Mass Balance of West Antarctic Ice Sheet from ICESat Measurements

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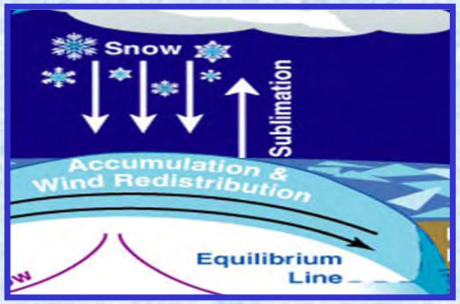
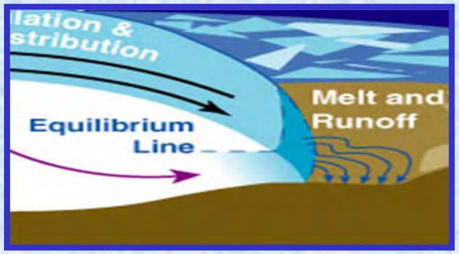
Antarctic Ice Sheet Mass Balance

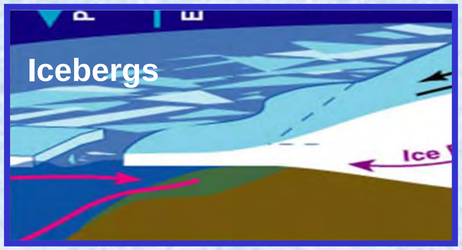
❑ 1900 Gt/yr approximate total input from precipitation – evaporation less blowing snow removal.

❑ Negligible output from surface melting and uncertain loss from basal melting.

❑ 1900 Gt/yr approximate output from ice discharge into ocean.







Mass balance methods:

a) Input – Output Method (IOM)

b) Volumetric by altimetry (e.g. ICESat)

c) Gravimetric (e.g. GRACE)

362 Gt/yr = 1 mm/yr of global sea level

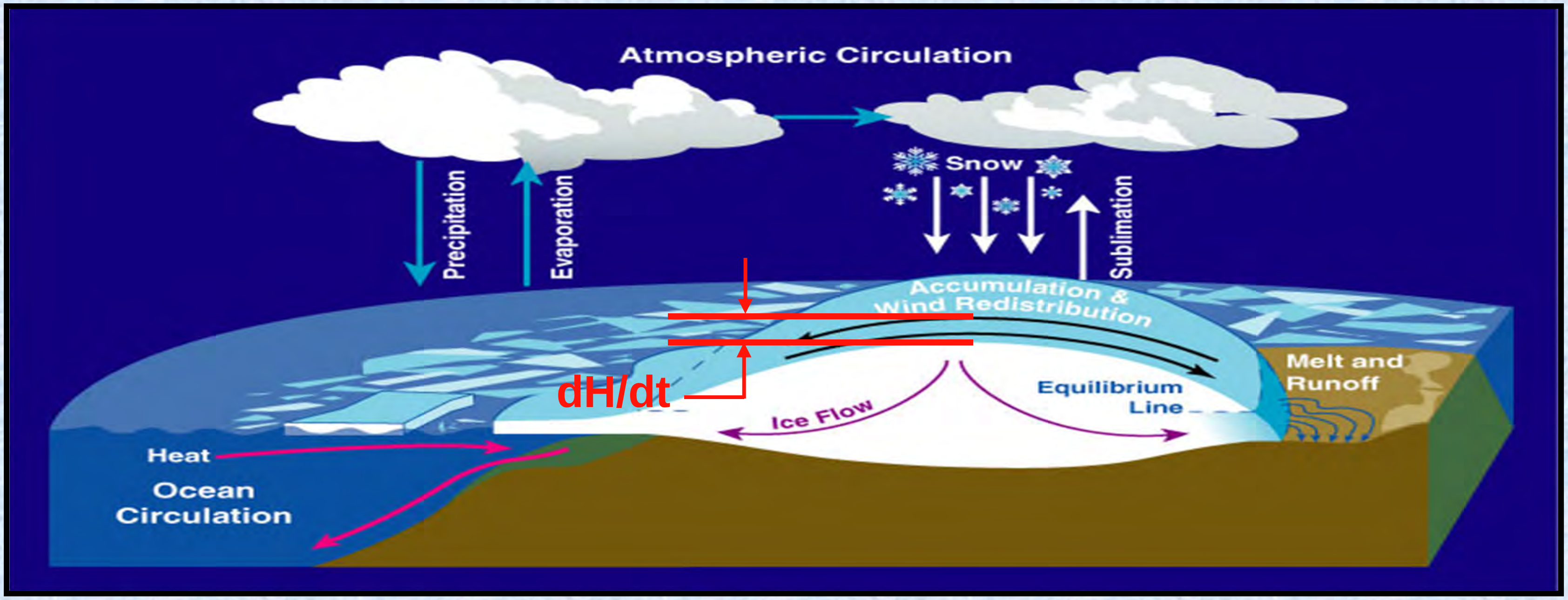
Key Issues about Antarctic Ice Sheet Mass Balance

- **The wide range of published values of the rate of Antarctic net mass change (+50 to -250 Gt/yr) showed a large uncertainty in the current (and recent) contribution to sea level rise (-0.1 to +0.7 mm/yr). Range is about 15% of input.**

- **Report s of large and accelerating rate of mass loss since the early 1990s are unconfirmed.**

- ***Overview and Assessment of Estimates of the Mass Balance of the Antarctic Ice Sheet: 1992 to 2009,*** Zwally and Giovinetto, In Surveys in Geophysics special issue on Cryosphere and Sea Level Change, May 2011.

Ice Sheet Mass Balance Primary Objective of ICESat



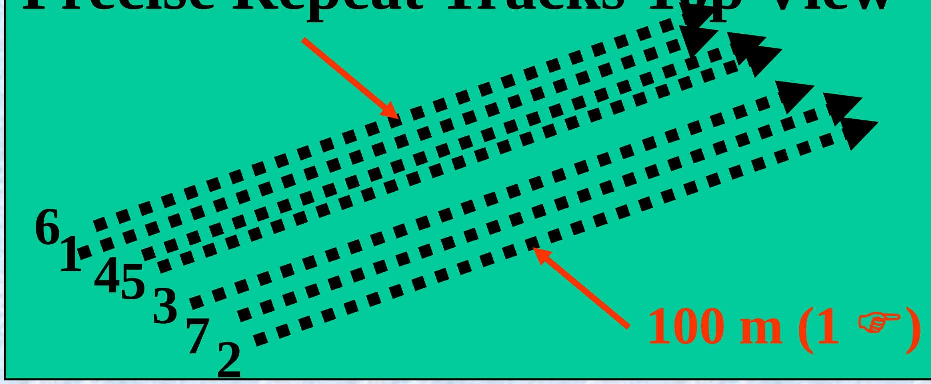
- ❑ Measure ice-surface elevation changes (dH/dt) from repeat measurements of elevation profiles along precise repeat tracks (minimal cross-track spacing) and at orbital crossovers.

