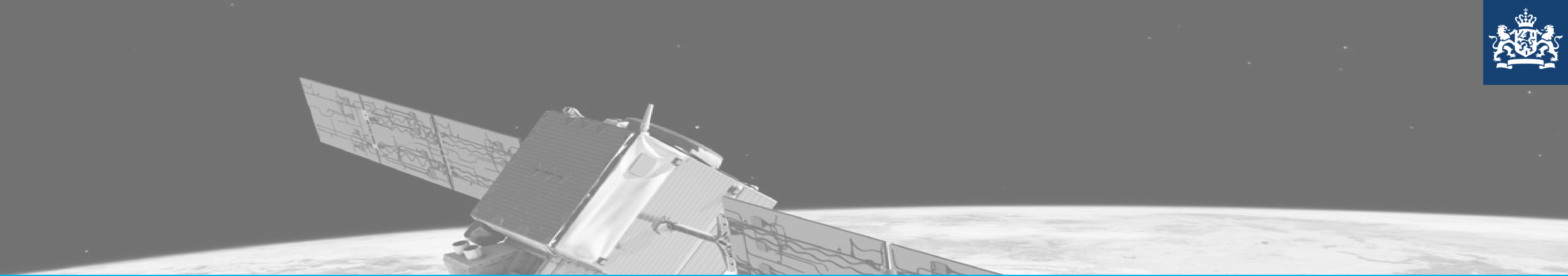
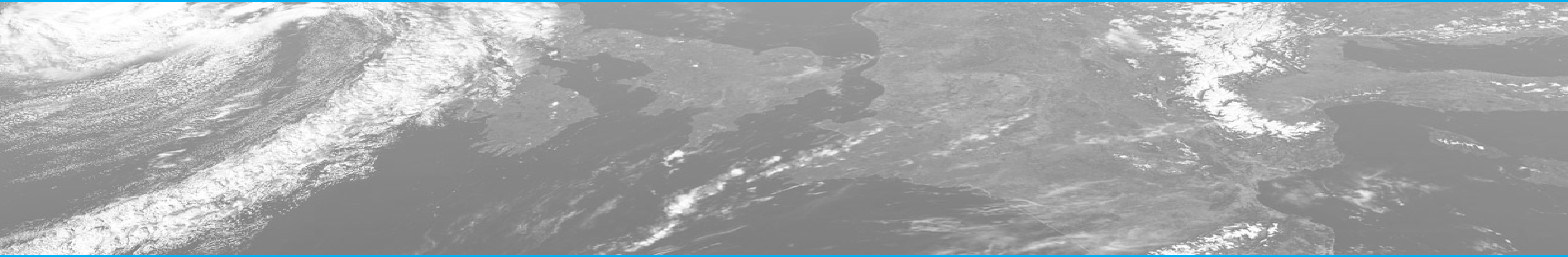
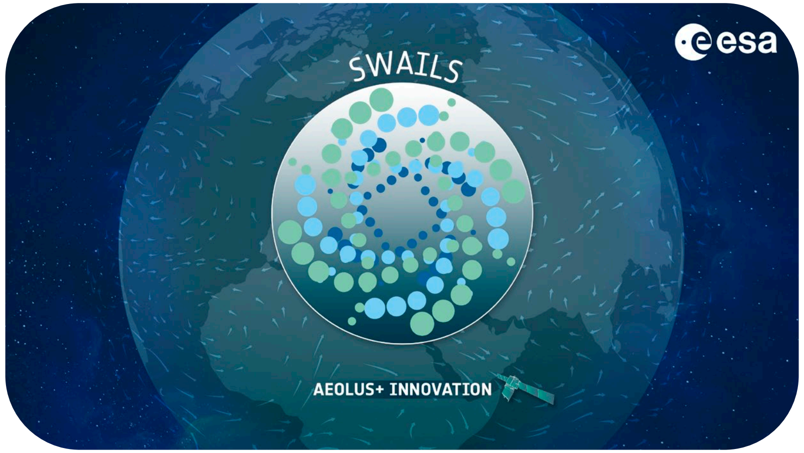


Lidar Aerosol Retrieval based on Information from Surface Signal of Aeolus

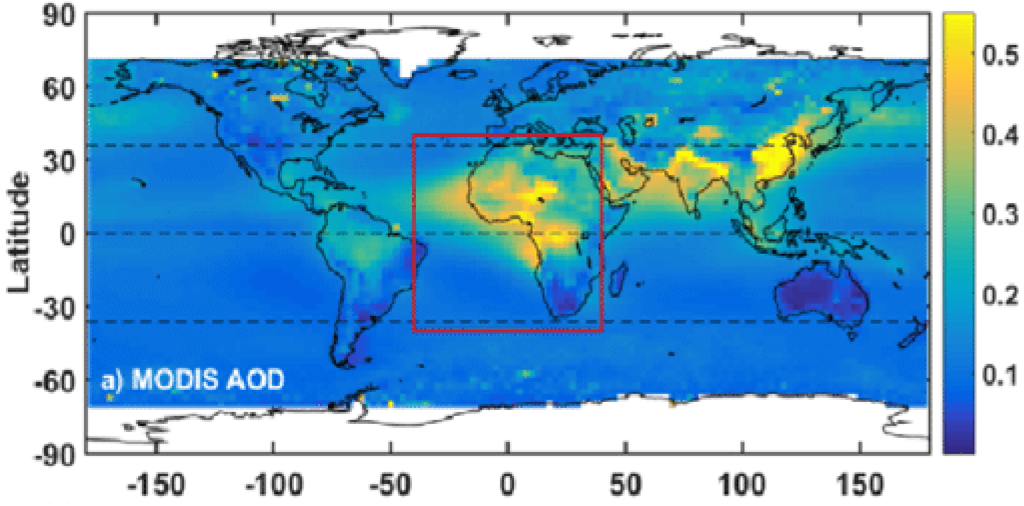
L. Labzovskii, G. J. van Zadelhoff, D. Donovan, D. Josset



RESEARCH AIM AND MOTIVATION



AOD distribution [Wang et al., 2018]



LARISSA – *Lidar Aerosol Retrieval Based on Information from Surface Signal of Aeolus*

RESEARCH AIM

To introduce independent AOD retrieval using lidar surface returns (LSR) from ocean for Aeolus

IMPLICATIONS

- New **independent** estimates from lidar surface returns -> No **assumption about** aerosol microphysics
- Empirically untested AOD retrieval at these lidar settings -> 37.5^o incidence, UV wavelength, LSR-based method
- Support **future aerosol-oriented spaceborne instruments** -> such as ATLID on EarthCARE

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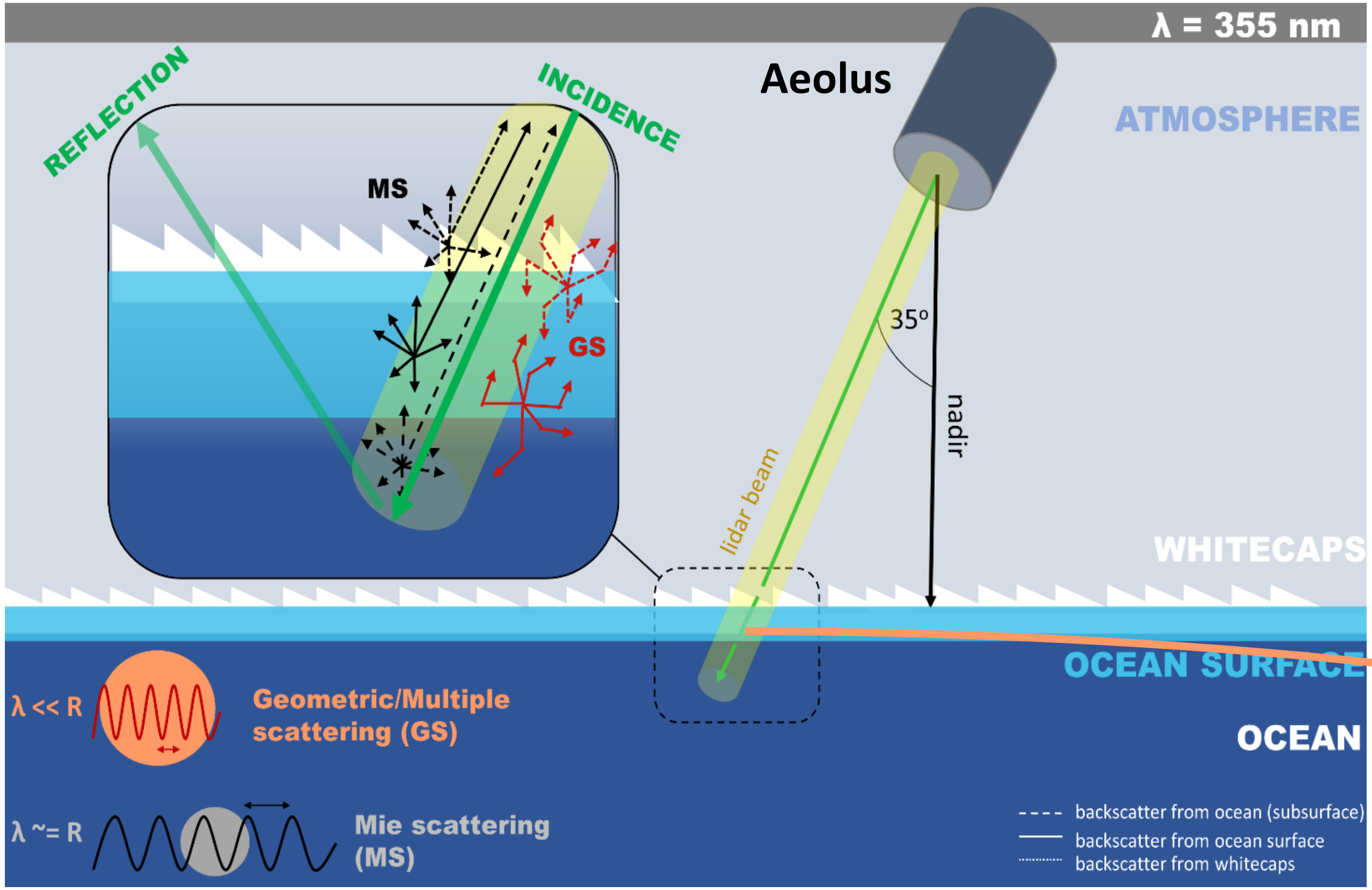
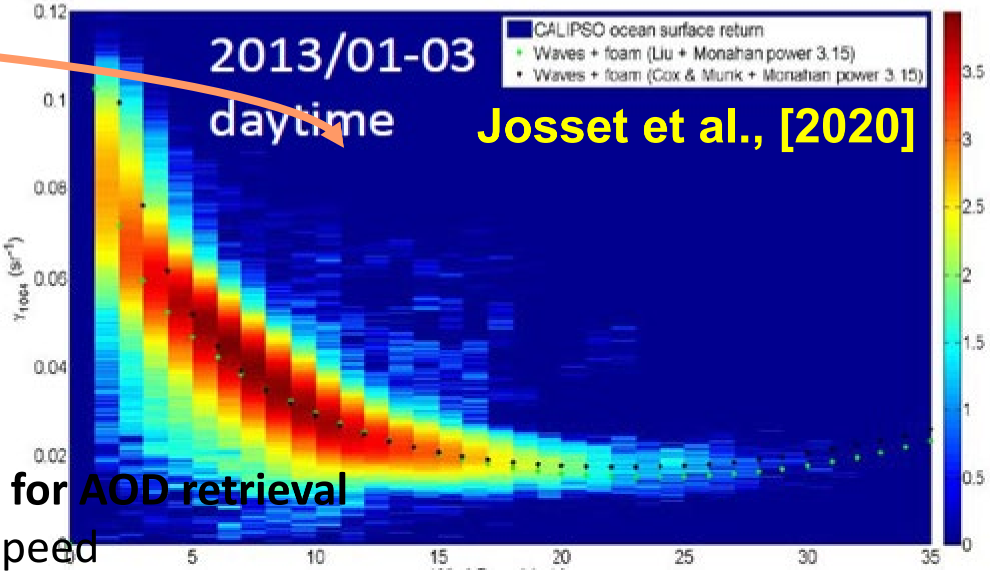
FUNDAMENTALS OF LSR-BASED AOD RETRIEVAL FOR AEOLUS



