Geophysical observations upstream of South Pole

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1. How can information advected into SPICEcore from upstream constrain flow history near South Pole? (following Lilien et al., 2018)

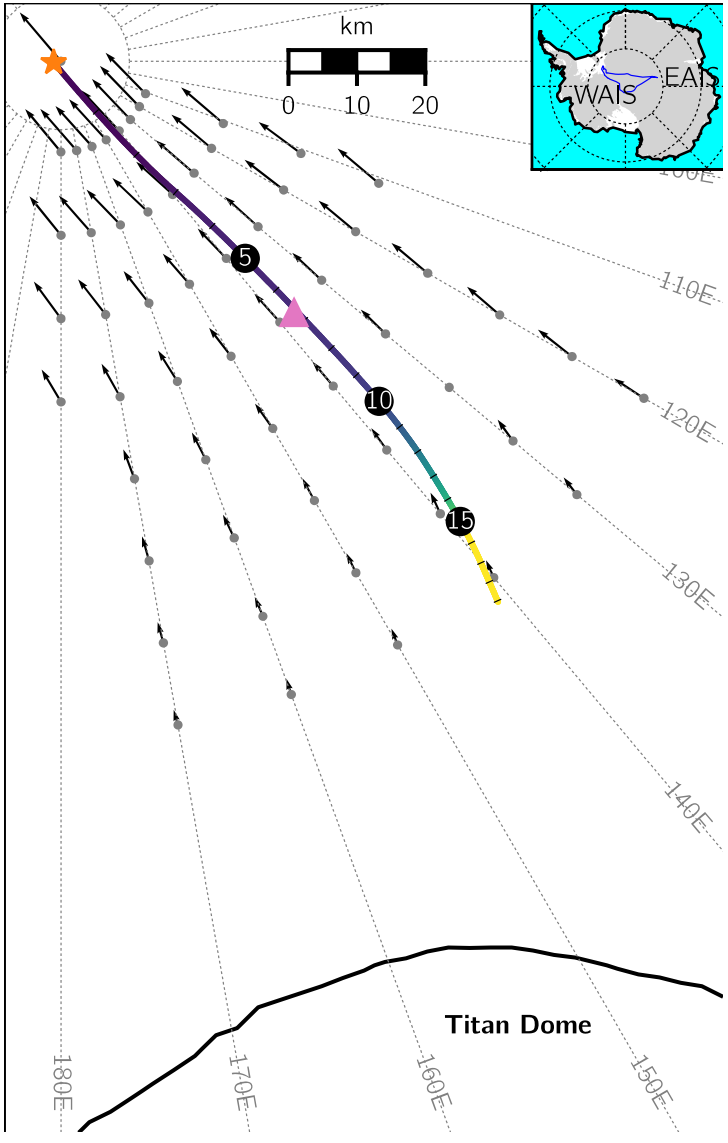
2. Data housed at U. Washington that may be useful to others here

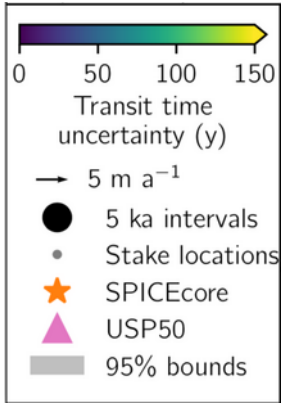
Flowline from GPS

- In polar gap for satellite-derived ice velocities
- 10 ka at ~70 km, 17 ka at ~100 km
- Flow direction at South Pole is a pretty good guess at the flowline for the first 75 km out

Assuming steady flow:

- **Age uncertainty is small** (~0.3%) at the 10,000 year mark
- **Transverse uncertainty is small** too (0.25 km std. dev.)

