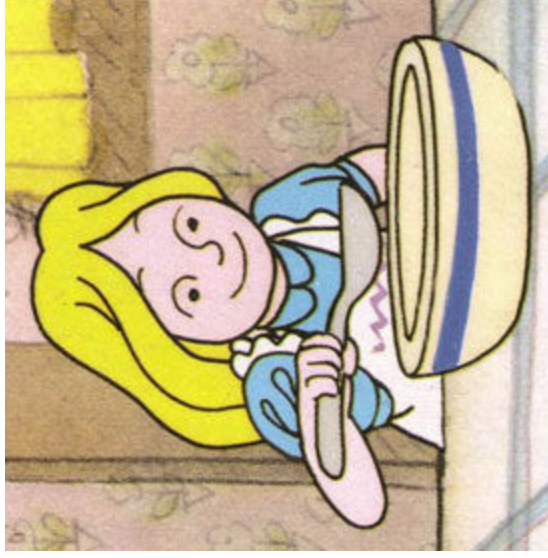
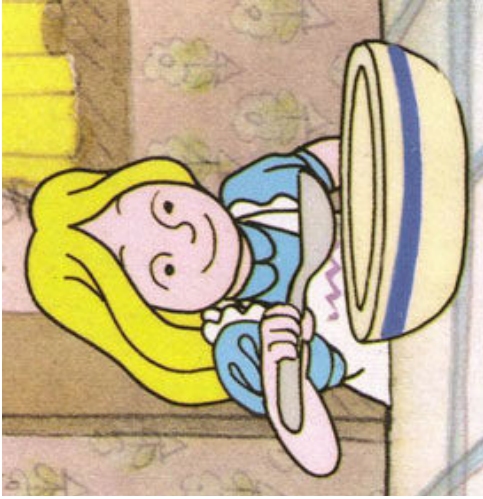


# Real-time Monitoring of Uncertainty due to Refraction in Multibeam Echosounding



J. Beaudoin  
Ocean Mapping Group  
University of New Brunswick



# Introduction

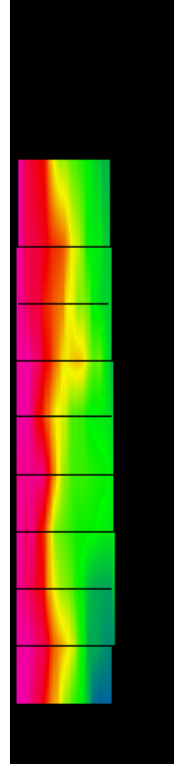
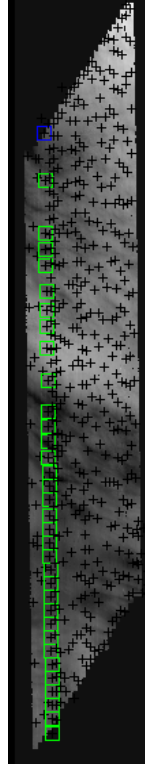
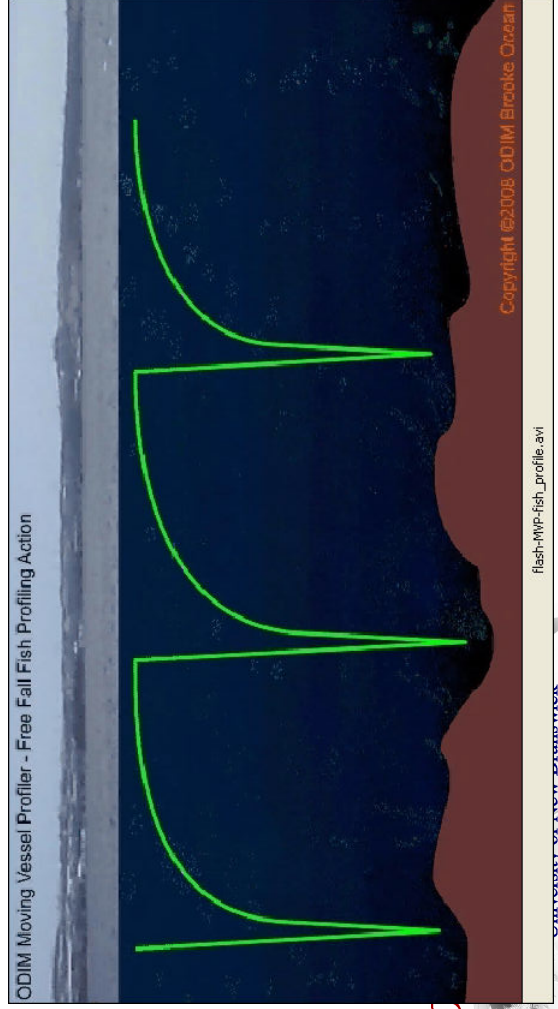


CSL Heron

CCGS Creed

CCGS Matthew

CCGS Amundsen



1450 m/s

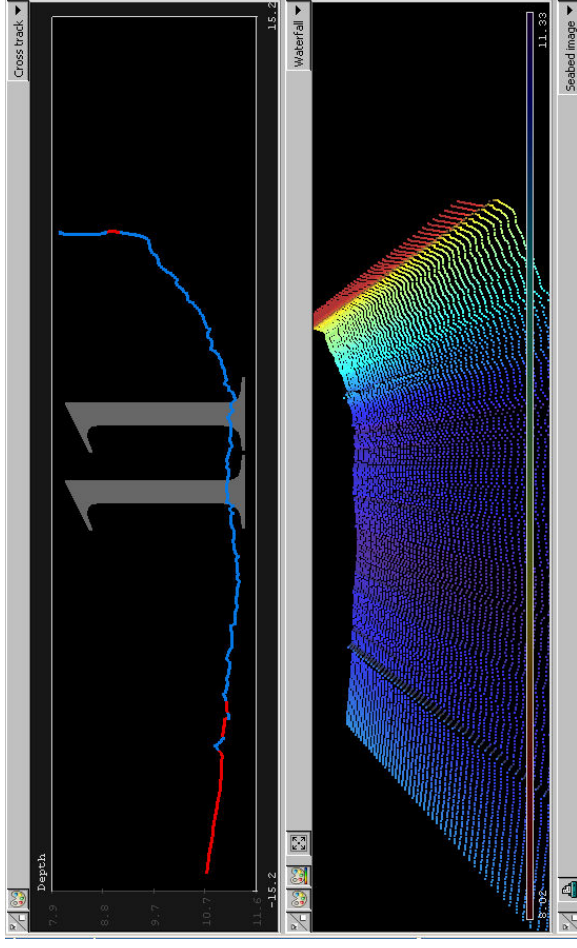
1500 m/s

2008

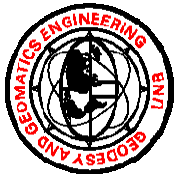
2

# Assessing Refraction Artifacts in Real-Time

- Highly subjective
- Requires constant vigil
- Can overreact over flat seafloors
- Can “underreact” over complicated topography
- Impossible for iso-velocity displays (e.g. Reson 81XX display)

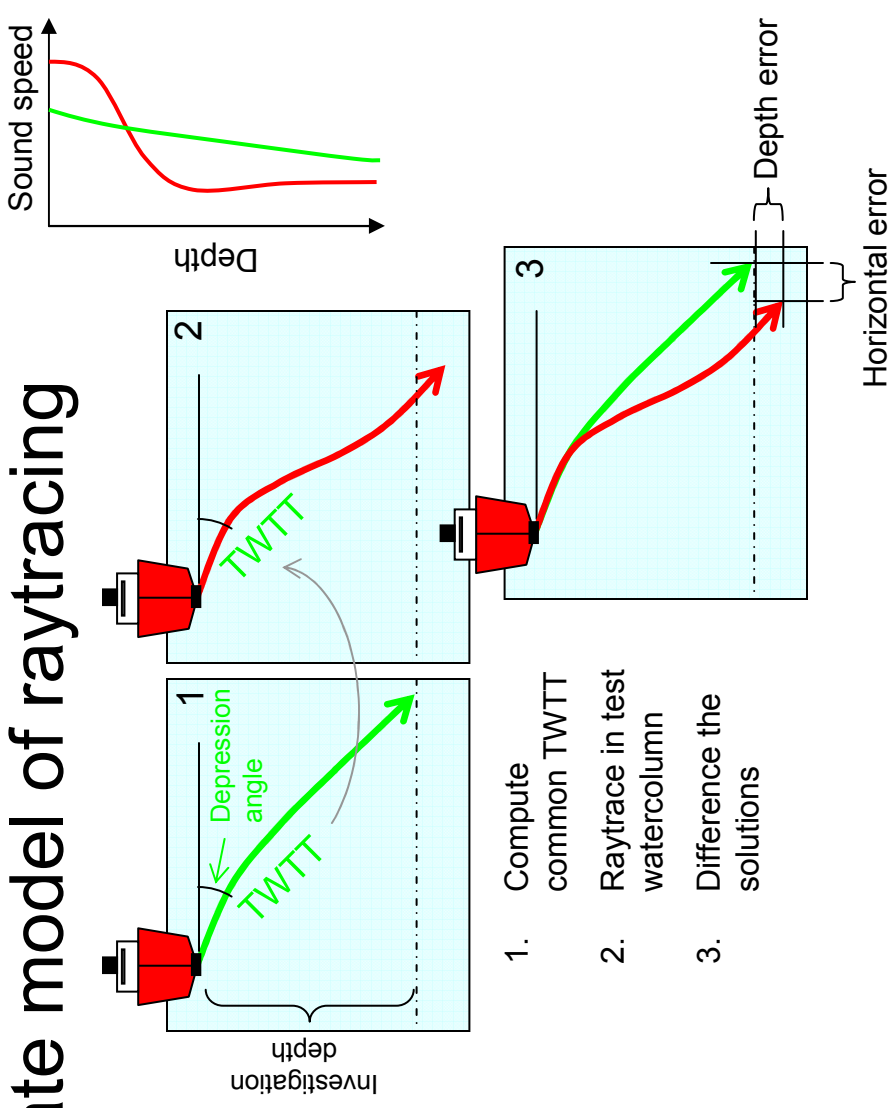


Shallow Survey 2008



# Proposed Approach: Raytracing Simulation

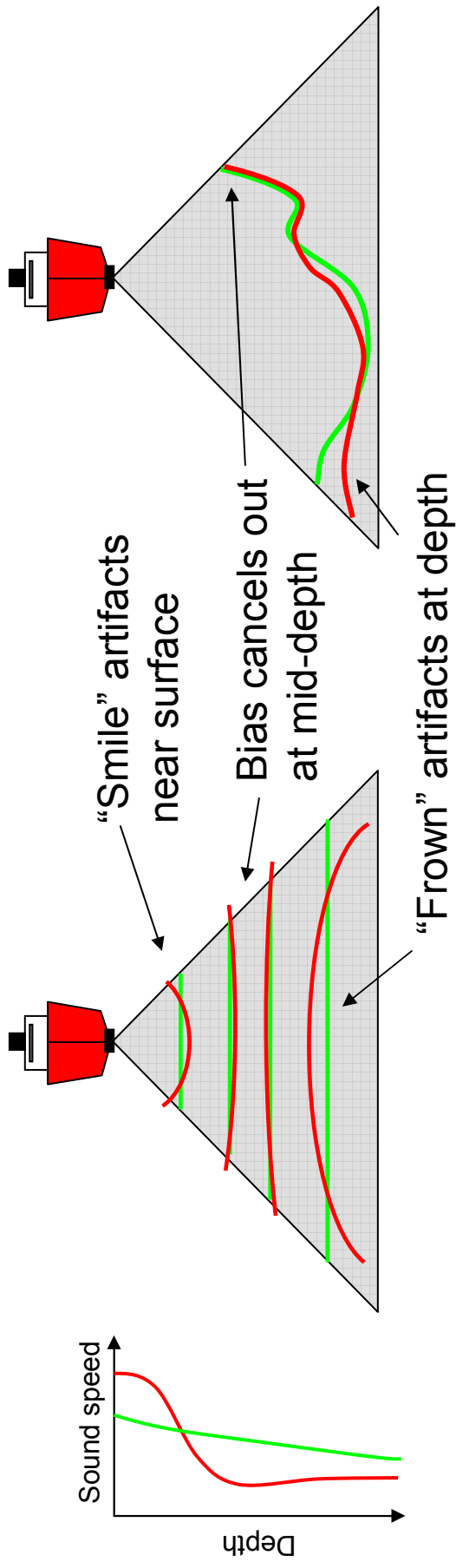
- Isolates raytracing portion of depth reduction procedure: no sounding data required!
- Requires accurate model of raytracing procedure:
  - Draft
  - Angular sector
  - Survey depth
  - Surface sound speed probe



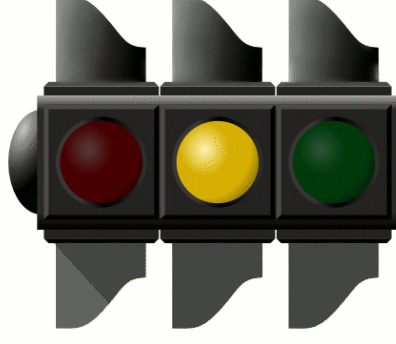
1. Compute common TWTT
2. Raytrace in test watercolumn
3. Difference the solutions

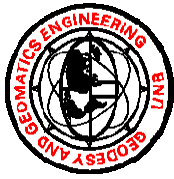


# Application to Real-Time Monitoring

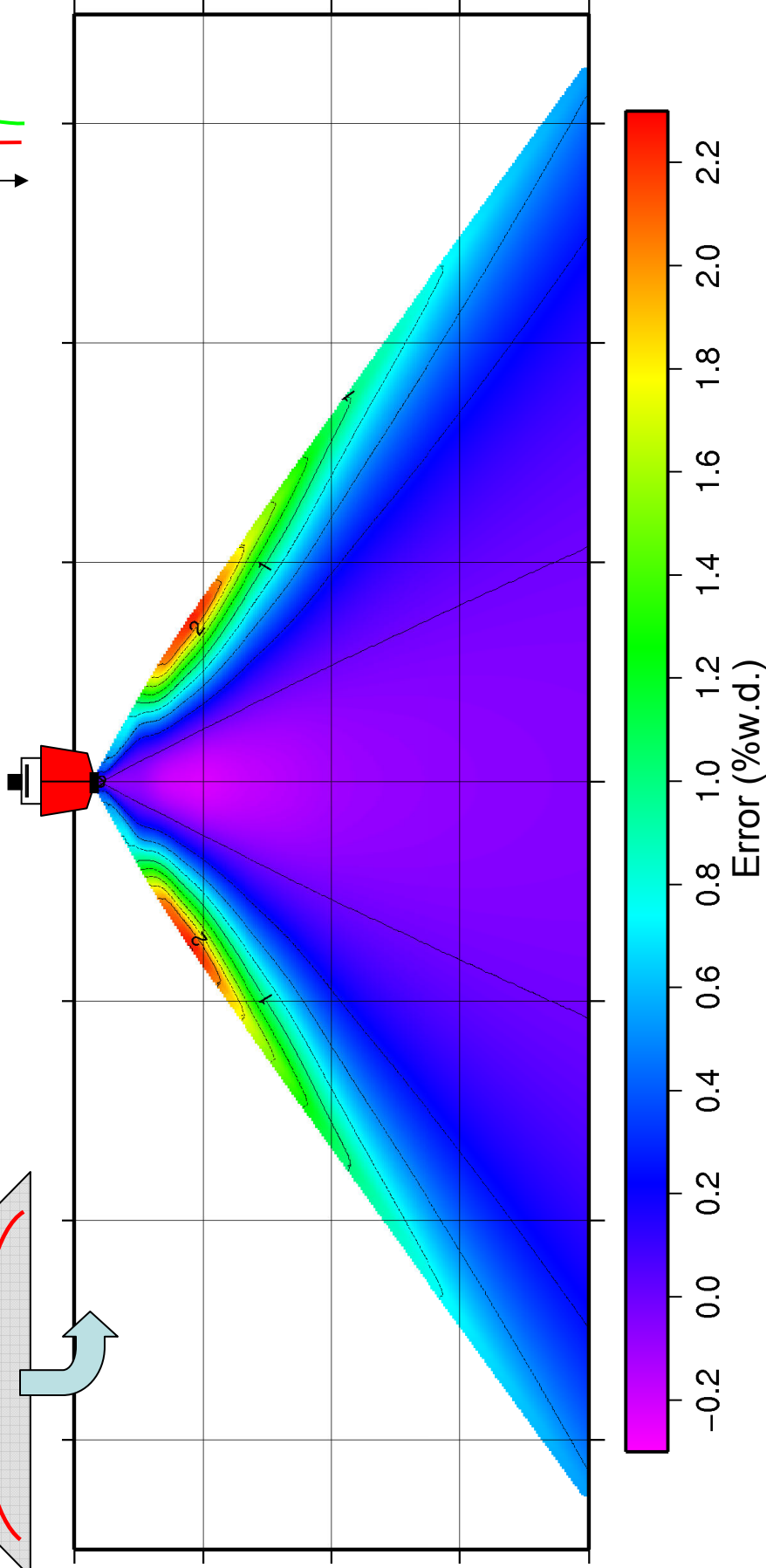
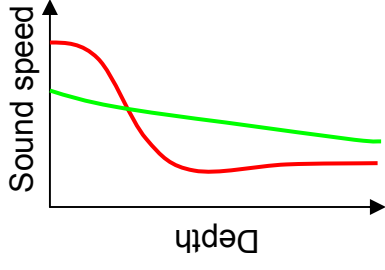
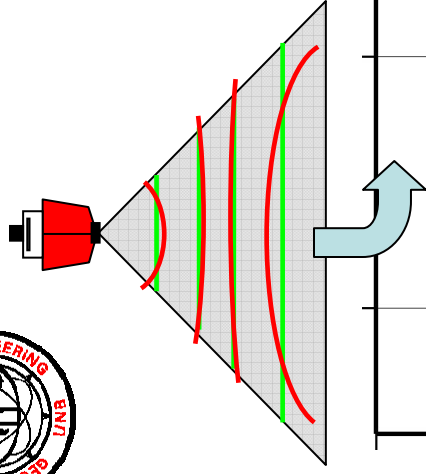


