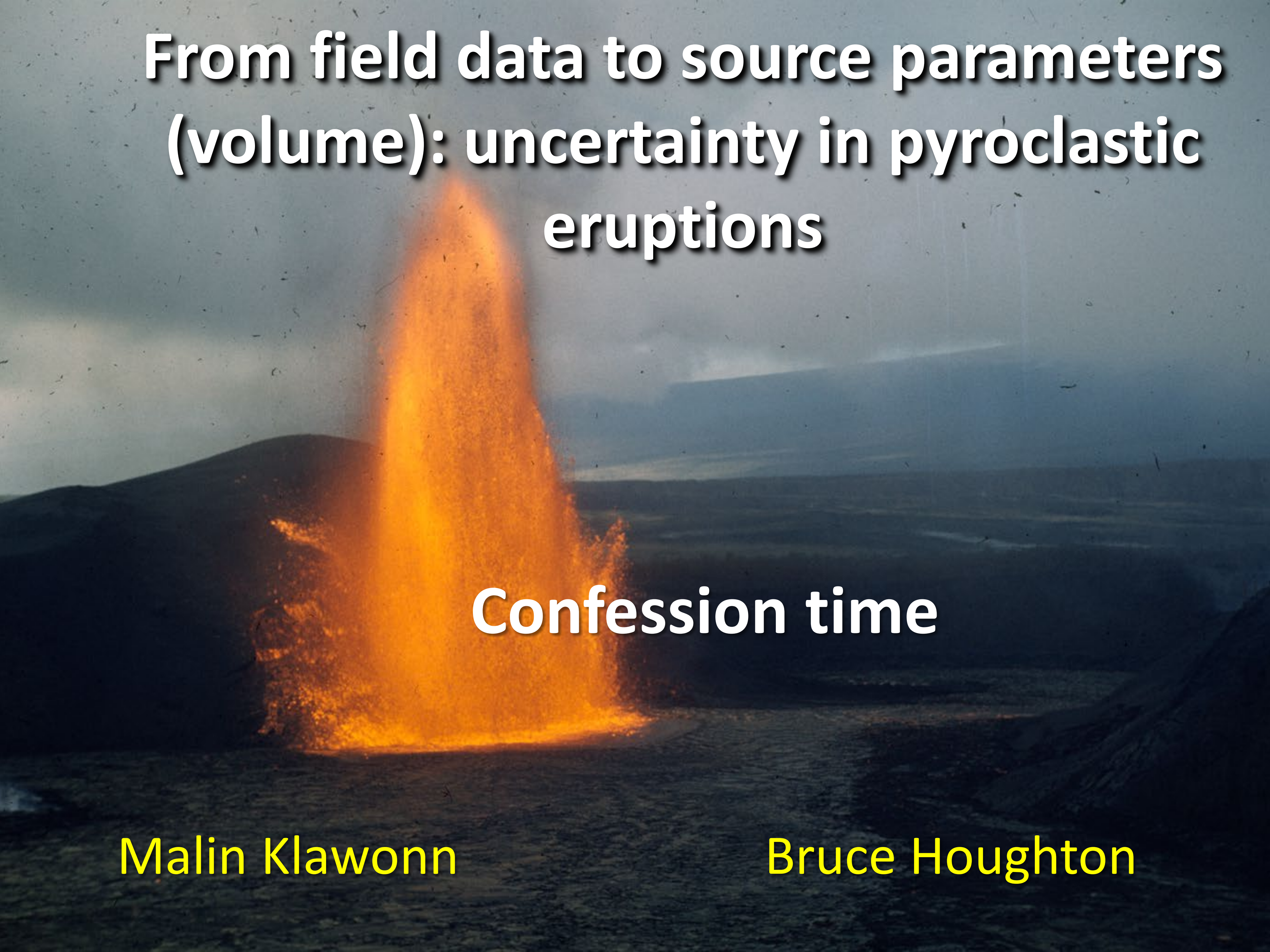
From field data to source parameters (volume): uncertainty in pyroclastic eruptions



Confession time

Malin Klawonn

Bruce Houghton

Tutorial Outline

Uncertainty of Eruption Magnitude (volume) estimates

- Background & research questions
- Experiment
- Results and conclusions

Confession 2

Physical volcanologists are non-conformists and nihilists….

……… *"all values are baseless and nothing can be known or communicated, ….. often associated with extreme pessimism and a radical skepticism"*

Protocols and standardized practices are an abomination to them, to be avoided at all costs

Thickness to volume

When estimating eruptive volume individuals make four sets of independent and subjective choices

- The spacing of thickness sites
- The selection and number of constraining contours
- The hand or machine contouring of thickness
- The choice of functions to fit to derive tephra volumes

What uncertainties are associated with these practices?

Paper 1: Reproducibility of Eruption Volume Estimates

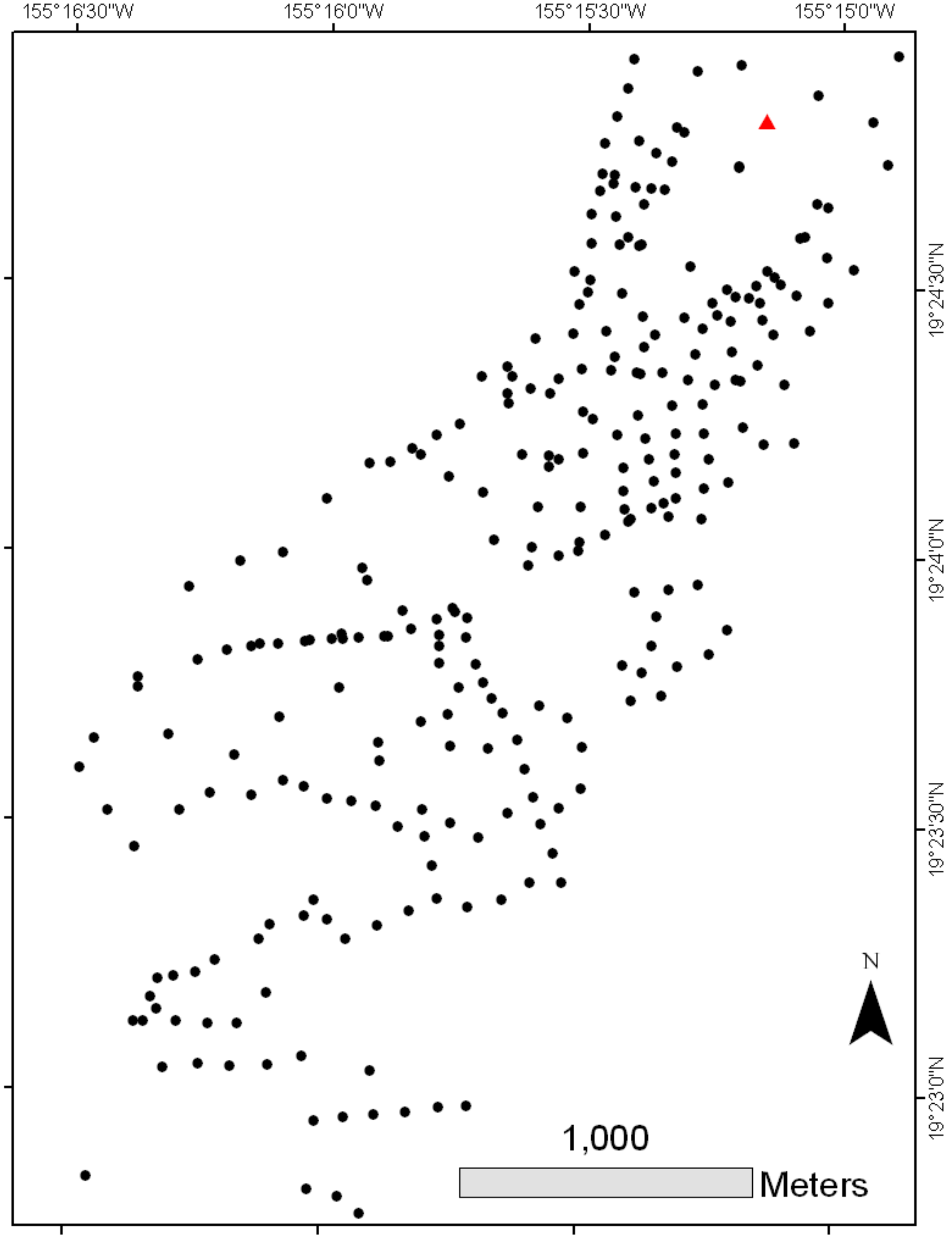
Klawonn, M.; Houghton, B.F.; Swanson, D.A.; Fagents, S.A.; Wessel, P.; Wolfe, C.J. 2014. Constraining explosive volcanism: Subjective choices during estimates of eruption magnitude. *Bulletin of Volcanology, 76*: 793-798. doi:10.1007/s00445-013-0793-3

Paper 2: From Field Data to Volumes: Constraining Uncertainties in Pyroclastic Eruption Parameters

Klawonn, M.; Houghton, B.F.; Swanson, D.A.; Fagents, S.A.; Wessel, P.; Wolfe, C.J. 2014. From field data to volumes: Constraining uncertainties in pyroclastic eruption parameters. *Bulletin of Volcanology, 76*: 839. doi:10.1007/s00445-014-0839-1

