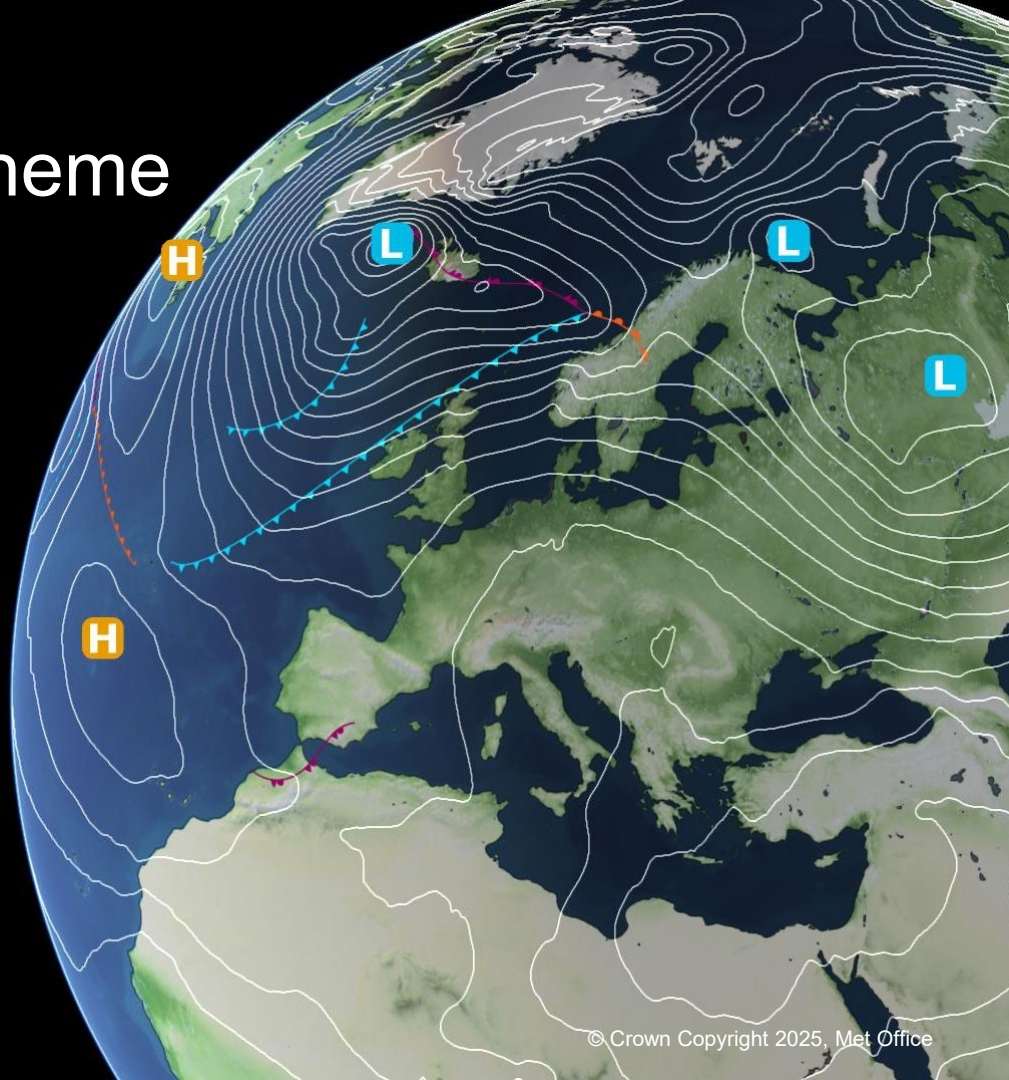


Developing the snow scheme in JULES for Arctic applications

JULES Science Meeting,
Leicester, September 2025

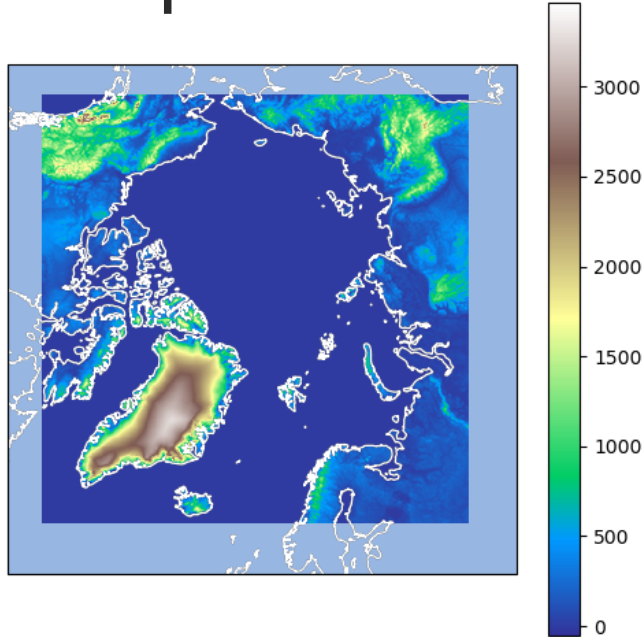
J. M. Edwards



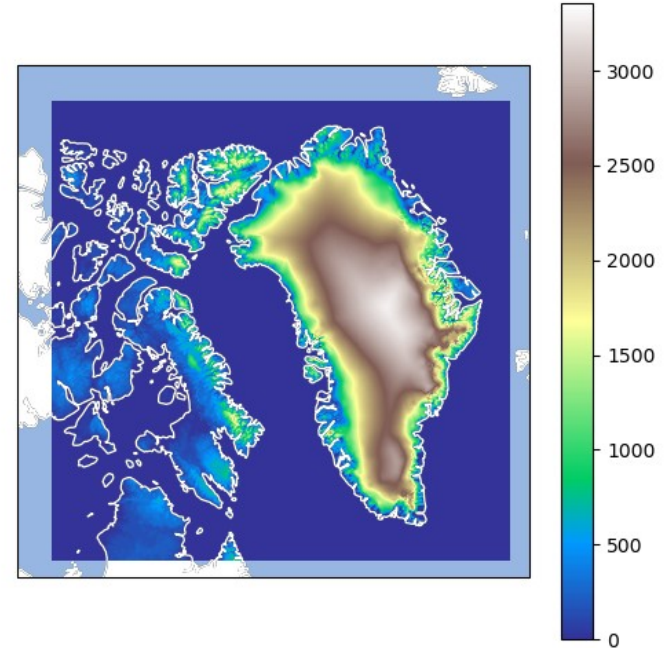
Background

- Because of continuing decreases in sea ice, there is growing interest in forecasting in the Arctic
- The Met Office is starting to explore options for improved forecasting in the Arctic
 - Convection-permitting model(s) in the Arctic?
 - A fully coupled (atmosphere – land – ocean – sea-ice – wave) model for the Arctic?
- We are moving from the UM to LFRic as the dynamical core
 - Cubed sphere rather than a lat-lon grid
