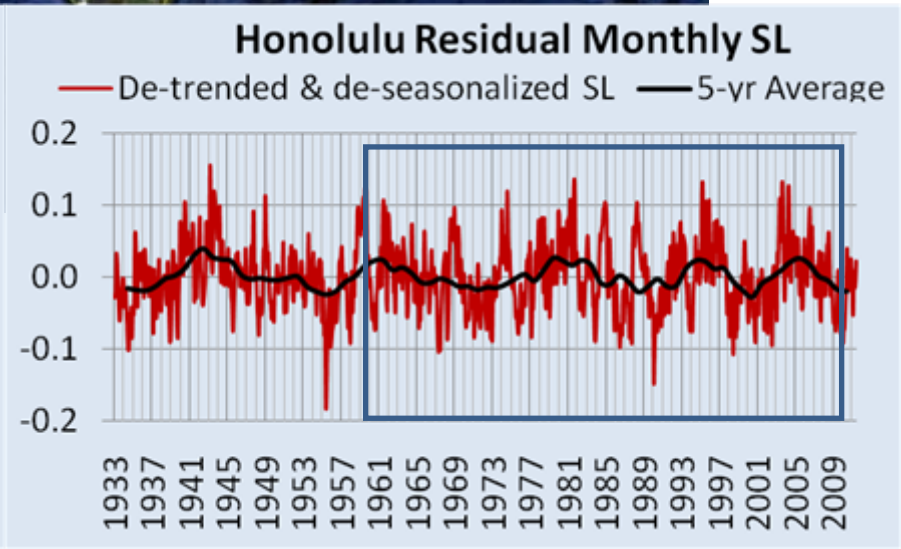


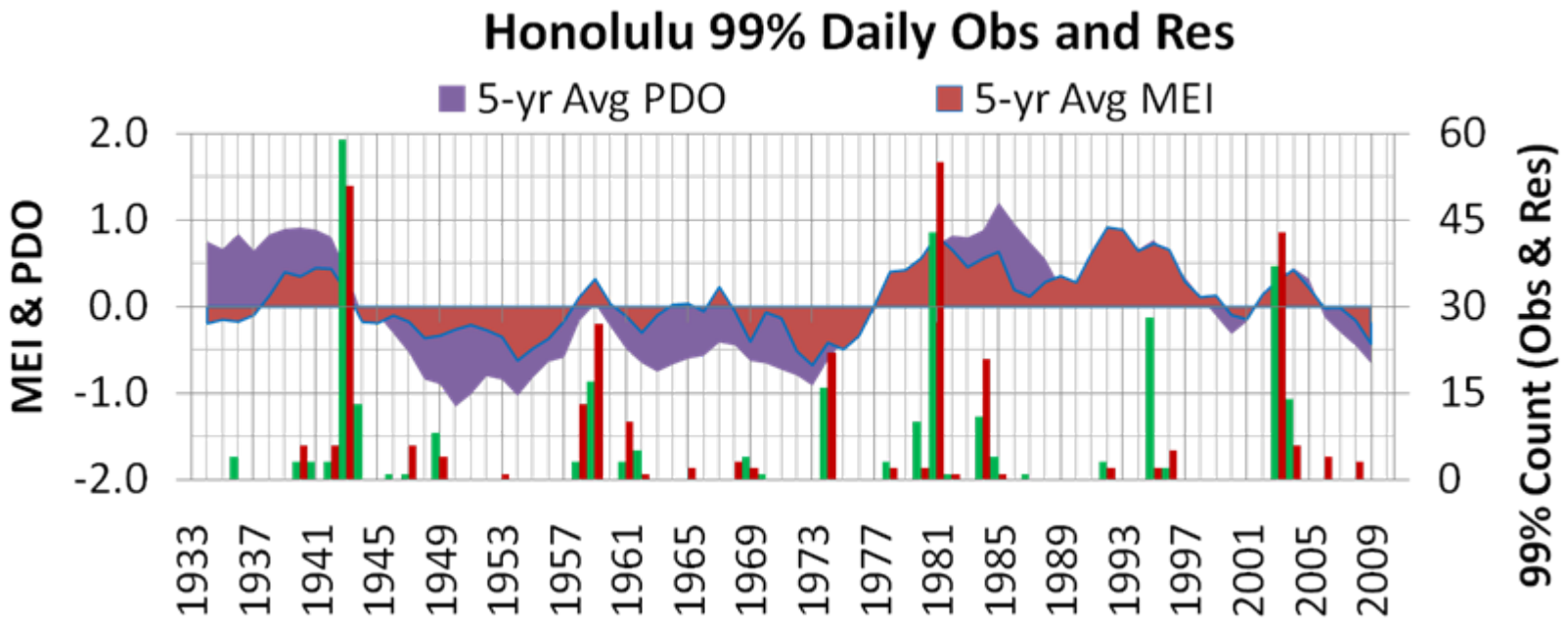
What is behind this decadal-scale variability in mean SL and related instances of daily levels at the 99% level?



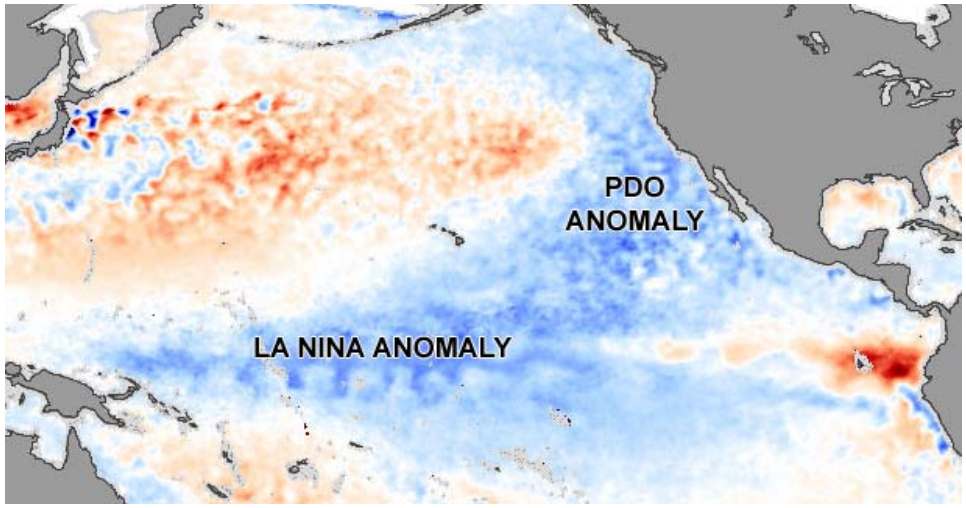
68.3% of variance

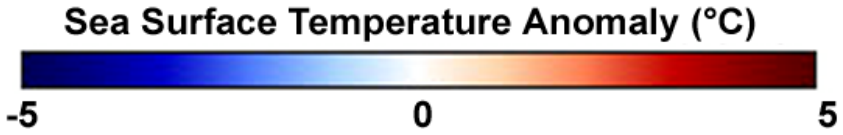




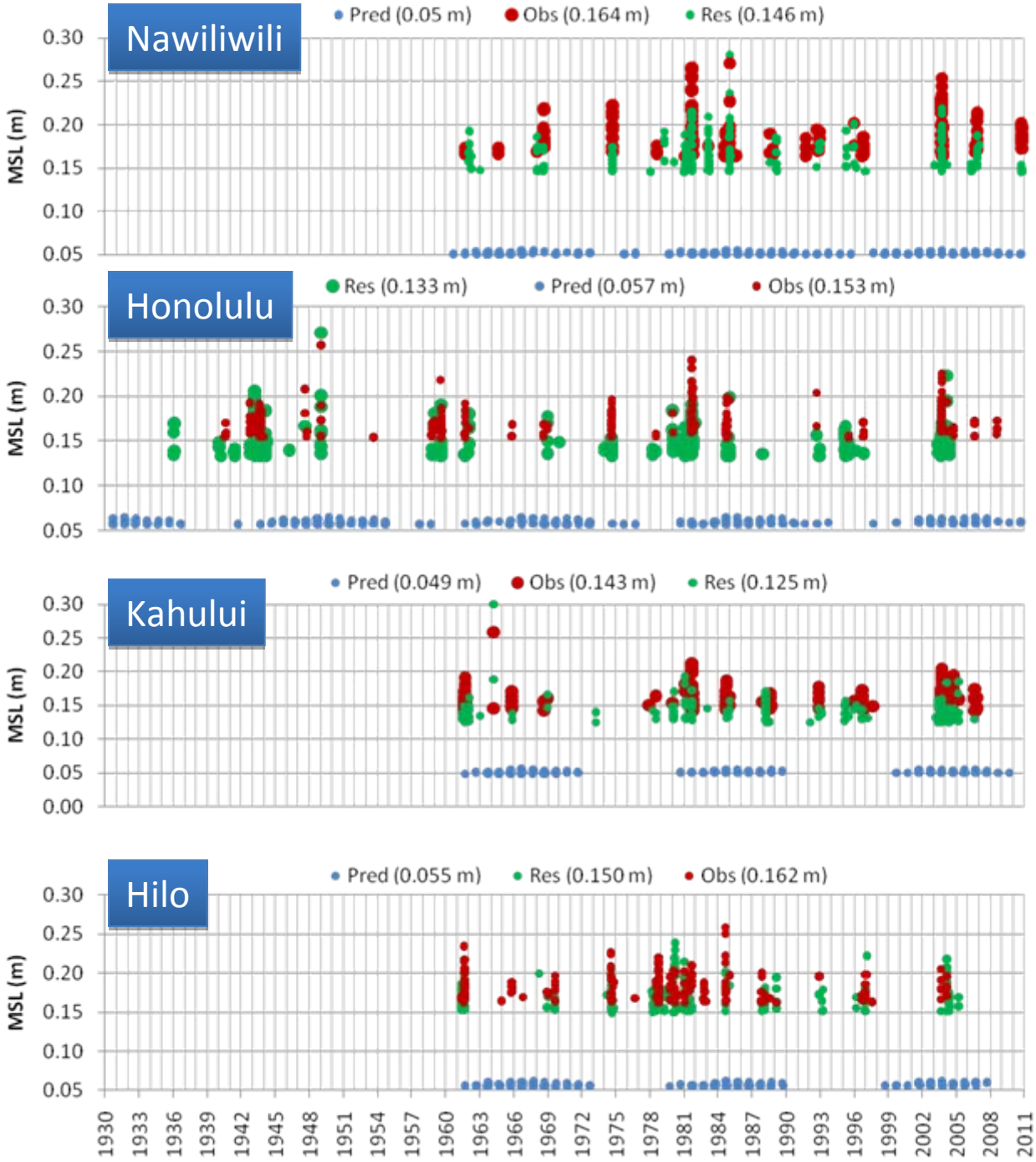


Hawaii: Decadal variability SL and 99% Obs/Res instances



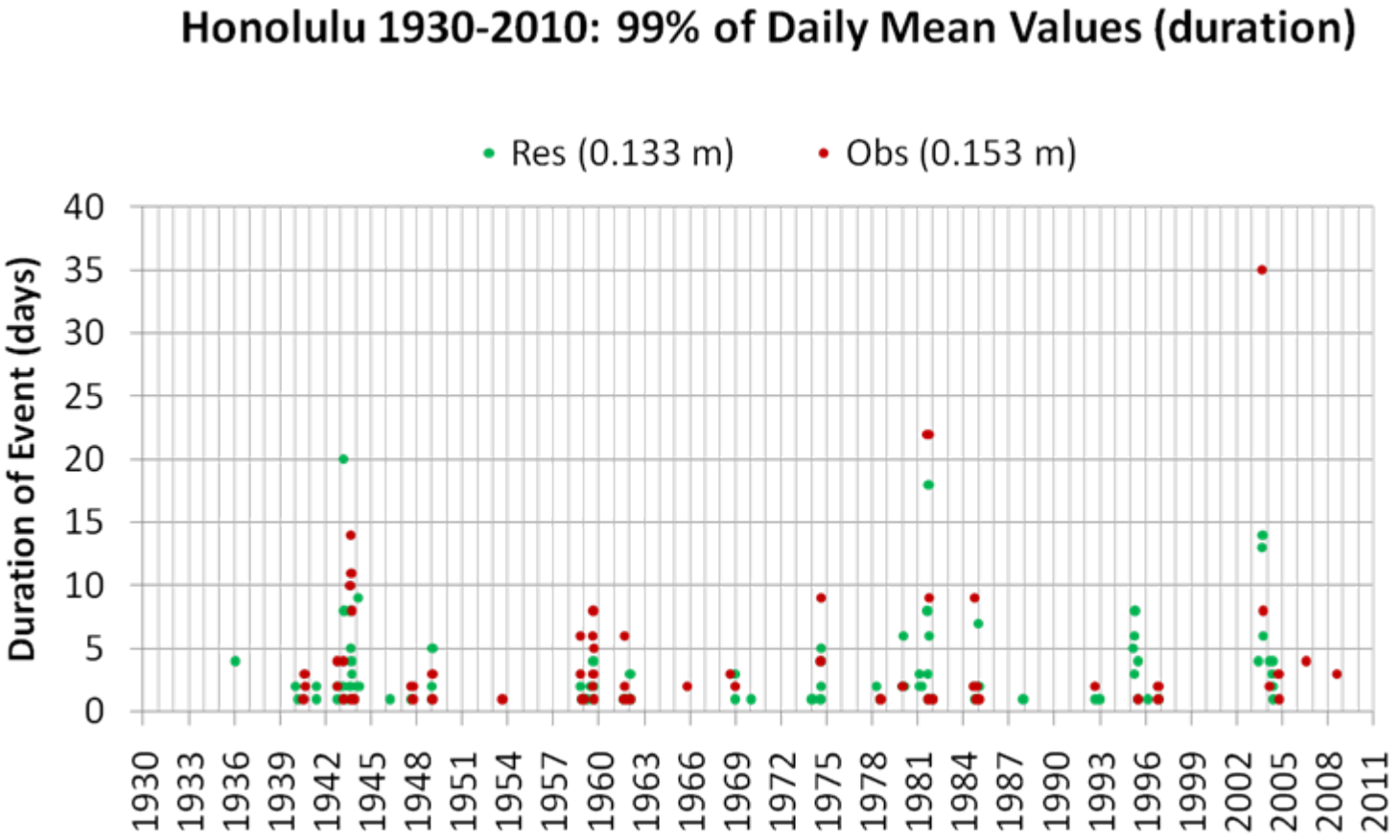


Responds to PDO/ENSO(MEI) forcing of tropics and teleconnected forcing w/in the North Pacific.



Similar to coherent monthly SL series are the 99% of daily Obs/Res

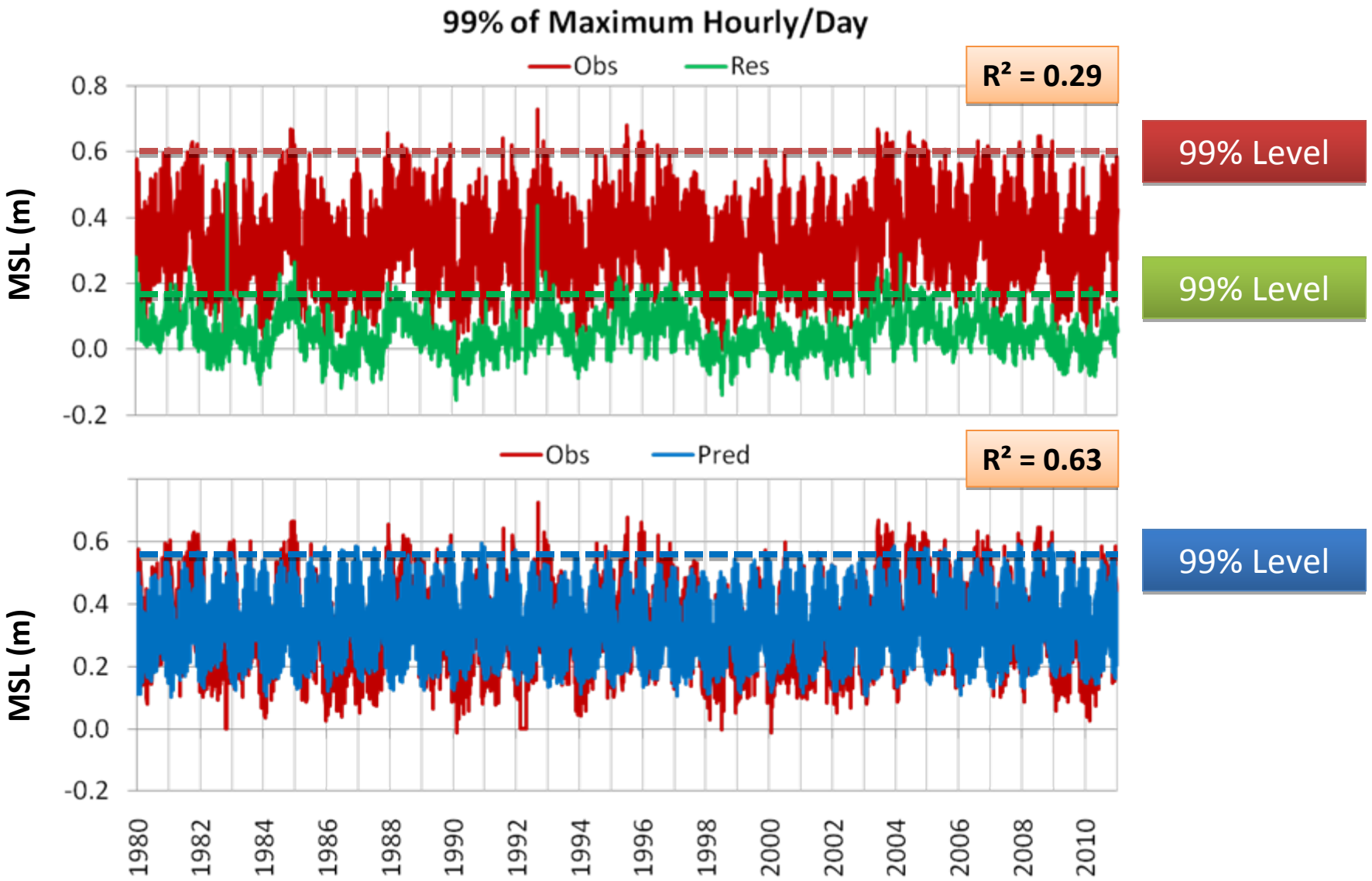
Daily values not separated by ‘events’ to give sense of duration of certain types of forcing.



