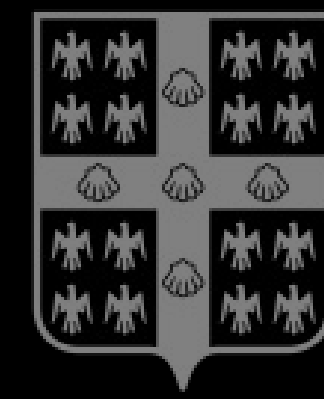


What Is a Good Day for Outdoor Photometric Stereo?

Yannick Hold-Geoffroy (Laval), Jinsong Zhang (Laval)
Paulo Gotardo (Disney Research, Pittsburgh), Jean-François Lalonde (Laval)



UNIVERSITÉ
LAVAL



Disney Research

Photometric Stereo

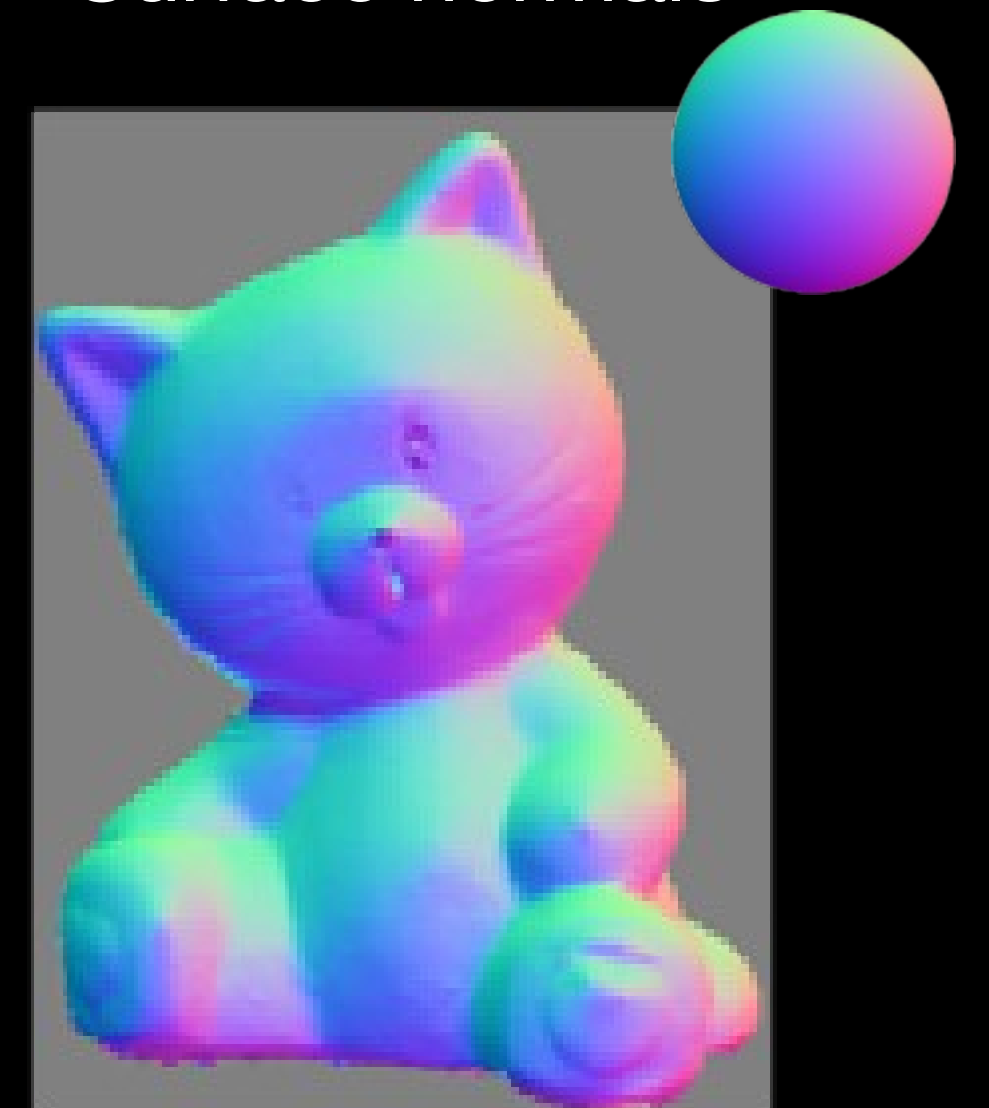
Images of object under different light directions



...



Surface normals



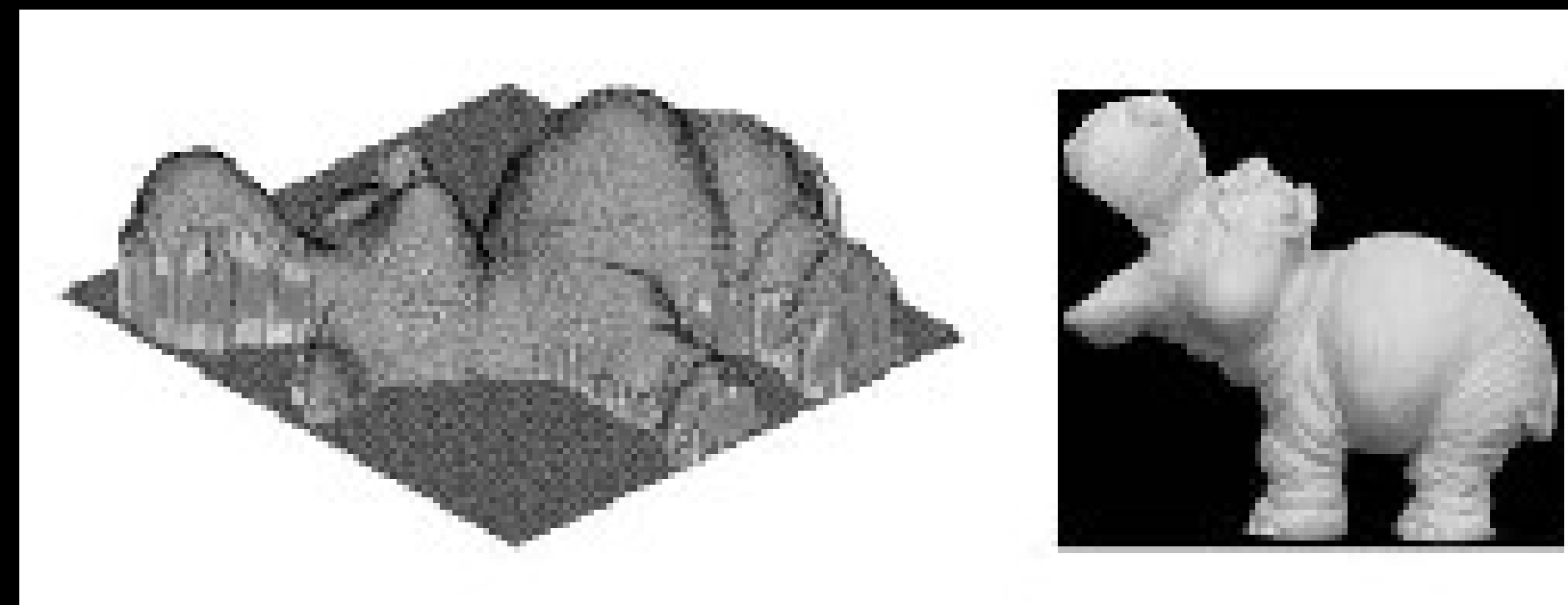
Photometric Stereo in the lab

Non-parametric,
spatially-varying reflectance



[Alldrin et al., CVPR '08]

Unknown (smooth) lighting



[Basri et al., IJCV '07]

Robust under specularities,
shadows, and noise



[Ikehata et al., CVPR '12]

Photometric Stereo — point light sources

pixel
intensity

light
direction

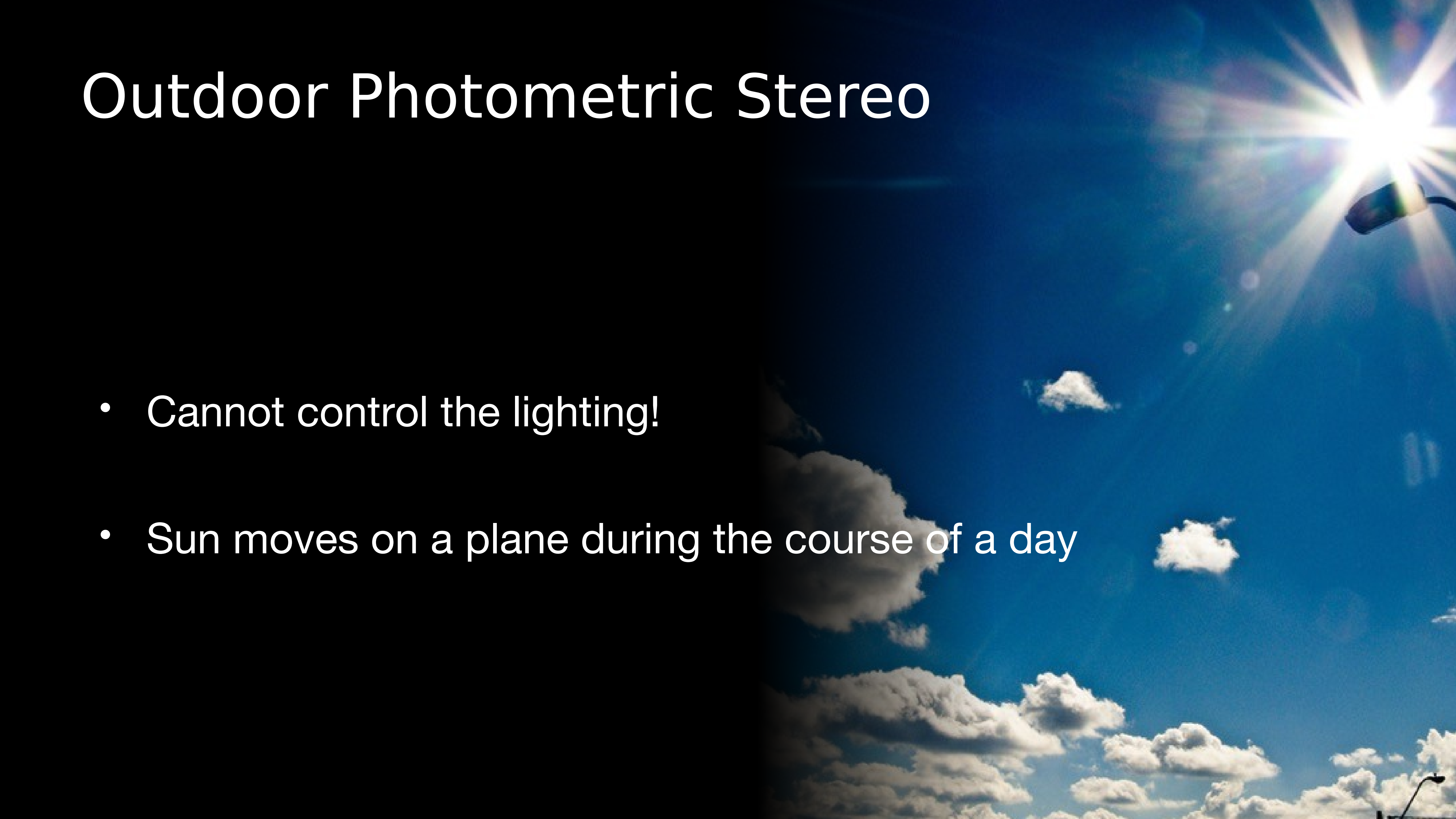
scaled
surface
normal

$$b_j = \mathbf{l}_j^T \mathbf{n}$$

$$\mathbf{b} = \begin{bmatrix} b_1 \\ b_2 \\ \dots \\ b_m \end{bmatrix} = \begin{bmatrix} \mathbf{l}_1^T \\ \mathbf{l}_2^T \\ \dots \\ \mathbf{l}_m^T \end{bmatrix} \mathbf{n} = \mathbf{L} \mathbf{n}$$

Outdoor Photometric Stereo

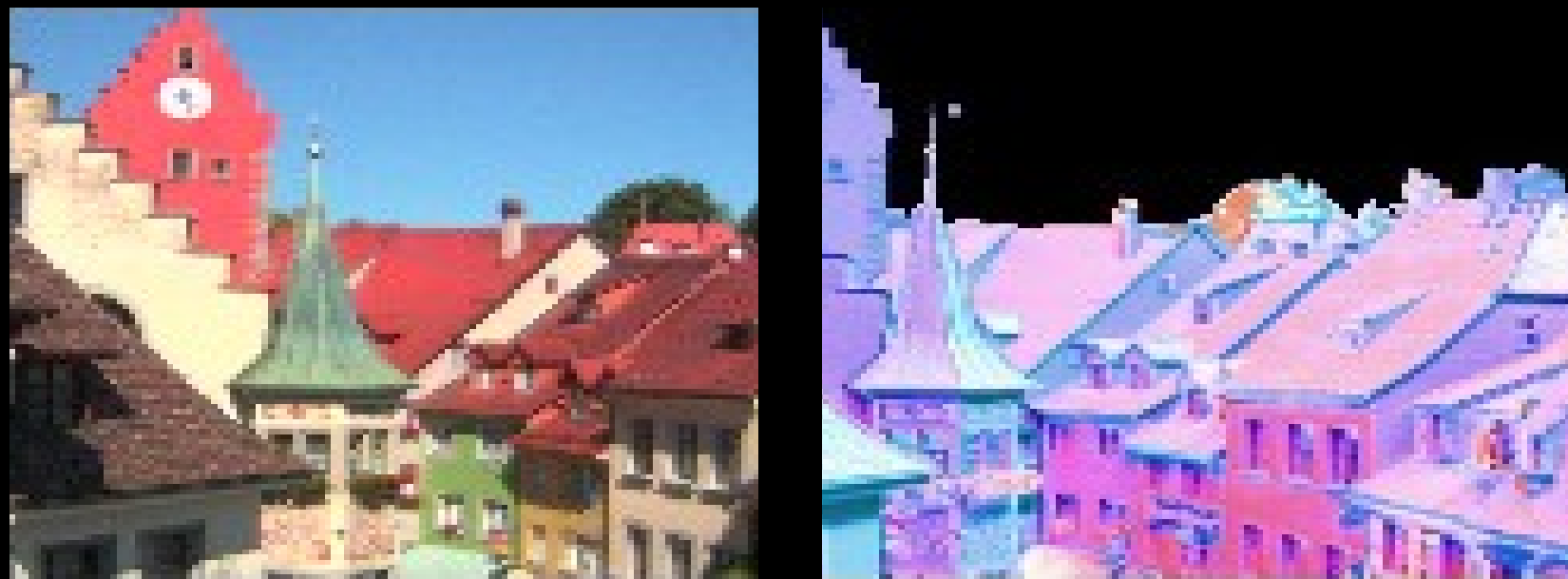
- Cannot control the lighting!
- Sun moves on a plane during the course of a day



