Using Metar Data to Calculate In-cloud Icing on a Mountain Site Near by the Airport

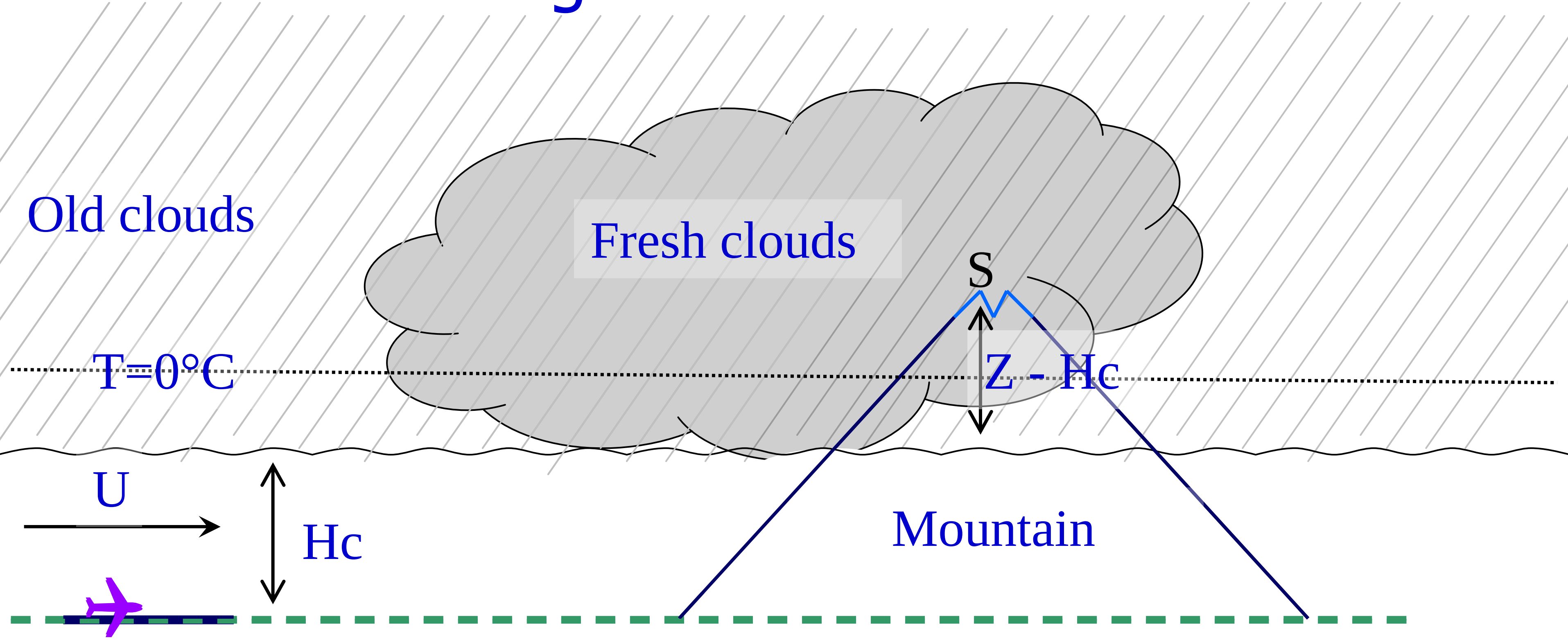
Knut Harstveit

Norwegian Meteorological Institute

Norwegian Meteorological Institute
met.no

In-cloud Icing – adiabatic modeling of liquid water content

Illustration of cloudy, maritime air entering a mountain area, forming fresh clouds at the lifting side of the mountain



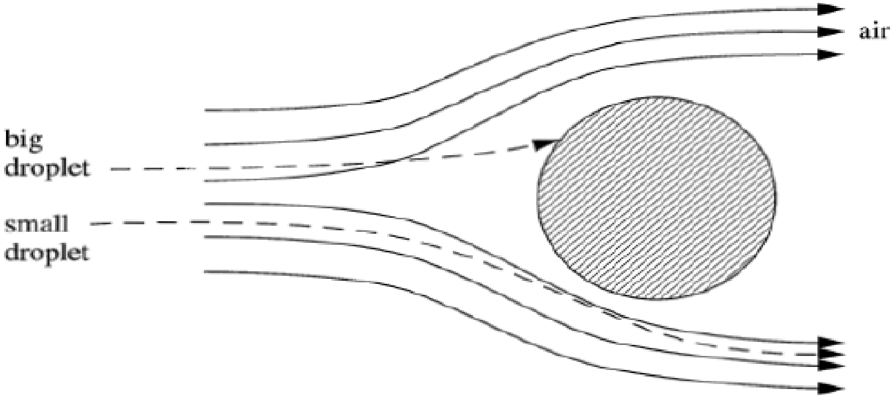
In-cloud Icing – Theoretical modeling of icing on a reference cylinder (vertical rotating cylinder of 3 cm diameter)

$$\frac{dM}{dt} = \alpha_1\alpha_2\alpha_3 \cdot w \cdot A \cdot V$$

- M - Ice accretion
- w - Water content
- A - Object cross section
- V - Wind speed
- α_1 - Collision coefficient
- α_2 - Sticking coefficient (=1)
- α_3 - Accretion coefficient

In-cloud Icing – Coefficients of efficiency

$$\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 \cdot w \cdot A \cdot V$$



$\alpha_1 \approx f(V, d, A)$; $0 < \alpha_1 \leq 1.0$

$\alpha_2 \approx 1.0$

$\alpha_3 \approx f(V, d, w, T_a, (e_a), A, \alpha_1)$; $0 < \alpha_3 \leq 1.0$

where T_a is air temperature, e_a vapour pressure, d droplet diameter.

