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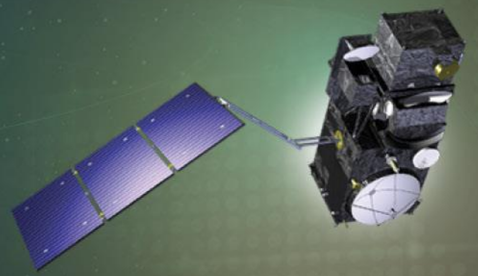

# 7th Sentinel-3 Validation Team Meeting 2022

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# Obstruction – an all-purpose cloud masking concept in response to manifold user requirements

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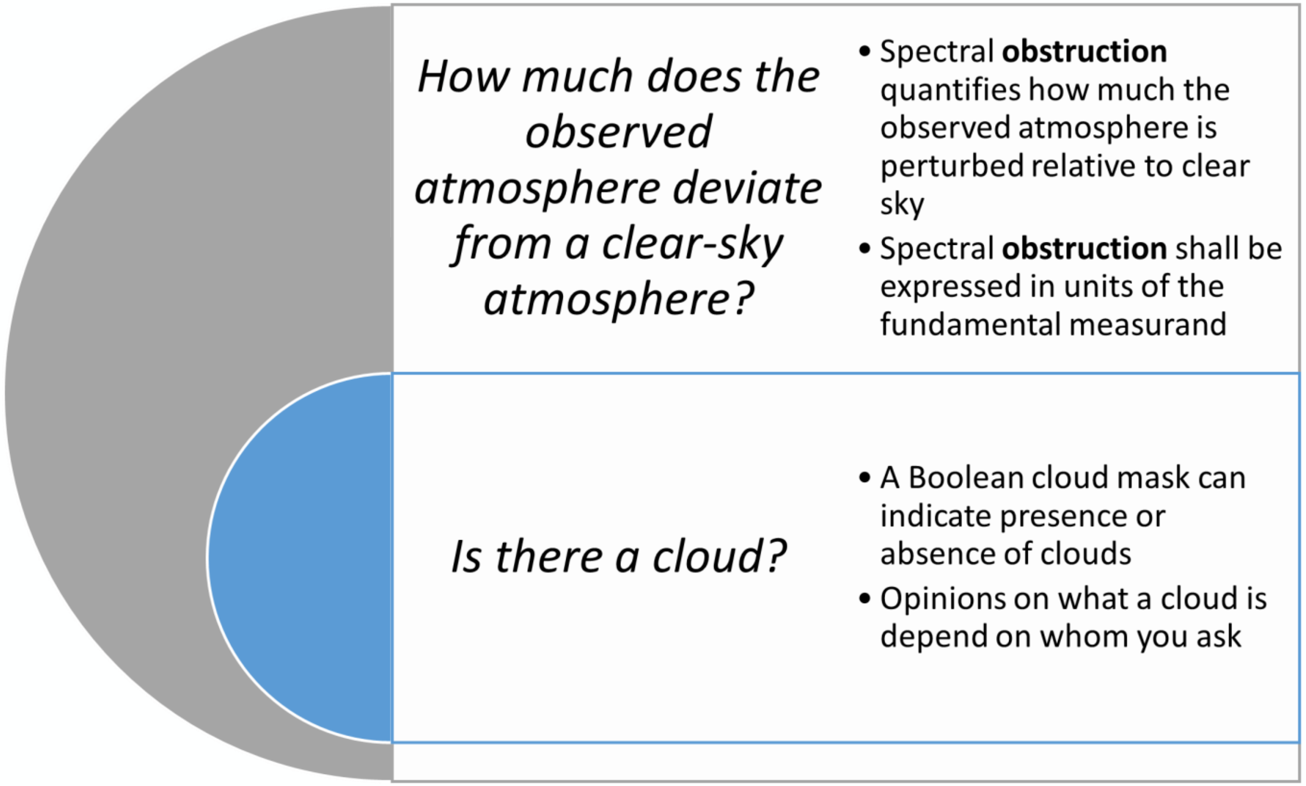
# THE IDEA (2/14)

- Reconsider the problem of cloud masking from the perspective of physics
- Reconsider the problem of cloud masking from the perspective of retrieval algorithms and applications
- Exploit possible synergies from S3 OLCI and SLSTR



