Estimating cloud base height from all-sky imagery using artificial neural networks.

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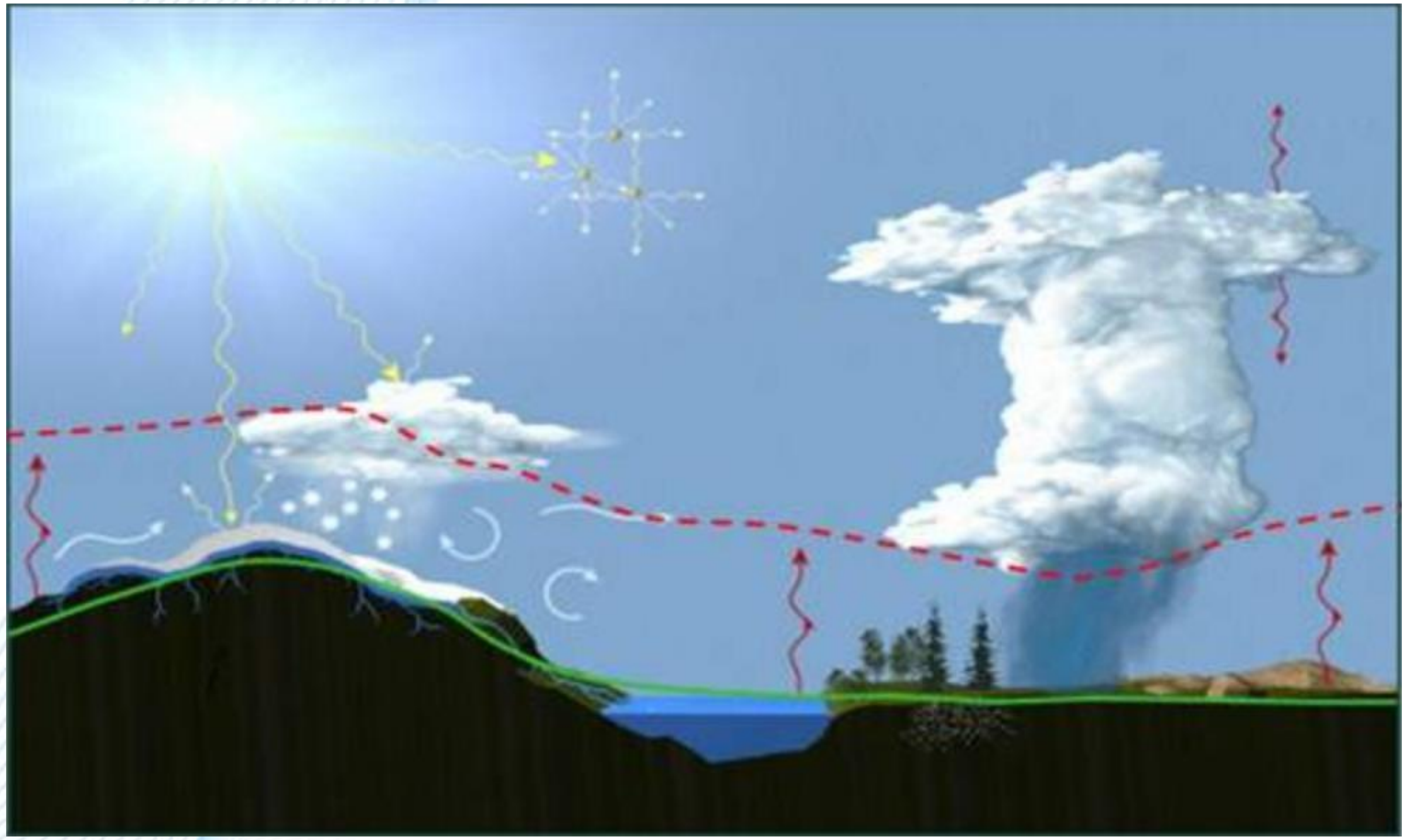
Motivation

Cloud Base Height(CBH) is important meteorological parameter of atmosphere.

CBH demonstrates strong correlation* with thickness Planetary Boundary Layer in cases with cumulus clouds.

CBH is important condition for building routes of aircrafts and conditions of take-off and landing planes.



*Anton Beljaars, The parametrization of the planetary boundary layer May 1992, European Centre for Medium-Range Weather Forecasts

Common methods for CBH estimation

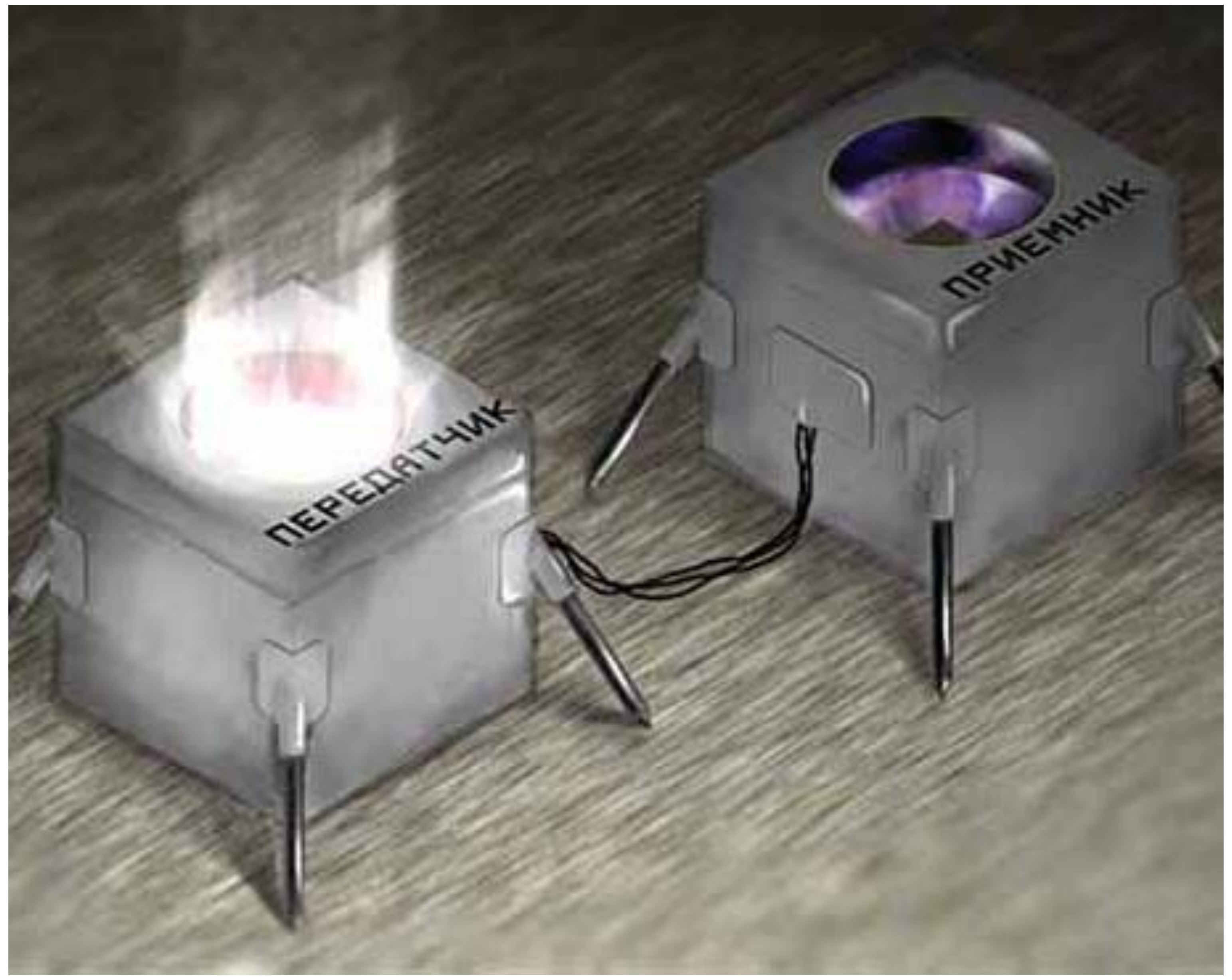
The most well-known methods for estimating the height of the CBH:

-Lidar.

-Aircrafts and weather balloons.

-Visual – expert classified cloud types.

-Parameterizations.



Schematic diagram of lidar operation

weather balloon

Research progress

The goal of the study is to create an automated algorithm for the assessment of CBH using pairs of photographs of the visible hemisphere of the sky expliting parallax effect. stages of the research:

- Collecting the Dataset of All-Sky Images over the Ocean (DASIO);

- Automated detection of visible Sun disk in all-sky images;

- Calibrating the all-sky cameras positioning through affine transformation of all-aky images;

- Aligning the images in all the pairs of the DASIO dataset;

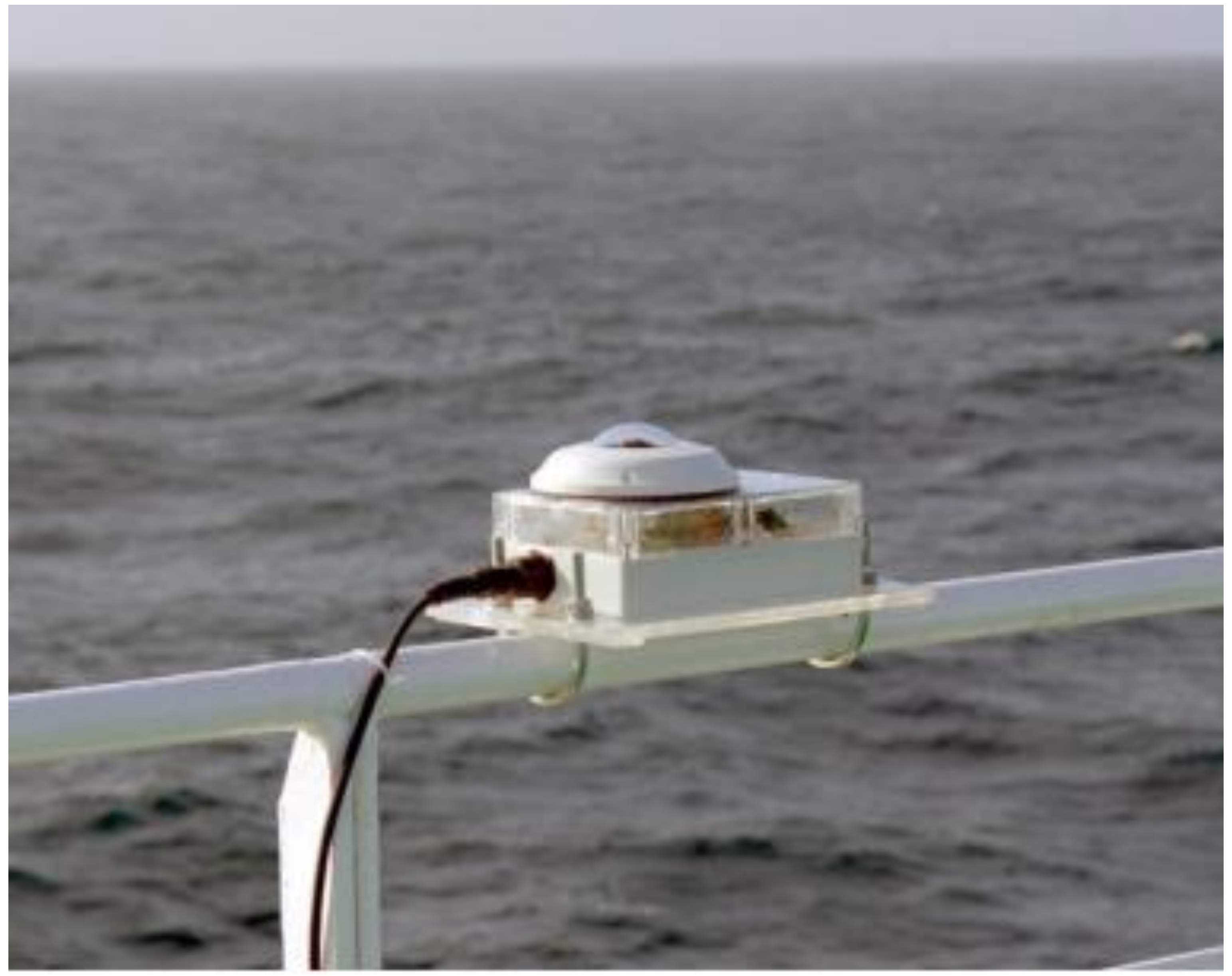
- Detecting and matching the keypoints in all the pairs of all-sky images of DASIO using either SIFT (as a baseline) or SuperGlue neural network;

