A NEW CLOUD PROPERTIES RETRIEVAL METHODOLOGY FOR IR MEASUREMENTS:

An application to MPACE 2004 field experiment

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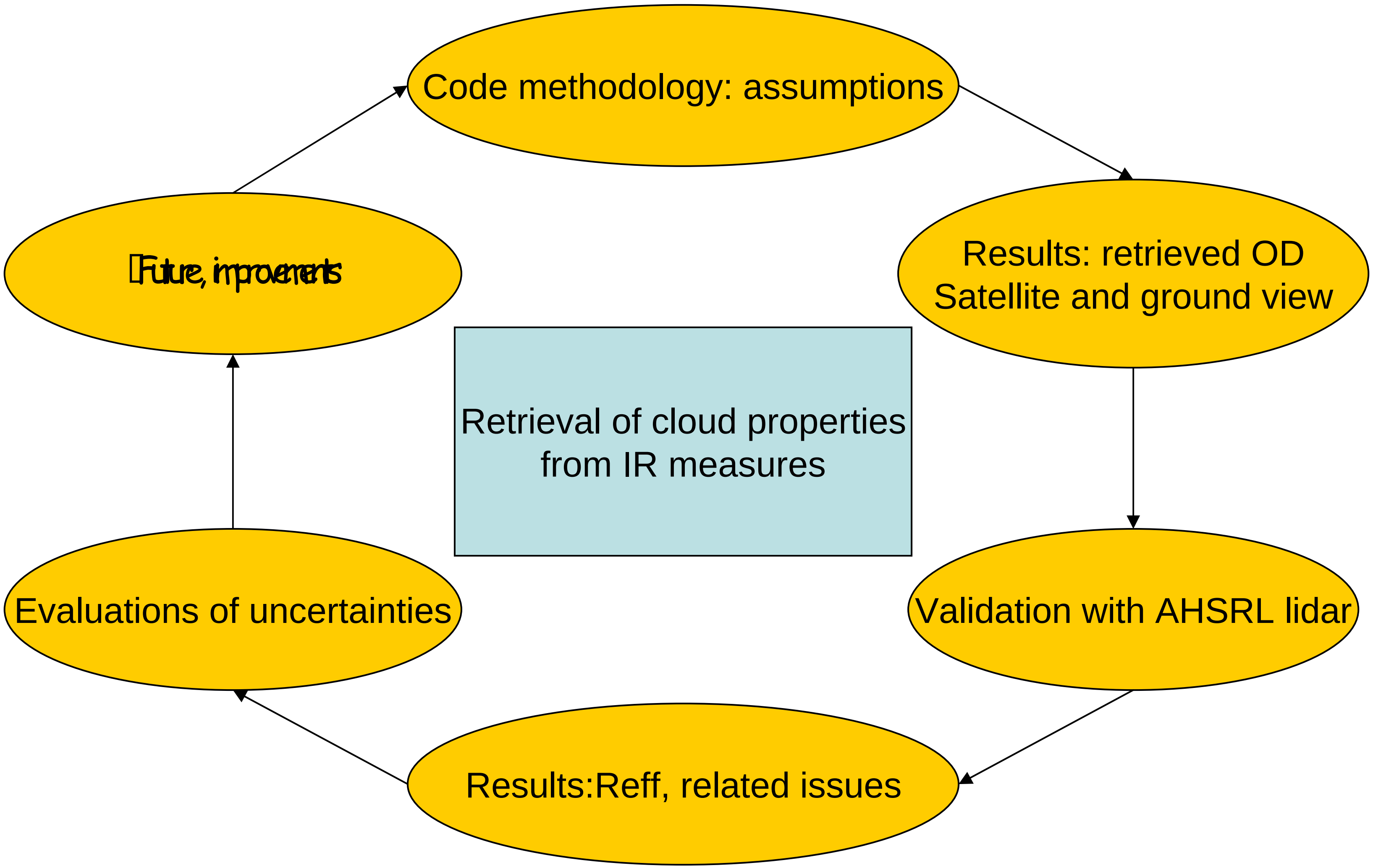
OVERVIEW:



Goal:

Use the best information available to derive a validation product for selected geographical sites

Satellite applications (?)

RT-RET: the Retrieval scheme/1

ORIGIN: Modification of a LbL-MS code based on doubling and adding algorithm (Evans and Stephens; Rizzi and Miskolczi)

A-PRIORI INFORMATION:

1. Cloud geometrical boundaries (➔ lidar/CO_2 slicing/…)
2. T and wv profiles (➔ ECMWF re-analysis grib files/radiosondes)

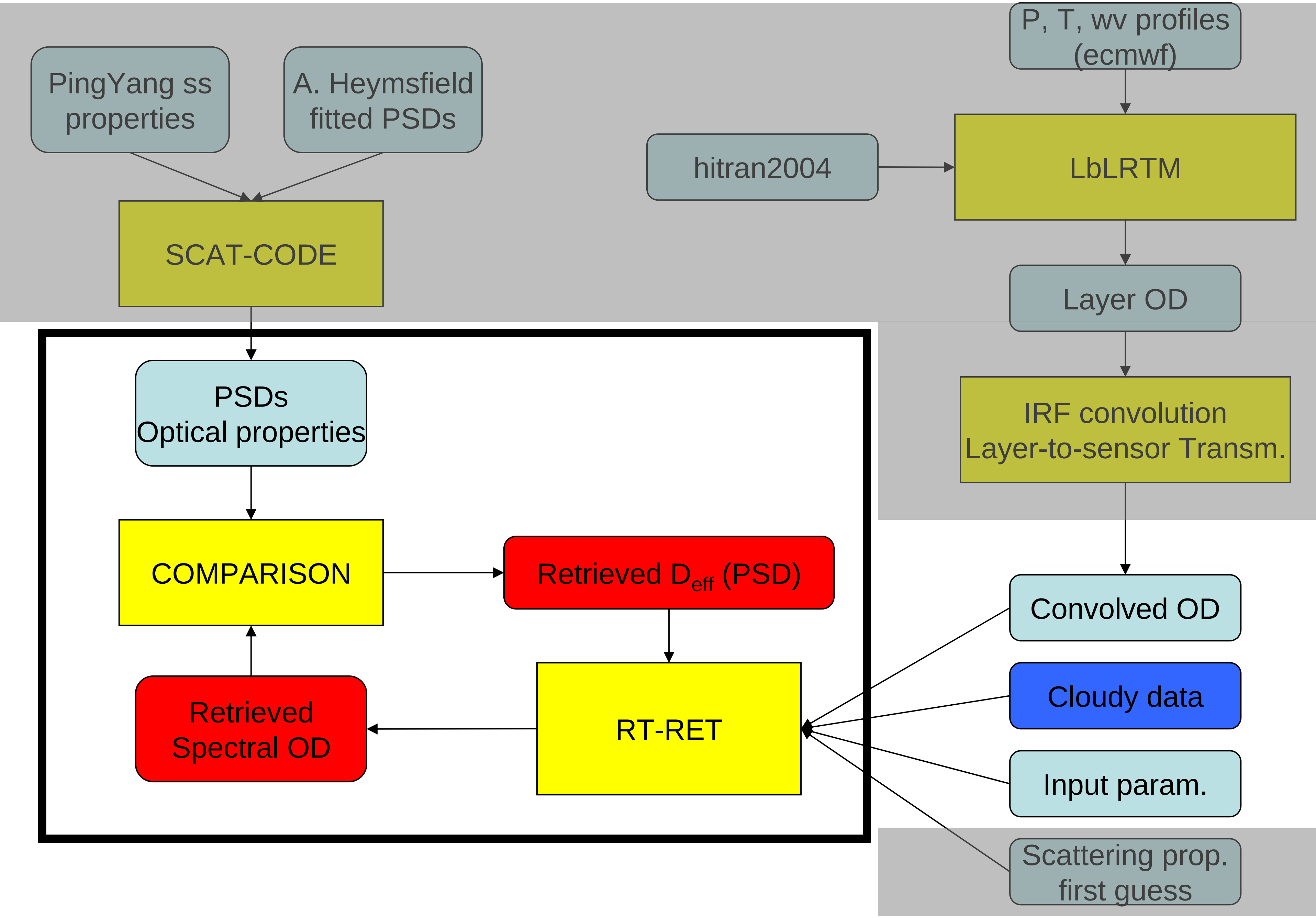
ASSUMPTION:

1. Cloud OD is homogeneous in the layer (investigate!)
2. Plane parallel geometry and multiples layer cloud

NEW FEATURES:

1. Optical depths space
2. Simplified phase function but multiple scattering processes accounted for
3. Applicable to multiple hyper-spectral sensors (ground-airborne-satellite)

RT-RET: the Retrieval scheme/2



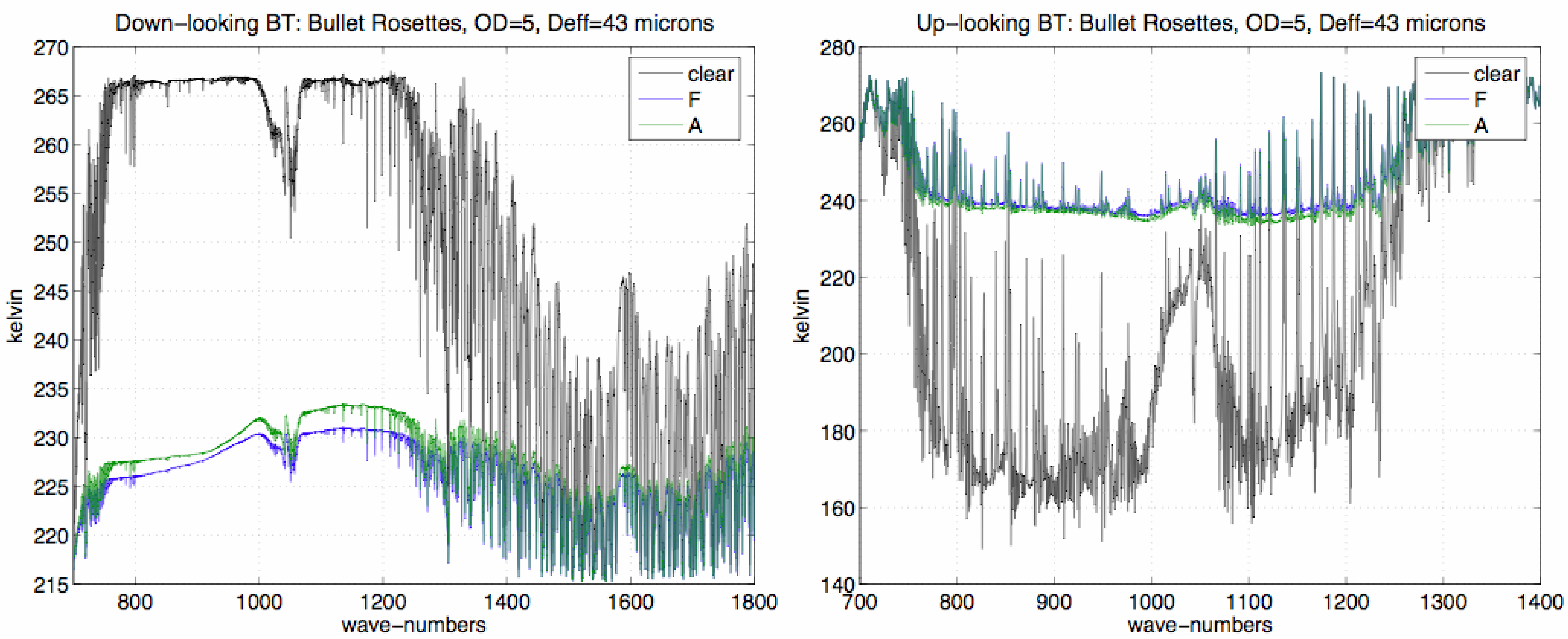
RT-RET: the Retrieval scheme/3

Scattering is a second term correction in the infrared window both from above and either below cloud measurements. Nevertheless it can**not** be neglected

Clear solution -------

F=full solution -------

A=absorption only -------

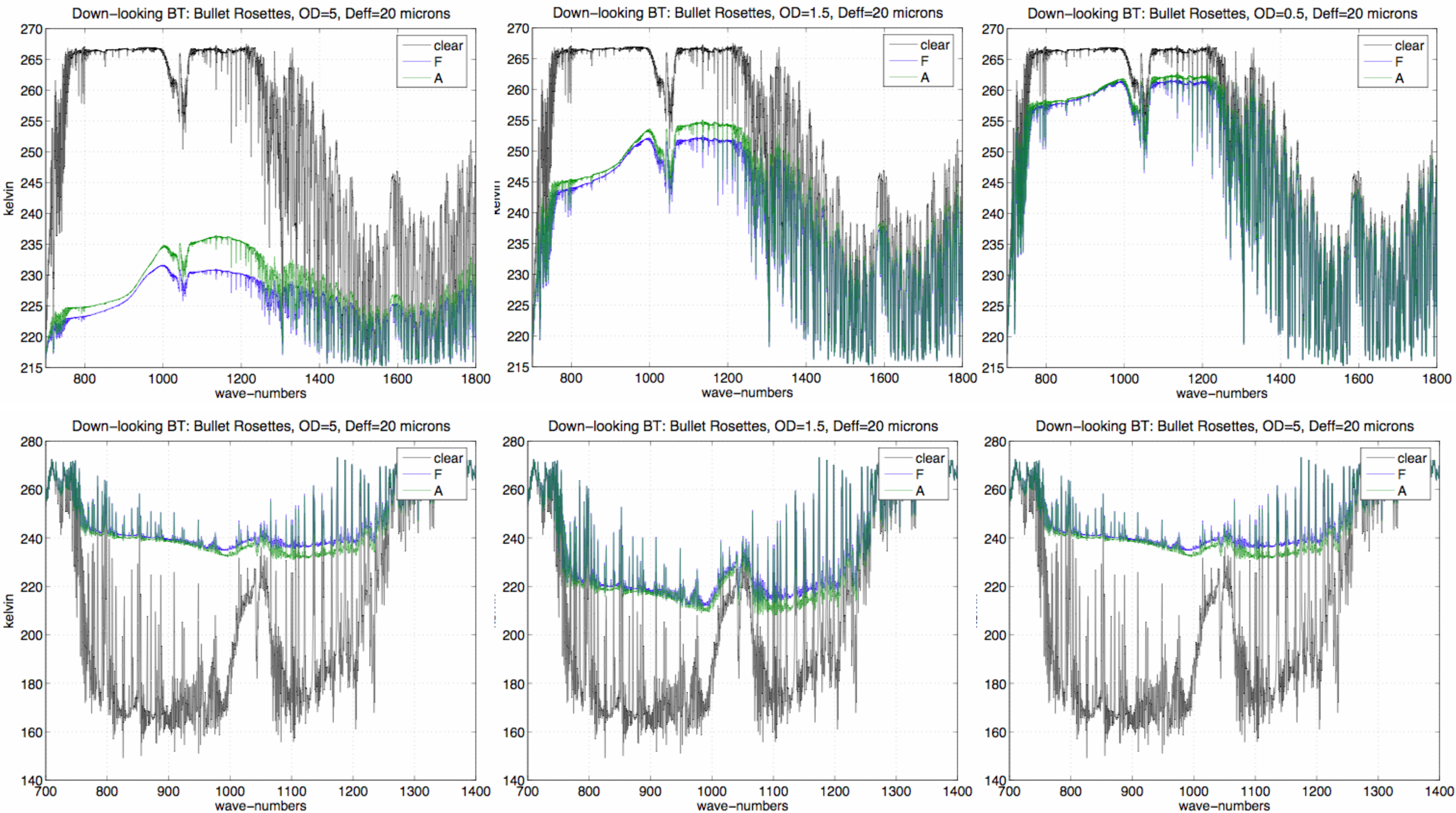


Knowledge of the T and wv profile is extremely important especially when up-looking.