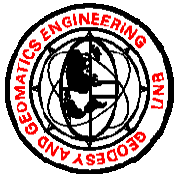
*It's important to see the whole picture*



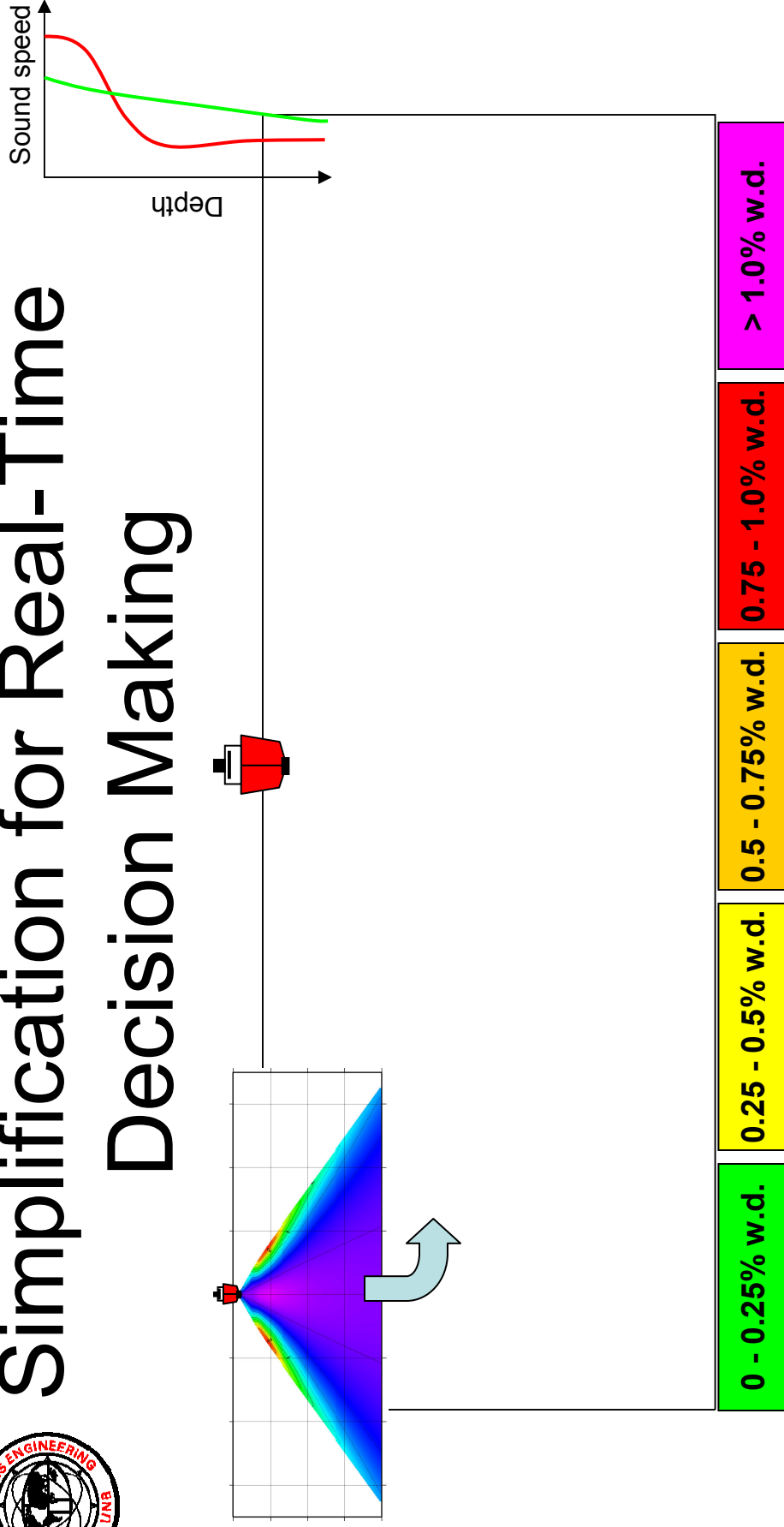


# Uncertainty Wedge



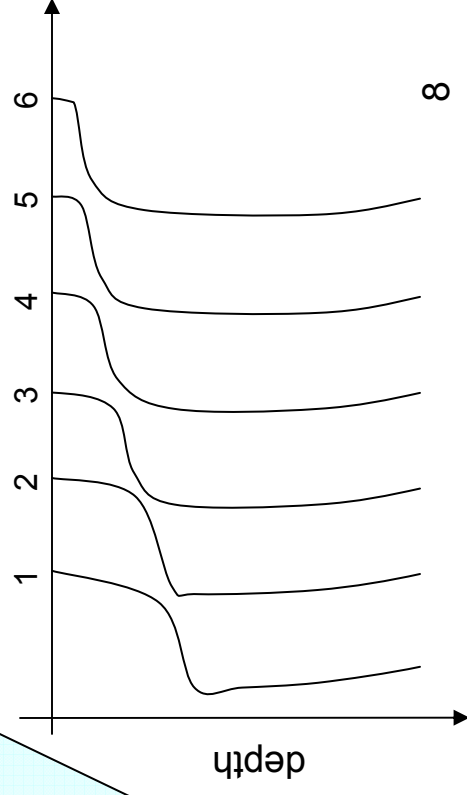
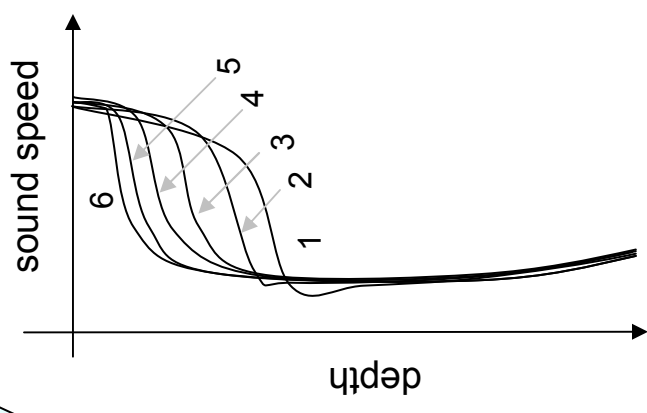
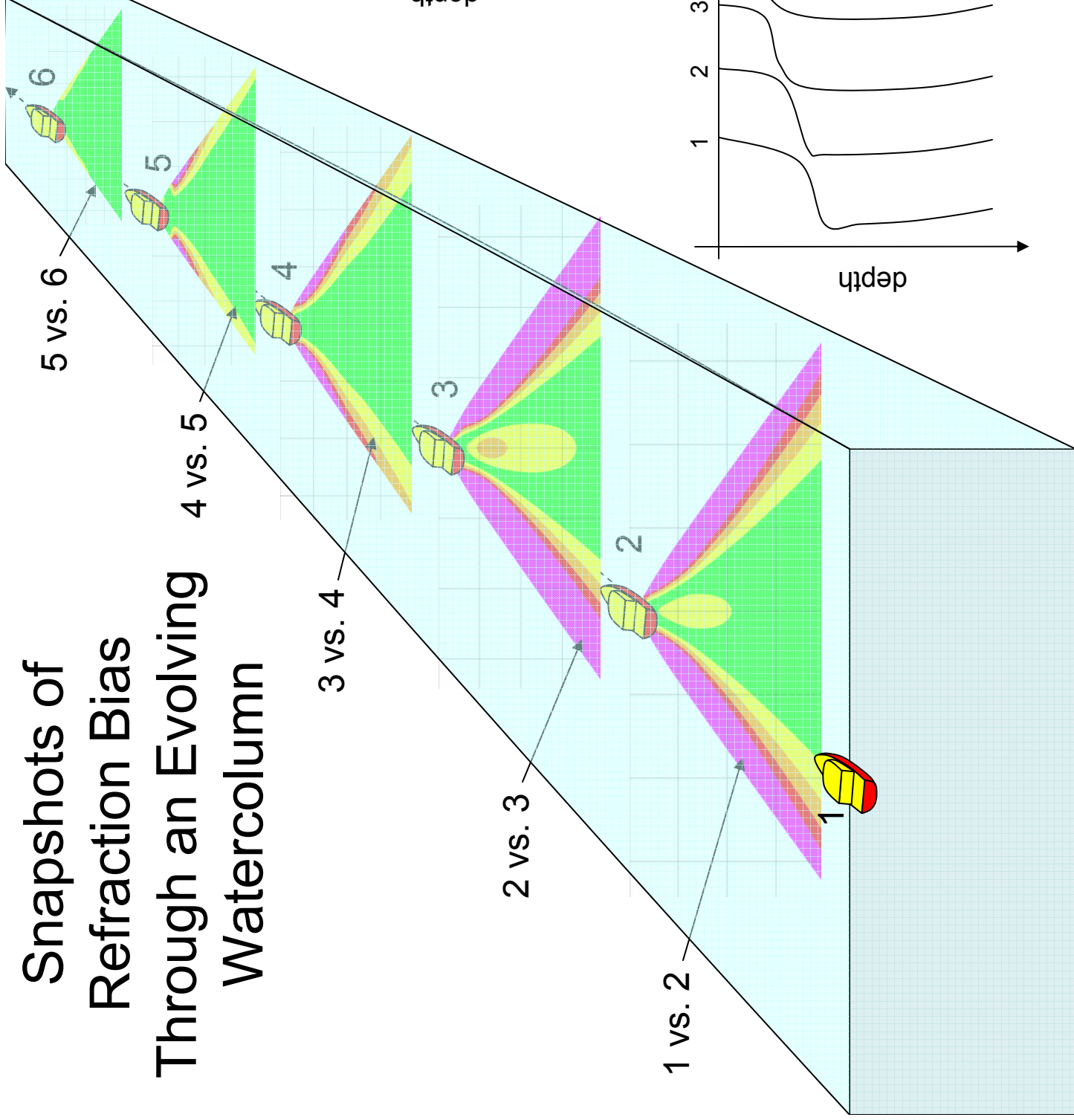


# Simplification for Real-Time Decision Making

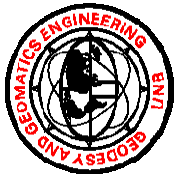


IHO Order	Allowable depth dependant portion of TVU
Special	0.75% w.d.
1a	1.3% w.d.
1b	1.3% w.d.
2	2.3% w.d.

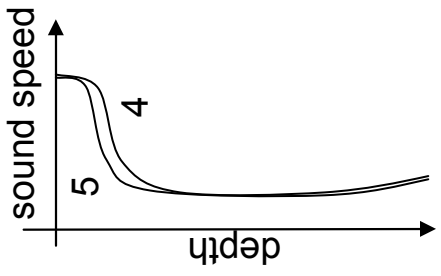
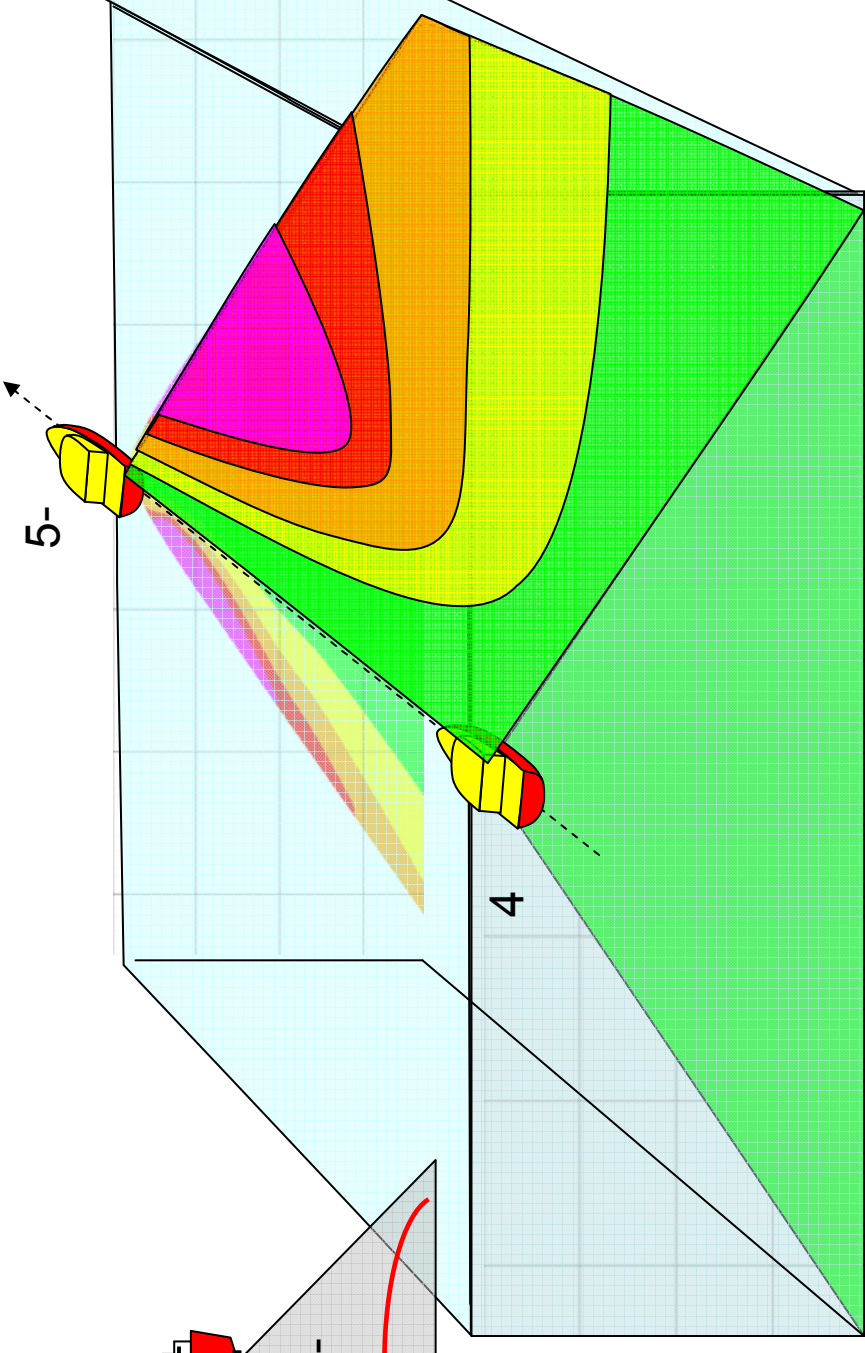
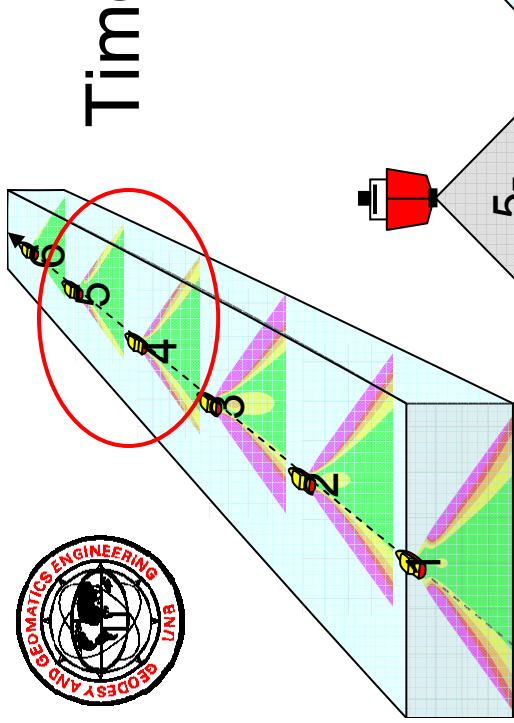
# Snapshots of Refraction Bias Through an Evolving Watercolumn



