

# Spatio-temporal overlay and aggregation



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## Abstract

The so-called “map overlay” is not very well defined and does not have a simple equivalent in space-time. This paper will explain how the `over` method for combining two spatial features (and/or grids), defined in package `sp` and extended in package `rgeos`, is implemented for spatio-temporal objects in package `spacetime`. It may carry out the numerical spatio-temporal overlay, and can be used for aggregation of spatio-temporal data over space, time, or space-time.

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## 1 Introduction

The so-called *map overlay* is a key GIS operation that does not seem to have a very sharp definition. The `over` vignette in package `sp` (Pebesma, 2012) comments on what paper (visual) overlays are, and discusses the `over` and `aggregate` methods for spatial data.

In the ESRI ArcGIS tutorial (ESRI, 2012), it can be read that

*An overlay operation is much more than a simple merging of linework; all the attributes of the features taking part in the overlay are carried through, as shown in the example below, where parcels (polygons) and flood zones (polygons) are overlaid (using the Union tool) to create a new polygon layer. The parcels are split where they are crossed by the flood zone boundary, and new polygons created. The FID\_flood value indicates whether polygons are outside (-1) or inside the flood zone, and all polygons retain their original land use category values.*

It later on mentions *raster overlays*, such as the addition of two (matching) raster layers (so, potentially the whole of map algebra functions, where two layers are involved).

In the open source arena, with no budgets for English language editing, the [Grass 7.0 documentation](#) mentions the following:

*v.overlay allows the user to overlay two vector area maps. The resulting output map has a merged attribute-table. The origin column-names have a prefix (a\_ and b\_) which results from the ainput- and binput-map. [...] Operator defines features written to output vector map Feature is written to output if the result of operation 'ainput operator binput' is true. Input feature is considered to be true, if category of given layer is defined. Options: and, or, not, xor.*

## 2 Overlay with method over

We loosely define *map overlay* as

- an operation involving at least two maps
- asymmetric – *overlay* is different from *underlay*
- either a *visual* or a *numerical* activity.

The method `over`, as defined in package `sp`, provides a way to numerically combine two maps. In particular,

```
R> over(x, geometry(y))
```

returns an integer vector of length `length(x)` with `x[i]` the index of `y`, spatially corresponding to `x[i]`, so `x[i]=j` means that `x[i]` and `y[j]` match (have the same location, touch, or overlap/intersect etc.), or `x[i]=NA` if there is no match. If `y` has data values (attributes), then

```
R> over(x, y)
```

retrieves a `data.frame` with `length(x)` rows, where row `i` contains the attributes of `y` at the spatial location of `x[i]`, and `NA` values if there is no match.

If the relationship is more complex, e.g. a polygon or grid cell `x` containing more than one point of `y`, the command

```
R> over(x, y, returnList = TRUE)
```

returns a list of length `length(x)`, with each list element a numeric vector with all indices if `y` is geometry only, or else a data frame with all attribute table rows of `y` that spatially matches `x[i]`.

### 3 Spatio-temporal overlay with method over

Package `spacetime` adds `over` methods to those defined for spatial data in package `sp`:

```
R> library(sp)
R> library(spacetime)
R> showMethods(over)
```

```
Function: over (package sp)
x="ST", y="STS"
x="STF", y="STF"
x="STF", y="STFDF"
x="STF", y="STI"
x="STF", y="STIDF"
x="STF", y="STSDF"
x="STI", y="STF"
x="STI", y="STFDF"
x="STI", y="STI"
x="STI", y="STIDF"
x="STI", y="STSDF"
x="STS", y="STF"
x="STS", y="STFDF"
x="STS", y="STI"
x="STS", y="STIDF"
x="STS", y="STSDF"
x="Spatial", y="Spatial"
x="SpatialGrid", y="SpatialGrid"
x="SpatialGrid", y="SpatialGridDataFrame"
x="SpatialGrid", y="SpatialPixels"
x="SpatialGrid", y="SpatialPixelsDataFrame"
x="SpatialGrid", y="SpatialPoints"
x="SpatialGrid", y="SpatialPointsDataFrame"
x="SpatialGrid", y="SpatialPolygons"
x="SpatialGrid", y="SpatialPolygonsDataFrame"
x="SpatialPoints", y="SpatialGrid"
x="SpatialPoints", y="SpatialGridDataFrame"
x="SpatialPoints", y="SpatialPixels"
x="SpatialPoints", y="SpatialPixelsDataFrame"
x="SpatialPoints", y="SpatialPoints"
x="SpatialPoints", y="SpatialPointsDataFrame"
x="SpatialPoints", y="SpatialPolygons"
x="SpatialPoints", y="SpatialPolygonsDataFrame"
x="SpatialPolygons", y="SpatialGrid"
x="SpatialPolygons", y="SpatialGridDataFrame"
x="SpatialPolygons", y="SpatialPoints"
x="SpatialPolygons", y="SpatialPointsDataFrame"
x="SpatialPolygonsDataFrame", y="SpatialPoints"
  (inherited from: x="SpatialPolygons", y="SpatialPoints")
x="xts", y="xts"
```

