MONASH University

Monash Structural Geophysics Group

School of Earth, Atmosphere and Environment

Loop

L. AILLERES, M. JESSELL, E. DE KEMP, G. CAUMON, F. WELLMANN, S. LOPEZ, M. HILLIER, G. LAURENT, G. COURRIOUX6, E. SCHETSELAAR, R. ARMIT, M. LINDSAY, P. CALCAGNO, P. COLLON, B. BRODARIC, C. LOISELET, T. CUI, J. DRONIOU, P. G BETTS, F. BONNEAU, A.R. CRUDEN, and many others…

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Centre for EXPLORATION TARGETING

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British Geological Survey
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CANADA 1842 GEOLOGICAL SURVEY - COMMISSION GÉOLOGIQUE

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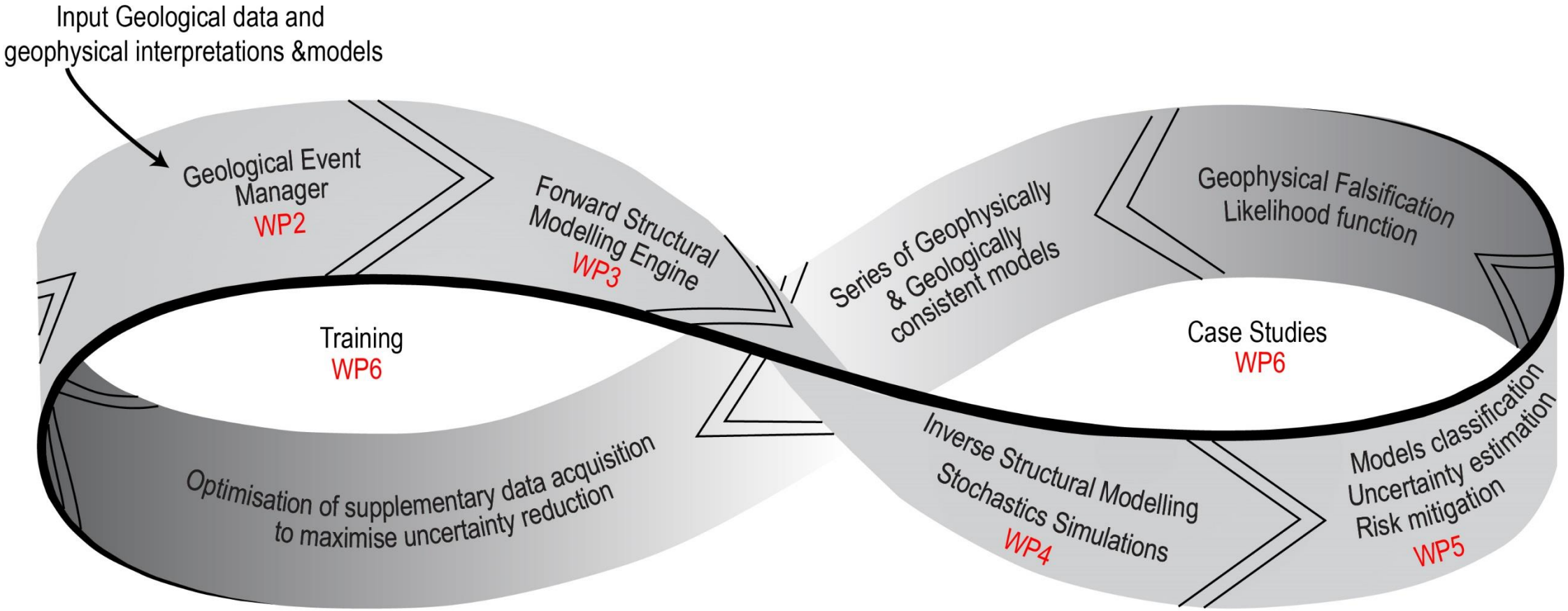
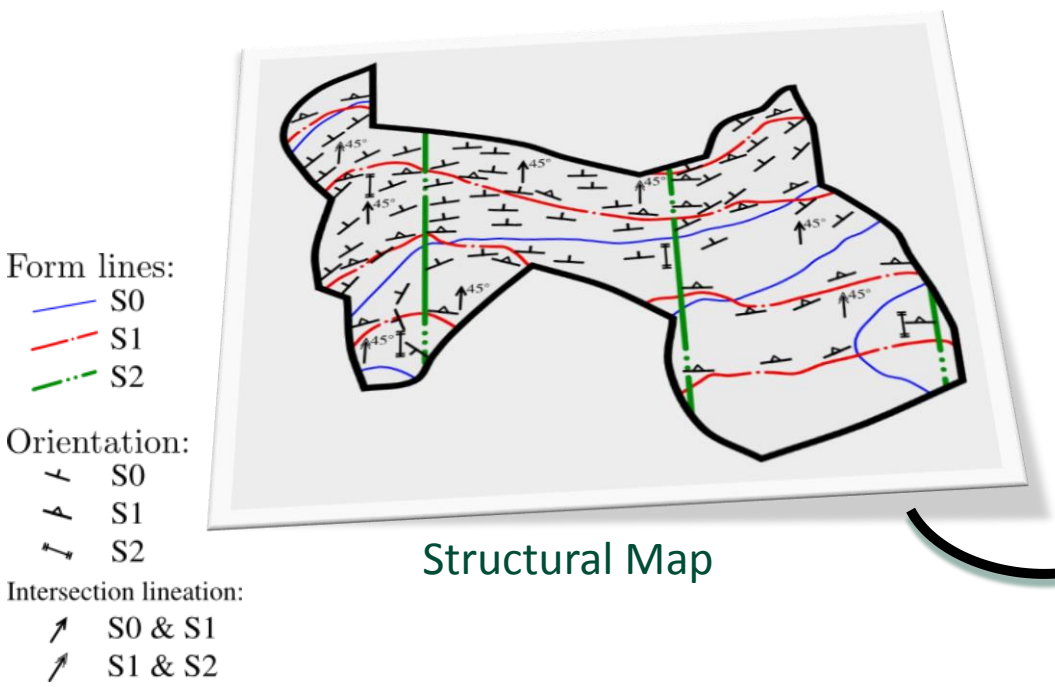
What is Loop

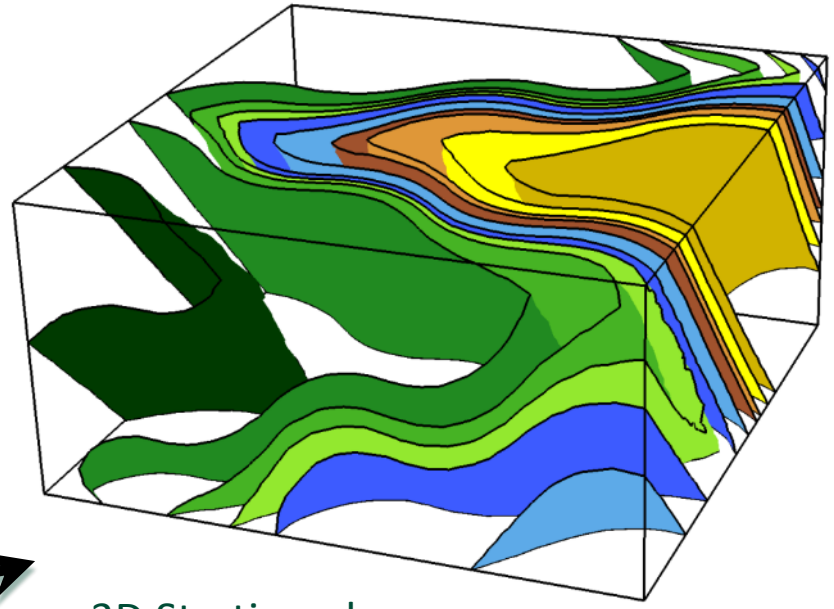

Input Geological data and geophysical interpretations &models
Geological Event Manager
WP2
Forward Structural Modelling Engine
WP3
Series of Geophysically & Geologically consistent models
Geophysical Falsification Likelihood function
Training
WP6
Case Studies
WP6
Optimisation of supplementary data acquisition to maximise uncertainty reduction
Inverse Structural Modelling Stochastics Simulations
WP4
Models classification Uncertainty estimation Risk mitigation
WP5

Quantitative Modelling of Geological Structures

- Structural data
- Geological knowledge



Structural Map



3D Stratigraphy

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Implicit modeling of folds and overprinting deformation

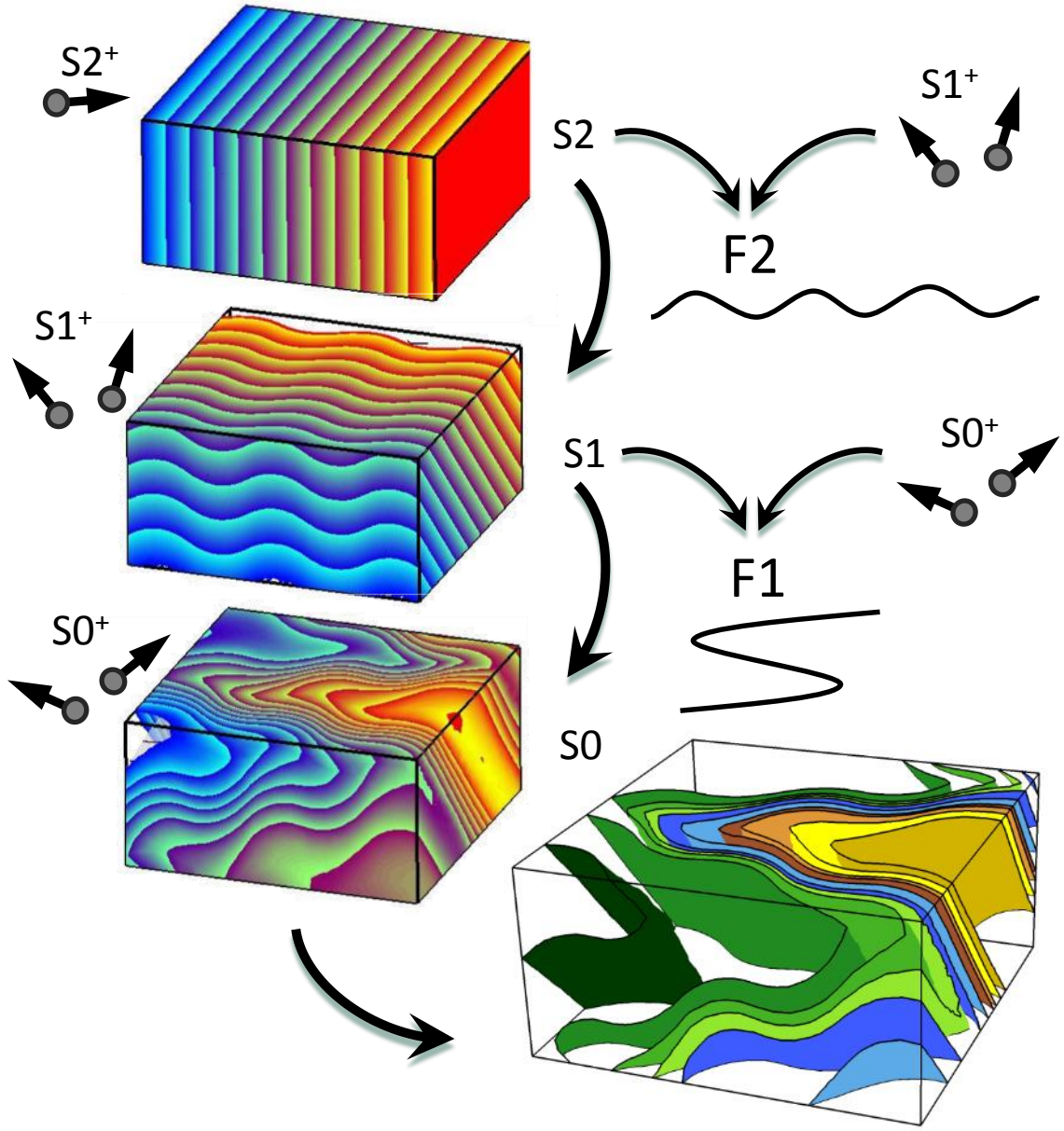
Gautier Laurent [a,b,*], Laurent Ailleres [a], Lachlan Grose [a], Guillaume Caumon [b], Mark Jessell [c], Robin Armit [a]

