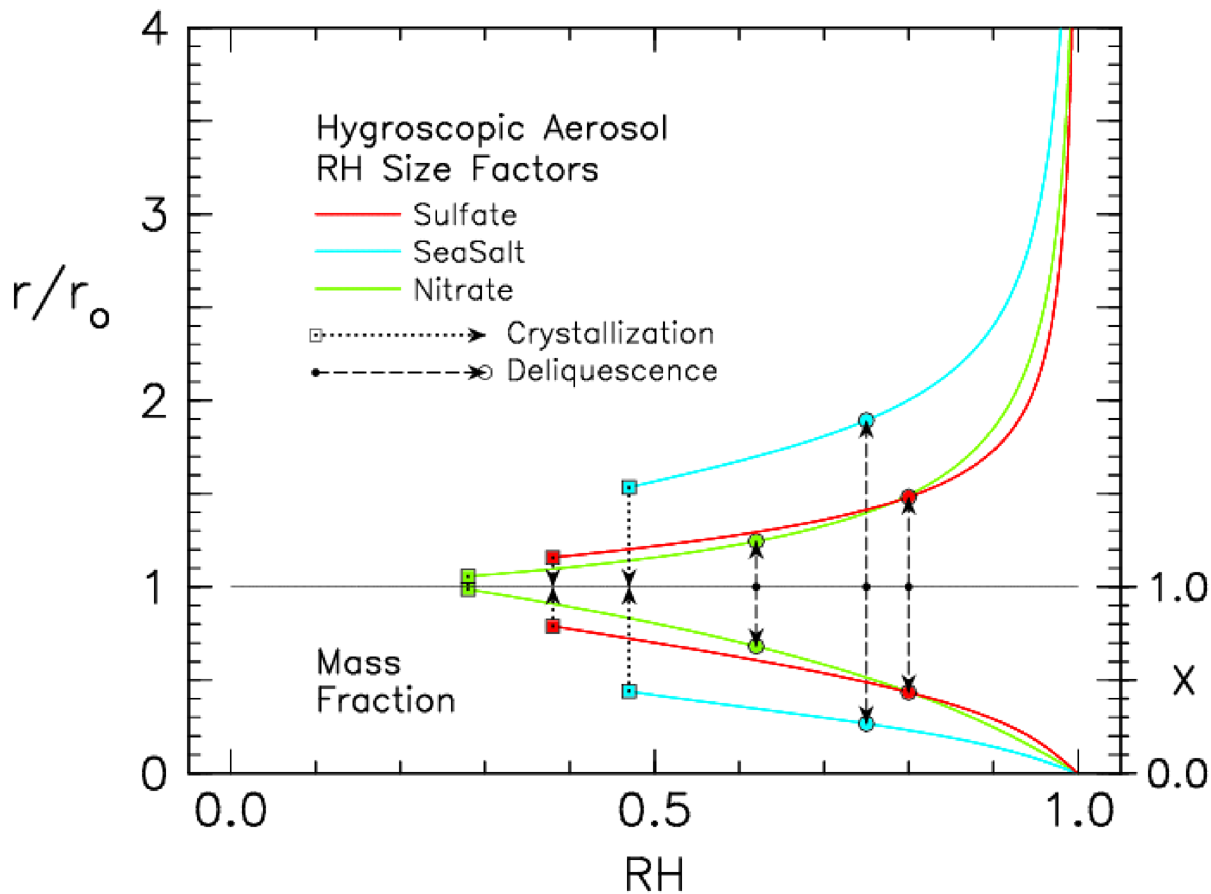
GCM Parameterization of Hygroscopic Aerosol Radiative Properties

The principal objective of this research effort is to develop and validate a comprehensive aerosol climatology for GCM climate modeling applications. The aerosol climatology consists of the principal atmospheric species each represented by a variable number of size bins. The aerosol geographic, vertical, and seasonal variability is obtained from chemistry-transport model results. The hygroscopic aerosol radiative parameter dependence on relative humidity is parameterized as an external mixture of the dry aerosol and a pure water aerosol, based on laboratory measurements by Tang and Munkelwitz [1991,1994,1996].