### 3.1 Time intervals or time instances?

When computing the overlay

```
R> over(x, y)
```

A space-time feature matches another space-time feature when their spatial locations match (coincide, touch, intersect or overlap), and when their temporal properties match. For temporal properties, it is crucial whether time is a time interval, or a time instance. When all `endTime` values are equal to the `time` times, time is considered instance. When one or more `endTime` values are larger than `time`, time is considered to reflect intervals.

Suppose we have two time sequences,  $T : t_1, t_2, \dots, t_n$  and  $U : u_1, u_2, \dots, u_m$ . Both are ordered:  $t_i \leq t_{i+1}$ .

Both  $T$  and  $U$  can reflect time *instances* or time *intervals*. In case they reflect time *instances*, an observation at  $t_i$  takes place at the time instance  $t_i$ , and has an unregistered (possibly ignorable) duration. In case they reflect time *intervals*, an observation “at”  $t_i$  takes place during, or is representative for, the time interval  $t_i \leq t < t_{i+1}$ . (The last time interval  $t_n$  is obtained by adopting the one-but-last time interval duration:  $t_n \leq t < t_n + (t_n - t_{n-1})$ ).

We define the time (instance or interval) pair  $\{t_i, u_j\}$  to match if

**for  $T$  instance,  $U$  instance:**

$$t_i = u_j$$

**for  $T$  interval,  $U$  instance**

$$t_i \leq u_j < t_{i+1}$$

**for  $T$  instance,  $U$  interval**

$$u_j \leq t_i < u_{j+1}$$

**for  $T$  interval,  $U$  interval**

$$\exists t : t_i \leq t < t_{i+1} \wedge u_j \leq t < u_{j+1}$$

which can be rephrased as the negation of  $t_{i+1} \leq u_j \vee t_i \geq u_{j+1}$  (where  $\vee$  denotes ‘or’), or alternatively expressed as

$$t_{i+1} > u_j \wedge t_i < u_{j+1}$$

where  $\wedge$  denotes ‘and’.

All these conditions fail for intervals having zero width (empty intervals), i.e. the case where  $T$  is interval and for some  $i$ ,  $t_{i+1} - t_i = 0$  or the case where  $U$  is interval and for some  $j$ ,  $u_{j+1} - u_j = 0$ .

## 4 Aggregating spatio-temporal data

The `aggregate` method for a `data.frame` is defined as

```
R> aggregate(x, by, FUN, ..., simplify = TRUE)
```

where `x` is the `data.frame` to be aggregated, `by` indicates how groups of `x` are formed, `FUN` is applied to each group, and `simplify` indicates whether the output should be simplified (to vector), or remain a `data.frame`. The `...` are passed to `FUN`, e.g. passing `na.rm=TRUE` is useful when `FUN` is `mean` and missing values need to be ignored.

For spatio-temporal data, the `x` argument needs to be of class `STFDF`, `STSDF` or `STIDF`. The `by` argument needs to specify an aggregation medium: time, space, or space-time.

## 4.1 Example data: PM10

Air quality example data are loaded by

```
R> data(air)
R> rural = STFDF(stations, dates, data.frame(PM10 = as.vector(air)))
R> class(rural)

[1] "STFDF"
attr(,"package")
[1] "spacetime"

R> class(DE_NUTS1)

[1] "SpatialPolygonsDataFrame"
attr(,"package")
[1] "sp"
```

it provides PM10 daily mean values (taken from [AirBase - the European Air quality dataBase](#)), for Germany, 1998-2009, where only stations classified as *rural background* were selected. The object `DE_NUTS1` contains NUTS-1 level state boundaries for Germany, downloaded from [GADM](#).

