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Performance Evaluation of Radiation Sensors for the Solar Energy Sector

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Performance Evaluation of Radiation Sensors for the Solar Energy Sector

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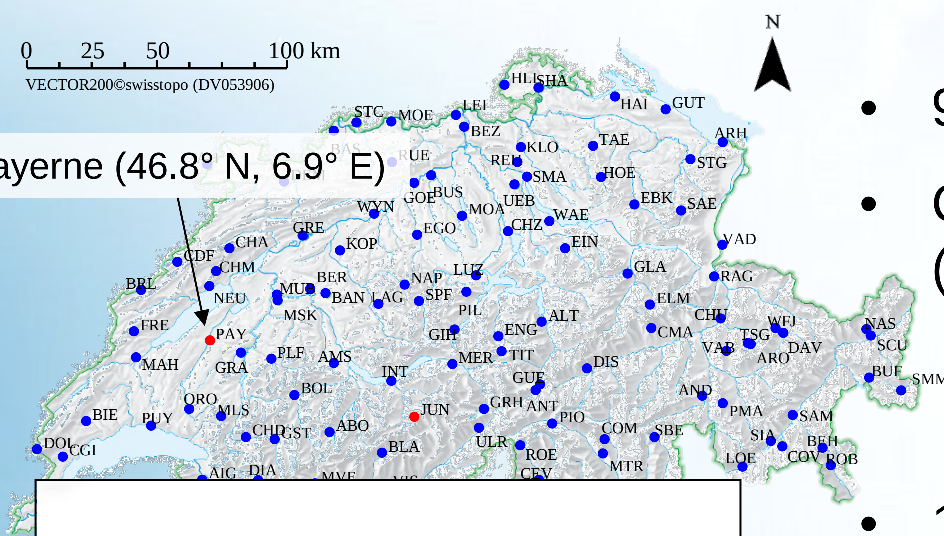
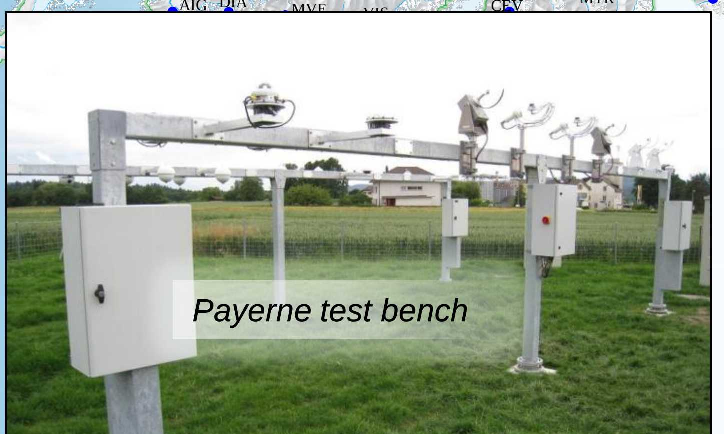
- Introduction
- Tested Instruments
- Reference Instruments
- Results, tested instrument performances
  - i) General, ii) by situation, iii) dependencies
- Conclusion

Introduction

Goal: Performance evaluation of radiation sensors allowing determination of components (diffuse & direct) → used by solar energy sector



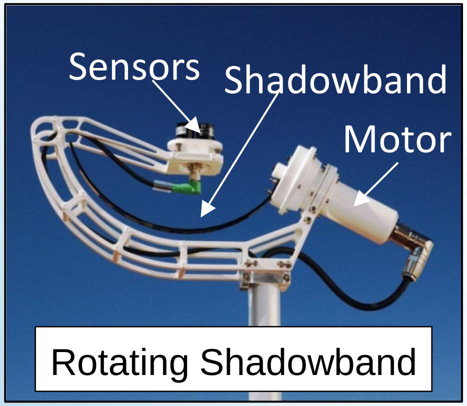


Payerne test bench

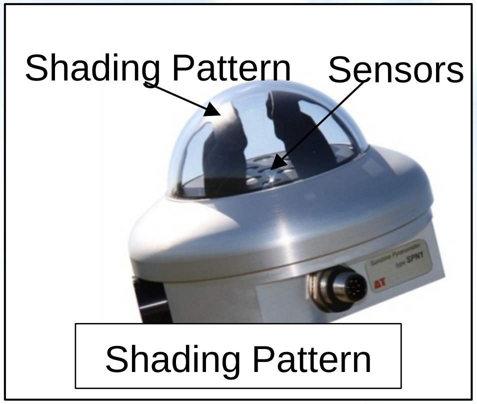
- 9 instruments tested
- Compared to reference instrument (BSRN)
    - Cloud cover: all-sky camera + longwave-based algorithm
- 15 months of measurement (two summers) 16/06/2012 → 15/09/2013
- Analysis on minute data
- Only solar zenith angle (SZA) ≤ 86°

Tested instruments

Two types of instruments:

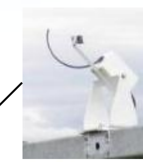


Rotating Shadowband

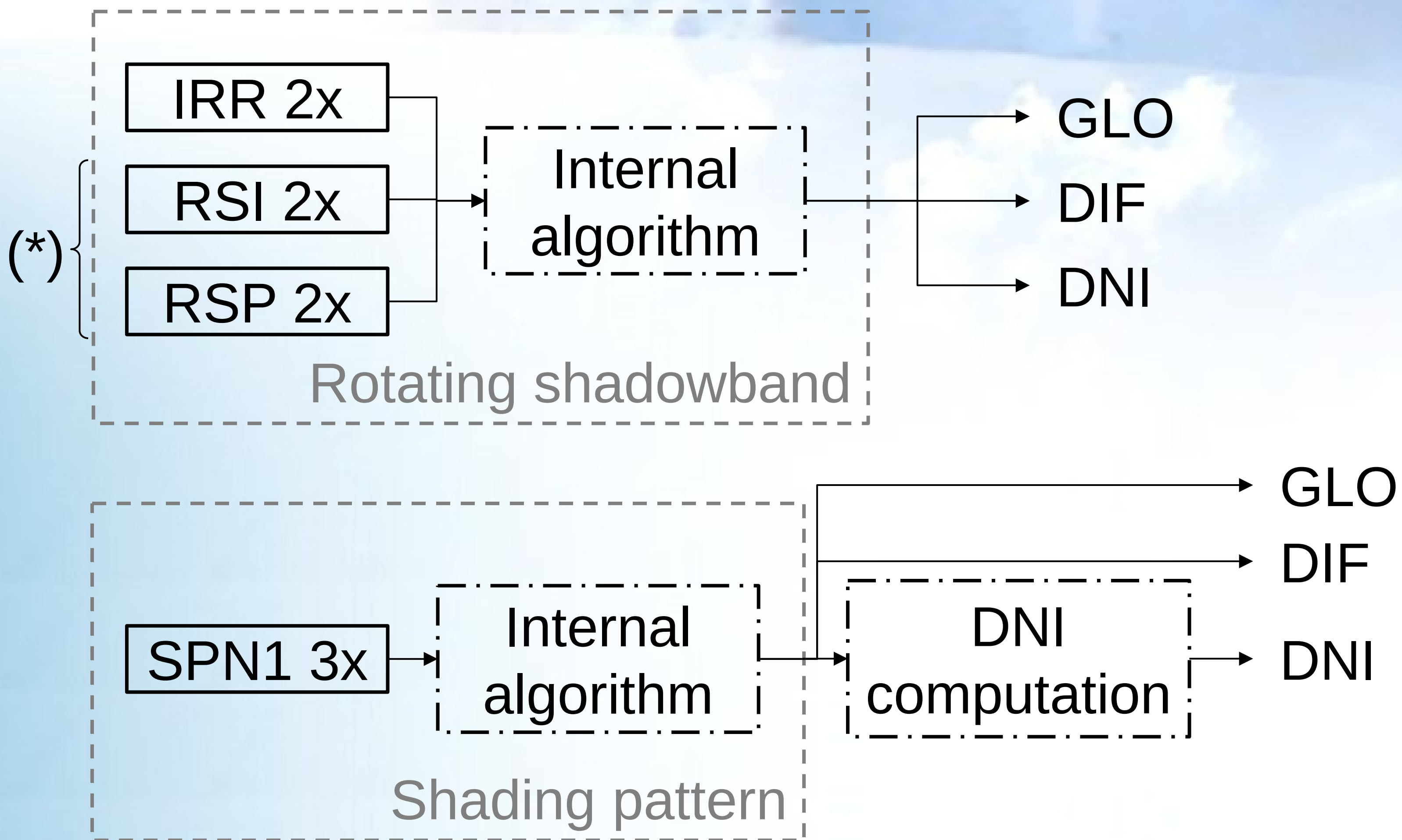


Shading Pattern

	Instrument	Provider	# instr.	Principle
RSI	IRR: Rotating Shadowband Radiometer	Irradiance	2	Rotating shadowband + LICOR
	RSI: Rotating Shadowband Irradiometer	CSP Services	2	Rotating shadowband + 2 LICORs (prototype)
	RSP: Rotating Shadowband Pyranometer	CSP Services	2	Rotating shadowband + LICOR
Δ-T	SPN1: Sunshine Pyranometer	Δ-T	3	Multiple thermopiles sensors (7) + elaborate fix shading pattern

