Spatio-temporal overlay and aggregation

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June 21, 2011

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 is used to carry out aggreation 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` comments on what paper (visual) overlays are, and discusses the `over` and `aggregate` methods for spatial data.

In the ESRI ArcGIS tutorial, 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 overlayed (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 has 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`

Being loosely defined, *map overlay* seems to have several properties:

- it involves at least two maps
- it may be asymmetric (*overlay* is not *underlay*)
- it may be a visual activity, or a numerical activity.

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

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

retrieves an array of `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), or `NA` if there is no match. If `y` has attributes, then

```
> 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

```
> 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 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:

```
> library(spacetime)
> 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="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="SpatialGridDataFrame"
x="SpatialPolygons", y="SpatialPoints"
x="SpatialPolygons", y="SpatialPointsDataFrame"
x="xts", y="xts"
```

3.1 Time intervals or time instances?

When computing the overlay

```
> 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 extents match. For temporal extent, it is crucial whether time is considered to be a time interval, or a time instance. Matching time instance is always considered.

The over methods in package spacetime have a boolean argument timeInterval which is by default TRUE for the cases where y derives from class STF or STS, and FALSE when y derives from class STI. When TRUE, the times of y are considered as time intervals, meaning that the times of x[i,j] and y[k,l] match if the time instant of x[i,j] is larger than or equal to the time instant of y[k,l], but less than the next time instant. The time interval length of the last time step is taken to be identical to the last time interval of an object.

Spatio-temporal objects with only one time step cannot be used to determine time intervals.

4 Aggregating spatio-temporal data

The aggregate method for a data.frame is defined as

```
> 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

```
> data(air)
> class(rural)

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

> 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

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

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

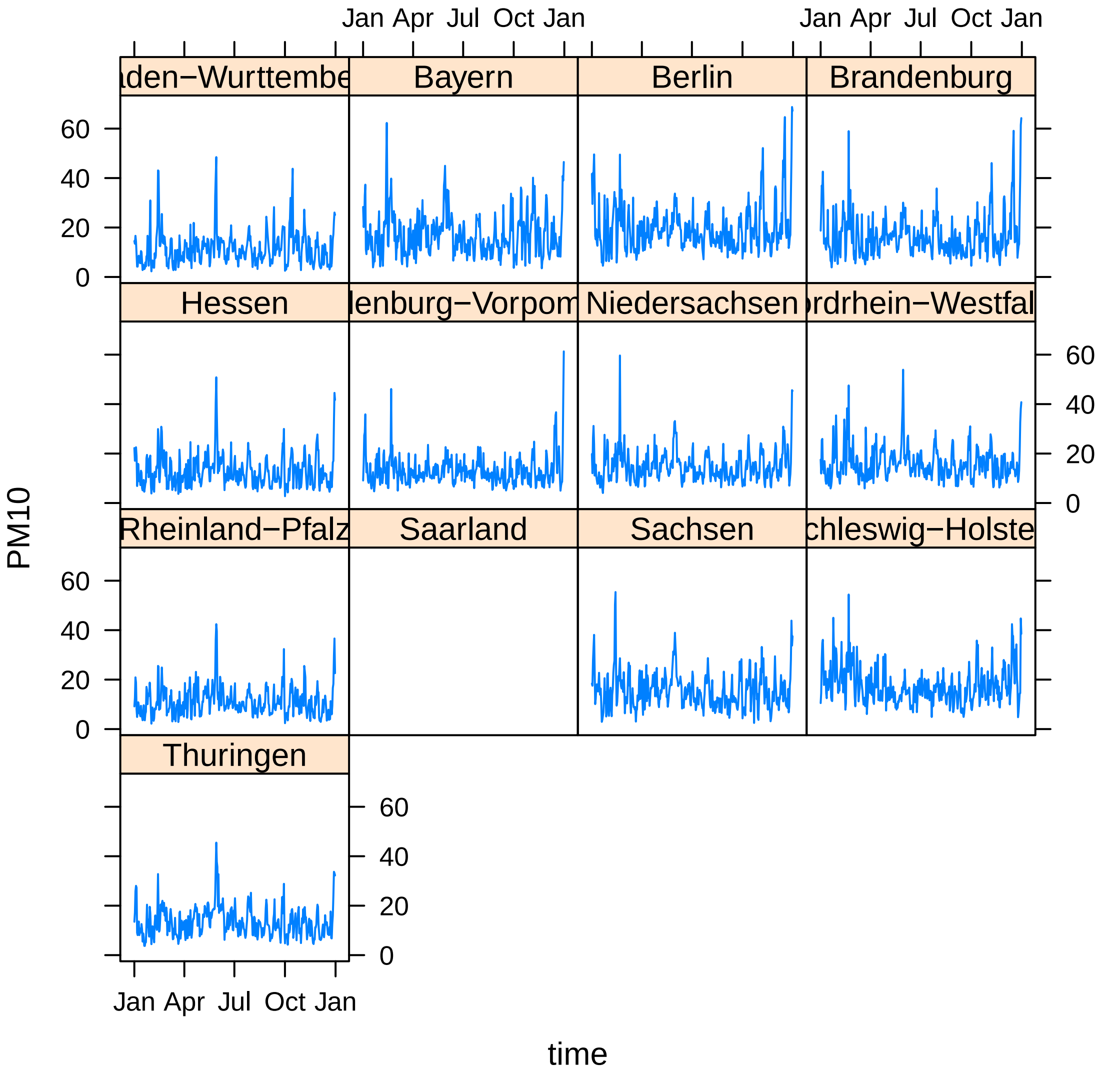
```
[1]  70 366   1
```

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

