All-sky model for erythemal ultraviolet radiation in Switzerland

L. Vuilleumier, D. Walker

Federal Office of Meteorology and Climatology MeteoSwiss

COST 726 Final Workshop

Warsaw, Poland

13-14 May 2009

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss

All-sky model for erythemal ultraviolet radiation in Switzerland

PhD thesis Daniel Walker

- Introduction
- Clear-sky radiation transfer
- Cloud modification factor for UV and SW
- Interpreting CMF_{UV} vs. CMF_{SW}
- Validation
- Conclusions

Motivations

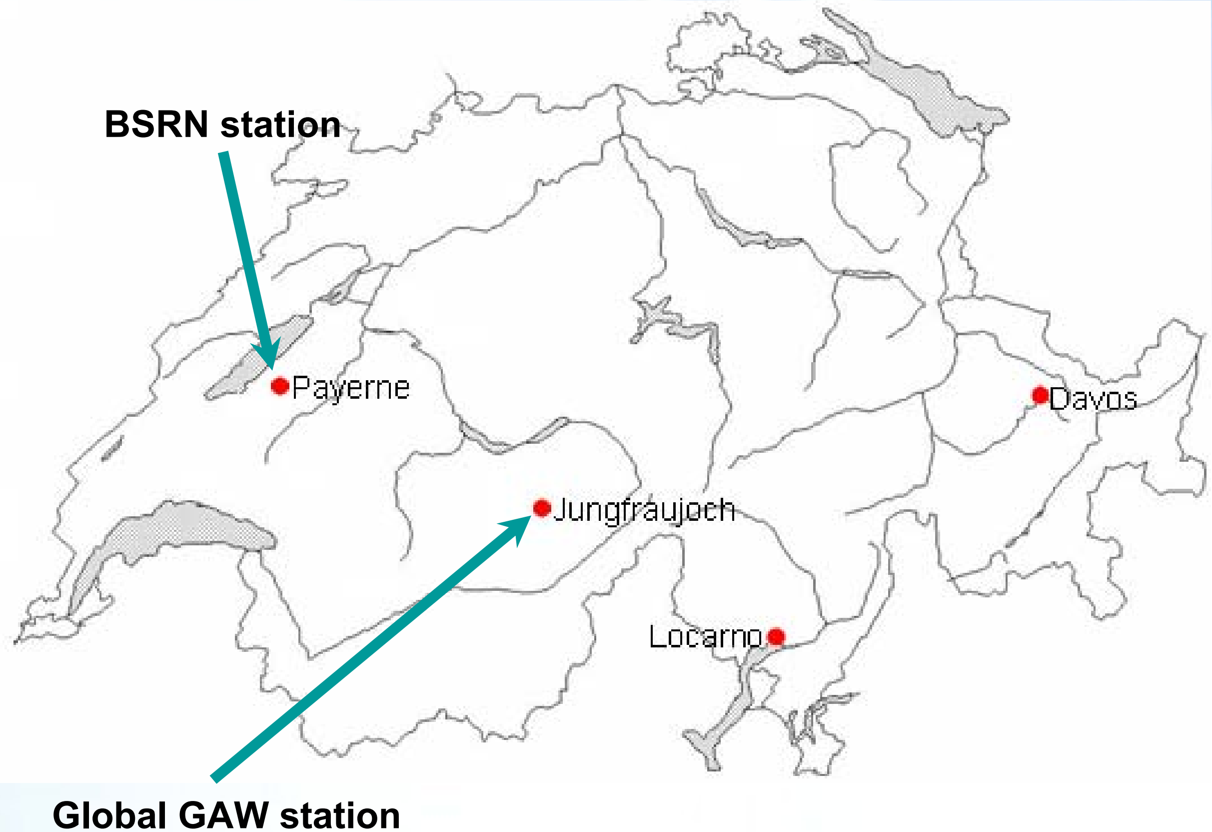
- Usual: UV radiation data desired by multiplicity of “clients” in Switzerland, but data are scarce and series are limited
- Technique of UV reconstruction based on clear-sky modeling and empirical cloud modification factor derived from SW measurement are efficient, but Swiss topography is complex and diversified (from lowland to high mountains)

Is it possible to generalize empirical determination of cloud effect from SW?

Such generalization would allow reconstructing UV at over 100 Swiss sites

Data

- UV radiation data is available as UV broadband erythemally weighted irradiance at 4 stations in Switzerland
- UV radiation data is available since the mid-1990's
- SW radiation data is available as high accuracy data at the same 4 stations and at standard accuracy at a large number of stations (between 70 and 130)



Clear-sky modeling validation

clear-sky UV

all stations:	RMS error:	<	5.5 mW/m^2	
	RMS:		**4.9 - 7.2%**	(instrument: ~7.5-9.5%)
	Corr:	>	0.99	
	n:		356 - 1931	
	$\theta < 40°$		3.5 - 5.0%	

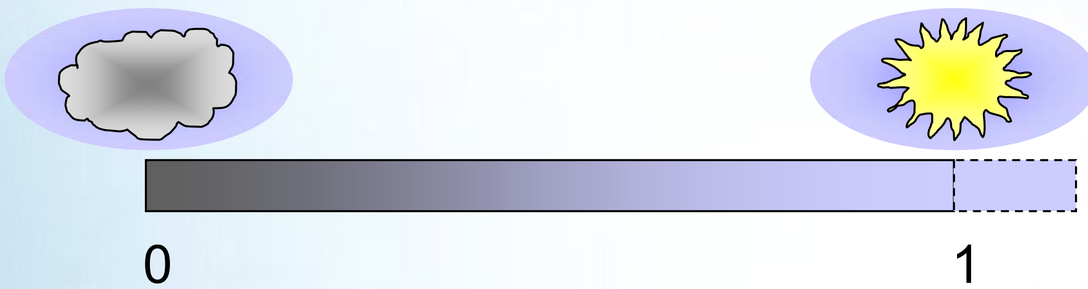
clear-sky SW

all stations:	RMS error:	<	20.8 W/m^2
	RMS:		**3.1 - 4.2%**
	Corr:	>	0.99
	n:		356 - 1931
	$\theta < 40°$		1.6 - 2.9%

How can cloud effect be assessed?

Cloud effect is assessed using an empirical cloud modification factor:

$$CMF = \frac{\text{irradiance (all sky)}}{\text{irradiance (clear sky)}} \qquad CMF_{UV} = \frac{UV_{obs}}{UV_{\text{modeled clearsky}}}$$



$$\frac{UV_{obs}}{UV_{clearsky}} = f\left(\frac{SW_{obs}}{SW_{clearsky}}\right) \longrightarrow UV_{allsky} = UV_{clearsky} * f\left(\frac{SW_{obs}}{SW_{clearsky}}\right)$$

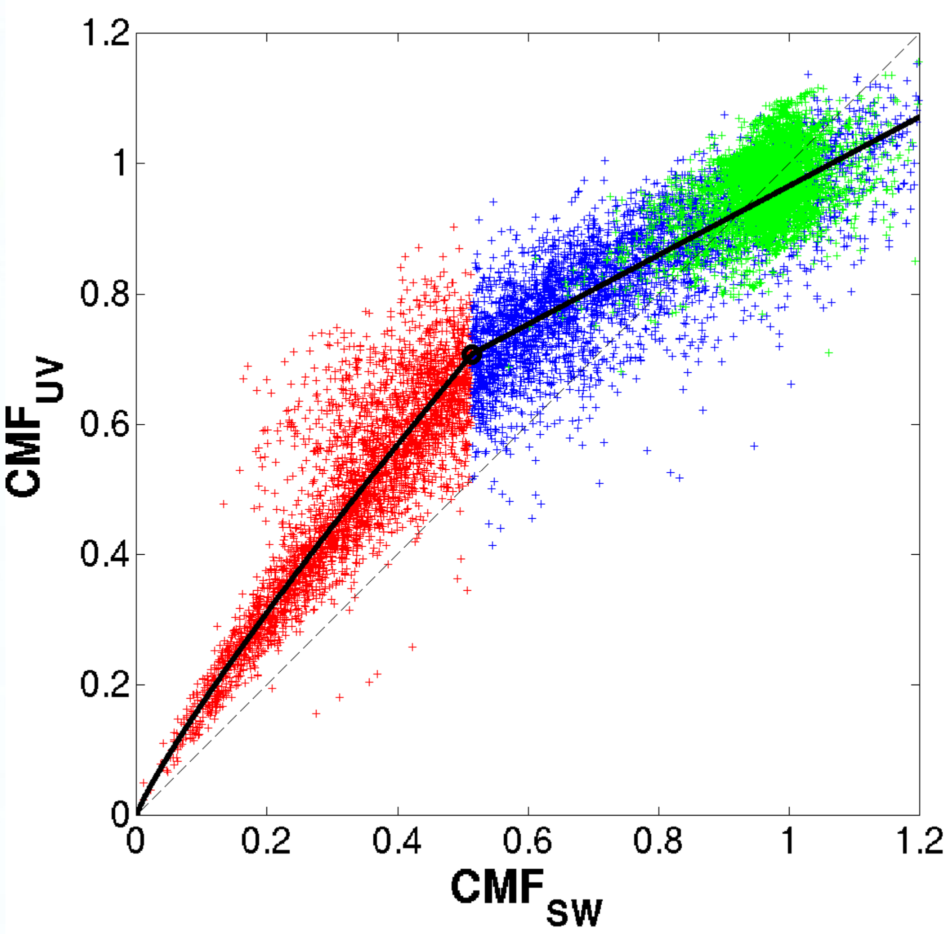
learning $\rightarrow f$ **application** $\rightarrow$ **$UV_{\text{all sky}}$**

