An Object Oriented Approach to Gradient & Tensor Data Processing

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Abstract

In an effort to maximise the re-useability of existing engineering codes that cover the gamut of Magnetic and Gravity processing, a new class of objects have been designed with the purpose of hiding the details (abstraction) of exactly what components of a field have been observed in a survey dataset. Historically, codes have mostly been written to filter, level and grid "scalar" line data, e.g. Total Magnetic Intensity.

A base class is written to continue to support this existing functionality, and instead of assuming the observed field is "a double precision floating point number", it is recast to be "observed".

A family of derived classes have been designed to honour all the commonly available airborne geophysical observation packages.

Specifically, for magnetic gradiometry systems, the magnetic intensity plus

1. vertical gradient only,
2. transverse gradient (wing tip sensors),
3. transverse & longitudinal gradient (wing tip & tail stinger)
4. all gradients (full tri-axial system),
5. all components of a field,
6. tensor gradients.

For moving platform gravity, the vertical component if available plus

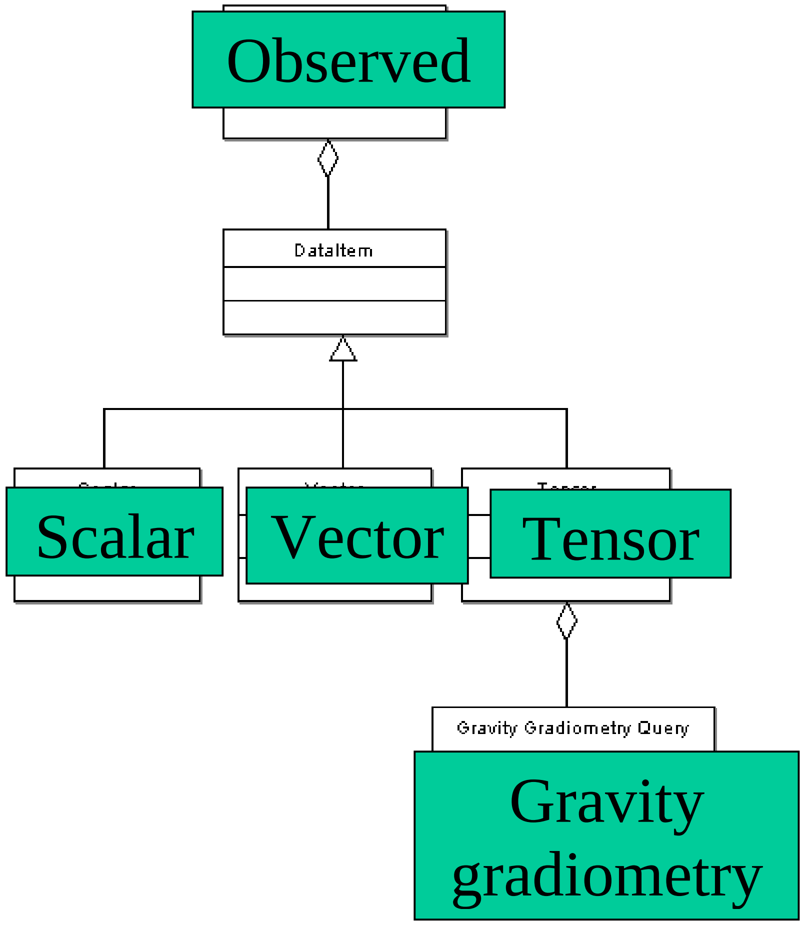
1. full tensor gradients (Bell)
2. Vertical component plus motion monitors (L&R / ZLS)
3. 2 horizontal curvature tensor (Falcon system)
4. 3 gravity components (Sander)

With this approach, each variant is delegated the task of enforcing any innate invariant relationships eg tensor and positive definite symmetric, trace invariance, rotational invariance, boost symmetry etc.

This innate behaviour can be relied upon to carry through in any process involving a manipulation of itself with another reading. This greatly assists the development of algorithms which work with all the various systems in a physically consistent way.

Object Oriented Design Elements

The first object oriented design that is being used to hide details of the actual data collected is shown.



