4th International Workshop on Waves, Storm Surges, and Coastal Hazards 2025

How to account for the uncertainty in weather forecasts during extreme weather

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Introduction

- Historical weather forecasts shows that we need include uncertainty in the forecast.
- The consequences of exceeding the forecasted extreme will often determine the required confidence level.

- Methods
  - Add a tabulated value on max Hs based on experience
    - uncertainty increases with lead time
  - Use of ensemble forecast
    - Focus on Hs or response

NORSOK N-006/N-005(in draft):
Integrity management of offshore structures and marine systems

Shut-down and unmanning

- A shut-down and unmanning procedure shall be implemented for facilities not satisfying ULS(ultimate limit states) or ALS(accidental limit states) requirements related to structural integrity.

- The procedure shall be determined in a way that ensures that the structural reliability of the facility with personnel on-board is not less than for ordinary manned platforms satisfying the ULS and ALS requirements.

- The unmanning procedure shall consider the forecast uncertainty,

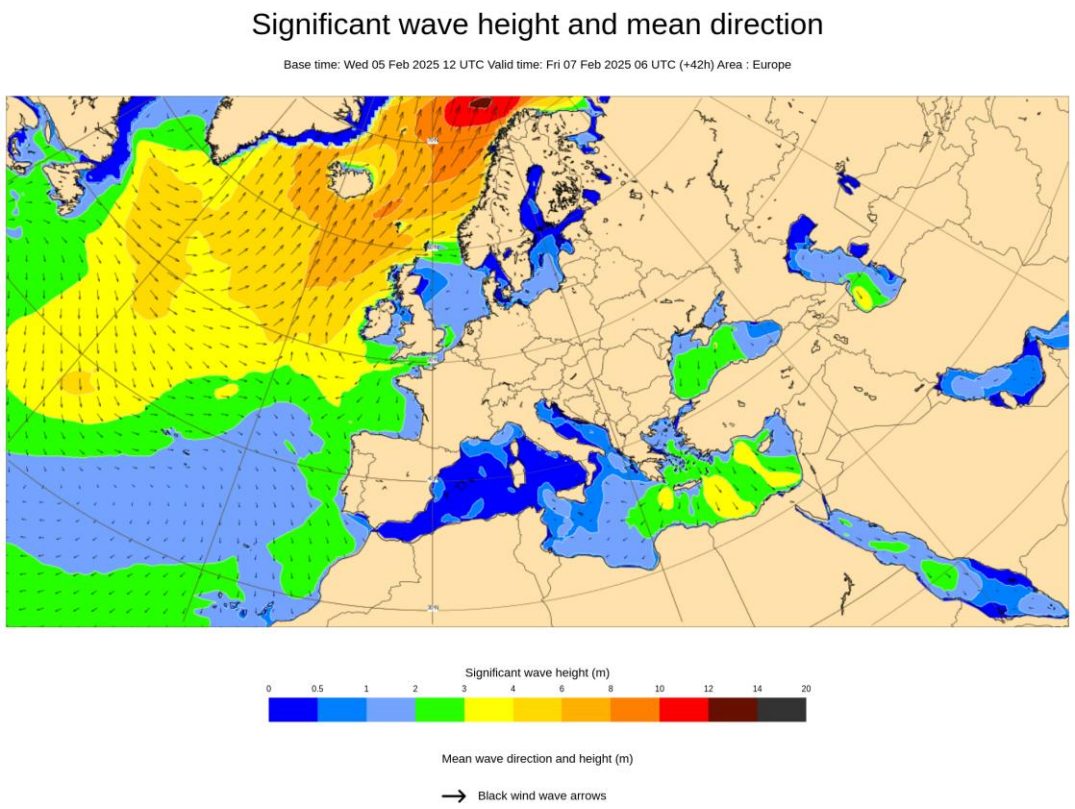
ECMWF Medium-range forecast (horizontal resolution 9 km)

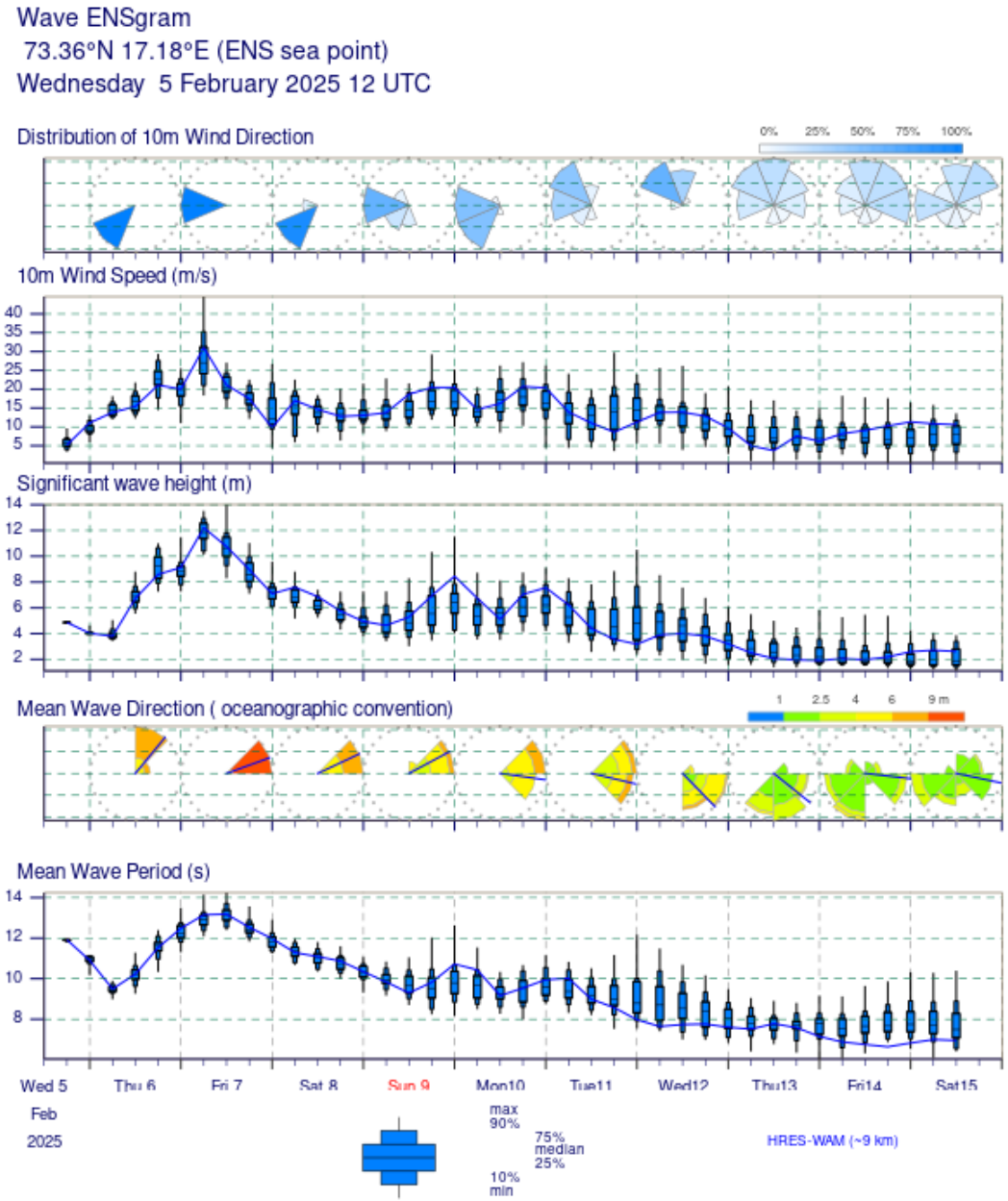
- HRES (deterministic)
  - One single forecast 10 days ahead

- ENS
  - ENS is an ensemble of 51 forecasts
    - One control forecast plus 50 forecasts each with slightly altered initial conditions and slightly altered model physics.

