STYRELSEN FÖR

VINTERSJÖFARTSFORSKNING

WINTER NAVIGATION RESEARCH BOARD

Forskningsrapport nr 13

CALCULATION OF ICE DRIFT IN THE BOTHNIAN BAY AND THE QUARK

JÄÄN LIIKKEEN LASKEMINEN PERÄMERELLÄ JA MERENKURKUSSA

BERÄKNING AV ISDRIFTEN I BOTTENVIKEN OCH NORRA KVARKEN

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PREFACE

The Winter Navigation Research Board presents its report No 13 - "Calculation of Ice Drift in the Bothnian Bay and the Quark". This report relates the progress made so far in evaluating a dynamical model to be used for ice situation forecasting. The work has been carried out by Mr. A. Valli and Mr. M. Leppäranta at the Institute of Marine Research in Helsinki.

The Winter Navigation Research Board expresses its appreciation to the work and its thanks to those who have contributed to it.

Helsinki and Stockholm May 1975

Helge Jääsalo Lennart Johansson

Calculation of Ice Drift in the Bothnian Bay and the Quark

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Abstract

Calculations of ice drift in the Bothnian Bay and the Quark were performed using the model developed by Yu. P. Doronin with some modifications. The results were compared with the analysis of a real situation and seen to be in good qualitative agreement with the latter.

Development of the Dynamical Model

The dynamical equation for ice drift is written in form

$$m \frac{d\bar{v}}{dt} = \bar{\tau}_a + \bar{\tau}_w + \bar{C} + \bar{G} + \bar{R} \qquad (1)$$

where m is the mass of ice per unit area. $\bar{\tau}_a$ and $\bar{\tau}_w$ are the frictional stresses of air and water flow on ice respectively, $\bar{C}$ is the Coriolis force, $\bar{G}$ is the component of gravitational force parallel to the surface and $\bar{R}$ is the force caused by surrounding ice.

The equation of mass continuity is

$$\frac{\partial m}{\partial t} = - \nabla \cdot (m\bar{v}) + \emptyset \qquad (2)$$

where the effect of thermodynamics has been included in $\emptyset$. The compactness of ice field can be defined by equation

$$m = \rho_i NH \qquad (3)$$

where H is the local average thickness of ice. In other words N is the relative magnitude of area covered by ice ($0 \leq N \leq 1$).

Because N and H are directly measurable quantities, they are used rather than m. The equation for H can then be written as

$$\rho_i N \frac{dH}{dt} = \rho_i N \left(\frac{\partial H}{\partial t} + \bar{v} \cdot \nabla H \right) = \phi_1 + m \qquad (4)$$

where ϕ_1 is the change of mass per unit area due to the thermodynamic increase in the average thickness H, and is a function that describes the effect of ridging to H. When expression (3) is substituted back to eq. (2) for m and eq. (4) is used, an equation for N is obtained in form

$$\rho_i H \frac{\partial N}{\partial t} = - \quad \rho_i H \nabla \cdot (N\bar{v}) + \phi_2 - m \qquad (5)$$

where ϕ_2 is the change due to the thermodynamic change in N, for example the formation of new ice, so that $\phi_1 + \phi_2 = m$.

In present work ϕ_1 and ϕ_2 are neglected because our main interest has been in forecasts of relatively short period. Further it is assumed that the effect of ridging can be neglected when $N<1$ or $\nabla\cdot\bar{v}\geq 0$. When $N = 1$ and $\nabla\bar{v}<0$, that is, the ice is converging, N and ∇N have been set equal to zero. Thus eqs. (4) and (5) reduce to

$$\frac{\partial H}{\partial t} + \bar{v}\cdot\nabla H = 0 \qquad (6a)$$

$$\frac{\partial N}{\partial t} + \nabla\cdot (N \bar{v}) = 0 \qquad (6b)$$

when $N<1$ or $\nabla\cdot\bar{v}\geq 0$, and

$$\frac{\partial H}{\partial t} + \nabla\cdot (\bar{v} H) = 0 \qquad (7a)$$

$$\frac{\partial N}{\partial t} = 0 \qquad (7b)$$

when $N = 1$ and $\nabla\cdot\bar{v} < 0$. In this model N never exceeds unity. In Doronin's model N is allowed to become greater than unity and the velocities have been corrected afterwards corrections being dependent on $\varepsilon = N-1$, so that N becomes smaller than unity.

In the present calculations the edge of fast ice has been assumed to be stable. Moreover, the boundary conditions on the border line of fast ice have been taken into account by setting the velocity component orthogonal to the border line equal to zero if the ice is drifting toward the fast ice.

The dynamics of ice is described by eq. (1). The acceleration term is small as compared to the others and has been neglected in present work. For example according to Buynitskij (1951) the ratio $m \frac{dv}{dt}/\overline{\tau}_a$ is of order $2 \cdot 10^{-3}$. Also the gravitational force is small since the tilting angles of the surface are negligible. In addition $\overline{\tau}_w$ had to be disregarded because of lack of knowledge of surface drifts. However, it can be a significant dynamical factor, which we wish to be able to account later. Thus the eq. (1) has been reduced to

$$\overline{\tau}_a + \overline{C} + \overline{R} = 0 \tag{8}$$

The Coriolis force $\overline{C}$ is well known as soon as the mass and velocity of ice are specified.

The wind stress has been estimated by the formula

$$\overline{\tau}_a = \rho_i C_{10} \overline{W}_{10} |\overline{W}_{10}| \tag{9}$$

where $\overline{W}_{10}$ is the wind velocity at the height of 10 metres. This estimation is somewhat rough and the statistical description of surface wind is just being developed. The coefficient C_{10} is strongly dependent on surface features of ice and has to be estimated separately for different types of ice. The values of surface wind velocity at the sea have been obtained through extrapolation based on the values on coastal stations. The coastal effects on wind velocity have not been taken into account and some inaccuracy may be due to this fact.

