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ASSESSING THE ICE PERFOMANCE OF SHIPS IN TERMS OF AIS DATA

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ABSTRACT
AIS (Automatic Identification System) data includes, among other things, the location, speed, course and heading of the reporting ship. A steaming ship transmits AIS messages every few seconds. In the Baltic most messages are received and stored by terrestial stations. This data includes tens of thousands ice transits to ports each year. When combined with ice cover information the data opens almost limitless possibilities to study performance of individual ships, navigational situations, and the whole winter navigation system. As the amount of data is very large, it is possible to impose very strict conditions on the identifiability of navigational situations and still have a dataset large enough for reliable analysis. Results based on all ice navigation during season 2010-2011, as identified from Finnish terrestrial AIS data, are presented. The ice data consists of daily ice charts gridded to 1 NM resolution. Each AIS message is linked with the ice chart variables in the nearest grid node. The particulars of the ships are obtained from a database. As an example the subset of cases of unassisted navigation is studied and the performance of different ice classes are compared. For 1A super vessels relationships between ice conditions and ship speed reduction, or ice resistance, can be extracted. For ships in lower ice classes the results are less straightforward as the ships typically must increase their power setting to maintain certain minimum speed in increasingly difficult conditions. That the power data is not included is the main shortcoming when AIS data is used to estimate ice resistance. Possible methods to get around this shortcoming are exemplified.

INTRODUCTION
Data on how ice cover affects ship performance is needed on several levels of planning. In ice performance considerations there are two main aspects: ice induced loads against the ship hull or propulsion system, and ice resistance. The ships should be designed so that the probability of severe ice damage resulting, for example, to an oil spill is minimal during the lifetime of the ship. The ship should also be able to maintain sufficient speed in the ice cover and be manoeuvrable. On the other hand, unnecessarily heavy structures and excessive propulsion power increase construction costs and fuel consumption. To get these just right for the intended operation profile is a design task with boundary conditions set by agreed rules on iceworthiness, safety, and energy efficiency. Both for the formulating of these rules and for the ship design the understanding of ice performance should extend to the detailed level of ship types and hull forms.

On the other hand, during the ice season estimates on the travel time and on the ability of the ships to navigate unassisted are needed. Reliable estimates would assist individual ship in their route planning and scheduling, shipowners in the strategic planning of fleet operations, and icebreakers in their planning of assistance configurations. In addition, the ports would benefit from increased predictability which would also allow better real time assessing of maritime risks. There are needs both for short term planning, aiming for optimising the present traffic situation, and for long term planning extending up to tens of years and aiming, for example, to the assessing of future icebreaker needs. One solution would be a holistic wintertime traffic simulation model that could be used for both purposes.

The traditional approach to ice resistance has been in terms of analytical and numerical modelling combined with model scale tests and full scale campaigns for selected vessel types (e.g. Myland and Ehlers 2014). A wintertime traffic simulation model would take as an input the present ice situation or climatological ice data sets, resistance formulas, and traffic data. There are three obstacles however. Resistance formulas exist only for certain homogenous ice types like level ice and uniform channel rubble although these are seldom encountered pure in the pack ice. On the other hand, the formulas have been validated for certain ship types and hull forms only. Most seriously, even if the full understanding of resistance would be at hand, the quality of ice information is not sufficient for realistic simulations. This is mostly due to the fact that ice thickness cannot yet be remotely sensed and thickness information relies on scattered observations and ice model results.

The AIS (Automatic Identification System) data offers here a possible way forward as it contains, among other things, the location and speed of vessel. Since 2002 IMO's SOLAS convention has required AIS data to be transmitted by internationally voyaging ships with gross tonnage exceeding 300 and by all passenger vessels (IMO 2002). As of 2014 AIS is running on more than 300 000 vessels. The transmitted data can be received by other ships in the same sea area, by terrestrial stations to about 100 km offshore, or by satellites. The broadcasting interval of the data depends on the navigation mode but is few seconds during regular steaming. For an icegoing vessel the data thus resolves the ice induced speed variations which greatly increases the usefulness of the data in ice transit analyses. Such data can be obtained in the Baltic with full terrestrial AIS coverage while satellite AIS data update rate is hours. After combining AIS data with sea ice information it is possible to study how the changes in concentration, thickness, ridging and other parameters of ice information are reflected by the speed of the ships. If results can be extracted, the ice information can be used in traffic simulations. This can be accomplished without paying heed to the actual quality of the ice information.