UV and SW cloud modification factors

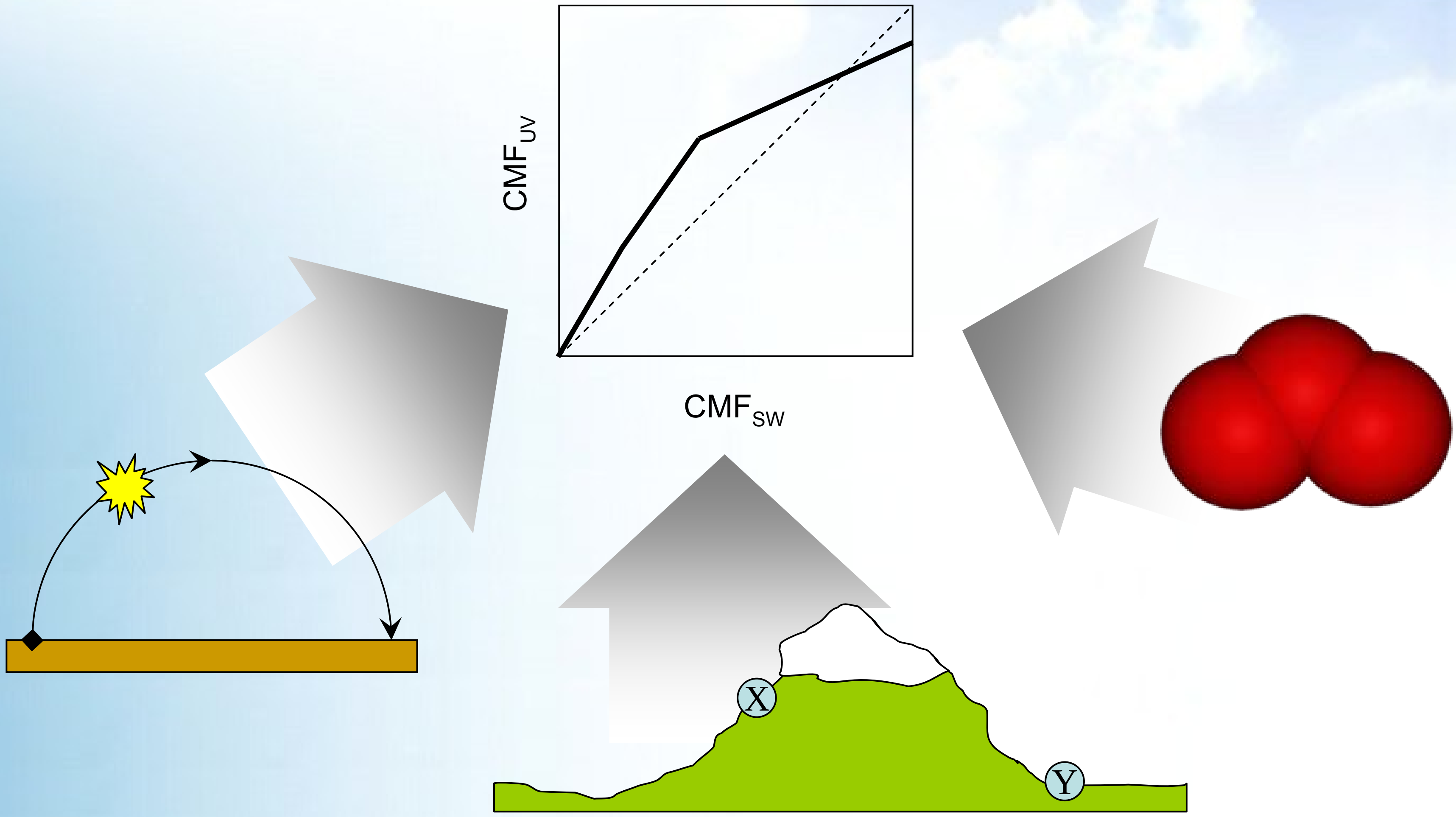
$$CMF_{UV} = f\,(CMF_{SW})$$

- separation in different clusters:
  - clear sky
  - weak attenuation
  - strong attenuation
- parameterized with two linear regressions (flexibility)
- excluding clear-sky
- lower regression (log)