However, the most significant uncertainty is involved in the term $\overline{R}$ that describes the force caused by the internal stress of the ice field. The full mathematical description based on the material properties of ice and statistical distributions of thickness and size of ice floes is too complex to be carried out.

Therefore some suitable phenomenological expression must be used. In his article Doronin uses the formula

$$\bar{R} = \alpha \nabla \cdot (N \nabla \bar{v}) \qquad (10)$$

where $\bar{v}$ is the velocity of ice and α is a constant. With concentration N near to the value 1 we expect the internal stress to be strongly dependent on H. Therefore the present preliminary calculation was made using the formula suggested by Udin

$$\bar{R} = \alpha_0 (1 + \mu H^2) \nabla \cdot (N \nabla \bar{v}) \qquad (11)$$

where α_0 and μ are coefficients to be determined by testing the model. However, we suggest a new expression for $\bar{R}$ that takes into account also the effect of thermodynamics on the motion of ice.

$$\bar{R} = k \left[N T_0 + (1 - N) (T_f - T) \right] H^{\beta} N^{\gamma} \nabla \cdot N \nabla \bar{v} \qquad (12)$$

where T_f is the freezing temperature and k, T_0, γ and β are the empirical parameters. When N is small there is only few distinct ice floes and their interaction is negligible. Hence $\bar{R} \sim 0$. When N approaches unity, great increase in $\bar{R}$ is expected. The simpliest function to describe this kind of behaviour is the power function and therefore N-dependence is taken to be of form N^{γ} . Also in the case of very thin ice $\bar{R}$ is small because the ice breaks very easily and therefore the internal stress cannot be great. A simple quess is again made putting $\bar{R} \sim H^3$. When N is small the formation of new ice tends to decrease the mobility of ice. The rate of freezing is proportional to T_f - T. Hence $\bar{R}$ is supposed to be proportional to T_f - T for small N. For N near to the value 1, on the other hand, the effect of thermodynamics is small and $\bar{R}$ is thus expected to be independent of T when N approaches unity. In the case $T > T_f$, T shall be put = T_f in order to avoid negative stress values in the calculations. Experiments using eq. (12) are going on for improving the model.

TESTING THE MODEL WITH REAL DATA

The numerical solution of the model (equations (6), (7), (8) and (11)) was programmed in Algol-Genius language and the programme was run on Datasaab D22 computer. The ice situation in the Bothnian Bay and the Quark 1.3. - 15.3.1973 was chosen for real data. Values $s_1 = 20'$, $s_2 = 10'$ ($\sim$18 km) were taken for the grid and t = 6 h for the time step. According to Courant-Friedrichs-Lewy criterion the numerical solution is stable if the calculated ice velocity does not exceed 0.6 m/s. Such can happen only when the wind velocity is extraordinary high. The expression (11) for internal ice stress was used with coefficients $\alpha_0 \in (3\cdot10^8, 6\cdot10^8)$, $\mu \in (1,2)$. The data given to the programme was the initial values of concentration and thickness of ice at the beginning of the testing period and the wind fields every sixth hour. The drift velocity of ice was assumed to be zero in the beginning. Calculations were made till 8.3. and then, beginning with new initial values, till 15.3.

The Meteorological Situation

In the first week the wind was blowing between from south - south-east, with velocity of 5-10 m/s. At the end of the week the wind began turning south-west. In the second week the wind was a bit stronger blowing from south-west and west. The temperature of air had average values -5^o- -10^oC in the first and 0^o- $+2^o$C in the second week.

The Ice Situation (see figs. 1-5)

During the period 1.3. - 15.3.1973 there was fast ice in the archipelago in the Bothnian Bay and the Quark. In the description below, only ice outside the coastal fast ice field is considered.

March 1st the Bothnian Bay was covered with compact, 15 cm thick ice. Along the Finnish coast there was a narrow lead running past Kallan and Tankar. In the Quark the compact ice cover extended to the latitude of Valassaaret. South of the compact ice boundary there was open pack ice.

In the beginning of the week the wind was blowing from south-east and the lead in the Finnish coast widened. March fifth the lead, the width of which was 20-30 km, was running from Hailuoto to 20 km northeast of Nordvalen. North of Ulkokalla there was thin new ice. In the northern parts of the Bothnian Bay and at the Swedish coast the ice was ridged.

Further on, the wind was turning and a narrow lead was formed along the Swedish coast from Nygrån to Umeå. South of the line Ulkokalla-Bjuröklubb the ice was broken into floes. In the Quark there was broken and scattered ice. This was the situation March eighth, when new initial values were given to the programme.

The wind was blowing from south-west and west and the ice was moving east in the Bothnian Bay. March 12th there was compact ice in the northern part of the Bothnian Bay and in the eastern part south of Ulkokalla. The lead off the Swedish coast began from Norströmsgrund, by Bjuröklubb it was about 20 km wide, and in the Quark the width was 30-40 km. In the Quark there was also open pack ice.

March 15th the situation was much the same. The lead extended a bit further north and the thickness of the ridged ice in the very northern part of the Bothnian Bay exceeded one metre. South of Tankar the ice near the Finnish coast was broken into floes.

The Model - Discussion of the Results

As seen in the figures, the model has worked at least qualitatively well. The leads open in the model in the same areas as in reality. Ridged ice and rafted ice can be seen in the model when the thickness becomes comparatively high; also in this case the model usually gave correct results. The biggest discrepancies are met with open pack ice and broken ice. Also the boundaries are smoother in the model than in the real situation. At a few special gridpoints (like in the edge of fast ice) the calculations gave unrealistic results when 5-7 days had passed.