RT-RET: the Retrieval scheme/4

The spectral shape of the radiance in the 800-1000 cm^{-1} window is mainly driven by the <u>absorption</u> processes independently of the size of the ice crystals

The slope of the radiance (esp. from above) in the 800-1000 cm^{-1} window band is not only habit dependent, but also OD and surface emissivity dependent (boundary conditions are very important)

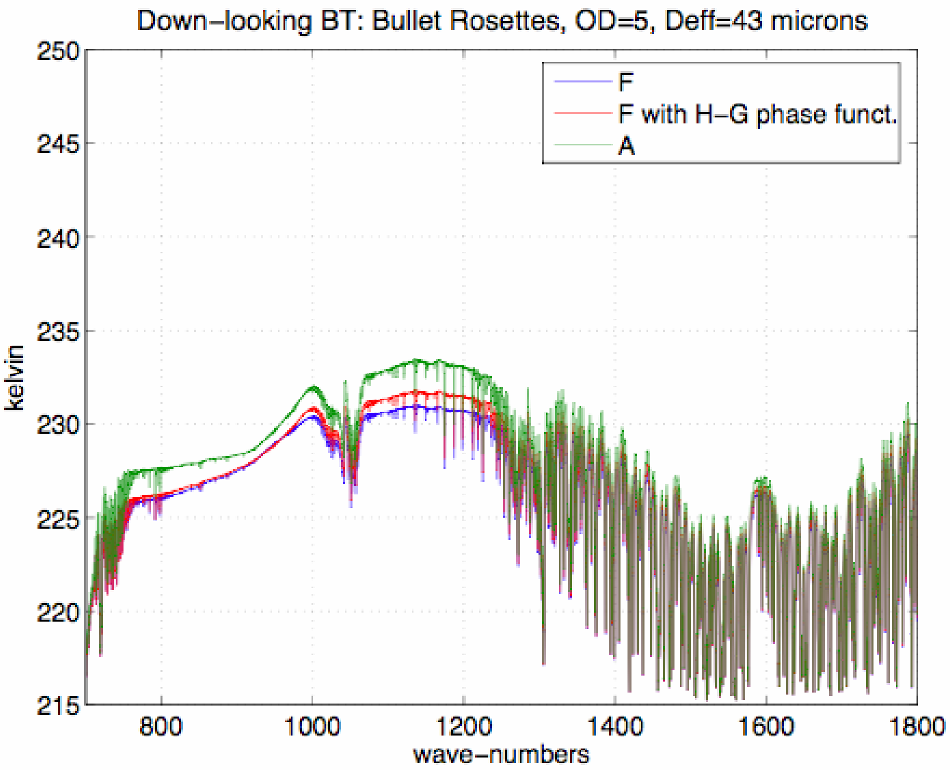


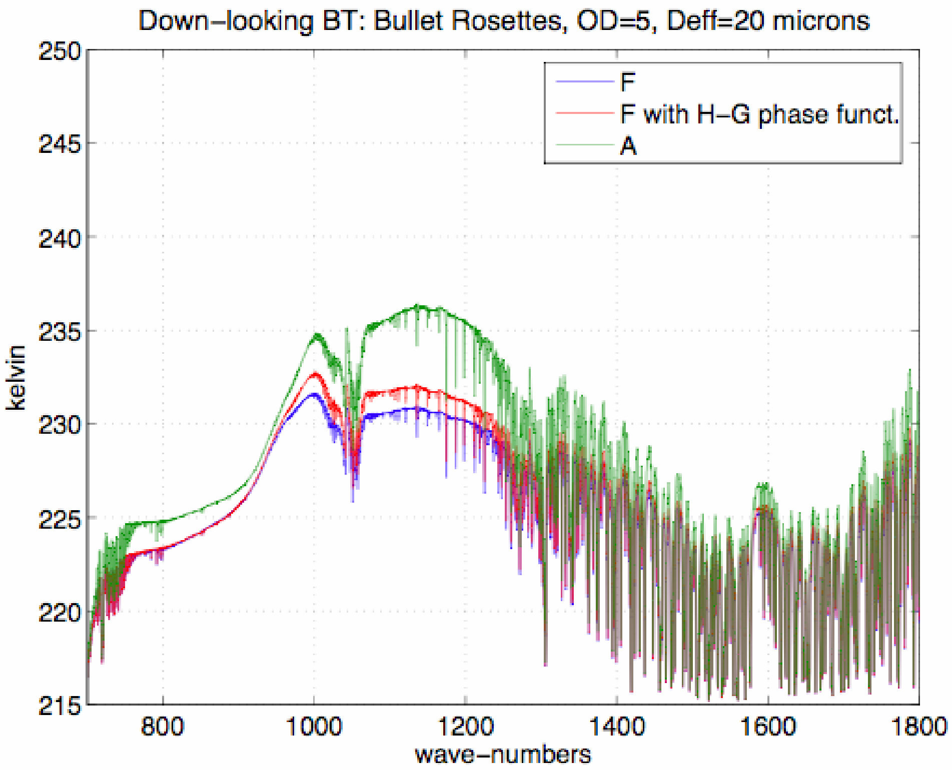
RT-RET: the Retrieval scheme/5

In the 800-1000 cm^{-1} window band the scattering properties of the PSDs are weaker dependent on the kind of habit (or mixtures of habits) constituting the PSD with respect to the 1050-1250 cm^{-1} band that contains more habit's information

Moreover a simplified phase function appears to represent a good approximation in that band.

Heeney-Greenstein phase function correction.





RT-RET: the Retrieval scheme/6

For every wave-number RT-RET finds the **"fake" OD** that makes the forward model computation match the data. The first guess scattering properties are obtained using spectral: ϖ and **g**.
The precision is user dependent and usually set to a threshold less than 0.5% in the radiance values.

Wave-numbers are analyzed **sequentially**.
To speed up computations the last OD value is used as input for the next wave-number analyzed

Convergence to the real value is obtained by changing the OD as follows:

$$\Delta OD = \frac{\Delta R}{(F_s - F_c) \cdot t_c}$$

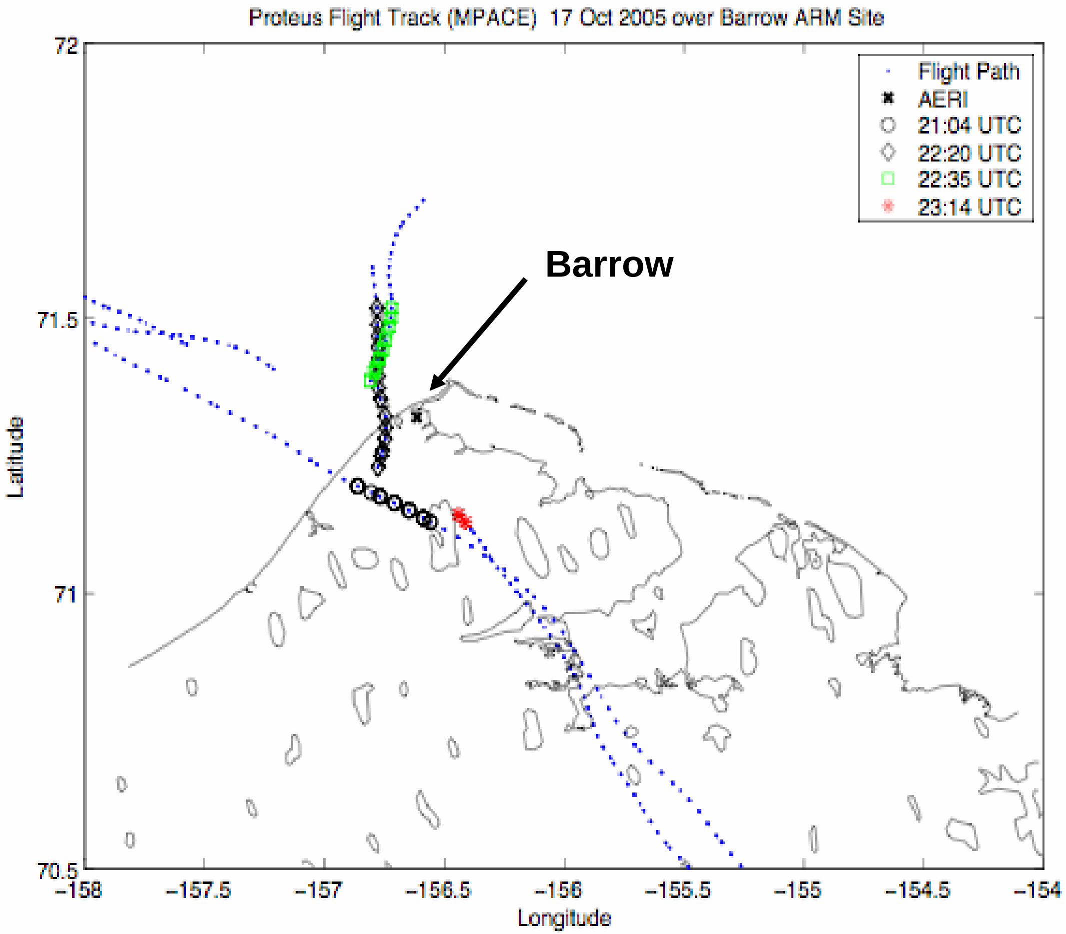
From the assumption that the up-ward radiance is: $R \approx t_c \cdot (\varepsilon_s F_s) + (1 - t_c) \cdot F_c$
and that the only variables are $t_c(OD)$ and R

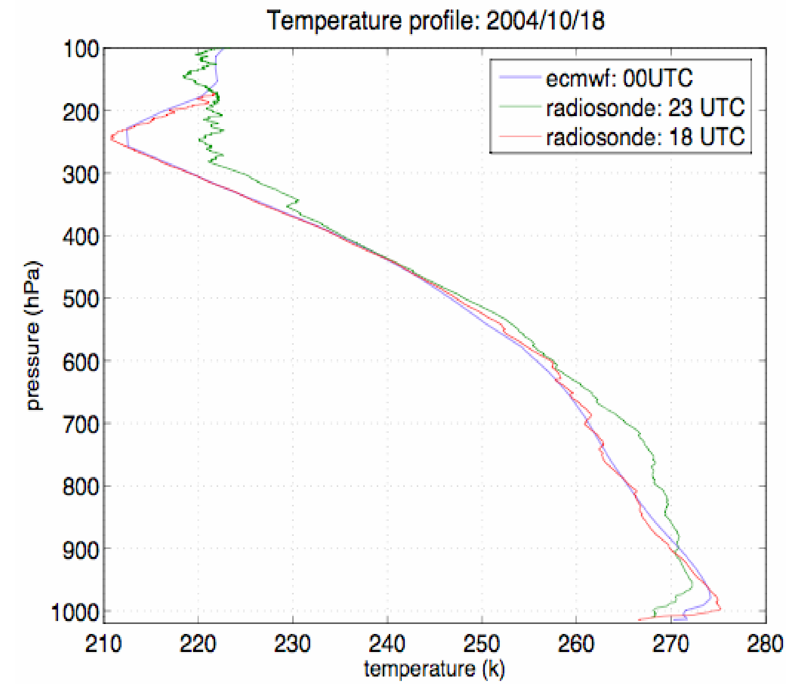
$$\Delta OD = \frac{\Delta R}{(-F_c) \cdot t_c}$$

From the assumption that the down-ward radiance is: $R \approx (1 - t_c) \cdot F_c$
and that the only variables are $t_c(OD)$ and R

Where:
t_c = cloud trasmissivity
R = *measured radiance*
F_c = *cloud radiance*
F_s = *surface radiance*
ε_s = *surface emissivity (assumed 1)*

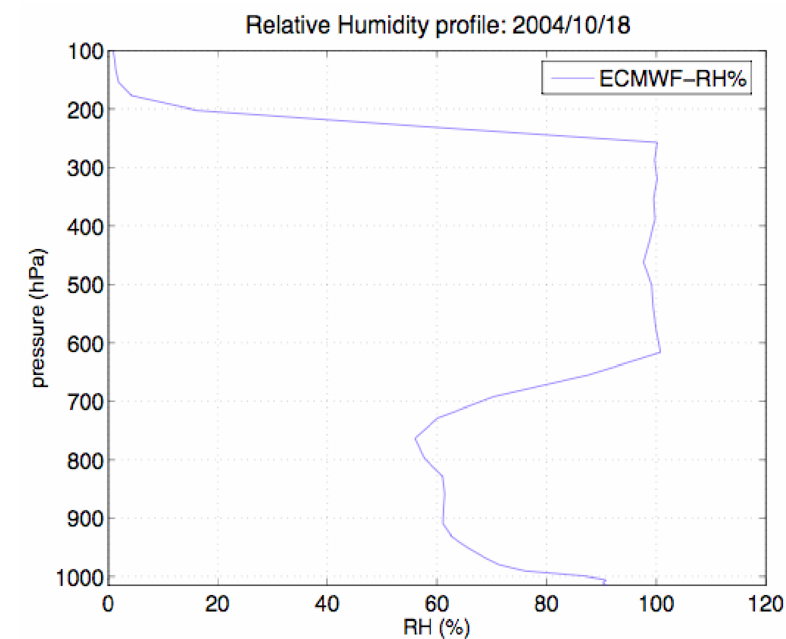
MPACE: October 17th 2004





QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

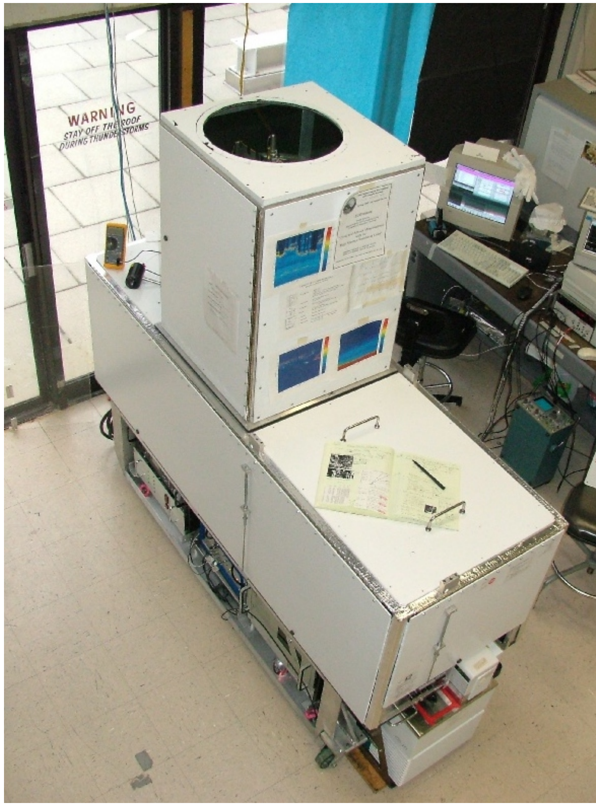
Hydrometeor from Cloud Particle Imager, CPI on Citation (Verlinde et al.)



AHSRL

The Arctic High Spectral Resolution Lidar

Multi-channel lidar capable of independent measurements of the **cloud depolarization, extinction, and backscatter cross-section.** Two signals can be processed to yield separate lidar returns from aerosol and molecular scattering. Separation is possible because the wavelength spectrum of the molecular lidar return is Doppler broadened by molecular thermal motion. The separation of molecular and aerosol returns permits the HSRL to measure the extinction and aerosol backscatter cross-sections independently.



The AHSRL specifications

Laser Wavelength:	532 nm
Length of laser pulse:	40 ns
Pulse repetition rate:	4 kHz
Laser power:	~0.4 W
Receiver FOV:	45 mrad
Altitude Resolution:	7.5 m
Maximum Recorded Alt:	30 km

Thanks to Ed Eloranta (SSEC)

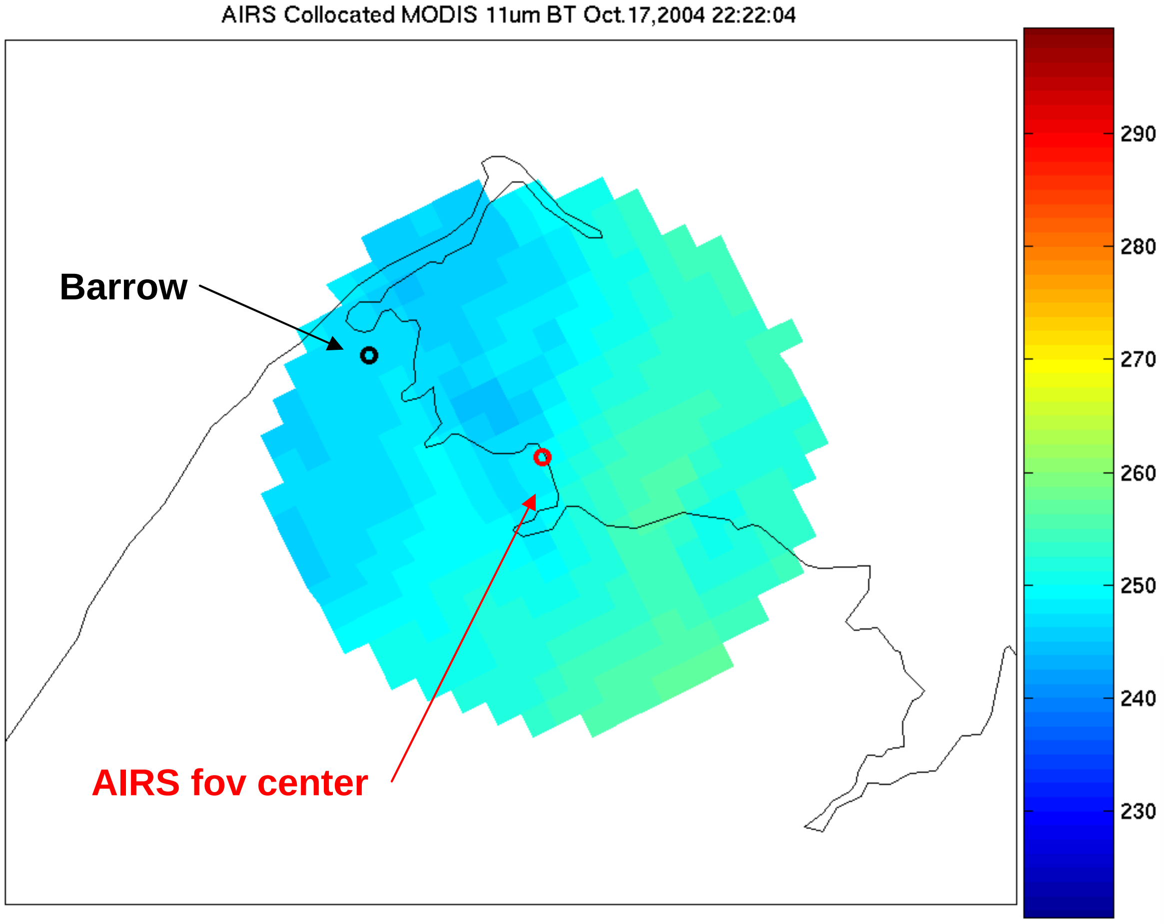
IR Sensors

AIRS: Atmospheric Infrared Sounder. Satellite (AQUA)