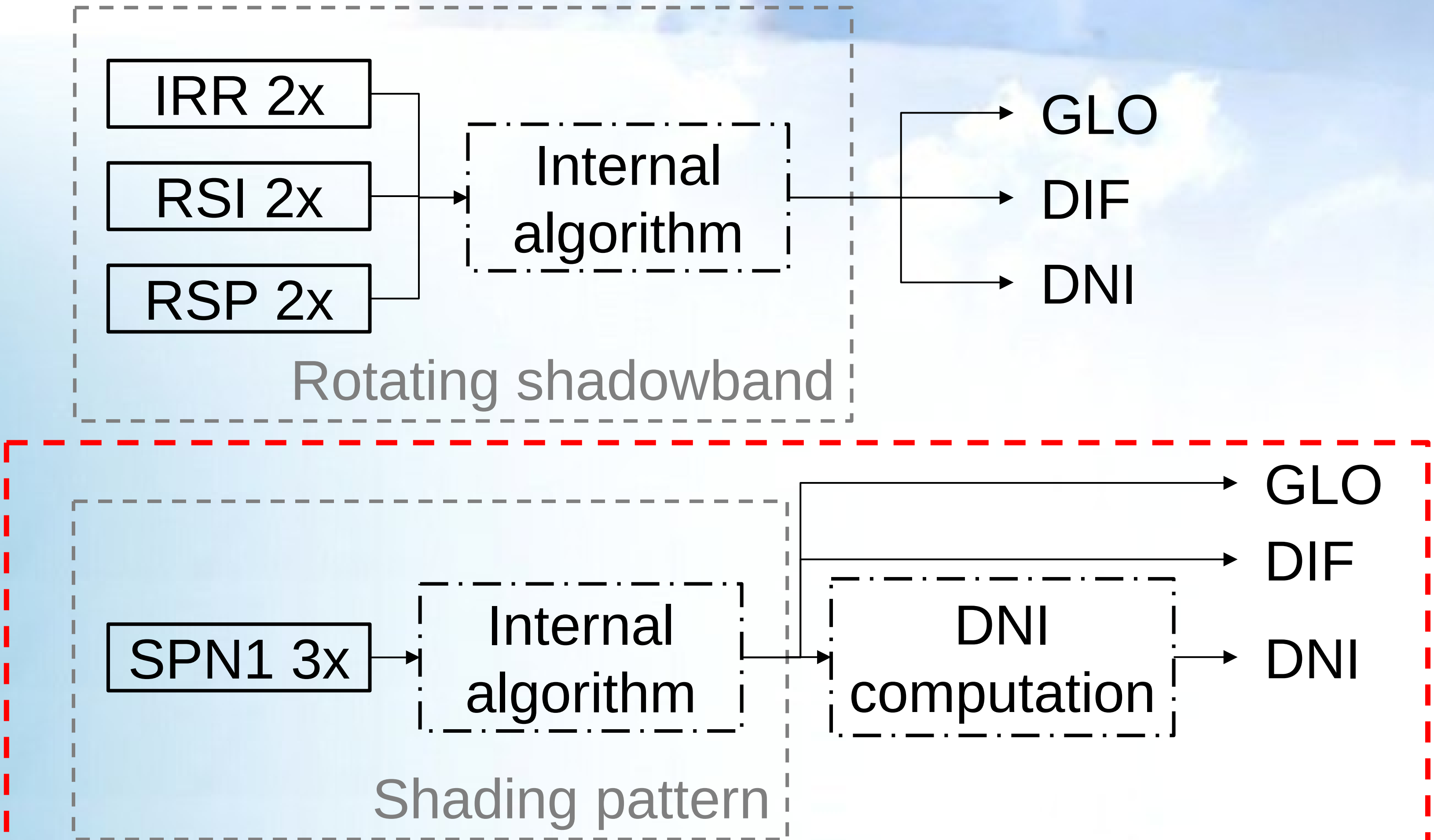


Tested instruments



(*) Provider offers post-treatment for these data

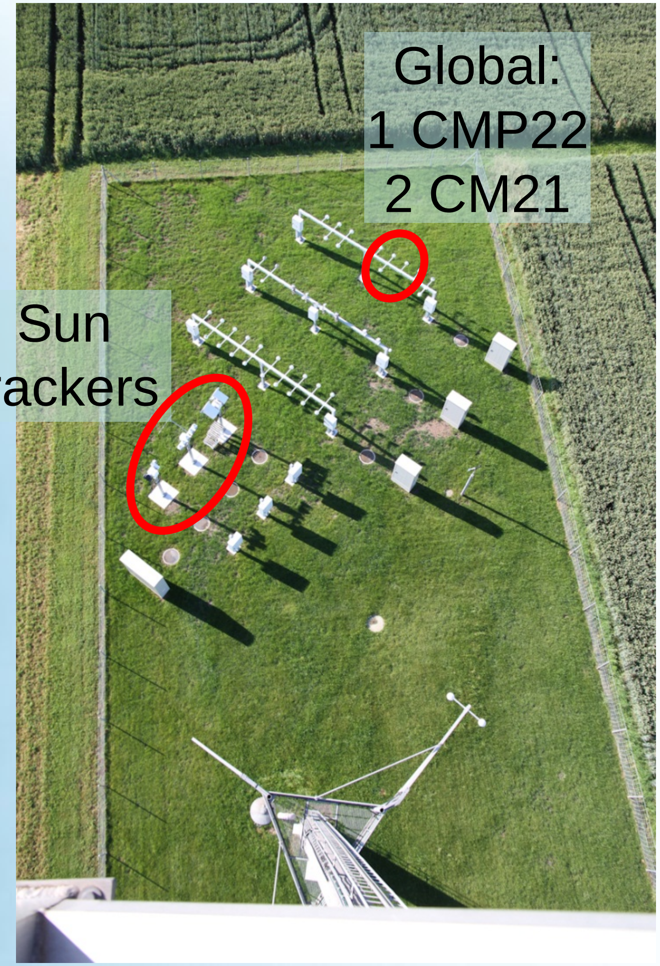
Tested instruments



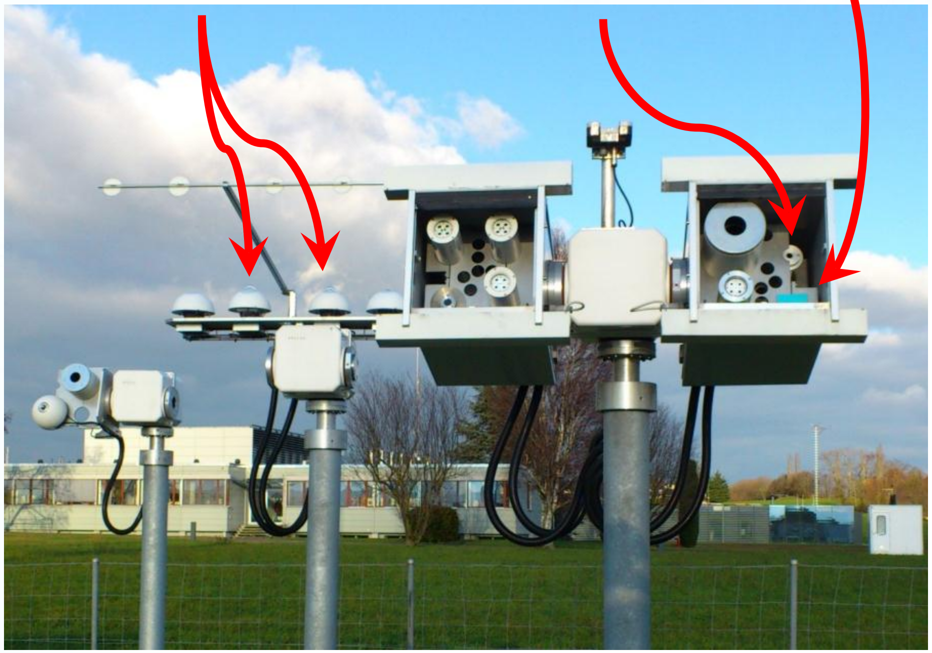
Badosa, J. et al., 2014. Solar irradiances measured using SPN1 radiometers: uncertainties and clues for development, *Atmospheric Measurement Techniques Discussion*, **7**, 8149-8191