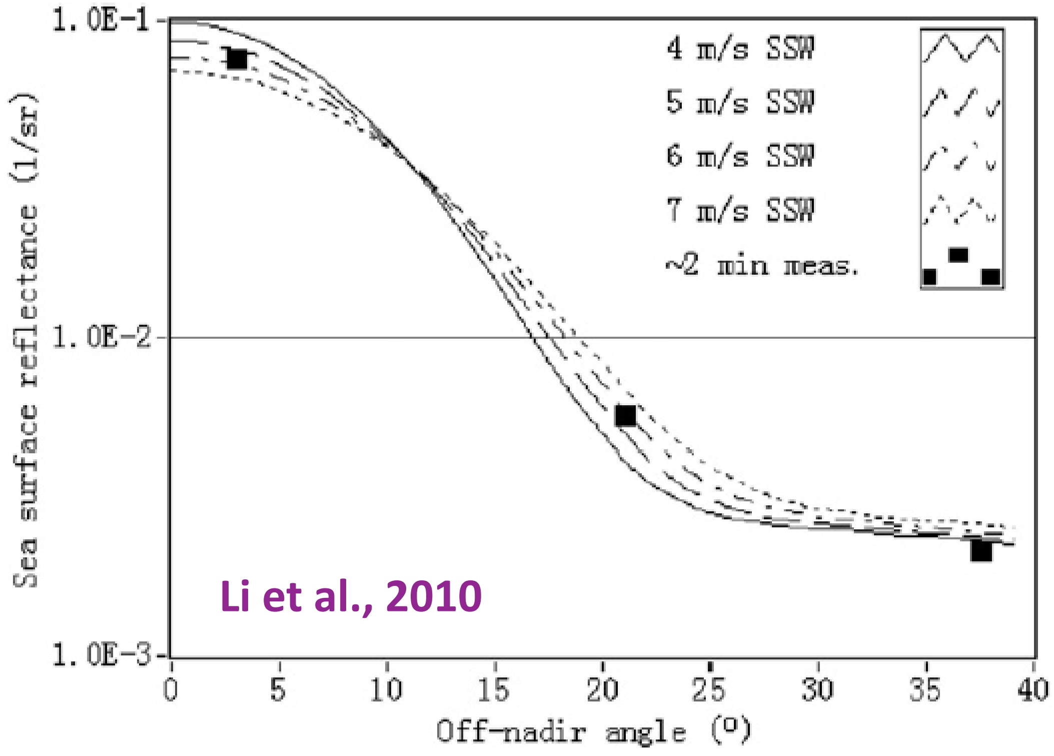
Instrument and data

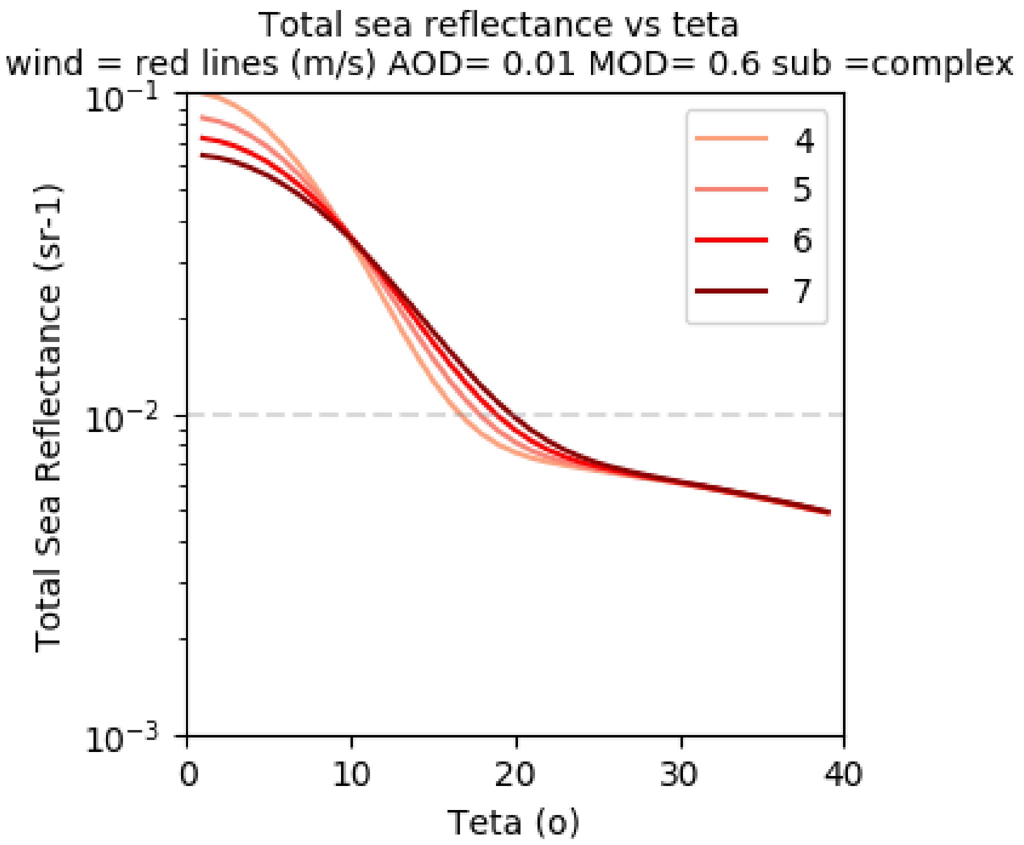
- **Instrument:** ALADIN (Atmospheric Laser Doppler Instrument) onboard Aeolus
- **Wavelength:** ~355 nm
- **Period:** Intensive Observation Period (IOP: 14 – 23 September 2019)
- **Input data:**
  - **L2 data:** Surface Integrated Attenuated Backscatter (from Mie Signal)
  - **AUX_MET:** Simulated near-surface wind speed
- **Validation data**:
  - **AEL PRO_L2**: Extinction Coefficient, Rayleigh Backscattering



- Light reflected away -> 2% of remaining backscattered light **can be used for AOD retrieval**
- In simple words -> **Inverse relationship** between LSR and surface wind speed
- Why complicated? -> Highly non-nadir angle of incidence, subsurface contribution at 355 nm

SUMMARIZED SURFACE REFLECTANCE CALCULATION





- **Good agreement with previous works** [Li et al., 2010] - > while Josset-2010 equation applied
- Despite good agreement in pattern/magnitude -> Potential **overestimation of subsurface component** at 37.5°

LSR WITH RELATION TO LAND COVER: FIRST 10 DAYS OF IOP

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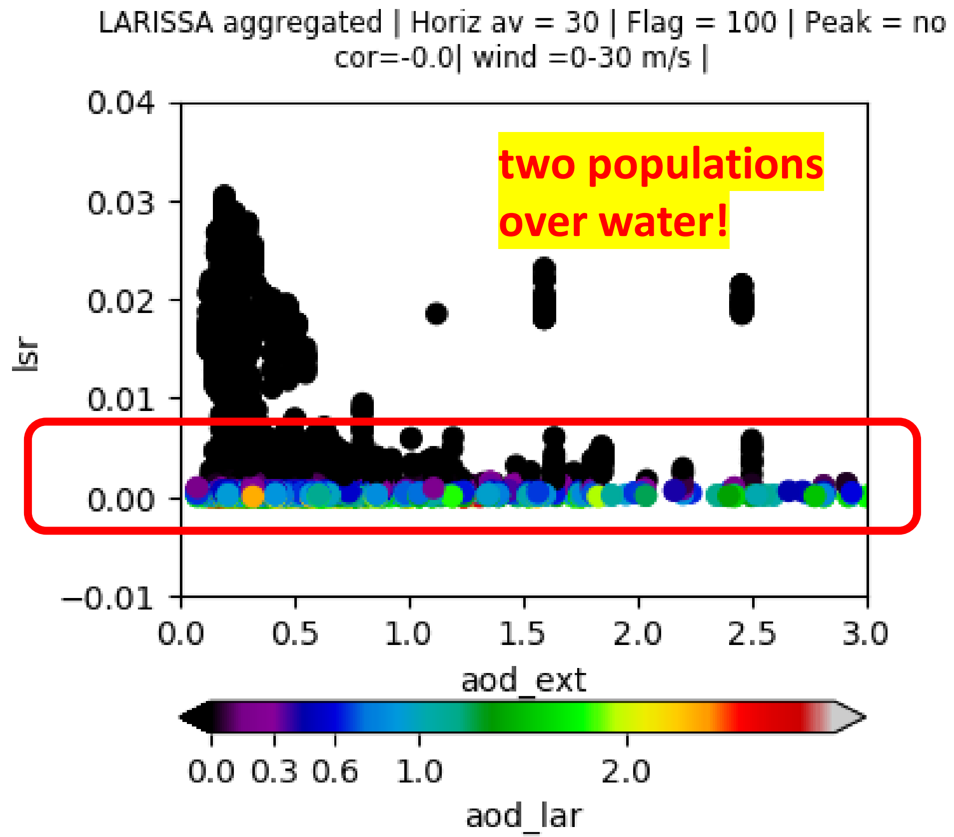
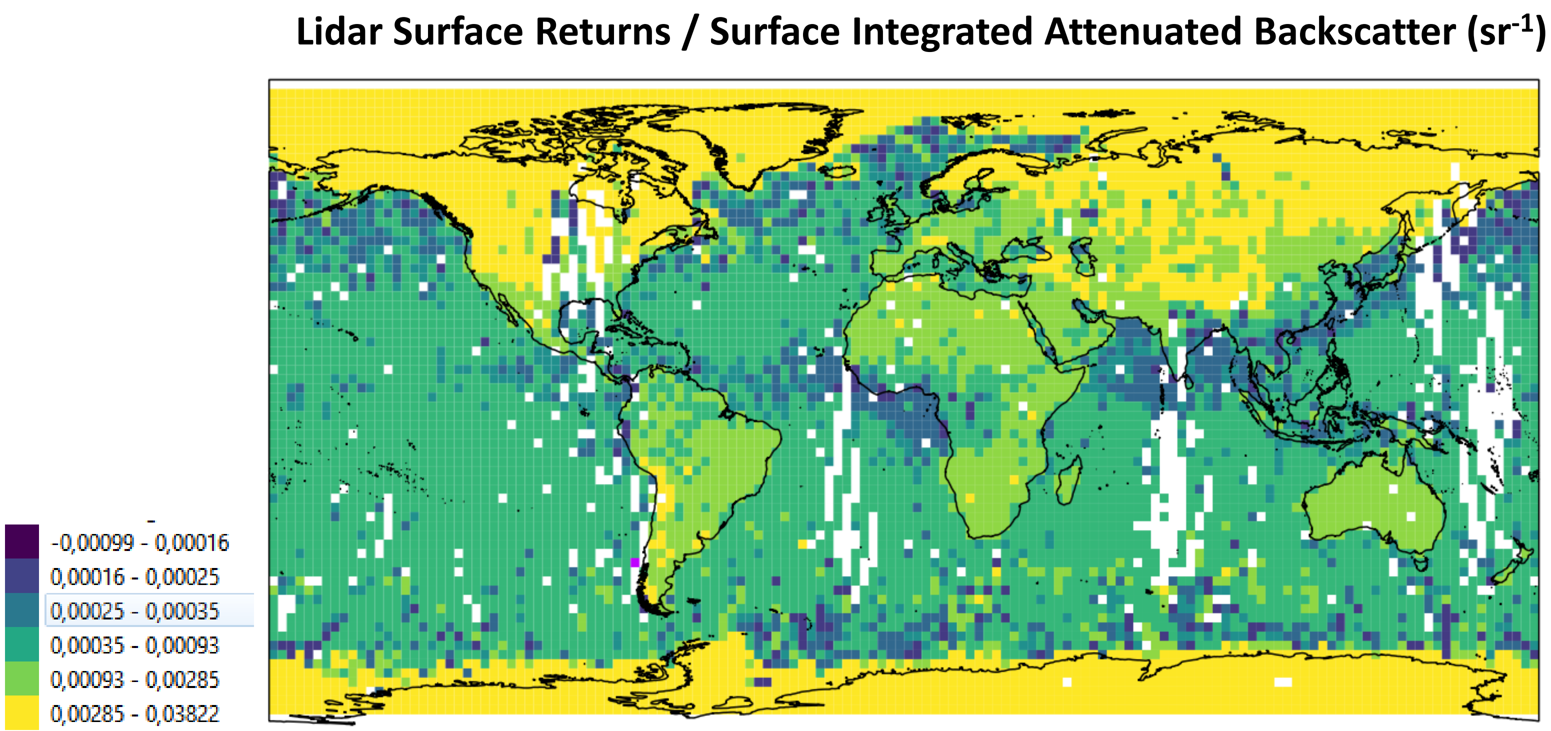