```
[1]  13 366   1
```

```
> summary(x)
```

```
Object of class STFDF
[[Spatial:]]
Object of class SpatialPolygonsDataFrame
Coordinates:
        min      max
x  5.871619 15.03811
y 47.269858 55.05653
Is projected: FALSE
proj4string :
[+init=epsg:4326 +proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs
+towgs84=0,0,0]
Data attributes:
      ID_0     ISO         NAME_0        ID_1          NAME_1
 Min.   :60   DEU:13   Germany:13   Min.   :753.0   Length:13
 1st Qu.:60                         1st Qu.:756.0   Class :character
 Median :60                         Median :761.0   Mode  :character
 Mean   :60                         Mean   :760.5
 3rd Qu.:60                         3rd Qu.:764.0
 Max.   :60                         Max.   :768.0

                     VARNAME_1 NL_NAME_1     HASC_1    CC_1     TYPE_1
 Bavaria                   :1   NA's:13   DE.BE  :1   NA's:13   Land:13
 Hesse                     :1             DE.BR  :1
 Lower Saxony              :1             DE.BW  :1
 Mecklenburg-West Pomerania:1             DE.BY  :1
 North Rhine-Westphalia    :1             DE.HE  :1
 (Other)                   :3             DE.MV  :1
 NA's                      :5             (Other):7
 ENGTYPE_1    VALIDFR_1    VALIDTO_1   REMARKS_1   Shape_Leng
 State:13   Unknown:13   Present:13   NA's:13   Min.   : 2.631
                                                1st Qu.:14.529
                                                Median :16.891
                                                Mean   :18.068
                                                3rd Qu.:24.519
                                                Max.   :32.255

   Shape_Area
 Min.   :0.1172
 1st Qu.:2.1541
 Median :2.6645
 Mean   :3.3126
 3rd Qu.:4.3832
 Max.   :8.6561

[[Temporal:]]
     Index                              ..1
 Min.   :2008-01-01 00:00:00   Min.   :3653
 1st Qu.:2008-04-01 06:00:00   1st Qu.:3744
 Median :2008-07-01 12:00:00   Median :3836
 Mean   :2008-07-01 12:00:00   Mean   :3836
 3rd Qu.:2008-09-30 18:00:00   3rd Qu.:3927
 Max.   :2008-12-31 00:00:00   Max.   :4018
[[Data attributes:]]
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
  2.181   9.933  13.750  15.020  18.370  68.750 366.000

