Radiance 2008 Workshop

A parametric evaluation of daylight provision for residential buildings using the UDI metric

or

When less (data) really is more

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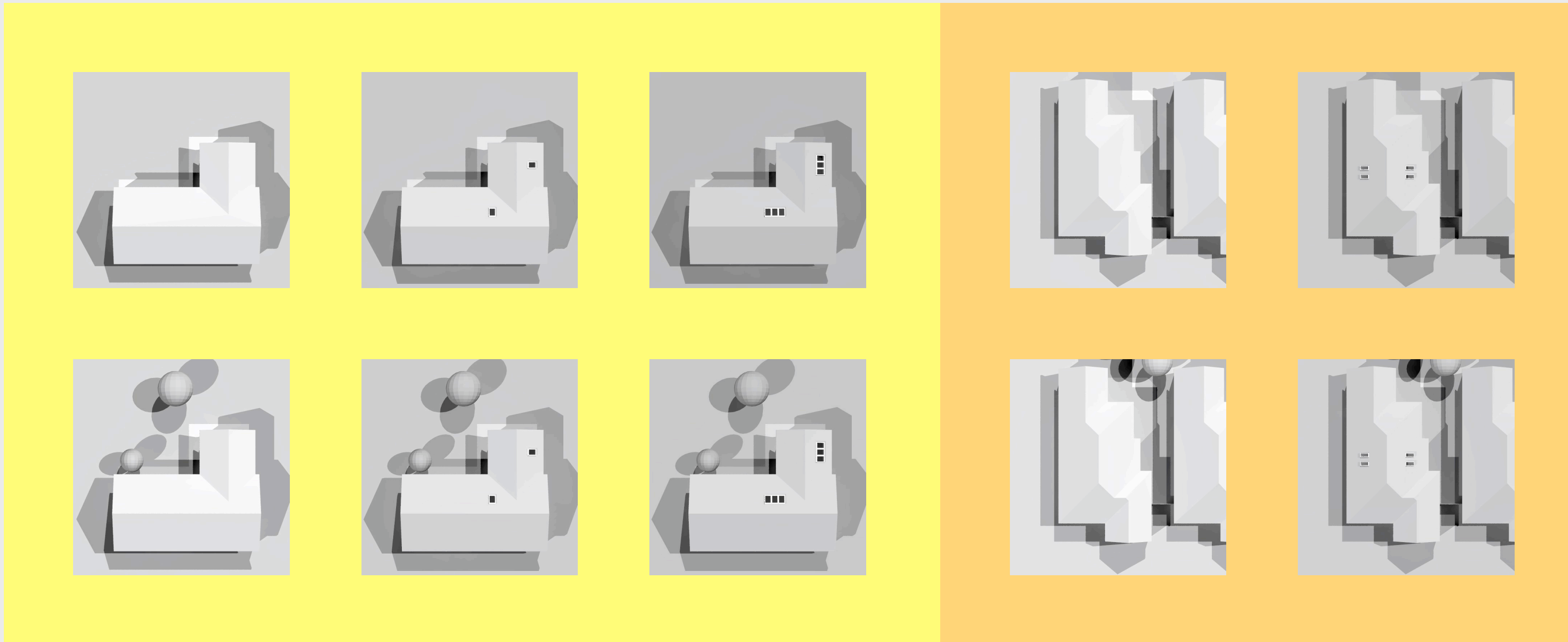
To quantify the change in daylighting performance of residential buildings due to the addition of skylights

Scope (parametric study)

- Five window designs for two building types, without and with obstruction.
- Six climates covering a range experienced in Europe and the USA.
- Eight orientations covering the cardinal and mid-cardinal points of the compass.
- Occupied period 08h00 to 20h00 (daylight saving time accounted for).

