

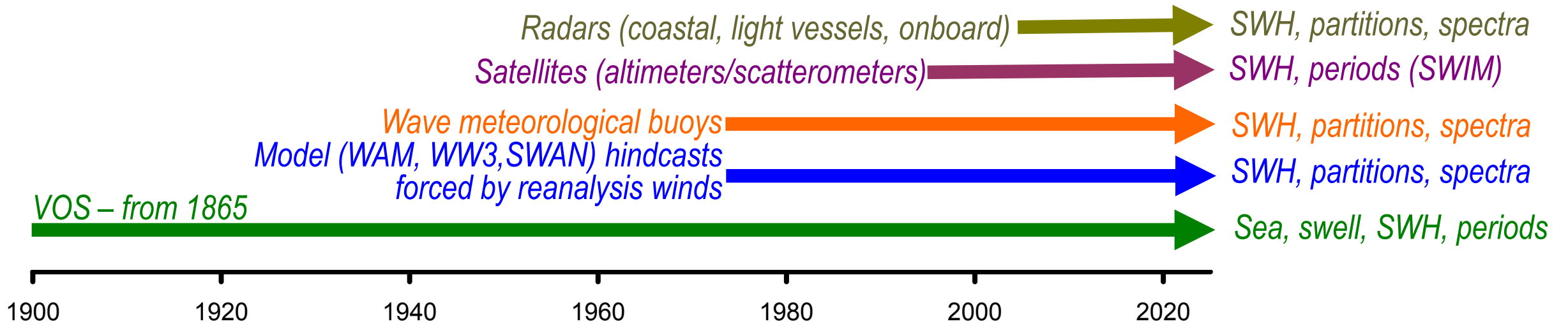


North Atlantic spectral wind wave climate from visual ship-based observations

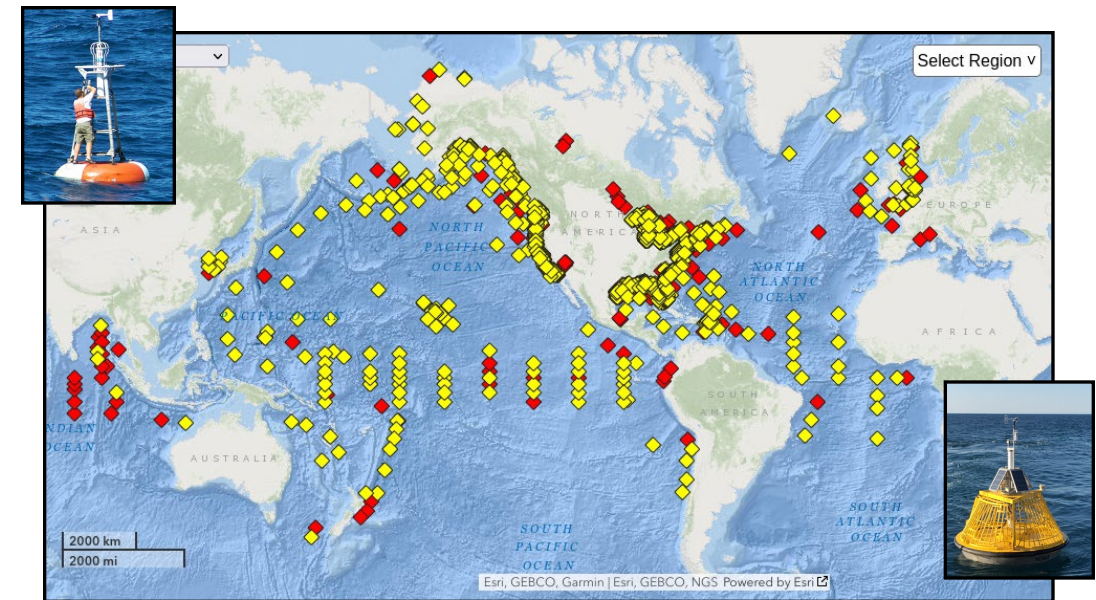
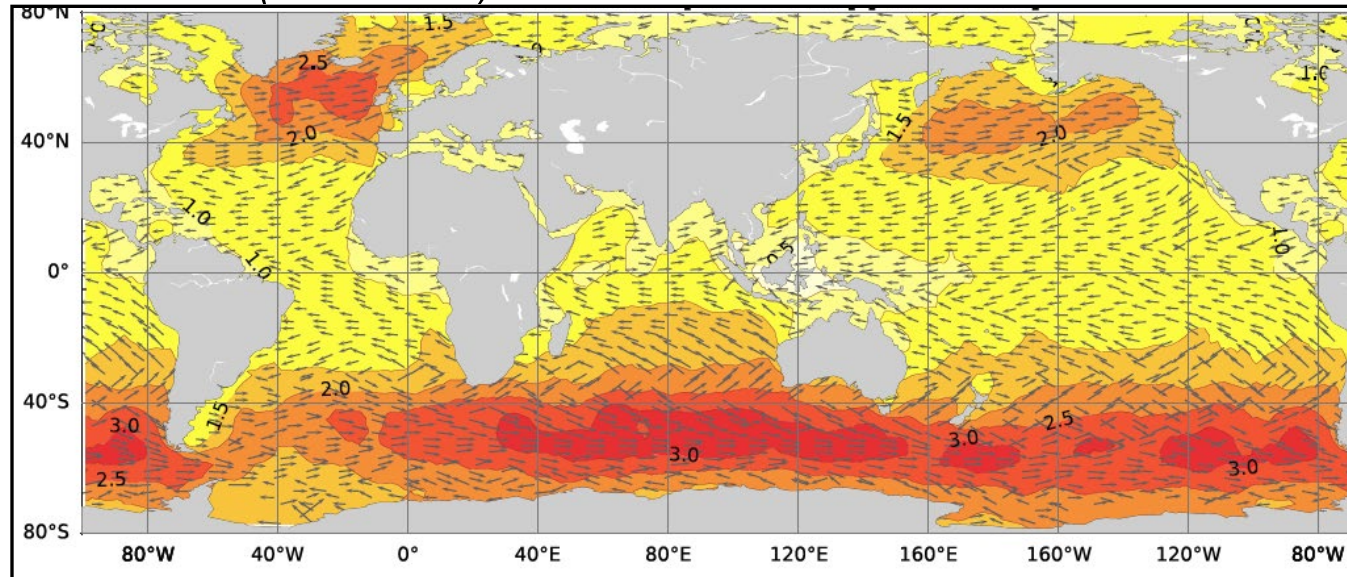
Vika Grigorieva, Sergey Gulev, Vitali Sharmar, gul@sail.msk.ru

- ☐ Sources of wind wave information – strengths and weaknesses
- ☐ Why spectral view of wind waves is important, from which source(s) can we get it? (examples)
- ☐ Visual wind wave observations – why they are valuable?
- ☐ How to reconstruct directional spectra from visual obs, where and when it is possible? → method
- ☐ NA spectral climatology and its validation

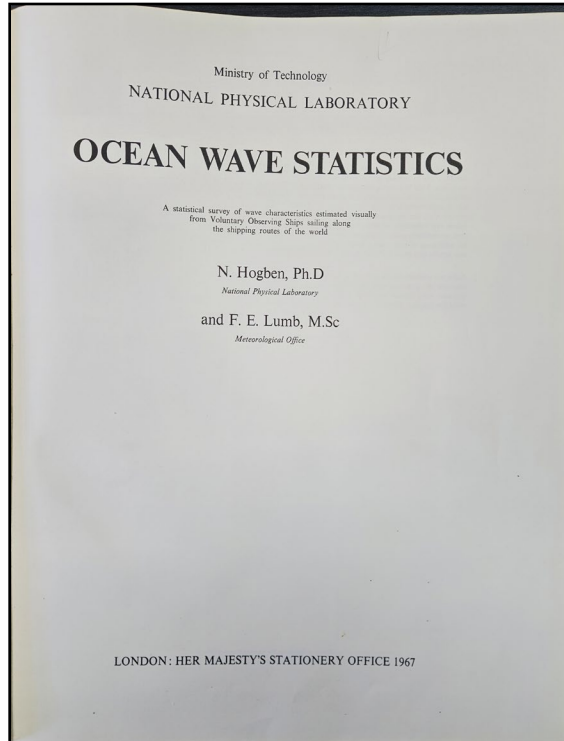
Wind wave data over the global oceans: satellites and buoys



SWIM SWH (2019-2024)



History of visual observations



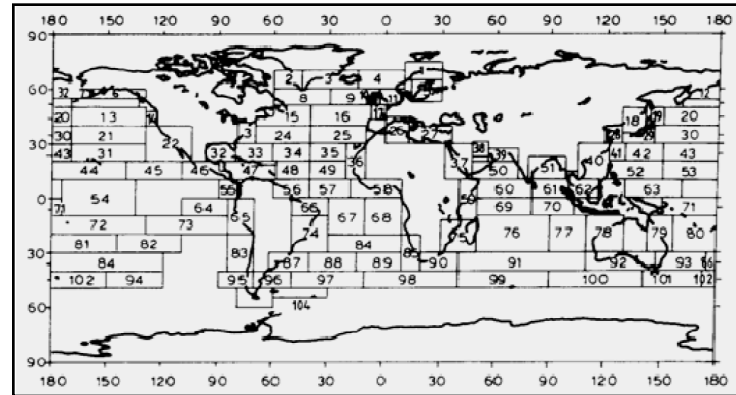
ALL SEASONS—ALL DIRECTIONS
FOR KEY TO WAVE HEIGHT AND WAVE PERIOD CODES SEE PAGE 3

AREA 11
WAVE PERIOD CODE

WAVE PERIOD CODE	1	2	3	4	5	6	7	8	9	10	TOTALS
1	100	100	100	100	100	100	100	100	100	100	1000
2	100	100	100	100	100	100	100	100	100	100	1000
3	100	100	100	100	100	100	100	100	100	100	1000
4	100	100	100	100	100	100	100	100	100	100	1000
5	100	100	100	100	100	100	100	100	100	100	1000
6	100	100	100	100	100	100	100	100	100	100	1000
7	100	100	100	100	100	100	100	100	100	100	1000
8	100	100	100	100	100	100	100	100	100	100	1000
9	100	100	100	100	100	100	100	100	100	100	1000
10	100	100	100	100	100	100	100	100	100	100	1000
TOTALS	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	10000

AREA 12
WAVE PERIOD CODE

WAVE PERIOD CODE	1	2	3	4	5	6	7	8	9	10	TOTALS
1	100	100	100	100	100	100	100	100	100	100	1000
2	100	100	100	100	100	100	100	100	100	100	1000
3	100	100	100	100	100	100	100	100	100	100	1000
4	100	100	100	100	100	100	100	100	100	100	1000
5	100	100	100	100	100	100	100	100	100	100	1000
6	100	100	100	100	100	100	100	100	100	100	1000
7	100	100	100	100	100	100	100	100	100	100	1000
8	100	100	100	100	100	100	100	100	100	100	1000
9	100	100	100	100	100	100	100	100	100	100	1000
10	100	100	100	100	100	100	100	100	100	100	1000
TOTALS	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	10000



JUNE 1998

GULEV AND HASSE

1107

North Atlantic Wind Waves and Wind Stress Fields from Voluntary Observing Ship Data

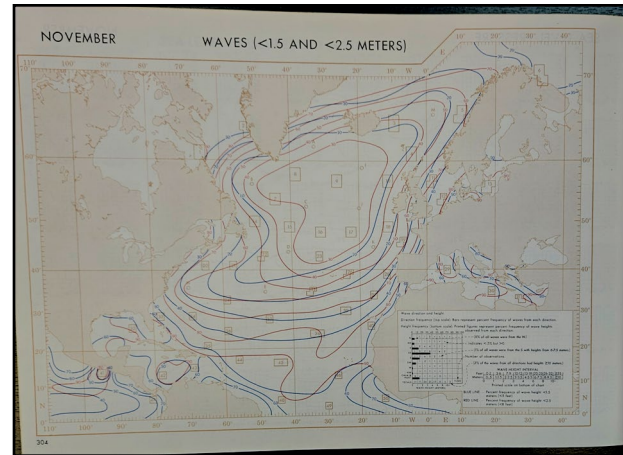
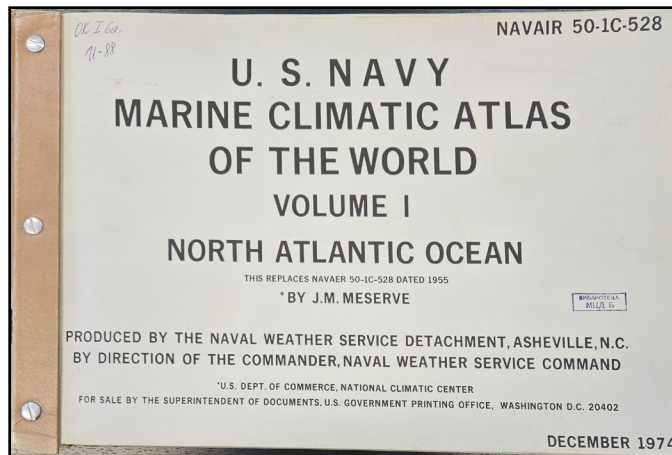
SERGEY K. GULEV* AND LUTZ HASSE

Institut für Meereskunde, Kiel, Germany

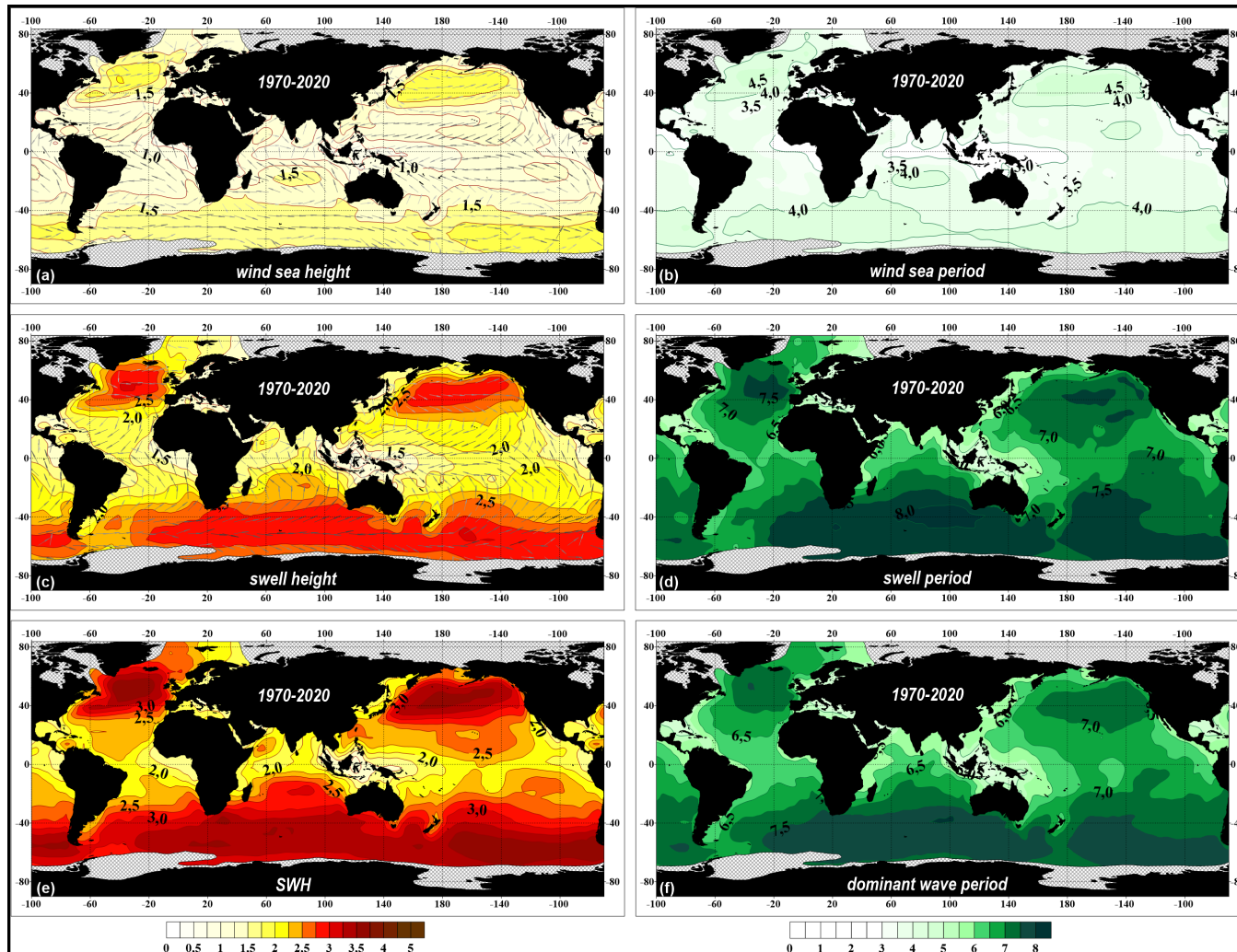
(Manuscript received 20 December 1995, in final form 2 September 1997)

ABSTRACT

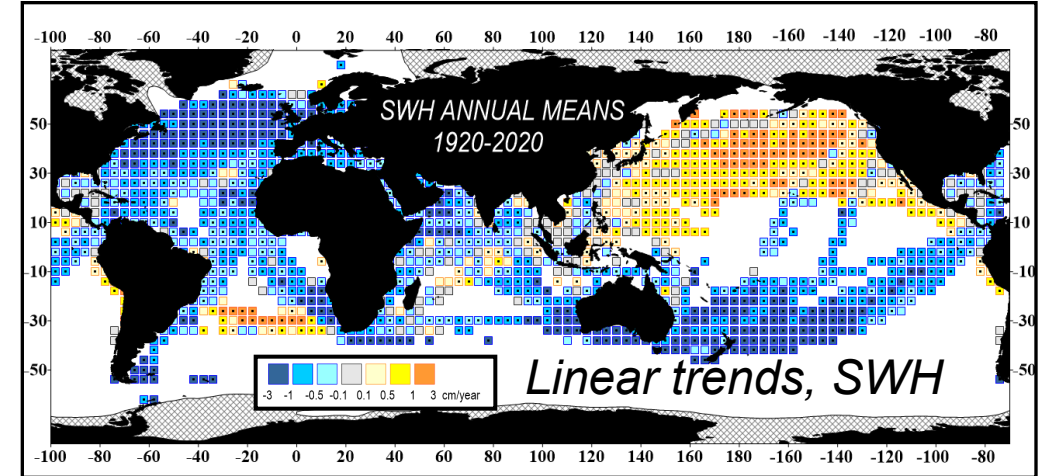
On the basis of the collection of individual marine observations available from the Comprehensive Ocean–Atmosphere Data Set, major parameters of the sea state were evaluated. Climatological fields of wind waves and swell height and period, as well as significant wave height and resultant period are obtained for the North Atlantic Ocean for the period from 1964 to 1993. Validation of the results against instrumental records from National Data Buoy Center buoys and ocean weather station measurements indicate relatively good agreement for wave height and systematic biases in the visually estimated periods that were corrected. Wave age, which is important for wind stress estimates, was evaluated from wave and wind observations. The climatology of wave age indicates younger waves in winter in the North Atlantic midlatitudes and Tropics. Wave age estimates were applied to the calculations of the wind stress using parameterizations from field experiments. Differences between wave-age-based and traditional estimates are not negligible in wintertime in midlatitudes and Tropics where wave-induced stress contributes from 5% to 15% to the total stress estimates. Importance of the obtained effects for ocean circulation and climate variability is discussed.



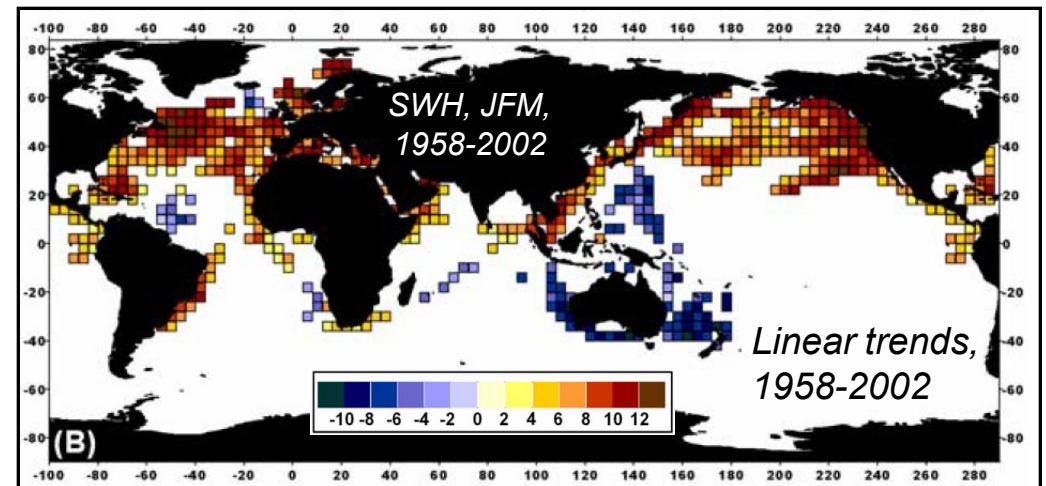
Wind wave data over the global oceans: VOS



