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STUDY ON ANALYSES OF VOLCANIC ERUPTIONS BASED ON ERUPTION CLOUD IMAGE DATA OBTAINED BY THE GEOSTATIONARY METEOROLOGICAL SATELLITE (GMS)

BY

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静止気象衛星「ひまわり」画像の噴火噴煙データにもとづく噴火活動の解析に関する研究

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序

当研究部では，経常研究「人工衛星による映像の火山観測への利用に関する研究」（昭和55～57年度），及び「衛星画像による火山活動検出に関する研究」（昭和58～60年度）の一環として爆発的火山噴火で発生する噴煙を人工衛星，特に静止気象衛星「ひまわり」の画像で検出し，噴火活動の推移の観測，噴火規模の推測を行うための基礎的研究を実施してきた。この報告はこれまで気象研究所研究報告，火山などに発表した論文（澤田，1983ａ，ｂ，1985）にデータを追加し，「ひまわり」の画像で検出された噴火噴煙に関する研究資料としてとりまとめたものである。

火山噴火は急速な物質放出を伴う自然現象であるが，立地条件によってはかなり大きな噴火ですらその発生検出が不確定となる場合がある。また，上昇した噴煙は広域に拡散して地上へ降下噴出物をもたらし，あるいは航空機の飛行に重大な障害を与えることがある。このような広域の火山観測，火山防災の観点に立つ場合，地上での諸観測と合わせ人工衛星画像による噴煙の検出，観測が有効な手段となる可能性がある。

「ひまわり」のセンサ及びその画像の地上分解能は小規模な噴煙を検出することが著しく困難であるが，画像取得時間間隔が他の軌道衛星と比べ短いという長所のゆえに短時間で変形，消散しやすい噴煙の検出に有効である。また，これまでの研究により比較的大きな噴火による噴煙についてはかなり良好に検出できることがわかってきた。噴火活動の減衰，噴煙の到達高度，熱放出率にもとづく噴火規模についてもそれぞれ推測あるいは判断ができる目途が得られた。

ただし，広域の火山活動のモニタ，火山防災の軽減に利用する上では噴煙の判別，データ処理システムなど解決すべき課題が多い。そして噴煙の上昇・拡散機構，ひいては噴火機構の研究へと発展させるためには，画像データと対比させ得る諸観測データがまだ不十分であり，所要の数値計算解析も充実させる必要がある。

しかしながら，火山噴火の検出や噴火活動状況の判断に「ひまわり」の画像の有用性を確認することができた点は本研究によって得られた成果の一つであり，これを踏まえて今後の火山観測，火山防災，噴火機構研究の面で人工衛星画像データの利用が進むことを期待するものである。おわりに本研究の実施にあたり「ひまわり」の画像のデータ処理等に種々御配慮いただいた気象衛星センター担当官各位に御礼申し上げる。

昭和62年２月

気象研究所地震火山研究部長

市　　川　　政　　治

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4. 1982 Galunggung	5. 1982 Soputan	6. 1982 Lopevi
7. 1983 Una Una	8. 1984 Soputan	9. 1984 Mayon

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概　　要*

本報告は気象研究所の経常研究「人工衛星による映像の火山観測への利用に関する研究」（昭和55年—57年度）、及び「衛星画像による火山活動検出に関する研究」（昭和58年—60年度）において実施した研究のうち、静止気象衛星「ひまわり」の画像で検出された噴火噴煙データの解析にもとづく噴火活動状況の把握に関する研究成果をとりまとめたものである。

第一章においては、静止気象衛星「ひまわり」（以下GMSと記す）の画像を用いた火山噴煙の解析の目的と、GMSセンサーの特性の概要、使用したGMSデータの種類、データ処理の方法等を述べてある。火山の噴火は噴煙の上昇を伴うので、噴煙の発見は火山噴火の発生を知る重要な方法の一つであり、さらに噴煙の広がりかたや高度の時間的変化などの状況を観測することは噴出物降下域の予測、航空機の安全航行のための監視、さらには火山噴火活動状況の把握に役立てることができる。しかし、噴煙はその外形や濃さが短時間で著しく変化し、広域に広がった噴煙の状況を地上からの観測だけで把握することは困難である。この点、広域にわたって拡散した噴煙の状況を観測する上で人工衛星の画像は大きな威力を発揮する。また、噴煙の時間的変化を把握する上では現在のところGMSの画像取得時間間隔は他の軌道衛星と比べて最も短い。ただし、GMSセンサーによる画像の地上分解能は軌道衛星と比べて劣るため、対象とできる火山噴煙はやや大きな現象に限らざるを得ない。

本研究ではGMS画像の写真及びデジタルデータを調査して噴煙を検出し得る割合を検討するとともに、噴煙データの解析によって噴火活動状況の把握の可能性を調べた。合わせて噴煙データにもとづく噴火活動による熱エネルギー放出量の推測、噴煙の拡散状況に関しても若干の検討、考察を行った。