Ten building types

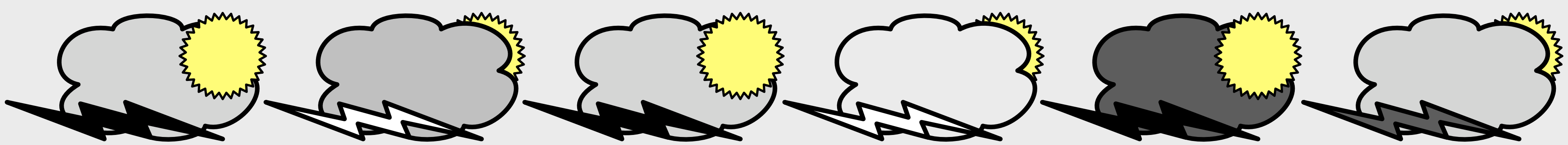


_u
unobstructed

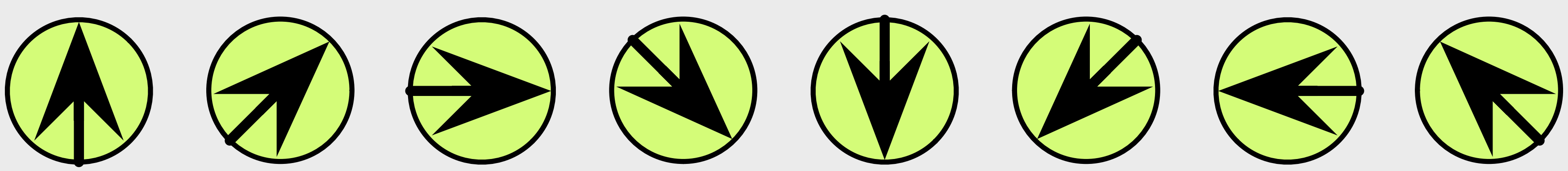
_o
obstructed

A1 A2 A3 B1 B2

Six climates



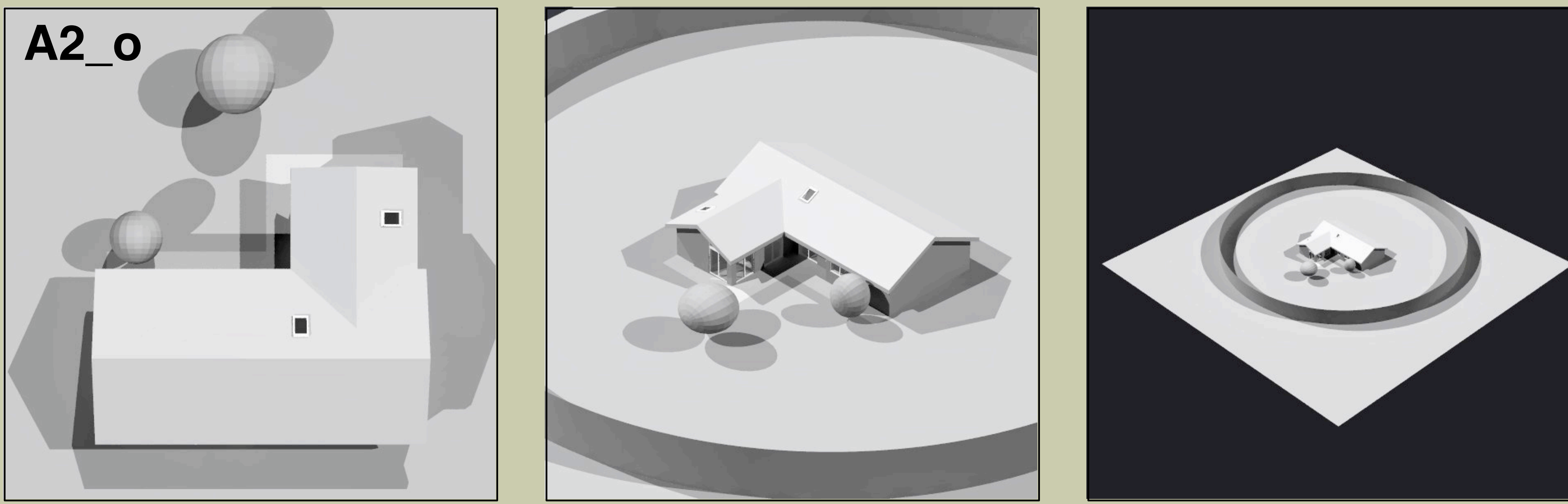
Eight orientations

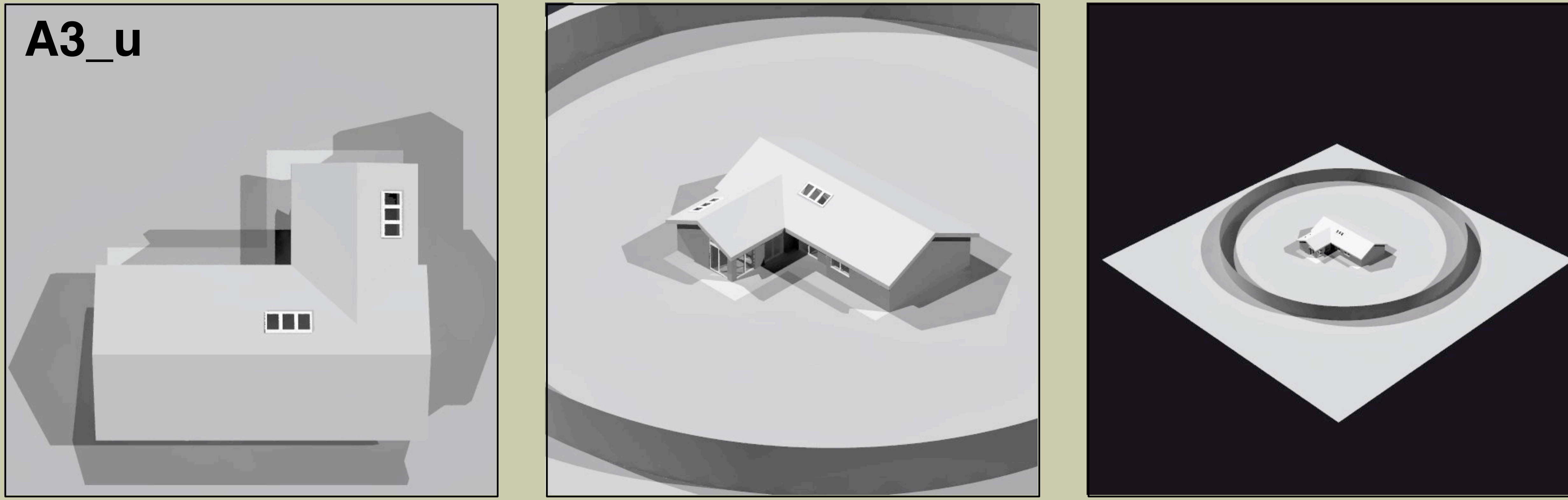


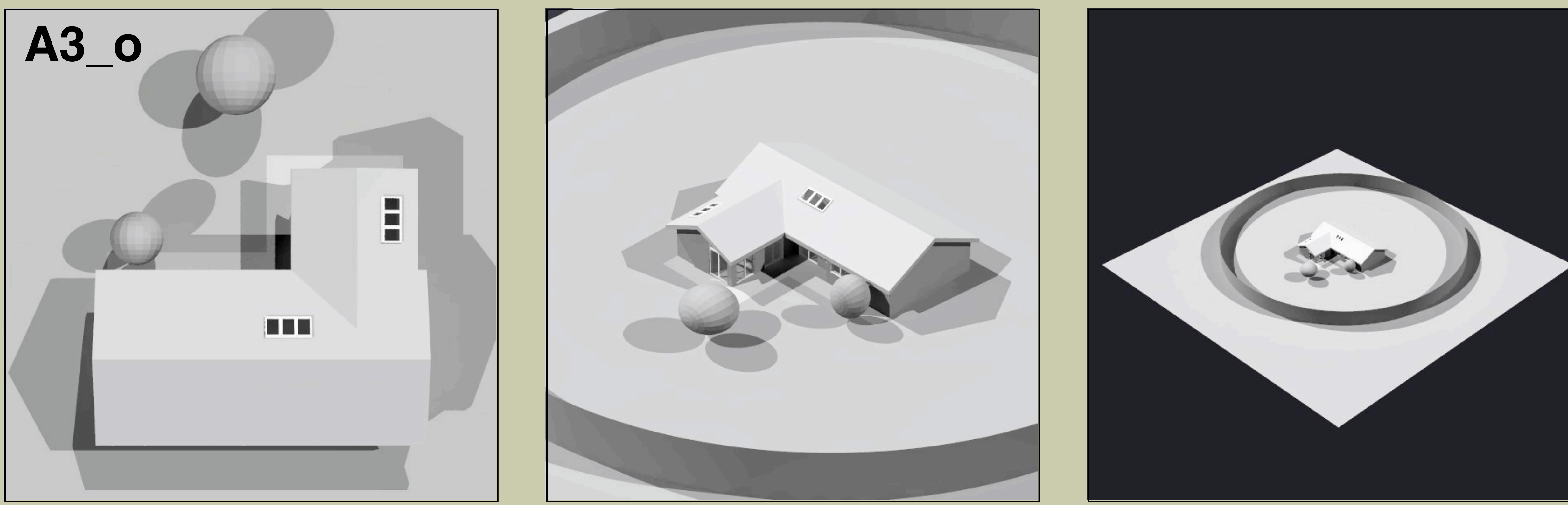

A1_u


A1_o

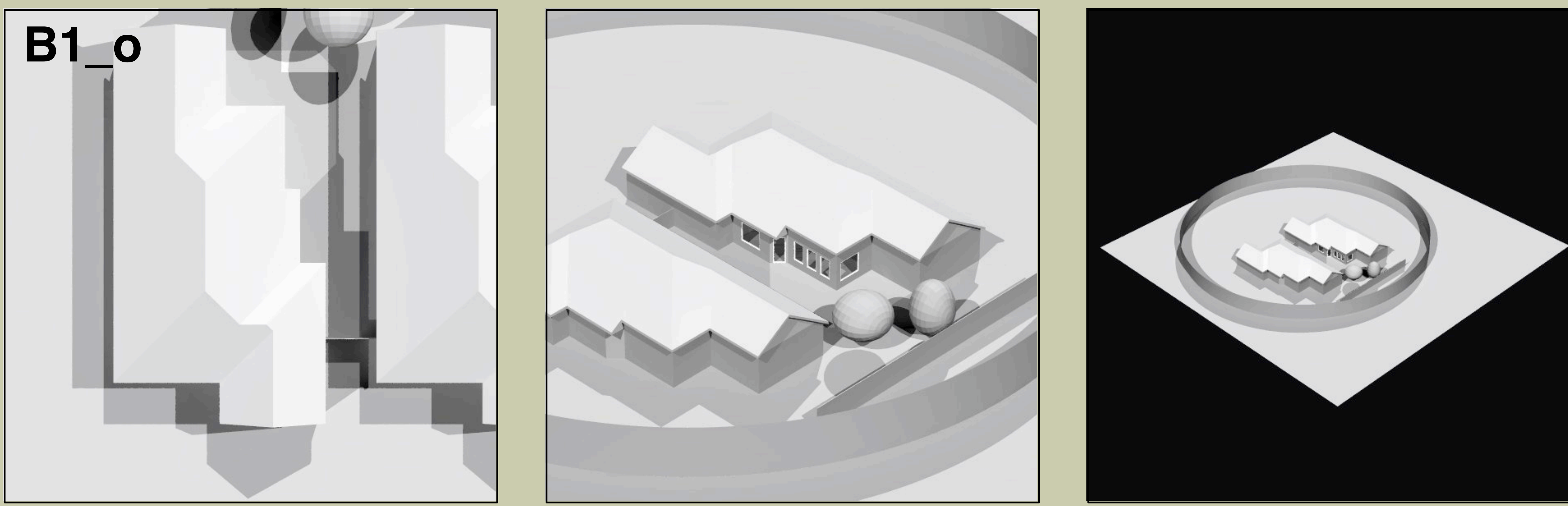

A2_u

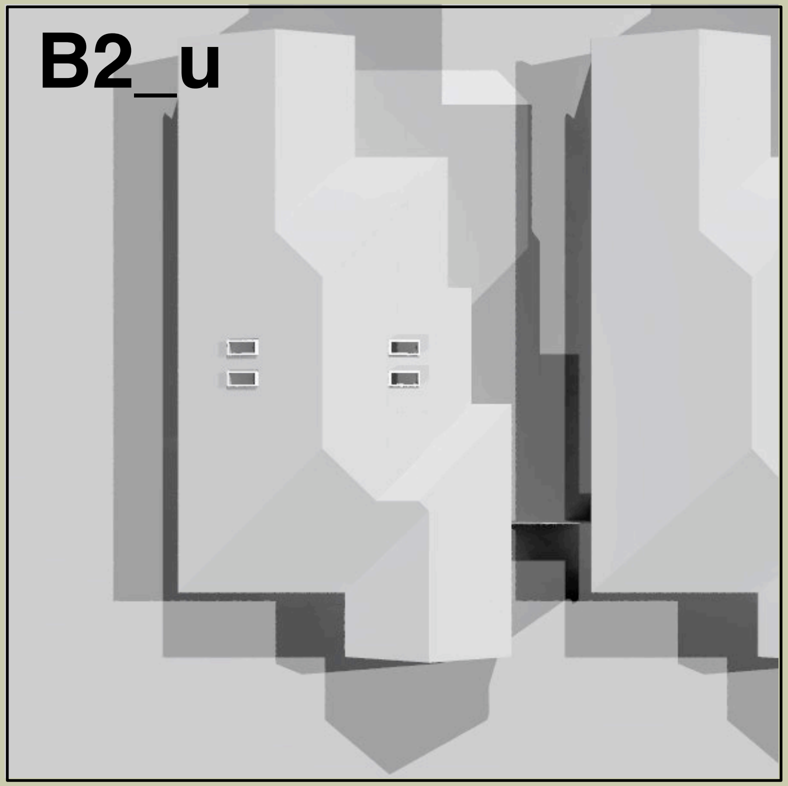

A2_o

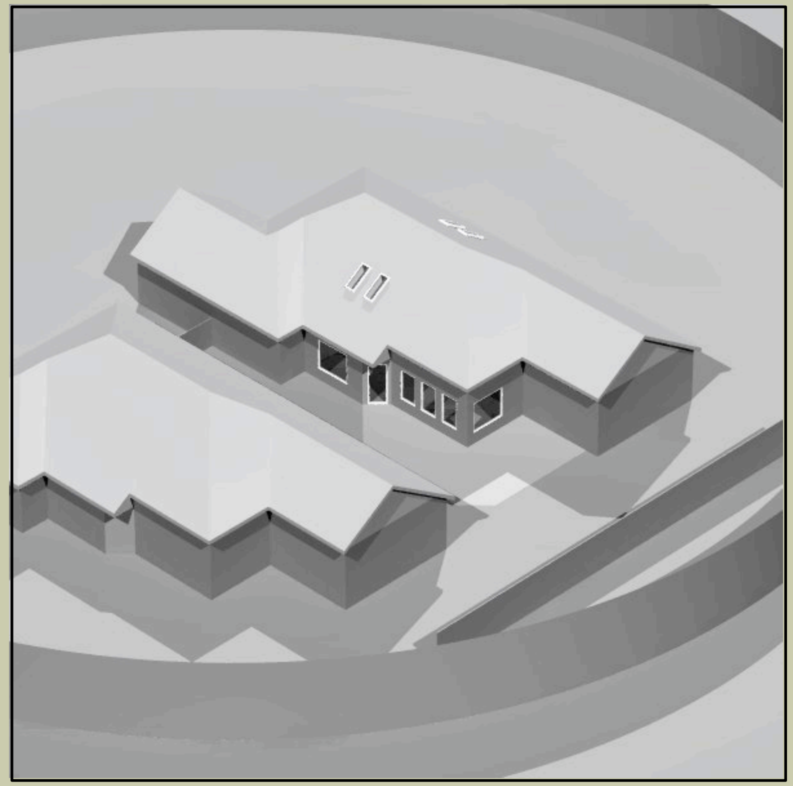

A3_u

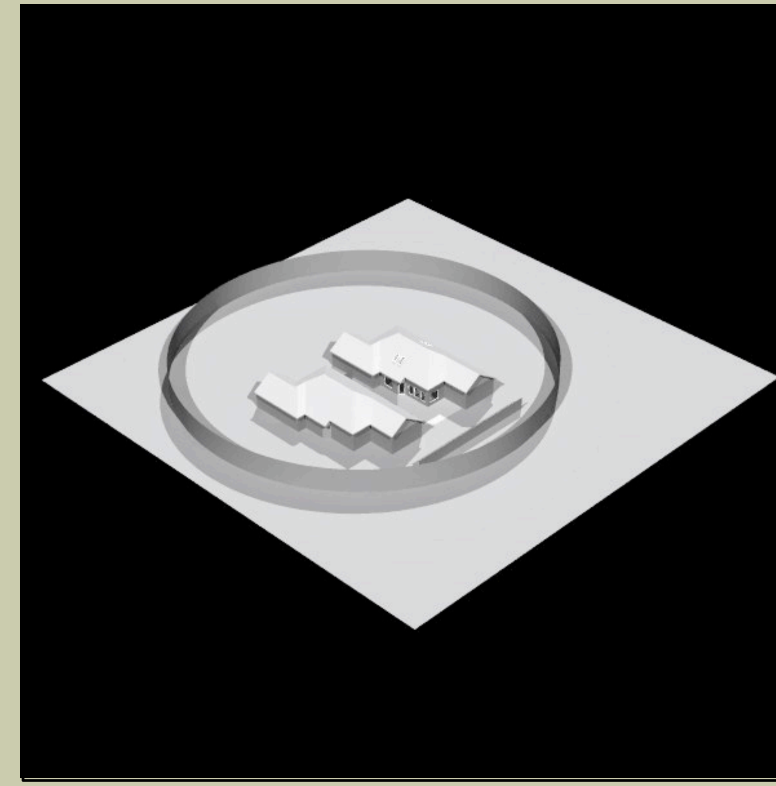

A3_o

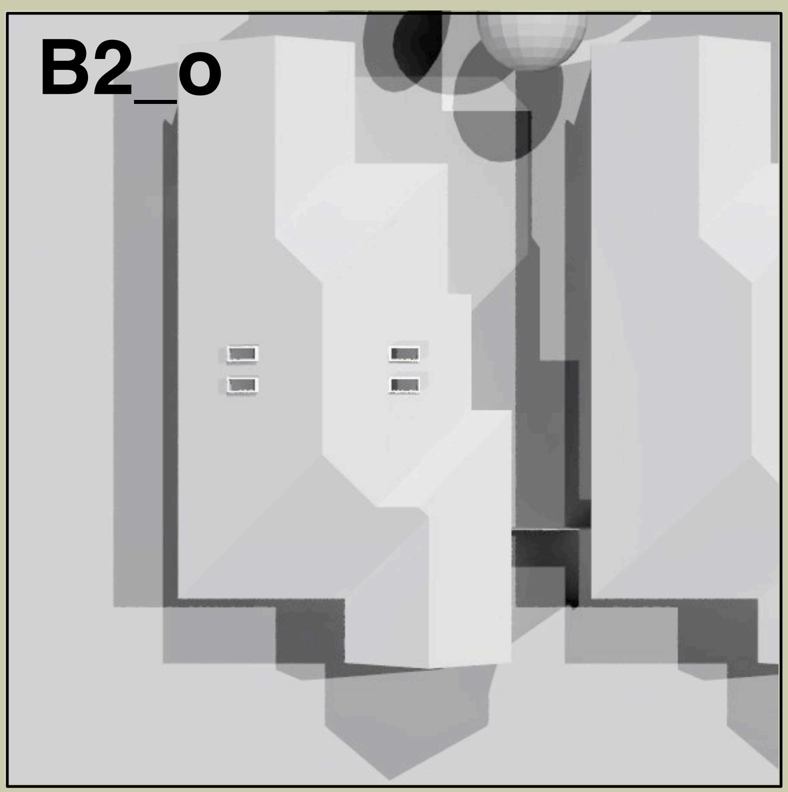

B1_u

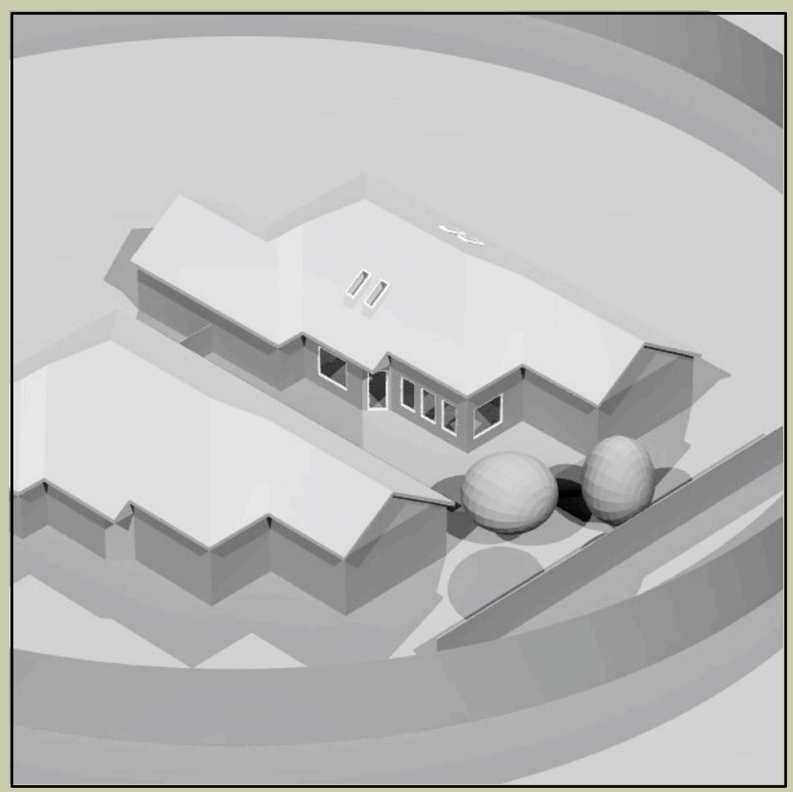

B1_o

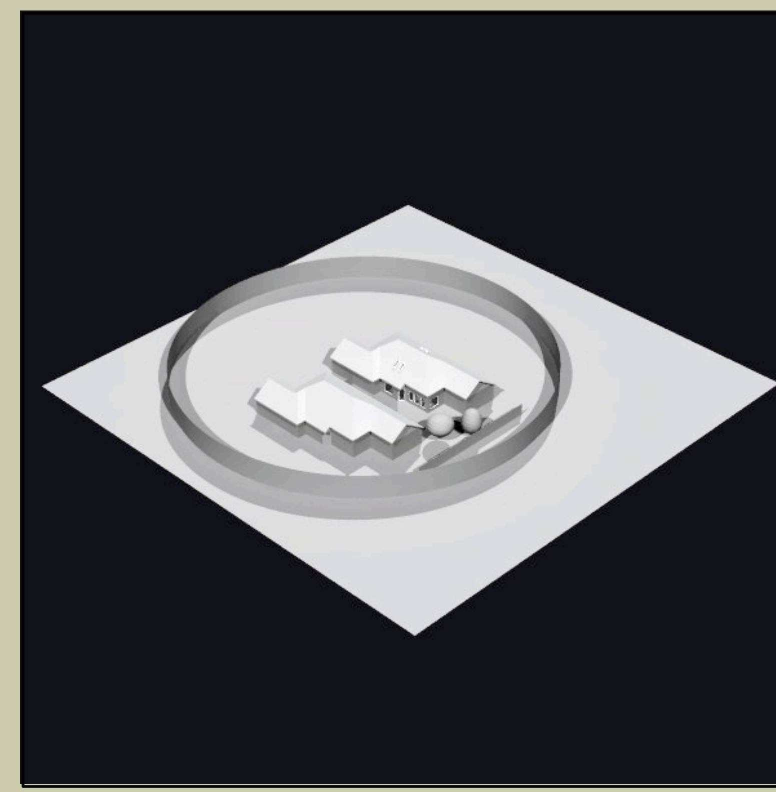

B2_u

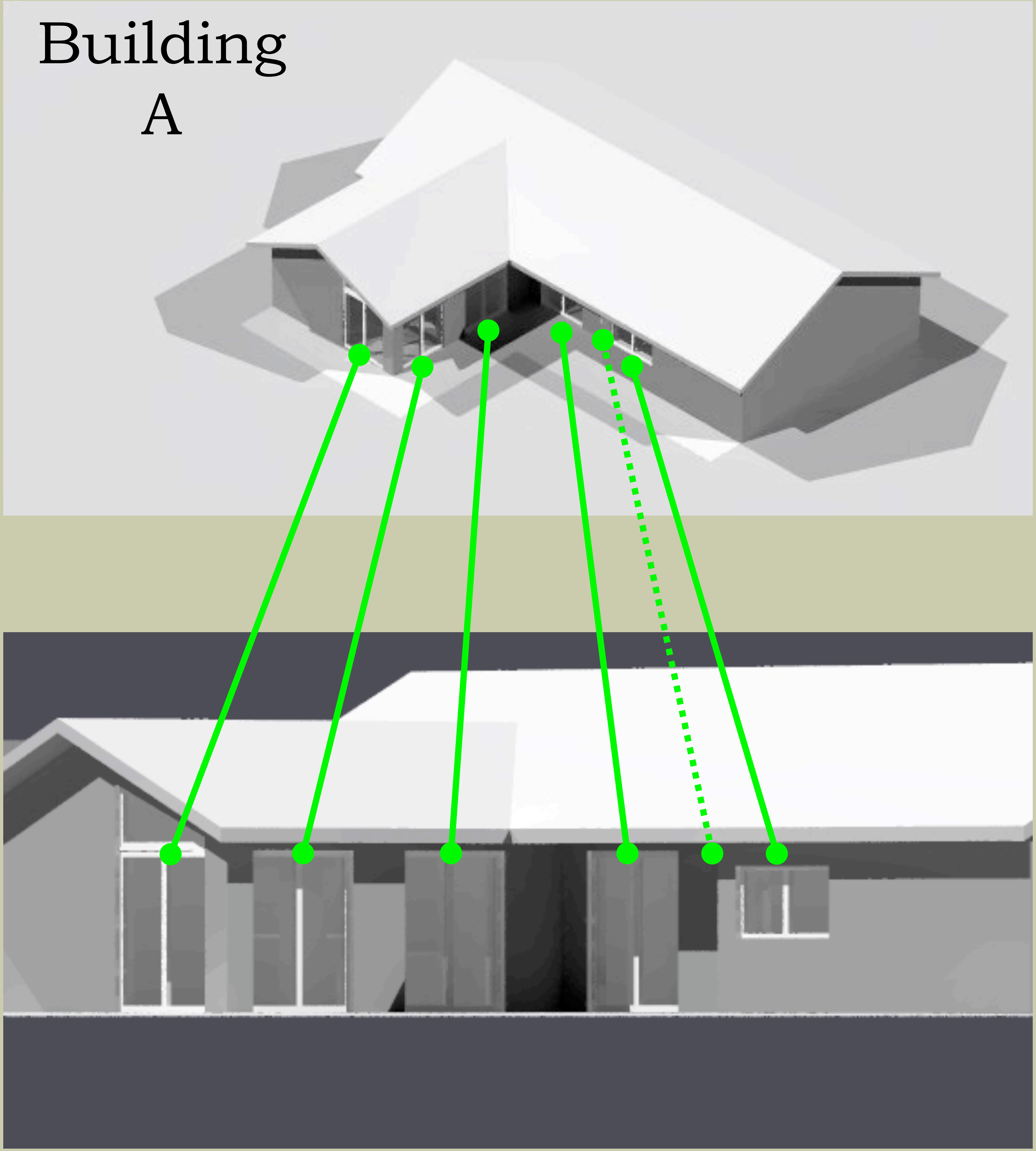


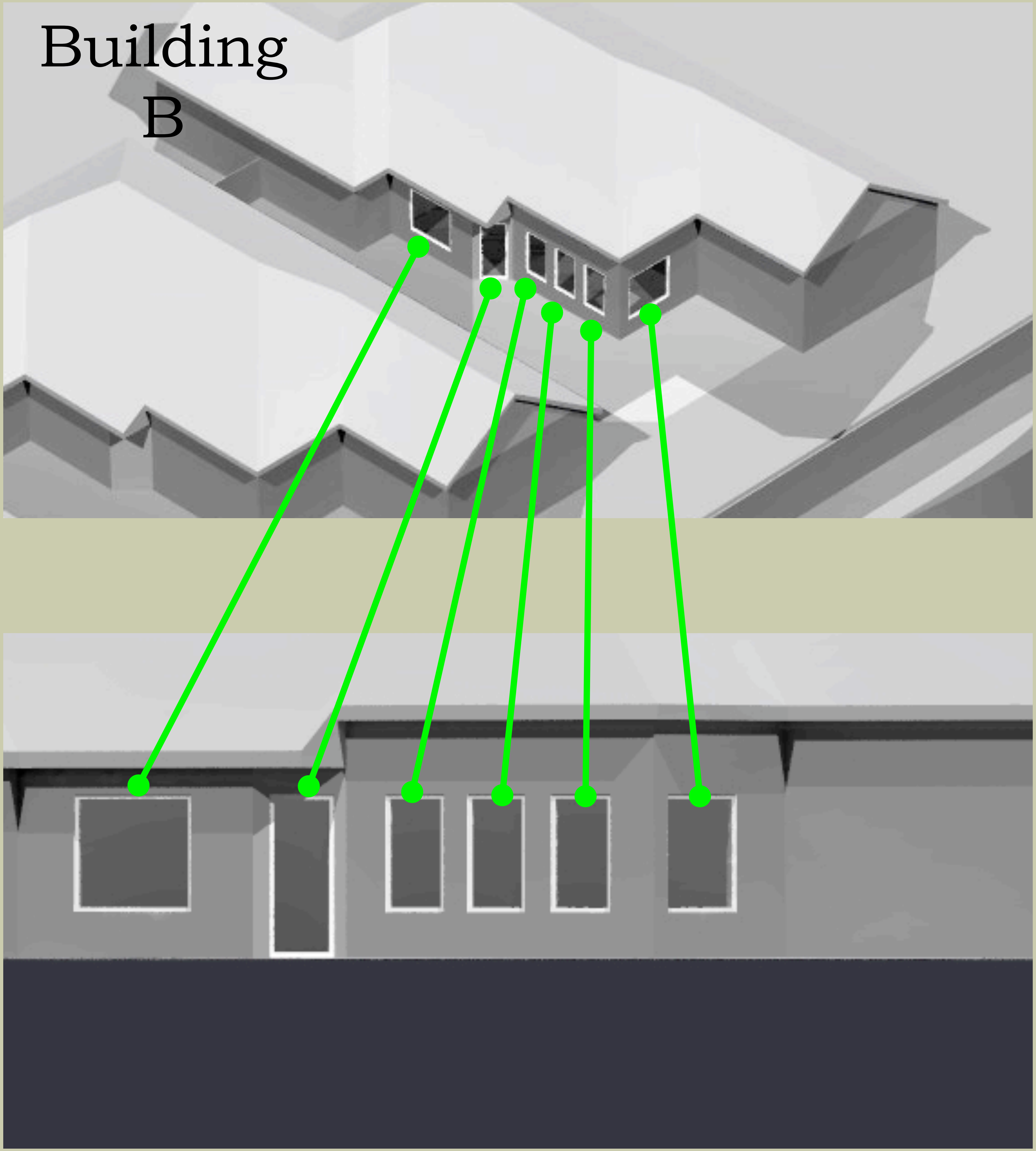


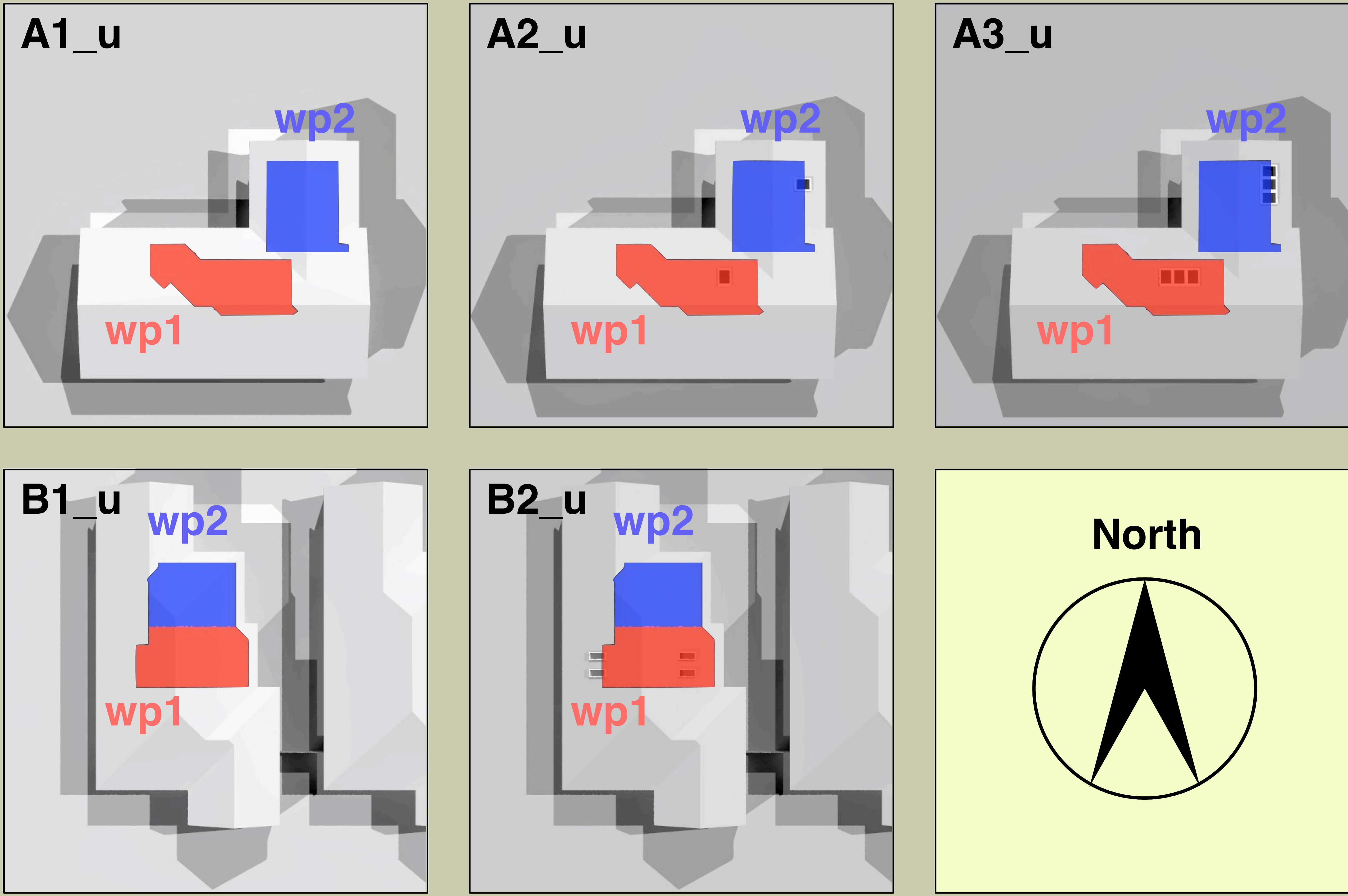

B2_o

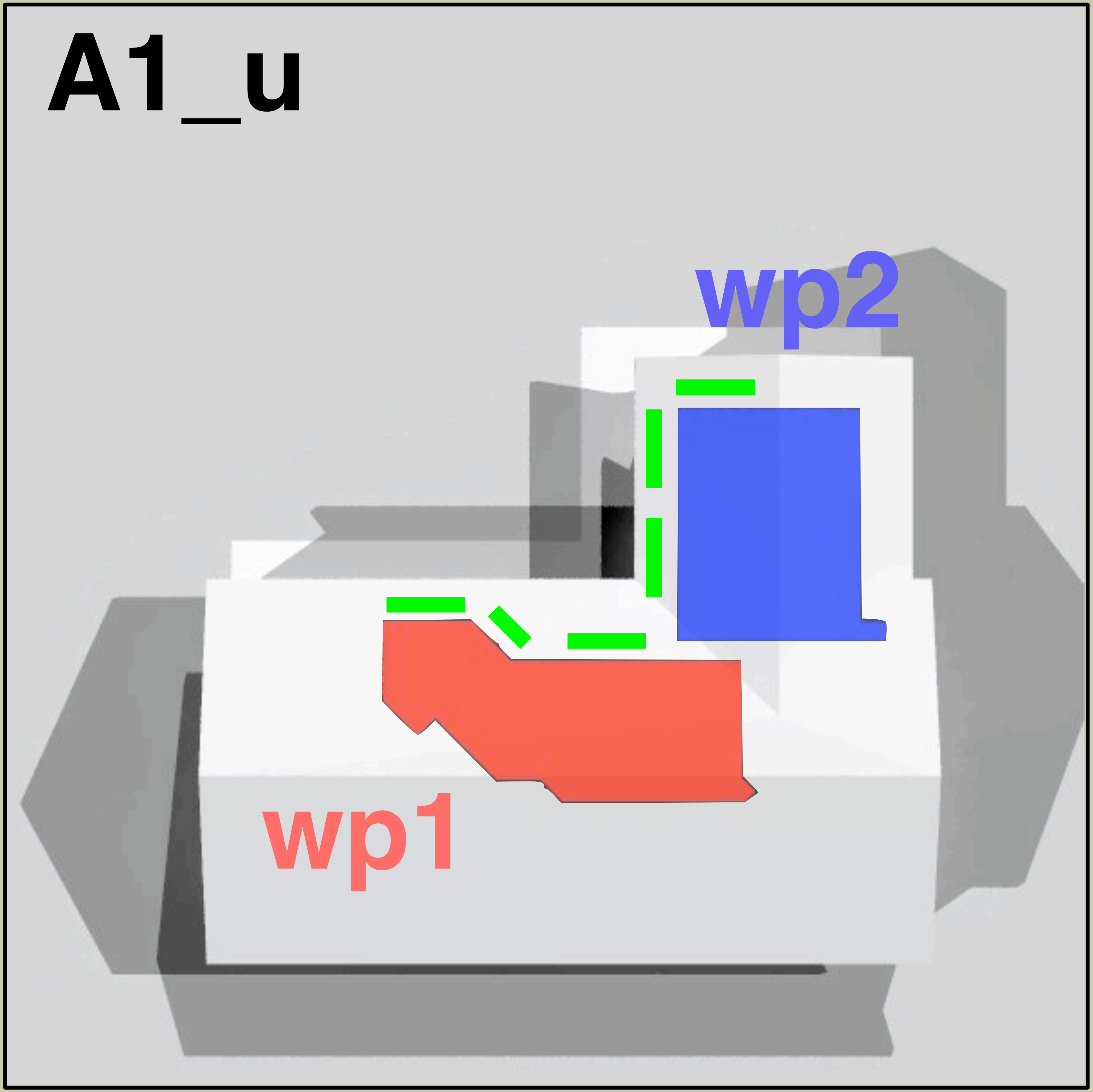


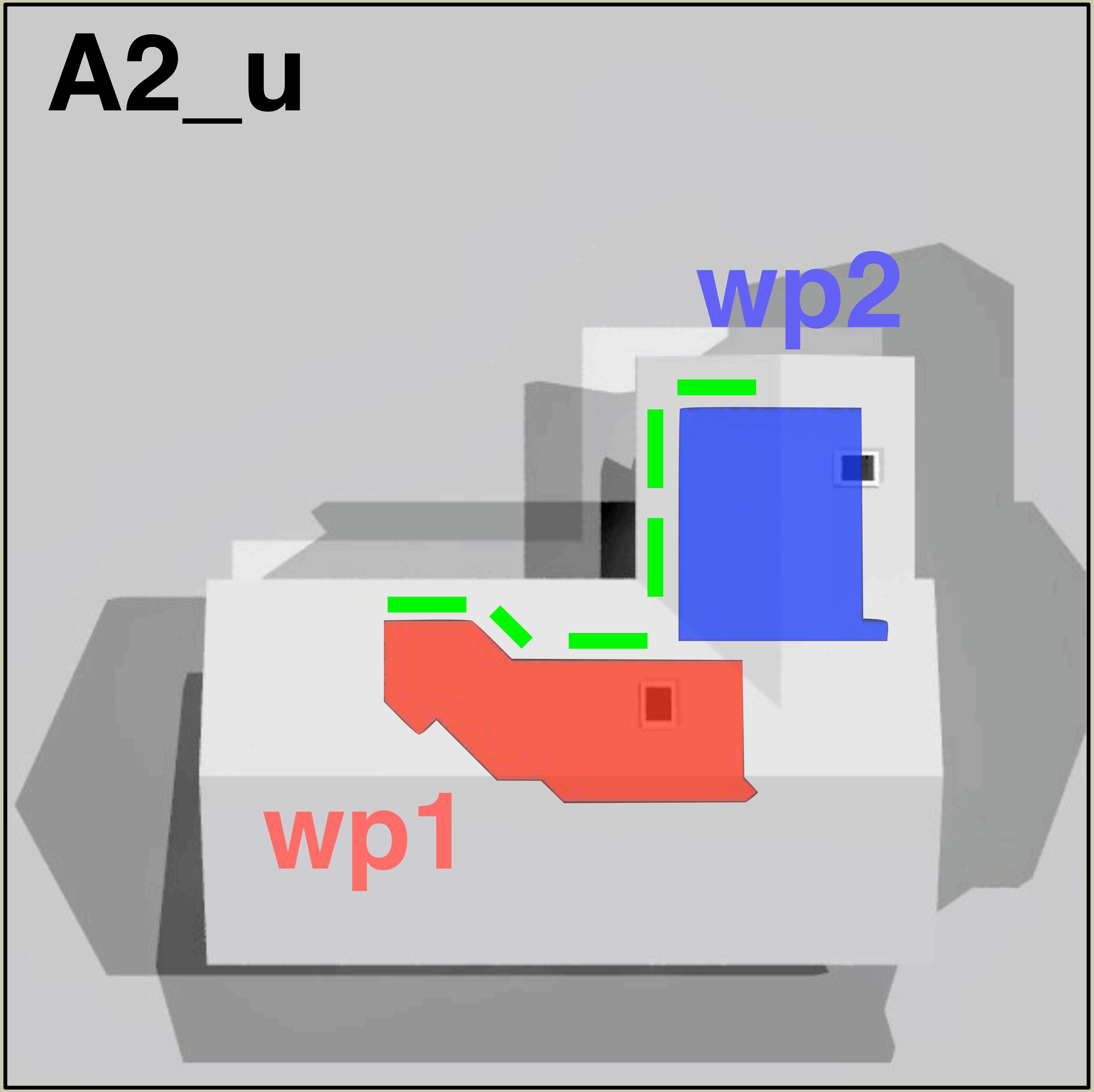


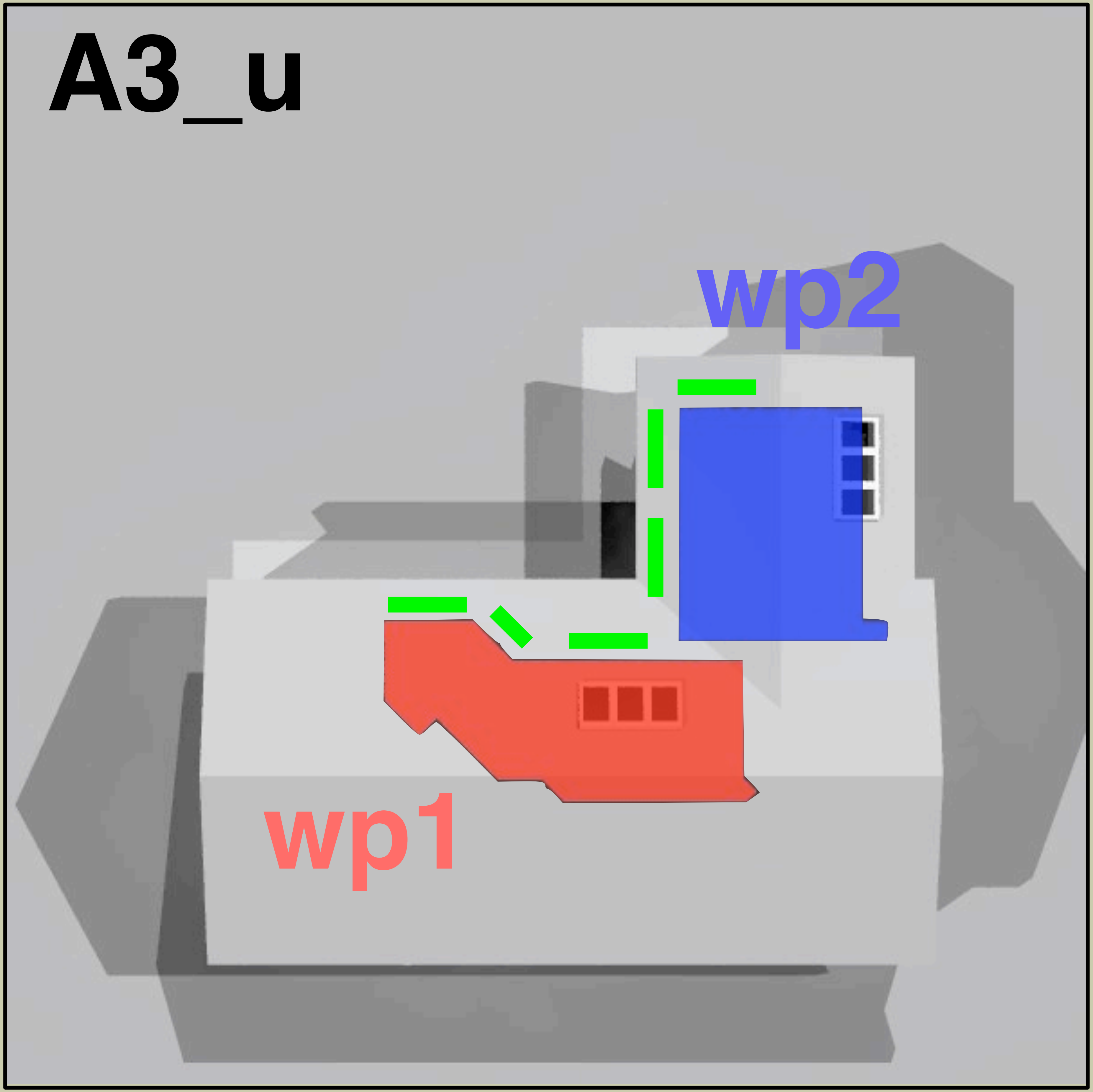

Building
A

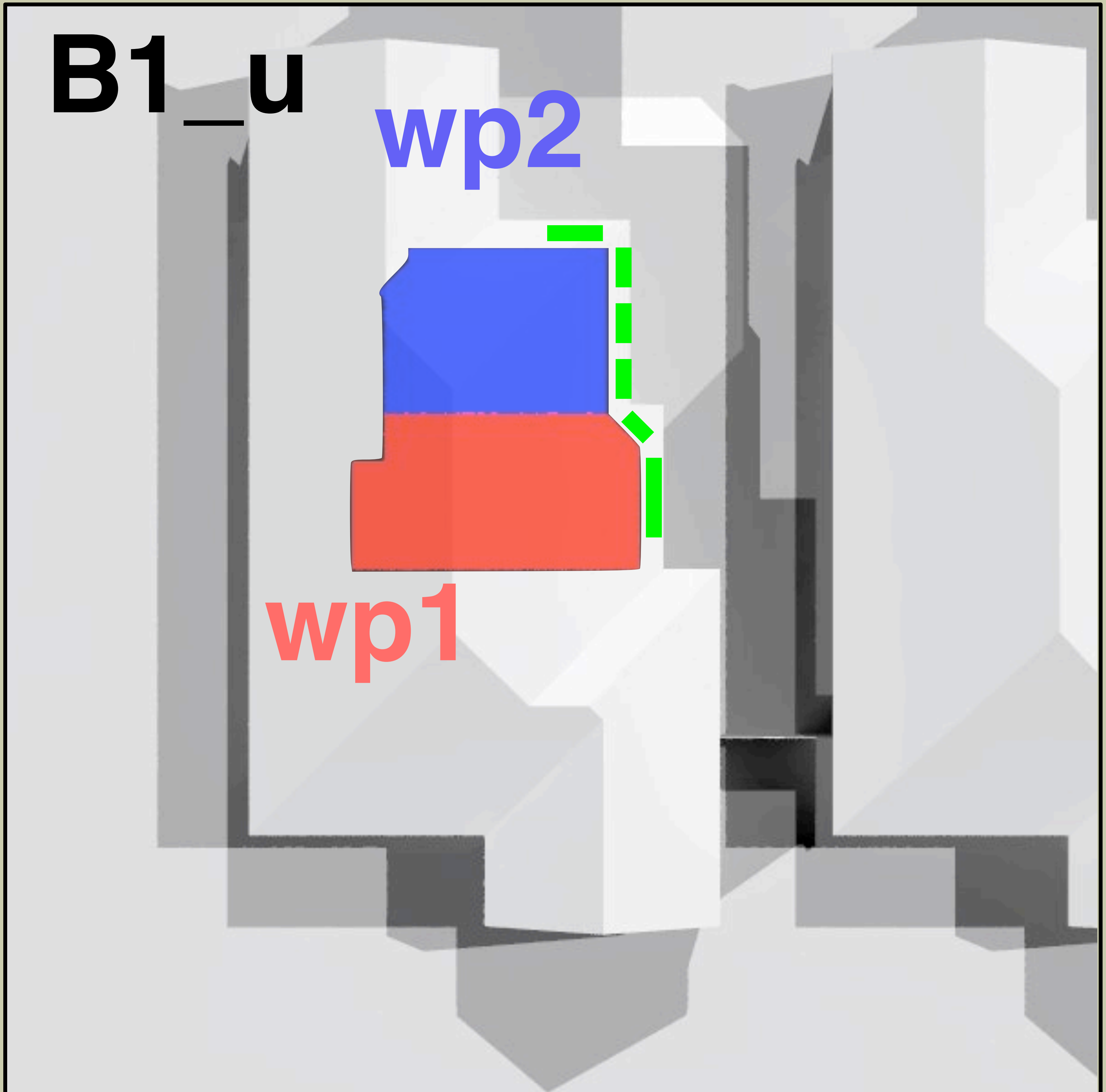

Building
B

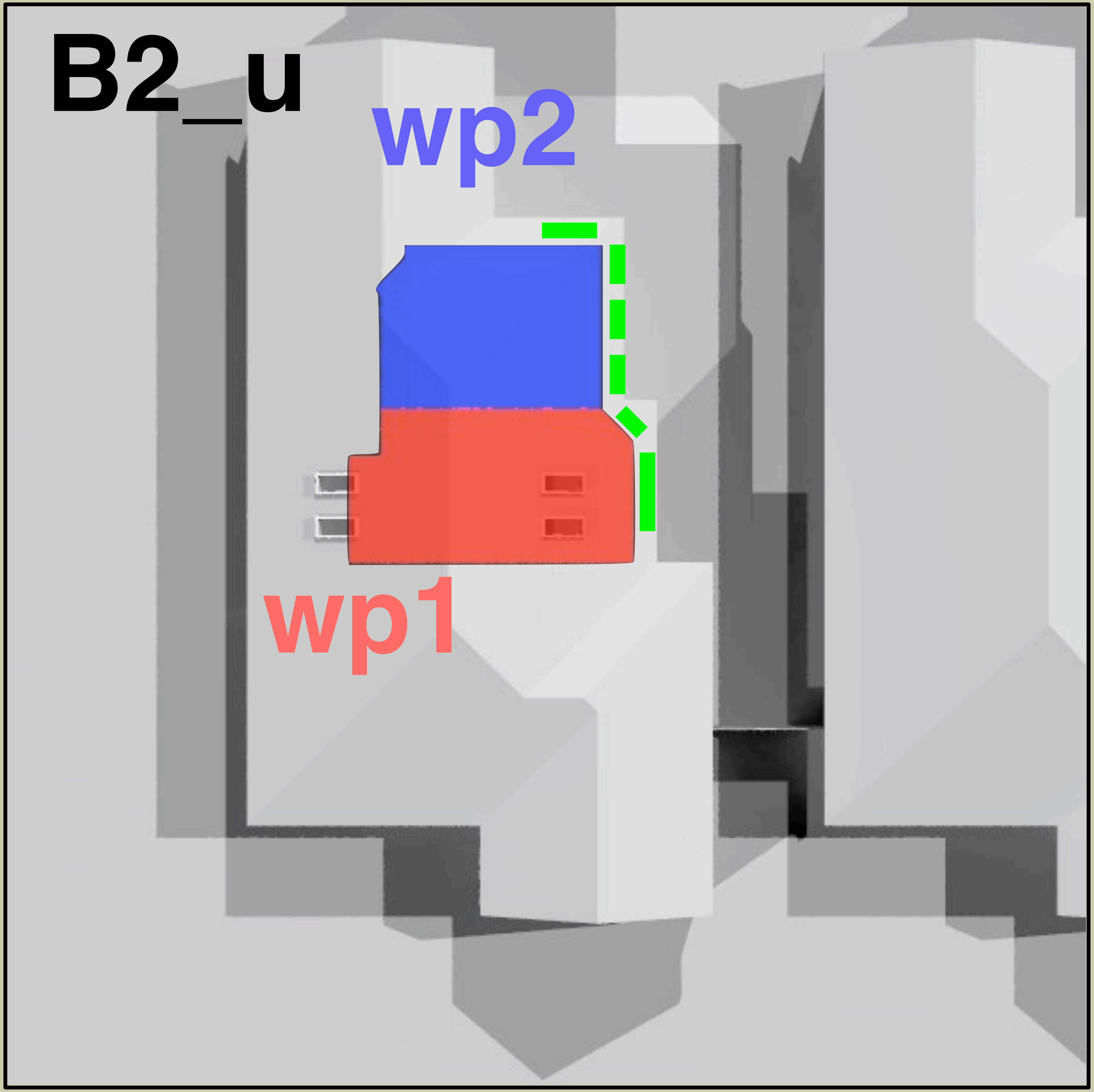

A1_u
wp2
wp1
A2_u
wp2
wp1
A3_u
wp2
wp1
B1_u
wp2
wp1
B2_u
wp2
wp1
North


A1_u
wp2
wp1


A2_u
wp2
wp1


A3_u
wp2
wp1


B1_u
wp2
wp1

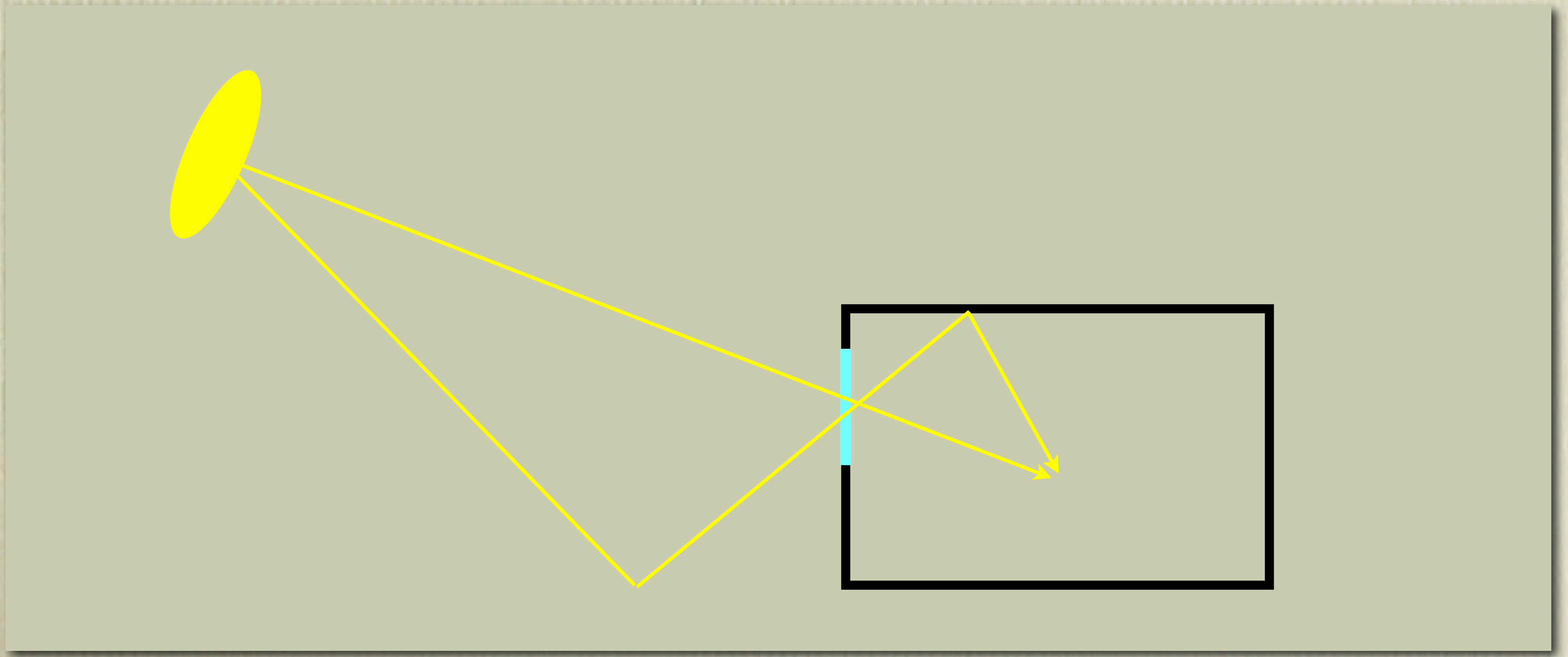

B2_u
wp2
wp1

“Brute-force” method

- Obtain basic climate data from the designated standard meteorological file for that locale.
- Generate a sky luminance distribution using a sky model based on the value for diffuse horizontal illuminance in the climate data.
- Create a description of the sun (position and luminance) from the value of direct normal illuminance in the climate data.
- Compute the internal daylight illuminance distribution - repeat for each time-step.

