IRS2012 – International Radiation Symposium 2012
06 – 10 August 2012, Berlin, Germany
Session 5: General Remote Sensing

Can Spatially Unresolved 3D Mixtures of Clouds & Aerosols be Disentangled using Multi-Angle Polarized Radiance Observations?

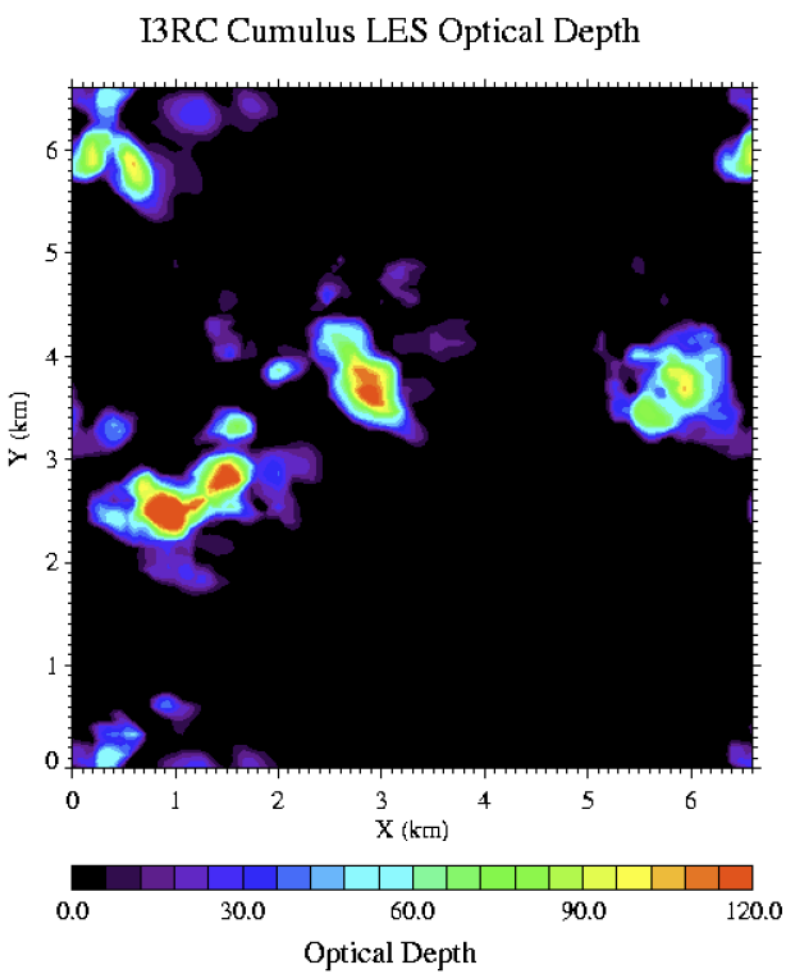
Anthony B. Davis, JPL/Caltech, Pasadena, Ca, USA
Michael J. Garay, JPL/Caltech, Pasadena, Ca, USA
Alexander Marshak, NASA - GSFC, Greenbelt, Md, USA
Claudia Emde, LMU, Munich, Germany

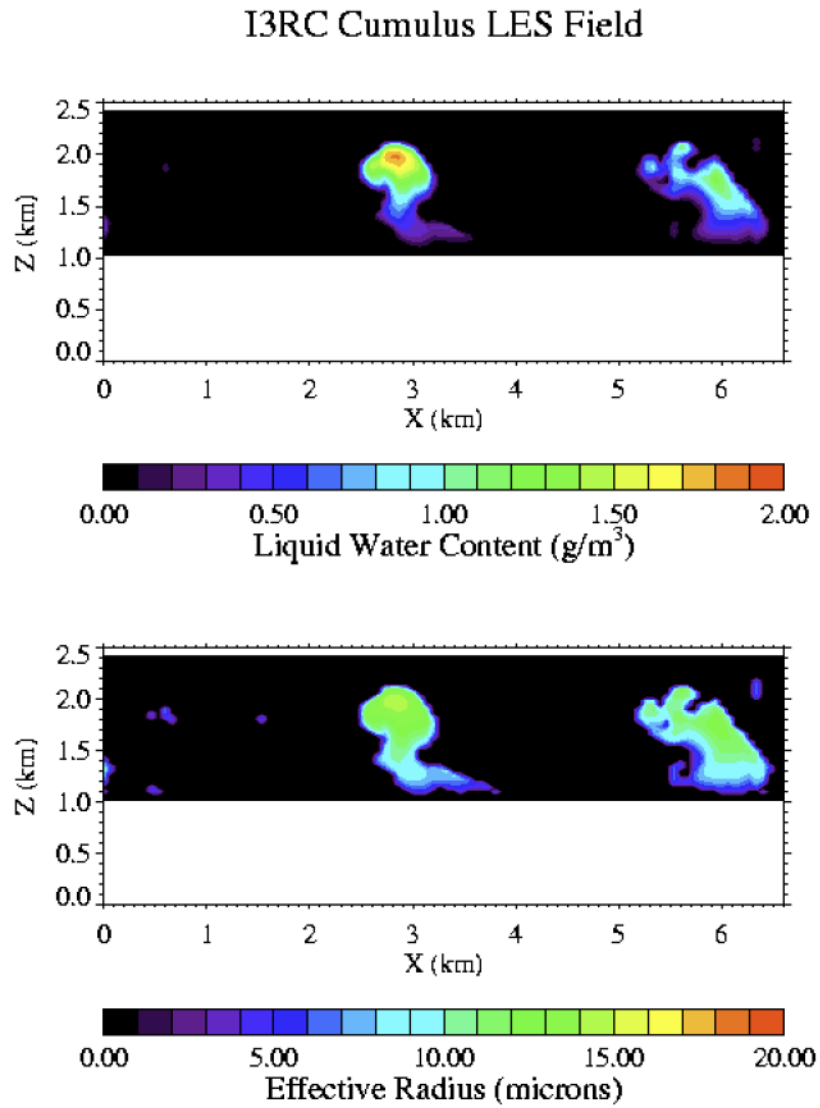
The Problem …

Motivation & Outline

- **Multi-angle spectro-polarimeters**
  - Large-footprints from space: POLDER/PARASOL, APS/Glory-2(?)
  - Future satellite missions: ESA's 3MI, JAXA's concept, NASA's ACE(?)
  - Airborne sensors: RSP, HySPAR, MSPI, PACS, etc.
- **Simulation framework**
  - Clouds, aerosols, gases
  - Polarized/vector radiative transfer (RT) models:
    - 3D for "data"
    - 1D for retrievals, starting with cloud/aerosol signal separation
- **3D RT damage assessment for APS**
  - Background aerosol
  - Heavy aerosol case
- **Summary, outlook, and the BIG PICTURE**

