ARCTIC ICE

The PIOMAS Arctic ice model is in fair agreement with with satellite and surface observations apart from a slight underestimating thickness of thick ice and overestimating thin ice. There have been small increases and larger reductions over recent years as shown by the Robinson spiral below.

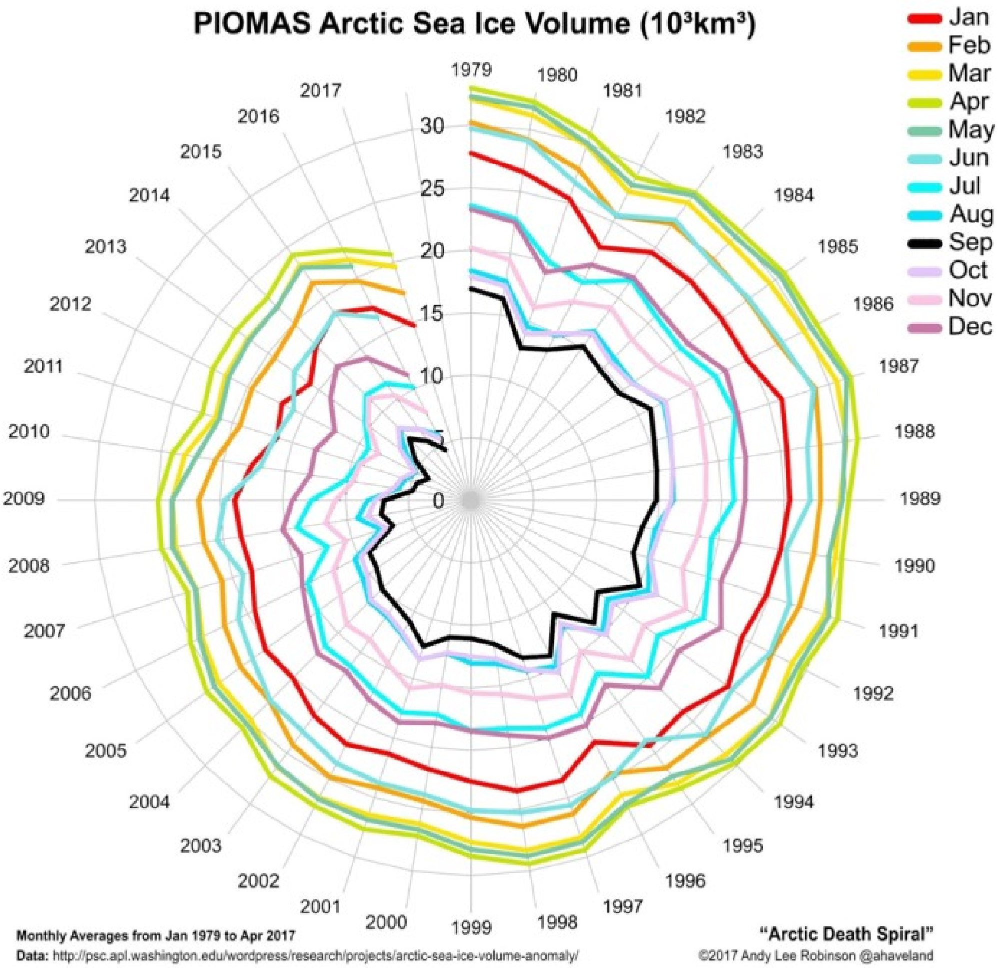
This note gives the outline of a calculation of the number of spray vessels needed to reflect solar energy equivalent to the latent heat of fusion of the missing ice. It depends on assumptions for cloud fraction, effective wake area, the concentration of condensation nuclei, the height of the boundary layer and the lifetime of nuclei. I have taken values from the literature without much confidence but this is a mathcad worksheet and will recalculate for other assumptions. Please send them to S.Salter@ed.ac.uk

The mean slope of the volume reductions has been about $Vmlt := 25000 \cdot \frac{m^3}{sec}$

We know the density of ice $\rho ice := 917 \cdot \frac{kg}{m^3}$ and its latent heat of fusion $Lht := 3.34 \cdot 10^5 \cdot \frac{J}{kg}$

