Revealing wind wave spectra from visual observations

Vika Grigorieva[1], Sergey Gulev[2], **Yaron Toledo**[1], Vitaly Sharmar[2]

1. Marine Engineering and Physics Lab (MEPL) Tel Aviv University, Israel
2. Sea Atmosphere Interaction And Climate Lab (SAIL) Shirshov Institute of Oceanology

Outline:

- An advancement from the conventional analysis of visually observed wave characteristics
- Wave spectra from separate estimates of wind sea and swell heights, periods, and directions of propagation
- Comparison with model, buoy, and ADCP spectra

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Visual wave observations

- Ship-based visual observations are carried out by marine officers and mates under the framework of the Voluntary Observing Ship (VOS, https://www.vos.noaa.gov/) program
- Unified observational standard was adopted for all merchant ships that measured meteorological characteristics and observed wind waves in 1853 (Brussels Marine Conference)
- The data is transmitted through the Global Telecommunication System and assimilated in ICOADS (International Comprehensive Ocean Atmosphere Data Set, https://icoads.noaa.gov/

VOS
Voluntary Observing Ship Scheme
Port Met Officers

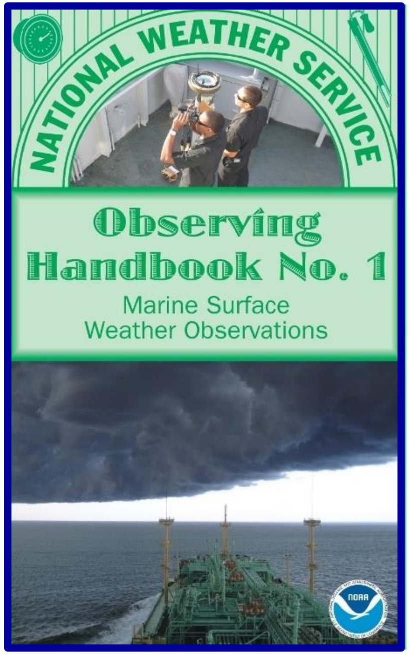
ICOADS

Voluntary Observing Ships (VOS)

https://www.vos.noaa.gov/

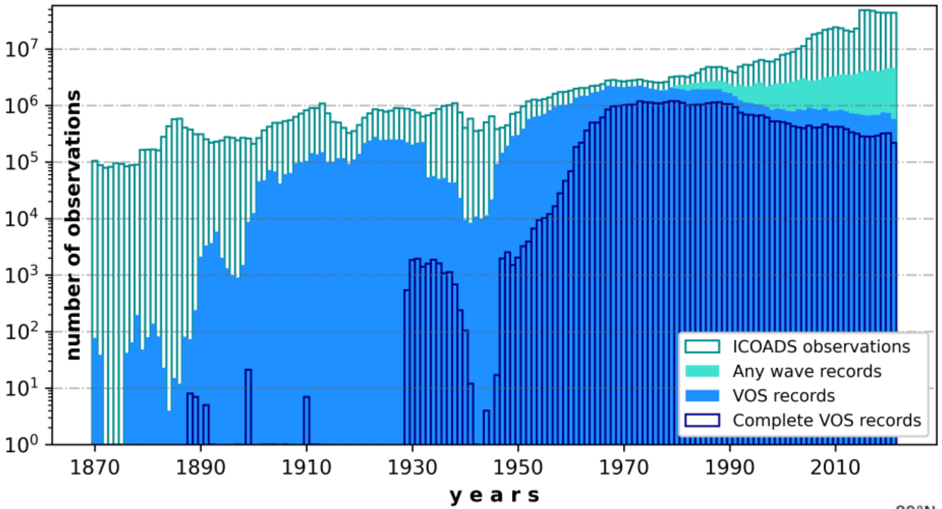
"Only YOU know the weather at your position. Report it at 0000, 0600, 1200, 1800 UTC to NOAA's National Weather Service"

- The longest continuity: **since 1870** onwards
- Observational practice has never been changed
- Separate estimates of wind sea and swell
- Do not require any calibration procedures



VOS
Voluntary Observing Ship Scheme
Port Met Officers

Voluntary Observing Ship data in ICOADS

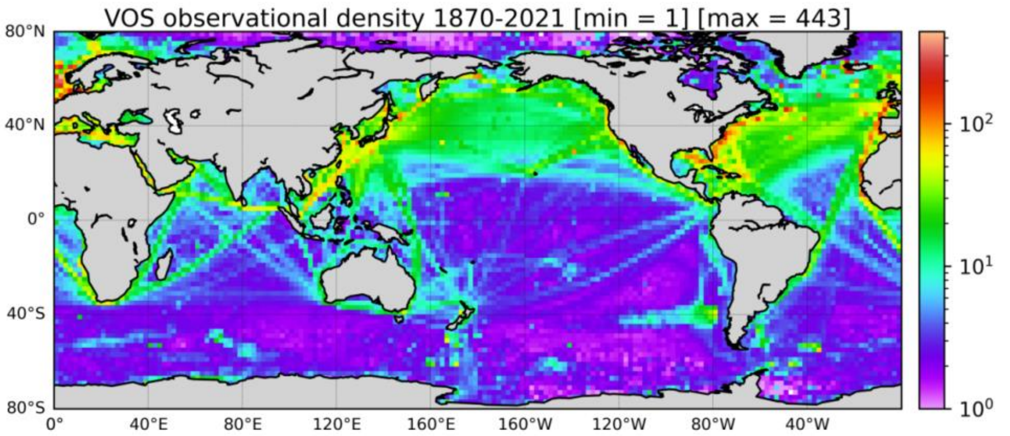


Each ICOADS record contains > 100 ocean and atmosphere characteristics at the given coordinates and UTC time