Sources of Uncertainty

- density of sites
- isopach choices
- estimation method



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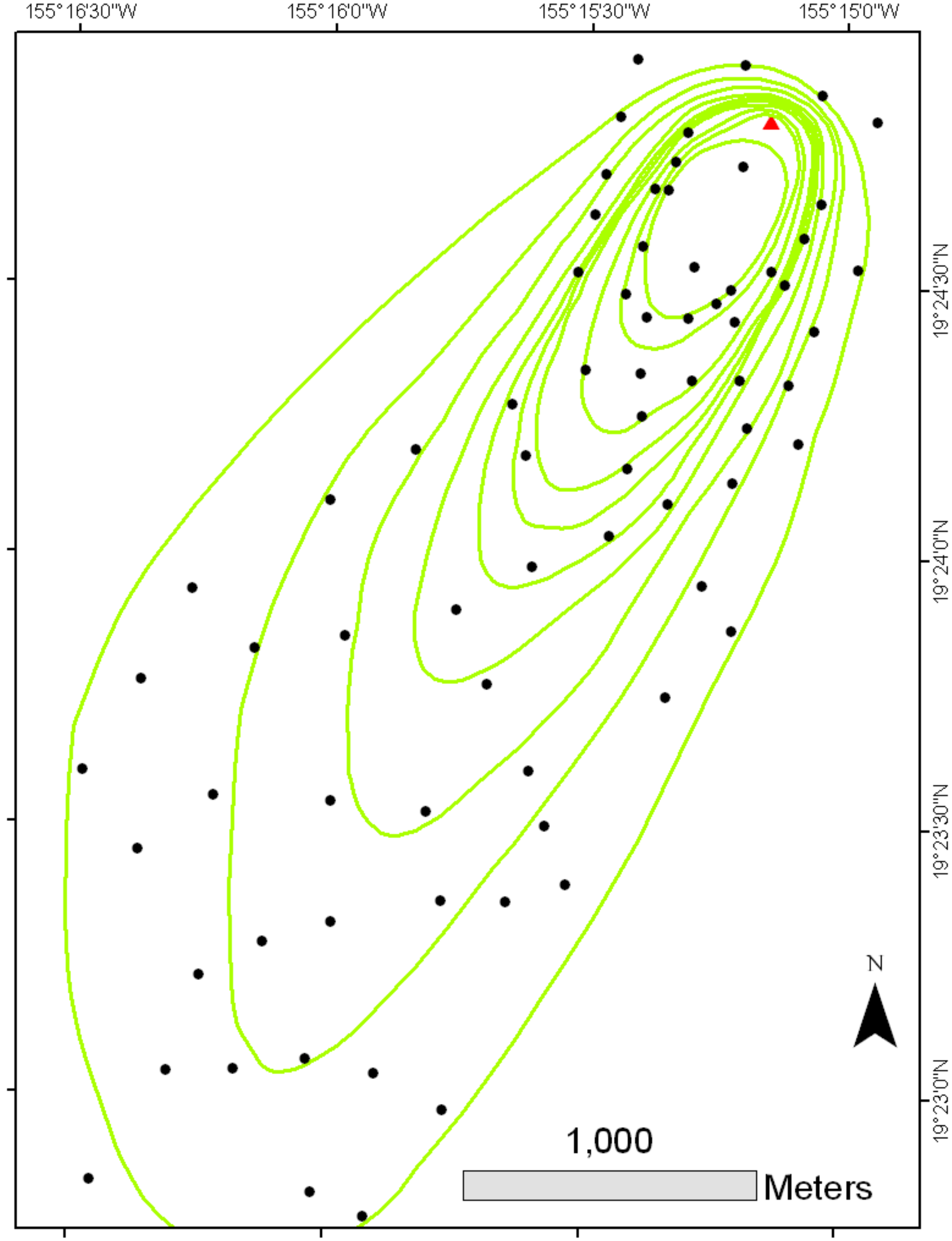

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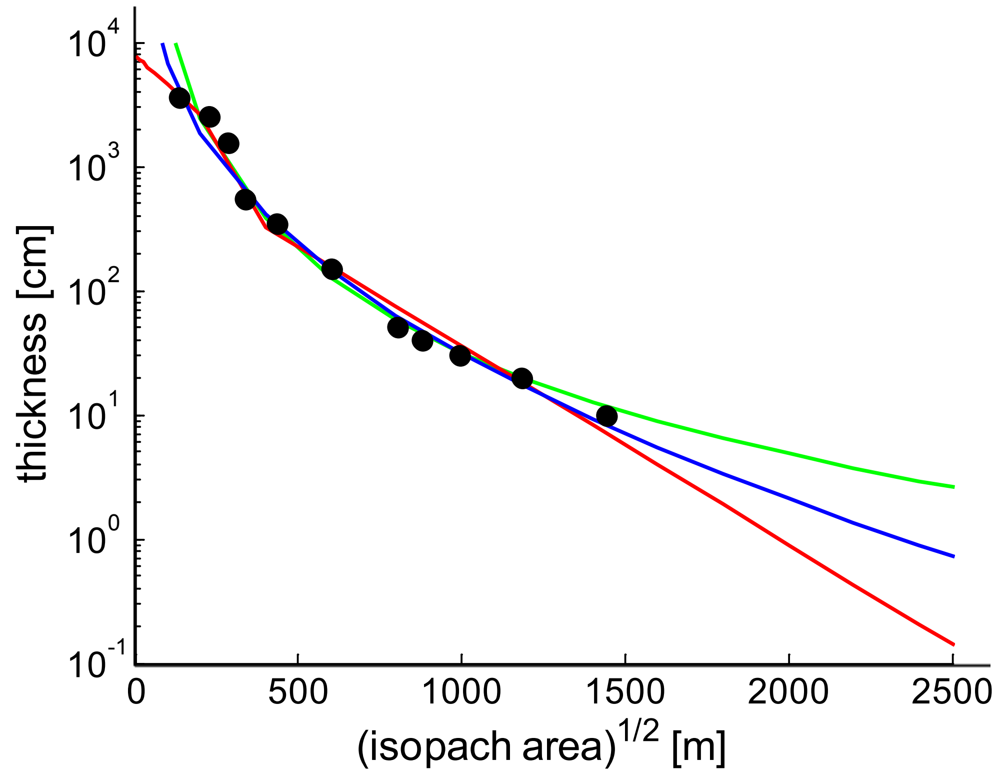


Estimation of Eruption Magnitude (Volume)

density of sites

isopach choices

estimation method

I. How does sampling density affect volume estimates?

II. What is the uncertainty due to different hand-drawn contours?

III. How do these methods affect volume estimates?

Background & Methodology

- The eruption
- Experiment setup
- Processing of data

Deposit Measurements → Isopachs → Estimation Method

Kīlauea Iki 1959 deposit

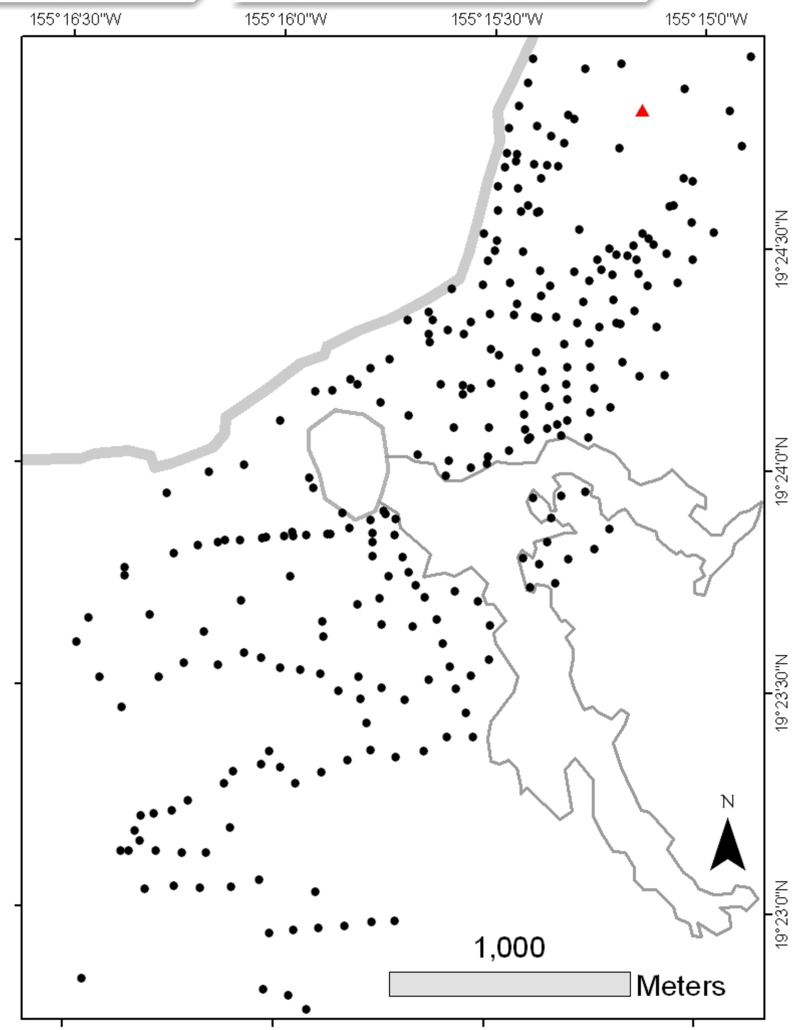
Wind-advected Hawaiian fountaining eruption

273 thicknesses measured over 11 km^2

Deposit Measurements → Isopachs → Estimation Method

Kīlauea Iki 1959 deposit

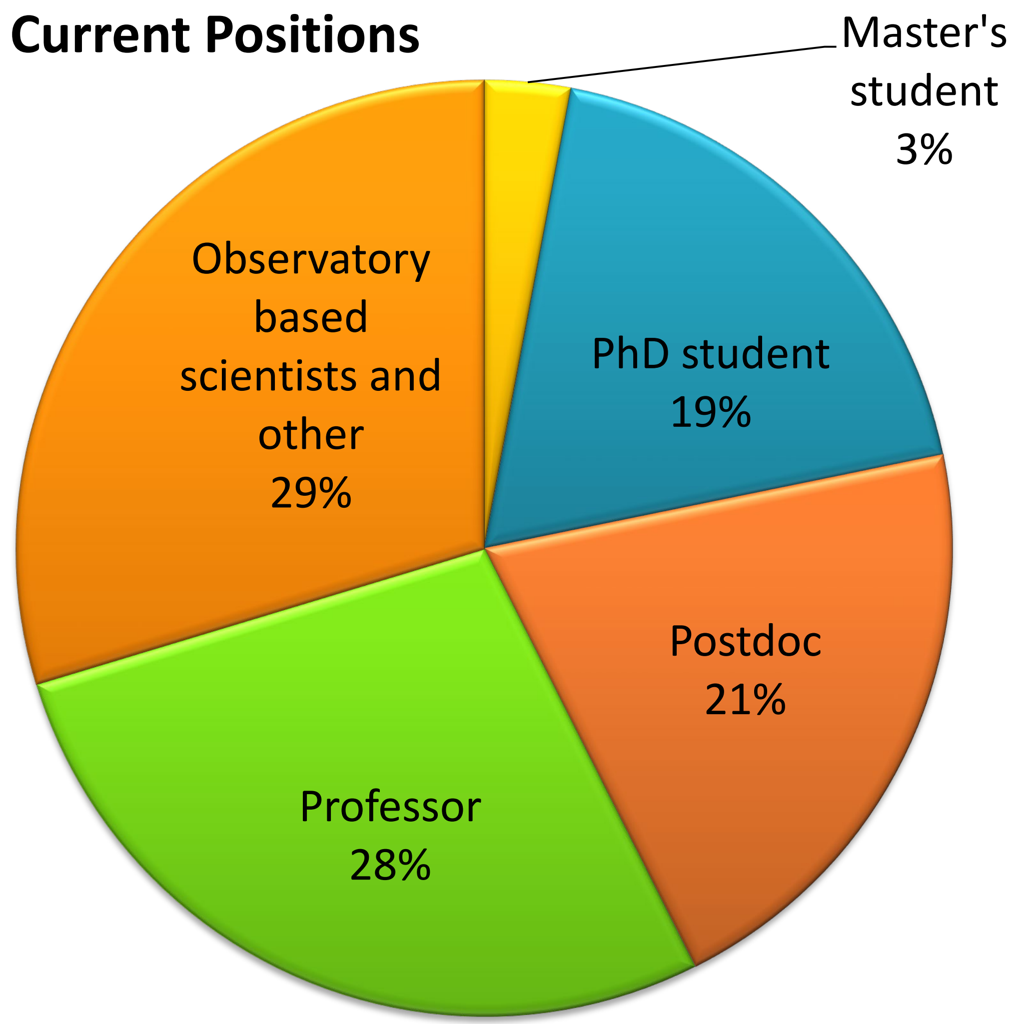
- 0.1 km^3
- 4 x 10^5 kg s^{-1}
- 16 episodes
- fountaining to 580 m
- lapilli to +16 km



