Package OceanView, visualisation of the output of a 3D hydrodynamic model.

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Abstract

The R (R Development Core Team 2013) package **OceanView** (Soetaert 2021a) is a compagnon package to the packages **plot3D** (Soetaert 2021b) and **plot3Drgl** (Soetaert 2021c). These packages contain functions for visualising multidimensional data in base R graphics (**plot3D**) or in openGL (**plot3Drgl**).

OceanView is specifically designed for visualising complex oceanographic data.

It can produce a.o. quiver plots, vector plots for visualising flows, it can create movie sequences for depicting particle tracks in 2-D and 3-D, and so on ...

Here we apply **OceanView** for plotting the output of a 3-D hydrodynamic model of the North Sea, as produced by the GETM software (Burchard and Bolding 2002).

Keywords: marine science, hydrodynamic models, 3-D data, 4-D data, quiver, image2D, R .

1. Preamble

This 'vignette' contains scripts to make figures of the output of the Northsea Model as created by the 3-D hydrodynamical model GETM (Burchard and Bolding 2002).

As the netcdf file with model output is very large (> 150 MB), it is not part of the package nor can it be downloaded. Hence you will not be able to recreate this vignette.

However, a similar (but significantly smaller) dataset, `Sylt3D` is part of the **OceanView** package:

```
example(Sylt3D)
```

2. Reading data

We use two packages here, **RNetCDF** (Michna and Woods 2020) for reading netcdf files, **OceanView** (Soetaert 2021a) for visualising output. Load the required packages:

```
library(RNetCDF)
library(OceanView)
```

Open the NETCDF file with the output of the Northsea simulation, and print its content: [1]

```
d.nc <- open.nc( "ns_06nm_sept_1997_3d.nc")
print.nc(d.nc)
```

```
dimensions:
        xc = 111 ;
        yc = 87 ;
        level = 26 ;
        time = UNLIMITED ; // (30 currently)
variables:
        int grid_type ;
        int vert_cord ;
        int ioff ;
                ioff:long_name = "index offset (i)" ;
        int joff ;
                joff:long_name = "index offset (j)" ;
        double dx ;
                dx:units = "m" ;
                dx:long_name = "grid spacing (x)" ;
        double dy ;
                dy:units = "m" ;
                dy:long_name = "grid spacing (y)" ;
        double xc(xc) ;
                xc:units = "m" ;
        double yc(yc) ;
                yc:units = "m" ;
        double lonc(xc, yc) ;
                lonc:units = "degrees_east" ;
                lonc:long_name = "longitude" ;
                lonc:valid_range = -180180 ;
                lonc:_FillValue = -999 ;
                lonc:missing_value = -999 ;
        double latc(xc, yc) ;
                latc:units = "degrees_north" ;
                latc:long_name = "latitude" ;
                latc:valid_range = -9090 ;
                latc:_FillValue = -999 ;
                latc:missing_value = -999 ;
        double convc(xc, yc) ;
                convc:units = "degrees" ;
                convc:long_name = "grid rotation" ;
                convc:valid_range = -180180 ;
                convc:_FillValue = -999 ;
                convc:missing_value = -999 ;
```

