What Is a Good Day for Outdoor Photometric Stereo?

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Disney Research

Photometric Stereo

Images of object under different light directions

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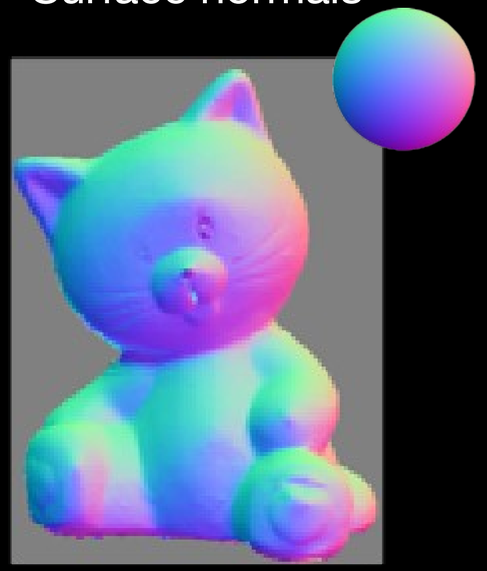
Surface normals

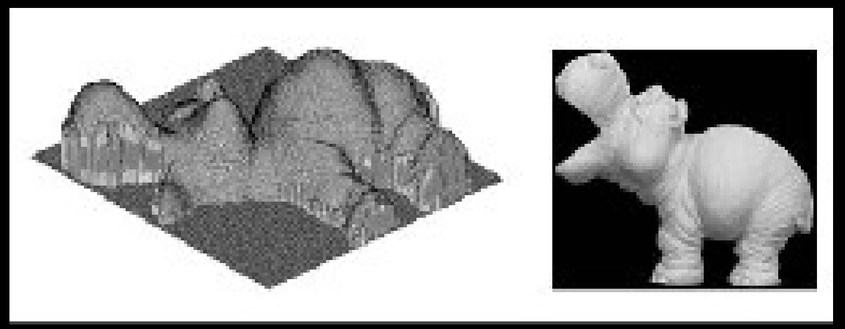


Photometric Stereo in the lab

Non-parametric,
spatially-varying reflectance

[Alldrin et al., CVPR ’08]

Unknown (smooth) lighting

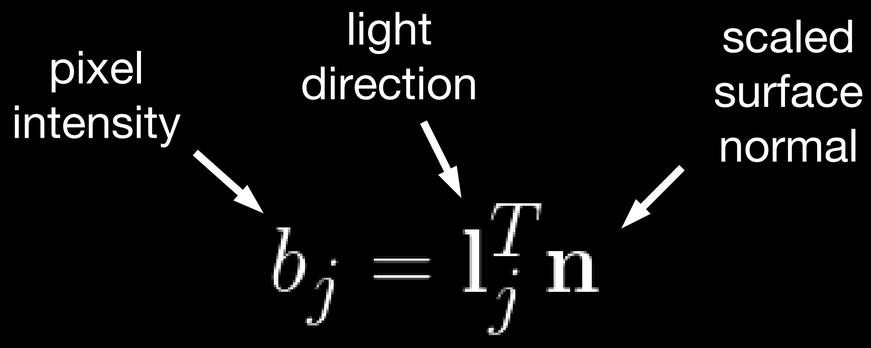


[Basri et al., IJCV ’07]

Robust under specularities,
shadows, and noise

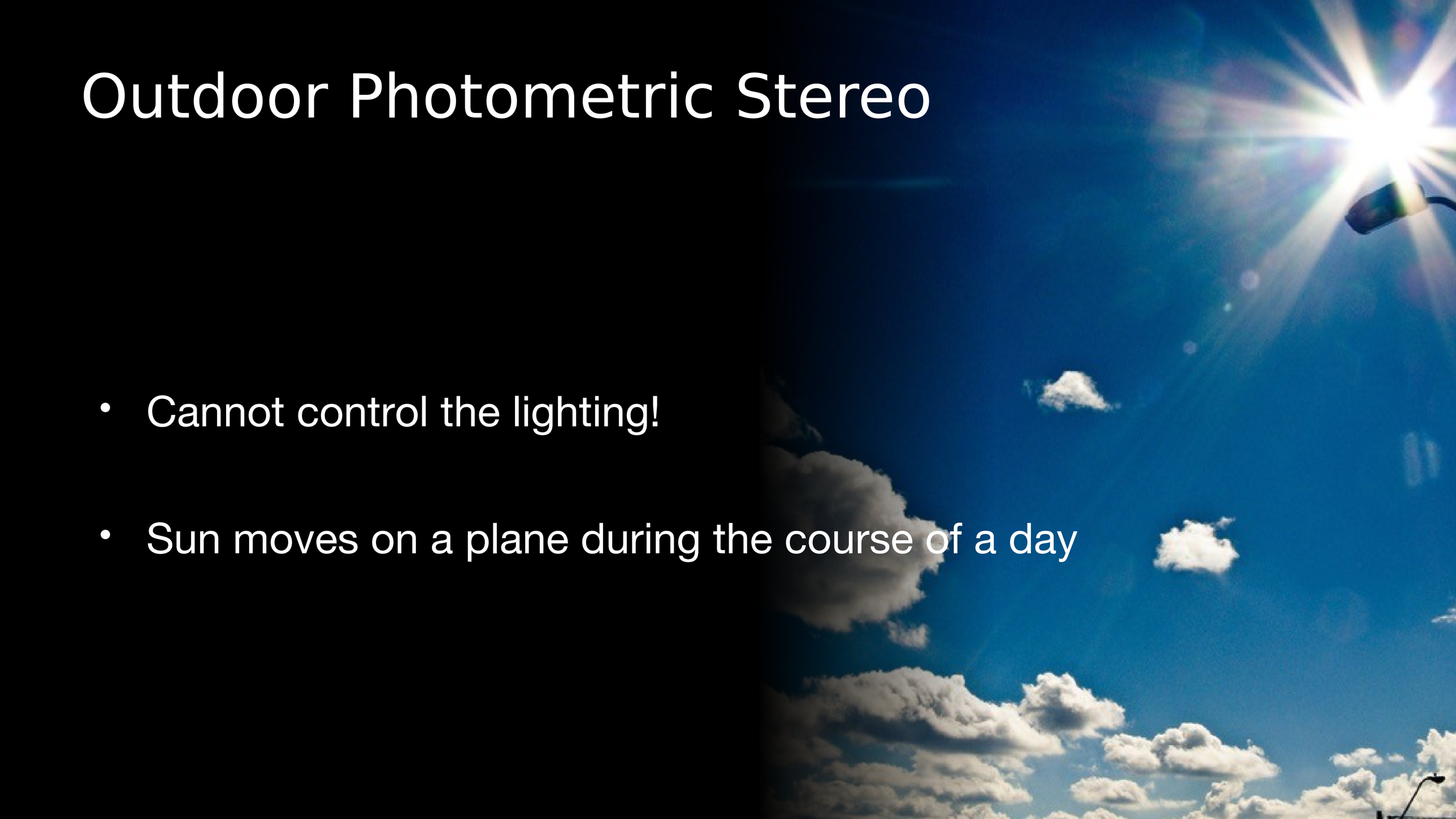
[Ikehata et al., CVPR ’12]

Photometric Stereo — point light sources



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

Outdoor Photometric Stereo



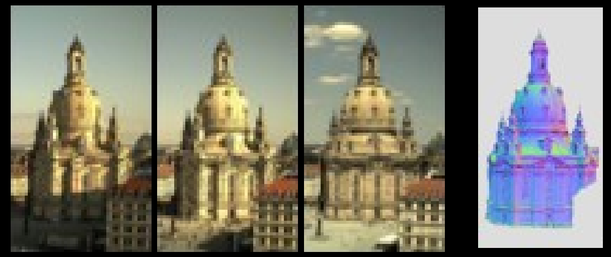
- Cannot control the lighting!
- Sun moves on a plane during the course of a day

Outdoor Photometric Stereo

Uncontrolled illumination!