- We have now defined the regional science configuration RAL3.3, including the double-moment CASIM microphysics scheme
- Whatever happens, we need to look at improved cryospheric physics

Current Experimental Domains with LFRic



Full Arctic: 8.33 km



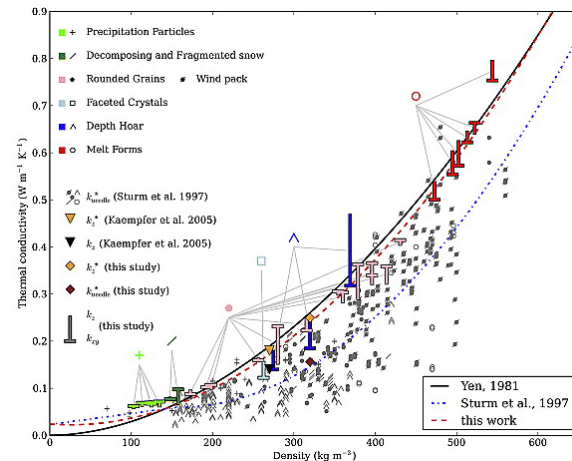
Greenland: 4.44 km

Fresh Snow Density from CASIM



Multilayer Snow in JULES

- Largely developed by Richard Essery (Best et al. 2011)
- Some enhancements for use in forecasting and climate models
- Operational for UK forecasting in 2017 and global forecasting in 2018 and used in CMIP7 simulations
- Multilayer scheme represents liquid and frozen water in the snowpack
- Currently we use up to 3 layers, 0.04, 0.12, 0.34 cm
- **Density is a key variable in the scheme**