[1] Note: the text in `boxes` is the R-code; the text below boxes in this `format` (if any) is output, produced by R.

```
double latu(xc, yc) ;
        latu:units = "degrees" ;
        latu:long_name = "latu" ;
        latu:valid_range = -9090 ;
        latu:_FillValue = -999 ;
        latu:missing_value = -999 ;
double latv(xc, yc) ;
        latv:units = "degrees" ;
        latv:long_name = "latv" ;
        latv:valid_range = -9090 ;
        latv:_FillValue = -999 ;
        latv:missing_value = -999 ;
double level(level) ;
        level:units = "level" ;
double bathymetry(xc, yc) ;
        bathymetry:units = "m" ;
        bathymetry:long_name = "bathymetry" ;
        bathymetry:valid_range = -54000 ;
        bathymetry:_FillValue = -10 ;
        bathymetry:missing_value = -10 ;
float time(time) ;
        time:units = "seconds since 1997-09-01 00:00:00" ;
        time:long_name = "time" ;
float elev(xc, yc, time) ;
        elev:units = "m" ;
        elev:long_name = "elevation" ;
        elev:valid_range = -1515 ;
        elev:_FillValue = -9999 ;
        elev:missing_value = -9999 ;
float u(xc, yc, time) ;
        u:units = "m/s" ;
        u:long_name = "int. zonal vel." ;
        u:valid_range = -33 ;
        u:_FillValue = -9999 ;
        u:missing_value = -9999 ;
float v(xc, yc, time) ;
        v:units = "m/s" ;
        v:long_name = "int. meridional vel." ;
        v:valid_range = -33 ;
        v:_FillValue = -9999 ;
        v:missing_value = -9999 ;
float h(xc, yc, level, time) ;
        h:units = "m" ;
        h:long_name = "layer thickness" ;
        h:_FillValue = -9999 ;
        h:missing_value = -9999 ;
float hcc(xc, yc, level) ;
```

```
                hcc:units = "" ;
                hcc:long_name = "hcc" ;
                hcc:valid_range = 01 ;
                hcc:_FillValue = -1 ;
                hcc:missing_value = -1 ;
        float uu(xc, yc, level, time) ;
                uu:units = "m/s" ;
                uu:long_name = "zonal vel." ;
                uu:valid_range = -33 ;
                uu:_FillValue = -9999 ;
                uu:missing_value = -9999 ;
        float vv(xc, yc, level, time) ;
                vv:units = "m/s" ;
                vv:long_name = "meridional vel." ;
                vv:valid_range = -33 ;
                vv:_FillValue = -9999 ;
                vv:missing_value = -9999 ;
        float w(xc, yc, level, time) ;
                w:units = "m/s" ;
                w:long_name = "vertical vel." ;
                w:valid_range = -33 ;
                w:_FillValue = -9999 ;
                w:missing_value = -9999 ;
        float salt(xc, yc, level, time) ;
                salt:units = "PSU" ;
                salt:long_name = "salinity" ;
                salt:valid_range = 040 ;
                salt:_FillValue = -9999 ;
                salt:missing_value = -9999 ;
        float temp(xc, yc, level, time) ;
                temp:units = "degC" ;
                temp:long_name = "temperature" ;
                temp:valid_range = 040 ;
                temp:_FillValue = -9999 ;
                temp:missing_value = -9999 ;

// global attributes:
                :title = "North Sea - 6nm" ;
                :history = "Generated by getm, ver. 1.8.0" ;
```

2.1. Reading the data

The data are read:

```
lat_c <- var.get.nc(d.nc, "latc")
lon_c <- var.get.nc(d.nc, "lonc")
time  <- var.get.nc(d.nc, "time")
```

```
level <- var.get.nc(d.nc, "level")
convc <- var.get.nc(d.nc, "convc")
xc    <- var.get.nc(d.nc, "xc") / 1000  # in km
yc    <- var.get.nc(d.nc, "yc") / 1000
dx    <- var.get.nc(d.nc, "dx") / 1000
dy    <- var.get.nc(d.nc, "dy") / 1000
hcc   <- var.get.nc(d.nc, "hcc")
h     <- var.get.nc(d.nc, "h")
bathy <- var.get.nc(d.nc, "bathymetry")
# get 2-D data
u     <- var.get.nc(d.nc, "u")
v     <- var.get.nc(d.nc, "v")
elev  <- var.get.nc(d.nc, "elev")
temp  <- var.get.nc(d.nc, "temp")
ww    <- var.get.nc(d.nc, "w")
uu    <- var.get.nc(d.nc, "uu")
vv    <- var.get.nc(d.nc, "vv")
```

Show some values: the grid spacing, and he ranges of the velocities: :

```
c(dx, dy)
```

```
[1] 11.112 11.112
```

```
range(uu, na.rm = TRUE)
```

```
[1] -1.217723  1.751082
```

```
range(vv, na.rm = TRUE)
```

```
[1] -1.303300  2.244228
```

```
range(ww, na.rm = TRUE)
```

```
[1] -0.01644286  0.02704342
```

2.2. Box depths

The output of the model lacks an output variable that has the depth, in the middle of each compartment. It is created from the thickness of each box (h). First we take the temporal mean of the box thicknesses:

```
hh <- apply(h, MARGIN = 1:3, FUN = mean)
```