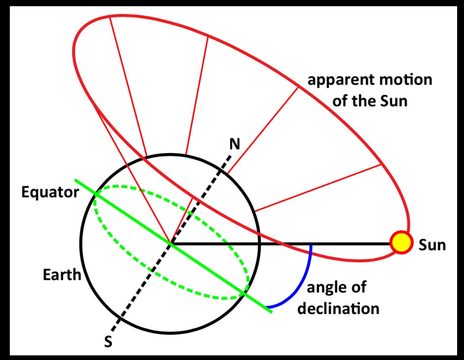
Months of data

[Abrams et al., ECCV'12]



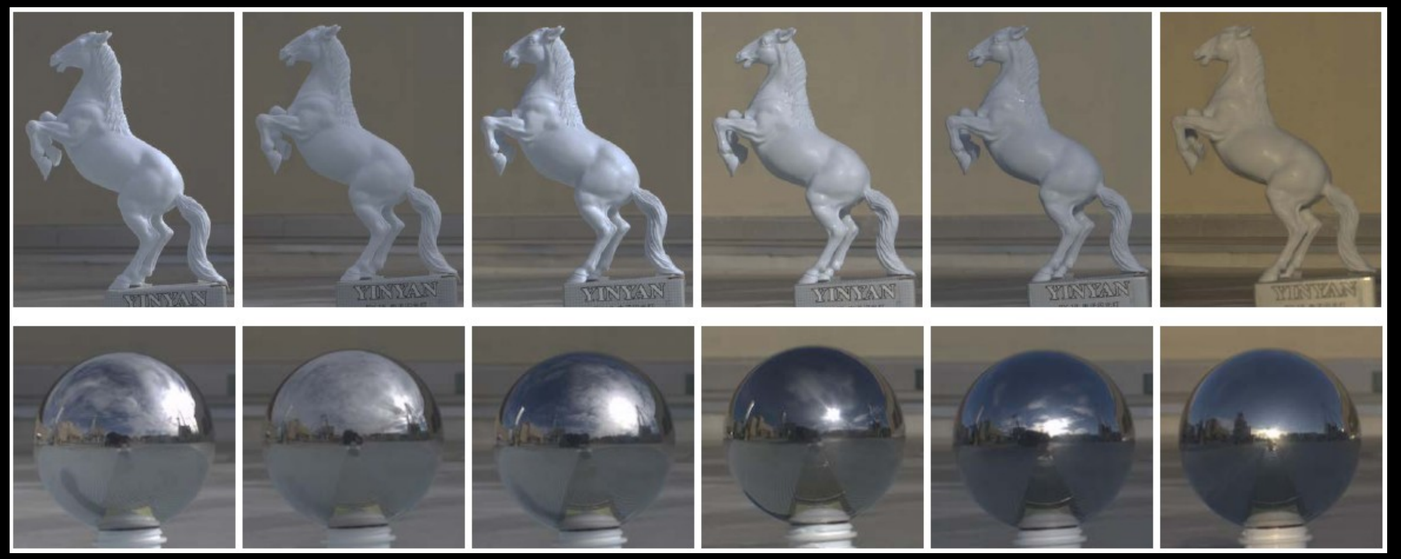
[Ackermann et al., CVPR'12]

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

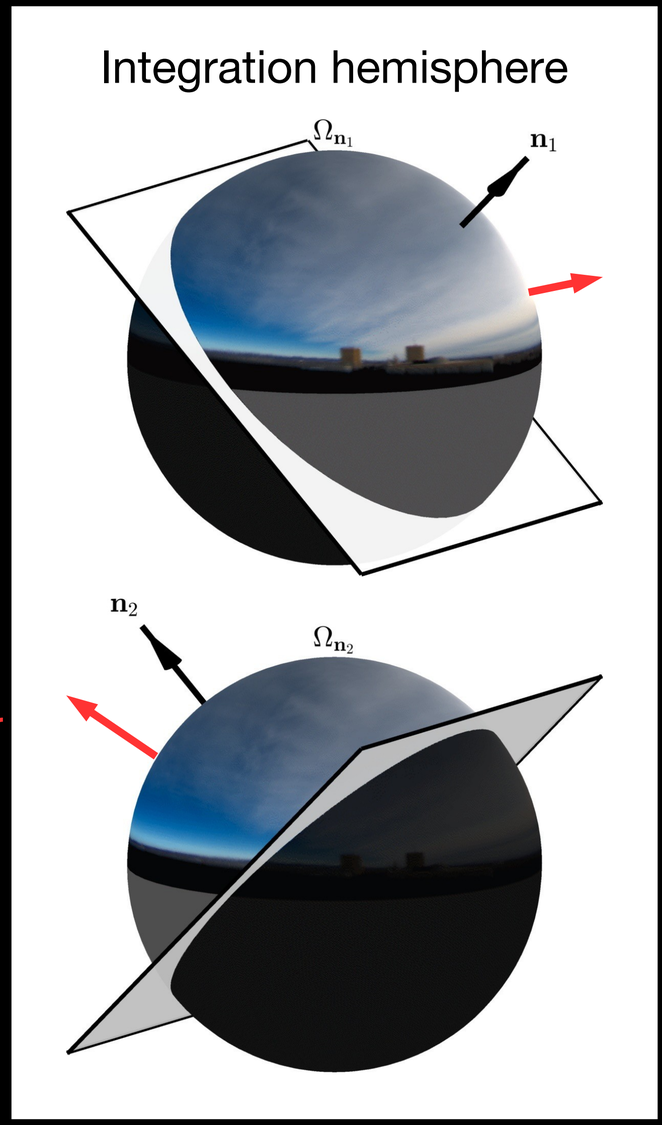
Photometric stereo — environment map lighting

pixel intensity

mean light vector

scaled surface normal

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



Point light source vs environment map lighting

Point light source

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

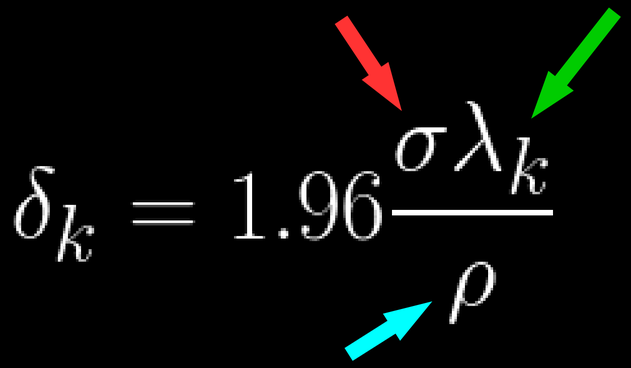
Matrix of **light directions**

Environment map

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

Matrix of **mean light vectors**

How well does Photometric Stereo work?



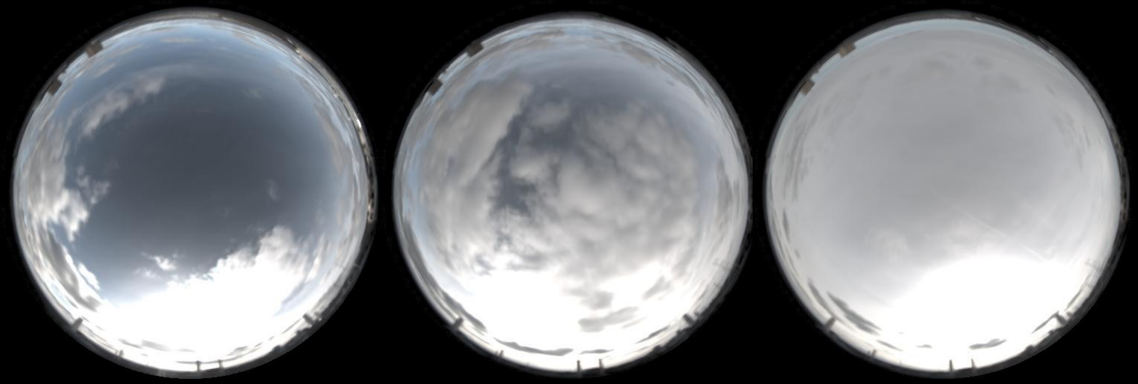
$$\delta_k = 1.96 \frac{\sigma \lambda_k}{\rho}$$