ECMWF

ECMWF | Charts

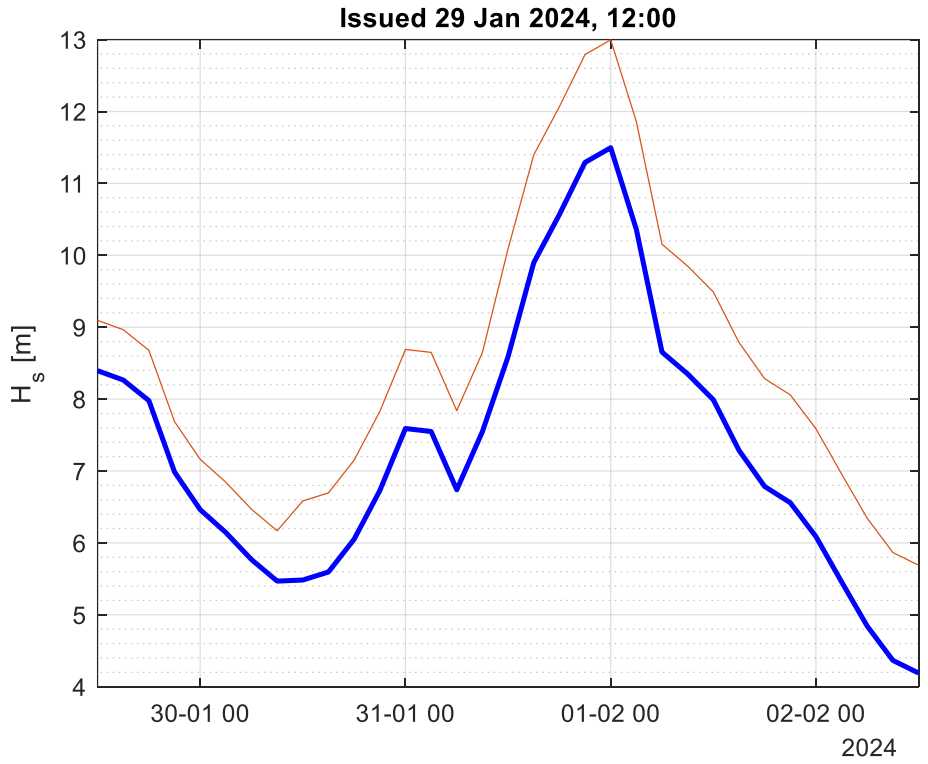




ECMWF is the European Centre for Medium-Range Weather Forecasts

Medium-range forecasts | ECMWF

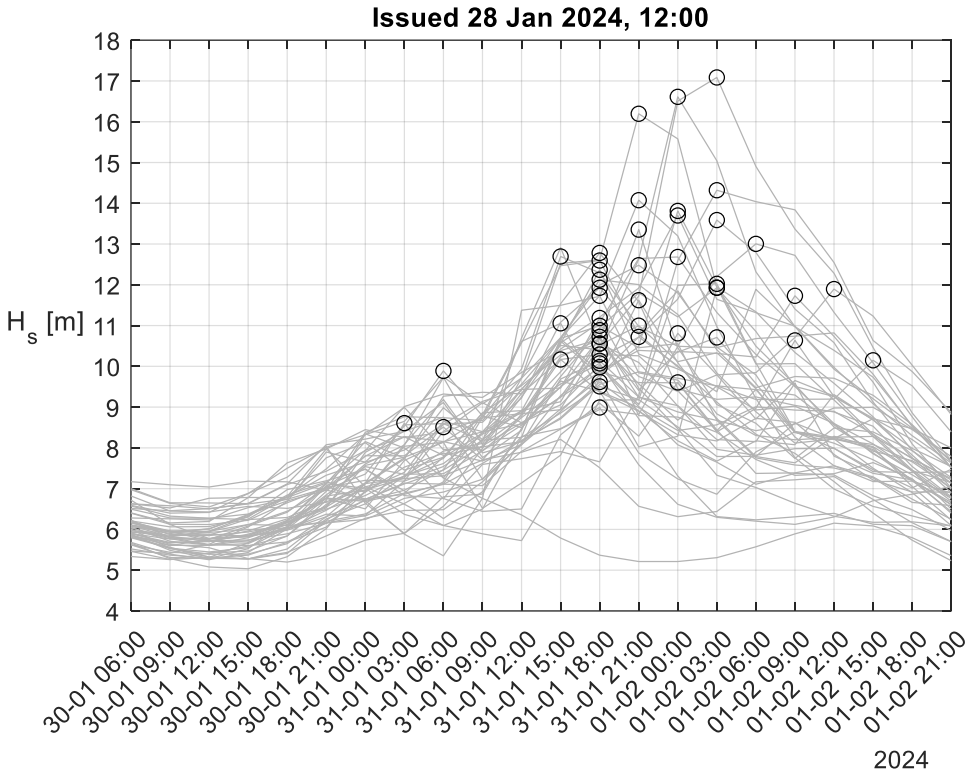
Guidance in NORSOK N-006:2015

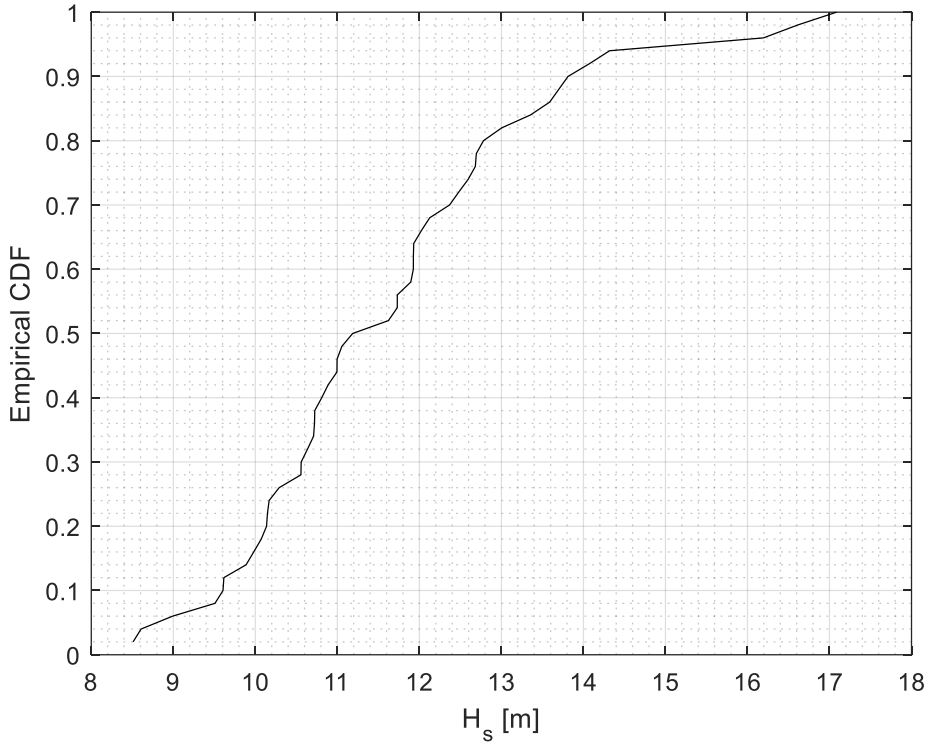


- In the N-006:2015 the following guidance is given:
- Unless other data are available, uncertainties in weather forecast may be accounted for by the following safety margins in the uncertainty in H_s.
  - 1.5 m for 72 h forecast
  - 1.1 m for 48 h forecast
  - 0.7 m for 24 h forecast

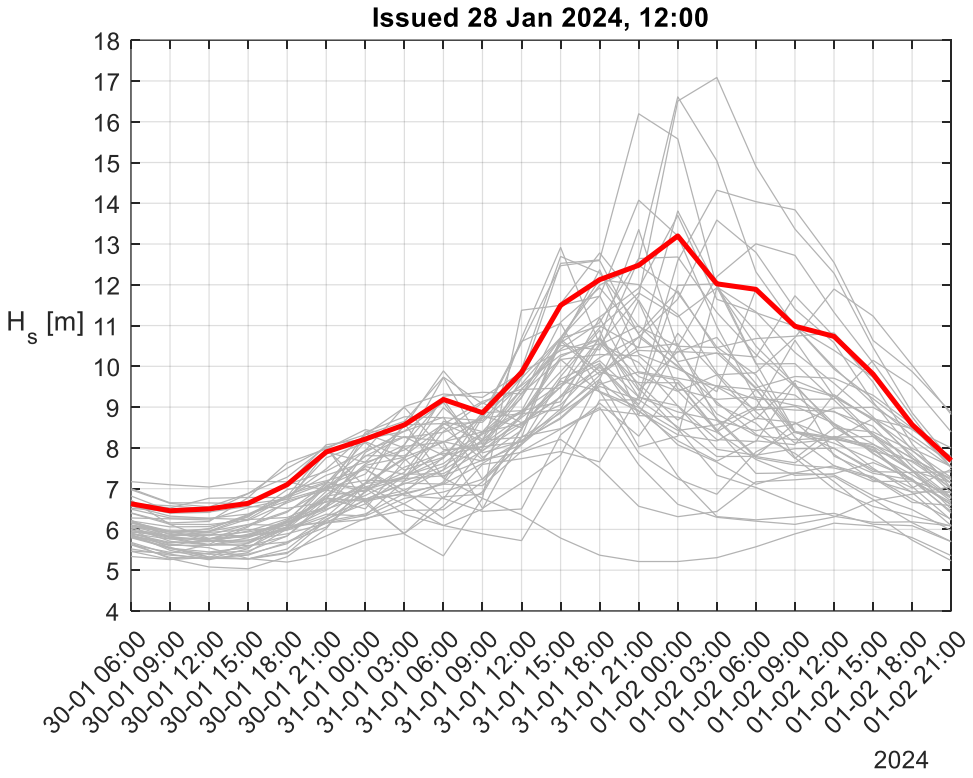
Although not specified, it is reasonable to assume that the initial sea state steepness is preserved.

