- **My topic this afternoon is "… (read) …"**
- **You'll understand presently why the word "refracted" is in parenthesis.**
- **My company is Hydrometronics based in the Houston area.**

Up-front Acknowledgments

- For permission to show these data:
  - Jim Thompson (FairfieldNodal)
  - Etienne Marc (FairfieldNodal)
- For valuable discussions:
  - Larry Scott (NCS SubSea)
  - Stuart Porteous (Ikatech)
  - Curt Schneider (ION Geophysical)
- For public-domain software used herein:
  - Thomas Mejer Hansen (DTU): SegyMAT SEG-Y reader for Matlab
  - DMNG: SeiSee SEG-Y viewer

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- **I offer my acknowledgements up front**
- **I want to thank … (read)**

- **FairfieldNodal have no responsibility for anything in this presentation**

OBS Positioning Primer

1. Positioning acoustics (e.g. USBL)
   - Accurate … if well executed … but expensive in time and equipment
2. Dedicated first break positioning lines
   - Extra time, but no extra equipment
   - Coarse observable … and too few of them
3. Wide-azimuth, far-offset first breaks
   - Uses existing production seismic data
   - Benefit of large-population statistics
4. Linear Move Out (LMO)
   - Subjective vis-à-vis least squares estimation

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- **First we begin with an OBS positioning primer**
- **There are four common positioning methods**
- **(Read)**

Theses of the Presentation

- Wide-azimuth, far-offset first breaks are, depending on Snell's Law and the configuration of the picking algorithm, mostly, <u>but not necessarily</u>, refracted
- First breaks are a coarse observable compared, for example, with USBL …
- … but wide azimuths and far offsets compensate for that and empower the modeling of velocity gradients, angular source-array response, anisotropy and <u>oscillator drift in OBN</u>

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- **The theses of this presentation are that … (read)**

Positioning Example Discussed

- FairfieldNodal 2014 OBN survey in Walker Ridge in the Gulf of Mexico
- Approximately 2100 meter water depth
- 300,000+ shots/node, 12-second records
- 9km circular offset (excellent geometry)
- 254 square kilometers of shots per node
- 3-month occupation by Z3000 node
- I divide the data into nine (9) mutually-exclusive, amply-populated zones (rings or annuli) to investigate first-break positioning repeatability

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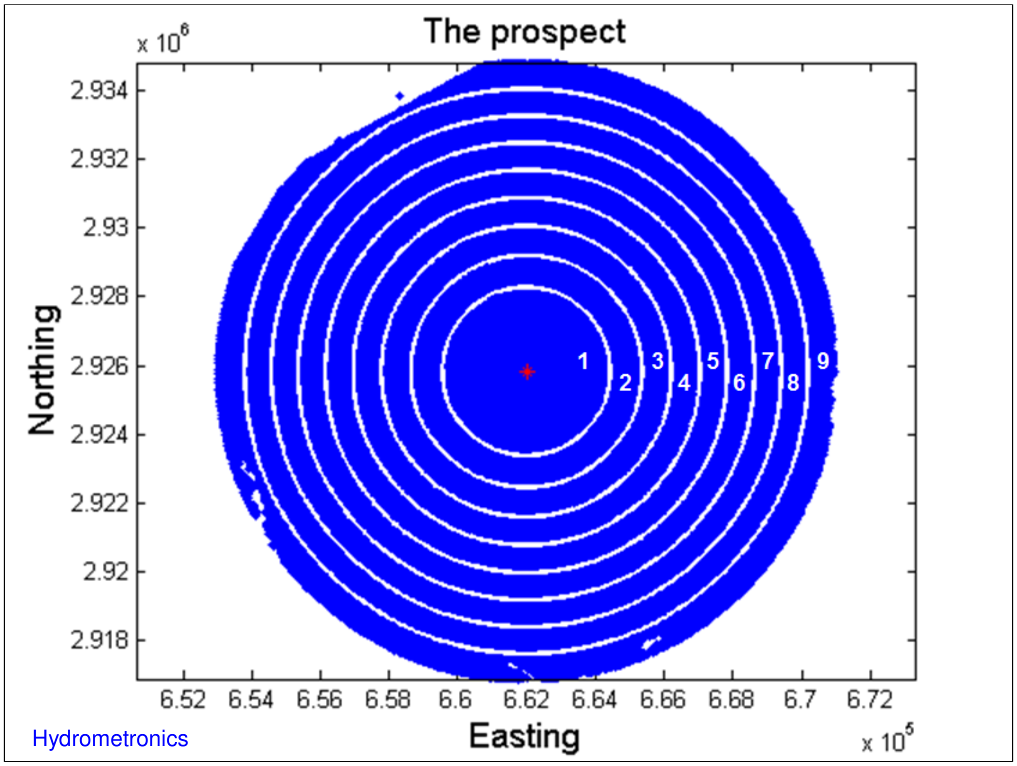
- **We need to dwell for a moment on the extraordinary example discussed this afternoon**
- **This is a FairfieldNodal survey shot last year in … (read)**



- This is the chosen node at the center in red
- The densely populated shots every 37.5 meters with a line spacing of 50 meters are in blue
- The 9 rings are numbered
- The somewhat ragged data in the 9th ring are due to the automated picking algorithm
- All the seismic data are there; they are just not picked well in the extremity.

Node 19614713							
Mode	Inner	Outer	X (E)	Y (N)	Depth	Picks Used	#
3-D	1300	2150	661987.3	2925836.9	2088	9970	1
2-D	2150	2650	661987.3	2925837.0	N/A	9056	2
2-D	2650	3150	661987.7	2925836.7	N/A	10996	3
2-D	3150	3650	661988.2	2925836.2	N/A	12815	4
2-D	3650	4150	661989.4	2925836.3	N/A	14613	5
2-D	4150	4650	661989.0	2925836.0	N/A	16516	6
2-D	4650	5150	661990.3	2925835.3	N/A	18366	7
2-D	5150	5650	661991.7	2925834.8	N/A	20255	8
2-D	5650	6150	661992.0	2925834.5	N/A	20788	9

USBL	deployment	661985.1	2925835.9	2092	N/A	N/A
USBL	retrieval	661988.2	2925837.7	2093	N/A	N/A

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- **The seismic data are picked and positioned my company's software called HmFBA, which stands for Hydrometronics First Break Analysis**
- **The red box to the right shows the 9 annuli and the number of picks in each annulus ranging from about 10,000 in the inner annulus and 20,000 in the outer annulus, which is larger in area**
- **The red box to the left shows the mutually-exclusive pick ranges in milliseconds**
- **These data are not important for your understanding of the presentation, just the knowledge that the 9 annuli are totally independent – no picks in common.**

Node 19614713							
Mode	Inner	Outer	X (E)	Y (N)	Depth	Picks Used	#
3-D	1300	2150	661987.3	2925836.9	2088	9970	1
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2-D	3150	3650	661988.2	2925836.2	N/A	12815	4
2-D	3650	4150	661989.4	2925836.3	N/A	14613	5
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USBL	retrieval		661988.2	2925837.7	2093	N/A	N/A

