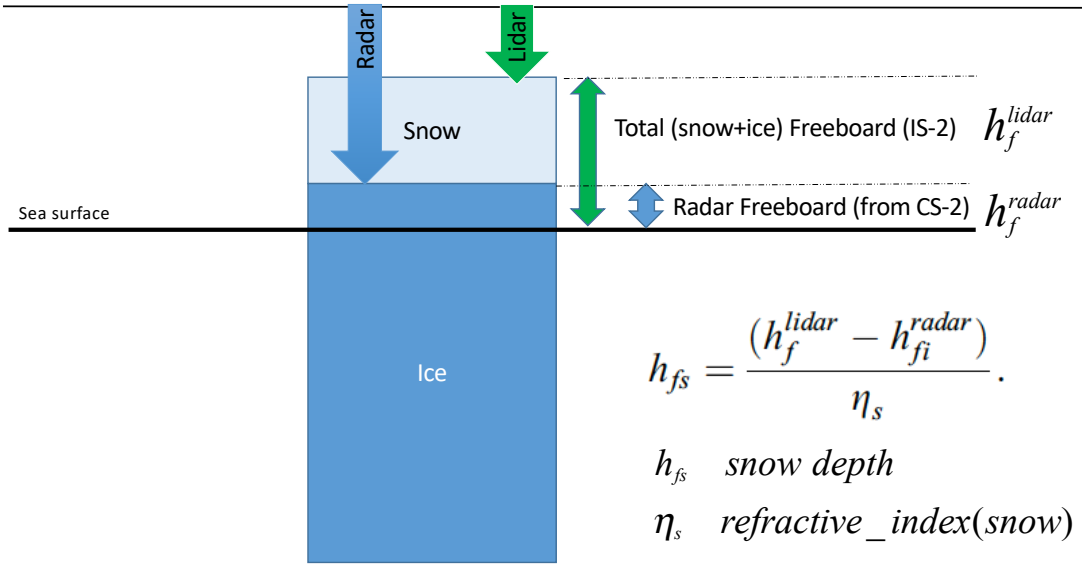
Snow depth from CryoSat-2 and ICESat-2 freeboards: Progress and on-going work

Ron Kwok
Applied Physics Laboratory
University of Washington
Seattle, WA

Acknowledgment: Sahra Kacimi (JPL), Melinda Webster (UAF),
Rob Massom (UTAS), Petra Heil (UTAS)

Measurement Principle



$$h_{fs} = \frac{(h_f^{lidar} - h_{fi}^{radar})}{\eta_s}.$$

h_{fs} *snow depth*

η_s *refractive_index(snow)*

Examined using CS-2, ATM lidar freeboards and snow depth from snow radar

ELSEVIER

Advances in Space Research 62 (2018) 1243–1250

(a COSPAR publication)

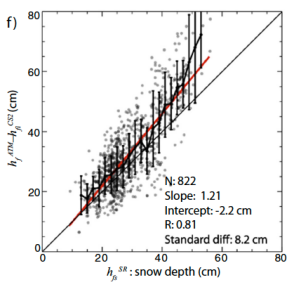
www.elsevier.com/locate/asr

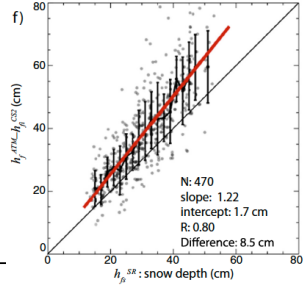
Potential basin-scale estimates of Arctic snow depth with sea ice freeboards from CryoSat-2 and ICESat-2: An exploratory analysis

R. Kwok [a,*], T. Markus [b]

[a] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA
[b] NASA/Goddard Space Flight Center, Greenbelt, MD 20771, USA

Received 24 January 2017; received in revised form 30 August 2017; accepted 5 September 2017
Available online 15 September 2017





$$h_{fs} = \frac{(h_f^{lidar} - h_{fi}^{radar})}{\eta_s}.$$

Arctic

Kwok, R., Kacimi, S., Webster, M. A., Kurtz, N. T., & Petty, A. A. (2020). Arctic snow depth and sea ice thickness from ICESat-2 and CryoSat-2 freeboards: A first examination. Journal of Geophysical Research: Oceans, 125, e2019JC016008. https://doi.org/10.1029/2019JC016008

Kwok, R. (2020): Arctic Ocean sea ice snow depth and ice thickness. PANGAEA, https://doi.org/10.1594/PANGAEA.914565

Antarctic

Kacimi, S., Kwok, R., The Antarctic sea ice cover from ICESat-2 and CryoSat-2: freeboard, snow depth, and ice thickness, The Cryosphere, 14, 4453–4474, 2020. https://doi.org/10.5194/tc-14-4453-2020

How to verify/validate snow depth retrievals? Examining and understanding details