In-cloud Icing – Data requirement

V - wind speed

T_a - air temperature

e_a - vapour pressure

w - liquid water content

d - droplet diameter

Icing modelling - Wind speed
(if on-site data during icing is missing)

$$V(H) = V(10)\left(\frac{H}{10}\right)^{n}$$

Site level above airport

Airport value

The exponent n is climatologically determined by using site data, or closest radio sonde station

Icing modelling – Temperature and water vapour

Air temperature

(if missing onsite)

$$T_a(z) = T_0 + k_1 \cdot z \qquad ; z \leq H_c$$
$$T_a(z) = T_0 + k_1 \cdot H_c + k_2 \cdot (z - H_c) \qquad ; z > H_c$$

k_1 = -0.0085 °C m^{-1} and k_2 = -0.005 °C m^{-1} (from mountain stations and airports near by)

Water vapour Saturation curve

$$e_{saturated} = 6.107 \cdot 10^{\frac{7.5 t_a}{237 + t_a}} ; t_a = T_a - 273$$

$$e_a \approx e_{saturated}$$

In-cloud Icing – liquid water content - adiabatic modeling

Liquid Water Content, w may be modeled from high quality cloud base data (for instance METAR – data from airports)

$$\boxed{w \approx a \cdot b \cdot \delta(z\text{-}Hc)}$$

- z - height above airport station
- Hc - cloud base
- a ≤ 1.0 - factor of droplet reduction
- b ≤ 1.0 - droplet ground deposit factor
- δ - adiabatic cloud water gradient

$$\boxed{\delta \approx 1.56(1+0.034\theta_w)}$$

$\theta_W \approx \theta_W (T_a, Hc)$ is the potential wetbulp temperature

In-cloud Icing – liquid water content adiabatic modeling

- Visibility measurements from a hill (Gamlemsveten)
- Cloud base observations at a near-by airport (Vigra)
- Optical theory (Behrs law, Mie's theory)
- Assuming narrow droplet spectrum (fresh clouds)

=>The average value of Nc $\approx$ 79 cm^{-3} (through the winter season 2003/04)

=>Simple geometry then give the average diameter d for a given amount, w

Nc $\approx$ 79 cm^{-3} may be assumed typical for maritime air in the North Sea and Norwegian Sea Region

In-cloud Icing – liquid water content adiabatic modeling

The model is suitable for exposed mountain sites where fresh clouds is formed by lifting of humid air above the mountain, if representative data may be found

Ice melting - ice shedding

Ice melting, energy balance method

$$Q_M \approx Q_H + Q_E + Q_R$$

where

Q_H is the sensible heat flux,

Q_E is the latent heat flux

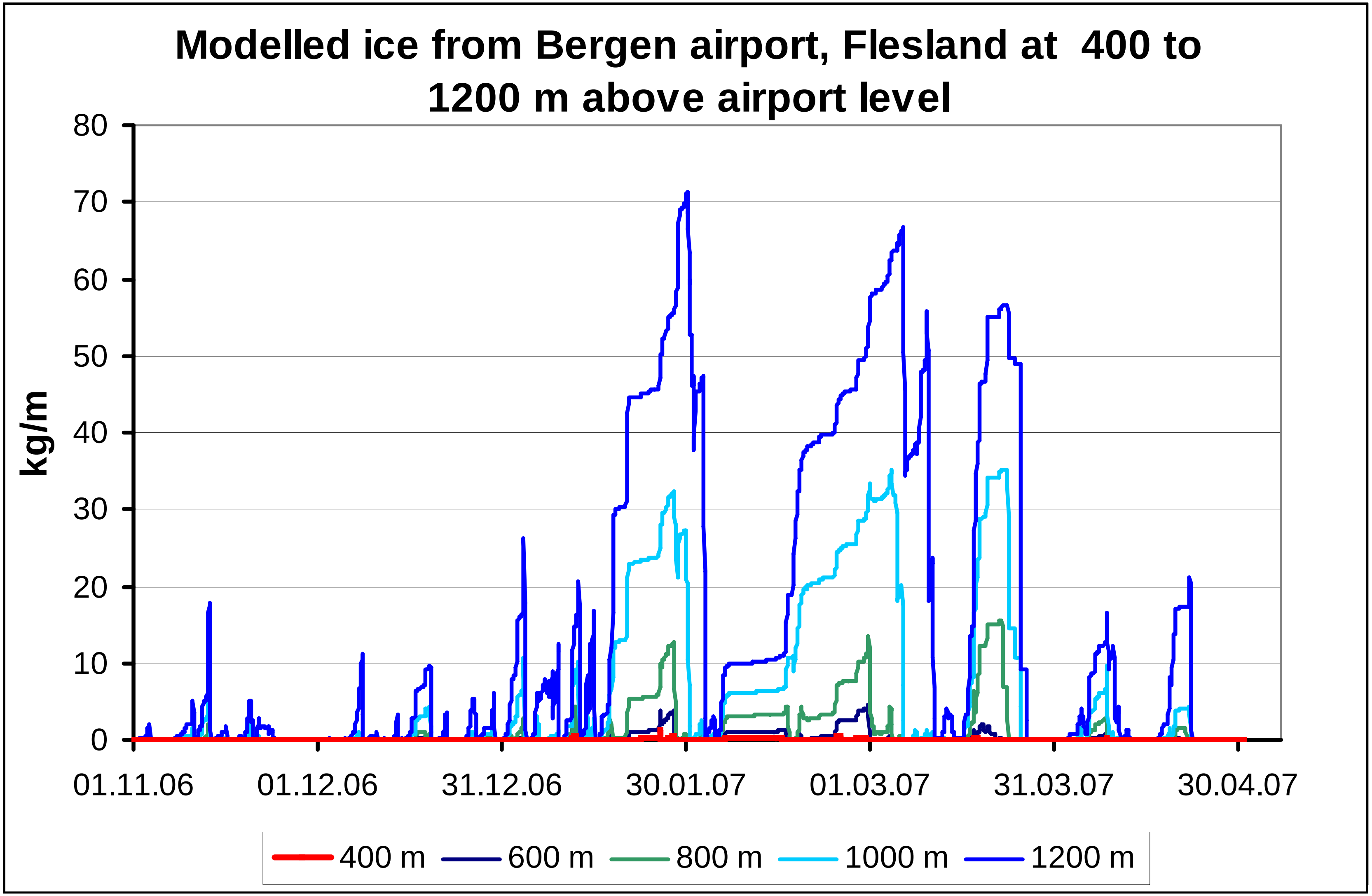
Q_R is the radiation heat flux

modeled as f (T_a, e_a, V)

