Summary of Expert Meeting for the study " Sentinel 3 Synergy Cloud Mask Development"

15-18 January 2021 (via teleconference)

The "Sentinel 3 Synergy Cloud Mask Development" study, funded & initiated by EUMETSAT since September 2019, aims at exploiting the spectral synergistic capabilities of OLCI and SLSTR instruments, on-board the Copernicus Sentinel-3 (S3) satellites, to develop a new atmospheric mask product primarily focused on clouds, but with significant efforts to distinguish from aerosols.

The study is conducted led by *Brockmann Consult* as Prime Contractor, supported by *Spectral Earth 7 GRASP S.A.S*. The Phase 1 of the study was completed in November 2020 and provided the baseline for the Cloud Mask (CM) algorithm approach, described in the form of technical note (TN) to be evolved in Phase 2 of the study into the final Algorithm Theoretical Basis Document (ATBD).
The purpose of the Independent Expert Workshop is the presentation and scientific dispute on this TN. The TN was provided to the experts in due time before the meeting, to allow their thorough review. The scientific dispute is intended to collect the opinion of experts, debate, and try to find a consensus, on the following aspects:

- Algorithm approach (benefits, shortcomings, room for improvements, etc.);
- Content of the TN (level of completeness, understanding, missing parts, etc.);
- Structure of the TN (sectioning, clarity of description, tables, figures, etc.);
- Suggestions for the content of the final Sentinel 3 Synergy CM product (from a user perspective);
- Any other comment and/or suggestion.

The Expert Workshop was help via teleconference on 15-18 January 2020. The list of participants and the meeting agenda are provided in Appendix A and B, respectively. The internal and external experts where chosen by EUMETS for their extensive experience with cloud/aerosol detections and L2 retrieval in general:

Claire Bulgin (Uni. Reading): cloud detection for sea and land surface temperature retrieval, aerosol-cloud interactions, retrieval of aerosol optical properties.

Gary Corlett (EUMETSAT): Oceanography products, cloud/aerosol masking applications

Nina Håkansson (SMHI/NWC SAF): atmospheric remote sensing of cloud and precipitation from imager instruments on polar orbiting satellites.

Rüdiger Lang (EUMETSAT): CO2 Project Scientist, operational products, cloud masking applications.

Jerome Riedi (Uni. Lille): remote sensing of the atmosphere (clouds, aerosols and water vapor), satellite based analysis of clouds/aerosols properties.

Phil Watts (EUMETSAT): clouds microphysical properties and related products (cloud masking, water vapour)

The following sections describe the topics discussed at the meeting (Sect. 1) and the the main recommendations of the experts for Phase 2 of the study (Sect. 2).

1. Introduction and background of the study

The meeting was opened with two introductory presentations by J. Chimot and L. Spezzi (EUMETSAT), which provided to the participants an overview of the objective/rationale of the study in the Sentinel 3 context and the study organisation. The presentations highlighted, in particular, the following points:

- Cloud masking is required in the S3 context for several downstream applications with very diverse users/needs covering not only land and water, but also atmospheric topics. This calls for an extended concept of CM, i.e., an **"atmosphere mask**" detecting clouds as well as other types of atmospheric obstructions (i.e., aerosols);
- The large variety of user needs calls also for a definition of atmospheric obstruction, which goes beyond the traditional flag classification (cloudy, clear, aerosol, mixed scenes, etc.). Thus, the S3 synergy CM aims at providing a top-of-atmosphere obstruction quantifying the level of radiance perturbation due to clouds and aerosols. This metric allow the user to set his own perturbation threshold depending on the application (clear-sky or obstructed-sky conservative). This crucial point of the study was illustrated by R. Quast (*Brockmann Consult*) during the expert meeting.
- Several users reported problems related to the accuracy of currently existing S3 single-sensors CMs, e.g., no clear cloud/aerosol discrimination, significant residuals over land vegetation & sea, tuning for ocean colours and sea surface temperature (SST) applications, but not for atmospheric applications such as retrievals of aerosol, fire and cloud properties.
- The synergy CM is tented as a standalone products covering the needs of several (possibly all) applications, providing information beyond the traditional binary CM, employing a physical approach, and giving users the option of being obstructed- or clear-sky conservative.
- The study led by Brockmann Consult is the first step of the specification & implementation of the S3 spectral synergy CM and it provides the algorithm prototype (together with ATBD, source code and user manual), but does not address yet some more complicated aspects (such as OLCI/SLSTR co-location issues, geometry, night time, dual view and use of fire channels, etc.).
- The objective of the expert meeting is to evaluate the preliminary ATBD (in the form of TN) provided by Brockmann Consult at the end of phase 1 of the study and answer to five specific questions to set a roadmap for Phase 2:
    1) Does the algorithm present an improvement w.r.t. accuracy on the critical cases compared to existing S3 single-sensor CMs?
    2) Does it follow the initial requirements?
    3) Does it properly address user needs?
    4) Is there any critical aspects missing in the algorithm approach and in the TN?
    5) Is there any specific recommendation about the proposed validation of the algorithm?