# OVERVIEW (3/14)

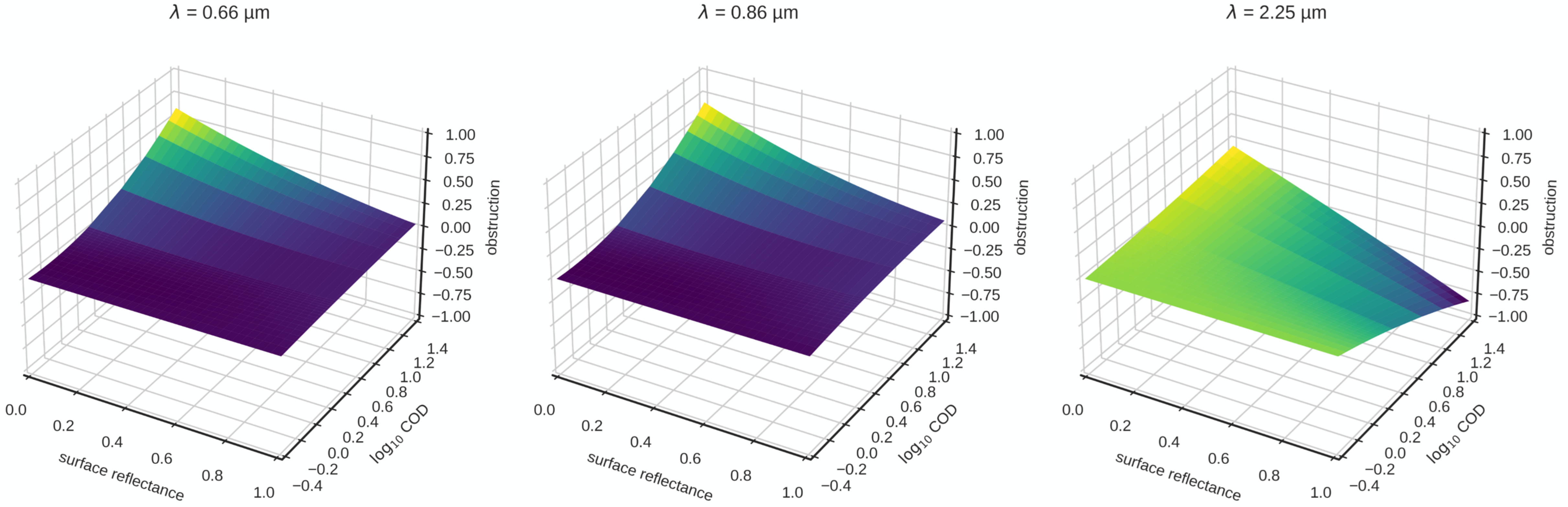
1. What is obstruction?
2. How do we retrieve obstruction?
3. How would you use it?
4. How does obstruction compare to existing S3 cloud masks?
5. Future roadmap

# WHAT IS OBSTRUCTION? (4/14)

- Obstruction quantifies how much the presence of a cloud perturbs a TOA signal in comparison to the (assumed) clear sky situation
- Obstruction is a spectro-radiometric quantity
- We express obstruction in units of TOA spectral reflectance (or brightness temperature)

$$\delta\rho_\lambda^{\mathrm{t}} = \underbrace{\rho_\lambda^{\mathrm{t}}(\mathrm{COD}, r_{\mathrm{eff}}, \mathrm{CTH}, \rho_\lambda^{\mathrm{s}}, \ldots)}_{\text{simulated obs.}} - \underbrace{\rho_\lambda^{\mathrm{t}}(0, r_{\mathrm{eff}}, \mathrm{CTH}, \rho_\lambda^{\mathrm{s}}, \ldots)}_{\text{assumed clear sky obs.}}$$

# WHAT IS OBSTRUCTION? (5/14)



# HOW DO WE RETRIEVE OBSTRUCTION? (6/14)

- We use MODIS WSA MCD43GF dataset to obtain an estimate of surface spectral reflectance and its variability
- We derive an initial guess of the cloud-effective state from existing cloud tests
- We use an OE framework to retrieve cloud-effective state variables and uncertainties from OLCI and SLSTR radiometry
- We compute TOA spectral reflectance for the retrieved state and for the assumed clear-sky state (for different wavebands)
- The difference between both is obstruction

$$\boldsymbol{x} = \underbrace{(\mathrm{COD}, r_{\mathrm{eff}}, \mathrm{CTH})}_{\text{cloud state}}$$

