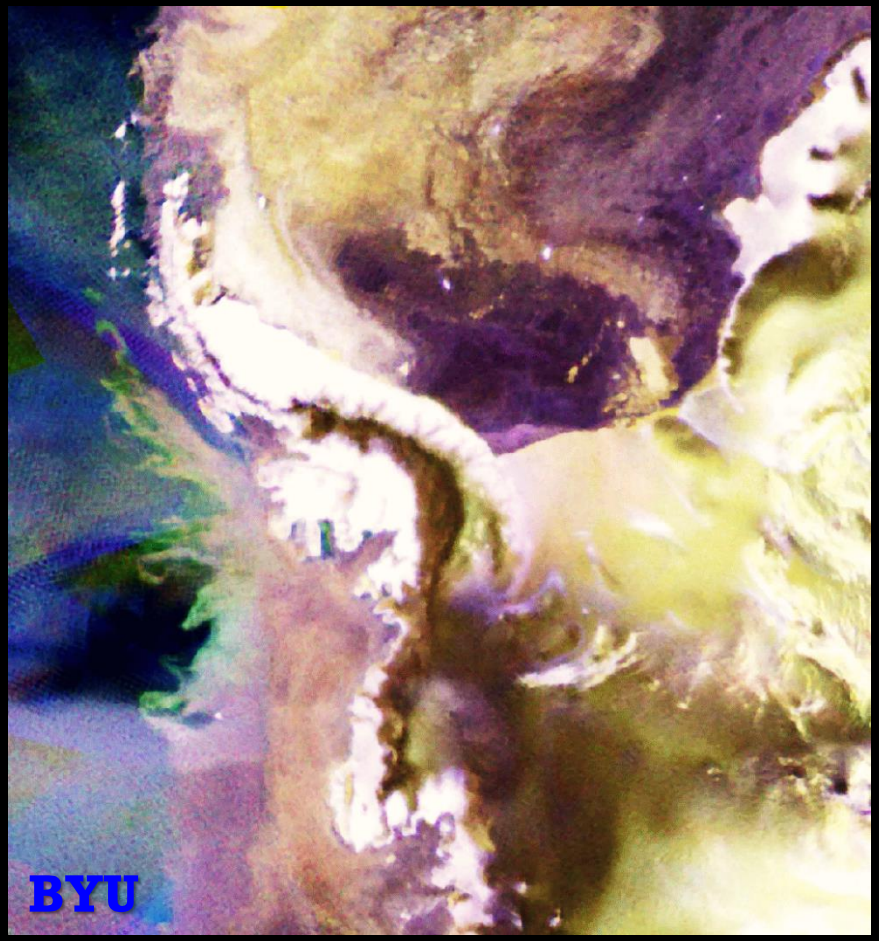
Predicting the Presence of Firn Aquifers on the Antarctic Peninsula using C-Band Satellite-Borne Scatterometry



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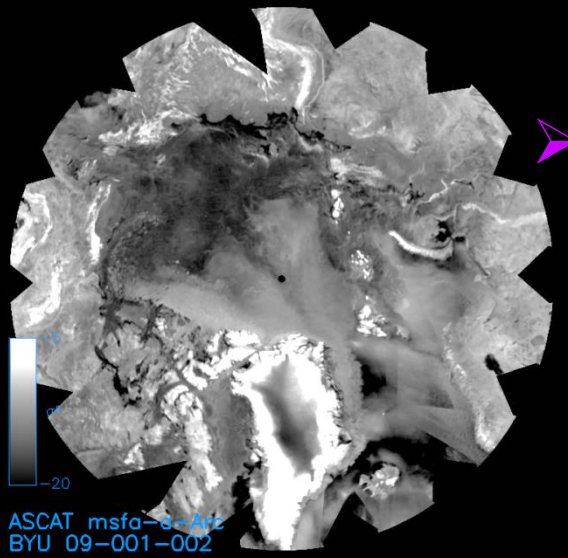
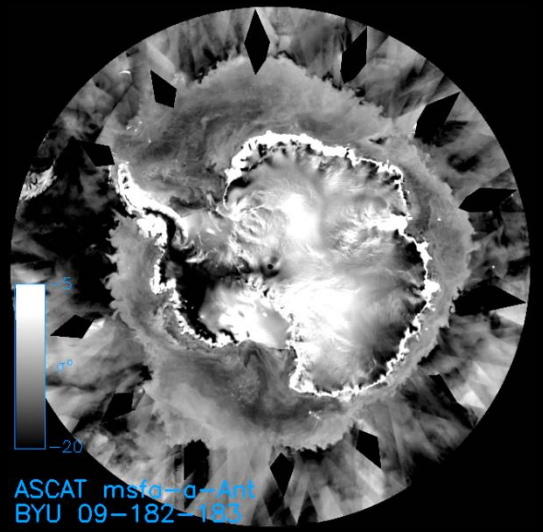
Outline

- **The Discovery of Greenland's Firn Aquifer**
  - **Winter season liquid meltwater retention in the upper snow and firn layers of ice sheets**



