An optimal parameters-based geographical detector model enhances geographic characteristics of explanatory variables for spatial heterogeneity analysis: Cases with different types of spatial data

Supplementary Information 2: Computation process and results of example cases

Note:

R package "GD: Geographical Detectors" version 1.7.

The codes can be run by R (>= 3.4.0).

Orders of codes are consistent with the orders in the article.

4.1 Spatial raster data of vegetation changes

```
library("GD")
data(ndvi_40)
head(ndvi_40)
```

```
##   NDVIchange Climatezone Mining Tempchange Precipitation   GDP Popdensity
## 1    0.11599         Bwk    low    0.25598        236.54 12.55    1.44957
## 2    0.01783         Bwk    low    0.27341        213.55  2.69    0.80124
## 3    0.13817         Bsk    low    0.30247        448.88 20.06   11.49432
## 4    0.00439         Bwk    low    0.38302        212.76  0.00    0.04620
## 5    0.00316         Bwk    low    0.35729        205.01  0.00    0.07482
## 6    0.00838         Bwk    low    0.33750        200.55  0.00    0.54941
```

Optimal discretization for multiple spatial variables (Figure 5)

```
## set optional discretization methods and numbers of intervals
discmethod <- c("equal","natural","quantile","geometric","sd")
discitv <- 3:7
## optimal discretization
ndvi.test <- ndvi_40
odc1 <- optidisc(NDVIchange ~ ., data = ndvi.test[, -(2:3)], discmethod, discitv)
odc1
## plot optimal discretization processes and results
plot(odc1)
## convert continuous variables to strata variables based on discretization breaks
ndvi.test[, 4:7] <- do.call(cbind, lapply(1:4, function(x)
  data.frame(cut(ndvi.test[, x+3], unique(odc1[[x]]$itv), include.lowest = TRUE))))
```

Factor detector (Figure 6):

```
## factor detector
mvgd <- gd(NDVIchange ~ ., data = ndvi.test)
mvgd
plot(mvgd)
```

Risk detector (Figure 7):

```
## risk detector: risk means
mvrm <- riskmean(NDVIchange ~ ., data = ndvi.test)
mvrm
plot(mvrm)
## risk detector: risk matrix
mvgr <- gdrisk(NDVIchange ~ ., data = ndvi.test)
mvgr
plot(mvgr)
```

Interaction detector (Figure 8a):

```
## interaction detector
mvgi <- gdinteract(NDVIchange ~ ., data = ndvi.test)
mvgi
plot(mvgi)
```

Ecological detector (Figure 8b):

```
## ecological detector
mvge <- gdeco(NDVIchange ~ ., data = ndvi.test)
mvge
plot(mvge)
```

