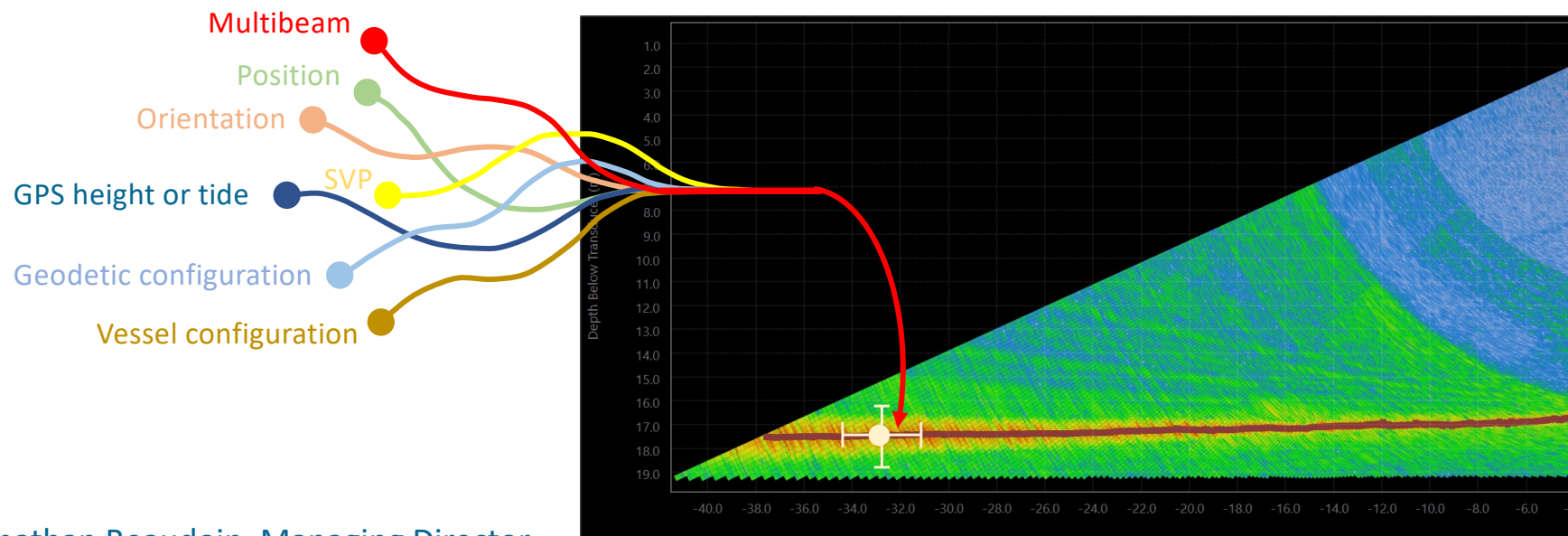


Demystifying Uncertainty – TPU and You

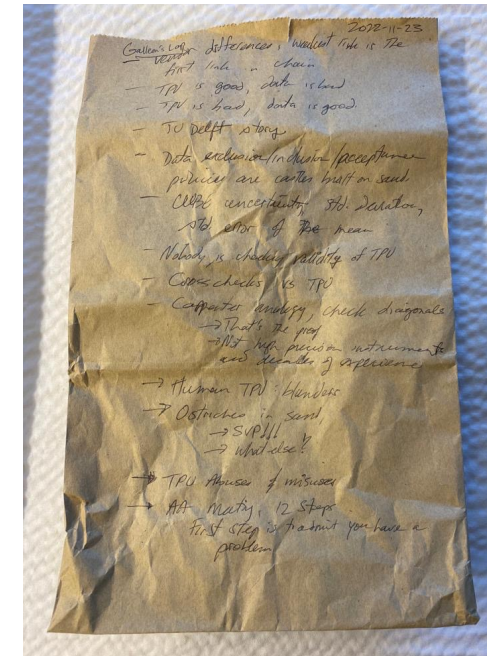


Jonathan Beaudoin, Managing Director
HydroOctave Consulting Inc.