2. Agreement on Phase 2 roadmap and conclusions

The algorithm approach and TN content were discussed in detail during the 2 days of the meeting and summarized during the final "Scientific Dispute" (see Appendix A) lead by B. Fougnie (EUMETSAT). All experts presented their comprehensive and complementary feedbacks via slides and summary documents. Moreover, all participants provided additional comments (see Appendix A).
The experts unanimously supported the approach for Phase 2 of the study and provided clear recommendations for improvement:

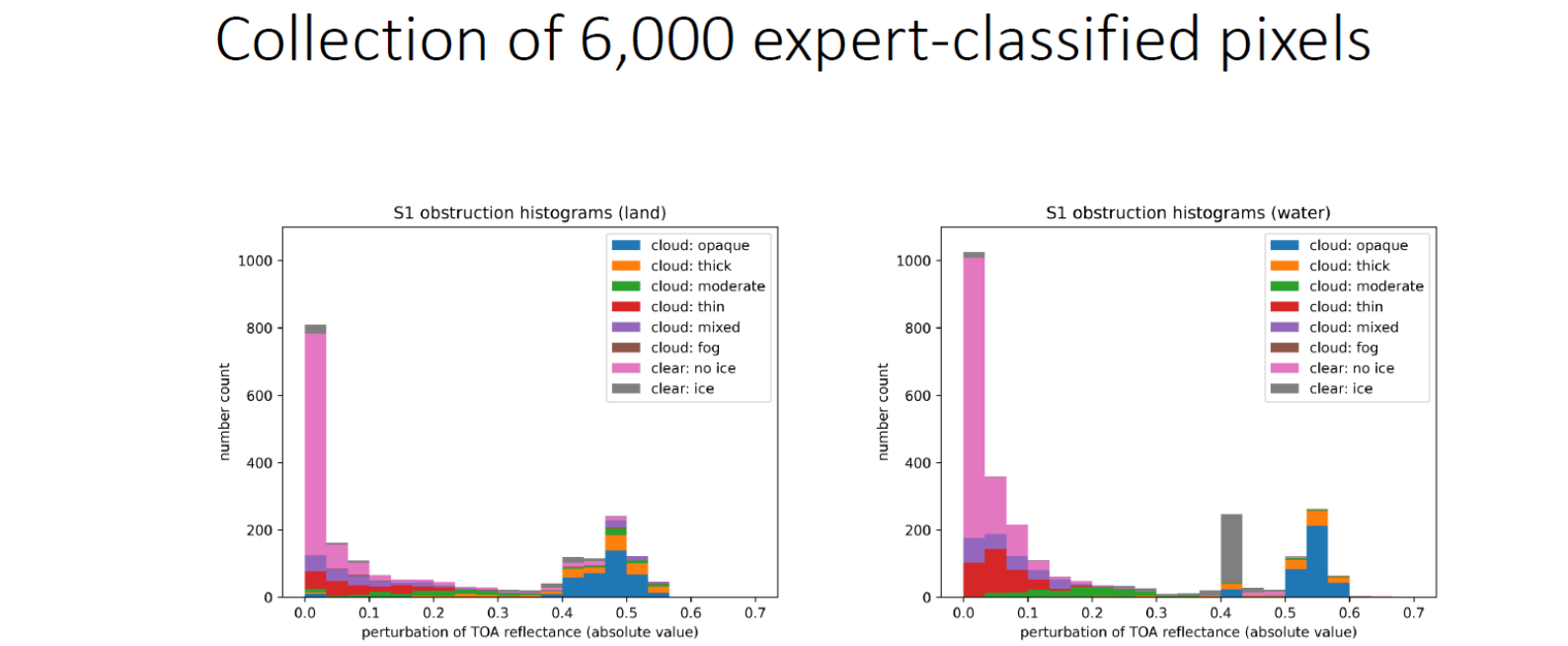
- Performance: The CM synergistic approach is promising and improvement vs. accuracy on critical cases was demonstrated (Figure 1). However, further validation is recommended in Phase 2 on an extended set of critical cases;