S-HIS: Scanning High-resolution Interferometer Sounder. Airborne (on Proteus)

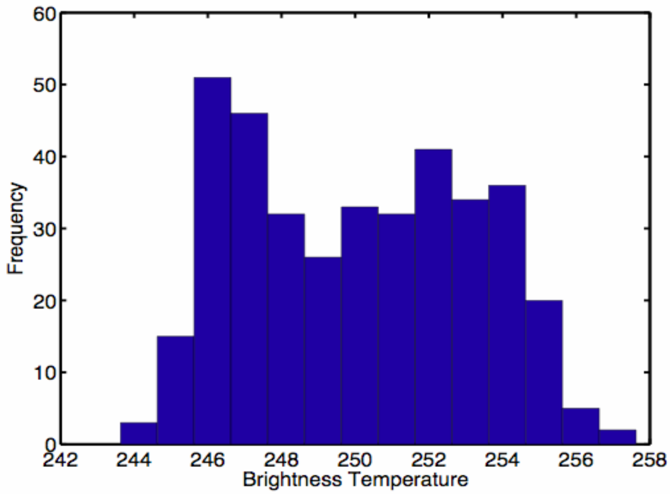
AERI: Atmospheric Emitted Radiance Interferometer (in rapid scan). Ground-base (Barrow)

AIRS data: Modis collocation



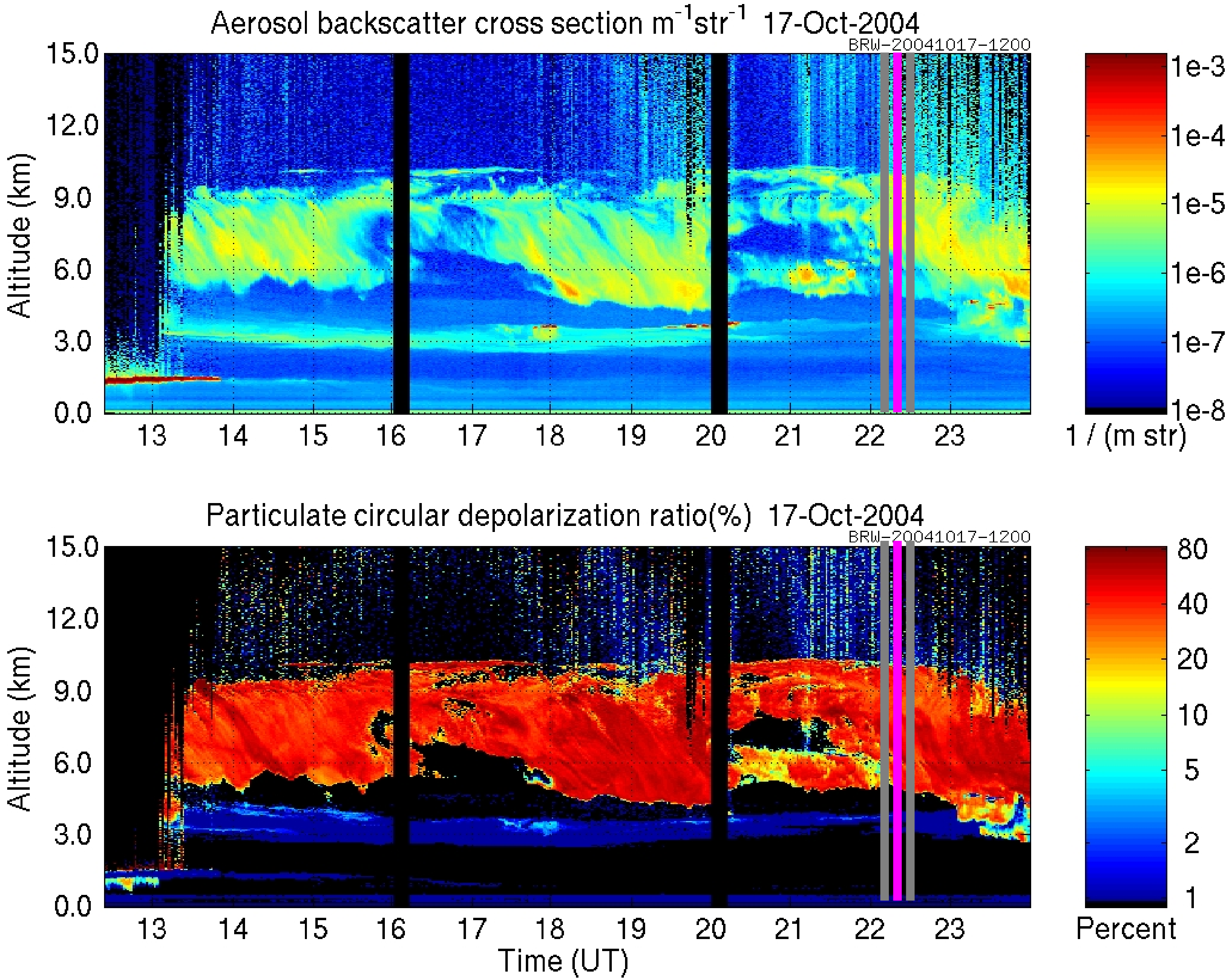
Advection of mid-upper level cloud

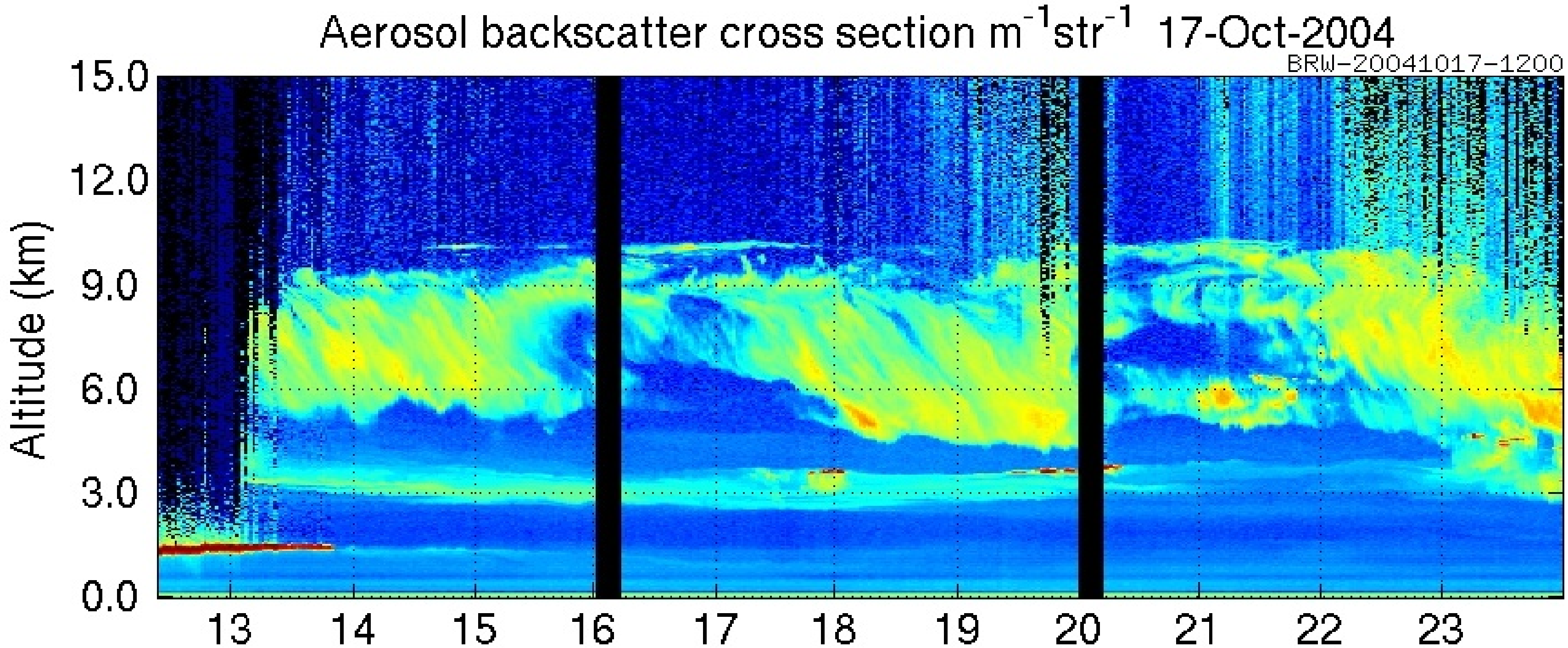
Modis BT Histogram



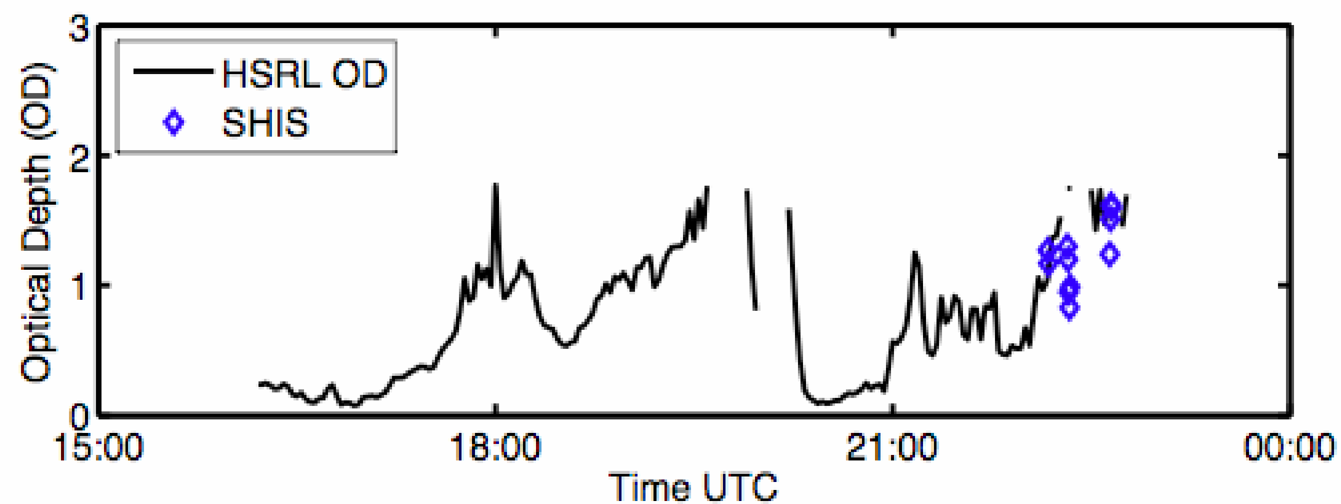
AHSRL data

AIRS overpass
S-HIS time coincident passes

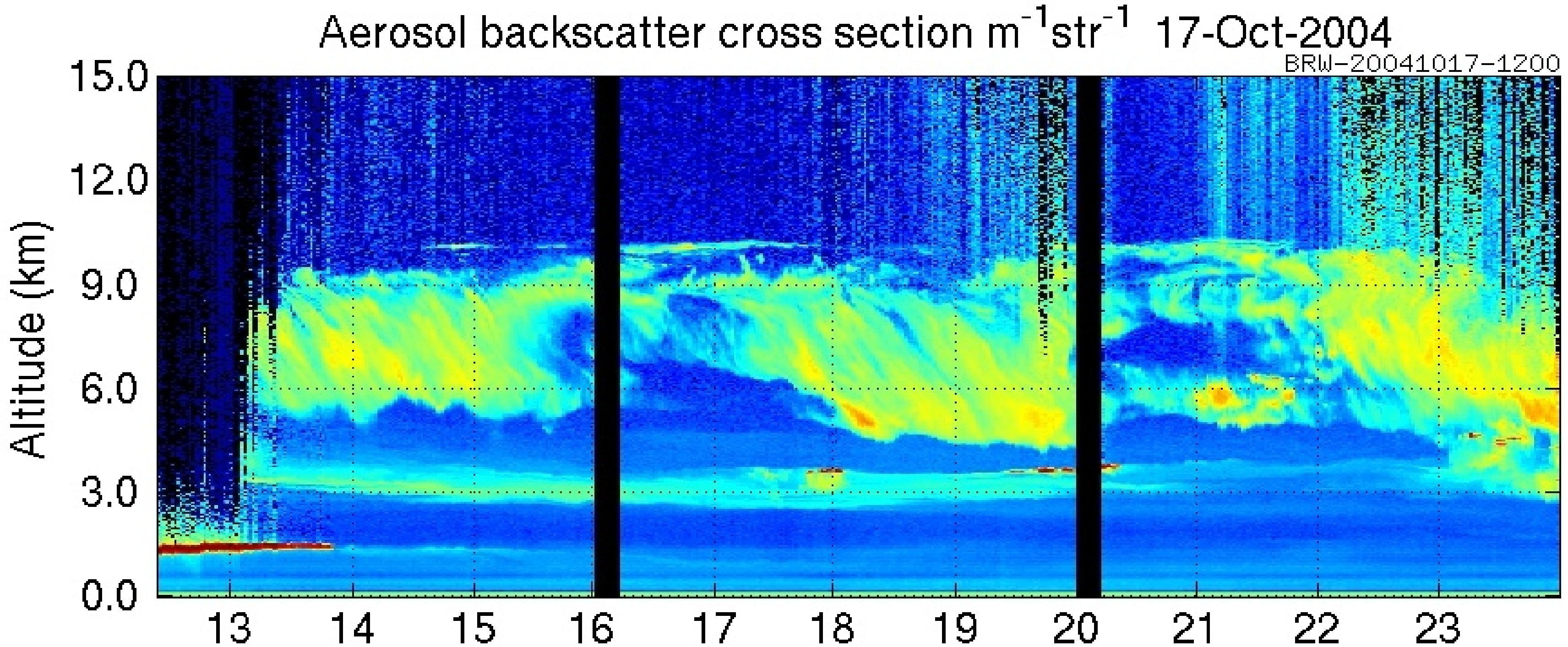




Aerosol backscatter cross section $m^{-1}str^{-1}$ 17-Oct-2004
BRW-20041017-1200
Altitude (km)
15.0
12.0
9.0
6.0
3.0
0.0
13
14
15
16
17
18
19
20
21
22
23



HSRL OD
SHIS
Optical Depth (OD)
3
2
1
0
15:00
18:00
21:00
00:00
Time UTC


Aerosol backscatter cross section m^{-1}str^{-1} 17-Oct-2004
BRW-20041017-1200
Altitude (km)
15.0
12.0
9.0
6.0
3.0
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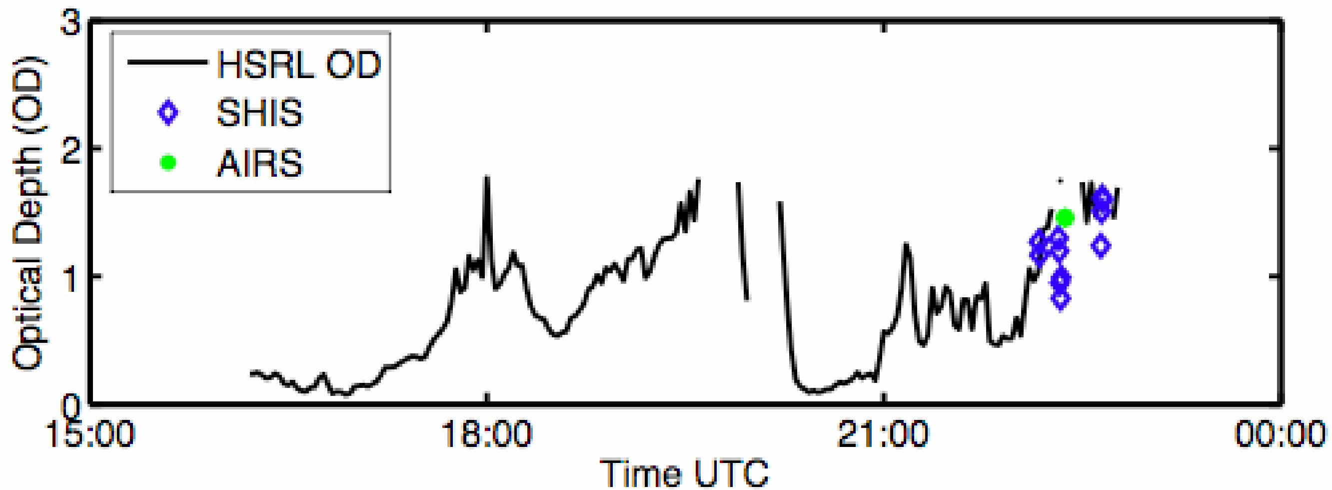
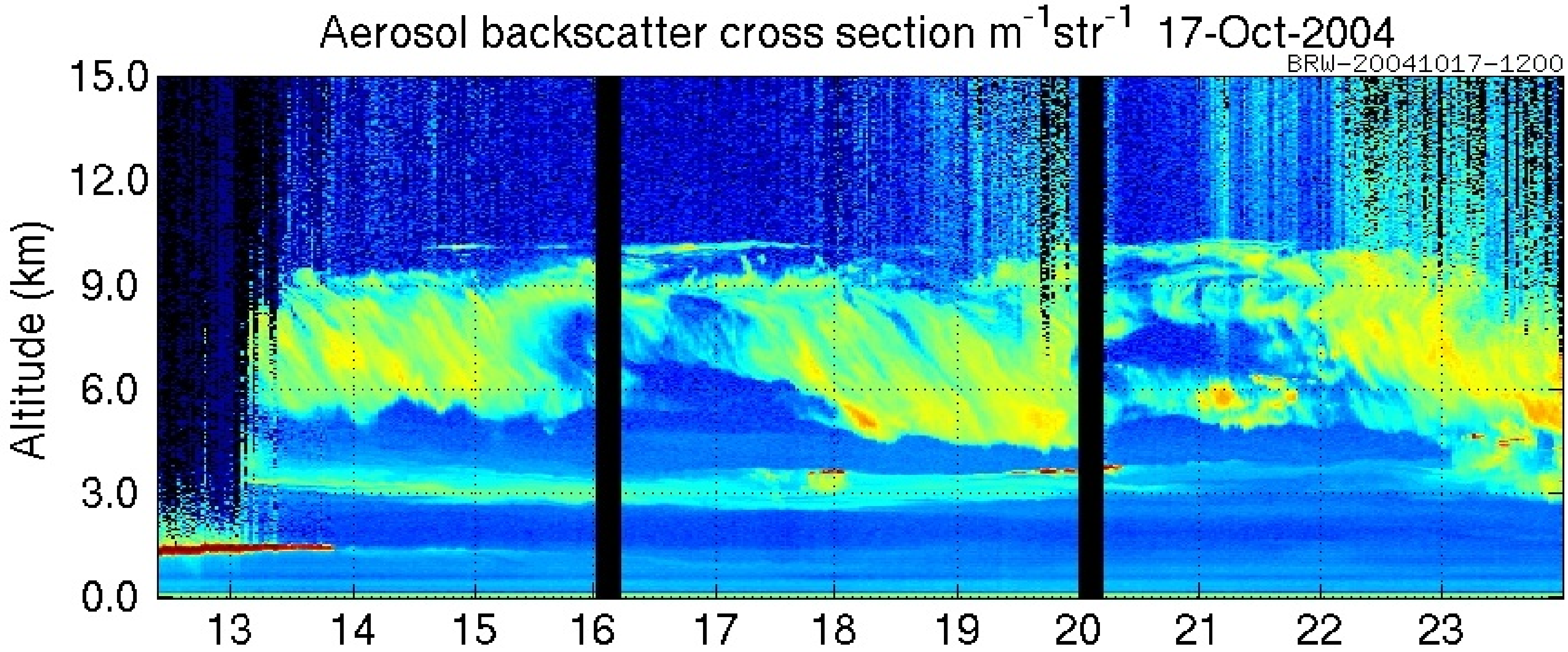

