IPROMO

28 SEP – 9 OCT 2020

GLACIER MONITORING USING TIME-LAPSE IMAGERY

The case study of the Planpincieux Glacier

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National Research Council of Italy

Research Institute of the Geo-hydrological Protection

Geohazard Monitoring Group

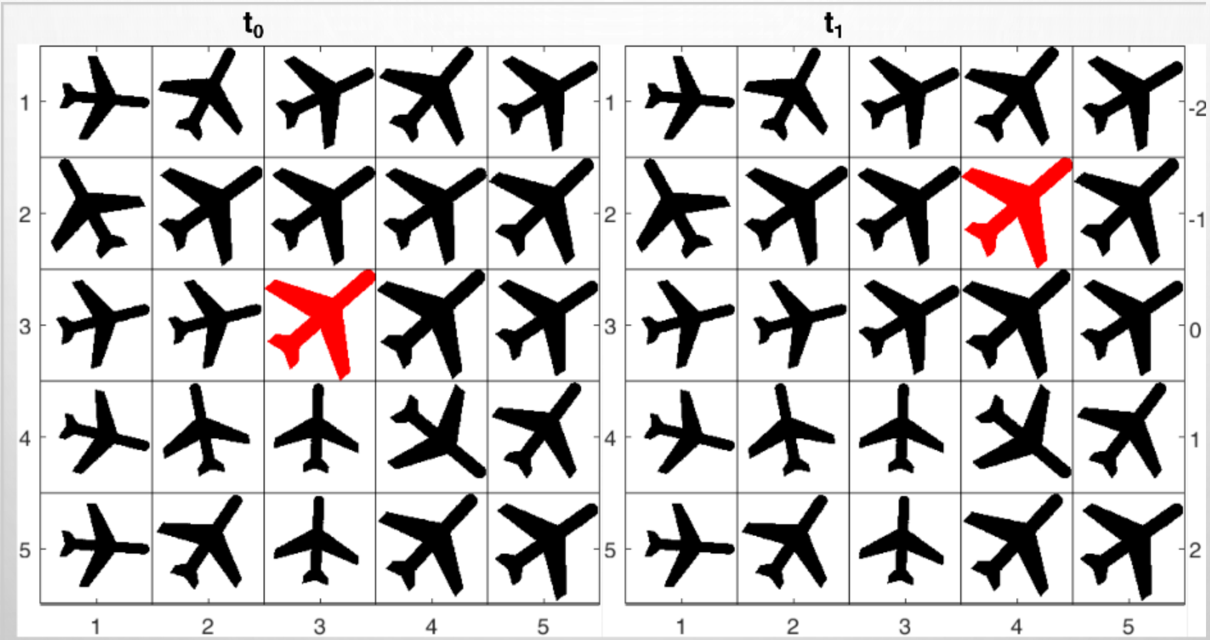
TABLE OF CONTENTS

Digital Image Correlation (DIC)

- DIC developed in the 80s for laboratory experiments
- In Earth Sciences, DIC was applied mostly on aerospace images during the 90s
- The first study of terrestrial DIC on glacier was in 2000 to measure the surface velocity of the Godely Glacier (NZ)[1]
- However, continuous DIC monitoring plans are rare

DIC - FUNDAMENTALS

THE PRINCIPLE OF DIC IS TO SEARCH FOR THE DISPLACEMENT OF AN IMAGE TILE BETWEEN TWO ACQUISITIONS OF THE SAME SCENE.

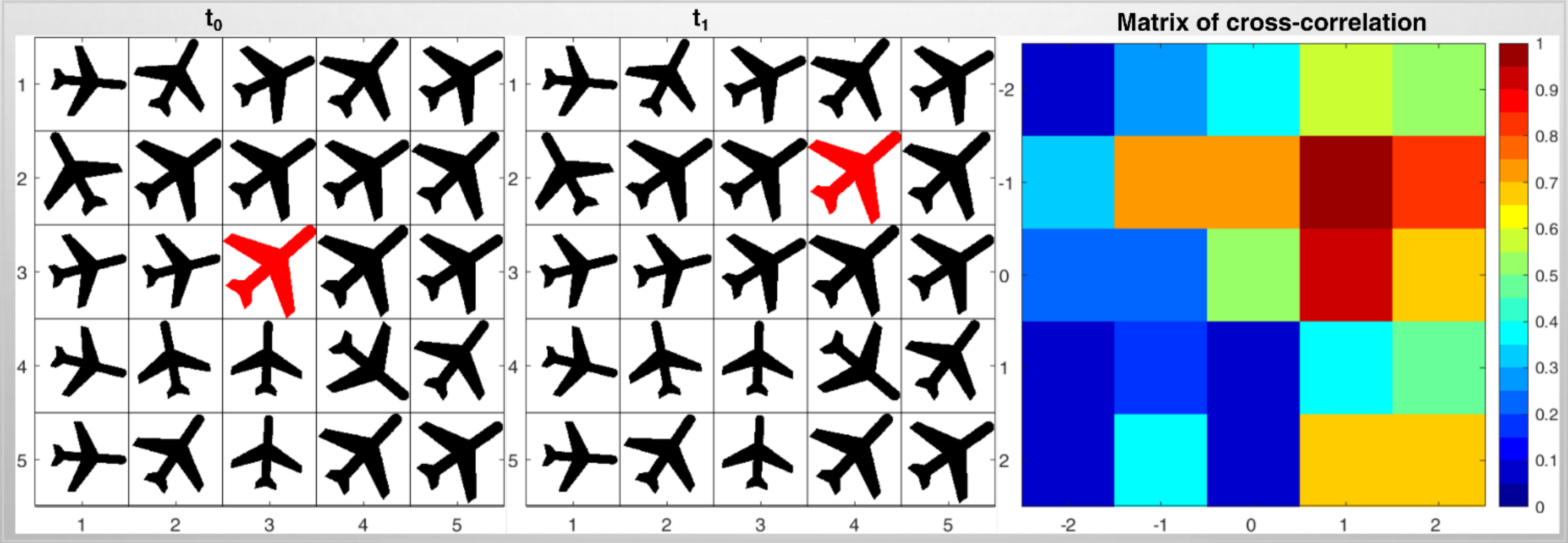


DIC - FUNDAMENTALS

THIS IS DONE WITH THE CALCULUS OF THE SPATIAL CROSS-CORRELATION (**CC**)

CC IS A SIMILARITY INDEX CALCULATED BETWEEN THE REFERENCE TEMPLATE AND MULTIPLE CANDIDATES OF SEARCHING TEMPLATES.

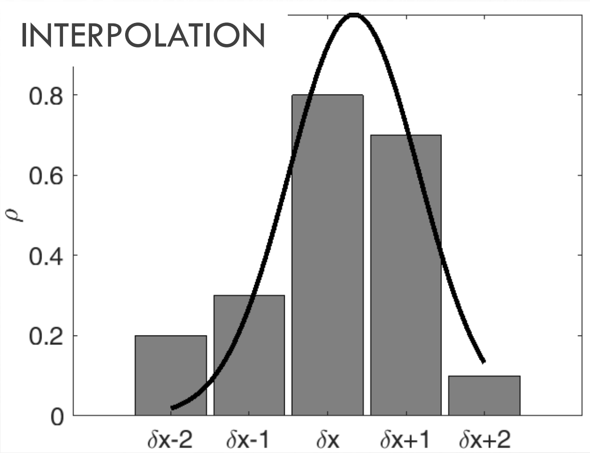
THE POSITION WHERE THE BEST SIMILARITY IS FOUND CORREPONDS TO THE DISPLACEMENT OF THE REFERENCE TEMPLATES.



DIC ACCURACY AND PRECISION

SUBPIXEL SENSITIVITY

ADOPTING AN INTERPOLATION OF THE CROSS-CORRELATION MATRIX IT IS POSSIBLE TO OBTAIN A ADOPTING AN INTERPOLATION OF THE CROSS-CORRELATION MATRIX IT IS POSSIBLE TO OBTAIN A SUB-PIXEL MEASUREMENT



UNCERTAINTY

TIPYCAL UNCERTAINTY IN GLACIOLOGICAL SURVEYS IS 0.5 – 1 PX

DIC - MONITORING APPLICATION

TYPICAL DIC APPLICATION FOR GLACIER MONITORING IS TO ACQUIRE AN **IMAGE SEQUENCE** USING A DSLR CAMERA

DIC PROCESSING PRODUCES **DAILY RESULTS**

DIC - PROCESSING

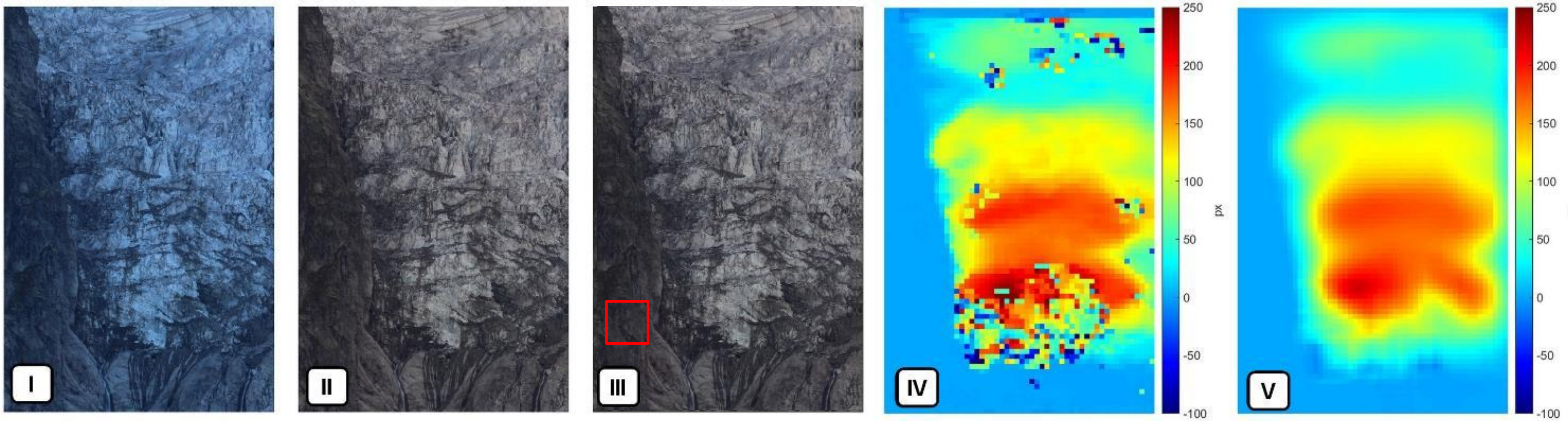


IMAGE SELECTION

IMAGE PROCESSING

COREGISTRATION

CROSS-CORRELATION

RESULT REFINEMENT

IMAGE SELECTION [2]

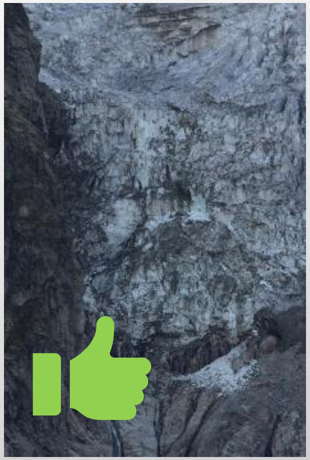
FUNDAMENTAL TO OBTAIN HIGH-QUALITY RESULTS