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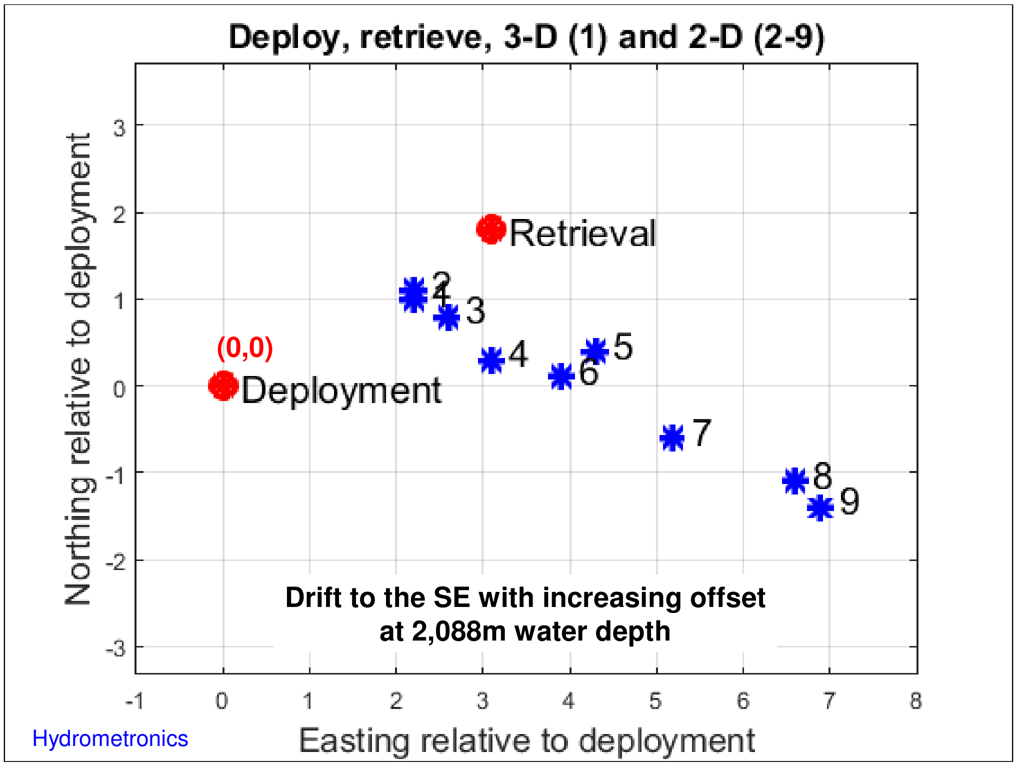
- **This red box gives the computed coordinates in UTM**
- **Again, the numbers are not important because we'll see a plot shortly**
- **But, in addition to the 9 independent first-break positions, we have the USBL positions at ROV deployment and ROV retrieval three months apart**
- **Securing the node firmly in the seabed takes about 5 minutes.**
- **Therefore, there are a lot of USBL data at deployment**
- **Retrieval is quicker and there are fewer data then**



•This is a plot of the USBL deployment and retrieval positions in red relative to the deployment position, which is (0,0) in this plot

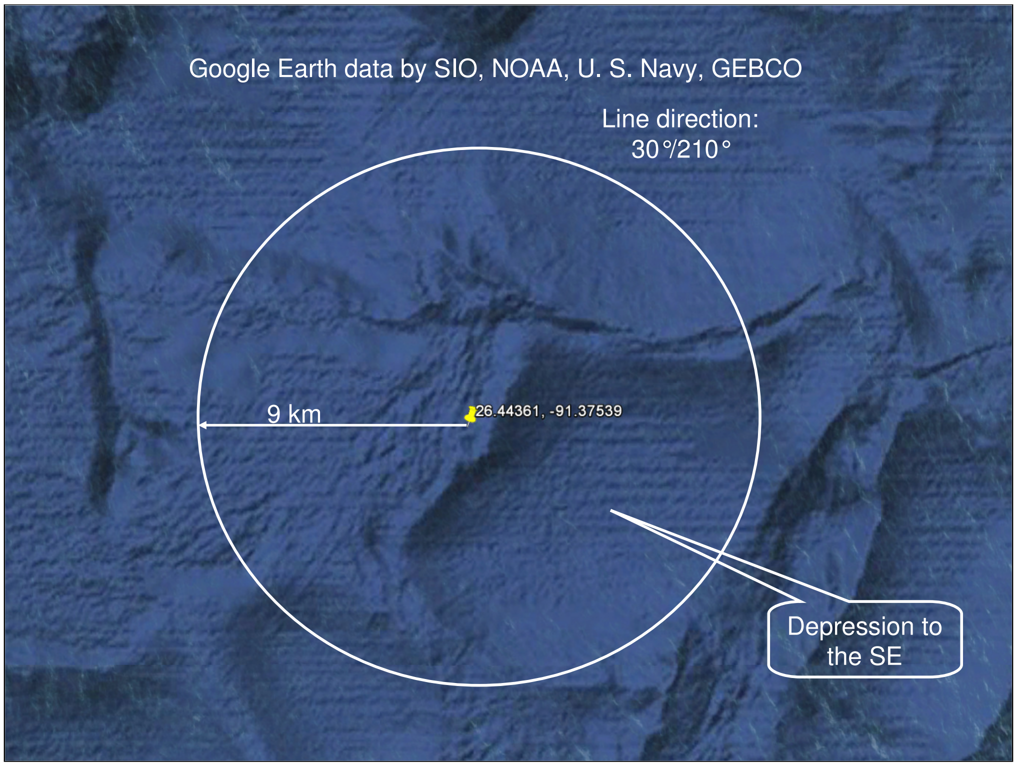
•The 9 independent first-break positions are plotted in blue.

•The first thing to notice is the excellent USBL positions. Easily understandable USBL accuracy specifications are difficult to come by from the manufacturers, but IMCA (the International Marine Contractors Association) published USBL guidance in 2011. For a well-maintained, well-calibrated system with 20cm GPS, better than 0.3% of the slant range can be expected. That's more than 6 meters at our depth of 2100 meters. And here we have a repeatability of less than 4 meters 3 months apart. This is a testament to excellent USBL practice.

•The second thing to notice is that the first-break positions drift to the SE as the annulus number increases.

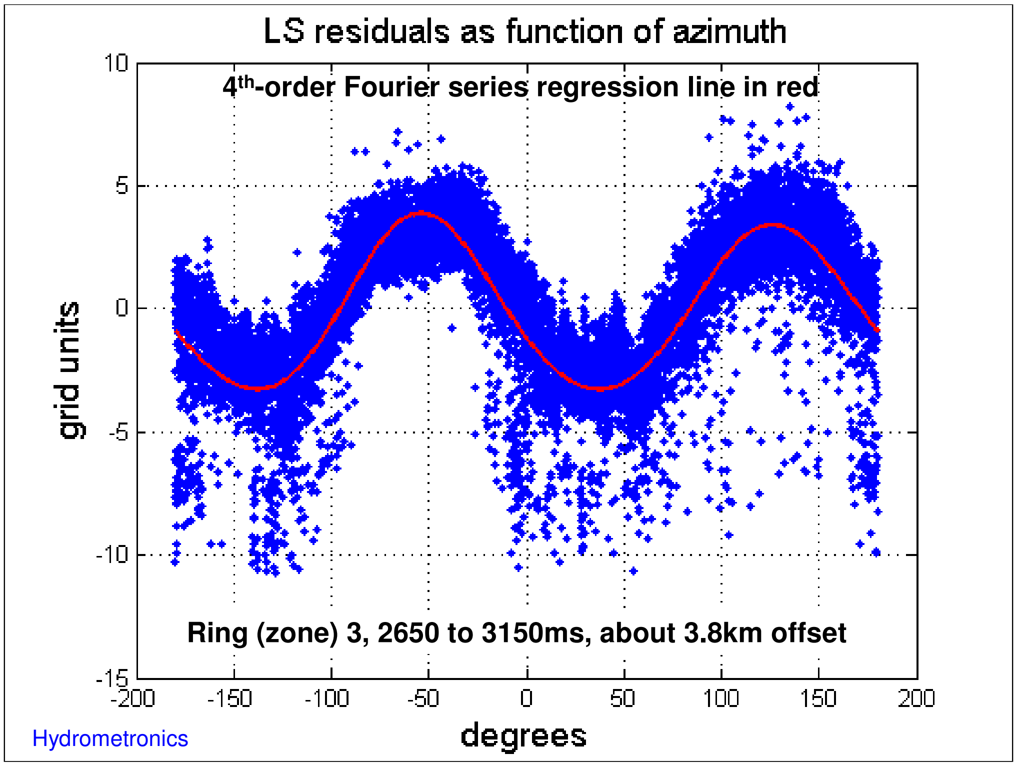
•Nevertheless, the overall agreement is not bad.

