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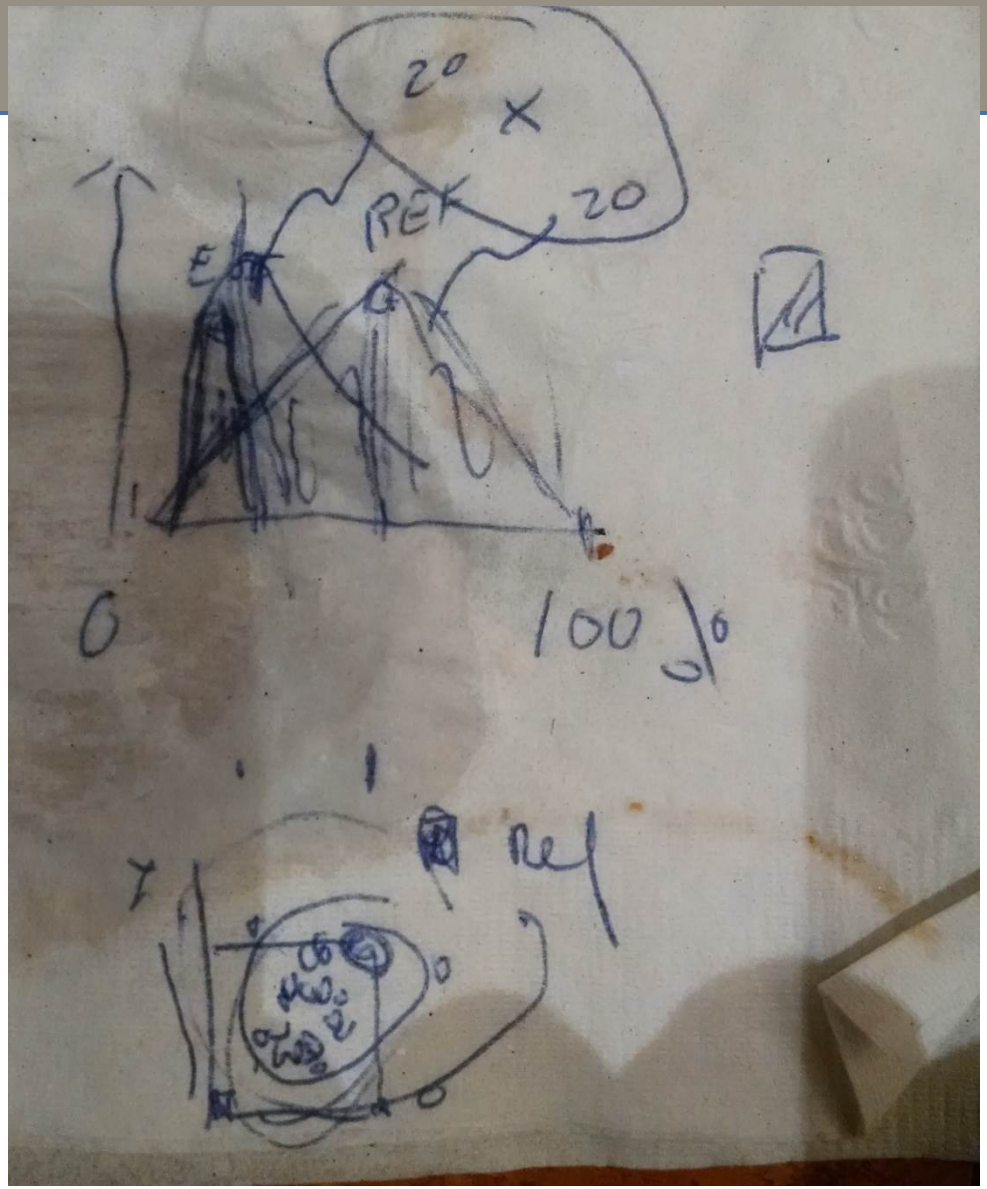
A Validation Protocol for Continental Scale Snow Extent Products that Incorporates Product and Reference Uncertainty

The Short Version



Objectives

- Identify requirements for validation and intercomparison of SE products.
- Identify issues that need to be addressed when performing validation (not including issues with data availability).
- Propose a framework for incorporating product uncertainty within validation and intercomparison.

GCOS Implementation Plan Target Requirements for SE (GCOS, 2010)

Horizontal Resolution	Vertical Resolution	Temporal Resolution	Accuracy	Stability
1km; **100m in complex terrain**	N/A	daily	5% (maximum error of omission and commission in snow area); location accuracy better than 1/3 IFOV with target IFOV 100m in areas of complex terrain, 1km elsewhere	4% (maximum error of omission and commission in snow area); location accuracy better than 1/3 IFOV with target IFOV 100m in areas of complex terrain, 1km elsewhere.

Note that errors are stated in terms of area and hence apply to SE as defined.
Hence the total area error should be within +/-5% of the actual error.
GCOS does not specify if this requirement corresponds to 100% of mapping units or
To some percentile (e.g. the 95%ile error).
We assume it is the latter since we cannot validate all mapping units.

Snow Extent Definition

Snow extent (SE) is defined as the unique area of snow covered surfaces projected on the local horizontal datum within a spatial mapping unit at a specified time.

Here unique implies that the projected area from two vertically superimposed snow covered surfaces is only counted once. The units of snow extent correspond to SI units for area (m^2).