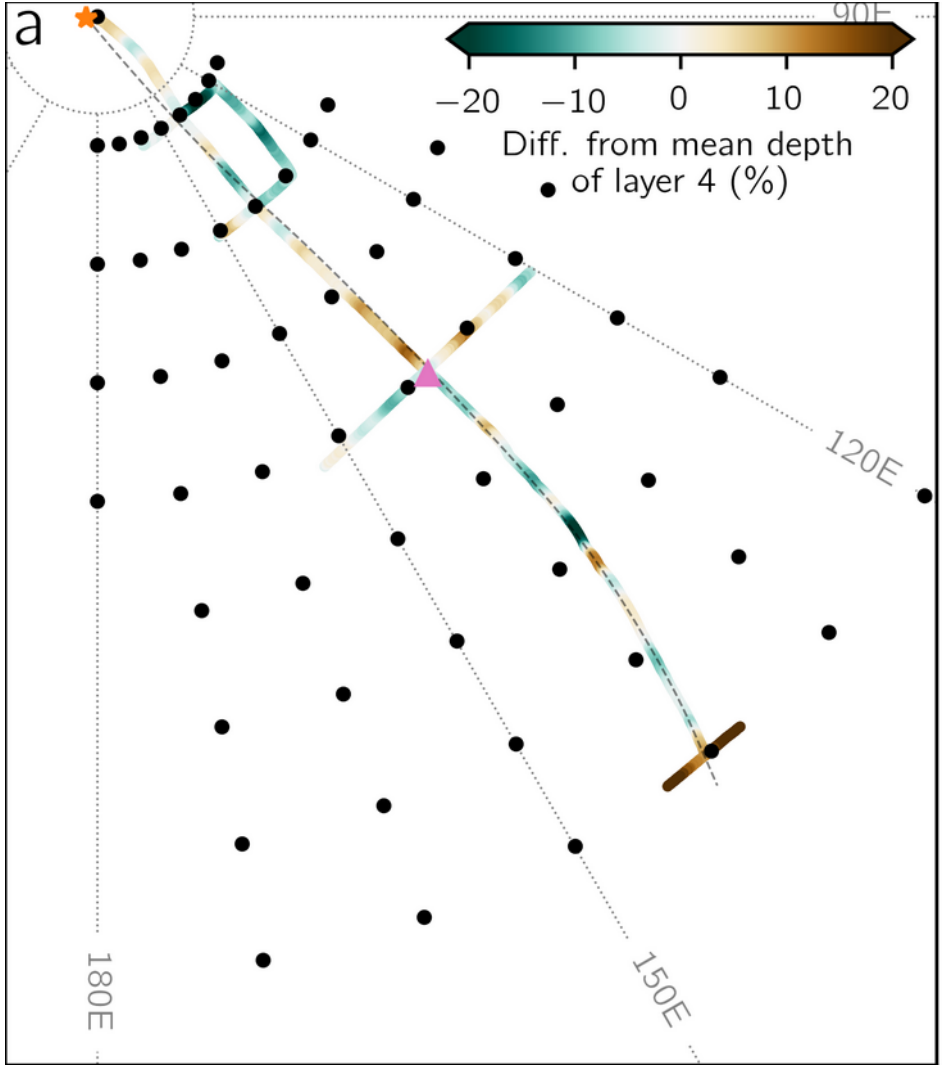




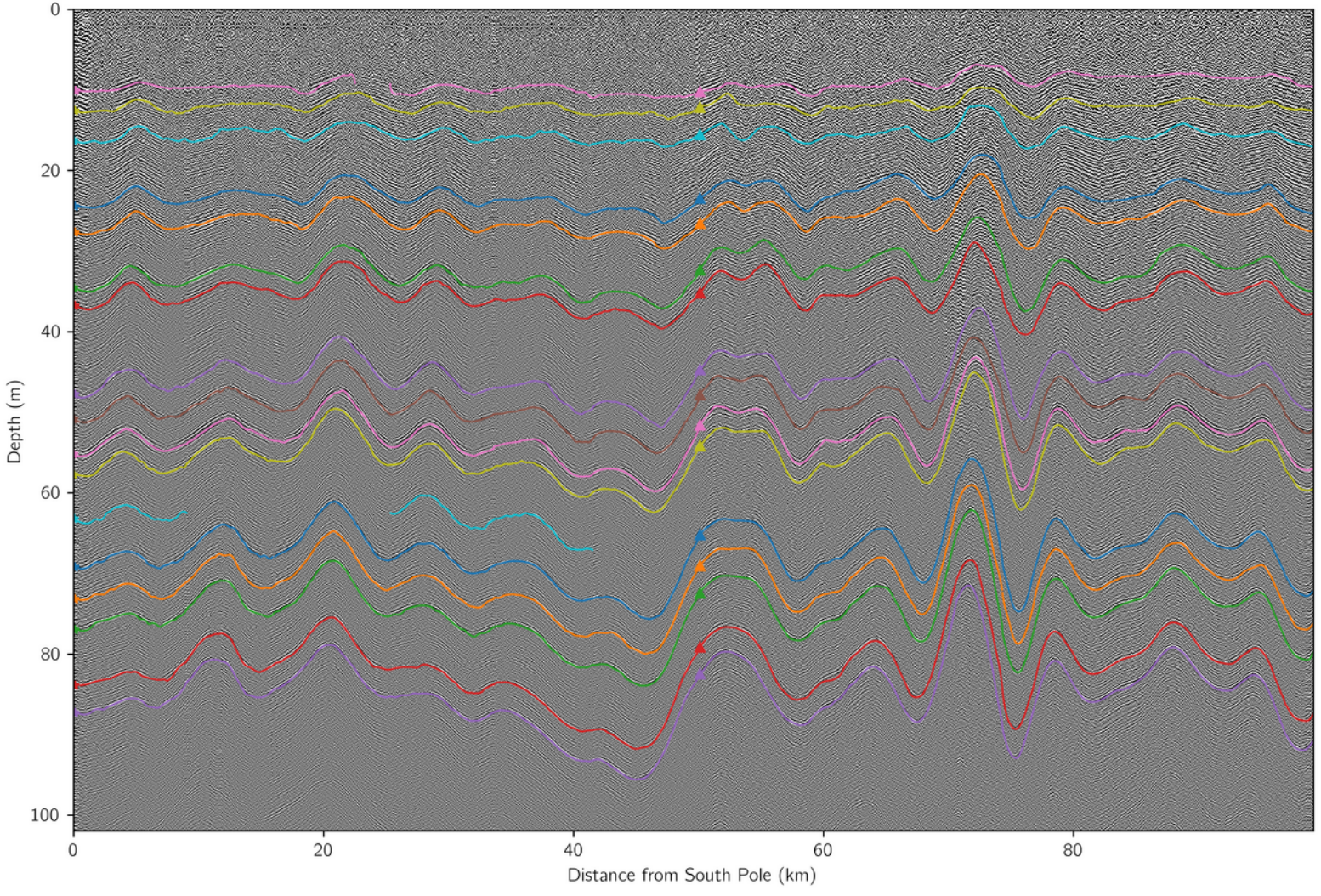
(Titan dome estimated from Bedmap2)

Shallow Radar

- 200 MHz GSSI Radar
- Acquired 100 line-km along the flowline
- Three perpendicular transects



Radar along flowline

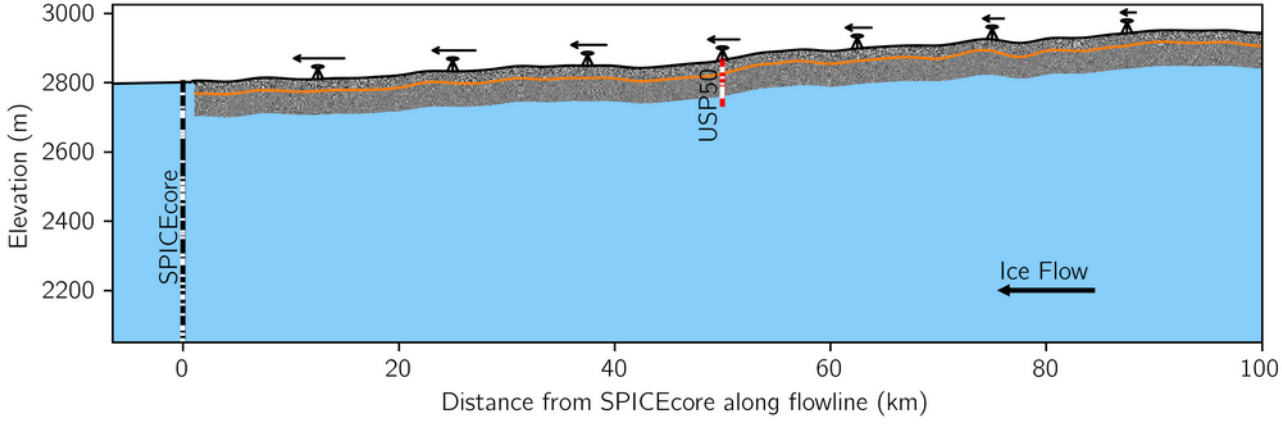


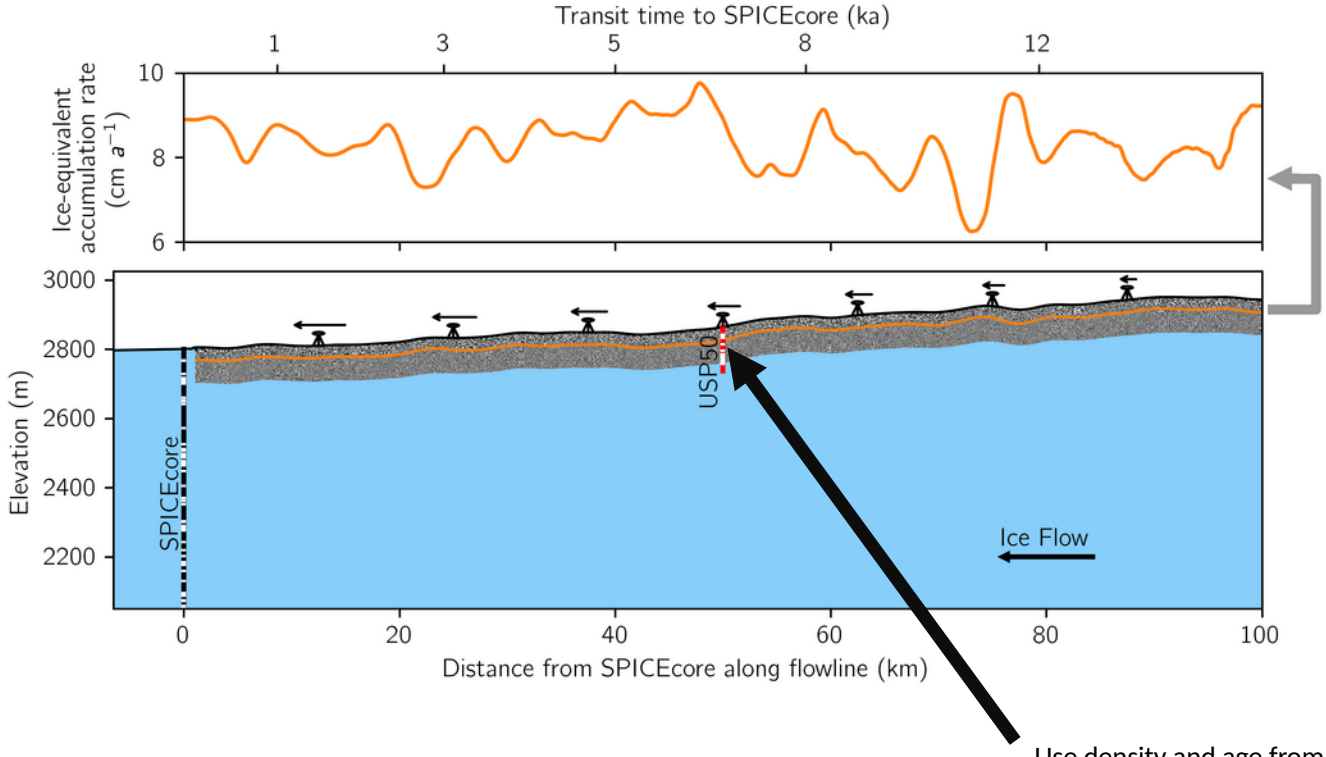
All layers vary ~20-25% in depth on 5 km horizontal scales