Worldwide 101 geologists

Hand-drawn contours

Free choice of contours values

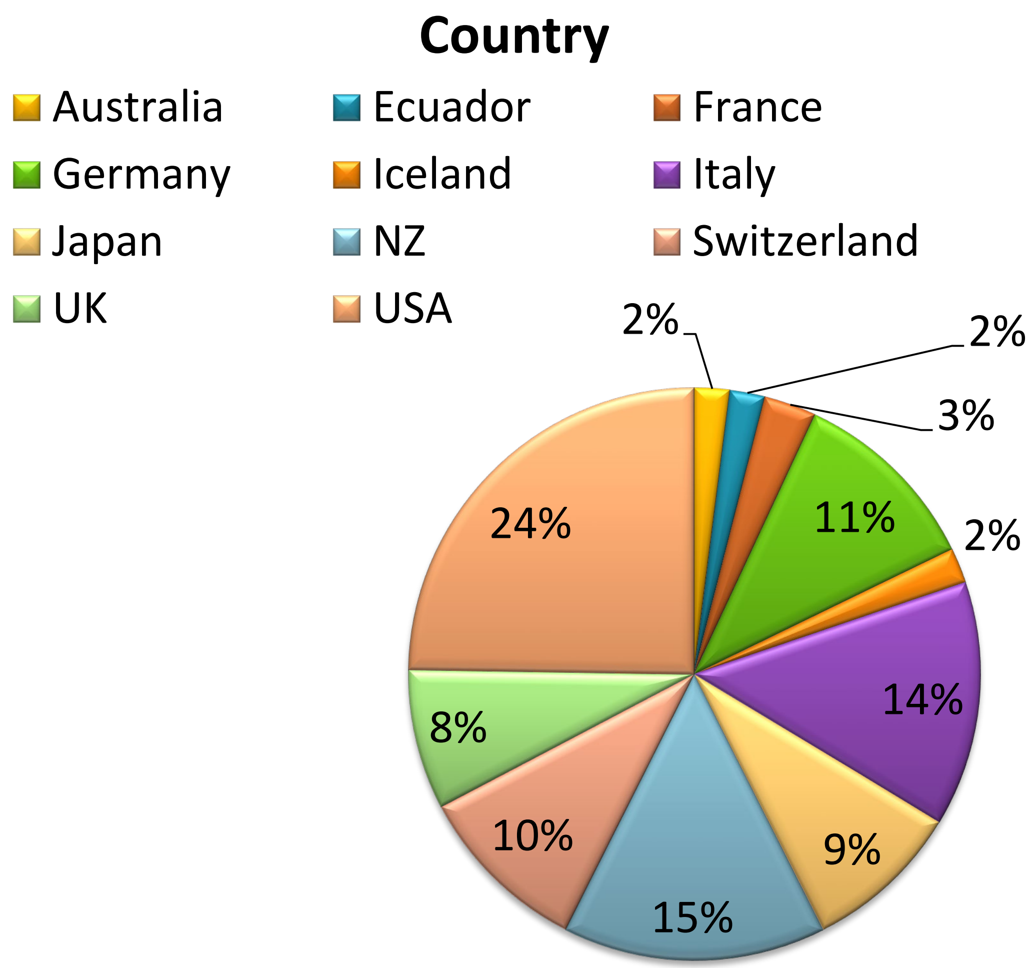


Deposit Measurements → Isopachs → Estimation Method

Worldwide 101 geologists

Hand-drawn contours

Free choice of contours levels



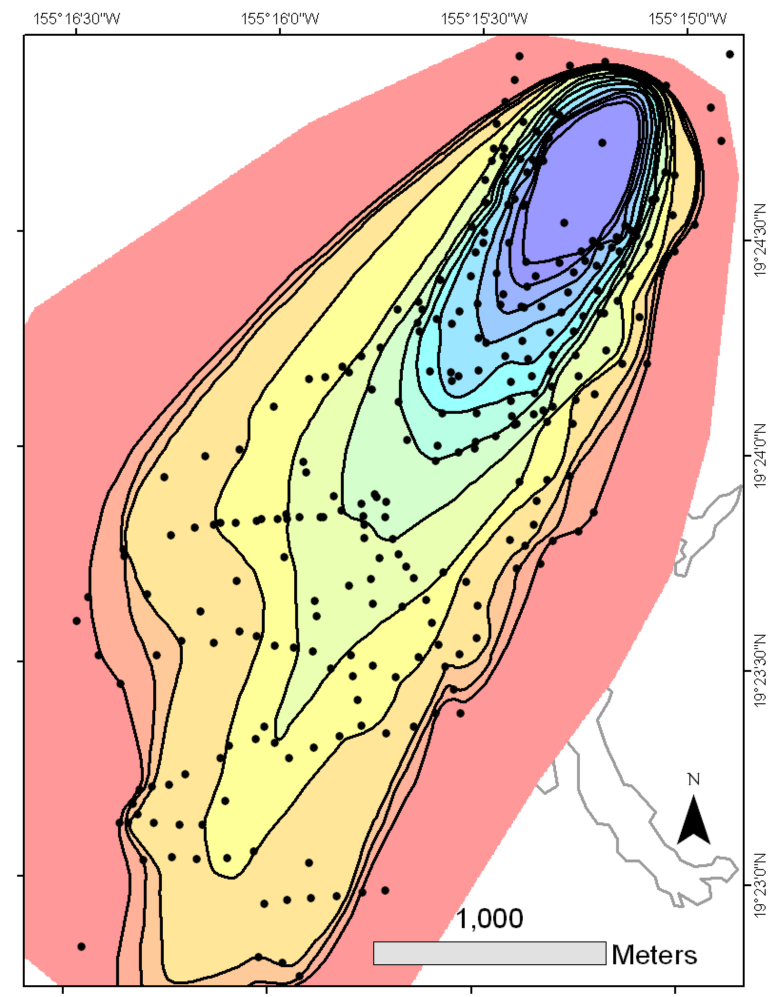
Deposit Measurements → Isopachs → Estimation Method

Digitized the contours in ArcGIS (ESRI),

- used Topo To Raster tool.

Calculated the volume:

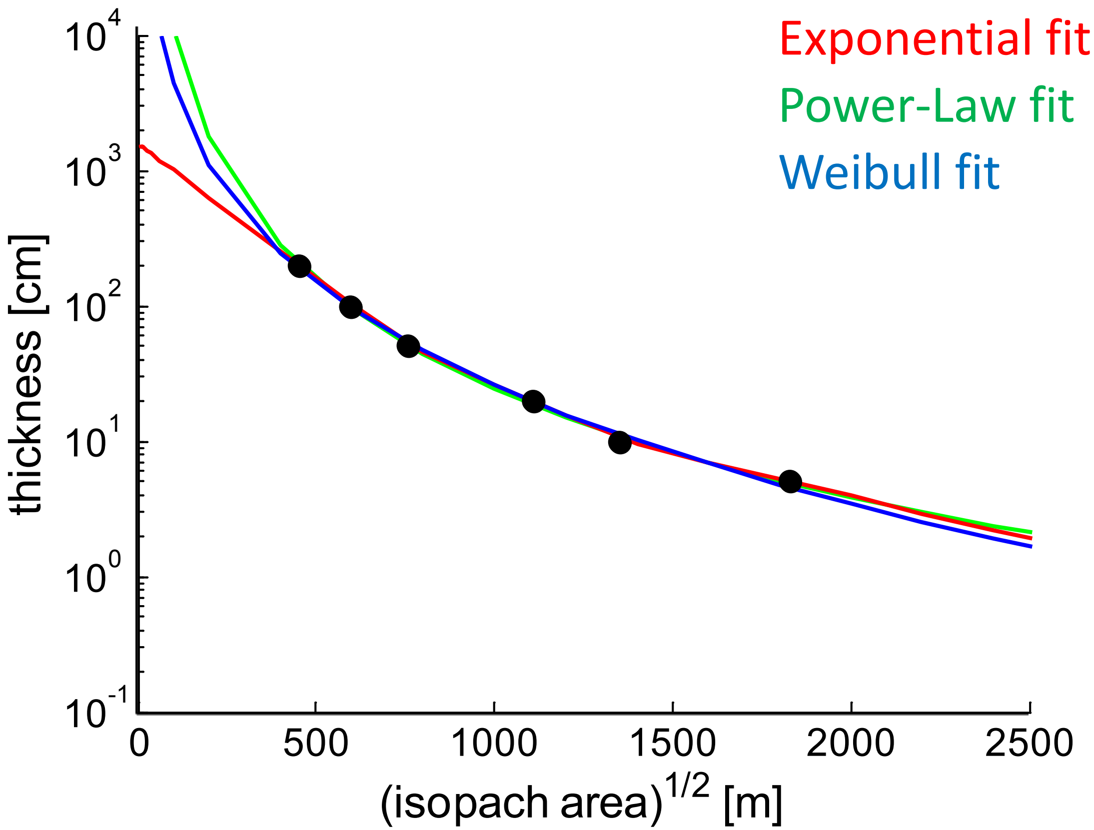
- used 3D Analyst Surface Volume tool,
- summing thickness across the surface.



Deposit Measurements → Isopachs → Estimation Method

Thickness vs (isopach area)$^{1/2}$

- **Exponential fit**
- **Power-Law fit**
- **Weibull fit**



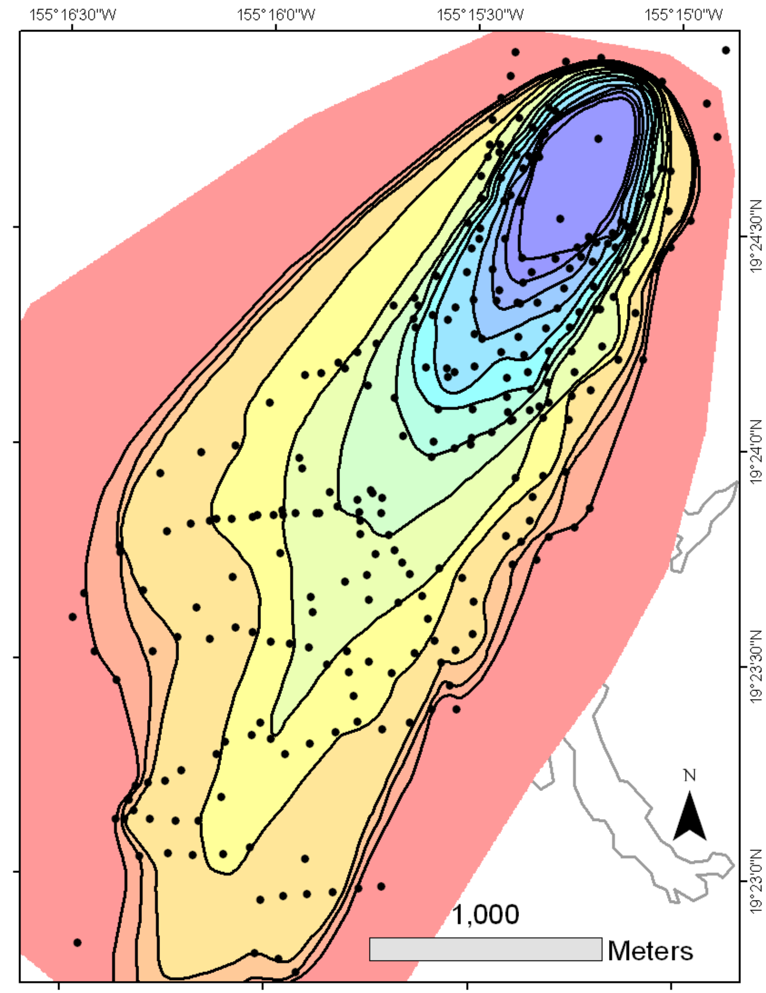
Deposit Measurements → Isopachs → Estimation Method

