ON THE USE OF RAPID SCANS

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ABSTRACT

Previous work on rapid scan images from geostationary satellites is summarised first. Then results from rapid scans with Meteosat-6 over the tropical region and the alpine area are reported. Wind fields from cloud and water vapour tracking in the water vapour channel (WV: 5.7 – 7.1 µm) with short interval scans are compared with the nominal 30-minute scans and generally more consistent wind fields are obtained with rapid scans. It is also shown that the upper level divergence of large scale tropical systems can be directly inferred from the wind field and that rapid scans provide higher divergence values. Finally perspectives for rapid scans from Meteosat Second Generation (MSG) are discussed.

1. Introduction

Previous work on rapid scan images from geostationary satellites has been mainly performed with GOES and GMS data. Recently rapid scans have been conducted with Meteosat-6 in support of the Mesoscale Alpine Program (MAP); preliminary results from this campaign and from test scans over the tropical belt are reported in this paper. A perspective in mind is to consider the use of the new generation of European geostationary satellites (MSG: Meteosat Second Generation) for taking images at intervals shorter than the routine scan interval of 15 minutes for the full disk. Currently image intervals of 30 minutes for full disk are considered as baseline and any shorter scan interval of the same area is considered as rapid scan. With the advent of MSG this definition becomes obsolete since 15 minute scans for the full disk become the standard. However previous work has shown that even shorter intervals are needed to properly observe convective events and short-lived clouds as tracers for the derivation of winds. Therefore this paper also discusses the use of MSG to support research on rapid scan applications in nowcasting and NWP; both may benefit from improved and more numerous atmospheric motion vectors and from a better understanding and parameterisation of deep convection.

2. Experience with Rapid Scans

Work on rapid scans from geostationary satellites has been mainly conducted by researchers in the US and by the Japan Meteorological Agency (JMA). Europe did perform rapid scans with Meteosat-1 in support of ALPEX (Alpine Experiment) in 1979, however it seems that the value of those efforts was never realised.

Hamada (1983) was among the first to suggest intervals of 15 minutes to better cope with the short lifetime and rapid deformation of cloud targets. Shenk (1991) substantiated this suggestion and provided a graphical presentation of the percent of useful tracers as a function of time interval between GOES (VAS) images. He argued that the optimum time interval for the tracking of cumulus type clouds over land is between 10 minutes and less than one minute, whereas displacement of high level cirrus clouds is fairly well depicted by the standard imaging interval of 30 minutes.

Other studies corroborate the suggestions by Shenk (1991). Uchida et al. (1991) studied low-level cloud motion winds around typhoons. They obtained winds of higher spatial density and closer to the typhoon centre when using 7.5 and 15 minutes as imaging intervals as opposed to 30-minute intervals. The 15-minute interval provides winds outside the 400 km radius from the typhoon centre whereas for the 30-minute interval the distance is 500 – 600 km. With 7.5-minute interval winds can be derived to a 200 km radius. The increase of low-level wind speed with proximity to the typhoon centre is also well depicted and increase from about 25 – 30 kts at 800 km distance to 55 kts at 200 km distance from the centre. It is important to mention that the Japan Meteorological Agency (JMA) makes a special effort to operationally derive low-level winds in the vicinity of typhoons (e.g. Takata, 1993). The cloud motion winds are used in the numerical analysis over the typhoon area and for the prediction of gale-force area winds by the forecasting division of JMA. In this context it interesting to note that the 3rd International Winds Workshop (Schmetz et al., 1997) recommended that imaging in research mode should be considered for quasi-operational application. The JMA practice to use 15-minute imagery to derive winds near typhoons was mentioned as a good example how research modes could soon become operational practice.

