Synthesized grounding line and ice shelf mask for Antarctica

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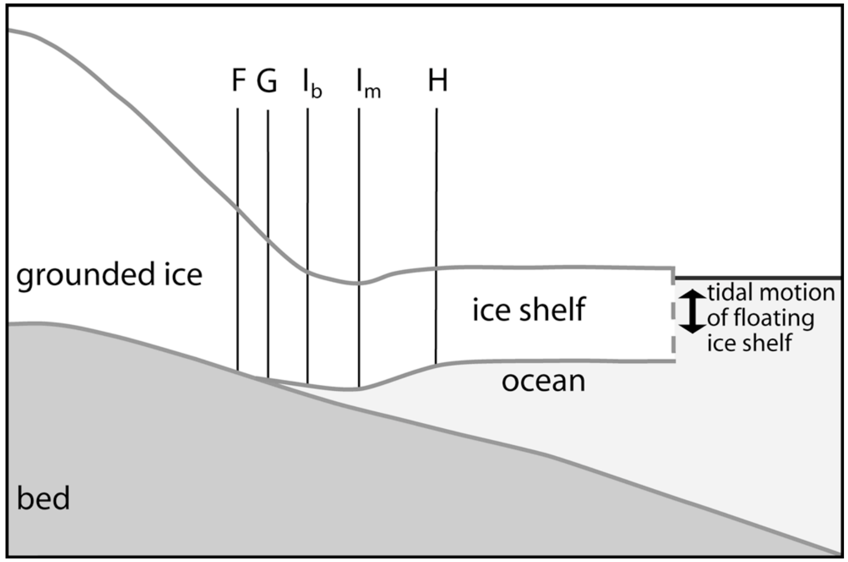
Background



- An accurate grounding line is essential for mass flux calculations and conversions from elevation changes to ice thickness changes
- Ice shelf mass budgets can be determined from satellite altimetry, but requires correction for buoyancy, tides and firn compaction
  - Tidal motion varies from zero (F) to free floating (H), and different techniques determine different points within the grounding zone (Fig. 2, Fricker et al. 2009)
  - Flexure limits (F and H) are most relevant for tidal corrections of altimetry data
  - H is not well known, but F and I_b (break in slope) has been extensively mapped

Existing grounding lines

- MOA, from MODIS imagery (250 m) 2003-2004
  - Break in slope (I_b) image technique (Scambos et al. 2007)
  - The only 100% complete product (continent and islands)
- ASAID, from Landsat image mosaic (15 m) 1999-2003
  - Break in slope (I_b), adjusted with ICESat (Bindschadler et al. 2011)
  - Consistent around the continent, but only 3 islands
- InSAR grounding lines (50 m) , 1994-2009
  - Multiple inner flexure lines (F) with dates (Rignot et al. 2011)
  - Incomplete coverage, large time span
- ICESat grounding points, 2003-2008
  - Break in slope and flexure limits (I_b, F and H) along ICESat tracks
  - Sparse coverage (Fricker/Brunt et al. 2006-10)

Synthesized grounding line

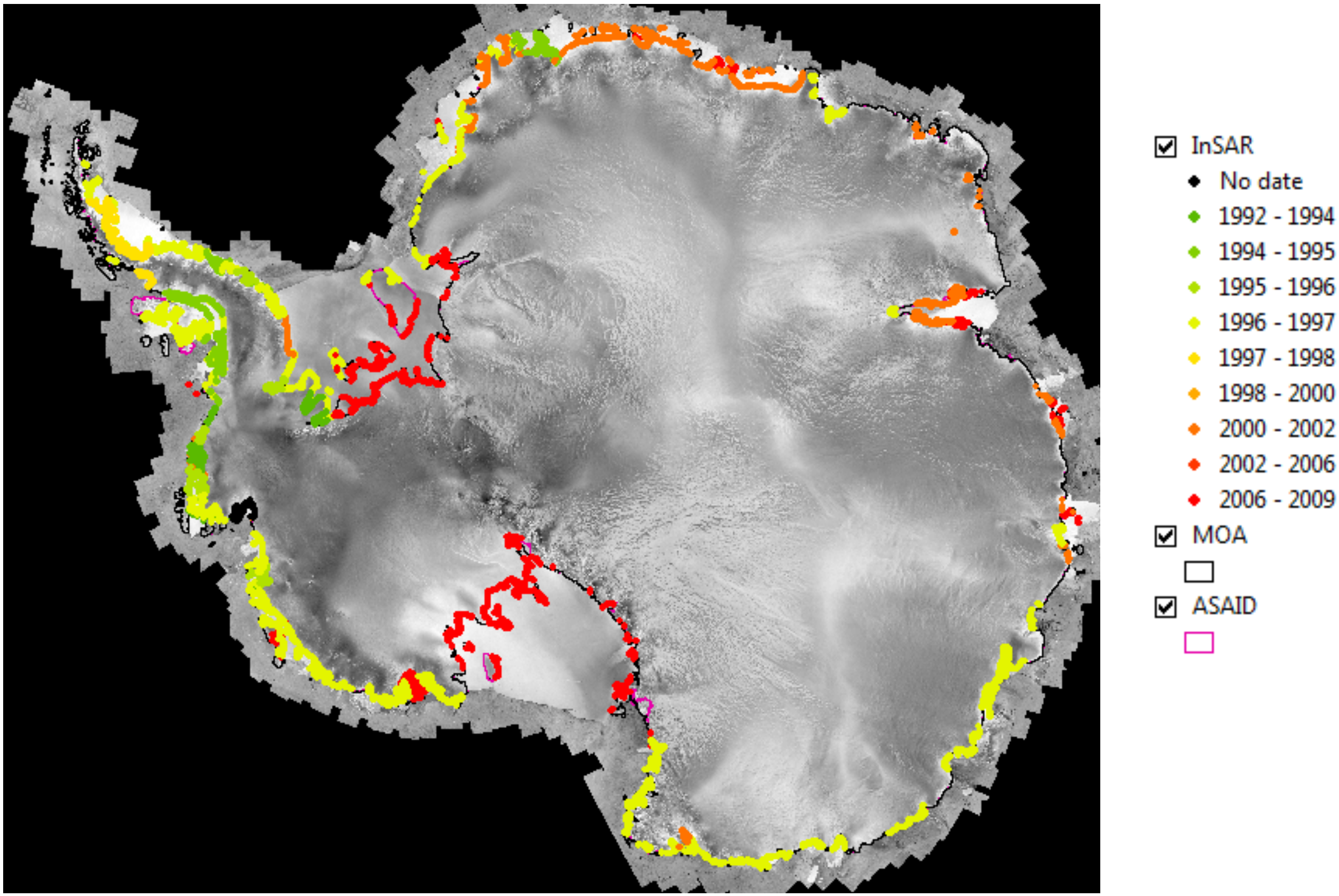
- Start with ASAID grounding line (I_b) as a vector file of polygons
- Add uncovered islands and ice rises from MOA
- Modify the polygons after 3 criteria:
  - Adjust polygons to fit with the newest available flexure data (F) from InSAR and ICESat whenever the deviation is more than 1 km
  - When multiple InSAR/ICESat data exist from the same time; choose the outermost grounding line (or the most continuous one)
  - Adjust polygons to MOA when ASAID deviates from land shoreline
- ICESat flexure points can only be used when the point density is sufficient or other features can be traced
- Visual check against image mosaics from MOA, RAMP and LIMA
- Additional data used for PIG, Thwaites, Smith and Amery

GIS processing

- ASAID, 1.5 Gb of points, needs to be simplified
  - select 1 of 10 points and generate polygons
  - smooth (PAEK 500 m) and simplify (50 m) -> 3.3 Mb
- Merge with MOA islands (not covered in ASAID)
- Intersect with vector grid of 5 deg lat and 10 deg long to decrease polygon sizes (=> faster to edit)
- Adjust polygons (trace or manual) to the preferred grounding line

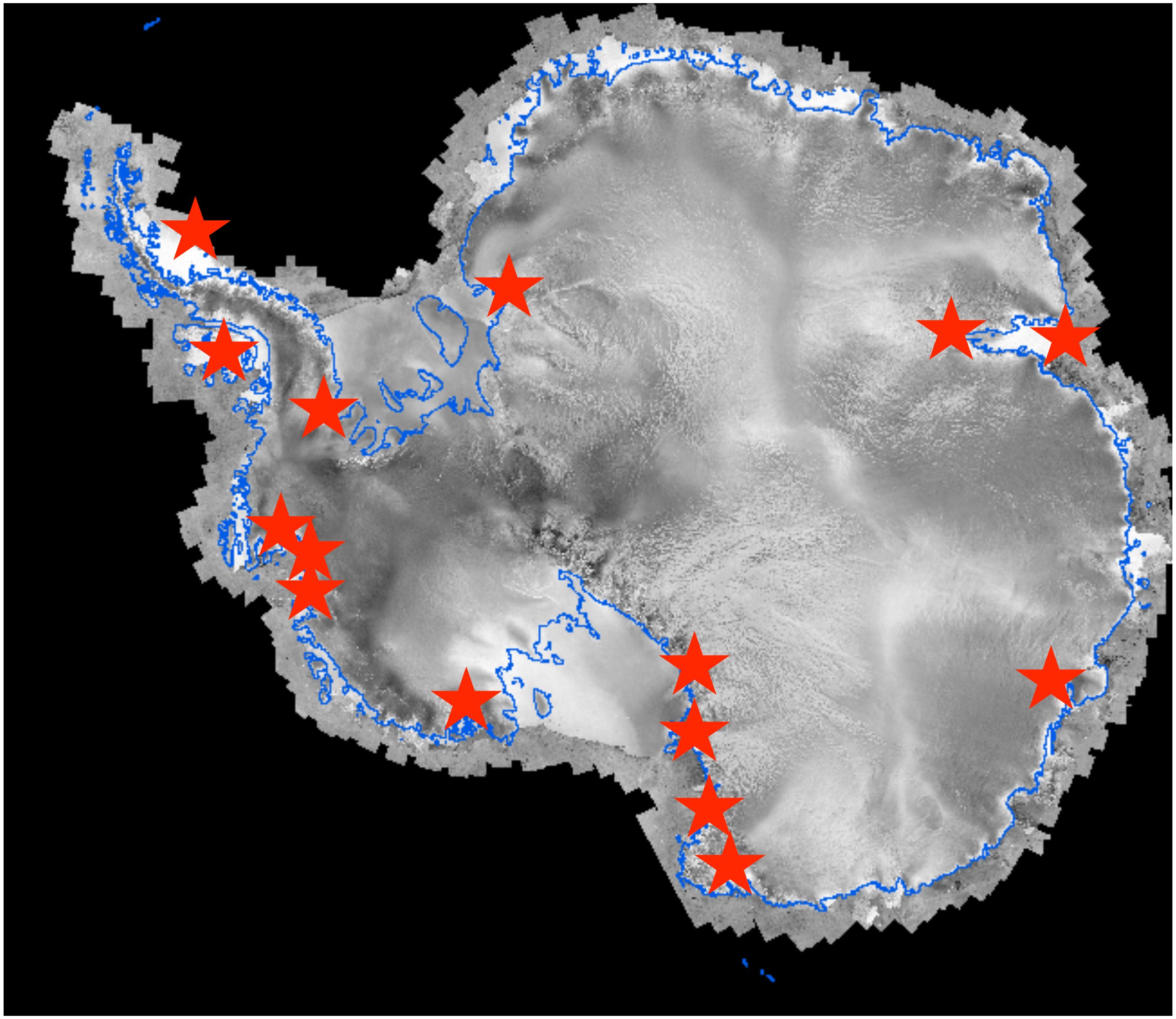
- After:
  - dissolve vector grid, smooth and simplify (10 m)
  - classify polygons: 1 = grounded ice or land, 2 = ice rises or connected islands, 3 = isolated islands, 4 = ice shelves
  - Rasterize to a 1 km^2 coded grid