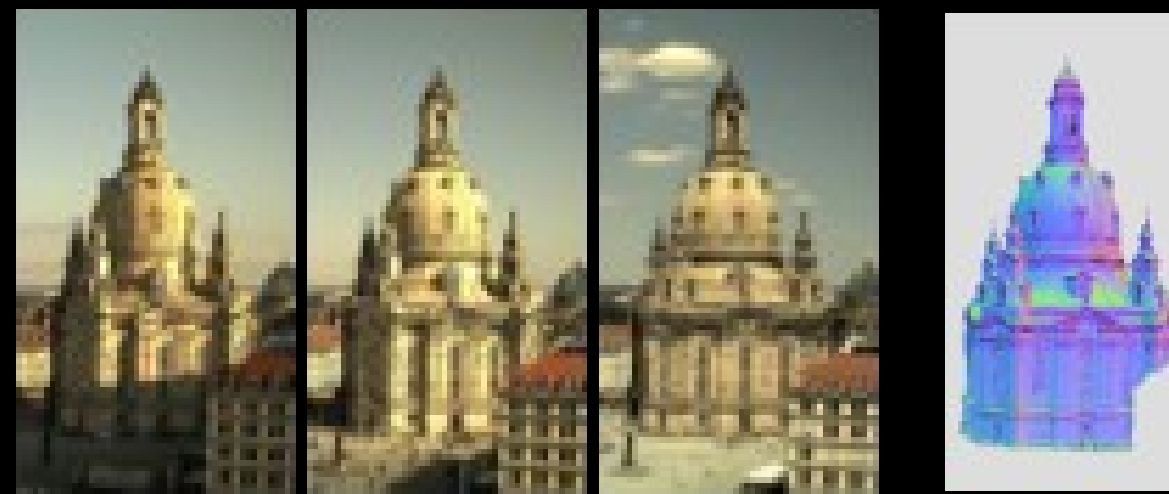
Outdoor Photometric Stereo

Uncontrolled illumination!

Months of data

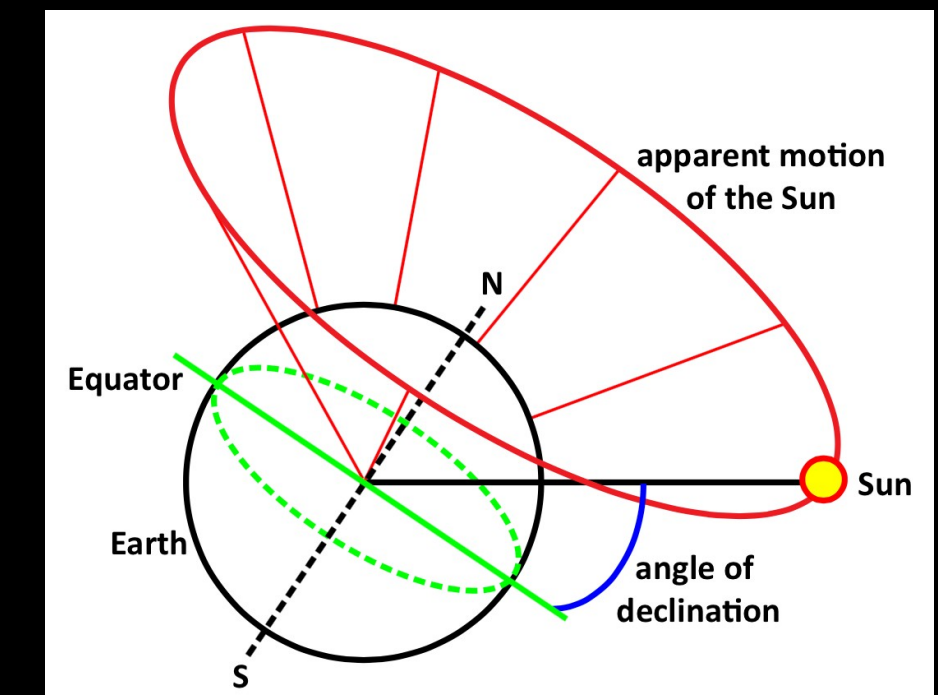


[Abrams et al., ECCV'12]



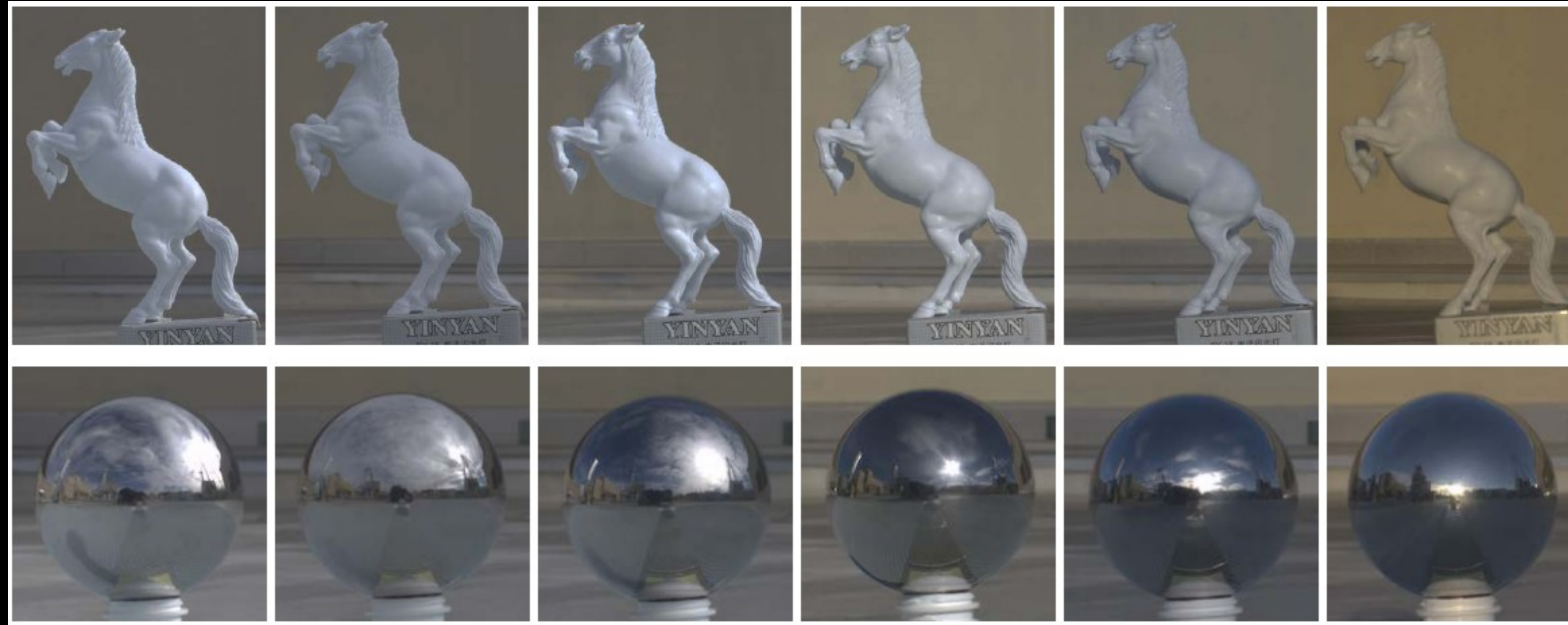
[Ackermann et al., CVPR'12]

Wait for a particular day



[Shen et al., Pacific Graphics '14]

Richer lighting models



[Yu et al., ICCP'13]

The quality of their results were degraded outdoors

When does Photometric Stereo
work outdoors?

Summary of our findings

- Best stability is obtained when:
 - 1) the sky is partially cloudy throughout the day
 - 2) surface patches are pointing south, above the horizon
 - 3) the sun path is low in the sky

Outline

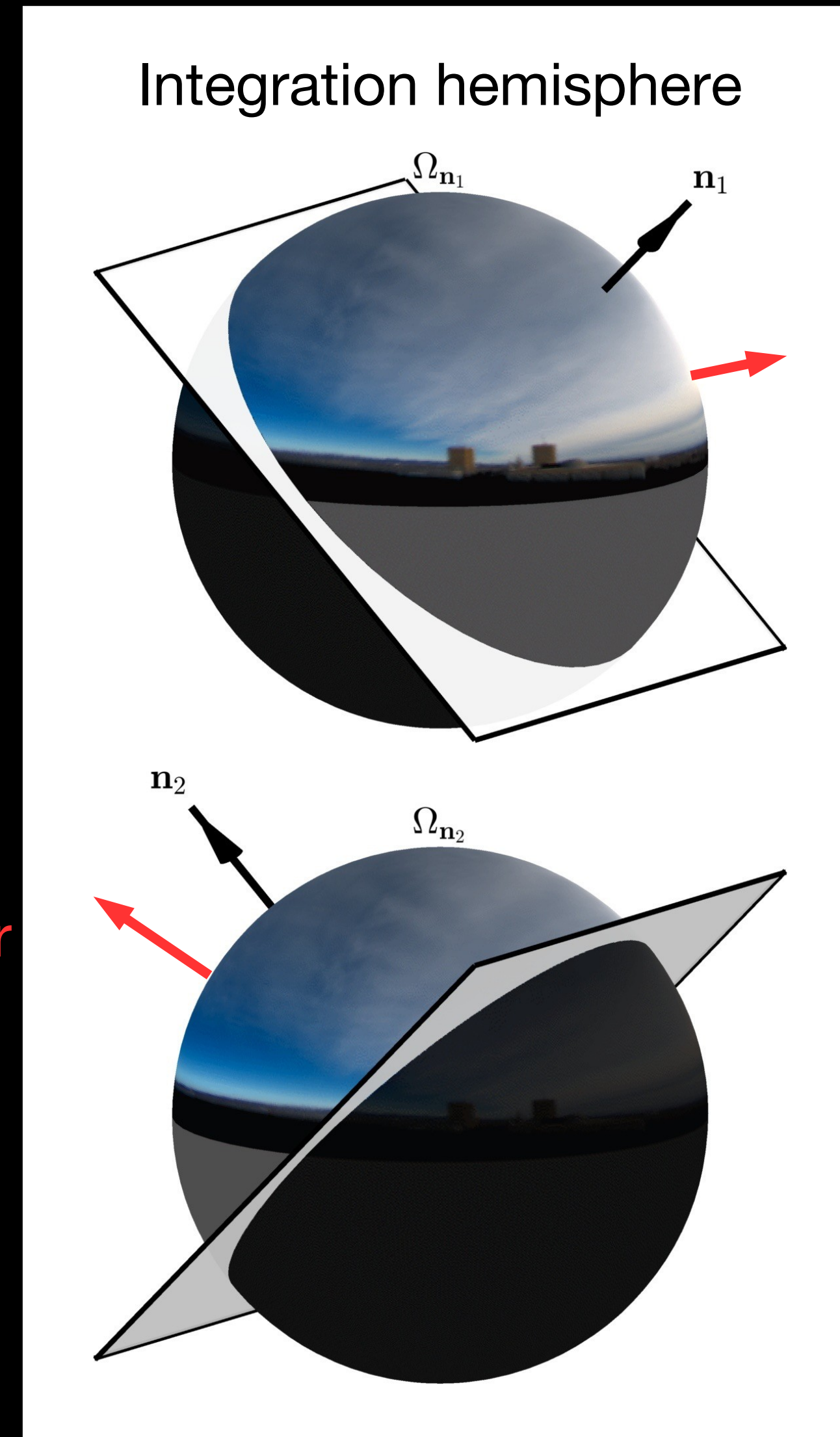
- theoretical analysis
- data
- results

Photometric stereo — environment map lighting

pixel intensity mean light vector scaled surface normal

$$b_j = \bar{\mathbf{l}}_j^T \mathbf{n}$$

mean
light
vector



mean
light
vector

Point light source vs environment map lighting

Point light source

$$b = \begin{bmatrix} b_1 \\ b_2 \\ \dots \\ b_m \end{bmatrix} = \begin{bmatrix} \mathbf{l}_1^T \\ \mathbf{l}_2^T \\ \dots \\ \mathbf{l}_m^T \end{bmatrix} \mathbf{n} = L\mathbf{n}$$

