DIGITAL IMAGE CORRELATION (DIC) IN SNOW MECHANICS: PRACTICAL CONSIDERATIONS AND APPLICATIONS

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ABSTRACT: In snow mechanics experiments, complex loading configurations and layered snow can produce highly non-uniform deformation, including strain localization, crushing, and fracture. Moreover, machine compliance, boundary motion, and rigid-body motion can cause the imposed displacement to differ from the deformation experienced by the snow. Digital Image Correlation (DIC) complements force and actuator-displacement measurements by providing non-contact surface displacement and strain fields directly on the specimen or snow profile. This contribution summarizes practical experience gained from two-dimensional DIC measurements of exposed snow surfaces. It follows the experimental workflow from planning and preparation to acquisition, processing, and interpretation. Particular attention is given to field of view, spatial and temporal resolution, camera geometry and calibration, pattern preparation, illumination, reference-image selection, synchronization, validation, and reporting. Case studies range from small laboratory tests to field-scale fracture experiments and model-based parameter identification. The aim is to provide a practical basis for designing and interpreting DIC measurements in snow mechanics.

KEYWORDS: digital image correlation, DIC, snow mechanics, snow slab avalanches, avalanche dynamics

1. INTRODUCTION

Snow is a porous and structurally heterogeneous material whose mechanical response depends on its microstructure, density, temperature, loading rate, and stress state (e.g. Shapiro et al. 1997; Mellor 1975). In many snow mechanical experiments, the objective is to quantify how snow deforms under an applied load. This is often more challenging than it appears. Actuator displacement may include machine compliance, boundary effects, or rigid-body motion, while deformation within the snow may localize in thin weak layers, compaction bands, or regions surrounding a propagating crack (Bergfeld et al. 2021; Barraclough et al. 2017). Likewise, field experiments such as skier loading or propagation saw tests may involve localized crushing and compaction that cannot be captured by external displacement measurements alone.

Digital Image Correlation (DIC) provides a simple and effective solution by measuring full-field surface displacements directly on the snow. Spatial derivatives of the displacement field provide strain fields, while time-resolved image sequences can be used to determine velocity and strain rate fields (Schreier et al. 2009). Snow is particularly well suited for DIC because its naturally bright surface can easily be covered with a dark speckle pattern, producing excellent image contrast with minimal preparation.

Optical methods were already used in early compression experiments to visualize snow deformation (Yosida et al. 1958). Over the past decade, DIC and related image-based methods have become a standard tool in experimental snow mechanics and have enabled studies of weak layer deformation, fracture propagation, compaction bands, moving snow, and inverse identification of material properties (e.g. Muhonen 2026; Leeflang 2026; Adam et al. 2026; Bergfeld et al. 2025; Bergfeld et al. 2021; De Biagi et al. 2019; Barraclough et al. 2017; Walters and Adams 2014; Walters and Adams 2012; van Herwijnen et al. 2010). However, applying DIC to snow requires several practical considerations related to patterning, illumination, image acquisition, and data interpretation.

Rather than reviewing DIC theory, this paper provides an overview of the main considerations for

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https://doi.org/10.15788/1790099169

applying DIC in snow mechanics and summarizes the practical experience gained from these applications. Following the workflow of a typical snow mechanics experiment, we discuss how to define the measurement objective, prepare the experimental setup, acquire and process images, and interpret the resulting displacement and strain fields.

2. PLANNING A DIC EXPERIMENT

2.1. Measurement objective and camera geometry

A DIC setup should be designed around three questions: What quantity is to be measured, at what spatial and temporal scales, and can the deformation be represented in two dimensions? These questions determine the camera geometry, required field of view, image scale, and frame rate. The measurement objective may be a relative displacement, a local strain, a velocity field, or a complete displacement field. The expected localization length and deformation rate then define the necessary spatial and temporal resolution, as discussed in the following sections.

Two-dimensional DIC measures motion projected onto the image plane and is therefore appropriate when the observed surface remains approximately planar and its motion is mainly in-plane. The camera should be aligned approximately perpendicular to this surface. Careful alignment reduces perspective-related errors, but it cannot correct genuine out-of-plane motion, which changes the apparent position and size of the pattern and may be interpreted as in-plane displacement (Sutton et al. 2008). In the snow experiments presented here, the camera position and experimental setup were designed to minimize such motion. Where substantial out-of-plane motion cannot be avoided, two-dimensional DIC is no longer sufficient.

