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学位論文題名

Recent Forest Fire and Lightning Trend in Alaska

（アラスカでの最近の森林火災と雷の傾向）

学位論文内容の要旨

Forest fire due to lightning flash is a very commonly occurring natural disaster in Alaska. Repeated lightning-caused forest fires adversely impact Alaska's residents and influence earth's atmosphere in every fire season. Recently Alaska had severe number of lightning flashes, 120,000 a year, which started around 300 fires in each of 2004, 2005, and 2007. These severe flash numbers were four times more than average years (31,000), but the burnt area of each year differed considerably. Burnt areas in 2004 and 2005 were the largest and 3^{rd} largest in the last 55 years (1956-2010), respectively. Alaska lost 10% of its boreal forest area due to vigorous forest fires in these two consecutive years. But the burnt area in 2007 was smaller than the average 3,541 km^2. To explain the background of the burnt areas in 2004, 2005, and 2007, it was required to investigate lightning and forest fire meteorology in Alaska, as the number of lightning flashes and lightning-caused fires were almost the same in these three years. Firstly, to characterize lightning occurrence trend in Alaska, this study examines a wide range of lightning-weather indices and parameters. For this purpose, past 23 years cloud-to-ground (CG) lightning data, radiosonde and weather data measured at Fairbanks since 1986 were analyzed, and weather maps at various heights, emagrams and satellite images were carefully analyzed. Furthermore, to characterize lightning occurrence pattern, "lightning" days were categorized into "less severe", "severe", "very severe", and "extremely severe" to notice controlling factors on the lightning severity. Secondly, to characterize forest fire occurrence in Alaska weather parameters like precipitation and temperature, NASA-MODIS hotspot data, lightning data, and fire data since 1956 to 2010 from University of Alaska Fairbanks and Alaska Fire Service were comprehensively analyzed.

The above analyses showed that Alaskan thunderstorms are mainly "ordinary cell thunderstorm" and naturally lightning flash occurs from May to August in Alaska, of which the middle of June and from the beginning to the middle of July is the most frequent lightning occurring period in Alaska. In Alaska, 2005 was the largest lightning year with 123,719 total annual flashes. The largest two lightning peaks with 13,027 and 12,017 flashes were the highest daily total of Category L_4 ($\geq$ 9,000 flashes/day) lightning ever detected in Alaskan lightning records. The topmost lightning (13,027 flashes) in the middle of June was assisted by higher "maximum air temperature" (T_{max}) of around 30 ℃ lasted for about 10 days, triggered by the northwesterly wind. The "temperature difference between 850hPa to 500hPa" ($\Delta Te_{850-500}$) exceeded 30 ℃, and intrusion of northern cold wind flow at 500hPa occurred in the middle of June. These situations made high air instability at the lower and upper atmospheric layers. Formation of a "warmer air mass" at 500hPa was also noticed during this anomalous lightning of June 15, 2005 which could enhance the size and intensity of thunderstorm. In 2004, total number of lightning flashes, 114,443 was the third largest lightning year in Alaska. Most of the peaks of more than 5,000 flashes per day were Category L_3 (6,000-8,999 flashes/day) lightning. These severe situations occurred when T_{max} and $\Delta Te_{850-500}$ exceeded 30 ℃, and formation of "thermal low" was noticed with existence of "Ocean low" in the North Pacific Ocean. During this period, the presence of "Ocean low" over the Gulf of Alaska for about two weeks sustained high moisture flow along the northern edge of Rocky Mountains. In 2007, 117,697 annual flashes was the second largest lightning year in Alaska. The lightning situations were assisted by higher T_{max} at the beginning of July and existence of "Ocean low" on the Gulf of Alaska. During this period, the presence of "Ocean low" over the Gulf of Alaska for about two weeks made high moisture flow directly through the Alaska Range. The "500hPa high" and "500hPa warmer air mass" was observed to form on the northwest of Alaska.

