The added value (or not) of using nested high resolution WaveWatchIII grids for quantification of extreme wave events along the U.S. and Canadian West Coasts in response to 21st century CMIP5 winds

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Motivation & Objectives

Need :
estimates of wave conditions for planning and management of coastal resources and hazards in the 21st century

Objective 1 of 2:

1) develop an easily accessible set of estimated wave return periods for the 21st century that can be used for forcing nearshore wave propagation models

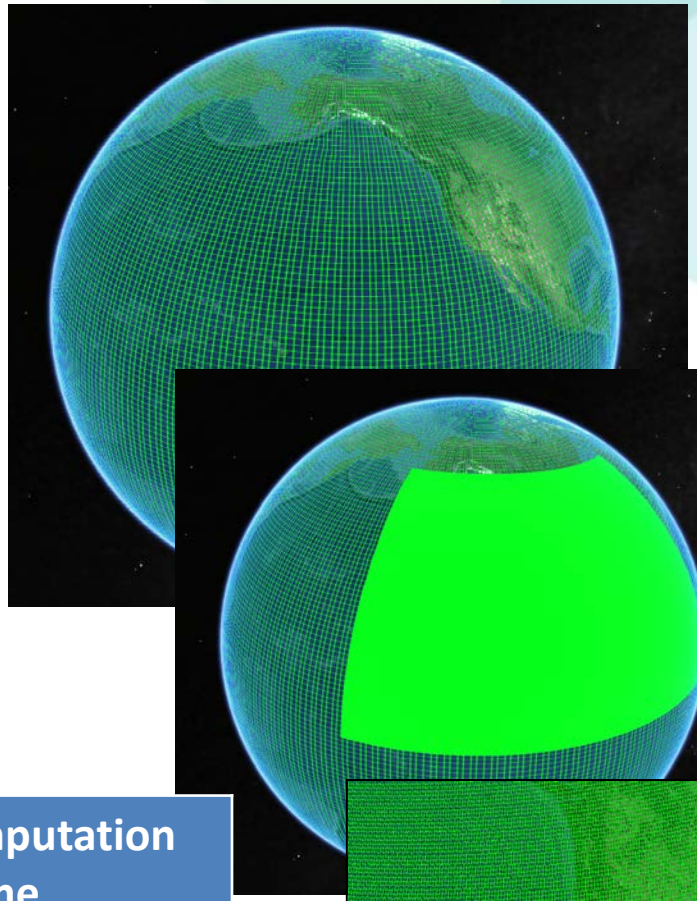
2) Assess the added value of including a higher resolution nested grid in attaining these estimates

USGS

Motivation & Objectives

Need:
Is there value added in nesting the higher-resolution grid at the cost of substantial increased computation time?

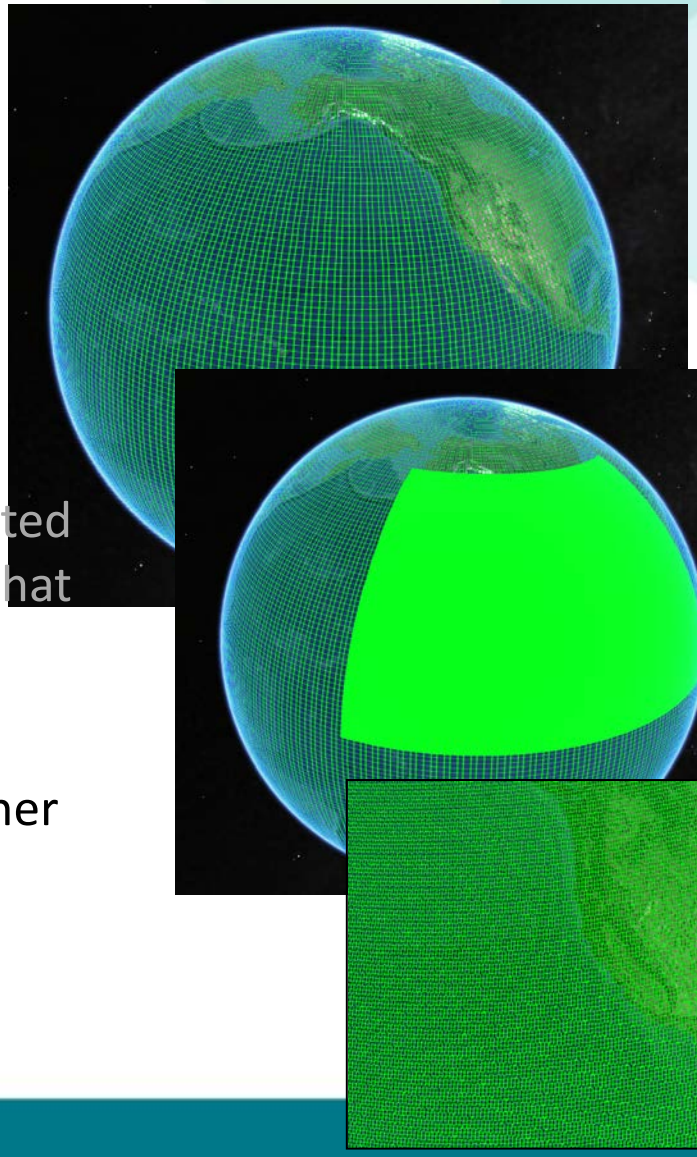
- Simulation time equivalent of 320 years -
(40yrs * 2scenarios *4GCMs)



grid	Computation time per year simulated	Total computation time
NWW3	3hrs/yr	40 days
ENP	6hrs/yr (= 9hrs in series)	120 days

Motivation & Objectives

Need:
Is there value added in nesting the higher-resolution grid at the cost of substantial increased computation time?

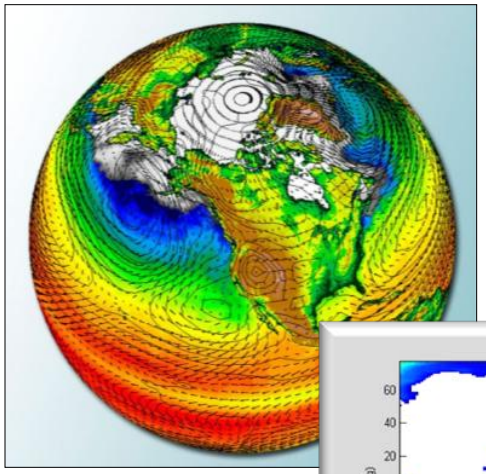


Objective 2 of 2:

1) develop an easily accessible set of estimated wave return periods for the 21st century that can be used for forcing nearshore wave propagation models

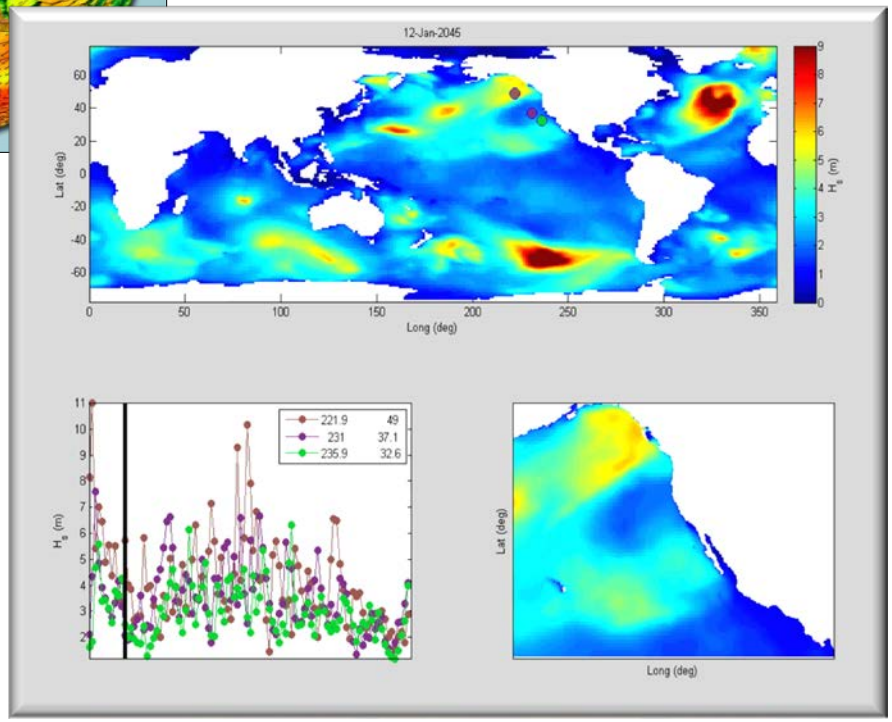
2) Assess the added value of including a higher resolution nested grid in attaining these estimates

Overview of Methodology

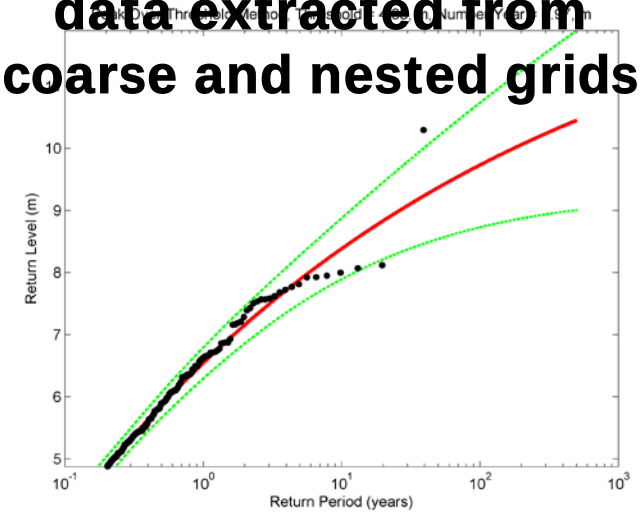


1. Global forcing using CMIP5 GCM winds

2. Simulate wave growth on 'coarse' global and nested higher resolution regional grids with Wavewatch3



3. Calculate & compare return periods of hourly data extracted from coarse and nested grids



USGS

Results and conclusions

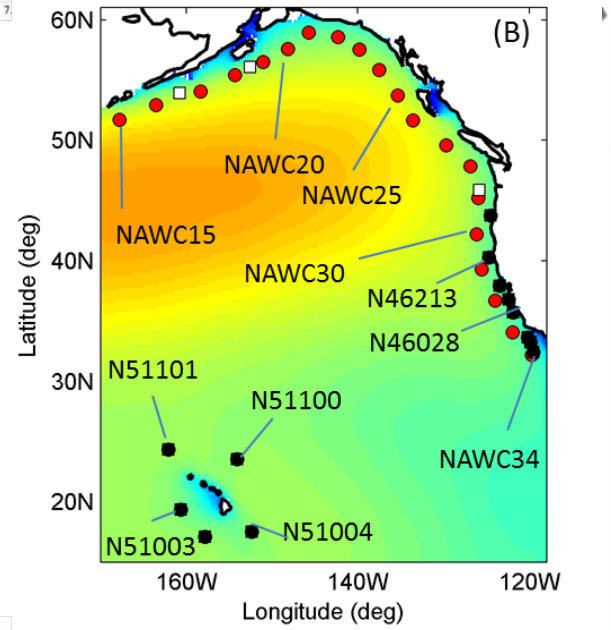
1 of 2

easily accessible set of estimated wave return periods for the 21st century

- 5-year interval return periods of bulk wave statistics (H_s, T_p, D_p) at 33 deep-water stations along the US and Canadian west coasts and Hawaii
- For two climate scenarios: RCP4.5 and RCP8.5