Work in the US on rapid scans started already in the 19-seventies. Rodgers et al. (1979) showed that high spatial resolution and short imaging intervals increase the number of low-level winds around a hurricane. The hypothesis of the work of Rodgers et al. (1979) was that low-level clouds around tropical storms are too short-lived to be tracked with standard 30- (or 15-) minute scan intervals. They derived cloud-tracked wind fields at high (200 hPa) and low altitudes (900 hPa) from rapid scans with SMS 2 at 7.5-minute intervals and with GOES-1 at 3 minute intervals, respectively, around tropical cyclones. The visible channel was used with spatial resolutions of 1, 2, 4 and 8 km. Those wind fields were compared with wind fields from 15- and 30-minute intervals: The result was that 10 (5) times as many clouds could be tracked with the rapid scans in comparison to the 30 (15) minute interval scans. They also demonstrated that the high temporal resolution necessitates a higher spatial resolution in order to get optimum results. A 2 km resolution was found adequate for low-level clouds over water. Generally, rapid scan full-resolution infrared and visible images minimised the ‘incorrect winds’ from tracking cloud elements which propagate by growing on one side and dissipating on the other side. Notable is also that the wind fields of Rodgers et al. (1979) had been validated with near simultaneous aircraft measurements. A similar study by Johnson and Suchman (1980) deriving winds from SMS in 1978 with 30, 15, 6 and 3 minute intervals concludes that nearly 10 times as many low-level cloud are extracted from 3 minute scans as compared to the 30 minute scans in cases of short lived clouds. They recommend scan interval of 6 – 10 minutes for the tracking of low-level clouds.

Purdom (1996) has also shown that very accurate mesoscale cloud track winds can be determined from rapid scans. Primarily he points out the much better target identification. A very interesting aspect is the use of a ‘cloud or storm relative animation’ which helps to identify secondary circulations around cloud systems. One minute or 30 second interval imagery provides the possibility to follow clouds even in complex weather situations.

Recently Velden et al. (2000) studied the optimal time lapse between images for different spectral channels on GOES- 10 for the derivation of winds. Generally speaking the number of winds, and quality too, increases with decreasing time intervals and increasing resolution; they found:

i) The optimum time interval for VIS images with 1 km resolution is 5 minutes
ii) For IR window images with 4 km resolution it is 10 minutes
iii) For water vapour images with 8 km resolution it is 30 minutes.

3. Rapid Scans with Meteosat-6

In preparation for and during the Mesoscale Alpine Programme (MAP, Levizzani et al. 1999) several rapid scans have been taken with Meteosat-6. Here we report on two cases of rapid scan images from the water vapour channel (WV: 5.7 – 7.1 µm) consisting each of three images: i) a rapid scan of the tropical belt from about 6.7° S to 9.5° N with 7.5-minute intervals and ii) a rapid scan over the Alpine region from about 40.6° N to 53.5° N with 5-minute intervals. In both cases the rapid scan wind fields are compared with wind fields from standard intervals of 30 minutes. Vectors from clouds and water vapour moisture displacements were derived using the Meteosat Second Generation (MSG) prototype algorithm described in more detail by Holmlund (2000). The vectors were derived with an extraction grid of 16x16 pixels, a 24x24 pixel template and a search-area of 72x72 pixels using a standard cross-correlation technique. Overlap was confined to a maximum of 30% of the template area in order to avoid tracking of the same feature. The wind fields were quality controlled following Holmlund (1998) and vectors with are quality indicator (QI) higher than 0.2 were retained.

An attempt was also made to derive wind divergence from the vector fields. Earlier work (e.g. Schmetz et al., 1995) has shown that it is difficult to infer divergence fields directly from the wind vectors since the differentiation amplified the noisy character of the wind field. Therefore a QI-weighted Barnes filter was run over the wind vectors before computing the divergence with finite differences over areas of 3x3 grid-points as described in Holmlund (2000). The idea behind the derivation of divergence fields is to test whether this quantity can be derived in a sensible manner from rapid scans. If yes, the wind data could be used in the data assimilation of a numerical model in order to create upper level divergence fields and hence initiate model convection in the correct geographical location.