Snow has a low heat capacity and its conductivity is a strong function of its density: e.g. Calonne et al. 2011

Physics affecting the density of lying snow

- Density generally increases as snowpack ages
 - Mechanical compaction
 - Equitemperature metamorphism
 - (Temperature-gradient metamorphism is not currently included)
- Initial density must be specified
 - Currently we used fixed values of 109 kgm^{-3} in the global model and 170 kgm^{-3} in regional model
 - A simple function of near-surface weather parameters?
 - Lower density in colder conditions
 - High wind speeds lead to compaction
 - **Prediction from microphysics?**
 - We need a double moment scheme to do this: first done in the Canadian model by Milbrandt et al. (2012)
 - RAL3.3 introduces the CASIM microphysics scheme (Field et al. 2023)

Microphysics schemes

- Water droplets and ice crystals come in a range of sizes
 - Bin microphysics: complex and expensive
 - Use a few moments of the size distribution
 - Single moment schemes: only mass mixing ratio – Wilson & Ballard (1999)
 - Double moment schemes: mass mixing ratio and number concentration – CASIM (Field et al. 2023)
- CASIM includes 5 hydrometeors: cloud droplets, rain drops, ice crystals, snow and graupel
 - Conversions between these species are parametrized

Mathematical formulation

- Size distributions of rain and snow can often be represented well as gamma distributions

$$\frac{dN}{dD} = n_0 D^\mu \exp(-\lambda D)$$

D is the maximum dimension of the particle.

- Definition of the gamma function

$$\Gamma(z) = \int_0^\infty t^{z-1} e^{-t} dt$$

- Moments of the size distribution

$$\mathcal{M}_q = \int_0^\infty D^q \frac{dN}{dD} dD = n_0 \frac{\Gamma(\mu + q + 1)}{\lambda^{\mu+q+1}}$$

- Properties of crystals often follow power laws:

$$\begin{aligned} m(D) &= cD^d \\ v(D) &= aD^b(\rho_0/\rho)^f \end{aligned}$$

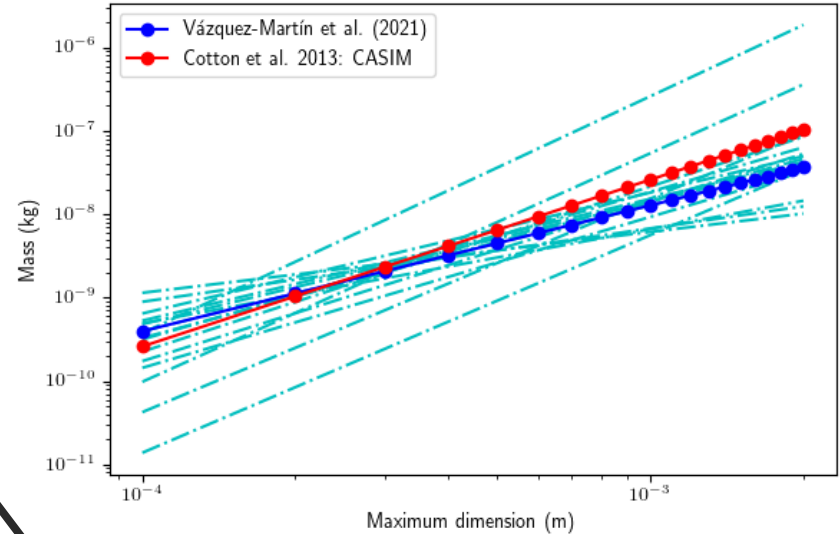
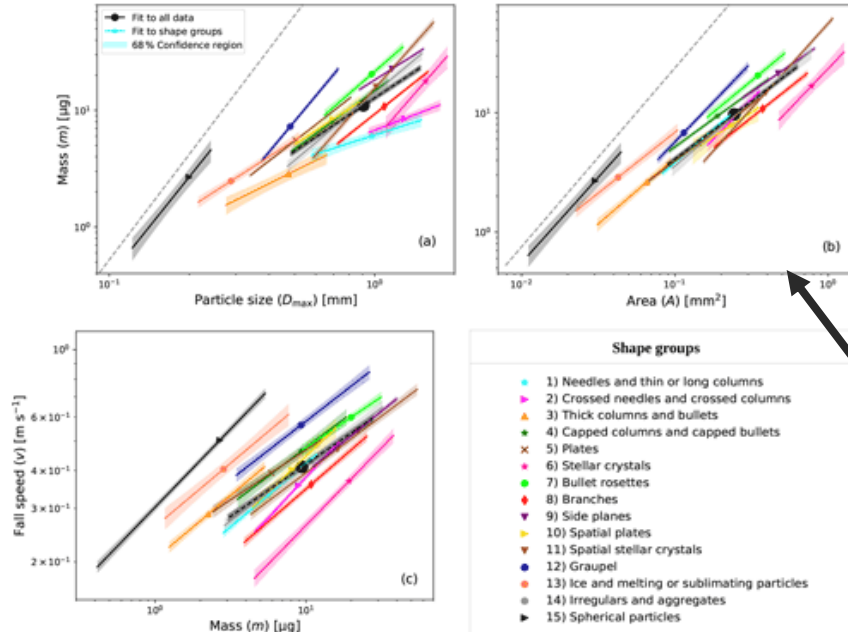
+ For spheres $m = (\pi/6)\rho_i D^3$