Implicit Structural Modelling Engine

1. Poly-deformation:
   - Model step by step
   - Restoration approach
     - going backward in time
   - Fold operator:
     - $S_{i-1} = Fi(S^{+}_{i-1} \mid P_i)$

2. Fold characterisation:
   - Statistics from data
   - Fold Frames
     - Using structural elements
   - Fold Profiles

‼ No deformation simulation
‼ Only geometric relationship



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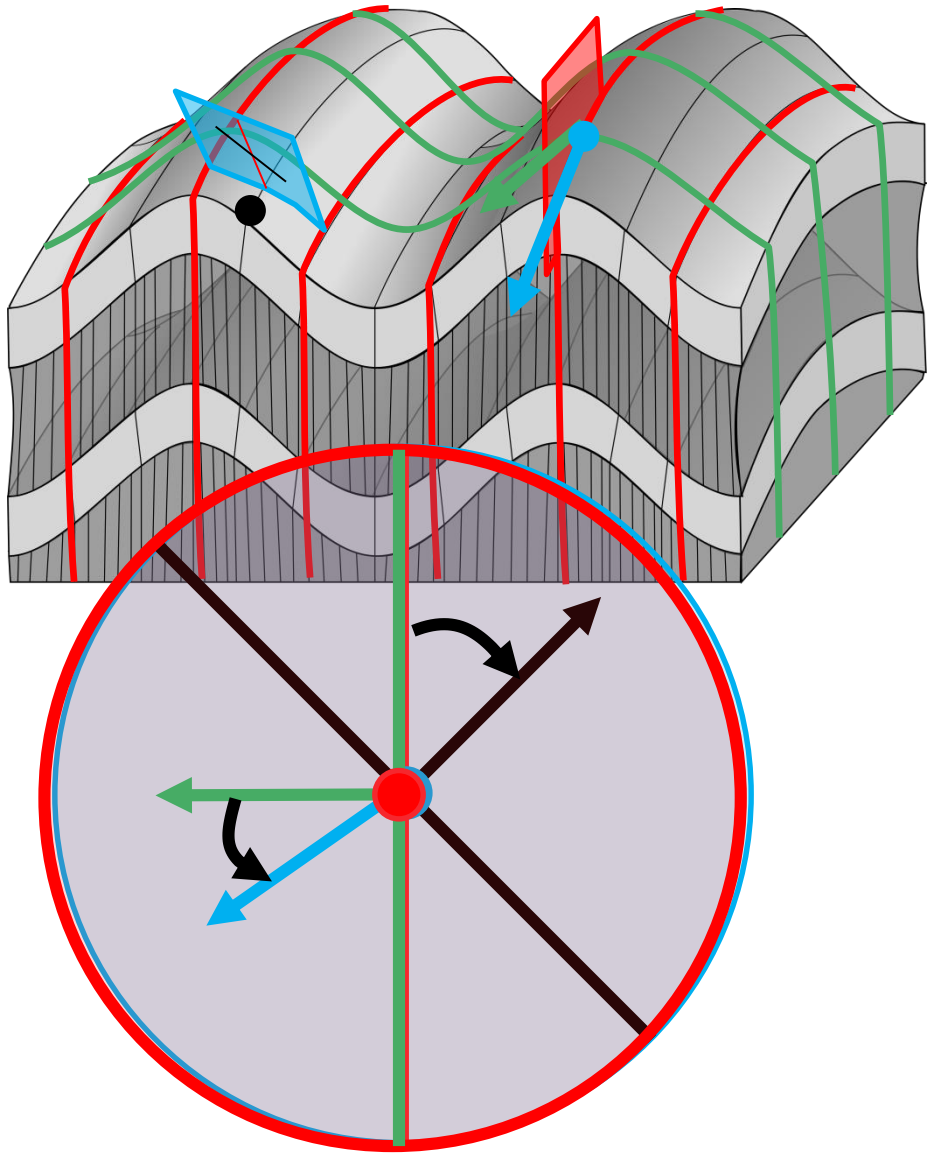
Implicit modeling of folds and overprinting deformation

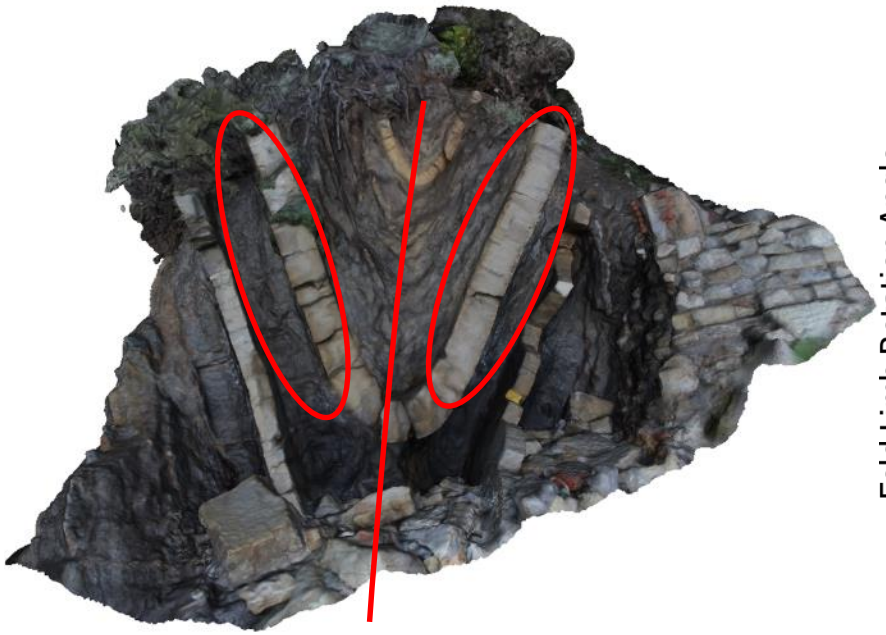
Gautier Laurent [a,b,*], Laurent Ailleres [a], Lachlan Grose [a], Guillaume Caumon [b], Mark Jessell [c], Robin Armit [a]

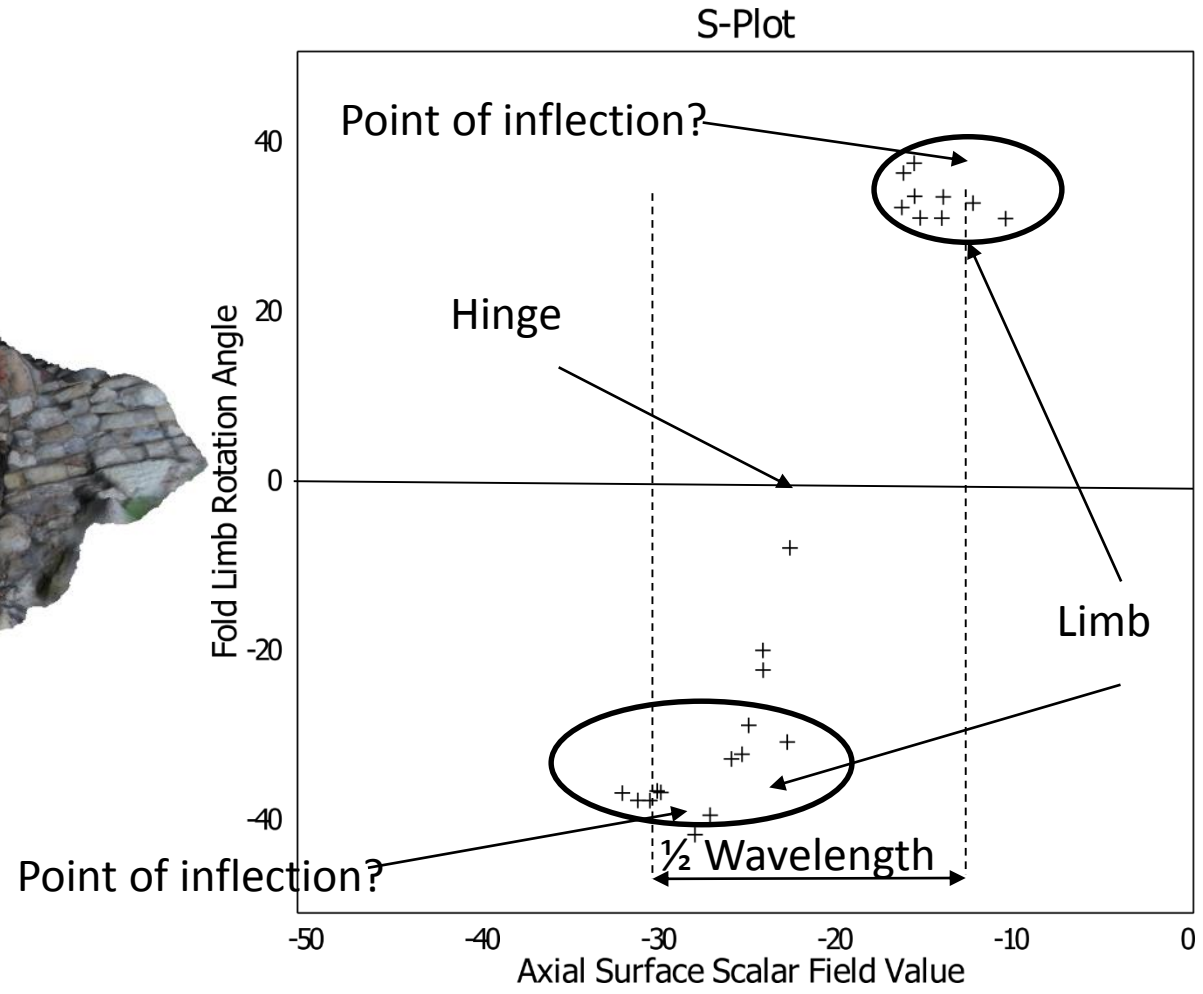
Implicit Fold Modelling: Quantifying fold geometry locally

