EAS observation conditions monitoring in the SPHERE-2 balloon experiment

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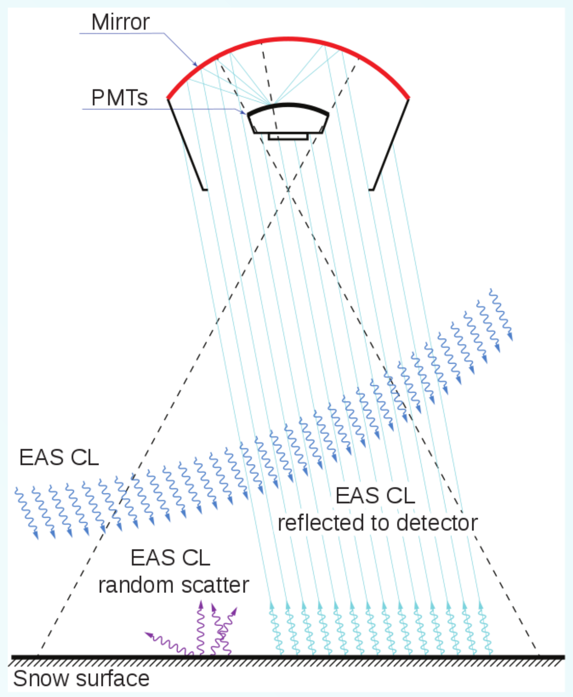
Abstract

The SPHERE project studies primary cosmic rays by detection of the Cherenkov light of extensive air showers reflected from the snow covered surface of the earth. The SPHERE project is the first successful implementation of a new EAS detection method — detection of reflected Cherenkov light using an aerial-based detector — a method first proposed by A. Chudakov and first implemented by R. Antonov [1]. The SPHERE-2 experiment was designed for primary cosmic ray studies in the 10–1000 PeV energy range. Measurements were performed in 2011--2013.

Here we present an overview of the SPHERE-2 [2] detector telemetry monitoring systems along with the analysis of the measurements conditions including atmosphere profile. The analysis of the detector state and environment atmosphere conditions monitoring provided various cross-checks of detector calibration, positioning, and performance.

SPHERE-2 detector

The SPHERE-2 balloon detector optics were comprised of a 1.5 m diameter spherical mirror with a 109 photomultiplier tube retina. The detector SPHERE-2 was lifted by a balloon to altitudes of up to 900 m above the snow covered surface of Lake Baikal, Russia.



SPHERE-2 experiment scheme.