- ❑ Derive spatially averaged elevation changes (dH/dt).

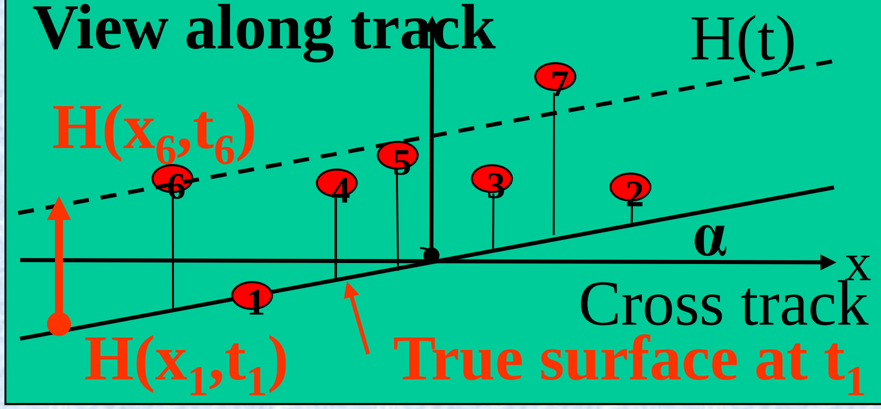
- ❑ Convert volume changes (dH/dt x area) to mass changes (dM/dt).
  - ❑ Correct for variable firn compaction (temperature driven).
  - ❑ Calculate density for dH(A(t))/dt due to trends in precipitation.
  - ❑ Correct for modeled bedrock motion dB/dt.

Deriving dH/dt from ICESat Repeat Tracks

Precise Repeat Tracks Top View



View along track

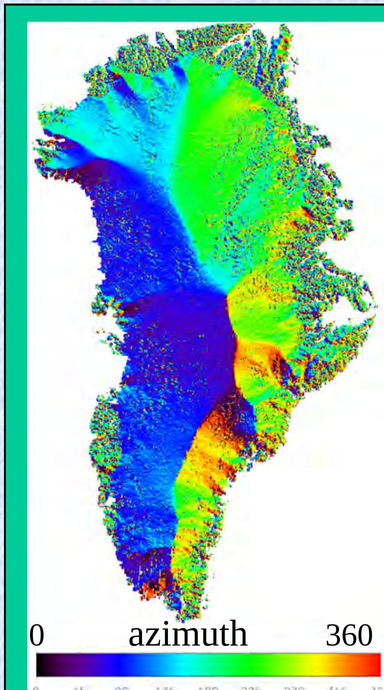


❑ **Measured surface elevation H(x,t) depends on surface slope (α) and position (x) across track.**

❑ **Solution of:**

$$H(X, \alpha\ t) = X \tan \alpha + t\ (dH/dt)$$

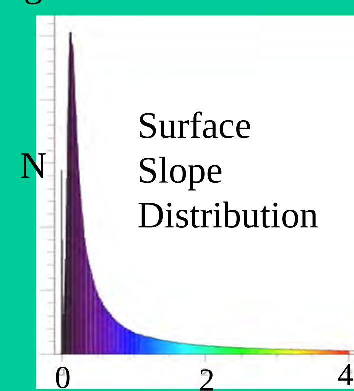
for dH/dt and α (assuming constant dH/dt and no seasonal cycle) requires >= 4 repeat data passes.

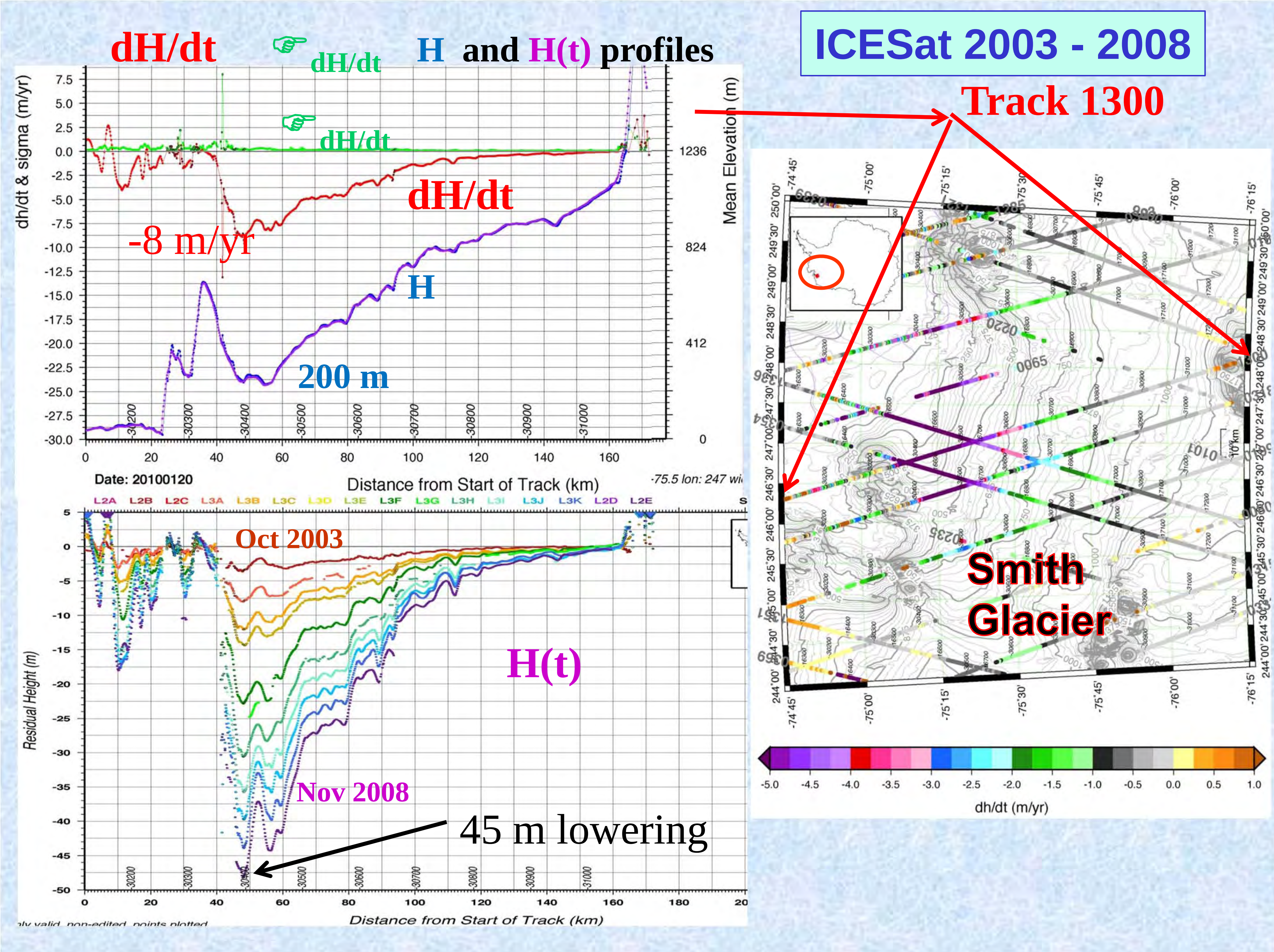


GREENLAND

❑ Direction and magnitude of ice-sheet slopes is highly variable.