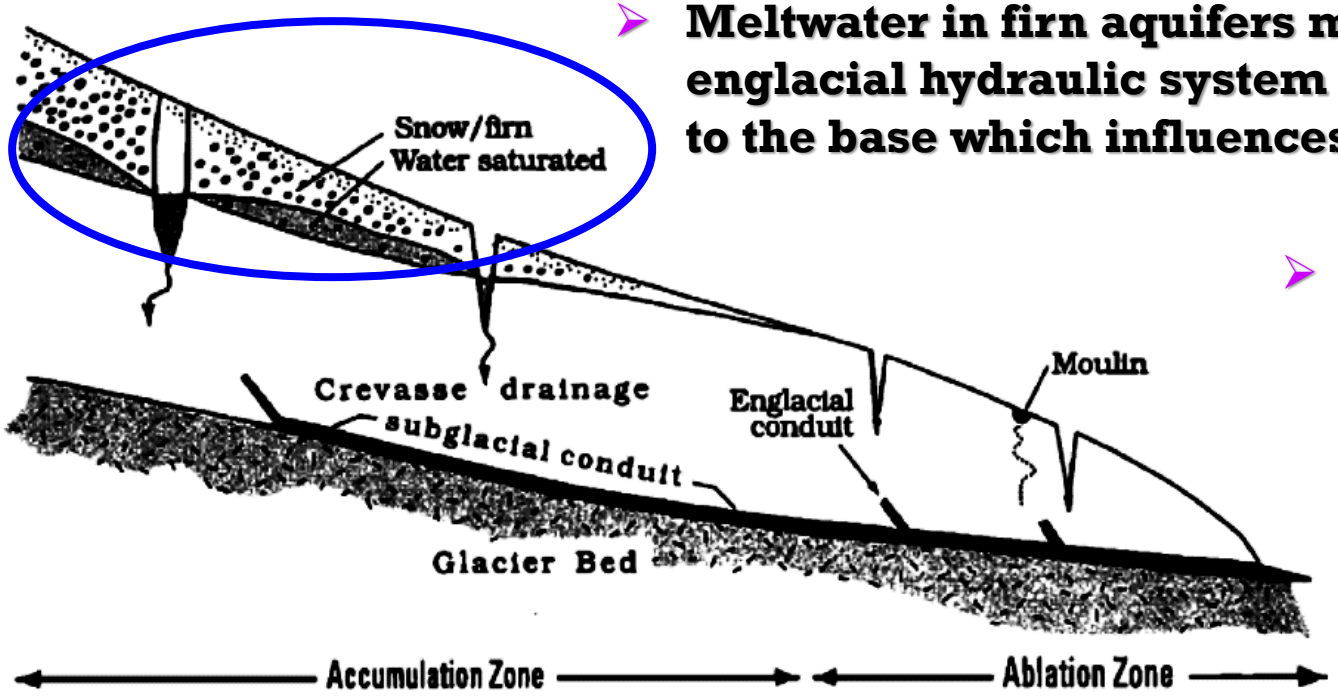
- **Satellite-Borne Observation**
  - **New microwave retrieval technique to map Greenland's firn aquifer from space using scatterometry**



- **Firn Aquifers in Antarctica???**
  - **Apply the retrieval technique developed for Greenland to the Antarctic Peninsula**

What is a Firn Aquifer???

- Firn aquifers are common features on temperate glaciers and form as the result of the percolation of liquid meltwater at depth
- Meltwater infiltrates laterally at the firn-ice boundary and saturates available pore space within the firn overlying the impermeable ice
- Meltwater in firn aquifers may enter the englacial hydraulic system and be transported to the base which influences ice dynamics
- Or meltwater may refreeze and densify the firn which generally occurs prior to the winter season