Burns Foster, Senior Consultant, SpatialNetics

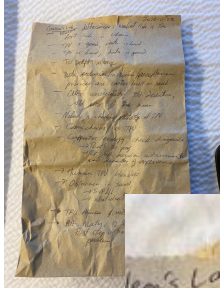
Canadian Hydrographic Conference 2024
St. John's, NL, May 23-May 30, 2024

Birth of a Manifesto



TPU "Paper Bag Manifesto"

Goal – Raise awareness that we need to work harder on this topic to master it and share ideas and resources to help



TPU Paper Bag Manifesto

2012-11-23
Leah's Logic
Differences, weakest link is the
first link in chain
TPU is good, data is bad
TPU is bad, data is good.
TU Delft story
Data exclusion/inclusion/acceptance
policies are castles built on sand.
- CLBE uncertainty, std. deviation,
std. error of the mean
- Nobody is checking validity of TPU
- Cross checks vs TPU

Coppenier analogy, check diagonals
→ That's the proof
→ Not high precision instruments
and decades of experience
→ Human TPU: blunders
→ Ostriches in sand,
→ SVP!!!
→ What else?
TPU Abuser & misuses
AA Matiy, 12 Steps
First step is to admit you have a
problem

Multibeam Crash Course

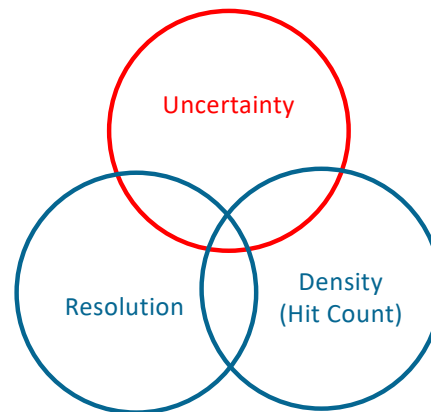
Curriculum

1. Sonar Controller and Acquisition System – Quick Tour
2. Resolution
 - a. Importance of Resolution
 - b. Review of Multibeam Fundamentals: Imaging Geometry, Typical Products
 - c. Review of Resolution: Beamwidth, beam steering and pulse length/type
 - d. Sensor specifics – How to operate your multibeam most effectively to achieve resolution goals
3. Density
 - a. Importance of Density
 - b. Review of Density: Speed, Swath/Beam geometry, Ping rate, Dual/Single Swath
 - c. Real-time Monitoring of Density
 - d. Other Effects: Motion effects, line planning/running, stabilization
 - e. Sensor specifics – How to operate your multibeam most effectively to achieve density goals
4. Uncertainty
 - a. Importance of Uncertainty
 - b. Survey Accuracy Standards & Orders
 - c. Achieving Standards – In Theory (TPU Tune-Up)
 - d. Achieving Standards – In Practice
 - e. Human Error
 - f. Sensor specifics – How to operate your multibeam most effectively to achieve uncertainty goals
5. Backscatter
 - a. Importance of Backscatter
 - b. Review of Backscatter Fundamentals
 - c. Impact of sonar settings changes
 - d. Backscatter Acquisition – General
 - e. Backscatter Acquisition – Sensor and Software Specific - How to operate your multibeam most effectively to achieve backscatter goals

Duration: 3.0 days classroom

Uncertainty

- a. Importance of Uncertainty
- b. Survey Accuracy Standards & Orders
- c. Achieving Standards – In Theory (TPU Tune-Up)
- d. Achieving Standards – In Practice
- e. Human Error
- f. Sensor specifics – How to operate your multibeam most effectively to achieve uncertainty goals



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Multibeam Crash Course

Summary - Connecting the dots between your survey specifications, deliverables, your mapping systems and your field procedures. Understanding how your minute-by-minute online decisions can help or hinder your goal to meet survey deliverable specifications.

Description - HydroOctave Consulting's unique approach to instruction provides direct value to the hydrographer by focusing on which sonar settings and/or survey design decisions are most impactful towards their end results. Practical instruction demonstrates clearly how surveyors can add value in their operational decision making. Theoretical concepts are covered lightly when necessary to give the concepts some backing without overwhelming the core concepts. The aim is to provide practical and actionable ideas to help a hydrographic surveyor the very next time they go to the field, making confident and informed decisions that achieve results.

Process - Prior to the workshop, a questionnaire is sent to all attendees inviting input on questions they'd like to have answered and proficiencies they'd like to master on the general topic of multibeam echosounding. This is reviewed with team leads and the curriculum below is refined and tailored to specific needs. The information drawn from the questionnaire helps pinpoint the most important topics within the curriculum framework and informs content for informal sessions when material falls outside of the proposed curriculum. This important step is what makes this course YOUR Multibeam Course where you learn exactly what YOU need.

At the end of the course, a recap session is conducted during which participants identify important concepts they have learned. Participants are challenged to set personal development goals to implement what they have learned in practice. The same thing is done at a team level with input from team leads to set team-based goals.

Pre-Requisites - Participants are expected to have basic familiarity with their mapping hardware and software with at least one field season of experience.

