ice streams stop and start: evidence and scenarios

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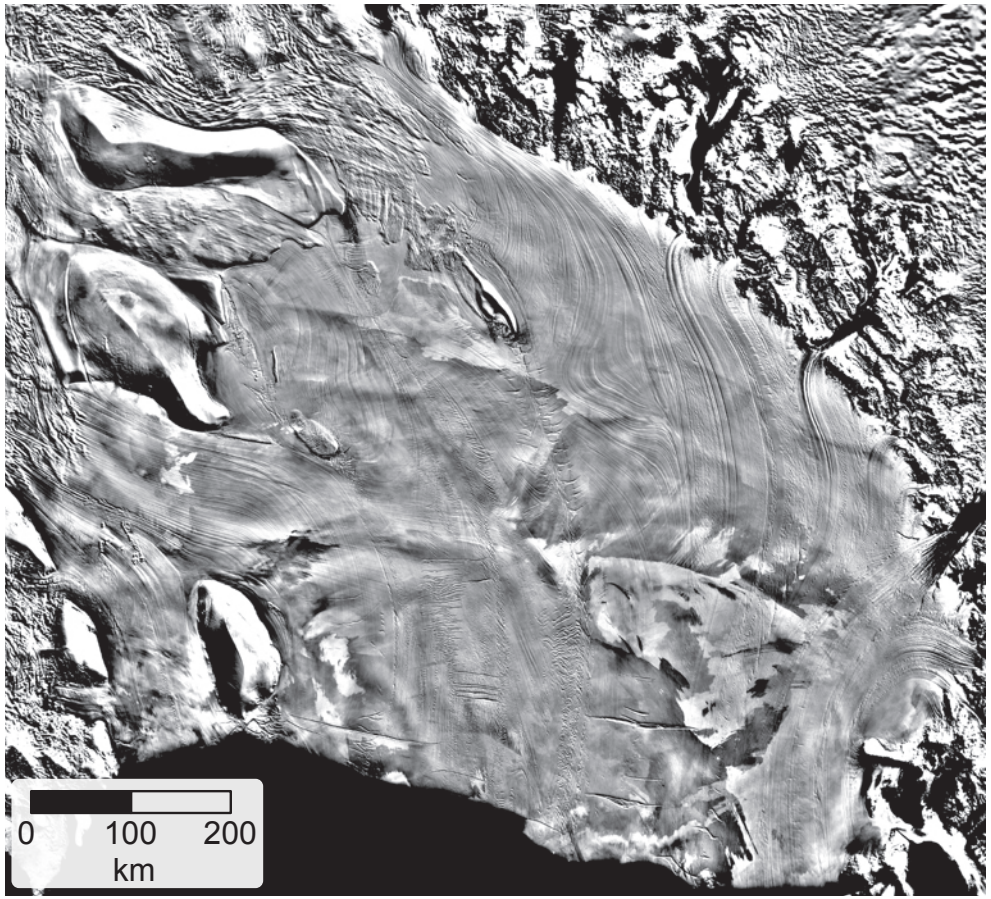
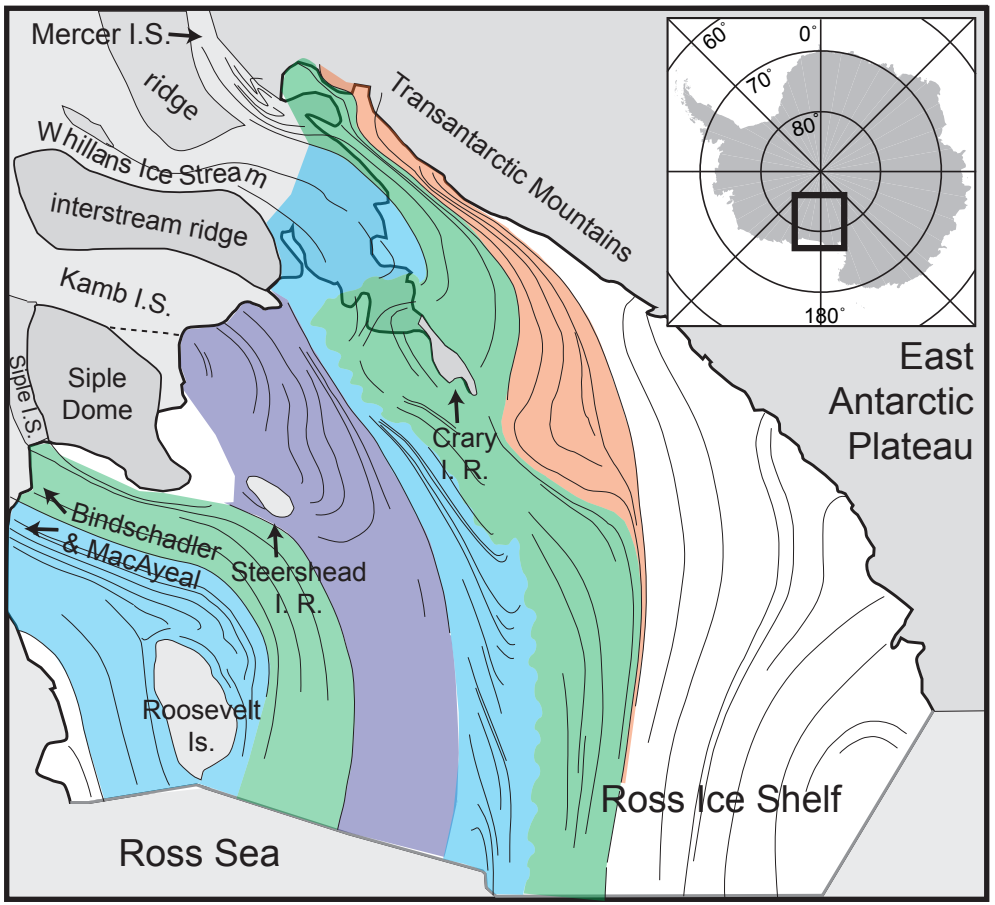


composite MODIS image



digitized streaklines
interpreted ice provenance

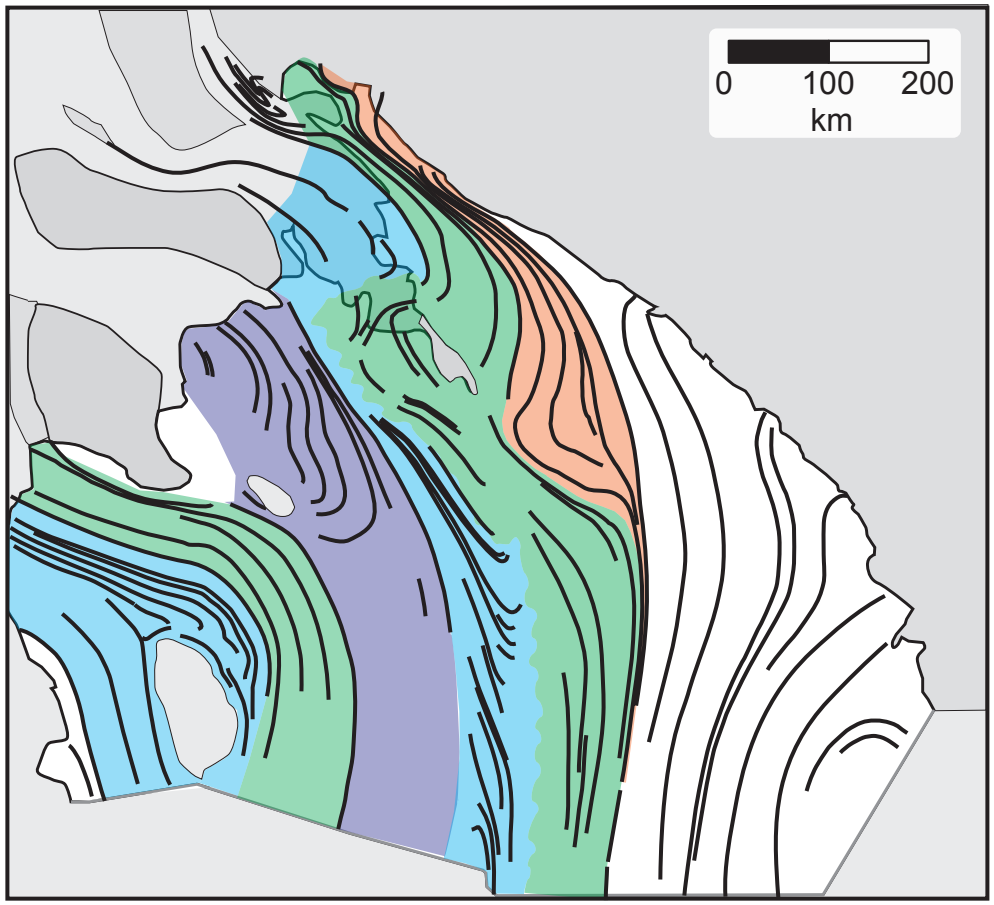
thanks to: Ted Scambos & Chris Shuman
funding from: NSF, NASA

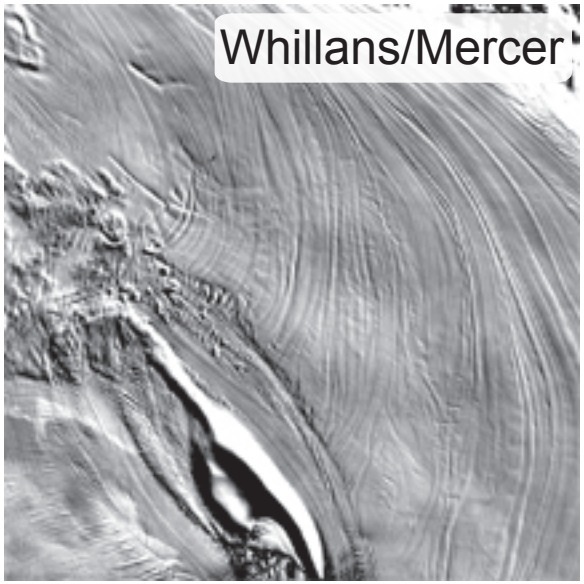
streaklines

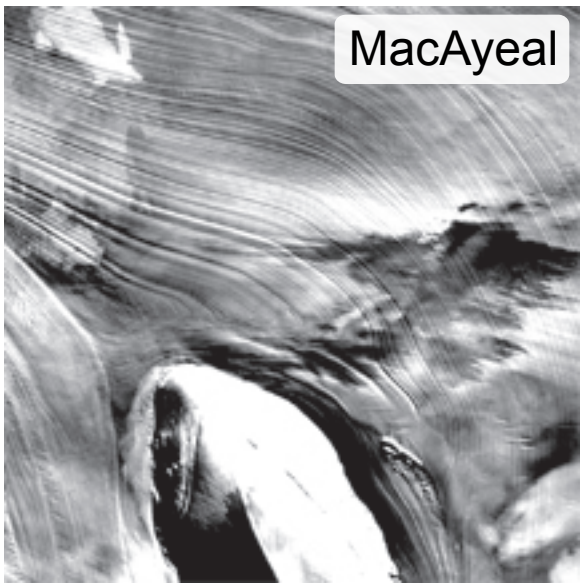
integrated kinematic history of ice shelf flow

