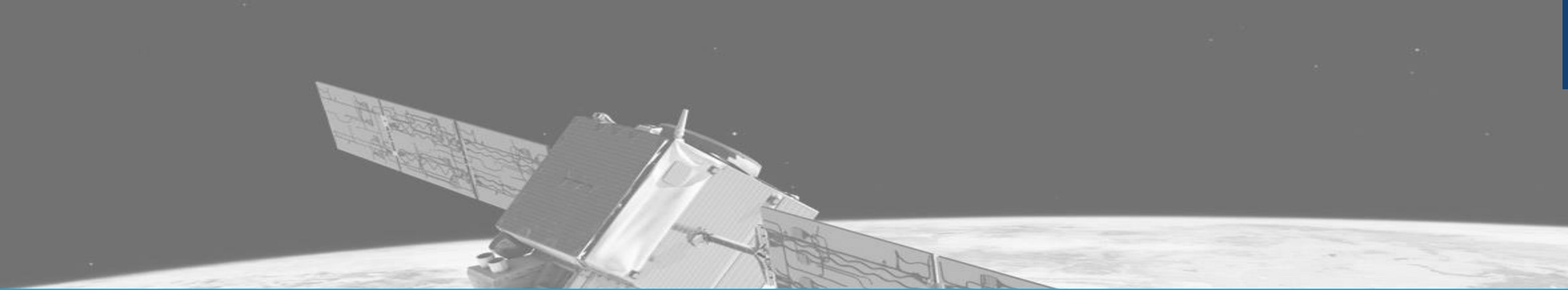
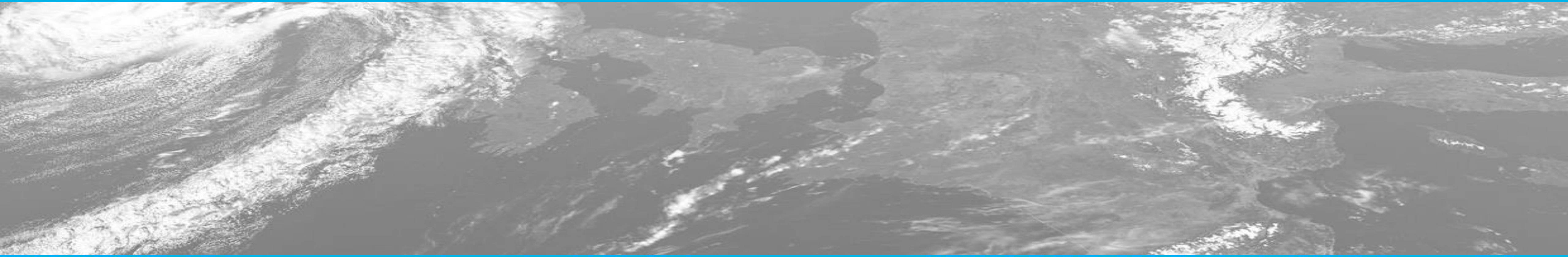


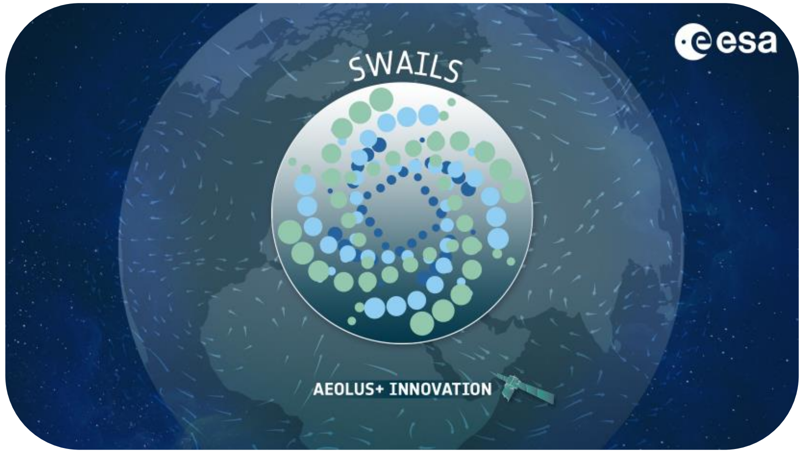
First results from AOD retrieval based on Ocean Lidar Surface Returns from Aeolus



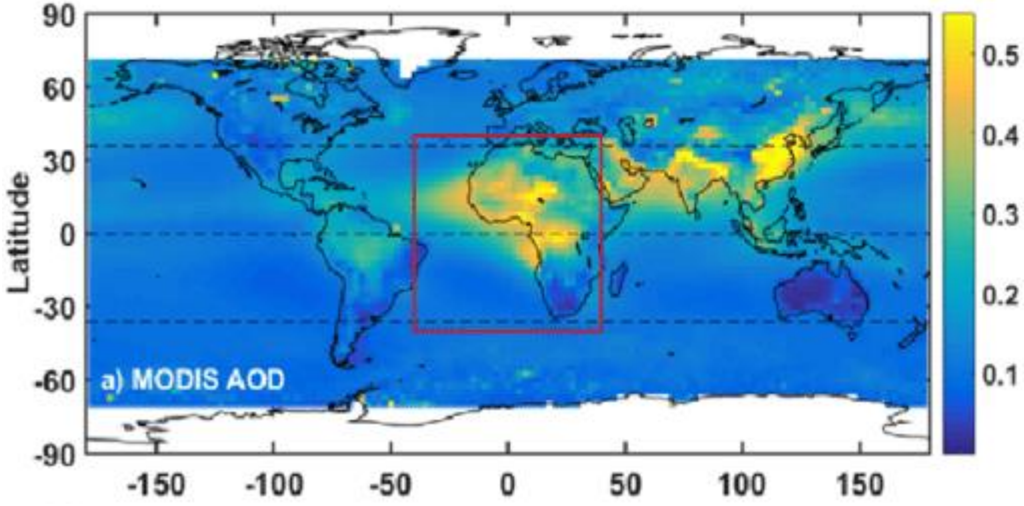
L. Labzovskii*, G. J. van Zadelhoff, D. Donovan, D. Josset

24.11.2021 | ATMOS 2021

RESEARCH AIM AND MOTIVATION



AOD distribution [Wang et al., 2018]



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

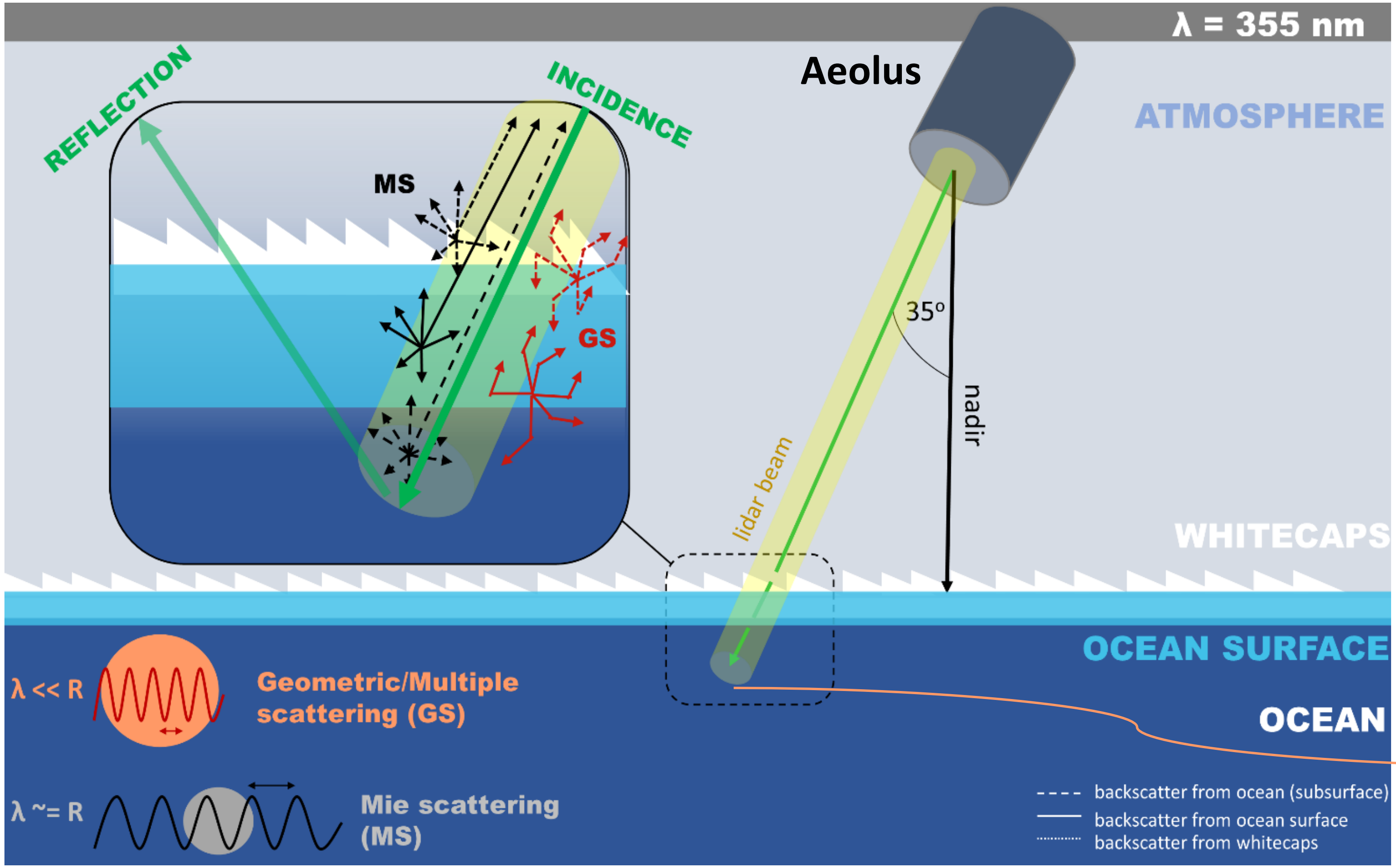
RESEARCH AIM

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

IMPLICATIONS

- New AOD estimates from lidar surface returns -> No **assumption about lidar ratio** or 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

FUNDAMENTALS OF LSR-BASED AOD RETRIEVAL FOR AEOLUS



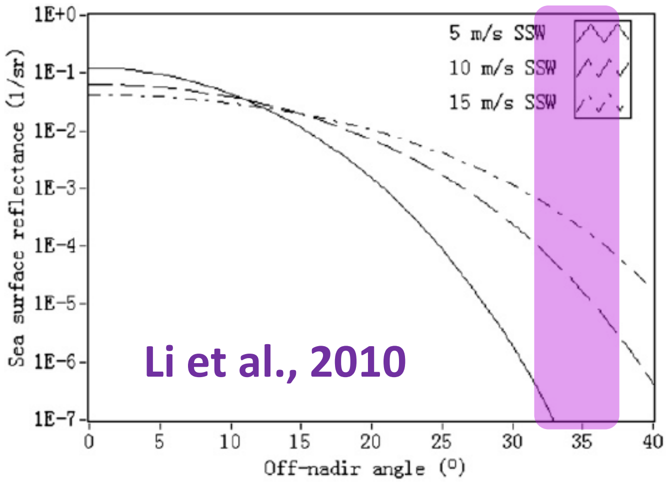
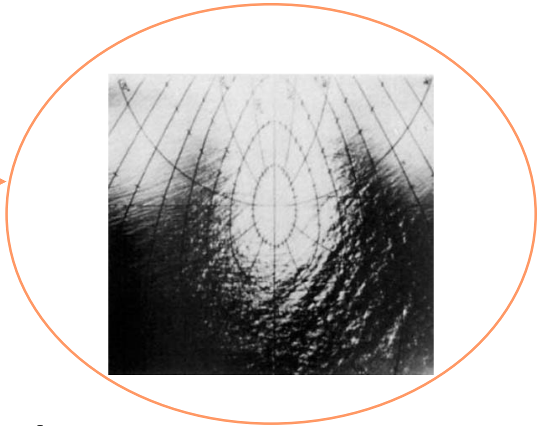


