**WMO SPICE Snow on Ground Analysis Outline**

1. **Experiment Objectives and Anticipated Outcomes**

The study objectives for the WMO SPICE Snow on Ground (SoG) study, as defined in the experiment plan, are as follows:

Primary Objectives

* + - 1. Characterize and recommend automated methods, appropriate for the measurement of total snow depth in a range of cold climate conditions. Different measurement strategies may be recommended for different climatic regimes and for various measurement purposes. The final report is expected to include recommendations regarding measurement thresholds, siting of instruments, availability of ancillary measurements for correcting the measurements of the snow depth sensors (e.g.location and siting of temperature for sonic corrections), instrument sensitivity and accuracy.
      2. Investigate and report on the measurement and reporting performance of snow depth sensors measuring total snow depth, over various time periods (minutes, hours, days), linking these measurements to the reference gauge measurements of total precipitation where possible.

Secondary Objectives

* + - 1. Assessment of the feasibility to derive reliable spatial representativeness based on using point measurements of snow depth and recommendations for future initiatives focusing on this issue.
      2. Assessment of the capability of automated sensors to determine the Snow Water Equivalent (SWE) of accumulated or freshly fallen snow, linking these measurements to reference gauge precipitation measurements and snow depth measurements (where possible).

Anticipated outcomes include:

1. Integrate the results from multiple sites to characterize the instruments under test measuring snow on ground, and identify their limitations. This should include assessments of thresholds, location and siting of snow depth instruments, and the corrections applied (such as temperature for sonic corrections), instrument sensitivity and accuracy.
2. Assess and characterize measurement errors and biases, and their correlation with the operational environment.
3. Assess the ability to estimate the SWE as a result of the correlation between the measurement of snow depth sensors (total or differential over a given period) and the total precipitation amount (R2, where available) Based on this analysis, recommendations can be made for making these linkages in national operation networks to estimate SWE where one set of this instrumentation are not available.
4. Assess the capabilities of automated non-conventional SWE measurement instrumentation to capture the changes in snowpack SWE over both the accumulation and melt periods commenting where possible on the sensor footprint, resolution, and other capabilities and limitations.
5. Report on the performance of various materials used as targets for the measurements based on the SPICE results, if available, and the review of the literature available on this topic.
6. **Analysis Plan**
7. Instrument Performance

In order to assess automated methods of measuring snow on the ground (snow depth AND SWE), a general metric of instrument performance is required. This can be categorized three ways: a)Instrument reliability, b)Instrument repeatability, and c)Instrument accuracy.

a) Instrument reliability is to be assessed by looking at the failure rate of the instrument that can be attributed to instrument specific factors (eg electronic failures) or environmental factors (eg instrument fails because of temperature) when using the instrument according to manufacturer design. Period of instrument failure need to be cross-referenced with site meta and ancillary data. Analysis will also document the frequency and reason for human intervention during the intercomparison period.

b) Instrument repeatability is the ability of the instrument to measure the static snow pack with minimal variability in the measurement. The instrument will be assessed by choosing relatively long periods when the snow pack (or snow free surface) is not changing or changing very slowly. During these conditions, variability in the instrument measurement can be considered noise and evaluated as such. Sources of instrument noise will be examined. Although this could be more easily done with no snow on the ground, it would be preferably to examine periods with snow as a snowpack could introduce complicating factors (such as a non-solid surface) that need to be factored into instrument performance.

c) Instrument accuracy will be assessed by comparing the instrument measurement to the manual reference measurement (frequency being dependent on instrument type and reference method) and assessing biases related to instrument errors or environmental factors.

2. Instrument Thresholds

Instrument threshold analysis can be categorized by a)physical and b)temporal thresholds.

a) The physical threshold is the threshold of the snow pack at which the sensor is able to make a reliable and accurate measurement. The various instruments under test will have different minimum and/or maximum physical thresholds. Minimum thresholds will be evaluated by assessing how soon and accurately the instrument registers a snow pack measurement as snow begins to collect on the target surface. This will be accomplished through manual reference measurements (and other manual observations), web camera observations (where available) and observations made with other SoG instrumentation at the site. Metrics for Instrument Performance also apply. The surface target needs to be considered in this assessment.

b) Temporal threshold is the minimum or maximum measurement frequency of the instrument at which it can make a reliable and accurate (and meaningful) measurement. The metrics for instrument performance will apply but this will also be dependent on the nature of the snowpack (how rapidly it changes) which will be environmentally dependent.

3. Linking SoG to Gauge Measurements

Analysis and procedures will be developed to link the snow depth as measured by SoG depth instrumentation to the liquid water equivalent of snow events as measured using the R2 or R3 reference. This will be done for case studies where we have a high degree of confidence in the accuracy of both the snow depth and the precipitation gauge measurements. These case studies will be used to develop and assess the capability of estimating snow depth from gauge measurements or vice versa, examining the density of event based snowfall, and testing the commonly used 10:1 snow depth to precipitation conversion factor. Ancillary data will be used to determine when and why procedures break down. This link will be examined at various time scales including hourly, 6-hourly, daily, and event scales. This analysis will be repeated for automated SWE measurements, linking these measurements to the R2 or R3 reference.

Further to this, SoG instrumentation will be assessed for the capability of determining start and end times of snowfall events, determining transition from rain to snow (or the reverse), and precipitation typing. Other ancillary meteorological data will be factored into this analysis.

4.Assessing spatial representation of point measurements

Where possible, point or multiple point measurements will be assessed, using established techniques, on their capability to represent spatial averages of snow depth or SWE. This is accomplished by comparing the spatial average of snow depth or SWE obtained using a multi-point snow course. Although this is more of a siting issue than an instrument issue, reporting should indicate recommendations as an outcome of SPICE.

Table 1: Site/Instrument/Analysis Matrix. Numbers indicate planned analysis (ie 1=Instrument Performance)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Site** |  |  |  |  |  |  |
| **Instrument** | **Sodonkyla** | **Hala Gasienicowa** | **Col de Porte** | **CARE** | **Caribou Creek** | **EVK2-CNR** | **Weissfluhjoch** |
| **SR50ATH** | 1,2,3,4 | 1,2 | 1,2,3,4 | 1,2,3,4 |  | 1,2,3,4 | 1,2,3 |
| **SR50** | 1,2,3,4 |  | 1,2,3,4 |  | 2,3,4(?) |  |  |
| **SHM30** | 1,2,3,4 |  | 1,2,3,4 | 1,2,3,4 |  |  | 1,2,3 |
| **SL300** | 1,2,3,4 |  |  | 1,2,3,4 |  |  |  |
| **USH-8** | 1,2,3,4 |  |  | 1,2,3,4 |  |  |  |
| **CS725** | 1,2,3,4 |  |  |  | 1,2,3,4 |  |  |
| **Lysimeter** |  |  |  |  |  |  | 1,2,3 |
| **SP3 Snow Pillow** |  |  |  |  |  |  | 1,2,3 |
| **SSG Snowscale** |  |  |  |  |  |  | 1,2,3 |

1. **Data Analysis Team for SoG (confirmed as of January 22, 2014)**

Craig Smith, Daqing Yang, Barry Goodison (Canada)

Timo Laine, Osmo Aulamo (Finland)

Yves-Alain Roulet, Audrey Reverdin (Switzerland)

Samuel Morin (France)