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Lessons 3 and 4:

Review of steps in making an aerosol retrieval.
Aerosol representation inside the 6SV radiative transfer model
Calculations using 6SV
Plotting of 6SV results
Discussion

Assimilation systems

Aerosol Optical Depth (AOD or τ):

$$\tau_\lambda = \int_{sfc}^{toa} \sigma_{e\lambda} dz$$

$$\sigma_{e\lambda} = \sigma_{a\lambda} + \sigma_{s\lambda}$$

$\sigma_{e\lambda}$ is the extinction parameter
$\sigma_{a\lambda}$ is the absorption parameter
$\sigma_{s\lambda}$ is the scattering parameter

These parameters are intensive and depend on particle size, shape and composition, but when you integrate them through the atmospheric column they combine to give us a extensive measure of their total optical effect.

AOD depends on the aerosol loading, the amount of particles in the column, not just on their optical properties.

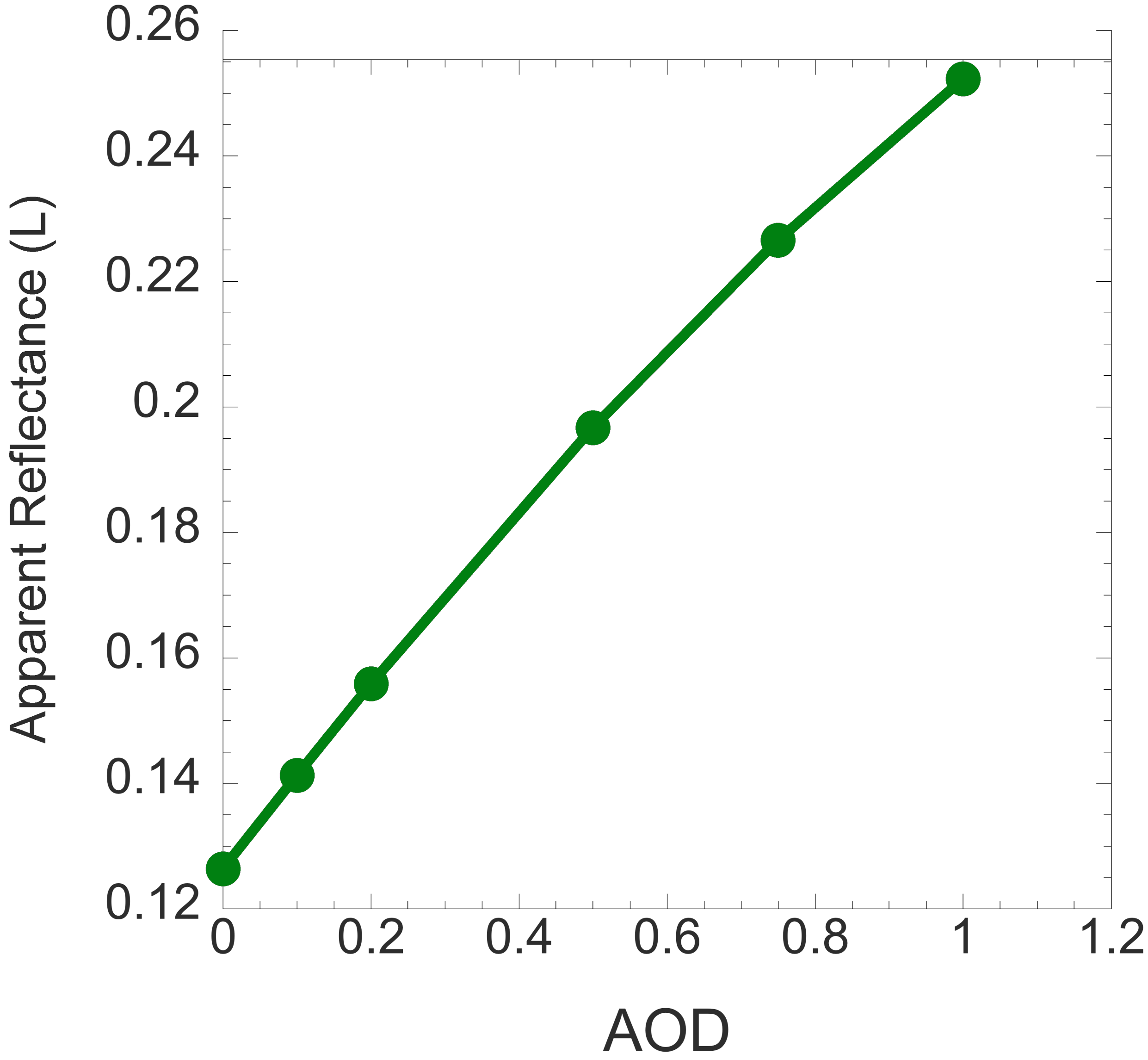
AOD and Aerosol Optical Thickness can be used interchangeably for our purposes.

$$\underbrace{L(\tau^{*},\mu_{o},\mu,\varphi)}_{\text{Radiance measured at satellite}} = \underbrace{L_{o}(\tau^{*},\mu_{o},\mu,\varphi)}_{\text{Radiance from atmosphere}} + \underbrace{\frac{RE_{o}T_{t}(\tau^{*},\mu)}{1-RS}}_{\text{Radiance from surface}}$$

μ_o = cos(solar zenith angle)
μ = cos(sensor zenith angle
φ = relative azimuth
τ^* = aerosol optical thickness

R = surface reflectance
E_o = extraterrestrial irradiance
T_t = total transmission
S = spherical albedo

Calculated L for a variety of AOD,
Assumed particle properties and surface reflectance
And for wavelength = 0.47 µm



Calculated L for a variety of AOD,
Assumed particle properties and surface reflectance
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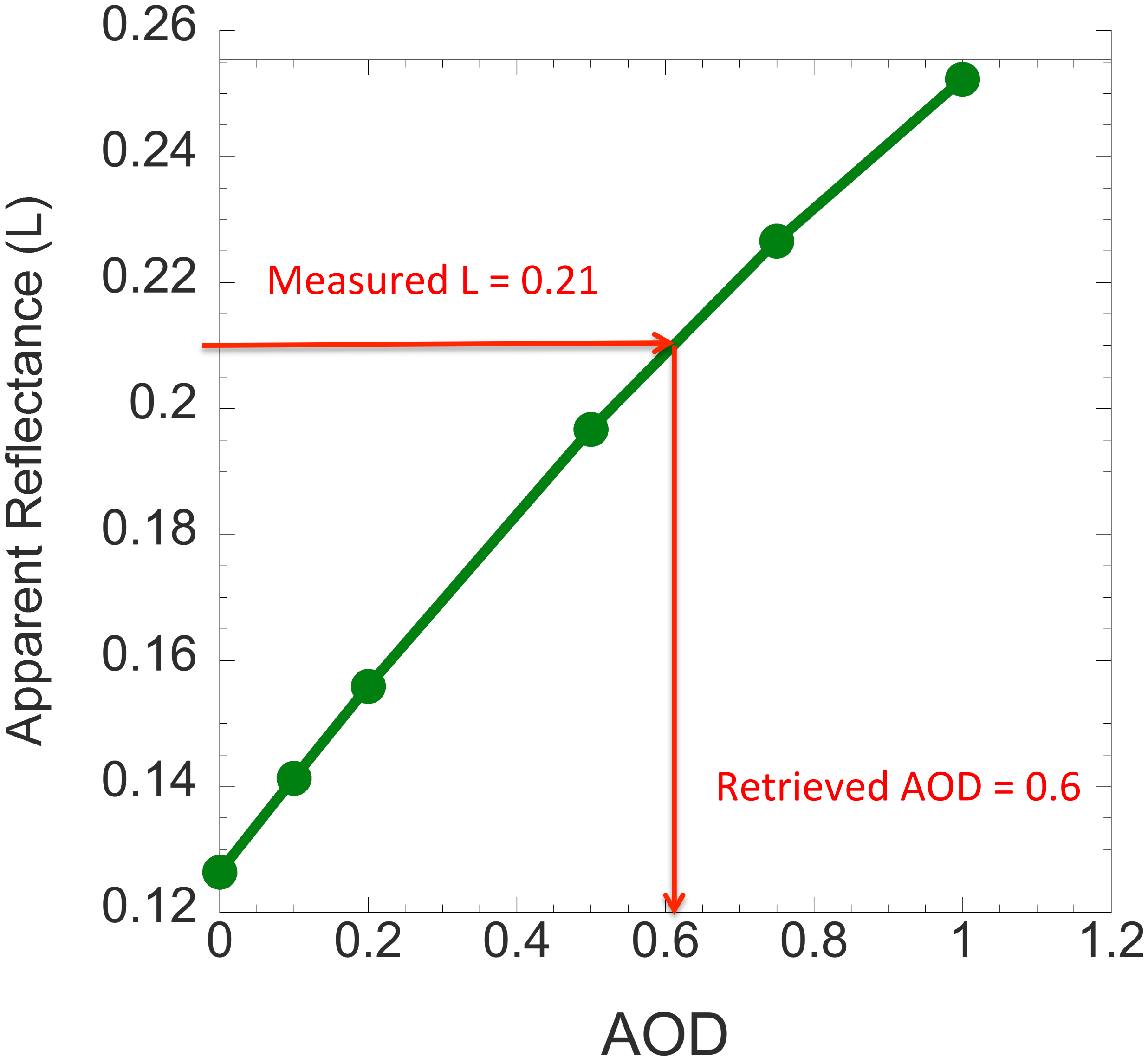
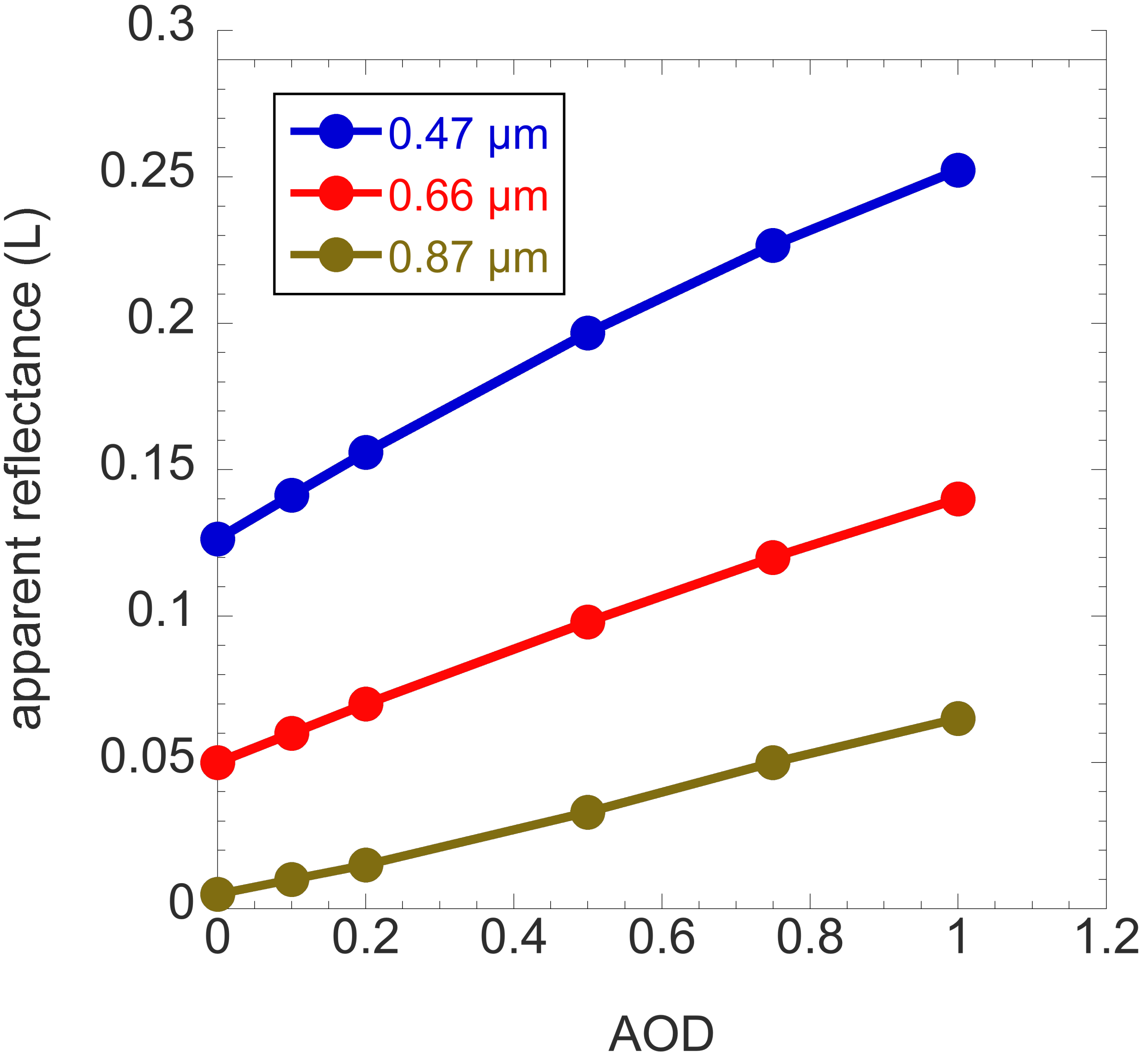
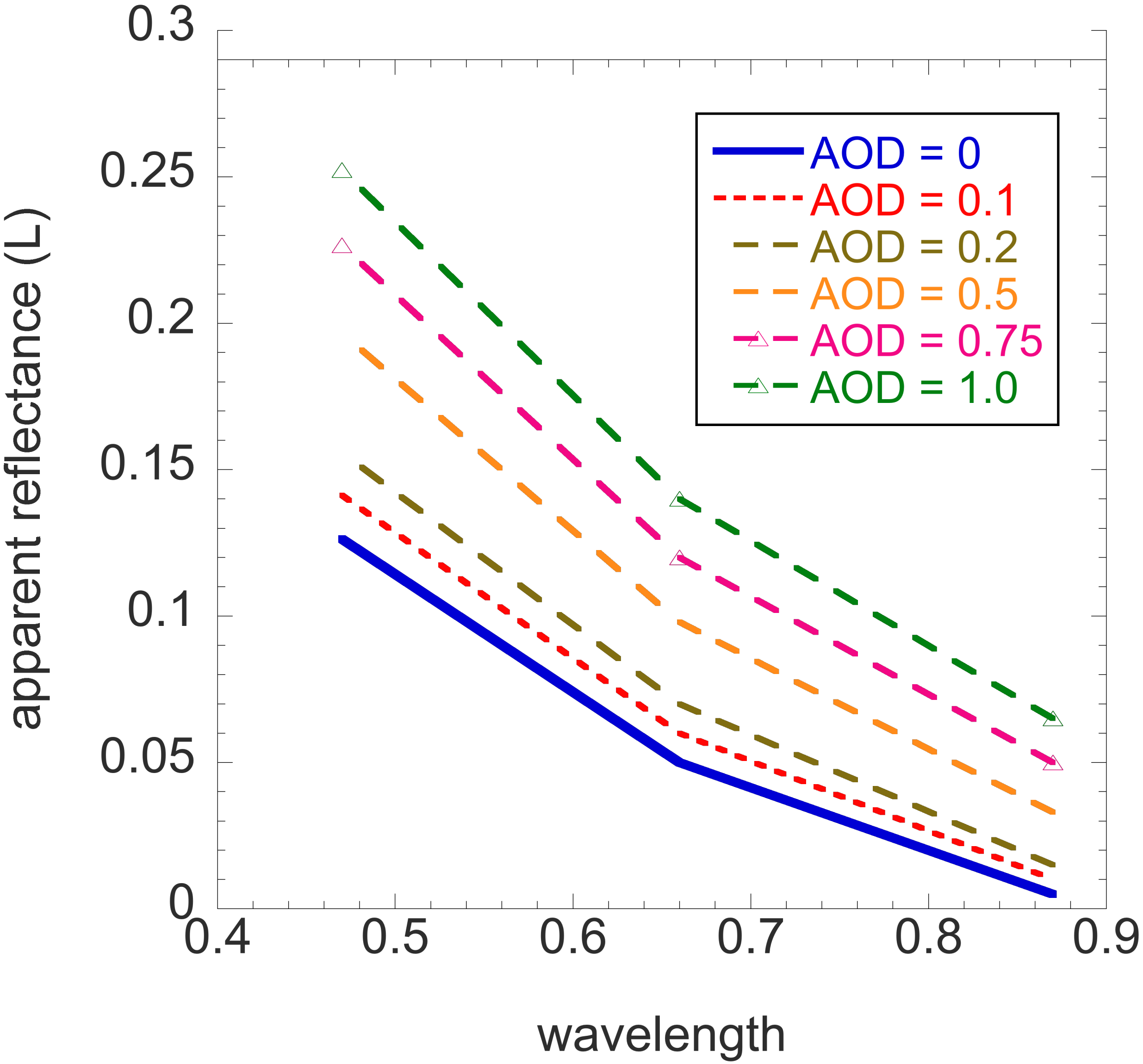