InSAR coverage and dates



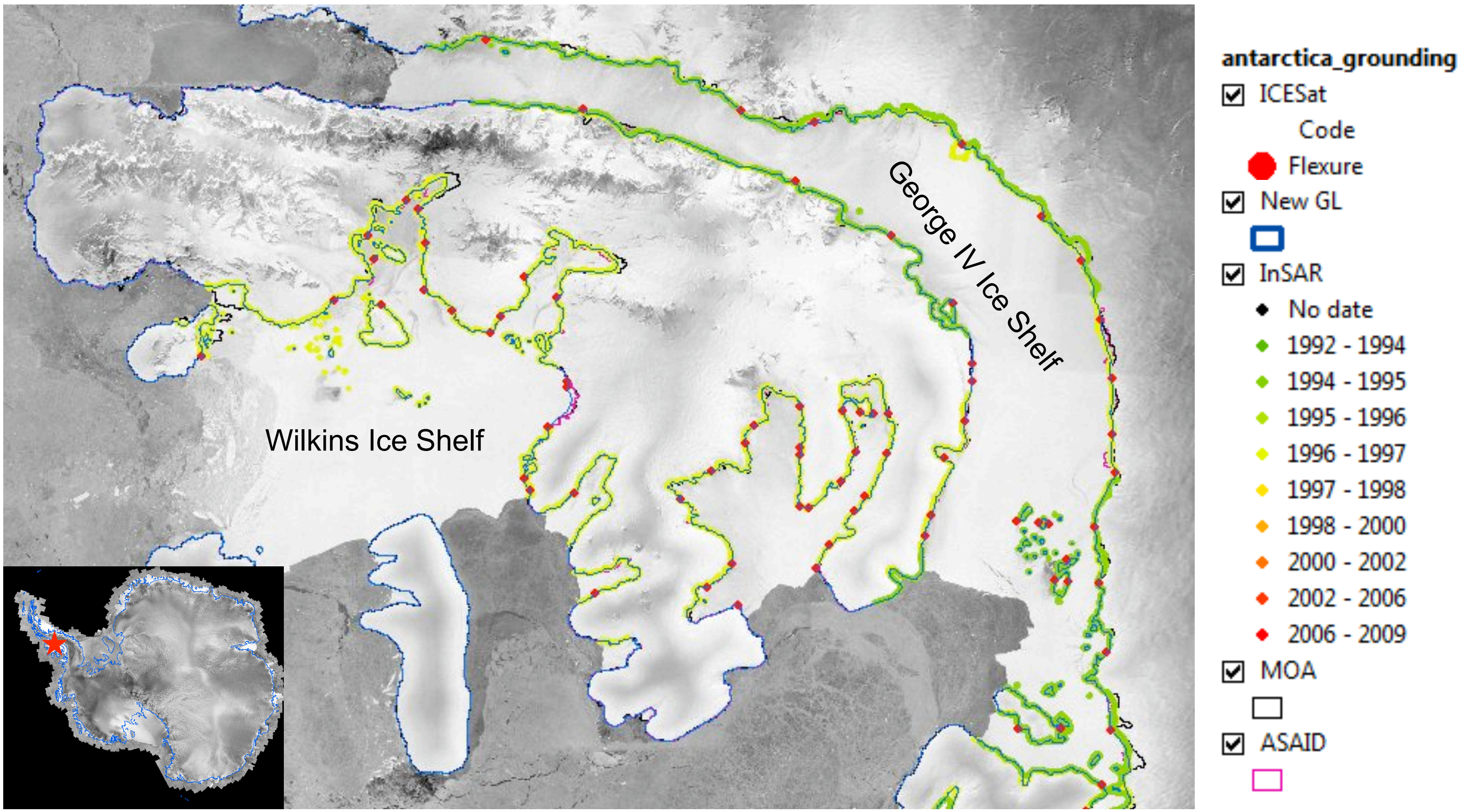
Coverage of InSAR grounding with color coded acquisition dates lines (Rignot et al. 2011).

Examples of difficult grounding lines



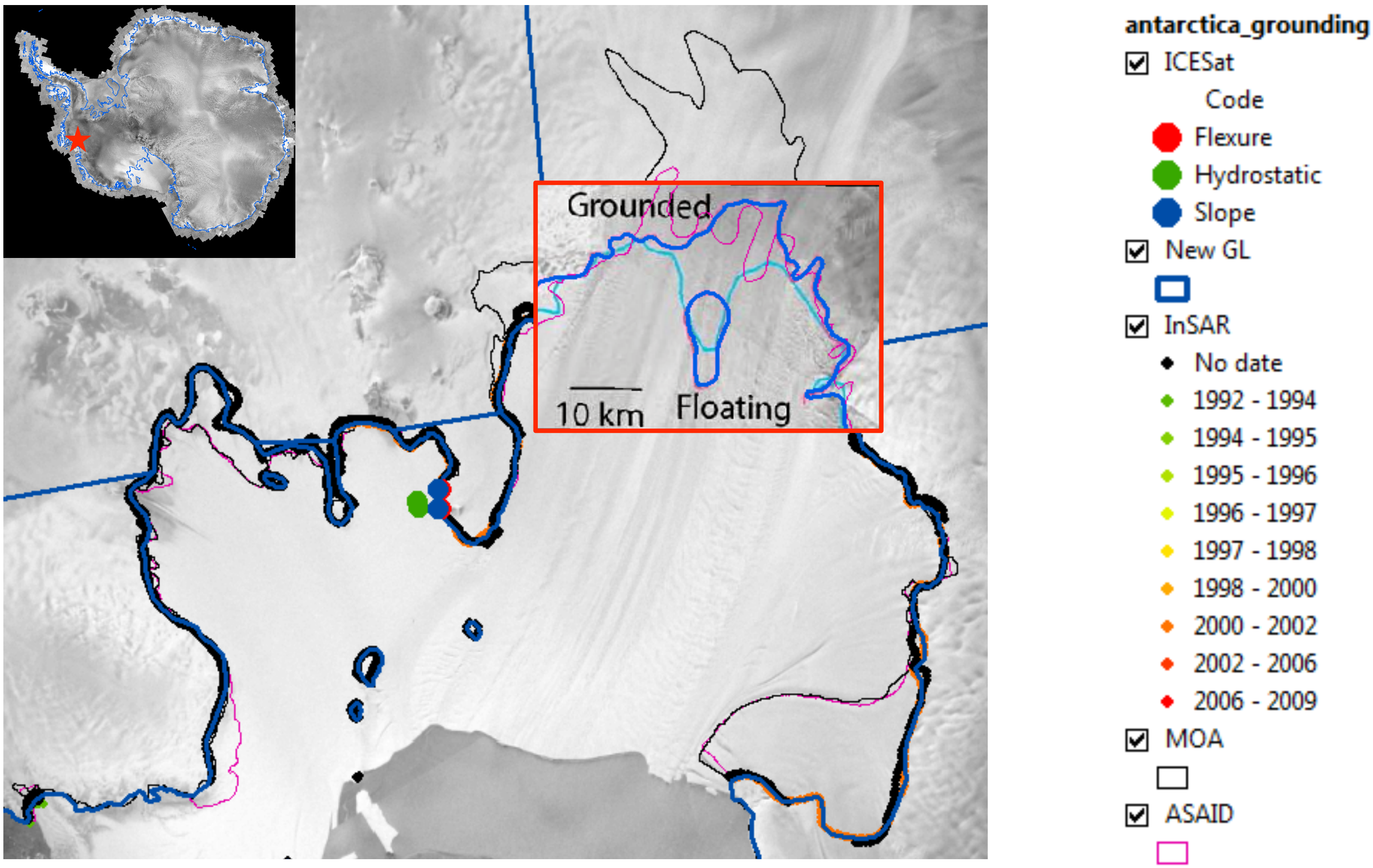
The synthesized grounding line shown on top of the RAMP mosaic (Jezek et al. 2002).
Stars show the location of example areas for the next slides (counterclockwise order).