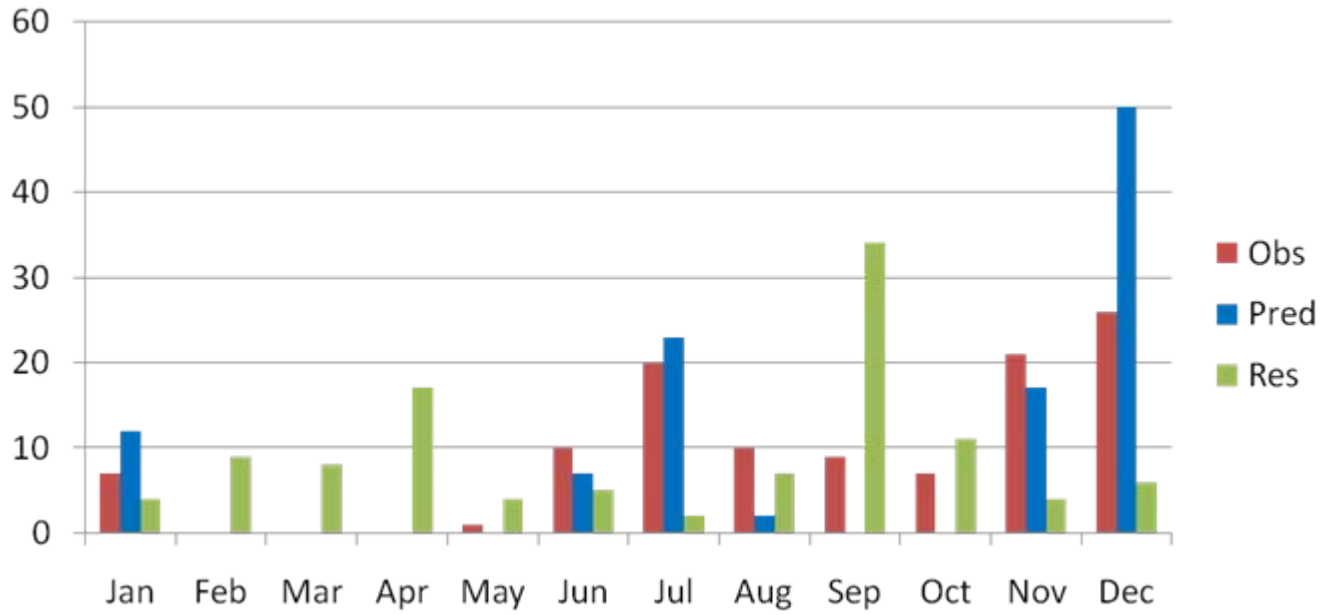
In terms of the duration, multiple 10+ day events.

Duration gives some insight as to forcing processes

1980 – 2010 Hourly Values



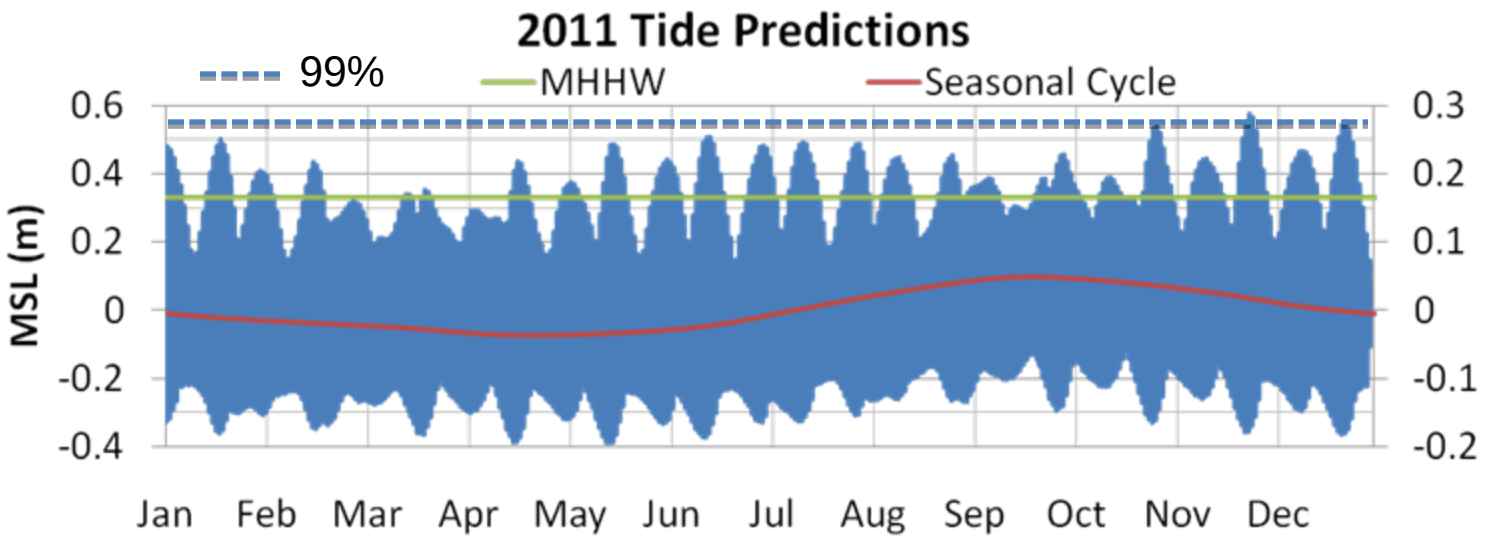
Monthly distribution of hourly 99% of 1980-2010 period

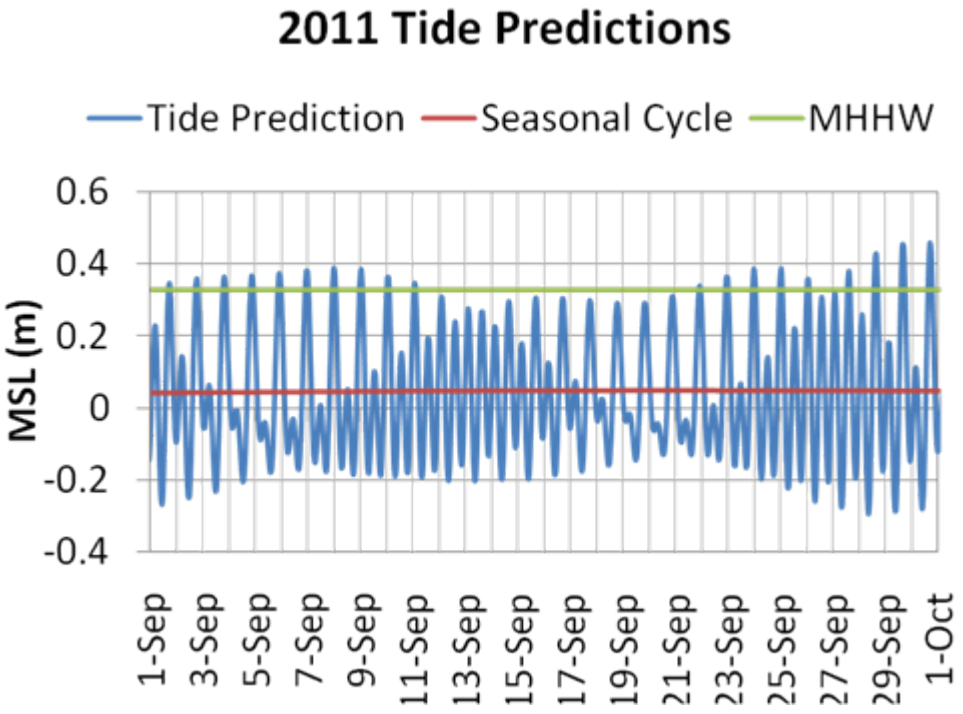


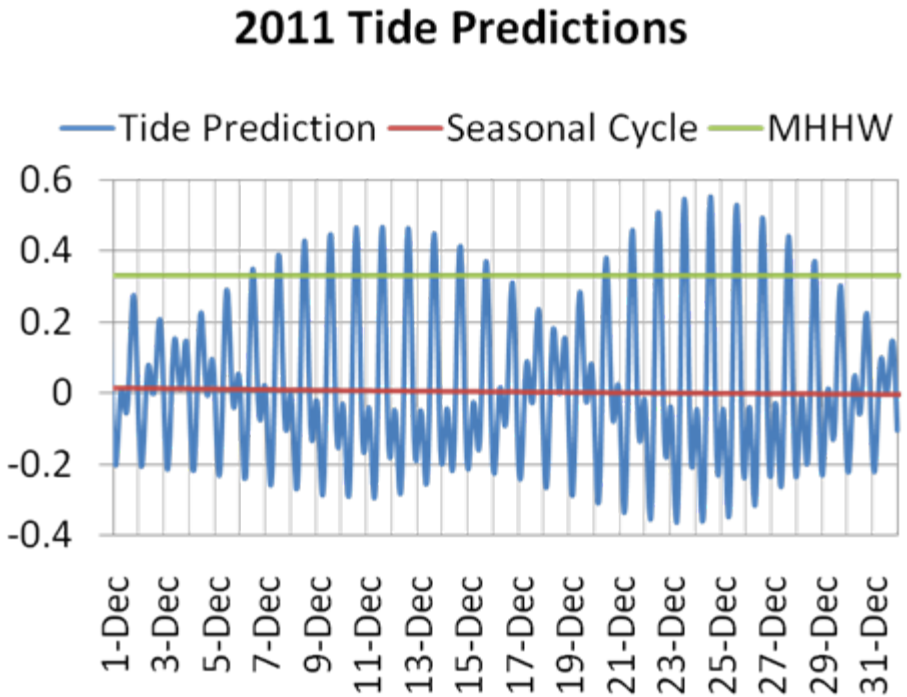
1. Highest instances of tide Jun/Jul and Nov-Jan
   - Solstitial driven (Merrifield et al., 2008)

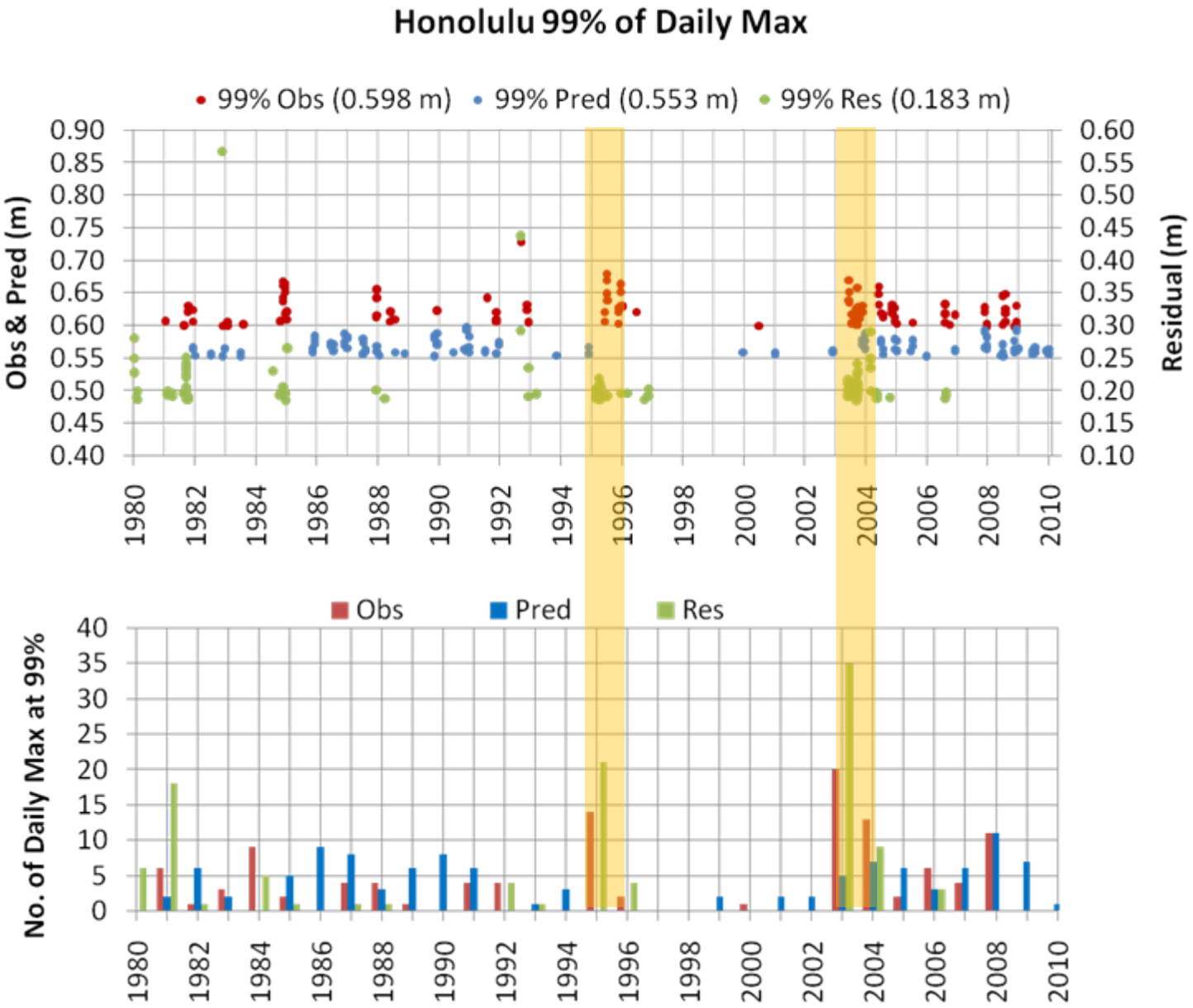
2. High number of observations during (1) tides and when high (3) residuals

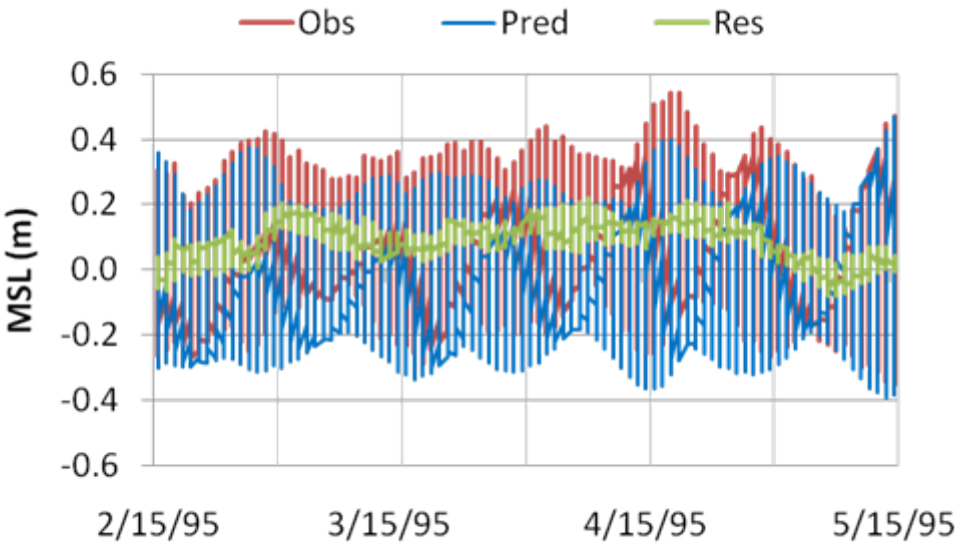
3. Residuals high in fall and spring


2011 Tide Predictions
99%
MHHW
Seasonal Cycle
MSL (m)
0.6
0.4
0.2
0
-0.2
-0.4
0.3
0.2
0.1
0
-0.1
-0.2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


2011 Tide Predictions
Tide Prediction
Seasonal Cycle
MHHW
MSL (m)
0.6
0.4
0.2
0
-0.2
-0.4
1-Sep
3-Sep
5-Sep
7-Sep
9-Sep
11-Sep
13-Sep
15-Sep
17-Sep
19-Sep
21-Sep
23-Sep
25-Sep
27-Sep
29-Sep
1-Oct

