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Analysis of the icing conditions for offshore wind power in Norwegian waters

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Winterwind 2011, Umeå

Background

- NVE (Norwegian Water Resource and Energy Directorate) have established focus areas for offshore development wind power in Norway (Havvind, 2010)

- 15 focus areas suggested.

- focus areas suggested based on a large number of criteria, also climatic considerations and icing.

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In-cloud icing

- Calculation of icing at different coastal locations based on cloud height observations

number of hours of icing per year at 300m and 400m height

Flyplass	*300m*	*400 m*
Røst	44	160
Andøya	72	222
Hasvik	36	162
Berlevåg	46	160
Vardø	57	164

- Icing from supercooled droplets will ba a minimal problem for offshore turbines with 100m hubheight

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Sea spray

- Strong winds generate sea spray.
- In combination with low temperatures, icing from sea spray is known to be challenging for vessels

A dangerous coating of ice on the NOAA Ship Miller Freeman in the Bering Sea, Alaska. Such icing can affect a ship's stability and cause capsizing. Photo from the NOAA Library Ship Collection. Photo courtesy of NOAA NMAO Pacific Marine Center

The forward bulkhead of the Research Vessel Knorr during a scientific cruise in the Labrador Sea in late winter 1997. Photographed by George Tupper. From Pickart (1997) in Oceanus Magazine.

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Sea spray icing

- The amount of sea spray is related to the wind speed near the water surface.
- In combination with low temperatures sea spray will freeze.
- Simple algorithm used in forcasting of sea spray icing for offshore vessels (Overland, 1990):

$$PPR = \frac{V_a (T_f - T_a)}{1 + 0.3(T_w - T_f)}$$

PPR = Icing Predictor

Va = Wind Speed (m s^{-1})

Tf = Freezing point of seawater (usually -1.7 °C or -1.8 °C)

Ta = Air Temperature (°C)

Tw = Sea Temperature (°C)

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Icing Predictor

PPR	<0	0-22.4	22.4-53.3	53.3-83.0	>83.0
Icing Class	None	Light	Moderate	Heavy	Extreme
Icing Rates (cm/hour) (inches/hour)	0	<0.7 <0.3	0.7-2.0 0.3-0.8	2.0-4.0 0.8-1.6	>4.0 >1.6

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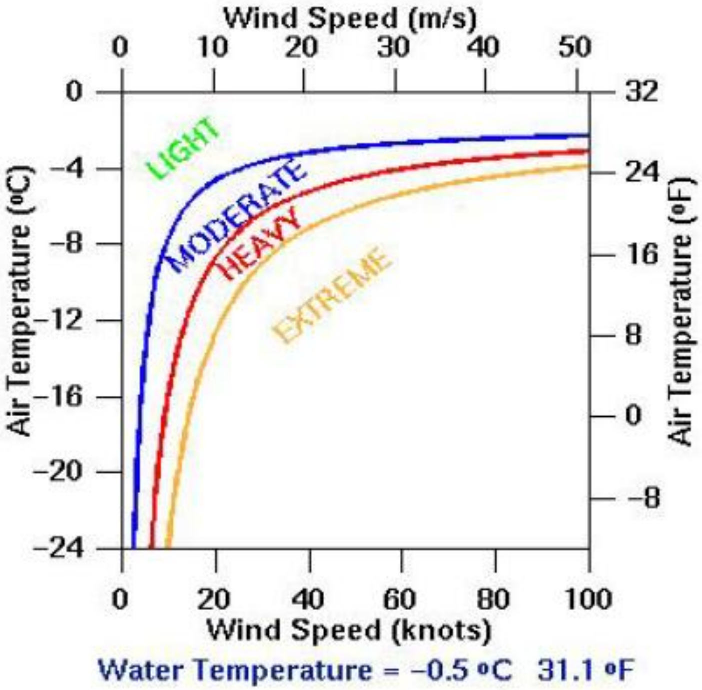