## 4.2 Spatial aggregation

To aggregate *completely* over space, we can coerce the data to a matrix and apply a function to the rows:

```
R> x = as(rural[, "2008"], "xts")
R> apply(x, 1, mean, na.rm=TRUE)[1:5]

2008-01-01 2008-01-02 2008-01-03 2008-01-04 2008-01-05
17.34950 16.06945 25.60065 27.24141 24.03417
```

A more refined spatial aggregation of time series can be obtained by grouping them to the state ("Bundesland") level. Here, states are passed as a `SpatialPolygons` object:

```
R> dim(rural[, "2008"])

      space      time variables
      70      366            1

R> x = aggregate(rural[, "2008"], DE_NUTS1, mean, na.rm=TRUE)
R> dim(x)
```

```

      space      time variables
      13        366          1

R> summary(x)

Object of class STFDF
  with Dimensions (s, t, attr): (13, 366, 1)
[[Spatial:]]
Object of class SpatialPolygonsDataFrame
Coordinates:
      min      max
x  5.871619 15.03811
y 47.269858 55.05653
Is projected: FALSE
proj4string : [+proj=longlat +datum=WGS84 +no_defs]
Data attributes:
      ID_0      ISO      NAME_0      ID_1
Min.   :60    DEU:13  Germany:13  Min.   :753.0
1st Qu.:60
Median :60
Mean   :60
3rd Qu.:60
Max.   :60
      NAME_1      VARNAME_1 NL_NAME_1
Length:13      Bavaria      :1    NA's:13
Class :character Hesse      :1
Mode  :character Lower Saxony :1
      Mecklenburg-West Pomerania:1
      North Rhine-Westphalia  :1
      (Other)                  :3
      NA's                     :5
      HASC_1      CC_1      TYPE_1      ENGTYPE_1      VALIDFR_1      VALIDTO_1
DE.BE  :1    NA's:13    Land:13    State:13    Unknown:13    Present:13
DE.BR  :1
DE.BW  :1
DE.BY  :1
DE.HE  :1
DE.MV  :1
(Other):7
REMARKS_1      Shape_Leng      Shape_Area
NA's:13    Min.   : 2.631    Min.   :0.1172
      1st Qu.:14.529    1st Qu.:2.1541
      Median :16.891    Median :2.6645
      Mean   :18.068    Mean   :3.3126
      3rd Qu.:24.519    3rd Qu.:4.3832
      Max.   :32.255    Max.   :8.6561

[[Temporal:]]
      Index      timeIndex

```

```

Min.    :2008-01-01    Min.    :3653
1st Qu.:2008-04-01    1st Qu.:3744
Median :2008-07-01    Median :3836
Mean    :2008-07-01    Mean    :3836
3rd Qu.:2008-09-30    3rd Qu.:3927
Max.    :2008-12-31    Max.    :4018
[[Data attributes:]]
      PM10
Min.    : 2.181
1st Qu.: 9.933
Median :13.755
Mean    :15.023
3rd Qu.:18.371
Max.    :68.750
NA's    :366

```

```
R> stplot(x, mode = "tp")
```

the result of which is shown in figure 1, which was created by

```
R> stplot(x, mode = "tp", par.strip.text = list(cex=.5))
```

An aggregation for all stations selected within a single area is obtained by using the country boundary DE, and aggregating the observations within Germany for each moment in time:

```
R> x = aggregate(rural[, "2008"], DE, mean, na.rm=TRUE)
R> class(x)
```

```
[1] "xts" "zoo"
```

```
R> plot(x[, "PM10"])
```

the plot of which is shown in figure 2.

### 4.3 Temporal aggregation

To aggregate *completely* over time, we can coerce the data to a matrix and apply a function to the columns:

```
R> x = as(rural[, "2008"], "xts")
R> apply(x, 2, mean, na.rm=TRUE)[1:5]
```

```

DESH001 DENI063 DEUB038 DEBE056 DEBE062
      NaN 18.41594      NaN 20.76446      NaN

```

Aggregating values *temporally* is done by passing a character string or a function to the `by` argument. For monthly data, we will first select those stations that have measured (non-NA) values in 2008,

```

R> sel = which(!apply(as(rural[, "2008"], "xts"), 2, function(x) all(is.na(x))))
R> x = aggregate(rural[sel, "2008"], "month", mean, na.rm=TRUE)
R> stplot(x, mode = "tp")

