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Quasi-Automatic Provision of Input for LINCOM and RIMPUFF, and Output Conversion

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Version 4

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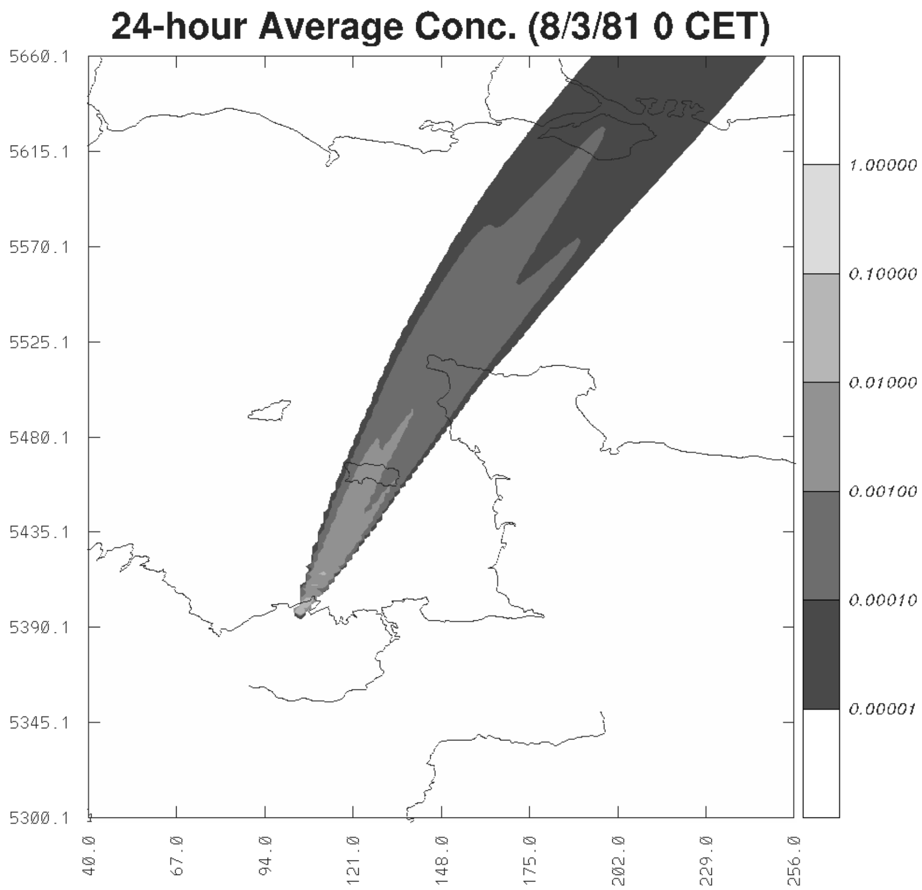

Contents

1 Introduction

Airborne spread of virus for contagious diseases, e.g. foot-and-mouth disease (FMD), may well be described by mathematical modelling on computers. The virus is contained in airborne aerosols exhaled by infected animals. Today it is possible to estimate the amount of virus excreted on a daily basis. Such estimates are based on inspection of the infected animals. And the minimum inhalation doses for infection are known with reasonable accuracy for a number of species. Based on adequate meteorological data, local- and meso-scale atmospheric flow and dispersion models may be used to predict the virus-dose patterns from infected herds. Such predictions will play a vital role in computer based real-time decision-support systems. The EpiMAN system, which utilises a geographical information system (GIS) for graphical display, is an example of such a decision-support system.

In case of flat terrain (or even moderate topography), the RIMPUFF local- and meso-scale atmospheric dispersion model [1, 2] may be run without the use of a flow model. In this case, there is no need for digitised topographical data. Such a calculation is merely based upon meteorological recordings from e.g. a number of meteorological towers. In case of more complex terrain, the LINCOM local- and meso-scale atmospheric flow model [3] may be utilised in order to provide a terrain-dependent wind field for the dispersion calculation. For very complex terrain, however, it is of great significance to have access to appropriately positioned wind-recording stations. For each meteorological station, a time series of weather recordings should be provided with the same time intervals. To run the LINCOM model, a file containing the terrain heights in the grid points for the (sub-)grid used for the flow and dispersion calculation should first be provided by the Digital Elevation Module (DEM) of the Geographical Information System (GIS).

The future user of the system cannot be expected to be an expert on local and meso-scale flow and dispersion modelling. Therefore, the present quasi-automatic set-up has been described which provides a realistic set of input parameters for LINCOM and RIMPUFF. These input parameters are based upon knowledge on the chosen grid and the available weather recordings. An expert user should, however, have the possibility of changing any of the many input parameters.

2 Virus Dose by Inhalation

The amount $\mathrm{d}N$ of virus, in units of TCID_{50}, inhaled in an infinitesimal time interval $\mathrm{d}t$ by an animal situated at time t at geographic location $\mathbf{r}$ may be expressed

$$\mathrm{d}N = c(\mathbf{r}, t)\, I\, \mathrm{d}t, \tag{2.1}$$

where $c(\mathbf{r}, t)$ is the concentration, in units of $\mathrm{TCID}_{50}/\mathrm{m}^3$, at point $\mathbf{r}$ and time t, and I is the inhalation rate of the animal, in units of $\mathrm{m}^3/24$ hr. Thus, the amount $N(\mathbf{r}, T, \Delta T)$ of virus inhaled in the period from time $T - \Delta T$ to T (e.g. $\Delta T = 24$ hr) is obtained by integration,

$$N(\mathbf{r}, T, \Delta T) = \int_{T-\Delta T}^{T} c(\mathbf{r}, t)\, I\, \mathrm{d}t. \tag{2.2}$$

