Note

Optimizing Sound Speed Profiling for Hydrographic Surveys

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Abstract

The IHO Standards for Hydrographic Surveys (S-44) requires that hydrographic surveys account for sound speed uncertainties in order to determine the Total Propagated Uncertainty. If variations in sound speed are significant, the horizontal and vertical position of a sounding can vary by as much as several meters.

Refraction artefacts can be typically dealt with in post-processing. This can be time consuming and require specialized processing expertise, especially in area of significant bathymetric relief and/or environmental variations in the water column.

In this paper, we examine the application of recent advances in refraction based uncertainty to the ODIM Moving Vessel Profiler (MVP) controller software in order to optimize sound speed profiling operations.

Résumé

Les normes de l'OHI pour les levés hydrographiques (S-44) exigent que les levés hydrographiques tiennent compte des incertitudes liées à la vitesse du son afin de déterminer l'incertitude totale propagée. Si les variations de la vitesse du son sont importantes, la position horizontale et verticale d'une sonde peut subir des variations de l'ordre de plusieurs mètres.

D'une manière générale, les éléments de réfraction peuvent être pris en compte dans le cadre du post-traitement. Ceci peut prendre un certain temps et requiert des compétences spécialisées dans le traitement, notamment pour un relief bathymétrique significatif et/ou pour des variations environnementales dans la colonne d'eau.

Dans cet article, nous examinons l'application des dernières avancées en matière d'incertitude basée sur la réfraction, au logiciel MVP (enregistreur de profils à partir d'un navire en mouvement) d'ODIM afin d'optimiser les opérations de détermination des profils de la vitesse du son.

Resumen

Las Normas de la OHI para Levantamientos Hidrográficos (S-44) requiere que los levantamientos hidrográficos tengan en cuenta la cuenta la incertidumbre sobre la velocidad del sonido con el objeto de determinar la Incertidumbre Total Propagada. Si las variaciones en la velocidad del sonido son significativas, la posición horizontal y vertical de una sonda puede variar tanto como varios metros.

Típicamente se puede considerar los elementos refractarios durante el post procesado. Esto puede tomar tiempo y requerir experiencia especializada en procesamiento, especialmente en áreas de relieve batimétrico significativo y/o variaciones ambientales en la columna de agua.

En este trabajo examinamos la aplicación de recientes progresos en la determinación de las incertidumbres basado en la refracción con el software de control del Perfilador del Movimiento de la Nave ODIM (MVP) con el objeto de optimizar las operaciones de perfilar la velocidad del sonido.

Introduction

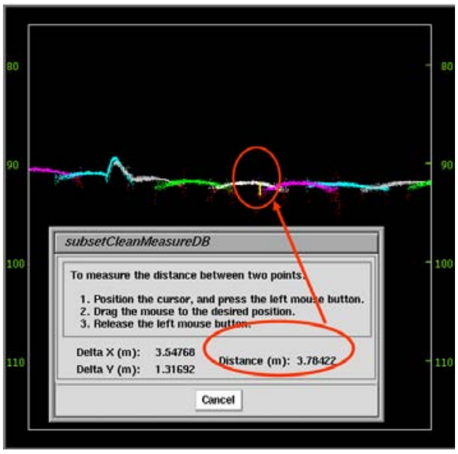
An important component to determining the Total Propagated Uncertainty (TPU) of a sounding is an understanding of the speed of sound through the water column. This is particularly true with multibeam surveys where the outermost soundings in the swath are subject to potentially large uncertainties resulting from an incorrect refraction correction due to poor knowledge of the spatial and temporal variations in the oceanographic properties that control the speed of sound. If variations in sound speed are significant, the horizontal and vertical position of a sounding can vary by as much as several meters. In such challenging situations, repeated and close observations of the sound speed are warranted in order to properly acquire and process multibeam data (Hughes Clarke et al, 2000; Cartwright 2003; DaSilva, 2001; Batton, 2004). It is thus essential that the hydrographer has a good understanding of the oceanographic characteristics of the survey area in order to monitor relevant changes in the water column and make the necessary observations to adequately correct for the refraction effects due to sound speed variations.