Grigorieva et al. 2021, 2022, JGR

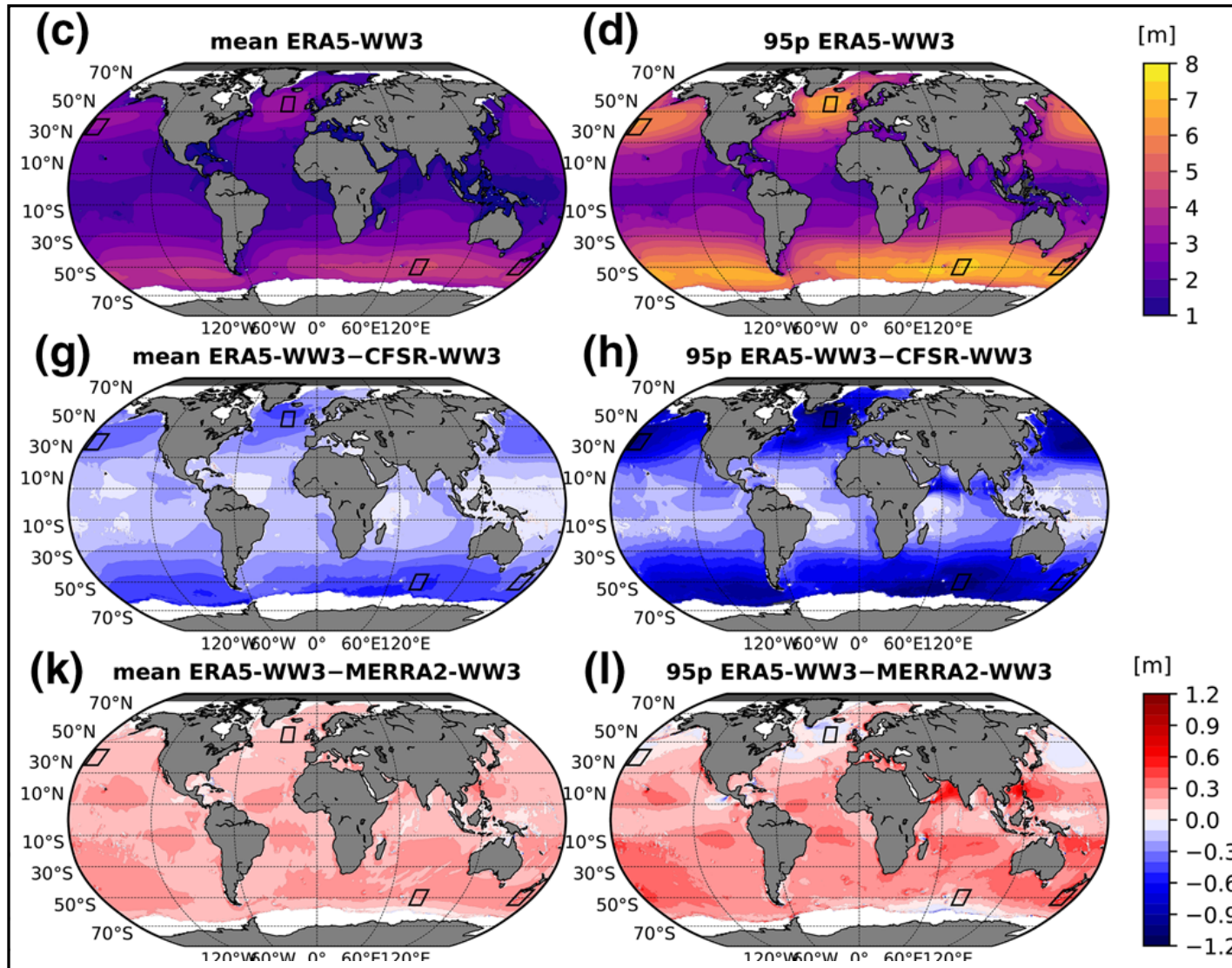


Grigorieva and Gulev 2023, JClimate, Collins et al. 2026

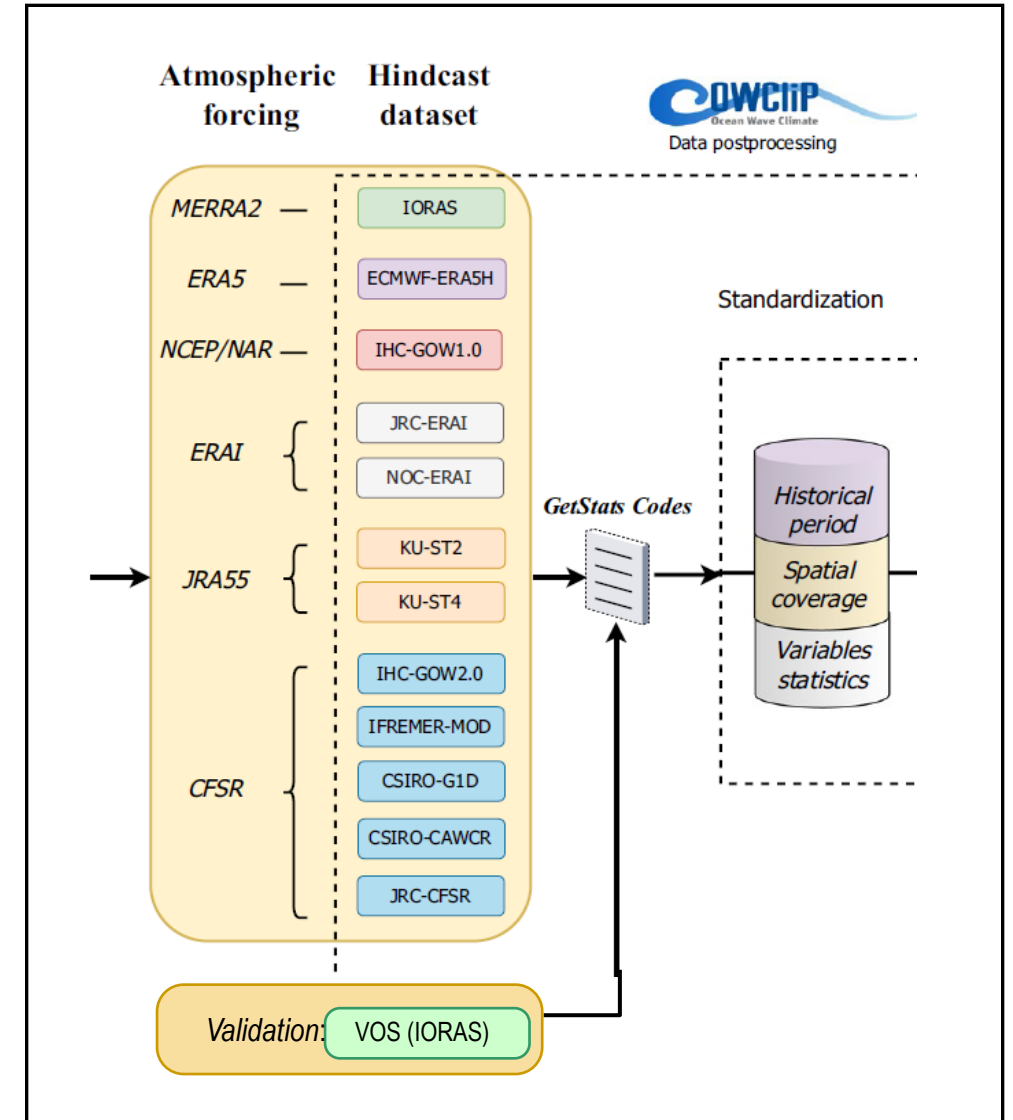


Gulev and Grigorieva 2006, GRL, AR4

Wind wave data over the global oceans: model hindcasts

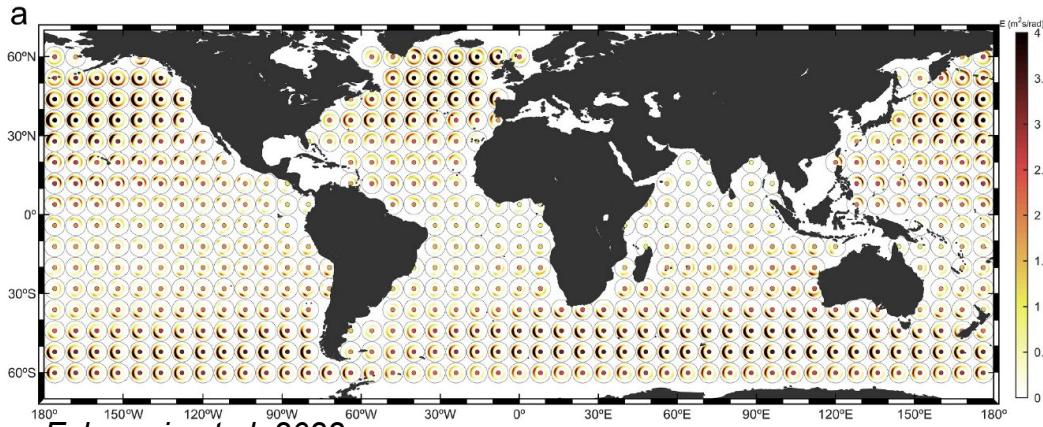


Sharmar et al. 2022, JGR

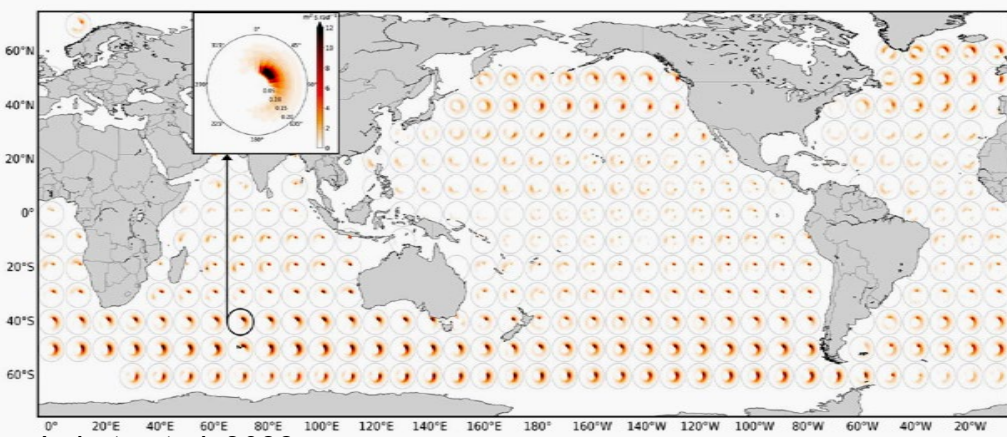
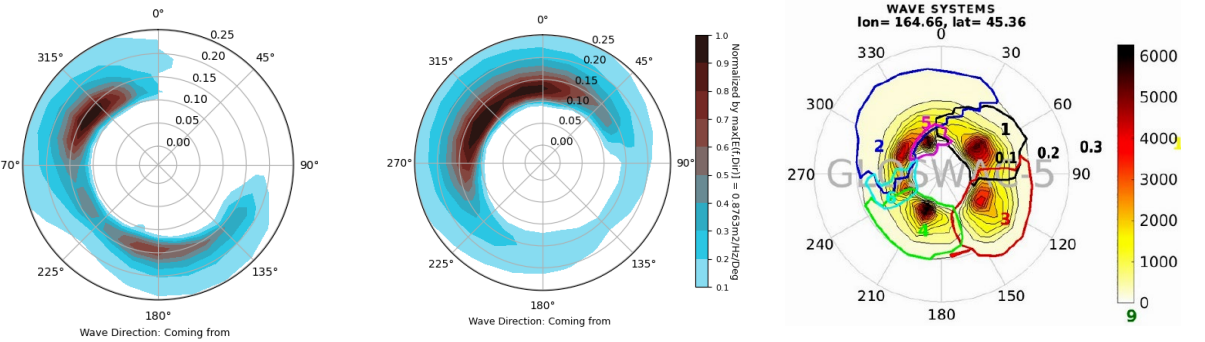


Erikson et al. 2021, Morim et al. 2022, Nature comm.

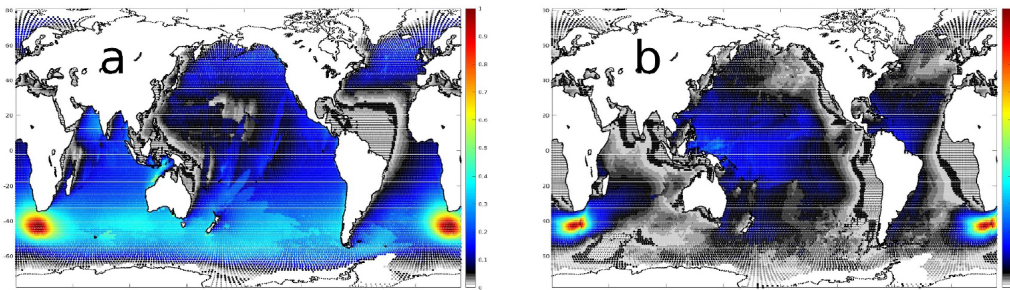
Only wave spectral models provide directional spectra



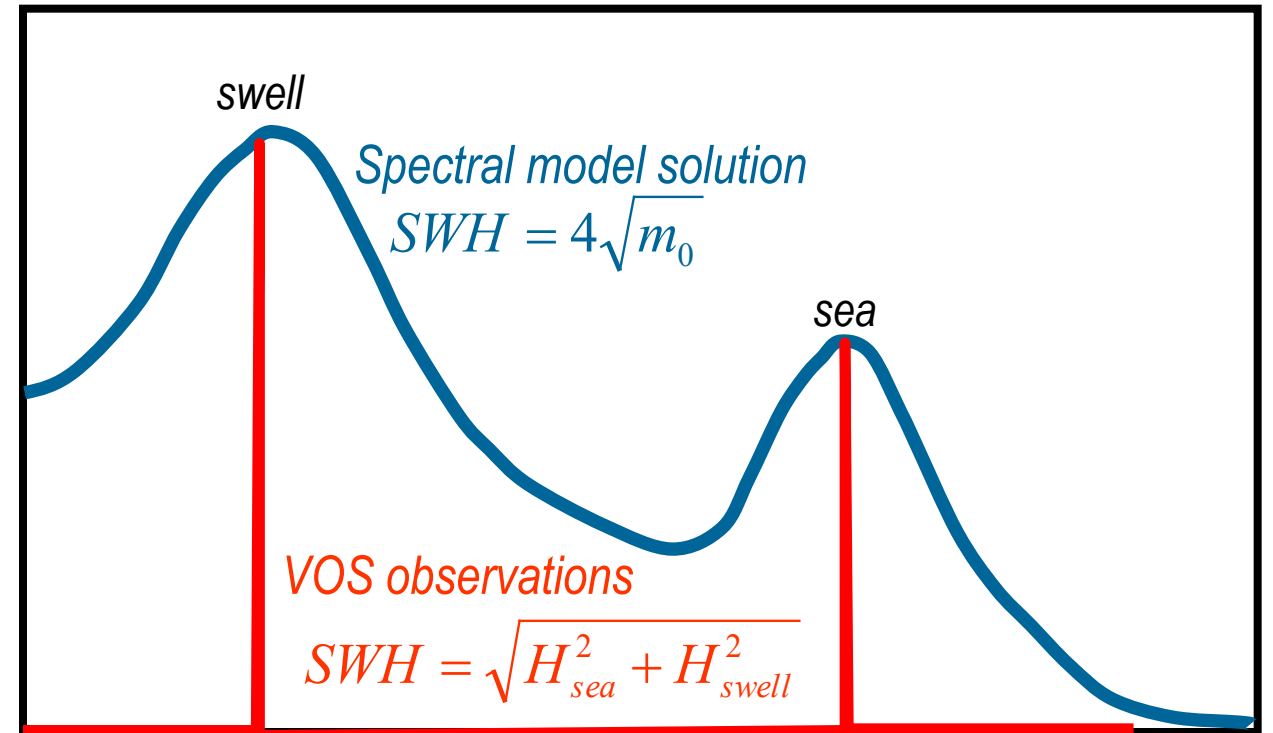
Echevaria et al. 2022



Lobeto et al. 2022



Portilla and Bildot 2025



Which waves we consider? $\rightarrow$

$$\omega^2 = gk \left[1 + \frac{\gamma_w k^2}{g} \right] \tanh(kd)$$

Frequency spectrum $\leftarrow$

Two-dimensional wave spectrum

$$S(f, \theta) = F(f)D(f, \theta)$$

Spreading function, satisfying to

$$\int_0^{2\pi} D(f, \theta) d\theta = 1$$

Longuet-Higgins et al. (1963):

$$D(\theta) = \frac{1}{\sigma} \left| \frac{\cos(\theta - \bar{\theta})}{2} \right|^{2s}$$

$$\sigma = \frac{2\sqrt{\pi}\Gamma(s + 1/2)}{\Gamma(s + 1)}$$

1st order
moments

$$\bar{\theta} = \arctan2(\langle \sin \theta \rangle, \langle \cos \theta \rangle)$$

$$s = \left(1 - \sqrt{\langle \sin \theta \rangle^2 + \langle \cos \theta \rangle^2} \right)^{-1} - 1$$

$$\langle \sin \theta \rangle \equiv \frac{1}{N} \sum_{i=1}^N \sin \theta_i \quad \langle \cos \theta \rangle \equiv \frac{1}{N} \sum_{i=1}^N \cos \theta_i$$

Pierson and Moskowitz (1964)

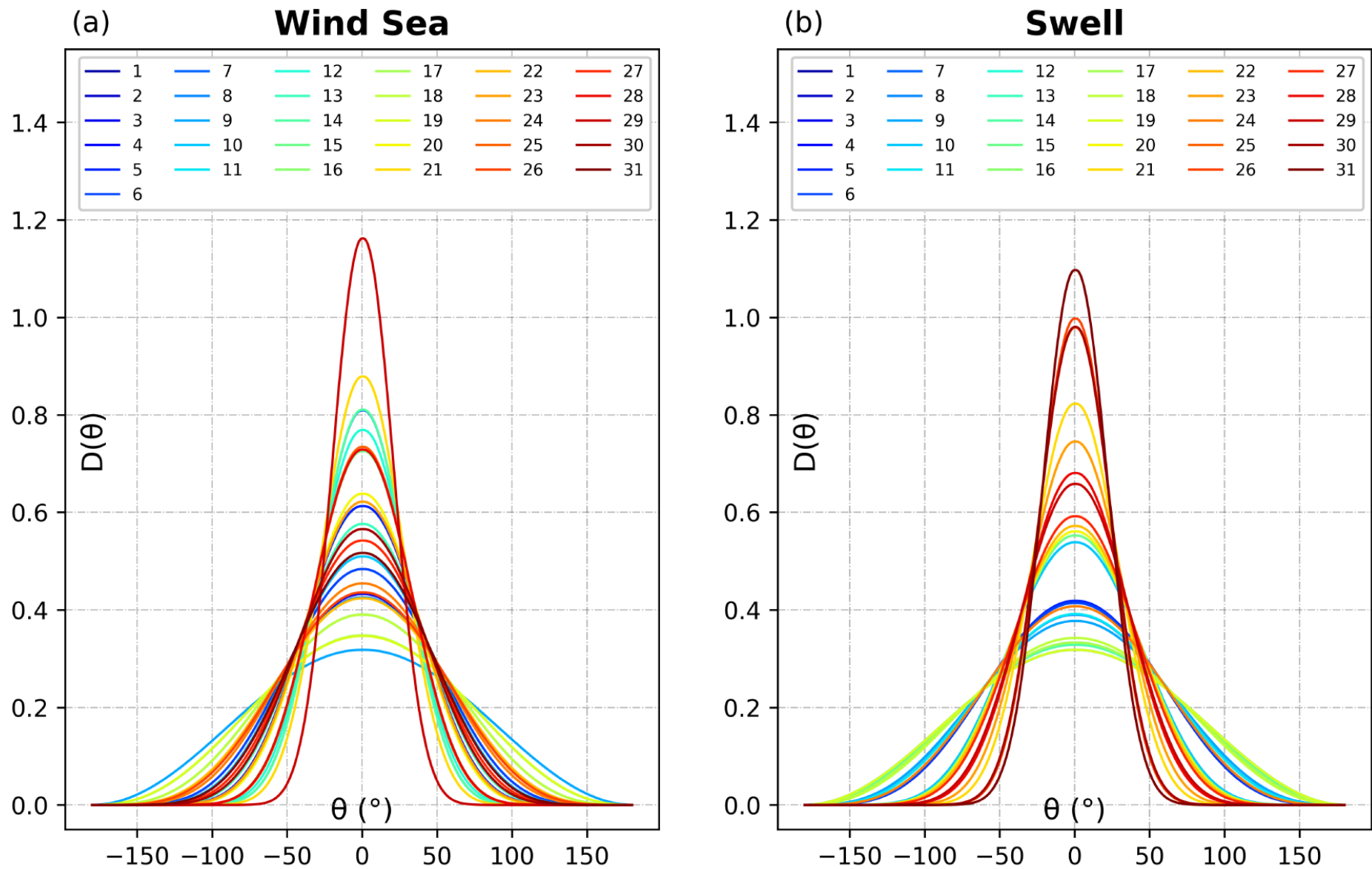
$$F_{\text{sea}}(f) = \frac{5}{16} H_s^2 \frac{f_p^4}{f^5} \exp \left[-\frac{5}{4} \left(\frac{f}{f_p} \right)^{-4} \right]$$

Burling (1959), Davidan et al. (1978)

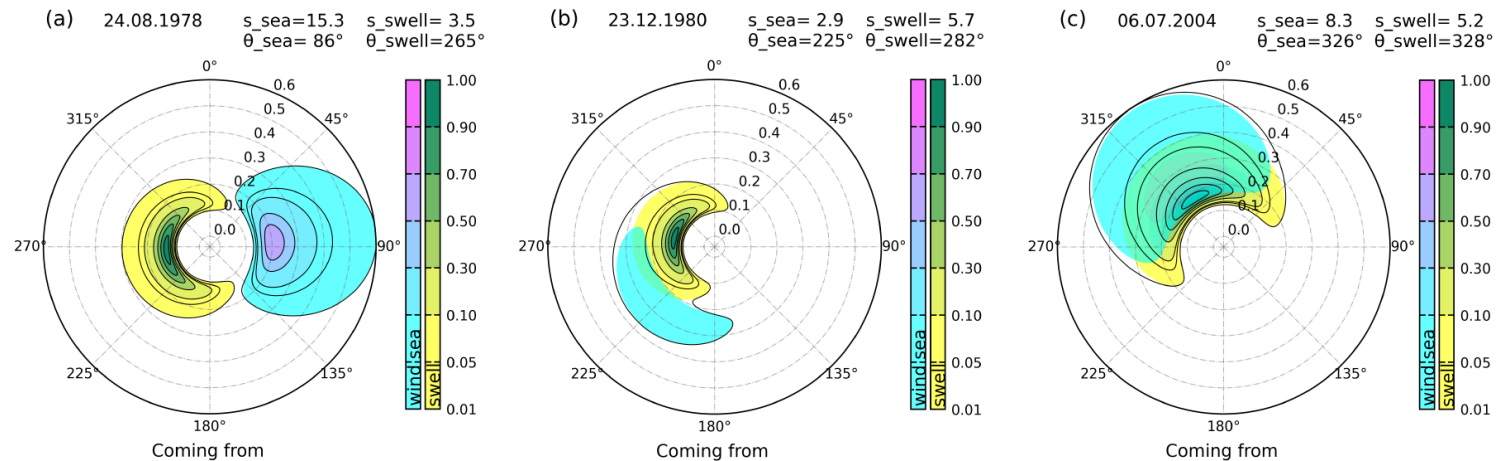
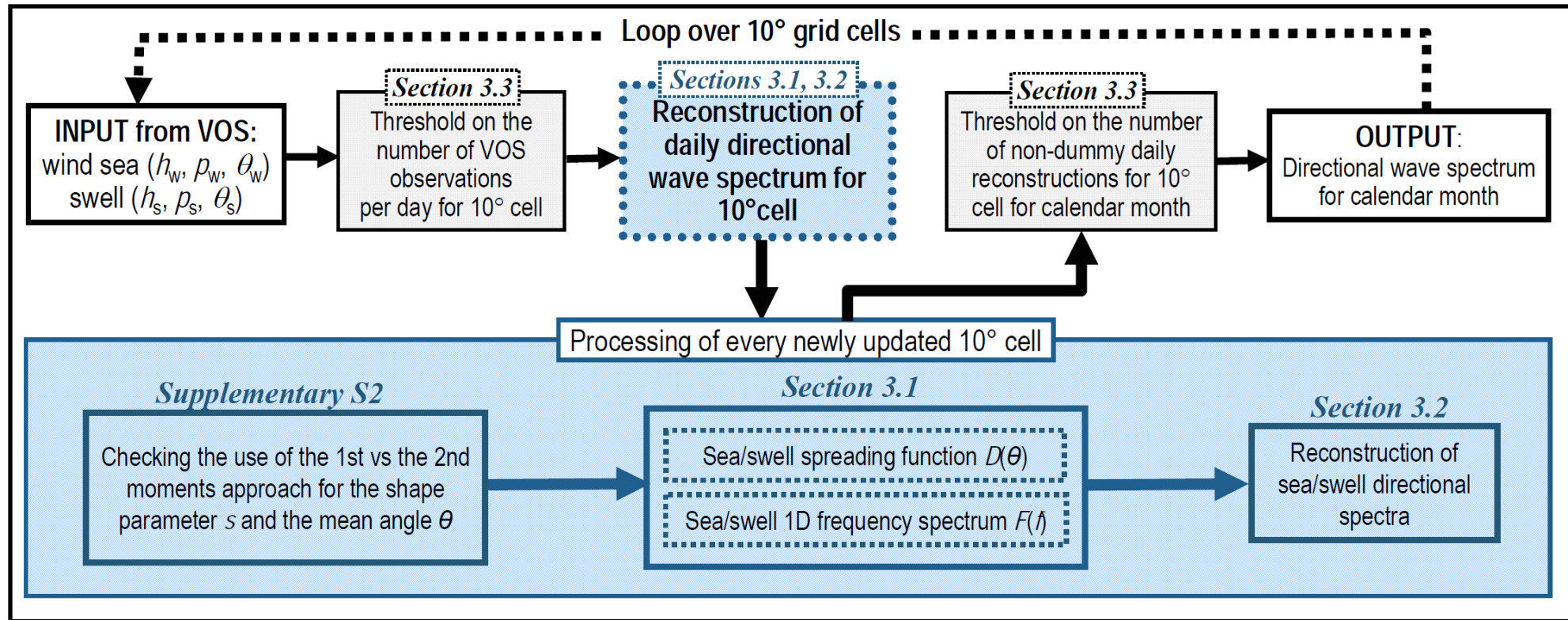
$$F_{\text{swell}}(f) = \frac{3}{\pi} H_s^2 \frac{f_p^5}{f^6} \exp \left[-\frac{6}{5} \left(\frac{f}{f_p} \right)^{-5} \right]$$

$$S(f, \theta) = F_{\text{sea}}(f)D_{\text{sea}}(\theta) + F_{\text{swell}}(f)D_{\text{swell}}(\theta)$$