Uncertainty Webinar

GeoEd > CHA Webinars

CHA Webinars Accuracy in Theory and Practice

On behalf of the Canadian Hydrographic Association, presented live by Jonathan Beaudoin on the 26th of January 2024 at 10:00am EST

It's incredibly important as a hydrographic surveyor to understand if our measurements are fit for purpose. One key determinant of fitness of measurements is their accuracy, or uncertainty, as we hear more often. It seems, however, that there's nothing more uncertain in surveying than the uncertainty of our measurements. We have mathematical tools that tell us the uncertainty levels we should, in theory, be able to achieve. But as is often said "In theory there is no difference between theory and practice. In practice, there is." Just how is it that surveyors go about ensuring they are achieving desired accuracy levels in practice? Join us for a lighthearted webinar where we discuss the difference between achieving accuracy in theory and achieving it in practice.

HydroOctave
CONSULTING

Uncertainty

Webinar hosted by Canadian Hydrographic Association

00:01 01:07:52

Uncertainty

- Importance of Uncertainty
- Survey Accuracy Standards & Orders
- Achieving Standards – In Theory (TPU Tune-Up)
- Achieving Standards – In Practice
- Human Error
- Sensor specifics – How to operate your multibeam most effectively to achieve uncertainty goals

Lan

Home

GeoEd Tutorial Webinar

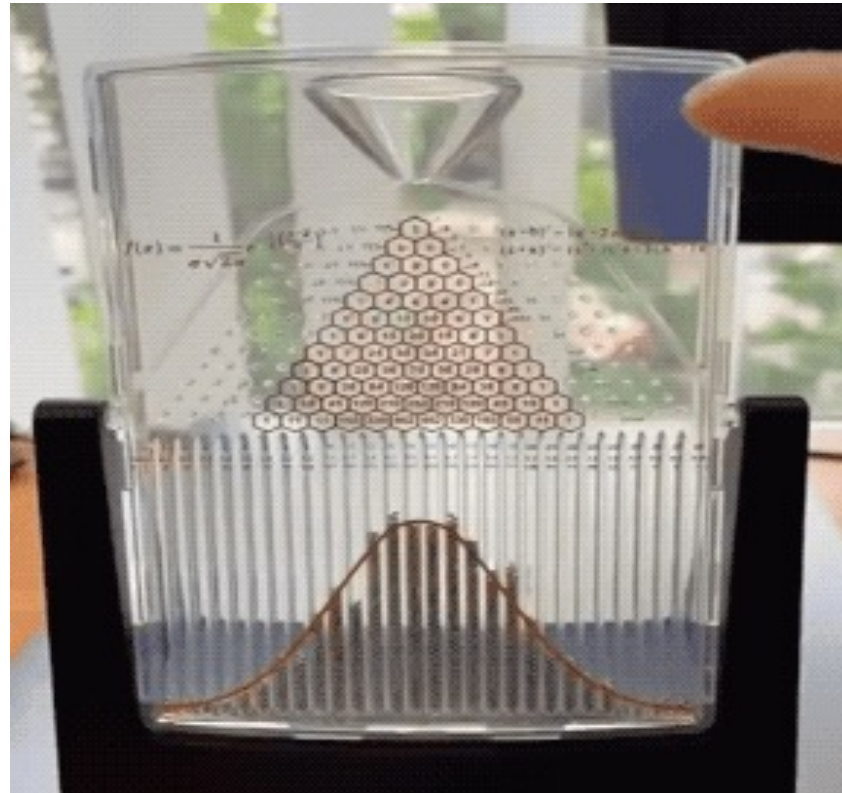
Our Purpose

Contact

Registered Providers Guide

User Login





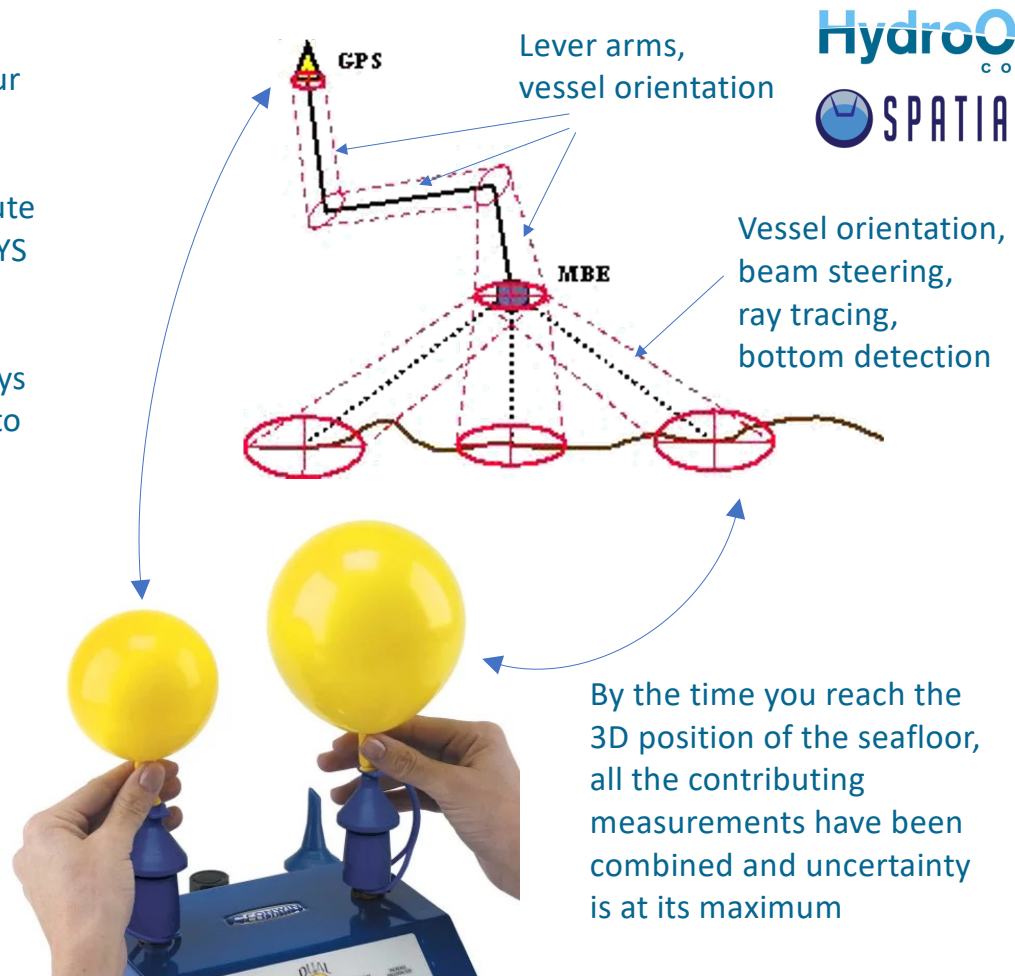
By the way, this thing is called a Galton Board

Think of the uncertainty ellipsoid around your initial position measurement as a balloon

Each time you add a measurement to compute the position of another place, you are ALWAYS adding more uncertainty

In this analogy, the uncertainty balloon always gets larger as you add more measurements to arrive at a displaced position

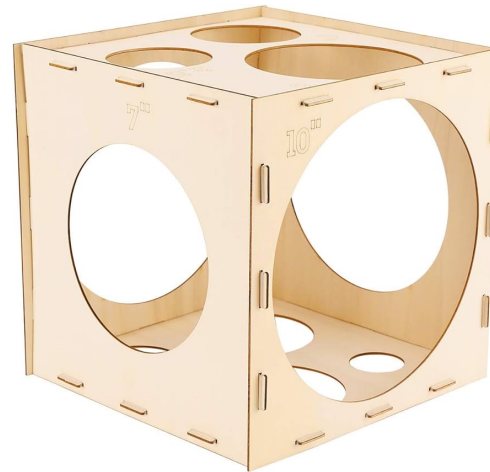
Uncertainty propagation methods exercise the georegistration mathematical model to understand how uncertainty of individual measurements combine to give the final uncertainty. You can predict the total propagated uncertainty (TPU).



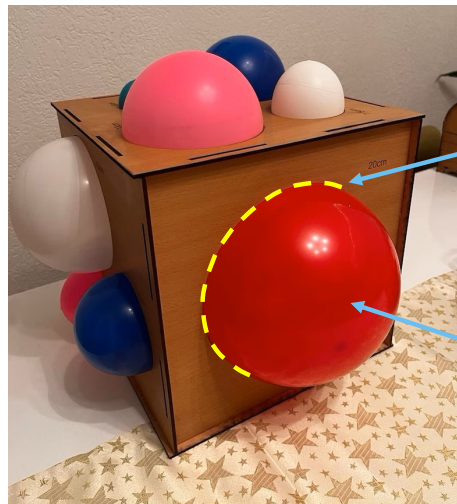


Ever wonder how they make these balloon arches so consistent?

TPU can be assessed beforehand to understand if you can meet the desired accuracy level. You can choose instrumentation and plan your survey (effective swath, coverage, line spacing)



They use templates to ensure consistent sizing



Allowable uncertainty you're trying to meet (where does this come from???)

Your sounding's uncertainty
Does it fit?
How can you ensure that it does?