Results of the optimal discretization and geographical detectors by the one-step function "gdm" for exploring factors of vegetation changes.

```
data("ndvi_40")
## set optional parameters of optimal discretization
discmethod <- c("equal","natural","quantile","geometric","sd")
discitv <- 3:7
## "gdm" function (~ 10.7 s)
ndvigdm <- gdm(NDVIchange ~ .,
               continuous_variable = c("Tempchange", "Precipitation", "GDP", "Popdensity"),
               data = ndvi_40,
               discmethod = discmethod, discitv = discitv)
ndvigdm
```

```
## Explanatory variables include 4 continuous variables.
##
## optimal discretization result of Tempchange
## method            :  sd
## number of intervals:  7
## intervals:
##  -0.39277 0.3106004 0.6614902 1.01238 1.36327 1.71416 2.065049 3.22051
## numbers of data within intervals:
##  93 102 82 151 99 100 86
##
## optimal discretization result of Precipitation
## method            :  equal
## number of intervals:  7
## intervals:
##  42.51 132.5014 222.4929 312.4843 402.4757 492.4671 582.4586 672.45
## numbers of data within intervals:
##  108 107 81 137 136 56 88
##
```

```
## optimal discretization result of GDP
## method             :  natural
## number of intervals:  7
## intervals:
##  0 9.9235 33.406 100.6513 289.6999 887.9468 4598.732 16589.09
## numbers of data within intervals:
##  325 84 79 90 84 46 5
##
## optimal discretization result of Popdensity
## method             :  quantile
## number of intervals:  7
## intervals:
##  0 0.2301671 0.9002686 2.021381 5.253373 14.80794 40.57514 970.8682
## numbers of data within intervals:
##  102 102 102 101 102 102 102
##
## Geographical detectors results:
##
## Factor detector:
##        variable         qv          sig
## 1   Climatezone 0.82183348 7.176240e-10
## 2        Mining 0.14111542 6.608981e-10
## 3    Tempchange 0.32655370 3.094152e-10
## 4 Precipitation 0.86935048 2.518923e-10
## 5           GDP 0.09514837 2.347511e-09
## 6    Popdensity 0.19618770 2.146283e-10
##
## Risk detector:
## Climatezone
##   itv    meanrisk
## 1 Bsk 0.143572961
## 2 Bwk 0.004536505
## 3 Dwa 0.321735000
## 4 Dwb 0.343155655
## 5 Dwc 0.444868361
##
## Mining
##         itv   meanrisk
## 1  very low 0.21008297
## 2       low 0.03294513
## 3    medium 0.30733460
## 4      high 0.26695286
## 5 very high 0.19176875
##
## Tempchange
##              itv   meanrisk
## 1 [-0.393,0.311] 0.03237419
## 2  (0.311,0.661] 0.07312216
## 3   (0.661,1.01] 0.22091646
## 4    (1.01,1.36] 0.32457258
## 5    (1.36,1.71] 0.29258313
## 6    (1.71,2.07] 0.23839880
## 7    (2.07,3.22] 0.17535547
##
```

```
## Precipitation
##          itv    meanrisk
## 1 [42.5,133] -0.01608009
## 2  (133,222]  0.02460271
## 3  (222,312]  0.07515988
## 4  (312,402]  0.22508642
## 5  (402,492]  0.31663221
## 6  (492,582]  0.45128393
## 7  (582,672]  0.44689250
##
## GDP
##                  itv  meanrisk
## 1           [0,9.92] 0.1460310
## 2        (9.92,33.4] 0.2295733
## 3         (33.4,101] 0.2217597
## 4          (101,290] 0.2818238
## 5          (290,888] 0.2605960
## 6      (888,4.6e+03] 0.2748348
## 7 (4.6e+03,1.66e+04] 0.2642400
##
## Popdensity
##           itv   meanrisk
## 1    [0,0.23] 0.04825588
## 2  (0.23,0.9] 0.13872392
## 3  (0.9,2.02] 0.17562520
## 4 (2.02,5.25] 0.25928089
## 5 (5.25,14.8] 0.27412971
## 6 (14.8,40.6] 0.25845363
## 7  (40.6,971] 0.27435755
##
## Climatezone
##   interval  Bsk  Bwk  Dwa  Dwb  Dwc
## 1      Bsk <NA> <NA> <NA> <NA> <NA>
## 2      Bwk    Y <NA> <NA> <NA> <NA>
## 3      Dwa    Y    Y <NA> <NA> <NA>
## 4      Dwb    Y    Y    N <NA> <NA>
## 5      Dwc    Y    Y    Y    Y <NA>
##
## Mining
##    interval very low  low medium high very high
## 1  very low     <NA> <NA>   <NA> <NA>      <NA>
## 2       low        Y <NA>   <NA> <NA>      <NA>
## 3    medium        Y    Y   <NA> <NA>      <NA>
## 4      high        Y    Y      N <NA>      <NA>
## 5 very high        N    Y      Y    Y      <NA>
##
## Tempchange
##         interval [-0.393,0.311] (0.311,0.661] (0.661,1.01] (1.01,1.36]
## 1 [-0.393,0.311]           <NA>          <NA>         <NA>        <NA>
## 2  (0.311,0.661]              Y          <NA>         <NA>        <NA>
## 3   (0.661,1.01]              Y             Y         <NA>        <NA>
## 4    (1.01,1.36]              Y             Y            Y        <NA>
## 5    (1.36,1.71]              Y             Y            Y           N
## 6    (1.71,2.07]              Y             Y            N           Y
```

```
## 7    (2.07,3.22]             Y             Y            N           Y
##   (1.36,1.71] (1.71,2.07] (2.07,3.22]
## 1        <NA>        <NA>        <NA>
## 2        <NA>        <NA>        <NA>
## 3        <NA>        <NA>        <NA>
## 4        <NA>        <NA>        <NA>
## 5        <NA>        <NA>        <NA>
## 6           Y        <NA>        <NA>
## 7           Y           Y        <NA>
##
## Precipitation
##     interval [42.5,133] (133,222] (222,312] (312,402] (402,492] (492,582]
## 1 [42.5,133]       <NA>      <NA>      <NA>      <NA>      <NA>      <NA>
## 2  (133,222]          Y      <NA>      <NA>      <NA>      <NA>      <NA>
## 3  (222,312]          Y         Y      <NA>      <NA>      <NA>      <NA>
## 4  (312,402]          Y         Y         Y      <NA>      <NA>      <NA>
## 5  (402,492]          Y         Y         Y         Y      <NA>      <NA>
## 6  (492,582]          Y         Y         Y         Y         Y      <NA>
## 7  (582,672]          Y         Y         Y         Y         Y         N
##   (582,672]
## 1      <NA>
## 2      <NA>
## 3      <NA>
## 4      <NA>
## 5      <NA>
## 6      <NA>
## 7      <NA>
##
## GDP
##             interval [0,9.92] (9.92,33.4] (33.4,101] (101,290] (290,888]
## 1           [0,9.92]     <NA>        <NA>       <NA>      <NA>      <NA>
## 2        (9.92,33.4]        Y        <NA>       <NA>      <NA>      <NA>
## 3         (33.4,101]        Y           N       <NA>      <NA>      <NA>
## 4          (101,290]        Y           Y          Y      <NA>      <NA>
## 5          (290,888]        Y           N          N         N      <NA>
## 6      (888,4.6e+03]        Y           N          Y         N         N
## 7 (4.6e+03,1.66e+04]        Y           N          N         N         N
##   (888,4.6e+03] (4.6e+03,1.66e+04]
## 1          <NA>               <NA>
## 2          <NA>               <NA>
## 3          <NA>               <NA>
## 4          <NA>               <NA>
## 5          <NA>               <NA>
## 6          <NA>               <NA>
## 7             N               <NA>
##
## Popdensity
##      interval [0,0.23] (0.23,0.9] (0.9,2.02] (2.02,5.25] (5.25,14.8]
## 1    [0,0.23]     <NA>       <NA>       <NA>        <NA>        <NA>
## 2  (0.23,0.9]        Y       <NA>       <NA>        <NA>        <NA>
## 3  (0.9,2.02]        Y          N       <NA>        <NA>        <NA>
## 4 (2.02,5.25]        Y          Y          Y        <NA>        <NA>
## 5 (5.25,14.8]        Y          Y          Y           N        <NA>
## 6 (14.8,40.6]        Y          Y          Y           N           N
```

```
## 7  (40.6,971]        Y          Y          Y           N           N
##   (14.8,40.6] (40.6,971]
## 1        <NA>       <NA>
## 2        <NA>       <NA>
## 3        <NA>       <NA>
## 4        <NA>       <NA>
## 5        <NA>       <NA>
## 6        <NA>       <NA>
## 7           N       <NA>
##
## Interaction detector:
##        variable Climatezone Mining Tempchange Precipitation    GDP Popdensity
## 1   Climatezone          NA     NA         NA            NA     NA         NA
## 2        Mining      0.8345     NA         NA            NA     NA         NA
## 3    Tempchange      0.8538 0.4223         NA            NA     NA         NA
## 4 Precipitation      0.9016 0.8861     0.9158            NA     NA         NA
## 5           GDP      0.8571 0.2438     0.3886        0.8959     NA         NA
## 6    Popdensity      0.8599 0.3588     0.4352        0.9035 0.2166         NA
##
## Ecological detector:
##        variable Climatezone Mining Tempchange Precipitation  GDP Popdensity
## 1   Climatezone        <NA>   <NA>       <NA>          <NA> <NA>       <NA>
## 2        Mining           N   <NA>       <NA>          <NA> <NA>       <NA>
## 3    Tempchange           N      Y       <NA>          <NA> <NA>       <NA>
## 4 Precipitation           Y      Y          Y          <NA> <NA>       <NA>
## 5           GDP           N      N          N             N <NA>       <NA>
## 6    Popdensity           N      N          N             N    N       <NA>
```

```r
plot(ndvigdm)
```