❑ Largest slopes at critical margins.

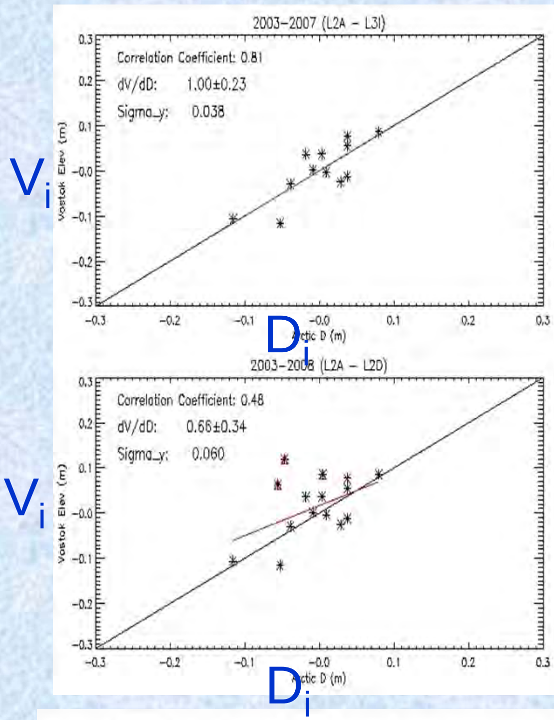




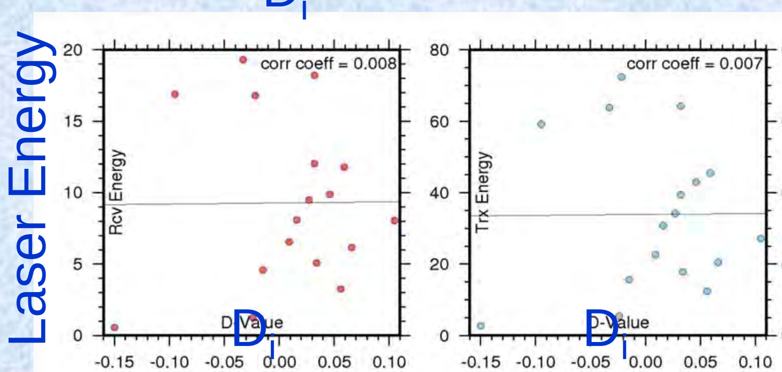
dH/dt ☞ dH/dt H and H(t) profiles
ICESat 2003 - 2008
Track 1300
☞ dH/dt
dH/dt
-8 m/yr
H
200 m
dh/dt & sigma (m/yr)
Mean Elevation (m)
Distance from Start of Track (km)
Date: 20100120
L2A L2B L2C L3A L3B L3C L3D L3E L3F L3G L3H L3I L3J L3K L2D L2E
Oct 2003
H(t)
Nov 2008
45 m lowering
Residual Height (m)
Distance from Start of Track (km)
Smith Glacier
dh/dt (m/yr)

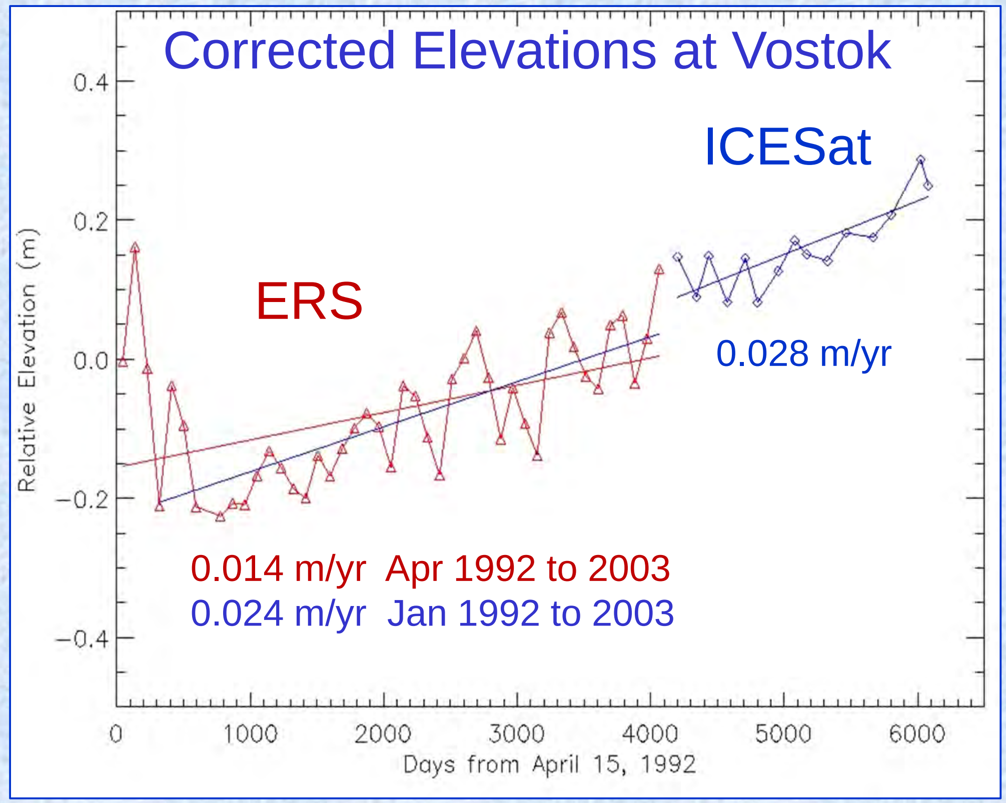
ICESat Range Bias Correction

- The relative mean level (D_i) of the Arctic Ocean within the sea ice pack is determined for each laser campaign (i).
- D_i (t) -0.003 m/yr is applied as bias correction to all observed elevations.