This study also discusses forest fire meteorology or forest fire activities in severe lightning years in Alaska. To assess forest fire activities, new concept parameters such as "number of live fires", and "accumulated final burnt area" (AFBA) were introduced. "Number of live fires" was extracted by using 'fire discovery date' and 'fire out date', and just shows number of fires on specified day. But it could explain not only fire situation but also fire activities indirectly. AFBA was calculated by using 'fire discovery date' and its final burnt area. Thus, AFBA could identify fatal fire days of each year. In addition, accumulated trends of number of lightning flashes, fires, burnt area, and hotspots were used to show their occurrence trends effectively.

In Alaska, 2004 was largest fire year since 1956 with burnt area 26,591 km^2, made by totally 257 fires. In 2004, totally three forest fire occurrence peaks were observed under severe lightning occurrence around 120,000. The trends in the number of fires and AFBA suggested fatal fires in 2004 occurred in the middle of June. Three fire active periods were identified by number of hotspots. They occurred at the end of June (responsible for around 35% of total burnt area), in the middle of July (responsible for around 25% of total burnt area), and in August (responsible for 40% of the total burnt area) under drought and high air temperature conditions. Thus, we may say fatal fire occurrence in the middle of June and active fire period in whole August made largest burnt area in the last half century. The third largest annual burnt area 18,822 km^2 was recorded in 2005 with totally 326 fires. Severe lightning flashes around 120,000 made two forest fire occurrence peaks responsible for burnt area. The AFBA and fire trend showed fatal fire occurrences in the middle of June and end of July. First fire active period in the middle of June was responsible for around 50% of the total burnt area. Second fire active period (responsible for around 80% hotspots) from the end of July and in August occurred by holding large number of live fires (around 100) under drought and high air temperature conditions. Most of the old and new fires in 2005 became active in this period. Thus, we may conclude fatal fire occurrence in the middle of June and end of July, and very active fire period in the middle of August made third largest burnt area in the last half century. In 2007, totally 259 fires made around 2,400 km^2 burnt area, one-tenth than 2004. Only one severe continuous lightning period in July made two forest fire occurrence peaks. But no severe fire occurred in 2007 under non-active lightning condition in June except one very large tundra fire in July. Some weak fires occurred under continuous severe lightning period in July. A small number of live fires (< 30) were occurred in August even under drought and high air temperature conditions. This weak fire activity was mainly due to precipitation around 200 mm throughout the fire season.

Finally, the study on characterization of lightning occurrence in Alaska concludes that, among the weather indices "lifted index" (LIFT) could be selected as sensitive to assess upper air instability and "environmental temperature at 850hPa" (Te_{850}) could be selected as sensitive to assess instability including warm and moist air masses. The possibilities of lightning forecasts in Alaska could be done using lightning occurrence, LIFT, and Te_{850}. As there is a time-lag between LIFT measurements (14:00) and the lightning peak (around 17:00), and around one day time-lag between Te_{850} and lightning occurrence, lightning forecasts using LIFT and Te_{850} could provide a simply applicable forecast index for Alaska. Apart from this, the study on characterization of fire occurrence in Alaska established that severe lightning ignited Alaska's forests in June and July. Under recent severe lightning occurrence most of the fatal fires occurred in June, and in June and July in 2004 and 2005, respectively. Large numbers of live fires in 2004 and 2005 became active until August under drought and high air temperature conditions which significantly contributed very large burnt area in these two years.

学位論文審査の要旨

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学位論文題名

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（アラスカでの最近の森林火災と雷の傾向）

2004年6月にアラスカで発生した森林火災は大規模化し、火災からの煙（ヘイズ）は、アラスカ内陸部を覆い尽くした。その後、ヘイズはカナダを通過し米国本土東部や南部にまで達し、環境面への悪影響が社会問題となった。この2004年の森林焼失面積は、26,000km^2に達し、火災統計のある過去55年間(1956～2010年)で最大となった。続く、2005年にも18,800km^2の森林が焼失し、この2年連続の森林火災による焼失面積は、日本の九州よりも大きく、アラスカ森林面積の約10%に達した。この2年連続の大規模森林火災の発生原因の一つに、激しい雷の発生があった。2004、2005年にアラスカでは、年平均3万回の約4倍もの約12万回もの雷が発生し、各々262と329件の火災を発生させていた。その後、2007年にも約12万回の雷が発生、259件の火災を発生させていたにも拘わらず、焼失面積は2,390km^2にとどまった。