f

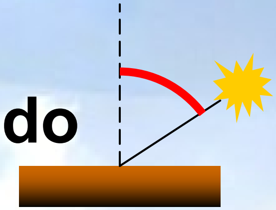


Factors influencing f

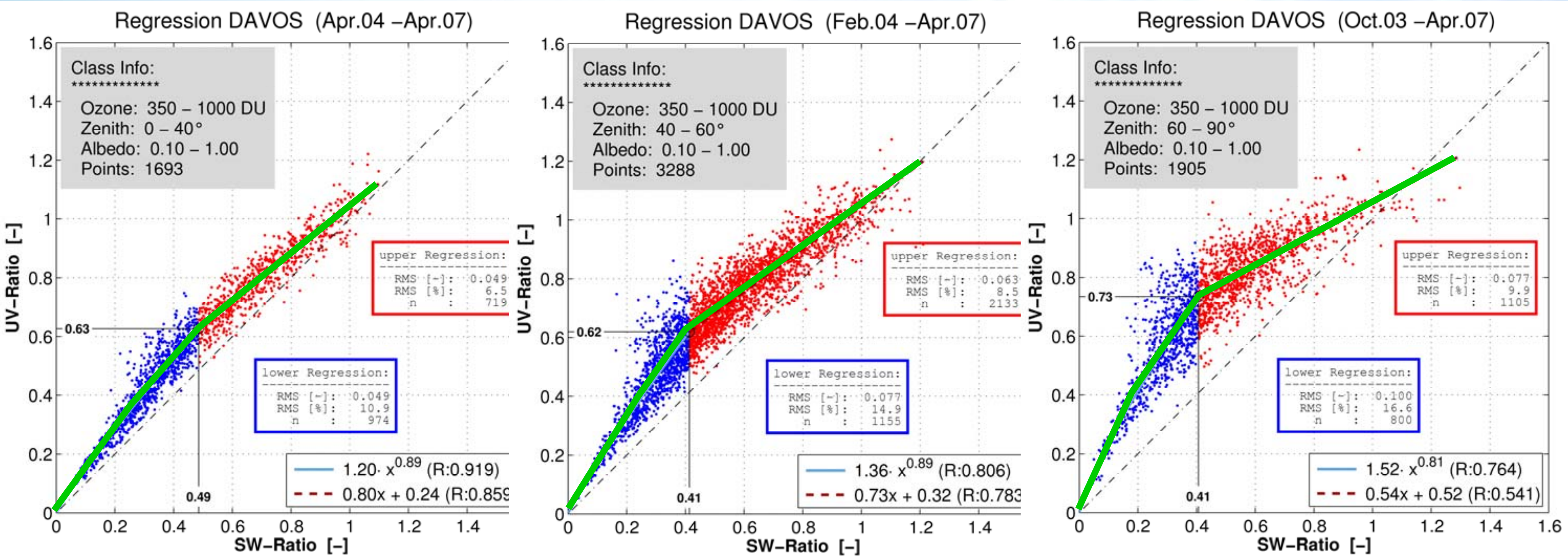


Factors influencing *f*



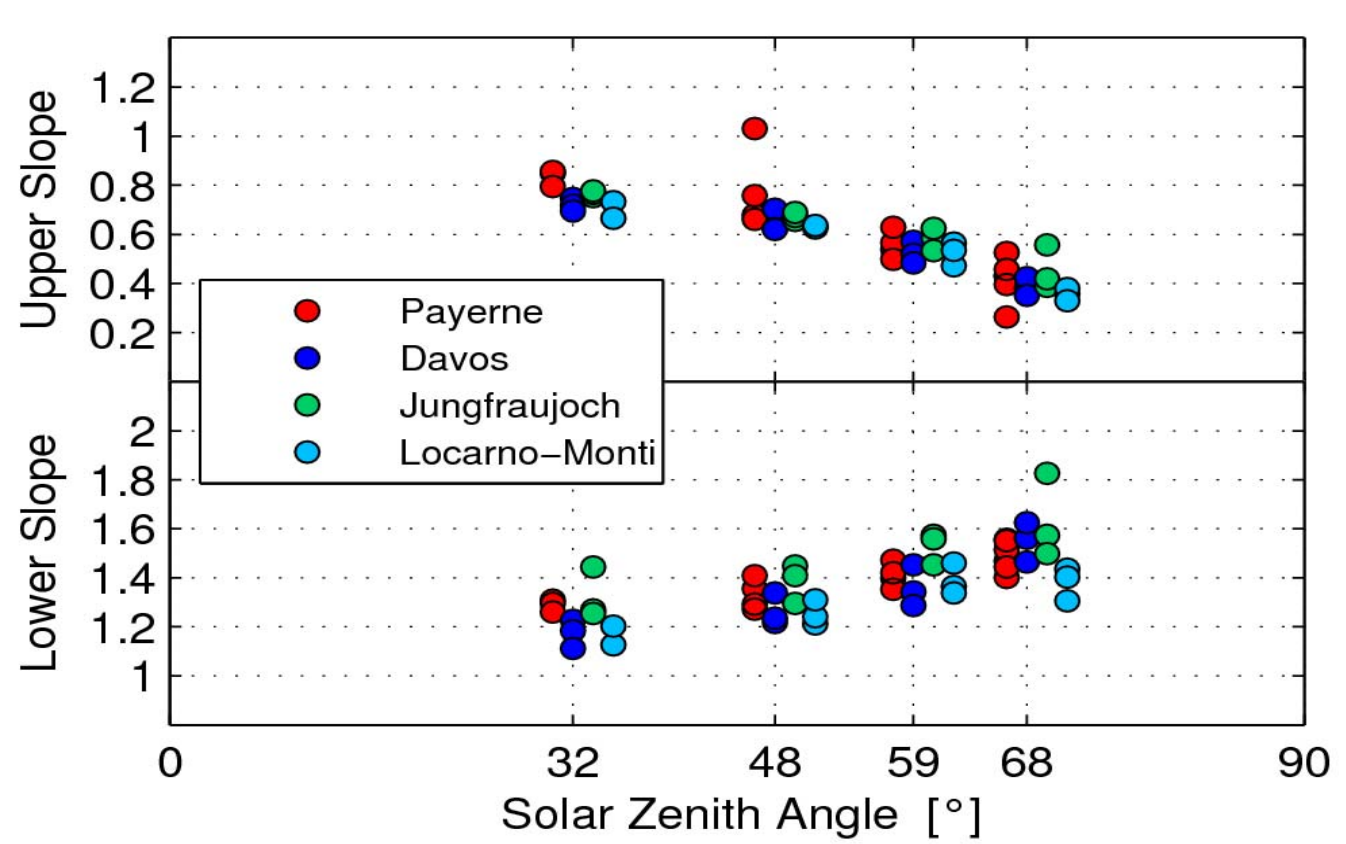


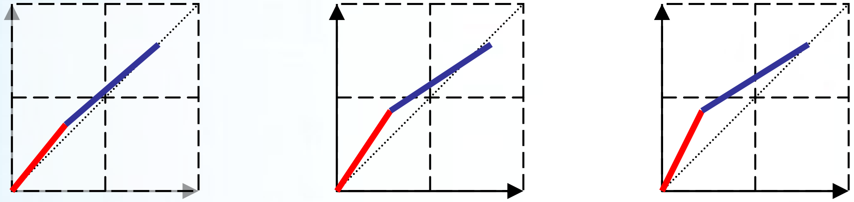
Dependency on: **ozone, zenith angle, albedo**



With increasing sza: - lower regression steeper
- upper regression flatter

Factors influencing *f*

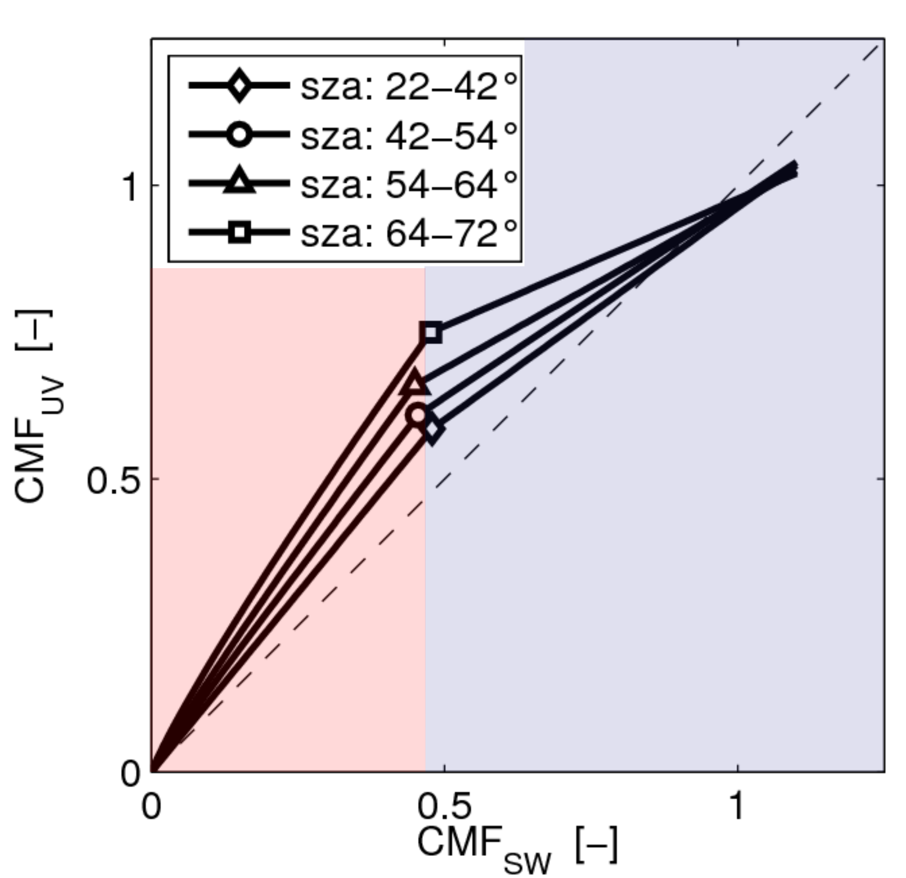




UV CMF empirical model

Did not find any other tested parameter yielding consistent and significant influence

→ UV CMF model:



Equation for estimating UV CMF

$$CMF_{UV} = \begin{cases} b_1(\theta) \cdot CMF_{SW}^{\;a_1(\theta)} \\ b_2(\theta) + a_2(\theta) \cdot CMF_{SW} \end{cases} \text{for} \quad CMF_{SW} \begin{cases} < CMF_{SW,break}(\theta) \\ \geq CMF_{SW,break}(\theta) \end{cases}$$

Interpreting CMF_{UV} vs. CMF_{SW}

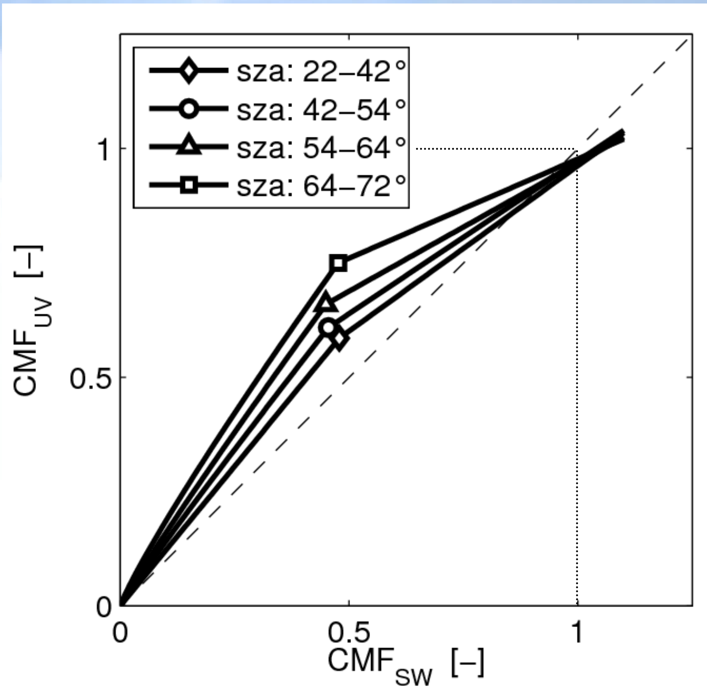
- CMF_{UV} vs. CMF_{SW} scatter plot almost always above 1:1 line

→ CMF_{UV} greater (closer to 1) than CMF_{SW}

→ Cloud effect weaker on UV than SW

- Rate of change (slope) of CMF_{UV} vs. CMF_{SW} greater than 1 for overcast situations