Reference instruments (BSRN)

See: L. Vuilleumier, et al. (2014), Accuracy of ground surface broadband shortwave radiation monitoring. *Submitted to J. Geophys. Res.*



Expanded uncertainty: direct ~1.3%
global, diffuse ~1.5%



Results:

level of detail

Instrument performance evaluation

a) Overall performance (general view, all conditions mixed)
b) Understand causes for errors (investigate dependences)

Performances depend on conditions (solar zenith angle, clouds)

→ to be estimated globally AND for specific conditions.

In following slides

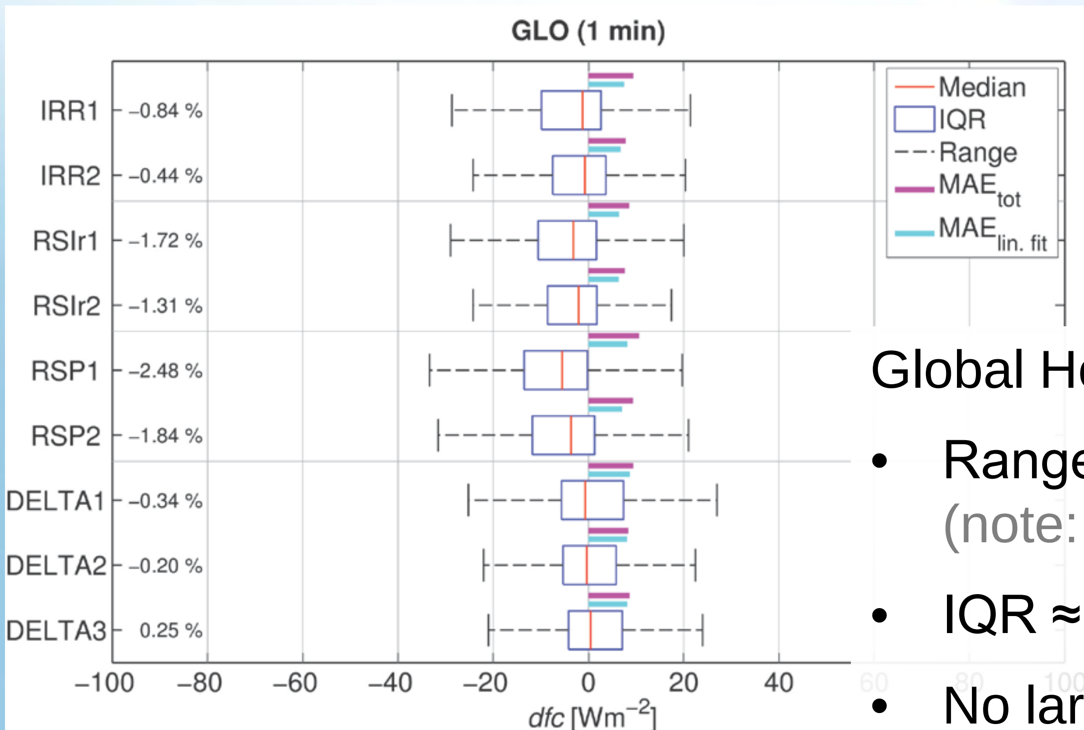
General (all measurements included)

Intermediate (by categories)

Detailed (continuous dependence)

Results:

Global, all (daytime) data

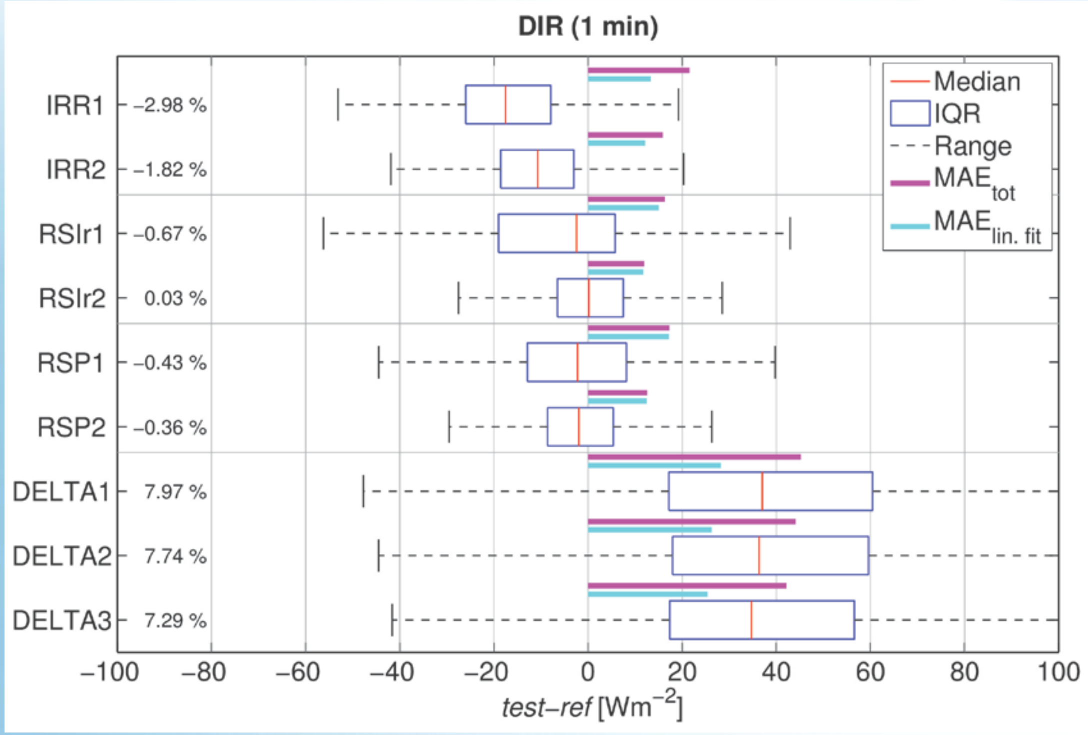


Global Horizontal Irradiance

- Range ≈ [-30 20] W/m^2 (note: many outliers not shown)
- IQR ≈ [-10 10] W/m^2
- No large biases
- No particular difference between Rotating Shadowband Irradiometers and Shading Pattern *at this level*

Results:

Direct, all (non-zero) data



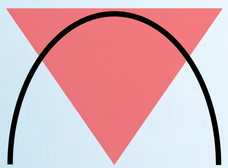
Direct Normal Irradiance

- Range ≈ [-50 125] W/m^2 (SPN1 up to 125 W/m^2)
- IQR ≈ [-30 20] W/m^2 (RSI)
  IQR ≈ [20 60] W/m^2 (SPN1)
- Strong difference between RSI and SPN1

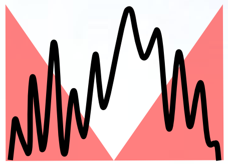
Results:

Categories (situations)

Two cases compared :
“favorable” and “difficult”



- Low variability
  DNI Variability < 10 Wm^{-2} min^{-1} (*)
  (fulfilled for at least 15 min)
- High solar elevation SZA ≤ 60°