MOSTLY DONE MANUALLY → HUMAN EFFORT REQUIRED

SHADOWS

SIMILAR ILLUMINATION

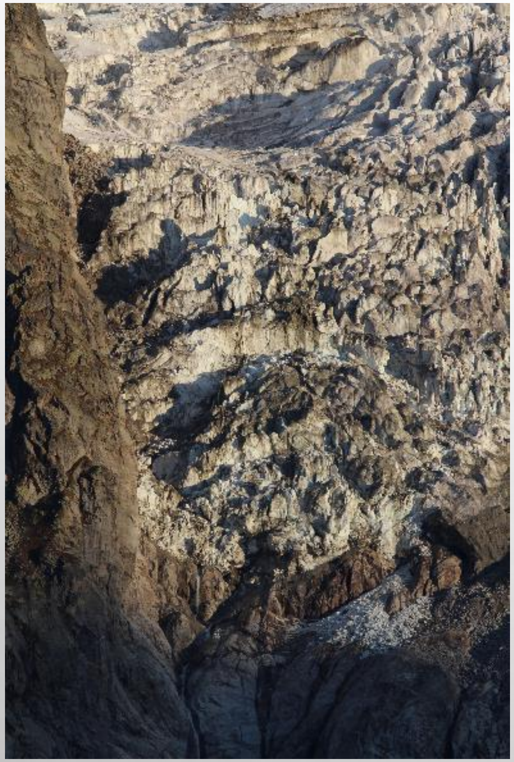
DIFFUSE ILLUMINATION



NO VISIBILITY

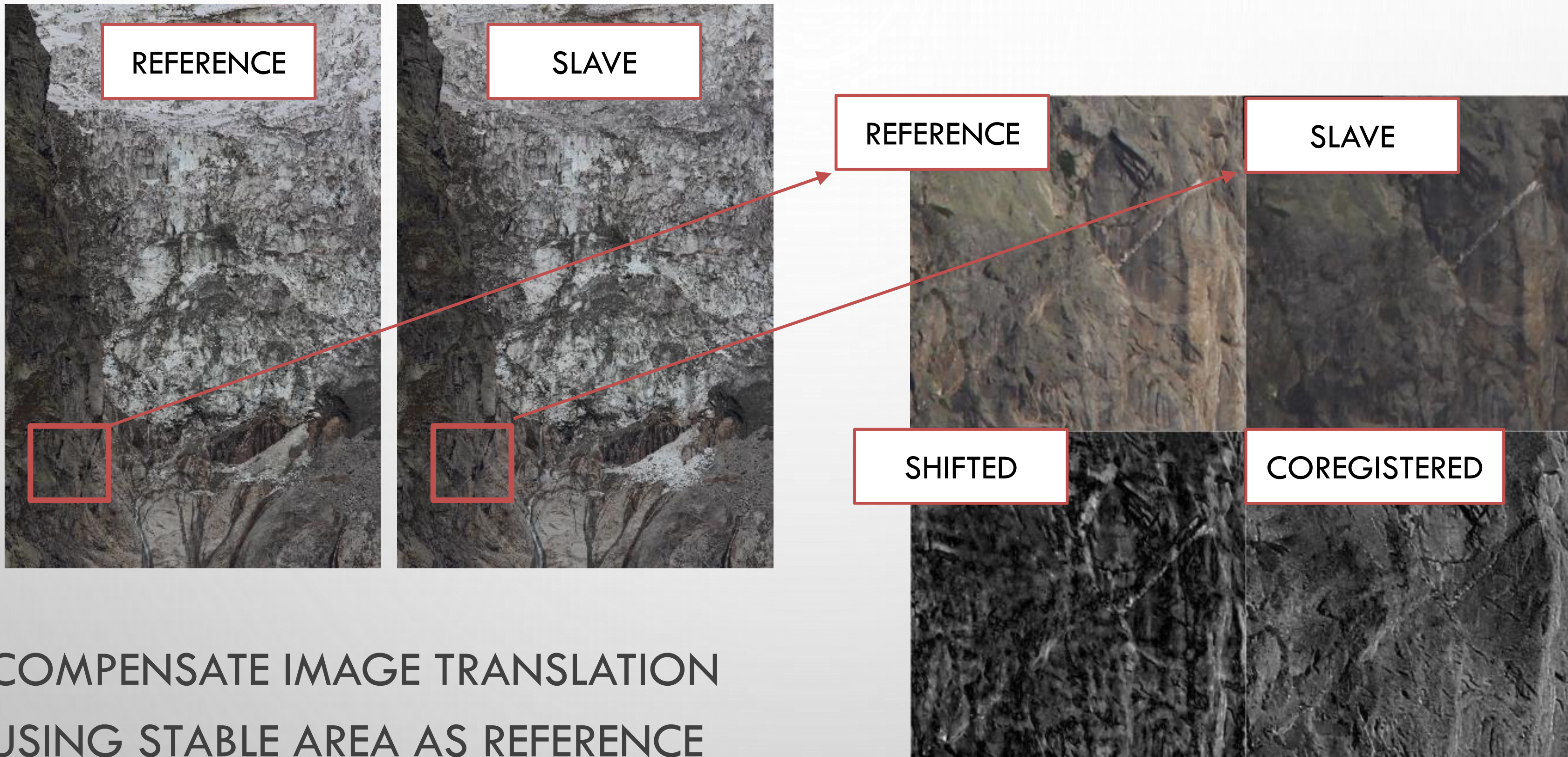
IMAGE PROCESSING

DIC WORKS WITH MONOCHROMATIC IMAGES



RGB to BW

COREGISTRATION

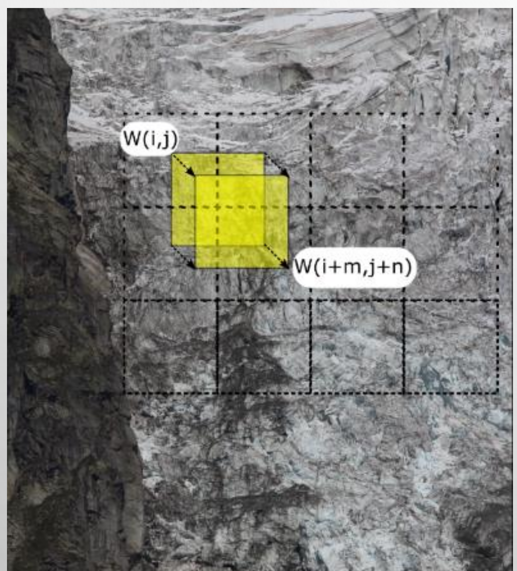


COMPENSATE IMAGE TRANSLATION

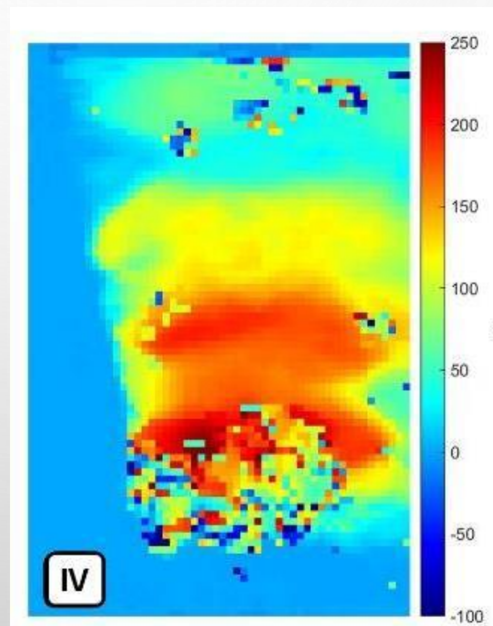
USING STABLE AREA AS REFERENCE

CALCULATING SURFACE DISPLACEMENTS

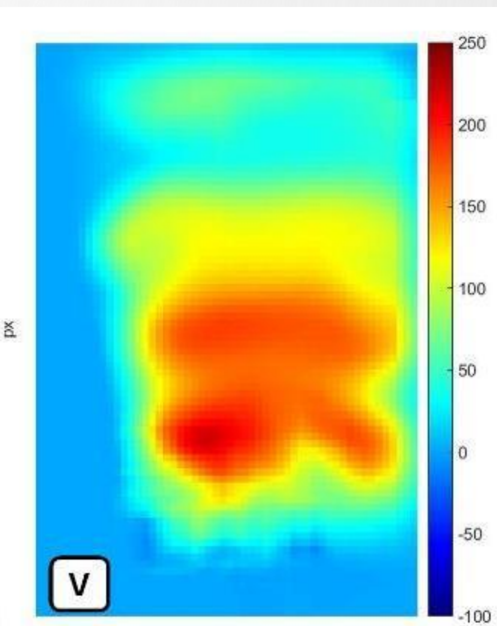
SLIDING WINDOW WHERE TO CALCULATE CROSS-CORRELATION



RAW RESULT



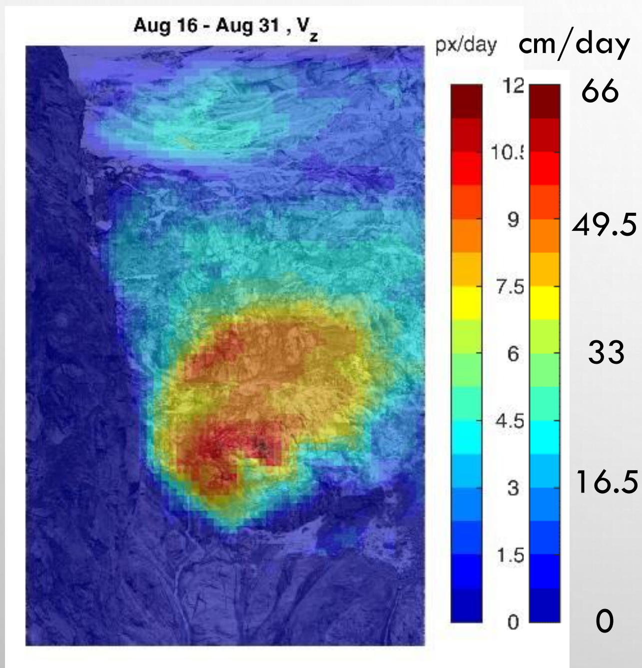
RESULT REFINEMENT



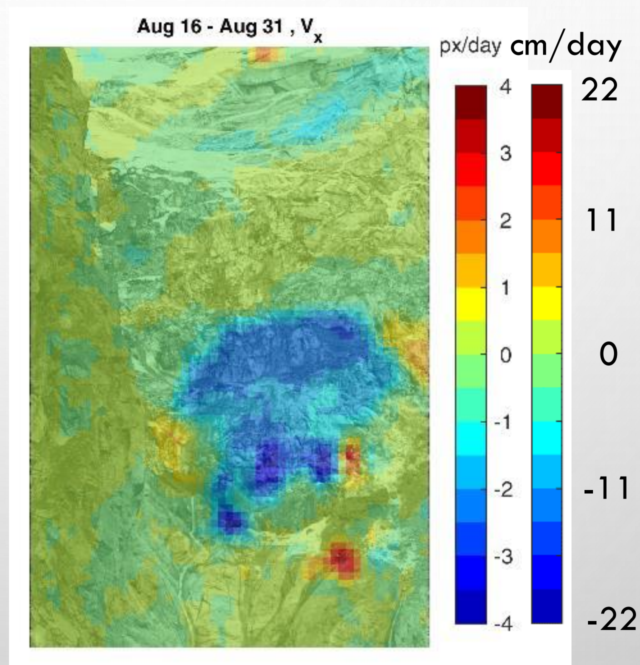
DIC - OUTPUT

MAPS OF DISPLACEMENT COMPONENTS ORTHOGONAL TO THE LINE OF SIGHT

VERTICAL COMPONENT



HORIZONTAL COMPONENT



METRIC CONVERSION

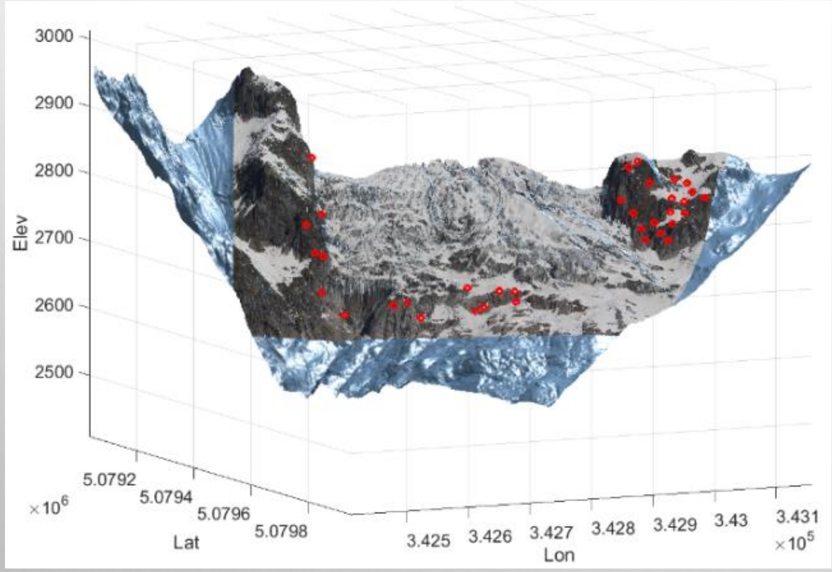
$$1\ \text{px} = 2D \tan\left(\frac{\operatorname{atan}\left(\frac{S}{2f}\right)}{R}\right)$$