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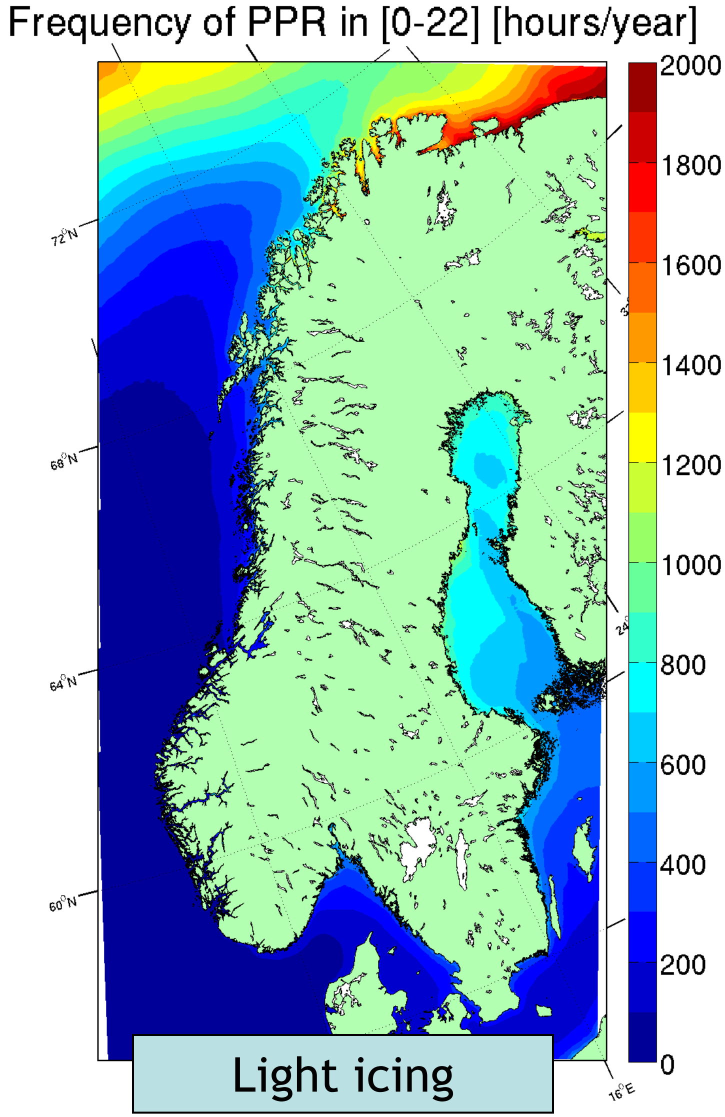
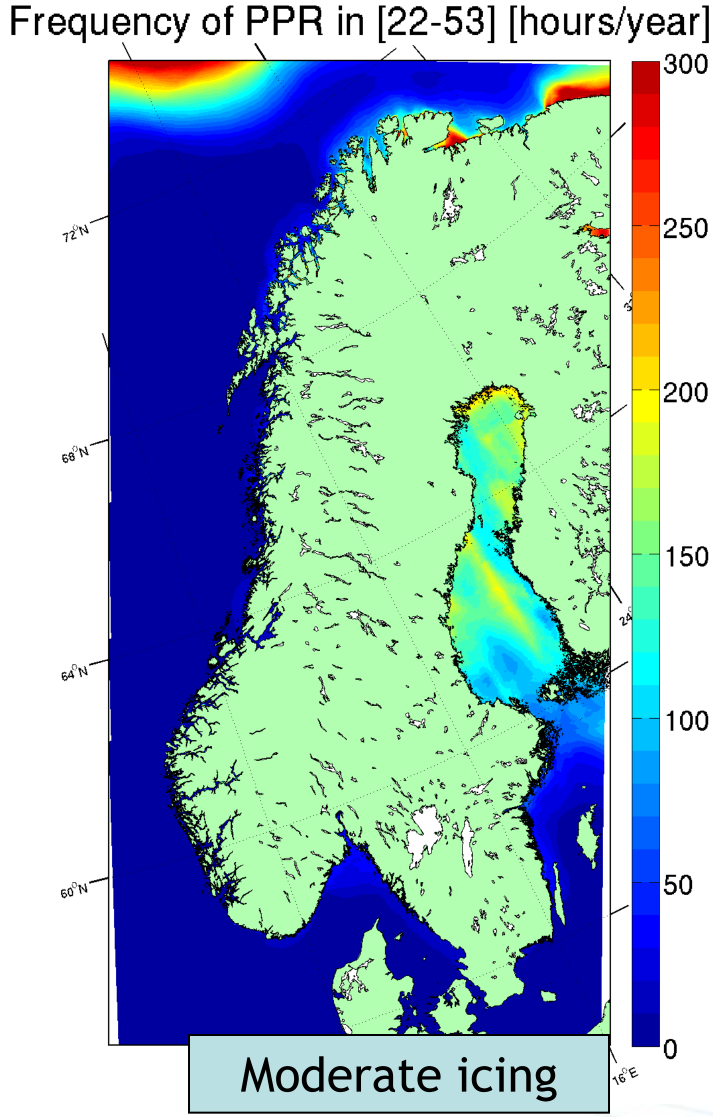
Frequency of sea spray icing