- Fold Axis Rotation Angle
  - Fold axis observation
  - Gradient of Y field
  - In (axial foliation) XY plane
- Fold Limb Rotation Angle
  - Folded foliation observation
  - Gradient of axial foliation (Z field)
  - Looking down plunge



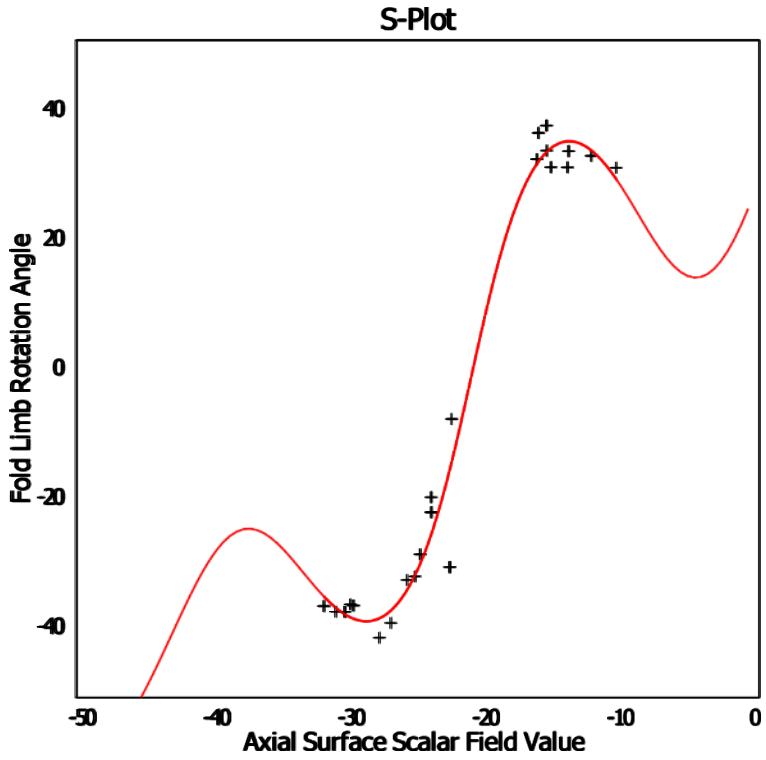
Fold geostatistics

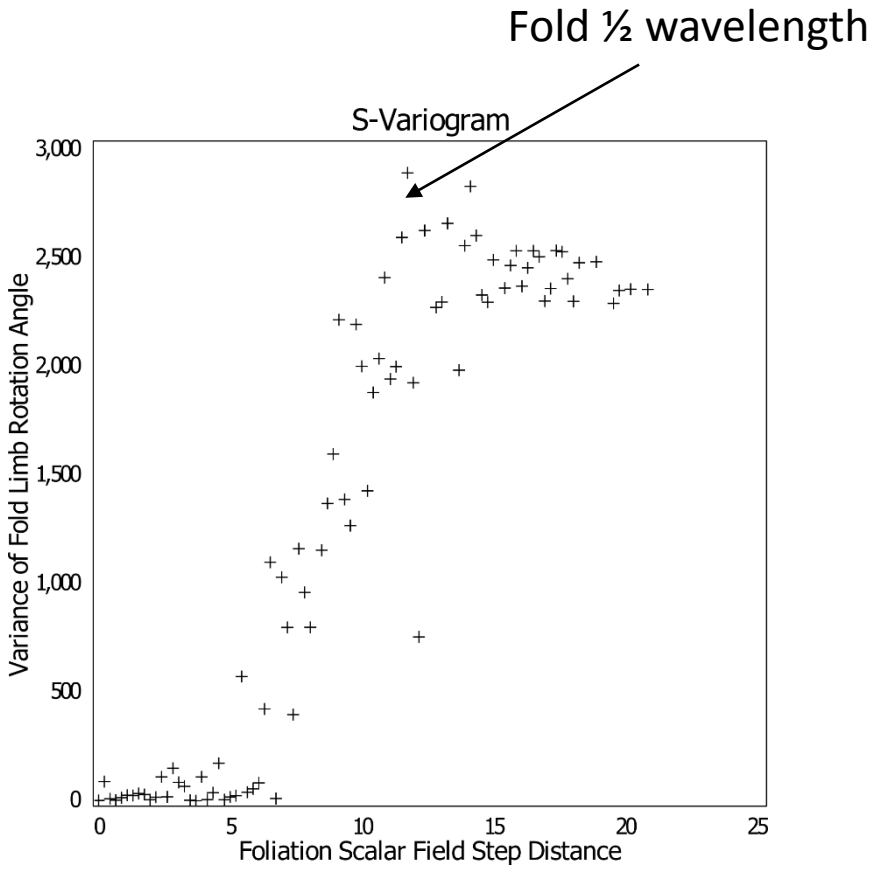




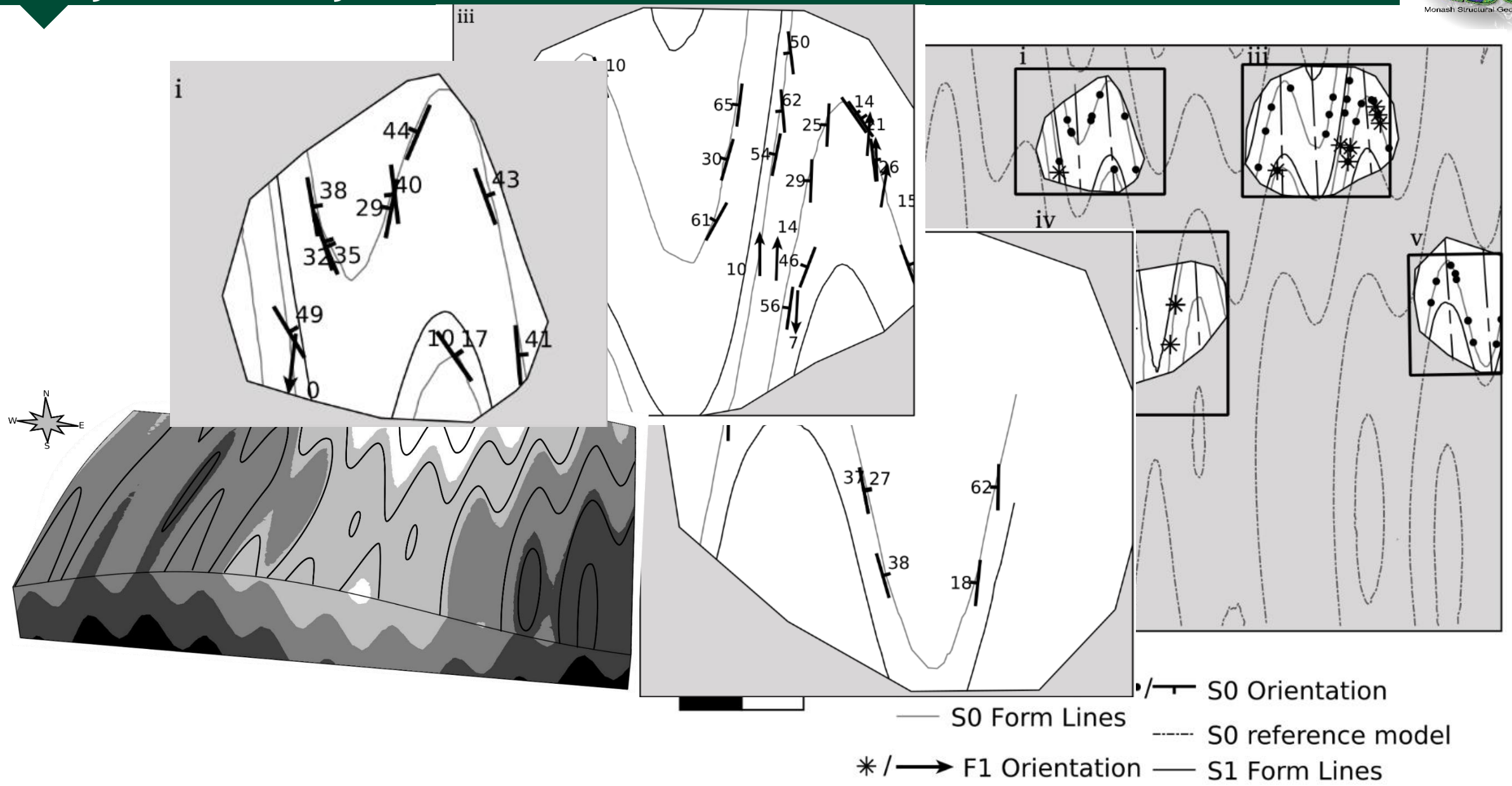
Fold geostatistics

- Interpolate gradient directly instead of angle
- Use fold wavelength as shape parameter