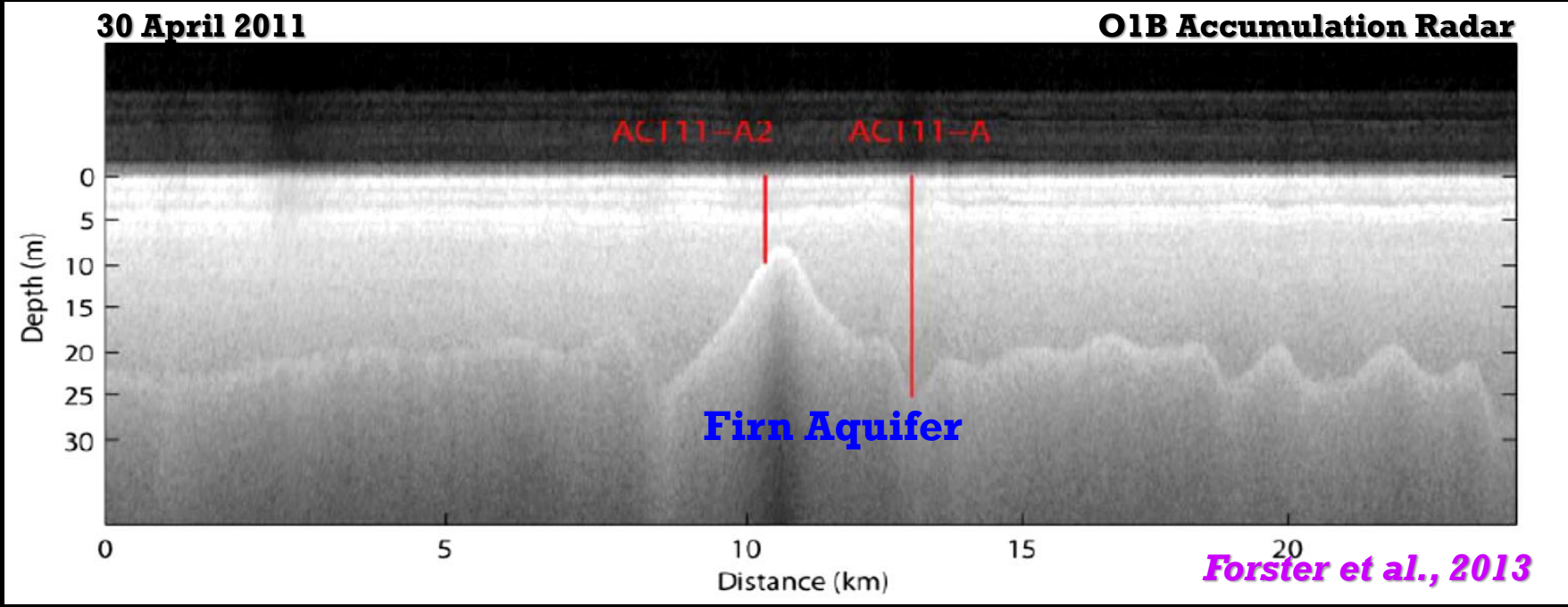
Fountain and Walder, 1998

The Discovery of Greenland's Firn Aquifer

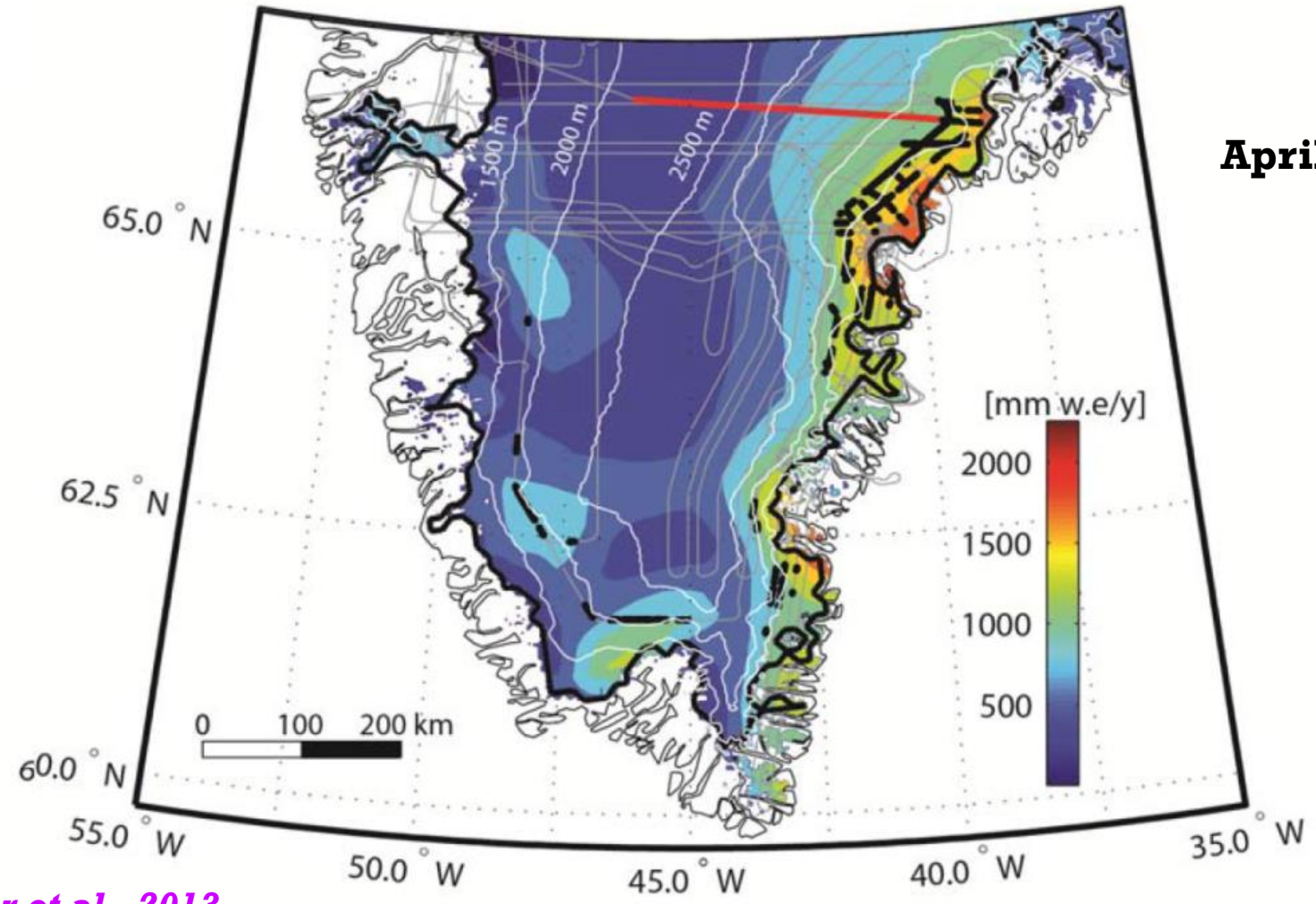
- **Observations**
  - **Field Data (FA-13 core)** [*Koenig et al., 2014, GRL*]
    - **Volume Estimate: ~140 ± 20 Gt (~0.4 mm SLR)**
  - **Airborne Data (Accumulation Radar)** [*Forster et al., 2013, NatGeo*]
    - **April , 2011, 2012 Retrievals**
    - **Located primarily in the SE, isolated regions in the SW**
    - **Depth to the Top : ~5-50 m**
      - **Influenced by local topography**
- **Modeling**
  - **RACMO2**
  - **Spatial Extent: ~70,000 km^2**
    - **Snow Accumulation (>800 mm y^{-1})**
    - **LMW Production + Rain (>650 mm y^{-1})**

Winter Season Liquid Meltwater Retention in Firn Aquifers

- **Firn aquifers on ice sheets can store large quantities of liquid meltwater during the winter season, can exist over large spatial extents at increased depths, and, can continuously fill over multiple years**
- **High winter season accumulation rates thermally insulates saturated firn allowing meltwater to be retained in liquid form**



Snow Accumulation vs. Firn Aquifer Locations



April 2011

Forster et al., 2013

Spatially Calibrated Polar MM5 Snow Accumulation Rates (1958-2008)
Firn Aquifer Locations retrieved from the O1B Ku-band Accumulation Radar (April 2011)

Research Question

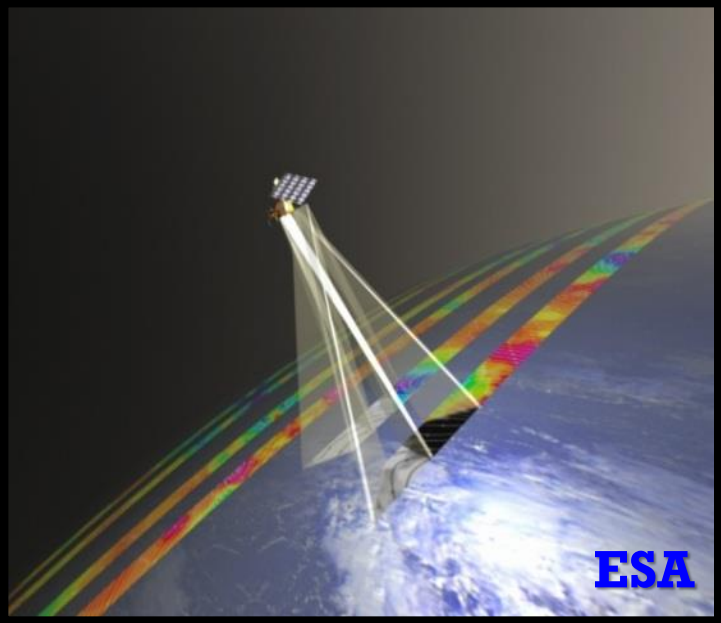
Can firn aquifers on ice sheets be observed from space using satellite-borne scatterometry???