Thickness vs (isopach area)$^{1/2}$

- Exponential fit
- Power-Law fit
- Weibull fit

Surface Interpolation

➢ Remove deposit above 350 cm



Thickness vs (isopach area)$^{1/2}$

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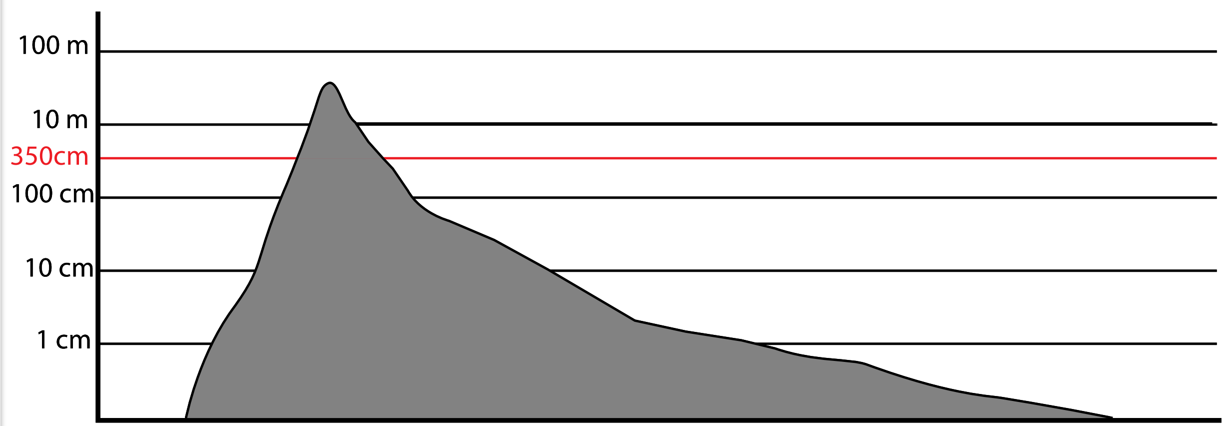


Results

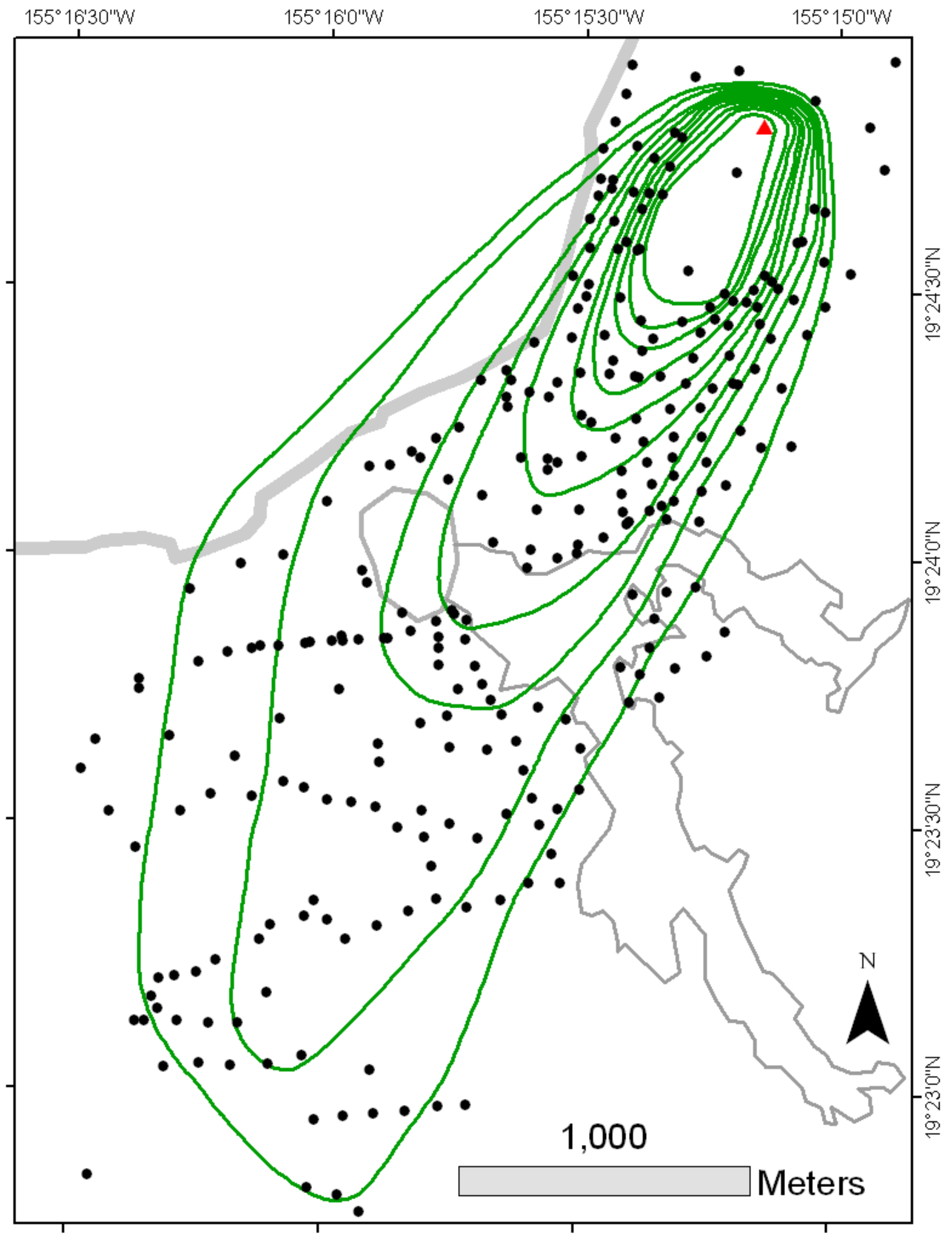
Contour shapes and density

Sampling density

Estimation methodology

Contours

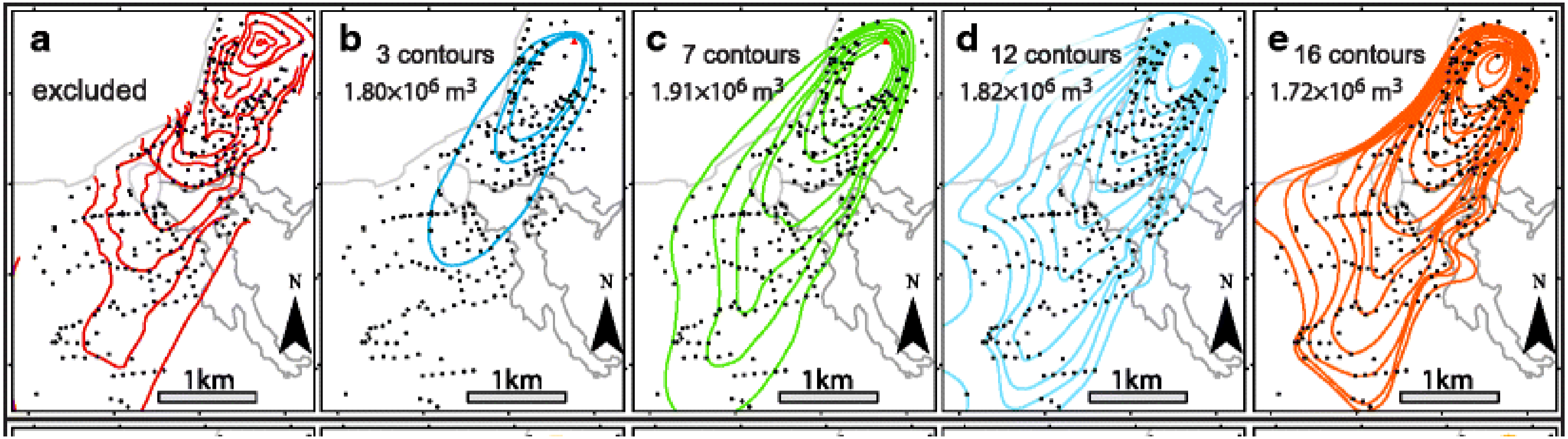
- Large variety of contours
  - Different number of contours
  - Different shape



Contour Number

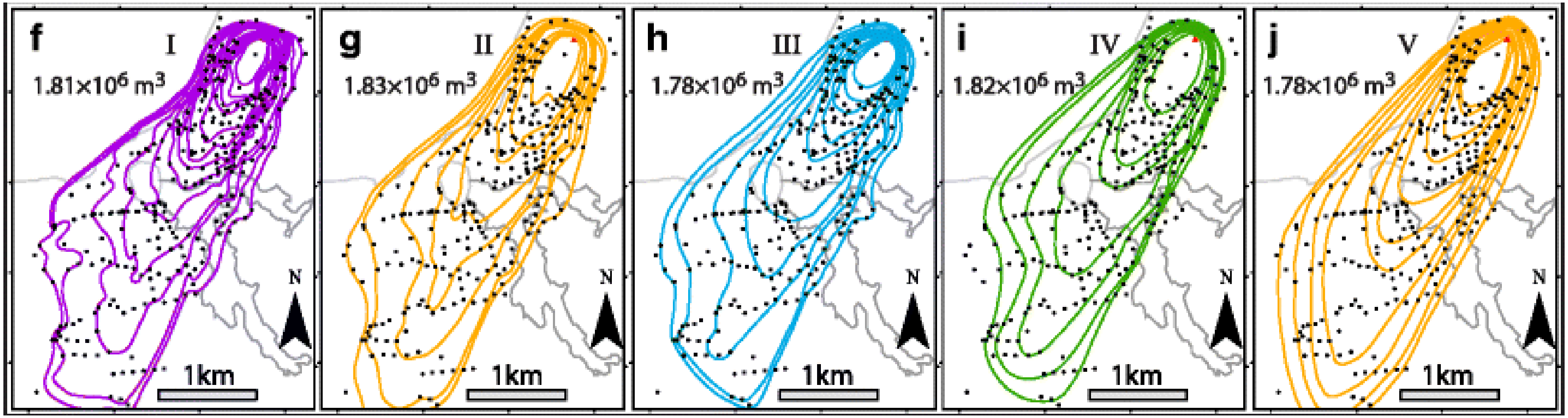
Number of contours 3 -16.   Mode 7

Dense map $1.82 \times 10^6\ m^3$
s = 6.5 %
V = range 1.5 to $2.1 \times 10^6\ m^3$