A complete wave record: wind sea and primary swell height, period, and direction

Accuracy: 0.5m, 1s, 10°

> **770** mln records in the ICOADS
> **175** mln contain at least one wave parameter (generally, wave height)
> **98** mln (~13%) provided by VOS
> **42** mln (~5.5%) complete wave records



Wave spectra from VOS

Simultaneously observed heights, periods, and directions of wind sea and swell systems can be theoretically regarded as peak spectral characteristics of wave partitions

Pierson-Moskowitz
for wind sea

$$S_{PM}(f) = 0.312H^2T_p^{-4}\,f^{-5}exp\left[-1.25\left(f/f_p\right)^{-4}\right]$$

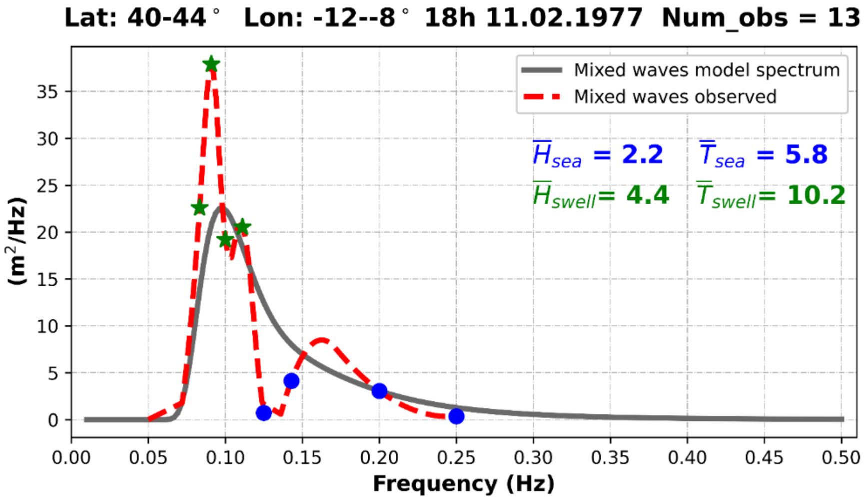
Gaussian-shaped model
for swell

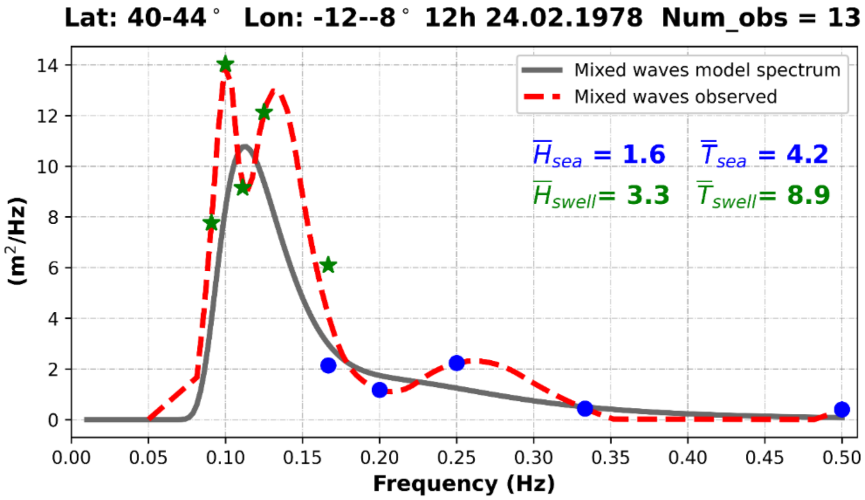
$$S(f) = \frac{6m_0}{f_p}\left(\frac{f}{f_p}\right)^{-6} exp\left[-1.2\left(\frac{f}{f_p}\right)^{-5}\right]$$

Directional spreading function $D(\theta) = \frac{1}{2\pi}(1 + \cos(\theta - \bar{\theta}))$ $\int_0^{2\pi} D(\theta)d\theta = 1$

Validation of VOS spectra

Synchronous daily observations in 4°x4° boxes are compared with model spectra revealed from daily mean wave characteristics





For well-sampled regions with > 10 reports per day model spectra are in a good agreement with pointwise observations

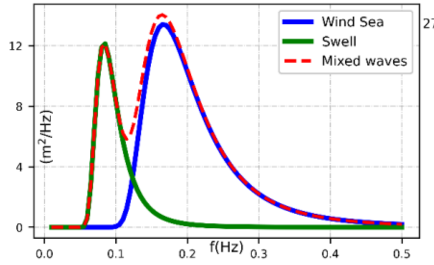
Individual visual observations

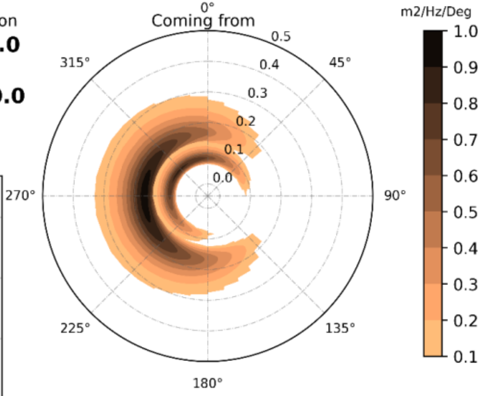
The observer's experience or the methods chosen for spectral wave partitioning can hinder the discrimination of wave systems where both components have the same periods (frequencies), close heights, and similar directions of propagation

Easy for partitioning

Lat: 58.1° Lon: 3.8° 06h 04.04.2022

	height, m	period, s	direction
VOS sea:	**5.0**	**6.0**	**270.0**
VOS swell:	**3.0**	**12.0**	**310.0**