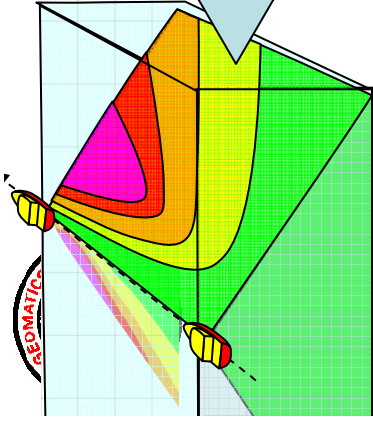




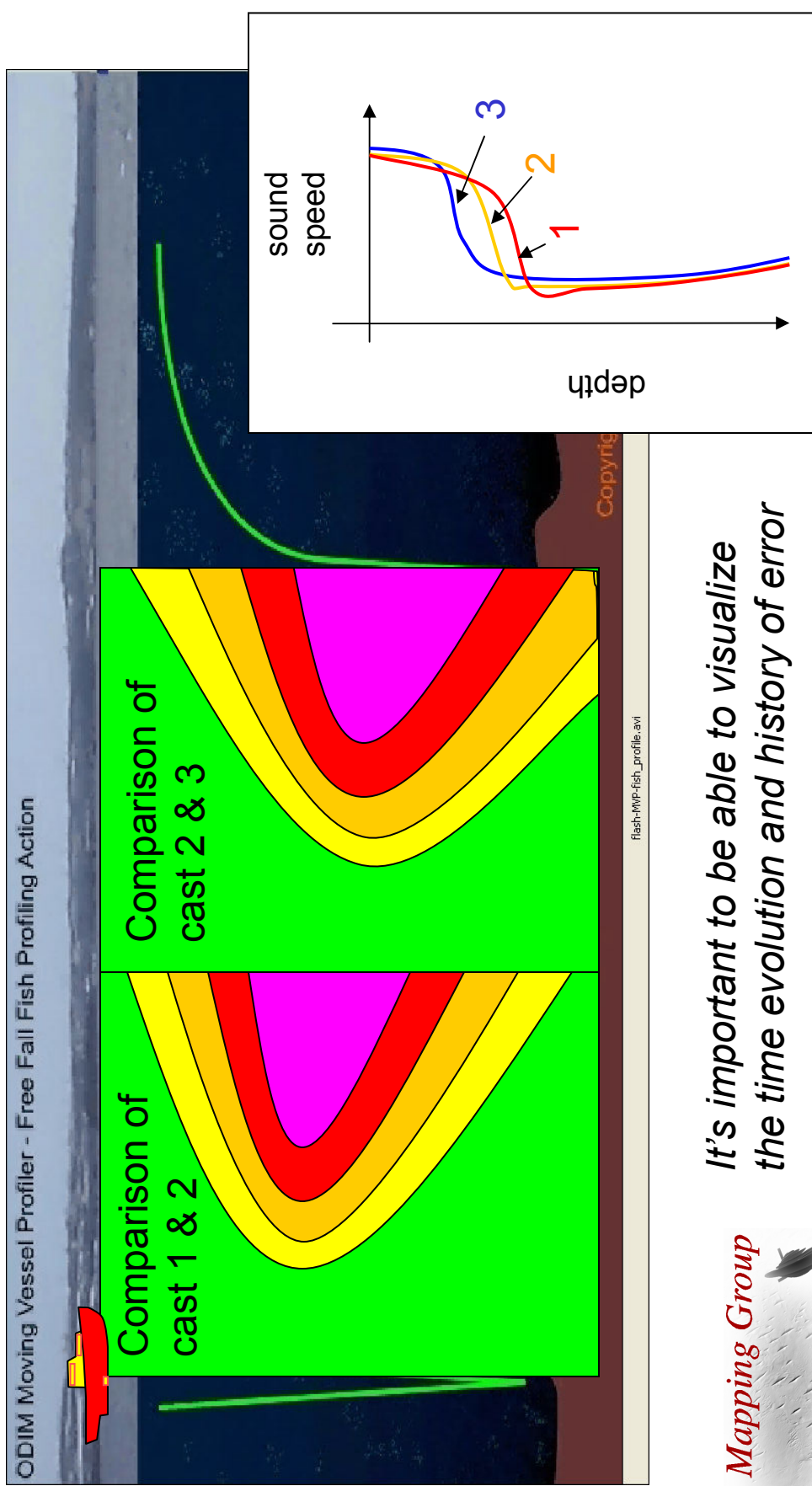
# Time Evolution of Bias Between Casts



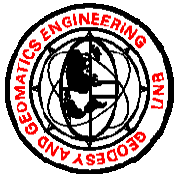
**HUGE ASSUMPTION:** Linear growth of bias with time  
Not unreasonable if you're sampling at a high rate but  
**DEFINITELY** not applicable if you're undersampling



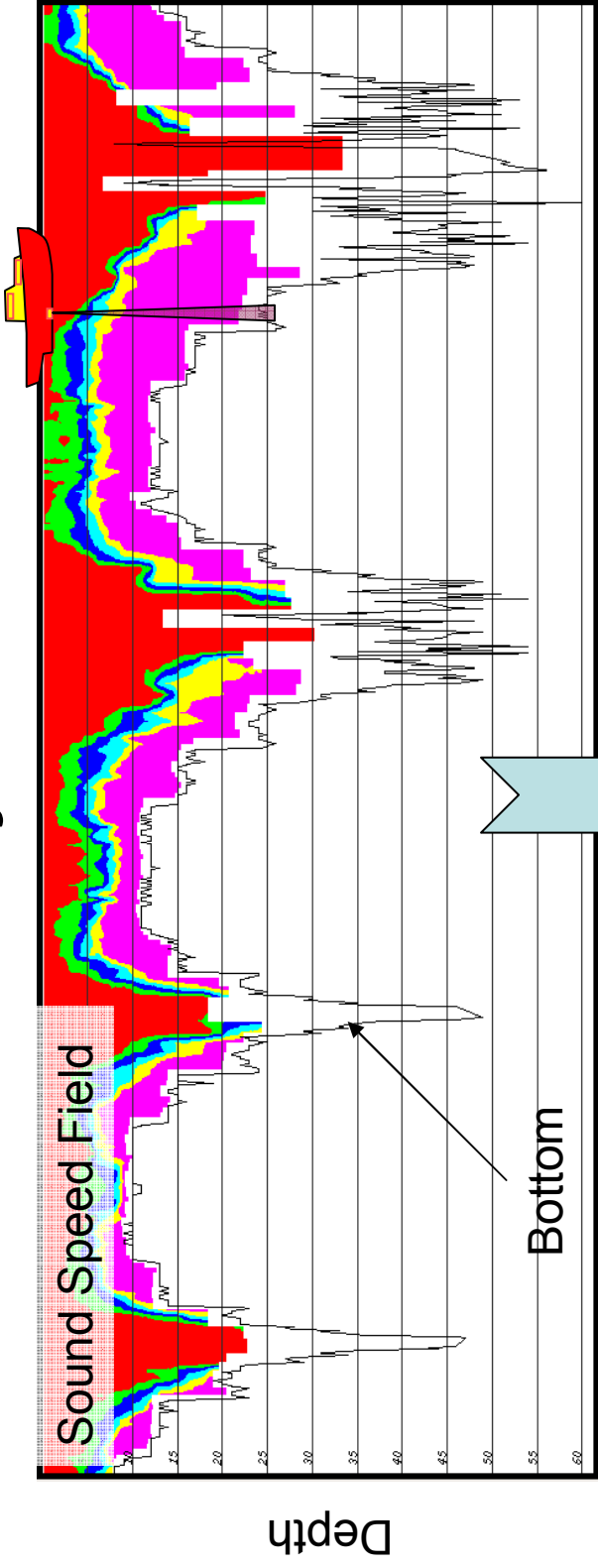
# Real-Time Uncertainty Visualization



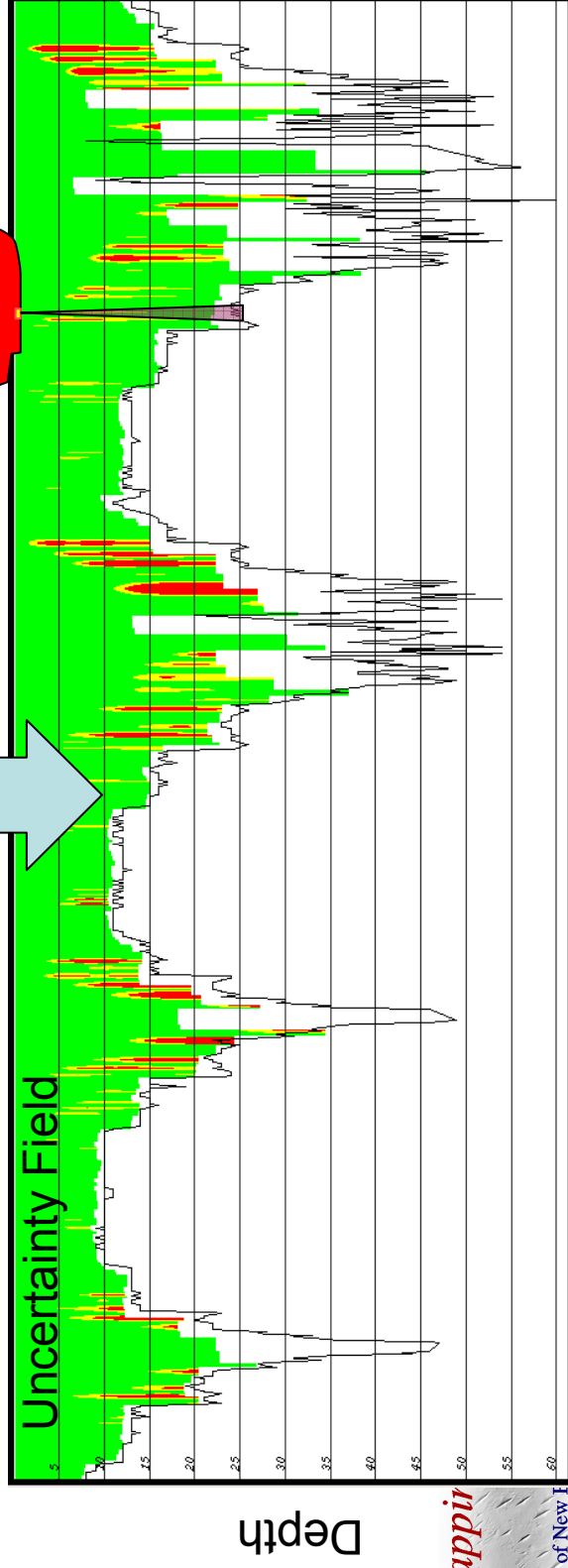
*It's important to be able to visualize the time evolution and history of error*