Wilkins and George VI Ice Shelfs



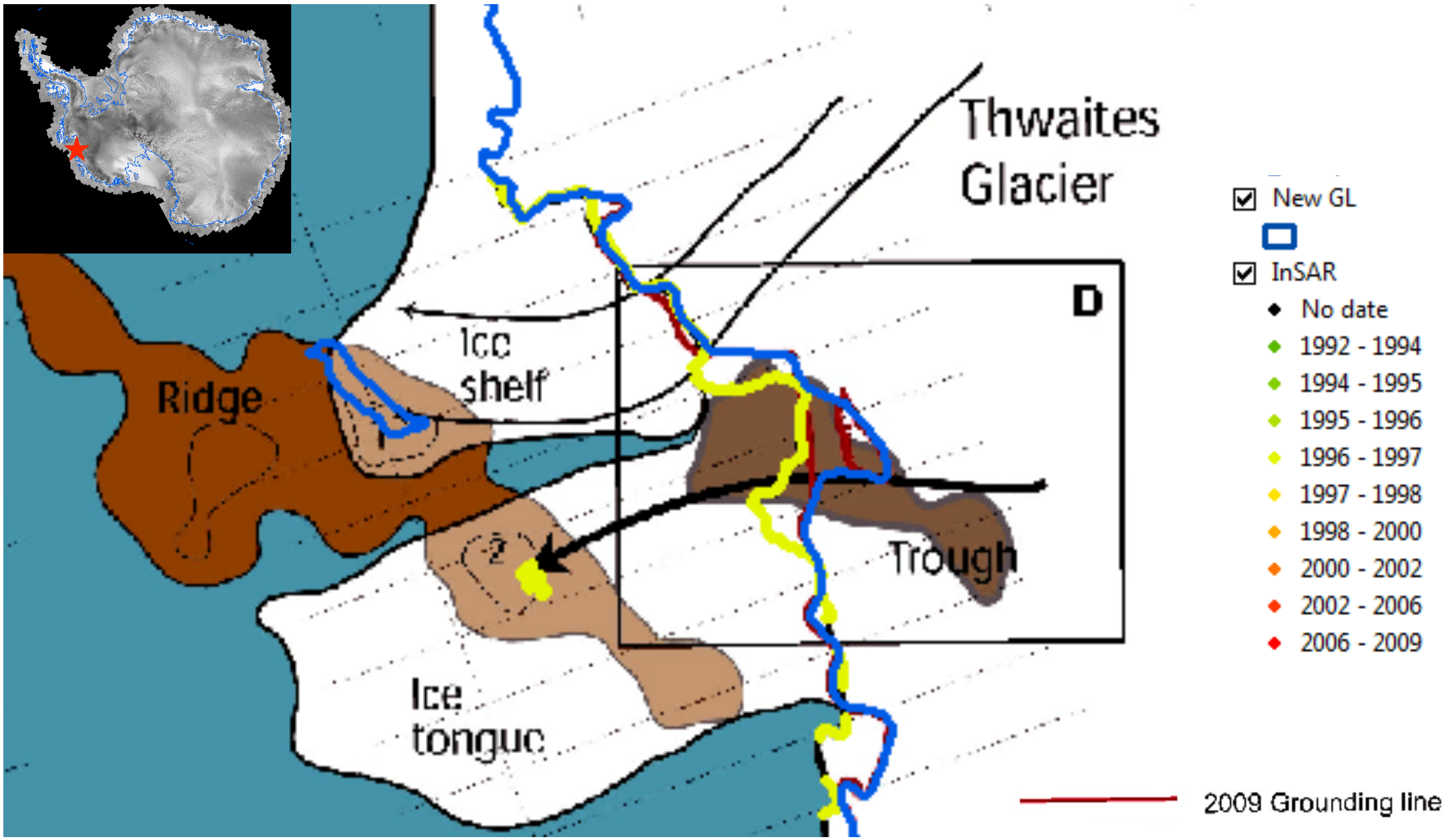
The grounding line mainly follows InSAR data from the 1990s which mostly agree with ASAID and MOA. Note all the tiny ice rises (in yellow) at Wilkins. Those smaller than ~1 km² were not included.

Pine Island Glacier



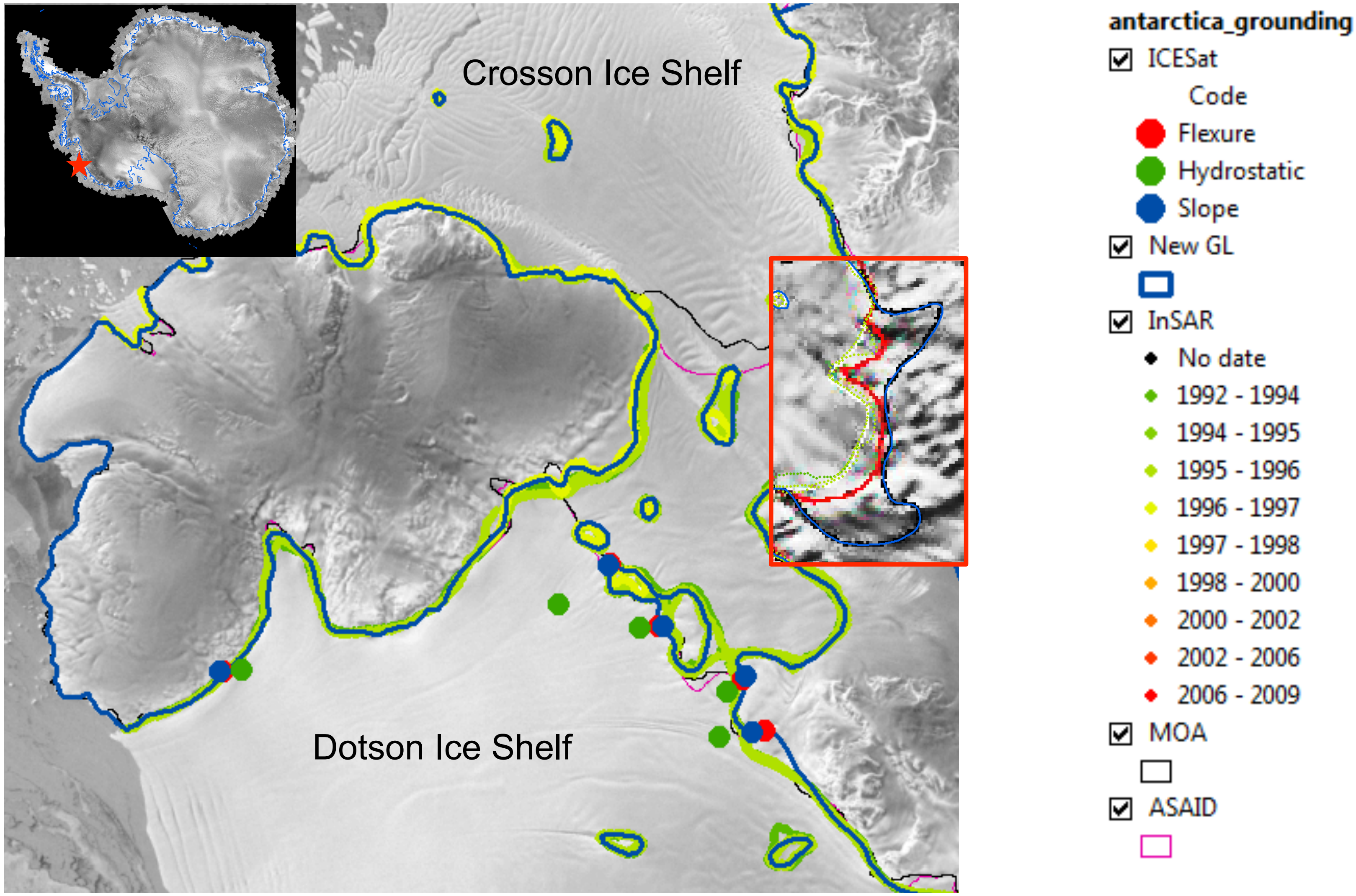
Large differences between MOA, ASAID and InSAR. The traced GL follows InSAR from year 2009 within the red box (Joughin et al. 2010) and unknown years elsewhere (Rignot et al. 2011). The straight blue lines are polygon subdivisions that get removed in the post-processing.

Thwaites Glacier



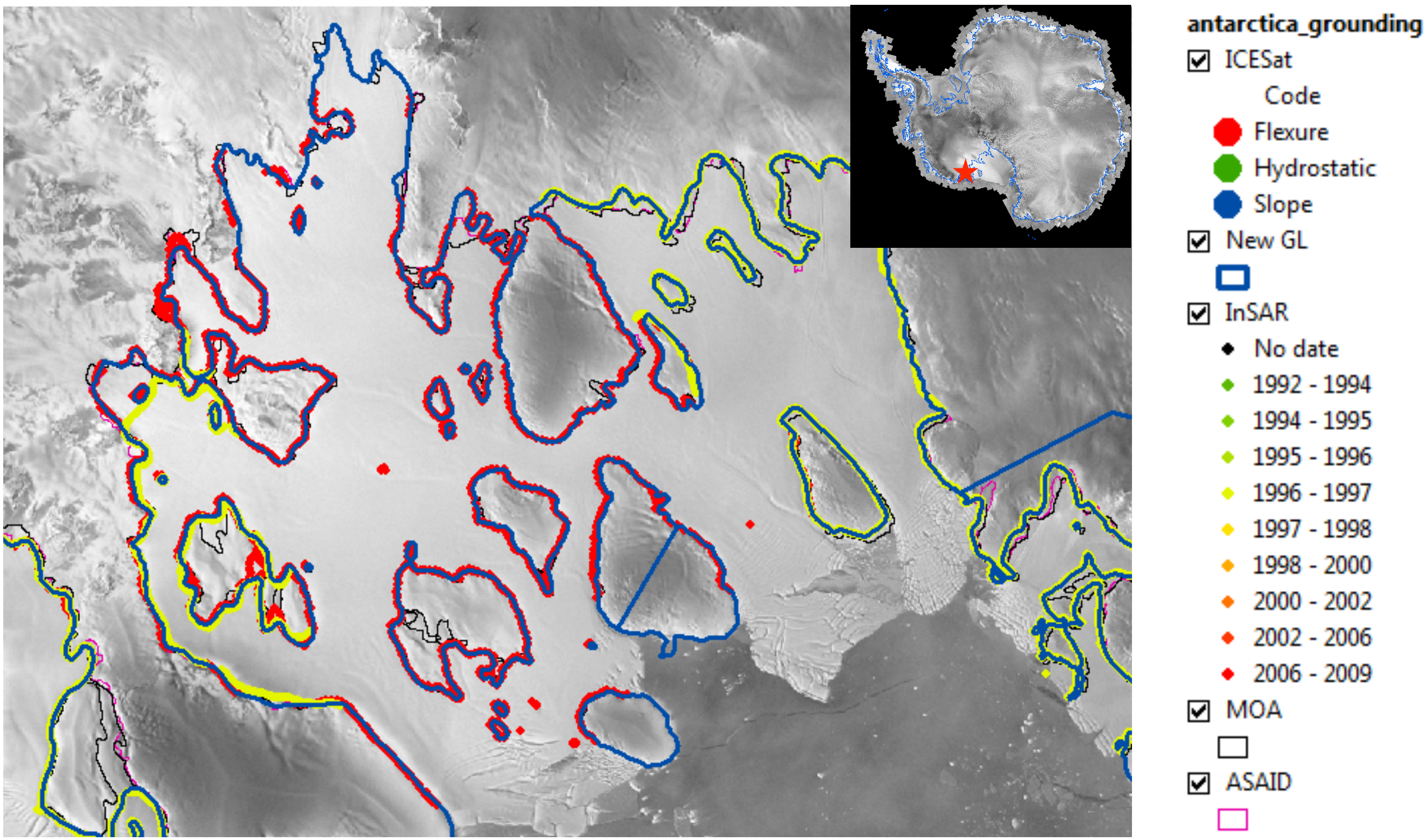
Thwaites has changed since the InSAR data from 1996, so the grounding line was adjusted to fit with a hydrostatic line from 2009 Icebridge data (Tinto et al. 2011). The ice rise at ridge 1 was added from 1992 InSAR data (Rignot et al. 2001). This ice rise is still grounded, while the smaller one at ridge 2 (yellow) has recently become ungrounded (Tinto et al. 2011).