Codes and data of the computation processes of the t-test for risk detector, interactions explored by the interaction detector and the F-test for ecological detector.

```r
## t-test of risk detector for the variable Climatezone
ndvigdm$Risk.detector$Climatezone
```

```
##    itv1 itv2          t        df          sig risk
## 1   Bsk  Bwk  17.730358 315.88563  2.637662e-49    Y
## 2   Bsk  Dwa -11.809163  52.13343  2.360201e-16    Y
## 3   Bsk  Dwb -19.658136 327.45054  2.276521e-57    Y
## 4   Bsk  Dwc -37.998231 304.88974 1.143504e-117    Y
## 5   Bwk  Dwa -22.770854  38.27911  7.381701e-24    Y
## 6   Bwk  Dwb -40.614567 215.91365 4.556501e-103    Y
## 7   Bwk  Dwc -81.337846 296.50585 8.422103e-205    Y
## 8   Dwa  Dwb  -1.395461  55.29265  1.684563e-01    N
## 9   Dwa  Dwc  -8.808167  38.78614  8.589747e-11    Y
## 10  Dwb  Dwc -12.080308 215.01449  5.524023e-26    Y
```

```r
## t-test of risk detector for the variable Tempchange
ndvigdm$Risk.detector$Tempchange
```

```
##              itv1          itv2           t       df          sig risk
## 1  [-0.393,0.311] (0.311,0.661]  -2.1784882 192.2786 3.058620e-02    Y
## 2  [-0.393,0.311]  (0.661,1.01]  -8.1978707 141.2153 1.345932e-13    Y
## 3  [-0.393,0.311]   (1.01,1.36] -16.0313363 234.0217 1.570643e-39    Y
## 4  [-0.393,0.311]   (1.36,1.71] -12.8583388 182.2434 2.393170e-27    Y
```

```
## 5  [-0.393,0.311]   (1.71,2.07] -10.9120573 189.5401 7.974504e-22    Y
## 6  [-0.393,0.311]   (2.07,3.22]  -7.4129666 170.1484 5.545589e-12    Y
## 7   (0.311,0.661]  (0.661,1.01]  -6.2085679 153.7650 4.757633e-09    Y
## 8   (0.311,0.661]   (1.01,1.36] -13.0734367 236.4896 9.325721e-30    Y
## 9   (0.311,0.661]   (1.36,1.71] -10.3773420 194.7078 2.309357e-20    Y
## 10  (0.311,0.661]   (1.71,2.07]  -8.3244706 199.8569 1.320714e-14    Y
## 11  (0.311,0.661]   (2.07,3.22]  -5.0504897 182.3930 1.063394e-06    Y
## 12   (0.661,1.01]   (1.01,1.36]  -4.4238549 156.7164 1.806223e-05    Y
## 13   (0.661,1.01]   (1.36,1.71]  -2.8636285 165.3820 4.731052e-03    Y
## 14   (0.661,1.01]   (1.71,2.07]  -0.7301574 154.8633 4.663970e-01    N
## 15   (0.661,1.01]   (2.07,3.22]   1.8775727 153.0666 6.234221e-02    N
## 16    (1.01,1.36]   (1.36,1.71]   1.5434067 214.0154 1.242095e-01    N
## 17    (1.01,1.36]   (1.71,2.07]   4.4408817 231.4842 1.387933e-05    Y
## 18    (1.01,1.36]   (2.07,3.22]   7.5356809 203.4925 1.565776e-12    Y
## 19    (1.36,1.71]   (1.71,2.07]   2.5434236 194.1126 1.175653e-02    Y
## 20    (1.36,1.71]   (2.07,3.22]   5.4107475 182.9856 1.947797e-07    Y
## 21    (1.71,2.07]   (2.07,3.22]   3.0896365 181.6485 2.319198e-03    Y
```

```r
## interactions explored by the interaction detector
ndvigdm$Interaction.detector$Interaction
```

```
##             var1          var2        qv1        qv2      qv12
## 1    Climatezone        Mining 0.82183348 0.14111542 0.8344738
## 2    Climatezone    Tempchange 0.82183348 0.32655370 0.8537915
## 3    Climatezone Precipitation 0.82183348 0.86935048 0.9015820
## 4    Climatezone           GDP 0.82183348 0.09514837 0.8571228
## 5    Climatezone    Popdensity 0.82183348 0.19618770 0.8599232
## 6         Mining    Tempchange 0.14111542 0.32655370 0.4223200
## 7         Mining Precipitation 0.14111542 0.86935048 0.8861185
## 8         Mining           GDP 0.14111542 0.09514837 0.2438202
## 9         Mining    Popdensity 0.14111542 0.19618770 0.3587628
## 10    Tempchange Precipitation 0.32655370 0.86935048 0.9158048
## 11    Tempchange           GDP 0.32655370 0.09514837 0.3885994
## 12    Tempchange    Popdensity 0.32655370 0.19618770 0.4351518
## 13 Precipitation           GDP 0.86935048 0.09514837 0.8958678
## 14 Precipitation    Popdensity 0.86935048 0.19618770 0.9035324
## 15           GDP    Popdensity 0.09514837 0.19618770 0.2165923
##          interaction
## 1        Enhance, bi-
## 2        Enhance, bi-
## 3        Enhance, bi-
## 4        Enhance, bi-
## 5        Enhance, bi-
## 6        Enhance, bi-
## 7        Enhance, bi-
## 8  Enhance, nonlinear
## 9  Enhance, nonlinear
## 10       Enhance, bi-
## 11       Enhance, bi-
## 12       Enhance, bi-
## 13       Enhance, bi-
## 14       Enhance, bi-
## 15       Enhance, bi-
```

```
## F-test of ecological detector
ndvigdm$Ecological.detector$Ecological
```

```
##             var1          var2         f          sig eco
## 1    Climatezone        Mining 0.2080971 1.000000e+00   N
## 2    Climatezone    Tempchange 0.2637874 1.000000e+00   N
## 3    Climatezone Precipitation 1.3616512 1.987113e-05   Y
## 4    Climatezone           GDP 0.1968338 1.000000e+00   N
## 5    Climatezone    Popdensity 0.2209808 1.000000e+00   N
## 6         Mining    Tempchange 1.2676168 7.915003e-04   Y
## 7         Mining Precipitation 6.5433453 0.000000e+00   Y
## 8         Mining           GDP 0.9458750 7.709827e-01   N
## 9         Mining    Popdensity 1.0619118 2.115358e-01   N
## 10    Tempchange Precipitation 5.1619268 0.000000e+00   Y
## 11    Tempchange           GDP 0.7461836 9.999515e-01   N
## 12    Tempchange    Popdensity 0.8377230 9.908628e-01   N
## 13 Precipitation           GDP 0.1445553 1.000000e+00   N
## 14 Precipitation    Popdensity 0.1622888 1.000000e+00   N
## 15           GDP    Popdensity 1.1226767 6.143133e-02   N
```

