Remote sensing of oil slicks

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Airborne remote sensing is very useful for oil-spill monitoring and surveillance. It ranks very high among available methods due to its capability of large area coverage with good resolution and speed for detection of oil slicks. It overcomes the drawback of expensive conventional surveying methods. An airborne remote sensing system used for monitoring and surveillance of oil comprises different sensors such as side-looking airborne radar, synthetic aperture radar, infrared/ultraviolet line scanner, passive microwave radiometer, laser beam fluorosensor and laser-illuminated active gated television. These sensors provide more objective information for detection, quantification and classification of oil as well as identification of a polluting vessel. A brief discussion and working principle of these sensors are presented and their capabilities discussed.

For a country like India with a long coastline, surrounded by busy shipping lanes together with growing number of offshore oil fields, pollution from oil is a continuous threat. Besides tanker accidents, offshore drilling and discharge of the refinery waste, the major source of oil pollution is the intentional dumping of bilge and bunker washings from the tankers[1]. The recent cases were (i) the collision of the tanker *Puppy* with bulk carrier *World Quinu* on 26 June 1989, spilling about 5000 tons of oil in the Arabian Sea about 1000 km south-west off Bombay[2]; (ii) grounding of the super tanker *Exxon Valdez* on 24 March 1989, spilling about 260,000 barrels of crude oil into the waters of Prince William Sound and subsequently along the Gulf of Alaska coast as far as Kodiak Island and the Alaskan Peninsula[3], and (iii) huge oil spill in the Persian Gulf off the coast Al-Khafji on 26 January 1991[4].

Oil spills will continue to happen unless steps are taken to curtail them. Although some positive steps are being taken as regards detection of accidental spills, the procedure adopted is inadequate at night and in poor weather conditions.

A synoptic view of a large coastal sea region like that of India cannot be achieved economically and efficiently by using land-based observation stations or patrol boats. Remote sensing from satellites for oil spill surveillance has been discounted to some extent for various reasons such as: (i) excessive cloud cover over coastal regions, (ii) inadequate resolution for oil spill management purposes, (iii) data retrieval time too long[5]. However, some success in oil slick detection from a SPOT satellite image of 1986 has been reported (via wave damping) by scientists of National Remote Sensing Agency, Hyderabad[6]. Recently, the estimation and monitoring of Gulf oil spill, using NOAA thermal channel data, have been reported[7]. The problem can be effectively tackled by airborne remote sensing with suitable sensors to work by day or by night and in all weather conditions. These sensors provide more objective information about the location and size of an oil slick than visual observations.

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Oil-spill monitoring and surveillance system

Ideally an airborne oil-pollution-monitoring system should be able to detect, quantify and classify oil in the sea. Since no single instrument can meet these requirements, it is necessary to compose a package of sensors. The system used for monitoring and surveillance of oil comprises various equipments for different stages. A brief description of the merits and working principle of each sensor is provided below. For optimal utilisation, the sensor package should be supplemented with high resolution aerial camera. This camera mainly provides hard copy data and source identification evidence.

Detection

Side-looking airborne radar

The side-looking airborne radar (SLAR) is useful for detection of oil on the sea surface and is capable of surveying a large area in a short period of time. SLARs used for oil-pollution monitoring typically cover a range of 25–30 km on each side of the aircraft with an uncovered area underneath equal to approximately twice the flight altitude[8]. It can be used by day or by night and in all weather conditions. SLAR imagery is produced by directing a beam of microwave radiation at the sea surface and measuring the strength of the backscatter. Oil slicks can be detected because they damp out capillary waves and reduce the amount of backscatter and as a result oil appears as a dark area on the radar display[9]. The SLAR should preferably work in a 'linear' response mode in order to bring out the relatively small variations caused by the oil slicks.

The SLAR's ability to cover a large area within a short time is unmatched by any other sensor. As an example, an aircraft moving at ground speed of 400 km per hour will cover an area of more than 25,000 km^2 per hour for oil-pollution monitoring and considerably more for some other applications such as fishery and custom inspection, mineral exploitation, land and forest mapping, etc. SLAR with dual-sided antenna (Danish Terma SLAR) can cover greater area up to 70,000 km^2 per hour[10].

