Ireland's EU Structural Funds Programmes 2007 - 2013

Co-funded by the Irish Government and the European Union

EUROPEAN REGIONAL DEVELOPMENT FUND

A 34-Year Nearshore Wave Hindcast for Ireland (Atlantic and Irish Sea coasts): Wave Climate and Energy Resource Assessment

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Summary

Context and motivation

The Irish wave climate:

- Ireland located in Northeast Atlantic
- An energetic wave climate: Atlantic versus Irish Sea
- A potential for both wind and wave renewable industry
- An energetic wave climate: a potentially harsh environment!

Is there a gap in our knowledge of Ireland's wave climate?

- Lack of regional/local long term wave climate studies – climate variability
- Buoy observations sparse (from 2001)
- Nearshore wave buoys (from 2008)

Methodology

Local area / regional wave model approach:

- WaveWatch III alpha version with an unstructured grid
- Focus on Irish coastal waters
    - Saves on computational resources
- High-resolution into the nearshore
    - Examination of intermediate depths
- Regional area wave model boundary forcing fields:
    - Global wave model data forces model boundaries in deeper water
    - 10m wind data over entire domain
    - High-quality global / regional models available – ERA-Interim reanalysis

Conclusions

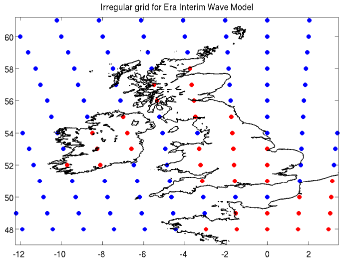
- A 34 year, high-resolution, nearshore wave hindcast was performed for Ireland: Atlantic and Irish Sea Coasts;
- The model was validated with observations from 17 wave buoys around Ireland: comparison between the observations and the model was found to be excellent;
- A strong spatial and seasonal variability was found for both significant wave heights and the wave energy flux;
- A strong correlation between the NAO teleconnection pattern and wave heights, wave periods and peak direction in winter and also to a lesser extent, in spring was also found on the west coast.

- 13 year hindcast using ERA-Interim wave data and high-resolution HARMONIE downscaled winds (2.5km) - SEAI project in collaboration with Met Éireann also under way.

Boundary forcing fields

ERA-Interim Reanalysis:

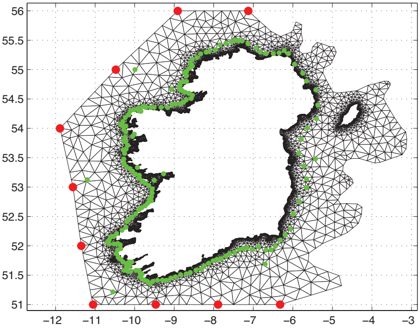
- Most recent global atmospheric reanalysis from the ECMWF
  - ECMWF (European Centre for Medium-Range Weather Forecasts)
- Reanalysis available from 1979 to present
- 79km resolution
- Assimilates satellite data:
  - altimeter wave-heights
  - scatterometer ocean surface winds



ERA-Interim wave model grid points: blue - sea point, red - land point.

Grid Construction

- An unstructured grid approach:
- Components
  1. Unstructured mesh
  2. Variable resolution depending on depth and depth gradient:
     - 250m in nearshore locations
     - 10km offshore
  3. 15,000 sea points
  4. Computational resources (regular versus irregular grid)
  5. Explicit scheme - CFL
- Grid boundary based on GSHHS vector shoreline dataset
  1. Landsat imagery used to correct shoreline
  2. Boundary created using:
     - UK east coast shoreline
     - ERA-Interim boundary feeding points in Atlantic

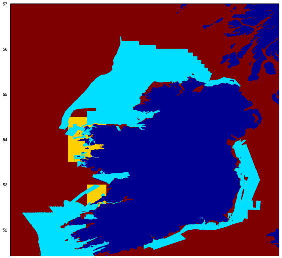


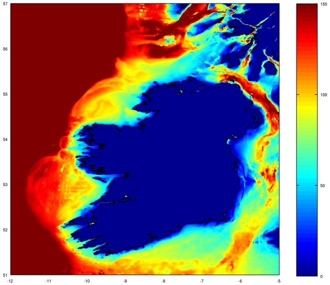
Unstructured grid and bathymetry depth for 34 year wave hindcast model run.

Red circles: ERA-Interim grid points.

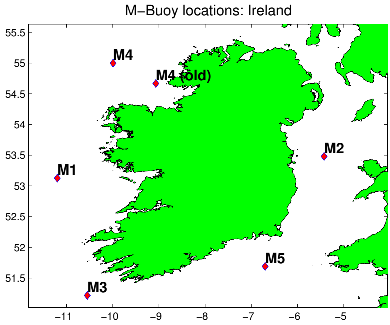
Bathymetry - Construction of DEM

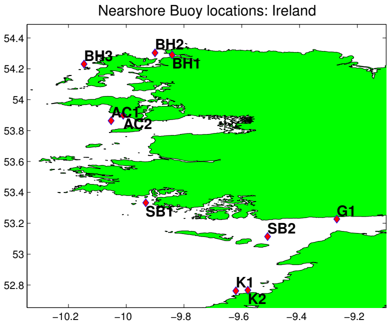
- INFOMAR: Integrated Mapping for the Sustainable Development of Ireland's Marine Resource
  1. Joint venture of GSI and Marine Institute
  2. High resolution data:
     - LiDAR: 2 to 5m resolution
     - Multi-beam echo-sounder (MBES): 10 to 80m resolution
- EMODnet (European Marine Observation and Data Network) and Oceanwise:
  1. To fill the missing areas in INFOMAR dataset
  2. 250m resolution (15")
- Bathymetry blended and smoothed - weightings (INFOMAR has priority)
- Creation of a "Master Grid" - artificial ridges from mismatches smoothed out





Validation: wave buoy locations





Left: Location of the M-buoys. Right: Location of the nearshore buoys.

- The wave model hindcast will be validated against available buoy data:
  - M-buoys as part of the Irish Marine Buoy Network provided by Met Éireann
  - Nearshore buoys provided by the Marine Institute, ESB and Shell

Validation: Duration of buoys observations

Table: Buoy location depth and duration of time series used in comparison with model data. Buoys listed in order of depth.