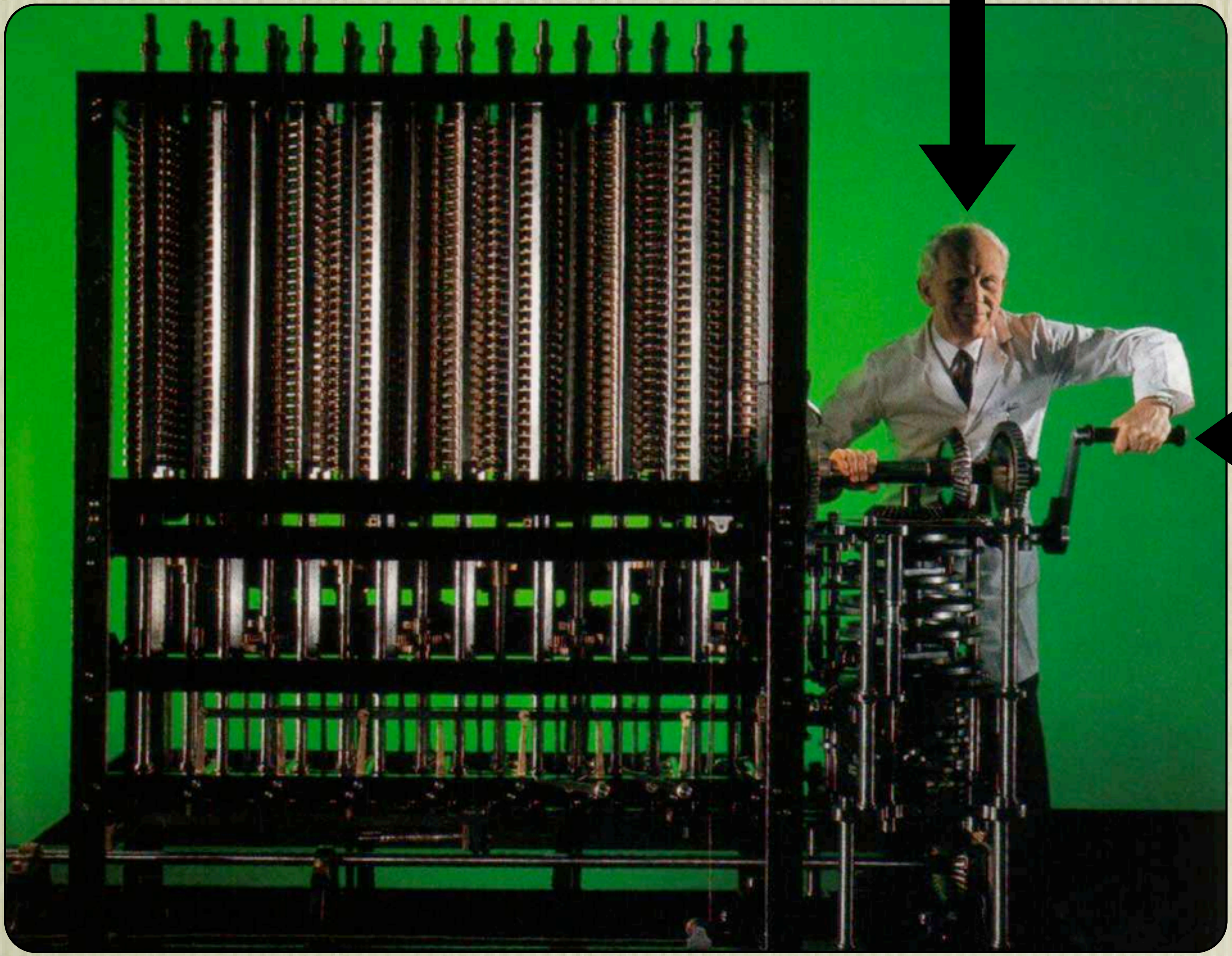
Daylight coefficient method

The daylight coefficient approach requires that the sky be broken into many patches. The internal illuminance at a point that results from a patch of unit-luminance sky is computed and cached.



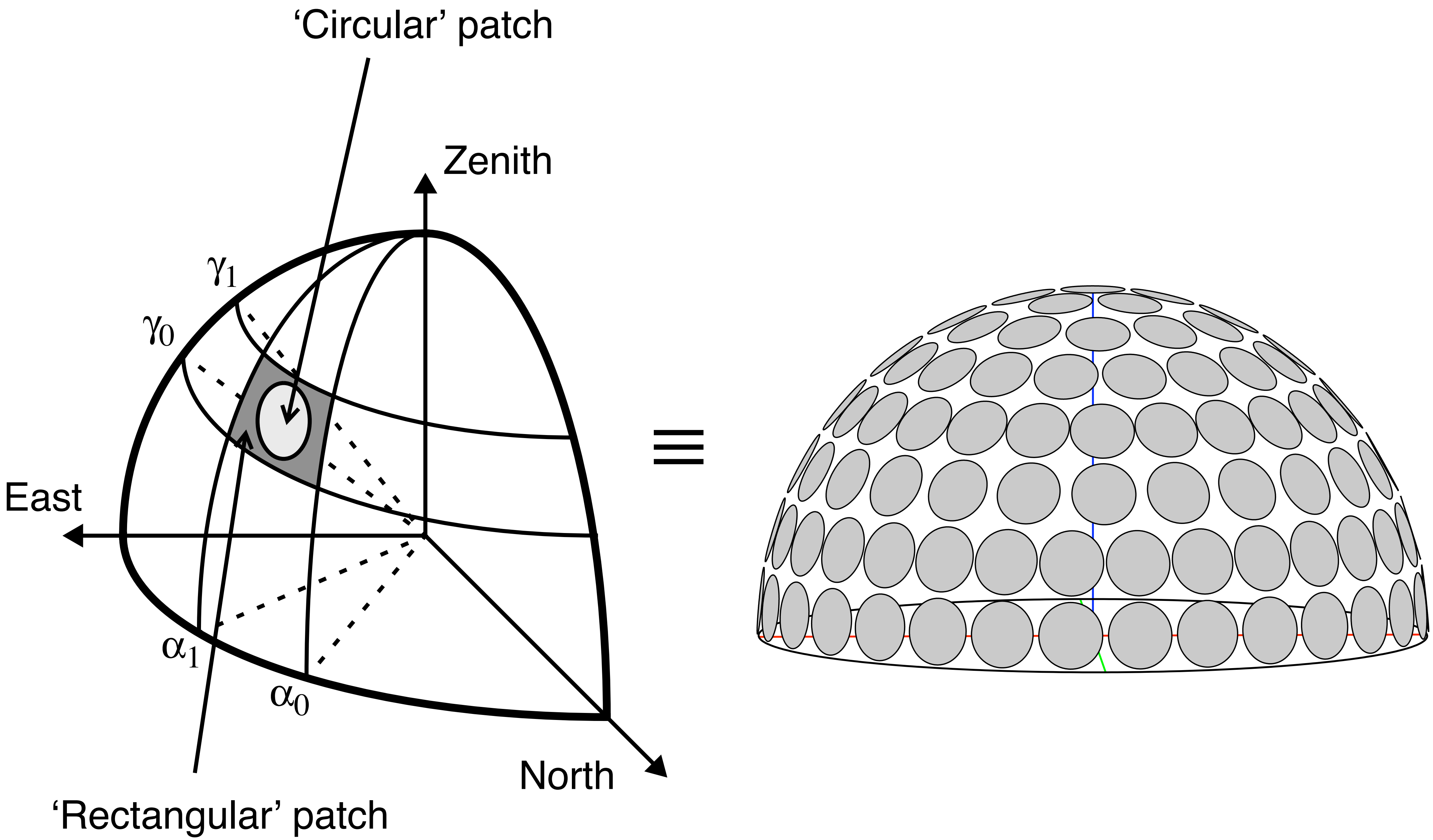
Computational “engine”*

Early-adopter (i.e. still uses the C-shell)

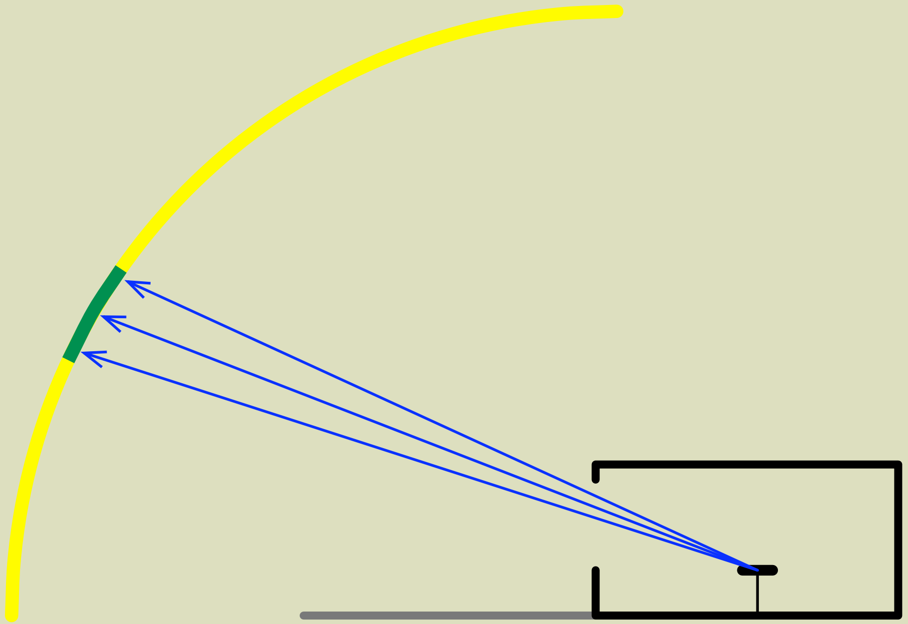


‘user-interface’

**Radiance*, of course!

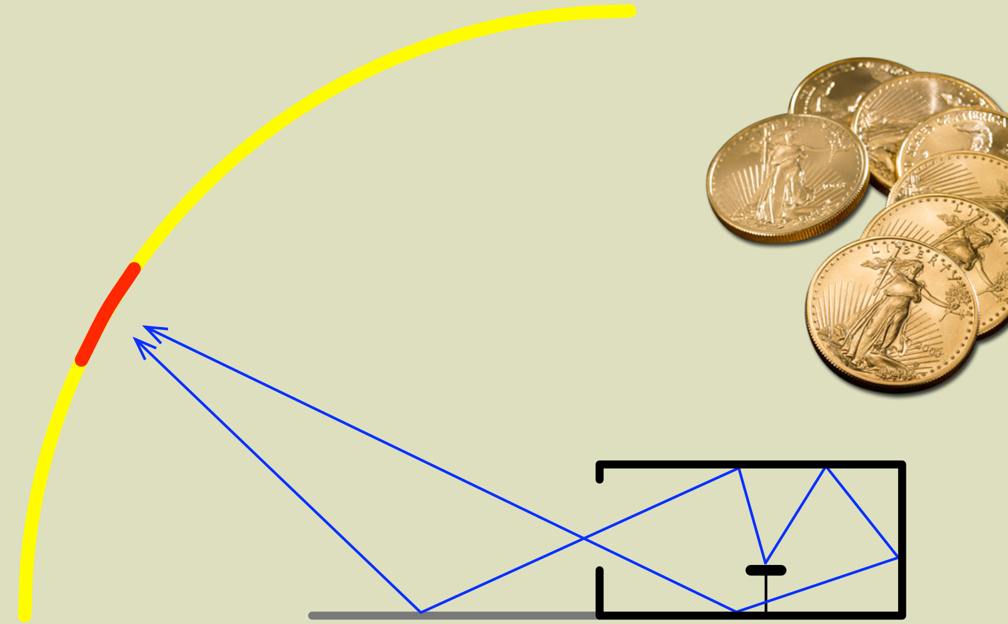

'Circular' patch
Zenith
γ_1
γ_0
East
α_1
α_0
North
'Rectangular' patch
≡

Direct sky component



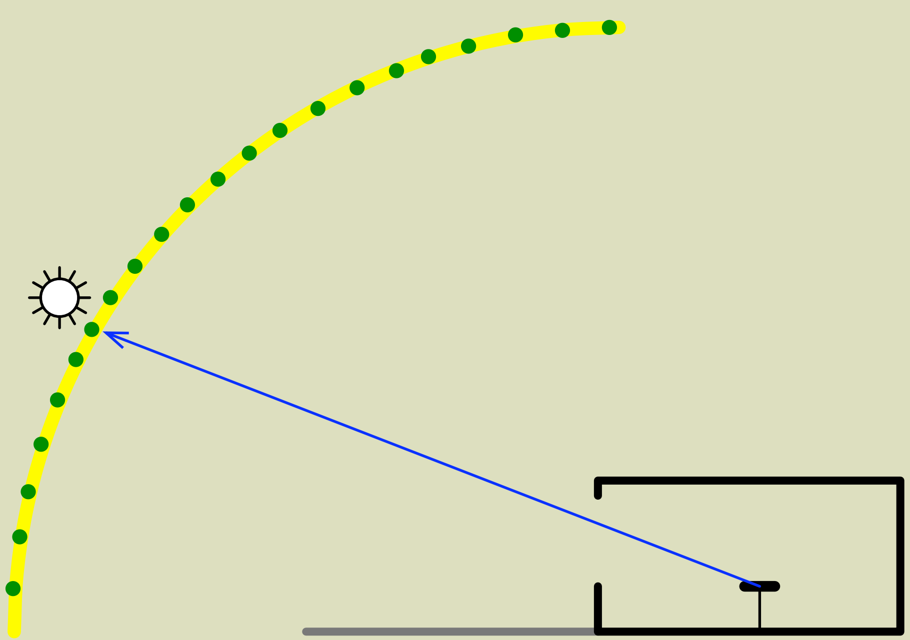
145 ‘rectangular’ **glow** patches

Indirect sky component



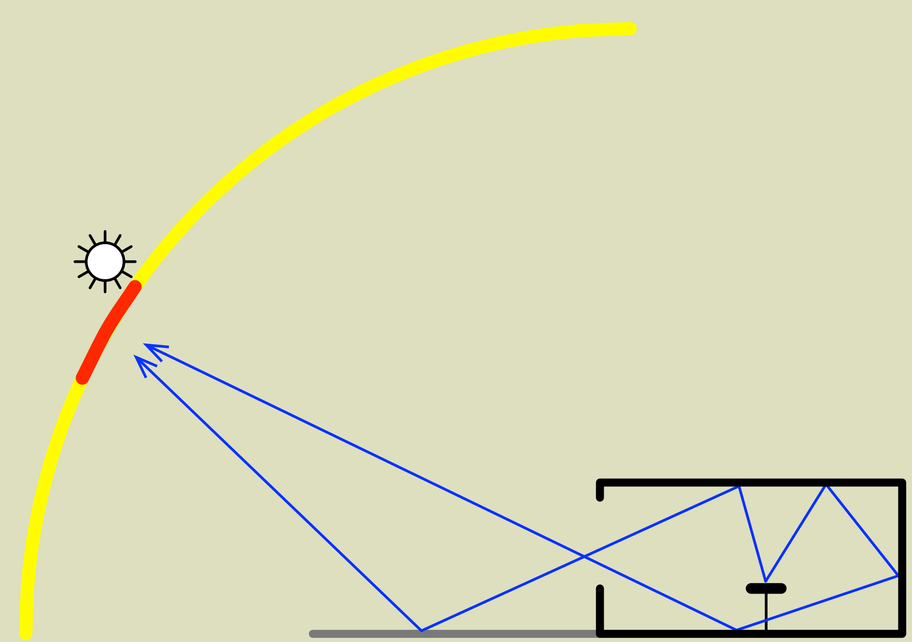
145 ‘circular’ **light** patches

Direct sun component



Use nearest of ~5000 **glow** ‘points’

Indirect sun component



Use nearest indirect **light** patch

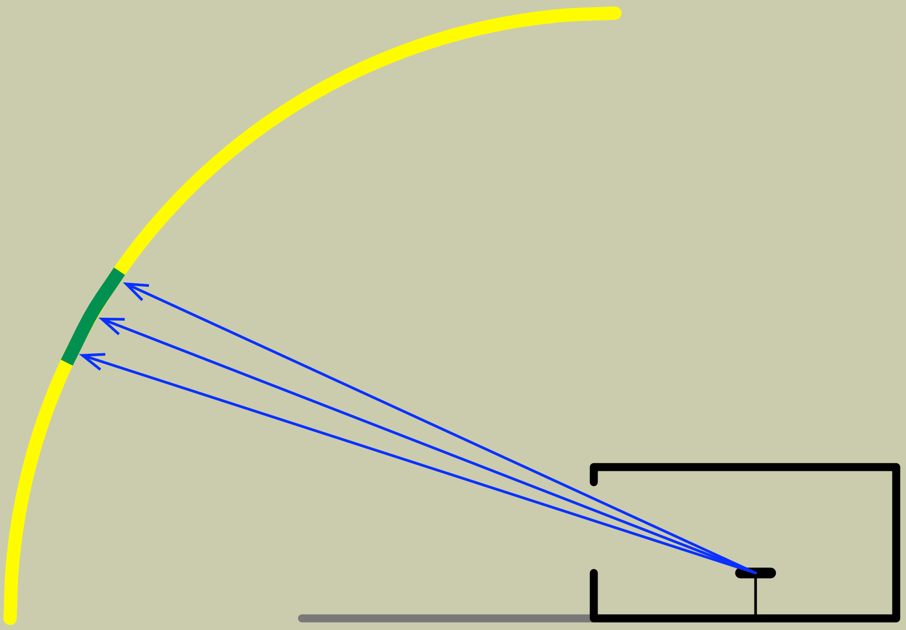
$$
\begin{aligned}
\mathbf{E} \quad = \quad & \mathbf{D}^{d145} \times \mathbf{c}^{145} + \\
& \mathbf{D}^{i145} \times \mathbf{c}^{145} + \\
& \mathbf{D}_{\beta}^{d5k} S^{sun} L^{sun} + \\
& \mathbf{D}_{\beta}^{i145} S^{sun} L^{sun}
\end{aligned}
$$

$$\mathbf{E} = \mathbf{D}^{d145} \times \mathbf{c}^{145} +$$

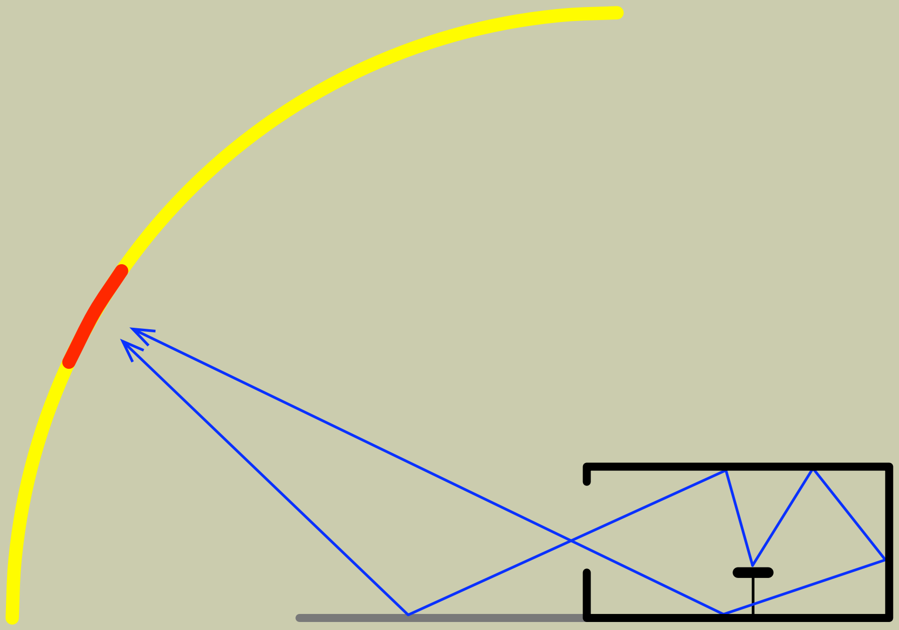
$$\mathbf{D}^{i145} \times \mathbf{c}^{145} +$$

$$\mathbf{D}_{\beta}^{d5k} S^{sun} L^{sun} +$$

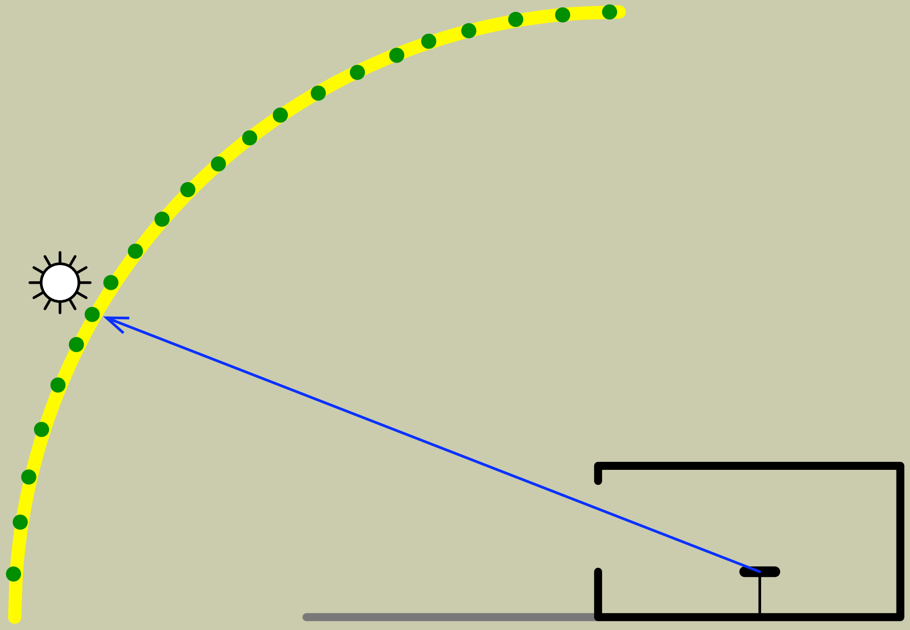
$$\mathbf{D}_{\beta}^{i145} S^{sun} L^{sun}$$



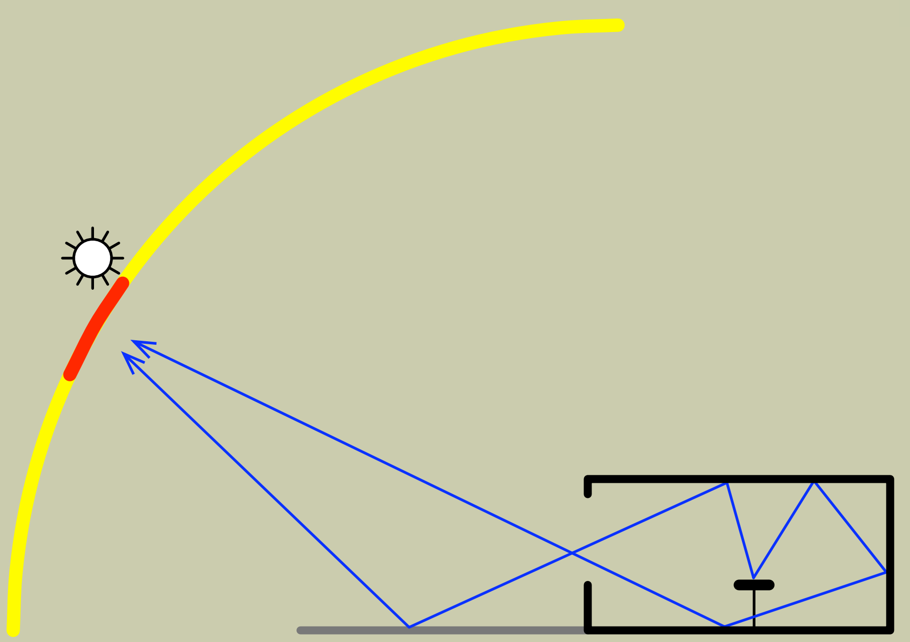
$$\mathbf{E} = \mathbf{D}^{d145} \times \mathbf{c}^{145} + \mathbf{D}^{i145} \times \mathbf{c}^{145} + \mathbf{D}_{\beta}^{d5k} S^{sun} L^{sun} + \mathbf{D}_{\beta}^{i145} S^{sun} L^{sun}$$



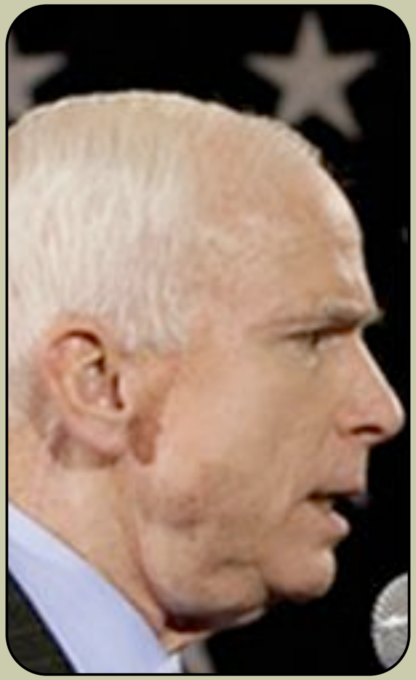
$$\mathbf{E} = \mathbf{D}^{d145} \times \mathbf{c}^{145} + \mathbf{D}^{i145} \times \mathbf{c}^{145} + \mathbf{D}^{d5k}_{\beta} S^{sun} L^{sun} + \mathbf{D}^{i145}_{\beta} S^{sun} L^{sun}$$



$$
\begin{aligned}
\mathbf{E} \quad = \quad & \mathbf{D}^{d145} \times \mathbf{c}^{145} + \\
& \mathbf{D}^{i145} \times \mathbf{c}^{145} + \\
& \mathbf{D}_{\beta}^{d5k} S^{sun} L^{sun} + \\
& \mathbf{D}_{\beta}^{i145} S^{sun} L^{sun}
\end{aligned}
$$

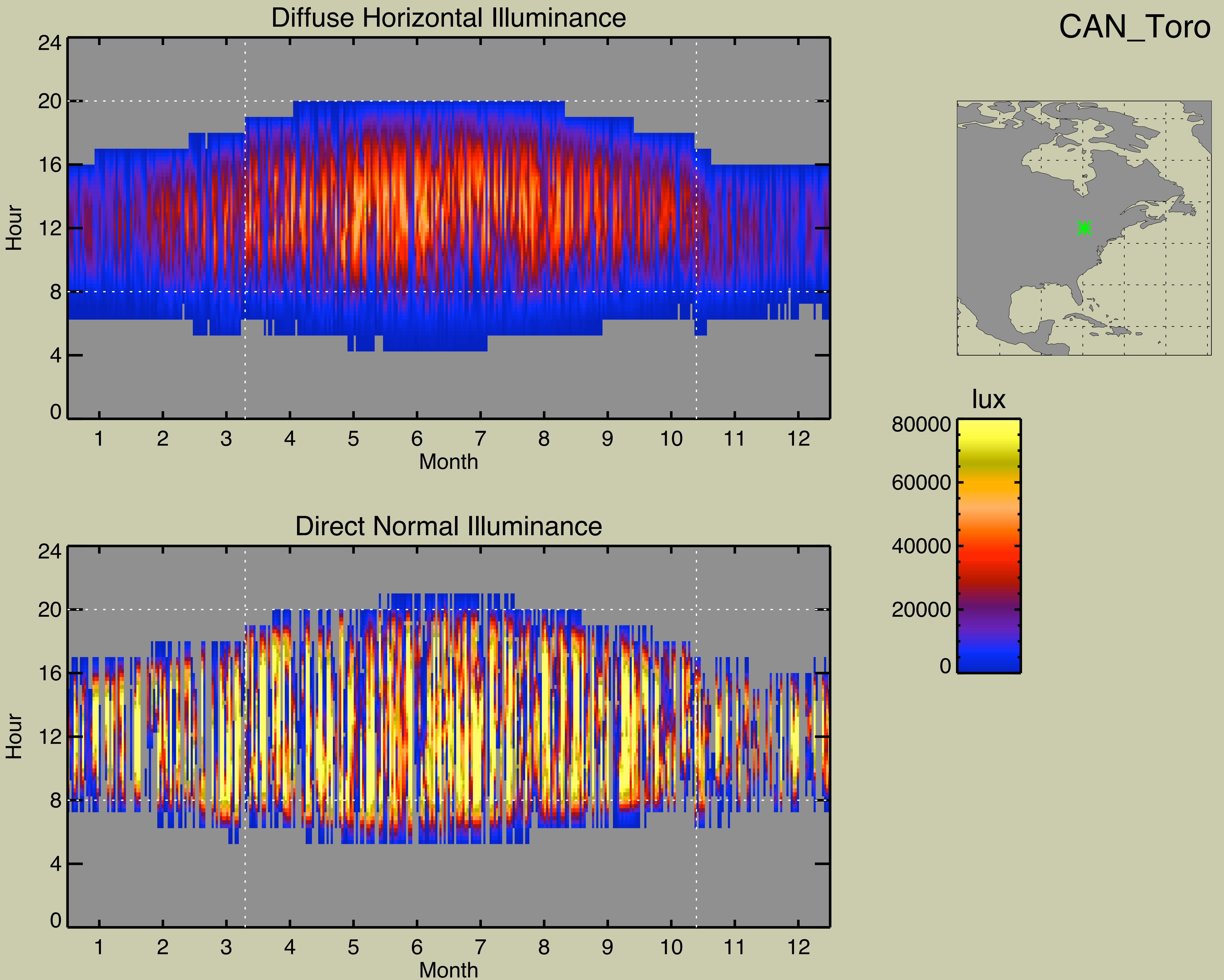


What about DAYSIM and rtcontrib?

