ESTIMATE OF THE NUMBER OF SATELLITE OVERPASSES SUFFICIENT FOR ACHIEVING SUCCESSFUL AREAL COVERAGE OF THE EARTH'S SURFACE OBSCURED BY CLOUDS DURING THE FIRST OVERPASS

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In this paper we present a technique and some results of statistical estimation of the number of satellite overpasses that provide 90% *probability of successful areal coverage of the Earth's surface given the cloud cover during the first overpass being* <3, 4–7, *and* 8–10.

Recently, satellite systems of optical sensing have become widely used to monitor global physical change of the environment and detect ground-based objects from space. High-orbiting lidars onboard MIR station and Shuttle spacecraft[1–4] are used for remote sensing of the underlying surface. However, their efficiency in both civil and military applications is substantially hindered by the cloud cover. This is obviously caused by the presence of cloudiness that can complicate or completely disable sensing of the underlying surface and detection of surface objects from space. As shown in Ref. 5, cloudiness may cover up to a half of the globe at any time.

In practice it is important to know the number of satellite overpasses across the region under study that provide a desired probability of successful areal coverage of the Earth's surface, obscured by continuous or broken cloudiness during the first overpass.

Here we describe an attempt to resolve this problem using a statistical approach. Let us first consider some methodological aspects of its possible implementation.

It is well-known that, when the surface conditions or the state of ground-based objects are estimated probabilistically from space with the account for screening by clouds, time statistics of the mean total cloudiness is used. In so doing, it is assumed that cloudiness is distributed uniformly over a 555×555 km^2 square within which it is determined, while no correlation is assumed to exist between the daily mean data. Indeed, under the assumption of uniformly distributed cloudiness, the probability P of the estimate of surface conditions in any small portion of the square is

$$P = 1 - N , \qquad (1)$$

where N is the square-mean cloud amount in fractions of unit.

Moreover, if the day-to-day cloud observations are assumed to be independent, then the probability of forecasting of the surface state from k daily satellite overpasses over a given region can be calculated from the formula

$$P = 1 - \prod_{i=1}^{k} N_i , \qquad (2)$$

where N_i is the average amount of total cloudiness over the ith day. In formula (2), the operator Π designates a product.

From formula (2), the probability P can be calculated for each particular case. The statistical structure of time variability of the mean amount of total cloudiness can be deduced by averaging data calculated by formula (2) over the entire initial sample.

Algebraically, this averaging is expressed by formula which is used to calculate the probability P of the forecast of the state of the Earth's surface during k satellite overpasses during a day. This formula has the form

$$P = 1 - \frac{1}{n} \sum_{j=1}^{n} \prod_{i=1}^{k} N_i . \qquad (3)$$

Here k is the number of satellite overpasses a day over the square, and n is the number of intervals with k daily values of the mean total cloud amount.

When applying formula (3) to archived data, one may, with any aniticipation, to precalculate the probability P of successful areal coverage of Earth's surface from different numbers of satellite overpasses over the region studied. This is very valuable in operational planning of satellite studies, but sometimes impractical due to the necessity of using many tables. However, in practice, it is not the probability of the events at a fixed number of satellite overpasses, but rather the number k of overpasses ensuring successful areal coverage of the Earth's surface with a preset (e.g., 90%) probability are used, as it is normally adopted in engineering calculations, is frequently used in practice.

In this paper, we follow this latter approach. From the available data set, we evaluated the number of

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satellite overpasses required to ensure prescribed probability ($P > 90\%$) of successful coverage of the Earth's surface, given 3; 4–7; and 8–10 initial cloud amount (i.e., during the first satellite overpass). Now let us briefly discuss the results of such probabilistic estimation.

We used an array of satellite data on the diurnal mean amount of cloudiness over the Northern hemisphere acquired from 1971 to 1980 and averaged over separate 555 km by 555 km squares centered at the nods of geographical grid with 10° longitude by 5° latitude cells.

The number of satellite overpasses sufficient for a successful coverage of the Earth's surface with the probability $P = 90\%$ was estimated for separate physical and geographical regions of the Northern hemisphere.