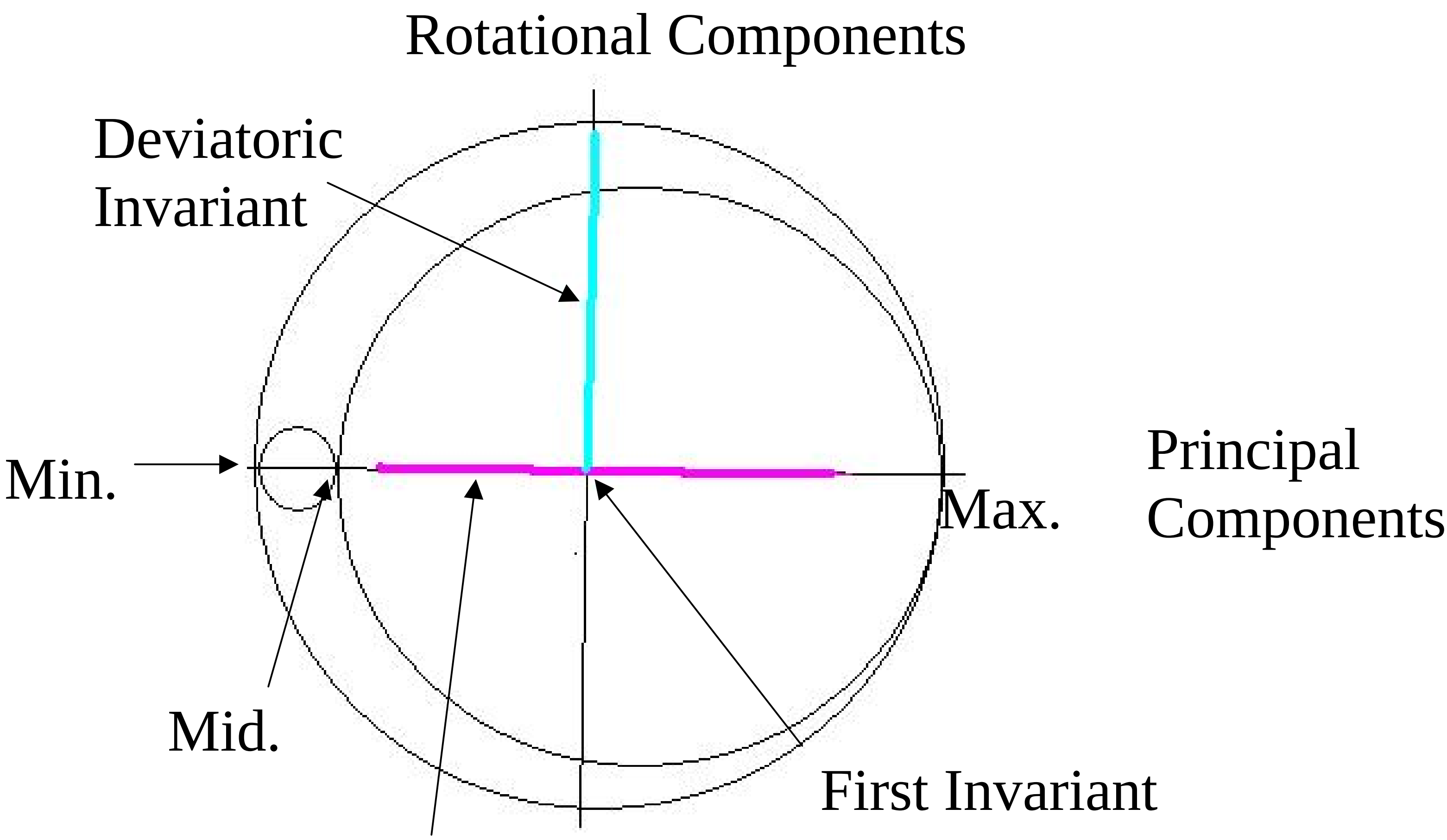
Refinement of this design, once the base class is established, can progress with minimum impact on applications and other libraries. Five variations on the vector class are immediately required for service, namely Magnetic and Gravity gradients, Magnetic and Gravity Components and a directional cosine vector.

A second area in observational geophysics that would benefit from an object design is compensation strategies – the treatment of monitors such as flux-gates, accelerometers etc.

Visualization Strategies

Tensor

A traditional means of understanding the relationship between tensor components is accomplished using a Mohr (1900) circle diagram. In the context of a processing system, a spreadsheet editor has been adapted to show Mohr’s circles for an observed series of tensor readings.