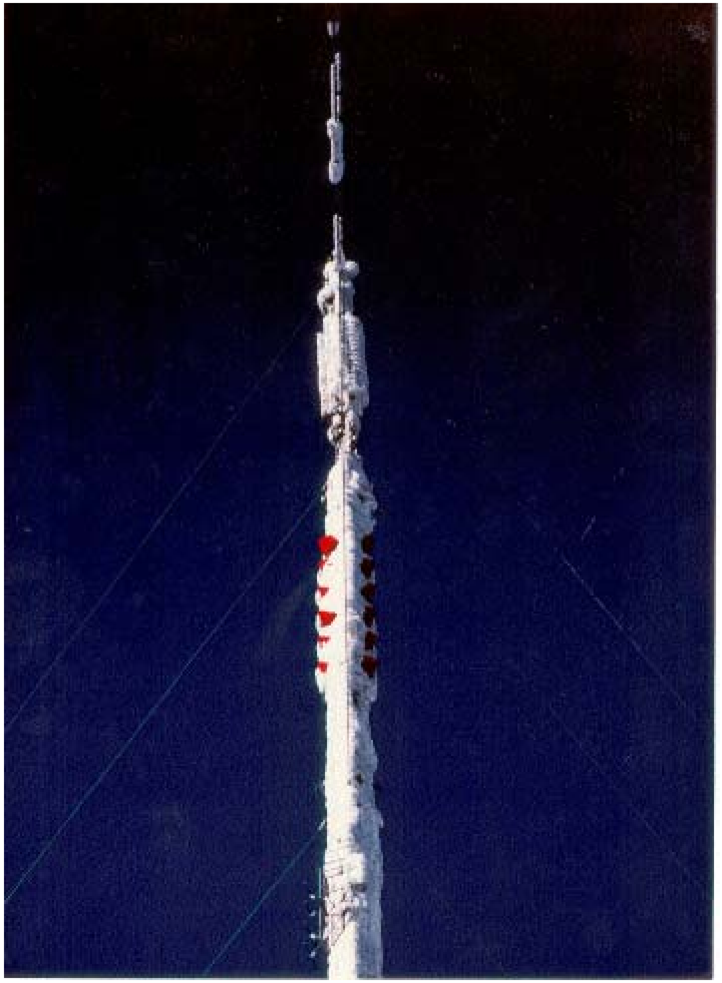
A shedding factor, S_{sh} is required to model the unloading. Data from the site Brosviksåta indicate that

$$S_{sh} \approx 5$$

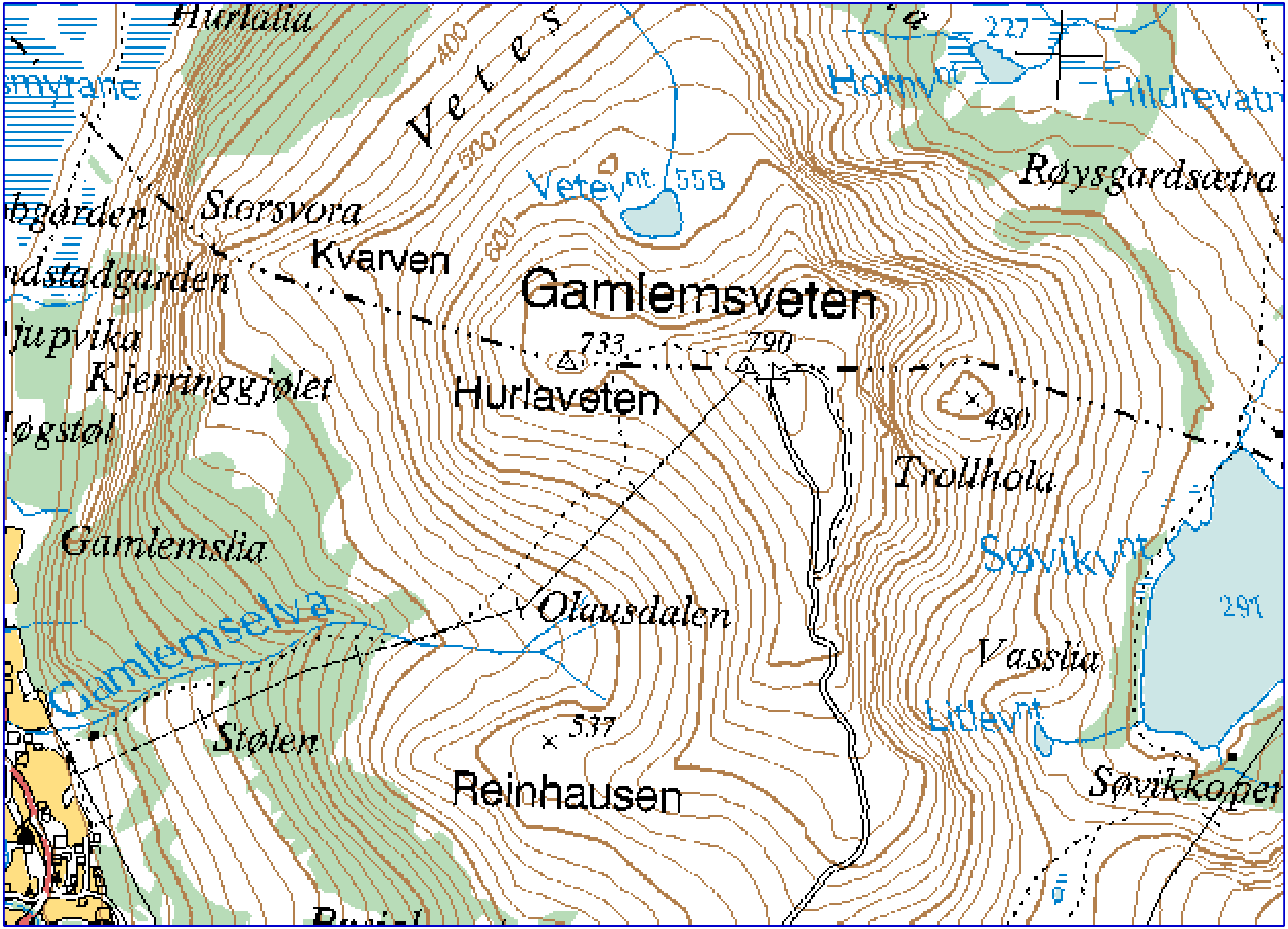
In-cloud icing at an exposed mountain site as function of the mountain height during the winter 2006/07