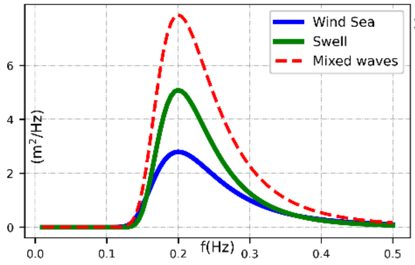


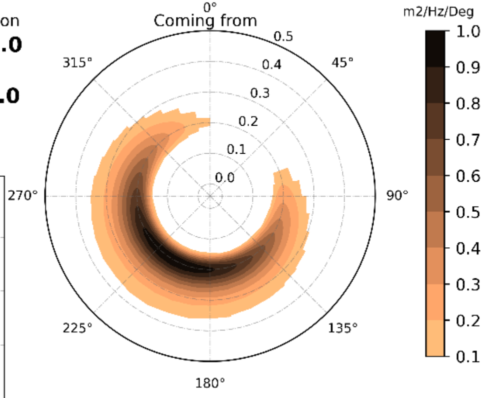


Hard to separate

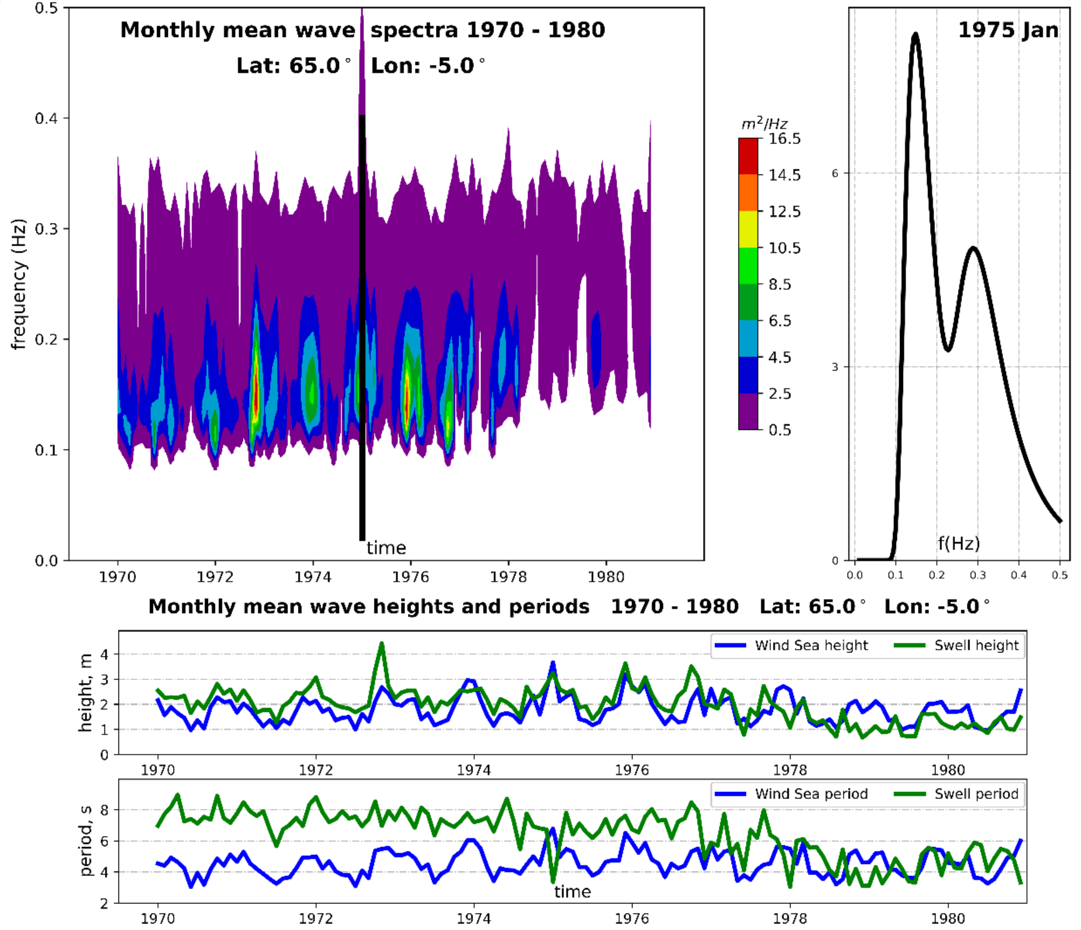
Lat: 61.2° Lon: 0.2° 06h 02.05.1975

	height, m	period, s	direction
VOS sea:	**2.5**	**5.0**	**230.0**
VOS swell:	**3.0**	**5.0**	**200.0**





Long-term timeseries of visual observations



In well-sampled regions, visual observations provide continuous timeseries of wave characteristics allowing for monitoring monthly, seasonal, and annual changes in heights & periods together with 1D spectra evolution

Reliable wind sea and swell data are available since 1963 – 60 years of observations

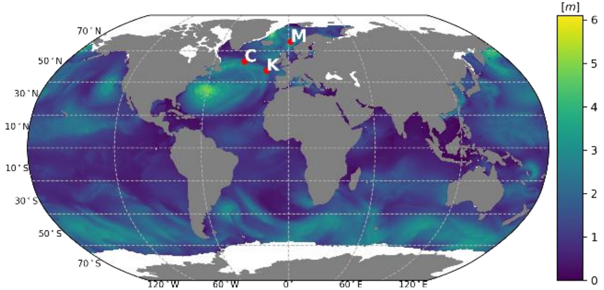
Data for comparison

DeepLev Station

The longest homogeneous timeseries in the Eastern Mediterranean derived from Acoustic Doppler Current Profiler (ADCP) mounted on the Deep Levantine mooring station (33°N, 34.5°E, depth = 1470m)