Defintion of mapped quantities

- **Snow extent (SE)** is defined as the unique area of snow covered surfaces projected on the local horizontal datum within a spatial mapping unit at a specified time. Here unique implies that the projected area from two vertically superimposed snow covered surfaces is only counted once. The units of snow extent correspond to SI units for area (m^2).
- **Product Mapping Unit (PMU)** : spatial region corresponding to a given product value
- **Snow Cover Fraction (SCF)** is SE/area of PMU.
- **Binary Snow Cover (Binary SE)** : the occurrence of snow cover (SE>threshold T) or snow free (SE < T) conditions in a mapping unit. Usually as a Boolean flag (True = snow cover; False=snow free).
- **Comparison Mapping Unit (CMU):** spatial region over which estimates of SE/SCF/Binary SE are derived from multiple products for the purpose of comparisons

Definition of Validation Terms

- **Total measurement uncertainty** includes systematic measurement error and random measurement error. Where there is only one product estimate for each mapping unit the total measurement uncertainty corresponds to the **accuracy** (JCGM-100 2008).
- **Bias**, is the expected value of the difference between corresponding product and reference estimates. Bias is an estimate of the systematic measurement error. (JCGM-100 2008).
- **Precision** is the dispersion of product estimates around their expected value for the same actual SE. Precision is an estimate of random measurement error. (JCGM-100 2008).
- **Completeness** is the proportion of valid retrievals over an observation domain. (JCGM-100 2008).
- **Stability** is defined as the change in accuracy (or bias) through time. (Padilla et al., 2014).

Validation Metrics: For Binary SE

Statistic	Description
Hits	Reference=snow; Product=snow
False Alarm	Reference = no snow; Product=snow
Misses	Reference=snow; Product=no snow
Correct Negative	Reference= no snow; Product= no snow
Probability of Detection	Hits/(Hits + False Alarms)
False Alarm Ratio	False Alarms/(Hits + False Alarms)
Probability of False Detection	False Alarms/(False Alarms + Misses)
Accuracy	(Hits + Correct Negatives)/(Hits + False Alarms + Misses + Correct Negatives)
Critical success index	Hits/(Hits + False Alarms + Misses)
Heidke skill score	2 * (Hits * Correct Negatives – False Alarms * Misses) / [(Hits + Misses) * (Misses + Correct Negatives) + (Hits + False Alarms) * (False Alarms + Correct Negatives)
Kappa	[(Hits + Misses) - (False Alarms + Correct Negatives)] / (Number Samples - (False Alarms + Correct Negatives)

Metrics to be reported over spatial and temporal partitions
defined by climate, land cover, DEM and season together with a confidence interval.

Validation Metrics: For SE or SCF

Table 2.2: Metrics for SCF intercomparison activities.

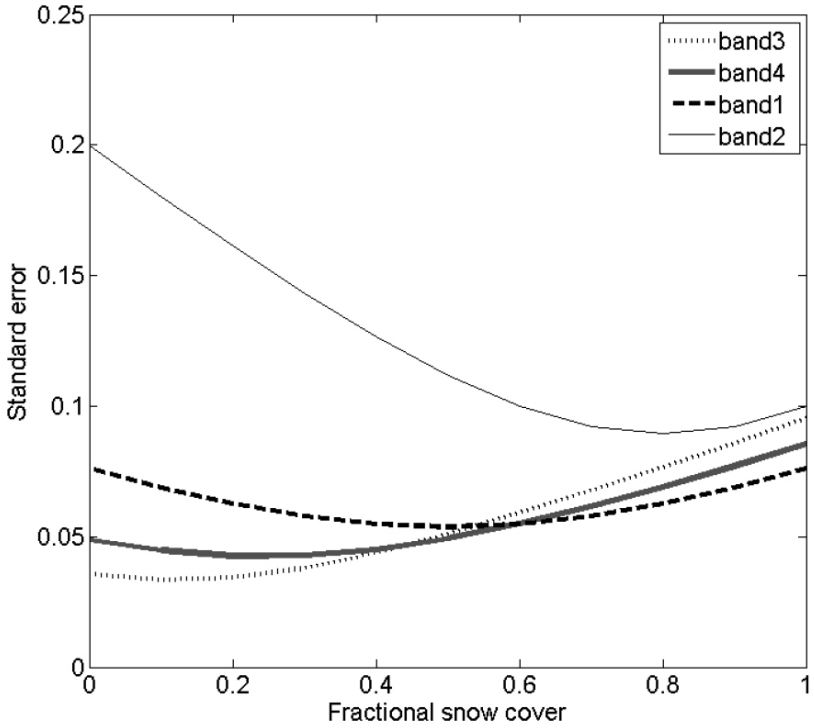
Performance	*Metric*	*Description*
Total Measurement Error	RMSD	Root Mean Square Difference
Total Measurement Error	RRMSD	Relative Root Mean Square Difference
Total Measurement Error	MAD	Median Absolute Difference
Total Measurement Error	RMAD	Relative Median Absolute Difference
Bias	Slope	Slope of Thiel-Sen linear fit to comparisons.
Bias	Offset	Offset of Thiel Sen linear fit to comparisons.
Precision	Bias Corrected RMSD	RMSD after removal of bias by applying Thiel-Sen linear fit

Metrics to be reported over spatial and temporal partitions defined by climate, land cover, DEM and season together with a confidence interval.