In-cloud Icing on a Telecommunication mast, 767 masl, Norway, February 1988



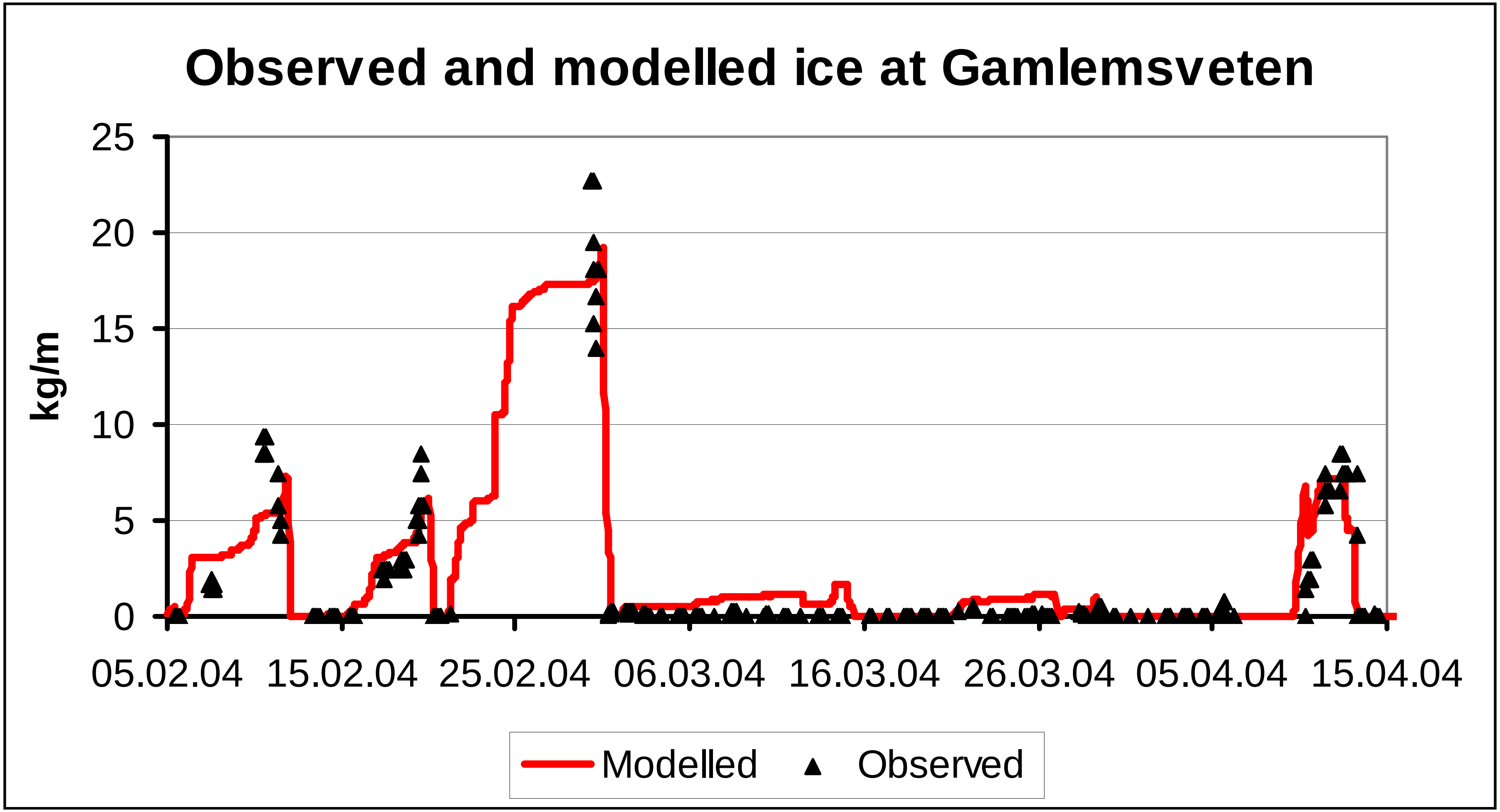
Site location - Gamlemsveten



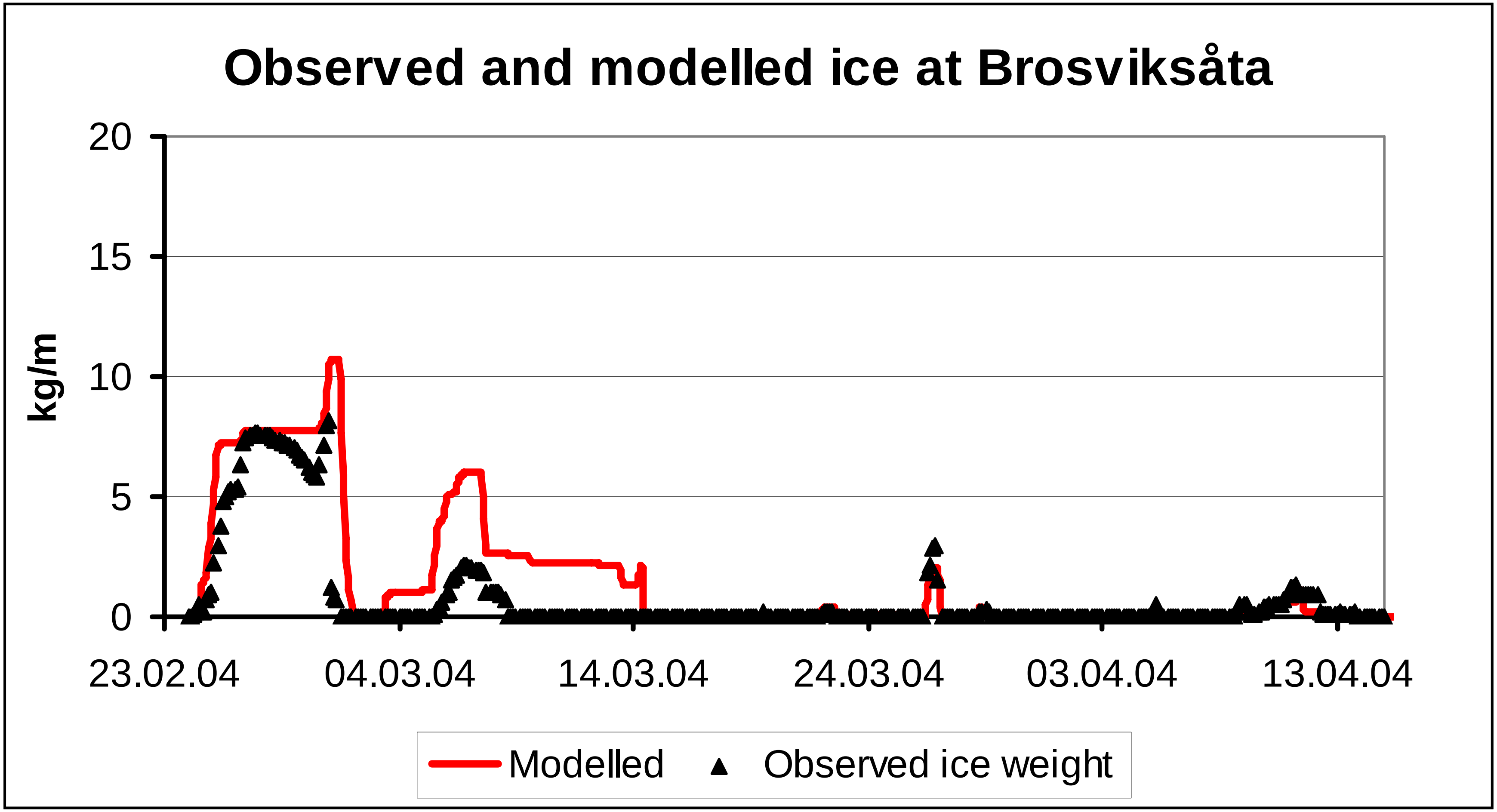
View of Gamlemsveten from SW