RCP 4.5

ID	lat (DD, N)	lon (DD,W)	median	RP = 1	(+/-)	RP = 5	(+/-)	RP = 10	(+/-)	RP = 15	(+/-)	RP = 20	(+/-)	RP = 25	(+/-)	RP = 30	(+/-)	RP = 35
46028	35.741	121.884	2.51	6.37	0.53	7.58	1.26	7.99	1.61	8.21	1.83	8.35	1.98	8.46	2.10	8.54	2.20	8.6
46042	36.789	122.404	2.49	6.48	0.54	7.70	1.22	8.11	1.54	8.31	1.73	8.45	1.86	8.55	1.97	8.63	2.05	8.6
46047	32.403	119.536	2.40	5.76	0.46	6.86	1.12	7.26	1.47	7.48	1.68	7.62	1.84	7.73	1.97	7.82	2.08	7.9
46069	33.670	120.200	2.16	5.38	0.45	6.46	1.10	6.85	1.42	7.06	1.63	7.19	1.78	7.30	1.90	7.38	1.99	7.4
46213	40.294	124.740	2.90	7.72	0.59	9.22	1.42	9.75	1.83	10.03	2.08	10.22	2.26	10.36	2.41	10.47	2.53	10.57
46214	37.945	123.470	2.69	6.98	0.54	8.29	1.27	8.74	1.62	8.97	1.83	9.13	1.98	9.24	2.10	9.33	2.20	9.4
46219	33.221	119.882	2.27	5.59	0.47	6.71	1.17	7.11	1.53	7.33	1.76	7.48	1.93	7.60	2.06	7.68	2.18	7.7
46229	43.769	124.551	2.88	7.70	0.53	9.19	1.31	9.74	1.71	10.04	1.96	10.24	2.14	10.40	2.29	10.52	2.41	10.6
51000	23.546	154.056	3.18	6.85	0.53	8.13	1.33	8.60	1.74	8.85	2.00	9.03	2.19	9.16	2.34	9.26	2.46	9.3
51002	17.094	157.808	2.91	5.45	0.34	6.39	0.95	6.79	1.31	7.01	1.55	7.17	1.74	7.29	1.89	7.39	2.03	7.4
51003	19.348	160.621	2.90	5.91	0.40	6.88	1.00	7.23	1.31	7.42	1.50	7.56	1.64	7.65	1.76	7.73	1.86	7.8
51004	17.525	152.382	2.79	5.39	0.40	6.41	1.12	6.83	1.53	7.06	1.81	7.23	2.03	7.36	2.20	7.46	2.36	7.5
51101	24.321	162.058	3.21	7.38	0.59	8.77	1.41	9.25	1.81	9.50	2.05	9.67	2.23	9.80	2.36	9.90	2.48	9.9
NAWC15	51.725	167.783	3.51	10.31	0.77	12.16	1.84	12.80	2.36	13.14	2.68	13.37	2.91	13.54	3.10	13.67	3.25	13.78
NAWC16	52.928	163.523	3.30	10.00	0.78	11.79	1.89	12.41	2.45	12.75	2.80	12.97	3.05	13.14	3.25	13.27	3.41	13.3
NAWC17	54.065	158.329	3.31	9.86	0.76	11.55	1.86	12.15	2.41	12.46	2.74	12.67	2.99	12.83	3.18	12.95	3.34	13.0
NAWC18	55.431	154.374	3.12	9.40	0.69	10.93	1.63	11.45	2.09	11.72	2.36	11.90	2.56	12.03	2.72	12.13	2.85	12.2
NAWC19	56.515	151.079	3.11	9.32	0.62	10.85	1.43	11.36	1.80	11.63	2.03	11.80	2.19	11.93	2.31	12.03	2.41	12.1
NAWC20	57.575	148.187	3.08	9.31	0.62	10.80	1.46	11.32	1.86	11.59	2.10	11.76	2.27	11.90	2.41	12.00	2.52	12.0
NAWC21	58.956	145.753	2.74	8.91	0.64	10.38	1.51	10.88	1.93	11.14	2.20	11.32	2.39	11.45	2.54	11.56	2.67	11.6
NAWC22	58.563	142.342	2.93	9.14	0.65	10.75	1.48	11.30	1.87	11.59	2.10	11.78	2.28	11.92	2.41	12.03	2.52	12.1
NAWC23	57.563	139.846	3.07	9.43	0.69	11.13	1.62	11.71	2.07	12.02	2.34	12.23	2.54	12.38	2.70	12.50	2.83	12.6
NAWC24	55.867	137.520	3.30	9.87	0.76	11.61	1.78	12.20	2.27	12.52	2.56	12.73	2.78	12.89	2.95	13.01	3.09	13.1
NAWC25	53.714	135.338	3.55	10.26	0.79	12.15	1.95	12.83	2.55	13.19	2.92	13.44	3.20	13.62	3.43	13.77	3.61	13.8
NAWC26	51.644	133.577	3.75	10.45	0.78	12.27	1.86	12.90	2.39	13.24	2.72	13.46	2.96	13.62	3.14	13.75	3.30	13.8
NAWC27	49.608	129.747	3.53	9.87	0.71	11.74	1.72	12.41	2.23	12.77	2.54	13.02	2.78	13.20	2.96	13.35	3.11	13.4
NAWC28	47.860	126.928	3.28	9														
NAWC29	45.232	126.006	3.24	8														
NAWC30	42.203	126.162	3.19	8														
NAWC31	39.278	125.558	3.02	7														
NAWC32	36.689	123.979	2.84															
NAWC33	34.075	121.975	2.67															



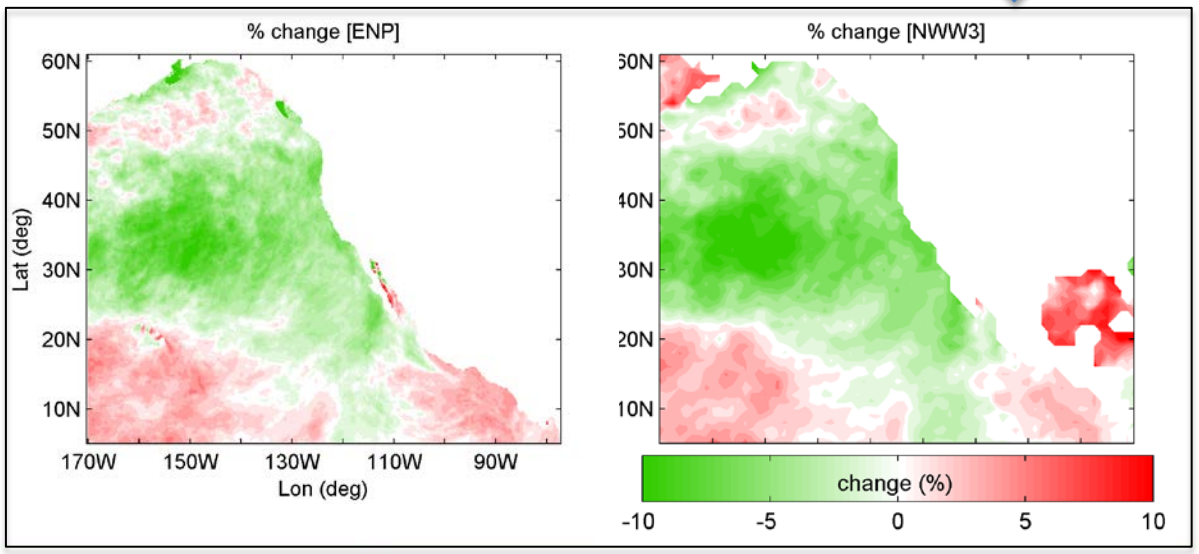
Results and conclusions

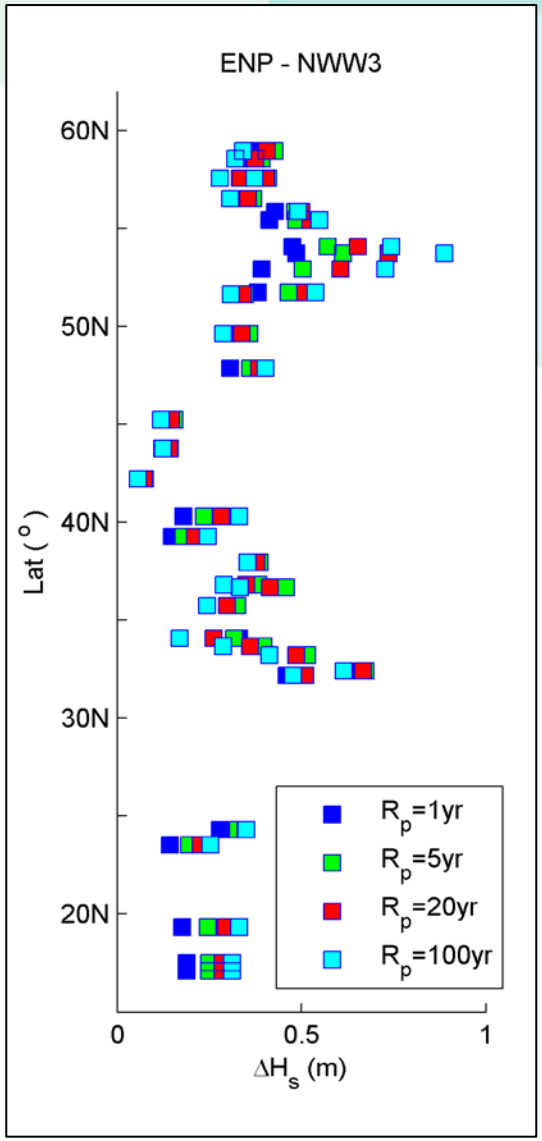
2 of 2

Added value of including ENP grid?

Yes for determining point-based extreme values.

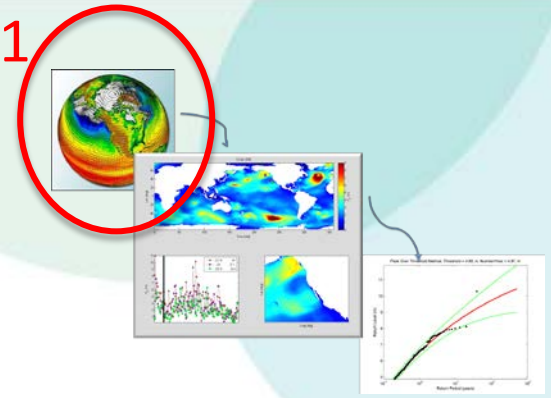
No for determining patterns and general changes.

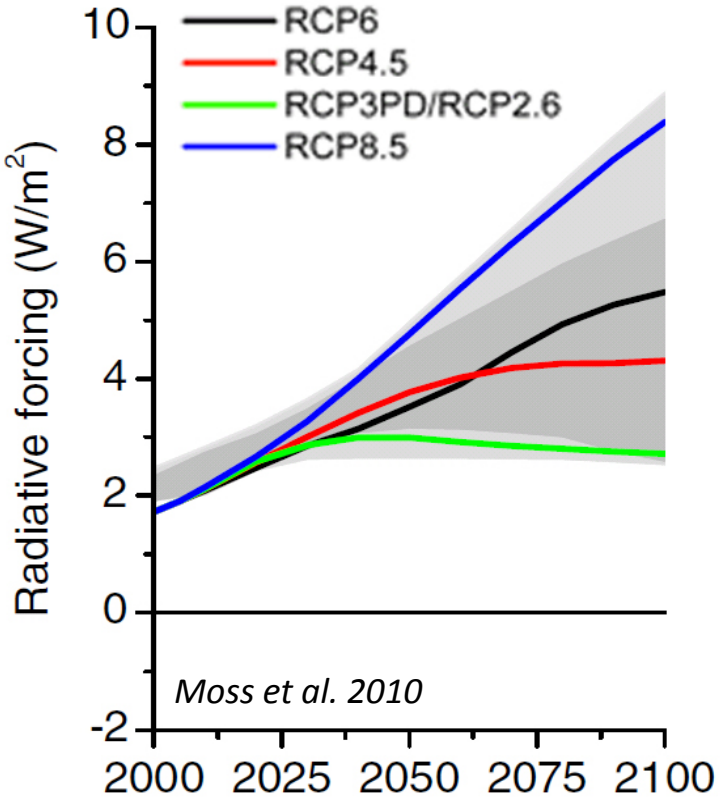




Methods

IPCC-AR5 Climate Change Scenarios





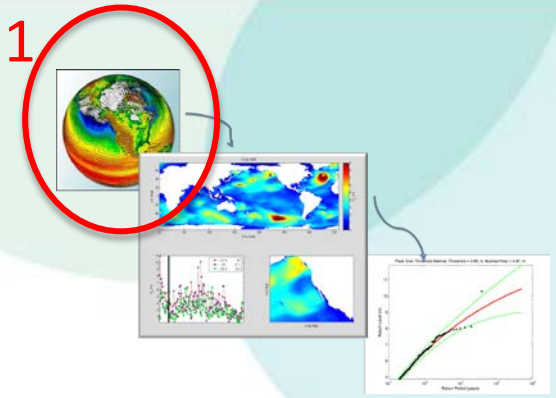
- Emission trajectories
- Labeled according to how much radiative forcing (W/m^2) would be produced by 2100
- Parallel development of climate models and socio-economic scenarios
- Contributions for IPCC AR5