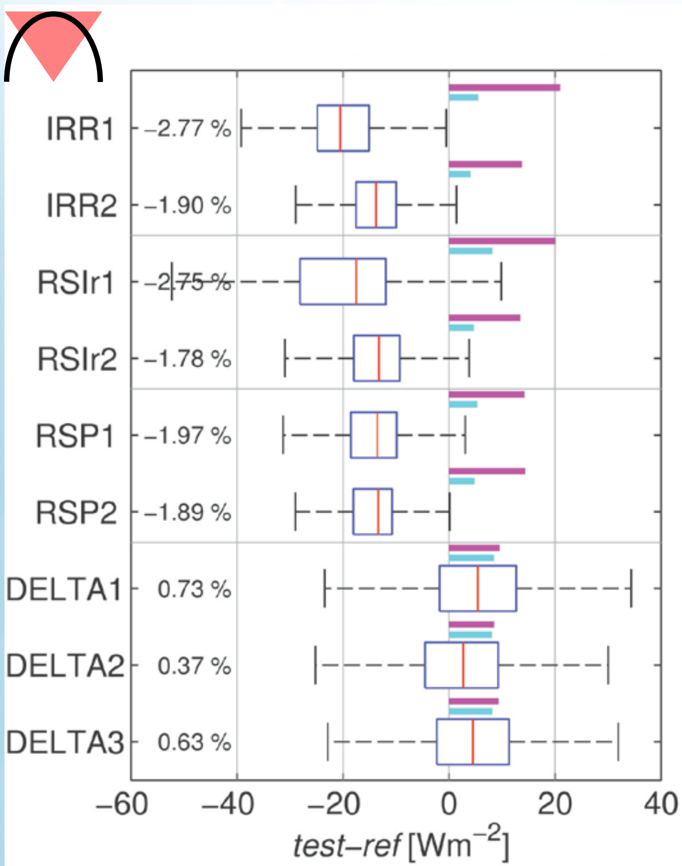
- High variability
  DNI Variability ≥ 10 Wm^{-2} min^{-1} (*)
- Low solar elevation (60° < SZA ≤ 86°)

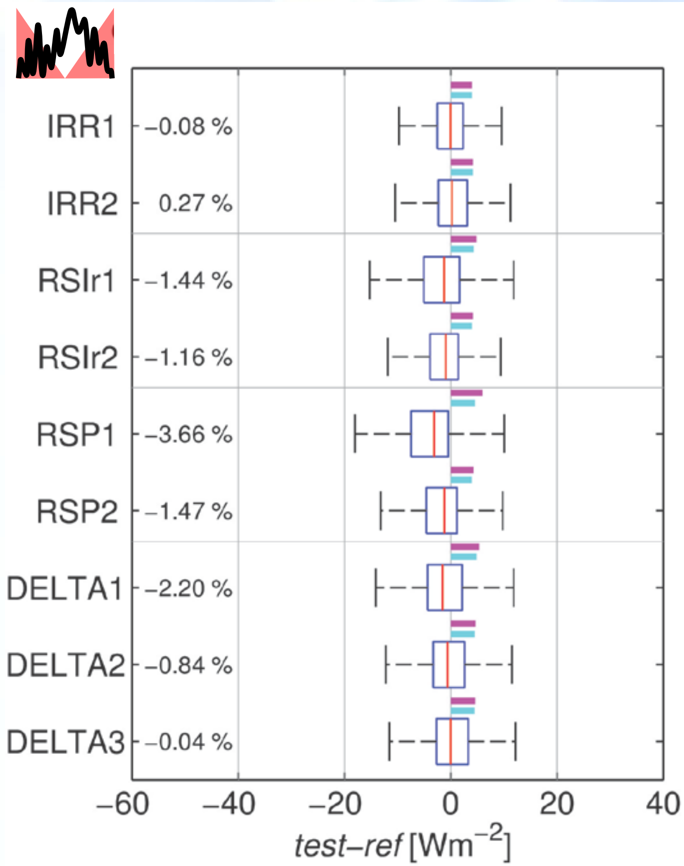
(*) Different limit for cos(SZA) ≤ 0.2

Results:

Global, categories (“favorable” & “difficult”)

Error [Wm^{-2}]:



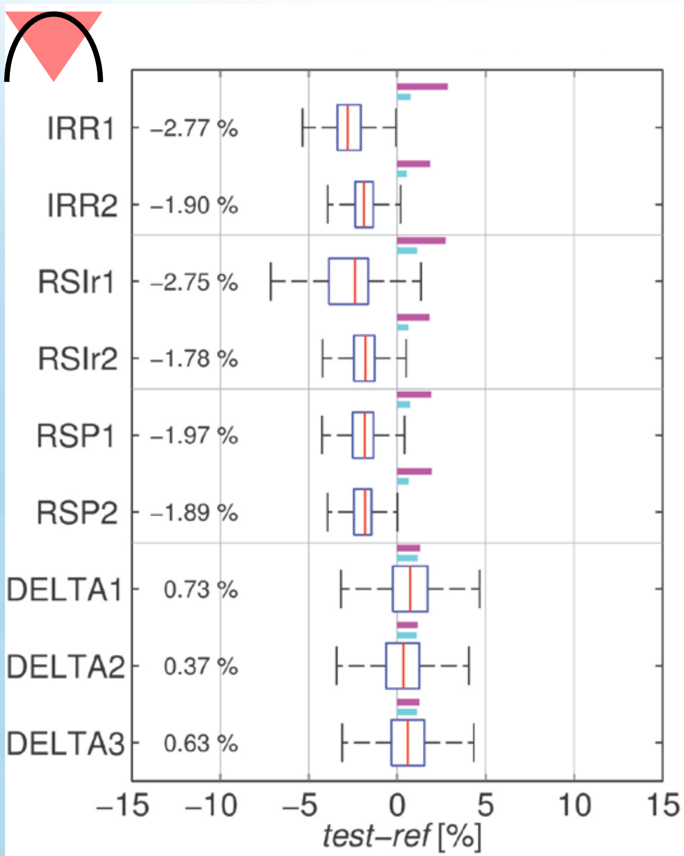


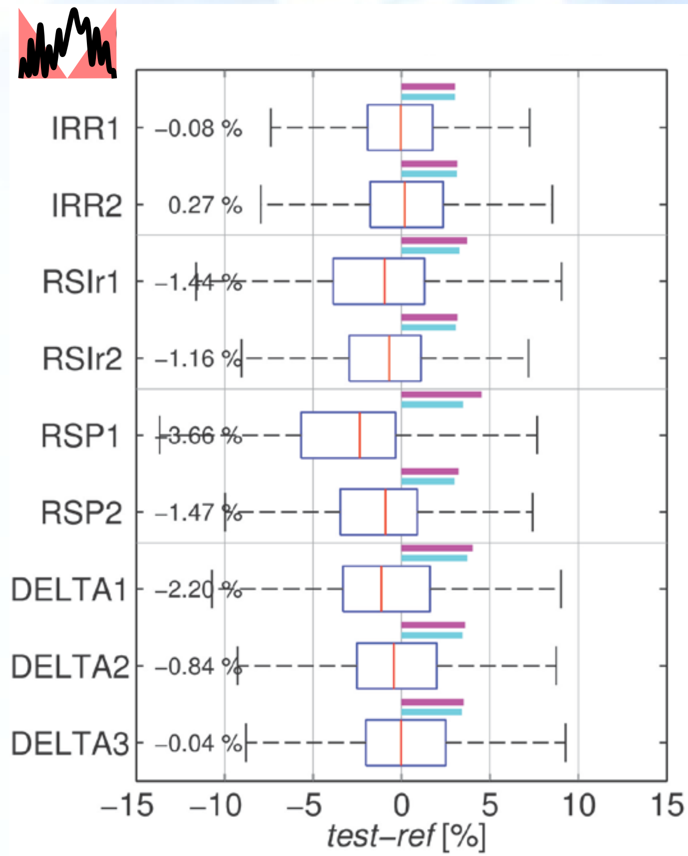
Larger error for favorable cases (larger absolute value)

Results:

Global, categories (“favorable” & “difficult”)

Relative error [%]: similar bias, but greater range and IQR for “difficult”