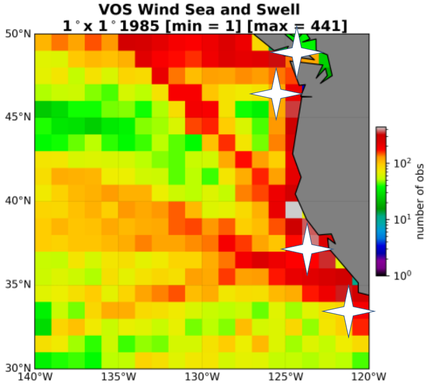
WaveWatchIII v.5.16

1-hour forcing from ERA5 (0.25x0.25)
25 frequencies and 24 directions
ST6, IC0, DIA
Partitioning: PTM2



NDBC directional wave stations

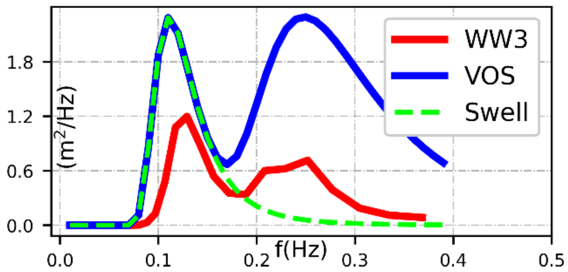
Northeast Pacific: 46028, 46029, 46041, 46042, 46086, 46087, 46088
deep and shallow waters, match-up in time, collocation radius < 50 km

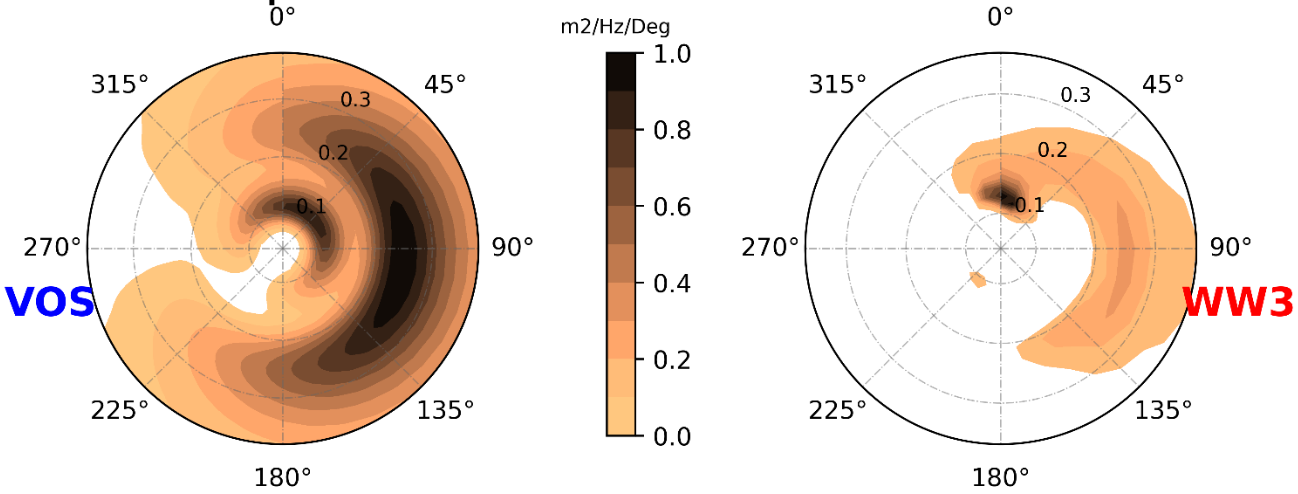


VOS – WW3

VOS	WW3
H_{sea} = 2.5	H_{sea} = 1.1
H_{swell} = 1.5	H_{swell} = 0.2
T_{sea} = 4.0	T_{sea} = 4.0
T_{swell} = 9.0	T_{swell} = 9.4
Hs = 2.9	Hs = 1.5
Td = 4.0	Tp = 7.9

1979/12/09 22h Lat: 66.0 ° N Lon: 2.0 ° W





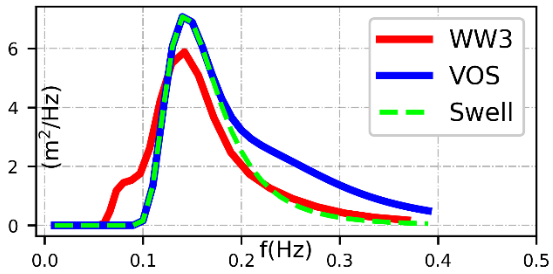
WW3 underestimates wave heights resulting in a disagreement in peaks' energy

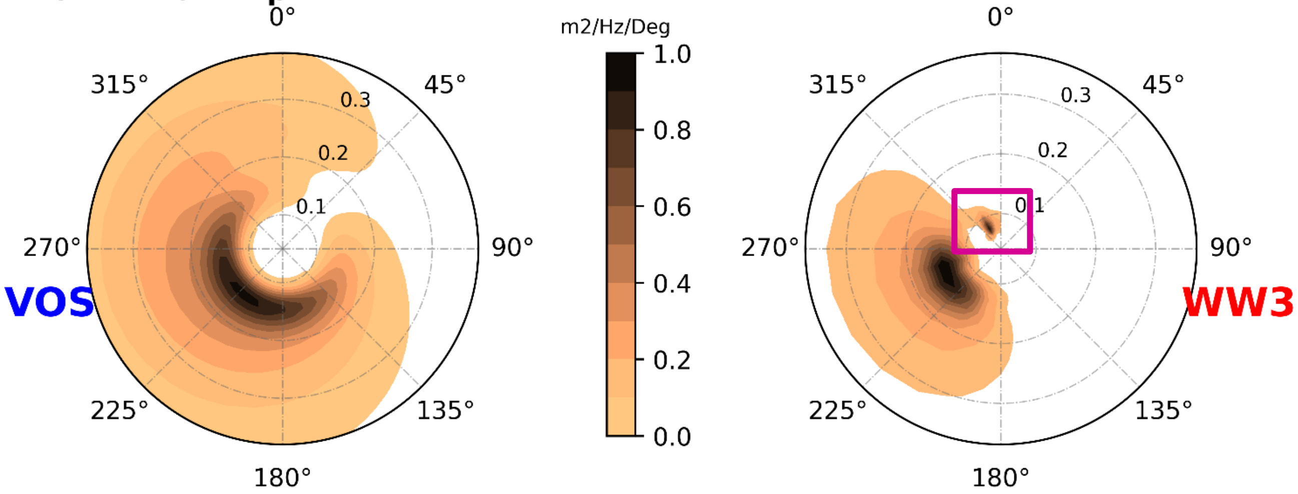
A good agreement in wave frequencies and directions provides similar patterns for both 1D and 2D spectra