第二章においては、GMSの画像データを利用できるようになった1977年末以降1985年末までの約8年間に、GMSの画像で検出された噴煙データの内容をとりまとめた。この期間にGMSの視野内では合計73火山が噴火した。発生した噴火の合計は227となり、年平均25.2の噴火が発生した。このうち、GMSの画像で噴煙を検出できたものは23火山における31の噴火であった。従ってGMS画像でその噴煙を検出できた火山噴火の割合は約14％となる。ただし、そのうちで雲の妨害の少ない良質の噴煙の状況を検出できた割合は約7％である。検出できた噴煙は高度約4㎞以上、広がりが約20㎞以上のものであった。ただし、高度10㎞前後以上へ上昇した規模のやや大きな噴火に伴う噴煙の殆どは検出されており、その拡散の状況もほぼ良好に把握することができた。

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第三章においては、噴煙が検出された23火山について噴煙の拡散状況に関する写真データをとりまとめるとともに、噴煙から判断される火山噴火活動の状況を考察した。噴煙として判断したものは全て報告された噴火の発生時刻ないしは時間帯と対応がつくものではあるが、一部には通常の雲との判別が完全にできないため噴煙でないものも含まれている可能性は残る。そのような画像データに対しては前章の表2-2の中で区別の記号を付してある。噴煙の拡散状況から見た場合、単発的噴火や連続した噴火活動の違いを噴煙の濃さや拡散の状況の判断にもとづいてかなり良好に把握することができた。また噴煙の中には水平距離にして火山から2000km以上の地域まで拡散したものもあり、噴火の様式、規模、気象条件によっては極めて広域にまで噴煙が拡散し得ることを示している。なお、噴煙にもとづく噴火発生の発見そのものは著しく困難であった。これは噴火発生直後の噴煙の広がり、高度がともに小さいためにGMS画像の地上分解能の上で制限されること、及びGMSの画像取得時間間隔の間に噴火が発生した場合が多いことによる。画像を検討する際、噴煙の根元が火山の位置から分離した時点をもって噴火活動の終息と判断することは殆どの場合問題はないが、地上、上空とも風速が小さい場合、あるいは上下で風向が著しく異なる場合には噴煙が火山上空に滞留するケースがあり、噴火活動の終息の判断には高層気象観測データの併用が不可欠である。

第四章においては、噴煙画像データの解析にもとづいて一部の火山の噴火噴煙の上昇速度、水平拡散係数を検討し、噴火活動継続時間に関する詳細な報告がある２、３の火山については噴煙の等温表面温度領域の面積と噴煙の温度プロファイル、すなわち噴煙塊の高度分布の垂直断面の時間的変化を検討した。噴煙の移動速度を見ると、周辺の風速よりわずかに早いというケースがある。噴煙の水平拡散係数についても10^9—10^{10}cm²/sというやや大きな値が得られた。噴煙の表面温度、すなわち高度分布の垂直断面及び表面の等温度領域の面積の時間的変化においては噴火の終了後でも一たん減少した噴煙高度、噴煙の中一やや上部における等温領域の面積が再び増大するという事例が見られた。これらの現象は一たん高空へ上昇した噴煙塊内部に熱源が保持されているため、噴煙塊がさらに拡張し得ると考えることもできるが、火山の上空そのものにおける高層気象観測データを得るには至っていないためにさらに検討を要する現象である。

第五章では噴煙と雲との識別、噴煙到達高度の推測値、噴煙にもとづく放出熱エネルギー量推測についていくつかの噴煙データから得られた結果を示し、それらの問題点を検討、考察した。また、噴煙の物理的性状に関する調査としてLANDSAT画像で得られた桜島の噴煙に関する結果も若干まとめた。そして火山噴火のモニターに人工衛星の画像を利用する場合の検討事項についても考察した。GMSの画像データにはT_{BB}すなわち、表面温度、及びアルベドの両出力値があるが、この２種のデータだけで噴煙と雲とを識別することは著しく困難である。ただし、1981年のAlaid火山の噴煙のように噴煙のアルベド値が雲のそれと比べ明らかに低い事例もあり、その他の火山についてもわずかながら噴煙のアルベド値が雲のそれよりも低いというケースが多い。し