•But my navigation colleagues were just not happy that the first-break positions exhibited systematic, not random, error



•My first thought was to look at the bathymetry, where you can see a significant depression to the SE

•Perhaps this was affecting the picks.



•The HmFBA software used in this analysis can slice and dice the least-squares residuals in many useful ways.

•This plot shows the residuals for ring 3 as a function of the azimuth of the pick on the horizontal axis

•Zero degrees (or north) is in the center. Degrees east are to the right of that and degrees west are to the left of that.

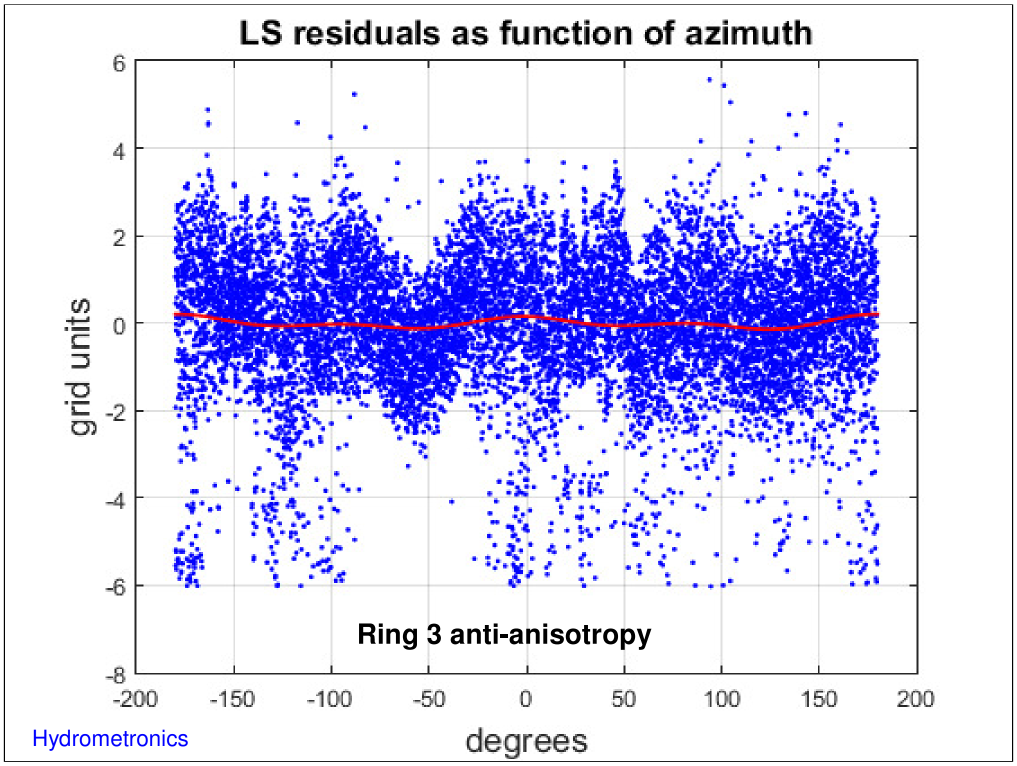
•The other rings show the same characteristics.

•I've practiced geodesy my entire career, but a geophysicist colleague told me that this is the signature of anisotropy with two complete cycles in 360 degrees.

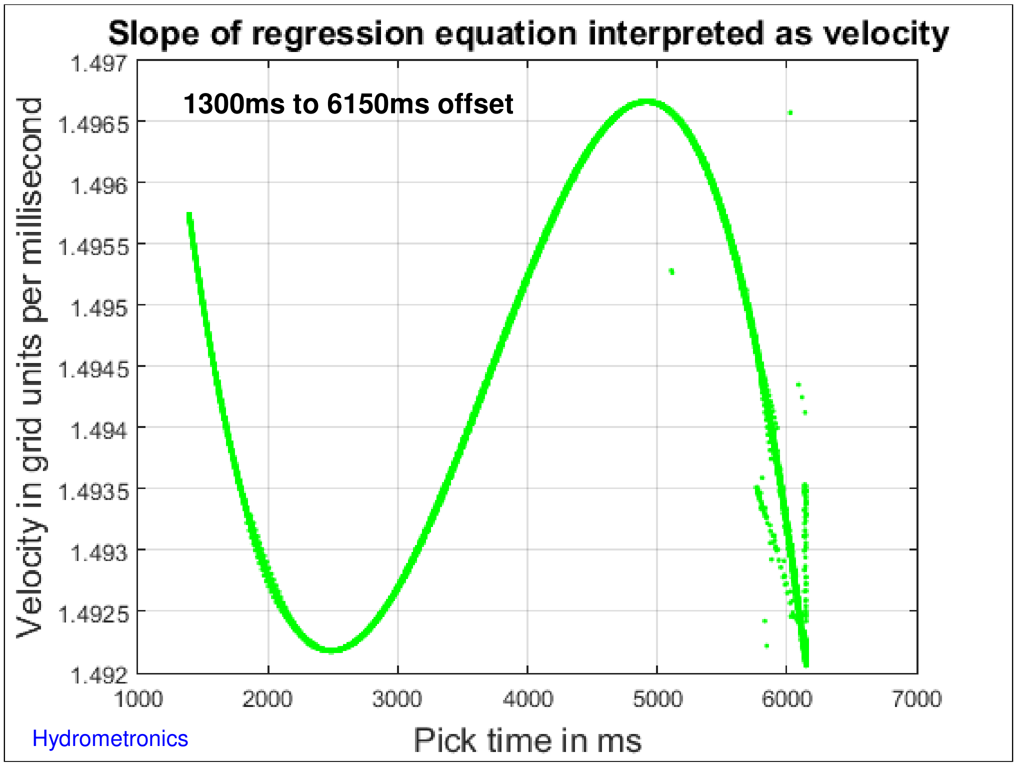
•So, we modified the software to compute a fourth-order Fourier series regression on these data and that line is plotted in red.

•This is where the extended abstract to this paper ended.