Island or peninsula?



MOA/ASAID suggests a grounded peninsula, while multiple InSAR lines (1992-1996) indicate that the two ice shelves are connected. Smith Glacier (red box) has changed recently and was adjusted to fit with MODIS data from 2007 (Rignot et al. 2008).

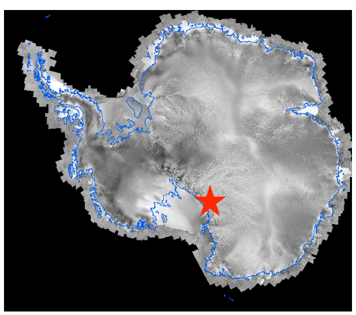
Ice rises and islands?

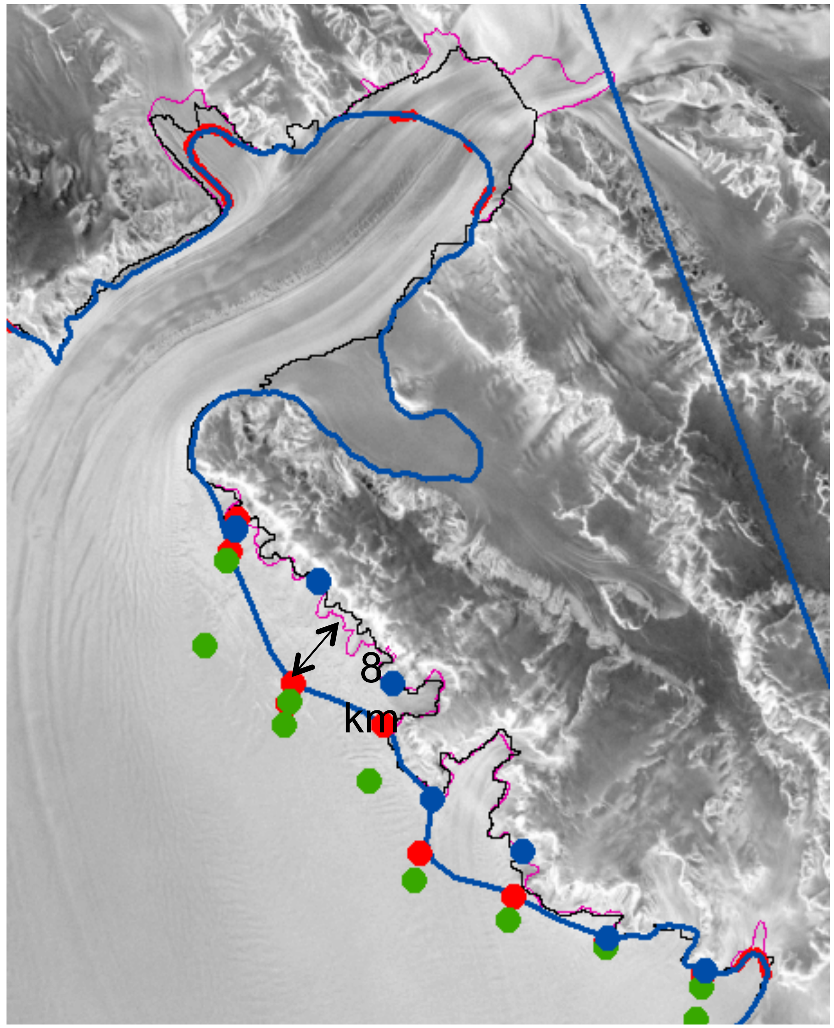


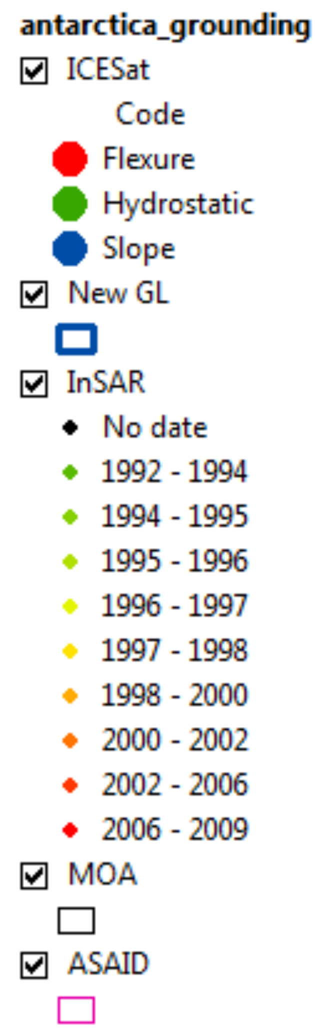
Some ice shelves have a lot of islands and ice rises and islands (here Sulzberger IS). All clearly defined features larger than ~1 km² were included.

Ross Ice Shelf

Little InSAR data over the outlets of the Transantarctic mountains, here Nimrod Glacier. InSAR lines and ASAID chosen as a best guess.

