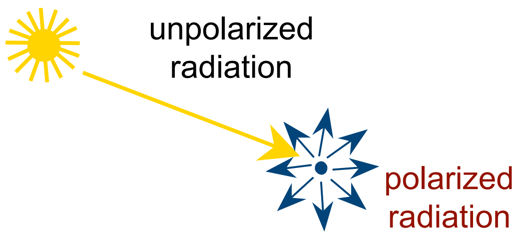
Validation of the 6S radiative transfer code for atmospheric correction of MODIS data

Eric F. Vermote & Svetlana Y. Kotchenova

Department of Geography, University of Maryland

Radiation polarization

A new version of 6S, which accounts for light polarization, has been developed.



The real situation
account for polarization

Vector codes
{ I, Q, U, V }

The artificial situation
no polarization

Scalar codes
{ I, 0, 0, 0 }

Degrees of polarization

90-100% - molecular atmosphere at 90^0 scattering angle

30% - small aerosol particles

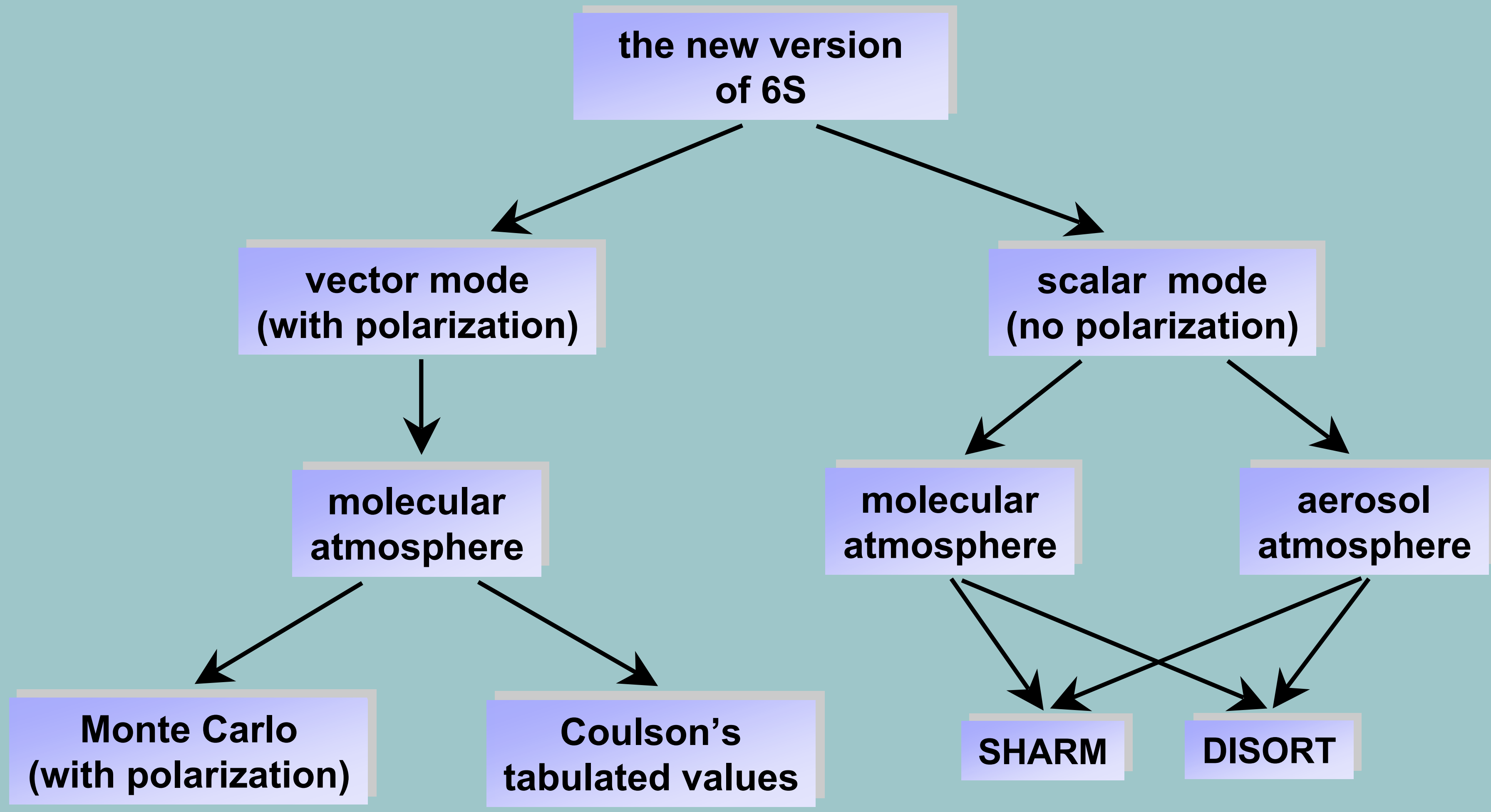
5-25% - snow

0-40% - ice

0-15% - sand

2-23% - vegetation

Validation of the new version of 6S



Scalar mode – a purely molecular atmosphere

- **geometry**: a wide range of {SZA, VZA, AZ}
- **optical thickness**: □= 0.1 (_ ≈ 0.53 _m), □= 0.3445 (_ = 0.4 _m), □= 0.5 (_ ≈ 0.36 _m)
- **ground reflectance**: □ = 0.0 (black soil) and □ = 0.25 (Lambertian)