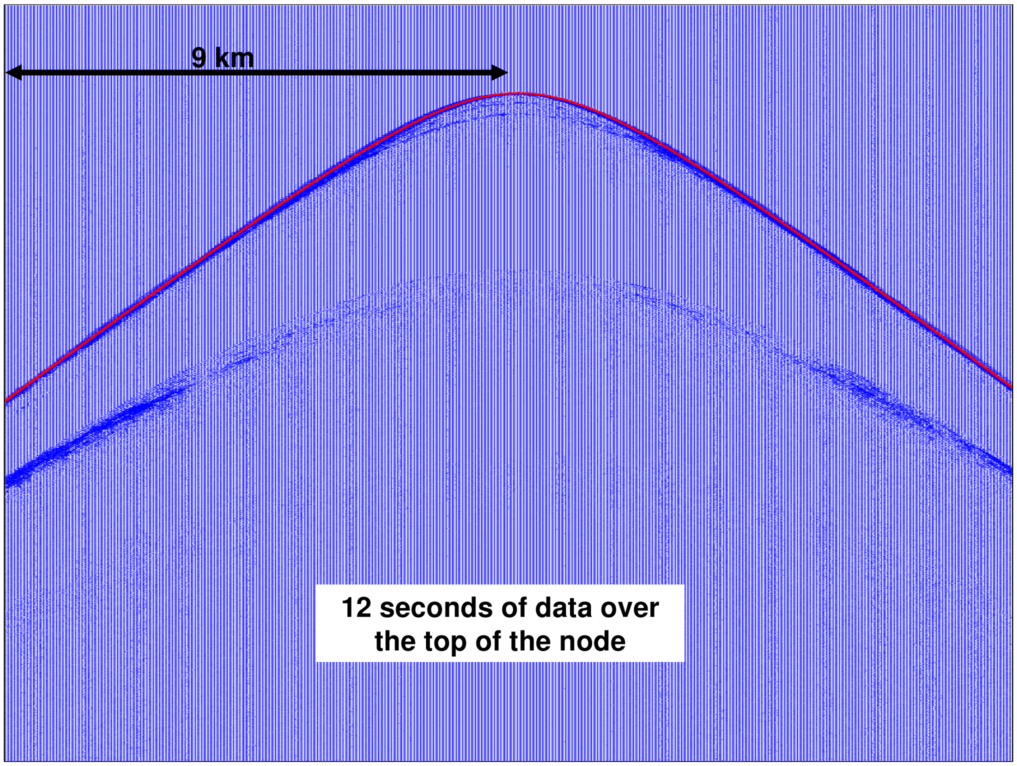
•Then we modified the algorithm to compensate for anisotropy



- After iteratively compensating for anisotropy the residual plot looks like this.
- But it didn't help much, changing the coordinates only a couple decimeters



- **What I missed in writing the abstract was this plot**
- **This the software-computed velocity of the energy over the range from 1300ms (which is right over the node at 2100 meters) out to 6150ms, which is 9 kilometers away**
- **Despite the variation seen in this plot, the variation on the vertical axis is very small … and it is the speed of sound in water, about 1.495 m/ms, the same as the weathering velocity in the SEG-Y!!!**

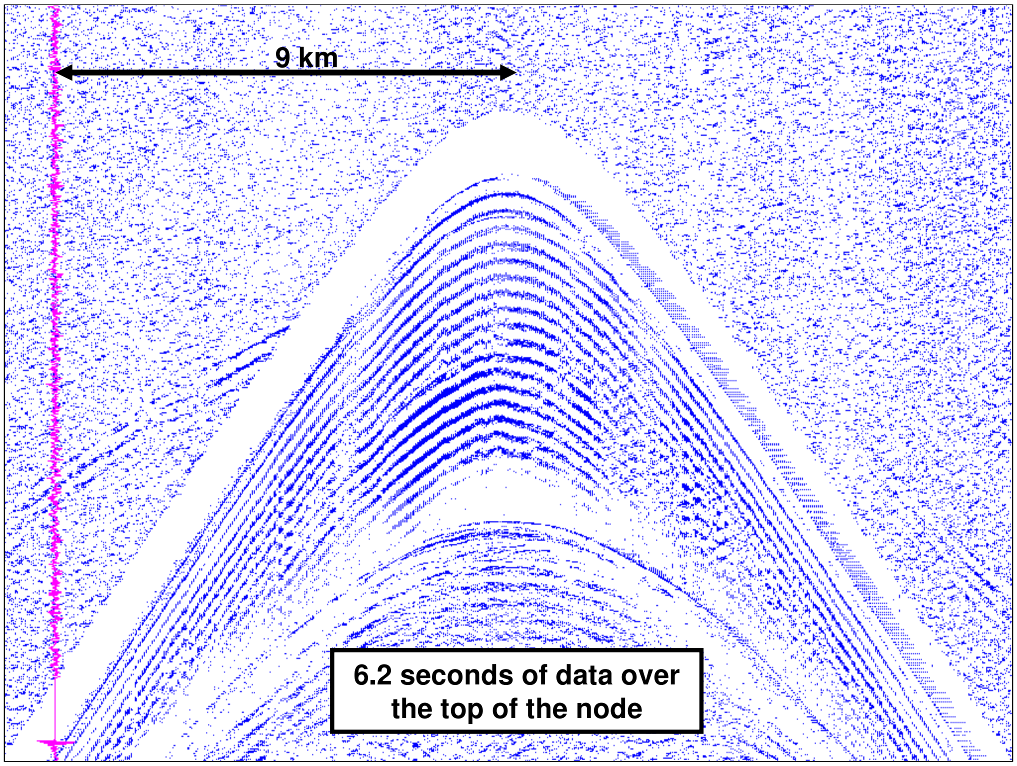


•Subsequent to the abstract another enhancement to the software was the plotting of seismic data with picks superimposed.

•This is a shot line right over the node out to 9 kilometers offset

•I'm sure it's clear to you that that the automated algorithm is picking direct water arrivals, which is confirmed by computing the Pythagorean distance from source to node

•In fact, I don't even see faster refractors.



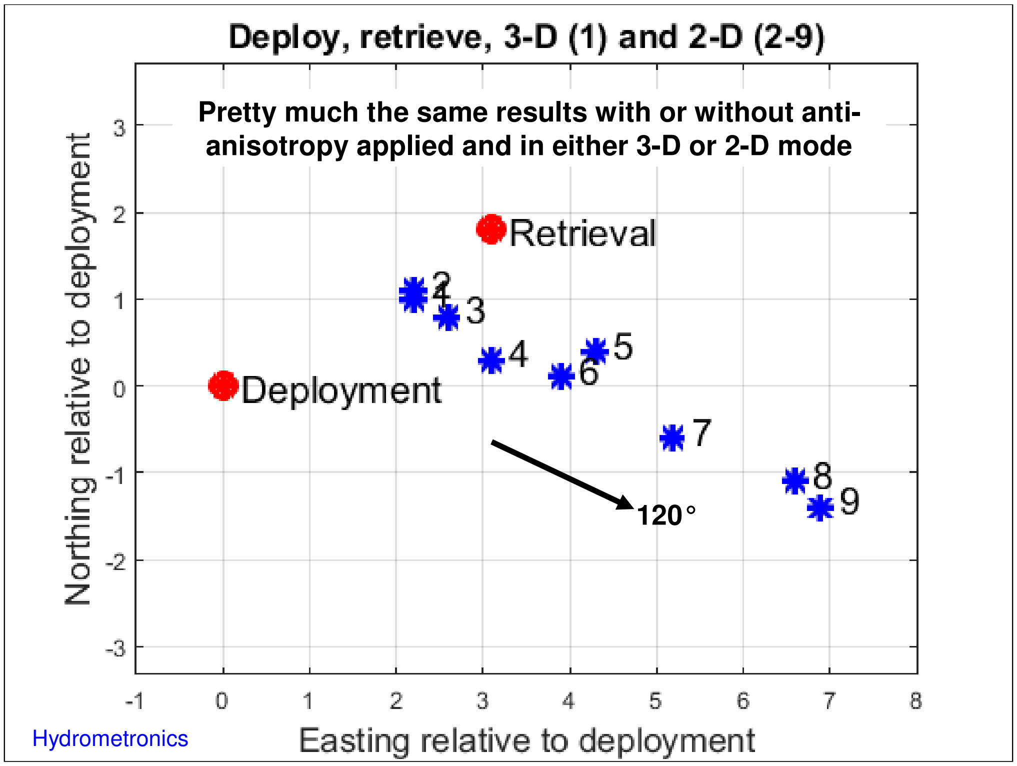
•My geophysicist colleague said there must be there faster refractors and recommended SeiSee by DMNG, which has gain control features not in HmFBA.