changes in
- ice stream discharge
- ice shelf grounding & ice rise formation

fold formation







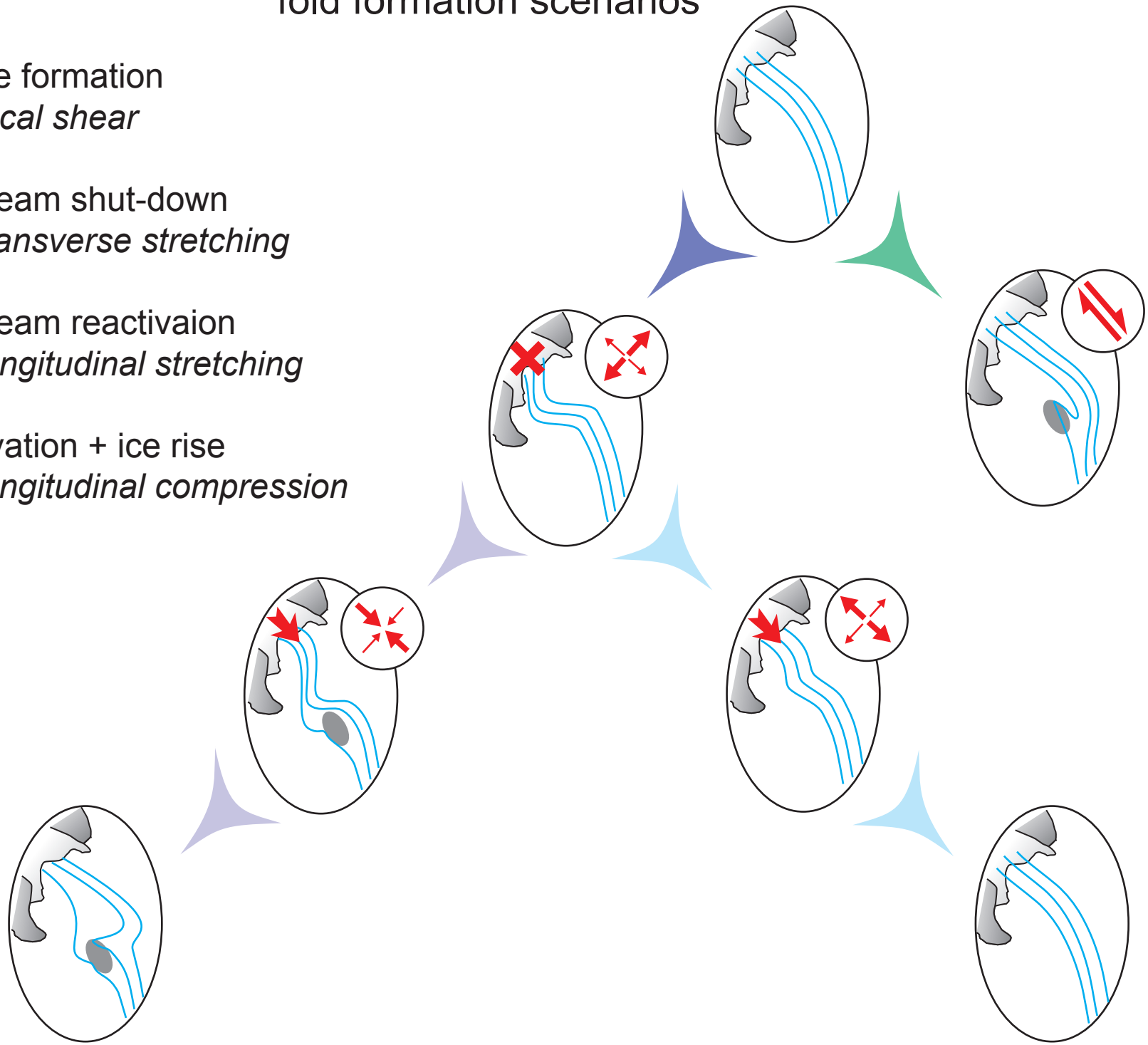
fold formation scenarios

ice rise formation
local shear

ice stream shut-down
transverse stretching

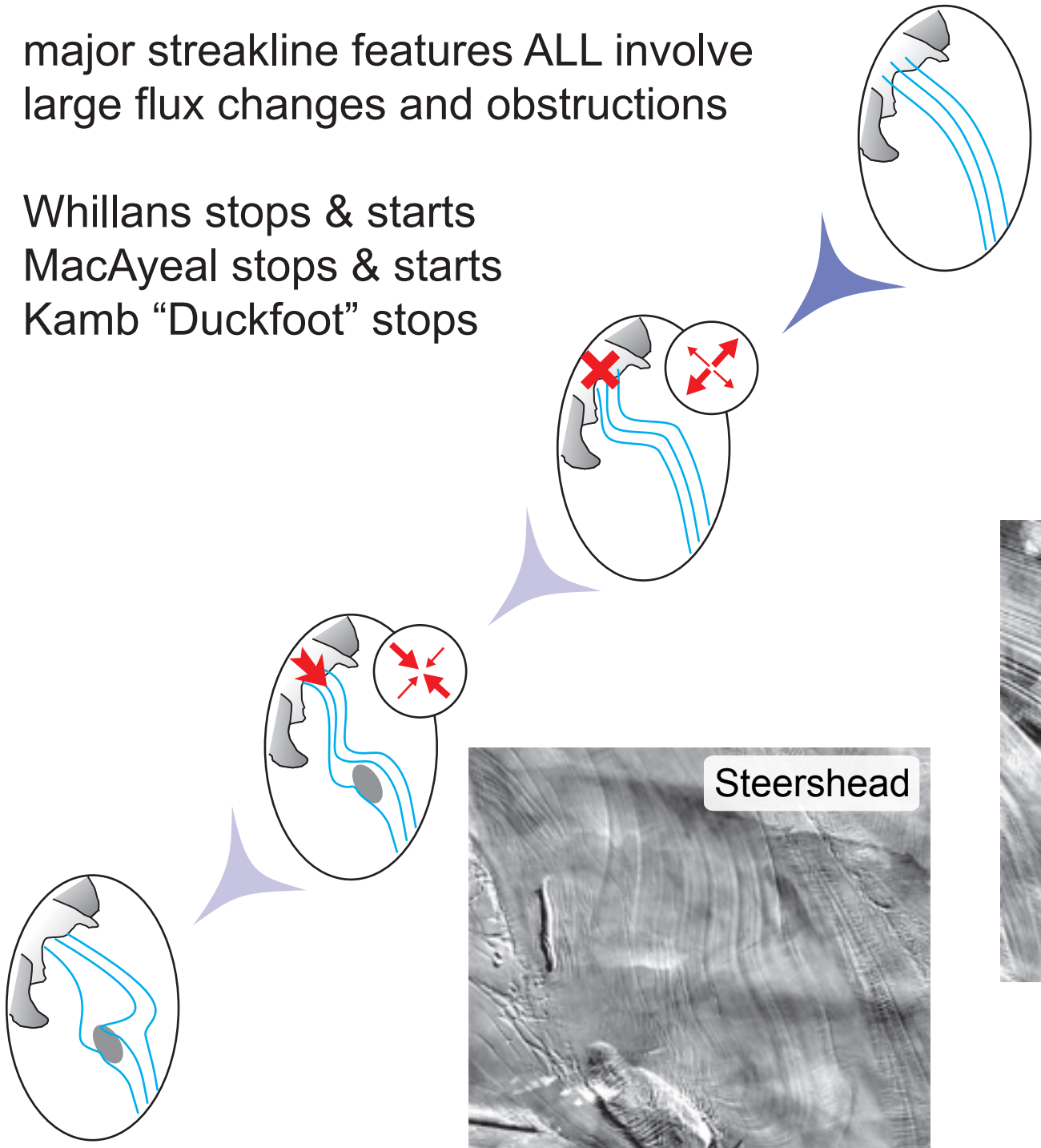
ice stream reactivaion
longitudinal stretching

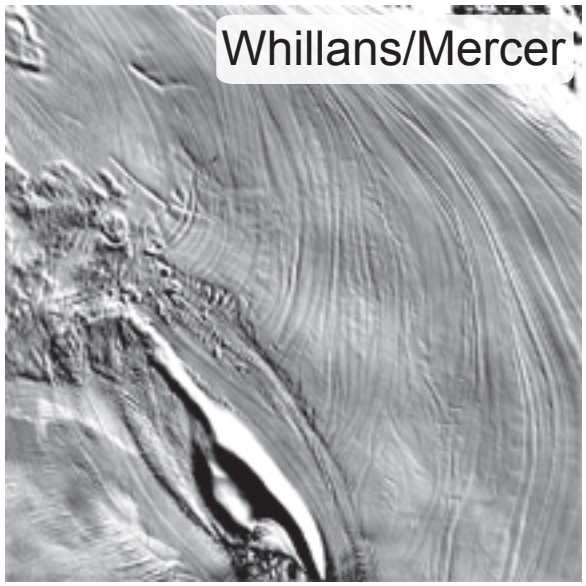
reactivation + ice rise
longitudinal compression

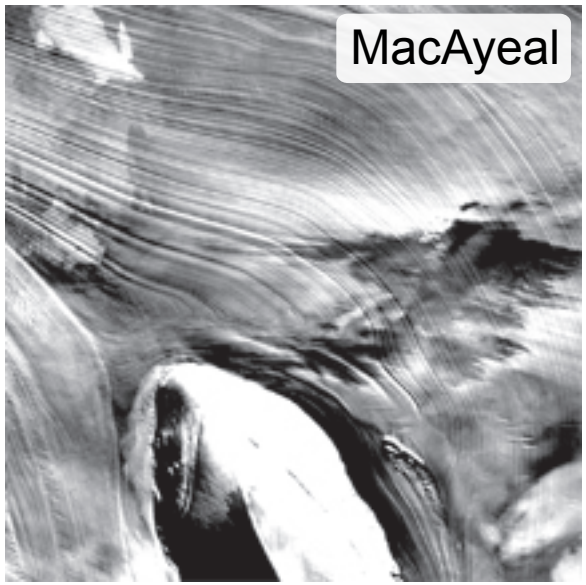


major streakline features ALL involve large flux changes and obstructions

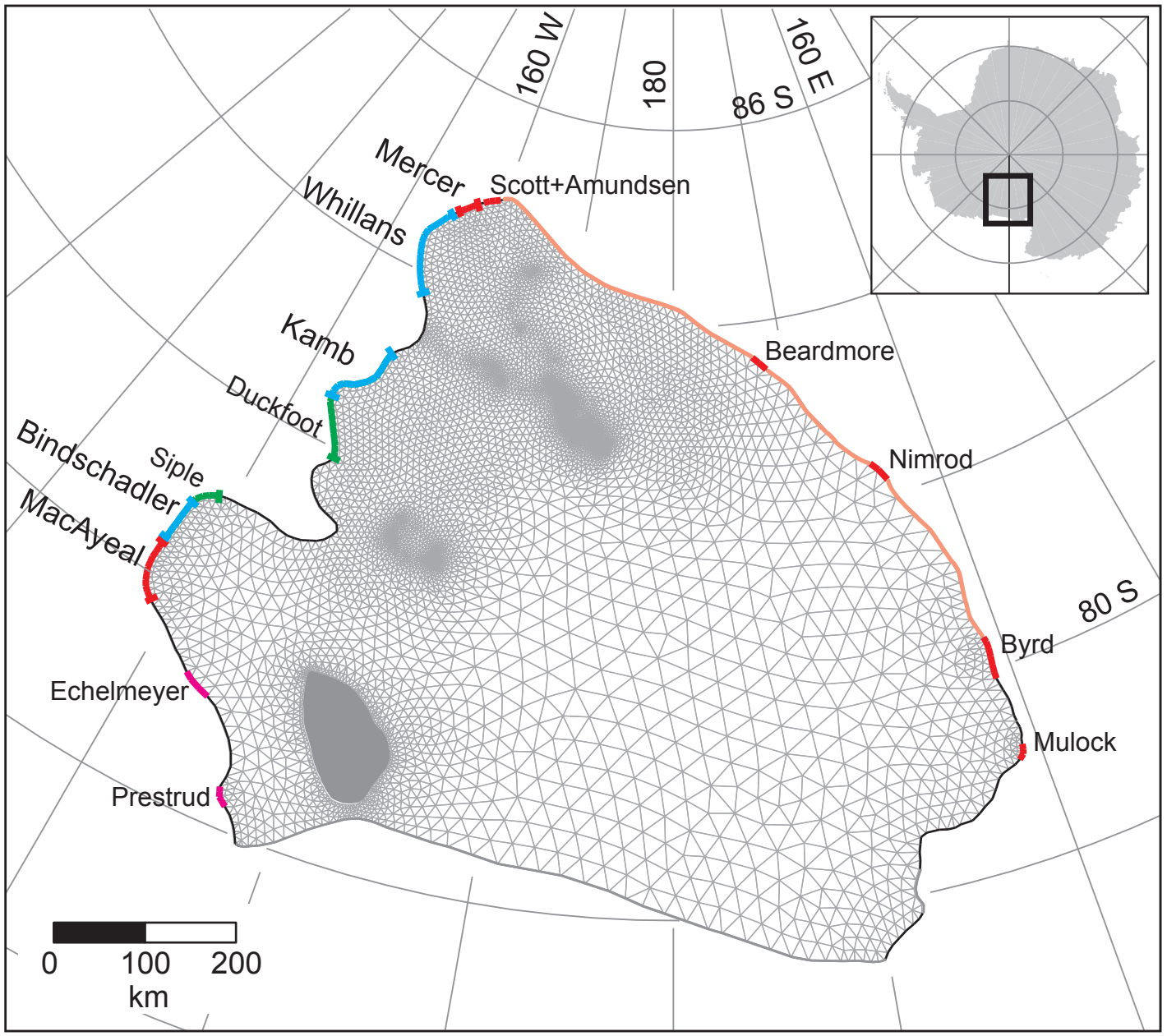
Whillans stops & starts
MacAyeal stops & starts
Kamb “Duckfoot” stops







ice shelf model basics



☆ coupled prognostic & diagnostic
standard ice-shelf equations
FEM

★ spatially variable flow-law rate factor
surface T & ice thickness
"shear margins" tuned to present-day conditions