MARCH – APRIL – MAY 2019

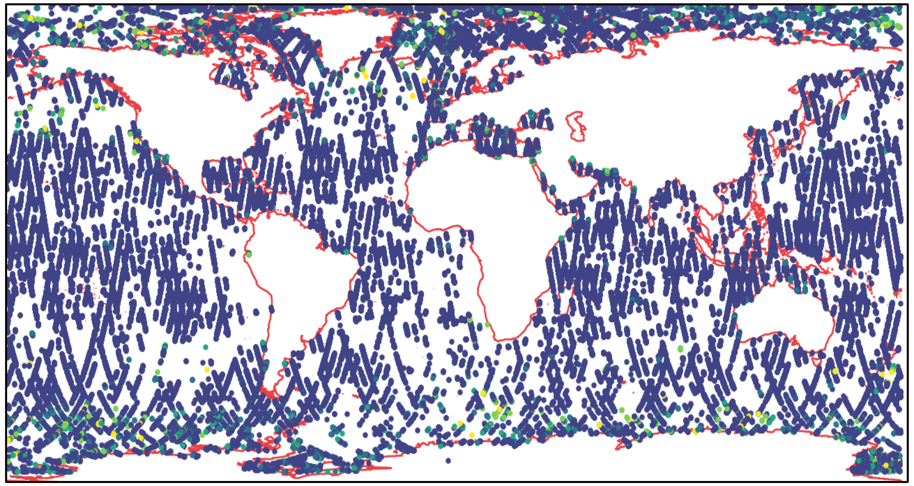
- There are two populations -> Weak LSR (0.0001 – 0.002 sr^{-1}) and strong LSR (0.002 – 0.04 sr^{-1})
- **Many satisfactory returns over oceans** (19-34%) according to SIAB vs $SIAB_{error}$ estimate
- As expected -> **Strongest UV returns over white surface** (Albedo > 0.90 for fresh snow [Varotsos et al., 2014; Weiler, 2017])
- Beyond expectations -> A week of **LSR reflects land cover patterns** (dark forests and arid areas are discernible)

WHERE IS USEFUL LSR POPULATION IS LOCATED? STRONG OR WEAK SIGNAL?

Weak population leads to erroneous estimates of AOD (< 0)

LSR (sr^{-1})

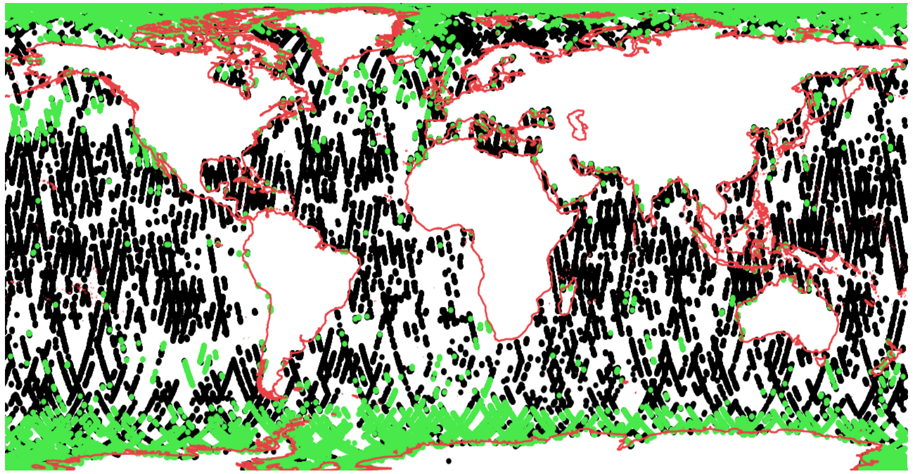
- -0.0001 - 0
- 0 - 0.0008
- 0.0008 - 0.0013
- 0.0013 - 0.0017
- 0.0017 - 0.0023
- 0.0023 - 0.3

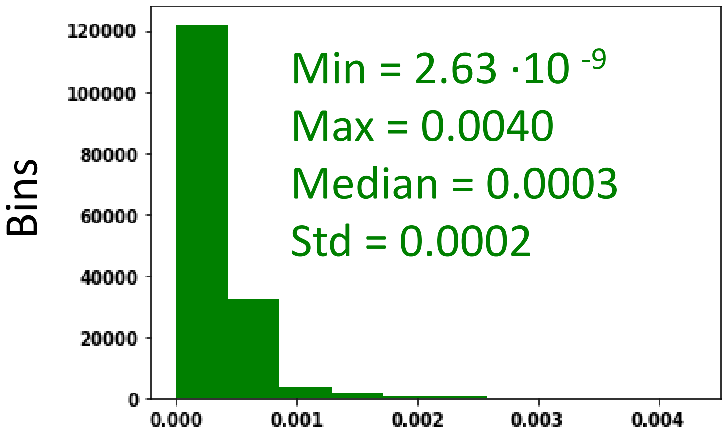


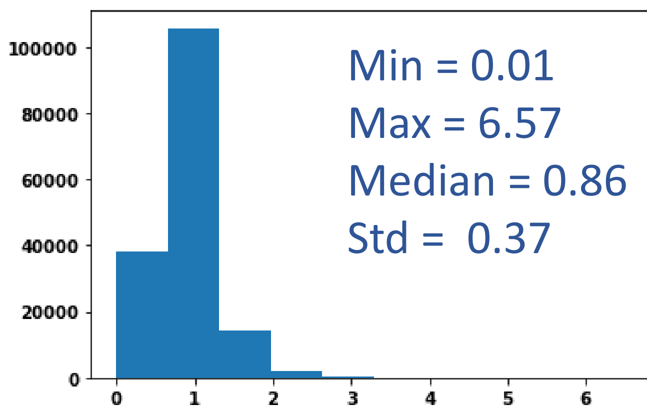
$$AOD = \frac{1}{2} \ln\left(\frac{Rs+Rw+Ru}{\gamma}\right) - OD_m$$