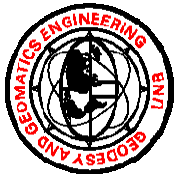


# Uncertainty Visualization

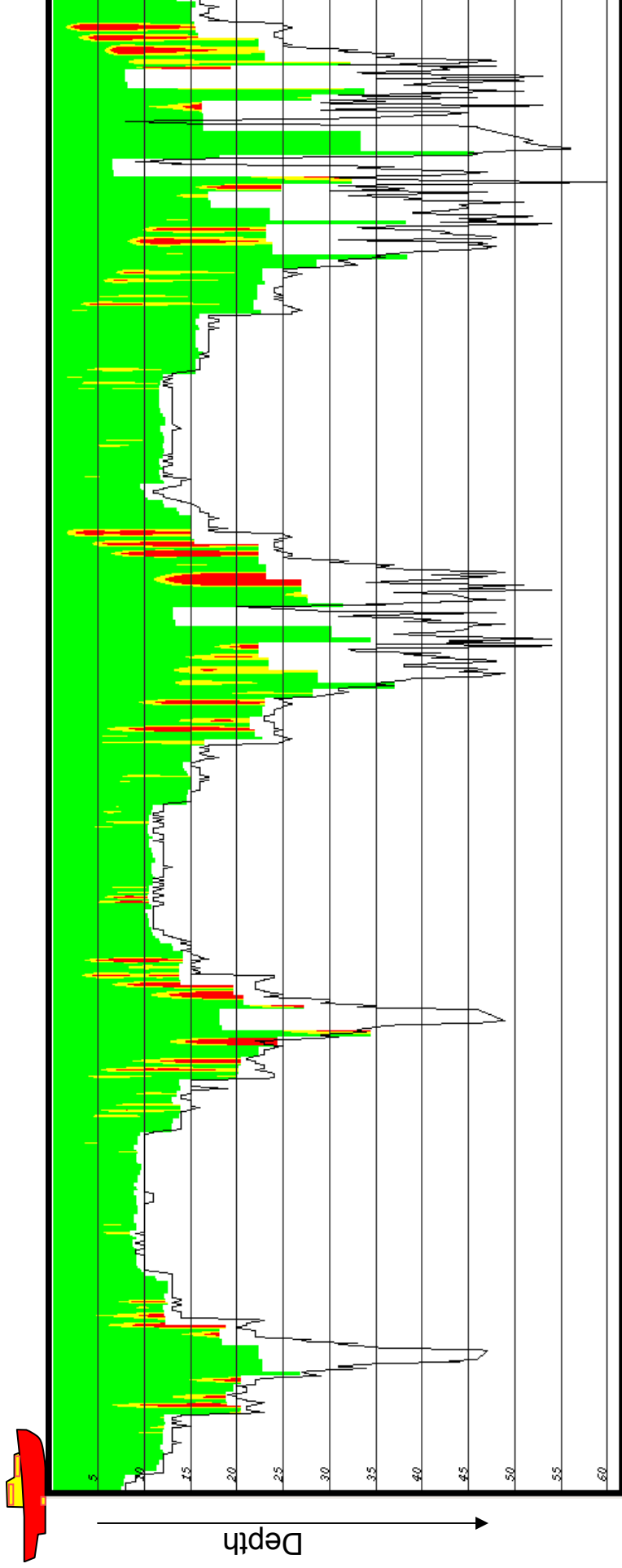


Error Analysis





# Real-Time Monitoring

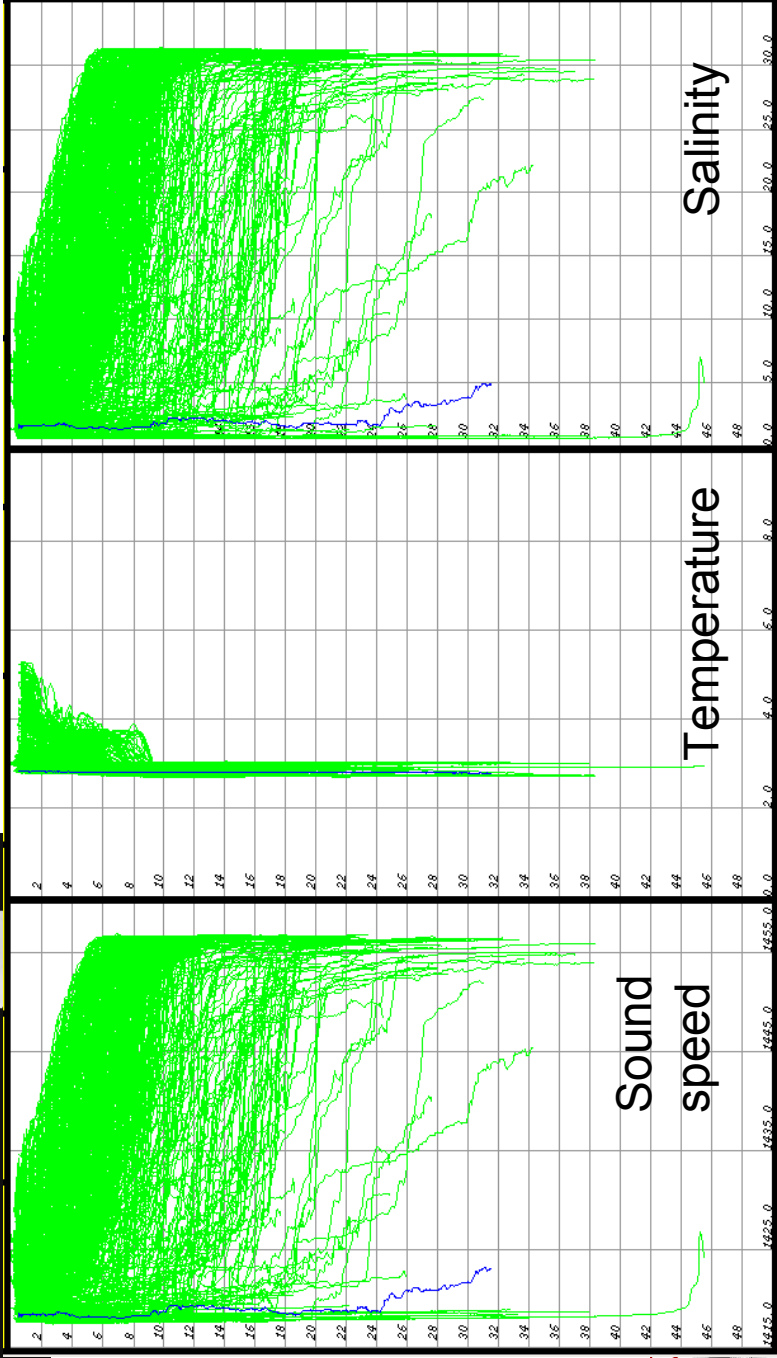
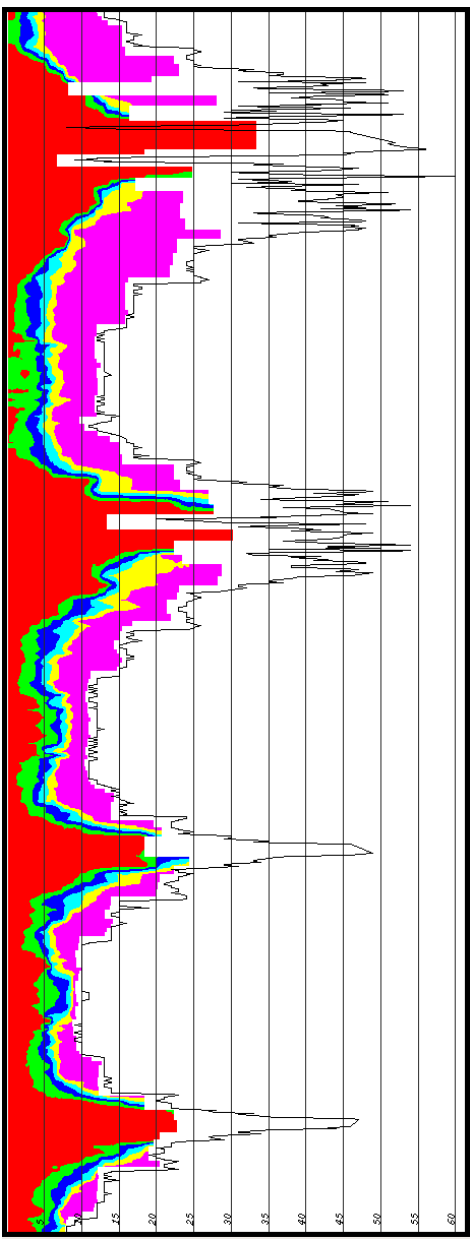
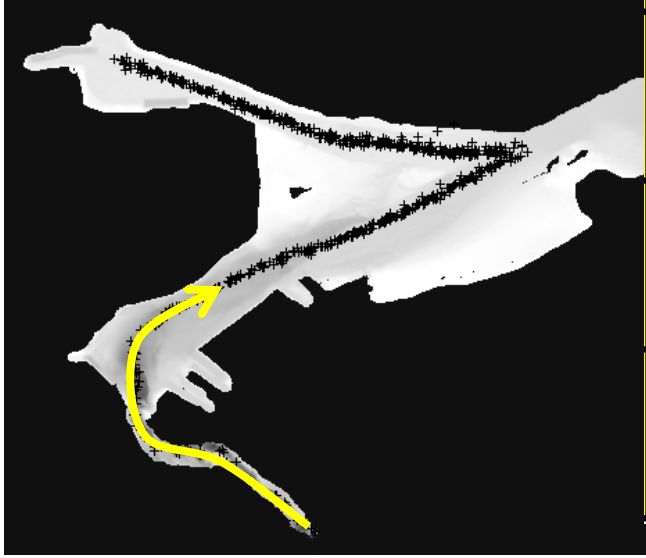


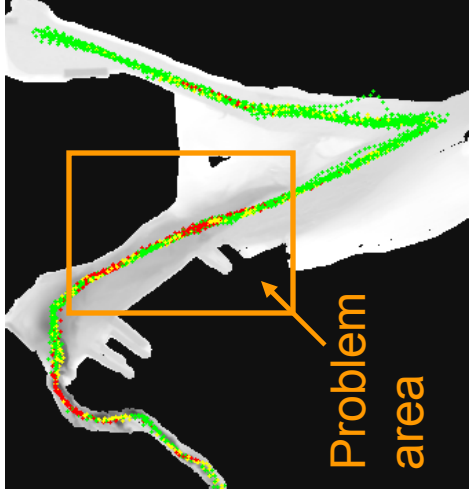
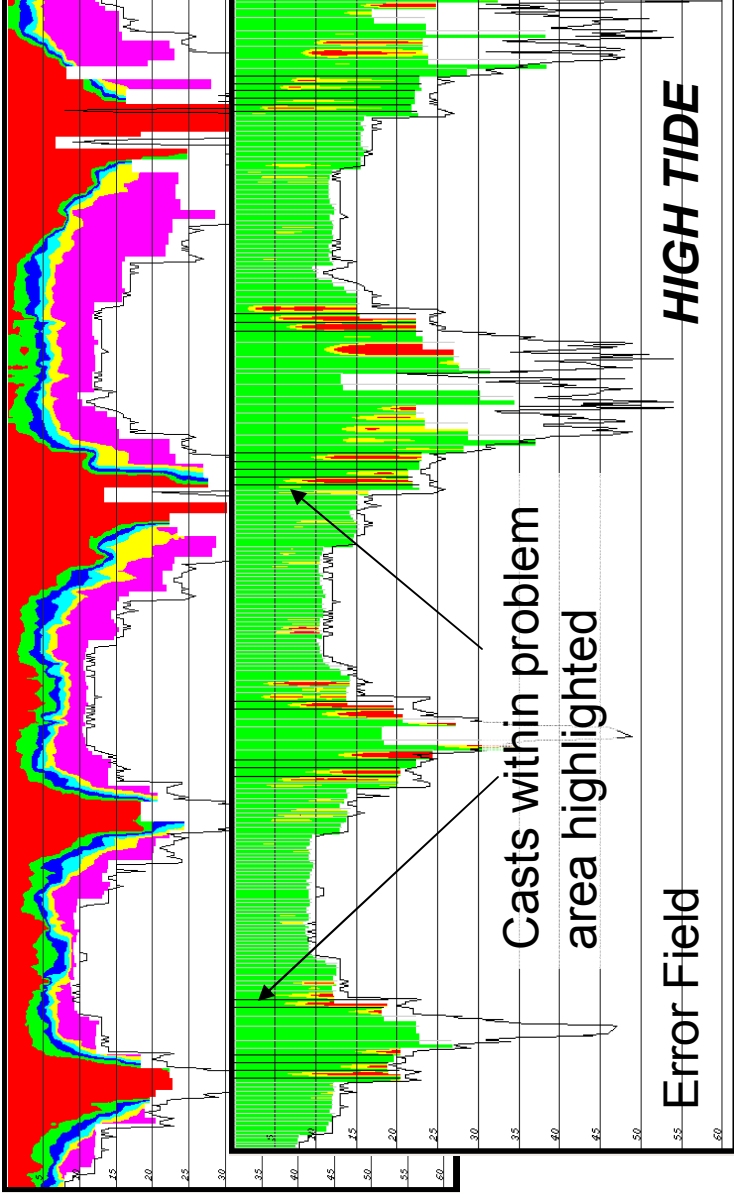


## Other Applications Error Analysis with Raytrace Simulation

- Pre-survey Analysis
  - CSL Heron, Port of Saint John (2008)
- Quality Assurance
  - CCGS Matthew, Advocate Bay (2008)
- Pre-survey Analysis
  - CCGS Matthew, EM710 acceptance trials (2005)

# Example 1: CSL Heron, Port of Saint John

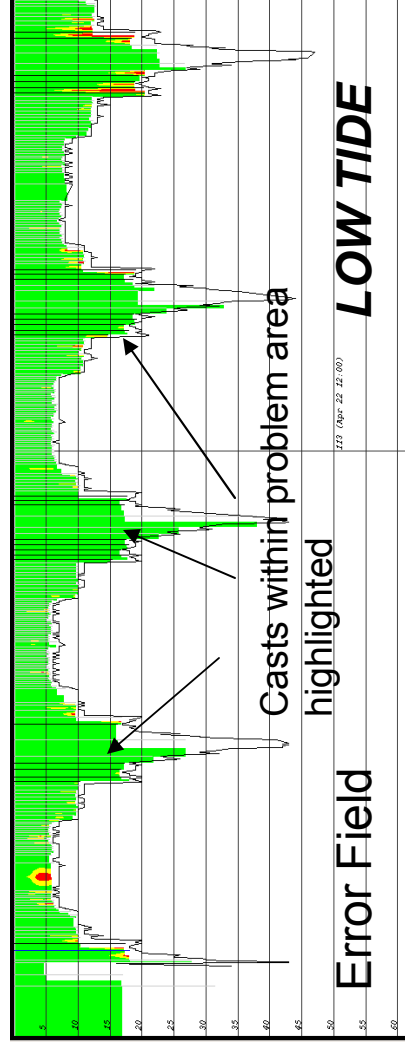


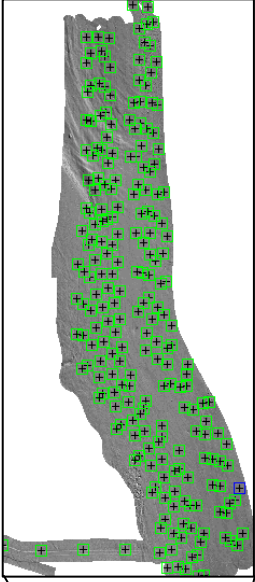
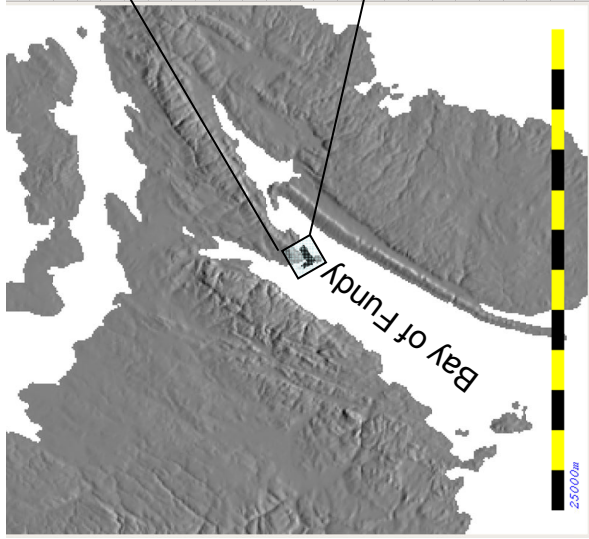


Geographic plot of depth error highlights areas where the watercolumn's rate of change exceeds our ability to sample it...

How does this affect survey planning?

- Less of our angular sector is within tolerable uncertainty, so can reduce line spacing in these areas to maintain accuracy
- Could reduce vessel speed to increase spatial sampling of the rapidly changing watermass
- Could survey at low tide

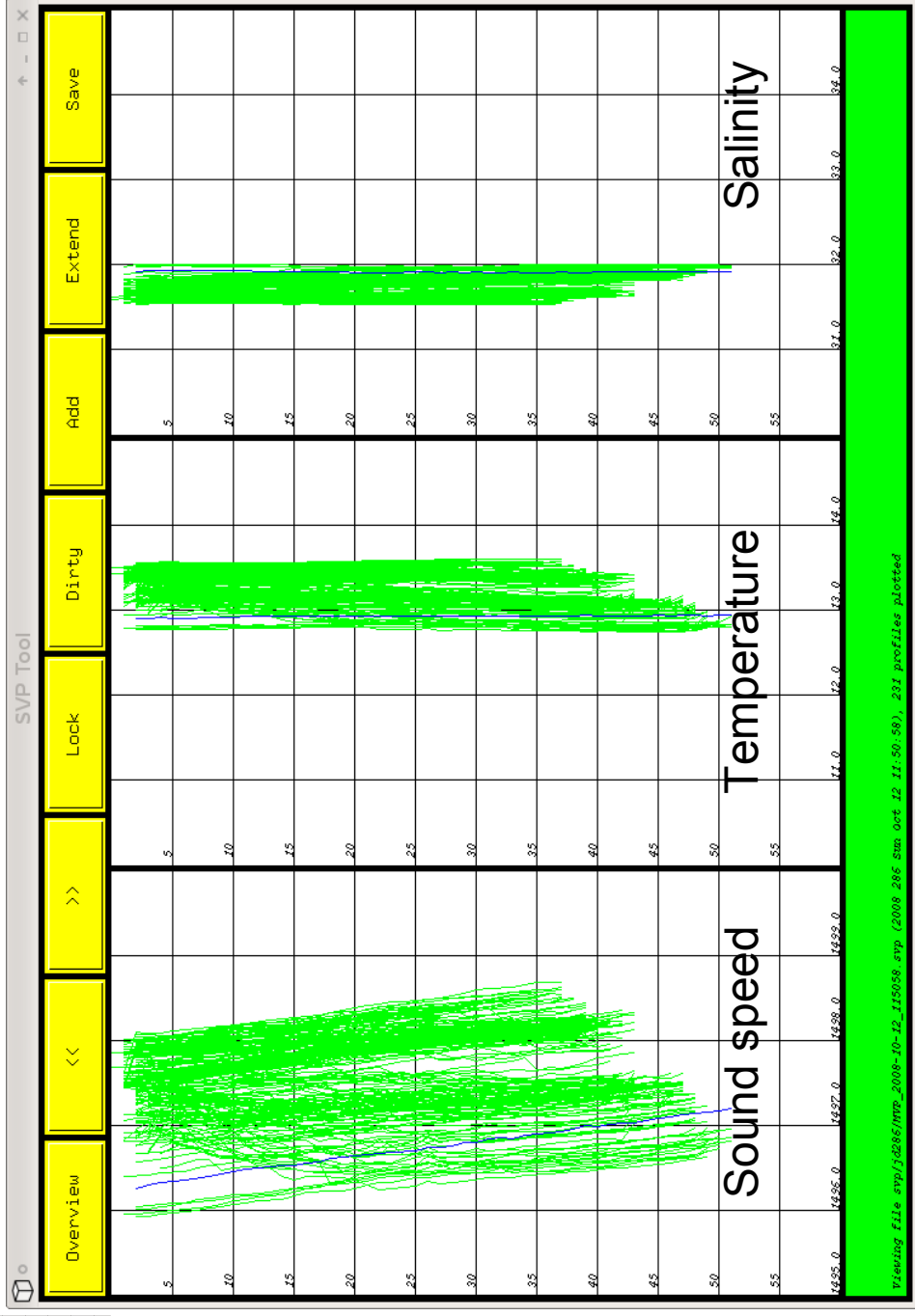




# Example 2: Post-Survey Quality Assurance



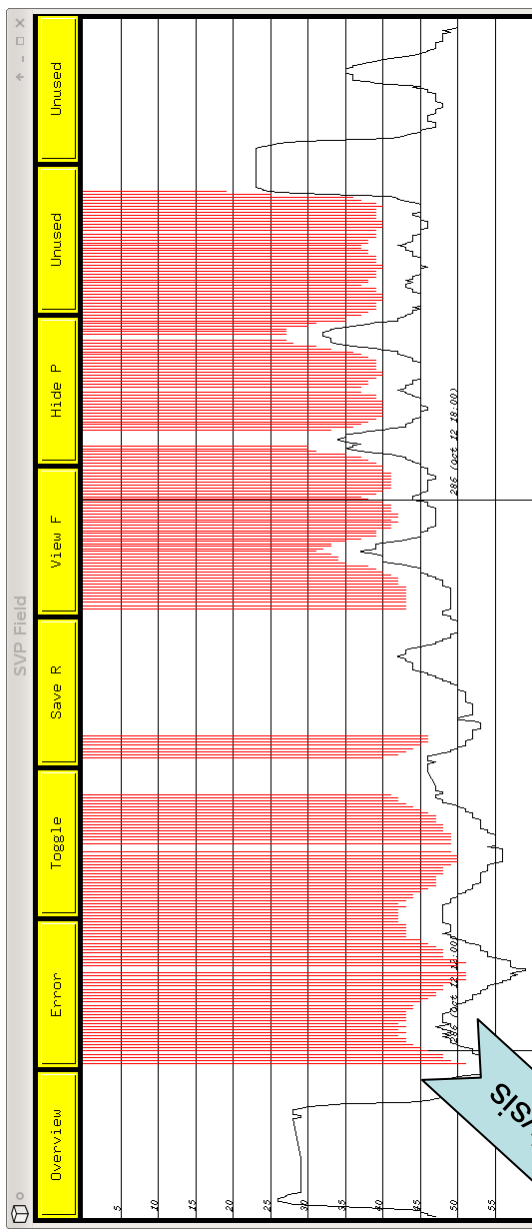
- CCGS Matthew
- EM710 (140° sector)
  - MVP200