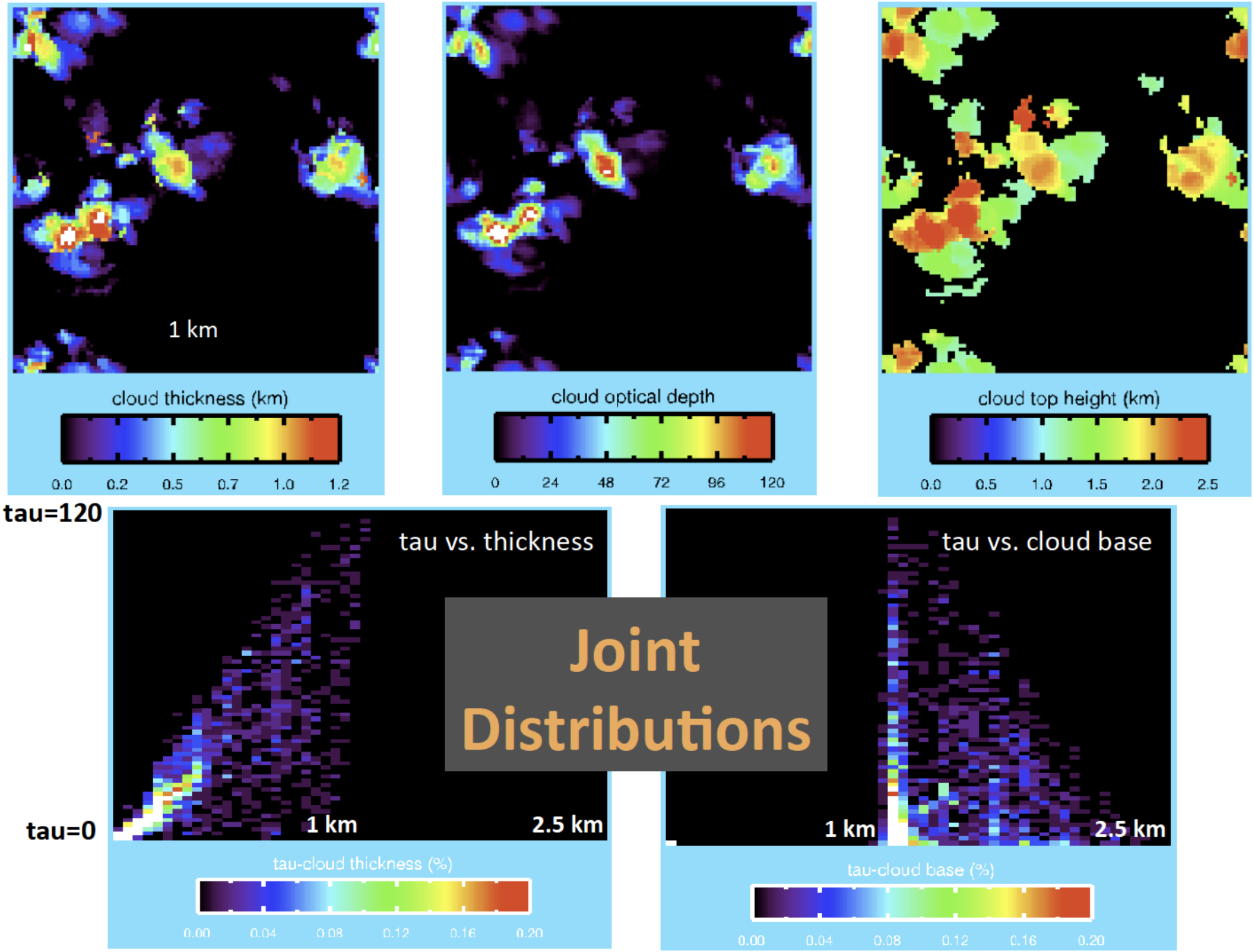
A well-documented test case …



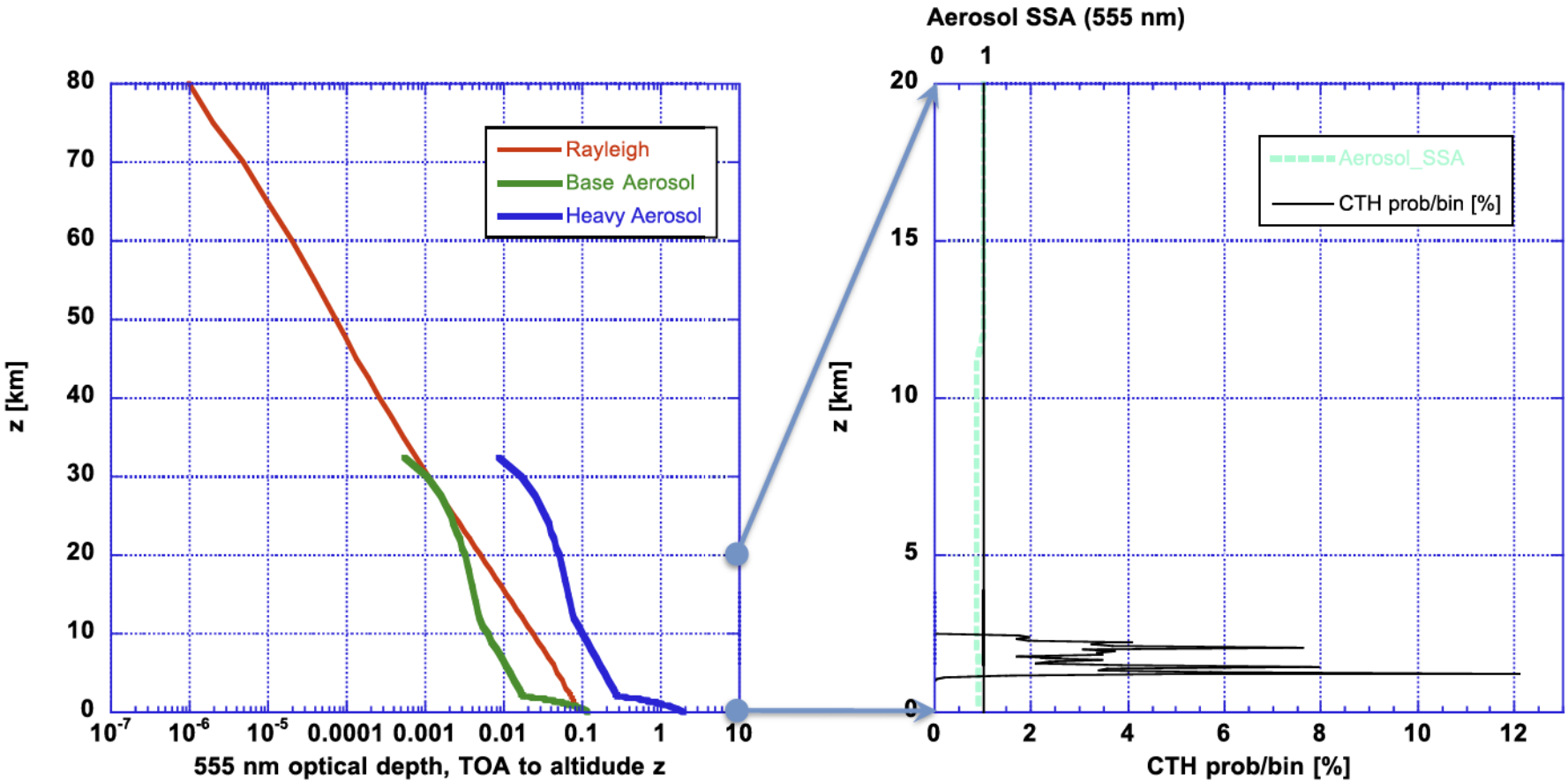


"I3RC" LES Cu field

192x192 columns, each 33.35x33.35 m^2; full domain is 6.4x6.4 km^2


1 km
cloud thickness (km)
0.0 0.2 0.5 0.7 1.0 1.2
cloud optical depth
0 24 48 72 96 120
cloud top height (km)
0.0 0.5 1.0 1.5 2.0 2.5
tau=120
tau=0
tau vs. thickness
1 km
2.5 km
tau-cloud thickness (%)
0.00 0.04 0.08 0.12 0.16 0.20
Joint Distributions
tau vs. cloud base
1 km
2.5 km
tau-cloud base (%)
0.00 0.04 0.08 0.12 0.16 0.20

Assumed Vertical Structure



MYSTIC default "continental average" aerosol (Angstrøm exponent ≈ 1.5) from:

Hess, M., P. Koepke, and I. Schult, Optical Properties of Aerosols and Clouds: The Software Package OPAC, *Bulletin of the American Meteorological Society*, **79**, 831-844 (1998).

Spectral properties

APS RSP Band	Wavelength (nm)	Rayleigh OD (no depol)	"Base" Aerosol OD (Hess et al)	"Heavy" Aerosol OD (16 x Base)	Aerosol SSA (col-avr)	Typical cloud SSA (C1 dist.)	Molecular Absorption OD
1	410	0.325116	0.17373	2.77970	0.90636	1	0.0000244
2	443	0.235930	0.15886	2.54107	0.90515	1	0.0012701
3	555	0.093565	0.11937	1.90992	0.89743	1	0.0323896
4	670	0.043506	0.09207	1.47310	0.88754	1	0.0154243
5	865	0.015492	0.06283	1.00520	0.85664	1	0.0000324
6	910	0.012628	0.05808	0.92932	0.84833	1	0.0331325
7	1370	0.002438	0.03182	0.50915	0.78931	N/A	6.8998300
8	1610	0.001276	0.02478	0.39640	0.77147	0.995912	0.0102883
9	2200	0.000365	0.01419	0.22696	0.75688	0.988633	0.0218413

τ parity

$(1-\omega g)\tau$ parity

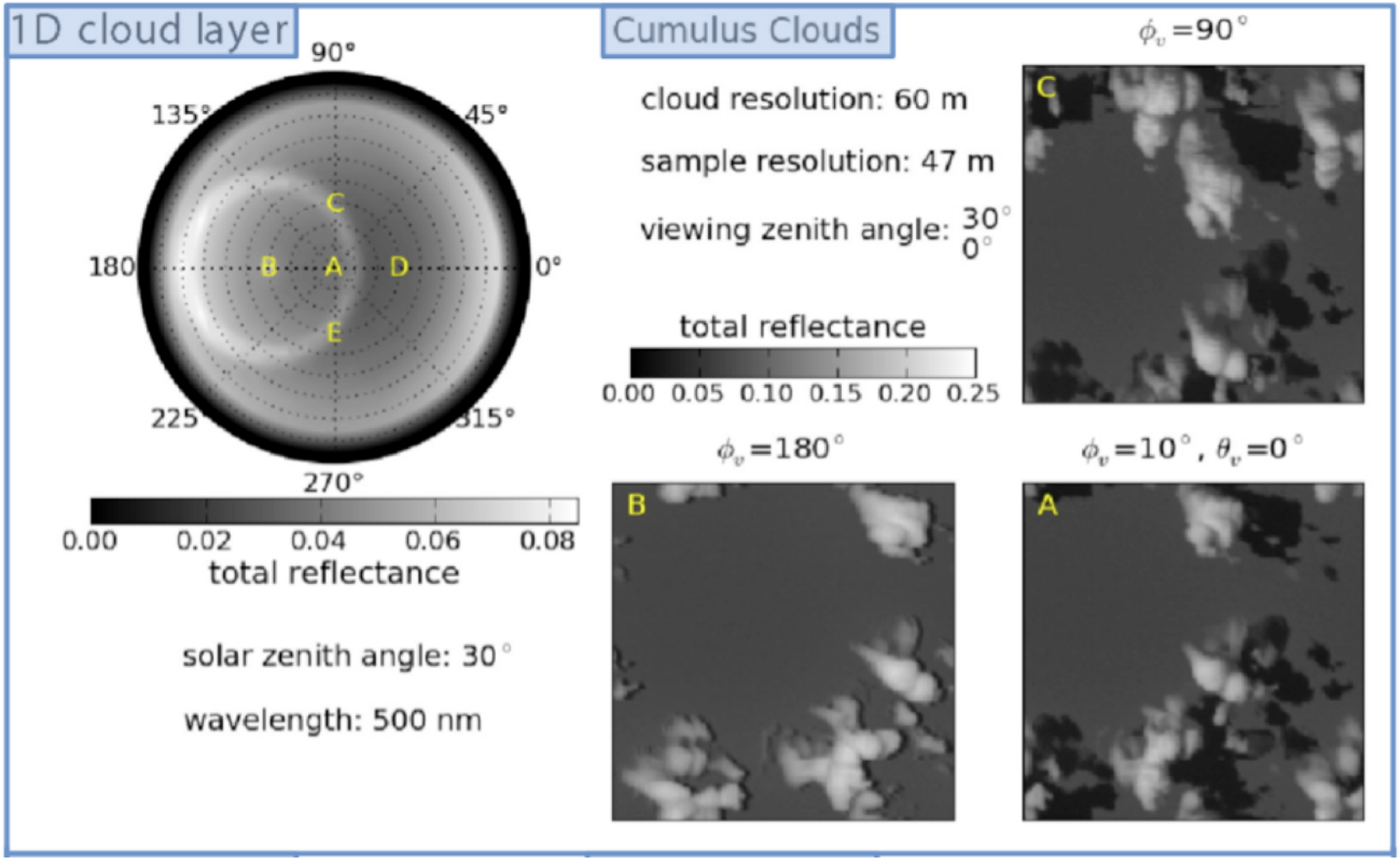
O_3 ← "US standard" profile

H_2O

Also, surface is black (absorbing) at all wavelengths.