VOS – WW3

VOS	WW3
H_{sea} = 2.0	H_{sea} = 0.8
H_{swell} = 3.0	H_{swell} = 3.0
T_{sea} = 4.0	T_{sea} = 12.4
T_{swell} = 7.0	T_{swell} = 7.1
Hs = 3.6	Hs = 3.1
Td = 7.0	Tp = 7.1

1979/12/04 10h Lat: 66.0 ° N Lon: 2.0 ° W

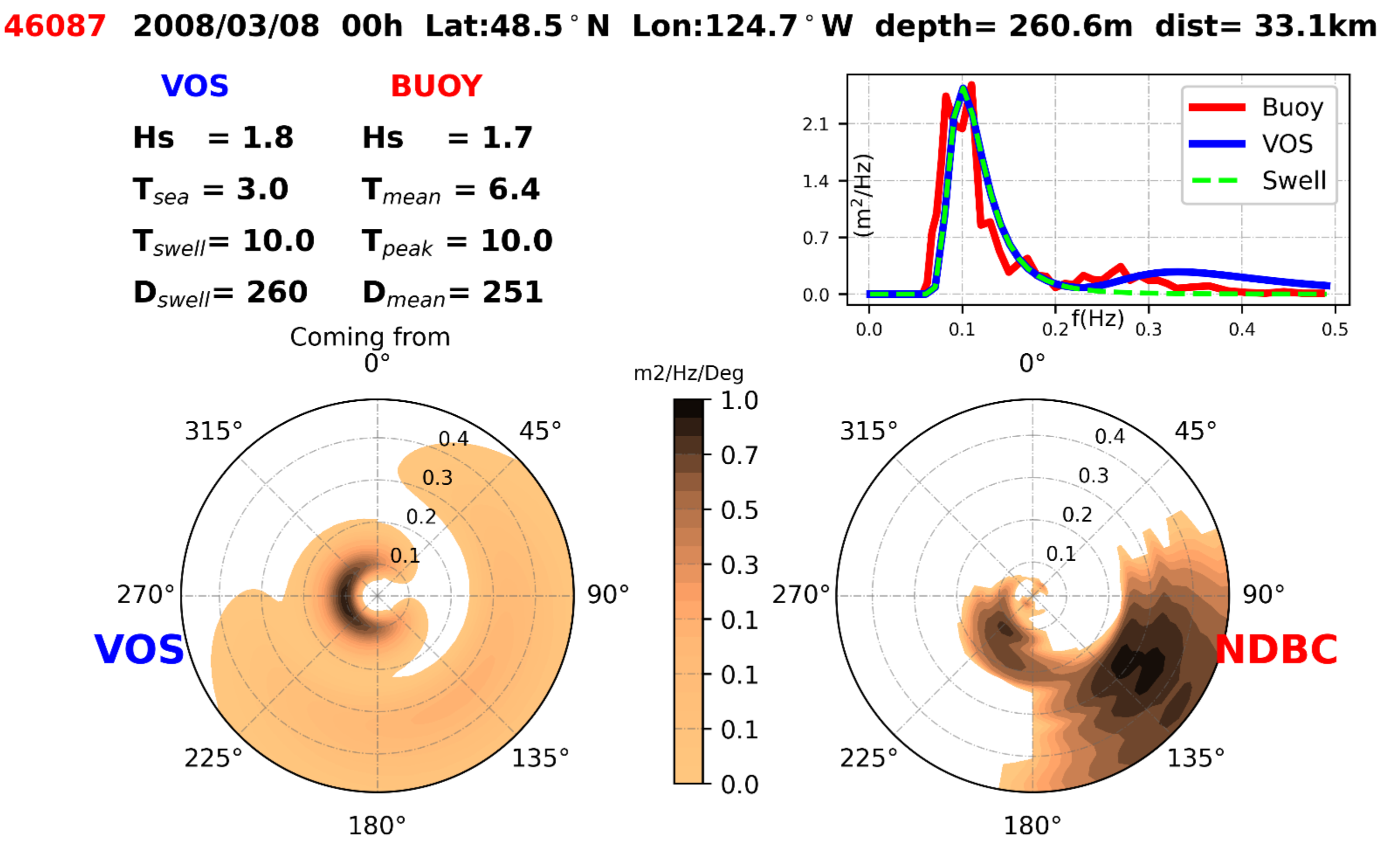




Matching in the primary spectrum peaks because of consistent swell characteristics

Identifying the second spectral peak as wind sea in WW3 led to the disagreement in wave heights & periods, as well as in 1D spectrum tails

VOS – NDBC: shallow water



Peak period matches VOS swell

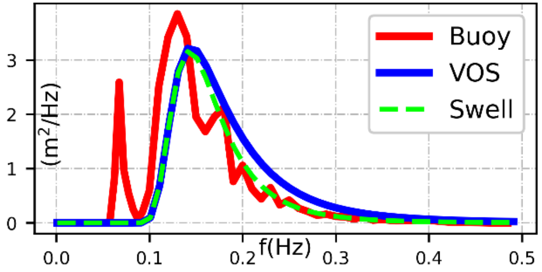
Wave heights (and the highest energy peak) are practically identical

