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Thickness Retrieval of Deformed Sea Ice with Airborne EM
Error Evaluation using a 3D Finite Element Forward Model

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Sea Ice

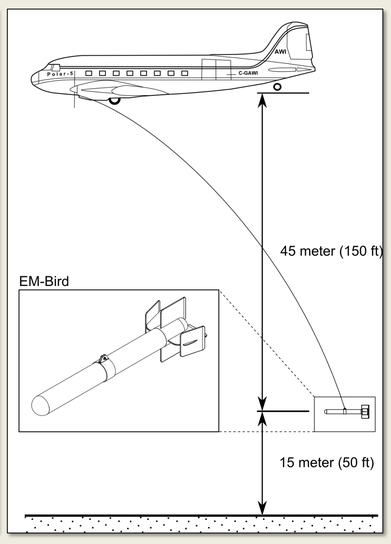
The sea ice cover is the interface between ocean and atmosphere has a significant impact on the polar climate system:

- surface albedo (intake of solar radiation)
- heat & momentum transfer between atmosphere and ocean
- saltwater formation & freshwater flux
- habitat for marine mammals & smaller organisms
- hazard to commercial operations

These properties are directly related to the thickness distribution of the ice cover. **Thickness information is sparse due to the remote location and demanding retrieval methods.**

Airborne EM Sea Ice Thickness Retrieval

Airborne electromagnetic (AEM) induction sounding is used for sea ice thickness retrieval from helicopters and fixed-wing airplanes. Since 2001, the Alfred Wegener Institute operates a towed frequency-domain EM sensor, the so-called EM-Bird.



Frequency
4 kHz

Coil Spacing
2.77 meter

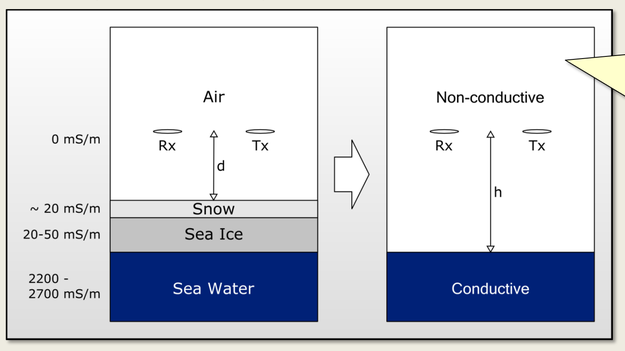
Footprint
40-50 meter

Recording Frequency
10 Hz

Laser Altimeter (100 Hz)

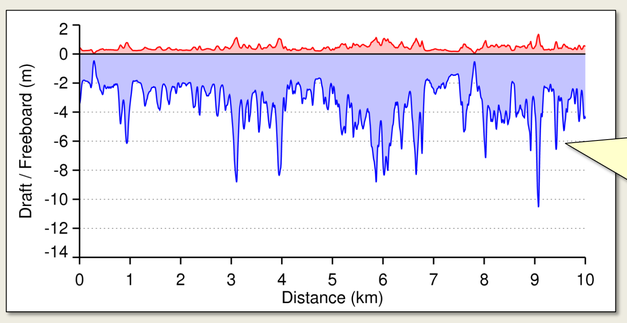
1D Ice Thickness Retrieval

The conductivity contrast between sea ice and sea water can be used to estimate the distance of the EM sensor to the ice-water interface assuming conditions of a homogenous halfspace. A laser altimeter measures the corresponding distance to the air-snow interface, yielding total (ice + snow) thickness.



1D assumptions:
- **Ice & Snow of negligible conductivity**
- **Ice level within footprint**

▶ **Homogenous halfspace**
(Only variable: sea water conductivity)



Typical sea ice thickness profile:
- **high spatial variability**
- **Thick ice: pressure ridges**

From in-situ validation data:
- **Underestimation of ridge thickness approx. 50 – 60 %**

Limitations of 1D Approach

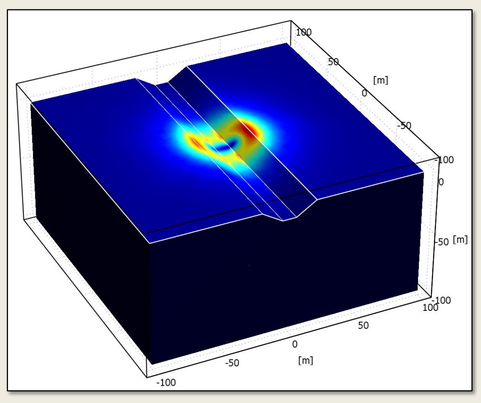
- Common ice deformation results in high thickness variability within EM footprint **(invalid 1D geometry assumption)**
- Salt water intrusion in blocky ice deformation structures **(invalid assumption of non-conductive sea ice layer)**

▶ **AEM ice thickness biased over deformed sea ice, which represents a large fraction of sea ice volume**