Analysis strategy

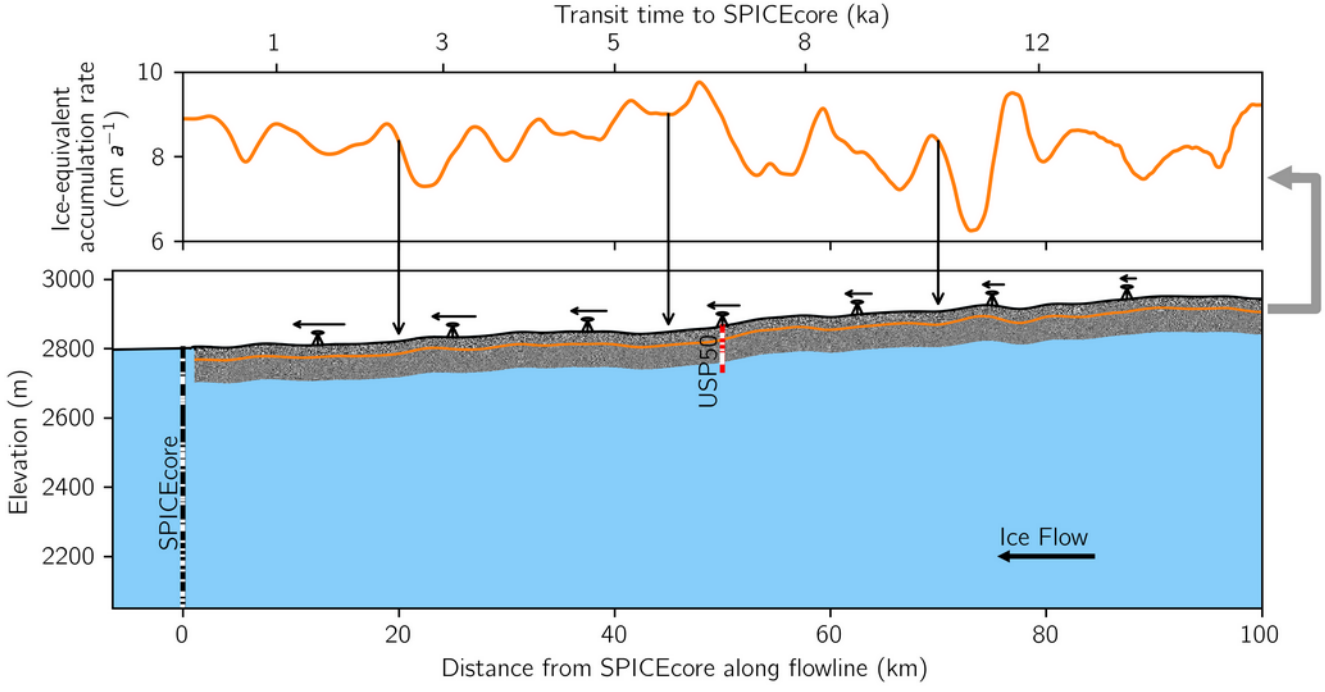
- Construct and compare two accumulation histories
  - First is derived from SPICEcore using a thinning model
  - Second is constructed from upstream conditions
- **If we get good correlation, flow direction and accumulation rate were unchanged**

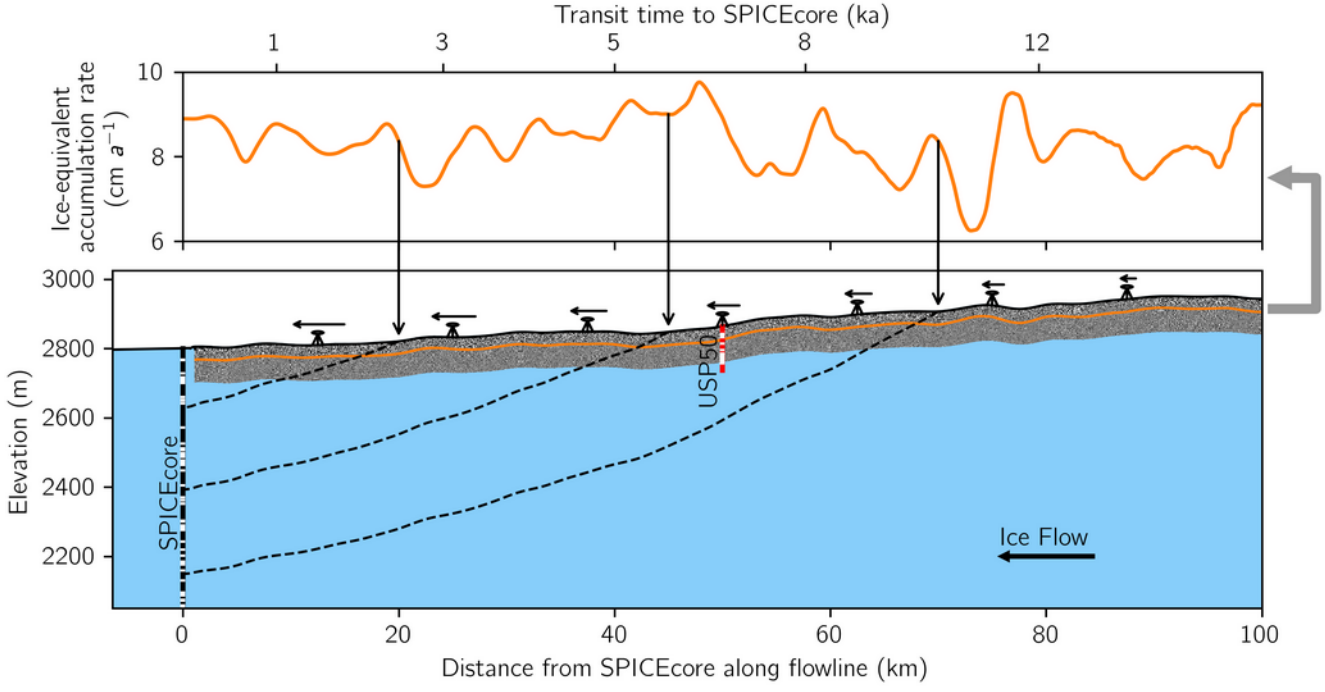
We start with the depth of a layer in the shallow radar (ask me later if you care which layer)