Automatic target positioning is one of the most useful features of the SLAR. The operator uses a light pen to mark an interesting feature in the imagery, and its geographic position is displayed in the data block. A small white circle identifies the feature which has been targeted. It is also possible to expand a particular part of the imagery so that it can be examined in more detail. The only major limitation of the SLAR as an oil pollution-detection device is its inability to see oil below the sea surface. Although SLAR does not produce any information about the slick thickness, it does indicate the total extent of the slick.

Synthetic aperture radar

The synthetic aperture radar (SAR) is being used for the detection and observation of oil slicks. Comparison of SLAR and SAR showed that x-band vertically polarized SAR was much superior than x-band horizontally polarized SLAR. On SLAR image, oil appears in white whereas it is black in SAR image. Oil is better detected on SAR images and the wave pattern disappears completely on those parts of the sea covered by the oil film[11].

Infrared/ultraviolet line scanner

The infrared/ultraviolet (IR/UV) line scanner provides high resolution spill detection directly below the aircraft and can be used as an additional sensor. In linescan systems, image is produced by scanning successive strips of the sea beneath the aircraft as it moves forward. The optical system focuses radiation onto detectors which are sensitive to infrared and ultraviolet wavelengths, thus building up an image from adjacent scan lines.

The IR sensor detects thermal differences between oil and water while UV sensor detects reflective differences between water and oil. The UV sensor detects the entire area covered by oil and enables slick dimension to be determined. It also provides for discrimination of false alarms occurring in the IR channels due to the surface thermal gradients (ship wakes). Since oil absorbs very strongly relative to water in the UV spectrum, oil on the sea surface will appear in strong contrast to the surrounding non-polluted water, even at a thickness of a few micrometers. In contrast, the thicker layers will be detected by IR sensor. It is therefore possible to point out the position of the biggest concentration within the spill area. UV sensor can be used during daylight and in conditions of good visibility whereas IR sensor will operate by day and by night but will not detect oil in rain or fog.

Quantification

Passive microwave radiometer

After detection of oil, the next step is quantification for which passive microwave radiometer is an important tool. It can be operated in day and night as well as in all weather conditions.

In the microwave region of the electromagnetic spectrum, water has an emissivity of approximately 0.4 and therefore, it appears cold. Oil has an emissivity of approximately 0.8 and consequently its brightness temperature is closer to its actual physical temperature. An oil film on water behaves as a matching layer at the air–water interface because oil has a dielectric constant between that of air and water. Reflection is minimized and emission will be maximum when the film has an effective thickness equal to an odd multiple of a quarter wavelength of the observed microwave energy. Therefore, as an oil film thickness on the water increases, the brightness temperature measured at a given microwave energy and radiometer look angle increases at first to a maximum and then oscillates between maxima and minima. Thus, two or more oil thicknesses can have the same brightness temperature.

A passive microwave radiometer measures brightness temperature which potentially contains information about atmosphere and surface parameters that could be retrieved using multi-frequency measurement. Higher emittance by oil is the primary effect used for detection of oil from the brightness temperature measured by microwave radiometer (MWR). By using two or more microwave frequencies, thickness ambiguities due to oscillations can be eliminated and the film thickness determined.