- Mass flux (precipitation rate)

$$F_M = \int_0^\infty m(D)v(D) \frac{dN}{dD} dD = n_0 a c (\rho_0/\rho)^f \frac{\Gamma(\mu + b + d + 1)}{\lambda^{\mu+b+d+1}}$$

Anything else that follows a power law is similar

Power Laws for Snow crystals



Vázquez-Martín et al. 2021

For most shapes mass is roughly proportional to cross-sectional area

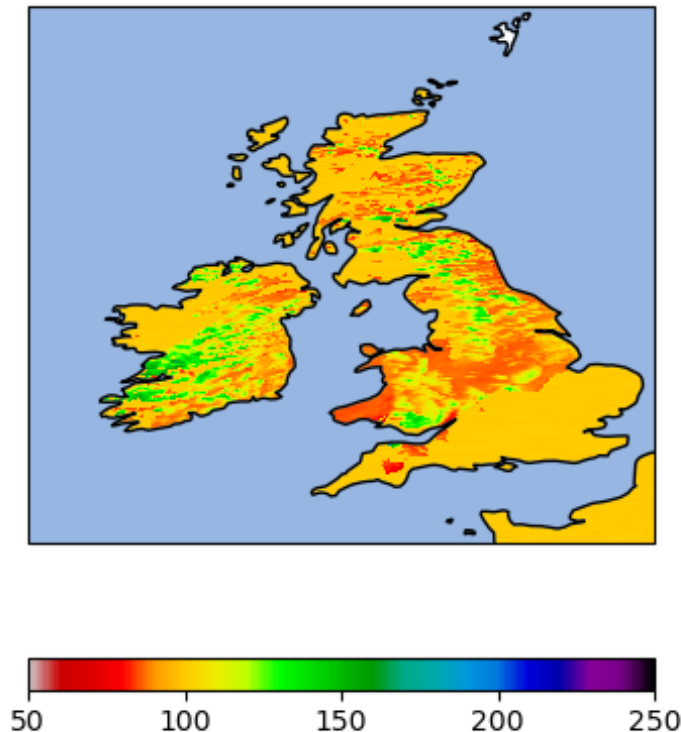
Calculating the fresh snow density from CASIM

- To get the density we need a volume flux in addition to the mass flux
- Milbrandt et al. (2012) associate each snow flake with the volume of the circumscribing sphere and then retune the mass dimension relationship
- We adopt a different assumption about the geometry
 - + We take the mass-dimension relationship from CASIM as given.
 - + Assume snow crystals are circumscribed by squat hexagonal columns, i. e. geometry is that of hexagonal plates: $A = (3\sqrt{3}/8)D^2$
 - + c. f. approximate proportionality of m and A in Vázquez-Martín et al. (2021)
 - + Take the thickness of the plate from the relationship given for hexagonal plates by Auer & Veal (1970): $h = 0.001D^{0.449}$
 - + Plates fall on to the ground and are randomly packed, so we multiply by a packing factor: it would be about 0.4 for randomly deposited cubes. A factor of 0.2 gives reasonable densities.