Then we take the cumulative sum of the box thicknesses. This gives the depth at the box interfaces:

```
depth <- hh
depth[ , ,1] <-  0
for (i in 26:2)
  depth[ , , i-1] <- depth[ , , i-1] + depth[ , , i]
```

Then we take the mean of the interfaces, to get the depth at the centre of a box.

```
for (i in 2:26)
  depth[ , , i] <- 0.5*(depth[ , , i-1] + depth[ , , i])
```

3. Plot bathymetry and grid

`jet2.col` from the package `plot3D` is a suitable color scheme, not too dark.

```
par(mfrow = c(2, 2))
col <- jet2.col(100)
#
# Plot every fourth grid point
plot(x = lon_c[seq(1, length(lon_c), by = 4)],
     y = lat_c[seq(1, length(lat_c), by = 4)],
     xlab = "longitude", ylab = "latitude",
     pch = ".", main = "grid points")
legend("bottom", legend = paste (c("x: ", "y: "), dim(lon_c)))
#
# Plot the bathymetry on the grid (distorted)
image2D(bathy, x = xc, y = yc, NAcol = "black",
      col = col, xlab = "km", ylab = "km",
      main = "Bathymetry on grid", clab = c("","","m"))
#
# The bathymetry on regular coordinates - shade emphasises bathymetry
image2D(bathy, x = lon_c, y = lat_c, NAcol = "black", shade = 0.15,
      col = col, main = "Bathymetry on coordinates",
      xlab = "longitude", ylab = "latitude", clab = c("","","m"))
#
# add transect line
lines(lon_c[30,], lat_c[30,]) # from where the sigma grid is plotted
#
# plot the sigma grid on transect line
matplot(x = yc, depth[30,,], type = "l", col = "black",
        main = "sigma grid", ylab = "depth, m", xlab = "y",
        lty = 1, ylim = c(140, 0))
lines(yc, bathy[30, ], lwd = 2, col = "red")
```

3.1. Another bathymetric view

Bathymetric data can also be plotted as perspective plots.

```
par(mfrow = c(1, 1))
# make bathymetry that does not have NAs (for z-values)
D <- bathy ;  D[is.na(D)] <- 0
persp3D(x = xc, y = yc, z = -D, colvar = -bathy,
  col = "grey", shade = 0.5, scale = FALSE, phi = 80,
  NAcol = grey(0.2), theta = 0, box = FALSE)
```

To zoom, rotate, cut, try:

```
plotrgl()
plotdev(xlim = c(-100, 500), ylim = c(5667, 6300), zlim = c(-50,0), phi = 50)
```

