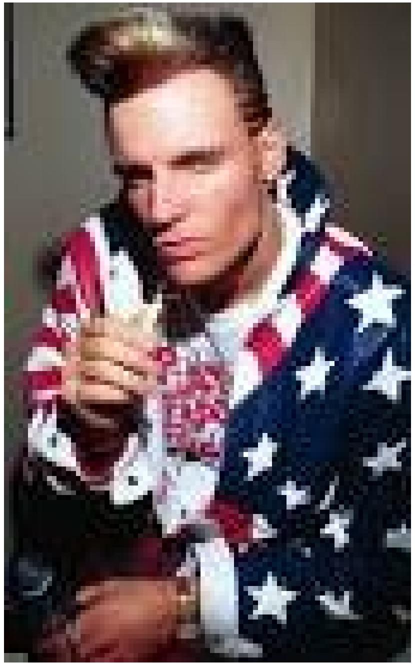
Astrophysics in Antarctica

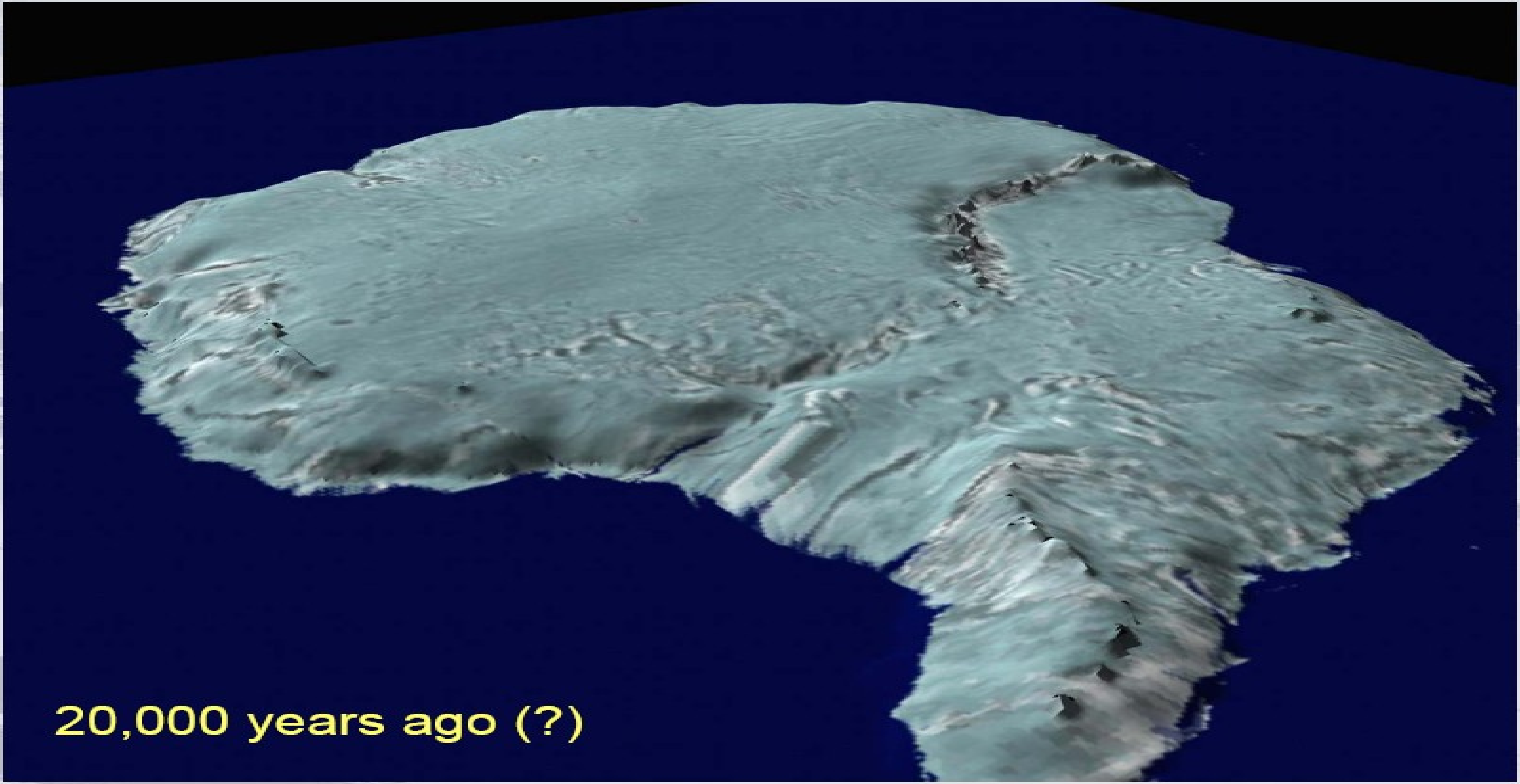
Geophysical Features

ICE, ICE, BABY

- Complex dielectric permittivity: $\varepsilon = \varepsilon' + i\varepsilon''$
- ε': Re(ε): $c = c_0/n$
- ε'': Im(ε): gives absorption
- Permittivity is a tensor!
  - Both absorption and wavespeed depend on polarization and propagation-direction



Ice history: Introduction



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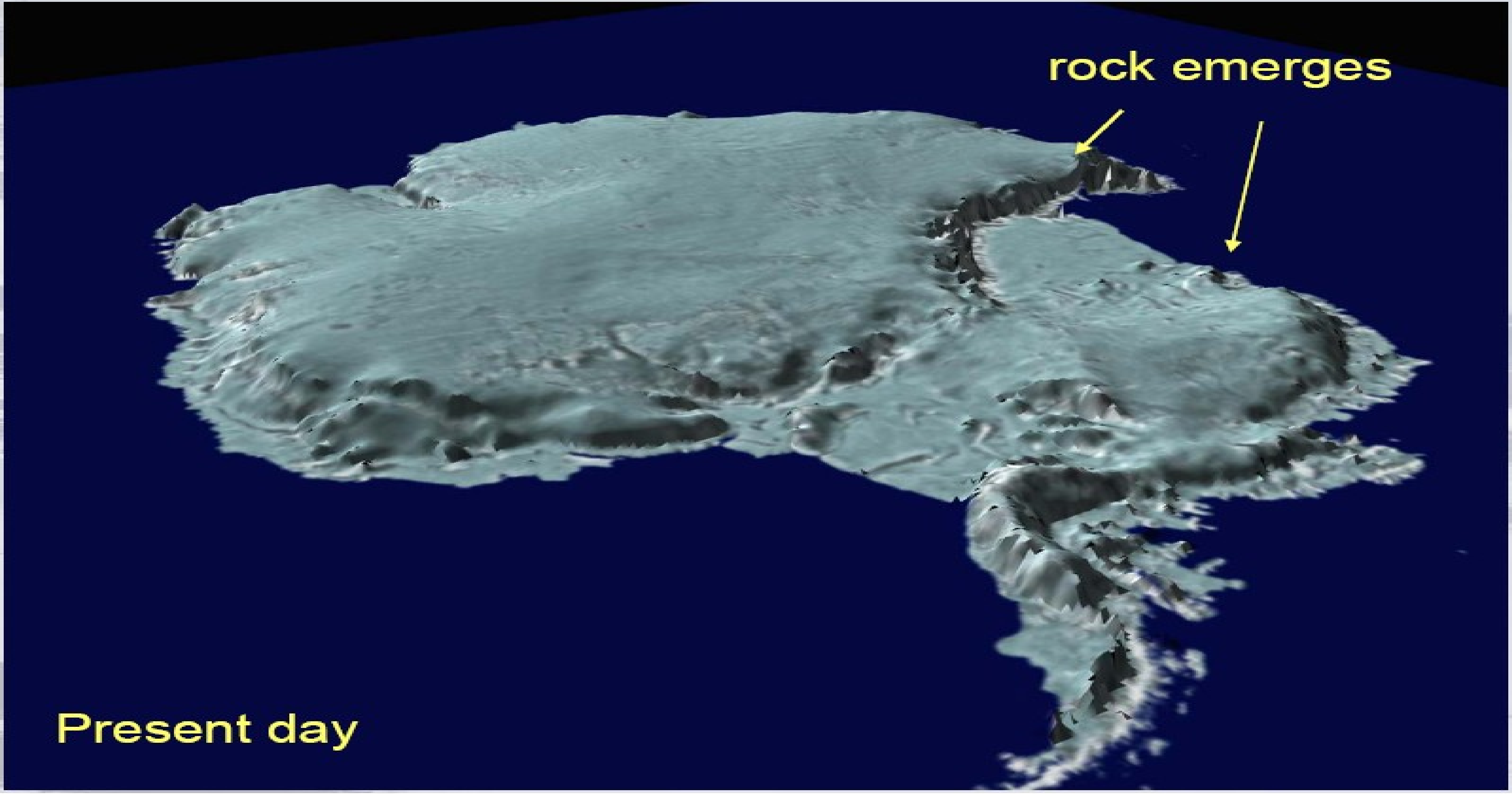
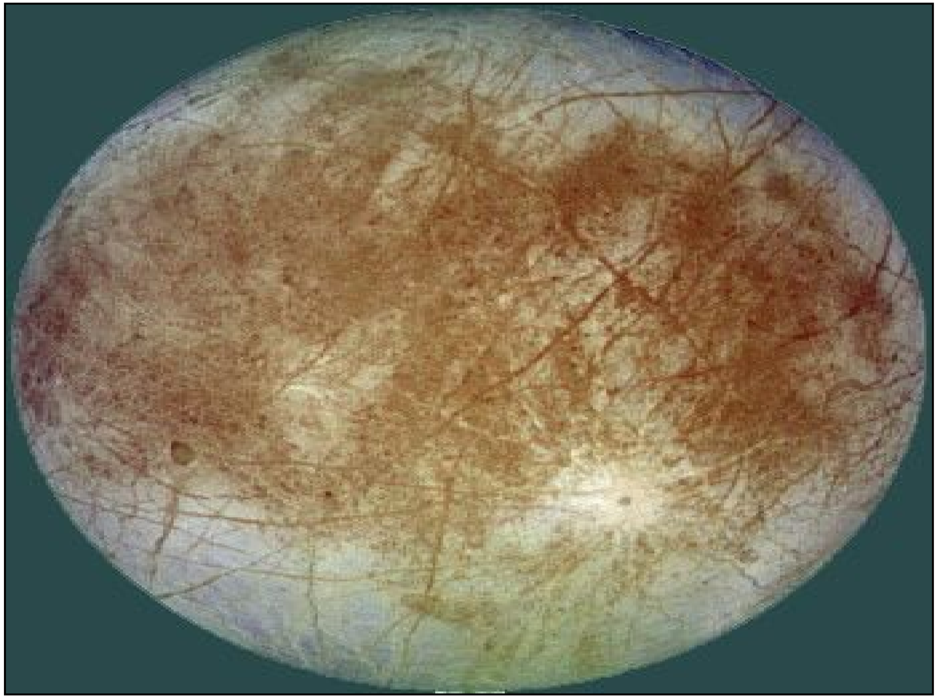
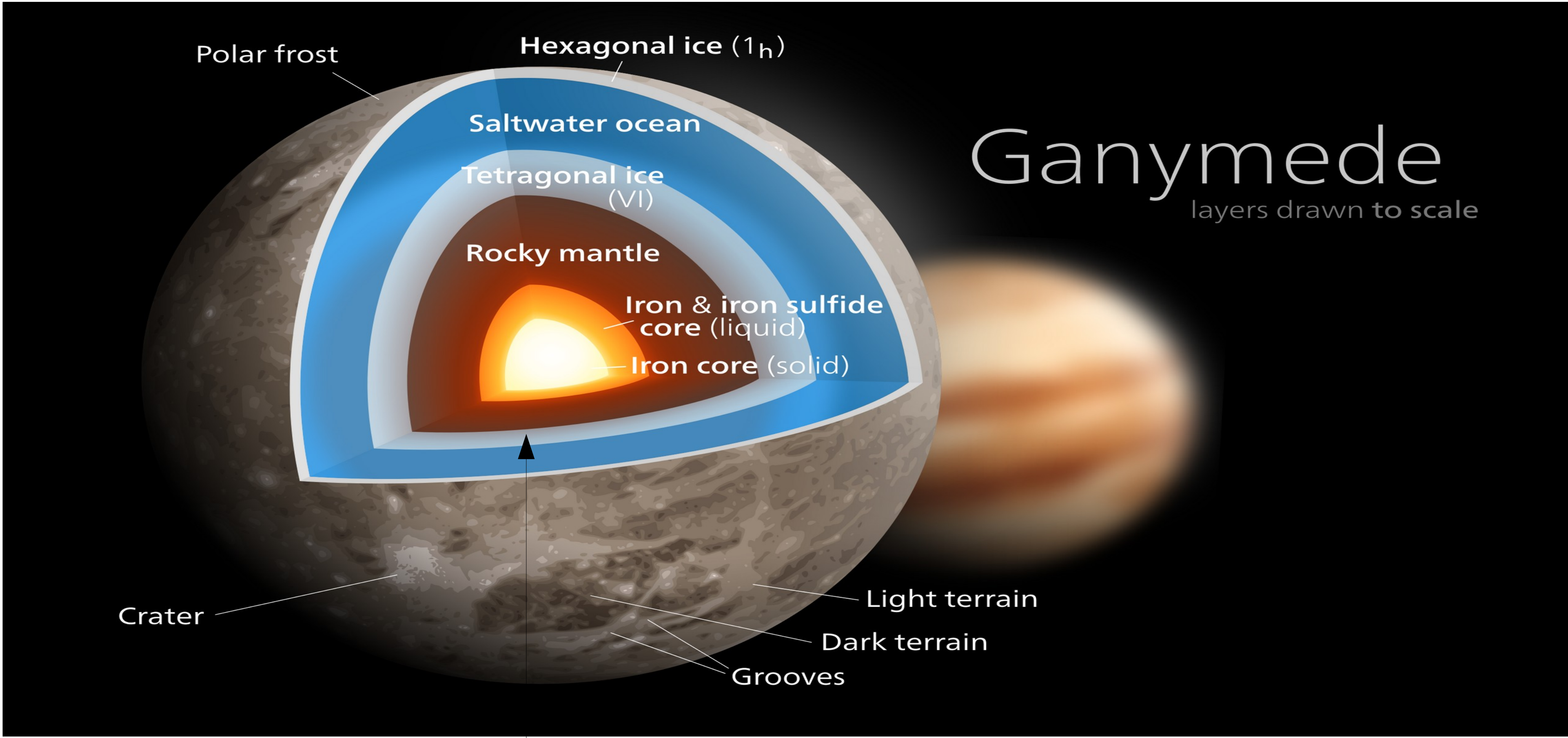


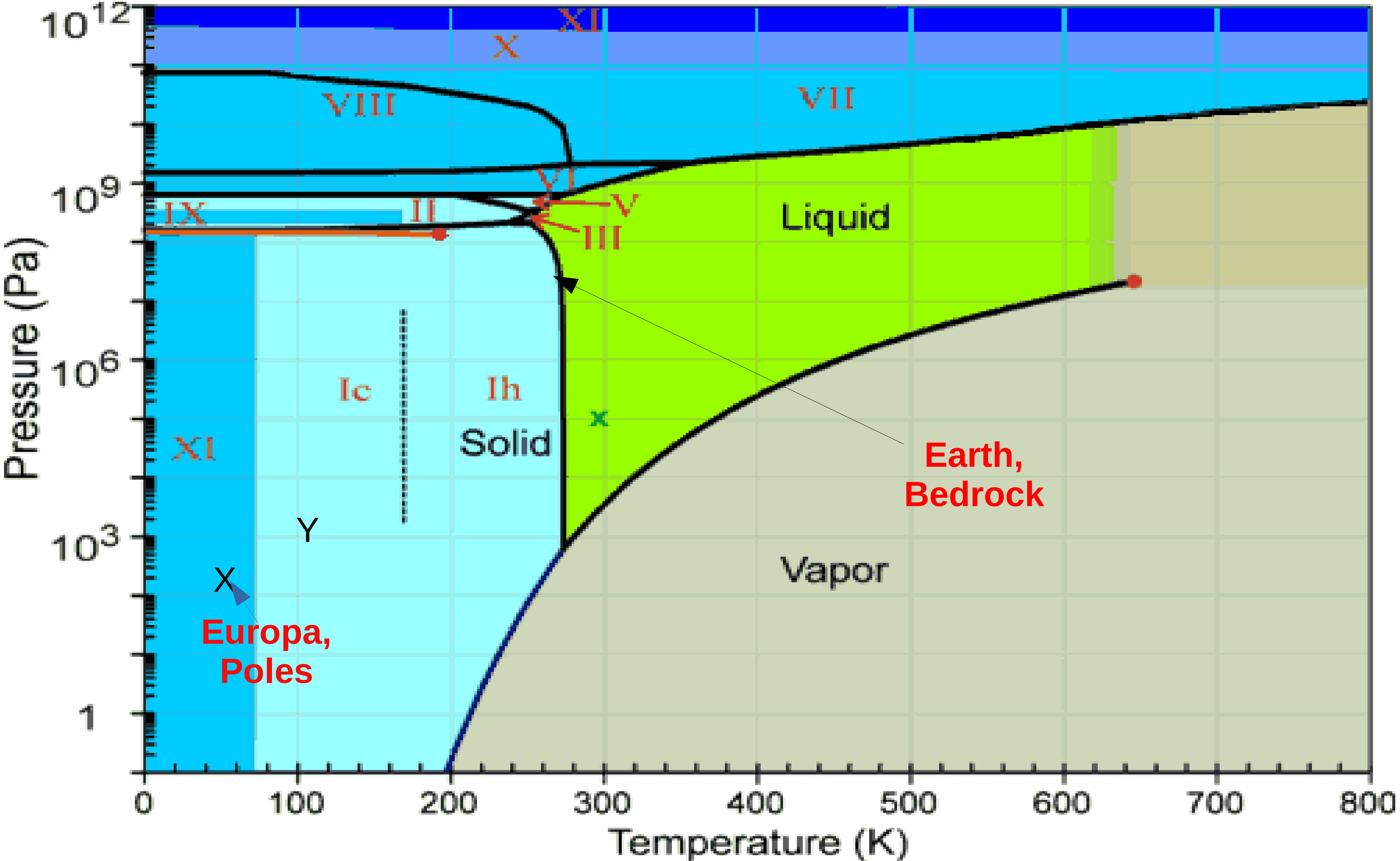
Icecaps elsewhere

Europa: Water ice - 70K; 10-80 km thick,
Life underneath icecap??