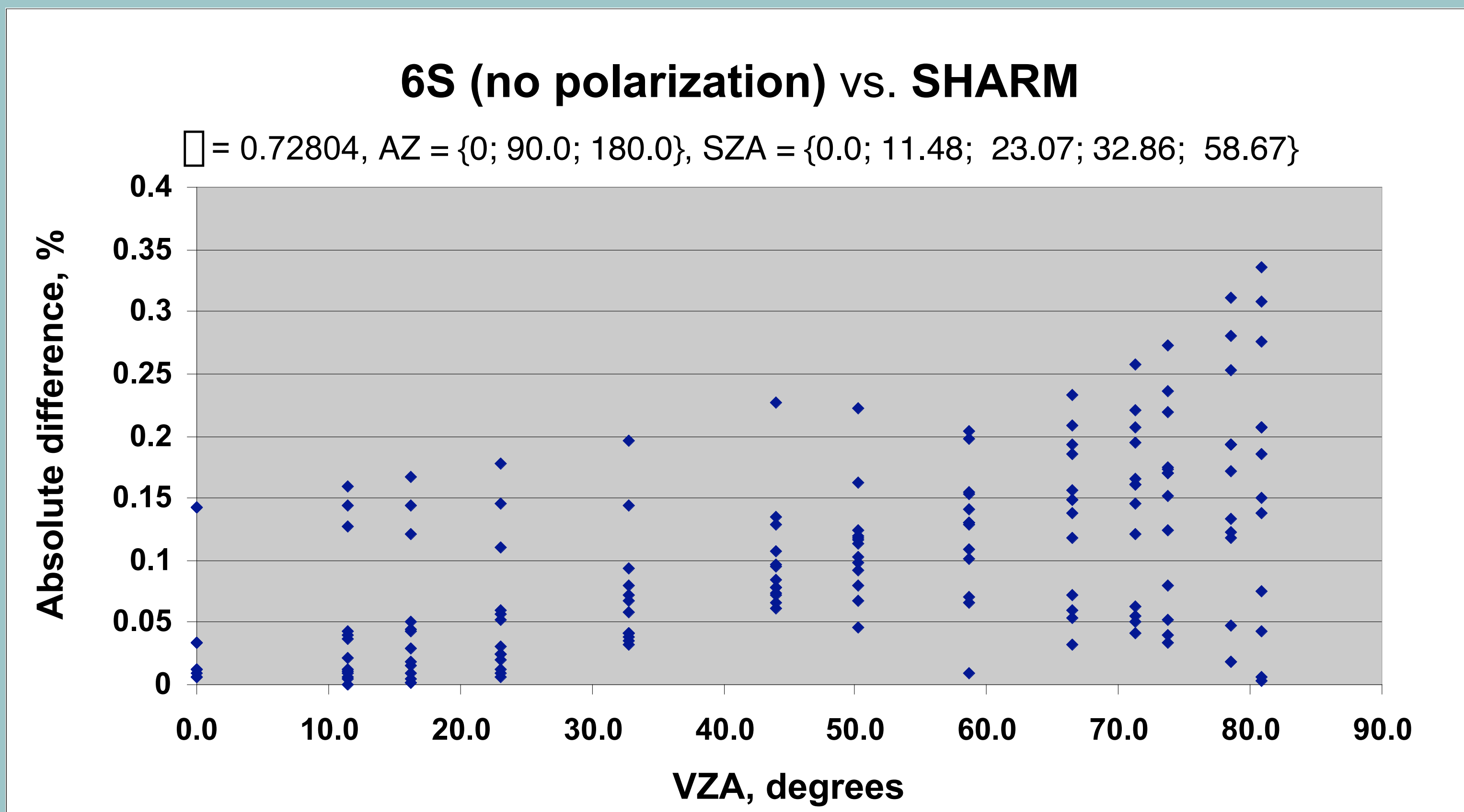
6S (no polarization) vs. **SHARM**

SZA = 23.07, □= 0.1, □ = 0.0									
VZA	AZ=0			AZ=90			AZ=180		
	6S no P	SHARM	Diff., %	6S no P	SHARM	Diff., %	6S no P	SHARM	Diff., %
0.00	0.037670	0.037716	0.12	0.037670	0.037716	0.12	0.037670	0.037716	0.12
16.26	0.041925	0.041975	0.12	0.037951	0.038001	0.13	0.034448	0.034498	0.14
43.95	0.052621	0.052691	0.13	0.041609	0.041679	0.17	0.034395	0.034467	0.21
66.42	0.075725	0.075864	0.18	0.058655	0.058791	0.23	0.052894	0.053033	0.26
78.46	0.119525	0.119793	0.22	0.097127	0.097389	[0.27]	0.097767	0.098037	[0.27]

SZA = 53.13, □= 0.5, □ = 0.0									
VZA	AZ=0			AZ=90			AZ=180		
	6S no P	SHARM	Diff., %	6S no P	SHARM	Diff., %	6S no P	SHARM	Diff., %
0.00	0.199325	0.199528	0.10	0.199325	0.199528	0.10	0.199325	0.199528	0.10
16.26	0.232722	0.232936	0.09	0.204205	0.204419	0.11	0.185162	0.185379	0.12
43.95	0.334549	0.334833	0.08	0.243129	0.243427	0.12	0.224300	0.224599	0.13
66.42	0.492756	0.493351	0.12	0.339829	0.340417	0.17	0.373486	0.374093	0.16
78.46	0.636885	0.638009	0.18	0.446680	0.447783	0.25	0.549265	0.550409	0.21

Scalar mode – a purely aerosol atmosphere

- **model**: 70% dust + 30% water-soluble
- **waveform**: _ = 0.694 _m
- **geometry**: a wide range of {VZA, SZA, AZ}
- **optical thickness**: □= {0.072804, 0.72804}



Vectorial mode – Monte Carlo

- **atmosphere**: purely molecular
- **optical thickness**: □= 0.35
- **geometry**: SZA = {0.0; 23.0; 57.0} + {VZA, AZ}
- **ground surface**: black soil