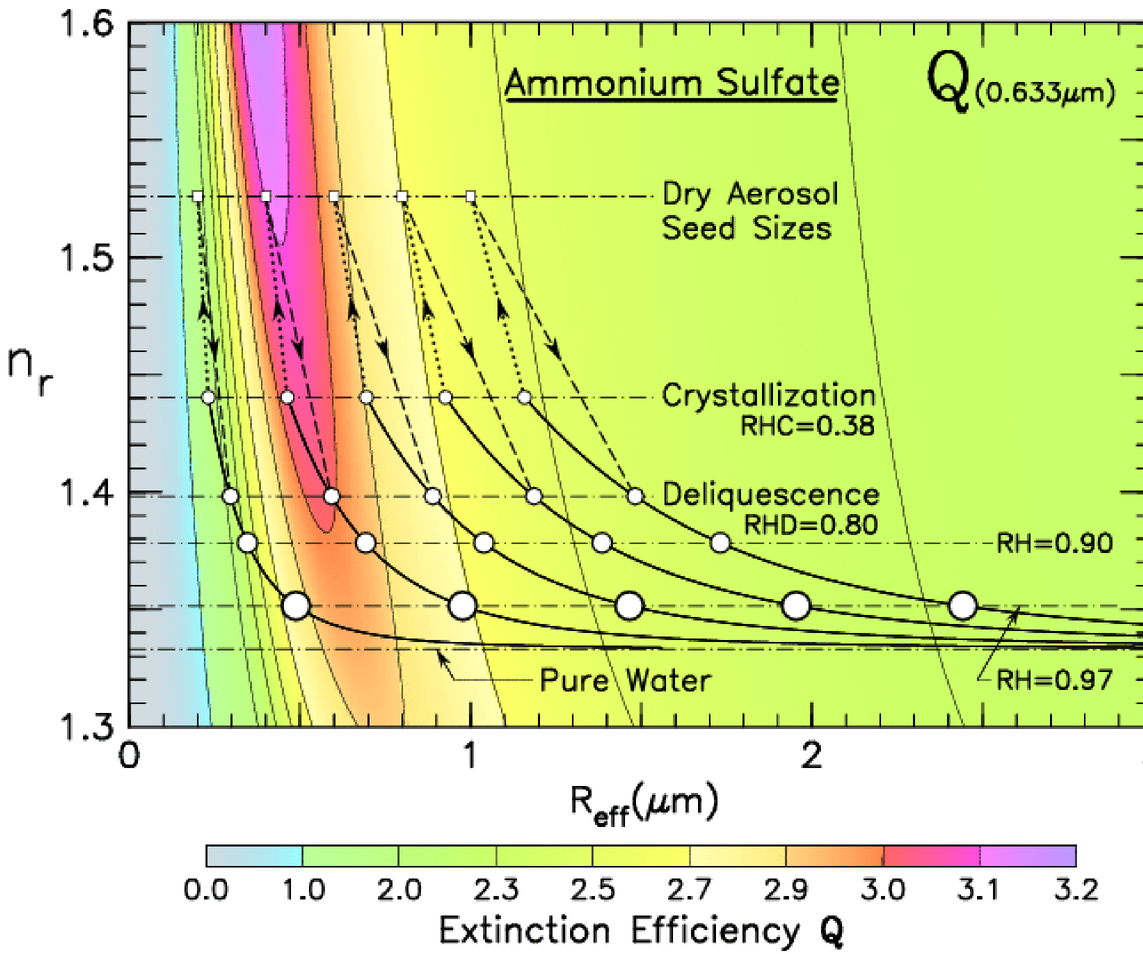
As a bi-product of the GCM aerosol climatology and aerosol radiative parameter parameterization, a number of physical parameters for individual aerosol species and for the entire aerosol ensemble are available as global monthly-mean maps for diagnostic comparison with MODIS, MISR, POLDER, and AERONET data. The physical parameters include aerosol optical depth at 550 nm, asymmetry parameter, single scattering albedo, and Angstrom exponent.