HSRL OD
SHIS
AIRS
Optical Depth (OD)
3
2
1
0
15:00
18:00
21:00
00:00
Time UTC



Aerosol backscatter cross section m-1str-1 17-Oct-2004
BRW-20041017-1200
Altitude (km)
15.0
12.0
9.0
6.0
3.0
0.0
13
14
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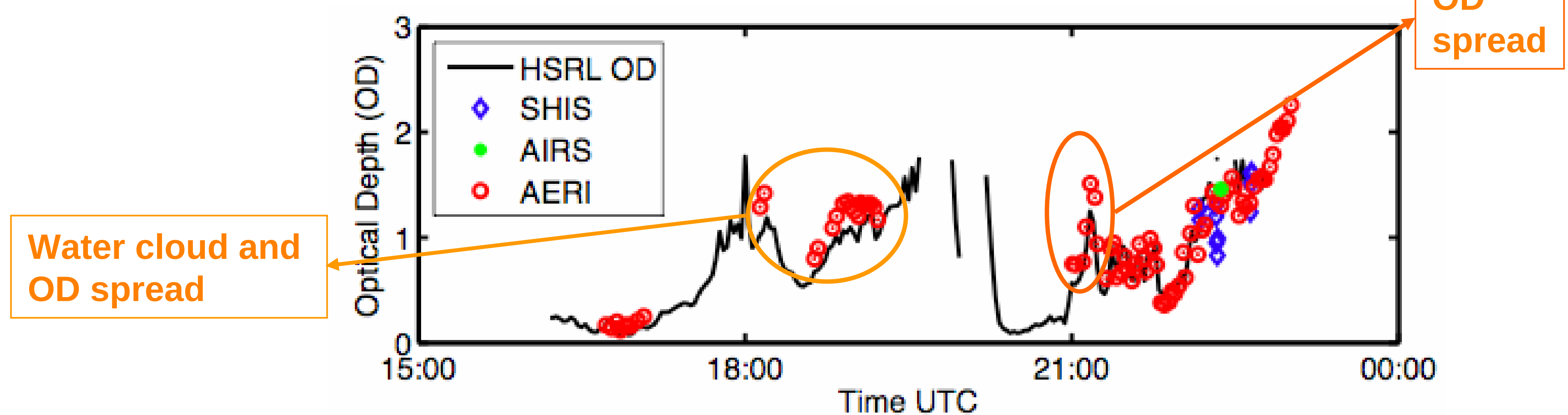
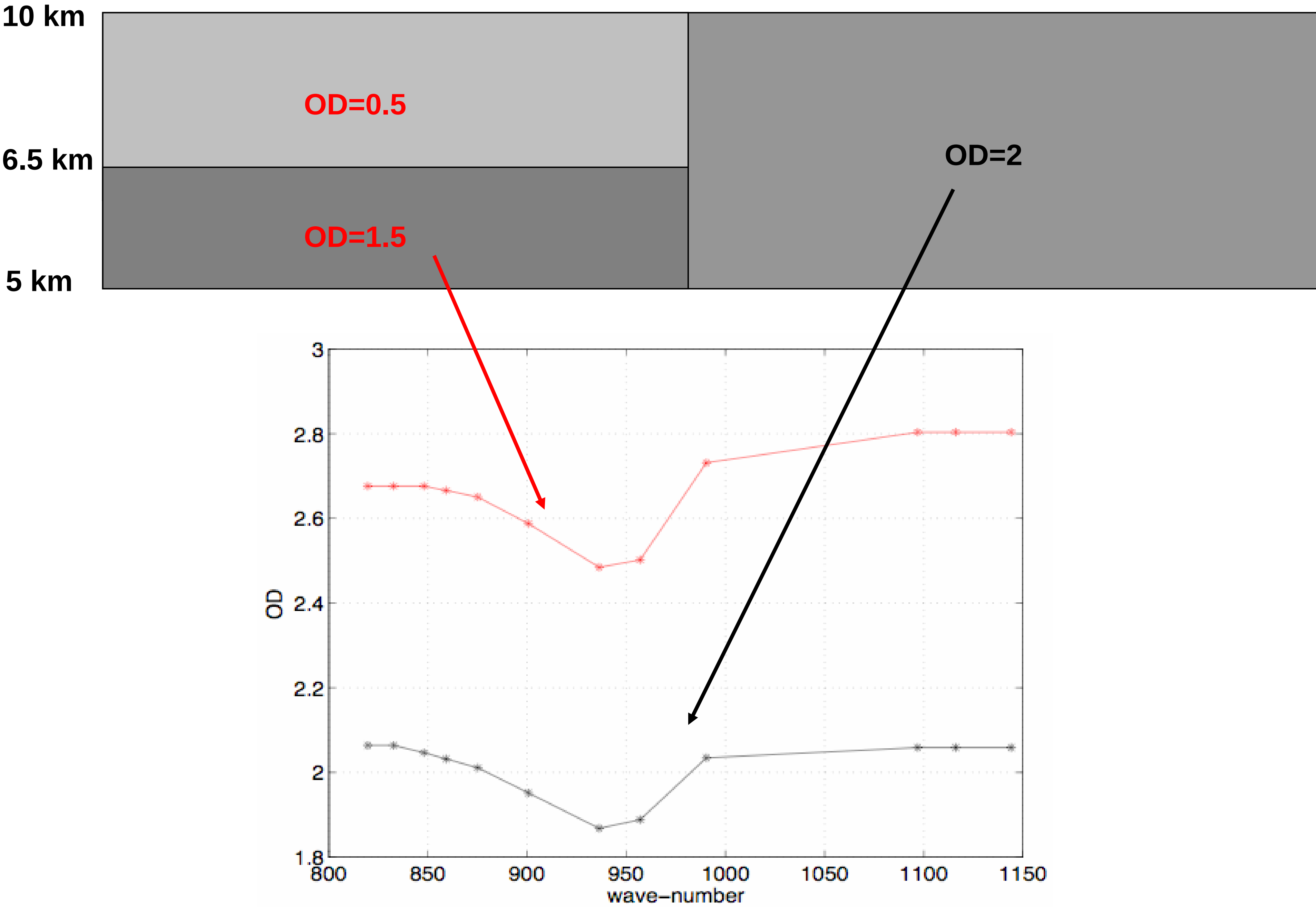
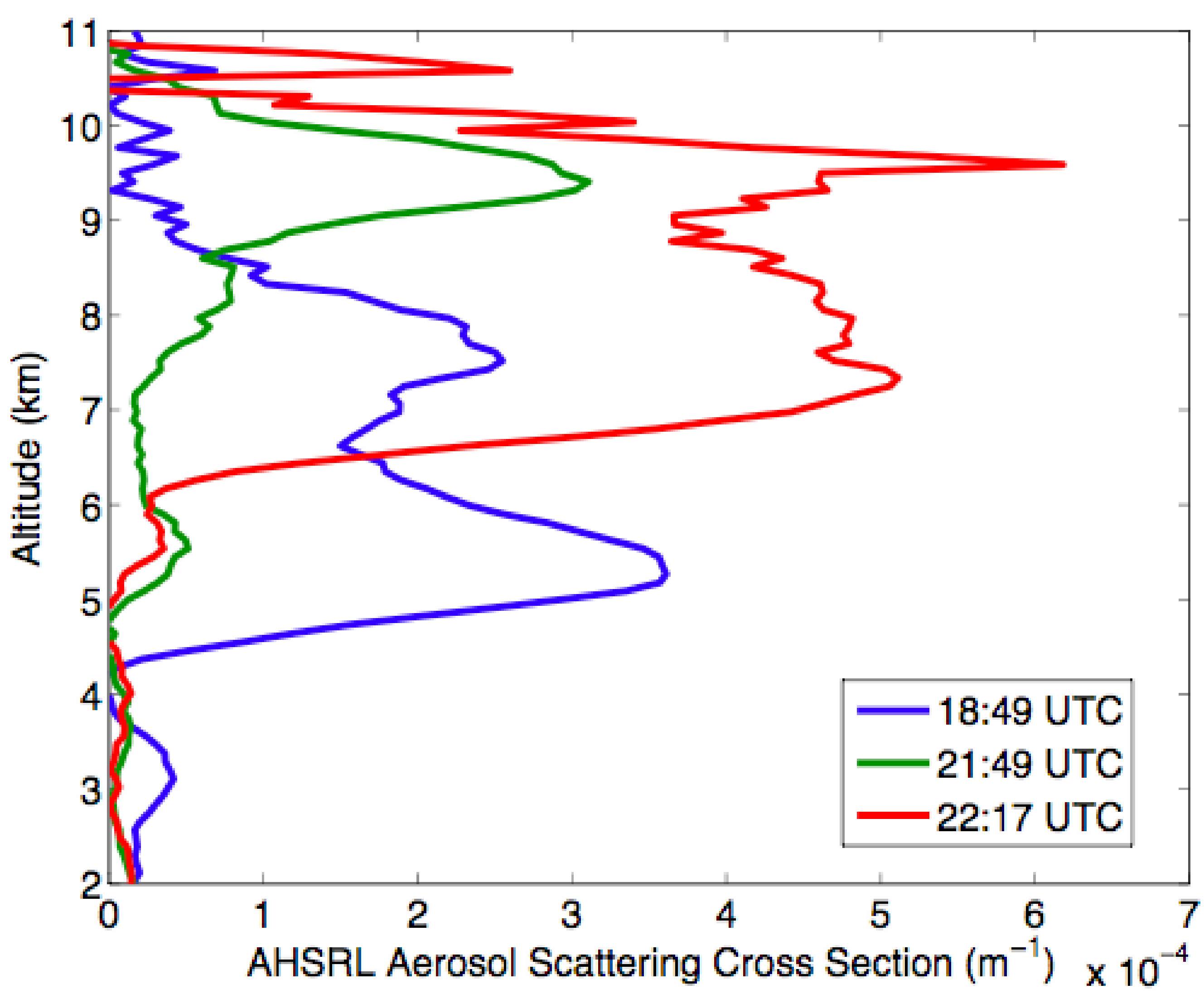


HSRL OD
SHIS
AIRS
AERI
Optical Depth (OD)
3
2
1
0
15:00
18:00
21:00
00:00
Time UTC
Water cloud and OD spread
OD spread

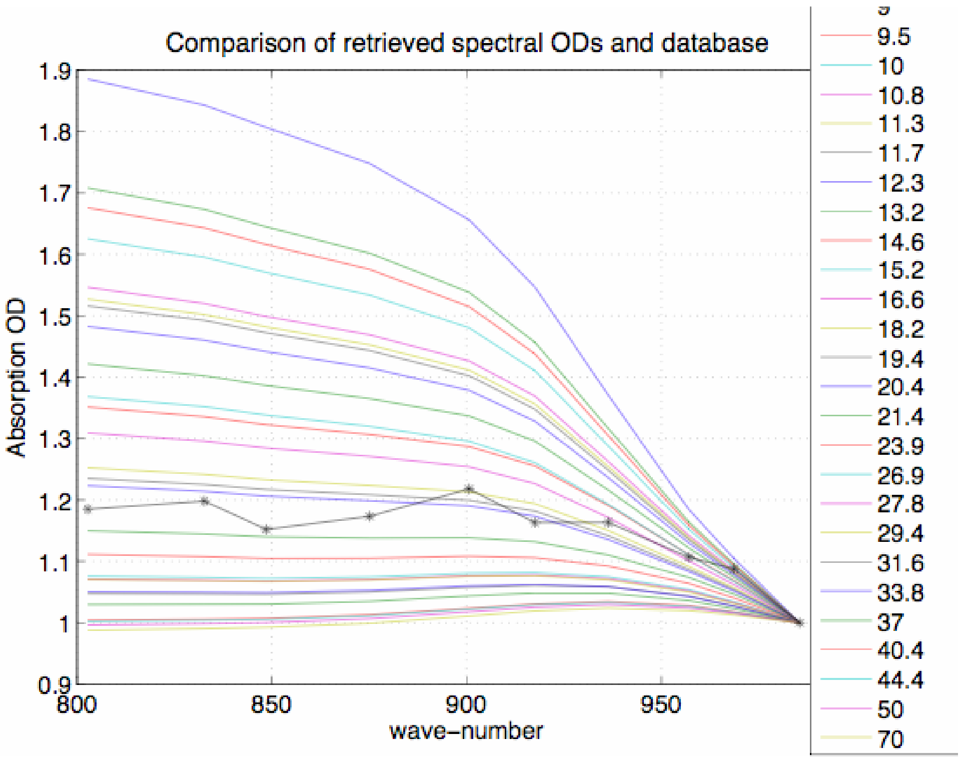
Simulation and retrieval: OD vertical non homogeneity