3.1 Tropical Rapid Scan

Figure 1 a and 1 b show the wind fields derived for the tropical Africa from three images with 7.5-minute intervals and 30-minute intervals, respectively. While both images indicate that the outflow of this large convective system of several hundred kilometres diameter can be derived with both scan intervals, it is clearly discerned that the rapid scan provides a more consistent wind field. The divergence derived from the rapid scan winds filtered with the Barnes scheme is shown in Figure 1c:

$$\nabla \cdot \vec{n} = -\frac{\partial w}{\partial p} \tag{1}$$

values of more 8. 10 $^{-5}$ m^{-1} are $\nabla \cdot \vec{n}$ observed. Using the relationship between horizontal wind divergence and the change of the vertical velocity ω with height pressure *p* we can estimate the mean vertical velocity in this tropical convective system from:

$$w(p) = w(p') - \int_{p'}^{p} \nabla \cdot \vec{n} \, dp \tag{2}$$

With the satellite derived divergence of: $\nabla \cdot \vec{n} = 8 \cdot 10^{-5} s^{-1}$

and the assumed boundary condition $w(p' = 100\,hPa) = 0$

we obtain a vertical velocity of about 0.5 m/s at 300 hPa, which is quite a realistic value for a tropical convective system. Divergence fields have also been derived from the nominal 30-minute scans (results not shown). While the geographical pattern looks very similar to Figure 1c, the maximum value is smaller by about 15%.