IN THE PLANPINCIEUX GLACIER
1 PX = 5.5 CM

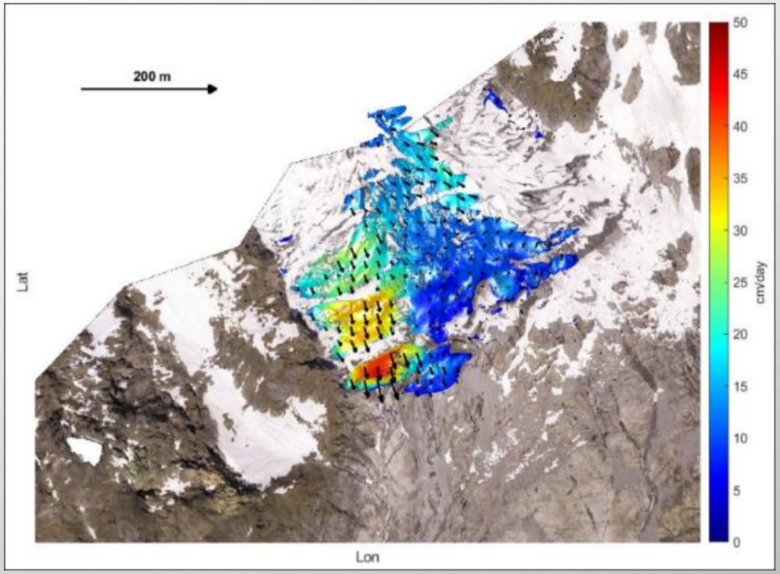
DIC - OUTPUT

RESULTS REPRESENTATION IN THE REAL-WORLD COORDINATES ALLOWS COMPARISON AND COUPLING WITH OTHER MONITORING SYSTEMS

ORTHORECTIFICATION



GEOREFERENCING



DIC: A VALUABLE TOOL FOR GLACIER MONITORING

PROS

- 2D SPATIALLY-DISTRIBUTED RESULTS
- REMOTE SENSING
- LOW COST AND PORTABLE HARDWARE
- OBSERVATION OF COMPLEX GEOMETRIES
- SIMPLE PROCESSING AND RESULT INTERPRETATION

CONS

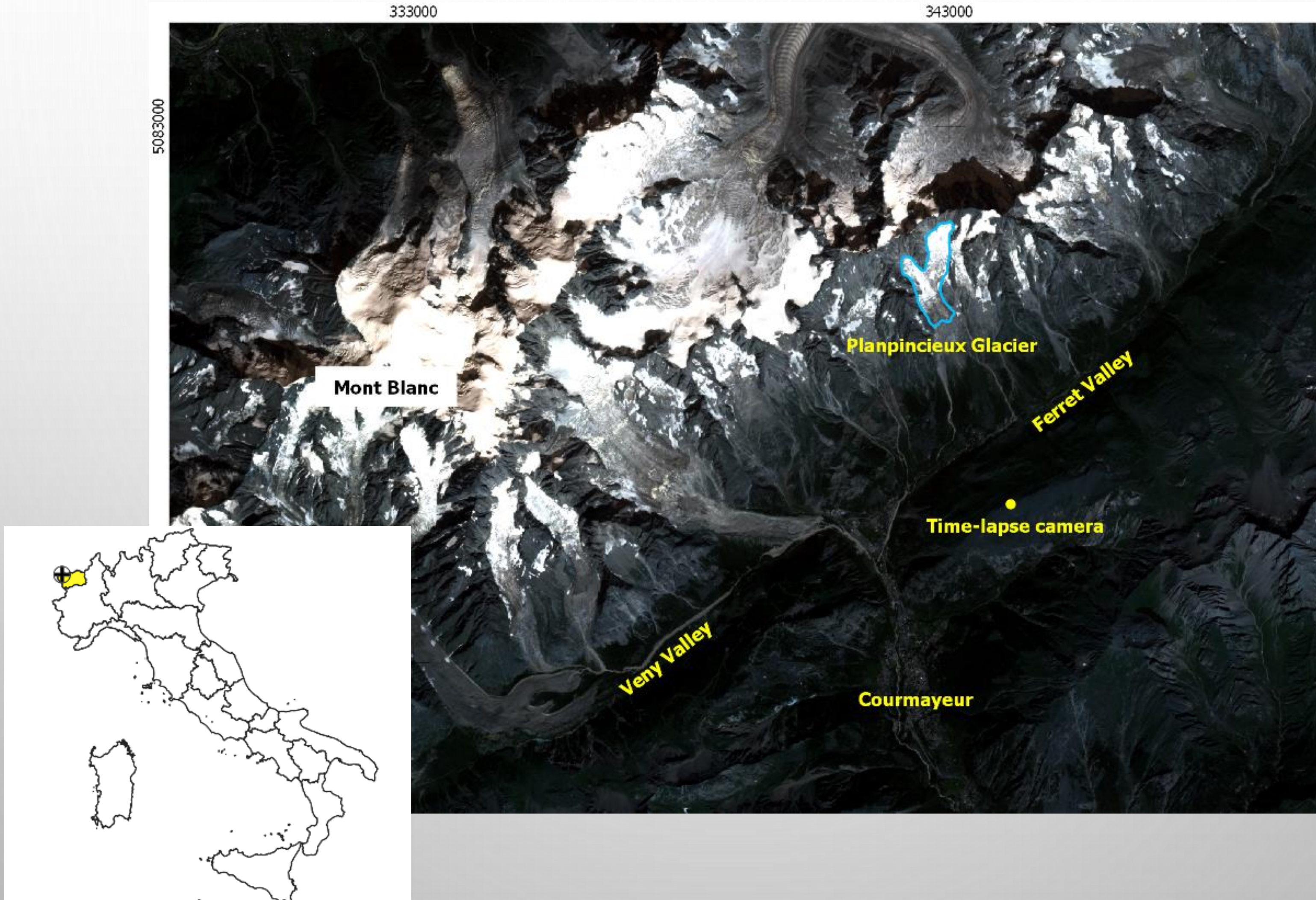
- IMPOSSIBLE DURING NIGHT AND BAD WEATHER
- SUFFERS SHADOW EFFECTS
- MANUAL IMAGE SELECTION
- NO 3D INFORMATION
- LOW SENSIBILITY OF THE MEASUREMENT (IRRELEVANT FOR FAST GLACIERS)

CASE STUDY: PLANPINCIEUX GLACIER [3]

VIEW FROM THE MONITORING STATION

PLANPINCIEUX GLACIER

AREA OF STUDY



PLANPINCIEUX GLACIER

GLACIER ELEVATION 2500-3500 M

ACCUMULATION AREA COMPOSED OF TWO CIRQUES

ABLATION AREA COMPOSED OF TWO LOBES IN TEMPERATE THERMAL REGIME

MONTITAZ LOBE ~30° STEEP WITH MANY CREVASSES

GLACIER TERMINUS IS IN CORRESPONDENCE OF A MORPHOLOGICAL STEP THAT CAUSES FREQUENT CALVING

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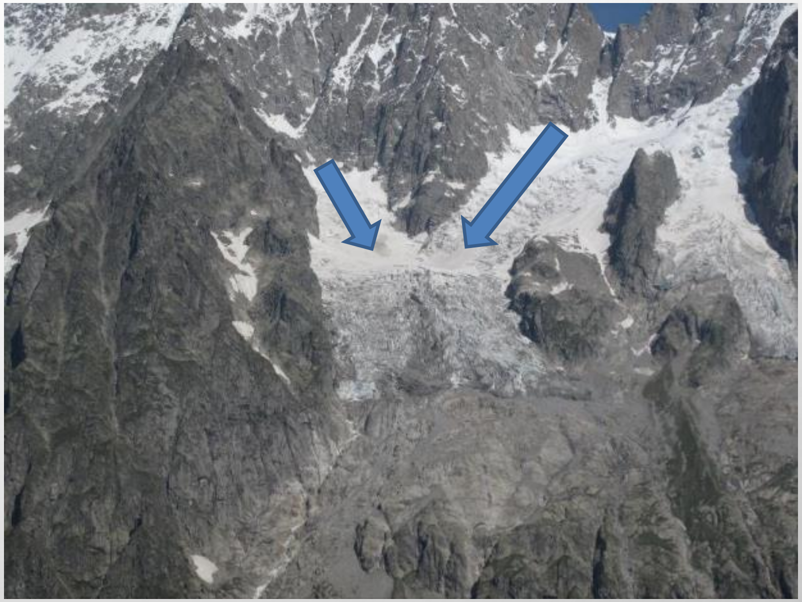

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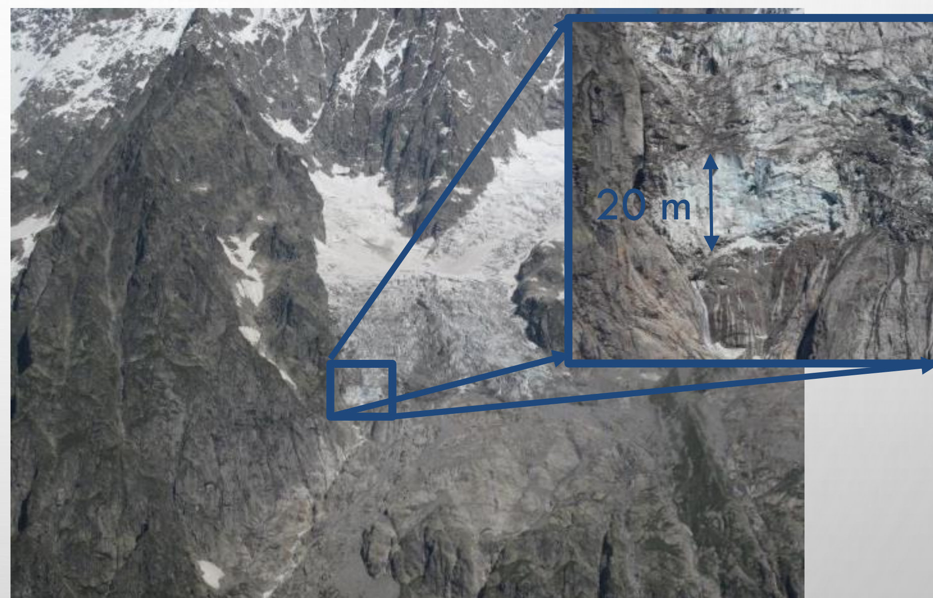
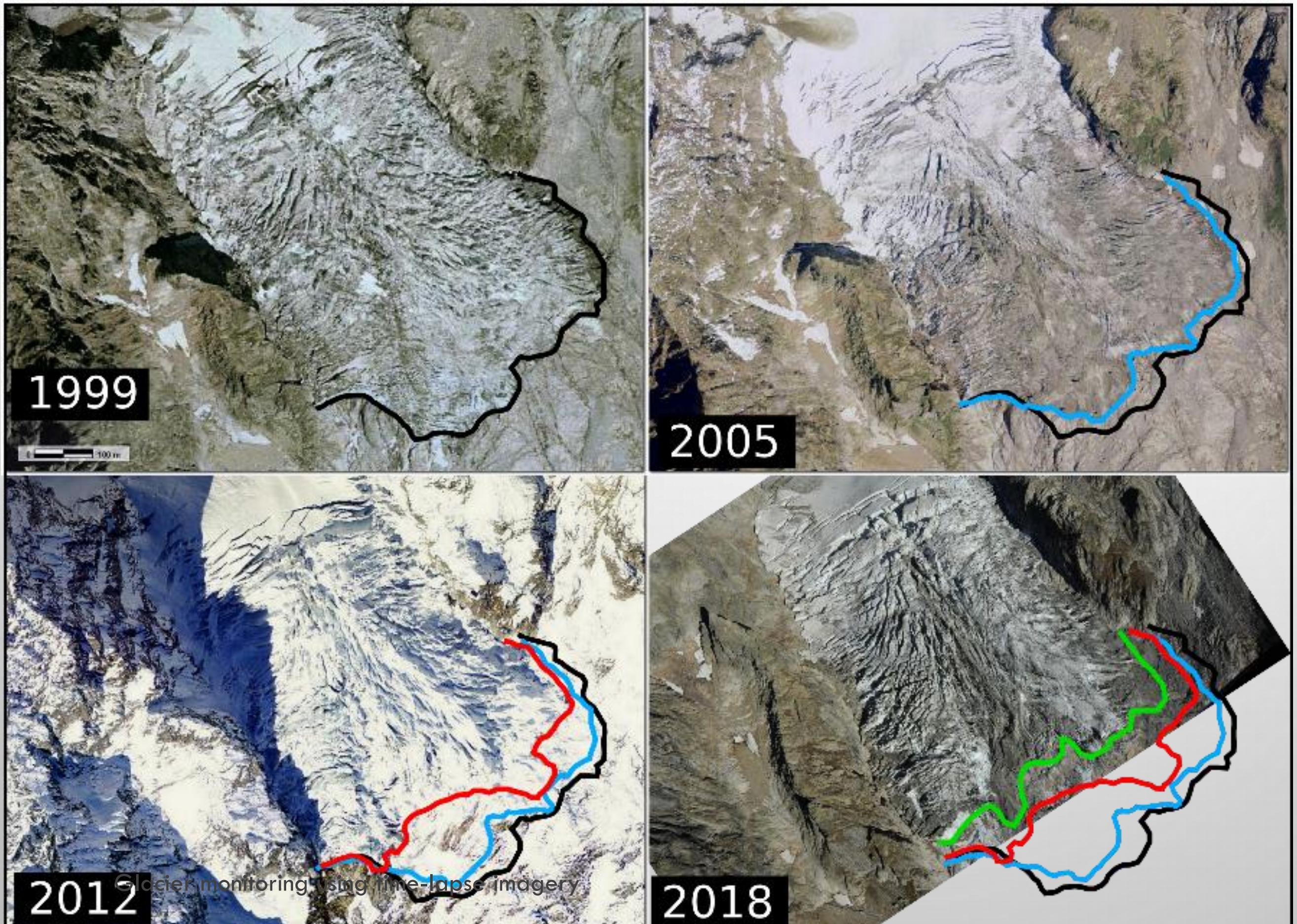