Tables I and II give examples of such an estimation for two different regions, namely the region I (30–60°N, 30°W–20°E) characterized as an oceanic region and encompassing most of the northern Atlantic; and region II (30–60°N, 80–130°E) characterized as a continental region and encompassing most of the Asian continent.

From Tables I and II, it is obvious that there exists a strong dependence of the required number of satellite overpasses on the total cloud amount during the first overpass over a given location.

TABLE I. Number of daily satellite overpasses over region I which provides successful areal coverage of the Earth's surface with probability $P \geq 90\%$ for different total cloud amounts during first overpass.

λ, deg.	Cloud amount during first satellite overpass																	
	≤ 3						4–7						8–10					
φ, deg.	−30	−20	−10	0	10	20	−30	−20	−10	0	10	20	−30	−20	−10	0	10	20
January																		
60	4	4	2	2	2	2	8	9	9	9	6	5	11	11	11	10	7	7
55	3	4	2	3	3	2	8	8	8	7	7	6	11	11	10	9	9	8
50	2	3	3	2	2	2	8	7	7	7	6	6	11	11	9	9	8	8
45	2	3	2	2	2	2	7	7	6	5	5	5	10	10	8	7	7	7
40	2	2	2	2	2	2	7	7	5	4	4	5	9	8	7	6	6	7
35	3	2	2	2	2	2	7	6	4	3	4	4	8	8	5	5	5	5
30	2	2	2	2	2	2	6	5	3	3	3	3	7	6	4	3	3	4
April																		
60	3	2	2	2	2	2	7	8	7	6	5	5	9	11	11	8	7	6
55	2	2	2	2	2	2	9	8	7	6	5	6	11	11	10	8	7	7
50	2	2	2	2	2	2	8	8	6	6	6	6	11	11	7	7	8	8
45	2	2	2	2	2	2	8	7	6	5	5	6	11	10	7	6	7	7
40	2	2	2	2	2	2	8	5	4	4	4	4	11	9	7	5	5	5
35	2	2	2	2	2	2	6	5	4	3	3	3	9	7	5	4	4	4
30	2	2	2	2	2	2	5	5	3	3	3	3	8	6	4	4	3	3
July																		
60	2	2	2	2	2	2	6	8	7	7	5	5	8	9	9	9	8	8
55	2	2	2	2	2	2	8	8	7	6	5	5	9	9	9	9	8	7
50	2	2	2	2	2	2	8	8	6	5	5	5	9	9	8	8	8	7
45	2	2	2	2	2	2	6	6	5	4	3	4	8	8	6	6	4	5
40	2	2	2	2	2	2	5	5	3	3	2	3	8	8	5	5	3	4
35	2	2	2	2	2	2	5	5	3	3	2	2	7	7		3	2	3
30	2	2	2	2	2	2	5	4	3	2	2	2	7	6	4	3	2	2
October																		
60	2	2	2	2	2	2	8	8	7	6	5	5	9	12	10	8	7	7
55	2	2	2	2	2	2	8	8	7	6	5	5	10	12	10	8	7	7
50	2	2	2	2	2	2	8	8	7	6	5	5	11	10	9	7	7	7
45	2	2	2	2	2	2	7	6	6	4	4	4	9	9	7	6	6	5
40	2	2	2	2	2	2	6	5	4	4	4	4	7	7	6	5	5	5
35	2	2	2	2	2	2	5	5	4	3	3	3	7	6	4	4	3	4
30	2	2	2	2	2	2	4	4	3	3	3	3	6	5	4	4	3	3

Note: negative sign convention is for the west latitudes.

TABLE II. Number of daily satellite overpasses over region II which provides successful areal coverage of the Earth's surface with probability $P \geq 90\%$ for different total cloud amounts during first overpass.