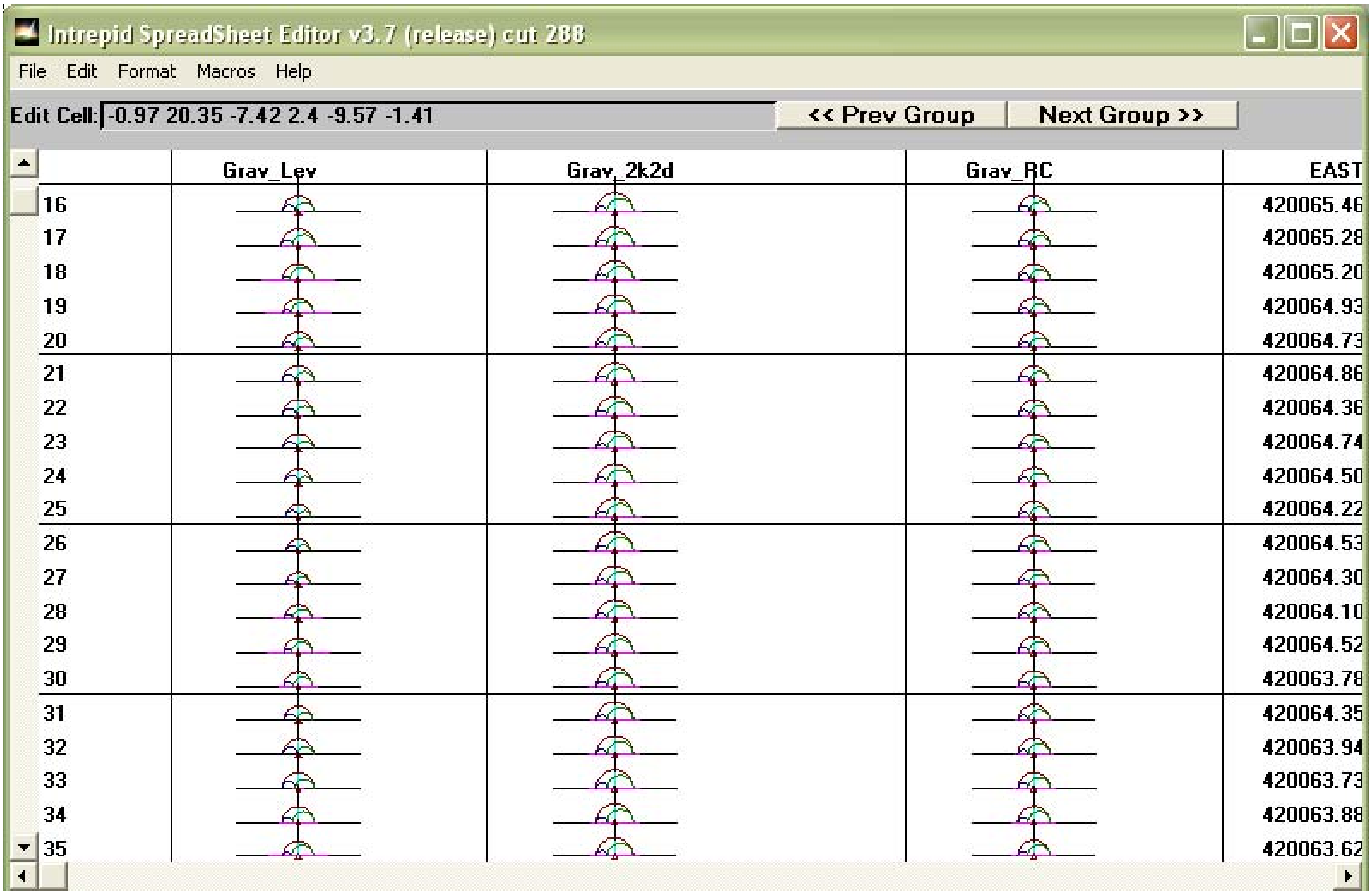
In the case of gravity gradiometry, the First Invariant of the tensor is supposed to be zero, and so a vertical axis is shown at this point. The tensors are symmetric, so only the top half need be shown. The horizontal axis represents the normal or principal components and the vertical axis represents the rotational gradients.

Each tensor has its principal components solved and used as a basis for drawing each circle scaled to the maximum difference in components for the current group.

The following snap of a spreadsheet tool shows each individual tensor before and after two filtering processes.

The Grav_Lev channel is as delivered from the contractor, the Grav_2k2d channel is the tensor filtered by a low pass on each individual component separately and finally, the Grav_RC is an RC filter applied to the tensor as a whole.

One possible critical approach is to examine the preserved ratios of the invariants using the Mohr circles.