γ – LSR
s, w, u – specular, whitecaps, subsurface
OD_m – molecular optical depth

NEGATIVE AOD / POSITIVE AOD

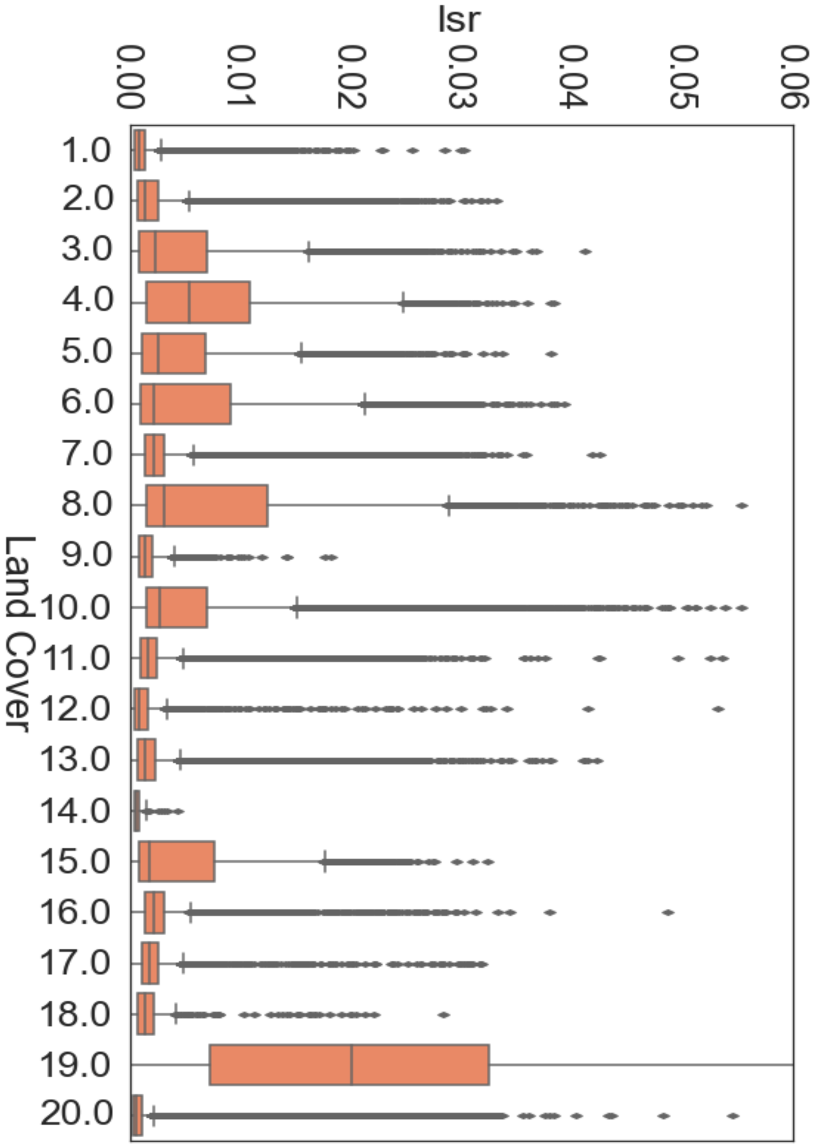




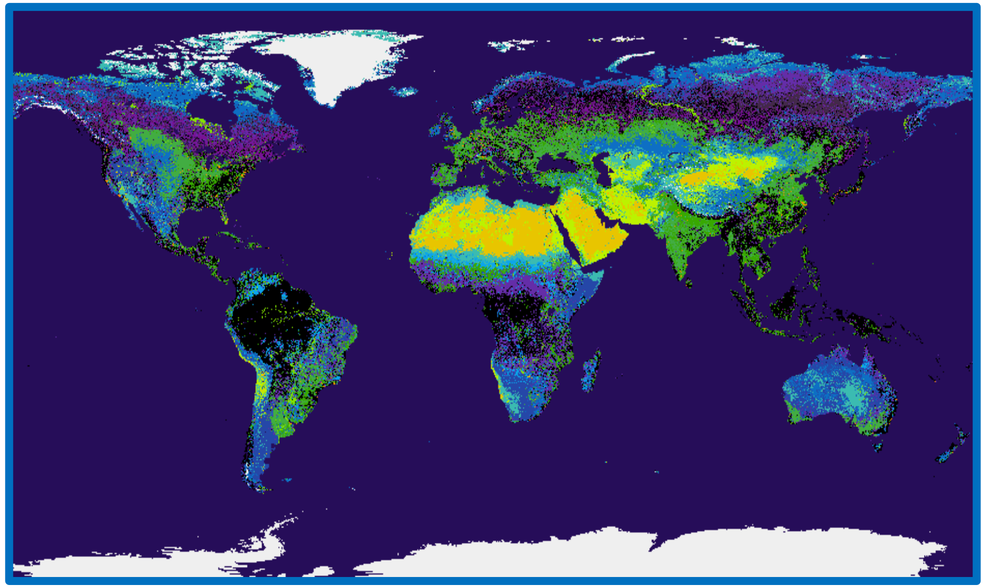


- **Useful LSR range = 0.001 – 0.004 (+/- 0.002)**

ESTIMATE OF LSR BASED ON LAND COVER WITHOUT SEA ICEA



1 Broadleaf Evergreen Forest
2 Broadleaf Deciduous Forest
3 Needleleaf Evergreen Forest
4 Needleleaf Deciduous Forest
5 Mixed Forest
6 Tree Open
7 Shrub
8 Herbaceous
9 Herbaceous with Sparse Tree/Shrub
10 Sparse vegetation
11 Cropland
12 Paddy field
13 Cropland Other Vegetation
14 Mangrove
15 Wetland
16 Bare area, consolidated (gravel,rock)
17 Bare area, unconsolidated (sand)
18 Urban
19 Snow Ice
20 Water bodies



GET: https://github.com/globalmaps/gm_lc_v3
Land Cover (GLCNMO) - Global version - Version 3

- Ice masking by using OSI-SAF ice mask -> Helps tackling the **strong LSR problem over sea**

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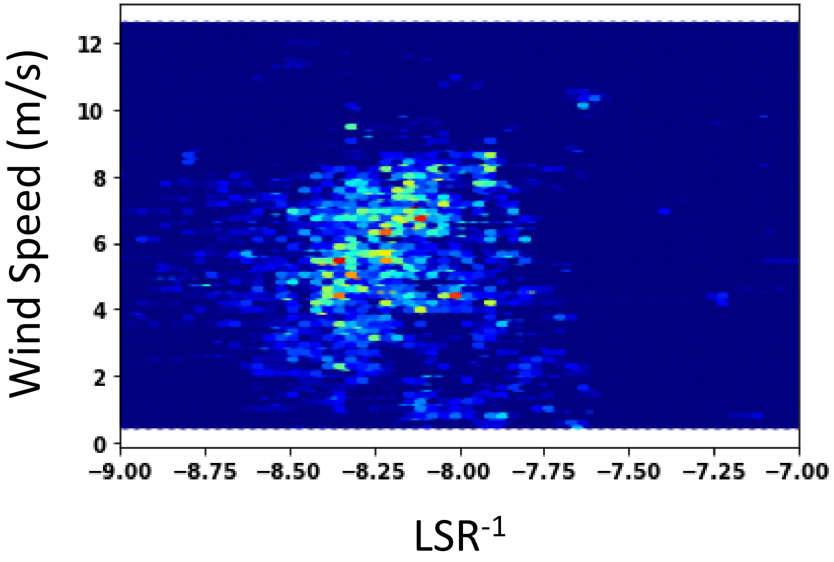
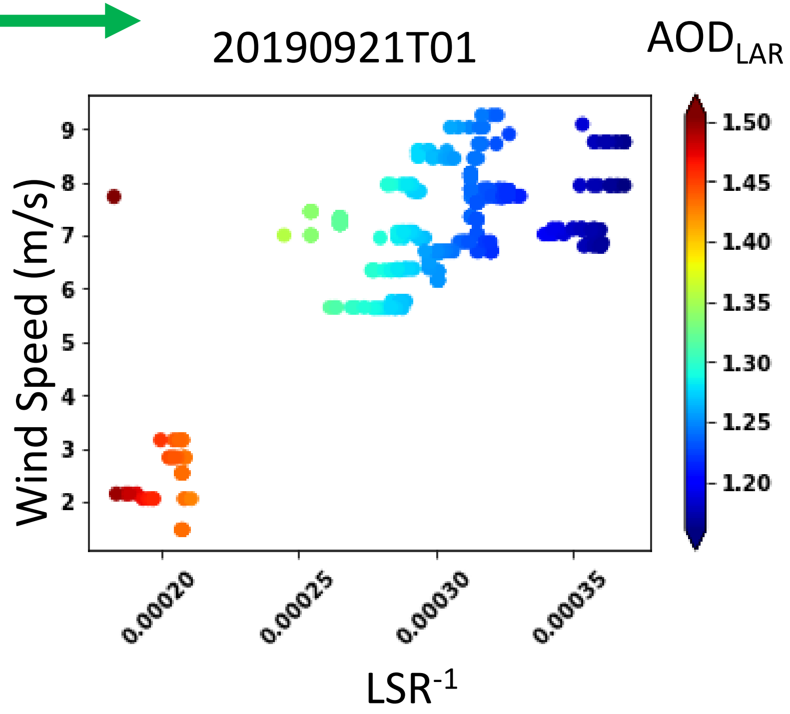
LSR SENSITIVITY TO WIND IN NORTH PACIFIC

NORTH PACIFIC AGGREGATED



DATE	CORREL
global__20190919T00 (FEW POINTS)	0.97
global__20190921T01	**0.75**
global__20190921T03	0.65
global__20190919T13	0.58
global__20190914T03	0.48
global__20190920T16	0.45
global__20190914T14	0.41
global__20190919T16	0.33
global__20190915T03	0.29
global__20190918T02	0.27
global__20190915T15	0.27
global__20190921T17	0.22
global__20190915T01	0.22
global__20190918T13	0.20
global__20190917T16	0.18
global__20190914T15	0.14
global__20190918T16	0.13
global__20190914T17	0.11
global__20190919T02	0.07
global__20190917T04	0.00
global__20190919T15	-0.11
global__20190919T04	-0.12
global__20190920T13	-0.13
global__20190921T14	-0.14
global__20190920T15	-0.17
global__20190915T17	-0.18
global__20190915T14	-0.36
global__20190917T14	-0.43
global__20190918T14	-0.50
global__20190917T01	-0.52
global__20190918T04	-0.55



- In some cases positive, in some -> Inverse association between LSR and wind speed

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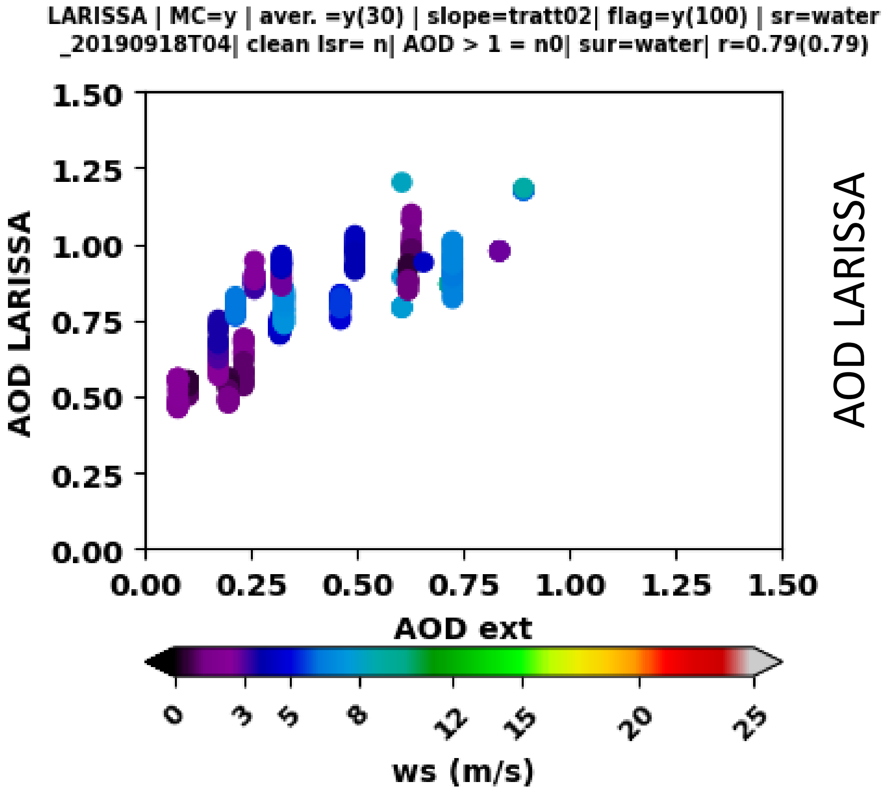
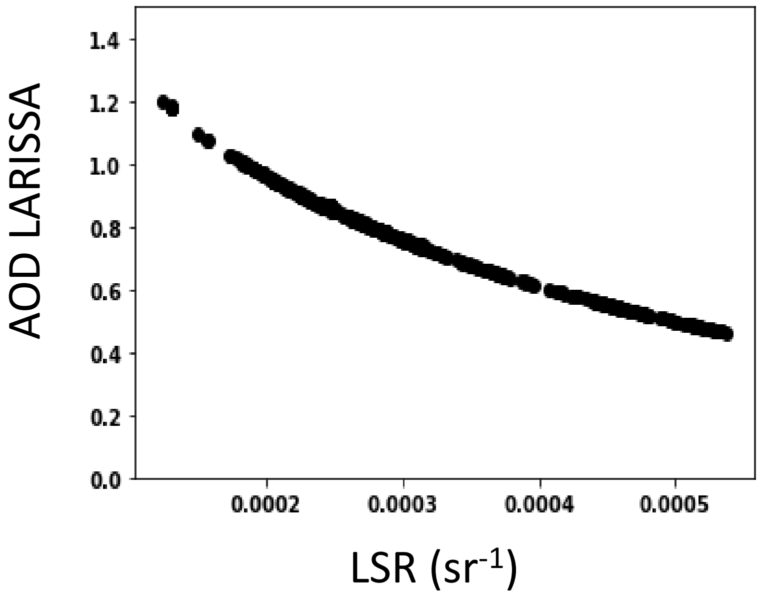
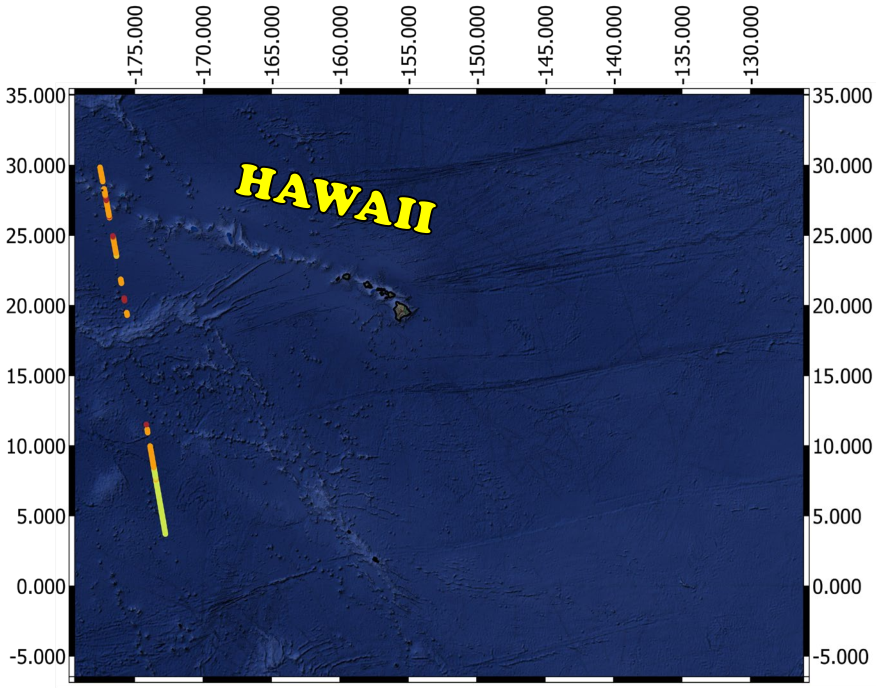
VALIDATION OF AOD_LARISSA vs AOD_EXT