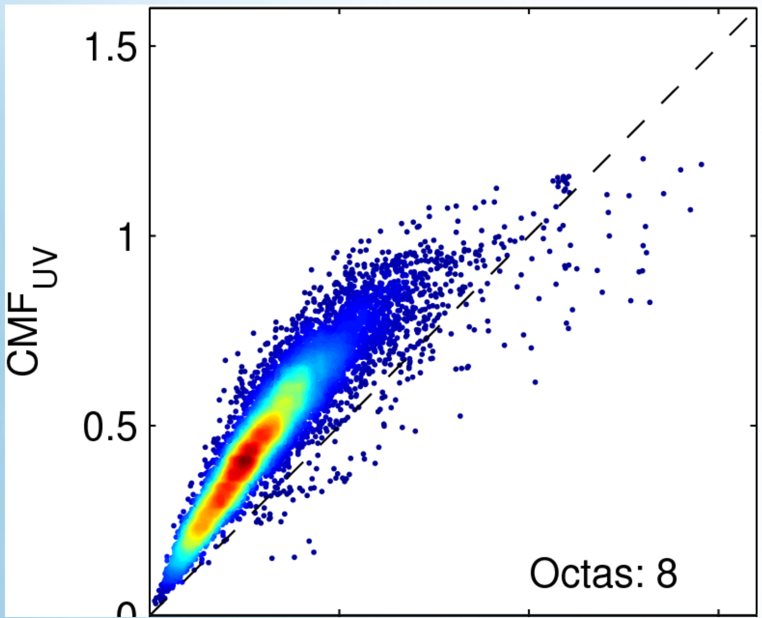
- Rate of change (slope) of CMF_{UV} vs. CMF_{SW} lower than 1 for scattered cloud situations

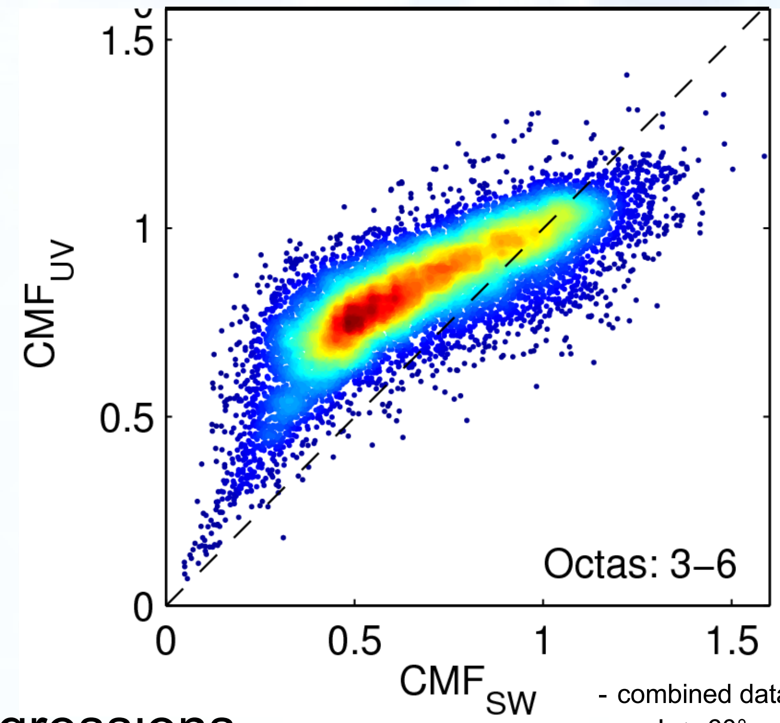


Interpreting CMF_{UV} vs. CMF_{SW}

Cloud cover (octa) determined from LW-based method

overcast and scattered clouds





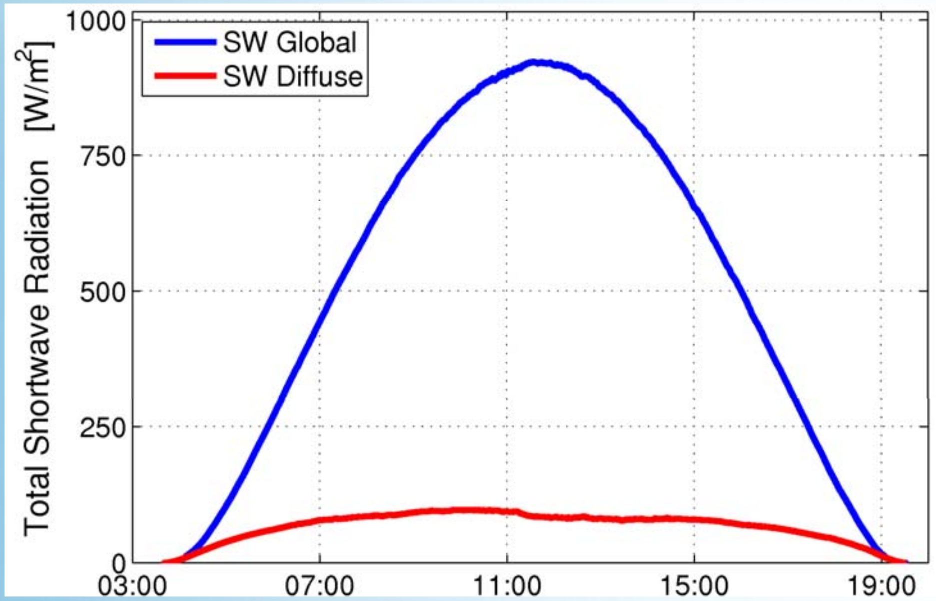
confirms: two separate regressions

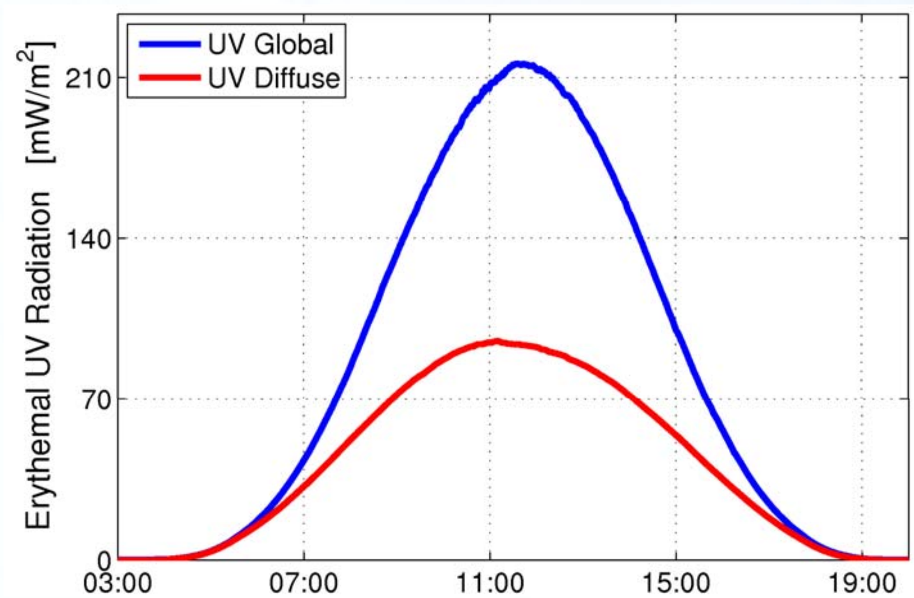
- combined data set of all stations
- sza's > 60°

octas derived from APCADA (Dürr and Philipona, 2004)