- Computing CBH exploiting parallax effect;

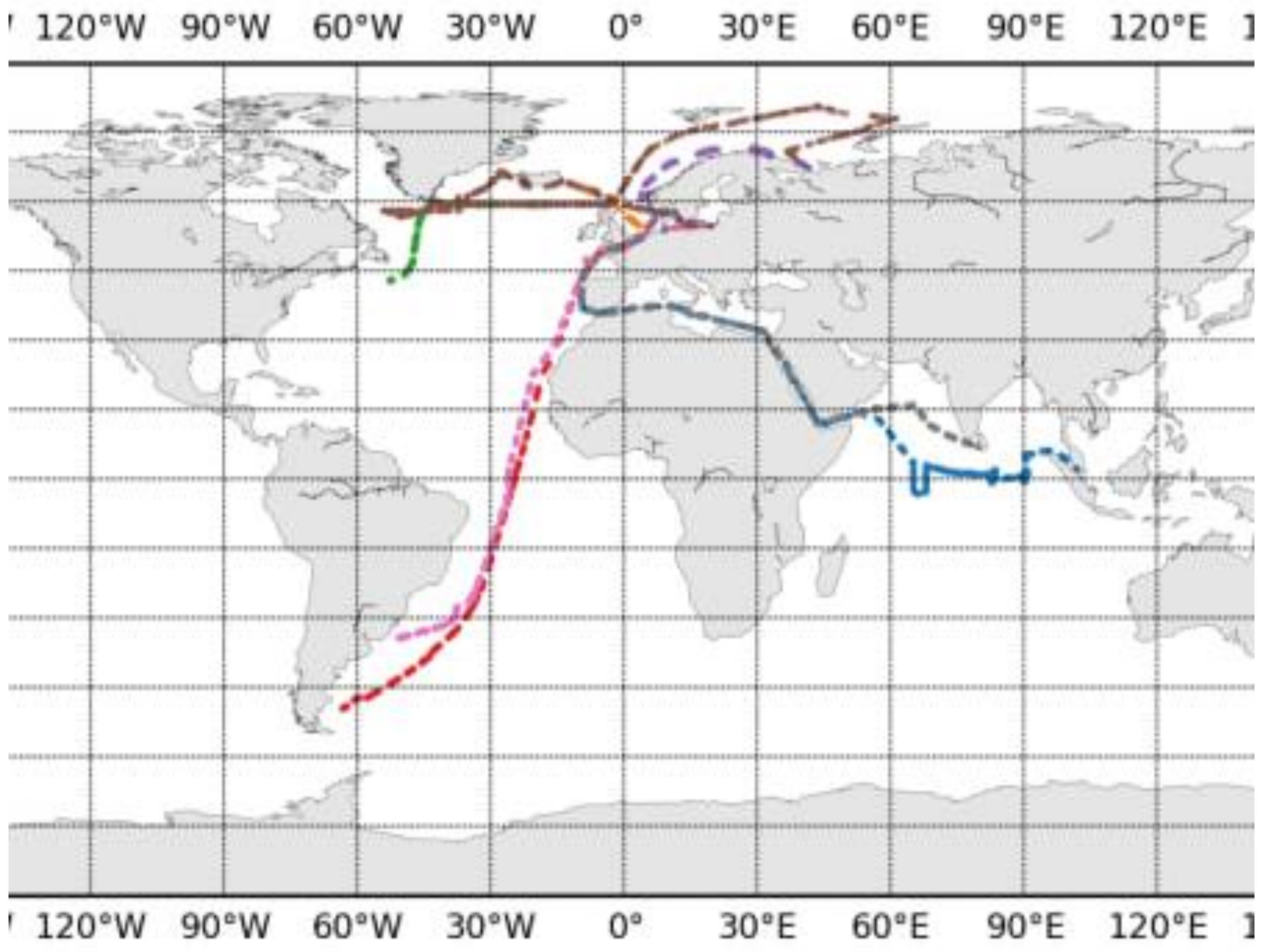
- Validation using ERA-5 reanalysis and quality assessment.

Data collection system «SAIL Cloud v.2»

Dataset of All-Sky Images over the Ocean (DASIO) contains more than 2.5 million photographs.



The camera mounted on the ship

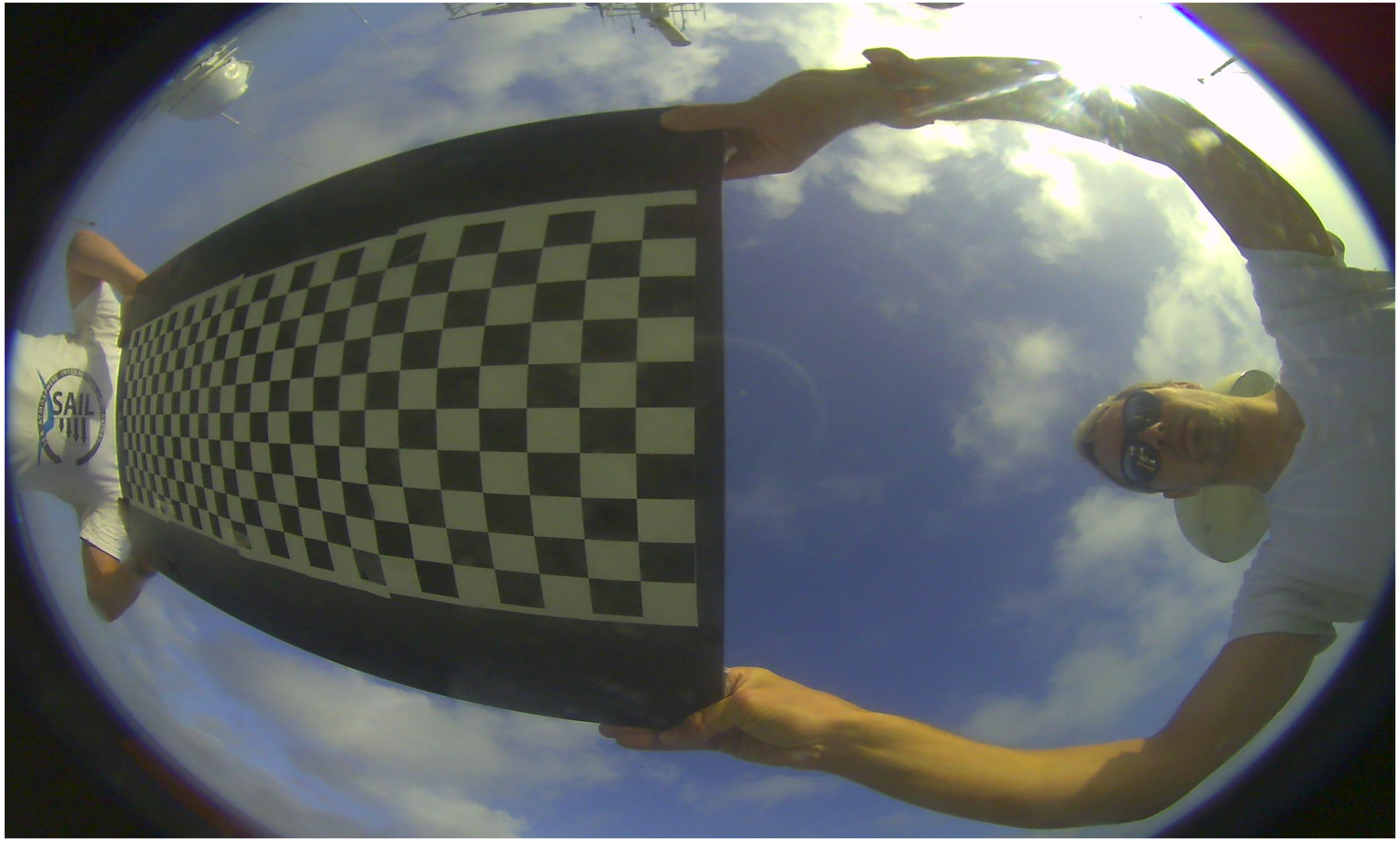


Expedition map

Distortion

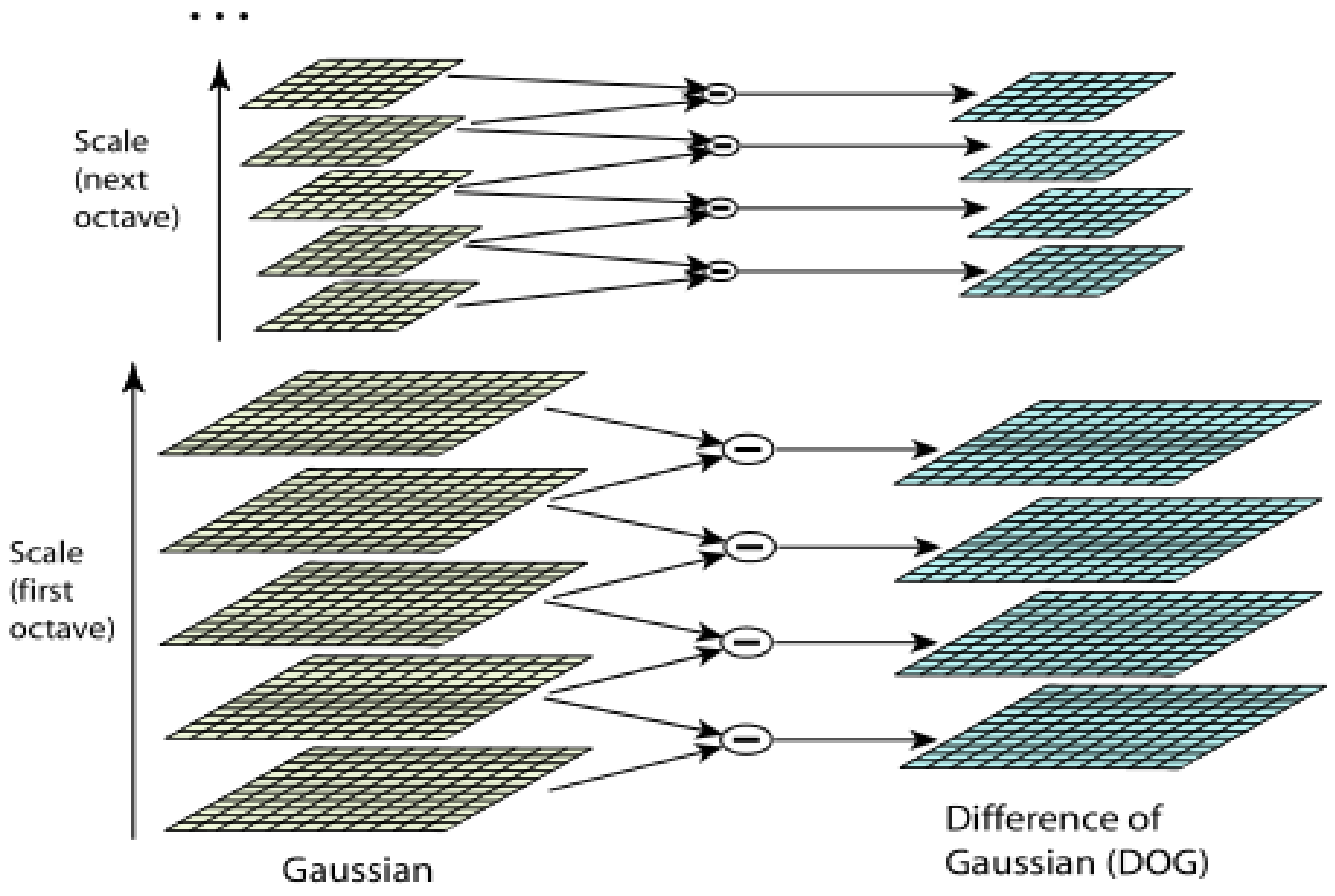
Features of all-sky images:

1. Strong distortion of the image at the edges of the visible area. Distortion results in strong variation of angle distance between pixels.
2. Viewing angle 180°(π radians) in vertical planes.
3. Image size is 1920*1920 px

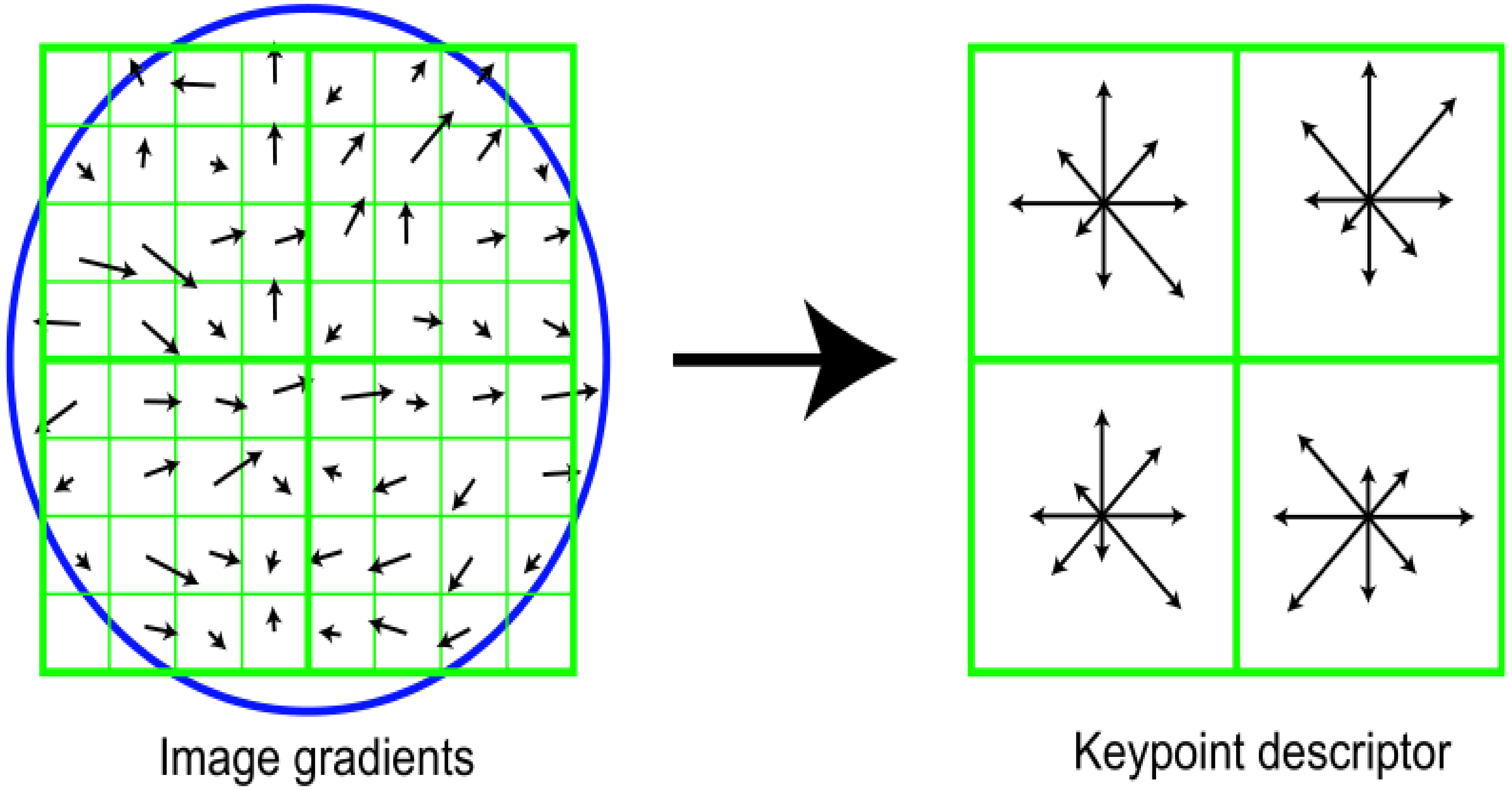


Lens distortion

SIFT

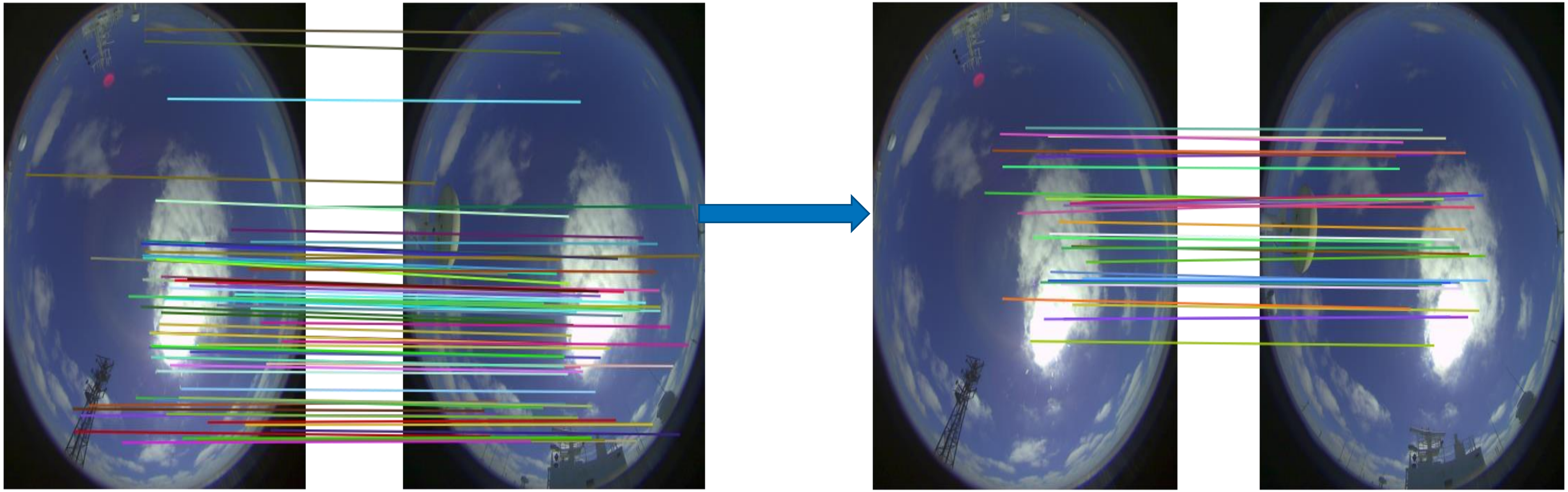


Building a pyramid of Gaussians and finding key points.



Extracting key point descriptors as a vector.

Filtering distortion



Key points found

Filtered key points for distance to the center of the image

Exploiting parallax effect

$$H = \frac{L}{2sin\frac{\alpha}{2}} \sim \frac{L}{\alpha} = \frac{1920L}{S\pi},$$

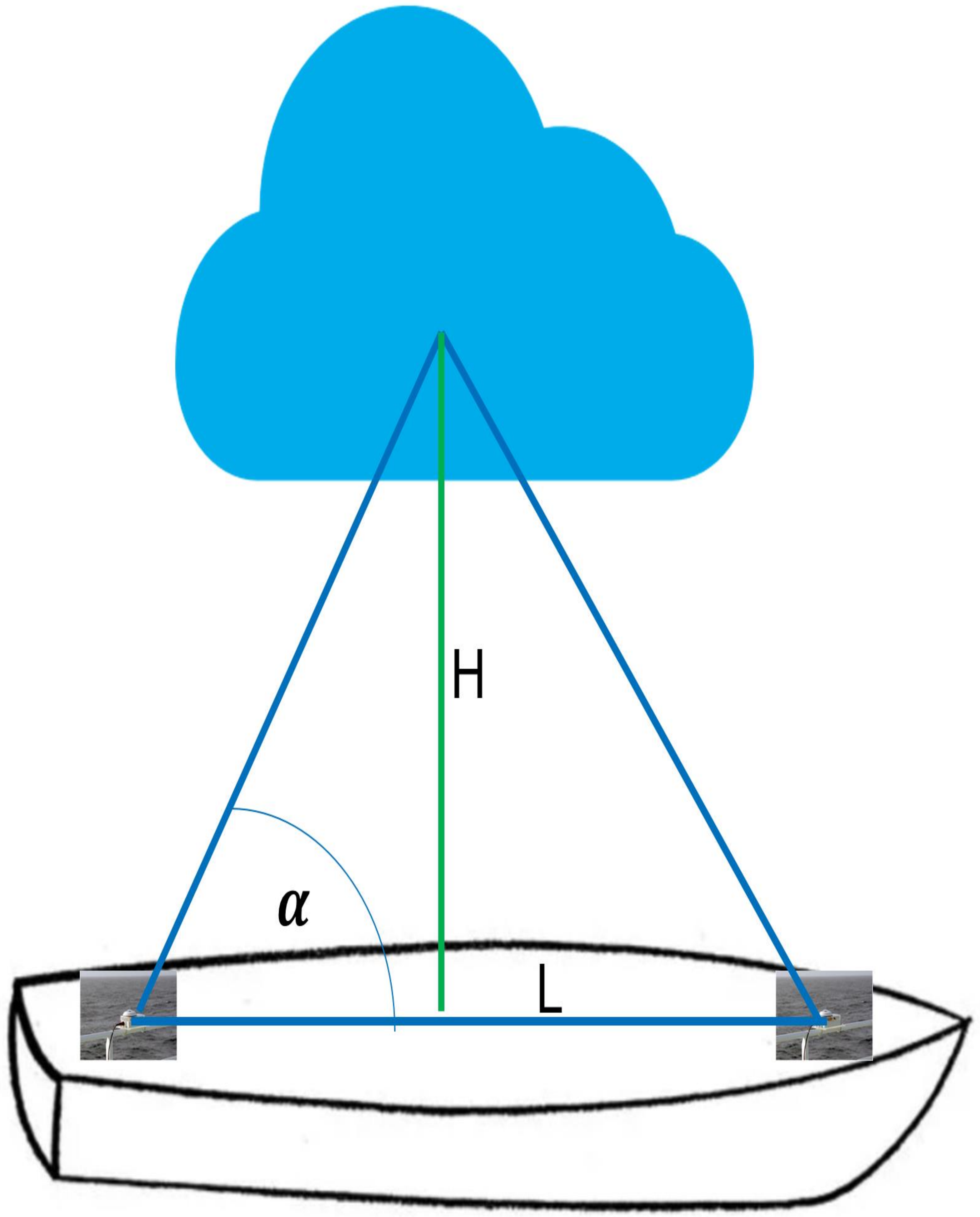
The angle α is calculated from the ratio $\frac{\alpha}{\pi} = \frac{S}{1920}$ (due to π radians of viewing angle per 1920 px.)