Use density and age from a shallow core we drilled to get the accumulation


Transit time to SPICEcore (ka)
1
3
5
8
12
Ice-equivalent accumulation rate (cm a^{-1})
10
8
6
3000
2800
2600
2400
2200
Elevation (m)
SPICEcore
USP50
Ice Flow
0
20
40
60
80
100
Distance from SPICEcore along flowline (km)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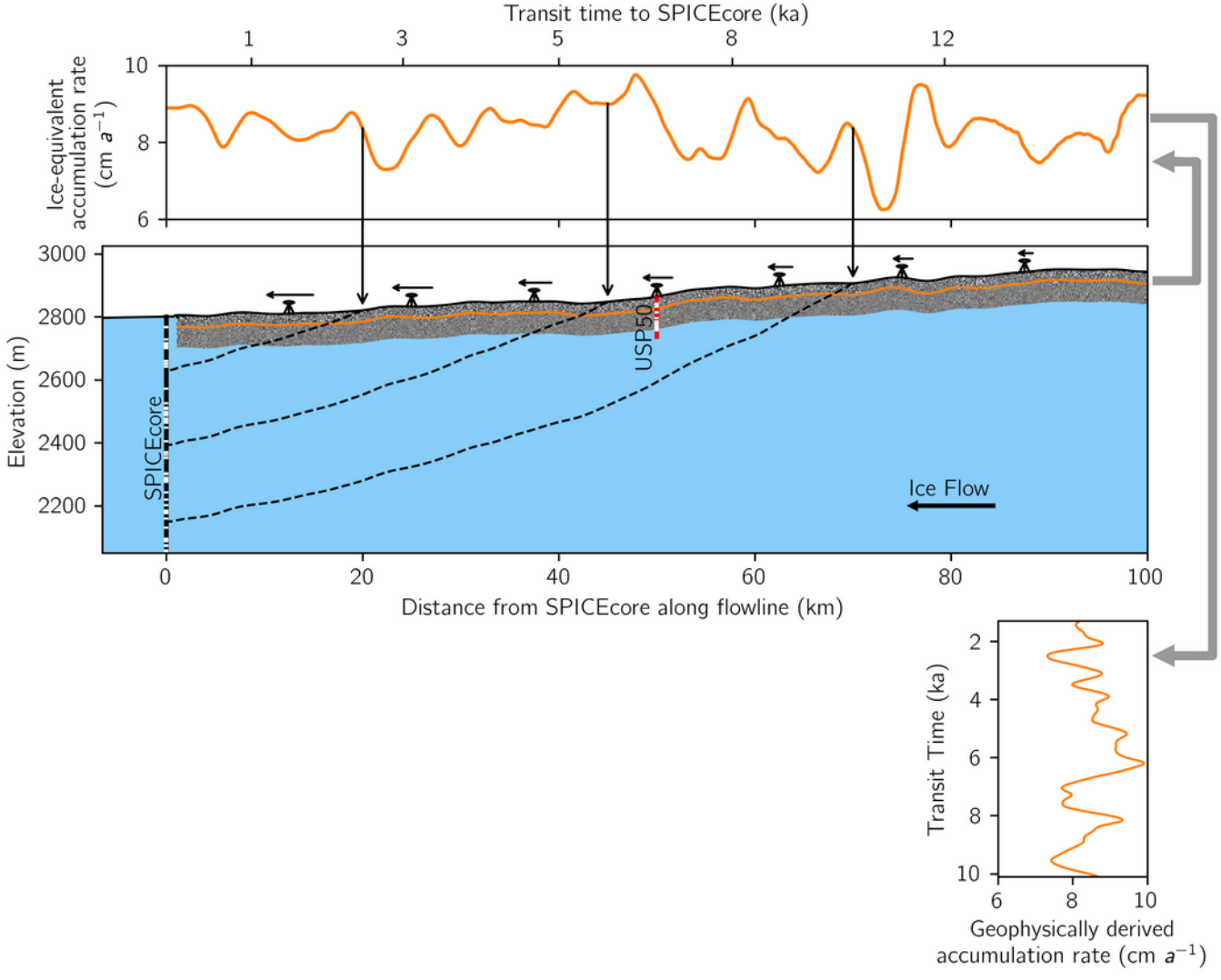
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8
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2800
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Elevation (m)
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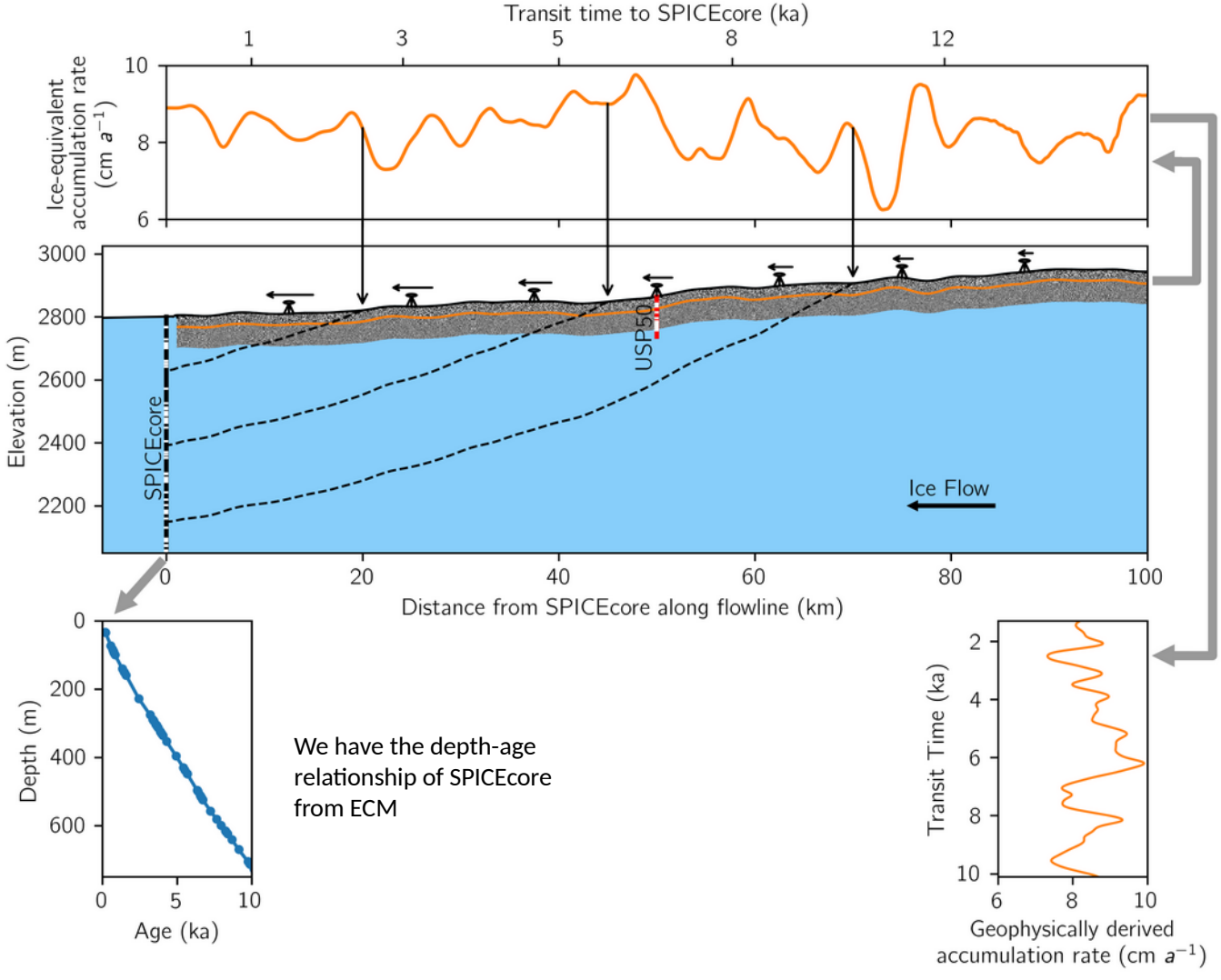
Ice Flow
0
20
40
60
80
100
Distance from SPICEcore along flowline (km)
Transit Time (ka)
2
4
6
8
10
6
8
10
Geophysically derived accumulation rate (cm a^{-1})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2600
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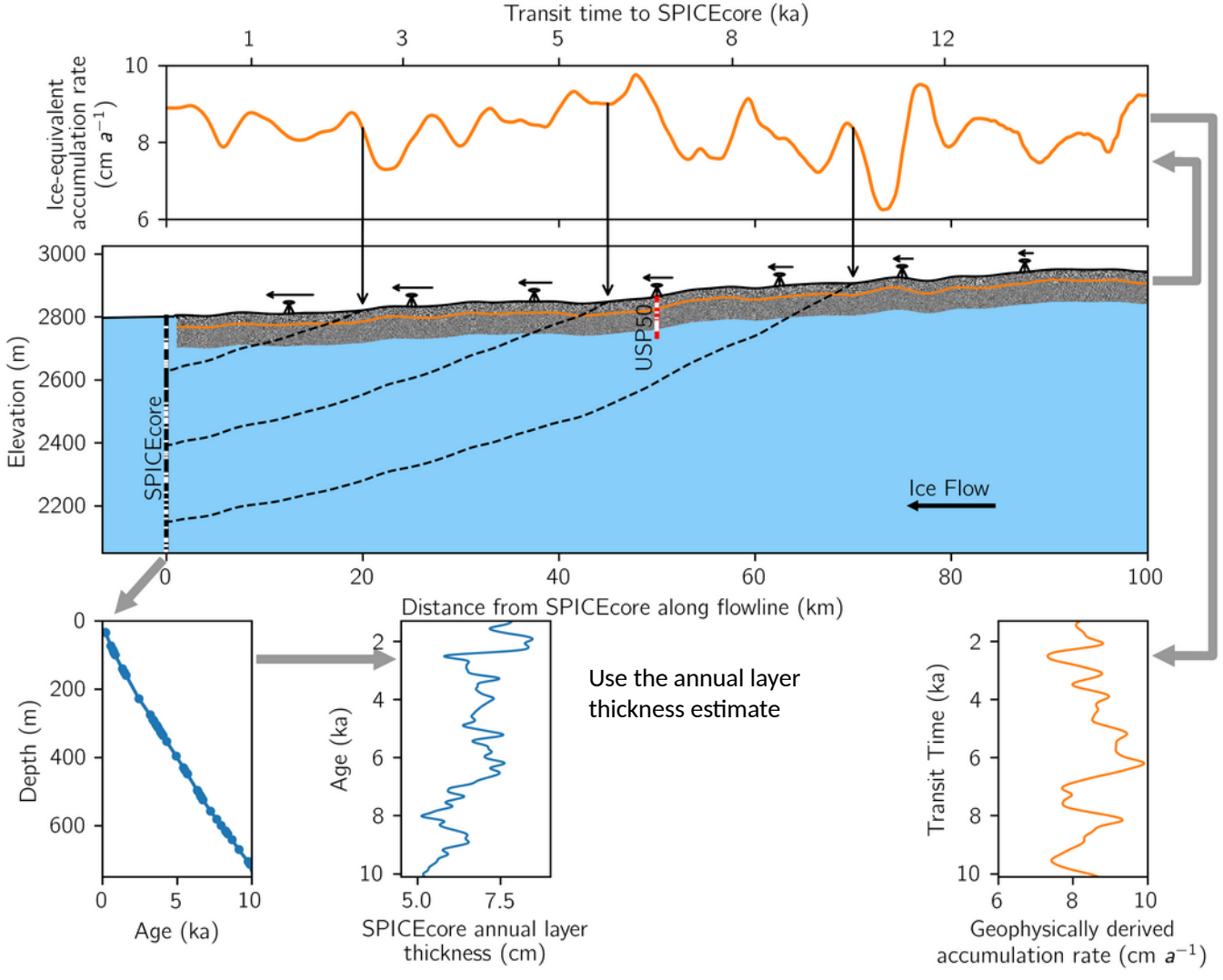
Elevation (m)
SPICEcore
USP50
Ice Flow
0
20
40
60
80
100
Distance from SPICEcore along flowline (km)
Depth (m)
0
200
400
600
0
5
10
Age (ka)
We have the depth-age relationship of SPICEcore from ECM
Transit Time (ka)