RCP4.5 ~ SRES B1 (AR5) (AR3)

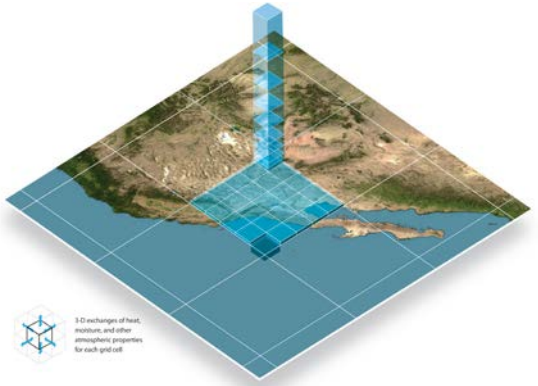
RCP8.5 ~ SRES A2 (AR5) (AR3)

Methods

IPCC-AR5 Climate Change Scenarios

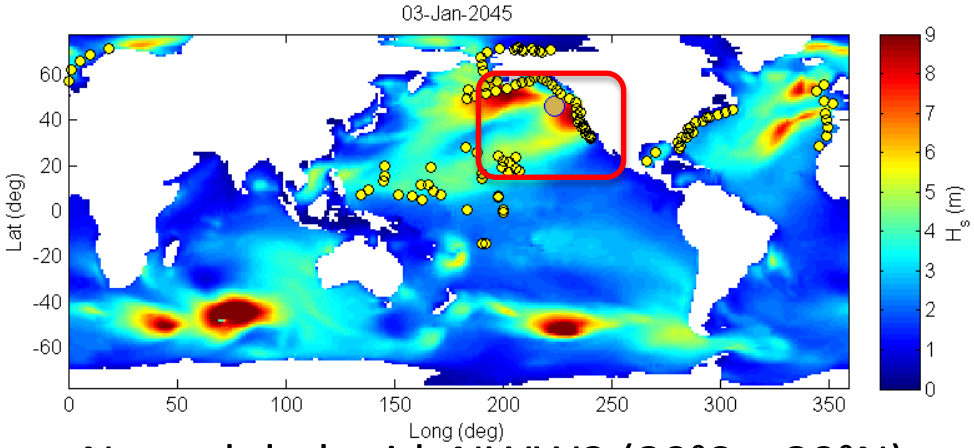


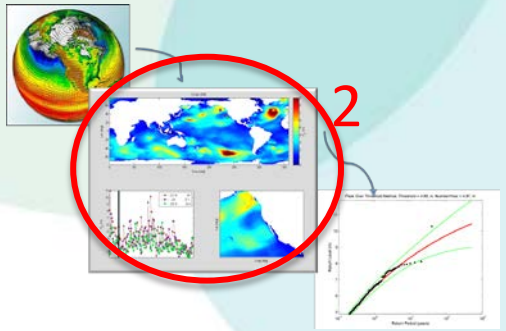
Modeling Center	model	GCM model resolution
Beijing Climate Center, Meteorological Administration, China (BCC)	BCC-CSM1.1	2.8^{o} x 2.8^{o}
Institute for Numerical Mathematics, Russia (INM)	INM-CM4	2^{o} x 1.5^{o}
Model for Interdisciplinary Research on Climate - AOEI, NIES, JAMSTEC, Japan (MIROC)	MIROC5	1.4^{o} x 1.4^{o}
NOAA Geophysical Fluid Dynamics Laboratory	GFDL-CM3	2.5^{o} x 1.5^{o}



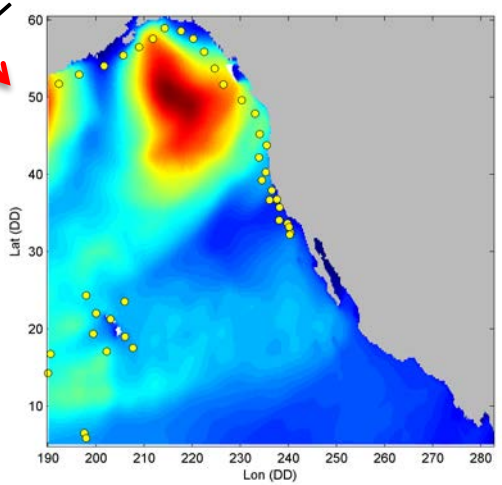
- 3 hourly winds converted to 10 m height
- Historical runs 1996-2006
- Projections
  - 2026-2045 & 2081-2100
  - RCP4.5 & RCP8.5

Methods – wave model





nested



Near global grid, NWW3 (80°S – 80°N)
1° x 1.25° spatial resolution

WavewatchIII version 3.14 (Tolman 1999)

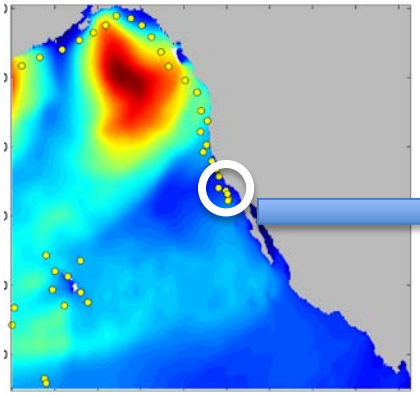
- Bathymetry and shoreline: DBDB2, v3.0 & GSHHS
- Wave spectra: 15° bins, 25 frequency bands from 0.04 to 0.5 Hz.

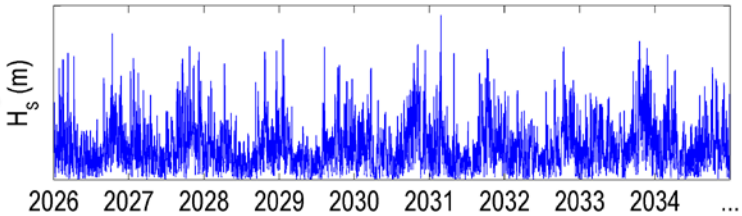
Data saved

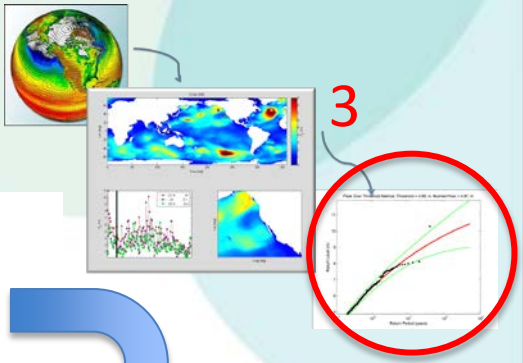
- Bulk parameters saved hourly at points coincident with deep water wave buoys and at ~300 km intervals along the U.S. and Canadian coasts
- Bulk parameters saved daily at each grid cell

Eastern North Pacific grid (ENP)
180°W to 130°W
0.25° spatial resolution (~27 km at latitude 37°N).

Methods – extreme value analysis





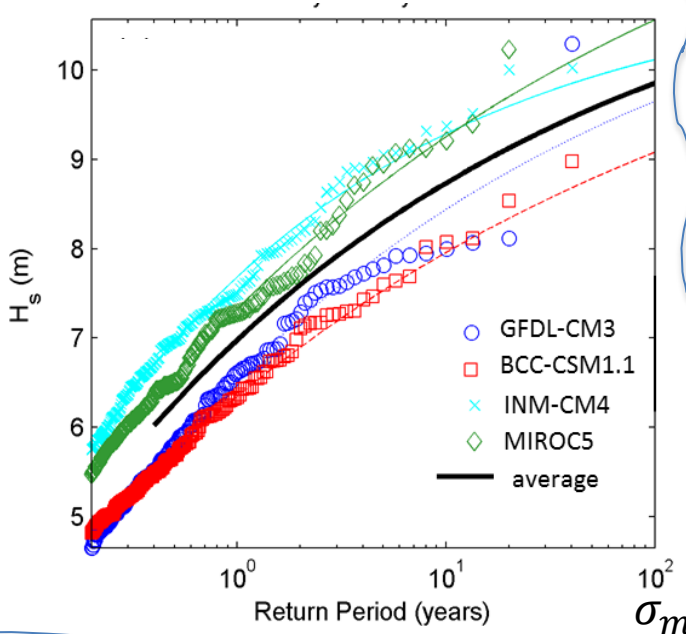


Select top 200 events at each station from each GCM run

GPD

$$F(x) = \begin{cases} [1 + \kappa\sigma^{-1}(x-u)]^{1/\kappa}; k \neq 0 \\ \exp(-(x-u)/\sigma);\ \kappa = 0 \end{cases}$$

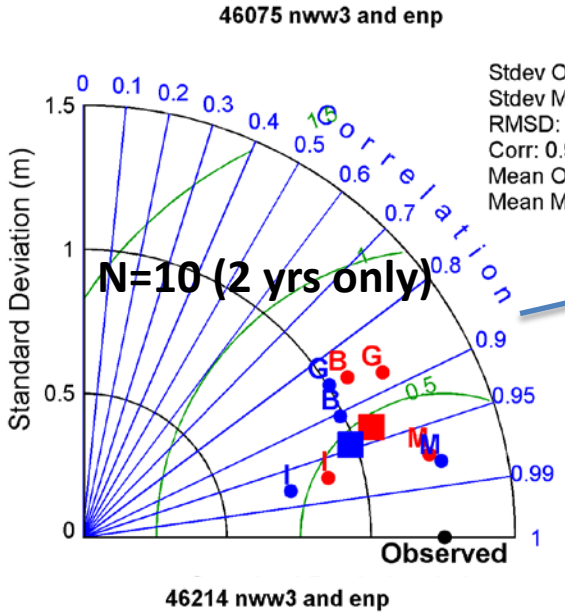
σ: scale parameter
κ: shape parameter
obtained by MLMs

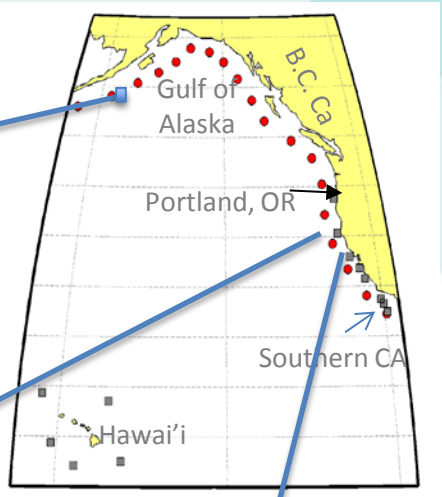


Mean of all 4 RP curves with uncertainty estimated with

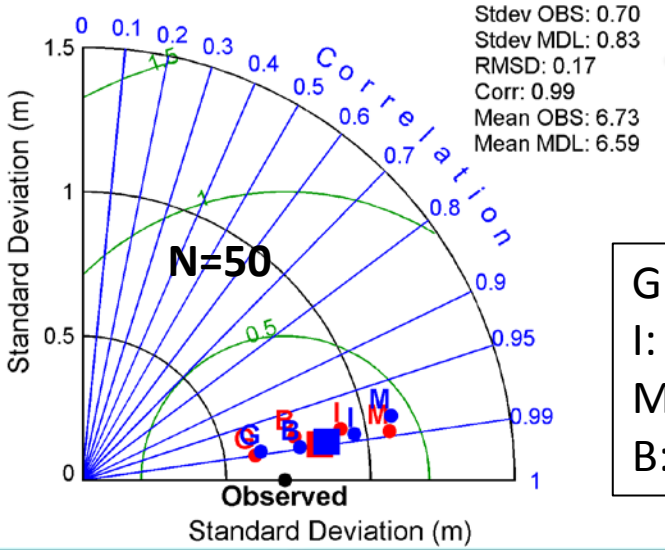
$$\sigma_m = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{\bar{x}})}{N-1}} N^{-0.5}$$