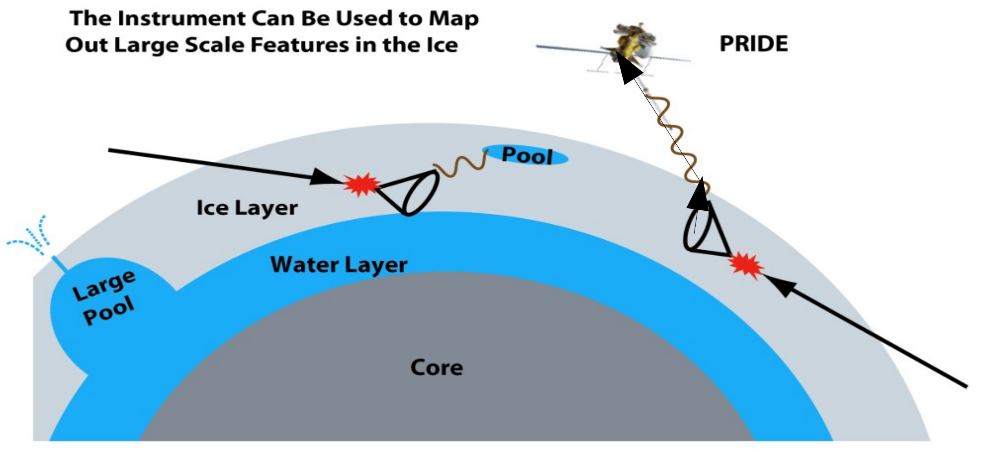
Ice VII melting point~355 K @ 2 GPa

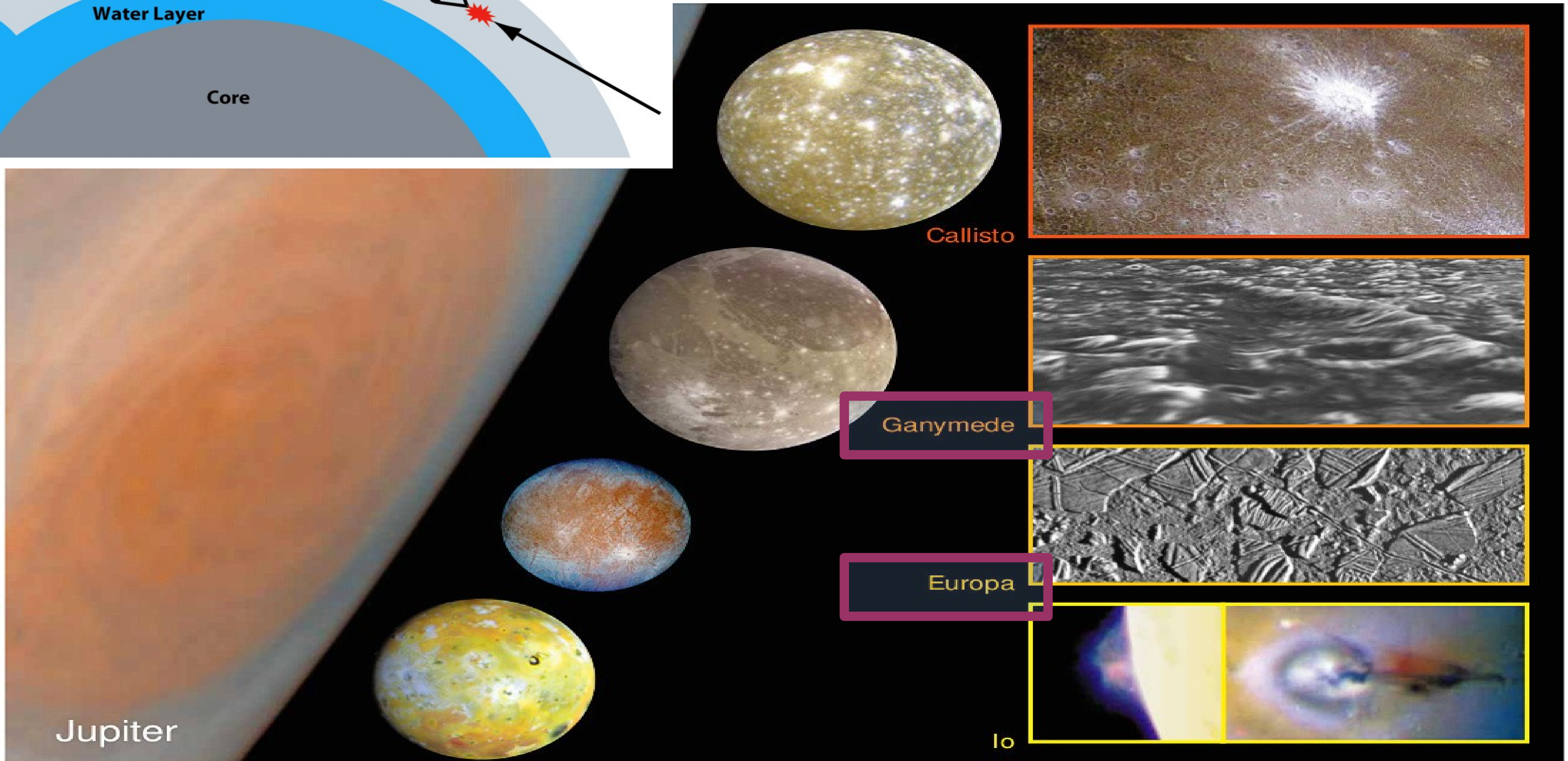


Pressure (Pa)
10^12
10^9
10^6
10^3
1
Temperature (K)
0
100
200
300
400
500
600
700
800
XI
X
VIII
VII
VI
V
IX
II
III
Liquid
Ic
Ih
Solid
x
XI
Y
X
Vapor
Earth,
Bedrock
Europa,
Poles