Contour shape

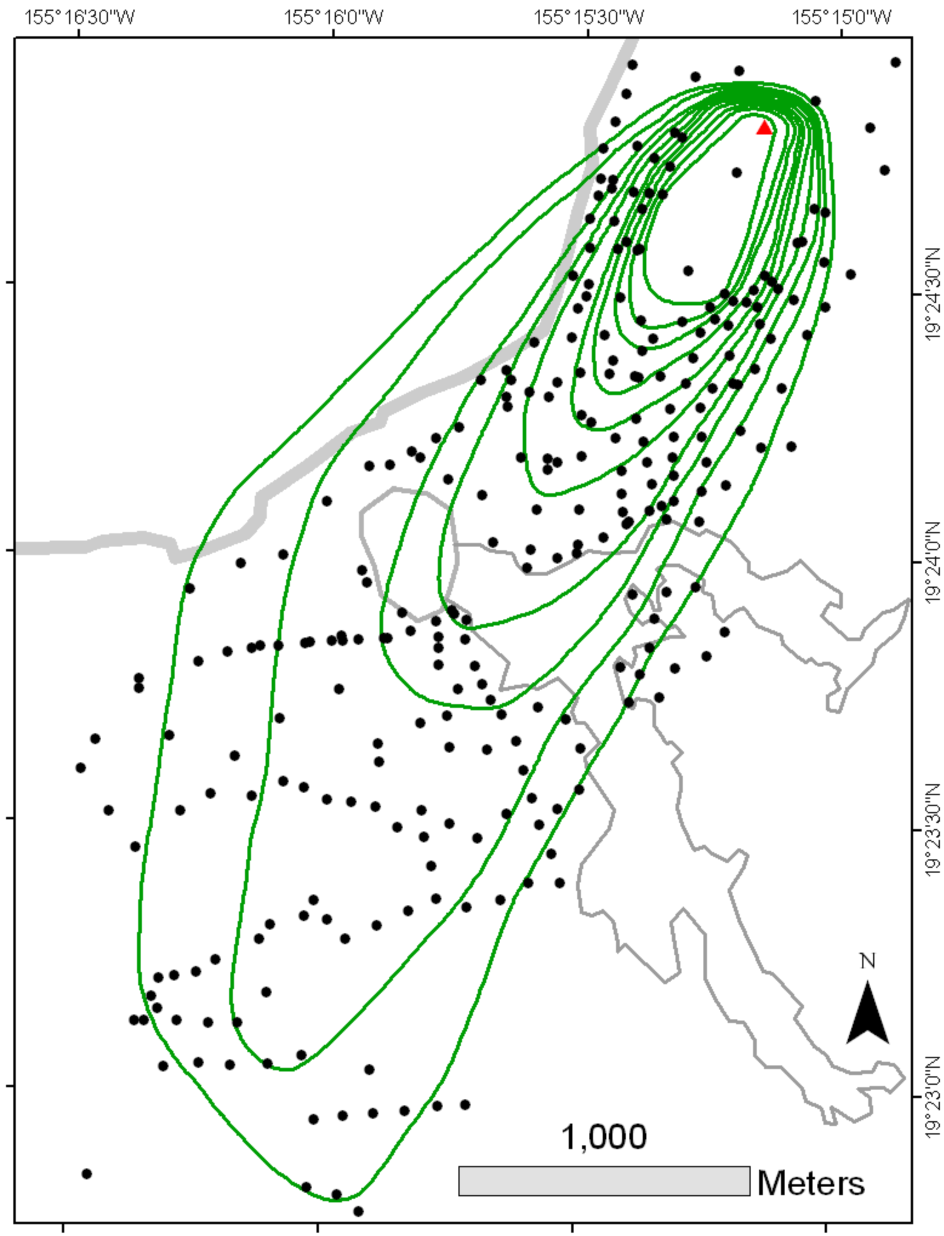
- Divide into 5 classes of decreasing complexity



Contour shape

- Divide into 5 classes of increasing complexity
- Smoothness does not affect area enclosed by an isopach or volume

I	$1.9 \times 10^6\ m^3$	s = 6.9 %
II	$1.8 \times 10^6\ m^3$	s = 4.9 %
III	$1.8 \times 10^6\ m^3$	s = 1.9%
IV	$1.8 \times 10^6\ m^3$	s = 7.6 %
V	$1.9 \times 10^6\ m^3$	s = 5.9%