Spreading functions

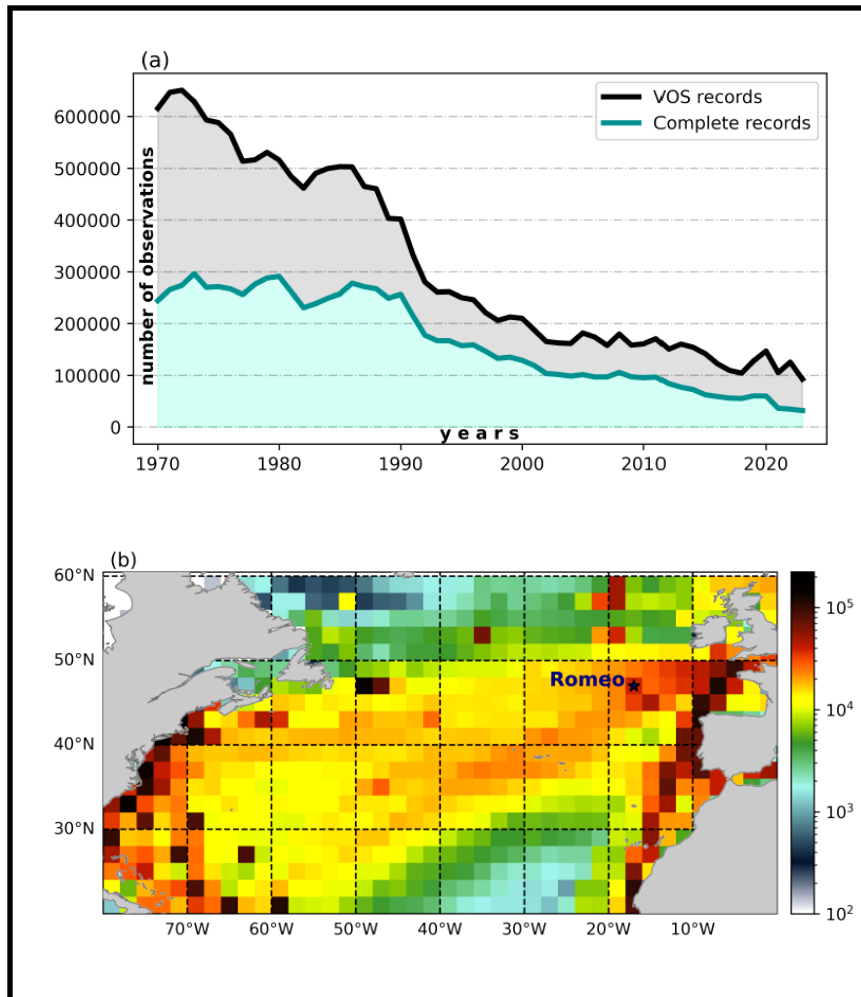


Flowchart of the algorithm

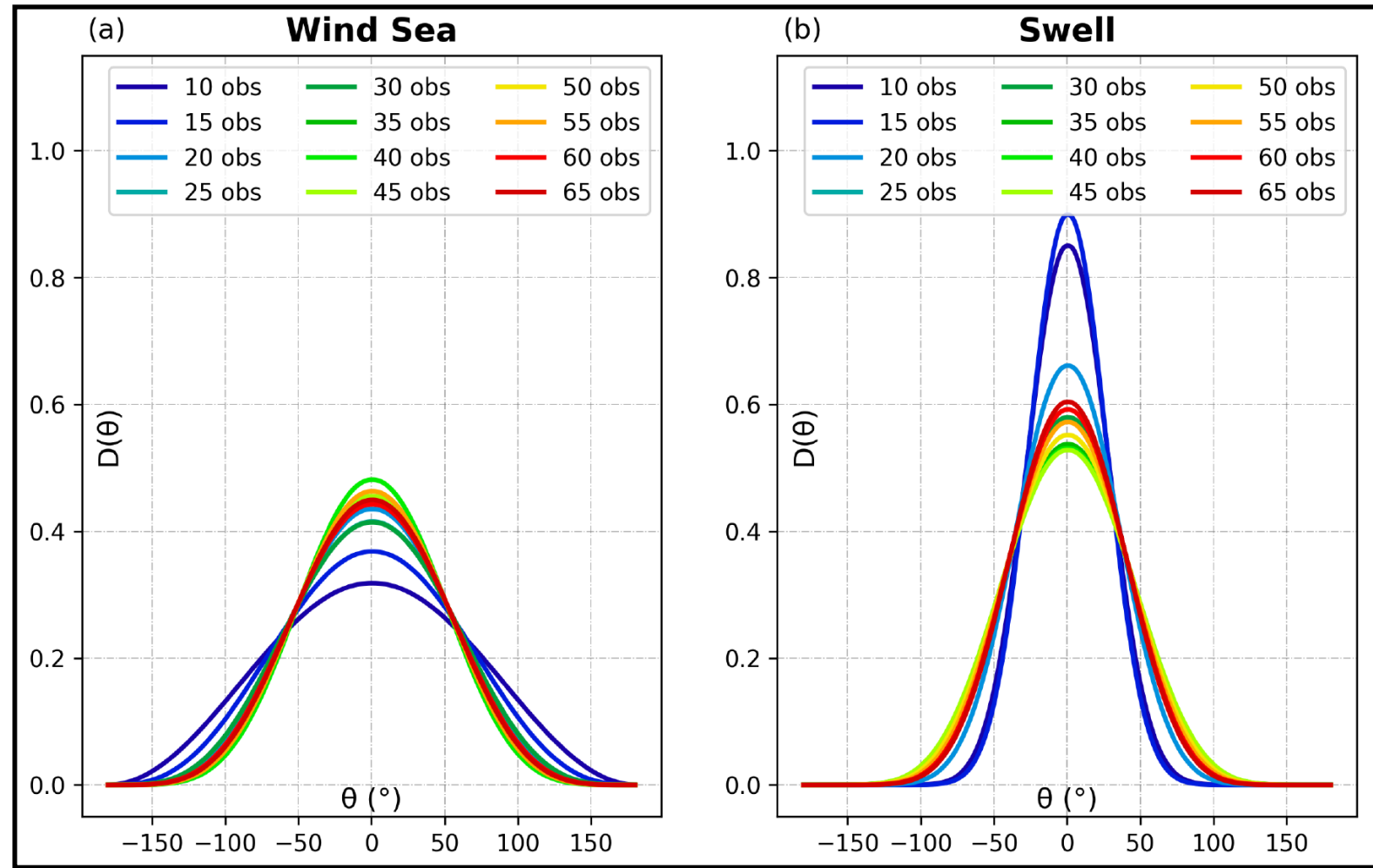


Thresholds: the number of obs in 10-degree cell

Mid-latitude NA

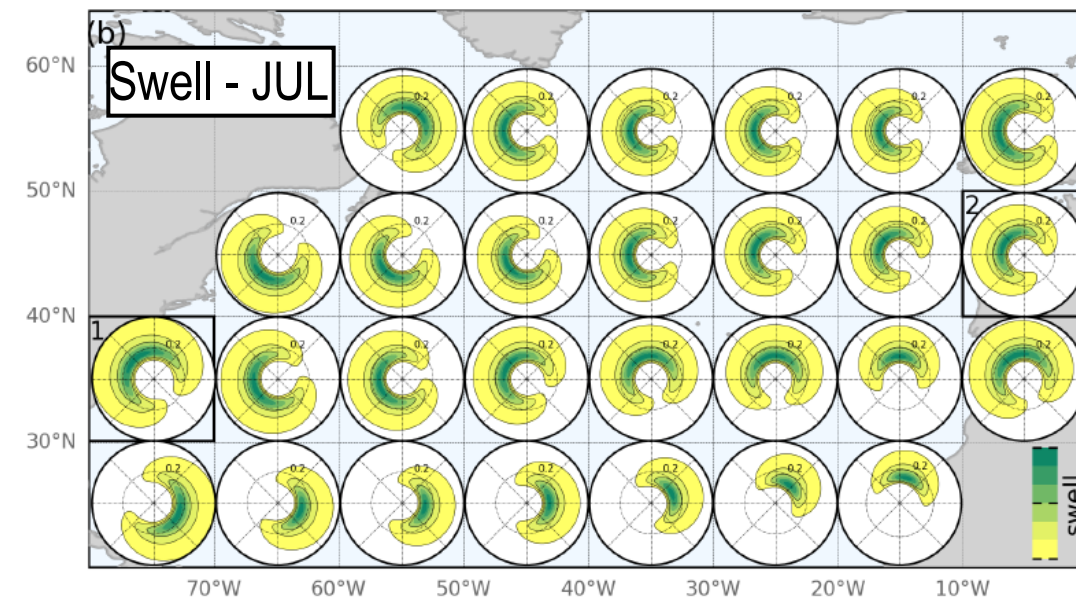
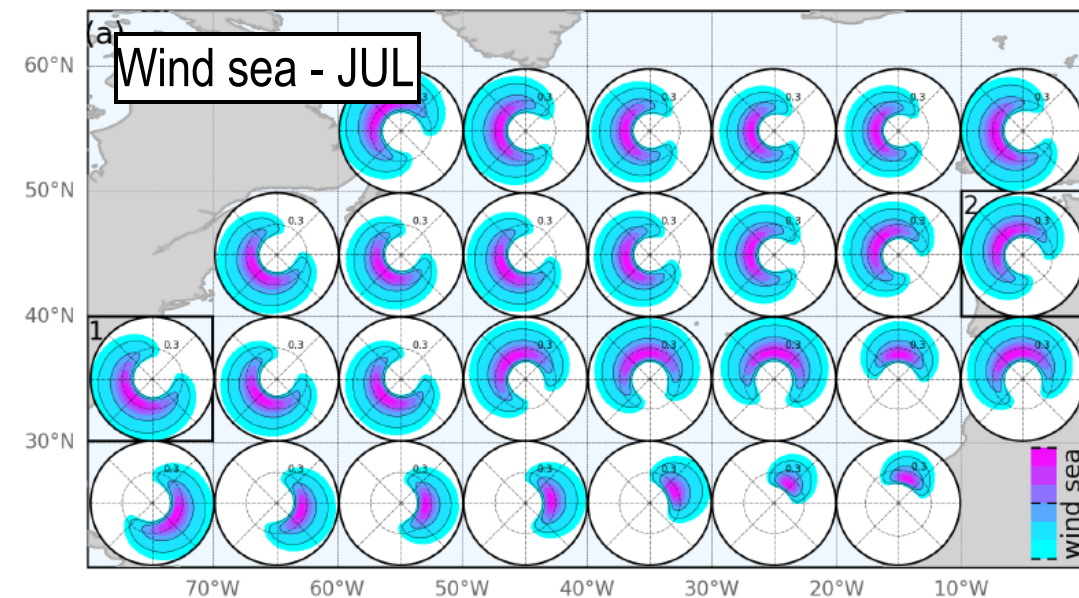
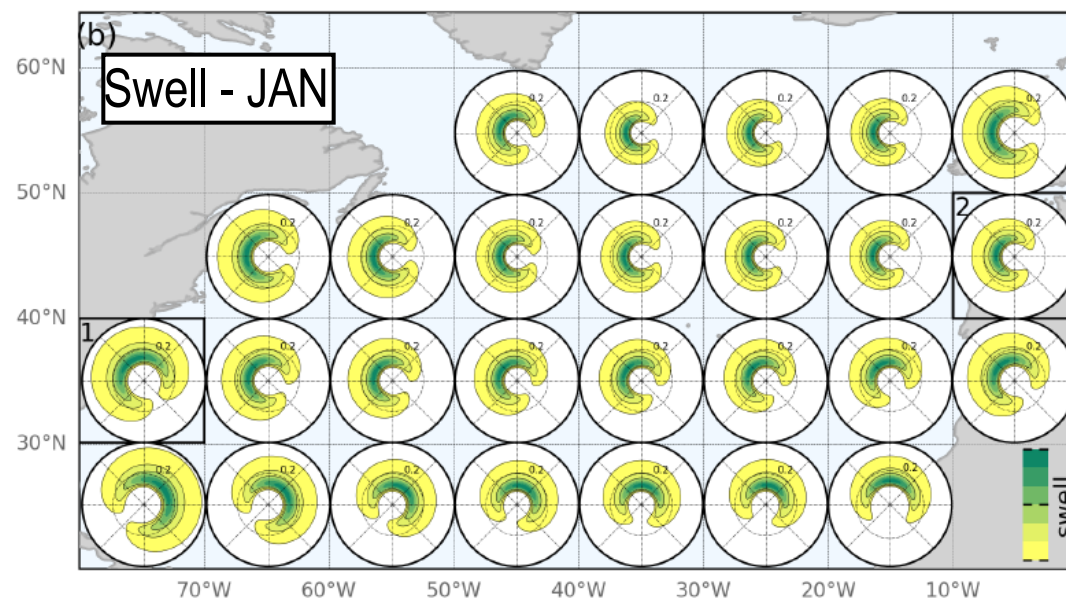
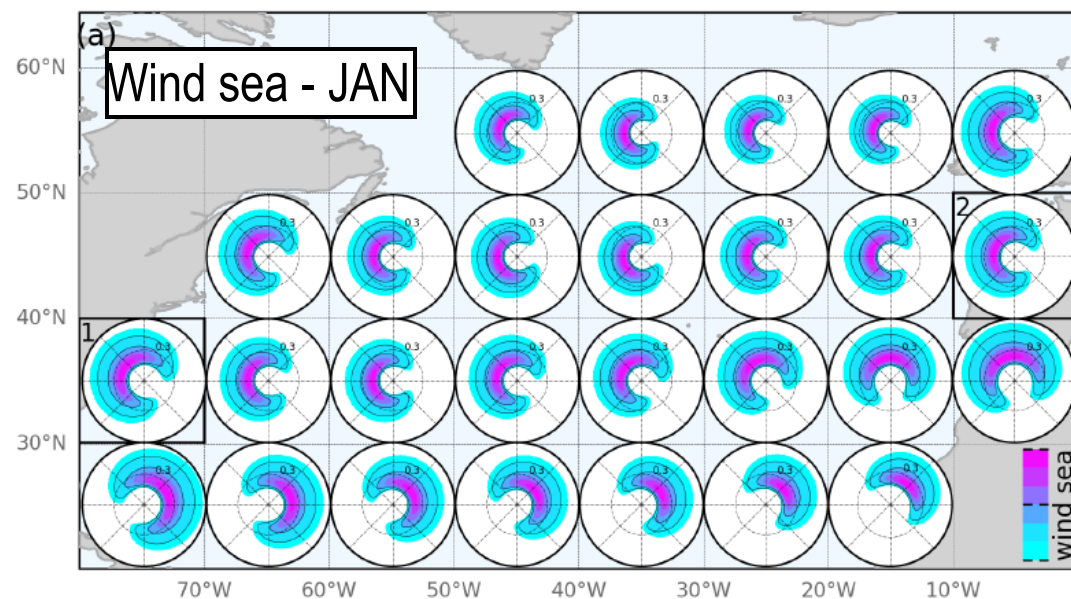


Spreading functions for randomly selected number of obs

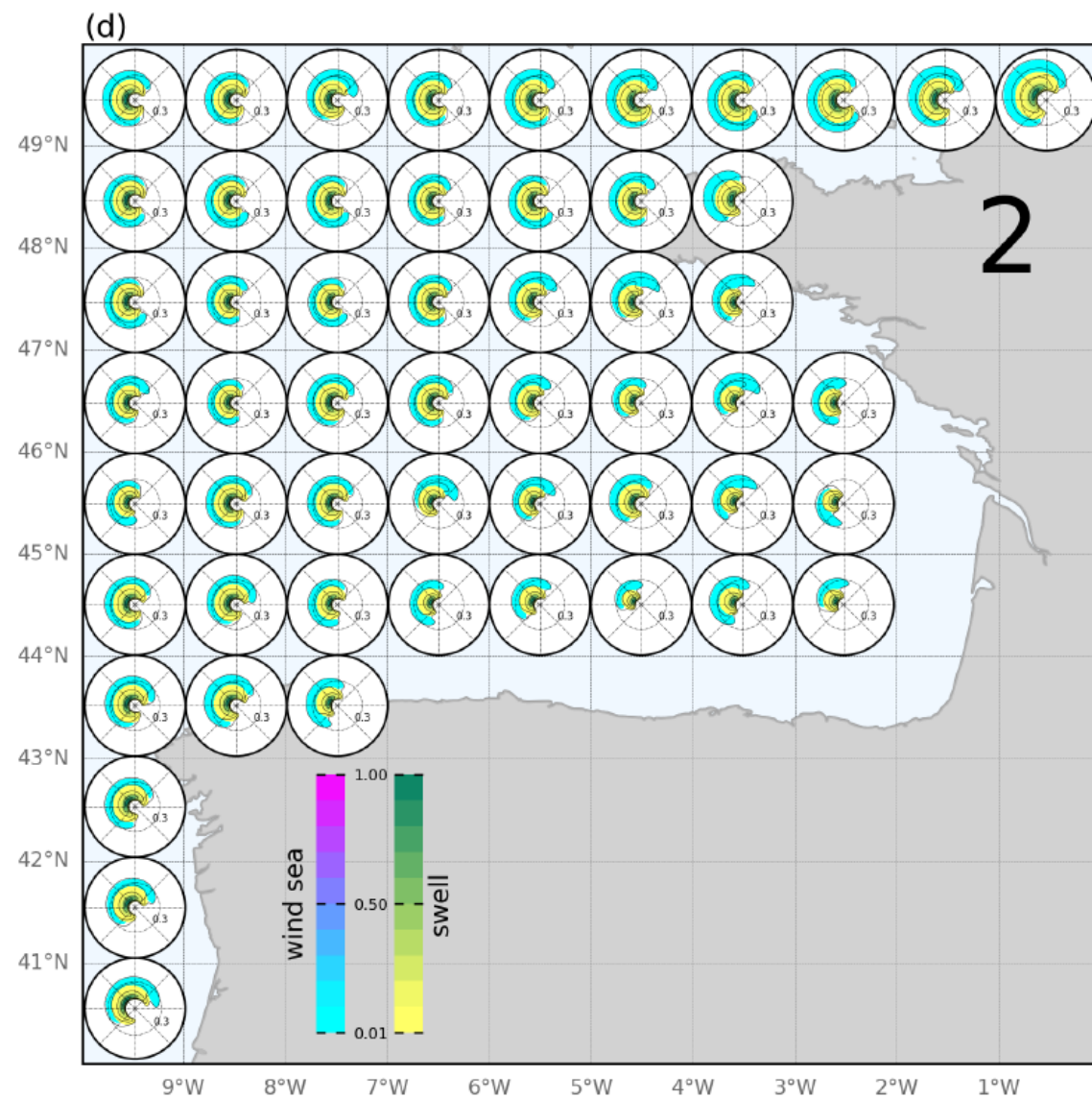
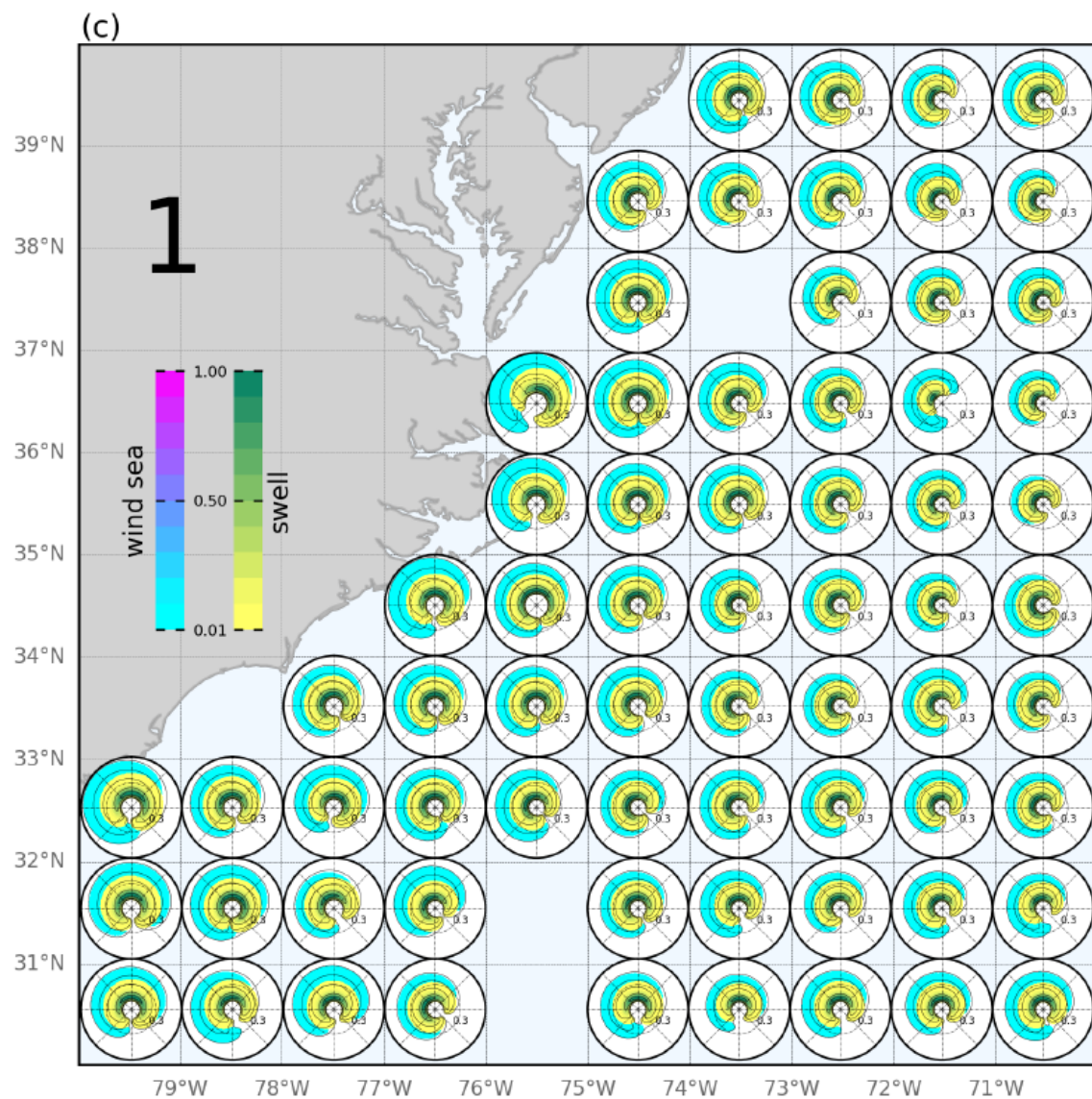


$N > 20$ (simultaneous obs), **$nd > 15$** (non-dummy days per month) → **robust estimate**

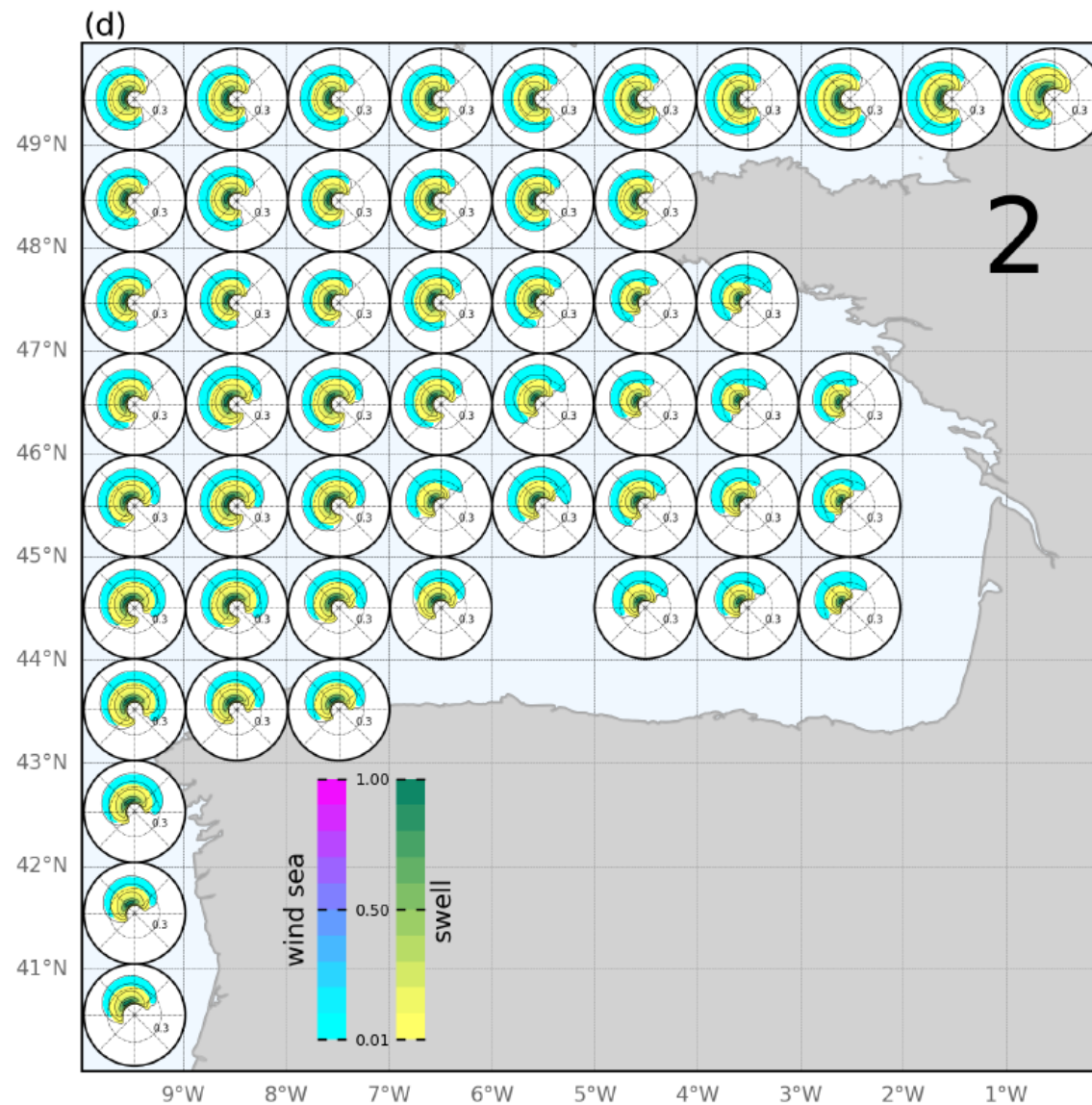
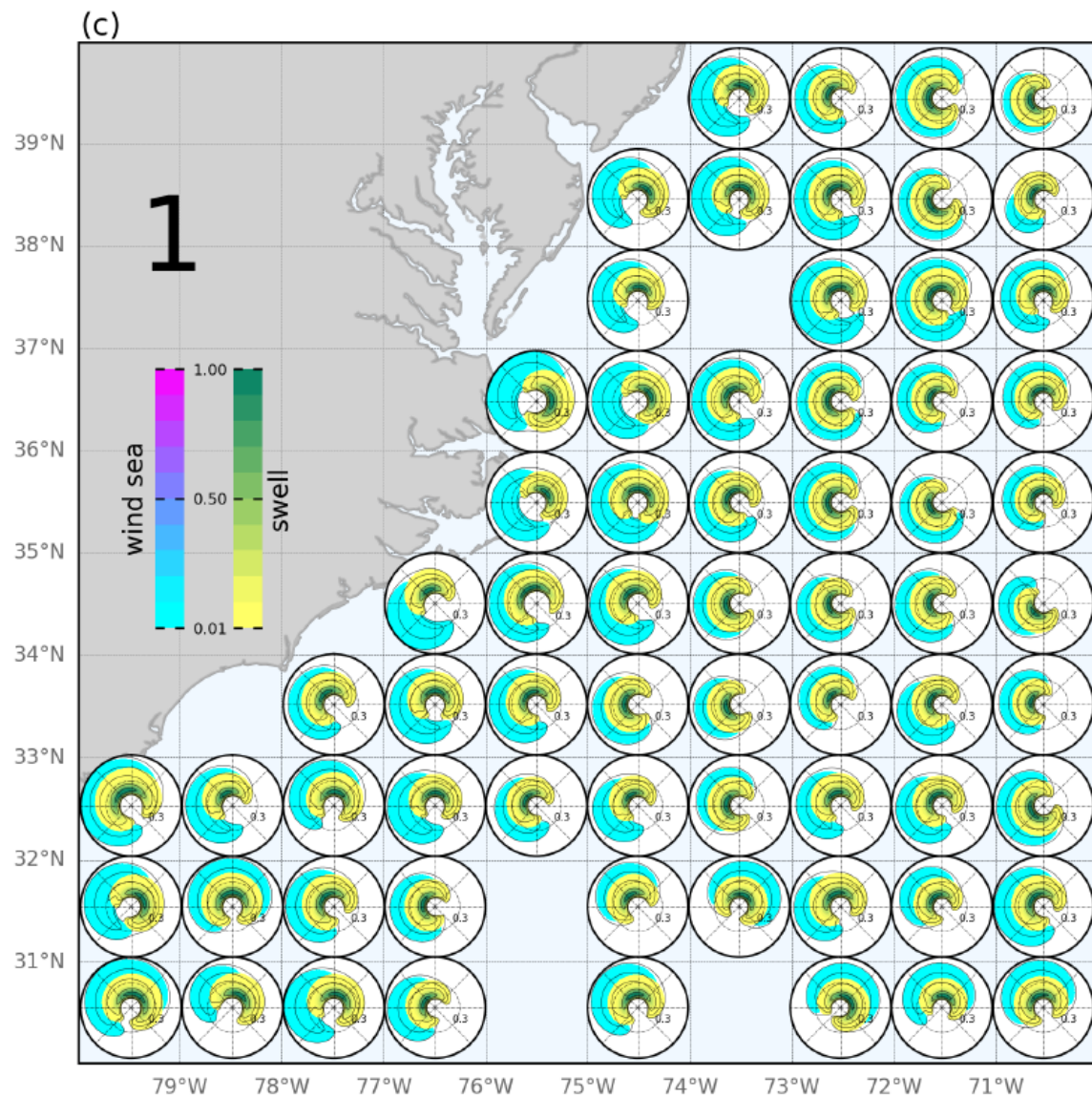
Reconstruction of directional spectra from VOS: NA (1970-2024) 10° cells