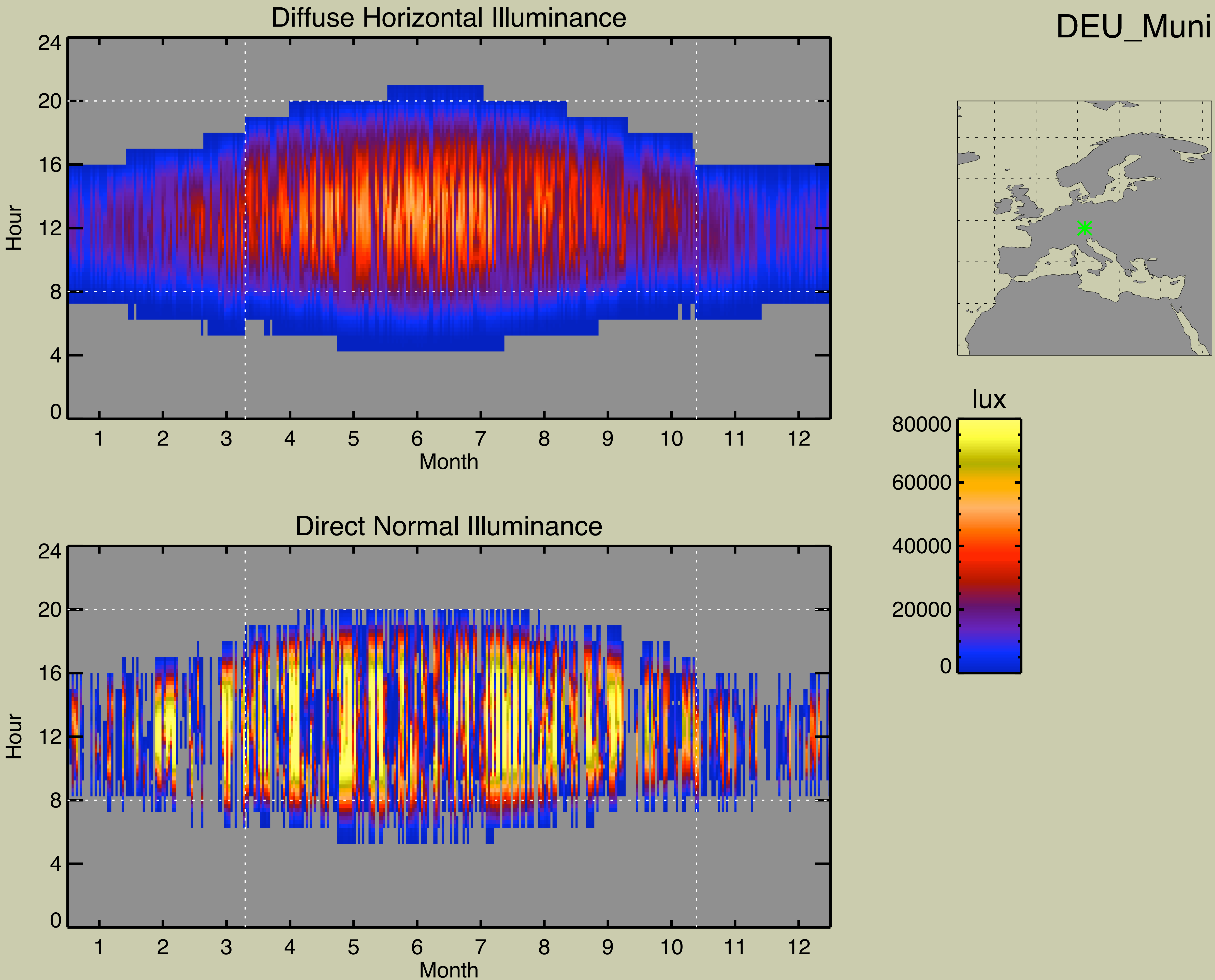


The Climates

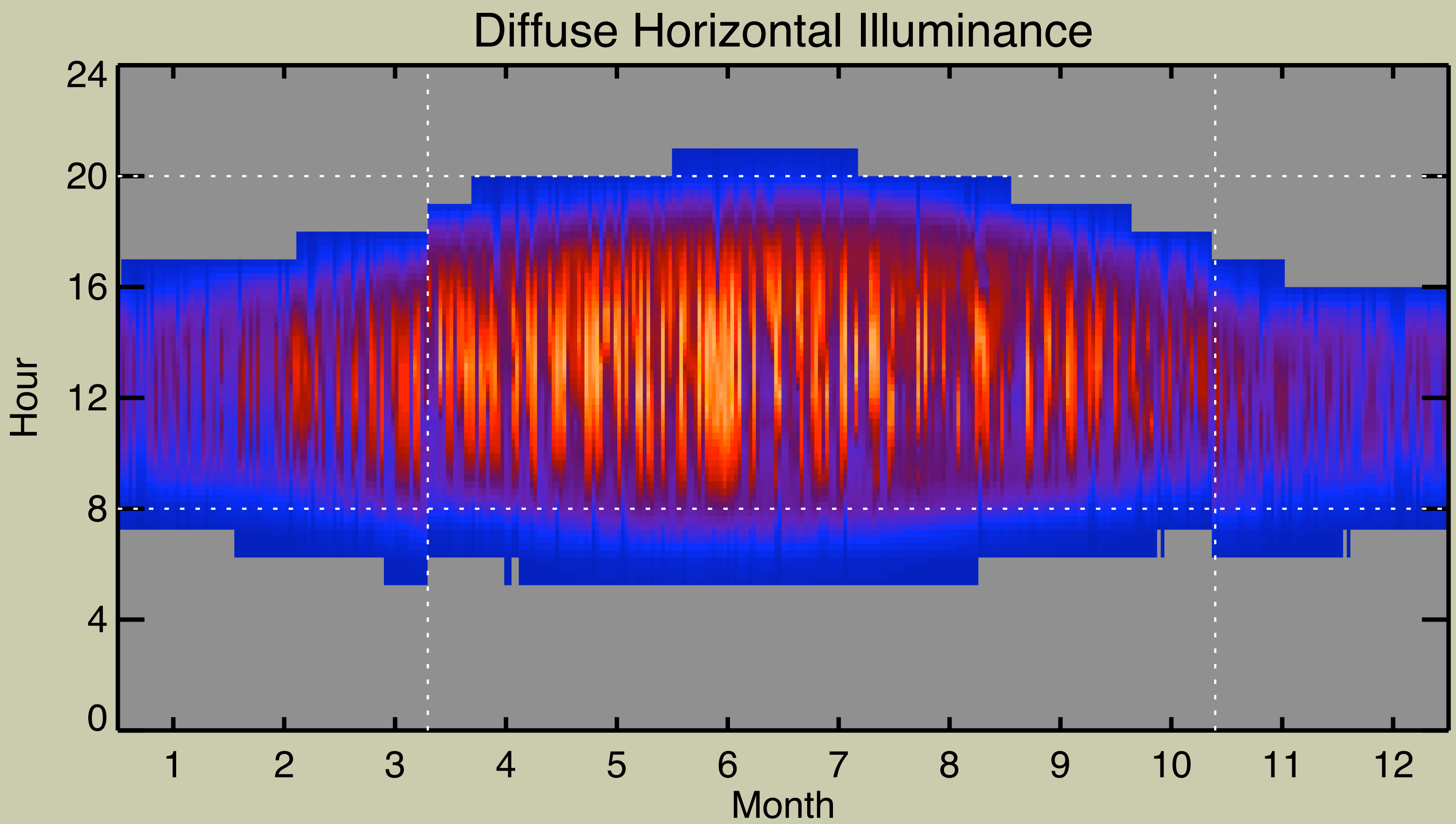
ID	City/ Station	Country	Latitude	Longitude	"Sunny" days
CAN_Toro	Toronto	Canada	43.67	79.63	138
DEU_Muni	Munich	Germany	48.13	-11.70	78
FRA_Nice	Nice	France	43.65	-7.20	182
GBR_Finn	Finningley	UK	53.48	1.00	39
USA_LosA	Los Angeles	USA	33.93	118.40	221
USA_Seat	Seattle	USA	47.45	122.30	109

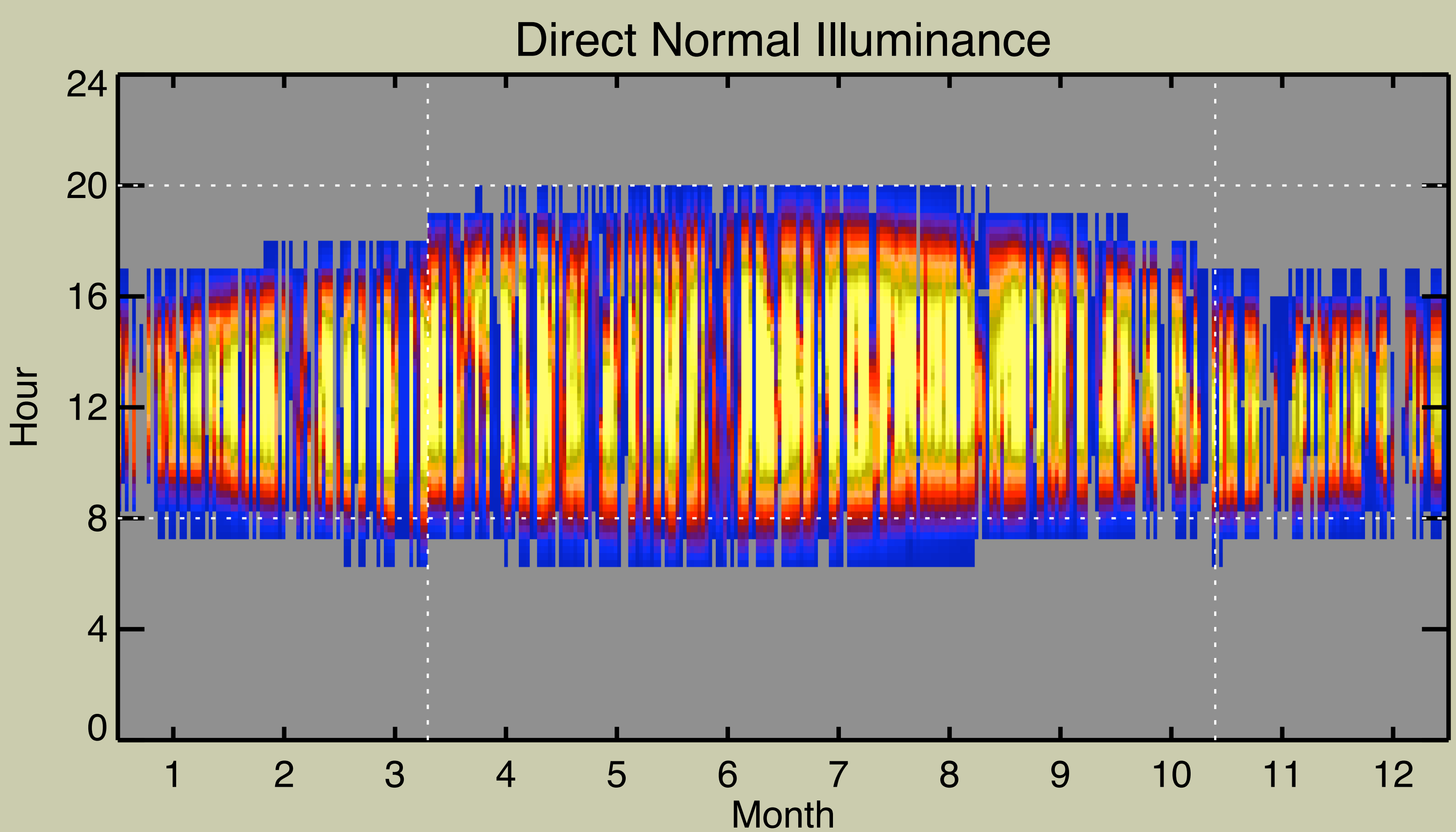


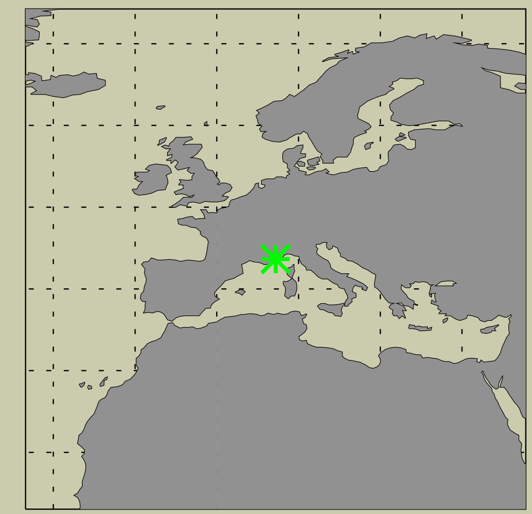
Diffuse Horizontal Illuminance
Hour
Month
Direct Normal Illuminance
Hour
Month
CAN_Toro
lux
80000
60000
40000
20000
0

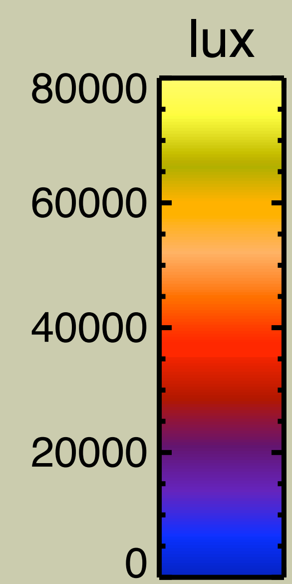

DEU_Muni
Diffuse Horizontal Illuminance
Direct Normal Illuminance
Hour
Month
lux
0
20000
40000
60000
80000

FRA_Nice

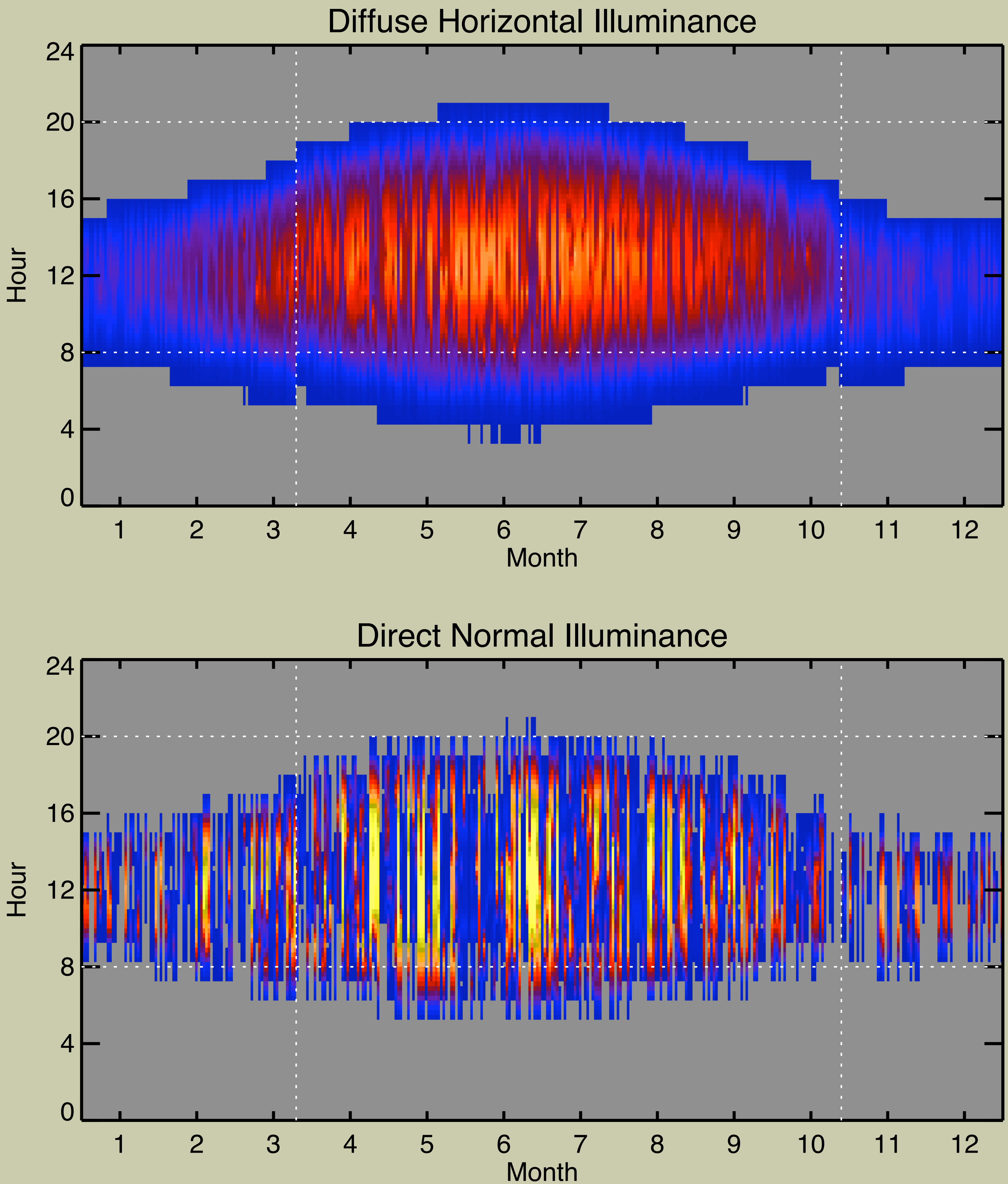

Diffuse Horizontal Illuminance
Hour
0
4
8
12
16
20
24
Month
1
2
3
4
5
6
7
8
9
10
11
12


Direct Normal Illuminance
Hour
0
4
8
12
16
20
24
Month
1
2
3
4
5
6
7
8
9
10
11
12

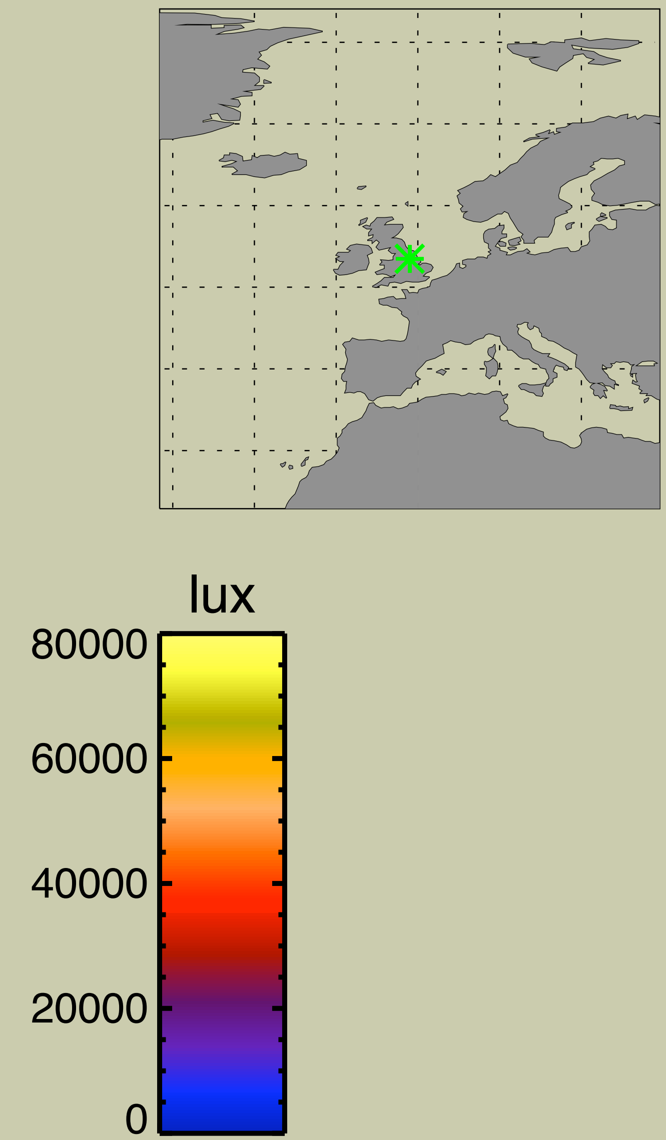



lux
80000
60000
40000
20000
0

GBR_Finn

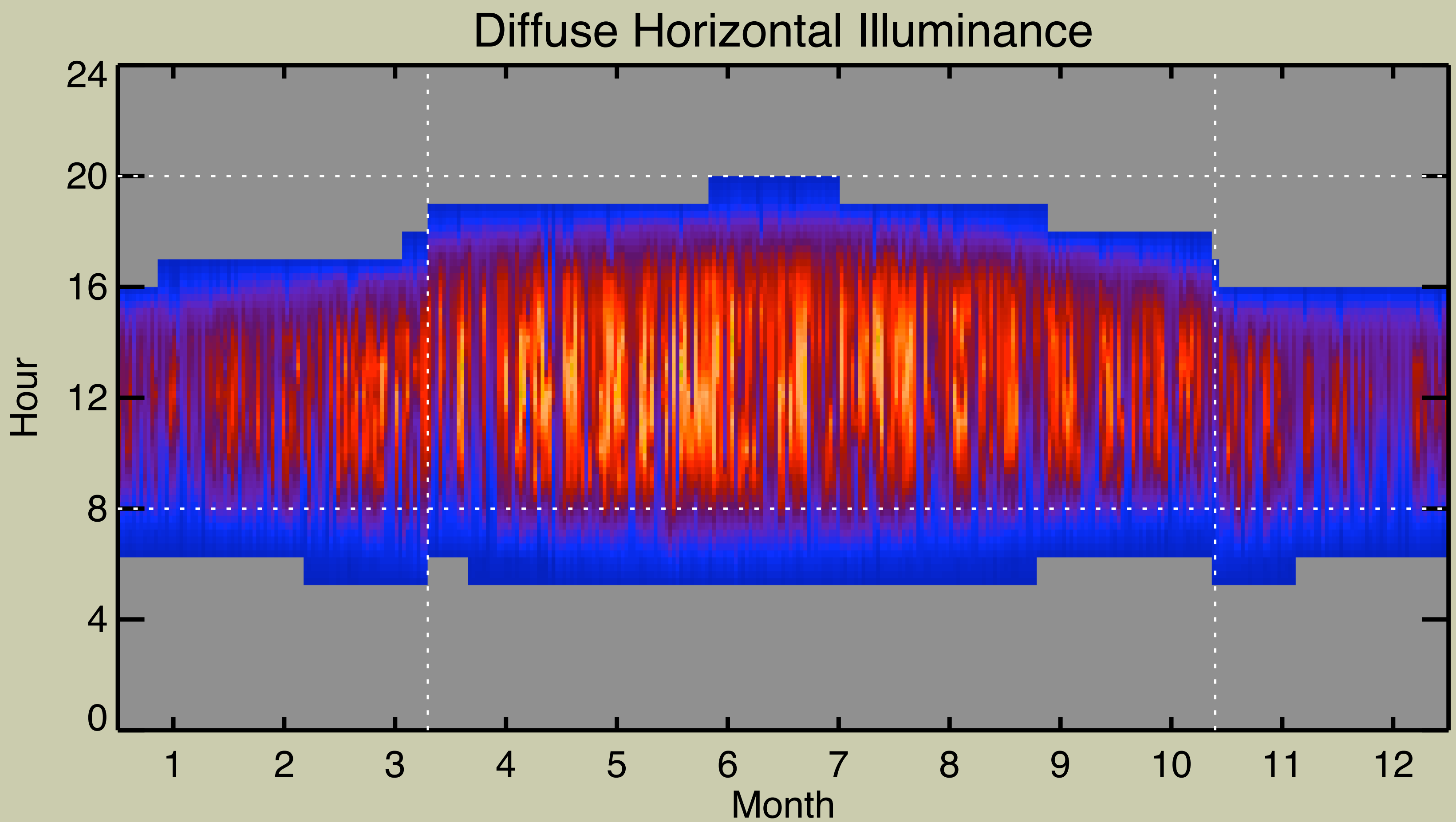


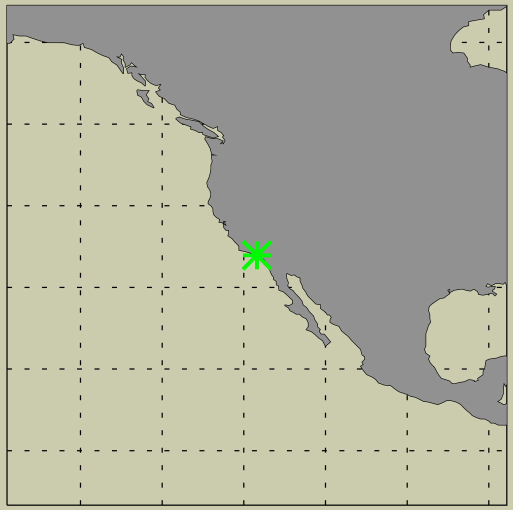
Diffuse Horizontal Illuminance
Hour
24
20
16
12
8
4
0
1
2
3
4
5
6
7
8
9
10
11
12
Month
Direct Normal Illuminance
Hour
24
20
16
12
8
4
0
1
2
3
4
5
6
7
8
9
10
11
12
Month

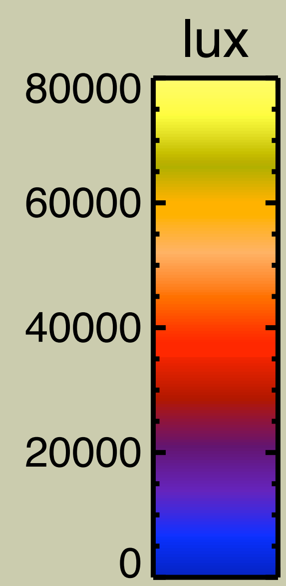


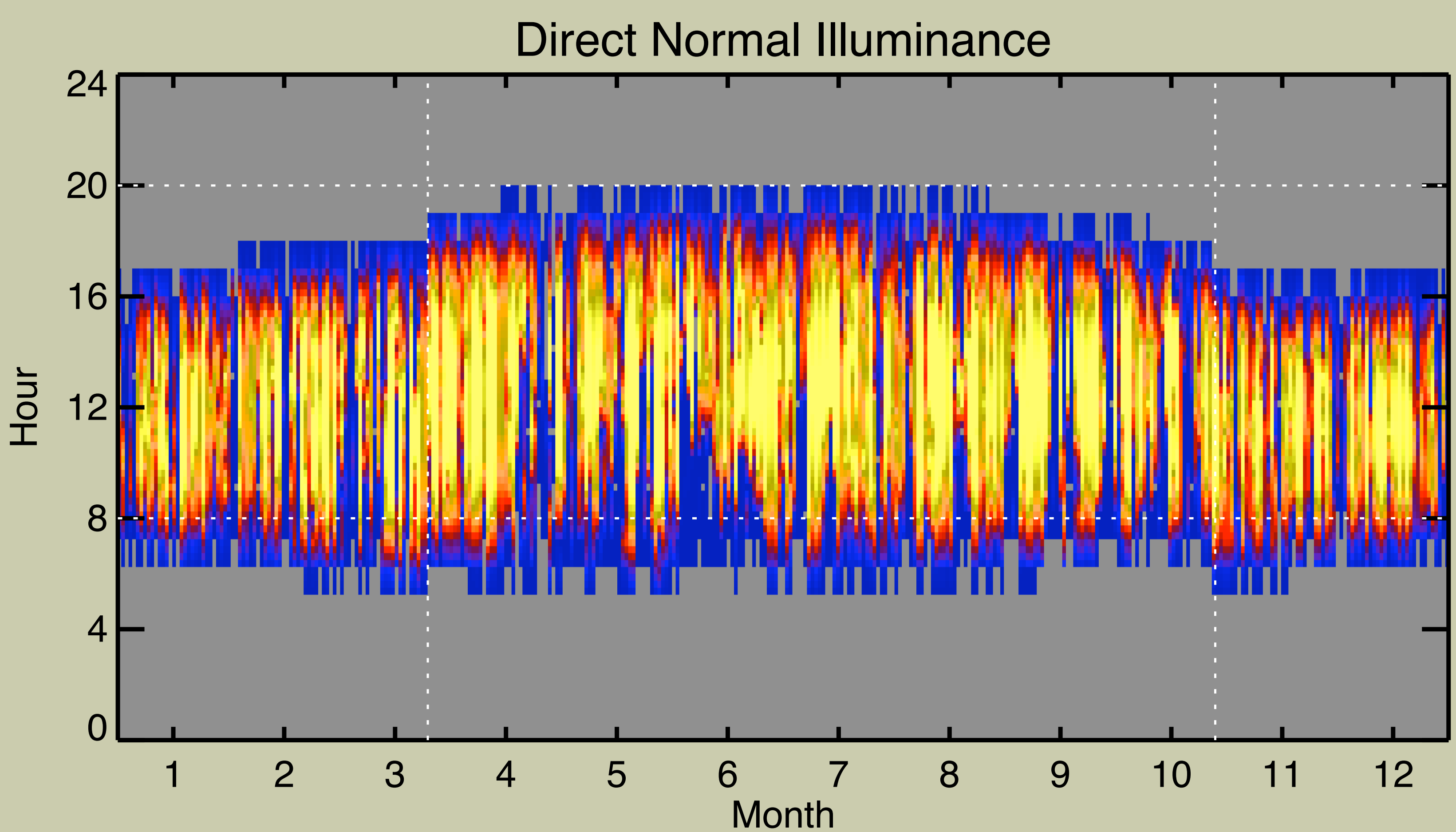
lux
80000
60000
40000
20000
0

USA_LosA


Diffuse Horizontal Illuminance
Hour
24
20
16
12
8
4
0
1 2 3 4 5 6 7 8 9 10 11 12
Month

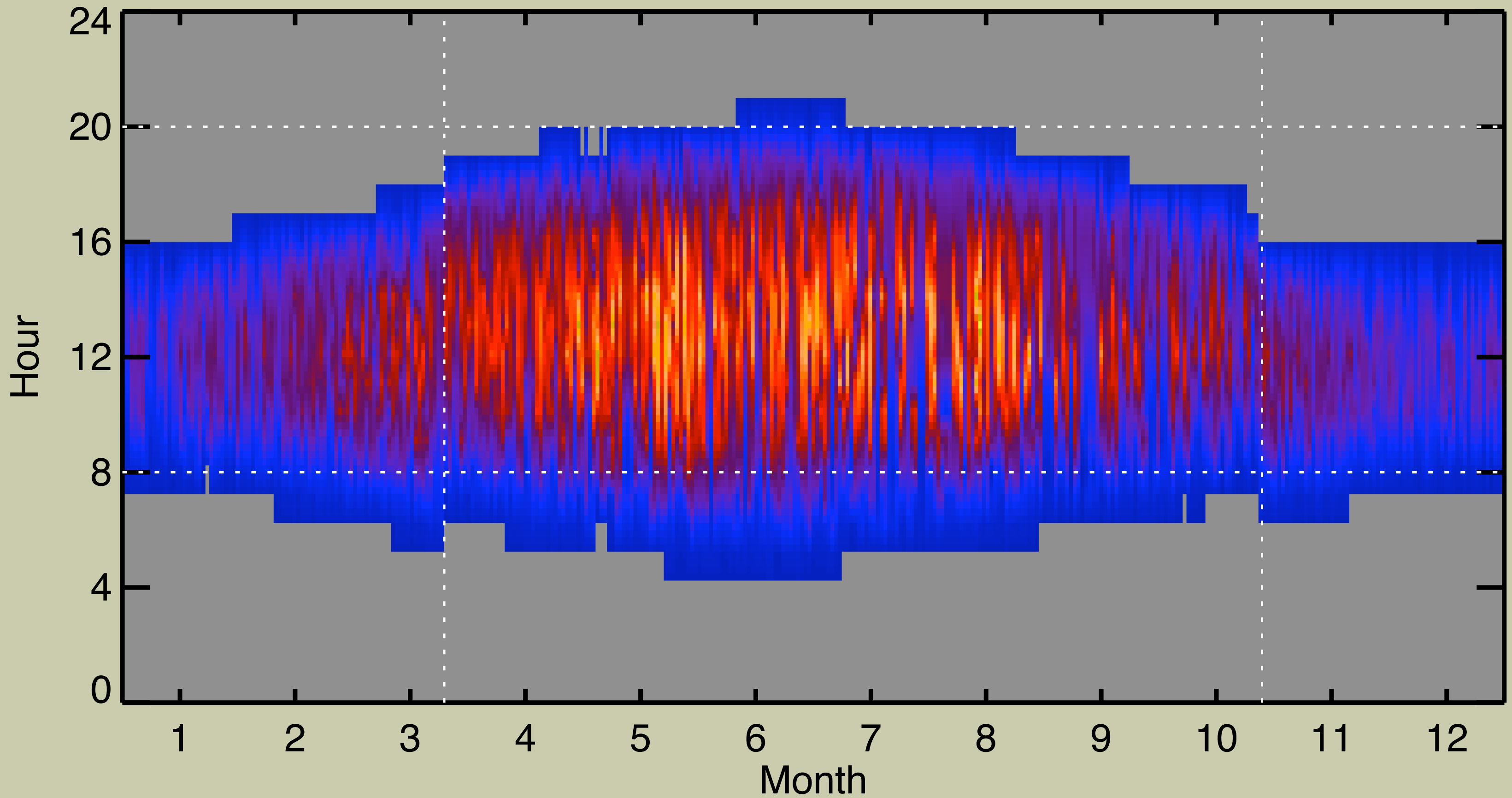


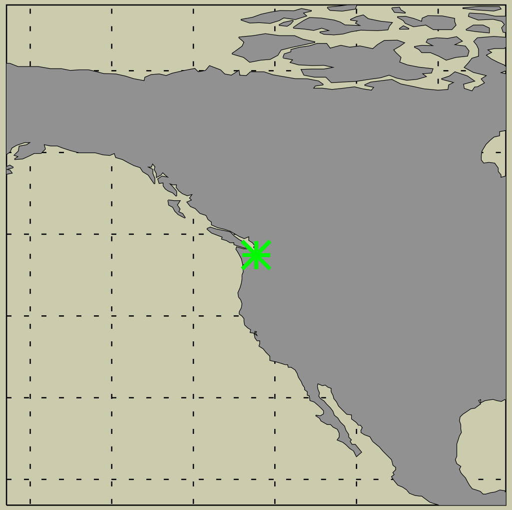

lux
80000
60000
40000
20000
0

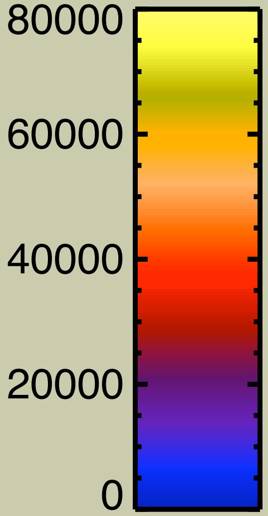

Direct Normal Illuminance
Hour
24
20
16
12
8
4
0
1 2 3 4 5 6 7 8 9 10 11 12
Month

USA_Seat

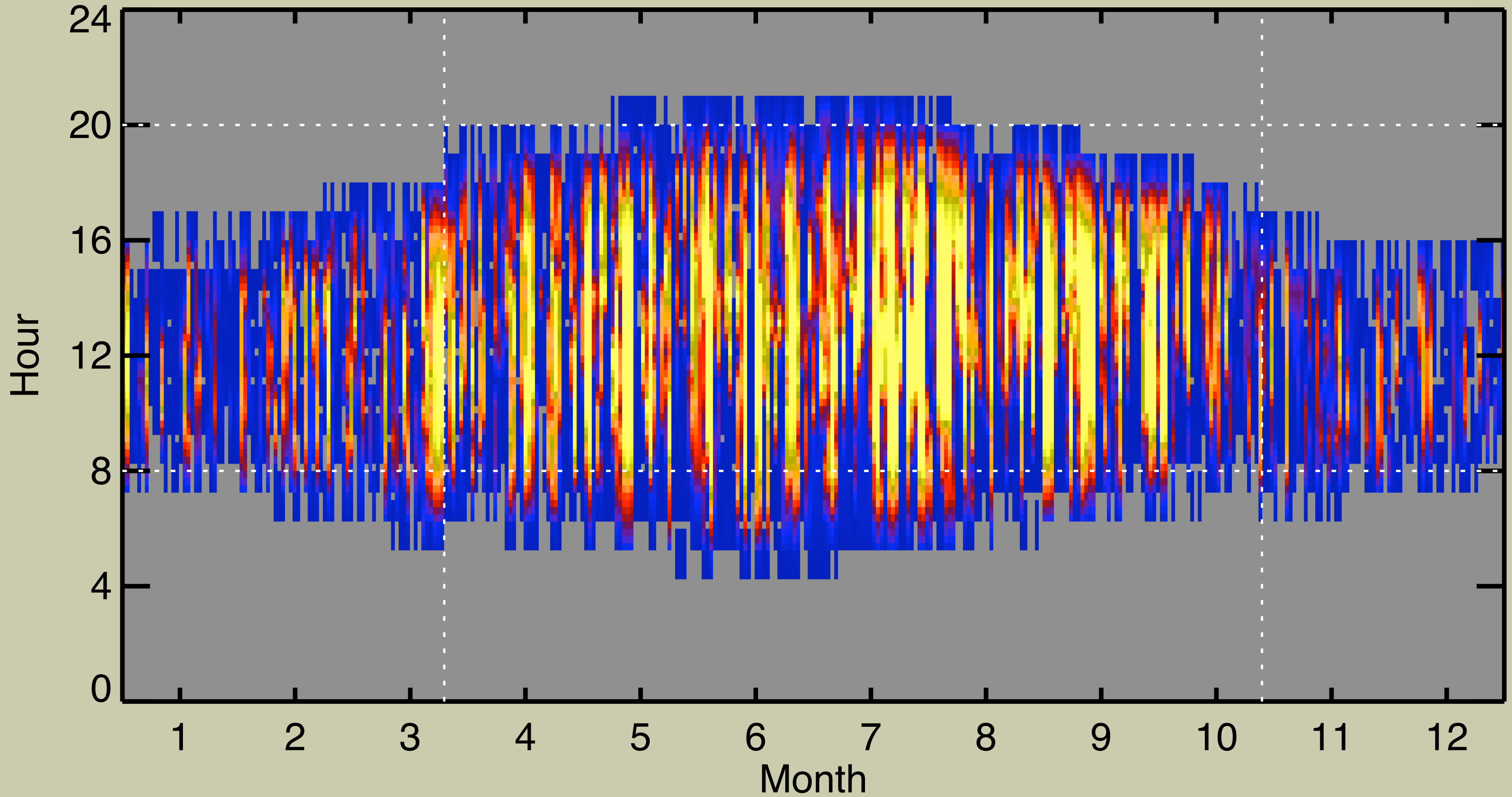
Diffuse Horizontal Illuminance







Direct Normal Illuminance



Useful Daylight Illuminance: A Climate-Based Metric

Useful Daylight Illuminance (UDI)

A Climate-Based Daylight Metric

What is 'useful' daylight?