GLACIER SHRINKAGE



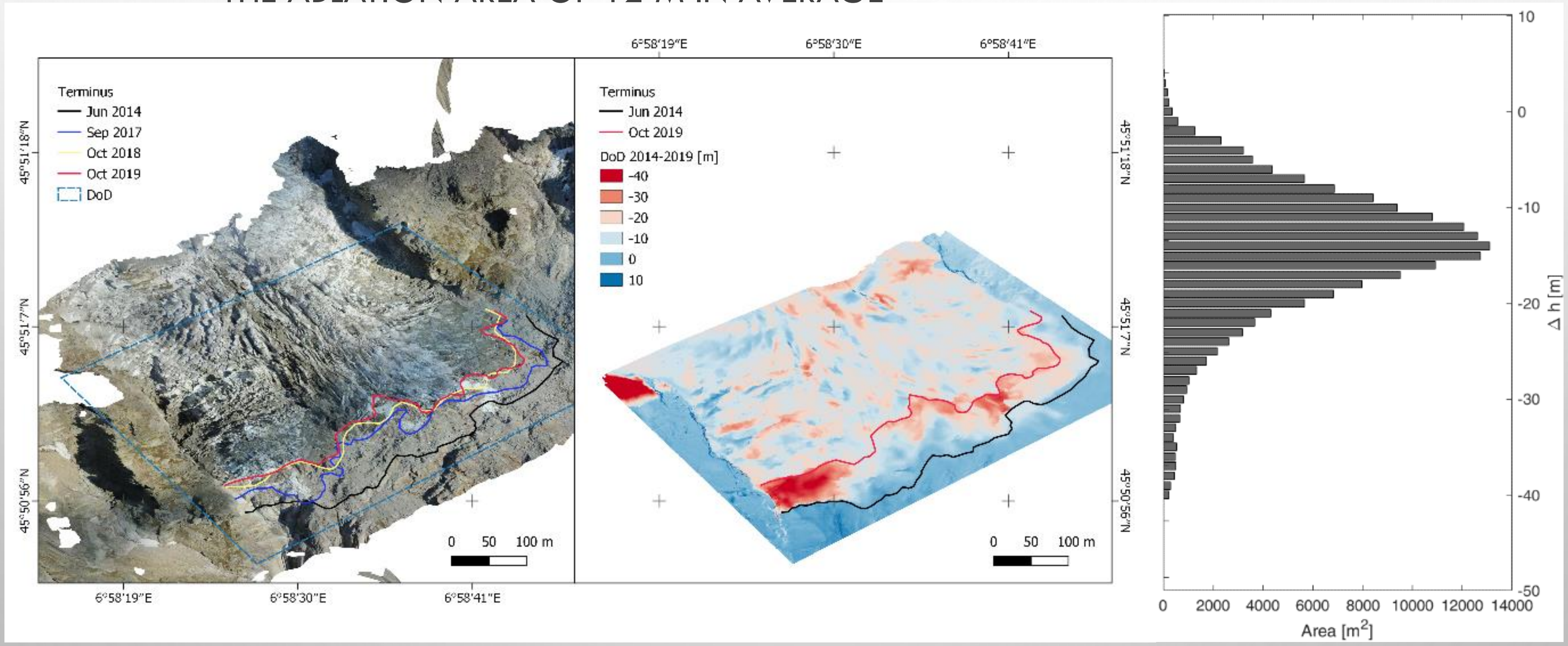
IN 20 YEARS THE GLACIER RETREATED A FEW HUNDRED METERS

GLACIER SHRINKAGE

DEM OF DIFFERENCE

BETWEEN 2014 AND 2019, THE GLACIER THICKNESS DECREASED IN THE ABLATION AREA OF 12 M IN AVERAGE

VOLUME LOST
$2.5\ 10^6\ m^3$



PLANPINCIEUX GLACIER MONITORING

IN THE PAST SEVERE ICE BREAK-OFFS OCCURRED FROM THE MONTITAZ LOBE (IN OROGRAPHIC RIGHT)

THE PLANPINCIEUX GLACIER IS CONTINUOUSLY MONITORED SINCE 2013 WITH A TIME-LAPSE CAMERA WHICH MEASURES THE SURFACE DAILY VELOCITY

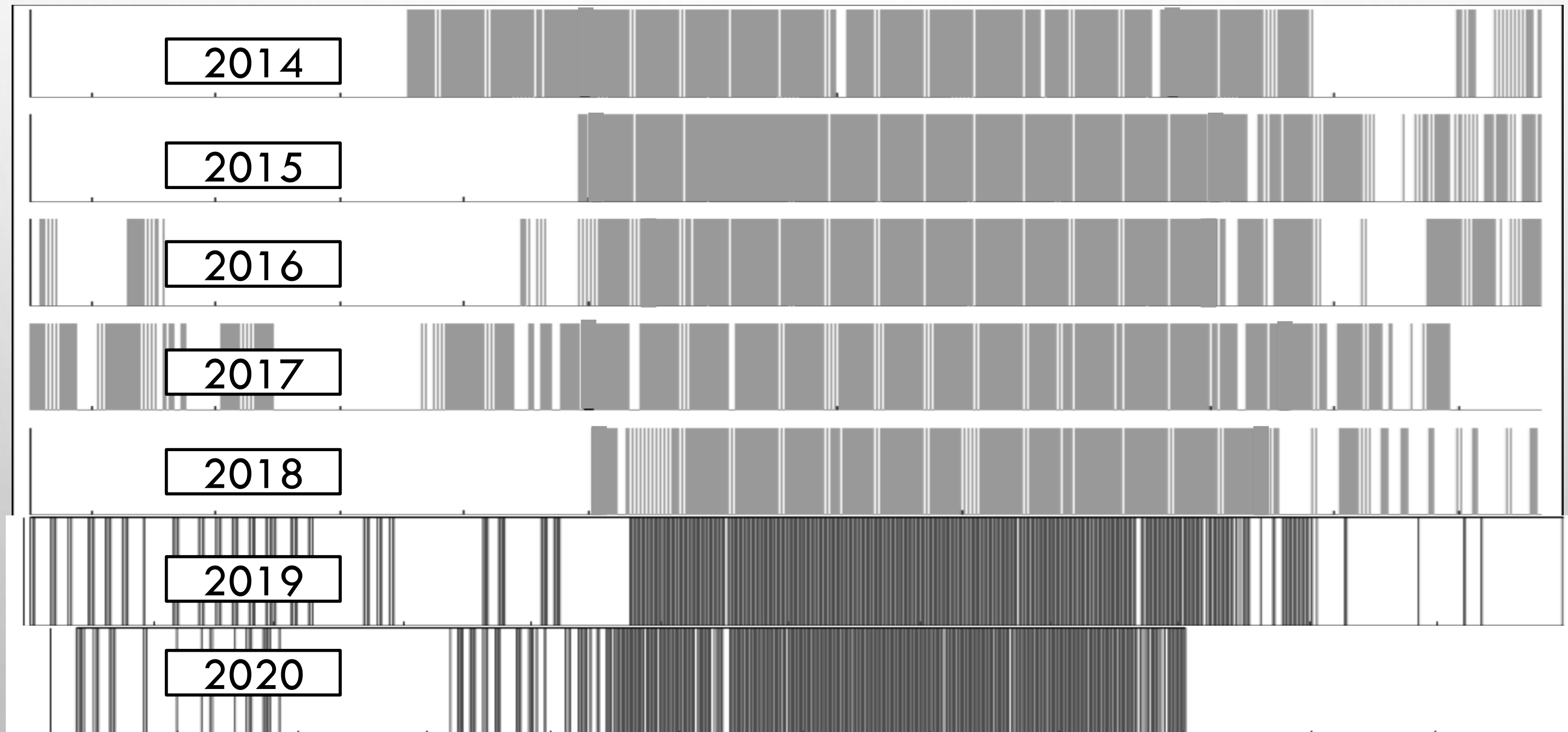
THE VISUAL INVESTIGATION OF THE IMAGES ALLOWS TO IDENTIFY THE BREAK-OFFS AND TO ANALYSE THE DEVELOPMENT OF INSTABILITY PROCESSES

PHOTOGRAPHIC MONITORING SYSTEM

- TWO TIME-LAPSE CAMERAS WITH DIFFERENT OPTICAL LENGTH OBSERVE DIFFERENT GLACIER PORTIONS
- SCHEDULED HOURLY ACQUISITION
- REMOTE CONTROL WITH GPRS CONNECTION
- AUTONOMOUS ENERGY SUPPLY WITH SOLAR PANELS
- GLACIER DISTANCE IS 3800 M
- HARDWARE GLOBAL COST APPROXIMATIVELY €10000

