ESA-MOST Dragon Cooperation

中国科技部-欧洲空间局“龙计划”合作

2017 DRAGON 4 SYMPOSIUM

2017年“龙计划”四期学术研讨会

SEMI-EMPIRICAL SIGNIFICANT WAVE HEIGHT RETRIEVAL USING SENTINEL-1 SAR IMAGERY

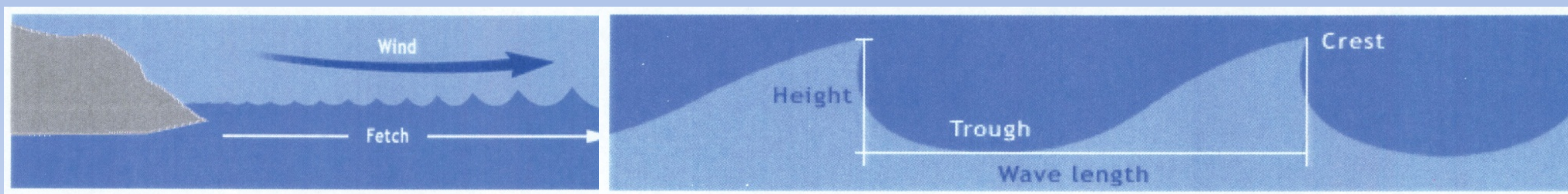
Fabian S. Pramudya, Jiayi Pan, Adam T. Devlin
The Chinese University of Hong Kong

26–30 June 2017 | Copenhagen, Denmark

2017年6月26-30日，丹麦 哥本哈根

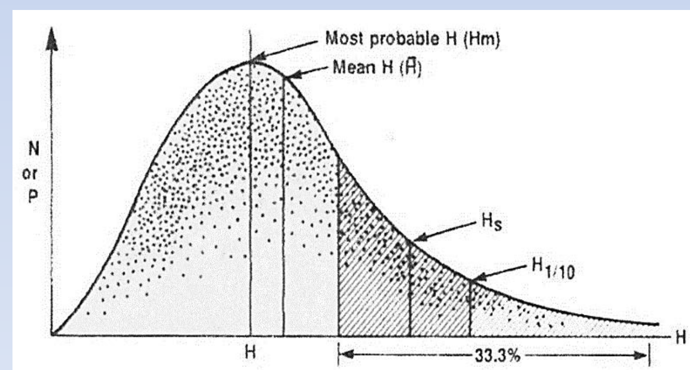
Background

Wave Formation and Dimension: Waves are formed by wind blowing along the water's surface. Wave height is dependent on a) wind speed; b) fetch length; and c) duration of time the wind blows consistently over the fetch.



Wave Pattern : Ocean waves can travel for thousands of miles. Waves that travel outside of their generation area and are no longer the result of the local wind are denoted "***swell***." Over time, swell groups will converge with other waves caused by distant storms traveling in different directions, which refract off coastlines.

Significant Wave Height (m) is calculated as the average of the highest one-third of all of the wave heights during the sampling period (http://www.ndbc.noaa.gov)

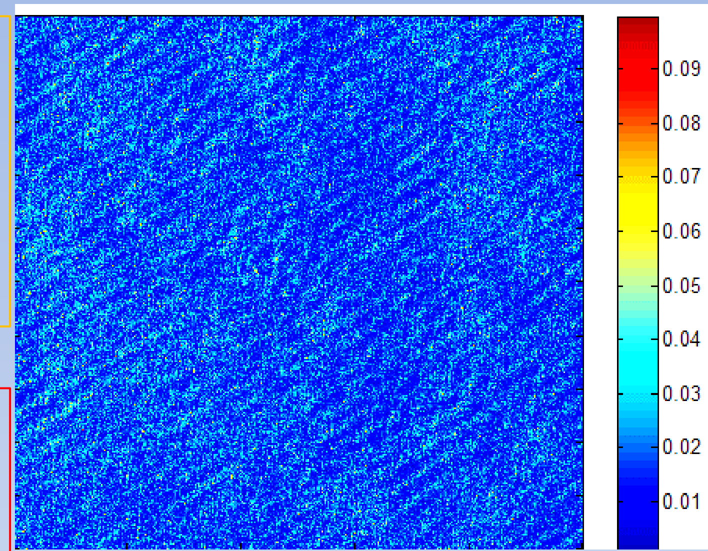


Contents are taken from:
http://www.vos.noaa.gov/MWL/apr_06/waves.shtml

SAR: Capturing the Wave

Why Synthetic Aperture Radar?
High spatial resolution, wide coverage, and high independency in any weather condition, and multi ocean surface parameters retrieval capability (wind, wave, internal wave, surface current;).

SAR and Significant Wave Height
In most SAR wave height retrieval schemes, the directional ocean wave spectrum is inverted from the SAR spectrum to compute wave height.