The introduction of the Moving Vessel Profiler (MVP) has shown that sound speed profiles can be collected at a high spatial and temporal resolution while the survey vessel is under way (Furlong et al, 1997). In this paper, we examine the application of recent advances in refraction based uncertainty to the MVP controller software. The addition of these advances allow for an optimization of the system such that sufficient sound speed profiles can be acquired to maintain a desired sounding accuracy while simultaneously minimizing the number of sound speed casts required to do so.

Refraction: Cause and Effect

The IHO Standards for Hydrographic Surveys (Special Publication S-44) requires that hydrographic surveys account for sound speed uncertainties in order to determine the TPU (which includes the THU (Total Horizontal Uncertainty) and TVU (Total Vertical Uncertainty)). The CHS and NOAA both stipulate in their field procedures and deliverables that the TPU of a sounding be determined (NOAA 2008 Field Procedures Manual; CHS Standards for Hydrographic Surveys). In many cases, charting agency survey requirements place the onus on the contractor (or the hydrographer) to provide all the necessary methods and processes such that the deliverable hydrographic data meet a desired accuracy standard. However, it can be argued that in regions of significant bathymetric relief, it is quite difficult to determine from processed data sets if sound speed uncertainties are properly modelled.

Figure 1 shows the familiar effect of inadequate sound speed information on multibeam data. In this particular instance of 90m water depths, the vertical spread between the outer beam sounding and the nadir beam is more then 3m[1]. Observation and analysis of this type of effect is relatively easy when the seafloor is flat. In this case, the decision to conduct sound speed casts more often is well supported.



To measure the distance between two points:

1. Position the cursor, and press the left mouse button.
2. Drag the mouse to the desired position.
3. Release the left mouse button.

Delta X (m): 3.54768
Delta Y (m): 1.31692
Distance (m): 3.78422

Figure 1: Bathymetric effect of unmodelled sound speed in flat seafloor

In the case of complex seafloor topography, it is more difficult to determine biases in bathymetry attributable to poorly modelled sound speed information as these could be masked by significant topographic variations.

Figure 2 shows the tidally driven change in the water column salinity in 4 sections of the Rotterdam shipping channel (each section is ~10km in length, water depth is ~15-25 m). The data were collected as a result of several hundred ODIM MVP30 casts with each section collected at different stages of the tide over a 3 day period (Beaudoin, 2009). The images illustrate that taking sound speed profiles once every several hours is not sufficient to capture the potentially large refraction effects associated with tidal influences.

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[1] Data provided by NOAA's Office of Coastal Surveys.