Differences in SW and UV radiation

Payerne, 2007-07-15





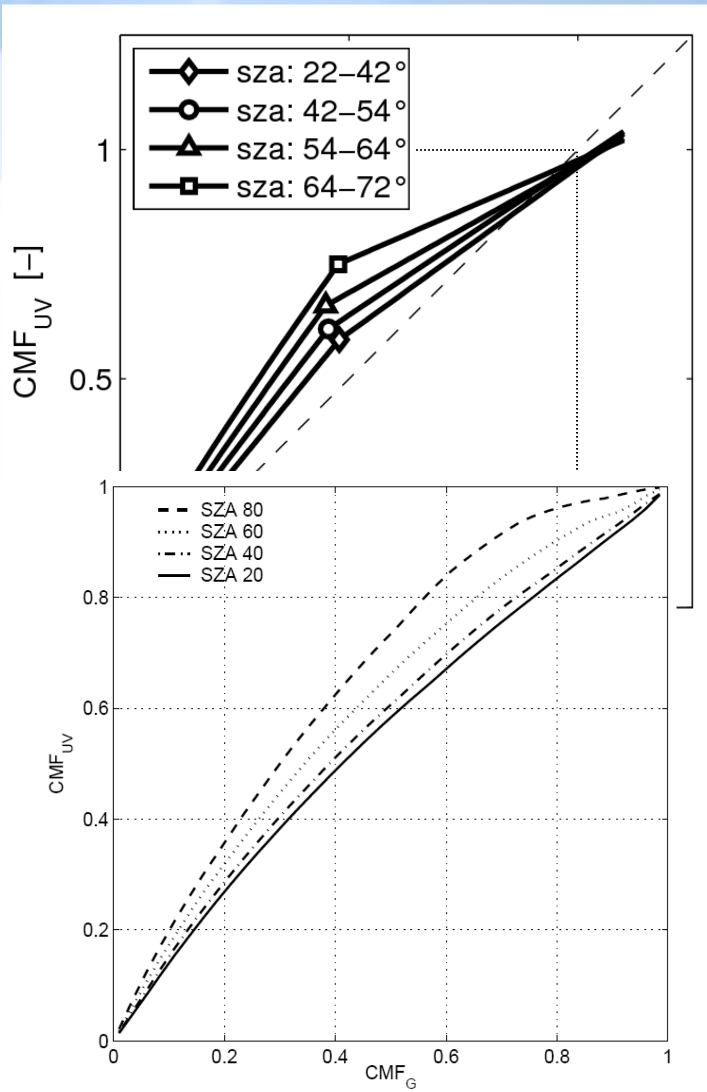
Interpreting CMF_{UV} vs. CMF_{SW}

- CMF_{UV} vs. CMF_{SW} scatter plot almost always above 1:1 line

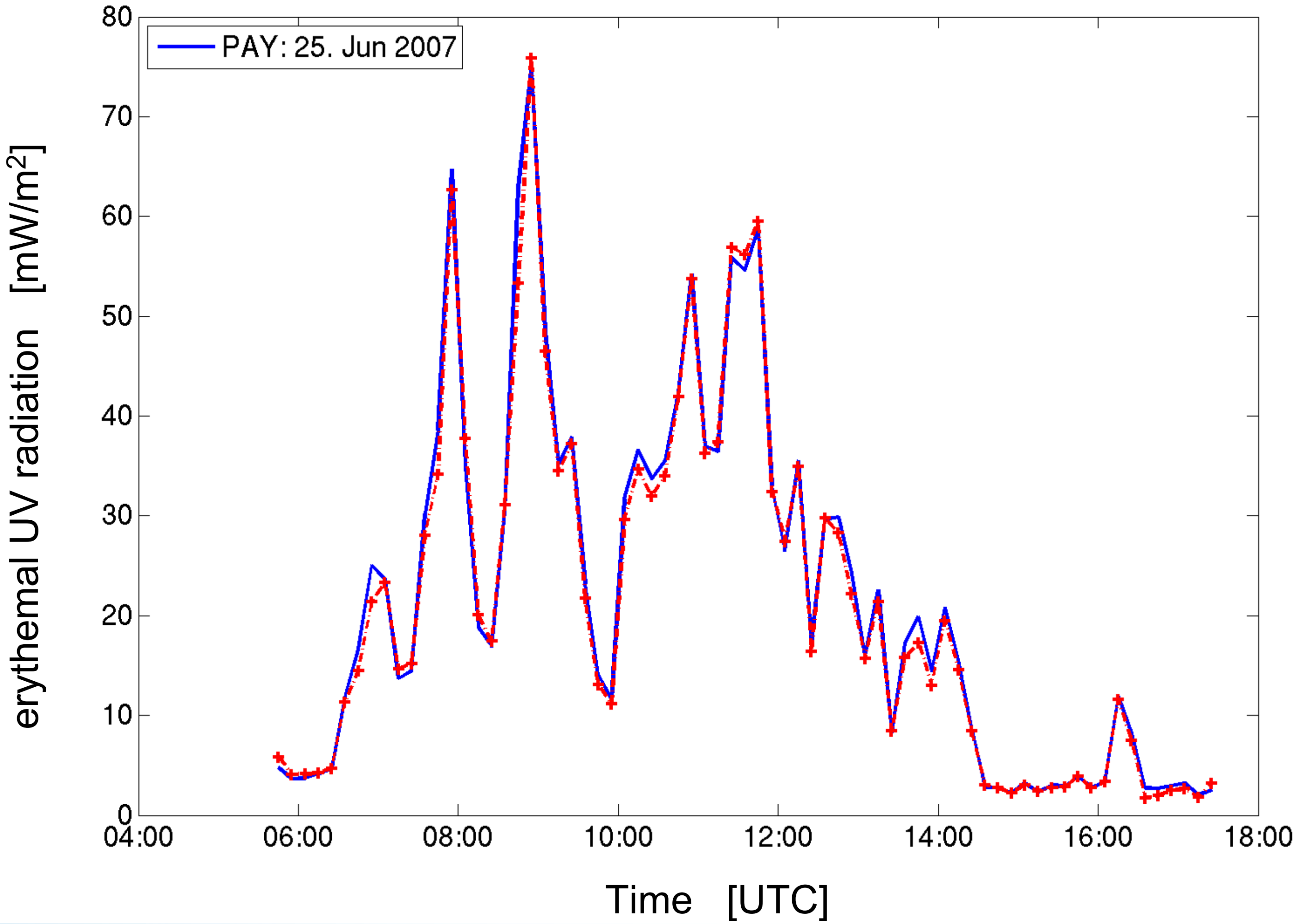
→ CMF_{UV} greater (closer to 1) than CMF_{SW}

→ Cloud effect weaker on UV than SW

- Rate of change (slope) of CMF_{UV} vs. CMF_{SW} greater than 1 for overcast situations (diffuse radiation is primary actor of change)
- Rate of change (slope) of CMF_{UV} vs. CMF_{SW} lower than 1 for scattered cloud situations (direct radiation is primary actor of change)



Validation: short term variability



Validation: overall agreement

- estimated vs. observed erythemal UV (~ a year data)
- based on 10 minutes time-resolution

	RMS		Bias	Corr	n
	mW/m^2		mW/m^2		
Payerne	4.5	10.8 %	-0.3	0.989	15790
Davos	5.6	9.3%	+1.6	0.991	17165
Locarno - Monti	6.5	10.6%	-3.1	0.991	13288
Jungfraujoch	7.1	11.9%	-1.6	0.988	8489

- for daily doses, the RMS errors reduce to 5.1-8.3%

Conclusions

- Cloud effect in UV can be successfully deduced from cloud effect in SW
- This allows deducing UV everywhere good quality SW data are monitored
  - Potential for producing estimated UV with wide spatial coverage
  - Potential for studying evolution of UV in the past
- Observed dependence of UV CMF on SW CMF can be understood from our knowledge of radiation transfer
- Advances in the understanding of cloud effect on SW can be safely applied to UV domain, taking into account observed relationship between CMF UV and CMF SW

Thank you

Questions? / Comments!

what do we know

Radiative Transfer Modeling and Theory say:

stronger cloud effect on SW than on UV,
which is amplified for large SZAs

Responsible are mainly two mechanisms:

- upward reflected radiation is back-scattered downward
  > this effect is stronger for shorter wavelengths

- different transmittance for diffuse and global radiation, which is depending on SZA.
  > diffuse component more important for shorter wavelengths

Bernhard et al. 2004,
Lindfors and Arola 2008
den Outer et al. 2005

Discussion

- developed UV reconstruction method
  - estimating UV back to early 1980s
  - 4 locations in Switzerland with different climate conditions
  - a high level of generalization is reached

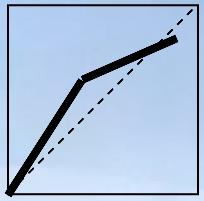
- method is based on:
  - comparison of cloud effects in the UV and SW radiation
  - using two separate linear regressions differentiating between mostly overcast and scattered cloud conditions

10'

- modeling clear-sky UV: 3.0 - 5.5 mW/m^2 (4.9 - 7.2%) RMS

  all-sky UV: 4.5 - 7.1 mW/m^2 (9.3 - 11.9%)