2
4
6
8
10
6
8
10
Geophysically derived accumulation rate (cm a^{-1})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2200
Elevation (m)
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USP50
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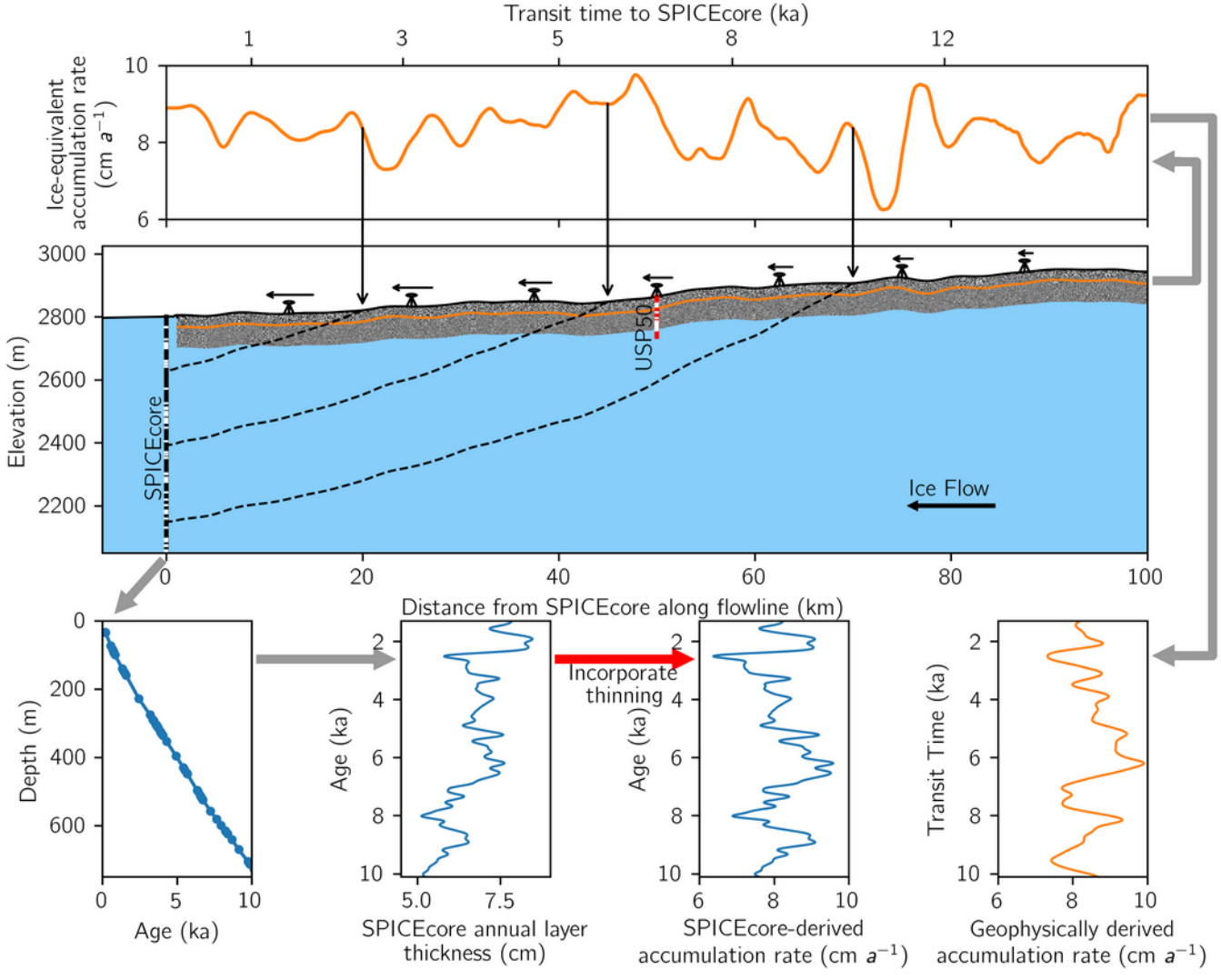
0
20
40
60
80
100
Distance from SPICEcore along flowline (km)
Depth (m)
0
200
400
600
0
5
10
Age (ka)
Age (ka)
2
4
6
8
10
5.0
7.5
SPICEcore annual layer thickness (cm)
Use the annual layer thickness estimate
Transit Time (ka)
2
4
6
8
10
6
8
10
Geophysically derived accumulation rate (cm a^{-1})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2600
2400
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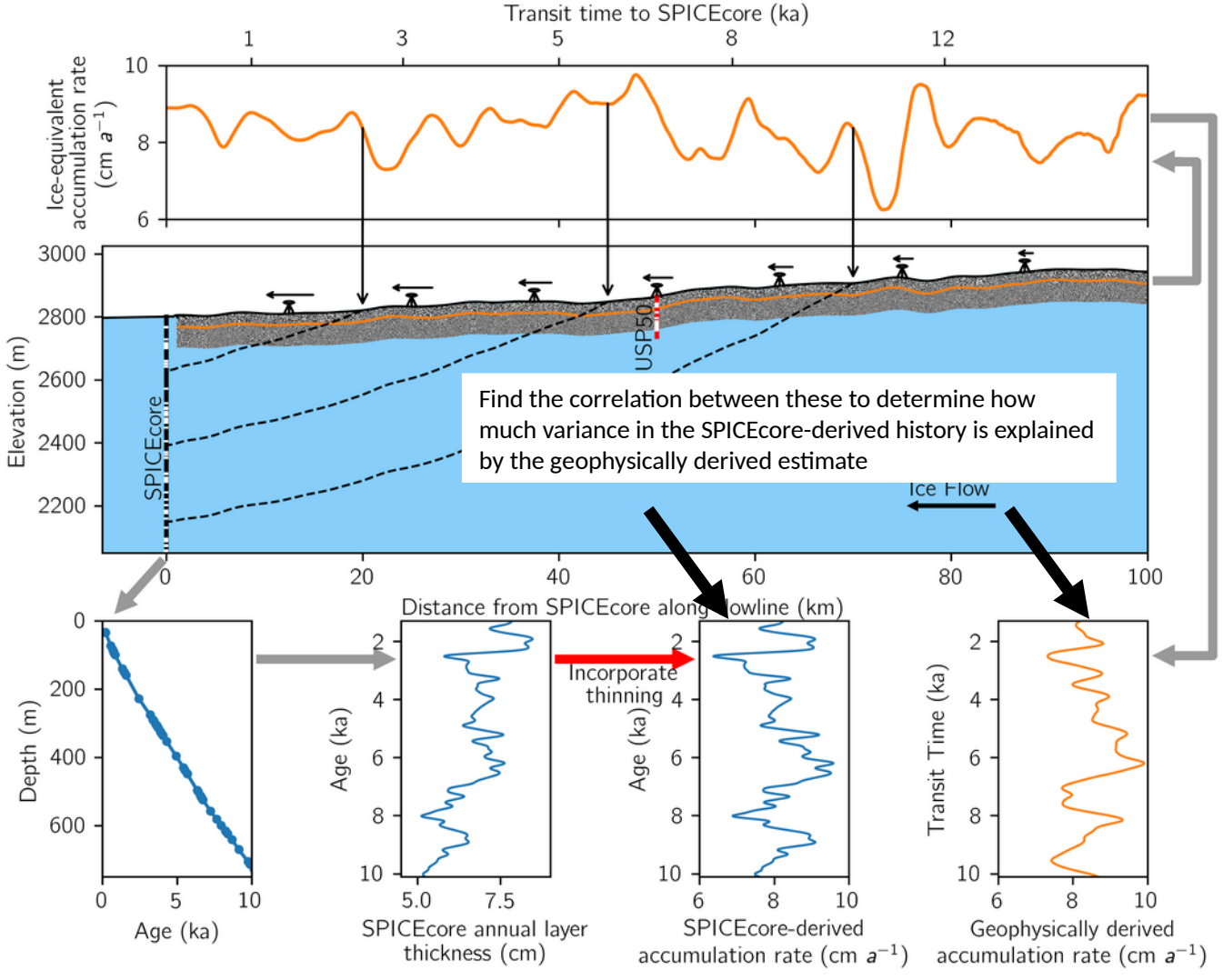
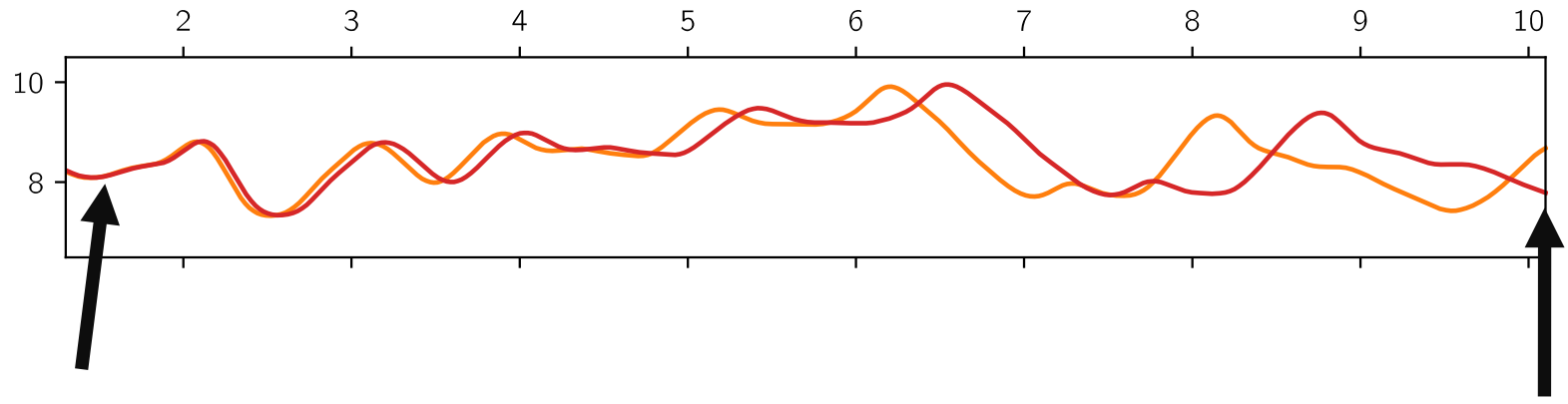
Elevation (m)
SPICEcore
USP50
Ice Flow
0
20
40
60
80
100
Distance from SPICEcore along flowline (km)
Depth (m)
0
200
400
600
0
5
10
Age (ka)
Age (ka)
2
4
6
8
10
5.0
7.5
SPICEcore annual layer thickness (cm)
Incorporate thinning
Age (ka)
2
4
6
8
10
6
8
10
SPICEcore-derived accumulation rate (cm a^{-1})
Transit Time (ka)
2
4
6
8
10
6
8
10
Geophysically derived accumulation rate (cm a^{-1})


