Effects of moonlight and cloud amount on the night sky brightness

Chu Wing SO (socw@hku.hk), Chun Shing Jason PUN (jcspun@hku.hk), Chung Fai WONG (terryfai@hku.hk)

Department of Physics, The University of Hong Kong (HKU), Pokfulam, Hong Kong

Abstract

Results of a quantitative study on the correlation between amount of cloud and the night sky brightness at urban and rural sites in Hong Kong are presented. The cloud amount and sky brightness were observed simultaneously and continuously from more than 320 hours of observations at each site obtained on multiple nights across different seasons. While the night skies were generally brighter when approaching overcast, different relations between the change in cloud amount and change in night sky brightness could be observed. Concrete correlation between the change in the cloud amount and the change in the night sky brightness were found more frequently in the urban area, together with a larger change in the sky brightness upon similar variation in the cloud amount. In addition, effects of moonlight on the observed night sky brightness were also studied and modeled. The extent of which these two natural meteorological and astronomical phenomena affect the measurement and monitoring of light pollution will be presented.

This project is supported by the Environment and Conservation Fund of the Hong Kong SAR government (ECF 10/2009, ECF 1/2007).

Introduction

With no legal regulations on the usage of outdoor lightings at night, the light pollution condition in Hong Kong is severe (Figure 1). It is expected that the **night sky brightness (NSB)** of Hong Kong is related to people's lighting practice, i.e. where, how, and when people use the lights, and the design of lighting fixtures, etc.

HKU is monitoring the local light pollution by establishing the "Hong Kong Night Sky Brightness Monitoring Network" (NSN). Stations of NSN are measuring NSB continually at multiple every minute. Data will be taken simultaneously every minute and transmitted to the data center via cell phone network. Currently, there are 17 observing stations in operation. Since May 2010, over 2.57 million data points had been collected. Details of NSN can be found from the project website:

http://nightsky.physics.hku.hk/

In this poster, we present the effects of moonlight and cloud amount on NSB using selected datasets from NSN.
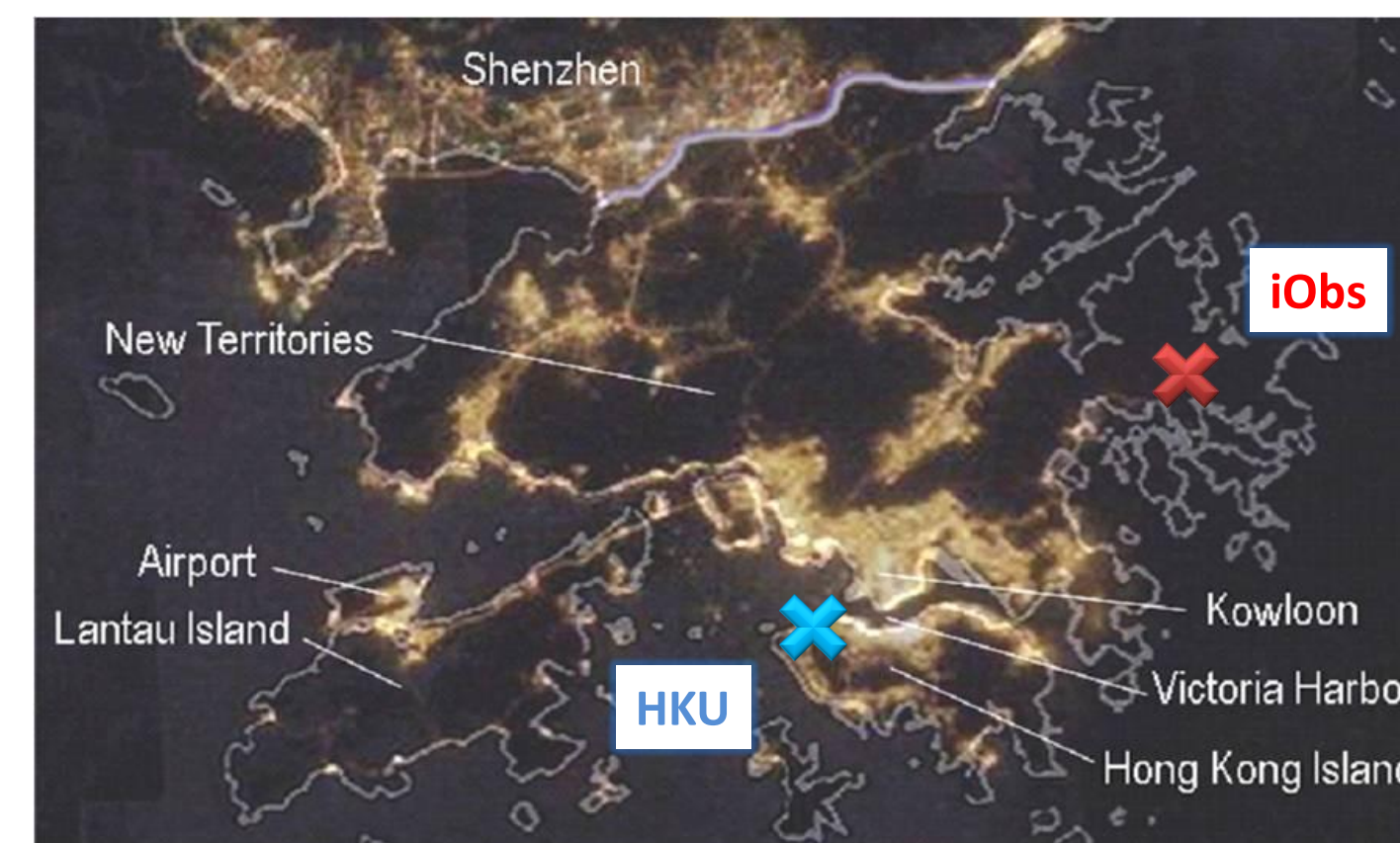