The principle is not new...

Actually, four UDI Categories

UDI fell-short: < 100 lux

UDI achieved:
100 to 2500 lux

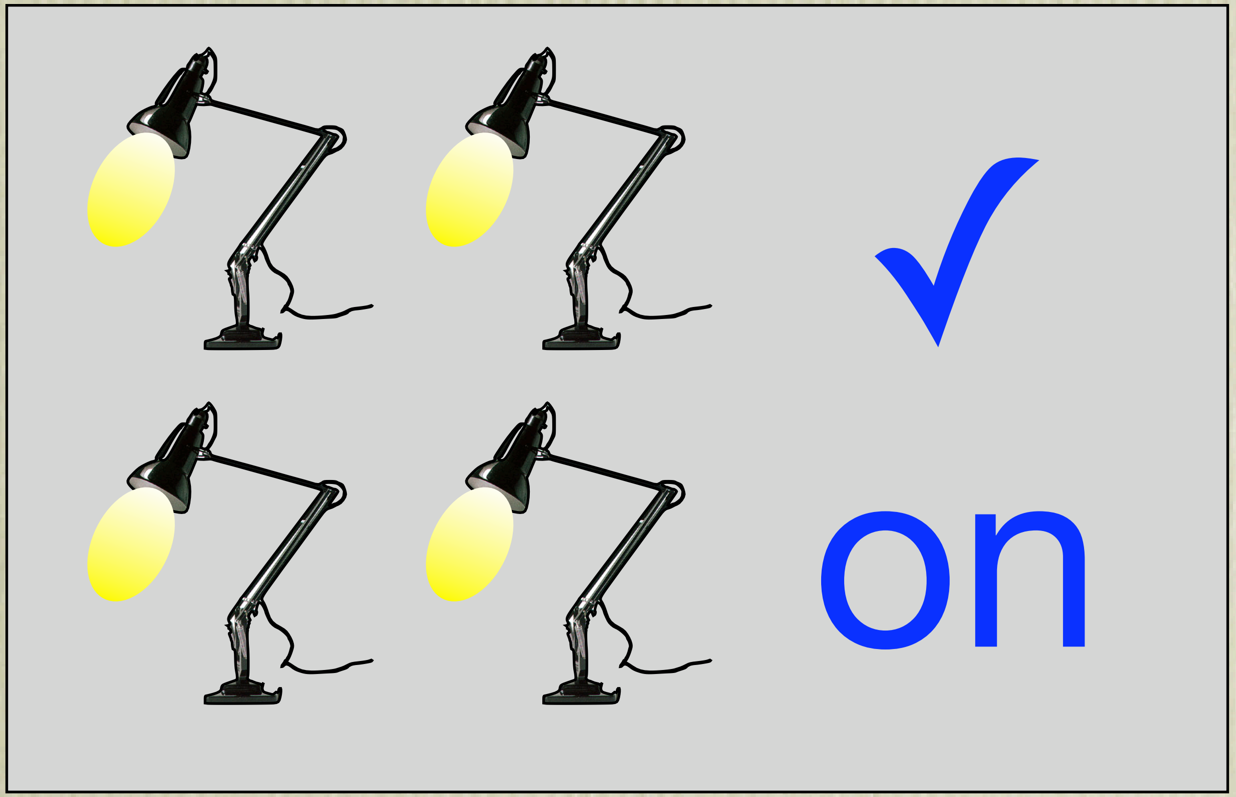
UDI supplementary:
100 to 500 lux

UDI autonomous:
500 to 2500 lux

UDI exceeded: > 2500 lux

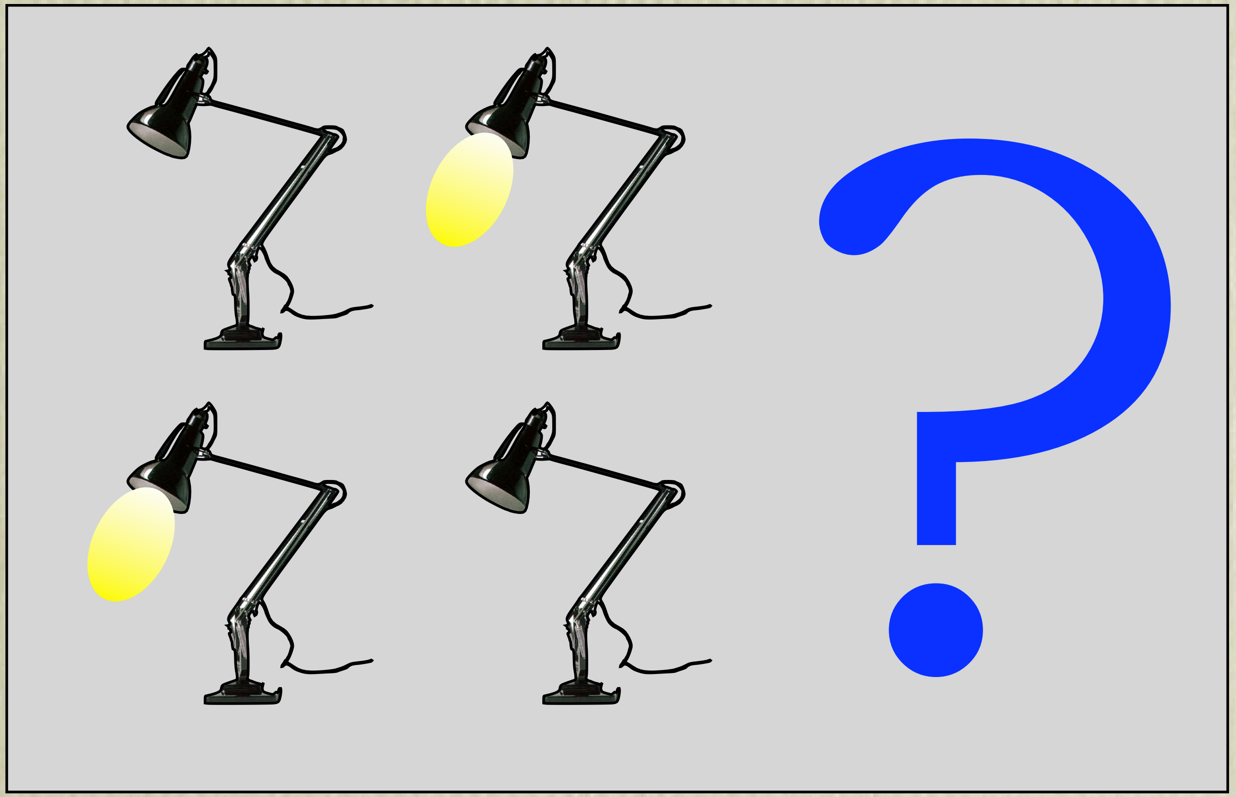
UDI fell-short

Occurrences less than 100 lux



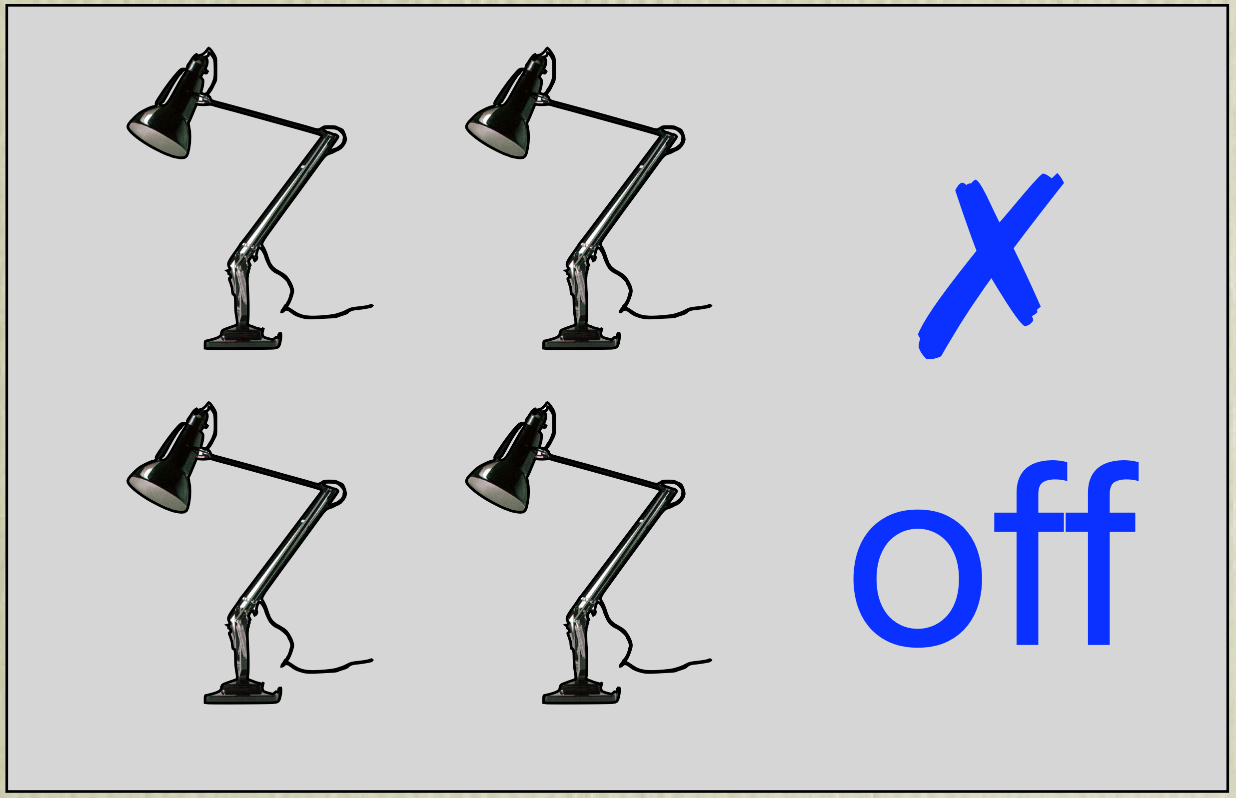
UDI supplementary

Occurrences 100 to 500 lux



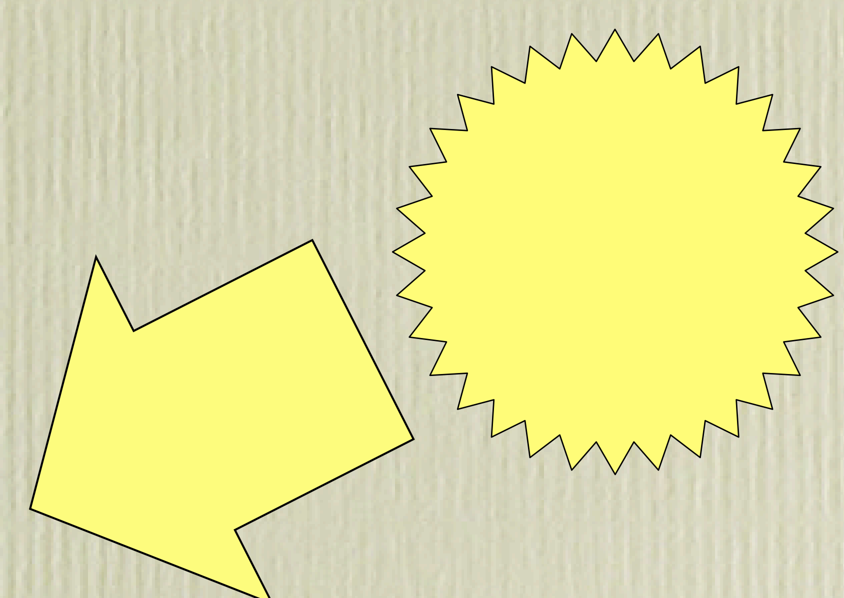
UDI autonomous

Occurrences 500 to 2500 lux



UDI exceeded

Occurrences > 2500 lux



UDI and "good daylighting"

There is reasonable certainty that illuminances in the UDI-a range will not result in a switch-on, whereas there is considerable uncertainty regarding the probability of a switch-on event for illuminances is in the UDI-s range.

Accordingly, maximisation of the occurrence of the UDI-a metric should be taken as the most reliable indicator that the overall level of electric lighting usage (for that space) will be low.

Quite a lot of illuminance data were generated from the DCs

- ~1,000 points on the workplane.
- ~16,000 time-steps (08h00-20h00 @15mins).
- 10 combinations of building type/obstruction.
- 8 orientations.
- 6 climates.
- 4 components of illuminance.

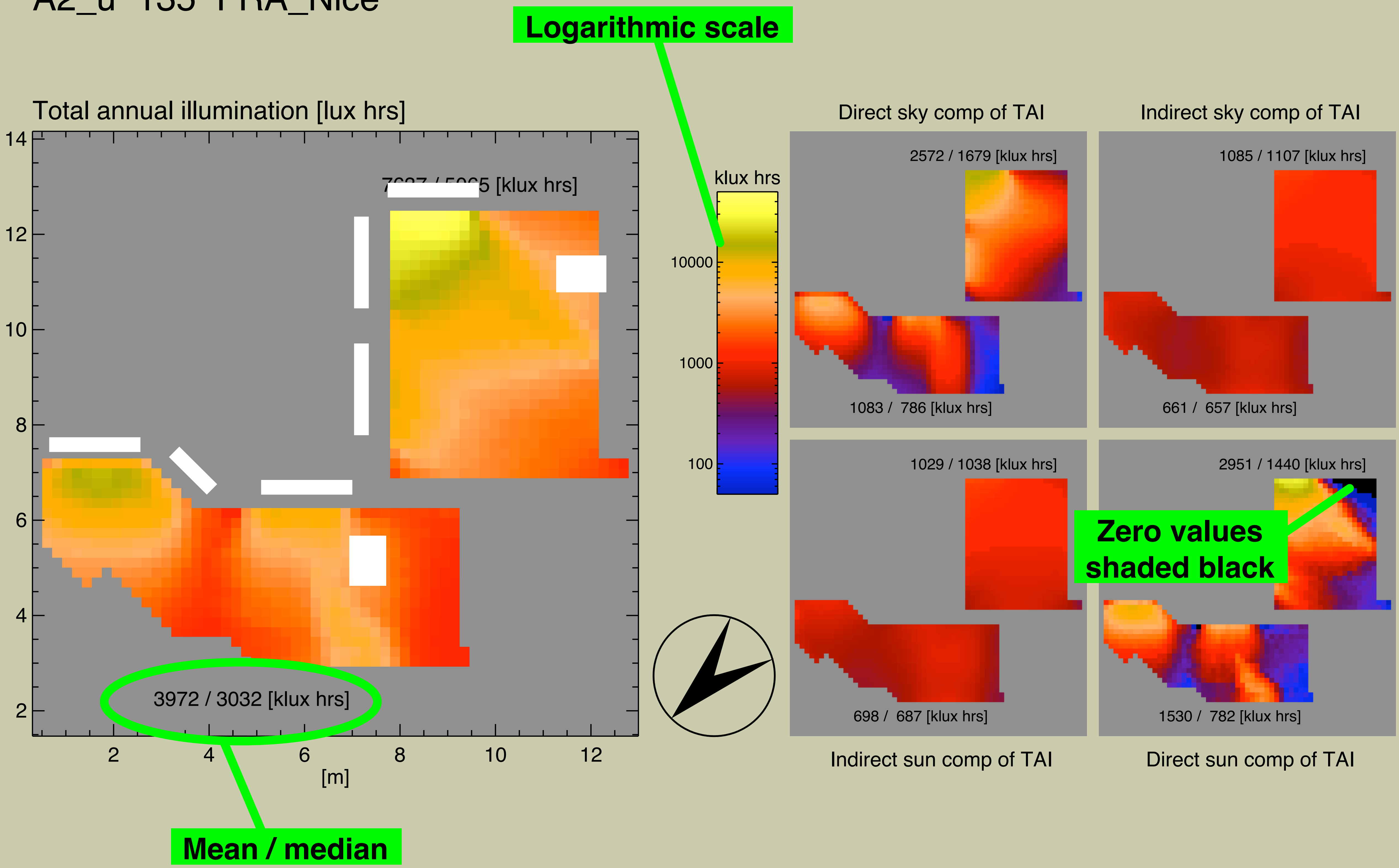
Approximately
30,720,000,000
illuminance predictions
were derived and processed