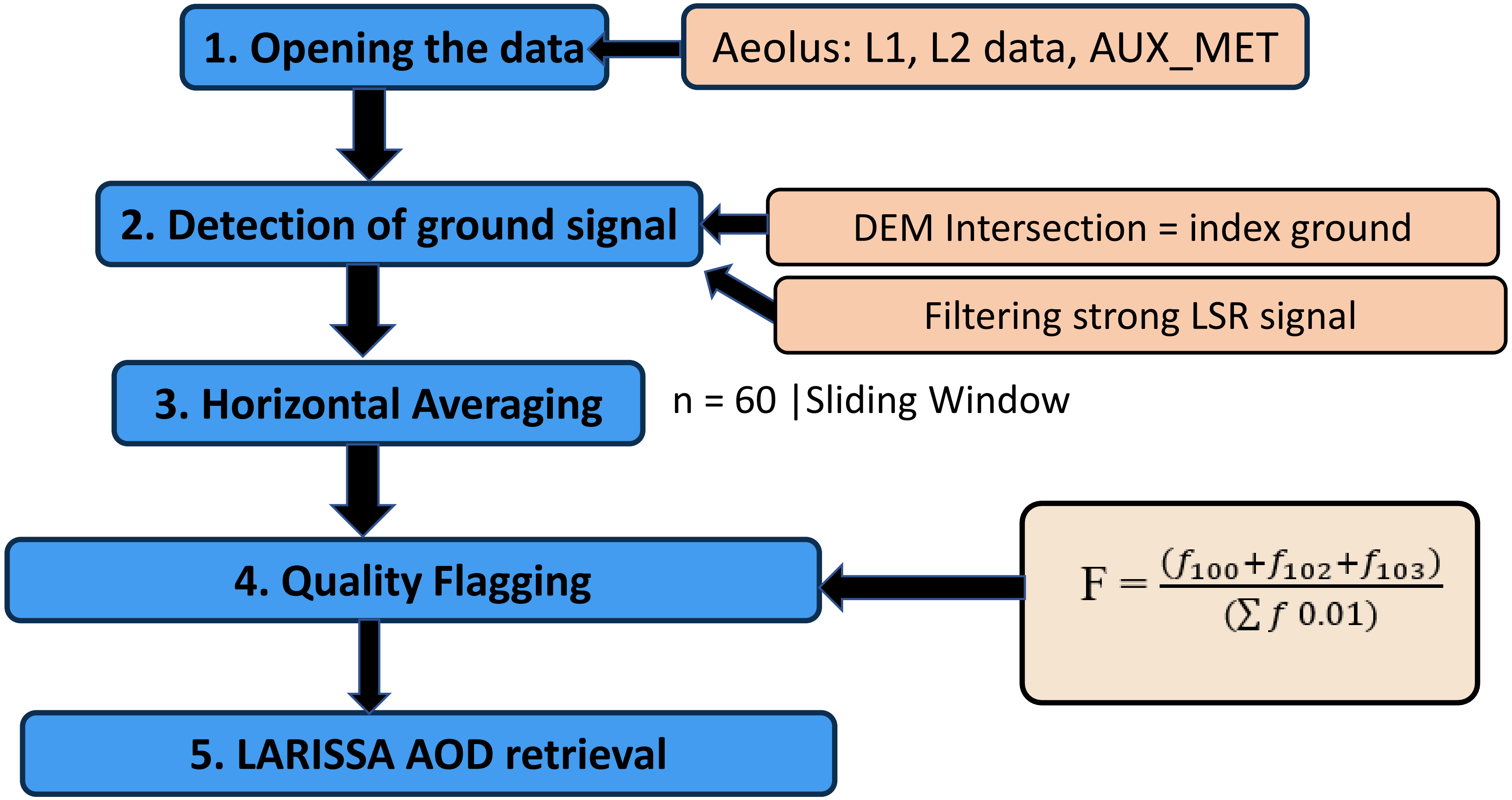
FIG. 4. Sea surface specular reflectance for different off-nadir angles and SSW at 355 nm.

[Cox and Munk, 1954]



- 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

METHODOLOGY



$$AOD_{LARISSA} = \frac{1}{2} \ln\left(\frac{specular+whitecaps+subsurface}{\gamma}\right) - \mathrm{OD_m}$$

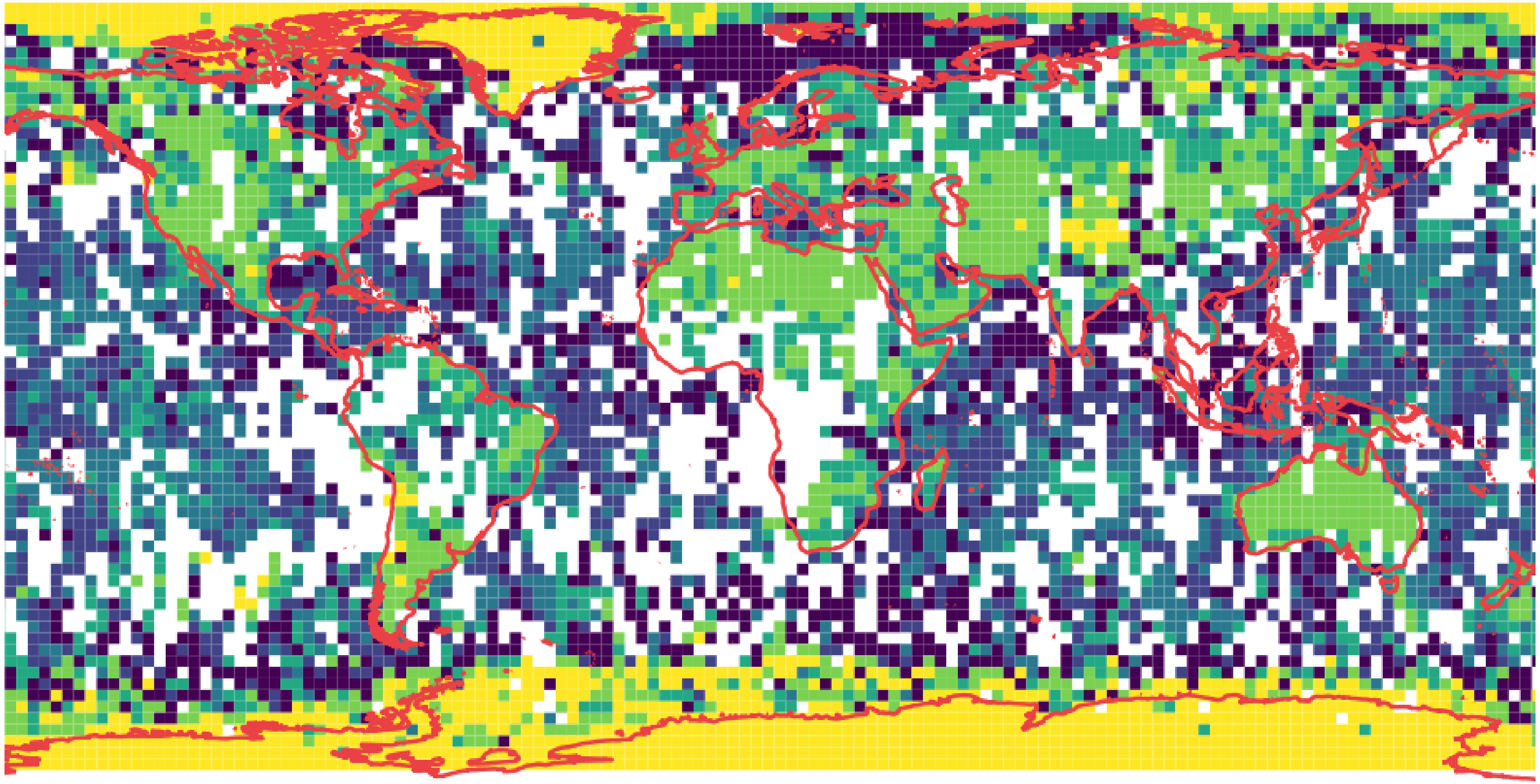
Josset et al, [2010]

- γ – SIAB (Surface Integrated Attenuated Backscatter) **is LSR or input from lidar**-> Calculated at the step (2)
- Quality **flagging is based on the Aeolus L2a AEL-PRO quality** flag (attenuated features forfeited)
- LARISSA retrieval (step 5) -> Based on **Josset et al., 2010 equation** from previous slides

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

USEFUL OBS. OVER OCEANS (%)

26.13 %
26.96 %
22.42 %
30.70 %
33.63 %
21.50 %
18.78 %
35.92 %
29.54 %
28.50 %

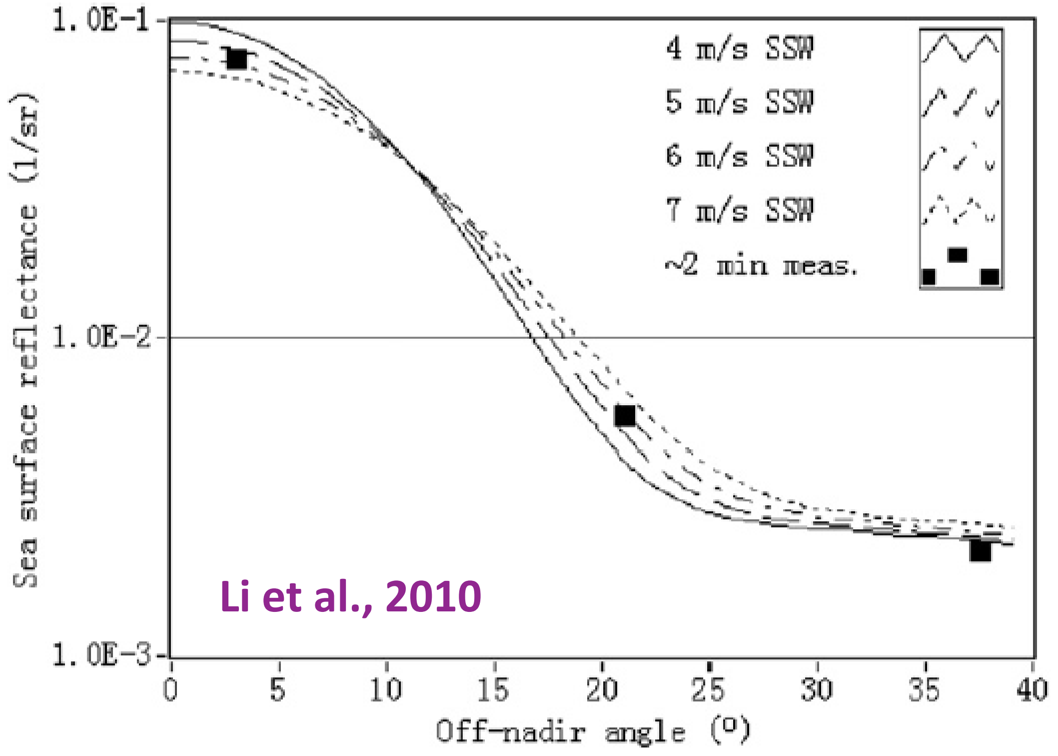


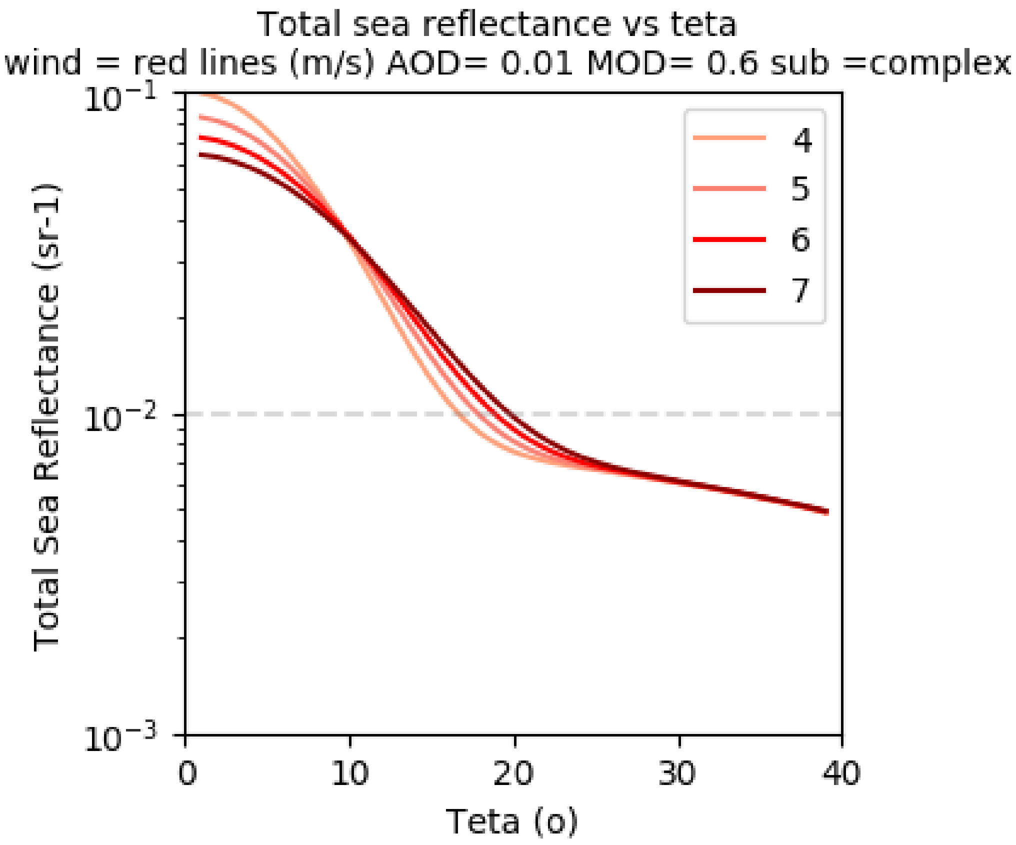
LSR (sr^{-1})

- -0,00099 - 0,00016
- 0,00016 - 0,00025
- 0,00025 - 0,00035
- 0,00035 - 0,00093
- 0,00093 - 0,00285
- 0,00285 - 0,03822

- **Very clear gradient** between land, ocean and ice surface
- **Many** strong returns over oceans (19-34%)
- 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)