Figure 1 :
Nighttime picture of Hong Kong taken from the International Space Station in space in 2003 (credit: NASA).

A) Effects of cloud amount on the night sky brightness

A1) Data Collection

- NSB data are taken with the Sky Quality Meter – Lens Ethernet (SQM-LE), which is protected by polycarbonate outdoor enclosure.
- NSB data from two of the NSN stations, namely iObs (rural) and HKU (urban), taken from 8 November 2010 to 2 May 2011 were compared with cloud observations. For locations of site, please refer to Figure 1. These NSB data were free from sunlight and moonlight and collected at mostly dry (rainless) nights. Data had be corrected for variations due to human sources.
- Cloud observations are taken by Boltwood Cloud Sensor II simultaneously as NSB measurements. The cloud sensor reports cloud amount by sensing effective IR sky temperature and comparing with the ambient ground level temperature. Cross-calibration between two cloud sensors were conducted.

A2) Cloud-NSB relations

The relations between the change in cloud amount on the change in NSB (cloud-NSB relations) were observed on selected 41 observational runs with over 320 hours of observations at each site. Figures 2 & 3 show typical runs, their cloud-NSB scatter plots and fittings.

Different relations on cloud-NSB were found. The values of fitted slope and the goodness of fit were diverse. While in general, there was a larger change in the urban sky brightness upon similar variation in the cloud amount (Figure 4), concrete correlation between the change in the cloud amount and the change in the night sky brightness were found more frequently in the urban area (Figure 5).
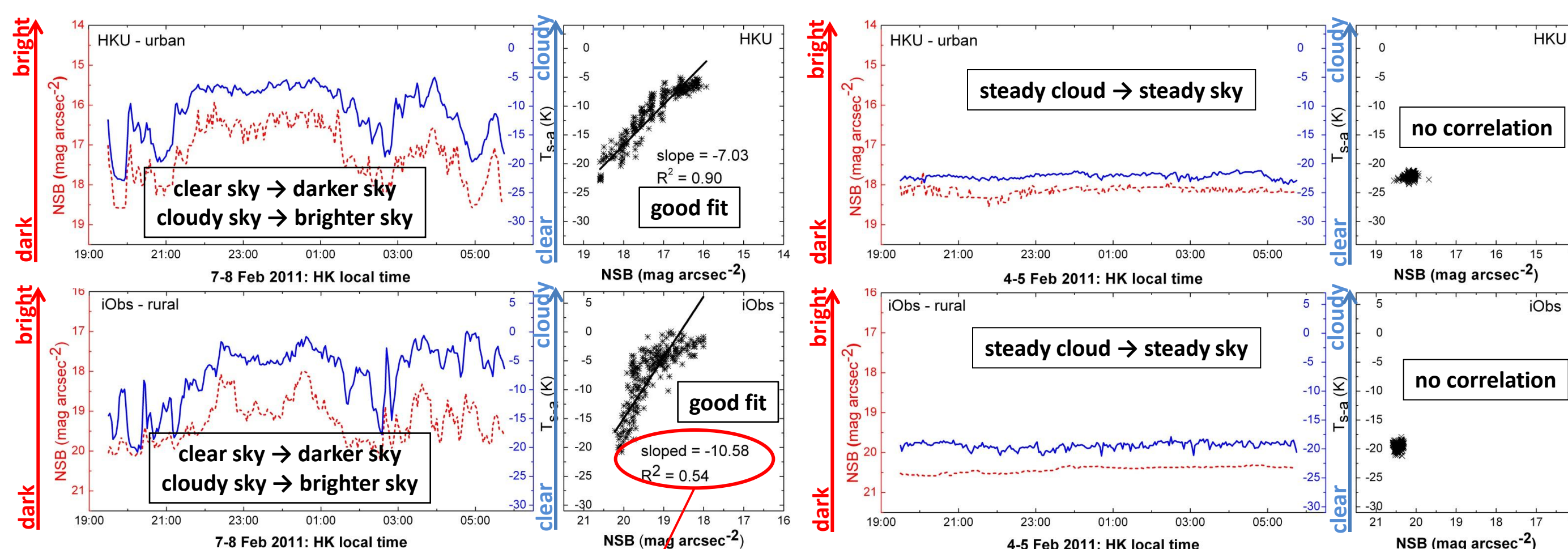

median slope:
-7.57 (urban)
-12.40 (rural)

slope = -7.03
R² = 0.90
good fit

clear sky → darker sky
cloudy sky → brighter sky

7-8 Feb 2011: HK local time

sloped = -10.58
R² = 0.54
good fit

clear sky → darker sky
cloudy sky → brighter sky

7-8 Feb 2011: HK local time

Figure 2:
Variations of NSB & cloud amount.