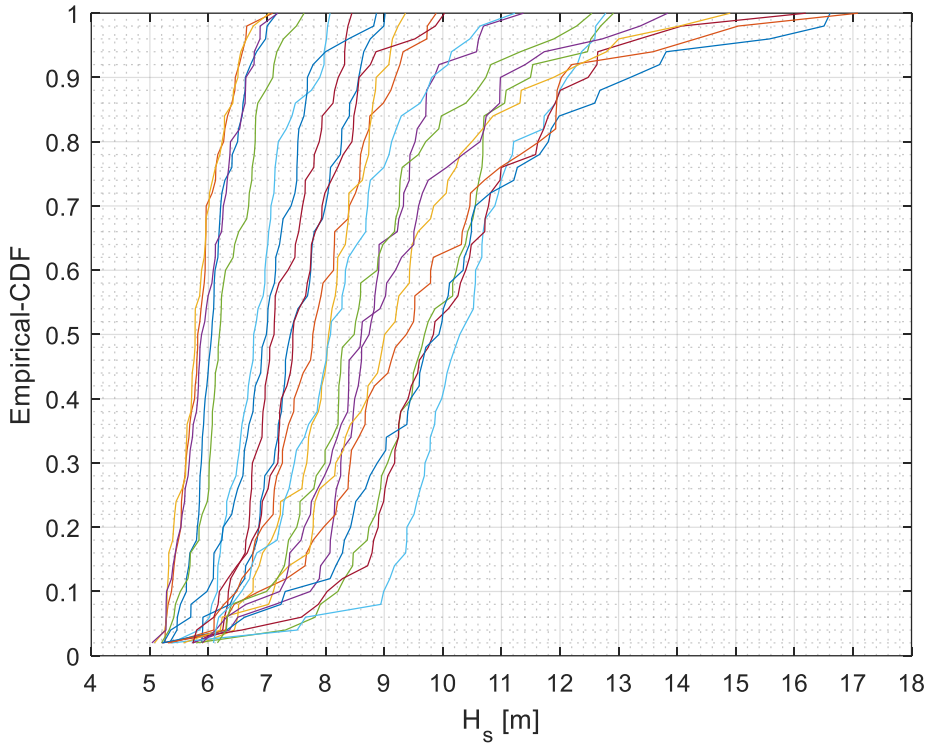
P90 of the largest of each ensemble member within a time window