- **Scatterometry provides near-daily ice-sheet wide observations**
  - **Fill in observational gaps along discontinuous IceBridge flight lines**
- **Potential to provide long term-observations**
  - **C- and Ku-band scatterometer climate record (1978-present)**
  - **Initial formation, changes in spatial extent or volume**

C-Band Satellite-Borne Scatterometry

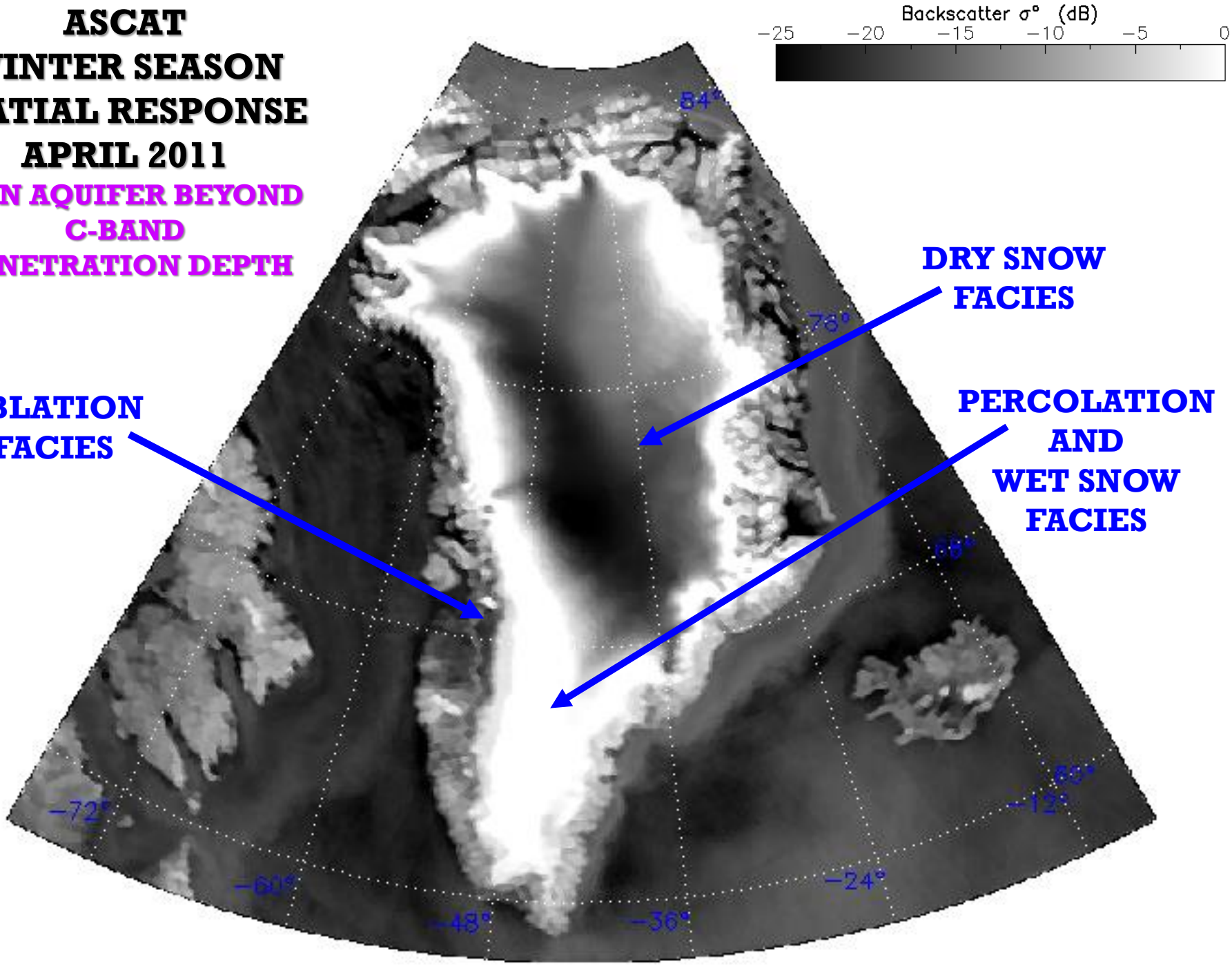
- **Advanced SCATterometer (ASCAT) aboard EUMETSAT's METOP–A satellite (2009 – present)**

- **C-band (5.3 GHz), VV polarization**
- **Penetration depth : <5 m in regions that experience melt and form ice layers**
- **Resolution Enhancement**
  - **40° incidence (mid-swath)**
  - **4.45 km pixel spacing**
    - **effective resolution 12-15 km**