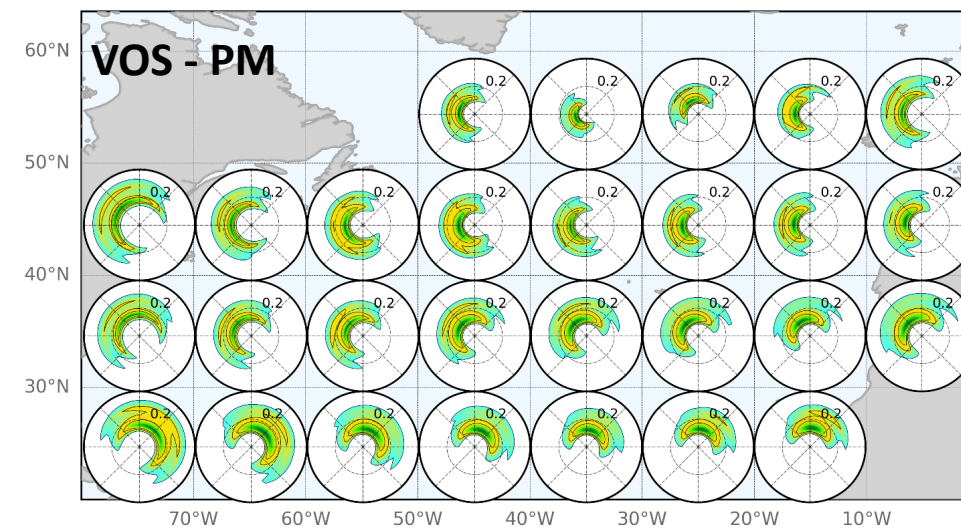
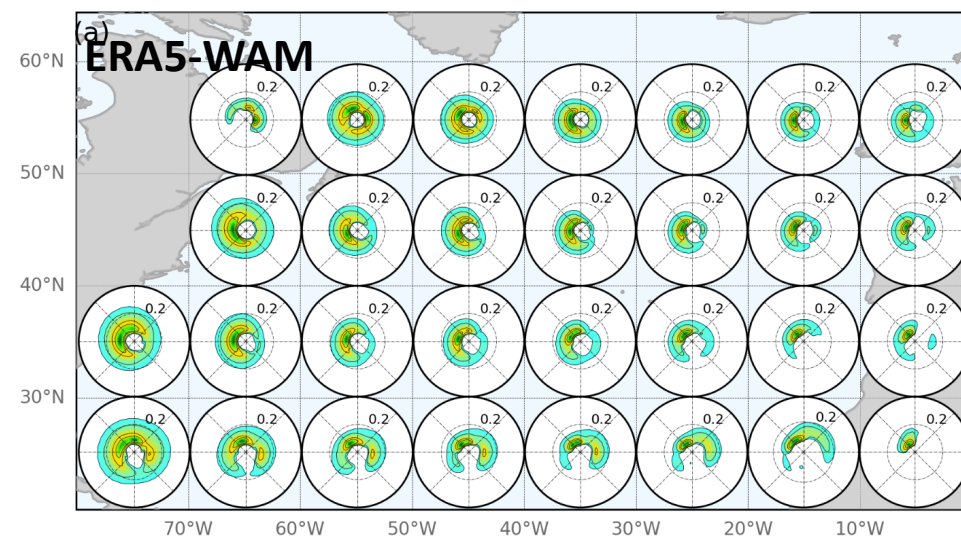
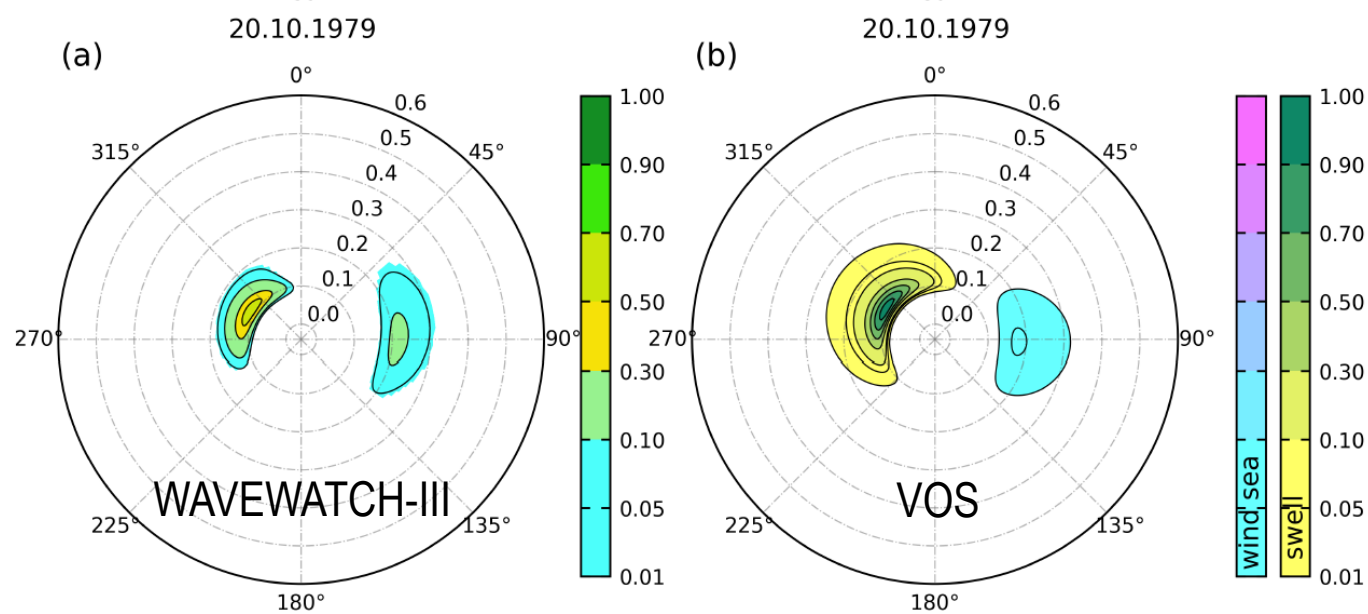
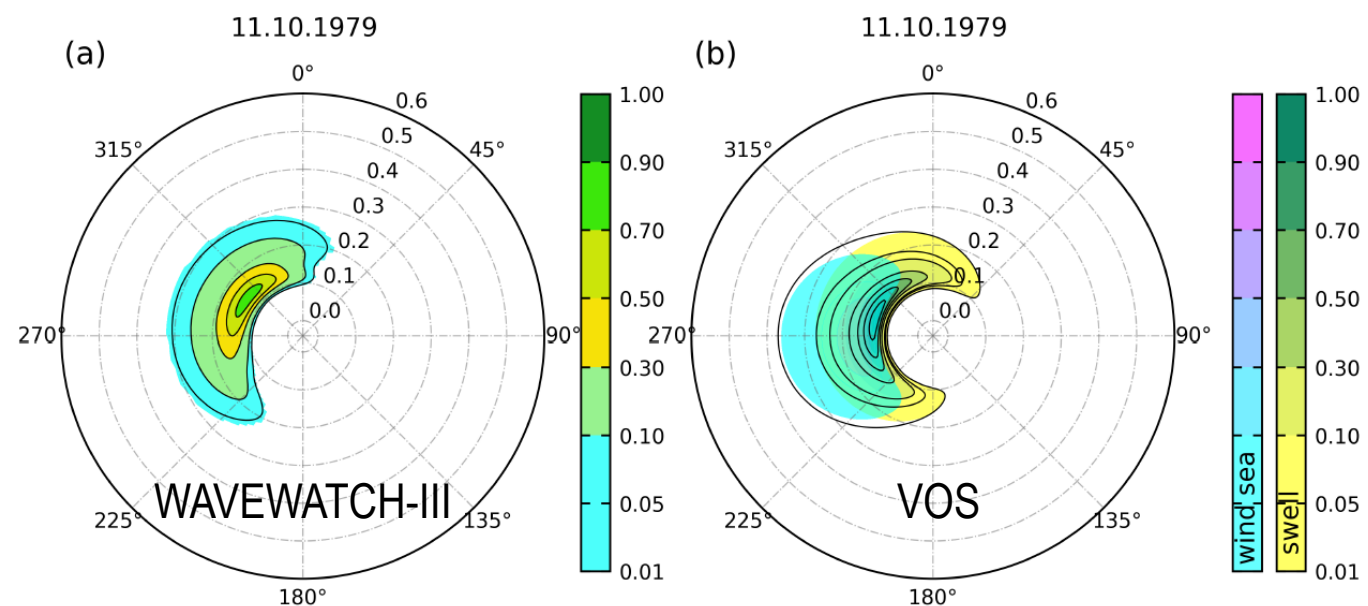
Reconstruction of directional spectra from VOS: NA- JAN (1970-2024) 1° cells



Reconstruction of directional spectra from VOS: NA-JUL (1970-2024) 1° cells

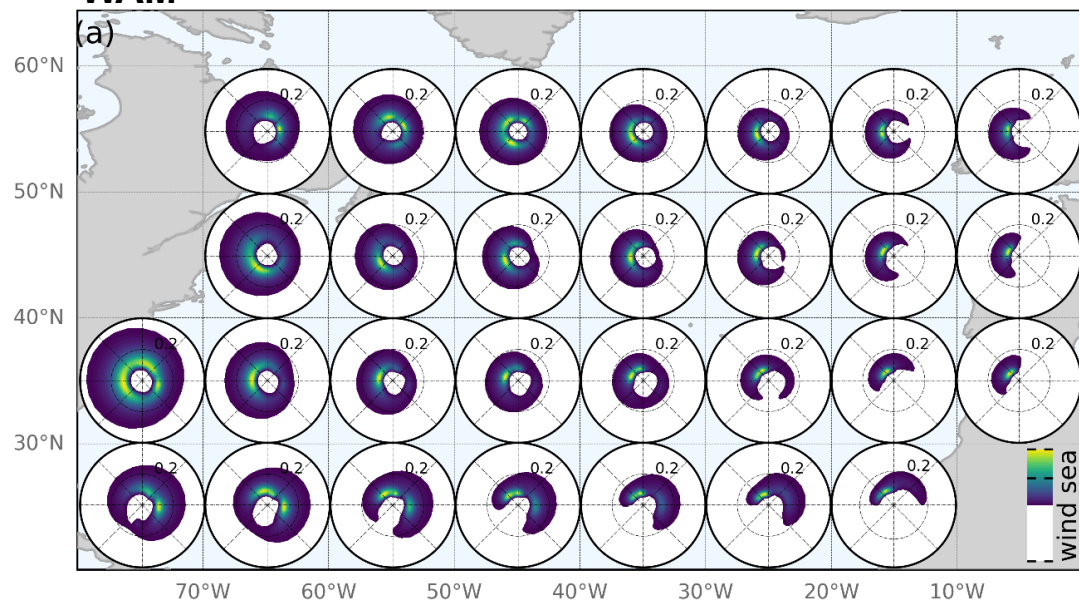


Validation against model spectra

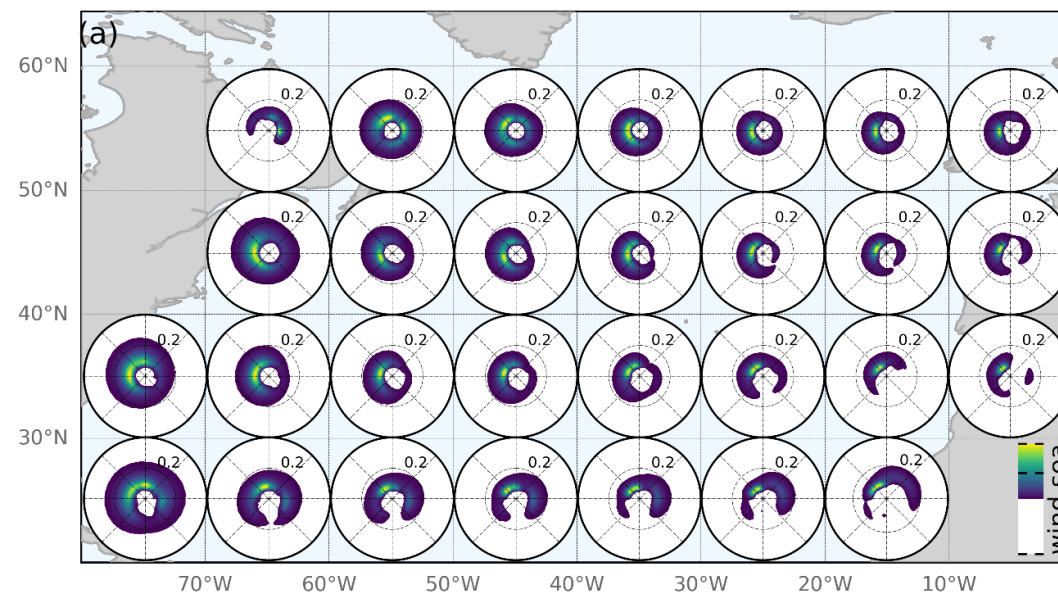


Validation against model spectra

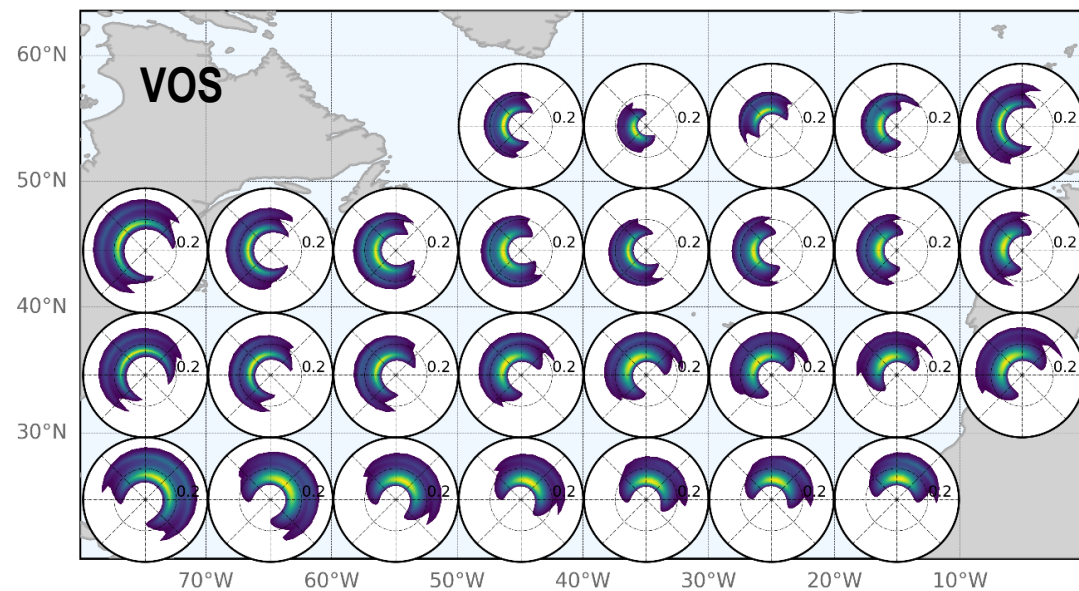
WAM



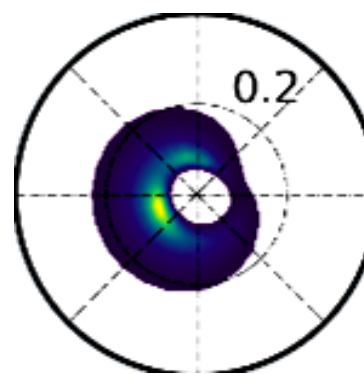
WAVEWATCH-III



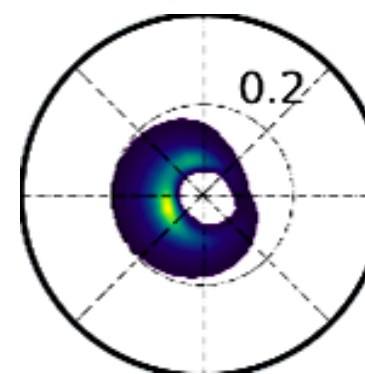
VOS



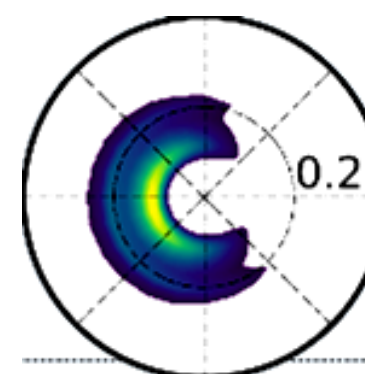
WAM



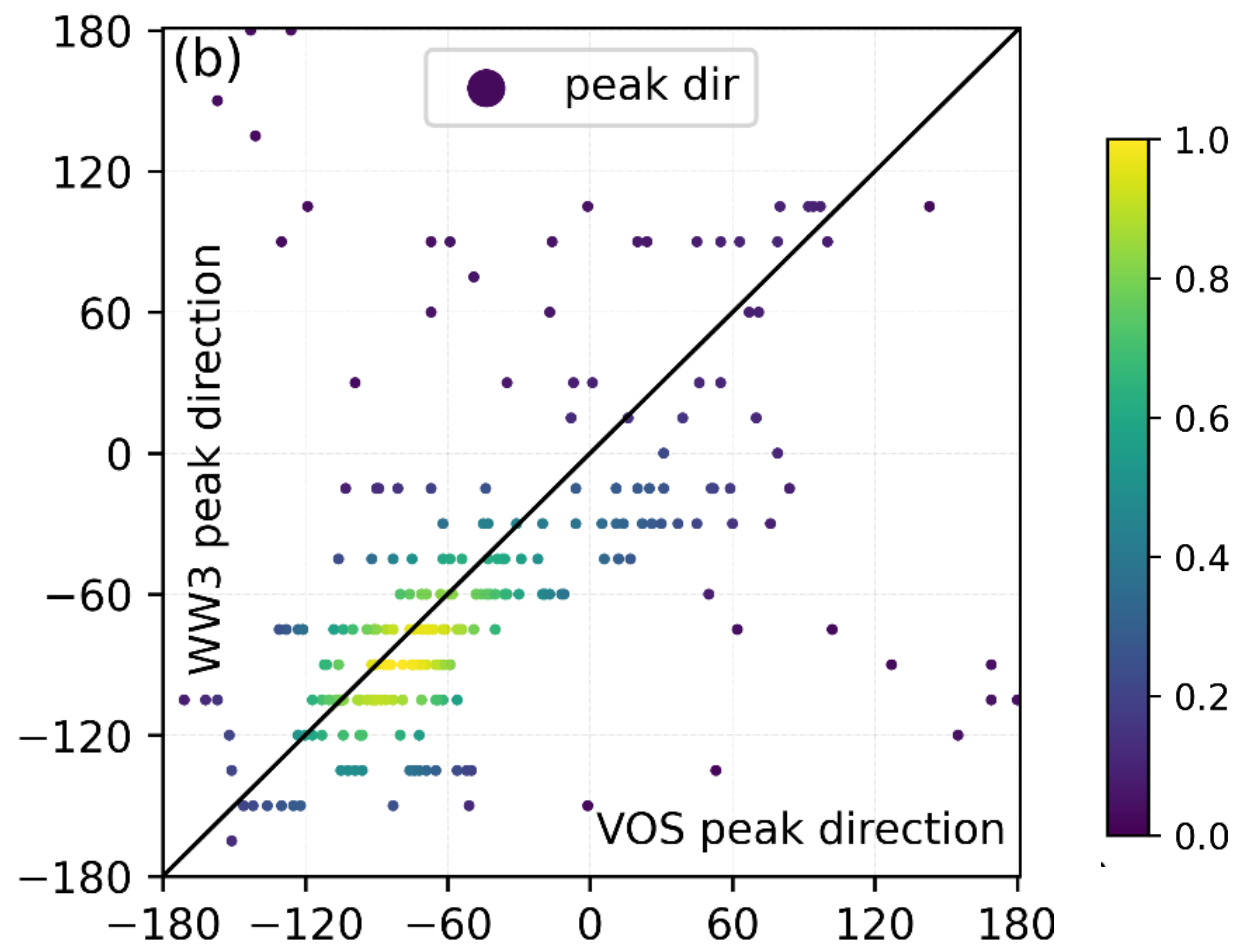
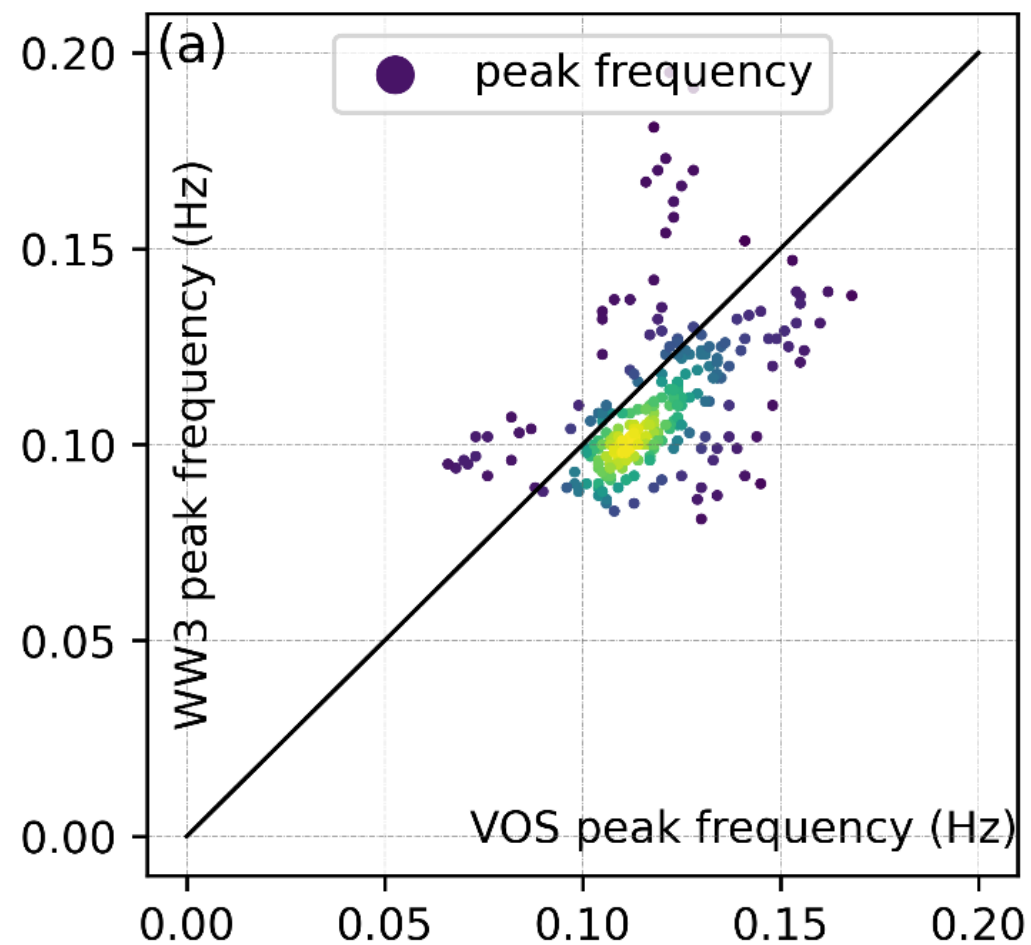
WAVEWATCH-III