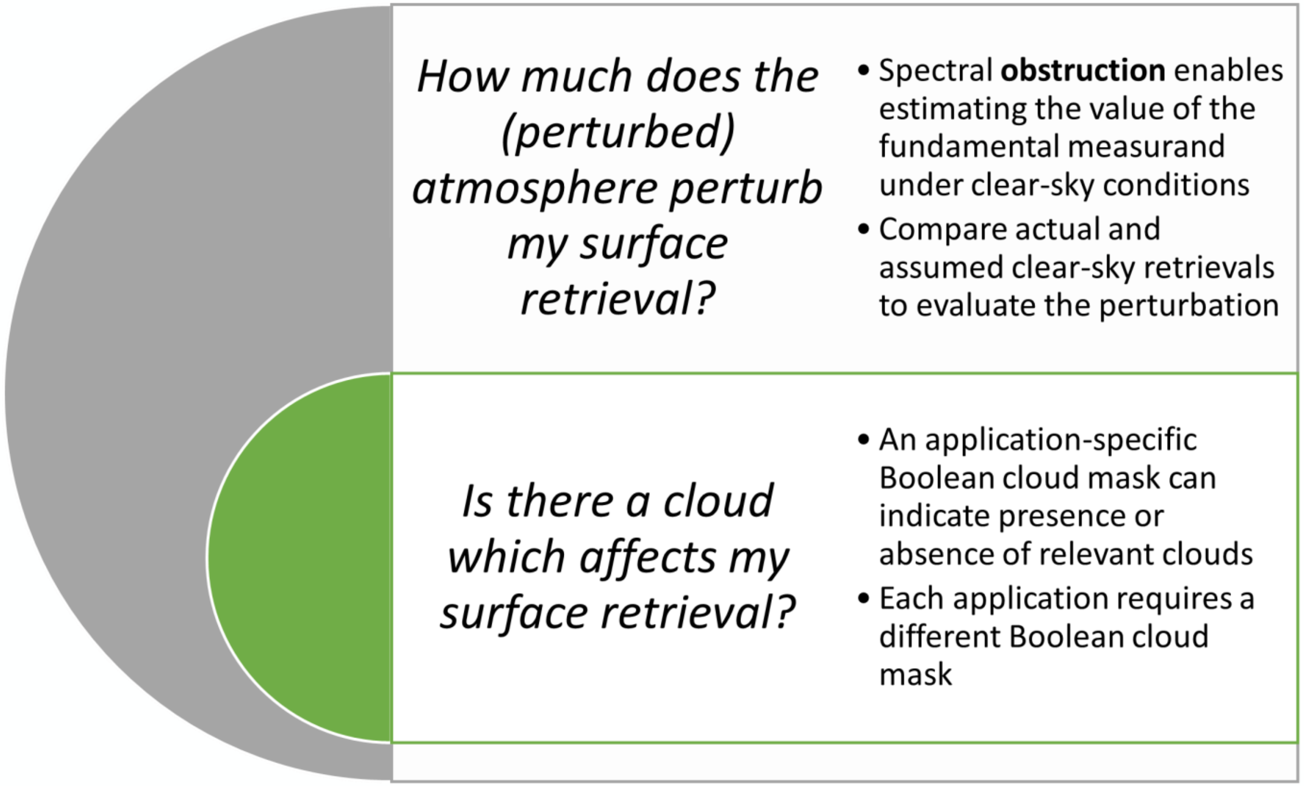
$$J(\boldsymbol{x}) = \underbrace{J^{\mathrm{OLC}}(\boldsymbol{x}) + J^{\mathrm{SLS}}(\boldsymbol{x})}_{\text{synergy term}} + \underbrace{\frac{1}{2}(\boldsymbol{x} - \widehat{\boldsymbol{x}})^{\mathrm{T}} \boldsymbol{U}_{\boldsymbol{x}}^{-1} (\boldsymbol{x} - \widehat{\boldsymbol{x}})}_{\text{prior term}}$$

$$\underbrace{J^{\mathrm{ins}}(\boldsymbol{x}) = \frac{1}{2} \boldsymbol{F}^{\mathrm{T}}(\boldsymbol{x}, \boldsymbol{\rho}^{\mathrm{s}}, \boldsymbol{\rho}^{\mathrm{t}}) \boldsymbol{U}_{\boldsymbol{F}}^{-1} \boldsymbol{F}(\boldsymbol{x}, \boldsymbol{\rho}^{\mathrm{s}}, \boldsymbol{\rho}^{\mathrm{t}})}_{\text{single–instrument term}}$$