- 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



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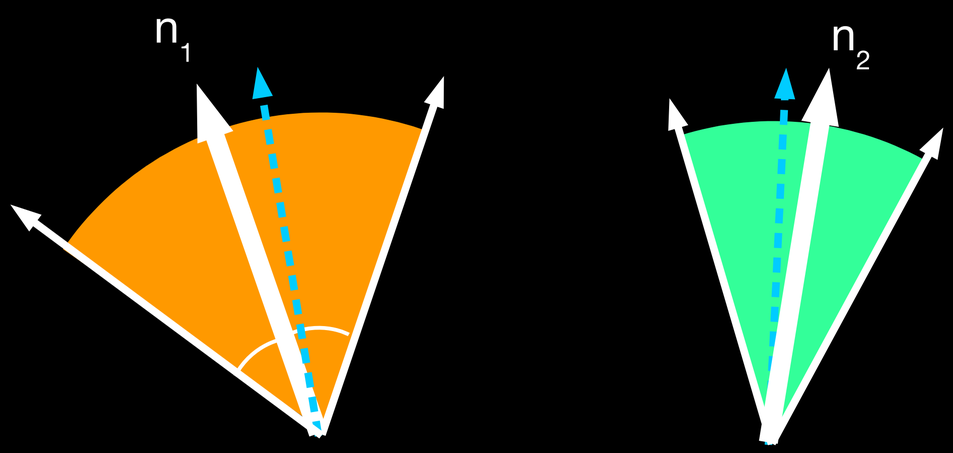
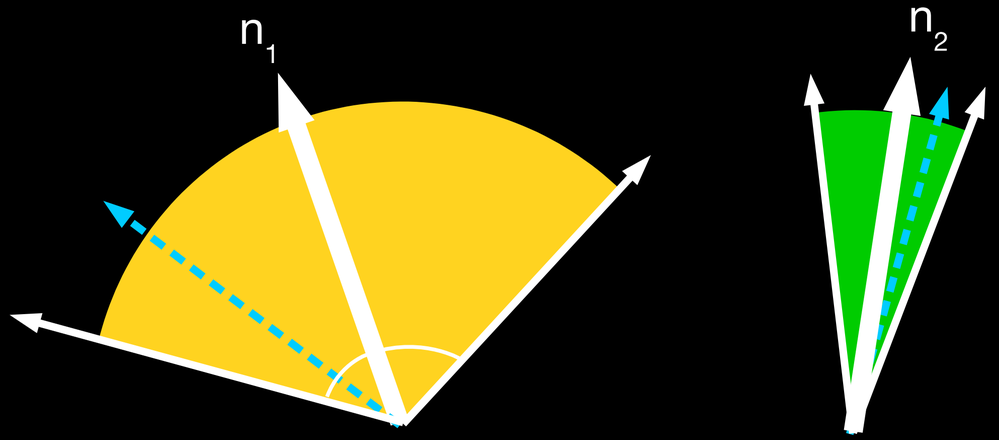
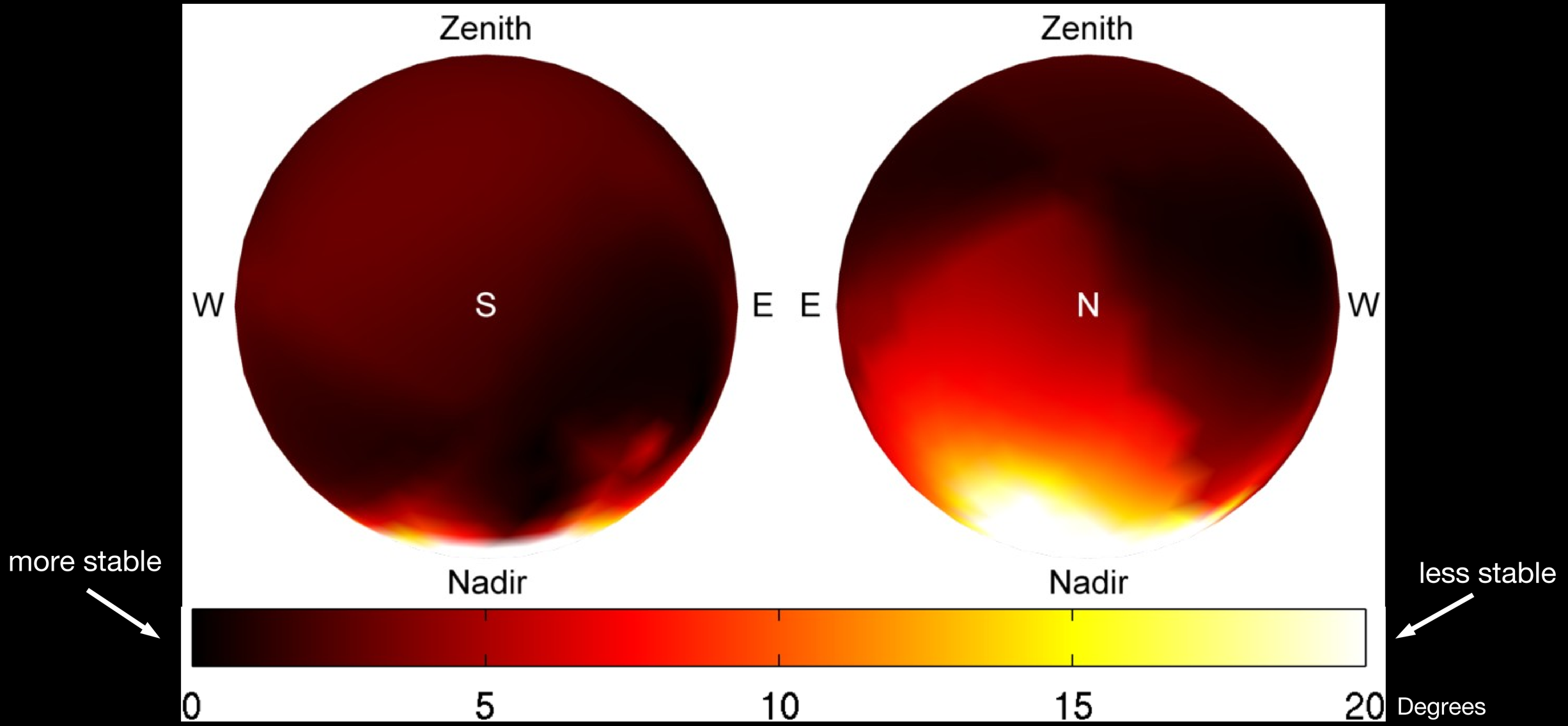