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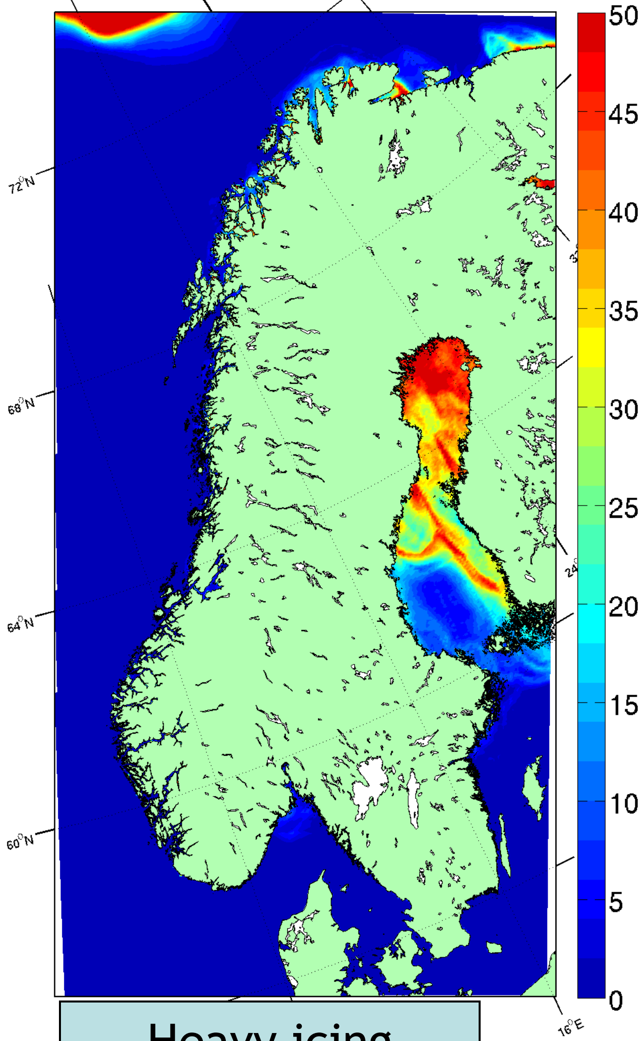
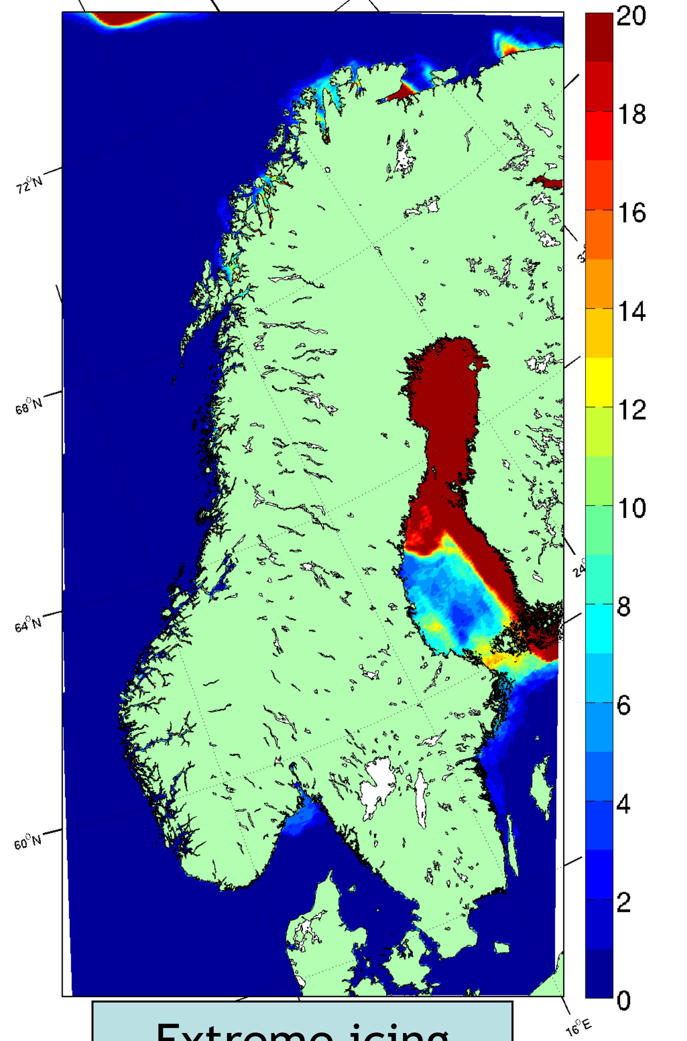
Frequency of sea spray icing