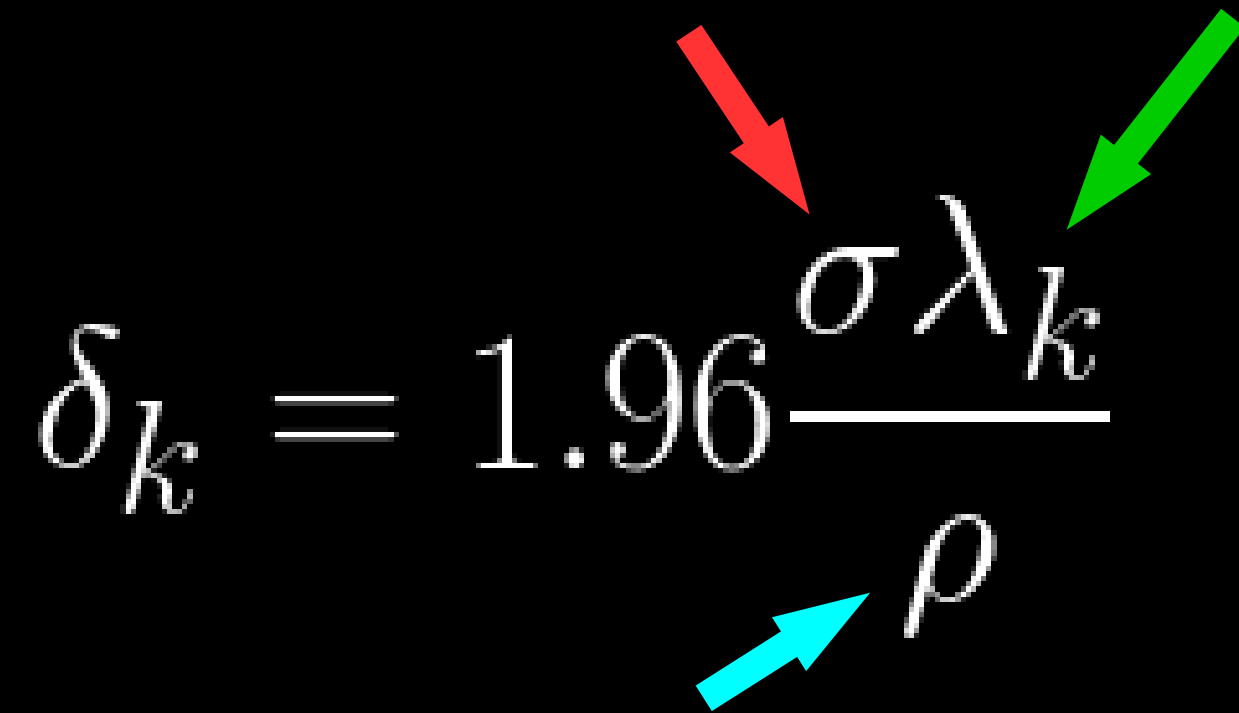
Matrix of **light directions**

Environment map

$$b = \begin{bmatrix} b_1 \\ b_2 \\ \dots \\ b_m \end{bmatrix} = \begin{bmatrix} \bar{\mathbf{l}}_1^T \\ \bar{\mathbf{l}}_2^T \\ \dots \\ \bar{\mathbf{l}}_m^T \end{bmatrix} \mathbf{n} = L\mathbf{n}$$

Matrix of **mean light vectors**

How well does Photometric Stereo work?

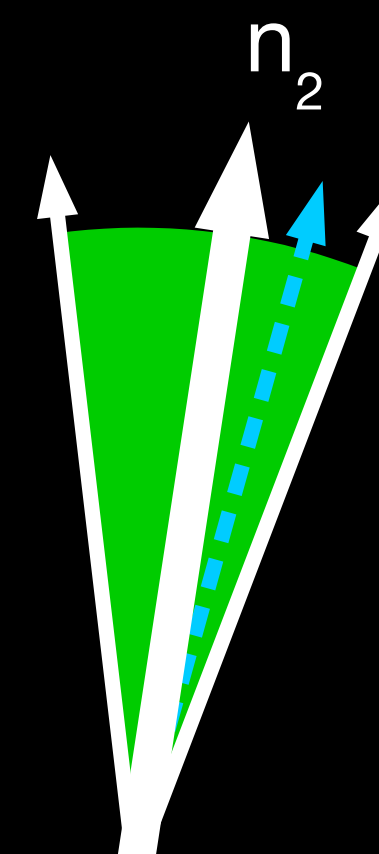
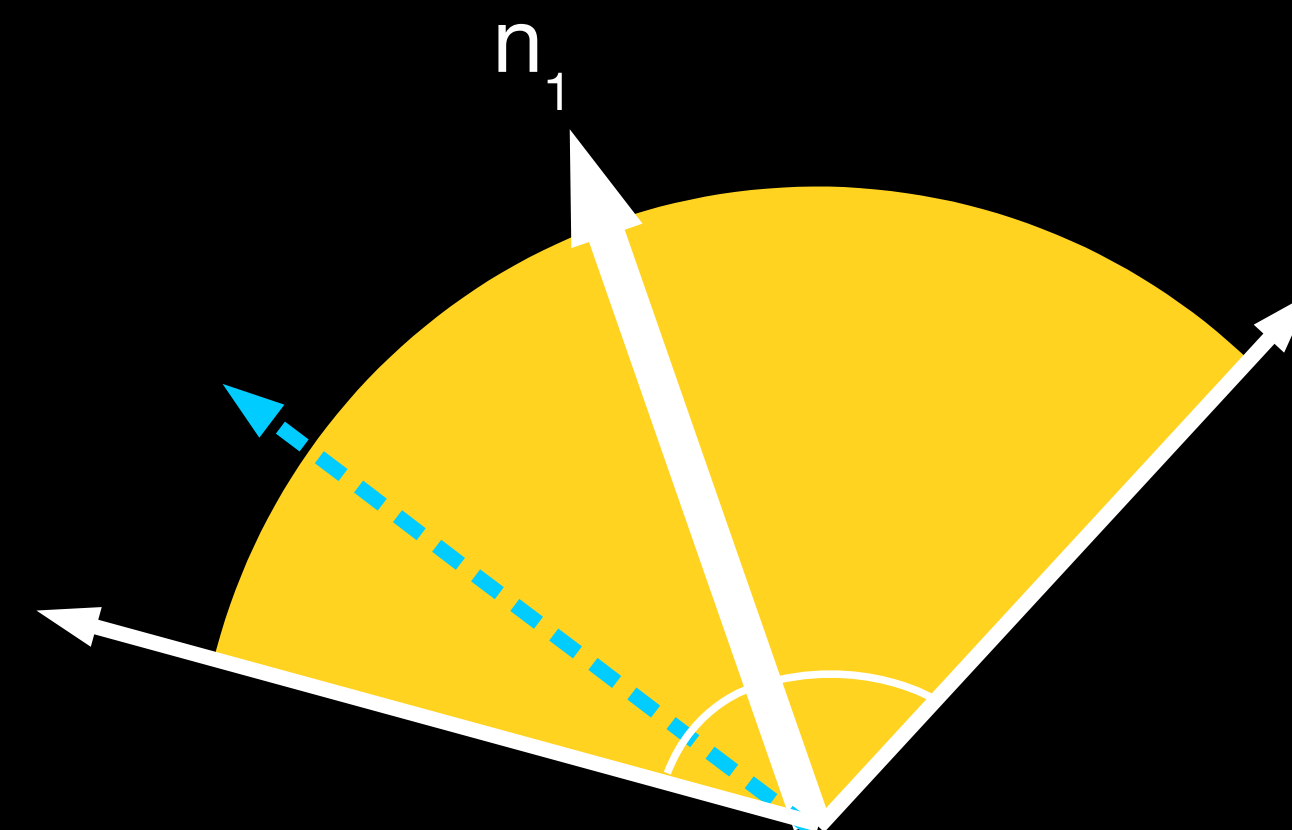
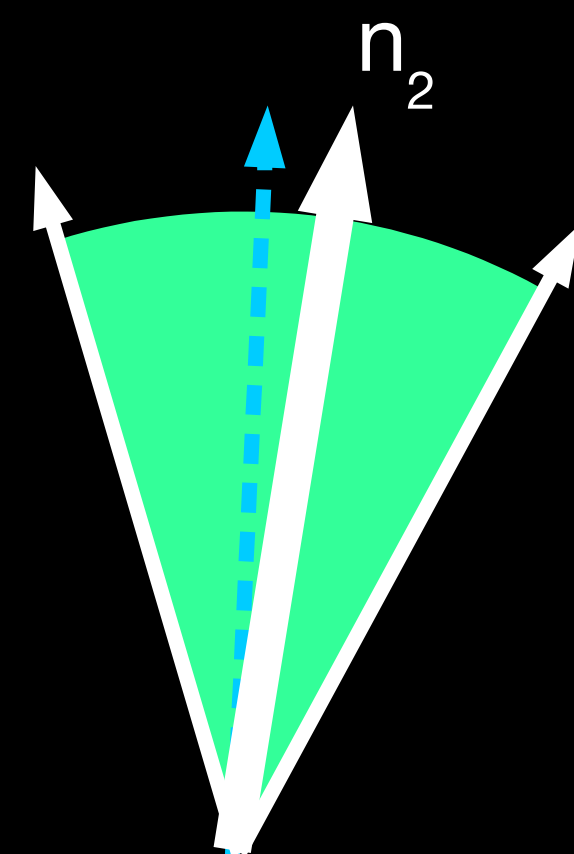
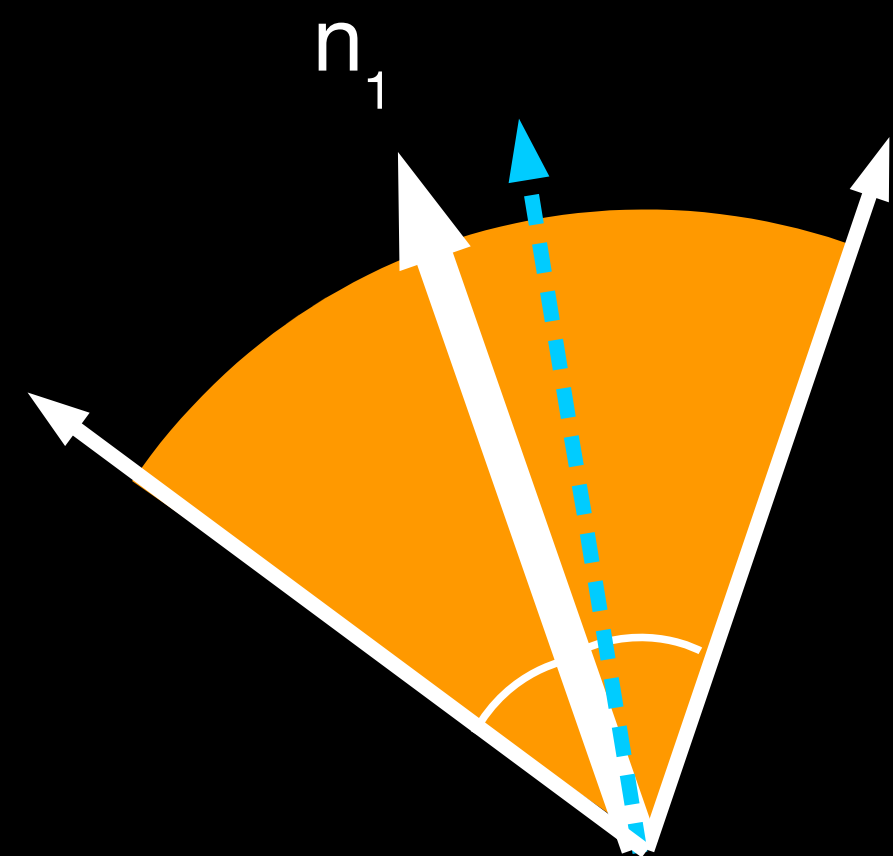
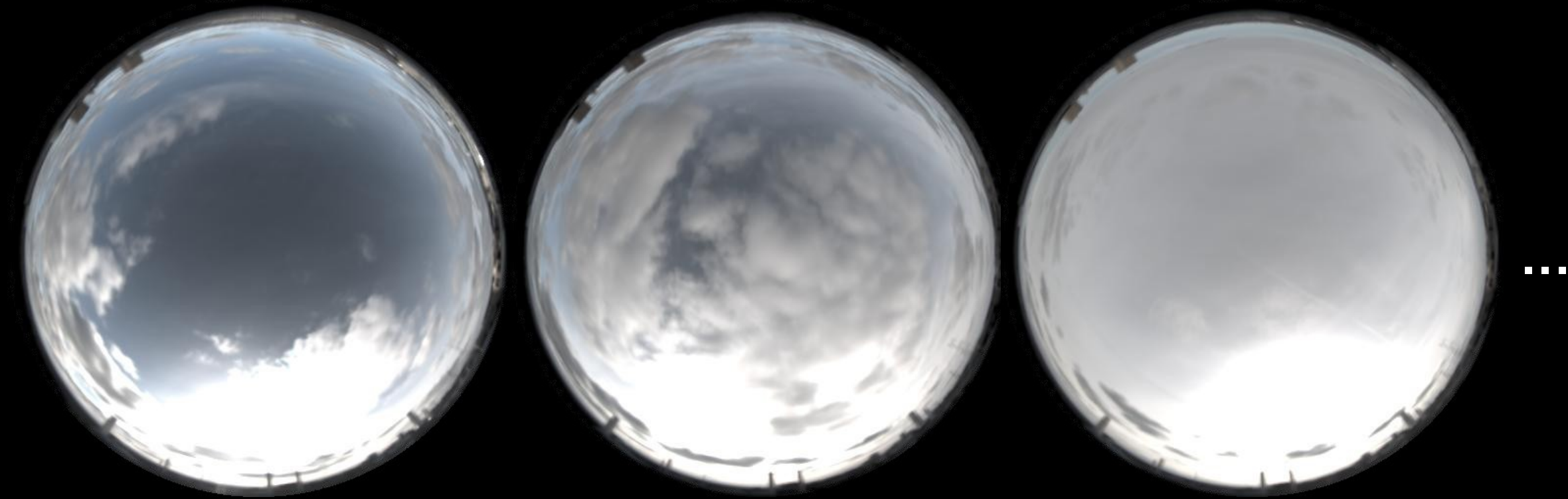

$$\delta_k = 1.96 \frac{\sigma \lambda_k}{\rho}$$

- Assume Gaussian noise on observations
- Reconstruction quality linked to:
 - noise variance
 - albedo of surface
 - related to the conditioning of matrix **L**
- Intuitive measure: 95% confidence interval in normal estimation error