Sources of Uncertainty During Comparisons

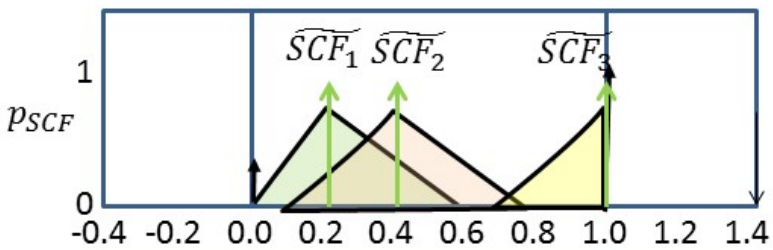
- Thematic Uncertainty – due to differences in mapped quantities in PMU
  - Uncertainty relating mapped SCF to SE
  - Uncertainty in measured SD to SE
  - Uncertainty relating binary SE to SE
- Spatial Uncertainty – due to differences in spatial scale within a CMU
  - Uncertainty with punctual measurement(s)
  - Uncertainty due to unmapped area
  - Reduction in uncertainty with aggregation
- Temporal Uncertainty – due to differences in temporal scale within CMUs
  - Uncertainty due to missing measurement dates
  - Uncertainty due to variation in SE during aggregation interval
  - Reduction in uncertainty with aggregation
- Statistical Uncertanity – due to sampling distribution
  - Selection of unbiased performance metrics
  - Reporting statistical uncertainty of derived metrics

Thematic Uncertainty - SCF



Modeled standard error (standard deviation) for FSC (range 0-1) applied to four MODIS bands, with contributions of wet snow and snow-free ground reflectance fluctuations.

Metsaemaeki,2009,.

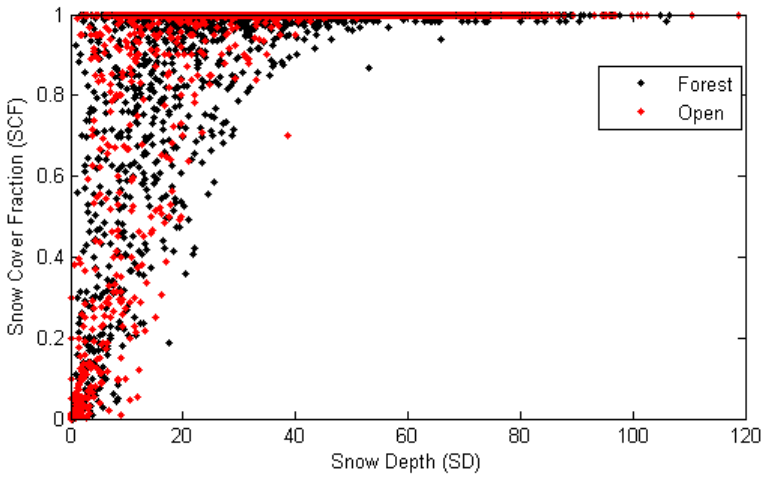


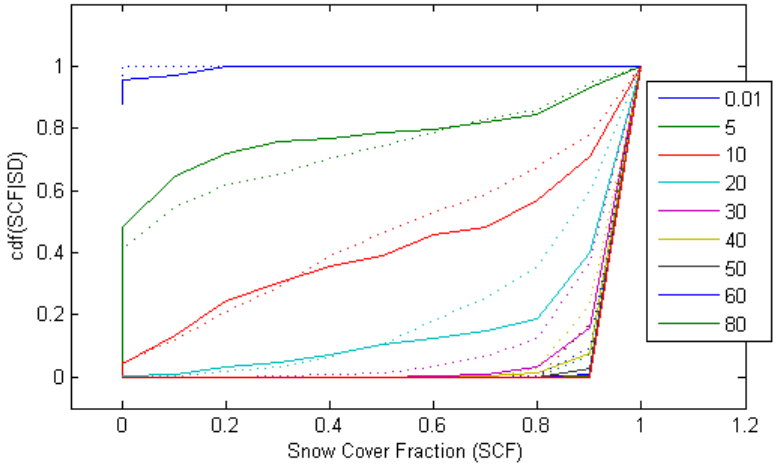
- Truncated triangular distributions used to represent uncertainty.
- Range defined by +/-95%ile range of uncertainty – can be assymetric.

Thematic Uncertainty - SD

Model the pdf(SCF|SD) for a given class of measurements and landscape.

Can use high-res imagery to calibrate over other areas.