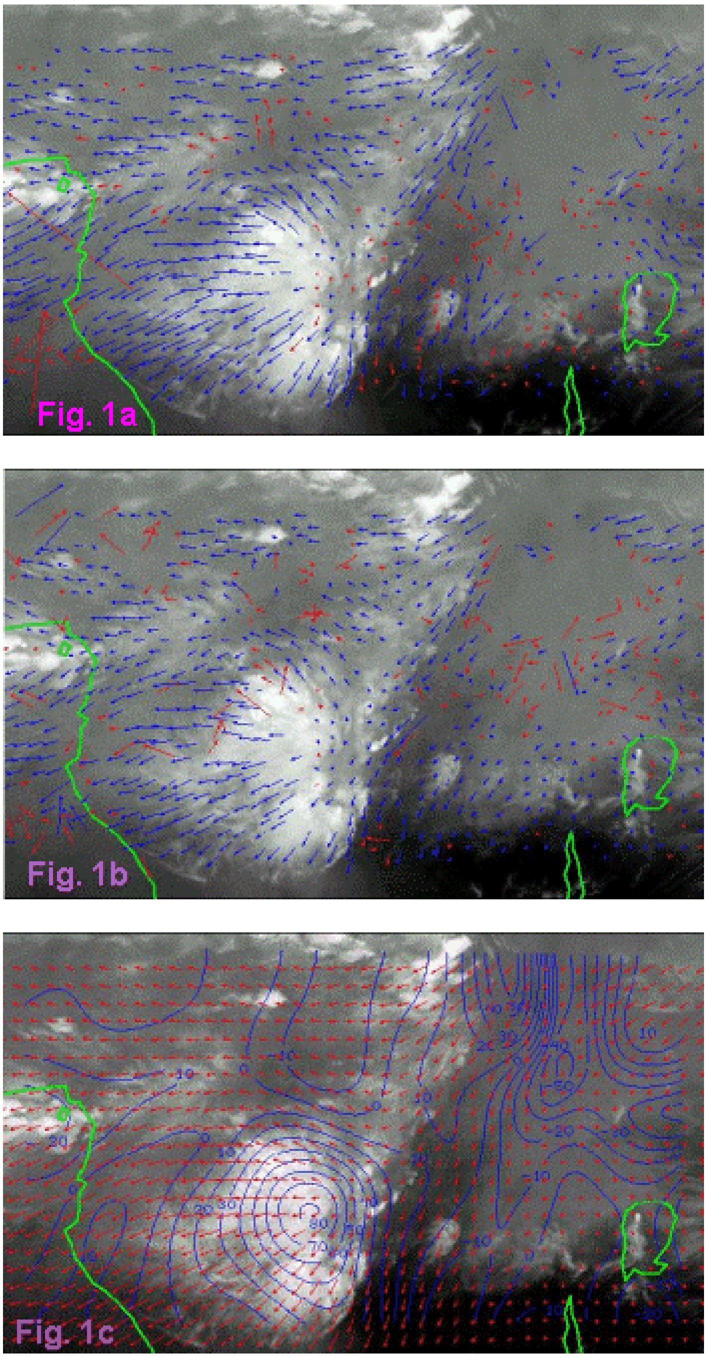


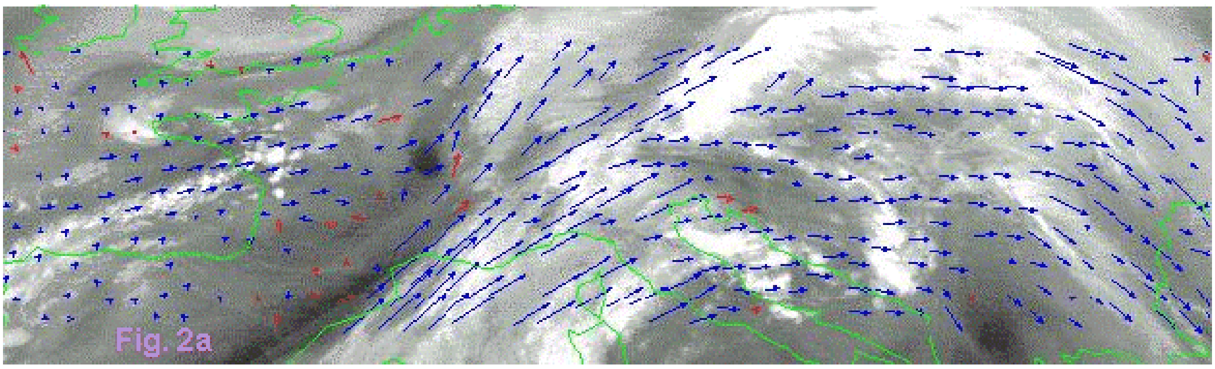
Figure 1. Wind fields derived from a triplet of WV images over tropical Africa (about 6.7° S to 9.5° N and 6.6° E to 36.1° E) from rapid scans with 7.5 minute intervals (Figure 1a) and nominal 30 minute scans (Figure 1b). Figure 1c shows the divergence field derived from Figure 1a; units are 10^{-6} s^{-1}, the maximum divergence value is higher than 8. 10^{-5} s^{-1}.

The success of the derivation of wind divergence from the wind vectors suggests that these data are useful indeed to trigger convection in the right geographical location in numerical weather prediction models. This would be clearly beneficial to the forecast models since they have deficiencies in predicting tropical deep convective systems correctly. However currently the potential benefit may be difficult to materialise because data assimilation systems do not handle the high density wind fields shown in Figures 1a and 1b. Instead they perform data thinning which may delete the information on the divergent flow.

We should also note that we tried to derive the divergence from the change of high level cloud cover *A* with time *t*:

$$\frac{1}{A}\frac{dA}{dt} = \nabla_h \cdot \bar{v} \qquad (3)$$

Unfortunately the tests did not succeed but provided unrealistic results presumably due to the high sensitivity to measurements of the cloud cover *A*. Further work with a finely tuned cloud classification scheme my lead to a better result. However it appears that the derivation of the divergence from the wind field is preferable anyway since it provides a continuous divergence field and not just a mean value for the whole convective system.



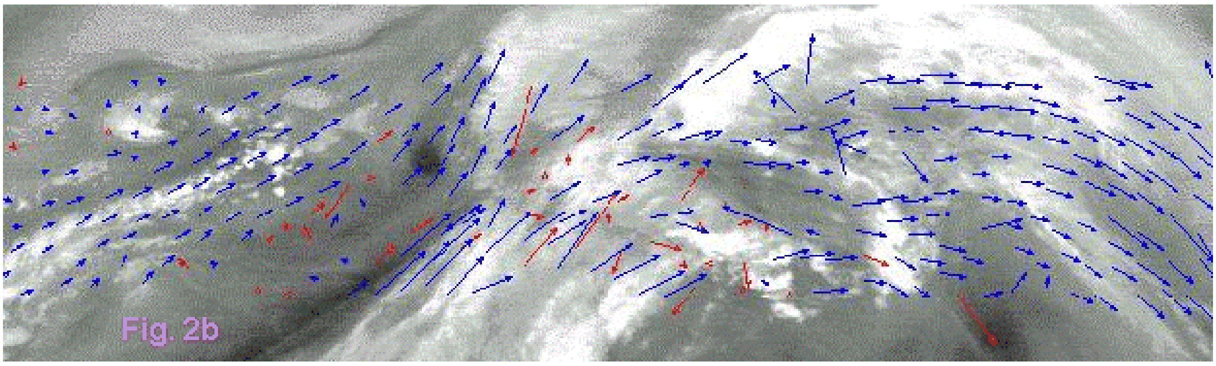


Figure 2. Wind fields derived from a triplet of WV images with rapid scans of 5 minute intervals (Figure 2a) and the nominal 30 minute scan (Figure 2b), respectively. The area covers the Alps and stretches from about 40.6° N to 53.5° N and 11.1° W to 28.5° E.