☆ grounding according to floatation

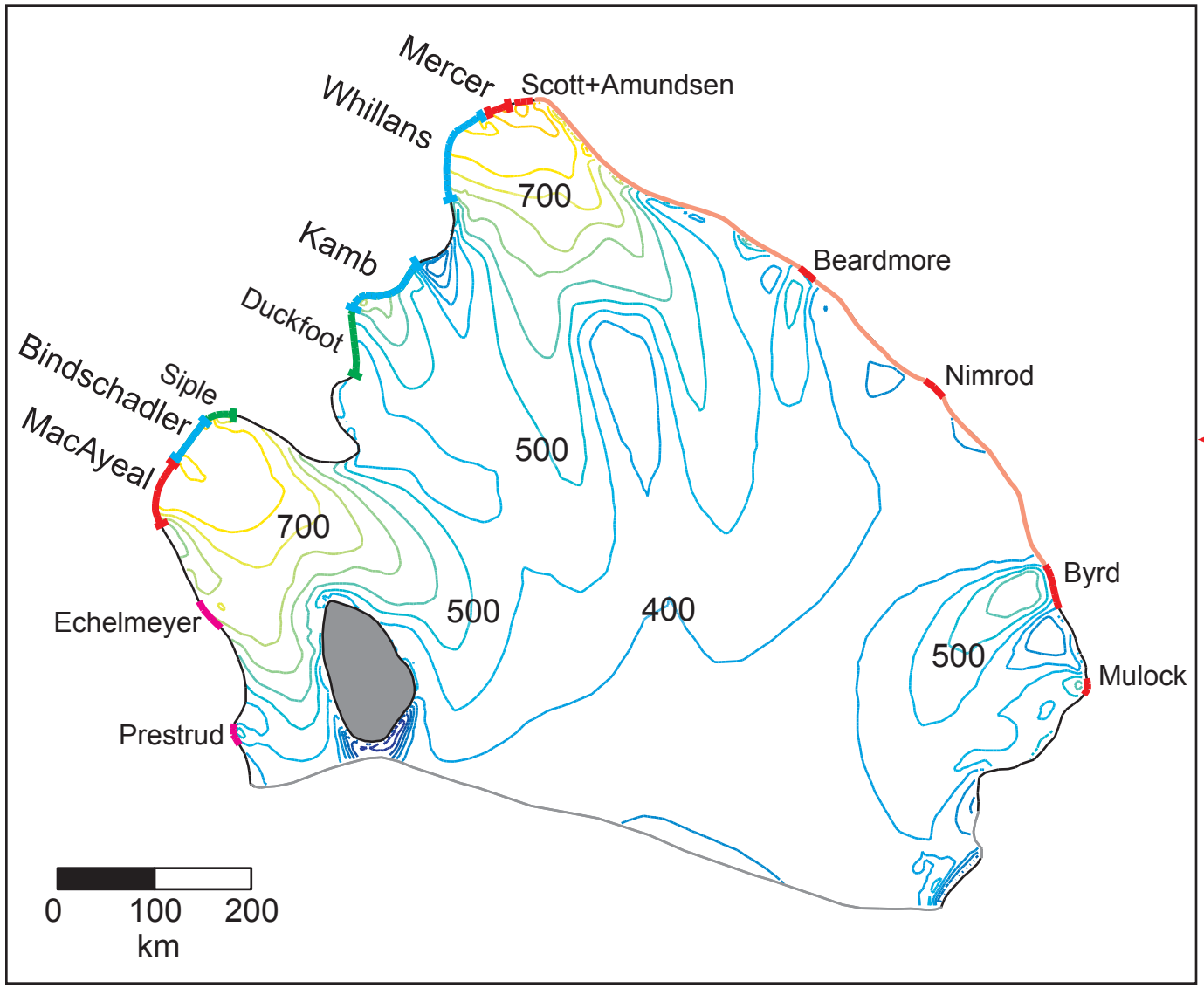
★ variable basal drag beneath
grounded ice
known ice rises

★ variable boundary influx
ice streams
major TAM outlet glaciers
smaller glaciers
gate width may vary

☆ lagrangian tracers

standard model initialization

ice thickness ci = 50 m



☆ boundary conditions for past state, 1600 years ago
- boundary fluxes
- Crary "ungrounded"
- Steershead "ungrounded"
- light ice plain grounding

☆ iterate to steady state

☆ several ice stream flux options

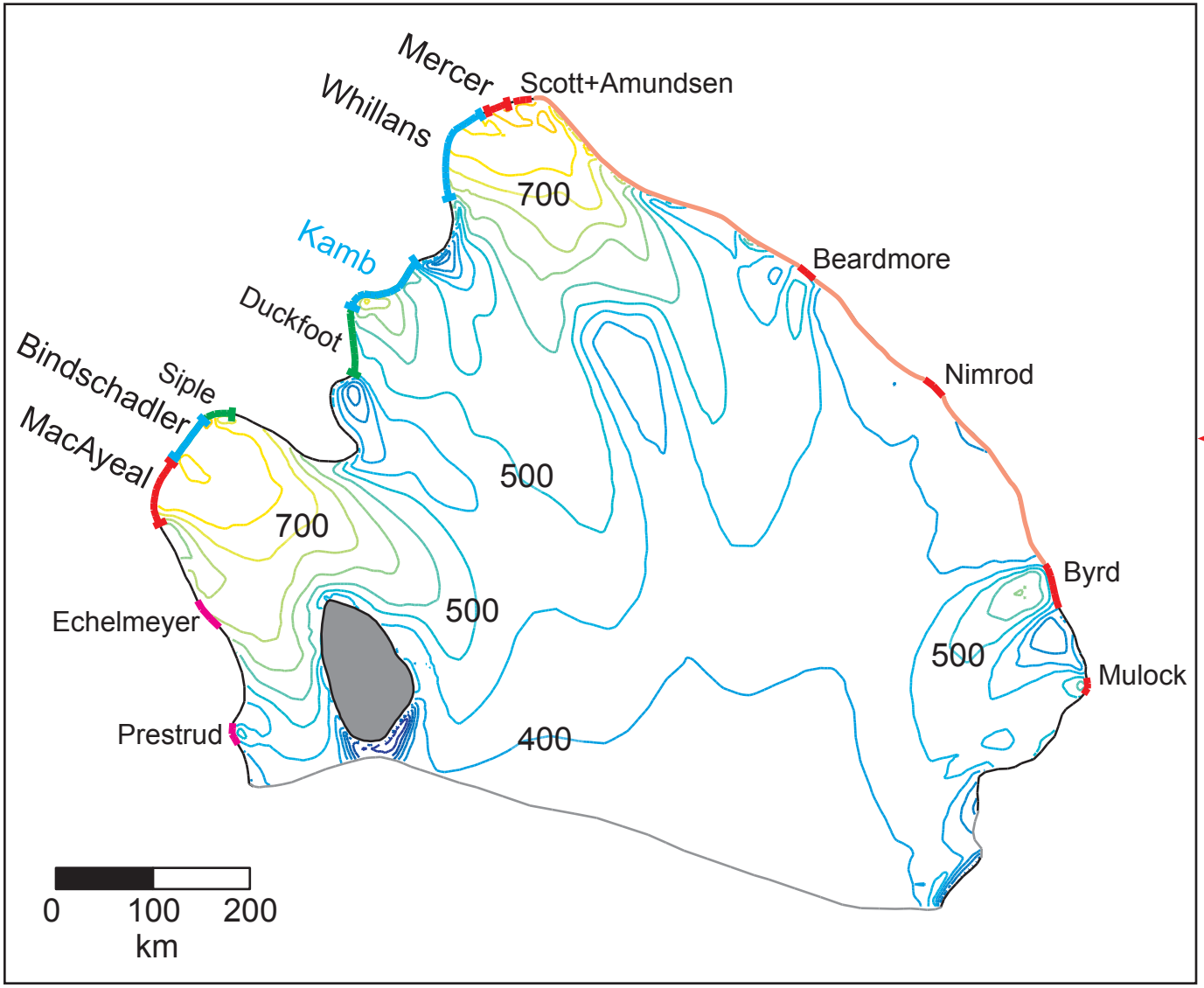
◀ boundary speeds for this solution

Mercer	400 m/a
Whillans	550 m/a
Kamb	300 m/a
Bindschadler	300 m/a
MacAyeal	350 m/a
Echelmeyer	140 m/a
Prestrud	200 m/a
Scott+Amundsen	170 m/a
Beardmore	470 m/a
Nimrod	250 m/a
Byrd	600 m/a
Mulock	290 m/a
general TAM	100 m/a

this is a robust geometry, controlled largely by bathymetry of the Ross embayment

model initialization: mighty, mighty Kamb

ice thickness ci = 50 m



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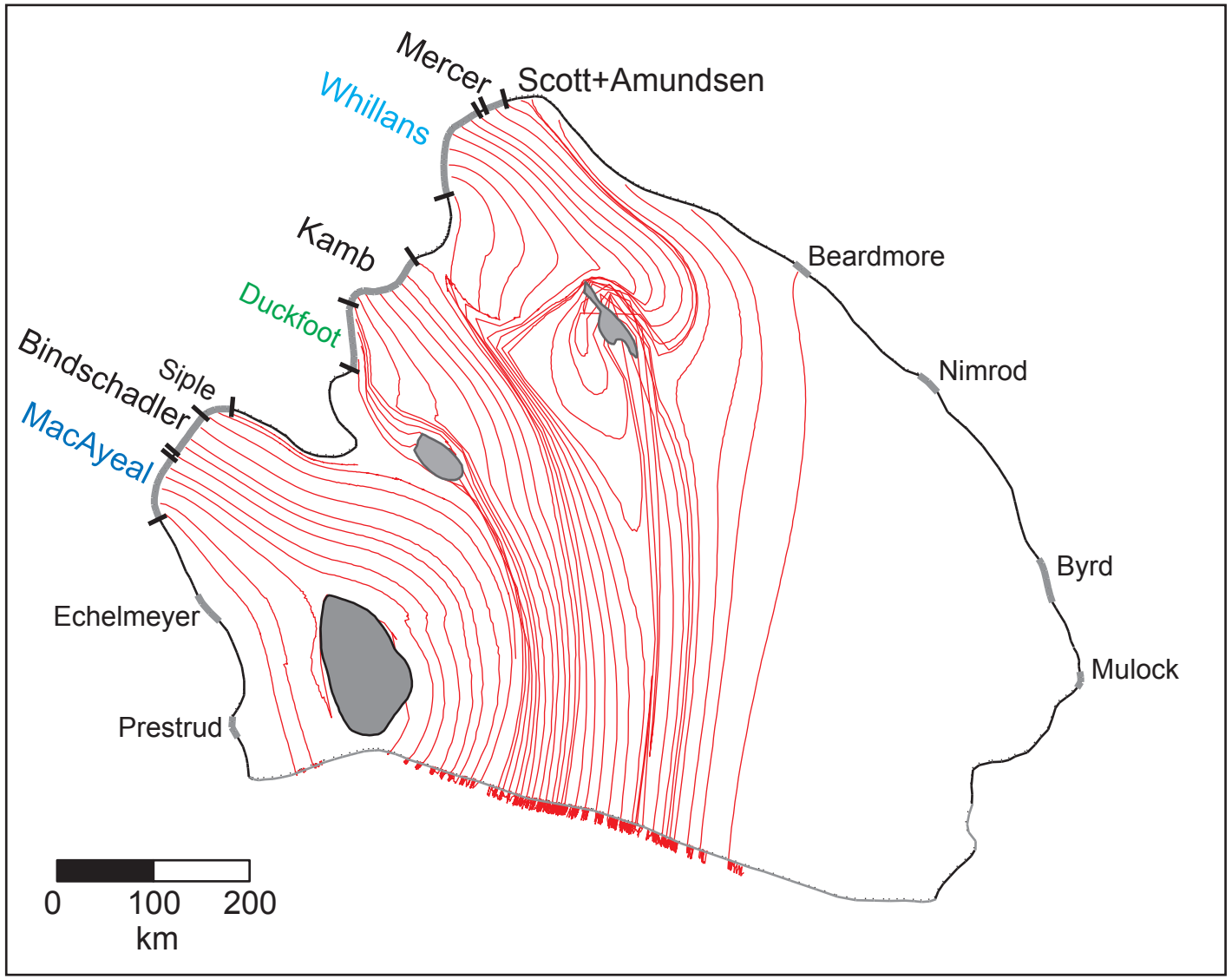
* 67% increase in Kamb volume flux

this is a robust geometry, controlled largely by bathymetry of the Ross embayment

streaklines at end of model run

benchmark model: cw timing and fluxes, mostly (transient #20)