Figure 1 shows change in the original brightness temperature as a function of the oil thickness. By using two frequencies such as 15 GHz and 37 GHz, it is

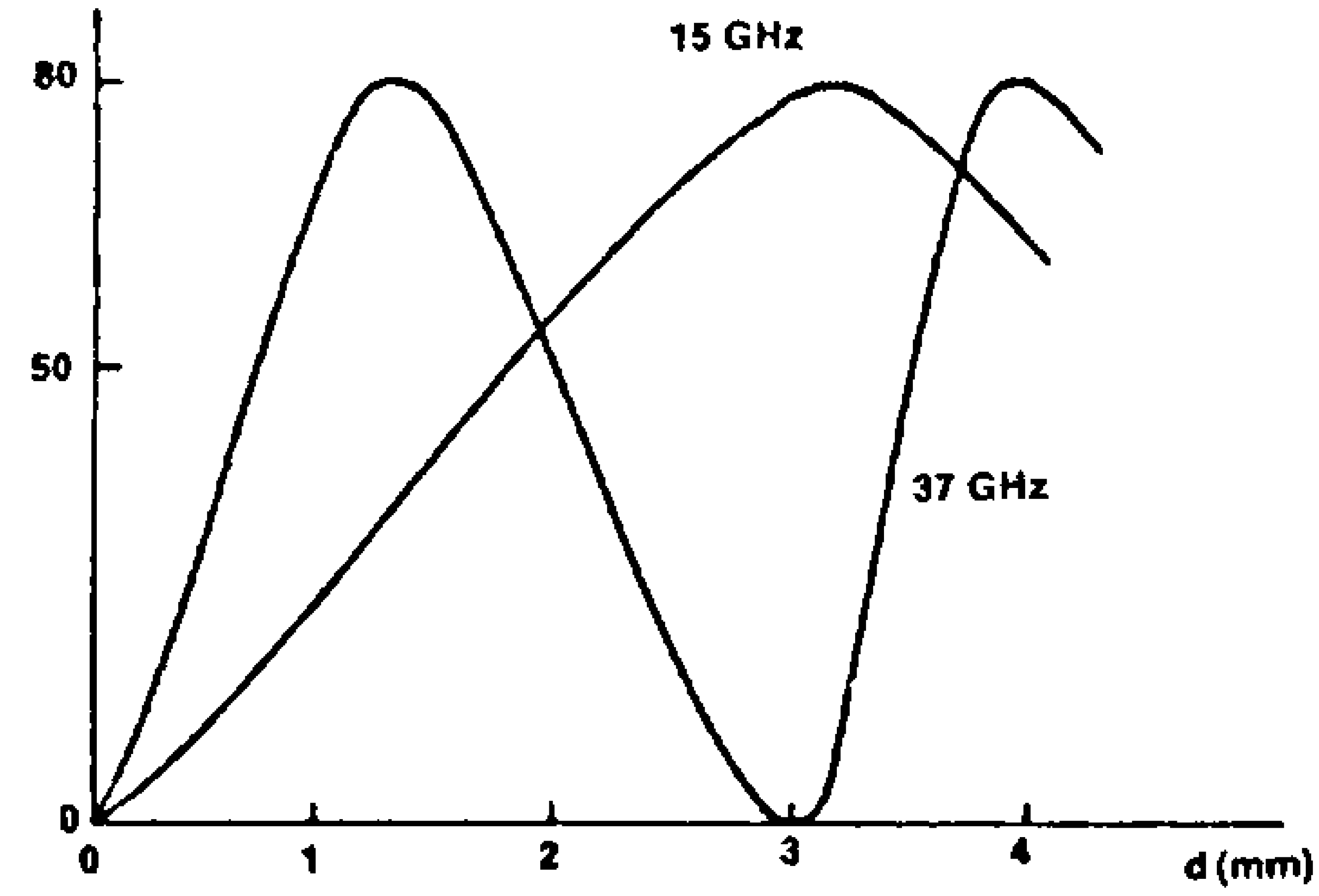

Figure 1. Changes in brightness temperature at 15 and 37 MHz for variable oil thicknesses. Vertical view. [From Soresen, 1984]