# HOW WOULD YOU USE IT? (7/14)

- ***You want to know how much your surface retrieval is disturbed by a cloud?***
- You use obstruction to compute TOA reflectance (or brightness temperature) under assumed clear-sky conditions from the observed signal
- Compute the difference between your actual and the assumed clear-sky retrieval
- You decide if your retrieval is significantly disturbed by a cloud or not

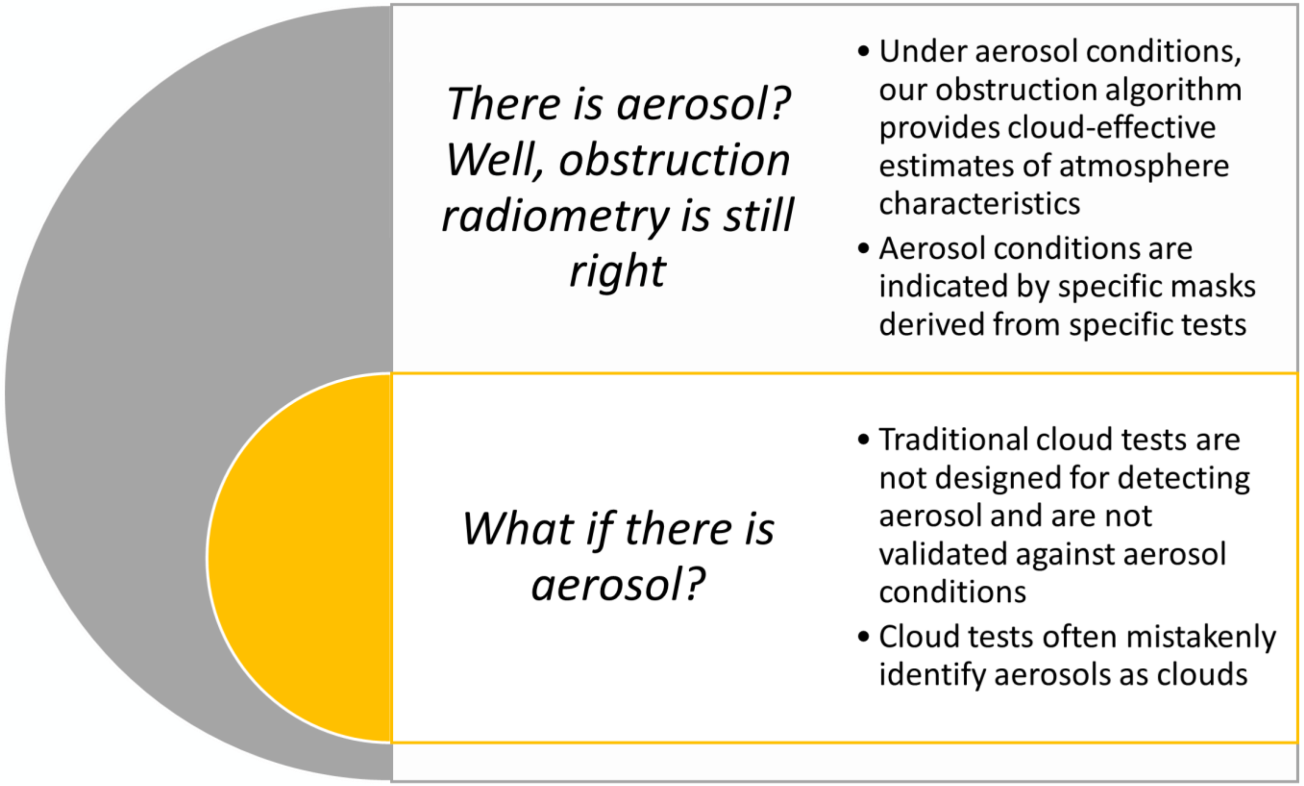
- *You do not need to conduct RT simulations yourself*