かし噴煙塊の輻射率、濃さ、厚さなどについての物理的性状が不明であるため、これらの現象を噴煙の一般的特性として議論することはできない。噴煙の到達高度は、表面温度の高層気象観測あるいは大気モデルによる気温プロファイルとを組み合わせて推測してあるが、第三章で示したように地上観測で得られた最高到達高度と大きくずれている場合もある。噴煙の表面温度は輻射率を一様に1.0として扱っていることも大きな原因かも知れない。噴煙のデータにもとづいて放出熱エネルギーを推測するにあたっては噴煙をplume riseと仮定したが、この方法で得られた結果と、噴出物の量から推測した熱エネルギーとの間にはほぼ比例関係が成立するようである。従って、噴煙によって得た放出熱エネルギーは爆発的噴火の規模、さらには噴出物量の推測の指標になり得る。ただし、より詳細な解析のためには今後噴煙の上昇、拡散の機構に関する研究を進める必要がある。噴煙の物理的性状を考察する事例としてLANDSATのMSSデータで得られた桜島の噴煙の反射特性を検討したが、その結果によれば噴煙の放射輝度レベルの特性は海面のそれと並行したものであり、かつ雲のそれとほぼ一致する場合が殆どであった。このことは桜島の噴煙の表面が雲と同様水滴や氷滴の集合体であることを推測させるものであり、微細な噴出物の粒子の含有にもとづく光学的特性への影響がないということになる。ただし、ここで扱った桜島の噴煙は、大きな噴火に伴う噴煙と比べ広がりが小さく、高度も低く、かつ、かなり薄いものであった。従って前記の結果が全ての噴煙について該当する現象であるとは考えにくい。最後に、人工衛星の画像を火山噴火活動のモニターに活用しようする場合、GMSのように画像取得のインターバルが短いことがまず必要である。噴煙の検出に関しては画像の地上分解能の向上のほか、噴煙内の火山ガスや噴出物粒子の含有量を判別し得るセンサーの組合せが有効であろう。噴煙塊拡散域の予測という立場から火山防災に寄与するためにはデータ処理のシステムも含め基本的な開発、研究がさらに必要である。

第六章ではこれまでの結論をとりまとめた。

本研究の実施にあたってはGMSデータの処理に際し気象衛星センターの由田建勝氏、矢高尹人氏をはじめとして解析課、データ処理課の各位に大変お世話をいただいたことを記してお礼申し上げます。

Abstract*

There are more than 300 active volcanoes within the field of view of the Geostationary Meteorological Satellite (GMS). Most of the active volcanoes make explosive eruptions accompanied by eruption clouds, and therefore, the occurrence of volcanic eruptions can be monitored by detection of volcanic eruption clouds. Generally, eruption clouds change their extent in a short time and disperse quickly, and the instantaneous field of view of GMS is not sufficient for the detection of small-sized eruption clouds. But the image - taking intervals of GMS, ranging from 30 minutes to 4 hours, is very effective in detecting eruption clouds which are likely to disperse in a short time, compared with the longer intervals of orbital satellites. The author carefully investigated GMS image data, mainly the photograph materials taken during late-1977 - 1985 and could detect eruption clouds on the GMS images for 23 volcanoes.

In this paper, many image photographs of eruption clouds taken by GMS are compiled to promote the understanding of eruption clouds. Observations of volcanic eruptions at several volcanoes and estimations of thermal energy releases based on eruption cloud data of several volcanic eruptions are processed. Fundamental analyses of rising and dispersing eruption clouds are also conducted. Besides, some problems for future satellite monitoring of volcanic eruptions are discussed. The GMS image data are examined on the basis of the reported eruptive activities in the field of view of GMS. There are 227 eruptions from 73 volcanoes during the above-mentioned period, and eruption clouds are detected in 31 eruptions from 23 volcanoes. The rate of detection of eruptions by eruption clouds in the GMS images is about 14 %, while the rate of detection of good-quality eruption cloud data unhampered by surrounding atmospheric clouds is about 7 %. The smallest domain and the lowest altitude of eruption clouds are about 20 km and 4 km, respectively. Judging from the recent ground resolution or instantaneous field of view of the GMS sensor, the image - taking intervals and the usual weather conditions around and over erupting volcanoes, the above-mentioned results are considered to be the upper limit of detection capability for eruption clouds by GMS image data. It is not easy to distinguish eruption clouds from

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atmospheric clouds only with T_{BB}, namely surface temperature data and albedo values of the GMS data, except some examples. Eruption clouds tend to show lower albedo values compared with atmospheric clouds at the same altitudes. However, large explosive eruptions with eruption clouds of altitudes higher than 10 km are almost all found in GMS images, and the time variations of domains of eruption clouds dispersed in a wide area are well monitored by GMS images. With analyses of time variations of altitudes of eruption clouds estimated from their surface temperature data and air-temperature profiles obtained by radio-sounding data at nearby volcanoes, the decays and reactivations of eruptions are well judged.

In order to understand the strength or magnitude of eruptions, released thermal energies based on eruption clouds data are estimated by applying the equation for plume rise proposed by Briggs (1969). Proportional relationships are recognized between the thermal energy releases estimated from eruption cloud data and those estimated from the mass of juvenile ejected materials by using the method proposed by Yokoyama (1957). This shows that the strength or magnitude of eruptions can be estimated from dispersing eruption cloud data obtained from GMS images.

Concerning the behavior of dispersing eruption clouds, it was noticed that some eruption clouds show slightly higher velocities than surrounding wind speed at respective altitudes. Expansions of eruption clouds several hours after the eruptions are also noticed. These phenomena may show that eruption clouds carry some heat sources inside and can expand during the dispersion. However, more detailed analyses of eruption cloud data including the physical or optical features and precise visual observational data of dispersing eruption clouds are needed.

The results given above show that the observations of eruption clouds by GMS image data are useful and effective for monitoring volcanic eruptions, estimating thermal energy releases of eruptions and investigating dynamic mechanisms of rising and dispersing eruption clouds.