本論文では、激しい雷発生のあった2004、2005、2007年に着目し、アラスカの雷発生の気象特性と激しい雷の発生原因に加え、森林火災発生後の火災挙動特性と大規模化の原因について研究した。特に、着火源である雷の発生特性を詳しく検討すると共に、着火後の火災の拡大過程に関しても、種々の評価変数の導入と適切な積算形式での評価を行って、総合的にアラスカの森林火災特性を明確にし、新たな知見を得たものである。

本論文は、全5章から構成されており、第1章は序文、第2章は従来の研究、第3章は方法論、第4章は結果と討論、第5章は結論である。各章の内容は以下のようである。

第1章の序文では、研究の背景について述べると共に、本研究の目的と内容の概要について記述している。

第2章の従来の研究では、過去のアラスカでの雷と森林火災に関する研究について記述している。

第3章の方法論では、1節で研究領域と雷検知の概要について、2節で解析に使用したデータ

セットについて、3節で種々の解析方法について記述している。

第4章の結果と討論での各節の内容は以下のようである。第4章の前半1～8節では、雷についてまとめられている。1節では雷の発生傾向、2節では雷の発生回数による分類、3節では雷の発生の気象条件を地表から高層までの圧力と温度などの検討から、LIFTなどの指標の評価、水蒸気の流れの把握、2005年の最も激しい雷発生条件の把握などをまとめ、4節では雷発生予測の可能性、5～7節では2004、2005、2007年のそれぞれの年の雷の異常発生、8節では雷発生密度について述べている。章後半9～16節では、森林火災についてまとめられている。9節では火災の傾向、10節では火災の分布と焼損面積、11節では火災の発生日と継続期間、12節では活火災数、13節では火災の傾向、14節では大規模火災の発生と焼損面積、15節では火災の活動と気象について述べられ、16節で森林火災特性がまとめられている。

第4章の結論では、アラスカの雷は主に熱雷であり、アラスカ内陸部に発達する熱的低気圧と高層の高気圧の形成が基本パターンであることを示し、雷指標のLIFTと850hPaでの気温を組み合わせた簡易式による雷発生の事前予測が可能な事を示した。これに加え、2004、2005、2007年の雷の異常発生の背景として、衛星画像の分析により水蒸気の供給ルートを把握した。2004年水蒸気の供給ルートは、アラスカ湾の低気圧の東進で、ロッキー山脈北端から、アラスカ内陸部に東側から間欠的に供給されていたこと、2005年水蒸気の供給ルートは、北西方向からアラスカ内陸部に供給されており、2005年の観測史上最も激しい雷の発生は、北方からの異常な寒気の流入によるものだったこと、2007年の連続的な雷の発生は、アラスカ湾の低気圧からアラスカ山脈を越えてアラスカ内陸部に間欠的な水蒸気供給だったことを明らかにした。次に、2004、2005、2007年の森林火災の特徴を明確にした。2004年の観測史上最大の火災発生の原因は、春先からの高温と日照りのもと、6月中旬の激しい雷により、森林火災が発生し、爆発的に燃え、アラスカ内陸部を覆い尽くすようなヘイズが発生、その後も少雨傾向が続き、7月、8月にも激しく燃えたためであると言える。2005年の観測史上3番目の火災発生の原因は、平年よりも多雨傾向が続いたにも拘わらず、7月下旬から日照り始まり、8月中旬に火災が活発化したためであると言える。2007年の平年並みの森林火災の理由は、2004、2005年と比べると、6月中旬に火災がほとんど発生しなかった、平年よりも多雨傾向で、日照りがほとんど起きなかった、ためであると言える。

これを要するに,著者は,アラスカにおける最近の激しい雷と大規模森林火災の発生原因を明確にしたばかりでなく、アラスカの雷と森林火災の発生特性に関する新知見を得たものであり,地球環境問題の改善という観点からの気象学、自然災害科学、農業環境工学などに加え、環境社会工学に貢献するところ大なるものがある。よって著者は,北海道大学博士(工学)の学位を授与される資格あるものと認める。