Intensity (non-polarized light)

MYSTIC computations by Claudia Emde, courtesy of Michael Mishchenko (Glory PI)

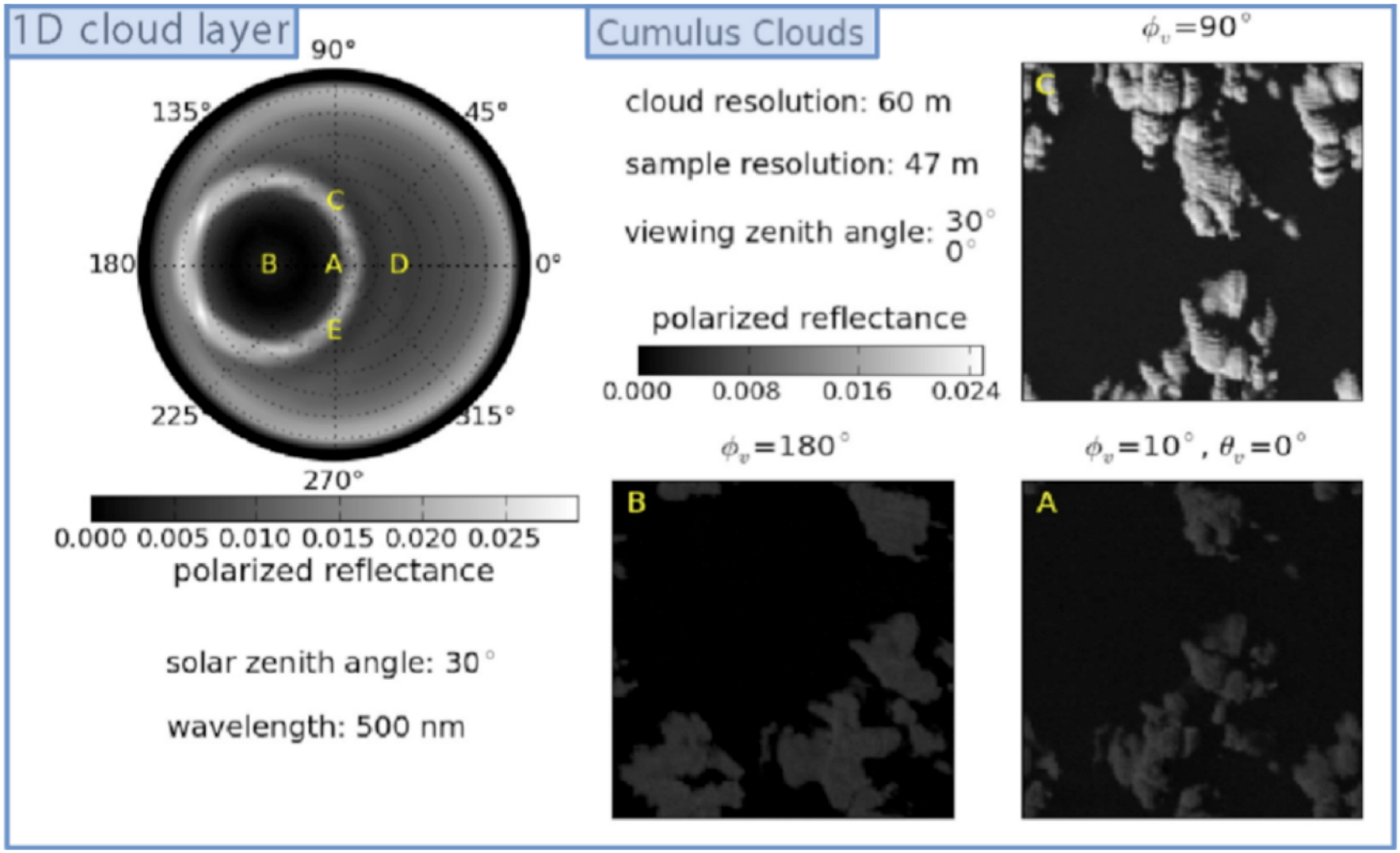


Note the reflecting surface: more dramatic effects!

Mayer, B. (2009). Radiative transfer in the cloudy atmosphere. *European Physical Journal - Conferences* **1**, 75-99.

Degree of Linear Polarization (DOLP)

vMYSTIC computations by Claudia Emde, courtesy of Michael Mishchenko (Glory PI)

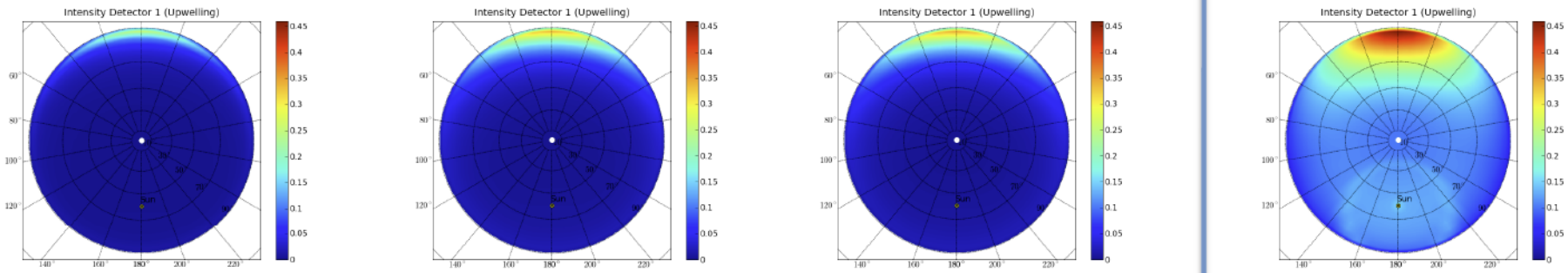


Note the reflecting surface: more dramatic effects!

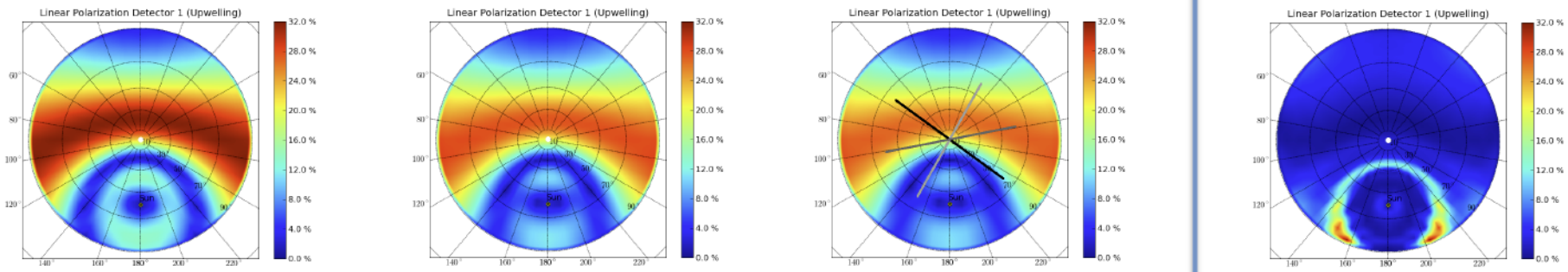
Emde, C., R. Buras, B. Mayer, and M. Blumthaler (2010). The impact of aerosols on polarized sky radiance: Model development, validation, and applications. *Atmos. Chem. Phys.* **10**, 383-396.

Linear mixing model using 1D vRT

$\tau_a = 0.05$ $\tau_a = 0.16$ $\tau_a = 0.20$ $\tau_c = 30.$



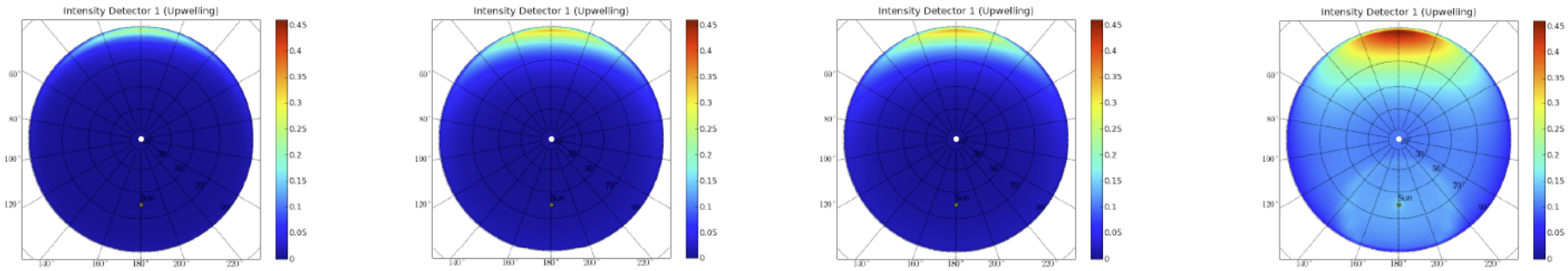
Here, we use vSOS: ↑ Intensity, DOLP ↓



Zhai, P.-W., Y.-X. Hu, C. R. Trepte, and P. L. Lucker (2009), A vector radiative transfer model for coupled atmosphere and ocean systems based on successive order of scattering method, *Opt. Express*, **17**, 2057-2079.

Linear mixing model using 1D vRT

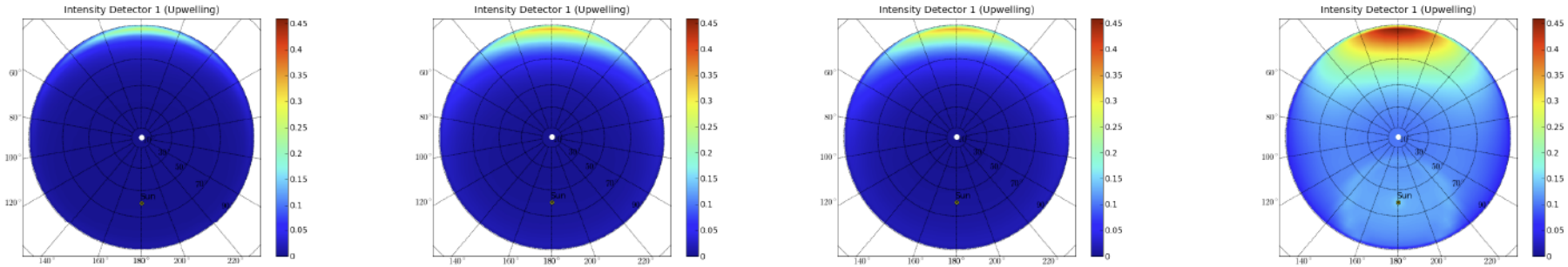
$\tau_a = 0.05$ **or** $\tau_a = 0.16$ **or** $\tau_a = 0.20$ **+** $\tau_c = 30.$



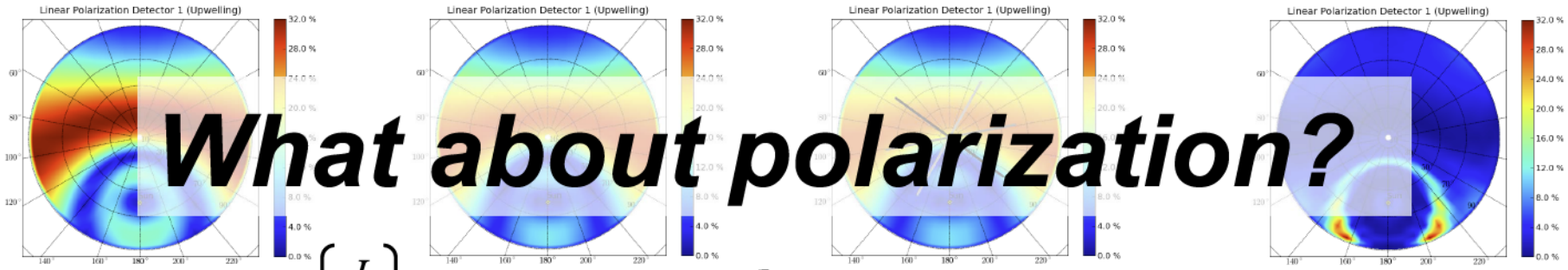
x (1–f_c) **x f_c**

Linear mixing model using 1D vRT

$\tau_a = 0.05$ **or** $\tau_a = 0.16$ **or** $\tau_a = 0.20$ **+** $\tau_c = 30.$



x (1–f_c) **x f_c**

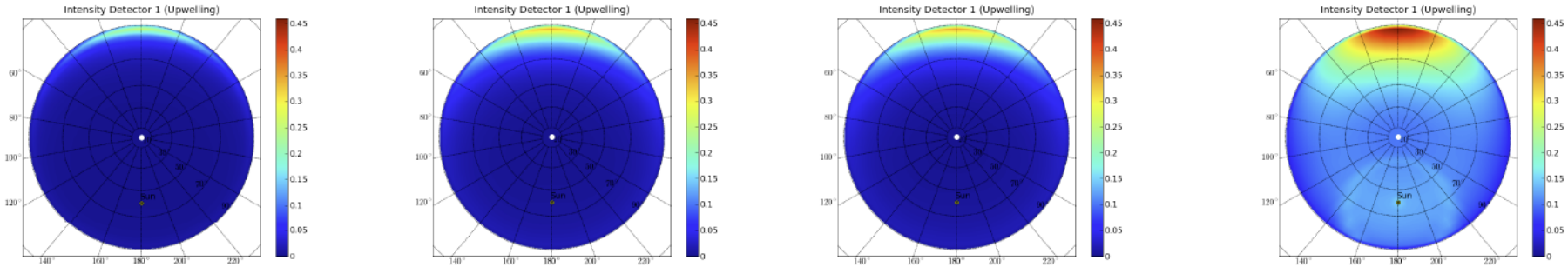


What about polarization?