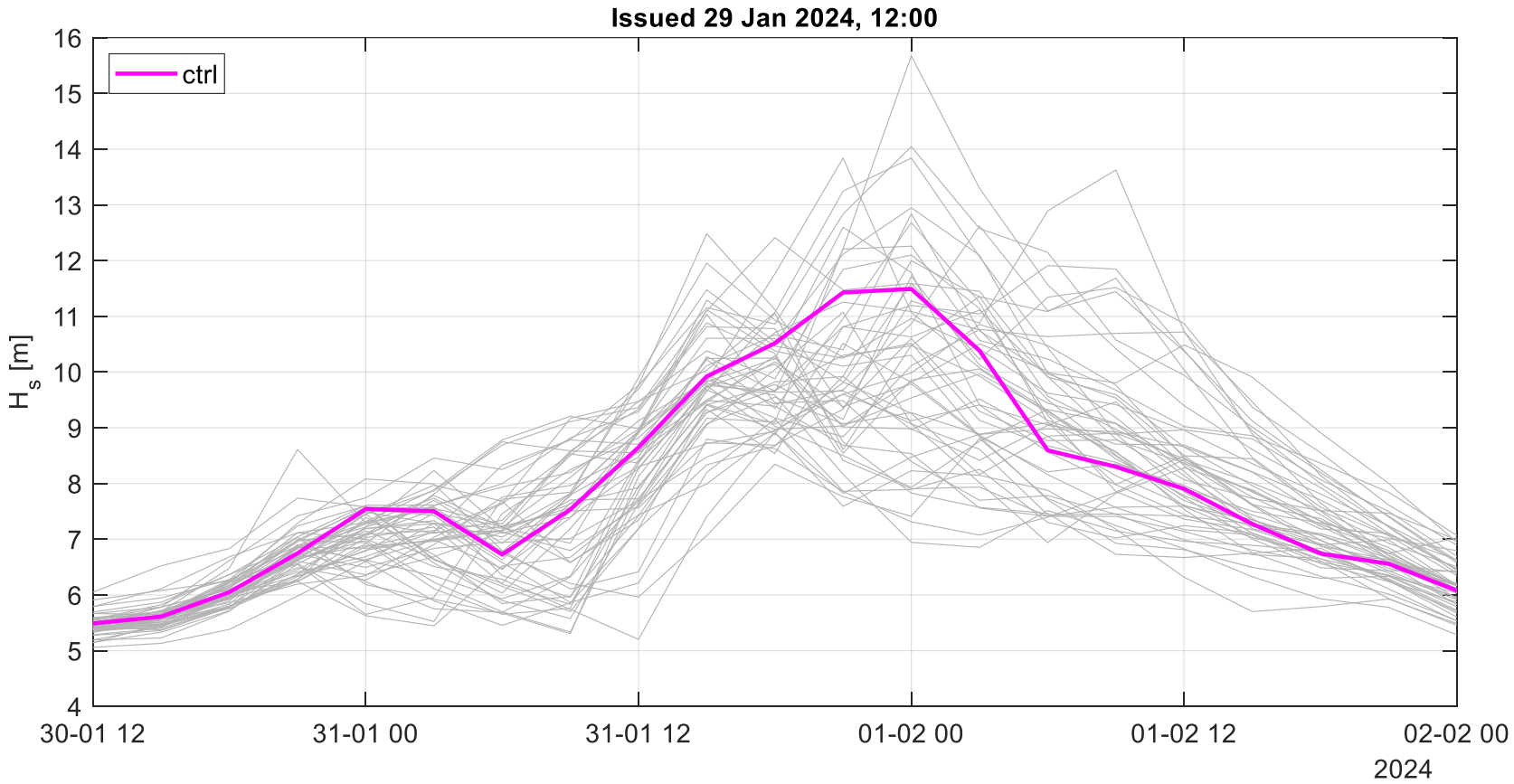


P90 of the largest at each time step within a time window





Ensemble forecast from 29-01-2024 12:00



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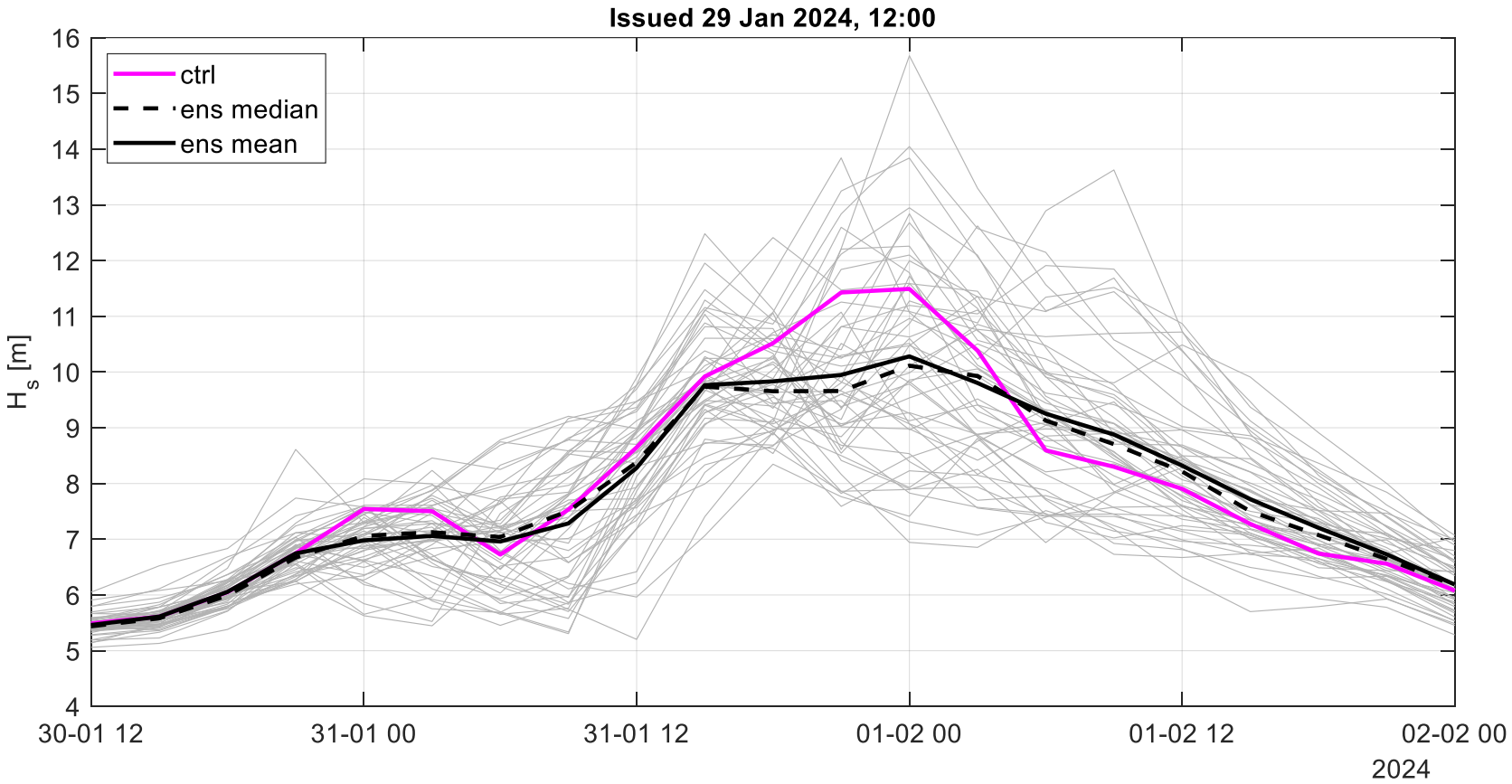

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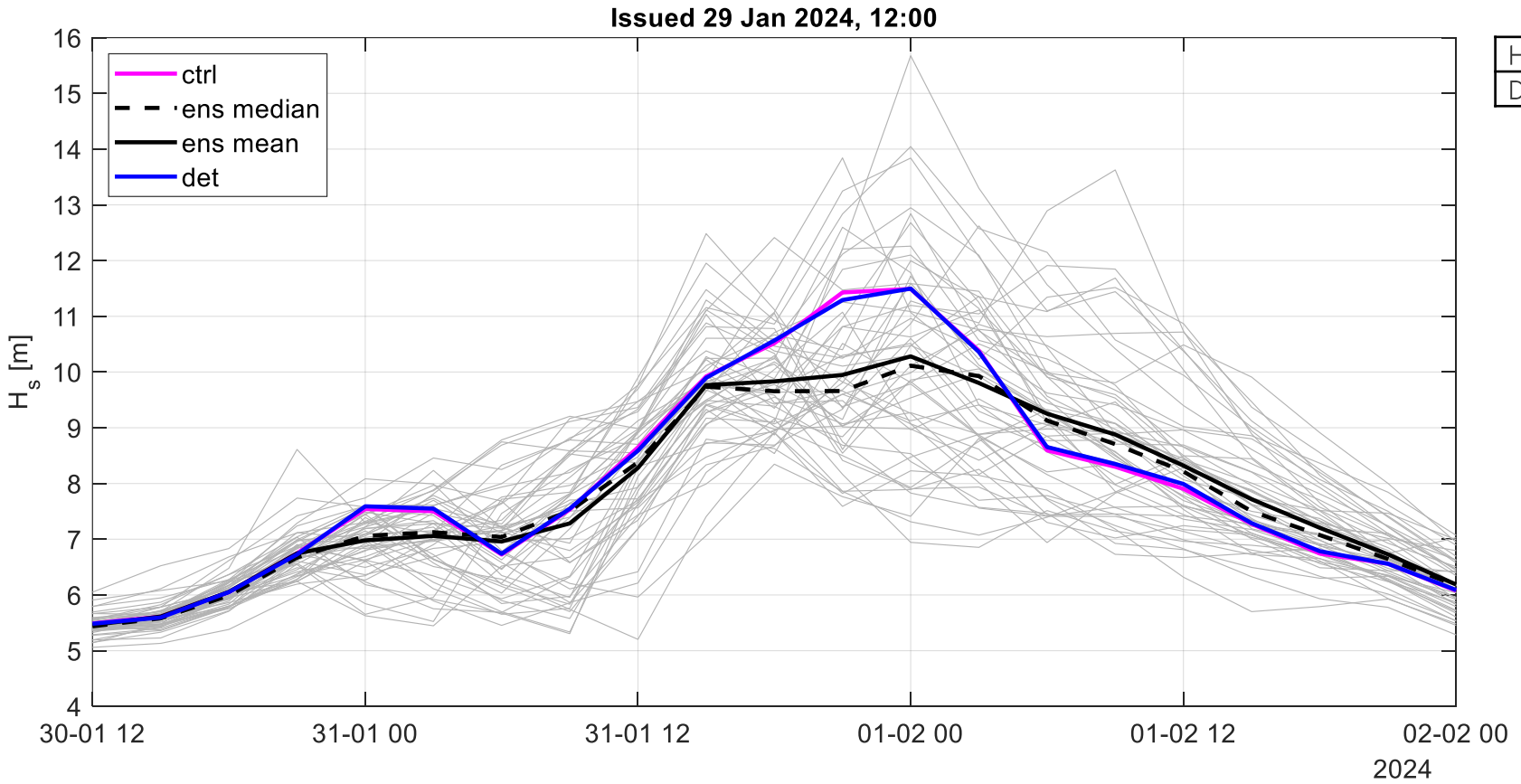
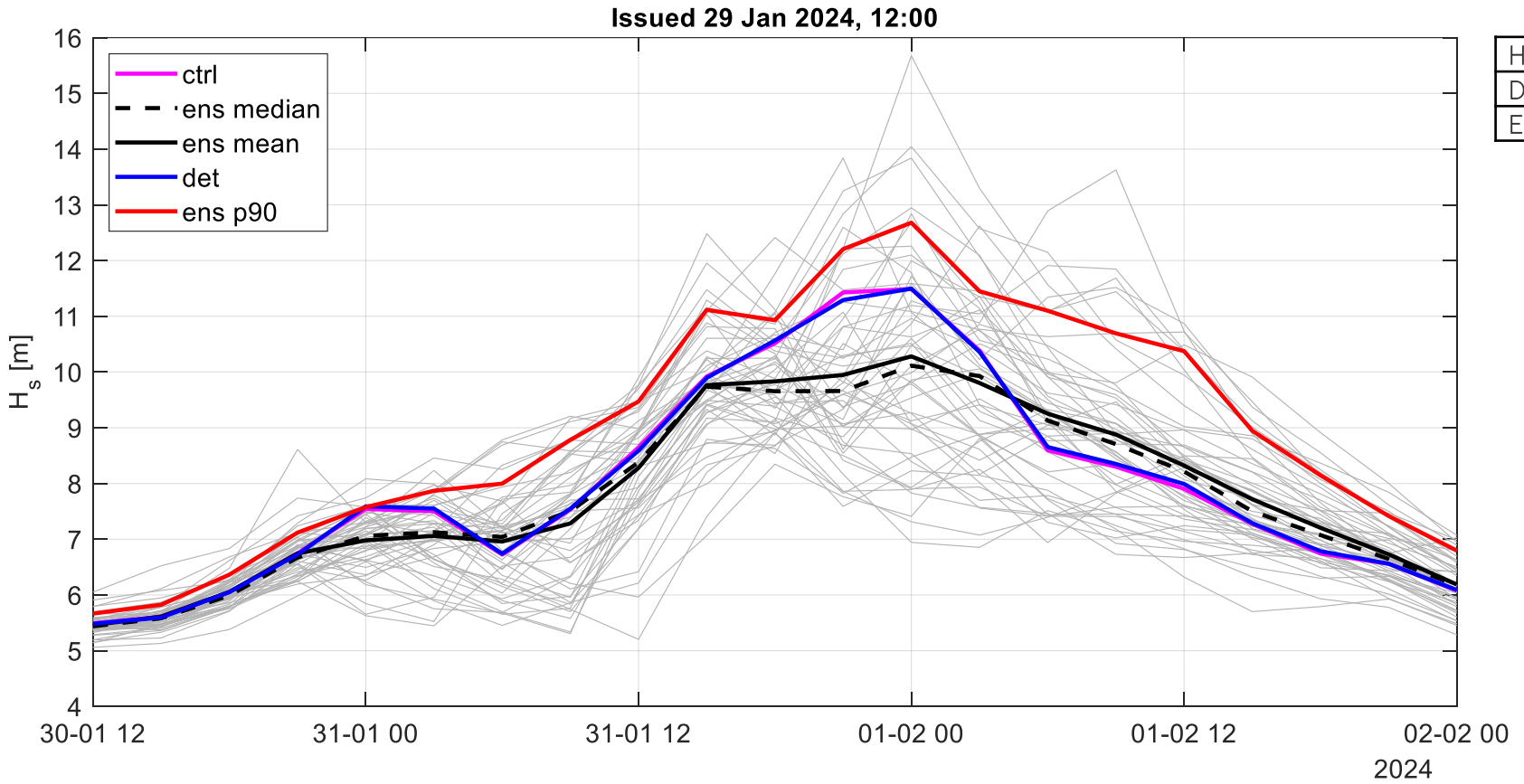