Measured L = 0.21

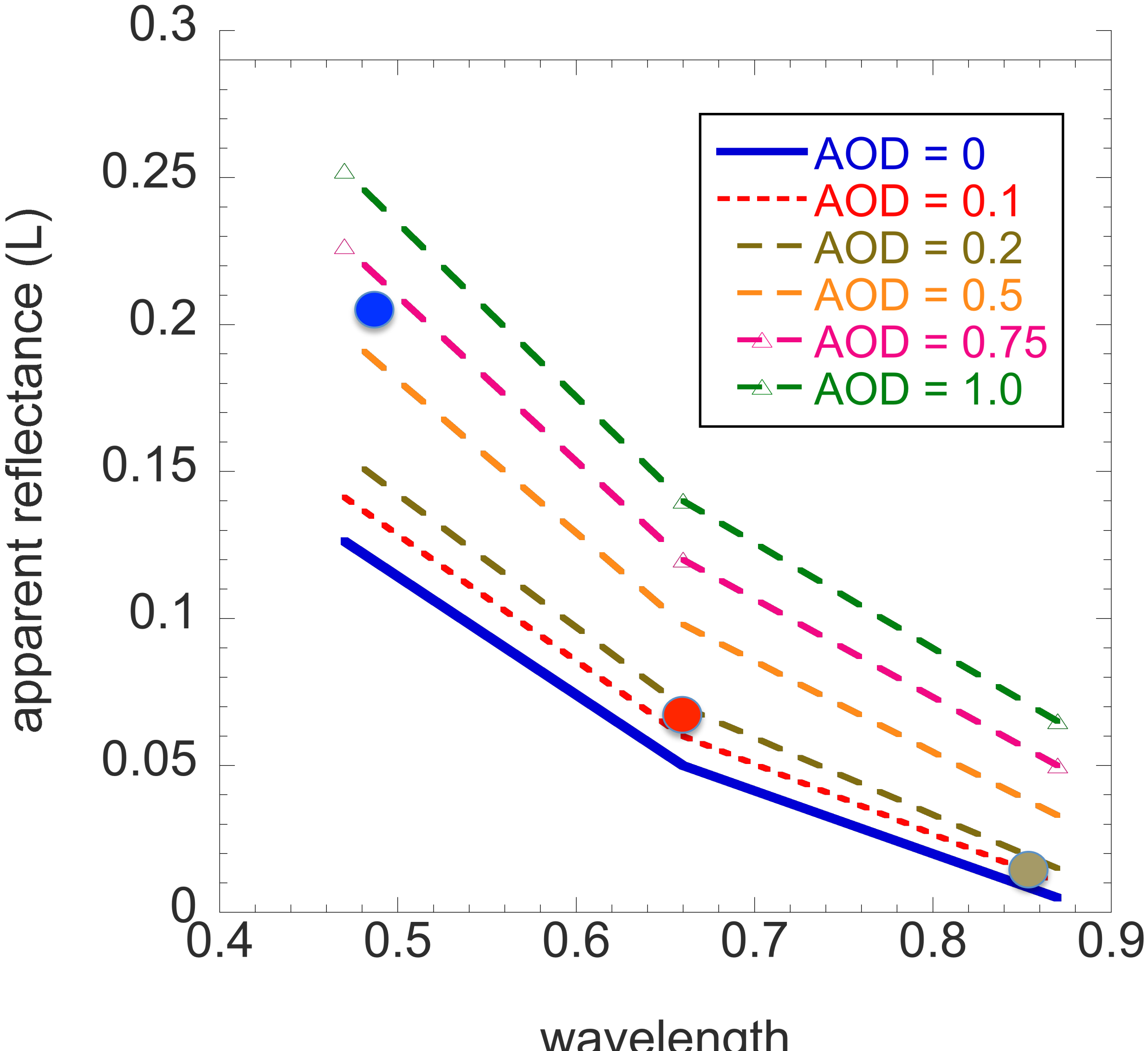
Retrieved AOD = 0.6


0.47 µm
0.66 µm
0.87 µm
apparent reflectance (L)
AOD
0
0.05
0.1
0.15
0.2
0.25
0.3
0
0.2
0.4
0.6
0.8
1
1.2

But we don’t do 3 individual wavelength retrievals. Instead we approach the problem in wavelength space.



But we don’t do 3 individual wavelength retrievals. Instead we approach the problem in wavelength space.



How do we build a Look Up Table?

6SV: On line access to radiative transfer calculations.

http://6s.ltdri.org/index.html

$$\tau_\lambda = \int_{sfc}^{toa} \sigma_{e\lambda} dz$$

$$\sigma_{e\lambda} = \sigma_{a\lambda} + \sigma_{s\lambda}$$

$\sigma_{e\lambda}$ is the extinction parameter
$\sigma_{a\lambda}$ is the absorption parameter
$\sigma_{s\lambda}$ is the scattering parameter

σ_e

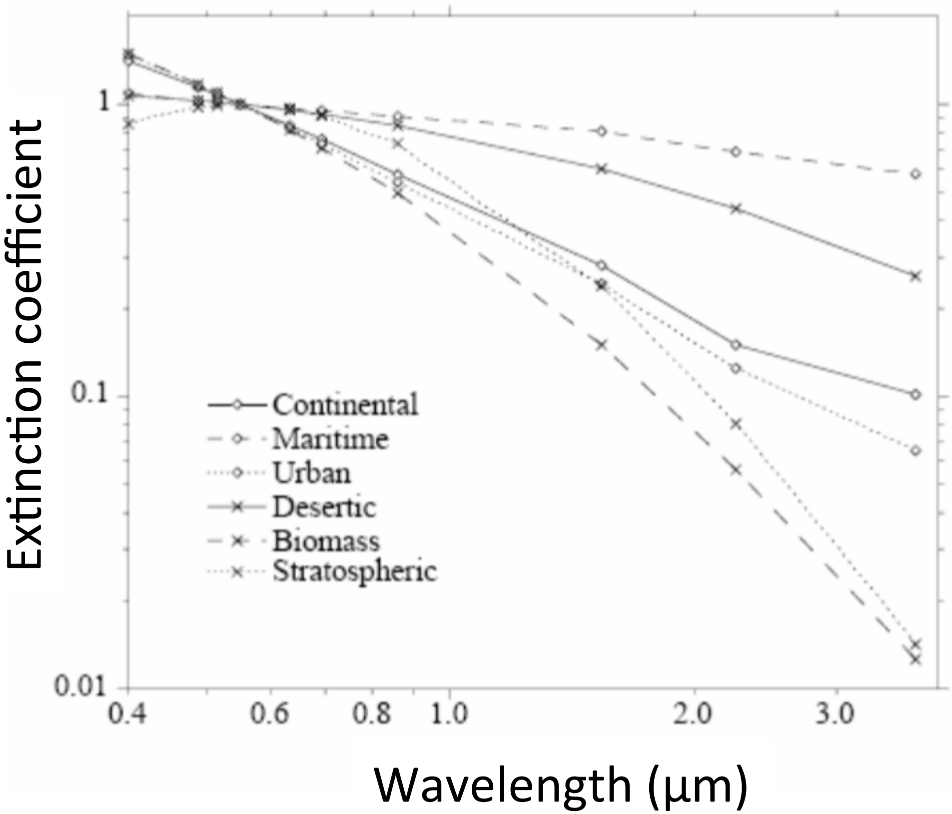


Fig. 1. Spectral dependence of the extinction coefficient for various aerosol models.

$$\tau_\lambda = \int_{sfc}^{toa} \sigma_{e\lambda} dz$$

$\sigma_{e\lambda}$ is the portion of the AOD that is intensive.

It depends on size, shape, composition, but NOT on amount.

If you normalize $\sigma_{e\lambda}$ at a particular wavelength you can see the spectral signature of different aerosol types.