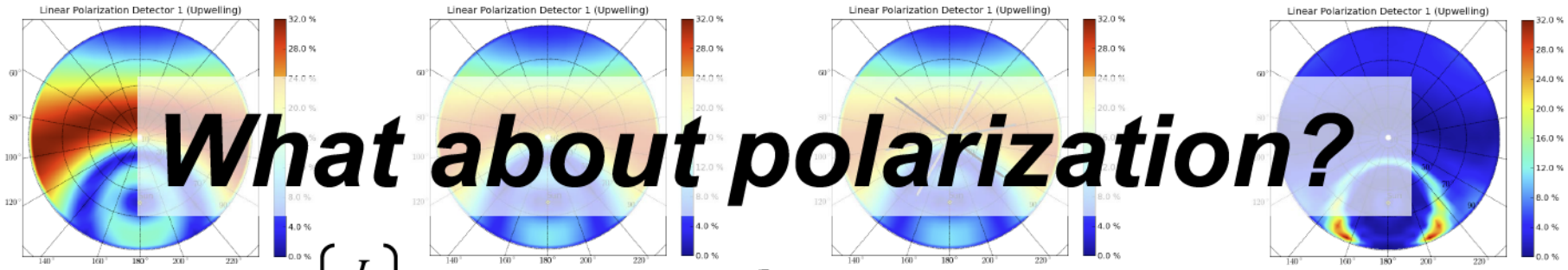
$$\mathbf{S} = \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} \Rightarrow \begin{cases} \mathrm{DOLP} = (Q^2+U^2)^{1/2} / I \\ \mathrm{AOLP} = \tan^{-1}(Q/U) / 2 \end{cases}$$

Linear mixing model using 1D vRT

$\tau_a = 0.05$ **or** $\tau_a = 0.16$ **or** $\tau_a = 0.20$ **+** $\tau_c = 30.$



x (1–f_c) **x f_c**

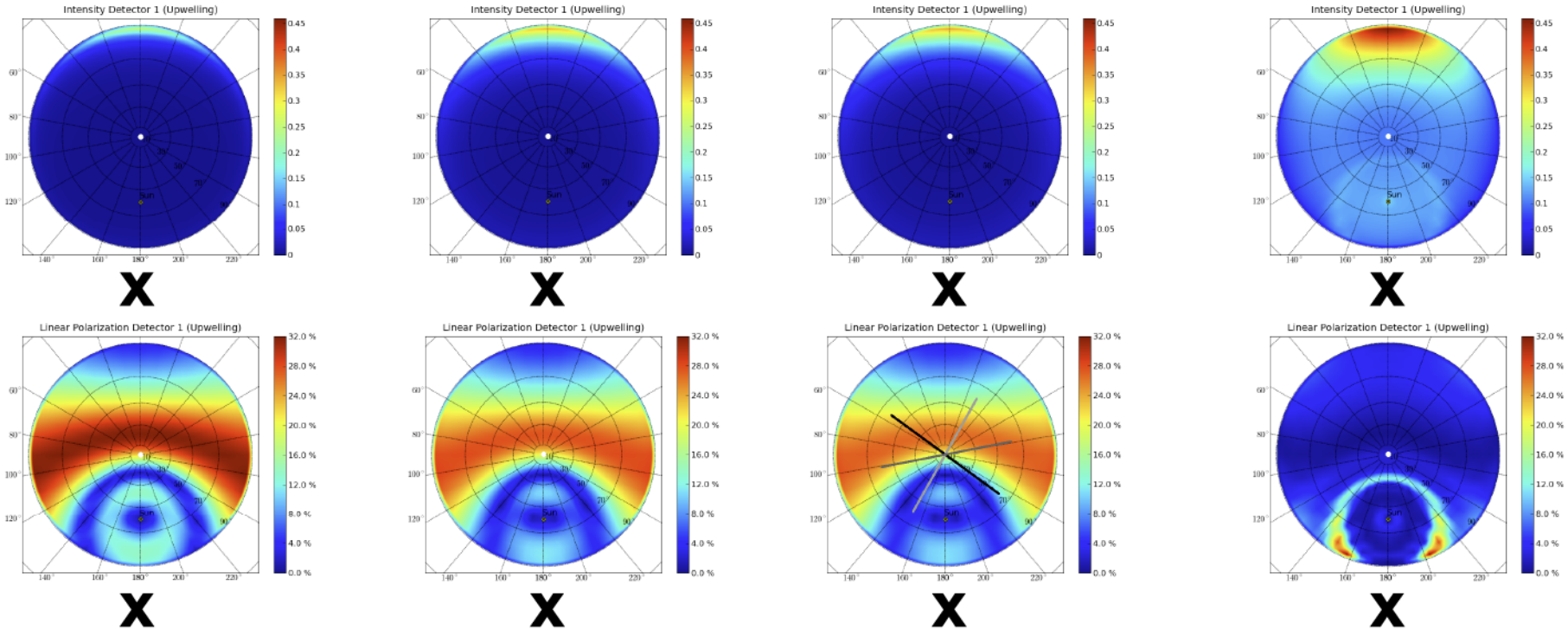


What about polarization?

$$\mathbf{S} = \begin{pmatrix} I \\ Q \\ U \\ \cancel{V} \end{pmatrix} \Leftrightarrow \begin{cases} \mathrm{DOLP} = (Q^2+U^2)^{1/2} / I \\ \mathrm{AOLP} = \tan^{-1}(Q/U) / 2 \end{cases}$$

Linear mixing model using 1D vRT

$\tau_a = 0.05$ **or** $\tau_a = 0.16$ **or** $\tau_a = 0.20$ **+** $\tau_c = 30.$



sin/cos[2 x AOLP($\tau_{a/c}$)]

x (1–f_c)

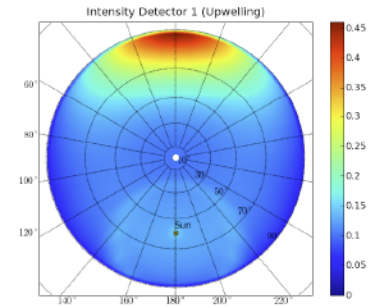
x f_c, etc.

As for I, add Q and U; then recompute DOLP.

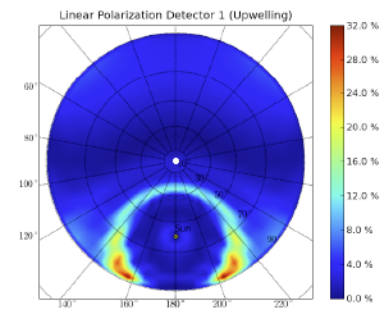
Linear mixing model using 1D vRT

True Cloud Fraction (fraction of grid containing ANY cloud water) is used: f_c = 0.23

τ_c = 30.



x



x

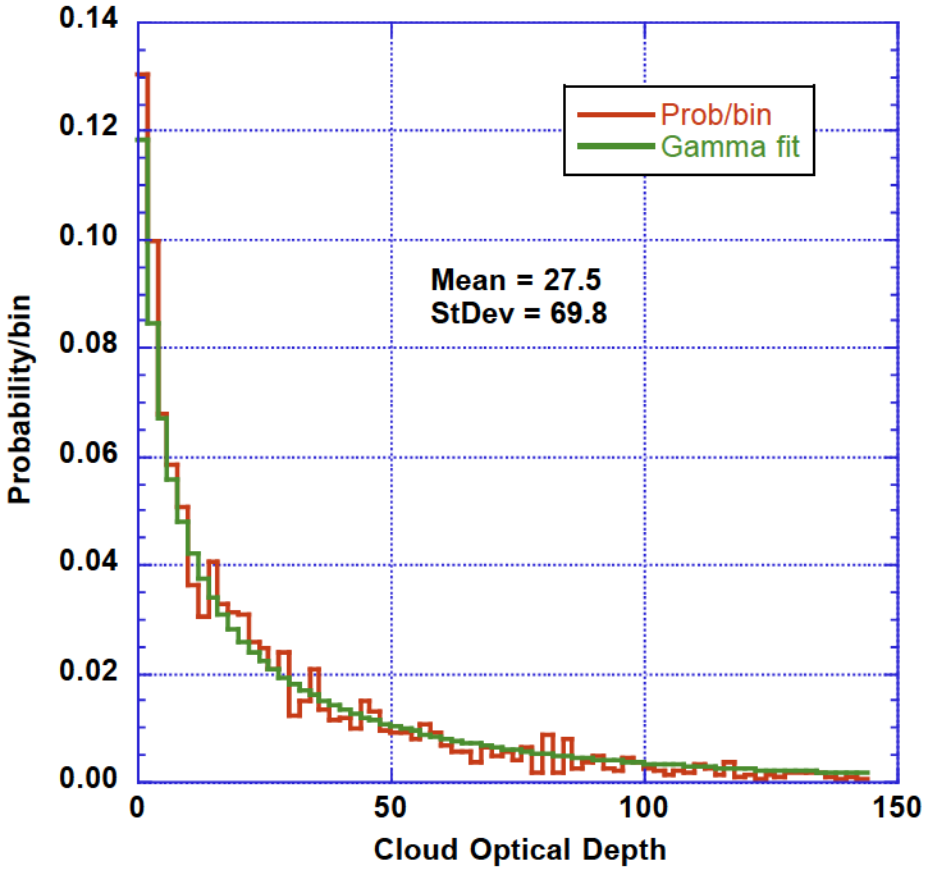
sin/cos[2 x AOLP(τ_c)]

x f_c, etc.

