Estimating Ice Thickness and Heat Flux in Polynyas from Passive Microwave Data

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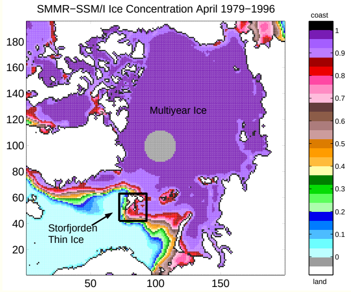
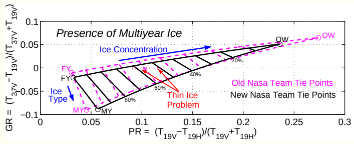
1 Arctic Sea Ice Concentrations

Since 1973 satellite microwave radiances are available to explore the global sea ice coverage. A widely used algorithm utilizes the polarization ratio PR at 19Ghz and gradient ratio GR at 19 and 37 Ghz vertical polarization to derive multiyear and first-year ice concentrations[1]. Based on data from the entire Arctic with increasing length of the timeseries the original tie points were changed[2]. Locally the signatures may differ due to weather, snow and ice properties. Recently [3]additional use of 85Ghz channels has improved the problematic ice concentration retrieval in thin ice areas.





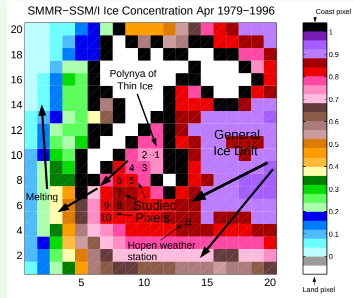
Many studies have focused on the ice concentration retrieval accuracy. In frequent oceanic applications the total heat flux is an important variable. We are interested in the uncertainty of heat fluxes retrievable from passive microwave data linked to a thin ice model.

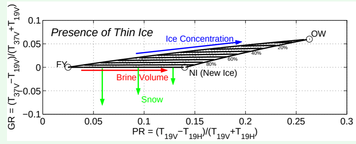
2 Storfjorden - A Thin Ice Area

We investigate a polynya near Svalbard. Persistent northeasterly winds lead to permant ice export to the West Spitsbergen Current creating a thin ice polynya during the whole winter. The PR-GR algorithm derives almost 0.2 too low ice concentrations. The definite absence of multiyear ice encourages an analysis of thin ice signatures. We extend a thin ice classification approach of Cavalieri [4]:

⇒ Ice type change from new ice (NI) to first-year ice (FY) is formulated as a contineous function of brine volume Vb_{ice}.

⇒ Snow thickness is included as an important variable in the heat balance of thin ice.





Our approch is based on the axes of snow, brine volume and open water in the PR-GR plain. We evaluate H_{ice}, H_{sno} and the total heat flux along the export path of thickening ice. The used pixels 1 to 10 were corrected for a weak land overlap effect.

3 Surface Heat Balance

We assume that the satellite 'sees' a liquid water signal consisting of the open water fraction FOW and brine volume Vb_{srf} in the upper 3cm of the ice cover fraction (1-FOW). The total heat loss from open water and growing thin ice is

$$Q_{tot} = Q_{open}(FOW, T_{air}, V_{air}) + Q_{ice}(1-FOW, H_{ice}, H_{sno}, T_{air}, V_{air})$$

Heat loss computations follow Maykut's [7] model computing the thin ice relation

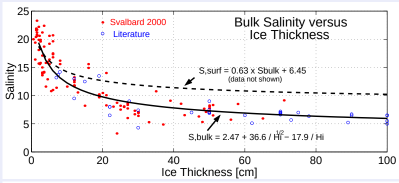
$$T_{ice} = f1(H_{ice}, H_{sno}, T_{air}, V_{air}, S_{ice})$$

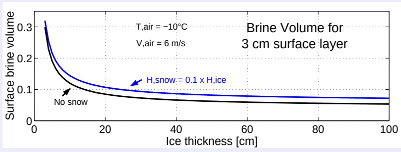
Relations between ice thickness and bulk salinity S_{ice} as well as the 3cm surface salinity S_{srf} from which the microwave signal emerges, were derived from thin ice cores obtainend during winter 2000 in Storfjorden and Svalbard:

$$S_{ice} = f2(H_{ice}),\ S_{srf} = f3(H_{ice})$$

The brine volume is related to S_{ice} and S_{srf} via [6]

$$Vb_{ice} = f4(T_{ice}, S_{ice})$$





Relations f1 to f4 yield an equation of state for the ice thickness:

$$H_{ice} = f5(T_{air}, V_{air}, H_{sno}, Vb_{srf})$$

4 PR-GR Transformations

We can now rewrite the heat balance

$$Q_{tot} = Q_{open}(FOW, T_{air}, V_{air}) + Q_{ice}(1-FOW, Vb_{srf}, H_{sno}, T_{air}, V_{air})$$

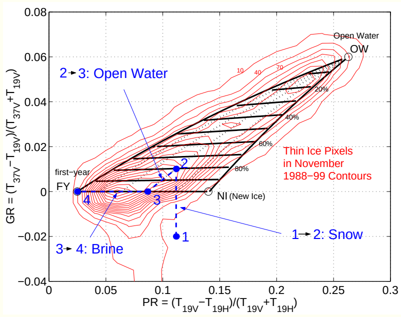
wherein T_{air} and V_{air} are obtainend from the Hopen weather station and FOW, Vb_{srf} and H_{sno} are related to the satellite signal via PR and GR:

⇒ Snow thickness is assumed linearily proportional to GR. By comparing Hopen precipitation and GR in the local SSM/I cells we find a relation similar to the Antarctic[7].