Model / data comparison

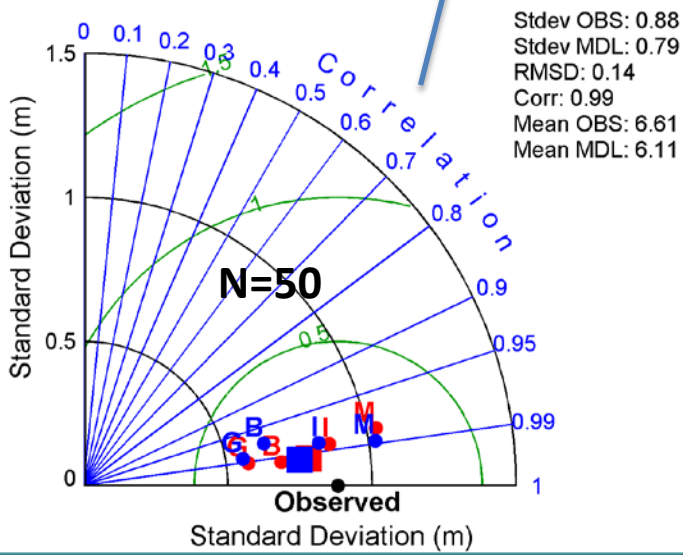




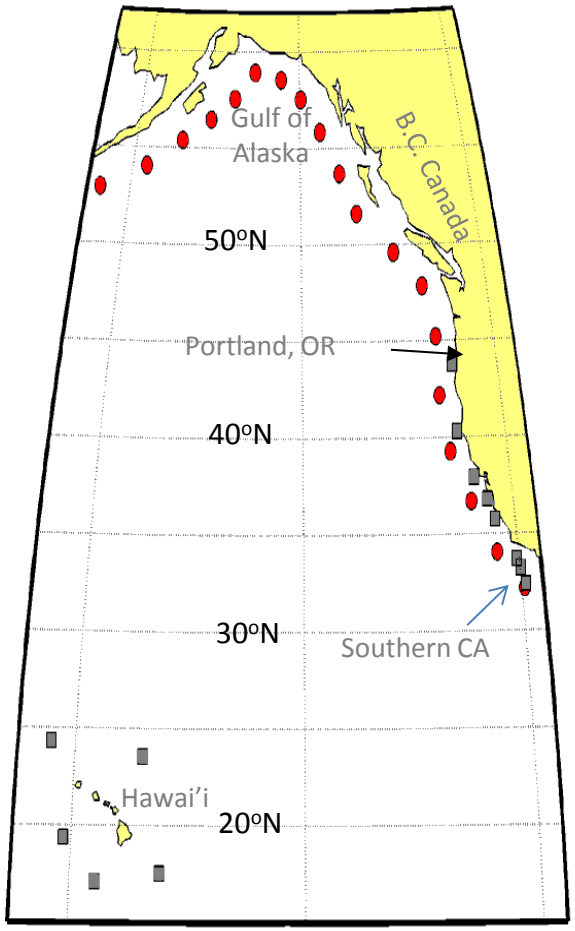
- NWW3 indiv. model
- ENP indiv. model
- multi-model avg.