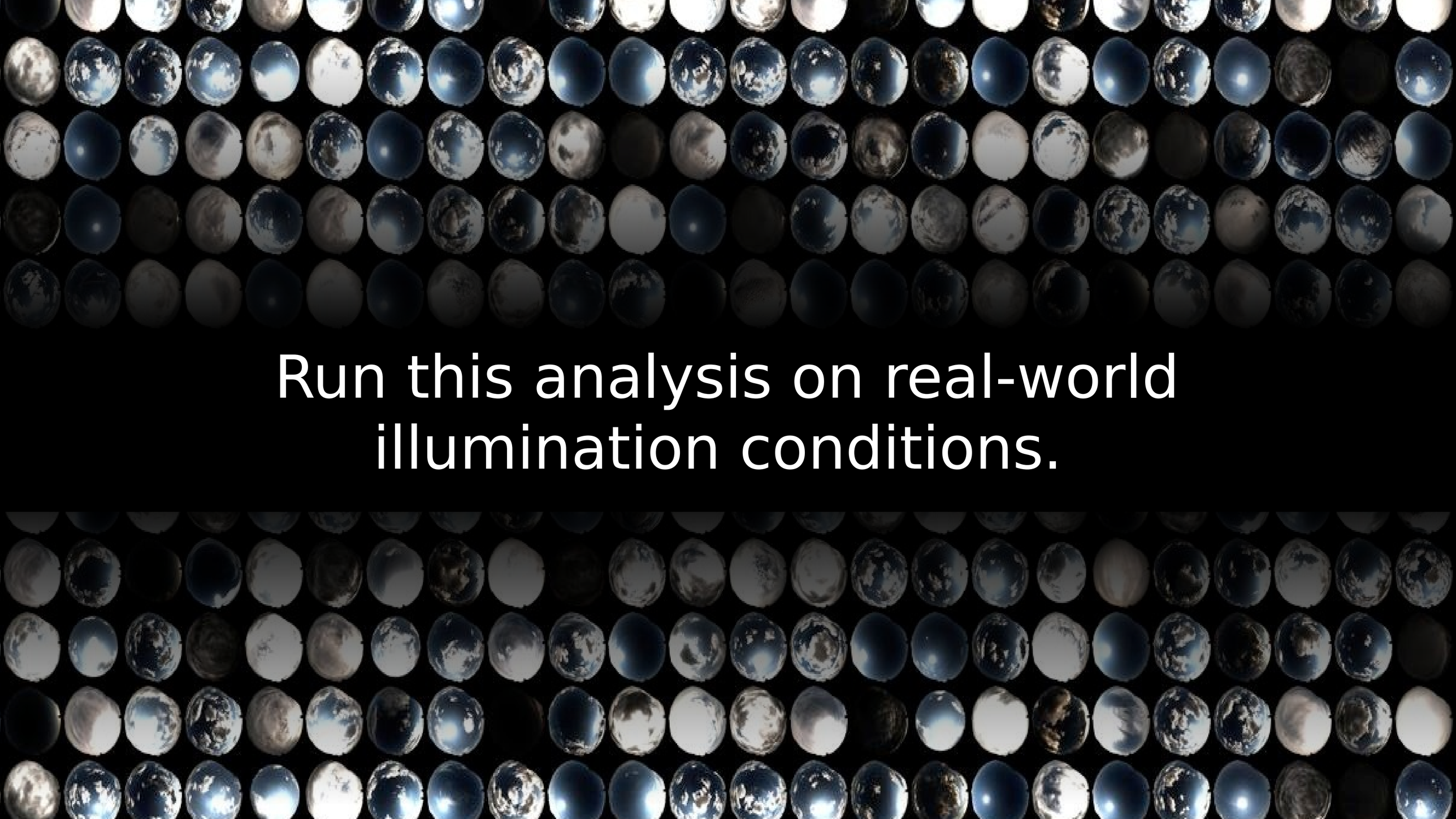


ground truth

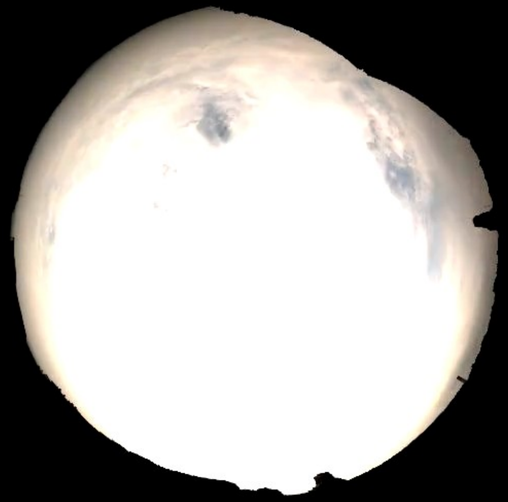
recovered normal

Example of confidence interval sphere

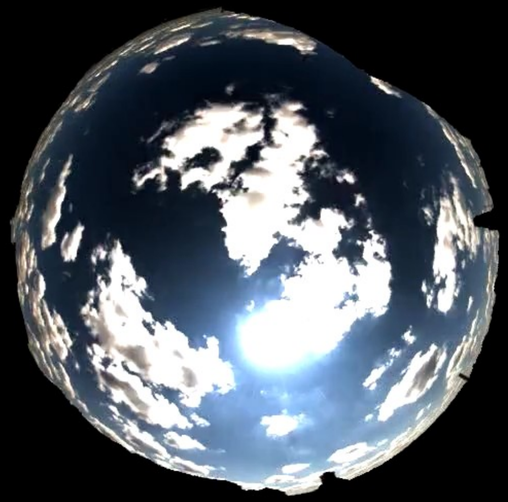




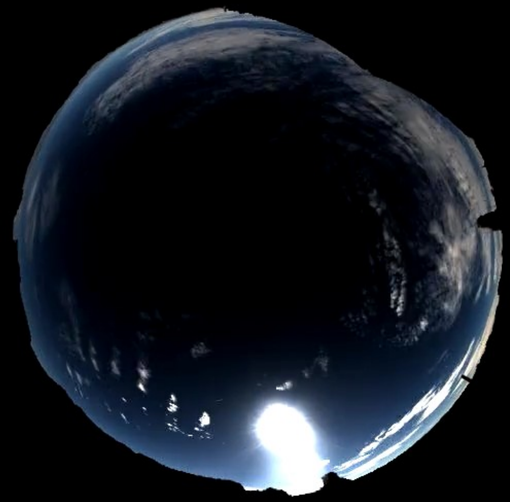
Run this analysis on real-world illumination conditions.