2.2. Field of view, spatial resolution, and measurement uncertainty

Snow experiments place very different demands on image resolution. A laboratory weak layer test requires many pixels across a small region, whereas a field fracture test may sacrifice local resolution to cover several meters. The physical image scale, often expressed in millimeters per pixel, indicates the available image detail but is not the spatial resolution of the DIC result. This distinction arises because DIC algorithms calculate displacement over a subset of pixels rather than at a single point, while subsequent strain calculations introduce even further spatial averaging. If a localization zone is smaller than these analysis lengths, it may appear wider and show a lower peak strain (Reu 2015). This is particularly important when the subset size or strain calculation length is comparable to or larger than the weak layer thickness. The calculated strain then includes deformation from adjacent snow and represents an effective strain over the measurement region rather than a strictly local weak layer strain (Bergfeld et al. 2021). The step size controls the spacing between reported points. Reducing it produces a denser but more strongly overlapping field; it does not recover detail already averaged by the subset.

Before selecting the camera and lens, the smallest displacement or strain of interest and the maximum acceptable uncertainty should be defined. The complete imaging and analysis procedure should then be tested under representative conditions (Jones et al. 2025). Increasing magnification reduces spatial averaging but also reduces the observable area. When the measurement scale approaches the size of individual grains or surface-hoar crystals, continuum strain becomes increasingly difficult to interpret (Bergfeld et al. 2021).

2.3. Temporal resolution and exposure time

The acquisition rate should be matched to the duration and velocity of the process. Slow creep experiments may require images only every few minutes or hours, whereas dynamic fracture requires several images while the crack remains within the field of view. For example, a crack moving at 130 m s^{-1} (Bergfeld et al. 2025) crosses a 0.5 m field of view in approximately 4 ms. At 1,000 frames per second, this corresponds to only about four frame intervals. This may be sufficient to detect crack passage but provides little detail about changes in crack speed or surrounding deformation.

A sufficient frame rate alone does not prevent motion blur. The exposure time must be short enough that movement during the exposure remains small relative to the recorded speckle size (Jones et al. 2025). Dynamic experiments therefore require both a suitable frame rate and sufficient illumination for short exposures. Field of view, frame rate, exposure time, illumination, recording duration, amount of data, and triggering should be chosen together.

3. EXPERIMENTAL PREPARATION

3.1. Equipment and documentation

Depending on the experiment, the equipment may include suitable lenses, a stable tripod or camera

frame, a laptop or data recorder, chargers and spare batteries, heating pads for cameras and batteries, a calibration target, a tape measure or scale bar, lighting, shading, and weather protection. Field experiments should be planned so that the camera, the supports, and the recorded specimen all remain stable in wind and on a deformable snow surface.

The final setup should be documented before loading begins. Relevant information includes the camera and lens, image resolution, frame rate, exposure time, aperture, focus, camera-to-specimen distance, field of view, physical image scale, specimen dimensions, environmental conditions, and the position of any external length reference. Fixed focus, exposure, and white balance are generally preferable to automatic settings that may change during the test (Jones et al. 2025).

3.2. *Camera positioning and calibration*

Camera positioning requires a compromise between image scale and experimental context. The measurement region should fill as much of the image as possible, while relevant boundaries and reference features, such as the loading plates or snow above and below a weak layer, remain visible. Once positioned, the camera should be mounted rigidly and protected against accidental movement. A stationary reference in the image can help detect apparent displacements caused by movement of the camera or experimental setup.

Once the camera, lens, focus, and recording resolution have been fixed, the camera should be calibrated. Several images of a planar calibration target with a known pattern, such as a grid of dots or a checkerboard, are recorded at different positions and orientations (Figure 1a). These images are used to determine the intrinsic camera parameters and correct for lens distortion (Zhang 2000; Jones et al. 2025).

The resulting calibration parameters are applied to the experimental images to correct lens distortion. A reference of known dimensions in the specimen plane is then used to determine the image scale, as shown in Figure 1b. This scale converts coordinates and displacements from pixels to physical units but is not required for dimensionless strain. Distortion correction remains necessary because lens distortion can bias the calculated strain (Jones et al. 2025). After calibration, the camera, lens, focus, and recording resolution should remain unchanged.