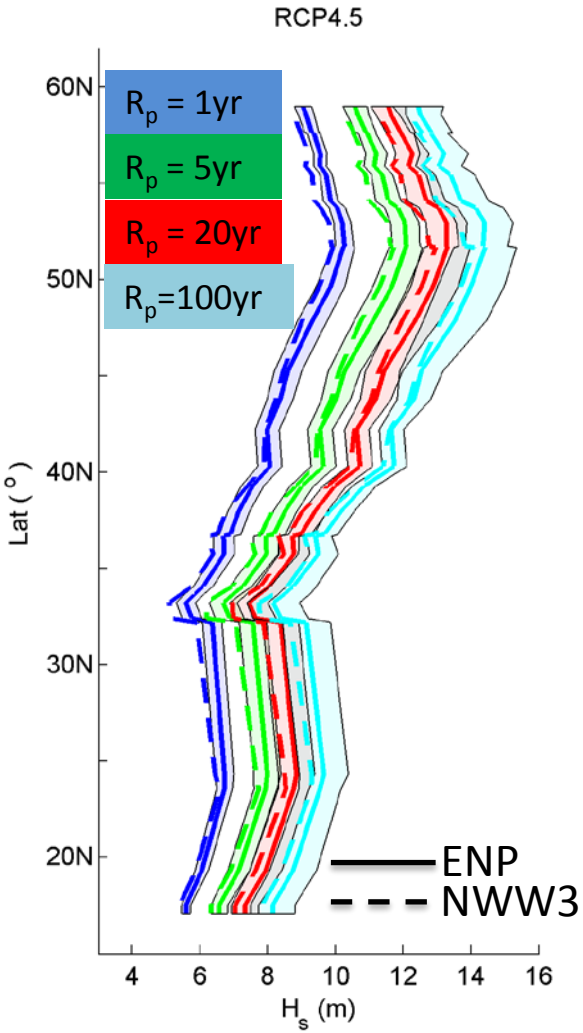


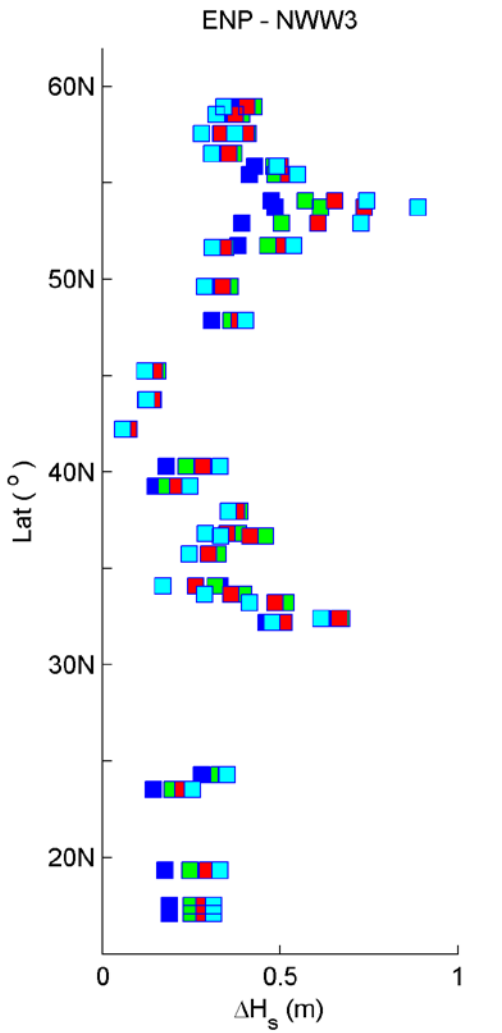
G: GFDL
I: INM
M: MIROC
B: BCC



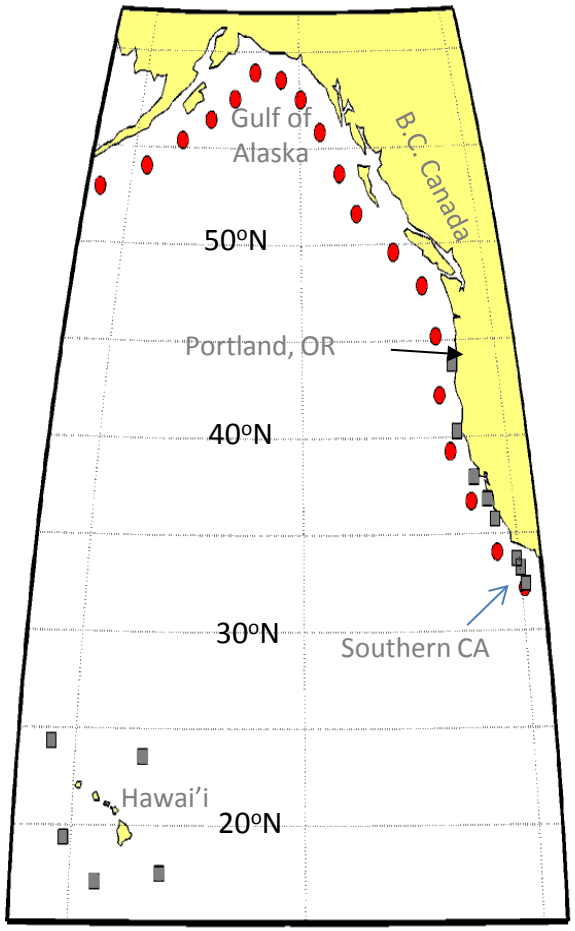
Results – objectives 1 & 2

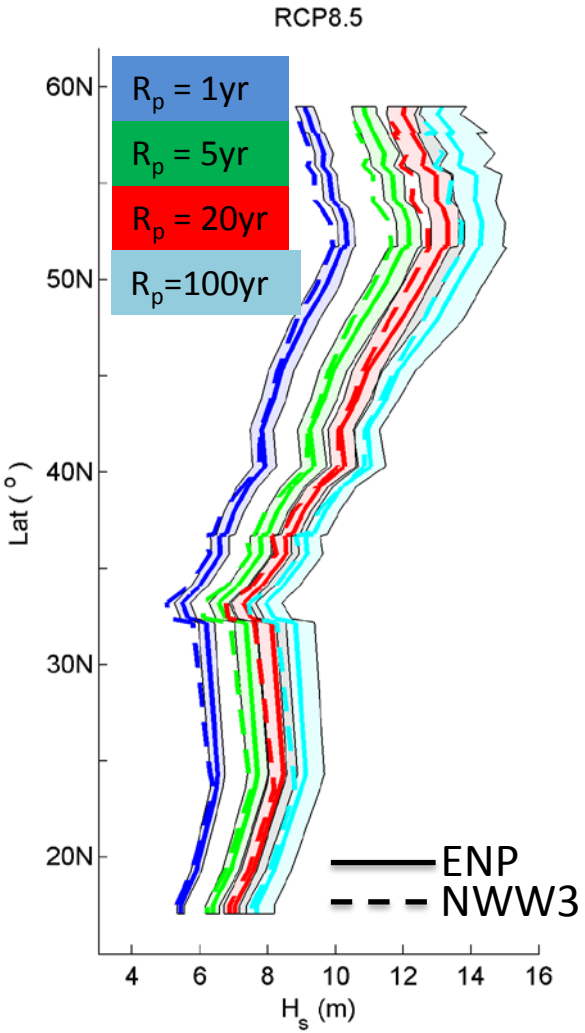


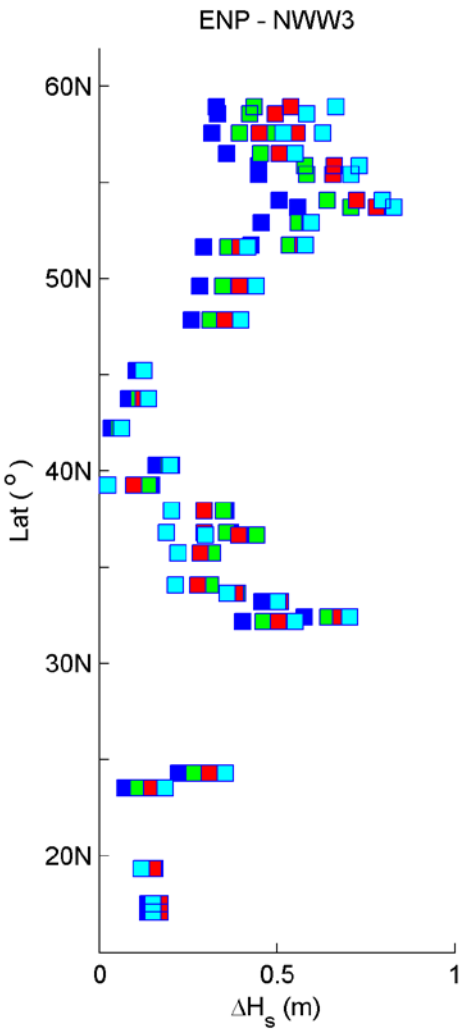




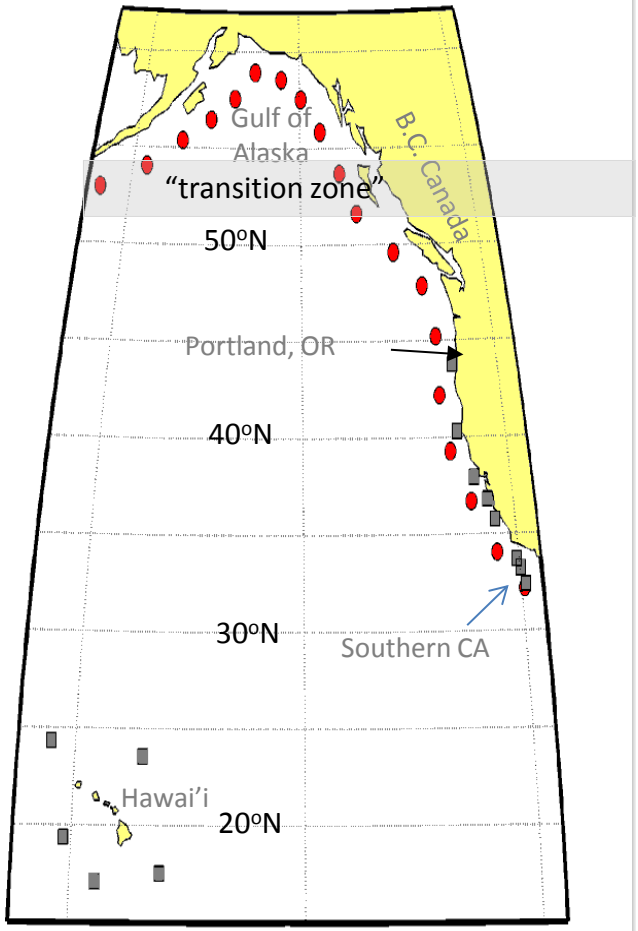
Results – objectives 1 & 2

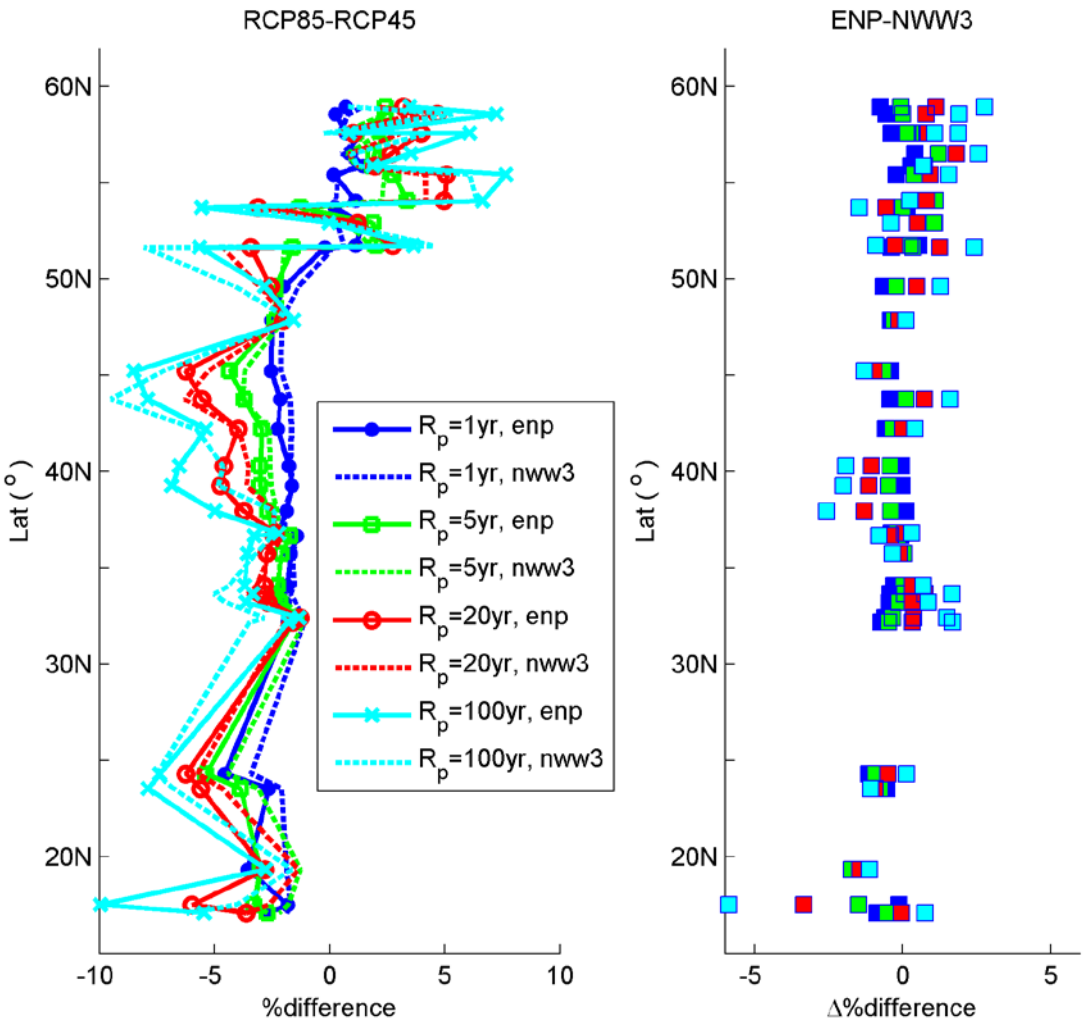




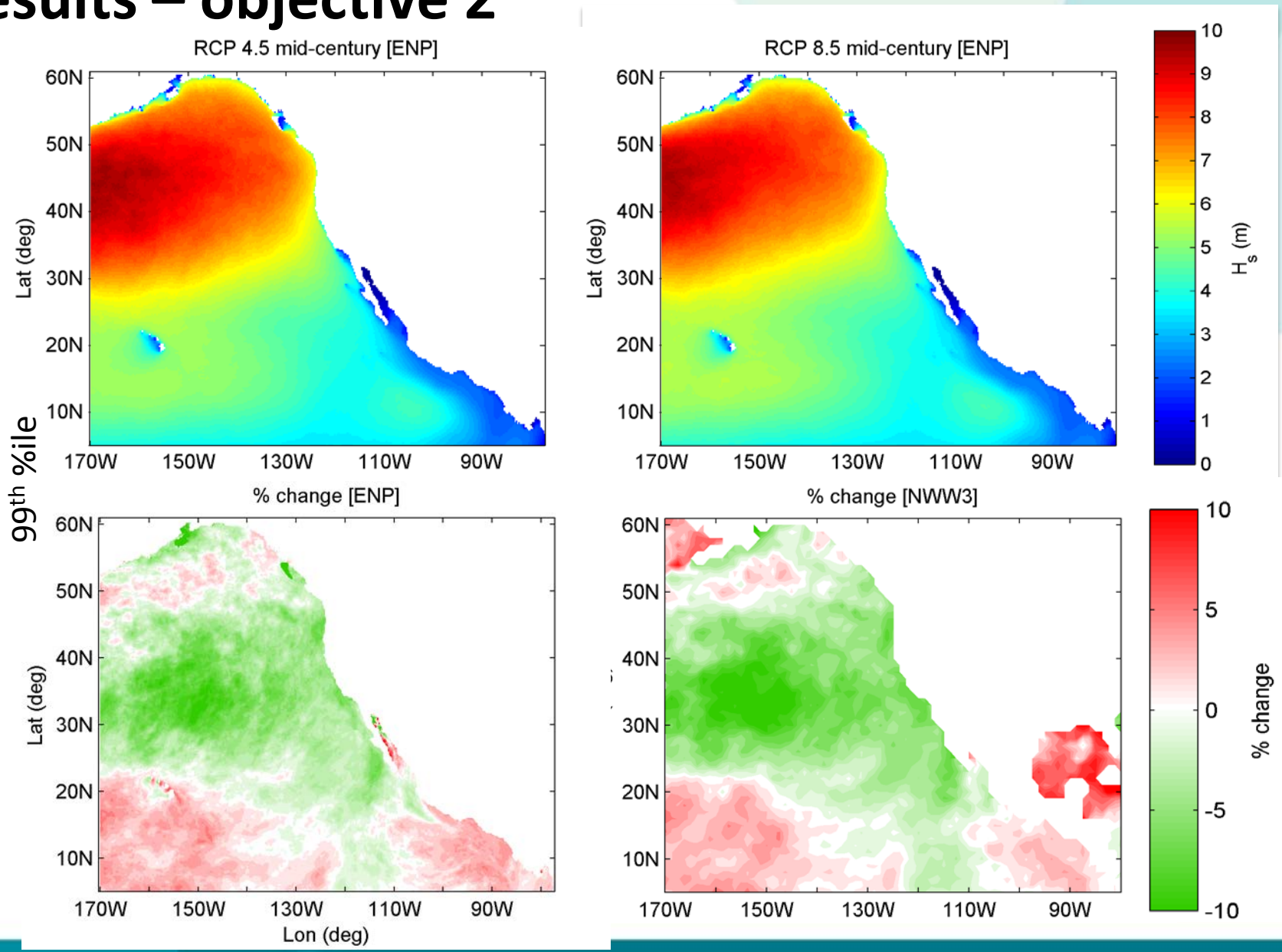


Results – objectives 1 & 2





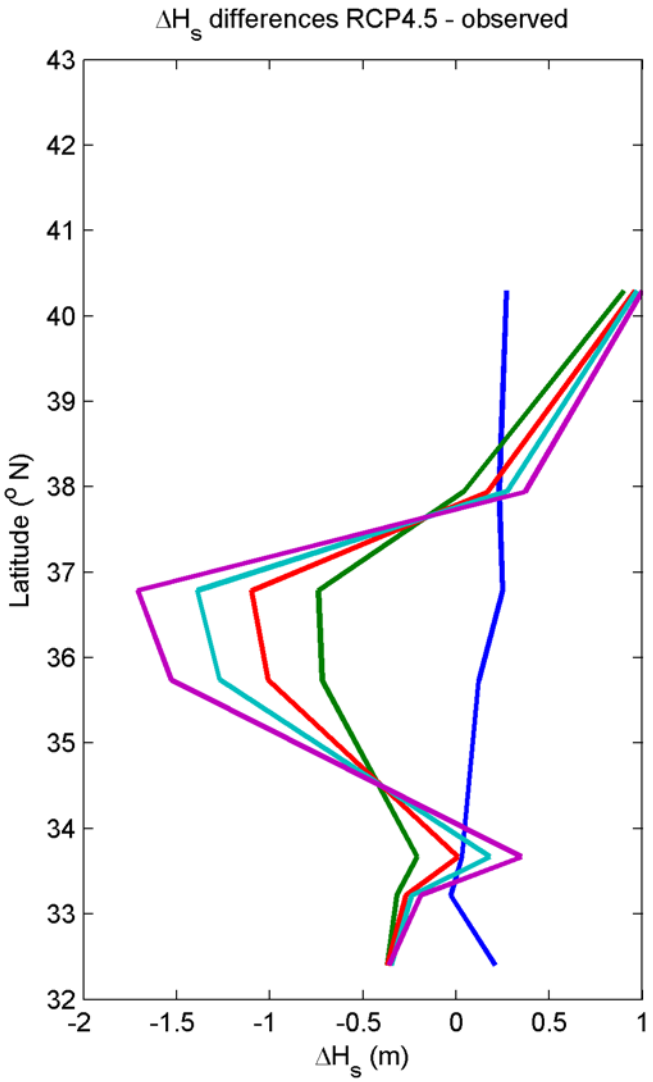
Results – objective 2



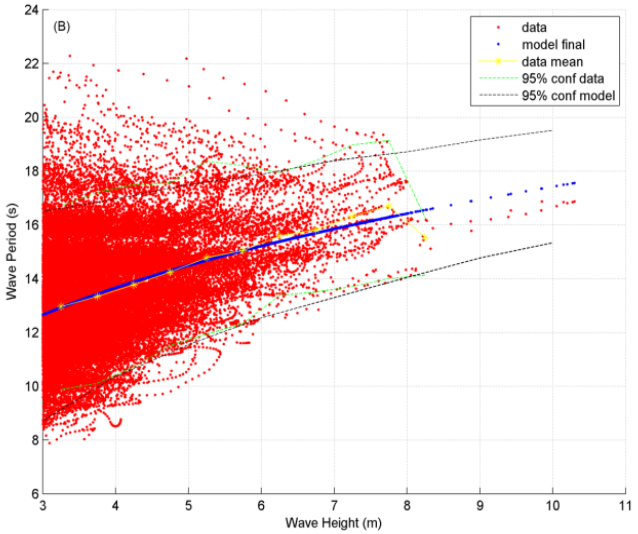
Results and conclusions

- Along the continental margins of HI and west coasts of U.S. and Canada, extreme SWHs of the 21st century are projected to show a latitudinal dependence (similar to present conditions) with a maximum 100yr return level of 14.5 ± 0.9m offshore of B.C. Canada.
- Comparison of the CMIP5 high (RCP8.5) and medium (RCP4.5) radiative climate scenarios indicate the presence of a transition zone at 52°N-54°N where the difference between projected SWHs (and T_p) changes sign.
    - South of the transition zone, RCP8.5, is expected to result in 10% lower SWHs compared to RCP4.5 for the 100 yr event. North of said transition zone, RCP 8.5 is expected to result in 8% higher 100 yr SWH. While values differ, trends are similar for all return periods.
- The use of a high resolution nested grid for estimation of extreme SWHs showed a difference of up to ~1m suggesting that for detailed extreme value analysis the additional computation time is worthwhile. However, when percent change is considered, particularly in a mapping manner, the trends and patterns are similar whether a coarse or finer grid is employed.