Online TPU Calculator



TPU for instrumentation planning

Goal - Ensure equipment choice/configuration, line plan and overlap plan can deliver on client's expectation of accuracy

Need to leave uncertainty budget headroom for reality & bad luck



<https://totalpropagatederror.com>

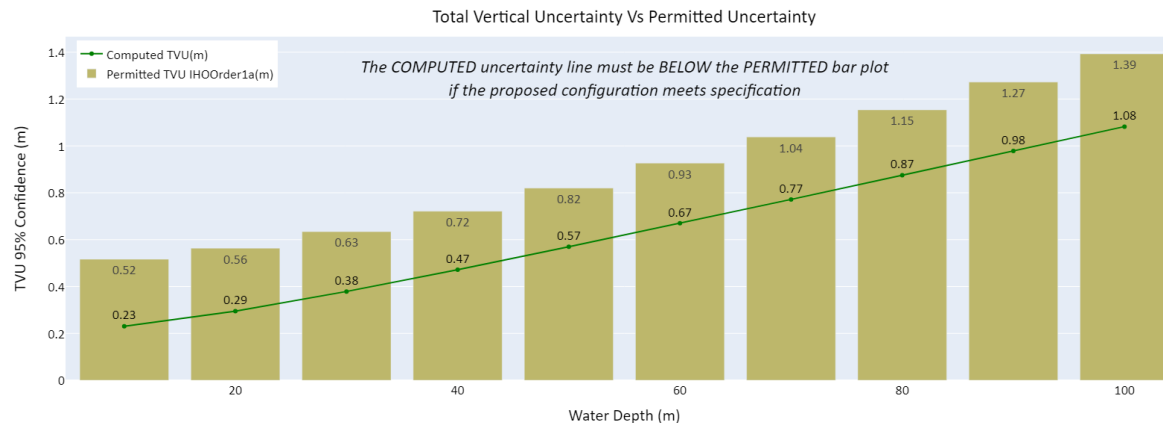
Reach Subsea Total Propagated Error Engine

Required Standard* Project Name* User Name* TPU Computation Date* TPU Engine Version*

Multibeam Sensor* Position System* Attitude Sensor* Draft Sensor* Tide Sensor* Tide Model* Squat Model*

Sector Angle* Ping Rate (Hz)* Swath Coverage (%)* Minimum Depth (m)* Maximum Depth (m)* Vessel Speed (Kts)* Mean Column SVP* Acceptable SVP Error*

Maximum Operating Pitch Condition* Maximum Operating Roll Condition* Maximum Operating Heave Condition* Patch Test Roll Uncertainty* Patch Test Pitch Uncertainty* GNSS Antenna Installation Uncertainty*



TPU vs Reality = Instagram vs Reality



“No battle plan ever survives the first encounter with the enemy”

“In theory there is no difference between theory and practice. In practice, there is.”