Results

Contours

Sampling density

Estimation methodology

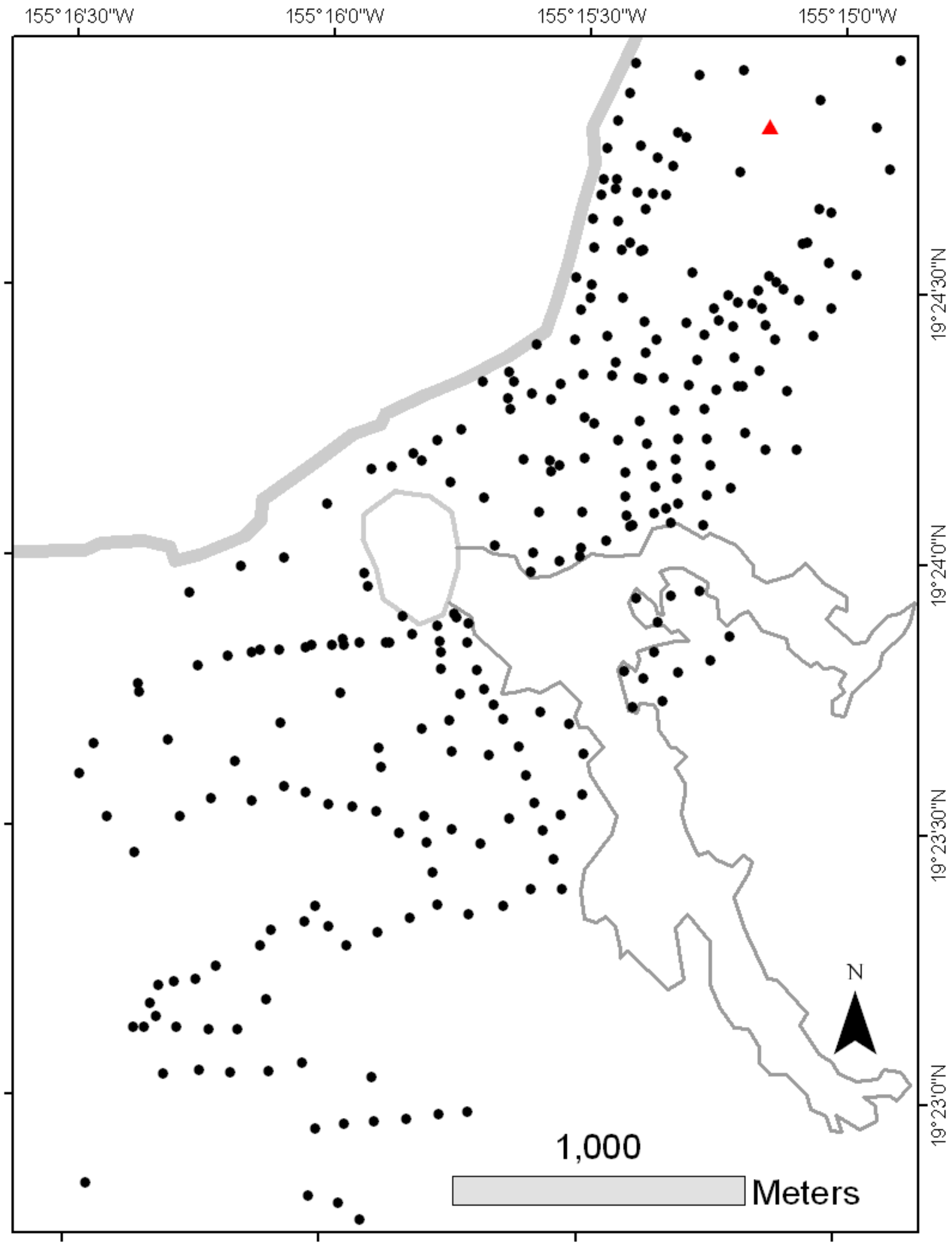
Different sampling density

Dense map   1.82 ×10^{6} m^{3}

- 273 measurements

V = range 1.5 to 2.1 ×10^{6} m^{3}

s = 6.5 %

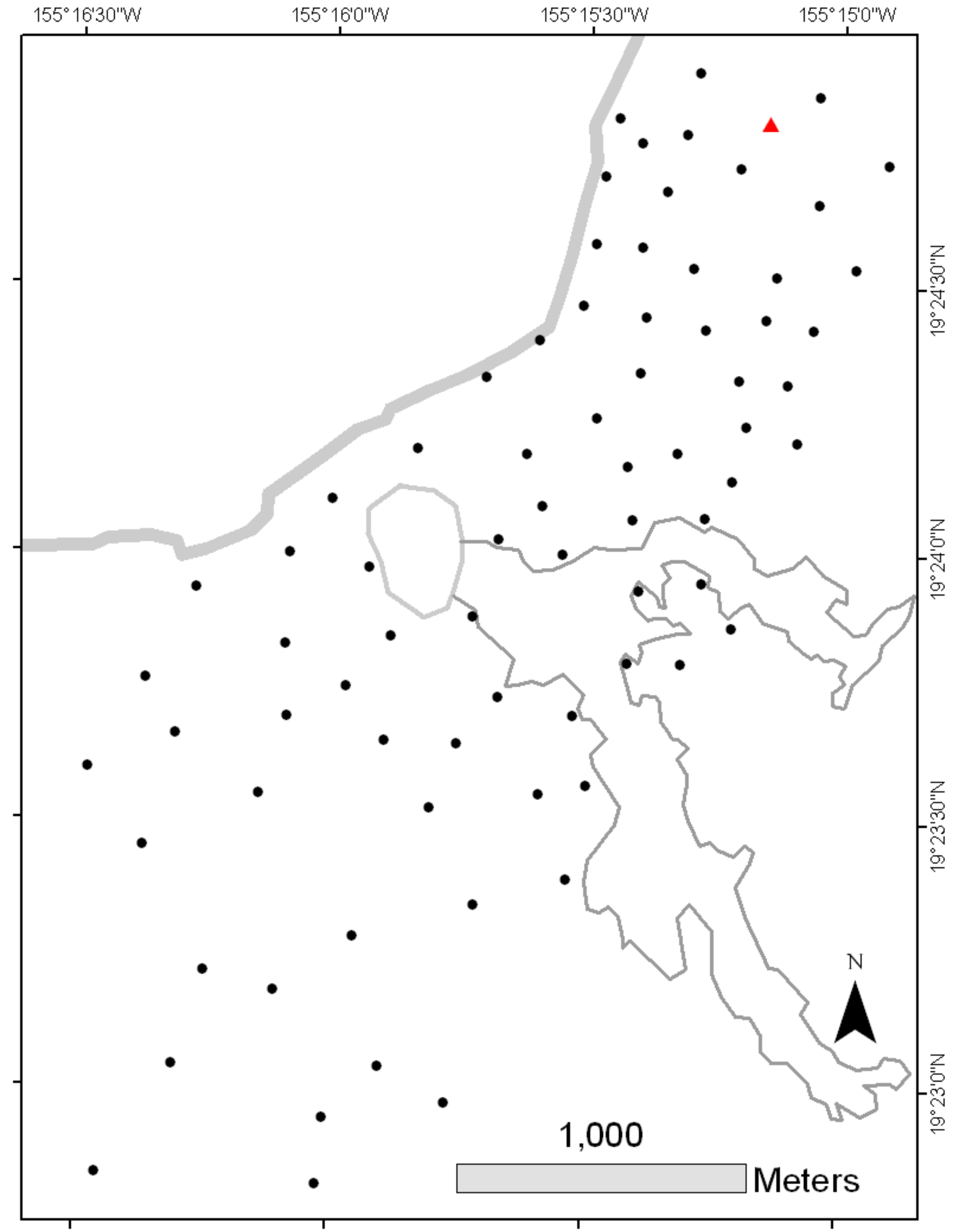


Different sampling density

Dense map 1.82×10^6 m^3
- 273 measurements

V = range 1.5 to 2.1 $\times 10^6$ m^3
s = 6.5 %

Subsample 1
- 75 measurements
- Equal spacing



Different sampling density

Dense map 1.82×10^6 m^3
- 273 measurements

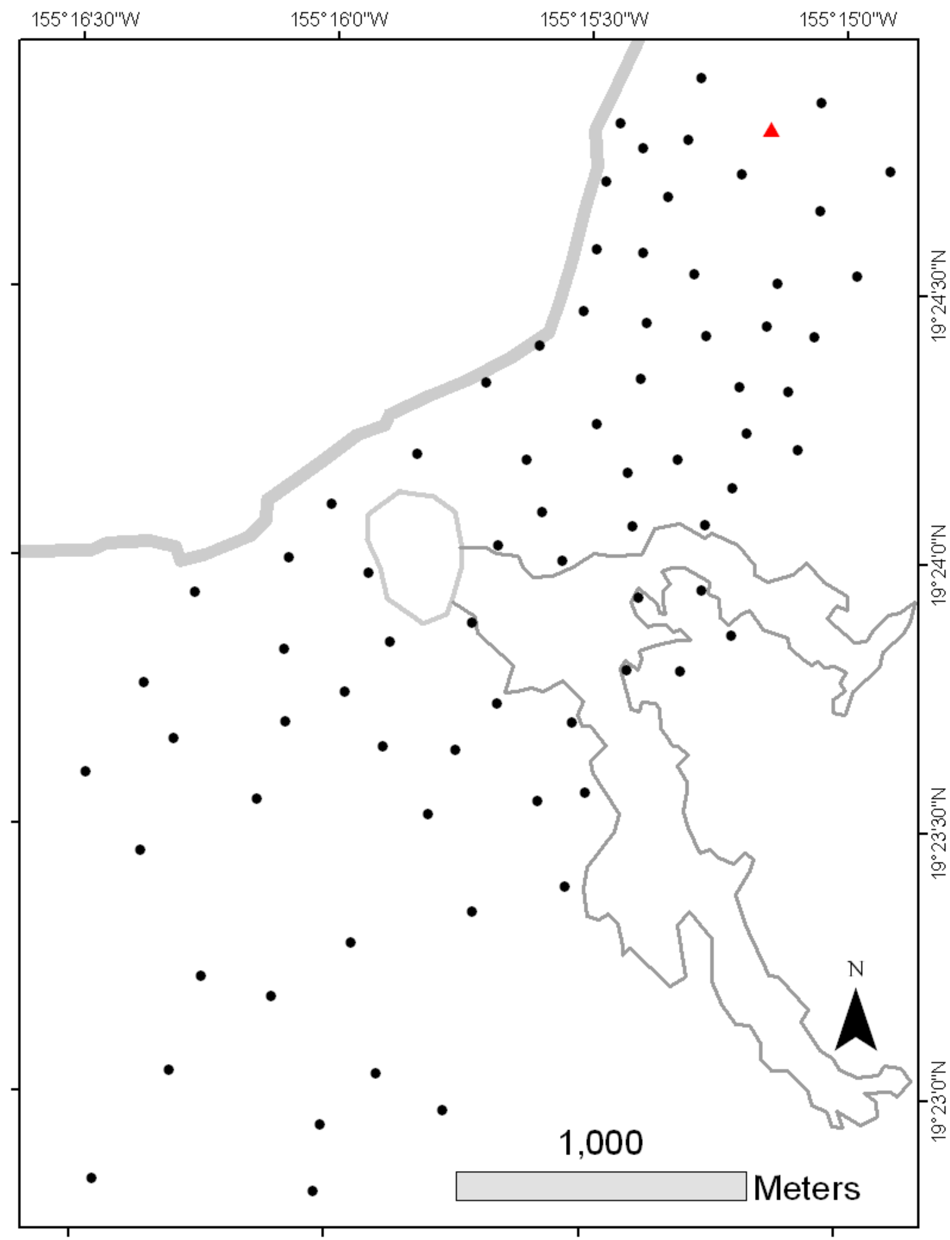
V = range 1.5 to 2.1 $\times 10^6$ m^3

s = 6.5 %

Subsample 1 1.78×10^6 m^3
- 75 measurements
- Equal spacing

V_1 = range 1.7 to 2.1 $\times 10^6$ m^3

s_1 = 8.2%



Different sampling density

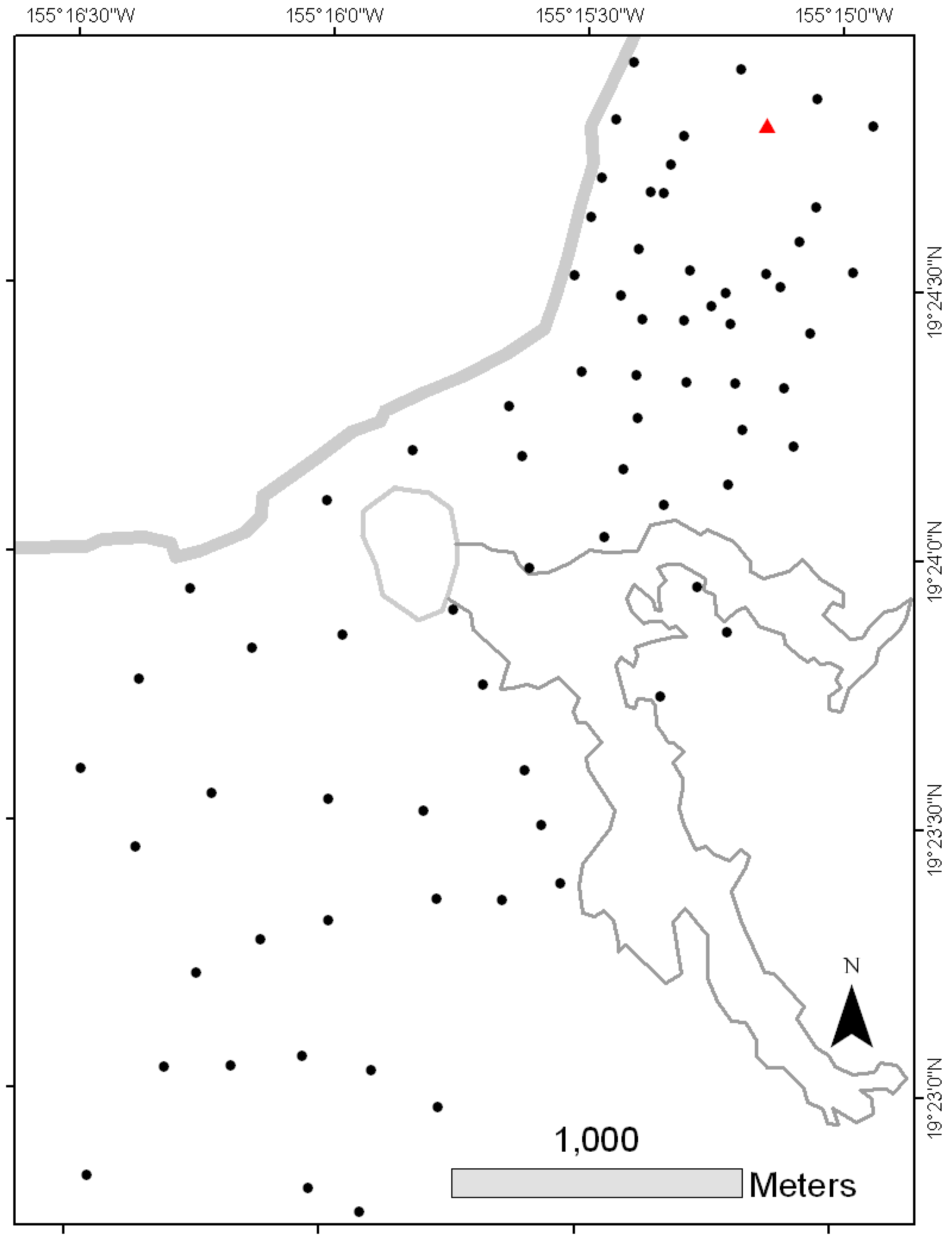
Dense map 1.82 ×10^{6} m^{3}
- 273 measurements