generally more negative slope & lower level of correlation in rural site

steady cloud → steady sky
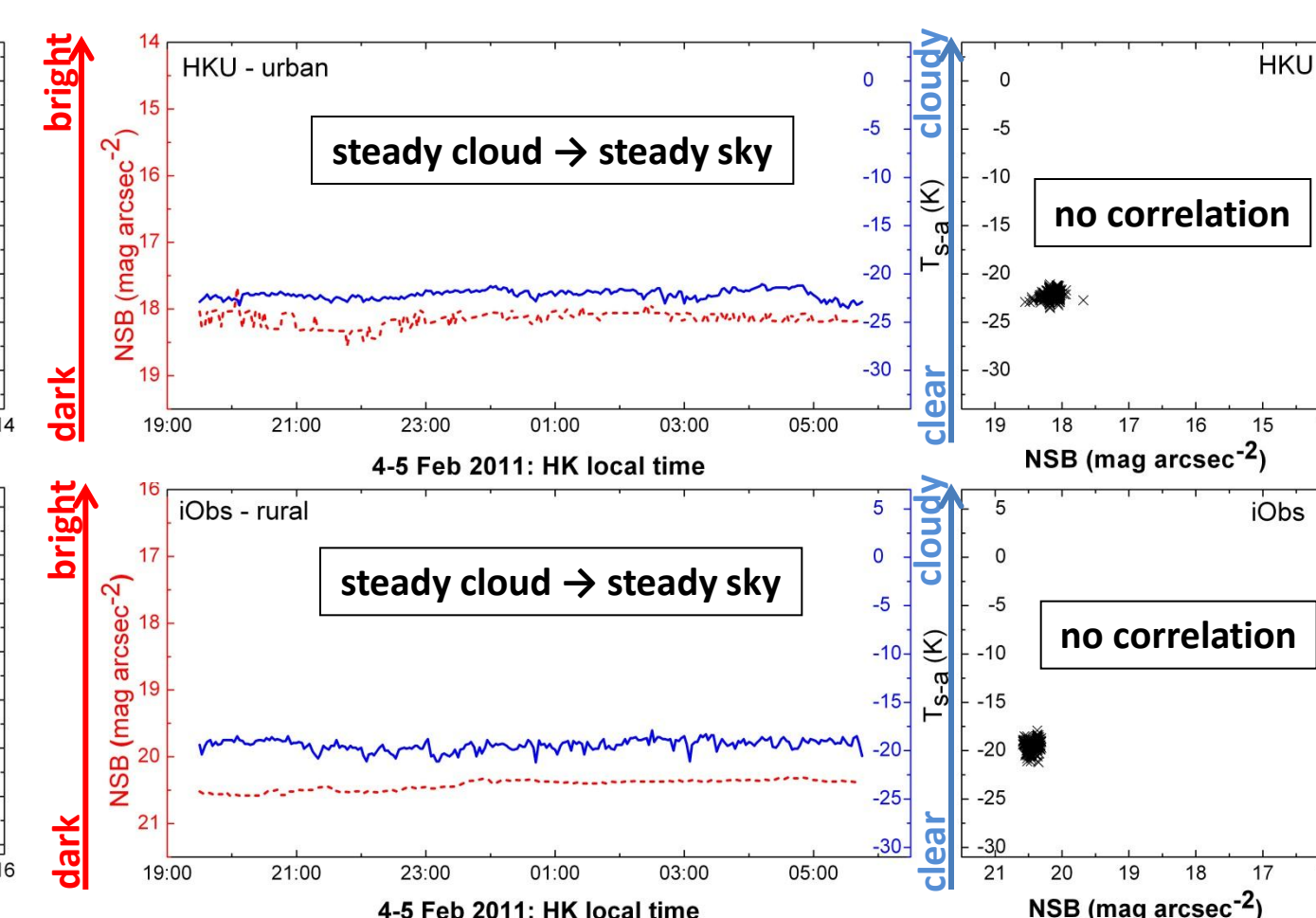no correlation

4-5 Feb 2011: HK local time

steady cloud → steady sky
no correlation