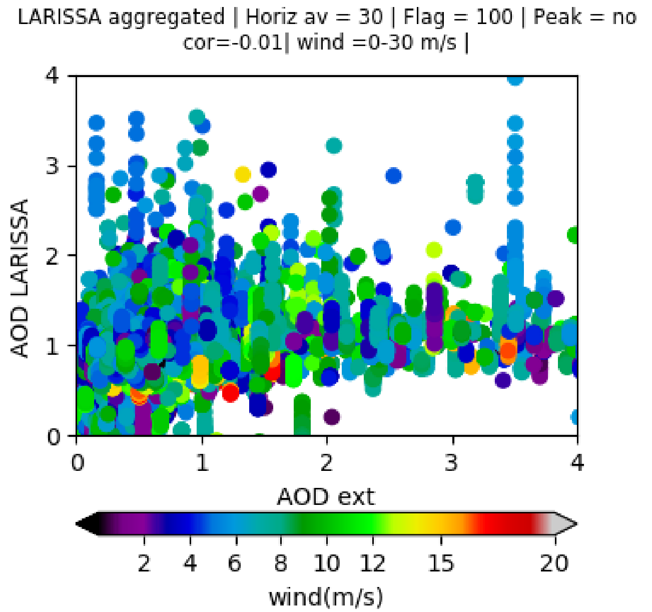


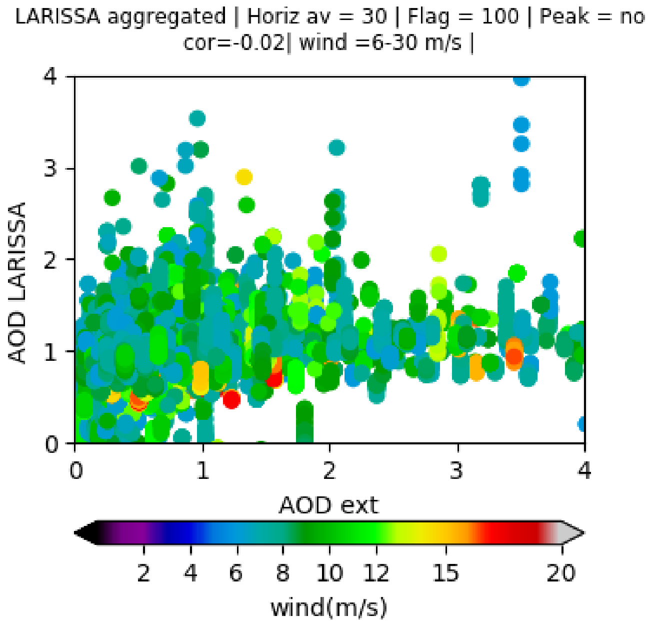


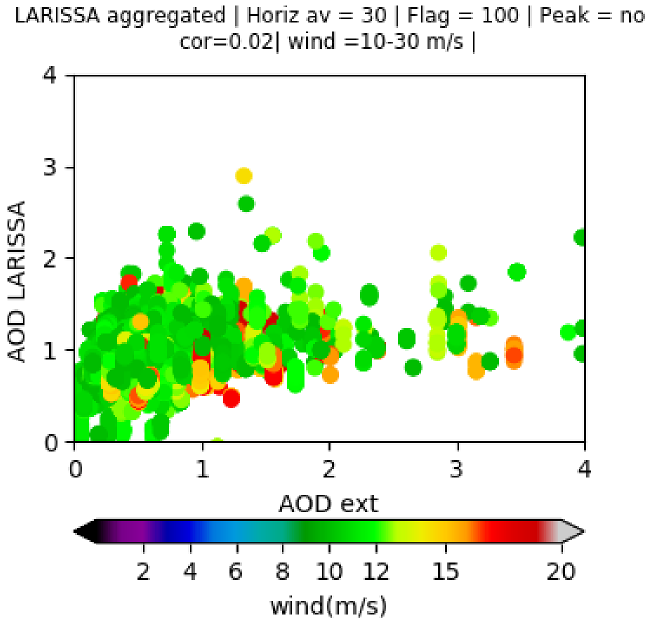


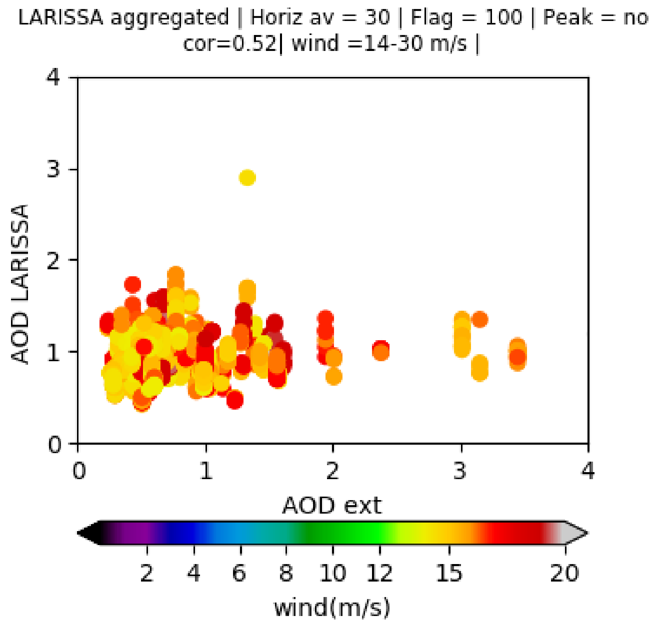
- The best AEL_PRO – LARISSA agreement case
- This case has good agreement -> **Only useful LSR signals (< 0. 0005)**
- LSR signal might require filtering based on magnitude as well
- Offset of ~0.50 between LARISSA and AEL_PRO -> Systematic or not?