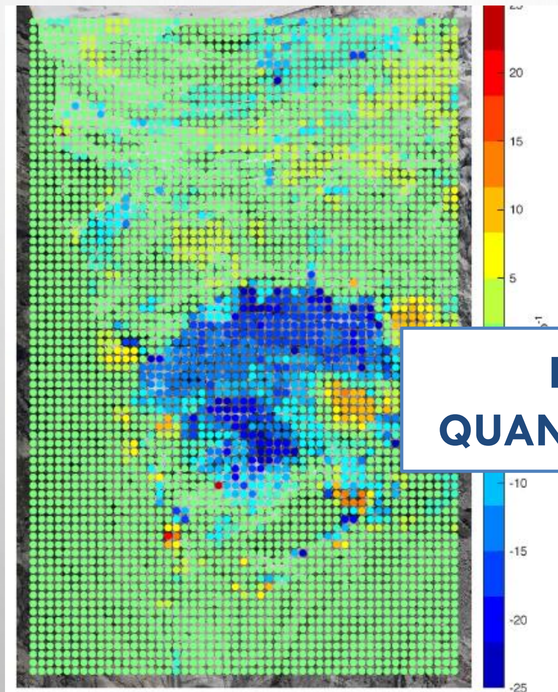
PHOTOGRAPHIC DATASET

MORE THAN **35000** IMAGES ACQUIRED IN 7 YEARS OF MONITORING
→ HIGH TEMPORAL RESOLUTION

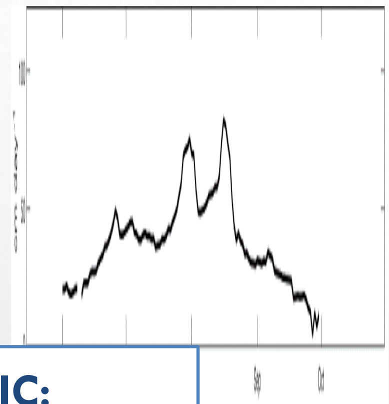


PRODUCTS OF THE MONITORING

MAPS OF DAILY MOTION

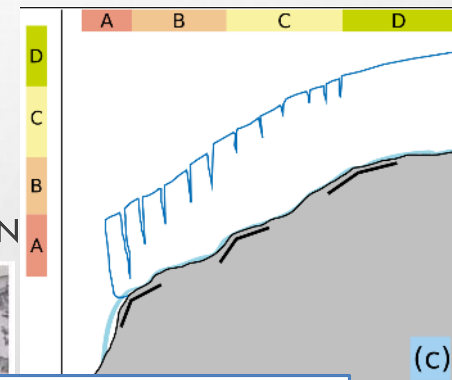


TIME SERIES OF VELOCITY

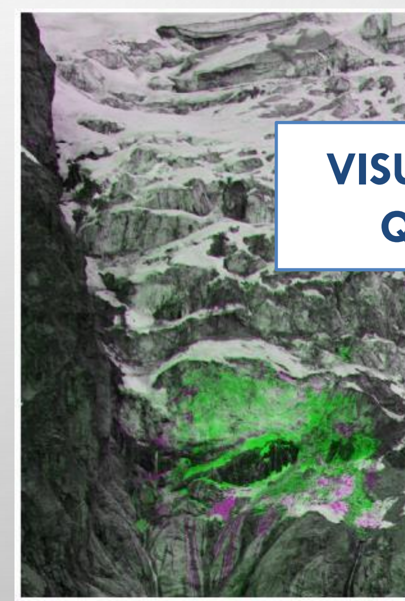


DIC: QUANTITATIVE

INSTABILITY PROCESSES

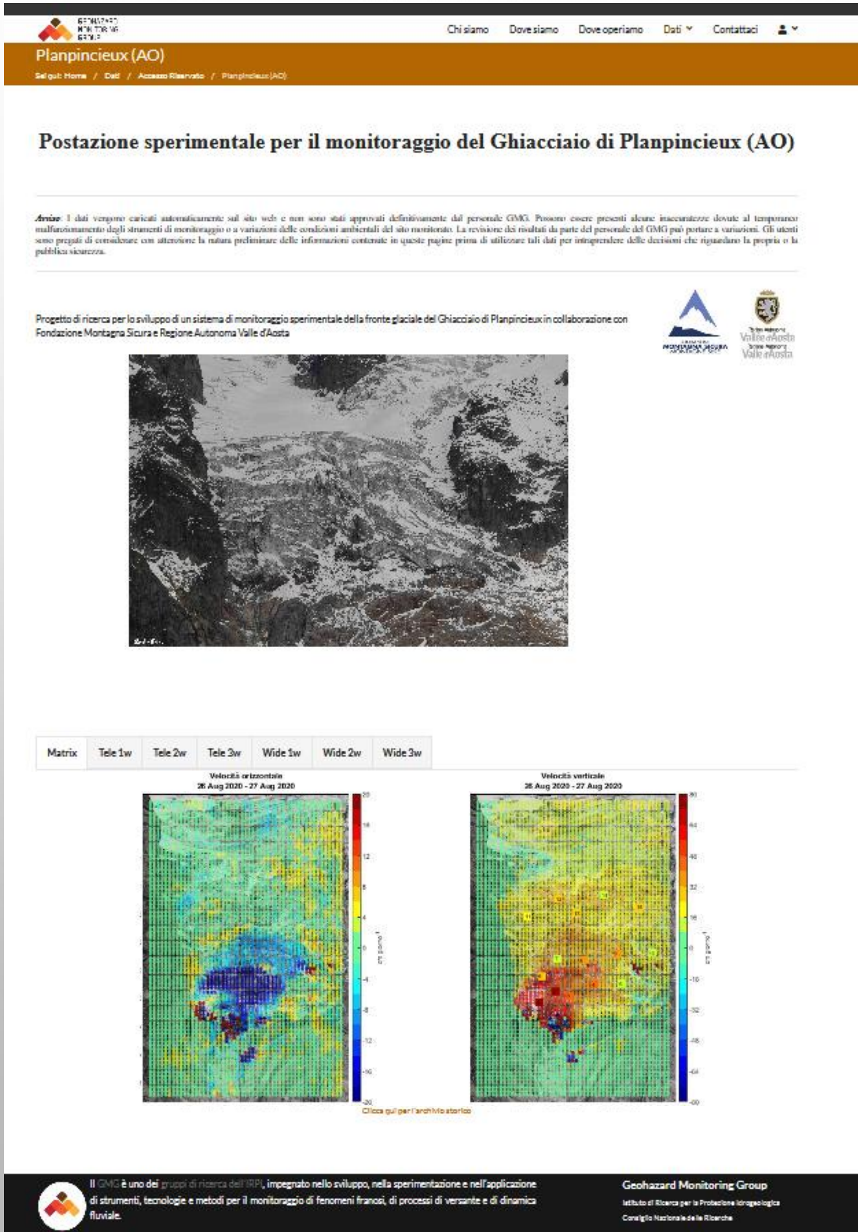


BREAK-OFF IDENTIFICATION



VISUAL ANALYSIS: QUALITATIVE

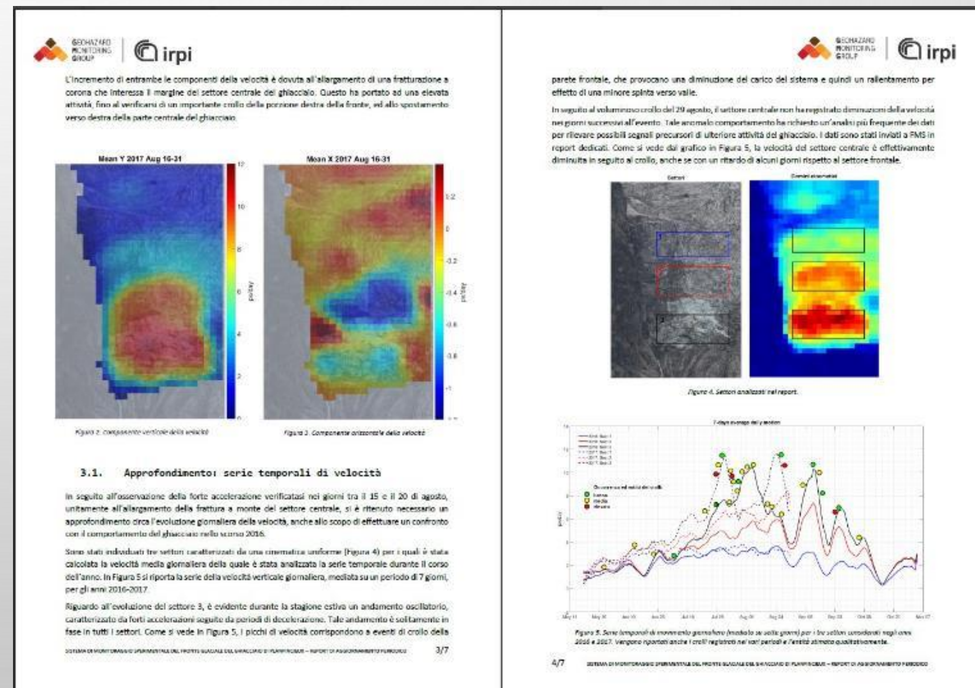
DAILY UPDATE WEB PAGE



MONITORING RESULTS ARE AUTOMATICALLY COMMUNICATED EVERY DAY TO THE AUTHORITIES ON A RESTRICTED-ACCESS WEB PAGE

PERIODICAL BULLETTINS DESCRIBE DETAILED INVESTIGATION OF THE GLACIER STATE AND REPORT THE VALIDATED RESULTS

PERIODICAL BULLETINS



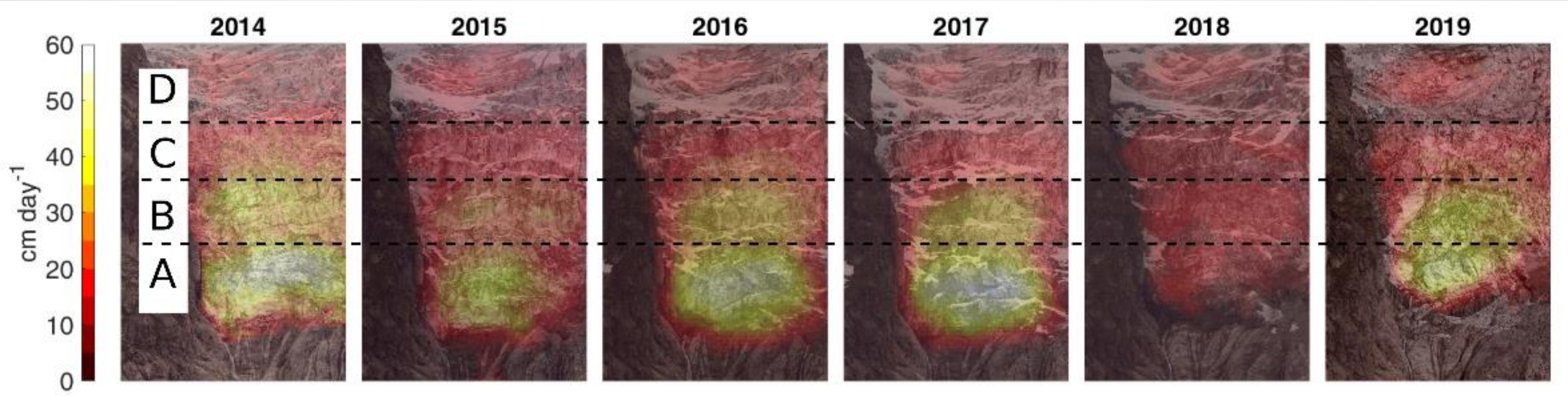
KINEMATIC DOMAINS OF THE MONTITAZ LOBE

THE SURFACE VELOCITY PATTERN IS TYPICALLY FORMED OF 4 DISTINCT KINEMATIC DOMAINS

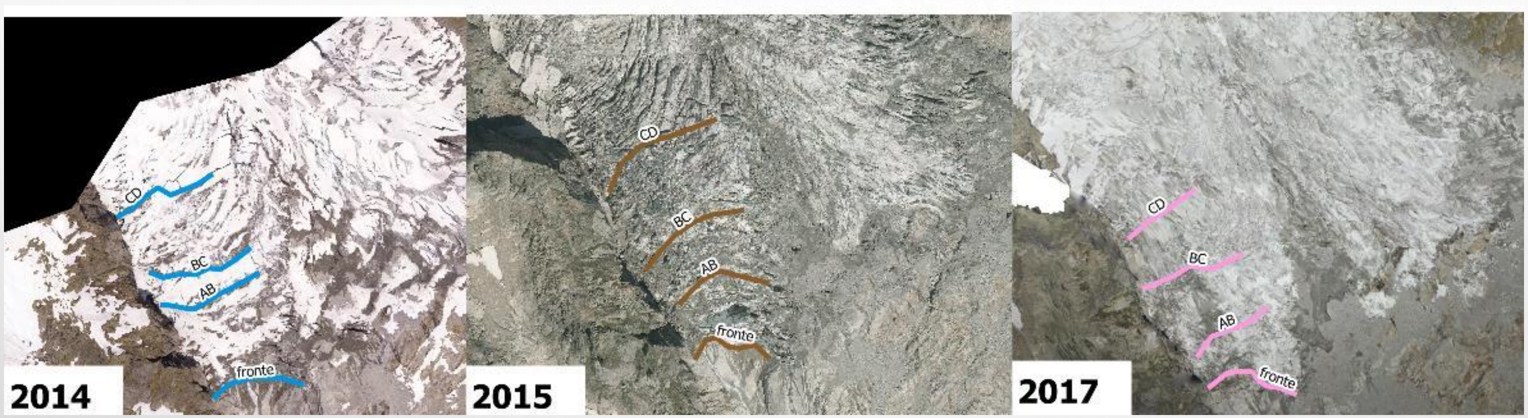
THE LIMITS OF THE KINEMATIC DOMAINS CORRESPOND TO THE CREVASSES WHICH DELIMITATE THE MORPHOLOGICAL SECTORS