The following figures briefly describe the the nature and approach taken to parameterize the effect of relative humidity on the size, density, and refractive index, and subsequently on the Mie scattering radiative parameters, of the principal hygroscopic aerosols (ammonium sulfate, sea salt, ammonium nitrate, and organic carbon). We demonstrate that the radiative parameters of solute aerosols can be accurately represented by an external mixture of pure dry and pure water aerosols.

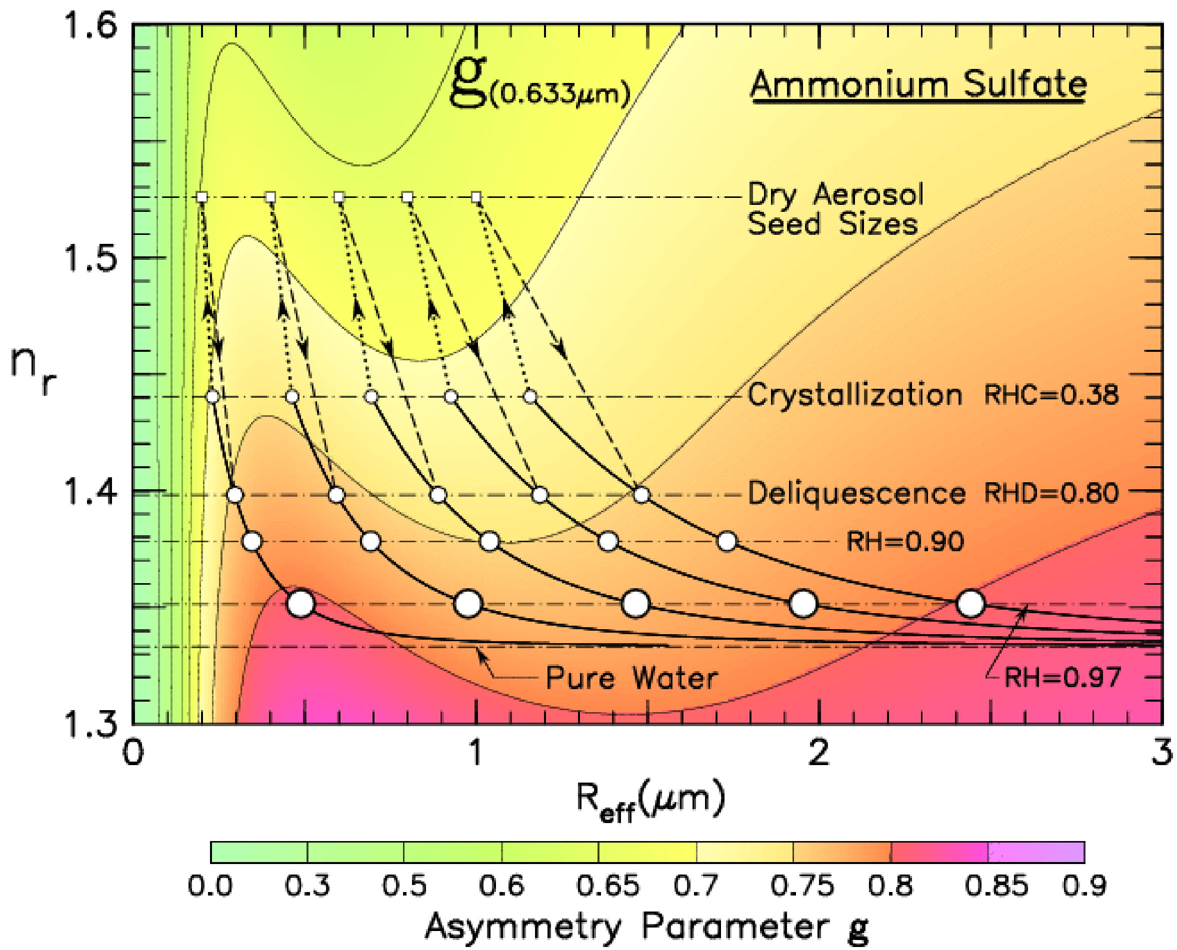
Comparison of GCM aerosol output results, which include hygroscopic aerosol relative humidity effects, with MODIS, MISR, POLDER, and AERONET data will serve to refine the selection of dry aerosol seed sizes and to validate chemistry-transport model aerosol spatial distributions.