Buoy	*Location*	*Depth* (m)	*Period* (mm/yy)
M3	SW of Mizen Head	155	01/03 - 12/12
M1	W of Aran Isl.	140	03/01 - 12/07
BH4	W of Belmullet	100	05/12 - 12/12
M2	E of Lambay Isl.	95	05/03 - 12/12
M4	Donegal Bay	72	04/03 - 11/12
M5	SE Coast	70	10/04 - 12/12
BH3	W of Belmullet	56	12/09 - 01/12
K1	Killard Point	51	11/11 - 01/12
AC1	Achill Isl.	43	11/11 - 08/12
BH1	Broadhaven Bay	38	01/09 - 10/09
K2	Killard Point	36	08/12 - 12/12
SB2	E of Aran Isl.	28	01/10 - 06/10
G1	Galway Bay	22	05/08 - 01/12
AC2	Achill Isl.	21	11/11 - 01/12
SB1	Mace Head	18	04/09 - 09/09
BH2	Broadhaven Bay	11	06/06 - 07/09

Comparison between the wave model and buoy observations:

Deep water (depths > 70m)

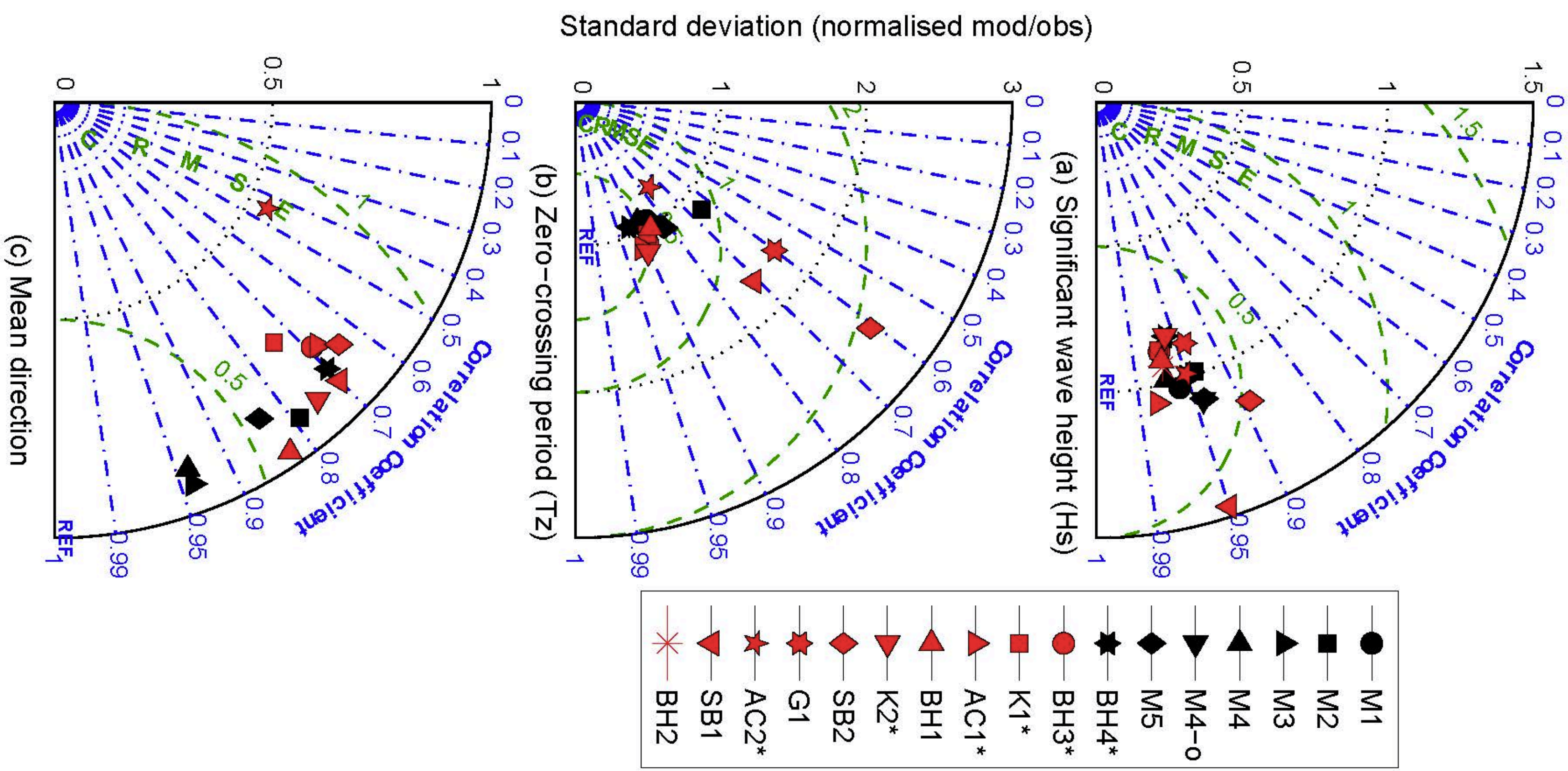
	Significant wave height				Period				Direction			
Buoy	*Bias* (*cm*)	*RMSE* (*cm*)	*R*	*SI* (%)	*Bias* (*s*)	*RMSE* (*s*)	*R*	*SI* (%)	*Bias* (*deg*)	*RMSE* (*deg*)	*R*	*SI* (%)
M3	-4	45	0.95	16	0.3	0.8	0.87	11	5	13	0.95	15
M1	-15	46	0.96	16	0.3	0.9	0.86	12	-	-	-	-
BH4	5	38	0.96	13	0.2	0.6	0.92	8	9*	20	0.7	29
M2	15	31	0.94	25	0.9	1.2	0.65	26	-15	24	0.77	14
M4	-1	39	0.97	13	0.2	0.7	0.98	19	2	13	0.94	15
M4(old)	-24	55	0.94	23	0.3	0.9	0.84	13	-	-	-	-
M5	-3	38	0.94	21	0.1	0.8	0.82	15	-6	18	0.84	14

Comparison between the wave model and buoy observations:

Moving towards the nearshore (depths < 56m)

	Significant wave height				Period				Direction			
Buoy	*Bias* (*cm*)	*RMSE* (*cm*)	*R*	*SI* (%)	*Bias* (*s*)	*RMSE* (*s*)	*R*	*SI* (%)	*Bias* (*deg*)	*RMSE* (*deg*)	*R*	*SI* (%)
BH3	11	40	0.97	15	0.2	0.7	0.89	10	7*	16	0.69	25
K1	31	53	0.97	12	0.0	0.7	0.88	7	4*	9	0.74	13
AC1	-14	34	0.98	15	-0.1	0.7	0.91	11	5*	13	0.68	14
BH1	2	31	0.97	16	0.1	0.9	0.86	14	4	11	0.83	25
K2	20	40	0.96	16	0.0	0.7	0.90	11	-0.5*	9	0.75	13
SB2	-5	17	0.89	27	-0.4	1.9	0.61	43	12	29	0.65	29
G1	7	18	0.94	25	-0.3	1.5	0.60	6	-	-	-	-
AC2	-6	43	0.95	11	-0.5*	1.5	0.76	12	6*	12	0.45	12
SB1	-36	44	0.95	52	-0.4	1.1	0.71	23	6	12	0.70	9
BH2	1	8	0.97	15	-	-	-	-	-	-	-	-