- Algorithm: The proposed algorithm approach matches the initial study requirements and address user needs. More specific parts of the algorithm have been discussed and will be implemented either in Phase 2 or on a follow-on version (e.g., strategy for the class masking, possible methodology alignment of the aerosol and cloud characterization, methods for uncertainty estimates, etc.);
- Content of the product: The final content of the product is still to be finalised. Many aspects were discussed (provision of flag, classification, definition of the obstruction, uncertainties, etc.) and have to be considered for phase 2. It was also recommended to conduct during phase 2 a survey on a sample test users (e.g., using the CM for downstream L2 and L3 applications) to ensure that the content of the final synergy CM product satisfies their needs;
- Documentation: There are no missing critical aspects in the study and in the TN. The TN needs to be readjusted/completed using the detailed feedbacks gathered during the expert meeting. The current structure of the TN shall be converted into ATBD structure by the end of Phase 2;
- Validation: The recommendation for the validation activity to be conducted in Phase 2 of the study are as follows:
    - The validation dataset needs to be global and extended with additional critical situations (e.g., snow/ice surface, ocean bloom, bright coastal water, etc.), to make sure that all critical cases are covered.
    - The performance of the synergy CM shall be also assessed vs. the impact on L2 or L3 downstream applications/products.
    - Validation shall be performed also vs. active measurements from the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO), which has established itself as a valid reference source for the validation of cloud/aerosol products.
    - Cross-comparison with existing cloud and aerosol products from other sensors can provide a useful insight on the uncertainty of the synergy. The methodology for comparing data from different sensors/satellite is complex and goes beyond the original scope of Phase 2. Thus, it will be done only if a simple method fitting the timeframe of Phase 2 is found.

EUMETSAT and Brockman Consult took actions to take into account all the above recommendations, and take on board those proved to be beneficial for the synergy CM algorithm and within the scope of the study. In particular, Brockmann Consult will incorporate expert's suggestions in the next version of the TN, which will be then converted into the final ATBD.

The meeting is declared successful and concluded with actions as above. Experts will be kept in the loop and invited to the final presentation of this study.

Figure 1: *Example of obstruction classification obtained by the new S3 synergy cloud mask algorithm. The stacked histograms of cloud obstruction for the SLSTR S1 channel (0.554µm) is expressed as hypothetical cloud-induced perturbation of the reflectance signal at the top of the atmosphere. The distribution shows an evident separation of actual clear-sky cases from actual cloudy cases. Cases of opaque clouds and thick semi-transparent clouds are virtually indiscernible and yield the highest level of cloud obstruction. Cases of thin and moderately thick semi-transparent clouds usually yield intermediate cloud obstruction values. Cases of non-permanent ice- or snow-covered surface and sun-glint under clear-sky yield obviously wrong obstruction values.*



APPENDIX A LIST OF PARTICIPANTS

EUMETSAT:

Loredana Spezzi (LS), Chair
Julien Chimot (JC), Co-chair
Bertrand Fougnie (BF), Co-chair
Gary Corlett (GC), expert
Rüdiger Land (RL), expert
Phil Watts (PW), expert
Alessio Bozzo (Abo), observer
Alessandro Burini (Abu), observer
Soheila Jafariserajehlou (SJ), observer/MoM
Hans J. Lutz (HL), observer
Francois Montagner (FM), observer
Igor Tomazic (IT), observer

External Experts:

Claire Bulgin (Uni. Reading) (ClB)
Nina Håkansson (SMHI/NWC SAF) (NH)
Jerome Riedi (Uni. Lille) (JR)

Brockmann Consult:

Carsten Brockmann (CaB)
Pavel Litvinov (PL) – GRAS-SAS
Rene Preusker (RP) – Spectral Earth
Ralf Quast (RQ)
Andi Walther (AW)
Jan Wevers (JW)

APPENDIX B MEETING AGENDA

Day 1 (15/01/2021)

09:30-09:45 Welcome (L. Spezzi)
09:45-10:00 Roundtable (all)
10:00-10:15 Introduction and agenda (L. Spezzi)
10:15-10:45 Presentation of the objective/rationale of the study in the Sentinel 3 context (J. Chimot)

10:45-11:15 Coffee Break

11:15-11:45 Presentation of the study and evolution during Phase I (L. Spezzi)
11:45-12:15 Overview of the TN (Brockmann Consult)

12:15-14:00 Lunch Break

14:00-15:30 Presentation of feedback from External Experts:
- 14:00-14:30 Claire Bulgin
- 14:30-15:00 Nina Håkansson
- 15:00-15:30 Jerome Riedi

15:30-16:00 Coffee Break

16:00-17:30 Presentation of feedback from EUMETSAT Internal Experts:
- 16:00-16:30 Gary Corlett
- 17:00-17:30 Phil Watts

17:30 End of Day 1

Day 2 (18/01/2021)

09:30-11:00 Scientific dispute (all, led by B. Fougnie)

11:00-11:30 Coffee Break

11:30-12:30 Agreement on Phase 2 roadmap
12:30-13:00 Revision of Minutes of Meeting

13:00 End of Day 2