Normalized Radar Cross Section (NRCS/ σ_o) of a SAR Image

Theoretical retrieval technique: Max-Planck Institute (MPI), Semi-Parametric Retrieval Algorithm (SPRA), Partition Rescaling and Shift Algorithm (PARSA), and others
Empirical Algorithm: CWAVE, CWAVE_ENV
Unconstrained Algorithm: European Space Agency's Algorithm, Lyzenga Algorithm. Limited to long wave regime due to high wavenumber cut-off and shows compromising result with Sentinel I

Contents are taken using actual Sentinel 1-A; Data Visualized in Matlab

Objectives

Develop a New Approach :

Semi-empirical algorithm, applicable to various kinds of SAR data. Derive ocean surface wave height in ***non-extreme sea state, without prior knowledge*** and evaluate the dependency between Hw and local environment (wind forcing, geomorphologic feature, SAR system limitation, etc).

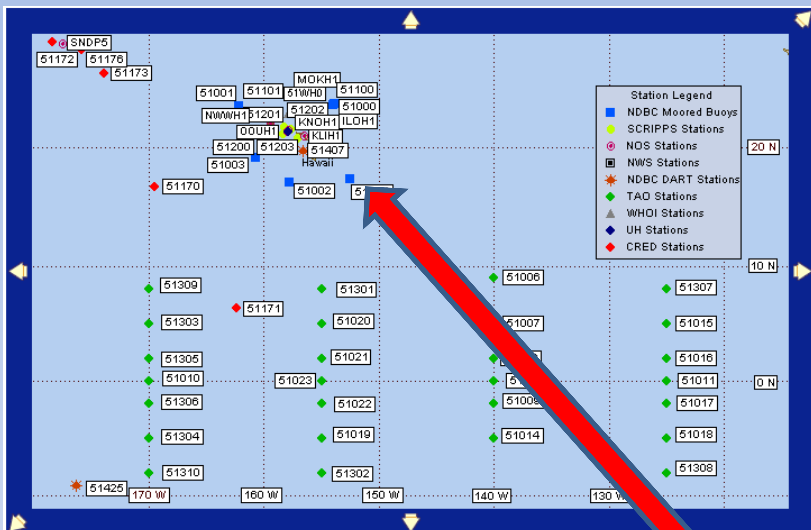
Research Objectives

1. Determination of ocean surface wave height using Sentinel-1 SAR datasets using this Semi-Empirical Algorithm
2. Propose a preliminary empirical update for the backscatter cross-section to incidence angle function for vertical polarization in a 5.405 GHz SAR system & necessary digital filtering method for better peak of dominant wavelength identification
3. Propose updated correction method for Bragg scattering and velocity bunching mechanism of ocean surface

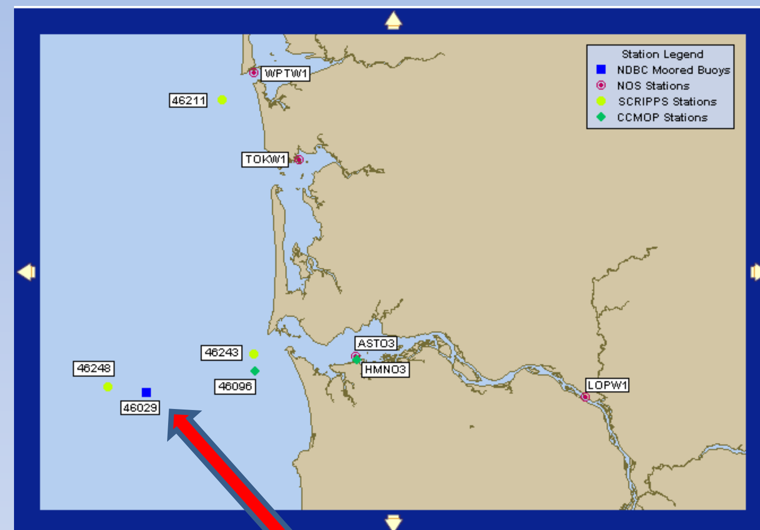
Area and Data

National Oceanic and Atmospheric Administration's
National Data Buoy Center
Center of Excellence in Marine Technology

Areas of Interest :
Hawaii and US West Coast



NDBC 51002, NDBC 51003, NDBC 51004
(Oct 2016 – Mar 2017)

