U.S. National Ice Center

USN

USCG

NOAA

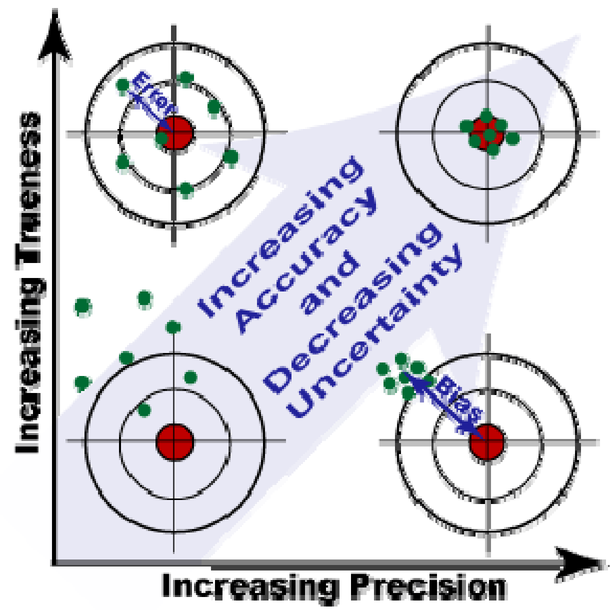
Quantifying Ice Charting Uncertainty

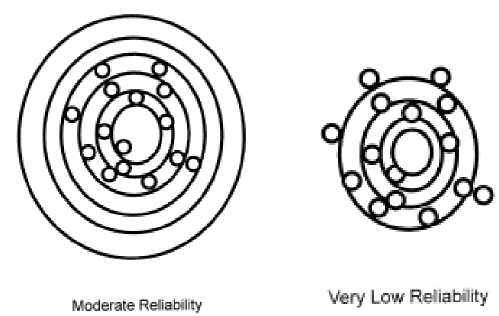
Sean Helfrich

17th IICWG, Ottawa, Oct 24, 2016

What is uncertainty?

- **Accuracy:** the agreement between the measurement and the true value
- **Uncertainty** is a parameter characterizing the range of values within which the value of the measurand lies within a specified level of confidence.
- **Error** is the difference between a measurement and the true value of the measurand.
- **Reliability** is the extent to which repeated measurements yields consistent results
- **Heterogeneity** is a measure of diversity





Subjective ice charts are prone to reliability, accuracy, and heterogeneity issues

Why add uncertainty?

1) Navigators using ice charts need to know the reliability/bias of the data before entering ice infested waters.
Missing in Risk Value in the Polar Code

2) Modeler would like to apply the data but lack uncertainty metrics to assimilate. Lack of reliable models for guidance makes ice forecasting challenging

3) Ice Climatology needs to understand the variability of the observations over time to

Uncertainty Error in the Charts

- Observational Error
- Charting/Publication time difference from observations
- Analyst bias
- Analysis Skill
- Analyst confidence
- Differences in imagery display
- “the unknown unknowns”

Uncertainty in the Polygons

- **Spatial heterogeneity**
  - Sources differ over a single polygon
  - Scale dependencies / Size of the polygon
  - What do ranges within CT/Sx/Fx values represent?
  - Unknown distribution
  - CT range may not represent all values within polygon
  - CT/Sx/Fx may share same polygon, but may have different uncertainty for each variable

- **Temporal heterogeneity**
  - Single polygon often built from imagery from multiple times

Past Examinations

CISDA – Regional Charts: Canadian Ice Service Ice Regime Regions (CISIRR) and Subregions with Associated Data Quality Indices , 2007

RT Tonboe et al. "*The EUMETSAT sea ice concentration climate data record*" The Cryosphere, 2016

MB Jensen, Ice chart uncertainty estimates, 2015

H. Titchner and N. Rayner: The use of ice chart observations and uncertainties in a climate record of sea ice concentrations, 2016

C. Geiger: ERDC/CRREL TR-06-16 September 2006

Giles M. Foody, Peter M. Atkinson: Uncertainty in Remote Sensing and GIS, 2015

J. Zhang, MF Goodchild: Uncertainty in Geographic Information, 2014

A SIGRID-based uncertainty

- Approach: Use existing SIGRID values with only minor additional information to determine standard deviation as a measure of uncertainty.

- Uncertainty calculations are assigned to each polygon as part of the SIGRID and are divided into **concentrations**, thickness, and floe size.