- Recognize that absolute accuracies are difficult to establish
- Time-variable behavior
- Spatial/temporal anomalies should be attributable to atmospheric forcing or other sensible physical arguments
  - Anomalies are those patterns that are unexpected based on climatology or expected behavior
- Positively/negatively correlated changes in IS-2 and CS-freeboards should be connected to physical processes
- Examining extremes in retrievals (sensitivity)

Some examples

Snow depth retrievals (Oct and Apr)

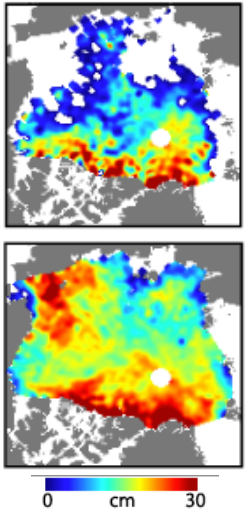
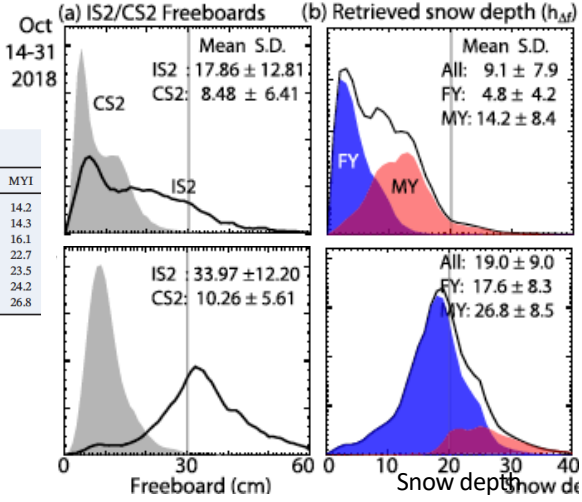


Table 1
Monthly Freeboard-Derived Snow Depth

cm	Mean	FYI	MYI
October	9.1	4.8	14.2
November	8.5	5.5	14.3
December	9.6	6.9	16.1
January	13.8	11.1	22.7
February	15.5	13.4	23.5
March	17.0	15.4	24.2
April	19.0	17.6	26.8



Cyclone and associated snowfall anomalies (1979-2019, ERA-Interim)

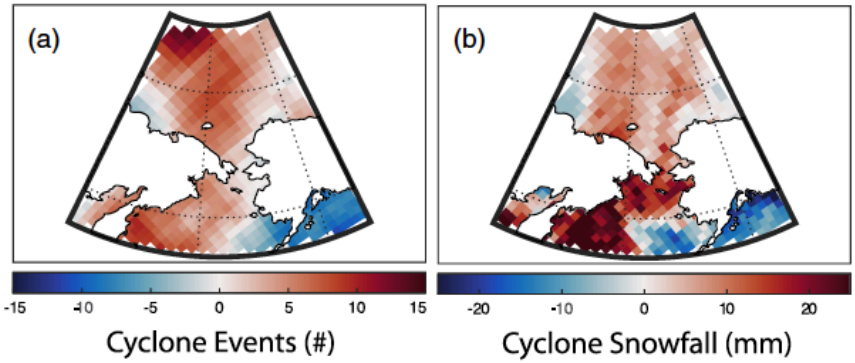
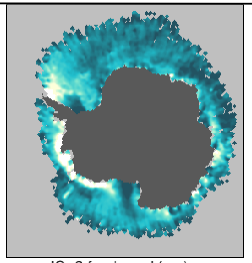


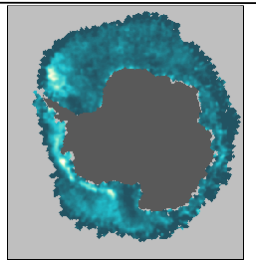
Figure 5. December–February anomalies in the (a) number of cyclone events and (b) cyclone-associated snowfall based on the 1979–2019 climatological mean using ERA-Interim reanalysis data. Cyclones were more frequent, stronger, and precipitated more snowfall for the 2018–2019 midwinter period than the climatological mean.

Antarctic September fields



IS–2 freeboard (cm)

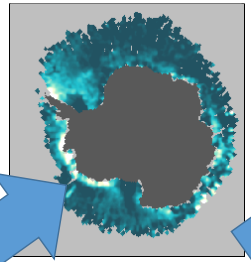
0 10 20 30 40 50 60 70



CS–2 freeboard (cm)

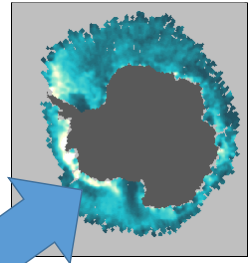
0 10 20 30 40

- Monthly gridded fields (25km)



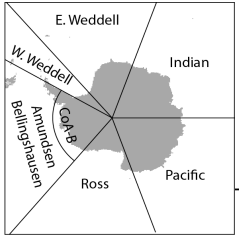
Snow depth (cm)