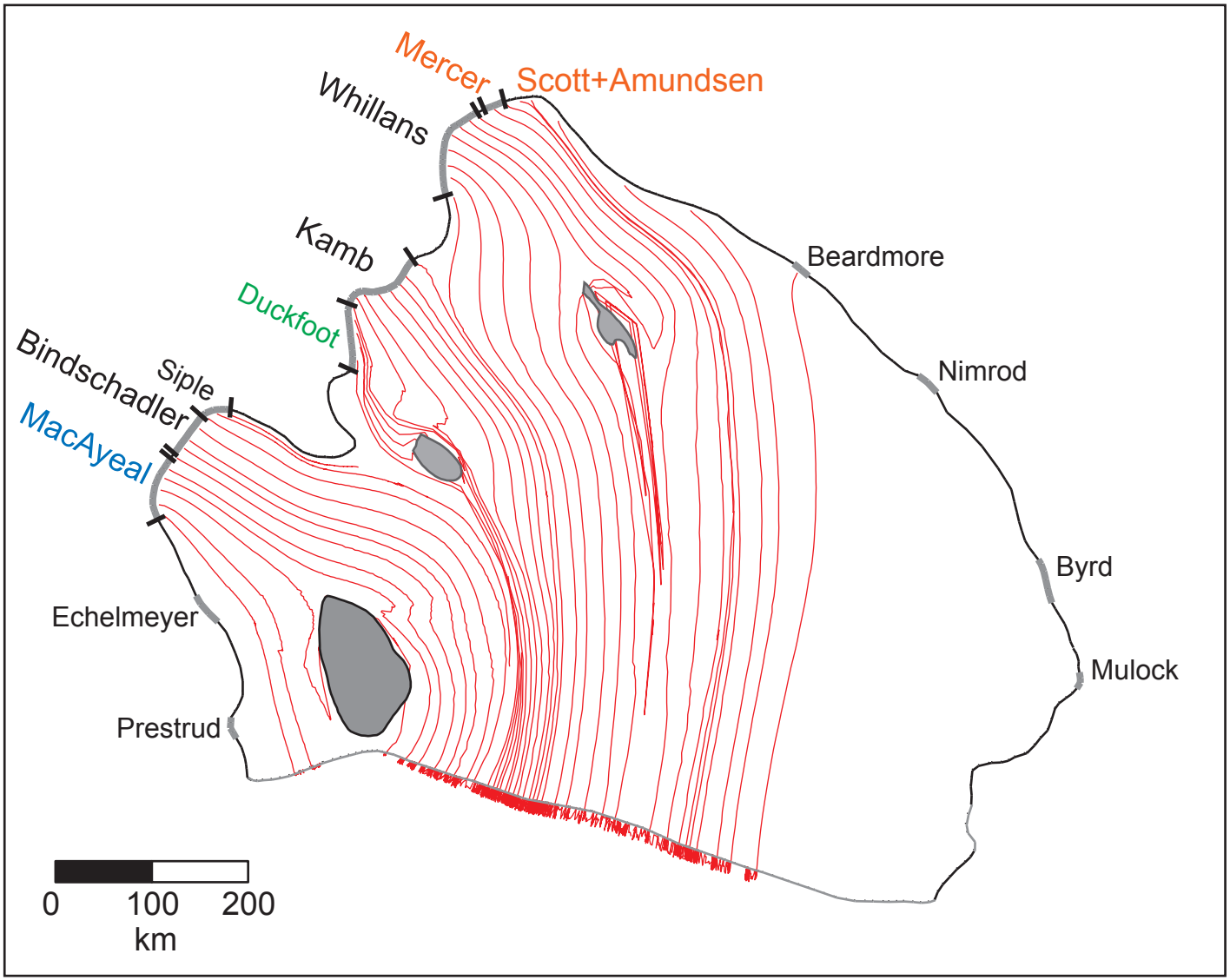
transient events

	(years ago)
1000	Crary Ice Rise off*
850	Whillans off
800	Mac Ayeal off
700	MacAyeal on
600	Kamb up
550	Duckfoot off
460	Siple off
450	Whillans on
360	Steershead off
350	Bindschadler & MacAyeal up
250	Kamb slows
150	Kamb off

* shear margins soften over 200 years

streaklines at end of model run

TAM-fed surges (no Whillans event)



transient events

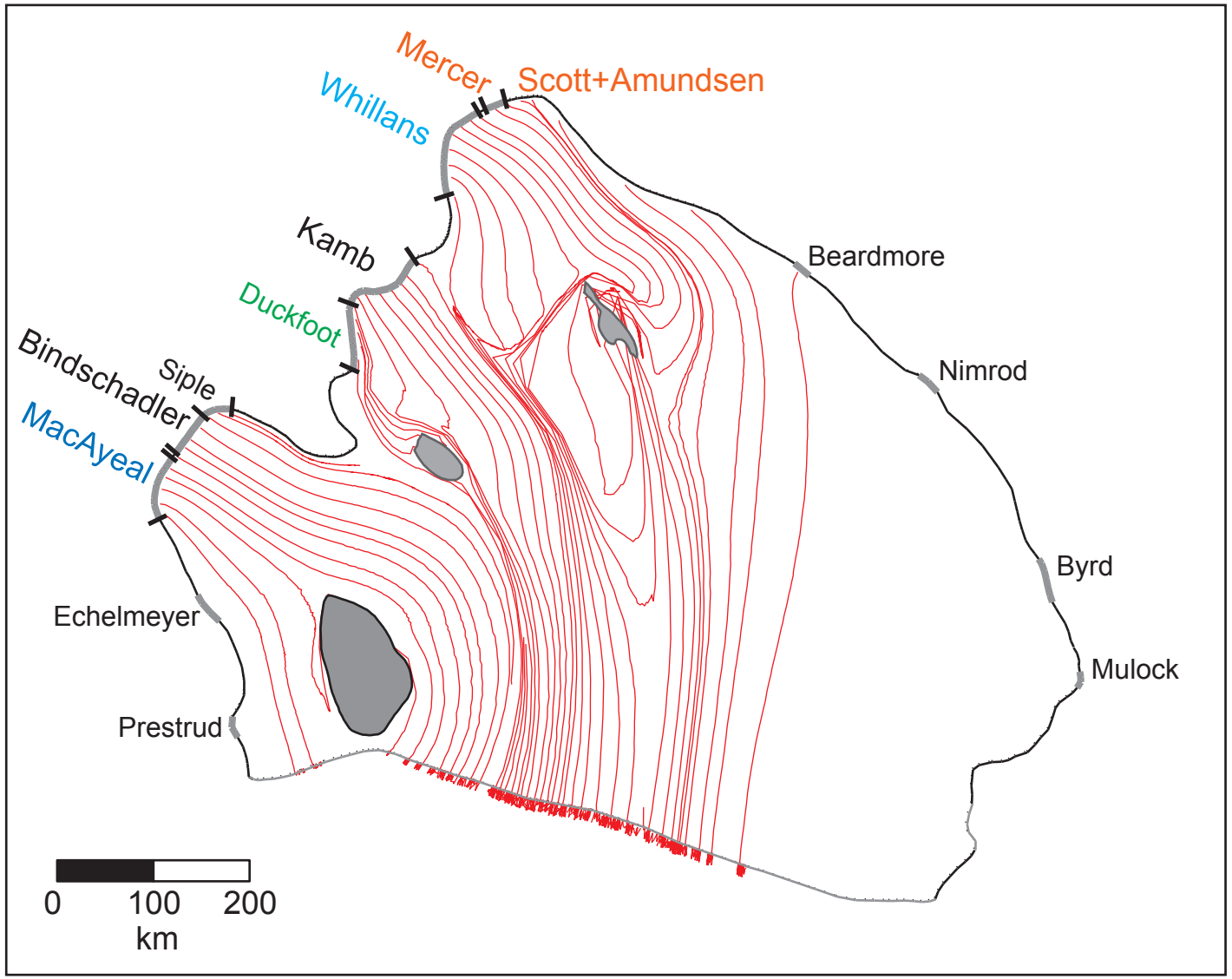
	(years ago)
1000	Crary Ice Rise off*
850	Mercer, Scott, Amundsen up**
800	Mac Ayeal off
650	MacAyeal on
550	Kamb up**
460	Siple off
460	Duckfoot off
450	Mercer et al. down
360	Steershead off
350	Bindschadler & MacAyeal up
150	Kamb off

* shear margins soften over 200 years

** flux doubles

streaklines at end of model run

TAM-fed surges + Whillans event + down-but-not-out MacAyeal



transient events

	(years ago)
1000	Crary Ice Rise off*
850	Whillans off
820	Mercer, Scott, Amundsen up**
800	Mac Ayeal down***
650	MacAyeal back up
600	Kamb up**
550	Duckfoot off
470	Mercer et al. down
460	Siple off
450	Whillans on
360	Steershead off
350	Bindschadler & MacAyeal up
150	Kamb off