Comparison of size effects of spatial units (Figure 9).

```
ndvilist <- list(ndvi_5, ndvi_10, ndvi_20, ndvi_30, ndvi_40, ndvi_50)
su <- c(5,10,20,30,40,50) ## sizes of spatial units
## set optional parameters of optimal discretization
discmethod <- c("equal","natural","quantile","geometric","sd")
discitv <- 3:7
## "gdm" function (~ 108 s)
gdlist <- list()
for (i in 1:6){
    gdlist[[i]] <- gdm(NDVIchange ~ .,
      continuous_variable = c("Tempchange", "Precipitation", "GDP", "Popdensity"),
      data = ndvilist[[i]], discmethod = discmethod, discitv = discitv)
}
## size effects of spatial units
sesu(gdlist, su)
```

4.2 Spatial point or areal data of H1N1 flu incidences

4.2.1 In the whole study area

```
data(h1n1_100)
head(h1n1_100)
```

```
##   H1N1   temp     prec    humi   popd   gdpd  rdds sensepop urbanpop medicost
## 1 2.02 22.257 2169.194 28.0085 171.24 0.4074 23.33  26.8913    52.74  94.1805
## 2 2.02 22.730 2131.414 44.7943 213.10 0.7876 26.55  26.8913    52.74  94.1805
## 3 2.02 23.288 2438.123 45.8407 288.81 1.5207 38.17  26.8913    52.74  94.1805
## 4 1.45 22.914 2251.993 24.3231 719.93 1.9710 53.61  23.9246    67.76  64.8081
## 5 1.45 22.566 2355.137 33.6370 791.68 3.4102 57.40  23.9246    67.76  64.8081
## 6 1.09 21.169 1658.817 34.9150  90.36 0.2519 17.24  28.0352    40.48  77.7068
##   Georegion
## 1         S
## 2         S
## 3         S
```

```
## 4          S
## 5          S
## 6          W
```