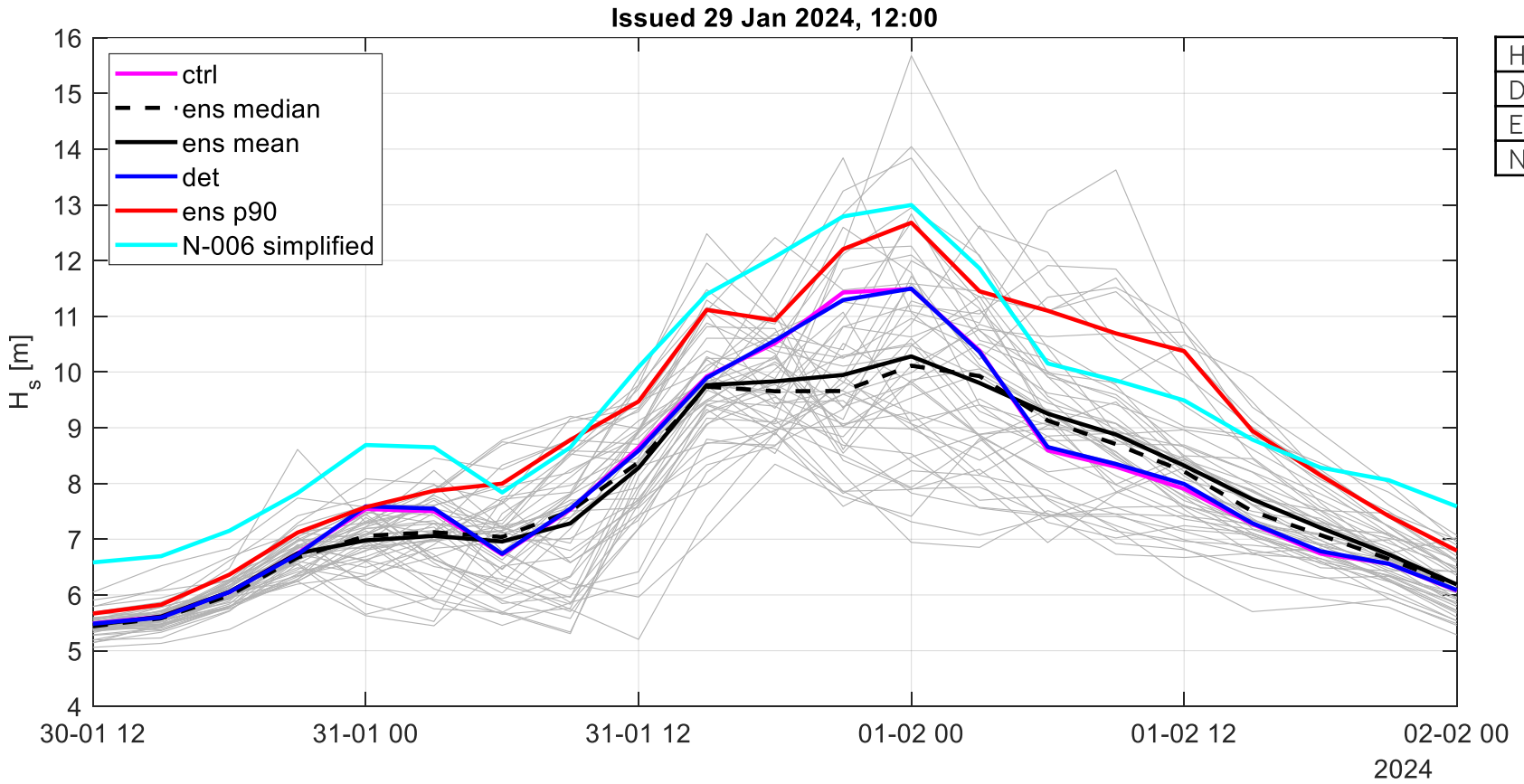
Hs [m]	
Deterministic	11.5

Ensemble forecast from 29-01-2024 12:00



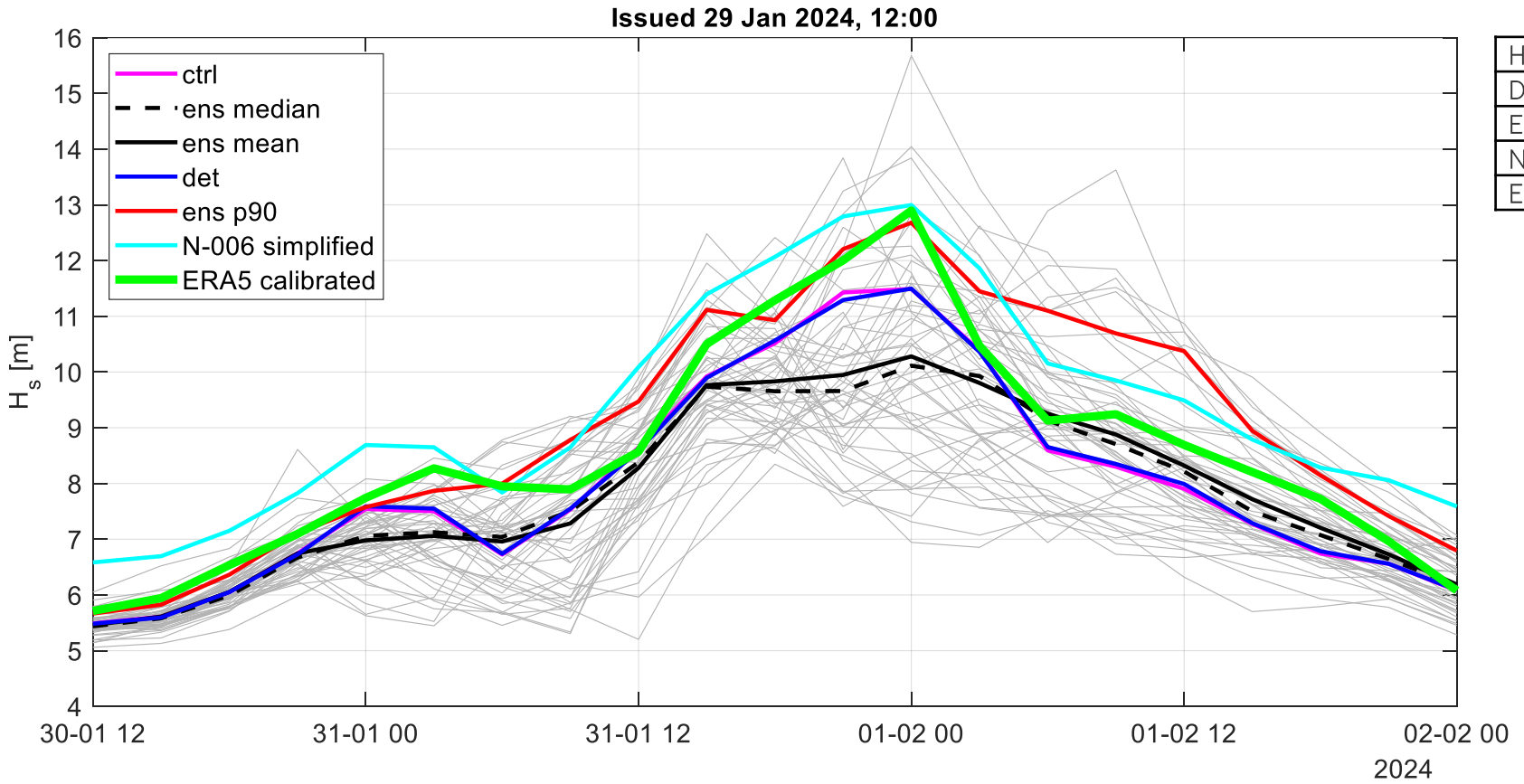
Hs [m]	
Deterministic	11.5
Ensemble P90	12.7