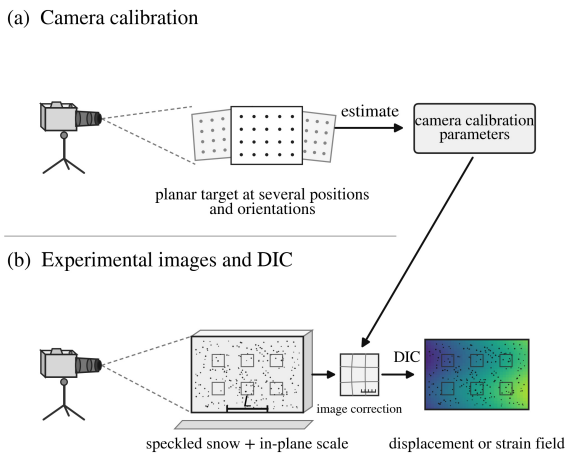


Figure 1: Camera calibration and its application to DIC measurements. (a) Images of a planar calibration target recorded at several positions and orientations are used to estimate the intrinsic camera parameters and lens distortion. (b) These parameters are applied to correct the experimental images, while a reference of known dimensions in the specimen plane defines the image scale before DIC is used to calculate displacement or strain fields.

3.3. *Pattern preparation*

A suitable speckle pattern must provide local intensity variations that remain attached to the same material points throughout the measurement. Snow already provides a bright background, so only the dark component of the pattern must be added. We commonly use a fine aerosol paint or chalk-based spray applied from sufficient distance to produce irregular features without forming a continuous dark layer.

Individual features should extend over several pixels, and each subset should contain several distinguishable features. The pattern feature size should be assessed in the recorded image rather than only on the specimen. Features that appear suitable by eye may be too small to resolve in a large field of view, while oversized features reduce local uniqueness (Jones et al. 2025). Pattern quality should therefore be checked at full image resolution and with the intended subset size.

3.4. *Illumination*

Reliable DIC requires illumination that provides sufficient contrast without saturation and remains stable throughout the recording. Snow strongly reflects visible light, so diffuse illumination should be used where possible and direct reflections avoided.

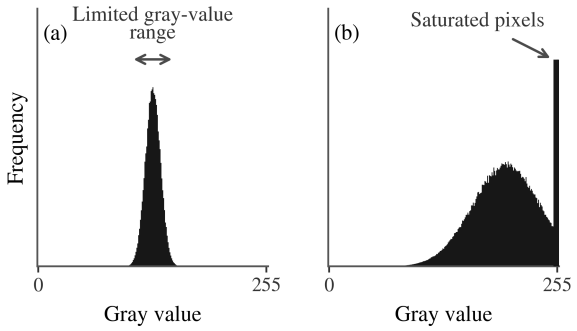


Figure 2: Examples of image-quality problems encountered on patterned snow surfaces. A narrow grey-value distribution indicates weak contrast, whereas a peak at 255 indicates saturation caused by overexposure or reflections.

Flickering artificial light can interact with the camera frame rate and exposure time, causing temporal aliasing, periodic brightness variations, or moving bands. The lighting should therefore be tested using the intended recording settings.

A grey-value histogram provides a quick check of contrast and exposure; two common warning signs are shown in Figure 2. A narrow distribution indicates low contrast, while a peak at 255 in an 8-bit image indicates saturated pixels caused by overexposure or reflections. Because a histogram contains no spatial or temporal information, the sharpness, size, and distribution of the pattern should also be checked directly in the images and across an image sequence.

In field experiments, illumination can change as clouds and shadows move, while direct sunlight may heat the dark pattern and cause local melting. We therefore shade the measurement surface with translucent curtains, which block direct sunlight while retaining diffuse daylight (Figure 3).

4. IMAGE ACQUISITION AND PROCESSING

4.1. Acquisition and synchronization

Before loading begins, a short stationary sequence should be recorded with the final camera position, illumination, and acquisition settings. This sequence can later be used to quantify measurement noise and identify camera movement, illumination changes, or vibration (Jones et al. 2025). Stationary regions outside the specimen are particularly useful in field experiments.

DIC measurements often need to be combined with force or stress data. A hardware trigger



Figure 3: Field setup using translucent curtains to shade the patterned snow surface from direct sunlight while retaining diffuse daylight.

or common time base is preferable (Jones et al. 2025). Otherwise, the experiment should include an event that can be identified in both signals, such as initial contact or the onset of loading.