In the figures 2-3 model forecasts and real situations are seen for the first week. The lead off the Swedish coast appears too small and off the Finnish coast somewhat too wide in the model. This is owing to ignoring the thermodynamics; new ice cover formed in this week in the lead north of Ulkokalla. So, the velocities of ice north of Ulkokalla were too high and the change in the direction of the velocity was too slow. Ridged ice in the model is in the right areas.

In the figures 4-5 forecasts and the real situations are seen for the second week. The main discrepancy is seen off the Finnish coast in the area Tankar-Helsingkallan. Also the lead off the Swedish coast is too wide in the northern part of the Bothnian Bay.

According to the calculations the velocity of ice was about 1-4 % of wind velocity. The direction of icedrift, owing to the coriolis effect, was 0°-15° to the right from the direction of wind.

DEVELOPING THE MODEL IN THE FUTURE

The main sources of errors in the model are (1) inaccuracies brought about when ignoring the effects of thermodynamics and sea currents (2) the errors in calculating the wind stress (3) the roughness of the initial values and (4) the approximation of internal ice stress. The attention in the future studies will be paid to (2) and (4). Situations where sources of errors (1) and (3) do not dominate will be simulated and confidence intervals for the parameters in the wind stress and internal ice stress functions will be sought. After this is done, the influences of thermodynamics and sea currents may be studied.

The numerical solution of the system of differential equations is stable in "normal" situations. When the velocity of wind is very high, shorter time-steps must be applied. Some work will be done to develop the numerical solution - especially in special areas like near the coastline and at the edge of compact ice and open water. To make the numerical solution more stable shorter distances between the grid points in the Quark are needed.

Still, there is a statistical problem in approximating the initial values of ice thickness and concentration with the help of a few observations. This work becomes important when real forecasts are made.

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Jään liikkeen laskeminen Perämerellä ja Merenkurkussa

Jään liikkeelle konstruoidun mallin avulla voidaan laatia lyhyen tähtäimen (1-7 vrk) ennusteita jään nopeudelle $\bar{v}$, paksuudelle H ja konsentraatiolle N (jään peitossa oleva suhteellinen osuus alueesta, $0 \le N \le 1$). Tietämys eräiden tekijöiden vaikutuksesta jään liikkeeseen on vielä sangen puutteellinen, minkä vuoksi mallia on jouduttu yksinkertaistamaan. Lisäksi saatavissa olevien havaintojen määrä rajoittaa mallin käyttöä todellisissa olosuhteissa.

Mallin kuvaus

Jään liikkeen dynaaminen yhtälö on muotoa (1), missä m on jään massa yksikköalueessa, $\bar{\tau}_a$ on tuulen ja $\bar{\tau}_w$ veden paine, $\bar{C}$ coriolisvoima, $\bar{G}$ painegradientti ja $\bar{R}$ jään sisäinen paine. Tuulen paine riippuu tuulen nopeudesta ja jään yläpinnan laadusta; vastaavasti veden paine riippuu veden virtausnopeudesta ja jään alapinnan laadusta. Maapallon pyörimisestä johtuva coriolisvoima riippuu jään nopeudesta ja massasta; coriolisvoiman vaikutuksesta jään liikesuunta poikkeaa hieman oikealle tuulen suunnasta. Painegradientti riippuu merenpinnan kaltevuudesta. Jään sisäistä painetta ei vielä kovin tarkasti tunneta. Se on lähinnä jään liikkeen ja massan funktio (erilaisia yritteitä yhtälöissä (10) - (12)).

Jatkuvuusyhtälön (2) pohjalta on johdettu yhtälöt (6) - (7) jään paksuudelle ja konsentraatiolle. Näissä on jo termodynamiikan osuus jätetty pois. Yhtälöitä (7) käytetään, kun jääkenttä on yhtenäinen (N=1) ja ahtautumista tapahtuu. Muulloin käytetään yhtälöitä (6).

Toistaiseksi on simuloinnissa käytetty mallina yhtälösysteemiä (6) - (8), (11). Yhtälöstä (1) on päästy (8):aan olettamalla eräitä termejä nollaksi. Painegradientti ja jään kiihtyvyys ovatkin mallin mittasuhteissa mitättömän pieniä. Sen sijaan veden virtauksen vaikutus jään liikkeeseen on merkitsevä, ja se on tarkoitus sovittaa malliin myöhemmin; tällä hetkellä siitä ei ole olemassa kyllin tarkkoja havaintoja.

Mallin avulla suoritettava ennustaminen

Mallin numeerinen ratkaisu sovellettuna Pohjanlahdelle on ohjelmoitu tietokoneelle. Numeerisessa ratkaisussa merialue on jaettu leveys- ja pituuspiirien mukaan verkkokaavioksi jaon tiheyden ollessa 10' leveys- ja 20' pituuspiireissä. Ohjelmalla lasketaan jään nopeus, paksuus ja konsentraatio verkon jokaisessa solmukohdassa kuuden tunnin välein. Lähtöarvoina annetaan ohjelmalle jäätilanne hetkellä 0 sekä tuuliennusteet.

Ennustusperiodin aikana kiintojään reunan oletetaan pysyvän likimain paikallaan. Eniten virhettä ennusteissa aiheuttaa veden virtauksen ja (kovan pakkasen sattuessa) jäätymisen huomiotta jättäminen.