6S (with polarization) vs. **Monte Carlo (**1 billion photons**)**

Difference, %								
SZA = 23.0, □= 0.35, □ = 0.0								
VZA / AZ	**0 - 22.5**	**22.5 - 45.0**	**45.0 - 67.5**	**67.5 - 90.0**	**90.0 - 112.5**	**112.5 - 135.0**	**135.0 - 157.5**	**157.5 - 180.0**
0 - 15.0	-0.02	-0.04	0.06	0.08	0.06	0.00	0.17	0.14
15.0 - 21.4	0.25	0.16	0.20	-0.13	0.20	0.24	0.21	0.09
21.4 - 26.6	0.15	0.01	0.03	0.17	0.25	0.09	0.13	0.06
26.6 - 31.1	0.41	0.20	0.21	0.13	0.01	0.26	0.02	0.19
31.1 - 35.3	0.02	0.22	0.36	-0.03	0.30	0.24	0.24	0.11
35.3 - 39.2	-0.06	0.08	0.37	0.09	0.23	0.20	0.12	0.09
39.2 - 43.1	0.15	-0.02	0.11	0.13	0.15	0.17	0.19	0.13
43.1 - 46.9	-0.04	0.11	0.20	-0.04	0.17	0.07	-0.01	0.22
46.9 - 50.8	0.22	0.18	0.14	0.15	0.19	0.14	0.07	0.14
50.8 - 54.7	0.25	-0.12	0.15	0.15	0.12	0.23	0.18	0.26
54.7 - 58.9	0.08	0.01	0.09	0.14	0.16	0.17	0.13	0.03
58.9 - 63.4	0.00	0.11	0.02	0.17	0.16	0.12	0.18	0.01
63.4 - 68.6	-0.15	-0.04	0.02	0.12	-0.01	0.13	-0.13	0.04
68.6 - 75.0	-0.14	-0.17	-0.25	-0.26	-0.07	-0.19	[-0.44]	-0.42
Nadir viewing	0.14							

Vectorial mode – Coulson's tabulated values

- **atmosphere**: purely molecular
- **geometry**: a wide range of {SZA, VZA, AZ}
- **optical thickness**: □= 0.1 (_ ≈ 0.53 _m) and □= 0.5 (_ ≈ 0.36 _m)
- **ground reflectance**: □ = 0.0 (black soil) and □ = 0.25 (Lambertian)

6S (with polarization) vs. **Coulson's tabulated values**

SZA = 23.07, □= 0.1, □ = 0.0									
VZA	**AZ=0**			**AZ=90**			**AZ=180**		
	Coulson	**6S with P**	**Diff., %**	**Coulson**	**6S with P**	**Diff., %**	**Coulson**	**6S with P**	**Diff., %**
0.00	0.039196	0.039093	**0.26**	0.039196	0.039093	**0.26**	0.039196	0.039093	**0.26**
16.26	0.043815	0.043702	**0.26**	0.039348	0.039239	**0.28**	0.035380	0.035277	**0.29**
43.95	0.054435	0.054291	**0.26**	0.042130	0.042002	**0.30**	0.033870	0.033754	**0.34**
66.42	0.076446	0.076244	**0.26**	0.057543	0.057365	**0.31**	0.050685	0.050520	**0.33**
78.46	0.118478	0.118176	**0.26**	0.093935	0.093667	**0.29**	0.093935	0.093667	**0.29**

SZA = 53.13, □= 0.5, □ = 0.0									
VZA	**AZ=0**			**AZ=90**			**AZ=180**		
	Coulson	**6S with P**	**Diff., %**	**Coulson**	**6S with P**	**Diff., %**	**Coulson**	**6S with P**	**Diff., %**
0.00	0.196483	0.196433	**0.03**	0.196483	0.196433	**0.03**	0.196483	0.196433	**0.03**
16.26	0.241067	0.240919	**0.06**	0.201067	0.201020	**0.02**	0.173083	0.173071	**0.01**
43.95	0.362167	0.362026	**0.04**	0.237950	0.237923	**0.01**	0.205133	0.205165	**-0.02**
66.42	0.532033	0.531709	**0.06**	0.330983	0.330847	**0.04**	0.363483	0.363403	**0.02**
78.46	0.676767	0.676159	**0.09**	0.434850	0.434524	**0.07**	0.555033	0.554672	**0.07**

Validation of the new version of 6S - Conclusions

- **The new vectorial version of 6S**, which accounts for **radiation polarization**, has demonstrated good agreement with **Monte Carlo** and Coulson's tabulated values for a wide range of geometrical and atmospheric conditions. The agreement is better than 0.5% for **Monte Carlo** and 0.35% for Coulson's.