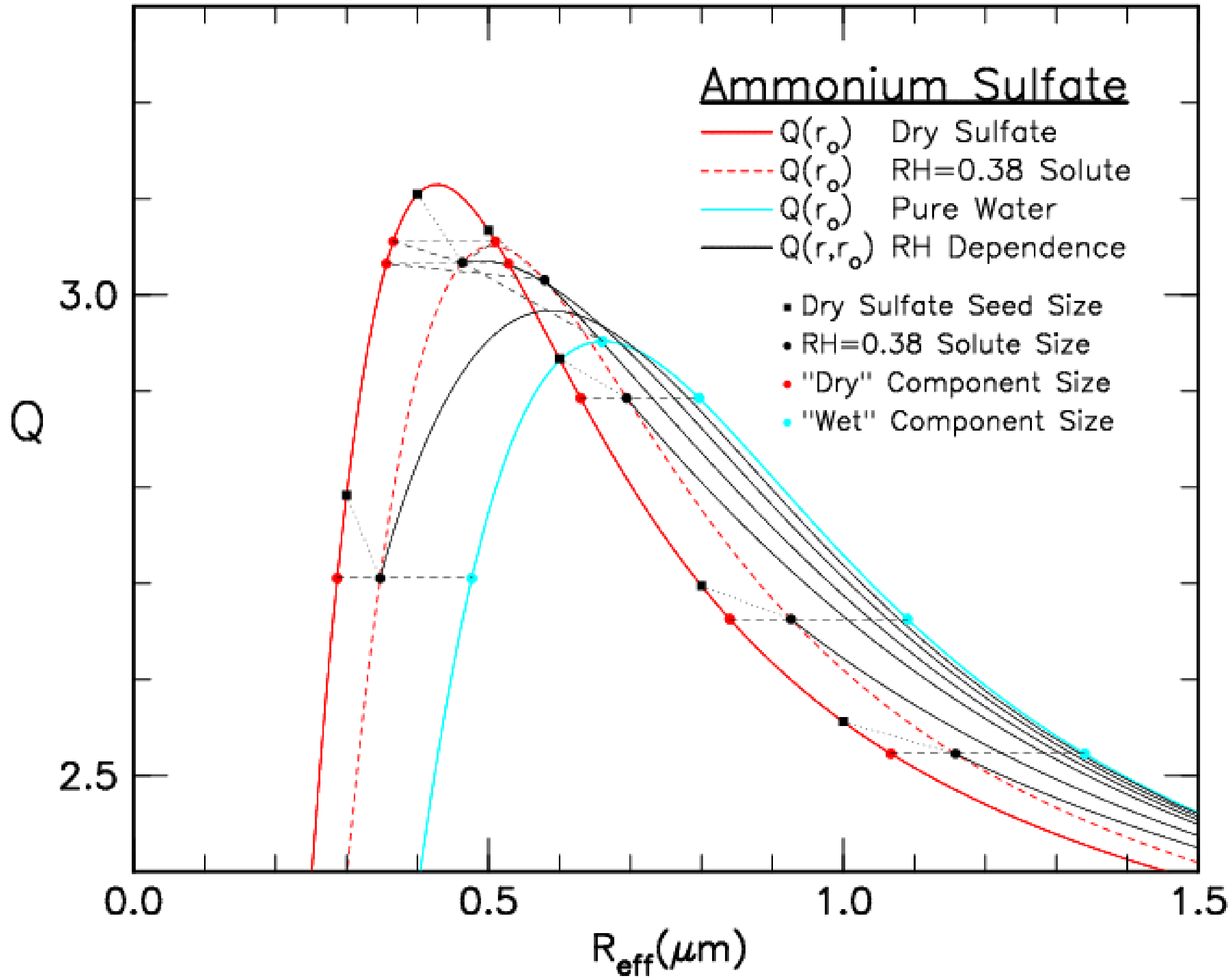
Hygroscopic aerosol size and (dry) mass fraction as a function of relative humidity relative humidity. The size, density, and refractive index of hygroscopic aerosols follows a hysteresis loop according to laboratory measurements by Tang and Munkelwitz [1991, 1994, 1996]. With rising relative humidity, a dry aerosol rapidly becomes a solute particle at the deliquescence point (filled circles), dropping from the equilibrium curve as RH decreases below the crystallization point (filled squares).