4-5 Feb 2011: HK local time

Figure 3:
Same as Figure 2 for another run.

less negative slopes in urban site → same change in cloud amount leads to more NSB change
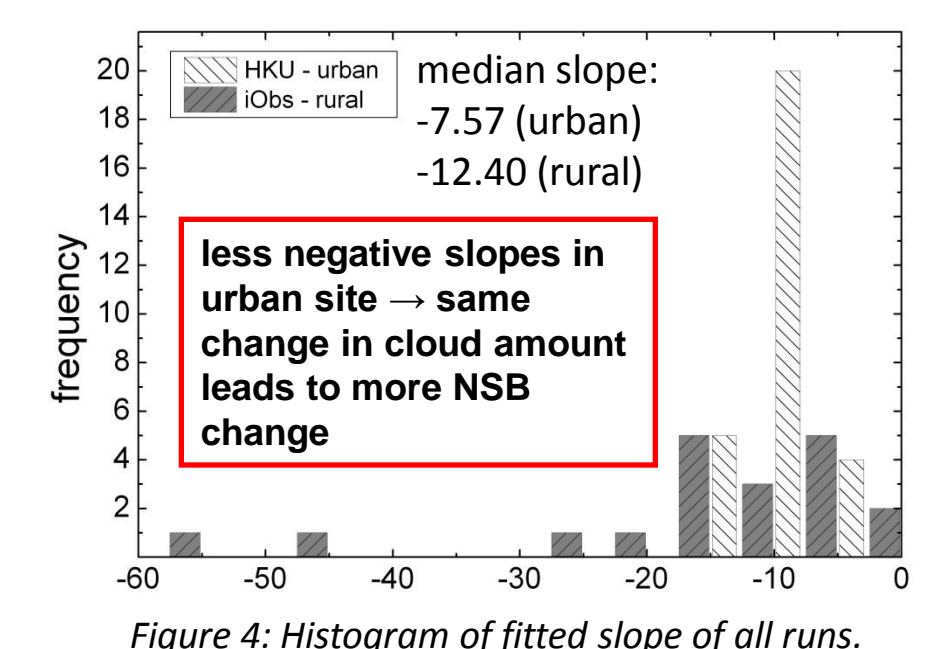
Figure 4: Histogram of fitted slope of all runs.