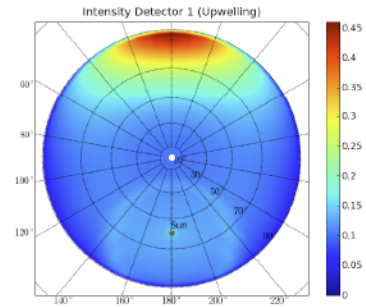
Linear mixing model using 1D vRT

True Cloud Fraction (fraction of grid containing ANY cloud water) is used: f_c = 0.23

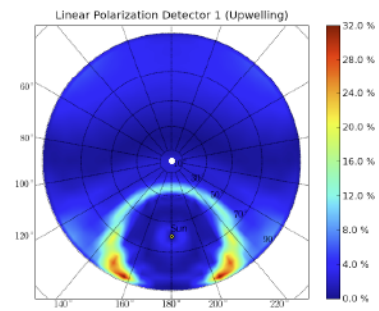
… MODEL UPGRADE: Independent (sub)Column Approximation (ICA), inside of cloudy fraction!



τ_c = 30.



x

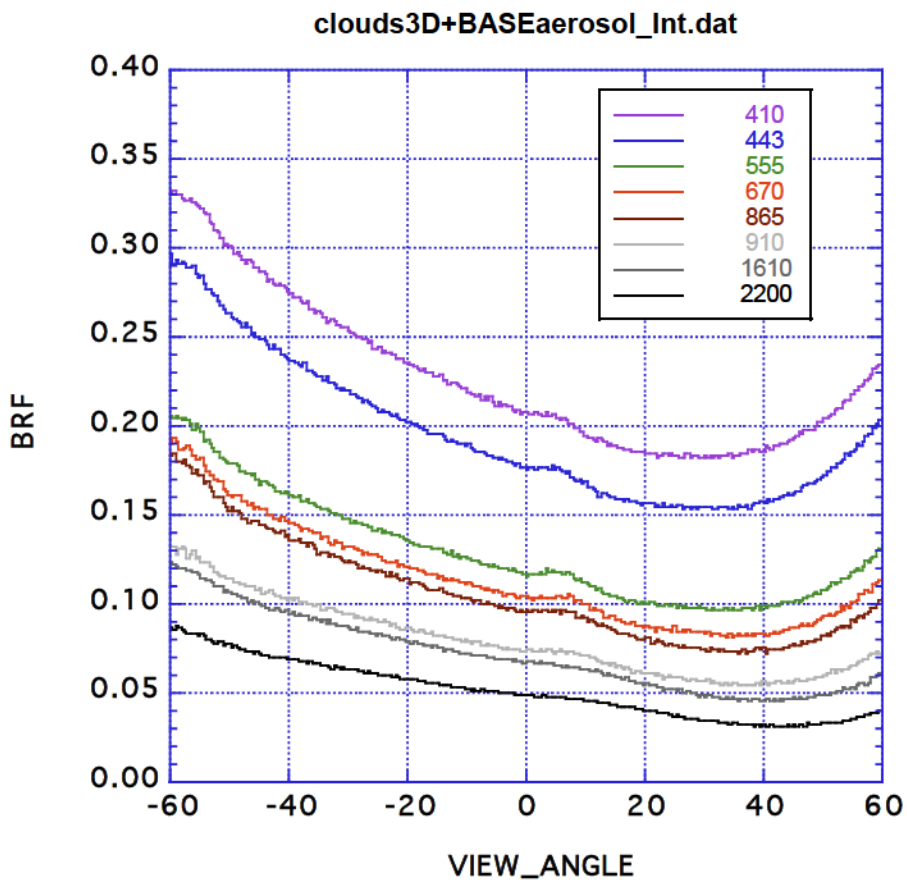


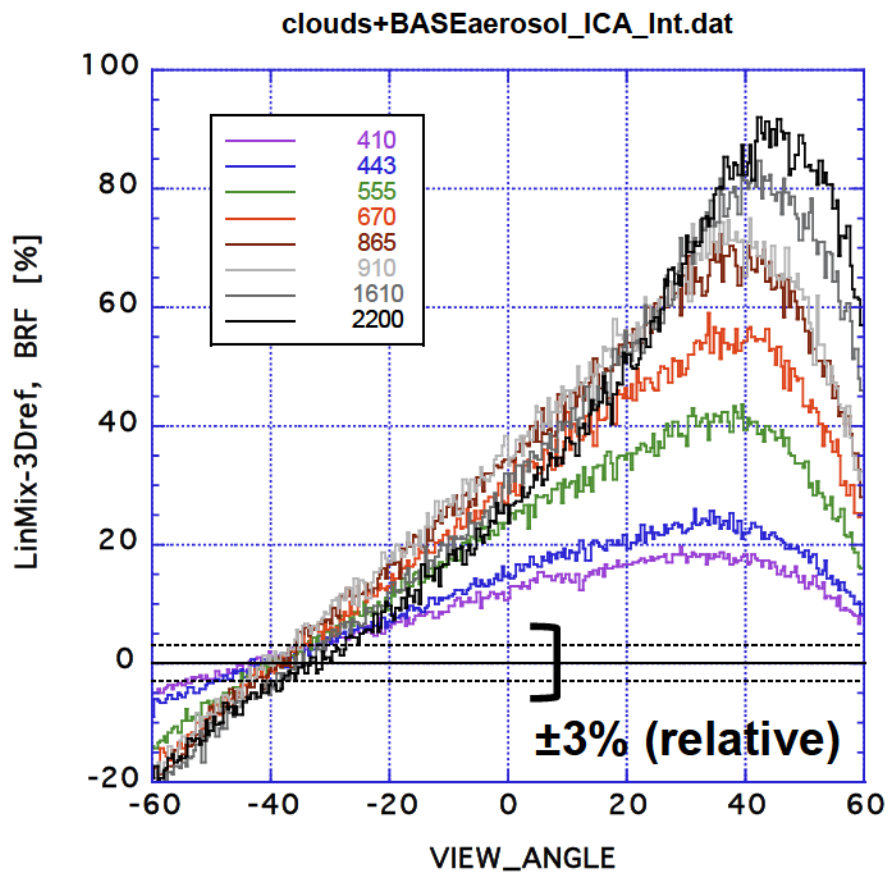
x

sin/cos[2 x AOLP(τ_c)]

x f_c, etc.

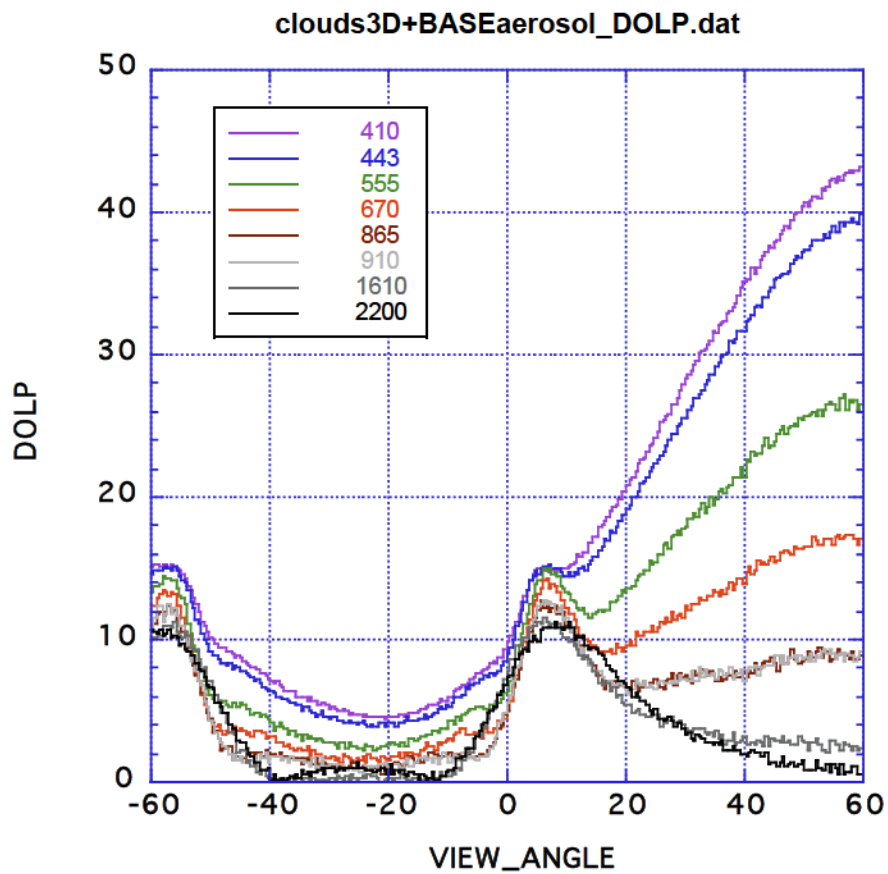
$\tau_{a,555}$ = 0.12, Intensity

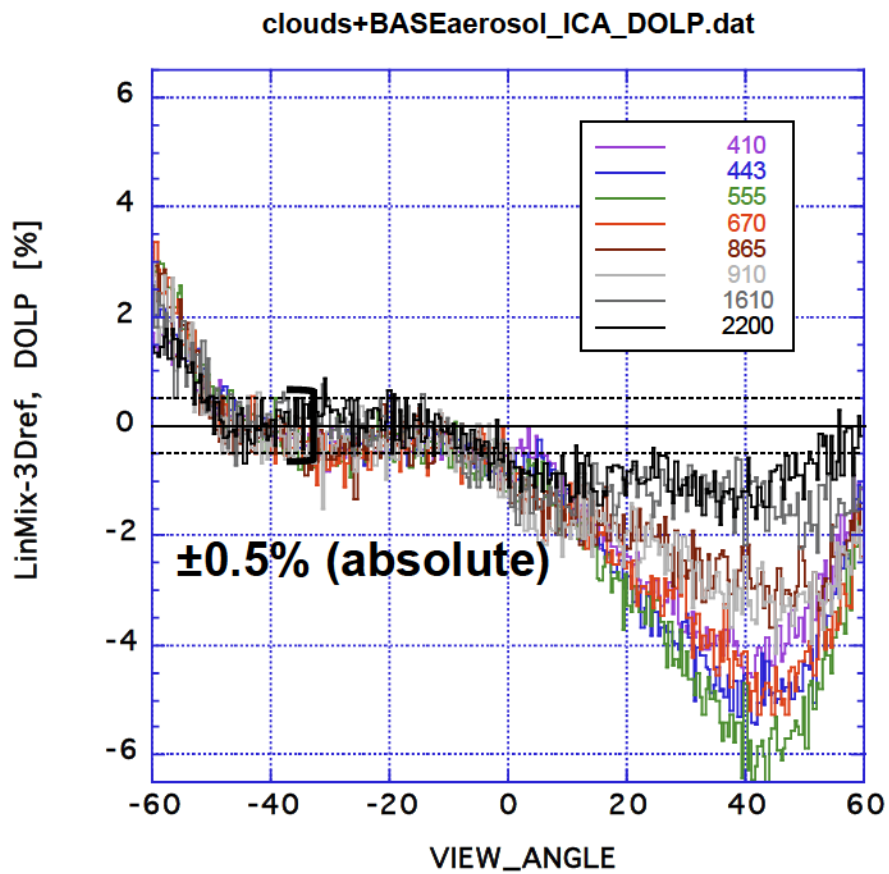




PARASOL-like (A-train) viewing geometry: SZA 33.45°, azimuth angles 44° and 224°.