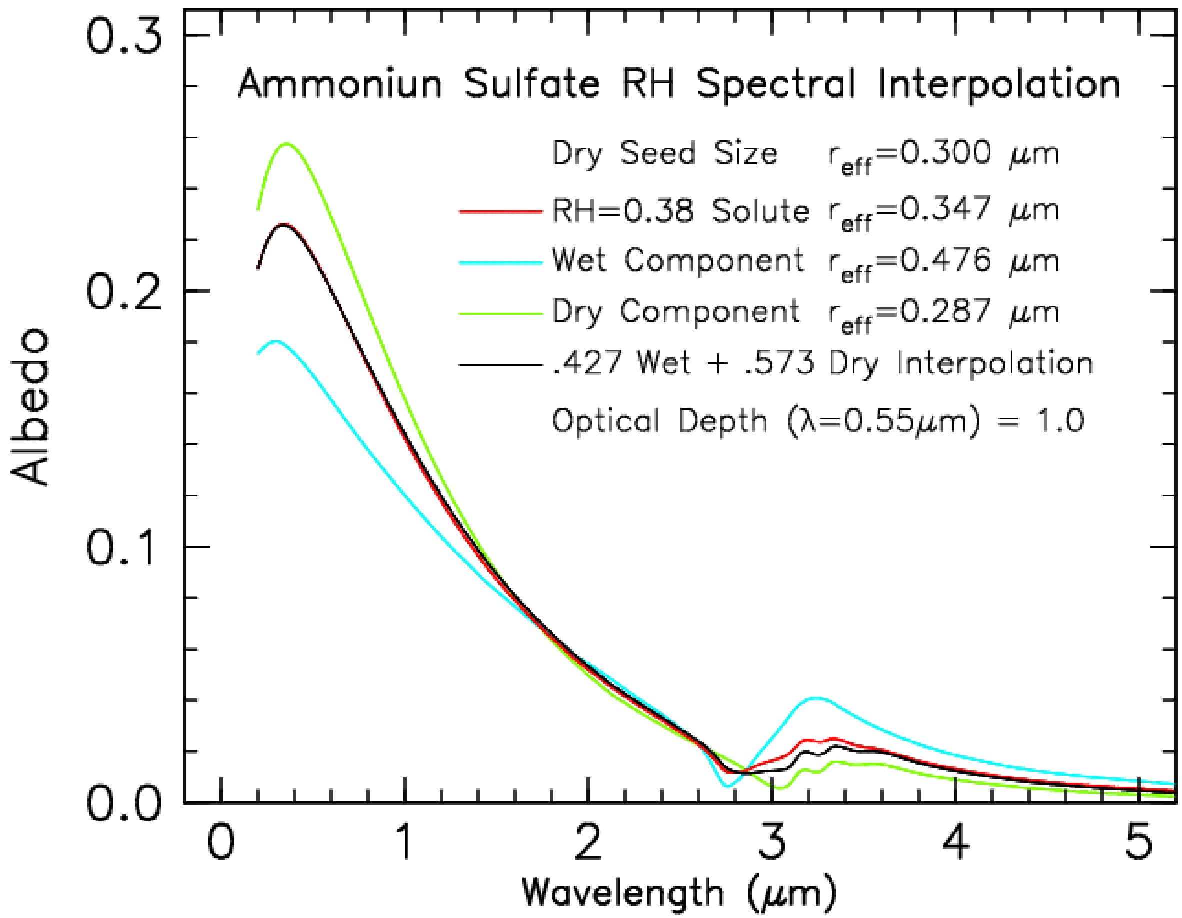
Relative humidity constrained tracks, according to laboratory measurements by Tang and Munkelwitz [1991, 1994, 1996], in Mie scattering extinction efficiency parameter map for selected dry sulfate seed sizes. White squares depict selected dry aerosol (200 to 1000 nm) seed sizes. Dashed arrow lines show deliquescence transitions at RHD=0.80. Dotted arrow lines depict crystallization points at RHC=0.38. White circles designate relative increase in solute aerosol size with increasing relative humidity.