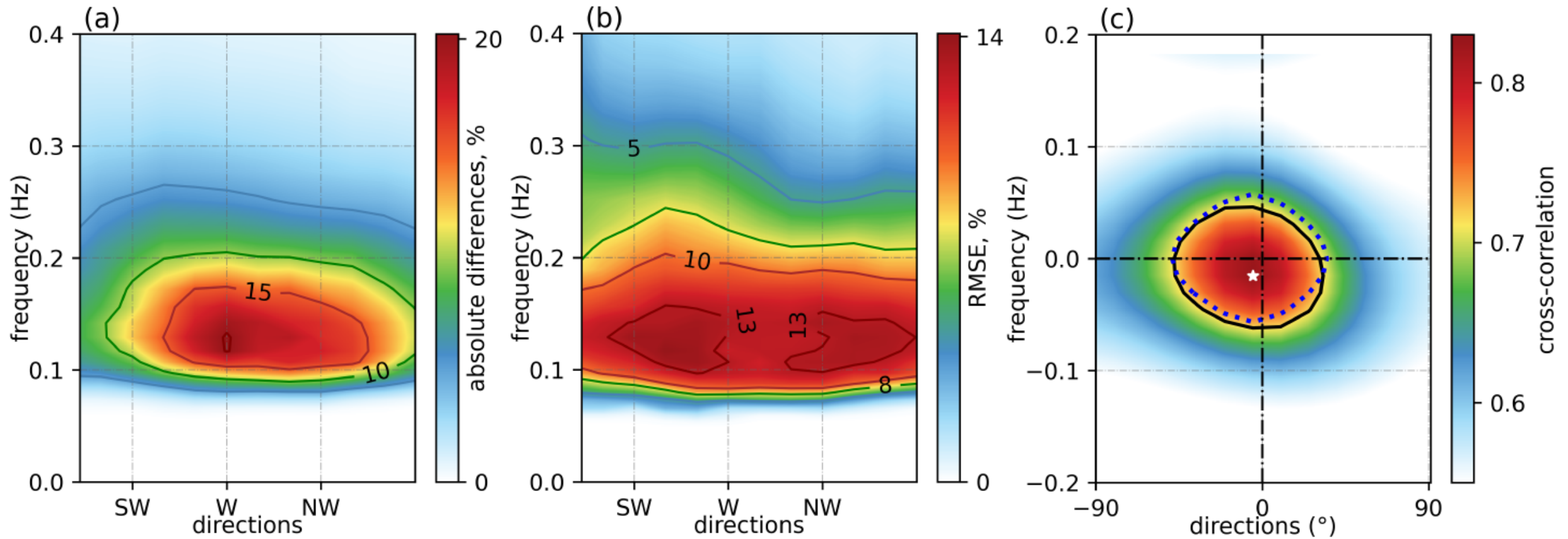
VOS



Validation against model spectra



Validation against model spectra



PM vs JONSWAP

Pierson and Moskowitz (1964)

$$F_{\text{sea}}(f) = \frac{5}{16} H_s^2 \frac{f_p^4}{f^5} \exp \left[-\frac{5}{4} \left(\frac{f}{f_p} \right)^{-4} \right]$$

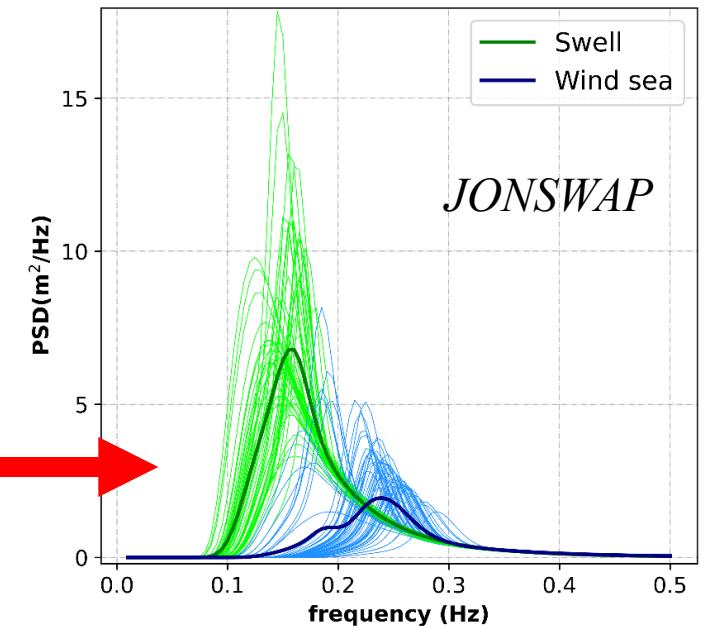
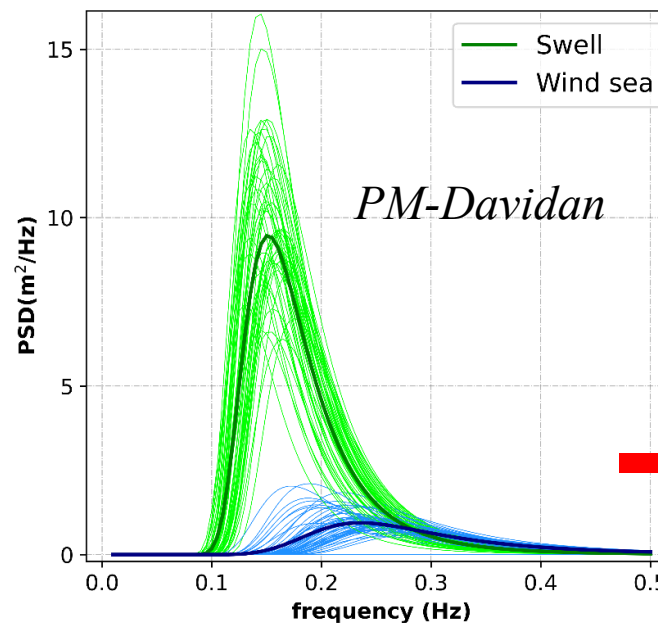
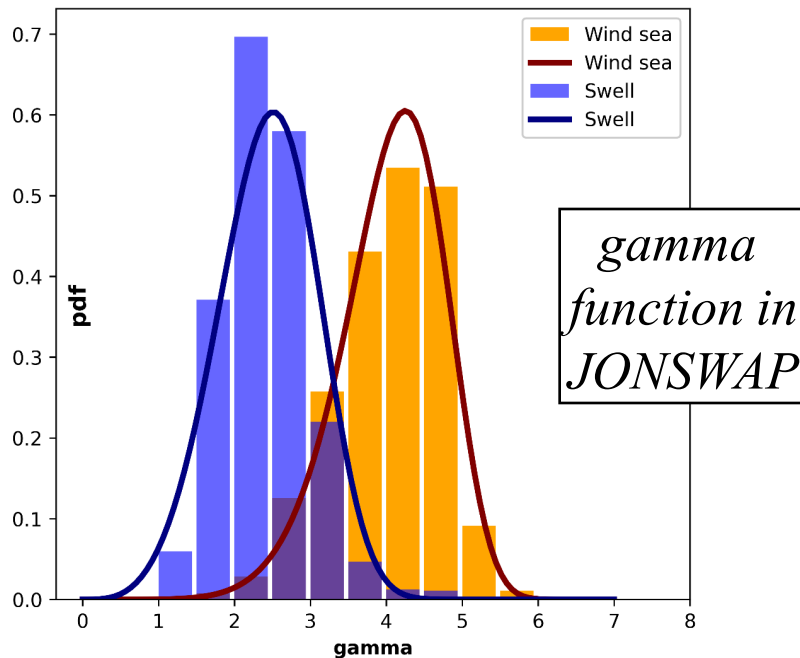
Burling (1959), Davidan et al. (1978)

$$F_{\text{swell}}(f) = \frac{3}{\pi} H_s^2 \frac{f_p^5}{f^6} \exp \left[-\frac{6}{5} \left(\frac{f}{f_p} \right)^{-5} \right]$$

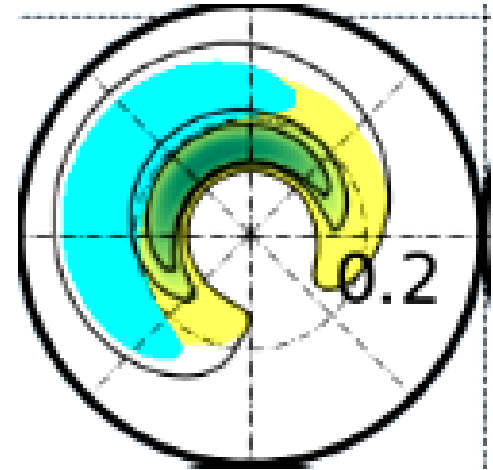
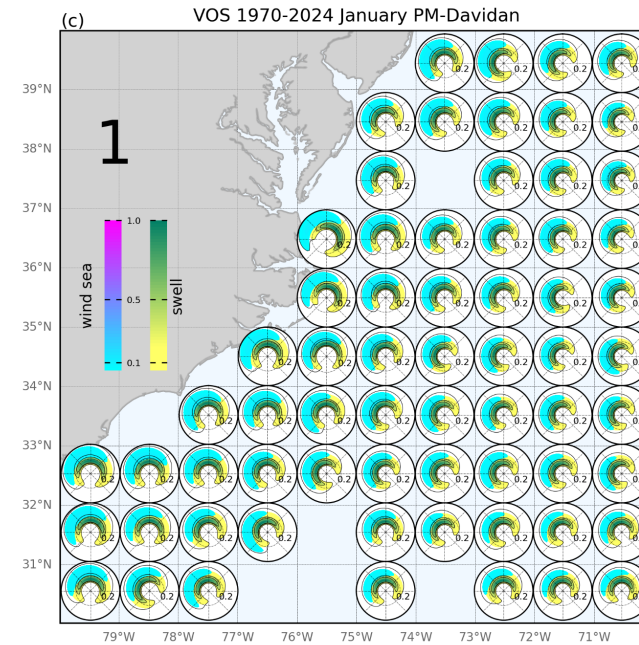
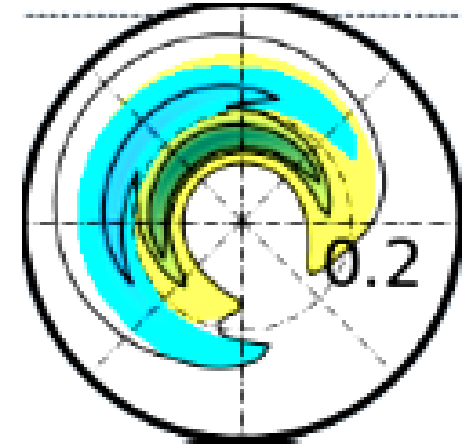
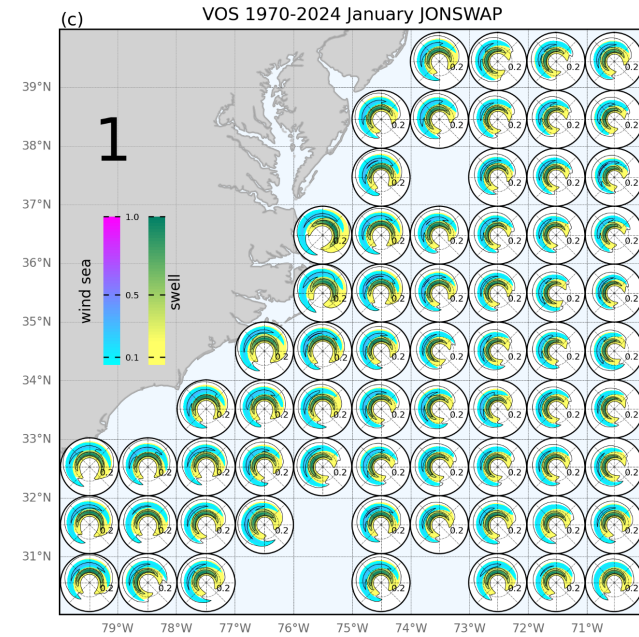
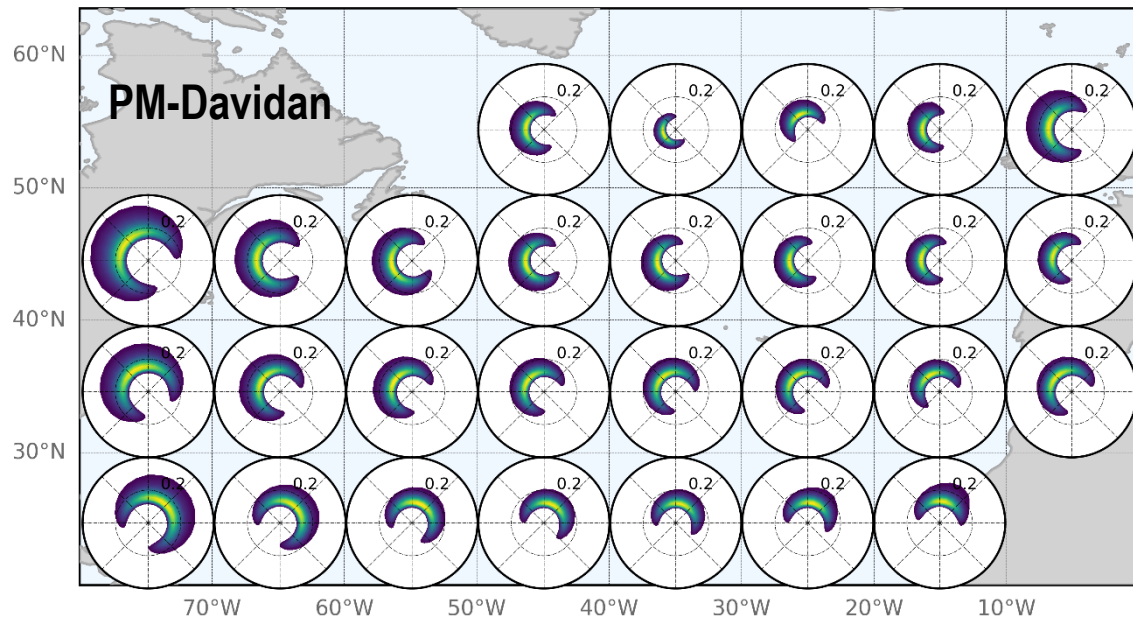
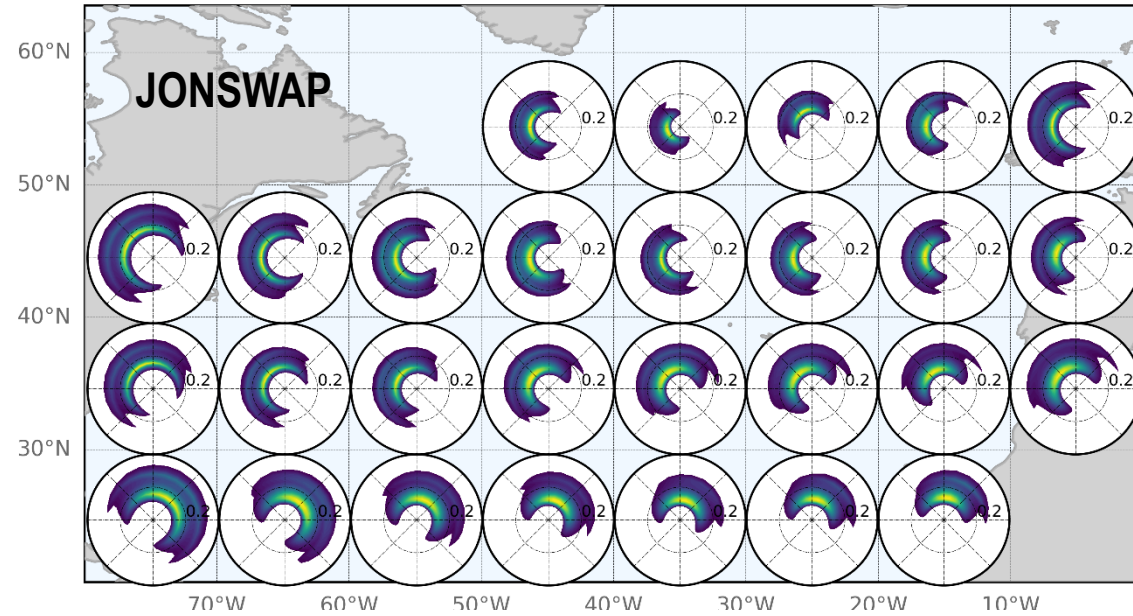
JONSWAP (1972)

$$S_{\eta}(f) = \alpha g^2 (2\pi)^{-4} f^{-5} \times \exp \left(-1.25 \left(\frac{f}{f_m} \right)^{-4} \right) \gamma^{\exp \left[\frac{-(f-f_m)^2}{2\sigma^2 f_m^2} \right]},$$

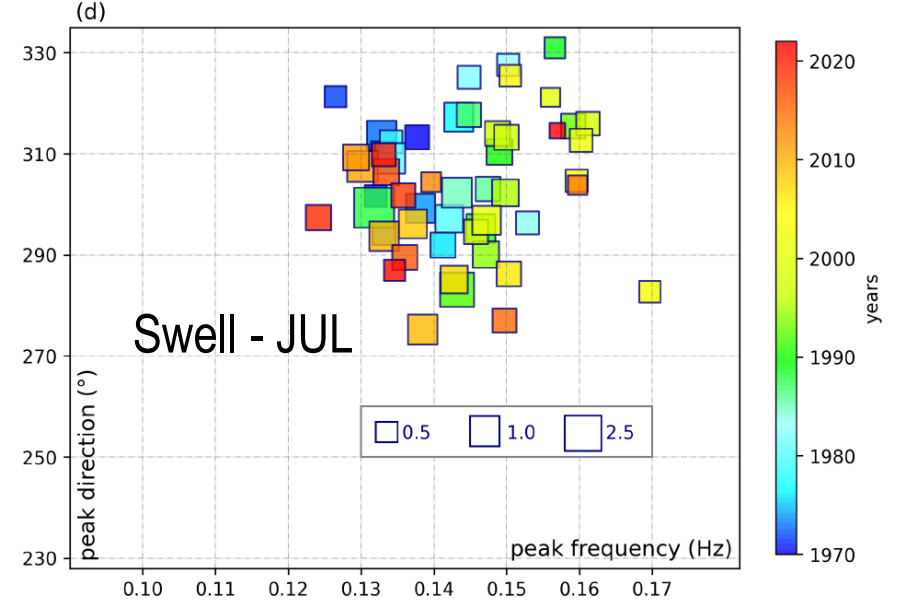
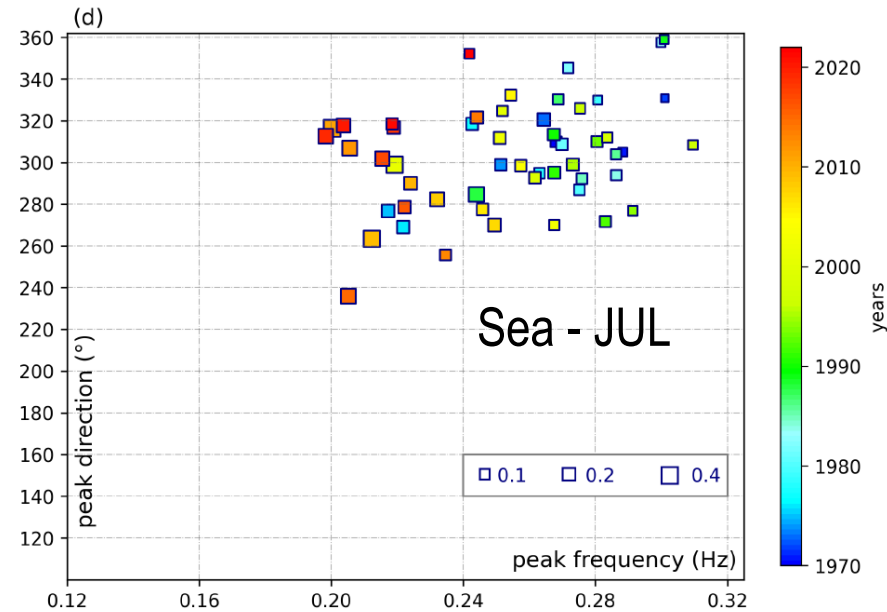
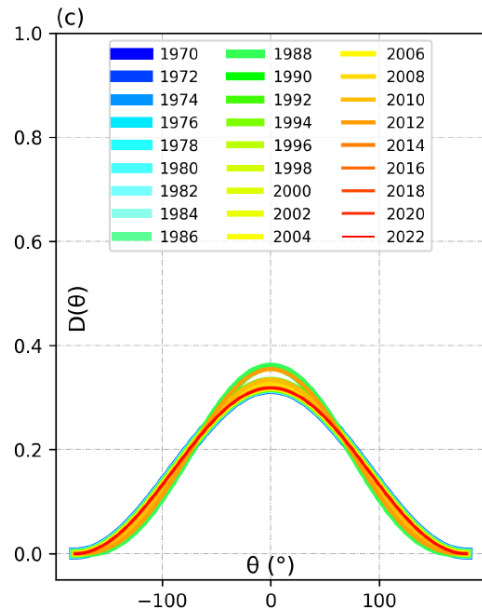
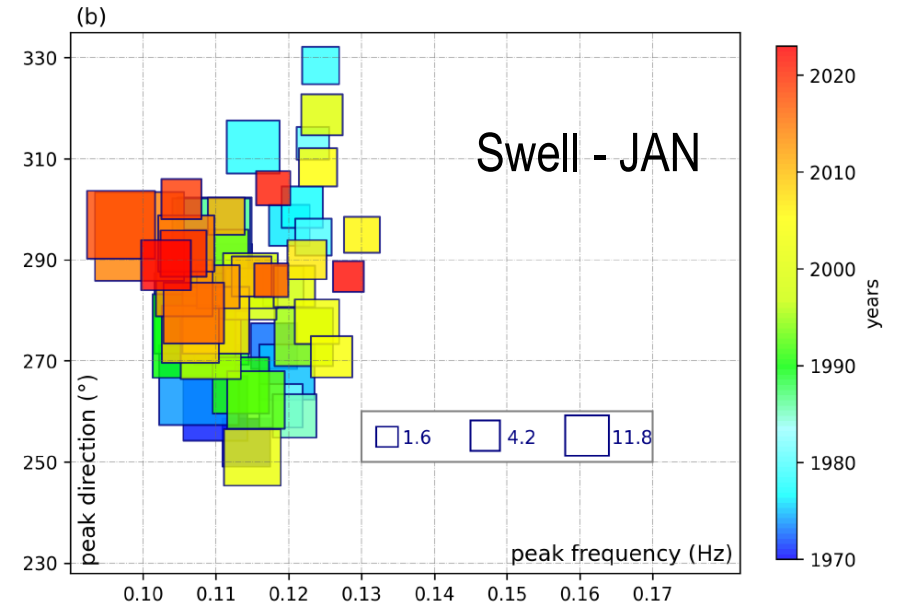
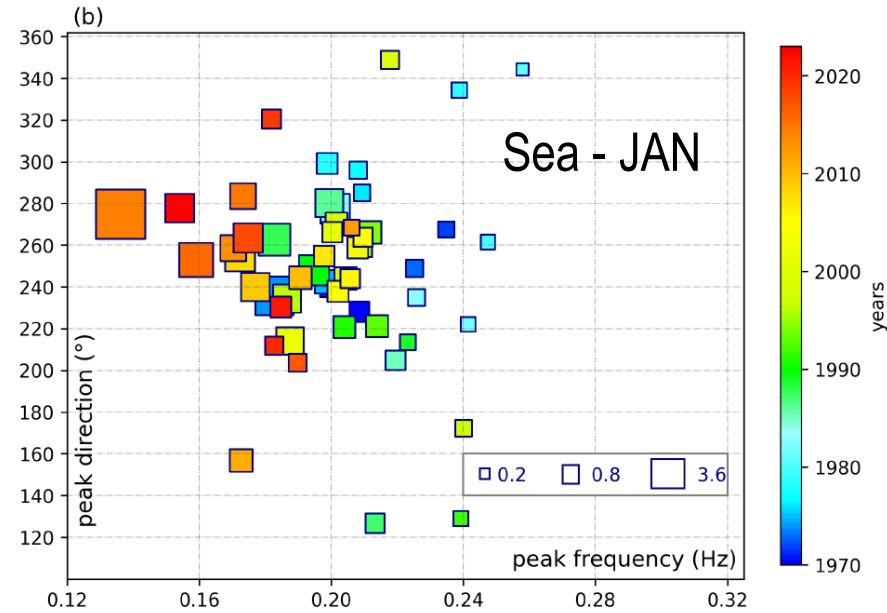
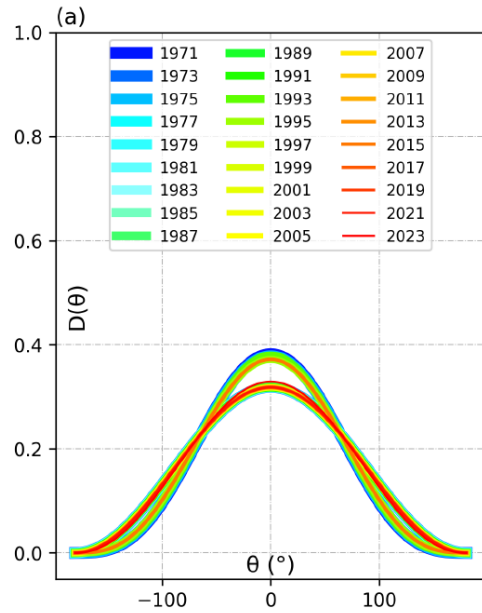
$$\sigma = \begin{cases} 0.07, & f \leq f_p \\ 0.09, & f > f_p \end{cases}$$



PM-Davidan vs JONSWAP



Interannual variability - provisional



CONCLUSIONS

- ❑ Directional wind wave spectra can be reconstructed from VOS, some theory however is needed
 - Longuet-Higgins – OK for spreading function
 - JONSWAP is likely more effective than PM-Davidan for integrating spectra
- ❑ NA is a good place for 10-degree, 1-degree is likely possible for coastal areas
- ❑ Compared to model hindcasts, reconstructed spectra capture well the direction and magnitude, but produce a bias in frequency (waves are shorter, likely due to swell), but we know to handle the bias
- ❑ Interannual variability for sea is reliable