Mallin testaus

Mallin testaamisessa valittiin vertailuaineistoksi jäätilanne Perämerellä ja Merenkurkussa 1.3. - 15.3.1973. Ohjelmalle annettiin jäätilanne 1.3. ja ennustus ulotettiin yhteen viikkoon; 8.3. annettiin uudet lähtöarvot, joiden pohjalta ennustettiin 15.3. asti. Kuvioissa 1-5 on esitetty todelliset ja mallista lasketut jäätilanteet.

Ensimmäisellä viikolla tuuli vaihteli idän ja etelän välillä nopeuden ollessa 5-10 m/s. Toisella viikolla tuuli oli hieman voimakkaampi ja kääntyi länteen päin. Ilman lämpötila oli ensimmäisellä viikolla keskimäärin -5^{o} - -10^{o}C ja toisella 0^{o}-$+2^{o}$C.

Kuviossa 1 on lähtötilanne 1.3.. Perämeri oli kauttaaltaan yhtenäisen jääkentän peitossa. Suomen rannikolla oli Tankarin ja Kallanin ohitse kulkeva railo, ja Merenkurkun eteläosassa oli hajanaista ajojäätä.

Ensimmäisellä viikolla railo Suomen rannikolla leveni, ja viikon lopulla avautui railo myös Ruotsin rannikolle. Ajojää Merenkurkussa siirtyi pohjoiseen päin. Pohjoisella Perämerellä jää ahtautui. Suomen rannikon puoleiseen railoon syntyi uutta jäätä. Mallissa on pääasiallinen poikkeama railojen leveydessä (kuviot 2-3), mikä johtuu siitä, ettei railossa tapahtunut jäätyminen voinut ilmetä mallista.

Toisella viikolla Ruotsin rannikon puoleinen railo leveni, ja Suomen puoleinen railo meni umpeen. Merenkurkkuun jäi ajojäätä, ja pohjoisella Perämerellä tapahtui ahtautumista. Kuvioista 4-5 nähdään, että poikkeama on taas suurin railon leveydessä.

Yhteenvetoa

Kuvioista ilmenee, että malli antoi ainakin oikeansuuntaisia tuloksia. Railojen leveyksissä oli poikkeamia, ja lisäksi konsentraation muutokset jääkentässä olivat mallissa loivempia kuin todellisuudessa. Paksuustuloksissa oli myös poikkeamia, mutta niiden suuruudesta ei voida sanoa paljon vertailuaineiston puutteellisuuden vuoksi.

Lähitulevaisuudessa on tarkoitus parantaa nykyistä mallia tarkentamalla tuulen paineen ja jään sisäisen paineen arvioita. Myöhemmin tullaan kiinnittämään huomiota veden virtauksen ja termodynamiikan mukaanottamiseen.

Beräkning av isdriften i Bottenviken och Norra Kvarken

Med hjälp av modellen för isdrift kan man utföra prognoser på kortsikt (1-7 dygn) för isens hastighet $\overline{v}$, tjocklek H och koncentration N (relativ andel av istäcke i ett område). Kännedomen om några faktorers inverkan på isdriften är ännu bristfällig, varför man har måst förenkla modellen. Härtill begränsar antalet föreliggande observationer modellens användning i verkliga situationer.

Beskrivning av modellen

Isdriftens dynamiska ekvation är av formen (1), där m är isens massa per enhetsyta, $\overline{\tau}_a$ är vindstressen på övre isytan och $\overline{\tau}_w$ vattenstressen på undre isytan, $\overline{C}$ corioliskraften, $\overline{G}$ tryckgradienten och $\overline{R}$ interna isstressen. Vindstressen beror på vindens hastighet och övre isytans kvalitet; liksom vattenstressen beror på vattnets strömninghastighet och undre isytans kvalitet. Corioliskraften följer av jordens rotation och den beror på isens hastighet och massa; corioliskraftens inverkar så, att riktningen av isdriften viker av i vindriktningen litet till höger. Tryckgradienten beror på lutande havsyta. Interna isstressen är inte ännu väl känd. Den är en funktion av isdrift och ismassa (olika försök i ekvationer (10) - (12)).

På grund av kontinuitetsekvation (2) har man skrivit ekvationerna (6) - (7) för isens tjocklek och koncentration. I dessa är termiska effekter redan bortlämnade. Ekvationen (7) används, när isfältet är enhetligt och isen konvergerar. Eljest används ekvationen (6).

Tillsvidare har man använt ekvationssystemet (6) - (8),(11) som modell vid simulering. Från ekvationen (1) har man kommit till (8) genom att antaga några termer vara noll. Tryckgradienten och accelerationen är mycket små i modellens skala. Däremot är inverkan av vattens strömming på isdriften betydande, och den skall inläggas i modellen i framtiden; i detta nu finns det inte tillräckligt noggranna observationer.

Prognosering med hjälp av modellen

Den numeriska lösningen av modellen tillämpad i Bottniska viken är programmerad för datamaskin. I den numeriska lösningen har man delat havsområdet enligt latituder och longituder i ett nät så att delningens täthet är 10' i latituder och 20' i longituder. Med programmet beräknas isens hastighet, tjocklek och koncentration i varje knutpunkt av näten och var sjätte timme. Som begynnelsevärden ges issituation vid tiden noll och vindprognoser till programmet.

Under prognoseringsperioden antas, att randen av landfast is håller sig ungefär på sin plats. Felen i prognosen följer framför allt av att man inte iakttar vattnets strömning och (vid stark köld) frysning.

Testning av modellen

Vid testning av modellen valdes issituationen i Bottenviken och Norra Kvarken 1.3. - 15.3.1973 som jämförelsematerial. Till programmet gavs issituationen 1.3. och prognoser utfärdes för en vecka; 8.3. gavs nya begynnelsevärden, med hjälp av vilka prognoserades till 15.3.. I figurerna 1-5 finns de verkliga och beräknade issituationerna.