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

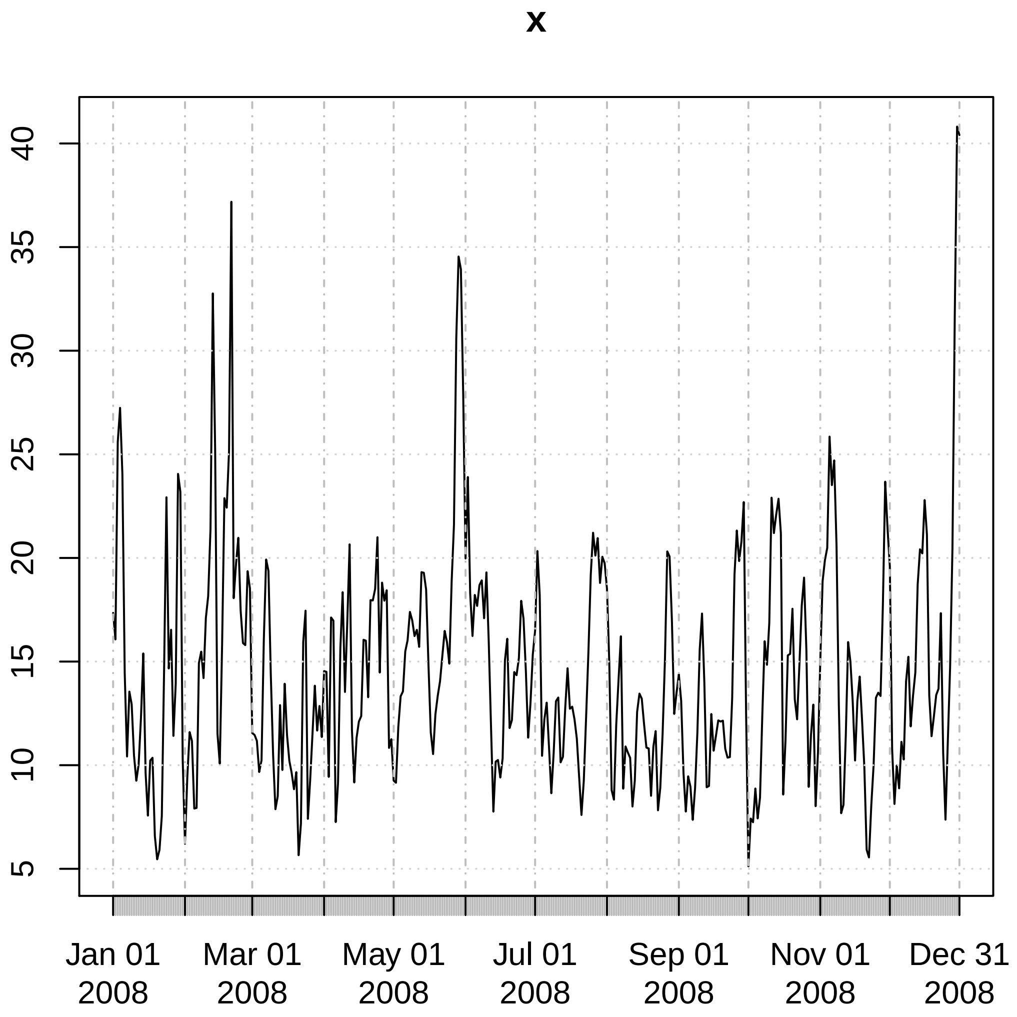


An aggregation for all stations selected within a single area is obtained by merging all states:

```
> library(rgeos)
> DE = gUnionCascaded(DE_NUTS1)
```

and then aggregating the observations within Germany for each moment in time:

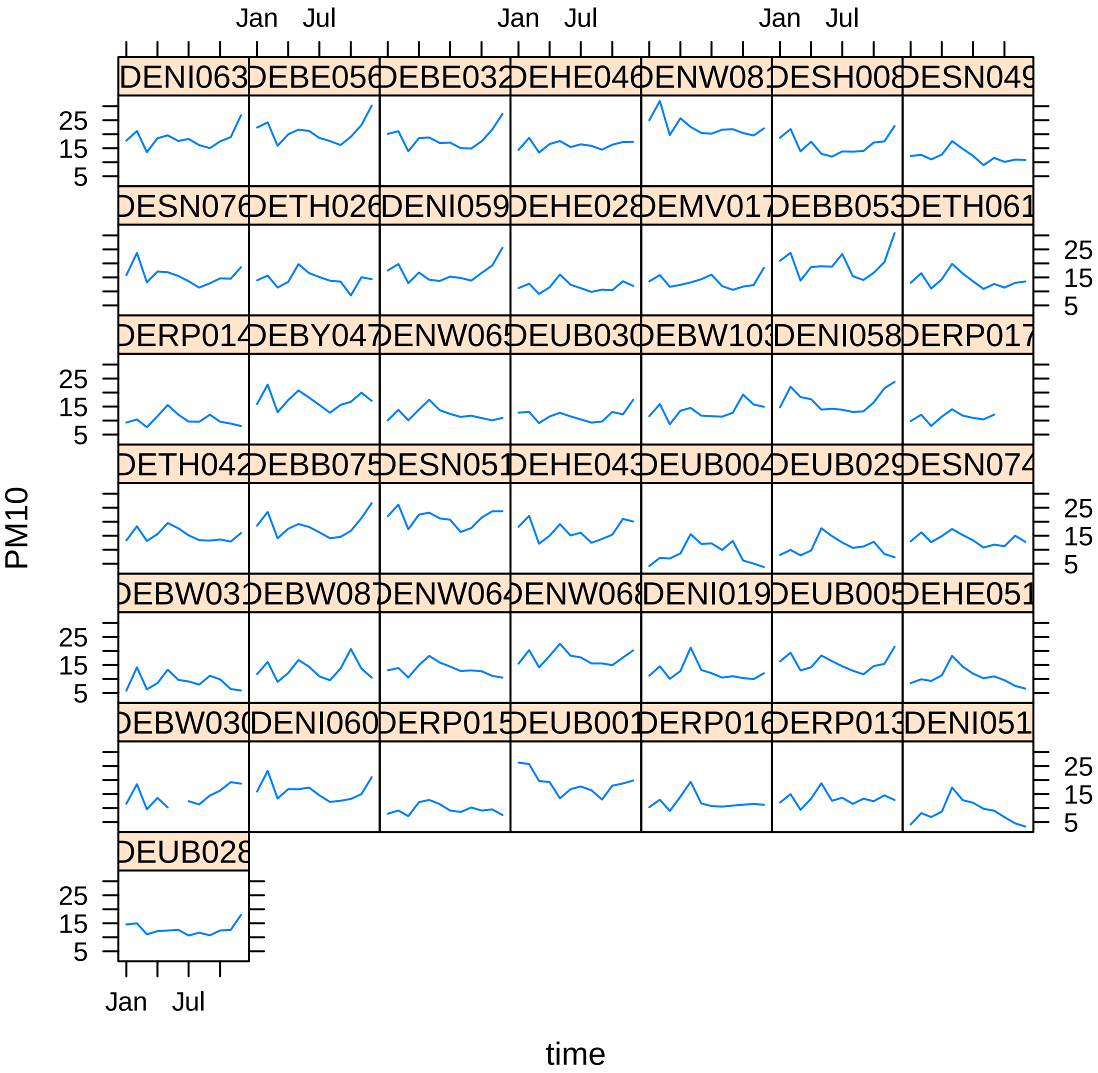
```
> x = aggregate(rural[, "2008"], DE, mean, na.rm = T)
> class(x)

[1] "xts" "zoo"

> plot(x)
```



4.3 Temporal aggregation

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:

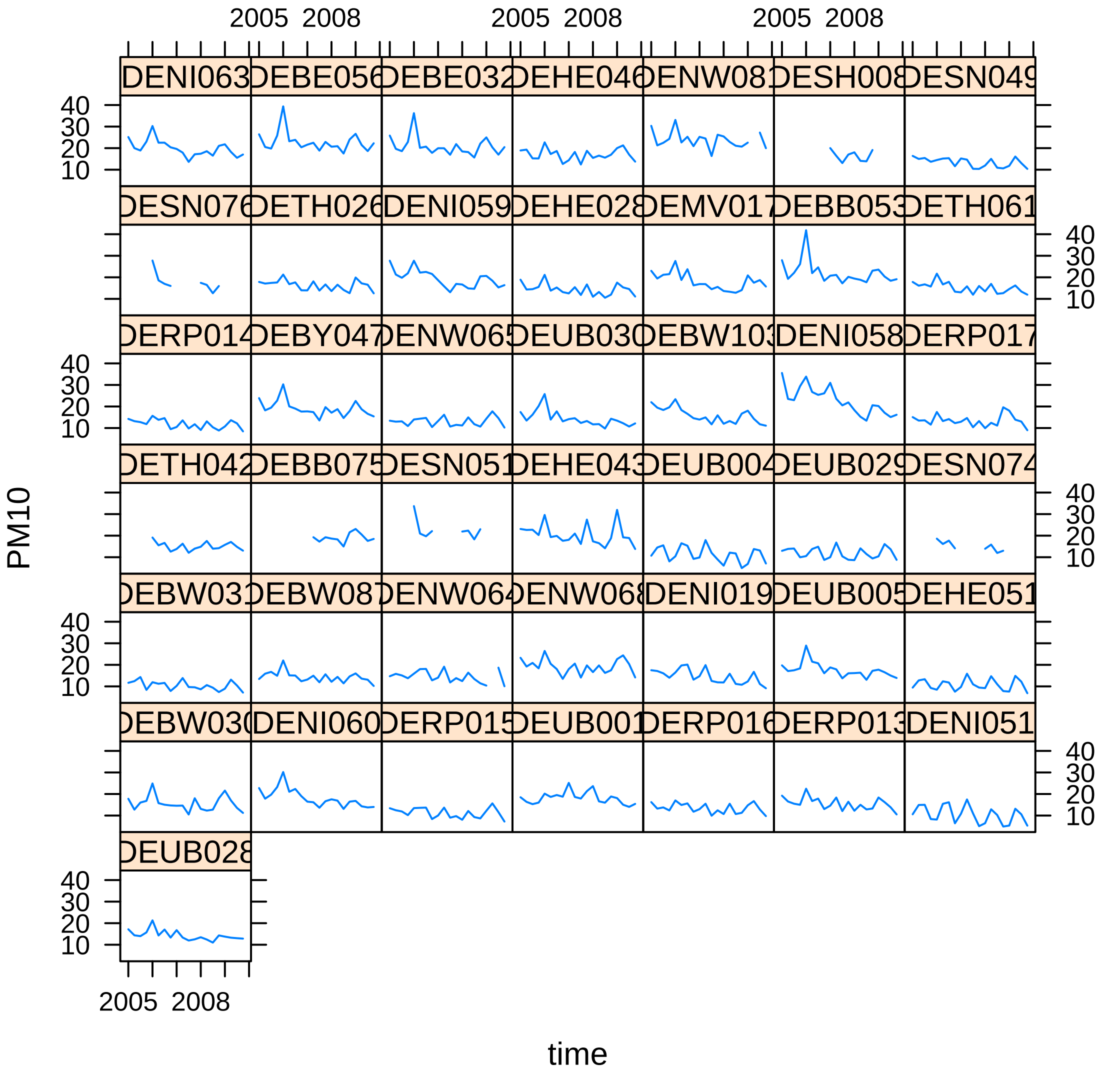
```
> sel = which(!apply(as(rural[, "2008"], "xts"), 2, function(x) all(is.na(x))))
> x = aggregate(rural[sel, "2008"], "month", mean, na.rm = T)
> print(stplot(x, mode = "tp"))
```



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:

```
> x = aggregate(rural[sel, "2005::2011"], as.yearqtr, mean, na.rm = T)
> print(stplot(x, mode = "tp"))
```



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:

```
> DE.years = STF(DE, xts(1:2, as.POSIXct(as.Date(c("2008-01-01",
+     "2009-01-01")))))
> aggregate(rural[, "2008::2009"], DE.years, mean, na.rm = TRUE)
```

```
                        PM10
2008-01-01 01:00:00 14.56871
2009-01-01 01:00:00 15.23961
```

4.5 Time intervals?

Spatial, temporal and spatio-temporal aggregation is all based on the `over` methods. Whether time is considered to be time intervals (for establising whether a space-time point falls, time-wise, inside an interval or coincides with the time point), depends on the defaults for the `over` methods.