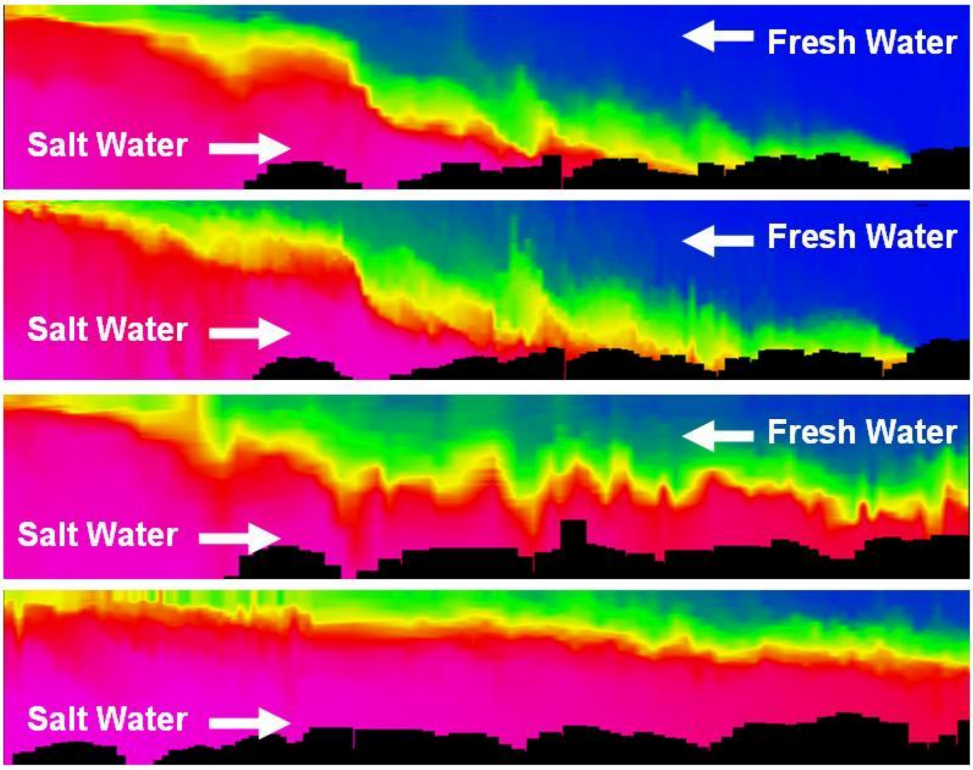


Figure 2: Sound speed variations resulting from tidal effects

Consequently, without a very good understanding of the oceanographic characteristics of the survey area it is inadvisable in many cases to assume that a limited amount of sound speed profiles will prove sufficient to meet the survey accuracy requirements.

The NOAA 2008 Field Procedure's Manual states:

> *"... the measured sound speed uncertainty depends on the spatial and temporal environmental variability and the frequency at which sound speed casts are taken. Typically, the amount of time required to obtain additional sound speed profiles is far less than that required to edit, or otherwise "fix", data afflicted with acoustic refraction artifacts."*

To this end, the ODIM MVP (Moving Vessel Profiler) has been introduced as a means of increasing spatial and temporal sound speed profiles though an integrated, real-time, and automated "vessel underway" winching system.

Real-time Water Column Profiling

The ODIM Moving Vessel Profiler (ODIM MVP) greatly enhances the productivity of CTD, Sound Speed and other specialized profiling by allowing water column casts to be conducted from an underway vessel. The ODIM MVP consists of sensors housed in a small, streamlined free fall fish, a conductor cable with strength member, a computer-controlled high speed hydraulic winch and a complete cable metering, launching and docking system. The sensor information is transmitted in real-time through the conductor cable to the survey vessel for immediate input into the multibeam collection system (and of course, for data processing).

The ODIM MVP allows the free fall fish to fall near-vertically. Deployment is executed under computer control and can be restrained by three parameters:

1) desired depth of cast,
2) preset height above the bottom, or
3) maximum cable out.

Using this concept, the system can achieve a much deeper depth for a given vessel speed than a comparable towed system. Once the programmed downcast depth has been reached, the fish is towed near the surface where it can be recovered or redeployed.

Figure 3a shows the MVP200 presently installed on board one of the Survey Motor Launches (SML) of the Royal Australian Navy (RAN). Figure 3b provides the Graphic User Interface of the MVP system labelling the relevant integrated system components.

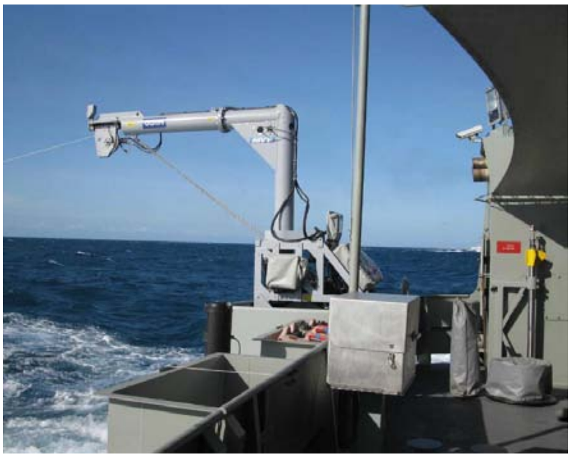
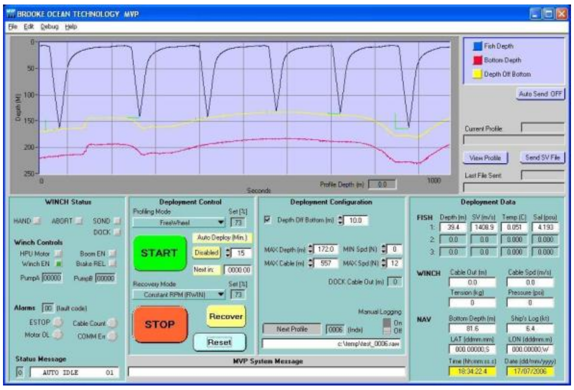