Transit time to SPICEcore (ka)
1
3
5
8
12
Ice-equivalent accumulation rate (cm a^{-1})
10
8
6
3000
2800
2600
2400
2200
Elevation (m)
SPICEcore
USP50
Find the correlation between these to determine how much variance in the SPICEcore-derived history is explained by the geophysically derived estimate
Ice Flow
0
20
40
60
80
100
Distance from SPICEcore along flowline (km)
Depth (m)
0
200
400
600
0
5
10
Age (ka)
Age (ka)
2
4
6
8
10
5.0
7.5
SPICEcore annual layer thickness (cm)
Incorporate thinning
Age (ka)
6
8
10
SPICEcore-derived accumulation rate (cm a^{-1})
Transit Time (ka)
Geophysically derived accumulation rate (cm a^{-1})

Do this 90 times for different assumptions about Holocene speed change

Speedup is linearly applied so that speeds are identical at present but slower (positive speedup) or faster (negative speedup) at 10 ka



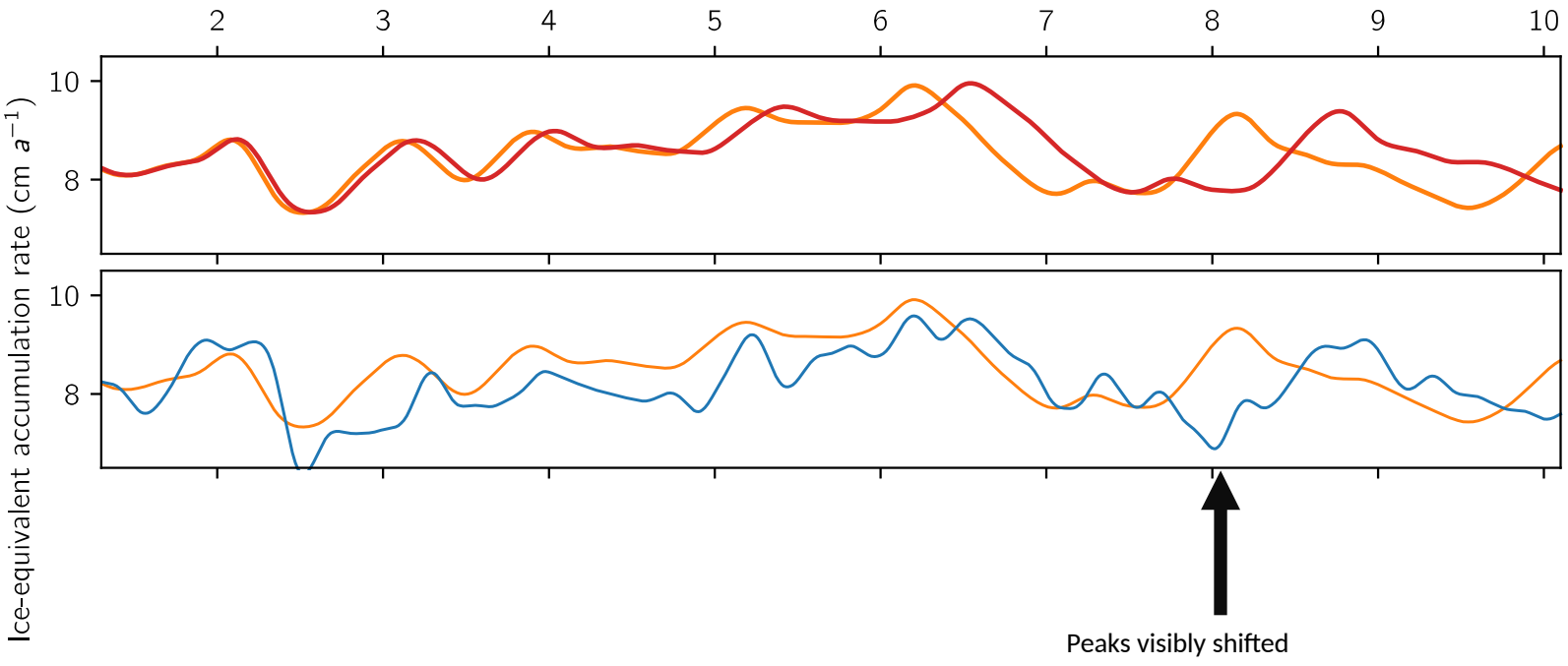
Histories nearly match at 1.3 ka since we linearly apply the speedup (i.e. 0% at present 15% at 10 ka)