The applicability of AIS data to research purposes has been realised but the applications are still few. In the Baltic the main application has been ship emission modelling (Jalkanen et al. 2013). Löptien and Axell (2014) made a study focusing to the Quark entrance on the northern part of Sea of Bothnia and to the severe winter 2011. They used archived AIS data with 5 minute intervals. The AIS-retrieved performance was compared with ice parameter fields from a forecast model. Icebreakers and ships closer than 0.2 NM to icebreakers were excluded leaving about 14000 data entries. Statistical analyses indicated that about 2/3 of the ship variation could be assigned to ice conditions. Otherwise Baltic AIS data has been used in winter navigation research and in maritime risk modelling (e.g. Montewka et al. 2015, Goerlandt and Kujala 2014) in routing scheme developments (Guinness et. al 2014) and in oil pollution monitoring (Bulycheva et al. 2014). Emission modelling has been the only Baltic application utilising full temporal, areal and ship coverage of the AIS while the others have used selected AIS data samples.

AIS, ICE CHART AND SHIP DATA

The full update rate AIS data received by official Finnish stations is administered by Finnish Traffic Administration. The range of the stations cover Gulf of Finland, Northern Baltic Proper and the Gulf of Bothnia with the exception of Swedish side of Sea of Bothnia. The amount or data is of the order of 10^9 messages annually. Finnish Meteorological Institute has access to the data for research purposes. A major application has been ship emission modelling (Jalkanen et al. 2013). This is based on ship speed, open water resistance formulas and a database on ship particulars and machinery. During the ice season ice resistance should be included to the formulas but this is still lacking. This constitutes one specific application of ship specific ice resistance data which also is a motivation to have for the combined AIS and ice data similar complete temporal and areal coverage.

The AIS data consists of coded messages. There are 27 basic message types containing different kinds of information. The basic navigational information is contained Type 1 or Position Report messages, which are most common and automatically transmitted. Types 2 and 3 are identical in content to Type 1 but serve special purposes. The Position Report messages are composed of time tag, message type identifier, message structure identifier, the actual message as 6 bit binary code, and a checksum. The messages can be decoded following the instructions of some AIS decoding manual which gives, among few other data, the ship MMSI (Marine Mobile Service Identity) number, position, speed over ground (SOG), course over ground (COG), true heading (HDG), and rate of turn (ROT).

The ice data is included in grid formats, and presently ice charts prepared by the Ice Service of FMI are used. Ice Services has generated gridded versions of the standard daily ice charts for various purposes since 2002. These code the graphic information of the ice chart by listing the ice parameters at each gridpoint. In the AIS context the gridded charts matching the resolution and grid extent of FMI operative ice forecast model HELMI are used. The basic resolution is 1 minute of latitude and 2 minutes of longitude, or about 1 NM at 60°N. In this resolution the boundaries between ice areas correspond to those of the original chart with practically no loss of information. The standard ice parameters are : 1) sea surface temperature, 2) ice concentration, 3) ice thickness, 4) minimum ice thickness, 5) maximum ice thickness, and 6) deformation type. The thickness is based on observations from ships and coastal stations. The deformation type numerals are

0	Level ice
1	Rafted ice
2	Slightly ridged ice
3	Ridged ice
4	Heavily ridged ice
5	Windrow (brash barrier)

Ship data is obtained from a databank collected by FMI Air Quality unit for ship emission research purposes. The basic data from IHS Fairplay is constantly being amended with additional hull and engine parameters from various sources. The number of ships in the database is about 60000 and covers in practice every vessel navigating in the Baltic. The data includes identification numerals for the ship, ship type and ice class, main particulars, and particulars of engines and propulsion system.

The basic datasets used in the analysis combine data from AIS Position Report message with ice chart data and ship data. The relevant AIS message data are arranged to daily tables that thus comprise all position reports from all ships navigating within the reach of Finnish AIS receivers during one day. To each AIS message is attached the grid coordinates of the nearest ice chart grid cell which links it to ice chart parameter values. Similarly, the MMSI number of each message links it with the ship database.