Thematic Uncertainty – Binary SE

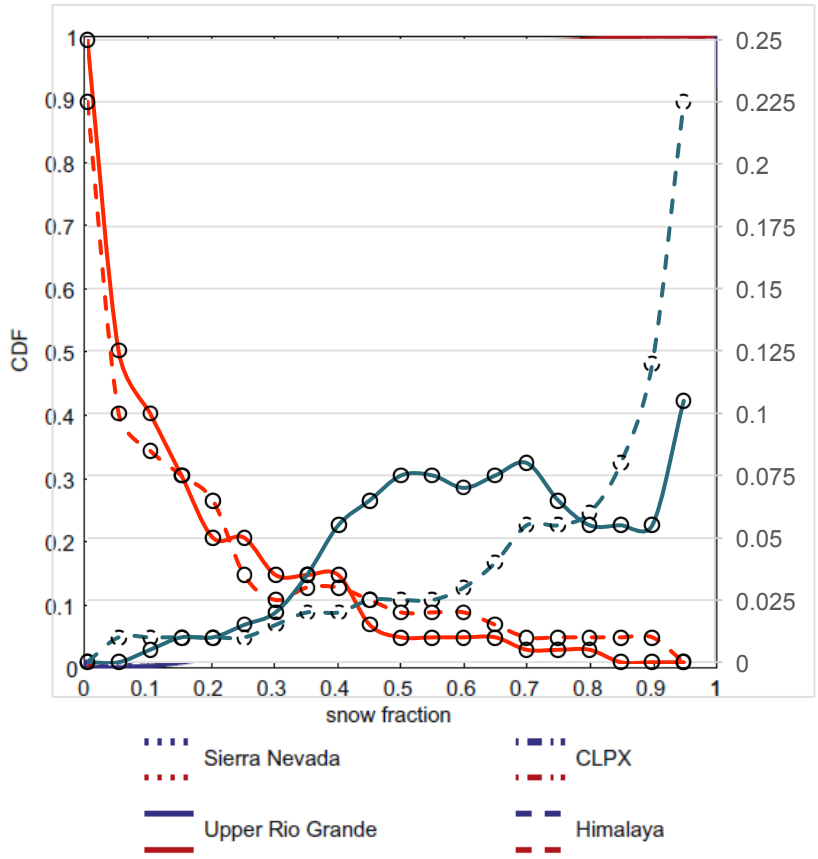


Fig. 3. Empirical cumulative distribution functions of fractional snow cover associated with identifications of snow and snow-free by MOD10A1 binary.

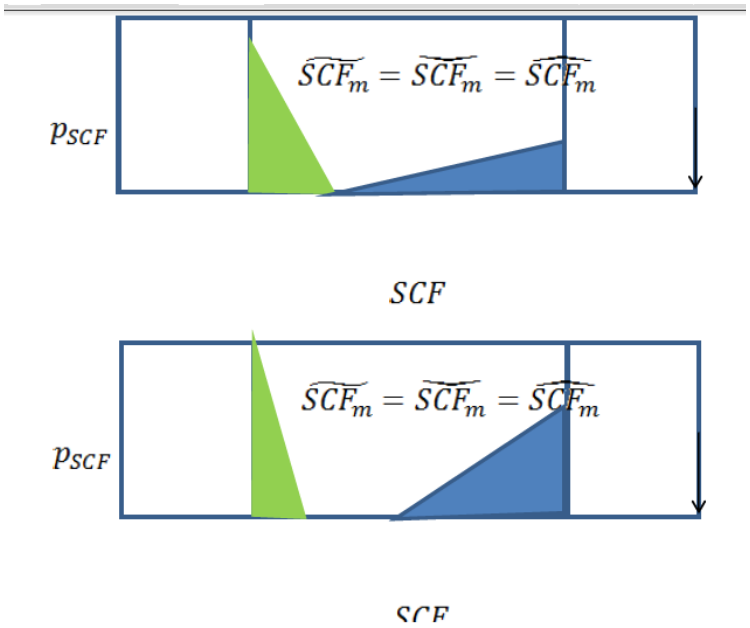
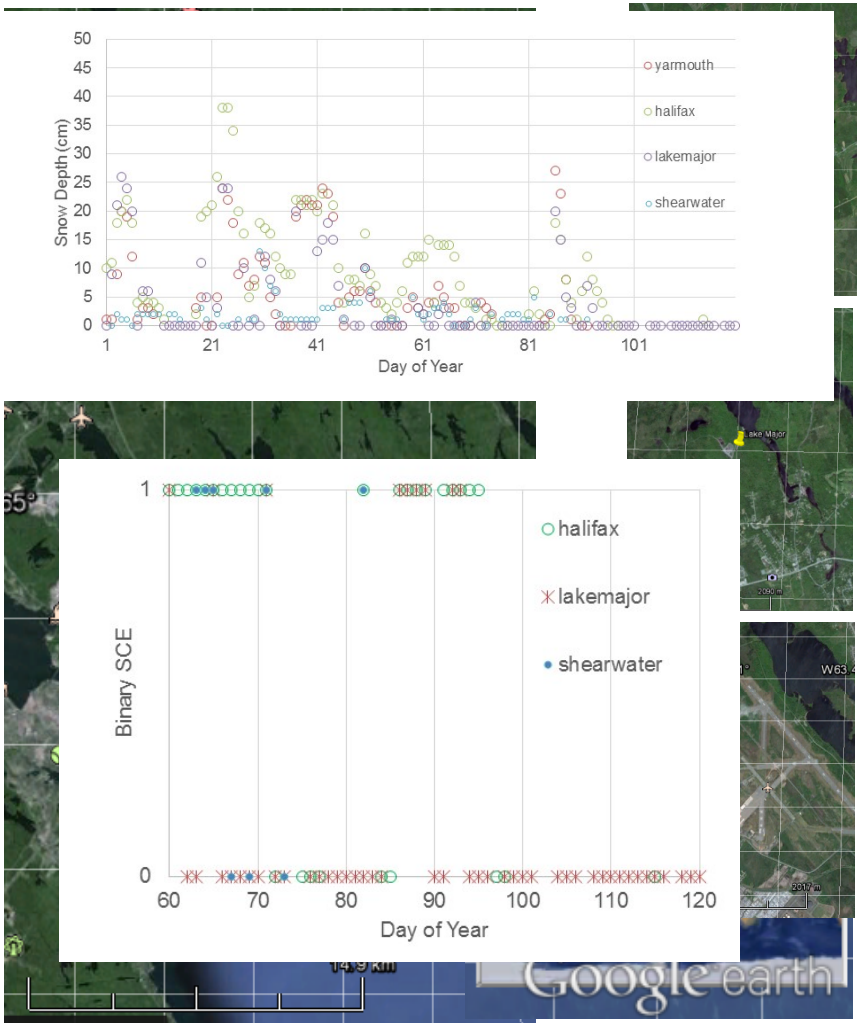