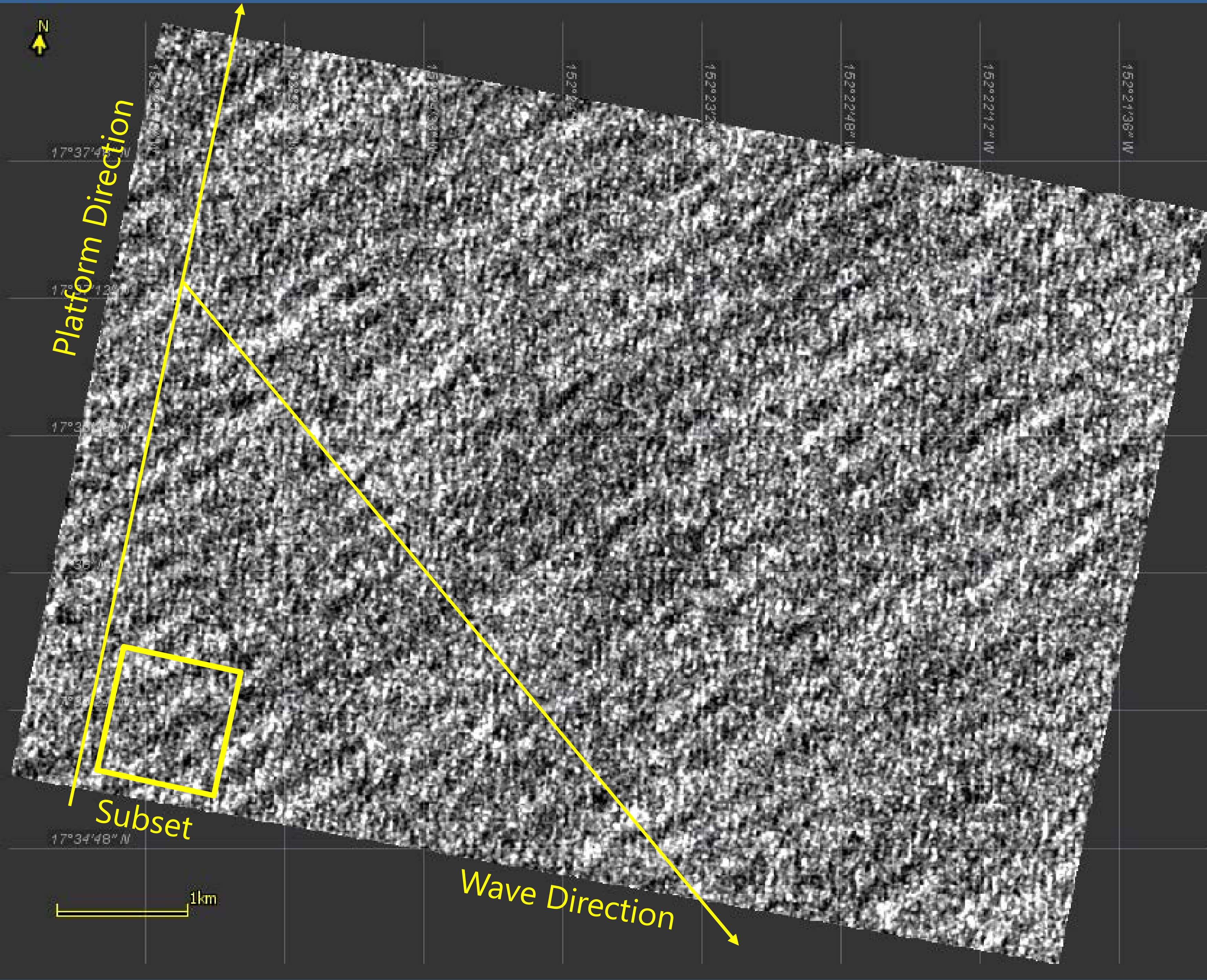


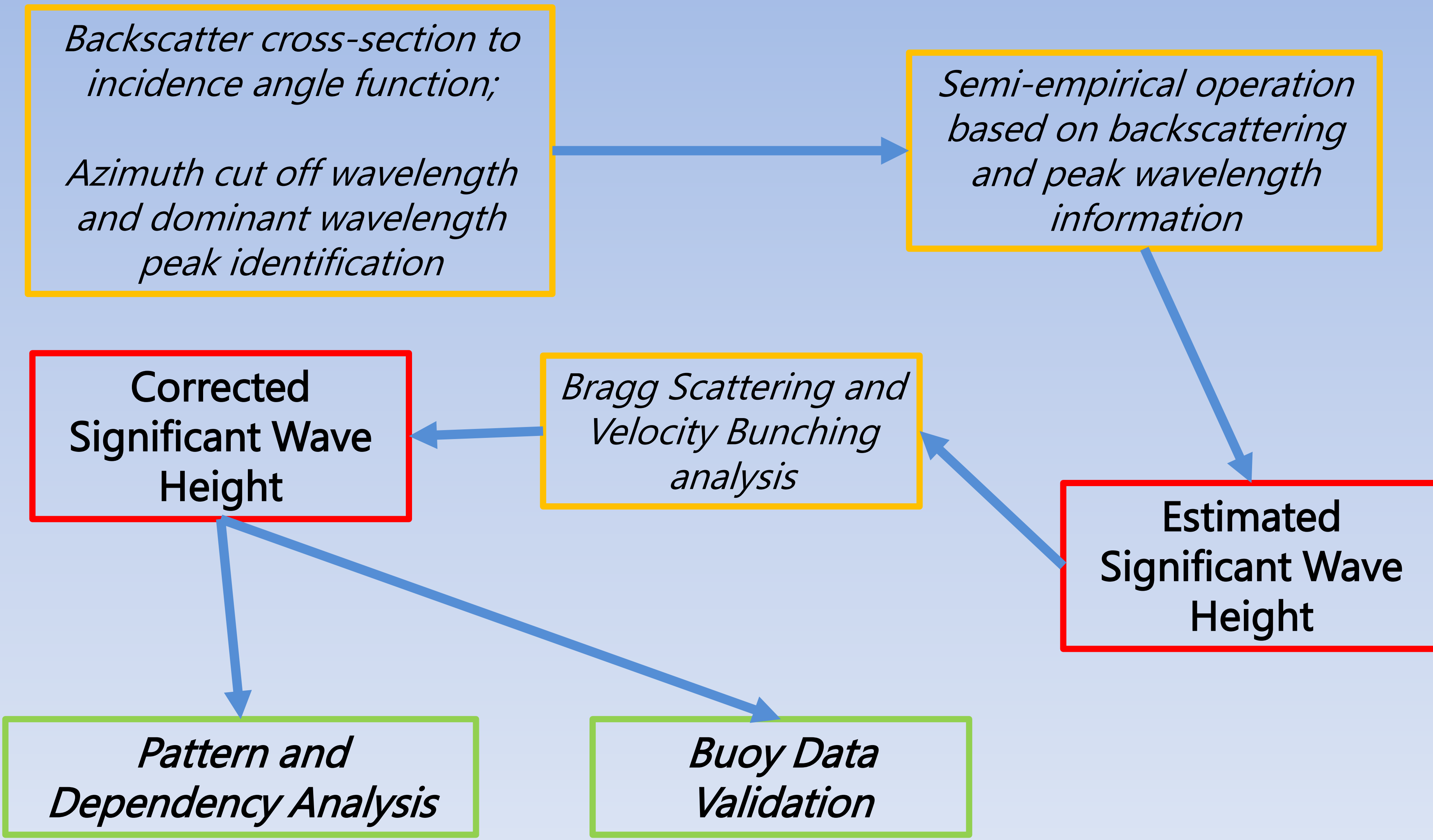
NDBC 46029
(Oct 2016 – Mar 2017)

Station 51004– 205 NM Southeast of Hilo, HI

Contents are taken from: http://ndbc.noaa.gov/

SENTINEL 1 SAR VV – IW SENSOR – NDBC 51004 HI




Backscatter cross-section to incidence angle function;
Azimuth cut off wavelength and dominant wavelength peak identification
Semi-empirical operation based on backscattering and peak wavelength information
Corrected Significant Wave Height
Bragg Scattering and Velocity Bunching analysis
Estimated Significant Wave Height