Taylor diagrams: Mean direction (left), Zero-crossing period (center), Hs (right)



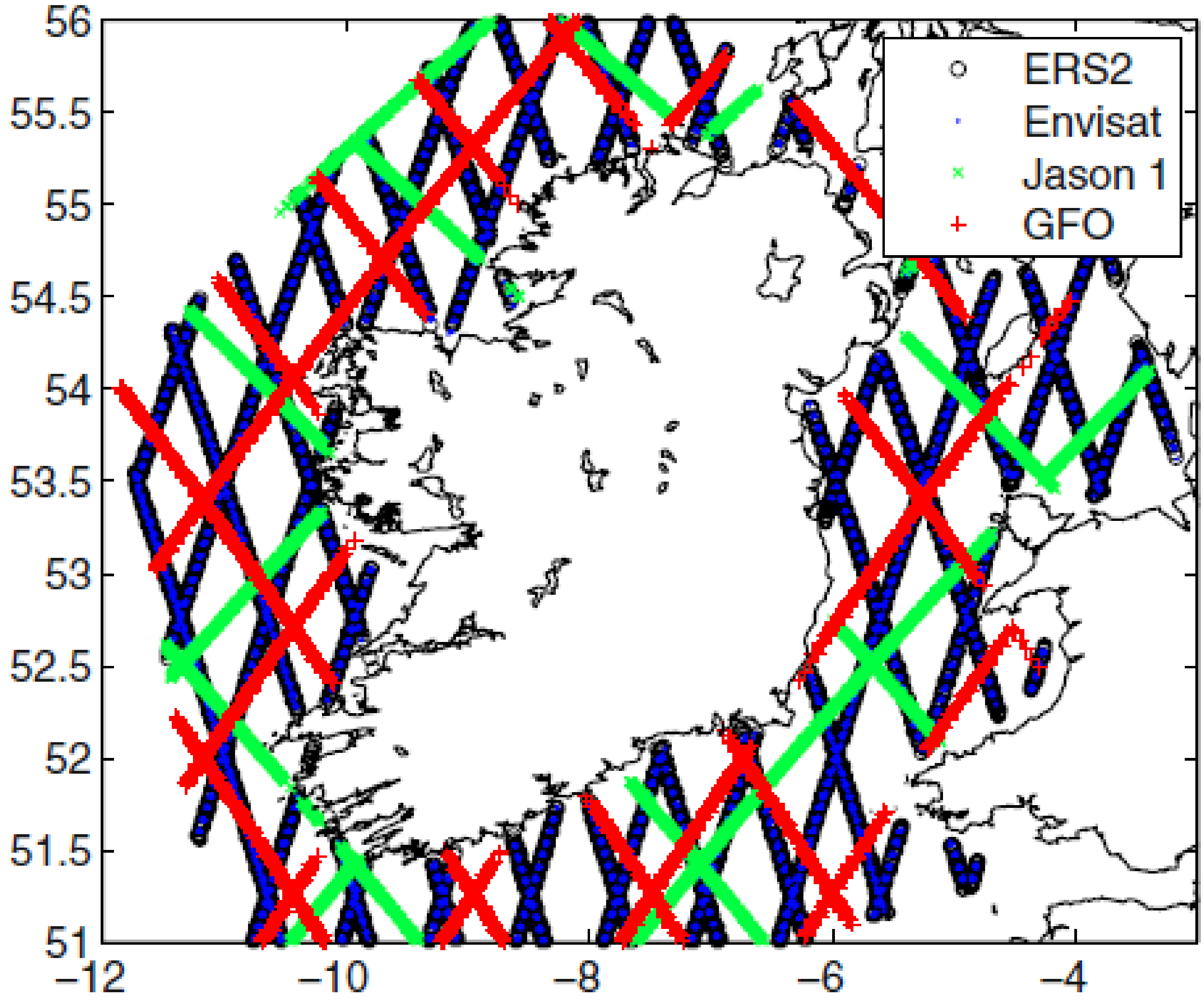
Black symbols: water depth > 60 m

Red symbols: water depth < 60 m

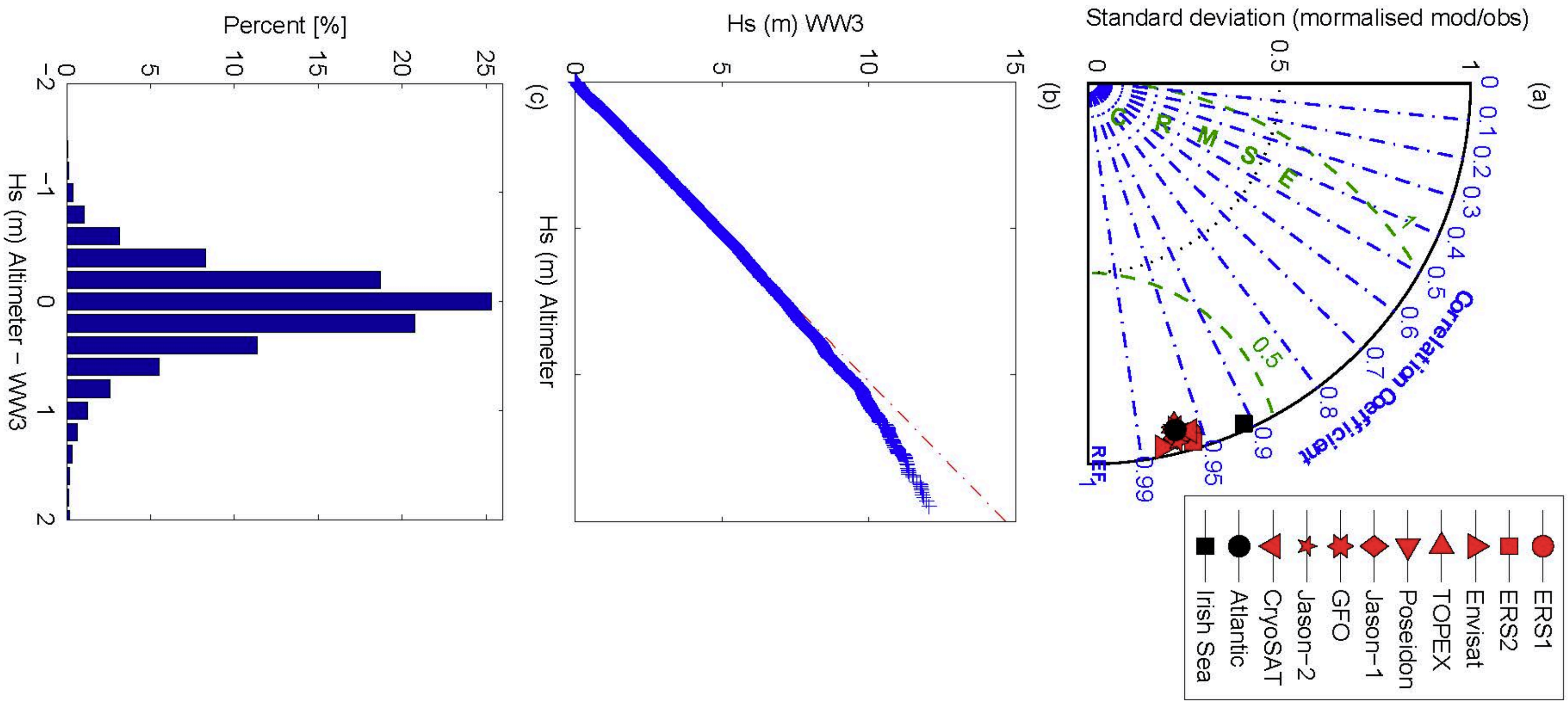
Satellite	Repeat cycle (days)	Period
ESA ERS-1	35	August 1991–June 1996
ESA ERS-2	35	May 1995–July 2011
ESA Envisat	35 (pre October 2010) 30 (post November 2010)	May 2002–April 2012
CNES/NASA TOPEX/Posidon	10	September 1992–October 2005
CNES/NASA Jason-1	10	January 2002–present
CNES/NASA Jason-2	10	July 2008 - present
US Navy/NOAA GFO	17	January 2000–September 2008
ESA/NOAA CryoSAT-2	30 (pseudo cycle)	January 2012–present