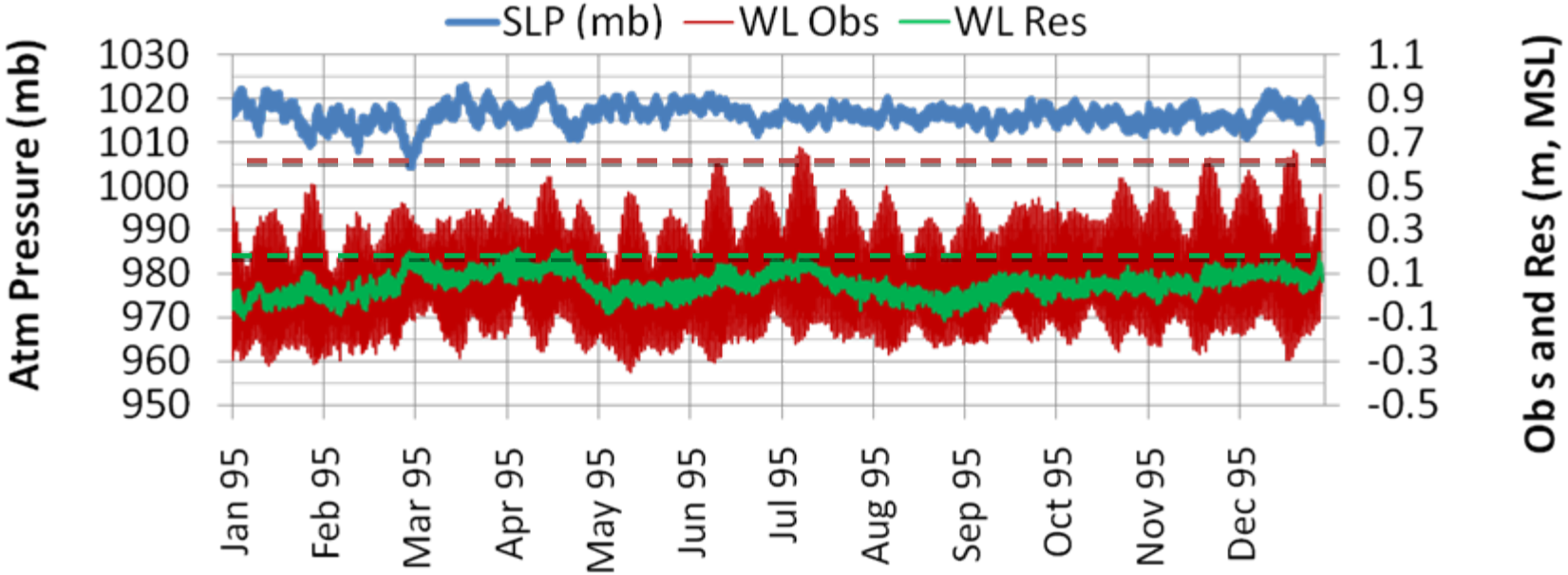

2011 Tide Predictions
Tide Prediction
Seasonal Cycle
MHHW
0.6
0.4
0.2
0
-0.2
-0.4
1-Dec
3-Dec
5-Dec
7-Dec
9-Dec
11-Dec
13-Dec
15-Dec
17-Dec
19-Dec
21-Dec
23-Dec
25-Dec
27-Dec
29-Dec
31-Dec


Honolulu 99% of Daily Max
99% Obs (0.598 m)
99% Pred (0.553 m)
99% Res (0.183 m)
Obs & Pred (m)
Residual (m)
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
Obs
Pred
Res
No. of Daily Max at 99%
40
35
30
25
20
15
10
5
0



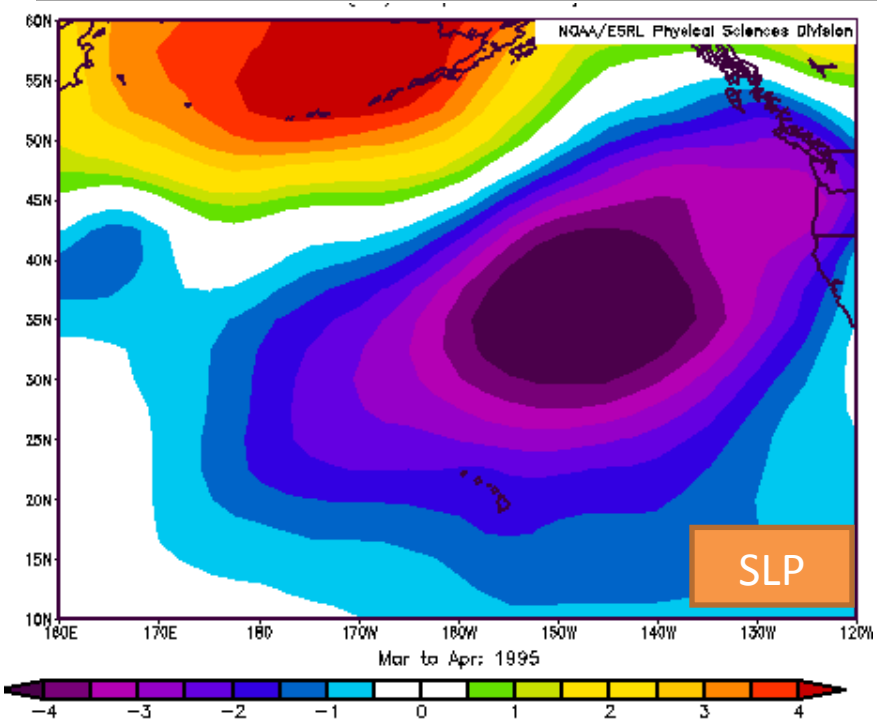
Feb – Apr 1995
"Event"

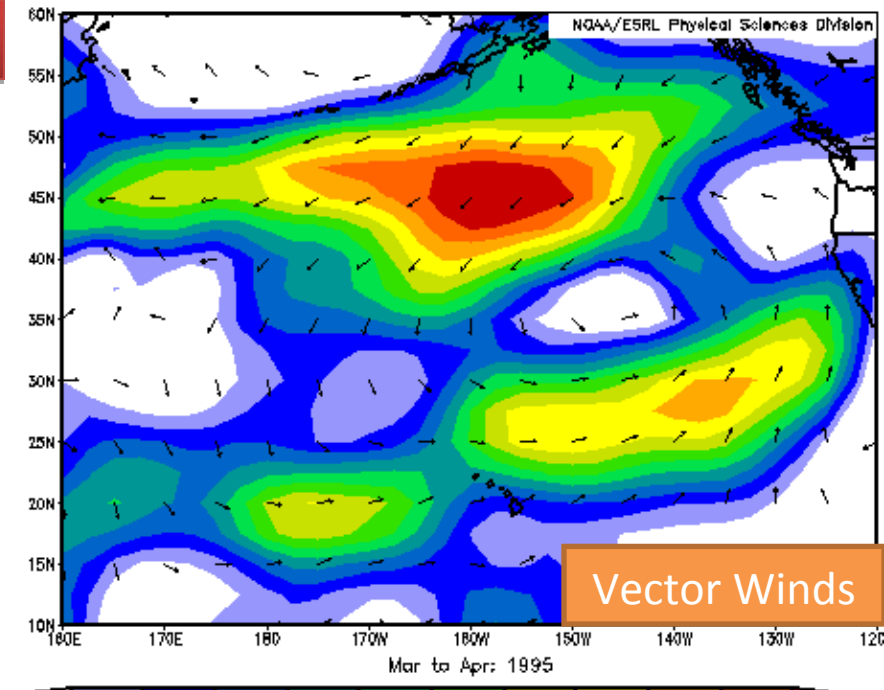
Elevated Residuals:
end Feb – Apr

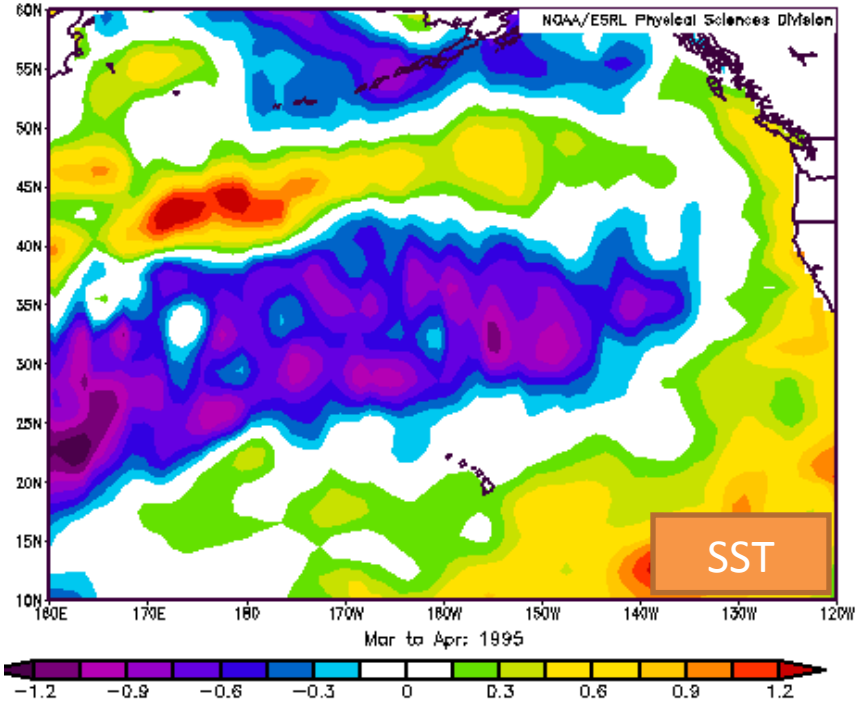


NCEP Anomaly from 1981-2010 Mean Climatology

NCEP Mar-Apr 1995 Composites

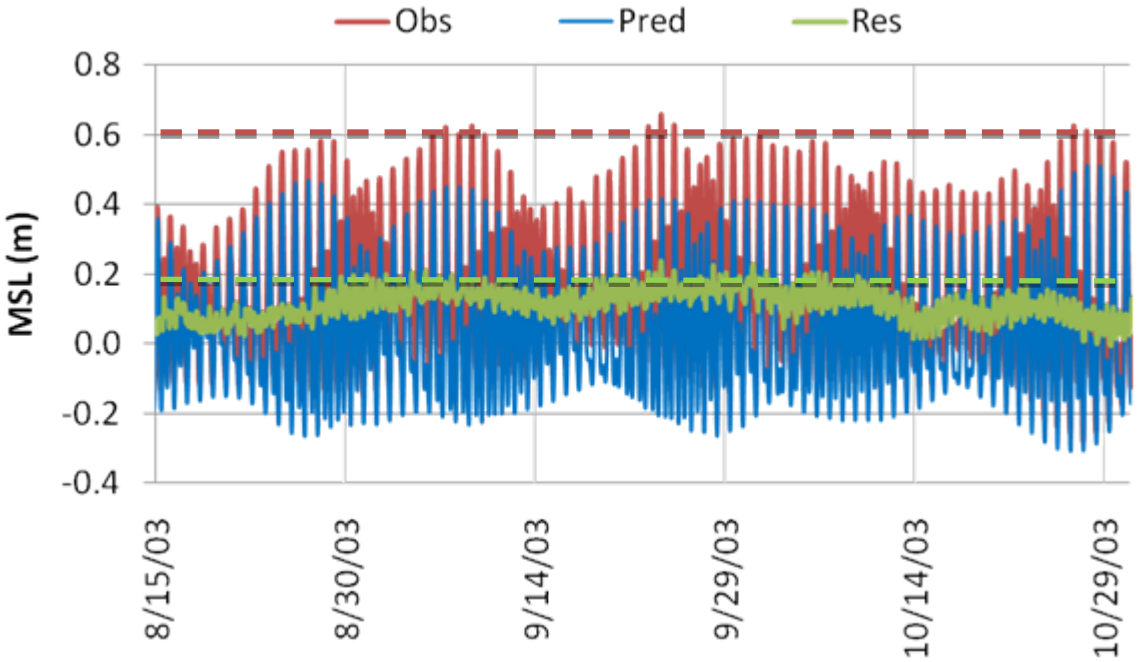






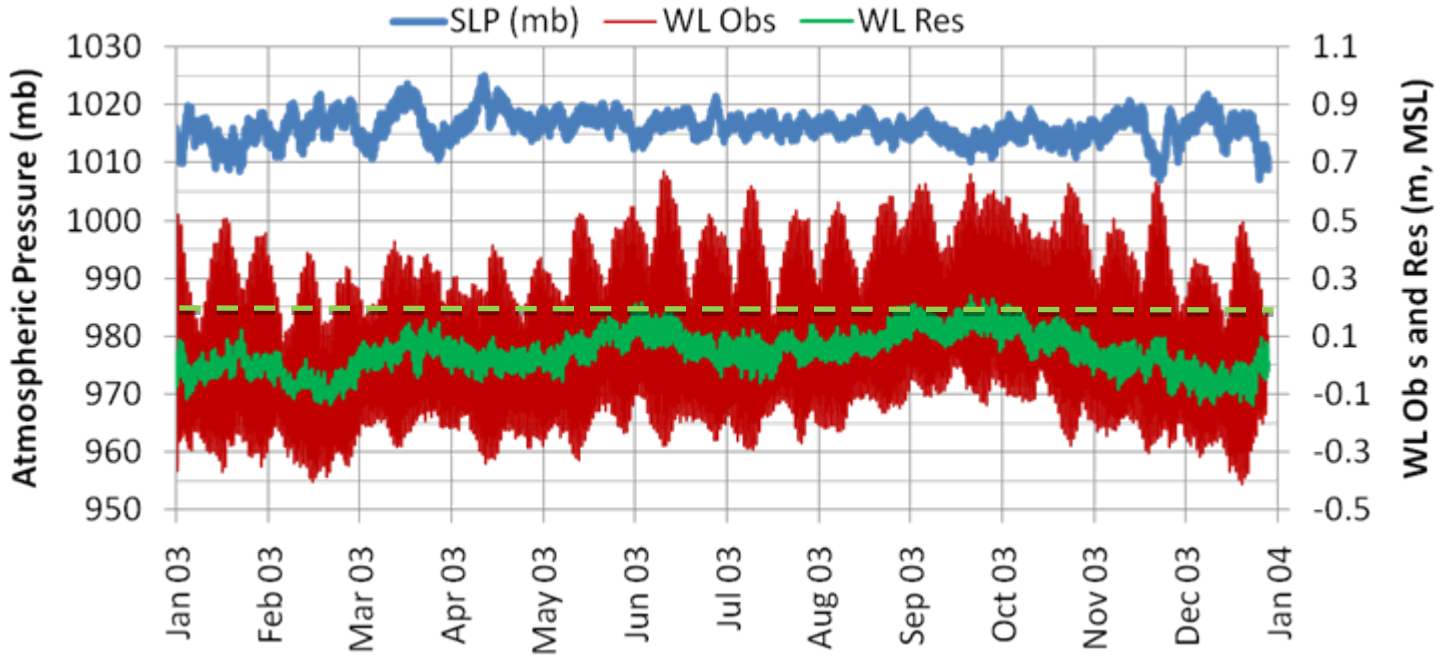
SLP – Winds/Ekman – SL/SSH

- **Aleutian low deepens**
- **Positive wind curl anomaly**
- **Counteracting the N. Pacific gyre / Ekman setdown w/in ‘horseshoe’**



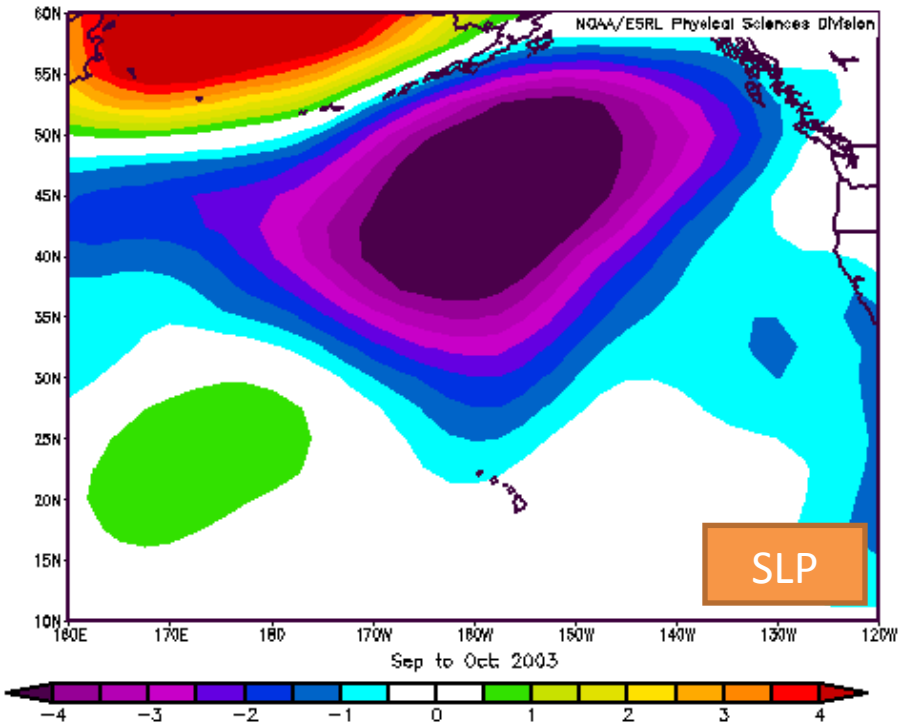
Sep –Oct 2003 "Event"

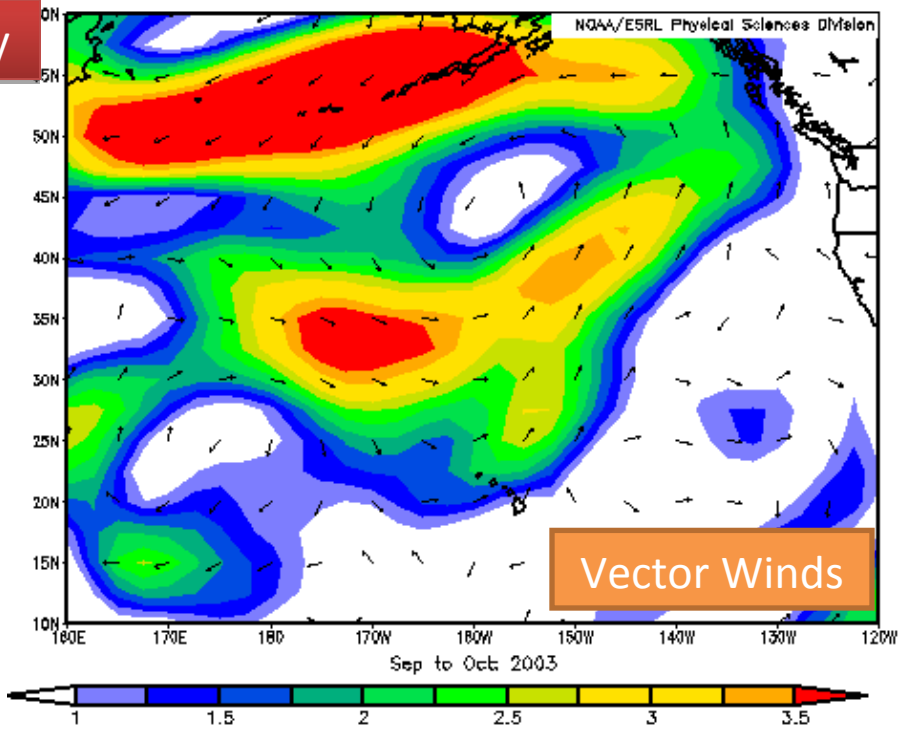
Elevated Obs/Res:

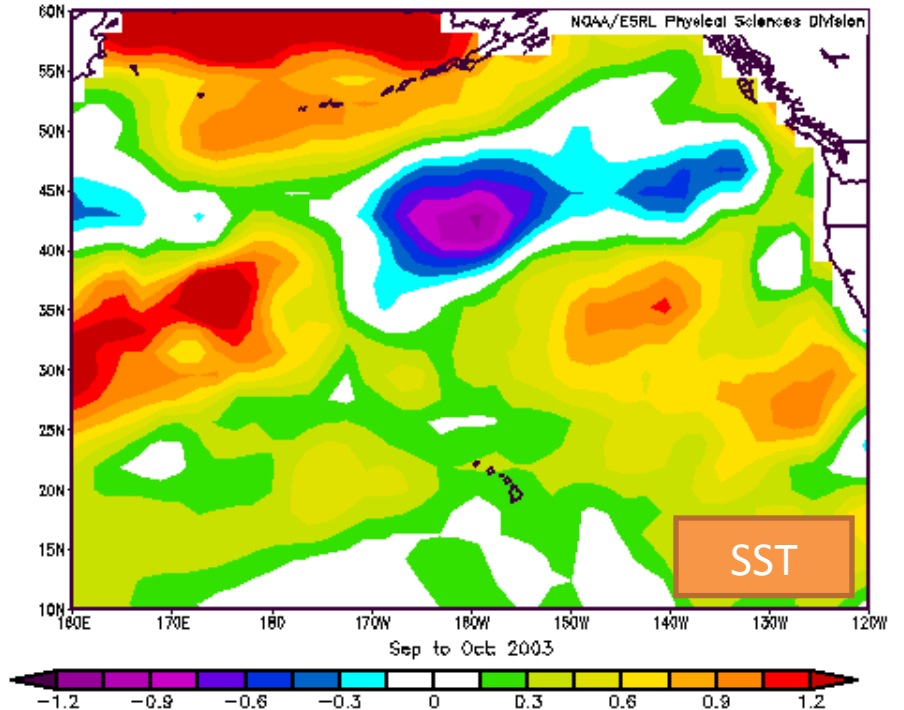


NCEP Anomaly from 1981-2010 Mean Climatology

NCEP Sep-Oct 2003 Composites







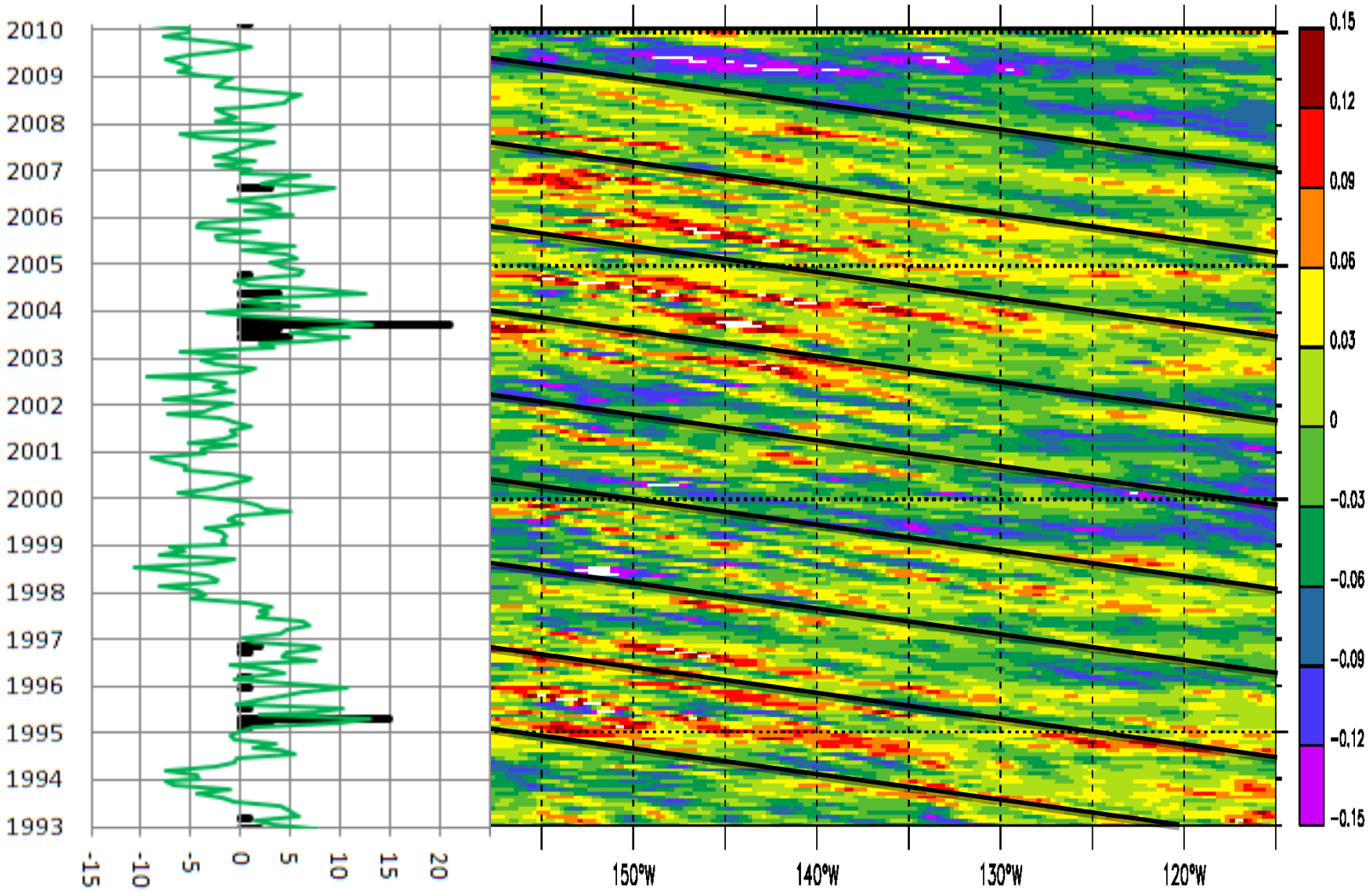
SLP

Winds/Ekman

SL/SSH

?

Propagation of a planetary wave: a downwelling Rossby Wave? (Firing and Merrifield, 2004; JGL)



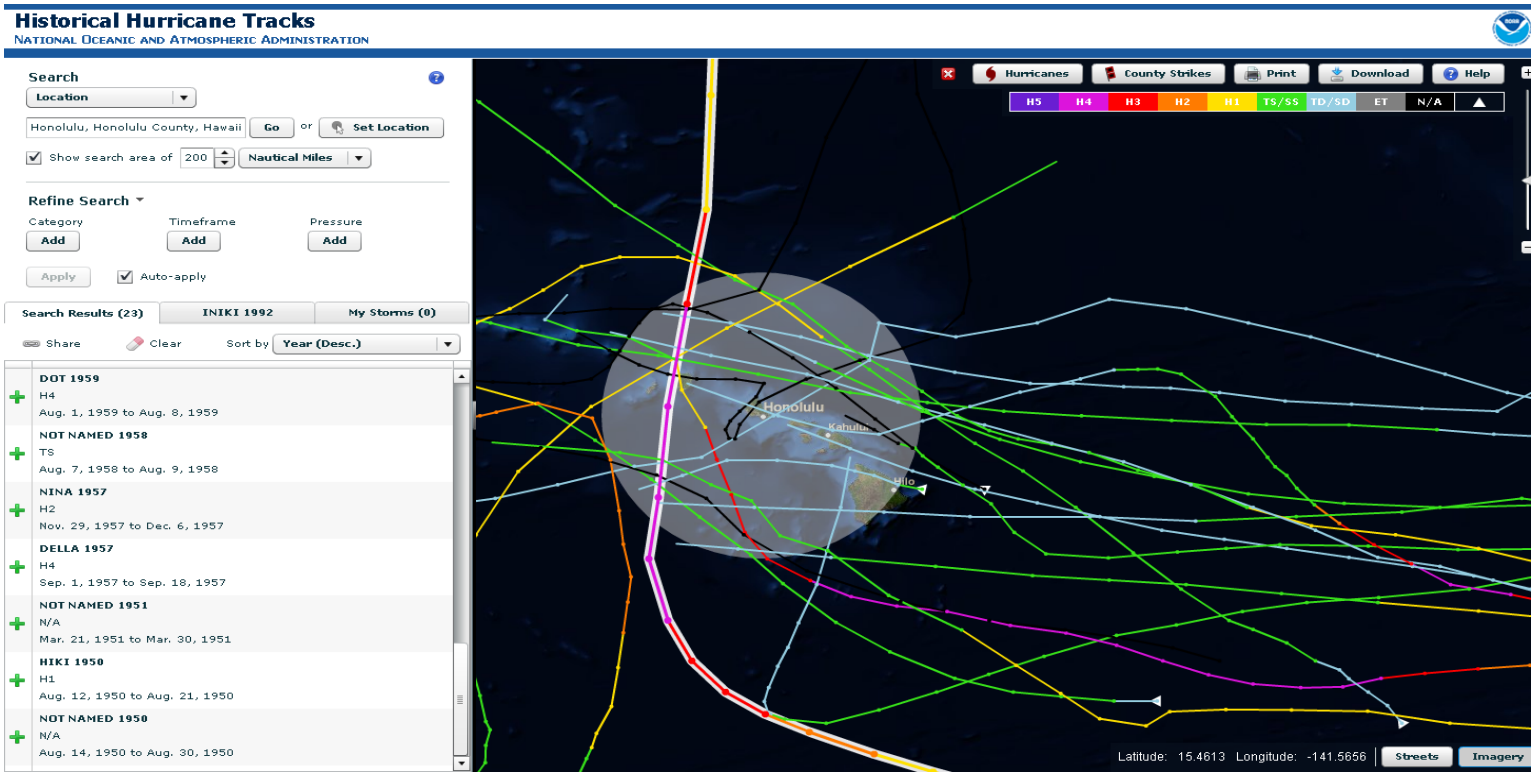
Monthly WL Residual (cm)
and
No. of 99% of Hourly Residuals

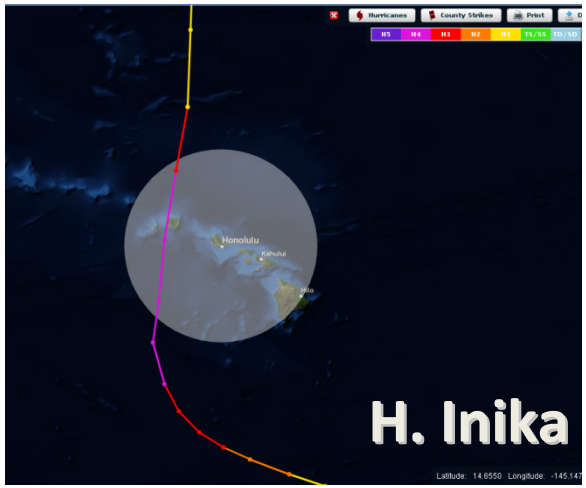
Time-longitude plot of AVISO altimetry along 21.3 N w/ mode-1 Rossby wave speeds as black lines

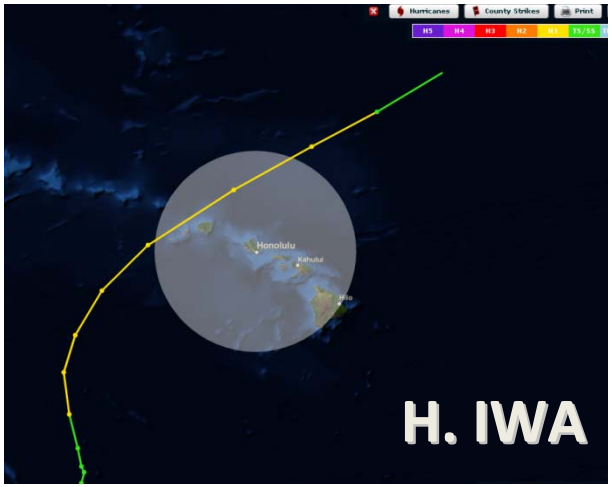
Top 10 Events	Obs (m, MSL)	Pred (m, MSL)	Res (m)	
99% (MSL)	~0.6	~0.55	~0.18	
11/24/1982 6:00	0.449	-0.118	**0.567**	Hurricane IWA
9/12/1992 1:00	***0.724***	0.287	**0.437**	**H. Iniki**
2/28/2004 19:00	0.162	-0.128	**0.290**	**Winter storm (largest 24-hr avg)**
1/9/1980 16:00	0.370	0.089	**0.281**	Storm?
1/14/1985 16:00	0.258	-0.007	**0.265**	Storm?
9/20/1981 17:00	0.420	0.17	**0.250**	H. Jova
9/24/2003 0:00	***0.657***	0.416	**0.241**	Rossby/Ekman
12/14/1992 3:00	0.135	-0.1	**0.235**	**Storm?**
10/1/2003 6:00	0.201	-0.029	**0.230**	Rossby/Ekman

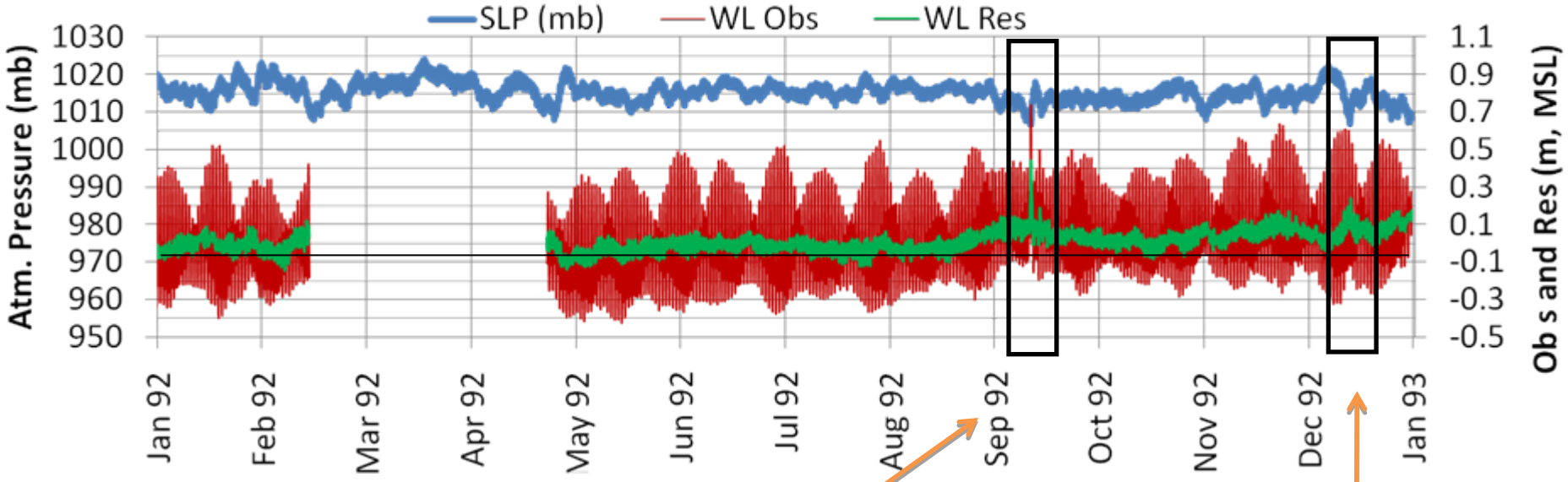
Detrended, 1980-2010 hourly values

Top 10 Events	**Obs (MSL)**	Pred (m, MSL)	Res (m)	
9/12/1992 2:00	**0.727**	0.296	***0.431***	Hurricane Iniki
7/11/1995 1:00	**0.679**	0.524	0.155	>Tide
6/14/2003 2:00	**0.670**	***0.544***	0.126	~Tide
11/24/1984 15:00	**0.667**	***0.546***	0.121	~Tide
12/23/1984 15:00	**0.664**	0.527	0.137	>Tide
12/22/1995 14:00	**0.663**	***0.551***	0.112	~Tide
6/4/2004 3:00	**0.660**	***0.551***	0.109	~Tide
9/24/2003 0:00	**0.657**	0.416	***0.241***	Rossby/Ekman
12/20/1987 14:00	**0.655**	***0.56***	0.095	~Tide
7/13/1995 3:00	**0.649**	0.516	0.133	>Tide


Historical Hurricane Tracks
National Oceanic and Atmospheric Administration
Search
Location
Honolulu, Honolulu County, Hawaii
Go
or
Set Location
Show search area of 200 Nautical Miles
Refine Search
Category
Timeframe
Pressure
Add
Add
Add
Apply
Auto-apply
Search Results (23)
INIKI 1992
My Storms (0)
Share
Clear
Sort by Year (Desc.)
DOT 1959
H4
Aug. 1, 1959 to Aug. 8, 1959
NOT NAMED 1958
TS
Aug. 7, 1958 to Aug. 9, 1958
NINA 1957
H2
Nov. 29, 1957 to Dec. 6, 1957
DELLA 1957
H4
Sep. 1, 1957 to Sep. 18, 1957
NOT NAMED 1951
N/A
Mar. 21, 1951 to Mar. 30, 1951
HIKI 1950
H1
Aug. 12, 1950 to Aug. 21, 1950
NOT NAMED 1950
N/A
Aug. 14, 1950 to Aug. 30, 1950
Hurricanes
County Strikes
Print
Download
Help
H5 H4 H3 H2 H1 TS/SS TD/SD ET N/A
Honolulu
Kahului
Hilo
Latitude: 15.4613 Longitude: -141.5656
Streets
Imagery