S – the distance in pixels between the key points after conversion,

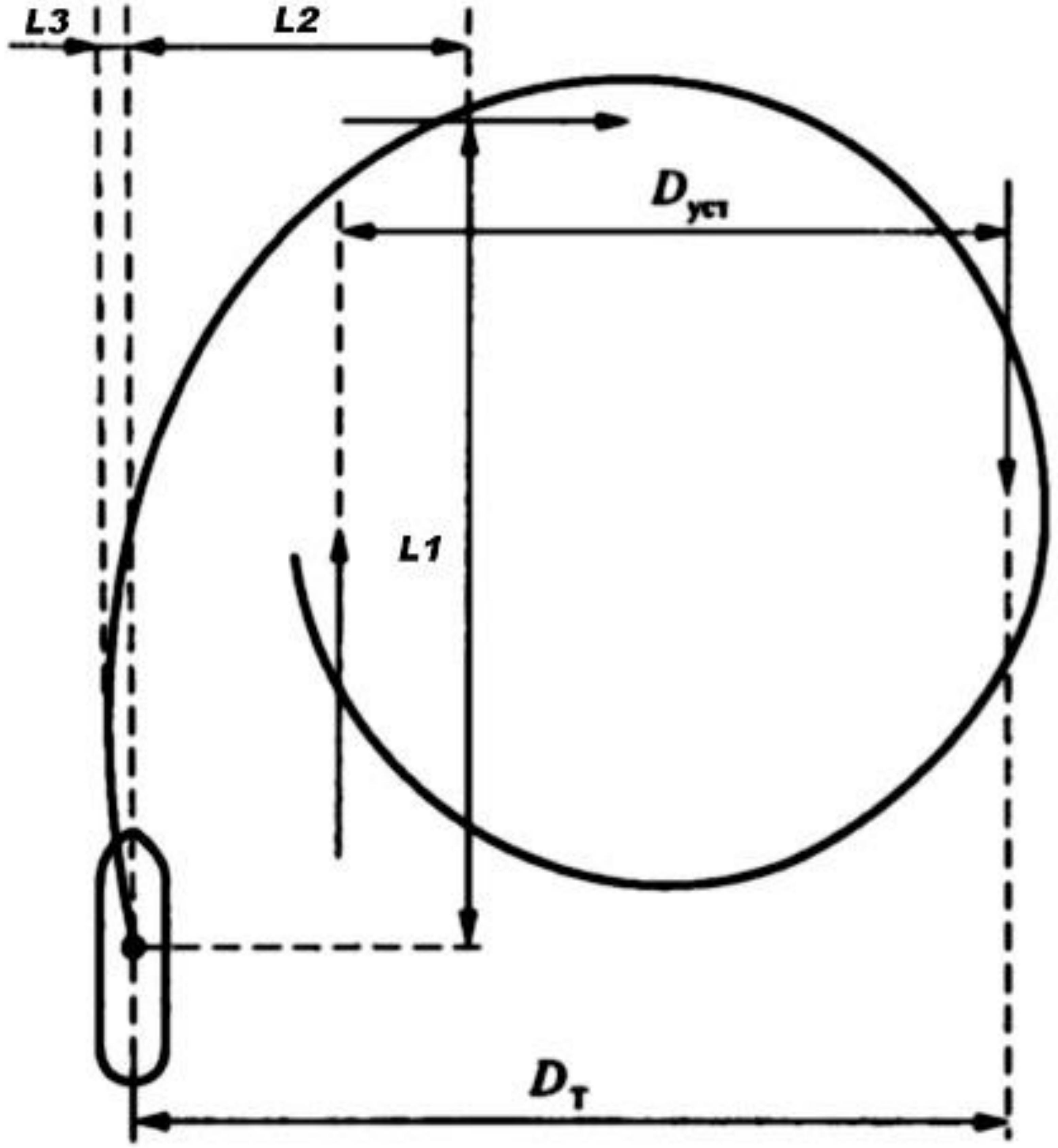
L – distance between cameras

~33.7 meters in AI-61.

~33.3 meters in AI-58.



Experiment Circulation



Circulation scheme

Circulation track in AI-61

Compensating inaccurate setup of cameras

A linear transformation of the form is applied:

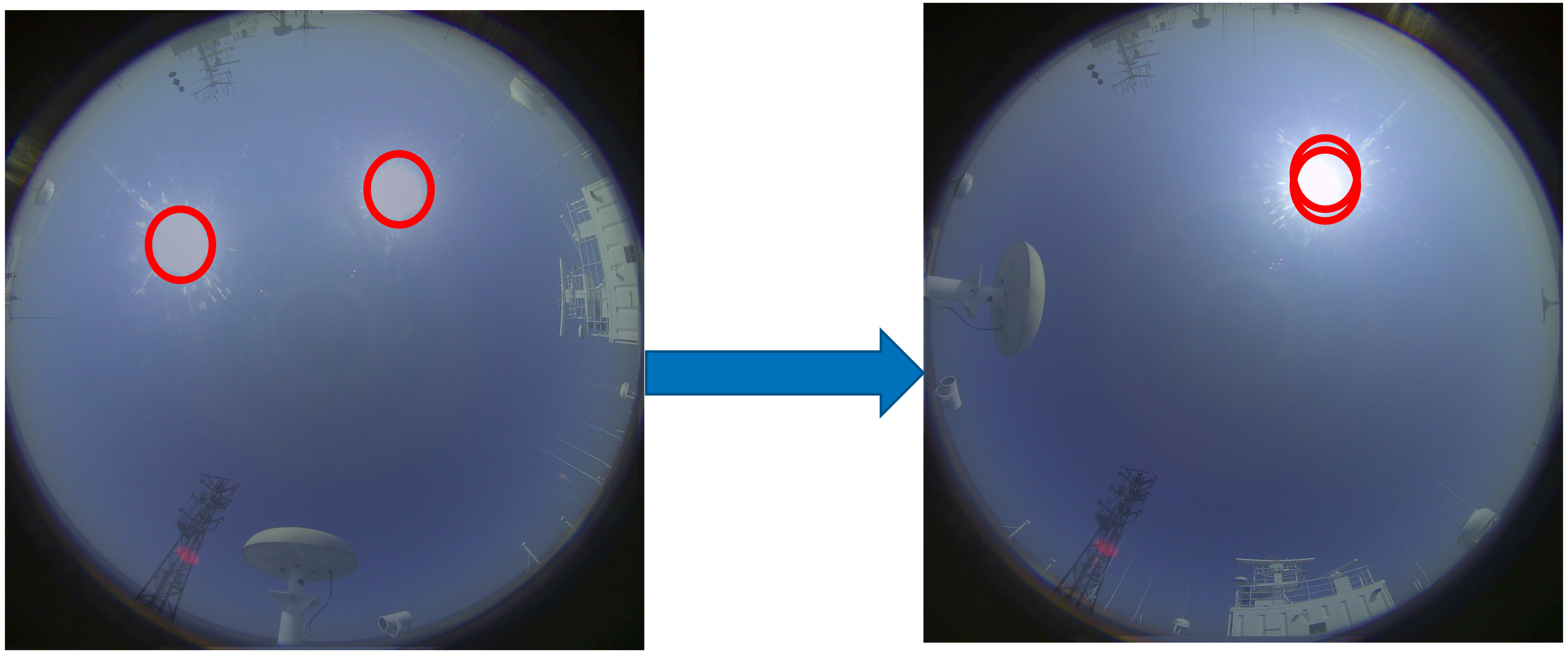
$$\begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix} = \begin{pmatrix} \cos\boldsymbol{\alpha} & -\sin\boldsymbol{\alpha} & a \\ \sin\boldsymbol{\alpha} & \cos\boldsymbol{\alpha} & b \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_1 \\ y_1 \\ 1 \end{pmatrix}$$

Then the following optimization problem is solved

$$\alpha, a, b = argmin_{\alpha,a,b} \sum_{n=1}^{N} \left\| \begin{pmatrix} x' \\ y' \end{pmatrix} - \begin{pmatrix} x_2 \\ y_2 \end{pmatrix} \right\|_2$$