σ_e

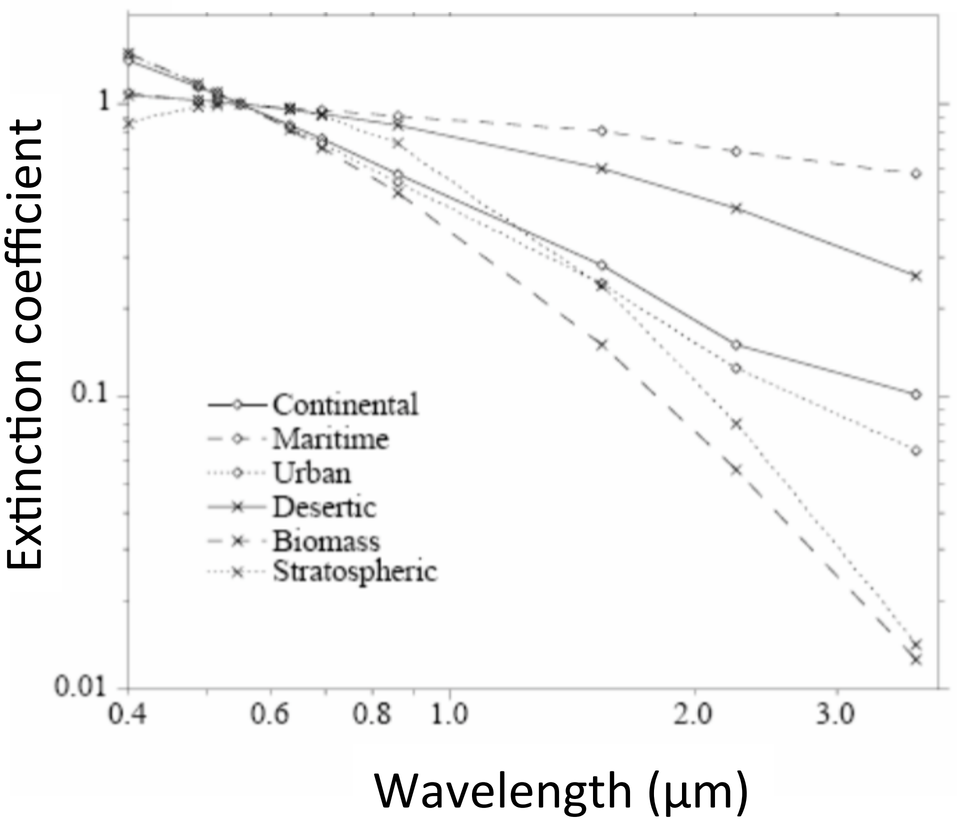


Fig. 1. Spectral dependence of the extinction coefficient for various aerosol models.

$$\tau_\lambda = \int_{\mathrm{sfc}}^{\mathrm{toa}} \sigma_{e\lambda}\, dz$$

Once you define the aerosol type (size, shape, composition), then you can model its spectral signature. The signature will not change no matter what the amount is.

6S User Guide Version 3, November 2006

σ_e

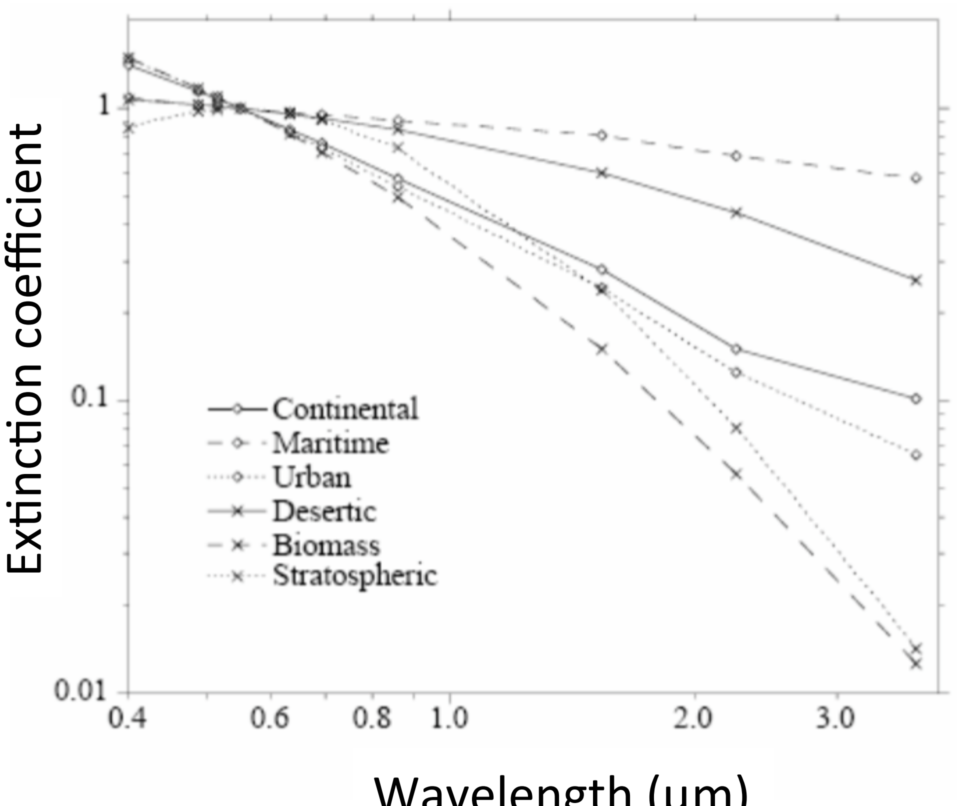


Fig. 1. Spectral dependence of the extinction coefficient for various aerosol models.

$$\tau_\lambda = \int_{\mathrm{sfc}}^{\mathrm{toa}} \sigma_{e\lambda} dz$$

Here we have 6 modeled aerosol types. Normalized at 550 nm to show the different spectral signature of each type. We will define the aerosol amount by AOD at 550 nm, and then all the other wavelength AODs will be calculated from thes spectral curves of extinction.

σ_e

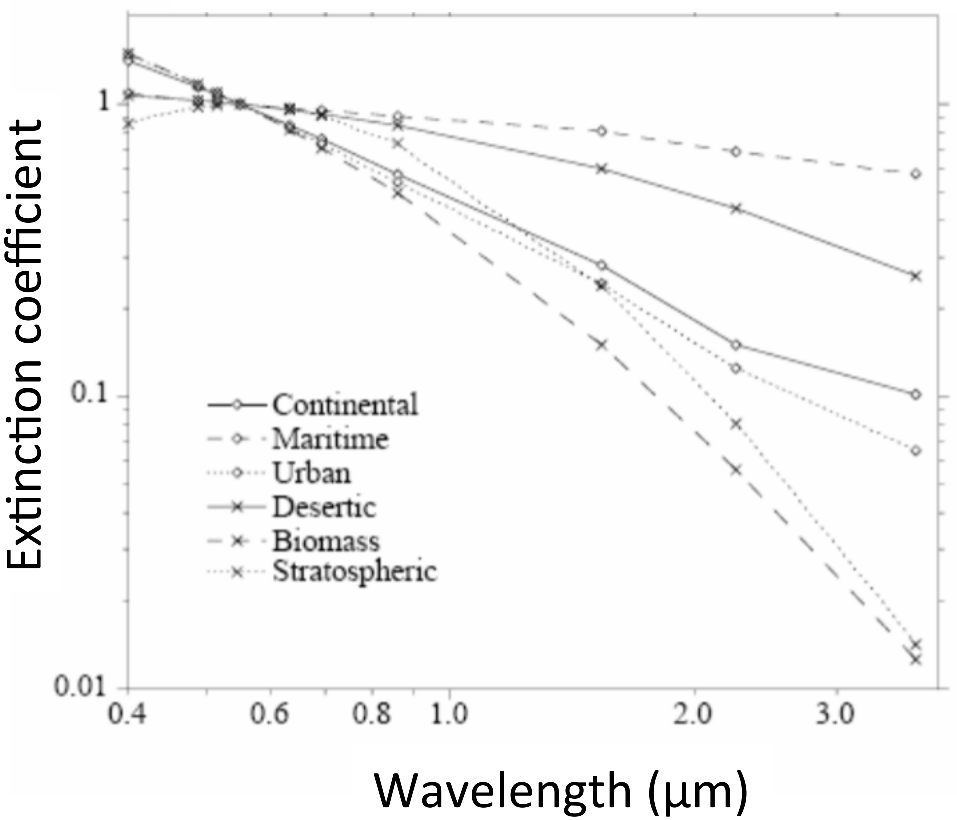


Fig. 1. Spectral dependence of the extinction coefficient for various aerosol models.

Absorption spectral signature

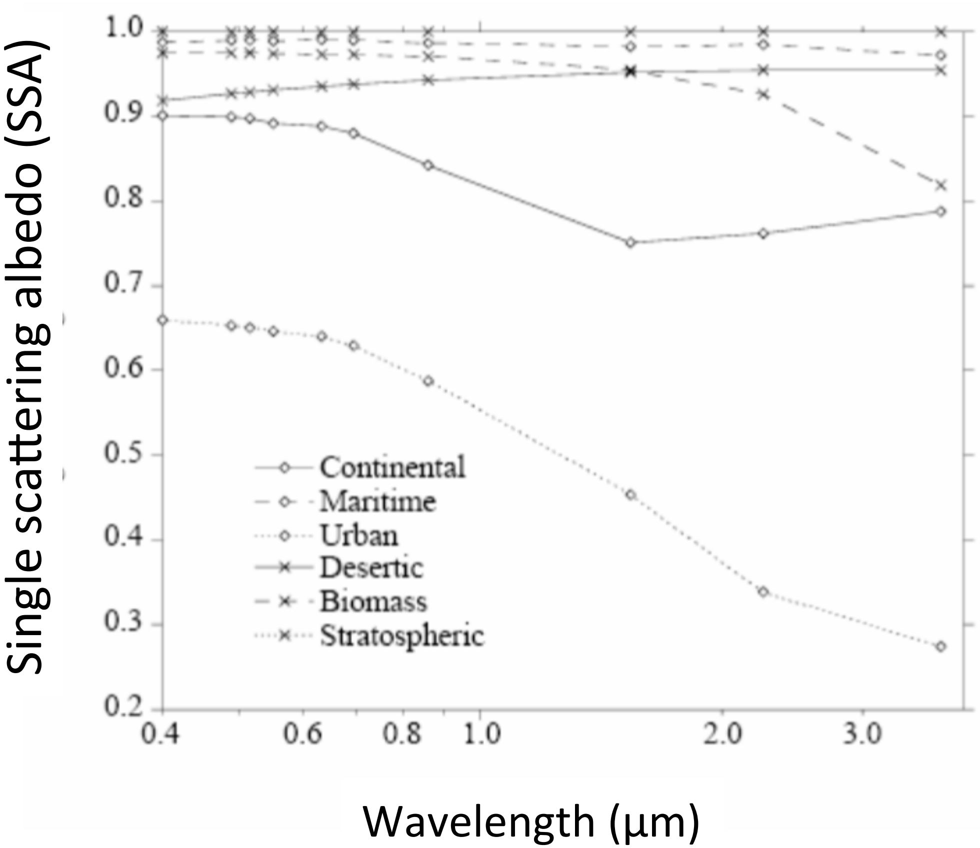


Fig. 2. Spectral dependence of the single scattering albedo for various aerosol models.

Angular signature

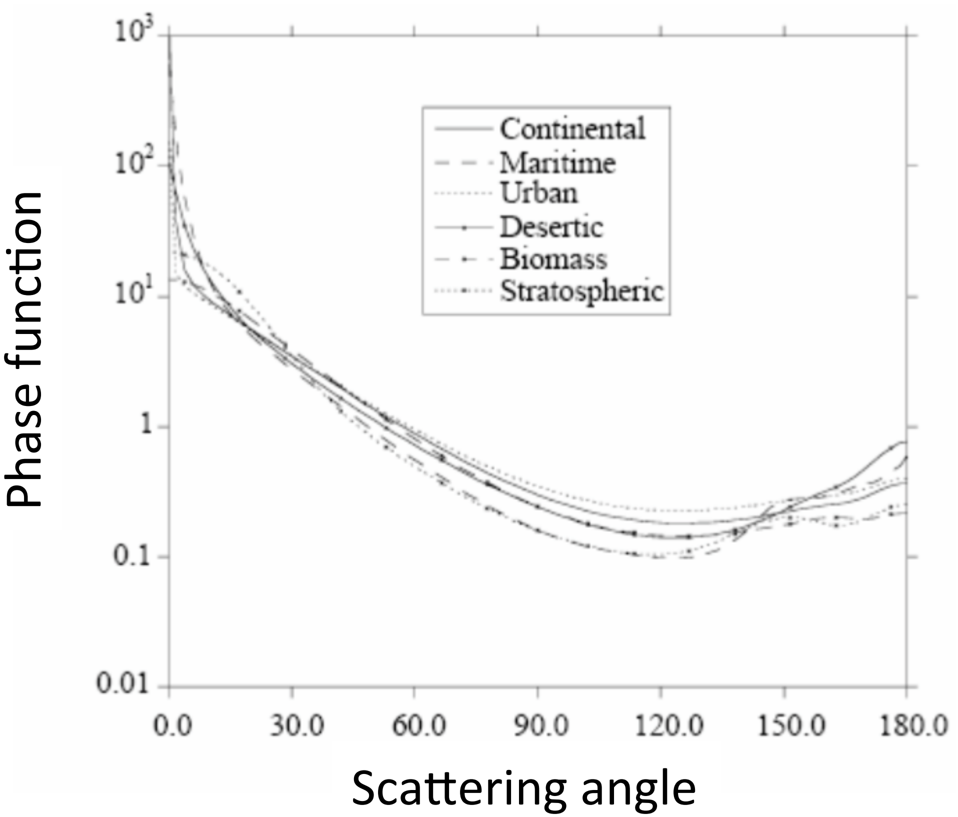
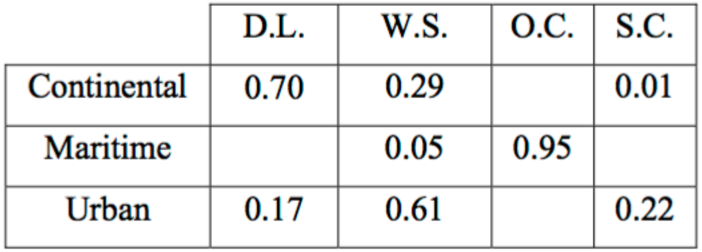


Fig. 4. Phase function at 550 μm versus scattering angle for various aerosol models.