SUMMARIZED SURFACE REFLECTANCE CALCULATION

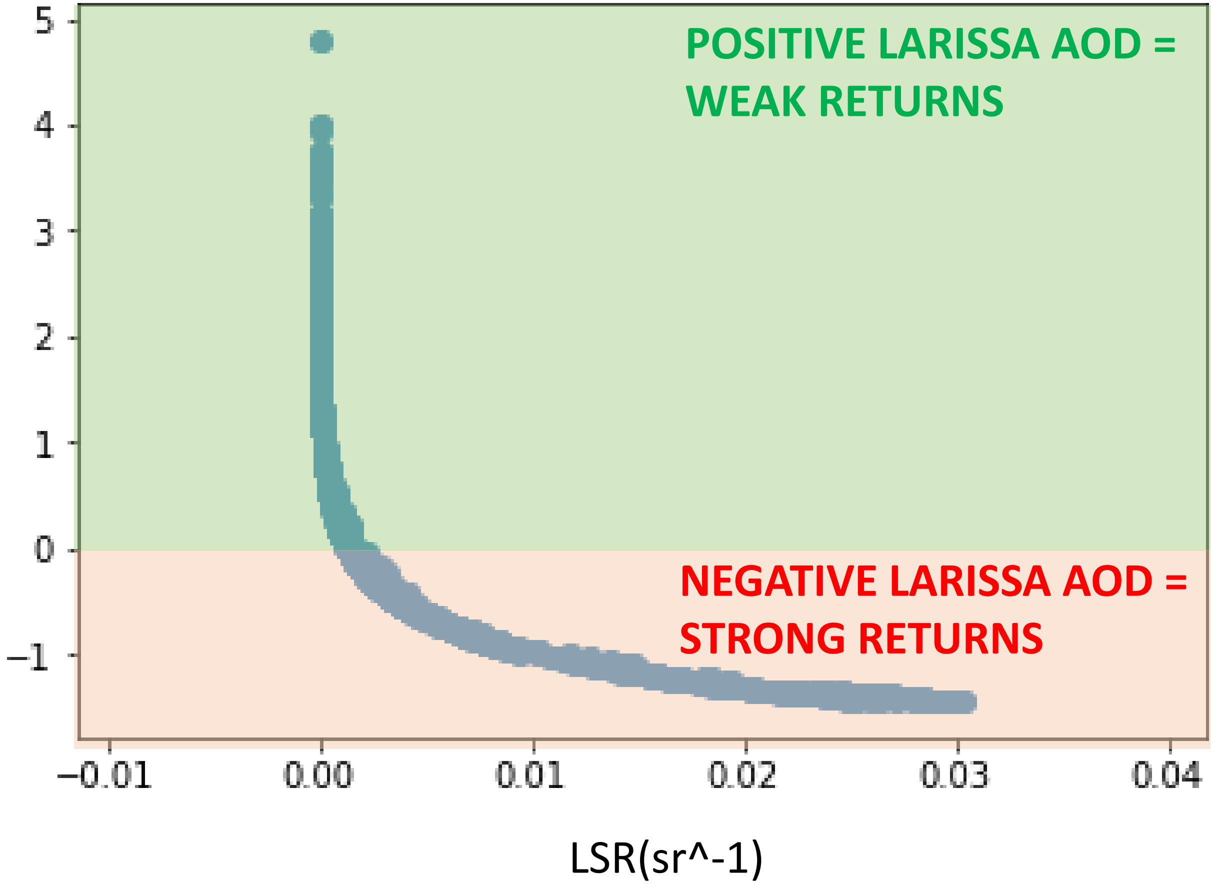


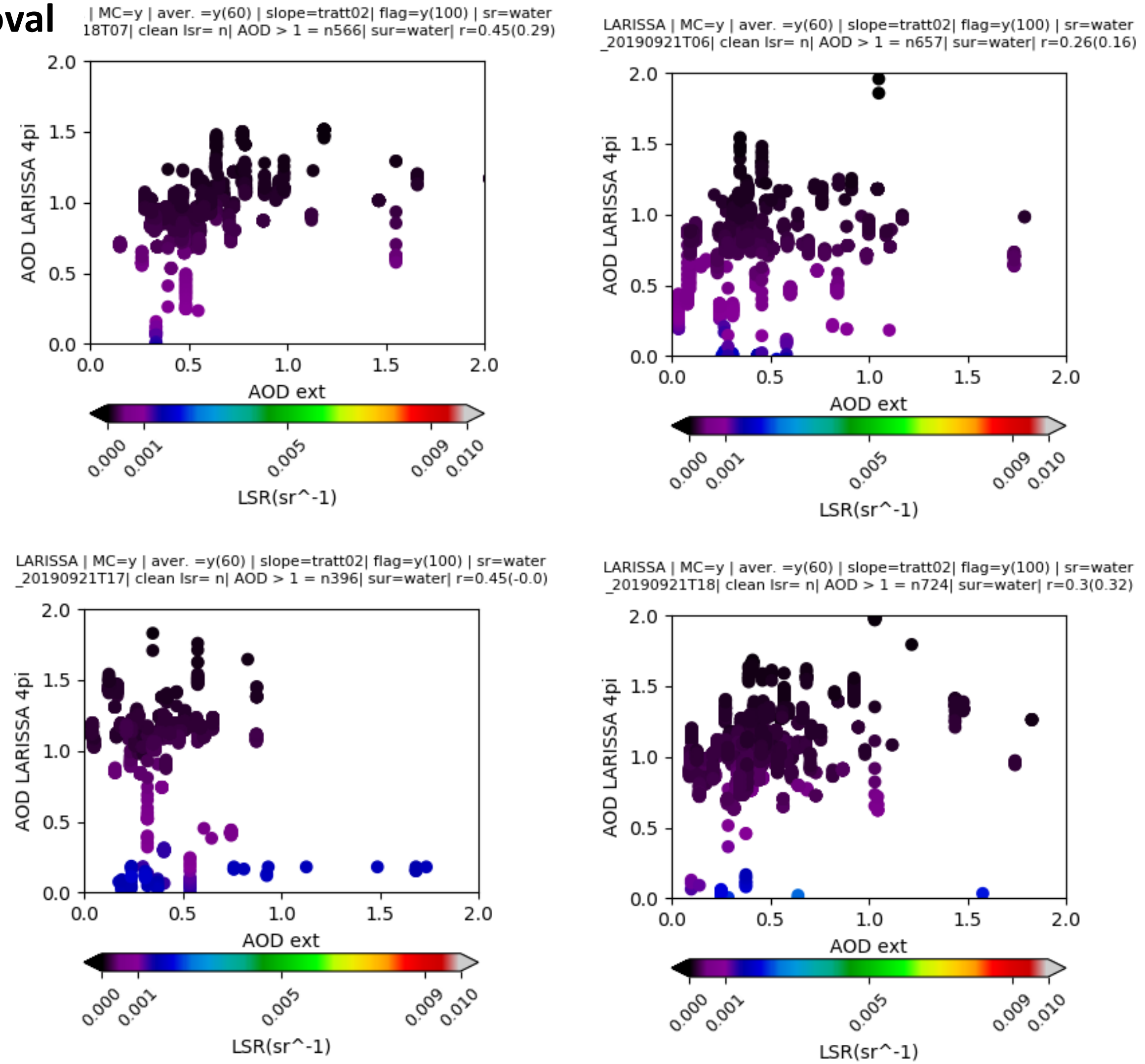


- **Good agreement with previous works** [Li et al., 2010] - > while Josset-2010 equation applied
- Despite good agreement in pattern/magnitude -> Potential **overestimation of subsurface component** at 37.5º

ANALYZING SELECTED CASES OVER ARABIAN SEA

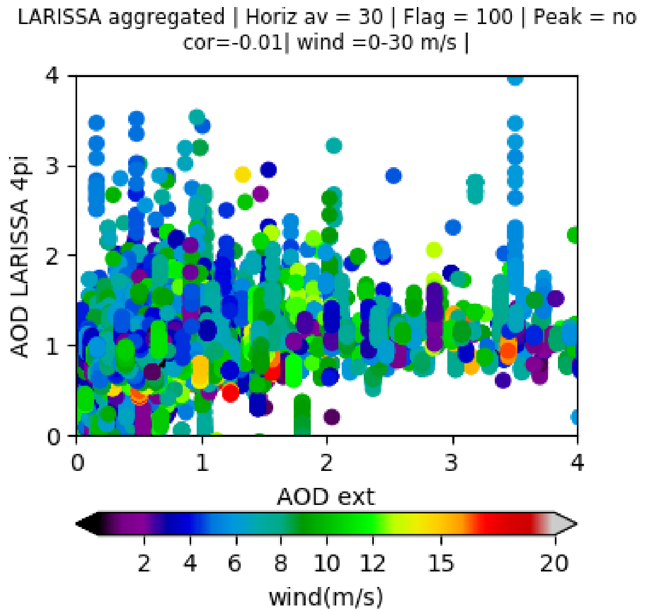
STEP 2: SIAB calculation from detection of surface and cloud removal

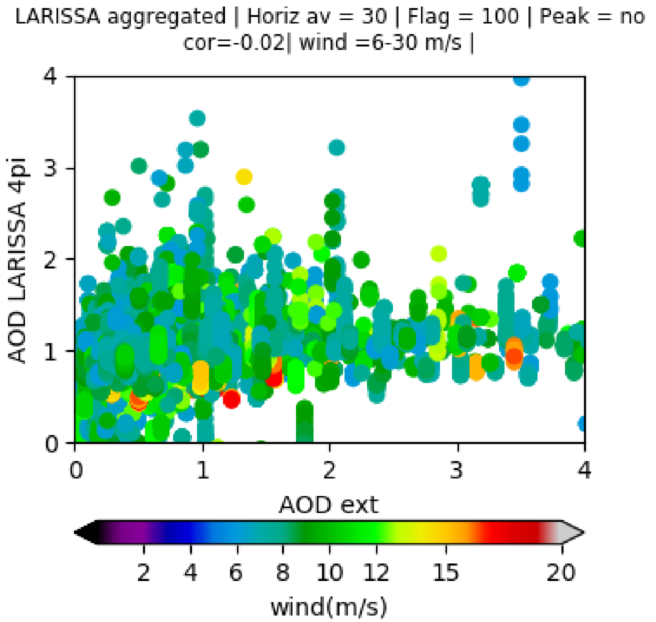


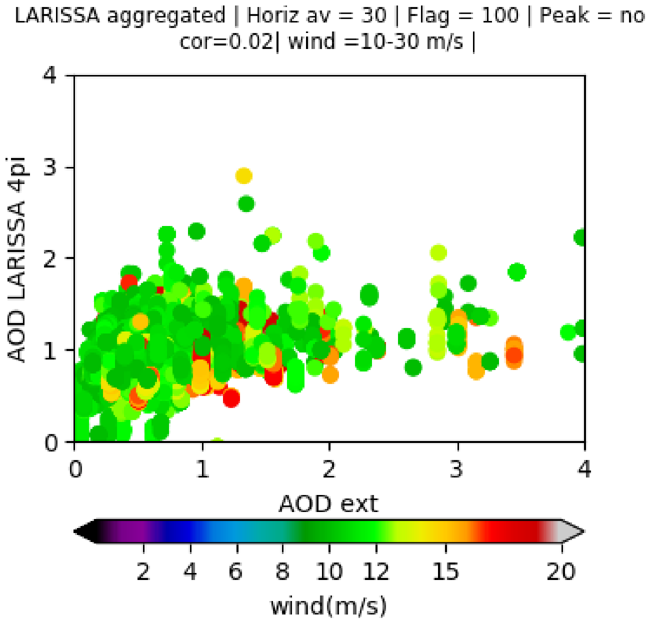


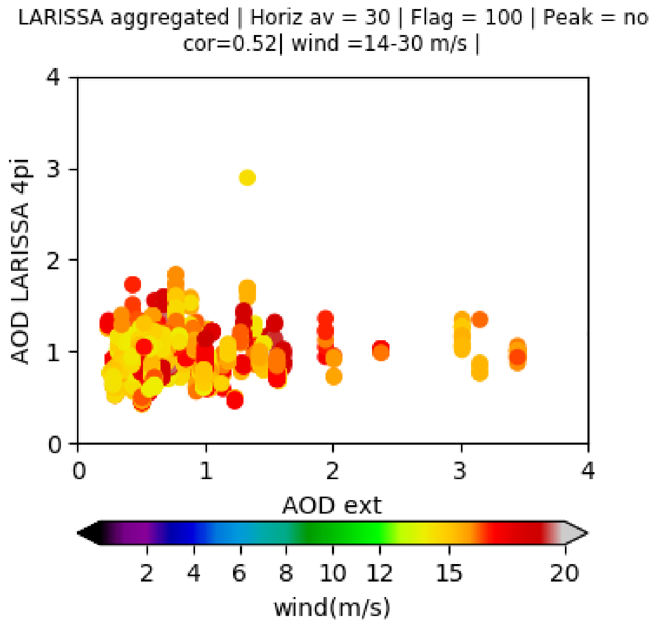
- **Quasi-linear relationship** between AODLARISSA and AOD-EXT is seen -> r = 0.26 – 0.45
- Lack of stronger relationship -> **Two distinct LSR populations** (weak and strong LSR)
- Strong ocean LSR (undetected sea ice/clouds/ocean color cluster?) > e-stimated maximum surface return -> **negative AOD**
- **No expected** sensitivity to near surface wind speed detected -> Winds are too weak or moderate