Pattern and Dependency Analysis
Buoy Data Validation

Method

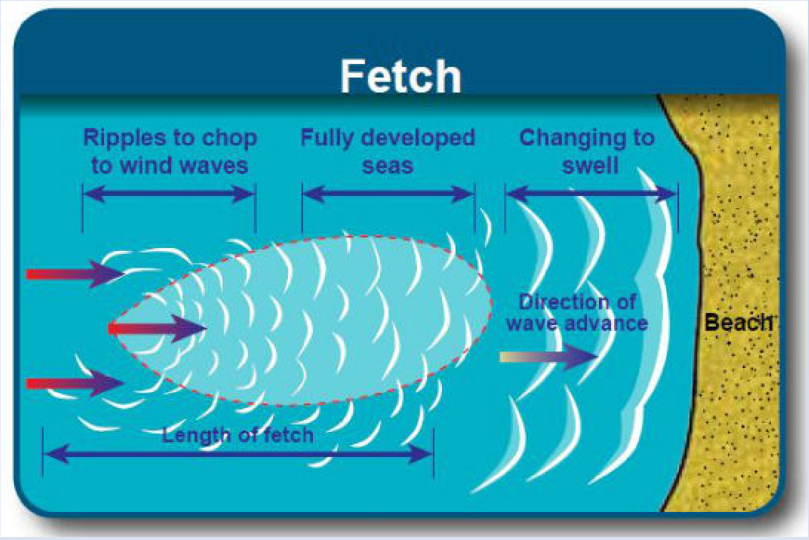
For a narrow-band swell-wave spectrum centered on wave number Ko, the slope of the sea surface, tan ϴr, is given by:

$$\frac{\tan \Theta r}{H_s} = \frac{|Ko|}{4} = \frac{\pi}{2\lambda_o}$$

We can determine H_s, if we know $\tan \Theta r$ and λ_o. From a digital image, we can determine λ_o by taking the 2-D Fourier transform. The determination of $\tan \Theta r$ is based on the relation of the backscattering cross-section of the sea surface to incident angle (Thomas, 1982).