The Results

An overview of the forms of presentation

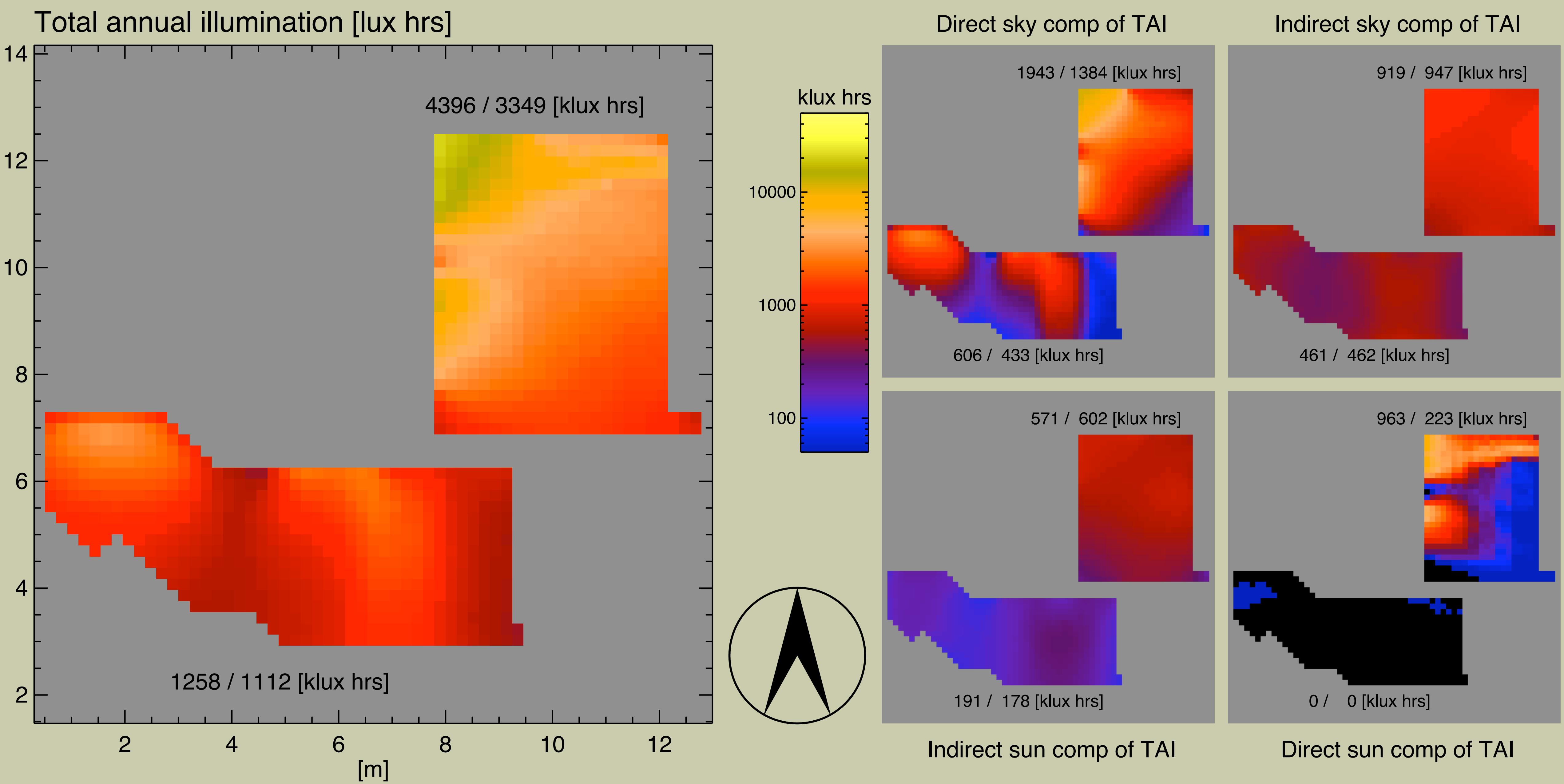
Total annual illumination values

A2_u 135 FRA_Nice

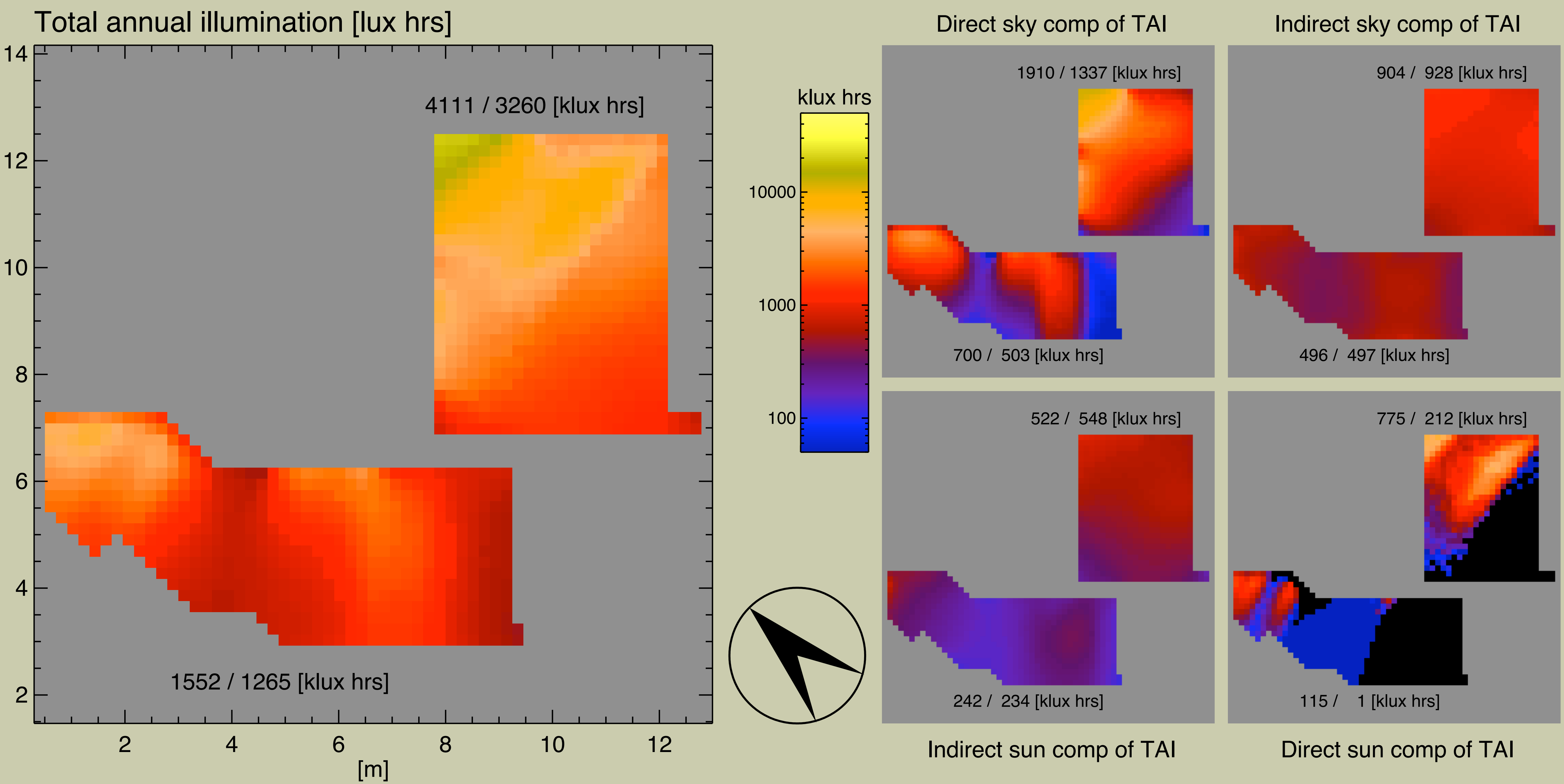


And now for all orientations

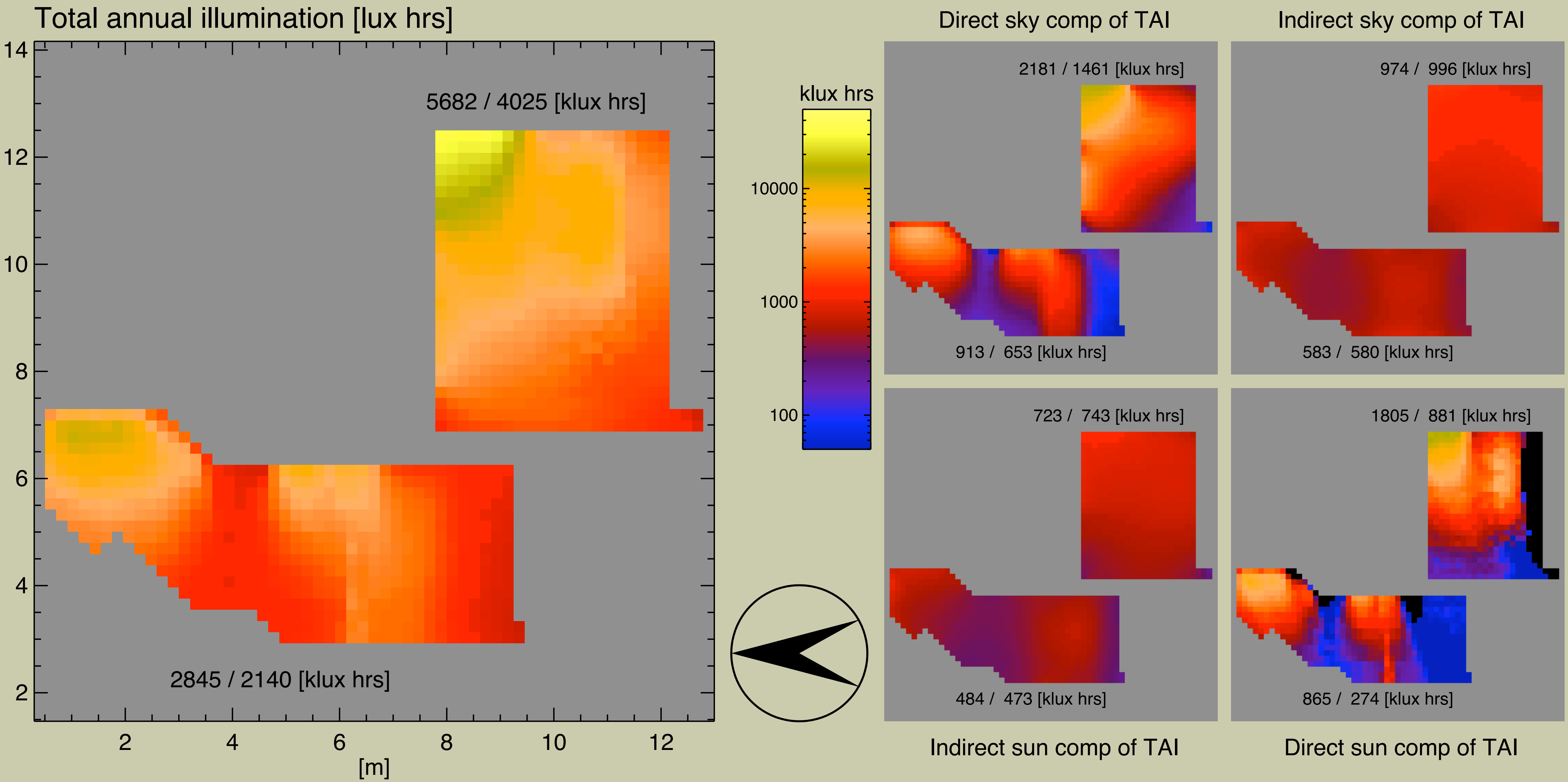
A2_u 000 FRA_Nice



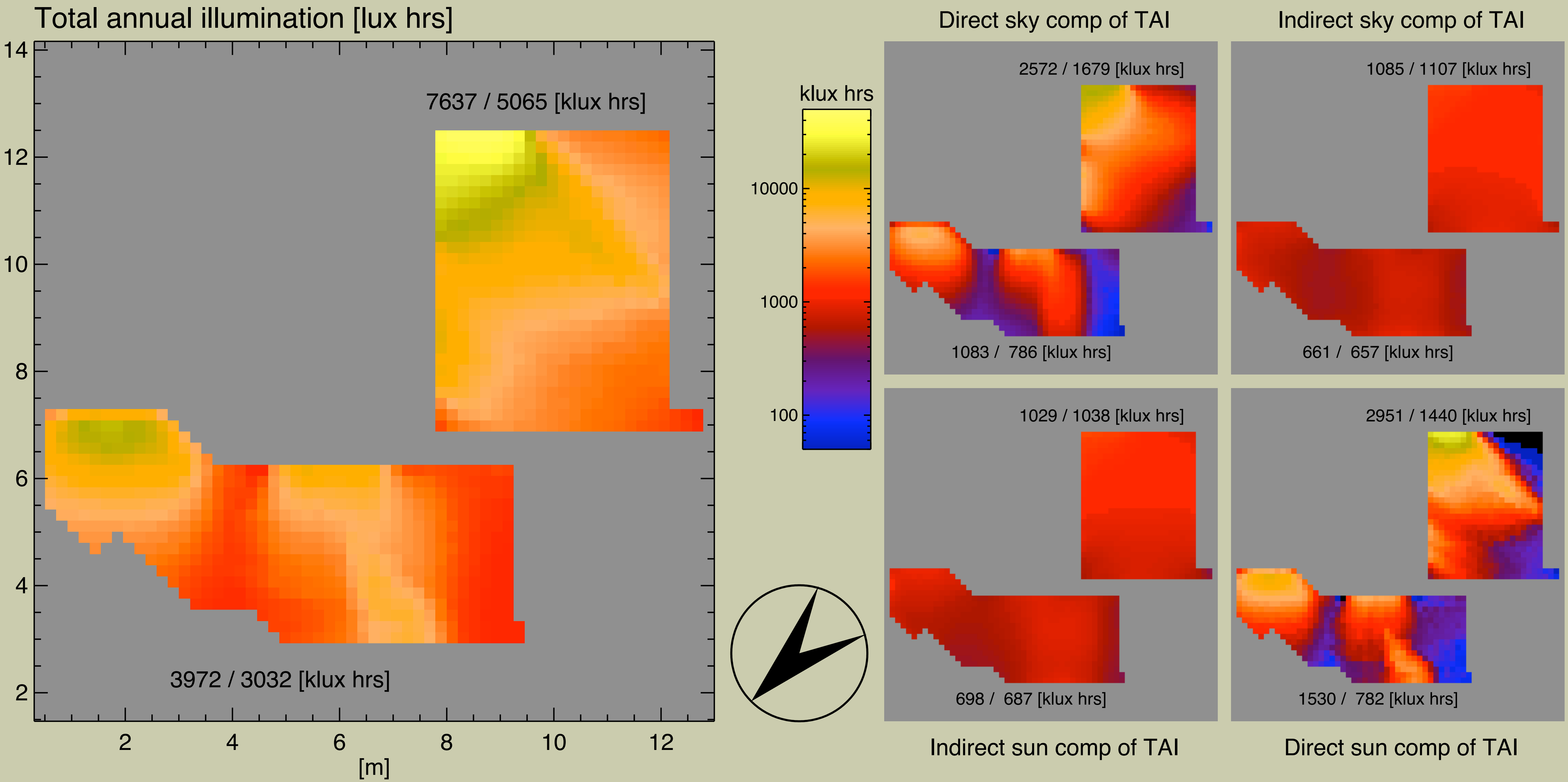
A2_u 045 FRA_Nice



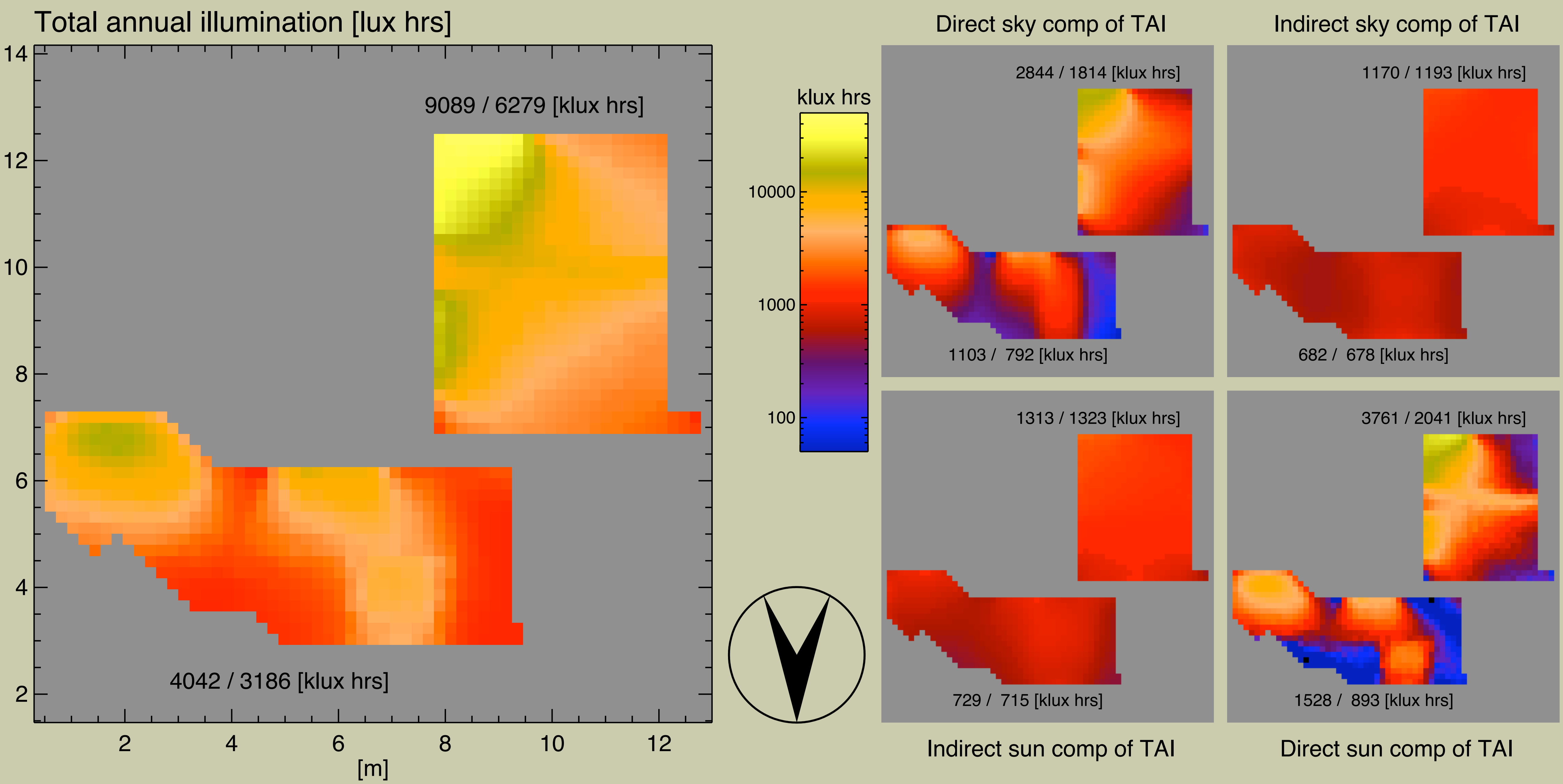
A2_u 090 FRA_Nice



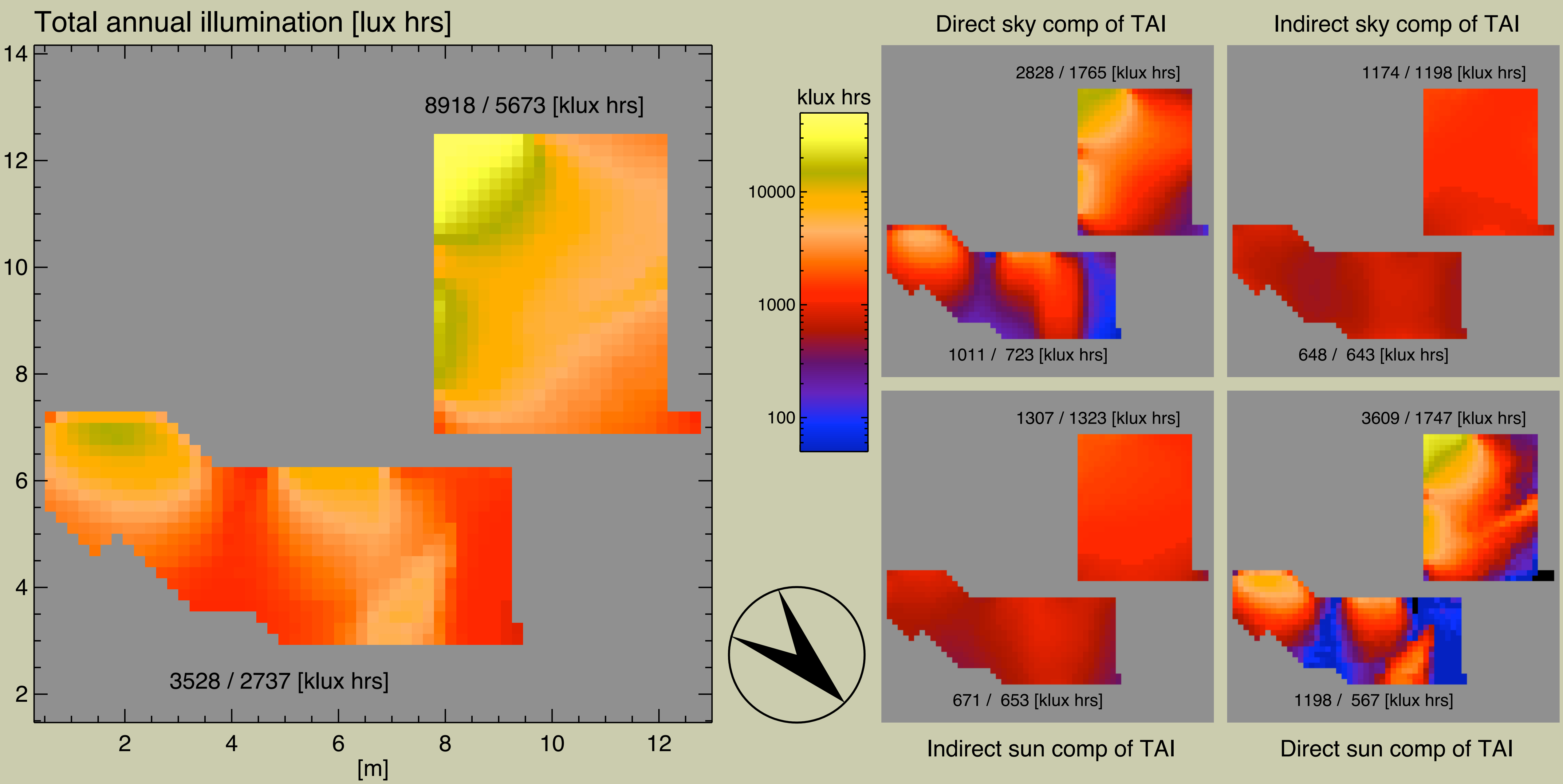
A2_u 135 FRA_Nice



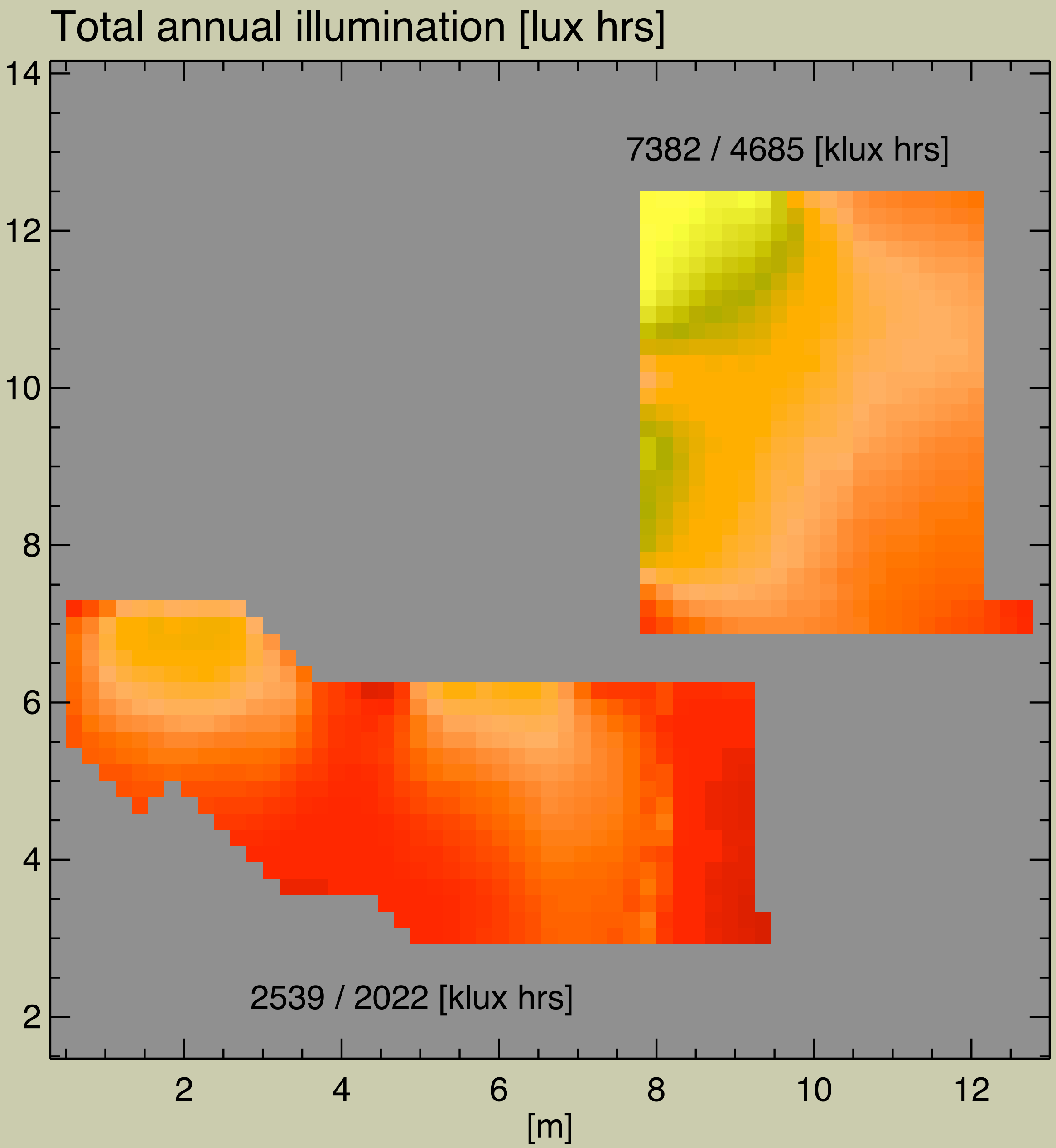
A2_u 180 FRA_Nice

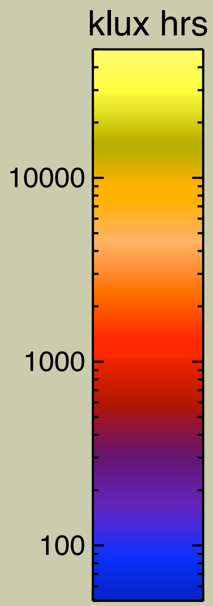


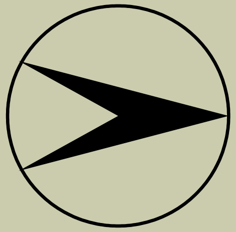
A2_u 225 FRA_Nice

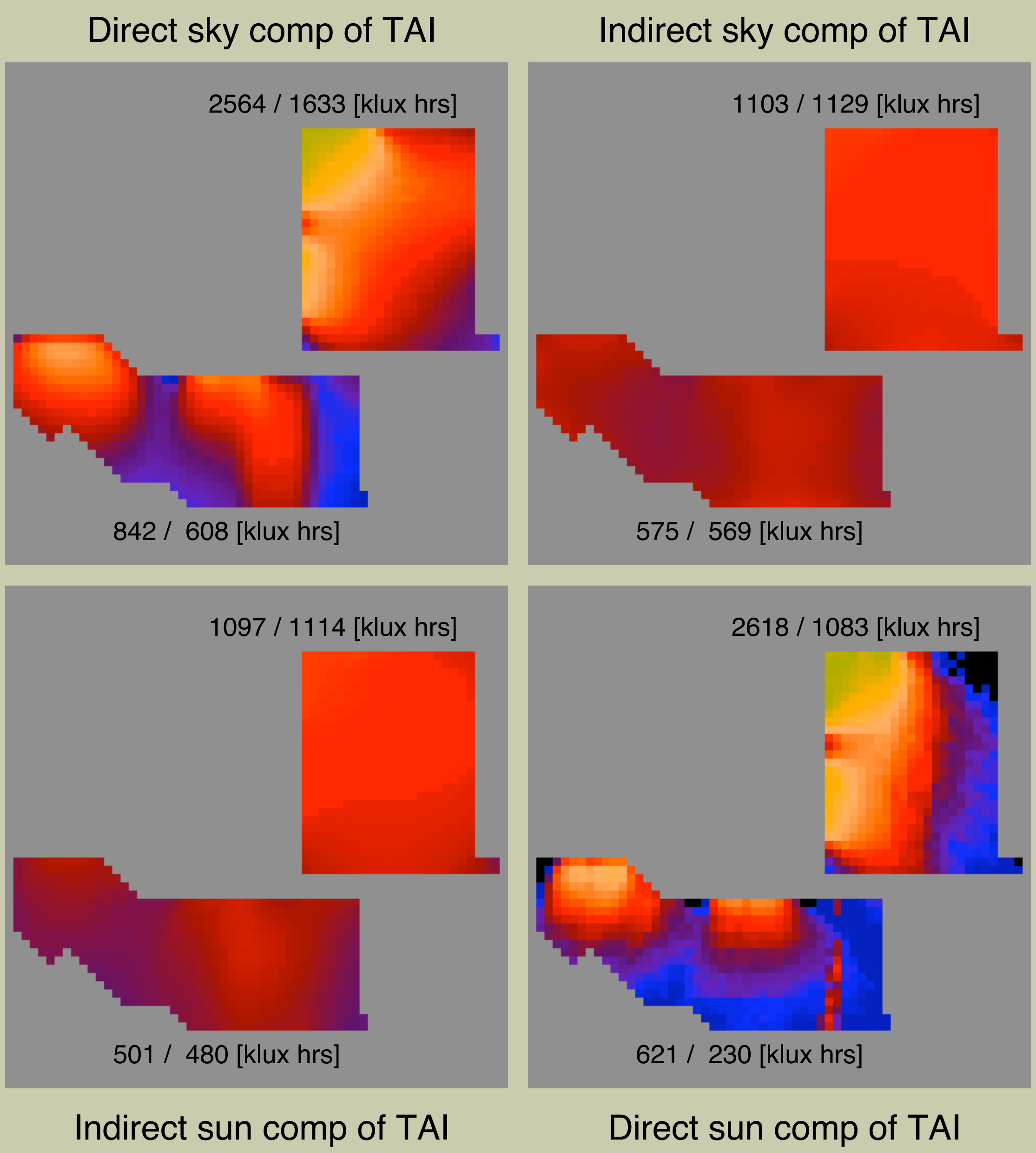


A2_u 270 FRA_Nice

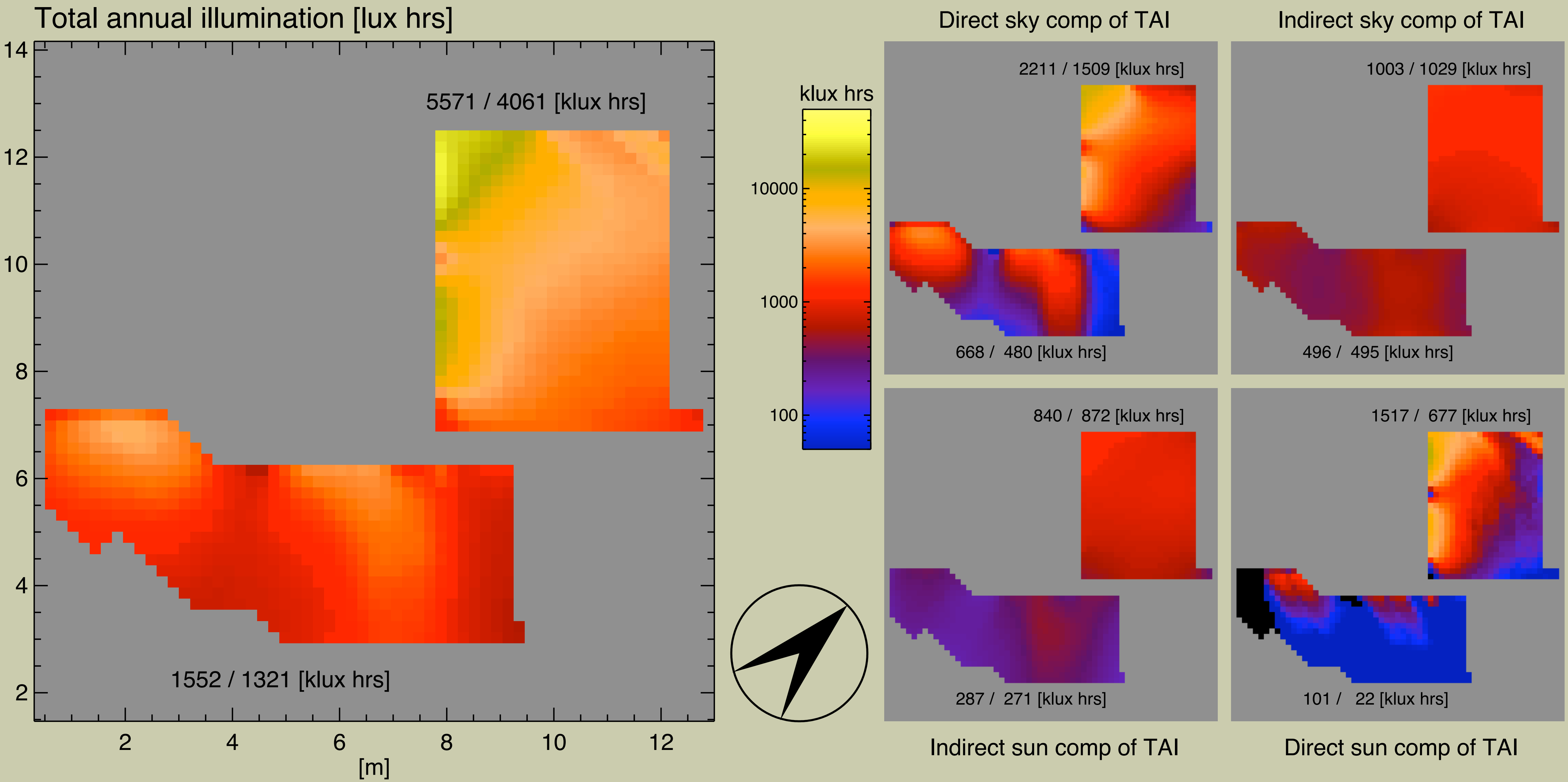




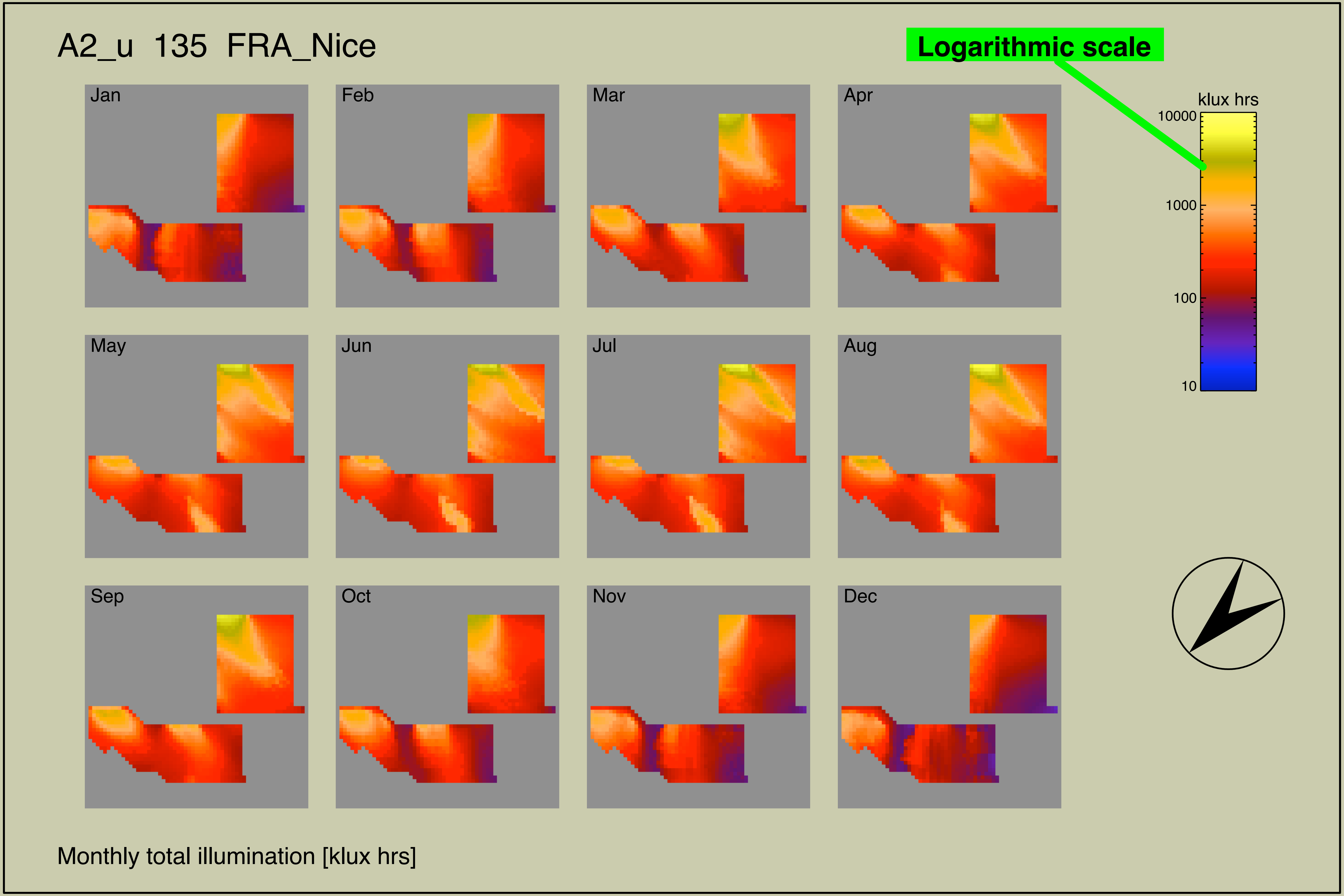




A2_u 315 FRA_Nice

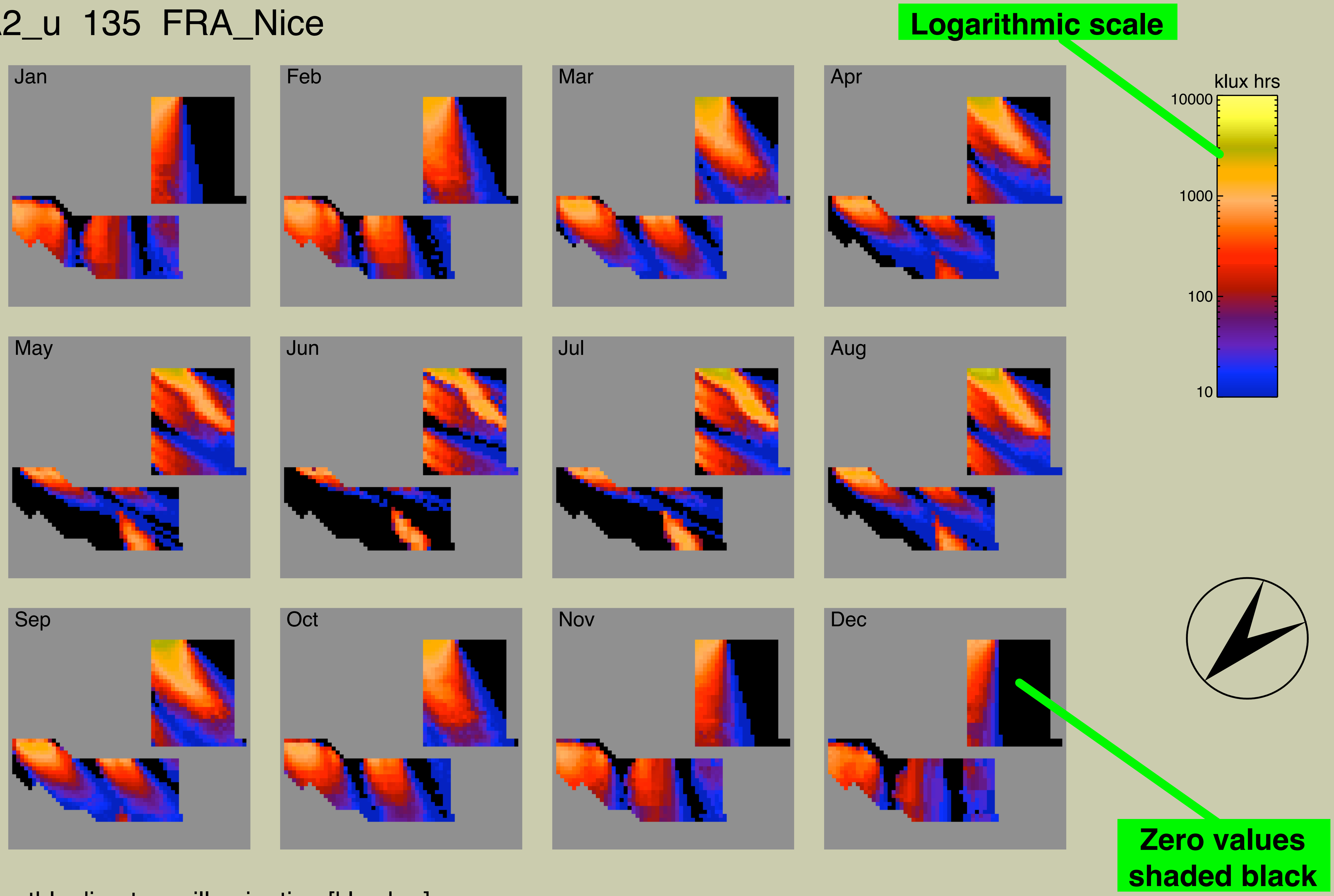


Total monthly illumination values


A2_u 135 FRA_Nice
Logarithmic scale
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
klux hrs
10000
1000
100
10
Monthly total illumination [klux hrs]