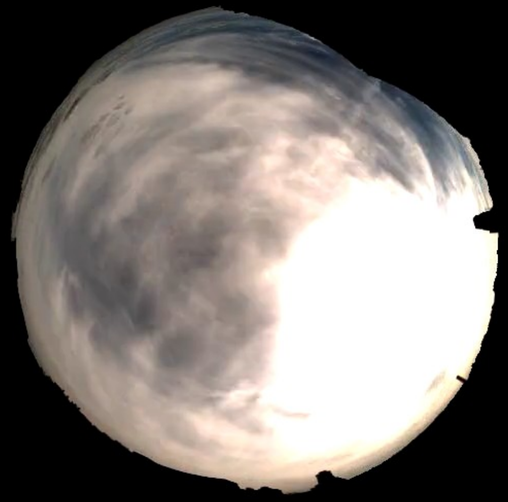
Over 3800 captures

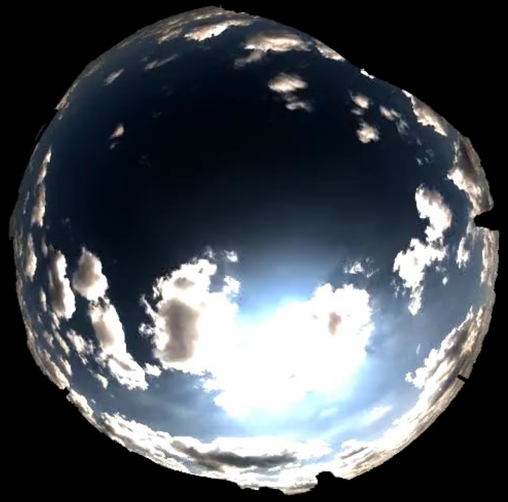


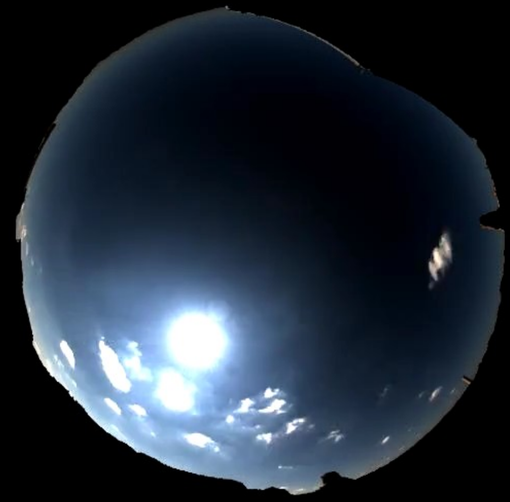
23 days



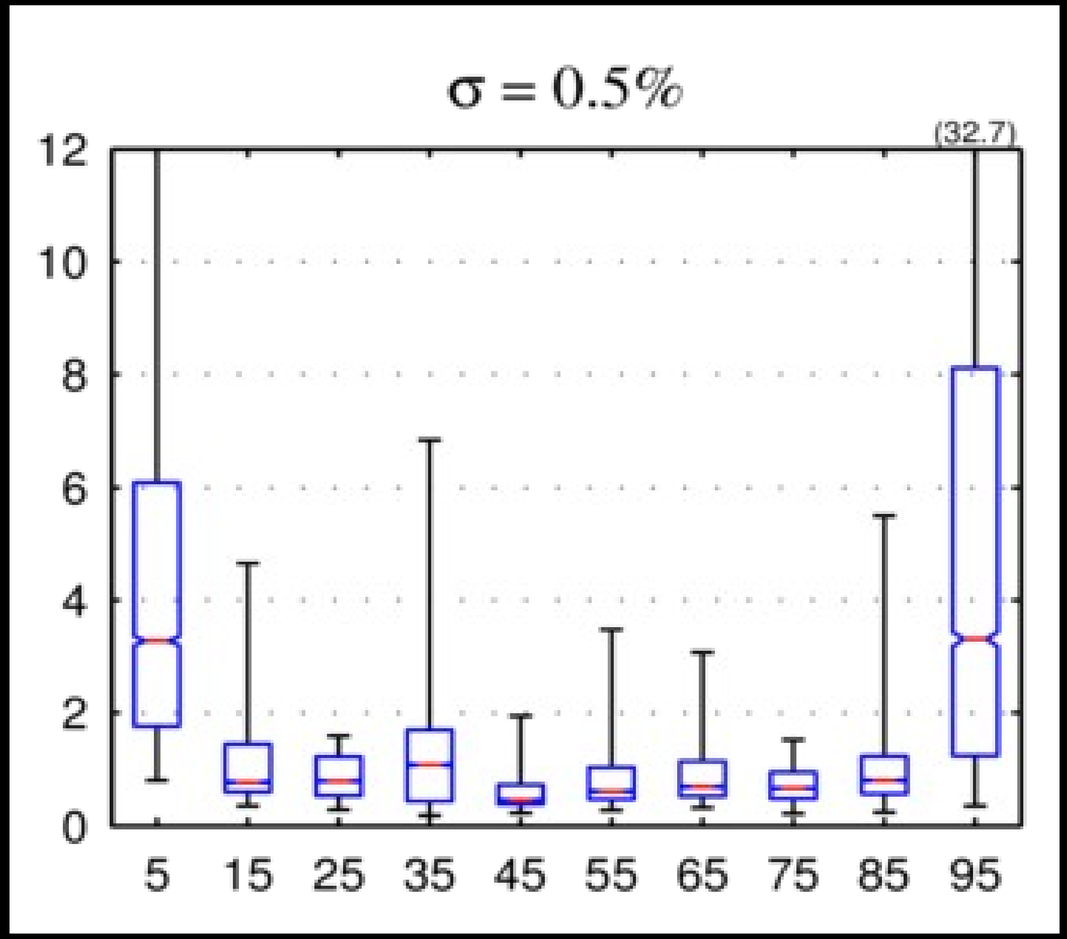
10 months



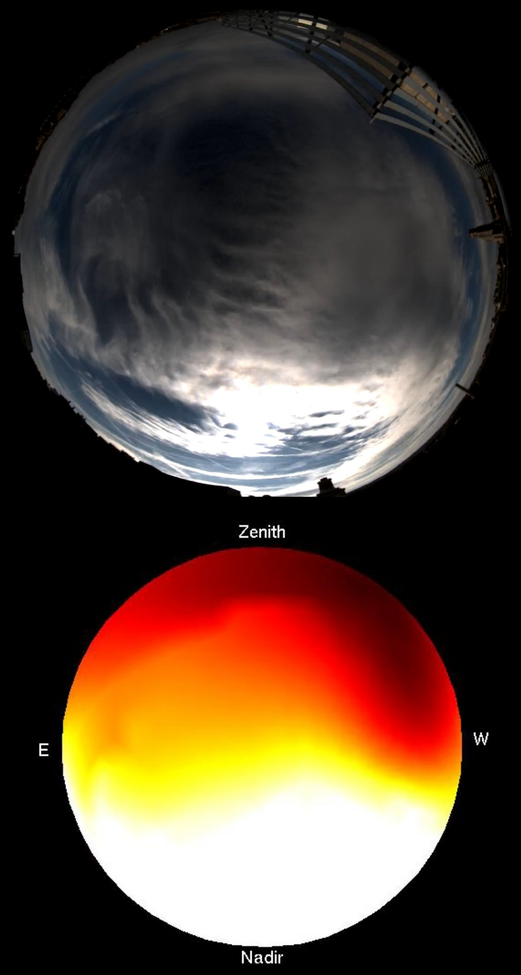


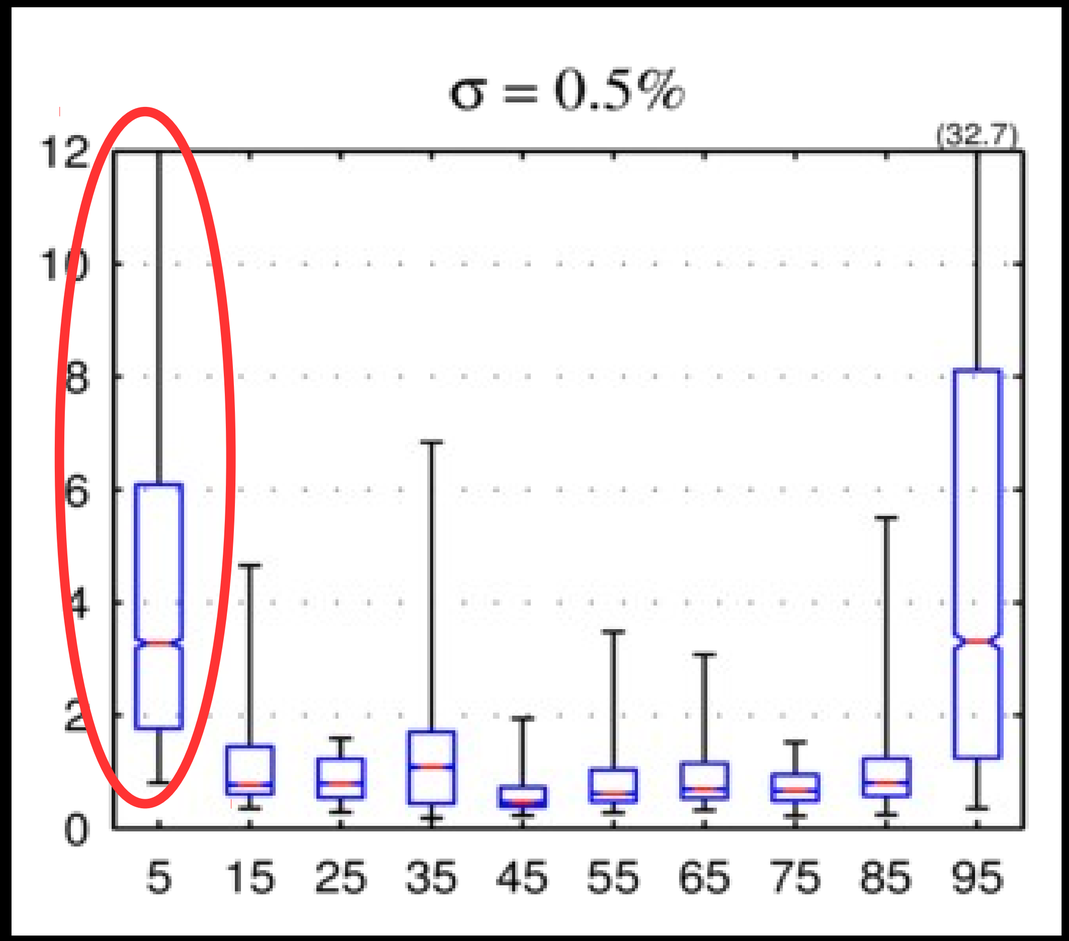