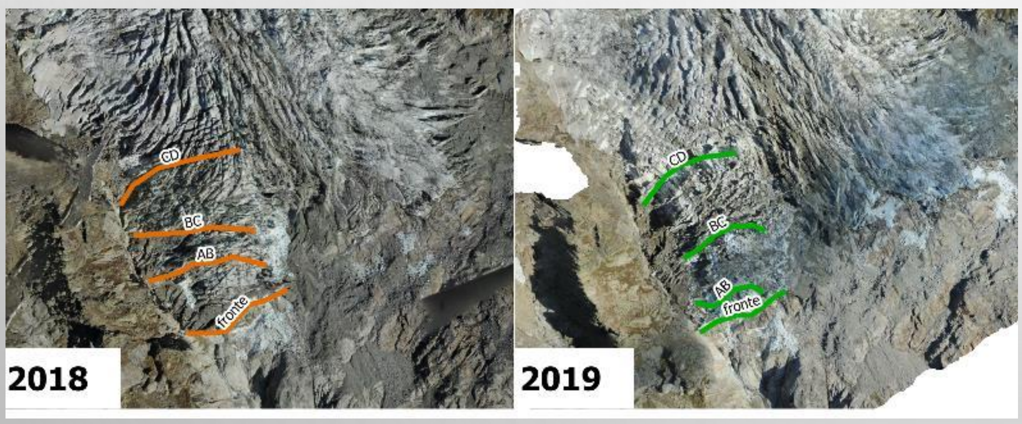
THE POSITION OF THE CREVASSES INDICATE WHERE THE STRONGEST TENSILE STRESSES ACT

THE PORTION BELOW CAN BECOME UNSTABLE AND COLLAPSE



MORPHOLOGICAL SECTORS OF THE MONTITAZ LOBE



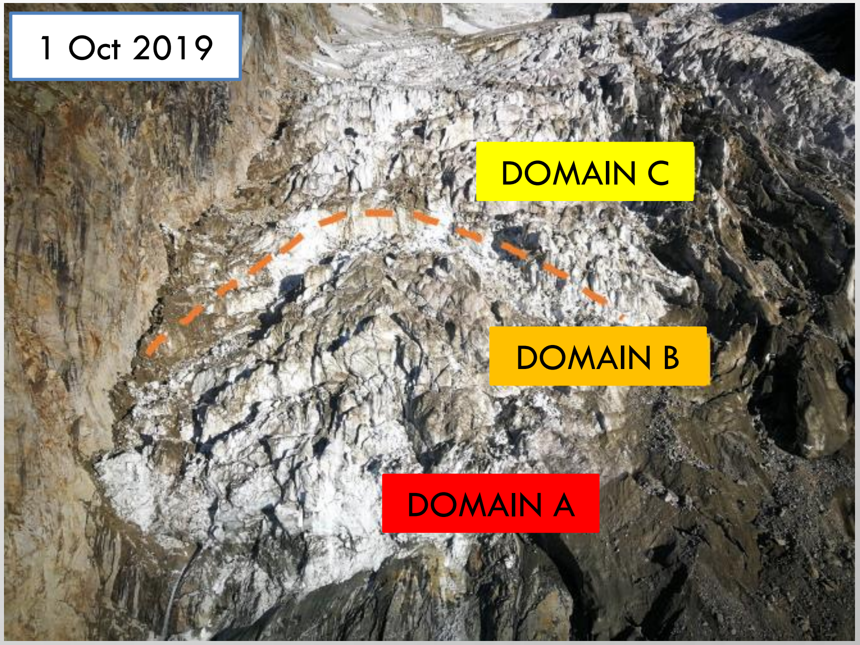


A SERIES OF CREVASSES DEVELOPS EVERY YEAR APPROXIMATELY IN THE SAME POSITION

THE MONITAZ LOBE IS COMPOSED OF DISTINCT MORPHOLOGICAL SECTORS WHICH SHOW DIFFERENT BEHAVIOURS

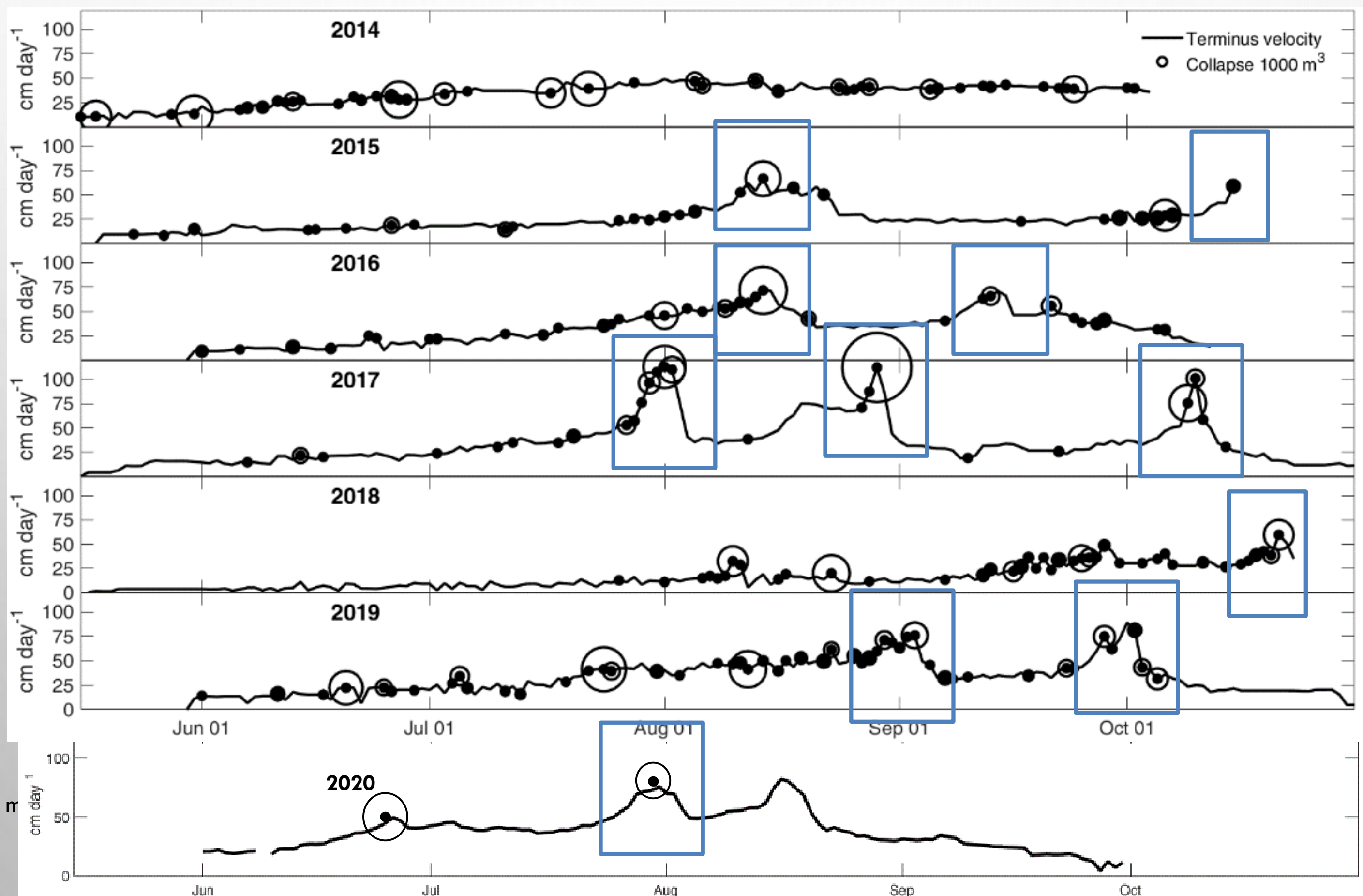
CRISIS OF 2019 AND 2020

IN 2019 AND 2020, THE TWO LOWER SECTORS MERGED → A LARGER VOLUME BECAME UNSTABLE (250000-500000 M^3)



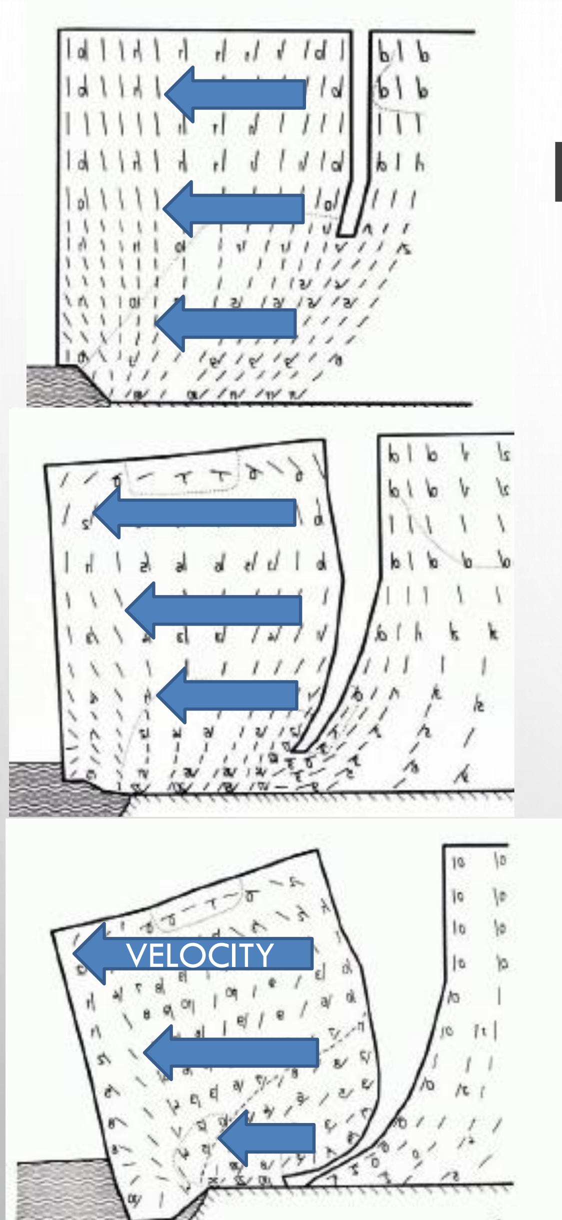
TIME SERIES OF DAILY VELOCITY

EVERY YEAR A FEW SPEED-UP PERIODS OCCUR AND CULMINATE WITH LARGE BREAK-OFFS

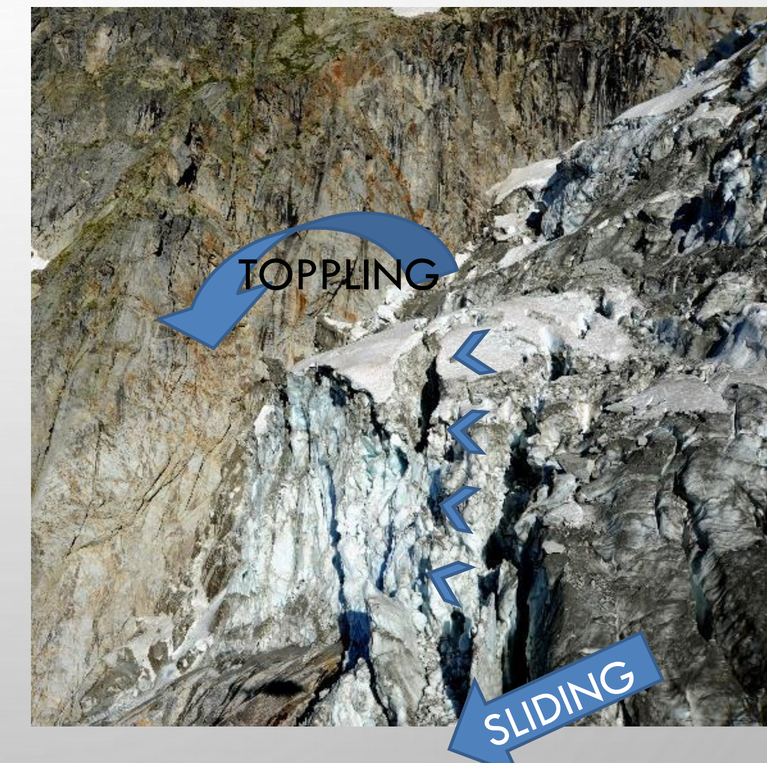


BREAK-OFF DYNAMICS

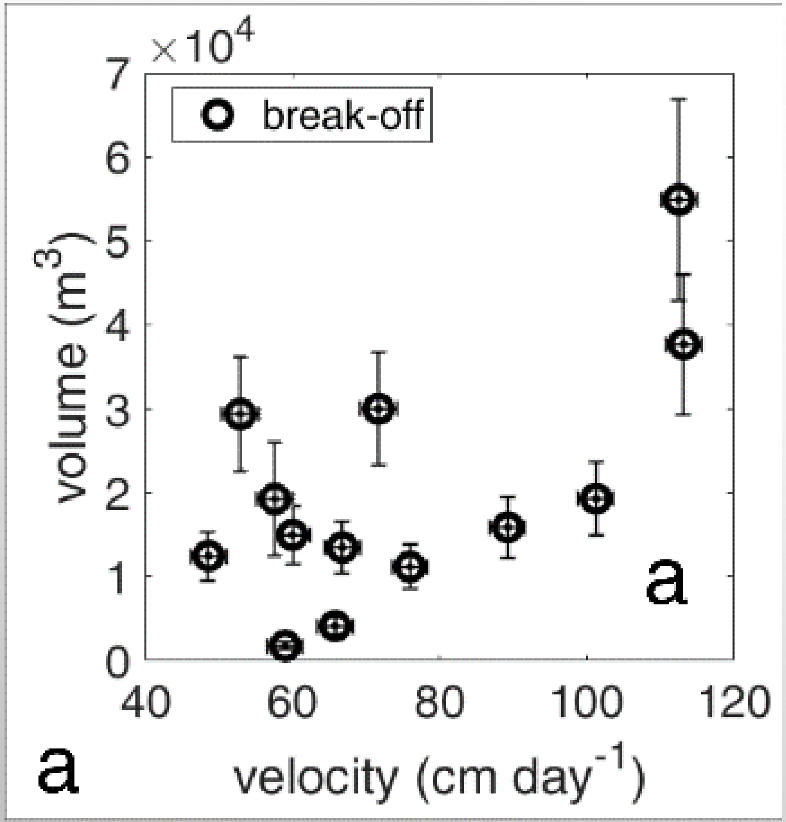
- THE CREVASSE DEVELOPMENT CAUSES THE TOPPLING OF THE ICE CHUNK
- THE GLACIER SLIDING SUM WITH THE ROTATIONAL MOVEMENT AND YIELDS THE ACCELERATION
- WHEN THE CREVASSE REACHES THE BEDROCK, THE ICE CHUNK COLLAPSES