•Here is that view with fewer seconds of data and, yes, the refractors are there, indeed.

•But, as you can see from the selected trace in pink, the refracted energy is barely above the noise.

•It is not likely to be well picked automatically, just manually.

•This situation is not common in shallow water.



•So, we're dealing with direct water arrivals.

•3-D mode positioning in the software is reserved for direct water arrivals.

•2-D mode positioning will process both direct and refracted arrivals

•Changing the mode from 2-D to 3-D – including a solution for the velocity of sound in water for every annulus - only made negligible differences in the positioning.

•Something else was going on to cause the drift to the SE at about 120 degrees in first-break positions

Questions

- Is scale factor in the UTM grid affecting positions and the residual plots? No.
- Is the apparent anisotropy an angular source-array response in the water? This is plausible.
- Could changes in water temperature affect the velocity of propagation of sound during the 3-month occupation of the node? Maybe, but no data to model that effect.
- Or … is there drift in the node's oscillator? This can be modeled.

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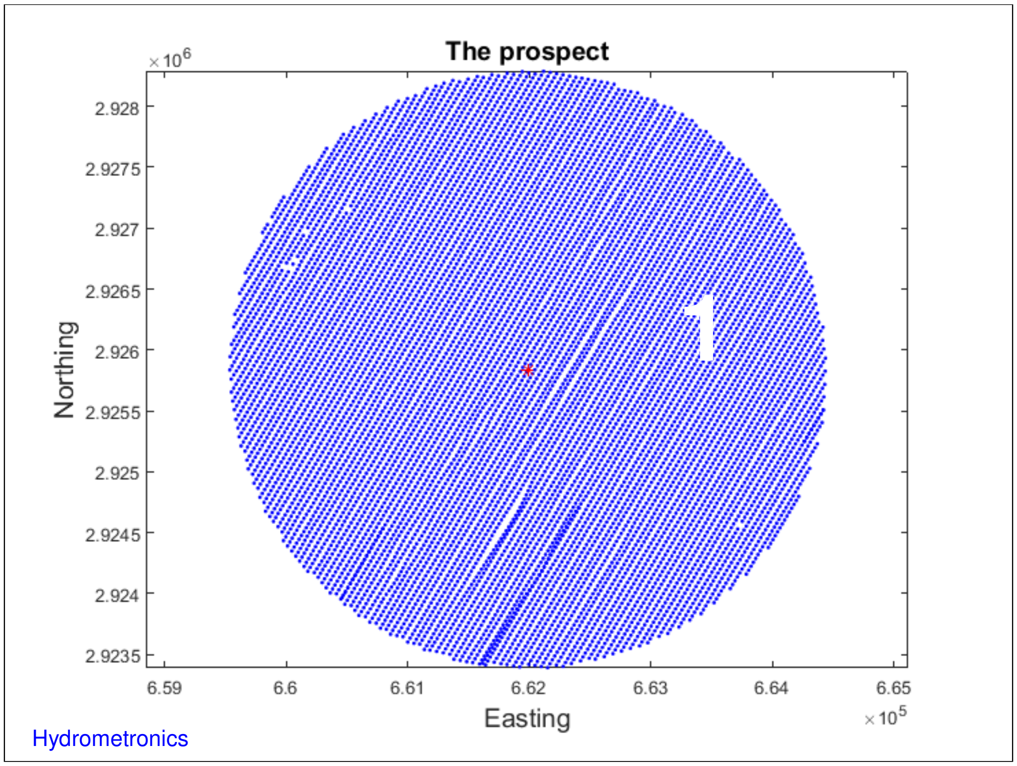
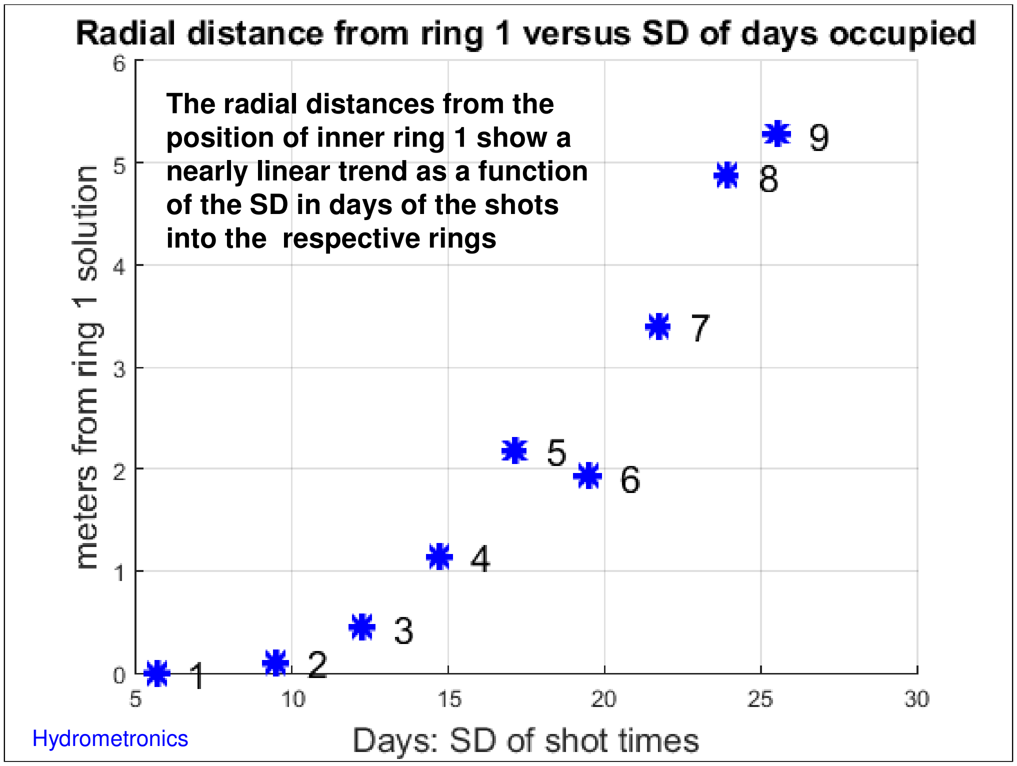
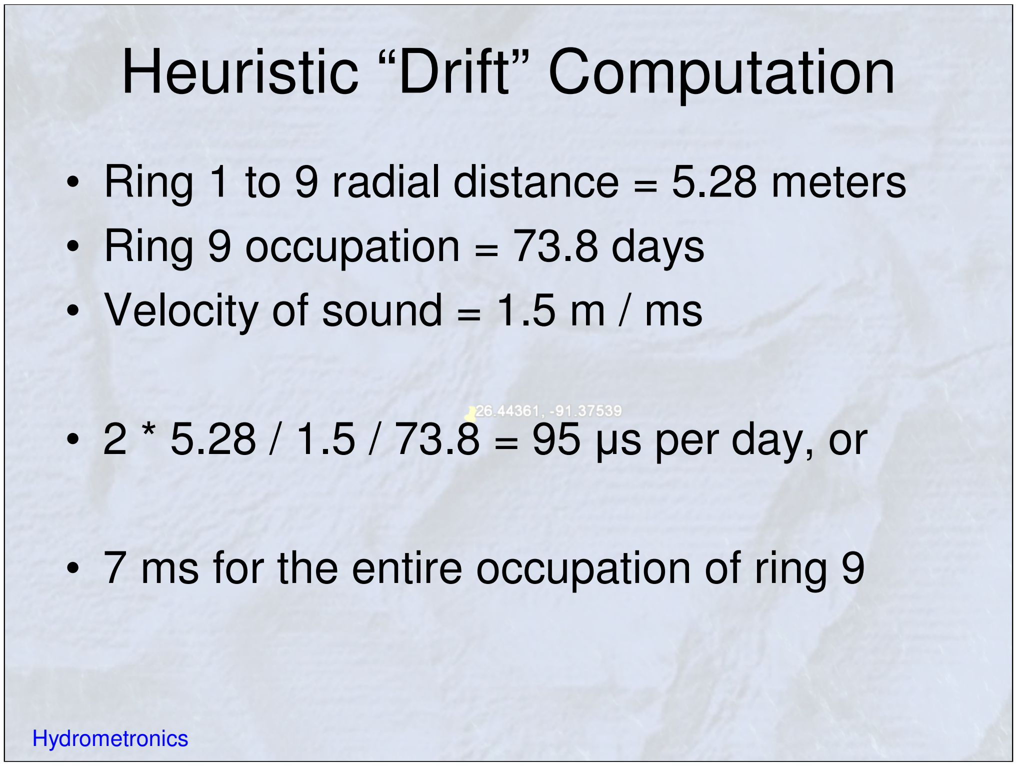
- **All this raised some questions**
- **(Elaborate on the bullets)**