Under första veckan var vinden mellan sydlig och östlig, hastigheten var 5-10 m/s. Under andra veckan var vinden litet hårdare och gick till västlig. Lufttemperaturen var i medeltal -5°- -10°C under den första och 0°- $+2^{\circ}$C under den andra veckan.

I figuren 1 visas initialsituationen 1.3.. Bottenviken var helt och hållet täckt av ett enhetligt isfält. Vid finska kusten gick en råk förbi Tankar och Kallan, och i södra delen av Norra Kvarken fanns det spridd drivis.

Under första veckan blev råken vid finska kusten bredare, och i slutet av veckan öppnades en råk också vid svenska kusten.

Drivis i Norra Kvarken drev norrut. I norra Bottenviken packades isen. I råken på finska sidan bildades ny is. I modellen finns den förnämsta avvikelsen i råkarras bredde (figurerna 2-3), vilket följer av att frysningen i råken inte kunde komma till synes i modellen.

Under andra veckan blev råken vid svenska kusten bredare och råken på finska sidan grodde igen. I Norra Kvarken fanns det ännu drivis och i norra Bottenviken packades isen. I figurerna 4-5 ses, att avvikelsen är som störst igen i råkens bredd.

Sammandrag

Det framgår av figurerna, att modellens resultat sammanfaller med verkligheten ganska bra. Avvikelser visade sig i råkarnas bredd, och därtill var förändringar av koncentrationen skarpare i verkligheten än i modellen. I resultaten för istjockleken fanns det också avvikelser, men om deras storlek kan inte sägas mycket, ty jämförelsematerialet är bristfälligt.

I närmaste framtid är syftet att förbättra den nuvarande modellen genom att precisera approximationer för vindstressen och interna isstressen. Senare skall man ta hänsyn till vattnets strömning och termodynamik.

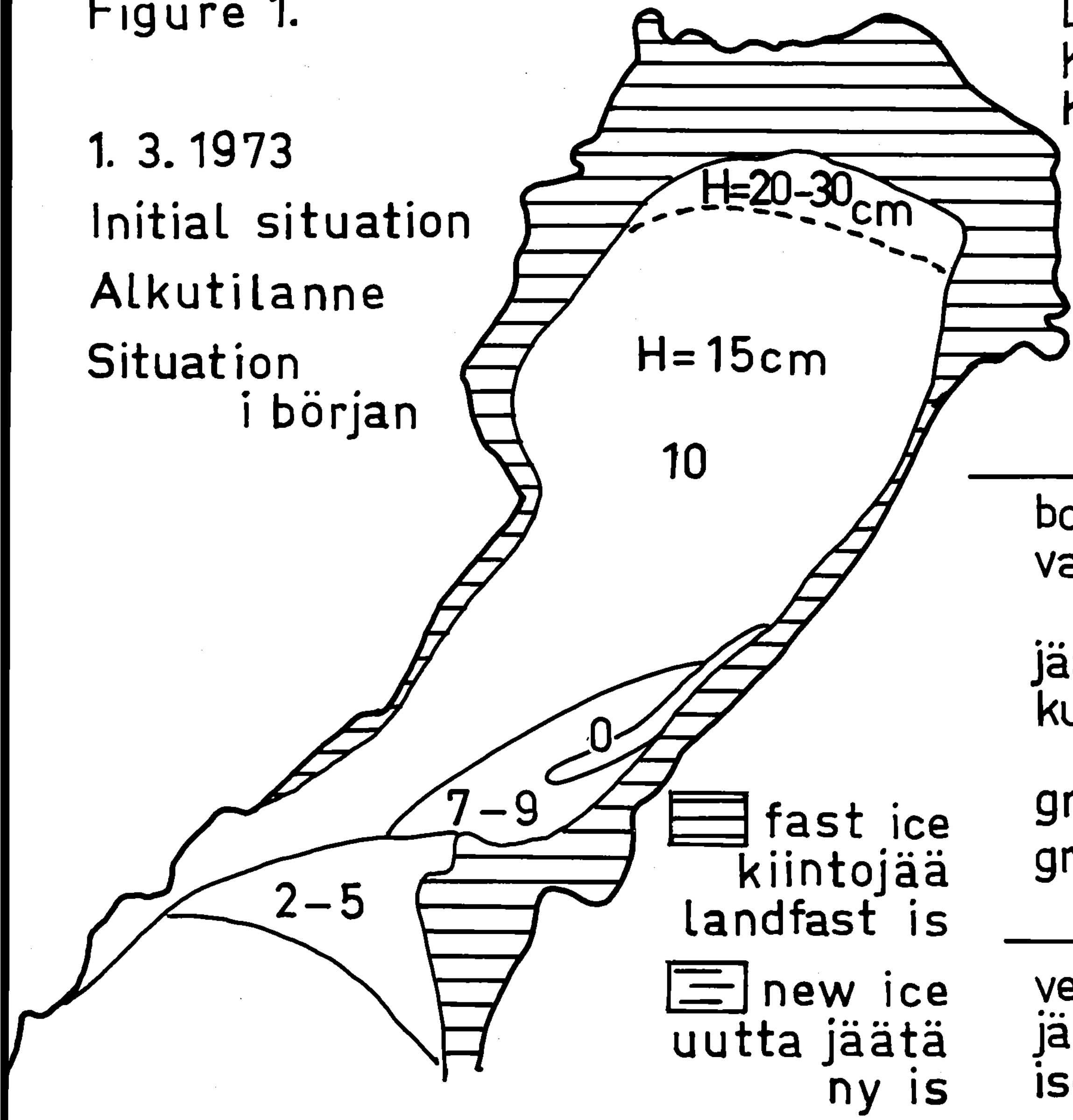
Figure 1.