Figure 4.4: Examples of probability density functions of SCF given binary snow cover status. Green for PDF(SCF|no snow) and blue for PDF(SCF|snow).

Rittger et al. 2014

Spatial Uncertainty – Punctual Measurements



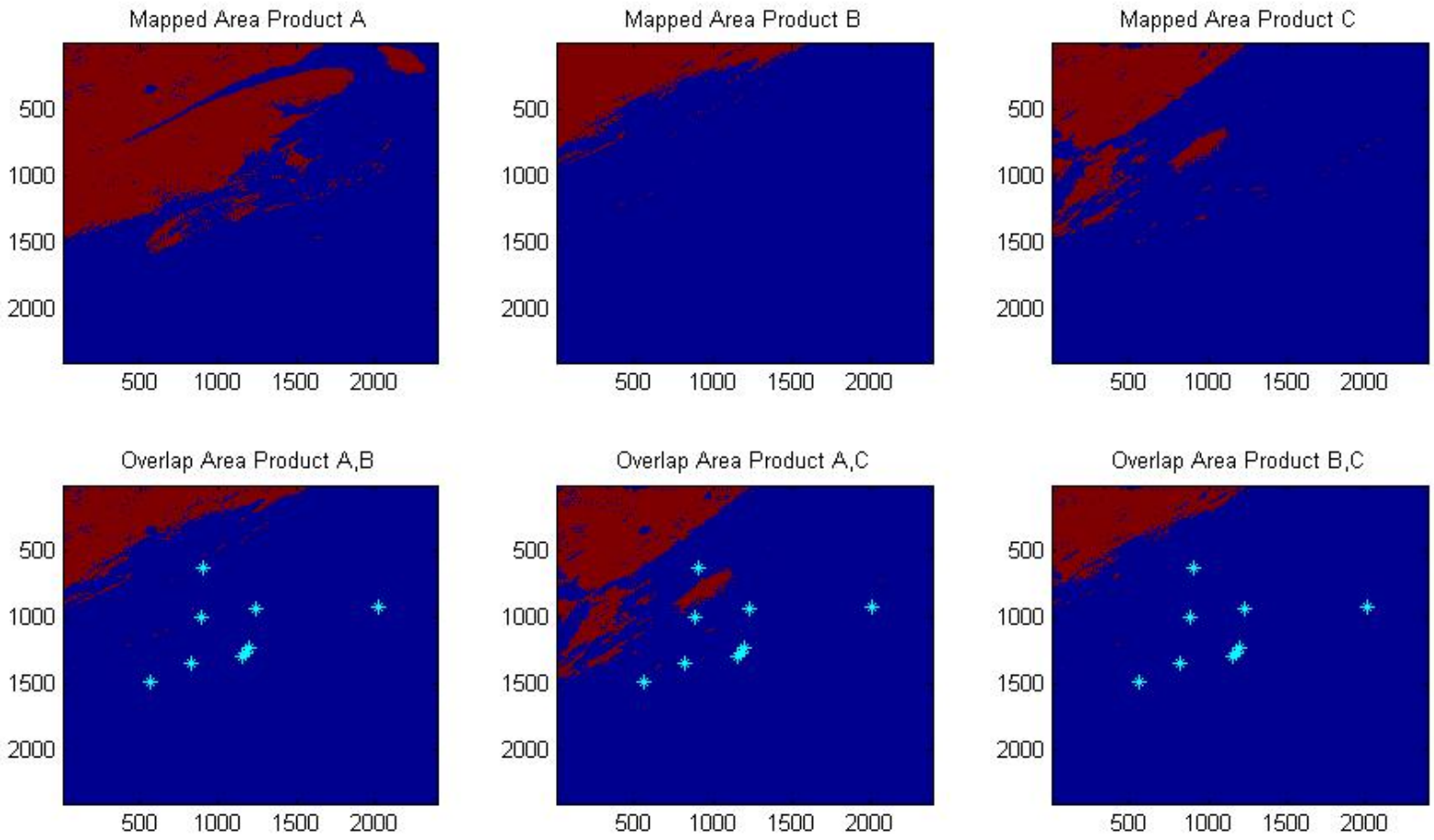
Implictly incorporated in thematic uncertainty relating SD for SCF