Total direct sun illumination

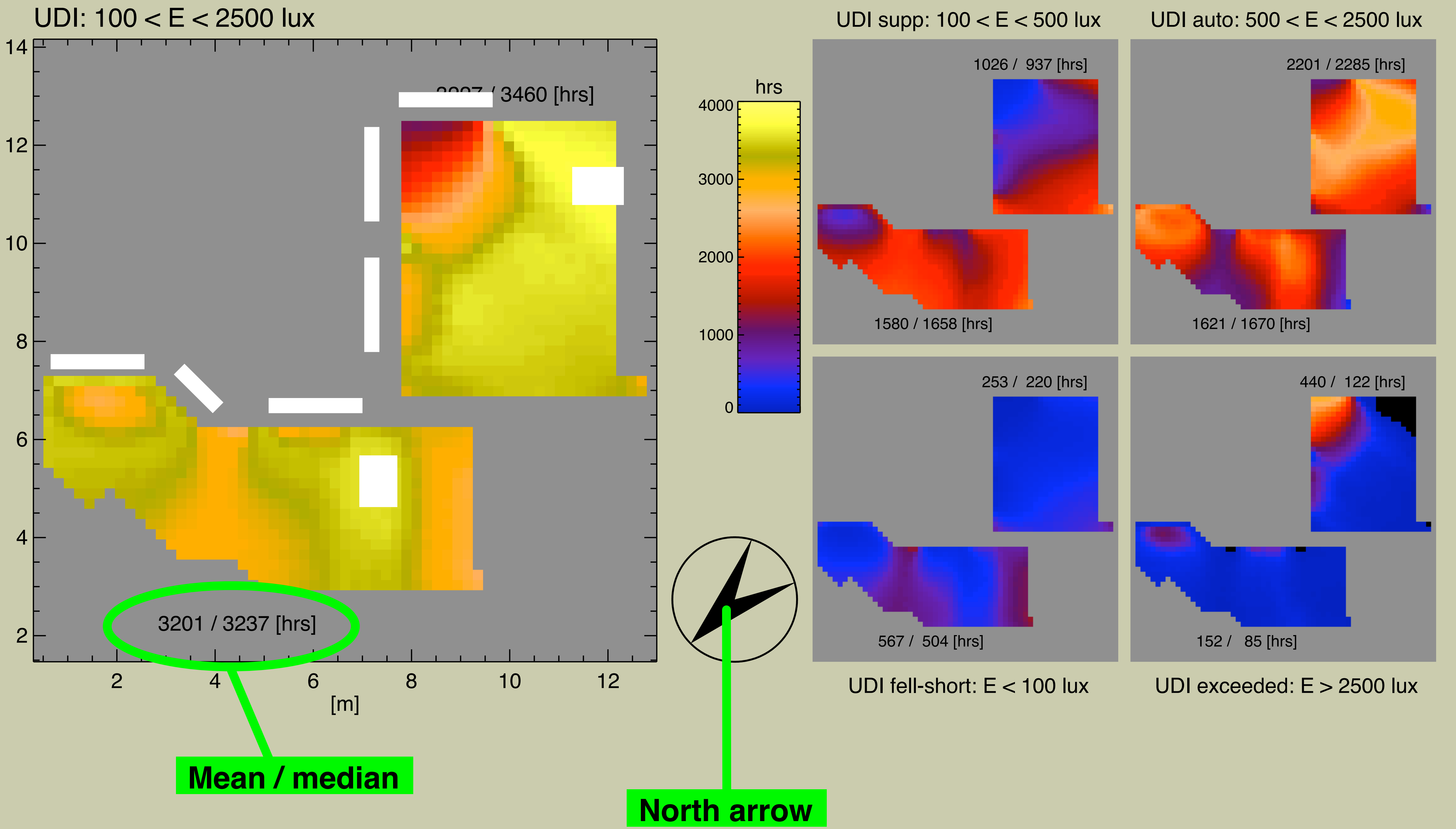
A2_u 135 FRA_Nice



Monthly direct sun illumination [klux hrs]