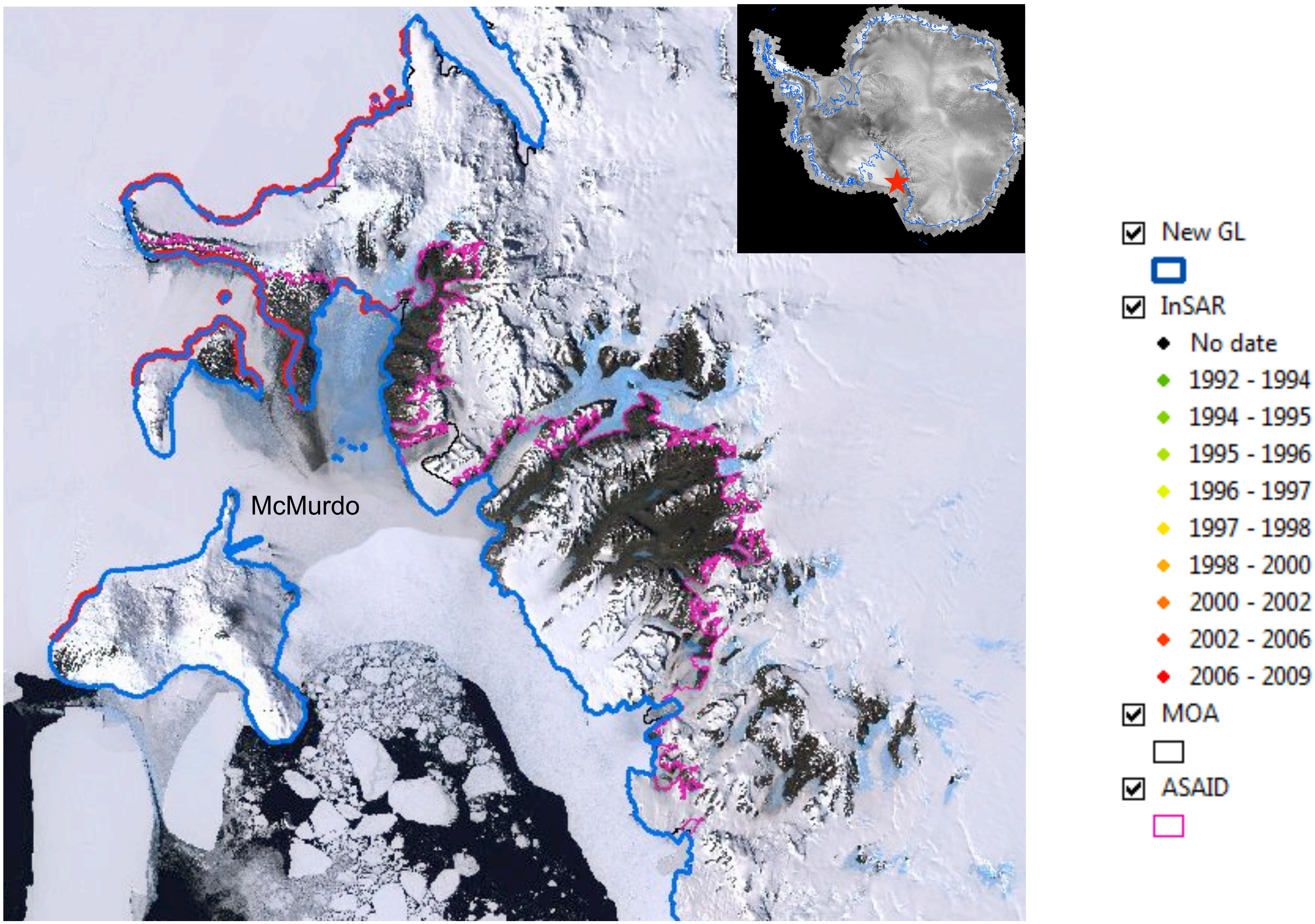






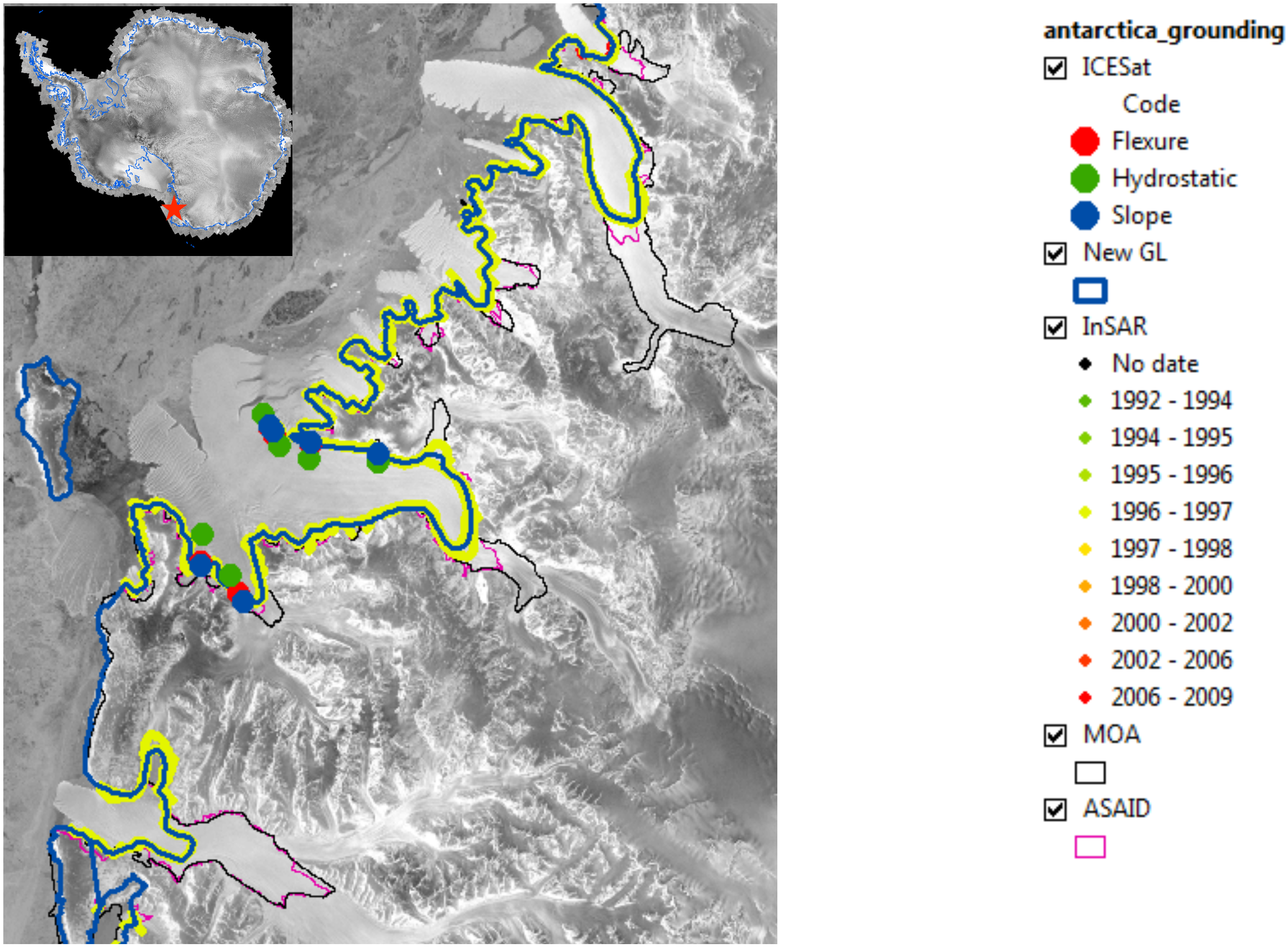
ICESat flexure points are often far "offshore" from MOA/ASAID on the east side of Ross, and there are few InSAR lines. Grounding lines were adjusted wherever the coverage of ICESat flexure points was considered sufficient (like in the example above).

Outlines around the Dry Valleys



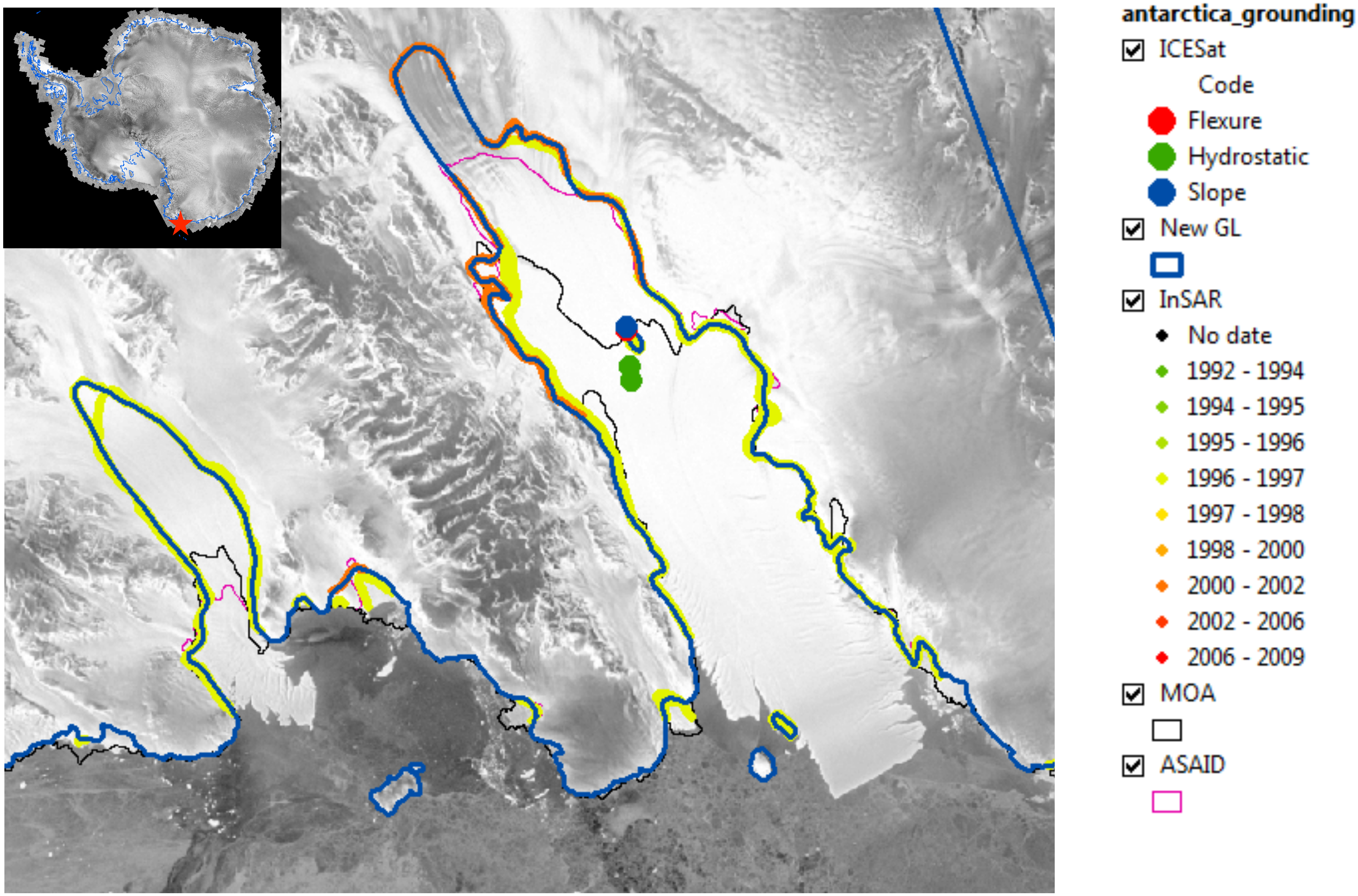
ASAID follows the ice boundary around the Dry Valleys. MOA's shoreline was used in this region.

Smaller ice shelf areas



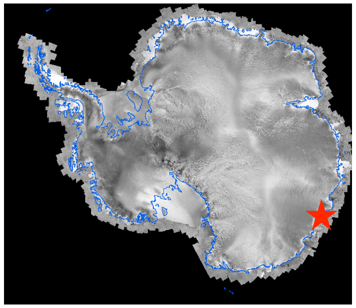
Typical example of decreased ice shelf area from InSAR (Borchgrevink and Aviator glaciers).

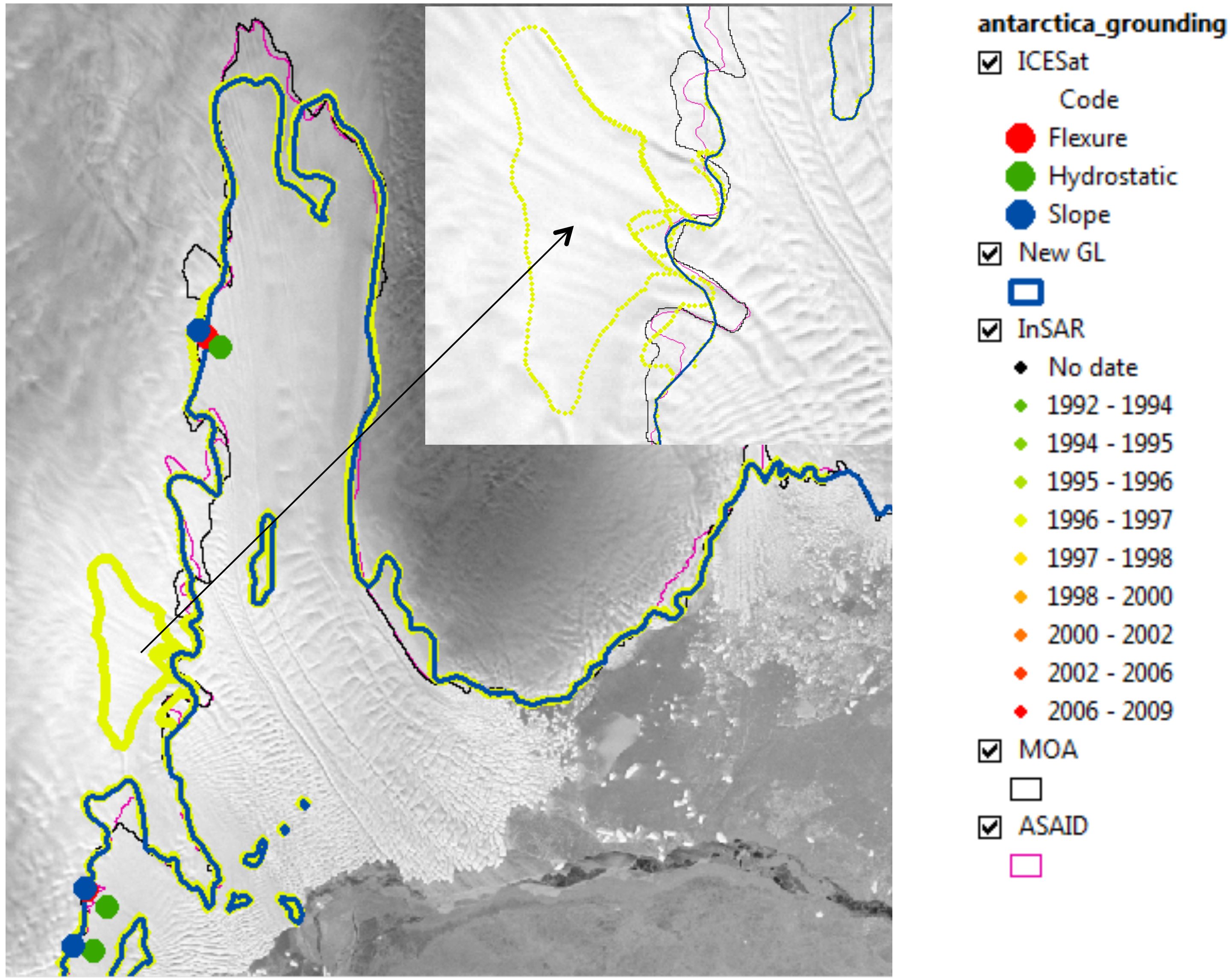
Larger ice shelf areas



Less typical example of increased ice shelf area from InSAR (Lille and Rennick glaciers).