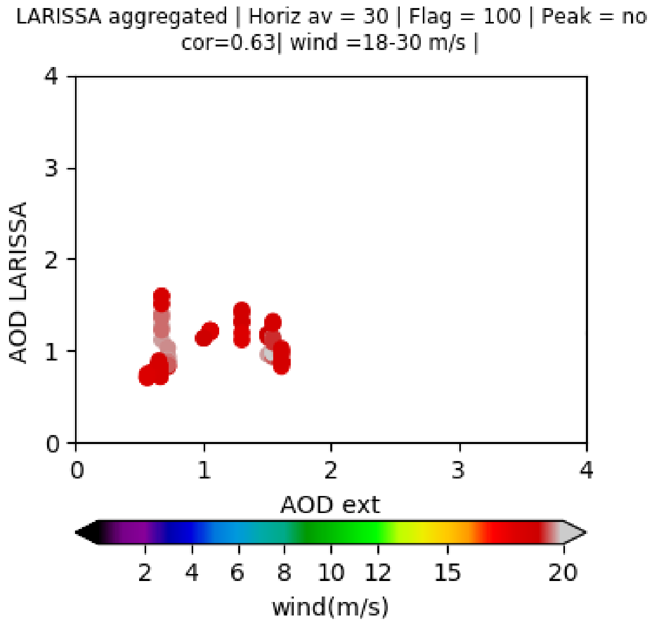
GLOBAL SCALES: NO STRONG SENSITIVITY TO WIND SPEED







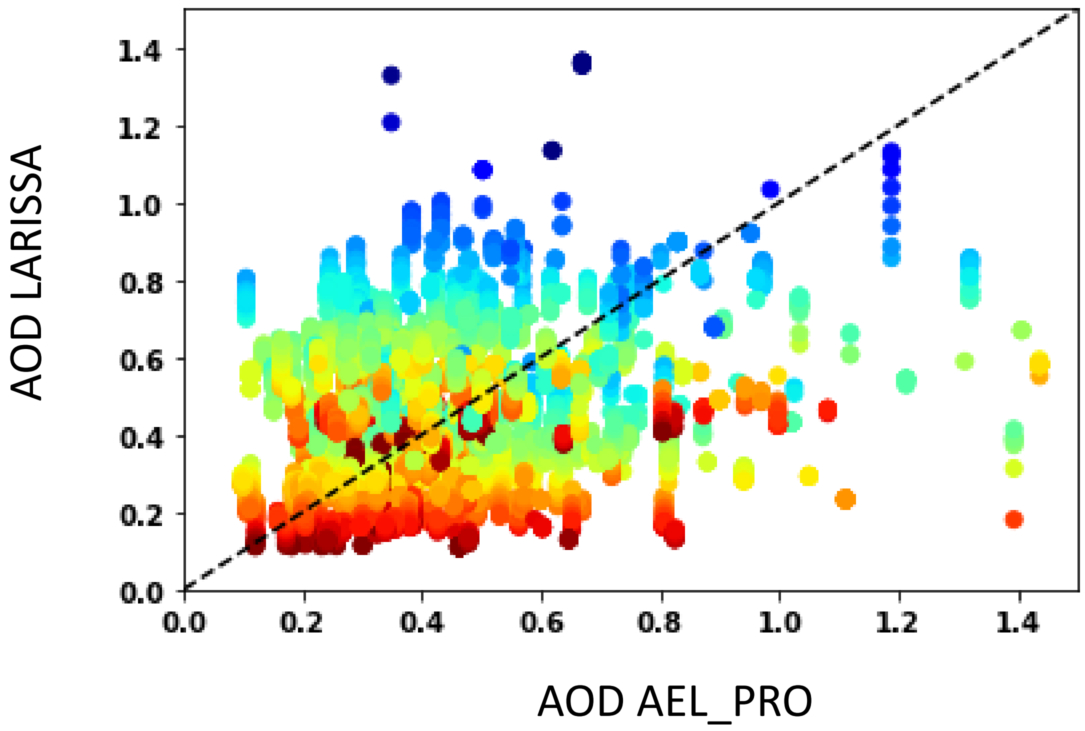




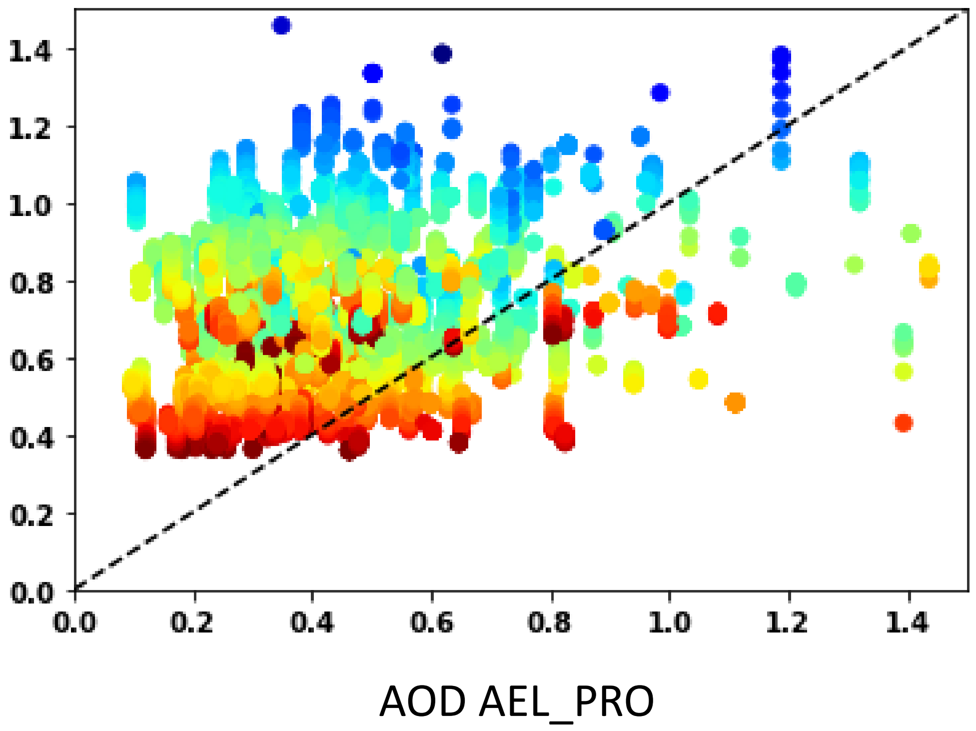
- Every plot -> **Binning based on wind range**
- At 10-30 m/s -> Visible improvement
- At 14-30 m/s -> Quantitative improvement (**r = 0.52**)
- Overestimation of AOD by LARISSA -> Offset is systematic

COMPARISON OF AOD_LARISSA vs AOD_AELPRO

Aggregated orbit: North Pacific (LARISSA corrected)

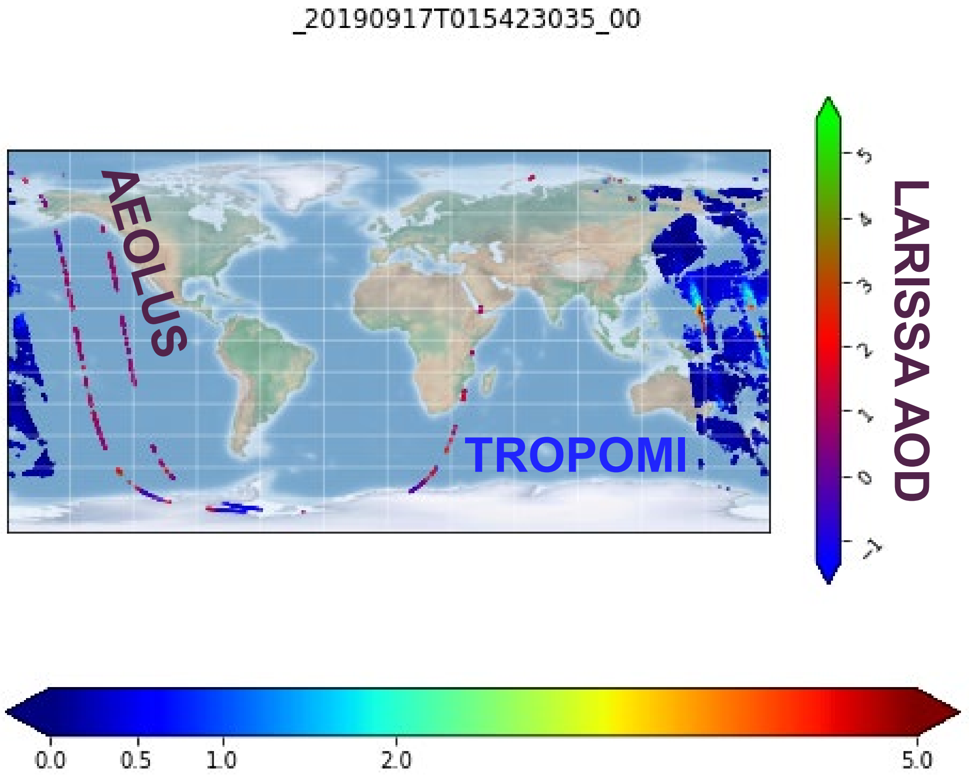


Aggregated orbit: North Pacific (uncorrected)



- The **correction of 0.50 (for AOD) seemingly corrects the lack of AEL_PRO-LARISSA agreement**
- Indication of consistent offset because these cases are taken from various orbits, but gap -> Consistent

LARISSA vs TROPOMI



LARISSA – TROPOMI agreement (r)

Date	LAR vs TROP (AOD > 0.3)
14.09.2019	**0.20**
15.09.2019	0.01
17.09.2019	**0.40**
18.09.2019	-0.10
19.09.2019	-0.36
20.09.2019	0.16
21.09.2019	0.15

LARISSA – OMI agreement (r)

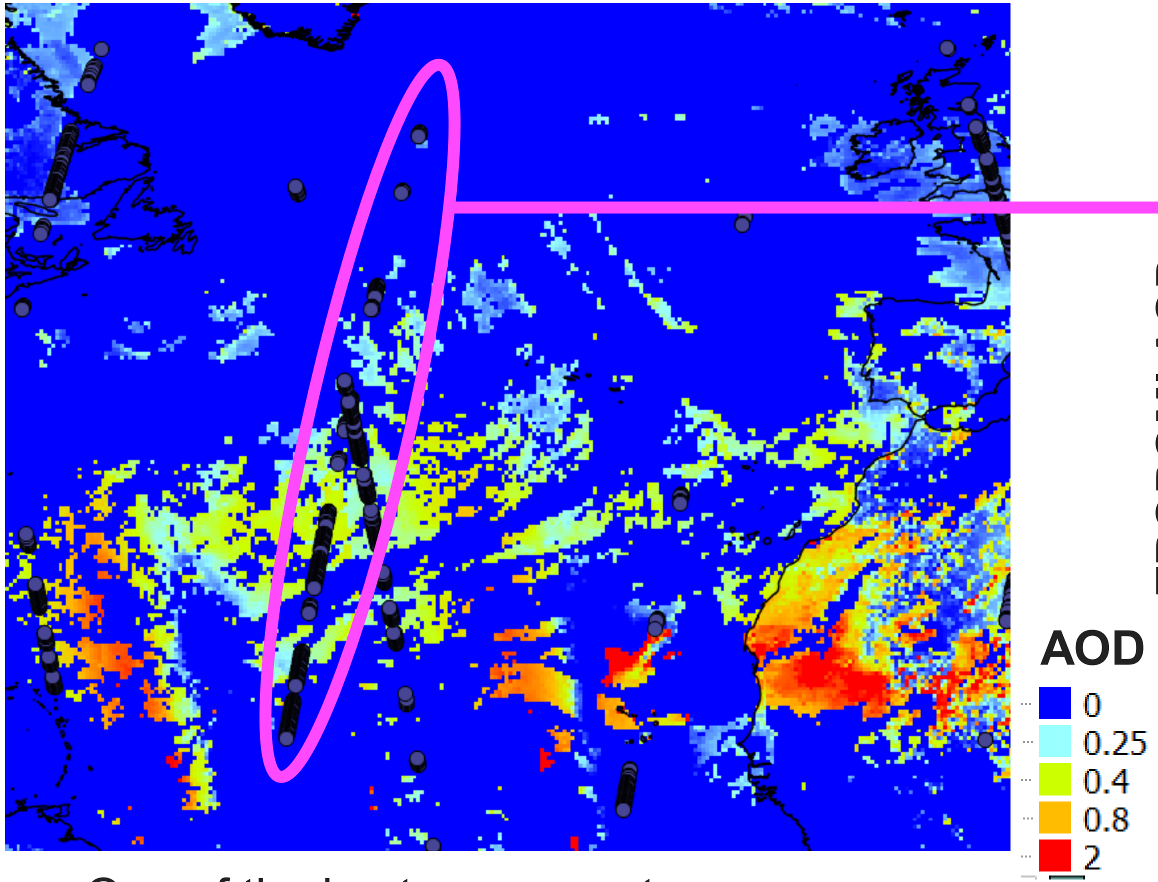
Date	LAR vs TROP (AOD > 0.3)
14.09.2019	0.17
15.09.2019	0.01
17.09.2019	0.01
18.09.2019	0.01
19.09.2019	0.12
20.09.2019	0.17
21.09.2019	0.07