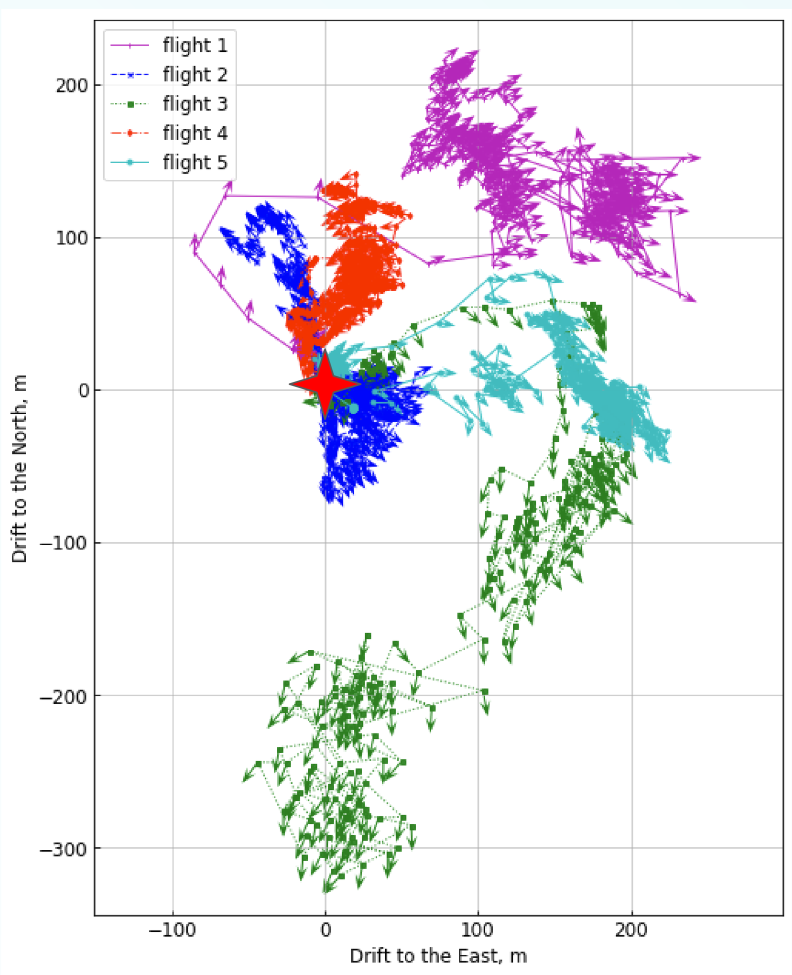
Interval	Parameter	Data	Accuracy	Range	Units
1 s	Detector position	GPS altitude	(1) *	−1500–18,000	m a.s.l.
		GPS position	3–5 (2) *	—	m
		GPS time (PPS)	1	—	μs
	Detector orientation	inclination angles (resolution) X,Y	0.3 (0.02) *	−25–25	deg
		compass azimuth (resolution) Z	2.5 (0.5) *	0–360	deg
	Control block	inner temperature	1.5	−40–70	°C
1 min	PMT status	anode current	0.03	0–125	μA
		mosaic temperature	1.5	−40–70	°C
	Power source	high voltage (HV1)	0.1	0–250	V
	Barometer	pressure	5	750–1100	hPa
		temperature	2	−20–60	°C
	Balloon barometer	pressure	3	0–1000	Pa
	Battery (19 V)	voltage	0.01	0–40	V
	Constant voltage (5 V)	voltage	0.01	0–40	V
10 min	PMT status	first dinode voltage	0.06	0–250	V
		PMT temperature	0.1	−30–50	°C
		supply voltage	0.006	0–25	V
	Trigger	counting rate	–	0–65,536	
	FADC boards	voltage (1.2, 2.5, 2.8)	0.001	0–4	V

* numbers in parentheses are given according to our own analysis

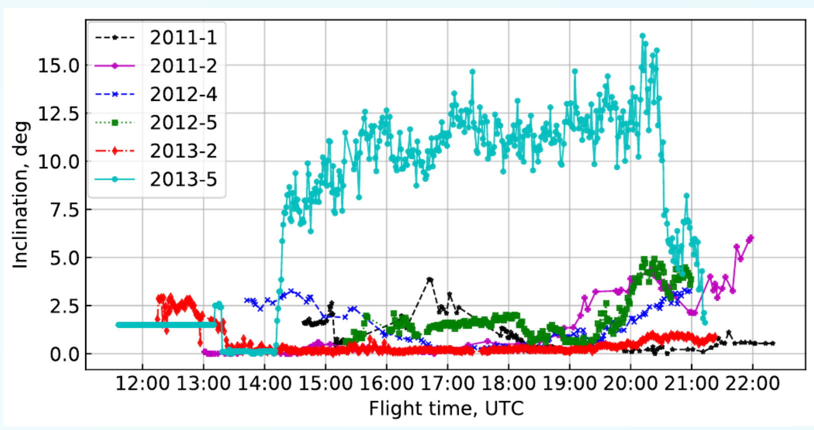
SPHERE-2 telemetry data readout intervals and sensors precision.