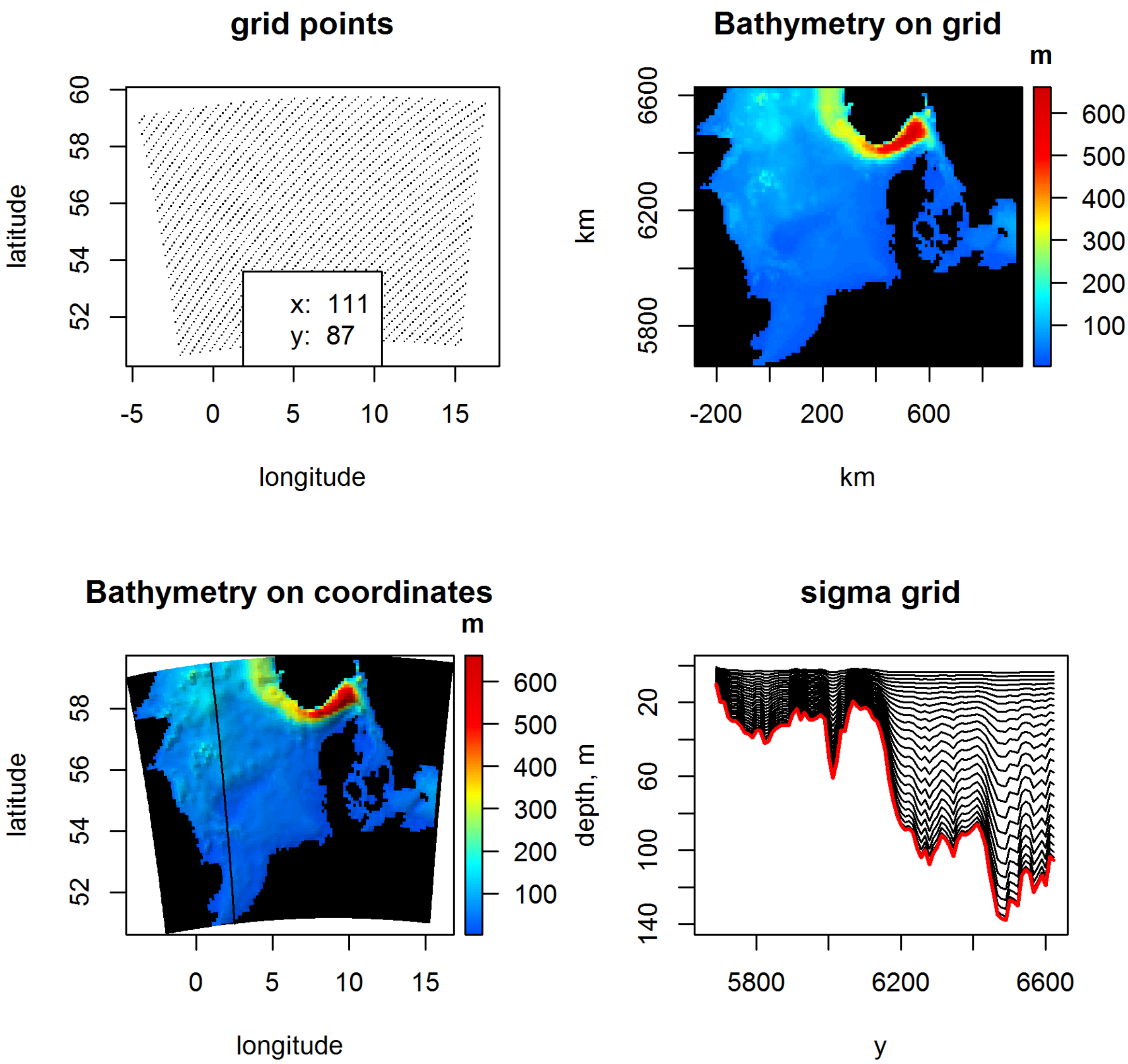


Figure 1: Bathymetry and grid

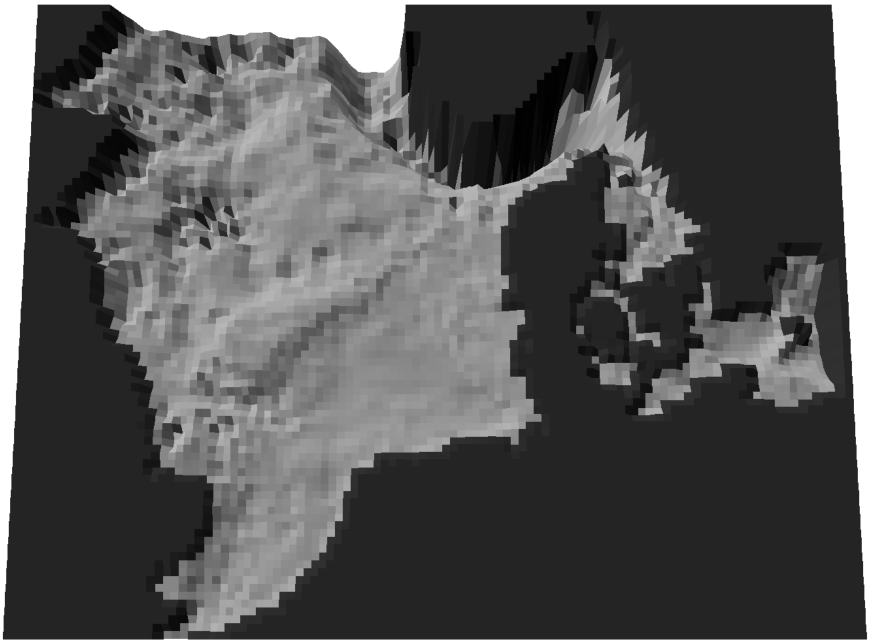


Figure 2: Bathymetry in perspective

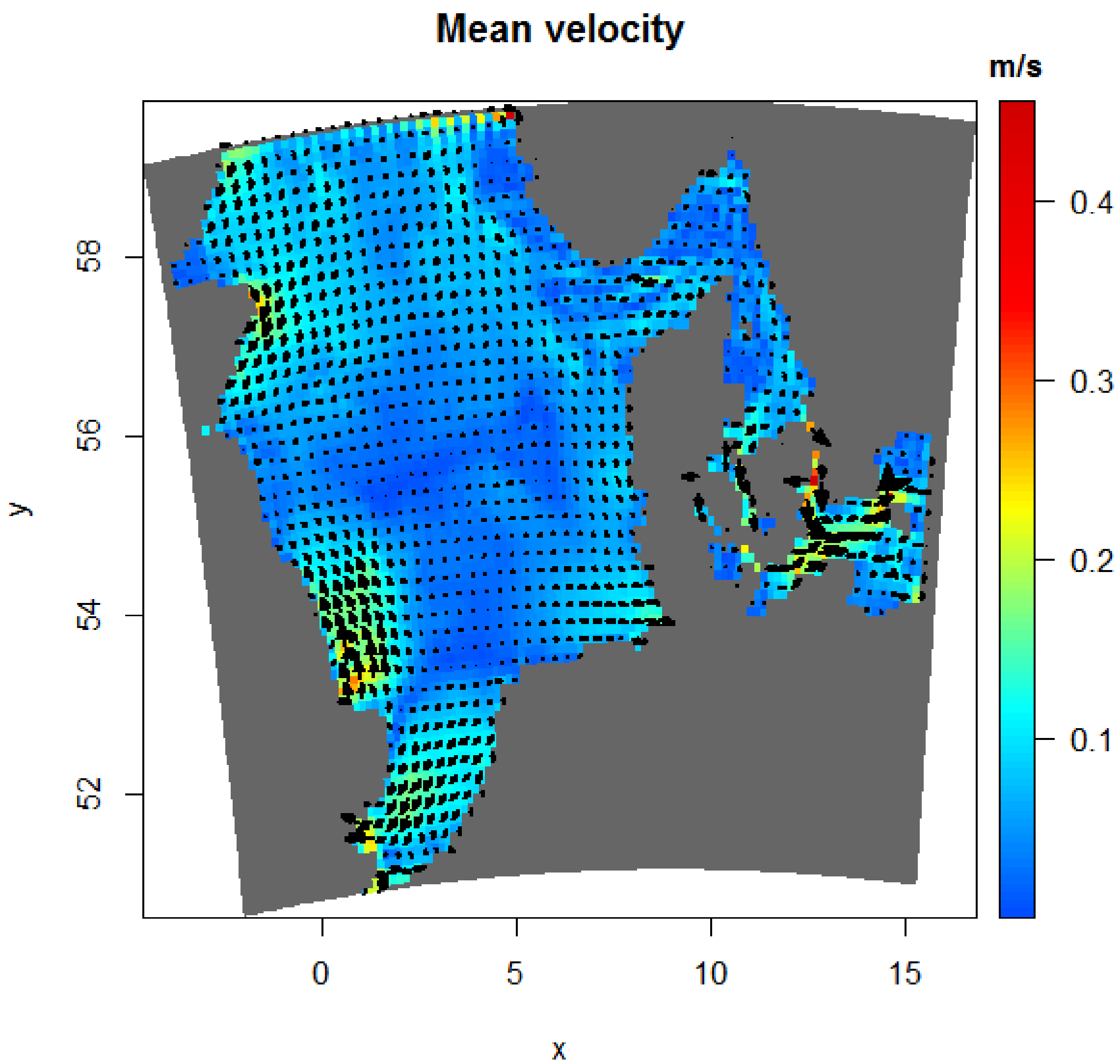
4. integrated velocities

The arrays u, v contain depth-average velocities, as they vary in time. We calculate the average velocity over the 30 days of the simulation:

```
U <- apply (u, FUN = mean, MARGIN = 1:2)
V <- apply (v, FUN = mean, MARGIN = 1:2)
meanV <- sqrt(U^2 + V^2)
```