In-cloud Icing on an observation mast, 790 masl, Gamlemsveten, 28. – 29. February 2004

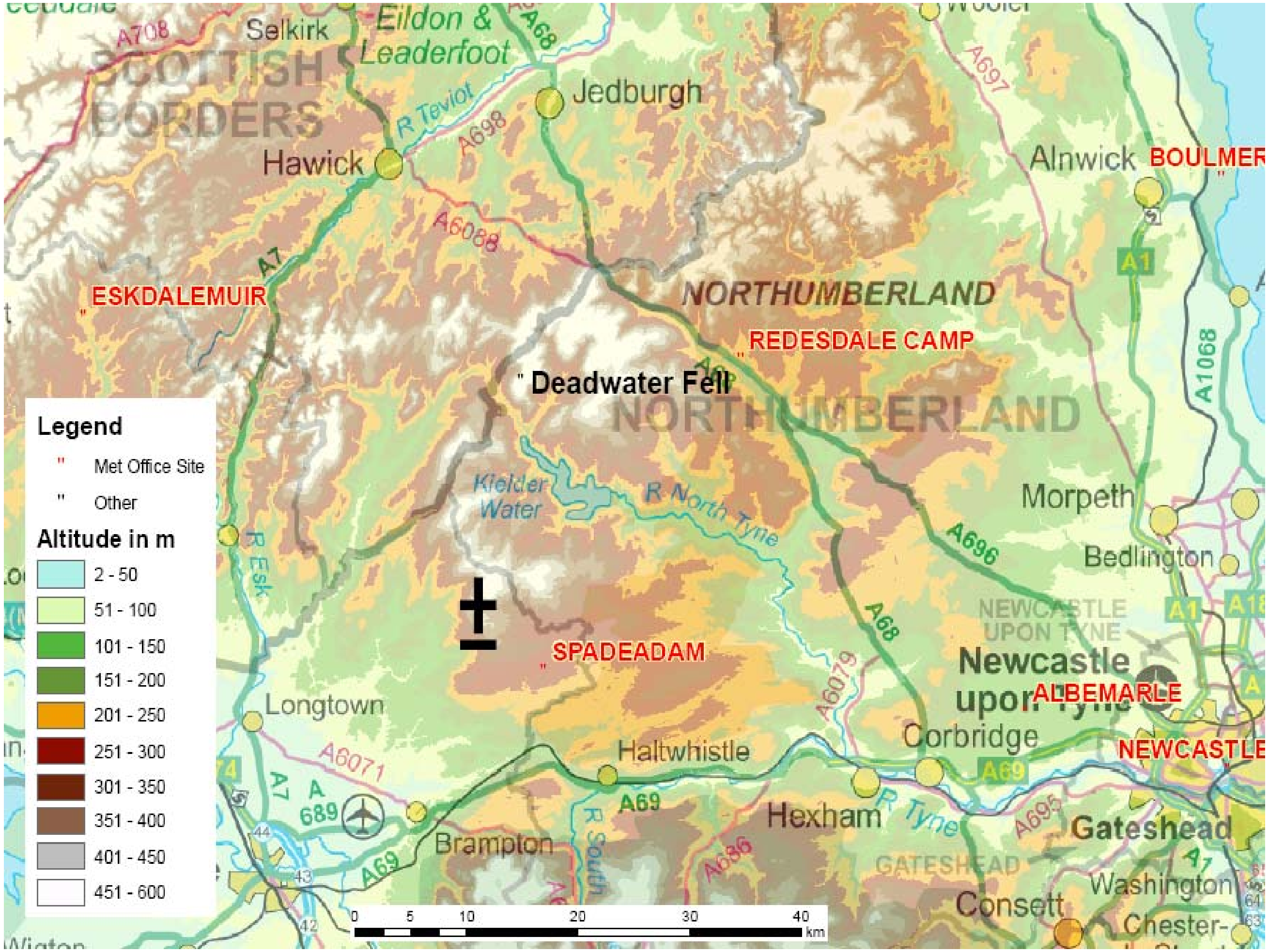
In-cloud icing at Gamlemsveten, 790 masl (768 m above airport level)