Ensemble forecast from 29-01-2024 12:00



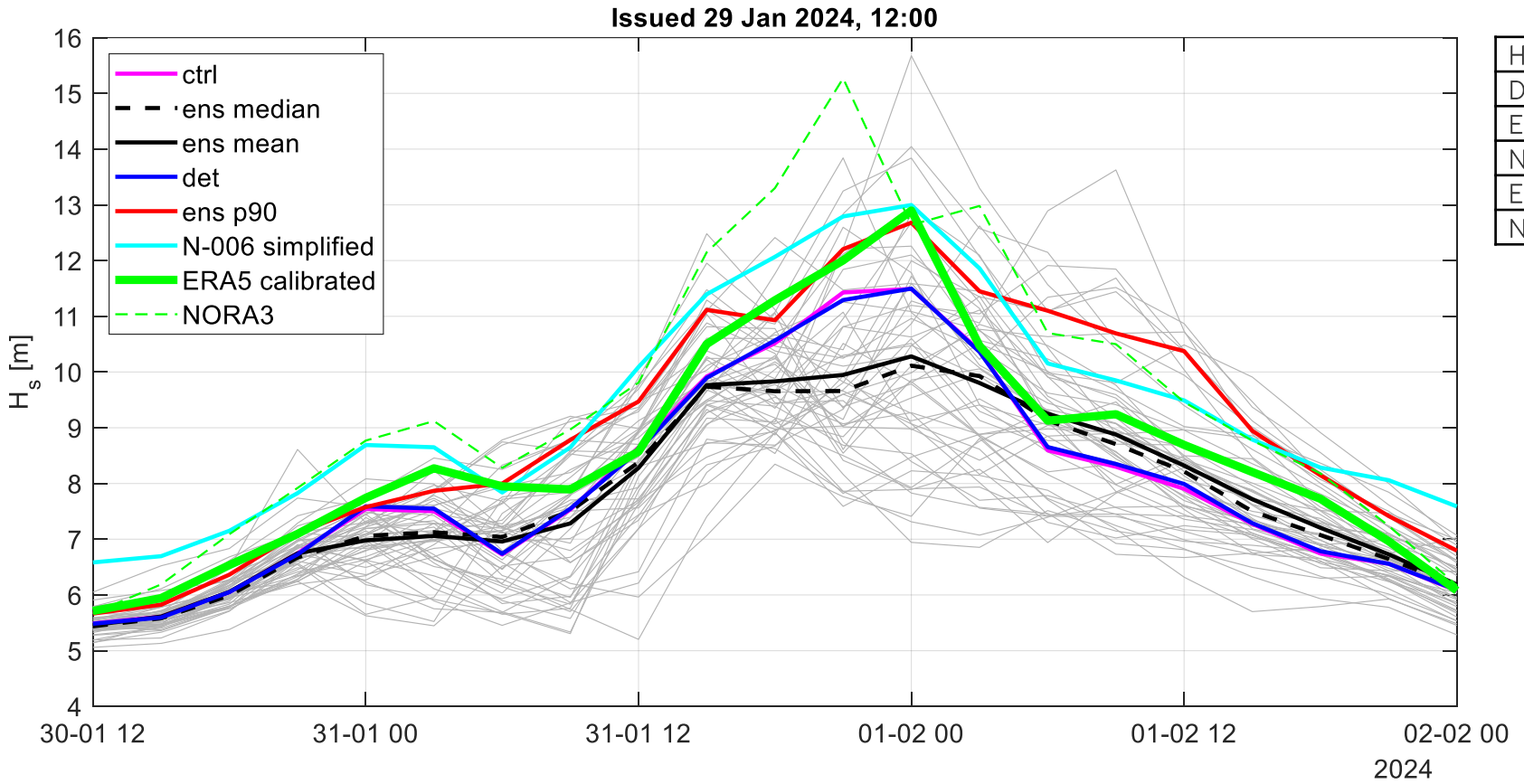
Hs [m]	
Deterministic	11.5
Ensemble P90	12.7
N006	13.0

Ensemble forecast from 29-01-2024 12:00



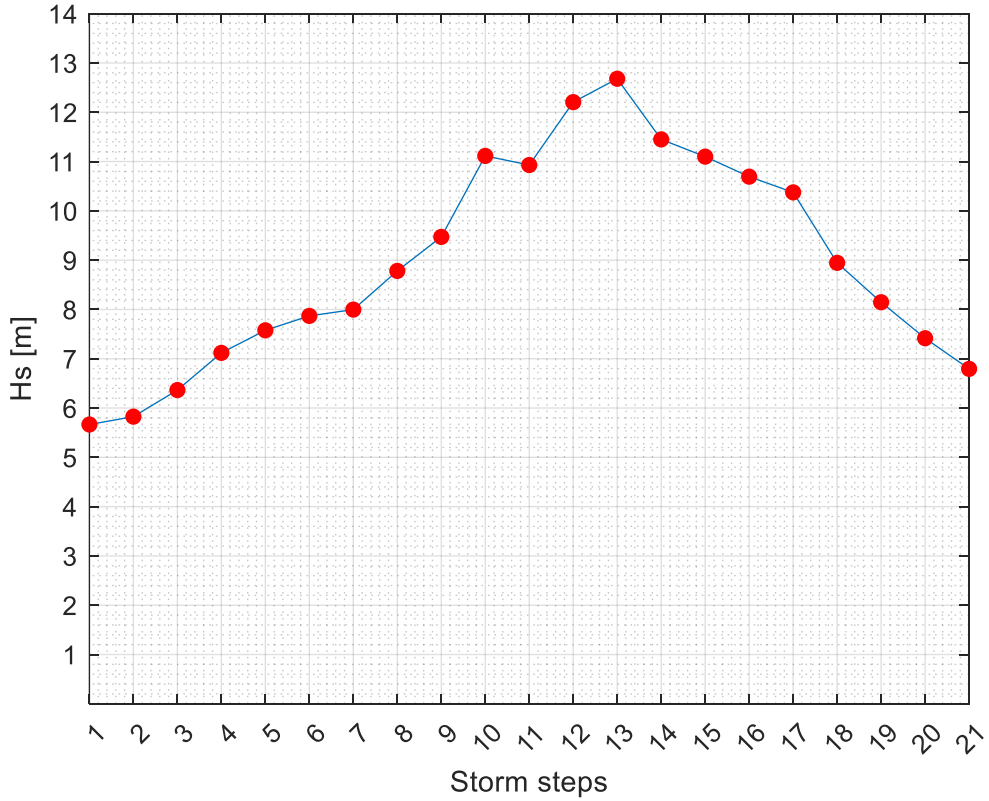
Hs [m]	
Deterministic	11.5
Ensemble P90	12.7
N006	13.0
ERA5 calibrated	12.9

Ensemble forecast from 29-01-2024 12:00



Hs [m]	
Deterministic	11.5
Ensemble P90	12.7
N006	13.0
ERA5 calibrated	12.9
NORA3	15.3

Distribution of the largest response in a «storm»,



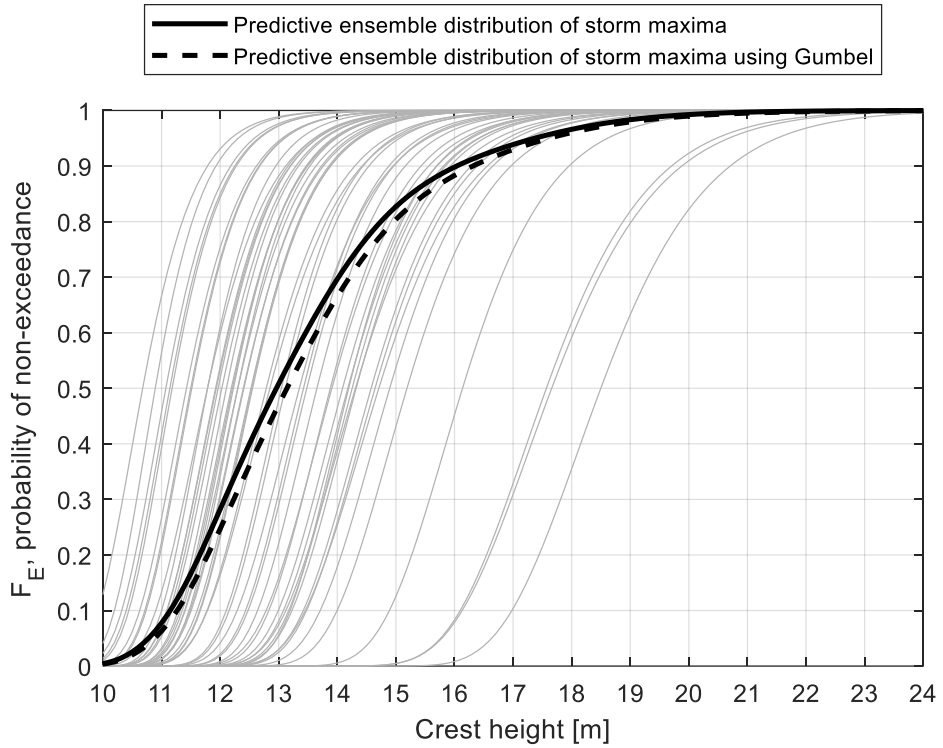
The distribution function for the extreme value y for ensemble member k with m storm steps is given by:

$$F_{Y|k}(y|k) = P\left[\left(Y_{1_k} \leq y\right) \cap \left(Y_{2_k} \leq y\right) \cap \cdots \left(Y_{m_k} \leq y\right)|k\right] = \prod_{m=1}^{m_k} F_{Y_{3h}m|k}(y|mk')$$

where $F_{Y_{3h}m|k}(y|\mathrm{k}) = F_{Ym|k}^{n_{3h}}(y|\mathrm{k})$

All relevant data for the response under consideration can be included at each time step.

Predictive distribution of maximum response derived from an ensemble

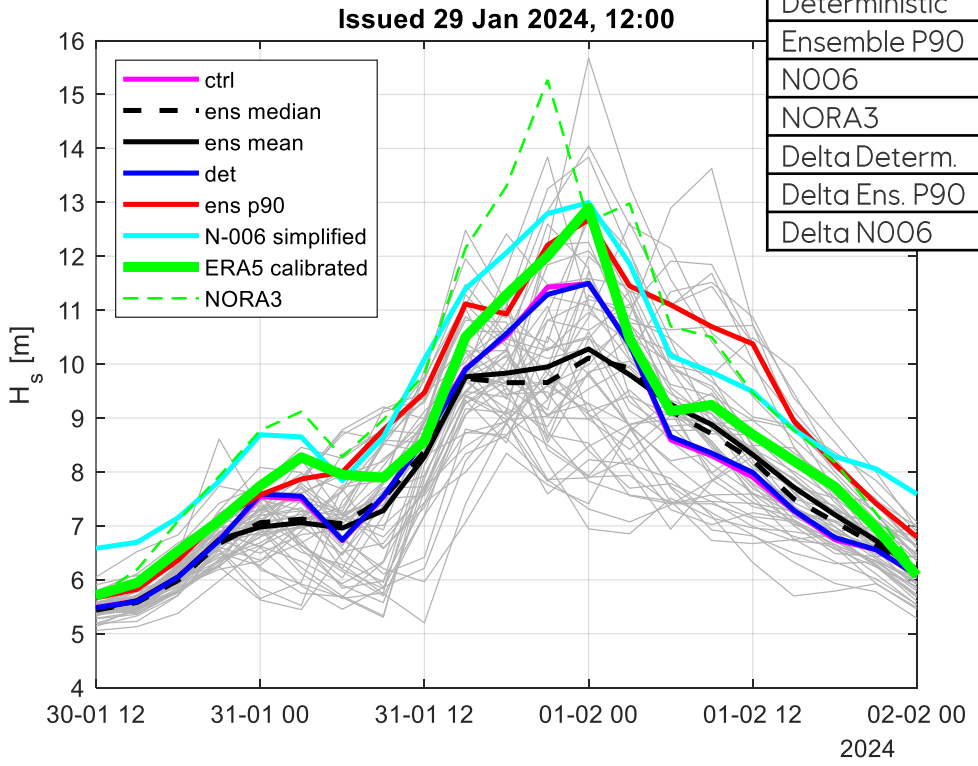


Each ensemble member is considered equally likely, with a probability of $1/k_0$. The marginal distribution of the maximum response over the storm is then obtained by averaging the probability distributions across all ensemble members.

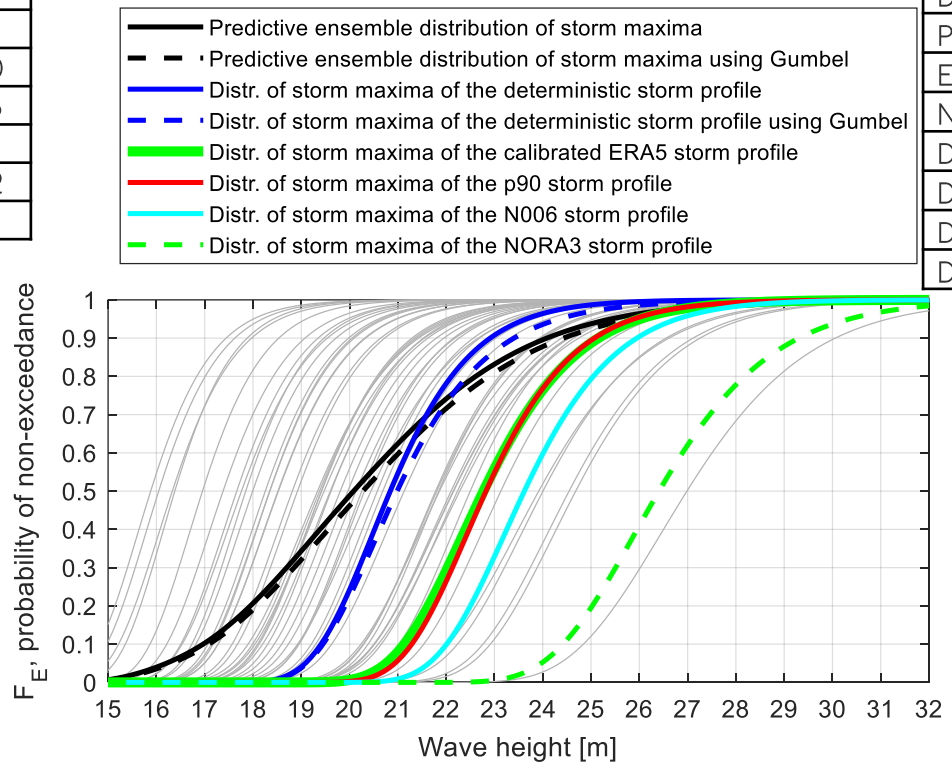
$$F_Y(y) = \frac{1}{k_0}\sum_k F_{Y|k}(y|\mathrm{k})$$

Comparing the models from 30-01 12:00 – 02-02-2024 12:00 for forecast issued 29-01-2024 12:00

Hs [m]	
ERA5 calibrated	12.9
Deterministic	11.5
Ensemble P90	12.7
N006	13.0
NORA3	15.3
Delta Determ.	-1.4
Delta Ens. P90	-0.2
Delta N006	0.1

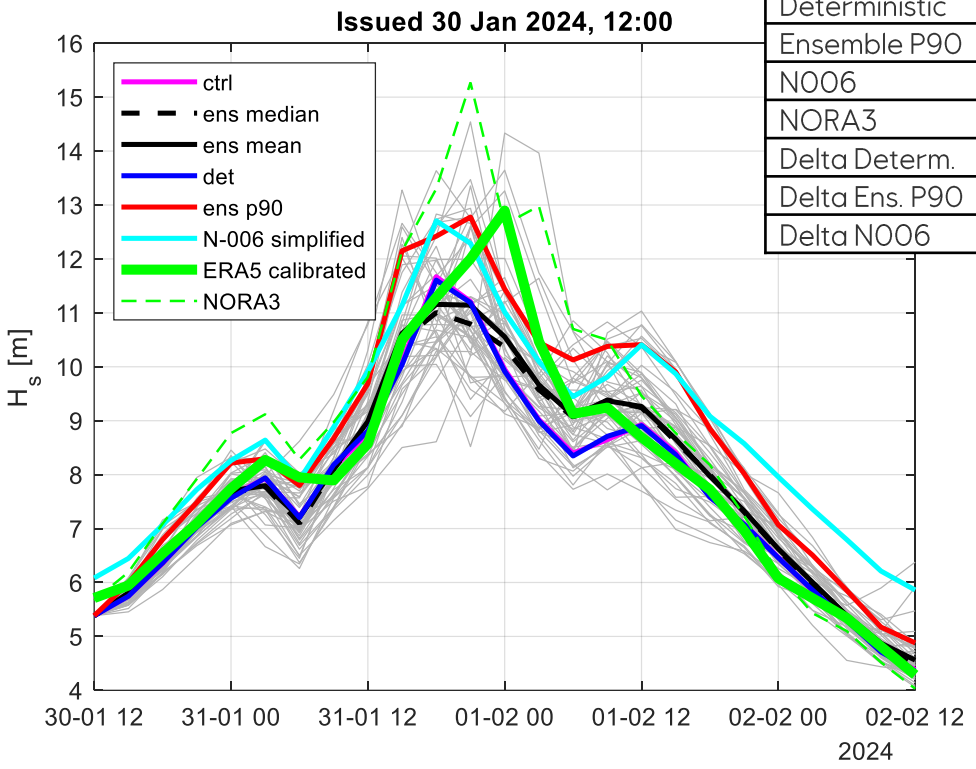


Wave height [m]	P90
ERA5 calibrated	25.2
Deterministic	22.9
Predictive	24.1
Ensemble P90	25.1
N006	25.9
Delta Determ.	-2.2
Delta Pred.	-1.1
Delta Ens. P90	-0.1
Delta N006	0.7