V = range 1.5 to 2.1 ×10^{6} m^{3}

s = 6.5 %

Subsample 1
- 75 measurements
- Equal spacing

Subsample 2
- 75 measurements
- Along roads and trails



Different sampling density

Dense map 1.82×10^6 m^3

- 273 measurements

V = range 1.5 to 2.1 $\times 10^6$ m^3

s = 6.5 %

Subsample 1

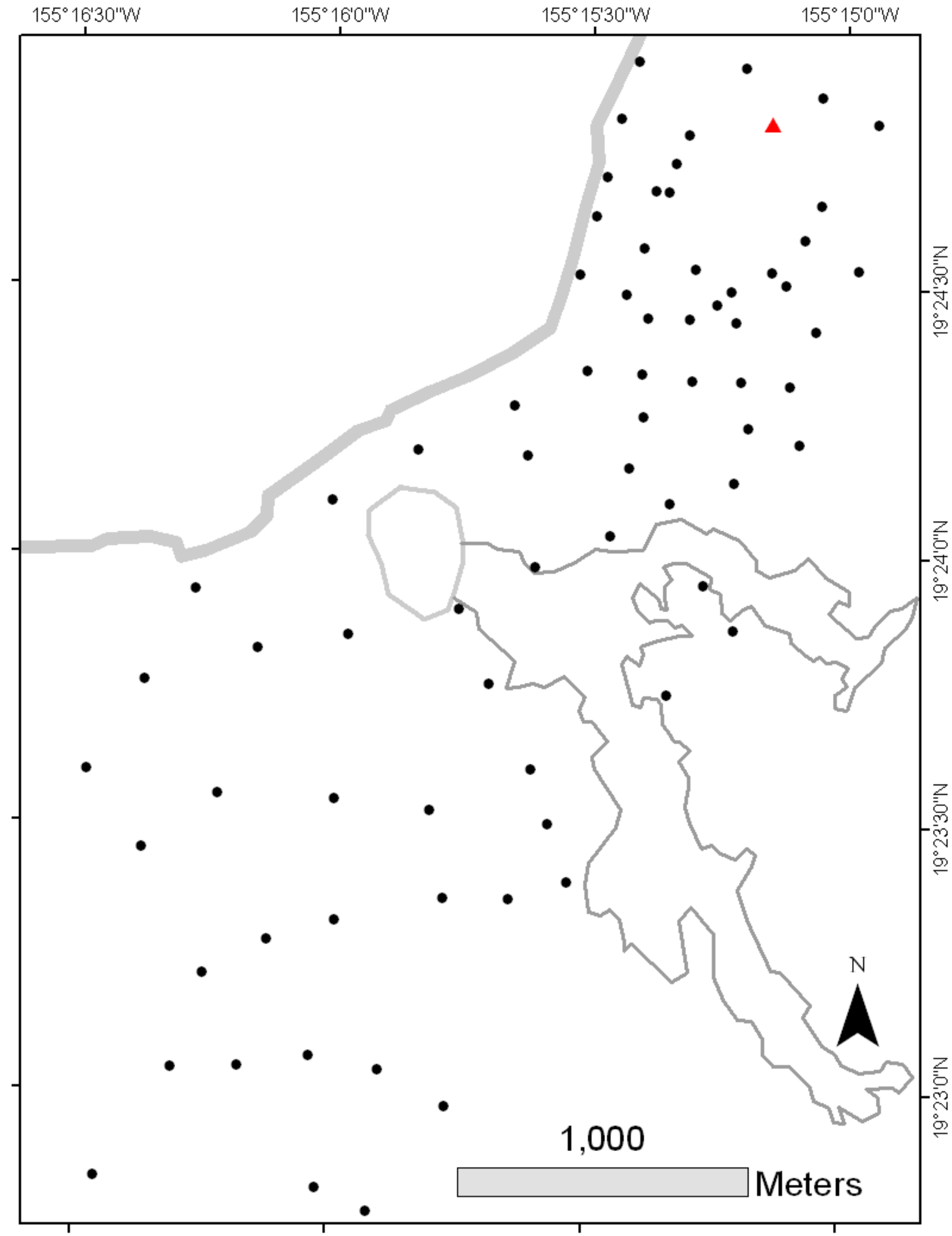
- 75 measurements
- Equal spacing

Subsample 2 1.89×10^6 m

- 75 measurements
- Along roads and trails

V_2 = range 1.6 to 2.1 $\times 10^6$ m^3

s_2 = 5.2 %



Different sampling density

Subsample 1 1.78×10^6 m^3

- 75 measurements
- Equal spacing

V_1 = range 1.7 to 2.1 $\times 10^6$ m^3

s_1 = 8.2%

Dense map 1.82×10^6 m^3

- 273 measurements

V = range 1.5 to 2.1 $\times 10^6$ m^3

s = 6.5 %

Subsample 2 1.89×10^6 m

- 75 measurements
- Along roads and trails

V_2 = range 1.6 to 2.1 $\times 10^6$ m^3

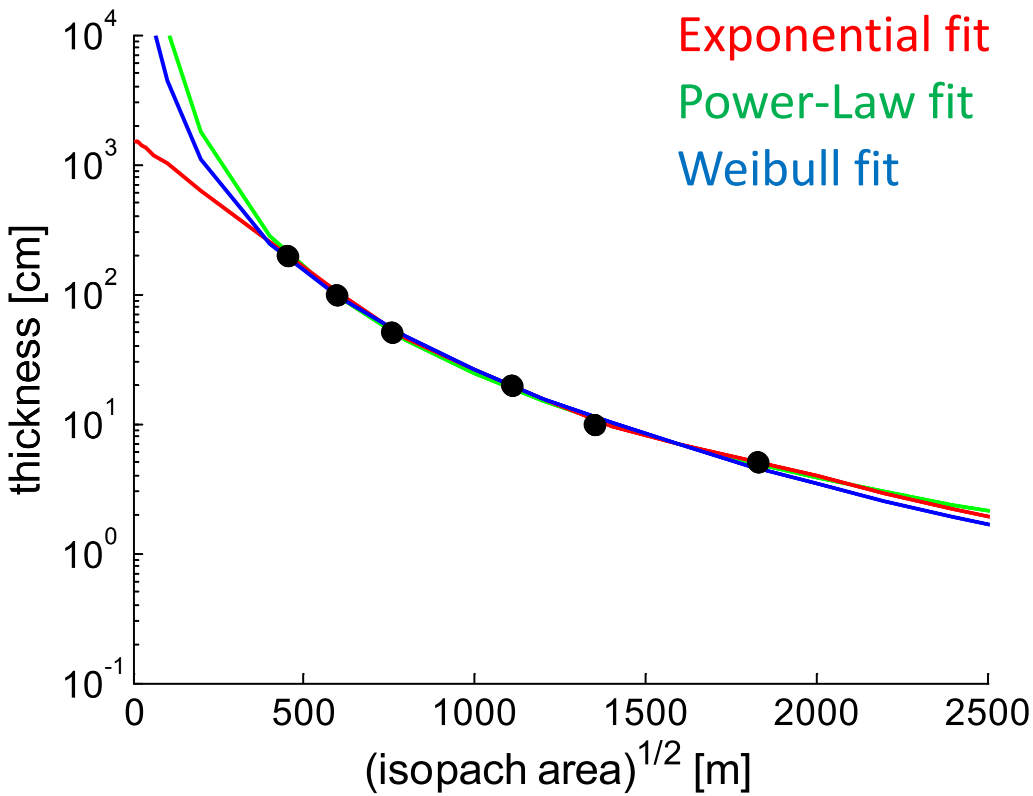
s_2 = 5.2 %

Results

Contours
Sampling density
Estimation methodology

Estimation Methods

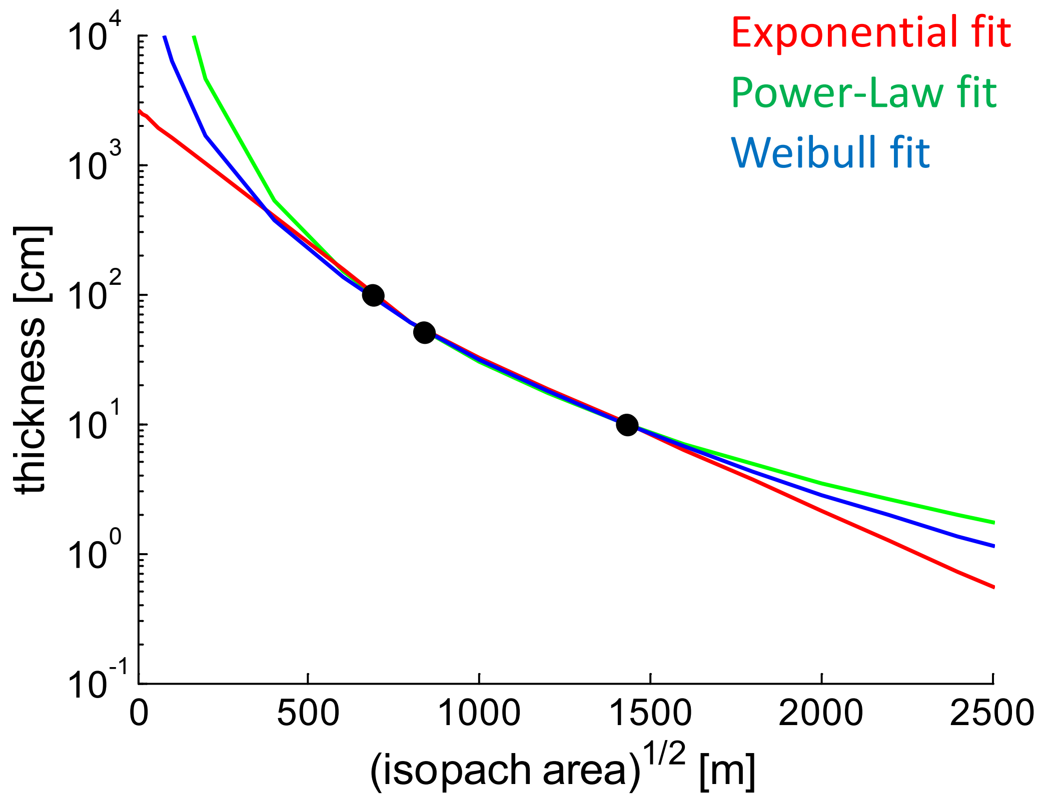
- Single Map Different Methods
  - Exponential Fit
    - 1 segment
    - 1-3 segments
  - Power-Law Fit
  - Weibull Fit
    - 3 weighing options
  - Surface



Estimation Methods

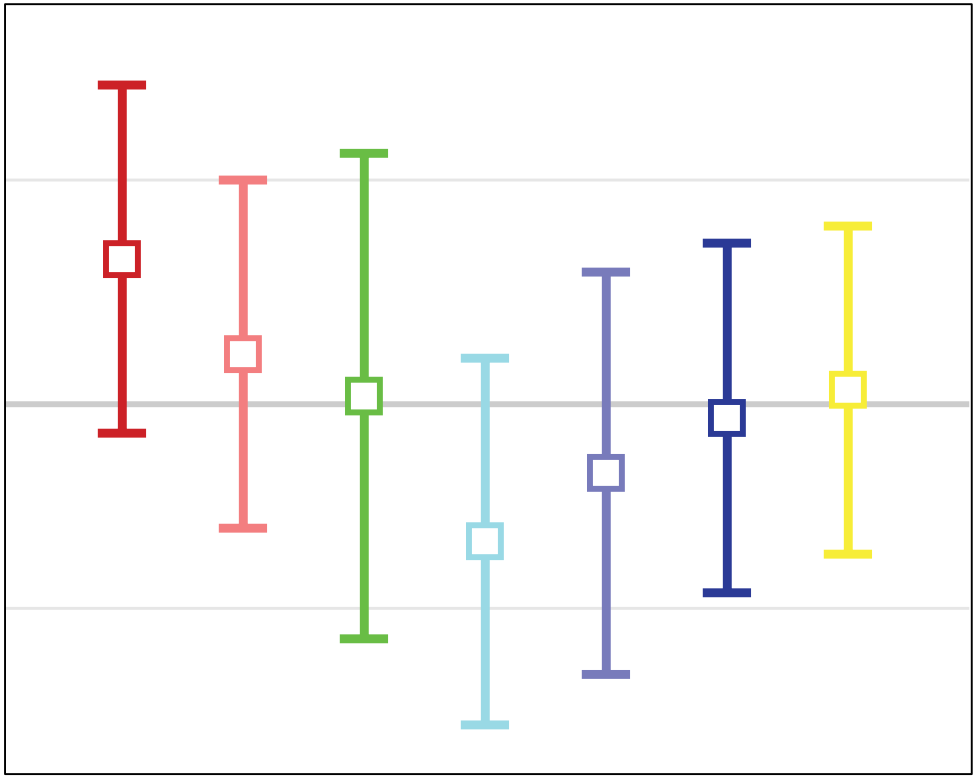
- Single Map Different Methods
  - Exponential Fit
    - 1 segment
    - 1-3 segments
  - Power-Law Fit
  - Weibull Fit
    - 3 weighing options
  - Surface

➢ s = 11.6% (7 methods)
➢ s = 5.6% (4 methods)