Discussion

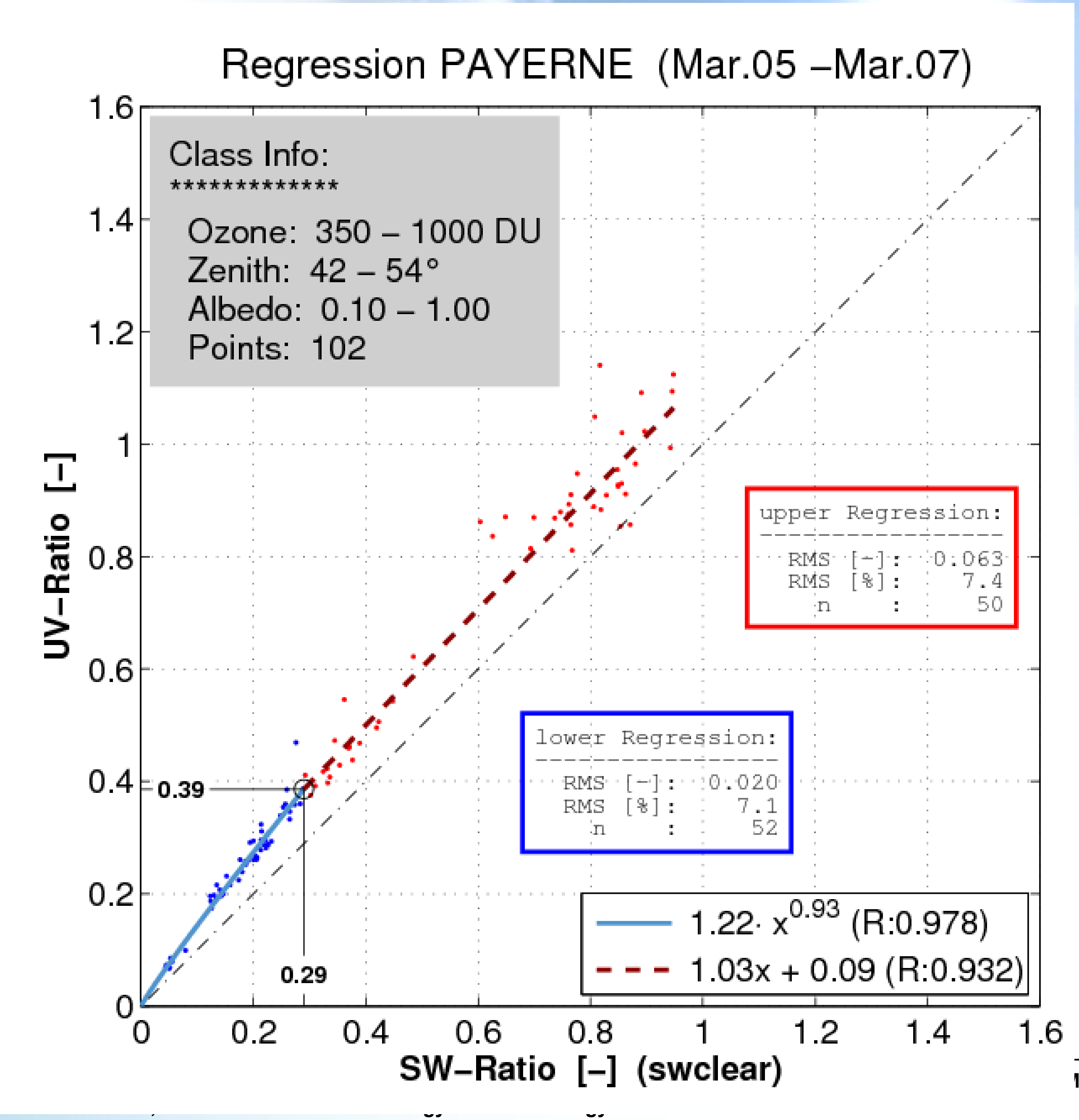


- Investigation of Cloud Effects
  - observed smaller cloud effect in UV radiation
    - for overcast conditions: CMF_{UV} amplification > 1
    - for scattered clouds (3-6): CMF_{UV} amplification < 1
  - differences in Cloud Effects
    - largest around CMF_{SW} 0.4 - 0.5
    - more pronounced for large SZAs
  - differences due to:
    - irradiance distribution diffuse/direct at top of cloud
    - upward reflection and back-scattering
  - in agreement with modeling studies and theory

Outlook

next steps:

- **Trend analysis** on reconstructed time-series
  - non-parametric Mann-Kendall tests
- assessing **spatial variability** by derivation of UV maps
  - currently in discussions with "satellite-group" at MCH
  - using Meteosat information
- searching application as **now-casting** tool for UV radiation at more than 70 stations in Switzerland



Regression PAYERNE (Mar.05 –Mar.07)
Class Info:
****
Ozone: 350 – 1000 DU
Zenith: 42 – 54°
Albedo: 0.10 – 1.00
Points: 102
upper Regression:
RMS [-]: 0.063
RMS [%]: 7.4
n : 50
lower Regression:
RMS [-]: 0.020
RMS [%]: 7.1
n : 52
1.22· x^0.93 (R:0.978)
1.03x + 0.09 (R:0.932)
0.39
0.29
UV–Ratio [–]
SW–Ratio [–] (swclear)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6

what do we know

1. transmission of clouds decrease with increasing SZAs
2. additional source for UV radiation due to upward reflection and stronger back-scattering (compared to SW)
3. direct component traverses clouds more easily for small SZAs but is "weaker" for larger SZAs
4. better transmission in UV for large SZA due to more important diffuse component (compared to global radiation)
5. direct component traverses clouds more easily for small SZAs
6. effect of absorption of near-IR only on SW

---

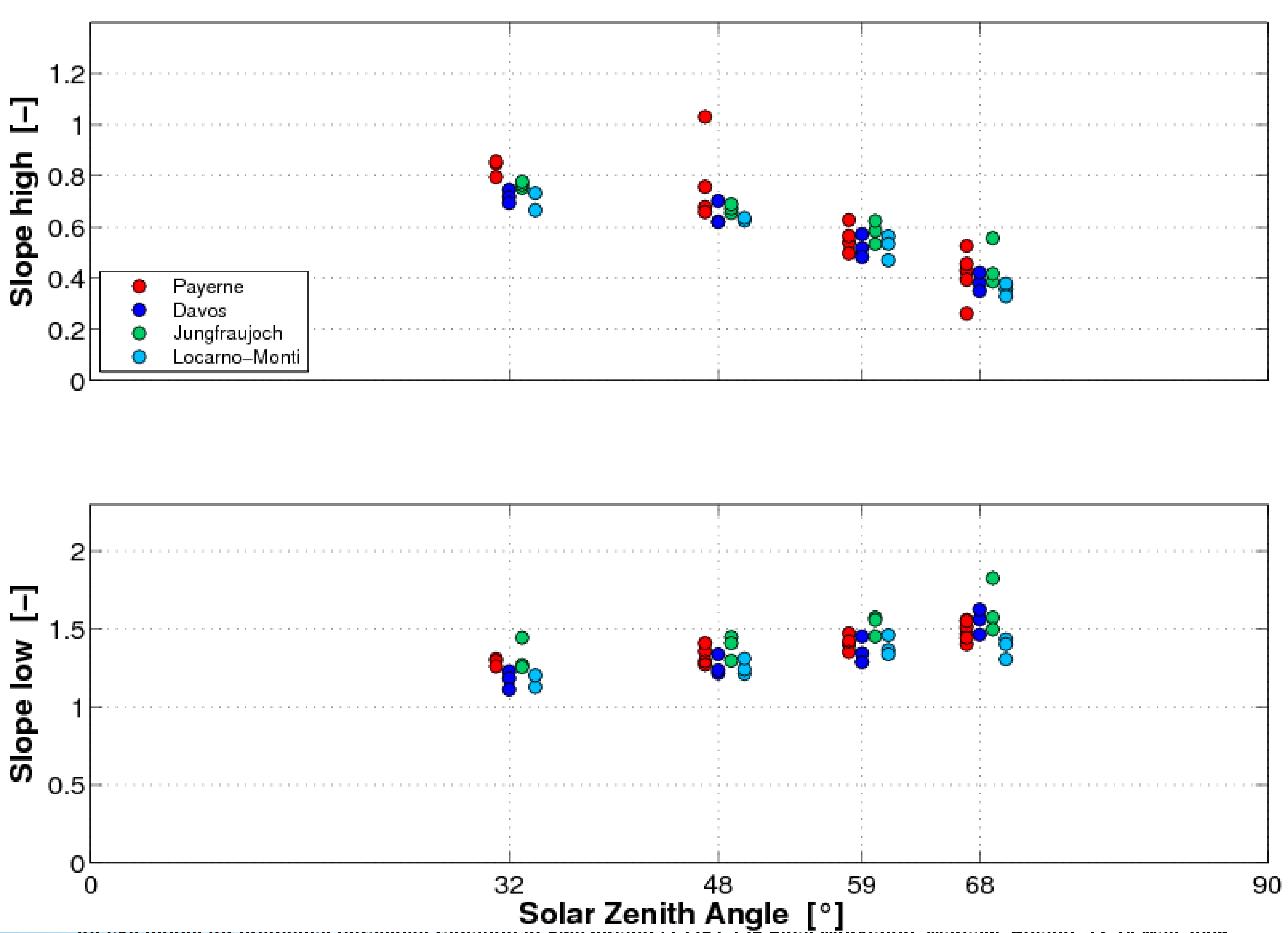
total: **stronger cloud effect on SW than on UV, which is amplified for large SZAs**