Figure 3a: ODIM MVP200 on RAN SML



Profile Depth (m) 0.0

Current Profile

Last File Sent

PumpA 00000 PumpB 00000

Alarms 00 (fault code)

Status Message 0 AUTO IDLE 01

Profiling Mode Freewheel Set [%] 73

Auto Deploy (Min.) Disabled 15

Next in: 0000:00

Recovery Mode Constant RPM (RWIN) Set [%] 73

☑ Depth Off Bottom (m) 10.0

MAX Depth (m) 172.0 MIN Spd (N) 0

MAX Cable (m) 557 MAX Spd (N) 12

DOCK Cable Out (m) 0

Manual Logging On Off

Next Profile 0006 (Index)

c:\temp\test_0006.raw

FISH	Depth (m)	SV (m/s)	Temp (C)	Sal (psu)
1:	39.4	1408.9	0.051	4.193
2:	0.0	0.0	0.000	0.000
3:	0.0	0.0	0.000	0.000

WINCH

Cable Out (m) 0.0 Cable Spd (m/s) 0.0

Tension (kg) 0 Pressure (psi) 0

NAV

Bottom Depth (m) 81.6 Ship's Log (kt) 6.4

LAT (ddmm.mm) 000.00000,S LON (dddmm.m) 000.00000,W

Time (hh:mm:ss.s) 18:34:22.4 Date (dd/mm/yyyy) 17/07/2006

Figure 3b: ODIM MVP200 Graphic User Interface

Figure 3b illustrates the advantages of a fully integrated system of the ODIM MVP sensor configuration into the survey vessel multibeam and GPS systems. The result is significant time savings in data transfer and mulitbeam processing.

Optimizing Sound Speed Profiling using an Uncertainty Wedge

Refraction artifacts can be typically dealt with in post-processing, this is time consuming and requires significant processing expertise.

The approach taken here is to monitor and assess refraction artifacts in real-time by monitoring the sound speed variability that is the cause of the artifact. This involves isolating the ray tracing portion of the depth reduction procedure and computing the bias in sounding depth and horizontal position that would be incurred had the most recent profile NOT been collected, i.e. the previously collected cast had been used instead (Beaudoin, 2008). *Figure 4* demonstrates the potential bias involved with using an outdated sound speed profile in the place of a more recently collected profile.

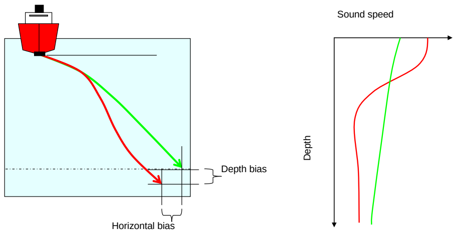


Figure 4: refraction based bias due to changing watercolumn conditions

As the potential bias can vary dramatically with depth and incidence angle, it is computed over the entire potential sounding space, from sounder to seafloor and across the entire angular sector. This allows for the creation of a wedge-shaped bias lookup table ("uncertainty wedge") which can be used to determine which, if any, portions of the mapped sector are suffering from unacceptable biases.

A visualization of the interrelationship of the "uncertainty wedge" with survey specifications (e.g. IHO S-44 Survey Specifications) and a multibeam swath is illustrated in Figure 5 (Beaudoin, 2008).