Table 4 Global comparison from 1991 to 2012 (21 years) between the model and satellite altimeter data from the CERSAT database for significant wave height (Hs): the mean of the satellite (X), the bias, the root-mean-square error (RMSE), the correlation coefficient (R) and the scatter index (SI) are shown

Hs	Number of points	X (m)	Bias (cm)	RMSE (cm)	R	SI (%)
All areas	523,471	2.29	7	39	0.97	17
Atlantic and Celtic Sea	376,099	2.69	5	39	0.97	15
Irish Sea	144,453	1.29	12	38	0.91	29

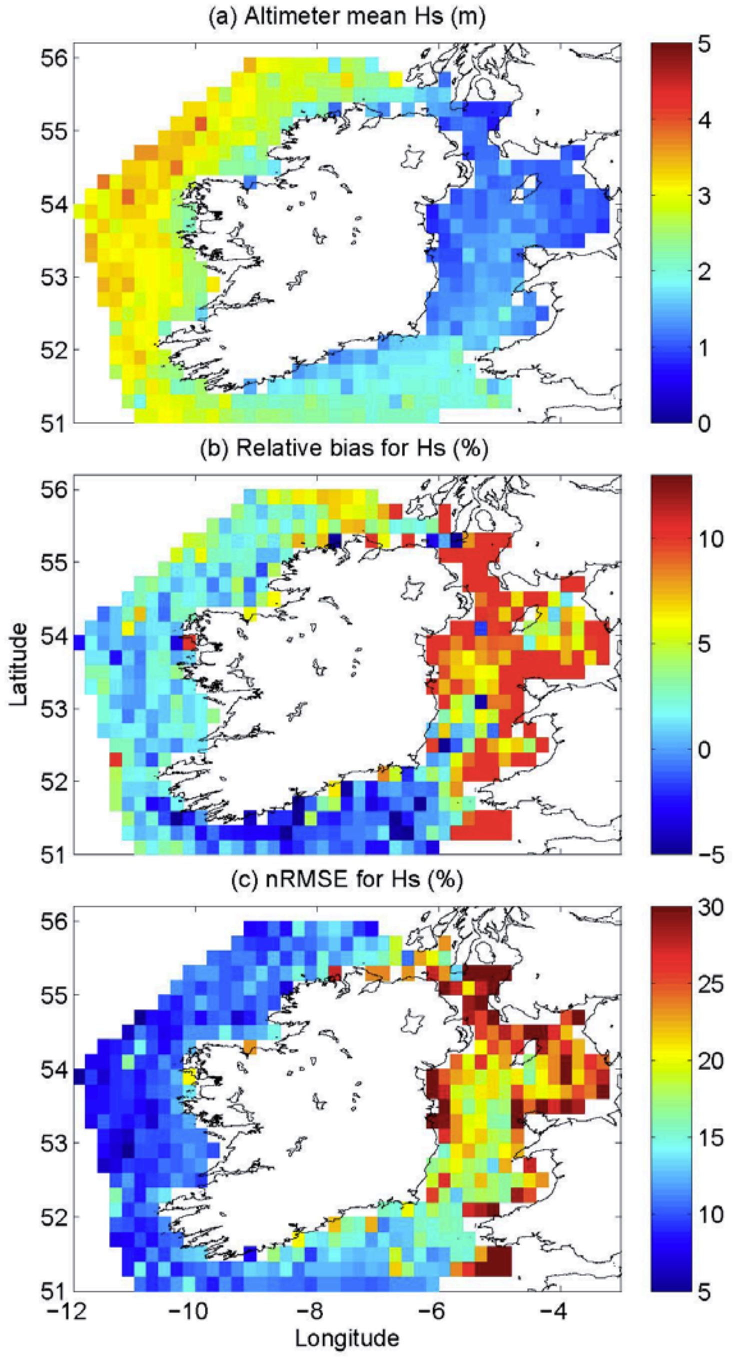

56
55.5
55
54.5
54
53.5
53
52.5
52
51.5
51
−12
−10
−8
−6
−4
ERS2
Envisat
Jason 1
GFO

Global comparison between altimeter and model (1991 – 2012)