1. 3. 1973

Initial situation

Alkutilanne

Situation
i början



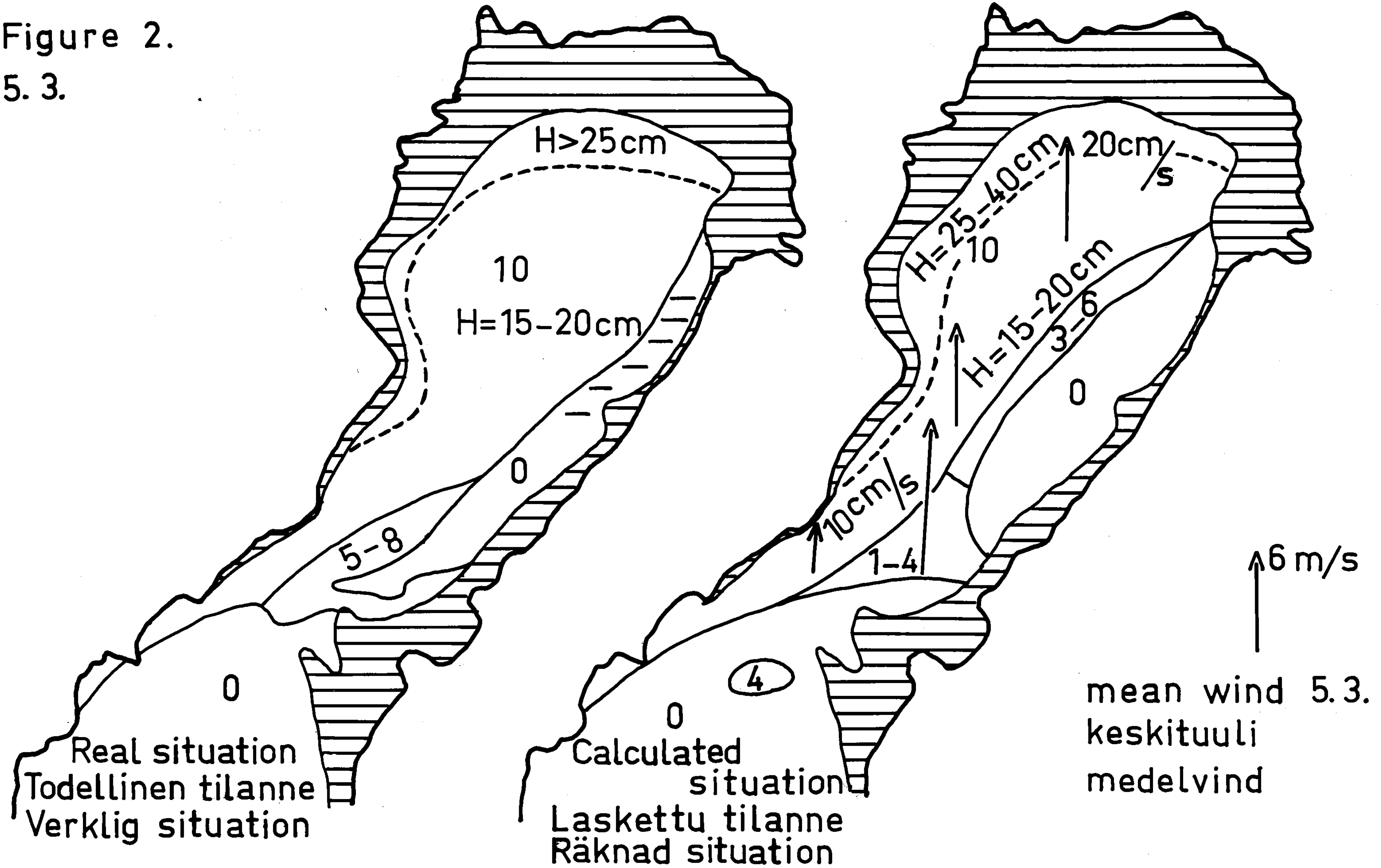
Description of maps (figures 1–5)
Karttaselitys (kuviin 1–5)
Kartbeskrivning (bilder 1–5)

\- - - - - -
boundary of areas differing in thickness, value given in each area by H= (cm)
jään paksuuden raja, paksuuden arvo ilmoitettu kussakin alueessa H= (cm)
gränsen av områden med olika tjocklekar värdet avgivet i varje område av H=(cm)

———
boundary of areas differing in concentration, value given in each area by a bare number (scale 1–10)
jään konsentraatioasteen raja, arvo ilmoitettu kussakin alueessa paljaana lukuna (asteikko 1–10)
gränsen av områden med olika koncentrationsgrader, värdet avgivet i varje område med bar siffra (skala 1–10)

⟶
velocity vector of ice (cm/s)
jään nopeusvektori (cm/s)
isens hastighetsvektor (cm/s)