If no distinct common event is available, the time offset may be estimated by cross-correlating the signals (Schöttner et al. 2026). Care is required when failure produces a force drop but a simultaneous jump in displacement or strain. In this case, comparable features, such as the absolute signal changes, should be cross-correlated rather than the original signals. An example is shown in Figure 4.

4.2. Reference strategy and changing surfaces

A fixed initial reference should be retained while correlation remains reliable (Jones et al. 2025). Each image is then compared with the same initial state (Figure 5a), so displacements are obtained directly relative to that state without accumulating errors between frames.

If the current image can no longer be correlated reliably with the initial image, the reference can be updated. In an incremental approach, each image is compared with the preceding image (Figure 5b), reducing the deformation and pattern change between correlated pairs. The resulting displacement increments must be accumulated to recover the total displacement, and measurement uncertainty can accumulate through the sequence (Pan et al. 2012). DIC software typically provides correlation residuals or other quality indicators that help identify worsening correlation and invalid regions (Jones et al. 2025).

For large deformations in granular materials, the

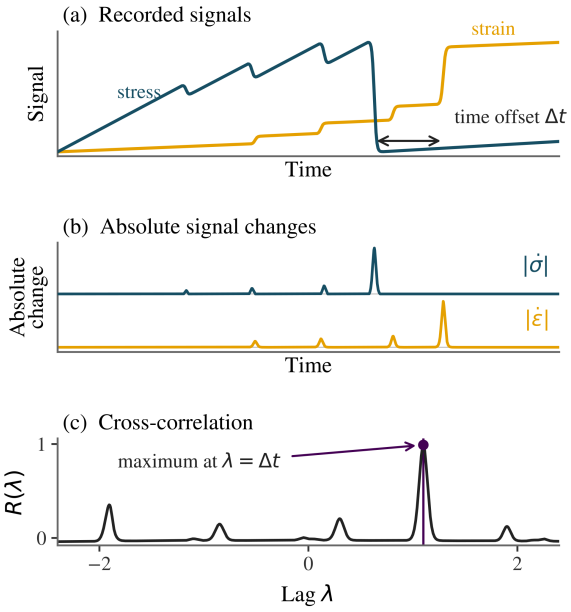


Figure 4: Synchronization of stress and DIC-based strain signals, adapted from Schöttner et al. (2026). (a) Corresponding events occur at different recorded times. (b) Absolute signal changes convert the stress drop and strain jump into comparable features. (c) The time offset is obtained from the lag at the maximum of their cross-correlation.

interpretation further depends on whether the same material points on the observed surface remain traceable. If they do, the increments can be accumulated to describe material deformation. Grain detachment, rearrangement, crushing, or exposure of a new surface may break this correspondence. Frame-to-frame correlation may then still provide short-term surface velocity fields while the local texture remains identifiable (White et al. 2003; Pinyol and Alvarado 2017).

Macroscopic fractures require special attention, because they represent a local displacement discontinuity. A conventional subset spanning the crack may lose correlation or smear the displacement jump. If correlation remains successful, the calculated strain may therefore represent the jump distributed over the size of the subset rather than a local material strain. However, displacements measured separately on either side of the crack remain useful (Jones et al. 2025; Poissant and Barthelat 2010).

4.3. *Processing, validation, and reporting*

Reliable DIC results require processing parameters matched to the measurement scale, validation under representative conditions, and transparent reporting.

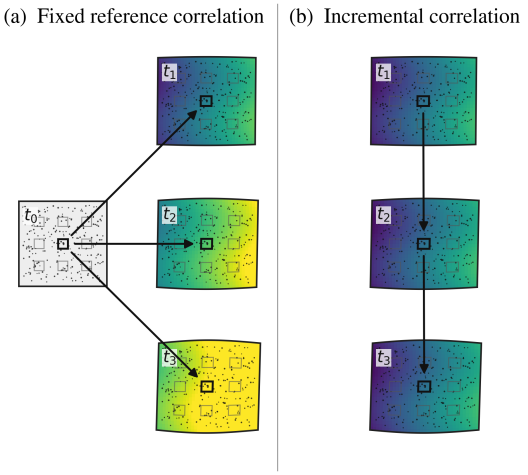


Figure 5: Comparison of fixed and incremental reference strategies. (a) With a fixed reference, every image is compared directly with the initial state. (b) With an incremental reference, consecutive images are compared and total displacement is obtained by accumulating the displacement increments, while their uncertainties propagate through the sequence.