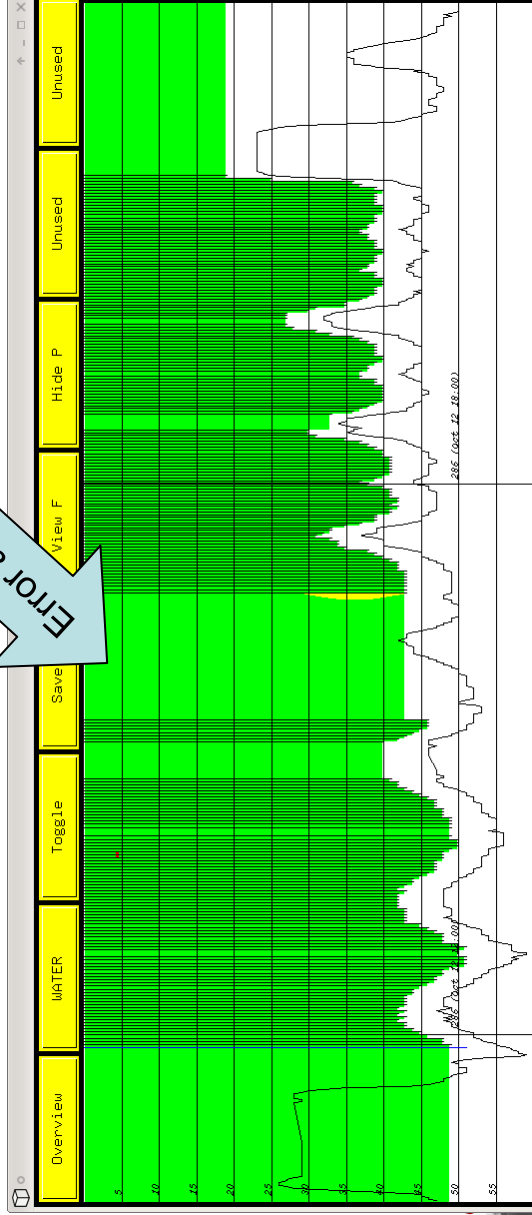
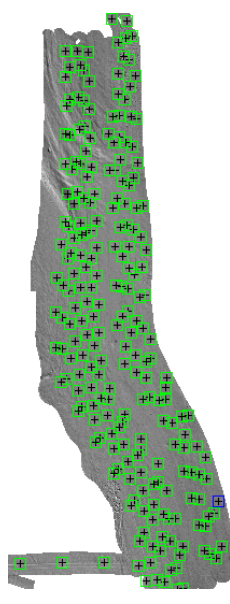


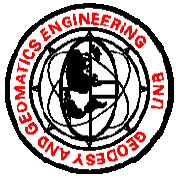
# Post-Survey Quality Assurance



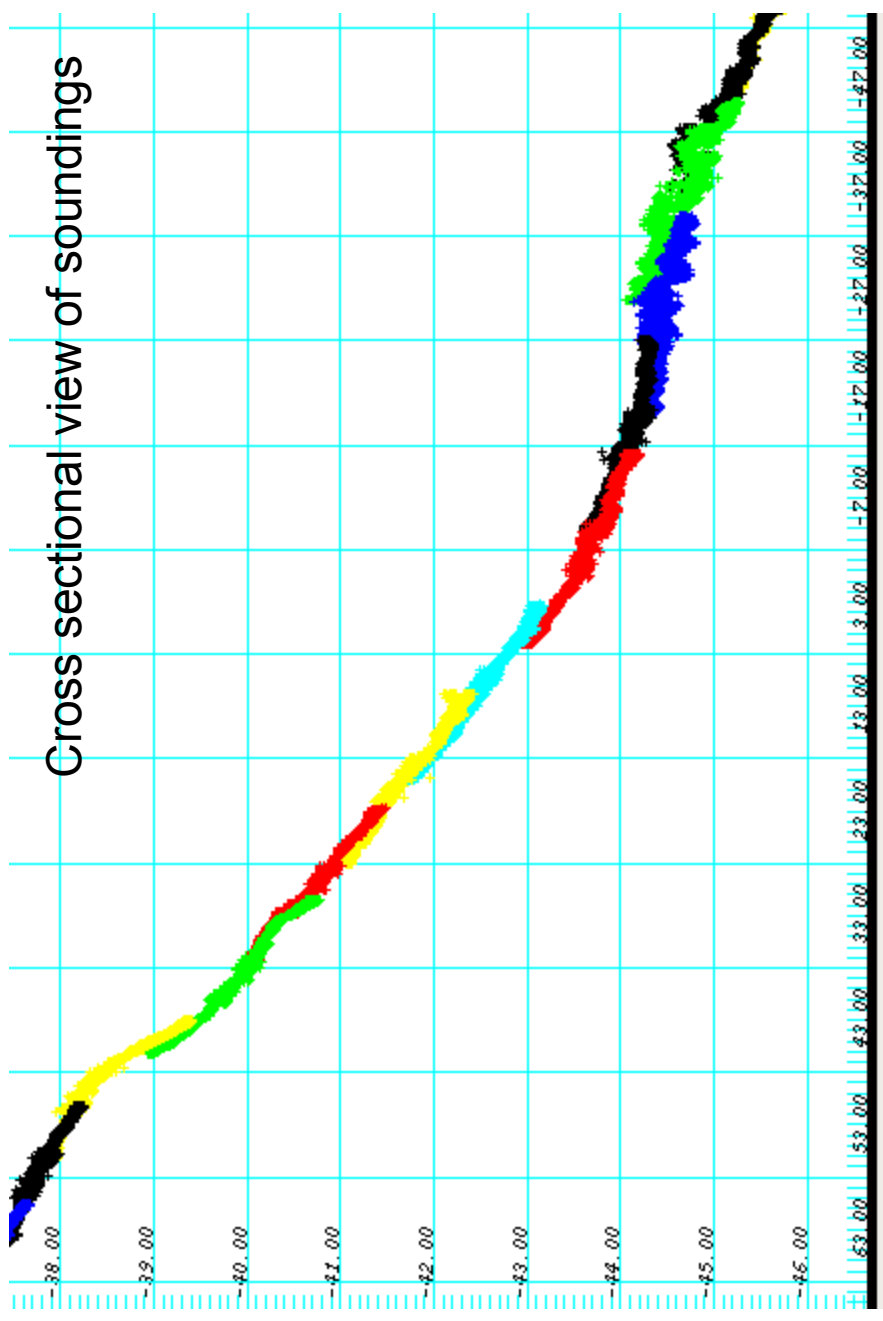
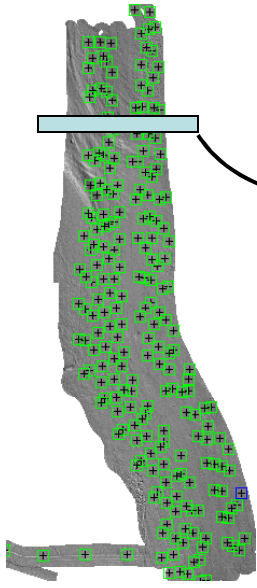
- 233 casts over 9.5 hr survey, 2 min. sampling interval

- Uncertainty due to refraction maintained within **+/- 0.02% w.d. !!**





# Post-Survey Quality Assurance



- Refraction uncertainty is noise in the error budget
- Largest source of uncertainty is water level
- Soundings shown here are tidally reduced with WebTide (2D barotropic hydrodynamic model)...
- CHS uses GPS/RTK tide

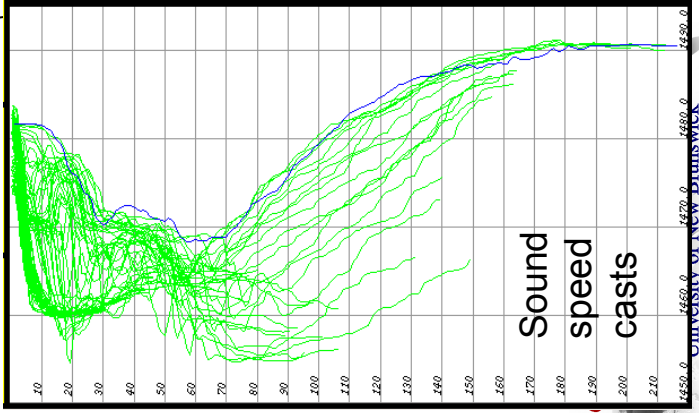
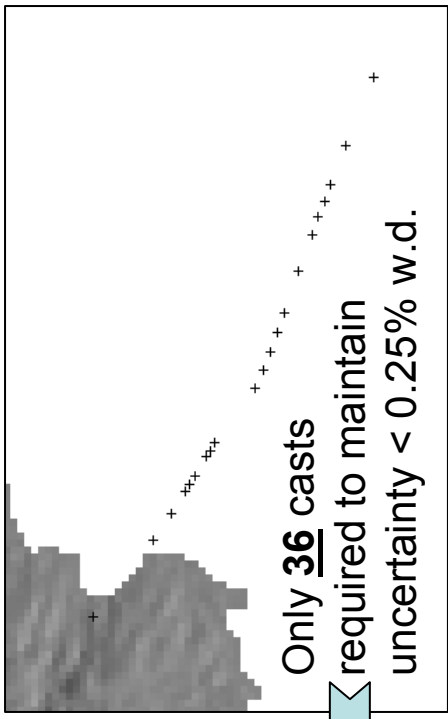
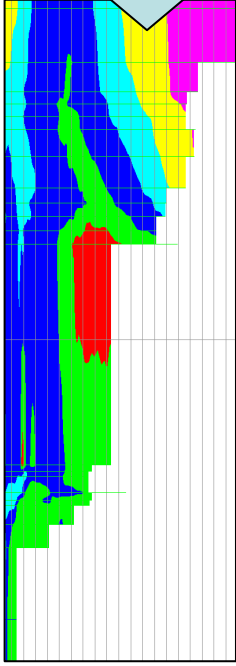
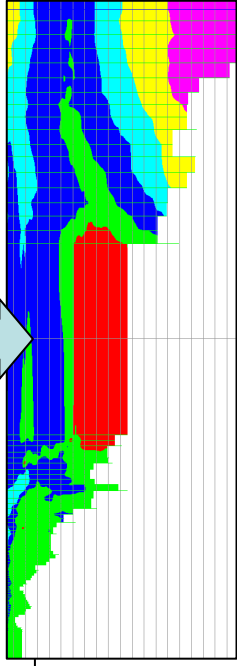
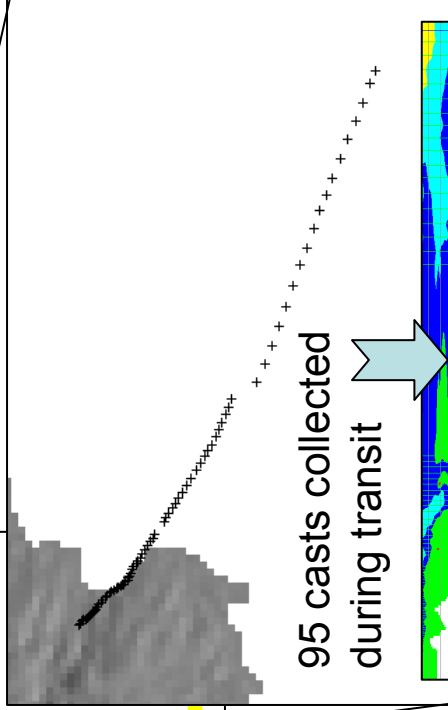
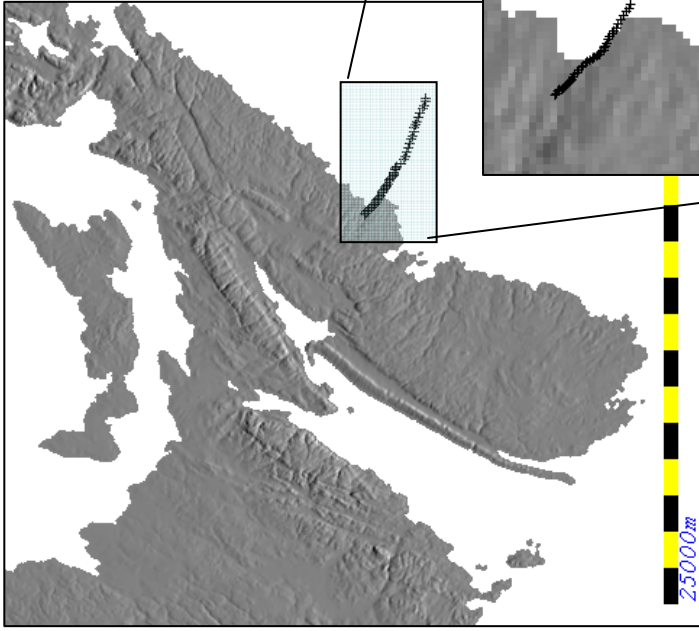
*Ocean Mapping Group*