# HOW WOULD YOU USE IT? (8/14)

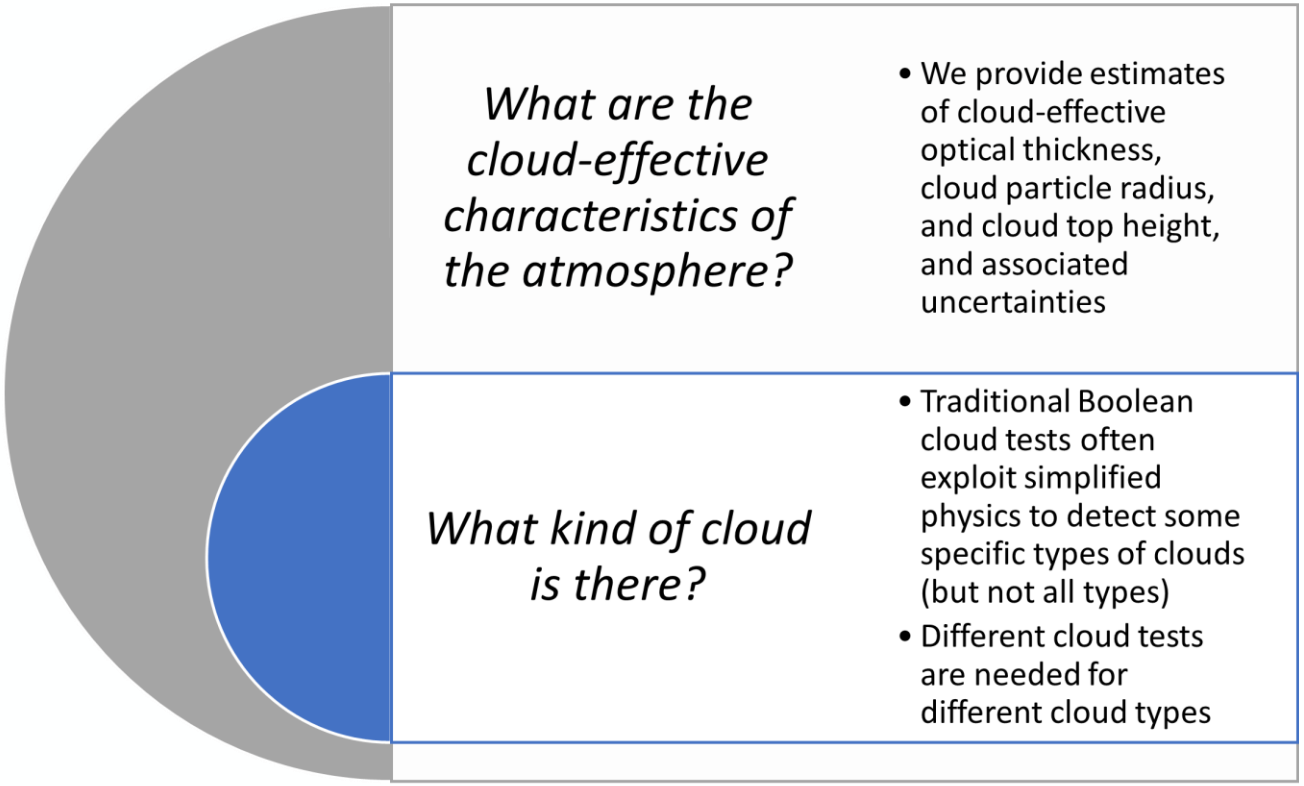
- ***If there is aerosol, obstruction still quantifies the radiometric perturbation quite right***
- Compute the difference between your actual and the assumed clear-sky retrieval
- You decide if your retrieval is significantly disturbed or not

- ***You are looking for aerosol events? We provide dedicated aerosol masks derived from specific tests***