PROCESSING AND SELECTING OF DATA

From the generated database subsets are selected for further analysis. This is done by imposing conditions on the navigational situation, area, time period, ice parameters, and ships. In the remaining part of this paper independent ice navigation during the ice season 2010-2011 is considered. Figure 1 shows a processing chain for generating a subset that can be used for the purpose. For the case study the set of ships is restricted to commercially navigating cargo carrying ships: bulk carriers, container ships, general cargo ships, special cargo ships, ro-ro ships, tankers of different kinds, and vehicle carriers. It is then required that the ships navigate in ice cover outside fast ice zone. Finally, it is required that there are no other ships in the proximity.

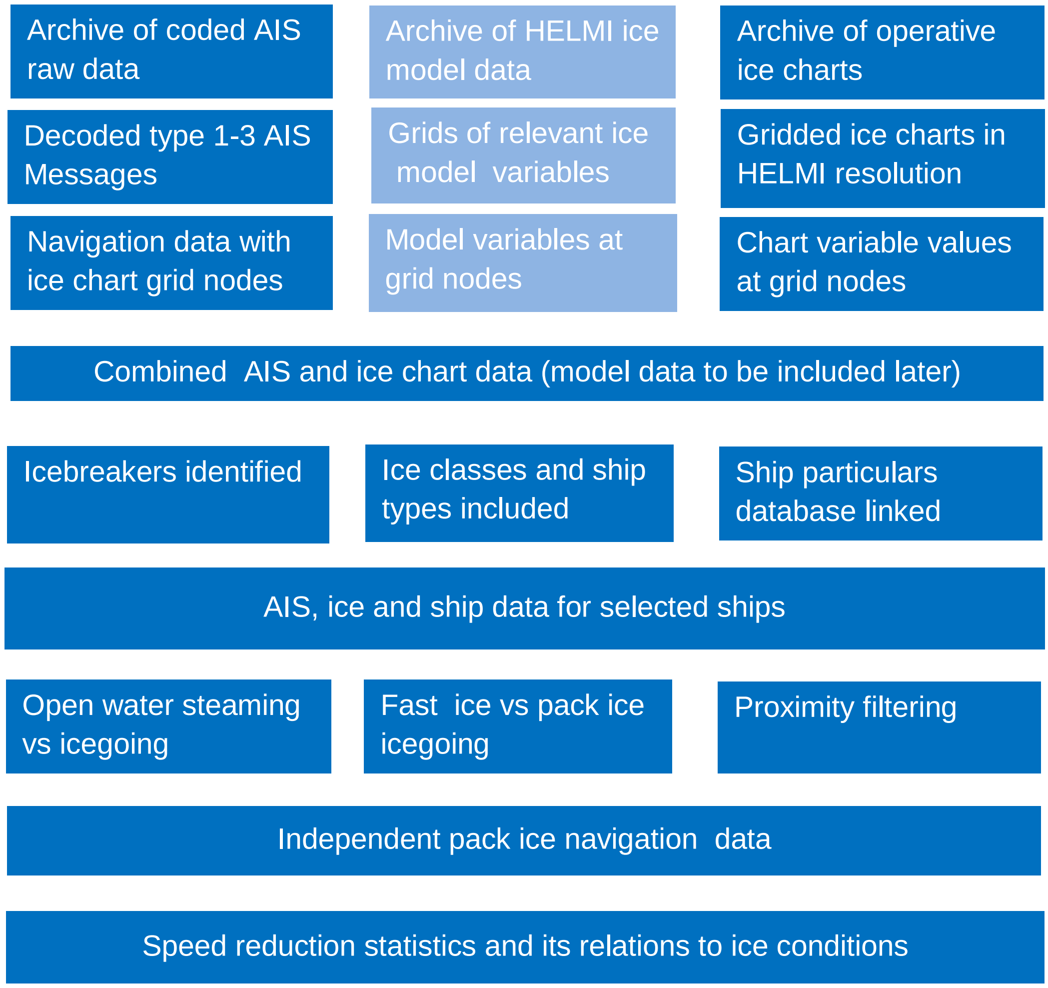

Figure 1. Generating of the datasets for independent ice navigation analyses.

The criterion for the proximity uses both time and space windows. If the ships are in the same time and space window they are classified as being close and potentially affecting each other's speed. The time window is selected to 10 minutes, during which a fast ship steaming with 18 knots traverses 3 NM. The space window is selected to 3 x 3 NM. Roughly, if the minimum distance between the tracks the two ships cover during 10 minutes is less than 3NM, the ships are too close and are not included to the independent navigation subset.