λ, deg.	Cloud amount during first satellite overpass																	
	≤ 3						4–7						8–10					
φ, deg.	80	90	100	110	120	130	80	90	100	110	120	130	80	90	100	110	120	130
January																		
60	4	4	2	2	2	2	4	4	4	4	4	4	6	6	6	6	5	4
55	3	4	2	3	3	2	4	4	4	4	4	4	6	6	4	5	4	3
50	2	3	3	2	2	2	4	4	4	4	4	4	6	5	5	4	4	4
45	2	3	2	2	2	2	4	4	4	4	4	3	6	6	3	4	5	3
40	2	2	2	2	2	2	3	3	3	3	3	3	4	4	3	4	4	4
35	3	2	2	2	2	2	4	3	3	3	3	5	5	5	5	6	5	4
30	2	2	2	2	2	2	3	3	3	3	4	5	4	4	5	7	5	7
April																		
60	3	2	2	2	2	2	5	5	5	5	6	6	6	7	7	7	7	7
55	2	2	2	2	2	2	4	5	5	5	5	6	5	6	6	7	7	7
50	2	2	2	2	2	2	4	5	5	5	4	6	6	6	6	6	6	7
45	2	2	2	2	2	2	4	4	4	4	4	4	7	5	5	5	5	6
40	2	2	2	2	2	2	4	3	4	4	4	4	5	4	5	5	4	5
35	2	2	2	2	2	2	4	5	5	4	4	4	6	7	6	6	4	5
30	2	2	2	2	2	2	3	5	3	5	5	3	5	6	7	6	6	6
July																		
60	2	2	2	2	2	2	5	5	6	7	7	7	6	7	8	8	8	8
55	2	2	2	2	2	2	5	5	5	7	7	7	6	6	7	8	8	8
50	2	2	2	2	2	2	4	5	6	5	5	7	5	6	7	7	7	7
45	2	2	2	2	2	2	4	4	5	5	5	5	5	6	6	6	6	7
40	2	2	2	2	2	2	4	4	4	5	4	6	5	4	4	6	6	5
35	2	2	2	2	2	2	4	4	5	5	4	6	5	5	6	5	5	6
30	2	2	2	2	2	2	4	5	6	5	4	7	4	7	7	6	7	7
October																		
60	2	2	2	2	2	2	5	5	5	4	4	4	8	8	7	5	5	5
55	2	2	2	2	2	2	5	5	4	4	4	4	7	8	6	5	5	5
50	2	2	2	2	2	2	4	5	4	4	4	4	5	6	6	5	5	5
45	2	2	2	2	2	2	4	3	3	3	3	4	5	4	4	5	5	5
40	2	2	2	2	2	2	3	4	4	4	4	4	4	3	4	4	4	4
35	2	2	2	2	2	2	3	4	4	4	4	4	4	4	6	6	5	5
30	2	2	2	2	2	2	3	3	4	4	4	4	3	5	5	6	3	6

For instance, the number of satellite overpasses required is the least (on the order of 2) when the initial cloud amount is <3. It is almost independent of the location and time of a year. The exception is the north-west of the region I during January, when this number is 3 or 4 overpasses. At the same time, the required number of overpasses is large when cloud amount is considerable (8–10 cloud cover), with the maximum value 10 to 12 for region I in January, April, and October.

It is also worth noting that when cloud amount is moderate (4–7) and considerable (8–10), the number of satellite overpasses varies differently for regions I and II. For example, while the number of overpasses giving successful coverage increases from 2–4 to 7–9 for 4–7 initial cloud cover and from 2–4 to 9–12 for 8–10 initial cloud cover when moving from south-east to the north-west of the region I (ocean), this is not the case with the continental region II. Moreover, successful coverage of the territory of this region is achievable with fewer satellite overpasses (mainly 3–5 for the initial cloud amount of 4–7 and 5–7 for 8 to 10 cloud amount).

Thus, during the operation of observing system, when meteorological information on cloud conditions is constantly received, the number of satellite overpasses required to provide for a preset probability of surface coverage can be successfully corrected based upon the results of cloud observations during the first overpass. In addition, the results obtained show that, in the cases of moderate to a heavy cloud cover, the considered northern Atlantic region will require much fewer satellite overpasses then the Asian continental one in order to be successfully viewed. This finding should be taken into account when satellite studies, including those by means of high-orbiting lidars, are planned.

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