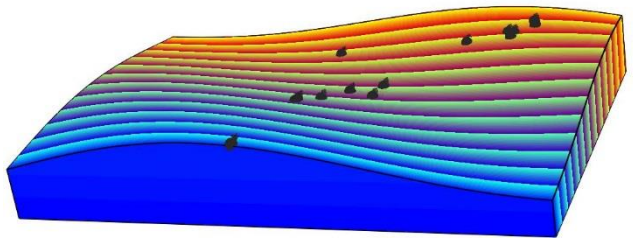


Todays case study

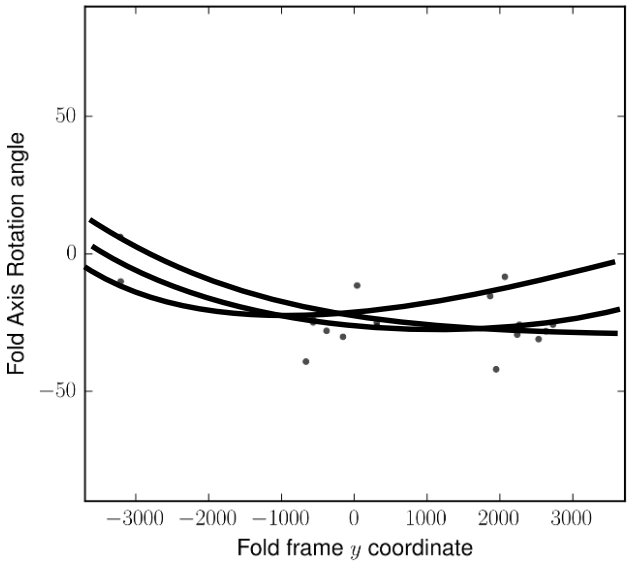


Fold Geostatistics

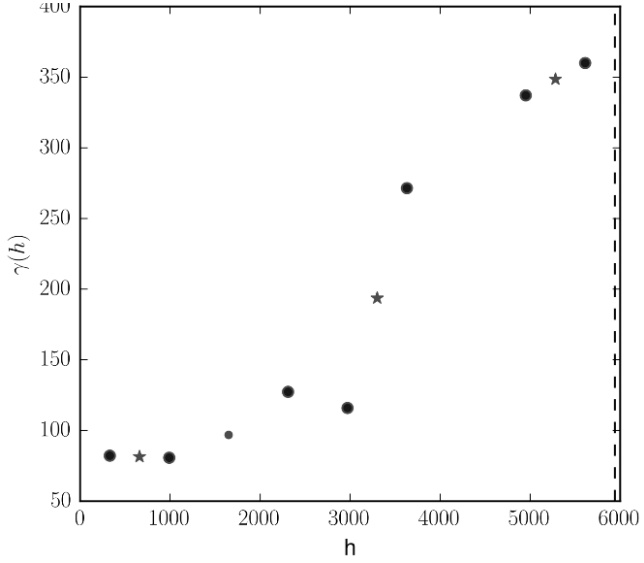
Fold frame y coordinate



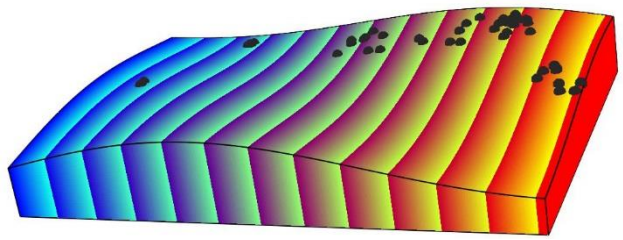
Fold Axis S-Plot



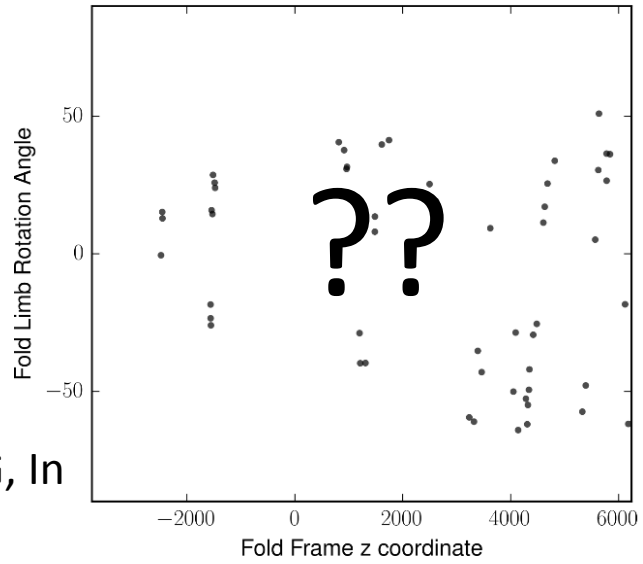
Fold Axis S-Variogram



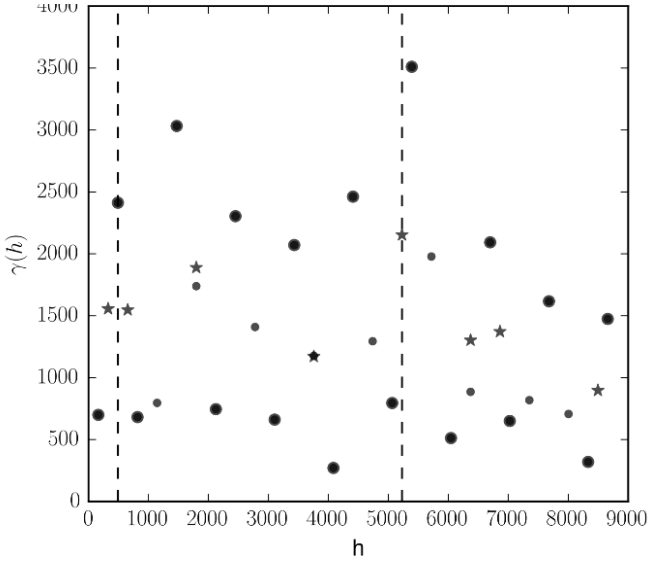
Fold frame z coordinate



Fold Limb S-Plot



Fold Limb S-Variogram



(Grose et al., 2017, JSG, In Press)

Bayesian Inference for Fitting Fourier Series Fold Geometry Model

- Parasitic folds modelled specifying multiple wavelength parameters

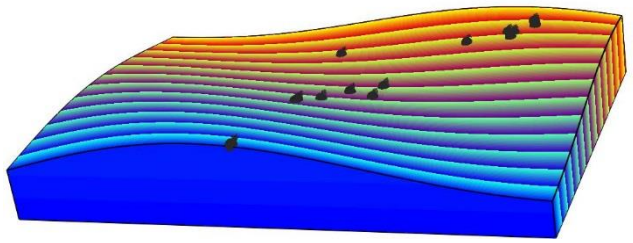
$$\hat{y}\,(x_i|A_0, A_{1..n}, \lambda_{1..n}) = A_0 + \sum_{n=1}^{N} B_n \cos\frac{2\pi}{\lambda_n} x_i + \sum_{n=1}^{N} A_n \sin\frac{2\pi}{\lambda_n} x_i + \text{uncertainty}$$

- Bayesian inference

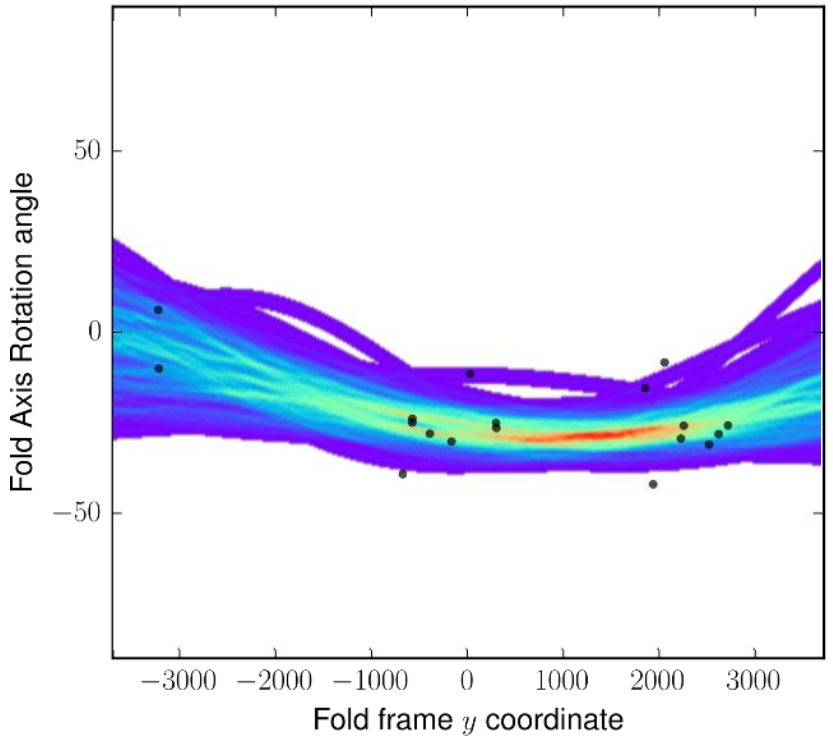
$$P(\theta|D) \propto P(D|\theta) \cdot P(\theta)$$

- Prior distributions:
  - Fourier coefficients – Normal distribution
  - Wavelength – Normal distribution
  - Uncertainty – Jeffery's prior (uninformative)
- Sample from joint posterior distribution using Gaussian likelihood function and Markov Chain Monte-Carlo sampler using PyMC2
- Find joint posterior distribution for BOTH rotation angles