Influence of cloud cover—quantitative

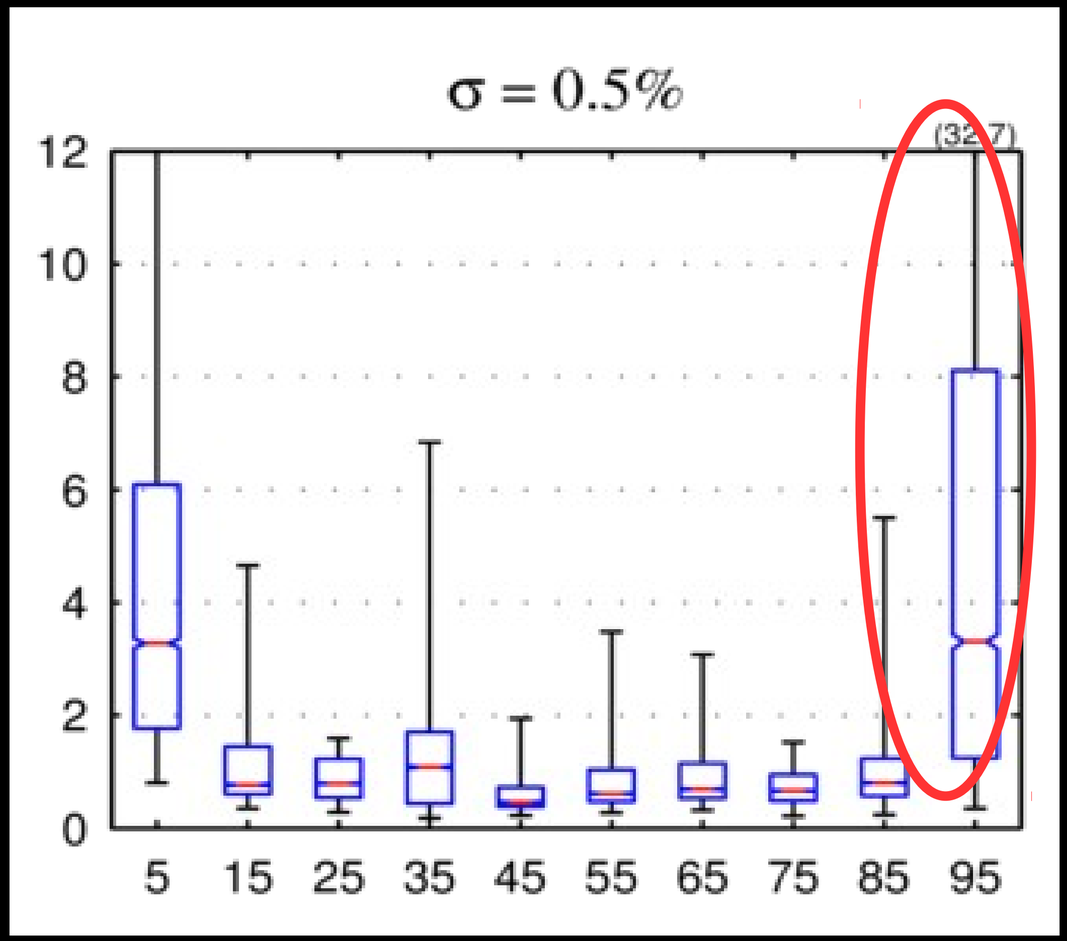


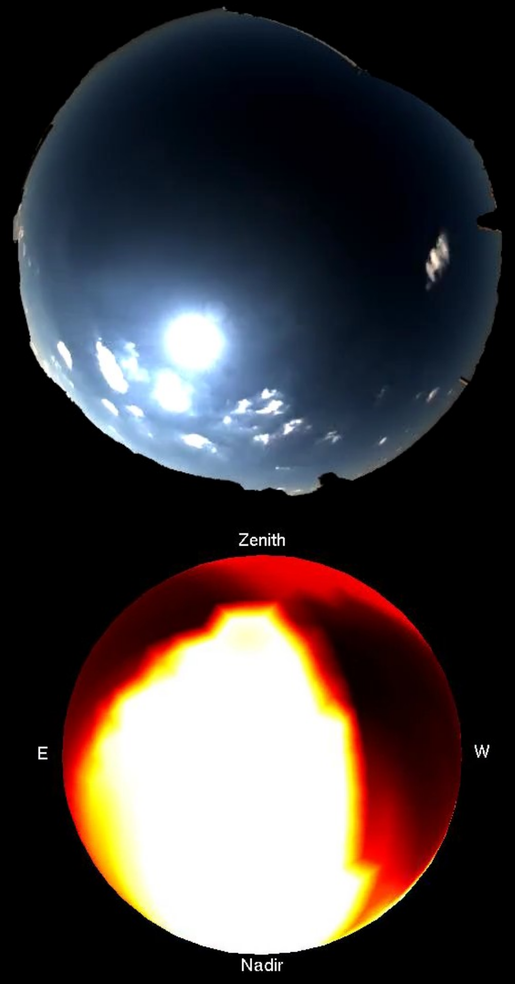
Influence of cloud cover—quantitative



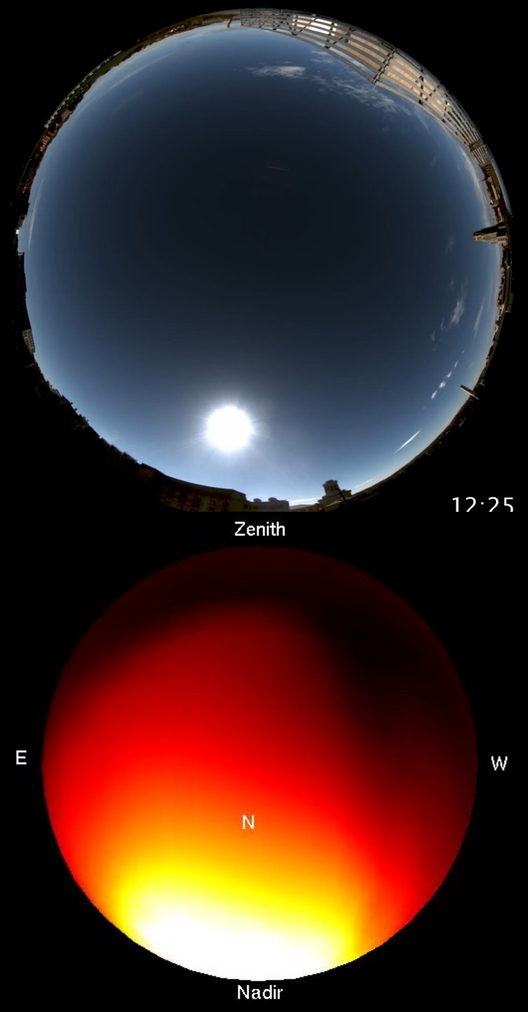


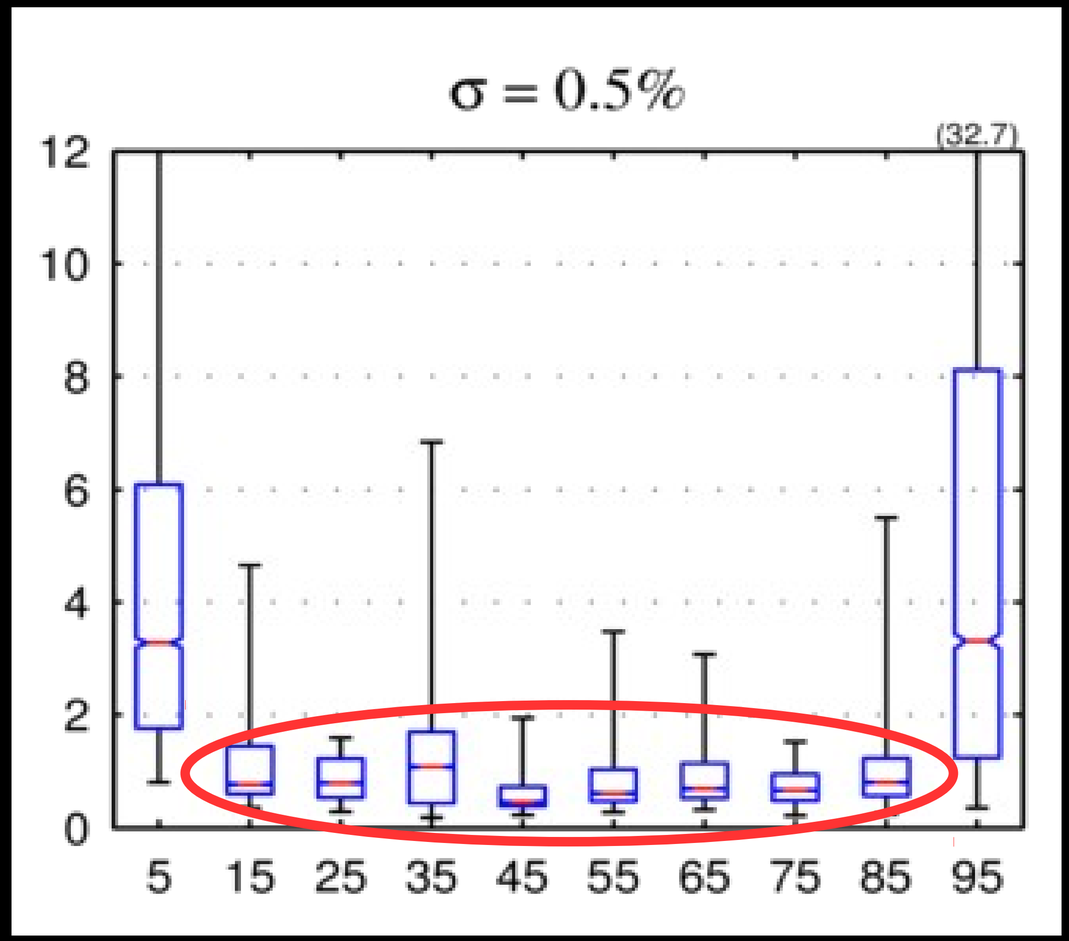
Influence of cloud cover—quantitative



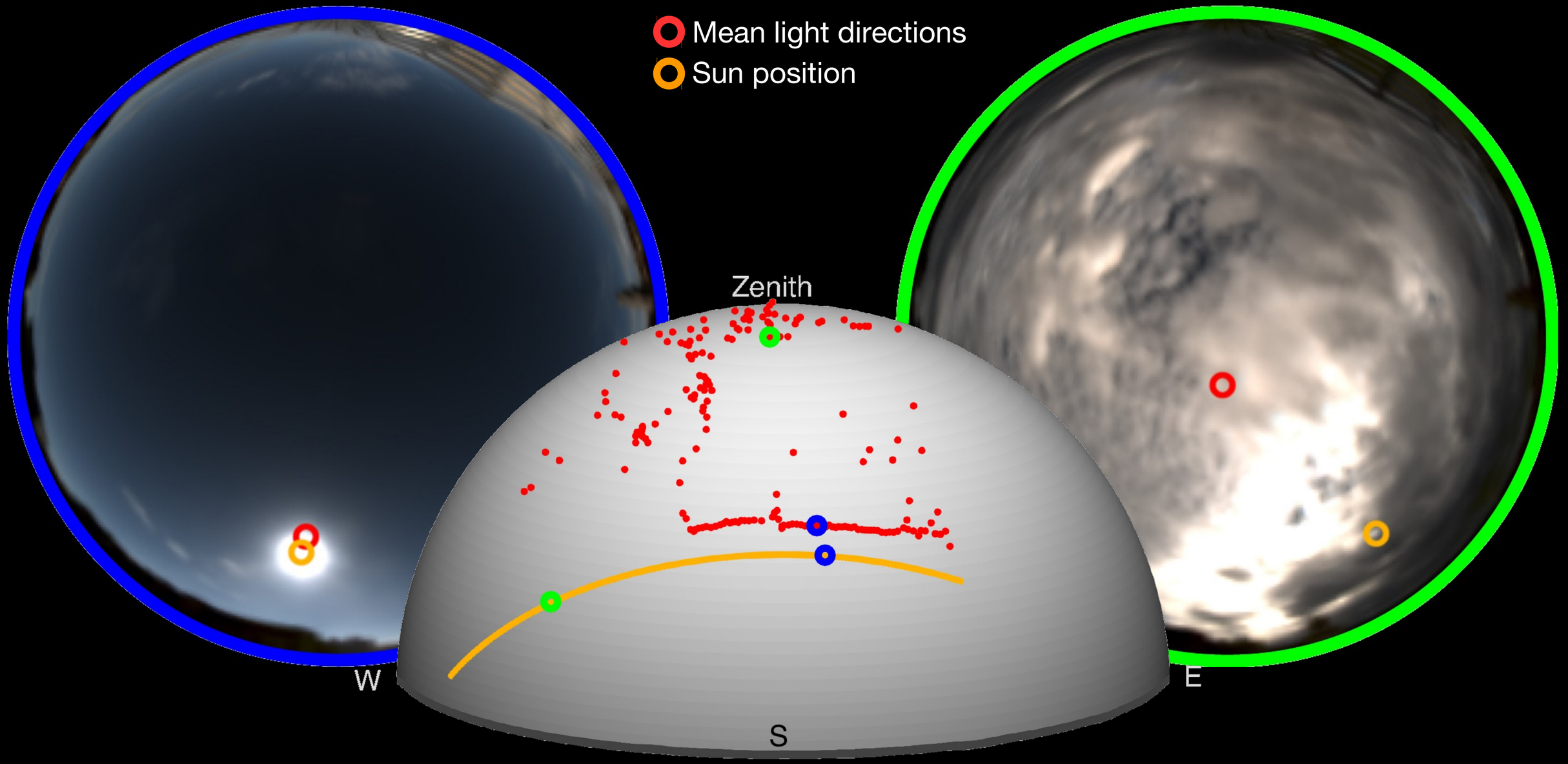