Relative humidity constrained tracks, according to laboratory measurements by Tang and Munkelwitz [1991, 1994, 1996], in Mie scattering asymmetry parameter map for selected dry sulfate seed sizes. White squares depict selected dry aerosol (200 to 1000 nm) seed sizes. Dashed arrow lines show deliquescence transitions at RHD=0.80. Dotted arrow lines depict crystallization points at RHC=0.38. White circles designate relative increase in solute aerosol size with increasing relative humidity.



Representation of solute particle radiative parameters (extinction efficiency and asymmetry parameter) as a weighted average of dry aerosol (solid red) and pure water (blue) aerosol properties. The dashed red line depicts the RH=0.38 crystallization point for sulfate aerosols. The black lines depict equilibrium RH dependent Q(R) for specified dry aerosol seed sizes. Since Q is the same (along horizontal dashed lines), the asymmetry parameter of the solute aerosol can be precisely matched as a weighted average of the pure dry and pure water aerosol values of the appropriate sizes, as indicated.



Spectral validation of the pure dry/pure water (PDPW) weighted average representation of solute aerosol radiative properties. The (reference) red curve utilizes Mie scattering parameters computed for the appropriate solute spectral refractive index at RH=0.38. The black line depicts the spectral albedo computed with the averaged PDPW radiative parameters. Thus, the radiative properties of a 300 nm dry sulfate aerosol, which becomes a 347 nm solute particle at RH=0.38, can be accurately represented as the weighted average of a pure dry 287 nm particle and a 476 nm pure water aerosol.

GISS ModelE Global Annual Mean Aerosols under Clear and Cloudy Sky Conditions

ANNUAL GLOBAL MEANS:	OPT DEPTH OF AEROSOL			FORCING vs NO AEROSOL		
	clr sky	cld sky	all sky	clr sky	cld sky	all sky
ALL SULFATES 2000 (GCM ambient RH)	.02992	.09466	.06782	-.971	-.539	-.718
ALL SULFATES 2000 (dry state RH=0)	.02091	.01968	.02019	-.962	-.306	-.578
(effective column mean RH)	RH=.47	RH=.93	RH=.88			
ALL NITRATES 2000 (GCM ambient RH)	.00864	.03138	.02195	-.378	-.404	-.393
ALL NITRATES 2000 (dry state RH=0)	.00562	.00593	.00580	-.279	-.084	-.165
(effective column mean RH)	RH=.64	RH=.95	RH=.92			
ORGANIC CARBON 2000 (GCM ambient RH)	.02417	.02260	.02325	-.972	-.220	-.532
ORGANIC CARBON 2000 (dry state RH=0)	.02098	.02404	.02277	-.869	-.179	-.465
(effective column mean RH)	RH=.73		RH=.38			
BLACK CARBON 1850	.00245	.00204	.00221	.091	.257	.188
BLACK CARBON 2000	.00980	.00883	.00923	.444	1.090	.822
SOIL DUST ONLY	.03038	.03033	.03035	-1.379	-.404	-.808
ALL AEROSOLS 1850	.08911	.27543	.19818	-3.488	-1.373	-2.250
ALL AEROSOLS 2000	.14115	.39265	.28838	-4.827	-1.412	-2.828
SEA SALT ONLY (GCM ambient RH)	.03824	.20486	.13578	-1.571	-.936	-1.199
SEA SALT ONLY (RH=0)	.01098	.01141	.01123	-.660	-.144	-.358
SEA SALT ONLY (RH=0.80)	.03989	.04139	.04077	-1.680	-.361	-.908
SEA SALT ONLY (RH=0.90)	.05721	.05948	.05854	-2.161	-.468	-1.170
SEA SALT ONLY (RH=1.00)	1.13387	1.17871	1.16012	-13.603	-2.252	-6.958