Results of OPGD-based analysis for H1N1 flu incidences (Figure 10).

```r
h1n1list <- list(h1n1_50, h1n1_100, h1n1_150)
su <- c(50, 100, 150)
## set optional parameters of optimal discretization
discmethod <- c("equal","natural","quantile","geometric","sd")
discitv <- 4:7
continuous_variable <- colnames(h1n1_50)[-c(1,11)]
## "gdm" function (~ 67 s)
gdlist <- list()
for (i in 1:3){
  gdlist[[i]] <- gdm(H1N1 ~ .,
               continuous_variable = continuous_variable,
               data = h1n1list[[i]],
               discmethod = discmethod, discitv = discitv)
}
## size effects of spatial units
sesu(gdlist, su)
```

```r
## recalculation with 100-km spatial unit
discmethod <- c("equal","natural","quantile","geometric","sd")
discitv <- 4:7
continuous_variable <- colnames(h1n1_100)[-c(1,11)]
h1n1.gdm.100 <- gdm(H1N1 ~ .,
               continuous_variable = continuous_variable,
               data = h1n1_100,
               discmethod = discmethod, discitv = discitv)
h1n1.gdm.100
```

```
## Explanatory variables include 9 continuous variables.
##
## optimal discretization result of temp
## method             :  equal
## number of intervals:  7
## intervals:
##  -7.092 -2.740286 1.611429 5.963143 10.31486 14.66657 19.01829 23.37
## numbers of data within intervals:
##  78 175 178 167 148 172 69
##
## optimal discretization result of prec
## method             :  natural
## number of intervals:  7
## intervals:
##  13.13 218.9193 407.3756 611.4574 828.5553 1176.74 1750.94 2569.669
## numbers of data within intervals:
##  171 153 196 204 108 120 35
##
## optimal discretization result of humi
## method             :  quantile
## number of intervals:  6
## intervals:
```

```
##  -109.0914 -54.95307 -29.4622 -8.1786 12.91037 41.38707 177.9288
## numbers of data within intervals:
##  165 164 165 164 164 165
##
## optimal discretization result of popd
## method             :  natural
## number of intervals:  6
## intervals:
##  0 15.4227 81.1539 225.1411 469.9451 989.8658 2786.56
## numbers of data within intervals:
##  471 140 184 100 71 21
##
## optimal discretization result of gdpd
## method             :  natural
## number of intervals:  7
## intervals:
##  0 0.059117 0.288647 0.666049 1.548748 3.410617 7.495601 22.1713
## numbers of data within intervals:
##  460 134 138 123 76 42 14
##
## optimal discretization result of rdds
## method             :  natural
## number of intervals:  7
## intervals:
##  0 3.9791 11.2851 21.8487 37.4985 62.3373 131.1288 316.5
## numbers of data within intervals:
##  396 150 145 153 73 55 15
##
## optimal discretization result of sensepop
## method             :  sd
## number of intervals:  6
## intervals:
##  18.5058 22.74193 24.14647 25.551 26.95554 28.36007 29.76461 31.3683
## numbers of data within intervals:
##  212 33 56 75 318 250 43
##
## optimal discretization result of urbanpop
## method             :  sd
## number of intervals:  4
## intervals:
##  23.71 35.0363 46.59943 58.16257 86.3
## numbers of data within intervals:
##  133 369 292 193
##
## optimal discretization result of medicost
## method             :  quantile
## number of intervals:  7
## intervals:
##  60.1877 64.8081 72.8208 79.1247 86.1034 95.1002 143.9295 158.2044
## numbers of data within intervals:
##  149 137 141 229 115 82 134
##
## Geographical detectors results:
##
```

```
## Factor detector:
##     variable         qv          sig
## 1       temp 0.49088033 1.838595e-10
## 2       prec 0.40566048 3.619388e-10
## 3       humi 0.17352575 2.380844e-10
## 4       popd 0.22000829 4.038251e-10
## 5       gdpd 0.21462378 7.726012e-10
## 6       rdds 0.23398371 7.034787e-10
## 7   sensepop 0.43308776 3.418482e-10
## 8   urbanpop 0.34291104 6.720092e-10
## 9   medicost 0.45571331 3.509079e-10
## 10 Georegion 0.07399135 6.481682e-11
##
## Risk detector:
## temp
##             itv  meanrisk
## 1 [-7.09,-2.74] 0.2285897
## 2  (-2.74,1.61] 0.2637714
## 3   (1.61,5.96] 0.3753933
## 4   (5.96,10.3] 0.6703593
## 5   (10.3,14.7] 0.6264189
## 6     (14.7,19] 0.8155233
## 7     (19,23.4] 1.5410145
##
## prec
##                   itv  meanrisk
## 1          [13.1,219] 0.6188889
## 2           (219,407] 0.4271242
## 3           (407,611] 0.4032143
## 4           (611,829] 0.3638725
## 5      (829,1.18e+03] 0.6881481
## 6 (1.18e+03,1.75e+03] 1.0233333
## 7 (1.75e+03,2.57e+03] 1.7288571
##
## humi
##             itv  meanrisk
## 1    [-109,-55] 0.4675152
## 2   (-55,-29.5] 0.5257927
## 3 (-29.5,-8.18] 0.5613333
## 4  (-8.18,12.9] 0.3378659
## 5   (12.9,41.4] 0.6747561
## 6    (41.4,178] 0.9697576
##
## popd
##              itv  meanrisk
## 1       [0,15.4] 0.3786624
## 2    (15.4,81.2] 0.6187857
## 3     (81.2,225] 0.8997826
## 4      (225,470] 0.8733000
## 5      (470,990] 0.6371831
## 6 (990,2.79e+03] 0.9028571
##
## gdpd
##              itv  meanrisk
```

```
## 1     [0,0.0591] 0.3791739
## 2 (0.0591,0.289] 0.6033582
## 3  (0.289,0.666] 0.8801449
## 4   (0.666,1.55] 0.9006504
## 5    (1.55,3.41] 0.7182895
## 6     (3.41,7.5] 0.6107143
## 7     (7.5,22.2] 1.0228571
##
## rdds
##           itv  meanrisk
## 1    [0,3.98] 0.3558586
## 2 (3.98,11.3] 0.5077333
## 3 (11.3,21.8] 0.8104828
## 4 (21.8,37.5] 0.9307843
## 5 (37.5,62.3] 0.7598630
## 6  (62.3,131] 0.6310909
## 7   (131,316] 0.9920000
##
## sensepop
##           itv  meanrisk
## 1 [18.5,22.7] 0.5559434
## 2 (22.7,24.1] 1.3181818
## 3 (24.1,25.6] 0.8432143
## 4   (25.6,27] 0.7149333
## 5   (27,28.4] 0.5564465
## 6 (28.4,29.8] 0.2841600
## 7 (29.8,31.4] 1.6716279
##
## urbanpop
##           itv  meanrisk
## 1   [23.7,35] 0.0300000
## 2   (35,46.6] 0.7440108
## 3 (46.6,58.2] 0.4399315
## 4 (58.2,86.3] 0.9071503
##
## medicost
##           itv   meanrisk
## 1 [60.2,64.8] 0.48510067
## 2 (64.8,72.8] 0.64489051
## 3 (72.8,79.1] 1.14609929
## 4 (79.1,86.1] 0.60742358
## 5 (86.1,95.1] 0.82208696
## 6  (95.1,144] 0.25109756
## 7   (144,158] 0.04186567
##
## Georegion
##   itv  meanrisk
## 1   N 0.3687603
## 2   S 0.8471154
## 3   W 0.5708451
##
## temp
##        interval [-7.09,-2.74] (-2.74,1.61] (1.61,5.96] (5.96,10.3] (10.3,14.7]
## 1 [-7.09,-2.74]          <NA>         <NA>        <NA>        <NA>        <NA>
```

```
## 2  (-2.74,1.61]             N         <NA>        <NA>        <NA>        <NA>
## 3   (1.61,5.96]             Y            Y        <NA>        <NA>        <NA>
## 4   (5.96,10.3]             Y            Y           Y        <NA>        <NA>
## 5   (10.3,14.7]             Y            Y           Y           N        <NA>
## 6     (14.7,19]             Y            Y           Y           Y           Y
## 7     (19,23.4]             Y            Y           Y           Y           Y
##   (14.7,19] (19,23.4]
## 1      <NA>      <NA>
## 2      <NA>      <NA>
## 3      <NA>      <NA>
## 4      <NA>      <NA>
## 5      <NA>      <NA>
## 6      <NA>      <NA>
## 7         Y      <NA>
##
## prec
##              interval [13.1,219] (219,407] (407,611] (611,829] (829,1.18e+03]
## 1          [13.1,219]       <NA>      <NA>      <NA>      <NA>           <NA>
## 2           (219,407]          Y      <NA>      <NA>      <NA>           <NA>
## 3           (407,611]          Y         N      <NA>      <NA>           <NA>
## 4           (611,829]          Y         N         N      <NA>           <NA>
## 5      (829,1.18e+03]          N         Y         Y         Y           <NA>
## 6 (1.18e+03,1.75e+03]          Y         Y         Y         Y              Y
## 7 (1.75e+03,2.57e+03]          Y         Y         Y         Y              Y
##   (1.18e+03,1.75e+03] (1.75e+03,2.57e+03]
## 1                <NA>                <NA>
## 2                <NA>                <NA>
## 3                <NA>                <NA>
## 4                <NA>                <NA>
## 5                <NA>                <NA>
## 6                <NA>                <NA>
## 7                   Y                <NA>
##
## humi
##        interval [-109,-55] (-55,-29.5] (-29.5,-8.18] (-8.18,12.9] (12.9,41.4]
## 1    [-109,-55]       <NA>        <NA>          <NA>         <NA>        <NA>
## 2   (-55,-29.5]          N        <NA>          <NA>         <NA>        <NA>
## 3 (-29.5,-8.18]          Y           N          <NA>         <NA>        <NA>
## 4  (-8.18,12.9]          Y           Y             Y         <NA>        <NA>
## 5   (12.9,41.4]          Y           Y             Y            Y        <NA>
## 6    (41.4,178]          Y           Y             Y            Y           Y
##   (41.4,178]
## 1       <NA>
## 2       <NA>
## 3       <NA>
## 4       <NA>
## 5       <NA>
## 6       <NA>
##
## popd
##         interval [0,15.4] (15.4,81.2] (81.2,225] (225,470] (470,990]
## 1       [0,15.4]     <NA>        <NA>       <NA>      <NA>      <NA>
## 2    (15.4,81.2]        Y        <NA>       <NA>      <NA>      <NA>
## 3     (81.2,225]        Y           Y       <NA>      <NA>      <NA>
```

```
## 4      (225,470]         Y           Y          N      <NA>      <NA>
## 5      (470,990]         Y           N          Y         Y      <NA>
## 6 (990,2.79e+03]         Y           Y          N         N         Y
##   (990,2.79e+03]
## 1           <NA>
## 2           <NA>
## 3           <NA>
## 4           <NA>
## 5           <NA>
## 6           <NA>
##
## gdpd
##         interval [0,0.0591] (0.0591,0.289] (0.289,0.666] (0.666,1.55]
## 1     [0,0.0591]       <NA>           <NA>          <NA>         <NA>
## 2 (0.0591,0.289]          Y           <NA>          <NA>         <NA>
## 3  (0.289,0.666]          Y              Y          <NA>         <NA>
## 4   (0.666,1.55]          Y              Y             N         <NA>
## 5    (1.55,3.41]          Y              N             Y            Y
## 6     (3.41,7.5]          Y              N             Y            Y
## 7     (7.5,22.2]          Y              Y             N            N
##   (1.55,3.41] (3.41,7.5] (7.5,22.2]
## 1        <NA>       <NA>       <NA>
## 2        <NA>       <NA>       <NA>
## 3        <NA>       <NA>       <NA>
## 4        <NA>       <NA>       <NA>
## 5        <NA>       <NA>       <NA>
## 6           N       <NA>       <NA>
## 7           Y          Y       <NA>
##
## rdds
##      interval [0,3.98] (3.98,11.3] (11.3,21.8] (21.8,37.5] (37.5,62.3]
## 1    [0,3.98]     <NA>        <NA>        <NA>        <NA>        <NA>
## 2 (3.98,11.3]        Y        <NA>        <NA>        <NA>        <NA>
## 3 (11.3,21.8]        Y           Y        <NA>        <NA>        <NA>
## 4 (21.8,37.5]        Y           Y           N        <NA>        <NA>
## 5 (37.5,62.3]        Y           Y           N           Y        <NA>
## 6  (62.3,131]        Y           Y           Y           Y           N
## 7   (131,316]        Y           Y           N           N           N
##   (62.3,131] (131,316]
## 1       <NA>      <NA>
## 2       <NA>      <NA>
## 3       <NA>      <NA>
## 4       <NA>      <NA>
## 5       <NA>      <NA>
## 6       <NA>      <NA>
## 7          Y      <NA>
##
## sensepop
##      interval [18.5,22.7] (22.7,24.1] (24.1,25.6] (25.6,27] (27,28.4]
## 1 [18.5,22.7]        <NA>        <NA>        <NA>      <NA>      <NA>
## 2 (22.7,24.1]           Y        <NA>        <NA>      <NA>      <NA>
## 3 (24.1,25.6]           Y           Y        <NA>      <NA>      <NA>
## 4   (25.6,27]           Y           Y           N      <NA>      <NA>
## 5   (27,28.4]           N           Y           Y         Y      <NA>
```

```
## 6 (28.4,29.8]           Y           Y           Y         Y         Y
## 7 (29.8,31.4]           Y           Y           Y         Y         Y
##   (28.4,29.8] (29.8,31.4]
## 1        <NA>        <NA>
## 2        <NA>        <NA>
## 3        <NA>        <NA>
## 4        <NA>        <NA>
## 5        <NA>        <NA>
## 6        <NA>        <NA>
## 7           Y        <NA>
##
## urbanpop
##      interval [23.7,35] (35,46.6] (46.6,58.2] (58.2,86.3]
## 1   [23.7,35]      <NA>      <NA>        <NA>        <NA>
## 2   (35,46.6]         Y      <NA>        <NA>        <NA>
## 3 (46.6,58.2]         Y         Y        <NA>        <NA>
## 4 (58.2,86.3]         Y         Y           Y        <NA>
##
## medicost
##      interval [60.2,64.8] (64.8,72.8] (72.8,79.1] (79.1,86.1] (86.1,95.1]
## 1 [60.2,64.8]        <NA>        <NA>        <NA>        <NA>        <NA>
## 2 (64.8,72.8]           Y        <NA>        <NA>        <NA>        <NA>
## 3 (72.8,79.1]           Y           Y        <NA>        <NA>        <NA>
## 4 (79.1,86.1]           Y           N           Y        <NA>        <NA>
## 5 (86.1,95.1]           Y           Y           Y           Y        <NA>
## 6  (95.1,144]           Y           Y           Y           Y           Y
## 7   (144,158]           Y           Y           Y           Y           Y
##   (95.1,144] (144,158]
## 1       <NA>      <NA>
## 2       <NA>      <NA>
## 3       <NA>      <NA>
## 4       <NA>      <NA>
## 5       <NA>      <NA>
## 6       <NA>      <NA>
## 7          Y      <NA>
##
## Georegion
##   interval    N    S    W
## 1        N <NA> <NA> <NA>
## 2        S    Y <NA> <NA>
## 3        W    Y    Y <NA>
##
## Interaction detector:
##     variable   temp   prec   humi   popd   gdpd   rdds sensepop urbanpop
## 1       temp     NA     NA     NA     NA     NA     NA       NA       NA
## 2       prec 0.5837     NA     NA     NA     NA     NA       NA       NA
## 3       humi 0.5754 0.4510     NA     NA     NA     NA       NA       NA
## 4       popd 0.5483 0.4984 0.3903     NA     NA     NA       NA       NA
## 5       gdpd 0.5483 0.5043 0.3906 0.2309     NA     NA       NA       NA
## 6       rdds 0.5482 0.5343 0.4138 0.2427 0.2444     NA       NA       NA
## 7   sensepop 0.7005 0.7133 0.6048 0.5992 0.6137 0.6125       NA       NA
## 8   urbanpop 0.6902 0.6333 0.4970 0.5177 0.5204 0.5369   0.7739       NA
## 9   medicost 0.7732 0.7568 0.6910 0.5951 0.6038 0.6254   0.7940   0.6127
## 10 Georegion 0.5266 0.4431 0.2183 0.3298 0.3261 0.3459   0.5874   0.4472
```

```
##    medicost Georegion
## 1        NA        NA
## 2        NA        NA
## 3        NA        NA
## 4        NA        NA
## 5        NA        NA
## 6        NA        NA
## 7        NA        NA
## 8        NA        NA
## 9        NA        NA
## 10   0.6297        NA
##
## Ecological detector:
##     variable temp prec humi popd gdpd rdds sensepop urbanpop medicost Georegion
## 1       temp <NA> <NA> <NA> <NA> <NA> <NA>     <NA>     <NA>     <NA>      <NA>
## 2       prec    N <NA> <NA> <NA> <NA> <NA>     <NA>     <NA>     <NA>      <NA>
## 3       humi    N    N <NA> <NA> <NA> <NA>     <NA>     <NA>     <NA>      <NA>
## 4       popd    N    N    N <NA> <NA> <NA>     <NA>     <NA>     <NA>      <NA>
## 5       gdpd    N    N    N    N <NA> <NA>     <NA>     <NA>     <NA>      <NA>
## 6       rdds    N    N    N    N    N <NA>     <NA>     <NA>     <NA>      <NA>
## 7   sensepop    N    N    Y    Y    Y    Y     <NA>     <NA>     <NA>      <NA>
## 8   urbanpop    N    N    Y    Y    Y    Y        N     <NA>     <NA>      <NA>
## 9   medicost    N    N    Y    Y    Y    Y        N        Y     <NA>      <NA>
## 10 Georegion    N    N    N    N    N    N        N        N        N      <NA>
```

```
plot(h1n1.gdm.100)
```