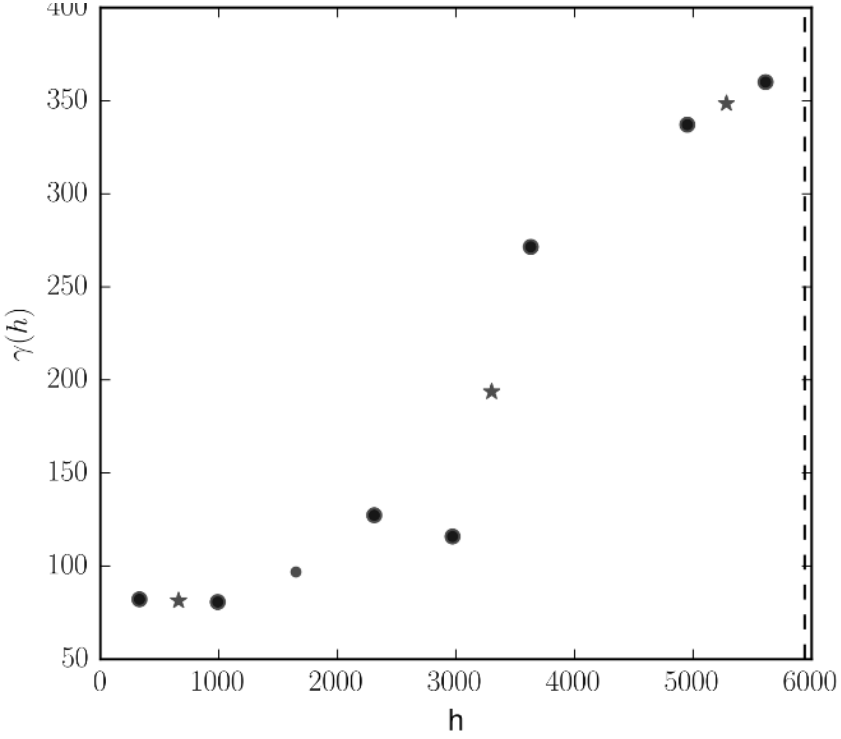
Fold axis rotation angle



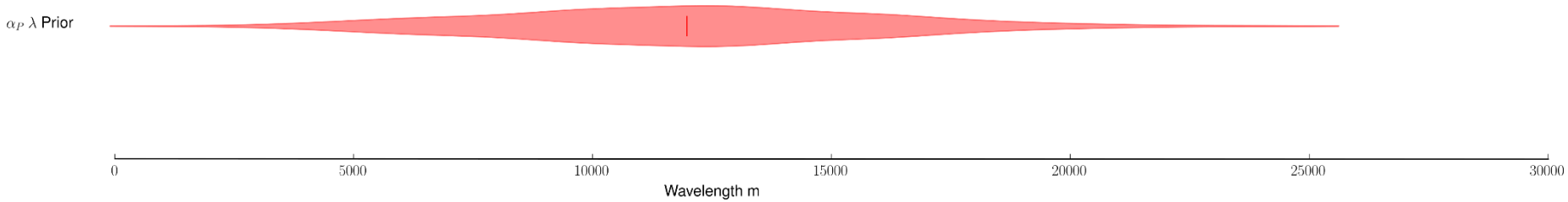
Fold Axis S-Plot



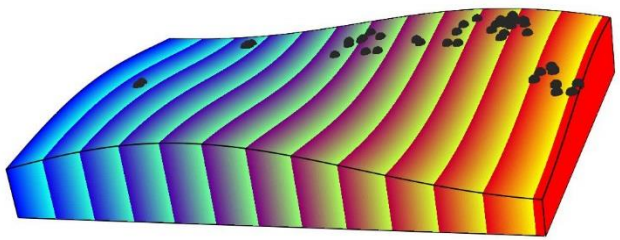
Fold Axis S-Variogram



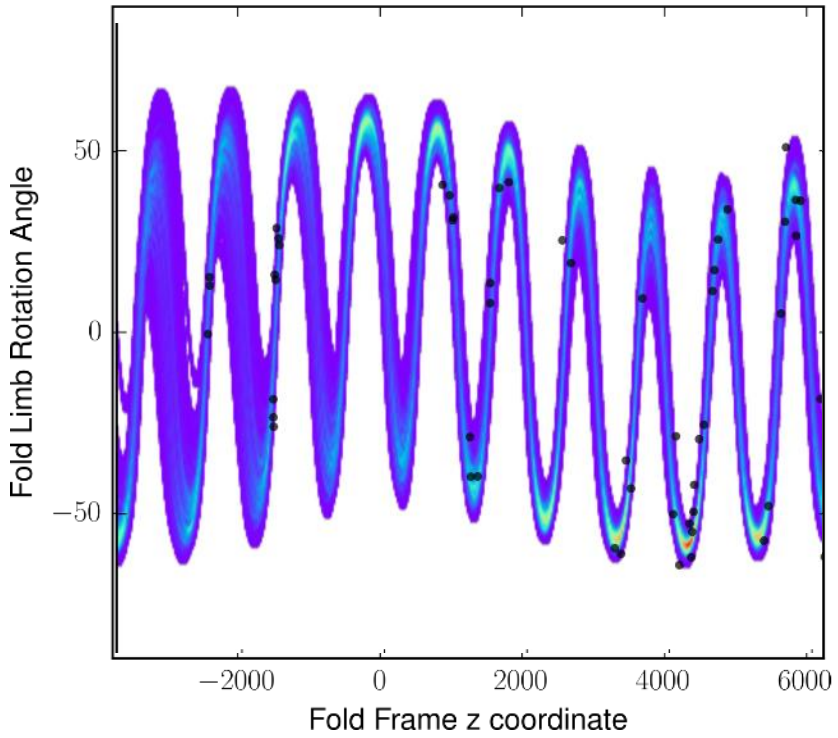
Wavelength PDF



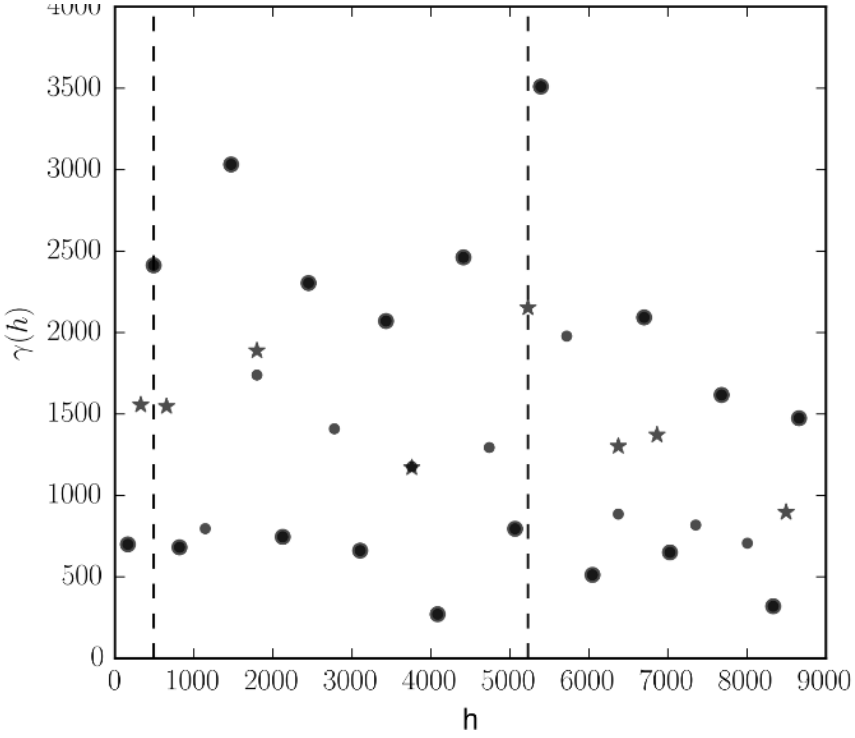
Fold Limb Rotation angle



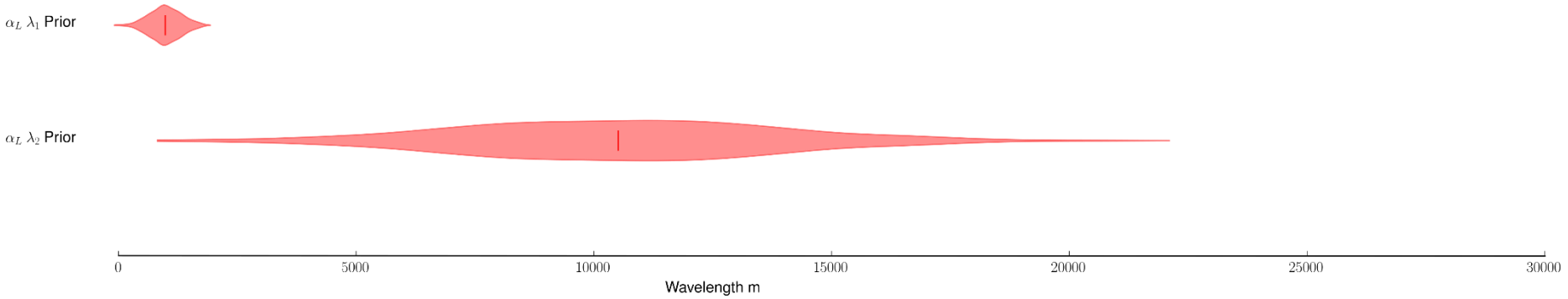
Fold Limb S-Plot



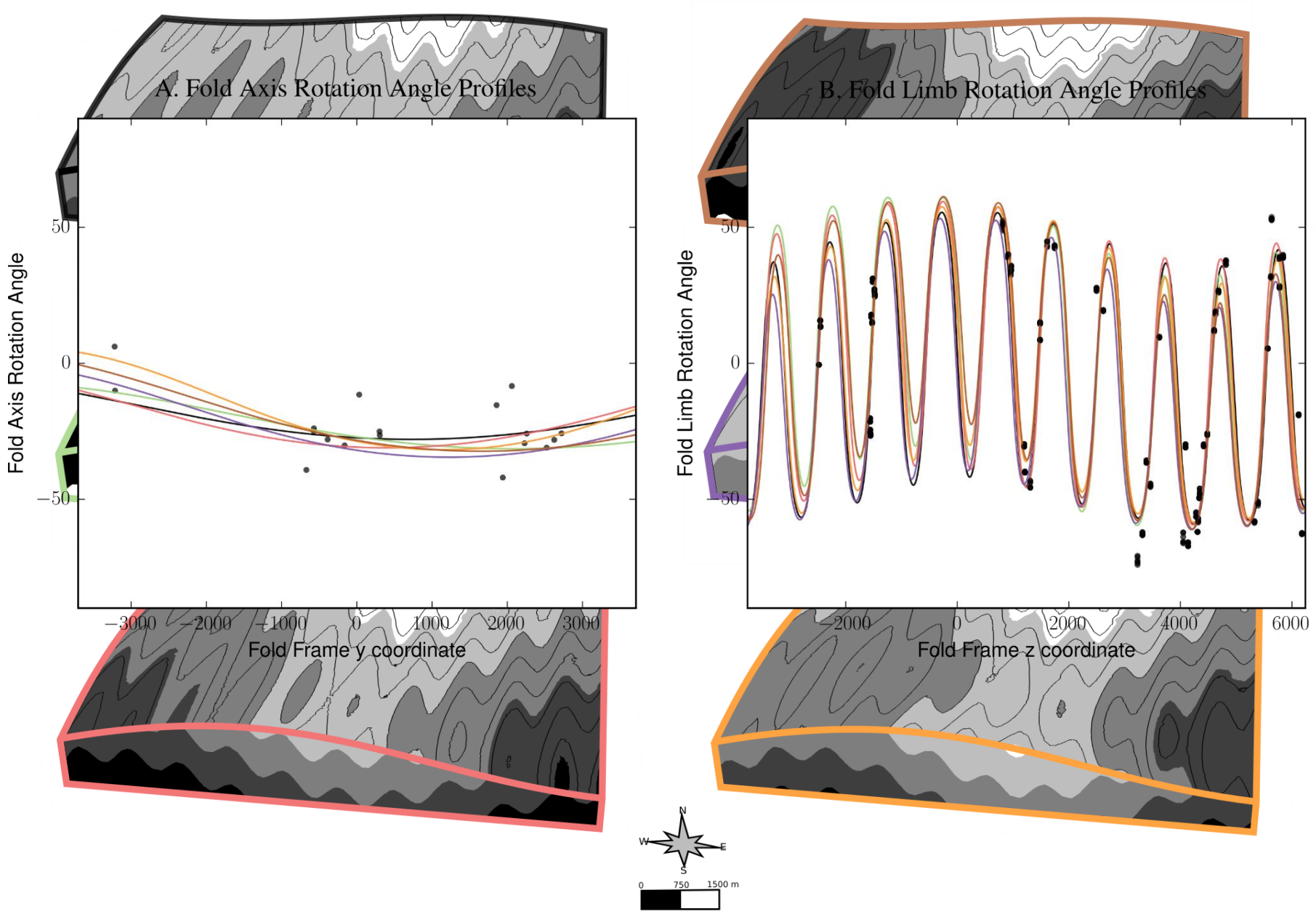
Fold Limb S-Variogram