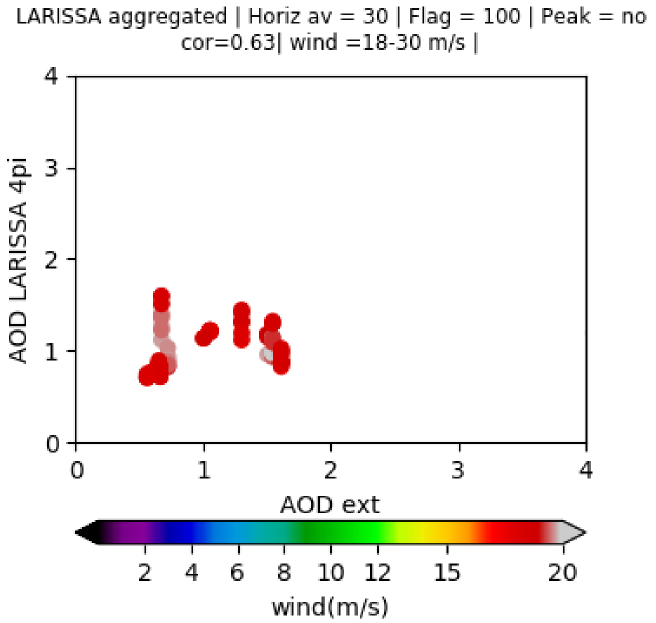
GLOBAL SCALES: NO STRONG SENSITIVITY TO WIND SPEED





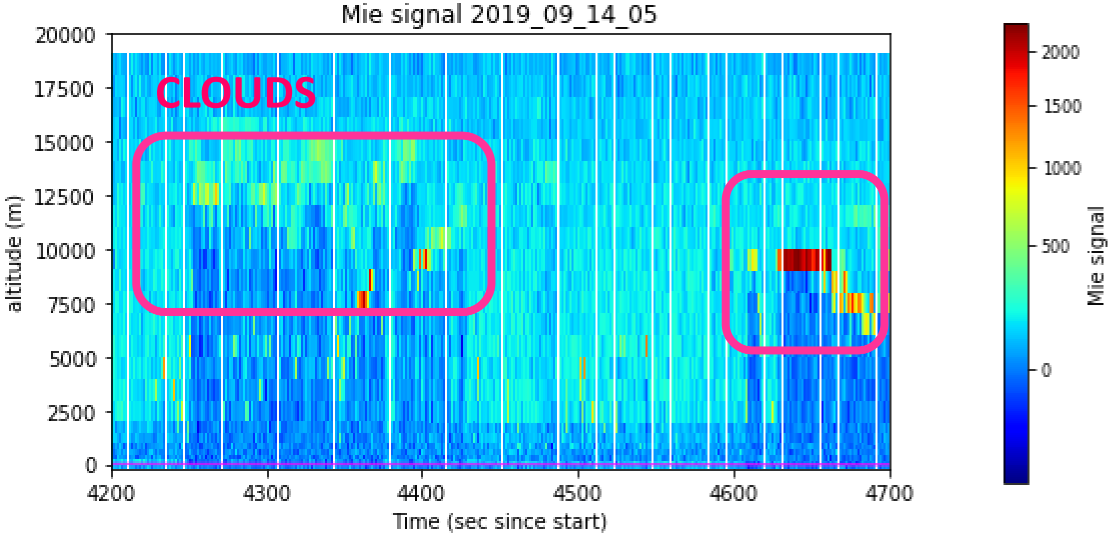


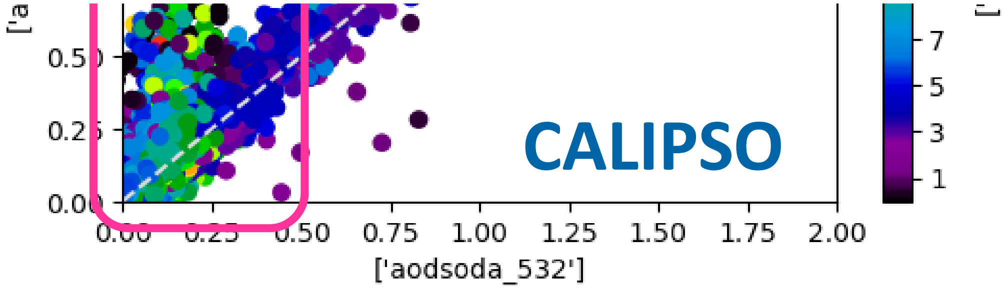


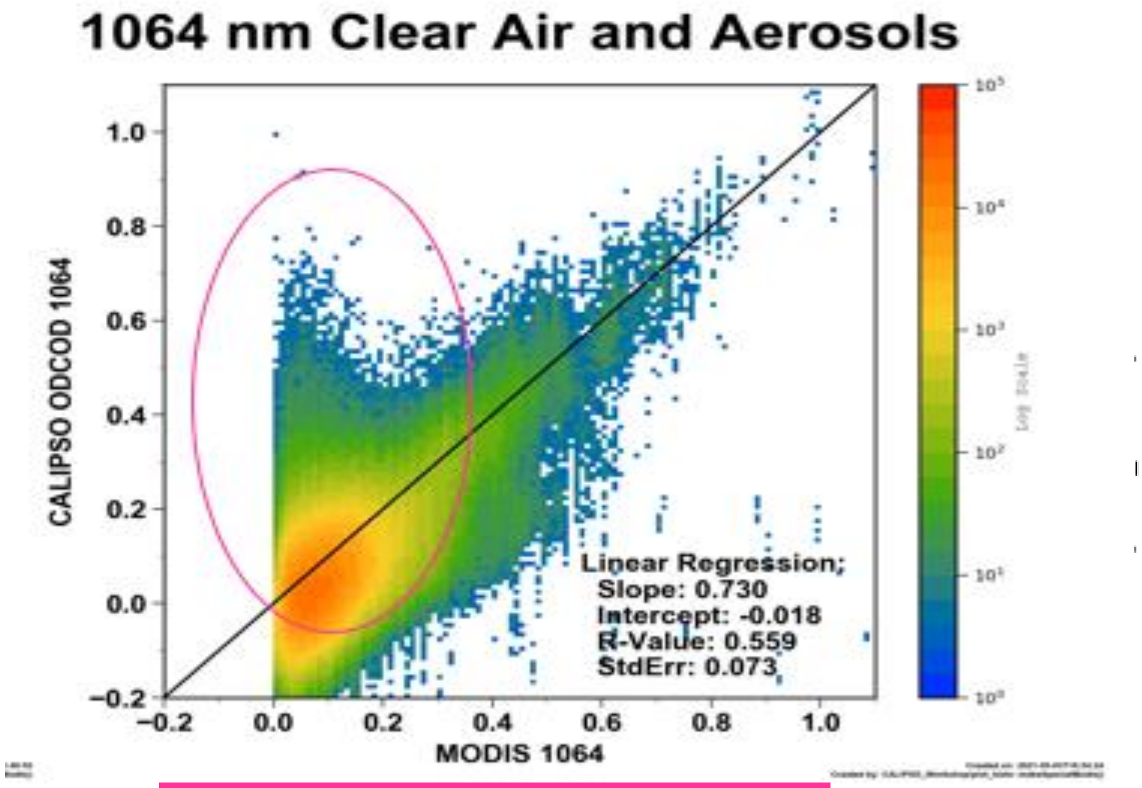


- Every plot -> **Binning based on wind range**
- At 10-30 m/s -> Visible improvement
- At 14-30 m/s -> Quantitative improvement (**r = 0.52**)
- Is **0.52** good correlation?

B4. Screening out clouds (Aeolus example)







ODCOD = Ryan et al., 2021 LSR-based AOD retreival

- LARISSA **agrees well with SODA** (5 km SODA*) -> r = 0.65 (outliers are minor according to right plot)
- All the outliers **are related to clouds** that were undetected
- Day: 2009-05-01 (all orbits during this day)

SODA* - Synergistic Optical Depth Retrieval

CONCLUSIONS AND FURTHER PLANS

CONCLUSIONS

- Non-nadir LSR-based AOD retrieval from Josset et al., 2010 tested 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

- AOD retrieval implies developed block for detecting strong LSR, quality flagging, parametrization with wind created -> **Fair agreement of $AOD_{LARISSA}$ with $AOD_{AEL2PRO}$** estimates from extinction coefficients

- Agreement between $AOD_{LARISSA}$ and $AOD_{AEL-PRO}$ **varies depending on the case** (r = 0.01 – 0.89)

- The sensitivity of LSR from Aeolus to **near-wind speed is lower than expected** -> **Some sensitivity exists at 13-30 m/s wind** (r = 0.52 for IOP global aggregated data

- 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

TO DO

- Validate both $AOD_{LARISSA}$ and AOD_{AELPRO} vs independent AOD estimate (AERONET, maritime AERONET, TROPOMI)
- Estimate the sensitivity of $AOD_{LARISSA}$ to subsurface conditions
- Use wind input not from model, but from collocated observations (HY-2A / HY-2B)
- Evaluate the robustness of LSR (i.e., potentially Bidirectional Reflectance Distribution Function and surface albedo due to land cover)

THANK YOU FOR ATTENTION

THANK YOU FOR ATTENTION


THANK YOU FOR
ATTENTION


THANK YOU FOR
ATTENTION

ADDITIONAL SLIDES

DETAILS: EXTINCTION AND ATTENUATED BACKSCATTER VS LARISSA AOD

"Simple" LARISSA

$$AOD = \mu \frac{1}{2} ln\left(\frac{\mu\, kC_L\rho_{fr}}{4\pi < S^2 > \gamma}\right)$$

"Complex" LARISSA

$$AOD = \frac{1}{2}\, ln(\frac{Rs+Rw+Ru}{\gamma})$$

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

- The problem last time was the lack of complex subsurface formulation (simplified)
- In fact -> Simple = nadir, complex = non-nadir

AOD calculation from summarized ocean reflectance

$$\gamma = T_L^2 \Bigg(\frac{(1-W)\rho_0}{4\pi\,\sigma^2 \cos^5(\theta')} \exp\left(\frac{-\tan^2(\theta')}{\sigma^2}\right) + W \cdot \frac{R_{f,eff}}{\pi} \cos(\theta')$$

$$+ \frac{\left(1 - W_{\downarrow} \cdot R_{f,eff\downarrow} - (1-W_{\downarrow}) R_{s\downarrow}(\theta'_{\downarrow})\right) [(1-W)]}{(1 - r_f R_u)} \cos(\theta') \frac{T_{s\uparrow}(\theta'_{\uparrow})}{m_{\uparrow}^2} \frac{R_u}{Q(\theta'_u)}$$

$$+ \frac{(1 - W_{\downarrow} \cdot R_{f,eff\downarrow} - (1-W_{\downarrow}) R_{s\downarrow}(\theta'_{\downarrow}))}{(1 - R_{f,eff} R_u)} W\left(\frac{1 - R_{f,eff}}{\pi}\right) \cos(\theta')\, R_u \Bigg)$$

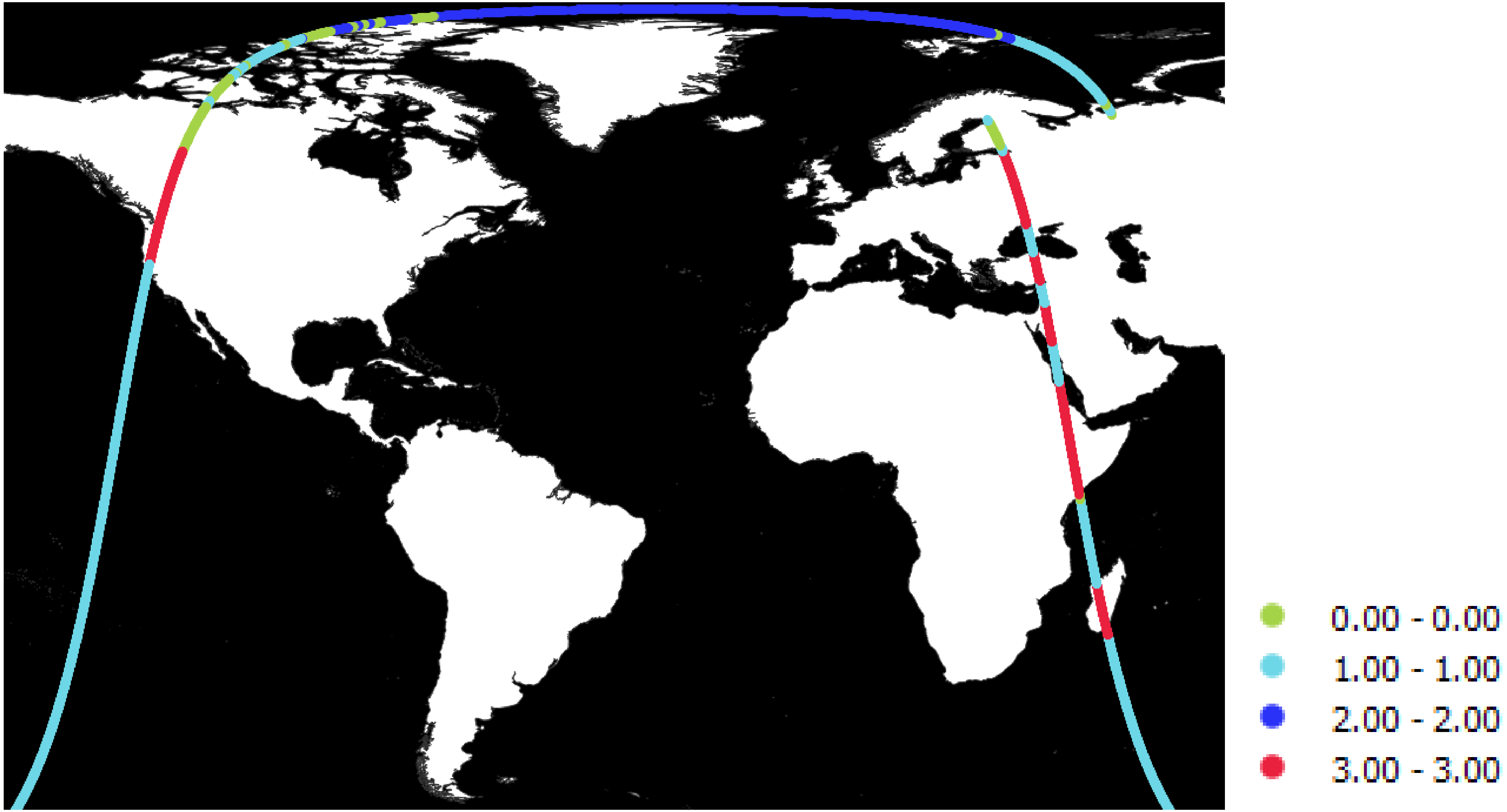
Originally formulated: Josset et al., 2010
Advantages: Subsurface considered
Used: never in empirical studies