In-cloud icing at Bråsviksåta, 723 masl (673 m above airport level)



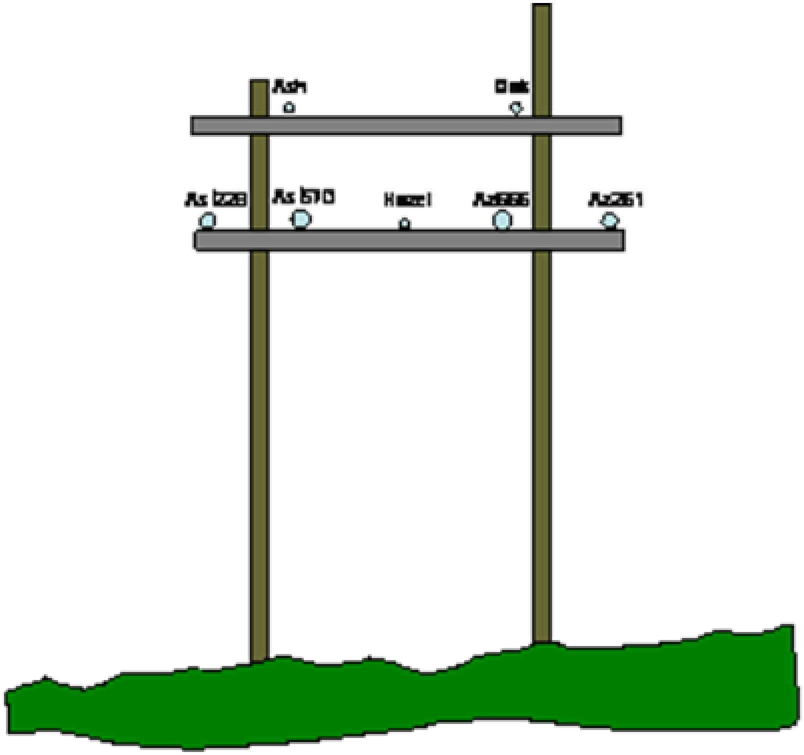
Deadwater fell, 580 masl, United Kingdom



The test site at Deadwater fell

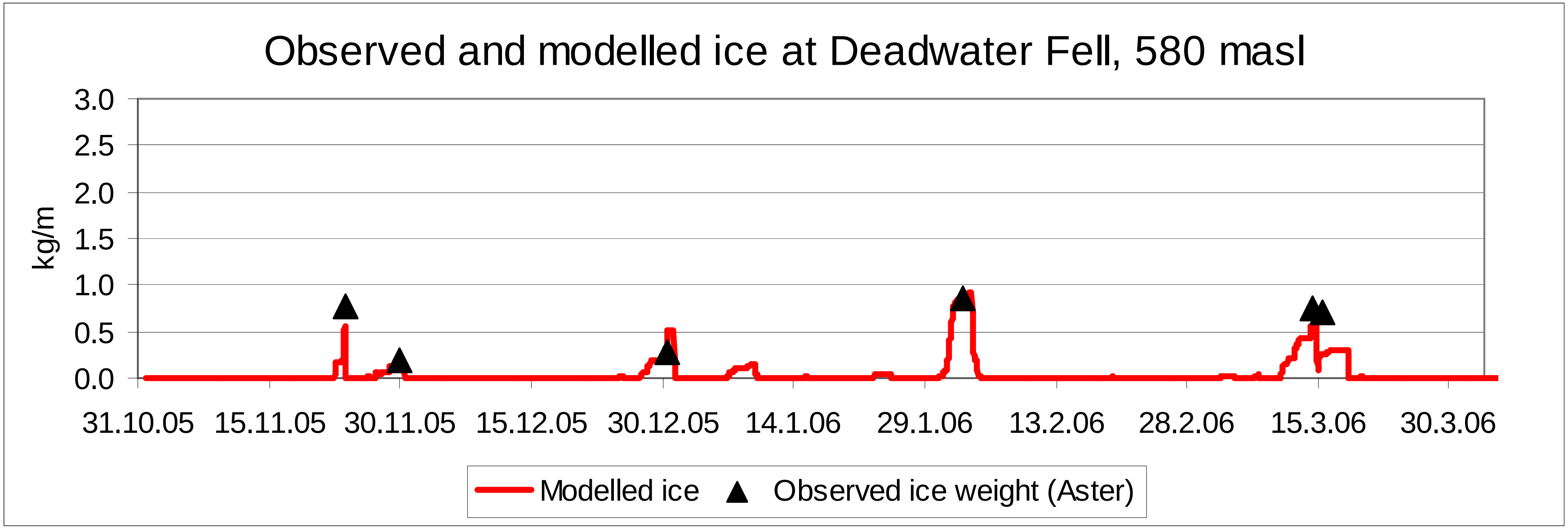
From Brian Wareing)