- **The new vectorial version of 6S**, used in the scalar mode, has demonstrated good agreement with the scalar code **SHARM**: better than 0.3% for a purely molecular atmosphere and better than 0.35% for a purely aerosol atmosphere.

- The observed difference is not of concern, as it is much less than the 2% accuracy of raw MODIS top-of-atmosphere reflectance data.

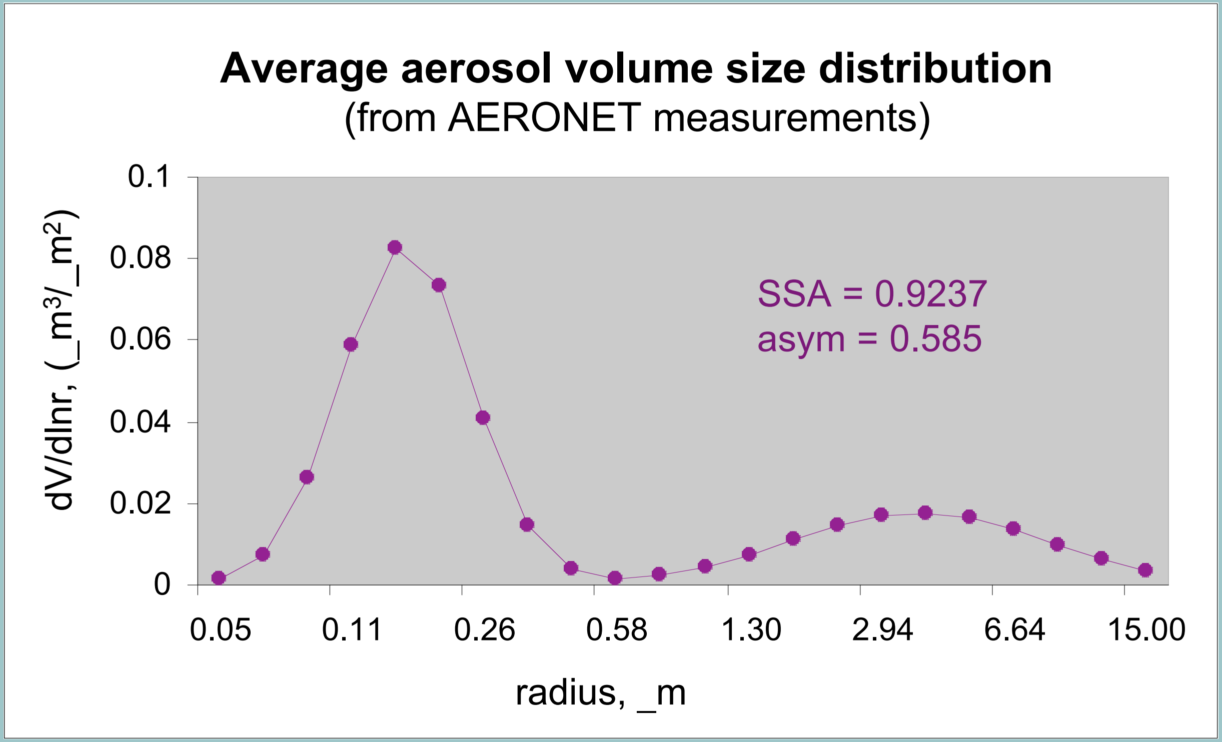
Effects of polarization – a purely molecular atmosphere