We plot the average velocities as quivers on an image:

```
par(mfrow = c(1, 1))
image2D(z = meanV, x = lon_c, y = lat_c,
      col = col, NAcol = grey(0.4),
      main = "Mean velocity", clab = c("","","m/s"))
quiver2D(U, V, x = lon_c, y = lat_c, add = TRUE,
      by = 2, scale = 3, lwd = 2, arr.max = 0.3)
```



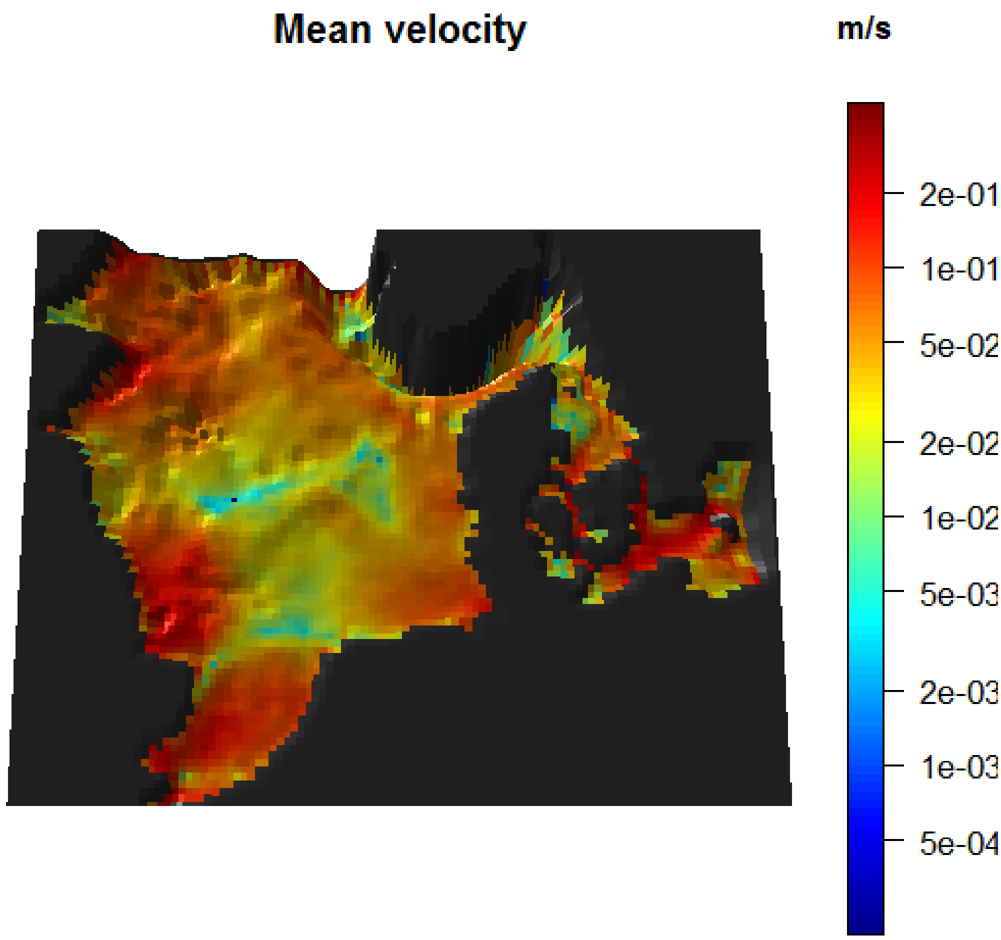
Try this, and use left and right mousekey:

```
image2Drgl(z = meanV, x = lon_c, y = lat_c,
      col = col, NAcol = grey(0.4),
      main = "Mean velocity")
quiver2Drgl(U, V, x = lon_c, y = lat_c, add = TRUE,
      by = 2, scale = 3, lwd = 2, arr.max = 0.2)
# select a rectangular region
cutrgl()
```

Velocity (log scale) draped on the bathymetry.

```
persp3D(x = xc, y = yc, z = -D, colvar = meanV,
  lighting = TRUE, scale = FALSE, phi = 80, box = FALSE,
```