Whereas we allow the concentration c to vary in time and space, we assume that the inhalation rate I is fixed, i.e. within the period considered, the animal is assumed to move around on a scale much smaller than the characteristic length scale of the dose plume, and the rate of inhalation is assumed constant in time. Under these assumptions, we may put I outside the integration and write

$$N = I \int_{T-\Delta T}^{T} c\, \mathrm{d}t = I\, \overline{c}\, \Delta T. \tag{2.3}$$

Here, the quantity $\overline{c}$ denotes the average concentration over the time interval from $T - \Delta T$ to T, which may be extracted from the RIMPUFF dose output. In the literature concerning atmospheric dispersion, the term dose is most often used for time integrated concentrations. Introducing the average rate of virus inhalation within this time interval, $\overline{n} = N/\Delta T$, in units of $\mathrm{TCID}_{50}/24$ hr, we may write

$$\overline{n} = I\, \overline{c}. \tag{2.4}$$

Let N_i denote the minimum dose, in units of TCID_{50}, to infect by the respiratory route for an animal of a given species exposed to virus for the period ΔT (e.g. 24 hours), cf. Table 1. For especially pigs, the minimum infectious dose is not known with great accuracy. Corresponding to the minimum infectious dose N_i, we may introduce a threshold value $n_i = N_i/\Delta T$, in units of $\mathrm{TCID}_{50}/24$ hr, for the average rate of virus inhalation. By using Eq. (2.4), we may further introduce a threshold value c_i, in units of $\mathrm{TCID}_{50}/\mathrm{m}^3$, for the average concentration,

$$c_i = n_i/I. \tag{2.5}$$

The cause of the period of 24 hours for the dose accumulation is that the minimum infectious doses are measured for such a period. Today, the

Species	Min. infectious dose N_i ($TCID_{50}$)	Inhalation rate I (m^3/24 hr)	Threshold conc. c_i ($TCID_{50}/m^3$)
Bovine	10	173	0.06
Porcine	15	52	0.3
Ovine	10	9	1

TABLE 1. Minimum infectious doses for 24-hour virus exposure [4, 5], inhalation rates and threshold values of 24-hour average concentrations, cf. Eq. (2.5).

correlation between minimum infectious dose and accumulation time is not known. Besides, the virus production is estimated on a daily basis.

3 Grid

The horizontal grid for the flow and dispersion calculation should be chosen by the operator of the system such that the grid contains the sources and the wind-recording meteorological tower(s). The borderlines of the grid should preferably be positioned such that the sources and weather stations are in the central part of the grid. However, whereas the sources *have* to be inside the grid, the weather stations need not. The grid spacing should be chosen such that

$$50 \lesssim \texttt{ICOLS} \leq 201, \tag{3.1}$$

$$50 \lesssim \texttt{JROWS} \leq 201, \tag{3.2}$$

where

$$\texttt{ICOLS} = \text{no. grid cells} + 1 \text{ in } x \text{ direction}, \tag{3.3}$$

$$\texttt{JROWS} = \text{no. grid cells} + 1 \text{ in } y \text{ direction}. \tag{3.4}$$

The parameters

$$\texttt{XUTM} = x \text{ coordinate of lower left corner (km)}, \tag{3.5}$$

$$\texttt{YUTM} = y \text{ coordinate of lower left corner (km)}, \tag{3.6}$$

and

$$\texttt{DELX} = \text{grid spacing in } x \text{ direction (m)}, \tag{3.7}$$

$$\texttt{DELY} = \text{grid spacing in } y \text{ direction (m)}. \tag{3.8}$$

Values of 50–100 for `ICOLS` and `JROWS` are usually sufficient for a calculation. Note that the CPU time is proportional to the 2nd power of `ICOLS` and `JROWS`. The parameters `DELX` and `DELY` must have the same value.

4 LINCOM

The operator of the system should at this state of the set-up have the possibility of running the dispersion calculation without using the flow model LINCOM. This is, of course, valid for flat terrain, but all right even for moderate topography. For very complex terrain, it is of utmost significance to have access to appropriately positioned wind-recording towers.

4.1 Terrain File

To run LINCOM, an ASCII file should be provided by the Digital Elevation Module (DEM) of the GIS. The file contains the following lines:

```
DSAA
<ICOLS> , <JROWS>
<XMIN>  , <XMAX>
<YMIN>  , <YMAX>
<ZMIN>  , <ZMAX>
```

And for each row ($j = 1, \ldots,$ JROWS),

<Z(i,j)> ($i = 1, \ldots,$ ICOLS).

(XMIN, YMIN) are the coordinates (metres) of the lower-left corner of the grid, (XMAX, YMAX) are the coordinates (metres) of the upper-right corner. Z is the terrain height at the grid points (metres), and, correspondingly, (ZMIN, ZMAX) are the minimum and maximum height values in the grid. The present version of LINCOM does not utilise this last information, however, so any value may be entered for ZMIN and ZMAX.

For a GIS such as ArcInfo, the values (e.g. terrain heights) are associated with the centres of the grid cells. These values must be interpolated (bilinearly) to the corners of the grid cells (the grid of the flow and dispersion calculations), or the grid may be shifted half a cell in each horizontal direction.

4.2 NPS*.SET

In order to run LINCOM, four additional files are necessary: NPSEAST.SET, NPSNORD.SET, NPSEAST2.SET and NPSNORD2.SET. The files are similar in structure, and most parameters should be left unchanged. An expert user may, however, wish to change the parameters e.g. by editing the files. A sample file is presented below.

The parameter

$$\texttt{IFILE2} = \langle\text{10-character name of terrain-data file}\rangle \tag{4.1}$$

(e.g. IFILE2 = DORSET.GRD), and the parameters

$$\texttt{NBUFX} = \langle 256 - \texttt{ICOLS}\rangle, \tag{4.2}$$

$$\texttt{NBUFY} = \langle 256 - \texttt{JROWS}\rangle, \tag{4.3}$$

and

$$\texttt{ZSFC} = \langle\text{wind observation height (m)}\rangle \tag{4.4}$$

for each of the four files NPSEAST.SET, NPSNORD.SET, NPSEAST2.SET and NPSNORD2.SET.