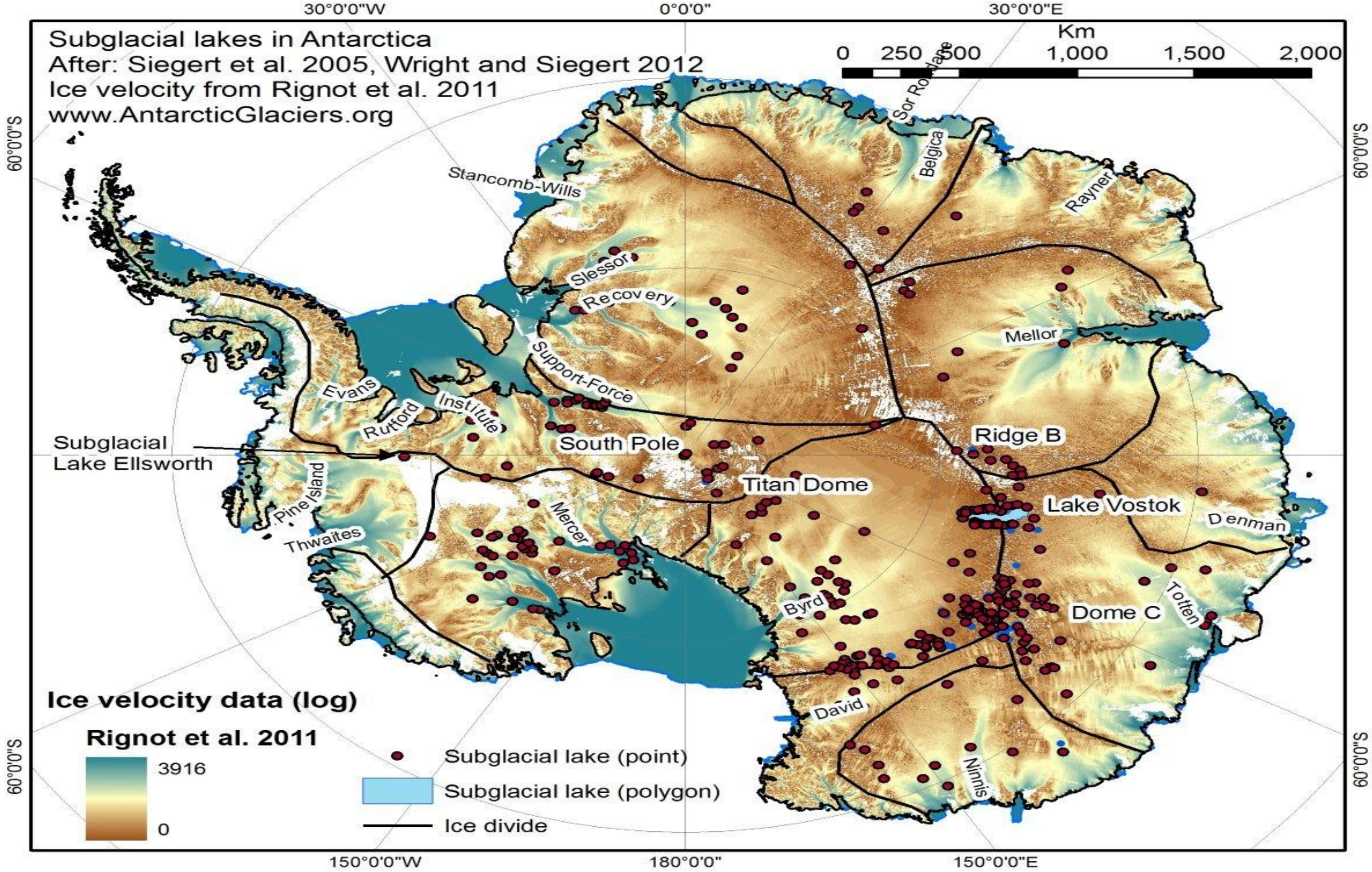
Enceladus

PRIDE Experiment: JPL, LPI, KU, OSU, UCI, APL

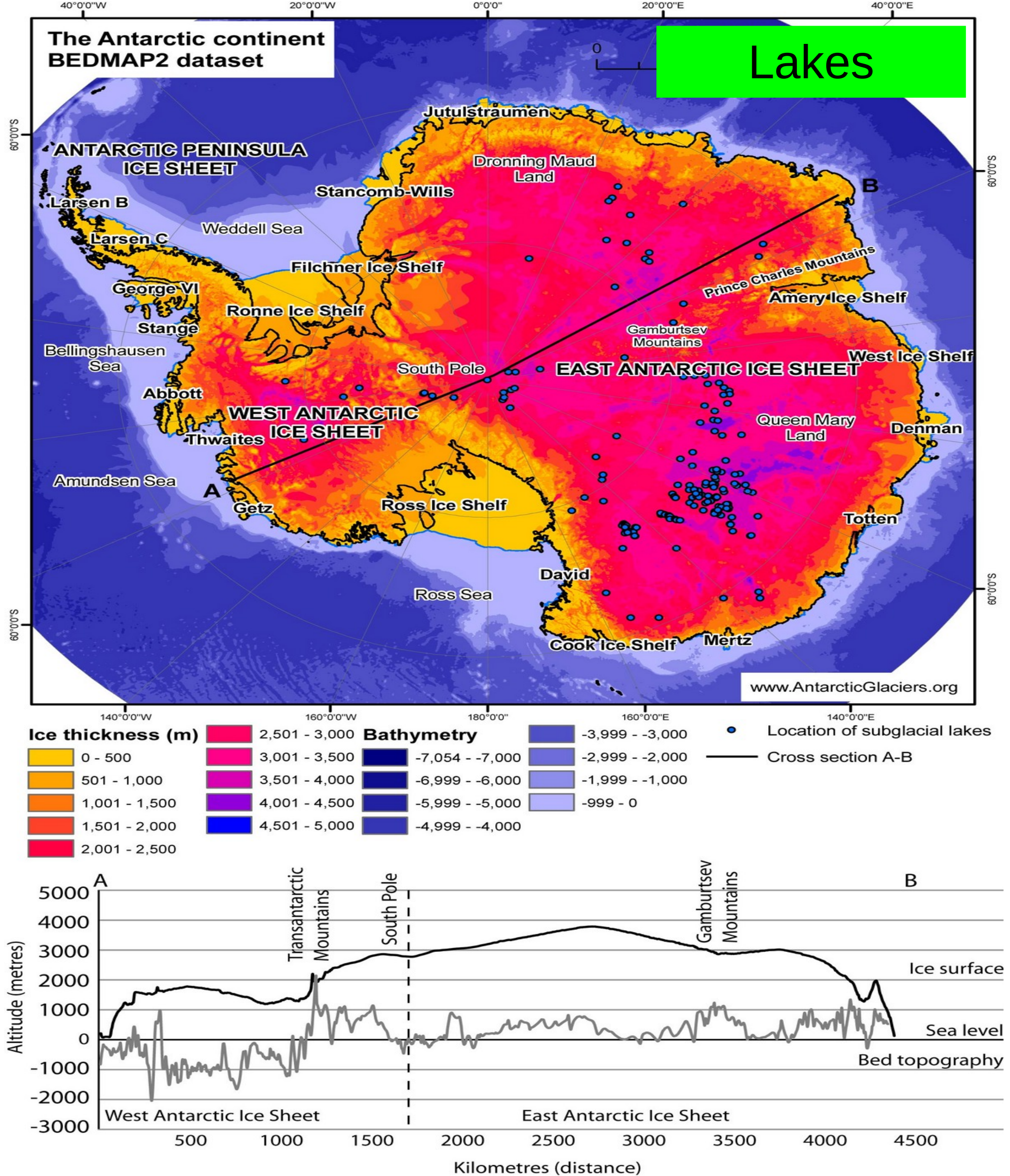




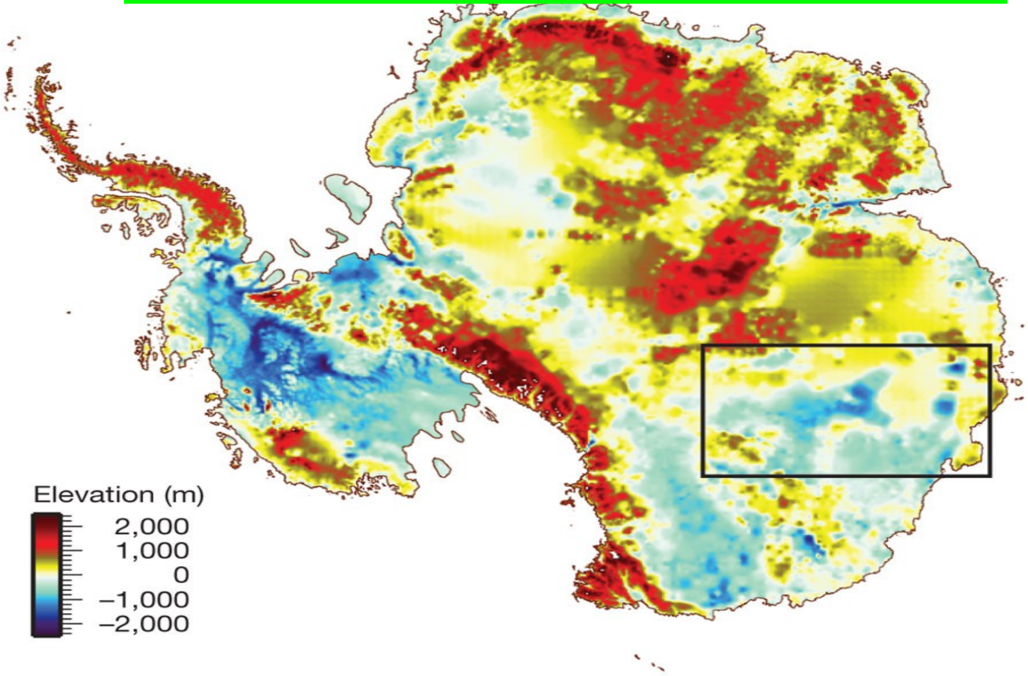
Sub-glacial lakes

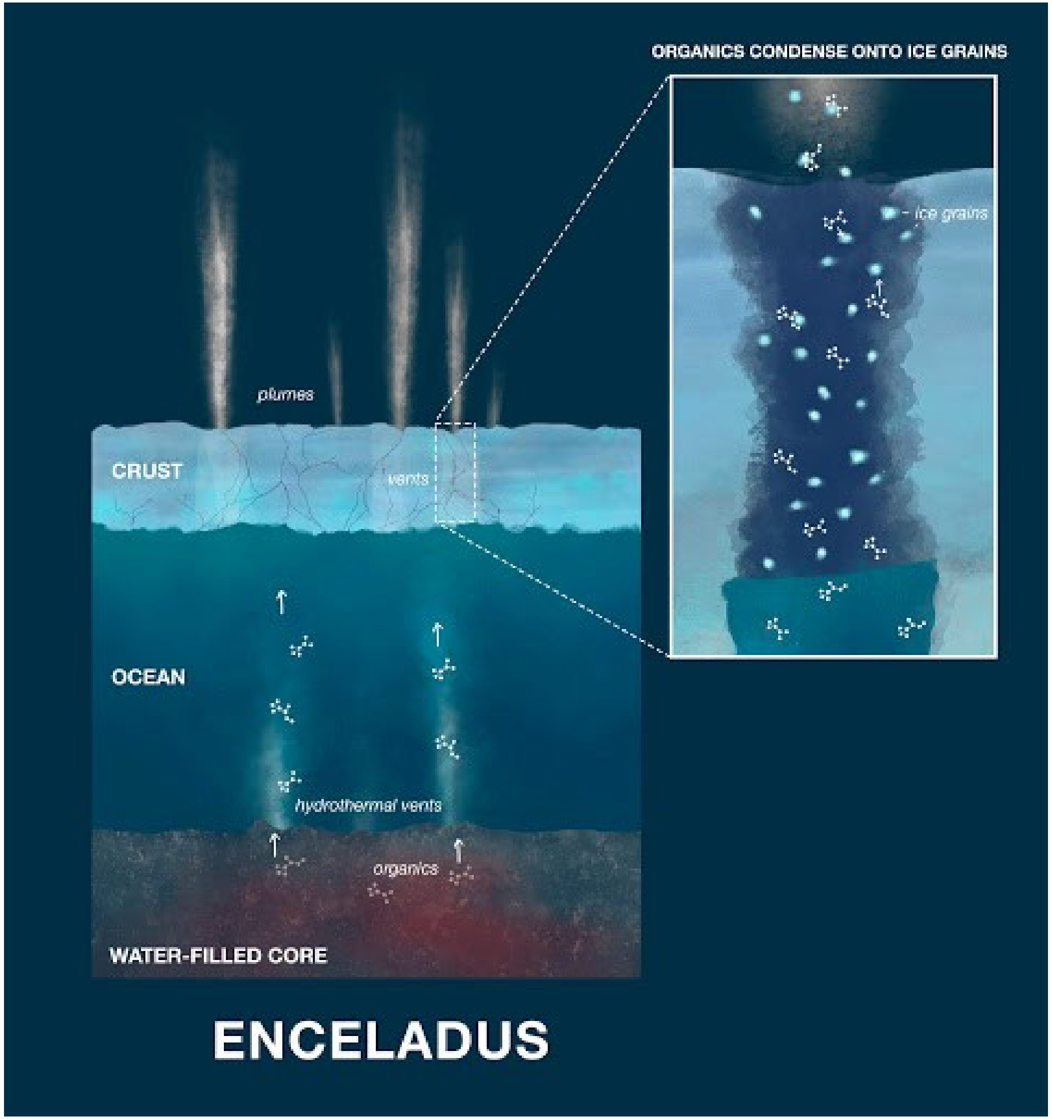


Lakes



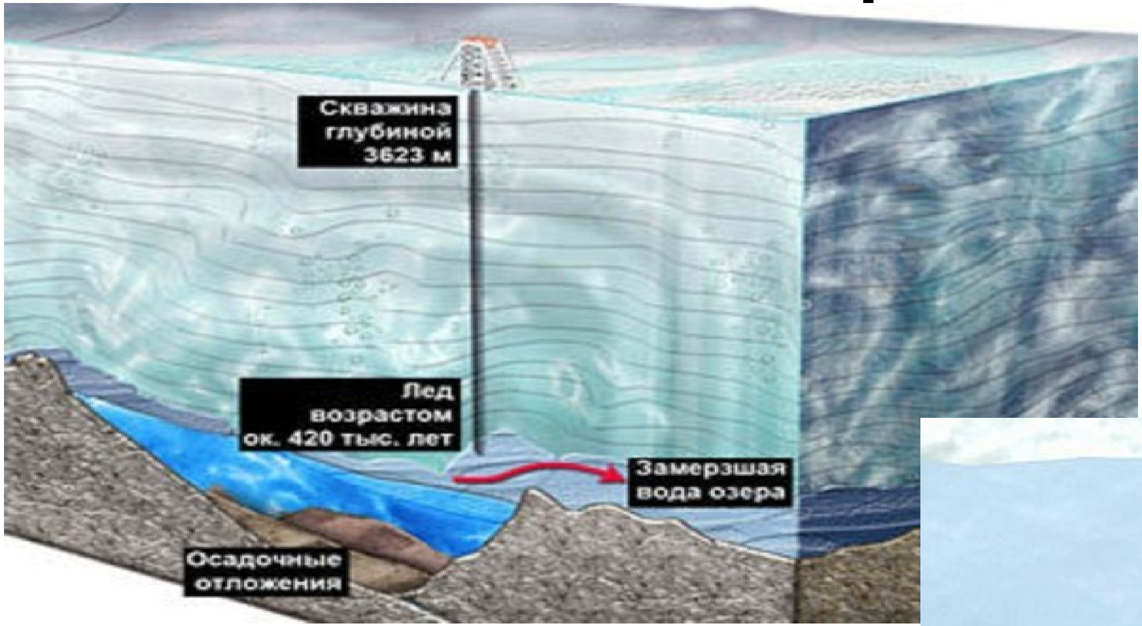
Land Elevation

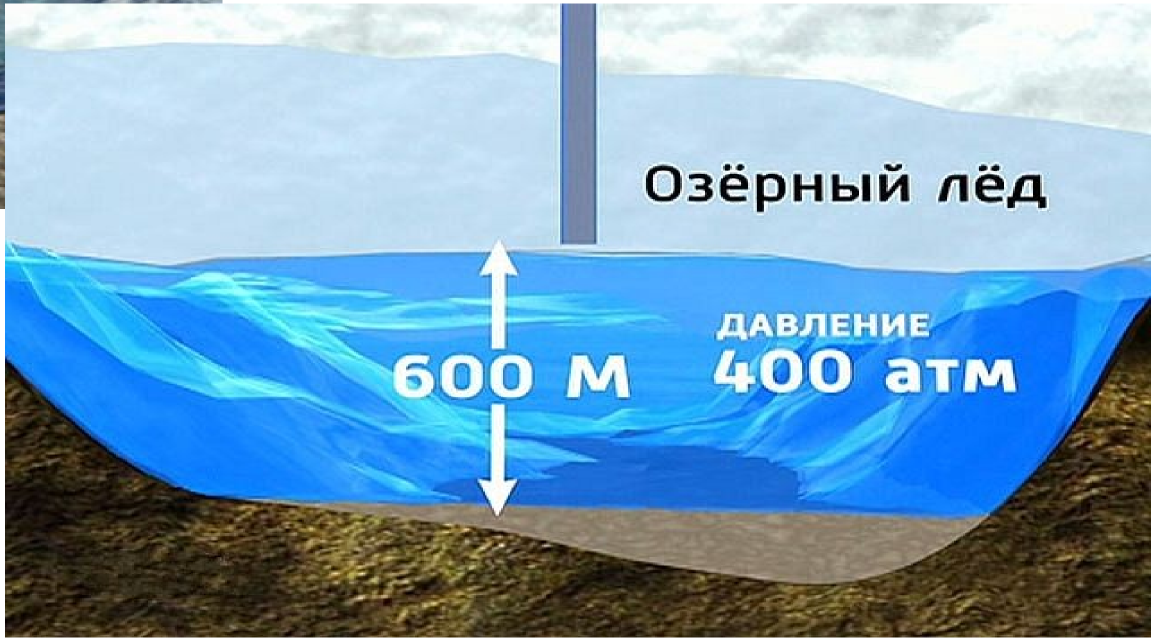




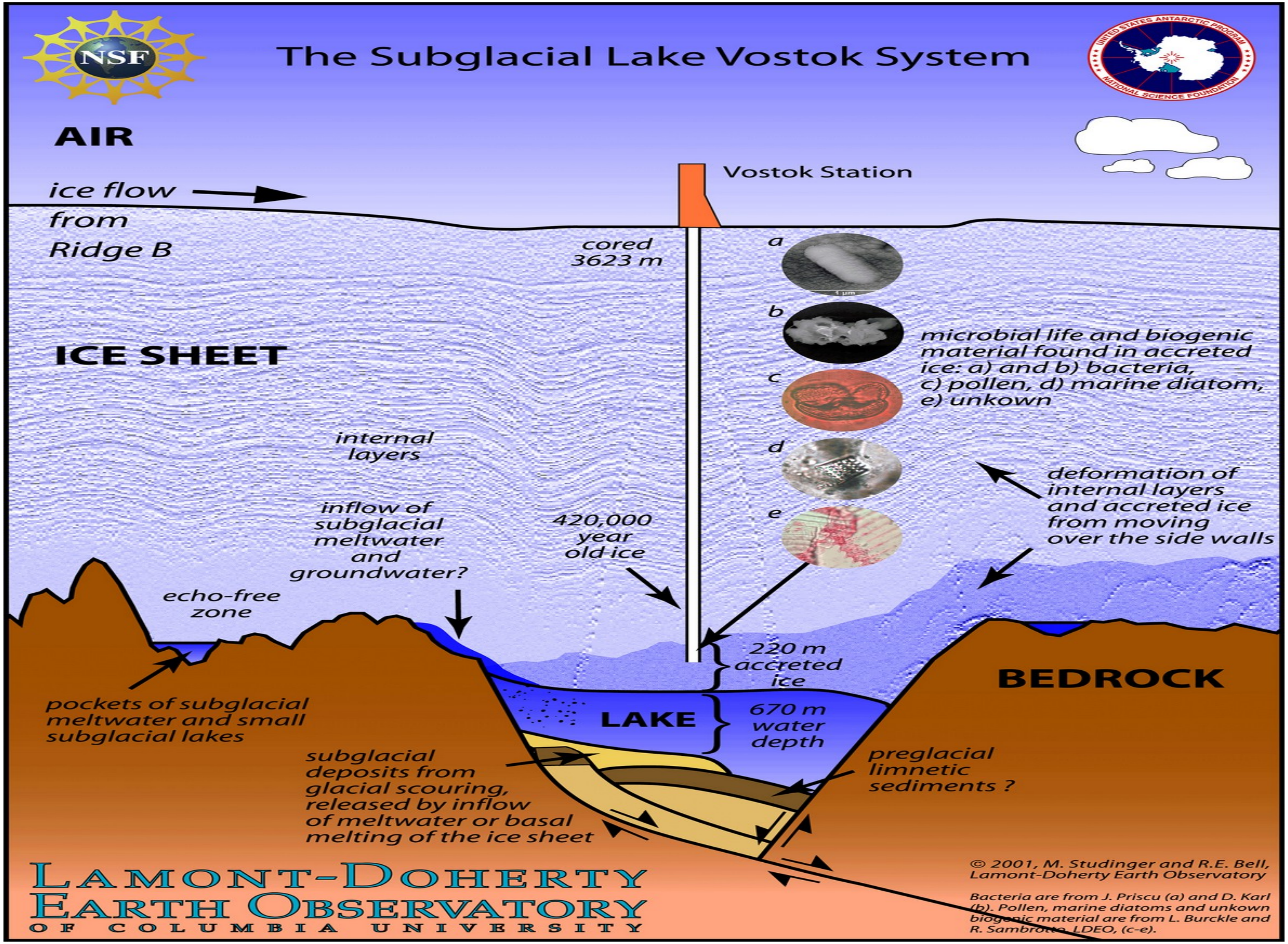
Tidal forces acting on fault lines in the moon's icy shell cause the sides of the faults to rub back and forth against each other, producing enough heat to transform some of the ice into plumes of water vapor and ice crystals.

Озеро Восток





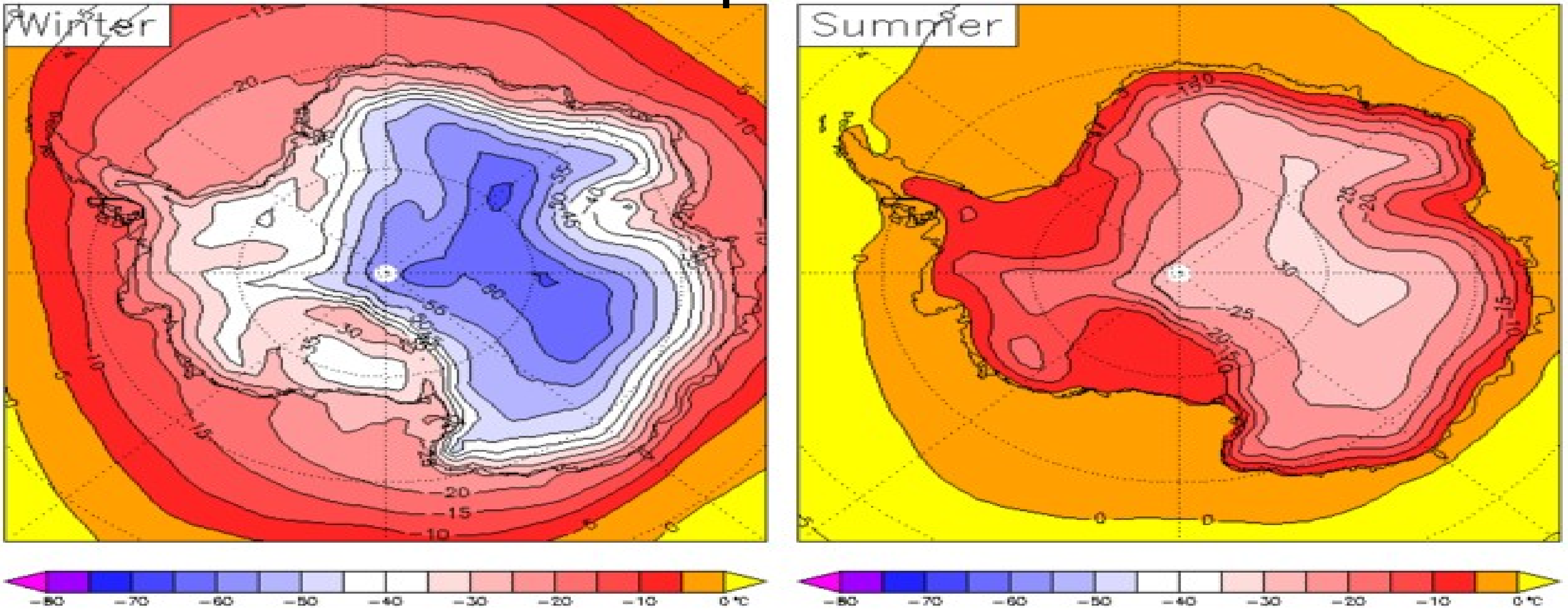
Life within the ice sheet



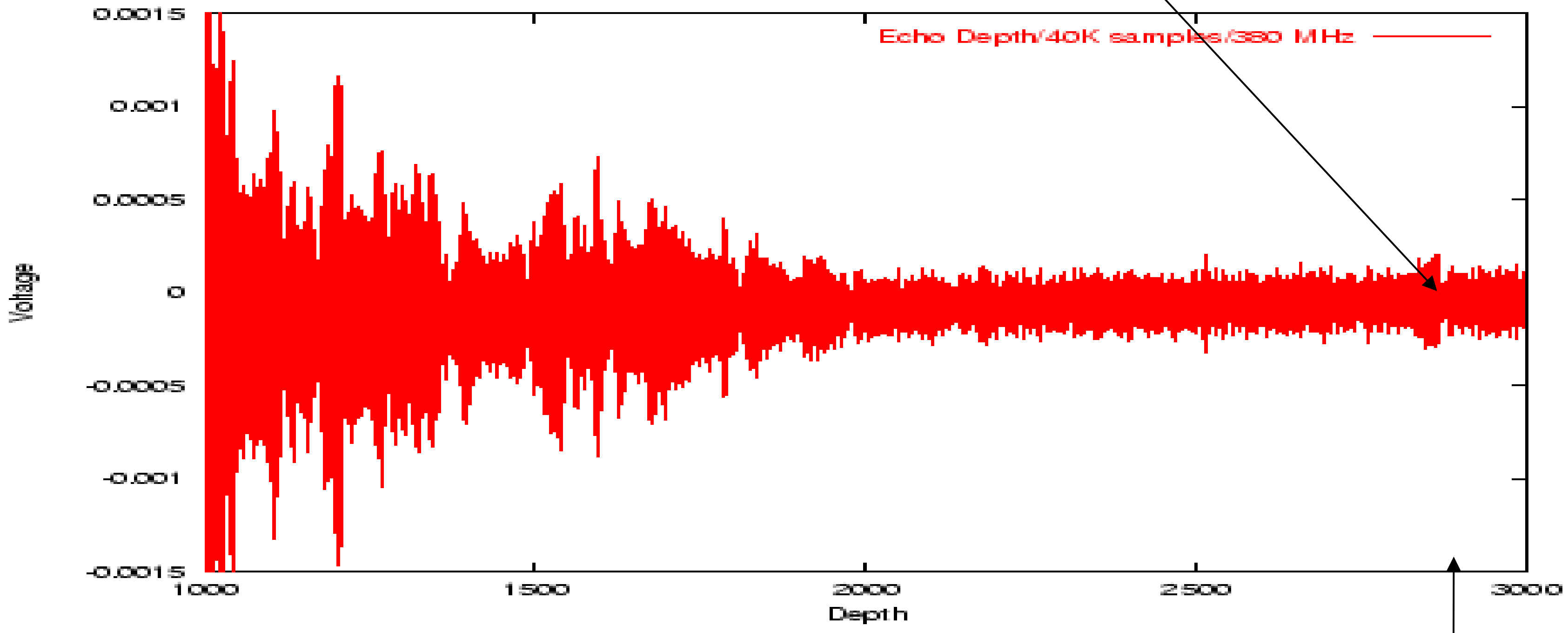
Aside: why doesn't lake freeze?

Why don't Europa/Enceladus lakes freeze?

Surface Temperature



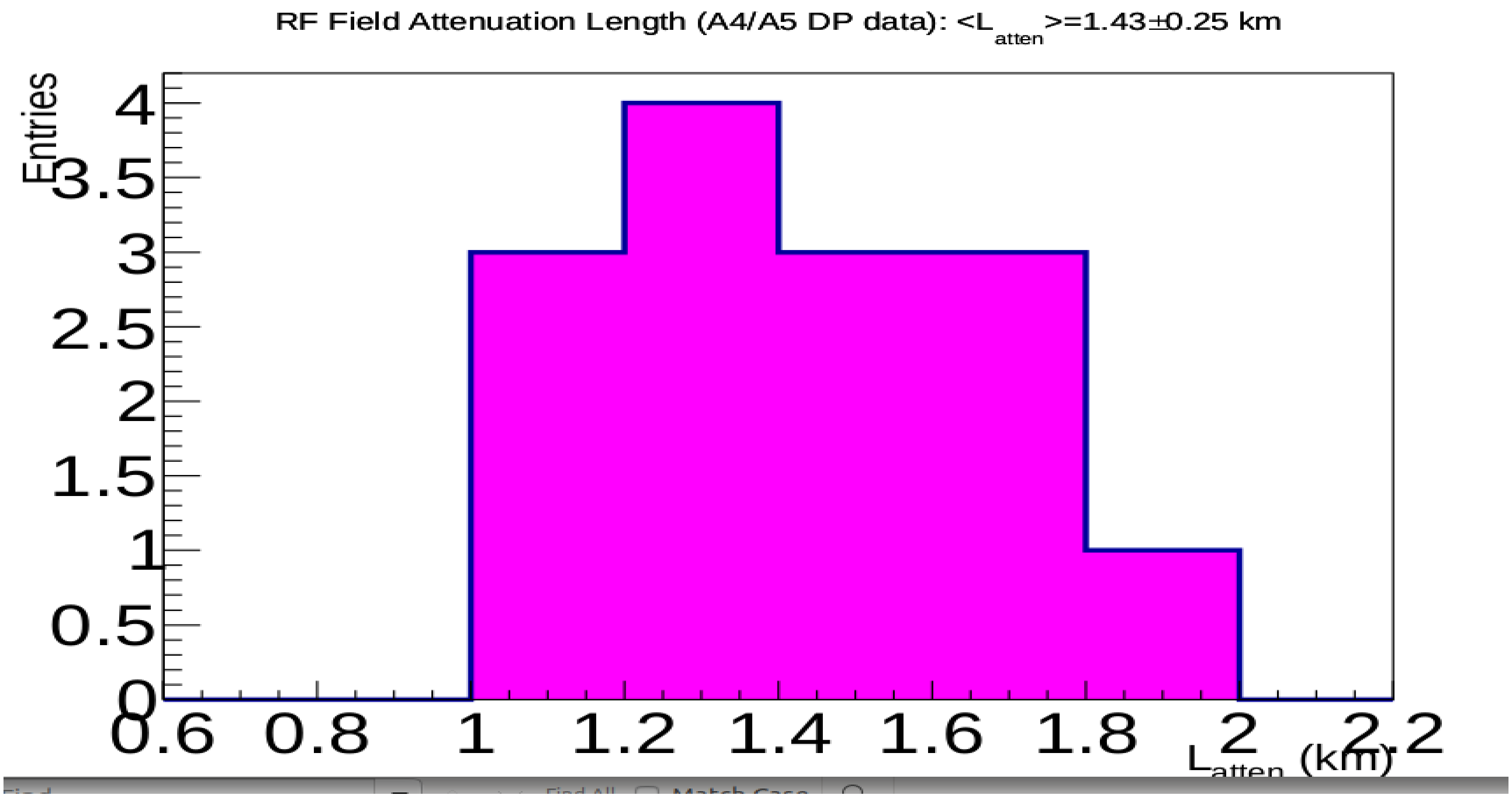
Bottom echo visible thru 5.6 km! Attenuation Length ~1.6 km. cf: Effective optical L_{atten} ~40 m (J. Glaciol. 51, 231 (2005).)



Bedrock/2850m

TAGLINE: Cold, clean ice is very RF-transparent (Europa, e.g.)

South Pole ε'' Data



N.B. Shadow Zone effective attenuation length ~ 500 m

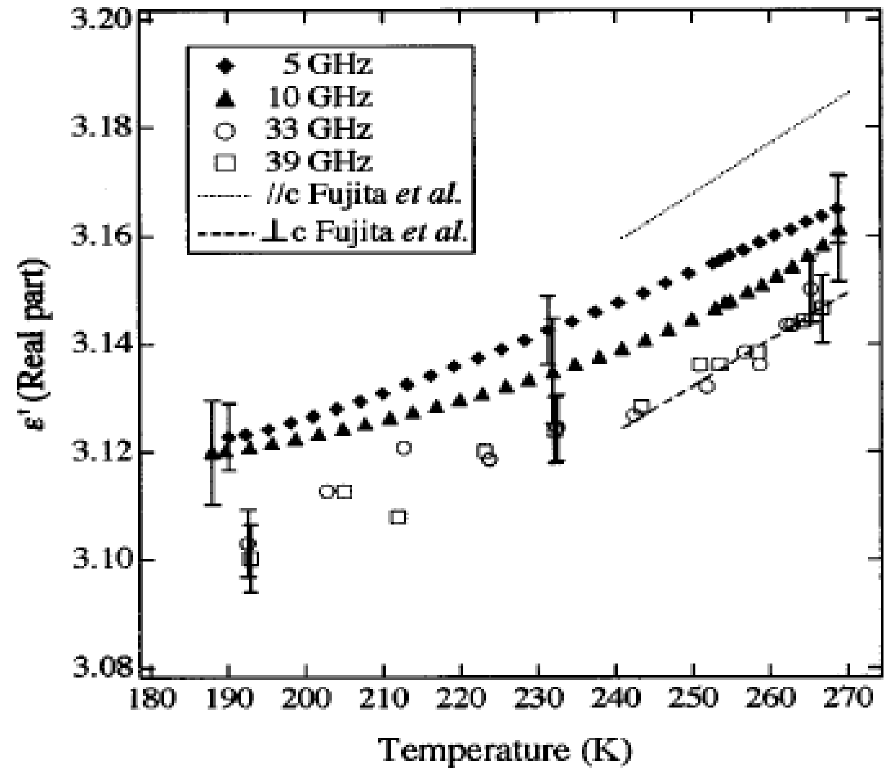
Cold Polar Ice Complex Permittivity

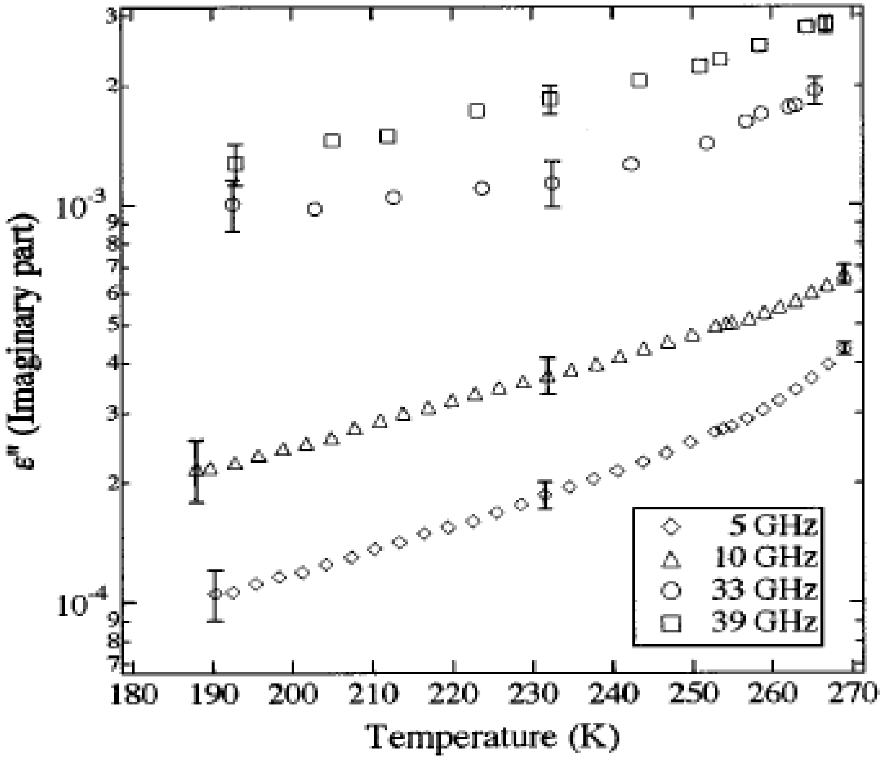
- **ε = ε' + iε''**
  - ε' = Real(**ε**): refractive-index (non-absorptive)
  - ε'' = Im(**ε**): attenuation length (absorption)
  - Tensor characteristics of **ε** => refractive index and attenuation length depend on polarization
    - =>`birefringence'

Permittivity of ice dependent on temperature.