	D.L.	W.S.	O.C.	S.C.
Continental	0.70	0.29		0.01
Maritime		0.05	0.95	
Urban	0.17	0.61		0.22

D.L. = Dust like
W.S. = water soluble (sulfate)
O.C. = ocean
S.C. = Soot

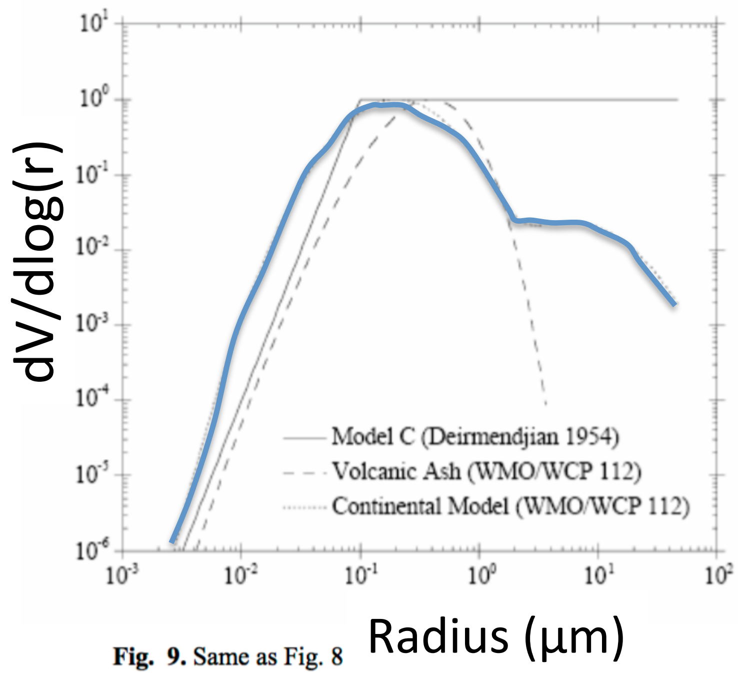


Fig. 9. Same as Fig. 8

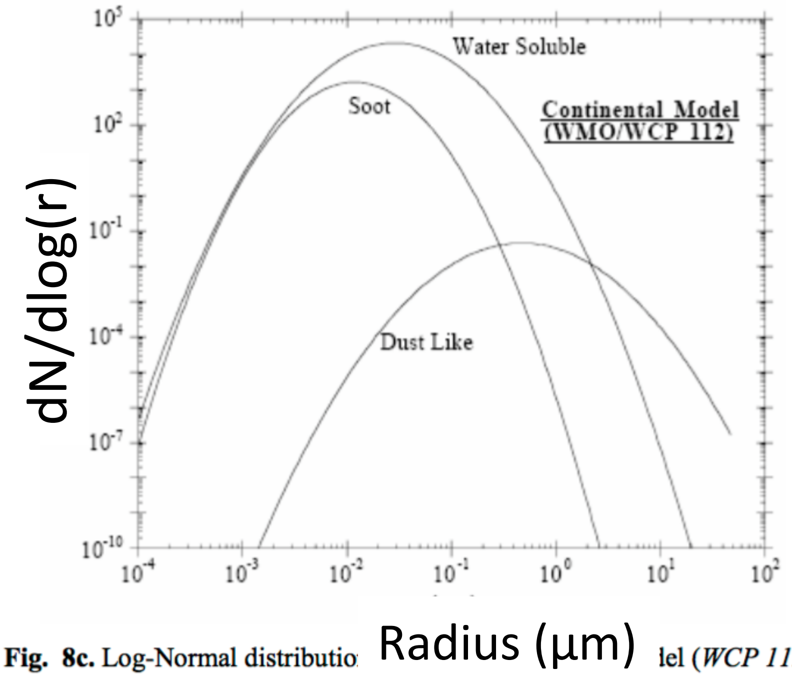
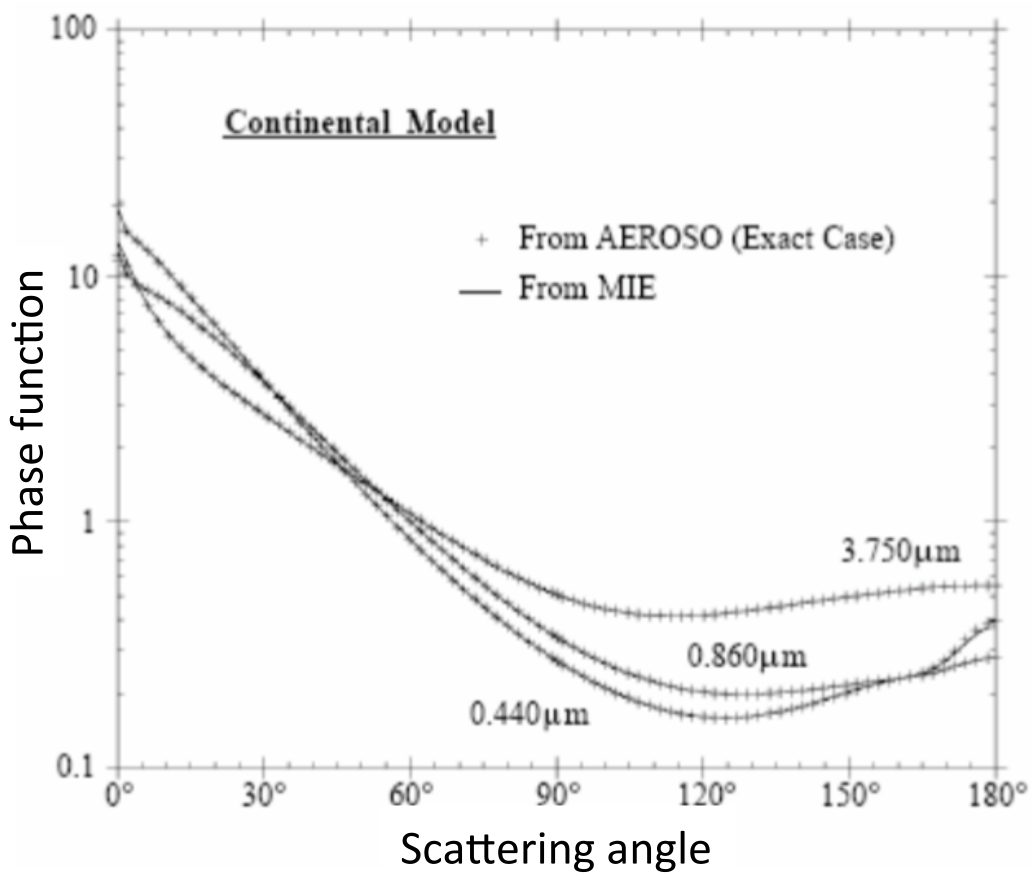


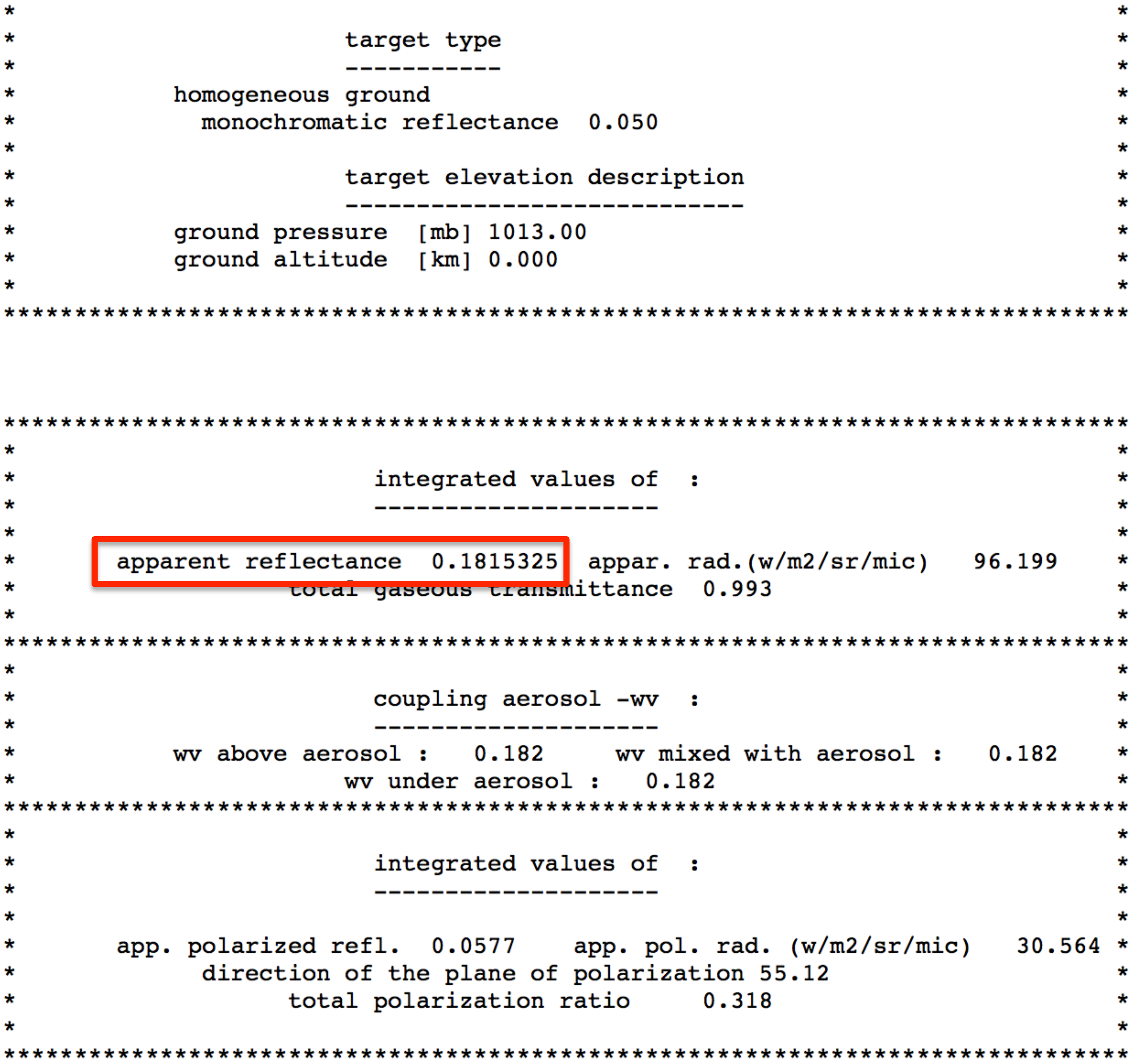
Fig. 8c. Log-Normal distributio lel (*WCP 112*).


Continental Model
+ From AEROSO (Exact Case)
— From MIE
3.750μm
0.860μm
0.440μm
100
10
1
0.1
0°
30°
60°
90°
120°
150°
180°
Phase function
Scattering angle

Running the 6SV radiative transfer code.