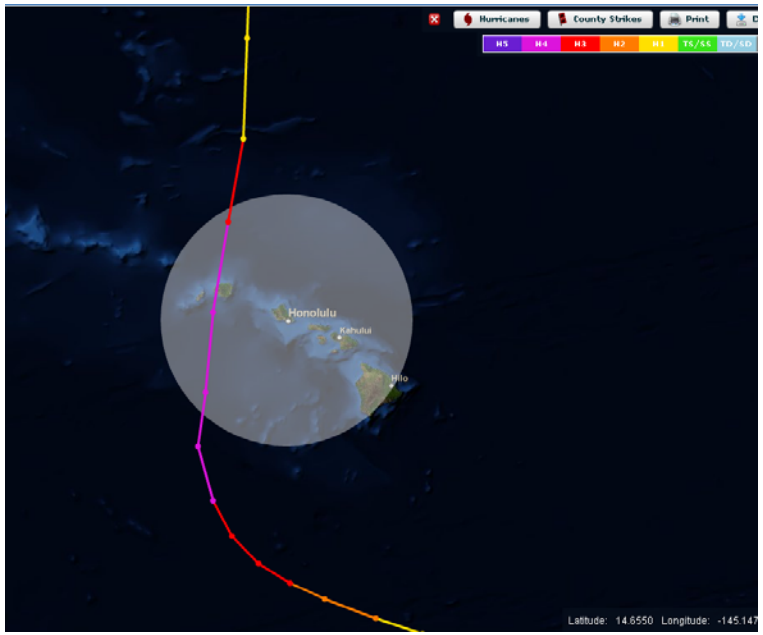

Honolulu
Kahului
Hilo
H. Inika

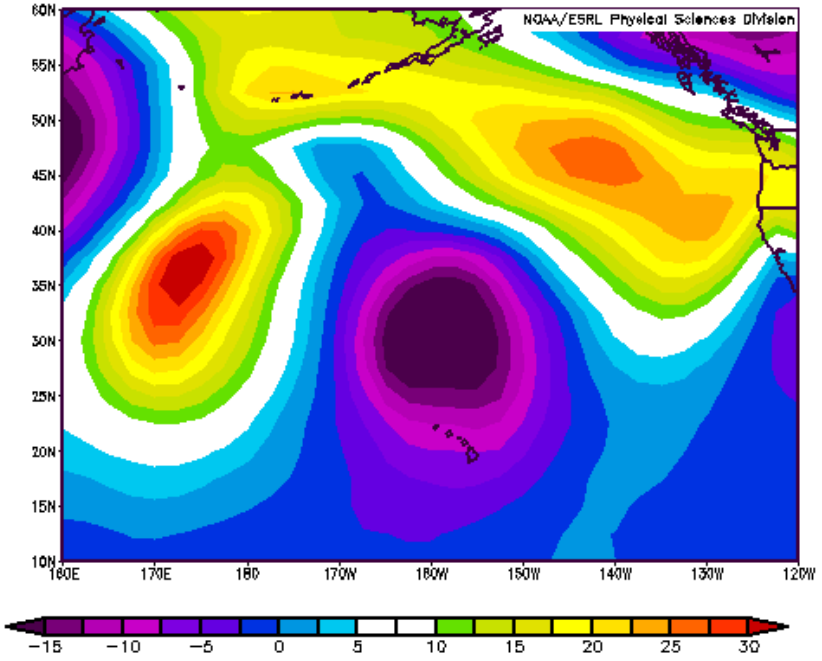

Honolulu
Kahului
Hilo
H. IWA

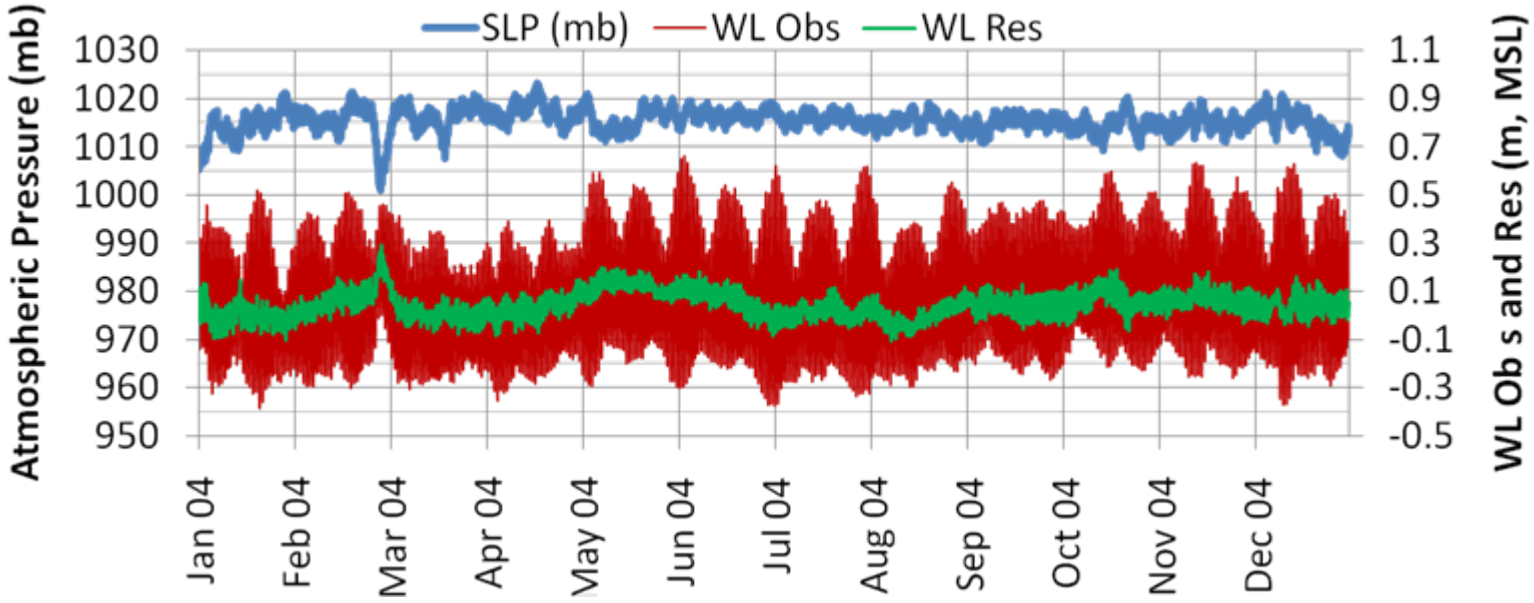


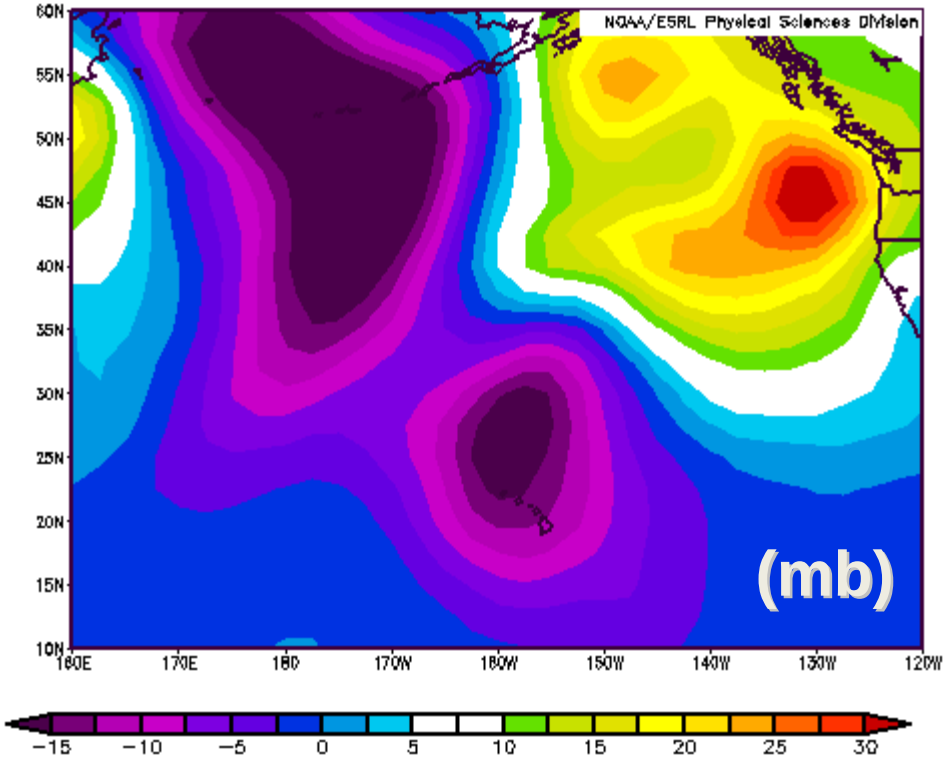
Hurricae Iniki

Difference in SLP (mb) between 12/14 and 12/10 (NCEP)







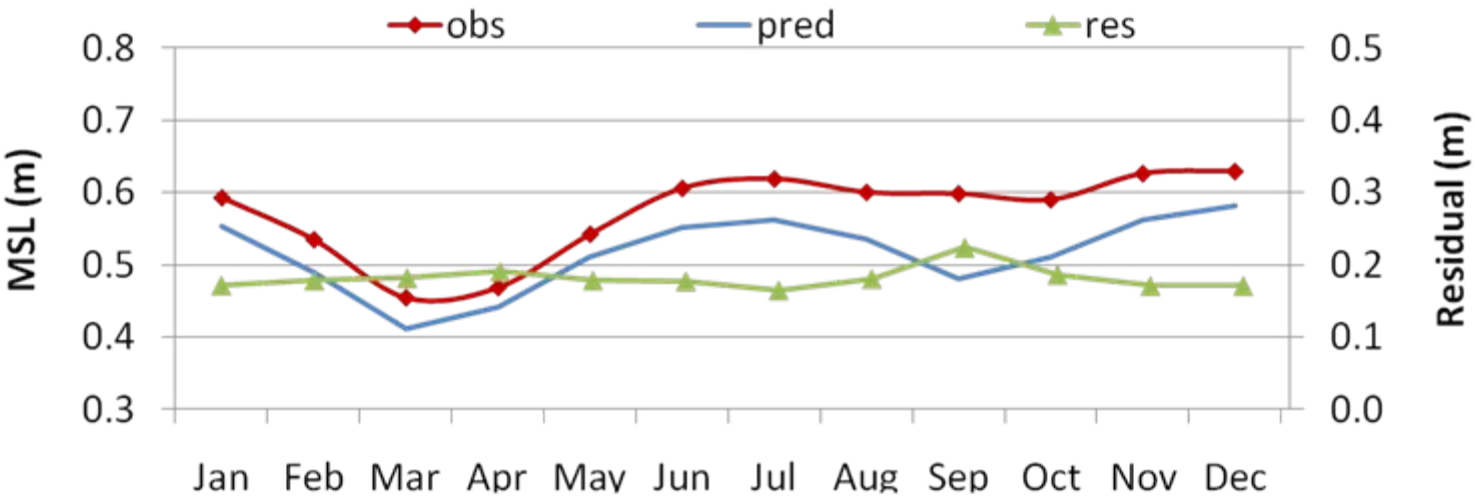


Feb/Mar 2004 "Event"

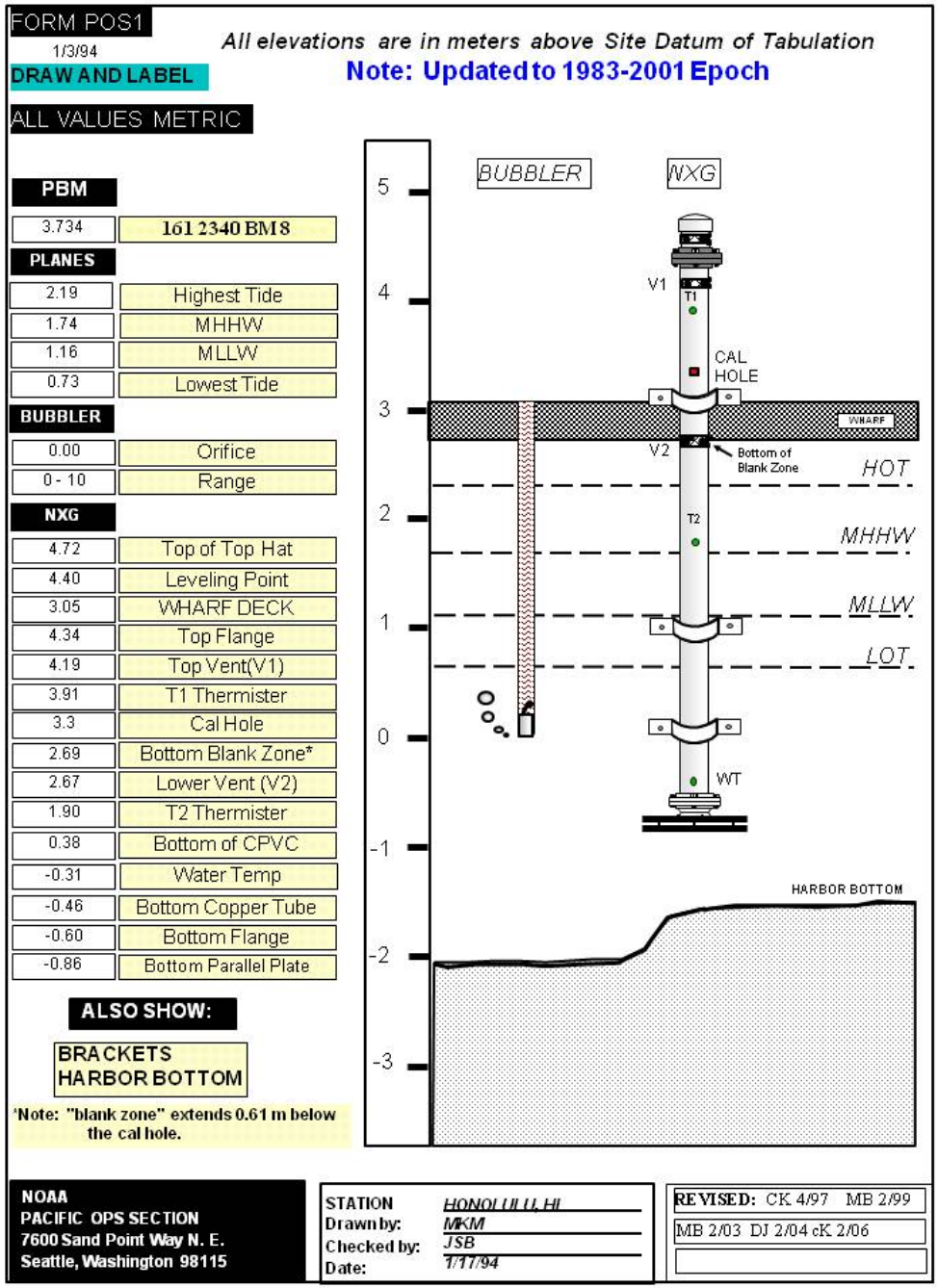
Strong Low & large inverse barometer effect

Difference in SLP: 2/28 - 2/24 (NCEP)

99% for each month computed by daily max of hourly values: 1980-2010



What is really concerning - total water level?
Ah yes, this is a Waves Conference!