11/06/2013

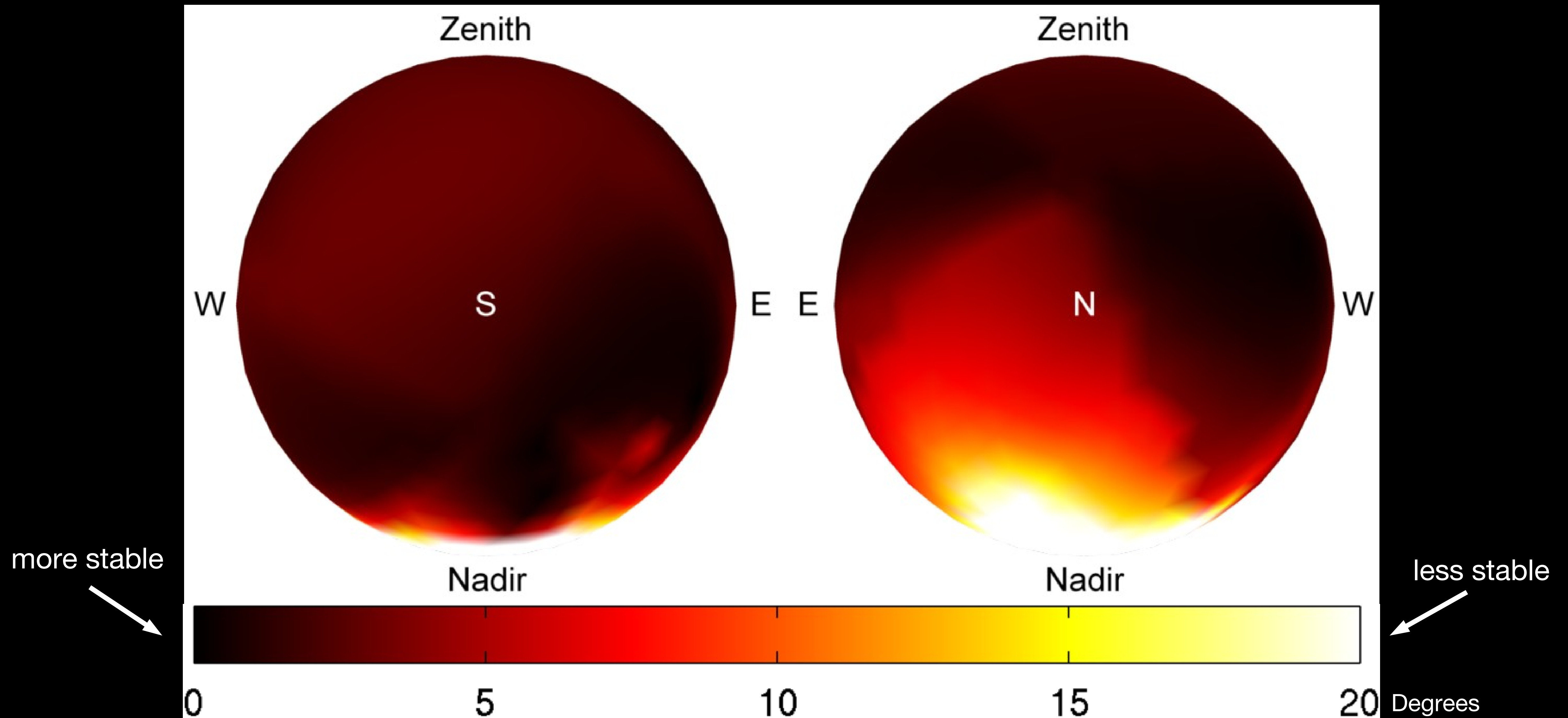


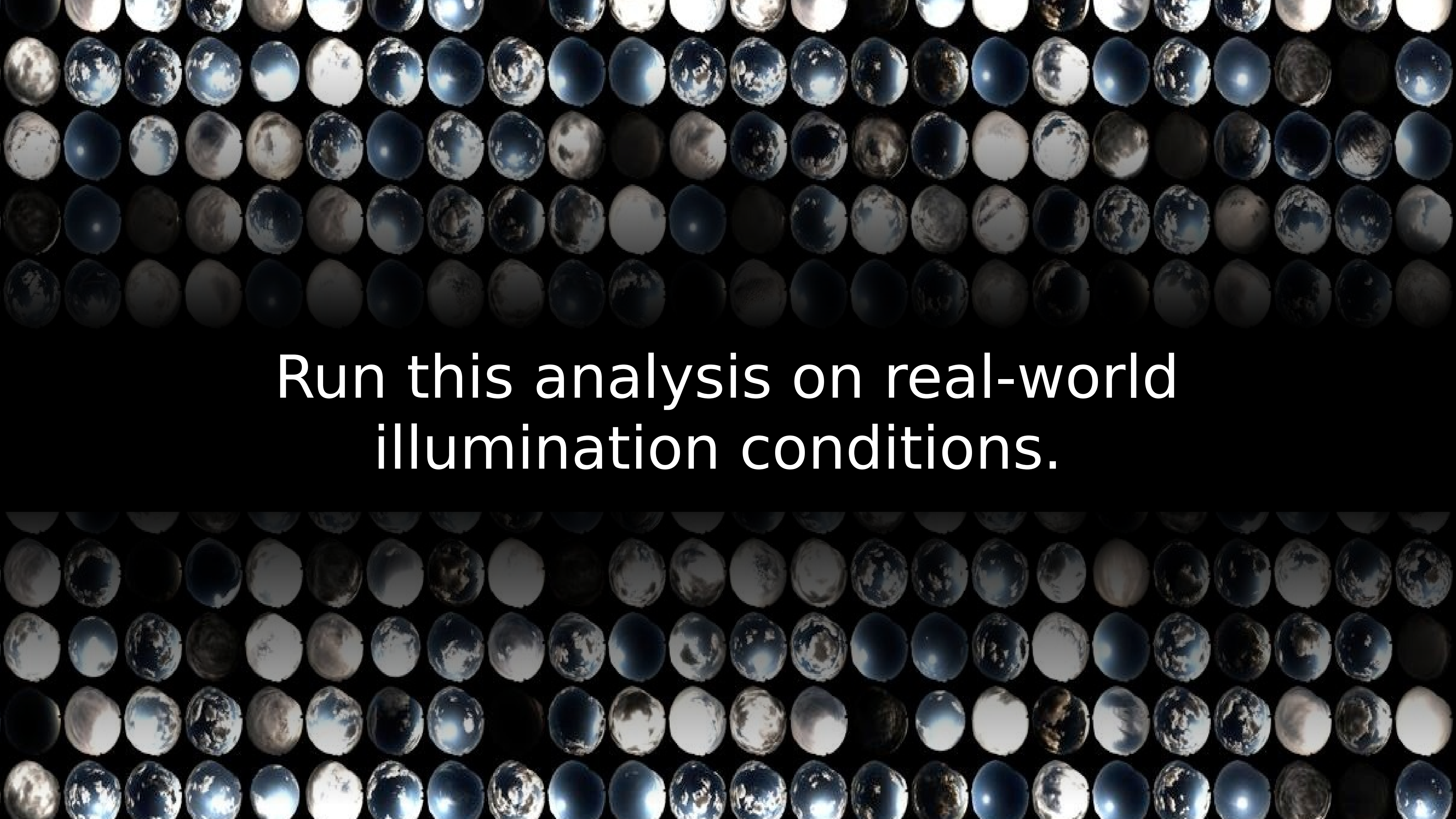
11/08/2014



← ground truth
← recovered normal

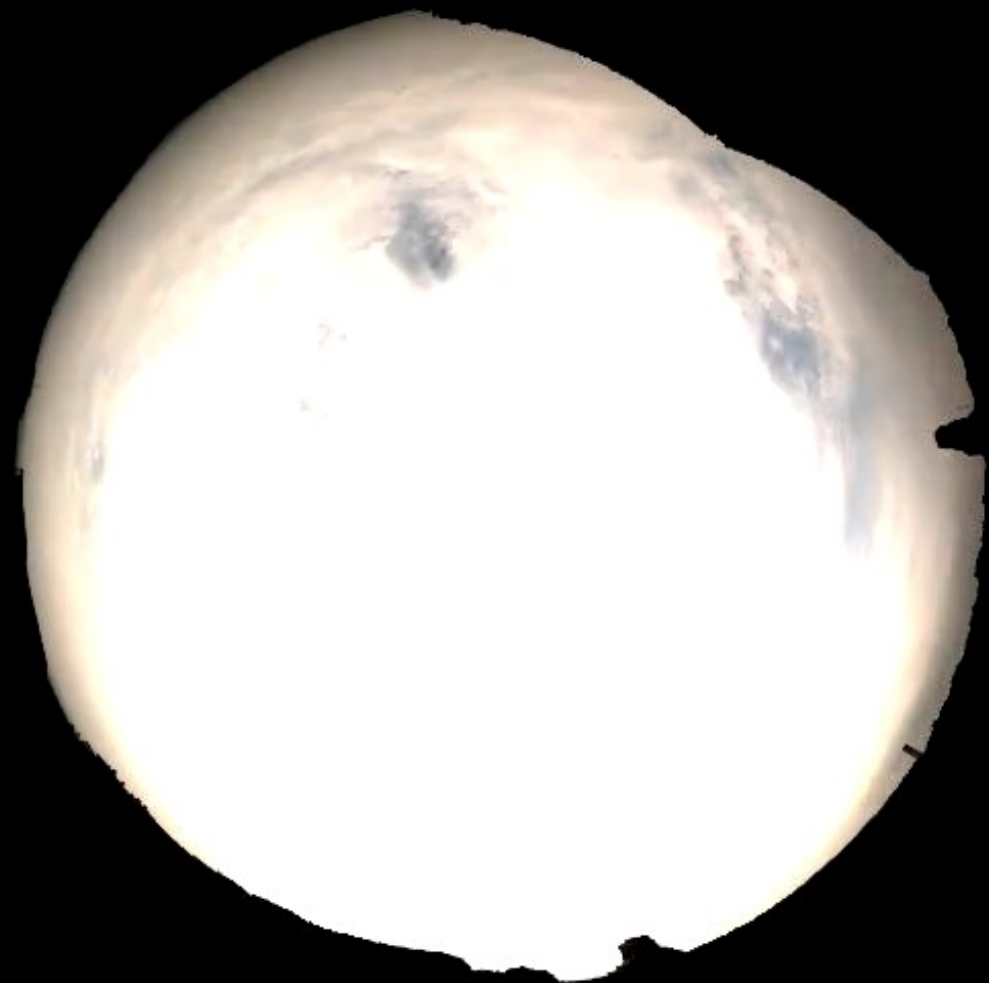
Example of confidence interval sphere



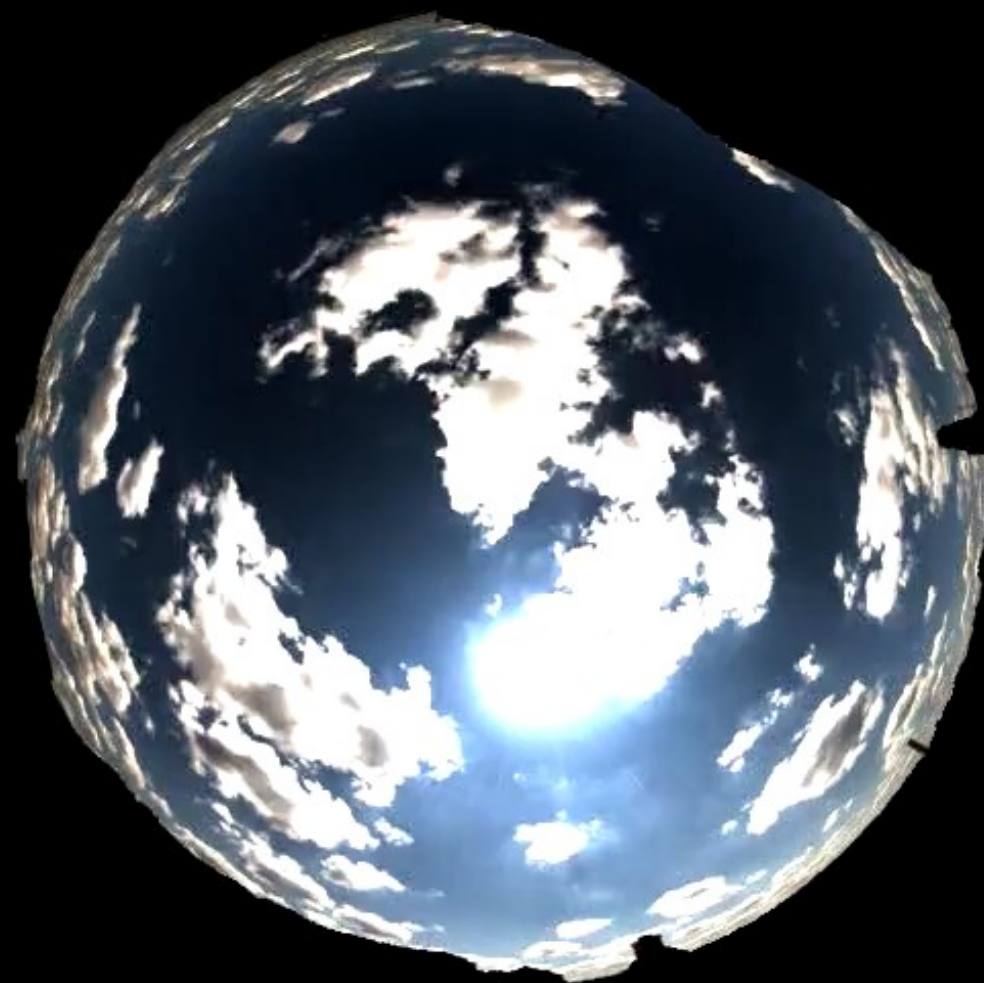
The background of the image is a grid of numerous small, circular images of the Earth. Each image shows a different perspective or lighting condition of the planet, ranging from bright, sunlit views to dark, shadowed views. The images are arranged in a regular grid pattern, creating a textured, mosaic-like effect. The text is centered in the middle of the image, overlaid on the grid.

Run this analysis on real-world
illumination conditions.