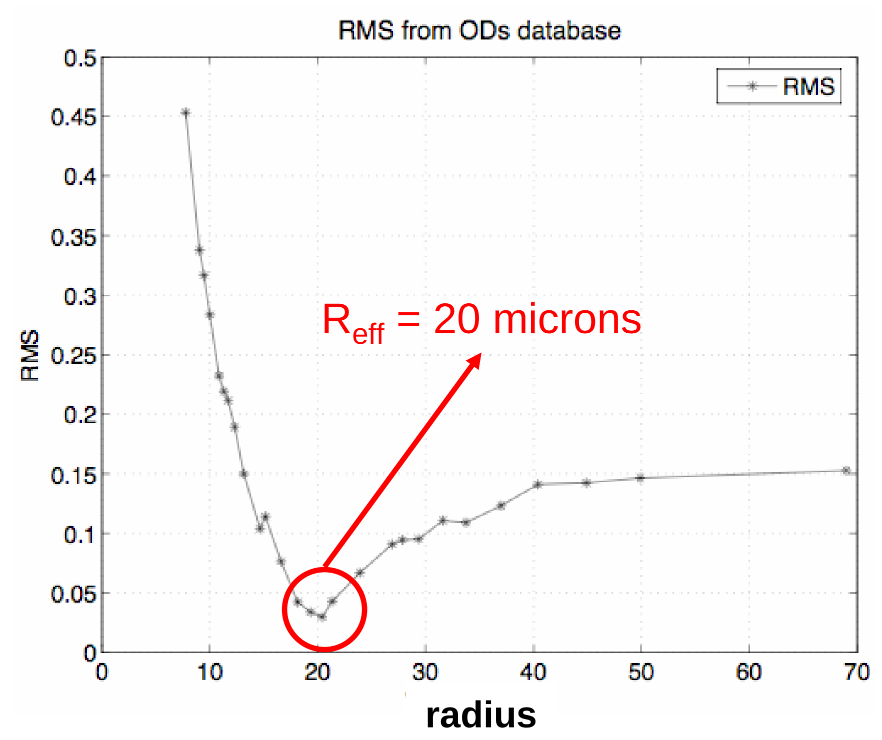


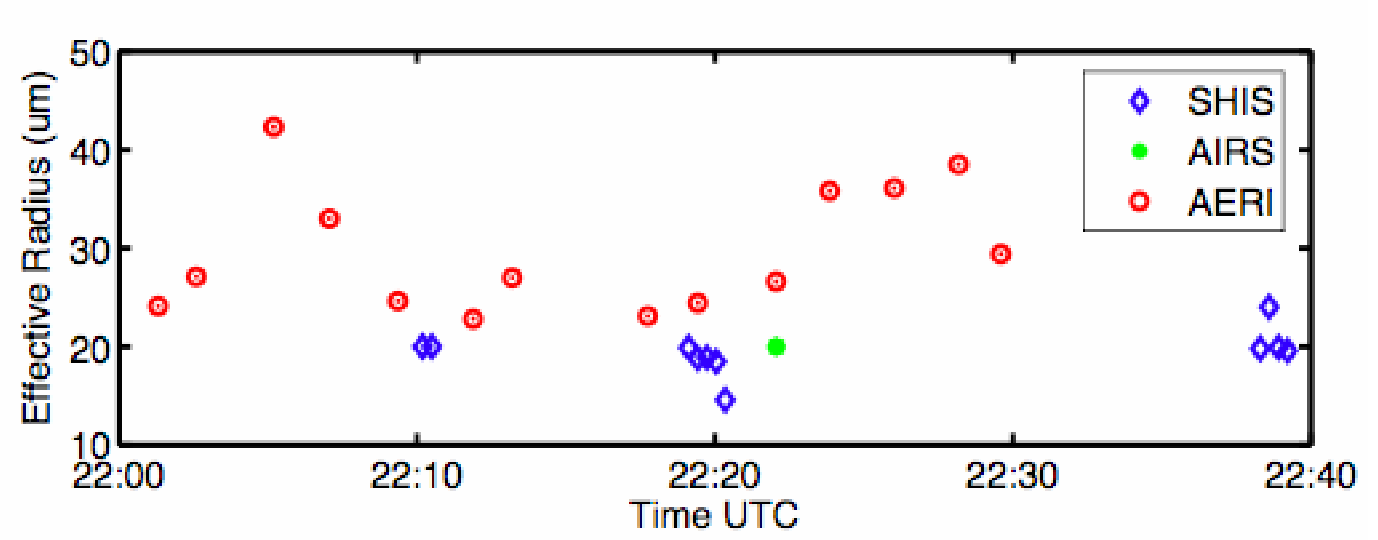
The real state: investigate the cloud "homogeneity"



Retrieval of the effective dimension

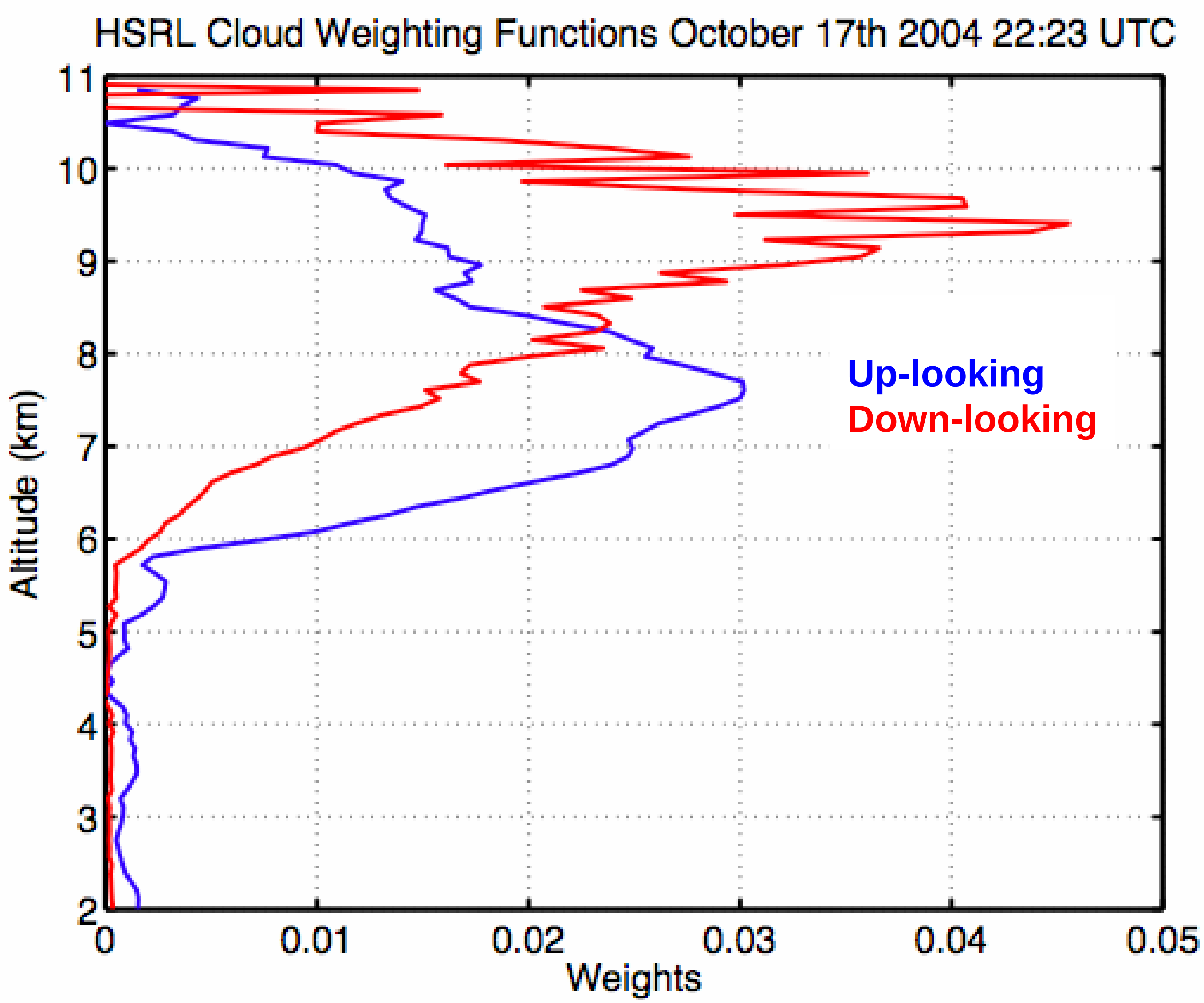




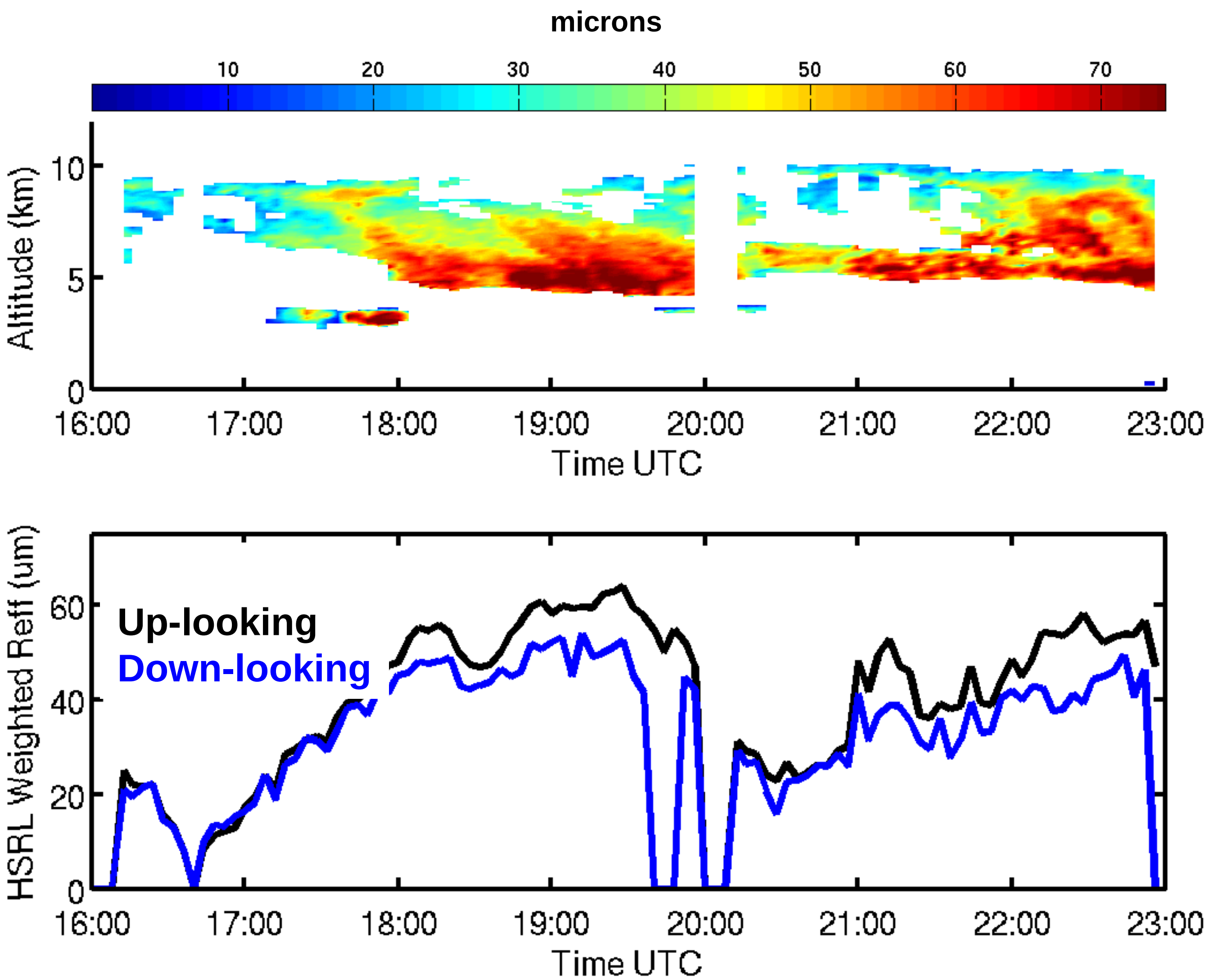


Lidar weighting functions

from layer to sensor transmittances



AHSRL/Radar effective radius retrieval

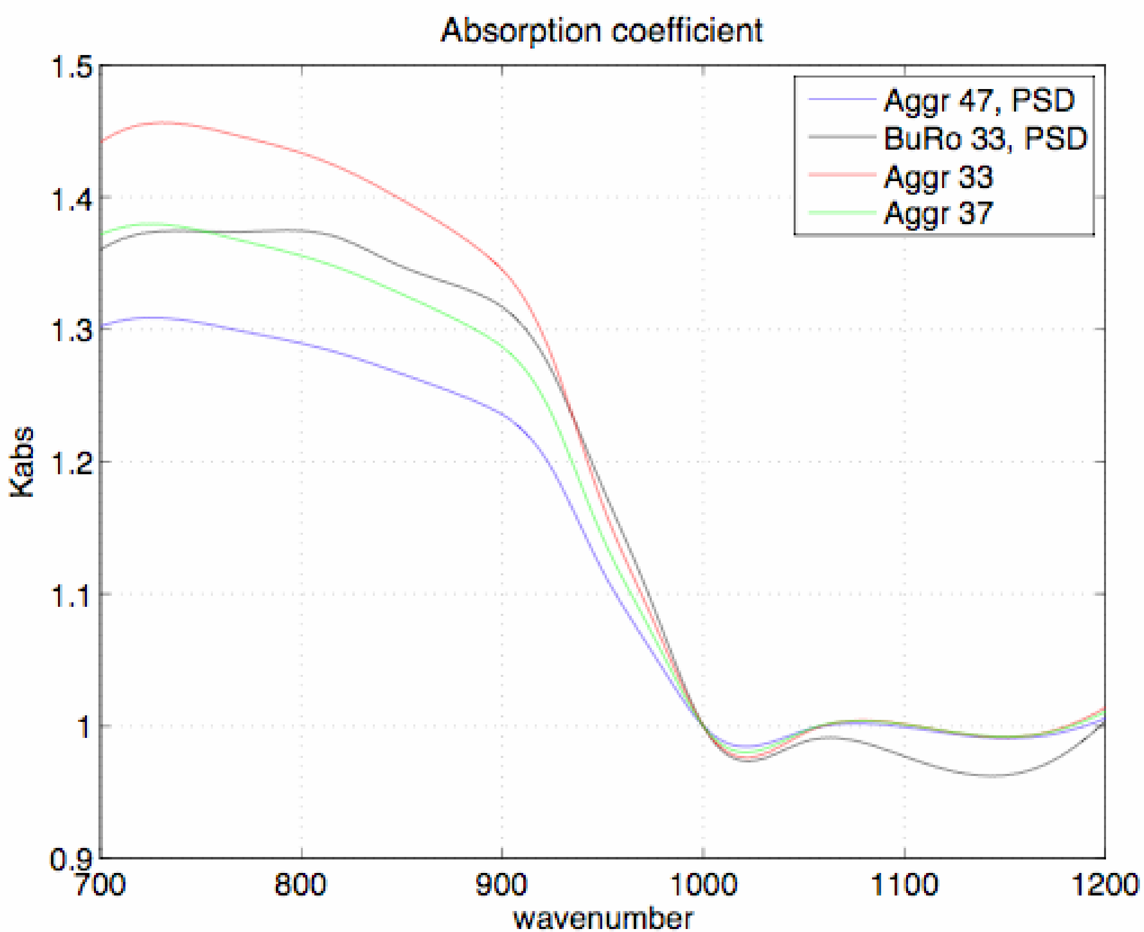


Retrieval of the effective dimension

AIRS

Bullett Rosettes: OD(900 cm^{-1})=1.3; OD(.532 um)=1.46; R_{eff}=20 microns ➔ IWC=0.013 g/m^3
Aggregates: OD(900 cm^{-1})=1.3; OD(.532 um)=1.36; R_{eff}=27 microns ➔ IWC=0.0097 g/m^3

[Mixture: OD=1.44, R_{eff}=33.5 microns *Xuebau Wu, Jun Li et al.* retrieval
(droxtals, hexagonal and aggregates)]



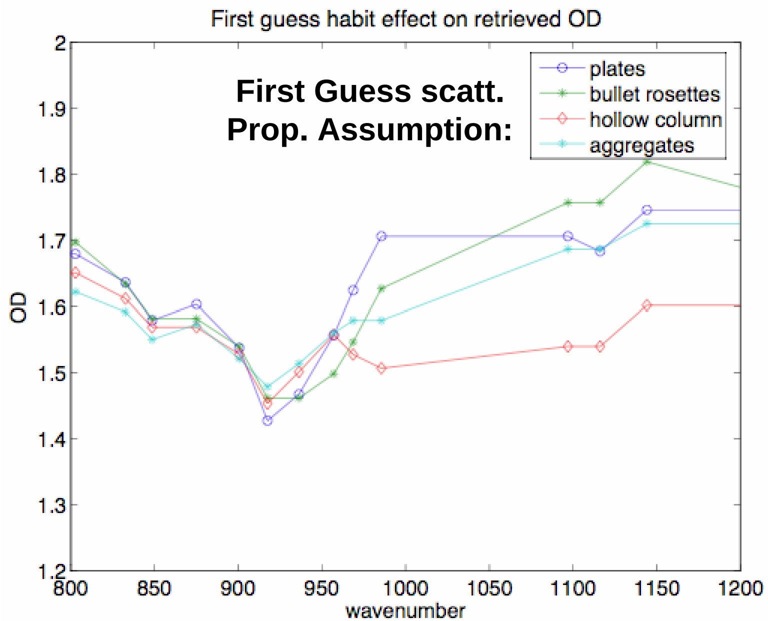
Considerations:

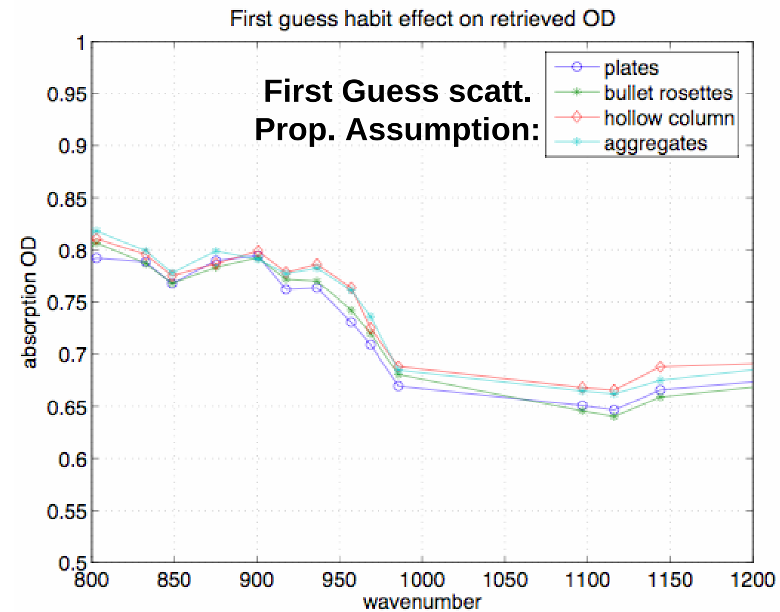
- IR optical properties effects on radiance are mostly defined by the particles' cross sectional area
- The effective dimension is volume/area dependent
- 'Bulky' particles have larger D_{eff} for the same PSD
- Comparison among different instruments must account for the habits and the PSDs assumptions
- AHSRL retrieves