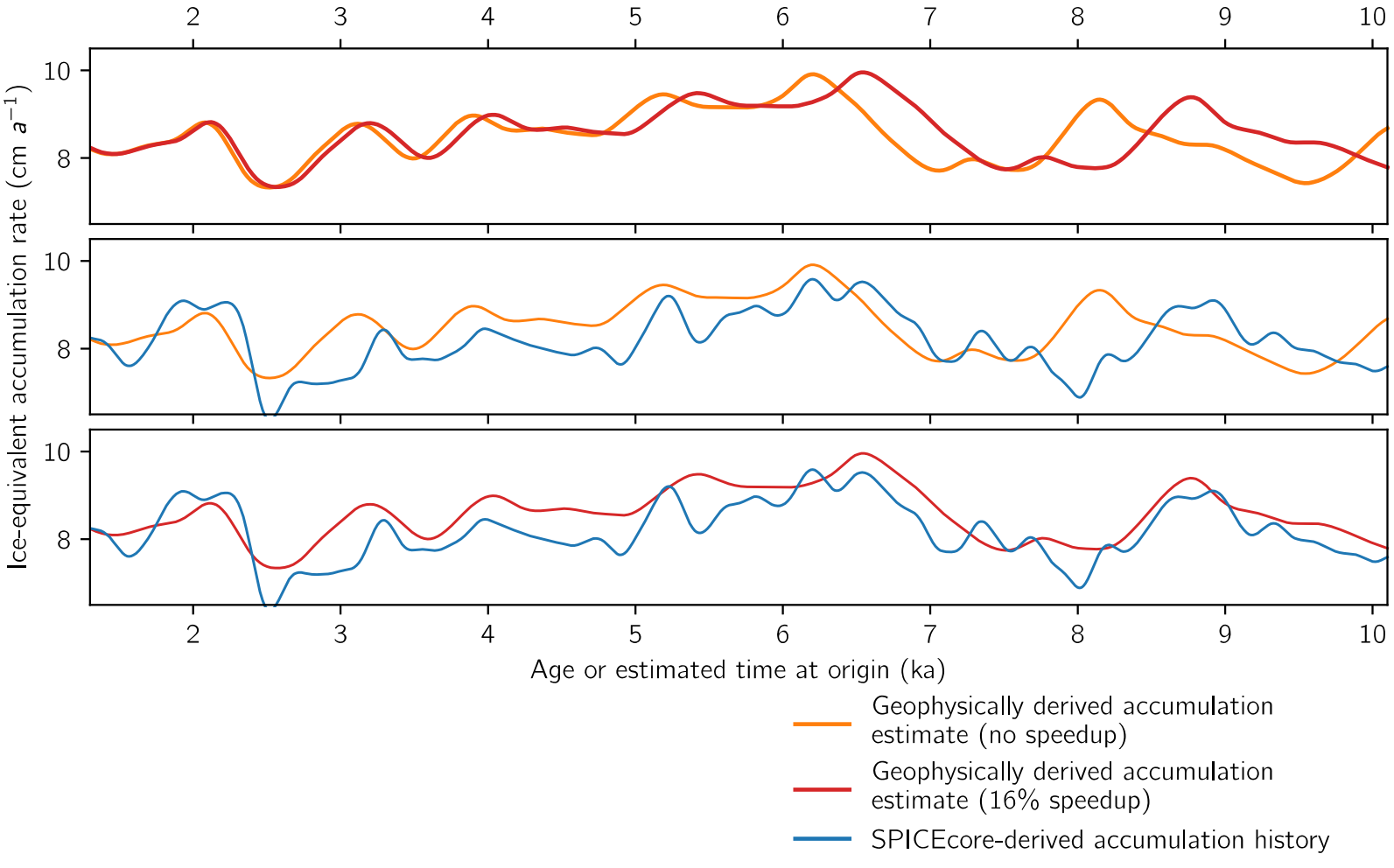
~7.5% offset at 10 ka

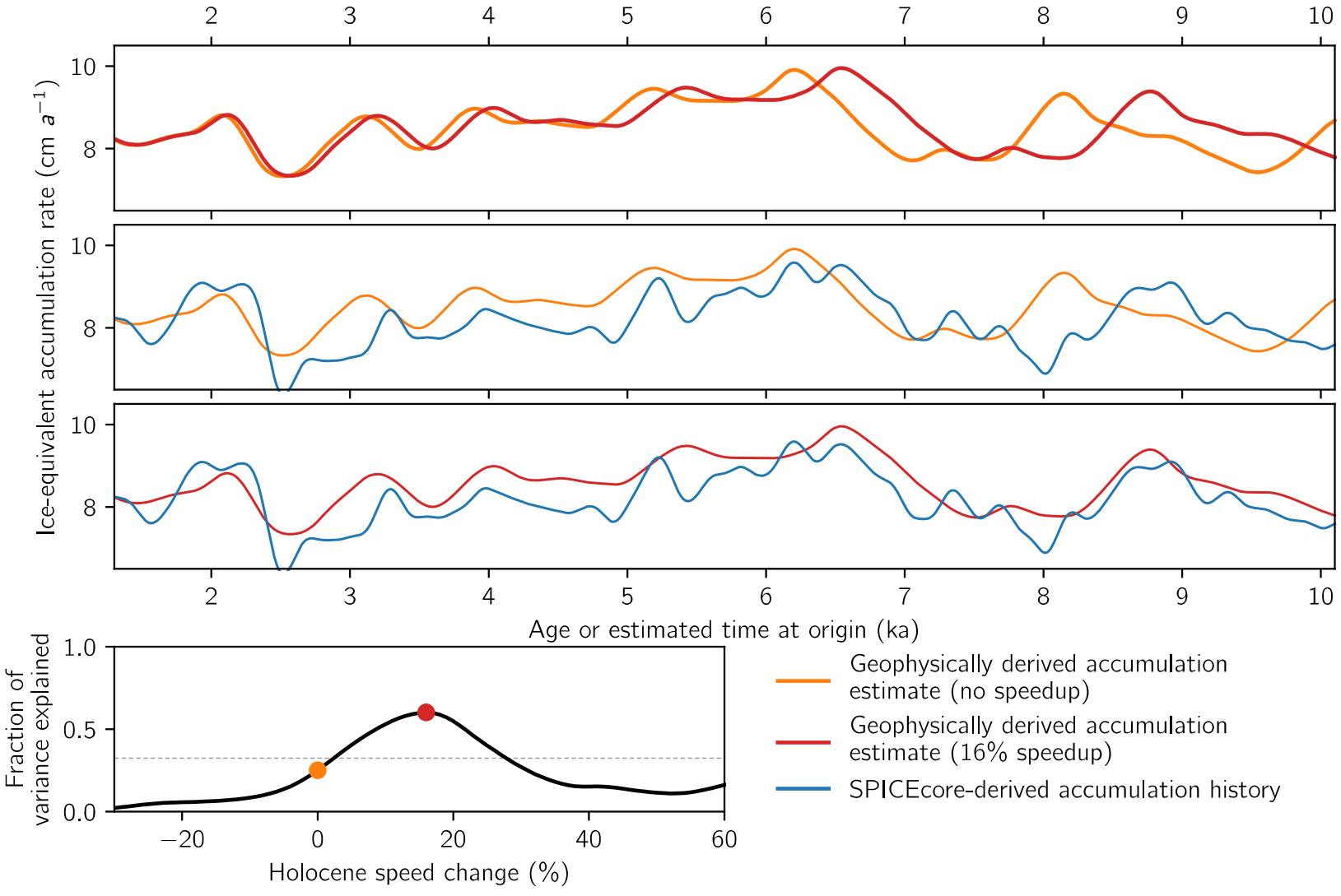
Geophysically derived accumulation estimate (no speedup)

Geophysically derived accumulation estimate (16% speedup)