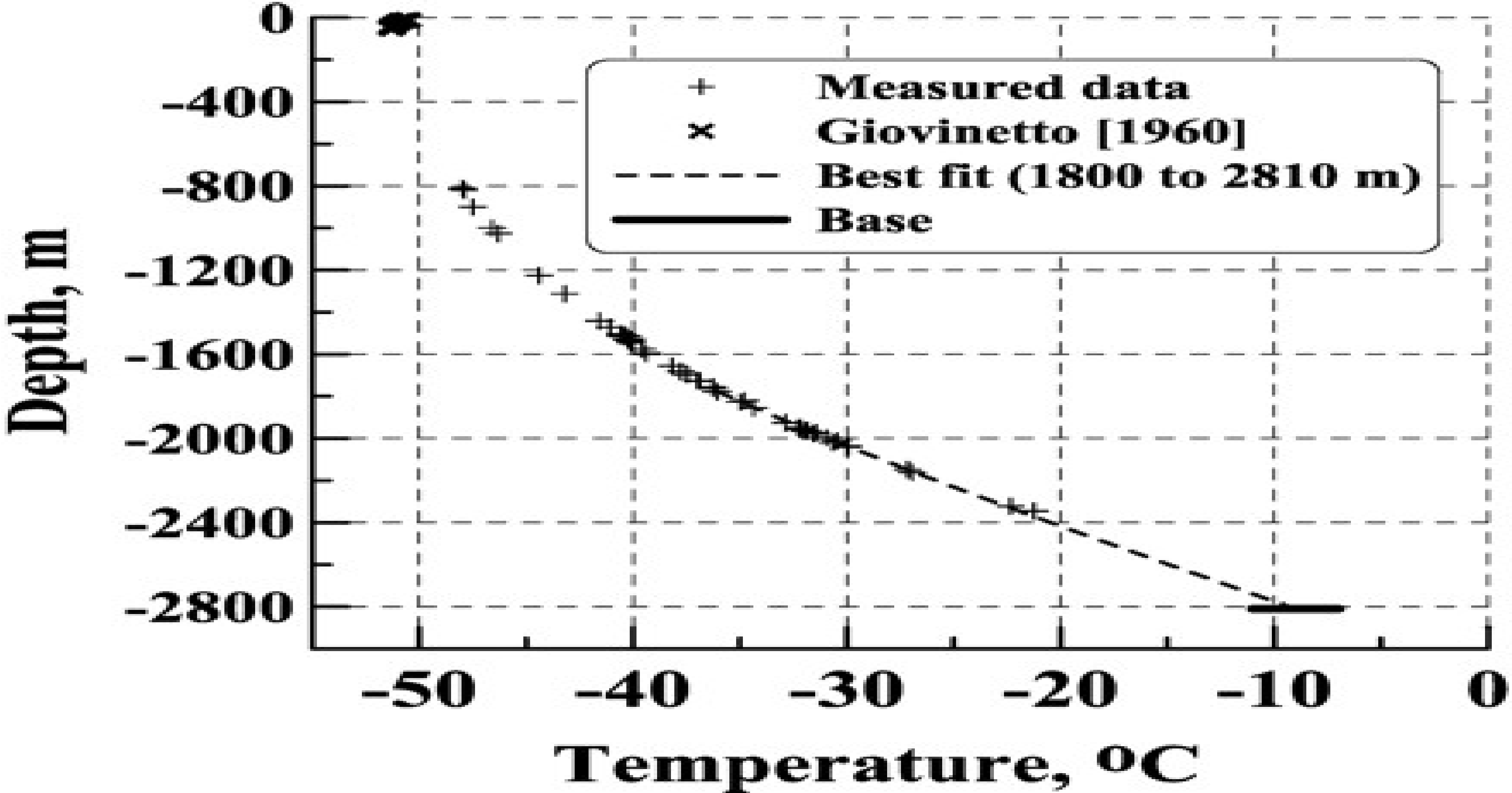
Matsuoka, T., S. Fujita and S.J. Mae. 1996. Effect of temperature on dielectric properties of ice in the range 5–39 GHz. *J. Appl. Phys,* **80**(10), 5884–5890.

1/ε = attenuation length

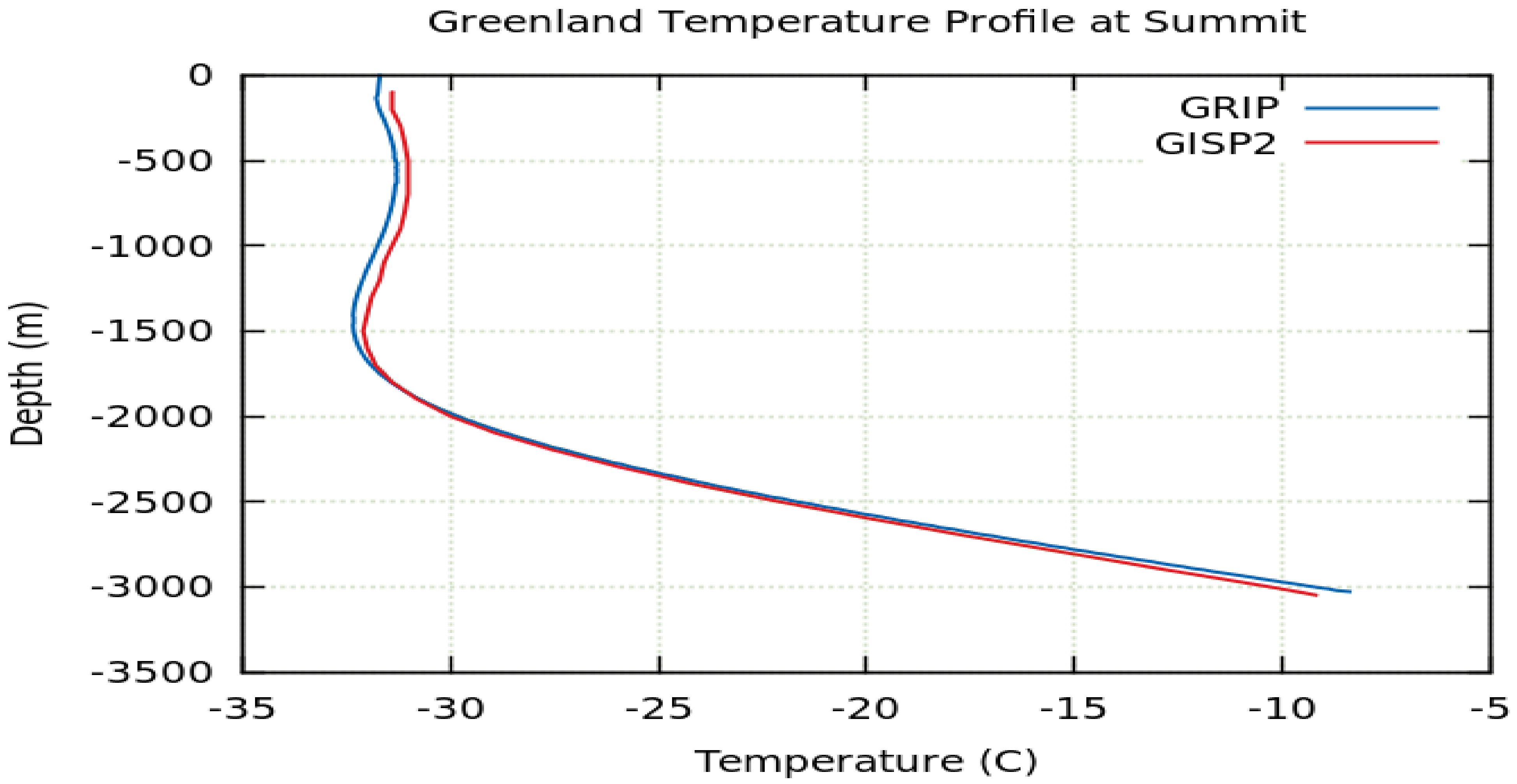




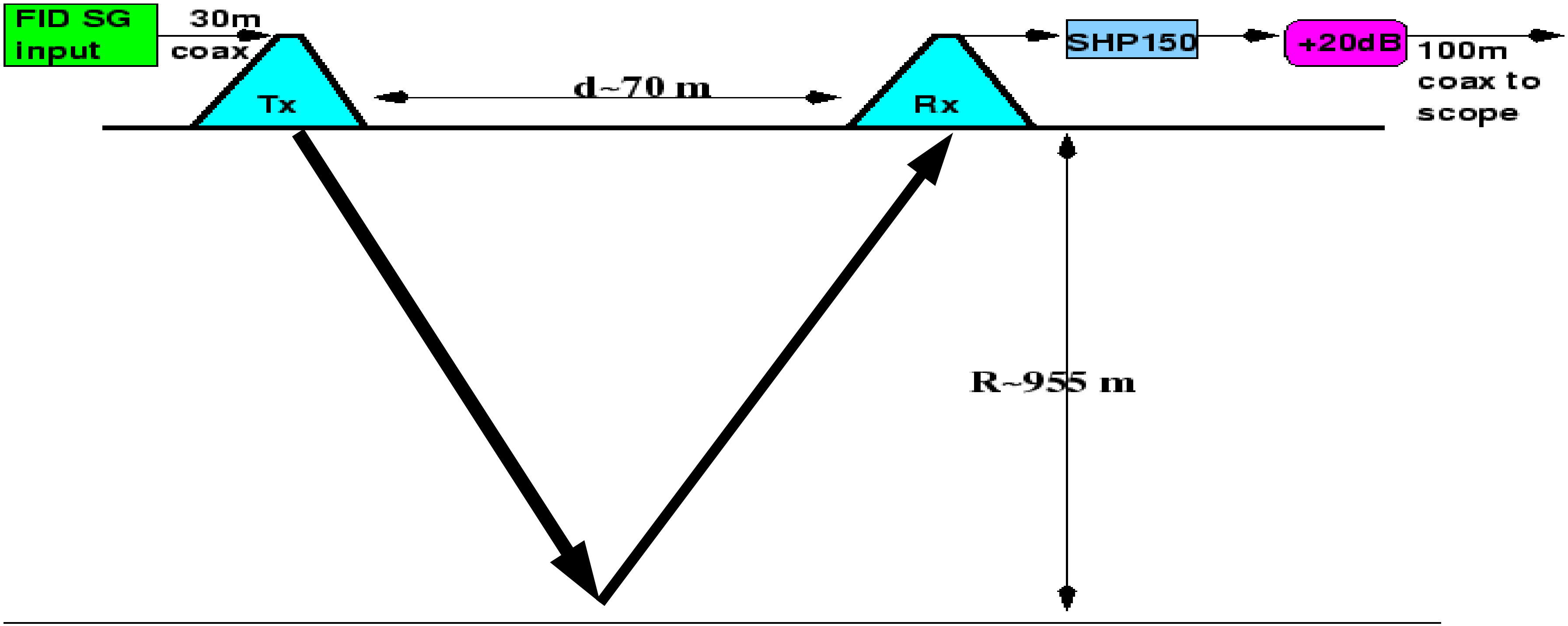
SP Temperature Profile (affects $L_{int}(z)$)



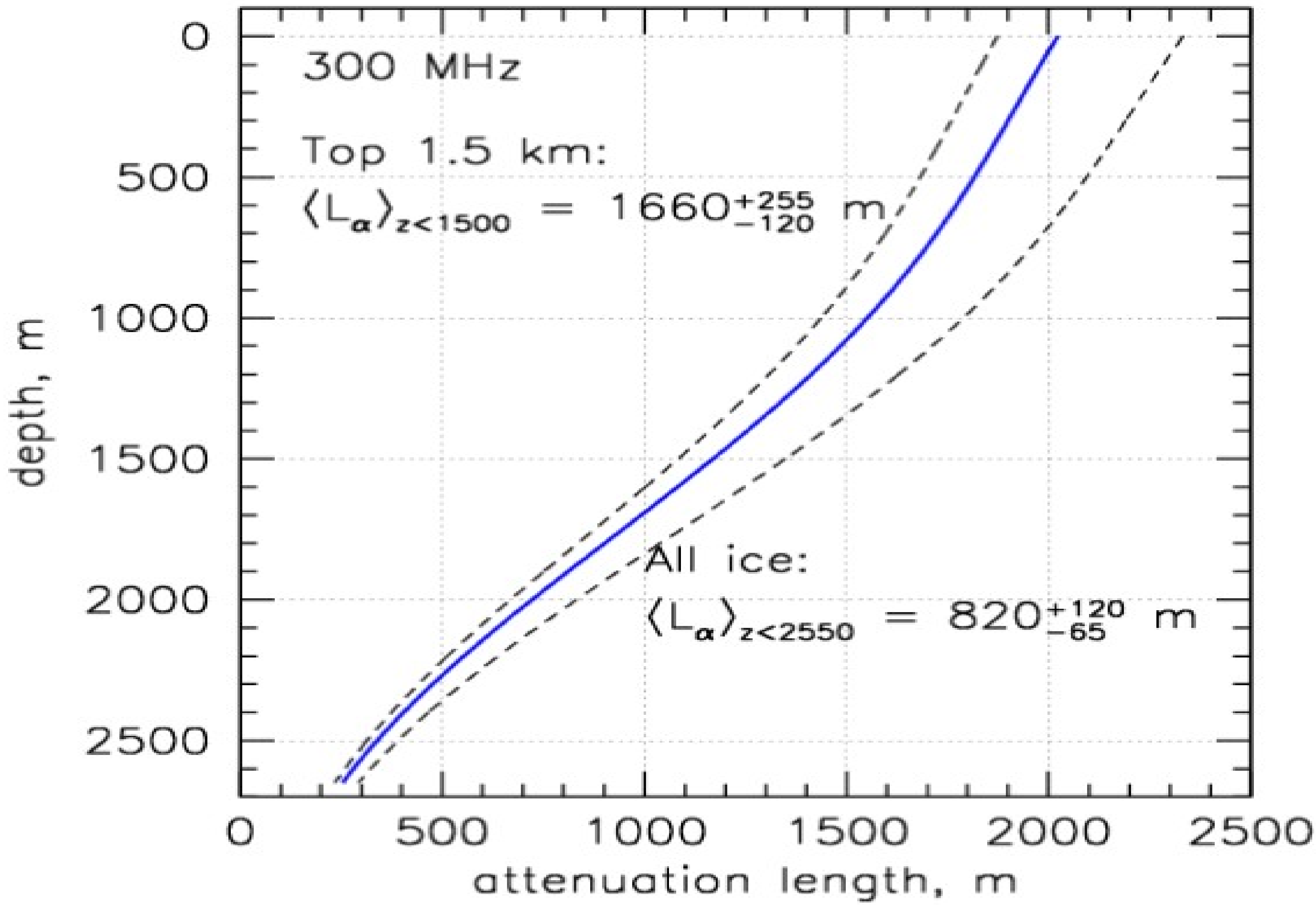
Greenland T(z)



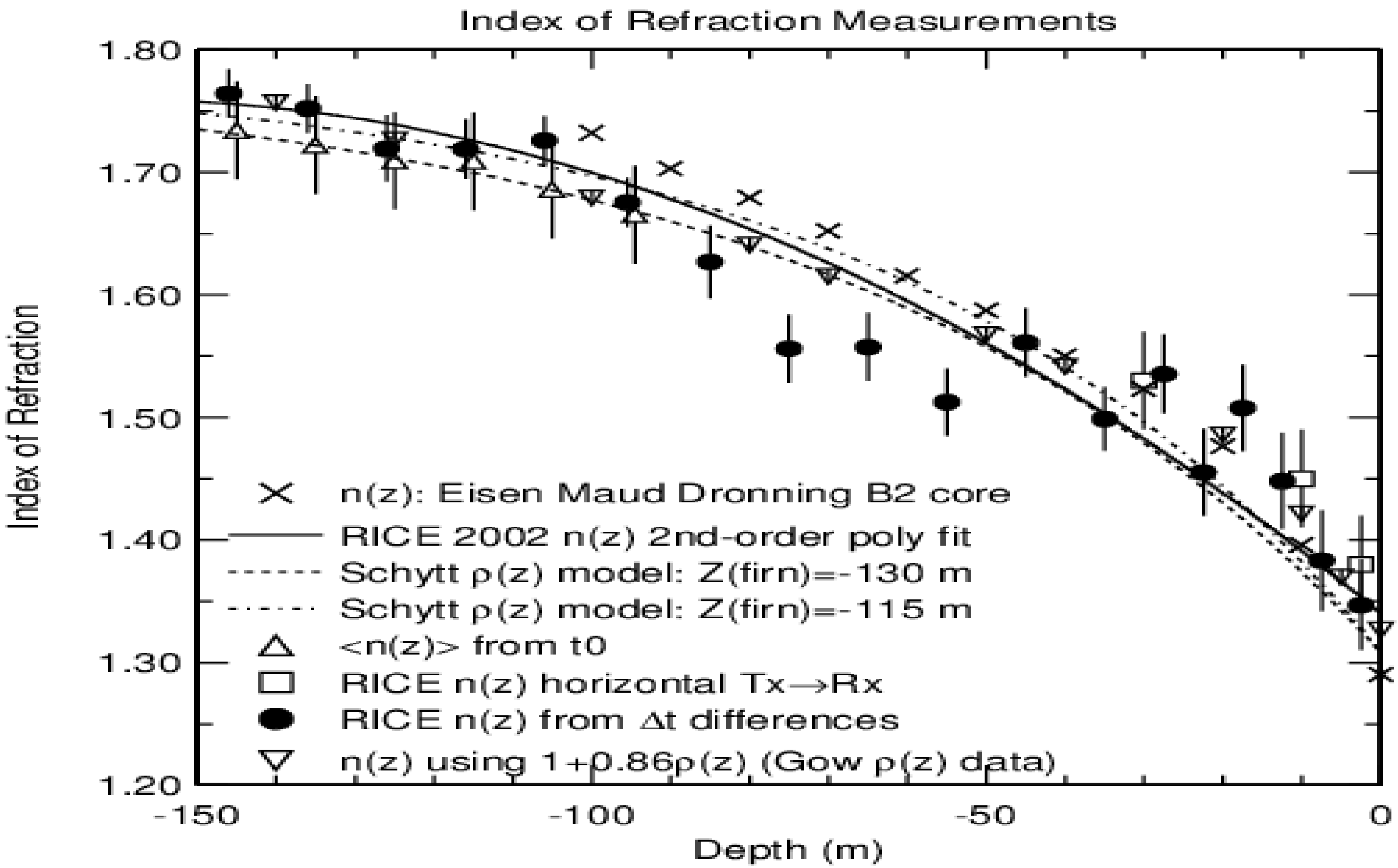
Birefringence tests: South Pole (R=2850 m) and Taylor Dome (R=955 m)