Wavelength PDFs

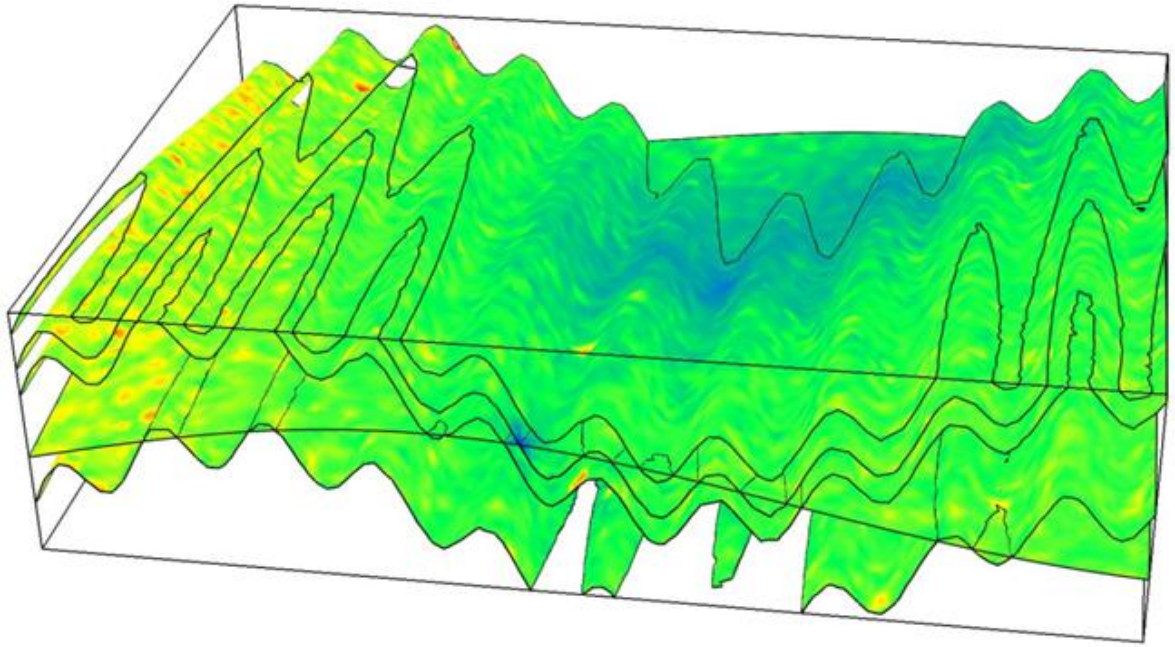


Sample models

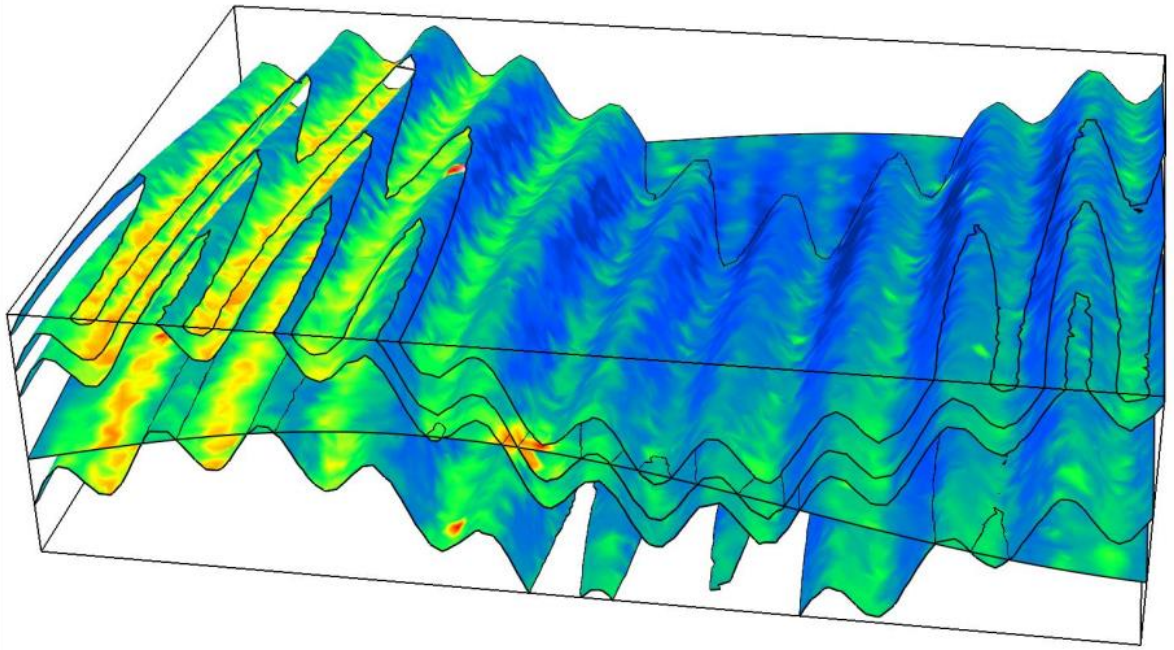


Comparing models

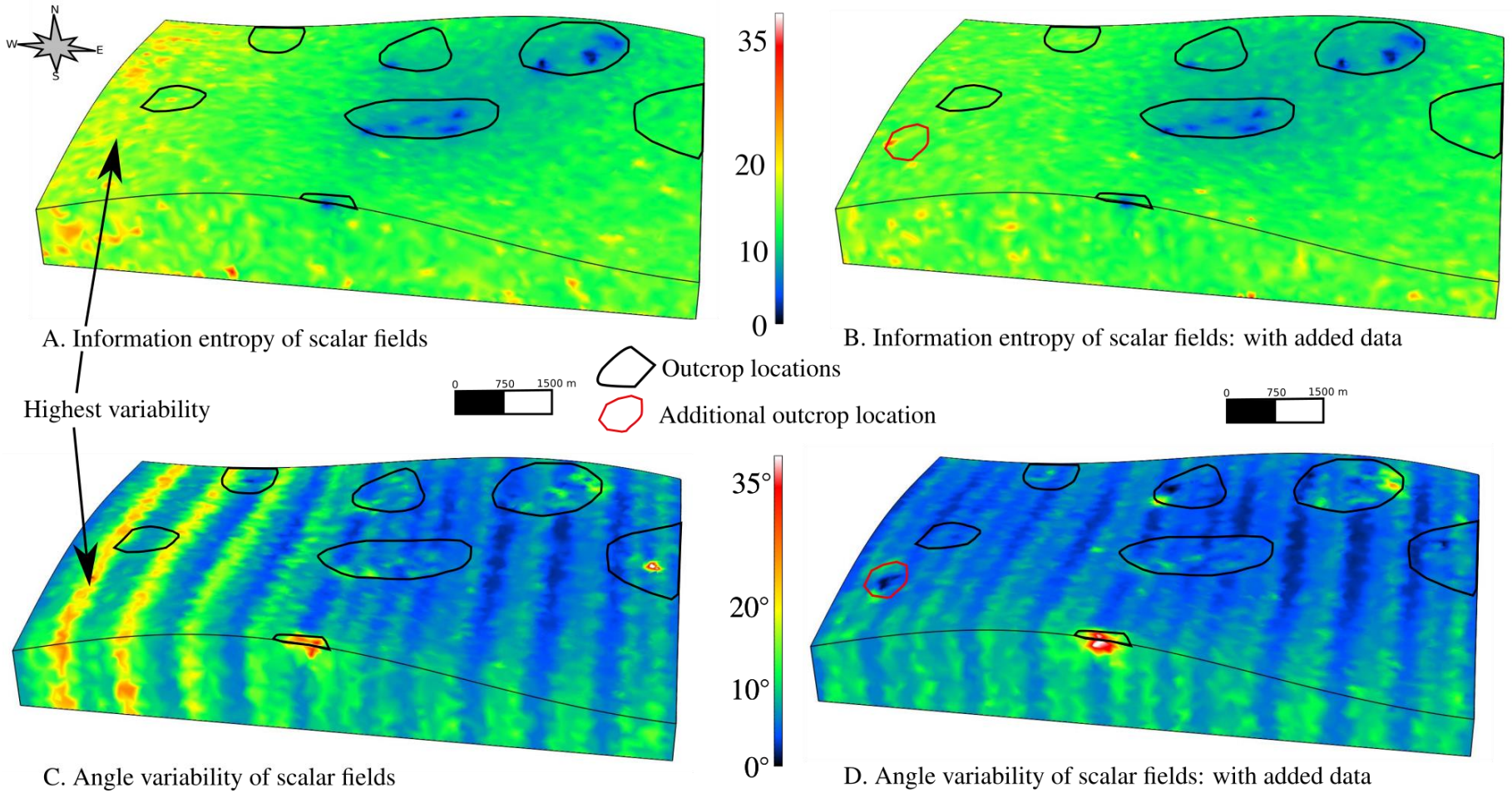
Uncertainty in scalar field value

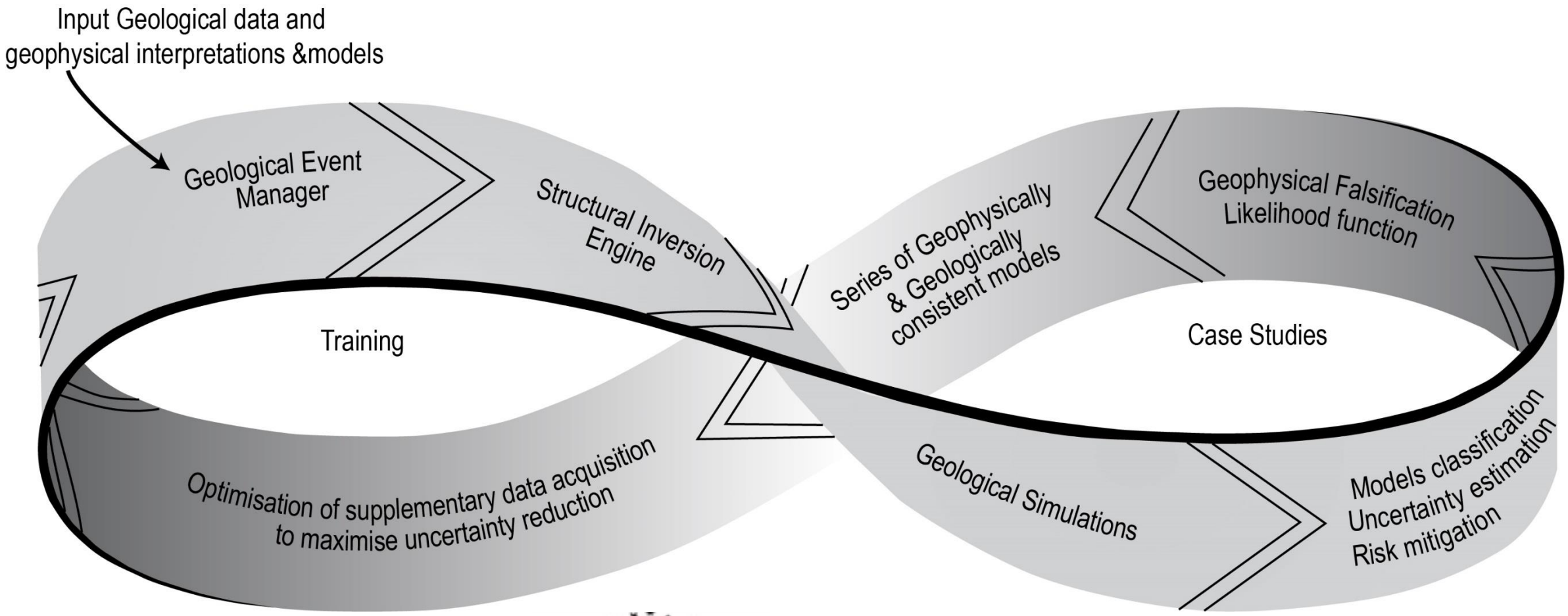


Uncertainty in scalar field geometry



Reducing uncertainty





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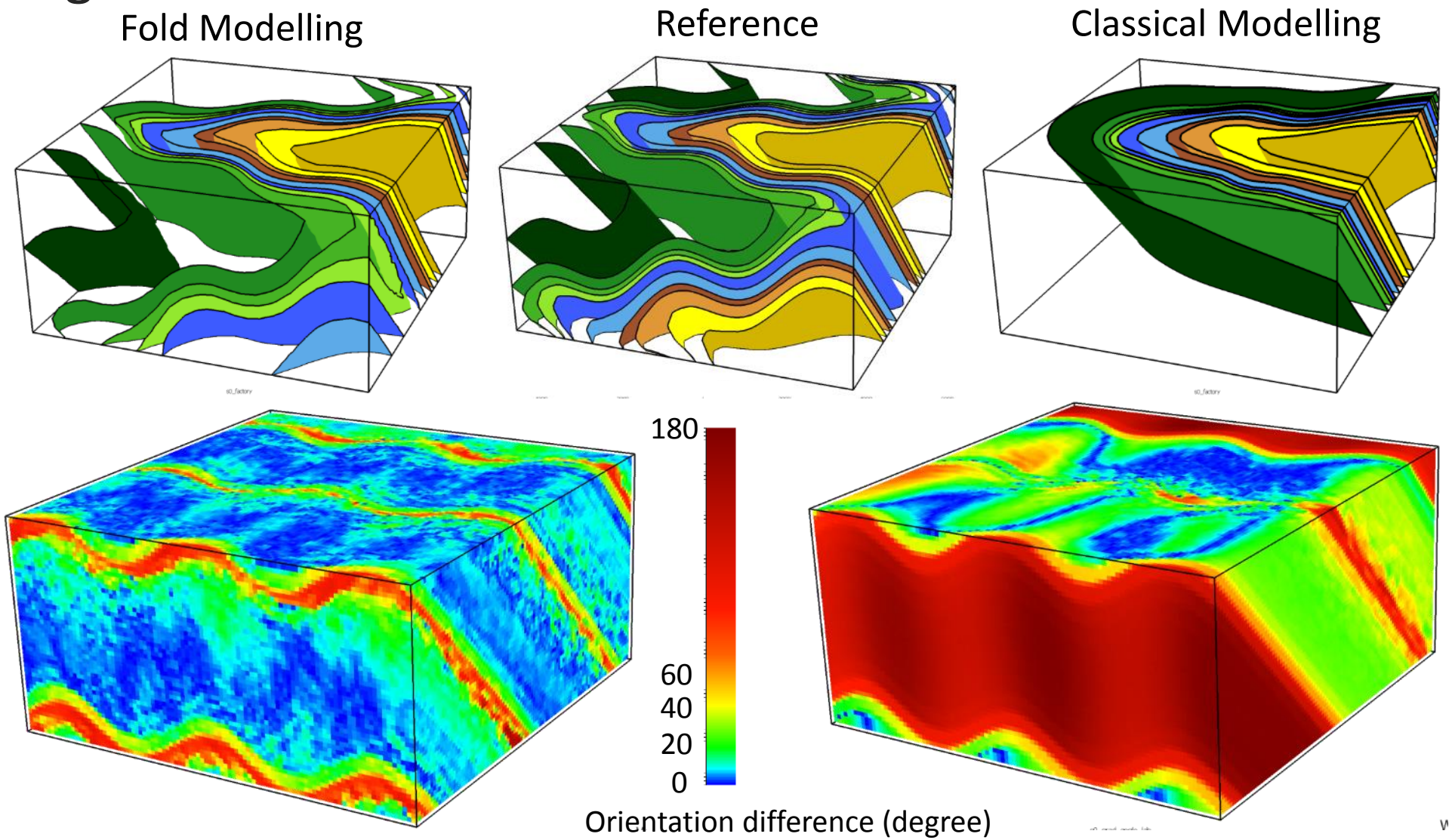
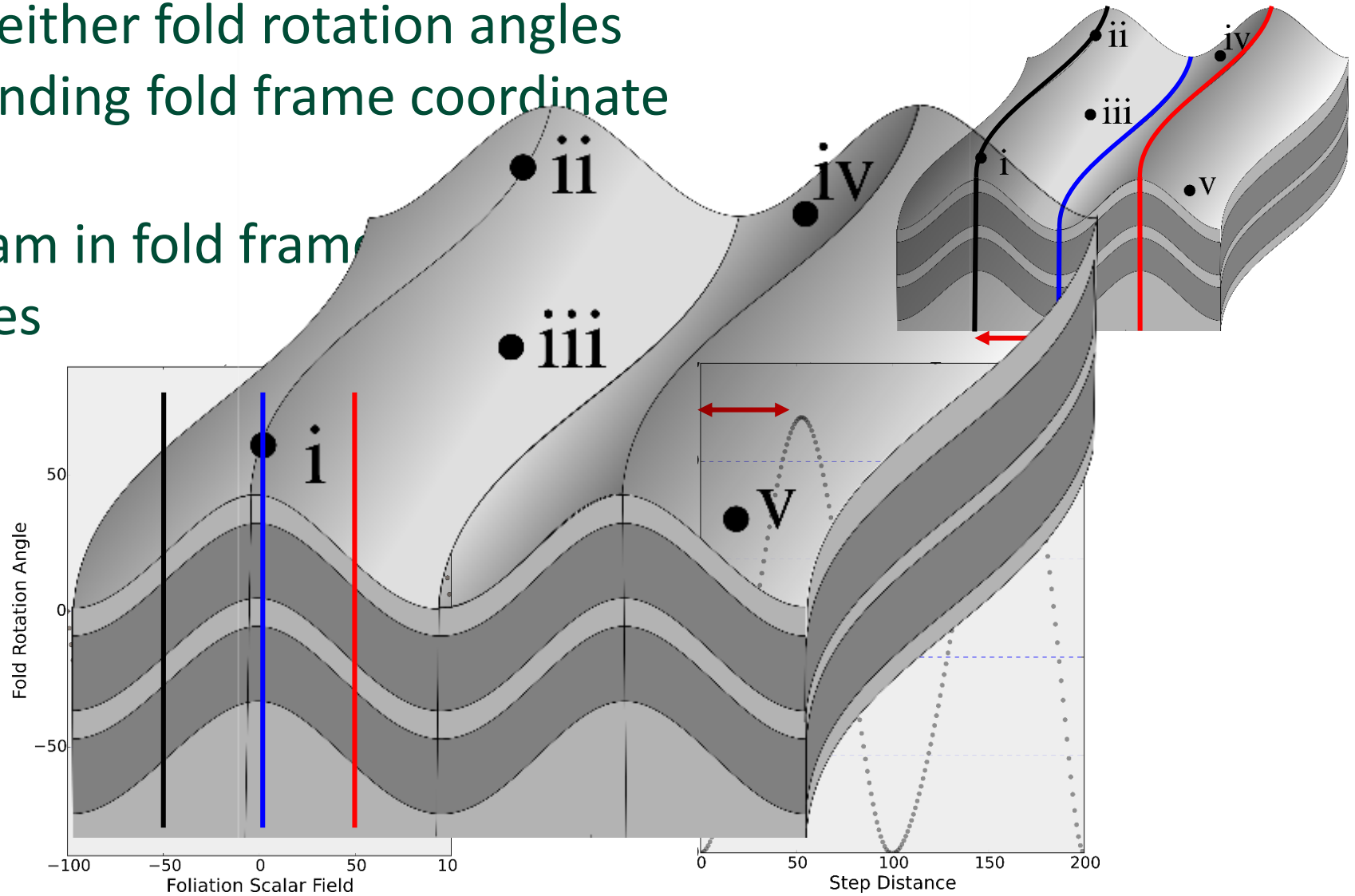