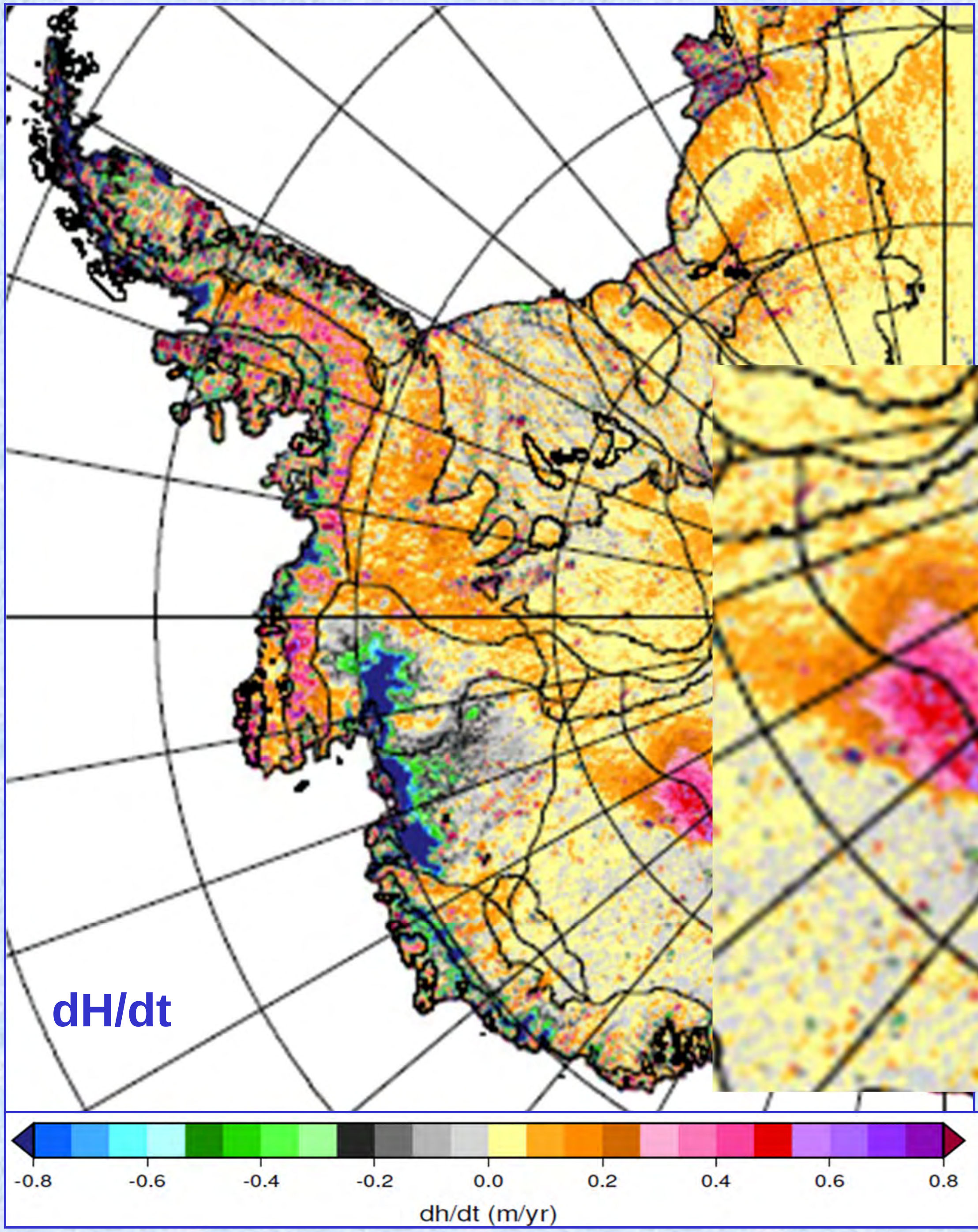
- The uncorrected elevations (V_i) at Vostok are well correlated with D_i. R = 0.81 for 2003-07 and R= 0.48 for 2003-2008.
- D_i is UNCORRELATED with laser energy! R=0.008