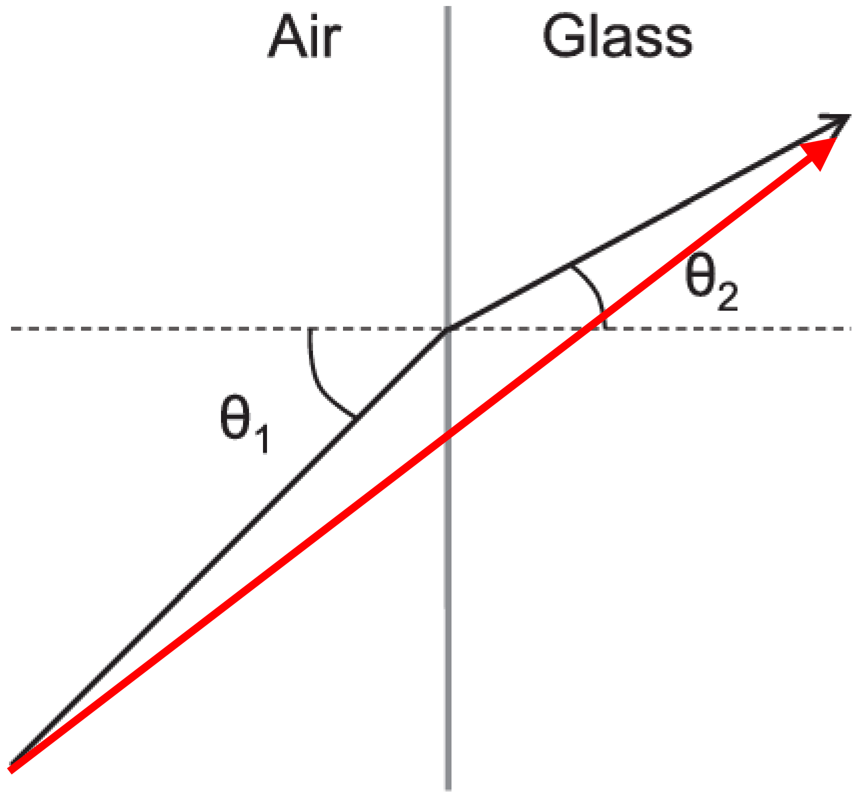
Attenuation length as f(depth)

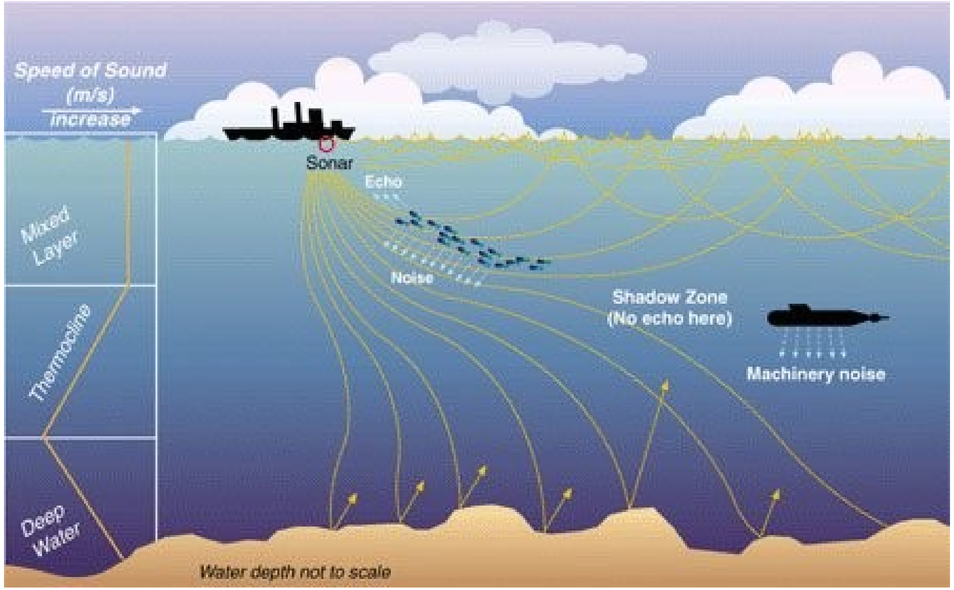


South Pole ε' Data

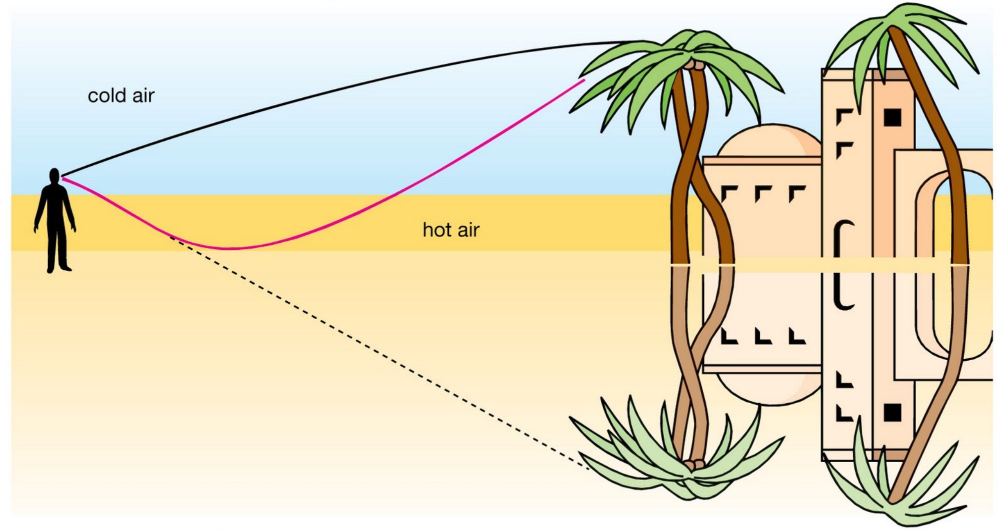


Fermat's Least time principle



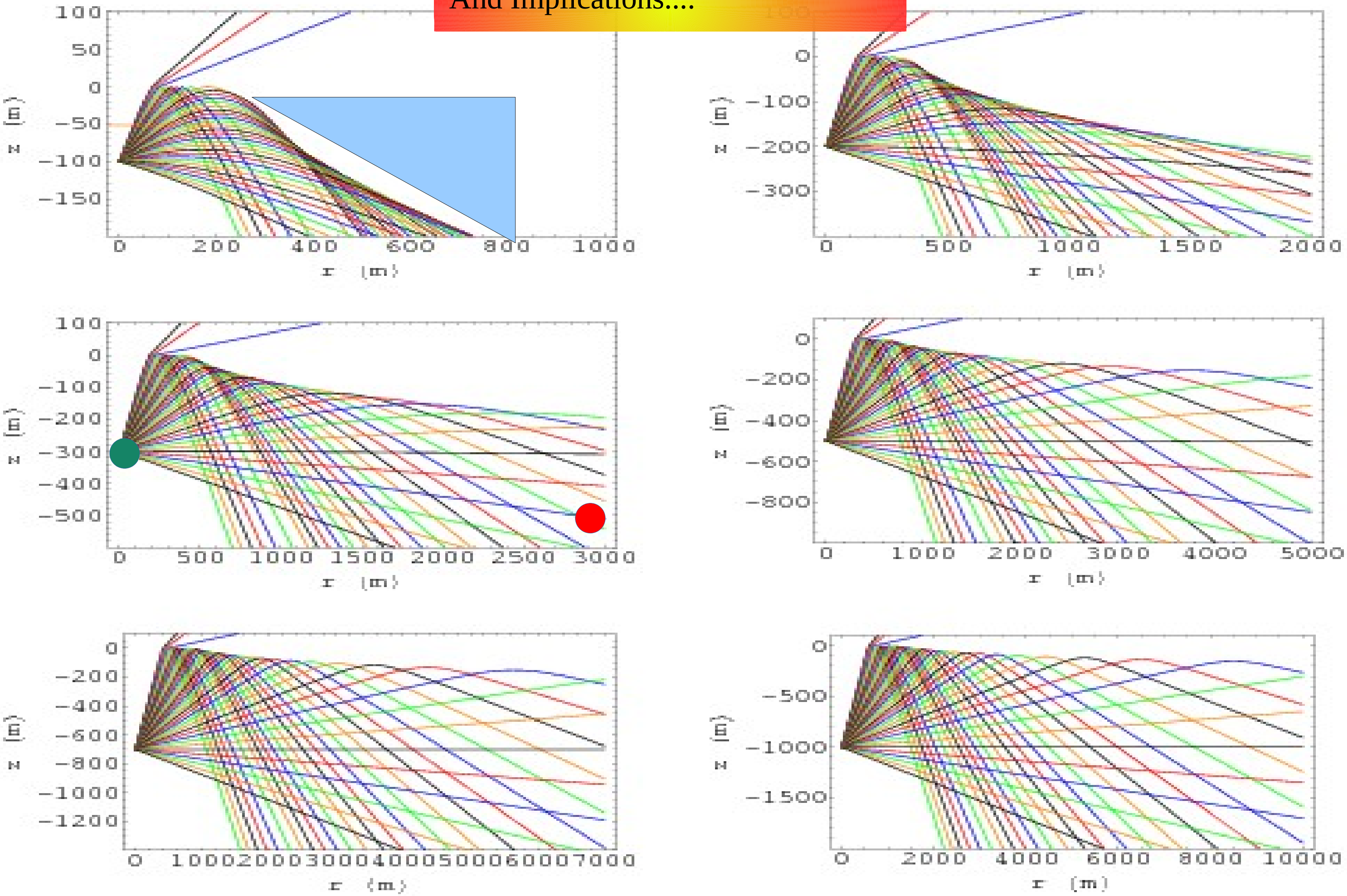


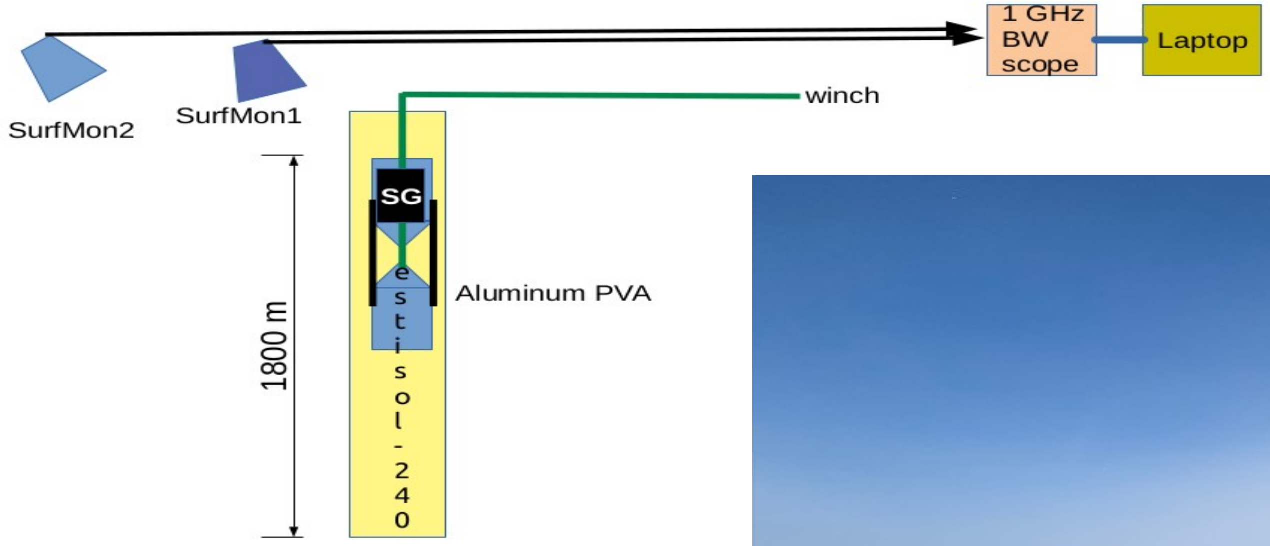
Fermat’s least time principle and mirages



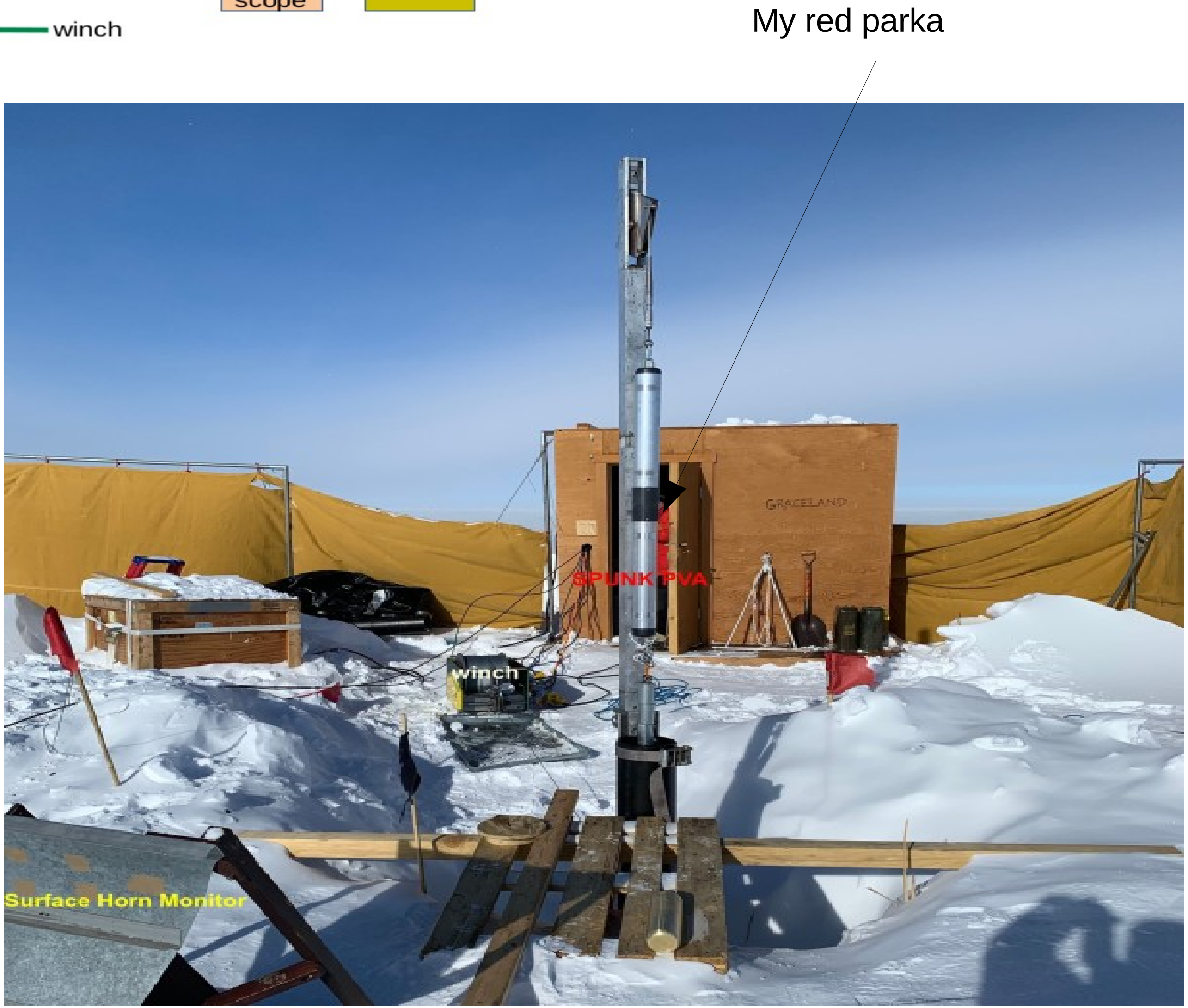
What is the effect of an index-of-refraction that changes with z?

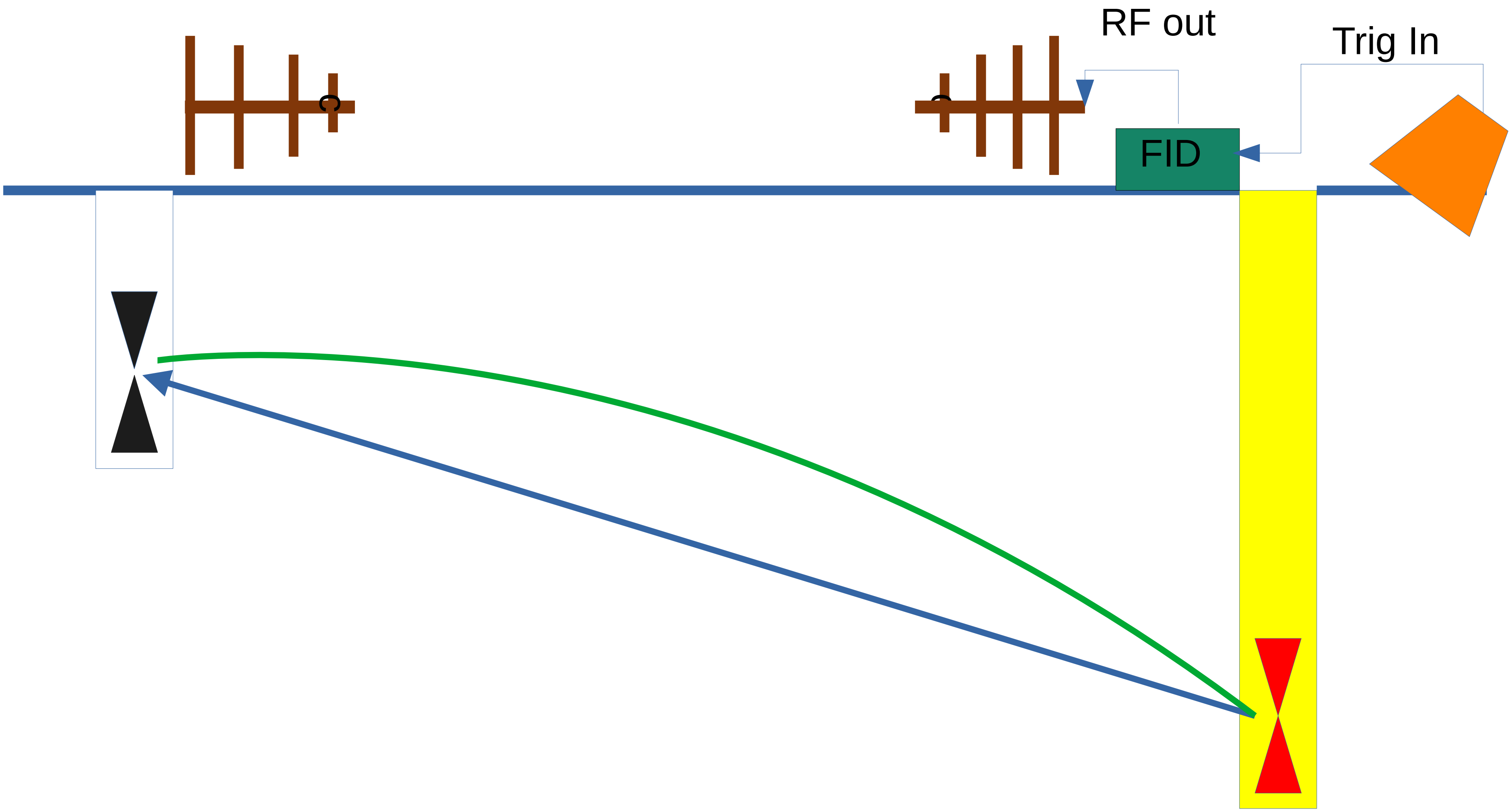
And Implications....