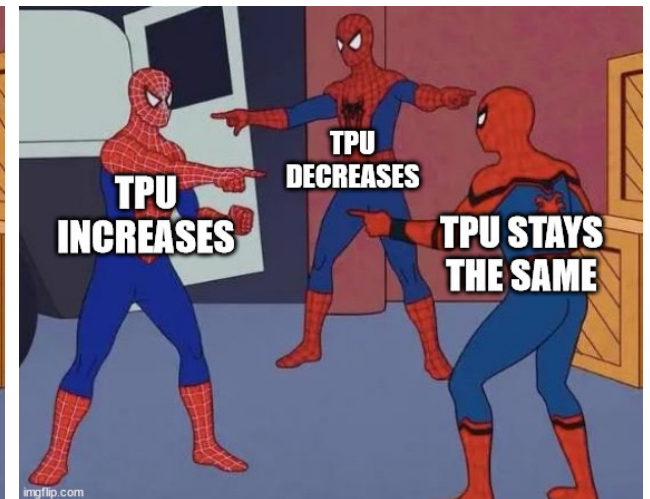
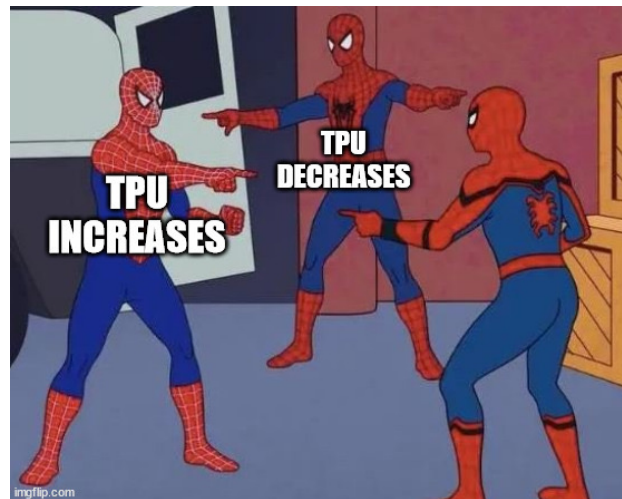
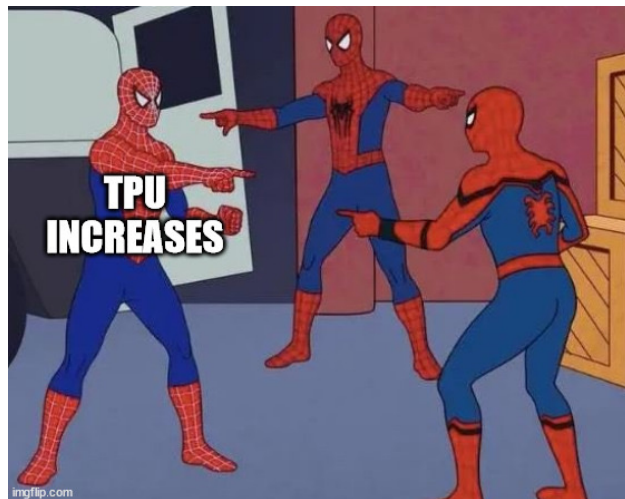
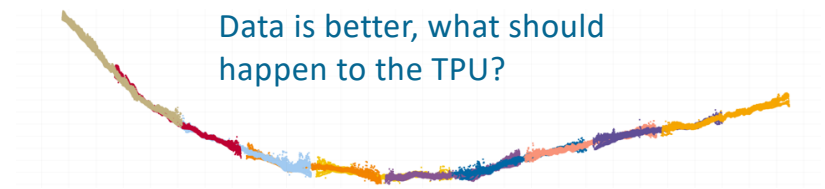
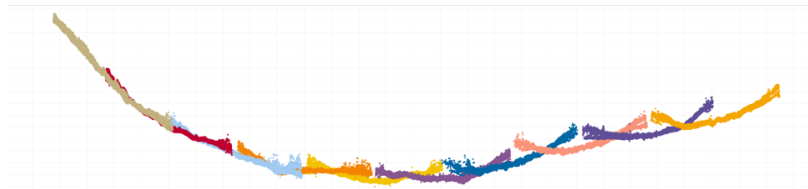
“Everybody has a plan until they get punched in the face.”

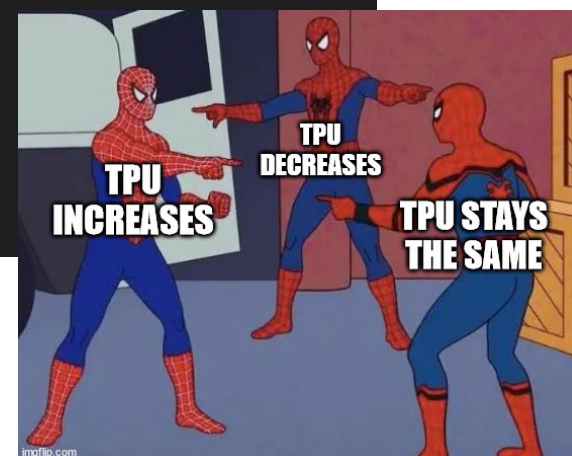
- Mike Tyson



This is the most common misconception we encounter:
“TPU Tells The Whole Story about Accuracy”

TPU Reaction To Specialized Tools?





TPU Quotable Quotes

Matt Wilson (NOAA) – “The data obviously has data quality issues, but according to the uncertainty everything is just fine and dandy.”

Larry Andrews (S.T. Hudson) – “In commercial world, repeatability is often more important than TPU. The proof ... is the agreement in solutions in areas of overlap.”

Anonymous – “It's too easy to fudge TPU parameters to fit a specification.”

Matt Wilson (NOAA) – “People say uncertainty, but they might mean TPU, or standard deviation; sounding uncertainty or grid uncertainty; CUBE uncertainty or something else; and it might be one sigma or two, but no one can ever find where it is written down and only a few people actually know.”

Larry Andrews (S.T. Hudson) – “Can have two boats, same kit – Get SAME TPU...but can still get a vertical bust between them.”

TPU Quotable Quotes

Anonymous – “We have limited means of validating environmental errors.”

Chris McHugh (Sulmara) - “Different software packages use different methods of computation so can turn out different results with same inputs.”

Duncan Mallace (XOCEAN) – “Filtering by TPU value I’ve never used as you can take out perfectly good soundings (say over wrecks).”