For NPSEAST.SET and NPSNORD.SET, the parameter

$$\texttt{Z(2)} = \langle\text{wind observation height (m)}\rangle, \tag{4.5}$$

(e.g. 10 metres) while for NPSEAST2.SET and NPSNORD2.SET,

$$\texttt{Z(2)} = \langle\text{effective height in which virus is released (m)}\rangle \tag{4.6}$$

(e.g. 6 metres assuming a slight plume rise).

In the files NPSEAST.SET and NPSEAST2.SET, the parameter

$$\texttt{DSFC} = 90., \tag{4.7}$$

while in NPSNORD.SET and NPSNORD2.SET,

$$\texttt{DSFC} = 0. \tag{4.8}$$

Cf. the C-shell script LINCBASE.scr for file-name handling etc.

The following is a sample NPSEAST.SET file. The few parameters which should be changed by the automatic procedure are typeset in bold face.

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!    NPS.SET                                                         !
!                                                                    !
!    This is the set-up file for LINCOM                              !
!    Comments can be placed only between sections with the           !
!    character "!" appearing in the first column                     !
!                                                                    !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!
! SET_1 ... I/O Path & File Names
!
!!!!!!!!!!________________________________!!!!!!!!!!!!!!!!!!!!!!!!!!!
!
  IPATHI= ./                                       : Input  File Path
  IPATHO= ./                                       : Output File Path
!
!!!!!!!!!!__________!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!
  IFILE2= DORSET.GRD           : Terrain Data File
  IFILE3= DUMMY.BLN            : Boundary Contour Data File
  OFILE1= NPS.LOG              : Log File for the Run
  OFILE2= NPS1E                : Output File for Wind Vectors
  OFILE3= U                    : Output File for U component
  OFILE4= V                    : Output File for V component
!
!!!!!!!!!!____________________!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!
! SET_2 ... Controlling Parameters for Code Flow
!
    DBUG= .FALSE.              : Flag for debugging (programmer only)
  LOG_FL= .TRUE.               : Flag for Log File
  PLT_FL= .FALSE.              : Flag for Output Plotting File
  PLT_AS= .FALSE.              : Flag for ASCII Plotting File
 WIND_FL= .TRUE.               : Flag for Output Wind Data
 WIND_AS= .FALSE.              : Flag for ASCII Wind Data File
 BUFZONE= .TRUE.               : Flag for buffer zone
  MIRROR= .FALSE.              : Flag for mirror image buffer
  OLDBUF= .TRUE.               : Flag for old buffer zone
 NEUTRAL= .TRUE.               : Flag for Neutral Case
    PERT= .FALSE.              : Flag for Perturbation Field Only
    IBLN= .FALSE.              : Flag for Plotting Terrain Outline
   THERM= .FALSE.              : Flag for Thermal Soln Only
   TOWER= .FALSE.              : Flag for plotting tower locations
!
!!!!!!!!!!____________________!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!
! SET_3 ... Controlling Parameters for Plotting
```

```
!
   CASE= P East              : Description of the Run
  NCASE= 001                 : Case Number Attached to the Run
   SIZE= 16.                 : Size of Plot (cm)
  ITHIN= 2                   : Thinning Factor for Plotting Density
  RATIO= 4.                  : Ratio of Vector Length to Grid Size
   IMJR= 4                   : Number of major ticks in X
   IMNR= 10                  : Number of minor ticks in X
   JMJR= 3                   : Number of major ticks in Y
   JMNR= 10                  : Number of minor ticks in Y
   PEN1= 4                   : Color for frame, title and labels
   PEN2= 4                   : Color for wind vectors
   PEN3= 2                   : Color for base boundary
   PEN4= 5                   : First color for terrain contours
   PEN5= 6                   : Second color for terrain contours
!
!!!!!!!!!!____________________!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!
! SET_4 ... Model Specifications (Neutral)
!
  NBUFX= 155                 : Buffer zone in X
  NBUFY= 155                 : Buffer zone in Y
 NZEROX= 4                   : Zero buffer in X
 NZEROY= 4                   : Zero buffer in Y
     K0= 256                 : Cut-off wavenumber in X
     M0= 256                 : Cut-off wavenumber in Y
   XSMP= 1                   : Output GRD file sampling rate in X
   YSMP= 1                   : Output GRD file sampling rate in Y
  SCALE= 1.                  : Terrain scaling factor
  DEPTH= 1000.               : Depth of Inversion Layer
   ZSFC= 10.                 : Measurement Height
   USFC= 1.                  : Measured Incident Wind Magnitude
   DSFC= 90.                 : Measured Incident Wind Angle

   SFZ0= 0.1                 : Surface roughness
   Z(1)= 0.0                 : First (bottom) layer (6 FT)
   Z(2)= 10.                 : Second layer (54 FT)
   Z(3)= 0.0                 : Third  layer (of the inversion height)
   Z(4)= 0.0                 : Fourth layer (of the inversion height)
   Z(5)= 0.0                 : Fifth  layer (of the inversion height)
    slf= 0.27                : For testing
    xlf= 1.00                : For testing
   slpo= 0.67                : For testing
!
!!!!!!!!!!____________________!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!
```