Intrepid SpreadSheet Editor v3.7 (release) cut 288
File Edit Format Macros Help
Edit Cell: -0.97 20.35 -7.42 2.4 -9.57 -1.41
<< Prev Group
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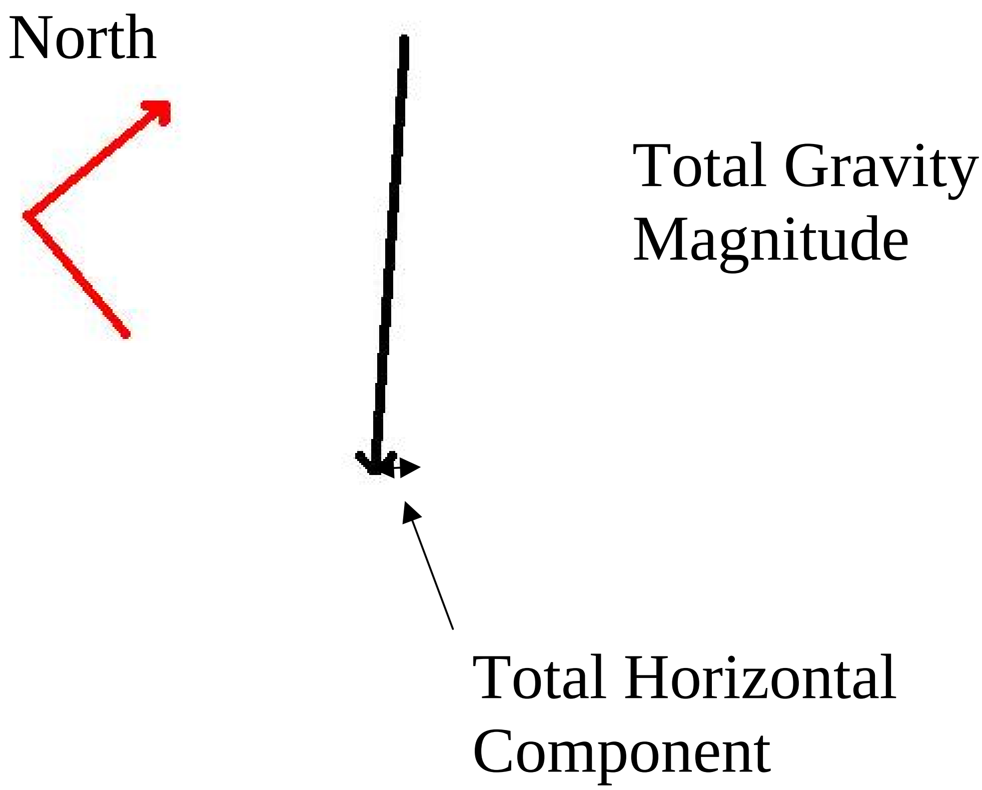
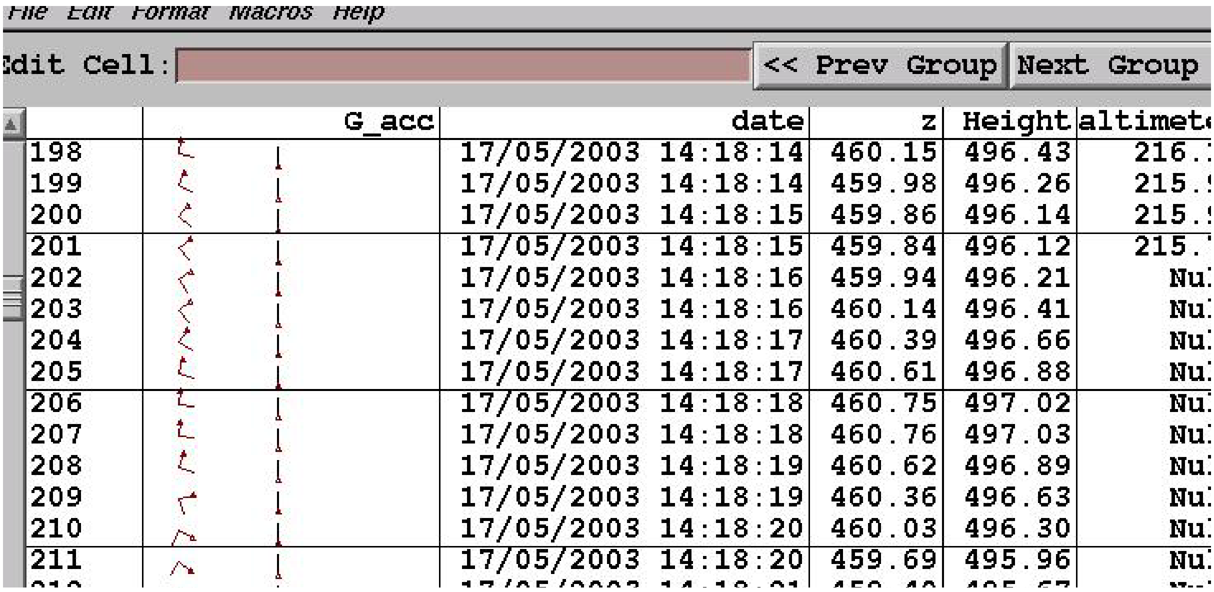
Grav_Lev
Grav_2k2d
Grav_RC
EAST
16 420065.46
17 420065.28
18 420065.20
19 420064.93
20 420064.73
21 420064.86
22 420064.36
23 420064.74
24 420064.50
25 420064.22
26 420064.53
27 420064.30
28 420064.10
29 420064.52
30 420063.78
31 420064.35
32 420063.94
33 420063.73
34 420063.88
35 420063.62