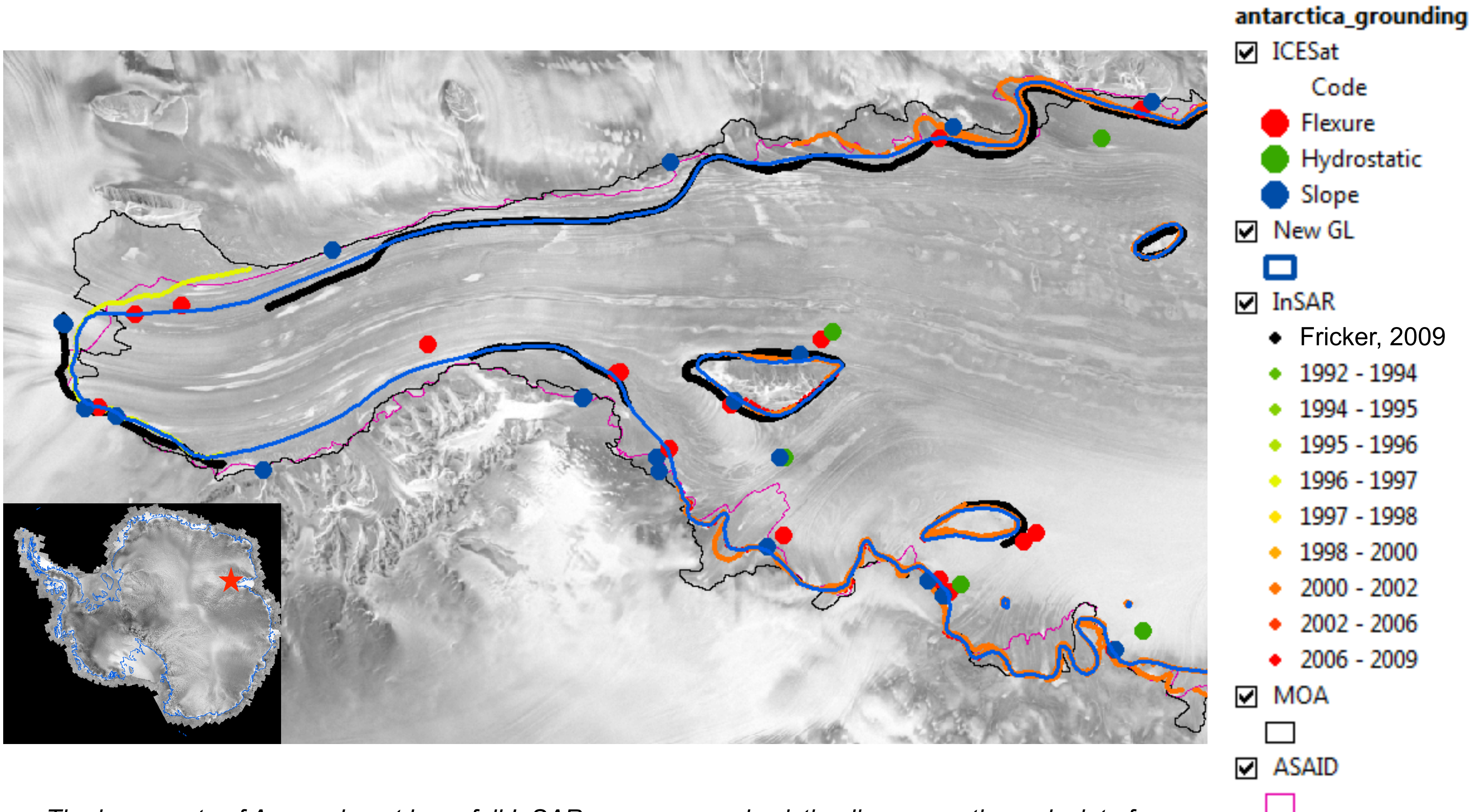
Multiple InSAR lines





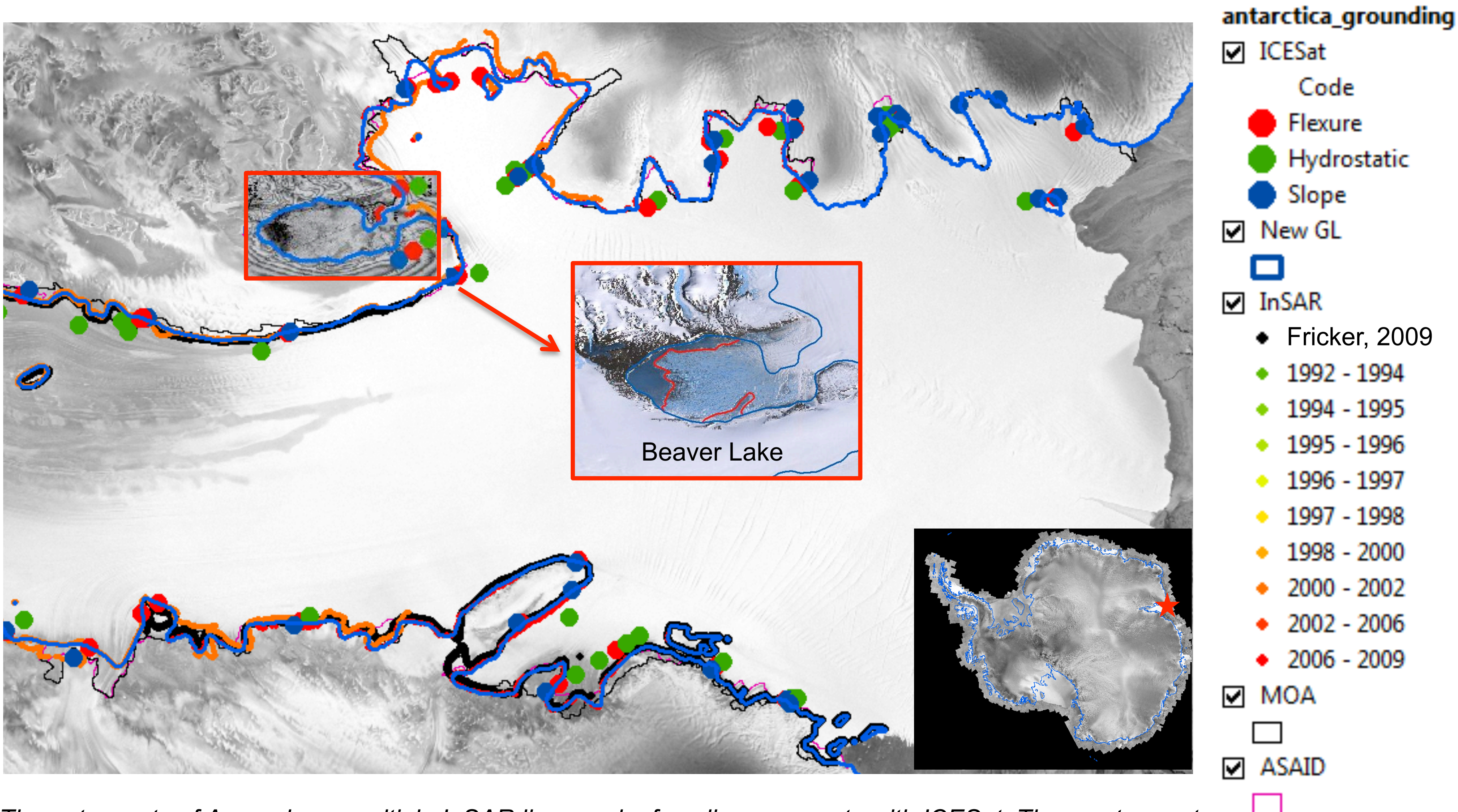
InSAR lines from the same year can be separated by up to 10 km, e.g. the sub-image from Totten Glacier.

Amery Ice Shelf



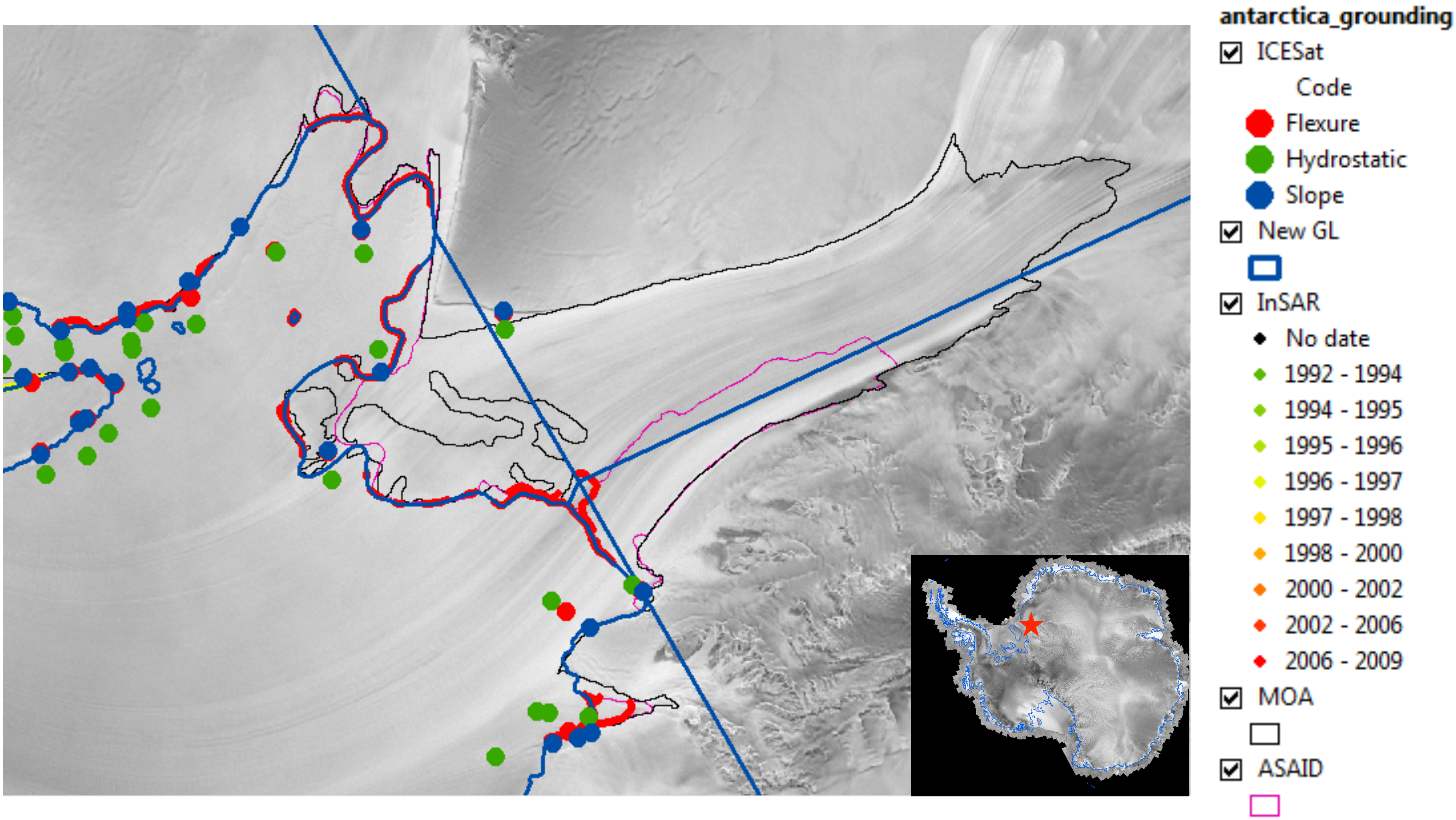
The inner parts of Amery do not have full InSAR coverage, and existing lines sometimes deviate from each other and from ICESat flexure points. A compromised line based on InSAR and ICESat was chosen.