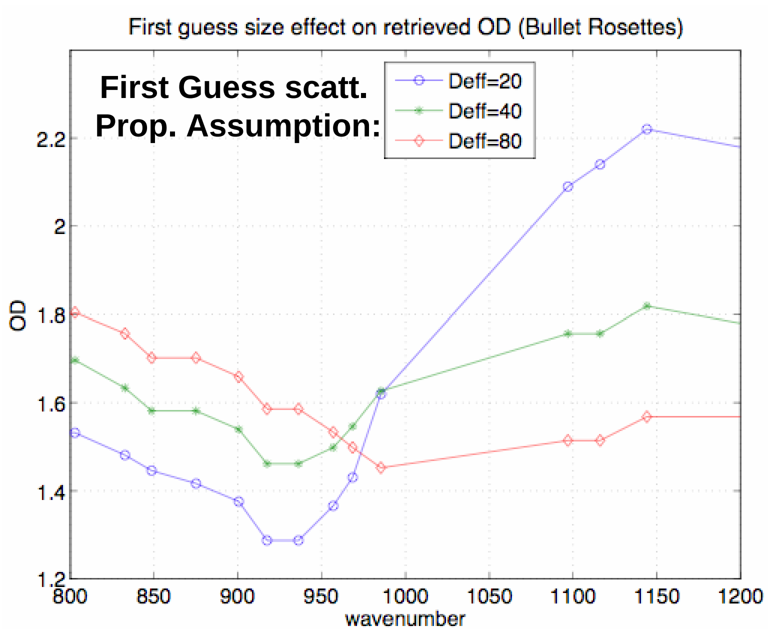
$$D'_{eff} = \sqrt[4]{\frac{9\langle V^2 \rangle}{\pi \langle A \rangle}}$$

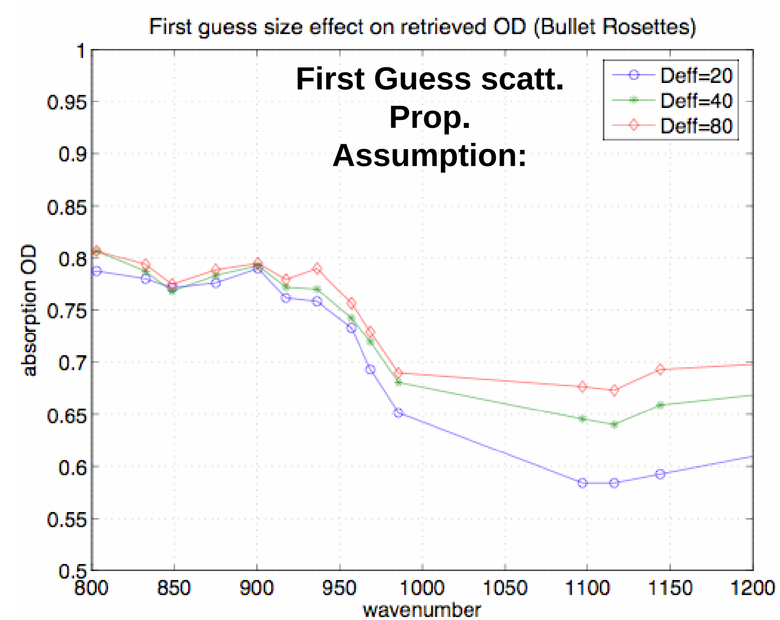
without any assumption on habit and PSD
➔ Future comparison

The Algorithm sensitivity: Uncertainties on first guess assumption

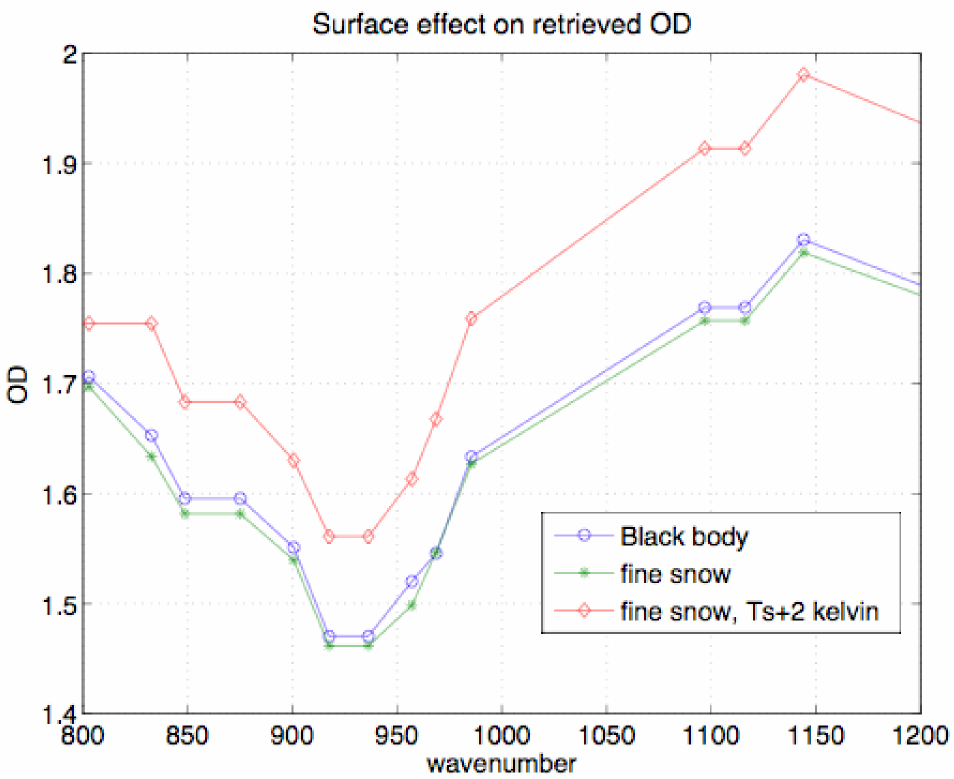


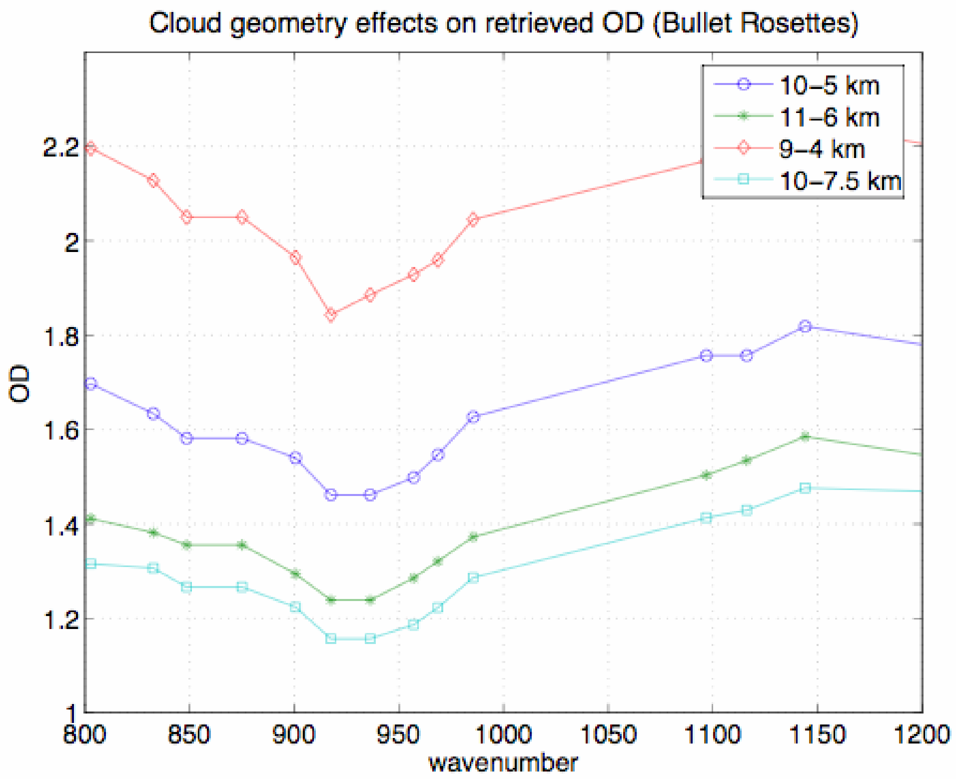






The Algorithm sensitivity: Uncertainties on surface properties and cloud geometry





$$R \approx t_c \cdot (\varepsilon_s F_s) + (1 - t_c) \cdot F_c$$

Interpretation requires accounting for cloud emission and attenuation
Ex.blu-cyan: cyan emits at lower T ➔ has to attenuate less to get the same R

Conclusions

A new retrieval code working in the OD space and accounting for MS processes. RT-RET works with ground-airborne-satellite sensors

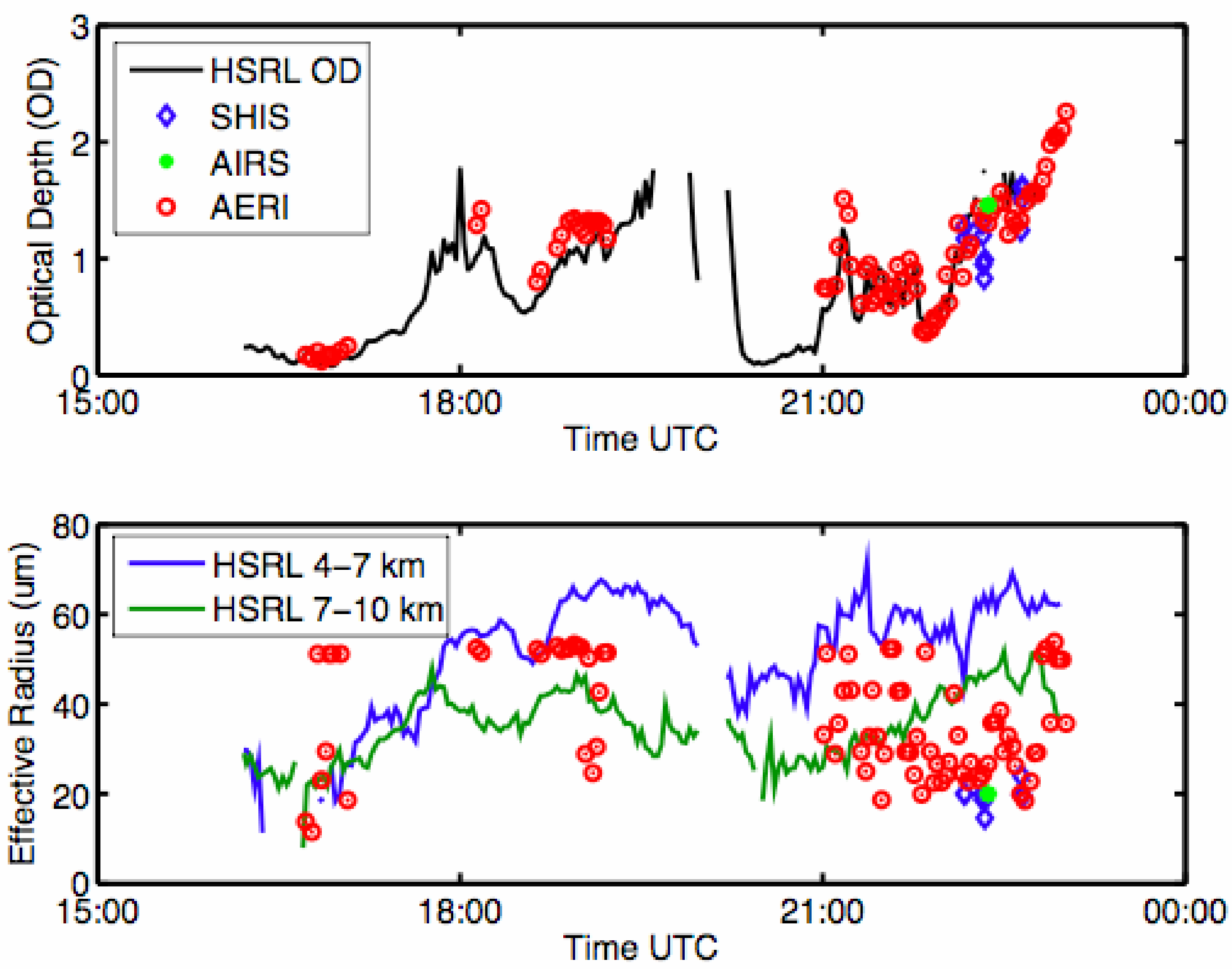
Limitations in cloud properties retrievals using IR only

Future

Improve in the speed/database/algorithm.

Validation case studies for certain geographical sites.

IR-Lidar/Radar consistent comparisons on particles retrieved dimensions: D'_{eff}



3
2
1
0
Optical Depth (OD)
HSRL OD
SHIS
AIRS
AERI
15:00
18:00
21:00
00:00
Time UTC
80
60
40
20
0
Effective Radius (um)
HSRL 4–7 km
HSRL 7–10 km
15:00
18:00
21:00
00:00
Time UTC

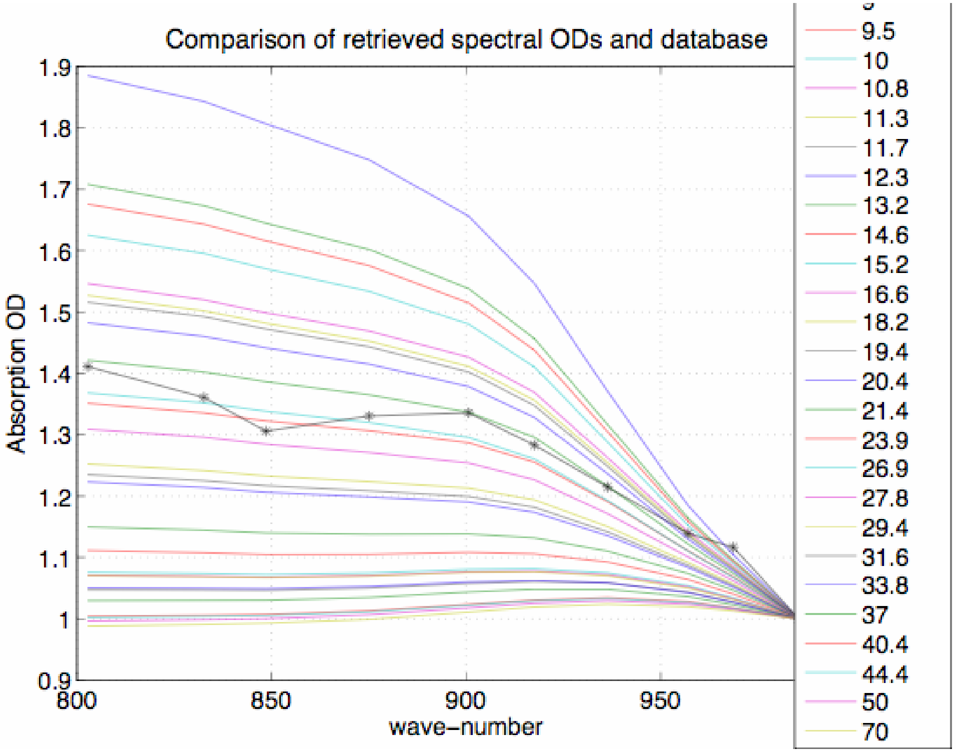
Effective Diameter Prime

is the fundamental quantity derived from the combination of lidar and radar backscatter cross sections, where and refer to the average volume-squared and average area of the cloud particles as defined by Donovan and Lammeren JGR, v106, D21, pp 27425. The only user supplied quantity required for this computation is the backscatter phase function for ice crystals.