Implicit Structural Modelling Engine

- Measuring differences



Fold geostatistics

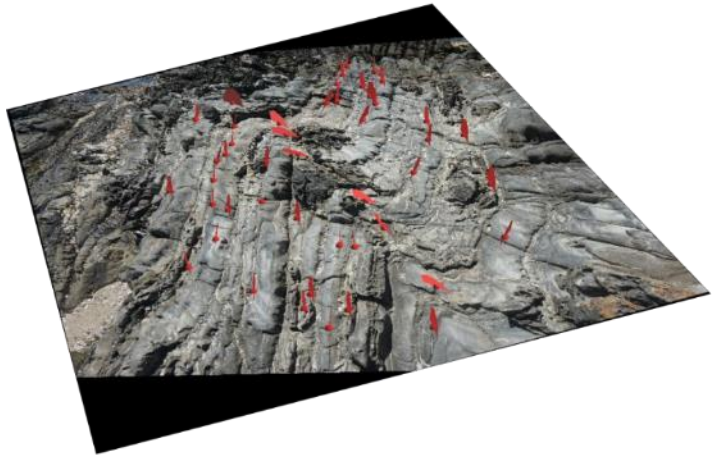
- S-Plot
  - Cross plot of either fold rotation angles and corresponding fold frame coordinate
- S-Variogram
  - Semi-variogram in fold fram
    rotation angles



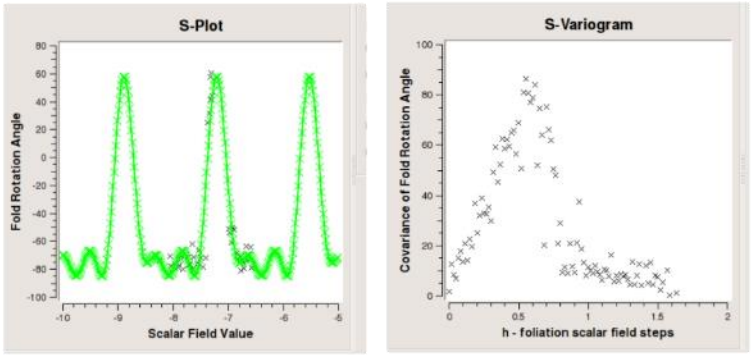
Accepted paper to J. Structural Geology: Structural Data Constraints for Implicit Modeling of Folds (Grose et al.)