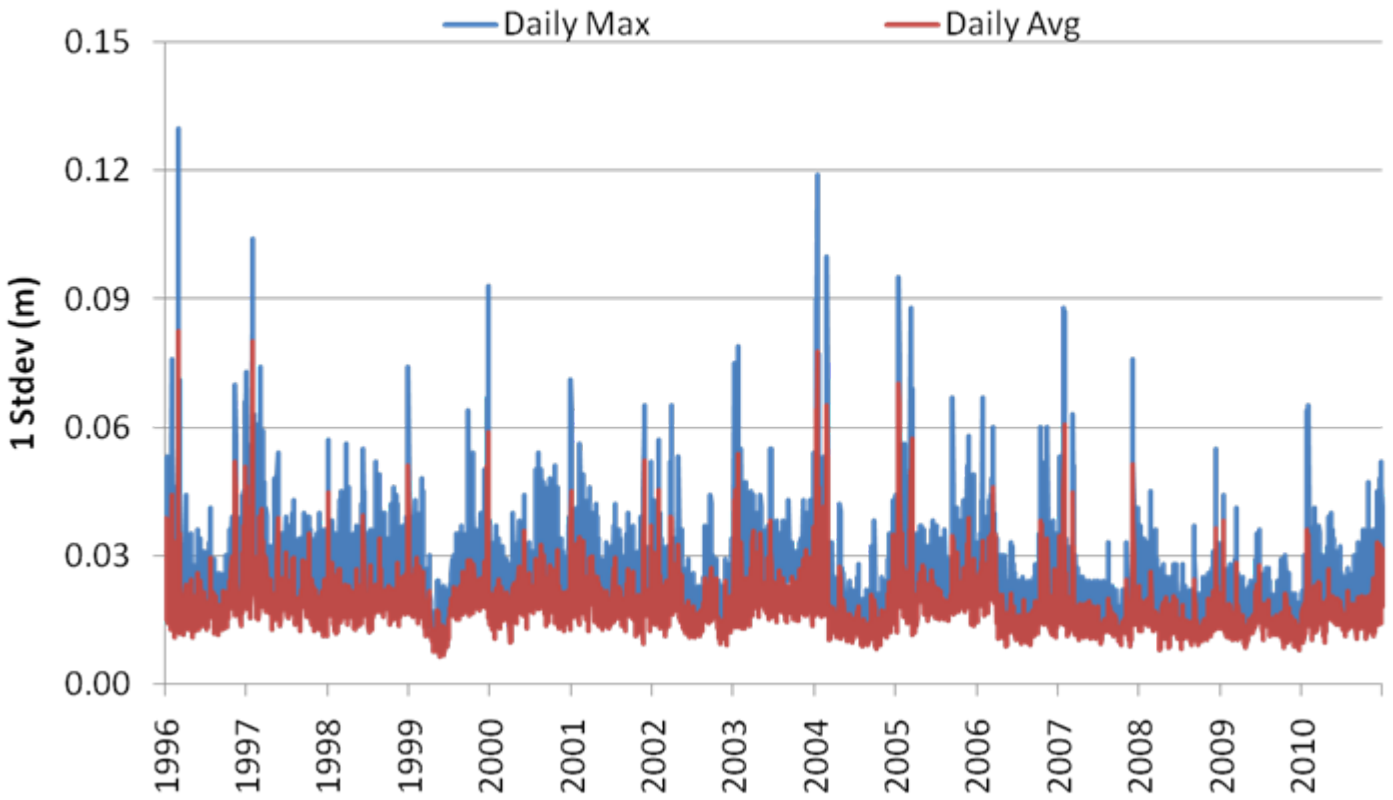


Investigate NOAA/CO-OPS 180-sec water level measurement

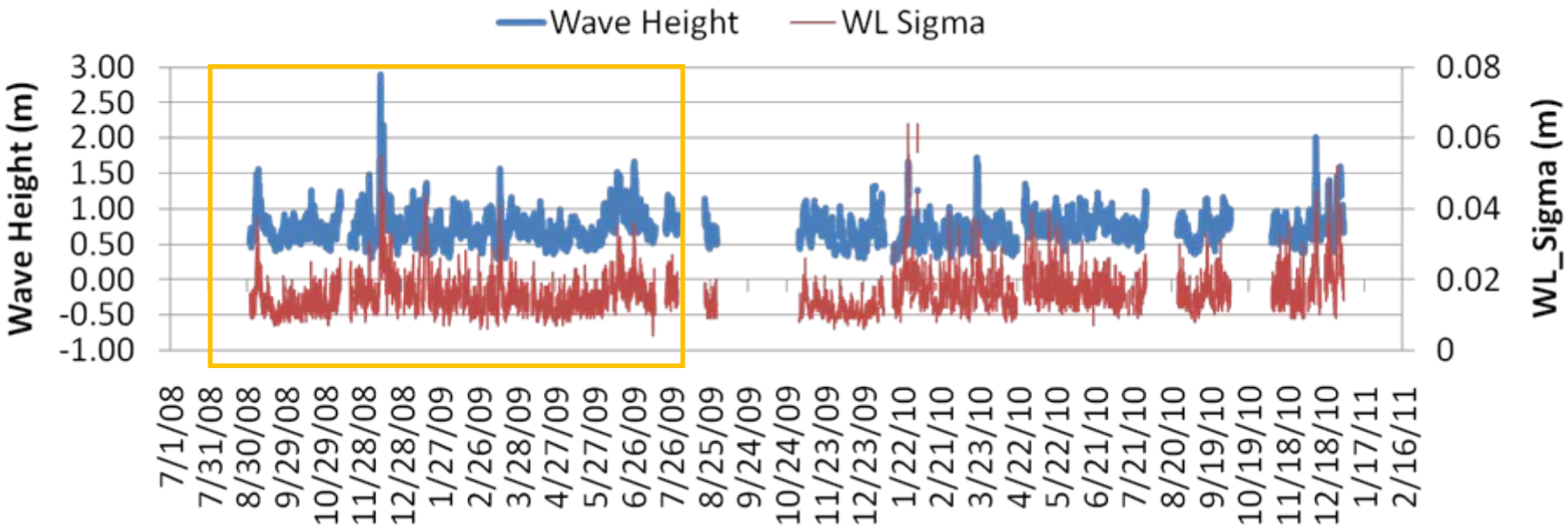
Every 6-min value is actually a 180-sec average sampled at 1-hz

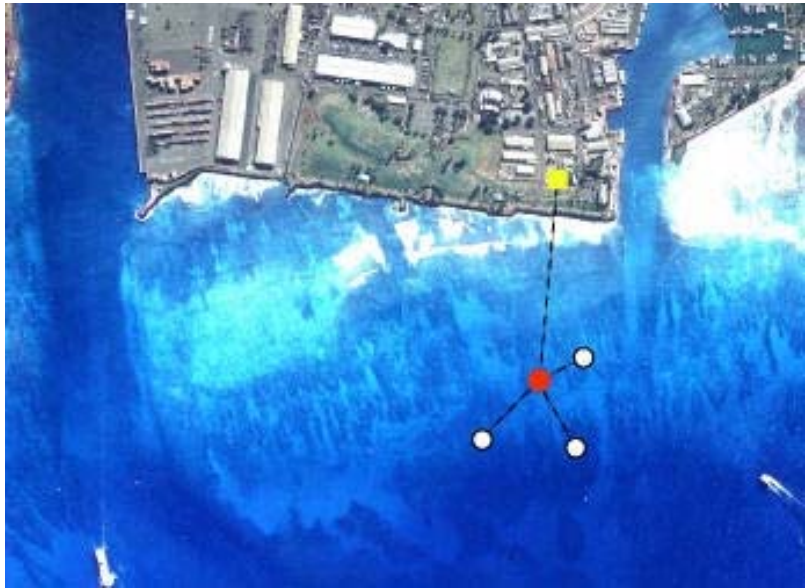
A record of the standard deviation of this 180-sec ensemble (1-Sigma).

Hourly WL Sigma of Individual 180-sec WL Measurement

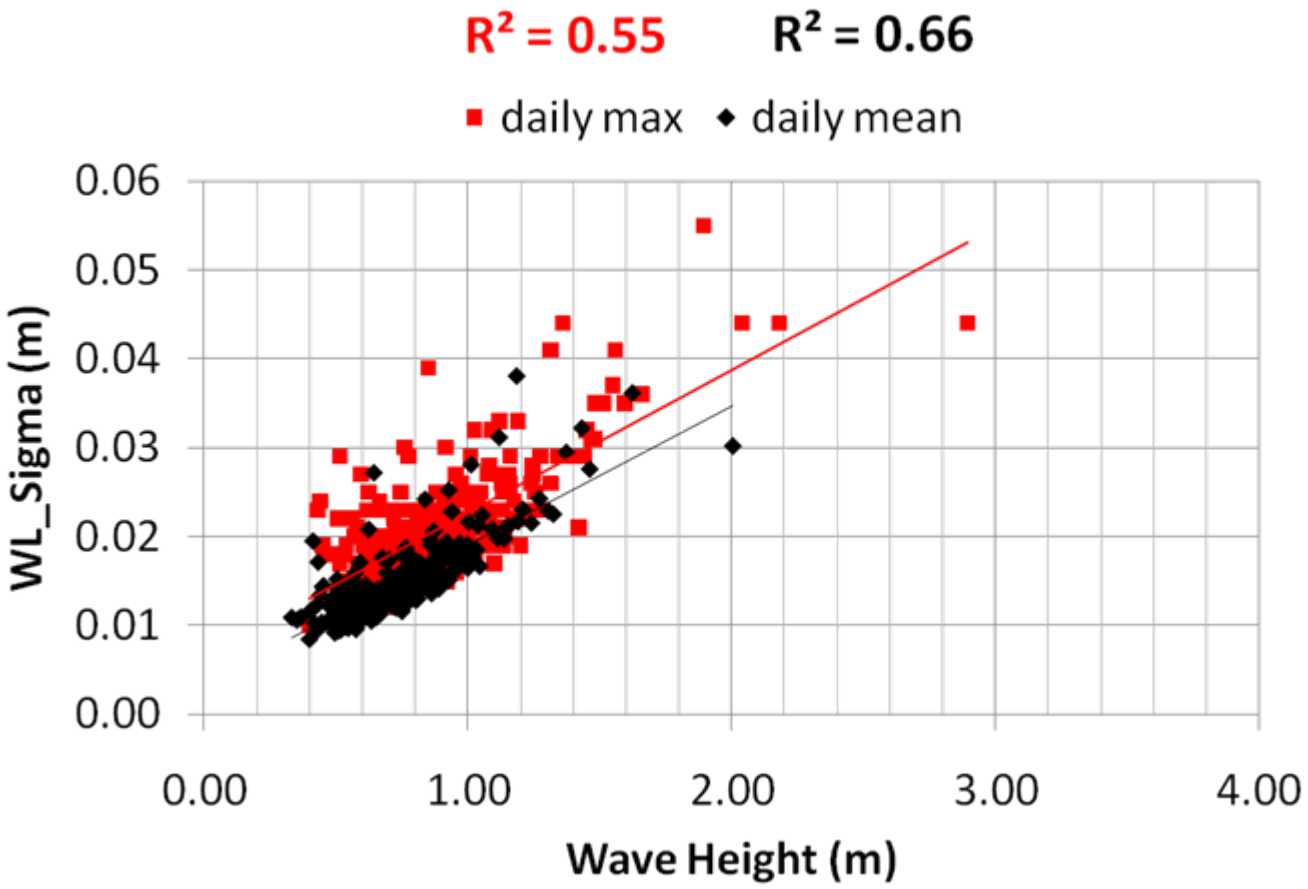


Comparison with a nearby wave-measuring buoy

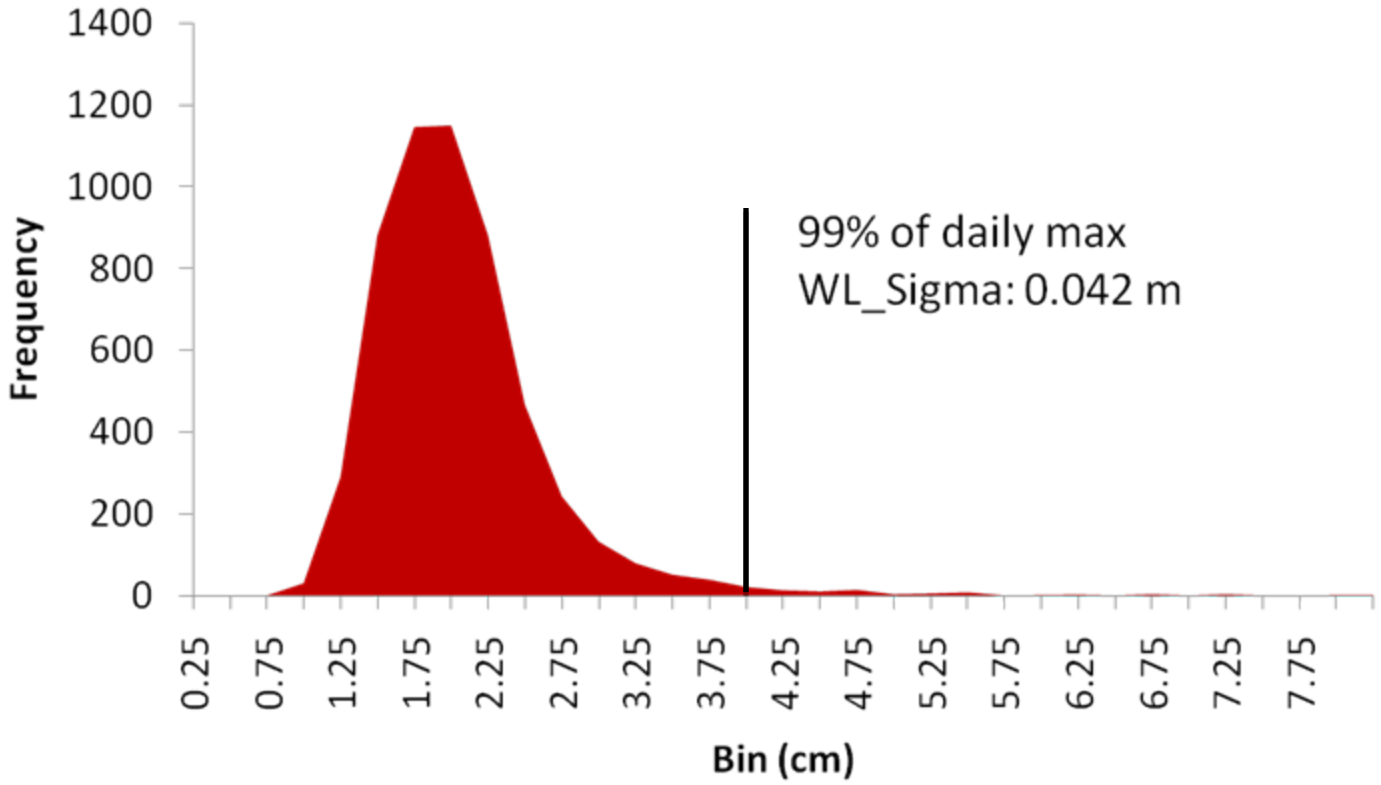




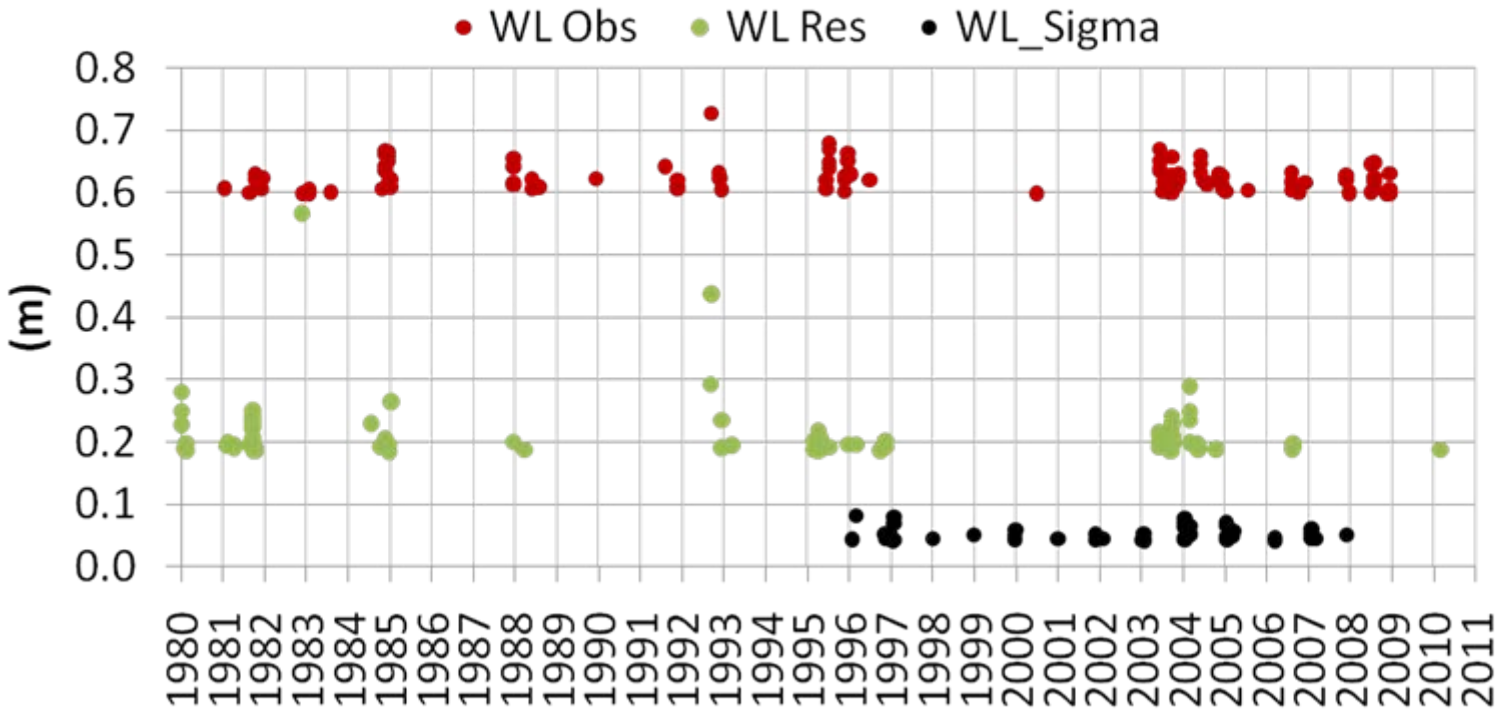
9/08-8/09: Daily Buoy Wave Height vs. Tide WL Sigma