# HOW WOULD YOU USE IT? (9/14)

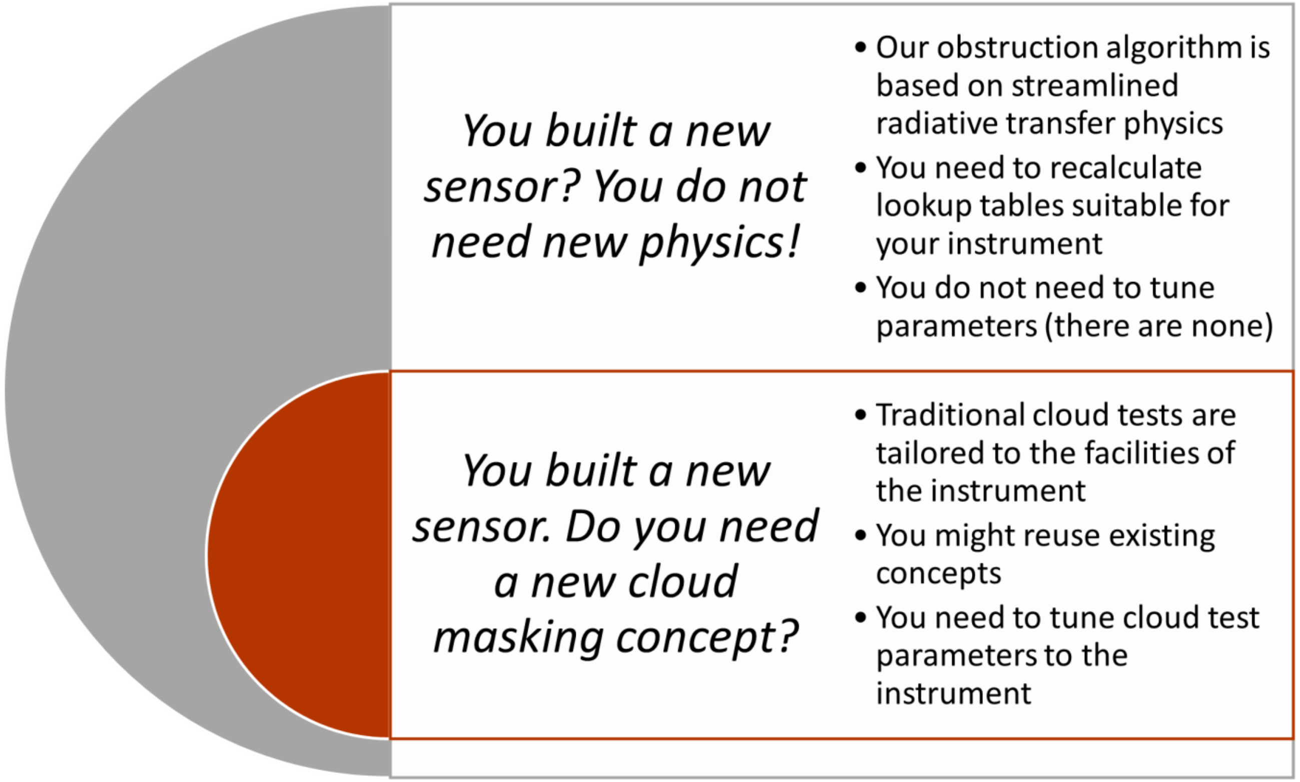
- ***You are looking for certain kinds of clouds?***
- You may use spectral obstruction to infer the kind of cloud (e.g., cirrus)
- You may use the retrieved cloud-effective state parameters and associated uncertainties to infer the kind of cloud
- You may use our cloud masks based on selected COD thresholds



# HOW WOULD YOU USE IT? (10/14)

- ***You are planning a new sensor and need a new cloud masking concept?***
- You may adapt and adopt our obstruction concept because you do not need new physics

- *We adapted our S3 obstruction retrieval algorithm to the Cloud Imager (CLIM) of the upcoming European CO2 mission (CO2M) allowing us to retrieve approximate 'cloud visibility height' (a simplified CTH)*



# HOW WOULD YOU CREATE A MASK? (11/14)

- Take the obstruction value (provided by our algorithm for selected wavebands)
- Apply a custom threshold to the obstruction value. Apply different thresholds over land and over water
- Obstruction (absolute) values greater than your custom threshold indicate a cloud
- Masks based on default thresholds are generated by our algorithm (see Table)

| Waveband | Instrument | Obstruction is expressed | Threshold value applied over | |
|---|---|---|---|---|
| | | | Land | Water |
| **443 nm** | OLCI | relative to TOA reflectance $\frac{\delta\rho_\lambda^t}{\rho_\lambda^t}$ | 0.10 | 0.10 |
| **754 nm** | OLCI | relative to TOA reflectance $\frac{\delta\rho_\lambda^t}{\rho_\lambda^t}$ | 0.10 | 0.50 |
| **554 nm** | SLSTR | relative to TOA reflectance $\frac{\delta\rho_\lambda^t}{\rho_\lambda^t}$ | 0.10 | 0.10 |
| **868 nm** | SLSTR | relative to TOA reflectance $\frac{\delta\rho_\lambda^t}{\rho_\lambda^t}$ | 0.10 | 0.50 |
| **1.61 µm** | SLSTR | relative to TOA reflectance $\frac{\delta\rho_\lambda^t}{\rho_\lambda^t}$ | 0.05 | 0.95 |
| **10.8 µm** | SLSTR | as brightness temperature difference | 3.50 | 0.75 |
| **1.37 µm** | SLSTR | as TOA reflectance difference | 0.05 | 0.05 |