Spatial analysis for data in three sub-regions (Figure 11).

```
## data in different regions
h1n1list <- list(h1n1_50, h1n1_100, h1n1_150)
h1n1.N <- lapply(h1n1list, function(x) x[which(x$Georegion == "N"), 1:10])
h1n1.S <- lapply(h1n1list, function(x) x[which(x$Georegion == "S"), 1:10])
h1n1.W <- lapply(h1n1list, function(x) x[which(x$Georegion == "W"), 1:10])
## select spatial unit
su <- c(50, 100, 150)
## set optional parameters of optimal discretization
discmethod <- c("equal","natural","quantile","geometric","sd")
discitv <- c(3:4)
continuous_variable <- colnames(h1n1_50)[-c(1,11)]
## "gdm" for region "N"
gdlist <- list()
for (i in 1:3){
  gdlist[[i]] <- gdm(H1N1 ~ .,
               continuous_variable = continuous_variable,
               data = h1n1.N[[i]],
               discmethod = discmethod, discitv = discitv)
}
sesu(gdlist, su) # => 150 km
## "gdm" for region "S"
gdlist <- list()
for (i in 1:3){
  gdlist[[i]] <- gdm(H1N1 ~ .,
               continuous_variable = continuous_variable,
               data = h1n1.S[[i]],
```

```
               discmethod = discmethod, discitv = discitv)
}
sesu(gdlist, su) # => 150 km
## "gdm" for region "W"
gdlist <- list()
for (i in 1:3){
  gdlist[[i]] <- gdm(H1N1 ~ .,
               continuous_variable = continuous_variable,
               data = h1n1.W[[i]],
               discmethod = discmethod, discitv = discitv)
}
sesu(gdlist, su) # => 150 km
## recalculation for datasets in different regions
## region "N"
h1n1.N.150 <- gdm(H1N1 ~ .,
               continuous_variable = continuous_variable,
               data = h1n1.N[[3]],
               discmethod = discmethod, discitv = discitv)
h1n1.N.150
plot(h1n1.N.150)
## region "S"
h1n1.S.150 <- gdm(H1N1 ~ .,
               continuous_variable = continuous_variable,
               data = h1n1.S[[3]],
               discmethod = discmethod, discitv = discitv)
h1n1.S.150
plot(h1n1.S.150)
## region "W"
h1n1.W.150 <- gdm(H1N1 ~ .,
               continuous_variable = continuous_variable,
               data = h1n1.W[[3]],
               discmethod = discmethod, discitv = discitv)
h1n1.W.150
plot(h1n1.W.150)
```