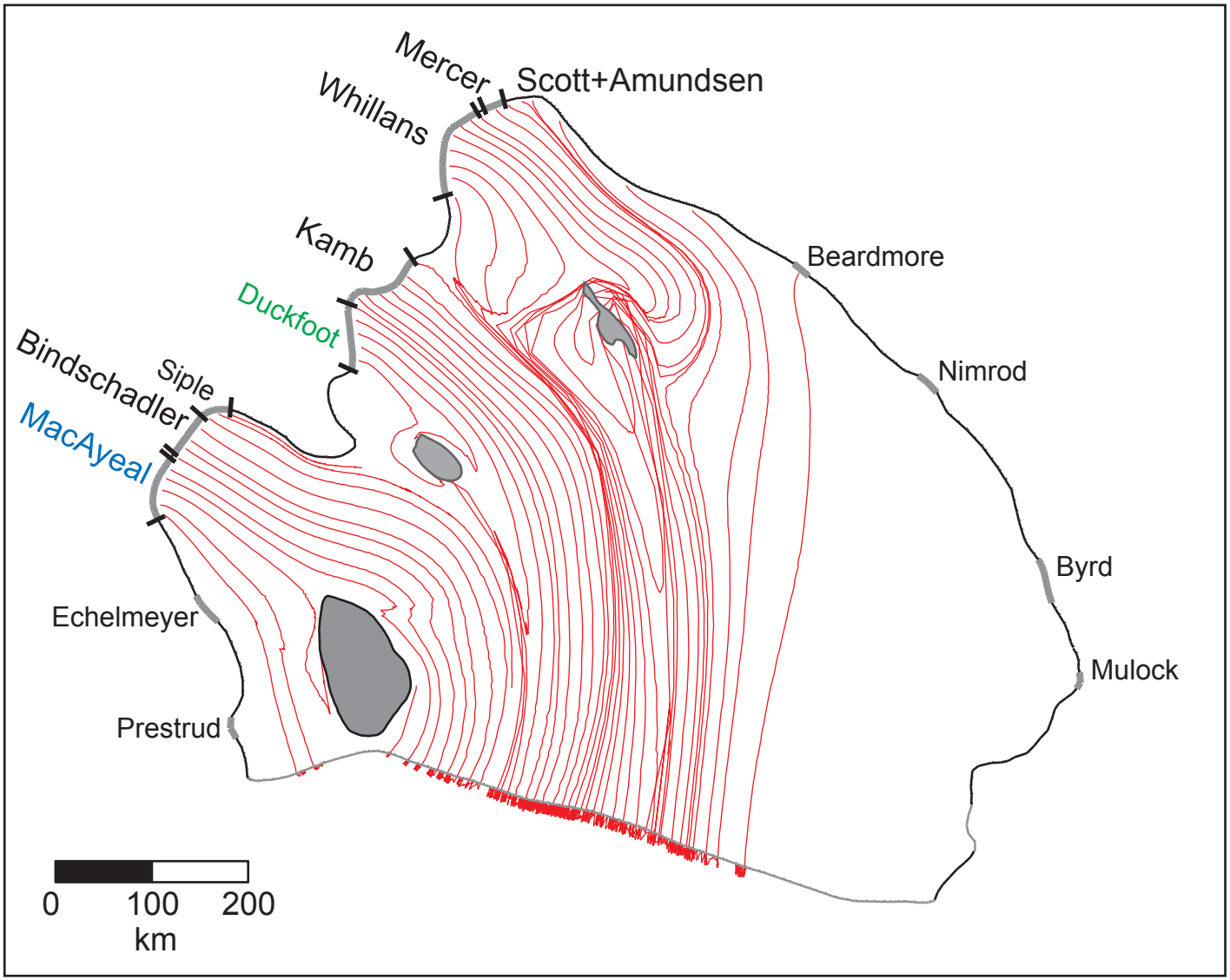
* shear margins soften over 200 years

** flux doubles

*** flux halves

streaklines at end of model run

Duckfoot forever + longer MacAyeal down



transient events

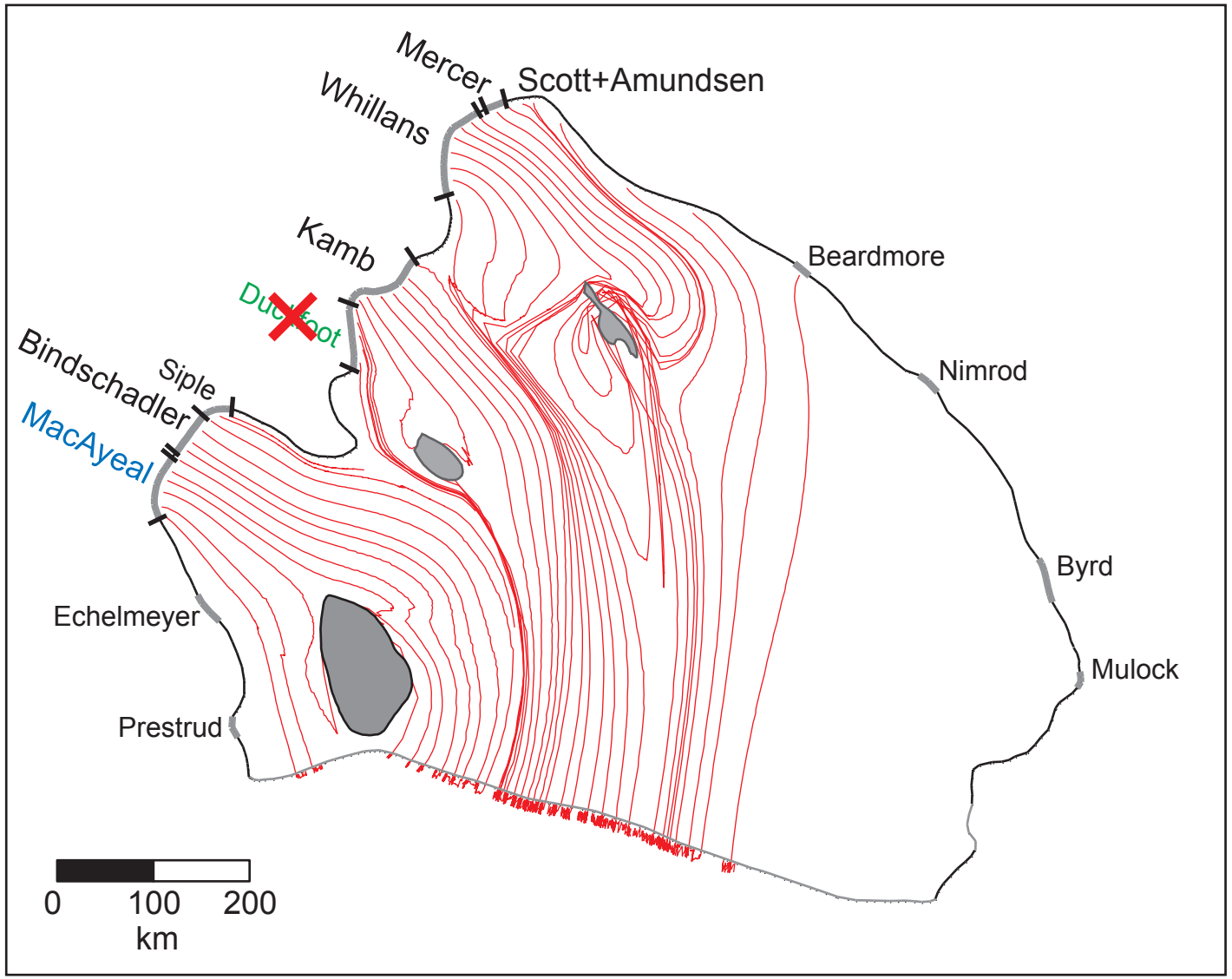
	(years ago)
1000	Crary Ice Rise off*
850	Whillans off
800	Mac Ayeal off
650	MacAyeal on
600	Kamb up**
500	Steershead tip
460	Siple off
450	Whillans on
350	Bindschadler & MacAyeal up
200	Steershead off
150	Kamb off

* shear margins soften over 200 years

** flux doubles

streaklines at end of model run

Duckfoot never + longer MacAyeal down + modified Steershead grounding



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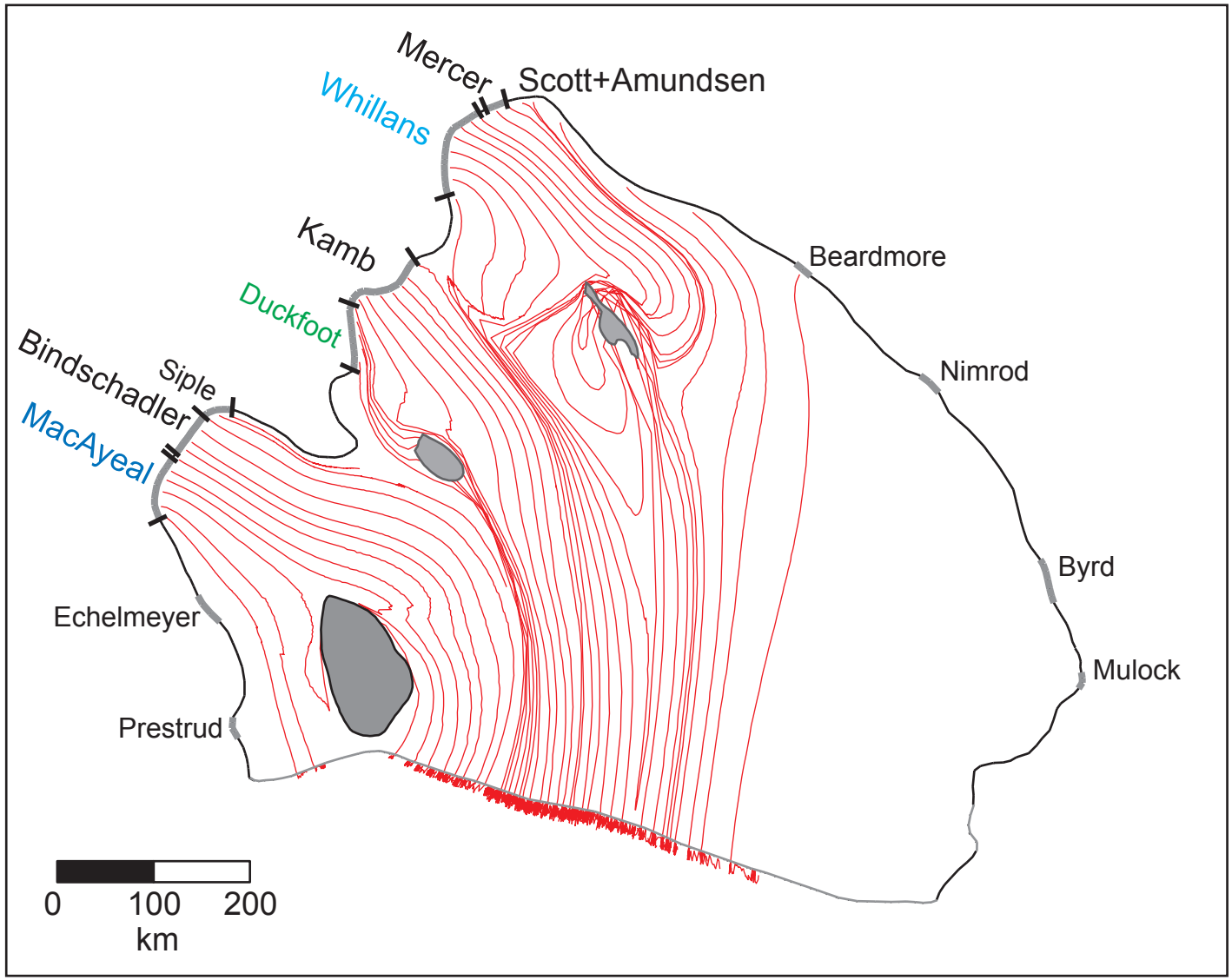
150	Kamb off

* shear margins soften over 200 years

** flux doubles

streaklines at end of model run

start from mighty, mighty Kamb + adjust Kamb bay timing + longer Mac (#28)