These parameters give us the simple empirical-physical properties of swell-waves, assuming that the wavelengths are constant and linearly distributed over a subset of images.

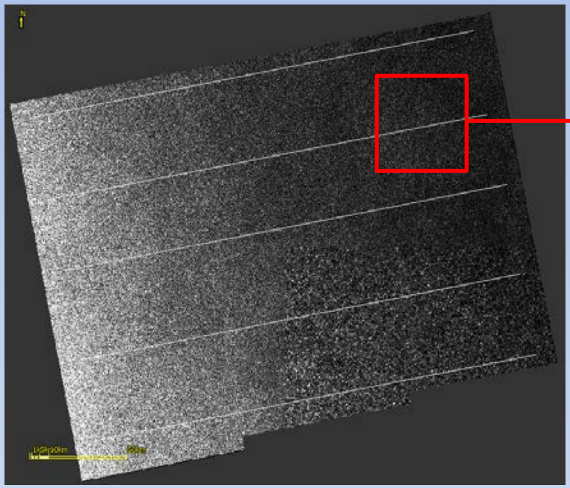
However, this equation is not suitable for understanding phenomena such as internal waves and very low to extreme sea state conditions.

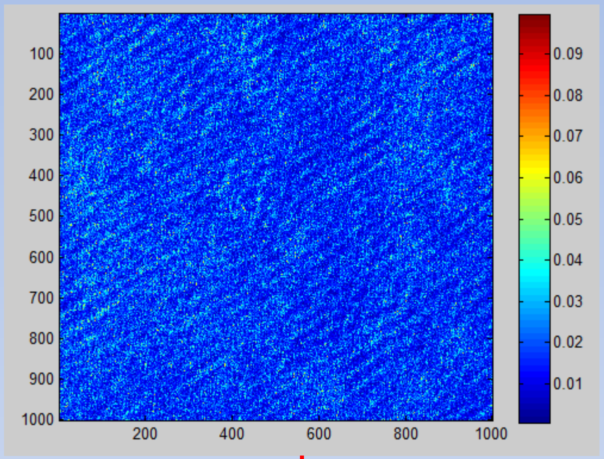


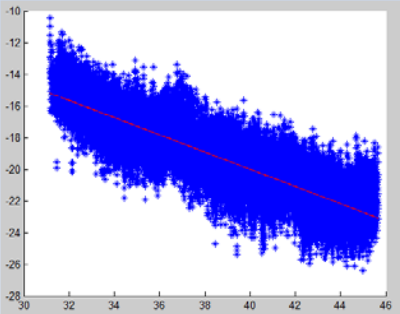
Backscatter Variation Slope

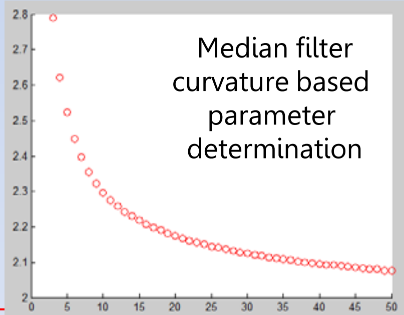
Updating the Valenzuela (1978) backscatter variation slope for vertical polarization from normalized radar cross section using curvature based median filter

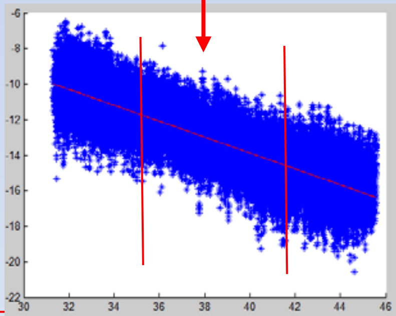
NRCS variance and average incidence angle of image subset





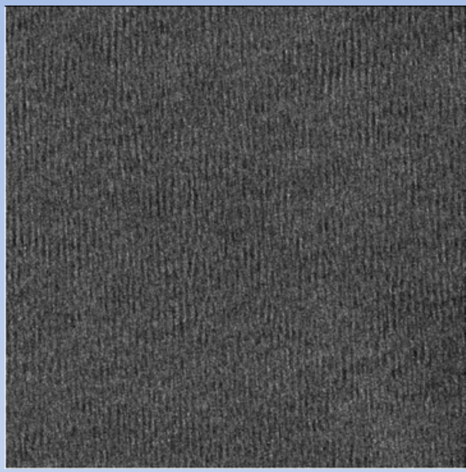






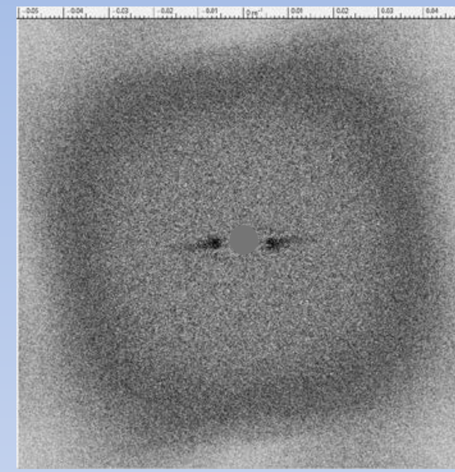
Variation and Contrast Analysis

Dominant Wavelength



10km

Contrast Limited Adaptive Histogram Equalization (CLAHE) Filtering
+
Median Filter
+
2D Fast Fourier Transform
Analysis (Hz, K, λ)