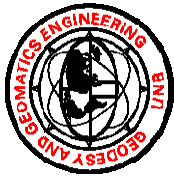


University of New Brunswick  
CANADA

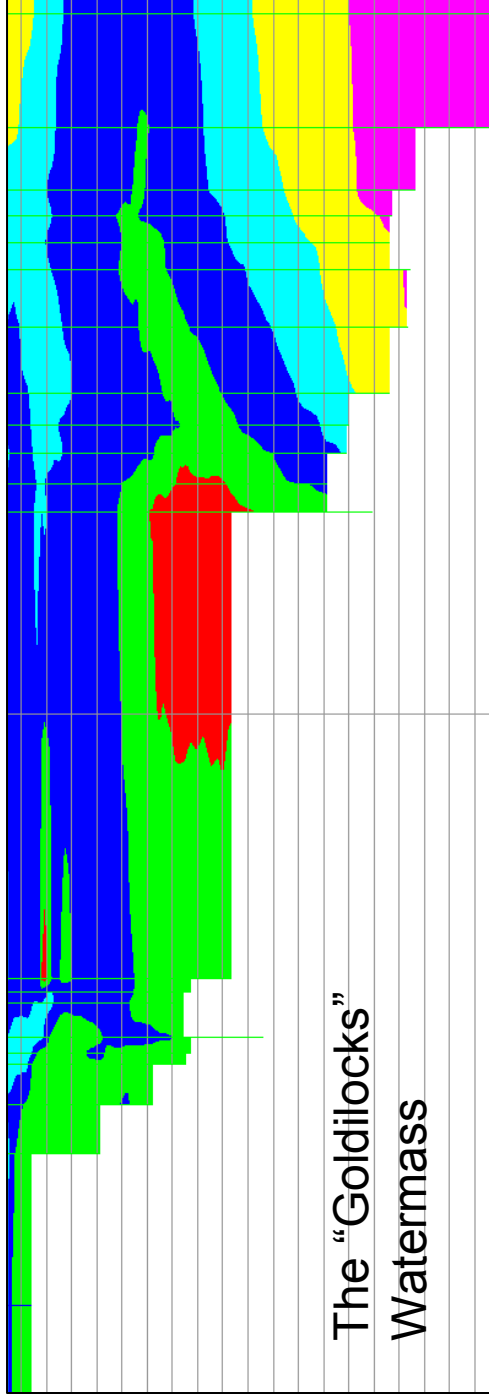
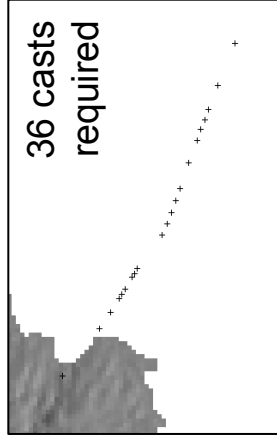
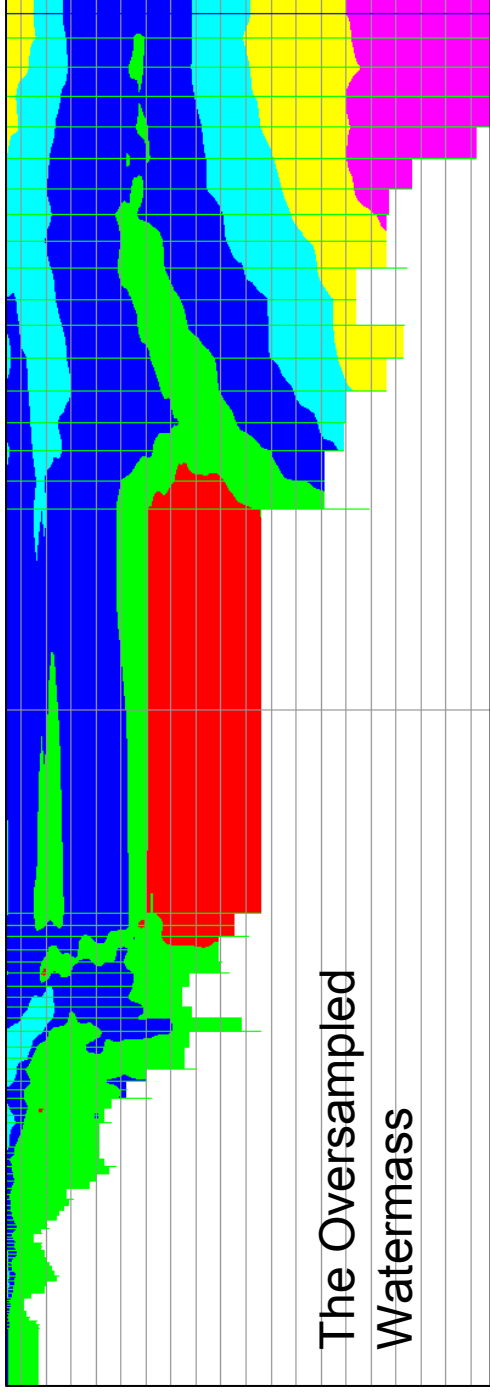
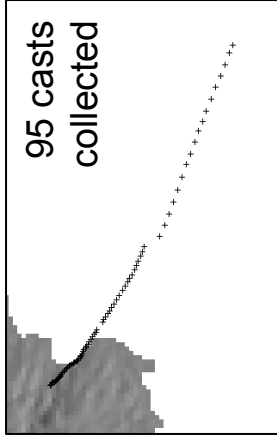
# Example 3: What is oceanographically significant?

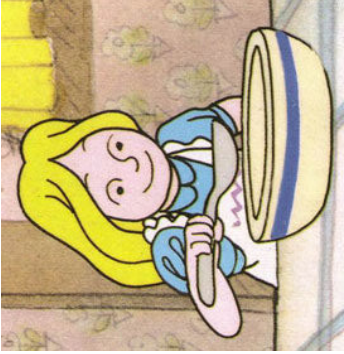
2005 CCGS Matthew EM710 Acceptance Trials



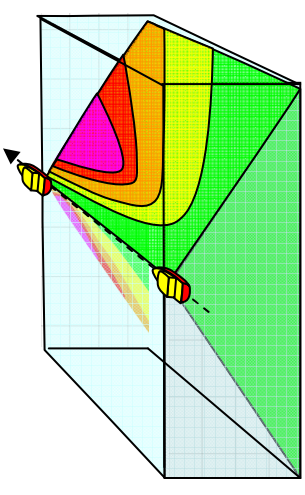


# The “Goldilocks” Watermass

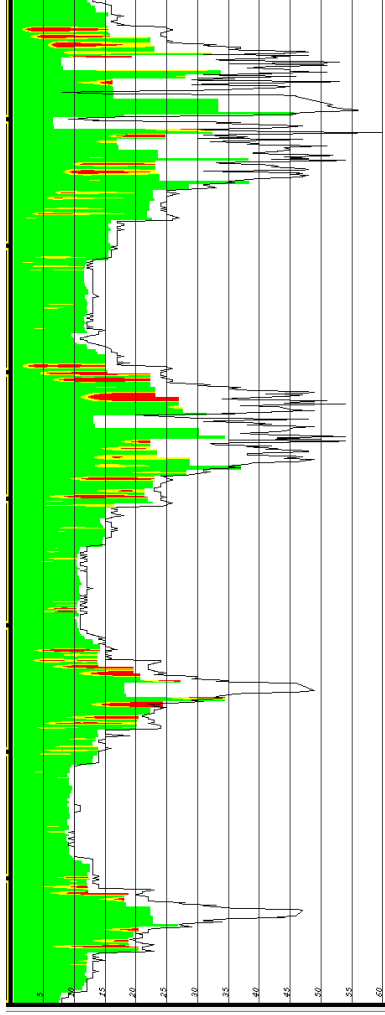




# Conclusion



- Ability to monitor watercolumn conditions as a source of error gives unprecedented control over refraction
- Surveyors can have confidence in refraction solution ***in real-time***
- The ability to “tune” MVP profile sampling rate can minimize wear on equipment while maintaining a desired accuracy: *The Goldilocks Watermass*
- Many other analysis problems are easily solved using the OMG/UNB SVP Toolkit: *Pre-analysis, QA*





# Future Work

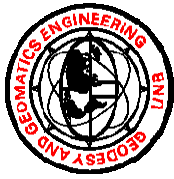


- Incorporation of UNB uncertainty monitoring in ODIM Brooke Ocean MVP controller
- Automated MVP deployment with error monitoring & error prediction
- Application of simulator to case of undersampled watercolumn



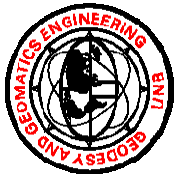
# Acknowledgements

- NSERC and CFI funding of ArcticNet NCE
- Sponsors of the UNB Chair in Ocean Mapping
  - U.S. Geological Survey
  - Kongsberg Maritime
  - Royal (U.K.) Navy
  - Fugro Pelagos
  - Route Survey Office of the Canadian Navy
  - Rijkswaterstaat
- Mike Lamplugh & Jon Griffin, CHS Atlantic
- ODIM Brooke Ocean
- Students of UNB HydroCamp 2008



## Shallow Survey 2008





# Extra Slides

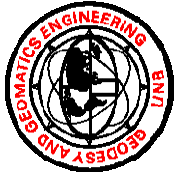


Shallow Survey 2008



# Simulation Subtleties

- Roll & Pitch
- Performance envelope
- Along-track slope
- Across-track topography



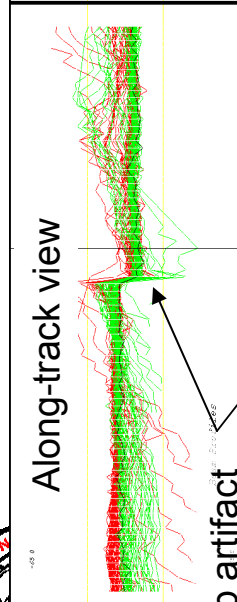
# Surface Sound Speed

- Can mimic use of a surface sound speed probe:
  - Retrieve sound speed at transducer depth from control cast
  - Use this to compute ray parameter for raytrace with test cast



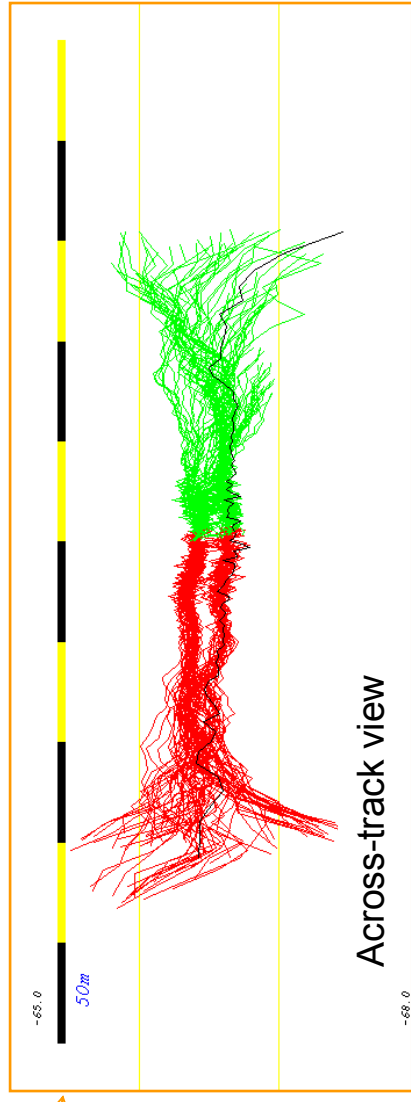
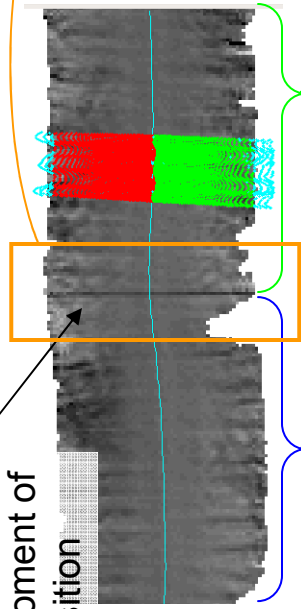
# Does this actually work??

## Refraction Step Artifacts

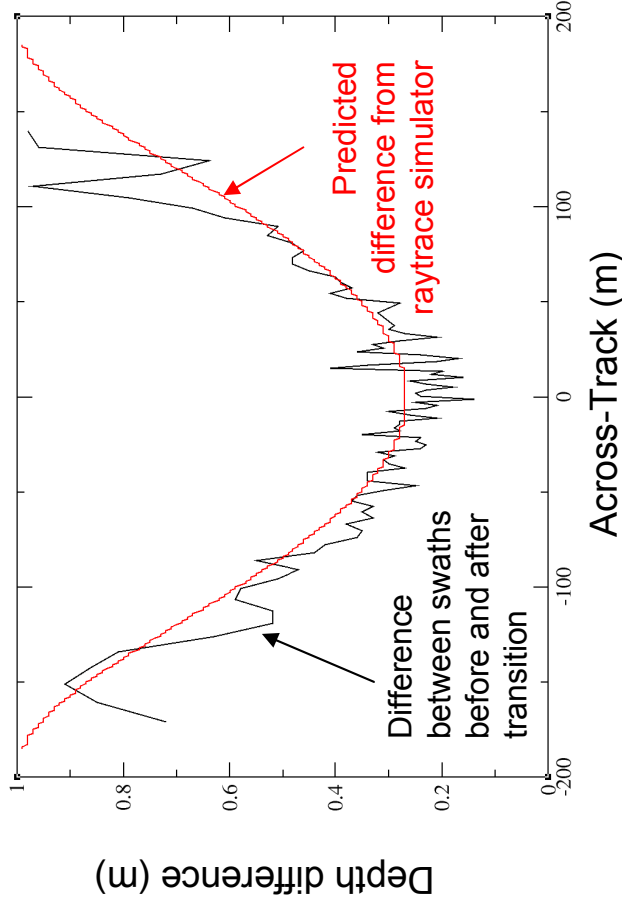
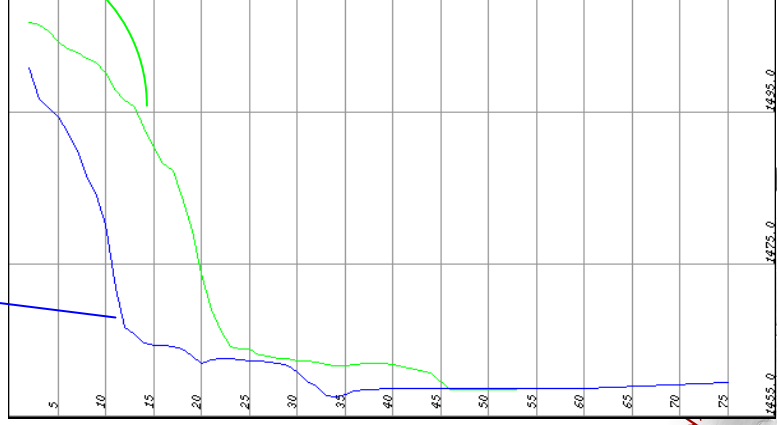


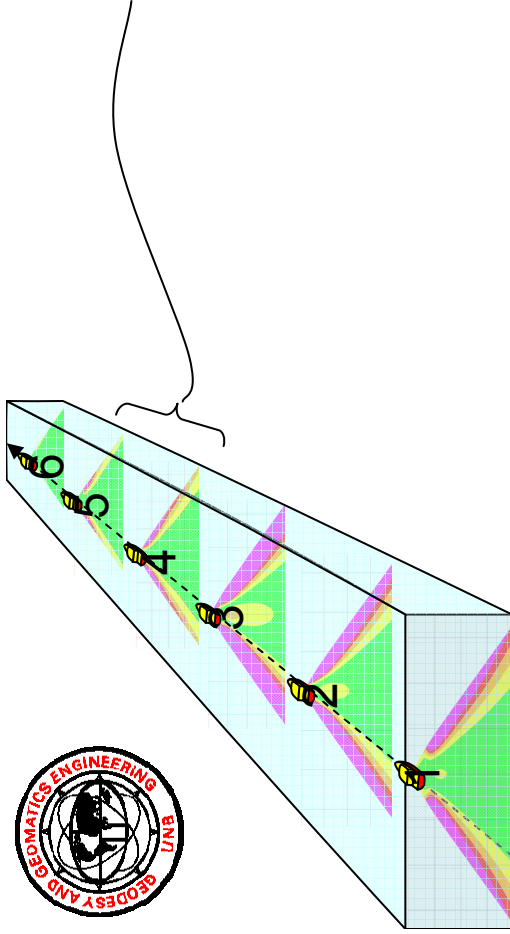
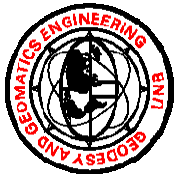
Along-track view

Step artifact at moment of transition



Across-track view





# What about in between casts?

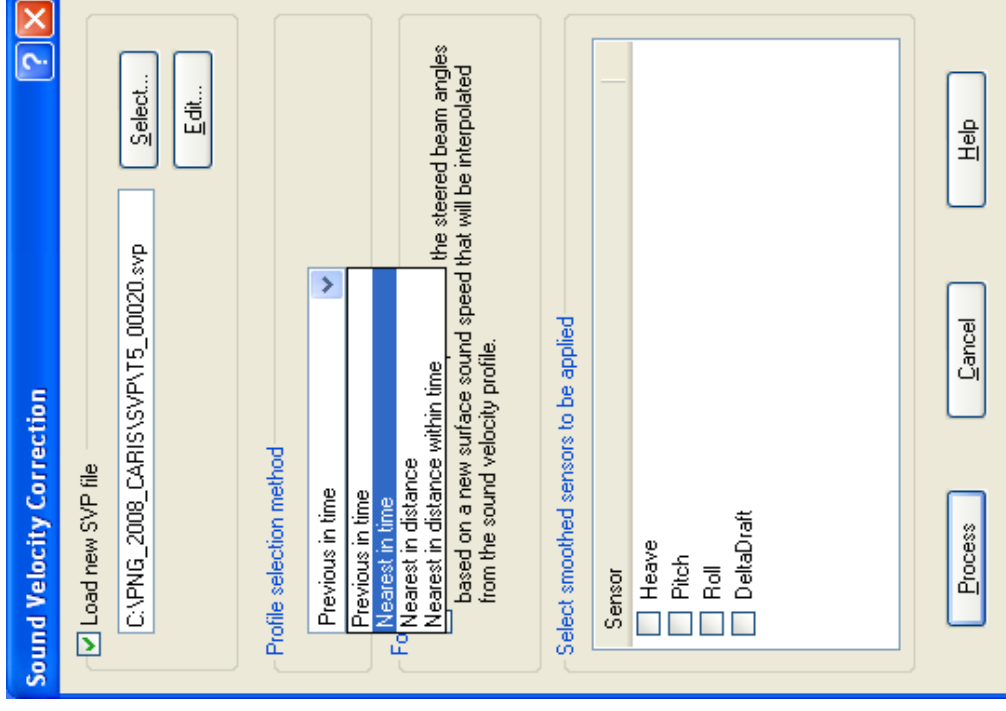
Depends if you are sampling the watercolumn at a high rate

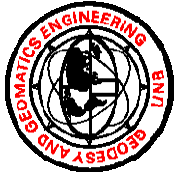
Yes?