Initial implementation

- Branches required in JULES, CASIM and the UM / LFRic to pass the calculated fresh snow density from CASIM to JULES
- LFRic branch not yet developed, so no simulations in the Arctic yet
- Some preliminary simulations have been carried out in the UM over the UK

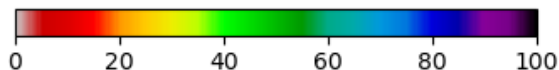
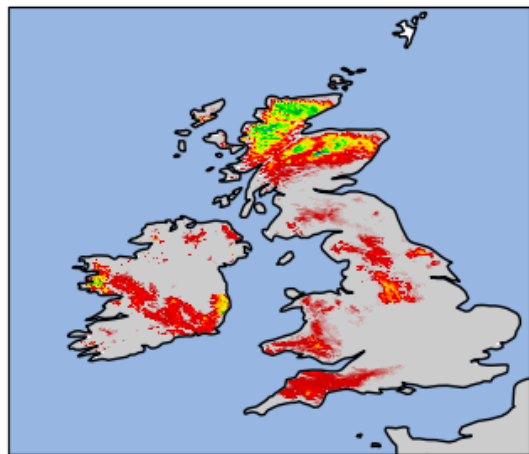
- Fresh snow density at 00 UTC on 02/03/2018
 - Default value of 100 kgm^{-2} where there is no snowfall
 - Larger values (up to $\sim 150 \text{ kgm}^{-2}$ in regions of upslope flow: generation of new smaller crystals)
 - Significant areas where density is below 100 kgm^{-2}
 - Wind-driven compaction not included here



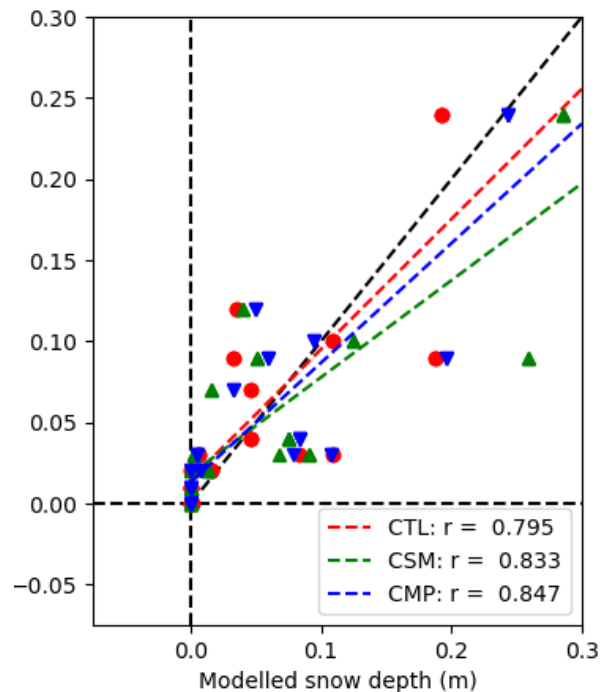


Met Office

T+96 forecast valid at 00Z on 22/11/24



Snow water equivalent (kgm-2)



Correlation of observed & forecast snow depth

Outlook

- Transition modelling efforts to LFRic
- Run over a pan-Arctic domain
 - We need a scheme that works everywhere, not just over the UK
 - Wind-driven compaction is very important in the Arctic: Wooley et al. (2024)
Sophisticated snowpack models such as Crocus and SNOWPACK struggle to properly simulate profiles of density and specific surface area (SSA) within Arctic snowpacks due to underestimation of wind-induced compaction, misrepresentation of basal vegetation influencing compaction and metamorphism, and omission of water vapour flux transport.
- Wet snow?
- More extensive assessment over the UK