Geometrical conditions: 0 (User defined)
30 90 60 135 7 15 (geometrical conditions)
Atmospherical model: Midlatitude Summer (wet)
Continental Model
AOD at 550 nm = 0.5
Target and Sensor altitude: sea level and satellite altitude
Spectral conditions: monochromatic and ignore the second question
wavelength = 0.47 μm
Ground reflectance: homogeneous surface,
no directionl effects
constant value for ro
0.05
Signal: no atm. Correction
Results

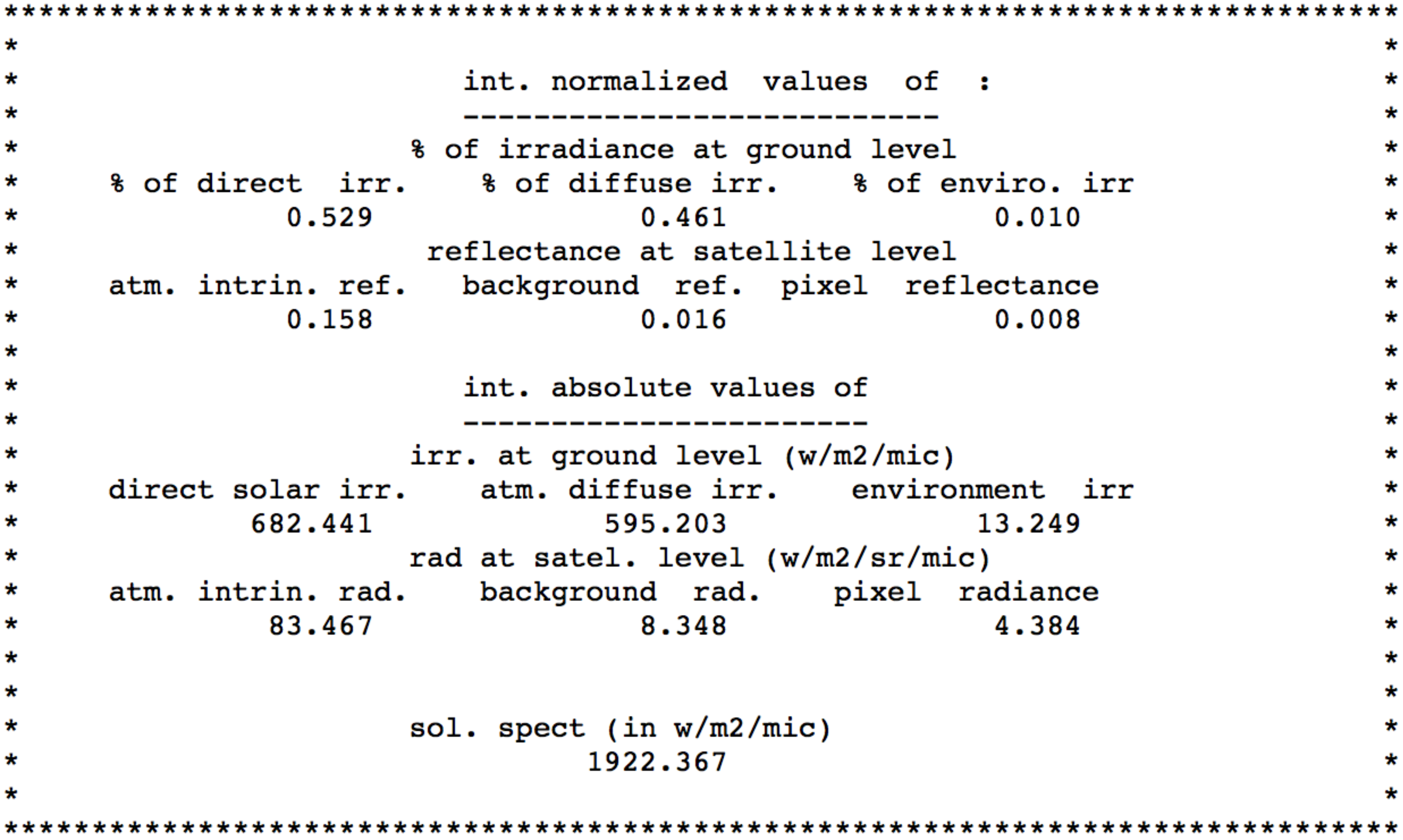
```
*                                                                             *
*                       geometrical conditions identity                       *
*                       -------------------------------                       *
*                       user defined conditions                               *
*                                                                             *
*   month:  7 day :  15                                                       *
*   solar zenith angle:   30.00 deg  solar azimuthal angle:      135.00 deg   *
*   view zenith angle:    60.00 deg  view azimuthal angle:       ****** deg   *
*   scattering angle:    115.66 deg  azimuthal angle difference: 270.00 deg   *
*                                                                             *
*                       atmospheric model description                         *
*                       -----------------------------                         *
*           atmospheric model identity :                                      *
*               midlatitude summer  (uh2o=2.93g/cm2,uo3=.319cm-atm)           *
*           aerosols type identity :                                          *
*               Continental aerosol model                                     *
*           optical condition identity :                                      *
*               visibility :  8.49 km  opt. thick. 550 nm :  0.5000           *
*                                                                             *
*                       spectral condition                                    *
*                       ------------------                                    *
*            monochromatic calculation at wl 0.470 micron                     *
*                                                                             *
*                       Surface polarization parameters                       *
*                       ----------------------------------                    *
*                                                                             *
*                                                                             *
* Surface Polarization Q,U,Rop,Chi    0.00000  0.00000  0.00000     0.00      *
*                                                                             *
```



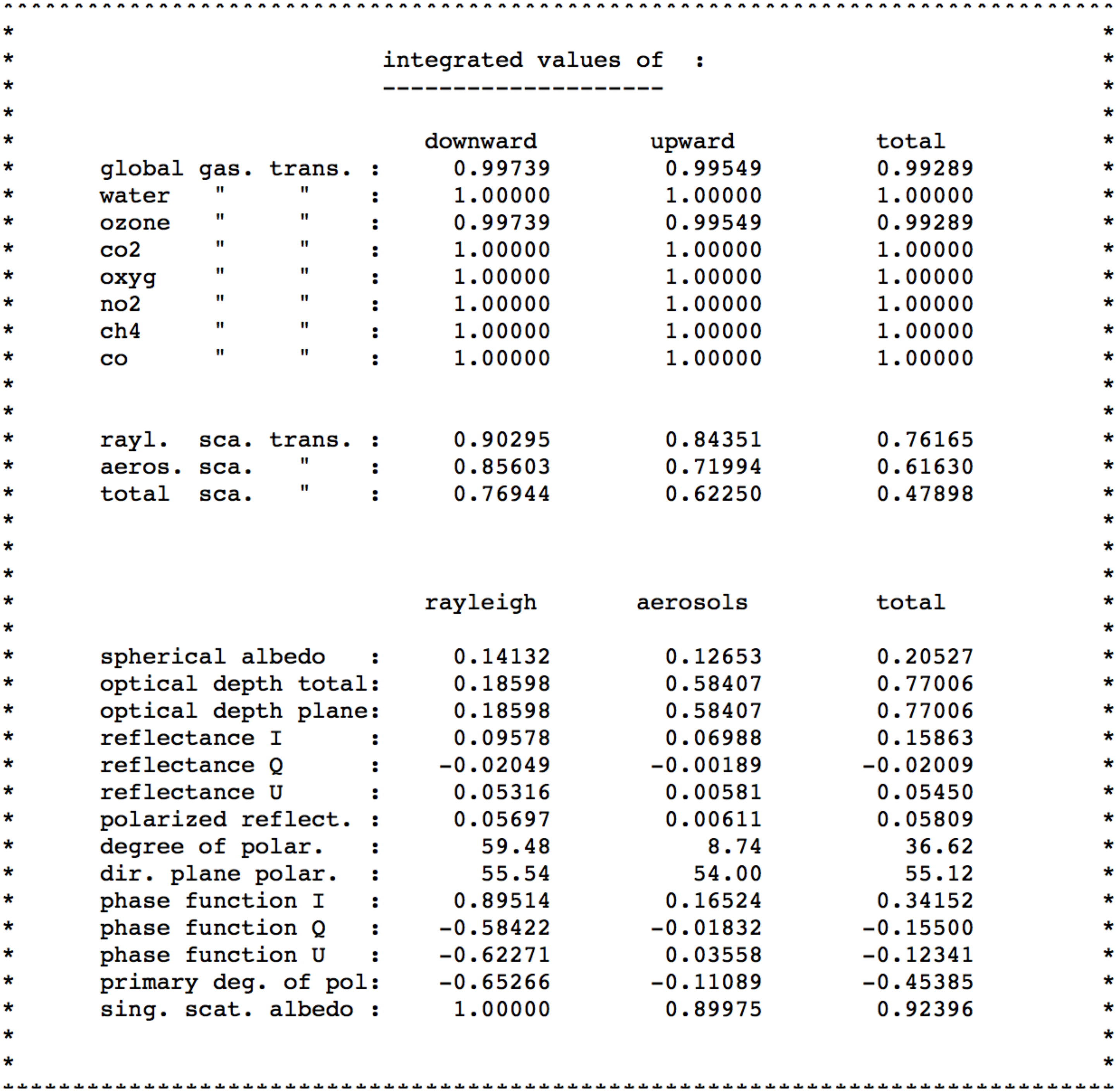
```
*                                                                             *
*                       target type                                           *
*                       -----------                                           *
*           homogeneous ground                                                *
*             monochromatic reflectance  0.050                                *
*                                                                             *
*                       target elevation description                          *
*                       ----------------------------                          *
*           ground pressure  [mb] 1013.00                                     *
*           ground altitude  [km] 0.000                                       *
*                                                                             *
*******************************************************************************



*******************************************************************************
*                                                                             *
*                         integrated values of  :                             *
*                         --------------------                                *
*                                                                             *
*       apparent reflectance  0.1815325  appar. rad.(w/m2/sr/mic)   96.199    *
*                   total gaseous transmittance  0.993                        *
*                                                                             *
*******************************************************************************
*                                                                             *
*                         coupling aerosol -wv  :                             *
*                         --------------------                                *
*           wv above aerosol :   0.182     wv mixed with aerosol :   0.182    *
*                       wv under aerosol :   0.182                            *
*******************************************************************************
*                                                                             *
*                         integrated values of  :                             *
*                         --------------------                                *
*                                                                             *
*       app. polarized refl.  0.0577    app. pol. rad. (w/m2/sr/mic)   30.564 *
*             direction of the plane of polarization 55.12                    *
*                   total polarization ratio     0.318                        *
*                                                                             *
*******************************************************************************
```



```
*******************************************************************************
*                                                                             *
*                         int. normalized  values  of  :                      *
*                         ---------------------------                         *
*                      % of irradiance at ground level                        *
*     % of direct  irr.    % of diffuse irr.    % of enviro. irr              *
*               0.529               0.461               0.010                 *
*                       reflectance at satellite level                        *
*     atm. intrin. ref.   background  ref.  pixel  reflectance                *
*               0.158               0.016               0.008                 *
*                                                                             *
*                         int. absolute values of                             *
*                         -----------------------                             *
*                      irr. at ground level (w/m2/mic)                        *
*     direct solar irr.    atm. diffuse irr.    environment  irr              *
*             682.441             595.203              13.249                 *
*                      rad at satel. level (w/m2/sr/mic)                      *
*     atm. intrin. rad.    background  rad.    pixel  radiance                *
*              83.467               8.348               4.384                 *
*                                                                             *
*                                                                             *
*                      sol. spect (in w/m2/mic)                               *
*                                1922.367                                     *
*                                                                             *
*******************************************************************************
```



```
*******************************************************************************
*                                                                             *
*                          integrated values of  :                            *
*                          --------------------                               *
*                                                                             *
*                             downward        upward          total           *
*      global gas. trans. :     0.99739        0.99549        0.99289         *
*      water   "     "    :     1.00000        1.00000        1.00000         *
*      ozone   "     "    :     0.99739        0.99549        0.99289         *
*      co2     "     "    :     1.00000        1.00000        1.00000         *
*      oxyg    "     "    :     1.00000        1.00000        1.00000         *
*      no2     "     "    :     1.00000        1.00000        1.00000         *
*      ch4     "     "    :     1.00000        1.00000        1.00000         *
*      co      "     "    :     1.00000        1.00000        1.00000         *
*                                                                             *
*                                                                             *
*      rayl.  sca. trans. :     0.90295        0.84351        0.76165         *
*      aeros. sca.    "   :     0.85603        0.71994        0.61630         *
*      total  sca.    "   :     0.76944        0.62250        0.47898         *
*                                                                             *
*                                                                             *
*                                                                             *
*                             rayleigh       aerosols         total           *
*                                                                             *
*      spherical albedo   :     0.14132        0.12653        0.20527         *
*      optical depth total:     0.18598        0.58407        0.77006         *
*      optical depth plane:     0.18598        0.58407        0.77006         *
*      reflectance I      :     0.09578        0.06988        0.15863         *
*      reflectance Q      :    -0.02049       -0.00189       -0.02009         *
*      reflectance U      :     0.05316        0.00581        0.05450         *
*      polarized reflect. :     0.05697        0.00611        0.05809         *
*      degree of polar.   :       59.48           8.74          36.62         *
*      dir. plane polar.  :       55.54          54.00          55.12         *
*      phase function I   :     0.89514        0.16524        0.34152         *
*      phase function Q   :    -0.58422       -0.01832       -0.15500         *
*      phase function U   :    -0.62271        0.03558       -0.12341         *
*      primary deg. of pol:    -0.65266       -0.11089       -0.45385         *
*      sing. scat. albedo :     1.00000        0.89975        0.92396         *
*                                                                             *
*                                                                             *
*******************************************************************************
```

The exercise

geometry	30,90,60,135
scat ang	137.66
AOD at 550	0.5
model	cont: 0.7, 0.29,0,0.01
sfc refl	0.05
profile	midlat sum (wet)
wavelength	
0.47	0.1997154
0.66	0.1024357
0.86	0.0792089
1.24	0.0612825
2.13	0.0448145

1. Start by duplicating the baseline results for 0.47 μm
2. Then change Spectral Conditions to duplicate the other 4 wavelengths.
3. Experiment with changing AOD at 550. Include AOD at 550 = 0 to see the Rayleigh signature.
4. Experiment with changing the model.
5. Experiment with changing the surface reflectance.
6. Experiment with changing the geometry.
7. Experiment with changing from wet to dry conditions (midlatitude winter).