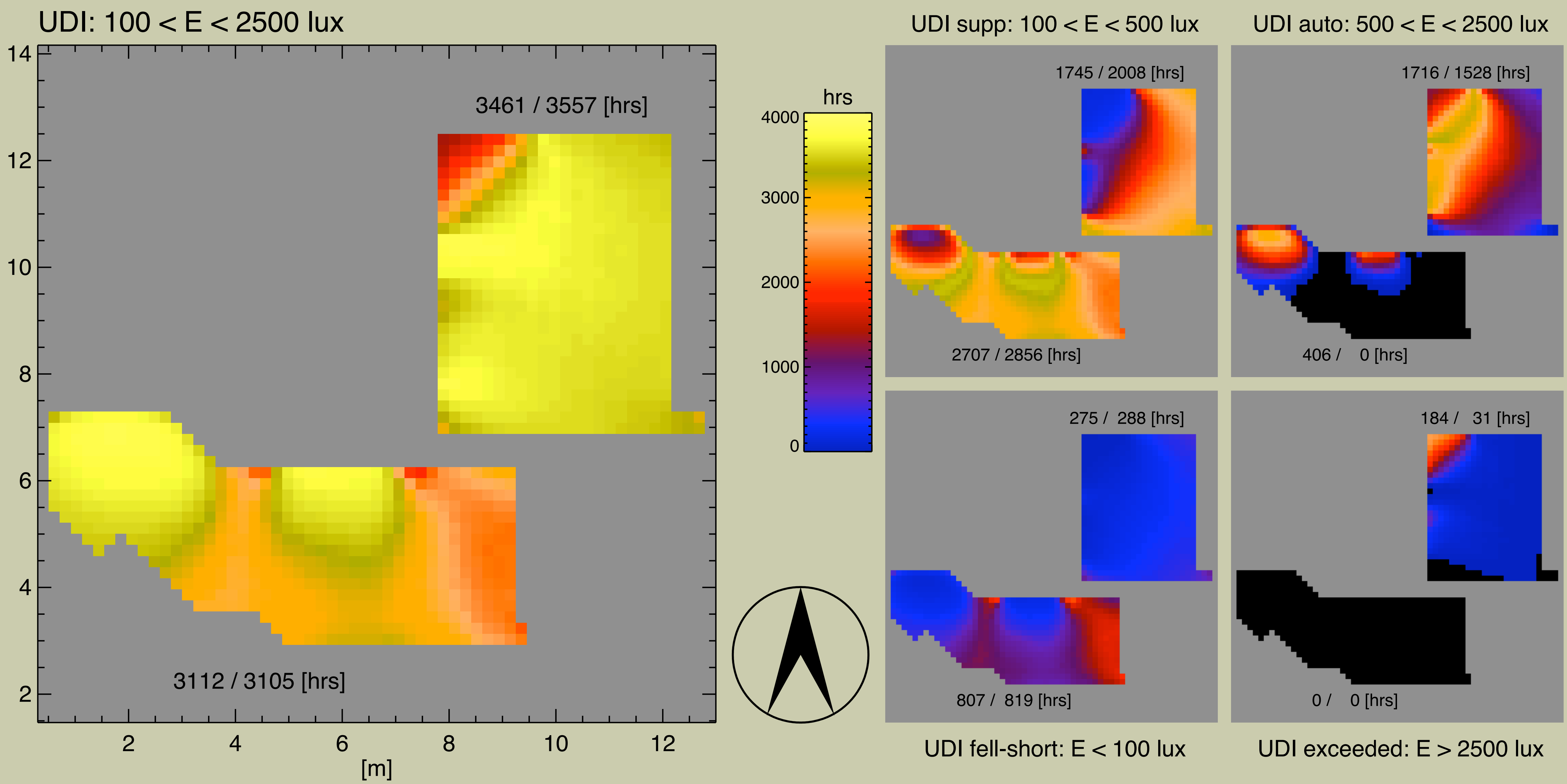
Useful daylight illuminance metrics

A2_u 135 FRA_Nice

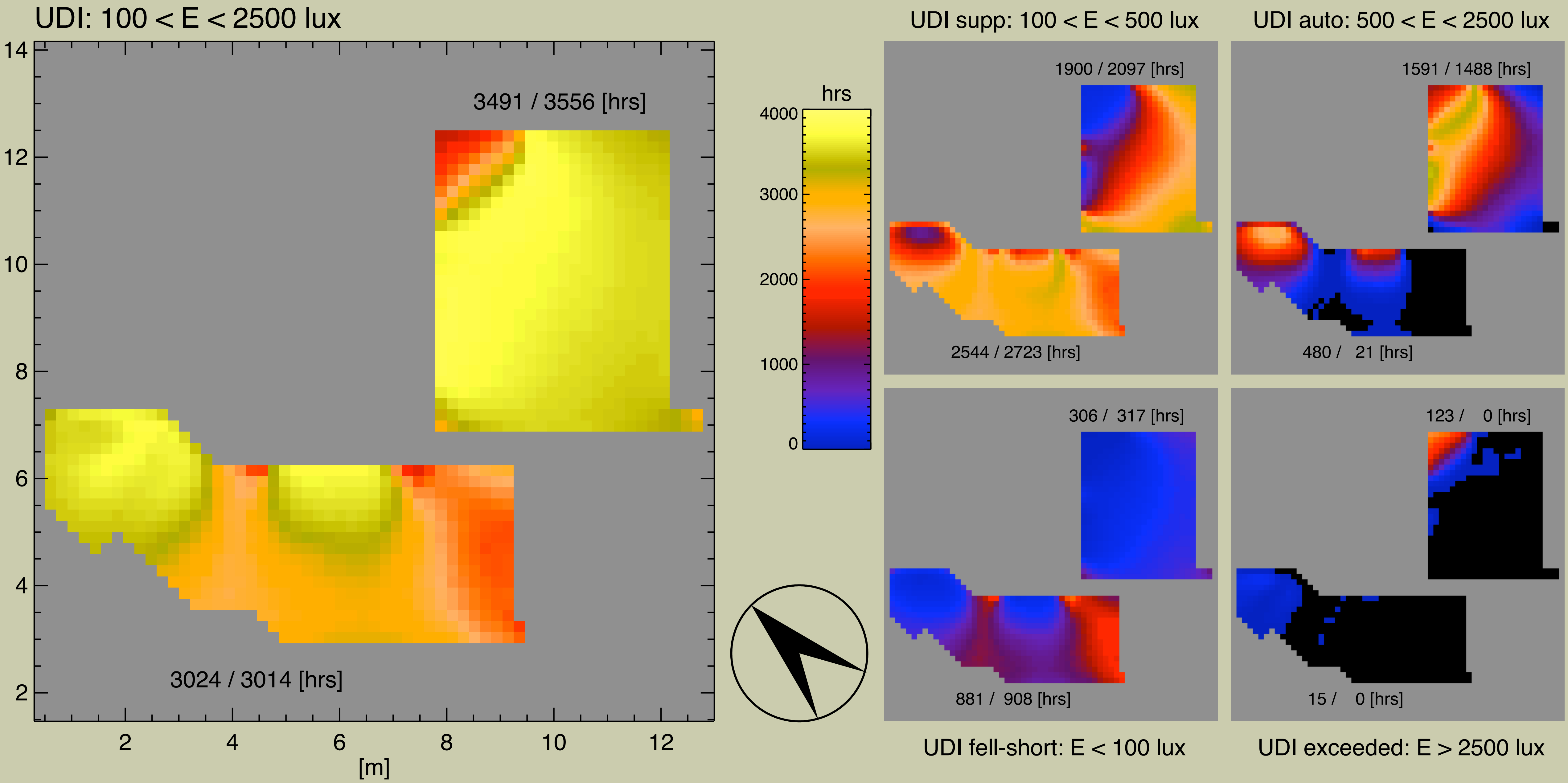


UDI across the workplane for all orientations

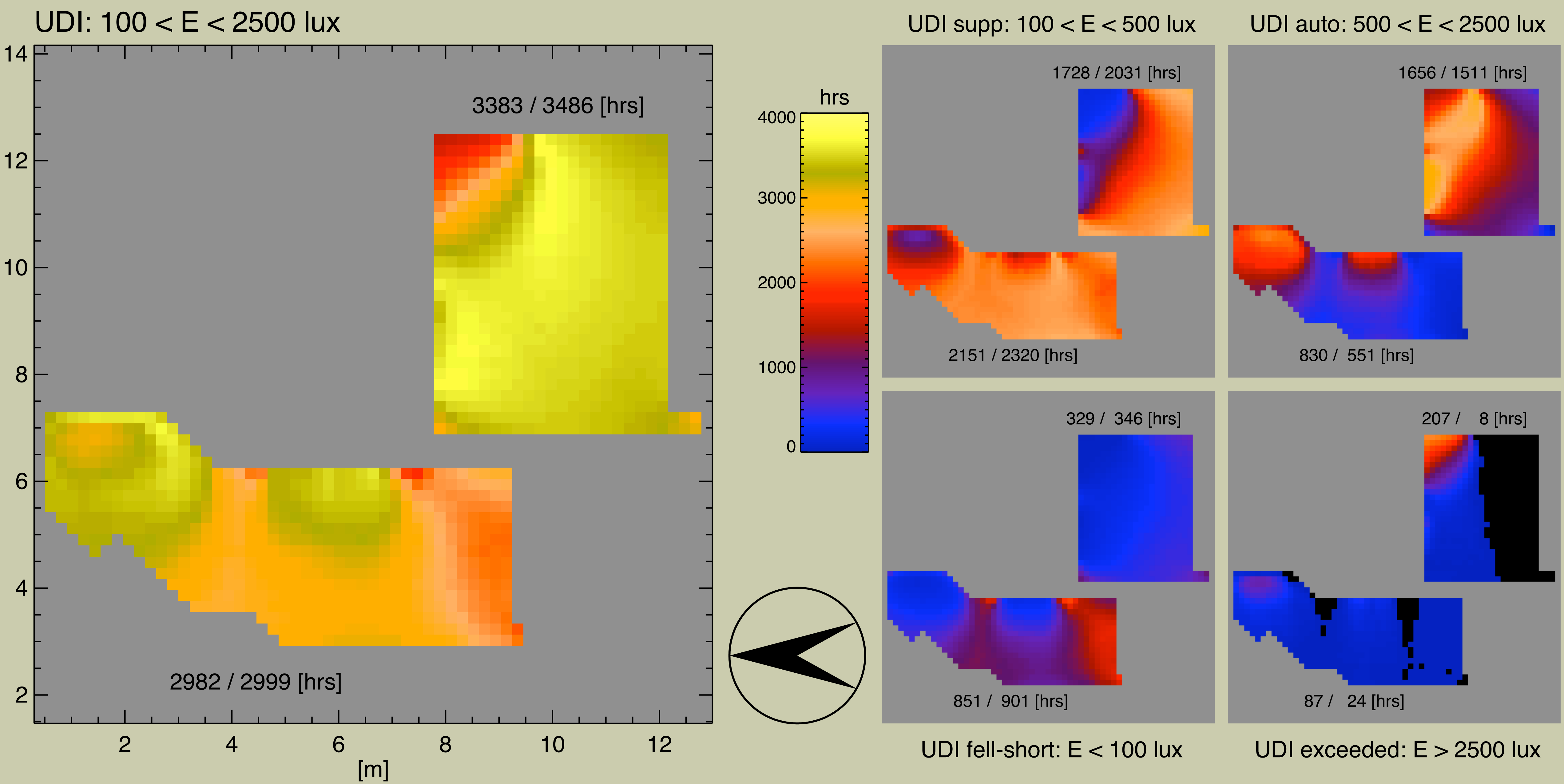
A1_u 000 FRA_Nice



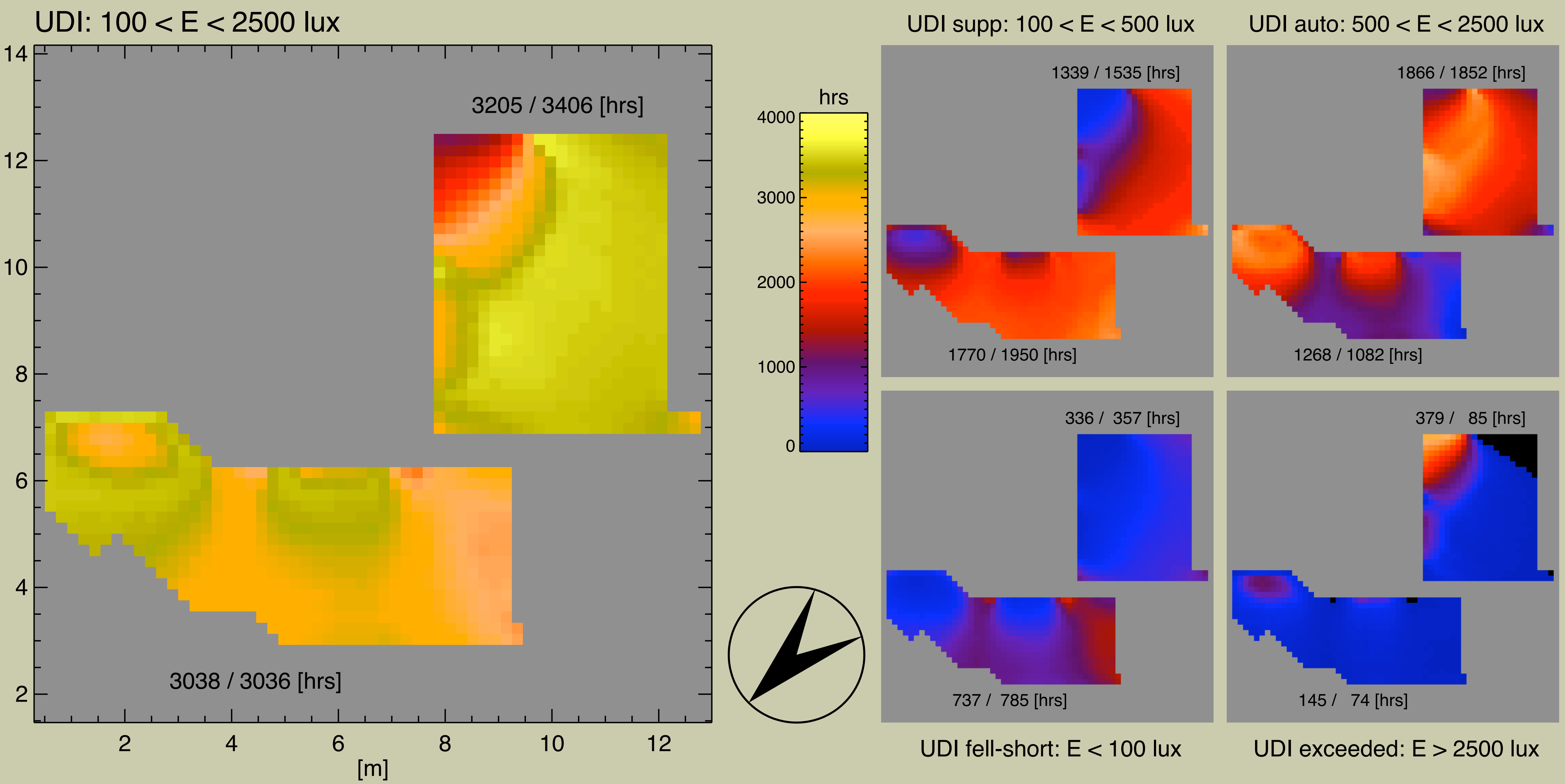
A1_u 045 FRA_Nice



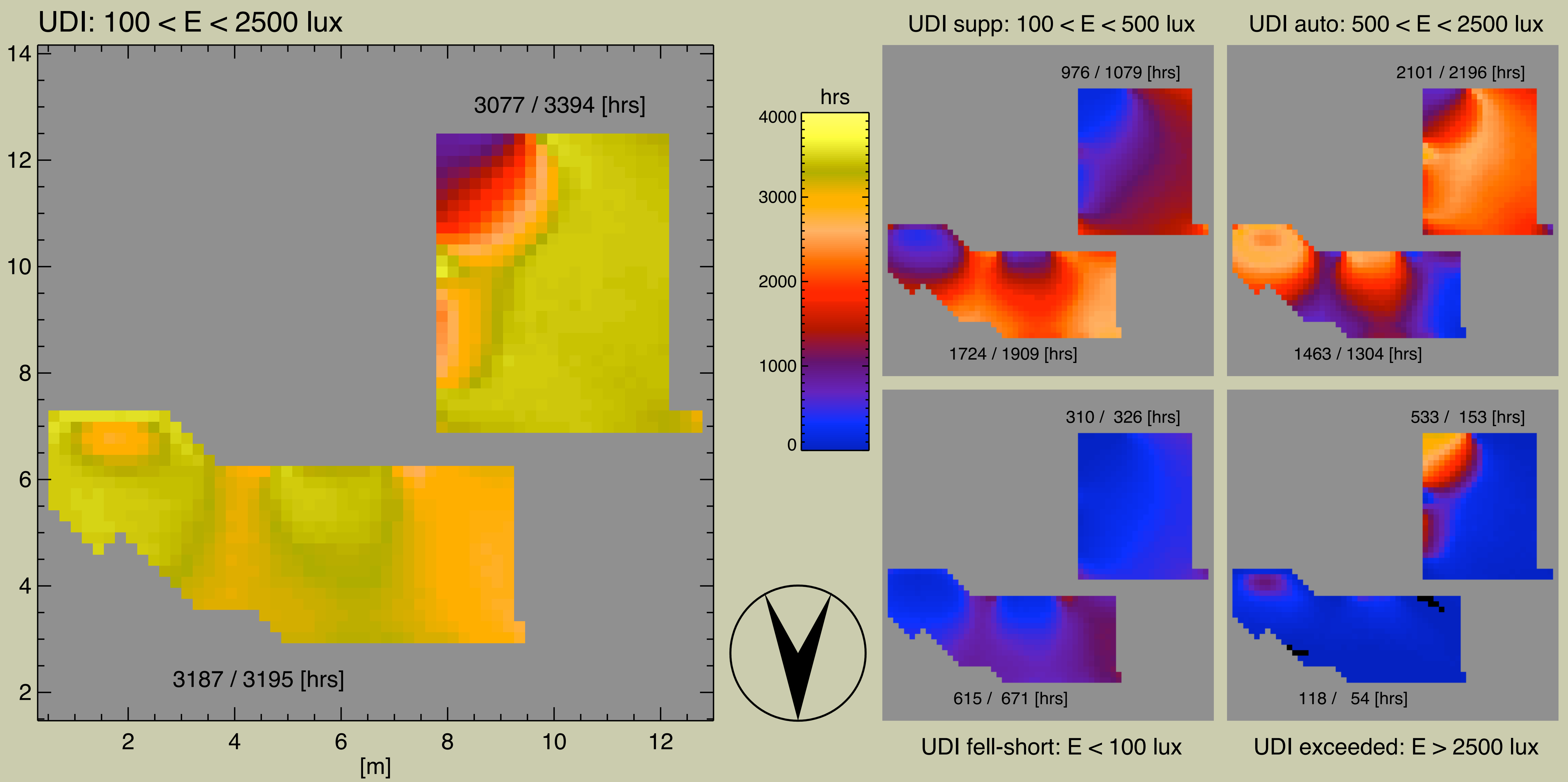
A1_u 090 FRA_Nice



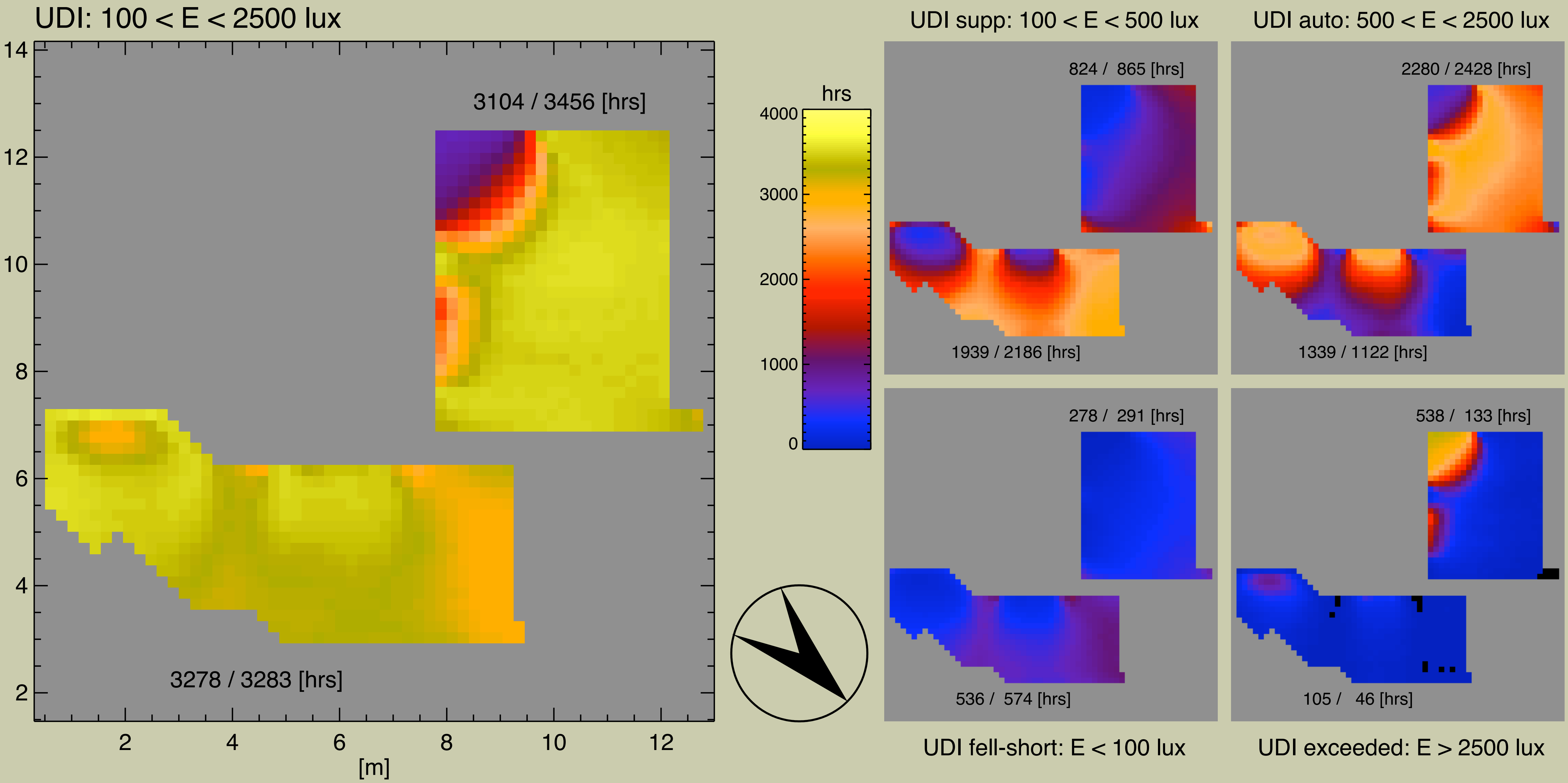
A1_u 135 FRA_Nice



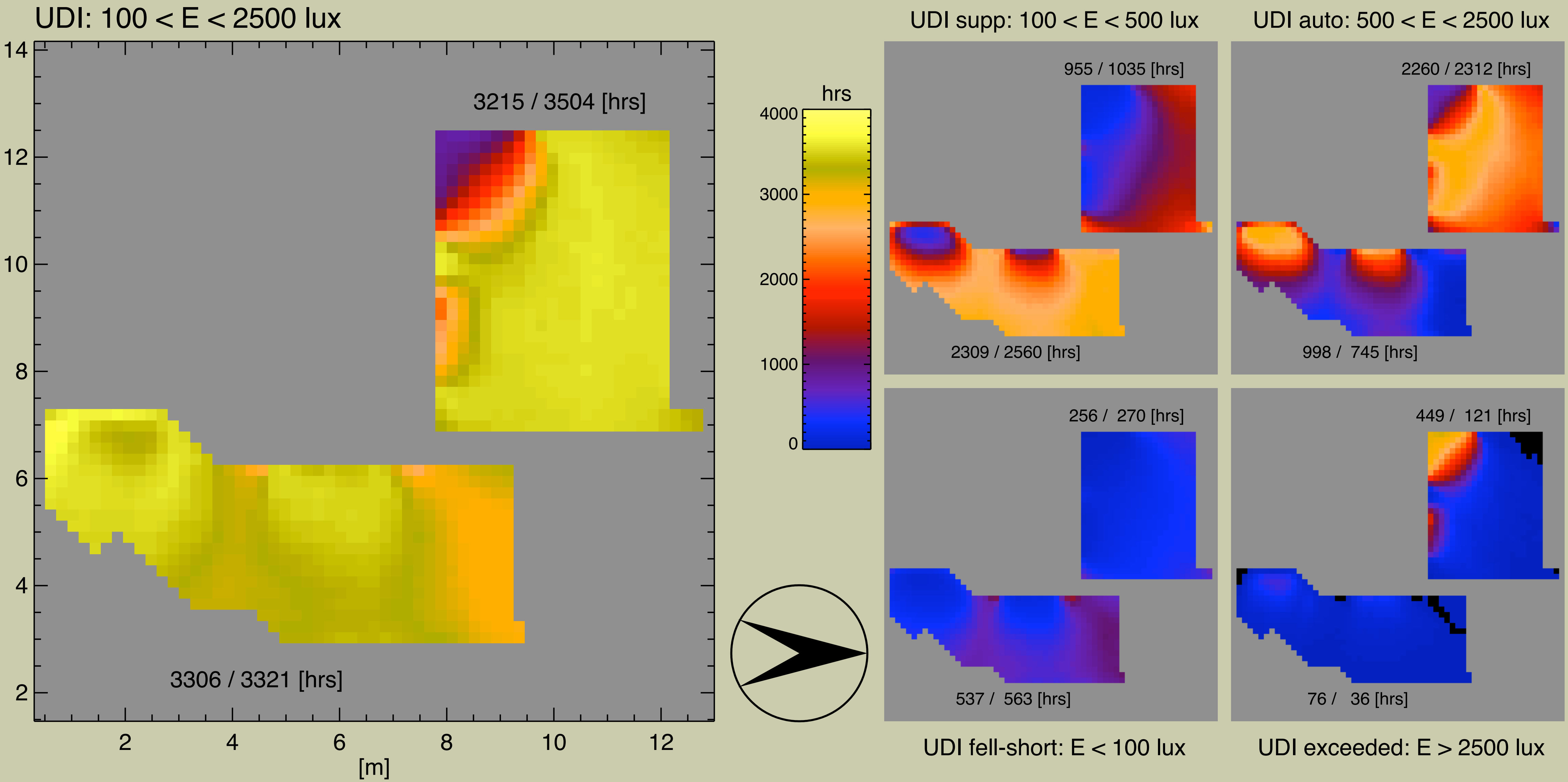
A1_u 180 FRA_Nice



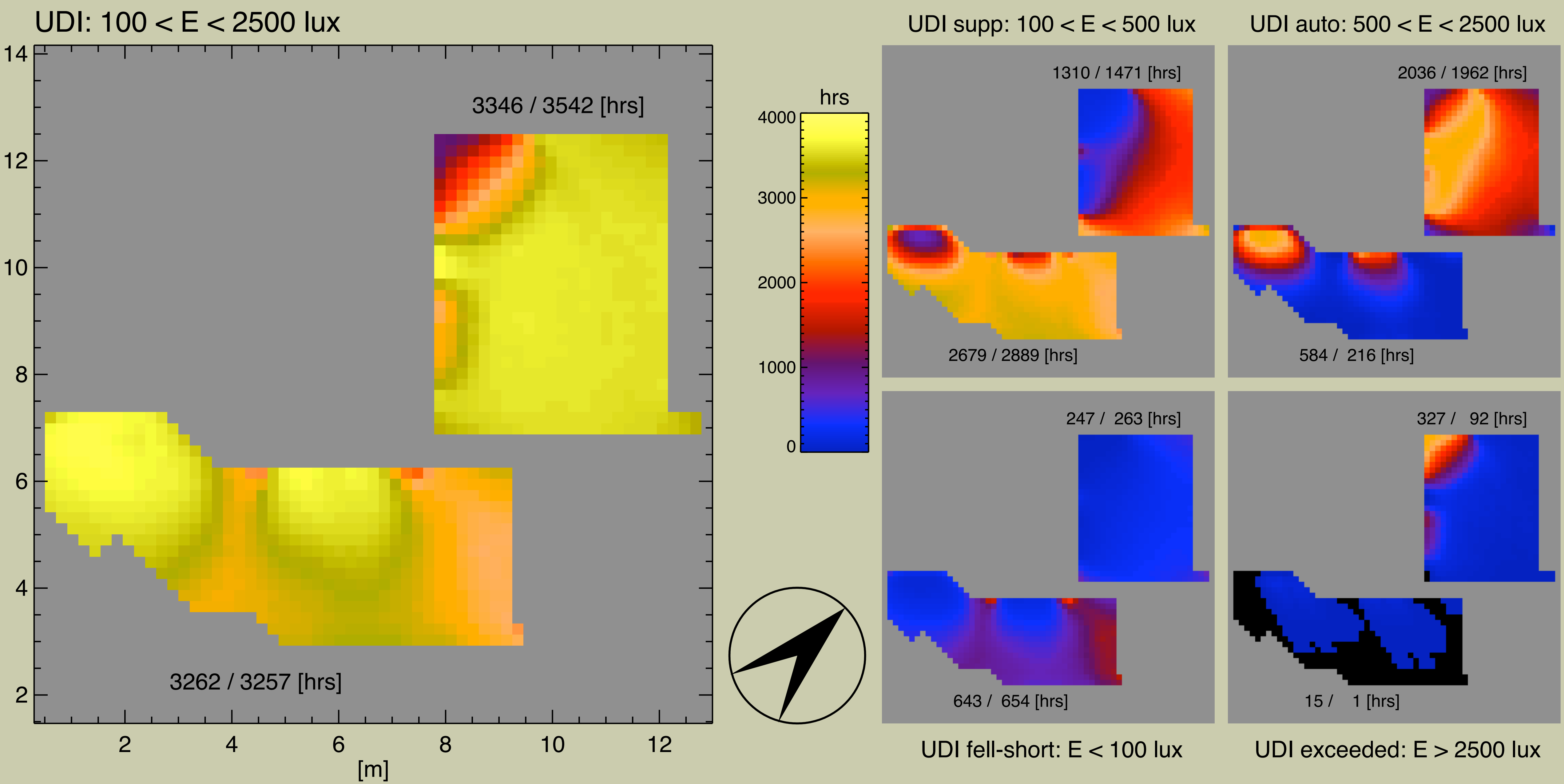
A1_u 225 FRA_Nice



A1_u 270 FRA_Nice



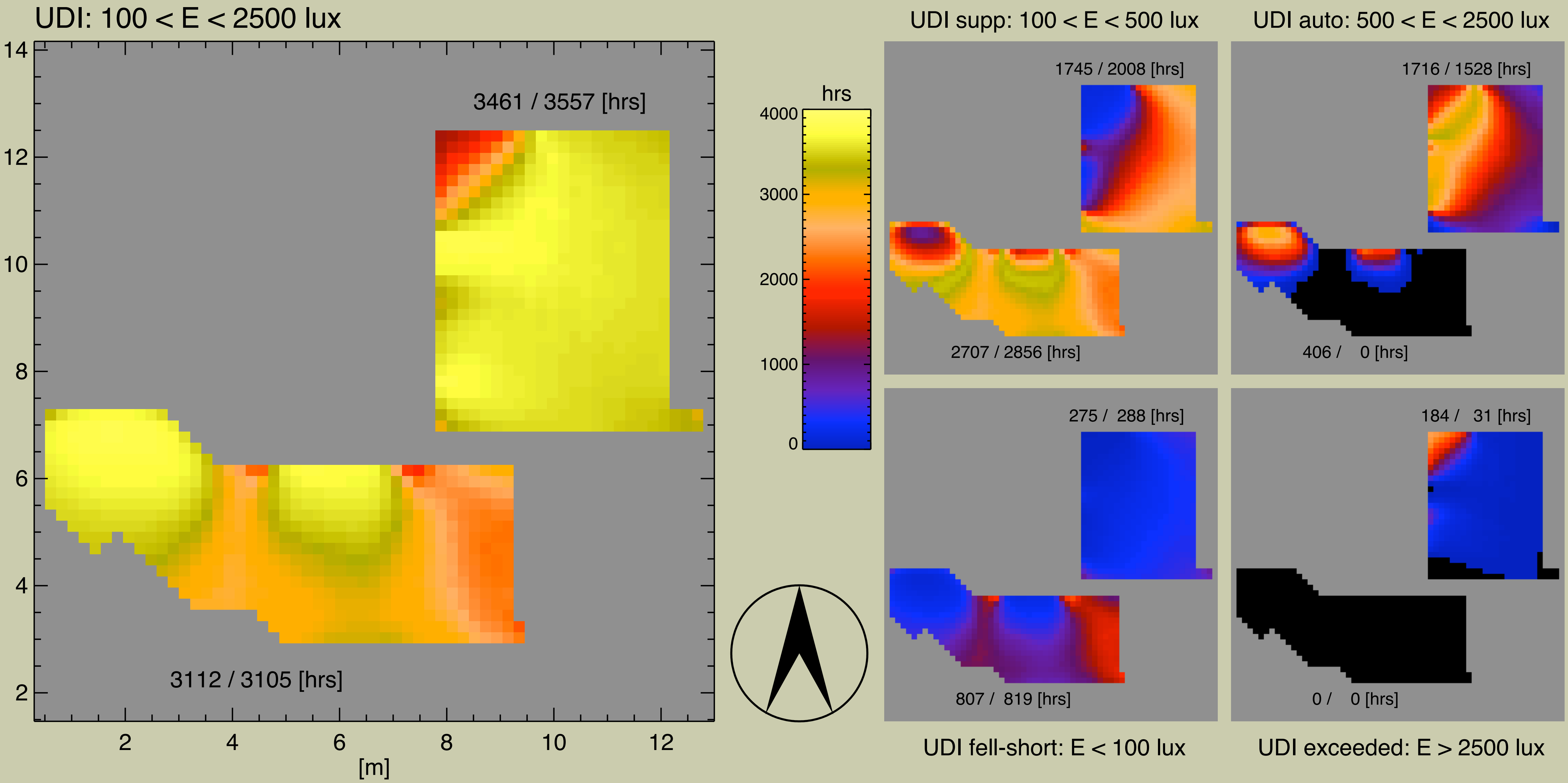
A1_u 315 FRA_Nice



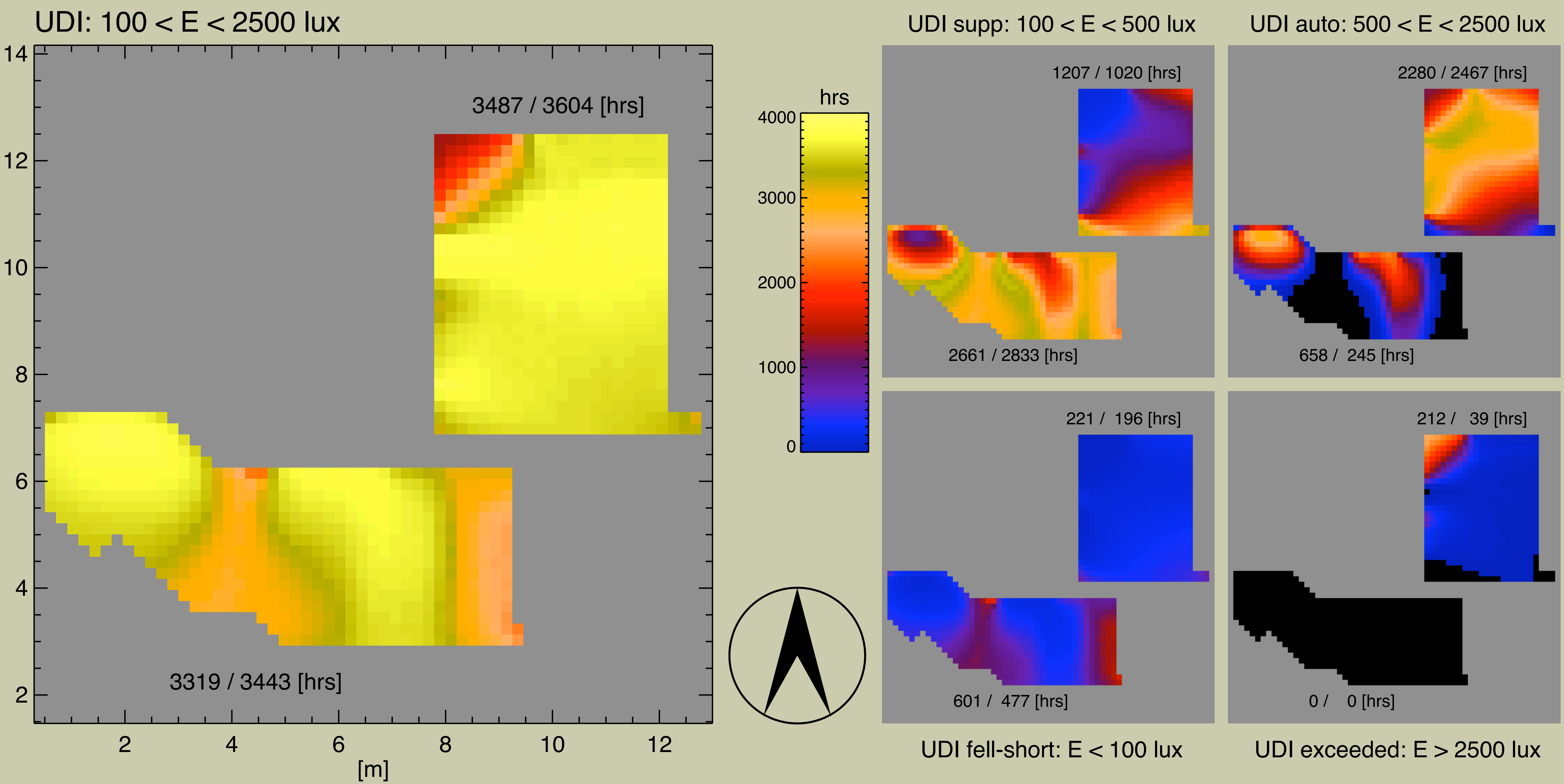
UDI across the workplane for three window designs

Orientation 0

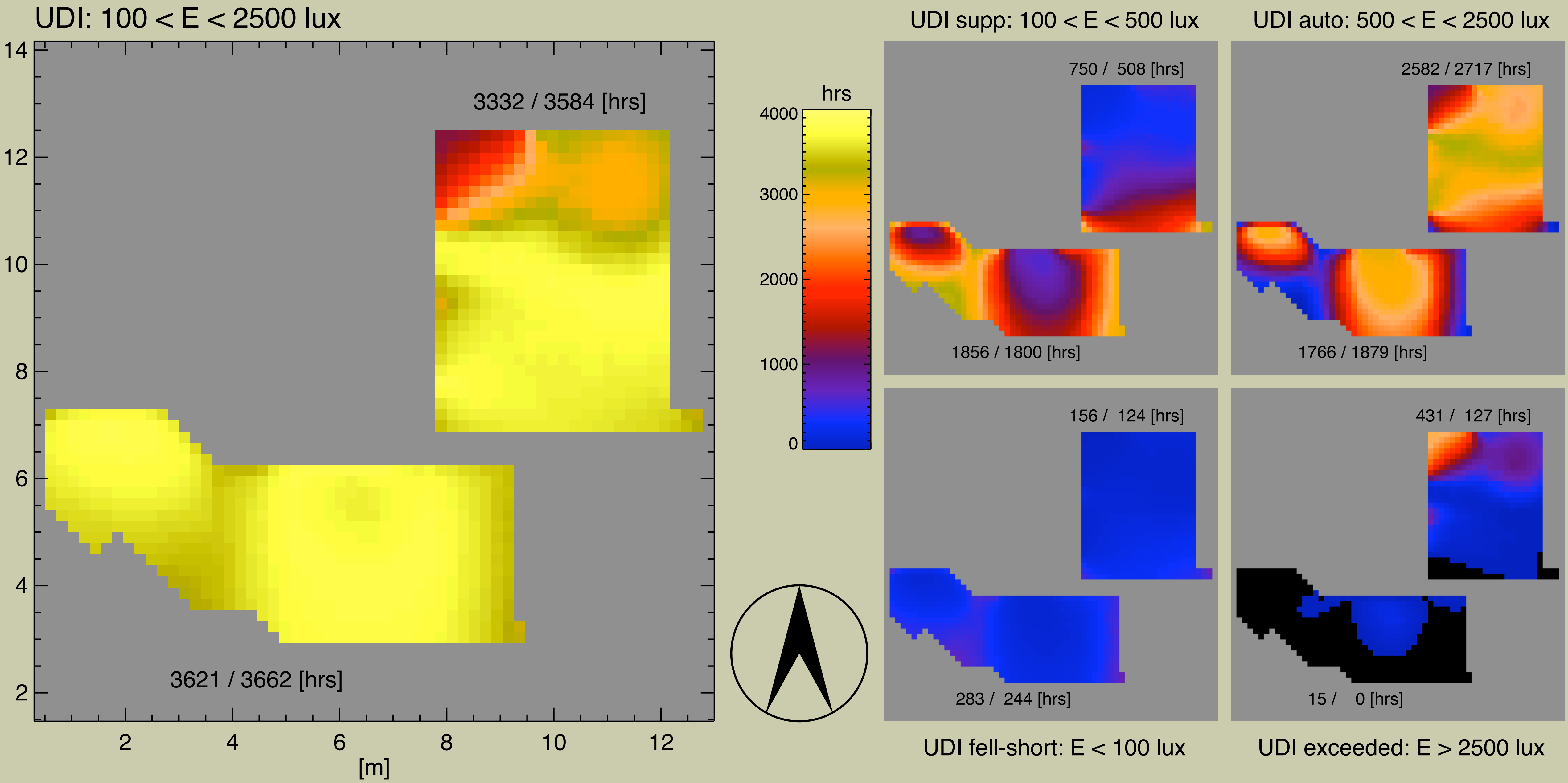
A1_u 000 FRA_Nice



A2_u 000 FRA_Nice

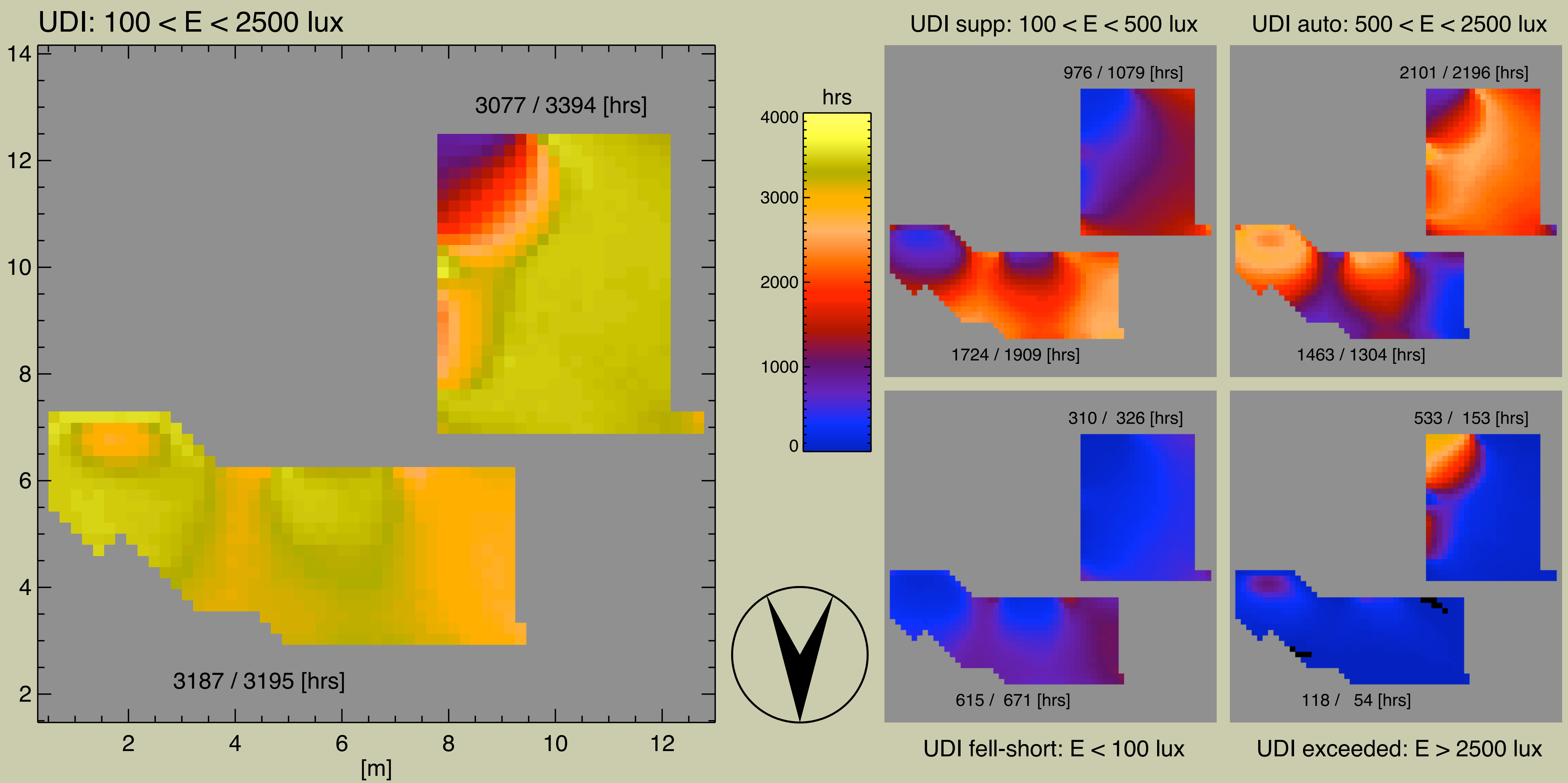


A3_u 000 FRA_Nice

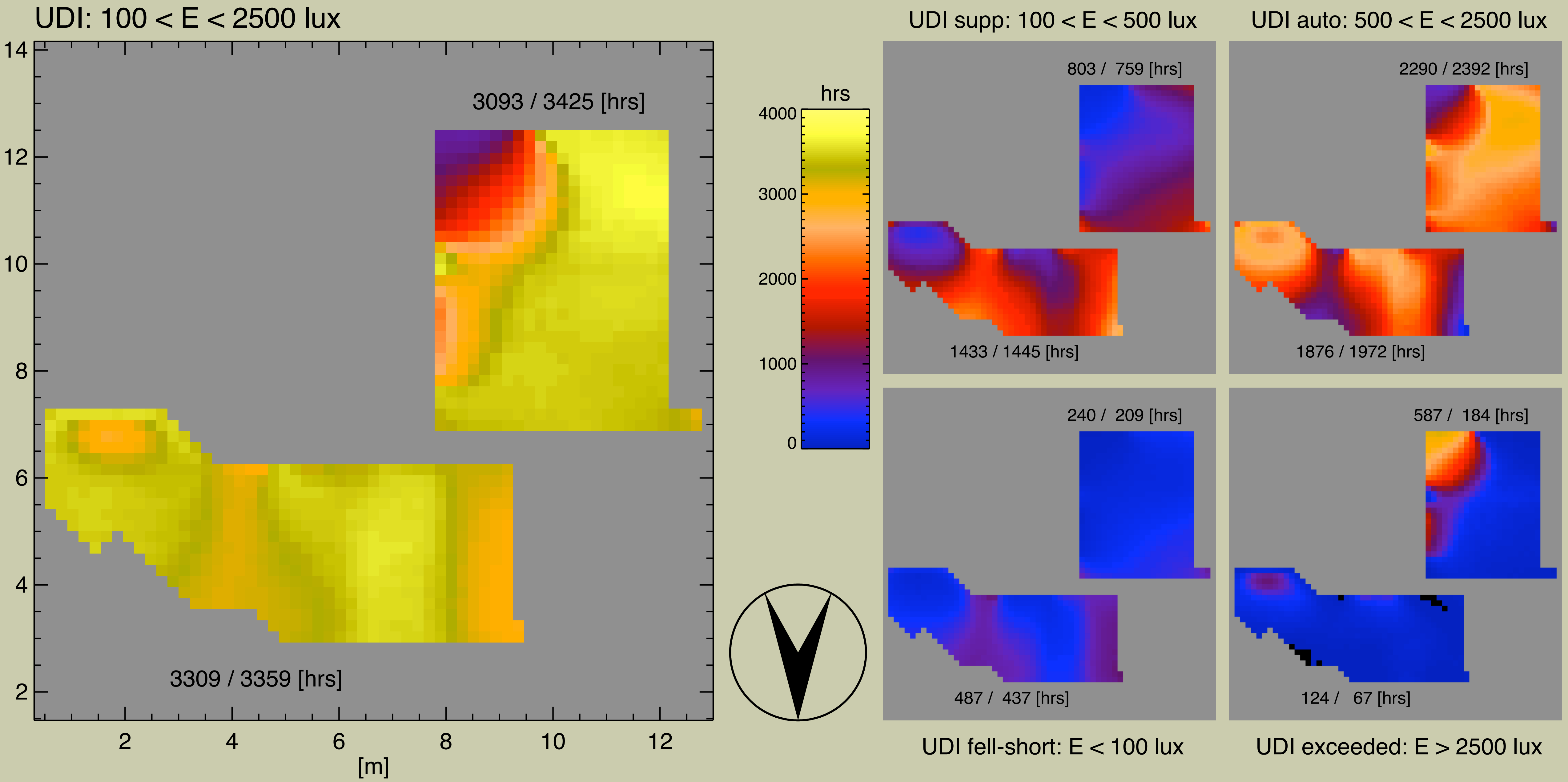


Orientation 180

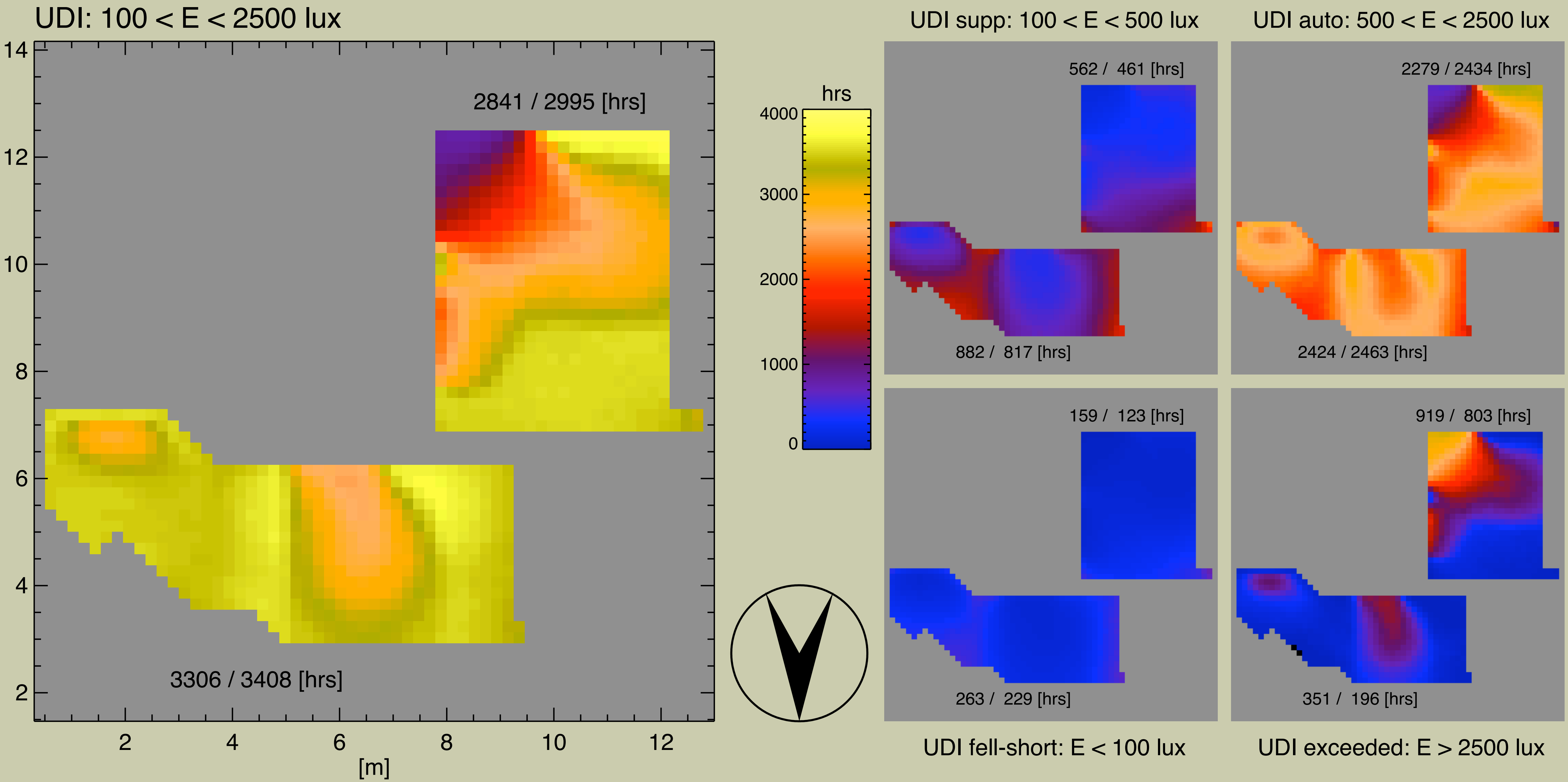
A1_u 180 FRA_Nice



A2_u 180 FRA_Nice



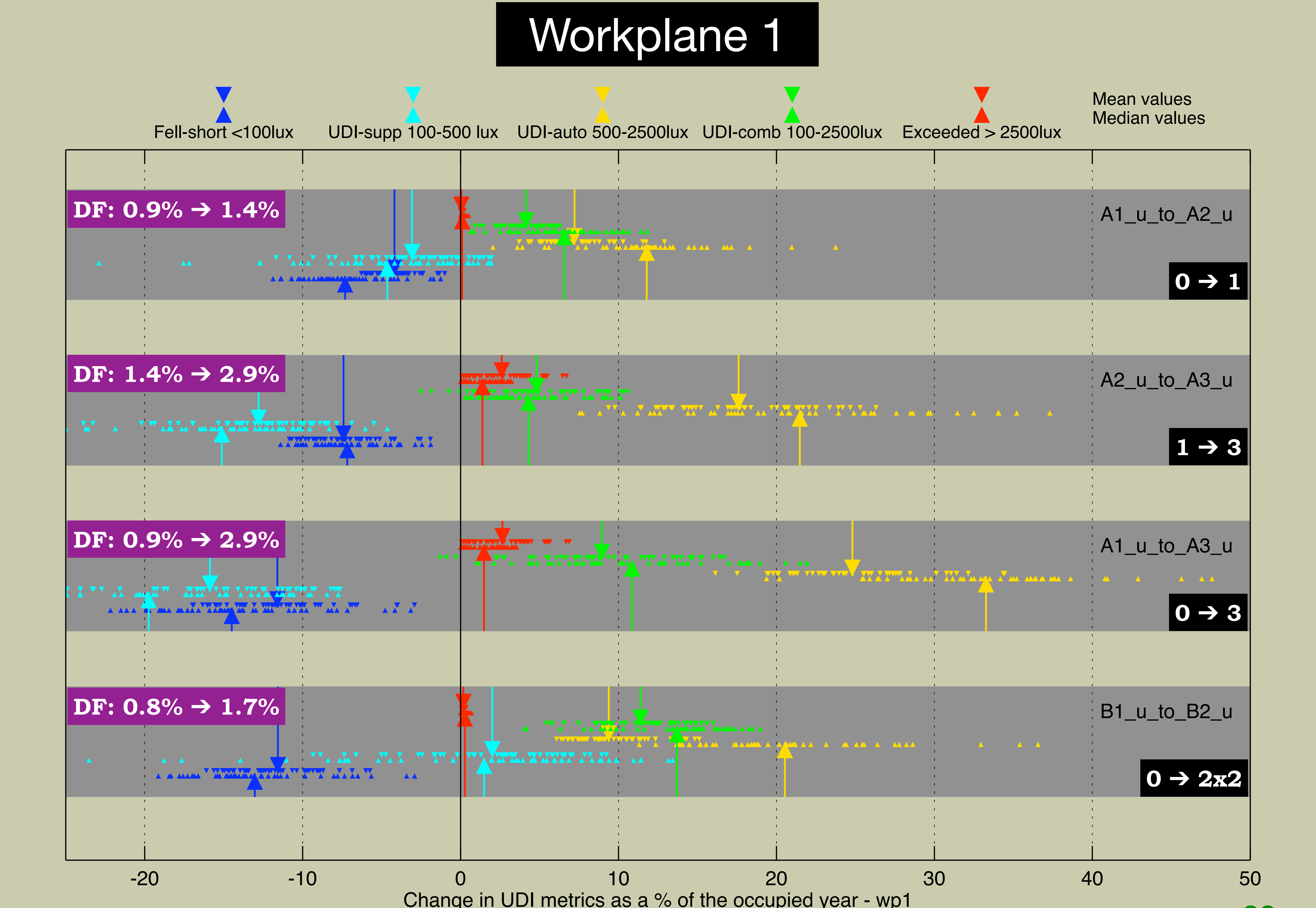
A3_u 180 FRA_Nice



Summary values: mean or median across the workplane?

The mean value is the most readily understood. However for this application where there are occasional ‘hot’ or ‘cold’ spots (but rarely both), the median is considered a more typical value, i.e. one that is more representative of the conditions across the floor and less influenced than the mean by an occasional ‘hot’ or ‘cold’ spot.

Overall graphical summary of change in UDI metrics


Workplane 1
Fell-short <100lux
UDI-supp 100-500 lux
UDI-auto 500-2500lux
UDI-comb 100-2500lux
Exceeded > 2500lux
Mean values
Median values
DF: 0.9% → 1.4%
A1_u_to_A2_u
0 → 1
DF: 1.4% → 2.9%
A2_u_to_A3_u
1 → 3
DF: 0.9% → 2.9%
A1_u_to_A3_u
0 → 3
DF: 0.8% → 1.7%
B1_u_to_B2_u
0 → 2x2
-20
-10
0
10
20
30
40
50
Change in UDI metrics as a % of the occupied year - wp1

0 → 3	UDI-f < 100	UDI-s 100 - 500	UDI-a 500 - 2500	UDI-e > 2500
GBR_Finn 000	**1319 to 377 hrs**	**2250 to 1780 hrs**	**0 to 1582 hrs**	**0 to 0 hrs**
GBR_Finn 180	**1059 to 362 hrs**	**1771 to 1118 hrs**	**853 to 2009 hrs**	**0 to 42 hrs**
USA_LosA 000	**522 to 208 hrs**	**3109 to 1478 hrs**	**1 to 2085 hrs**	**0 to 0 hrs**
USA_LosA 180	**550 to 207 hrs**	**1989 to 606 hrs**	**1248 to 2553 hrs**	**6 to 154 hrs**

DF: 0.9% → 2.9%

0 → 3	UDI-f < 100	UDI-s 100 - 500	UDI-a 500 - 2500	UDI-e > 2500
GBR_Finn 000	**-22%**	**-11%**	**+36%**	**0%**
GBR_Finn 180	**-16%**	**-15%**	**+26%**	**+2%**
USA_LosA 000	**-7%**	**-37%**	**+48%**	**0%**
USA_LosA 180	**-8%**	**-32%**	**+30%**	**3%**

DF: 0.9% → 2.9%

Conclusions

A final thought:

Valuing Daylight

Acknowledgements

This study was commissioned by VELUX

The report has been made freely available and can be downloaded from the either the VELUX Daylight website or Mardaljevic's IESD pages:

http://www.thedaylightsite.com

http://www.iesd.dmu.ac.uk/~jm

Thank you