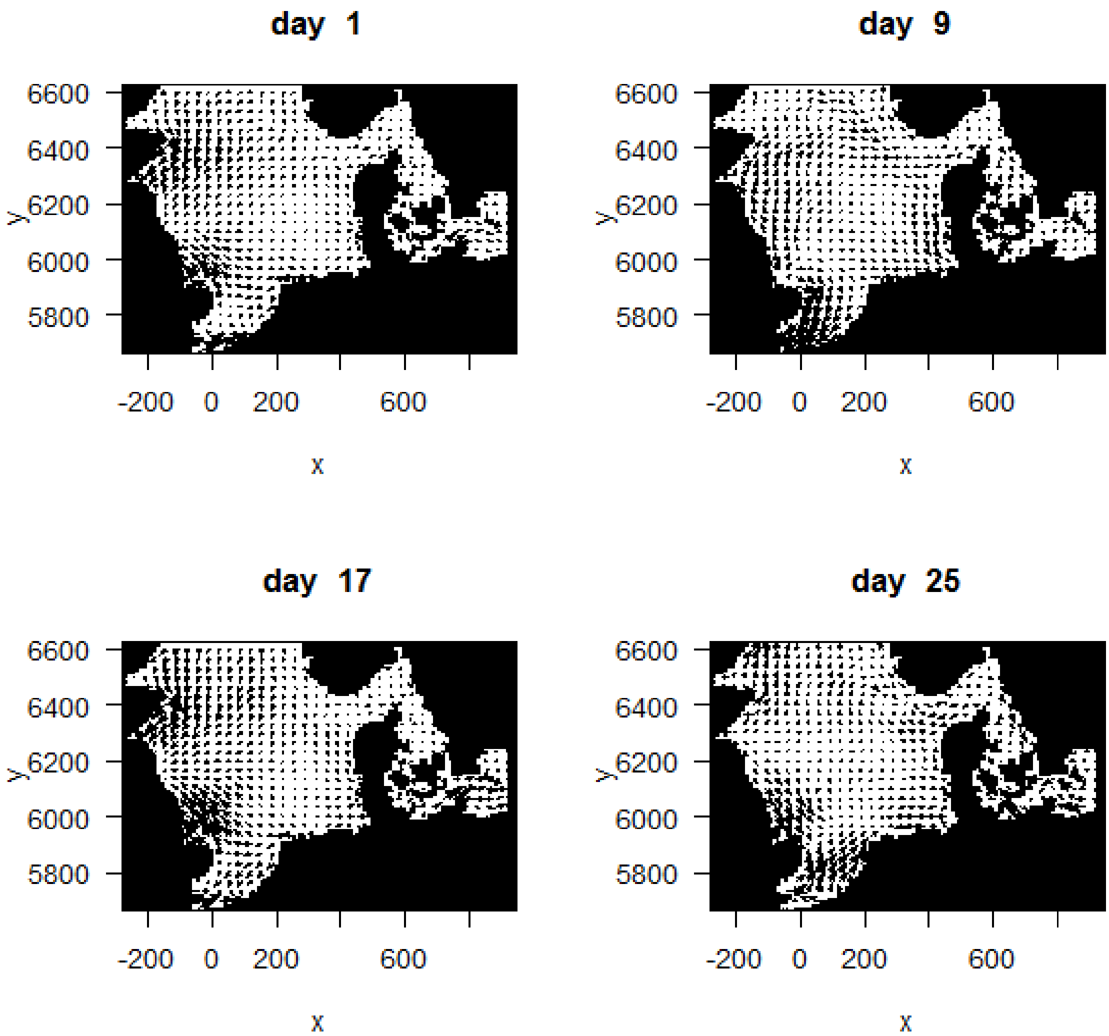
```
log = "c", clab= "m/s", main = "Mean velocity",
NAcol = grey(0.2), theta = 0, inttype = 2)
```



5. Quivers at selected time points

We can also easily visualise quivers at selected time points:

```
tselect <- time[seq(from = 1, to = 30, by = 8)]
par(oma = c(0, 0, 2, 0), las = 1)
quiver2D(u, v, x = xc, y = yc,
       subset = (time %in% tselect),
       scale = 3, arr.max = 0.2, by = 3, mask = bathy,
       NAcol = "darkgrey", main = paste("day ", tselect/86400))
```