Influence of cloud cover—quantitative





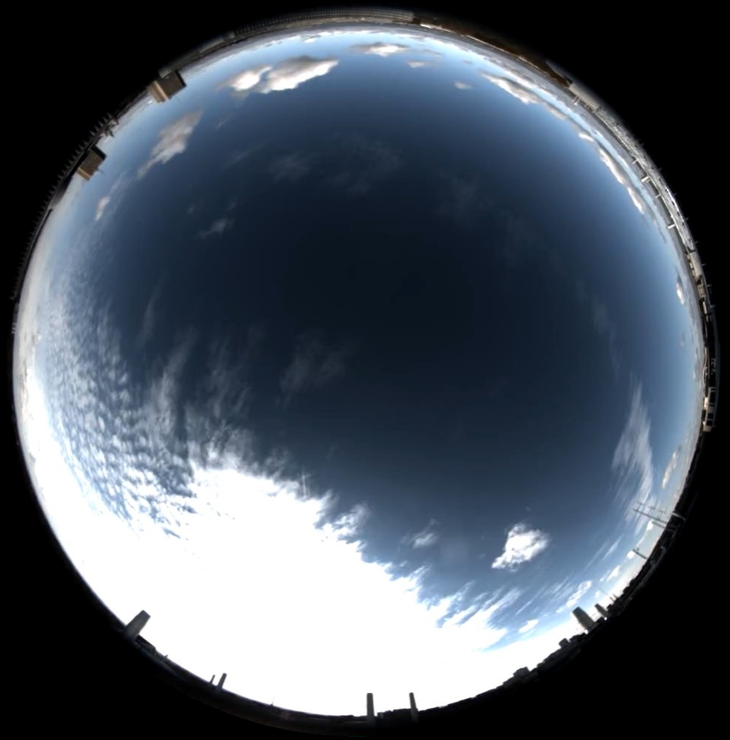
Influence of cloud cover



Real data

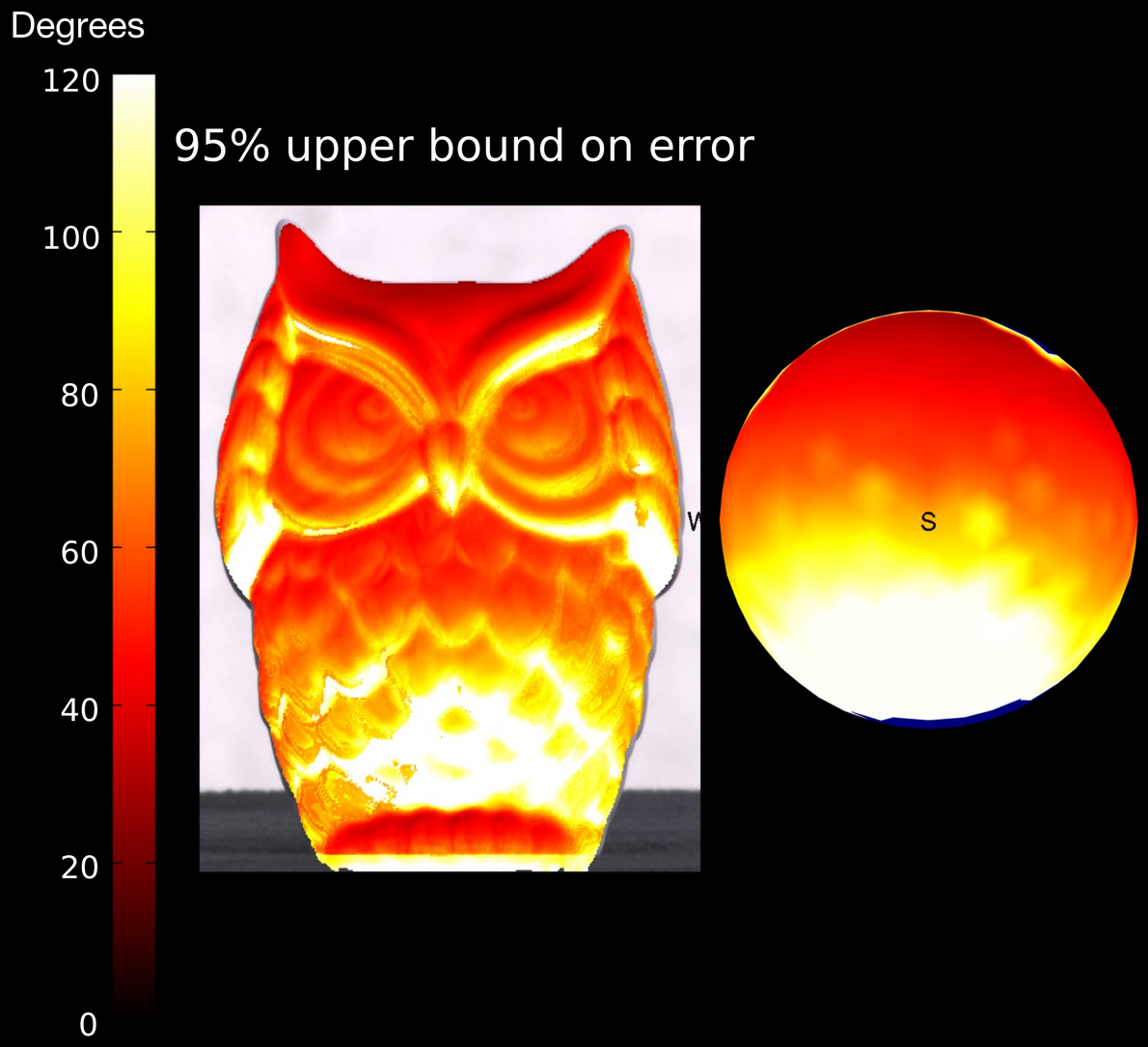
Owl statuette

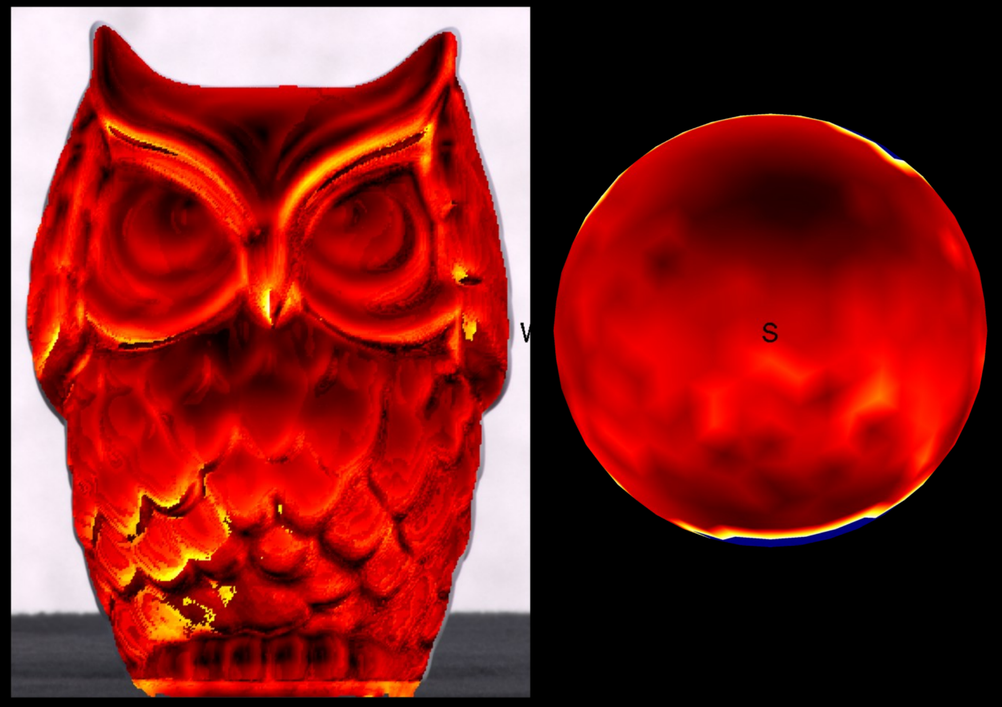
Corresponding Sky Capture



Normal map

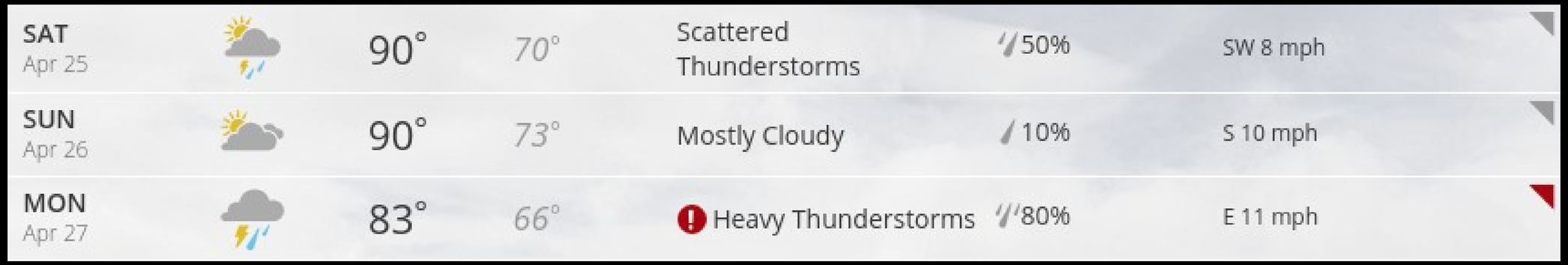