3.2 Rapid Scan for the Alpine Region

Figure 2 shows the comparison of wind fields derived from rapid scans with 5-minute intervals and 30-minute intervals, respectively. Clearly the tracking based on rapid scans (2a) provides a much better depiction of the flow. However, as the image contains cloudy and clear sky features in close proximity, which are all tracked, the flow does not correspond to one well defined altitude level. This makes the derivation of divergence fields rather difficult, which is in contrast to the tropical convective system in Figure 1 where mainly cirrus outflow has been tracked.

4. MSG Capabilities

The Meteosat Second Generation (MSG) satellite will provide 15-minute full disk imagery during nominal operations, i.e. the temporal image resolution is twice as good as for the present Meteosat satellite series. Even shorter scan periods than the nominal 15-minute repeat cycle are possible by shortening the repeat cycle of image taking. A repeat cycle consists of a full cycle of image acquisition by the instrument, starting with the forward scan, followed by the repositioning of the scanning mirror and by the standby period where no scanning mirror motion takes place.

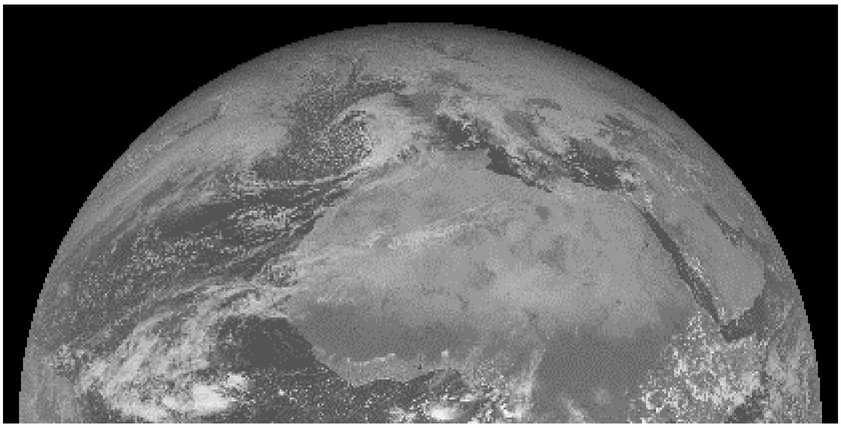


Figure 3a. Northern Hemisphere: 7’30’’ scan, i.e. 2 limited scans per 15 minutes, 1856 lines are scanned for 11 channels of MSG and 5568 lines for the HRVIS channel, which however has only half the E-W extension of the other channels.

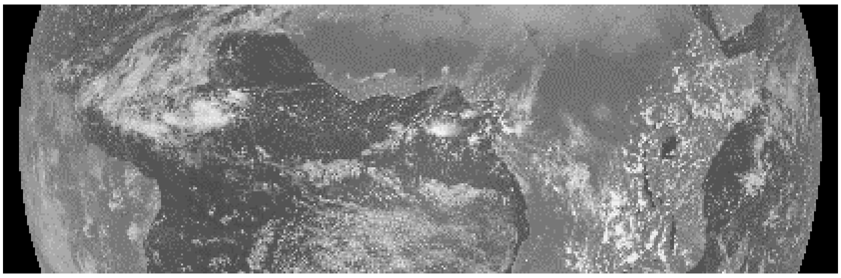


Figure 3b. Scan of tropical belt for a period of 5’, i.e. 3 limited scans per 15 minutes.

Figure 3c. Scan of the tropical belt for a period of 3’45’, i.e. 4 limited scans per 15 minutes.