average R²:
0.84 (urban)
0.65 (rural)

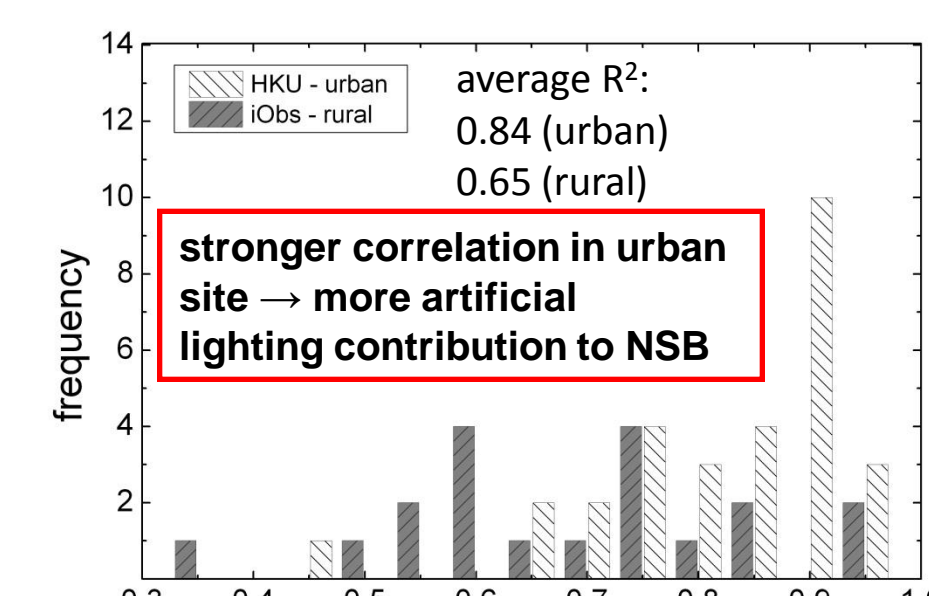stronger correlation in urban site → more artificial lighting contribution to NSB

Figure 5: same as Figure 4 for coefficient of determinant.

B) Effects of moonlight on the night sky brightness

B1) Data Collection

NSB data from iObs (rural) taken from 2 September 2010 to 30 June 2012 were compared with Moon properties. Those NSB data were free from sunlight, but contained all observations made under any other sky conditions. Other NSB observing details remained the same as described in Section A1.

B2) Model on prediction of moonlight

Krisciunas & Schaefer (1991, PASP, 103, 1033) modeled the effects of moonlight on V-band photometry observations by semi-empirical relations connecting direct and scattering (Rayleigh and Mie) moonlight and lunar properties. Please refer to their article for formulae.

Due to the ultra-wide angle of acceptance of SQM-LE sensor, we modified the model by considering the total amount of moonlight detected in the field-of-view of sensor. It can be achieved by performing integrations of B_{moon}, the moonlight contribution, and B_{dark}, dark-time sky background value (set as 20.4 mag arcsec^{-2} equivalent), along the zenith angle (phi) and azimuth (theta) directions, and weighted by the angular sensitivity of SQM-LE (the factor R):

$$I_{moon2SQM} = 2 \int_{\phi=0}^{\phi_{max}} \int_{\theta=0}^{\pi} R \cdot B_{moon} (\sin \phi) d\phi d\theta \qquad I_{dark2SQM} = 2 \int_{\phi=0}^{\phi_{max}} \int_{\theta=0}^{\pi} R \cdot B_{dark} (\sin \phi) d\phi d\theta$$