1. Are you stuck with real-time reduced soundings (e.g. REA)?  
....Or....
2. Can you post-process using "nearest in time"

No?

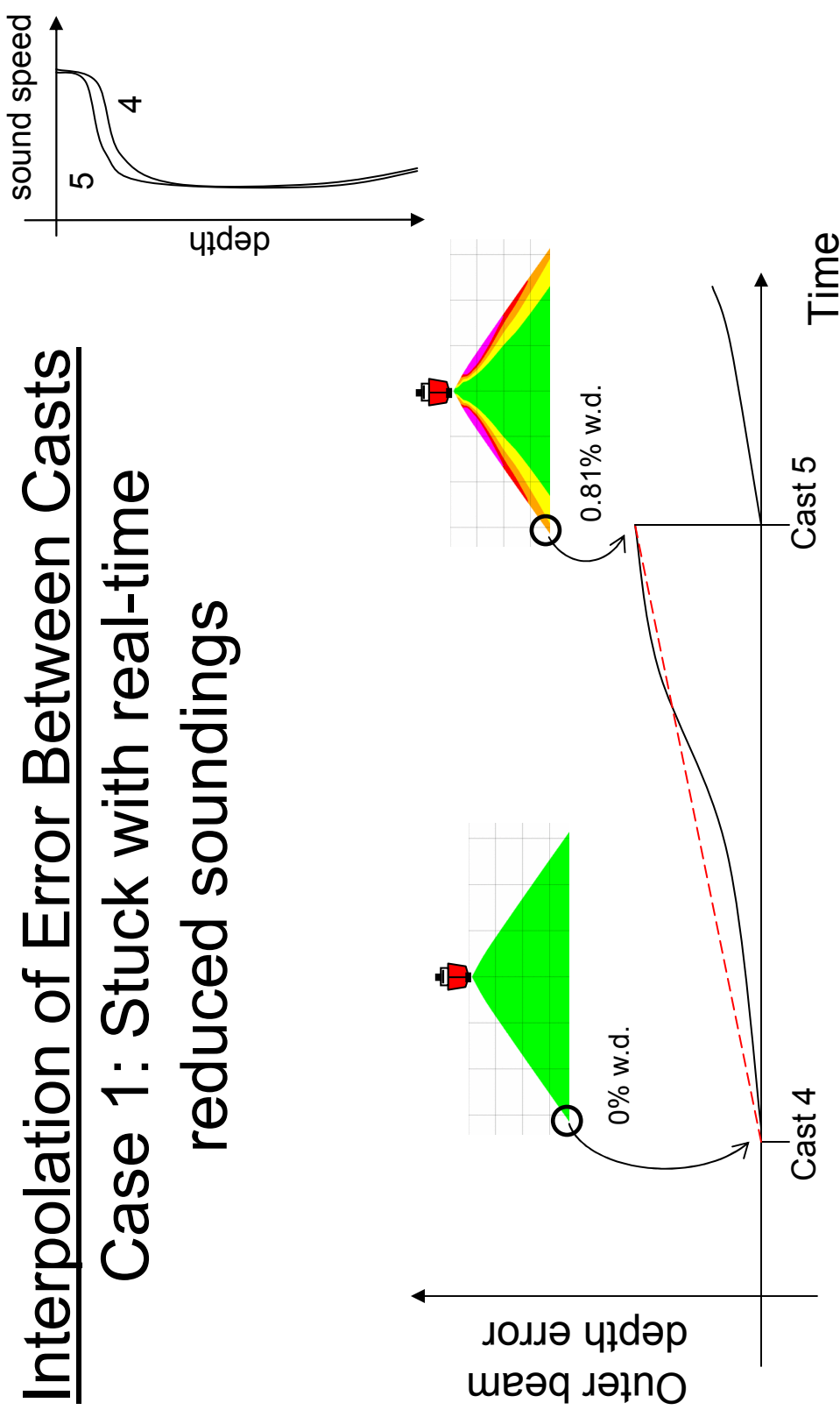
3. Hmmmm



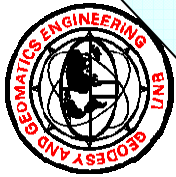


# Interpolation of Error Between Casts

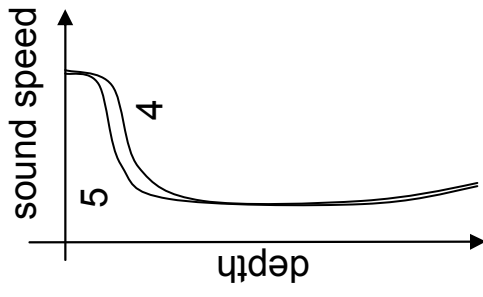
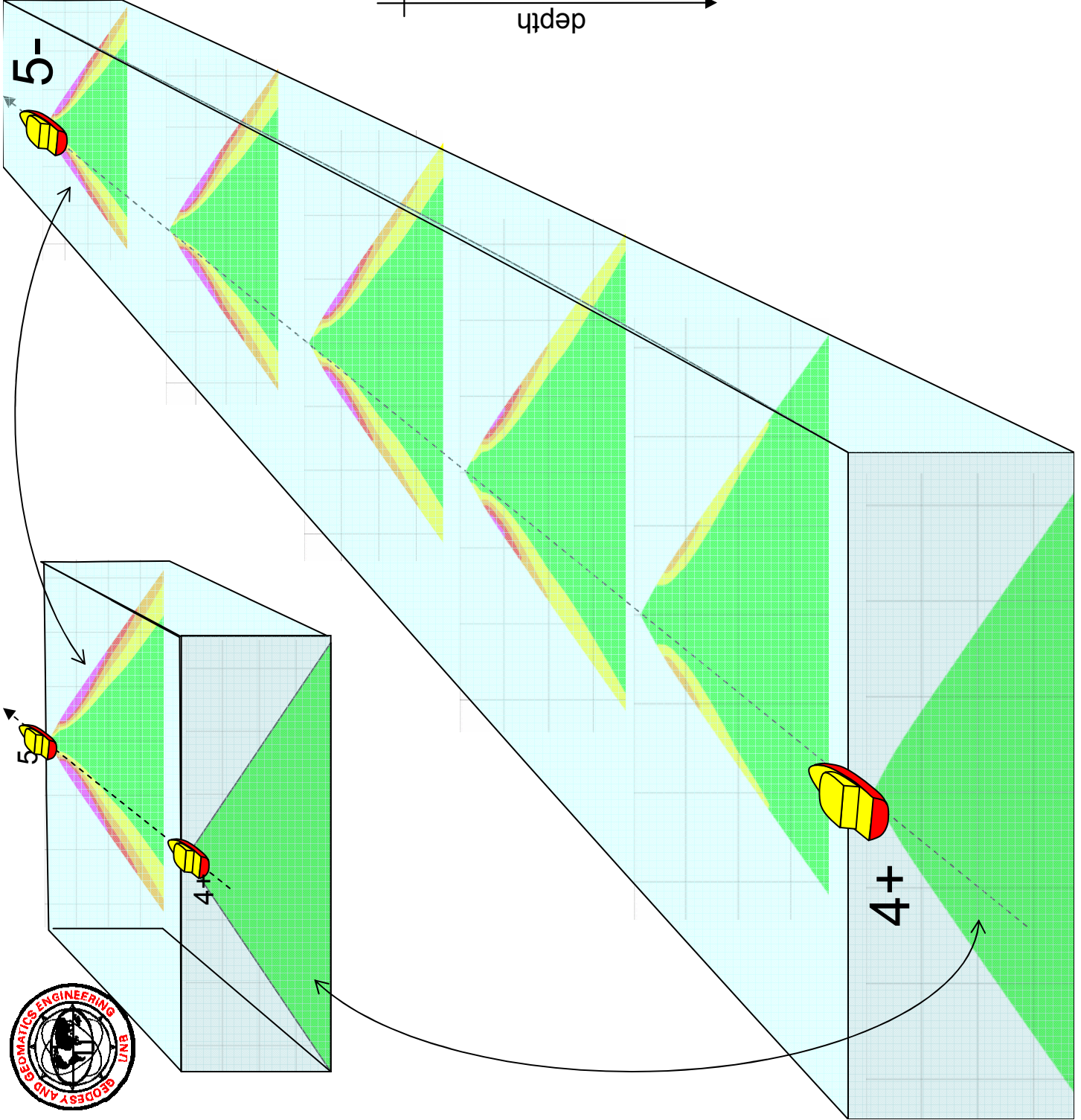
## Case 1: Stuck with real-time reduced soundings

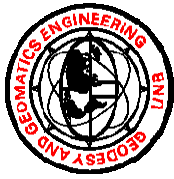


- Cast 4 is used up to the moment that cast 5 is acquired
- Error is zero at moment just after acquisition of cast 4
- Error increases with time (linearly?), reaching a maximum just prior to collection of cast #5
- Error returns to zero after acquisition of cast 5, increasing until the next cast



# Case 1: Stuck with real-time reduced soundings

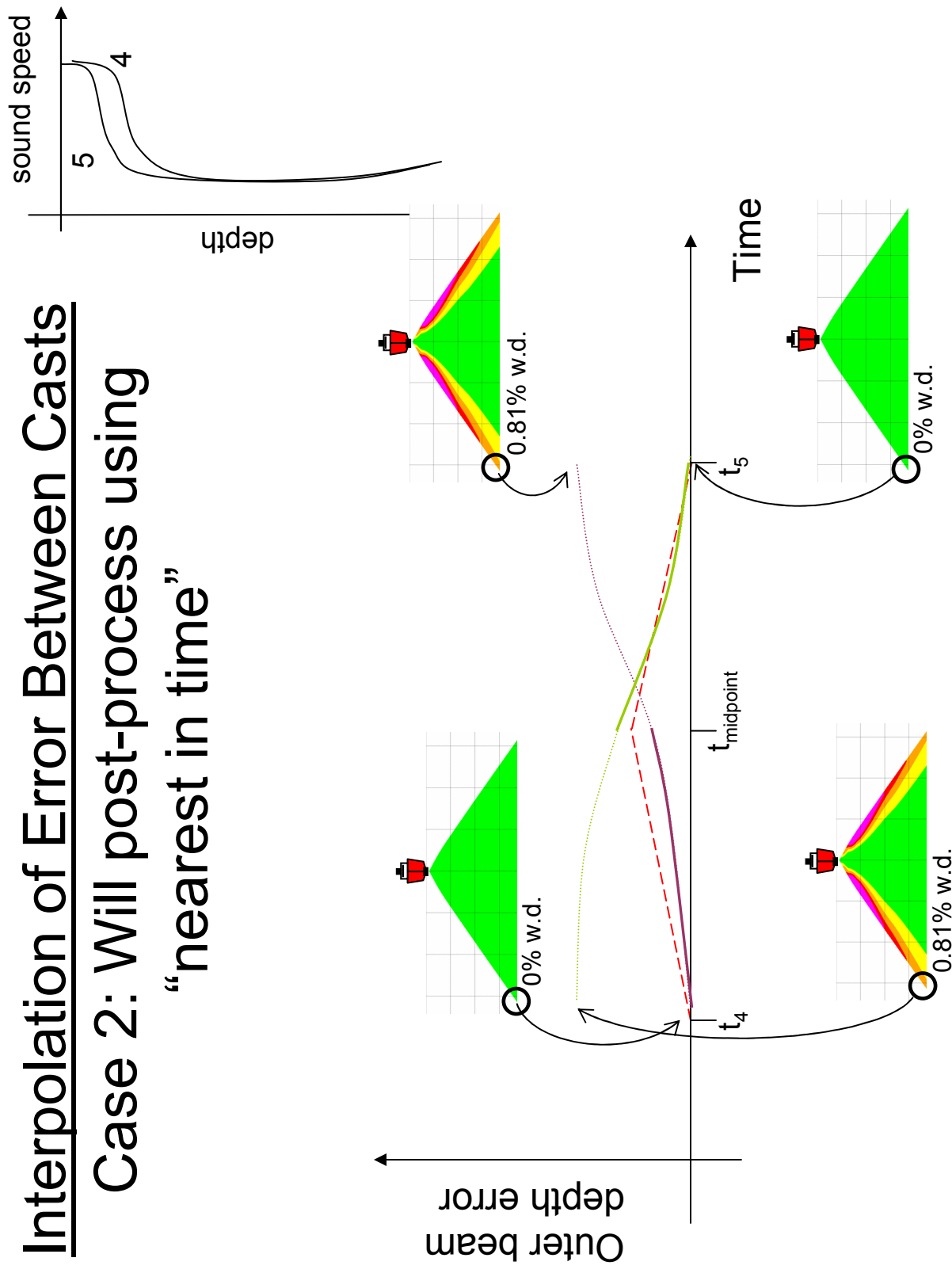




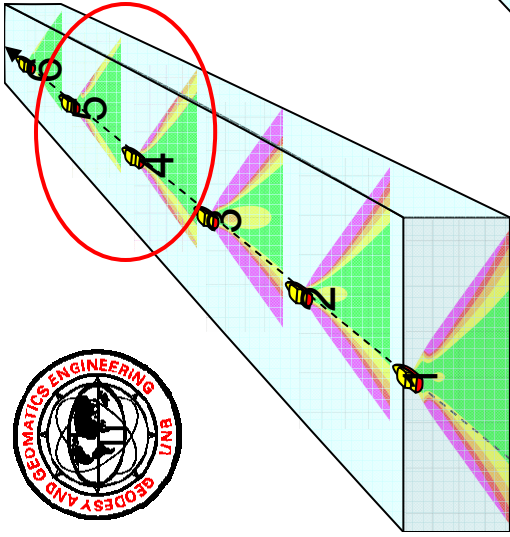
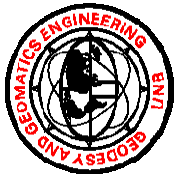
# Interpolation of Error Between Casts

## Case 2: Will post-process using

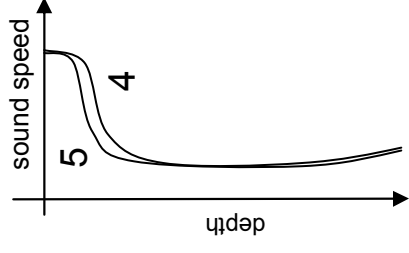
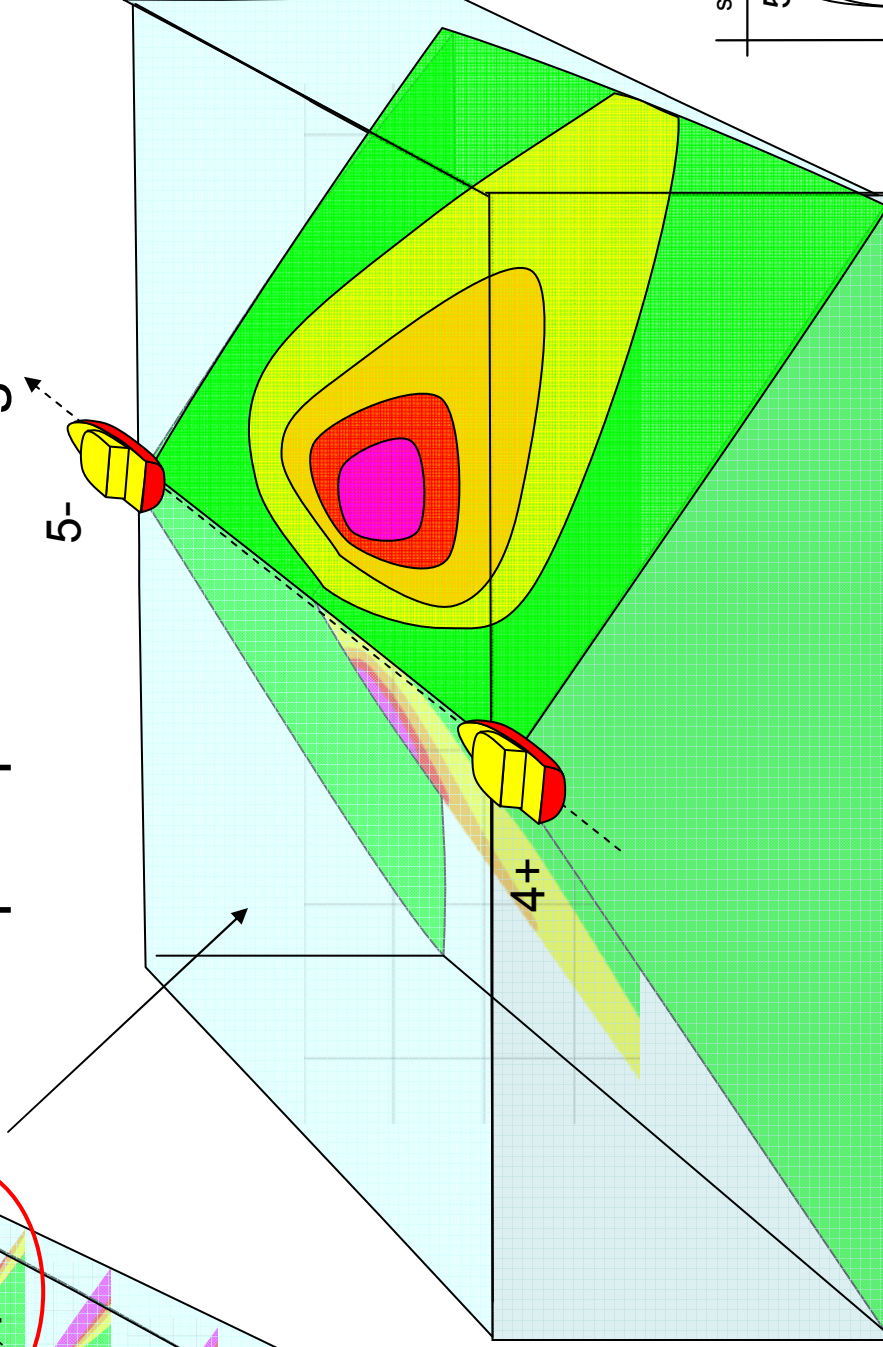
“nearest in time”