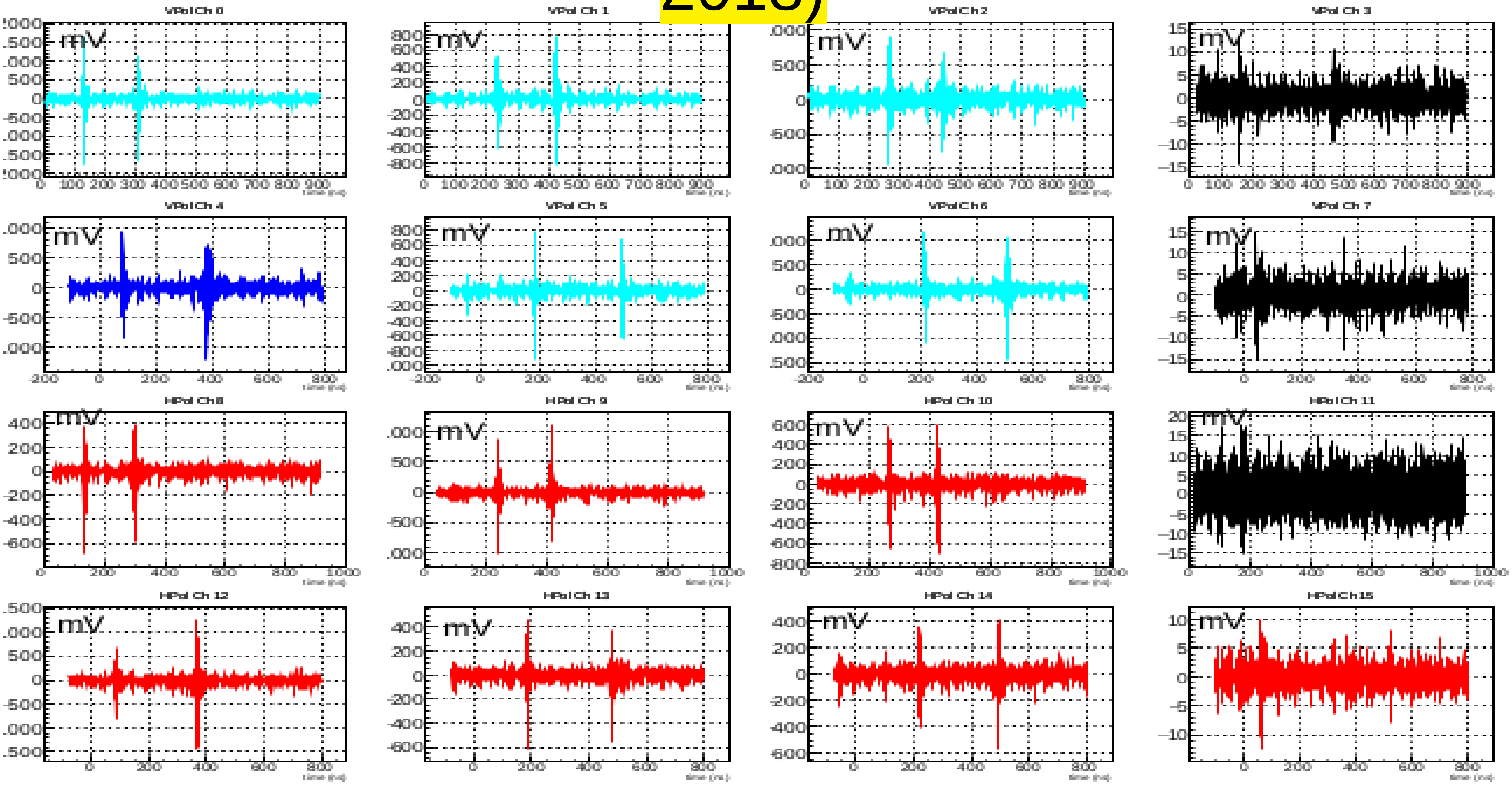


SPICE core testing (Dec., 2018)




RF out
Trig In
FID

Double pulses and refraction – SPICE core data (Dec., 2018)



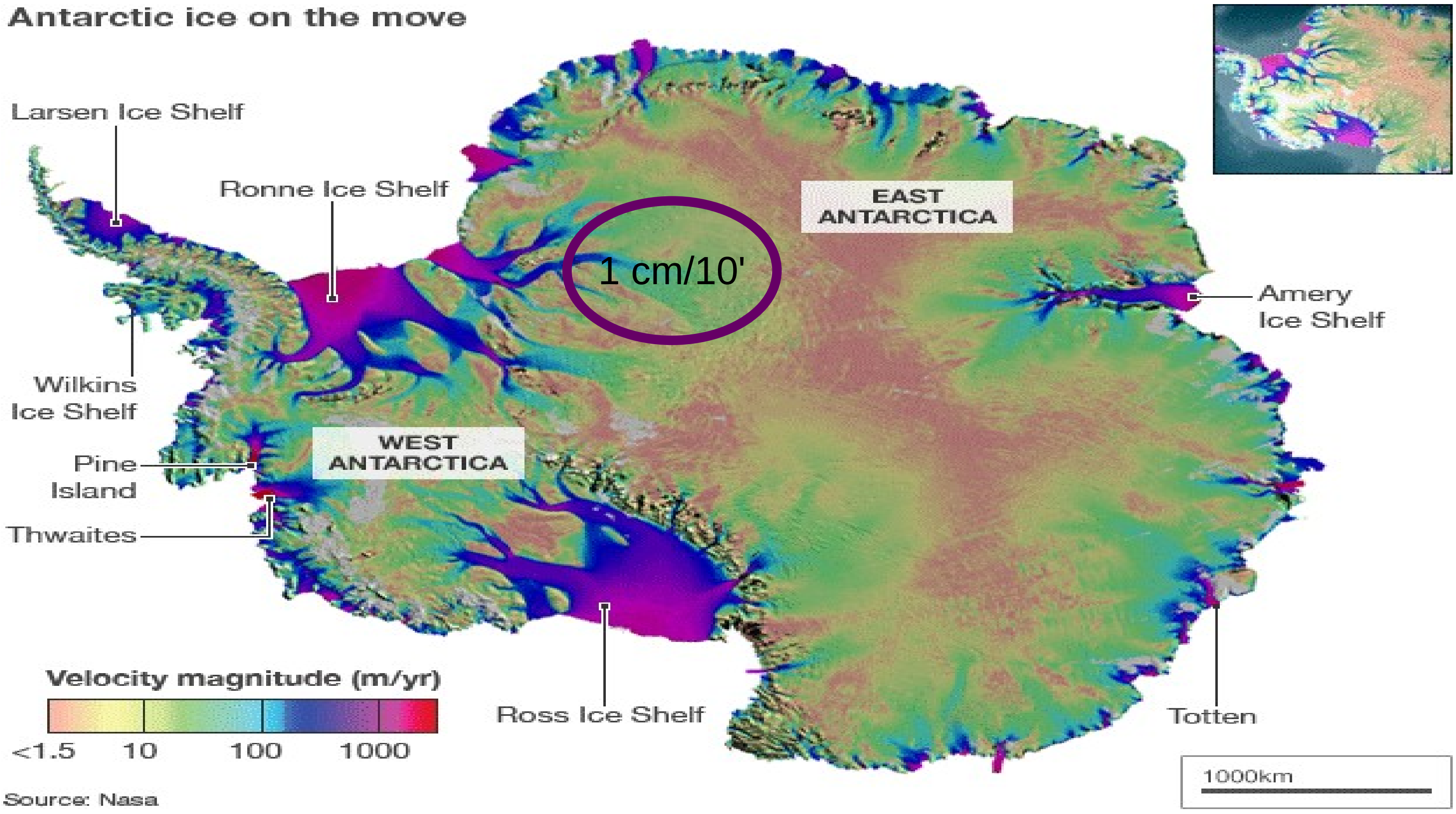
Antarctic Ice moves!!

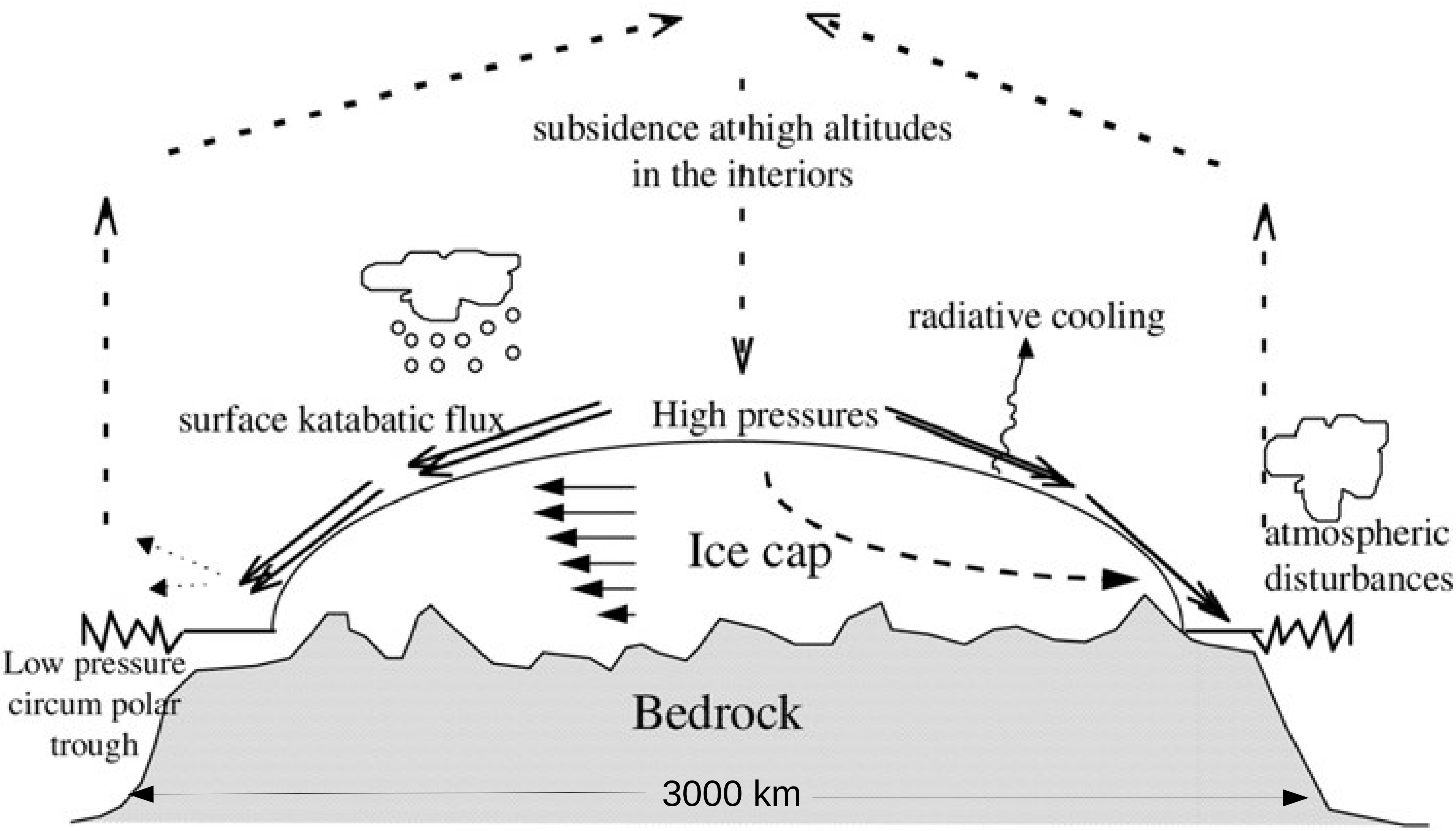
Previous year's South Pole

Last year's South Pole

This year's South Pole

Still, it Moves!




subsidence at high altitudes
in the interiors
radiative cooling
surface katabatic flux
High pressures
Ice cap
atmospheric
disturbances
Low pressure
circum polar
trough
Bedrock
3000 km

Ice Streams

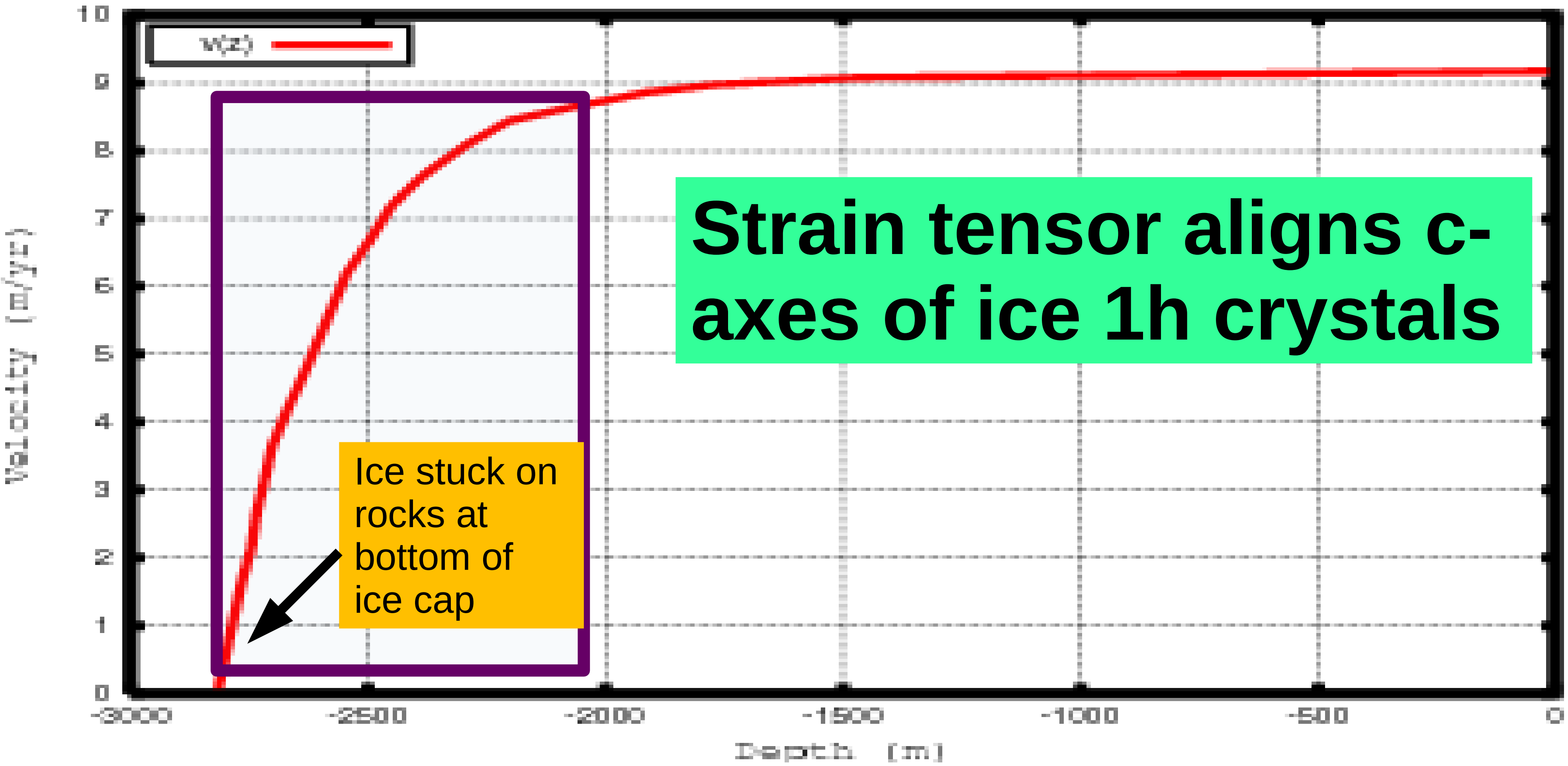
Present day glaciers

	AREA (km^2)
South polar region	12 535 000
North polar region	2 081 616
North America	76 880
South America	26 500
Europe	9 276
Asia	115 021
Africa	12
Pacific Australasia	1 015

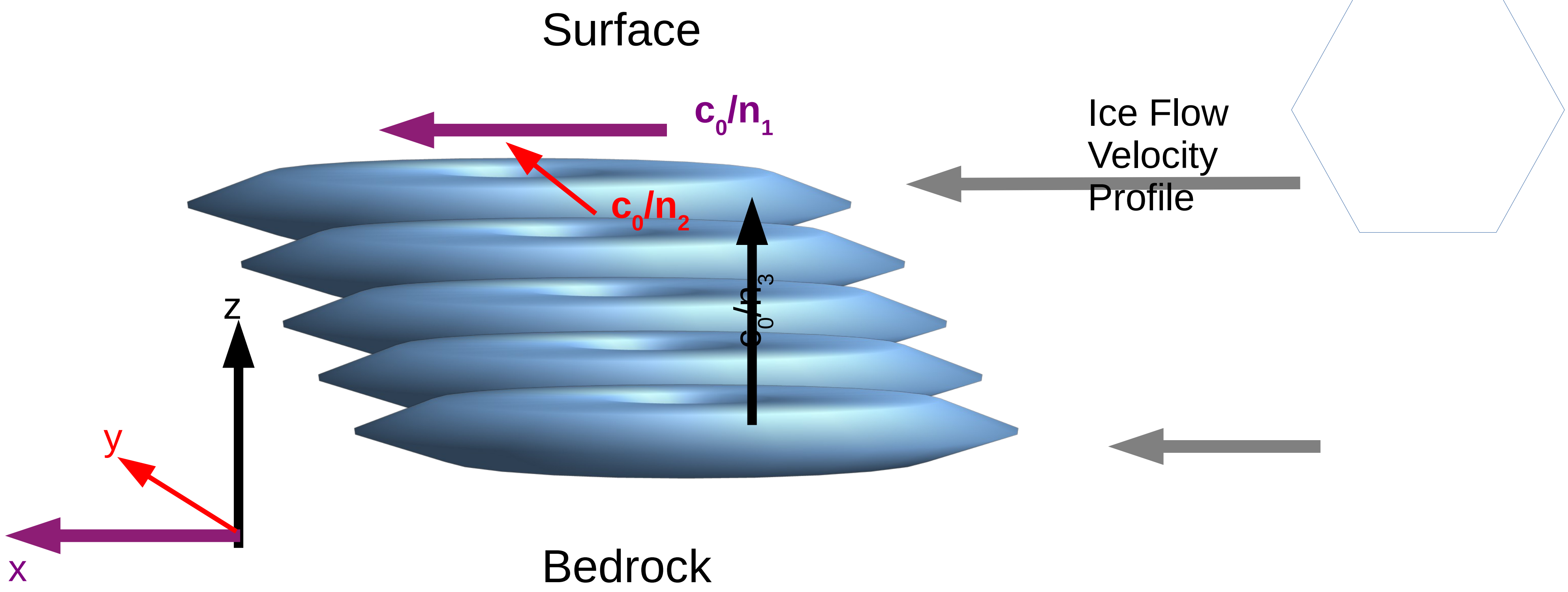
Total world coverage 14 898 320 km^2

http://ralph.swan.ac.uk/geg344/

South Pole slip/stick Velocity profile



Ice c-axes (symmetry axes and light velocity)