Need to be calibrated using high-res SCF for other measurements

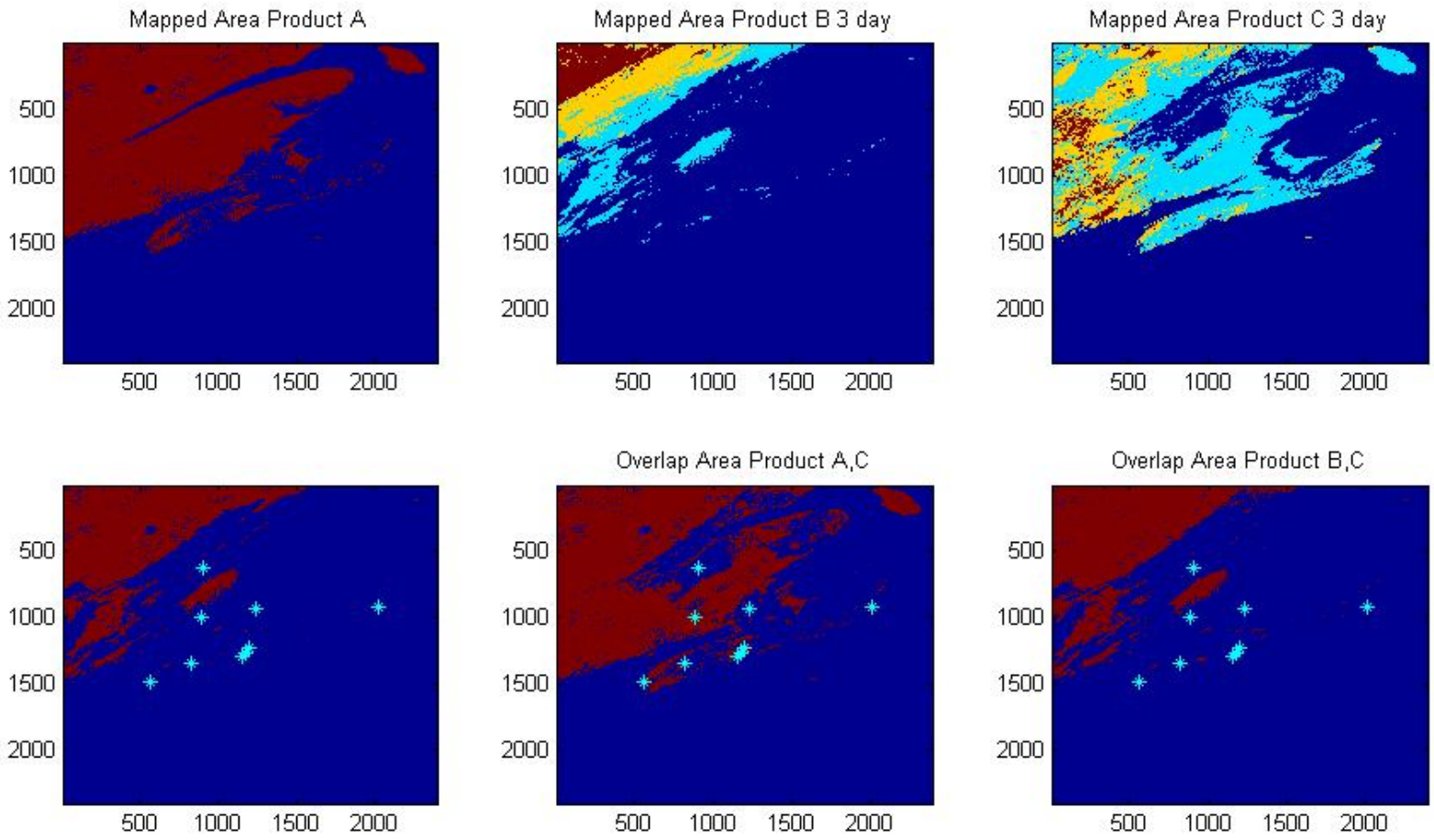
Need to be calibrated using Landsat class SCF when scaling to >>size of transects

Multiple sampls in a grid cell combined in same manned as multuiple SCF measurements in grid cell (see later) so natural variability is included.