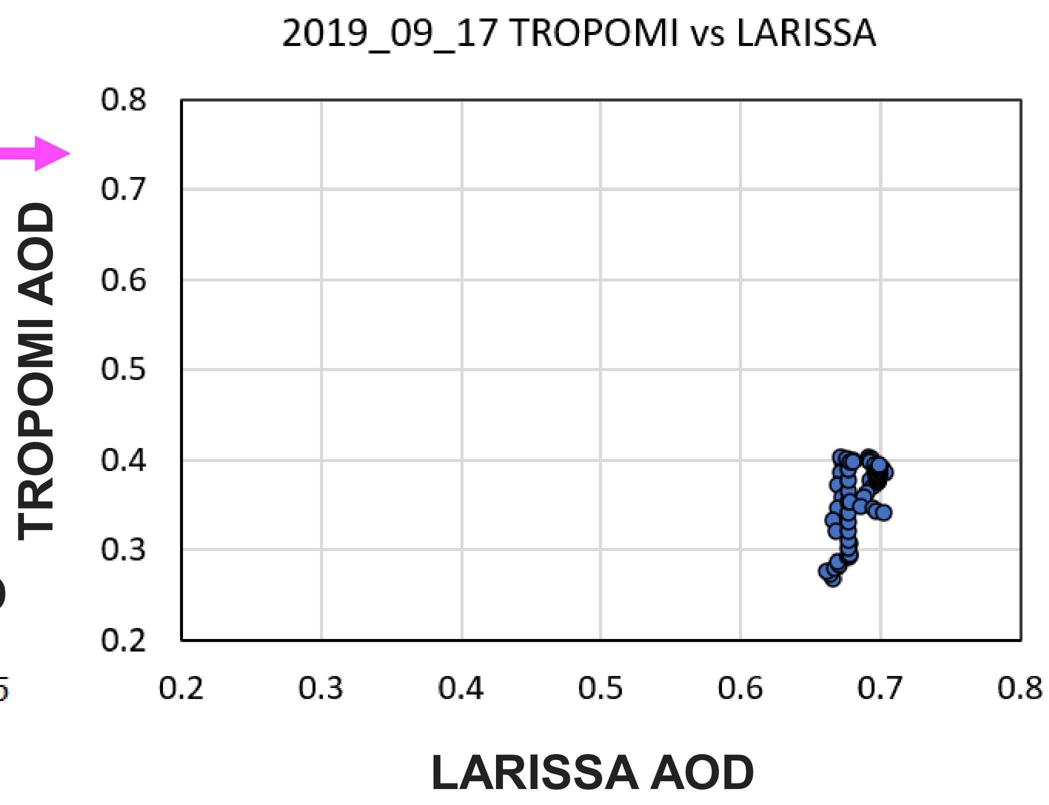
OVERALL RESULTS

- No statistical agreements for aggregated data, but some strong agreement cases (for OMI r > 0.70, for TROPOMI r ~0.60) can be found

CAN WE FIND THE SHORTEST TIME DIFFERENCE BETWEEN TROPOMI AND AEOLUS?

TROPOMI vs AEOLUS 2019 09 17





- One of the best agreement cases
- R = 0.60 between TROPOMI AOD and LARISSA
- Once again ~ +0.30 offset of LARISSA compared to validation source is noticed, LARISSA always overestimates validation sources

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CONCLUSIONS AND FURTHER PLANS

CONCLUSIONS

- Non-nadir LSR-based AOD retrieval from Josset et al., [2010] applied with unique lidar setup (37.5^o incidence, UV wavelength) -> **tested for Aeolus for the first time**
- The signal strength of the Aeolus ocean LSR is weak and **dominated by sub-surface reflectance**
- Sea surface reflectance model -> **Fair agreement with previous expectations ->** Subsurface might be overestimated
- Agreement between $AOD_{LARISSA}$ and $AOD_{AEL-PRO}$ **strongly varies** (r = 0.01 – 0.89), worse for AOD_{LAR} vs AOD_{TROP} (< 0.60)
- Offset between $AOD_{LARISSA}$ and reference AOD datasets -> Direct input for future similar retrievals, explaining why **sub-surface reflectance is overestimated**
- Additional result -> **Unexpectedly clear gradient between not only land and sea, but between different land cover types** when LSR is averaged on 1x1 degree grid


THANK YOU FOR
ATTENTION

METHODOLOGY AND RESULTS

AEOLUS

LARISSA AOD

AELPRO AOD

EXTERNAL DATA

TROPOMI AOD 355 NM

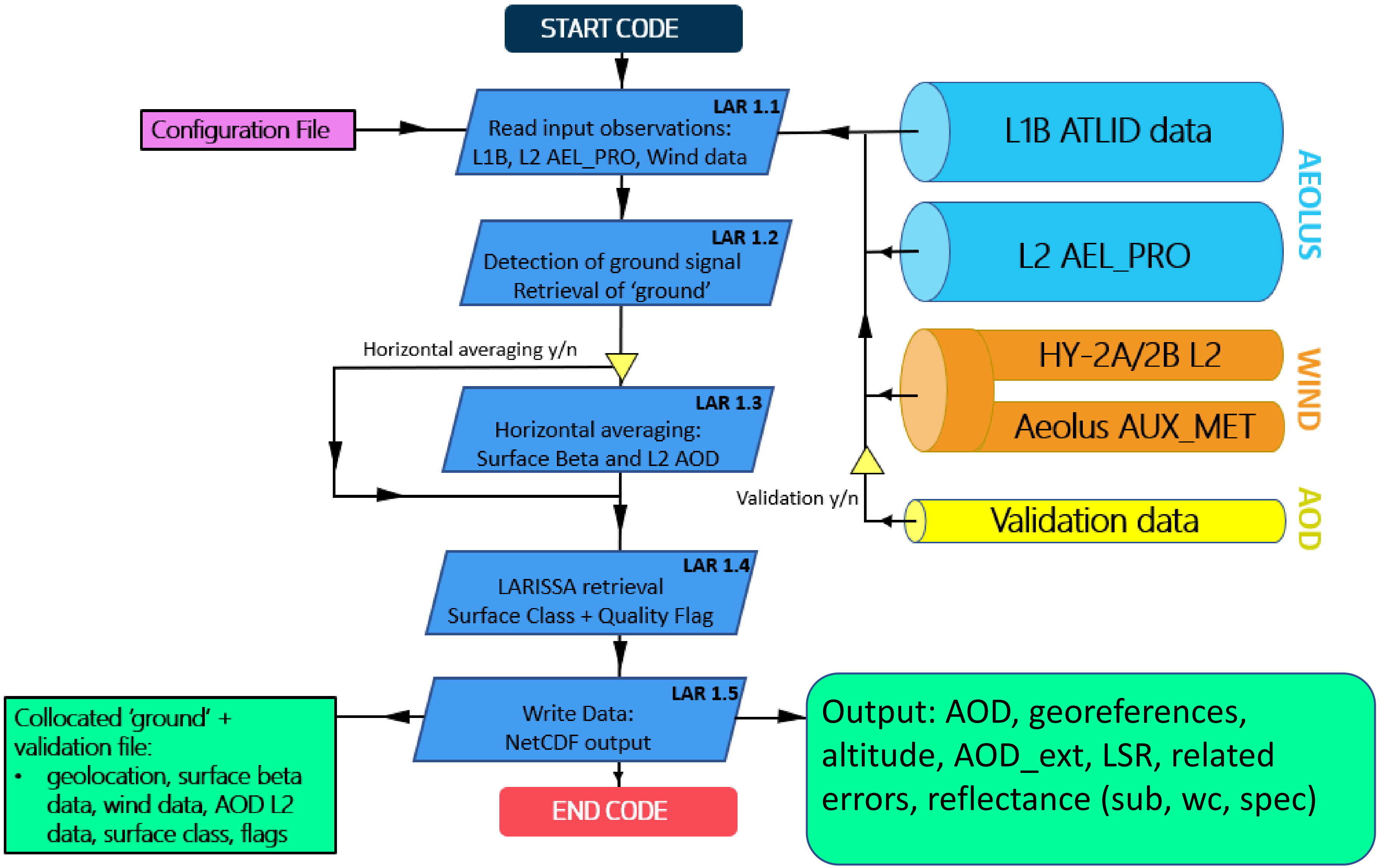
OMI AOD 355 NM

AERONET (ISLANDS)

AERONET (MARITIME)

VALIDATION BLOCK

THE STATUS OF THE SOFTWARE BY LAST PM



- All modules had been created and finalized according to the commitments by previous PM, but some optimizations were still required (done now)

REFLECTANCE TERMS:WHITECAPS AND SPECULAR REFLECTANCE

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SPECULAR TERM

$$\gamma = T_L^2\left(\frac{(1-W)\rho_0}{4\pi\,\sigma^2\cos^5(\theta')}\exp\left(\frac{-\tan^2(\theta')}{\sigma^2}\right) + W\cdot\frac{R_{f,eff}}{\pi}\cos(\theta')\right.$$
$$+\frac{\left(1-W_\downarrow\cdot R_{f,eff\downarrow}-(1-W_\downarrow)R_{s\downarrow}(\theta'_\downarrow)\right)[(1-W)]}{(1-r_f R_u)}\cos(\theta')\frac{T_{s\uparrow}(\theta'_\uparrow)}{m_\uparrow^2}\frac{R_u}{Q(\theta'_u)}$$
$$\left.+\frac{(1-W_\downarrow\cdot R_{f,eff\downarrow}-(1-W_\downarrow)R_{s\downarrow}(\theta'_\downarrow))}{(1-R_{f,eff}R_u)}W\left(\frac{1-R_{f,eff}}{\pi}\right)\cos(\theta')\,R_u\right)$$