Anonymous – “Use of IHO TPU standards subsea (e.g. ROV & AUV) is meaningless and using those standards in 'Engineering Land' is inappropriate.”

Pim Kuus (Reson) – “Please, please make the point that a multibeam, or any other sensor, is not IHO compliant to whatever order. The TPU relates to the whole measurement.”

Anonymous - “All Hydrographers should come with a warning label and a TPU rating.”

TPU Quotable Quotes

Brian Calder:

1. Most people misunderstand the reason to have uncertainty. The goal, from my point of view, is to have a calibration for the behaviors of the data: you want to know what the reasonable range of uncertainty is, so you can tell when the actual data isn't. In CUBE/CHRT, this means telling when an input sounding is inconsistent with the current depth track, and also how much to believe the depth that you're given. A consequence of this misunderstanding is that people often try to micro-specify the uncertainty down to the millimeter, when all they really need is to be in the right ballpark. The key statement I use to describe this to the students is: if I tell you that the depth is $10\text{m} \pm 1\text{m}$, that's really important, but if I tell you the depth is $10\text{m} \pm 0.9\text{m}$ or $10\text{m} \pm 1.1\text{m}$, that's irrelevant. A 10% uncertainty in depth is important; a 10% uncertainty in the uncertainty isn't. So you need to estimate uncertainties that match the data, remembering that your sins will surely find you out: if you significantly underestimate, you'll get depths split when they shouldn't be; if you overestimate you'll get smeared objects. Being in the ballpark is really important.
2. Cross-lines aren't uncertainty, they're repeatability. Cross-lines, or any other data-to-data comparison, measure how well you can do the same thing twice, and don't capture anything that's common-mode. Consequently, you'll likely end up with an underestimate of the actual uncertainty. On the other hand, forward-modeled uncertainty (e.g., the HGM model or any of the variants) is typically an over-estimate of the uncertainty, since you need to make simplifying assumptions and the nature of hydrographers is to be conservative. Therefore, you're likely to get a bounding estimate from the pair, which isn't a bad thing: you should be able to squeeze the estimates with better methods.
3. While most people pay lip-service to generating uncertainty, they don't often use it. You can make most processing systems generate some form of uncertainty for the outputs, but it typically isn't shown by default, and isn't often turned on. But it's critical information to understand any statistical model. Thus, when people complain (a pet peeve) that "the surface doesn't honor the soundings", my second question is "did you look at the uncertainty?" (The first is "did you set the resolution correctly?"). If they did, they'd more often than not see that the uncertainty estimate happily spans the data evidence, even if the depth is in the mid-range due to (typically) bad configuration.
4. Sounding uncertainty isn't survey uncertainty. This one is typically the manufacturers: "my system meets IHO Order X uncertainty". The uncertainty in S.44 is a systemic uncertainty for the whole survey system, not any one component of it!
5. Specification of uncertainty. In the statistical sense, it doesn't really matter how you write the uncertainty: you can write variance, standard deviation, 95% CI, 99% HDR, or anything else, so long as you say what you did. In the hydrographic world, people like to have less flexibility, and therefore get stressed about what to report and how. It would probably be better if we just chose one method and got on with it; getting agreement for that would be really nice. I'd suggest 95% CI with a sample count (so that anyone who cares can do small-sample correction).
6. Uncertainty in sparse data is trickier than you think. It's relatively simple to estimate uncertainty in dense multibeam data, but if you have sparse (e.g., archive) data, it's not always possible to estimate an uncertainty in meters reliably. I wrote a paper on this ages ago, but the basic argument is that the bit of the surface that you don't observe in sparse data can come back to bite you, and even if you use the best-available methods to estimate the uncertainty of the data that you do see, you can't capture the short-range components, and therefore you will always make bad estimates. More importantly, they're often too optimistic: you can make estimates of the uncertainty of the unseen which look very persuasive, but assume that the surface is smooth between sparse observations and are therefore unable to predict objects in the unseen, or even just swales in the seafloor (we've seen evidence of both in even small datasets). My approach to this was to estimate risk of under-keel clearance failure (another paper) which I think has a lot to recommend it; there are a number of approaches to this now (it's the core of NOAA's Precision Navigation for example).
7. Data Quality is not uncertainty. There's a lot of discussion on this just now with the IHO Data Quality Working Group (although they've also been discussing it since at least 2008 and still haven't come to a conclusion). Their goal is to provide a fuller description of data (e.g., completeness, provenance, method) in addition to depth uncertainty, but it seems to be pushing more towards "a better CATZOC", which is still more about the survey as a unit than the data points themselves. This seems to be creeping backwards into S.44 world at the minute, and even NOAA has some suggestion of using CATZOC to help with survey data rather than cartographic data. I feel that's a really bad precedent.