Processing settings should be tested over a plausible range. If displacement or peak strain changes strongly with subset size, strain calculation length, or filtering, the result is not robustly resolved at the selected scale (Reu 2015; Jones et al. 2025).

Validation is recommended to assess the plausibility of DIC results and identify potential sources of error. A stationary sequence recorded under the final experimental conditions and processed with the same settings provides an estimate of the noise floor and may reveal vibration or illumination artifacts. For example, active cooling fans used in many high-speed cameras can produce a nearly sinusoidal displacement artifact in the DIC signal (e.g. Bergfeld et al. 2025). A stationary sequence does not, however, assess errors caused by calibration, perspective, or out-of-plane motion. A known displacement or deformation, or an independent measurement, is needed when measurement accuracy must be assessed (Haddadi and Belhabib 2008). Further guidance is provided by Jones et al. (2025).

For comparison between studies, the reported information should include camera geometry and image resolution, field of view, physical image scale (e.g. mm pixel^{-1}), frame rate and exposure time, calibration procedure, representative pattern size, DIC software and correlation criterion, subset and step sizes, strain calculation settings, reference

strategy, filtering, excluded regions, and any additional uncertainty estimate (Jones et al. 2025).

5. APPLICATIONS AND INTERPRETATION

The examples below are organized by what DIC adds to an experiment: separating specimen deformation from apparatus motion, resolving transient fields, retaining useful information during very large deformation, and supporting inverse parameter identification. Each example links the useful DIC output to its main design choice and interpretation limit; Table 1 summarizes these lessons.

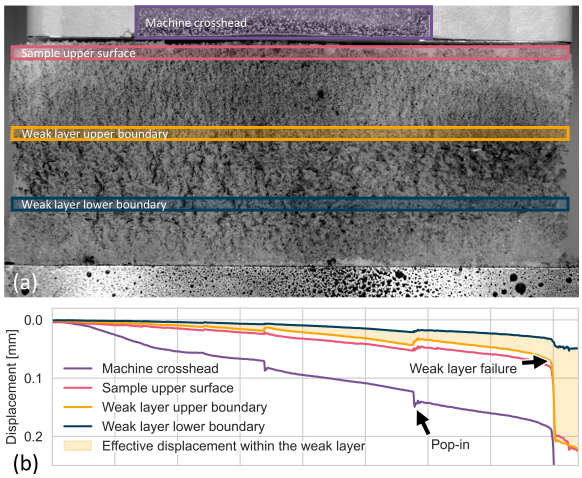


Figure 6: Weak layer deformation in a small-scale compression test. (a) Tracking regions on the crosshead, specimen surface, and weak layer boundaries. (b) Displacement histories; the shaded difference between the two boundary signals gives the effective weak layer deformation. Example from Schöttner et al. (2025).

5.1. *Isolating weak layer deformation*

Tracking both weak layer boundaries separates layer deformation from crosshead motion and deformation of the adjacent snow. Figure 6a shows the tracking regions, while Figure 6b shows their displacement histories. The difference between the boundary signals gives an effective weak layer deformation and largely cancels motion common to both tracking regions, such as uniform image translation due to camera motion. It remains an average over the tracked regions.

5.2. *Resolving transient fracture fields*

For non-uniform, rapidly changing deformation, the full field becomes the main result. In the large-scale propagation saw test in Figure 7, high-speed DIC resolves strain localization along the weak layer. The large field of view trades spatial resolution against coverage, while the frame rate and exposure time must capture several sharp images during crack passage.



Figure 7: High-speed DIC during a large-scale propagation saw test. (a) Patterned snow profile and camera setup. (b) Strain measure $\varepsilon_{xx}^2 + \varepsilon_{zz}^2$ during crack propagation, showing localization along the weak layer. Example from Bergfeld et al. (2021).

5.3. *Interpreting very large deformation*

During very large deformation, grain rearrangement and material entering or leaving the image eventually prevent correlation with a fixed reference. Incremental correlation can still provide short-term velocity fields while texture persists between images, as shown for a drag plate experiment in Figure 8.