The proximity criterion is rather stringent in comparison with that of Löptien and Axell (2014) who excluded ships closer than 0.2 NM to icebreakers and did not exclude commercial vessels close to each other. All data for the ice season 2010-2011 comprises about 500 million entries. After the imposed conditions the selected subset comprises about 26 million entries, which is still a very large number. This is one of the basic virtues of analyses based on full update rate AIS data: even if the stringency of the conditions is overdone there still remains enough data for robust results. The subset is restricted further by requiring navigation in compact ice cover, or that concentration is at least 90 per cent; 16 million entries remain. Finally as the traffic situations in the Gulf of Finland are often complicated, the analysis is restricted to the Gulf of Bothnia (Sea of Bothnia and Bay of Bothnia), leaving about 5 million entries of data.

RESULTS: SHIP SPEED AND ICE THICKNESS

The subset selected for the case study comprises thus cargo carrying ships navigating independently in compact pack ice cover of the Gulf of Bothnia during the ice season 2010-2011. The effect of ice conditions to the ship speed is studied for this set. The speed statistics may include the effect of idling, either due to waiting of being beset, in which case the speed quantifies advancing towards to destination. If the idling is excluded, the speed quantifies icegoing speed. The threshold of idling was set to 1 kn. Thus the average icegoing speed is defined as the average of speeds exceeding 1 kn.

Figure 2 shows the overall average speed as a function of charted ice thickness. It is seen that the ships generally maintain well their icegoing speed in all ice thickness classes, and that the degree of ridging has little effect. These features are probably related to the fact that also independent navigation mostly follows ice channels opened by the icebreakers. Including idling the speeds decrease and for larger thicknesses the ships spend about half of their independent time idling. The speed minimum occur for 35 cm thick ice after which the average speeds increase again. The reason is not clear. Löptien and Axell (2014) found also that the speed decrease levelled after 30 cm and suggested that this is related to the cannel navigation and icebreakers. Another possible explanation is that the ships increase power setting because they are otherwise stopped by thicker ice features. This then increases their speed in the thinner ice types that cover most of the track length. Further analyses focusing on the ship configurations rather than individual ships may clarify the issue in the future. In any case, from Figure 3 it is seen that ice ships in Finnish-Swedish ice class 1A or 1B seek to maintain their speed in thicker ice while in the ice class 1A Super the speed decreases in a roughly linear manner.

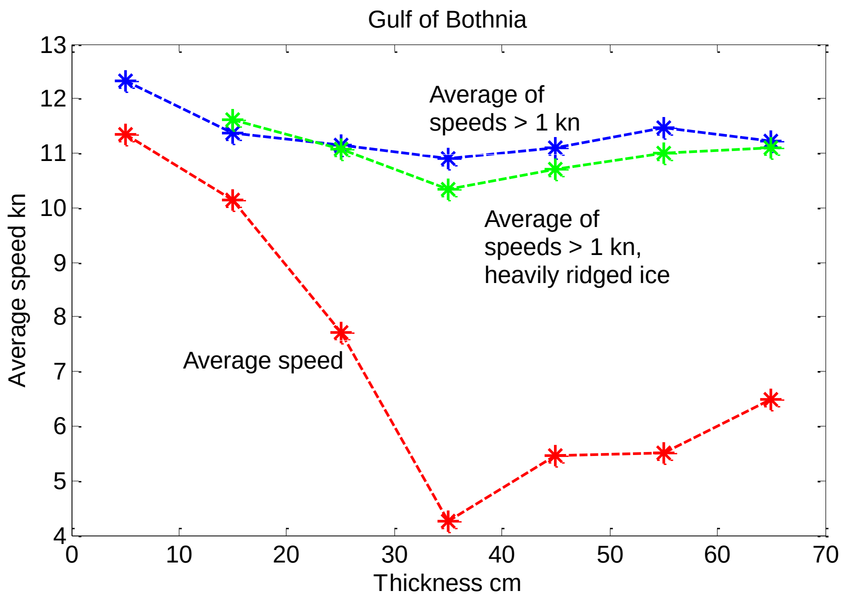

Figure 2. The dependency of average icegoing speed
and average speed on ice thickness for the case study subset.