4.3 Spatial line segment data of road damage

```
data(road_GD)
head(road_GD)
```

```
##    damage speed soiltype population vehicles
## 1 325.772   110  Tenosol     227.42      420
## 2 325.772   110 Hydrosol     227.42      420
## 3 325.772   110 Hydrosol     227.42      420
## 4 325.772   110 Hydrosol     227.42      420
## 5 325.772   110 Hydrosol     227.42      420
## 6 325.772   110 Hydrosol     227.42      420
```

Results of OPGD-based analysis for the road damage conditions (Figure 12).

```
## set optional discretization methods and numbers of intervals
discmethod <- c("equal","natural","quantile","geometric","sd")
discitv <- c(3:7)
```

```r
continuous_variable <- colnames(road_GD)[c(4,5)]
## geographical detectors with optimal parameters
gdm_road <- gdm(damage ~ .,
                continuous_variable = continuous_variable,
                data = road_GD,
                discmethod = discmethod, discitv = discitv)
gdm_road
```

```
## Explanatory variables include 2 continuous variables.
##
## optimal discretization result of population
## method             :  quantile
## number of intervals:  5
## intervals:
##  1.04 10.4 53.13 215.19 357.15 2489.72
## numbers of data within intervals:
##  1001 1008 1038 982 971
##
## optimal discretization result of vehicles
## method             :  equal
## number of intervals:  7
## intervals:
##  100 815 1530 2245 2960 3675 4390 5105
## numbers of data within intervals:
##  2986 1020 468 115 224 117 70
##
## Geographical detectors results:
##
## Factor detector:
##     variable        qv          sig
## 1      speed 0.0108854 2.334147e-05
## 2   soiltype 0.1977133 3.204566e-10
## 3 population 0.0846682 6.368206e-11
## 4   vehicles 0.1202810 3.536698e-10
##
## Risk detector:
## speed
##     itv meanrisk
## 1 40-50 356.1679
## 2 60-70 374.0222
## 3    80 342.7952
## 4    90 336.2123
## 5   100 300.0822
## 6   110 387.7802
##
## soiltype
##          itv meanrisk
## 1 Calcarosol 473.1282
## 2  Chromosol 370.2571
## 3   Hydrosol 366.9375
## 4   Kandosol 340.3882
## 5    Podosol 869.3997
## 6    Sodosol 347.1542
## 7    Tenosol 530.9144
```

```
##
## population
##              itv meanrisk
## 1    [1.04,10.4] 354.3701
## 2    (10.4,53.1] 484.5460
## 3     (53.1,215] 353.8543
## 4      (215,357] 358.7460
## 5 (357,2.49e+03] 342.4888
##
## vehicles
##                   itv meanrisk
## 1           [100,815] 354.0679
## 2      (815,1.53e+03] 412.7972
## 3 (1.53e+03,2.24e+03] 438.7350
## 4 (2.24e+03,2.96e+03] 300.5194
## 5 (2.96e+03,3.68e+03] 296.8623
## 6 (3.68e+03,4.39e+03] 715.4692
## 7 (4.39e+03,5.10e+03] 384.2573
##
## speed
##   interval 40-50 60-70   80   90  100  110
## 1    40-50  <NA>  <NA> <NA> <NA> <NA> <NA>
## 2    60-70     N  <NA> <NA> <NA> <NA> <NA>
## 3       80     N     Y <NA> <NA> <NA> <NA>
## 4       90     N     Y    N <NA> <NA> <NA>
## 5      100     Y     Y    Y    Y <NA> <NA>
## 6      110     Y     N    Y    Y    Y <NA>
##
## soiltype
##     interval Calcarosol Chromosol Hydrosol Kandosol Podosol Sodosol Tenosol
## 1 Calcarosol       <NA>      <NA>     <NA>     <NA>    <NA>    <NA>    <NA>
## 2  Chromosol          Y      <NA>     <NA>     <NA>    <NA>    <NA>    <NA>
## 3   Hydrosol          Y         N     <NA>     <NA>    <NA>    <NA>    <NA>
## 4   Kandosol          Y         Y        Y     <NA>    <NA>    <NA>    <NA>
## 5    Podosol          Y         Y        Y        Y    <NA>    <NA>    <NA>
## 6    Sodosol          Y         Y        Y        Y       Y    <NA>    <NA>
## 7    Tenosol          Y         Y        Y        Y       Y       Y    <NA>
##
## population
##         interval [1.04,10.4] (10.4,53.1] (53.1,215] (215,357] (357,2.49e+03]
## 1    [1.04,10.4]        <NA>        <NA>       <NA>      <NA>           <NA>
## 2    (10.4,53.1]           Y        <NA>       <NA>      <NA>           <NA>
## 3     (53.1,215]           N           Y       <NA>      <NA>           <NA>
## 4      (215,357]           N           Y          N      <NA>           <NA>
## 5 (357,2.49e+03]           Y           Y          Y         Y           <NA>
##
## vehicles
##              interval [100,815] (815,1.53e+03] (1.53e+03,2.24e+03]
## 1           [100,815]      <NA>           <NA>                <NA>
## 2      (815,1.53e+03]         Y           <NA>                <NA>
## 3 (1.53e+03,2.24e+03]         Y              Y                <NA>
## 4 (2.24e+03,2.96e+03]         Y              Y                   Y
## 5 (2.96e+03,3.68e+03]         Y              Y                   Y
## 6 (3.68e+03,4.39e+03]         Y              Y                   Y
```

```
## 7 (4.39e+03,5.10e+03]         Y              N                   Y
##   (2.24e+03,2.96e+03] (2.96e+03,3.68e+03] (3.68e+03,4.39e+03]
## 1                <NA>                <NA>                <NA>
## 2                <NA>                <NA>                <NA>
## 3                <NA>                <NA>                <NA>
## 4                <NA>                <NA>                <NA>
## 5                   N                <NA>                <NA>
## 6                   Y                   Y                <NA>
## 7                   Y                   Y                   Y
##   (4.39e+03,5.10e+03]
## 1                <NA>
## 2                <NA>
## 3                <NA>
## 4                <NA>
## 5                <NA>
## 6                <NA>
## 7                <NA>
##
## Interaction detector:
##     variable  speed soiltype population vehicles
## 1      speed     NA       NA         NA       NA
## 2   soiltype 0.2428       NA         NA       NA
## 3 population 0.1173   0.3158         NA       NA
## 4   vehicles 0.1438   0.4712     0.4237       NA
##
## Ecological detector:
##     variable speed soiltype population vehicles
## 1      speed  <NA>     <NA>       <NA>     <NA>
## 2   soiltype     Y     <NA>       <NA>     <NA>
## 3 population     Y        N       <NA>     <NA>
## 4   vehicles     Y        N          N     <NA>
```

```r
plot(gdm_road)
```