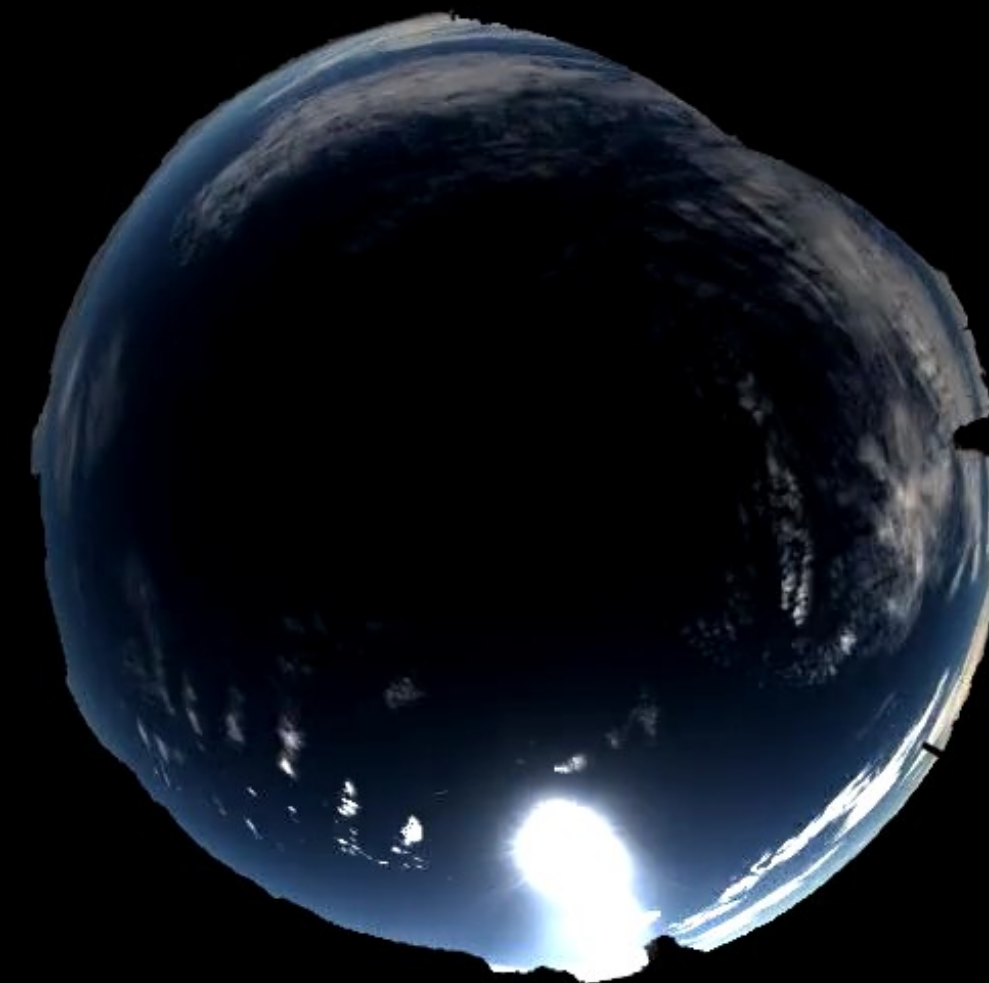




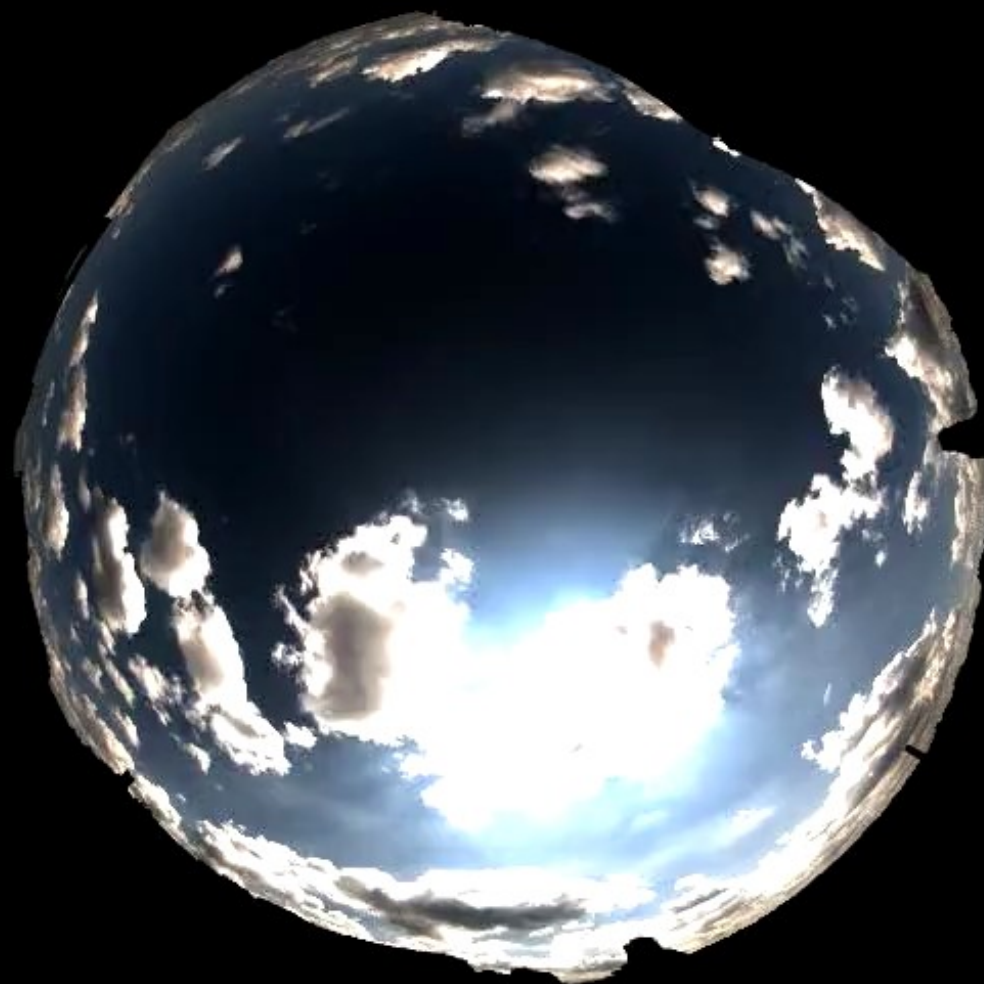
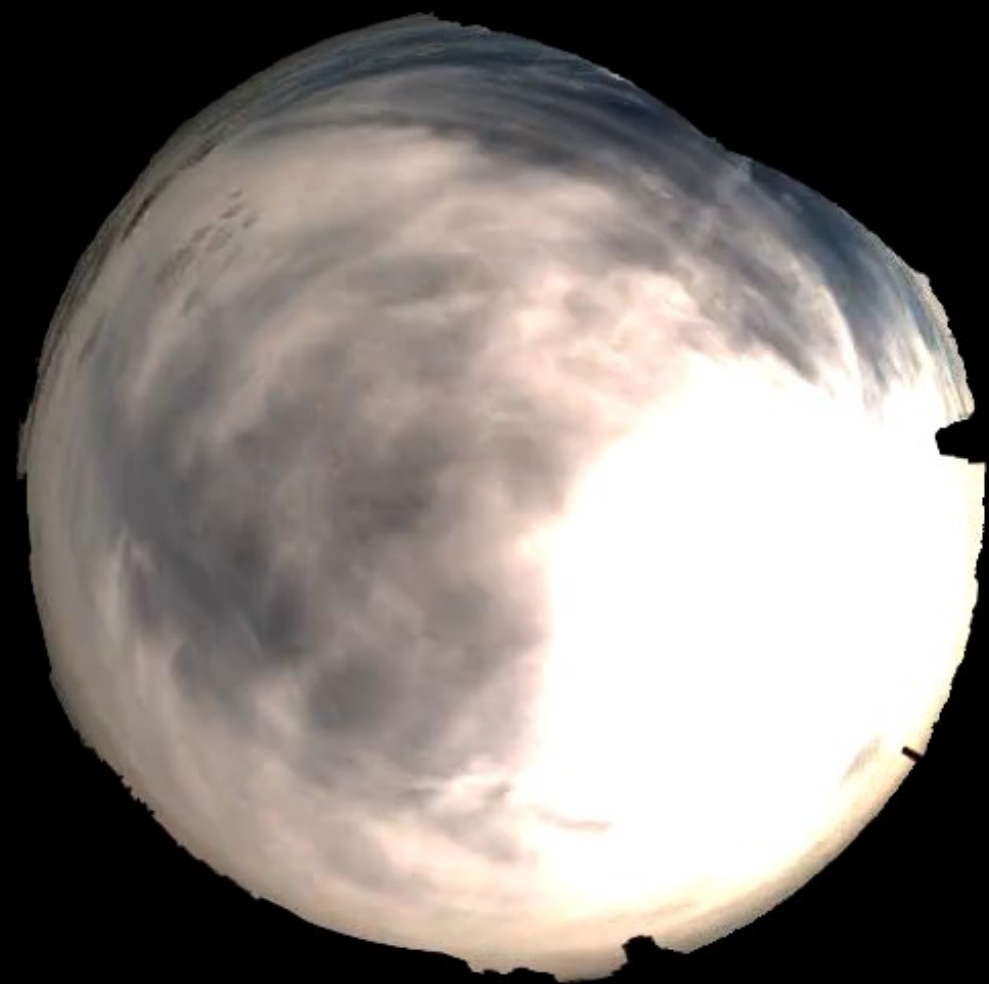
Over 3800 captures