SPICEcore-derived accumulation history

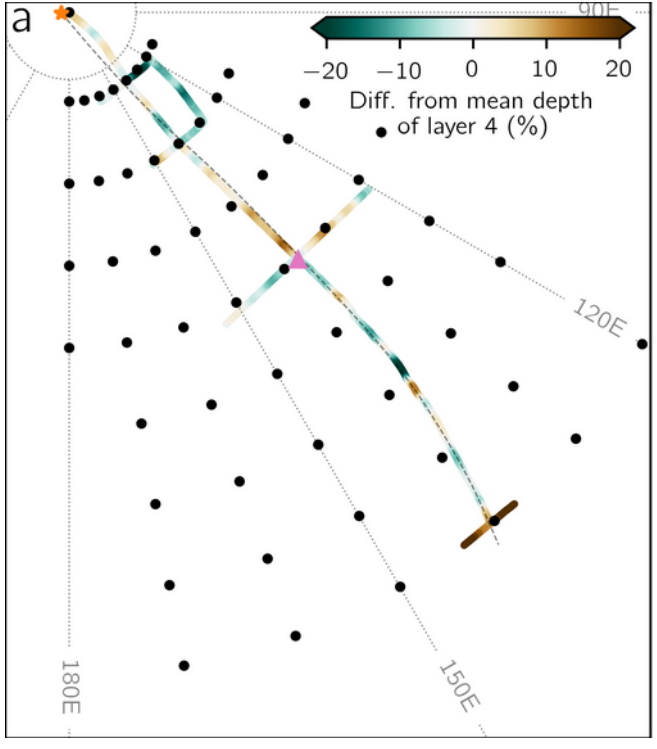

2
3
4
5
6
7
8
9
10
10
8
10
8
Ice-equivalent accumulation rate (cm a^{-1})
Peaks visibly shifted
Geophysically derived accumulation estimate (no speedup)
Geophysically derived accumulation estimate (16% speedup)
SPICEcore-derived accumulation history


2
3
4
5
6
7
8
9
10
10
8
Ice-equivalent accumulation rate (cm a^{-1})
Age or estimated time at origin (ka)
Geophysically derived accumulation estimate (no speedup)
Geophysically derived accumulation estimate (16% speedup)
SPICEcore-derived accumulation history


Ice-equivalent accumulation rate (cm a^{-1})
Age or estimated time at origin (ka)
Fraction of variance explained
Holocene speed change (%)
Geophysically derived accumulation estimate (no speedup)
Geophysically derived accumulation estimate (16% speedup)
SPICEcore-derived accumulation history

Since accumulation varies a lot on short (~2 km) spatial scales

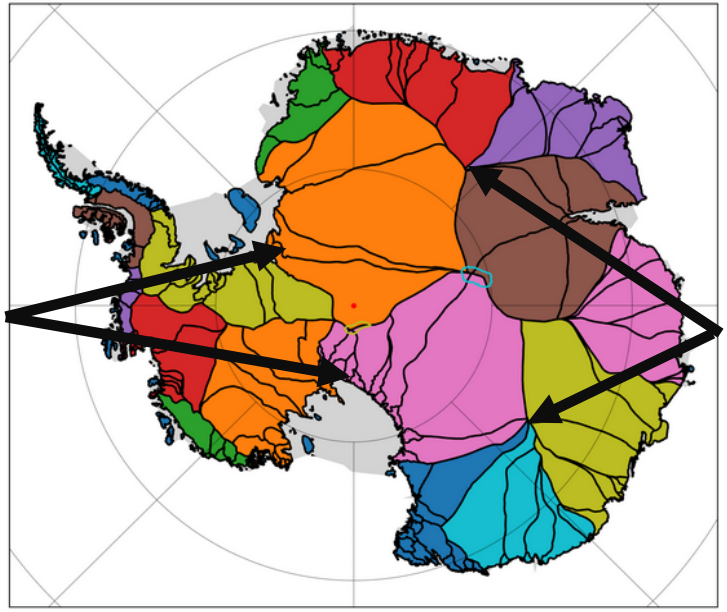
Flow direction and accumulation patterns have been nearly constant for 10,000 years



Ice has sped up ~14-15% since 10 ka

- Assuming no sliding, ice flow speed has a cubic dependence on slope, quadratic dependence on thickness. 15% increase can result from:
  - **4% increase in slope**
  - **3% increase in thickness**
  - Deep temperature increase

100s of meters of thinning (e.g. Bentley 2016, Mackintosh 2014)



~100 m of thickening (Parrenin 20017)

Conclusions

- The combination of ice core and radar data provide a **new type of constraint on Holocene flow** in the interior of the EAIS

- We infer **15% speedup through the Holocene**, with **constant patterns of accumulation and flow direction**

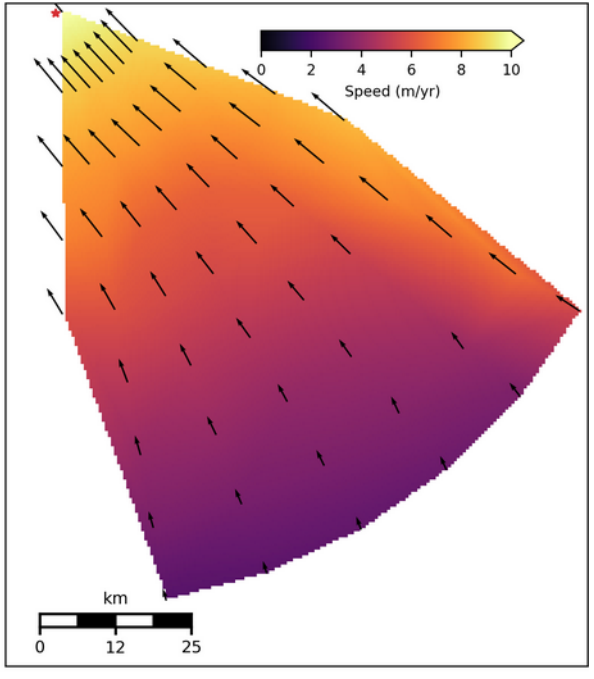
- This is a **useful constraint on models**, which do not agree on speedup or slowdown in the region (e.g. Pollard and DeConto 2009 and 2016)

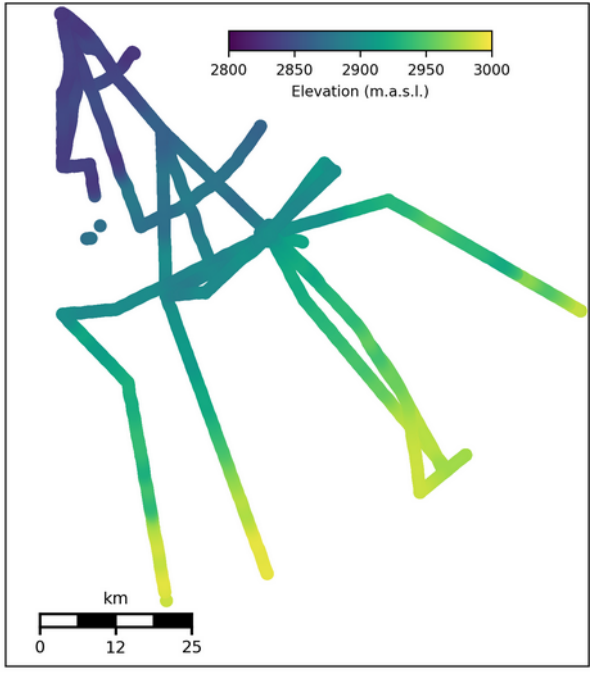
- **Most layer thickness variability is the result of spatial variation** rather than temporal variation in accumulation

(Lilien et al., 2018)

Other UW Data that may be useful

- GPS velocities and (sparse) surface elevation upstream (on USAP data portal)





Other UW Data that may be useful

- GPS velocities and (sparse) surface elevation upstream (on USAP data portal)
- Deep and shallow radar (200 and 7 MHz, impulse radars) along 100 km of flowline (shallow on USAP portal)
- Isotope and surface temperature variations in the 100 km upstream (effect on SPC14 presented in Fudge et al., 2020)
- Measurements of density, temperature, and firn compaction rates 50 km upstream (Stevens et al., forthcoming)
- ApRES repeats at South Pole and 50 km upstream (quadpole, I think Carlos Martín is presenting these here)