- Specular
- Whitecaps
- Subsurface

Instrument and data

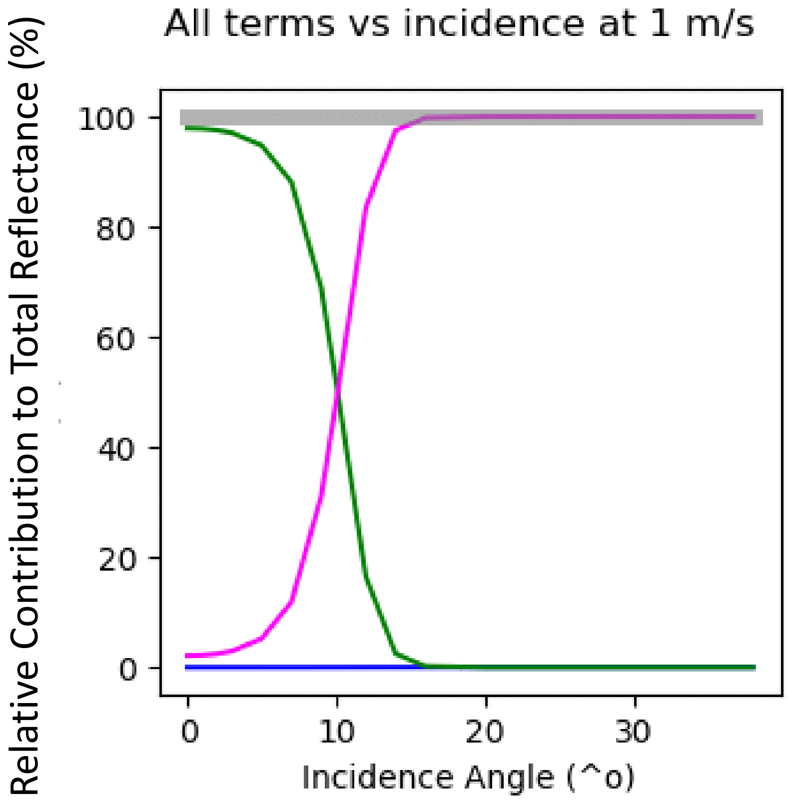
- **Instrument:** ALADIN (Atmospheric Laser Doppler Instrument) onboard Aeolus
- **Wavelength:** ~355 nm
- **Period:** Intensive Observation Period (IOP: 14 – 23 September 2018)
- **Input data:**
  - **L2 data:** Surface Integrated Attenuated Backscatter (from Mie Signal)
  - **AUX_MET:** Simulated near-surface wind speed
- **Validation data**:
  - **AEL PRO_L2**: Extinction Coefficient, Rayleigh Backscattering

SEA FLAGGING STRATEGY IS SIMPLIFIED



- We use these flags to distinguish sea surfaces from land
- 1 and 2 are sea surfaces, 0 and 3 are land

ALL TERMS VS INCIDENCE ANGLE AT WIND SPEED = 4 M/S



- Total term
- Specular
- Subsurface (simplified)
- Whitecaps (Rf,eff = 0.22)

- Whitecaps -> Negligible at 1-5 m/s, importance increases with angle as well
- Subsurface term dominates at low winds (> 99%) for > 10° incidences
- Specular term is basically in counterphase with subsurface

SUBSURFACE TERM TESTING: JOSSET-2010 PARAMETRIZATION

SUBSURFACE TERM

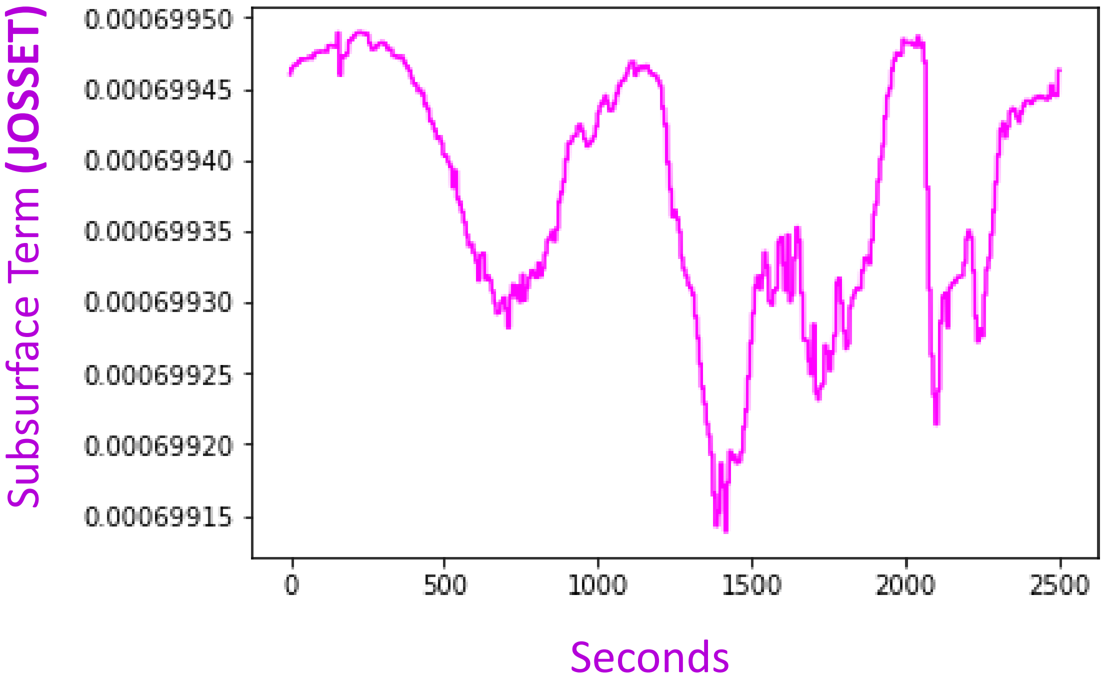
$$\gamma = T_L^2 \left(\frac{(1-W)\rho_0}{4\pi\,\sigma^2 \cos^5(\theta)} \exp\left(\frac{-\tan^2(\theta)}{\sigma^2}\right) + W \cdot \frac{R_{f,eff}}{\pi} \cos(\theta) \right.$$

$$+ \frac{\left(1 - W_\downarrow \cdot R_{f,eff\downarrow} - (1-W_\downarrow) R_{s\downarrow}(\theta_\downarrow)\right)[(1-W)]}{(1 - r_f R_u)} \cos(\theta') \frac{T_{s\uparrow}(\theta'_\uparrow)}{m_\uparrow^2} \frac{R_u}{Q(\theta'_u)}$$

$$\left. + \frac{(1 - W_\downarrow \cdot R_{f,eff\downarrow} - (1-W_\downarrow) R_{s\downarrow}(\theta_\downarrow))}{(1 - R_{f,eff} R_u)} W\left(\frac{1 - R_{f,eff}}{\pi}\right) \cos(\theta)\, R_u) \right)$$

$$R_u = \frac{R_0 \cos(\theta)}{\pi}$$

0.002236



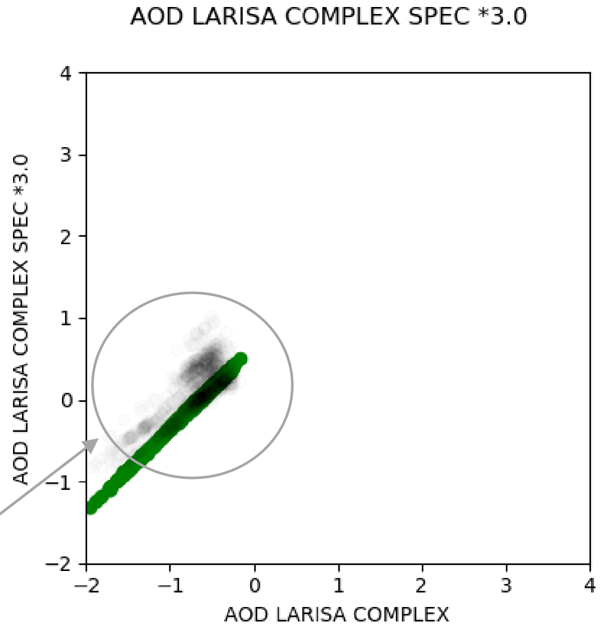
SUBSURFACE ANALYTICAL = 0.000377 (Ru = 0.01 assumed)

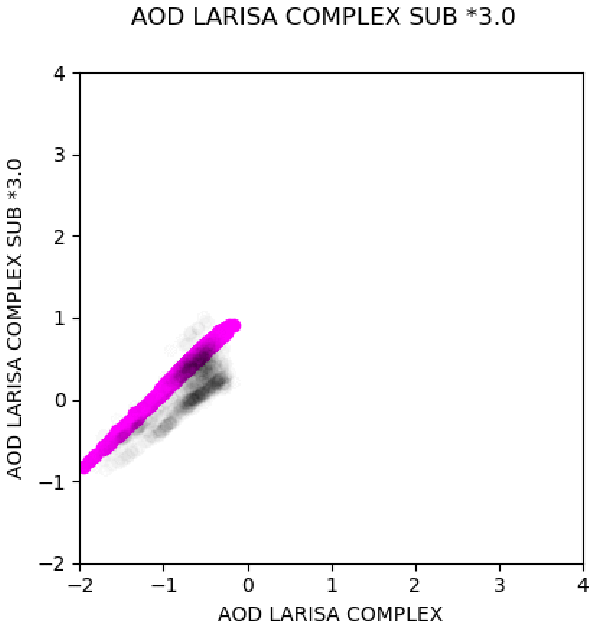
SUBSURFACE JOSSET PARAMETRIZATION = 0.0006991 – 0.0006994

- Reasonable agreement with analytical formulation
- Josset formulation > Analytical formulation (as expected)

ALL AOD TERMS VS WIND SPEED RANGE (MEANS)