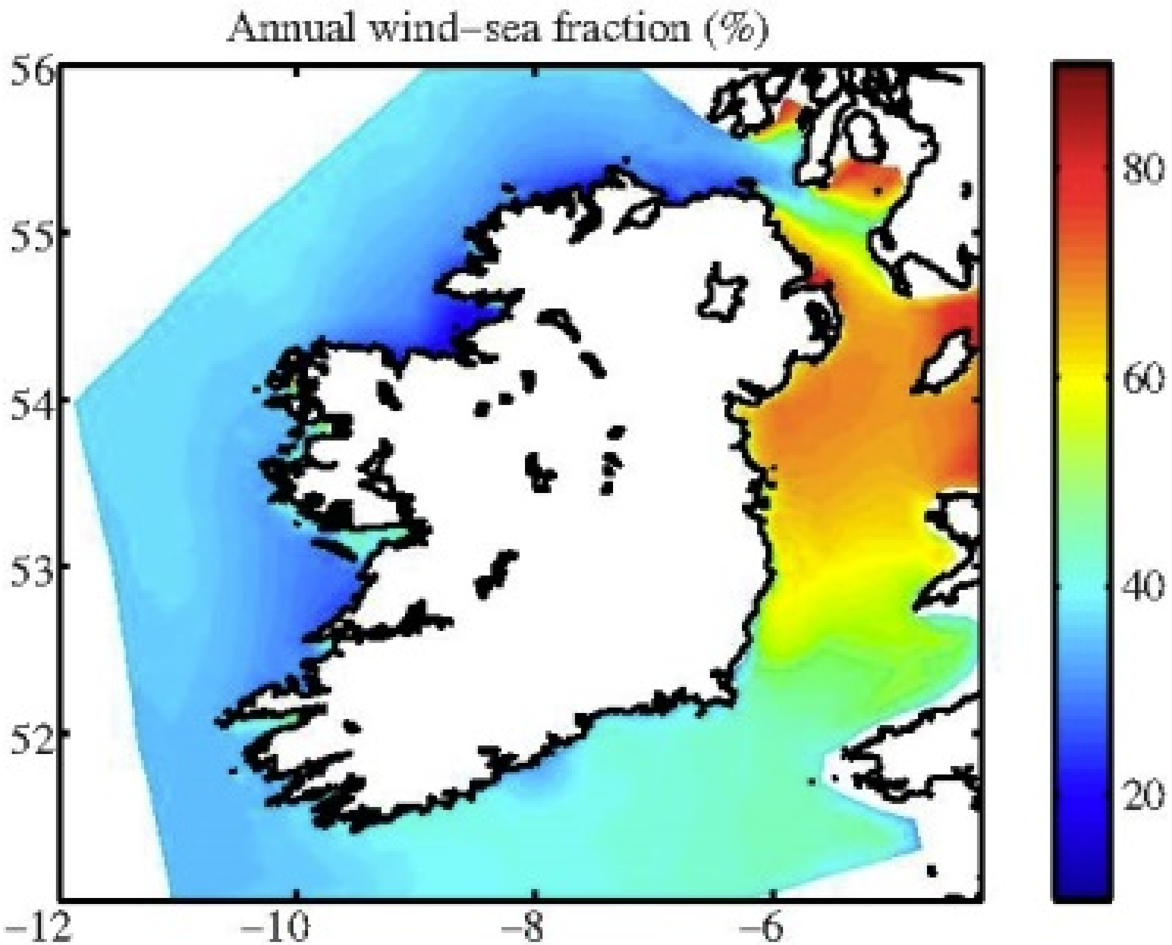


Spatial quality index maps for Hs of the collocated CERSAT satellite altimeter data (observed) and the wave model hindcast (WW3)

1991 – 2012

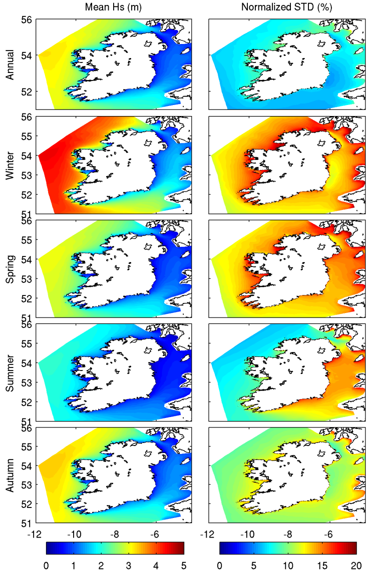


Average of the wind-sea fraction of the wave energy spectra (1979 – 2012)



Analysis: Significant wave height

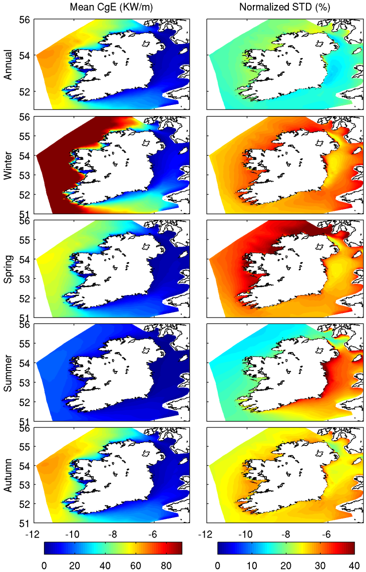
- In winter, the Atlantic coast is exposed to highly energetic sea states – mean Hs close to 5m;
- In contrast, mean Hs values do not exceed 2m on the Irish Sea coast in any season;
- Significant interannual variability of Hs:
  - up to 15% for the annual means
  - over 25% in winter and spring;
- On the Atlantic coast the interannual variability more pronounced in the nearshore.



Left panels: annual and seasonal mean significant wave height (Hs). Right panels: normalized standard deviation of the means (%), which quantifies the interannual variability.