Amery Ice Shelf



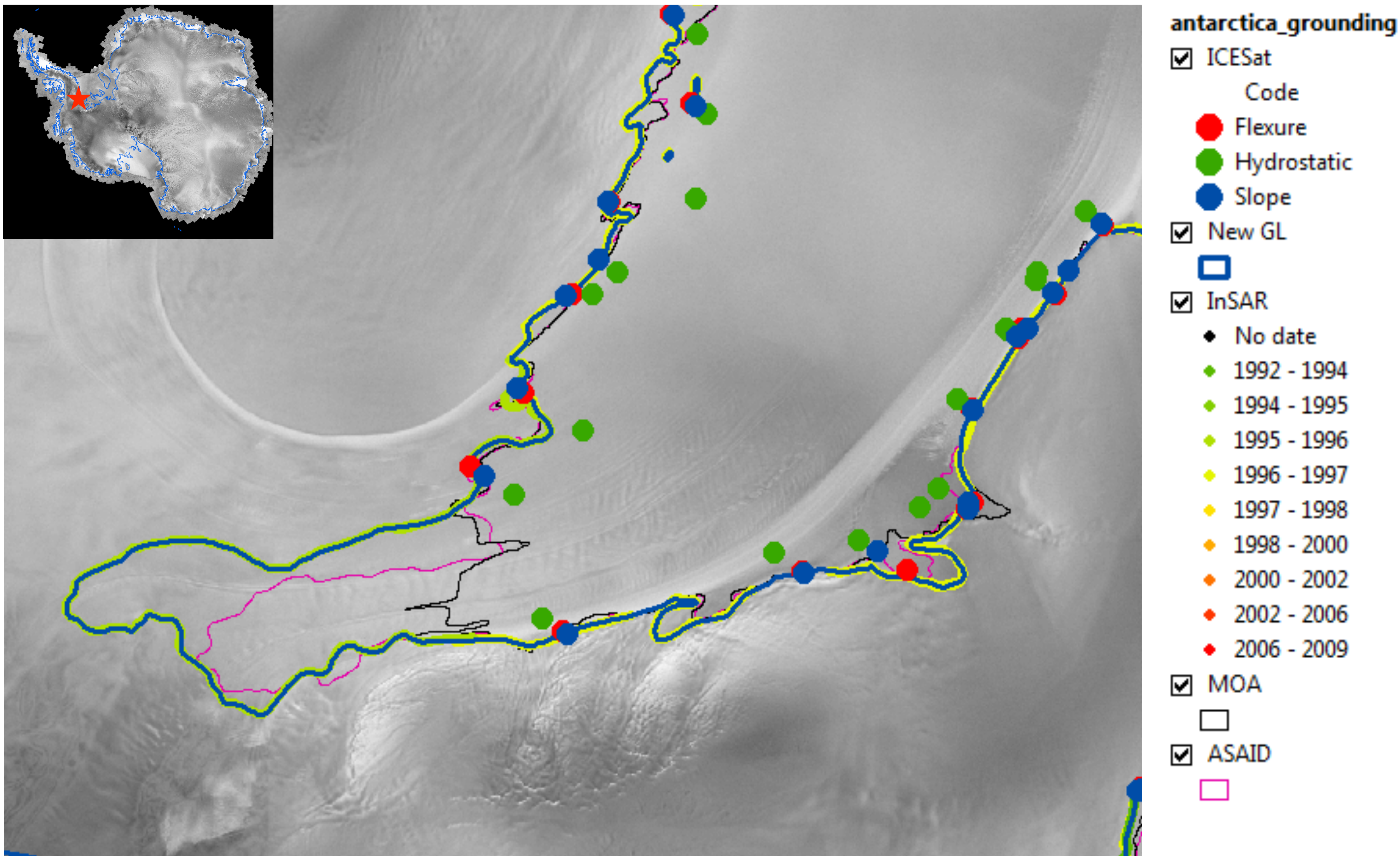
The outer parts of Amery have multiple InSAR lines and a few disagreements with ICESat. The most recent InSAR data were given highest priority. The bay in the red box is an epishelf lake, Beaver Lake, that exhibit tidal fluctuations and was included according to InSAR data from 1996 (Galton-Fenzi et al. 2012). The enlarged box shows the extent of the lake and its ice shelf on top of LIMA (Bindschadler et al. 2008).

Filchner-Ronne Ice Shelf



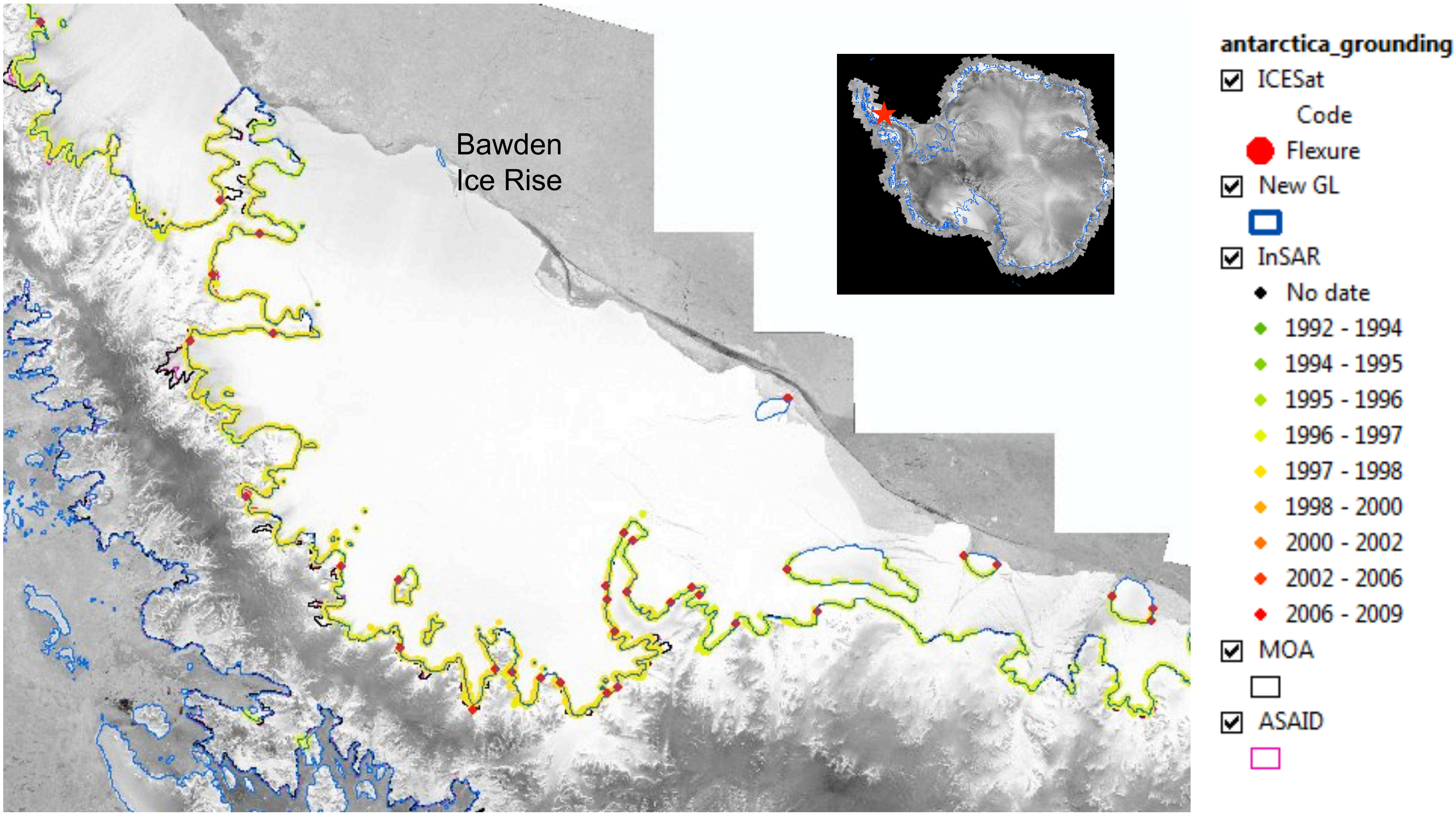
Bayley and Slessor ice streams (left to right). The grounding line is mainly based on new InSAR data. ICESat indicates a more complex pattern. The sensitivity to tides is probably high for both ice streams.