If specular term is too high, complex LARISSA becomes similar to simple LARISSA

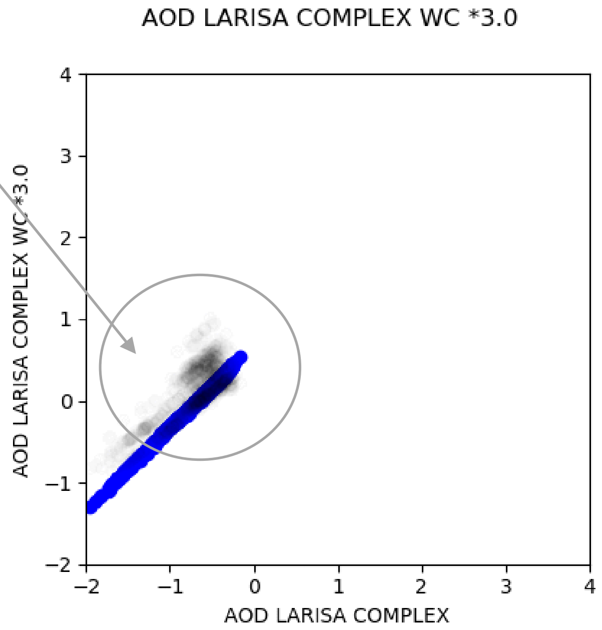




Subsurface strongly affects AOD magnitude

AOD LARISSA SIMPLE

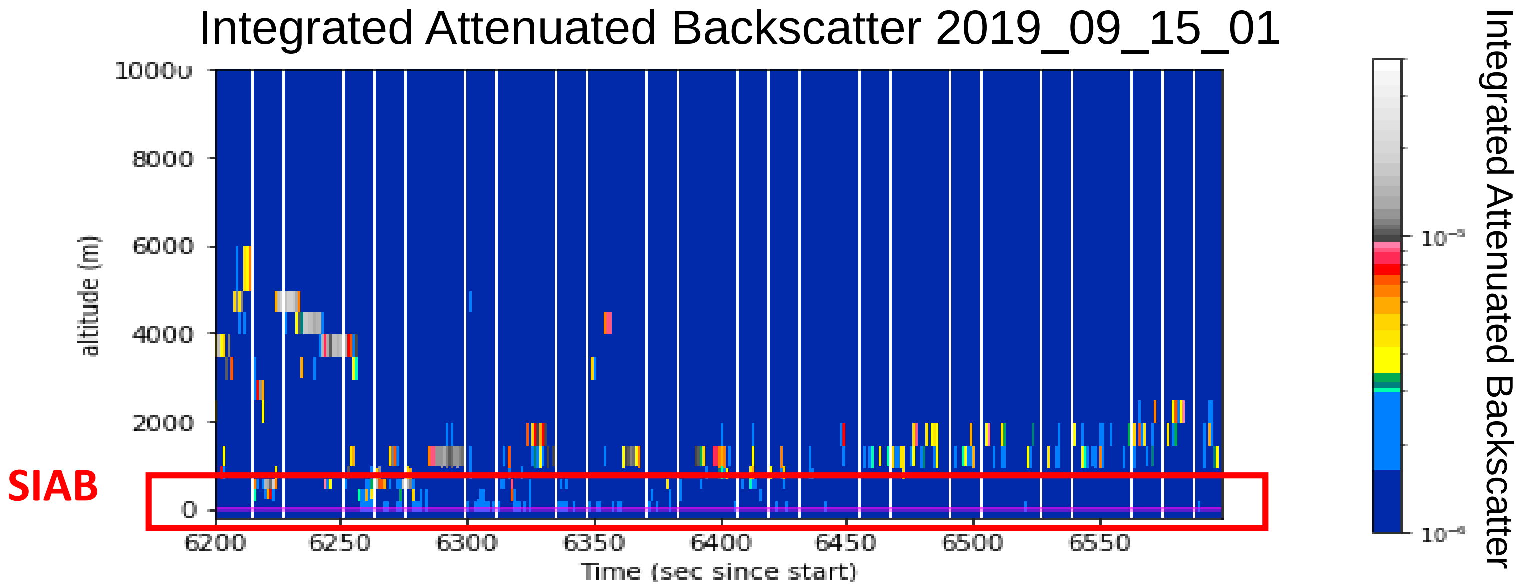
Similar effect to specular enhancement

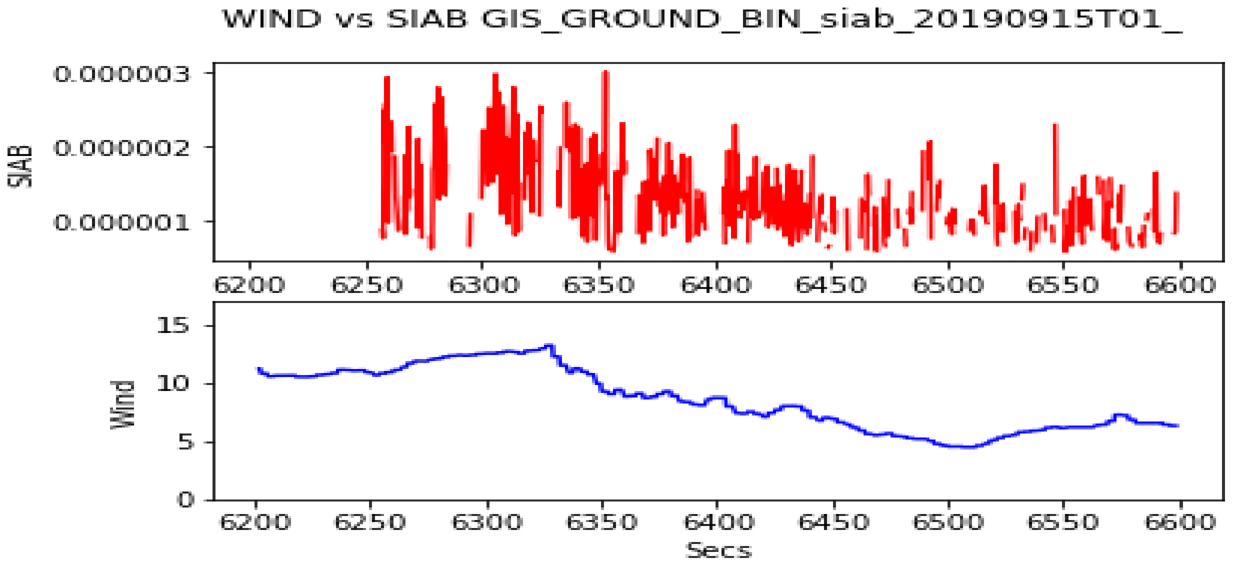


- Angle = 37.5º, fixed
- Every plot -> Modification of single term: sub, whitecap, spec.
- If subsurface changed -> **Offset of AOD**
- If specular changed -> Spread along y-axis **(that is why non-nadir is not effective)**

$$AOD = \frac{1}{2}\, ln\left(\frac{4\pi(Rs+Rw+Ru)}{\gamma}\right)$$

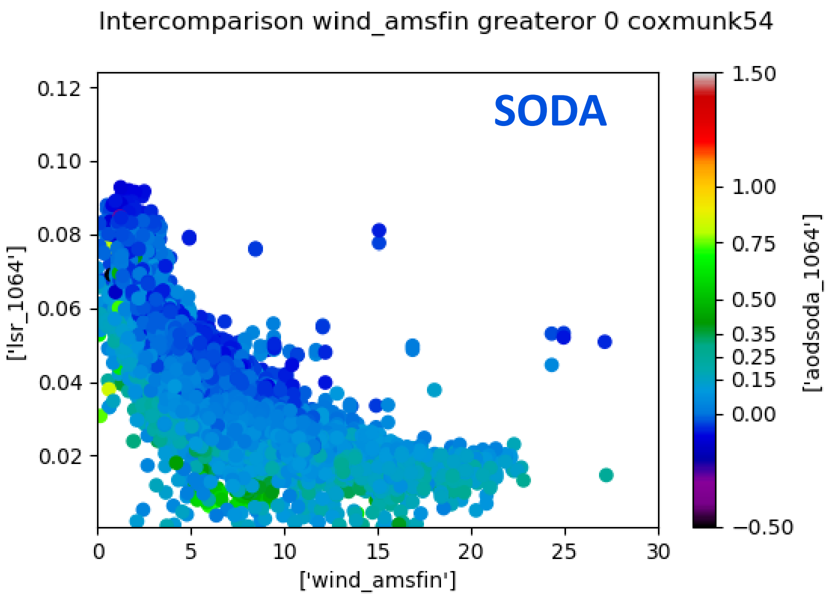
“Complex” LARISSA

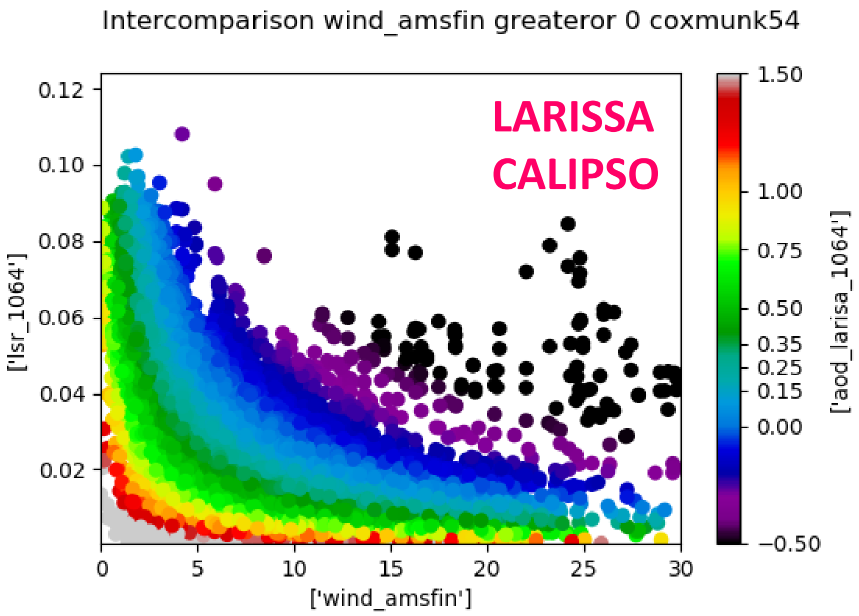




Testing period: Selected Cases of IOP (September 2019)
Retrieval: Non-nadir (complex)
Lidar Surface Return: L2_AEL_PRO
Wind: AUX_MET Aeolus
Reference AOD: AOD from L2_AEL_PRO Extinction
Collocation: KDTree
What do we test: Complex AOD equation, sea slope formulations, flagging, horizontal averaging, subsurface dependence

DO YOU REMEMBER THIS PLOT FROM CALIPSO?

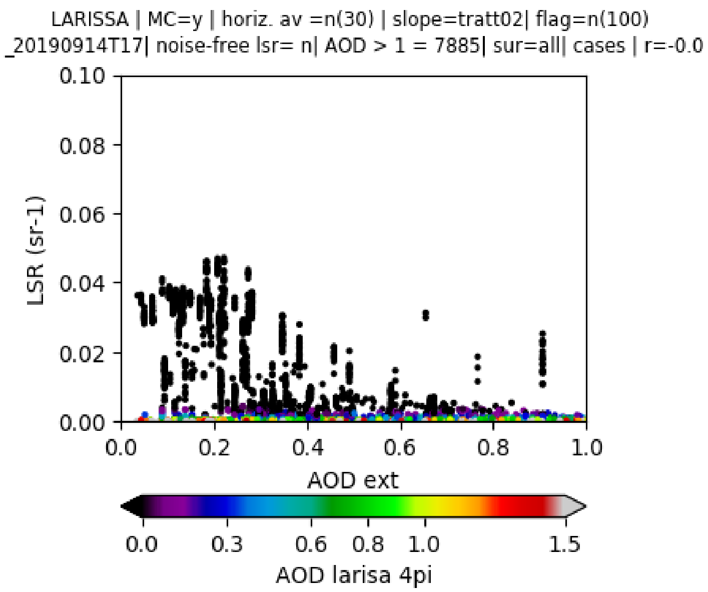




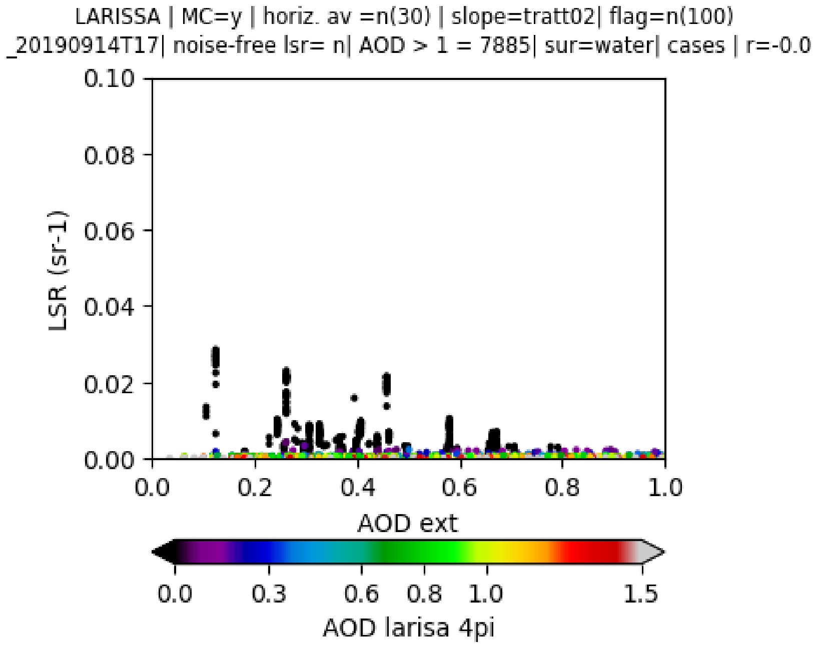
- Can we reach something similar? In this case, the sensitivity to wind will be evident