Dominant/ Peak Wavelength

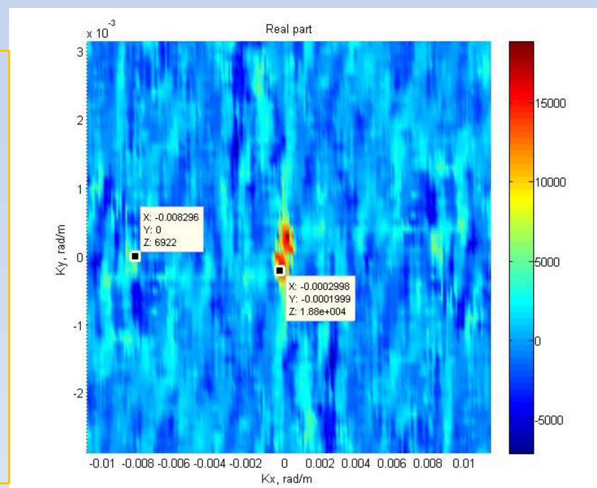
Wave Direction (*ambiguity*)

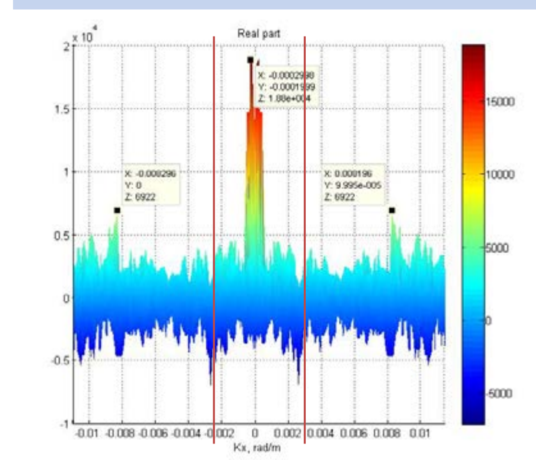
Azimuth Cut-off wavelength

Azimuth Cutoff Wavelength

Why it is important?

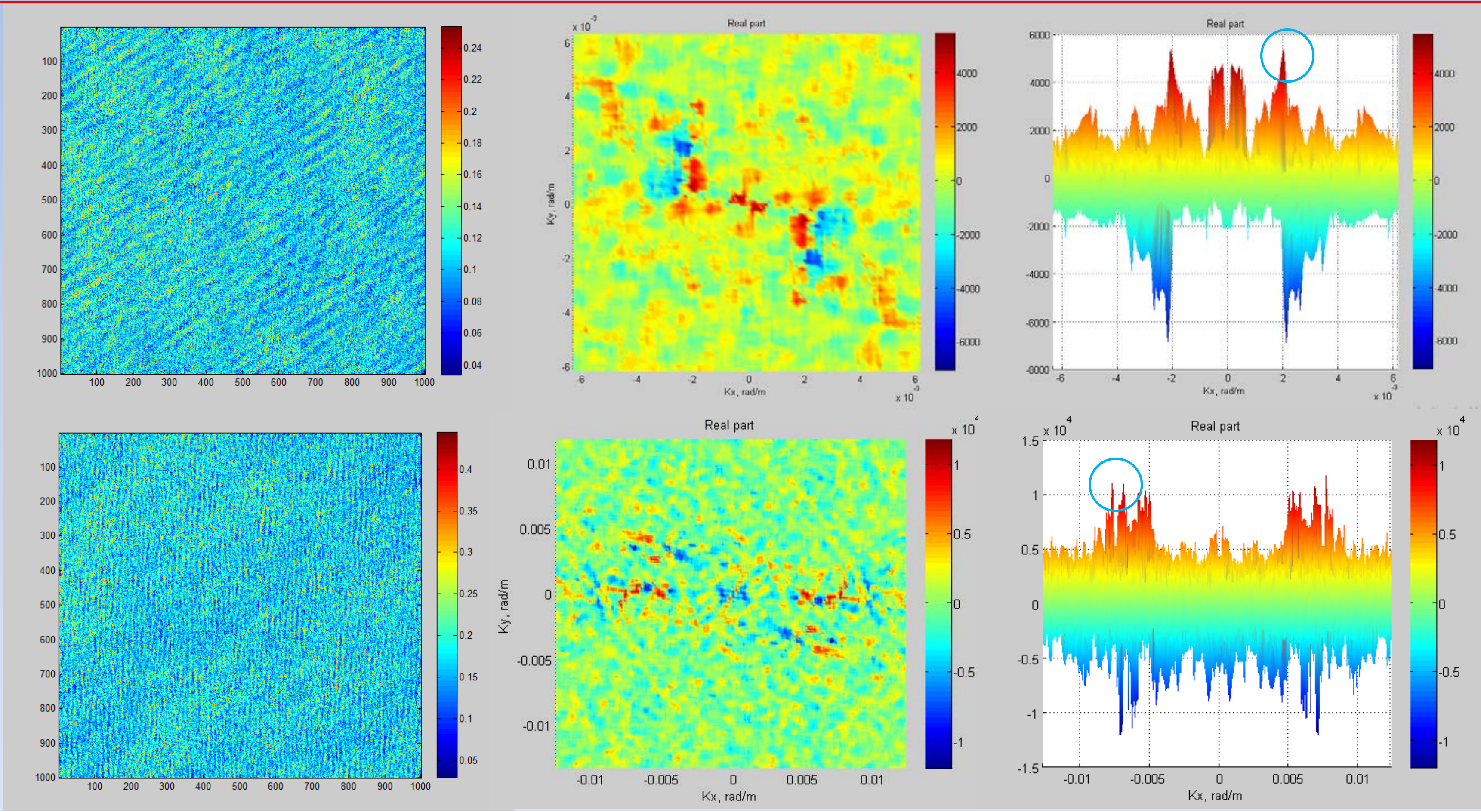
The peak wavenumber value is the dominant wavelength with highest amplitude outside the azimuth cut-off wavelength boundary