Vector

For Gravity components, as measured by a system such as Sander's, the predominant signal is the traditional vertical component. The maximum horizontal component swings around all points of the compass, reflecting the lower signal to noise ratio as much as the density variations. The following graphical mimic is proposed for this case.



The following is a sample of the Timmins data set from Sander showing the gravity component displayed in a mimic of the above form.



File Edit Format Macros Help

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	G_acc	date	z	Height	altimete
198		17/05/2003 14:18:14	460.15	496.43	216.
199		17/05/2003 14:18:14	459.98	496.26	215.
200		17/05/2003 14:18:15	459.86	496.14	215.
201		17/05/2003 14:18:15	459.84	496.12	215.
202		17/05/2003 14:18:16	459.94	496.21	Nu
203		17/05/2003 14:18:16	460.14	496.41	Nu
204		17/05/2003 14:18:17	460.39	496.66	Nu
205		17/05/2003 14:18:17	460.61	496.88	Nu
206		17/05/2003 14:18:18	460.75	497.02	Nu
207		17/05/2003 14:18:18	460.76	497.03	Nu
208		17/05/2003 14:18:19	460.62	496.89	Nu
209		17/05/2003 14:18:19	460.36	496.63	Nu
210		17/05/2003 14:18:20	460.03	496.30	Nu
211		17/05/2003 14:18:20	459.69	495.96	Nu

Statistical Quantities

Another immediate challenge is to create summary statistics for these data types. There is a very large and well established set of methods for directional field vector data that is used in paleomagnetics. Fisher (1953) suggested that the distribution of vectors on a unit circle is analogous to a normal distribution. This is being pursued.

For tensor gradient data, the principal components are pressed into service to act as Maximum, Minimum and Mean analogues. Timmins & Hagar dataset are used to illustrate possible new styles of enhanced statistical reporting.


```
Detailed Info on Grav_Lev

  Type    = Tensor field data
  Max Eigenvalue = 57.199669
  Mid Eigenvalue = -3.053063
  Min Eigenvalue = -55.346865
  Units        = Unknown
  Mean EigenVector 1
   Declination  = -10.312410 deg.(Bearing)
   Inclination  = -29.422615 deg.(Dip)
   Std Dev      = 65.206898 deg.

  Mean EigenVector 2
   Declination  = -49.548060 deg.(Bearing)
   Inclination  = 19.172563 deg.(Dip)
   Std Dev      = 63.012274 deg.

  Mean EigenVector 3
   Declination  = -59.209271 deg.(Bearing)
   Inclination  = 26.489885 deg.(Dip)
   Std Dev      = 41.219689 deg.

  Samples  =179507
  Nulls    =0
  Groups   =105
  Precision=Tensor
  Format   =
```

Aircraft Compensation

A variety of compensation systems have evolved.

The first set for magnetics are derived from Leliak (1962) and is essentially a Vector compensation for Yaw, Roll and Pitch of the aircraft in the Earth’s magnetics field.

A second set for moving platform gravity measurements derive from the LaCoste decorrelation. Up to 8 secondary accelerations may be monitored as an aid to correcting the observed gravity.

A generalization of these methods is considered possible.