Filchner-Ronne Ice Shelf



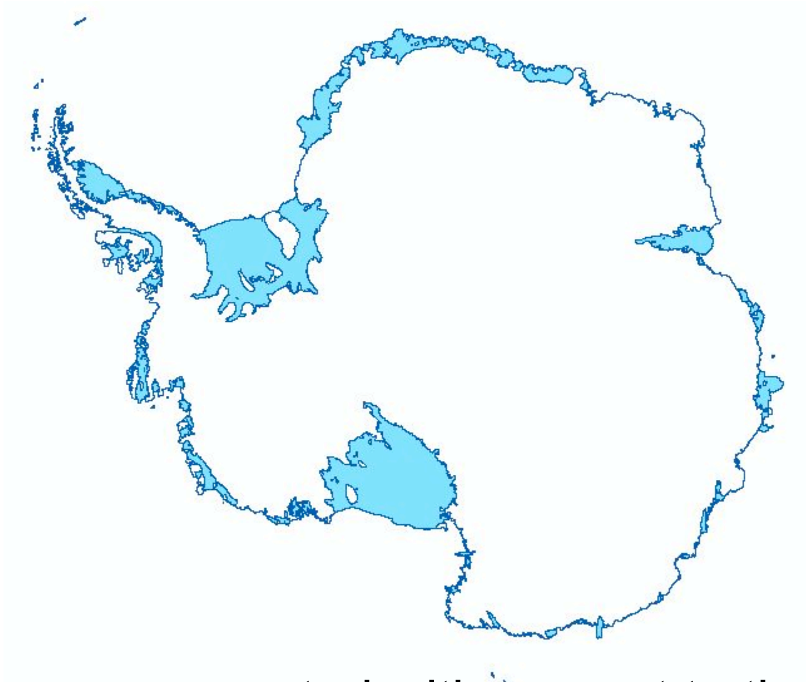
Evans Ice Stream. The 1994 InSAR line extends 80 km inland from MOA. Agrees with InSAR from Sykes et al. 2009.

Larsen C Ice Shelf



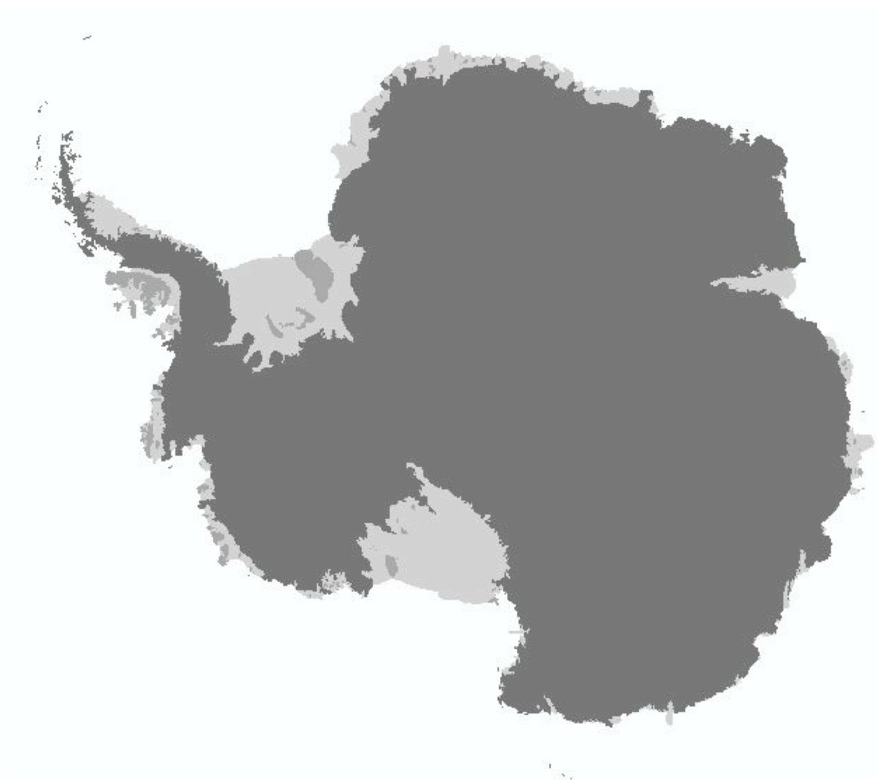
The grounding line over Larsen C mainly follows InSAR data from the 1990s which mostly agree with those from ASAID and MOA. Bawden Ice Rise was added according to Jansen et al. 2010.

Ice shelf outlines



- Ice shelf outlines were generated with respect to the MOA coastline:
  – Intersect the grounding polygons with the MOA 2004 coastline
  – Remove all polygons < 1 km2
  – Remove polygons that does not look like ice shelves in MOA, LIMA and RAMP (i.e. open ocean, land and random delineation differences)
- Result: 238 ice shelves with a total area of 1,554,800 km^2
  – A similar intersection between the MOA products gives 197 ice shelves and a 20,000 km^2 larger area. The area difference is mainly due to ice streams where the break-in-slope is inland from the tidal flexure limit of InSAR/ICESat

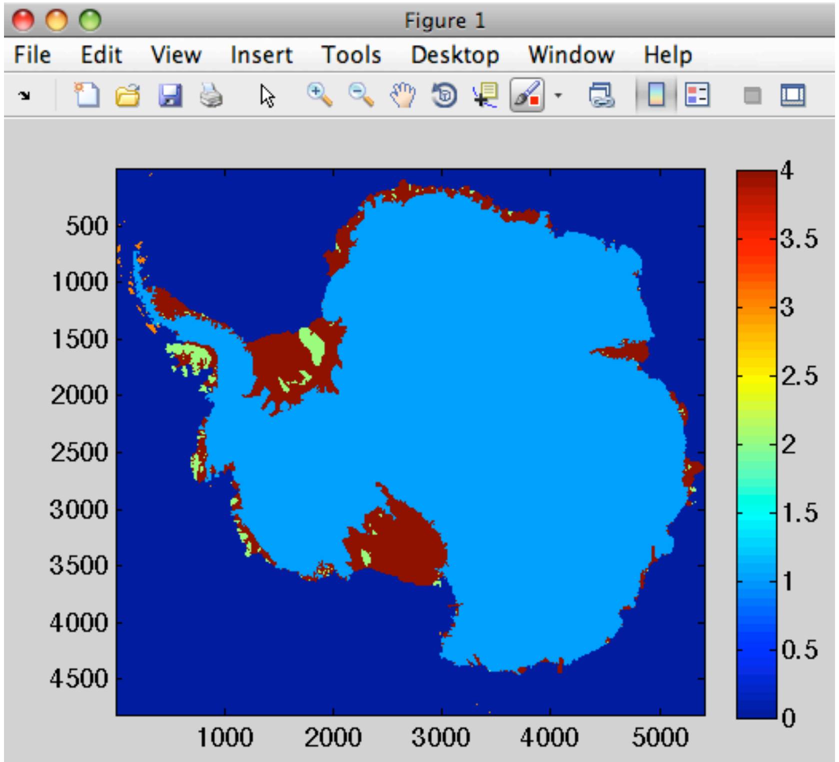
Final products



Vector shapefile with all polygons (7 Mb)

Classified polygons:
1 = grounded ice or land, 2 = ice rises or connected islands, 3 = isolated islands, 4 = ice shelves

Also a lat/long gridded version with smaller polygons



Raster mask in GEOTIF format (400 Kb)

1 km cells with surface codes:
0 = open ocean, 1 = grounded ice or land, 2 = ice rises or connected islands, 3 = isolated islands, 4 = ice shelves

Matlab plot:
imagesc(geotiffread('scripps_antarctica_mask1km_v1.tif'));

References

Bindschadler, R., P. Vornberger, A. Fleming, A. Fox, J. Mullins, D. Binnie, S. J. Paulsen, B. Granneman, and D. Gorodetzky (2008), The Landsat Image Mosaic of Antarctica, *Remote Sensing of Environment*, *112*(12), 4214-4226.

Bindschadler, R., et al. (2011), Getting around Antarctica: new high-resolution mappings of the grounded and freely-floating boundaries of the Antarctic ice sheet created for the International Polar Year, *Cryosphere*, *5*(3), 569-588.

Brunt, K. M., H. A. Fricker, L. Padman, T. A. Scambos, and S. O'Neel (2010), Mapping the grounding zone of the Ross Ice Shelf, Antarctica, using ICESat laser altimetry, *Annals of Glaciology*, *51*(55), 71-79.

Fricker, H. A., and L. Padman (2006), Ice shelf grounding zone structure from ICESat laser altimetry, *Geophysical Research Letters*, *33*(15).

Fricker, H. A., R. Coleman, L. Padman, T. A. Scambos, J. Bohlander, and K. M. Brunt (2009), Mapping the grounding zone of the Amery Ice Shelf, East Antarctica using InSAR, MODIS and ICESat, *Antarctic Science*, *21*(5), 515-532.

Galton-Fenzi, B. K., J. R. Hunter, R. Coleman, and N. Young (2012), A decade of change in the hydraulic connection between an Antarctic epishelf lake and the ocean *Journal of Glaciology*, *58* (208), 223-228.

Jansen, D., B. Kulessa, P. R. Sammonds, A. Luckman, E. C. King, and N. F. Glasser (2010), Present stability of the Larsen C ice shelf, Antarctic Peninsula, *Journal of Glaciology*, *56*(198), 593-600.

Jezek, K., and RAMP Product Team. 2002. *RAMP AMM-1 SAR Image Mosaic of Antarctica. Fairbanks, AK: Alaska SAR Facility, in association with the National Snow and Ice Data Center, Boulder, CO. Digital media.*

Joughin, I., B. E. Smith, and D. M. Holland (2010), Sensitivity of 21st century sea level to ocean-induced thinning of Pine Island Glacier, Antarctica, *Geophysical Research Letters*, *37*.

Rignot, E. (2001), Evidence for rapid retreat and mass loss of Thwaites Glacier, West Antarctica, *Journal of Glaciology*, *47*(157), 213-222.

Rignot, E., J. Mouginot, and B. Scheuchl (2011), Antarctic grounding line mapping from differential satellite radar interferometry, *Geophysical Research Letters*, *38*.

Scambos, T. A., T. M. Haran, M. A. Fahnestock, T. H. Painter, and J. Bohlander (2007), MODIS-based Mosaic of Antarctica (MOA) data sets: Continent-wide surface morphology and snow grain size, *Remote Sensing of Environment*, *111*(2-3), 242-257.

Sykes, H. J., T. Murray, and A. Luckman (2009), The location of the grounding zone of Evans Ice Stream, Antarctica, investigated using SAR interferometry and modelling, *Annals of Glaciology*, *50*(52), 35-40.

Tinto, K. J., and R. E. Bell (2011), Progressive unpinning of Thwaites Glacier from newly identified offshore ridge: Constraints from aerogravity, *Geophysical Research Letters*, *38*.