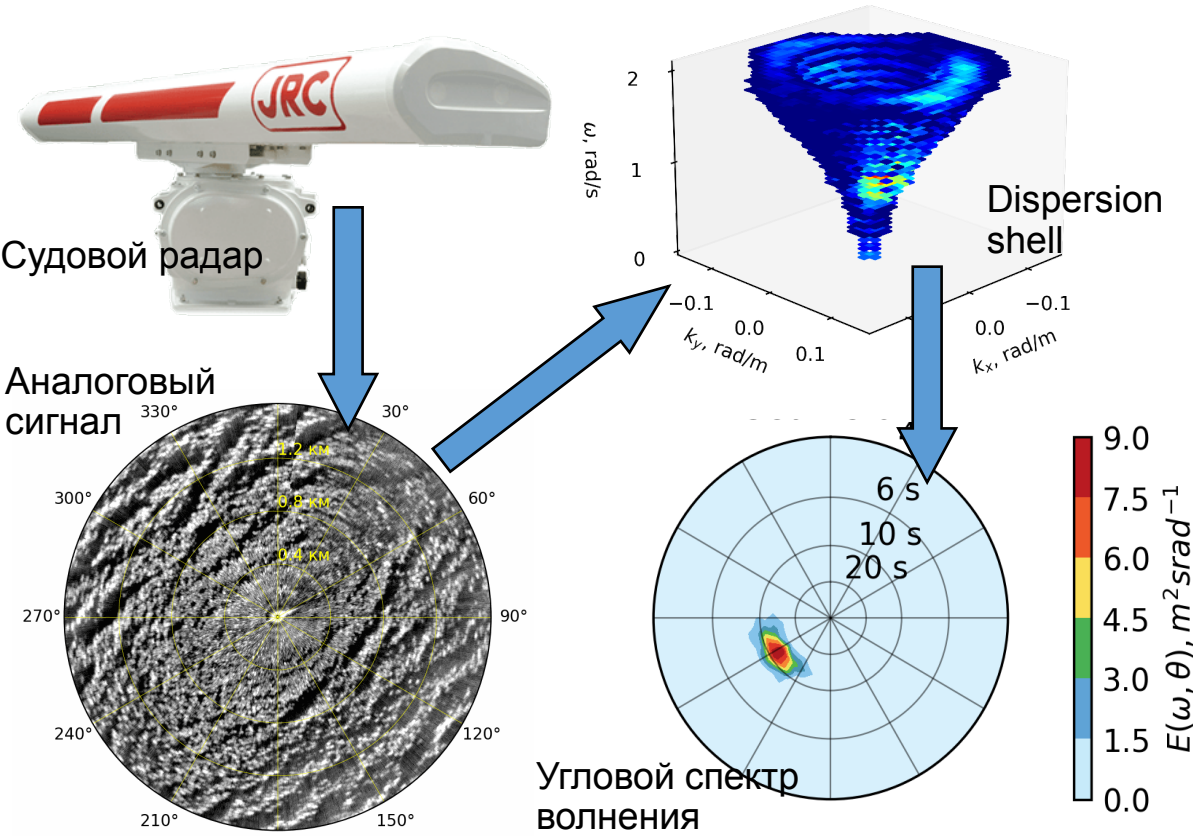
VOS waves ~~still~~ have ~~a~~ ^{the} future

Создание глобальной системы наблюдения за ветровыми волнами в открытом океане на основе судовых навигационных радаров

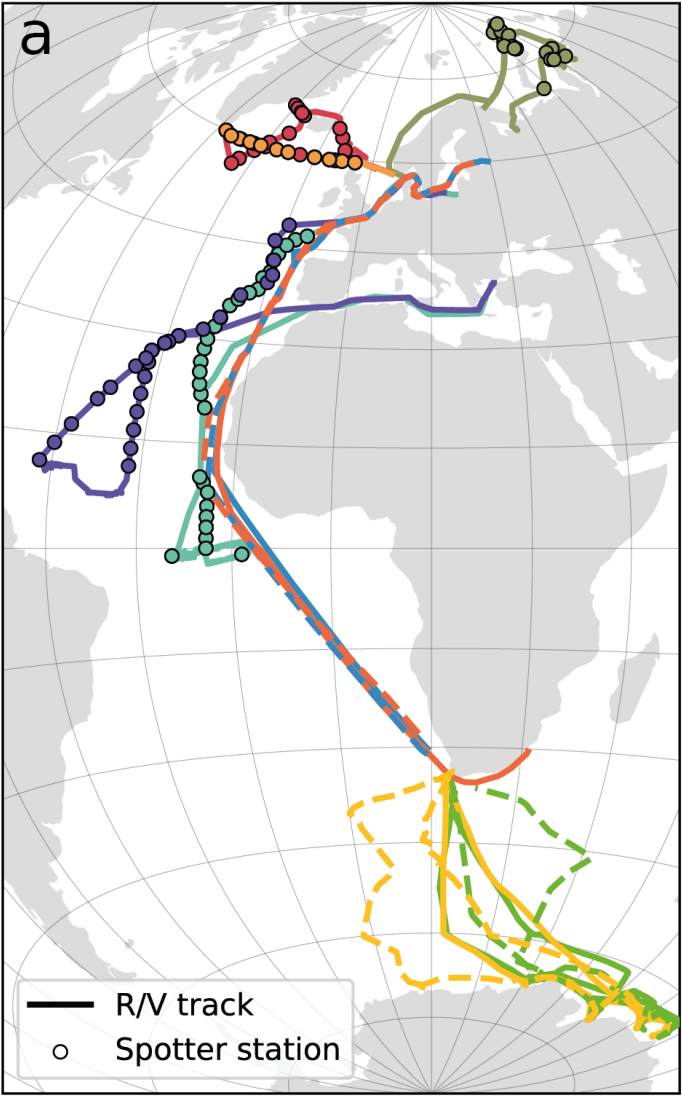
Ежова Е.А., Тилинина Н.Д.,
Гулев С.К., Гавриков А.В., и др.

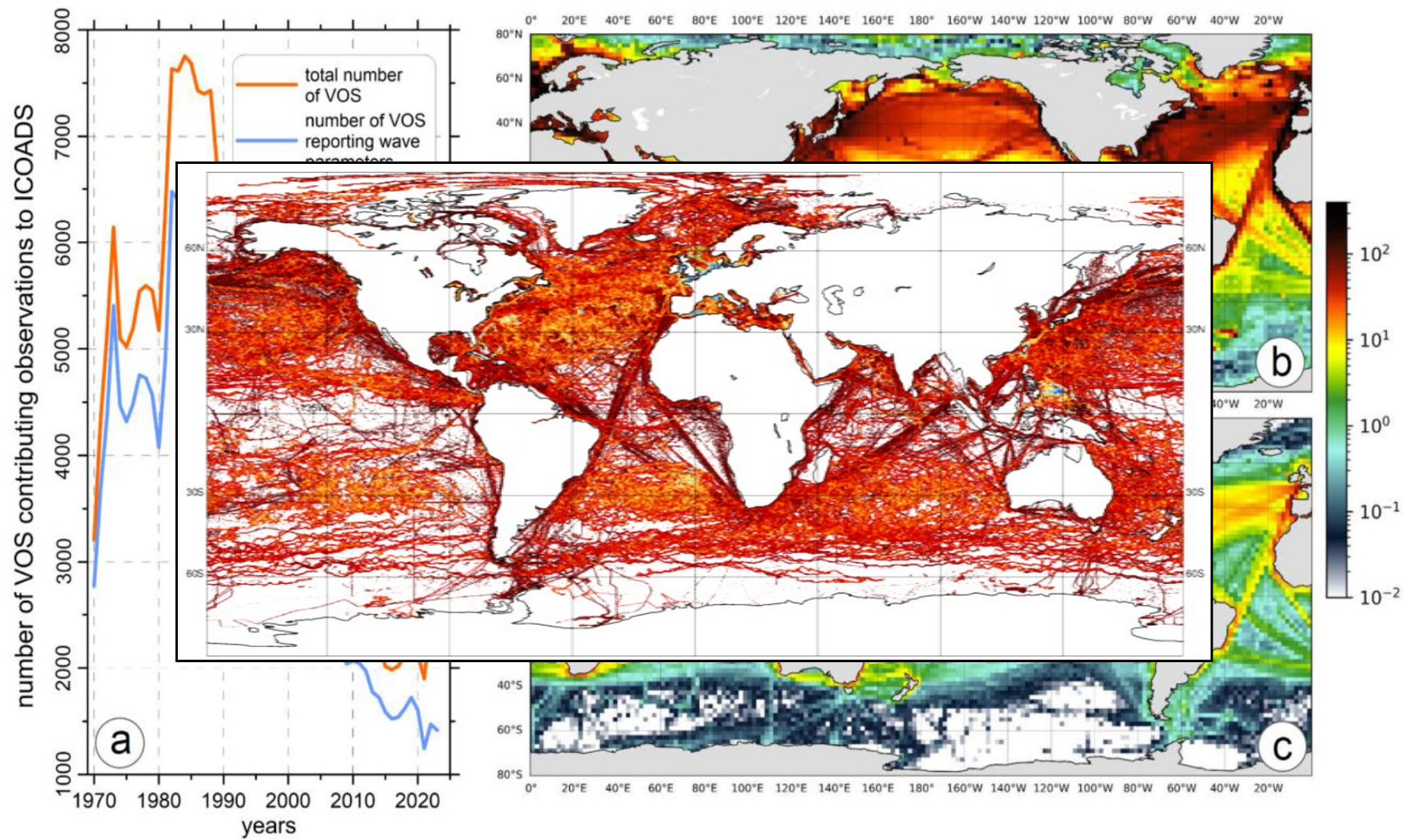
Идея: использование оперативных аналоговых данных навигационных радаров для получения полной информации о ветровых волнах

Что сделано: Создана недорогая приставка к любому судовому радару, конвертирующая аналоговый сигнал в цифровой и реализующая алгоритм расчета всех параметров волнения с частотой 30 сек.



- 7 рейсов НИС
- ~ 4000 часов валидации (буй)
- Оснащено 6 судов:
 - Ак. Иоффе
 - Ак. Сергей Вавилов
 - Ак. Мстислав Келдыш
 - Ак. Федоров
 - Ак. Трешников
 - Проф. Мультановский
- Перспектива массового использования





Accepted

Measuring Ocean Surface Waves

Clarence O. Collins III^{1,2,3}, Andre Amador⁴, Alexander Babanin³, James Behrens^{5,6}, Alvise Benetazzo⁷, Filippo Bergamasco⁷, Chris Blenkinsopp⁸, Philippe Bonneton⁹, Øyvind Breivik^{10,11}, Kai H. Christensen^{10,12}, Luke Colosi⁶, Kevin Ewans^{3,13}, Johannes Gemmrich¹⁴, Hannah Glover¹⁵, Laurent Grare⁶, Vika Grigorieva¹⁶, Sergey Gulev¹⁶, Danièle Hauser¹⁷, Lars R. Hole¹⁰, Gaute Hope¹⁰, Isabel Houghton¹⁸, Je-Yuan Hsu¹⁹, Nathan J. M. Laxague²⁰, Luc Lenain⁶, Björn Lund²¹, Annika O'Dea¹, Mara Pistellato²², Anne Karin Magnusson¹⁰, Kévin Martins²³, Yoshinao Matsuba²⁴, Mark McAllister²⁵, Malte Müller^{10,12}, Marcello Passaro²⁶, Jean Rabault¹⁰, Hugh Roarty²⁷, Pieter Smit¹⁸, Madison M. Smith²⁸, Hitoshi Tamura²⁹, Natalia Tilinina¹⁶, Ben Timmermans³⁰, Jim Thomson³¹, Joey Voermans³, Meagan Wengrove¹⁵, Lucy R. Wyatt³², Jeseon Yoo³³, Ian Young³, Christopher J. Zappa³⁴, Dongxiao Zhang³⁵



Published

ARTICLE

<https://doi.org/10.1038/s43247-022-00654-9>

OPEN

Check for updates

Global ocean wave fields show consistent regional trends between 1980 and 2014 in a multi-product ensemble

L. Erikson^{1,2,3}, J. Morim^{1,2,3}, M. Hemer³, I. Young⁴, X. L. Wang⁵, L. Mentaschi⁶, N. Mori⁷, A. Semedo⁸, J. Stopa⁹, V. Grigorieva¹⁰, S. Gulev¹⁰, O. Aarnes¹¹, J.-R. Bidlot¹², Ø. Breivik^{11,13}, L. Bricheno¹⁴, T. Shimura⁷, M. Menendez¹⁵, M. Markina¹⁰, V. Sharmar¹⁰, C. Trenham³, J. Wolf¹⁴, C. Appendini¹⁶, S. Caires¹⁷, N. Groll¹⁸ & A. Webb¹⁹



Research paper

Real-time open ocean wind waves from navigation radars for a truly global wind wave operational observing system

Elizaveta Ezhova^{a,b}, Natalia Tilinina^a, Sergey Gulev^{a,c,*}, Vitali Sharmar^a, Alexander Gavrikov^a, Boris Trofimov^d, Sergey Bargman^d, Peter Koltermann^e, Vika Grigorieva^{a,f}, Alexander Suslov^a

Published

In revision

North Atlantic spectral wind wave climate from visual ship-based observations

Vika Grigorieva^{1,2}, Sergey Gulev^{2,3}, Kirill Grigoriev⁴, Yaron Toledo¹, Vitali Sharmar^{2,5}

¹Tel Aviv University ²P.P. Shirshov Institute of Oceanology ³Université Grenoble Alpes, Saint-Martin-d'Hères, France ⁴Moscow State University ⁵Euro-Mediterranean Center on Climate Change, Lecce, Italy

¹Chaim Levanon St 55, Tel Aviv-Yafo, 6997801, Israel

²36, Nakhimovskiy prospect, Moscow, 117997, Russia

³621 avenue Centrale 38400 Saint-Martin-d'Hères

⁴Leninskie Gory 1., Moscow, Russia

⁵via Marco Biagi 5 - 73100 Lecce, Italy

2nd order moments

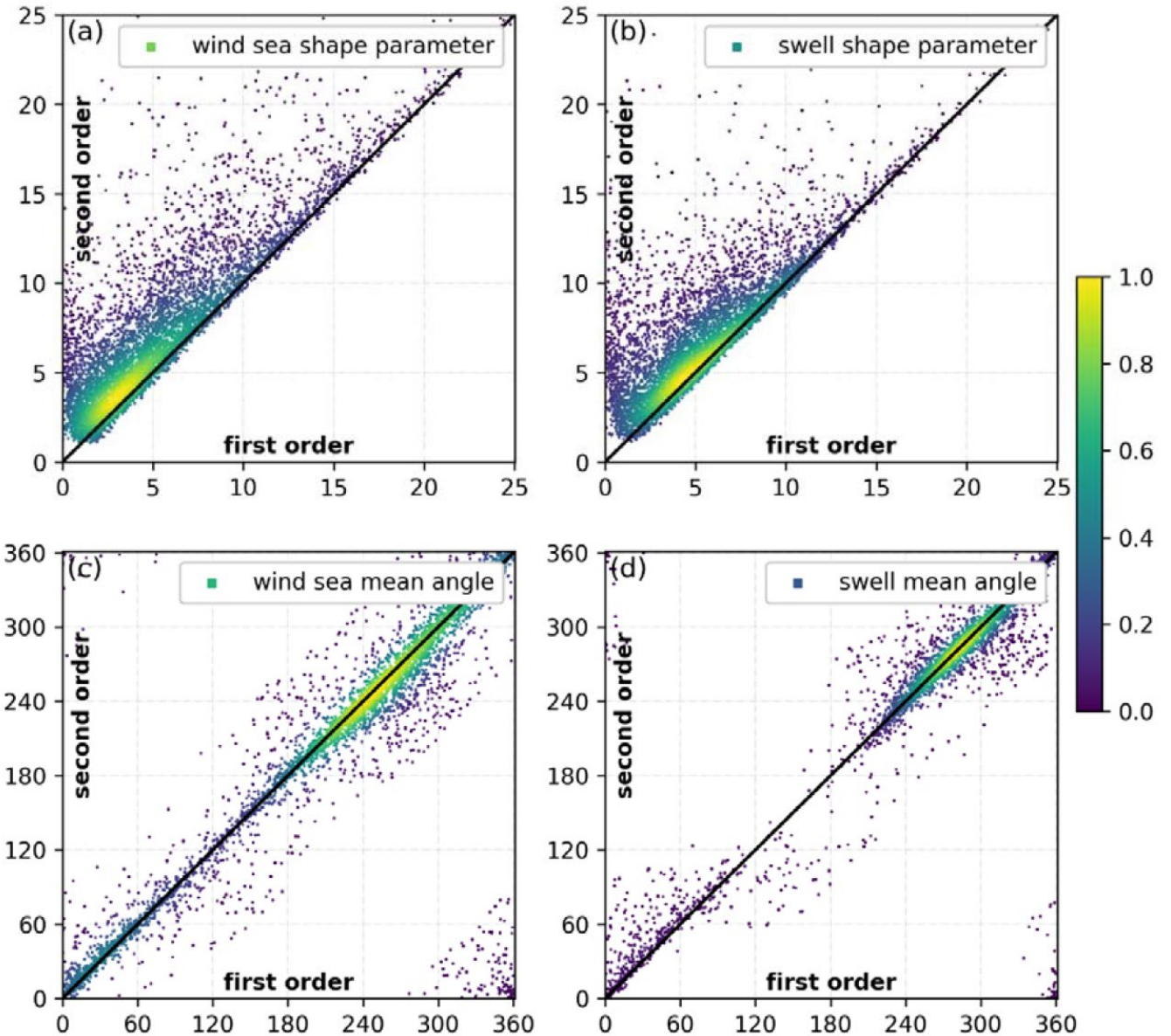
$$\bar{\theta} = \frac{1}{2} \left(\tan^{-1} \frac{\langle \sin 2\theta \rangle}{\langle \cos 2\theta \rangle} \right)$$

$$S = \frac{1 + 3r_2 + \sqrt{r_2^2 - 14r_2 + 1}}{2(1 - r_2)}$$

$$\langle \sin 2\theta \rangle = \frac{1}{N} \sum_1^N \sin 2\theta_i$$

$$\langle \cos 2\theta \rangle = \frac{1}{N} \sum_1^N \cos 2\theta_i$$

$$r_2 = (\langle \sin 2\theta \rangle^2 + \langle \cos 2\theta \rangle^2)^{1/2}$$

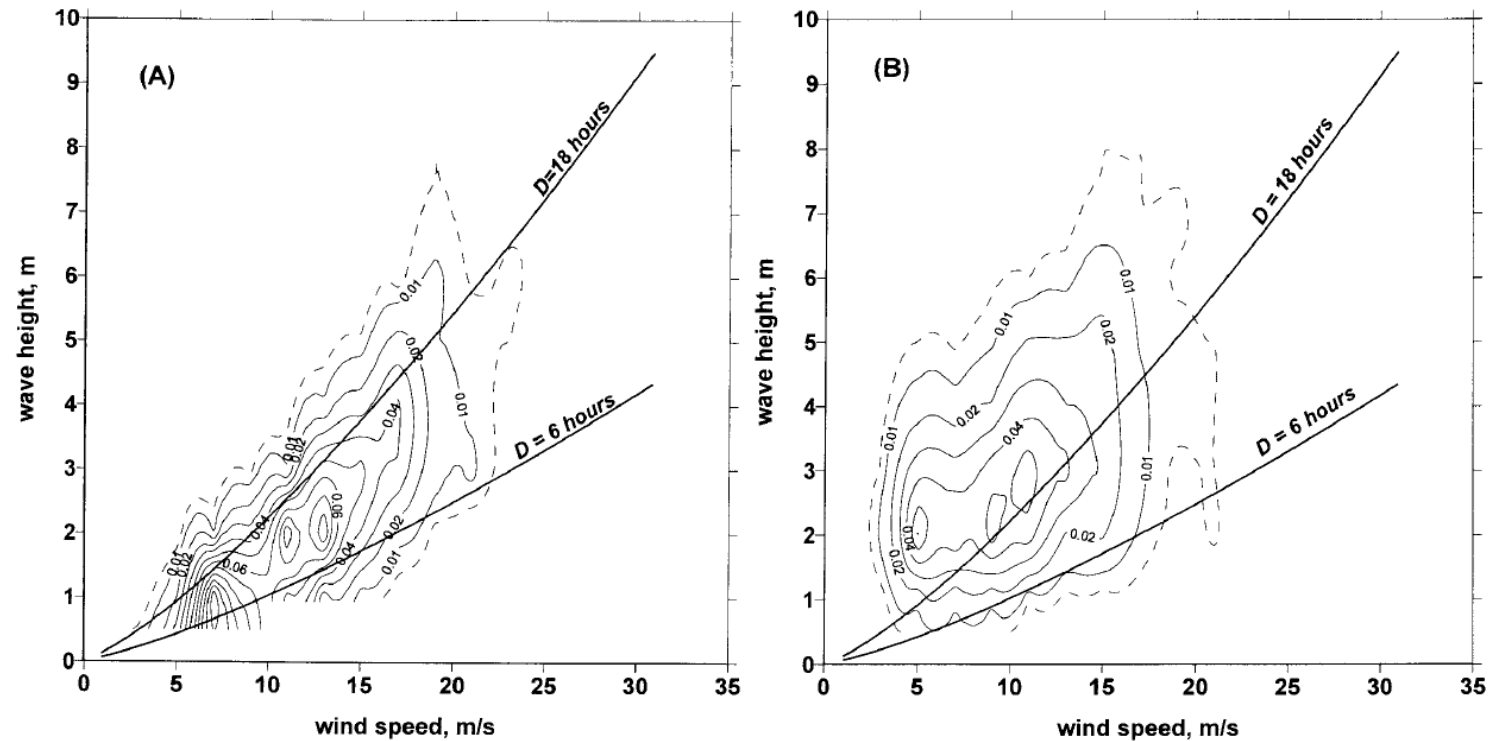


CHANGES OF WIND WAVES IN THE NORTH ATLANTIC OVER THE LAST 30 YEARS

SERGEY K. GULEV^{a,b,*} and LUTZ HASSE^b

^a *P. Shirshov Institute of Oceanology, RAS, 36 Nakhimovsky Ave., 117218 Moscow, Russian Federation*

^b *Institut fuer Meereskunde, Kiel, Germany*



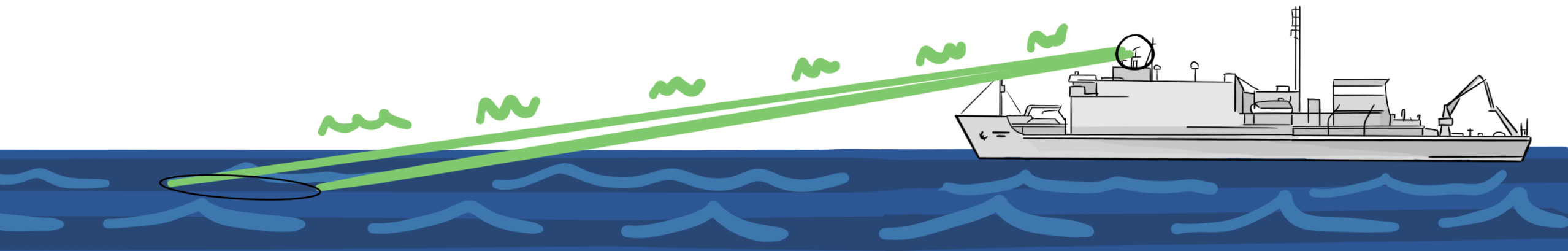
S.K. GULEV AND L. HASSE

Figure 4. Joint probability distributions (portions of unity) of the wind sea and wind speed (A) and swell and wind speed (B). Solid lines correspond to the JONSWAP dependencies of the wave height of wind velocity for different durations, as given by Carter (1982)



Создание глобальной системы наблюдения за ветровыми волнами в открытом океане на основе судовых навигационных радаров

Ежова Е.А., Тилинина Н.Д., Гулев С.К., Гавриков А.В., Суслов А.И.