```
! SET_5 ... Model Specifications (Thermal Forcing)
!
     XLP= 100.                 : Scale Height for Particular Soln
  THETA0= 1.0                  : Potential Temperature at z=0
   DELTA= 5.E-4                : Small Number for TAN(x) undefined
     EPS= 5.E-4                : Small Number for 1/x undefined
```

4.3 LINCOM Output

Running the LINCOM atmospheric flow model as described in Sect. 4 results in a log file, `NPS.log`, and the following eight binary output files: `UENPS.GRD`, `UNNPS.GRD`, `VENPS.GRD`, `VNNPS.GRD`, `UENPS2.GRD`, `UNNPS2.GRD`, `VENPS2.GRD` and `VNNPS2.GRD`. These files, which contain information regarding the perturbations of the wind field induced by the terrain, are subsequently read by the RIMPUFF atmospheric dispersion model.

5 RIMPUFF

In order to run the RIMPUFF atmospheric dispersion model, two input files are necessary: `INDATA` and `WINDDA`. Sample files appear below. The parameters in these files should not be changed except for those described below. However, an expert user should have the opportunity to set all parameters, e.g. by editing these files once they have been created by the quasi-automatic provision. As it appears from the RIMPUFF manuals [2, 1, 3], many additional parameters may be entered. These parameters obtain default values by the programme.

All time parameters are integers in units of seconds since the beginning of the wind recording(s). In case of more than one wind-recording station, the wind records are supposed to be simultaneous.

5.1 INDATA

The parameters `ICOLS`, `JROWS`, `XUTM`, `YUTM`, `DELX` and `DELY` are described in Section 3.

Presently, up to 50 sources are allowed by the programme. The number of sources is `NRMULT`, and the horizontal coordinates (in kilometres) are (`XSOURC`(i), `YSOURC`(i)), $i = 1, \ldots,$ `NRMULT`. The parameters `ZSOURC`(i) are the corresponding heights (in metres) in which virus is released, cf. Section 4.2.

The start and end times (integer number of seconds) for the release from source no. i are `STRTRL`(i) and `STOPRL`(i), respectively.

With the integer parameter `NRELSE` (seconds), one may choose to stop the sources at the same time regardless of the setting of the source terms. This is, however, not relevant for foot-and-mouth disease modelling, and thus one should choose a value larger than the time interval of concern, e.g. thousand days

$$\texttt{NRELSE} \sim 1000 \times 24 \times 60^2. \tag{5.1}$$

The viability of virus as a function of the relative humidity (RH) of the atmosphere is very low at RH less than 55% [6]. At RH $\approx$ 55%, the viability increases drastically to a constant value at higher values of RH. Thus the dependence of viability on RH may be modelled as an "on/off switch" turning the source on above 55% RH, and off below.

Assuming that virus have no effect of aging, and that the deactivation is a random process, it follows that the decay of virus is exponential in time. The exponential decay constant λ (sec^{-1}) for the virus in question is given by the parameter `ISDCAY`(i). By definition, the half life $T_{1/2}$ is given in terms of the decay constant by $T_{1/2} = \ln 2/\lambda$. The decay constant λ may be calculated from the (secondary) decay rate s (log. viability/hour), cf. Ref. [6], by the following formula

$$\lambda = \frac{\ln 2}{\log_{10} 2} \times \frac{s}{60^2} = 0.64 \times 10^{-3} \times s. \tag{5.2}$$

The decay rate s (hour^{-1}) depends on the virus strain. A typical value is 0.5 hour^{-1} (Donaldson, private communication).

The source strength is `SOURST`(i) in units of TCID_{50} per second averaged over the time of interest (24 hours).

A realistic value of the parameter `CHEMIN` may be calculated as follows,

$$\texttt{CHEMIN} = 2.6 \times 10^{-13} \times \min\{\texttt{SOURST}(i) \mid i = 1, \ldots, \texttt{NRMULT}\}. \tag{5.3}$$

The parameter `TAU` is the integer number of seconds between puff releases. A realistic value is

$$\texttt{TAU} = \texttt{ITSP}, \tag{5.4}$$

the averaging time for the wind records (`ITSP` *must* be an integer multiple of `TAU`).

The parameter `NTADV` is the integer number of seconds between each advection step. A realistic value is

$$\texttt{NTADV} = 0.15 \times \texttt{DELX}. \tag{5.5}$$

Besides, `TAU` *must* be an integer multiple of `NTADV`.

`MAPTIM` is the integer number of seconds between output of dose, e.g. `MAPTIM` = 21600 for output each 6 hours.

The parameter `PENTPF` takes on the values

$$\texttt{PENTPF} = \begin{cases} \text{.true.} & \text{for puff splitting (pentafurcation),} \\ \text{.false.} & \text{otherwise.} \end{cases} \tag{5.6}$$

As CPU time is of little concern for the flow and dispersion calculations, one should choose `PENTPF` = .true. as default. In case puff splitting is selected, an additional parameter `SYMPEN` is needed. This parameter identifies the threshold standard deviation σ_y in the horizontal Gaussian distribution of the puffs for pentafurcation. A realistic value is

$$\texttt{SYMPEN} = \texttt{DELX}. \tag{5.7}$$

Finally, the parameter `ISMODE` is a stability index mode directing the computation of lateral and vertical standard deviation of the puffs according to Table 2. Cf. the following discussion in Section 5.2.

`ISMODE`	σ_y	σ_z
1	Pasquill-Turner	Pasquill-Turner
2	Pasquill-Turner	Vertical direction deviation
3	Lateral direction deviation	Pasquill-Turner
4	Lateral direction deviation	Vertical direction deviation

TABLE 2. Corresponding values of the stability index mode `ISMODE` and the lateral and vertical standard deviation of the puffs.

The following is a sample `INDATA` file:

```
&PRIMDA
TITLE=' ',
ICOLS=101,JROWS=101,DELX=500.,DELY=500.,DELZ=1.,
KOORD=1,XUTM=400.0,YUTM=100.0,
NTADV=75,TAU=3600,MAPTIM=86400,NRELSE=8640000,
CHEMIN=3.12E-9,
ISMODE=1,
INPRNT='YES',OUTDAT='OUTPUT',OUTMOD='DOSE',
OUTPUF='NOOUTP',OUTWFD='NOOUTP',OUTAIR='OUTPUT',OUTScreen='NOOUTP',
PENTPF=.true.,SYMPEN= 500.,
DETPKT=.FALSE.
&END
&RELDAT
PUFFTX=' ',
NRMULT=3,
XSOURC(1)=428.912,YSOURC(1)=119.937,ZSOURC(1)=6.,
STRTRL(1)=0,STOPRL(1)=86400,SOURST(1)=12000.,
ISNAVN(1)='Virus  ',ISDCAY(1)=0.
XSOURC(2)=429.487,YSOURC(2)=109.351,ZSOURC(2)=6.,
STRTRL(2)=200,STOPRL(2)=86000,SOURST(2)=12000.,
ISNAVN(2)='Virus  ',ISDCAY(2)=0.
XSOURC(3)=409.000,YSOURC(3)=132.000,ZSOURC(3)=6.,
STRTRL(3)=0,STOPRL(3)=43200,SOURST(3)=14000.,
ISNAVN(3)='Virus  ',ISDCAY(3)=0.
&END
&STABDA
STABTX=' ',
ZMTAB(1)=1600.,ZMTAB(2)=1200.,ZMTAB(3)=800.,ZMTAB(4)=500.,
ZMTAB(5)=300.,ZMTAB(6)=200.,
DEPMOD=1,OUTDEP='NOOUTP',
VDTAB(1,1)=0.40E-2,VDTAB(2,1)=0.30E-2,VDTAB(3,1)=0.30E-2,
VDTAB(4,1)=0.20E-2,VDTAB(5,1)=0.07E-2,VDTAB(6,1)=0.05E-2,
VDTAB(1,2)=1.00E-2,VDTAB(2,2)=1.00E-2,VDTAB(3,2)=1.00E-2,
VDTAB(4,2)=0.70E-2,VDTAB(5,2)=0.30E-2,VDTAB(6,2)=0.20E-2,
VDTAB(1,3)=1.00E-2,VDTAB(2,3)=1.00E-2,VDTAB(3,3)=1.00E-2,
VDTAB(4,3)=1.00E-2,VDTAB(5,3)=0.60E-2,VDTAB(6,3)=0.60E-2,
VDTAB(1,4)=1.00E-2,VDTAB(2,4)=1.00E-2,VDTAB(3,4)=1.00E-2,
VDTAB(4,4)=1.00E-2,VDTAB(5,4)=1.00E-2,VDTAB(6,4)=0.70E-2,
VDTAB(1,5)=1.00E-2,VDTAB(2,5)=1.00E-2,VDTAB(3,5)=1.00E-2,
VDTAB(4,5)=1.00E-2,VDTAB(5,5)=1.00E-2,VDTAB(6,5)=1.00E-2,
LDTAB(1)=0.000042,LDTAB(2)=0.000106,LDTAB(3)=0.000233,
TIMRAI(1)=1692,TIMRAI(2)=2628,TIMRAI(3)=2232,
SIGYIN=50.,SIGZIN=6.
&END
```

5.2 WINDDA

In this file, values are assigned to parameters used by the wind-interpolation routines in RIMPUFF.

$$\begin{aligned}
\texttt{TIME} &= \langle\text{5-character string for time, format: HH:MM}\rangle, & (5.8)\\
\texttt{DATE} &= \langle\text{9-character string for date, format: DD-MMM-YY}\rangle, & (5.9)\\
\texttt{ITSP} &= \langle\text{integer averaging time for wind obs. (sec)}\rangle, & (5.10)\\
\texttt{NP} &= \langle\text{number of wind-observation stations (max. 10)}\rangle, & (5.11)\\
\texttt{NSTL} &= \texttt{NP}, & (5.12)\\
\texttt{NFX} &= \texttt{ICOLS}, & (5.13)\\
\texttt{NFY} &= \texttt{JROWS}, & (5.14)\\
\texttt{RCH} &= \max\{\texttt{ICOLS} \times \texttt{DELX}, \texttt{JROWS} \times \texttt{DELY}\}, & (5.15)\\
\texttt{HWOBS} &= \langle\text{height of wind-speed measurements (m)}\rangle. & (5.16)
\end{aligned}$$

In many cases, hourly wind recordings will be sufficient corresponding to $\texttt{ITSP} = 3600$.

As noted in Section 4, the user of the system should have the opportunity of running the dispersion model without first executing the flow model. According to this choice,

$$\texttt{FLOFLD} = \begin{cases} \text{.true.} & \text{LINCOM and RIMPUFF,} \\ \text{.false.} & \text{RIMPUFF only.} \end{cases} \qquad (5.17)$$

Set

$$\texttt{ITLinc} = \texttt{ITSP}. \qquad (5.18)$$

For each wind-recording meteorological tower ($i = 1, \ldots, \texttt{NP}$), the following data must be given:

$$\begin{aligned}
\texttt{NAMST}(i) &= \langle\text{6-character station name}\rangle, & (5.19)\\
\texttt{X}(i) &= \langle x \text{ coordinate of station (km)}\rangle, & (5.20)\\
\texttt{Y}(i) &= \langle y \text{ coordinate of station (km)}\rangle. & (5.21)
\end{aligned}$$

For a quasi-automatic system, one might use the following

$$\begin{aligned}
\texttt{ISXMIN}(1) &= \texttt{XUTM} \times 1000, & (5.22)\\
\texttt{ISXMAX}(1) &= \texttt{XUTM} \times 1000 + (\texttt{ICOLS} - 1) \times \texttt{DELX}, & (5.23)\\
\texttt{ISYMIN}(1) &= \texttt{YUTM} \times 1000, & (5.24)\\
\texttt{ISYMAX}(1) &= \texttt{YUTM} \times 1000 + (\texttt{JROWS} - 1) \times \texttt{DELY}, & (5.25)
\end{aligned}$$

and for $i = 2, \ldots,$ NP

$$\begin{aligned}\texttt{ISXMIN}(i) &= (\texttt{X}(i) - 10) \times 1000, \quad (5.26)\\ \texttt{ISXMAX}(i) &= (\texttt{X}(i) + 10) \times 1000, \quad (5.27)\\ \texttt{ISYMIN}(i) &= (\texttt{Y}(i) - 10) \times 1000, \quad (5.28)\\ \texttt{ISYMAX}(i) &= (\texttt{Y}(i) + 10) \times 1000. \quad (5.29)\end{aligned}$$

For each wind-observation time, a wind-data record is written in the `WINDDA` file below the Fortran namelist `WINPAR`. A wind-data record begins with a line containing a 5-character string giving the time (e.g. `'17:40'`), and it ends with a line containing a 4-character string `'EOWR'`, except for the last line which is `'STOP'` instead. In between a line appears for each station. The first parameter in this line is the (case-sensitive) station name (`NAMST`(i)), the second parameter indicates the lateral stability (see below), the third indicates the vertical stability (see below), the fourth is the wind direction (incident wind angle) in degrees, the fifth is the wind speed in metres per second, and the sixth is the rain intensity in millimetres per hour. The stability parameters should be given in accordance with the parameter `ISMODE` described in Table 2. Modern anemometers may provide the lateral and/or vertical standard deviation of the wind direction which are much better indicators of atmospheric stability than the Pasquill-Turner index [7]. In case `ISMODE` is 1 or 2, the *lateral* stability is given by the Pasquill-Turner stability index (a character `'A'`, ..., `'F'`), otherwise the standard deviation of the horizontal wind direction (in degrees). In case `ISMODE` is 1 or 3, the vertical stability is given by the Pasquill-Turner index, otherwise the standard deviation of the vertical wind direction (in degrees). Cf. Table 3 for details.

Insolation/cloud cover		Wind speed (m/s)				
		< 2	2–3	3–5	5–6	> 6
Day	strong insolation	A	B	B	C	C
	moderate insolation	B	B	C	D	D
	slight insolation	B	C	C	D	D
Day or night	overcast	D	D	D	D	D
Night	$\geq 1/2$ cloud cover	F	E	D	D	D
	$< 1/2$ cloud cover	F	F	E	D	D

TABLE 3. Pasquill-Turner stability classes. A: very unstable, B: unstable, C: slightly unstable, D: neutral, E: nearly stable, and F: stable.

The following is a sample `WINDDA` file:

```
&WINPAR
WNDTLE=' ',
TIME='00:00',DATE='24-DEC-94',ITSP=3600,
NP=2,NFX=101,NFY=101,NSTL=2,
RCH=50500.,
FLOFLD=.true.,ITLinc=3600,Fitting=.true.,Leveldif=.true.,
HWOBS=10.,
NAMST(1)='met_01',X(1)=443.179,Y(1)=117.981,
ISXMIN(1)=400000,ISXMAX(1)=450000,
ISYMIN(1)=100000,ISYMAX(1)=150000,
NAMST(2)='met_02',X(2)=420.000,Y(2)=132.000,
ISXMIN(2)=410000,ISXMAX(2)=430000,
ISYMIN(2)=122000,ISYMAX(2)=142000,
&END
'00:00'
'met_01', 'D', 'D', 113.0,  8.08,  0.400
'met_02', 'D', 'D', 130.0,  4.10,  0.200
'EOWR'
'01:00'
'met_01', 'D', 'D', 119.0,  8.08,  0.200
'met_02', 'D', 'D', 130.0,  4.10,  0.100
'EOWR'
.
. (84 lines deleted)
.
'23:00'
'met_01', 'D', 'D',  88.0, 13.56,  0.000
'met_02', 'D', 'D',  80.0, 12.30,  0.000
'STOP'
```

In order to save CPU time, it is advisable to produce RIMPUFF simulations corresponding to more than 24 hours, i.e. include wind records in the WINDDA file covering more than one day. Thus it is sufficient to make one total RIMPUFF simulation covering the whole period of interest instead of multiple runs, each corresponding to a 24-hour period. Due to the fact that RIMPUFF outputs the virus concentration integrated over time from the beginning of the wind records contained in WINDDA, one will have to make differences between the dose output at a given time and the dose corresponding to 24 hours before. This task is performed by the Rimpuff2ArcInfo module, cf. Sect. 5.3.1.

5.2.1 *Wind Profile*

The height at which the wind speed is measured is supposed to be the same for all stations. If this is not the case, one may use the following stability-dependent parametrisation relating the wind speed u at height h above ground, e.g. $h = 10$ m, with the observed wind speed u_{obs} at height h_{obs},

$$u = u_{\text{obs}} \left(\frac{h}{h_{\text{obs}}} \right)^m . \tag{5.30}$$

The wind-profile coefficient m depends on the stability category and the underlying terrain. In Table 4, default values for m are given [8].

Underlying surface	Stability class					
	A	B	C	D	E	F
Seas or lakes	0.03	0.05	0.06	0.08	0.10	0.12
Agricultural	0.10	0.15	0.20	0.25	0.35	0.40
Cities or woodlands	0.16	0.24	0.32	0.40	0.56	0.64

TABLE 4. Wind-profile coefficient m [8].

5.2.2 *Time Interpolation*

As the RIMPUFF dispersion model assumes constant weather conditions in between the weather recordings, it may be advisable to interpolate the obtained meteorological data in time (linear interpolation should be sufficient) to hourly values or less. Otherwise, false finger-like structures may appear in case of rapid changes in the weather conditions. Such structures may be smoothed out by interpolating the meteorological data in time.

Based on a graphical display of the meteorological data obtained, and possibly consulting a meteorological duty forecaster with a knowledge of the general weather pattern for the area of concern, the user (operator) of EpiMAN may decide upon a suitable time interval for interpolation, or may decide not to utilise atmospheric dispersion modelling in case of low quality or highly varying meteorological data.

An interpolated stability category may of course be obtained by interpolating the wind speed and the cloud cover, and subsequently utilise Table 3. Or one may assign numbers to the stability index (A: 1, B: 2, ..., F: 6). The interpolated stability category is then obtained by interpolating these numbers (floats), and subsequently rounding off to an integer.

When interpolating wind speed and direction, one faces the problem that the wind direction (in degrees) may jump 360°. As an example, assume that the wind direction is 350° at 1 o'clock and 10° at 3 o'clock. Naively, one might interpolate to a value of $(350° + 10°)/2 = 180°$ valid at 2 o'clock instead of the more sensible value of 0°.

One way of circumventing this problem is to decompose the wind vector in components u and v,

$$\begin{cases} u &= w \sin(\theta \times \pi/180° + \pi) \\ v &= w \cos(\theta \times \pi/180° + \pi), \end{cases} \tag{5.31}$$

where the wind speed is w, and the direction θ (degrees). The u and v components are interpolated (linearly) to the values u_i and v_i. From these, the interpolated values of wind speed, w_i, and direction, θ_i, may be derived,

$$\begin{cases} w_i &= \sqrt{u_i^2 + v_i^2} \\ \tan(\theta_i \times \pi/180° + \pi) &= u_i/v_i. \end{cases} \tag{5.32}$$

The latter equation is easily solved by using the C or Fortran inverse trigonometric function `atan2`,

$$\theta_i = 180°/\pi \times (\mathtt{atan2}(u_i/v_i) + \pi). \tag{5.33}$$

5.3 RIMPUFF Output

Running the RIMPUFF model as described above results in two output files, `OUTSTAB` and `OUTAIR_B.DAT`, as well as standard output.

The `OUTSTAB` file is an ASCII file containing information regarding the stability areas and the coordinates of the meteorological stations used in the calculation. The other file, `OUTAIR_B.DAT`, is binary and contains the essential results of the calculation, viz. the dose. The dose D, i.e. time integrated concentration from the beginning of the simulation to time T,

$$D(\mathbf{r}, T) = \int_0^T c(\mathbf{r}, t)\, \mathrm{d}t, \tag{5.34}$$