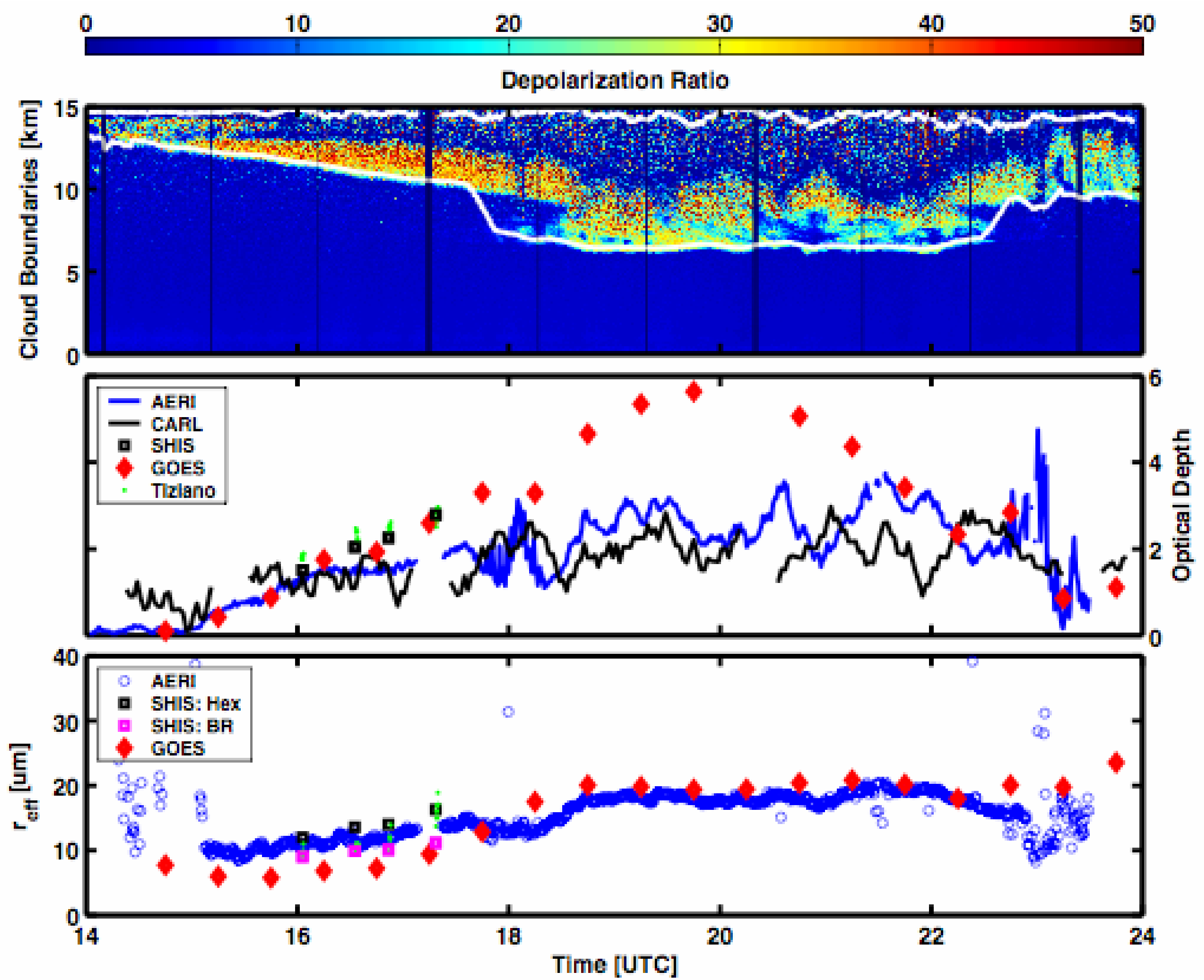
Could be computed from hsrl measurements for each point within the cloud, however the measurement is sensitive altitude averaging lengths and averaging times. Short averages are likely to have excessive noise. Long averages are likely to mix regions of low and high scattering. As a result, we have decided to allow the user to specify this value as a cloud average. It is recommended that an independent analysis of the data be used to determine an appropriate value for p180_ice. Errors in effective_diameter_prime are proportional to the 4th-root of the error in .f

S-HIS effective dimension retrieval

Reff=14 microns



Texas 2002



0
10
20
30
40
50
Depolarization Ratio
Cloud Boundaries [km]
15
10
5
0
AERI
CARL
SHIS
GOES
Tiziano
Optical Depth
6
4
2
0
40
30
20
10
0
r_{eff} [um]
AERI
SHIS: Hex
SHIS: BR
GOES
14
16
18
20
22
24
Time [UTC]

PARAMETERS DEFINING THE GAMMA

Gamma Type SD have been fitted to measured PSDs using:

1st, 2nd and 6th moments of the PSDs

Correlation coefficients $r^2 > 0.8$

$$N(D) = N_0 D^{\mu} e^{-\lambda D}$$

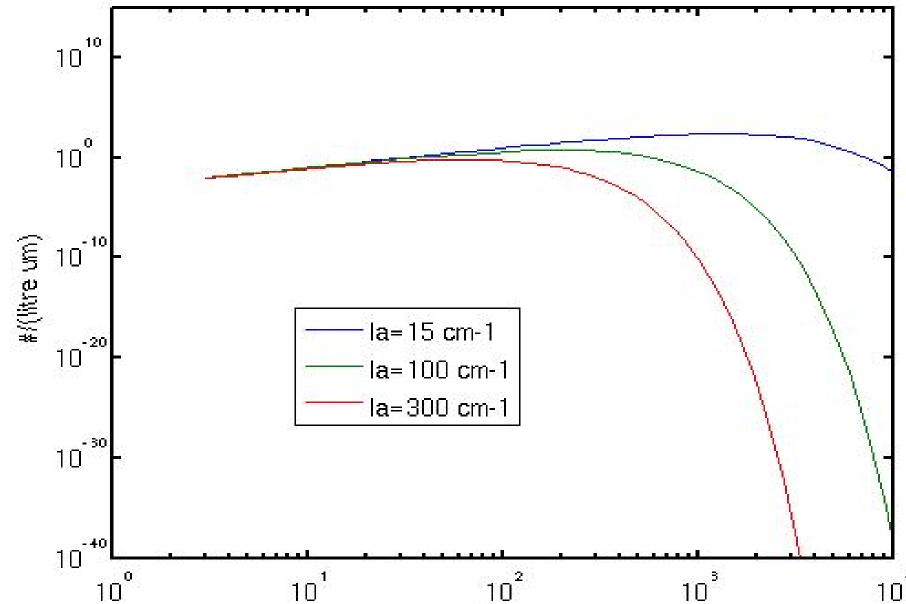
D = dimension (cm)

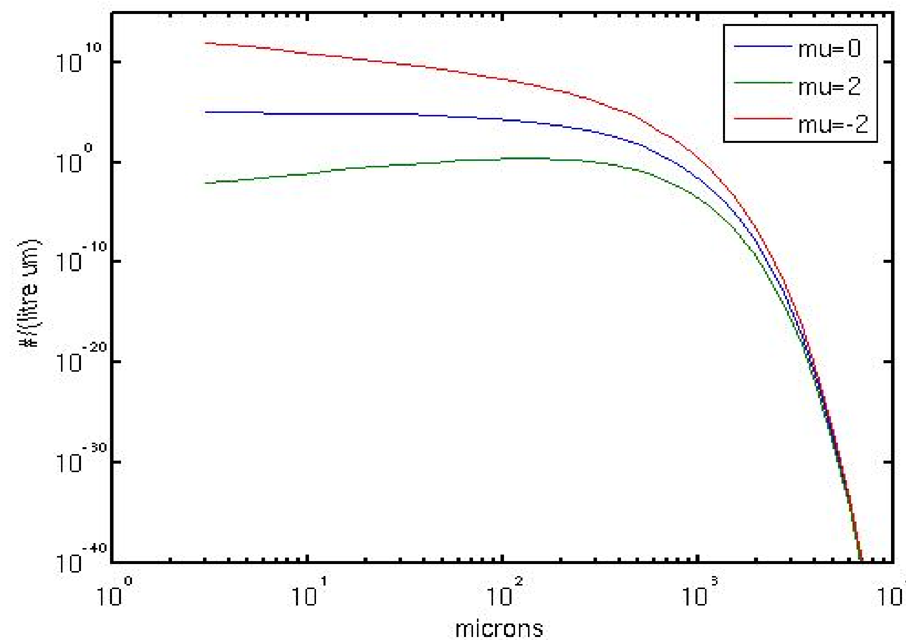
N_0 = intercept

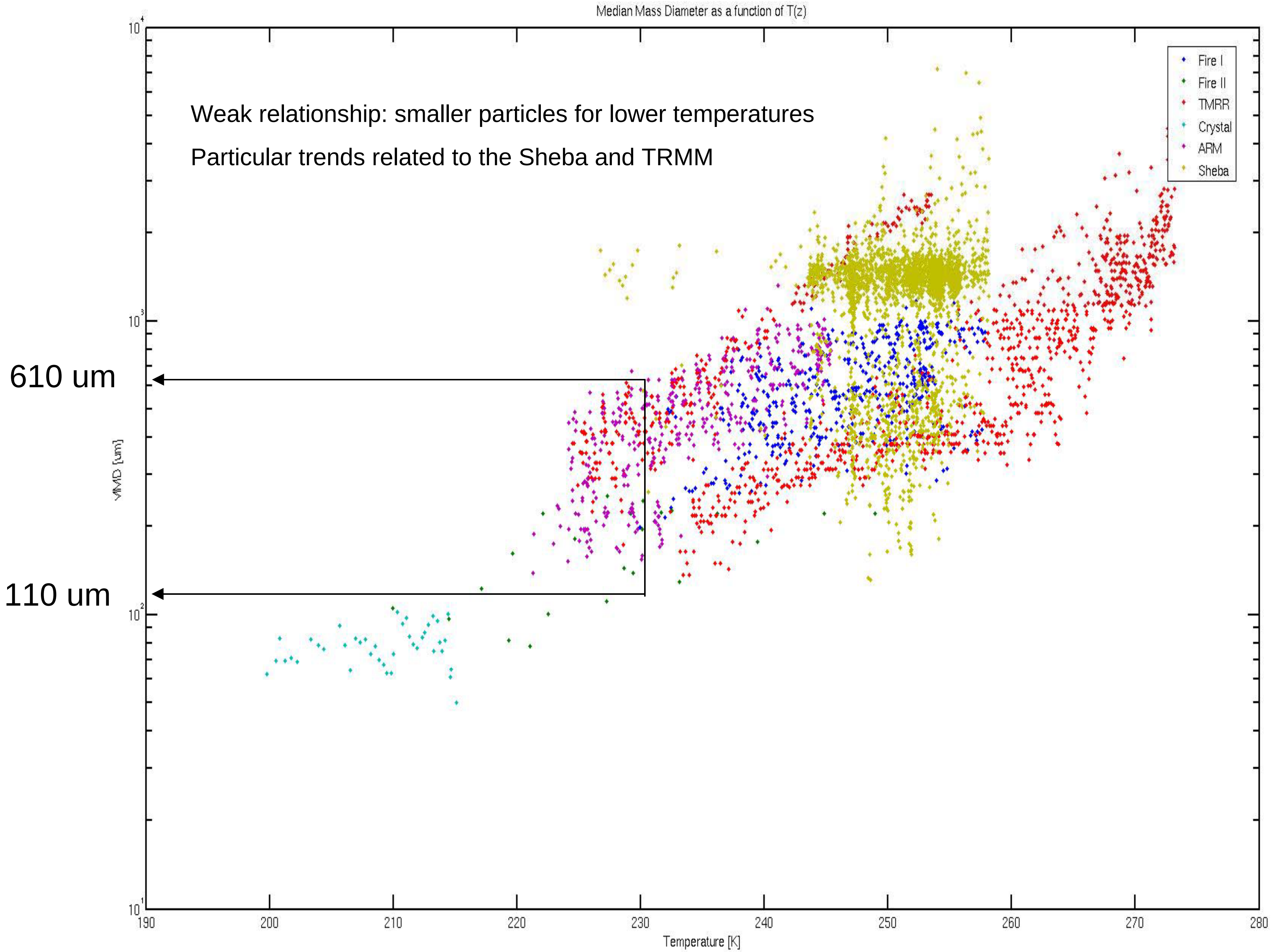
λ = slope

μ = dispersion (when =0 --> exp.)

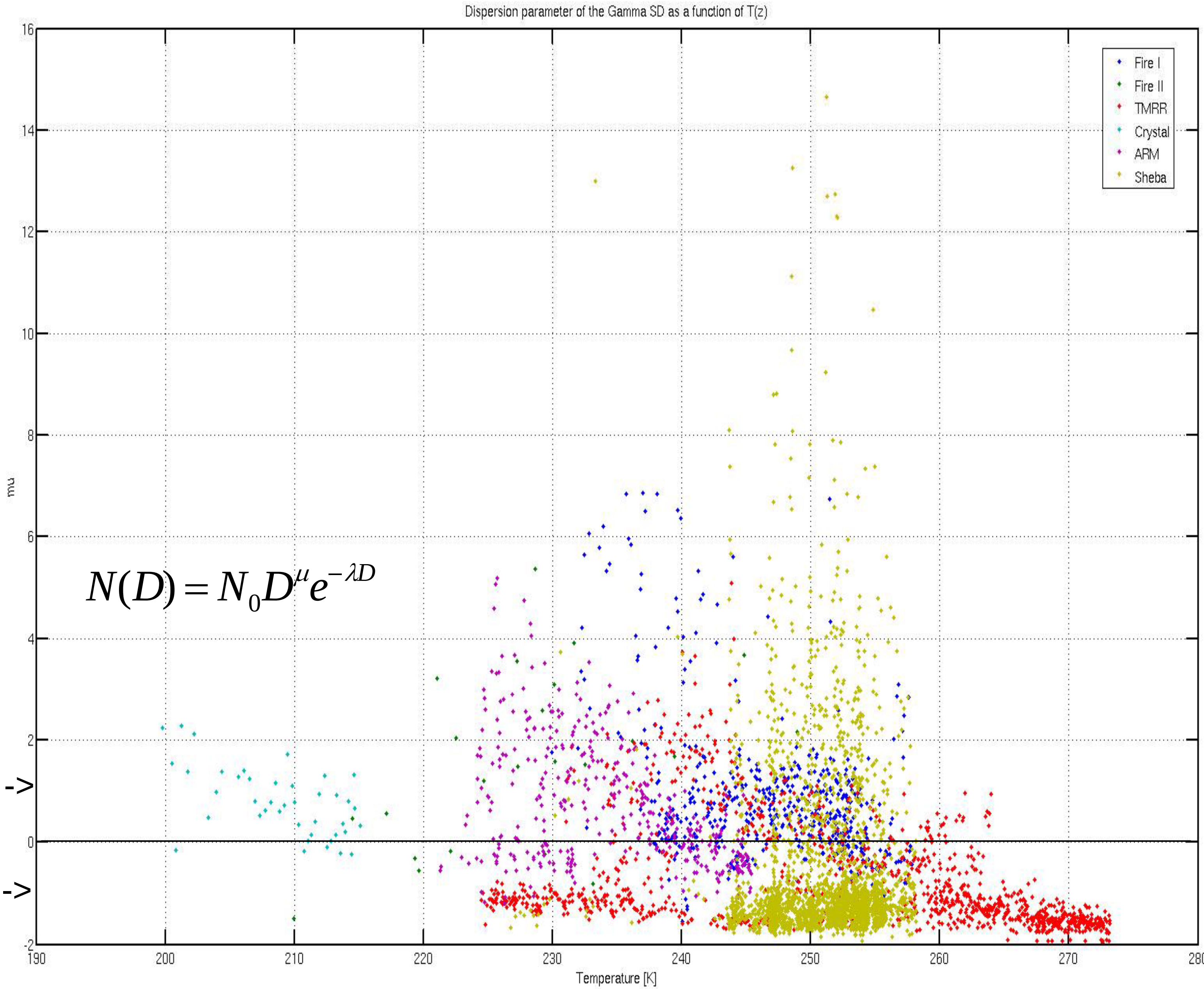
Additional: IWC, DMM, T







Ice clouds ← △ → water/mixed phase?