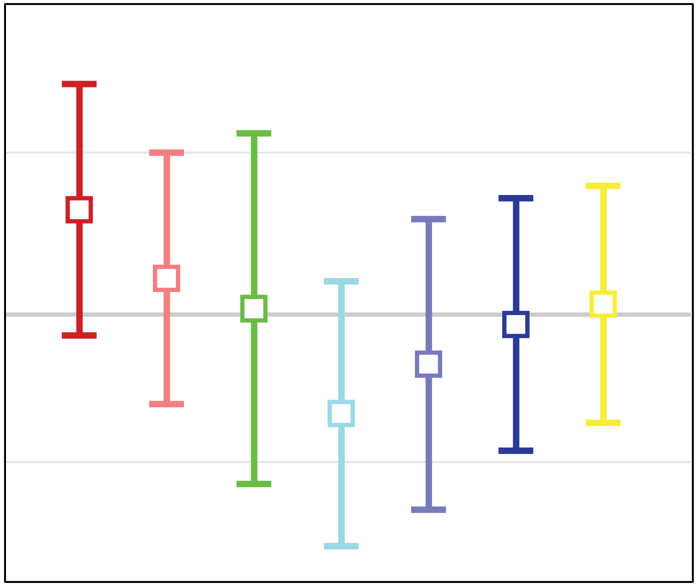
Estimation Methods

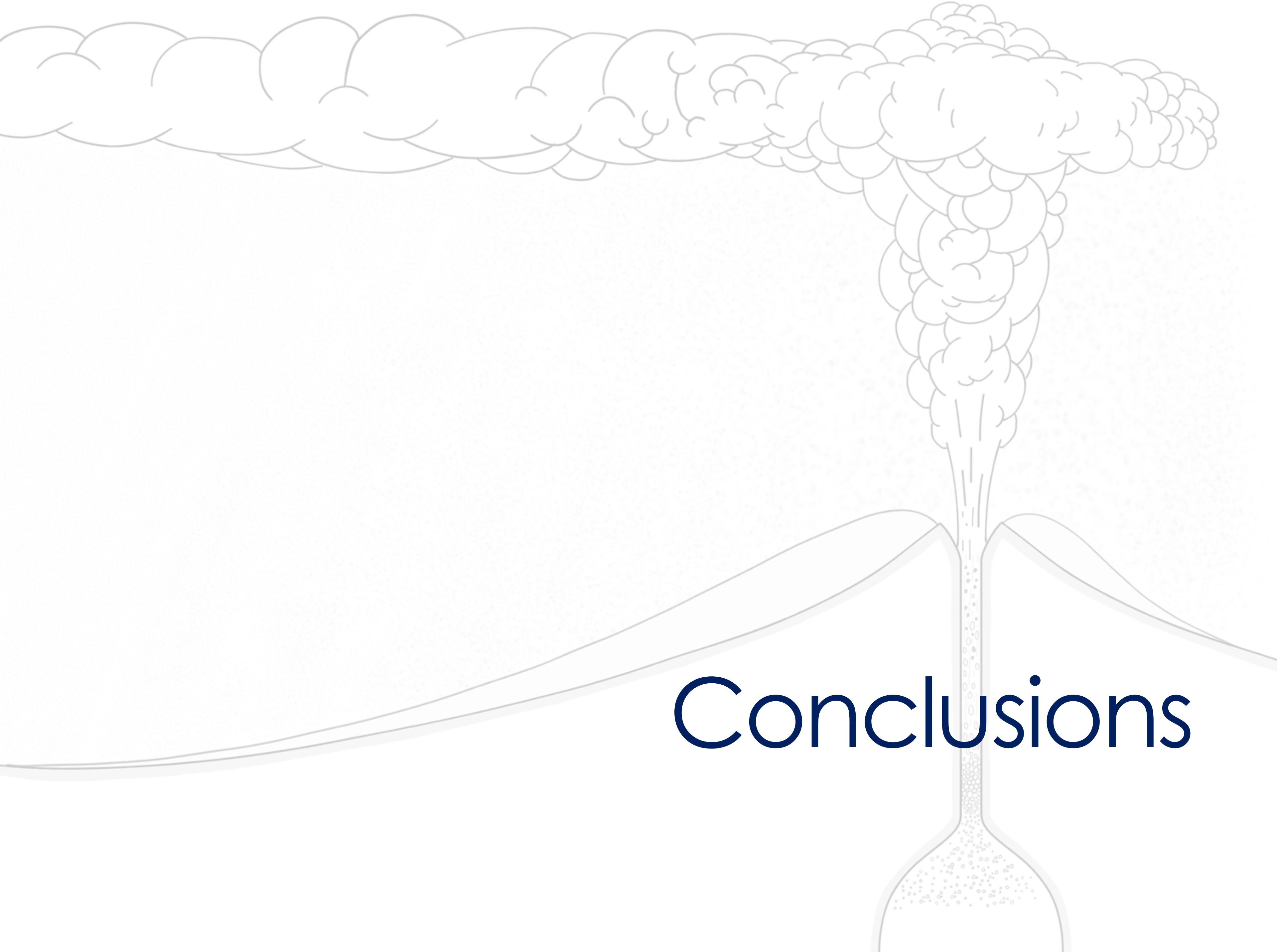
- Exponential Fit
  - 1 segment
  - 1 to 3 segments
- Power-Law Fit
- Weibull Fit
  - 3 weighing options
- Surface Interpolation



Estimation Methods

- Exponential Fit
  - s = 13.5% (1 segment)
  - s = 7.6%   (1-3 segments)
- Power-Law Fit
  - s = 10.8%
- Weibull Fit
  - s = 8.7% (no residual weighting)
  - s = 9.3% (with residual weighting)
  - s = 7.8% (with strong residual weighting)
- Surface Interpolation
  - s = 7.3%





Conclusions

Uncertainty of eruption volume estimates

Density of Measur. sites

I. How does sampling density affect volume estimates?

Isopachs

II. What is the uncertainty due to different hand-drawn contours?

Estimation Method

III. How do methods affect volume estimates?

Uncertainty of eruption volume estimates

Density of Measur. sites

Mean volumes very consistent, but may yield a biased mean or larger spread

Isopachs

II. What is the uncertainty due to different hand-drawn contours?

Estimation Method

III. How do methods affect volume estimates?

Uncertainty of eruption volume estimates

Density of Measur. sites

Mean volumes very consistent, but may yield a biased mean or larger spread

Isopachs

5% to 12% ↔ Logarithmic scale of Volcanic Explosivity Index (VEI)

Estimation Method

III. How do methods affect volume estimates?

Uncertainty of eruption volume estimates

Deposit Measur. sites

Mean volumes very consistent, but may yield a biased mean or larger spread

Isopachs

5% to 12% ⟺ Logarithmic scale of Volcanic Explosivity Index (VEI)

Estimation Method

Similar to hand-drawn contours

- $s = 11.6\%$ (7 methods)
- $s = 5.6\%$ (4 methods)

Conclusions

The biggest constraint is the quality of the data which is excellent in the medial field and poorer closer and further from vent

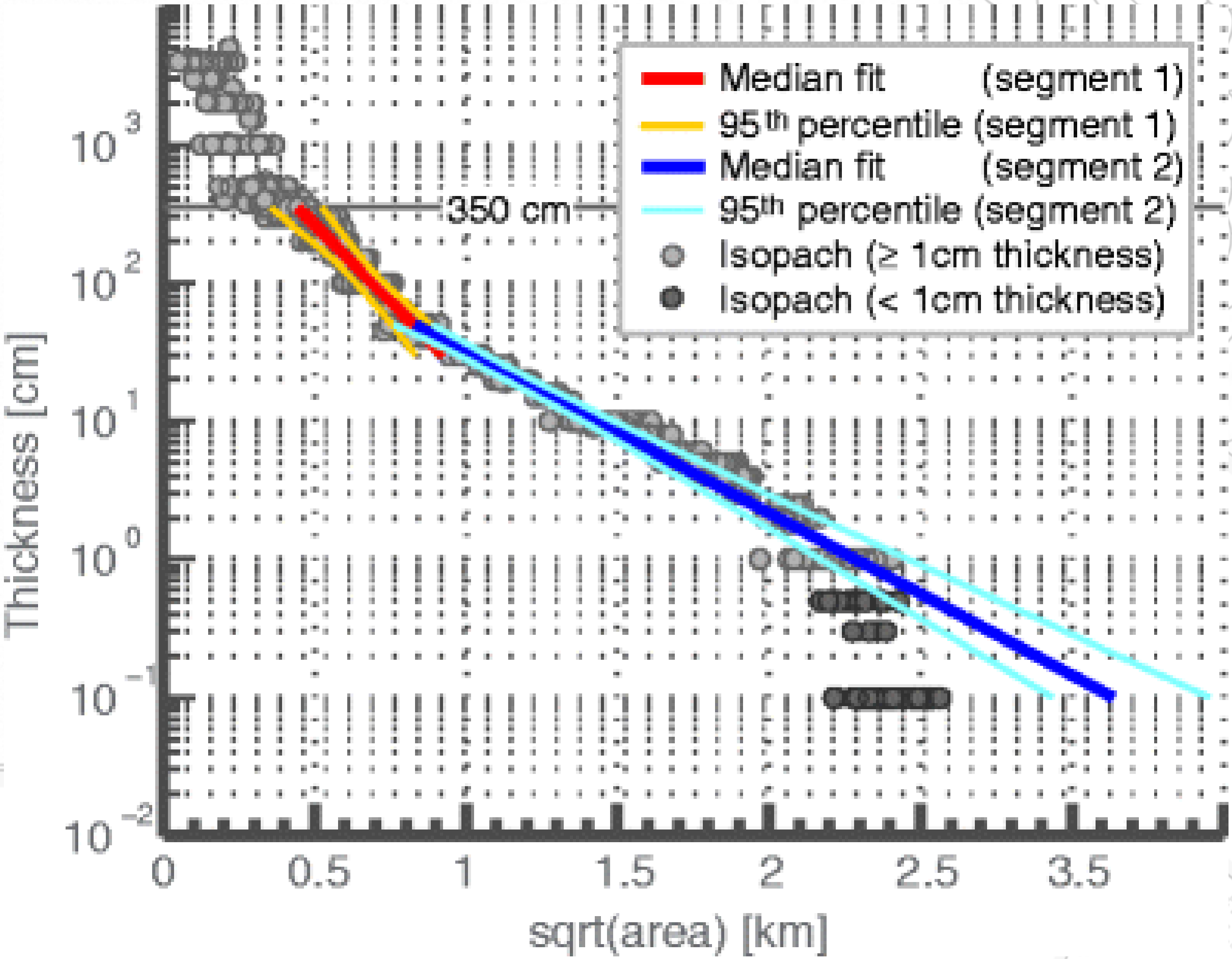
Proximal issues

- lack of exposure (welding)
- incomplete preservation
- intercalated locally dispersed material

Distal issues

- thickness modification begins during eruption
- zero cm does not mean no deposition
- isopachs should not be drawn beyond the range of data values

Conclusions 2



The way forward?

Digitizing of 2019 data
Spline fits to data
Evaluation of uncertainties in individual isopachs
Evaluation of uncertainties in individual measurements