The scalar code SHARM vs. Coulson's tabulated values

SZA = 0.0, □= 0.5, ? = 0.36 ?m									
VZA	AZ=0			AZ=90			AZ=180		
	Coulson	SHARM	Diff., %	Coulson	SHARM	Diff., %	Coulson	SHARM	Diff., %
0.00	0.188490	0.171847	8.83						
16.26	0.187900	0.173096	7.88						
43.95	0.190130	0.186916	1.69						
66.42	0.219760	0.234279	-6.61						
78.46	0.264930	0.291785	-10.14						
SZA = 23.07, □= 0.1, ? = 0.53 ?m									
VZA	AZ=0			AZ=90			AZ=180		
	Coulson	SHARM	Diff., %	Coulson	SHARM	Diff., %	Coulson	SHARM	Diff., %
0.00	0.039196	0.037716	3.77	0.039196	0.037716	3.77	0.039196	0.037716	3.77
16.26	0.043815	0.041975	4.20	0.039348	0.038001	3.42	0.035380	0.034498	2.49
43.95	0.054435	0.052691	3.20	0.042130	0.041679	1.07	0.033870	0.034467	-1.76
66.42	0.076446	0.075864	0.76	0.057543	0.058791	-2.17	0.050685	0.053033	-4.63
78.46	0.118478	0.119793	-1.11	0.093935	0.097389	-3.68	0.093935	0.098037	-4.37
SZA = 53.13, □= 0.5, ? = 0.36 ?m									
VZA	AZ=0			AZ=90			AZ=180		
	Coulson	SHARM	Diff., %	Coulson	SHARM	Diff., %	Coulson	SHARM	Diff., %
0.00	0.196483	0.199528	-1.55	0.196483	0.199528	-1.55	0.196483	0.199528	-1.55
16.26	0.241067	0.232936	3.37	0.201067	0.204419	-1.67	0.173083	0.185379	-7.10
43.95	0.362167	0.334833	7.55	0.237950	0.243427	-2.30	0.205133	0.224599	-9.49
66.42	0.532033	0.493351	7.27	0.330983	0.340417	-2.85	0.363483	0.374093	-2.92
78.46	0.676767	0.638009	5.73	0.434850	0.447783	-2.97	0.555033	0.550409	0.83