- This plot zooms into the innermost annulus, ring 1.
- I show it to exhibit the shooting line direction, which is about 30 degrees to the north and 210 degrees to the south
- The shooting lines are perpendicular to the drift in first-break positions
- Also, the shooting of this project progressed from the east to the west, from right to left.
- That means in this 3-month occupation there is a significant gap in time between the picks in the east and the picks in the west



- This is the plot that broke the log jam!
- It shows the radial distance from ring 1 (zero for ring 1) to the other rings as a function of the standard deviation (SD) in days of the relative shot times into the respective rings.
- Days are on the horizontal axis and radial distance is on the vertical axis.
- Ring 9 has the longest radial distance and the largest SD of 25.5 days.
- Ring 9 has a total occupation of 73.8 days between the first and last shot.
- I chose the SD for the plot because it averages out irregularities in the shooting such as the occasional infill.
- The near-linear trend is clear.
- What is this?
- As mentioned, it might be changing temperature in the water column over the 3 month the node was on the bottom.
- But … no data to model that.
- Or, it might be oscillator drift in the node, which I can easily model linearly as a function of the relative times of the shots.
- So, I did what I can do.

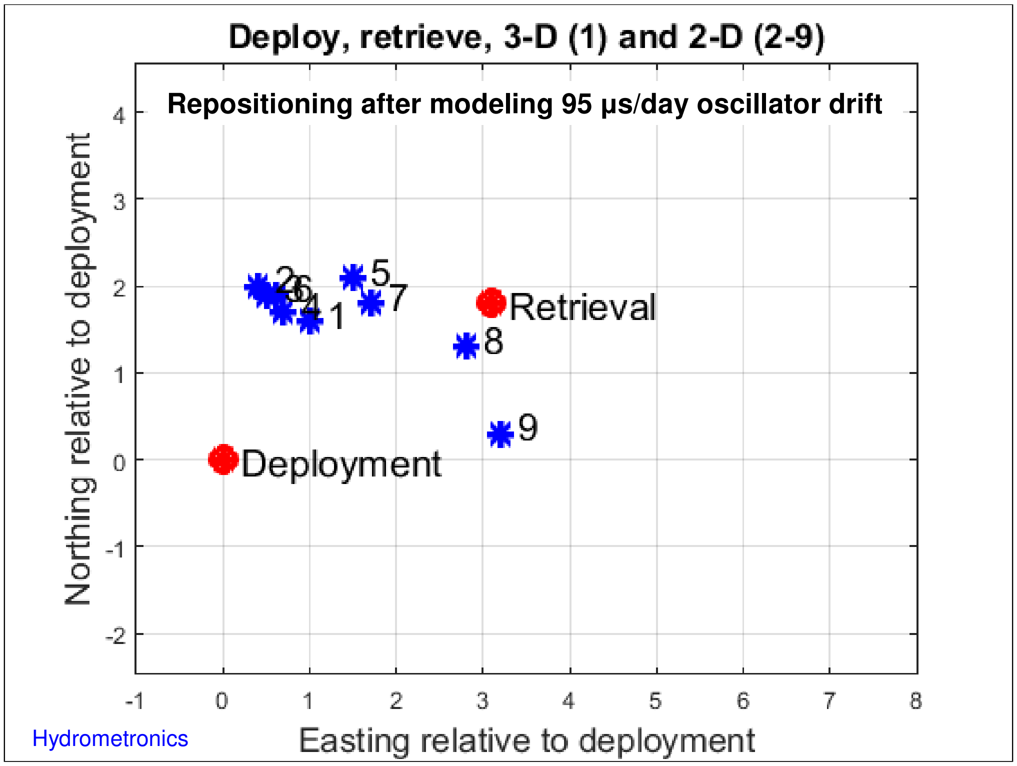


•This is my heuristic drift computation

•(Read to the first three bullets)

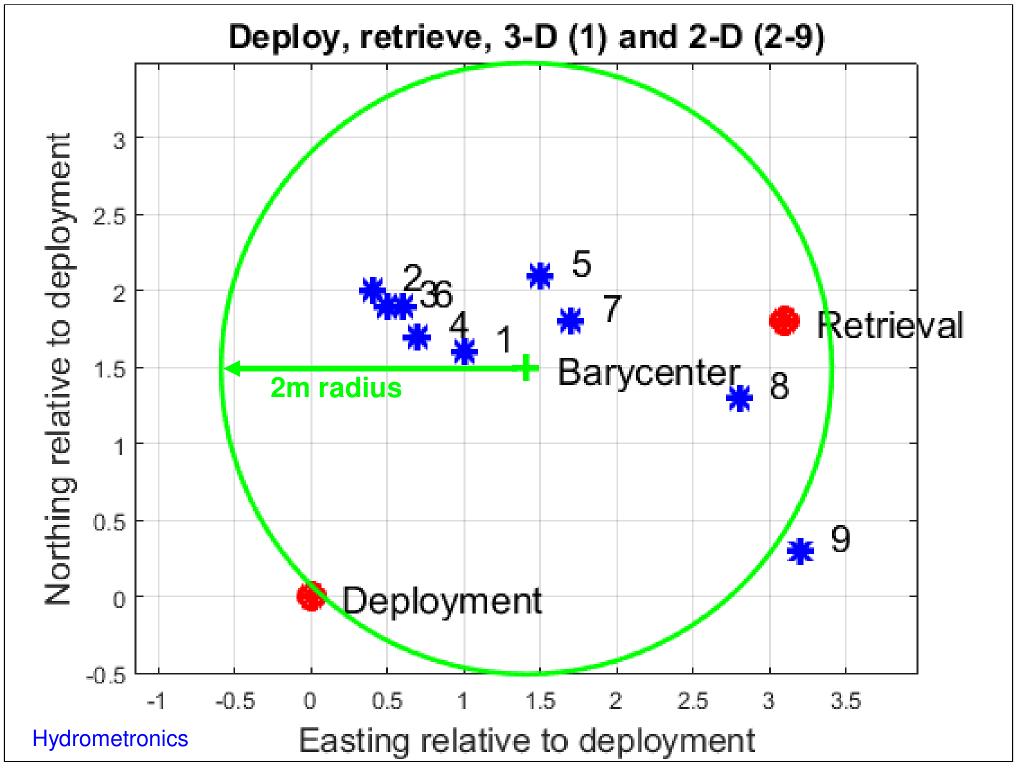
•The number 2 in the fourth bullet is a factor required by the least-squares algorithm to shift the first-break position the requisite amount since the picks are two-sided in the direction of drift to the SE.