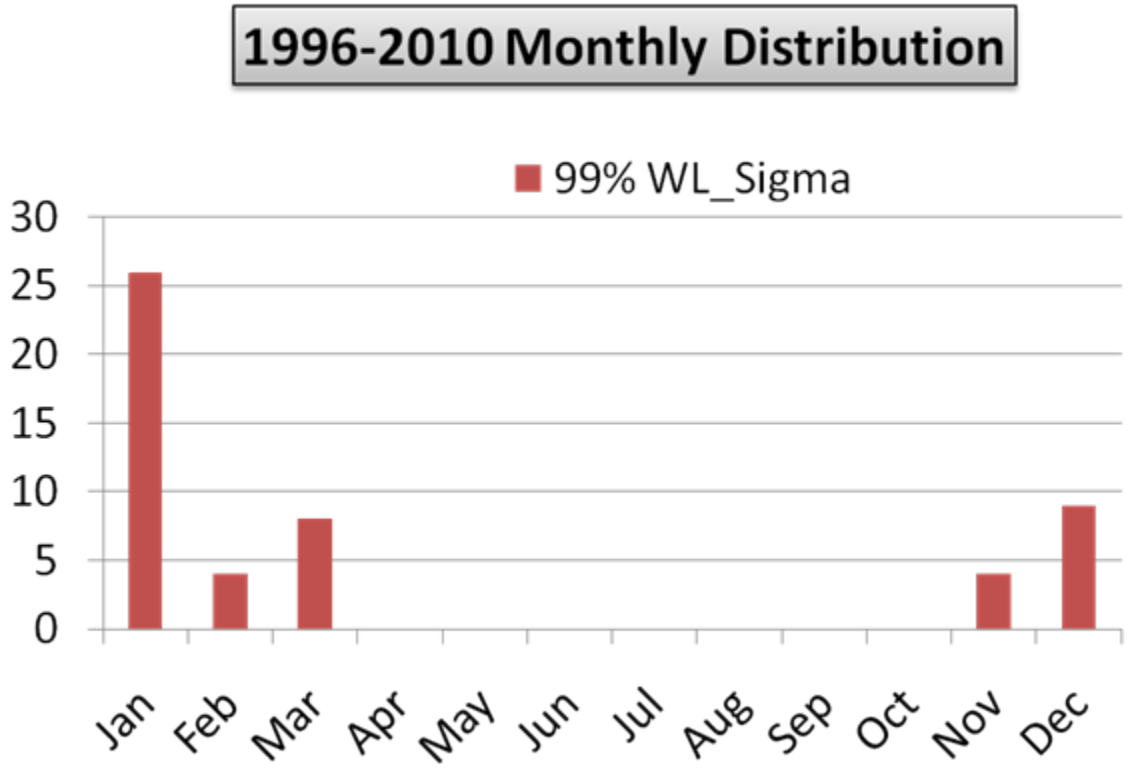


Distribution of 1996-2010 Daily Avg WL_Sigma



99% of 1980-2010 WL Obs & Res and 1996-2010 WL Sigma




1996-2010 Monthly Distribution
99% WL_Sigma
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

A measure (subjective?) of 'visible' coastal event – usually in terms of wave

NOAA Satellite and Information Service
National Environmental Satellite, Data, and Information Service (NESDIS)

National Climatic Data Center
U.S. Department of Commerce

DOC >NOAA >NESDIS >NCDC Search Field: Search NCDC

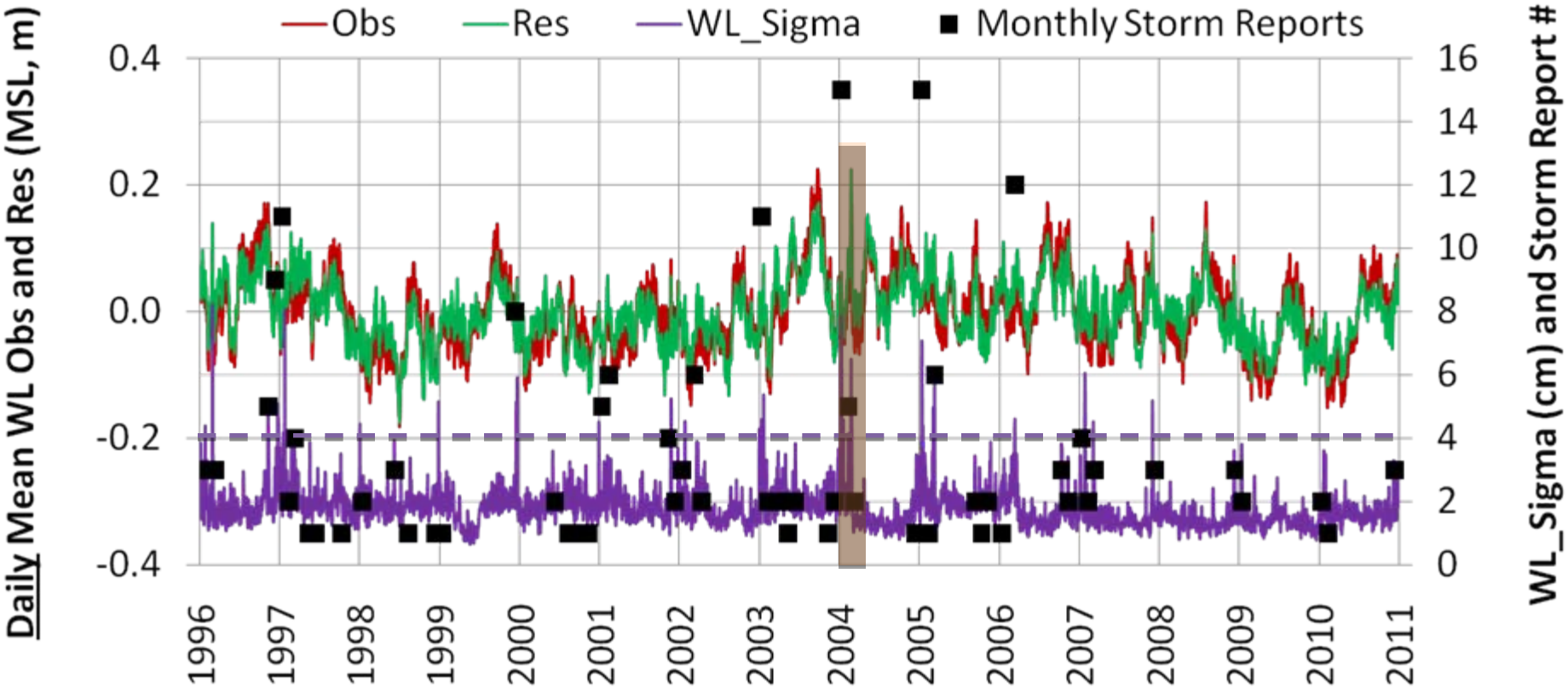
Event Record Details

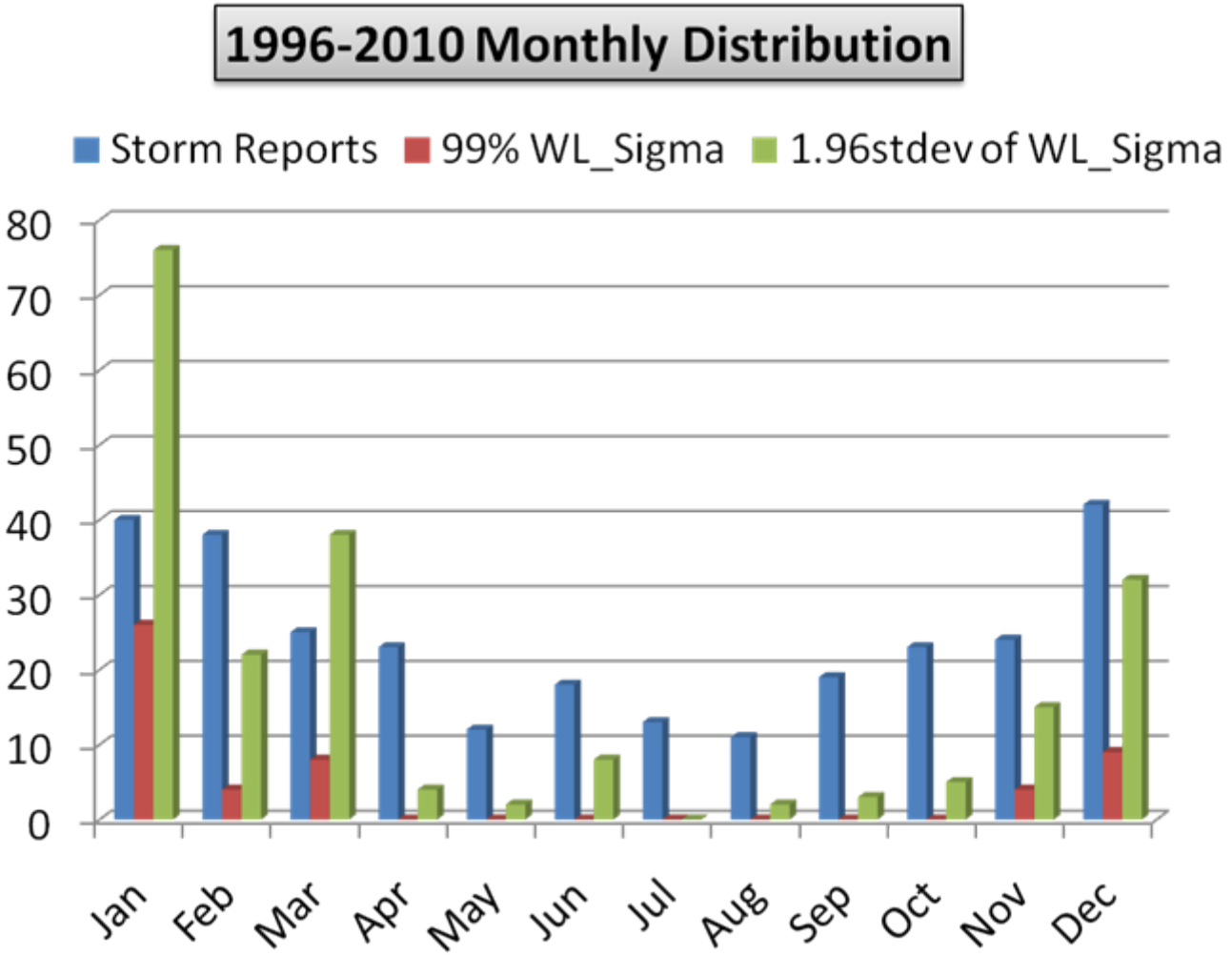
Event: **Heavy Surf/high Surf**
Begin Date: **27 Feb 2004, 08:00:00 AM HST**
Begin Location: **Not Known**
End Date: **29 Feb 2004, 06:00:00 PM HST**
End Location: **Not Known**
Magnitude: **0**
Fatalities: **1**
Injuries: **0**
Property Damage: **$ 0.0**
Crop Damage: **$ 0.0**

State: **Hawaii**
Map of Counties
Zones affected: **Kauai Leeward, Kauai Windward, Niihau, Oahu North Shore, Oahu South Shore**

Description:
A deep storm low far northwest of the state generated surf of 15 to 25 feet along the north-facing shores of Kauai, Oahu, Maui, and Molokai, and 6 to 12 feet along the west-facing shores of those isles and the west-facing shores of the Big Island of Hawaii. A large wave at Waimea Bay on Oahu's North Shore swept a 20-year old female soldier, from Schofield Barracks, out to sea late in the evening on the 27th. She presumably drowned. No serious property damage or injuries were reported. F20IW

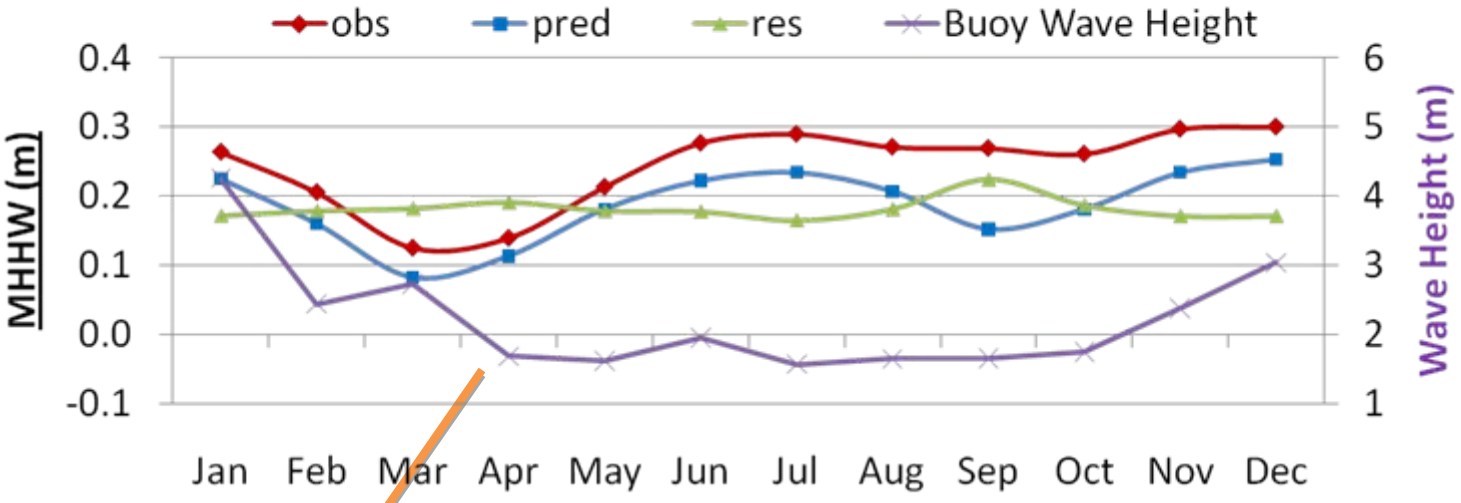
Overlay of 1996-2010 WL Obs/Res, WL_Sigma and Monthly Storm Reports



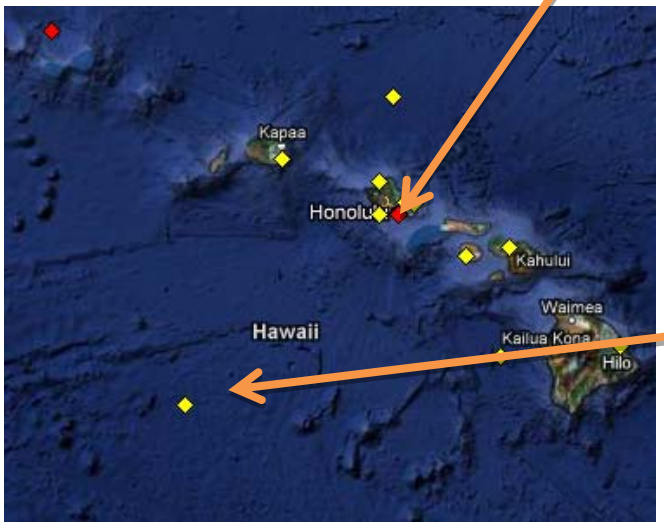

1996-2010 Monthly Distribution
Storm Reports
99% WL_Sigma
1.96stdev of WL_Sigma
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

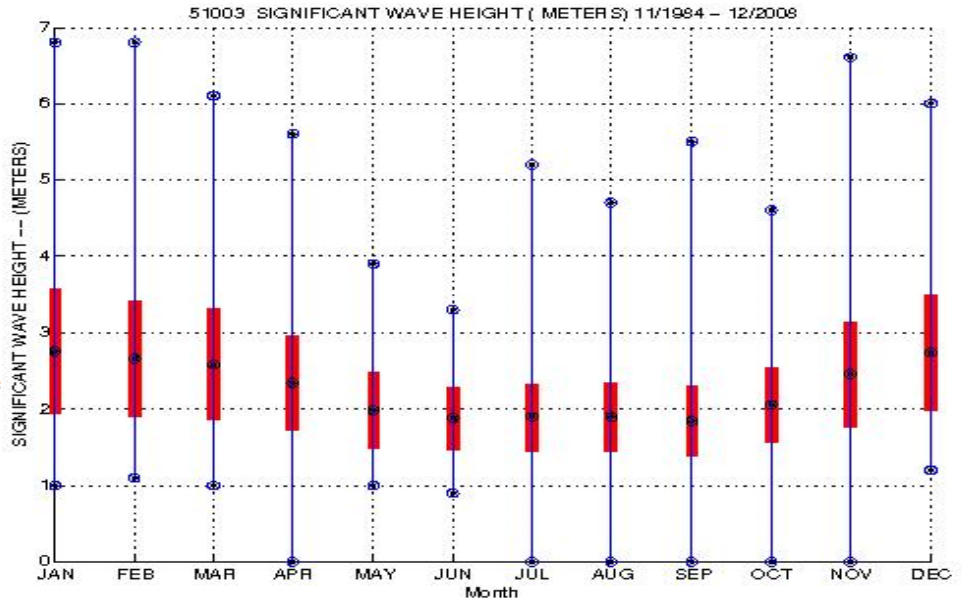
99% by month of daily max WL (1980-2010) and daily mean WL_Sigma (1996-2010)

MHHW - MSL: ~0.33m



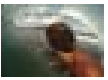
Linear conversion of WL_Sigma series to significant wave height at the near-shore buoy and climatology from offshore buoy





