# Waiting for CRISTAL

# **Evaluation of a Snow Depth product** using Ka/Ku Dual-Frequency Altimetry

# **Impact on Sea Ice Thickness Estimation**



OSTST, Venice 2022

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### Motivations





## **Motivations**





# Why Sea Ice Thickness (SIT) ?







[E.Blockley et al, 2018]



- to improve forecasts using SIT data assimilation
  - to better understand the ice dynamics and improve climatic projections (e.g., albedo effect)
  - to access to sea ice volume variations
  - to study impacts of freshwater inflow on <u>ocean circulation</u>
  - for <u>navigation</u> safety
  - ice algae, plankton, etc., development, ...

### How to measure Sea Ice Thickness ?





## **Sea Ice Thickness by Altimetry: principle**





hydrostatic equilibrium equation

# Sea Ice Thickness by Altimetry: Effect of Snow



# How to Estimate Snow Depth over Sea Ice?



#### Until recently, only the Warren 1999 climatology



[Warren et al (1999). Snow Depth on Arctic Sea Ice Journal of Climate, 12(6), 1814-1829.]







Data from 1940-1990 measurements !

# **Modified Warren Climatology to Account for Clim Change**





# How to Estimate Snow Depth over Sea Ice ?



#### **Models of Snow Accumulation**

Using:

- Re-analyses models (MERRA2, ERA5, ...) for snow precipitations and wind
- Sea Ice Drift



#### Main Available Snow Depth Products

PIOMAS	1980-now	NH
GIOMAS	1980-now	NH+SH
NESOSIM	2002-2011 2012-now	NH
SnowModel-LG	1980-2018	NH
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#### Multi-frequency Passive Radiometers

AMSR-E (2002-2011) and AMSR-2 (2012-now)



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+ [Winstrup LPS 2019]

+ [Braakmann-Folgmann et al 2019]

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ASD Ka/Ku	[Guerreiro et al 2016] [Garnier et al 2021]	2013- now	82°NH+ SH
DuST Ka/Ku	[Lawrence et al 2018]	2013- now	82°NH
Ku/ laser	[Kwok 2020]	2018- 2019	NH

-> motivated bi-frequency polar alti CRISTAL<sub>12</sub>

# **Snow Depth from bi-frequency Altimetry**



# **Snow Depth from bi-frequency Altimetry**





Saral (LRM Ka)



-0.20 -0.15 -0.10 -0.05 0.00 0.05 0.10 0.15 0.20

[Garnier et al. in The Cryosphere 2021] 14

# **Products comparison (example for April 2015)**





### **Comparison against OIB airborne Snow Radar**





# **Comparison against OIB Snow Radar**





airborne snow radar from OIB













[Garnier et al, TC 2021] 17

# **CRISTAL Copernicus Polar Altimeter**



### First Ka/Ku satellite altimeter ... for 2027





Simultaneous freeboard and snow depth mesurements !

# **Confidance**?















# Penetration highly depends on Snow Type !



V.Nandan, J.Stroeve, J.Yackel, ..., MOSAIC, etc. 20

EGO

# **FYI Snow Penetration correction**



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[Nandan et al, GRJ 2017] Effect of Snow Salinity on CryoSat-2 Arctic First-Year Sea Ice Freeboard Measurements

BGEP mooring (principle schema)



illustration of the principle from hydro-international.com

Penetration correction law in FYI snow layer:

 $\Delta_{S} = 1.4022229 + 0.9114689H_{S} - 0.0437265H_{S}^{2} + 0.00061H_{S}^{3}$ 



# Main priorities (1/3)



- Ka/Ku (p)LRM approach works well ... in Spring over West Arctic basin
- About no snow depth data East of Arctic, in Autumn and Winter, and whole Antarctic
- Operation Ice Bridge has ended -> no more systematic snow depth measurements planned

#### => <u>1. Urgent need for reference in-situ data:</u>

- Continuity of **airborne snow radar** measurements (CristalAir?, OIB?, AWI?, ...)
- Alternative lower cost methodologies such as drone-borne snow radar or altimeter



# Main priorities (2/3)



- => 2. Need for studies dedicated to Ku/Ka over sea ice and snow
  - Penetration, Sea ice roughness effects on the range (sea ice "SSB"!)
  - SAR, SARin, FF-SAR, ...
  - Simulators
  - Developed adapted model based retrackers



E.g., ESA PolarMonitoring project (2019-2020) over land ice which would need for **a follow on over sea ice**.

# Main priorities (3/3)



#### => <u>3. Importance to limit delays for the launch of CRISTAL</u>

- CryoSat-2 is already 12 years old (17 years old in 2027)
- no relay => no more Arctic sea ice thickness survey in summer from ~2025







- 1. Snow depth in-situ data
- 2. Retrackers adapted to sea ice (sea ice state bias, snow penetration, SAR/SARin)
- 3. Limit delays for CRISTAL launch: for now keep trying 2027

# Thank you !



### Annexes

### **Snow laser/Ku versus Ka/Ku**



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# Ka/Ku Snow Depth Validation with OIB





# Importance of Snow over Sea ice

LEGOS

- snow acts as a thermal insulator
  - => it slows down the growth of the sea ice
- snow acts as an UV reflector
  - => it increases the ice <u>albedo</u>
- snow acts as a light filter
  - => it limits planktonic development under the ice
- snow acts as a gas filter
  - => it limits ocean/atmosphere gas exchanges
- snow increases ice friction
  - => it limits ice breakers progression





1 Key Knowledge Gap [IPCC Special Report of the Ocean and Cryosphere (SROC]) "Snow depth on sea ice is essentially unmeasured, limiting mass balance estimates and ice thickness retrievals"