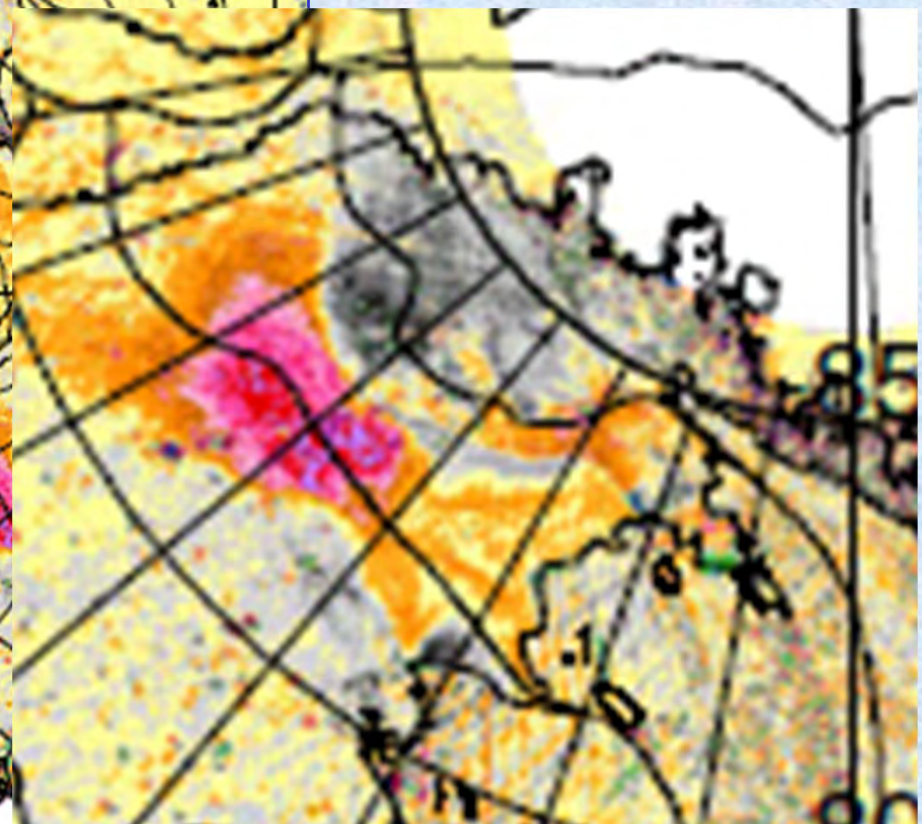


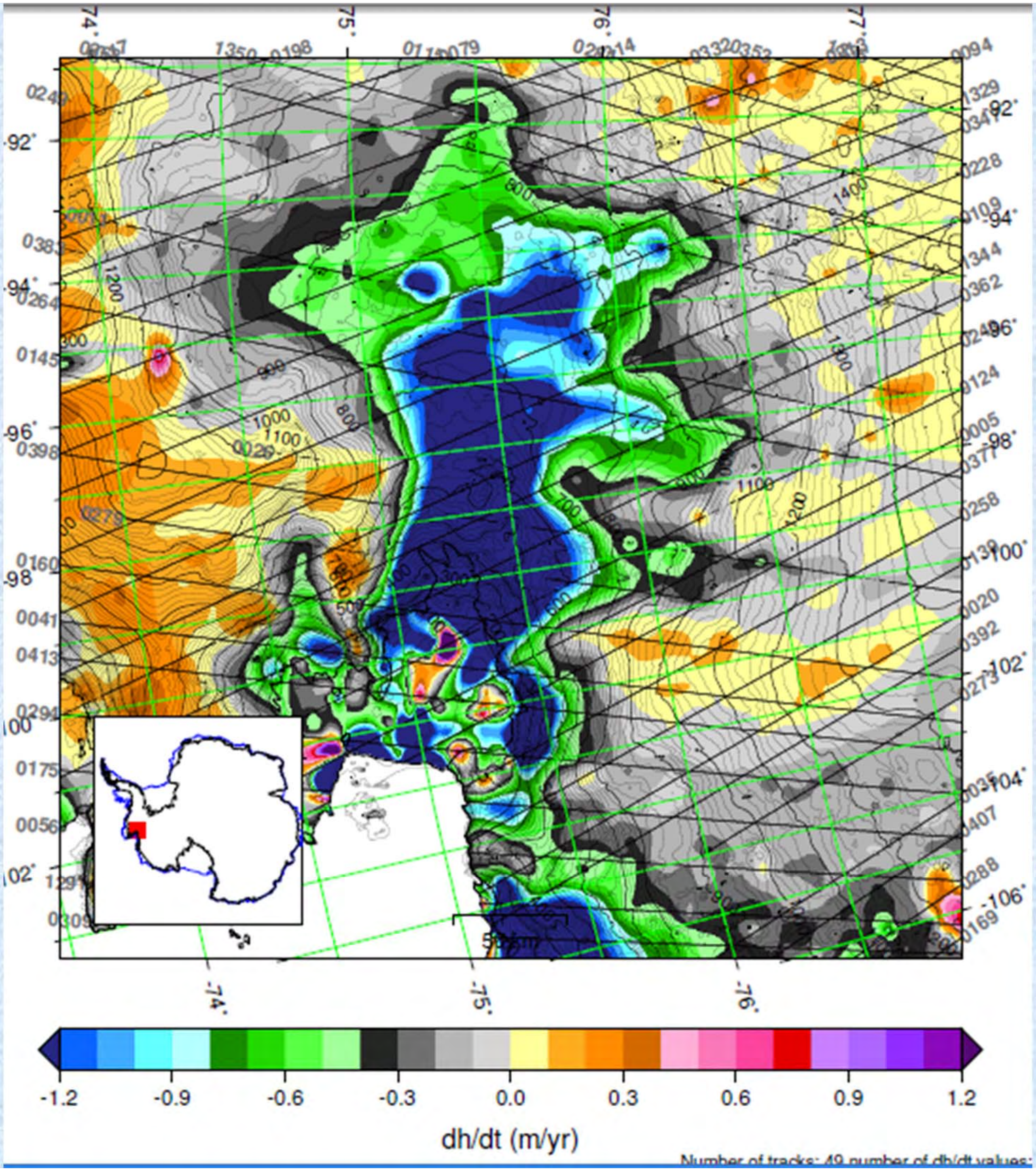


ICESat 2003-2008

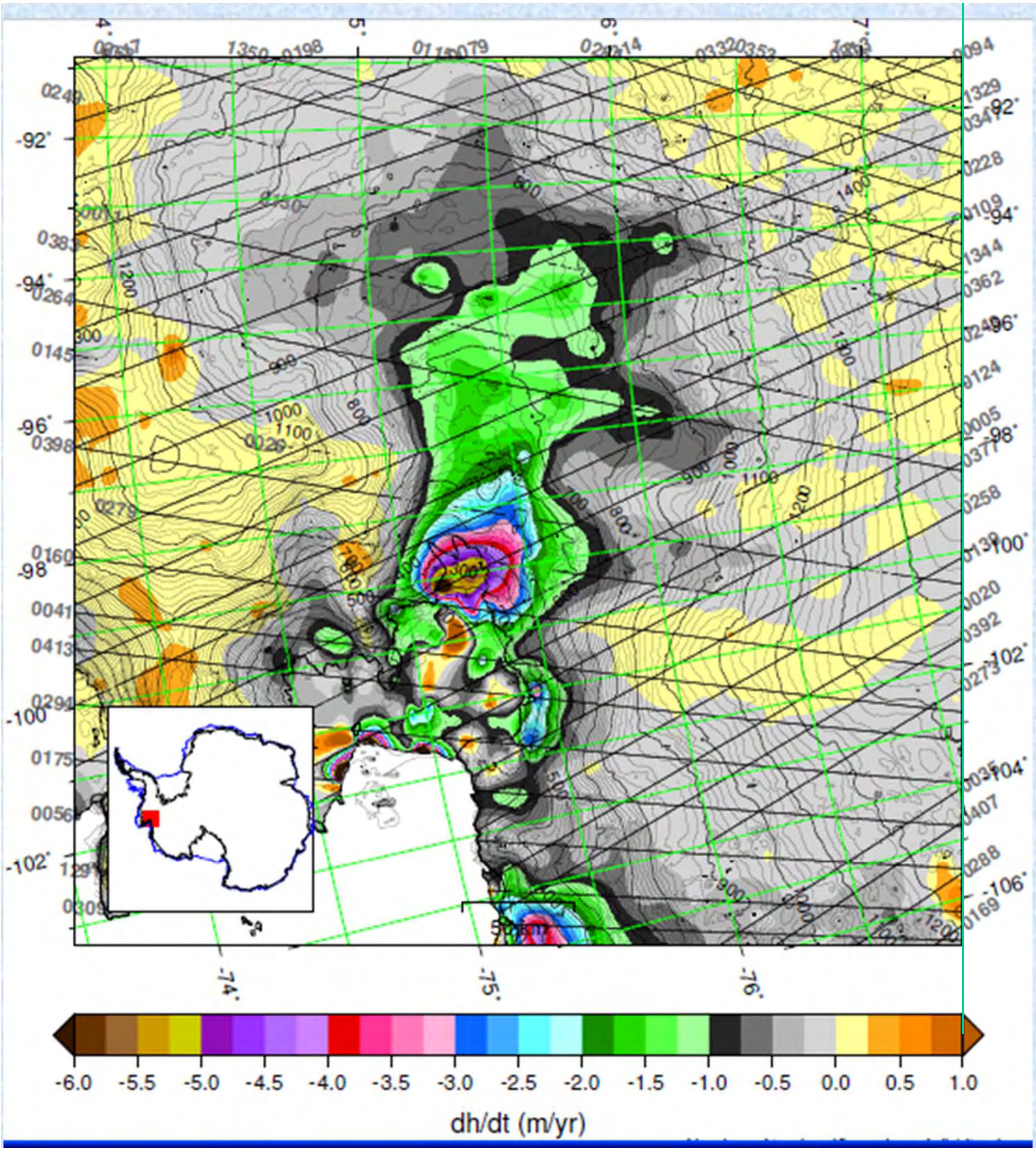
Elevation Change dH/dt (m/yr)