cf. Eq. (2.3), is output in units of $\mathrm{TCID}_{50} \times \mathrm{sec/m}^3$, The first record of `OUTAIR_B.DAT` is `XUTM, YUTM`. For each output time step `ITOTIM` $= n \times$ `MAPTIM`, the following records are present in the file: first a 72-character string, the next record is `ICOLS, JROWS, DELX, DELY, ITOTIM`, which is followed by the dose array.

5.3.1 *Interfacing RIMPUFF with ArcInfo*

In order to present the calculated doses by the GIS, the binary RIMPUFF output file `OUTAIR_B.DAT` needs to be converted to the right format.

As mentioned in Sect. 4.1, the ArcInfo GIS expects values associated with the centres of the grid cells. The Rimpuff2ArcInfo programme, written by the author of this document, splits `OUTAIR_B.DAT` into separate ASCII files, one for each output time step $\texttt{ITOTIM} = n \times \texttt{MAPTIM}$. These files comply with the ArcInfo format, and contain the calculated 24-hour average concentrations bilinearly interpolated to the centres of the grid cells. The average concentrations, output by Rimpuff2ArcInfo in units of $\mathrm{TCID}_{50}/\mathrm{m}^3$, are calculated by making 24-hour differences in the RIMPUFF dose output (5.34) as noted in Sect. 5.2,

$$
\begin{aligned}
\overline{c}(\mathbf{r}, T, \Delta T) &= \frac{1}{\Delta T}\int_{T-\Delta T}^{T} c(\mathbf{r}, t)\,\mathrm{d}t \\
&= \frac{1}{\Delta T}\left(\int_0^T c(\mathbf{r}, t)\,\mathrm{d}t - \int_0^{T-\Delta T} c(\mathbf{r}, t)\,\mathrm{d}t\right), \qquad (5.35)
\end{aligned}
$$

with $\Delta T = 24$ hr, so as to be directly comparable with the threshold average concentrations listed in Table 1. Each name of the resulting files contains a time stamp in seconds since the beginning of the simulation (`ITOTIM`) corresponding to the end time T of the 24-hour integration period, cf. Eq. (5.35).

The Rimpuff2ArcInfo interface is used by ‘piping’ a file name to the executable (Unix command: `echo ‘file name’ | Rimpuff2ArcInfo`). The present limitations of the interface are the following:

- The length of the string ‘file name’ must be less than 201 characters
- As for RIMPUFF, the maximum grid is: 200×200 grid cells
- As for ArcInfo, the parameters `DELX` and `DELY` have to be the same
- 24 hours in seconds, $24 \times 60^2 = 86\,400$, has to be an integer multiple of the parameter `MAPTIM`
- The smallest value of `MAPTIM` corresponds to one hour in seconds, i.e. $\texttt{MAPTIM} = 3600$

6 Meteorological Data

The LINCOM/RIMPUFF flow and dispersion model system requires either input from meteorological surface weather observations or from a high-resolution numerical weather-prediction (NWP) model. The necessary data are *wind (e.g. 10-m), precipitation, relative humidity* and *cloud cover.*

6.1 Meteorological Stations

In case an FMD outbreak occurs, it is of great significance to obtain relevant meteorological data without undue delay.

First, one will have to locate existing meteorological weather-recording stations in the vicinity of the infected farm(s). If such meteorological towers exist, they may be owned and run by e.g. a national meteorological institute, research institutions or private companies. In case data are available, and also historical data for the past days, the data will probably not have the same quality. Some wind-recording devices may provide digital data, others may not. And the format may be different. Also the time intervals between recordings may vary (e.g. 1, 3 or 6 hours). This will, of course, imply difficulties for the user of the system when interfacing with the flow and dispersion module.

Furthermore, the meteorological stations may not be positioned ideally for the scenario. The weather-recording station(s) should represent the average conditions for the area of concern. Possibly, there are no weather recordings at all near the infected area. If the airborne transport takes place across a large lake or a strait, relevant data are likely to be missing. And if the airborne transmission takes place across a national frontier, the provision of relevant meteorological observations may be obstructed by bureaucracy, cf. Sect. 6.3.

Of course, the emergency headquarter may decide to set up one or more meteorological towers at relevant positions in the area of interest. But in such a case, there will be a lack of historical data.

6.2 Numerical Weather Prediction (NWP) Models

A meteorological database containing the output of a numerical weather-prediction (NWP) model, e.g. the HIRLAM model (HIgh Resolution Limited Area Model) [9–11] running operationally at the Danish Meteorological Institute, contains historical meteorological data as well as forecasts. Some of the benefits gained by using such a database are *real-time* and *historical* meteorological data consisting of analysed meteorological fields, as well as *forecasts.* Analysed meteorological data are consistent with the available observations and the governing equations for atmospheric motion. Limited-area NWP models cover large areas, e.g. the whole EU and third countries.