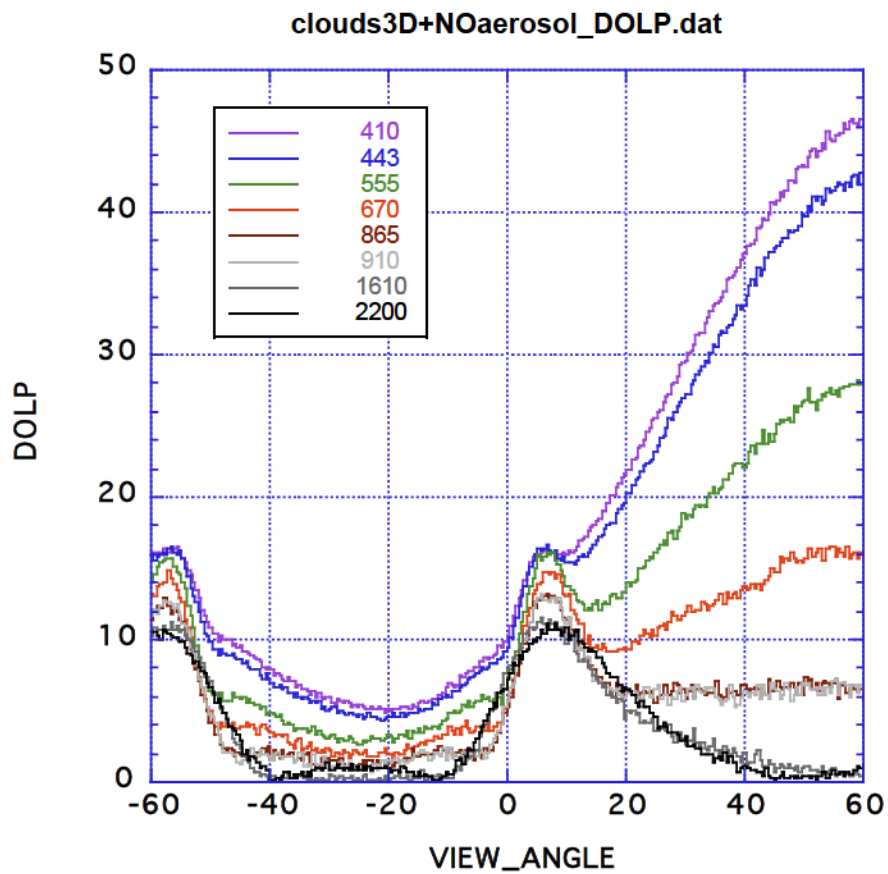
$\tau_{a,555}$ = 0.12, DOLP

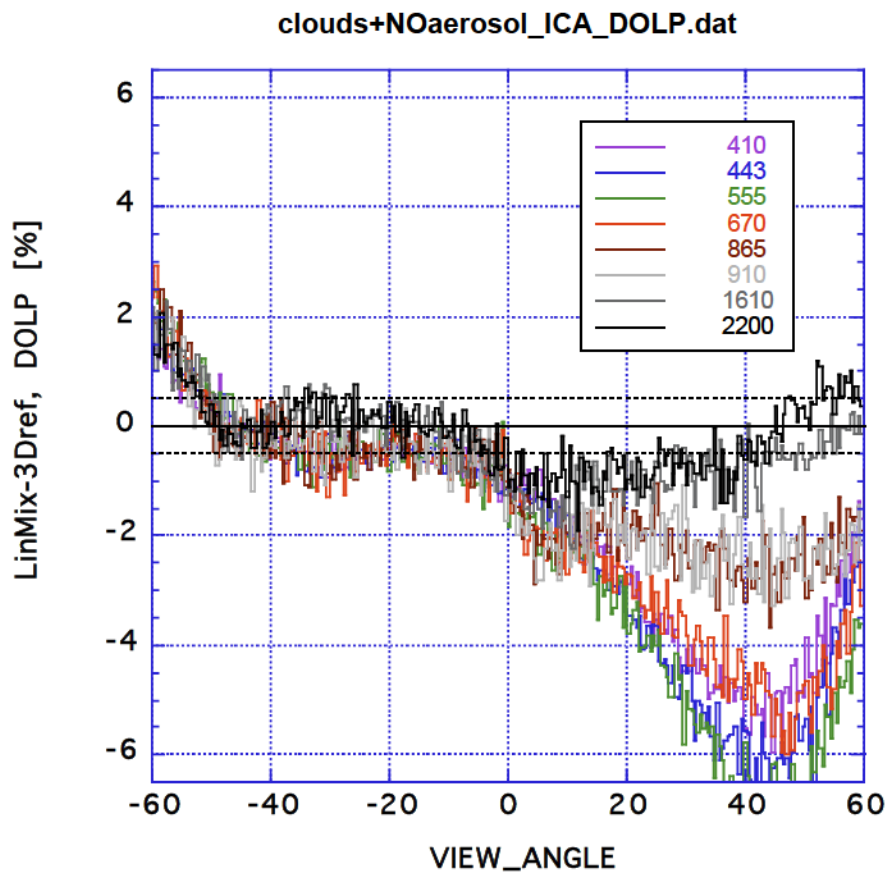




PARASOL-like (A-train) viewing geometry: SZA 33.45°, azimuth angles 44° and 224°.

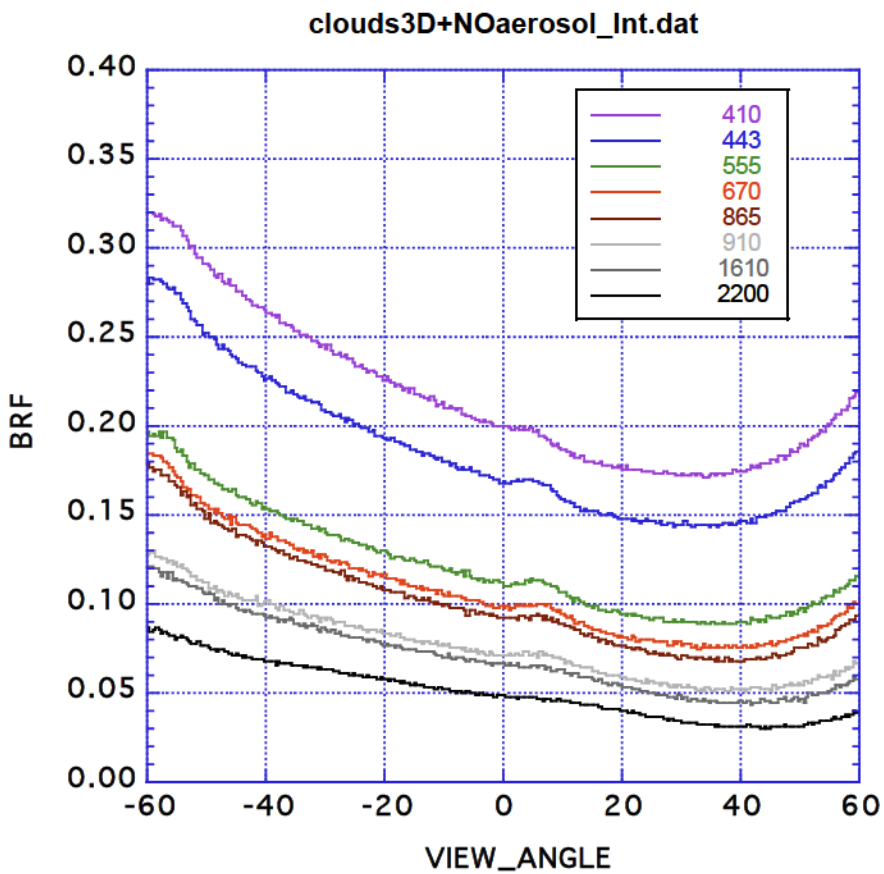
$\tau_{a,555}$ = 0.00, DOLP

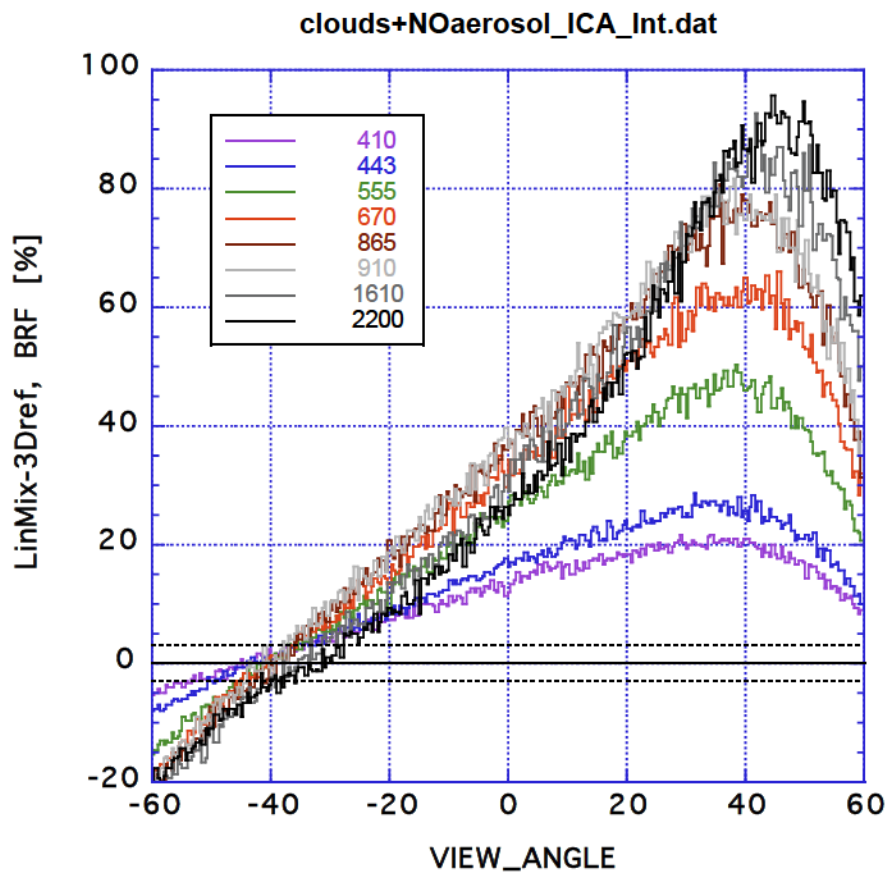




PARASOL-like (A-train) viewing geometry: SZA 33.45°, azimuth angles 44° and 224°.