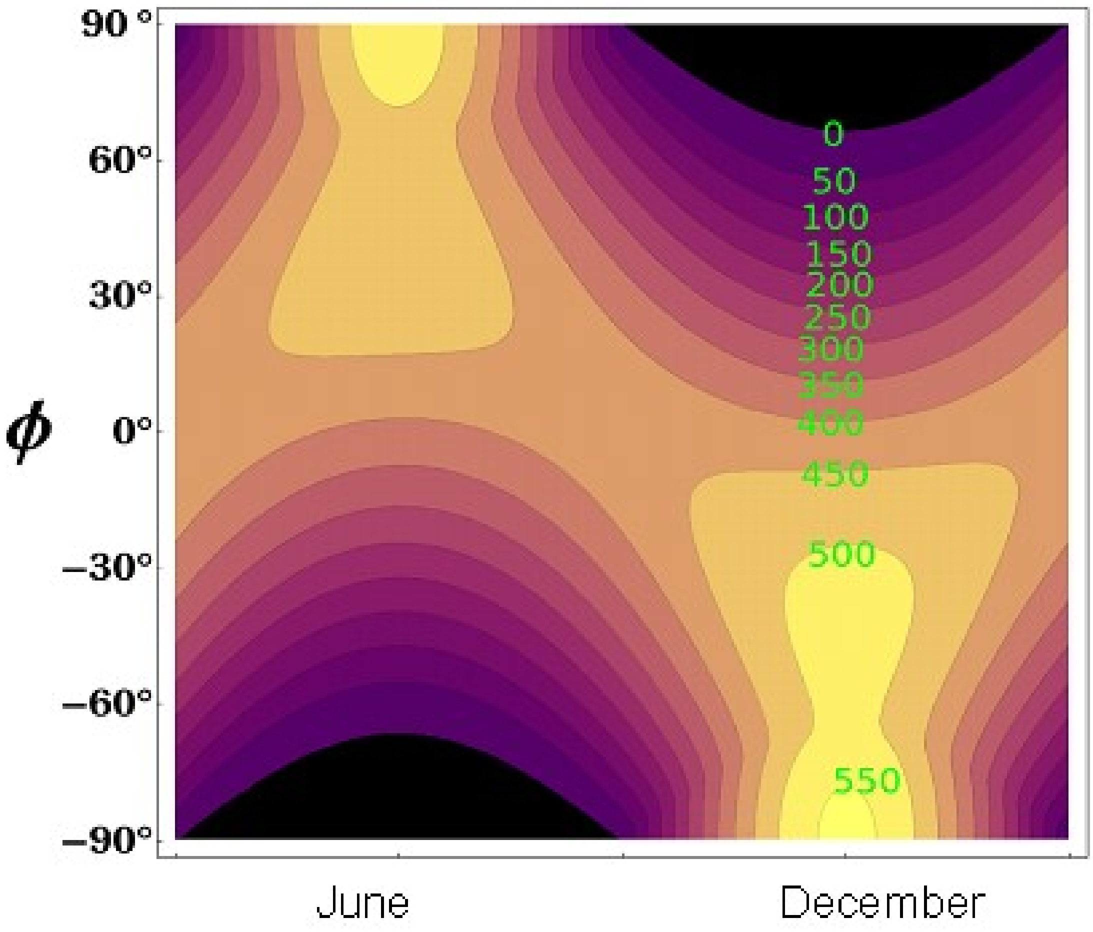
So annual energy for melting as $Enmelt := Vmlt \cdot \rho ice \cdot Lht \cdot 1 \cdot yr = 2.416 \times 10^{20} J$

Encyclopaedia Britannica gives the area of the Arctic as $Area := 14 \cdot 10^6 km^2$
Note that the area of Greenland is 2.166 million km2 total and 1.756 million km2 is covered by ice.
Spray vessels have narrow wakes so we choose an effective area fraction $Karea = 0.175$ to be treated.
In fact the wake would spread with a width having a Gaussian distribution .



Monthly updates are available from https://www.haveland.com/

At the summer solstice the input of solar energy to the poles is higher than the 440 watts per square metre at the equator. This is because solar energy is coming in over 24 hours.



The map above from Wikipedia shows top of atmosphere a solar input $Psol := 450 \cdot \frac{watt}{m^2}$

Allow for scattering from top of atmosphere to cloud top $Psol := \frac{Psol}{2} = 225 \cdot \frac{watt}{m^2}$

We want to cool during a time $T := 60 \cdot day$

The solar energy input during the cooling period $Ensol := Area \cdot Psol \cdot T = 1.633 \times 10^{22} J$

To remove the latent heat of ice in time T is a power of $Powrem := \frac{Enmelt}{T} = 4.661 \times 10^{13} W$

The US mean power is $PowUS := 4.654 \cdot 10^{11} watt$ so the ratio $\frac{Powrem}{PowUS} = 100.15$!!!!!