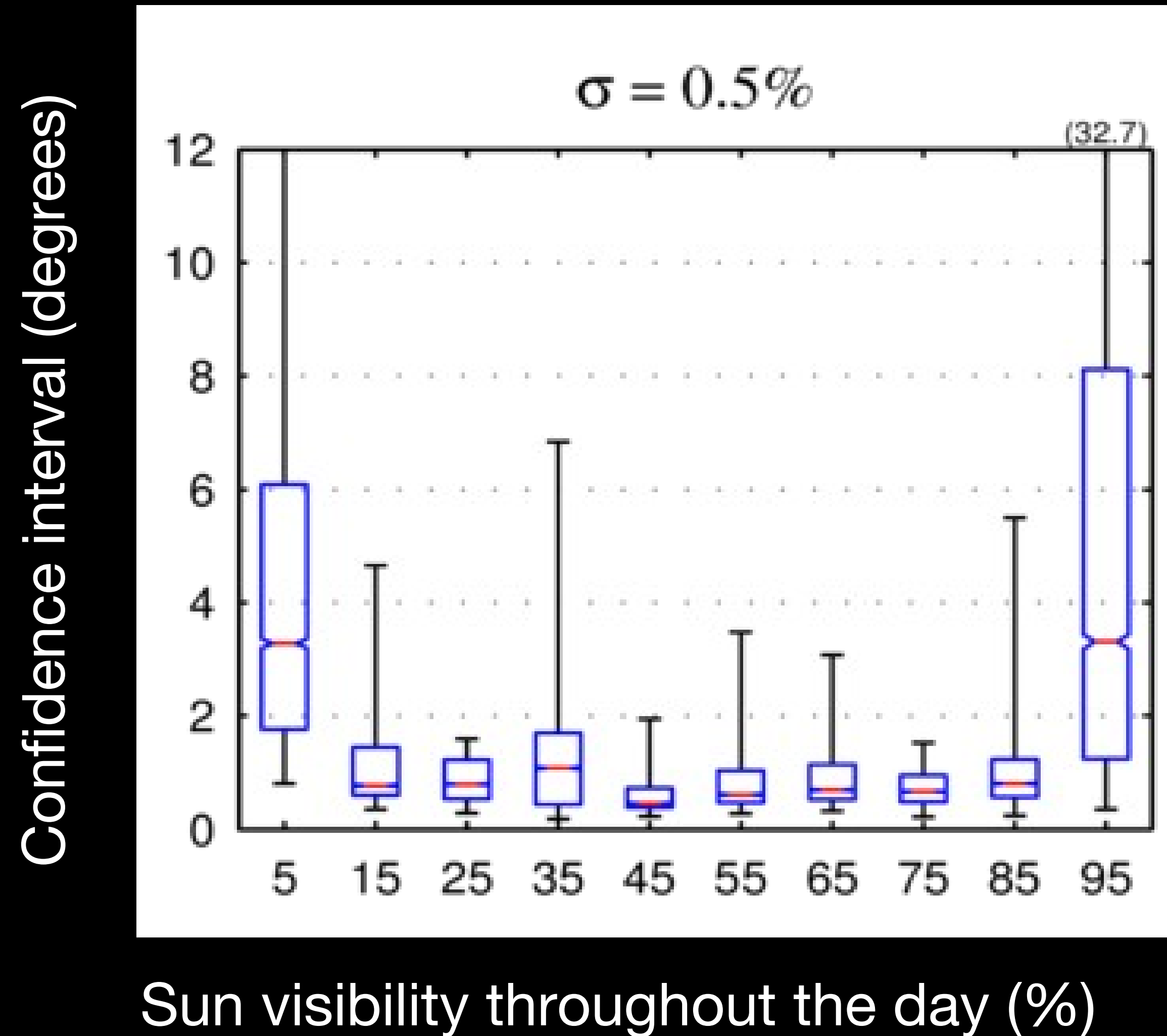
23 days



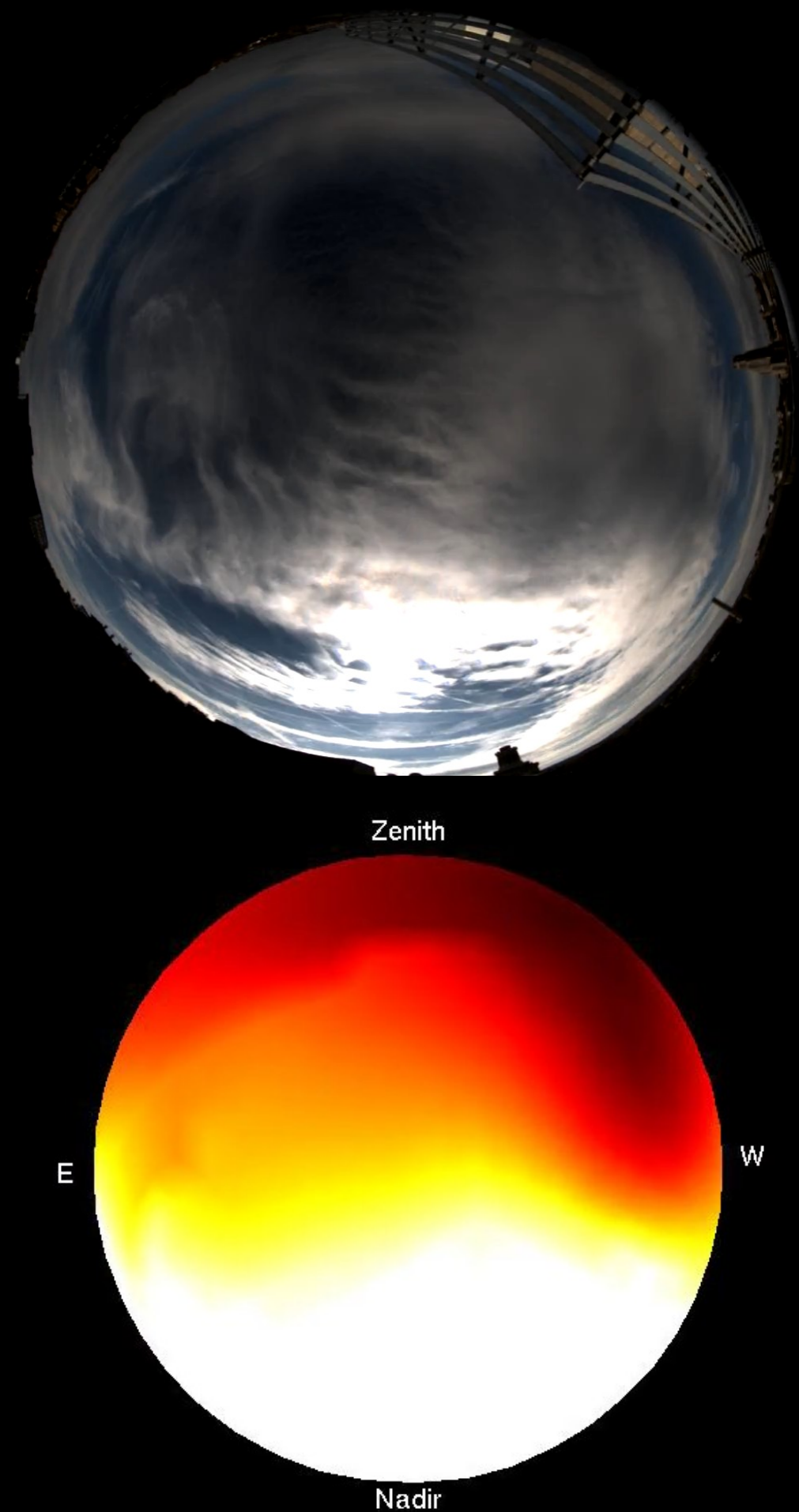
10 months



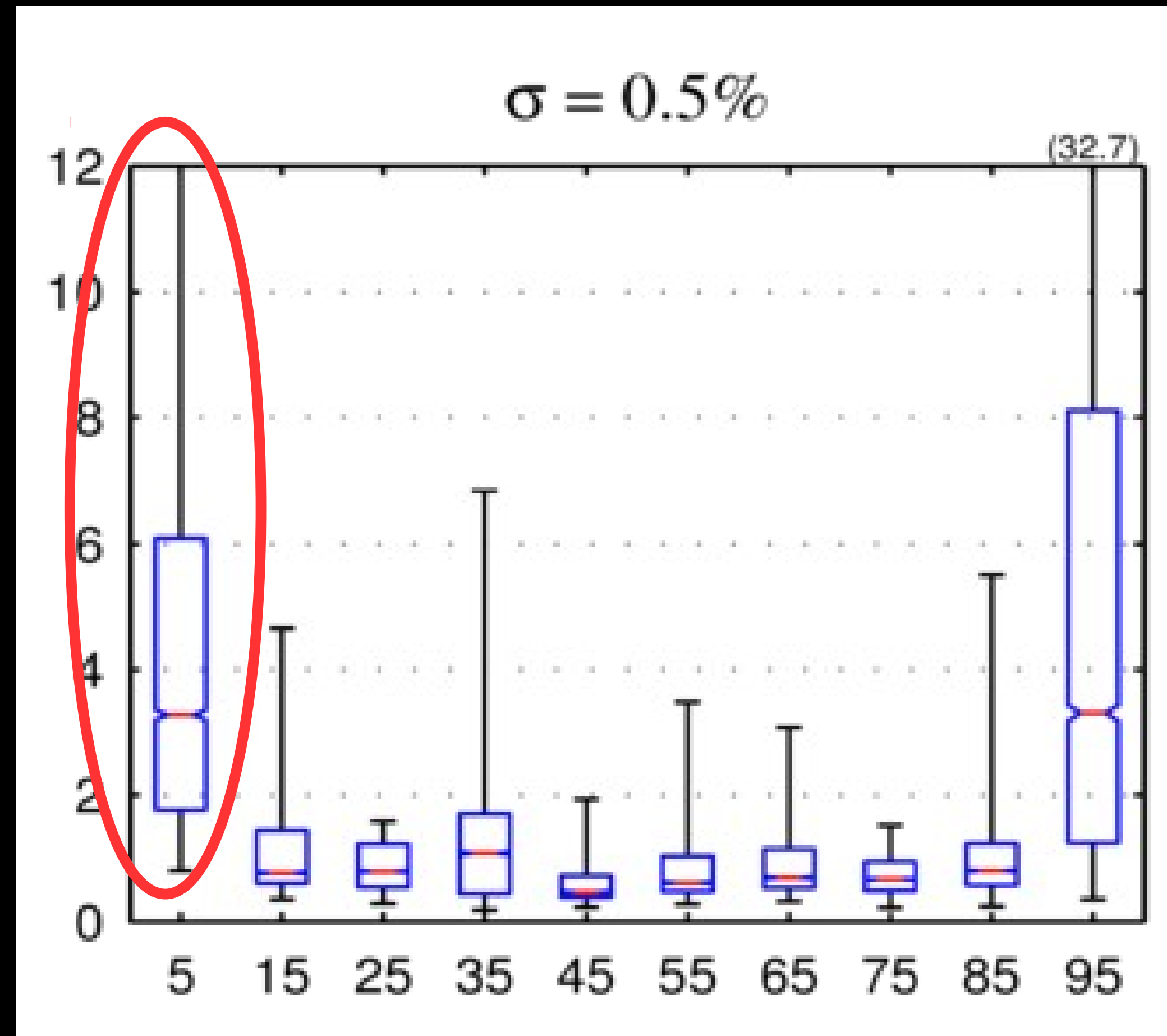
Influence of cloud cover—quantitative



Influence of cloud cover—quantitative



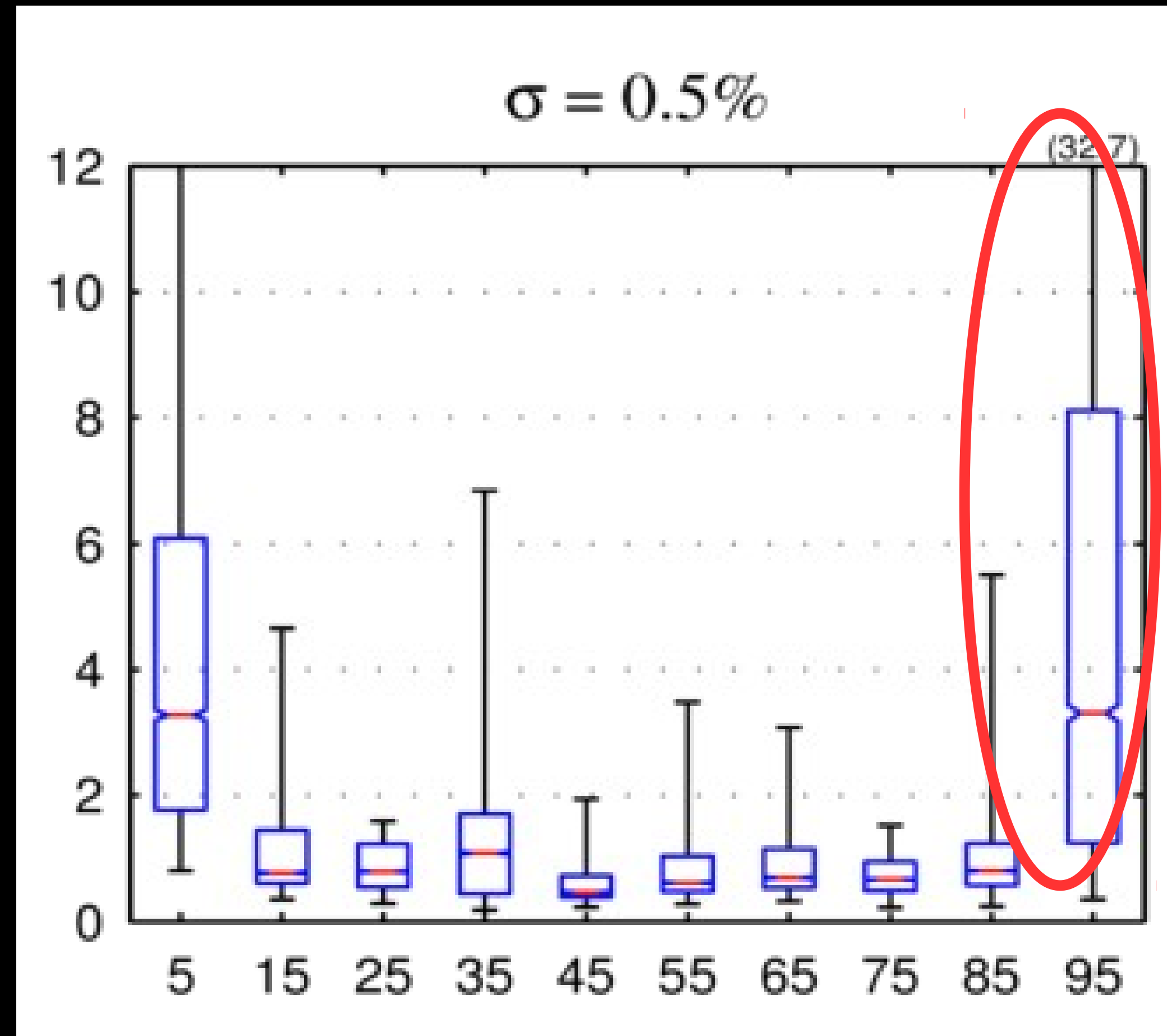
Confidence interval (degrees)



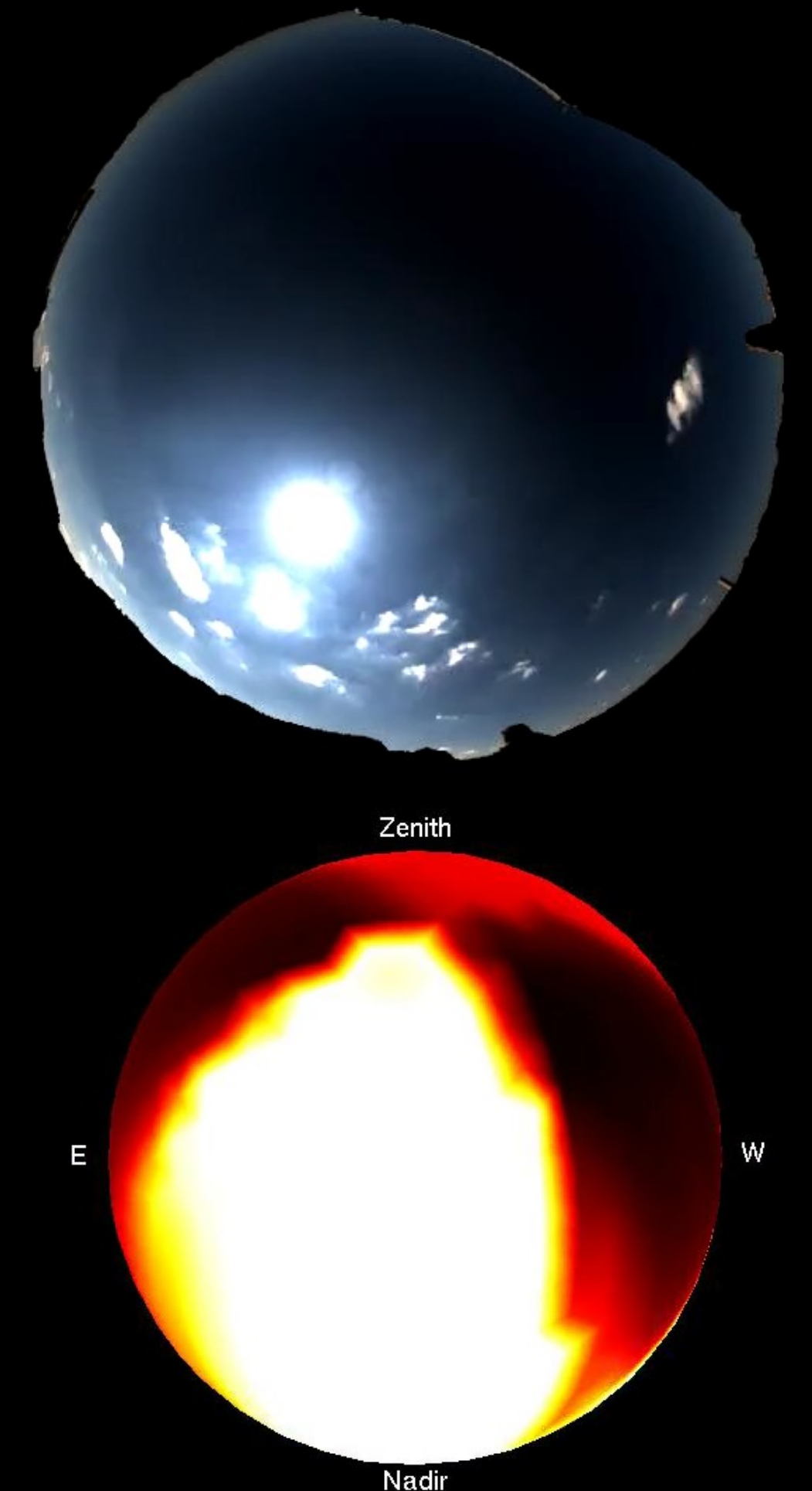
Sun visibility throughout the day (%)