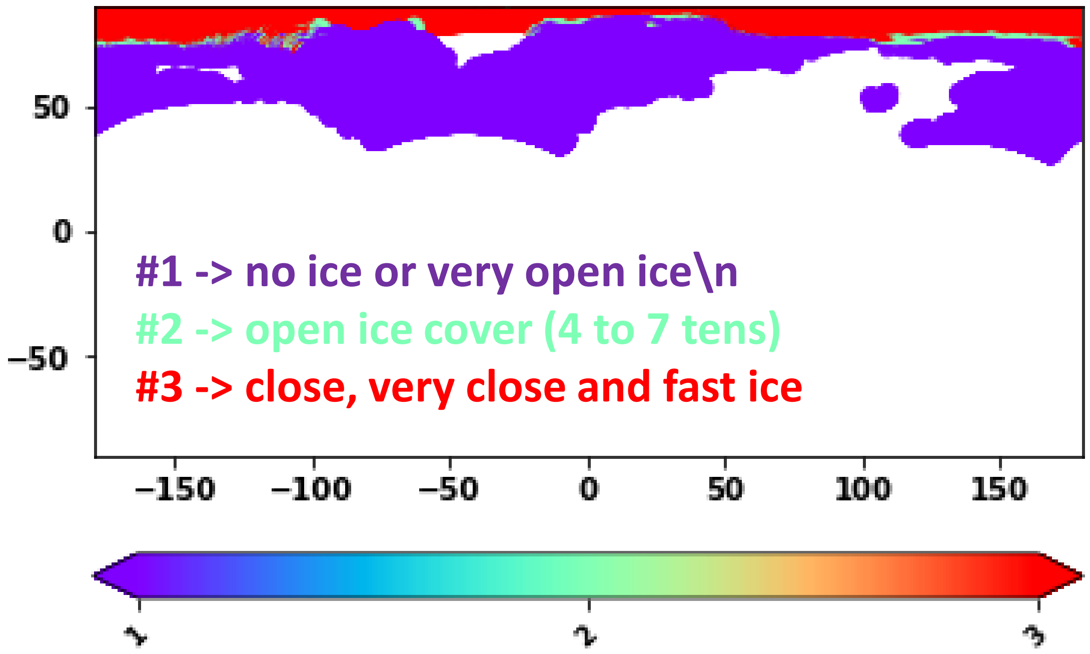
WHITECAPS TERM

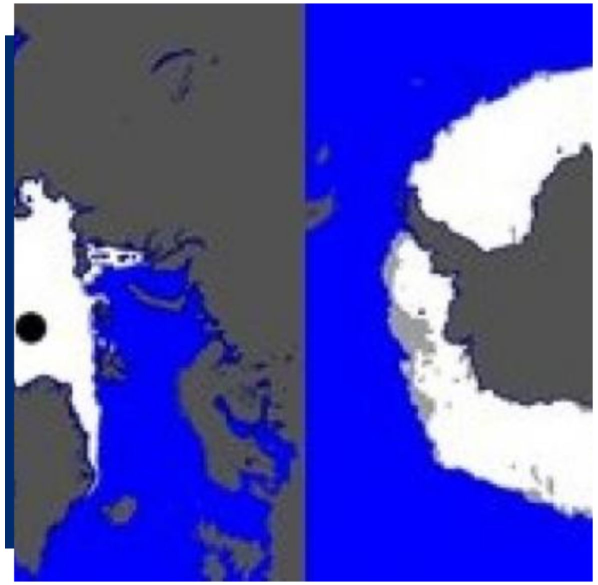
```
spec_term = ((1-w_area) * fresnel) / (4 * np.pi * slope * np.cos(np.deg2rad(angle))**5) * np.exp ((-np.tan(np.deg2rad(angle))**2)/slope)

wc_term = w_area * (w_ref/np.pi) * np.cos(np.deg2rad(angle)) #calculating whitecap terms of summarized reflectance
```

- I assume this effect might be related to wind/slope or angle?

ICE MASK USE





Global Sea Ice Edge

Operational

version OSI-403-b since 15/09/2015, version OSI-403-c since 30/05/2017

S-OSI_-NOR_-MULT-GL_NH_EDGEn_-201909151200Z.nc	Daily Sea Ice Edge Analysis from OSI SAF EUMETSAT	Local File
confidence_level	confidence level	Geo2D
ice_edge	sea ice edge	Geo2D
lat	latitude coordinate	Geo2D
lon	longitude coordinate	Geo2D
Polar_Stereographic_Grid	Polar Stereographic Grid	—
status_flag	status flag for sea ice edge retrieval	Geo2D
time	reference time of product	—
time_bnds	time bnds	1D
xc	x coordinate of projection (eastings)	1D
yc	y coordinate of projection (northings)	1D

- Based on ASCAT backscatter
- We can choose 2 and 3 (stringent threshold) to filter out all possible ice cases
- The box within specific grid cell is chosen and ice flag is assigned

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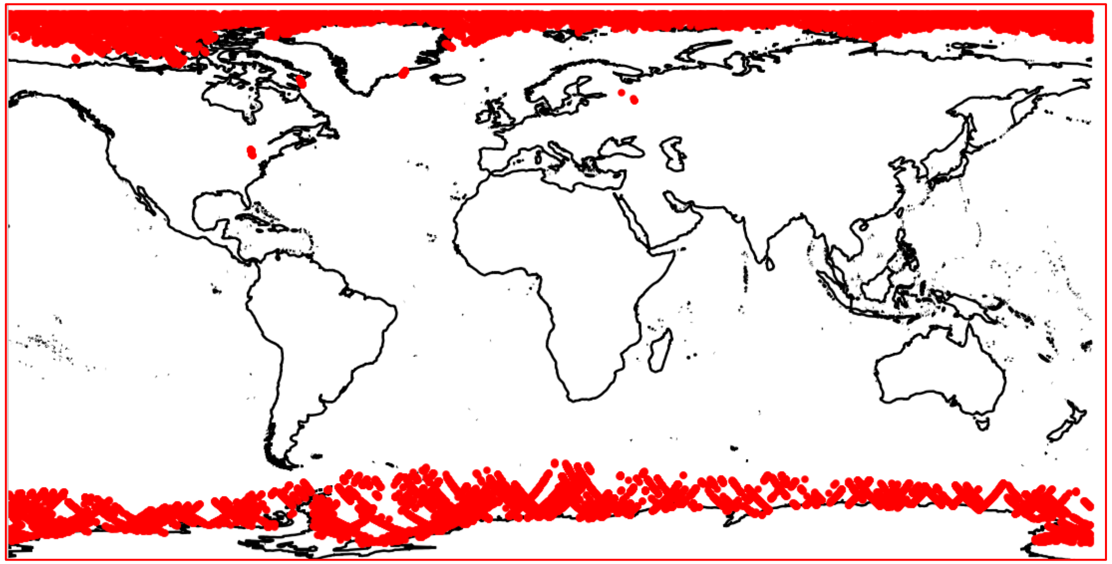
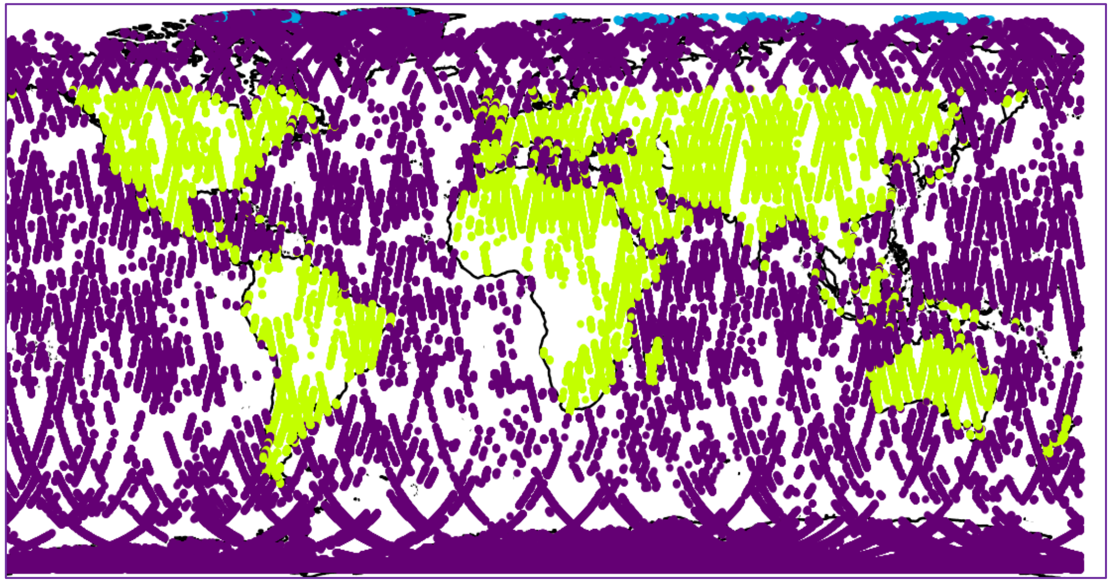
CHECKING THE CONSISTENCY OF ICE MASK

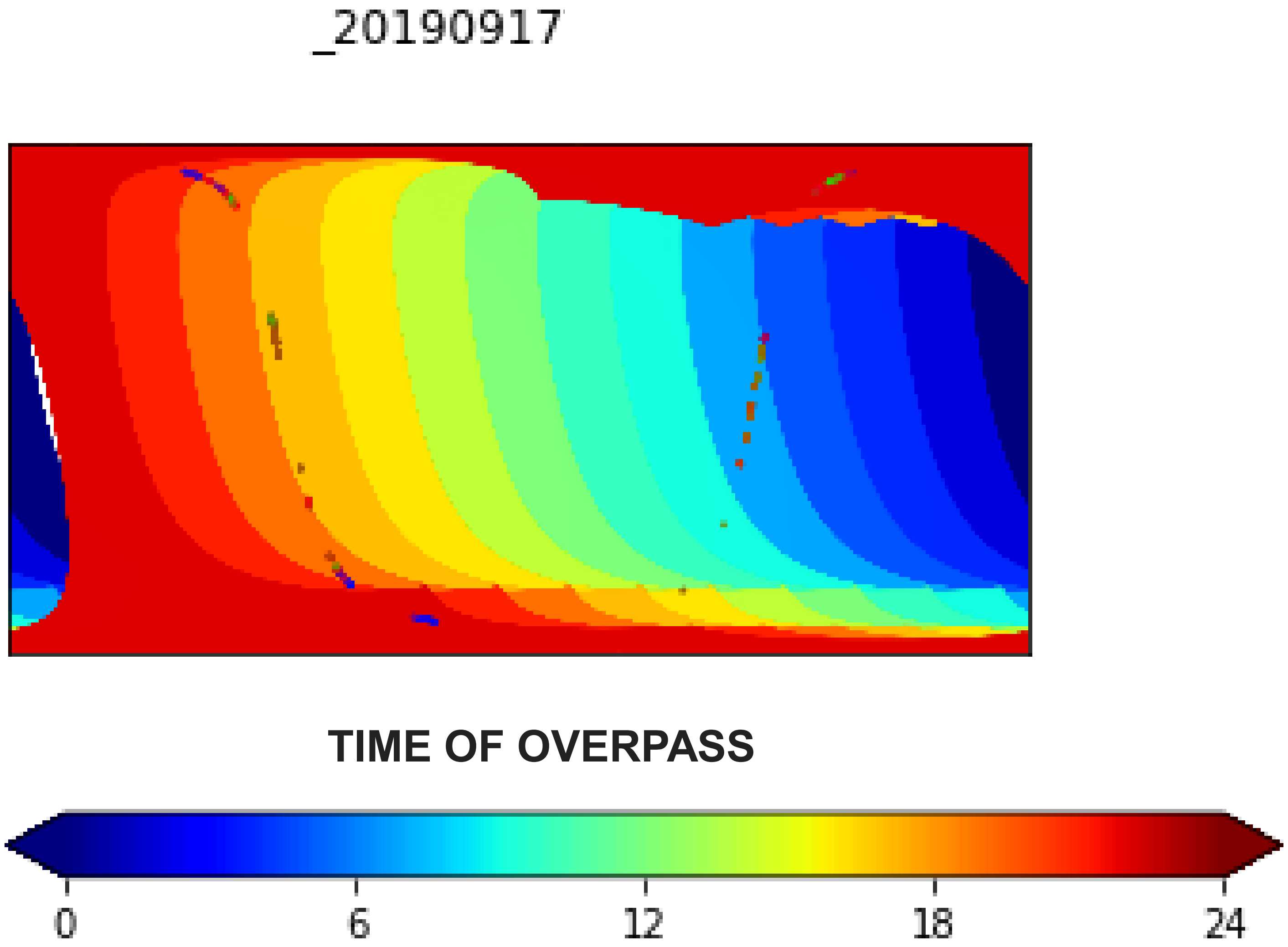


ICE MASK | FLAG = 4



NOT ICE | FLAG = 1,2,3

LARISSA vs TROPOMI TIMING



- There is no perfect timing collocation, but we can aggregate TROPOMI and Aeolus observations daily by assuming homogeneity of aerosol layers and collocate TROPOMI points based on defined time/location difference