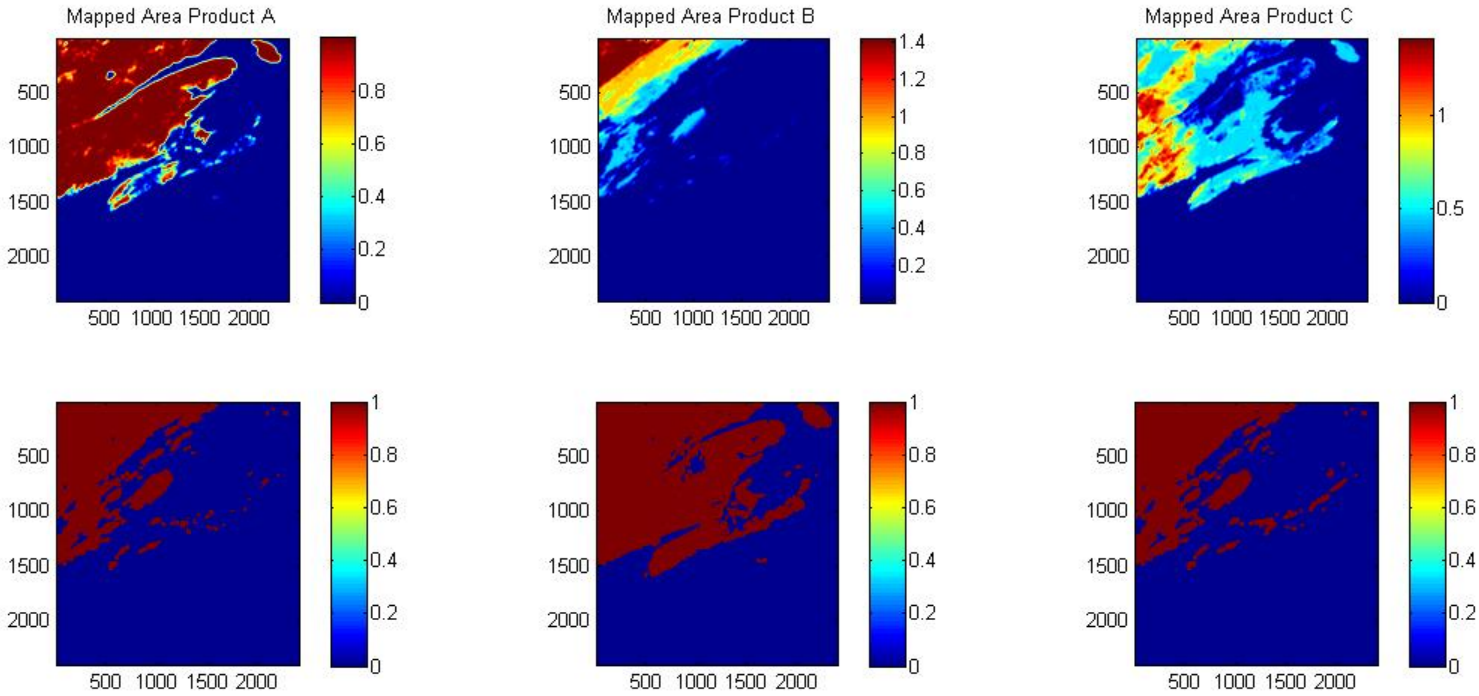
Issues with Unmapped Areas



Temporal Aggregation



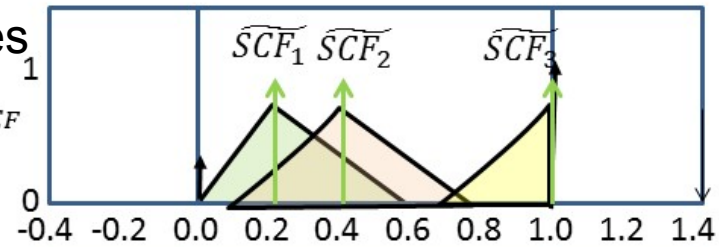
25km Spatial + 3d Temporal Aggregation



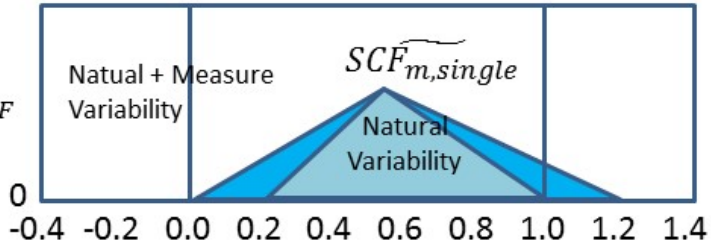
Aggregating SCF in a Comparison Unit

Mapped Areas

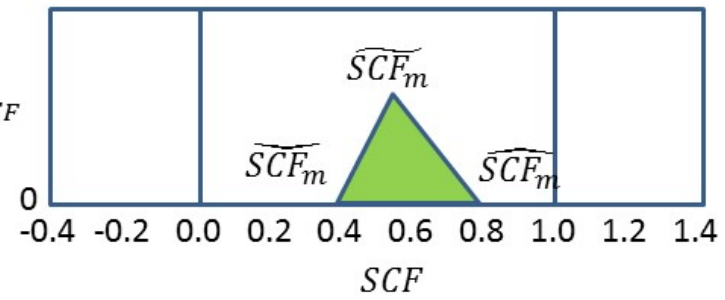
3 product estimates



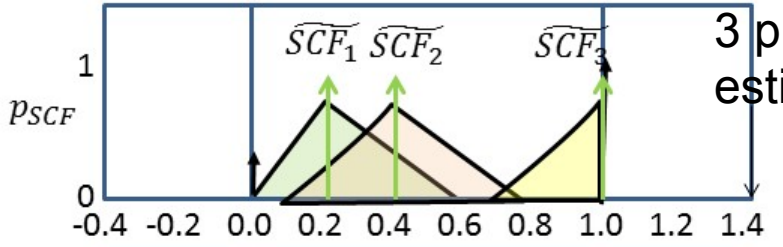
single estimate



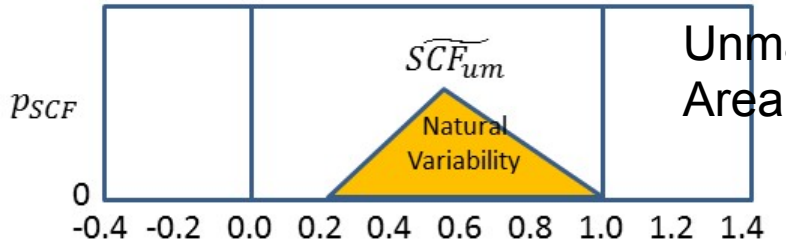
Mean estimate



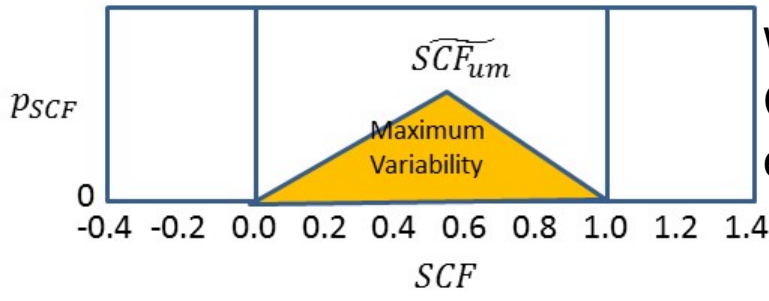
Unmapped Areas



3 product estimates



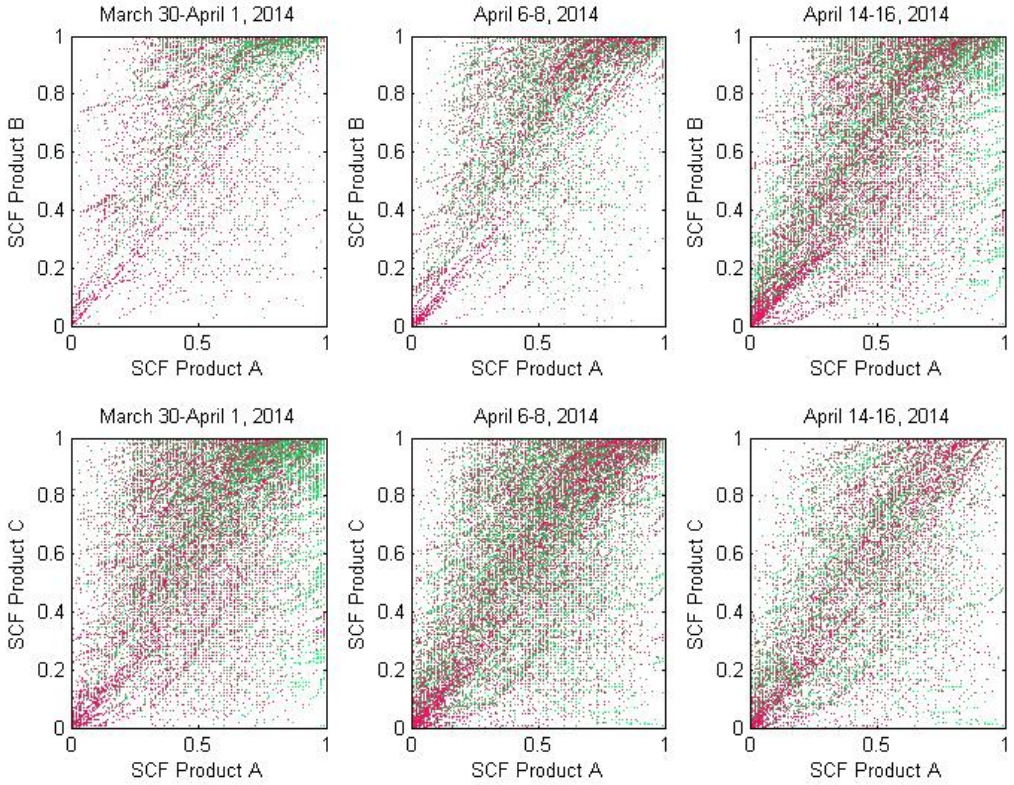
Unmapped Area est.

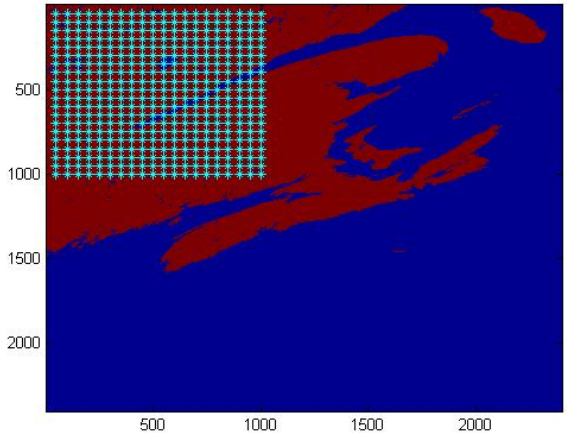


Worst Case est.

PDF sampled using monte-carlo methods 20+ times per comparison unit.
Classification metrics are then based on applying T=0.5 to SCF samples.

Example





400 site locations
5km spatial aggr.
1day temporal aggr.
20 random realizations/loc
1000 random pairs/site/loc

Conclusions

Uncertainty due to thematic, spatial and temporal differences in reference and product SE estimates can be substantial.

Spatial and temporal aggregation will be required to provide 'balanced' comparisons.

Thematic conversion between SD, binary SE and SCF and dealing with uncertainty of unmapped areas is required.

Relating all measurements to pdf(SCF) is one approach. Data suggest unimodal, bounded pdfs (e.g. triangular)

Aggregation will reduce variability during persistent SCF conditions and increase variability during varying SCF conditions. Montecarlo sampling can allow for precision estimates of metrics.