The horizontal resolution of NWP models today is typically 20–50 km with 20–30 layers in the vertical, but through the development of still faster computers, this resolution is constantly being reduced. Presently, NWP models with a horizontal resolution of less than 5 km are developed at a number of meteorological institutes throughout the world. From the output of an NWP model, one may obtain parameters such as wind (speed and direction) at different heights, precipitation intensity, cloud cover and relative humidity. In addition, one may derive e.g. the atmospheric stability, the height of the atmospheric boundary layer (the mixing layer), the wind shear and temperature gradients. The latter parameters, which may be utilised as additional input to the LINCOM/RIMPUFF model complex, are not recorded by standard weather-recording stations.

Today limited-area NWP models normally utilise a basic time step of 3–4 minutes and dump the meteorological fields each three hours which, in fact, is quite adequate for the purpose of describing the airborne spread of FMD virus.

An atmospheric flow- and dispersion-model complex as e.g. LINCOM/RIMPUFF may well utilise data from a limited-area NWP model. From the output of the NWP model, one may simulate (hypothetical) meteorological weather-recording stations. The LINCOM flow model may subsequently be used to take into account the effect of the high-resolution terrain data (from the DEM of the GIS) on the wind.

A dispersion calculation based upon an operational NWP database gives, with insignificant delay, a prediction of the spread of virus even for outbreaks outside national frontiers and for airborne transmission across water.

Dispersion models not utilising data from NWP models but from a single (or a few) weather-recording stations assume persistent weather conditions when making forecasts for the plume spread. However, the time scale of interest for FMD outbreaks (days) is so long that the assumption of persistence is seldomly valid. Also for this purpose, numerical forecasts are beneficial.

6.3 Availability of Meteorological Data

Regarding the availability of meteorological data useful to the flow and dispersion model complex LINCOM/RIMPUFF from national meteorological offices or the European Center for Medium-range Weather Forecast (ECMWF), the following information have been obtained from Deputy Director, Dr. Klaus Hedegaard, the Observation Department at the Danish Meteorological Institute (DMI), and Head of Operations Section, Dr. Bernard Strauss, the Meteorological Division at ECMWF.

- Provision of meteorological data from ECMWF within an ECMWF member state must always be requested through the national meteorological service
- ECMWF does not have available weather recordings which are not sent out on the Global Telecommunication System (GTS) to the ECMWF member states
- In general, national meteorological services *do* have weather data which are not transmitted on the GTS. Certain countries transmit only a fraction of their available data
- The horizontal resolution of the observational data available from the GTS varies considerably, but a resolution of 100–200 km seems to be common
- The time resolution of the data available from the GTS for 10-m wind, relative humidity and cloud cover is in general 1 hour for UK, Denmark and Germany, while it is 3 hours for most other countries. The time resolution of the data available from the GTS for precipitation is in general 3 hours for Denmark and France, while it is 6 hours for most other countries
- The required meteorological data for the LINCOM/RIMPUFF system may, alternatively, be obtained from a high-resolution NWP model, e.g. the HIRLAM model (HIgh Resolution Limited Area Model) [9–11] which is operational at DMI, and which covers all of EU and third countries. Thus, the data may be obtained from *one* meteorological service only. This implies a prediction of the spread of virus with insignificant delay, even for outbreaks where there are no ideally positioned weather-recording stations nearby

7 GUI, Plots and Archiving

In the communication between the system and the user by the graphical user interface (GUI), it is advised to use general terms with as little relation to the technicalities of the model complex as possible. One may for instance use the term flow model instead of LINCOM, atmospheric dispersion model instead of RIMPUFF, puff-splitting technique instead of pentafurcation etc.

On the plots showing the calculated dose patterns (time integrated virus concentrations or average concentrations), the virus-excreting farms and the weather-recording stations being used should be clearly marked. Also the boundaries of the (sub-)grid used for the flow and dispersion calculation should be indicated. And a colour table should appear giving the colour coding of the dose plumes. Besides, a time stamp showing the valid time for the dose plume is of great significance. It should be clearly indicated whether this time is the initial or final time for the (24-hour) time interval.

When archiving meteorological data, a time stamp should be given. And it should be clearly stated whether this time is the initial or final time for the dose time interval. In case use is being made of NWP data (with the possibility of utilising forecasts), it should also be indicated whether historical (analysed) meteorological data are used or forecasts.

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