Time-aware Structural Engine: RBF + Fourrier series

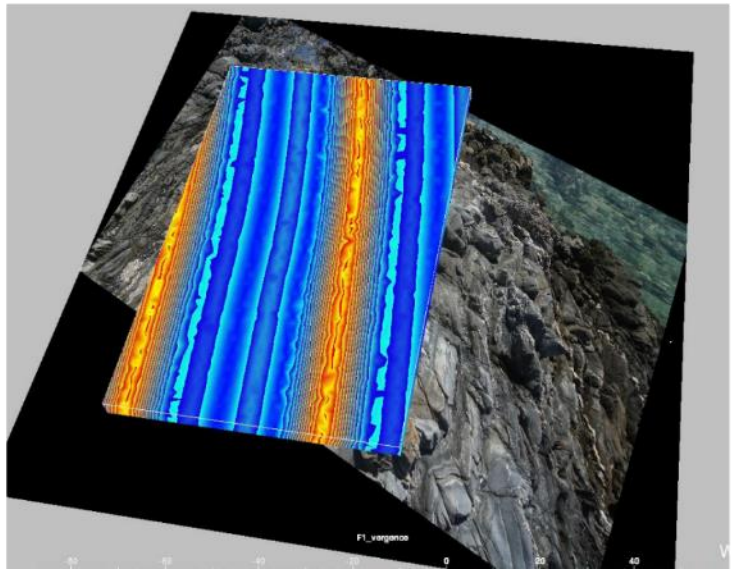
A) Outcrop image with field observations



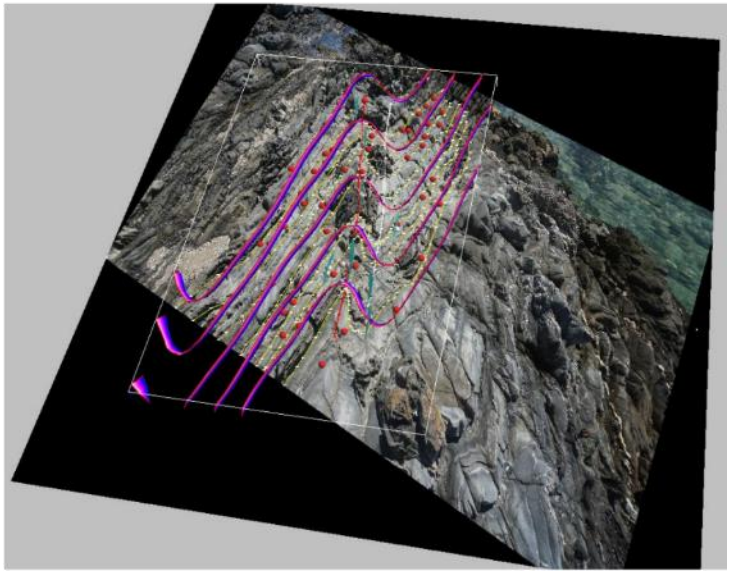
B) Foliation plots: Left S-Plot of S1 and S0 with interpolate profile (green). Right S-variogram S1 and S0.



C)Fold limb rotation angle scalar field interpolated from B

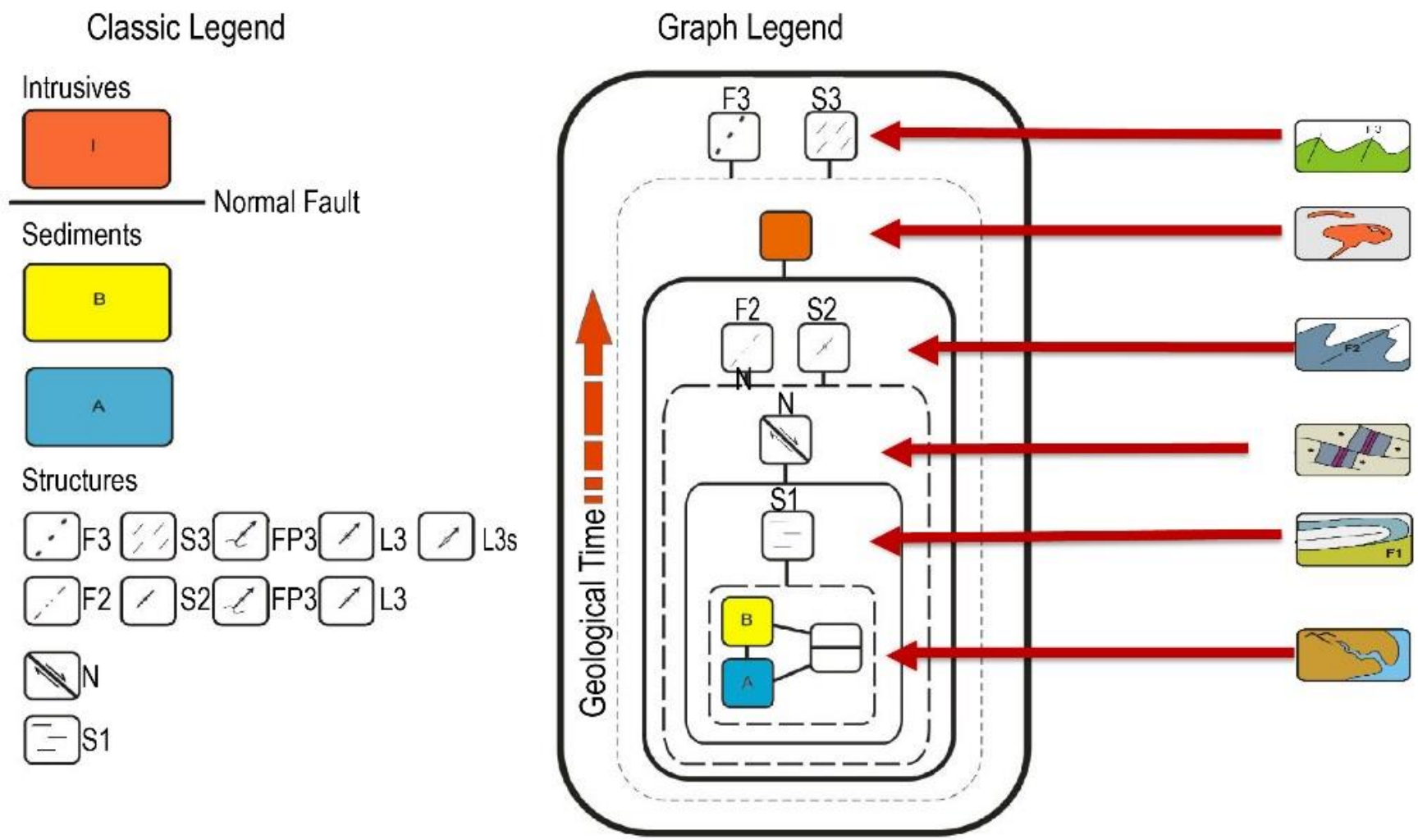


D) Final geometrical model showing form surfaces for bedding



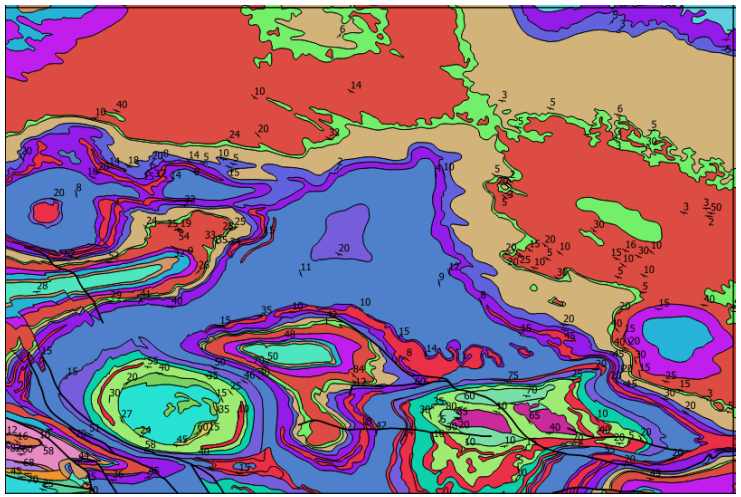
(Grose et al., Laurent et al.)

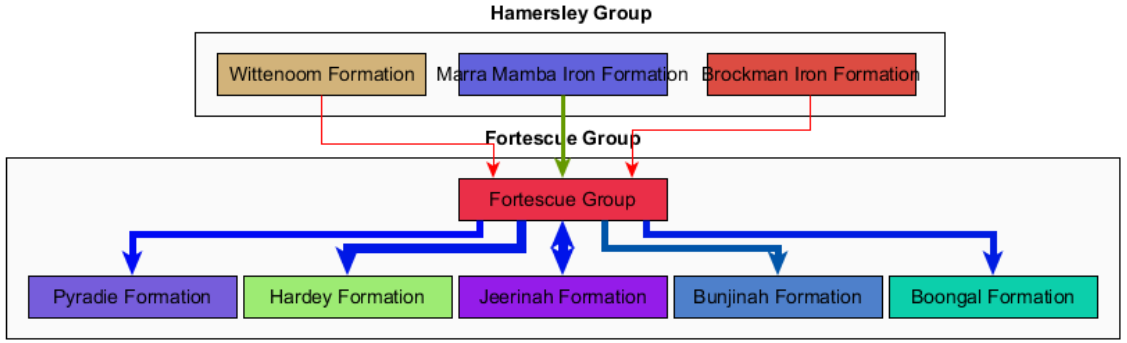
Geological Event Manager

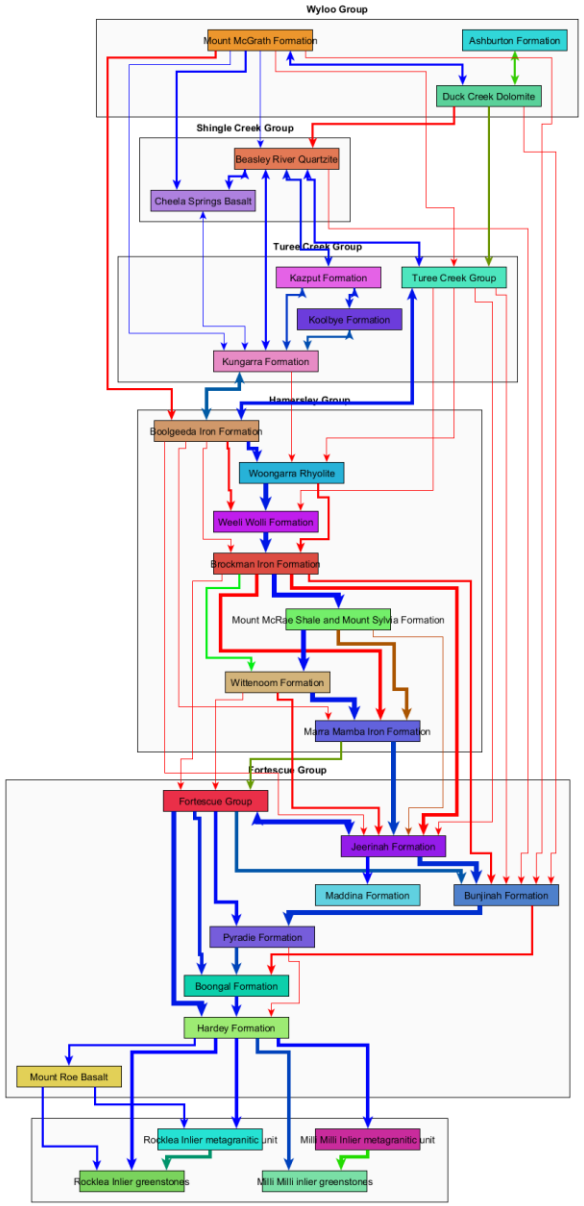


De Kemp et al., Exploration 17

Geological Topology from maps







Ogarko 2016