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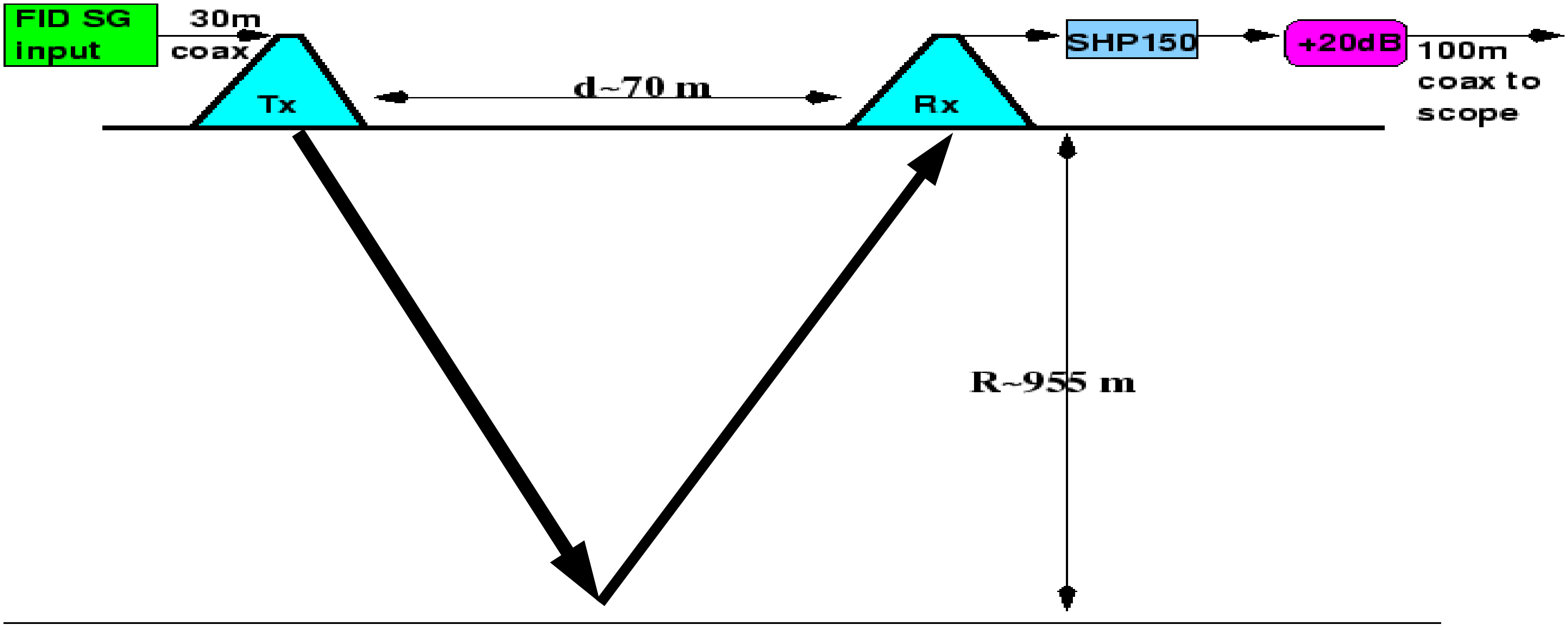
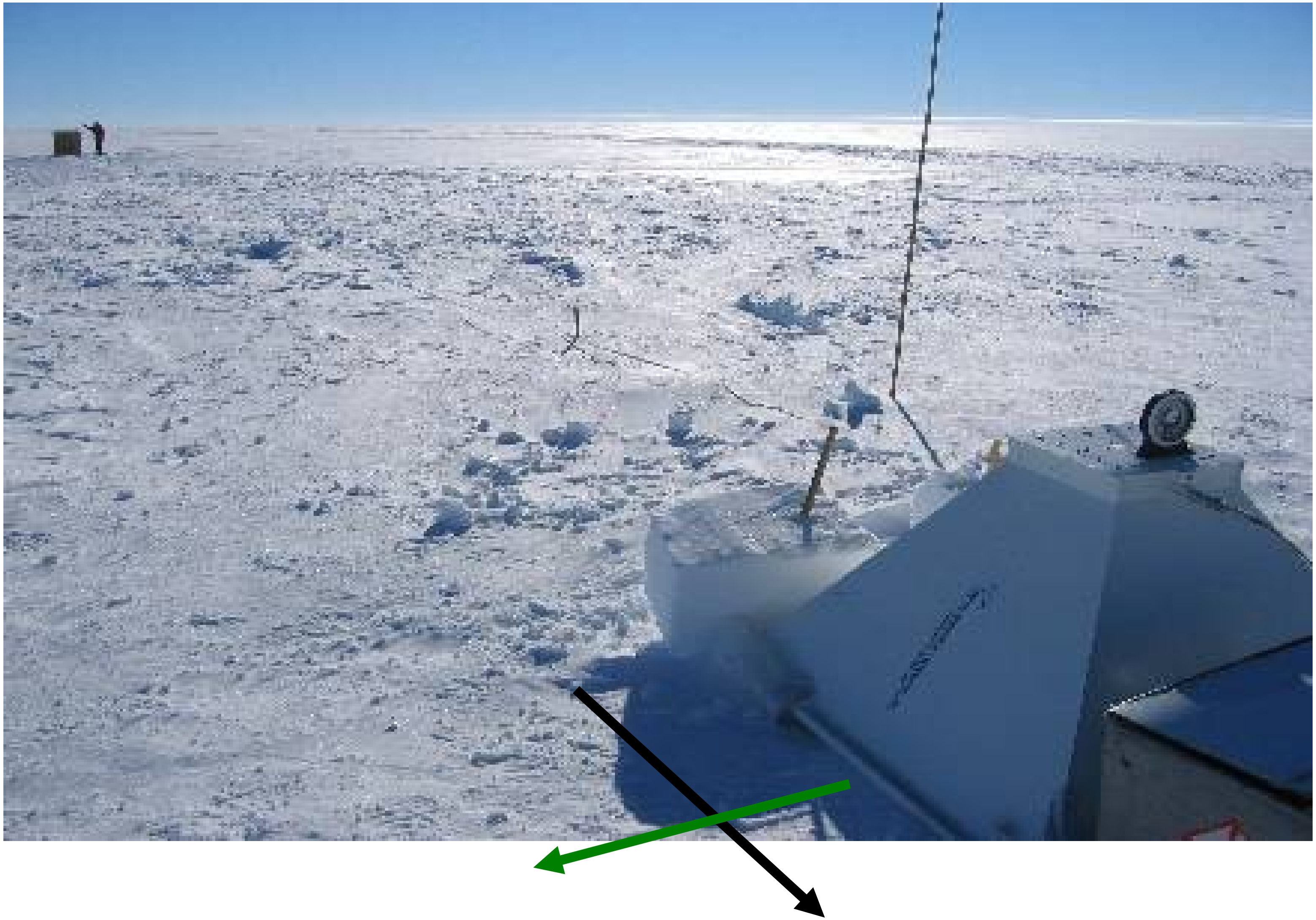


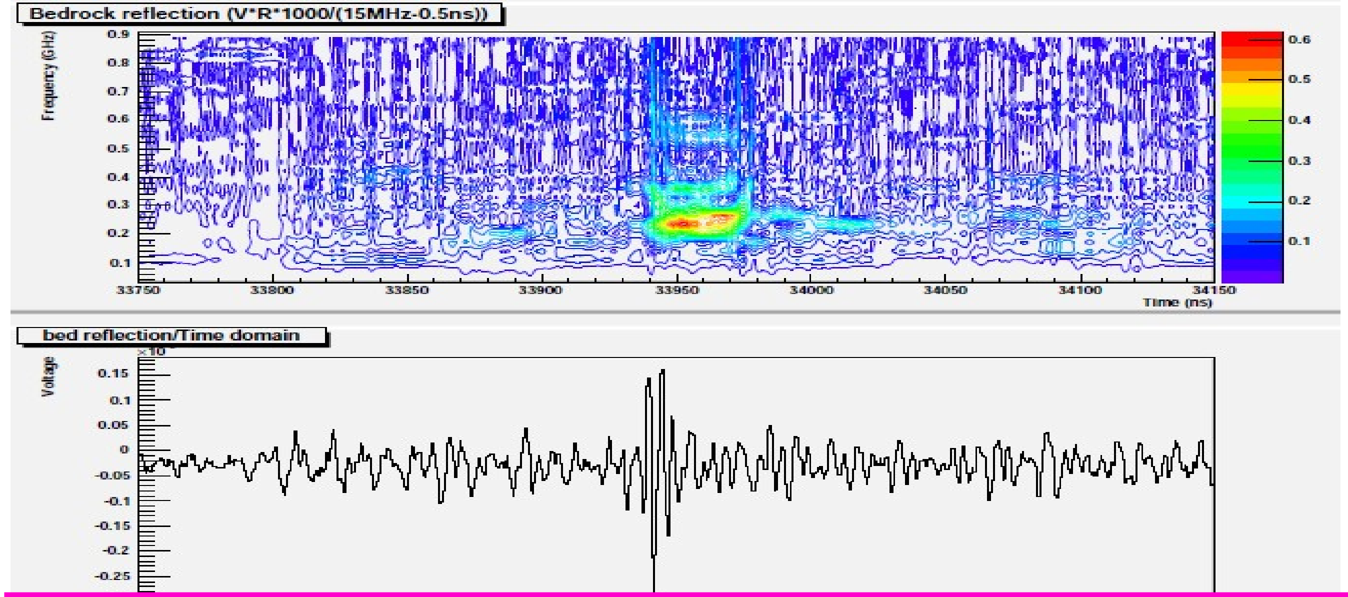
Taylor Dome Basecamp –*in situ* measurements of RF properties Investigate birefringence (Astropart.Phys.29:130-157,2008)


HONDA

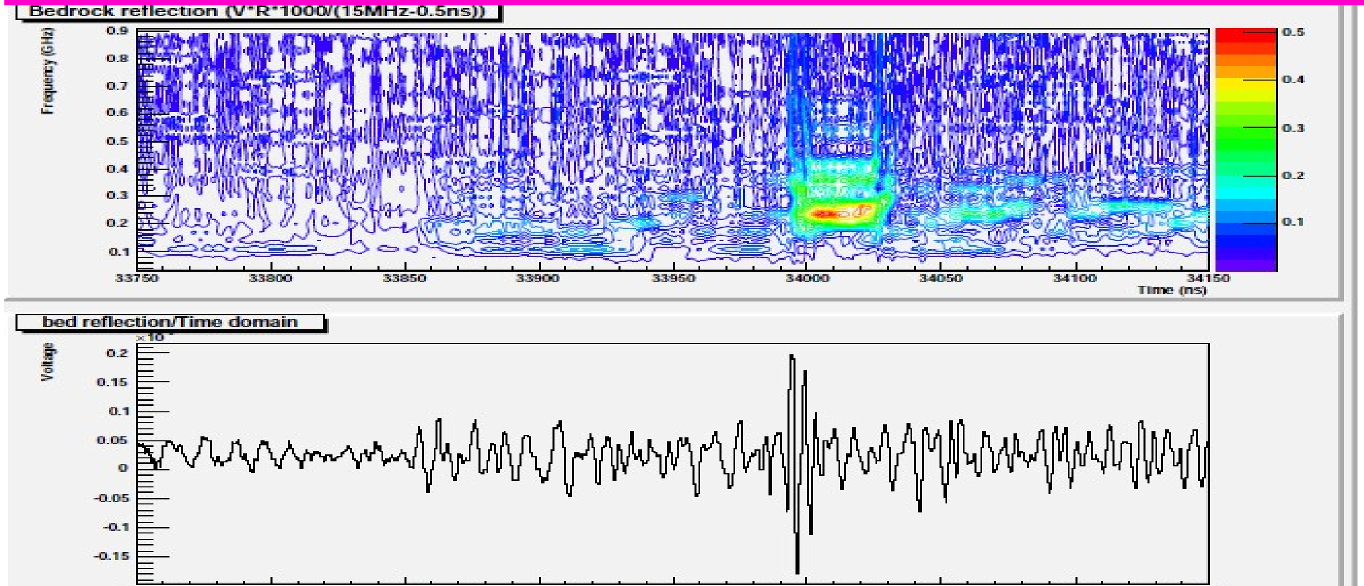


Bottom Reflection Studies.

Horn antennas send waves polarized along two perpendicular axes

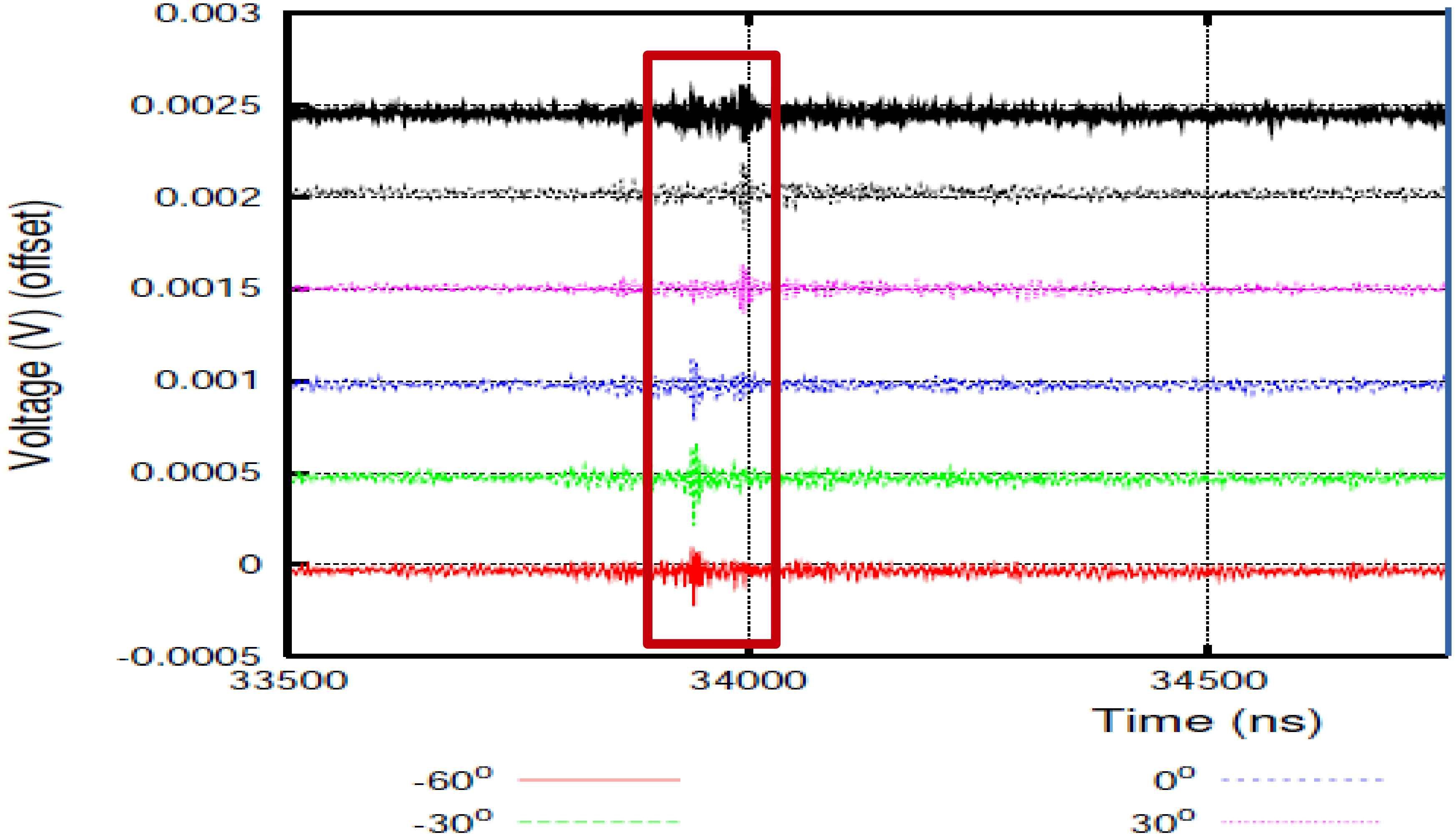


Polarization parallel to ice-flow direction



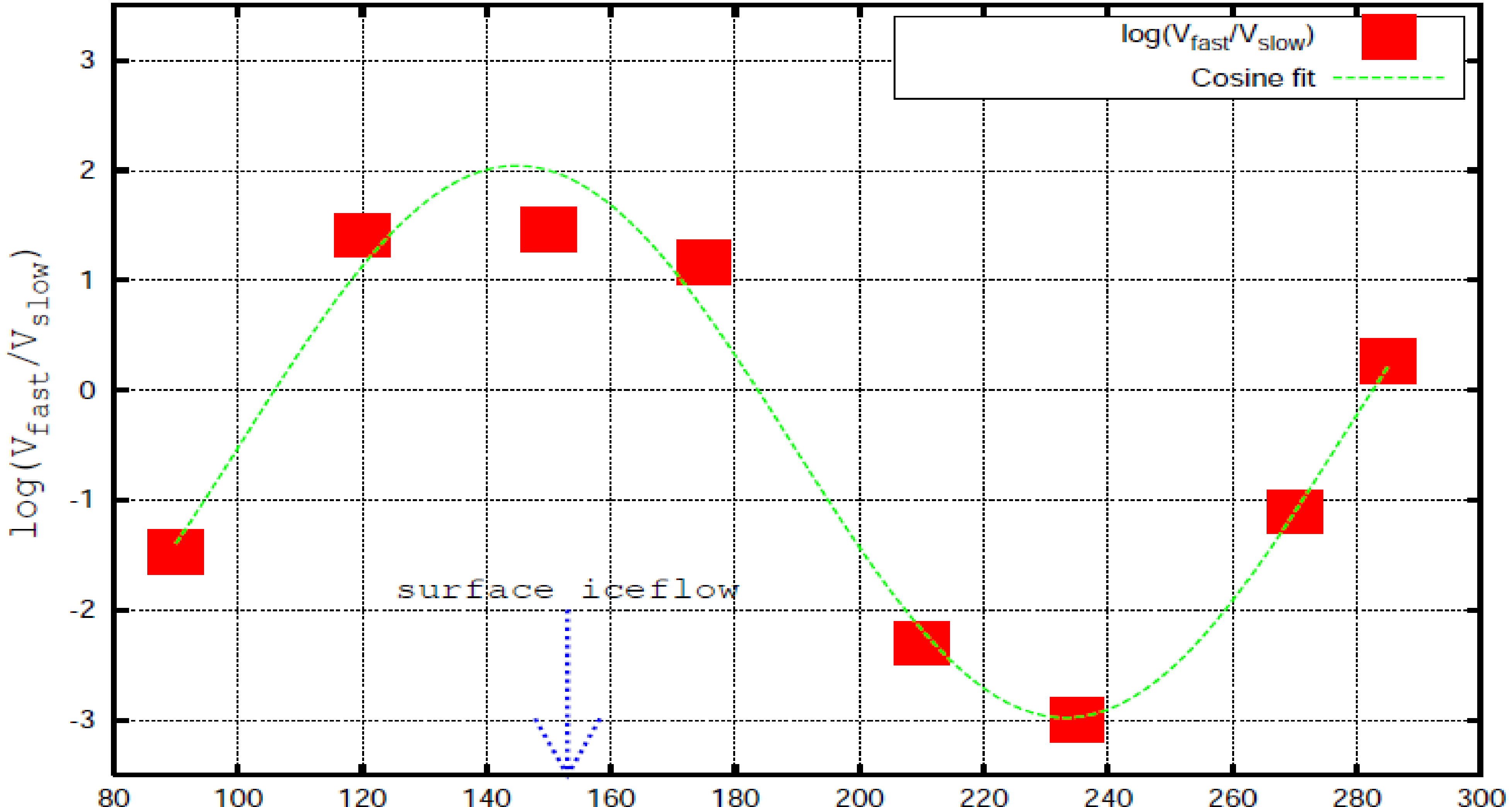
Polarization Perpendicular to ice-flow direction

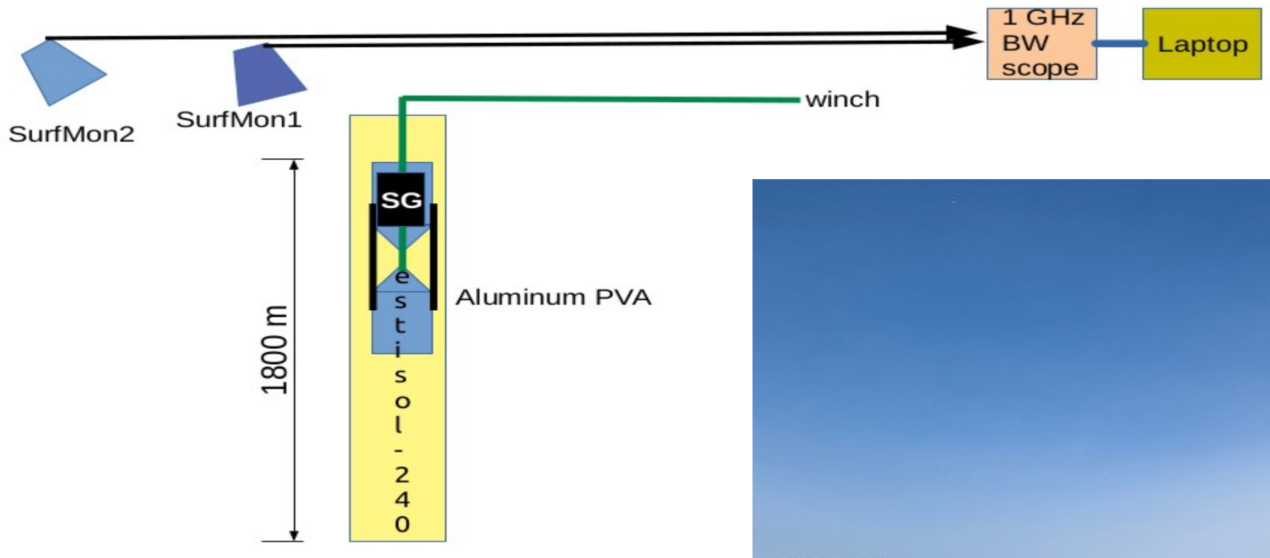
Data on ice birefringence V(polarization)



Can also derive attenuation length from this graph

Ratio of V(fast)/V(slow)