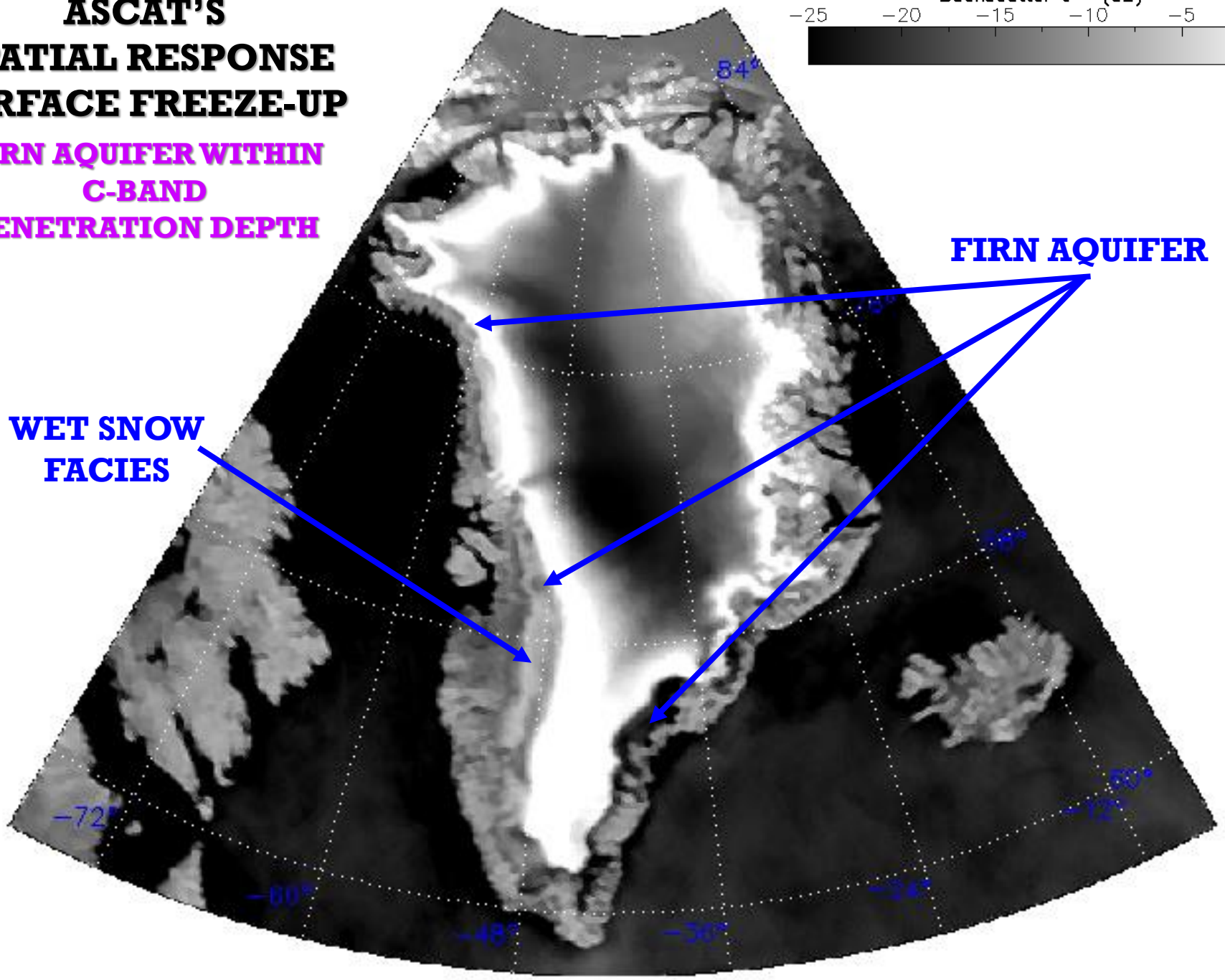
ASCAT WINTER SEASON SPATIAL RESPONSE APRIL 2011