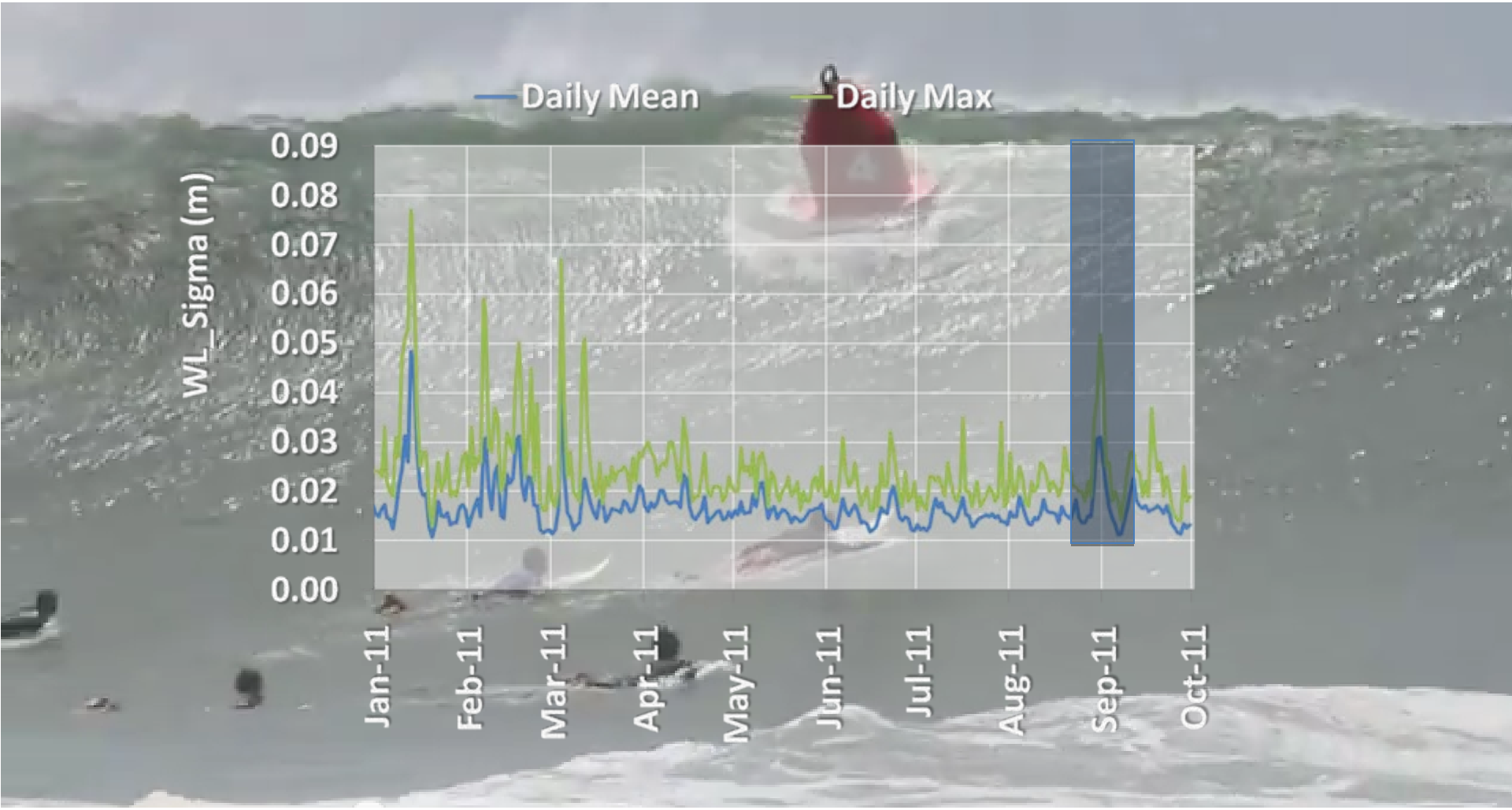
Late Aug 2011 – “largest south swell in years”

Biggest Ala Moana surf in 10 years

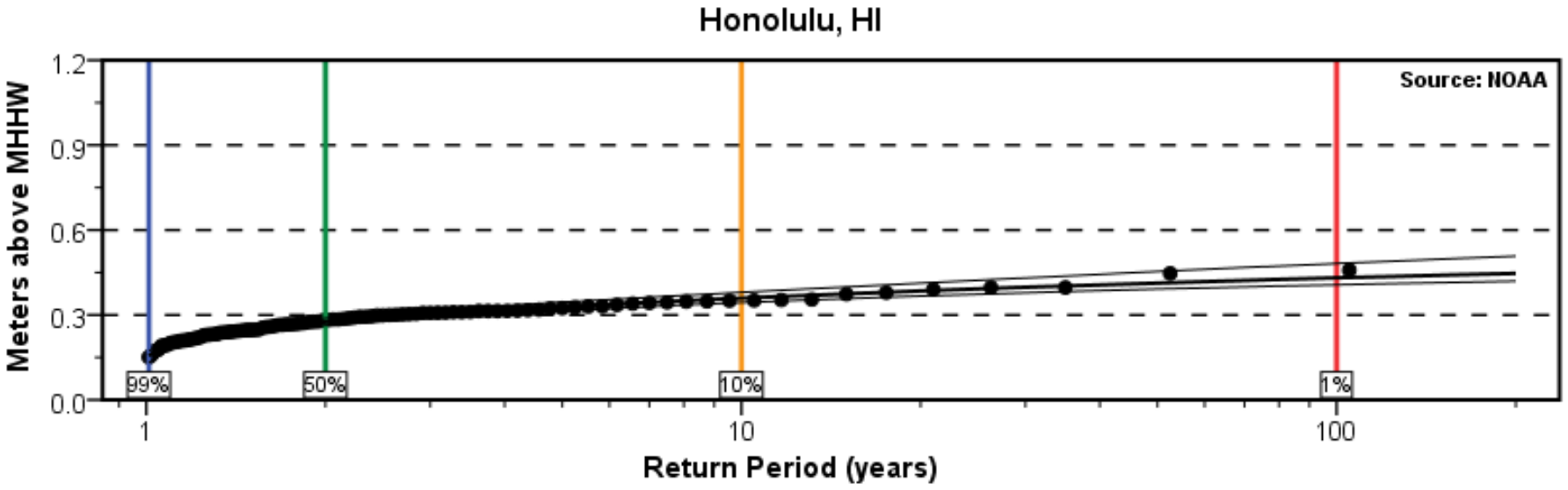


120 videos

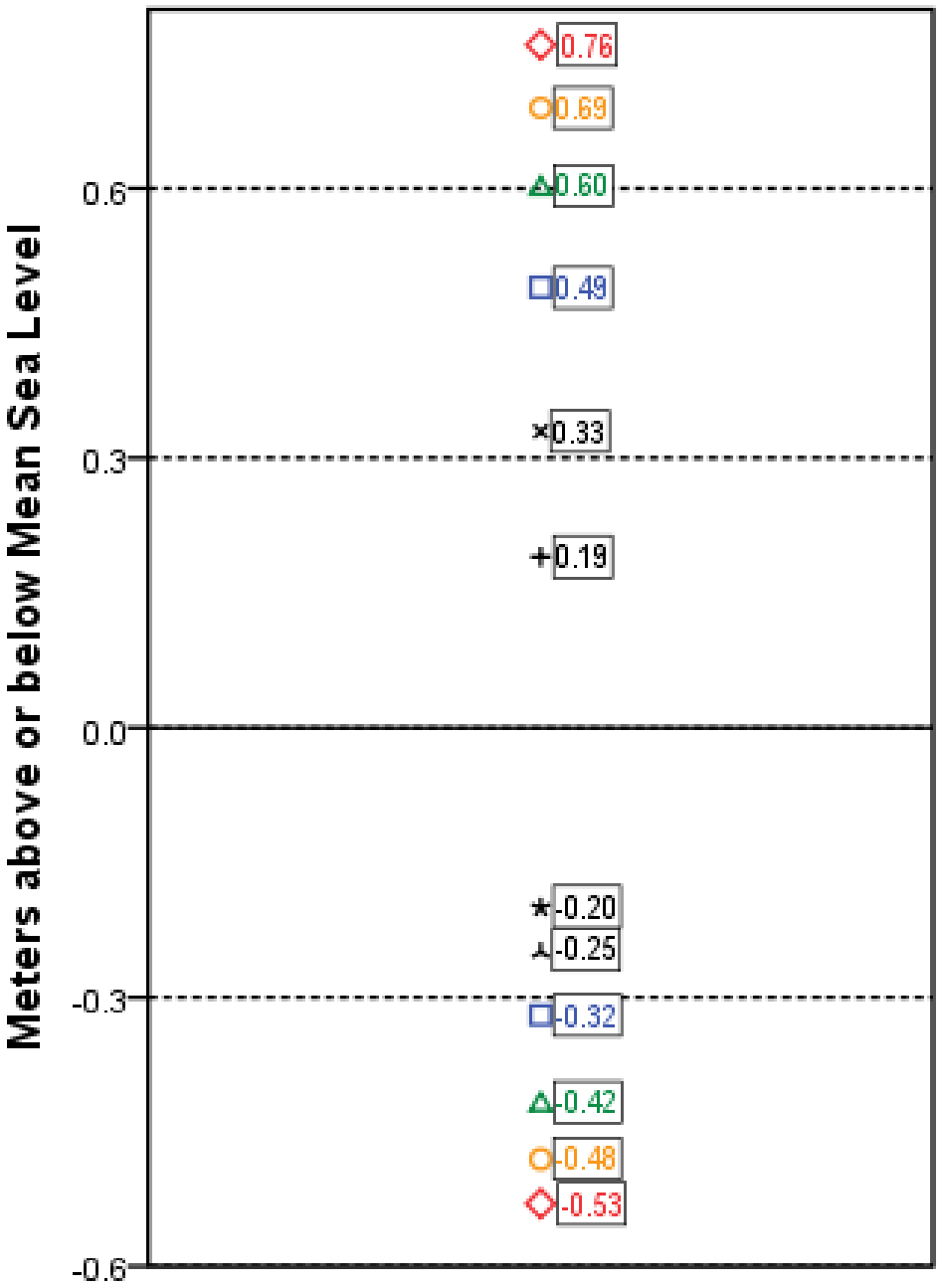
Subscribe



NOAA is starting to provide guidance on 'observed' ocean variability from storm-tide events.



Subtle, non-stationary changes in the frequency domain could begin to affect future exceedance levels relative to today.

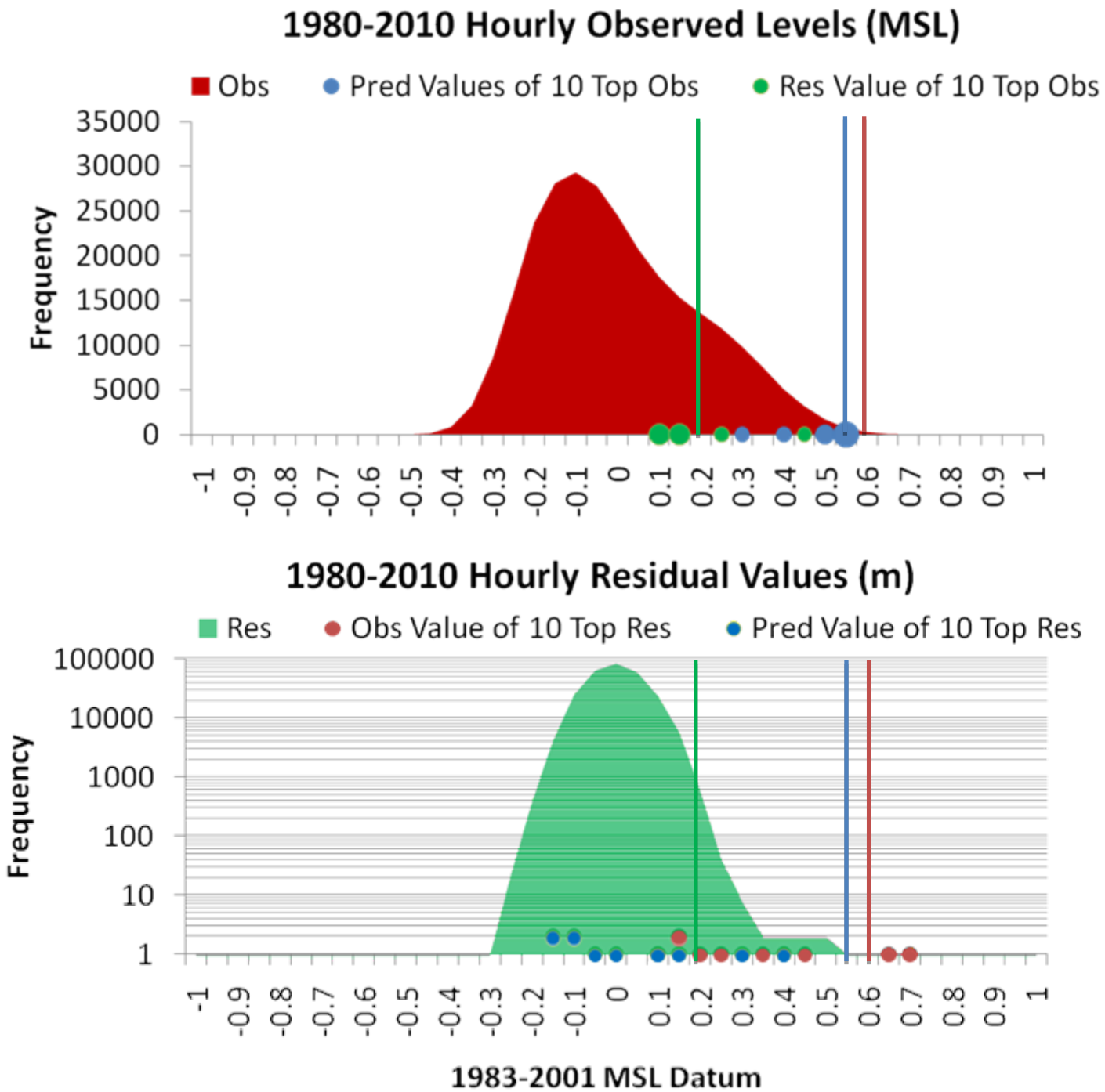


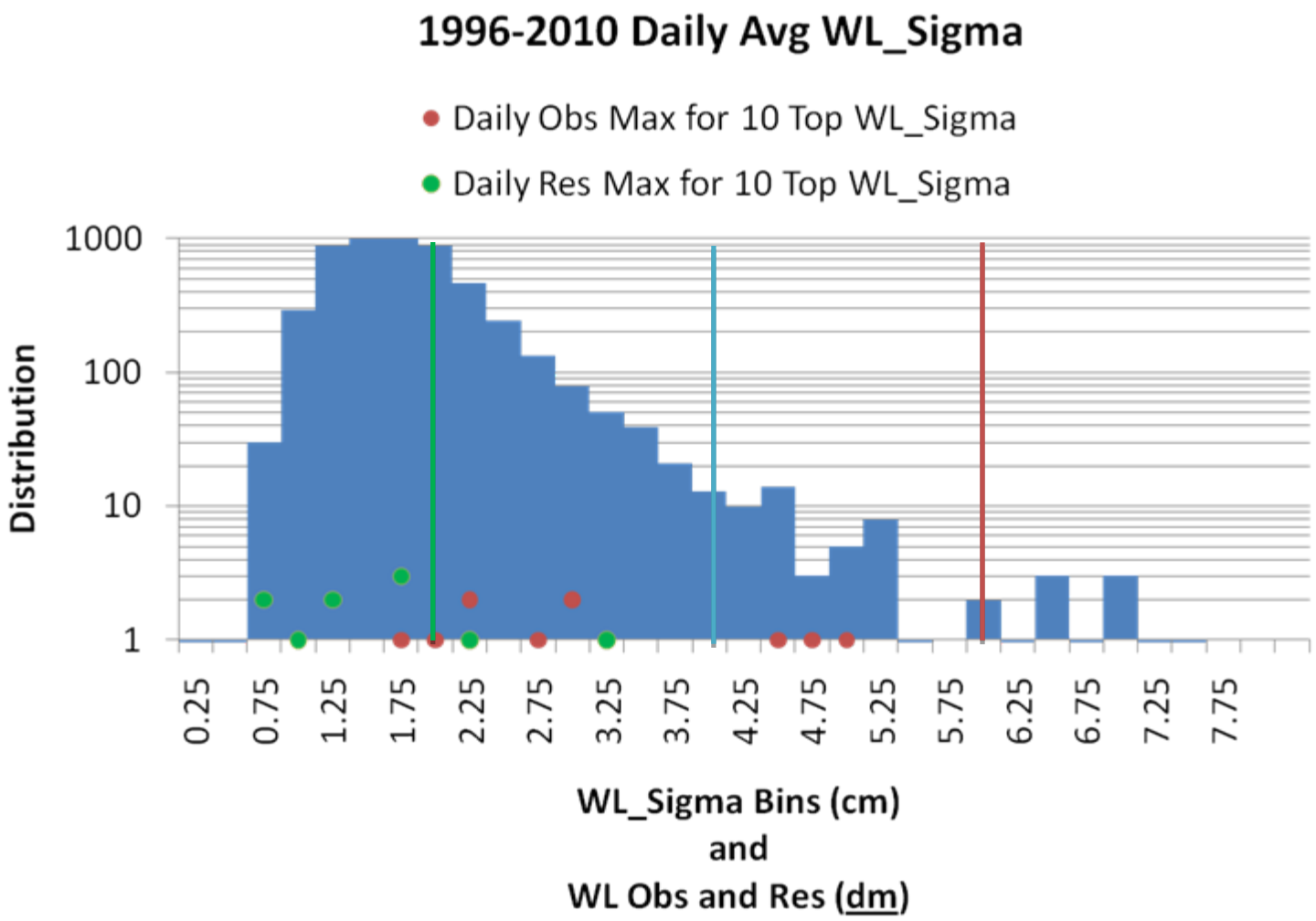
NOAA references this data to local tidal datums.

Datums
- 1%
- 10%
- 50%
- 99%
- MHHW
- MHW
- MLW
- MLLW

99% of hourly Obs (1980-2010) ~ 2-yr event

Are today's extreme statistics going to be relevant tomorrow?


1980-2010 Hourly Observed Levels (MSL)
Obs
Pred Values of 10 Top Obs
Res Value of 10 Top Obs
Frequency
35000
30000
25000
20000
15000
10000
5000
0
-1
-0.9
-0.8
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1980-2010 Hourly Residual Values (m)
Res
Obs Value of 10 Top Res
Pred Value of 10 Top Res
Frequency
100000
10000
1000
100
10
1
1983-2001 MSL Datum


1996-2010 Daily Avg WL_Sigma
Daily Obs Max for 10 Top WL_Sigma
Daily Res Max for 10 Top WL_Sigma
Distribution
1000
100
10
1
0.25
0.75
1.25
1.75
2.25
2.75
3.25
3.75
4.25
4.75
5.25
5.75
6.25
6.75
7.25
7.75
WL_Sigma Bins (cm)
and
WL Obs and Res (dm)

To Conclude:

Hawaii/Honolulu non-tidal water levels/extremes respond to:

- **Long/short period gyre spin-up/down**
- **Atmospheric pressure "L" events,**
- **Rossby waves**
- **Hurricanes**
- **Tides!**

For regions like Hawaii that are:

- **tidally dominated in terms of water level**
- **heavily impacted from waves/run-up**

important to have more of a 'total water level' based probability curve.