TPU Quotable Quotes

Brian Calder:

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6. Uncertainty in sparse data is trickier than you think
7. Data Quality is not uncertainty

TPU Myths, Misconceptions, Sore Spots & Sins

Inappropriate selection of survey standard for the job

Human Error in TPU calculation configuration

TPU input not capturing “real-life” factors: oceanography, tides, human error, bottom detection noise level

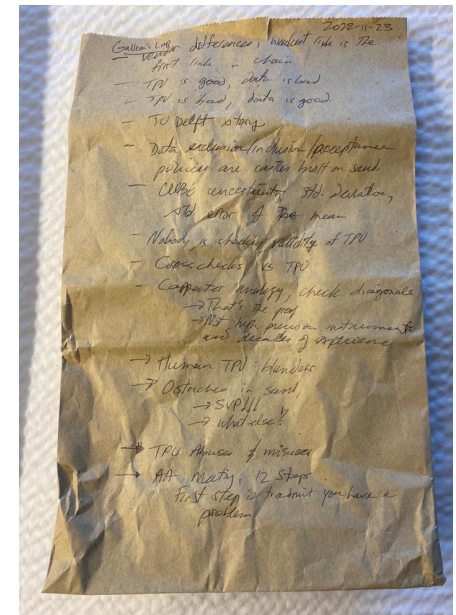
Using TPU to reject measurements

Tweaking TPU inputs to meet TPU spec

Not looking at data itself to assess quality

Lack of standard TPU engine (Can't compare TPU outputs from different software vendors!)

Using TPU alone to choose between different survey data sets



Achieving Standards – In Theory vs In Practice

TPU lets us plan for the job

TPU helps us understand what
accuracy we might achieve

TPU doesn't capture how things
actually went

Need other methods to capture
achieved data quality

Different tools for different jobs

Important to know when to use
each tool & limitations of each



Resources – Theory, Terminology & Nomenclature



United States Department of Commerce
Technology Administration
National Institute of Standards and Technology

*NIST Technical Note 1297
1994 Edition*

*Guidelines for Evaluating and Expressing
the Uncertainty of NIST Measurement Results*

Covers core concepts needed to start with an understanding of how to treat uncertainty in our measurements as hydrographers.



NIST Technical Note 1900

**Simple Guide for Evaluating and
Expressing the Uncertainty of NIST
Measurement Results**

Antonio Possolo



Resources – Theory, Terminology & Nomenclature



MBES Uncertainty For for NOAA's Office of Coast Survey

April 2024

Brian Calder ^a, Bart Buesseler ^b, Glen Rice ^b, Matthew Wilson ^b, Harper Umfress ^b

^a Center for Coastal and Ocean Mapping & Joint Hydrographic Center

^b NOAA's Office of Coast Survey

Executive Summary

NOAA's Office Of Coast Survey requires consistency in metadata to enable new and innovative products and processes that are of high value to the public. Thanks to recent advances within hydrography, the current metadata requirements for the uncertainty values of Multibeam Echosounder (MBES) data within the Bathymetric Attributed Grid (BAG) file format have been found to be inadequate and in need of refinement. This paper provides the background leading up to this need, a brief overview of the intention behind uncertainty values, and finally a revised version of MBES uncertainty requirements to support current and future products. These new requirements mandate the use of Combined Uncertainty and Bathymetric Estimator (CUBE)¹ or CUBE with Hierarchical Resolution Techniques (CHRT)² gridding algorithms to effectively exclude spurious data from consideration, and computes a variance and resulting uncertainty from those remaining data points (or "pings") for the resulting depth estimation of any individual grid node.

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Background

NOAA Information Quality Act Policy states effectively used by the public³. In hydrograph coverage, feature detection capability, and use of the bathymetry provided by NOAA's bathymetry uncertainty needs to have a solid definition.

Coast Survey's understanding of Uncertainty metadata was being designed in 2003. It has

¹ B. R. Calder and L. Mayer: Automatic Processing Data, Geochem., Geophysics, and Geosystems (G. B. R. Calder and G. A. Rice: Computational / Computers and Geosciences, 106:49-59, 2017).
² The entire policy can be read at the following link: <https://www.noaa.gov/organization/information/quality-guidelines>



What Should the Community Do With TPU?

Use TPU for planning. Stop There.

Either stop using TPU inappropriately, or we should strive to improve it

There should be a community vetted and open source TPU engine

There probably should be a TPU working group

Need education to help data collectors and data users understand limitations of TPU