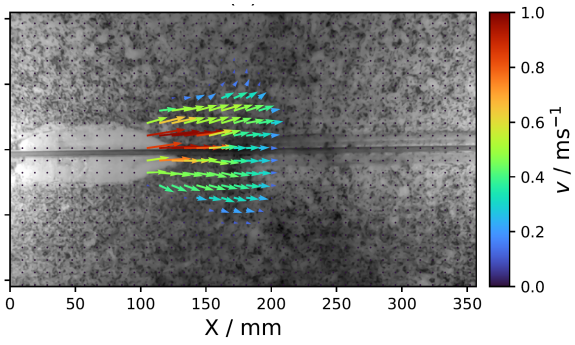


Figure 8: Velocity field ahead of a moving drag plate. Arrows show direction, while colour indicates velocity magnitude. Example from Muhonen (2026).

Application	What DIC adds	Key design choice	Interpretation limit
Laboratory weak layer test	Isolates weak layer deformation from apparatus motion	Track both boundaries and synchronize DIC with force signal	Deformation is averaged over the tracked regions
Field propagation saw test	Maps transient deformation and strain localization	Balance field of view, spatial resolution, frame rate, and exposure time	Peak strain depends on spatial averaging near the crack
Very large deformations	Provides time-resolved velocity fields	Incremental reference approach	Represents short-term motion rather than accumulated material deformation
Finite-element model updating	Provides displacement fields for estimating effective model parameters	Compare measured and simulated displacement fields over matching regions	Identified values are effective properties within the chosen modeling framework

Table 1: Useful DIC output, key design choice, and interpretation limit for four applications in snow mechanics.

5.4. *Identifying material parameters*

Full-field data can also support inverse parameter identification. In the workflow shown in Figure 9, measured and simulated displacement fields are compared over matching regions to identify an effective elastic modulus (Adam et al. 2026). The calibrated model then supports fracture analysis.

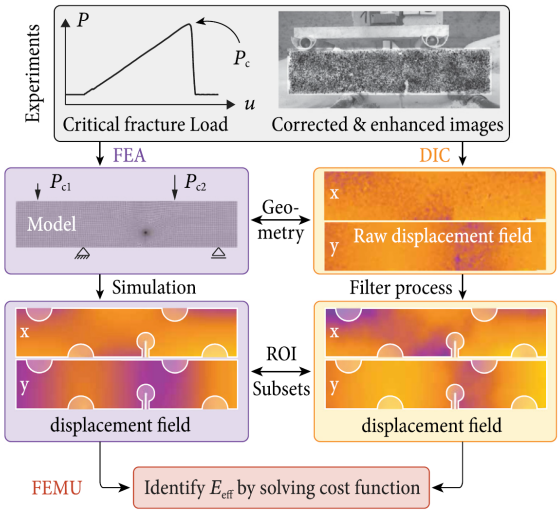


Figure 9: Finite-element model updating with DIC data. Load data and horizontal and vertical displacement fields obtained from corrected images provide the experimental input. The measured and corresponding finite-element fields are compared over matching regions to identify an effective elastic modulus. Workflow from Adam et al. (2026).

6. BEST-PRACTICE CHECKLIST

- **Define the goal.** Specify whether the required result is relative displacement, strain, velocity, or a full field for inverse identification. Define the relevant length and time scales and verify that a two-dimensional description is appropriate.

- **Plan the acquisition.** Select field of view, image scale, frame rate, and exposure time together. Use a resolved, locally unique pattern, stable diffuse illumination, rigid camera support, and calibration in the specimen plane.

- **Check the setup.** Fix the camera settings, verify triggering and synchronization, document the final setup, and record a stationary sequence under the same conditions as the experiment.

- **Select the processing scale.** Choose subset, step, strain calculation, and filtering settings according to the deformation scale. Use a fixed reference while correlation remains reliable; otherwise update it only while the pattern remains identifiable between frames.

- **Validate and report.** Quantify the noise floor, inspect fixed regions and correlation loss, and use known motion or an independent measurement when accuracy must be assessed. Report the settings and interpret results at their effective spatial resolution.

7. CONCLUSIONS

2D DIC separates local snow deformation from apparatus and boundary motion and provides displacement fields for transient processes and inverse parameter identification. As a surface method, its resolution is set by the imaging and processing scales. Camera geometry, image scale, frame rate, and reference strategy must match the process. Out-of-plane motion, cracks, and pattern changes limit interpretation. Stationary and known-motion tests help distinguish artifacts from physical signals.

ACKNOWLEDGMENTS

AI tools were used to improve the language, readability, and visual presentation of this manuscript.

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