MODIFIED FROM IKEN, 1977 [4]



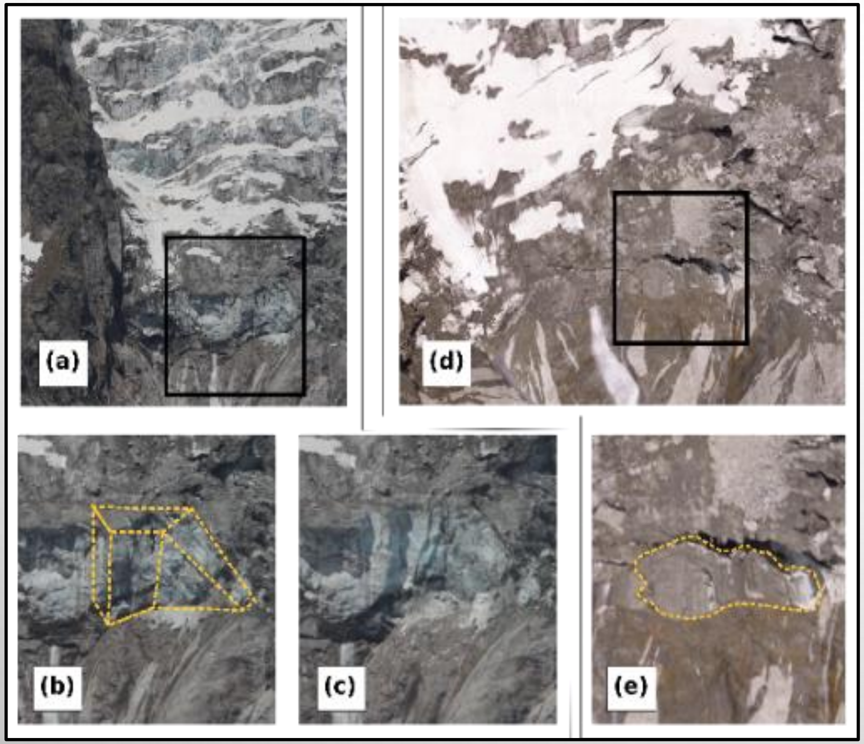
VELOCITY vs VOLUME



IT HAS BEEN IDENTIFIED A MONOTONICAL RELATIONSHIP BETWEEN MAXIMUM GLACIER VELOCITY AND BREAK-OFF VOLUME DURING THE SPEED-UP PERIODS

A-PRIORI ESTIMATE OF THE VOLUME

BREAK-OFF VOLUME ESTIMATE

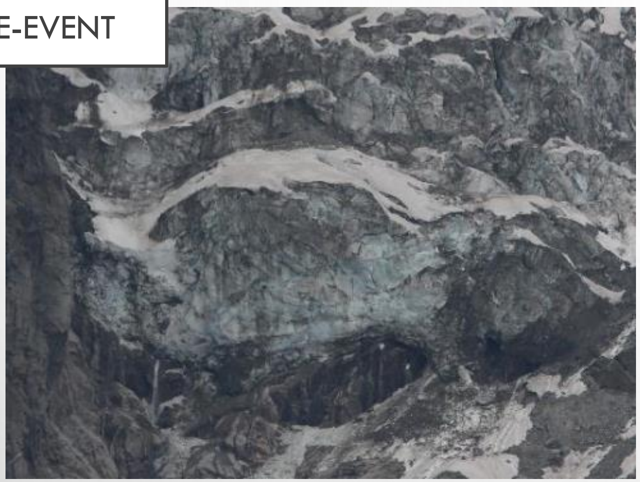


VOLUME IS ESTIMATED WITH 2D IMAGES ADOPTING ASSUMPTIONS OF ICE AND BEDROCK GEOMETRY

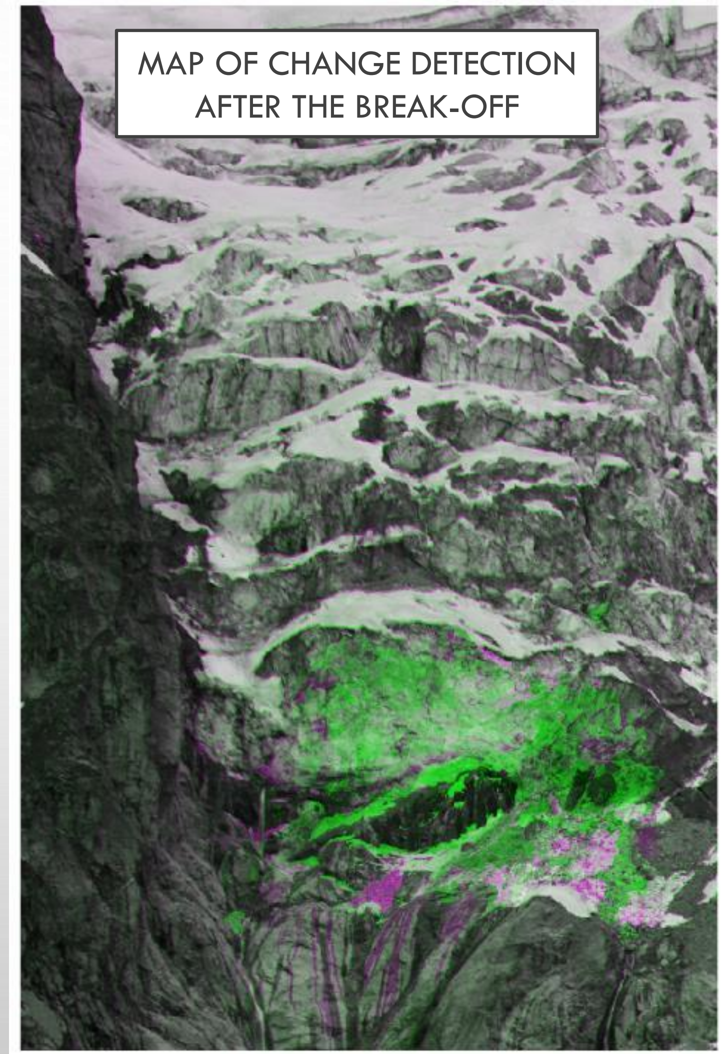
GOOD AGREEMENT WITH LIDAR DATA

BREAK-OFF IDENTIFICATION

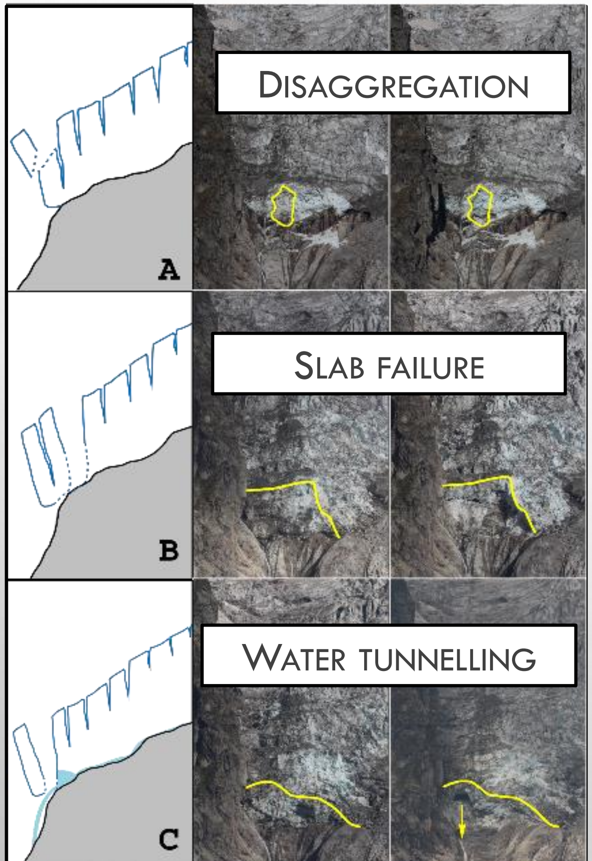
PRE-EVENT



POST-EVENT



BREAK-OFF CLASSIFICATION

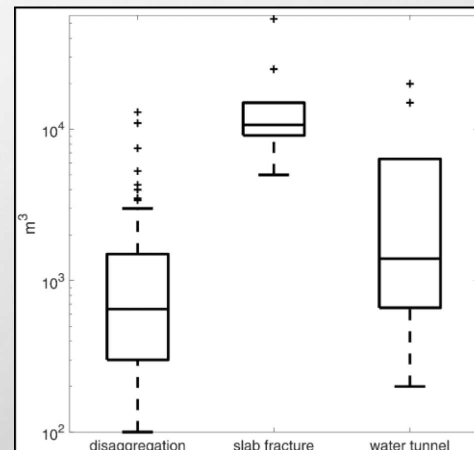


DISAGGREGATION: TOPPLING OF SMALL FRAGMENTS (10^3 M^3) DUE TO THE MOTION BEYOND THE BEDROCK CLIFF

SLAB FAILURE: DETACHMENTS OF LARGE ICE LAMELLA (10^4-10^5 m^3) DELIMITED BY LARGE CREVASSES OFTEN PRECEEDED BY ACCELERATION

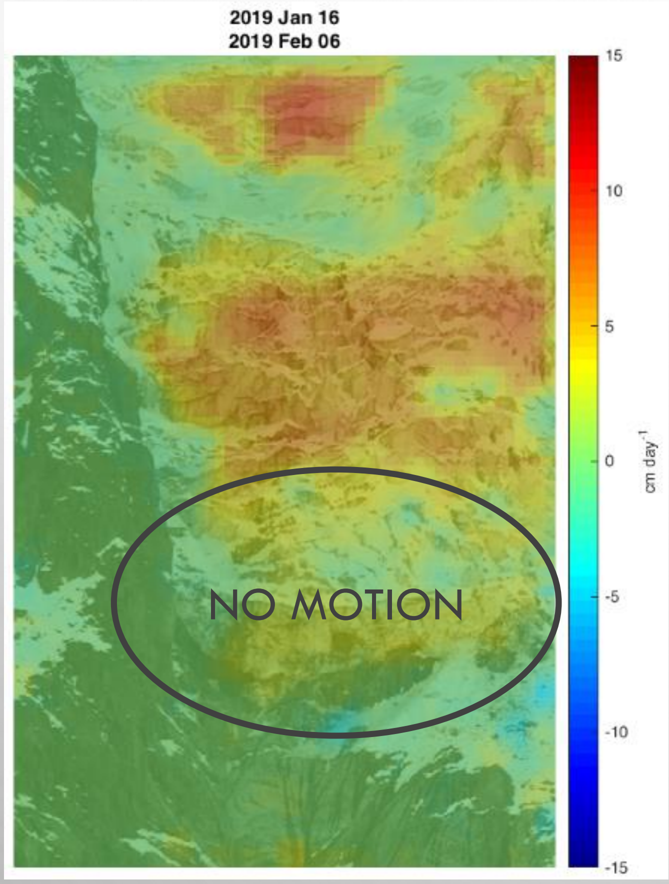
WATER TUNNELLING: DEVELOPMENT AND COLLAPSE OF ENDOGLACIAL TUNNELS

BREAK-OFF VOLUME FOR EVERY BREAK-OFF PROCESS



WHAT MAKES THE GLACIER MOVE?