Dominant Wavelength

The peak wavenumber value is usually the point with the highest amplitude as seen in the figure below. It also located near the lowest amplitude area, as the pattern of wave strike shown in the left side, and the right side showing the X/Z cross section



Preliminary Results

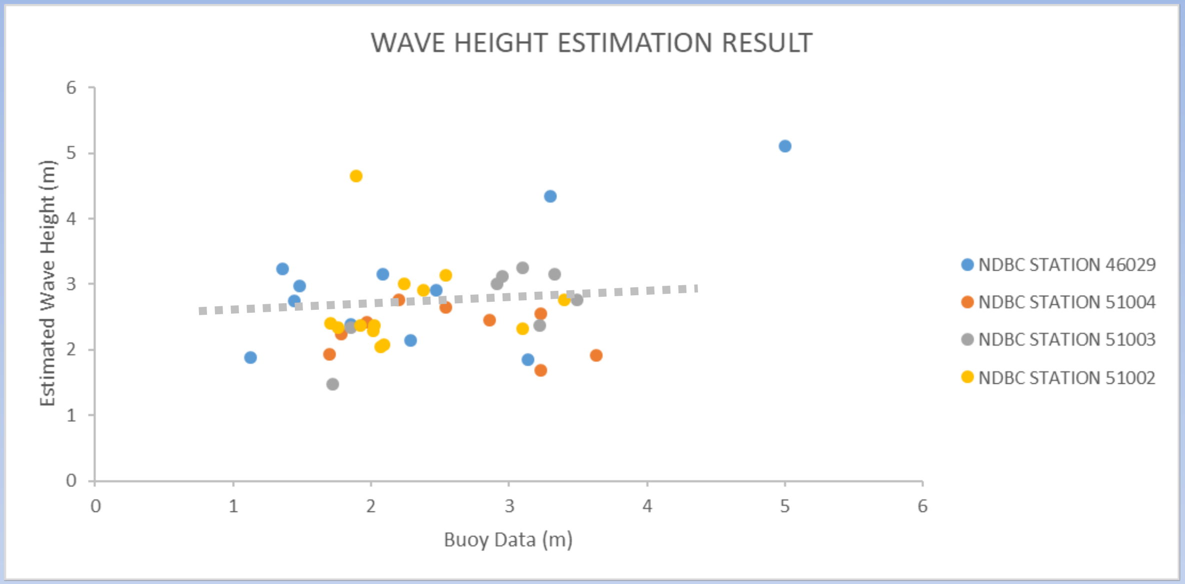
STATION 51002	INC	W_DIR	WSPD	WV_DIR	DOM WL COR	Hs COR	Buoy Hs	Δ Hs
1/11/2016	35.71	65	10.8	266.6335393	790.5586753	2.330425	3.1	-0.769575
13/11/2016	35.71	65	6.5	277.3523794	574.2811515	2.28432166	2.015	0.269321658
7/12/2016	35.71	64	4.4	279.833564	707.4631992	2.91477735	2.38	0.534777352
19/12/2016	35.71	91	1.7	313.8308607	1553.894736	4.6566798	1.89	2.766679804
31/12/2016	35.71	57	6.9	264.2894069	765.4809236	3.00860795	2.24	0.768607952
12/1/2017	35.71	80	7.9	271.6523047	517.5819788	2.04274335	2.07	-0.02725665
24/1/2017	35.71	63	9.9	265.667686	813.5916309	2.75825919	3.4	-0.64174081
5/2/2017	35.71	83	3.3	279.2726018	542.3187772	2.39821067	1.71	0.688210675
17/2/2017	35.71	84	6.8	294.3255752	672.1918503	3.13411674	2.54500208	0.555002083
1/3/2017	35.71	104	9.3	279.9777126	491.0780884	2.33804315	1.76	0.578043153
13/3/2017	35.71	77	5.5	246.297354	601.3203686	2.37020351	2.02	0.350203511
25/3/2017	35.71	80	9.1	280.6697828	766.9545698	2.37131682	1.92	0.451316821
6/4/2017	35.71	65	8.95	274.4971516	603.2036189	2.07317273	2.09	-0.01682727