⇒ Brine volume is assumed to be proportional to PR. Vb_{srf} of 3cm new ice (NI), when it first becomes opaque for the satellite, is estimated as 35% from observations.

⇒ In the two PR-GR dimensions only two of the unknowns Vb_{srf}, H_{sno} and FOW can be determinend. The open water fraction FOW is varied in the realistic range 1% to 10%.

By setting the open water fraction in the true range observed by SAR, RADARSAT and our fieldwork we derive a range of corresponding snow and ice thicknesses. Graphically we move from an observation point 1 to an assumed ice concentration point 2 and get the snow thickness. The ice type is definend by Vb_{srf} at 3. Observed T_{air} and V_{air} yield the ice thickness and heat flux via the thin ice model.

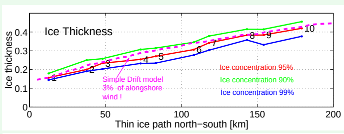


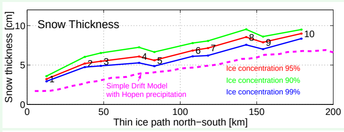
5 Results: Ice, Snow and Heat Flux

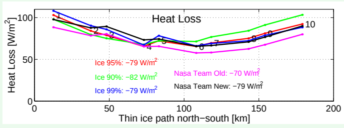
The results are shown for November-April 1988-1999 for assumed ice concentrations 90%, 95% and 99% and excluding 1/3 of the data due to weather effects. They are compared to a simple advection model of ice originating in pixel 1 and drifting southwards at 3% of the alongshore wind as found from ARGOS beacons during winter 1999. Although based on the same meteorological data the agreement is encouraging.

The ice thickness increases like in the drift model from 15 to 40 cm over the path of 180km. Snow thicknesses are somewhat larger than accumulation in the drift model. During field work 1999-2000 we also found a snow layer of 5-7 cm at most positions.

Most interesting is that the retrieved heat loss is insensitive to the assumed ice concentration. Moreover, if we compute the heat flux simply with the 'apparent' open water fractions from the Nasa Team algorithms, we find very similar results, the new Nasa Team heat fluxes matching perfectly the thin ice model.







6 Discussion

+ In contrast to uncertain ice concentration retrieval passive microwave PR19-GR1937 ratios appear very effective to derive the overall surface heat balance over thin ice.
+ As the satellite measures a temperature signal biased by surface emissivities, the stability in the heat flux retrieval points to the self-consistency of the applied method.
+ Ice and snow thicknesses were derived in good agreement with a simple dynamic drift model, lending creedence to the approach.
+ The new more consistent Nasa Team algorithm tie points[2] seem to be better suited to derive heat fluxes in polynyas from the 'apparent' (despite less correct) ice concentrations. However, this question needs further investigation.
? Enhancement with 85 Ghz channels should be useful to correct weather effects and land overlap. It is unclear if the heat flux retrieval can be improved as the ice concentrations.
? More Validation data[8] of PR and GR with brine volume, surface properties as frost flowers and brine-wetted snow must be obtainend to validate the heat flux tie points.
? Very slight changes in the thin ice thickness distribution or snow cover of the ice pack may be misinterpreted as large ice concentration changes. What are the relative evolutions of open water, Vb_{ice}, H_{sno} within climatic variability as seen by the satellite?

1.*Cavalieri, D.J., P. Gloersen, C.L. Parkinson and H.J. Zwally* (1992) DMSP SSM/I NASA Tech. Memorand., 104559, 126pp; 2.*Cavalieri, D.J., P. Gloersen, C.L. Parkinson, J.C. Comiso and H.J. Zwally* (1999) J. Geophys. Res., 104, 15803-15814; 3.*Markus, T. and D.J. Cavalieri* (2000) IEEE Trans. Geosc. Rem. Sens., 38, 1387-1395; 4.*Cavalieri, D.J.* (1994) J.Geophys. Res., 99, 12561-12572; 5.*Maykut, G.* (1978) J. Geophys. Res., 83, 3647-3658; 6.*Cox, G.F.N. and W.F. Weeks* (1988) J.Geophys.Res., 93, 12559-12460; 7.*Markus, T. and D.J. Cavalieri* (1998) Antarct. Res. Ser., 74, 19-39; 8.*Wensnahan, M., G. Maykut and T. Grenfell* (1993) J. Geophys. Res., 98, 12453-12468.