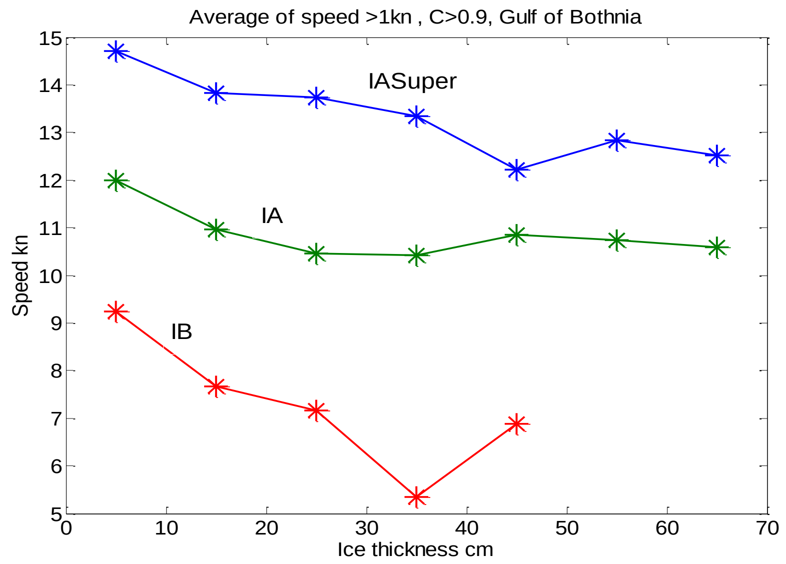

Figure 3. The average icegoing speed for different ice classes.

If the ships do not maintain their power setting, applicable thickness-speed relationships cannot be obtained with a simple analysis. The speeds of 25 most frequenting ships in 1A Super ice class for 5 cm and 45 cm thick ice are compared in Figure 4. The decrease is consistent and no ships exceed in thicker ice their thin ice speed, which is likely to be about same as open water speed. A similar plot for the IA class reveals different picture: a considerable fraction of the ships increase their speed in thicker ice while for the remaining ships the variation in speed change is large around the decreasing trend. This indicates that 1A Super class ships typically maintain their power setting when entering thicker ice types as the speed does not decrease too much and probably the ships are not stopped by local thick ice sections either. On the other hand, in 1A class other ships evidently use more power in thicker ice.

