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Modeling long distance dispersal of airborne foot-and-mouth disease virus as a polydisperse aerosol – Application to the emergence of a new strain from Egypt to Israel

Ziv Klausner [a, b], Eyal Klement [a], Eyal Fattal [b, *]

[a] Koret School of Veterinary Medicine, The Robert H. Smith Faculty of Agriculture, Food and Environment, The Hebrew University, Israel
[b] Applied Mathematics Department, Israel Institute for Biological Research, Ness-Ziona, Israel

HIGHLIGHTS

- Airborne FMDV was modeled as polydisperse aerosol with size-dependent deposition.
- Biological decay was modeled using new data of naturally produced aerosol.
- The plausibility that LDD of FMD will occur over desert and water LUCs was analyzed.
- This approach was compared to modeling as passive tracer or monodisperse aerosol.
- In variable wind conditions other approaches may under estimate the affected area.

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ABSTRACT

Long distance dispersal (LDD) of airborne aerosol of foot-and-mouth disease (FMD) virus was extensively modeled in the literature. Most studies modeled this aerosol in simplistic approach as a passive tracer, neglecting physical and biological mechanisms that affect bio-aerosols such as the FMD aerosol. This approach was justified either because under persistent wind these mechanisms lower the extant of downwind hazard or on the grounds that the effect of some of the physical mechanisms on particles as small as the FMD particles (0.015–20 μm) is supposed to be negligible compared to the effect of atmospheric turbulence. Even when the FMD aerosol was treated as aerosol, it was assumed that it is monodisperse, i.e., all its particles are of the same size. The aim of the study is to examine whether these simplistic approaches are indeed justified when dealing with LDD of a bio-aerosol under actual atmospheric conditions. In order to do so, the influence of a more realistic modeling of the FMD aerosol as a polydisperse aerosol was compared to passive tracer and to monodisperse aerosol. The comparison refers to a case of a widespread FMD outbreak that occurred in 2012 in Egypt. This outbreak involved the emergence of a new serotype in Egypt, SAT2 and concern was raised that this serotype will advance further to Asia and Europe. Israel is located on the land bridge between Africa, Asia and Europe, and shares a long desert border with Egypt as well as a long Mediterranean shore adjacent to Egypt's shore. This unique location as well as the fact that Israel does not have any cattle trade with its neighboring countries make Israel an interesting test case for the examination of the necessary conditions for the long distance dispersal (LDD) of a new FMD strains from Africa to Europe. The analysis in this study shows that under quasi-stationary wind conditions modeling FMD dispersal as a passive tracer results in a significantly longer hazard distance. Under non-stationary conditions this modeling assumption results in an under-estimation of the hazard distance in comparison to the results of polydisperse aerosol. In these conditions modeling the FMD dispersal as a monodisperse aerosol results in similar under-estimation. The implications of such under-estimation may be severe because it may lead authorities in a threatened area to refrain from taking the necessary protective measures. Therefore, the modeling of

Abbreviations: FMD, foot-and-mouth disease; FMDV, foot-and-mouth disease virus; LDD, Long distance dispersal; LT, Lagranigian wind trajectory; CLW, cold low to the west; SCLN, Shallow Cyprus low to the north; SL, Sharav low; TCID50, 50% tissue culture infectious dose; MLD50, median lethal dose for mice; LUC, land use category.

* Corresponding author. Applied Mathematics department, Israel Institute for Biological Research, P.O. Box 19, Ness-Ziona 7410001, Israel.
E-mail addresses: ziv.klausner@mail.huji.ac.il (Z. Klausner), eyal.klement@gmail.com (E. Klement), eyalf@iibr.gov.il (E. Fattal).

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the FMD aerosol as a polydisperse aerosol is preferable, leading to realistic estimation both under non-stationary and stationary wind conditions.

1. Introduction

Foot-and-mouth disease (FMD) is a highly contagious viral disease which affects a wide variety of cloven-hoofed animals, including domestic livestock in extensive production systems such as cattle, sheep and pigs (Alexandersen et al., 2003a). The disease bears direct economic implications on the affected animal farms, and indirectly on all the farms, dairy and meat production industry in the surrounding area because of the restrictions posed by the quarantine control (Alexandersen et al., 2003a).