```

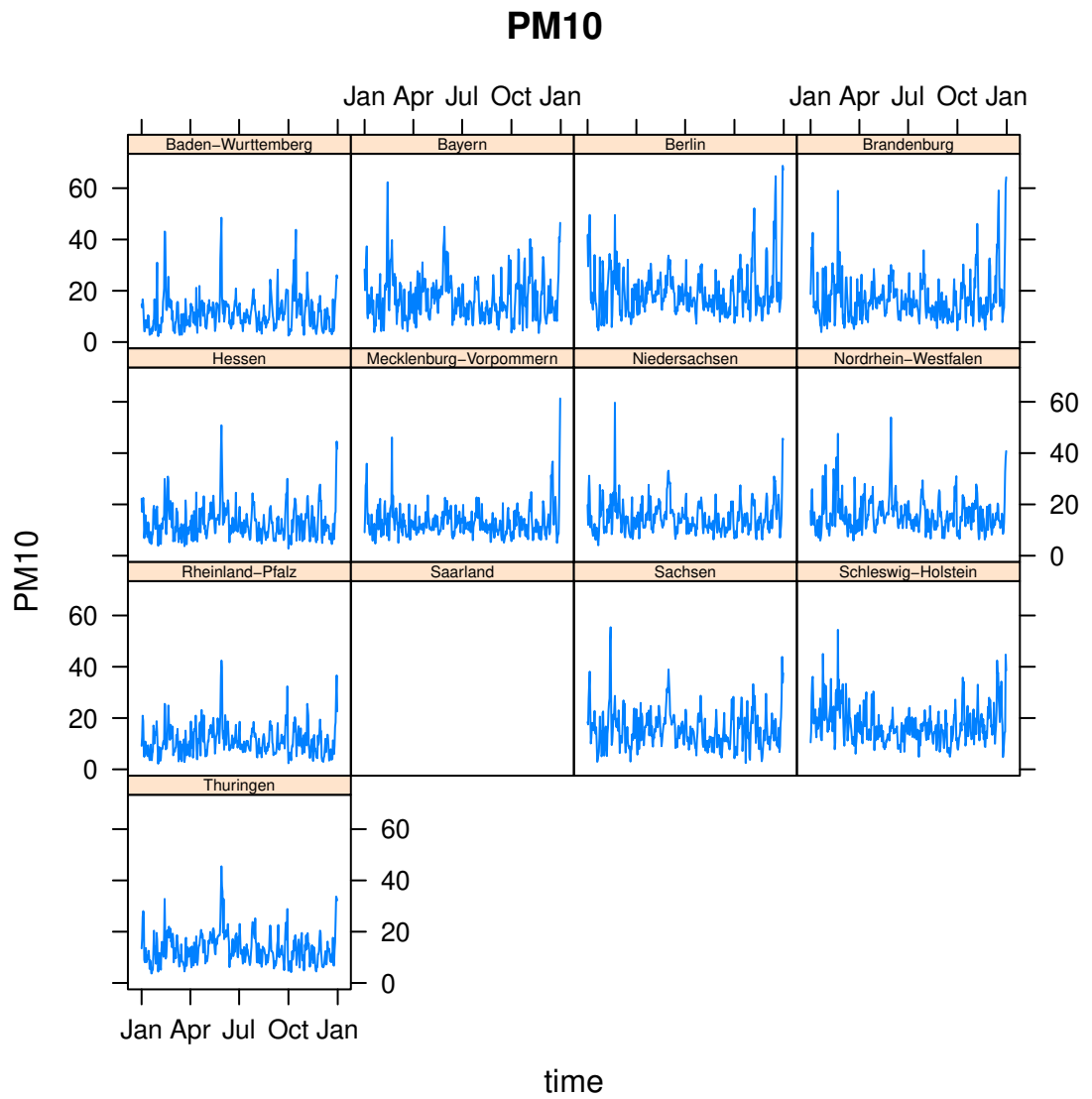


Figure 1: Daily PM10 values, aggregated (averaged) over states

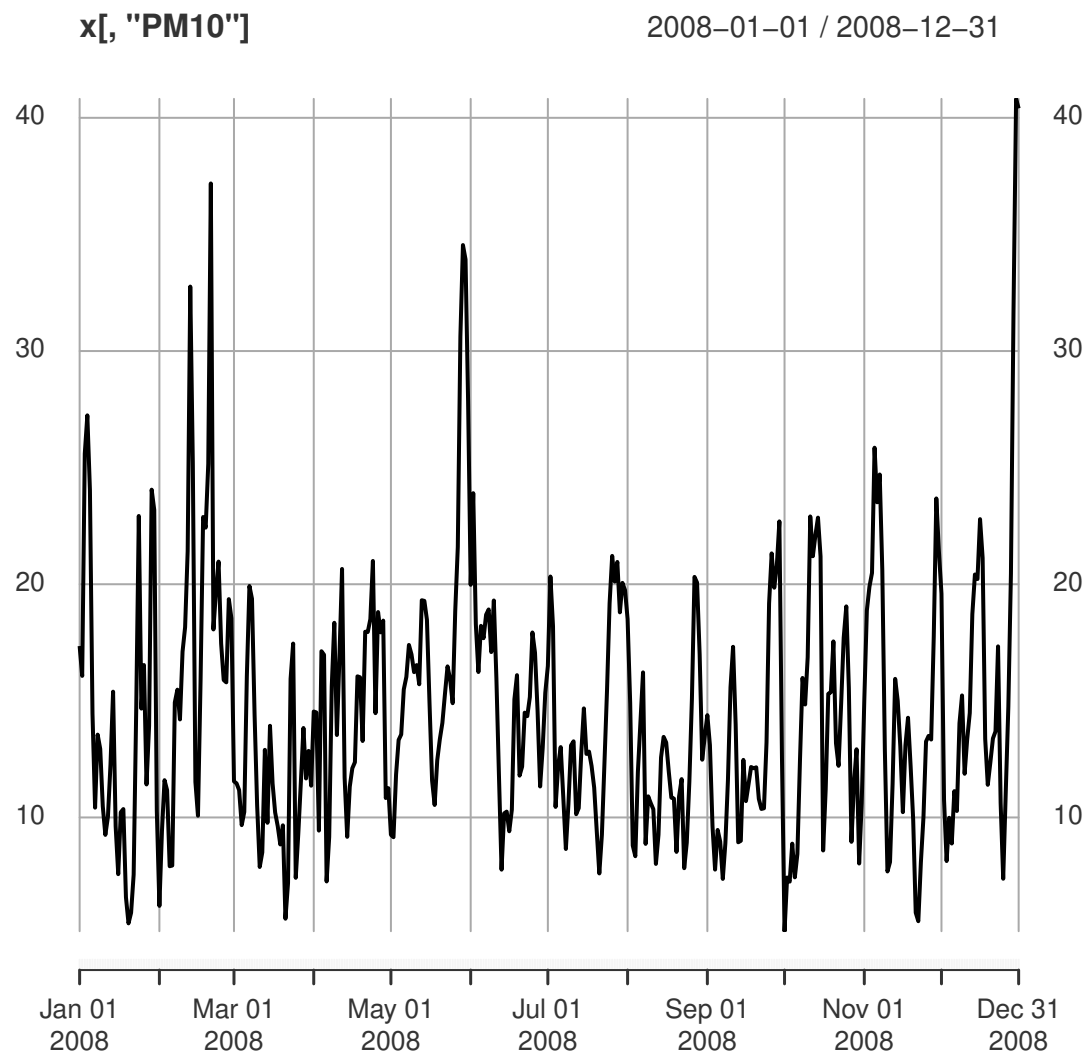


Figure 2: Time series plot of daily rural background PM10, averaged over Germany

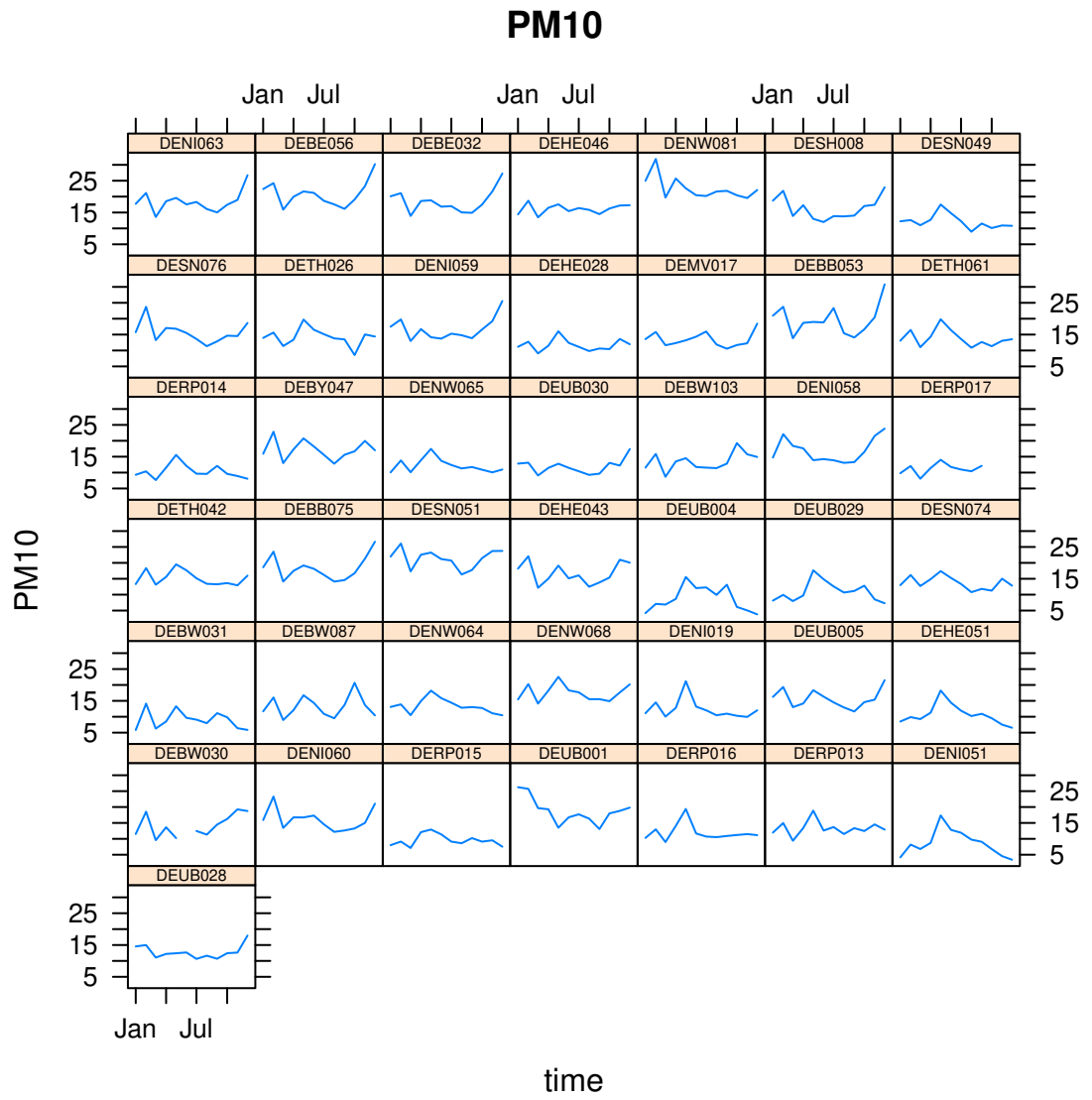


Figure 3: Monthly averaged PM10 values, for those rural background stations in Germany having measured values

shown in figure 3

The strings that can be passed are e.g. "year", but also "3 days". See `?cut.Date` for possible values. Aggregation using this way is only possible if the time index is of class `Date` or `POSIXct`.

An alternative is to provide a function for temporal aggregation. The function `as.yearqtr` from package `zoo` transforms dates to quarters, and hence allows aggregation to quarterly values, in this example medians:

```
R> library(zoo)
R> x = aggregate(rural[sel,"2005::2011"], as.yearqtr, median, na.rm=TRUE)
R> stplot(x, mode = "tp")
```

shown in figure 4. Aggregating to monthly values is obtained by function `as.yearmon`, aggregating to years by creating the function

```
R> as.year <- function(x) as.numeric(floor(as.yearmon(x)))
```

Further information can be found in `?aggregate.zoo`, which is the function used to do the processing.

## 4.4 Spatio-temporal aggregation

Aggregation over spatio-temporal volumes can be done by passing an object inheriting from `ST` to the `by` argument:

```
R> DE.years = STF(DE, as.Date(c("2008-01-01", "2009-01-01")))
R> aggregate(rural[, "2008::2009"], DE.years, mean, na.rm=TRUE)
```

	PM10	timeIndex
2008-01-01	14.56871	1
2009-01-01	15.23961	2

## 4.5 Time intervals

If all data concern time instances (`endTime` equals `time`), then time instances are being matched, else overlapping time intervals are being matched. In case intervals are being matched, empty intervals are never matched.