Bernhard et al. 2004,
Lindfors and Arola 2008
den Outer et al. 2005

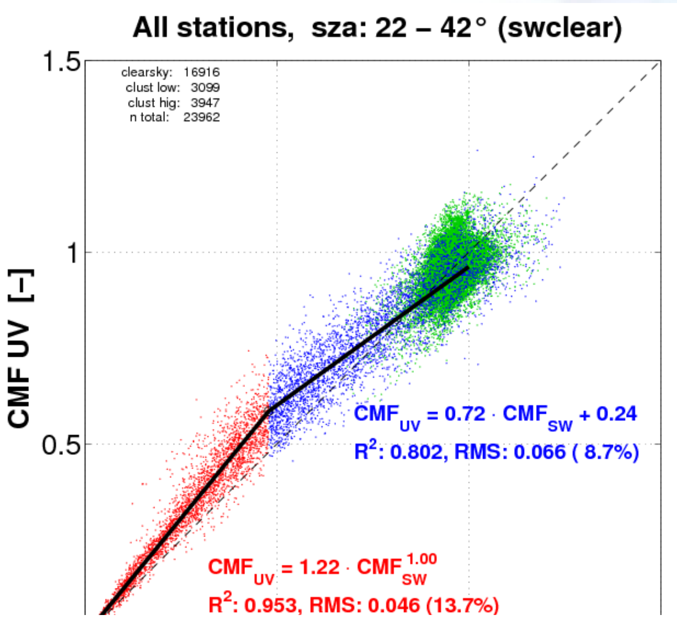
clearsky validation SW

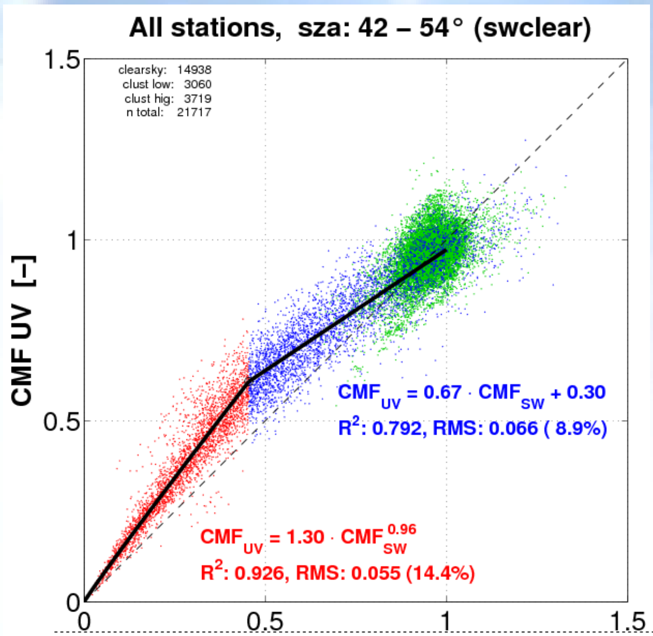
	RMS	RMS	Corr	slope
Payerne:	15.2	3.4%	0.991	1.01
Davos:	14.6	3.0%	0.991	1.02
Locarno:	20.2	4.1%	0.987	0.98
J.fraujoch:	17.3	3.0%	0.997	1.06