AI-61:1500 pairs

AI-58:1300 pairs

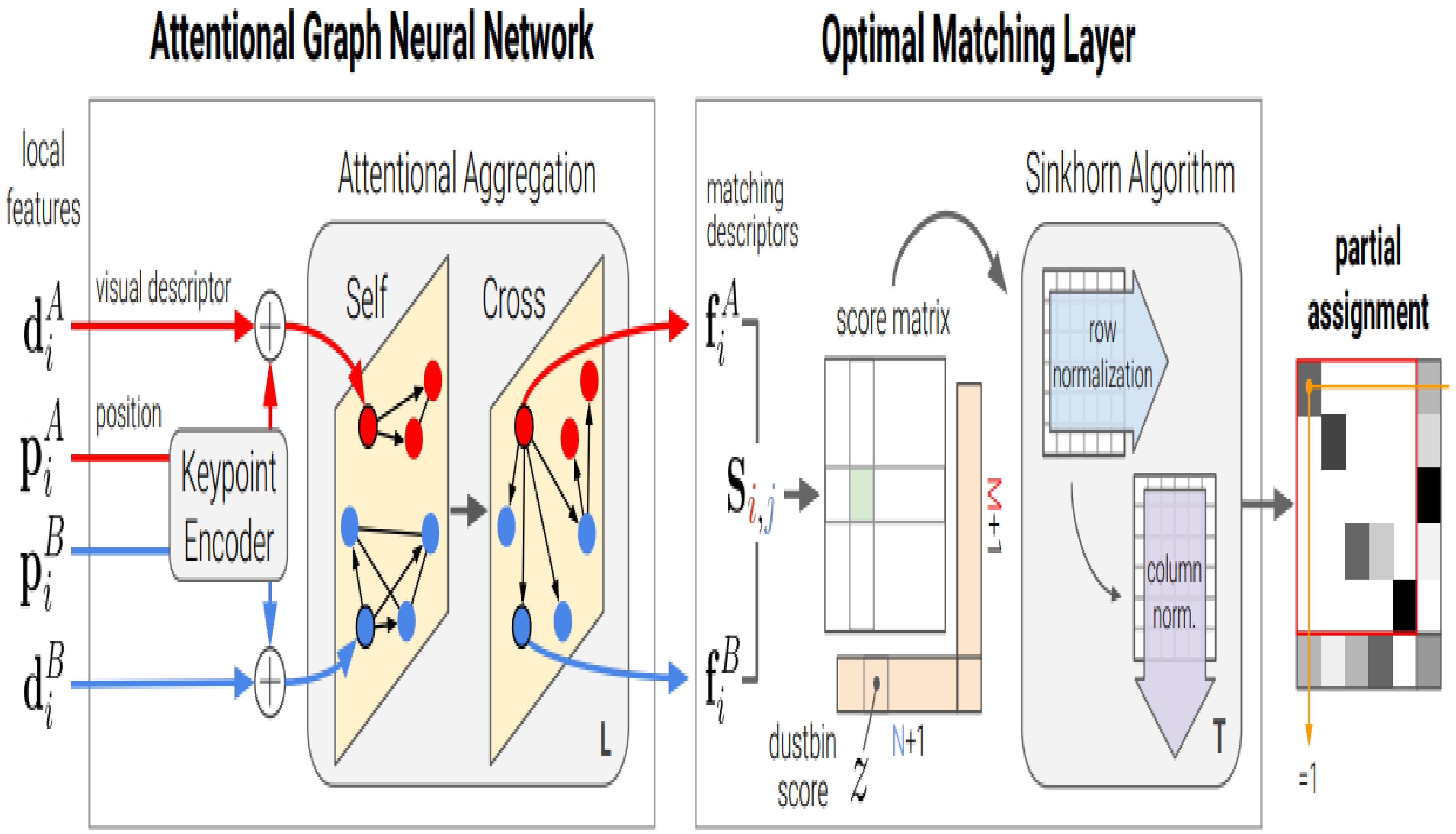


Before and after transformation

SuperGlue

transformation

Graph neural network for reverse transformation

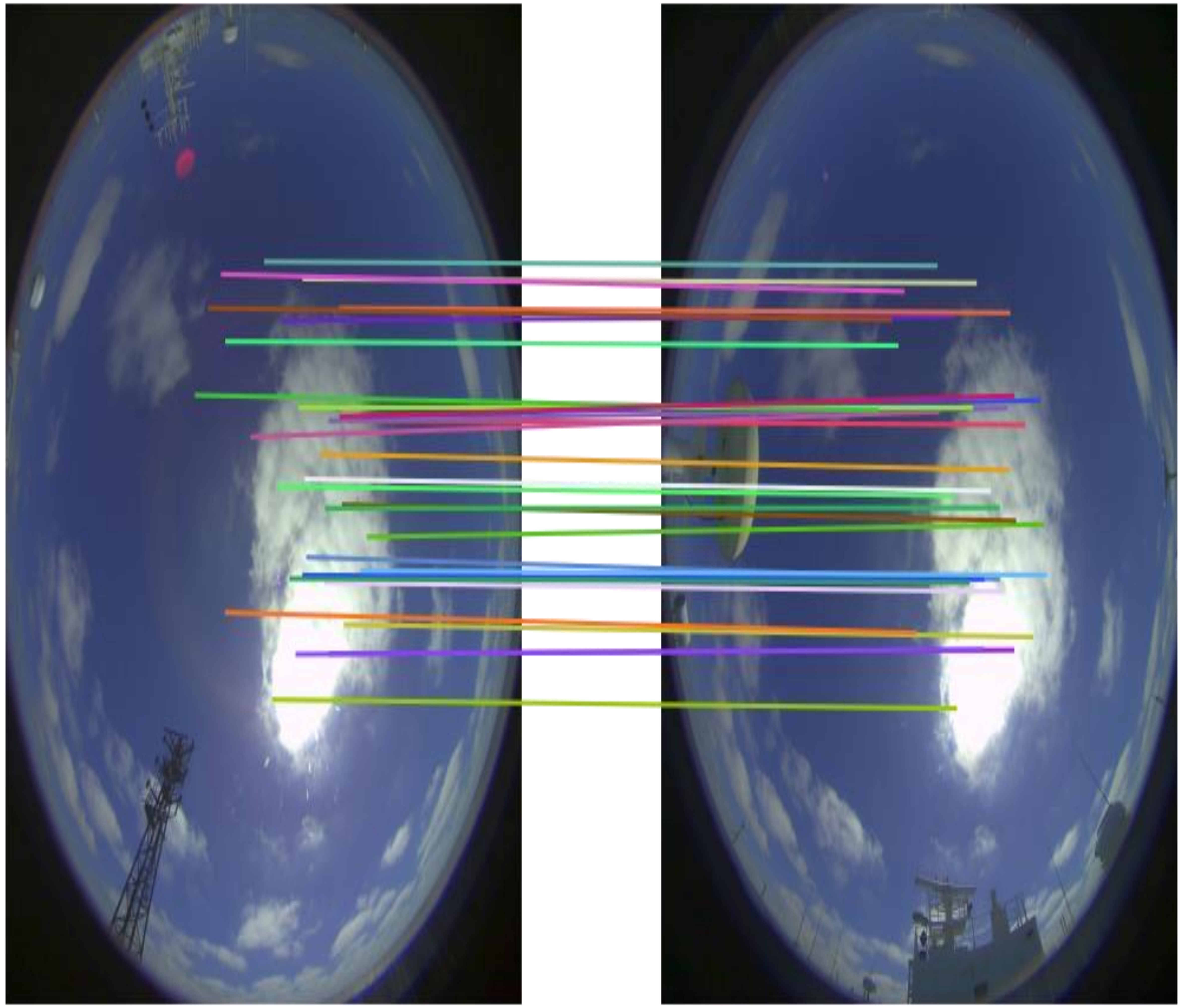


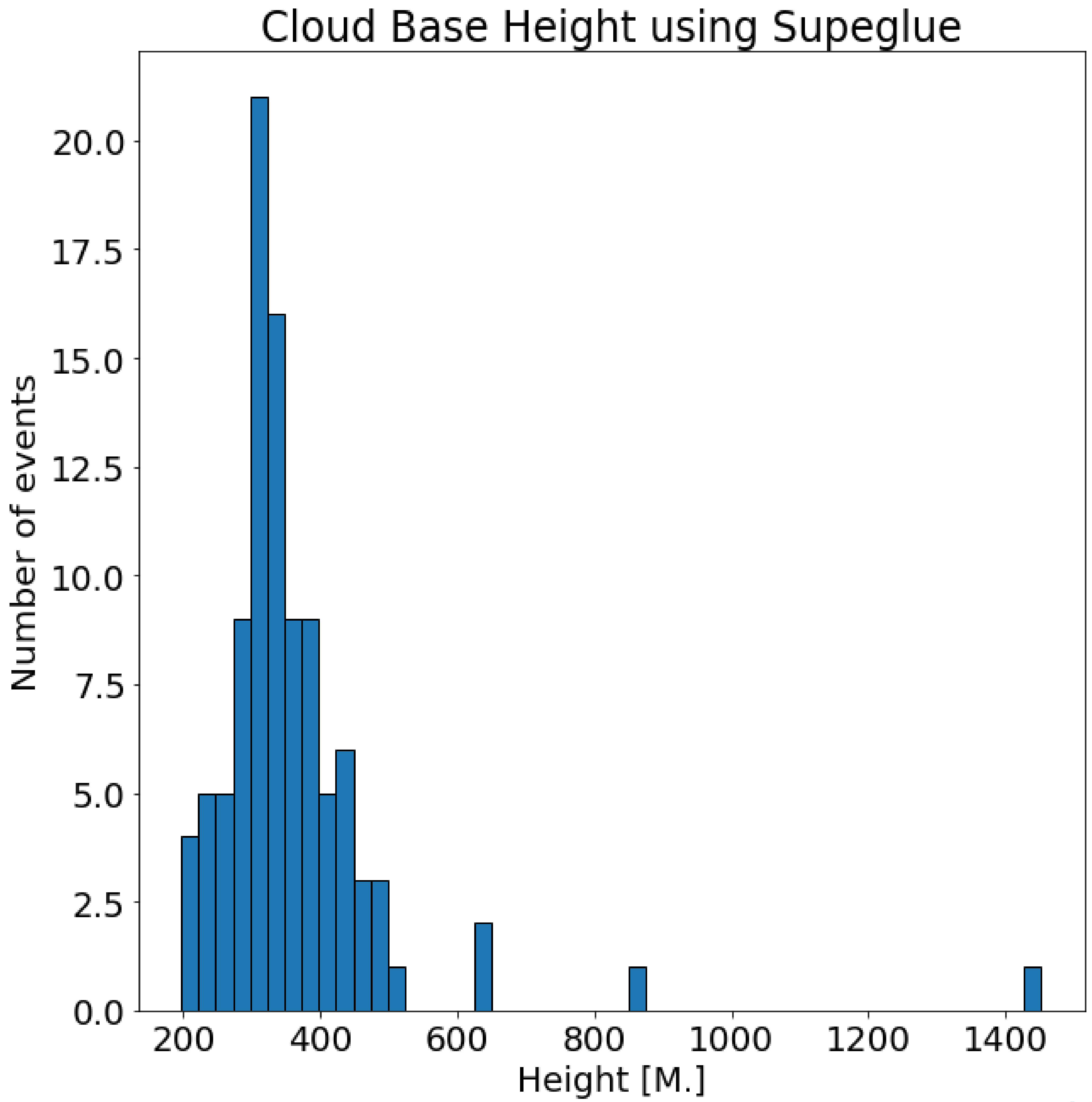
Architecture of the artificial neural graph network Superglue

*From the original paper**

*Sarlin et al. SuperGlue: Learning Feature Matching with Graph Neural Networks, March 2020. arXiv:1911.11763 [cs]