Analysis: CgE

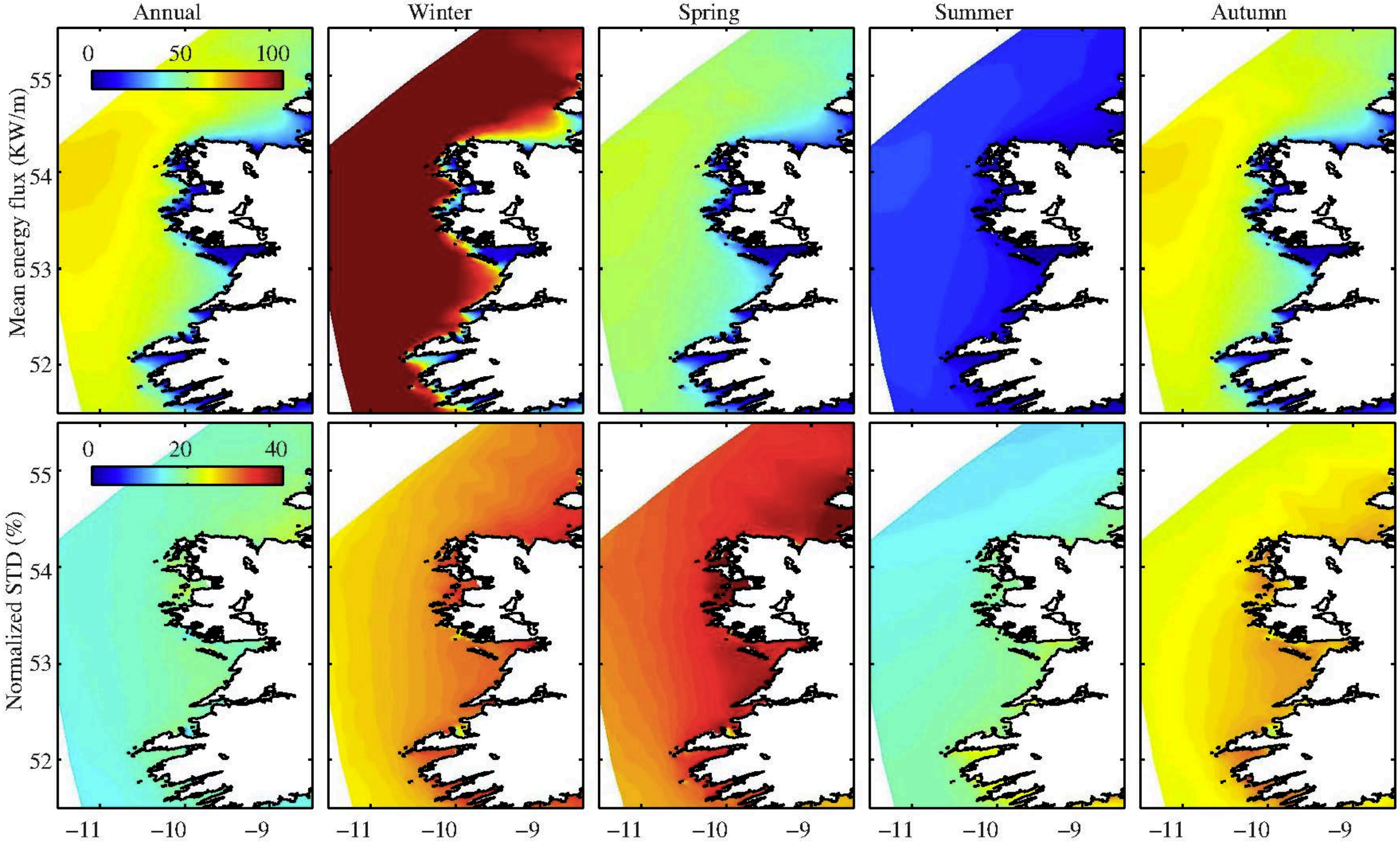
- In winter CgE over 130kW/m;
- Decrease in energy levels from winter to summer dramatic – West Coast energy levels of 20kW/m in summer months;
- Variability larger than Hs:
  - up to 25% in mean annual levels
  - well over 35% in mean CgE winter and spring levels on North and West Coast;
- Can this variability be linked to larger scale atmospheric circulation patterns such as the North Atlantic Oscillation NAO?



Left panels: annual and seasonal mean wave energy flux (kW/m of wave crest). Right panels: normalised standard deviation of the means (%) which is a measure of the interannual variability of the wave energy resource.

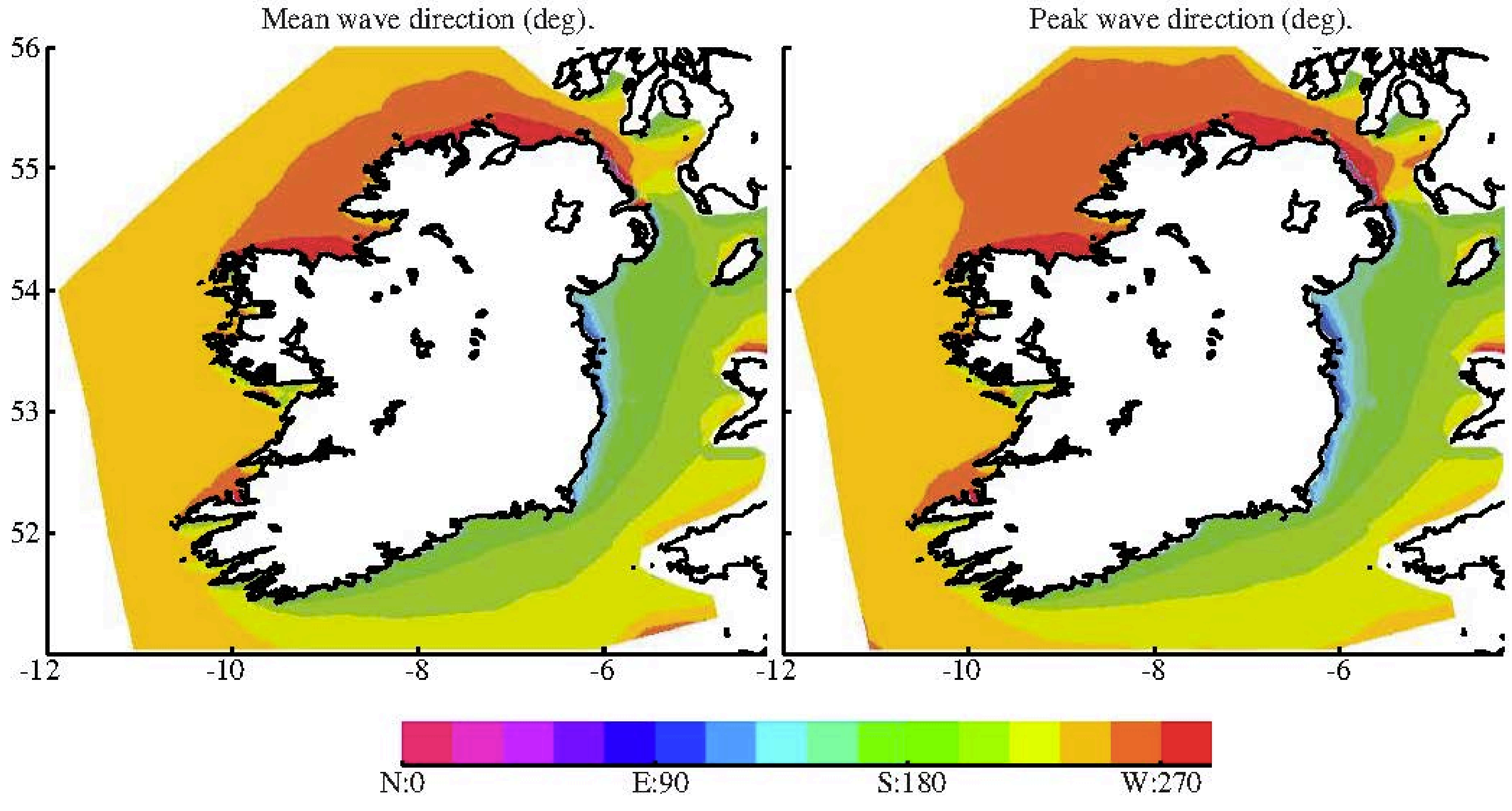
Wave power per unit crest (kW/m) (1979 – 2012)

Top: Means, Bottom: Normalised STD (%) – measure of interannual variability of wave energy ressource