CHECKING DAVE'S DATA AND ORBIT

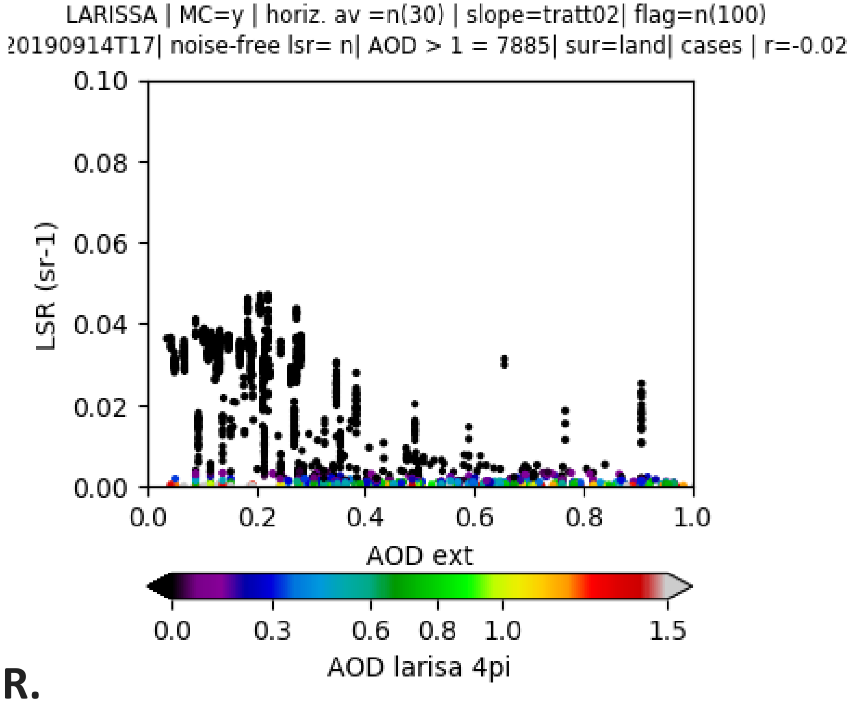
ALL SURFACES



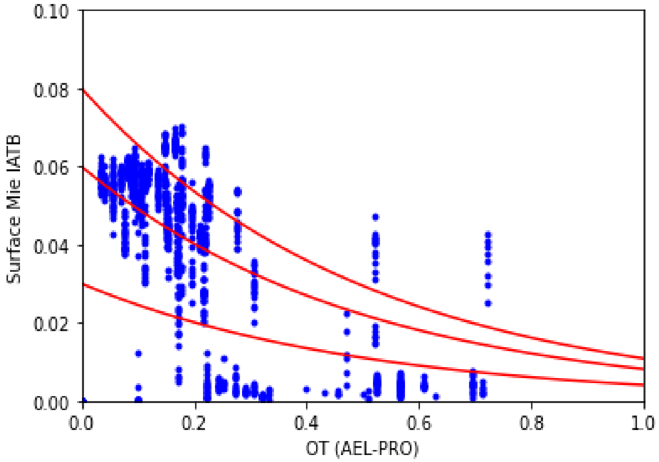
WATER



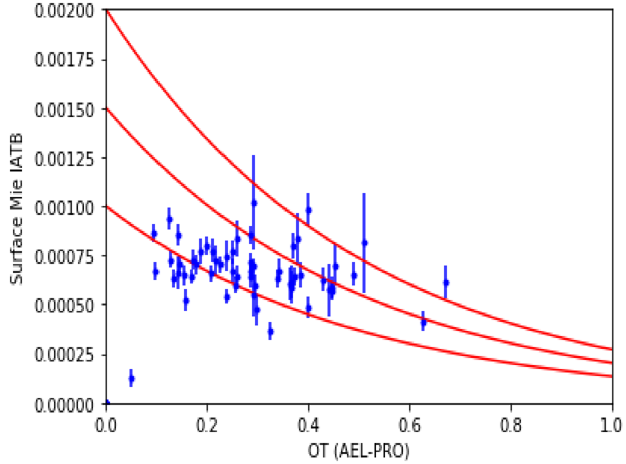
LAND



ALL SURFACES / DAVE'S DATA



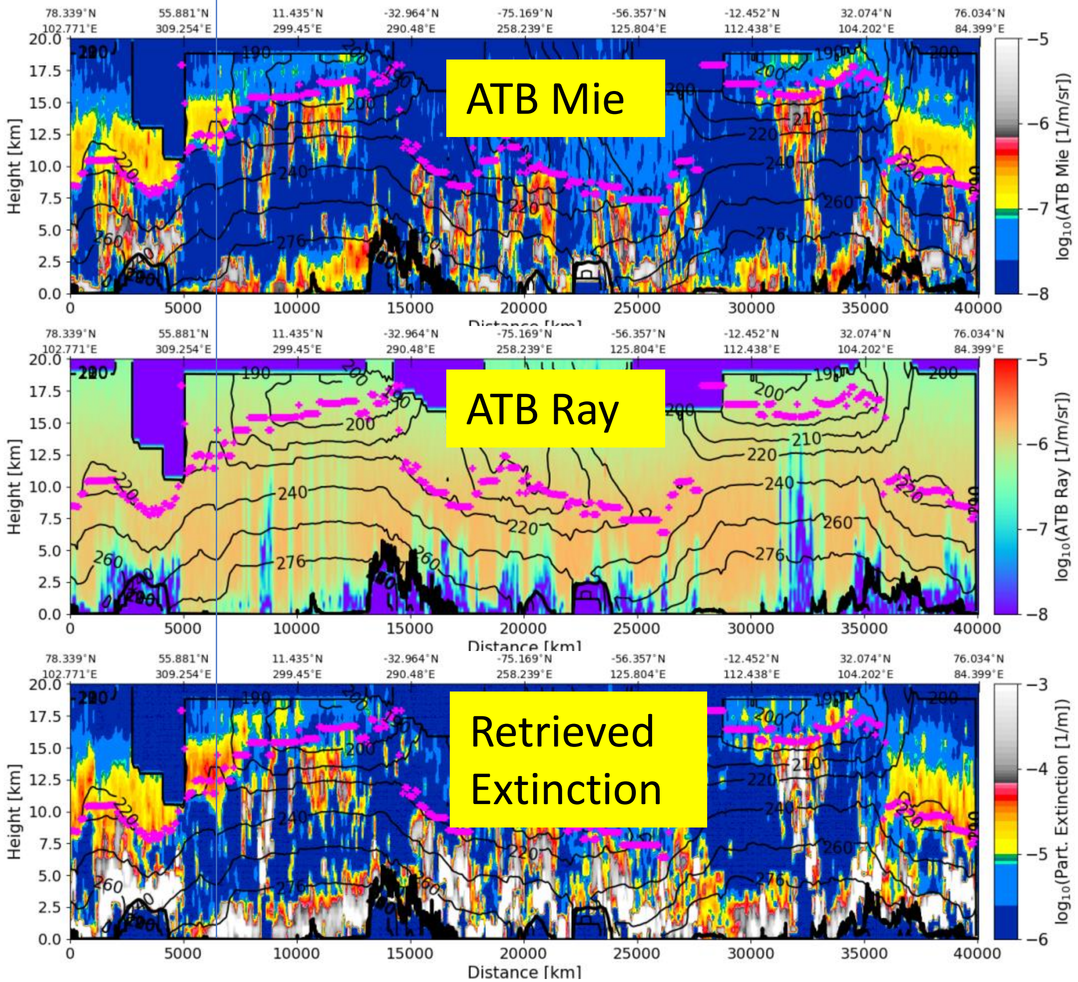
OVER OCEAN 'HARDCODED' BY DAVE'S PROGR.



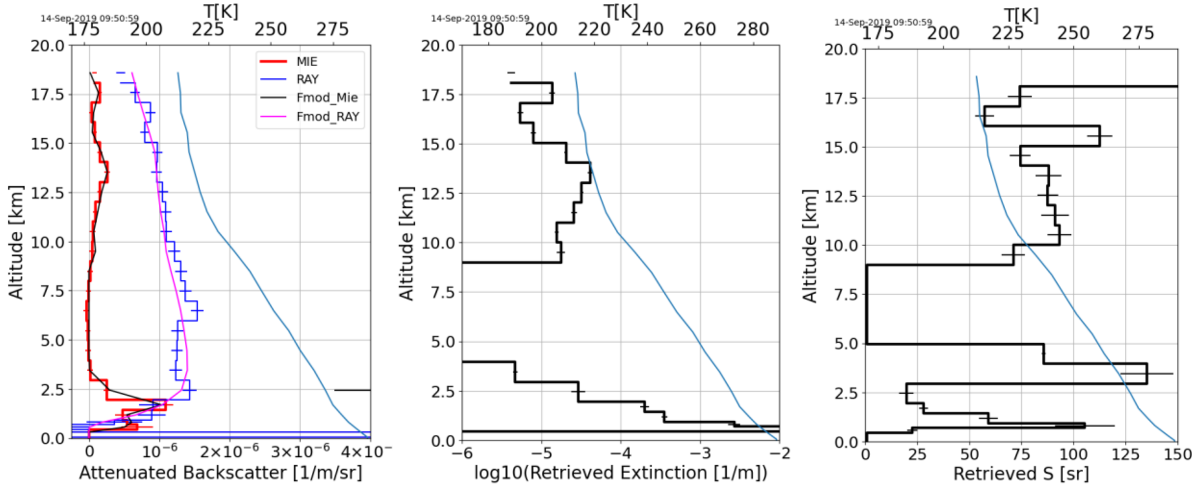
- There is no such large difference between my SIAB and Dave's SIAB
- However, my range is more narrow
- This plot is done using my program, not Dave's program

WHAT IS AEL_PRO?

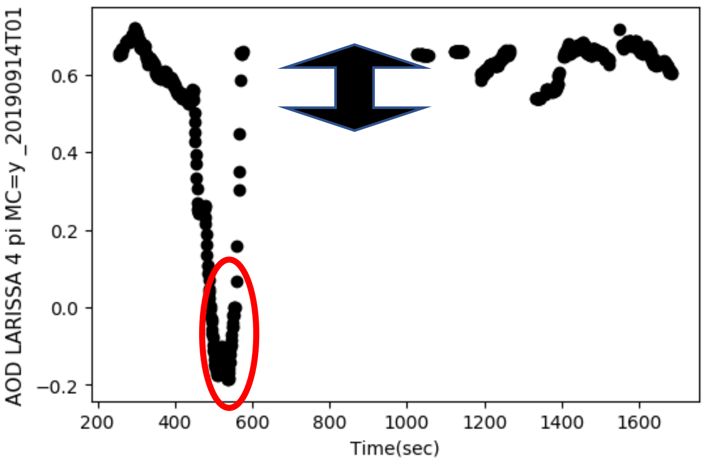
AEL-PRO is an optimal-estimation/forward-modelling approach for retrieving Aeolus extinction and backscatter **profiles**. It is inspired by the A-PRO algorithm developed for the EarthCARE Lidar (ATLID).

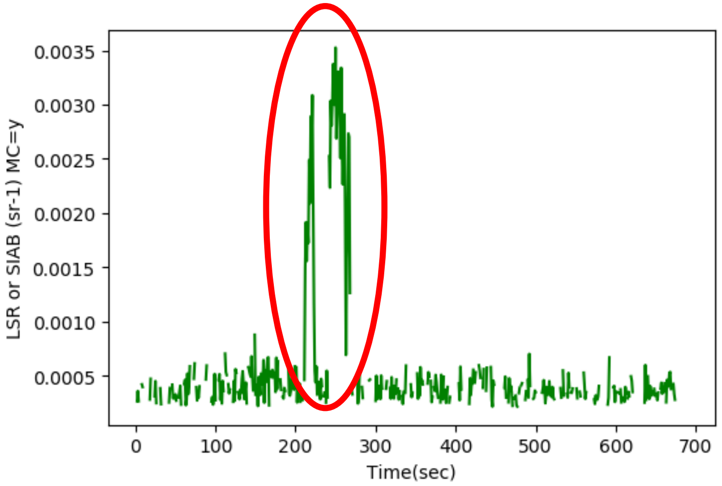


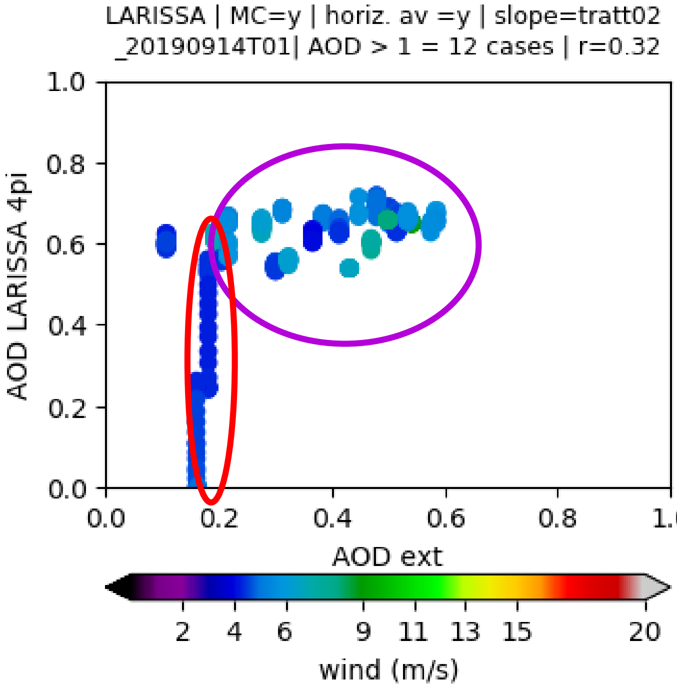
aeolus DISC
DLR DoRIT ECMWF cnrs s[&]t ABB serco