Pine Island Glacier



Pine Island Glacier

Surface Elevation Change Including Firn Compaction

$dH(t)/dt = A(t)/\rho_{sf} - V_{fc}(t) - A_b(t)/\rho_i - V_{ice} + dB/dt$

Measured — firn compaction — bedrock motion

For non-steady state, we rewrite terms as perturbations from steady-state:

$dH/dt = dH^A/dt + dC_{AT}/dt + dH_{bd}/dt + dB/dt$

Assume effects of A(t) and T(t) on the compaction rate dC_{AT}/dt are separable:

$dC_{AT}/dt = dC_A/dt + dC_T/dt$

$dH/dt = dH^A_{CA}/dt + dC_T/dt + dH_{bd}/dt + dB/dt$

Where $dH^A_{CA}/dt = dH^A/dt + dC_A/dt$

direct — compaction change

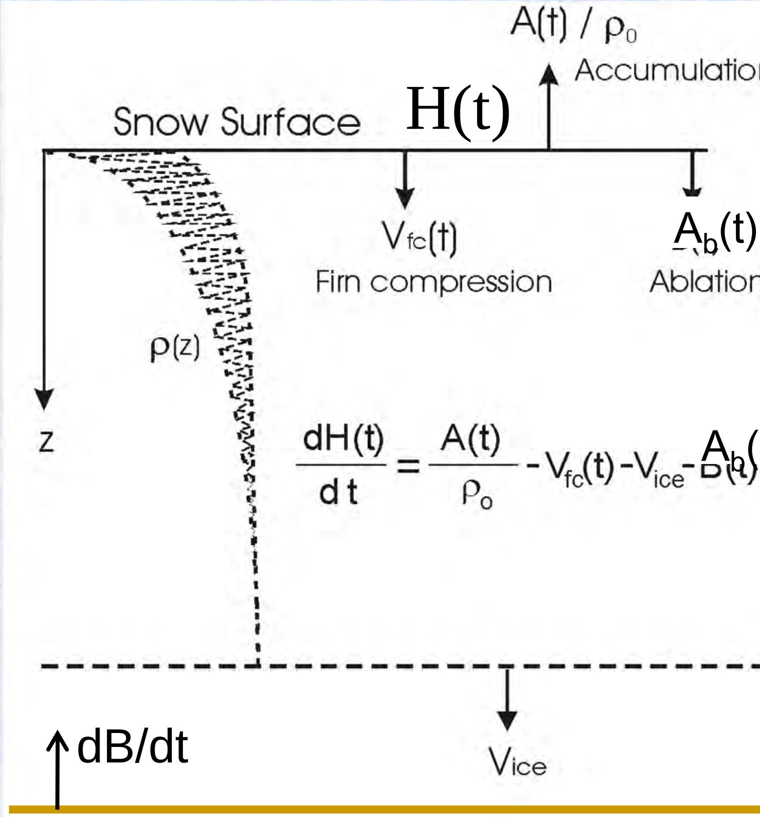
Define $dI/dt = dH/dt - dC_T/dt - dB/dt$

Then $dI/dt = dH^A_{CA}/dt + dH_{bd}/dt$

Mass change

$dM/dt/\text{area} = [\rho_A \, dH^A_{CA}/dt + \rho_i \, (dH_{bd}/dt)]$

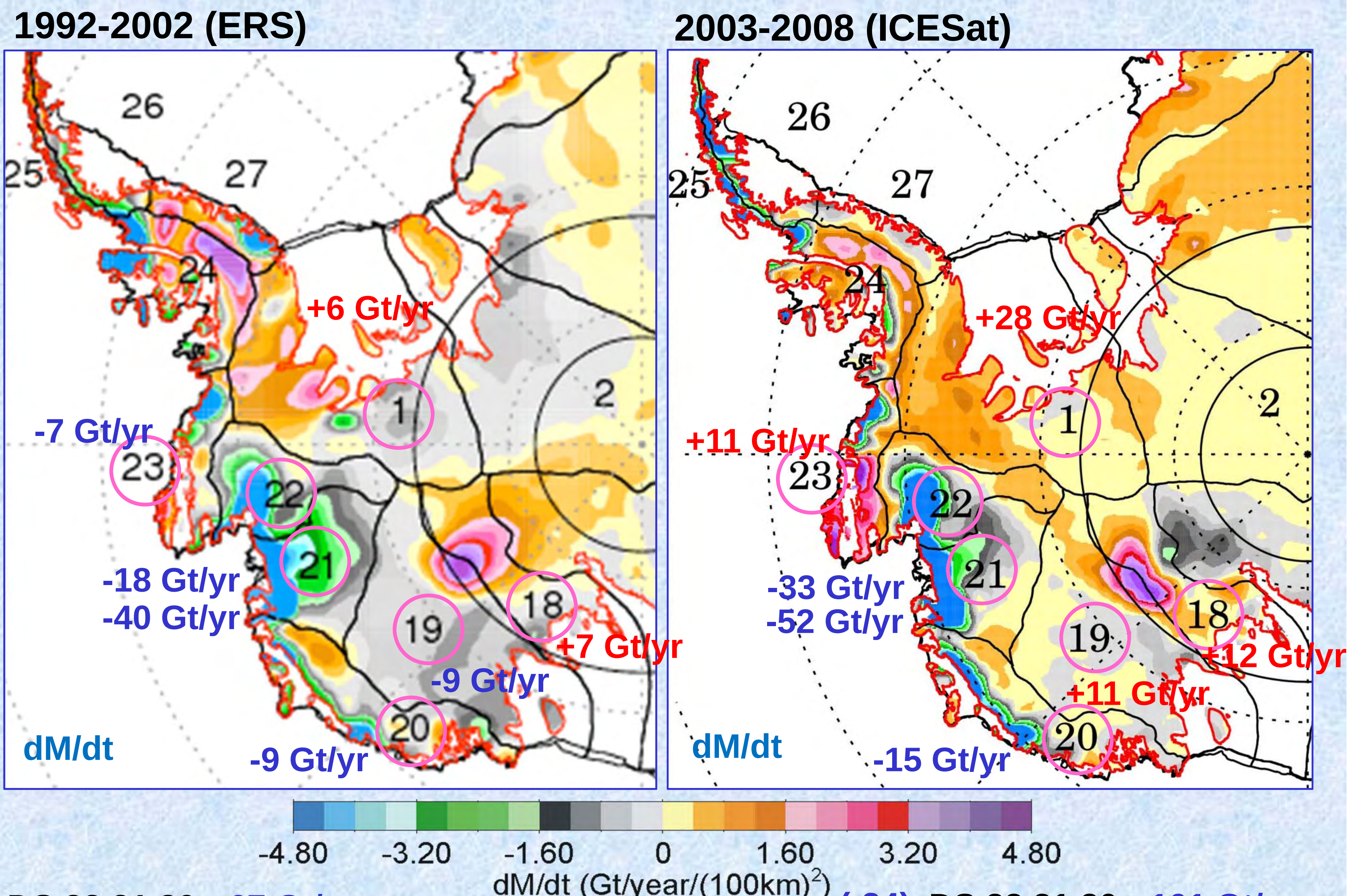
accumulation — ablation/dynamic



dC_T/dt and dC_{AT}/dt calculated with firn-compaction model driven by T(t) from AVHRR record and A(t) = <A> A(T(t)) using sensitivity of 5%/K.