Telemetry monitoring

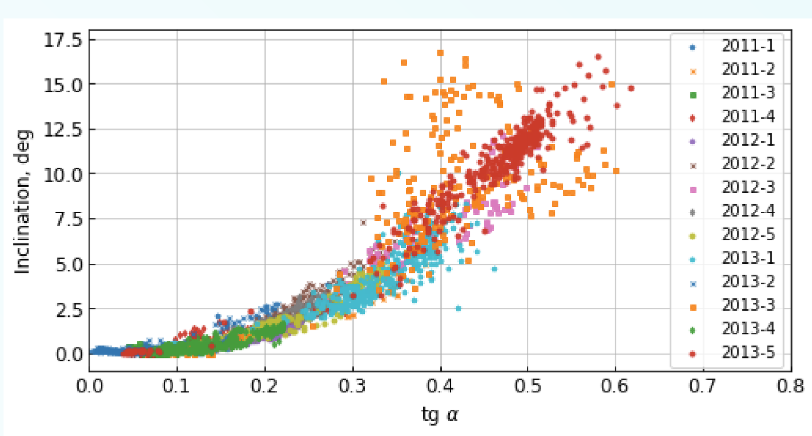
The SPHERE-2 detector's position and inclination depend on wind conditions near the detector. The wind was quite constant for most of the time, and the balloon position was rather stable and varied slowly.



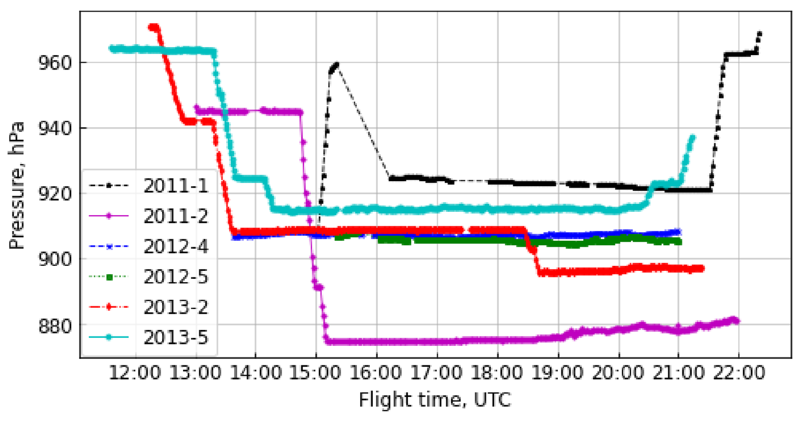
The SPHERE-2 detector drift in 2013. Points indicate detector position in 1 min intervals, arrows indicate the detector magneto- meter orientation. The start point is located at zero coordinates.



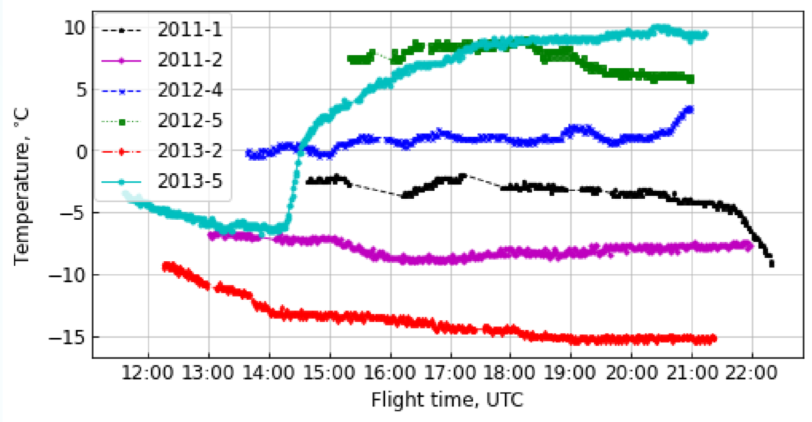
The detector inclination according to the inclinometer sensor during several flights.



Detector inclination against the ratio of detector drift from the start point to the detector altitude (which roughly translates into the tether inclination angle). See [3] for details.