- Do each experiment one at time.
- Record the apparent reflectance at the particular wavelength.
- Record the input conditions for each set of calculated apparent reflectances.

Assimilation: Observationally-assisted modeling

https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/

https://gmao.gsfc.nasa.gov/research/aerosol/

https://gmao.gsfc.nasa.gov/GMAO_products/reanalysis_products.php

- Buchard, V., C.A. Randles, A.M. da Silva, A. Darmenov, P.R. Colarco, R. Govindaraju, R. Ferrare, J. Hair, A.J. Beyersdorf, L.D. Ziemba, and H. Yu, "The MERRA-2 Aerosol Reanalysis, 1980-onward, Part II: Evaluation and Case Studies," J. Clim., 10.1175/jcli-d-16-0613.1 (2017).

- Randles, C.A., A.M. da Silva, V. Buchard, P.R. Colarco, A. Darmenov, R. Govindaraju, A. Smirnov, B. Holben, R. Ferrare, J. Hair, Y. Shinozuka, and C.J. Flynn, "The MERRA-2 Aerosol Reanalysis, 1980-onward, Part I: System Description and Data Assimilation Evaluation," J. Clim., 10.1175/jcli-d-16-0609.1 (2017).

Peter Colarco (my personal contact for most GEOS or MERRA questions)

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Hongbin Yu (a MERRA user for aerosol transport with an excellent understanding of the pluses and minuses of the data.)

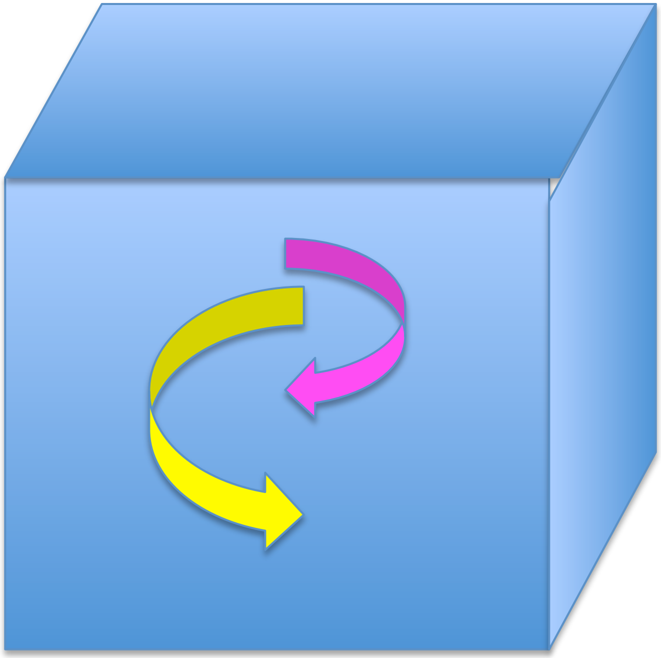
hongbin.yu-1@nasa.gov

Mian Chin (my best friend who is a modeler and can talk about the different components that make up AOD in the assimilation system – like black carbon).

mian.chin-1@nasa.gov

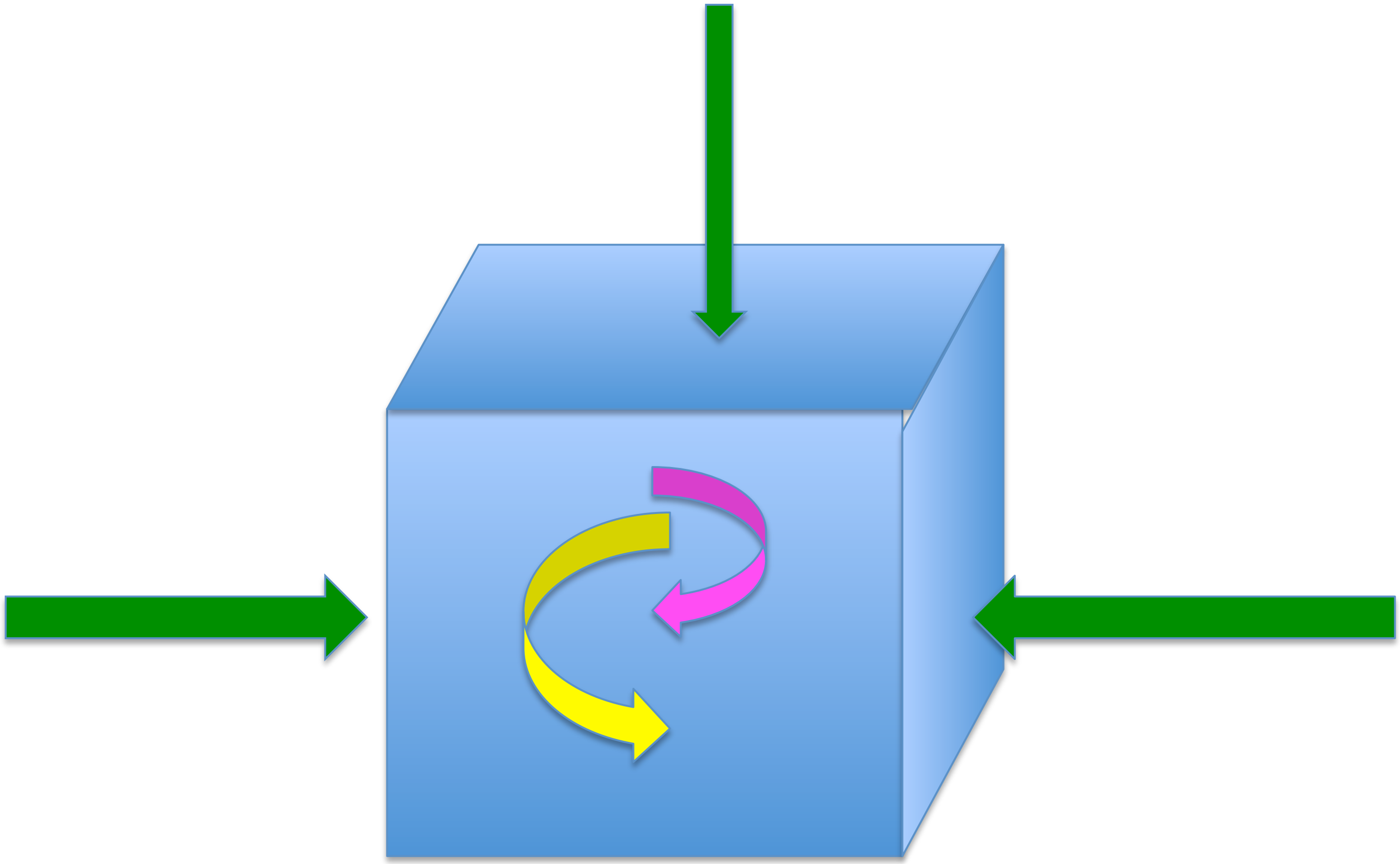
A normal atmospheric or chemical transport model

- Intialized
- then it goes off on its own to create its own reality.
- That reality can be very realistic because it is based on our best understanding of the physics and chemistry of the Earth system.
- But it also can create an alternative reality.
- Very useful for making numerical experiments.

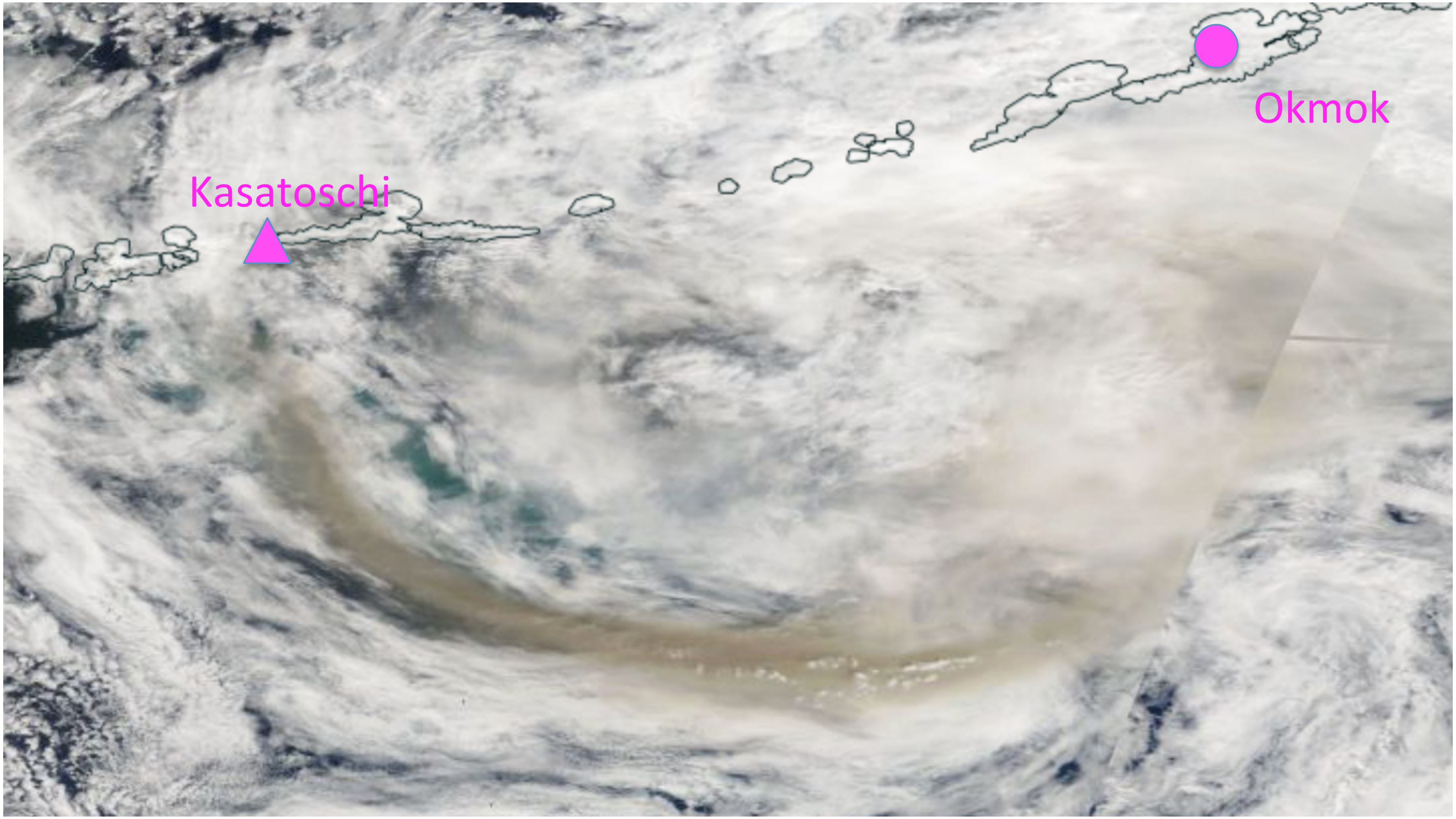


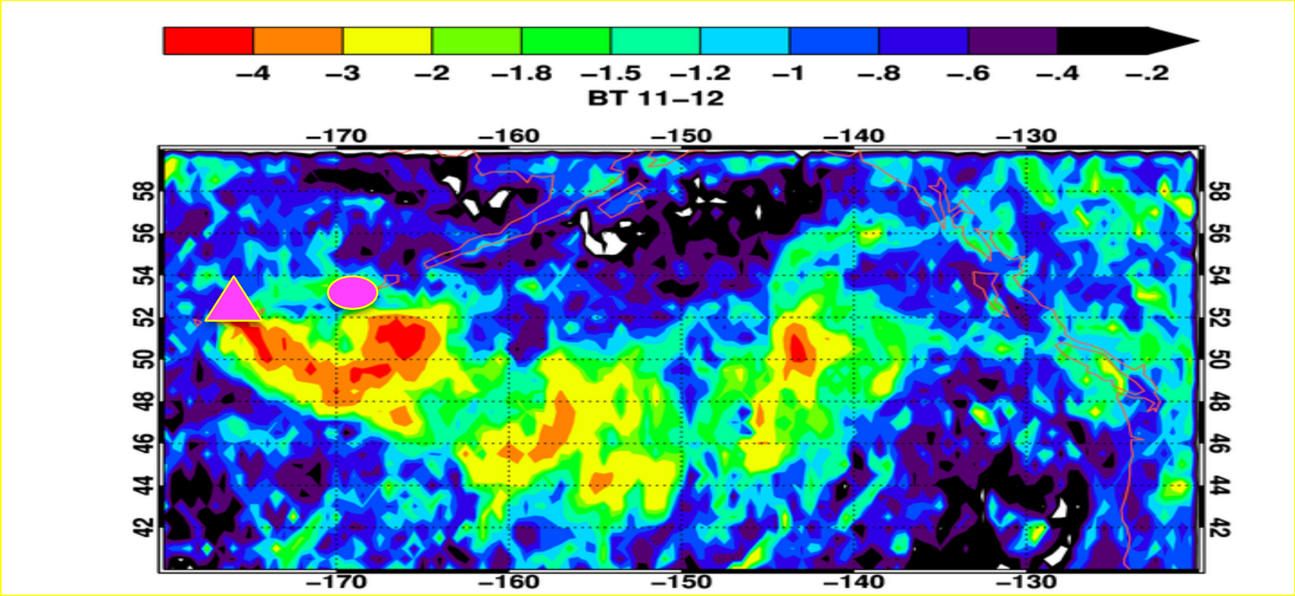
In an assimilation system:

- Initialized
- Starts to move air and chemical species around according to our best understanding of the physics and chemistry of the Earth system
- Before it goes too far it acquires actual observations – (e.g. Satellite-derived AOD).
- Then it adjusts itself in order to agree with the observations
- Before moving ahead like a model
- Then it adjusts itself again to agree with the observations.
- Much better representation of observable fields (like AOD) than a normal model.
- Can be used to infer parameters that are <u>not observable </u>(like black carbon or aerosol in cloudy environments or maybe dust deposition into the ocean).
- Some faith in these inferred parameters because (a) the model is physical and (b) it is constrained by observations.
- But these inferred parameters are NOT observed and cannot be used for validation. They provide something a little bit more realistic for comparison to model results.

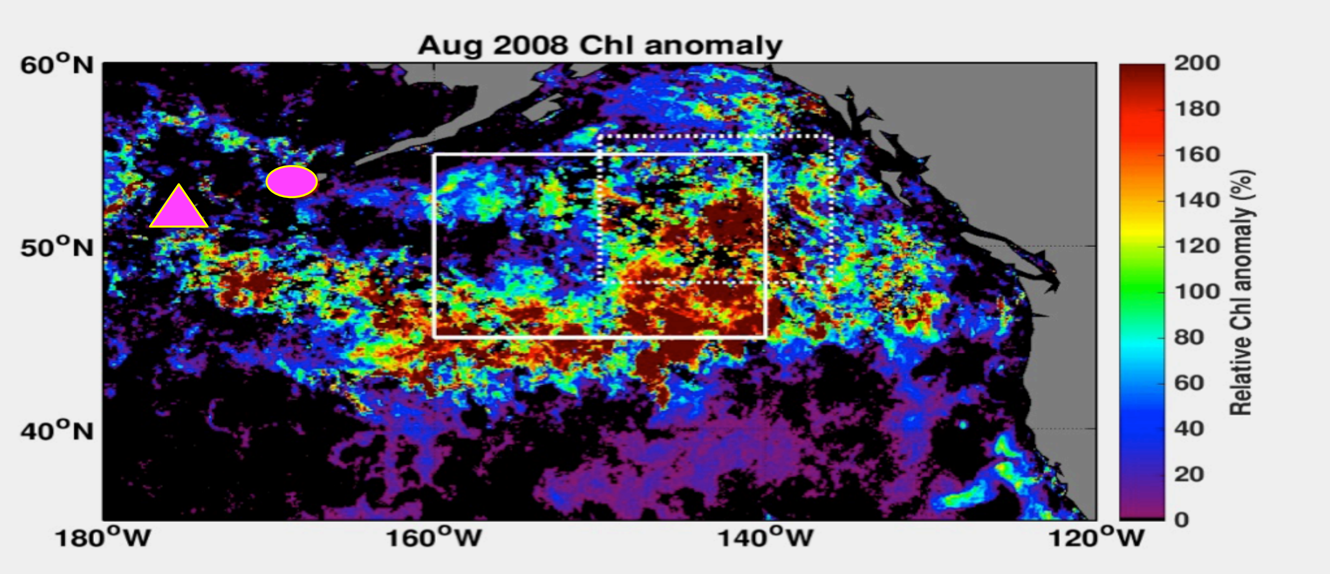


Okmok and Kashatoschi eruptions July-August 2008



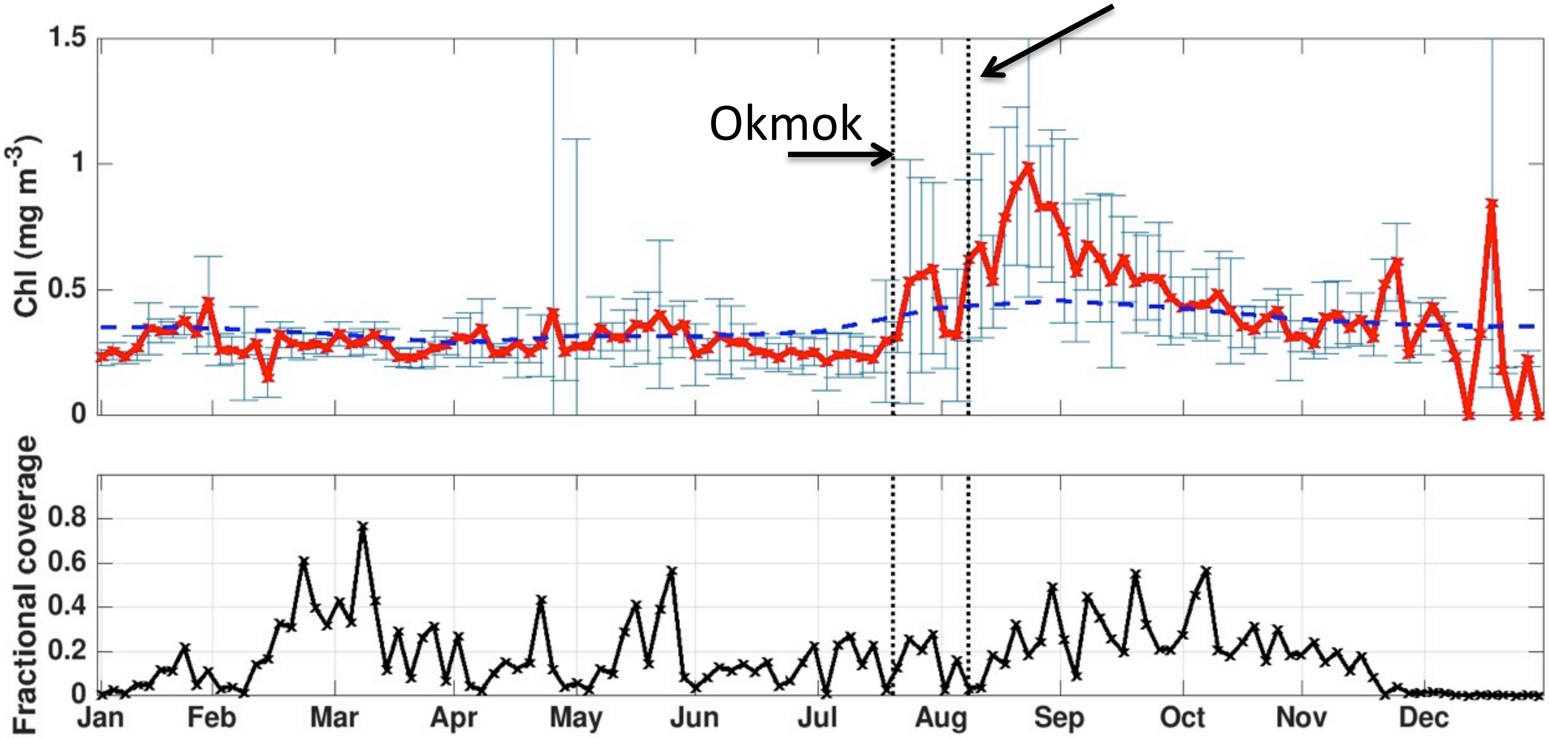


MODIS Brightness differences (11 µm – 12 µm) are sensitive to airborne volcanic ash.
(left) 4-day composite. 8-12 Aug 2008. Both Okmok and Kasatochi are active in this period.



Relative MODIS-derived ocean chlorophyll anomaly of monthly mean August 2008 vs. climatology. Spatially, the paths of the ash from both volcanoes are evident in elevated chlorophyll.