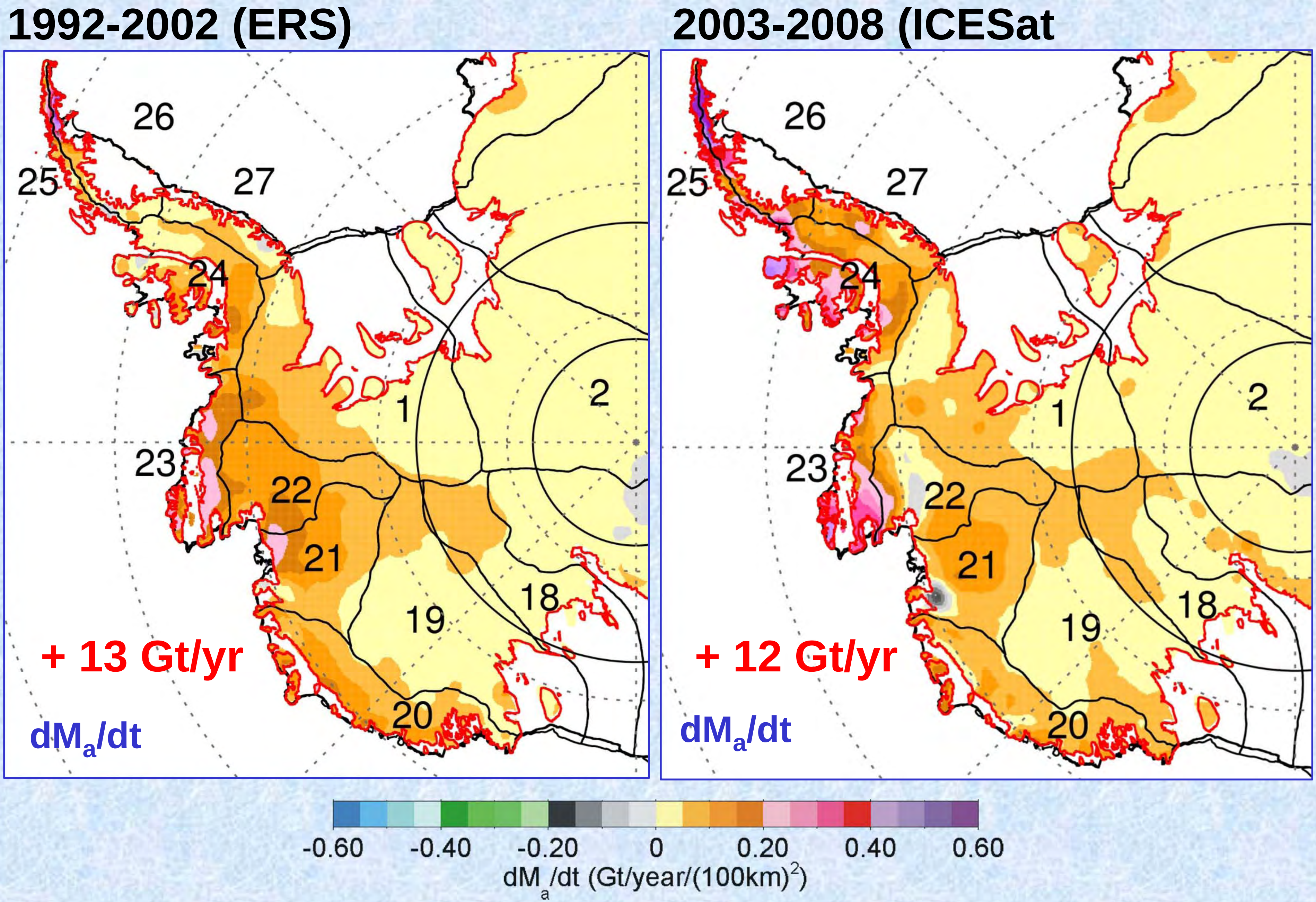
$\rho_A = \Delta M_a / \Delta H^A_{CA}$

$\rho_A = (A(T(t)) \, dt \; / \; (dH^A_{CA}/dt) \, dt$



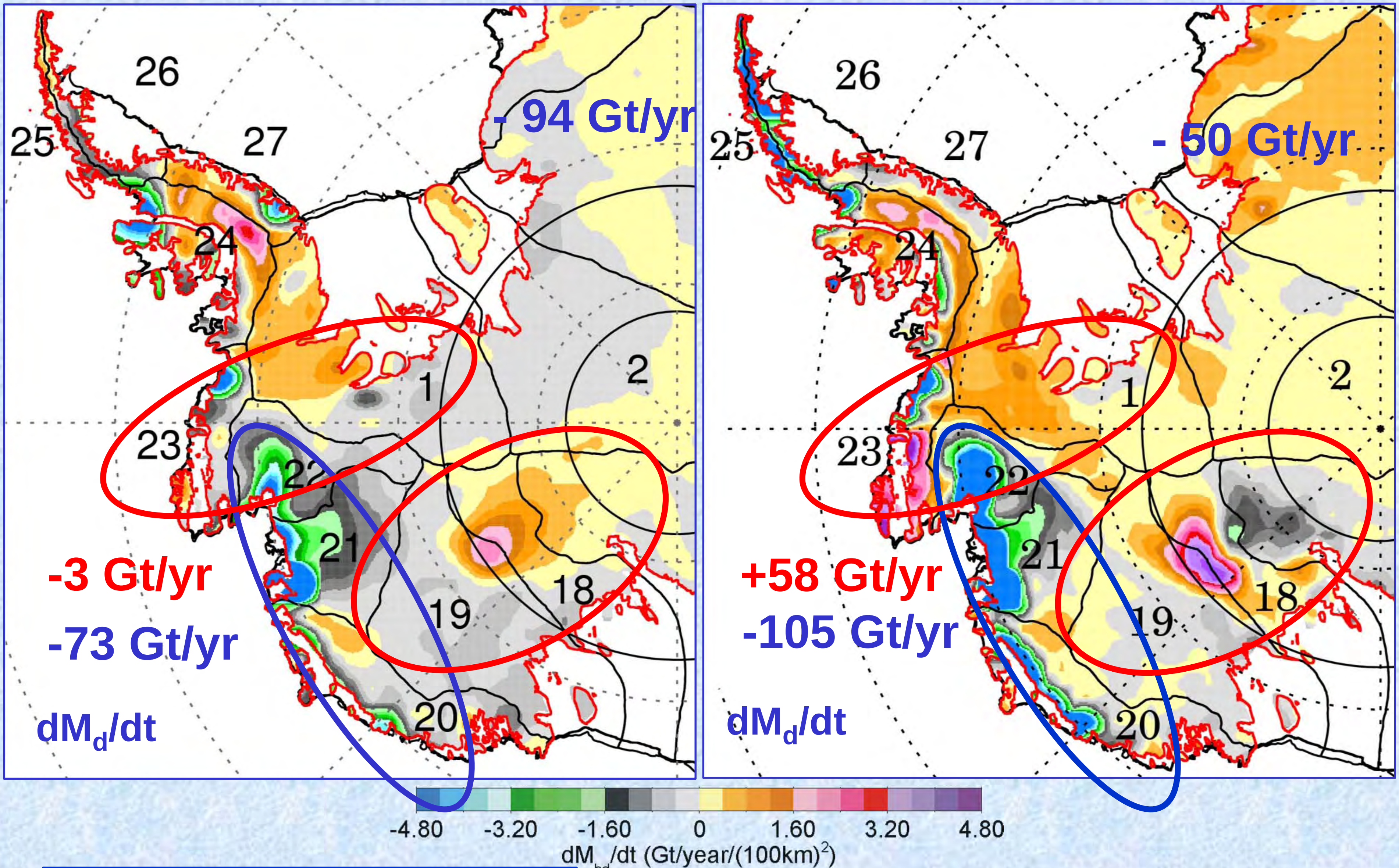
1992-2002 (ERS)	2003-2008 (ICESat)
DS 22,21,20: -67 Gt/yr	**(-34) DS 22,21,20: -101 Gt/yr**
DS 23,1,18,19: 4 Gt/yr	**(+58) DS 23,1,18,19: +62 Gt/yr**
Total: -63 Gt/yr	**Total: - 38 Gt/yr**