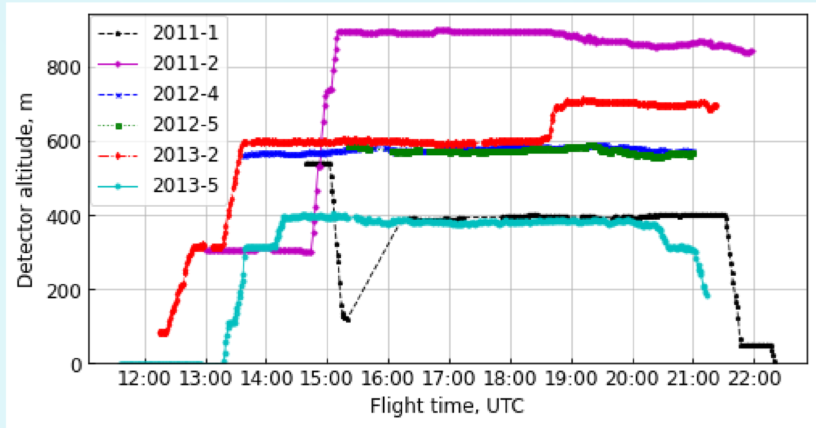


Air pressure according to the barometer sensor data during 2011–2013 flights.



Air temperature near the PMT mosaic during 2011–2013 runs.

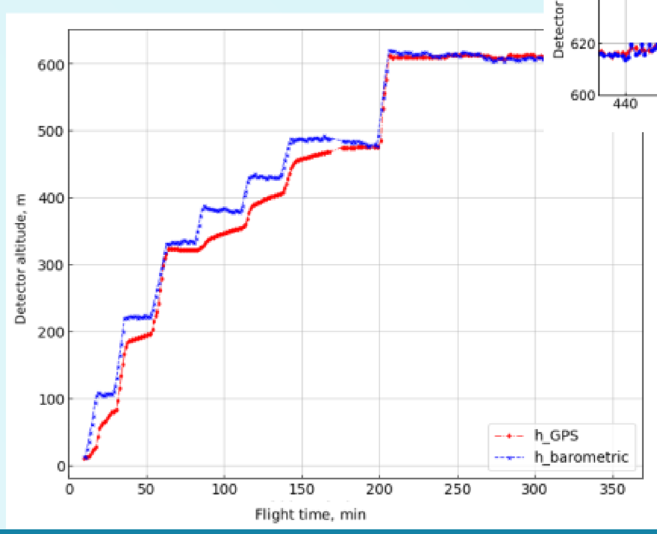
GPS altitude correction

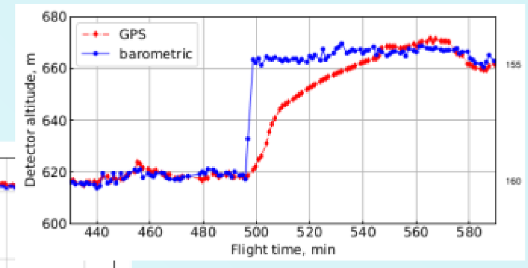


Altitude of the SPHERE-2 detector carried by the BAPA tethered balloon according to the GPS data.

The detector altitude was measured by GPS module and checked by pressure detector. After rapid changes in altitude due to the balloon ascent or descent, the GPS registered height lagged behind the corresponding pressure change and varied in a smoothed fashion due to the GPS internal error correction algorithm.

To correct a smoothed GPS altitude the "barometric altitude" was calculated. To identify anomalous intervals high-pass digital Butterworth filter was applied. The correction was made for 220 min, where 68 triggers were registered.





An example of the difference in altitudes measured by GPS and barometric altitudes in flight 2013-2.