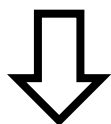


Судовая РЛС

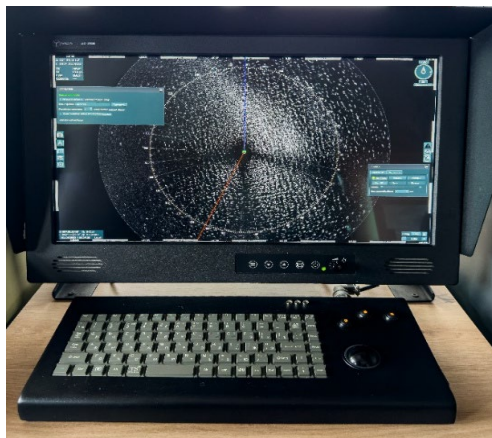
РЛС – радиолокационная станция



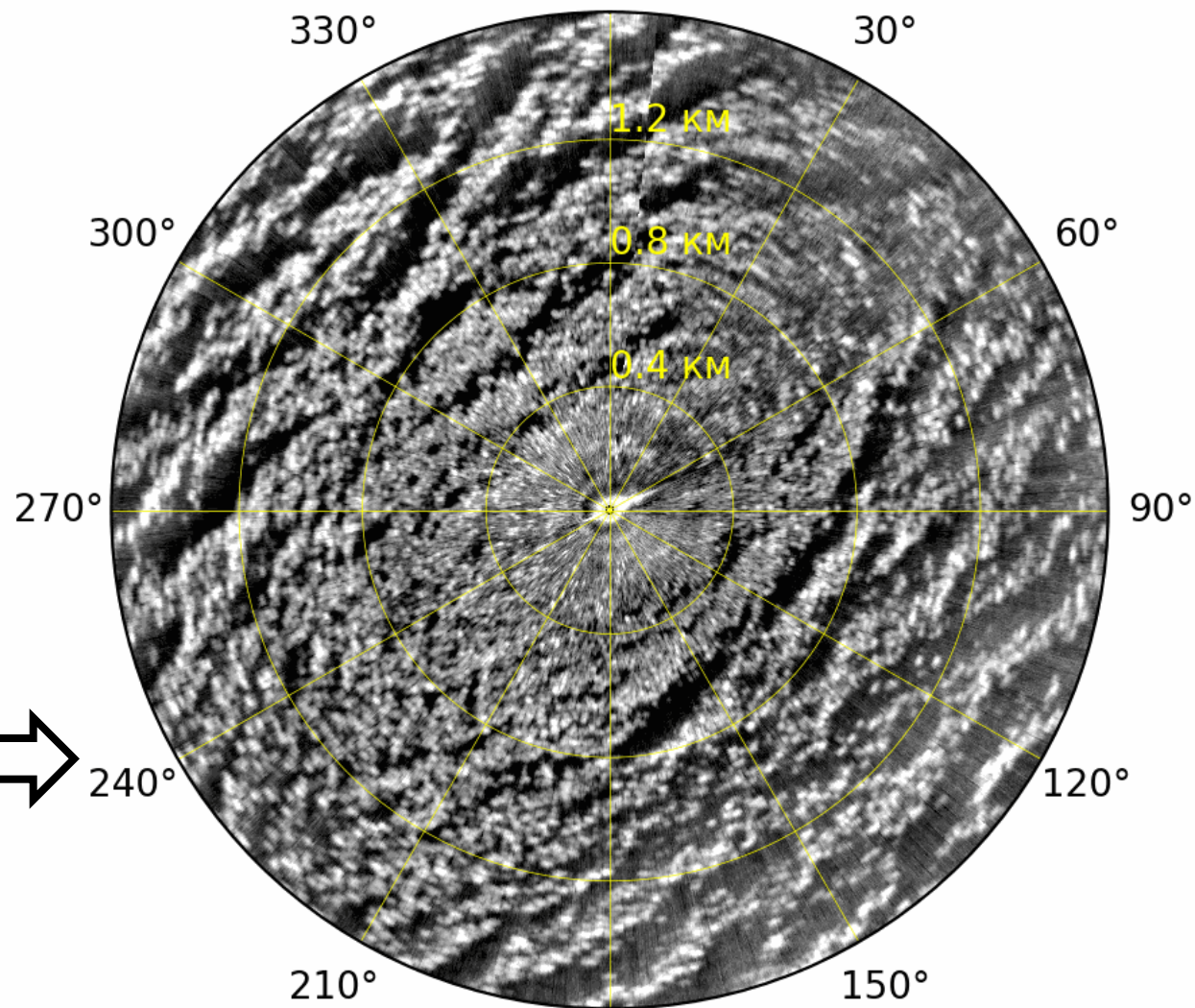
антенна
РЛС



судовые
навигационные
системы

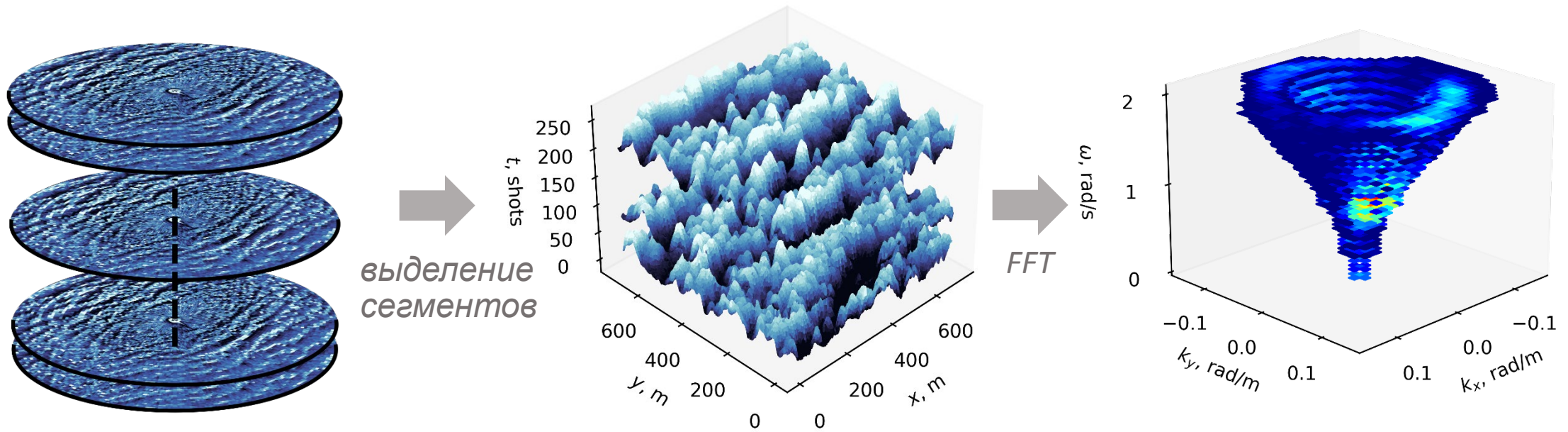


РЛ индикатор
*SeaVision*³



РЛ изображение морской поверхности

Алгоритм обработки



Оценка положения дисперсионной кривой

где ω – частота, $\mathbf{k}$ – волновой вектор, g – ускорение свободного падения, $\mathbf{V}$ – скорость РЛС относительно неподвижной воды

⁴Young, I. R., Rosenthal, W., & Ziemer, F. (1985). A three-dimensional analysis of marine radar images for the determination of ocean wave directionality and surface currents. *Journal of Geophysical Research: Oceans*, 90(C1), 1049-1059.

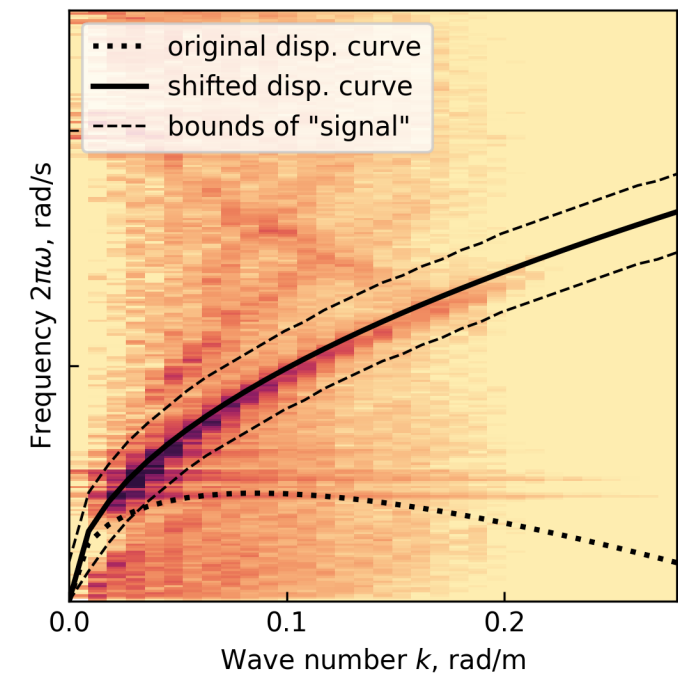
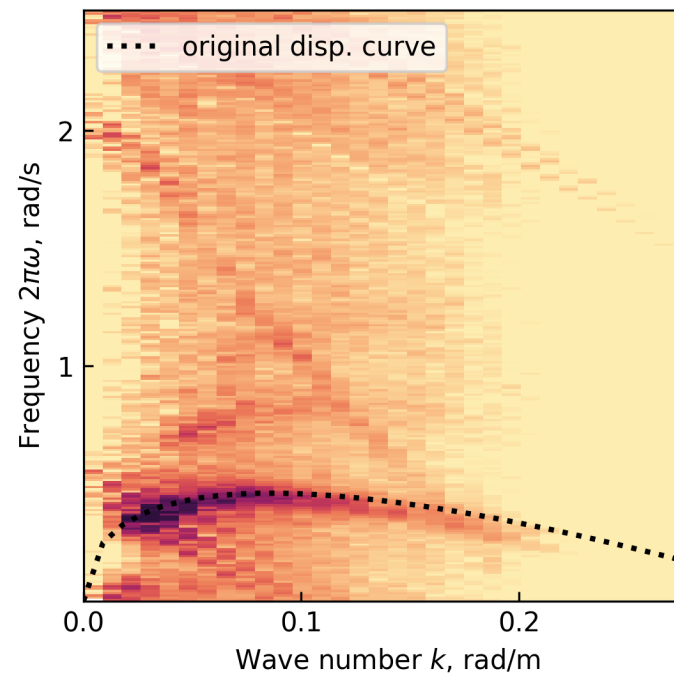
Приведение спектра к стационарной СО

В движущейся системе отсчета



В стационарной СО

Отношение сигнал-шум⁵



$S(\omega, k)$ спектр до и после преобразования

где A , B – калибровочные коэффициенты

Алгоритм был
протестирован на
скоростях до 9 м/с

⁵Nieto Borge, J., G. R. Rodríguez, K. Hessner, and P. I. González, 2004: Inversion of Marine Radar Images for Surface Wave Analysis. *J. Atmos. Oceanic Technol.*, **21**, 1291–1300.

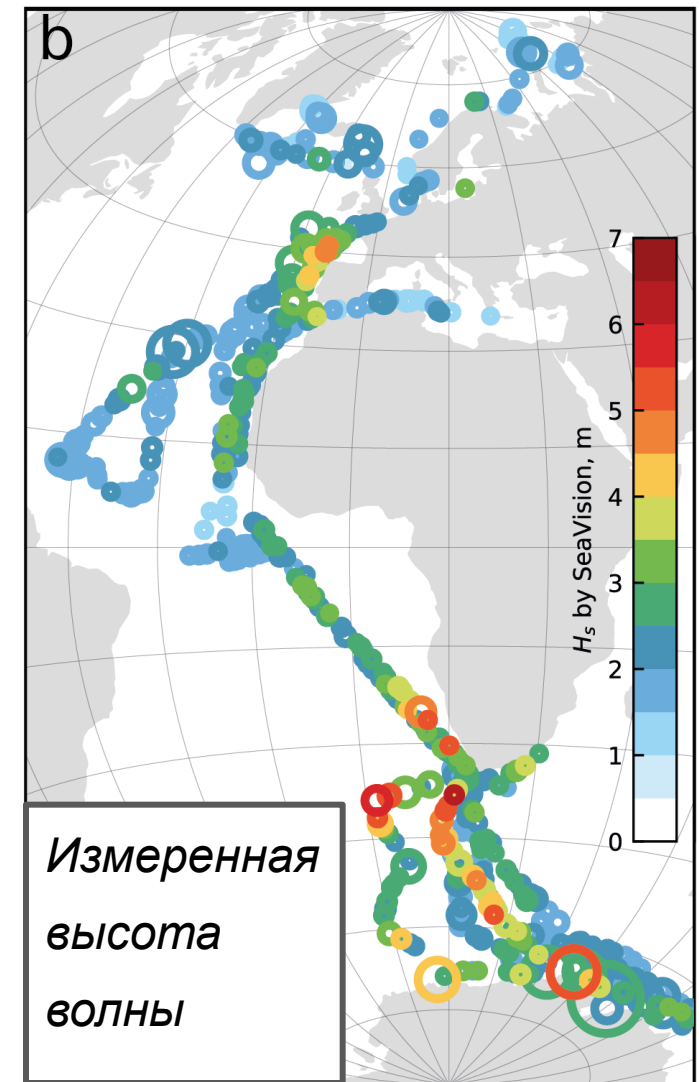
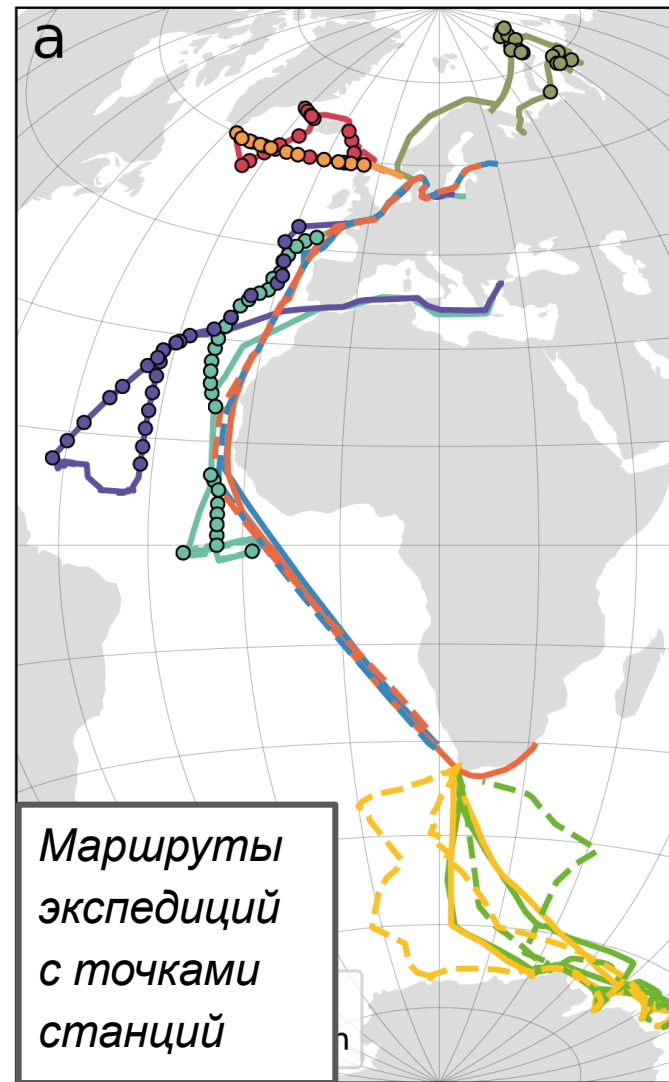
Аппробация в экспедициях

7 экспедиций с 2020 г

109 станций с буем Spotter

3956 подспутниковых
измерений (200 км)

1348 часов наблюдений

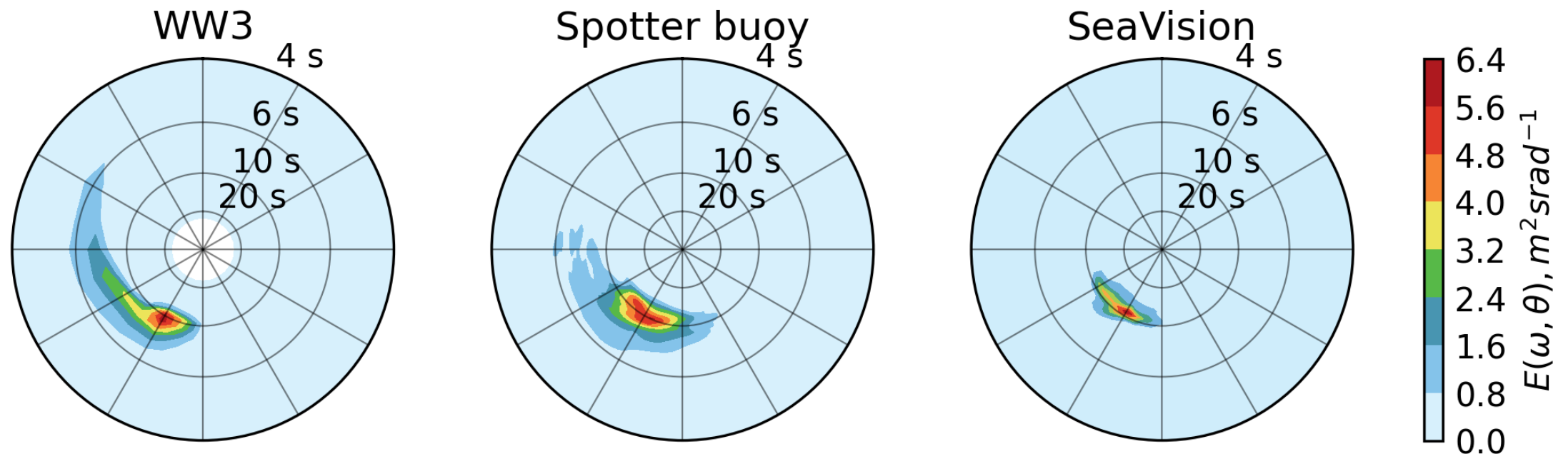


	— ASV50	— AI57	— AI58	— AI63	— AI65	— AF50/1	— AF50/2	— AF52/1	— AF52/2
N_{buoy}	26 (96)	11 (97)	16 (127)	30 (197)	26 (657)	— AF50/3	— AF50/4	— AF52/3	— AF52/4
N_{SV}	100 (376)	23 (119)	51 (368)	164 (377)	566 (1371)	600 (1893)		884 (1233)	
N_{alti}	64 (279)	15 (101)	26 (186)	75 (239)	318 (962)	462 (1654)		311 (535)	

Направленный спектр

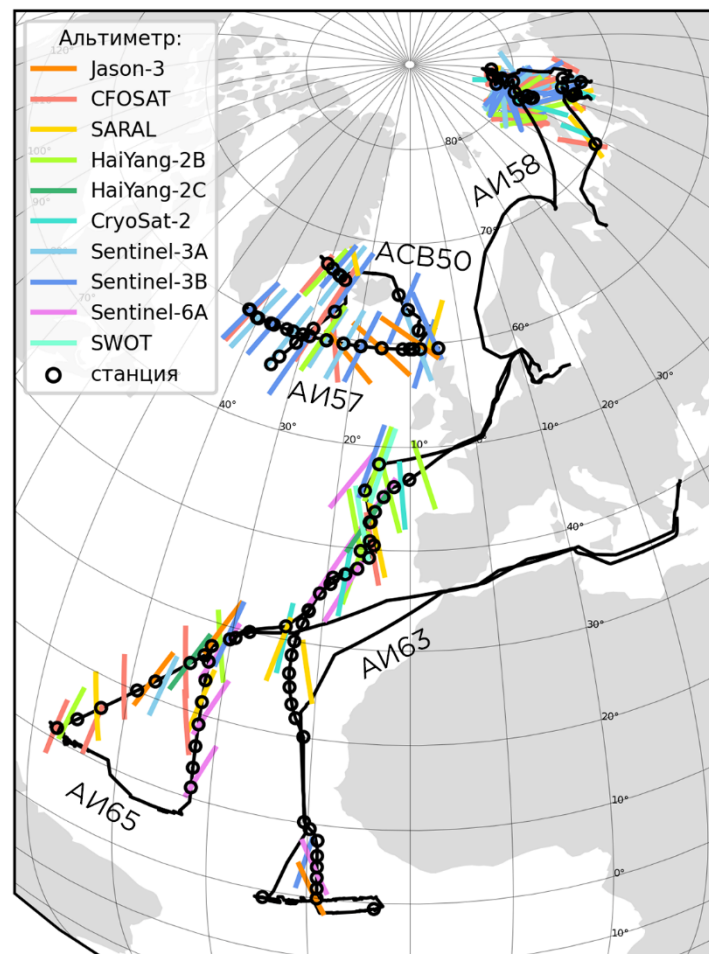
Для восстановления направленного спектра по данным буя Spotter использовался метод EWDM⁶, также выполнялось моделирование WaveWatch III. Восстановленные спектры оказались соответствующими, РЛС дают более узкий спектр, что подтверждается подобными работами.

2 Sept 2020 13:00 UTC ($H_s \sim 2.7$ m)

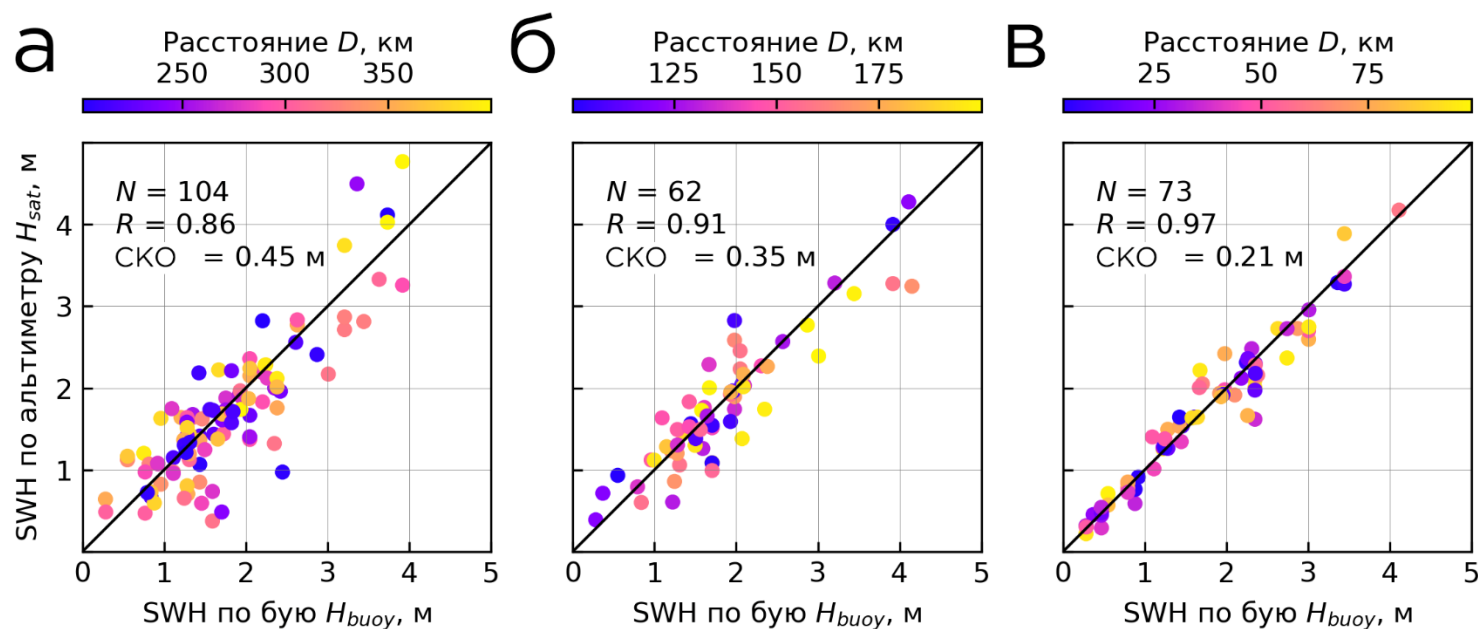


⁶Peláez-Zapata, D., V. Pakrashi, and F. Dias, 2024: Ocean Wave Directional Distribution from GPS Buoy Observations off the West Coast of Ireland: Assessment of a Wavelet-Based Method. *J. Atmos. Oceanic Technol.*, **41**, 749–765.