Frequency of PPR in [53-83] [hours/year]



Heavy icing

Frequency of PPR in [83-1000] [hours/year]



Extreme icing

Frequency of sea spray icing

- We will experience cases with sea spray icing in the northern part of the Norwegian coastline.
- But will this be a problem for wind power operations?
- How far up does the sea spray reach?

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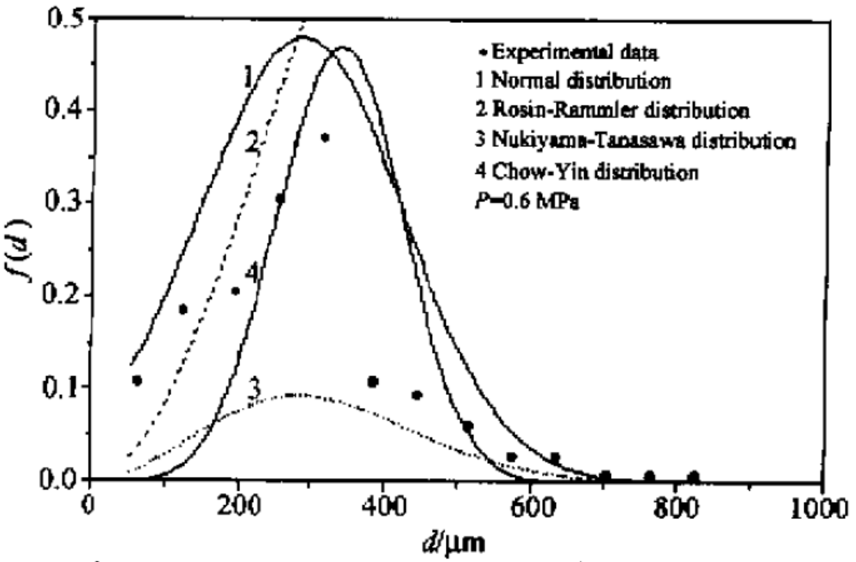
Vertical extent of sea spray

- typical median droplet size:
  - sea-spray: 200-300µm
  - cloud droplets: 10-20µm

Sea spray consists of large droplets that does not reach very high.