Atmosphere profile

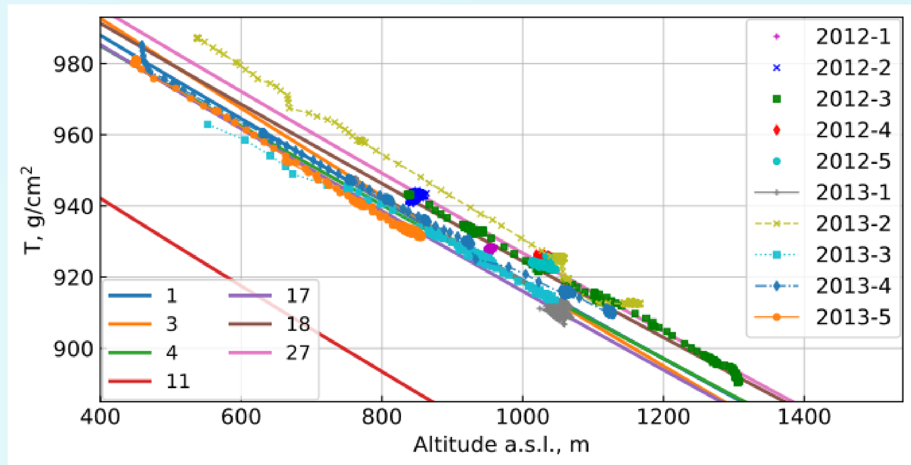
CORSIKA atmosphere model 11 was used for modeling and estimations at the SPHERE-2 experiment planning stage. However, our data show that this choice was not ideal.

The atmosphere density profiles were reconstructed from the experimental data at altitudes below 900 m above the ice.

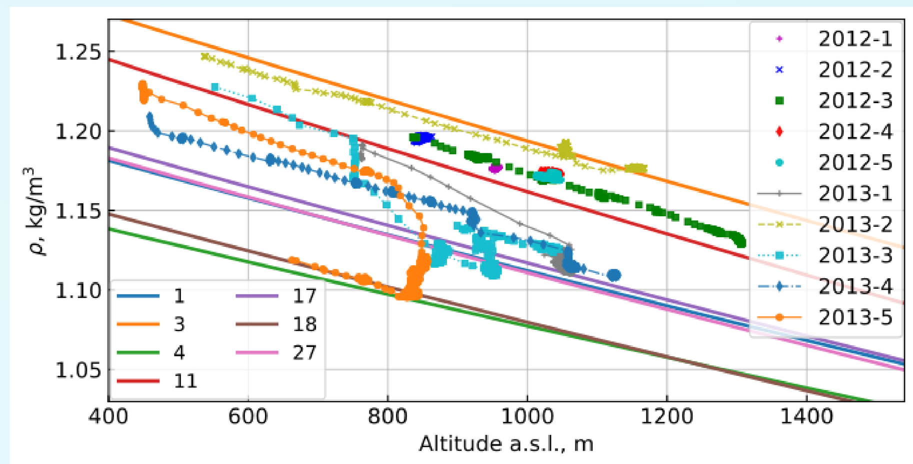
Mass overburden data were reconstructed from atmospheric pressure measurements and air density was estimated based on both air pressure and temperature around the balloon.

Substantial changes of the atmosphere model affect the total number of Cherenkov photons and the estimates of primary energy by no more than 5% on average.

The mass-sensitive parameter based on the Cherenkov light lateral distribution function steepness [4] is extremely sensitive to the atmosphere model.



Mass overburden versus altitude. Experimental points and CORSIKA profiles (solid lines with corresponding model numbers).



Atmosphere density versus altitude. Experimental points and CORSIKA model density profiles (solid lines)

Conclusions

The SPHERE-2 detector which operated in 2008–2013 has a large array of supplementary sensors that allowed to control and later reconstruct the state of the detector and measurement conditions.

For the reflected Cherenkov light method the information on detector position and orientation is vital. Their values were measured with good precision and reliability and were cross-checked using experimental data.

Measurements of air pressure and temperature during flights gave information on the atmospheric state that will allow to introduce different atmospheric models into analysis and to account their strong impact on the results.

Availability of the data on the atmospheric state at the moment of the EAS detection allows more accurate primary mass reconstruction. Carrying out daily measurements of the state of the atmosphere in different layers of the atmosphere is critical for reconstructing the composition of cosmic rays. This is important not only for balloons, but also for ground based installations.

References

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4. Antonov, R., et al. Event-by-event study of CR composition with the SPHERE experiment using the 2013 data. J. Phys. Conf. Ser. 2015, 632, 012090. doi: 10.1088/1742-6596/632/1/012090