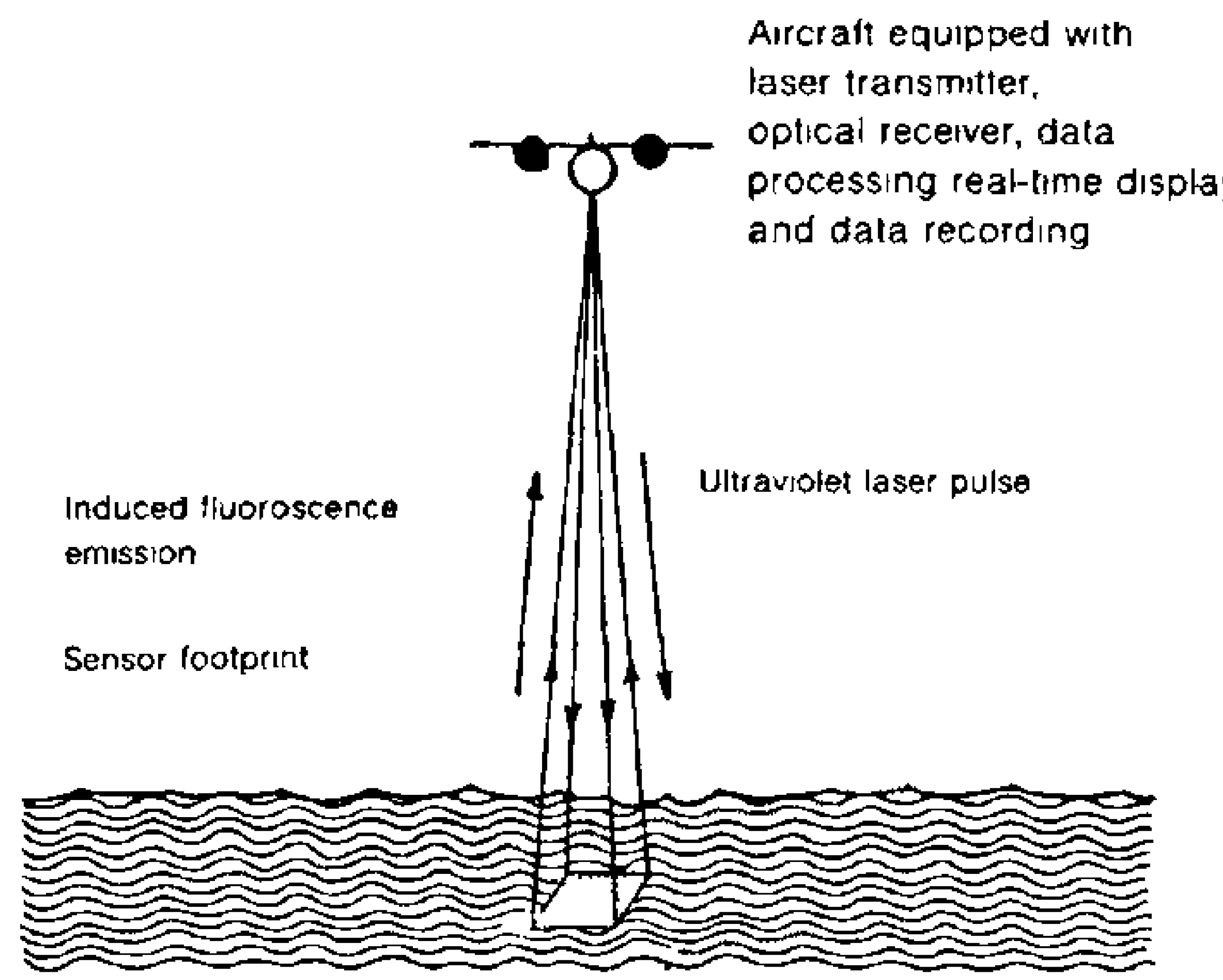

Figure 2. Laser fluorosensor operation principle. [From Soreson, 1984]

possible to determine oil thickness from 1.0 mm to 4.0 mm (ref. 10).

Because of its ability to determine oil thickness/quantity of oil under all weather conditions, a MWR can help not only in locating higher oil concentration within the slick during clean up operation by oil-combating vessels but also in avoiding costly clean up operation for less significant/minor slicks.