B3) Moon-NSB relations

The relations between the change in Moon properties on the change in NSB (moon-NSB relations) were investigated by plotting raw observations of NSB at iObs over a long period against Moon altitude and phase in Figure 6. It is found that bright (dark) skies were mostly observed when approaching full (new) Moon and/or Moon at high (low) altitude, it is clear that NSB were affected by moonlight.
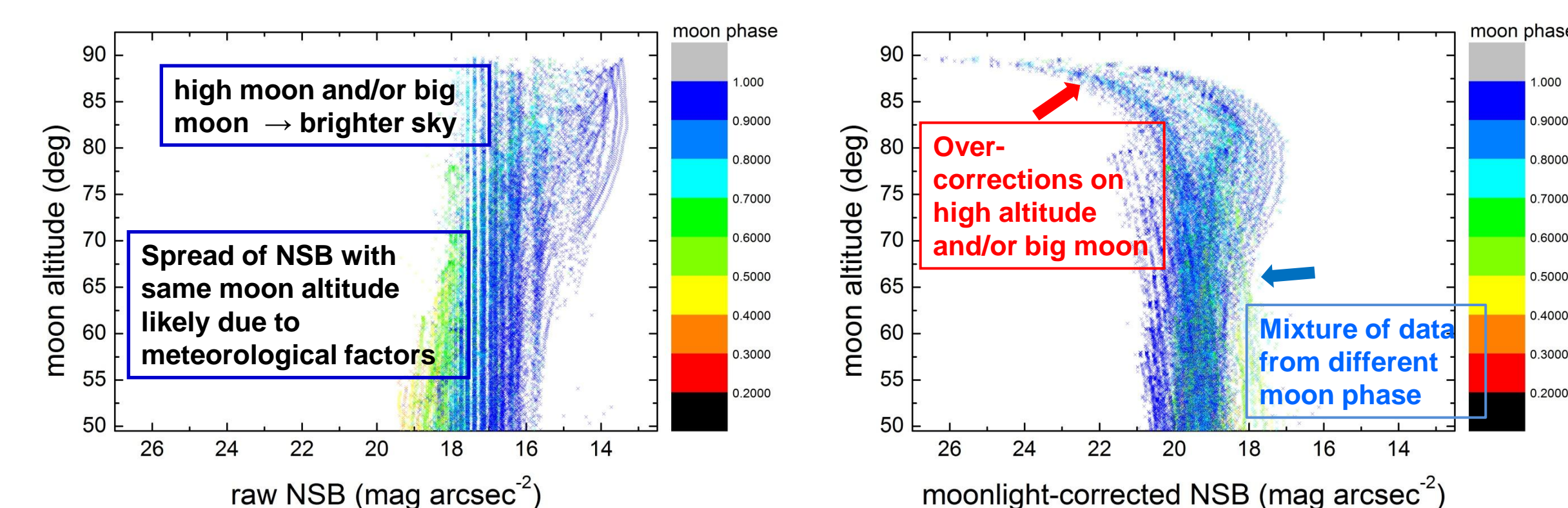

high moon and/or big moon → brighter sky

Spread of NSB with same moon altitude likely due to meteorological factors

Figure 6:
Plot of 30k raw observations of NSB at the rural site obtained from Sept 2010 to Jun.

Over-corrections on high altitude and/or big moon

Mixture of data from different moon phase

Figure 7:
Same as Figure 6 for results of moonlight correction.

mean NSB after moon correction at constant level

Figure 8 (left):
The means of NSB before and after moonlight-correction.