Thank you!

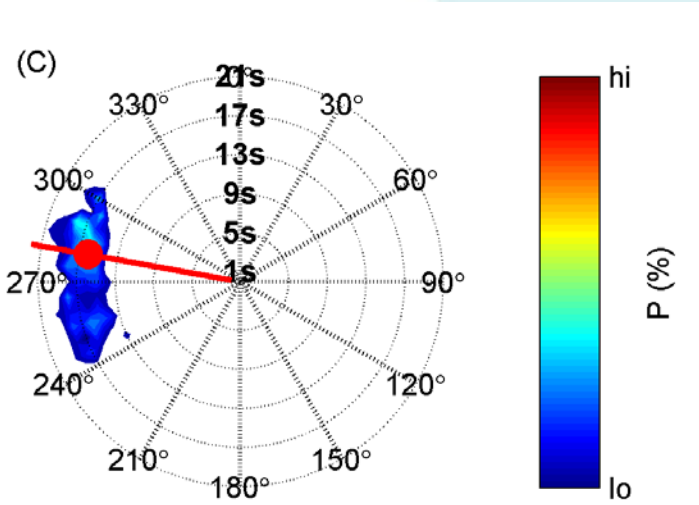

ΔH_s differences RCP4.5 - observed
Latitude (° N)
ΔH_s (m)
43
42
41
40
39
38
37
36
35
34
33
32
-2
-1.5
-1
-0.5
0
0.5
1

Methods –T_p & D_p associated with R_p SWH

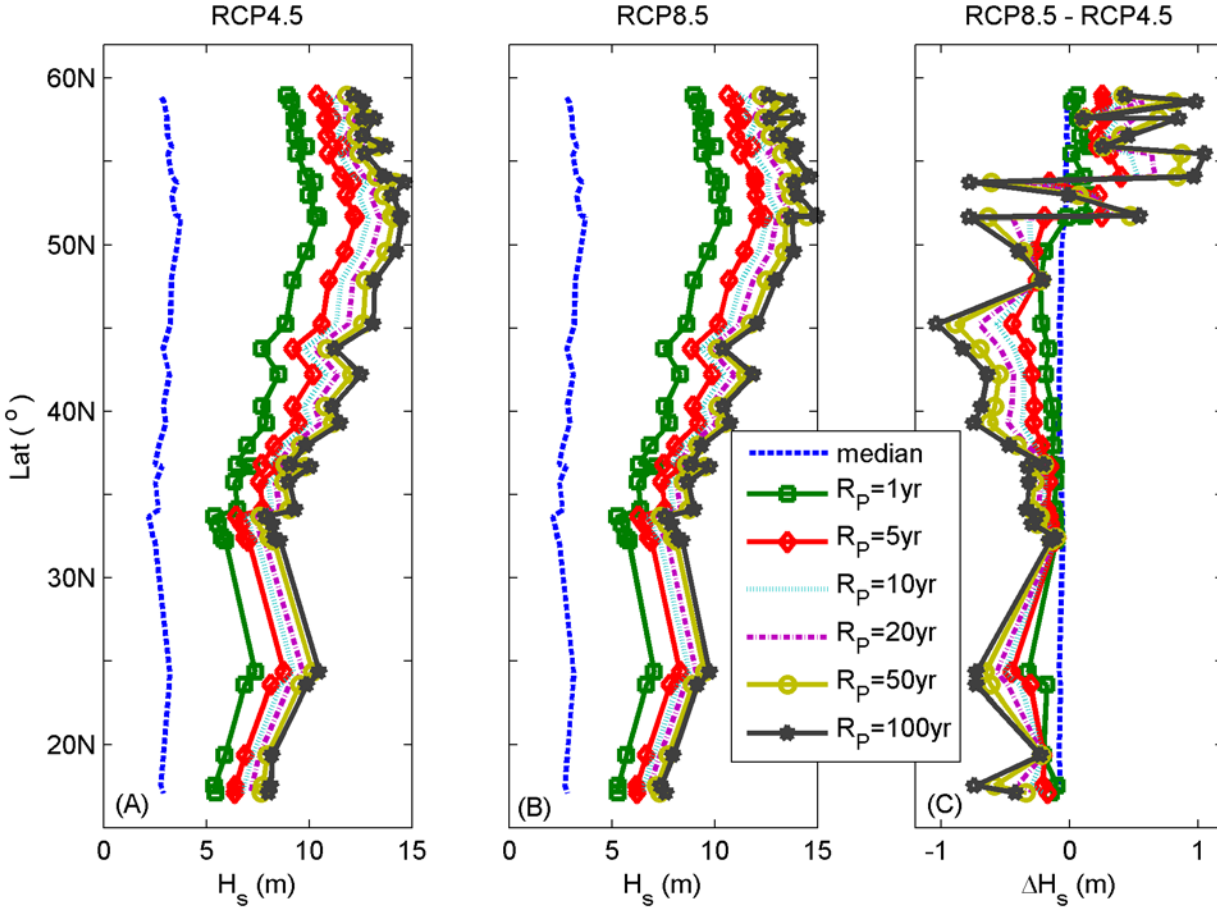


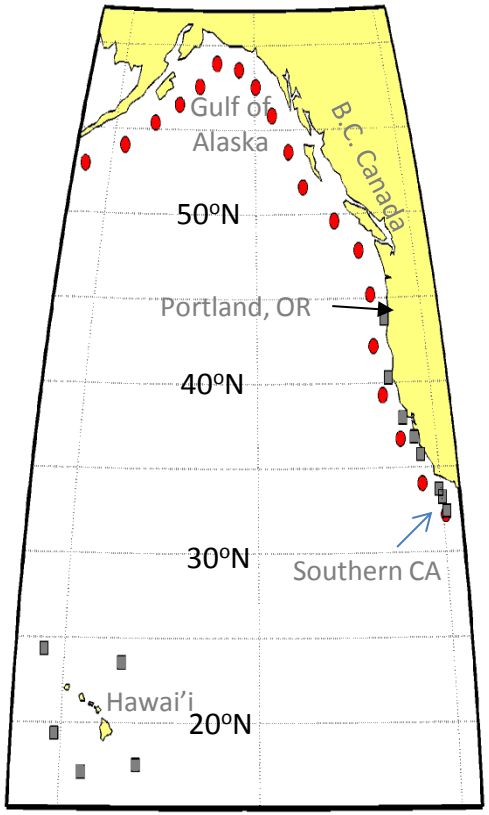
modified from Callaghan et al. 2008. T_p variability modeled with a normal distribution and μ & σ related to H_s

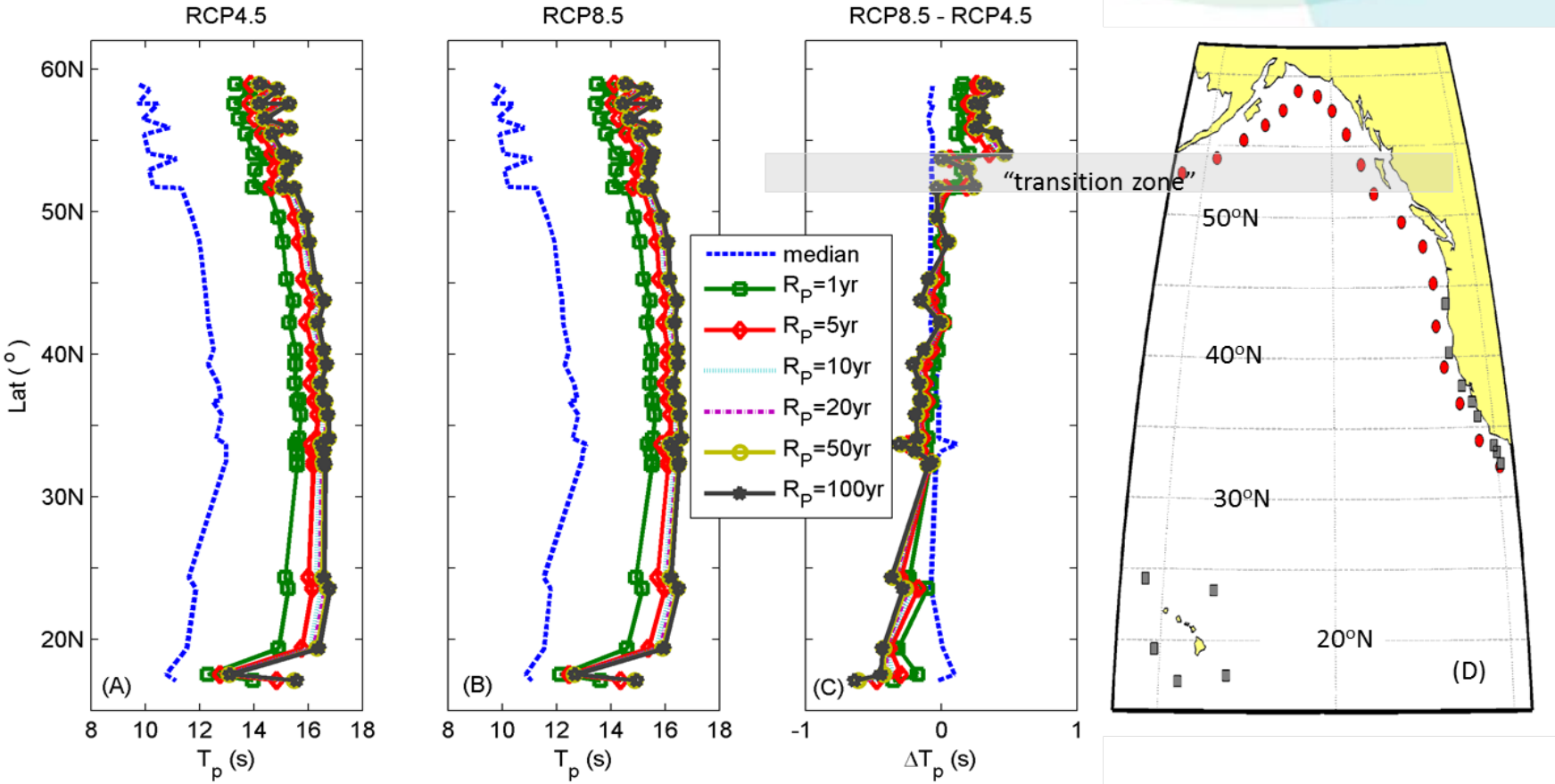
$$(\mu,\sigma) = (aH_s^b, \left(\frac{2c}{H_s}\right)^{.5})$$