- Calculations include factors for Reliability and Accuracy to differentiate between uncertainty introduced by the data sources, “smearing” of the imagery into polygons, the imagery interpreter, and time difference.

- Values range from 0-100 (0 = no uncertainty)

The Basic Formula for Ice Concentrations

Cumulative Data Source Uncertainty

Spatial Uncertainty Propagation

Analyst Confidence Uncertainty

Temporal Uncertainty Propagation

$$\text{PICU} = \left(\left(\sum_{i=1}^{n} DS * \%\right) - \text{CTr}\right) + Var(CT_{space}) + A_{SKILL} + \text{A}_{\text{CONF}} + \text{A}_{\text{DIFF}} + \text{Var}(\text{CT}_{\text{time}})$$

Polygon Ice Con. Uncertainty

CT Range

Analyst Skill Uncertainty

Differential Analyst Range and Bias

Each element of the formula represent normalized error factors that accumulate range from 0-100 (0 = no uncertainty)

Data Source Uncertainty

Each Imagery type is assigned a standard deviation

Source	Ice Con σ
None	100
RadarSat 2 (Single Pol)	10
RadarSat 2 (Dual Pol)	7.5
AMSR 2 (Brightness Temp)	50
AMSR 2 (Ice Con)	40
AVHRR (Channel 1)	20
AVHRR (Multi Spectral)	15
Sentinel 1 (HH)	10
Sentinel 1 (VV)	12
Sentinel 1 (HH) 500m	15
Sentinel 1 (VV) 500m	17
MODIS (Single VIS Channel)	15
MODIS Ice Cover	30
MODIS (Single IR Channel)	30
ASCAT	30

Source	Ice Con σ
SAR Composite	16
SAR Ice Identification	
VIIRS (Single VIS Channel)	15
VIIRS (Single IR Channel)	17
VIIRS / MODIS(Multi-Channel)	12.5
VIIRS Ice Concentrations	20
VIIRS Ice Cover	30
VIIRS Snow Cover	30
Foreign Regional Ice Chart	22
HR RS2 Ice Charts	12
SSMI/S Ice Concentrations	40
Ship Report	20
Aircraft SLAR (GPS nav)	10
Landsat	10

These summation of these values from all data source are then subtracted from the CT Range

Spatial Uncertainty Propagation

Taylor Series approximations can estimate the uncertainty propagation over polygons

$$\mathrm{Var\ (CTspace)} = \left(\sum_{i=1}^{n} Var\ (Ai)\right) \quad \left(\frac{\partial g}{\partial Ai}\right)^{2}$$

By examining area and error relations the following quadratic was determined

$$\mathrm{Var\ (CTspace)} = (2E^{-13}x^{2} - 7E^{-06}x)$$

… However, the formula will likely be CT dependent, thus equations for each CT should be derived

Analyst Skill, Confidence, and Bias

$$(A_{CONF} + A_{SKILL} + A_{DIFF})$$

$$A_{CONF} = \text{Range Ice Conc.} * (1\text{-}3)$$

$$A_{SKILL} = (0 - 5) * .5$$

$$A_{DIFF} = \text{Analyst Bias - Range Ice Conc.}$$

CT	Range	Bias
00	0	14
01	5	28
02	10	21
10	5	21
12	5	22
13	10	25
18	40	45
20	5	25
24	10	22
30	5	22
35	10	22
40	5	22
46	10	23
50	5	23
57	10	25
60	5	25
68	10	22
70	5	22
79	10	22
80	5	22
81	10	27
90	5	27
91	5	28
92	0	12
95	2.5	28

A_{CONF}

Analysts use High (1), Medium (2), or Low (3) confidence to depict the reliability they have in the polygon identification.

A_{SKILL}

Analysts can be assigned a skill ranking factor to account for differences in analyst expertise (0-5)