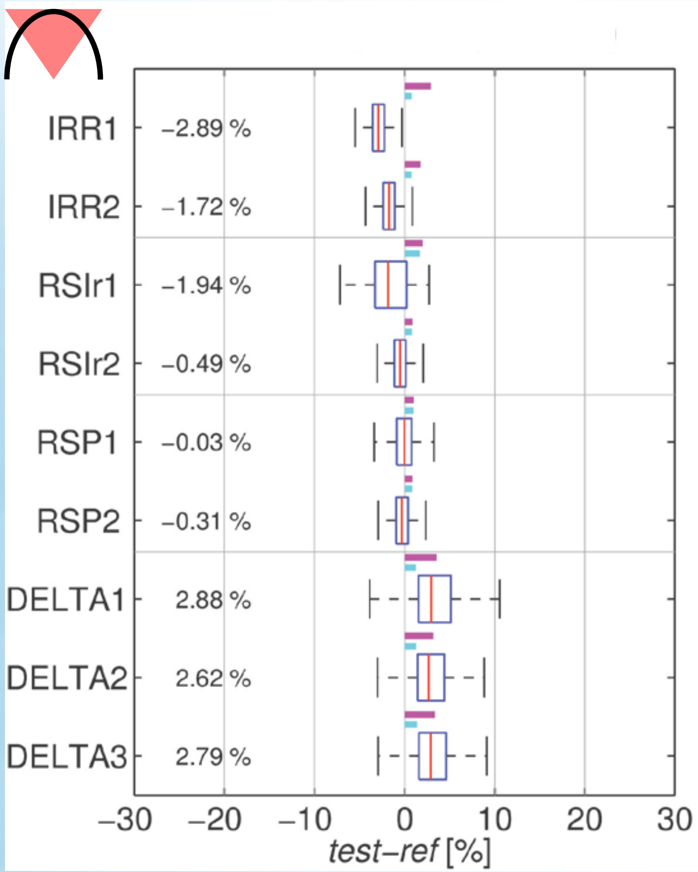


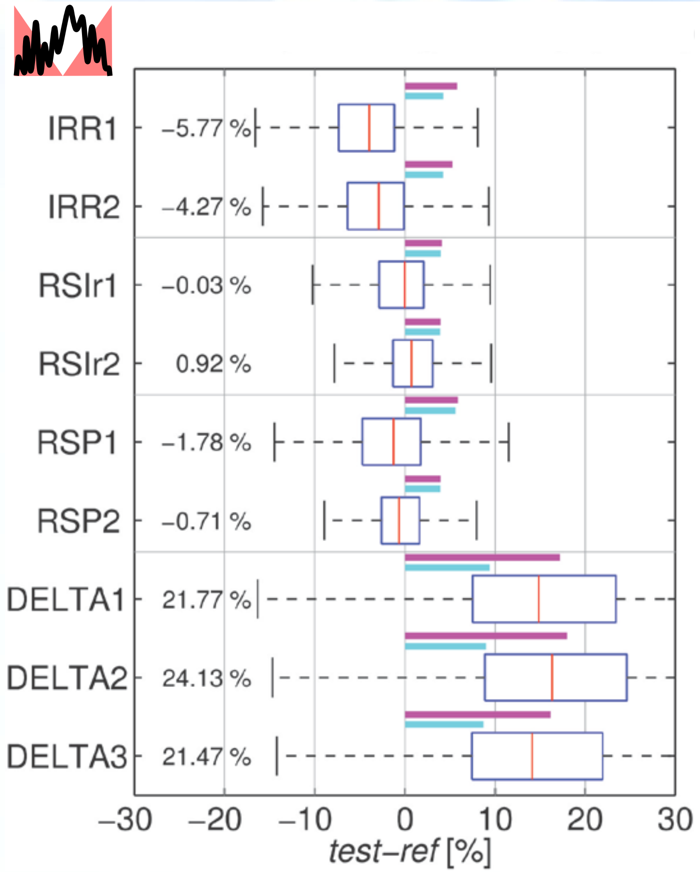
Smaller relative error for favorable cases

Results:

Direct, categories (“favorable” & “difficult”)

Relative error [%]: large bias for SPN1, larger range and IQR for “difficult”





Caution: scale is doubled with respect to previous slide

Results:

Global, categories ("favorable" & "difficult")

Global Horizontal Irradiance:

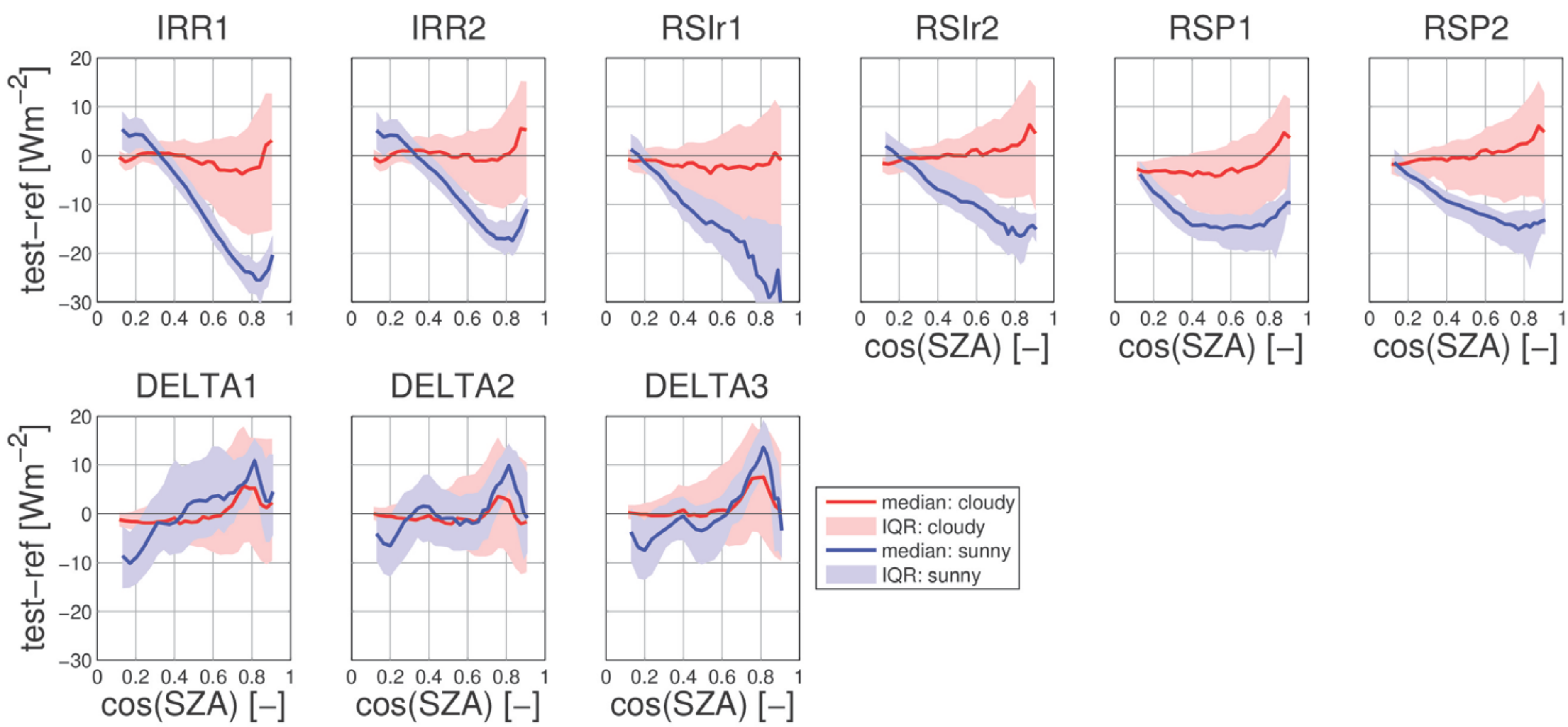
- Favorable: ~[-7 +5] %
- Difficult: ~[-15 +10] %

	IQR Wm^{-2}	
	favorable	difficult
IRR1	9.7	4.8
IRR2	7.6	5.4
RSI1	16.2	6.8
RSI2	8.7	5.3
RSP1	8.6	7
RSP2	7.3	5.7
Δ-T1	14.5	6.5
Δ-T2	13.8	5.9
Δ-T3	13.7	5.9

Results:

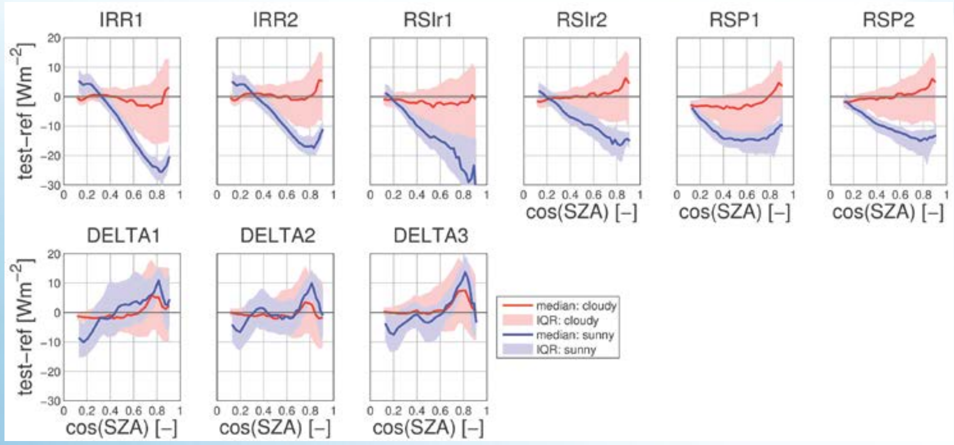
Global, dependence on SZA

Investigating the source of errors:



Results:

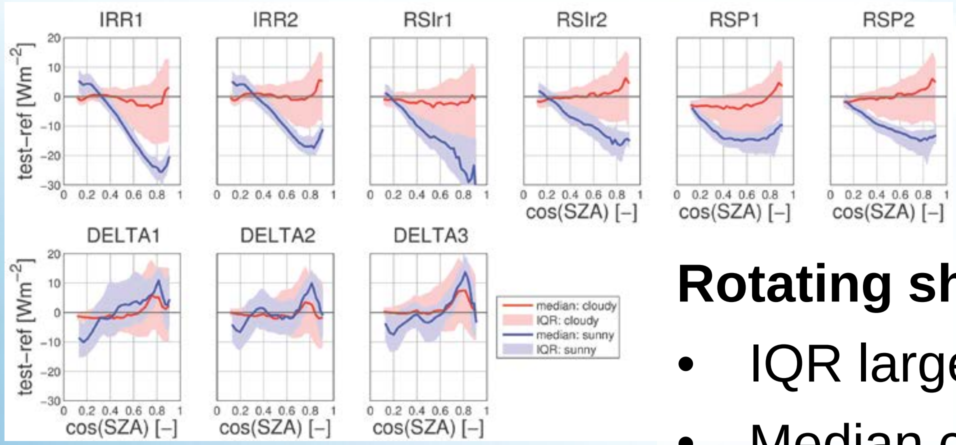
Global, dependence on SZA



	Average IQR around median Wm^{-2}	
	favorable	difficult
IRR1	6.0	11.8
IRR2	5.9	10.8
RSI1	11.6	13.7
RSI2	7.3	11.0
RSP1	7.1	12.4
RSP2	6.1	11.6
Δ-T1	14.5	14.2
Δ-T2	12.4	12.7
Δ-T3	11.4	12.9

Results:

Global, dependence on SZA



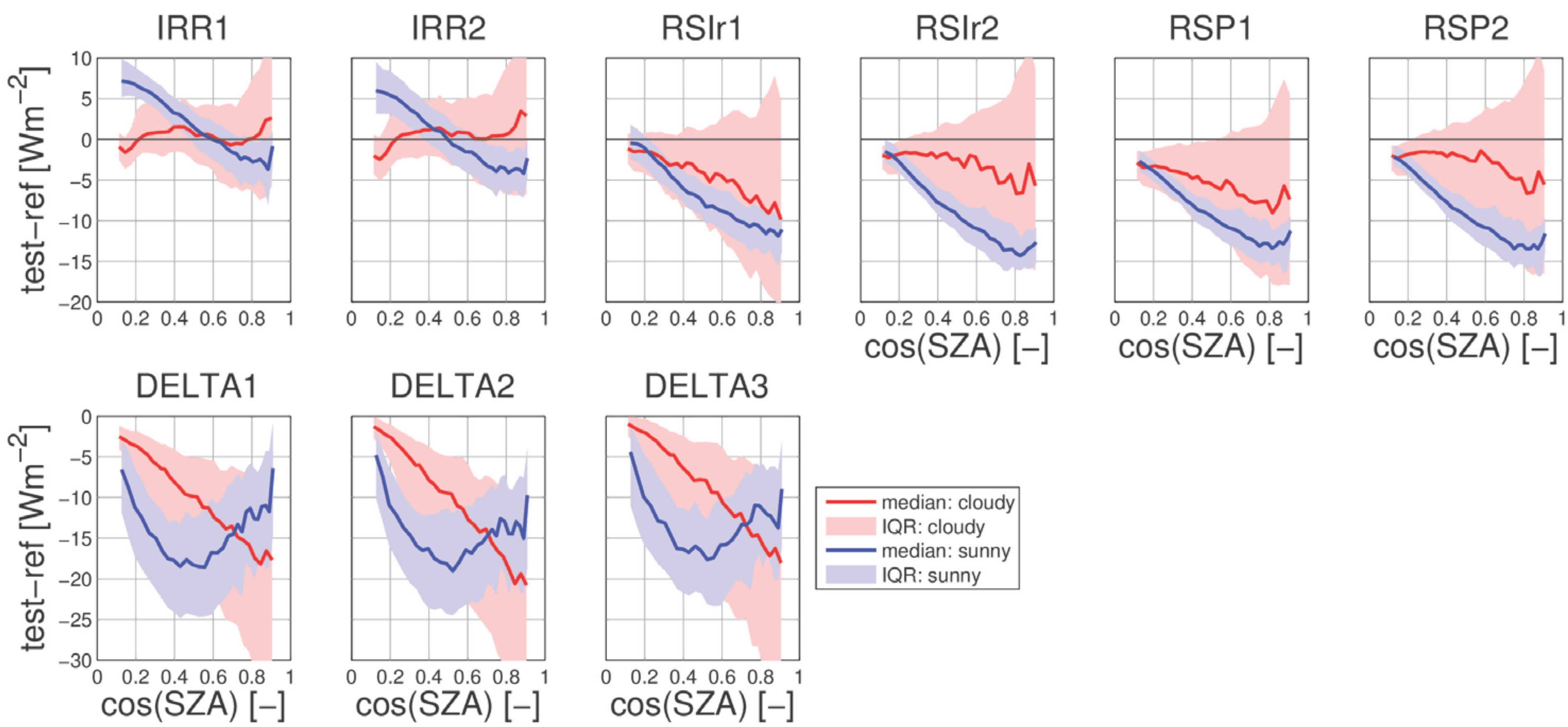
Rotating shadowband Irradiometers:

- IQR larger for cloudy cases
- Median closer to zero for cloudy case
- Sunny case systematically underestimated
- **Strong SZA dependence**
  (spectral or cosine effect?)
- Similar behavior for both instruments of each provider → linked to manufacturer?

Characteristics common to **all tested shadowband irradiometer** → linked to instrument concept ?

Results:

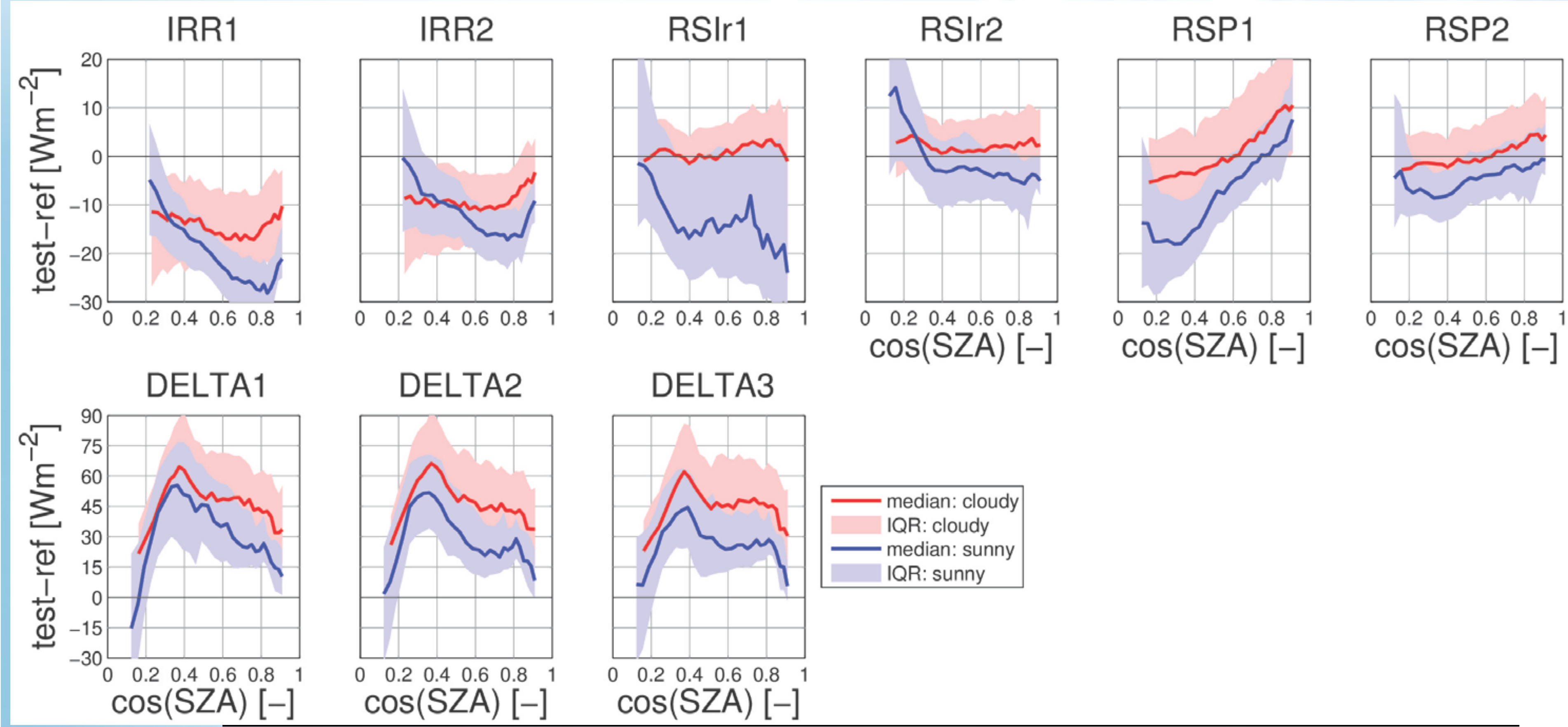
Diffuse, dependence on SZA



Results:

Direct, dependence on SZA (from instrument) →

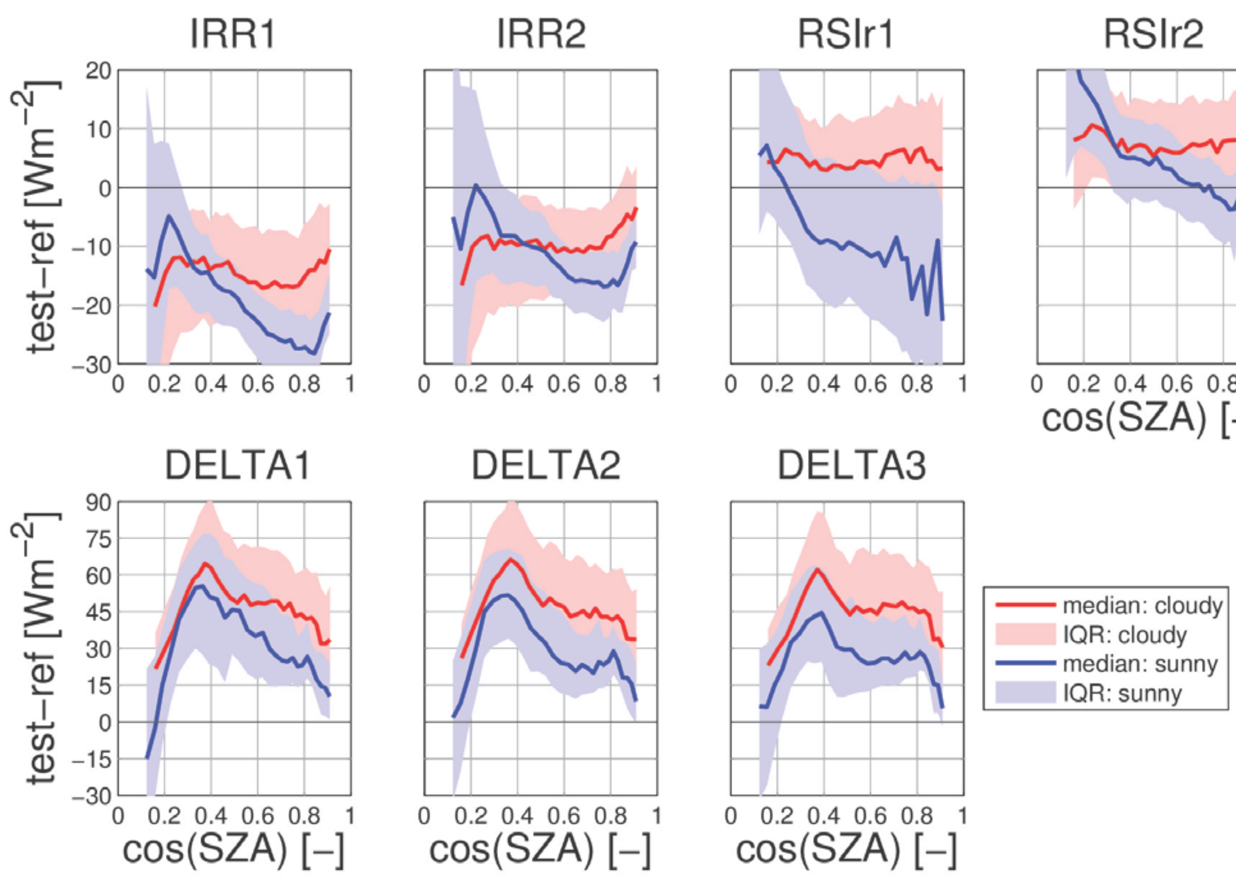
Zero DNI events excluded (pyrheliometer-determined)



Results:

Direct, dependence on SZA (recomputed)

Zero DNI events excluded (pyrheliometer-determined)

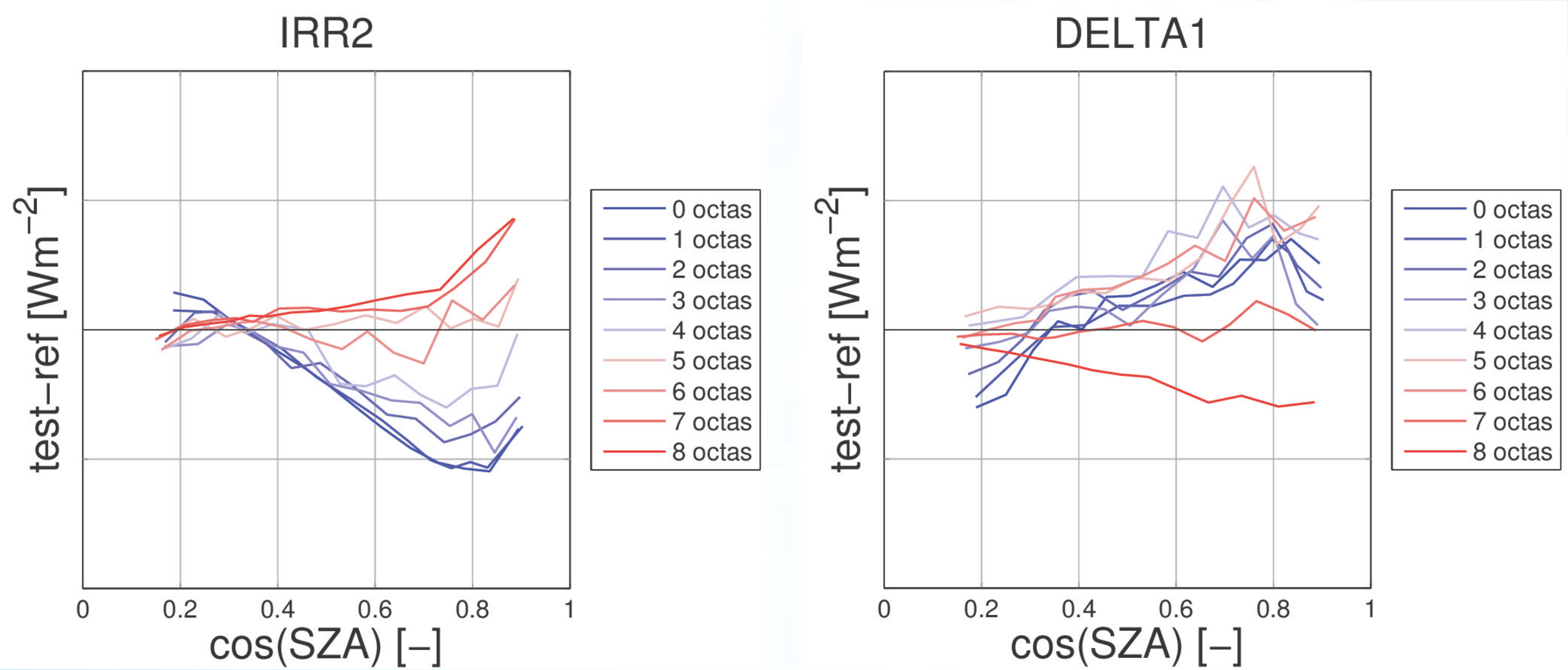


$$\frac{GHI - DfHI}{\cos(SZA)}$$

Results:

Global, Influence of cloud cover

Medians for different cloud coverages

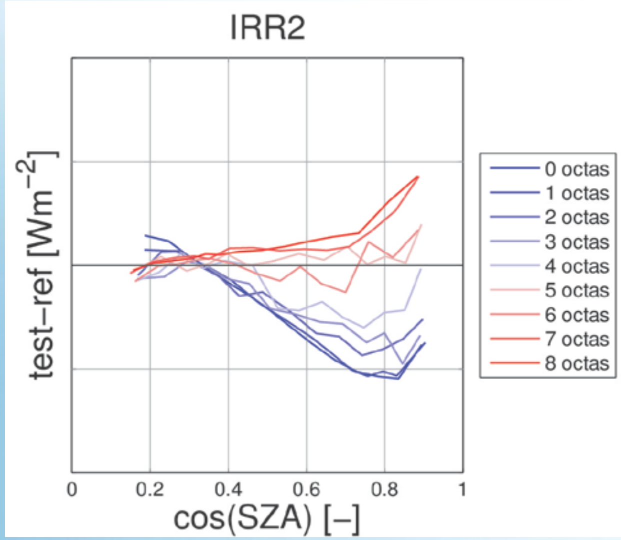


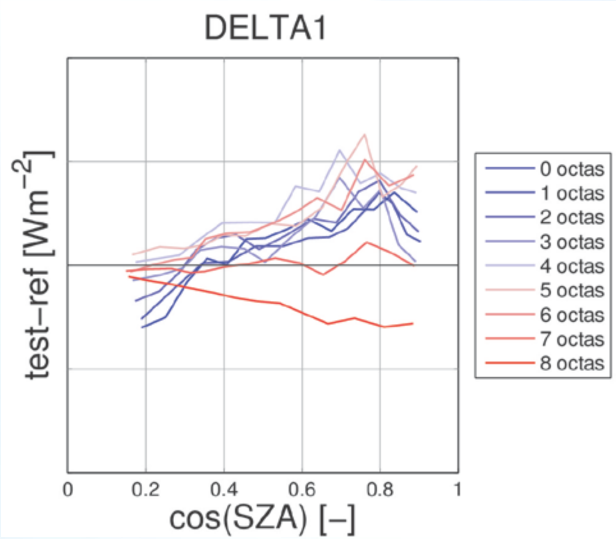
Octas determined from APCADA (based on LW downward irradiance)

Dürr, B., Philipona, R., 2004. Automatic cloud amount detection by surface longwave downward radiation measurements, *Journal of Geophysical Research*, **109**, D05201

Results:

Global, Influence of cloud cover





- Rotating shadowband irradiometers median value improves progressively with cloud cover (but IQR becomes larger)
- Δ-T SPN1 little error dependence on clouds, (overcast – 7-8 octas – is different)

Conclusion

Error global:	all daylight data:	[-30 +20] Wm^{-2}	([-10 +8] %)
	"difficult":	[-15 +10] Wm^{-2}	([-15 +10] %)
	"favorable":	[-50 +30] Wm^{-2}	([-7 +5] %)
Error direct:	all nonzero data:	[-60 +125] Wm^{-2}	([-10 +22] %)
	RSI only:	[-60 +40] Wm^{-2}	([-10 +7] %)
	"difficult":	[-55 +140] Wm^{-2}	([-15 +45] %)
	"favorable":	[-60 +90] Wm^{-2}	([-7 +10] %)
	RSI only:	[-60 +30] Wm^{-2}	([-7 +3] %)

RSIs show similar tendency for global:

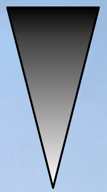
- lower cloudiness → larger GHI dependence on SZA
- Δ-T SPN1 diffuse underestimated → strong overestimation of direct
- Spectral/cosine effect not yet fully separated (working on it)

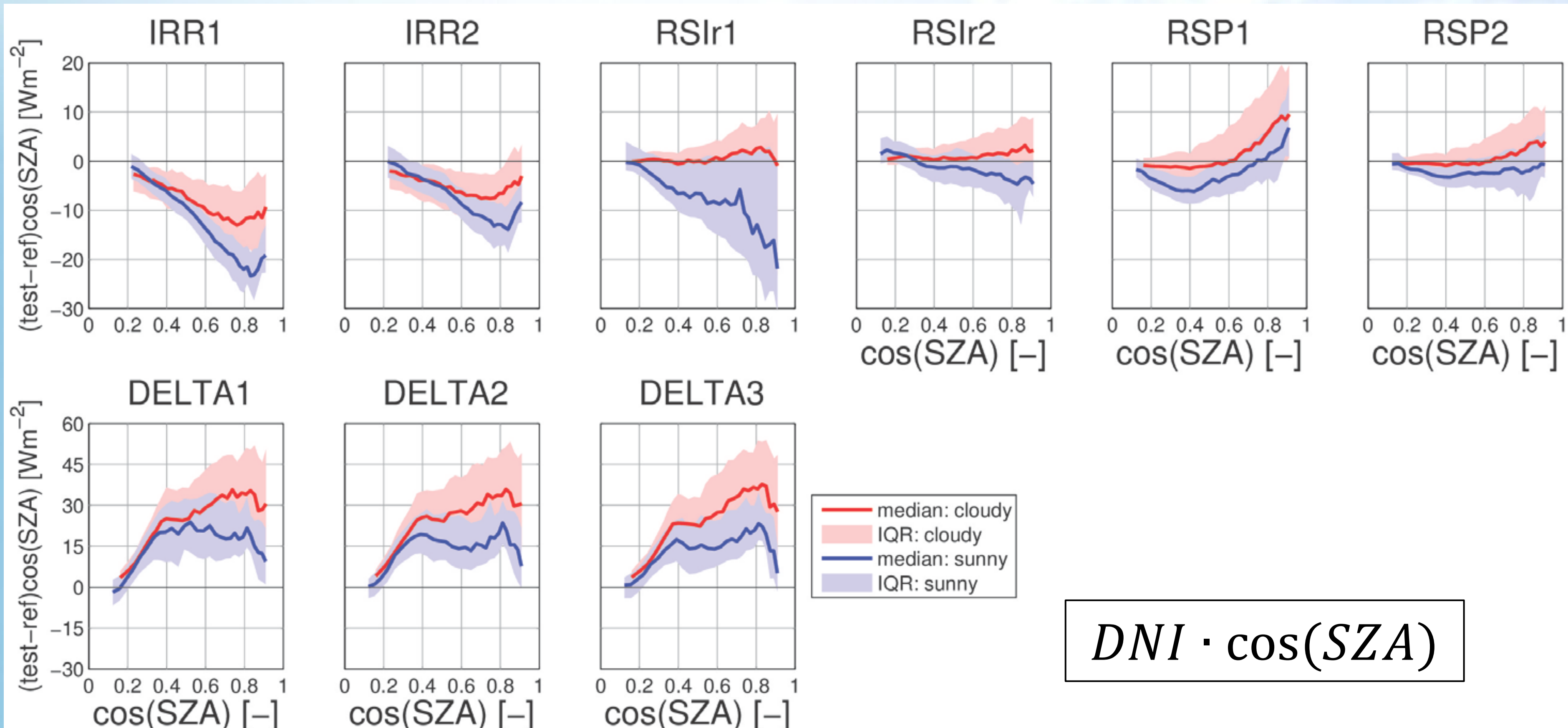
Thank you

Questions? / Comments!

Results:

Direct, dependence on SZA (from instrument) →





$$DNI \cdot \cos(SZA)$$