Accumulation-Driven Mass Change



Dynamic-Driven Mass Change

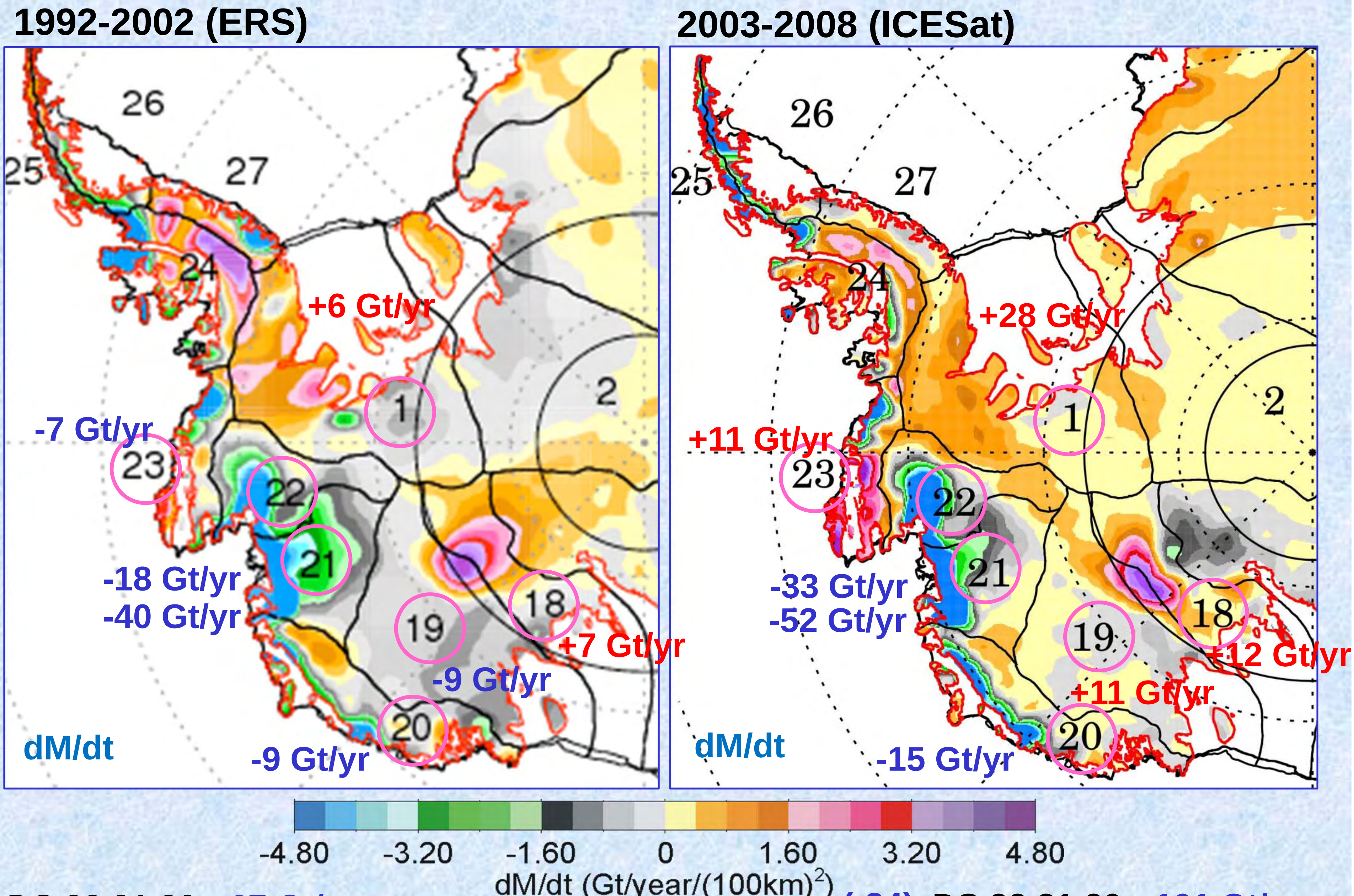
1992-2002 (ERS) **2003-2008 (ICESat**



26 Gt/yr net dynamic increase

32 Gt/yr increase in dynamic thinning

55 Gt/yr increase in dynamic thickening



DS 22,21,20: -67 Gt/yr
DS 23,1,18,19: 4 Gt/yr
Total: -63 Gt/yr

(-34) DS 22,21,20: -101 Gt/yr
(+58) DS 23,1,18,19: +62 Gt/yr
Total: - 38 Gt/yr

Climate warming in Arctic and increasing ice loss in Greenland (-171 Gt/yr)!

West Antartica (-38 Gt/yr) and Peninsula (-27 Gt/yr) have a net loss (-65 Gt/yr).

Antarctica: Overall, ice sheet now has small positive balance (+38 Gt/yr)!

Thank you!