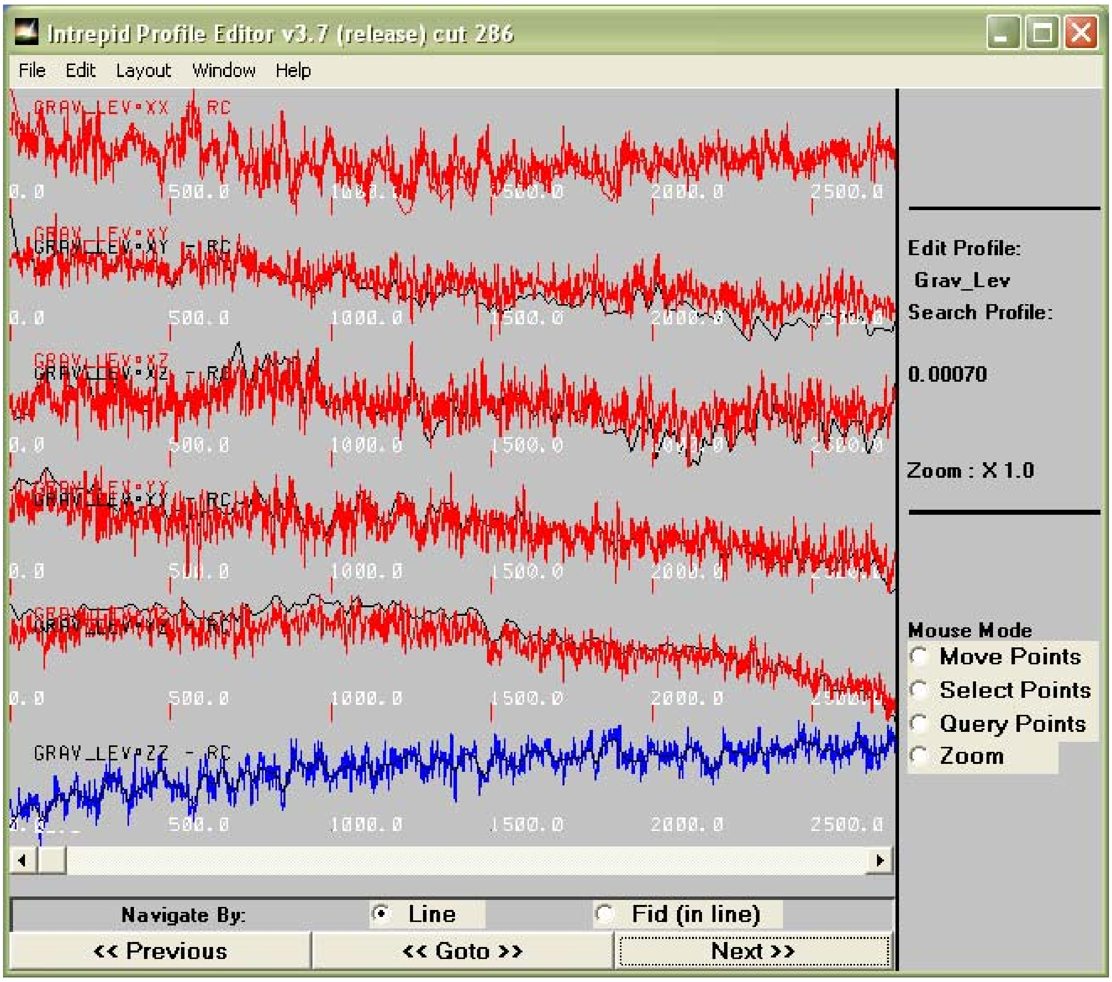
Treatment of Noise

In dealing with the complexity of an observed data package, it is also appropriate to think about whether the signal to noise ratio may be improved by taking all of a series of observations taken in time, and for instance honouring the invariants of a tensor while a noise or spike filtering operation is performed. The Lacoste RC filter code has been used as a test on observed Bell tensor and the Timmins data to explore the possibilities. This filter can be made recursive and simply implemented. The modification to allow for a tensor is then simple.

Summary for a Tensor Filter

- Adapted from L. Lacoste for curvature calculation and filtering
- Uses a stack of original and transformed or filtered observed values
- Uses the time in seconds (sampling time say 1 sec or 10 sec)
- p & q are filter weights or convolve factors for a sample point operator based on time
- Similar in operation to the RC or Kalman filter but works on the whole tensor.

The following is an example of a line from the marine Hagar Bell Tensor data from the North Sea showing raw and filtered data using this Tensor filter.