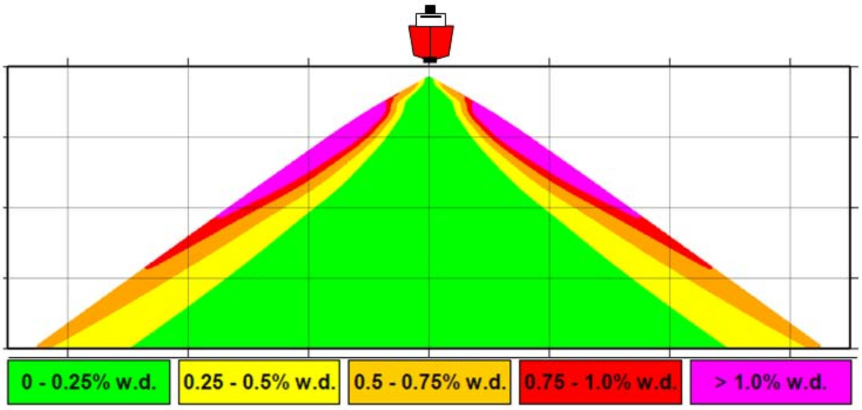
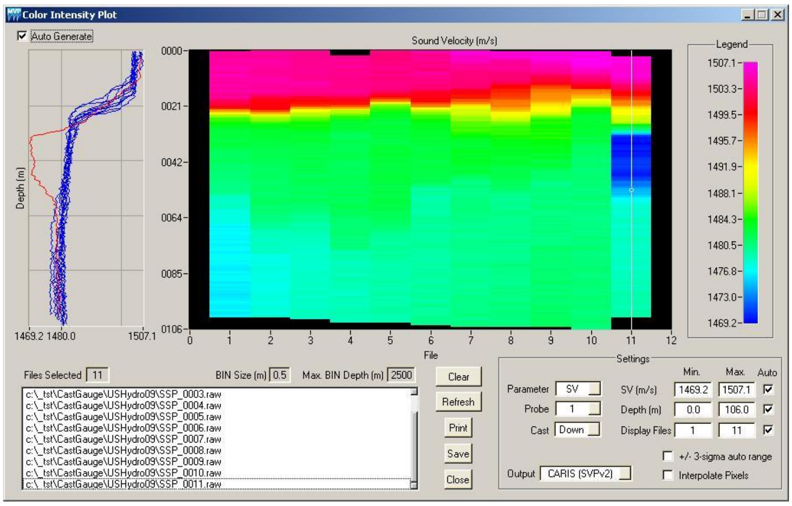


Figure 5: Sound Speed "Uncertainty Wedge" (Beaudoin, 2008)



☑ Auto Generate

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Settings

Parameter SV
Probe 1
Cast Down
Output CARIS (SVPv2)

	Min.	Max.	Auto
SV (m/s)	1469.2	1507.1	☑
Depth (m)	0.0	106.0	☑
Display Files	1	11	☑

☐ +/- 3-sigma auto range
☐ Interpolate Pixels

Figure 6: ODIM MVP along track Sound Speed

By comparing sequential pairs of sound speed casts, the hydrographer can ascertain if the current profiling rate is sufficient for maintaining accuracy. With the "uncertainty wedge" the hydrographer is acutely aware of the impact sound speed collection rates on sounding accuracies. Using this tool to monitor sound speed variability has the potential to greatly reduce refraction artifacts in the raw data – thus minimizing post-processing efforts.

The MVP "CAST Gauge" Advantage

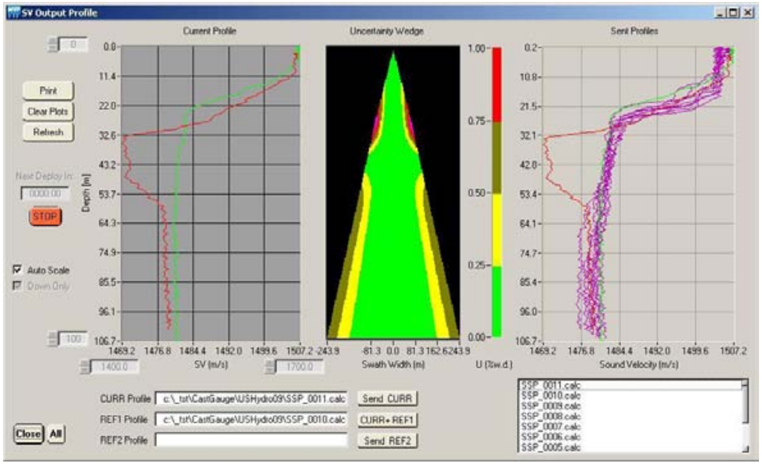
The benefits of this approach are realized when we integrate the concept to the ODIM MVP technology. The goal is to provide a mechanism that will enable the hydrographer to predict when to make a sound speed cast based on quantifiable information such as the sounding uncertainty due to changing water column conditions as observed along a sequence of casts performed by the MVP in real-time.

Again, it is clarified here that the uncertainly value in this context is the difference between the "truth" or epoch 2 sound speed profile, to the sound speed profile of epoch 1. No consideration at this point is given to measurement uncertainty of the sensor itself.

Figure 6 shows a sequential set of sound speed casts collected using an ODIM MVP200.