SuperGlue: CBH estimation results





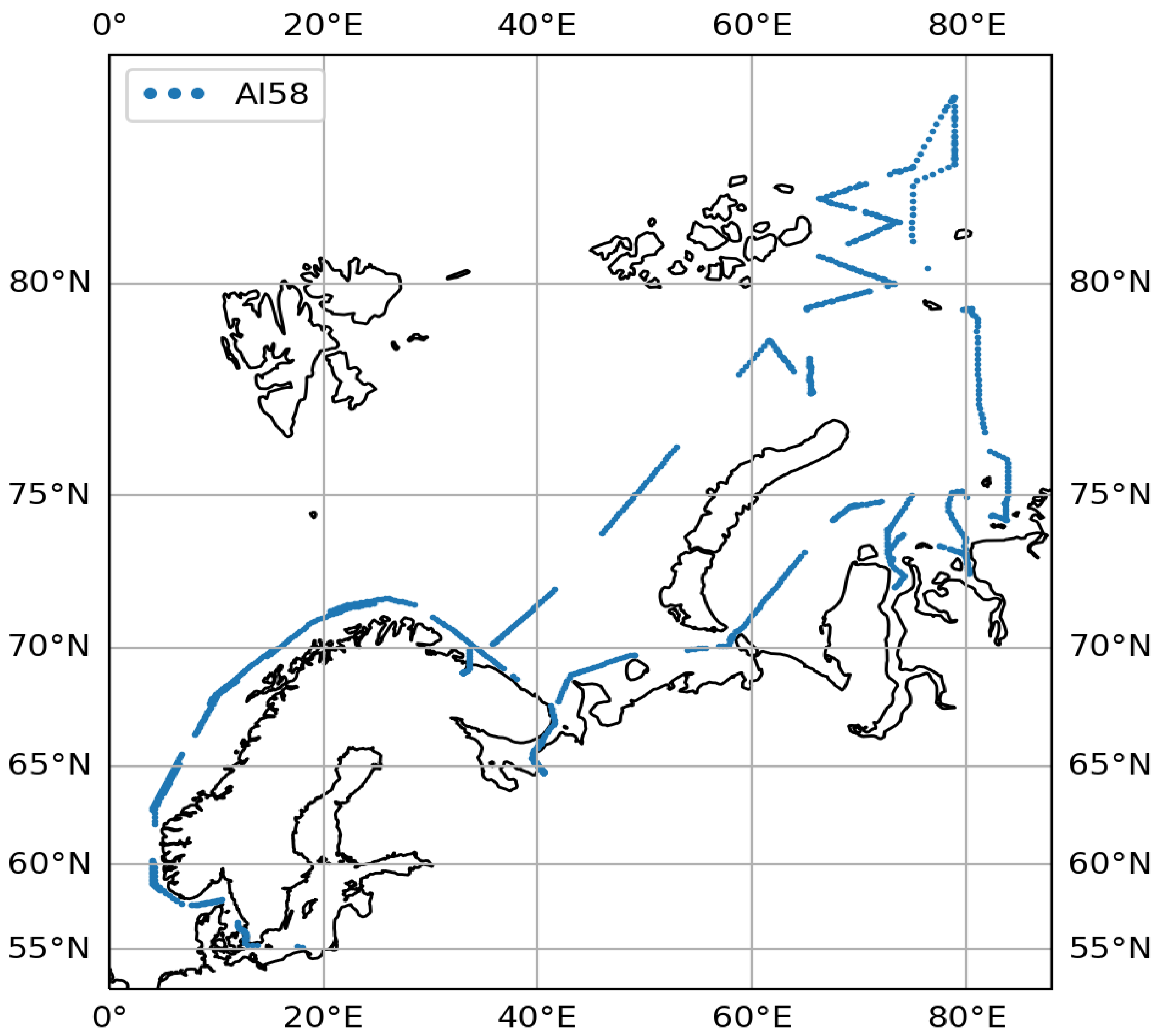
Comparison with ERA-5

August 2022 – Arctic,

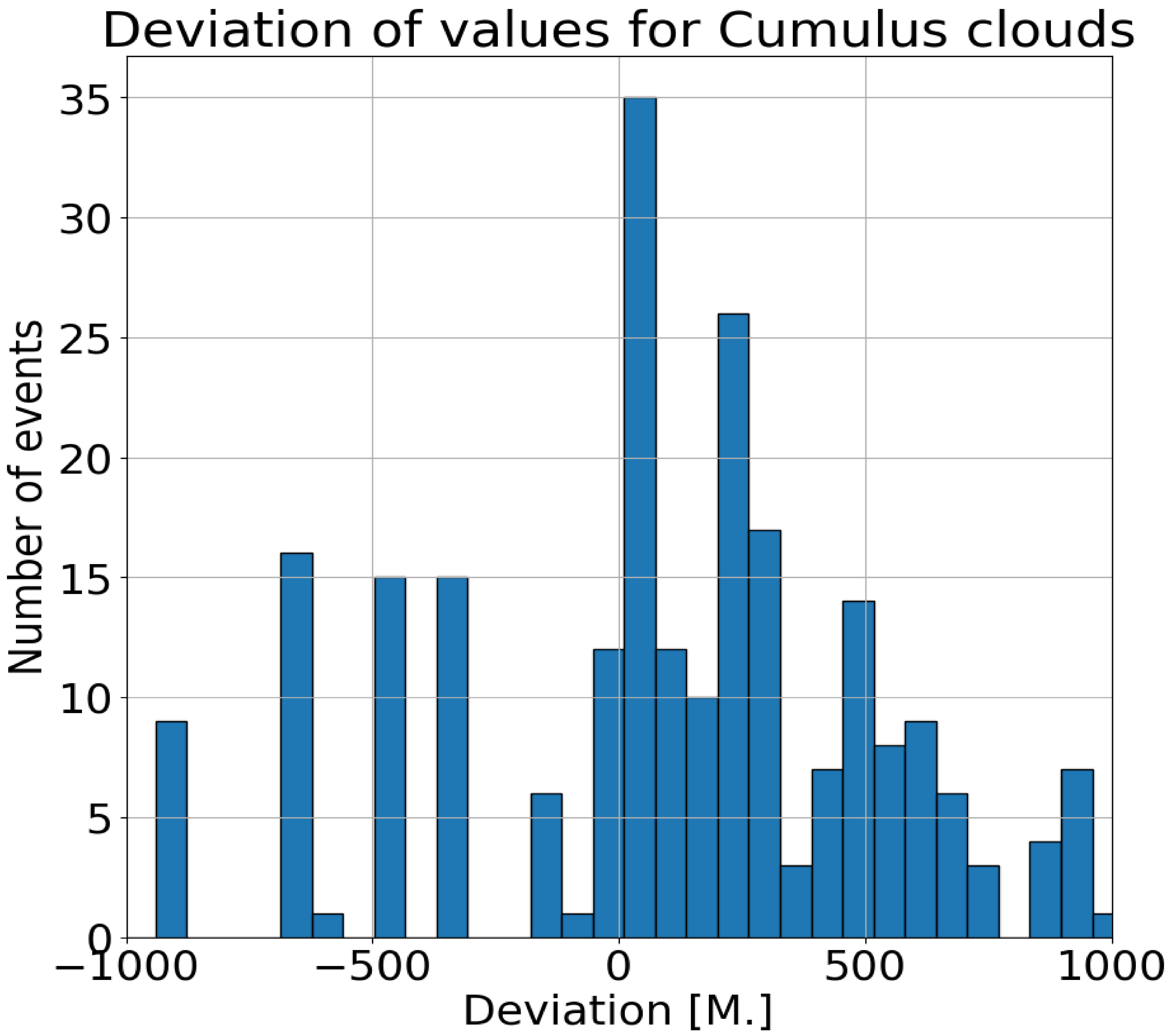
Sc. Und prevails and frequent fogs, polar day conditions.

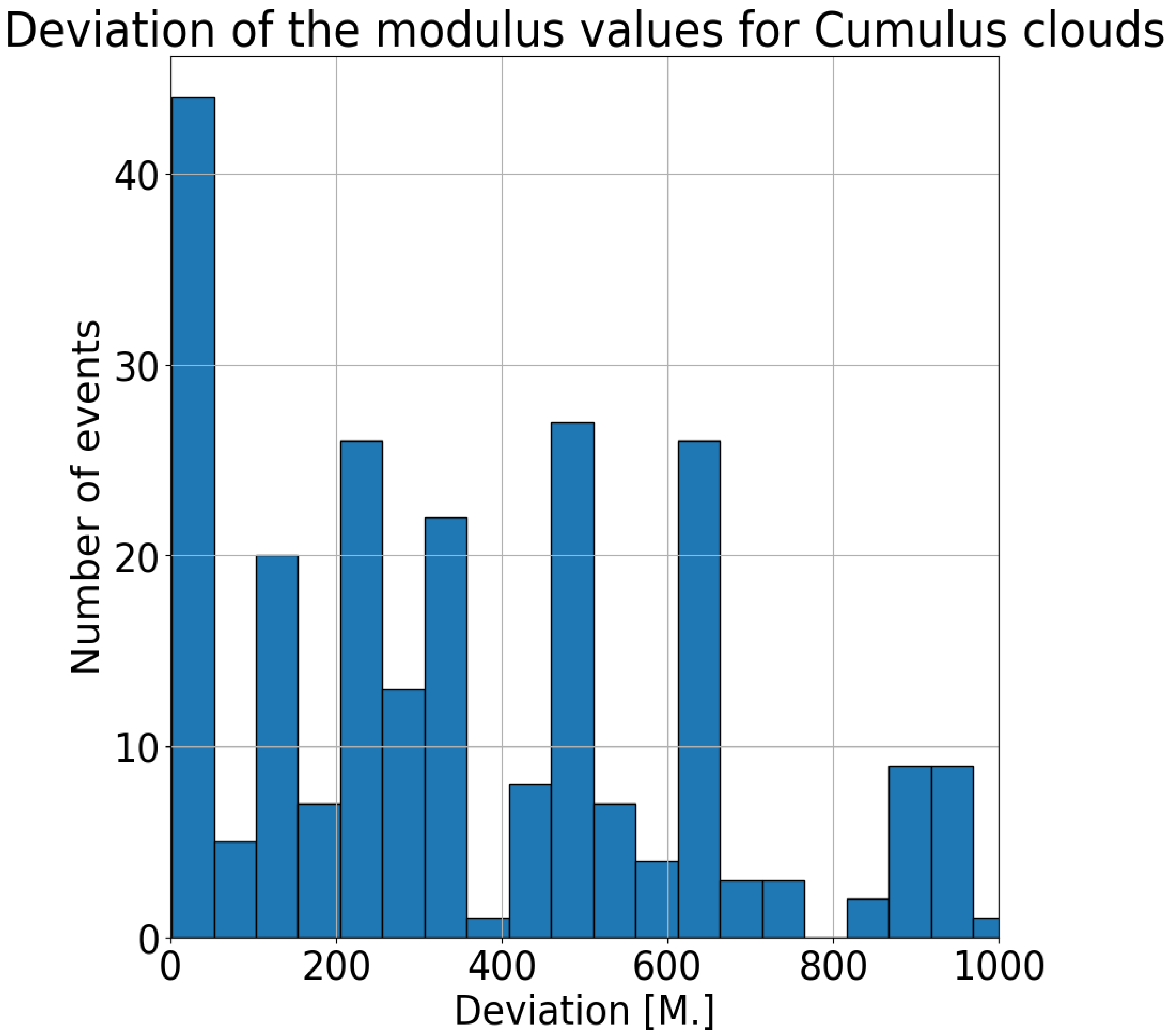
September 2022 – Atlantic,

Ac. Und and Cu. prevail.