FIRN AQUIFER BEYOND C-BAND PENETRATION DEPTH

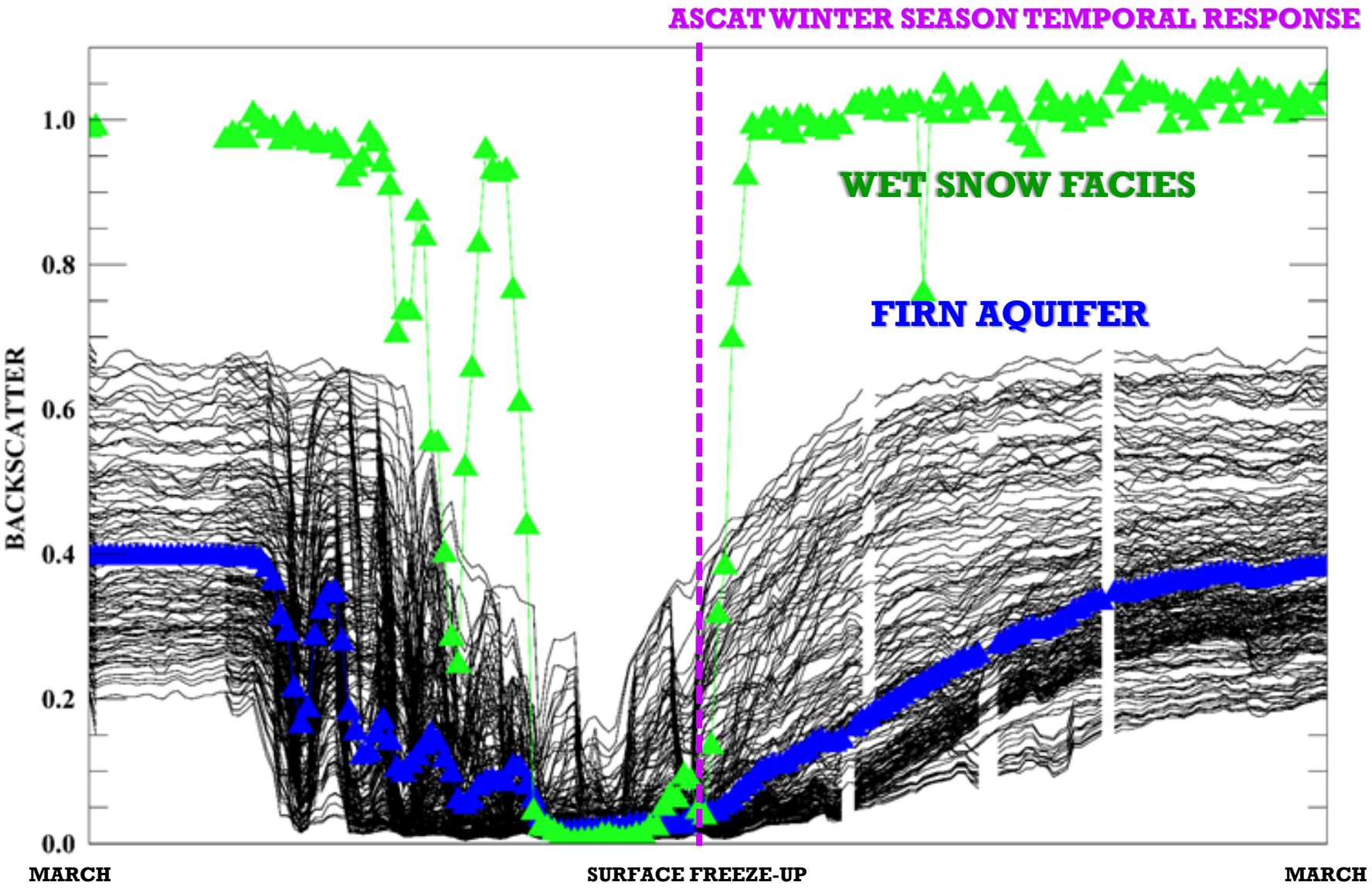


ASCAT'S SPATIAL RESPONSE SURFACE FREEZE-UP

FIRN AQUIFER WITHIN C-BAND PENETRATION DEPTH

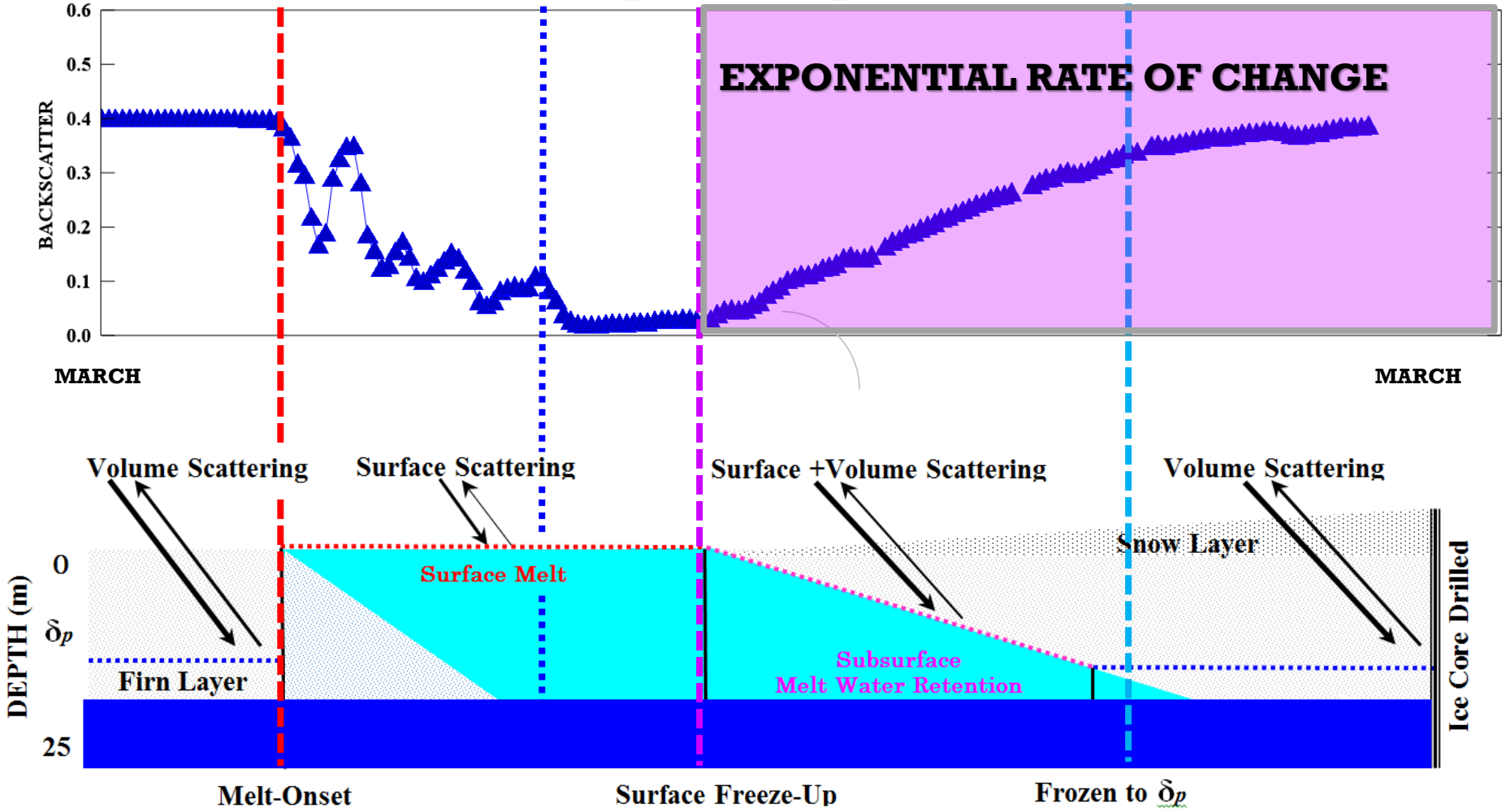


C-band Firn Aquifer Signatures



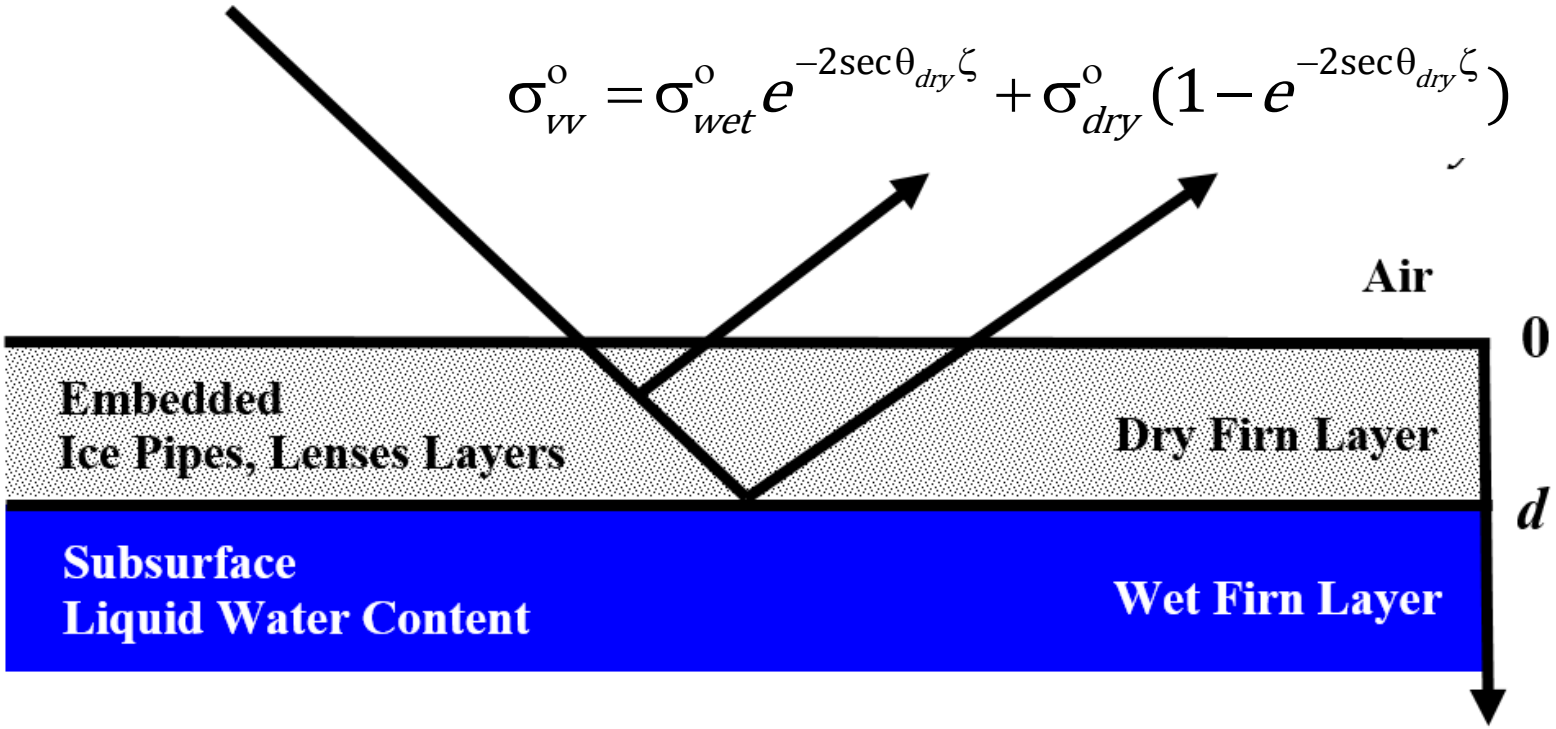
Conceptual Model
C-Band Firn Aquifer Signature