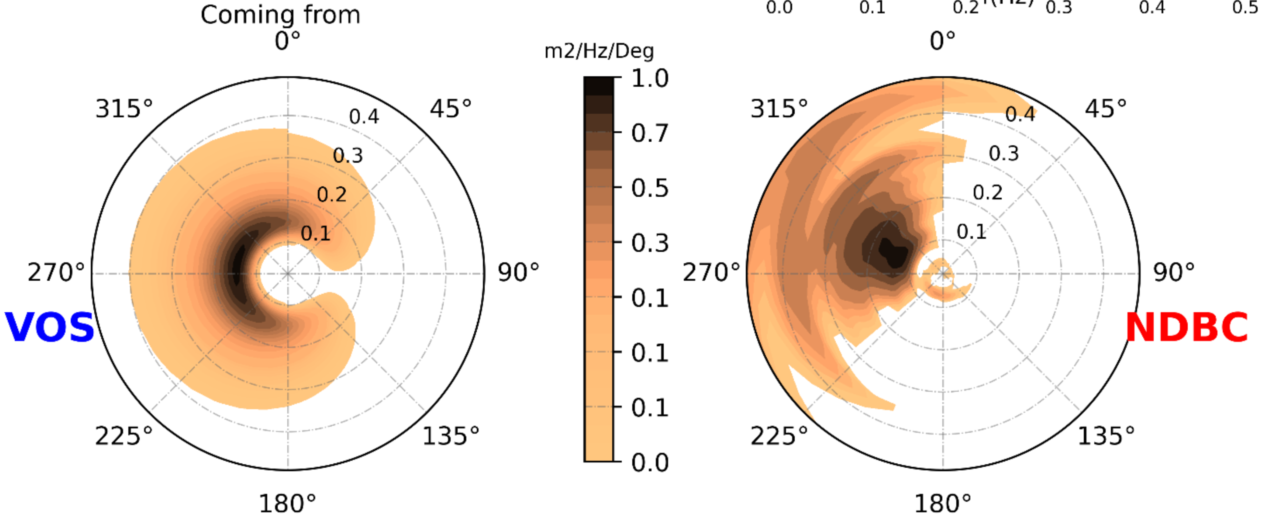
2D spectra coincide in directional distributions but the buoy shows more sophisticated spectral features

VOS – NDBC: deep water

46086 2009/04/26 06h Lat:32.5°N Lon:118.1°W depth= 1844.7m dist= 43.9km

VOS	BUOY
Hs = 2.0	Hs = 2.1
T_{sea} = 5.0	T_{mean} = 6.1
T_{swell} = 7.0	T_{peak} = 9.1
D_{swell} = 280	D_{mean} = 298





VOS does not prove a spurious buoy spectral peak at low frequency (~ 0.07 Hz, 14s)

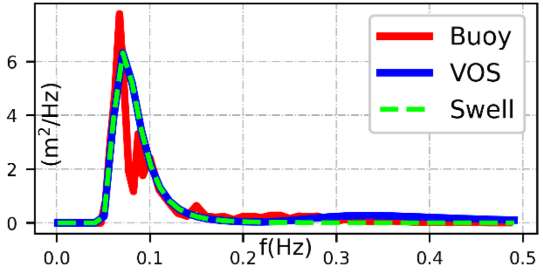
VOS closely reproduces the shape of 1D buoy spectrum, although with a shift between buoy's peak and visual swell frequencies

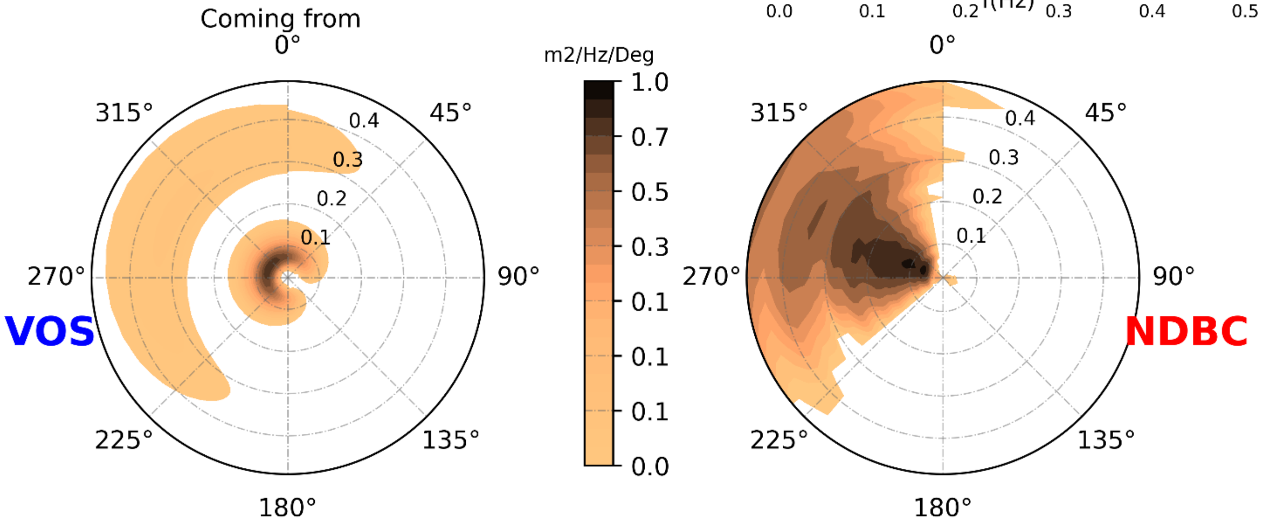
Wave heights agree well

VOS – NDBC: deep water

46086 2009/12/01 07h Lat:32.5°N Lon:118.1°W depth= 1844.7m dist= 43.5km

VOS	BUOY
Hs = 2.0	Hs = 2.0
T_{sea} = 3.0	T_{mean} = 7.6
T_{swell} = 14.0	T_{peak} = 13.8
D_{swell} = 300	D_{mean} = 291