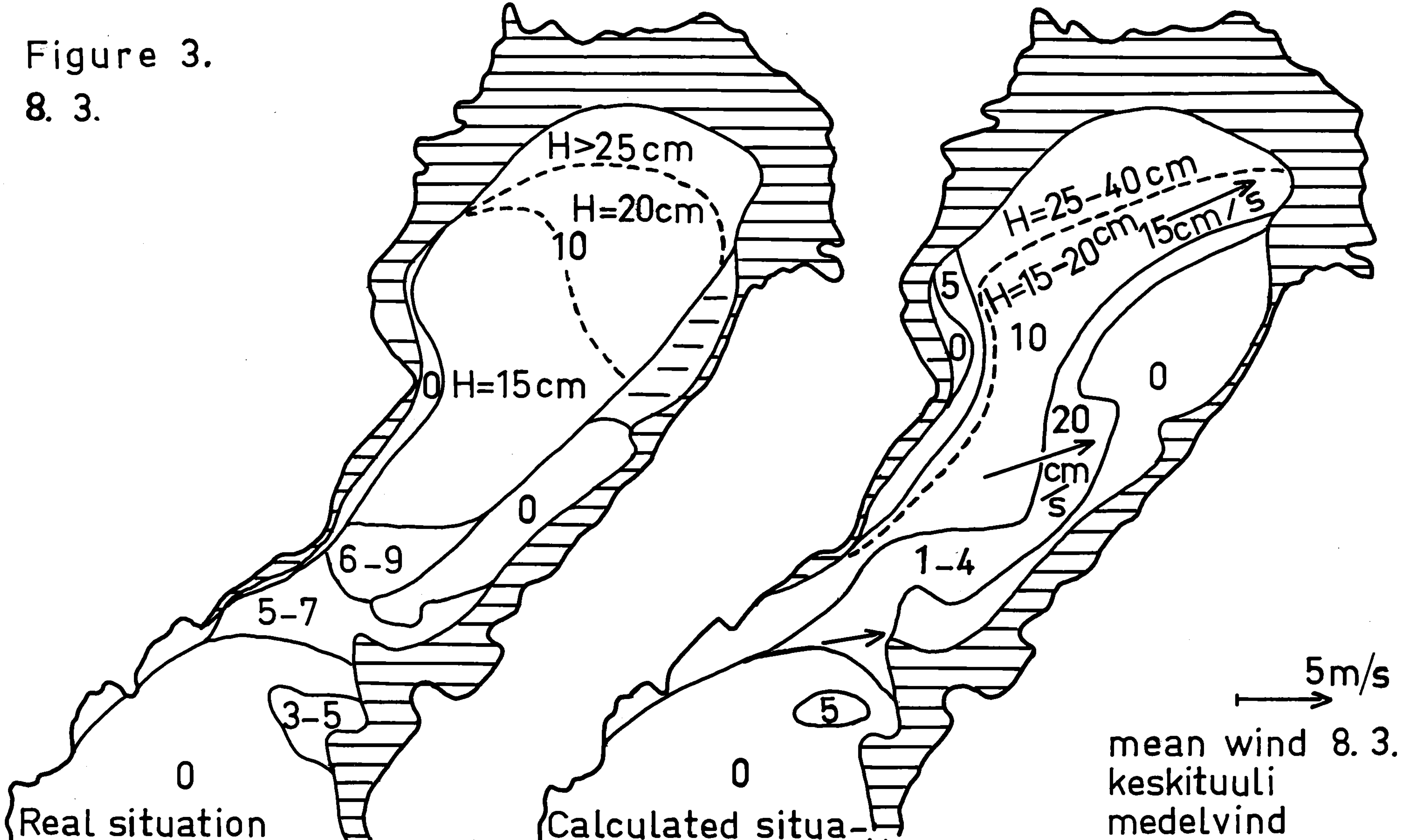
Figure 2.
5.3.



Real situation
Todellinen tilanne
Verklig situation

Calculated situation
Laskettu tilanne
Räknad situation

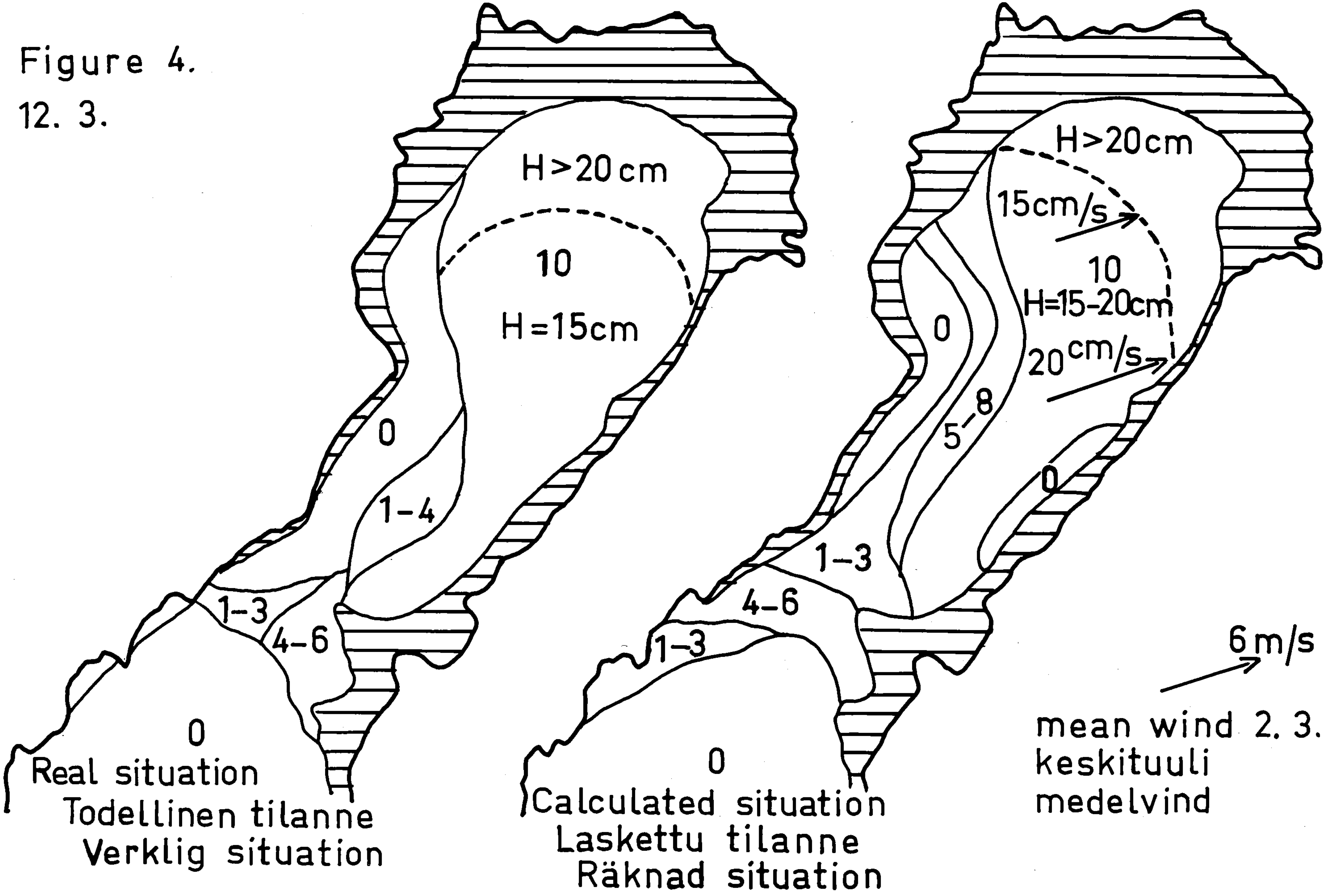
Figure 3.
8. 3.