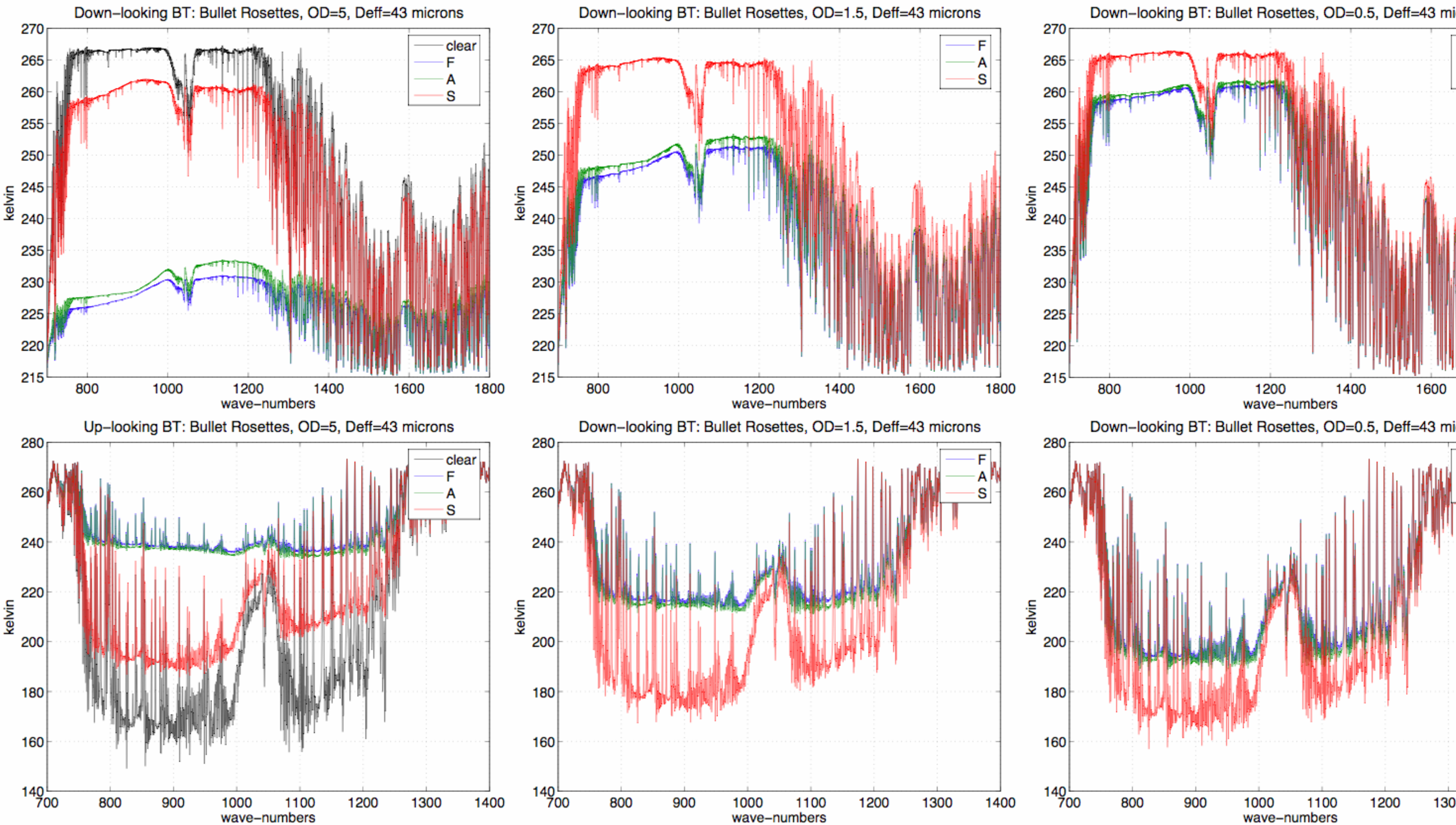


$$N(D) = N_0 D^{\mu} e^{-\lambda D}$$

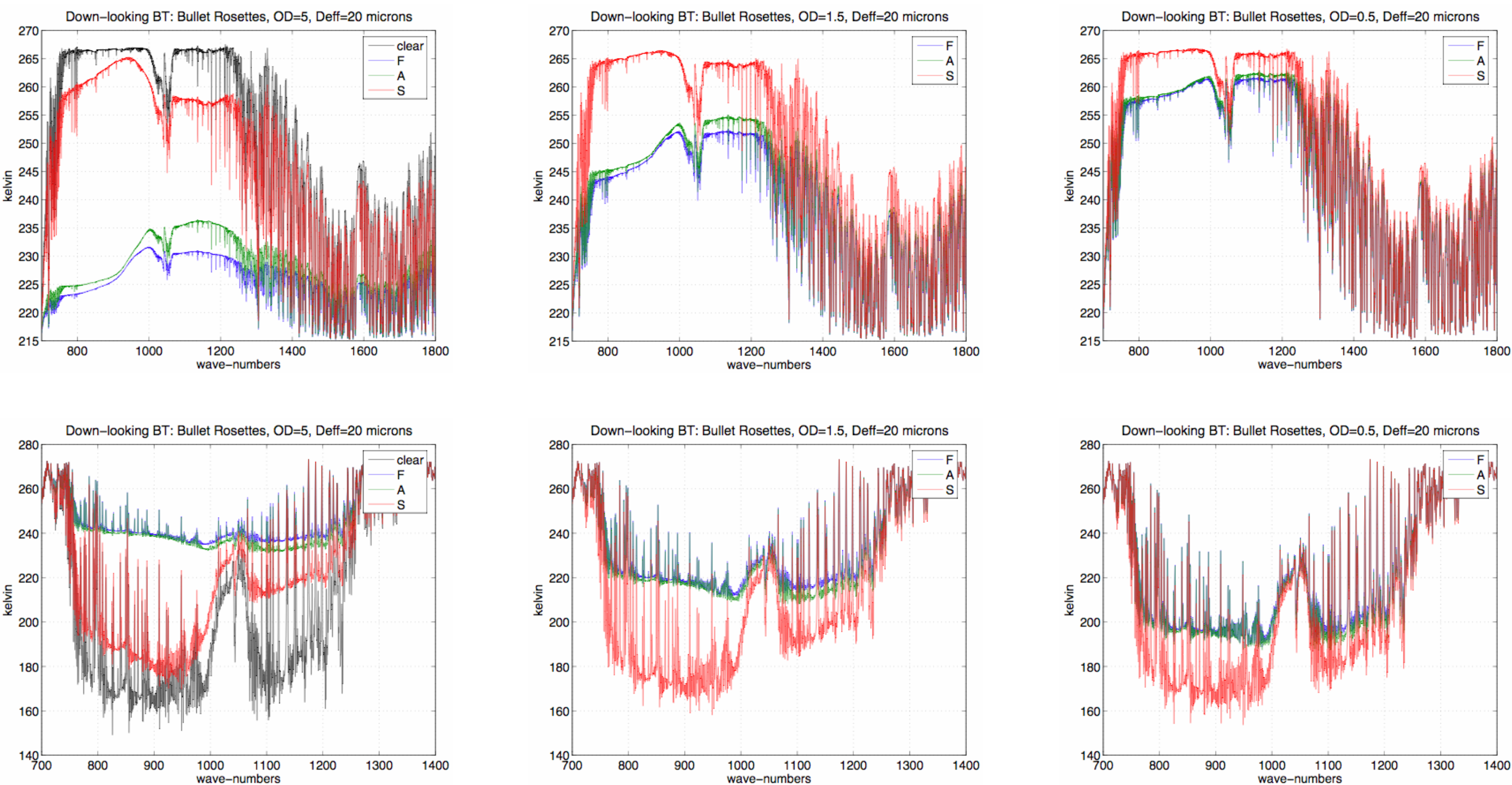
Under exp ->

Over exp ->

TRMM deep convection --> over exponential

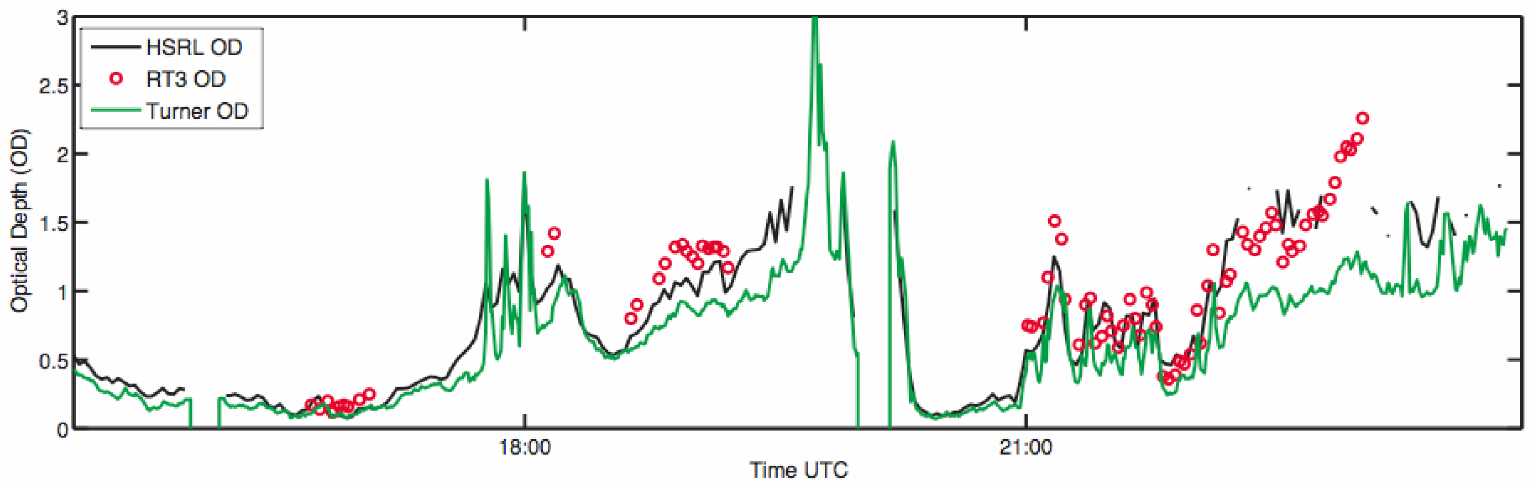


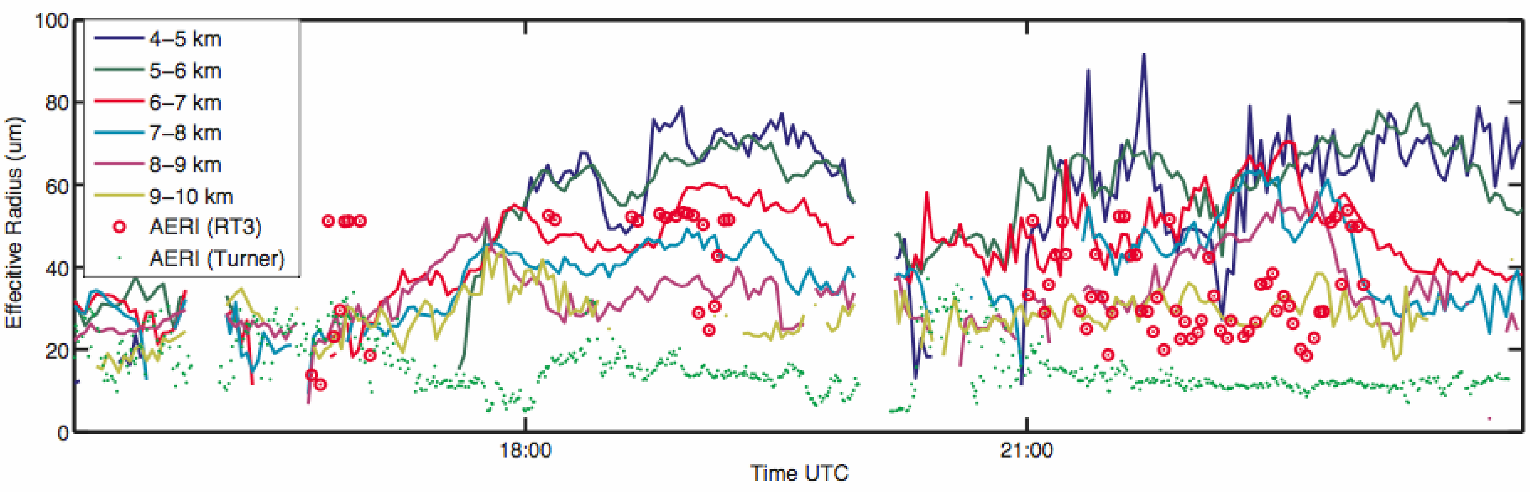
Down–looking BT: Bullet Rosettes, OD=5, Deff=43 microns
Down–looking BT: Bullet Rosettes, OD=1.5, Deff=43 microns
Down–looking BT: Bullet Rosettes, OD=0.5, Deff=43 mi
Up–looking BT: Bullet Rosettes, OD=5, Deff=43 microns
Down–looking BT: Bullet Rosettes, OD=1.5, Deff=43 microns
Down–looking BT: Bullet Rosettes, OD=0.5, Deff=43 mi
clear
F
A
S
kelvin
wave–numbers

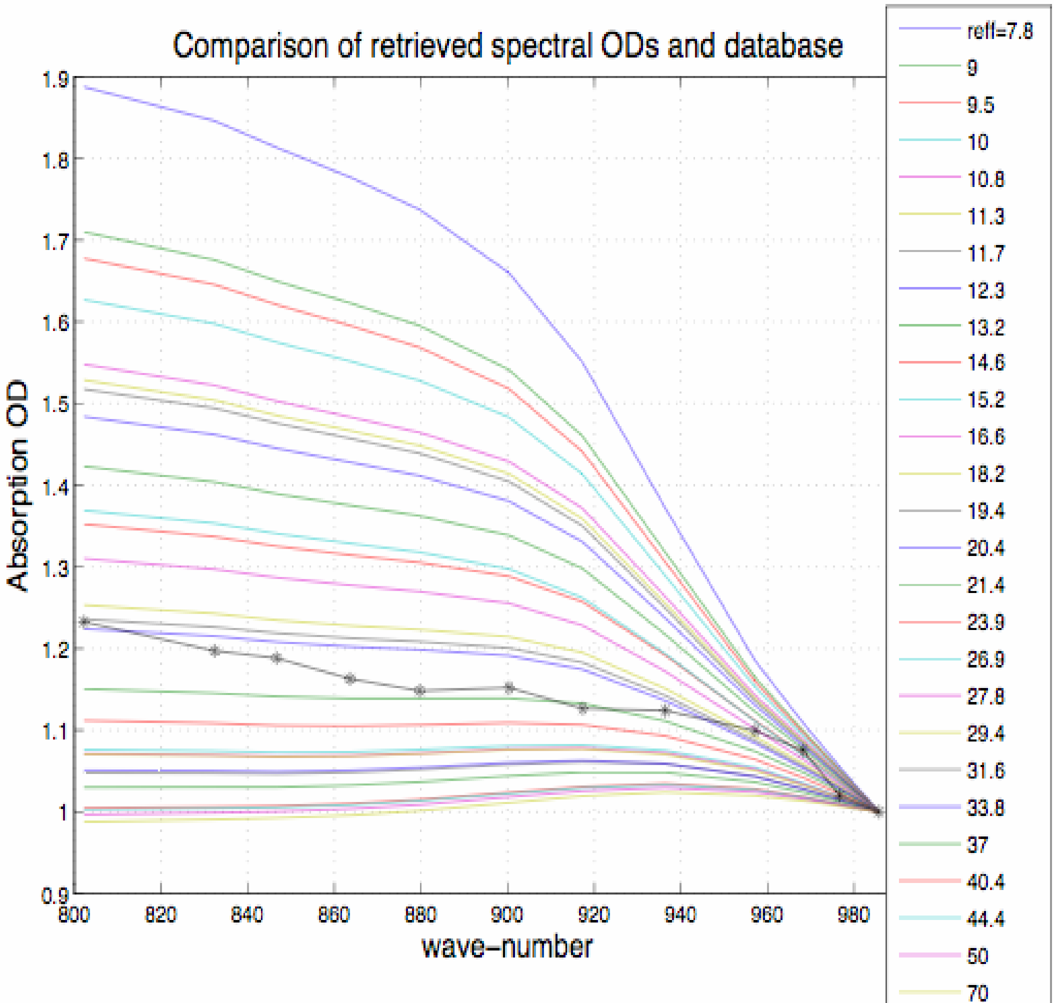


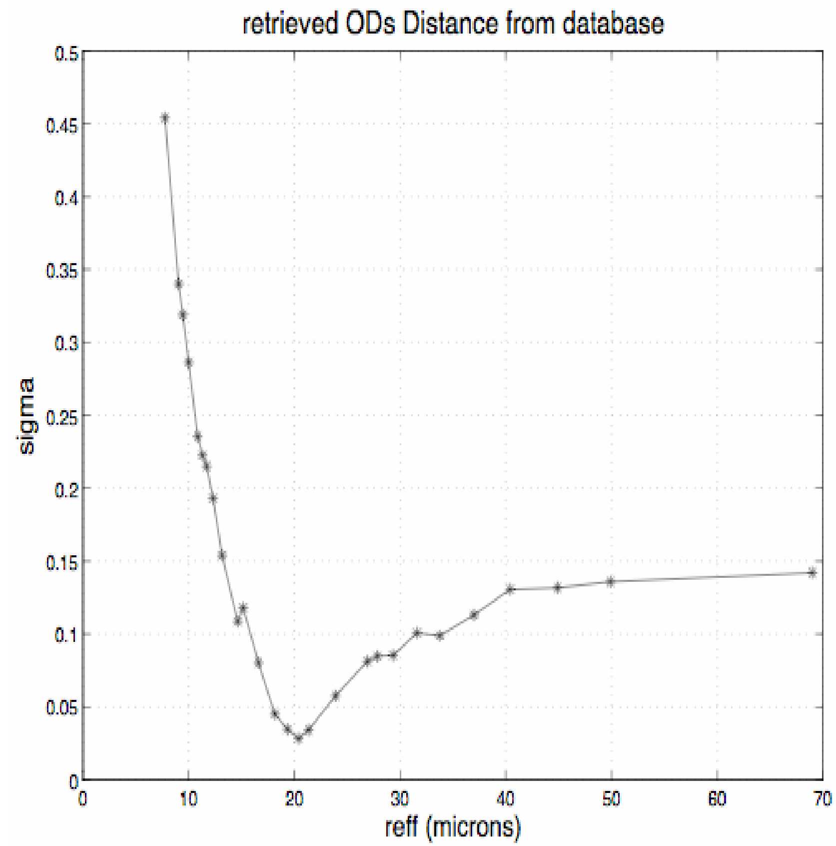
Down–looking BT: Bullet Rosettes, OD=5, Deff=20 microns
clear
F
A
S
kelvin
wave–numbers
Down–looking BT: Bullet Rosettes, OD=1.5, Deff=20 microns
F
A
S
kelvin
wave–numbers
Down–looking BT: Bullet Rosettes, OD=0.5, Deff=20 microns
F
A
S
kelvin
wave–numbers
Down–looking BT: Bullet Rosettes, OD=5, Deff=20 microns
clear
F
A
S
kelvin
wave–numbers
Down–looking BT: Bullet Rosettes, OD=1.5, Deff=20 microns
F
A
S
kelvin
wave–numbers
Down–looking BT: Bullet Rosettes, OD=0.5, Deff=20 microns
F
A
S
kelvin
wave–numbers

Up-looking Retrieval and AHSRL comparison






Comparison of retrieved spectral ODs and database
Absorption OD
wave−number
reff=7.8
9
9.5
10
10.8
11.3
11.7
12.3
13.2
14.6
15.2
16.6
18.2
19.4
20.4
21.4
23.9
26.9
27.8
29.4
31.6
33.8
37
40.4
44.4
50
70


retrieved ODs Distance from database
sigma
reff (microns)