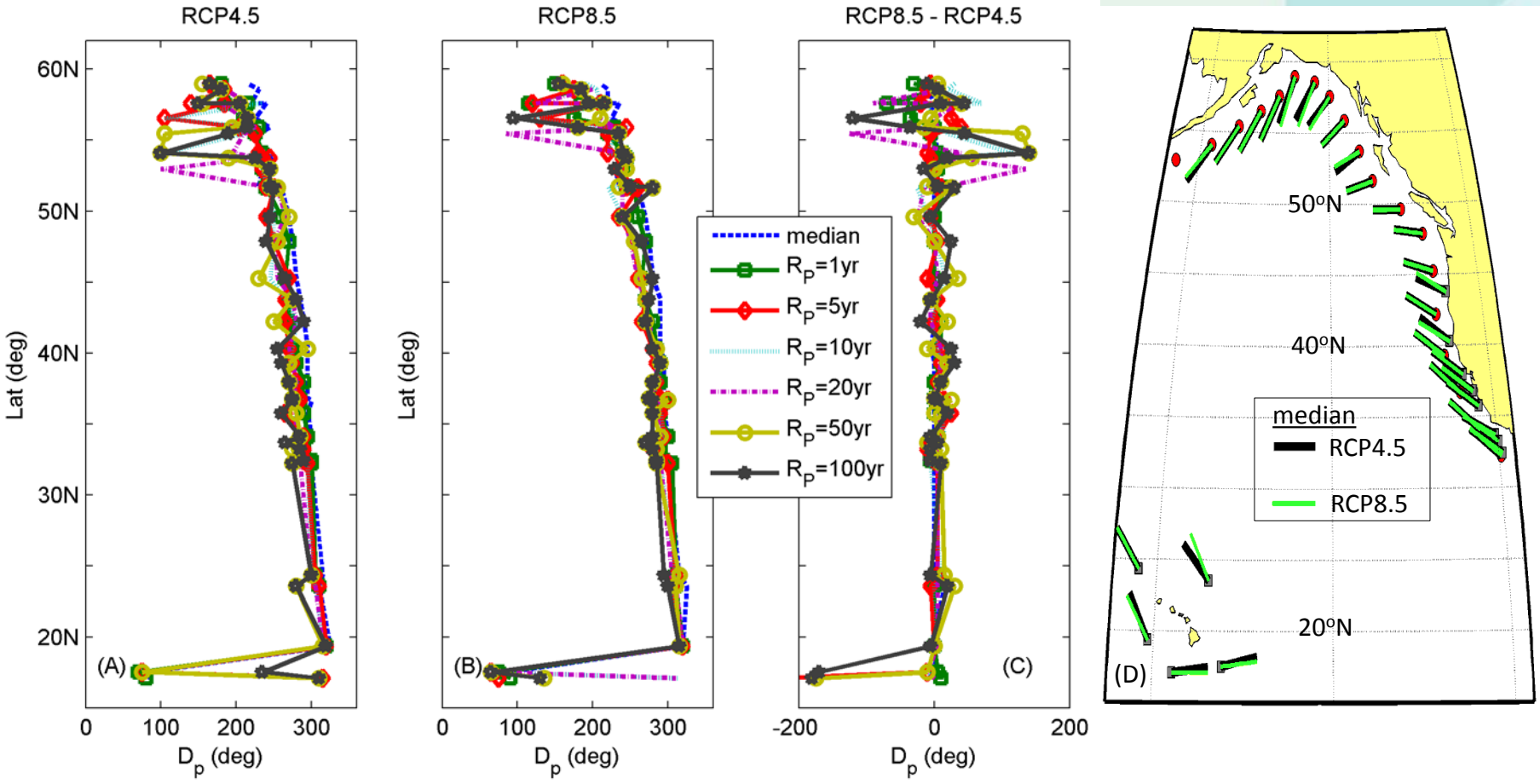


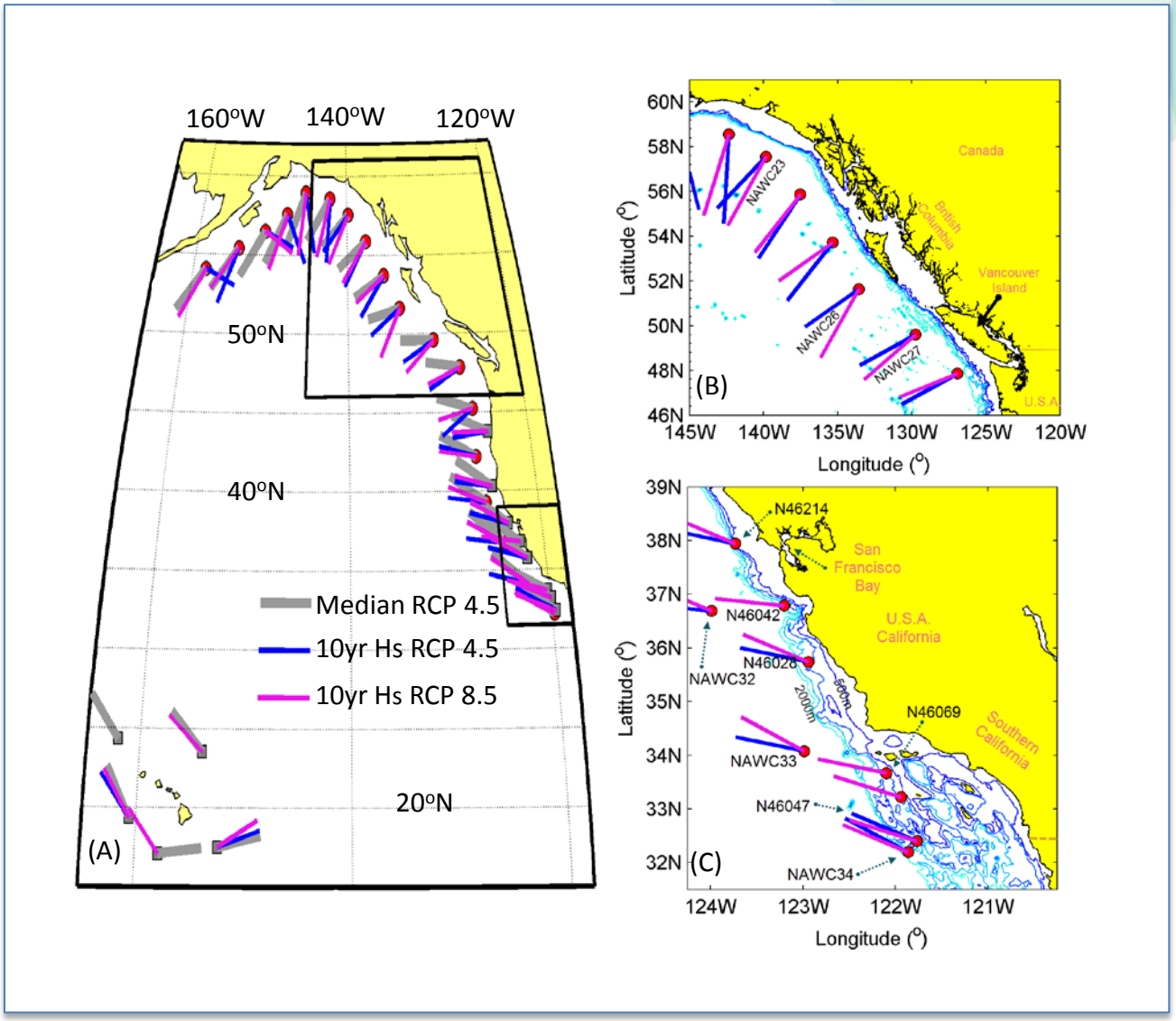
Dp found from joint probability of H_s (0.5m bins), T_p (2s bins), and D_p


RCP4.5
RCP8.5
RCP8.5 - RCP4.5
60N
50N
40N
30N
20N
Lat (°)
(A)
(B)
(C)
0
5
10
15
-1
0
1
H_s (m)
H_s (m)
ΔH_s (m)
median
R_P=1yr
R_P=5yr
R_P=10yr
R_P=20yr
R_P=50yr
R_P=100yr

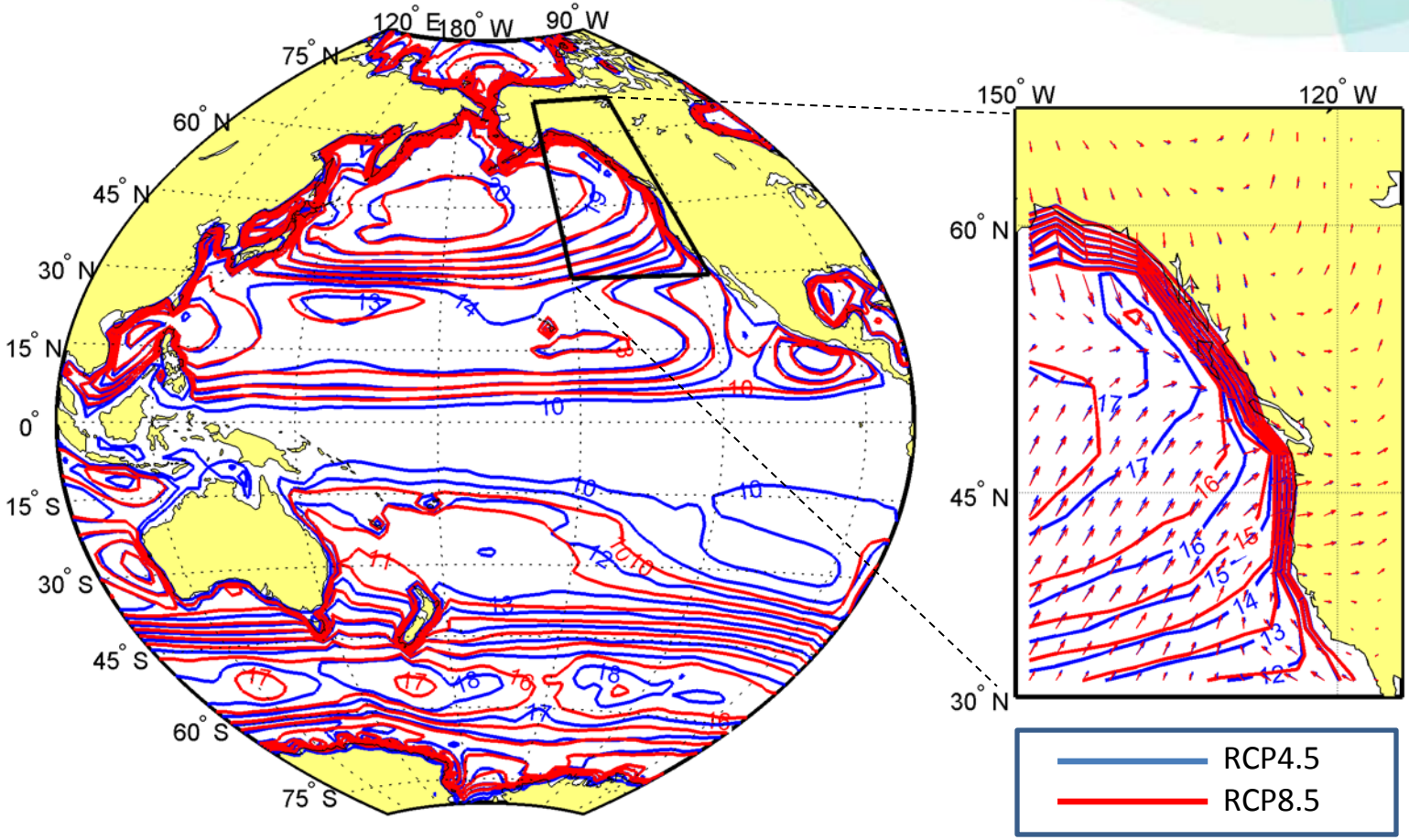

Gulf of Alaska
B.C. Canada
50°N
Portland, OR
40°N
30°N
Southern CA
Hawai'i
20°N


RCP4.5
RCP8.5
RCP8.5 - RCP4.5
60N
50N
40N
30N
20N
Lat (°)
(A)
(B)
(C)
8
10
12
14
16
18
-1
0
1
T_p (s)
ΔT_p (s)
median
R_P=1yr
R_P=5yr
R_P=10yr
R_P=20yr
R_P=50yr
R_P=100yr
"transition zone"
50°N
40°N
30°N
20°N
(D)