Real situation
Todellinen tilanne
Verklig situation

Calculated situation
Laskettu tilanne
Räknad situation

Figure 4.
12. 3.

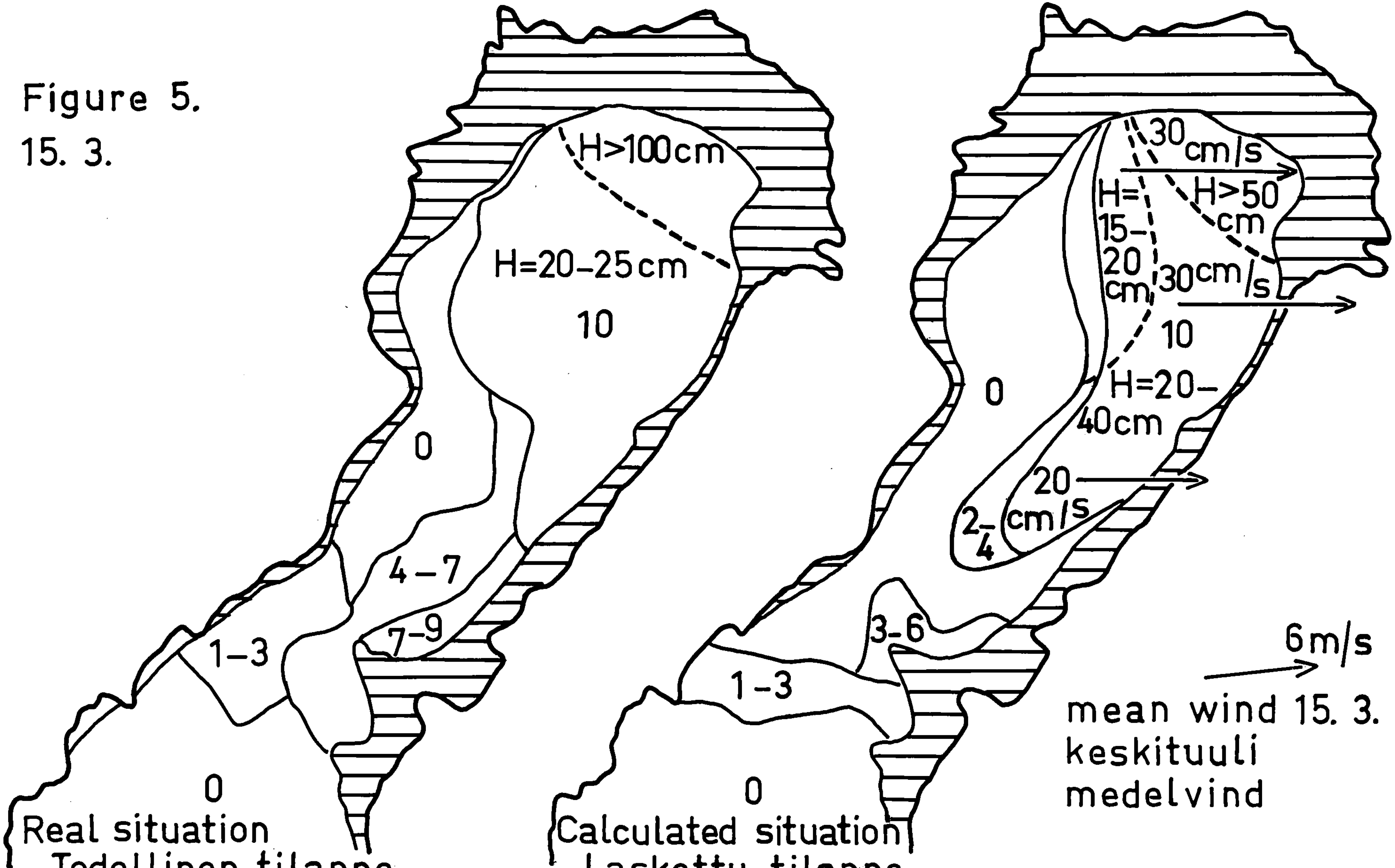


Real situation
Todellinen tilanne
Verklig situation

Calculated situation
Laskettu tilanne
Räknad situation

mean wind 2. 3.
keskituuli
medelvind

Figure 5.
15. 3.



Real situation
Todellinen tilanne
Verklig situation

Calculated situation
Laskettu tilanne
Räknad situation

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