Characteristic Firn Aquifer Signature

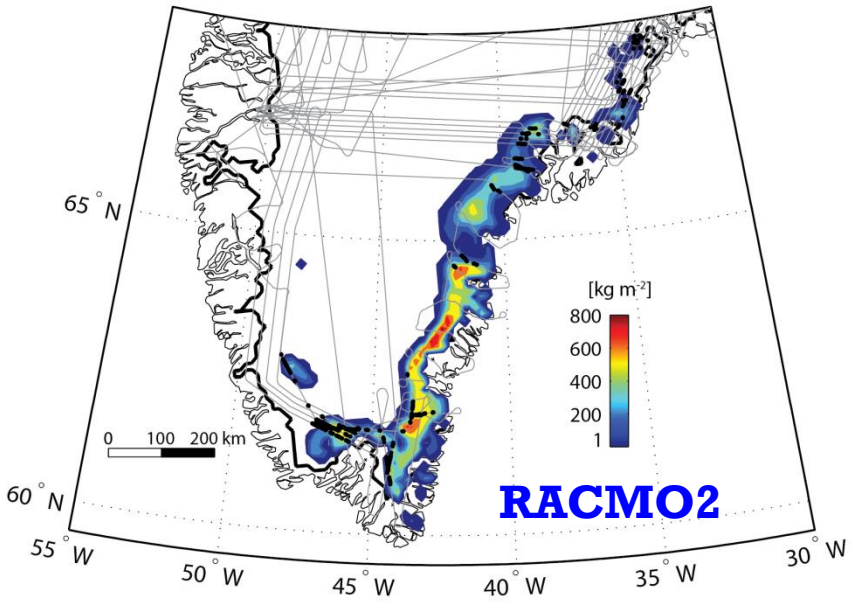


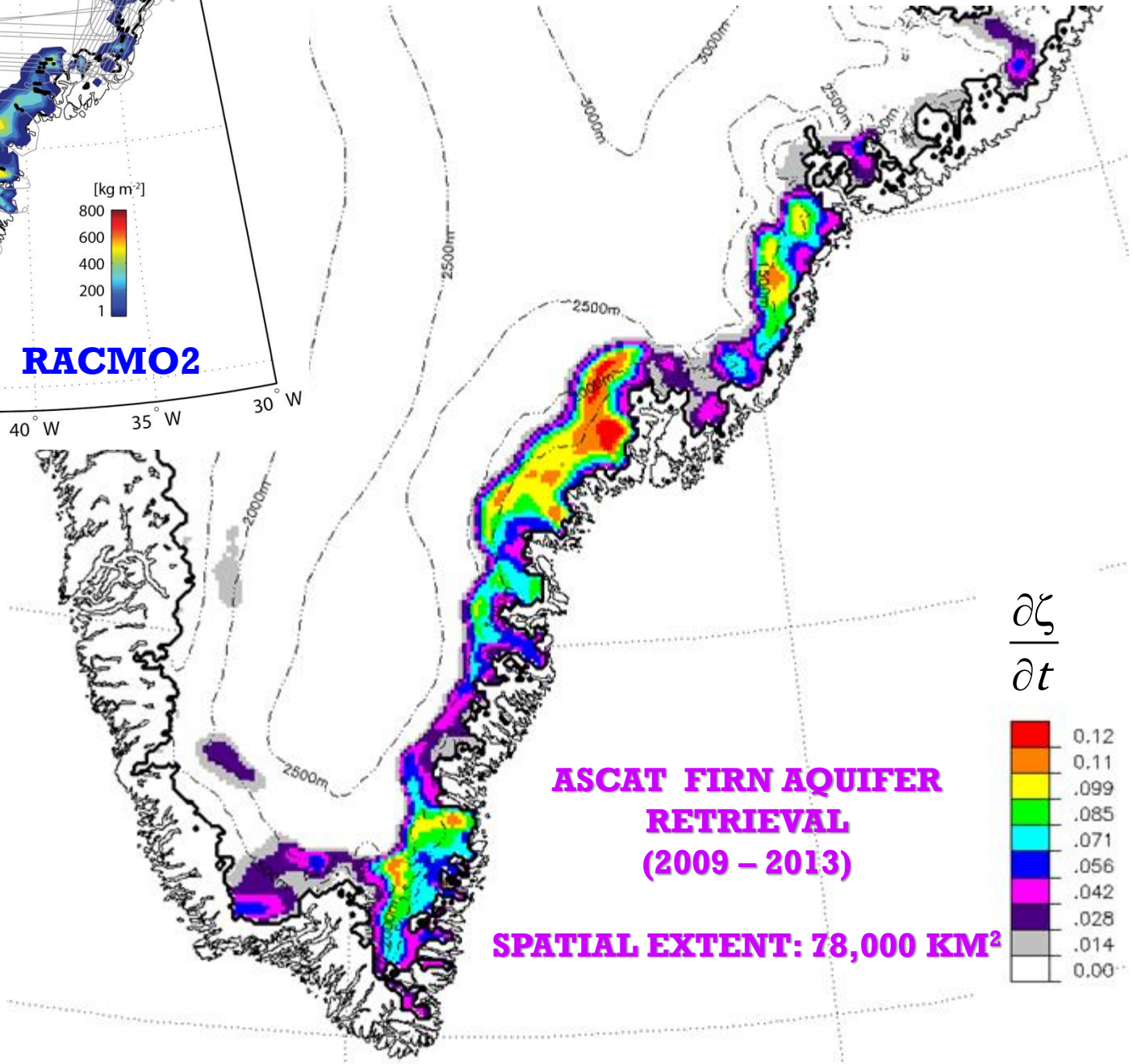
Firn Aquifer Model
Two -Layer Radiative Transfer Equation