0 10 20 30 40 50 60

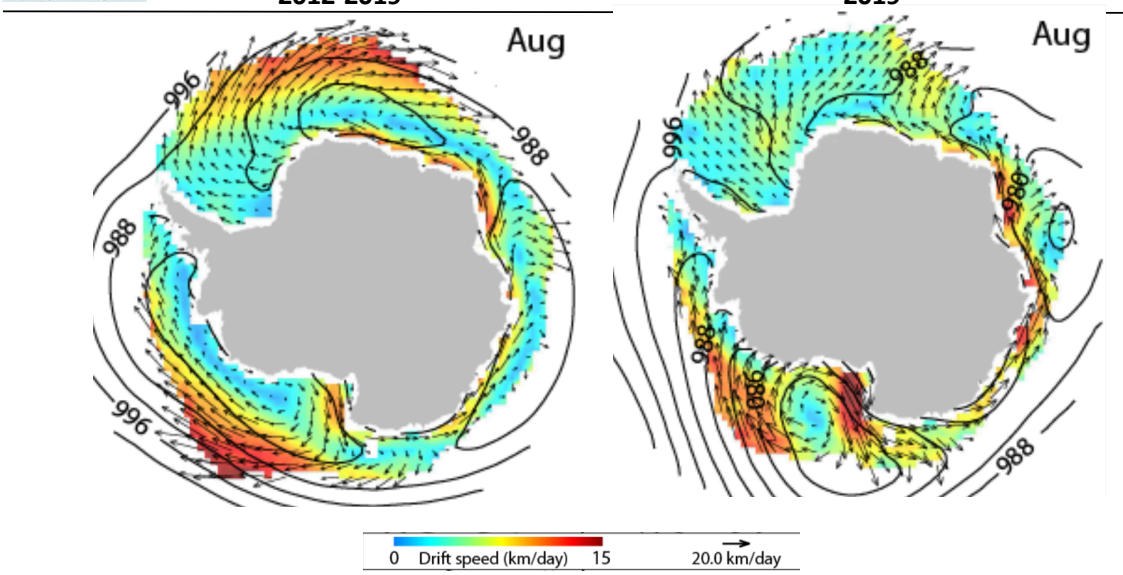


Sea ice thickness (m)

0 1 2 3 4 5



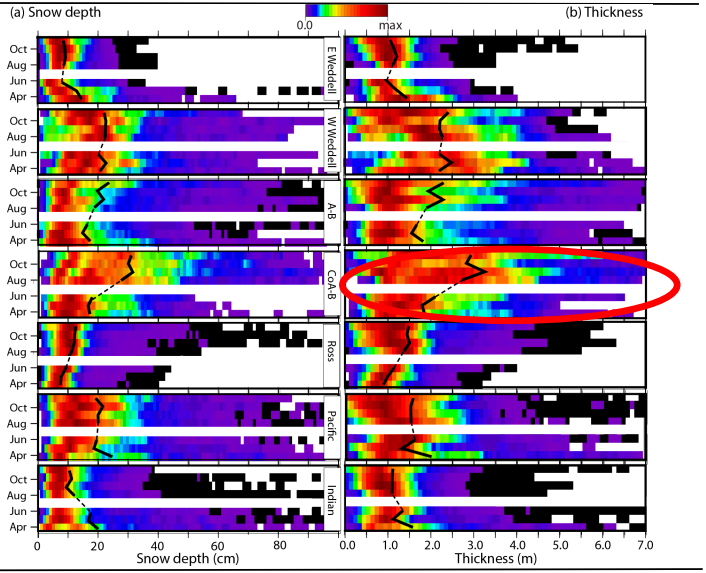
Ice convergence along A/B coast in 2019



Time-varying distributions

- Correlated changes in ice and snow thickness.
- Convergence increase the tails of the thickness distribution, but why is there correlated changes in snow as well?
- Hypothesis (Takenobu et al. (2016))
  - Ice cover closed
  - No snow loss into leads
  - Or, increase snow fall as well.
  - Testing hypothesis with ERA5.

- Thickest Ice (≥2m) and snow in the ***Bellingshausen*** and ***Western Weddell.***
- Thinnest ice layer in the ***Ross*** and ***Eastern Weddell*** sector (<1.5 m).
- Weak seasonal cycle.



Processes and time-varying snow properties

- Salinity: increasing evidence of biases in the ice freeboard estimates from CS-2 (from our retrievals and others) due to salinity at the snow-ice interface Need to better understand the evolution of brine the snow layer

- Urgent need for coordinated measurements of time-varying snow properties (salinity, density, temperature) especially in the Antarctic for developing simple models usable in snow depth/thickness retrievals from altimetry.

AIR • SEA • ICE
Polar Science Center

Summary Remarks

- Status/on-going work
  - Assessment of the Arctic/Antarctic snow depth
  - Examine seasonal and interannual variability
  - Refinement of retrievals based on understanding of salinity at the snow-ice interface.