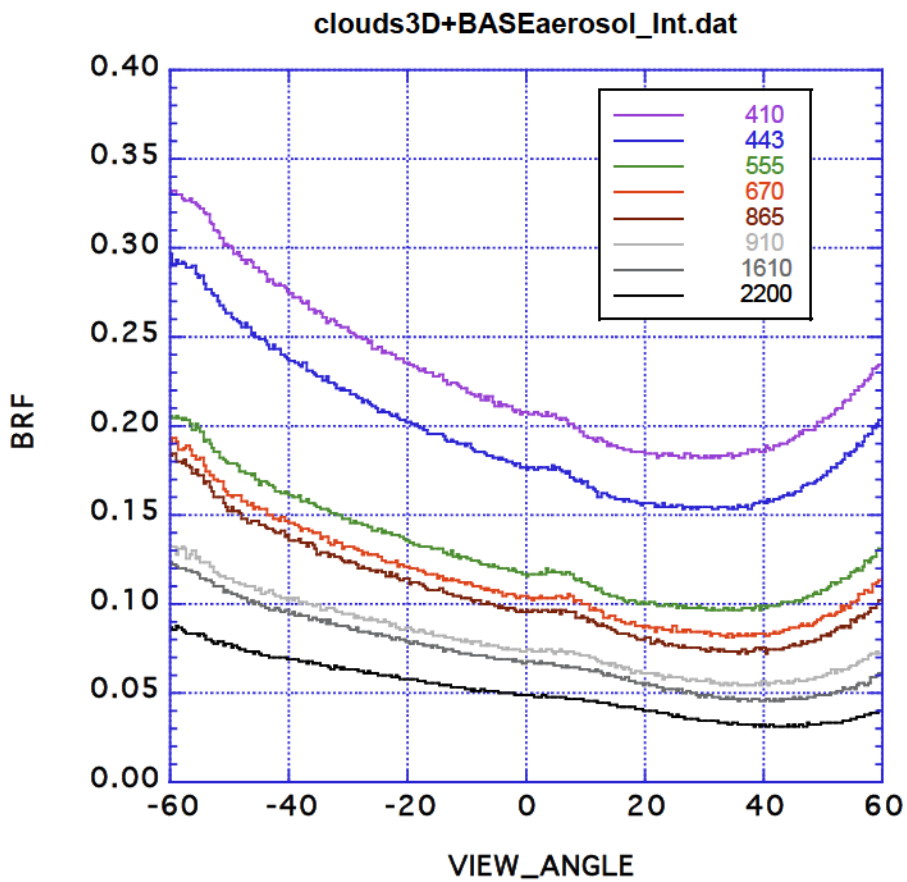
$\tau_{a,555}$ = 0.00, Intensity

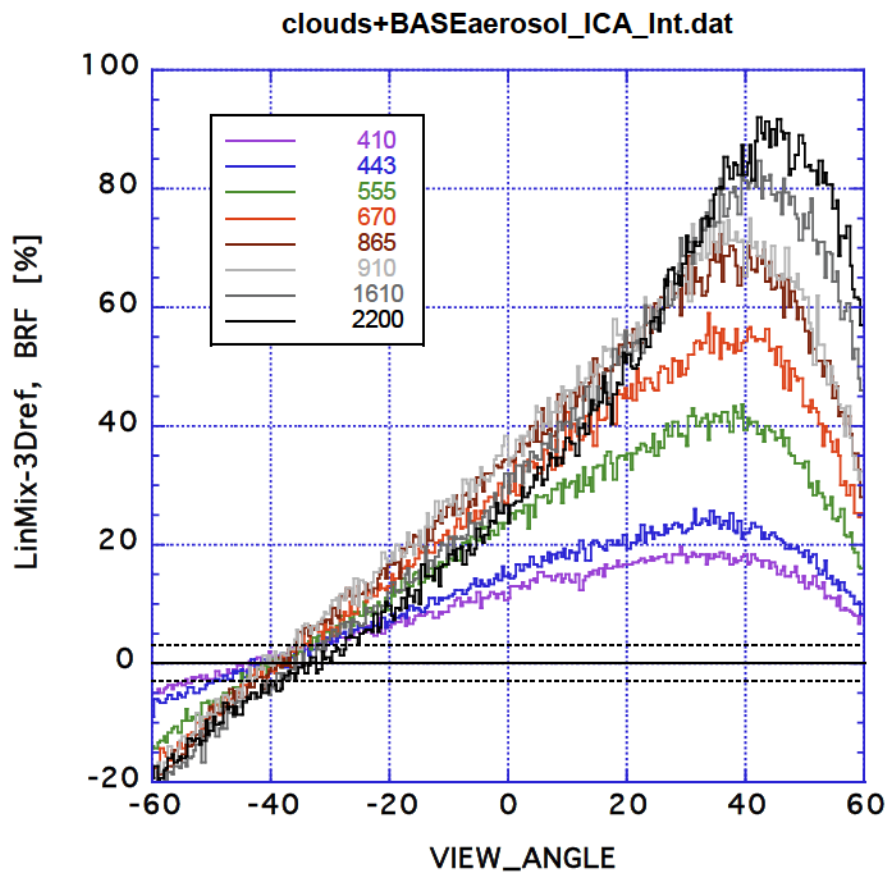




PARASOL-like (A-train) viewing geometry: SZA 33.45°, azimuth angles 44° and 224°.

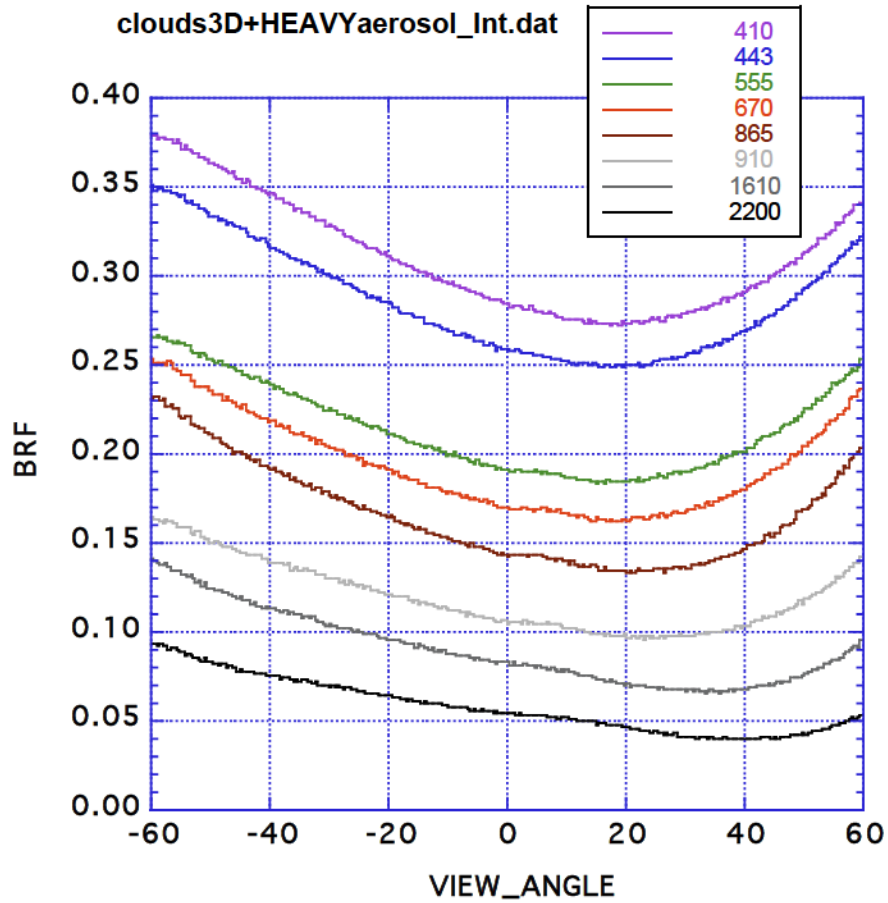
$\tau_{a,555}$ = 0.12, Intensity

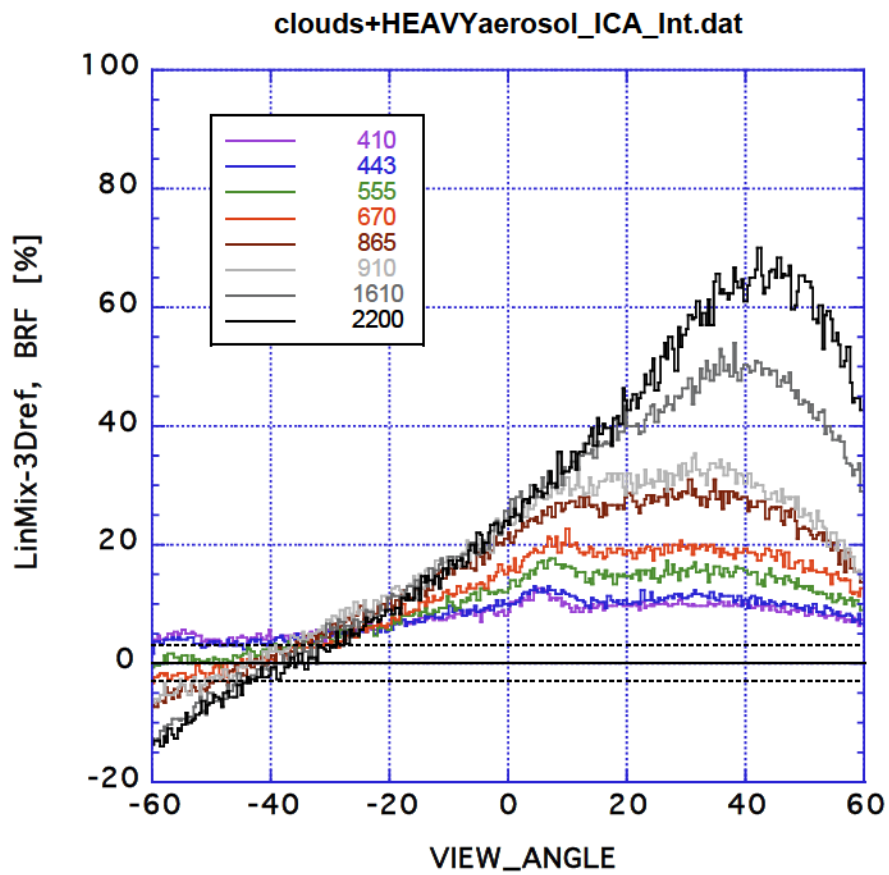




PARASOL-like (A-train) viewing geometry: SZA 33.45°, azimuth angles 44° and 224°.