Подспутниковые измерения



Выполняется прогноз пролета спутников в радиусе 200 км от маршрута судна⁷



Распределение высот волнения, измеренных буюм (абсцисса) и альтиметром (ордината) в зависимости от расстояния между их точками измерения (цвет)

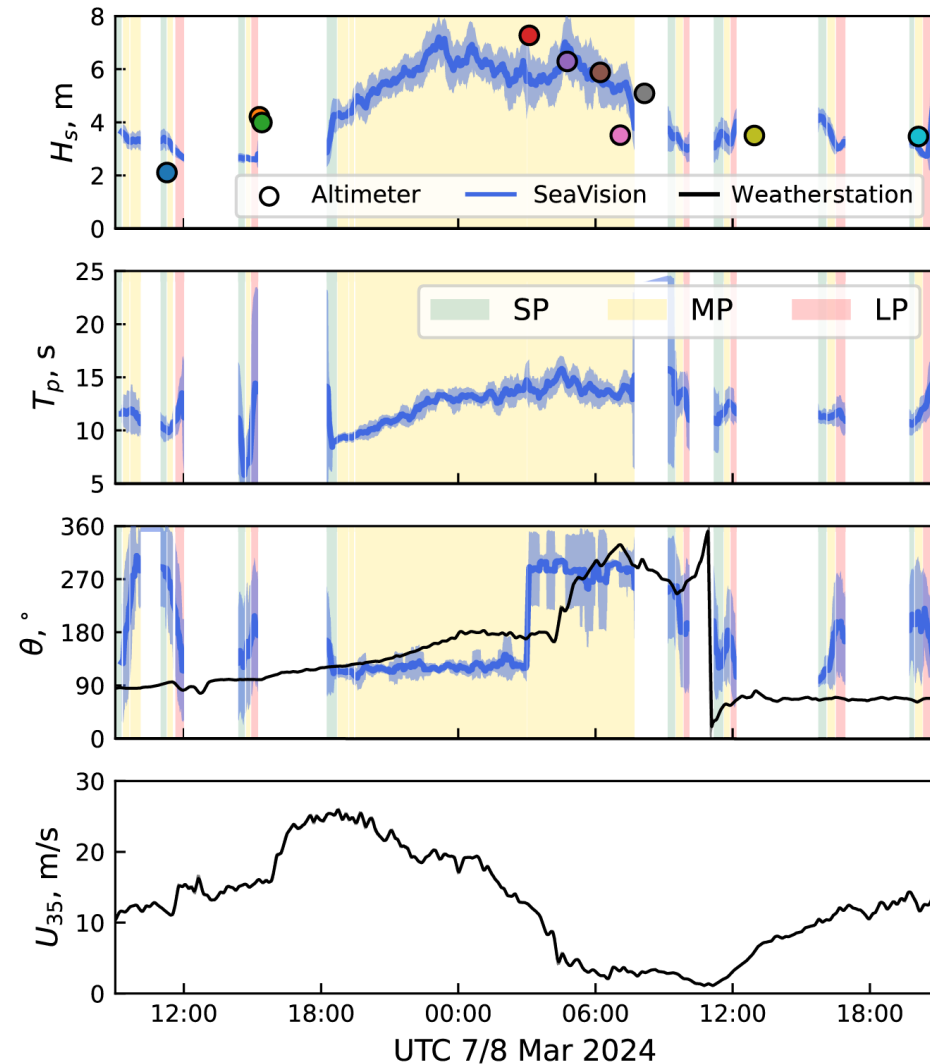
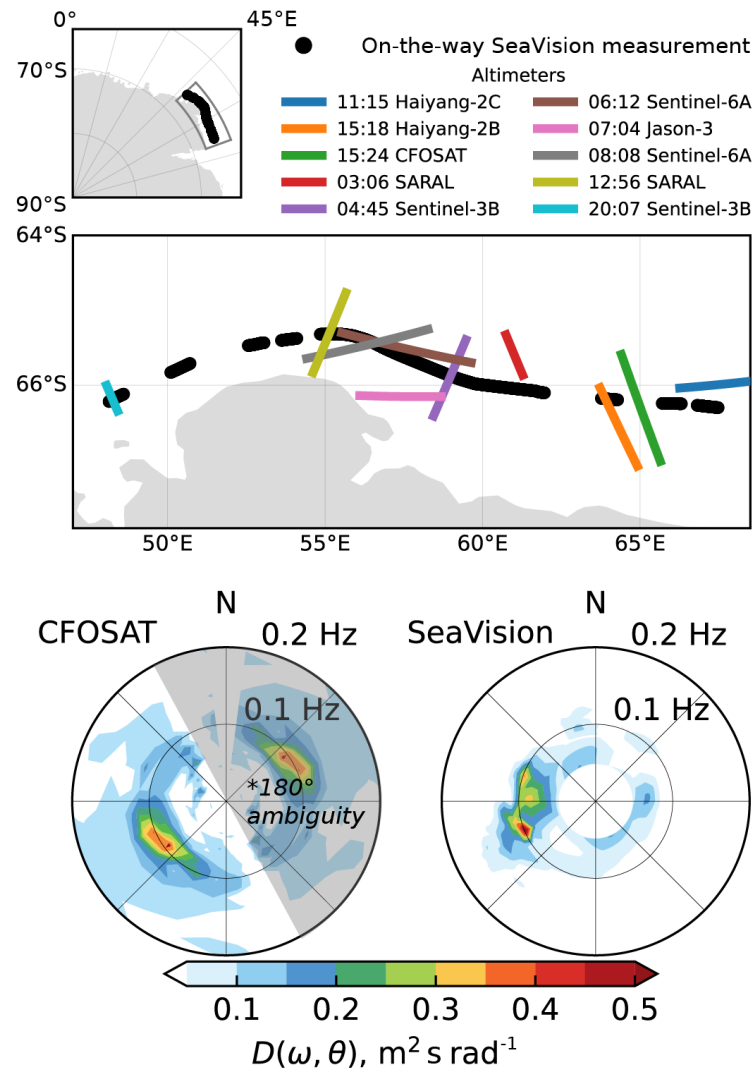
⁷ Ежова, Е., Гавриков, А., Тилинина, Н. 2024. Область применимости данных спутниковой альтиметрии для валидации алгоритмов оценки высоты ветрового волнения, Океанологические исследования, Т. 52 № 4.

Пример шторма

Значительная высота достигала 8 метров, были восстановлены все спектральные параметры

Данные спутниковой альтиметрии показывают высокую степень сходства

Был сопоставлен с данными скаттерометра направленный спектр



Измерения 7-8 марта 2024 по пути из моря Содружества в море Космонавтов

Наш «флот»

НИС «Академик Иоффе»



НИС «Профессор Мультановский»



НИС «Академик Сергей Вавилов»



НИС «Академик Мстислав Келдыш»



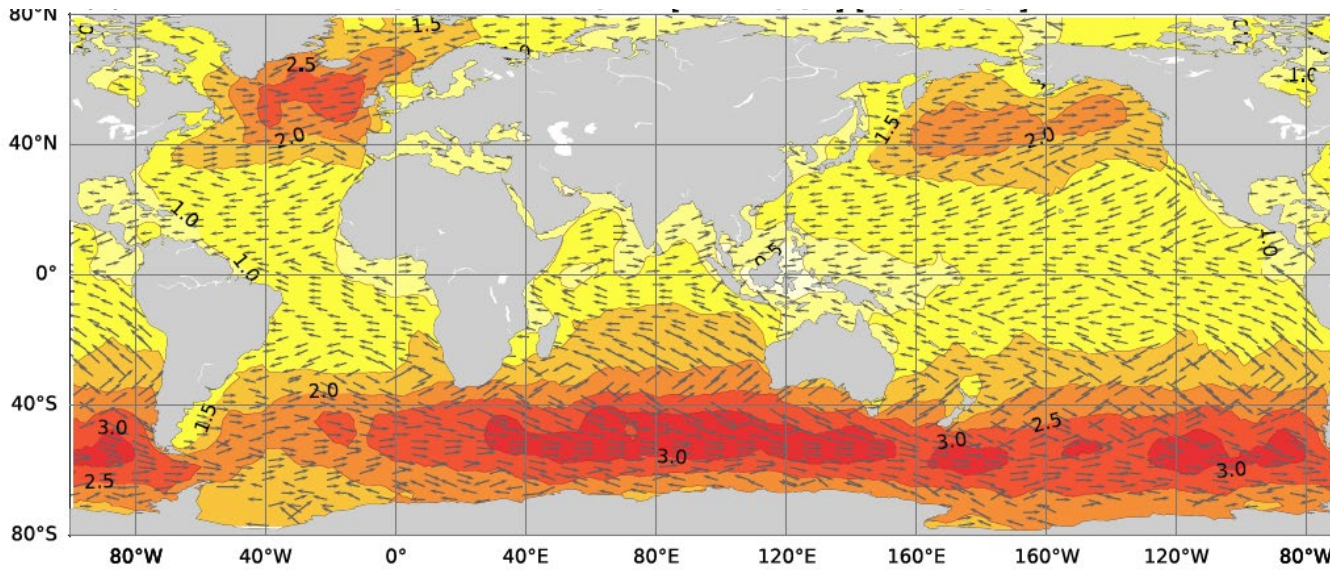
НЭС «Академик Фёдоров»



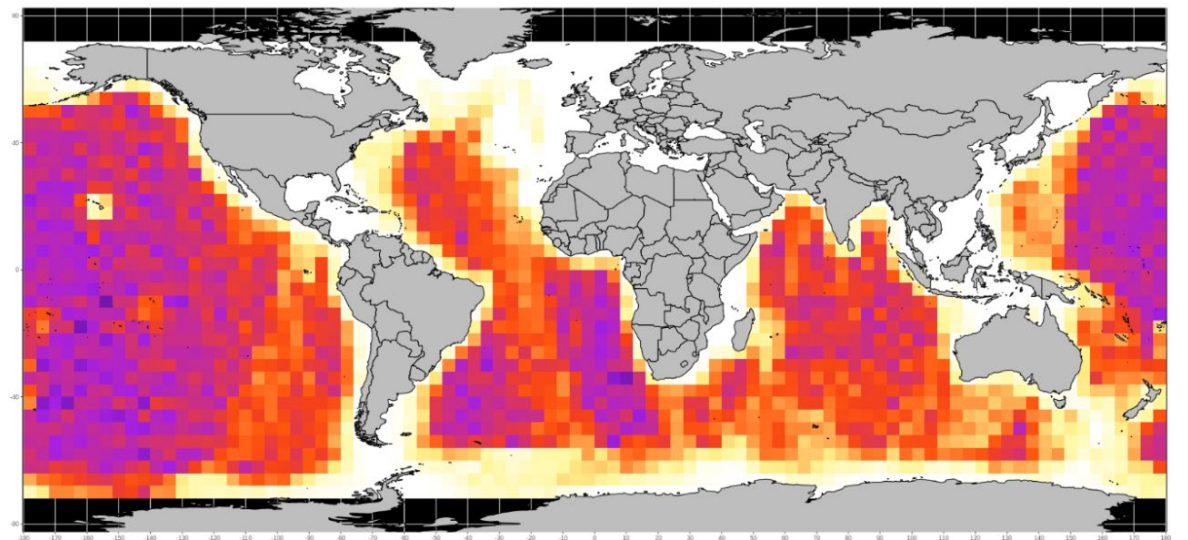
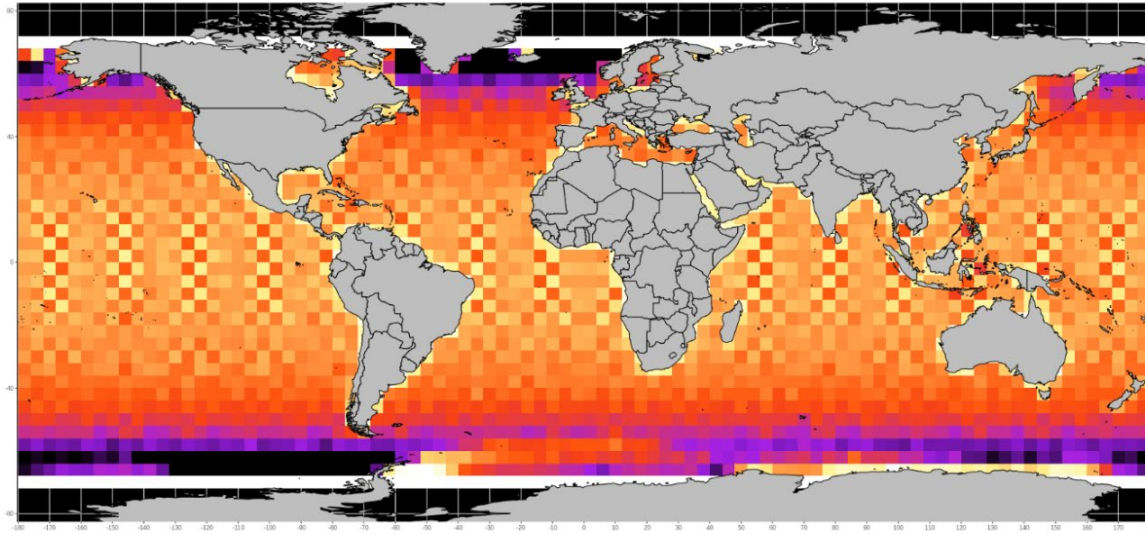
НЭС «Академик Трёшников»



Wind wave data over the global oceans

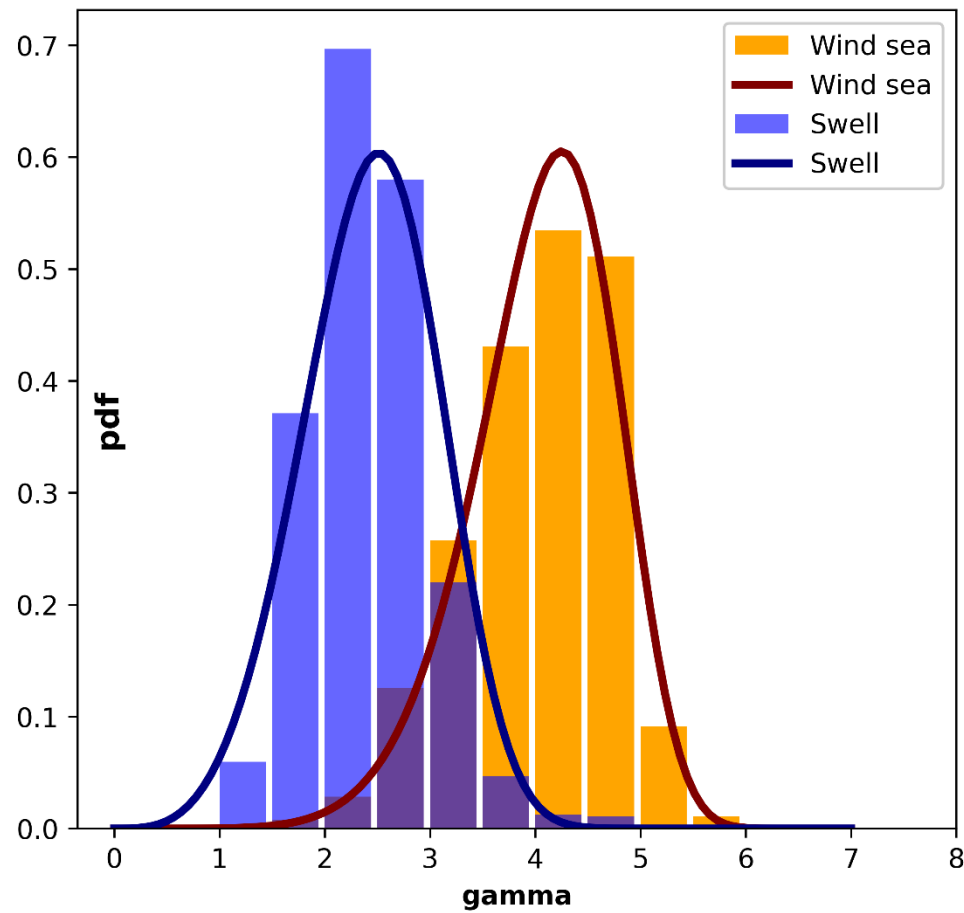


SWIM SWH (2019-2024)

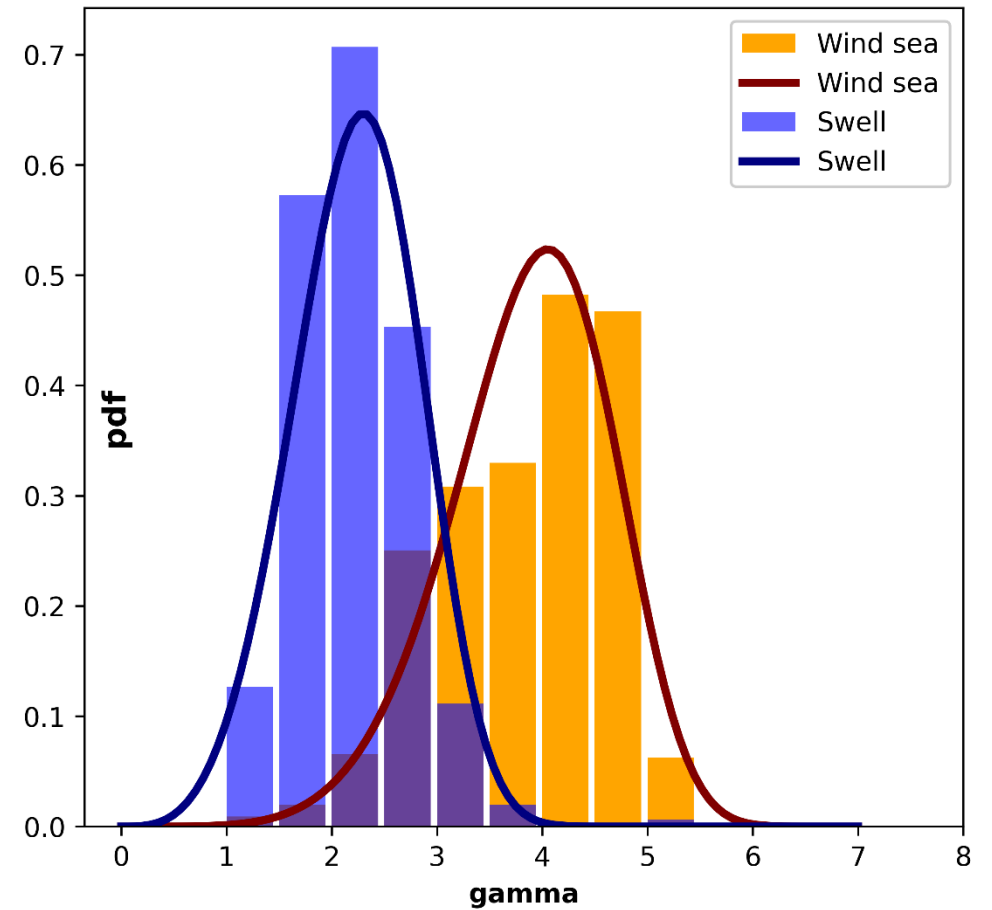


Parameter gamma in the JONSWAP all boxes monthly mean values

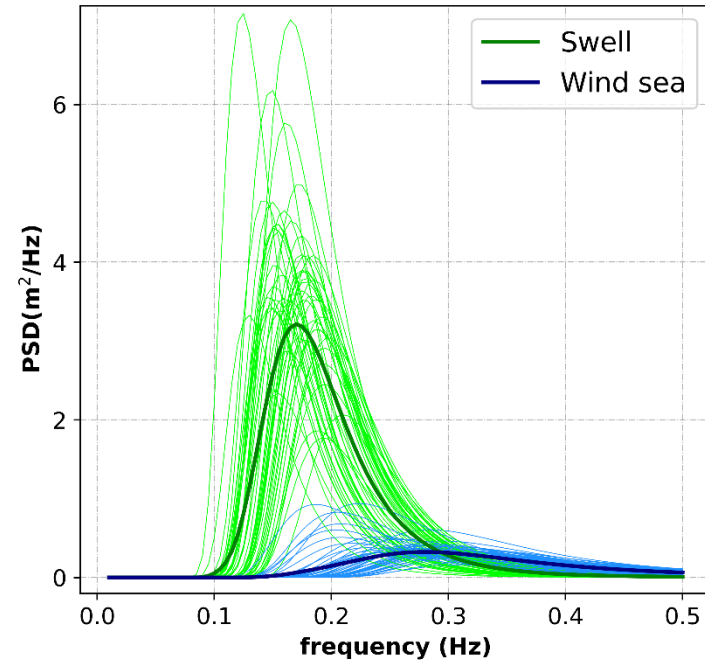
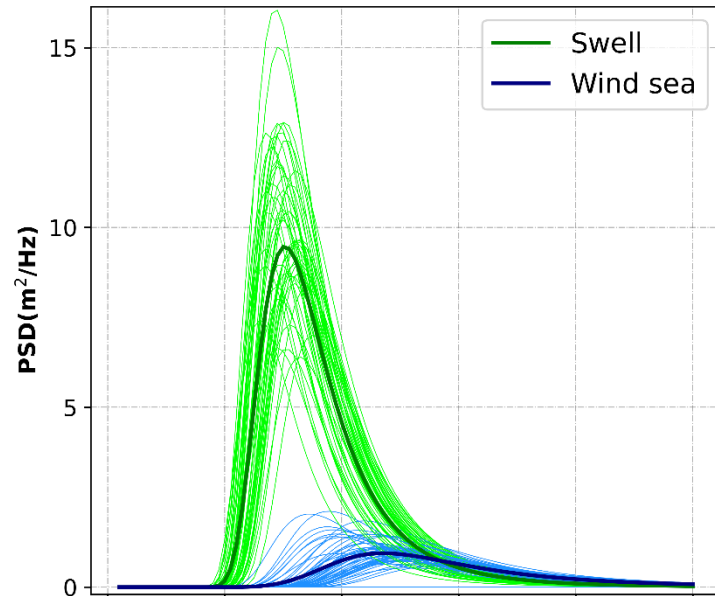
January



July

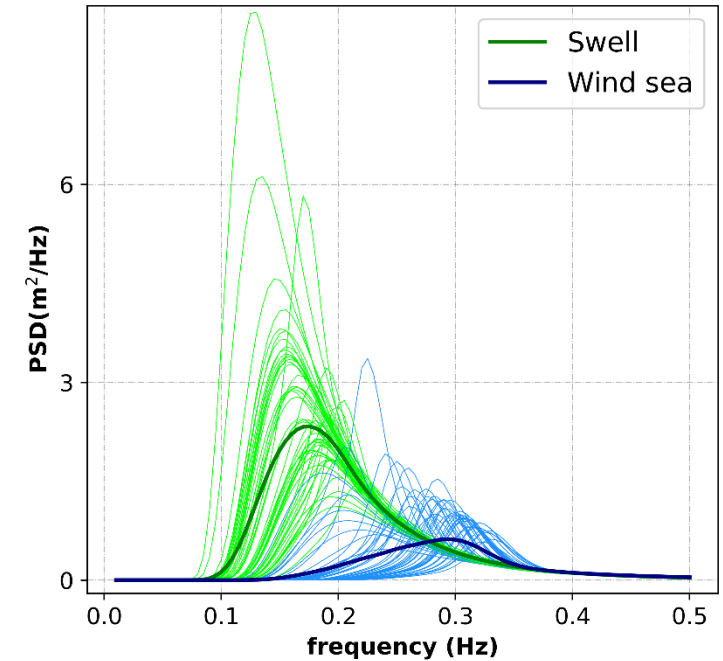
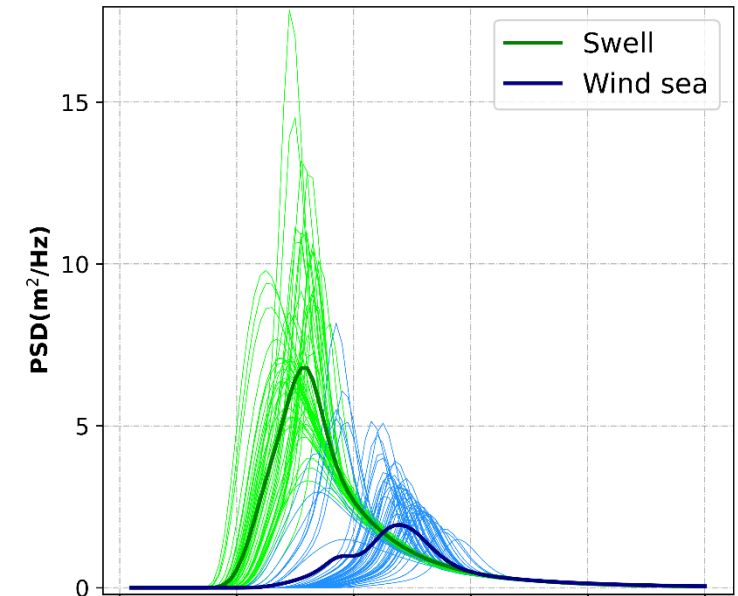


Frequency spectra 1970-2023 Western Atlantic coast “1”: PM-Davidan vs. JONSWAP

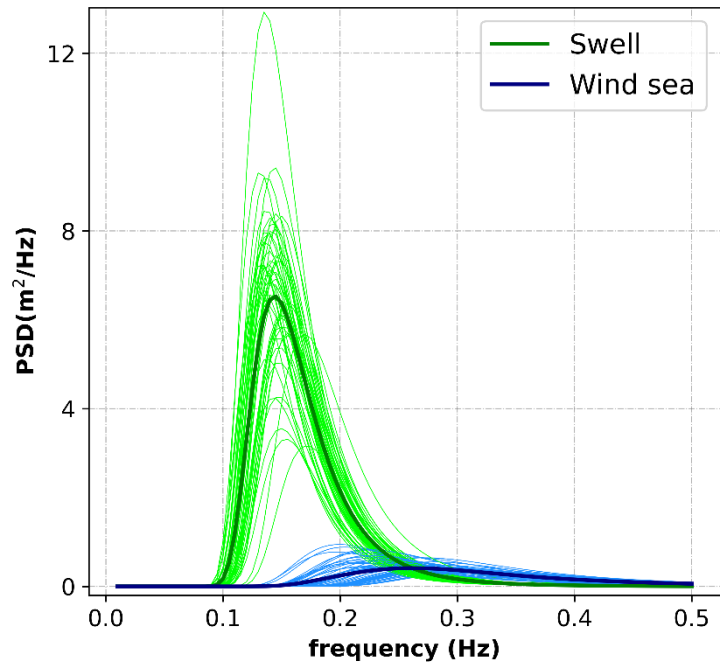
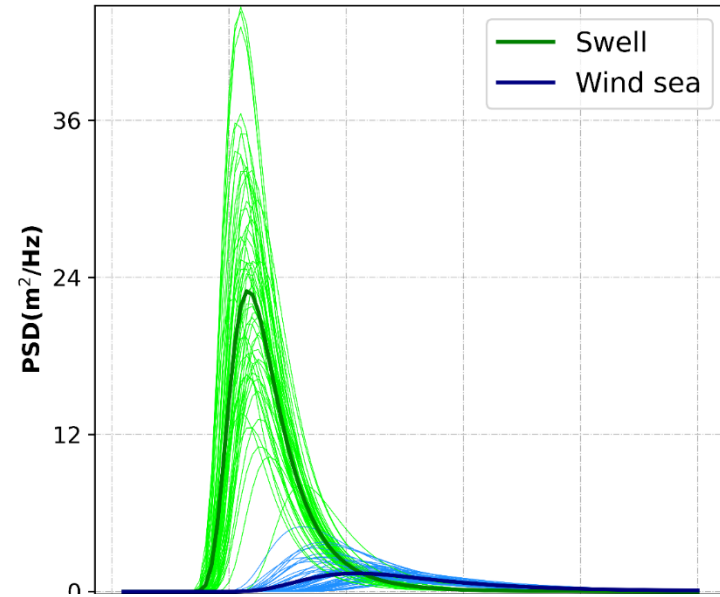


Januaries

Julies



Frequency spectra 1970-2023 Eastern Atlantic coast “2”: PM-Davidan vs. JONSWAP



Januaries

Julies