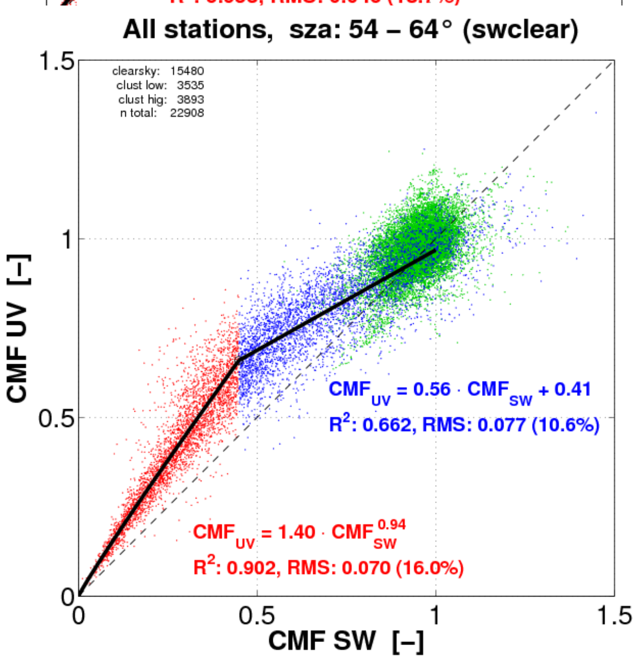
relationships slopes

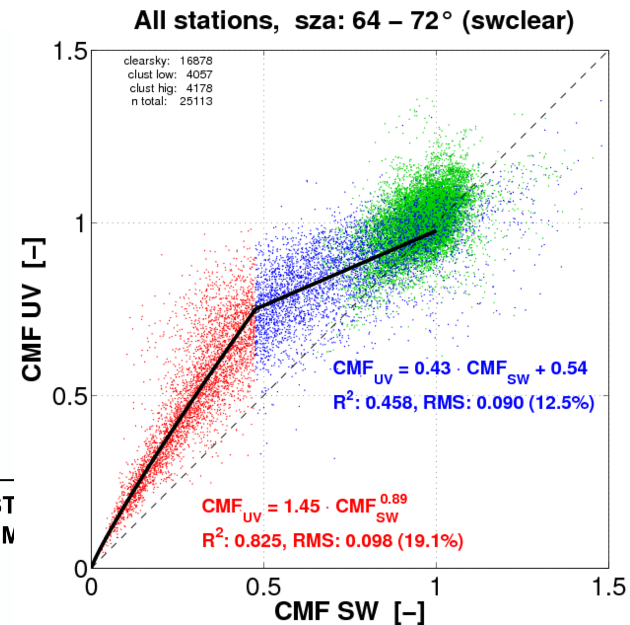


relationships

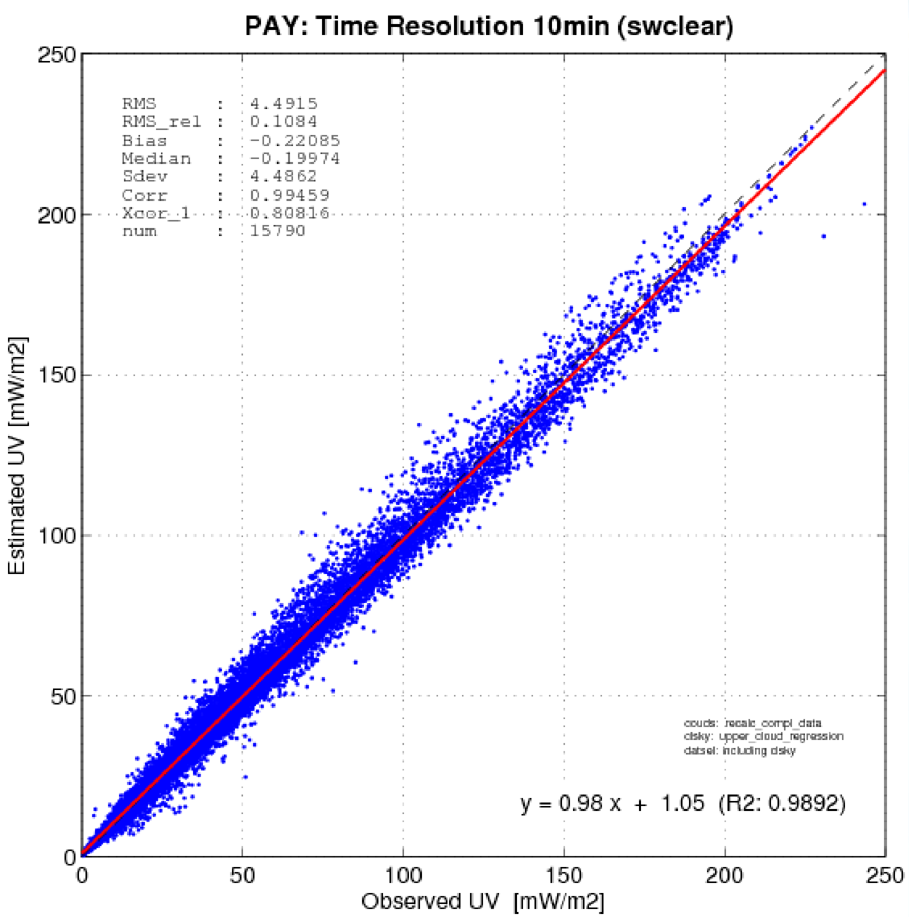


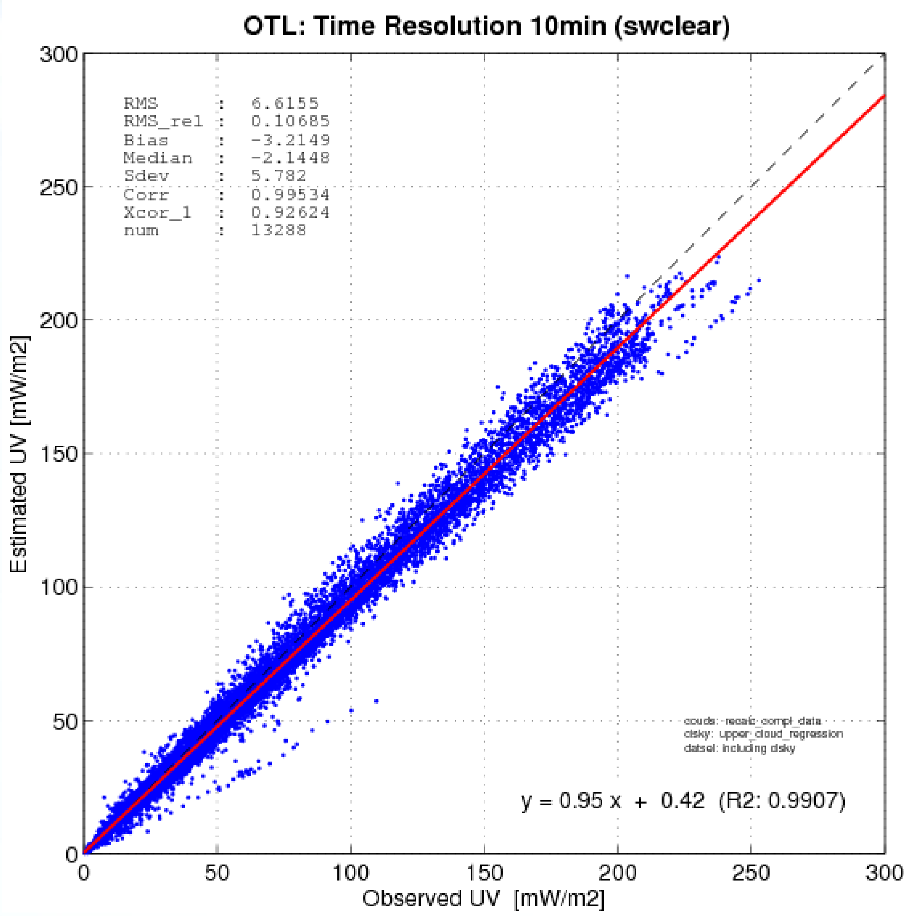




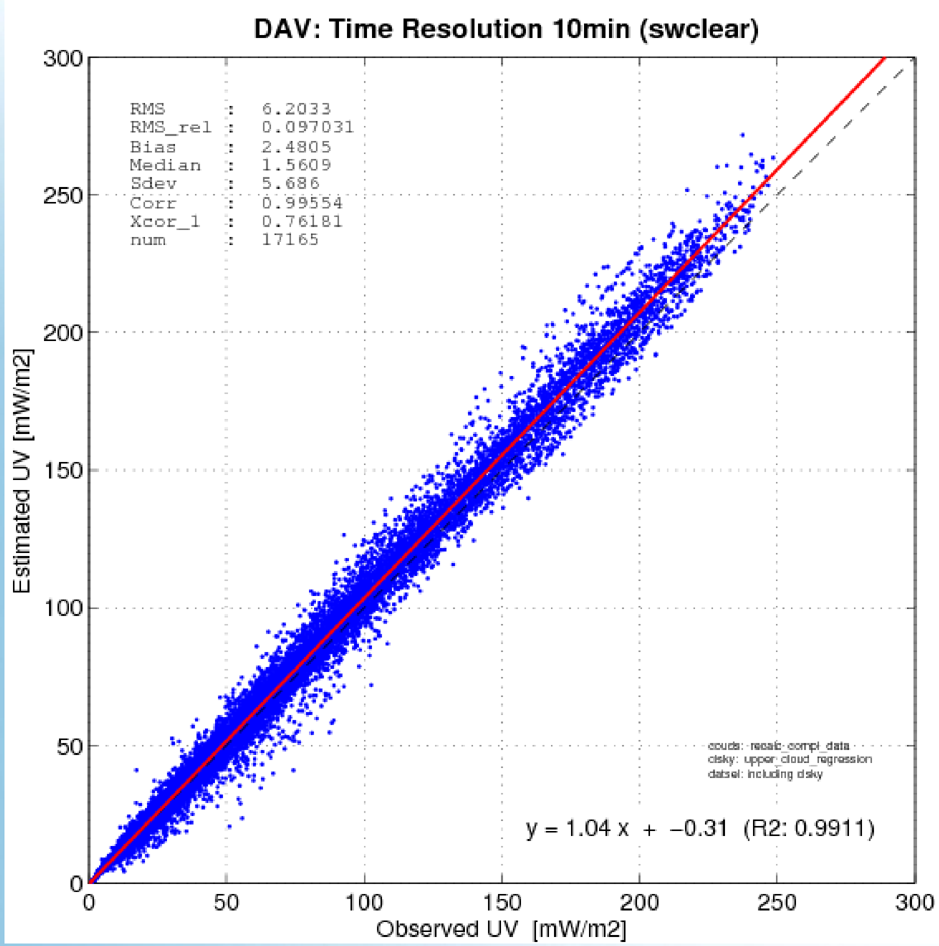


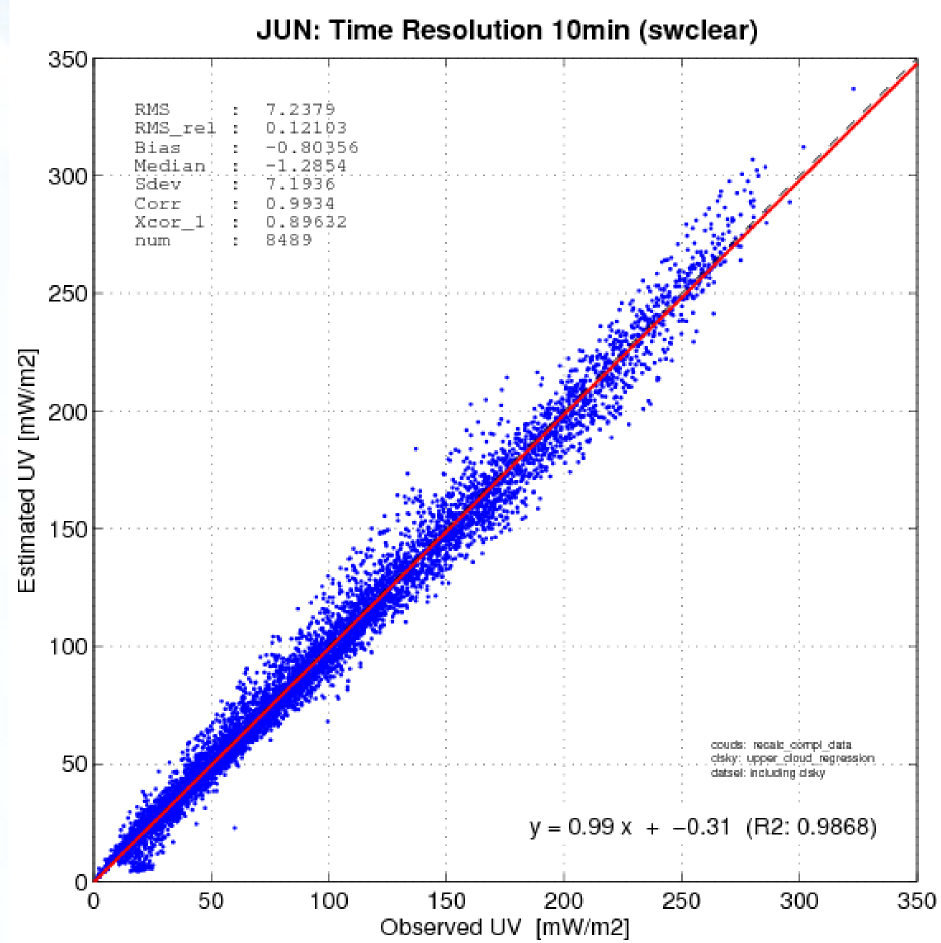
validation


PAY: Time Resolution 10min (swclear)
RMS : 4.4915
RMS_rel : 0.1084
Bias : -0.22085
Median : -0.19974
Sdev : 4.4862
Corr : 0.99459
Xcor_1 : 0.80816
num : 15790
clouds: recalc_compl_data
clsky: upper_cloud_regression
datsel: including clsky
y = 0.98 x + 1.05 (R2: 0.9892)
Estimated UV [mW/m2]
Observed UV [mW/m2]
0
50
100
150
200
250


OTL: Time Resolution 10min (swclear)
RMS : 6.6155
RMS_rel : 0.10685
Bias : -3.2149
Median : -2.1448
Sdev : 5.782
Corr : 0.99534
Xcor_1 : 0.92624
num : 13288
clouds: recalc_compl_data
clsky: upper_cloud_regression
datsel: including clsky
y = 0.95 x + 0.42 (R2: 0.9907)
Estimated UV [mW/m2]
Observed UV [mW/m2]
0
50
100
150
200
250
300

validation


DAV: Time Resolution 10min (swclear)
RMS : 6.2033
RMS_rel : 0.097031
Bias : 2.4805
Median : 1.5609
Sdev : 5.686
Corr : 0.99554
Xcor_1 : 0.76181
num : 17165
y = 1.04 x + −0.31 (R2: 0.9911)
Estimated UV [mW/m2]
Observed UV [mW/m2]
0
50
100
150
200
250
300


JUN: Time Resolution 10min (swclear)
RMS : 7.2379
RMS_rel : 0.12103
Bias : -0.80356
Median : -1.2854
Sdev : 7.1936
Corr : 0.9934
Xcor_1 : 0.89632
num : 8489
y = 0.99 x + −0.31 (R2: 0.9868)
Estimated UV [mW/m2]
Observed UV [mW/m2]
0
50
100
150
200
250
300
350