Results on real data

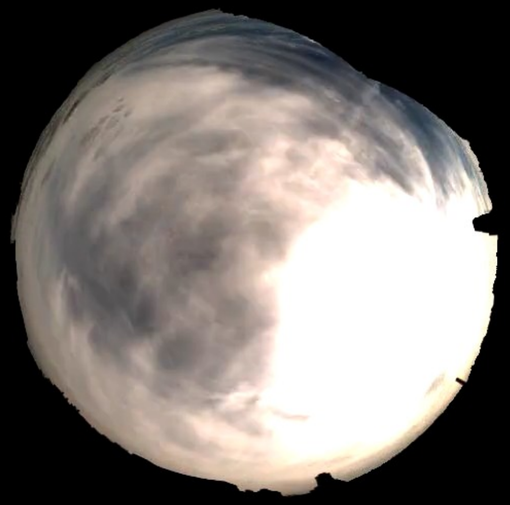
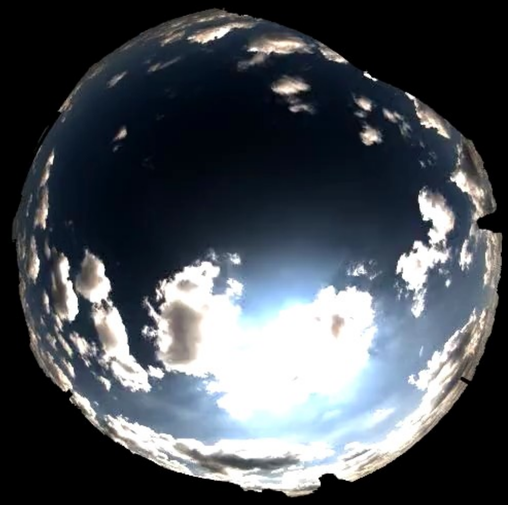
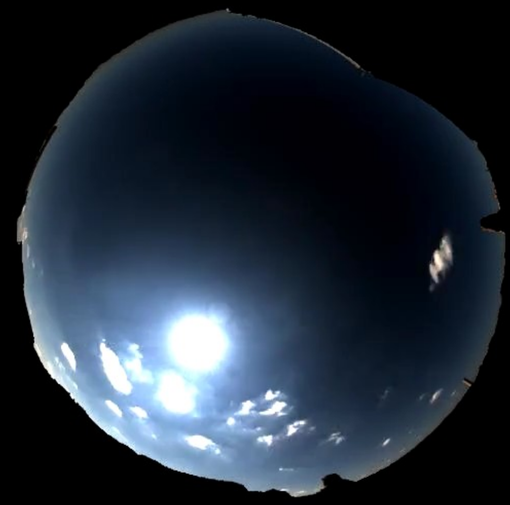




When will Photometric Stereo work outdoors?

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



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

Thank you!