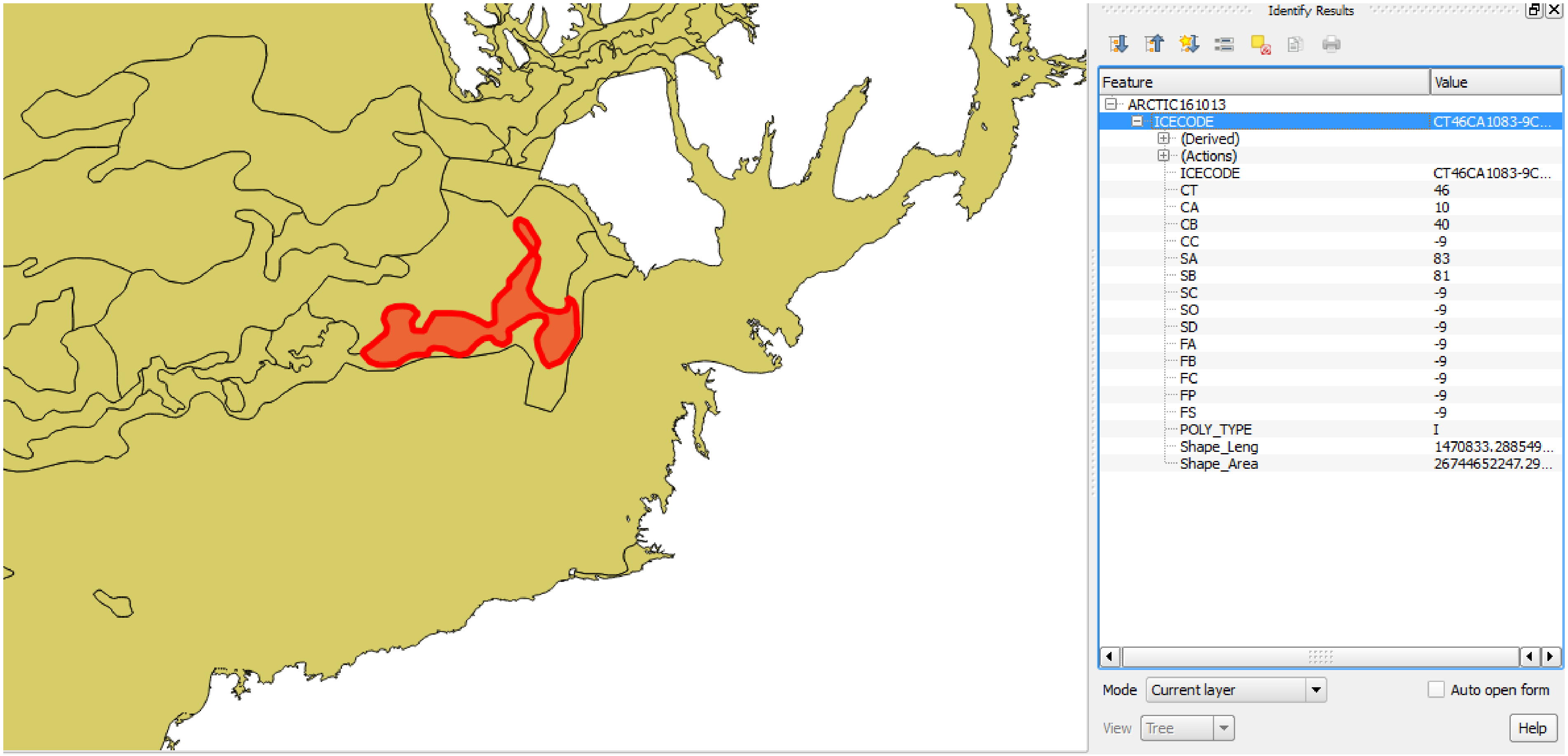
Temporal Uncertainty Propagation

Taylor Series approximations can also estimate the uncertainty propagation over time

$$\text{Var (CTtime)} = \left(\sum_{i=1}^{n} Var\ (T1)\right)\left(\frac{\partial T2}{\partial T1}\right)^{2}$$

… But I'm not there yet on a calculation of the Standard Deviation between ice charts over time, and this is also likely to be vary based on CT

An Example



<u>Data Sources</u>

30% RadarSat 2 HH

70% MODIS – Band 1&2

Anal Skill : 0

Anal Conf: High

An Example

$$\text{PICU} = \left(\left(\sum_{i=1}^{n} DS * \%\right) - \text{CTr}\right) + \text{V}ar(CT_{space}) + A_{SKILL} + \text{A}_{\text{CONF}} + \text{A}_{\text{DIFF}} + \text{Var}(\text{CT}_{\text{time}})$$

$$\text{PICU} = (10.75\text{-}10) + 0.19 + 0 + 10 + 13 + ?$$

$$\text{PICU} = 23.94$$

Future Work

- Alter the calculations of the data source by the season,CT
- Generate improved spatial and temporal error propagation metrics.
- Refine the Data Source errors (need more feedback)
- Further examine analysis bias from more intercomparion
- Add uncertainties Sx and Fx values.
- Develop a color code for navigators based on uncertainty
- Work with others in IICWG and modelers