Influence of cloud cover—quantitative

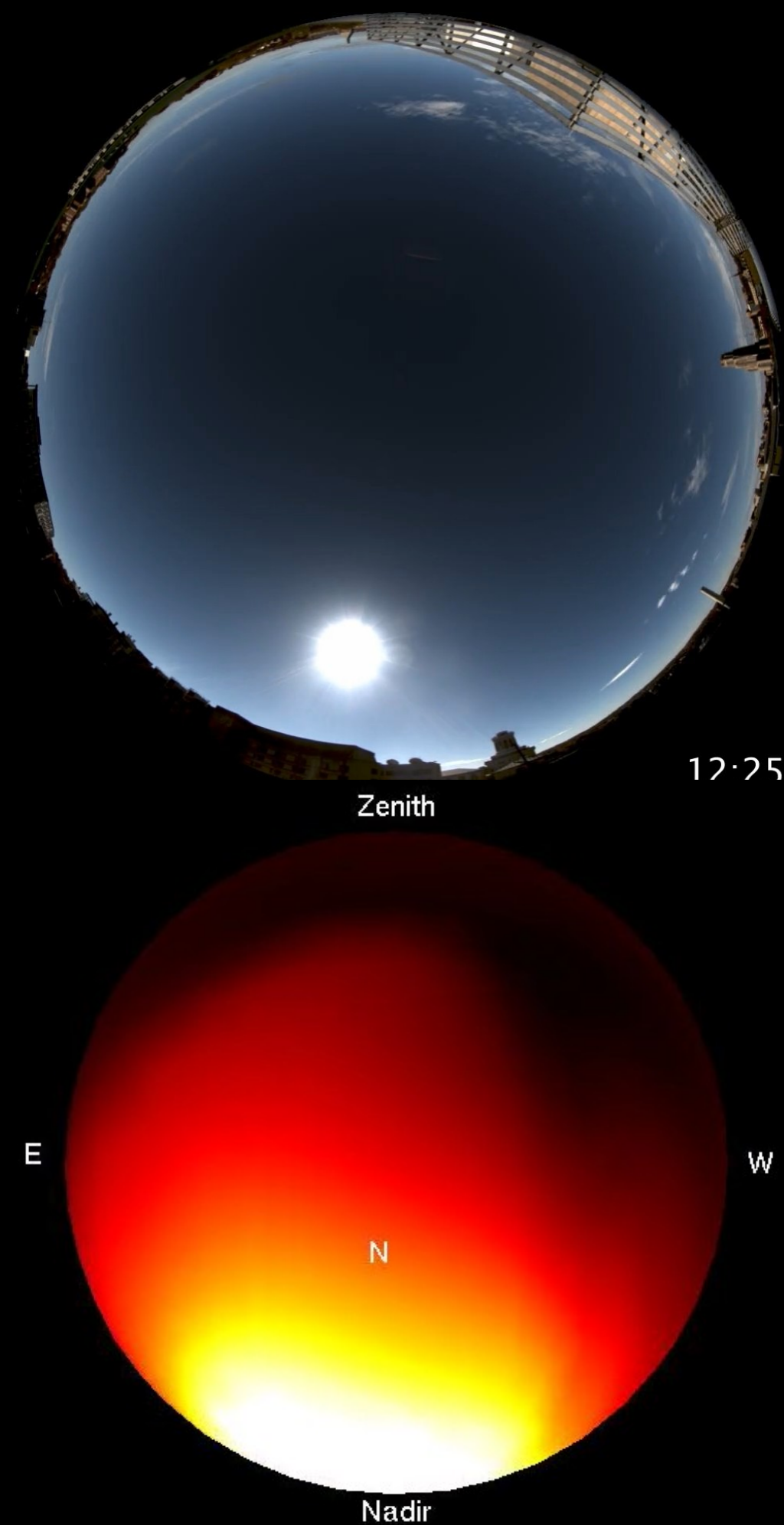
Confidence interval (degrees)



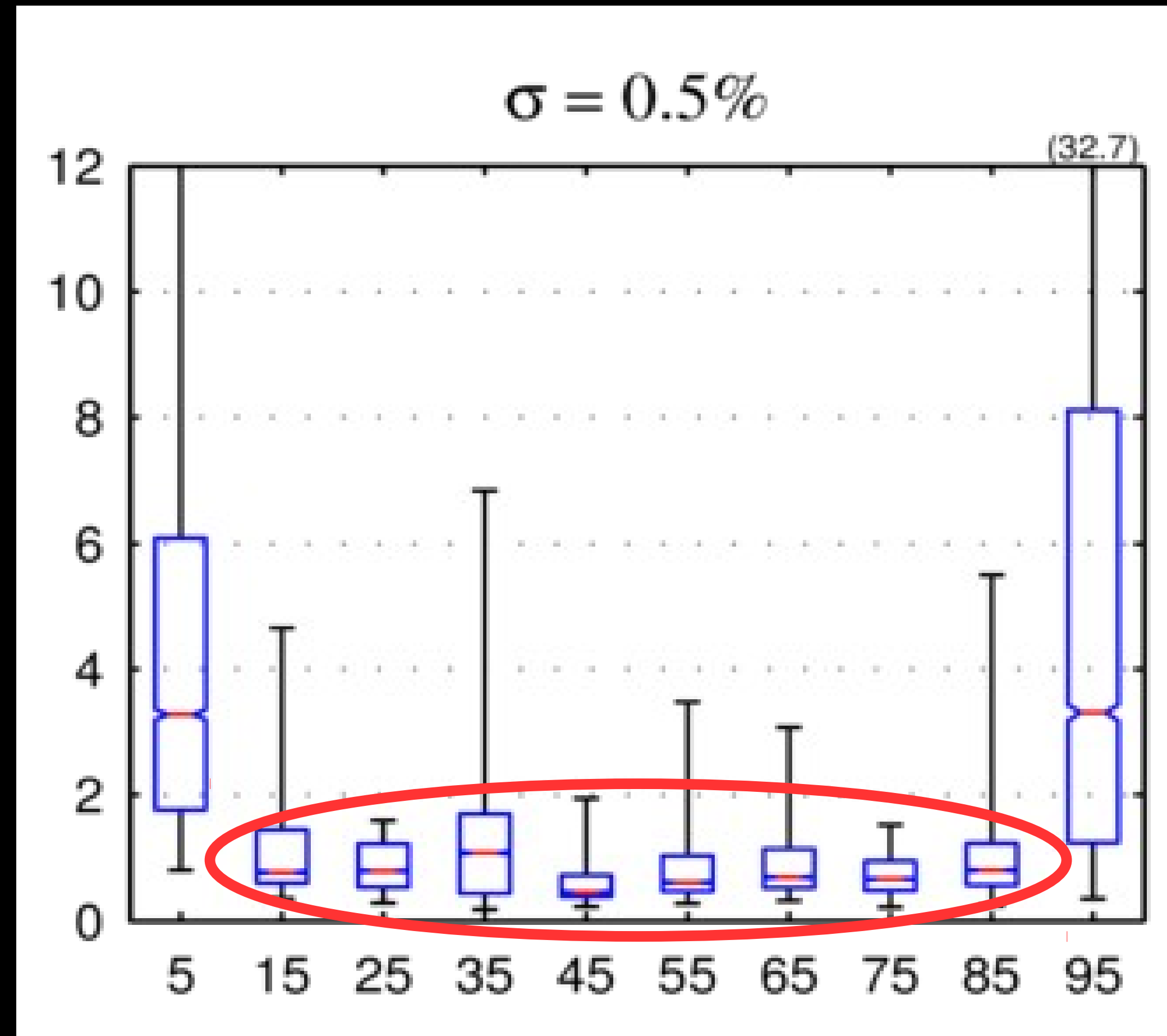
Sun visibility throughout the day (%)



Influence of cloud cover—quantitative

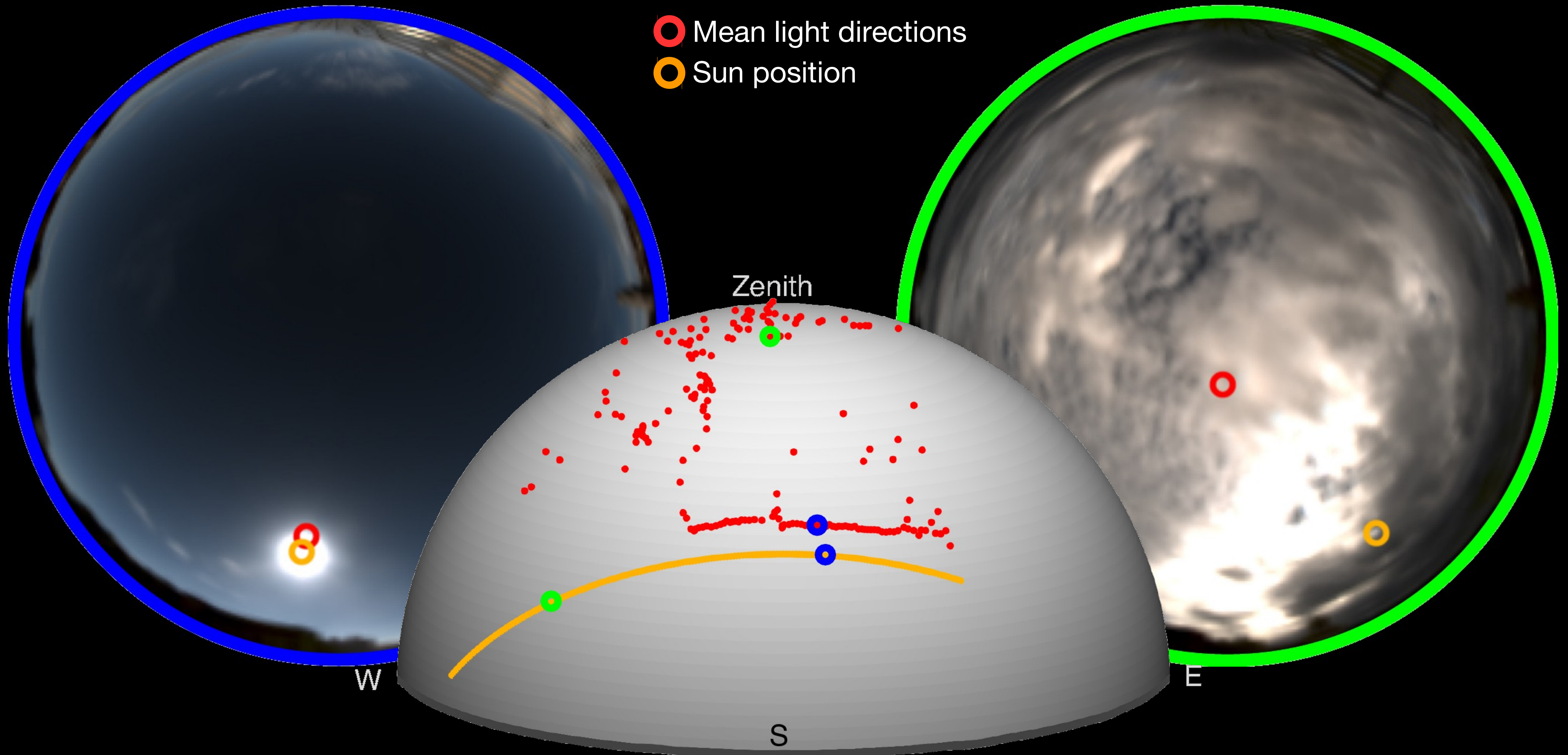


Confidence interval (degrees)



Sun visibility throughout the day (%)