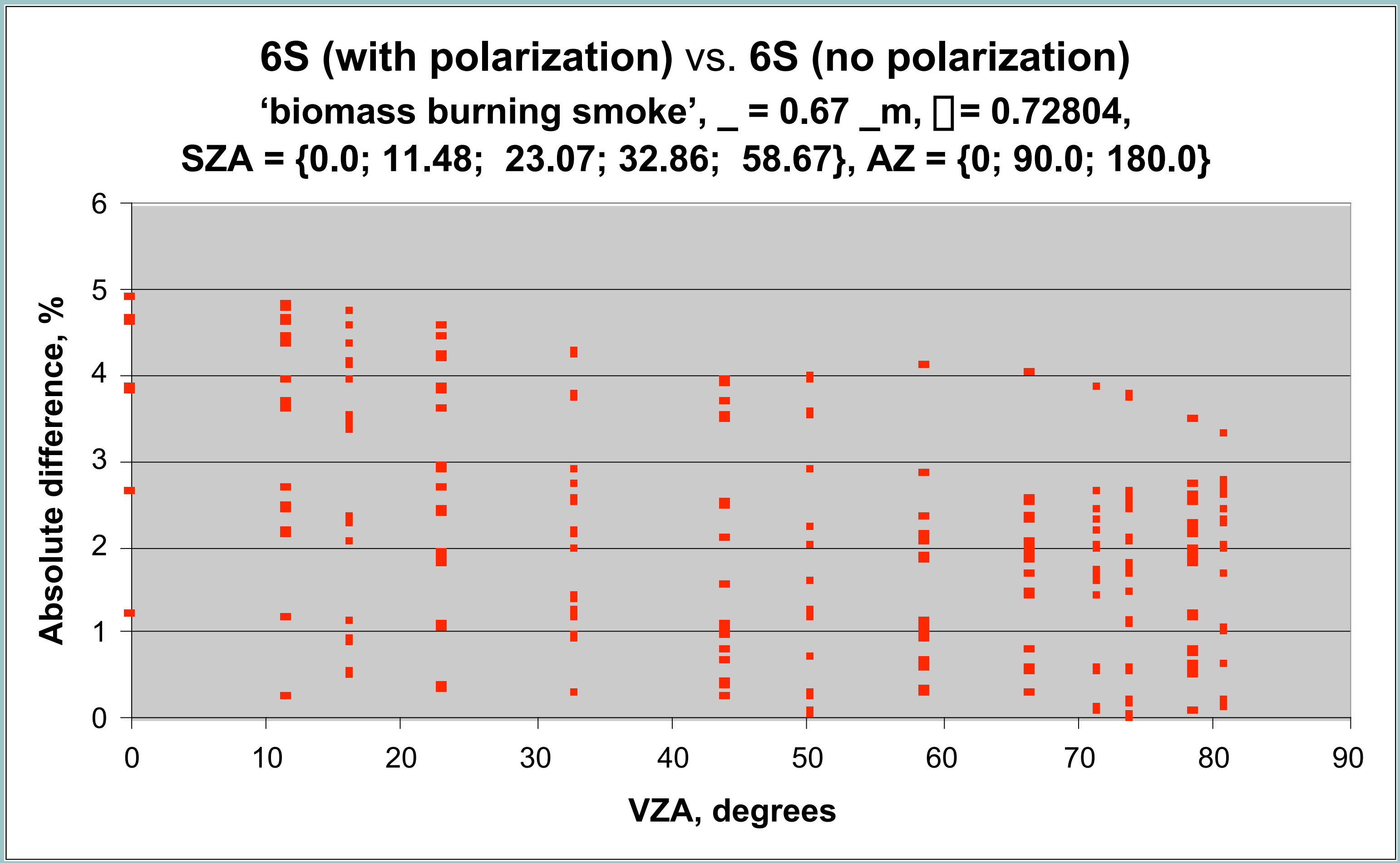
Effects of polarization – a purely aerosol atmosphere (1)

The scalar **(no polarization)** and the vectorial **(with polarization)** versions of **6S** have been compared for a '**biomass burning smoke**' aerosol model. This model is a typical pattern produced by forest fires over the Amazonian tropical forest region in Brazil.



Reference - *O. Dubovik et al., J. Atmos. Sci., 59, pp.590-608, 1996*

Effects of polarization – a purely aerosol atmosphere (2)



Retrieval of ocean surface reflectance (1)

MODIS AQUA data, collected over the Hawaii islands, have been corrected using the new version of the **6S** code **(with polarization)** and AERONET measurements collected at Lanai island. The corrected data were with surface reflectances measured by MOBY (the Marine Optical Buoy System) just above the ocean surface.