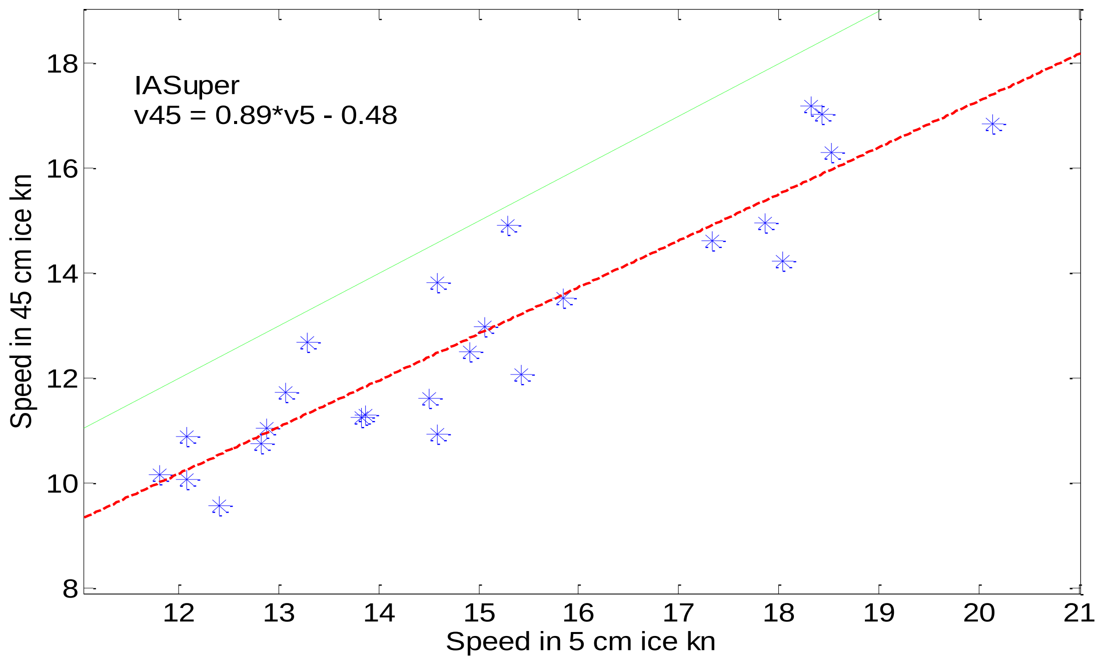

Figure 4. The speed reduction for ice class 1A Super ship traffic.
Ships with more than 3000 entries of data have been selected.
The green line indicates that the speed remains the same.

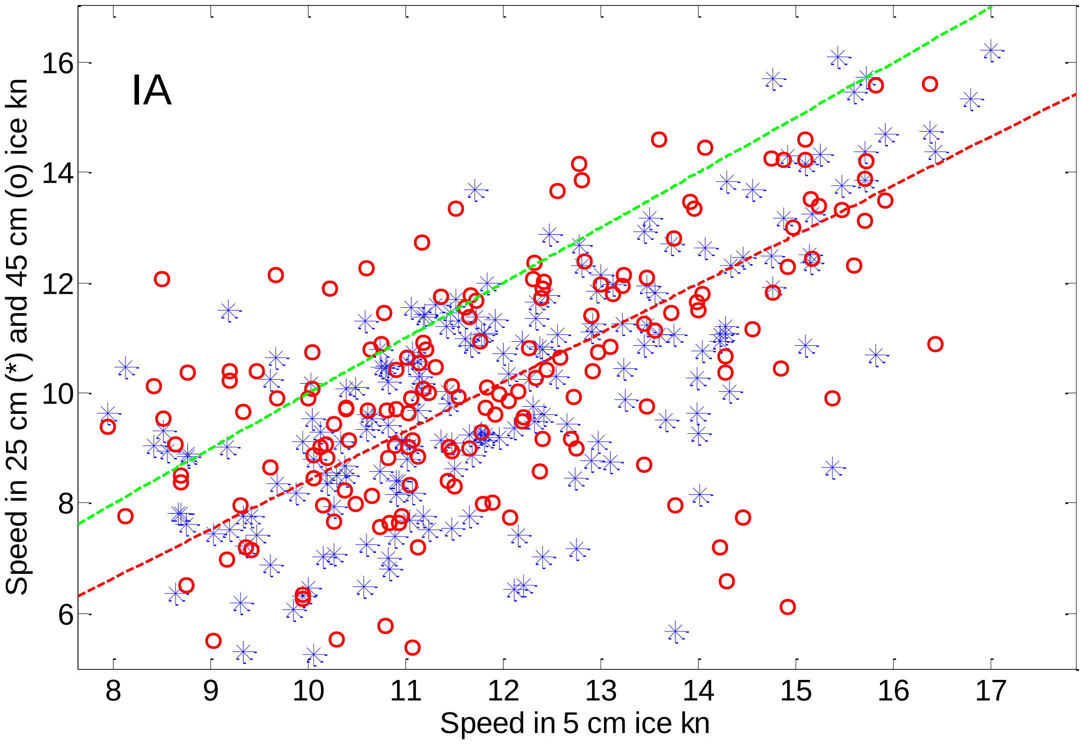

Figure 5. The speed reduction for ice class 1A ship traffic.
Ships with more than 3000 entries of data have been selected.
The green line indicates that the speed remains the same.

Basing on the previous considerations a relationship between increasing ice thickness and speed reduction appears obtainable for ships in ice class 1A Super. The result shown in Figure 3 is not proper for the purpose as it refers to the pooled data to which the ships contribute differently. Ships having most navigation hours in the Northern Baltic are also expected to be best suited for the conditions and show least speed decrease. This affects the averages and decreases the slope in Figure 3. Instead, the speed reduction curve is calculated for each ship separately and the overall relationship is the obtained as the average over the family of curves. This average is taken over 45 ships. The result is shown in Figure 6. The relationship is linear to 55 cm thickness and follows the equation

$$v = v_o(1 - 0.004h)$$

It appears here also that the ships consider 20% reduction to the speed acceptable after which they seek to maintain the speed, typically at about 11-12 kn.