# HOW DO EXISTING S3 CLOUD MASKS PERFORM? (12/14)

| | | OLCI IDEPIX CLOUD | | SLSTR PROBABILISTIC/ BAYES MODERATE | | SLSTR SUMMARY CLOUD | | SLSTR THIN CIRRUS | | SLSTR GROSS CLOUD | | SLSTR 1.37 MM THRESHOLD | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCORE | LAND | WATER | LAND | WATER | LAND | WATER | LAND | WATER | LAND | WATER | LAND | WATER |
| Producer´s view | POD | 78.4 | 72.0 | 88.5 | 93.1 | 85.9 | 96.4 | 43.4 | 28.1 | 36.0 | 57.5 | 53.3 | 35.3 |
| | FNR | 21.6 | 28.0 | 11.5 | 6.9 | 14.1 | 3.6 | 56.6 | 71.9 | 64.0 | 42.5 | 46.7 | 64.7 |
| | FAR | 12.2 | 4.2 | 27.6 | 30.8 | 26.9 | 22.2 | 6.5 | 1.1 | 1.0 | 11.5 | 1.9 | 0.1 |
| | SPC | 87.8 | 95.8 | 72.4 | 69.2 | 73.1 | 77.8 | 93.5 | 98.9 | 99.0 | 88.5 | 98.1 | 99.9 |
| User´s view | PPV | 88.9 | 95.3 | 79.9 | 78.3 | 79.8 | 83.8 | 89.2 | 96.7 | 97.8 | 85.7 | 97.1 | 99.8 |
| | FDR | 11.1 | 4.7 | 20.1 | 21.7 | 20.2 | 16.2 | 10.8 | 3.3 | 2.2 | 14.3 | 2.9 | 0.2 |
| | FOR | 23.4 | 25.9 | 16.4 | 10.6 | 19.3 | 5.2 | 42.9 | 46.4 | 44.5 | 36.4 | 37.1 | 43.4 |
| | NPV | 76.6 | 74.1 | 83.6 | 89.4 | 80.7 | 94.8 | 57.1 | 53.6 | 55.5 | 63.6 | 62.9 | 56.6 |
| | ACC | 82.6 | 82.8 | 81.3 | 82.2 | 80.2 | 87.9 | 65.7 | 60.4 | 64.1 | 71.7 | 73.3 | 64.8 |
| | **ACB** | **83.1** | **83.9** | **80.5** | **81.2** | **79.5** | **87.1** | **68.5** | **63.5** | **67.5** | **73.0** | **75.7** | **67.6** |