$$\sigma^{o}_{vv} = \sigma^{o}_{wet} e^{-2\sec\theta_{dry}\zeta} + \sigma^{o}_{dry}\left(1 - e^{-2\sec\theta_{dry}\zeta}\right)$$

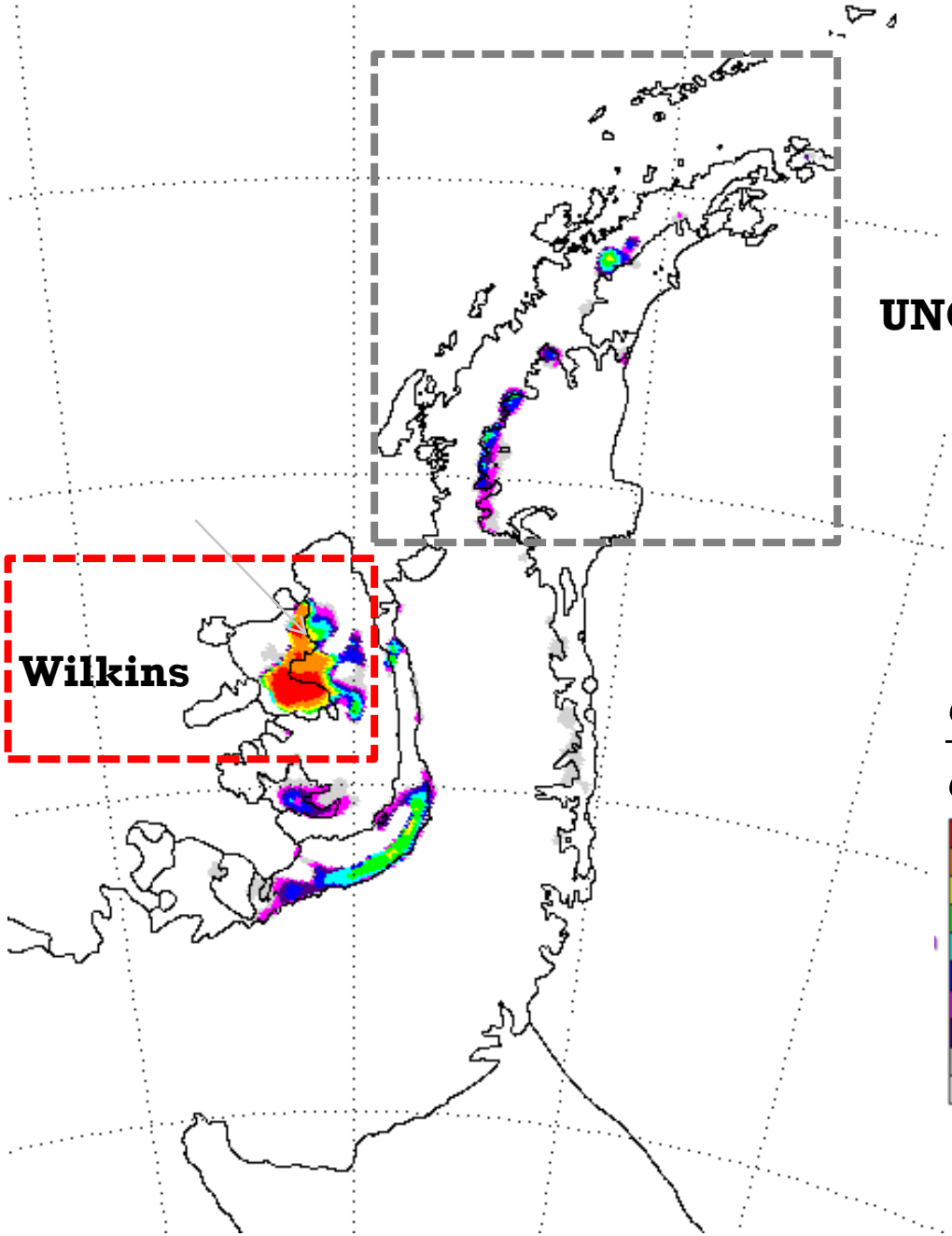


Firn aquifer model derived from a simple two-layer radiative transfer equation and describes the exponential rate of change in backscatter as a function of changes in the depth of the dry layer with time using the parameter $\frac{\partial \zeta}{\partial t}$


65 ° N
60 ° N
55 ° W
50 ° W
45 ° W
40 ° W
35 ° W
30 ° W
0 100 200 km
[kg m-2]
800
600
400
200
1
RACMO2


3000m
2500m
2000m
1500m
1000m
500m
$\frac{\partial \zeta}{\partial t}$
0.12
0.11
.099
.085
.071
.056
.042
.028
.014
0.00
ASCAT FIRN AQUIFER RETRIEVAL (2009 – 2013)
SPATIAL EXTENT: 78,000 KM²

INITIAL PREDICTION MAP



ASCAT GREENLAND FIRN AQUIFER RETRIEVAL (2010 – 2014)

SPATIAL EXTENT : 68,000 km²