transient events

	(years ago)
1000	Crary Ice Rise off*
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670	Duckfoot off
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500	Steershead tip
460	Siple off
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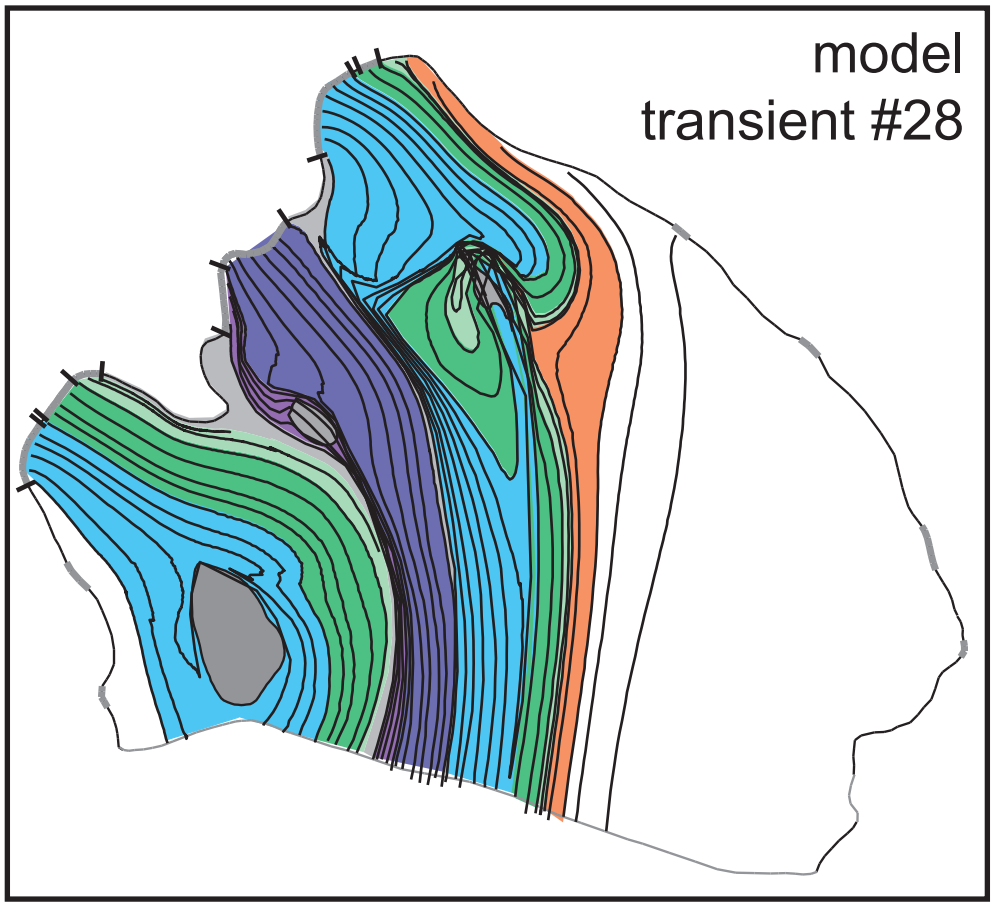
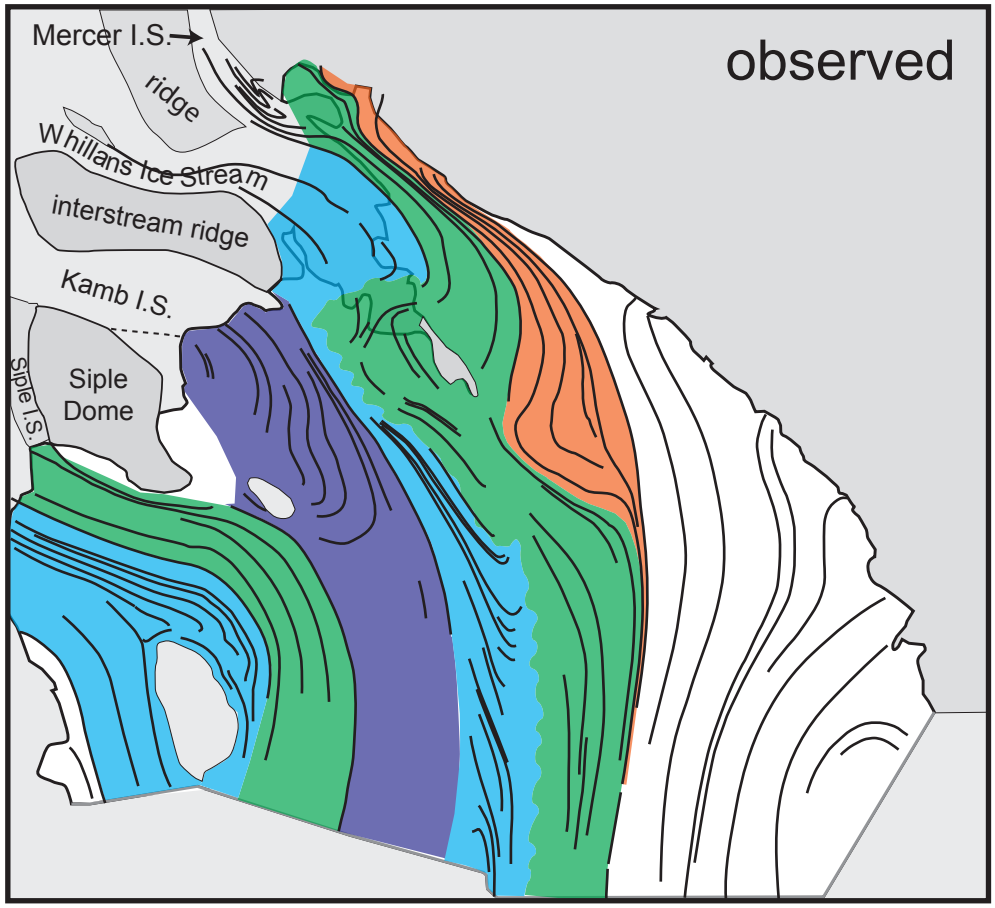
200	Steershead off
150	Kamb off

* shear margins soften over 200 years

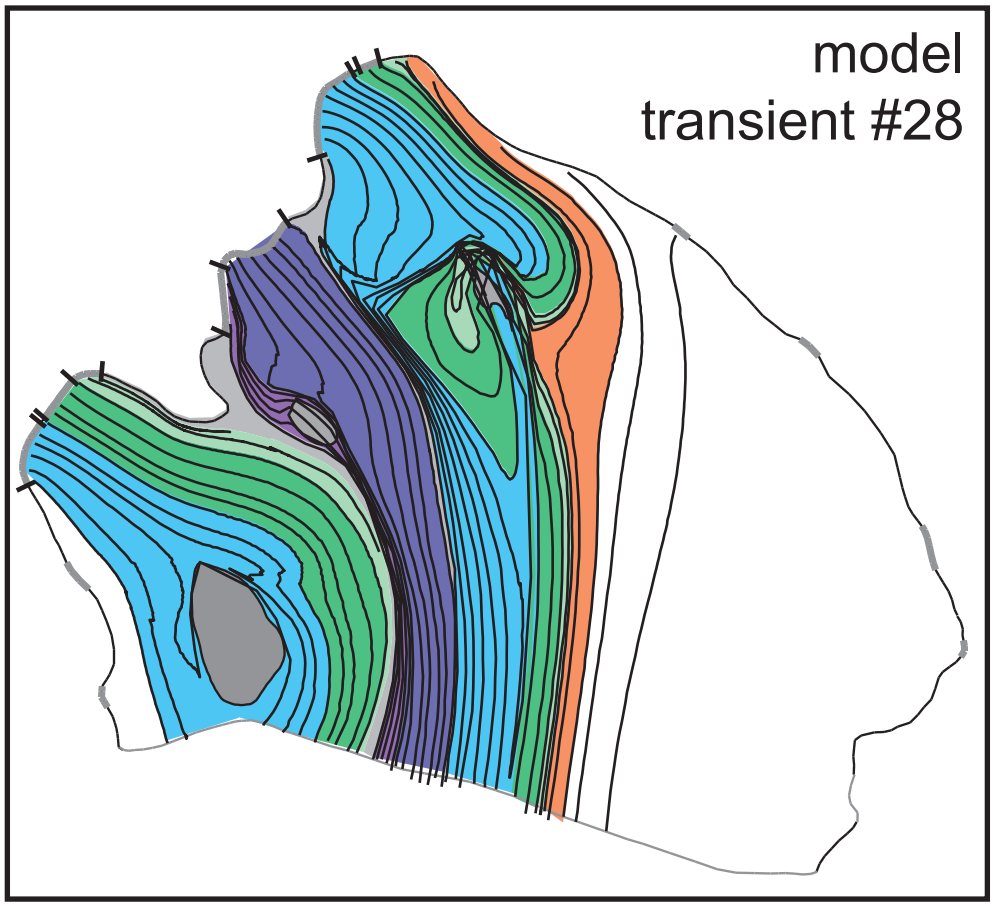
Kamb outlet 500 m/a
66% larger flux than standard

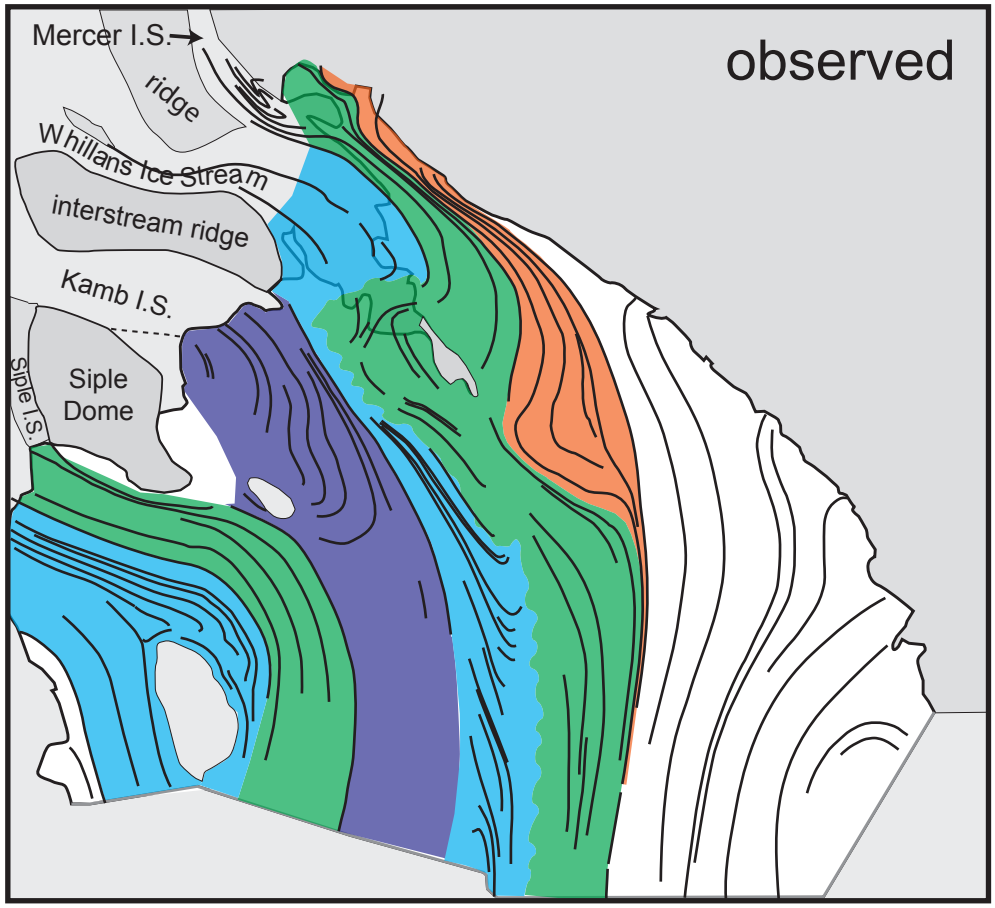




unavoidable conclusions

- ☆ streaklines can be simulated with relatively simple scenarios
  ice stream off/on cycles, *not surges, not ice rises alone*
- ☆ Whillans off/on cycle about 850 to 450 years ago
- ☆ MacAyeal off/on cycle about 800 to 650 years ago
- ☆ something's missing: TAM ice too important in current models



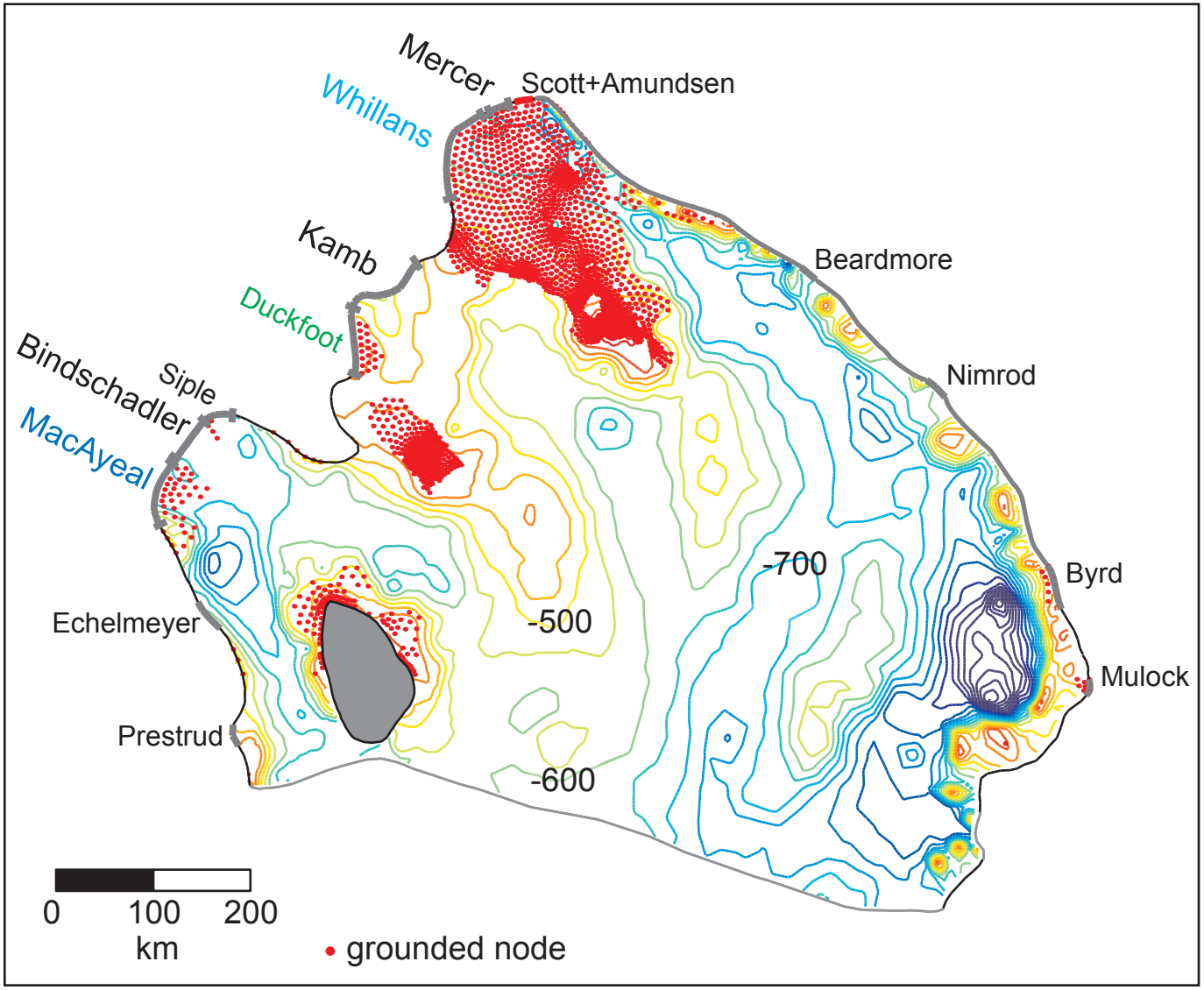


collateral information

- ☆ details about Duckfoot shutdown, did it slow then stop?
- ☆ grounding line migrates rapidly across ice plain
  advance & retreat
- ☆ grounding line position depends in part on interaction among outlets
- ☆ thickness away from grounding line has limited use for retrodiction