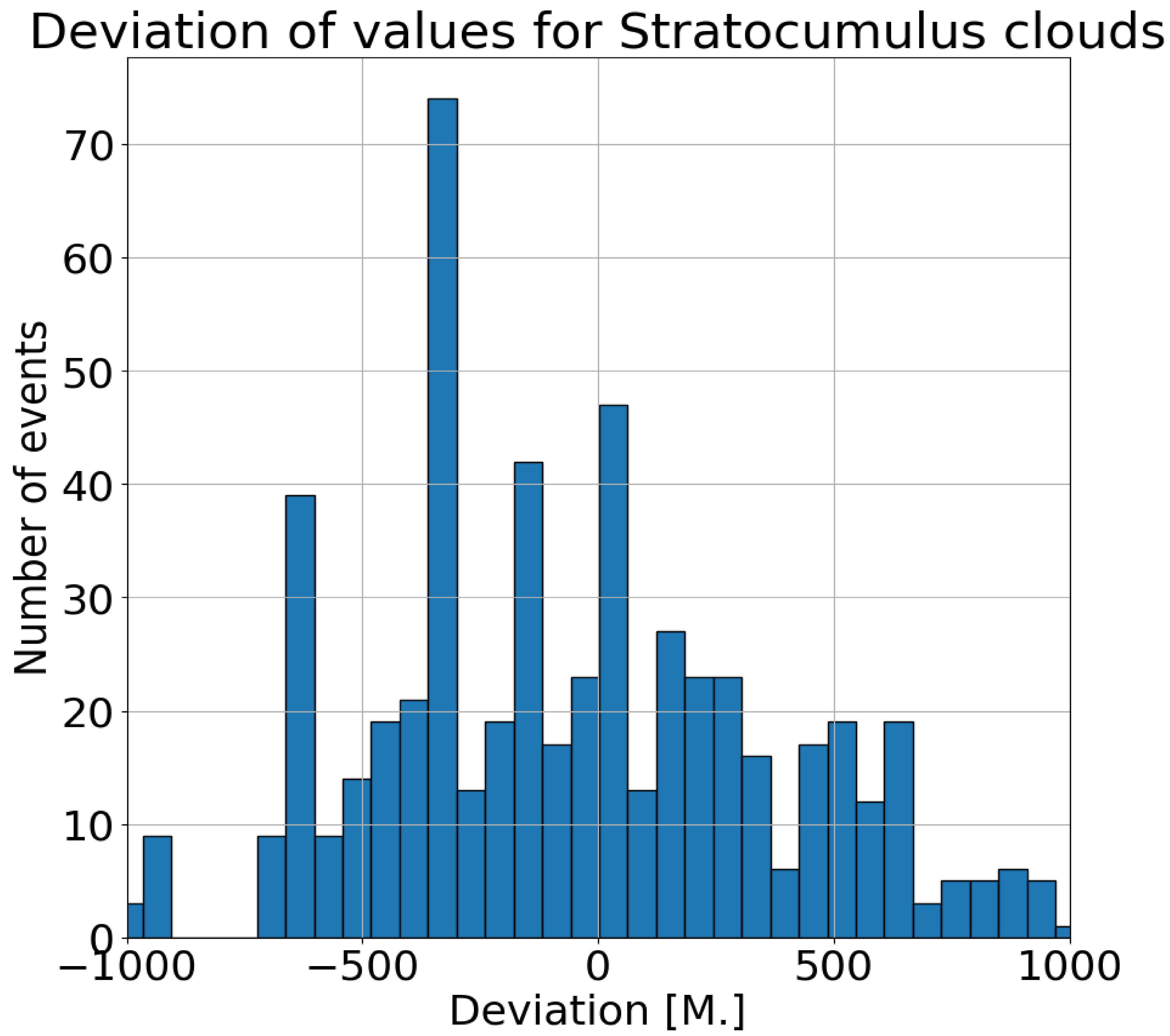


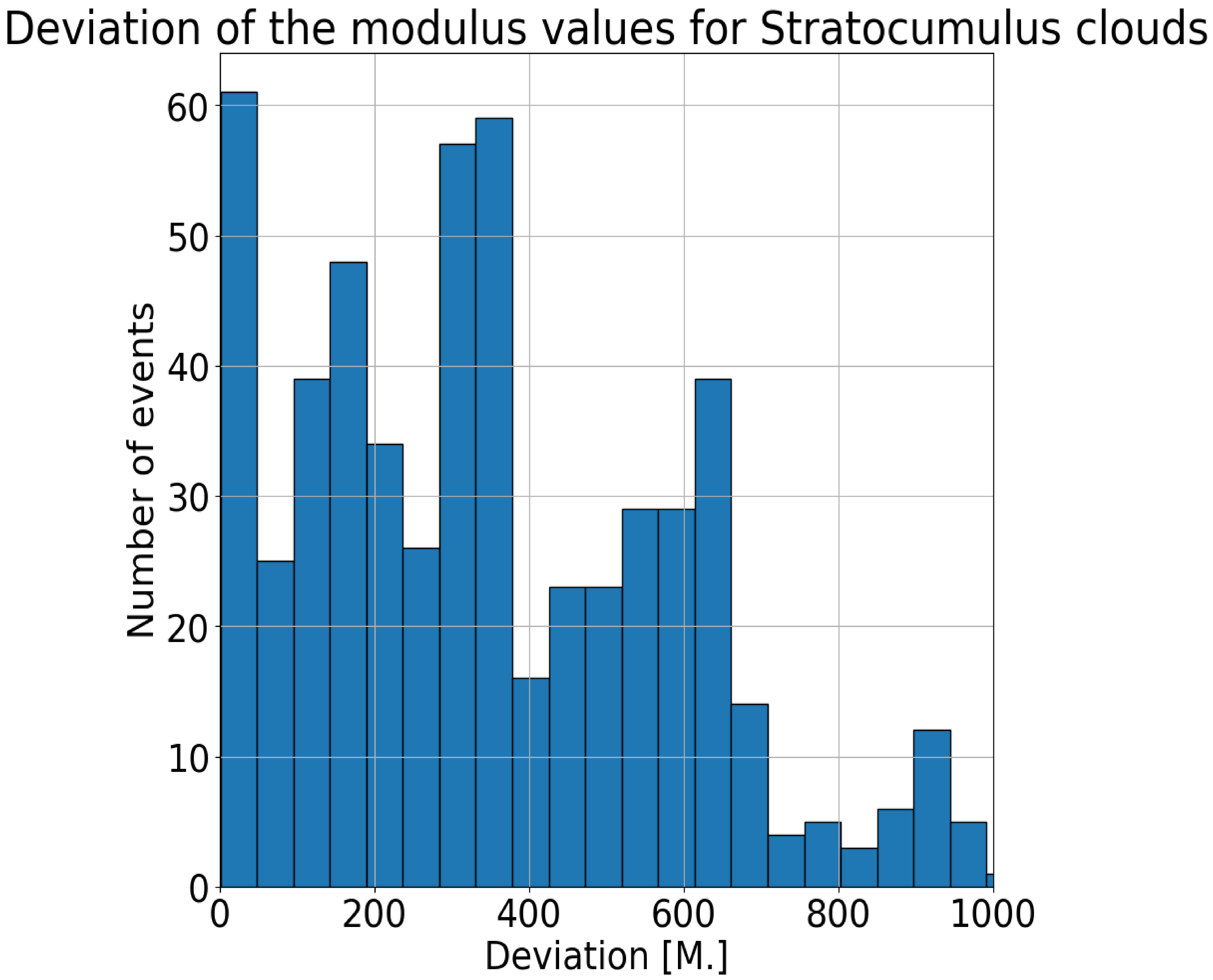
Comparison with ERA-5





Comparison with ERA-5





Conclusion

- We present an approach exploiting parallax effect and keypoints detection and matching for estimating cloud base height using all-sky images acquired by our low-cost optical package Sail Cloud v.2;
- We also present the way compensating inaccurate setup of all-sky cameras through post-processing the pairs of images;
- We tested two methods for keypoint detection and matching: SIFT and SuperGlue neural network; the latter delivers substantially more matching keypoints;
- We demonstrate the results using expeditions AI-58 and AI-61 as an example;
- Based on AI-58, we validated CBH with ERA-5 reanalysis data;

  The most close correspondence is observed for Cu and Sc clouds

  The most dissimilar estimates are for cirrus clouds Ci, Cs

Outlook

Promising approach improvements:

-Improved algorithms for detecting and filtering key points.

-Extending the database of photographs.

-Mathematical correction of the distortion of the fisheye camera.

Promising applications:

-Calculating the area of cloud coverage.

-Calculating the speed of clouds movement.

-Comparison of results with CALIPSO/CloudSat satellite data

Estimation of the characteristic error

Error of indirect measurements:

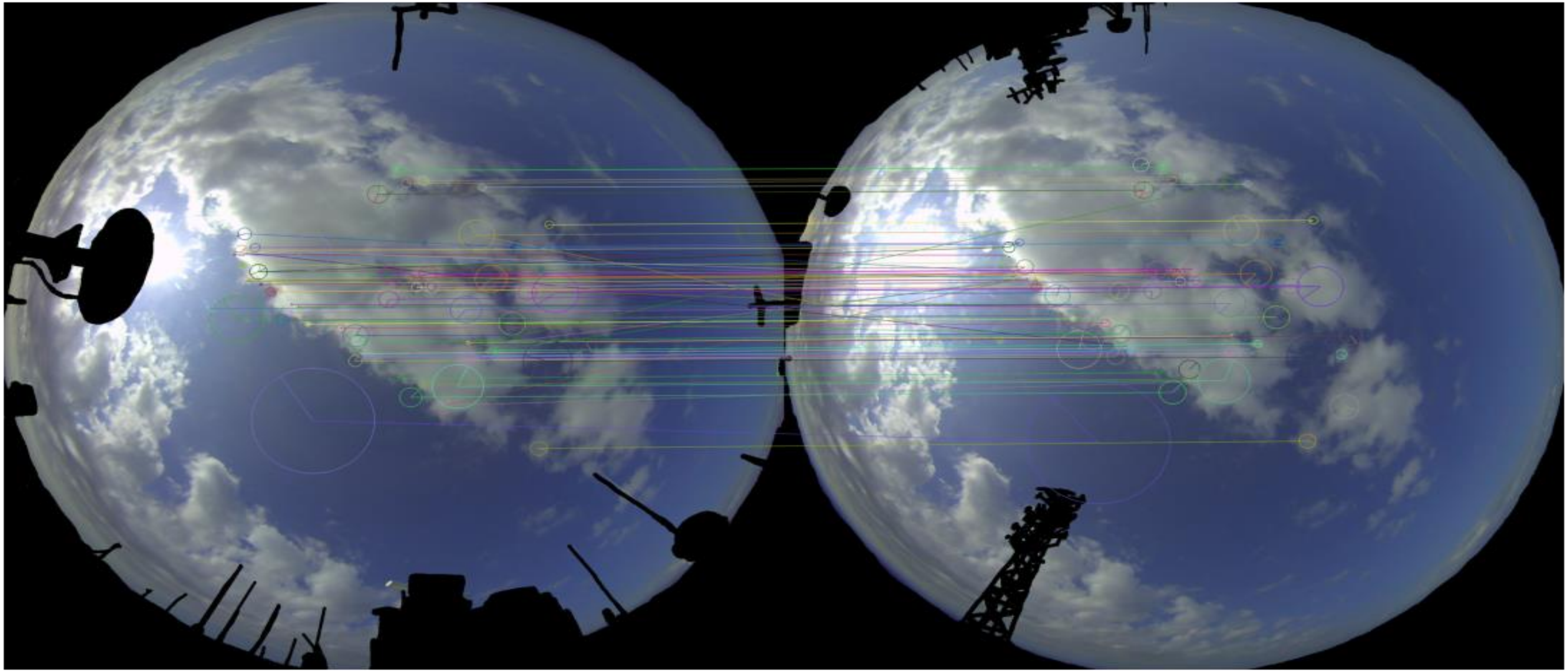
$$\boldsymbol{H} = \frac{\mathbf{1920}\boldsymbol{L}}{\boldsymbol{S\pi}}$$

$$\Delta_H = \sqrt{\left(\frac{\partial H}{\partial L}\Delta_L\right)^2 + \left(\frac{\partial H}{\partial S}\Delta_S\right)^2} =$$