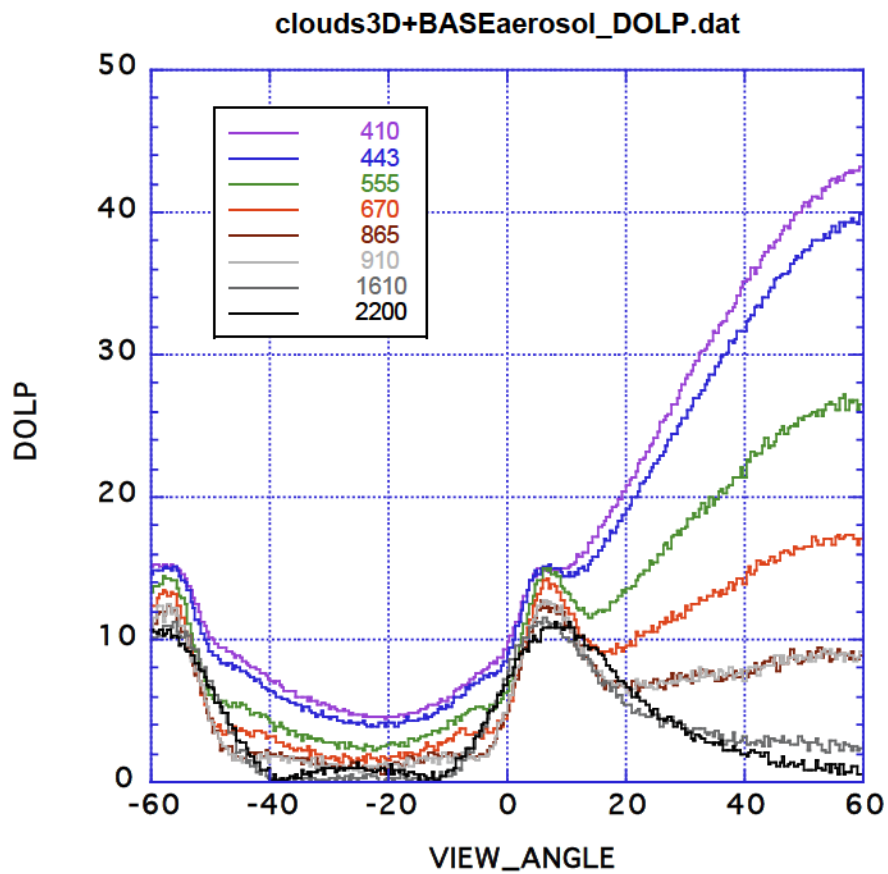
$\tau_{a,555}$ = 1.91, Intensity

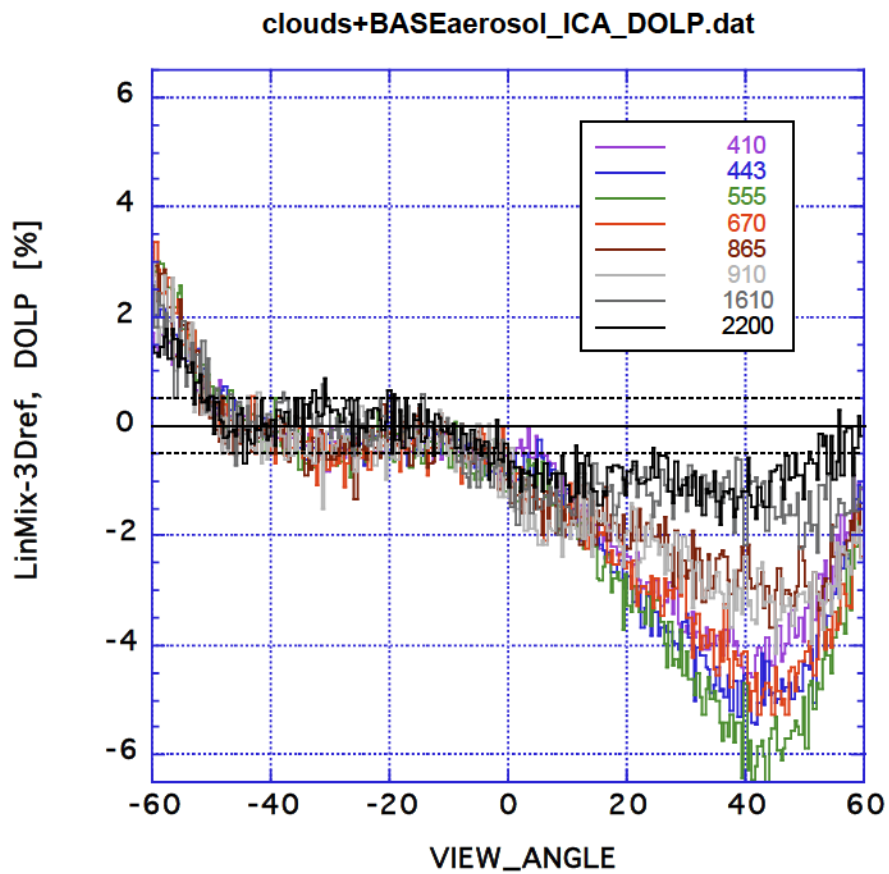




PARASOL-like (A-train) viewing geometry: SZA 33.45°, azimuth angles 44° and 224°.

$\tau_{a,555}$ = 0.12, DOLP





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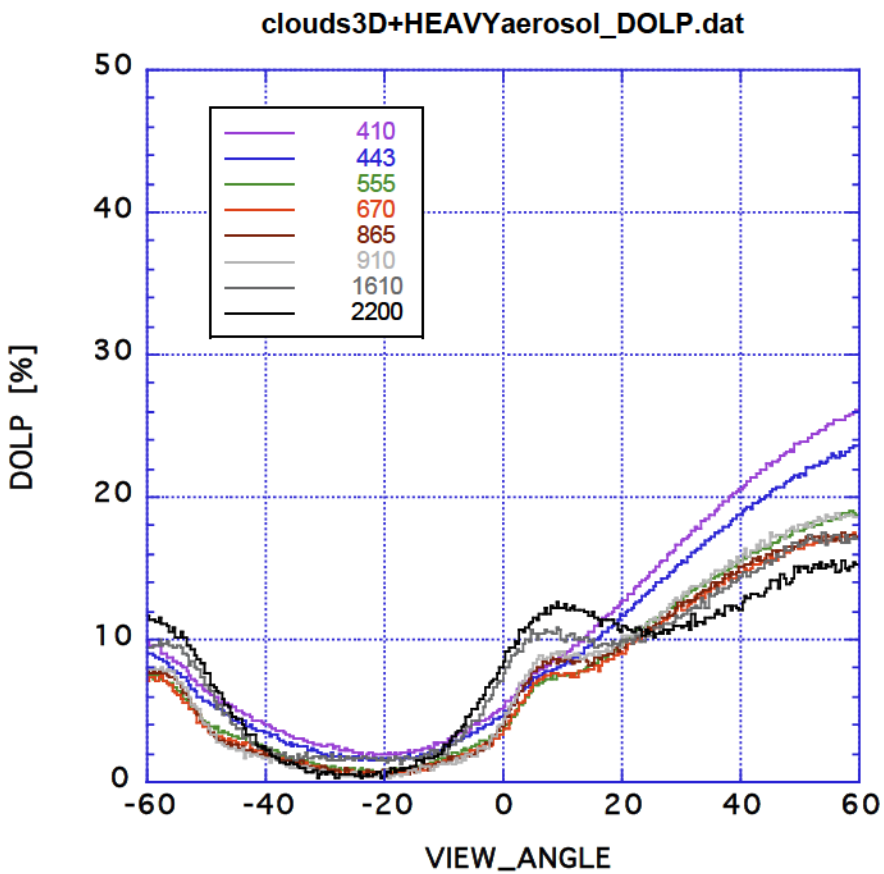

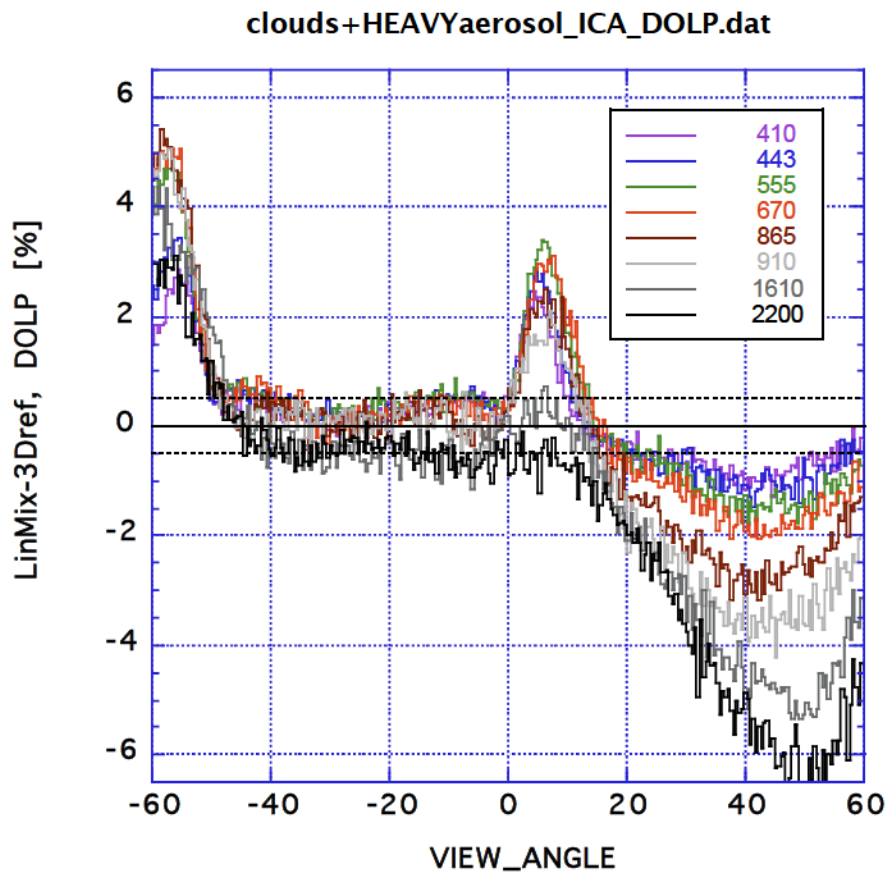

PARASOL-like (A-train) viewing geometry: SZA 33.45°, azimuth angles 44° and 224°.

Summary & Outlook

- **Aerosol-Cloud Disentanglement Challenge**
  - Low AOD: Need only predictor of "clouds alone" 3D RT effect on I
  - High AOD: Also need such a predictor for I_{pol} (use 1-scattering?)
- **"Big Picture" take-home message**
  - Use high-fidelity 3D RT modeling capability, including hardware, to develop/test/break/repair algorithms (or instruments) pre-launch.

Thank you! ***Questions?***

Acknowledgments:
NASA/SMD/ESD/Radiation Sciences sponsorship
Discussions with members of Glory Science Team

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