benchmark model (transient #20) end of model run

grounded ice & BEDMAP bed elevation ci = 50 m



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* shear margins soften over 200 years

benchmark transient model (#20) end of model run

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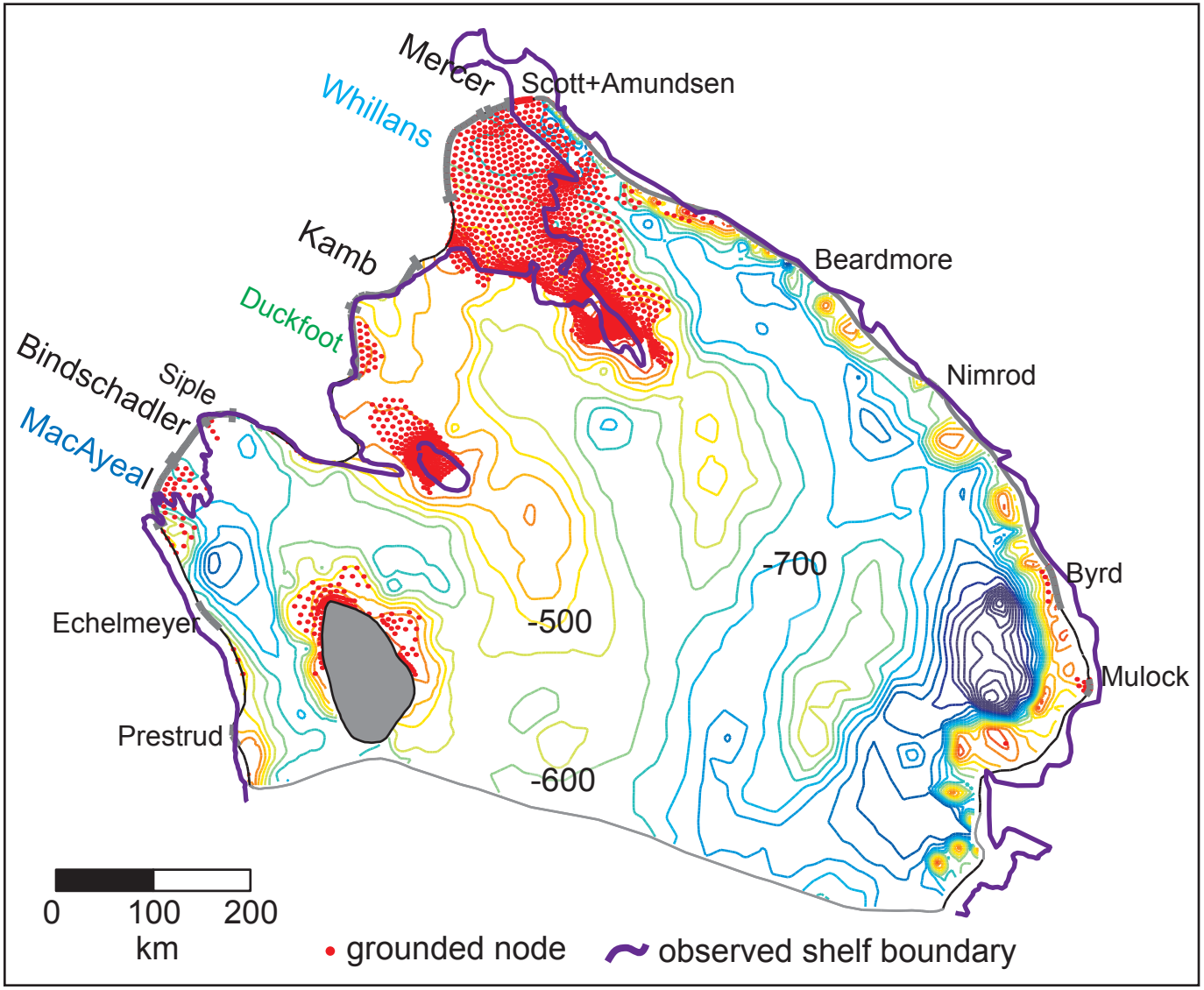

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mighty, mighty Kamb transient (#28) end of model run

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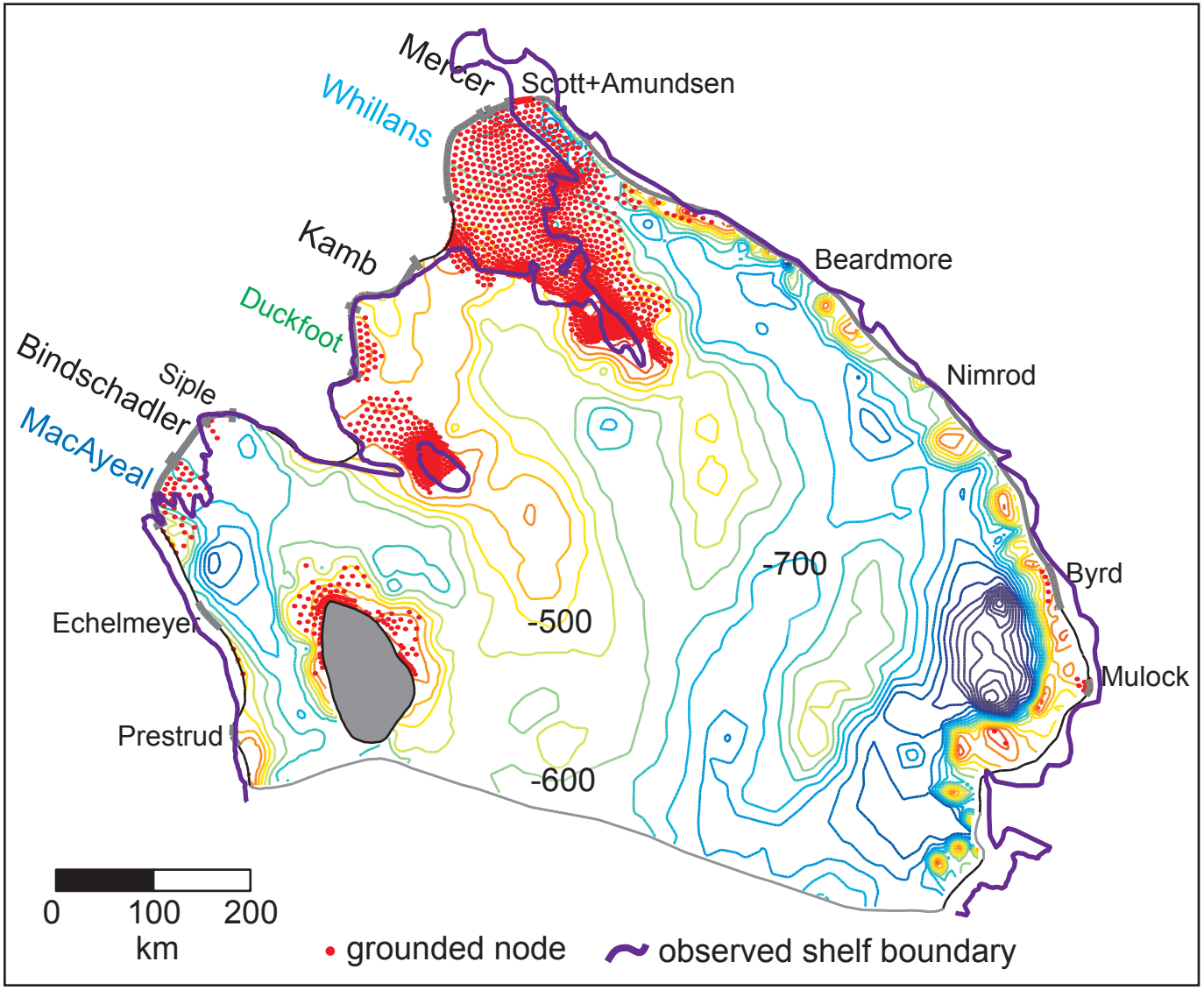

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Kamb outlet 500 m/a
67% larger flux than standard

model initialization: standard

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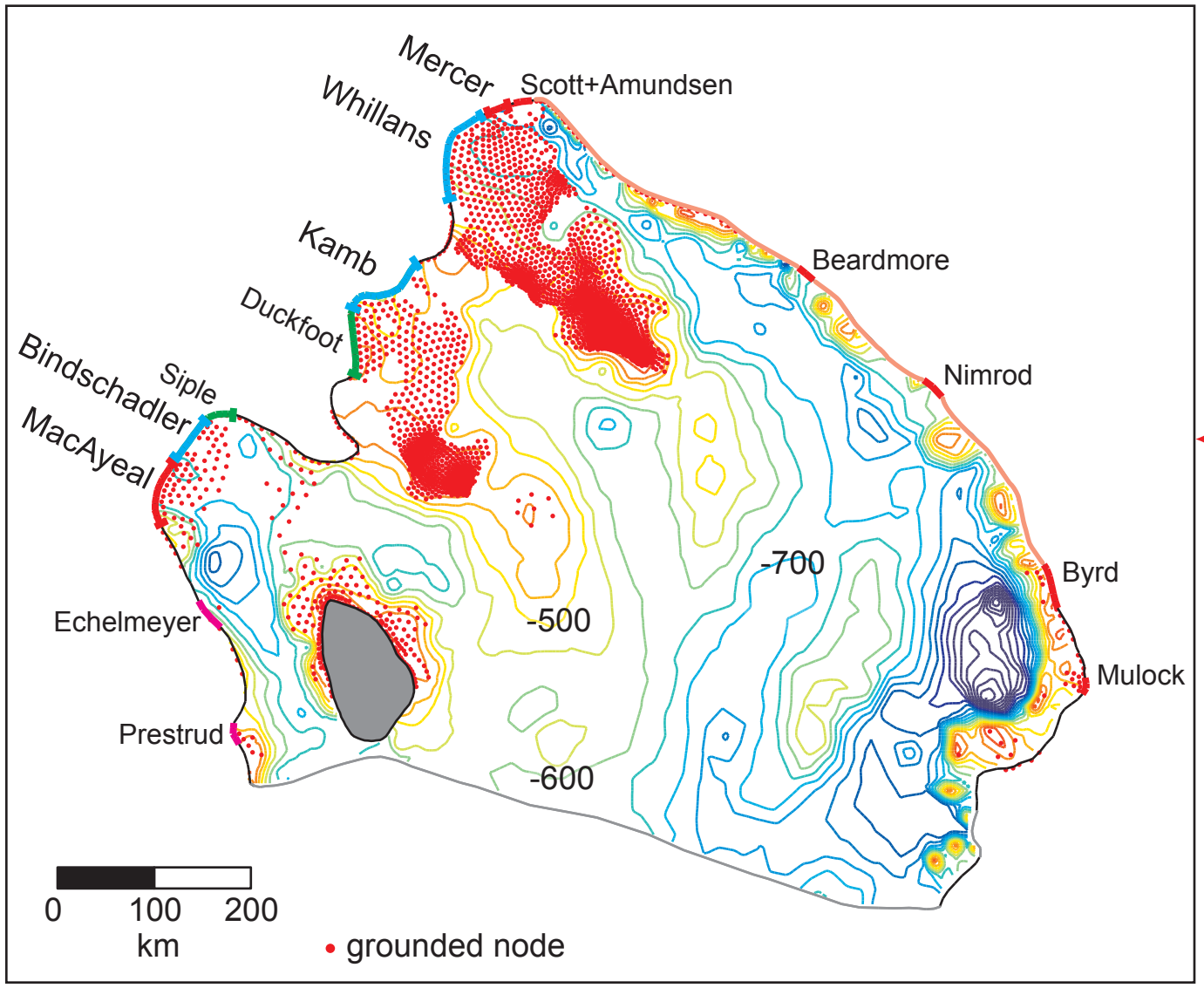