Chlorophyll

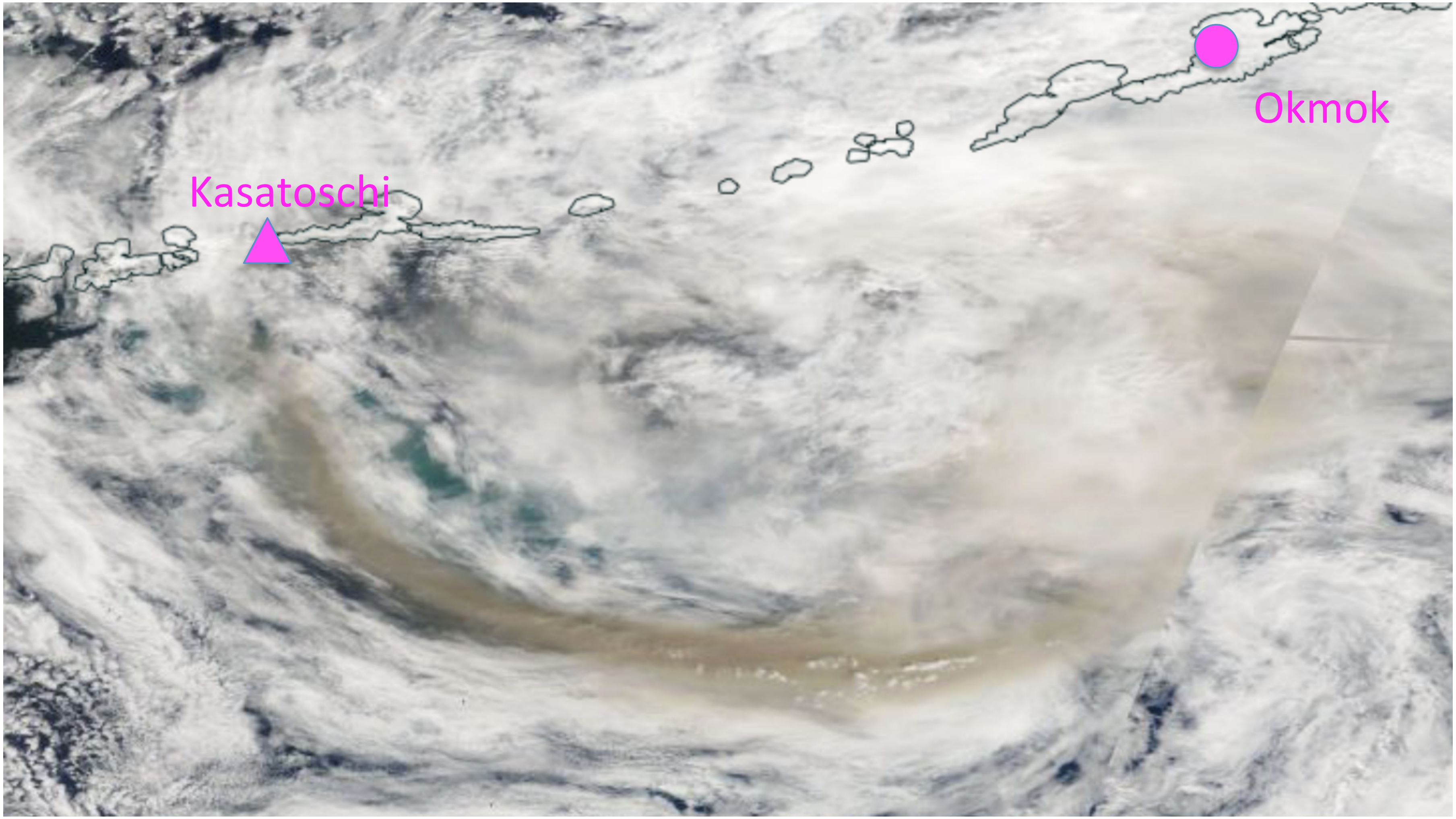


Kasatoschi

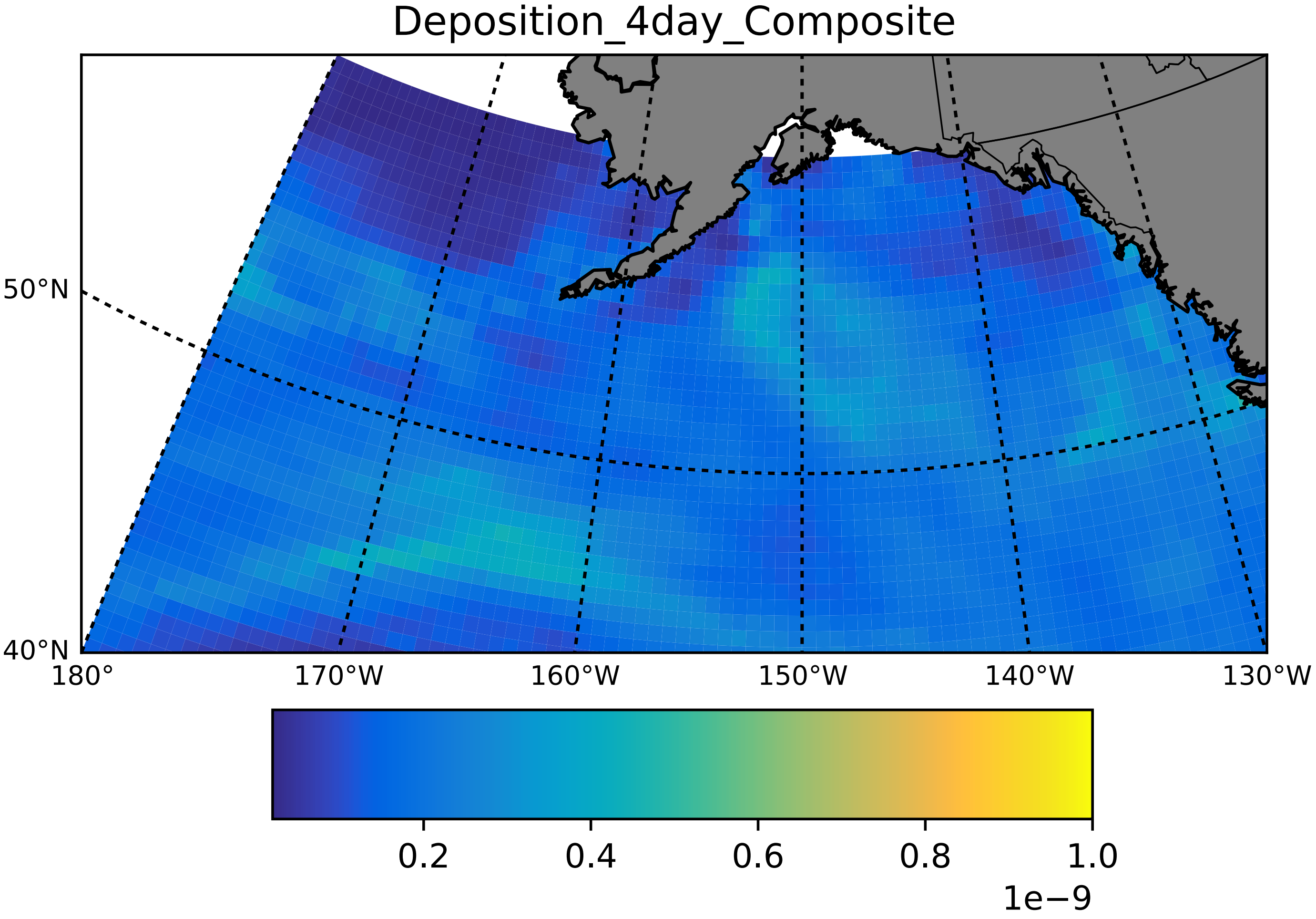
Okmok

We would like to link the ocean signal more substantially to particles falling into the water, not just what appears in the atmospheric retrievals.

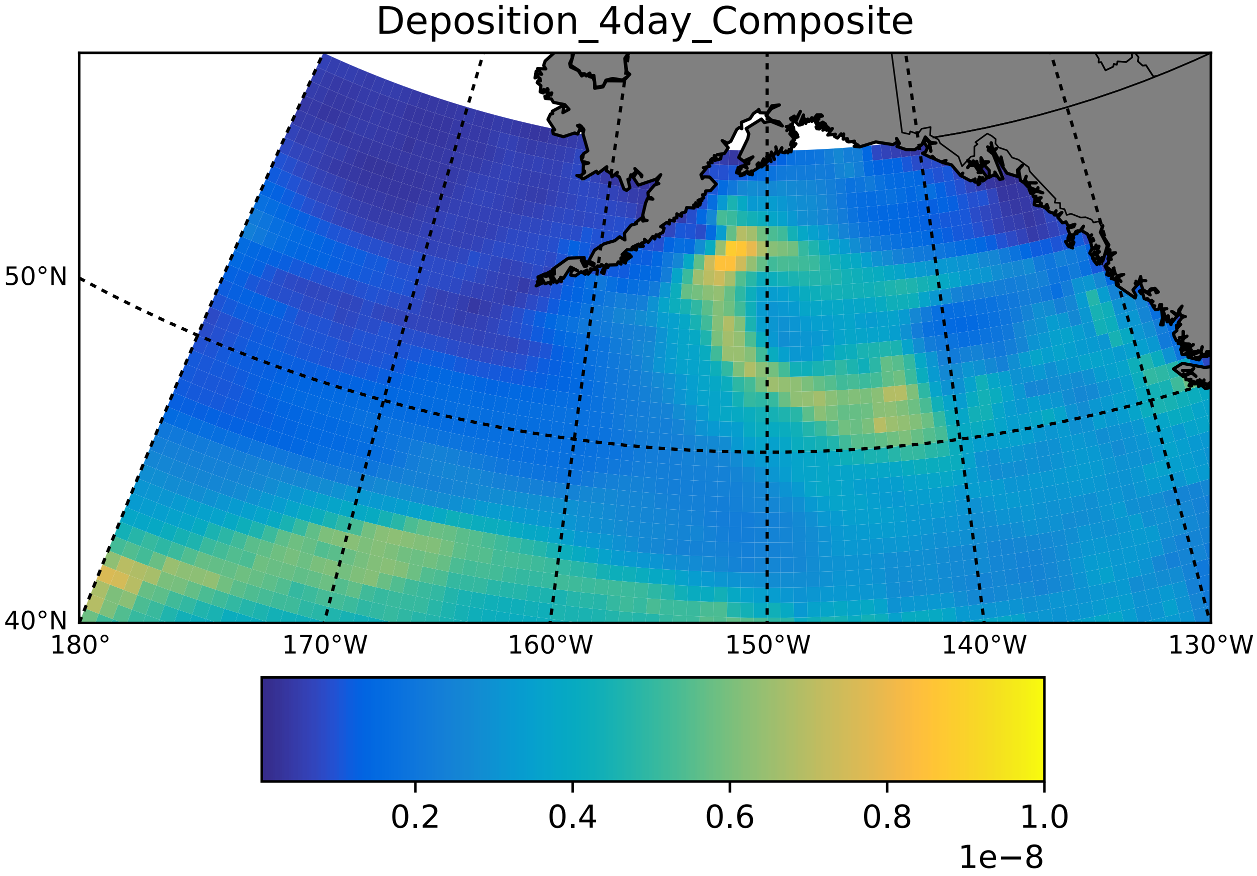
Okmok and Kashatoschi eruptions July-August 2008



Aerosol deposition with NO sea salt



Total aerosol deposition flux (includes all aerosol types)



Model is humming along representing aerosol system,

When suddenly out of now where volcanic ash appears

“What large AOD you have!” cries the model

The model does the only thing that it can do, and that is add aerosol mass.

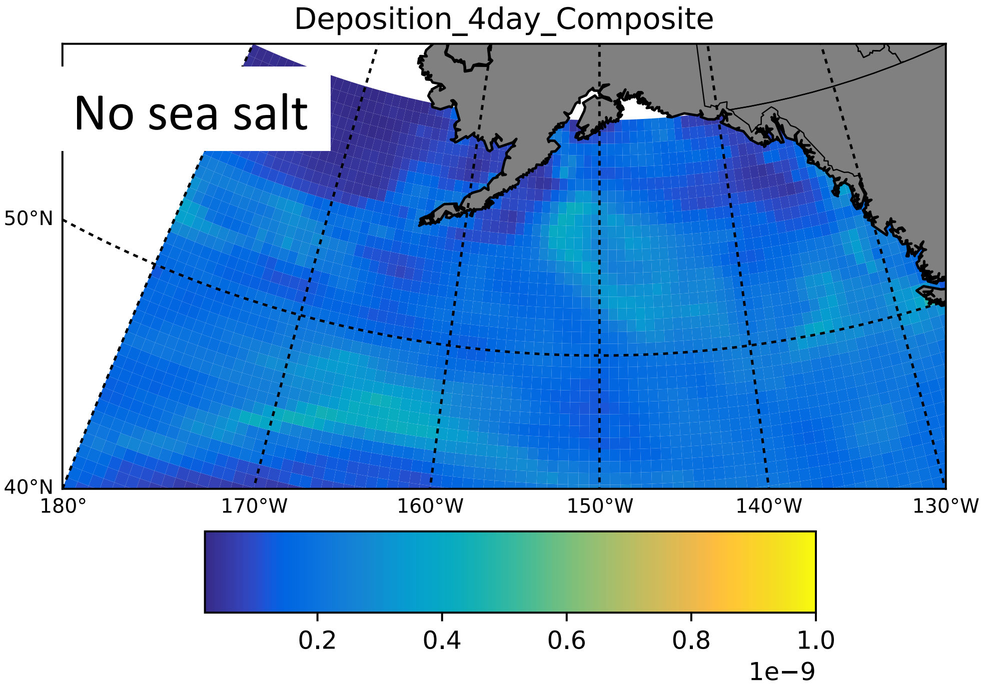
Where does it gets the mass? It’s a model. It just creates mass out of nothing.

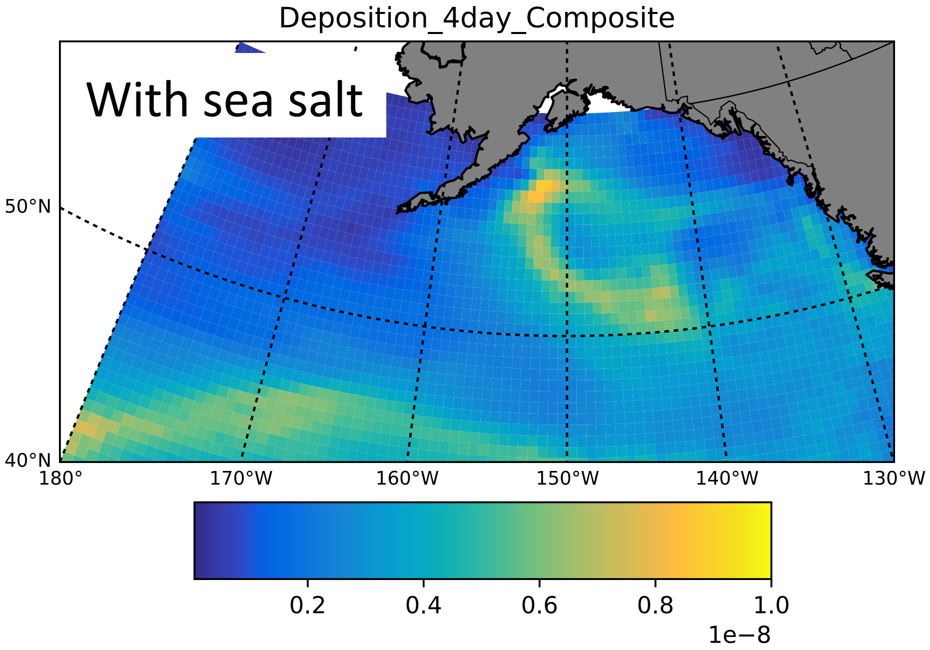
But where does it put its mass?

Which component aerosol does it increase?

At what level in the atmosphere?

The model decides, “ I will just increase whatever aerosol I already have there!”





The only aerosol that the model had in the Gulf of Alaska was sea salt.

So it made more sea salt.

Which was close to the ocean.

Which deposited into the ocean.

Can we use this to say that volcanic ash, in these quantities, deposited into the ocean?