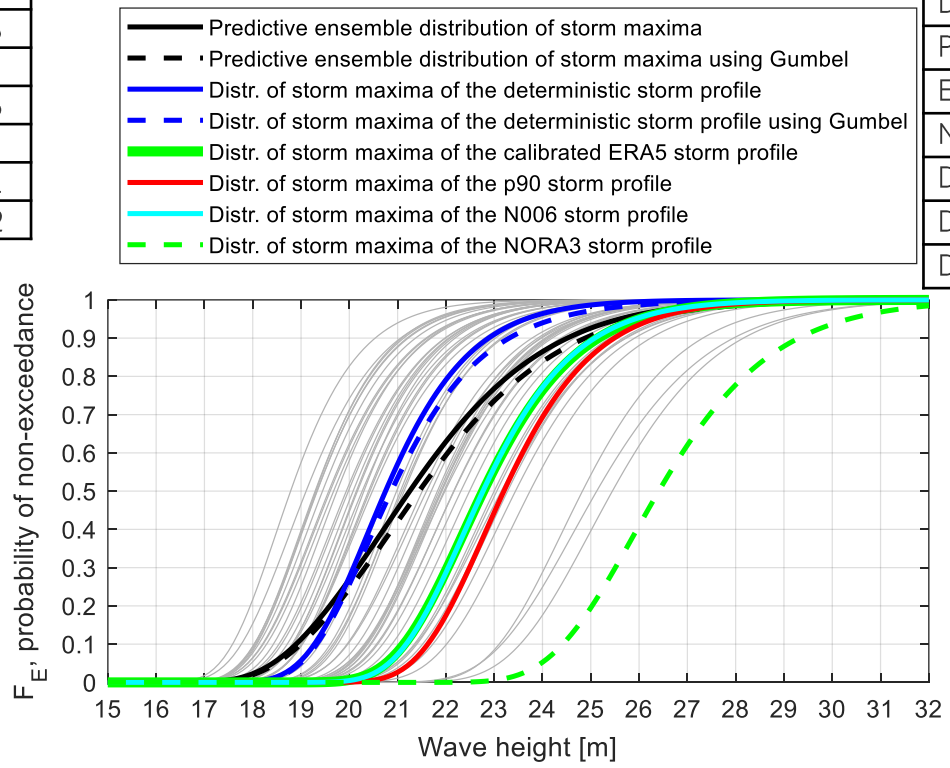


Comparing the models for forecast from 30-01 12:00 – 02-02-2024 12:00 for forecast issued 30-01 12:00

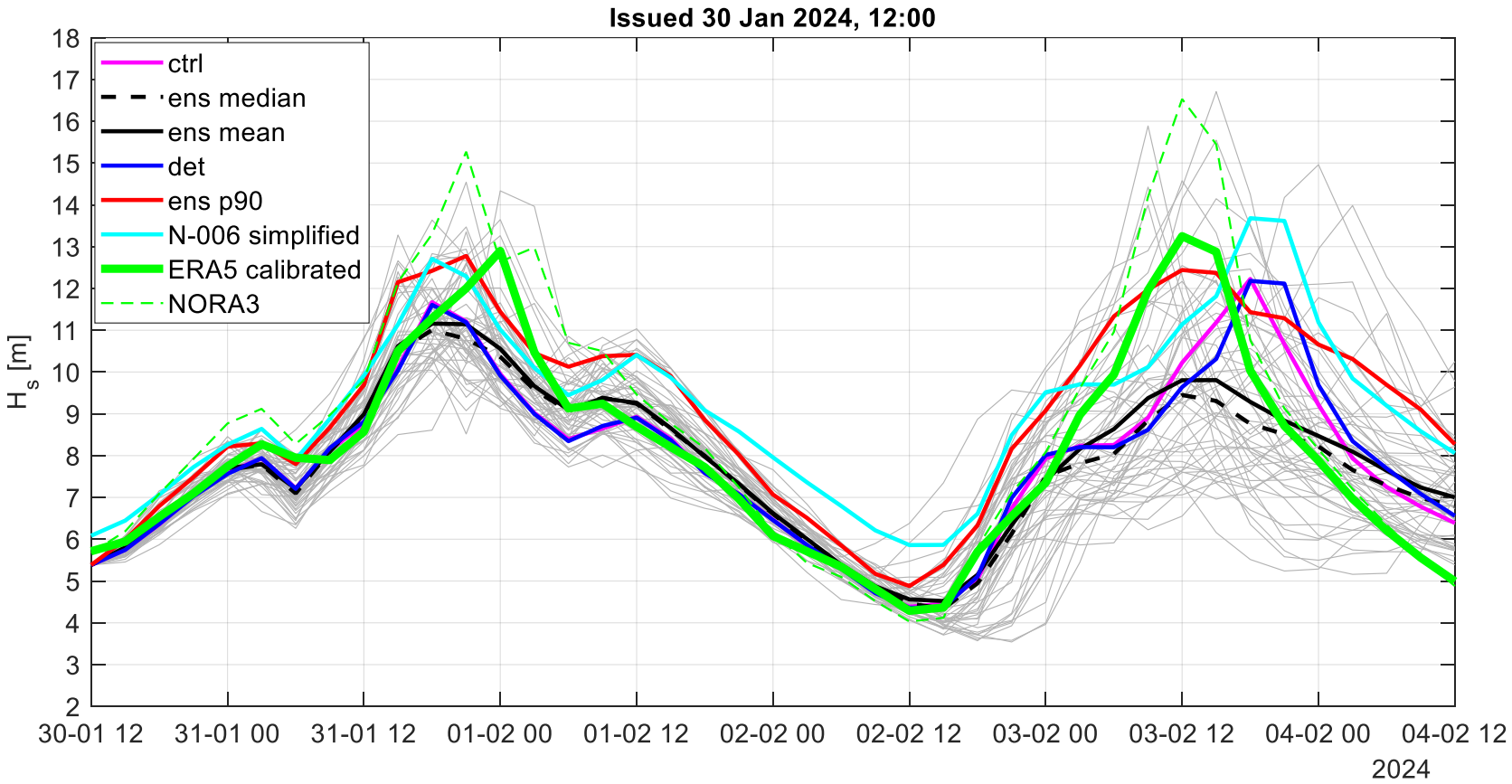
Hs [m]	
ERA5 calibrated	12.9
Deterministic	11.6
Ensemble P90	12.8
N006	12.7
NORA3	15.3
Delta Determ.	-1.3
Delta Ens. P90	-0.1
Delta N006	-0.2



Wave height [m]	p90
ERA5 calibrated	25.2
Deterministic	22.9
Predictive	24.5
Ensemble P90	25.5
N006	25.1
Delta Determ.	-2.3
Delta Pred.	-0.6
Delta Ens. P90	0.3



Another storm after Ingunn, but very large uncertainty day 4 and 5 day



Summary

- The uncertainty in the Ingunn storm seems to be addressed by the methods presented herein.
- The simplified approaches that only consider the uncertainty in the maximum sea state, in combination with the expected wave period, cannot be applied for responses where the sea state steepness is important.
- The most versatile approach is to consider all relevant parameters at each time step for every ensemble member. This allows for the estimation of the predictive distribution of the maximum response over the storm profiles described by the ensemble members, and can further be compared against the distribution of the maximum response in the storm using the deterministic forecast.
- The relative uncertainty can be assessed by comparing the predictive distribution and the distribution of the response using the mean (or median) storm profile.

Acknowledgment

- Øistein Hagen, DNV, is acknowledged for discussions in connection with the preparation of this presentation.

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