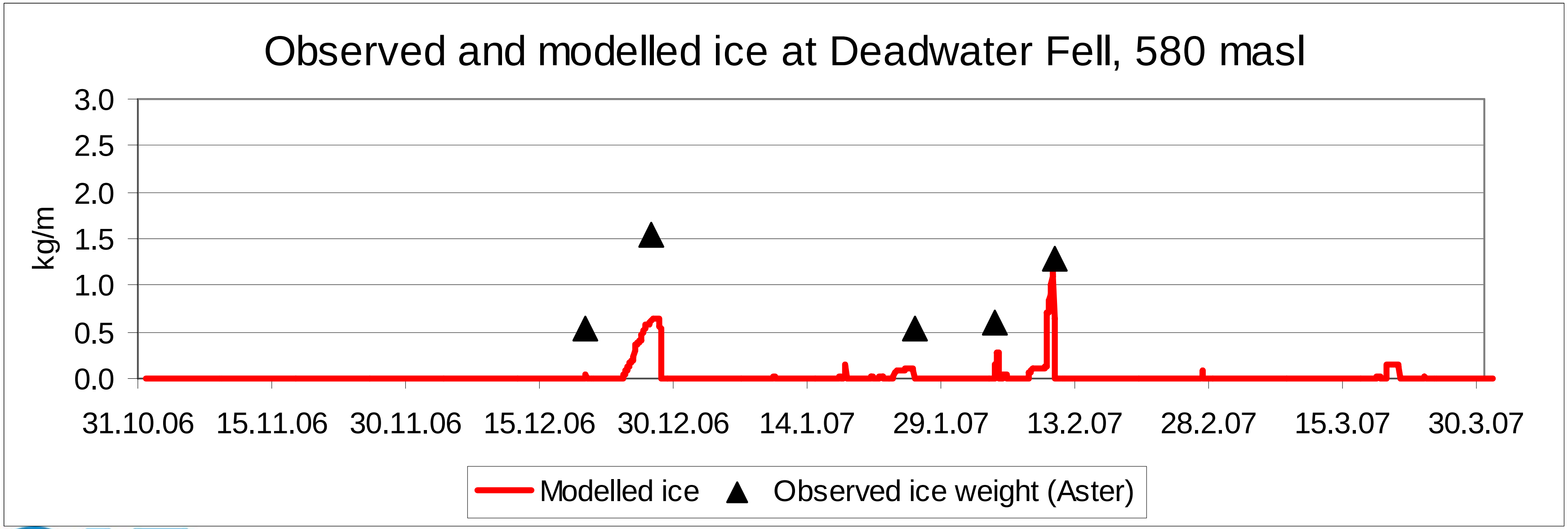
The test site at Deadwater fell, United Kingdom (from Brian Wareing)



From Brian Wareing)

In-cloud icing at Deadwater fell, 580 masl (435 m above cloud base station)





In-cloud Icing - Method of Ahti & Makkonen

$$\boxed{\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 \cdot w \cdot A \cdot V}$$

a_1 increases with V

a_1 decreases with A

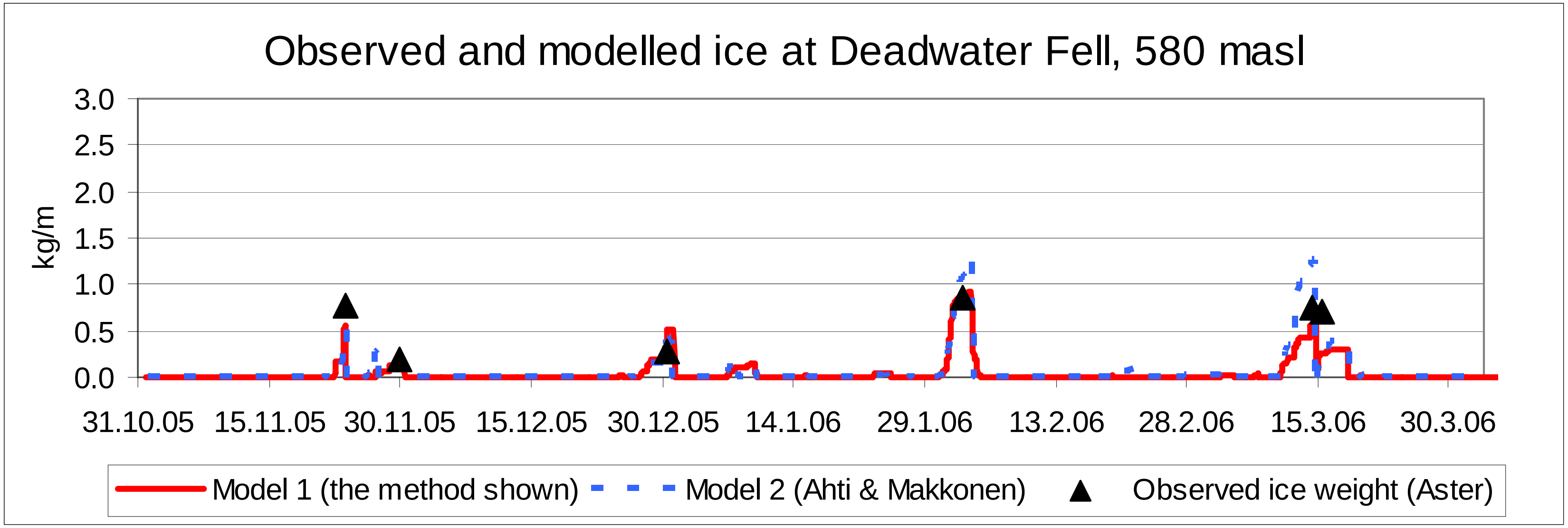
Variations in a_2 and a_3 only slightly contributions

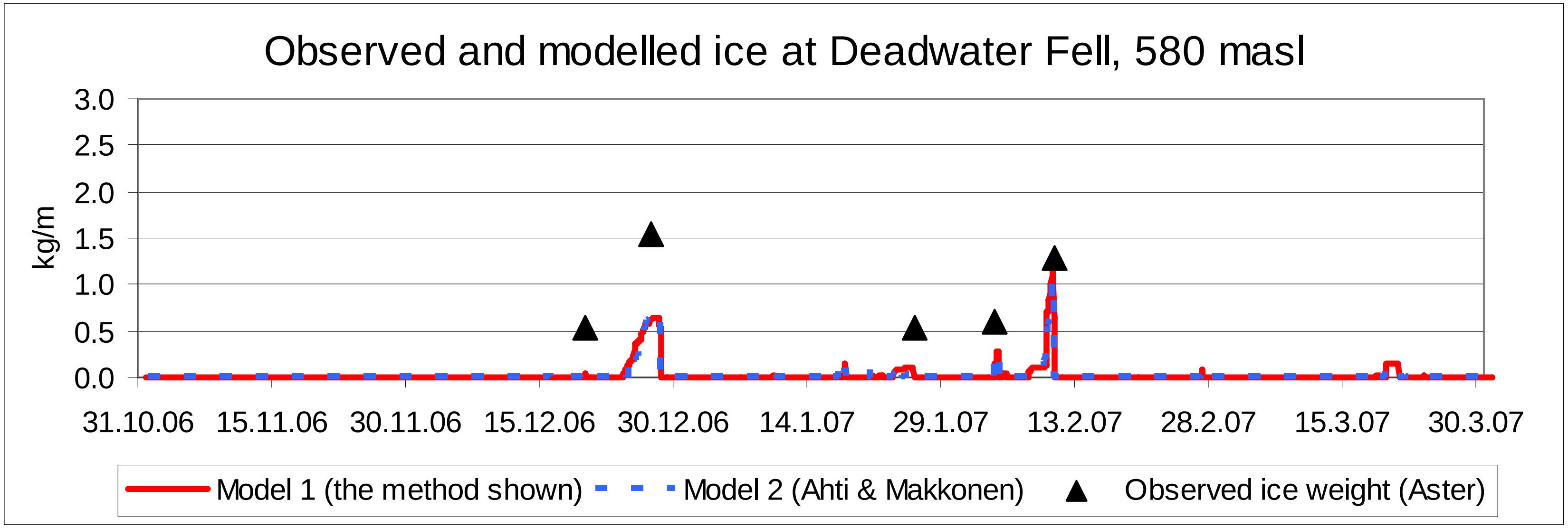
If variations of w and N_C are small compared to V