Over a free water surface the number of sea-spray droplets over 20m height will be minimal



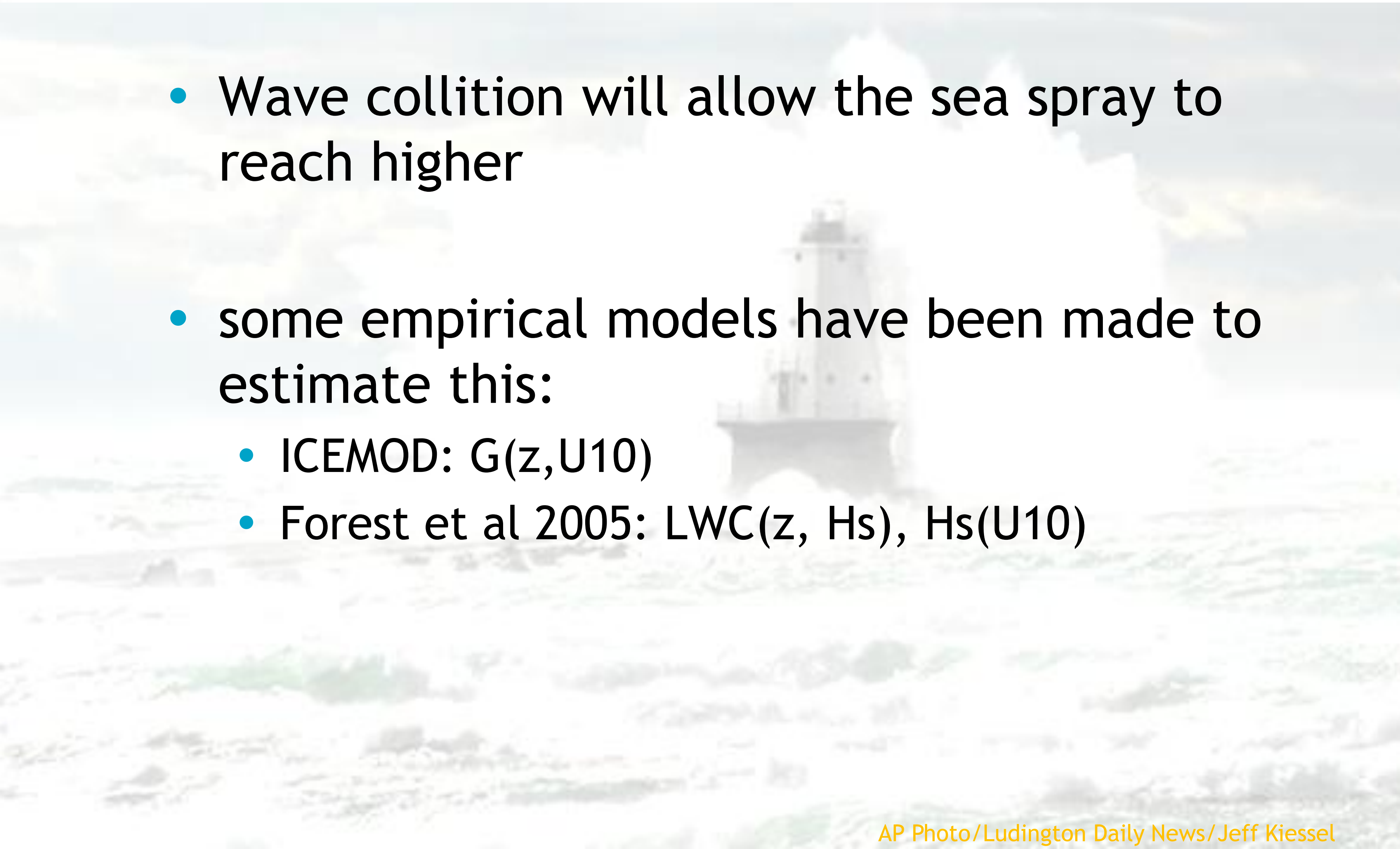
Figur 6-3 Dråpefordeling fra et eksperiment. Fra Wang Xishi et.al (2002).