•The computed "drift" (and I have "drift" in quotes here because this is just a model) is 95 microseconds per day or 7 milliseconds for the entire occupation of the ninth annulus.

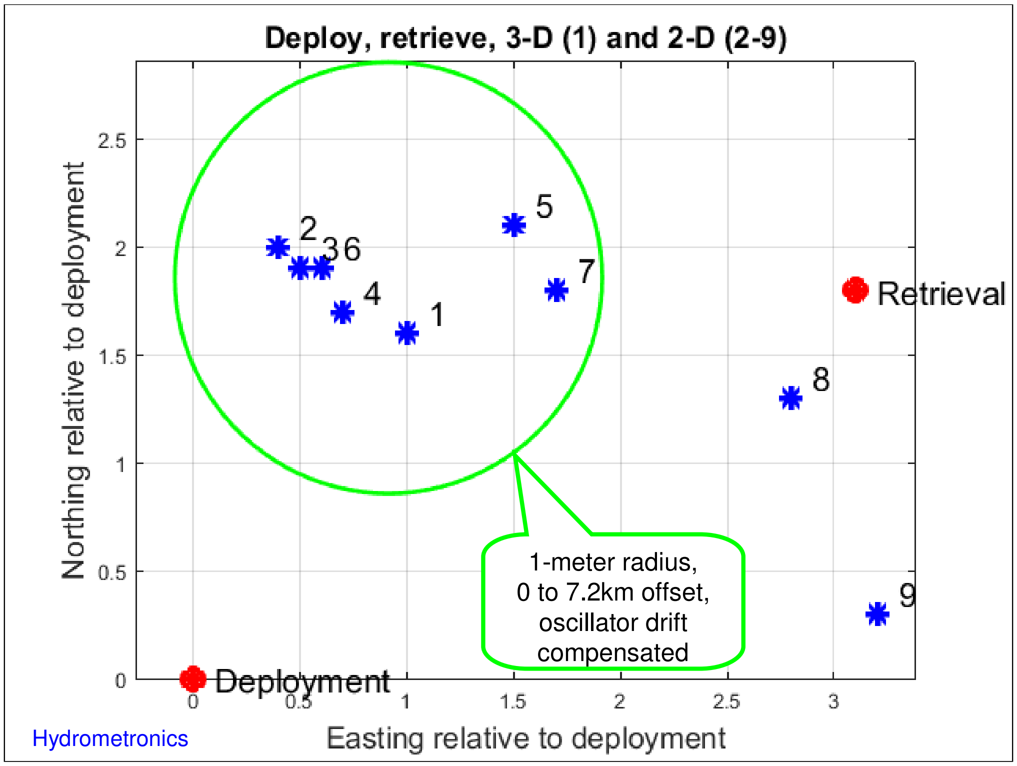


•So, after modeling hypothetical oscillator drift in the software and repositioning, the situation looks very different.

•Still a bit of trend, but much more random.



•In fact, if we plot the barycenter of all 9 first-break positions plus the USBL positions and draw a circle with a radius of 2 meters we capture almost all of it

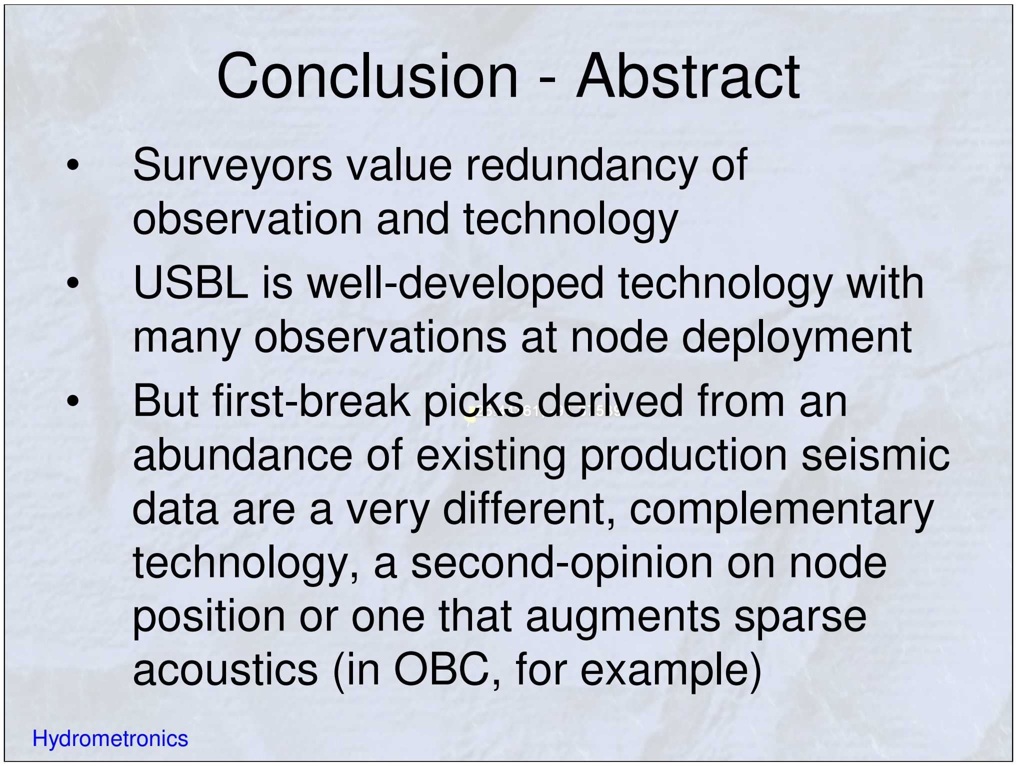


•Or, if we look just at the first-break inliers, those with a horizontal distance from the node of less than 7.2 kilometers, we can capture them all with a radius of 1 meter around their barycenter

•That is really extraordinary!

•Why isn't it even tighter?

- **•Water temperature changes are not modeled**
- **•Non-linear drift in the oscillator is not modeled (again "drift" in quotes)**
- **•Tides are not modeled, but then the tidal range is less than a meter in range in Walker Ridge and probably averaged out given the amount of data**



•There is, of course, more to be said, but time is up.

•I have two conclusions

•The first conclusion is that of the abstract … (read)

•This conclusion applies to refracted as well as direct arrivals, but I am currently restricted by NDAs from showing those data

•Maybe another paper!

Conclusion - Presentation

- Oscillator drift is an acknowledged reality for ocean-bottom nodes
- *In situ* drift is usually linear on average, but jarring motion (e.g. deployment, retrieval) can upset that linearity
- Therefore, a method of calibrating drift *in situ* is desirable and valuable
- I have described such a method (“drift” in quotes) using wide-azimuth, far-offset, first-break positions

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- **The second conclusion is that of the presentation (read)**
- **(Next slide)**

Summary of Conclusions

- Wide-azimuth, far-offset first breaks can provide positions comparable to USBL
- Wide-azimuth, far-offset, first-break positions can model *in situ* oscillator drift in a ocean-bottom node
- Addendum follows

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•These two bullets summarize my conclusions

•Thank you.