The most common infection route of FMD is by direct contact between animals, usually by inhalation of the infectious aerosol emitted in the exhaled breath of an infected animal (Donaldson and Alexandersen, 2002; Kitching et al., 2005). This route, as well as other forms of contact, can be controlled in the event of a FMD outbreak by keeping the surrounding area under quarantine, imposing restrictions on movement and applying disinfectants. However, the emitted infectious aerosol can also take an airborne route and spread via atmospheric transport. Such uncommon scenarios can be considered low probability-high consequence events because the disease may spread rapidly beyond the disease-control areas. There are several historic FMD outbreaks in which wind transport mechanisms enabled long distance travel of the virus, either across sea or land (Donaldson and Alexandersen, 2002; Donaldson et al., 1983). The most notable transport events occurred in March 1981, over a distance of 300 km of sea from northern France (Brittany) to the Isle of Wight (A. Donaldson et al., 1982) and during 1967–1968 in the UK, in which the maximal distance of airborne dispersion over land was at least 60 km, possibly up to 150 km (Hugh-Jones and Wright, 1970).

Israel is a special test case for studies of long distance dispersion of FMD. While the movement of individual foot-and-mouth disease virus (FMDV) strains in the Middle East is related to trading relationships and uncontrolled animal movement between open borders (Knowles et al., 2007; Samuel and Knowles, 2001), the borders of Israel are either closed or closely controlled and livestock trade with its neighbors is limited. This is primarily true regarding the southern border which lies in a desert area and thus reduce the probability for FMDV transmission by wild animals as well. While its borders are controlled, Israel's unique geographic location on the land bridge connecting Africa, Asia and Europe, enables disease to cross its borders via atmospheric mechanisms and even further on from there. It was suggested, through a combination of phylogenetic evidence and backwards Lagranigian wind trajectories analysis, that a circulation exists that enables the transmission and periodical re-introduction of vector borne disease between Israel and Turkey (Aziz-Boaron et al., 2012). Moreover, several studies who analyzed the potential of long distance spread of disease via atmospheric routes from Egypt to Israel in the case of vector borne diseases have concluded that such spread is possible and has occurred in several instances (Garrett-Jones, 1962; Klausner et al., 2015).

In February 2012 a widespread FMD outbreak has begun in Egypt following the emergence of the SAT2 serotype. Until then nearly all outbreaks in Egypt (since 1972) and in Israel (since 1990) were resulted by the O serotype which is endemic in all the countries in the Middle East (Ahmed et al., 2012; Bellaiche, 2011; Knowles et al., 2007; Samuel and Knowles, 2001). Moreover, at least in one instance Egyptian and Israeli isolates were found to originate from the same O1 FMDV (Stram et al., 1995). The major SAT2 outbreak in Egypt has raised concern in Israel about the possibility of this emerging serotype to spread to Israel. Preliminary outbreak prevention steps were taken by the Israeli veterinary services in southern Israel, including a vaccination campaign and restriction on stock animal movement.

Regardless of the control measures taken against this risk, the severe impact of a scenario in which an airborne aerosol generated at an outbreak location in Egypt might be transported by the atmosphere deep into Israel and circumvent the disease control area could not be overlooked without a thorough examination. This was the motivation of this study whose aim is to examine the plausibility of such scenario by investigating the necessary conditions for such a scenario to occur. The examination was conducted using computer simulations of the atmospheric transport and dispersion of a FMD aerosol. During its travel through the atmosphere the FMD aerosol is affected by deposition and biological decay processes, which might change the concentration of viable virus in the air. Therefore, care was given to model these processes as realistically as possible.

2. Methods

The question of long distance virus aerosol dispersion is composed of several layers. First, the source term which in this case is the amount of virus aerosol emitted into the air at the source location should be quantified. Now, supposedly some of this aerosol has arrived to a given destination location, the threshold doses should be defined. These are the minimal amount of the virus required to be inhaled by the susceptible species in order to incite infection. When the source and thresholds are defined, the transport and dispersion process itself should be dealt with. A wind trajectory should connect the source and destination in order to provide a route for the aerosol to travel. During its travel the airborne aerosol is prone to deposition and decay processes. All these should be defined, quantified and modeled as described in this section.

2.1. Source term

Although the precise mechanism in which FMDV particles are created and released into the air is not fully known, airborne virus aerosol are found in the environment of infected animals (Gloster et al., 2007). Measurements of the amount of this aerosol in the vicinity of experimentally infected animals have shown that the amount of airborne virus aerosol recovered varies among the different FMD serotypes and animal species. Among livestock, the amount of virus retrieved near infected pigs is much higher than that retrieved from cattle and sheep. The differences depends on the virus strain, where in some strains the emission of pigs compared to cattle and sheep is greater by as much as three orders of magnitude (e.g., O2 Brescia, A5 Eystrup) and in other strains the difference is smaller than 2 order of magnitude (e.g., O1 BFS 1860) (Donaldson et al., 1970).

The maximal amount of virus emitted was measured with the C