Sea spray, wave collisions

AP Photo/Ludington Daily News/Jeff Kiessel

Sea spray, wave collisions

- Wave collition will allow the sea spray to reach higher
- some empirical models have been made to estimate this:
  - ICEMOD: G(z,U10)
  - Forest et al 2005: LWC(z, Hs), Hs(U10)



AP Photo/Ludington Daily News/Jeff Kiessel

F_L_G

- Forest et al. (2005):

$$LWC(z) = 1.35 H_S^2 eksp(-0.53z)$$

Hs = Hs(U10), significant waveheight

$U_{10} = $ 10 *min average wind speed at* 10 *m height*

ICEMOD

Horjen and Vefsnmo (1986), Jørgensen et al. (1986):

- G(z) - sea spray flux [kg/m²s]:

$$\overline{G}(z) = M_0 U_{10} \{1-(1-10^{-2}U_{10})e^{-(\frac{4z'+2}{9})^2}\} e^{-kU_{10}{}^{2/3}(z')^2}$$

$$M_0 = 2\pi 10^{-4} kg/m^3$$
$$k = 5.88 \cdot 10^{-2} (s/m)^{2/3}$$
$$z' = (2z/H_s) - 1$$
$$U_{10} = \ 10\ min\ average\ wind\ speed\ at\ 10\ m\ height$$

Hs = Hs(U10), significant waveheight

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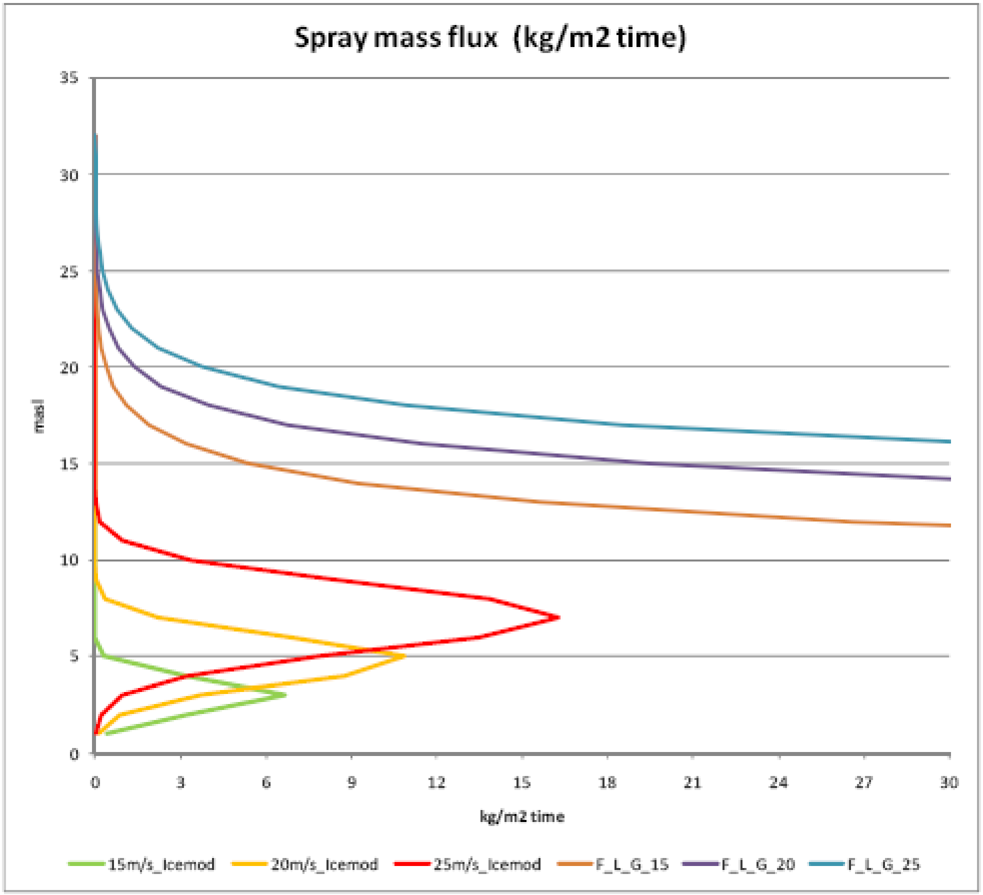
Vertical extent of sea spray



Limit for icing > 10g/hr:

v	*ICEMOD*	*F_L_G*
15 m/s	7 m	28 m
20 m/s	10 m	30 m
25 m/s	14 m	33 m

small values above 30 m

Summary

- Icing from low clouds will be negligable for the offshore wind farms
- Icing on the rotor blades will also be minimal above 30 m height
- icing on the turbine tower and the access to the turbines is probably the largest challenge considering offshore icing in Norwegian waters.

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