If the cloud fraction is $Cf := 0.8$ and Latham's spray was evenly effective over the whole Arctic area we would have to change the reflectivity by only $\Delta Ref := \frac{Enmelt}{Cf \cdot Ensol} = 0.0185$

But because of narrow wakes we treat only a small area increase to $\Delta Ref := \frac{\Delta Ref}{Karea} = 0.106$

A lower cloud fraction will imply a longer life of nuclei.

The North Atlantic nuclei concentration from Vallina $CCN1 := \frac{100}{cm^3}$

This is much higher than for mid Pacific perhaps because of Icelandic volcanoes.

Assume cloud depth $Zc := 200 \cdot m$ and liquid water content in the cloud is $Lw := \frac{0.3 \cdot mL}{m^3}$

From Schwartz and Slingo the present reflectivity is $Refl := \frac{0.15 \cdot Zc \cdot Lw^{\frac{2}{3}} \cdot CCN1^{\frac{1}{3}}}{0.15 \cdot Zc \cdot Lw^{\frac{2}{3}} \cdot CCN1^{\frac{1}{3}} + 0.827} = 0.43$

If the boundary layer depth is $Zmbl := 300 \cdot m$

The air volume over the whole Arctic is $Vol := Area \cdot Zmbl = 4.2 \times 10^{15} \cdot m^3$

The number of nuclei over the whole Arctic is $Nnuc1 := Vol \cdot CCN1 = 4.2 \times 10^{23}$

Reflectivity must be increased to $Ref2 := Refl + \Delta Ref = 0.536$
We can rearrange the Schwartz and Slingo equation above to give

the new nuclei concentration $CCN2 := \left(\frac{Ref2 \cdot 0.827}{0.15 \cdot Zc \cdot Lw^{\frac{2}{3}} - Ref2 \cdot 0.15 \cdot Zc \cdot Lw^{\frac{2}{3}}} \right)^3 = 357.7 \cdot \frac{1}{cm^3}$

We cannot pick and choose individual clouds so we must treat the whole Arctic region.

The number of nuclei in the air mass must be raised to $Nnuc2 := Vol \cdot CCN2 = 1.502 \times 10^{24}$

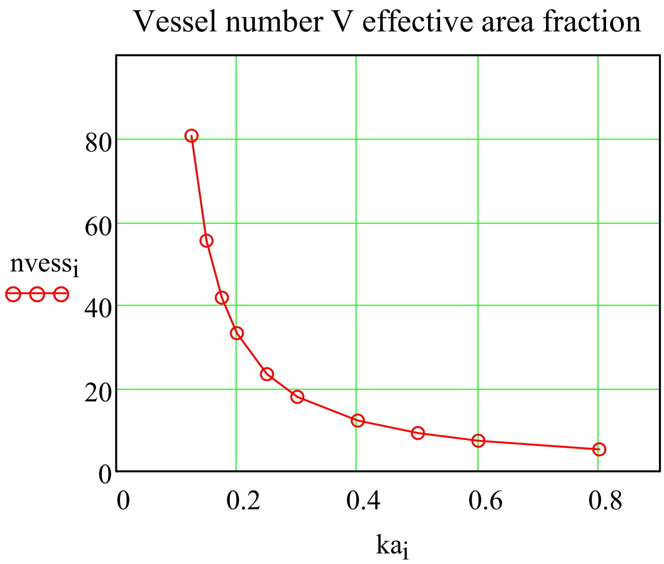
The extra number must be $Nnucext := Nnuc2 - Nnuc1 = 1.082 \times 10^{24}$

If the effective life time is $Life := 3 \cdot day$ and the spray rate per vessel $Nspr := \frac{10^{17}}{sec}$

The vessel number for the present choice of $Karea \equiv 0.175$ is $Nvess := \frac{Nnucext}{Nspr \cdot Life} = 41.8$

Choose range $n := 10$ and $i := 1 .. n$ and a selection of area fractions and resulting vessel numbers.
Enter each into the tables below and plot

area fraction $ka_i :=$	vessels $nvess_i :=$
0.125	80.7
0.15	55.5
0.175	41.8
0.2	33.2
0.25	23.4
0.3	17.9
0.4	12.2
0.5	9.2
0.6	7.4
0.8	5.3



The Twomey equation is close to a logarithmic relationship so we do not want high spray in a small region. Rapid changes in wind direction and movements of spray vessels will help to get a more even spread. We can operate well clear of the ice especially over water which is moving towards the Arctic from the Norwegian and Bering currents. Cooling tundra outside the Arctic would increase snow cover and reduce methane release and so would be welcome. Because of uncertainties I suggest using the words 'below 100 vessels'. In other months vessels can be used for hurricane moderation.