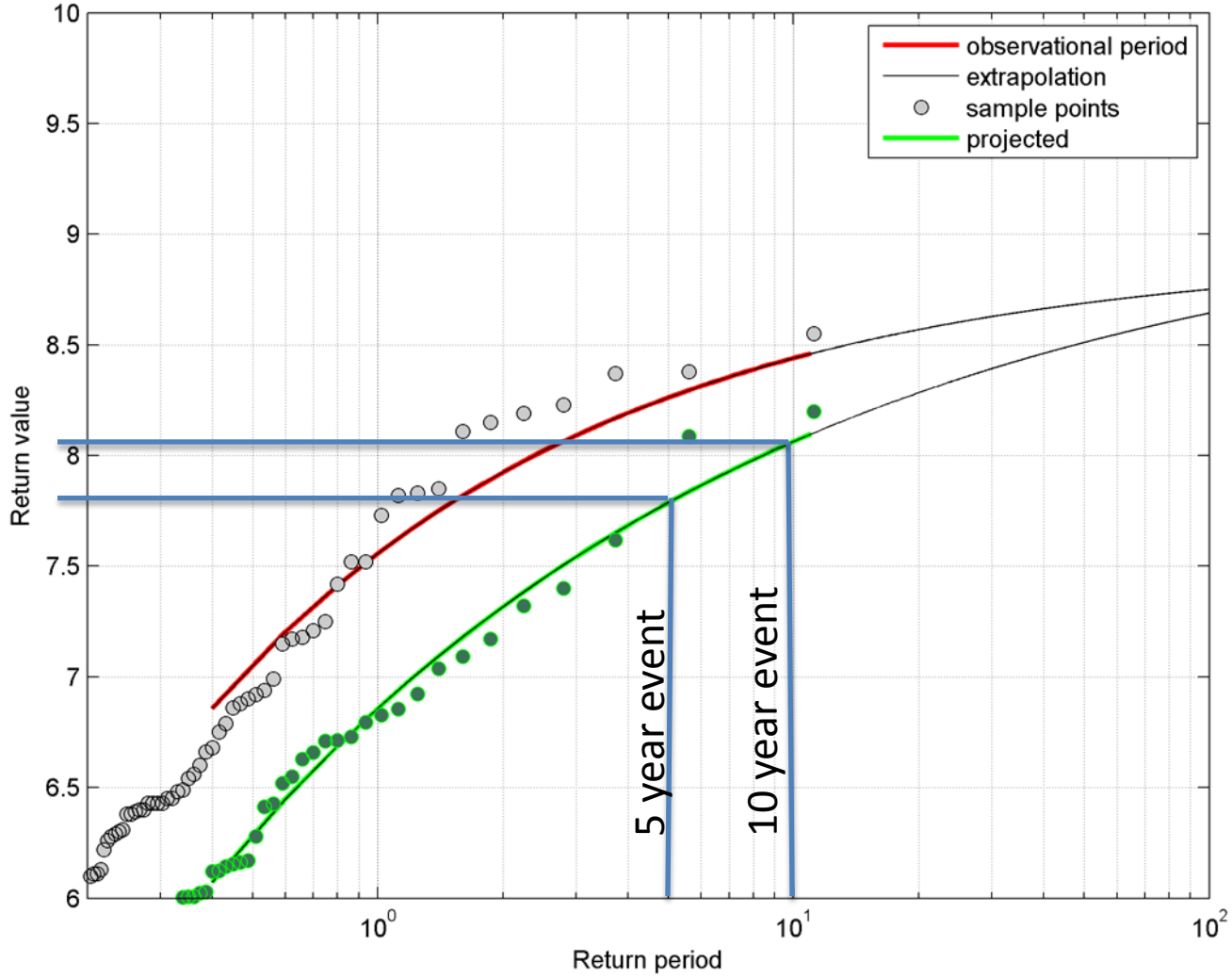

RCP4.5
RCP8.5
RCP8.5 - RCP4.5
60N
50N
40N
30N
20N
Lat (deg)
0
100
200
300
D_p (deg)
(A)
(B)
(C)
-200
median
R_P=1yr
R_P=5yr
R_P=10yr
R_P=20yr
R_P=50yr
R_P=100yr
50°N
40°N
20°N
median
RCP4.5
RCP8.5
(D)


160°W
140°W
120°W
50°N
40°N
20°N
(A)
Median RCP 4.5
10yr Hs RCP 4.5
10yr Hs RCP 8.5
60N
58N
56N
54N
52N
50N
48N
46N
Latitude (°)
Canada
British Columbia
Vancouver Island
NAWC23
NAWC26
NAWC27
U.S.A.
(B)
145W
140W
135W
130W
125W
120W
Longitude (°)
39N
38N
37N
36N
35N
34N
33N
32N
N46214
San Francisco Bay
N46042
U.S.A. California
N46028
NAWC32
200m
500m
N46069
Southern California
NAWC33
N46047
NAWC34
(C)
124W
123W
122W
121W
Longitude (°)

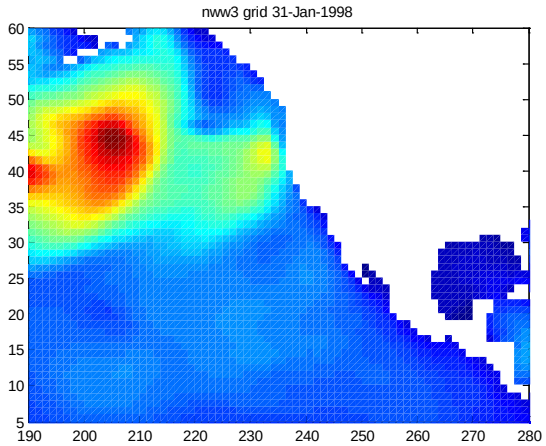
Projected 95th %ile winds for years 2026-2045 & 2081-2100

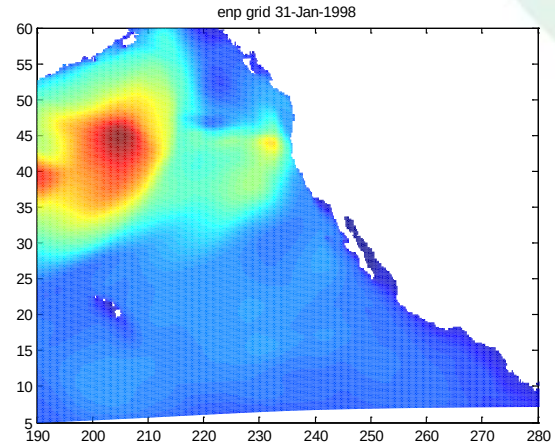


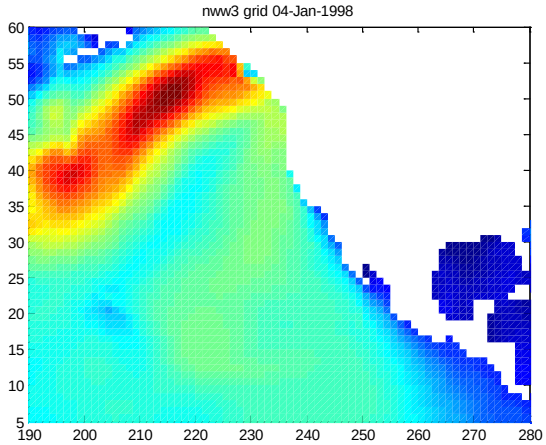
The 21st century wave climate for planning purposes

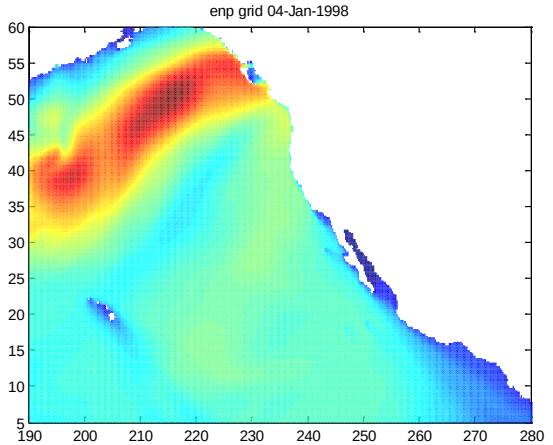


USGS









Global grid (nww3)

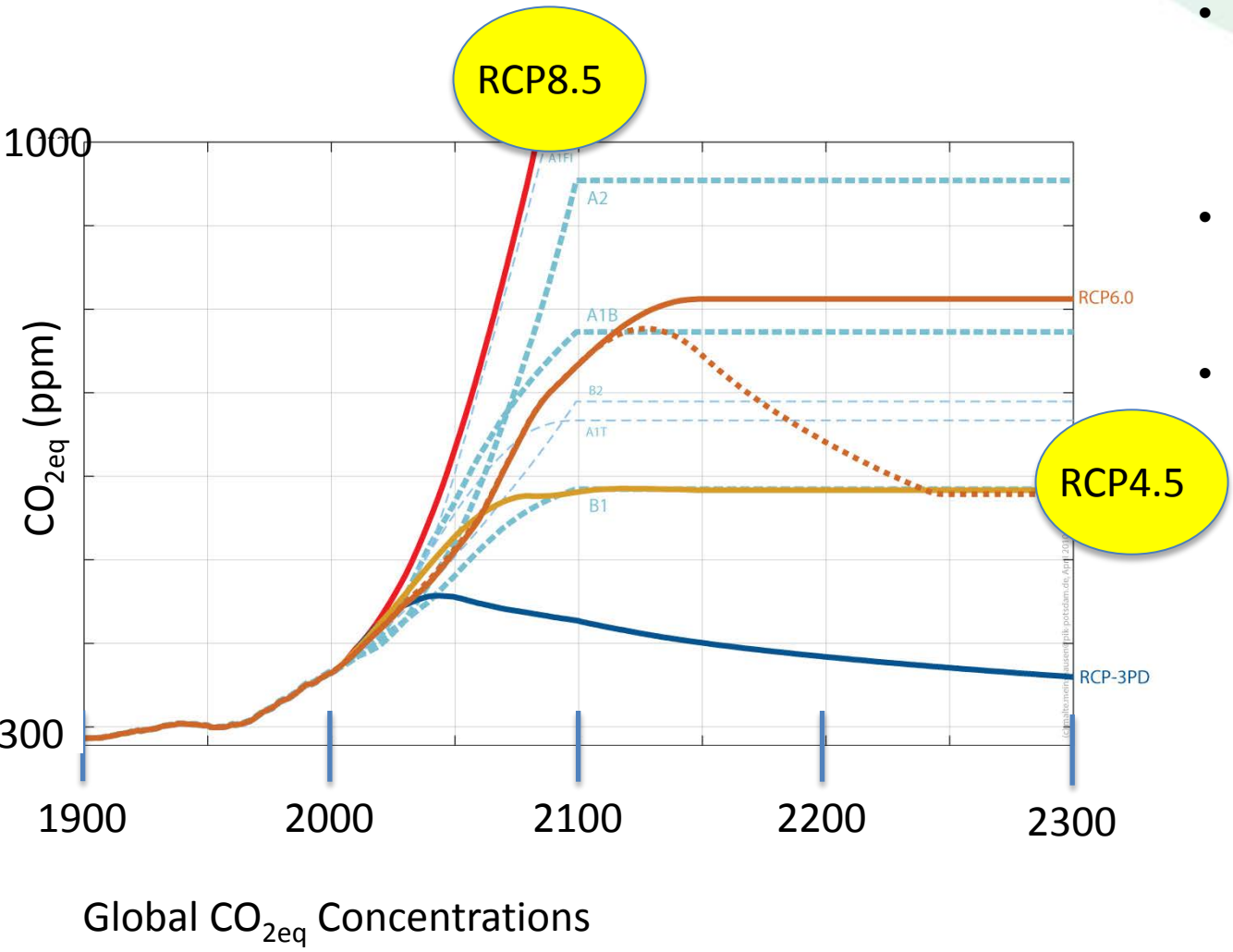
- 1.2° x 1° resolution

Eastern North Pacific Grid (enp)

- 0.25° resolution
- hourly outputs at observation stations
- daily map outputs
- Computation time
  - nww3: 3 hr/yr
  - enp: add another 6 hr/yr

50 years * 2 scenarios * 4 GCM models @ 3hrs/yr (nww3) or 9hrs/yr (nww3+enp)
nww3 grid: 1200 hrs (50 days)
nww3 + enp grid: 3600 hrs (150 days)

Climate Scenarios and Representative Concentration Pathways (RCPs)



Global CO_{2eq} Concentrations

- Emissions trajectories
- Labeled according to how much radiative forcing (W/m^2) would be produced at 2100
- Parallel development of climate models and socio-economic scenarios
- Contributions for IPCC AR5