Moon correction reduced the spread of NSB
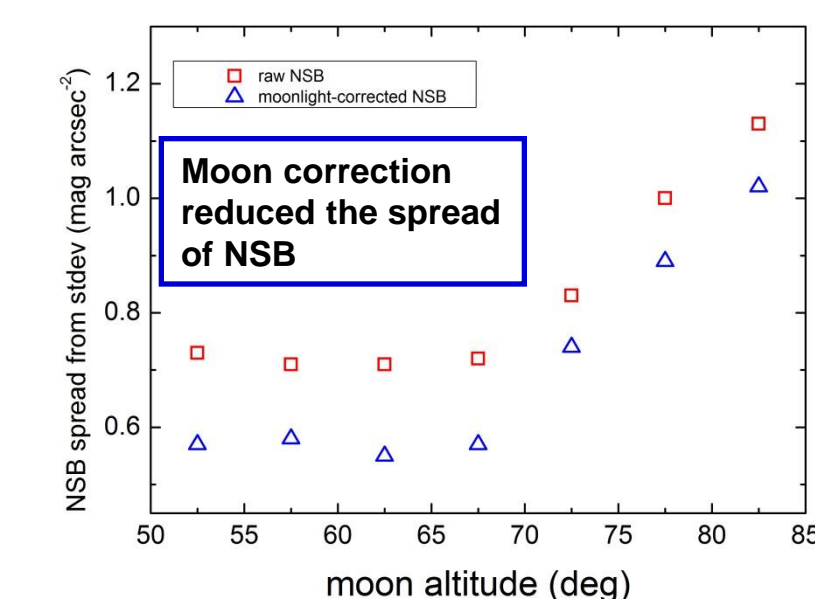
Figure 9 (left):
Same as Figure 8 for standard deviations which measured the spreads of NSB.

To test the above model prediction, we plotted the NSB after moonlight-correction in Figure 7. The goodness of the moonlight prediction model can be visualized by comparing Figures 6 & 7. It seems that the model over-estimated the moonlight effects for altitude greater than ~80 degrees, where the corrected NSB reached somewhere greater than 22 mag arcsec^{-2}. On the other hand, the model nicely corrected moonlight at low angles by observing the statistic on corrected NSB on Figure 8, which shows the means of moonlight-corrected NSB were reduced and looked similar. In addition, the spread of NSB, measured by standard deviation of data, were reduced by at least ~10% after moonlight-correction as seen from Figure 9.
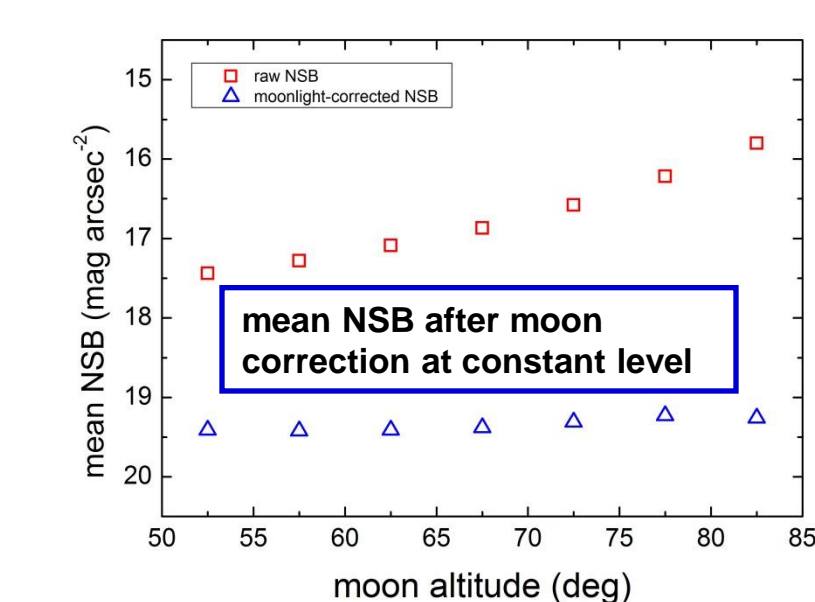
Conclusions

- Strong linear correlations over the change in IR cloud amount and the change in night sky brightness at urban and rural sites were generally observed, where the effect was more obvious in the heavy-light-polluted urban site.
- It is possible to remove the effect of moonlight from sky brightness observations from existing model, provided that the Moon is low and/or small in phase.
- Futures works: investigating effects of other factors on NSB, improving the moonlight model.