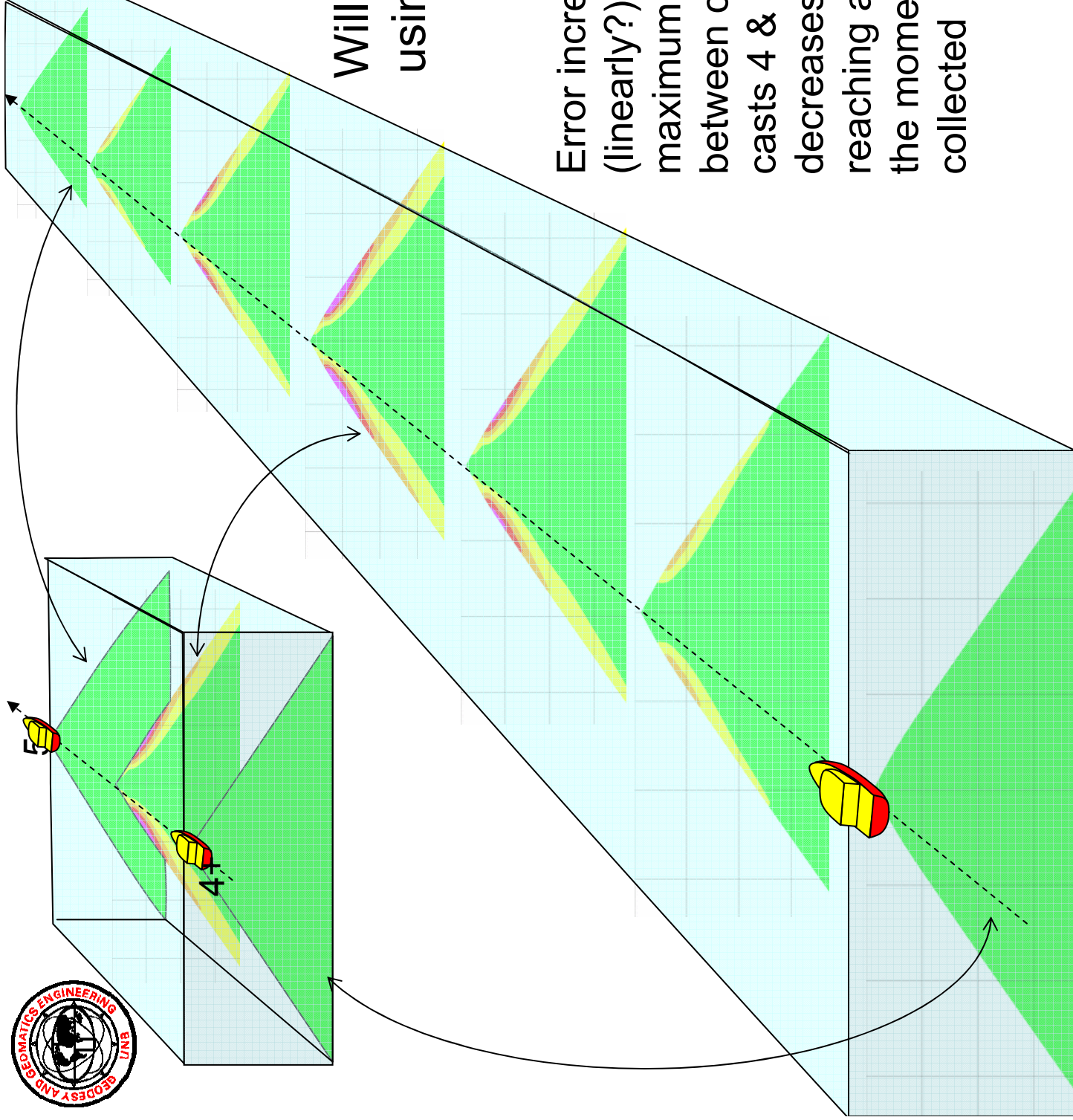






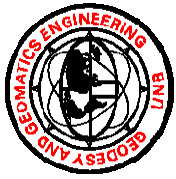
## Case 2: Will post-process using "nearest in time"





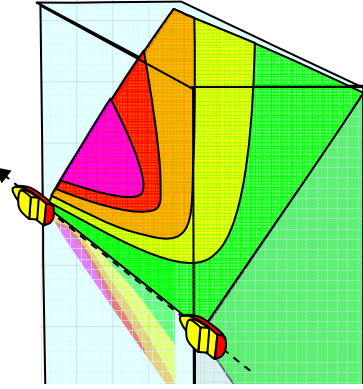
Case 2:  
Will post-process  
using “nearest in  
time”

Error increases with time  
(linearly?), reaching a  
maximum at the midpoint  
between collection of  
casts 4 & 5; error then  
decreases with time,  
reaching a minimum at  
the moment cast 5 is  
collected

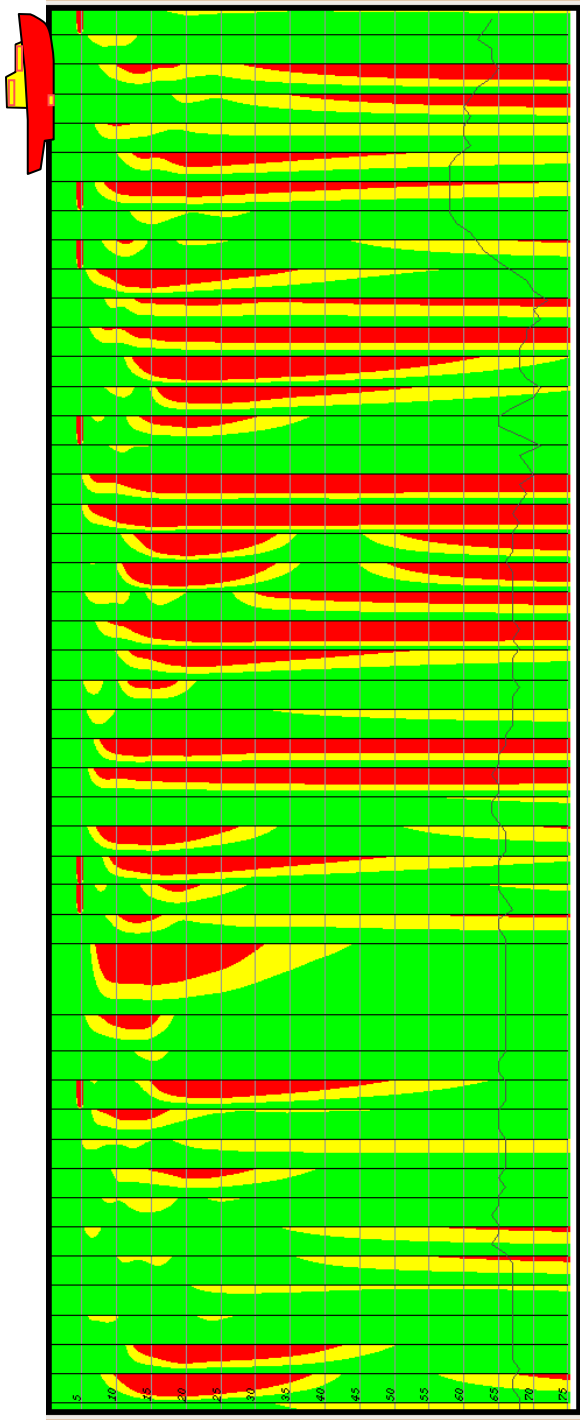


# Case 1 vs. Case 2

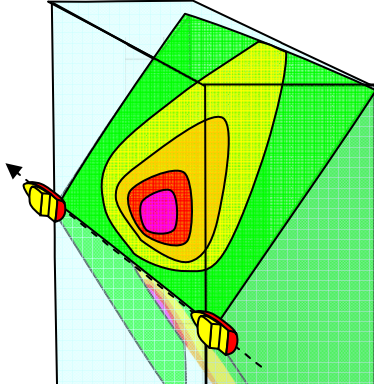
Last observed in time



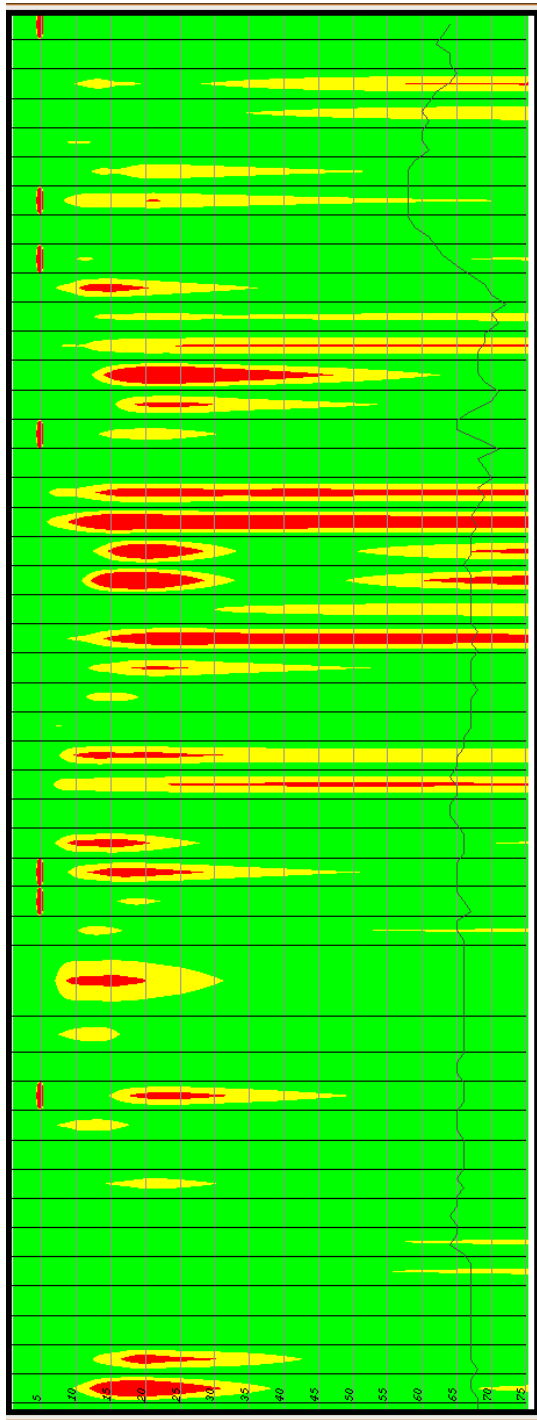
Depth



Closest in time



Depth

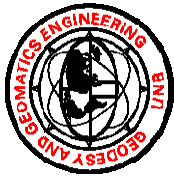


Time

*Ocean Mapping Group*

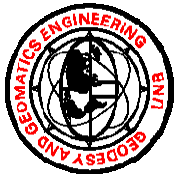


University of New Brunswick  
CANADA



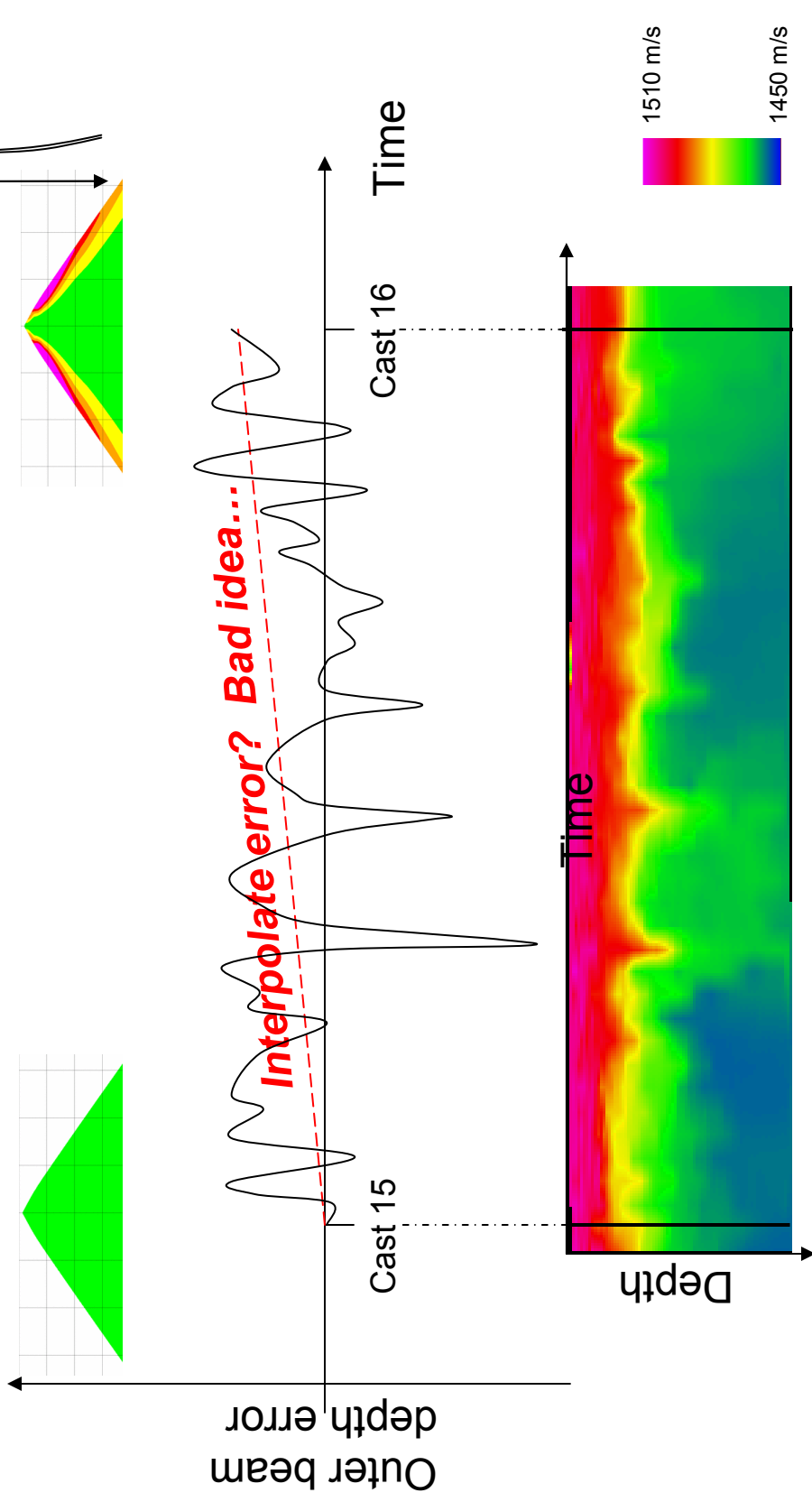
# Case 3: Undersampled Watercolumn

- Imprudent to interpolate, BUT...
- Snapshot of uncertainty is still a useful metric that can be used to compile an “average” uncertainty
- ESS: uncertainty of averages
- UNB: average of uncertainties



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## Case 3: Undersampled Watercolumn



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