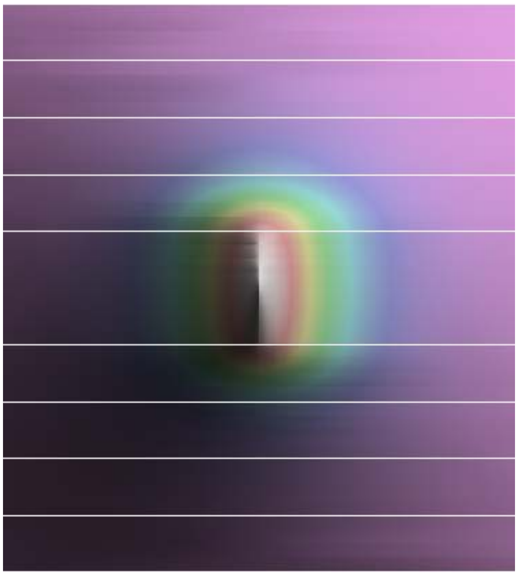
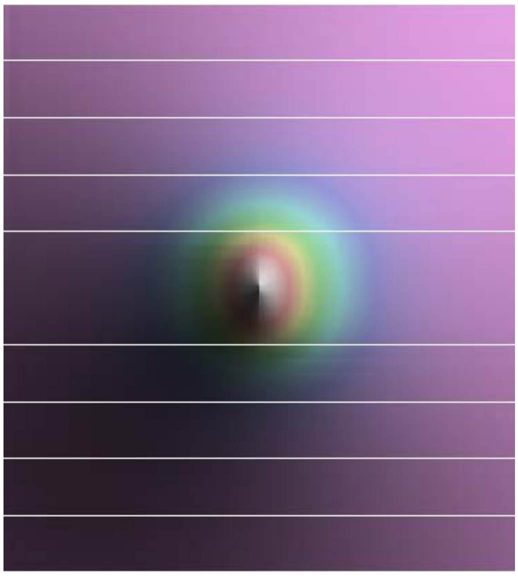
Interpolation Strategies

We sourced real data and also created model data that is representative of each type of observed data variation. The main process to bed the approach in was chosen to be gridding and some of its variations on Potential Field algorithms ie

1. Akima Spline (use observed gradient transformed to be along line),
2. Minimum Curvature (Briggs, 1974)
3. Nearest Neighbours (blend gradient contribution with field estimate).

The key to success here is to ask how gradient information can be used to create a superior representation of the field as an interpolation is being made and to examine each multiple, addition and division involved tosee how this should be implemented when Vector or Tensor components or gradients are involved. Having looked at each case, it proved possible to define “appropriate overloaded operator rules” for each case, and so in the pre-existing application codes, there was very little change evident.

A typical change might be that a weighting factor is forced to be a second term in a multiplication, instead of being either first or second. Si newZ = wt1 * z1 + wt2 * z2 is changed to be newZ = z1 * wt1 + z2 * wt2. This simple change helps a compiler recognize we are dealing with these smart observed objects, and chooses the correct way to calculate the overall result.

The left image is standard gridding and the right image shows gradient enhanced gridding. The missing observation line is used to stress test the algorithm.

Levelling

Vector Field Data

Misclosure at a cross-over point for a Field becomes the vector difference.
Does the Observation Instrumentation's calibration drift in time? If so, how?
Diurnal correction is also a vector operation.

Tensor Gradients

Misclosure tensor is vector difference of 3 Principal components.
Falcon 2D Horizontal Tensor is what needs to be levelled
Network adjustment/ Loop levelling is easiest process to implement

Current Status

The processes that have progressively been updated to include support for this smart observed data object are

1. Gridding
2. Profile Editing of the complete Tensor
3. Loop levelling
4. Spreadsheet editor – mimic displays
5. Project manager support
6. Import into new persistent database types
7. Statistical improvements

It can be said that there is a very large increase in the use of computer Heap space when these methods are used, but this challenge is easily met by newer generation desktop computing systems.

Virtuous Outcomes

A pleasing outcome from such a general approach is that new acquisition systems recording variations on the theme of components, gradients and or second order gradients, that so far do not exist, may be accommodated in the context of a tried and true processing stream, without software having to be completely rewritten from the ground up.

Another unexpected outcome, is having accommodated a heading correction in say magnetic gradient system, the same code is immediately re-useable for the self weight corrections in a gravity tensor context.

Other Transformations

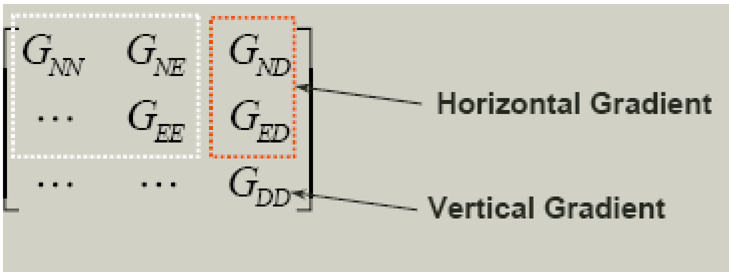
Further to this approach, the ability to transform observed potential field data to any of its gradients or components can also be accomplished in the Fourier and Spatial domain using the Hilbert transform. This transform exploits the rotational symmetry inherent in Field data.

FALCON Discussion

This approach is immediately needed when raw observational data from a "FALCON" like system is to be processed. There is almost a complete horizontal 2D gravity tensor being observed, and it is possible to draw the corresponding Mohr circle. The main unknown is the centre of the circle, as it cannot be assumed to lie at zero in the principal component space.