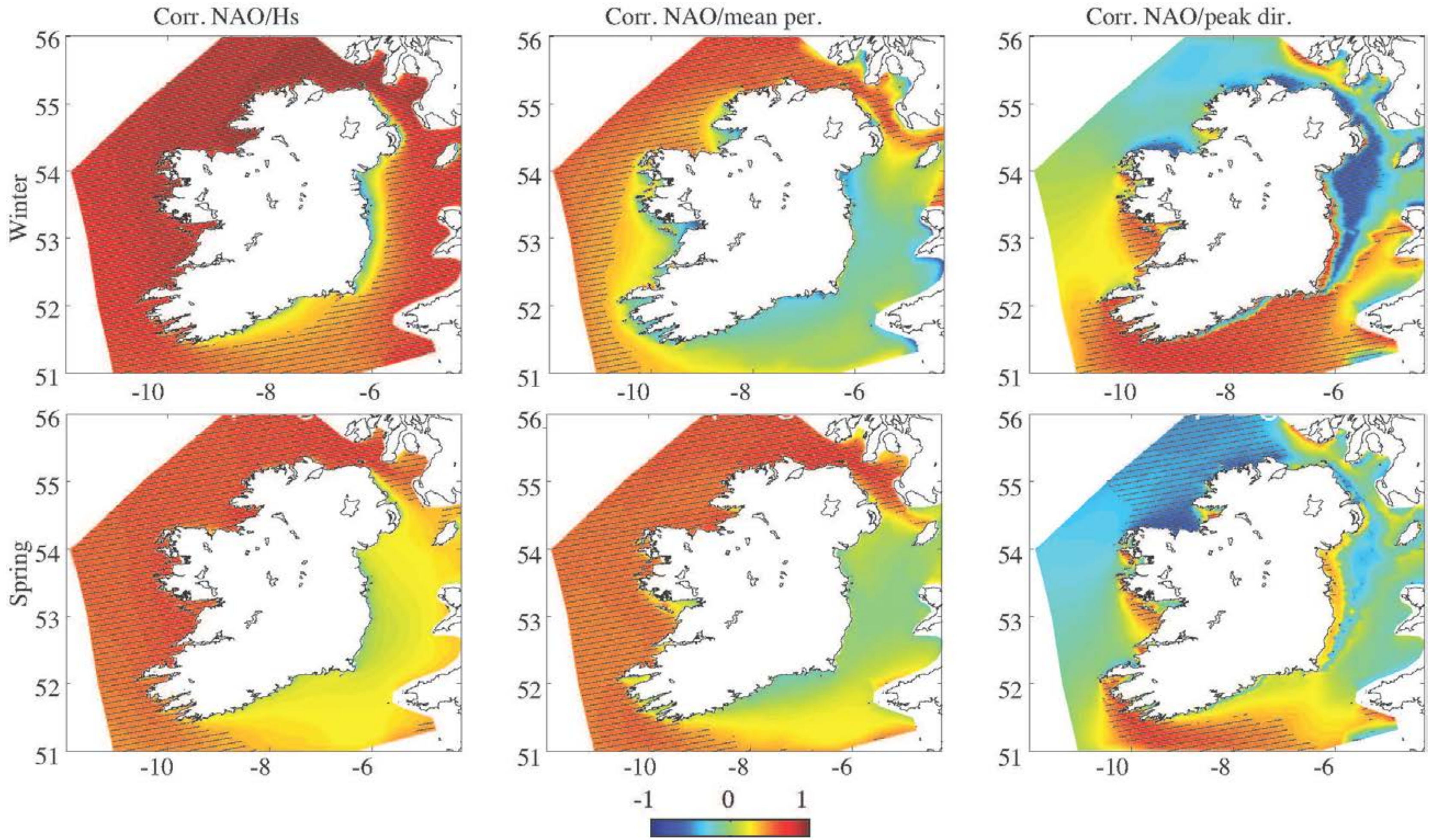


Directionality of the Irish wave climate (1979 – 2012)

Left: Annual average mean wave direction
Right: Annual average peak wave direction

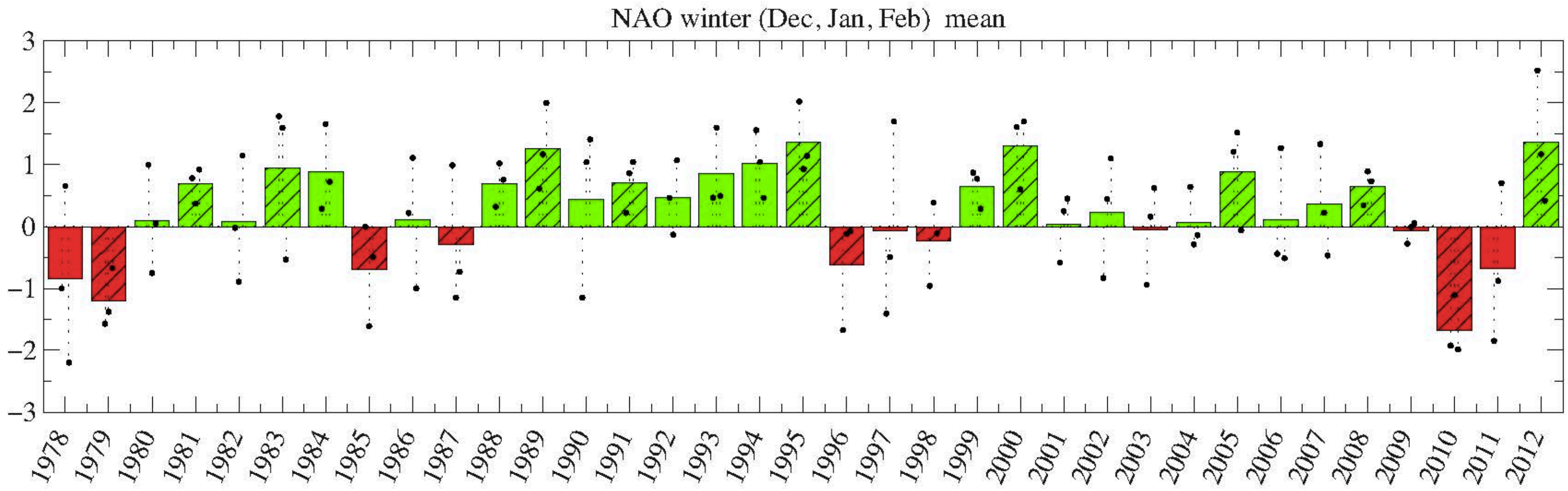


Correlation coefficient between NAO and seasonal averages (for winter and spring) of Hs, mean period and peak direction