Classification

Laser beam fluorosensor

Classification dealt with here concerns discrimination between oil categories (light fuel, heavy fuel, crude, etc.) and the determination of oil types (i.e. Arabian light crude, Kuwait crude, Bombay High crude, etc.). The laser fluorosensor enables the remote classification of oil according to main oil groups. Oils are known to absorb strongly in the ultraviolet end of the spectrum. A portion of this energy is reemitted at longer wavelengths and this is known as fluorescence, which enables oils to be remotely detected. Three parameters, fluorescence intensity, emission spectrum and lifetime of the emitted signal, are sufficiently characteristic of a particular oil to enable its differentiation from other oils and hence its classification. Even thin oil patches can be classified. However, some closely related spectral signatures may fail to be distinguished by the laser beam fluorosensor (LFS), which may pose a limitation in some cases.

The laser fluorosensor is an active sensor which means that it provides its own source of illumination. For oil pollution classification, a narrow beam of ultraviolet light is emitted co-axial with the receiver optics, which collect the fluorescent light from the target (Figure 2). The fluorescent return signal at wavelengths longer than the laser wavelength, is detected by a range-gated spectrum analyser. Time-gating the detector in synchronization with the backscattered radiation pulse permits the system to be operated in full daylight[10]. Classification of oil is very useful for the response team to identify the methods of recovery or dispersal.

Identification of a polluting vessel

For applications such as identification of an intentional oil spill, a laser-illuminated active gated television and an airborne photographic camera linked to the aircraft navigation system for time and position annotation would be useful to produce evidence of an oil-spilling vessel's unlawful activity.

Laser-illuminated active gated television

This system is in a developing stage and will serve as an important tool for identification of a polluting vessel specially during night time and can form a part of this surveillance system. This system illuminates the target by means of a laser and can operate day and night. It has also got the capability to 'zoom in' and 'lock onto' the target and hence will be able to read the letters while the aircraft is flying past the ship up to 0.5 km away[12]. Additional camera in the system will help to have a photographic record of the oil spills and ships in the area. The system also acts as the computerized control centre. It has a multipurpose television monitor on which SLAR, UV/IR line scanner images can be displayed. In addition, because the system is coupled to an inertial navigation system, the position of any target

Table 1. A summary of sensors capabilities.

Sensors	Real time	Day	Night	Near all weather	Quantity/thickness	Classification	Submerged oil	Good resolution	Mapping	Long range/large area	Data link to ground	Documentation incl. position	Frequency / wavelength
Side looking air borne radar	X	X	X	X					X	X	X	X	9.4 GHz
Infrared L S	X	X	X					X	X		X	X	8–14 µm
Ultraviolet L S	X	X						X	X		X	X	0.3–0.4 µm
Passive microwave radiometer	X	X	X	X	X						X	X	15–37 GHz
Laser fluorosensor	X	X	X			X	X				X	X	337 nm

(MASSIN, 1981)

indicated by the operator on the SLAR display is automatically calculated.

A summary of sensors capabilities is given in Table 1. All these sensors are interfaced to a video monitor which gives real time presentation of the image inside the aircraft. A complete set of navigational data such as date, time and aircraft position, heading and altitude is displayed on all the images. A standard video cassette recorder can be used to record all the images for replay after landing. These data can also be transmitted in real time to a shore-based pollution control centre or an oil-combating vessel, using a powerful VHF down link system.

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Inadvertent modification of atmospheric electricity

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Human activities on different scales of space and time cause a change in electrical state of the atmosphere or cloud electrification. Ionization and nuclei introduced into the atmosphere by human activities may contribute to such modification. Urbanization, desertification and air pollution, which modify cloud electrification characteristics, can influence the evolution of precipitation and dynamics of clouds.

Like inadvertent modification of weather and climate, some activities of man cause modification of atmospheric electricity on different scales of space and time[1]. The global electric circuit reflects world-wide events happening at the same time and influencing the magnitude of parameters measured at any place. Local processes also shape the spatial and temporal variations of these parameters. We need to understand how the global and local components have contributed and will continue to contribute in future to shape various atmospheric electric parameters at different places. We

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