DISCUSSION

A database combining full update rate AIS data with charted ice conditions was presented and applied to the performance of ships navigating independently in pack ice. This was done in a sweeping manner and without going too much into the detail except in terms of ice classes. The application is to be considered as a preliminary example rather than final result as it just scratches the surface of the database potential and more robust results are expected in continued analyses.

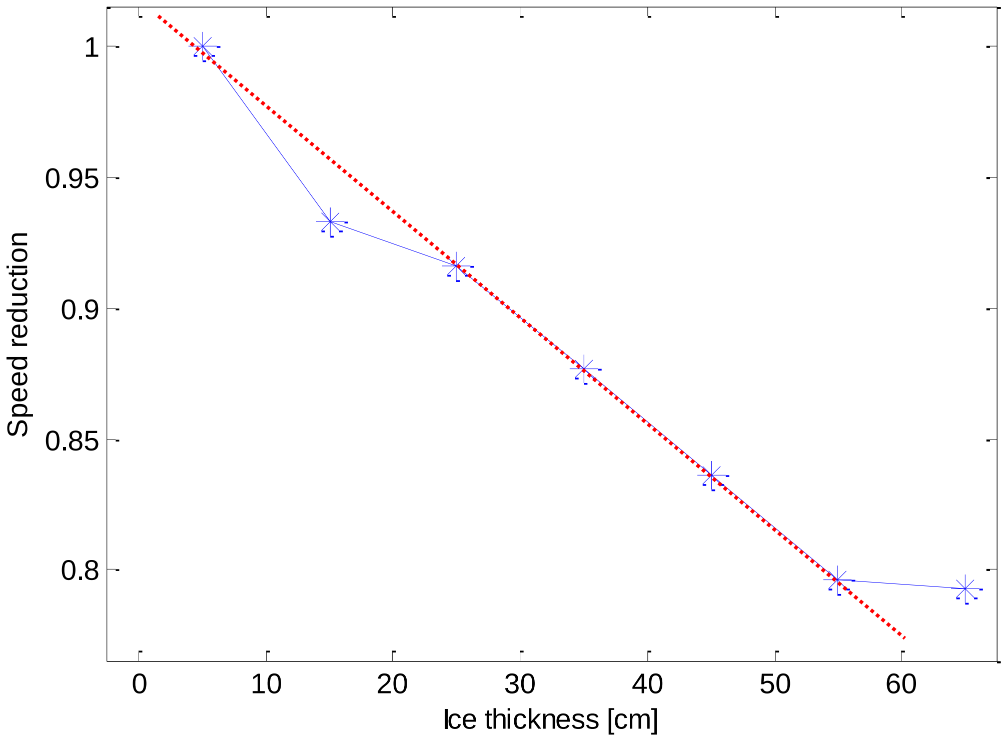

Figure 6. The reduction of ship speed as a function of ice thickness for ice class 1A Super.

First, the database is planned to become expanded to cover all ice seasons from season 2007-2008 which will make possible detailed analyses of the ice performance of individual ships. Ice model reanalyses, and possibly SAR images as well, are included to the ice information part of the database. Second, fully independent ice navigation is rather an exception in the Baltic. The ships follow ice channels and move in convoys or must take in some other way into account the other ships ahead or behind. Thus the other ships may affect the navigation tactics and speed even though they would not be close by. The icebreaker assistance configurations complicate the navigational situation with convoys, waiting times and meeting points. All this, together with the ships' intention to reduce fuel costs, may affect the navigation. The analysis should thus be proceed from the recognition of different traffic situations. The icebreaker assistance guidelines and operation logs provide a frame for this. One target of the winter navigation research is to be able to do routing or simulate the traffic. In the Baltic it is unlikely that this could be based only on the individual ships' ability to navigate in different ice types but a more holistic approach is required.

The main shortcoming of AIS data is that the propulsion power is not known. It cannot be known for sure whether sudden speed reduction is due to entering more difficult ice or due to reduced power setting, although it is possible to formulate certain indicators that suggest the latter is the case. Thus as considers ice resistance the AIS based work cannot replace the more theoretical approaches to ice resistance but these support each other. Finally, the obtaining of propulsion data if not from all then from selected vessels instrumented for the purpose would greatly increase the already big promises of AIS data analyses. Any investment to this would soon pay itself back in more efficient winter navigation system.

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