## References

- ESRI (2012) ESRI ArcGIS Tutorial. [http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Overlay\\_analysis](http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Overlay_analysis)
- Pebesma, 2012. Map overlay and spatial aggregation in `sp`. Vignette in package `sp`, <https://cran.r-project.org/web/packages/sp/vignettes/over.pdf>

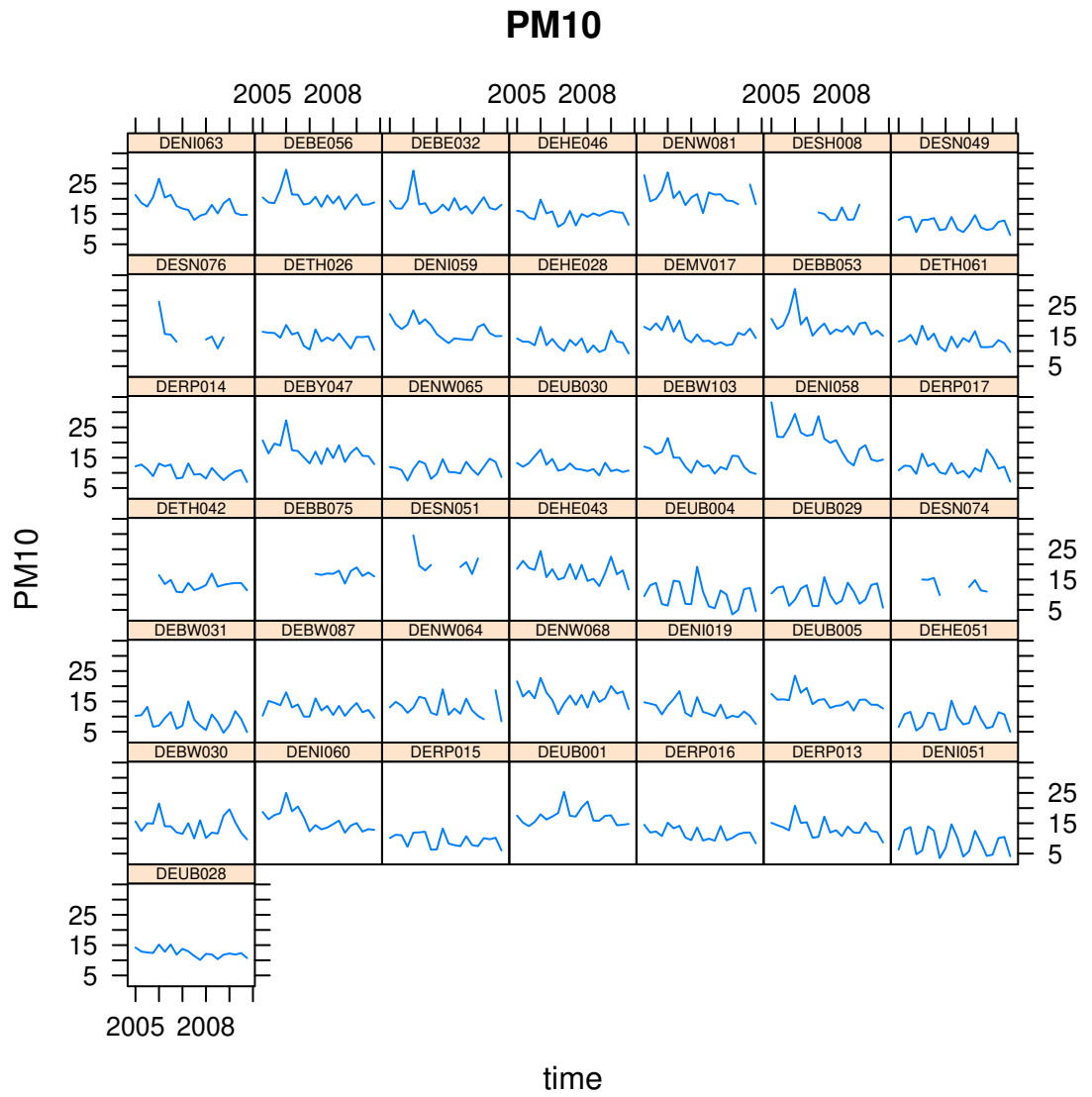


Figure 4: PM10 values, averaged to quarterly medians of daily averages