=>

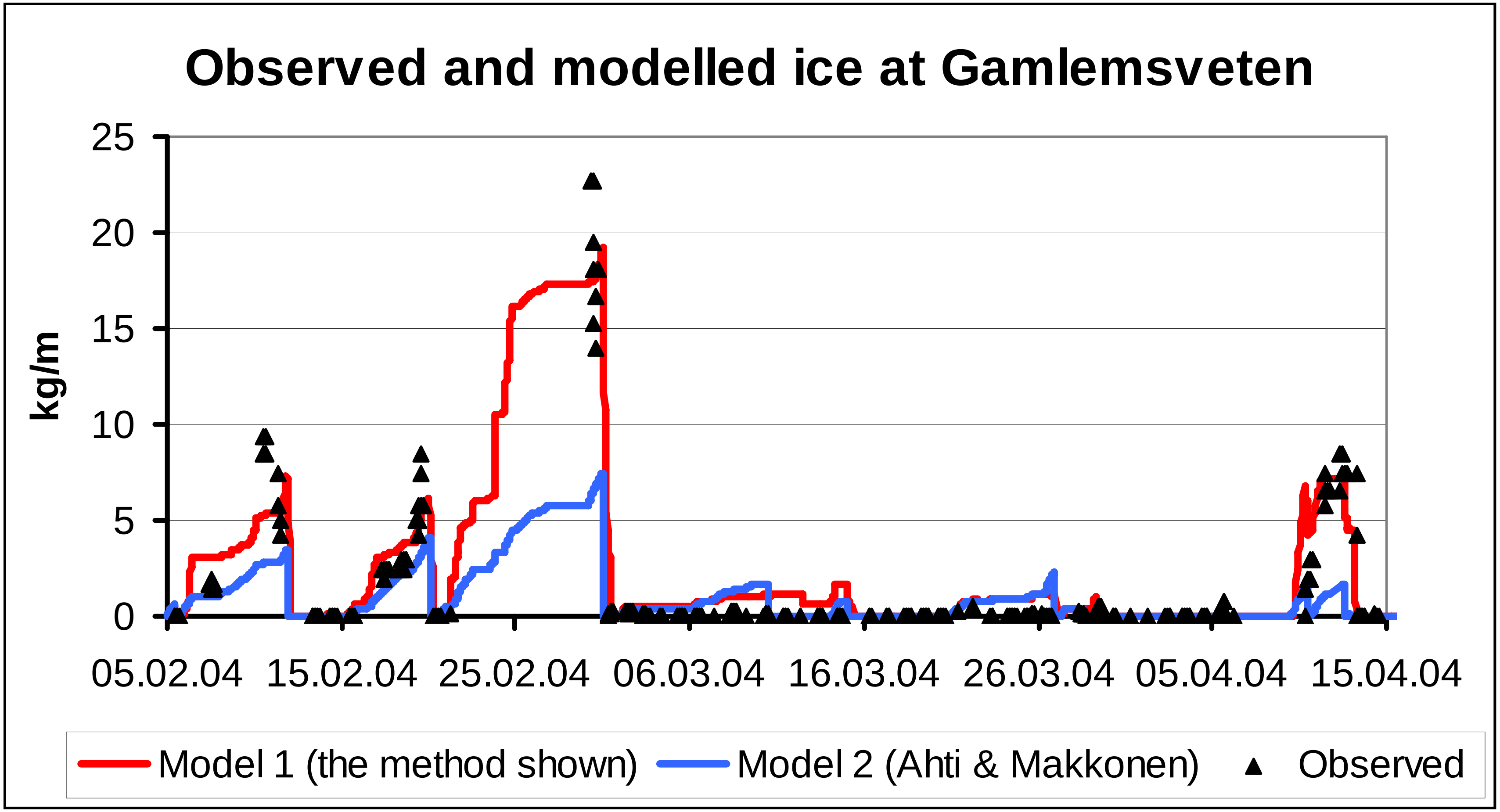
$$\boxed{dM \approx const \cdot V \cdot dt}$$

In-cloud icing at Deadwater fell, 580 masl (435 m above cloud base station)


Observed and modelled ice at Deadwater Fell, 580 masl


Observed and modelled ice at Deadwater Fell, 580 masl

In-cloud icing at Gamlemsveten, 790 masl (768 m above airport level)



In-cloud Icing - Method of Ahti & Makkonen

A systematic difference between the two methods:

- A&M smooth out variations in w, and has no further cloud water increase above cloud base

$$\boxed{dM \approx const_1 \cdot w \cdot V \cdot dt \approx const_2 \cdot V \cdot dt}$$

- the adiabatic method use the equation

$$\boxed{w \approx a \cdot b \cdot \delta (z - H_C)}$$

which has a rapid increase above cloud base

CONCLUSION

At exposed sites in maritime regions, the adiabatic cloud water model may be used to calculate in-cloud icing. The model as well as ice observations suggest very strong height gradients

Input data may be taken from near-by airports. For representative cloud stations, there are very nice agreement between the modeled and the observed ice.

For more distant stations, climatic icing loads still can be modeled.