Addendum

- A comment after the presentation of this paper was that positional shift with increasing annulus number could be explained by (changing) water velocity and that water velocity can be solved for
- Slide 17 already acknowledged that changing water velocity could account for the positional shift, but that there was no data provided to model that effect
- The HmFBA software used in this analysis does solve simultaneously for position and water velocity as seen in slide 13
- Solving for velocity as a function of time is another matter because grouping the picks as a function of time destroys the balance in geometry required for competent positioning
- Given a node position one can easily solve for velocity as a function of time by inversing source and node positions, but solved velocity then becomes a function of the node position chosen (e.g. USBL deployment, retrieval, or one of the annuli)
- Subsequent to this presentation FairfieldNodal provided PIES (pressure inverted echo sounder) data correlated with the position and occupation of the node analyzed
- This addendum explores the positioning consequences of the PIES data provided. Plots follow.

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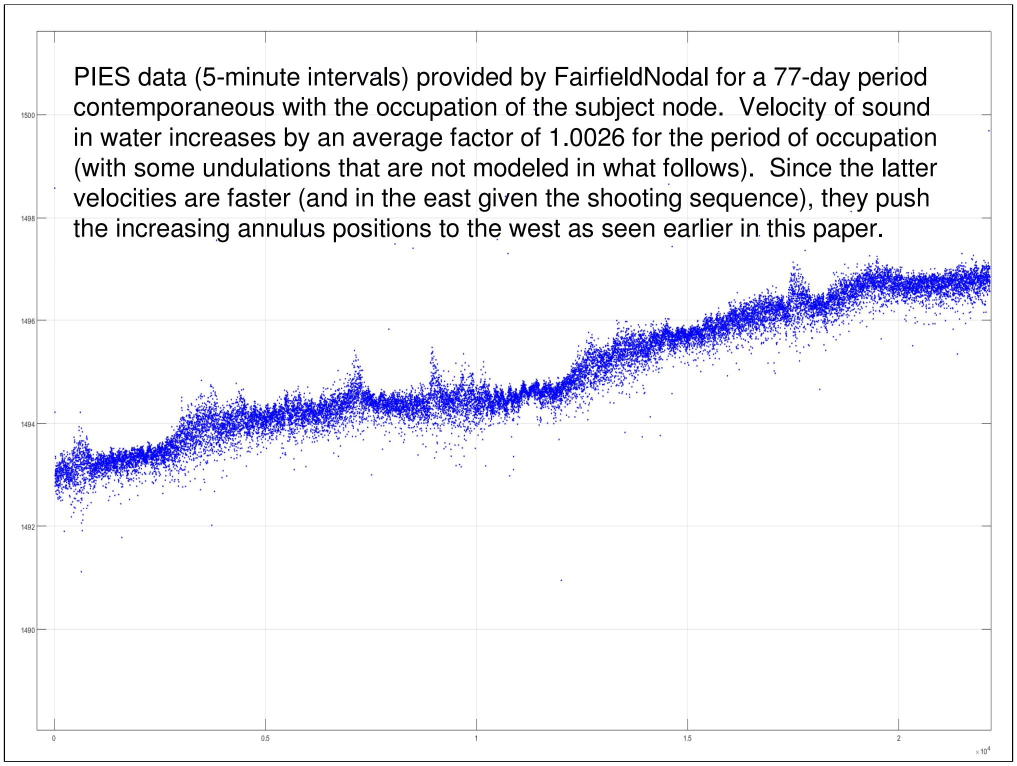
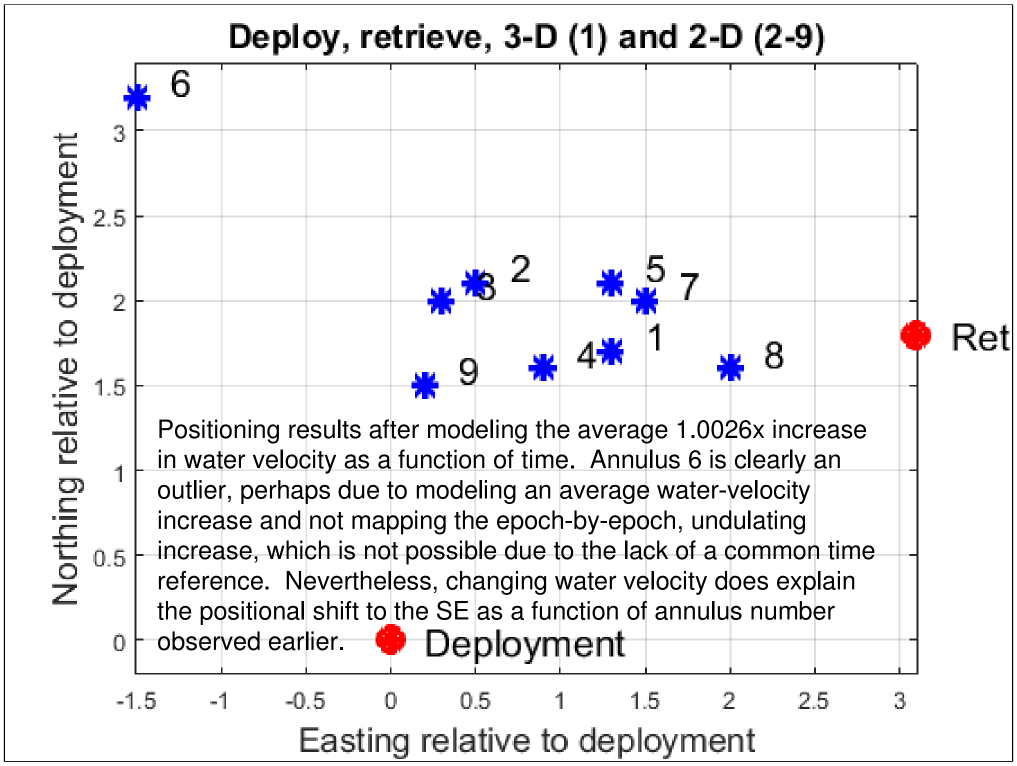


PIES data (5-minute intervals) provided by FairfieldNodal for a 77-day period contemporaneous with the occupation of the subject node. Velocity of sound in water increases by an average factor of 1.0026 for the period of occupation (with some undulations that are not modeled in what follows). Since the latter velocities are faster (and in the east given the shooting sequence), they push the increasing annulus positions to the west as seen earlier in this paper.


Deploy, retrieve, 3-D (1) and 2-D (2-9)
Northing relative to deployment
Easting relative to deployment
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
3
2.5
2
1.5
1
0.5
0
6
2
3
5
7
1
4
8
9
Ret
Deployment
Positioning results after modeling the average 1.0026x increase in water velocity as a function of time. Annulus 6 is clearly an outlier, perhaps due to modeling an average water-velocity increase and not mapping the epoch-by-epoch, undulating increase, which is not possible due to the lack of a common time reference. Nevertheless, changing water velocity does explain the positional shift to the SE as a function of annulus number observed earlier.

Conclusion - Addendum

- Sound velocity data are critical for long-occupation nodes for both first-break positioning and for seismic processing.
- Nevertheless, the (second) conclusion of this presentation is not vitiated.
- Some nodes can have small calibrated oscillator drift; other nodes can have large calibrated oscillator drift.
- The methods herein can solve for that drift, but VP in water must be accounted for with observed data (such as PIES).