The color intensity plot is an intuitive graphical presentation of sound speed variability over a survey line. The observed sound speed color legend is shown on the right. When set to automatically update, the image of the developing variability is updated in real-time.

Each file represents a cast and each display will represent the accumulated casts taken over a line.



☑ Auto Scale
☑ Down Only

CURR Profile c:_tst\CastGauge\USHydro09\SSP_0011.calc
REF1 Profile c:_tst\CastGauge\USHydro09\SSP_0010.calc
REF2 Profile

SSP_0011.calc
SSP_0010.calc
SSP_0009.calc
SSP_0008.calc
SSP_0007.calc
SSP_0006.calc
SSP_0005.calc

Figure 7: ODIM MVP "CAST Gauge"

Figure 7 shows the Uncertainty Wedge integrated with the MVP Controller software to form a **CAST** (Computer Assisted Sound speed Technology) **Gauge** for sound speed in the water column. The right side of *Figure 7* shows sequential water column sound speed profile plots over time. Focusing on the two distinct profiles on the left side of Figure 7, if profile # 11 (red) is the most recent profile with # 10 (green) being the previous profile, comparison of the two profiles using the "Uncertainty Wedge" (centre wedge image) shows that the difference is < 0.75% W.D. for the entire angular sector at the maximum survey depth. If a maximum of 1.00% W.D. uncertainty is assumed to be the cut-off, this means that the water column was adequately sampled between epochs #10 and #11.

The ODIM MVP **"CAST Gauge"** will greatly enhance the hydrographer's knowledge of the oceanographic environment in the survey area. This will reduce the overall cost of the survey by reducing the amount of time spent "fixing" sound speed artifacts in the multibeam data in addition to automating the acquisition of sound speed profiles while underway.

Summary

Due to potentially high spatial and temporal variability, the sound speed component of TPU is one of the most difficult parameters to monitor. To reduce this uncertainty it is recommended to increase sound speed profile acquisition rates. This approach is quite costly if it involves stopping a survey vessel. The ODIM MVP provides the advantage of automatically acquiring sound speed profiles while the survey vessel is underway and transporting that data to the multibeam system in real-time.

The software behind the MVP "**CAST Gauge**" (Computer Assisted Sound speed Technology) has been developed to optimize operational cost and at the same time monitor and maintain sounding accuracy. The "CAST Gauge" integrates the "Uncertainty Wedge" concept of computing and visualizing sound speed uncertainty by comparing ray path analysis from one epoch to the next and displaying this result in real-time. In this way the hydrographer can execute sound speed casts based on a near real-time quantitative analysis of sounding uncertainty and thus minimize the cost of maintenance and service on the MVP winch; as well the prime outcome which is a hydrographic survey that meets a desired accuracy standard.

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Biographies

Derrick R. Peyton is Director of Business Development at ODIM Brooke Ocean. He holds a Diploma in Surveying Technology, a BSc and MSc in Geodesy and Geomatics Engineering, and an MBA. He has acquired certification as a Professional Engineer in Canada, a Canada Lands Surveyor, and an IHO Category "A" Hydrographer. He has conducted various surveys on a world wide basis in disciplines that include offshore seismic and construction, port development, UNCLOS, cable & pipeline route, and nautical charting.

Jonathan Beaudoin is a PhD student studying with the Ocean Mapping Group (OMG) at the University of New Brunswick in Fredericton, New Brunswick. His main research interest is the application of oceanographic databases for multibeam surveying. Jonathan is also a research assistant for the ArcticNet project, which sees him involved in all stages of ArcticNet mapping operations in the Canadian Arctic. He holds bachelor degrees in Geomatics Engineering and Computer Science, both from UNB.

Mike Lamplugh works out of the Bedford Institute of Oceanography as a Hydrographic Project Manager with the Canadian Hydrographic Service. His first multibeam survey was in 1990. One of his more recent accomplishments (of which he is very proud) was to complete the northern inshore route along the Labrador coast. This project, started by the British Admiralty in 1932 took 75 years to complete. In August and September of 2009 he is working with the Danish aboard the Swedish icebreaker ODEN on the Canadian & Danish claims (UNCLOS) in the eastern Canadian Arctic in the vicinity of the North Pole.

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