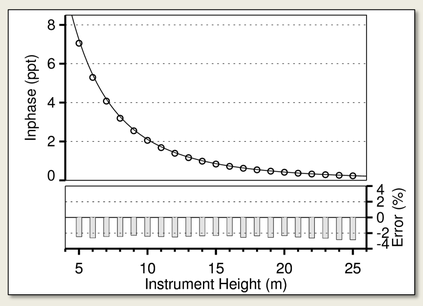
Error Estimation using a 3D Forward Model

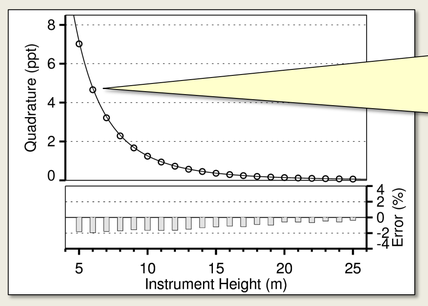
The Model:

Software	Comsol Multiphysics (AC/DC Module)
App. Mode	Magnetostatics (Magnetic Potential, Induction Currents)
Grid	Tetraheder (Finite-Elements)
Size	120k – 400k Elements
Computer	HP Workstation (2 Xeon-CPU's, 20 GB Ram)



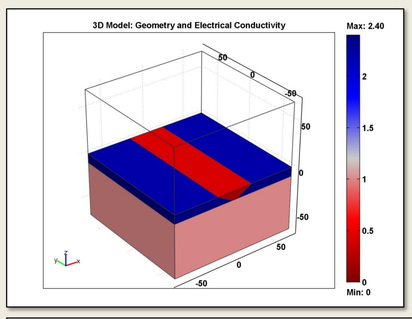
Model precision:

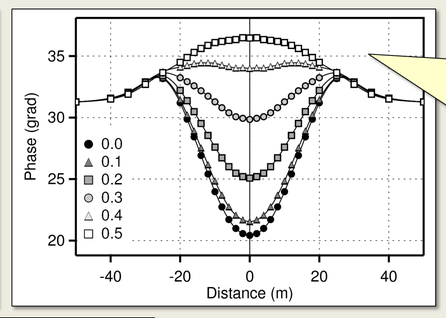




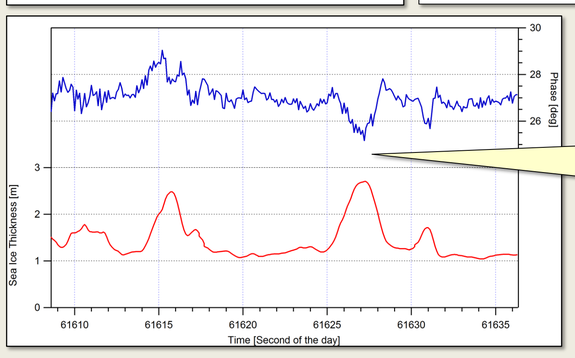
Comparison 3D homogoneus halfspace (marker) **vs. 1D numerical solution** (line)

2D case: Sea Ice Pressure Ridge





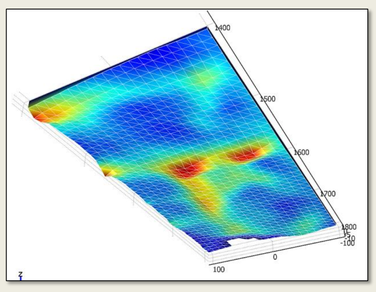
Phase anomaly (model) for sea ice pressure ridges of variable porosity (0 – 0.5)

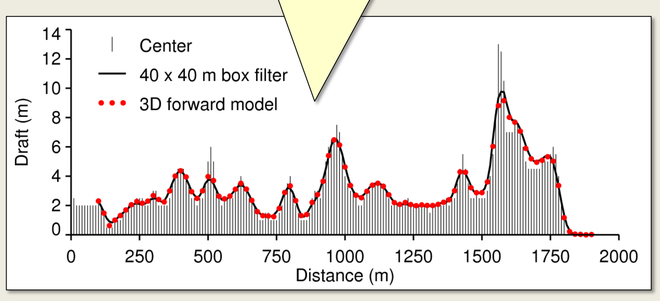


Phase anomaly in recorded data
(top: phase, bottom: thickness)

Center: point (true) thickness
Box filter: Footprint weighted true thickness
Model result shows underestimation of maximum point thickness but agrees with box filter

3D case: typical ice deformation zone





Conclusions & Discussion

- 3D Finite-Element Model for Frequency-Domain Electromagnetics
- Application to sea ice thickness retrieval with airborne EM
- Error evaluation of 1D Interpretation:
  - Underestimation of peak thickness of pressure ridges: 50 – 60%
  - Overestimation of pressure ridge width
  - ▶ Mean sea ice thickness almost conserved value
- Phase anomaly may yield water content of ridges
- Outlook: Further studies on multi-frequency EM-Bird