Wind speed lower than 2 m/s and higher than 9 m/s

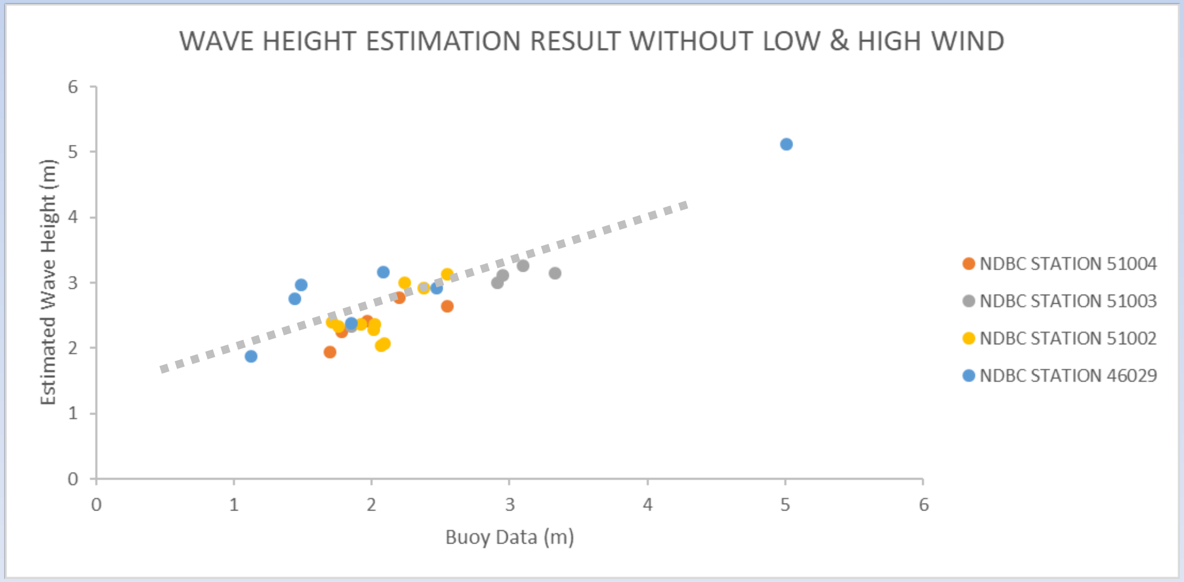
STATION 51003	INC	W_DIR	WSPD	WV_DIR	DOM WL COR	Hs COR	Buoy Hs	Δ Hs
3/11/2016	42.96	48.5	8.25	314.4327336	645.7798197	3.00856848	2.915	0.093568476
15/11/2016	42.96	48	8.25	270.069066	555.691461	2.37606531	3.225	-0.84893469
27/11/2016	42.96	108	10.45	234.8658069	1397.007965	2.76221884	3.49	-0.72778116
9/12/2016	42.96	119.5	9.2	238.5704344	2186.412621	1.46951102	1.725	-0.25548898
21/12/2016	42.96	68.5	5.75	297.5252257	576.0804225	3.15528023	3.33	-0.17471977
2/1/2017	42.96	50	4	320.0796079	360.9488274	2.33142704	1.85	0.48142704
14/1/2017	42.96	130	4.5	268.393997	430.8813753	3.25748509	3.1	0.157485095
26/1/2017	42.96	75	7	309.3405182	584.7658882	3.11887878	2.95	0.168878775

Outliers; assumed to be random error

Preliminary Results



$R^2 = 0.041$
RMSE = 0.6815m



$R^2 = 0.7333$
RMSE = 0.5063m

(*) All stations included, Blue dots are the stations near from Columbia River

Conclusions and Future Work

The data used in this preliminary study is sparse, but we can see how the estimated H_s is affected by wind forcing

The understanding of these effects, including internal waves and other phenomena could improve results.

Future work will focus on 4 NDBC Stations near Hawaii and 3-4 Stations near the Columbia River,


THANK YOU
for your attention and questions

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