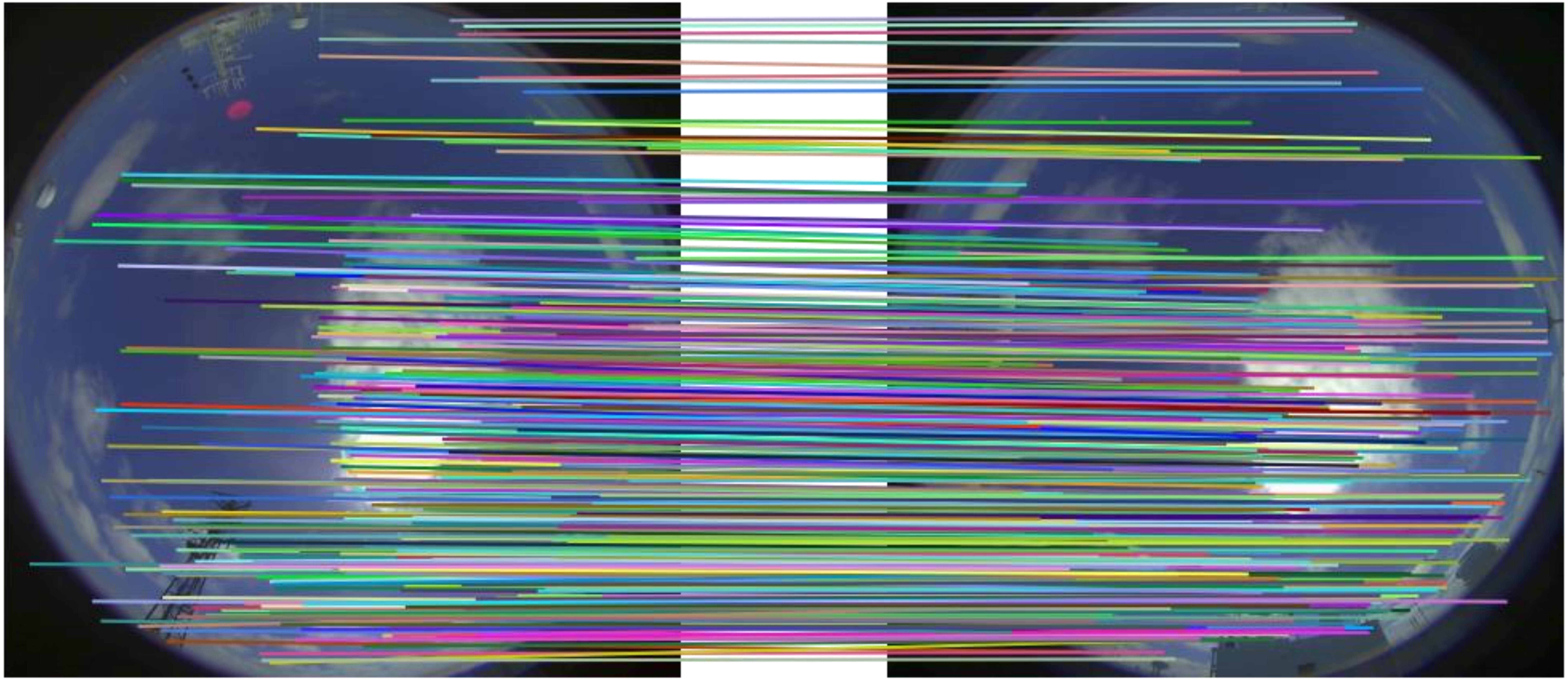
$$\sqrt{\left(\frac{1920\Delta_L}{S\boldsymbol{\pi}}\right)^2 + \left(\frac{1920L\Delta_S}{S^2\boldsymbol{\pi}}\right)^2} = 103{,}7 \text{ м}$$

In more detail, it is necessary to calculate for each expedition separately.

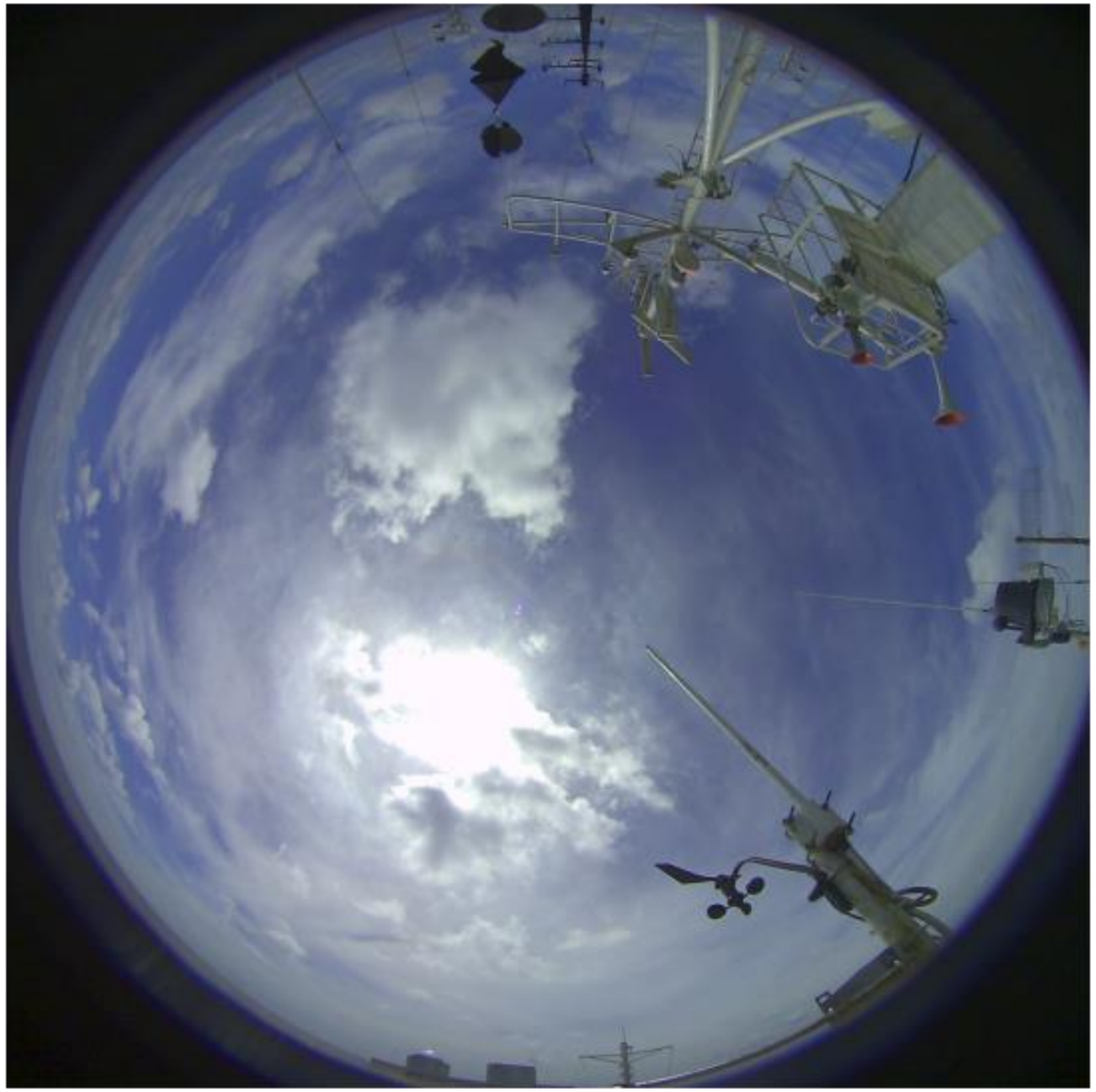
SIFT results

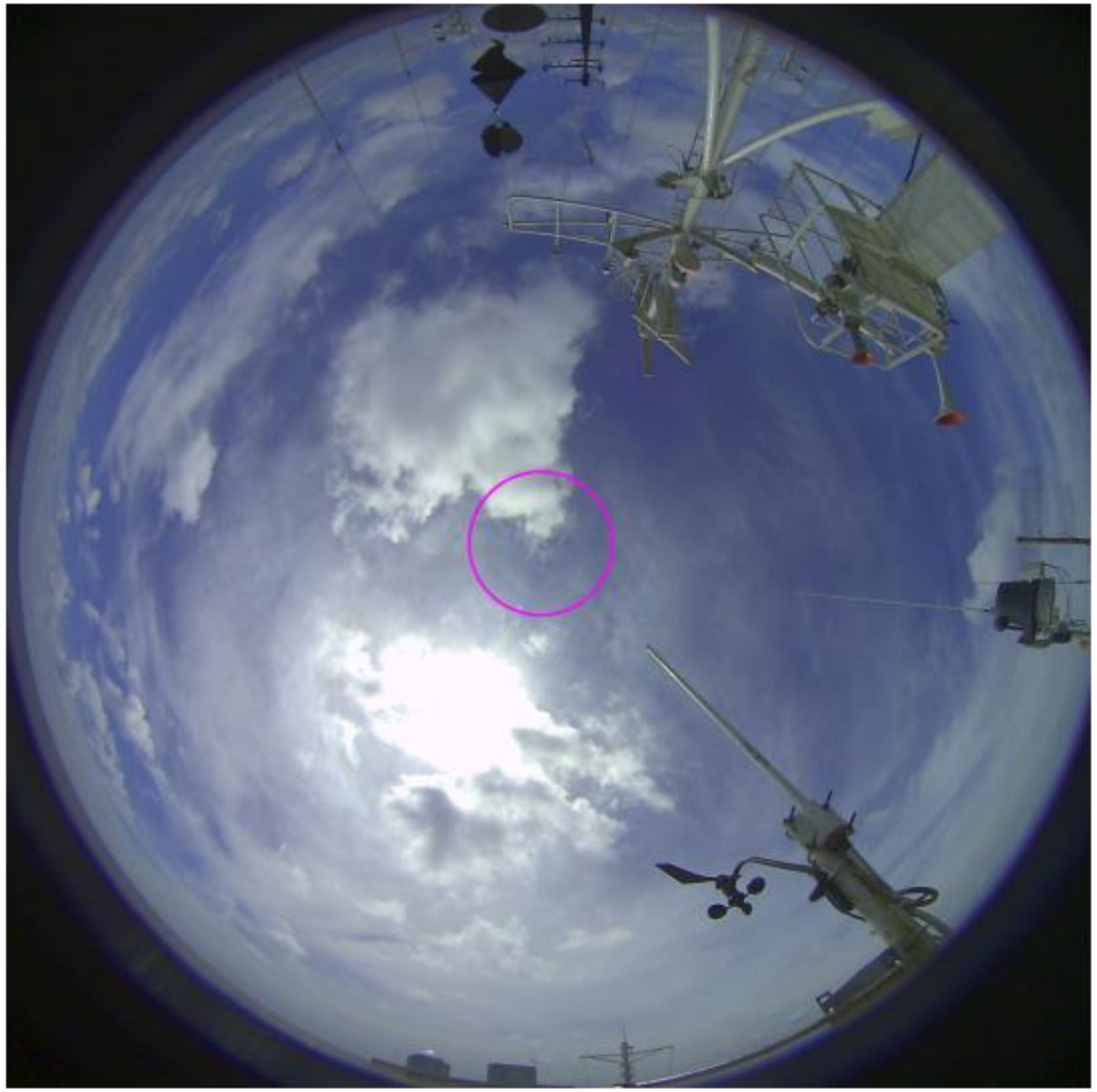


Superglue with all key-points



Resnet 152





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