# HOW DO OBSTRUCTION-BASED MASKS PERFORM? (13/14)

| | | OBSTR. MASK 443 NM (OLCI) | | OBSTR. MASK 753 NM (OLCI) | | OBSTR. MASK 554 NM (SLSTR) | | OBSTR. MASK 868 NM (SLSTR) | | OBSTR. MASK 1.61 MM (SLSTR) | | OBSTR. MASK TIR (SLSTR) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCORE | LAND | WATER | LAND | WATER | LAND | WATER | LAND | WATER | LAND | WATER | LAND | WATER |
| Producer´s view | POD | 90.3 | 90.2 | 87.5 | 91.4 | 89.7 | 90.8 | 87.3 | 92.3 | 89.0 | 87.0 | 88.4 | 89.8 |
| | FNR | 9.7 | 9.8 | 12.5 | 8.6 | 10.3 | 9.2 | 12.7 | 7.7 | 11.0 | 13.0 | 11.6 | 10.2 |
| | FAR | 14.6 | 10.0 | 11.4 | 9.0 | 12.7 | 8.9 | 12.5 | 10.5 | 15.0 | 7.9 | 16.8 | 11.6 |
| | SPC | 85.4 | 90.0 | 88.6 | 91.0 | 87.3 | 91.1 | 88.5 | 89.5 | 85.0 | 92.1 | 83.2 | 88.4 |
| User´s view | PPV | 88.0 | 91.0 | 90.1 | 91.9 | 89.3 | 92.0 | 90.0 | 90.8 | 87.5 | 92.5 | 86.2 | 89.7 |
| | FDR | 12.0 | 9.0 | 9.9 | 9.1 | 10.7 | 8.0 | 10.0 | 9.2 | 12.5 | 7.5 | 13.8 | 10.3 |
| | FOR | 11.9 | 9.7 | 14.3 | 9.6 | 12.2 | 10.1 | 14.5 | 8.7 | 13.3 | 13.7 | 14.2 | 11.4 |
| | NPV | 88.1 | 90.3 | 85.7 | 90.4 | 87.8 | 89.9 | 85.5 | 91.3 | 86.7 | 86.3 | 85.8 | 88.6 |
| | ACC | 88.1 | 90.7 | 88.0 | 91.2 | 88.6 | 91.0 | 87.9 | 91.0 | 87.1 | 89.4 | 86.0 | 89.2 |
| | **ACB** | **87.9** | **90.1** | **88.1** | **91.2** | **88.5** | **90.9** | **87.9** | **90.9** | **87.0** | **89.6** | **85.8** | **89.5** |

# VALIDATION SUMMARY (14/14)

## Main achievements

- Derived cloud optical depth and spectral obstruction resolve cloud structure mostly well
- Obstruction-based masks perform as well as or better than existing S3 cloud masks on the pixel validation dataset
- Obstruction-based masks mitigate some problems of existing S3 cloud masks (broken clouds, systematic overscreening or underscreening of clouds)
- Aerosol masks recognize Sahara dust outbreaks, smog over Yellow Sea, volcanic aerosol, and burning biomass

## Main deficiencies

- Accuracy of obstruction and the performance of cloud detection depend on accuracy of surface reflectance background map
- Depending on errors in the background map, some typical cloud masking problems remain (snow and ice, coastlines)
- Likewise, agricultural areas, topographic variation, dry-fallen lakes can be misidentified as cloud
- Aerosol masks are too sensitive to sun-glint and to low optical depth of clouds and aerosols

# ROADMAP TOWARD OPERATIONAL IMPLEMENTATION

- Targeting 2025 (±1 year) EUMETSAT is preparing a suite of cloud products from S3, including CTP derived from OLCI (**ITT OCTPO2**) and the obstruction concept presented in this talk (**ITT S3-SYN-CM**). Mandated by member state NWP services and Copernicus
- At present, prototype versions of these algorithms are validated, available at EUMETSAT, and running off-line for further internal analysis, and scientific and software optimization
- Aim to improve both algorithms by using a compatible pre-calculated Sentinel-3 Land Surface Reflectivity auxiliary dataset (**ITT S3 LSR** won by GRASP SAS and BC as partner) within the next 18 months
- Additional necessary developments are under internal discussion. To be announced in near future
- Major lessons from the obstruction study are being transferred to the CO2M L2 cloud mask product from the CLIM sensor (with likely feedback into S3 LSR)

SCAN ME

S3-SYN-CM
web page

# EXPLANATION OF STATISTICS

- A mask is termed cloud-conservative if the cloud false alarm rate (FAR) is low
- A mask is termed clear-conservative if the cloud FAR is high

| | Score | Name | Remark |
|---|---|---|---|
| Producer´s view | POD | Probability of detection (or producer's accuracy cloud) | High for a clear-conservative mask |
| | FNR | False negative rate | Complement of POD |
| | FAR | False alarm rate | Complement of SPC |
| | SPC | Specificity (or producer's accuracy clear) | High for a cloud-conservative mask |
| User´s view | PPV | Positive predictive value (or user's accuracy cloud) | High for a cloud-conservative mask |
| | FDR | False discovery rate | Complement of PPV |
| | FOR | False omission rate | Complement of NPV |
| | NPV | Negative predictive value (or user's accuracy clear) | High for a clear-conservative mask |
| | ACC | Accuracy | Rate of correct predictions |
| | **ACB** | **Accuracy, balanced** | **Rate of correct predictions, robust against imbalanced datasets** |