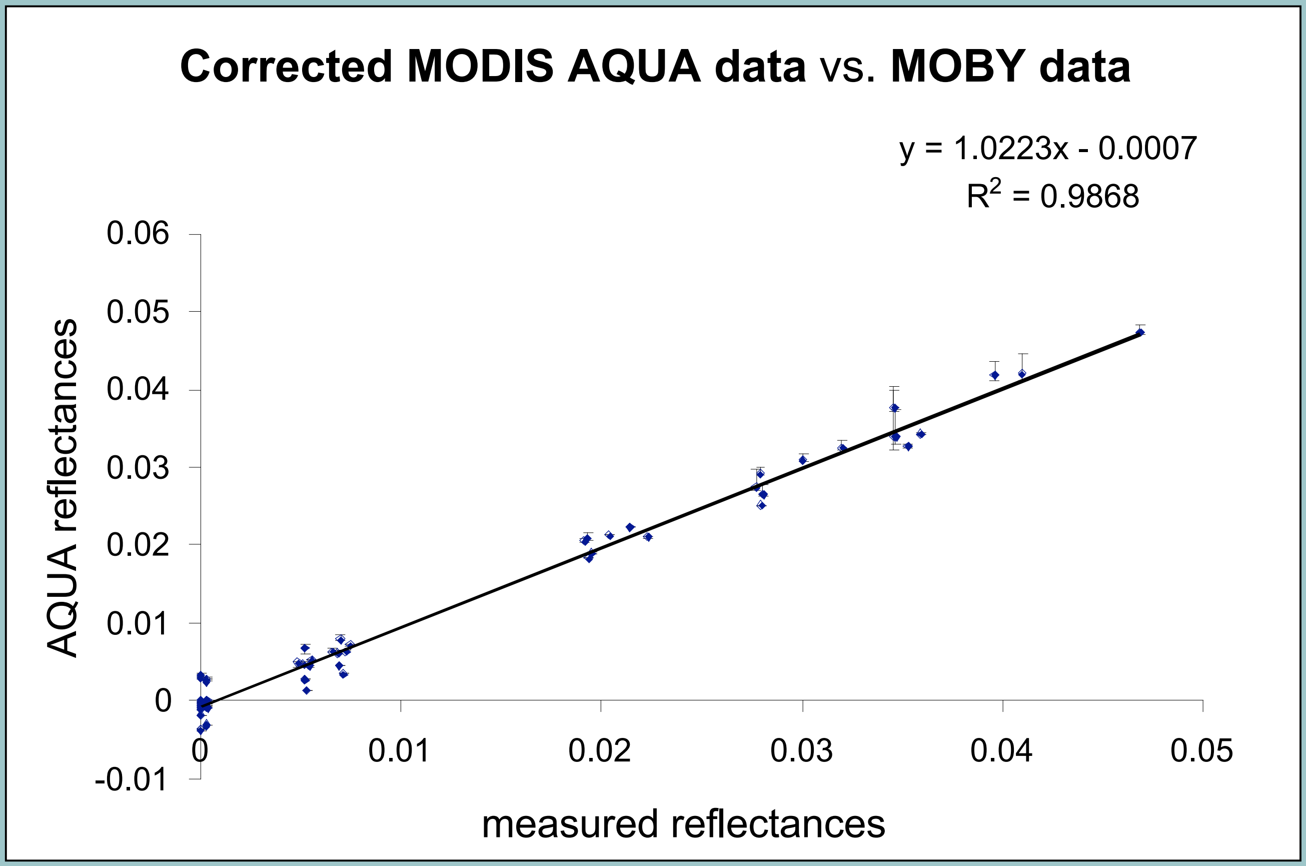
The MOBY data

dates = {January 2, February 1, February 10, September 3, September 19, October 6, October 22; 2003}

_ = {412; 443; 490; 530; 550; 667; 678} nm.

Retrieval of ocean surface reflectance (2)

The agreement between the corrected AQUA and the MOBY surface reflectances was 0.001 to 0.002 for the 400-550 nm region.



Effects of polarization - Conclusions

- Ignoring the effects of **radiation polarization** leads to large errors in calculated top-of-atmosphere reflectances. The maximum relative error is more than 10% for a purely molecular atmosphere and is up to 5% for a purely aerosol atmosphere.

- Account for **radiation polarization** is extremely important for atmospheric correction of remotely sensed data, especially those measured over dark targets, such as ocean surface or dark dense vegetation canopies.

Future plans

- Further ‘theoretical’ validation of the new version of 6S
  - comparison with Monte Carlo for aerosol and mixed atmospheres
  - inclusion of anisotropic surfaces
  - refinement of the code

- Use of the new version of 6S for the inversion of AERONET measurements (depends on funding). Collaboration with O. Dubovik

- Further ‘experimental’ validation of the new version of 6S
  - retrieval of ocean surface reflectance and comparison with MOBY data
  - comparison with ground-measured surface reflectances

- Calculation of new Look-Up Tables for the atmospheric correction algorithm