Averaged winter (Dec, Jan, Feb) NAO index

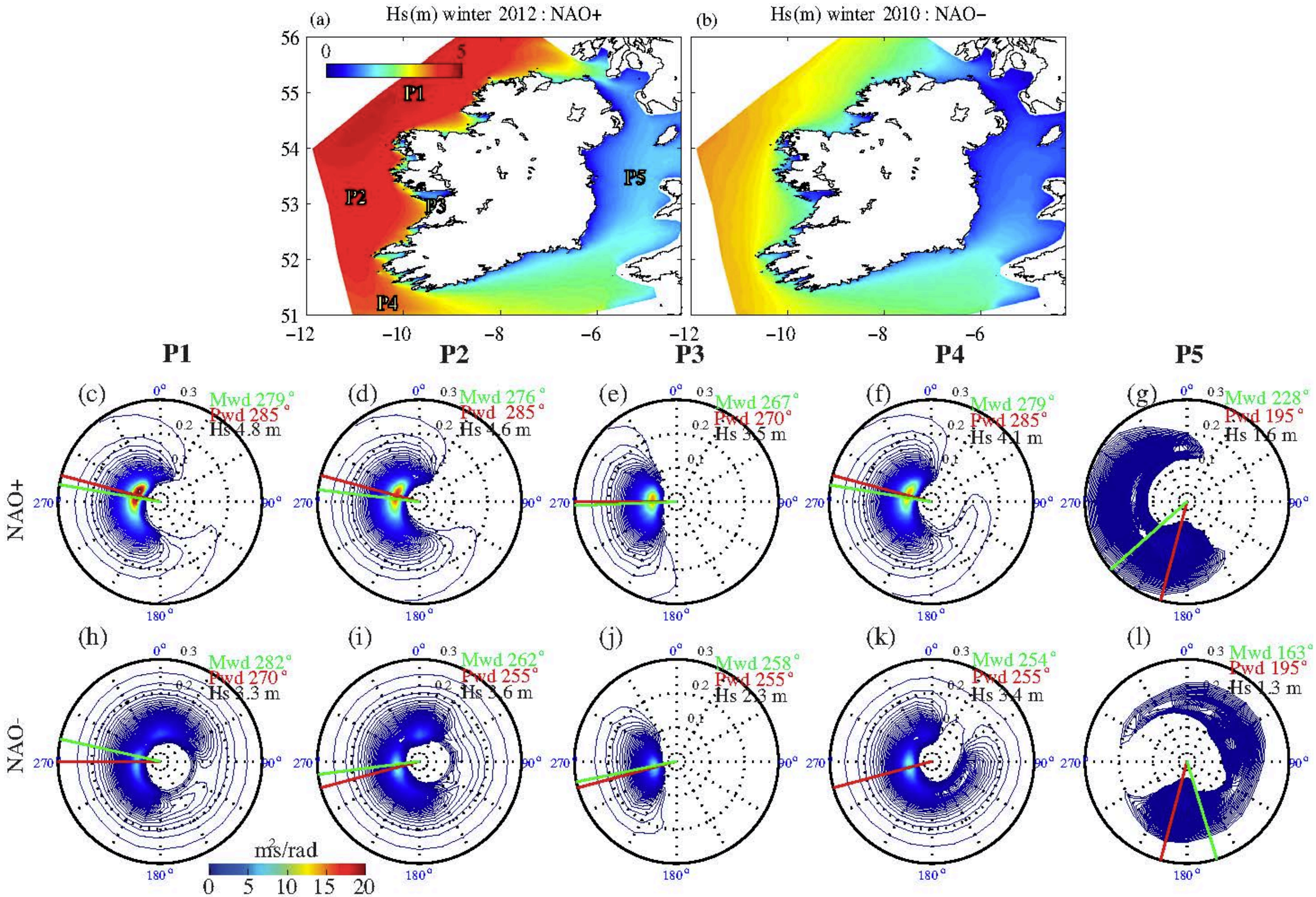
Dashed lines: Monthly averaged NAO indexes for Dec, Jan, Feb of each year



Left: Hs for winter 2012 – max NAO winter index

Right: Hs for winter 2010 – min NAO winter index

Bottom: Averaged wave-variance density spectra (the five locations are shown on the map)



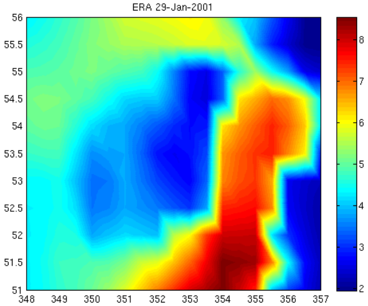
Further work

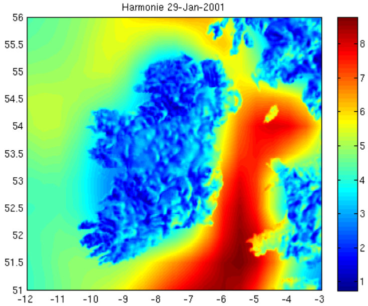
SEAI project: "Nearshore Wave and Wind Climate on the West Coast of Ireland: Spatial and Seasonal Variability with Applications to the Renewable Energy Sector"

- Joint project in collaboration with Met Éireann
- ERA-Interim winds downscaled using HARMONIE model:
  1. Developed by HIRLAM (HIgh Resolution Limited Area Model) in close collaboration with the ALADIN consortium and ECMWF
  2. Non-hydrostatic mesoscale model with 2.5km resolution
  3. hourly outputs of U10 and V10
- Initially a 13 year wave and wind hindcast (2000 - 2012)
- This study will go beyond just marine renewable energy applications - marine applications
- Wind and wave resource - the first joint study for Ireland at high-resolution
- Weather window analysis

Dynamical downscaling of winds

ERA-Interim versus Harmonie 10m wind





Acknowledgements

- This study was supported by the Sustainable Energy Authority of Ireland (SEAI) through the Renewable Energy Research Development & Demonstration Programme. SEAI is partly financed by Ireland's EU Structural Funds Programme co-funded by the Irish Government and the European Union;
- Additional funding was provided through the SFI project "High-end computational modelling for wave energy systems";
- Boundary forcing data (wave spectra and wind field data) provided by ECMWF through the MARS archive;
- Buoy data for validation was provided by ESB, Met Éireann and MI Ireland;
- The INFOMAR bathymetric datasets were provided by the GSI and MI;
- The VORF vertical datum software was provided by the GSI;
- Many thanks to M. Osborne (OCEANWISE) for his help with the UKHO bathymetry;
- The authors thank Dr. C. Sweeney and Prof. P. Lynch (UCD School of Mathematical Sciences) for helpful discussions and Dr. F. Ardhuin (Ifremer) for advice regarding the WAVEWATCH code;
- The numerical simulations were performed on the Stokes cluster at the Irish Centre for High-end Computing (ICHEC) and at the Swiss National Computing Centre under the PRACE DECI 10 project "Nearshore wave climate analysis of the west coast of Ireland".

Thank you!

Aileen's wave at the Cliffs of Moher, Co. Clare.