For the MSG SEVIRI instrument the level 1.0 full disc images comprise 3834 by 3834 pixels for all channels except for the high-resolution visible channel, which comprises 5751 by 11235 pixels. The full disc is created within 12 minutes of forward scanning followed by a retrace and adjustment period of 3 minutes. For a limited scan a start and end line within the full disc view can be selected for the forward scan. It should be noted that a limited scan always covers the full width of a nominally scanned image line, i.e. the coverage is only limited in North-South direction. Figure 3 shows three examples of area coverage that can be obtained from MSG with different rapid scan intervals.

4.1 Science Issues to be Addressed with Rapid Scans

Geostationary satellites offer the unique possibility to observe atmospheric phenomena at time intervals that are compatible with their life cycle. As explicitly mentioned in the MSG Programme Proposal a ‘typical example for nowcasting is severe weather which has small features that undergo rapid development. This requires high spatial as well as high temporal resolution and rapid delivery of the data'. It is known that the rapid development of severe weather would require images taken at intervals of a few minutes in order to visualise the rapid changes in a comprehensible manner; generally speaking 15 minute or 30 minute intervals are not always sufficient.

In addition to the demonstrated utility of rapid scans for the derivation of winds (e.g. Velden et al., 2000), MSG could also provide data to address fundamental questions with regard to cloud development and convection or, generally speaking, the fast component of the hydrological cycle. Relevant questions are:

- It has been demonstrated that advanced cloud parameters (optical depth, cloud phase and effective particle size) can be inferred from MSG. This is very important for studies on cloud top structure that might help solving fundamental open questions (e.g. thermal structure, ice crystal injections above the storm, rotational features, waves). Will rapid scan be relevant for the study of very rapid phenomena at the cloud top?
- If the answer to the above question is yes, the question arises whether multispectral images, taken in rapid scan mode, will be relevant to operational nowcasting?
- Is the observation of rapid cloud development a good complement to observations of instability and what is the relative merit of both observations in nowcasting? Here the underlying thought is that forecasters may wish to see frequent updates of images over areas of rapid cloud development. This could complement a clear-sky instability product. Cloud development may also be a useful quantity for use in future short-range numerical forecast models.
- MSG has the potential to monitor tropical convection with rapid scans (e.g. with 7.5-minute intervals). Therefore it could be worth while to consider regular rapid scans (at least during certain periods) to conduct novel studies on tropical deep convection? Such image data and derived products could reveal important aspects of deep convection, e.g. one could observe the transition of water to ice, the outflow from convective systems and the corresponding water vapour transport. The data set could also serve as a stringent test of convective parameterisations in large scale models.
- Since rapid scans can provide better wind fields it may be useful to perform rapid scans operationally during certain times. For instance rapid scans during the Hurricane season over the tropical Atlantic could help the analysis of the early development of tropical easterly wave disturbances in numerical forecasting systems (Reed et al., 1986).

5. Conclusion

The utility rapid scans from geostationary satellites for the derivation of winds and for nowcasting application has been demonstrated by various researchers, mainly in the US and in Japan (see section 2). Europe has made little effort to utilise the potential of rapid scans until the most recent use of Meteosat-6 to support MAP in 1999 (Levizzani et al., 1998). This may be understood by the particular weather prevailing in Europe that often does not call for short interval observation of rapidly changing convective systems. However, it appears that the advantage of rapid scans for the derivation winds from short-lived clouds would already justify the scheduling of rapid scans (e.g. Velden et al., 2000).
With the advent of MSG multispectral images of rapidly developing convective systems might cast new light on our understanding of this part of the hydrological cycle. Specific questions are spelled out in section 4.1.

The paper has also shown that wind fields derived from rapid scans over the tropical belt and over the alpine region provide better and spatially more consistent wind fields, thus confirming results of earlier work. A novel result is the direct derivation of divergence fields of large scale tropical systems from the tracked wind field. Realistic divergence features with maxima above 8.10^{-5} s^{-1} have been obtained, whereby the rapid scan results provide 15 % higher divergence values than the nominal rapid scan intervals of 30 minutes. It is argued that the use of such high density winds (without data thinning) in numerical data assimilation systems for NWP would help the analysis and forecasting of large scale convective cloud systems.

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