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model initialization: mighty, mighty Kamb

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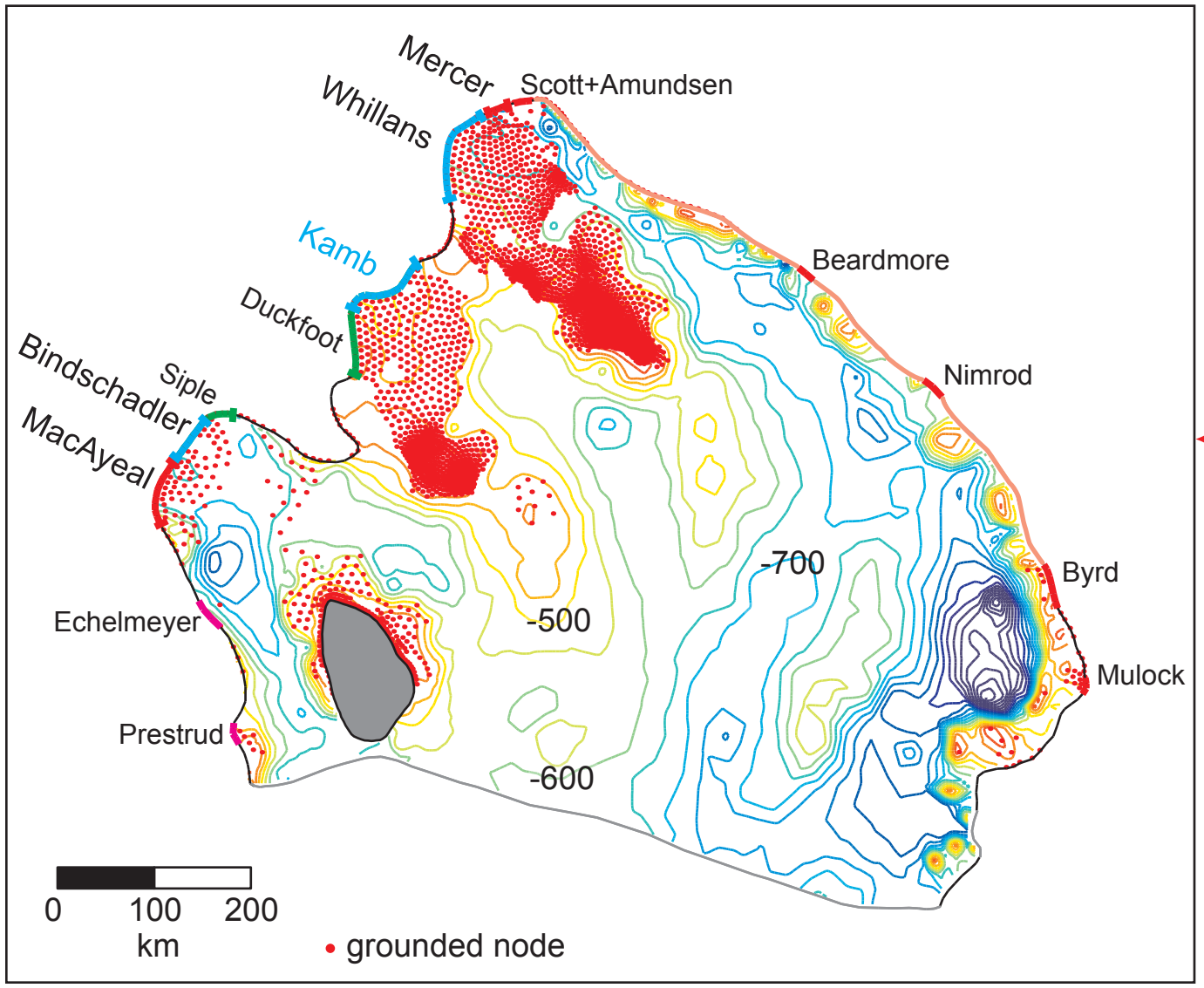

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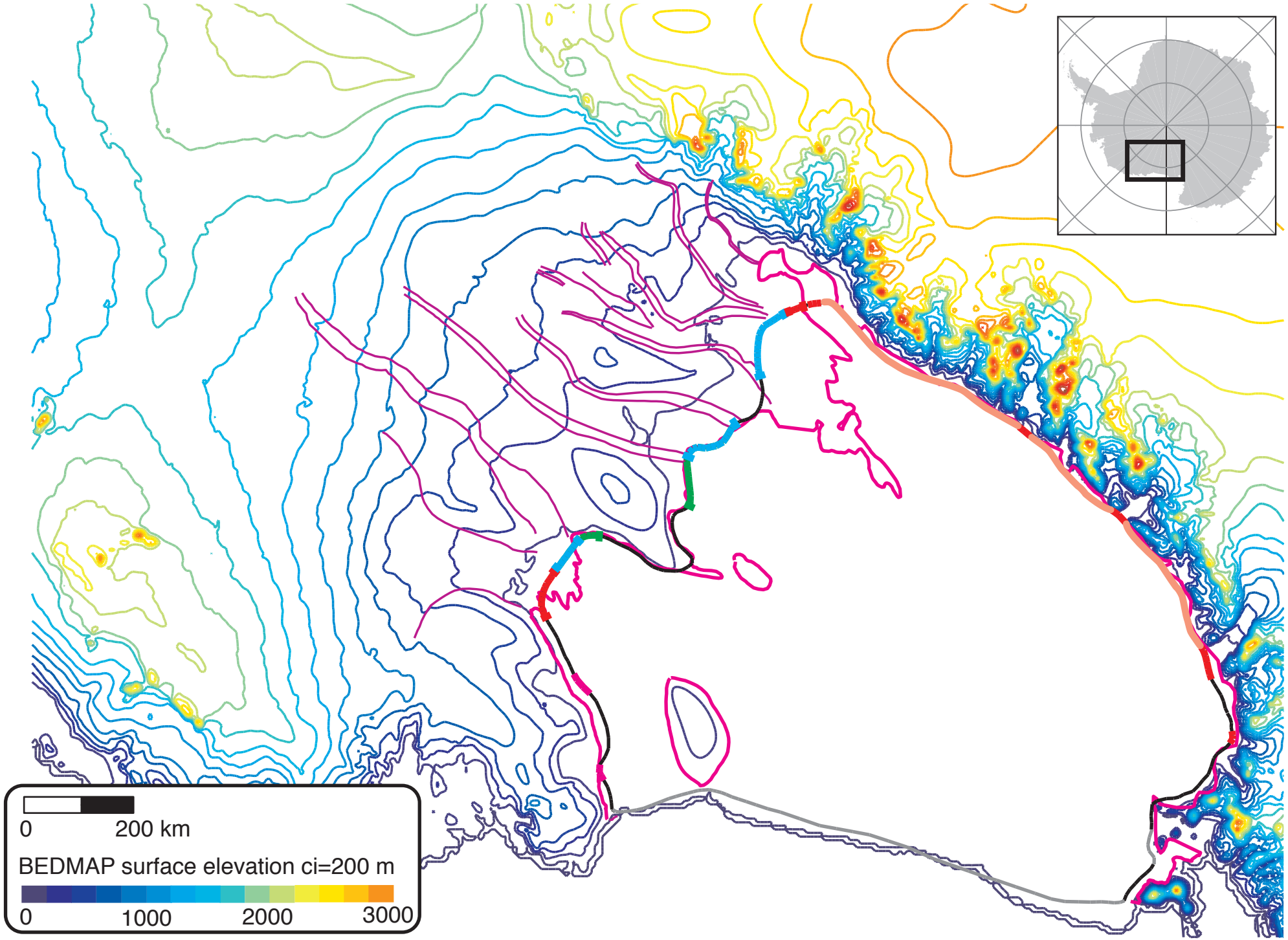
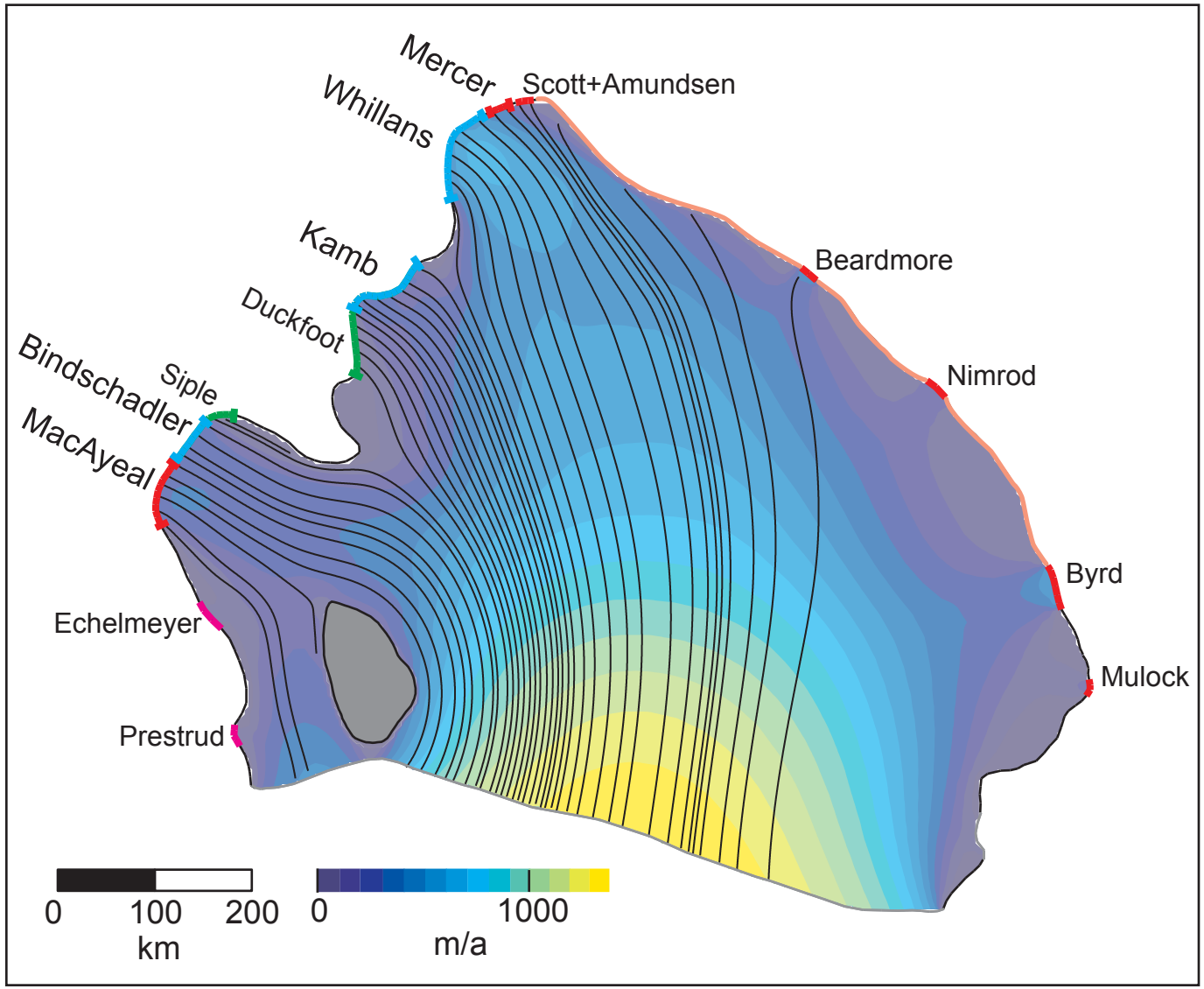
numerical model domain in Ross Sea embayment



transient experiments

standard inititalization
streamlines & ice speed ci = 100 m/a



- ☆ begin from one of several initializations
- ☆ 1600 year transient histories
  - ground ice rises
  - change boundary influxes
- ☆ streakline simulation
  - track ice parcels through changing velocity field
- ☆ compare with modern at end
  - streaklines
  - provenance map
  - (thickness, grounding line)