In this case, the so-called Gne & Guv components of curvature are observed and in one case, for both A & B sets of accelerometers.

$$\begin{pmatrix} G_{NE} \\ \frac{1}{2}(G_{NN} - G_{EE}) \end{pmatrix} = \begin{pmatrix} G_{NE} \\ G_{UV} \end{pmatrix}$$

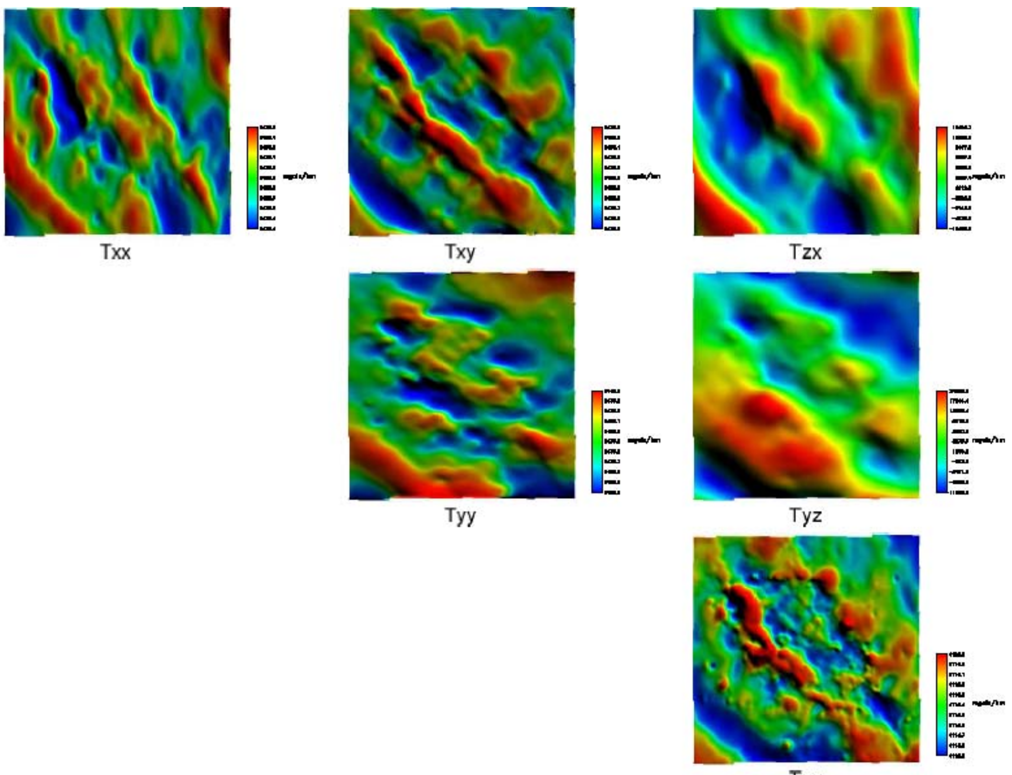


Even with the aid of the tensor Invariant properties, it is not possible to fully populate a tensor from a single observation. One is obliged to make a further assumption, such as

1. assume we have a coherent line of samples to which a FFT can be applied,
2. solve for an equivalent layer for each component and iteratively improve the fit.
3. use a spatial Hilbert transform

This is not necessarily such a penalty, as line based processing is stock in trade for this industry. At the same time, one can then choose to calculate other useful quantities representative of the data, such as statistics, instantaneous phase, and noise characteristics.

As an illustration, the following is a standard (L&R) marine gravity dataset which has been transformed into a pseudo tensor observed survey.



Bouguer Gravity Tensors

Conclusions

Smarter computational support for new generation geophysical datasets is here to stay.

Processing the “OBSERVED” package as an object can be achieved
–Hides details from processes that do not need to know
–Presents Field physics issues naturally

Most of the needed technology already exists in closely related geoscience disciplines.

Instrumentation engineers should be encouraged to gather still more real-time characteristics and to report them, as there is little excuse for not being able to extract more value from this data post-mission.

References

Briggs, I.C., Machine Contouring Using Minimum Curvature, *Geophysics, Vol. 39, NO. 1 (February 1974), p. 39-48, 3 Figs, 3 Tables.*

Fisher, R.A. (1953). Dispersion on a sphere. *Proc. Roy. Soc. London*, A217, 295-305.

Mohr, O. (1900). Welche Umstände bedingen die Elastizitätsgrenze und den Bruch eines Materials? *Z. Ver. Dt. Ing.*, 44, 1524-30; 1572-77.