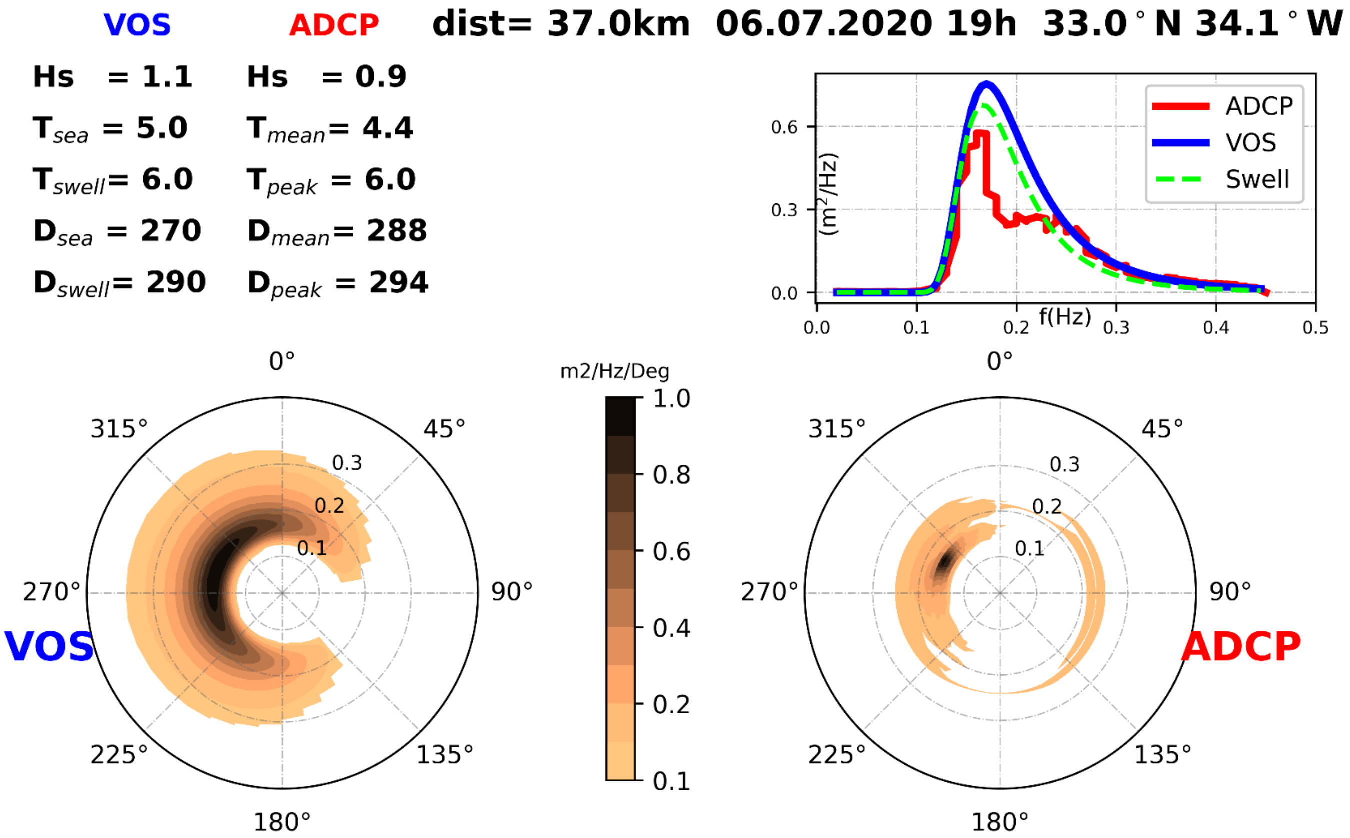


All parameters are identical

Long swell forms a sharp peak

Short and small wind sea does not make a significant impact on the spectral power

VOS – ADCP



Peak period (and energy peak) matches VOS swell

Identical tails of 1D spectra shapes

ADCP also detects two wave systems but on slightly different frequencies

Good agreement in directional distributions

VOS – ADCP

parameter	ADCP	VOS	r
Wave height (m)	$\overline{Hm0} = 1.46$ $\overline{H_{1/3}} = 1.4$	$\overline{SWH} = \sqrt{(h_{sea}^2 + h_{swell}^2)} = 1.6$	0.87 0.87
Wave period (s)	$\overline{Tm02} = 5.2$	$\overline{Dominant\ period^{(*)}} = 5$	0.65
Wave direction (degree)	$\overline{Dmean} = 259$ $\overline{Dpeak} = 254$	$\overline{D_{sea}} = 241$ $\overline{D_{swell}} = 256$	