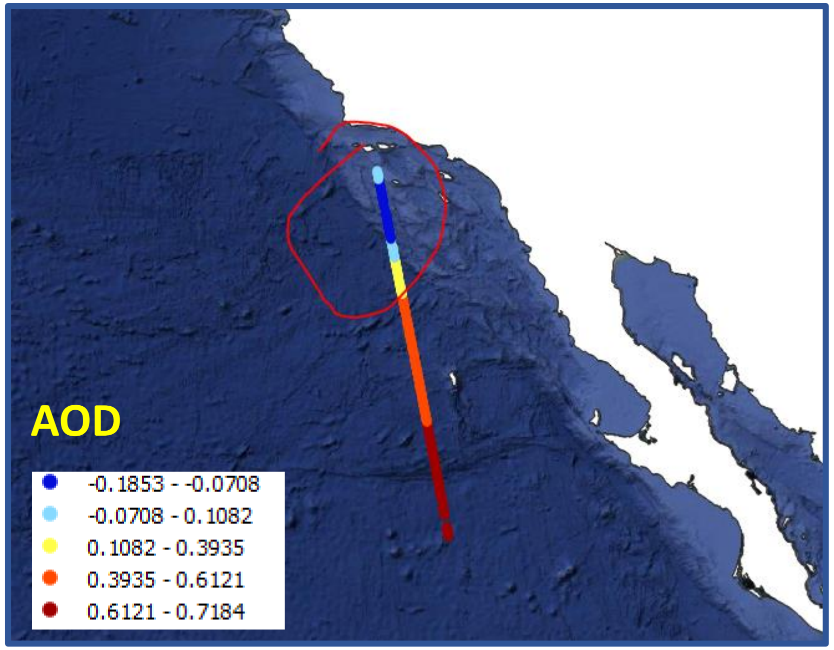
2019_09_17-T01 CASE (SAME BUT AVERAGED)



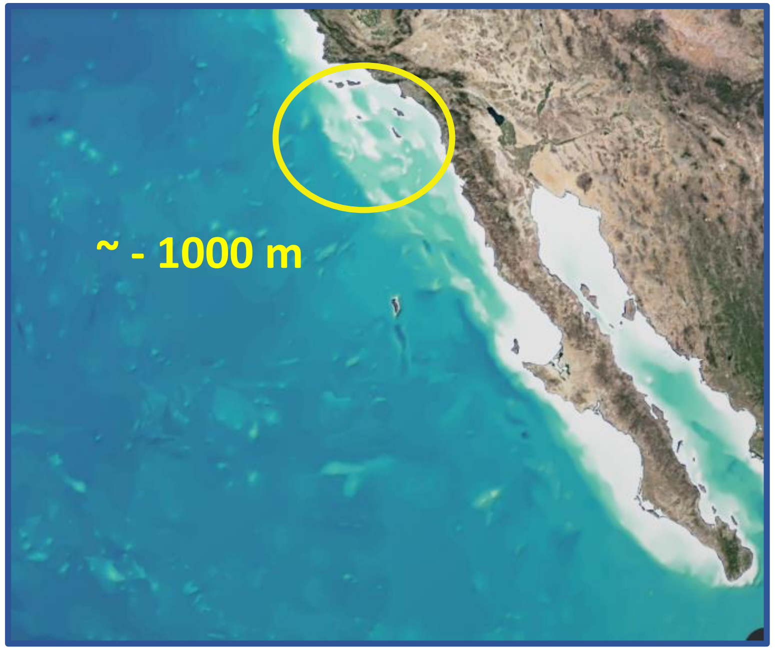




Google Imagery

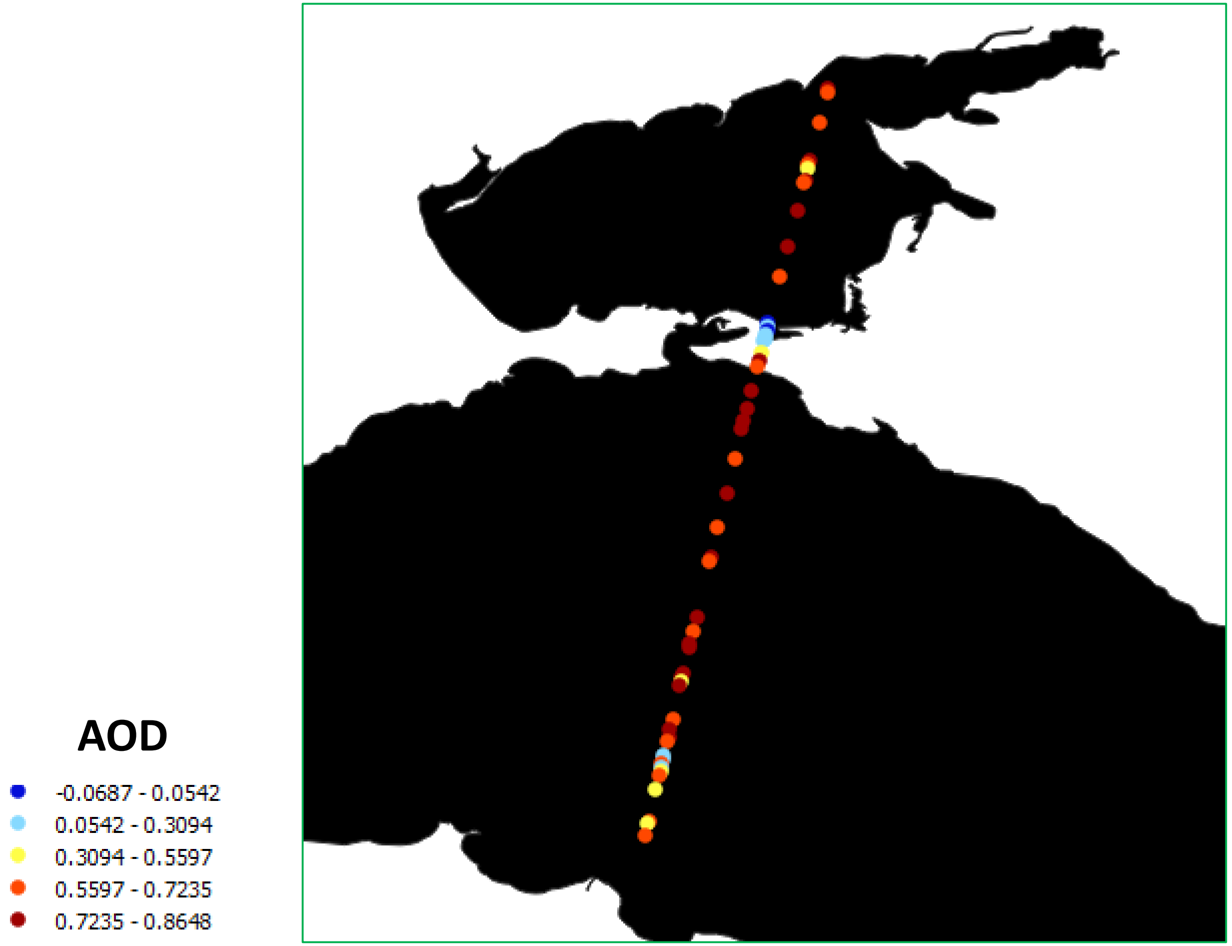


Seafloor Depth, NOAA



- Erroneous AOD coming **from shallow waters (similar to CALIPSO cases I tested over India)**

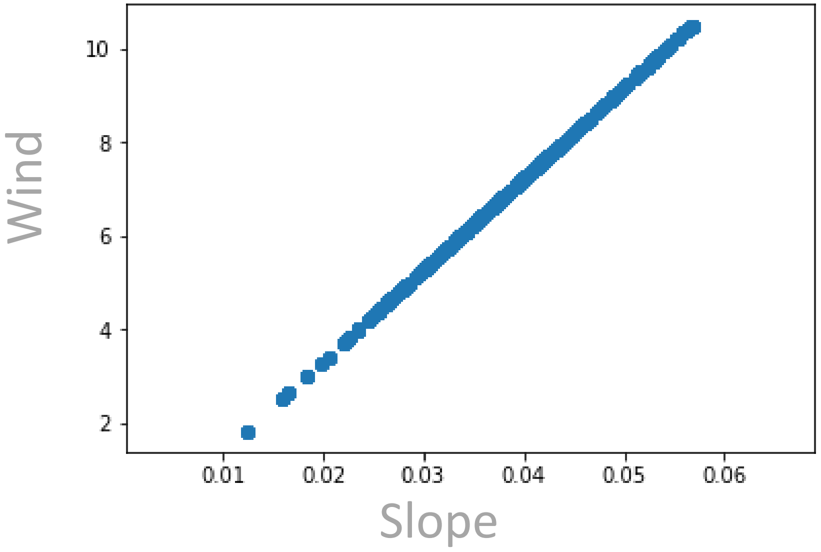
WHAT IS SEEN AS SEA IS NOT ALWAYS SEA



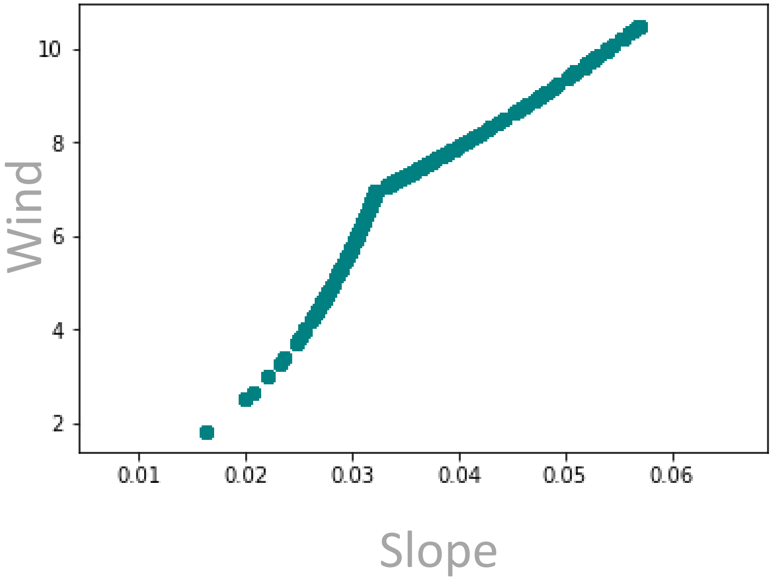
- What is flagged as 'sea' is **not always sea**
- These cases are minor -> To be corrected at the later stage, **otherwise confusing erroneous AOD (<0)** emerges

COMPARISON OF WIND-DIRECTION-INDEPENDENT AND DEPENDENT SLOPES

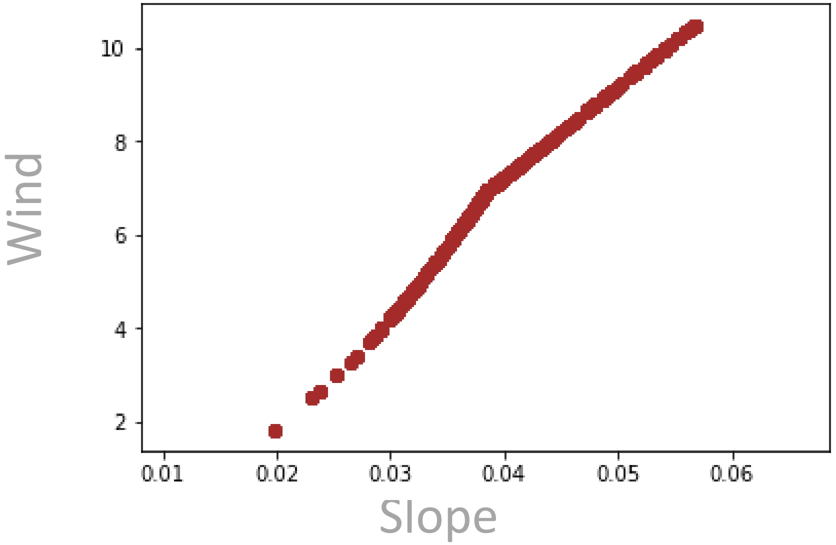
COX AND MUNK



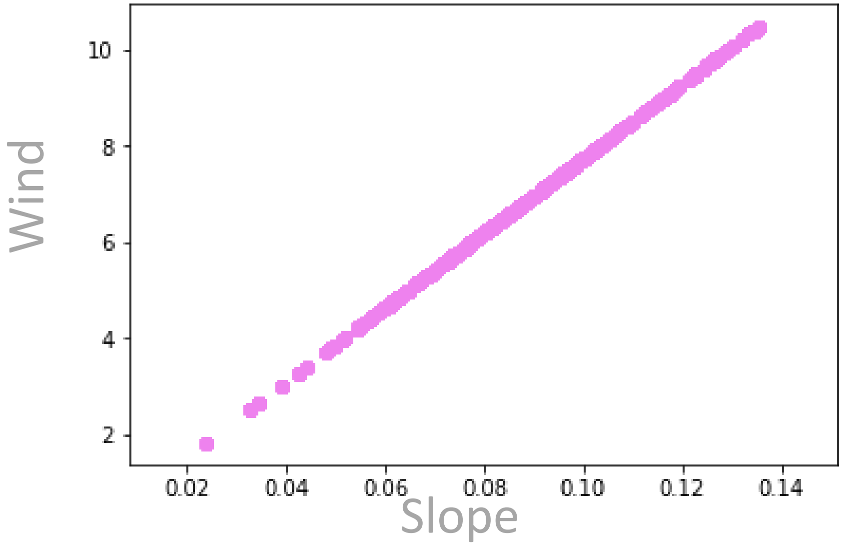
WU-1990



HU-2008



TRATT-2002 (WIND DIRECTION-DEPENDENT)



- **Piece-Wise functions are not advisable to use**
- **Cox and Munk and Tratt are different**
- Tratt-02 incorporated to the program SWAILS