Influence of cloud cover

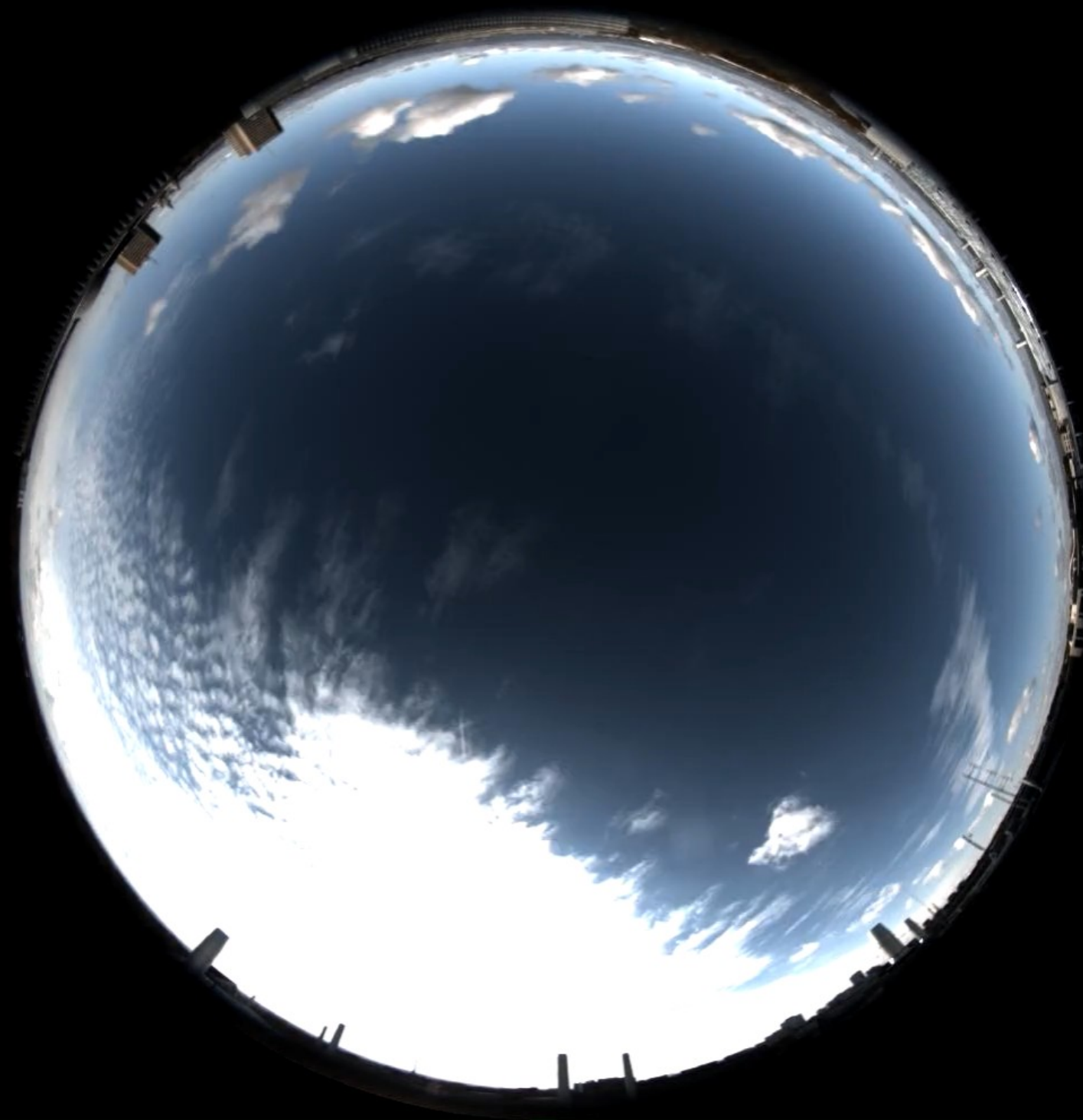


Real data

Owl statuette



Corresponding Sky Capture



Normal map



Results on real data

Degrees

120

100

80

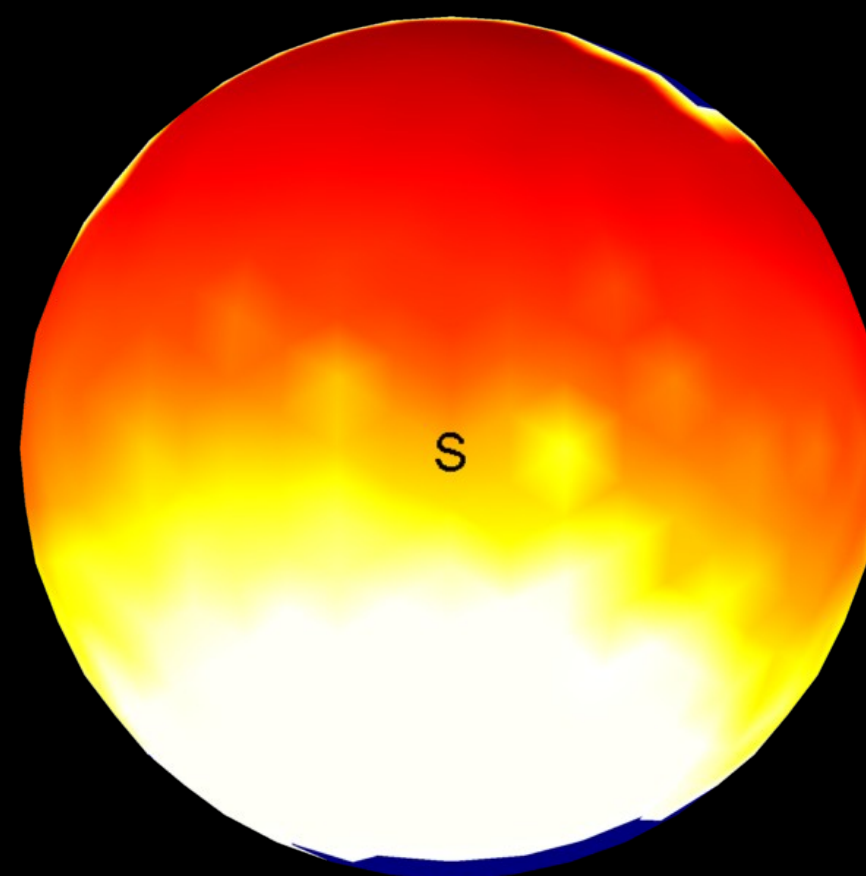
60

40

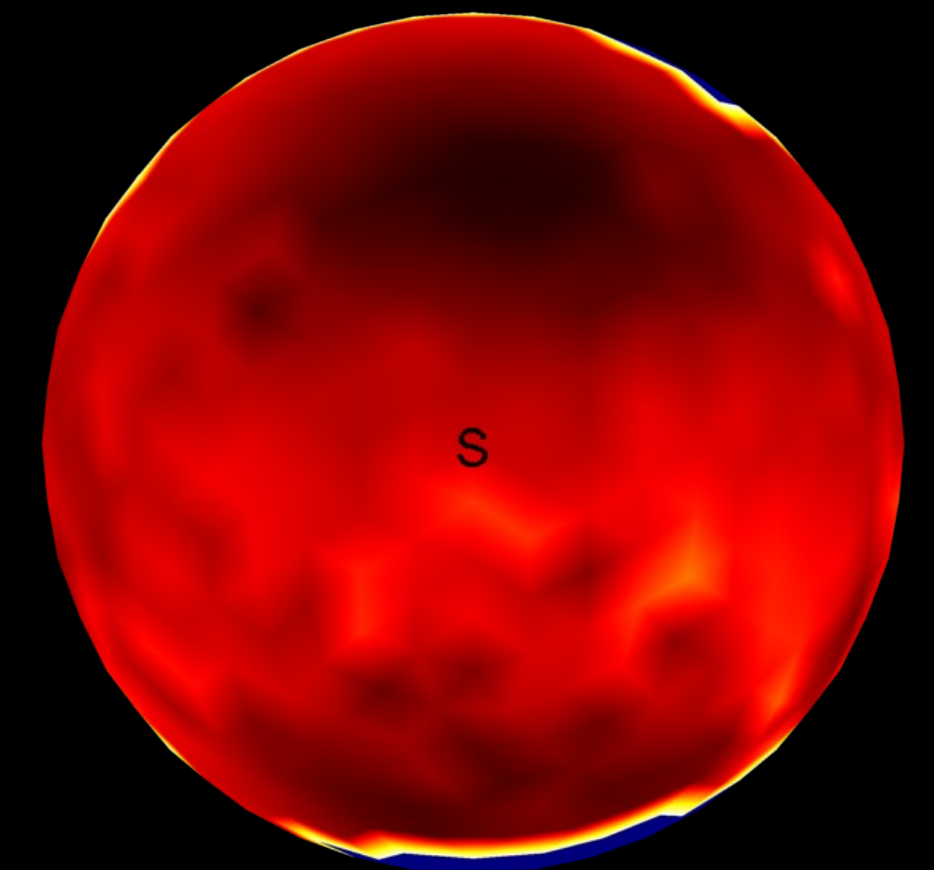
20

0

95% upper bound on error



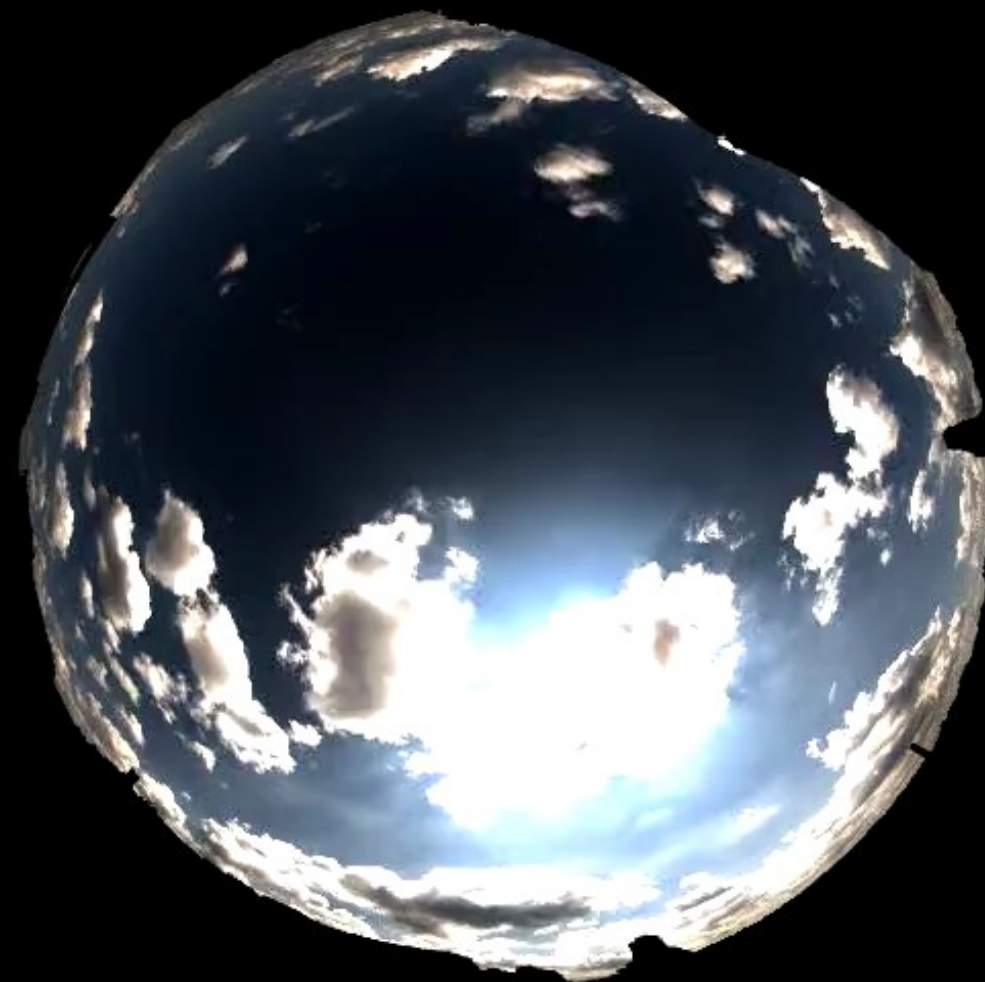
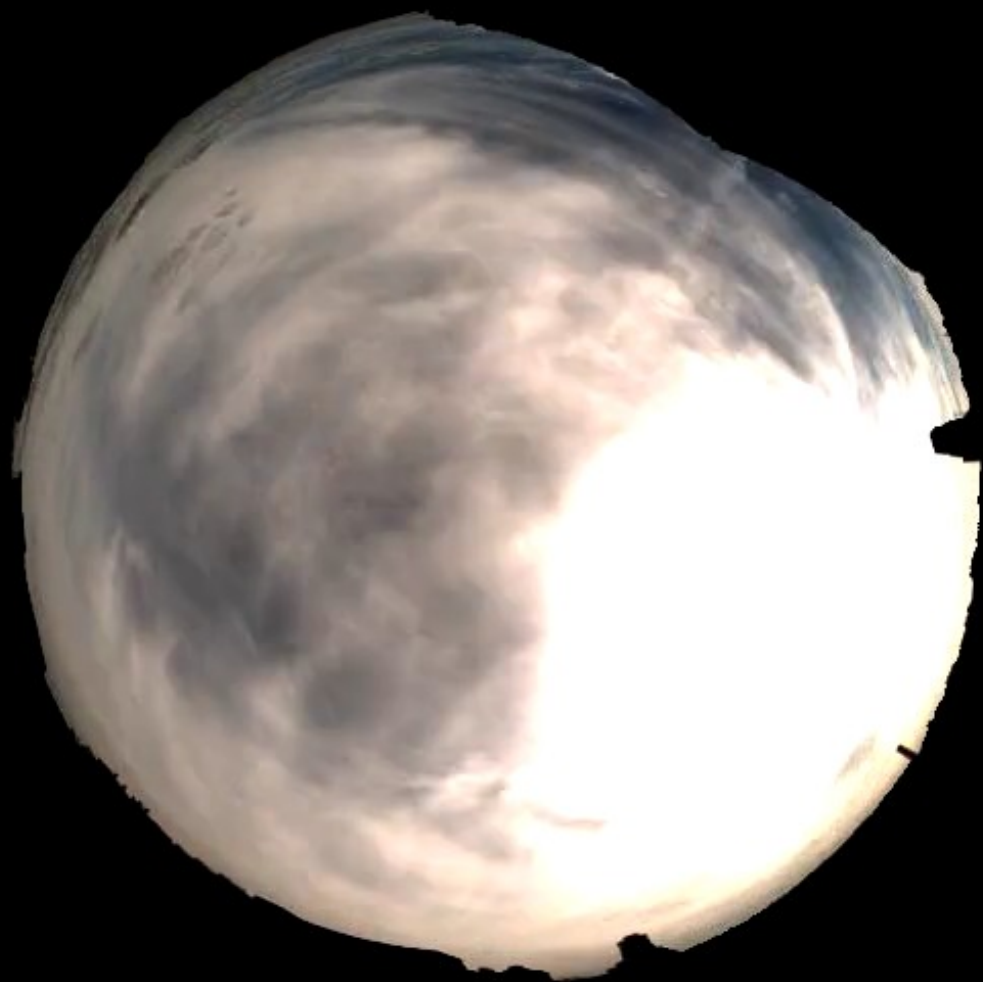
Error with ground truth



When will Photometric Stereo work outdoors?

- Reconstruction stability is a function of :
 - Noise, surface albedo and lighting conditions
- Best to use mixed skies

SAT Apr 25		90°	70°	Scattered Thunderstorms	50%	SW 8 mph
SUN Apr 26		90°	73°	Mostly Cloudy	10%	S 10 mph
MON Apr 27		83°	66°	! Heavy Thunderstorms	80%	E 11 mph



<http://vision.gel.ulaval.ca/~jflalonde/projects/outdoorPS/index.html>

Thank you!