GRAVITY MORE RELEVANT DURING WINTER



WINTER BEHAVIOUR

DURING THE WARM SEASON, THE FRONTAL PORTION PARTIALLY DETACHES FROM THE MAIN GLACIER BODY

IN THE COLD SEASON, THE LOWER PART FREZEES AGAINST THE BEDROCK

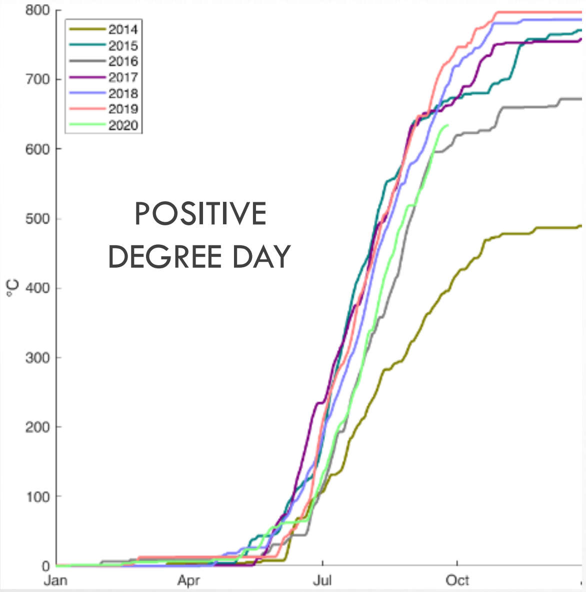
THE GLACIER BODY MOVES FOR GRAVITY

WHAT MAKES THE GLACIER MOVE?

LIQUID WATER

FACILITATES SLIDING

- **ICE MELTING** → HIGH TEMPERATURE CAN INCREASE GLACIER VELOCITY (?)
- **WATER PERCOLATION** → THE PRESENCE OF SNOW/THE ABSENCE OF CREVASSES ON THE GLACIER SURFACE CAN REDUCE SLIDING (?)



VELOCITY vs TEMPERATURE

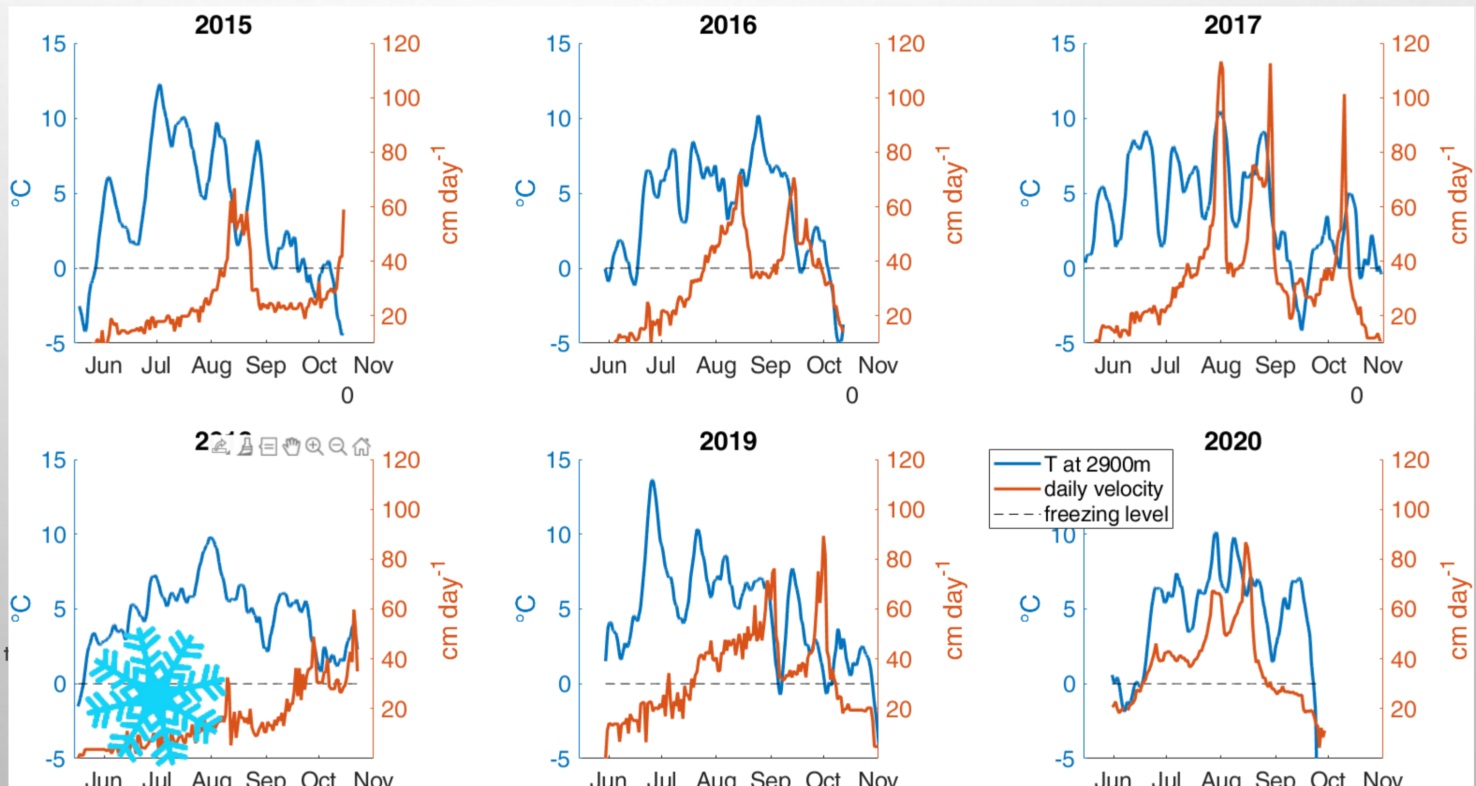
SUMMER 2014 WAS MUCH COOLER THAN USUAL → IN 2014 SPEED-UP PERIODS DID NOT OCCUR

A CLEAR RELATION BETWEEN VELOCITY AND TEMPERATURE DOES NOT APPEAR

TEMPERATURE AT 2900 M

FRONTAL VELOCITY

Glacier monitoring using t

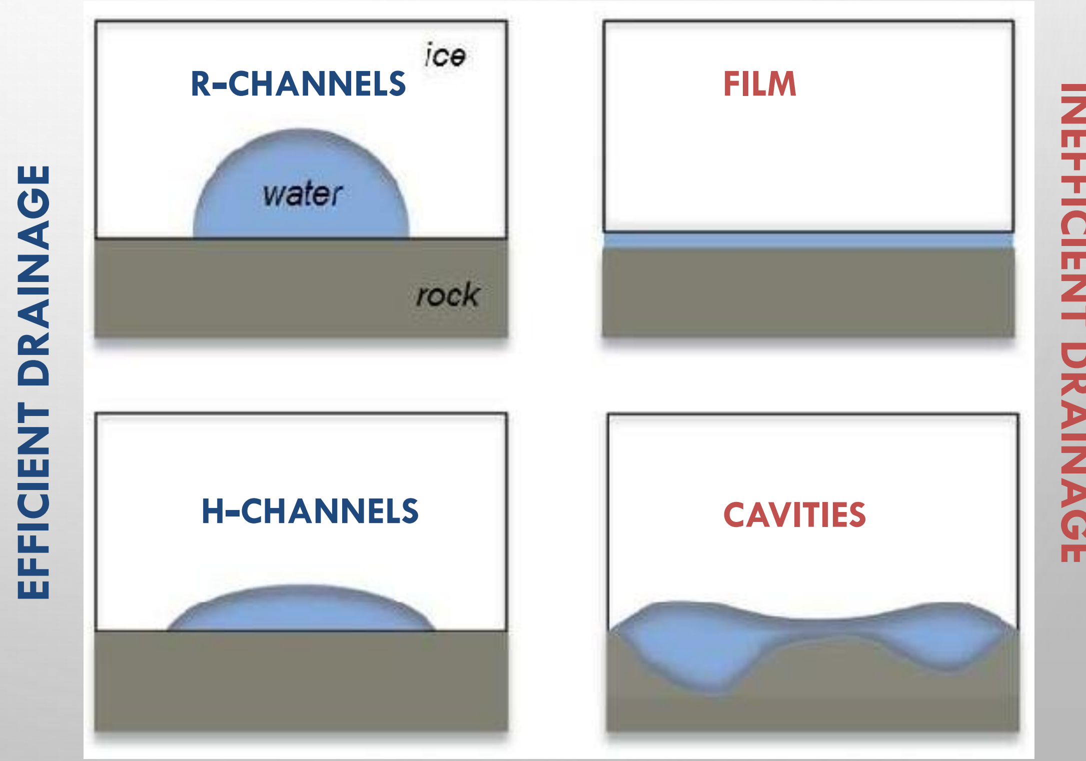


HYDRAULIC SYSTEM[5]

WELL-DEVELOPED HYDRAULIC SYSTEM FACILITATES THE WATER DRAINAGE AND **DECREASES THE GLACIER SLIDING**

DIFFUSE SMALL CHANNELS, FILM AND WATER POCKETS INCREASE THE BASAL PRESSURE AND **CAUSE THE GLACIER SLIDING**

HYDRAULIC SYSTEM CAN CHANGE FOR THE GLACIER MOTION



CONCLUSIONS

DIC PROVIDES MAPS OF SURFACE KINEMATICS. THE DISPLACEMENT PATTERN INDICATE WHERE THE STRONGEST STRESSES ACT. THIS IS IN ACCORDANCE WITH THE FORMATION AND POSITION OF CREVASSES.

THEREFORE, THE ANALYSIS OF THE KINEMATIC MAPS CAN BE A FIRST EVALUATION TO IDENTIFY POSSIBLE UNSTABLE BODIES AND TO ESTIMATE THEIR VOLUME.

THE VELOCITY-VOLUME RELATIONSHIP CAN PROVIDE AN A-PRIORI ESTIMATE OF THE BREAK-OFF.

A STRONG VELOCITY INCREASE CAN BE A PRECURSOR OF A LARGE COLLAPSE

TIME-LAPSE IMAGERY CAN BE A VALUABLE TOOL FOR RISK ASSESSMENT

DIC PROVIDES RESULTS WITH DAILY TEMPORAL RESOLUTION AND CANNOT BE APPLIED DURING NIGHT AND BAD WEATHER

PRESENTLY, IT IS NOT POSSIBLE TO PREDICT THE ISTANT OF THE BREAK-OFF

DIC CAN NOT BE USED FOR EARLY WARNING ACTIVITIES

THANK YOU

BIBLIOGRAPHY

1. EVANS, A. N. (2000). GLACIER SURFACE MOTION COMPUTATION FROM DIGITAL IMAGE SEQUENCES. *IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING*, *38*(2), 1064-1072.
2. DEMATTEIS, N., GIORDAN, D., & ALLASIA, P. (2019). IMAGE CLASSIFICATION FOR AUTOMATED IMAGE CROSS-CORRELATION APPLICATIONS IN THE GEOSCIENCES. *APPLIED SCIENCES*, *9*(11), 2357.
3. GIORDAN, D., DEMATTEIS, N., ALLASIA, P., & MOTTA, E. (2020). CLASSIFICATION AND KINEMATICS OF THE PLANPINCIEUX GLACIER BREAK-OFFS USING PHOTOGRAPHIC TIME-LAPSE ANALYSIS. *JOURNAL OF GLACIOLOGY*, *66*(256), 188-202.
4. IKEN, A. (1977) MOVEMENT OF A LARGE ICE MASS BEFORE BREAKING OFF. *JOURNAL OF GLACIOLOGY*, 19(81), 595-605
5. RÖTHLISBERGER, H. (1972). WATER PRESSURE IN INTRA-AND SUBGLACIAL CHANNELS. *JOURNAL OF GLACIOLOGY*, *11*(62), 177-203.

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