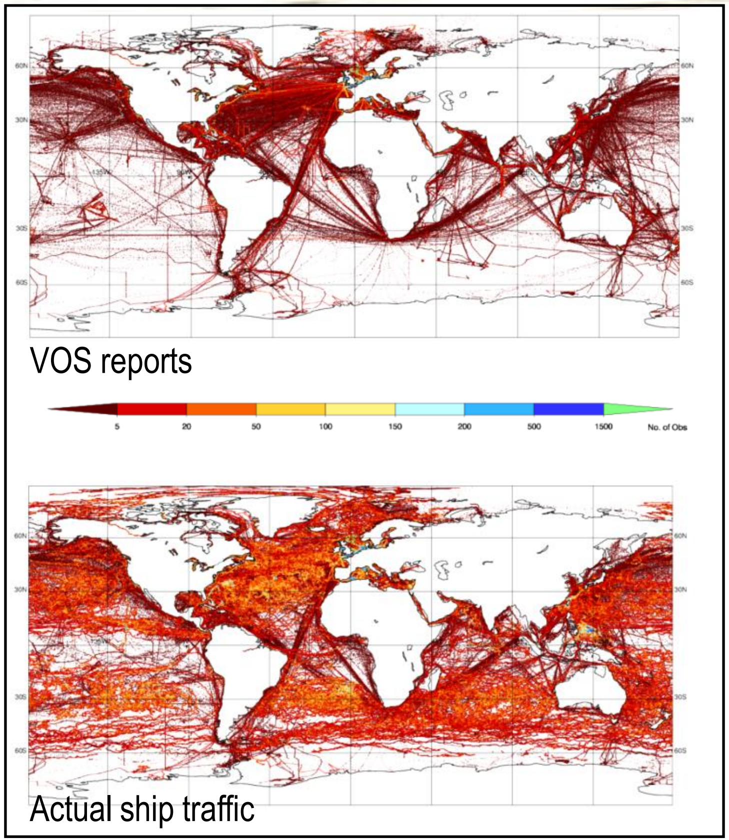
A comparison of VOS and ADCP data within a 50 km radius and a 30 min time lag (66 pairs) shows a very close match for conventional parameters in terms of mean values. The highest correlation was found for wave heights

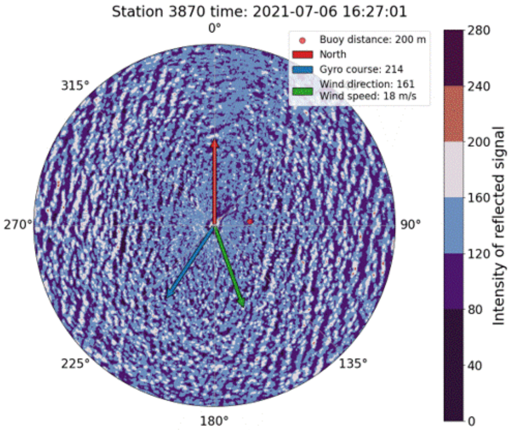
(*) Dominant wave period (Td) within visual observations is the period reported for the highest wave of wind sea and swell, which corresponds to the definition of the zero-up crossing period in the instrumental data (Srokosz & Challenor, 1987)

Conclusions

- Revealing wave spectra from visual observations enhances the conventional set of parameters and provides more detailed information about wind sea and swell partitioning and identification in models, buoys, and ADCP via a comparison in coincident points of space-time
- Examining the discrepancies in wave spectra gives insight into the nature of the disagreement in individual wave observations amid a general consistency of mean values for all datasets under study
- For the first time ADCP data has been compared with visual wave observations
- Visually observed short waves ($T < 3s$) can complement local buoy and ADCP measurements which are limited by their frequency range of 0.04 – 0.25 Hz

Perspectives: visual observations + VM X-band radars





Newly developed **SeaVision system** digitizes analogue signals from navigation radars providing estimates of wind wave characteristics

A broad implementation of SeaVision opens a potential for enhancing massive ship-based observations and ensuring homogeneous global coverage

Tilinina *et al.*, 2022. Wind waves in the North Atlantic from ship navigational radar: SeaVision development and its validation with the Spotter wave buoy and WaveWatch III, *Earth Syst. Sci. Data*, 14, 3615–3633, https://doi.org/10.5194/essd-14-3615-2022.

Thank you for your attention!

Yaron Toledo
toledo@tauex.tau.ac.il

Sergey Gulev
gul@sail.msk.ru

Vitaly Sharmar
sharmar@sail.msk.ru

Vika Grigorieva
grigorieva@tauex.tau.ac.il

Accuracy

Parameter	VOS	Satellites	NDBC	Radars
Wave height	0.5 m	0.4 m (or 10%)	0.2 m (or 5%)	0.5 m (10%)
Wave period	1 s	–	≥1 s	0.2 sec
Wind speed	1 m/s	1.5 m/s	1 m/s	-
Direction	10°	17-20°	10°	2°

Formal ranges

Parameter	VOS	Satellites	Buoys	Radars
Wave height	0-50 m	0.5-14 m	0-35 m	> 0.5 m
Wave period	0-30 s	–	0-30 s	4-20 sec
Wind speed	0-50 m/s	3-20 m/s	0-62 m/s	> 3 m
Duration	1888+	1985+	1972+	
Coverage	Global	Global	Local, nearshore	Local, nearshore

Wave data	Strengths	Weaknesses
Visual wave observations	**Q**uantity (~3000 ships worldwide); **C**ontinuity (1869+); **A**ccuracy; **I**n-situ **S**eparate estimates of wind sea and swell characteristics	**S**pace-time inhomogeneity; **F**air weather bias
Satellites	**N**ear global coverage; **A**ll-weather capability	**O**ne-and-only wave parameter is measured directly; **A** unique Cal/Val procedure for each mission is required; **A**t most 2 times/day at given location; **N**oise at low winds & near land
Buoys	**C**oastal areas (heavy travelled and modelled); **A**ccuracy; **T**imeliness **S**ea height measured directly	**S**ea height is not available on all platforms; **S**ensitive instruments susceptible to failure in harsh marine environment; **M**ooring failures
Model hindcast	**G**lobal coverage; **S**pace-time homogeneity	**D**epend on forcing winds, parametrizations, and configuration of the model; **W**ave heights, periods, directions are derived from wavenumber-direction spectra

VOS – DeepLev

VOS | **ADCP** | **dist = 35.0km 23.10.2018 06h 32.7°N 34.4°W**

VOS	ADCP
H_s = 1.4	H_s = 1.1
T_{sea} = 4.0	T_{mean} = 4.0
T_{swell} = 7.0	T_{peak} = 5.8
D_{sea} = 120	D_{mean} = 57
D_{swell} = 40	D_{peak} = 10