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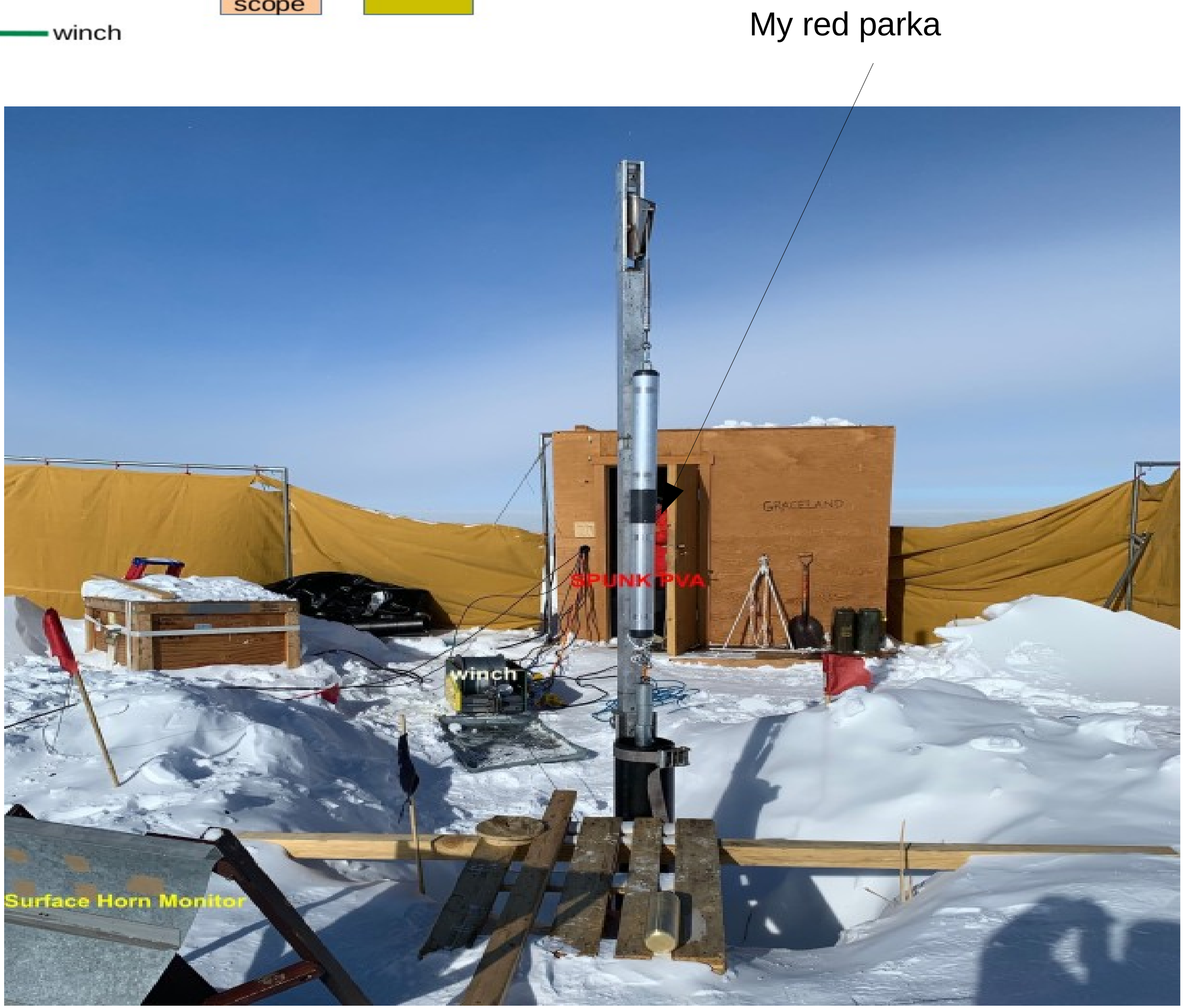
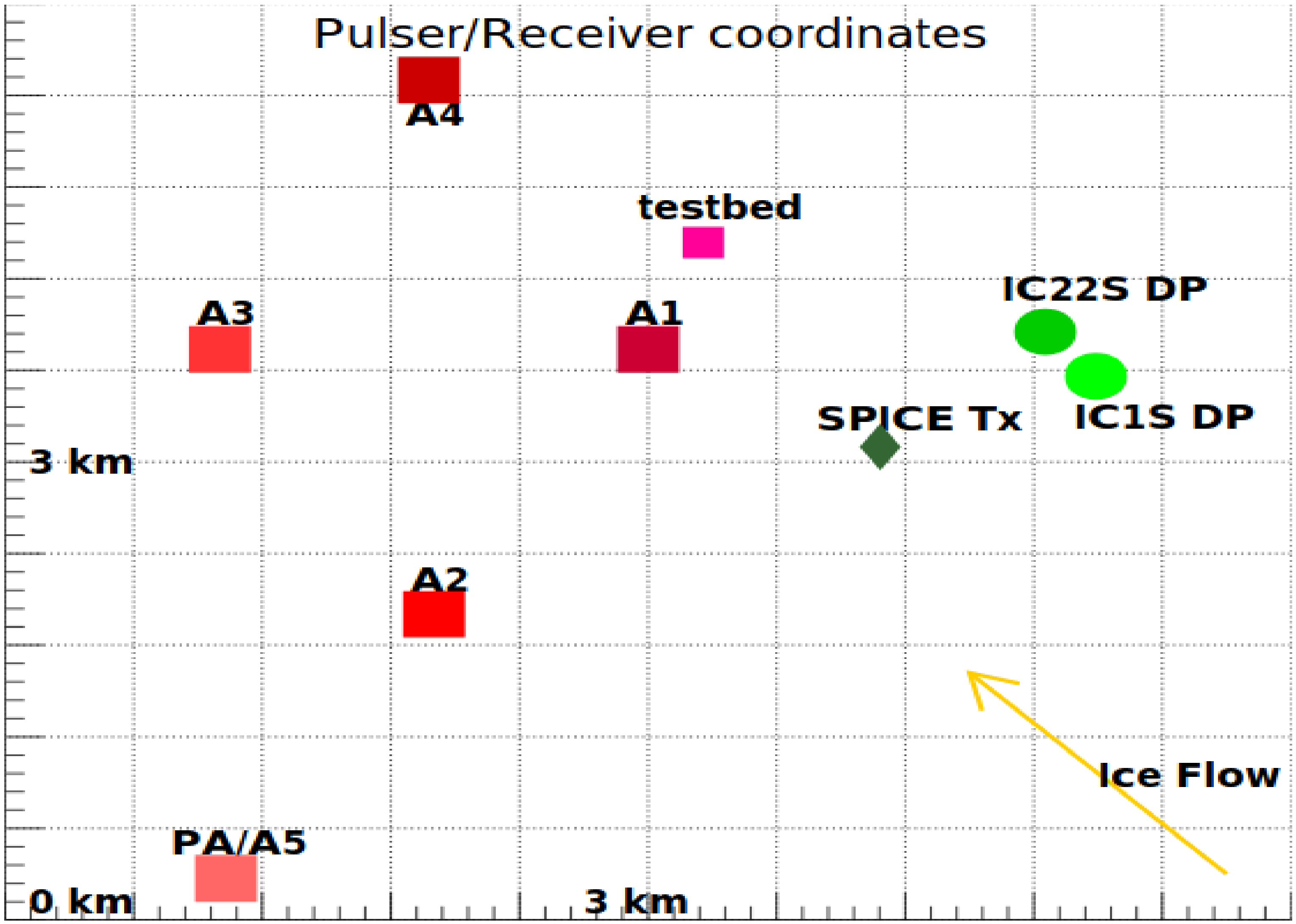
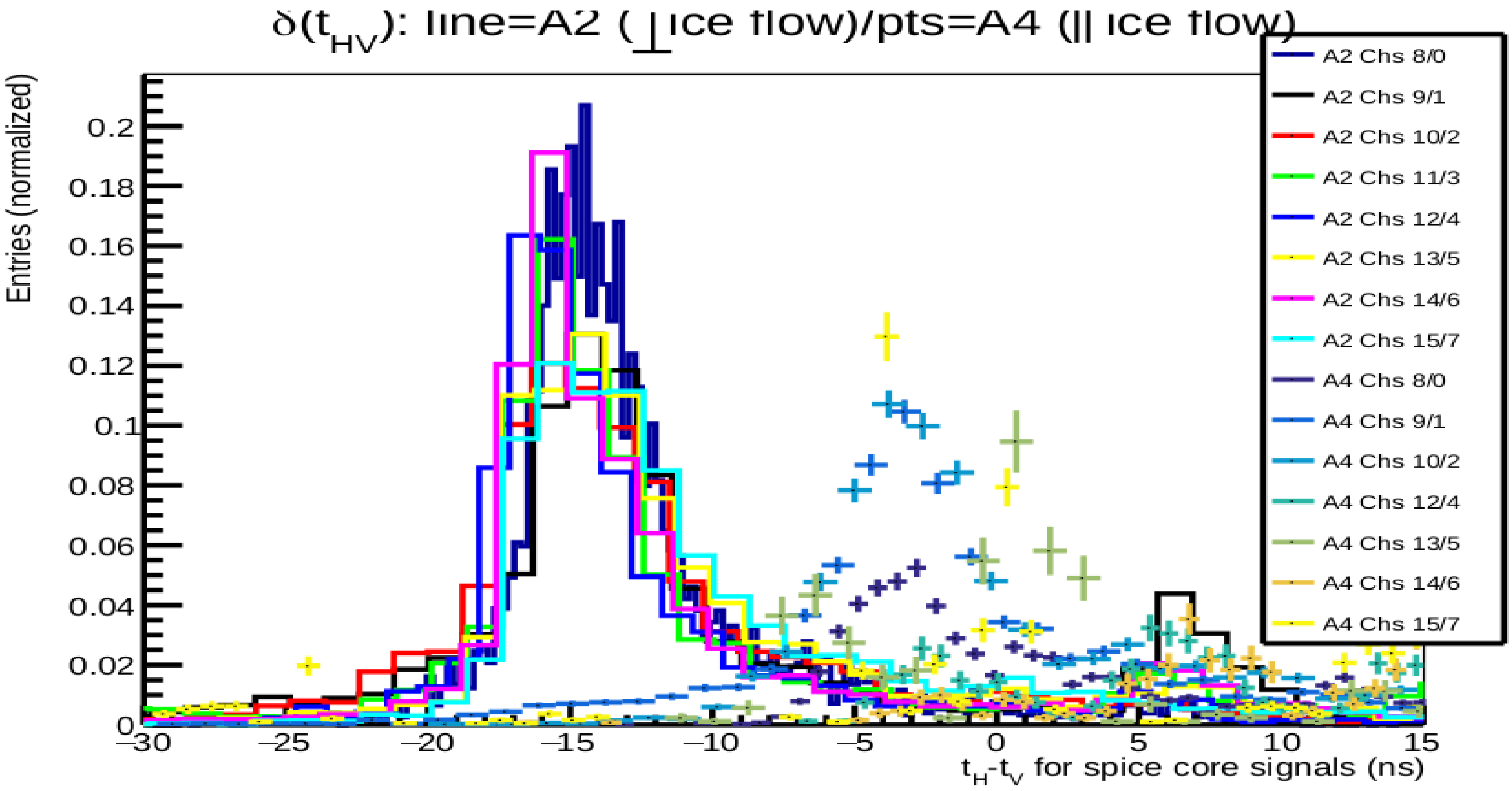




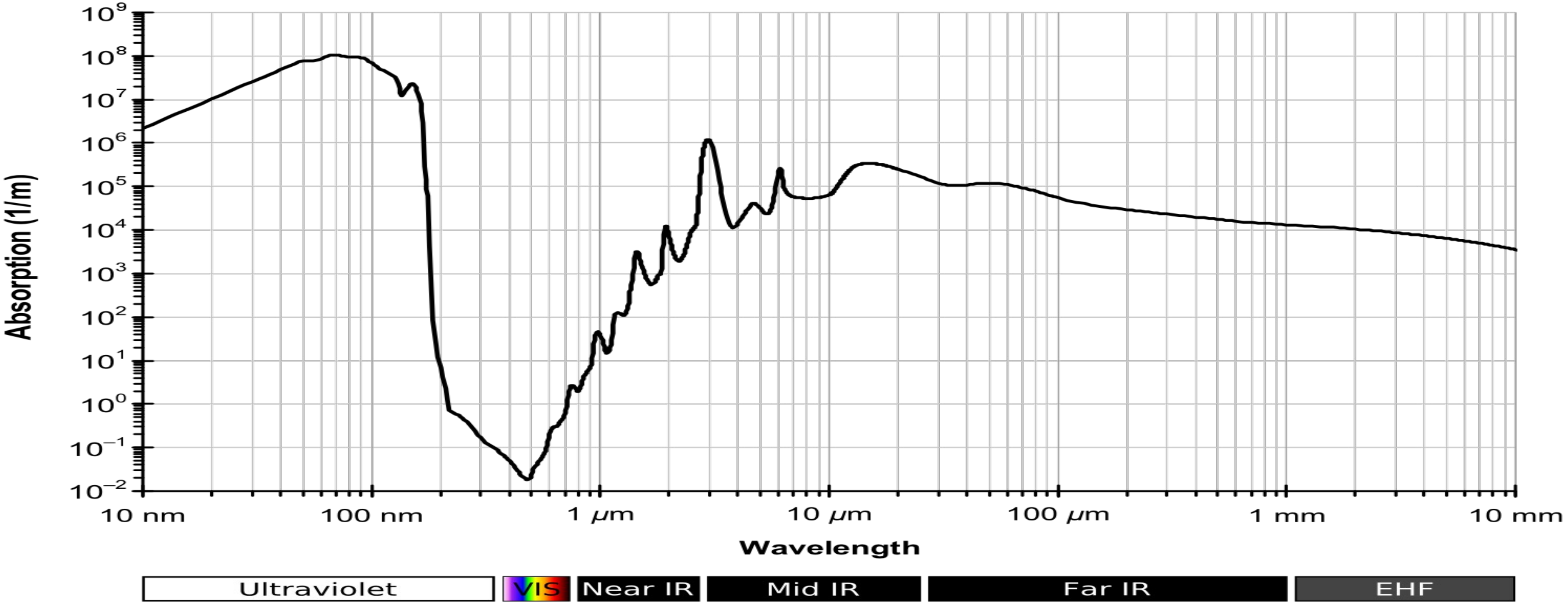
Pulser/Receiver coordinates
A4
testbed
IC22S DP
A3
A1
SPICE Tx
IC1S DP
3 km
A2
Ice Flow
PA/A5
0 km
3 km

Birefringence! (Estimate n_o-n_e)



Why is Antarctica a good place to do astronomy?

It's cold: 0.03% average humidity=>little or no absorption of CMB at 2.3 K (2.1 mm)



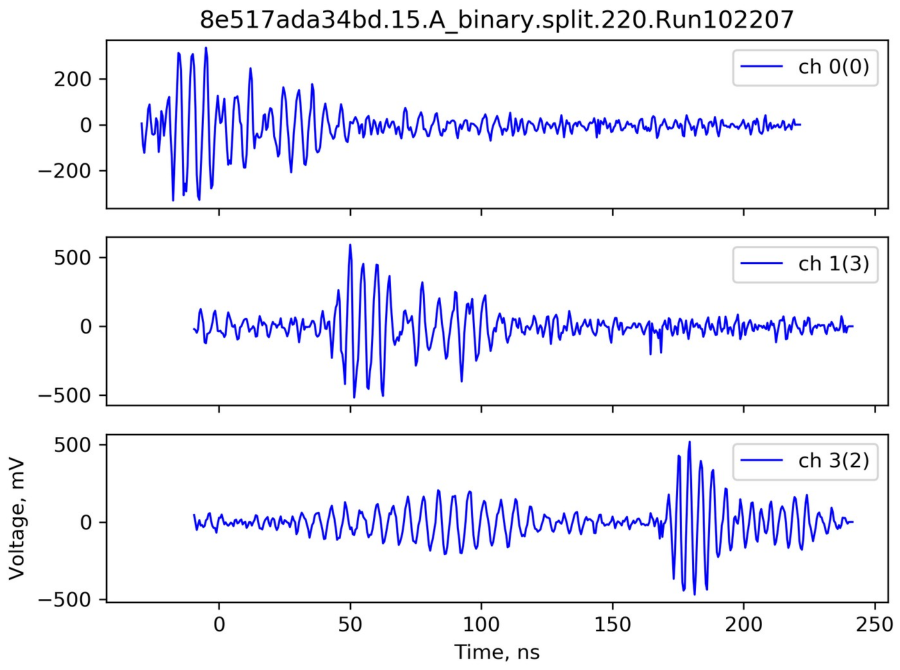
Cold, clean ice: Attenuation length for optical~40 m, Attenuation length for radio~2 km

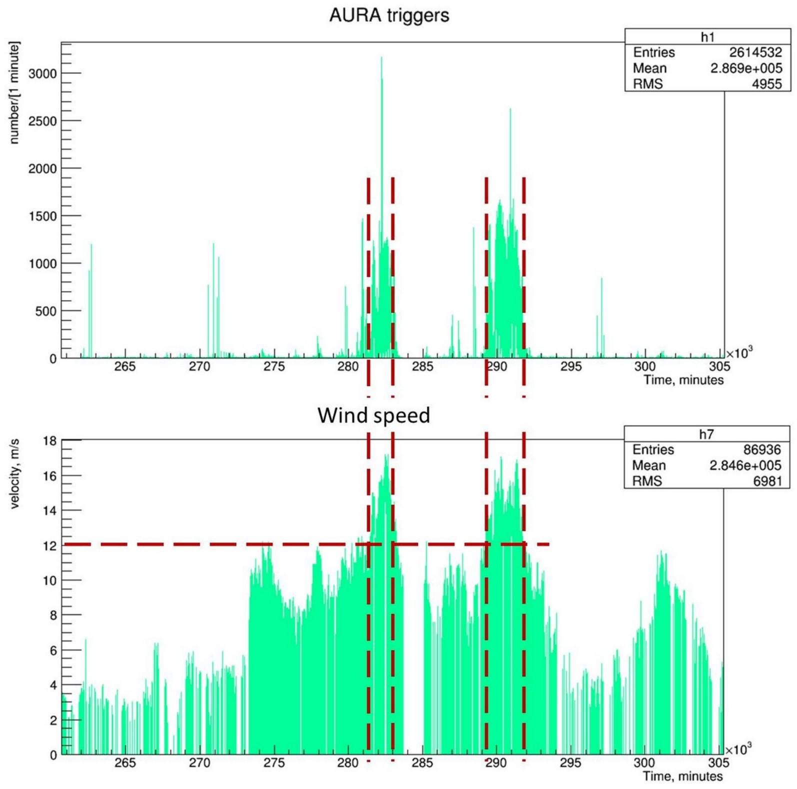
Auroral Studies: Geomagnetic focusing of field lines

Meteorite Searches: Easy Peasy

Consequences of cool, dry climate

Triboelectric effect (Masha Mikhailova): Wind blowing over snow generates discharge





Ice Exercises

1. Estimate the pressure at the bottom of 3 km of ice, assuming ρ_{ice}=0.93(water)
2. Assume Antarctic ice has an index-of-refraction n_{ice}=1.78. Find the time required for a radio wave to travel from the surface, reflect off the bedrock 3 km deep, and back to the surface again.
3. In fact, Antarctic ice has a property called "birefringence", wherein different polarizations travel with different speeds.
   1. Find the time difference between two radio waves if n_x=1.778 and n_y=1.782
   2. You have a radio receiver which is only sensitive to one polarization. Sketch the amount of received power as a function of polarization angle.
4. Now take into account the fact that the first 100 meters of the ice sheet is less dense ("firn"). Assume the index of refraction in the first 100 meters follows: n(z)=1.+0.78*(z/100), after which n(z) is constant at n=1.78. Determine the time once again. Assume the ice can be modeled by the same physics that governs a scale height; calculate the expected depth n(z) profile and determine the time to traverse thickness of ice and draw ray from A to B.
5. Given two receivers, separated by 10 meters.
   1. Determine the maximum time difference between the hit times for a plane wave
6. Suppose the attenuation length L of ice has a dependence on temperature that decreases linearly with temperature, such that L(273K)=250 m and increases by 10 meters per degree Kelvin (so, L=350 m at a temperature of 263K, etc). A radio signal with amplitude 2 kV is emitted spherically, broadcast through 2.8 km of ice and back again. Assuming that the surface temperature in Antarctica is 220K and that the temperature increases linearly, with depth, to 270K at the bedrock, what is the expected echo amplitude measured at the surface?
   1. Same question for Enceladus

Low temperature environment testing in Lawrence, KS

the Checkers supermarket vegetable freezer