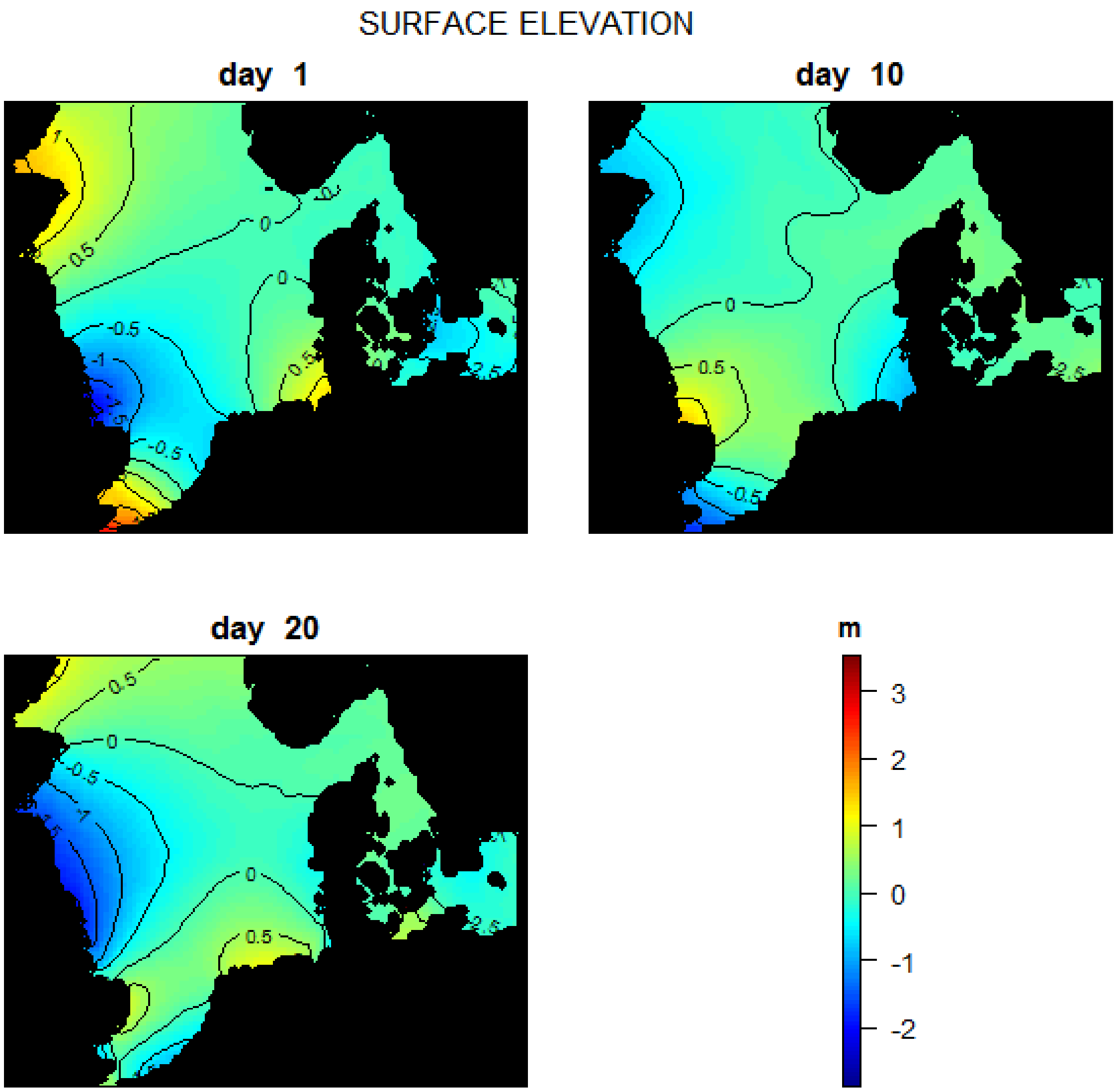


6. surface elevation, for selected time steps

To depict the surface elevation at 3 time points, we use `image2D`.

```
zlim <- range(elev, na.rm = TRUE)
tselect <- time[c(1, 10, 20)]
```

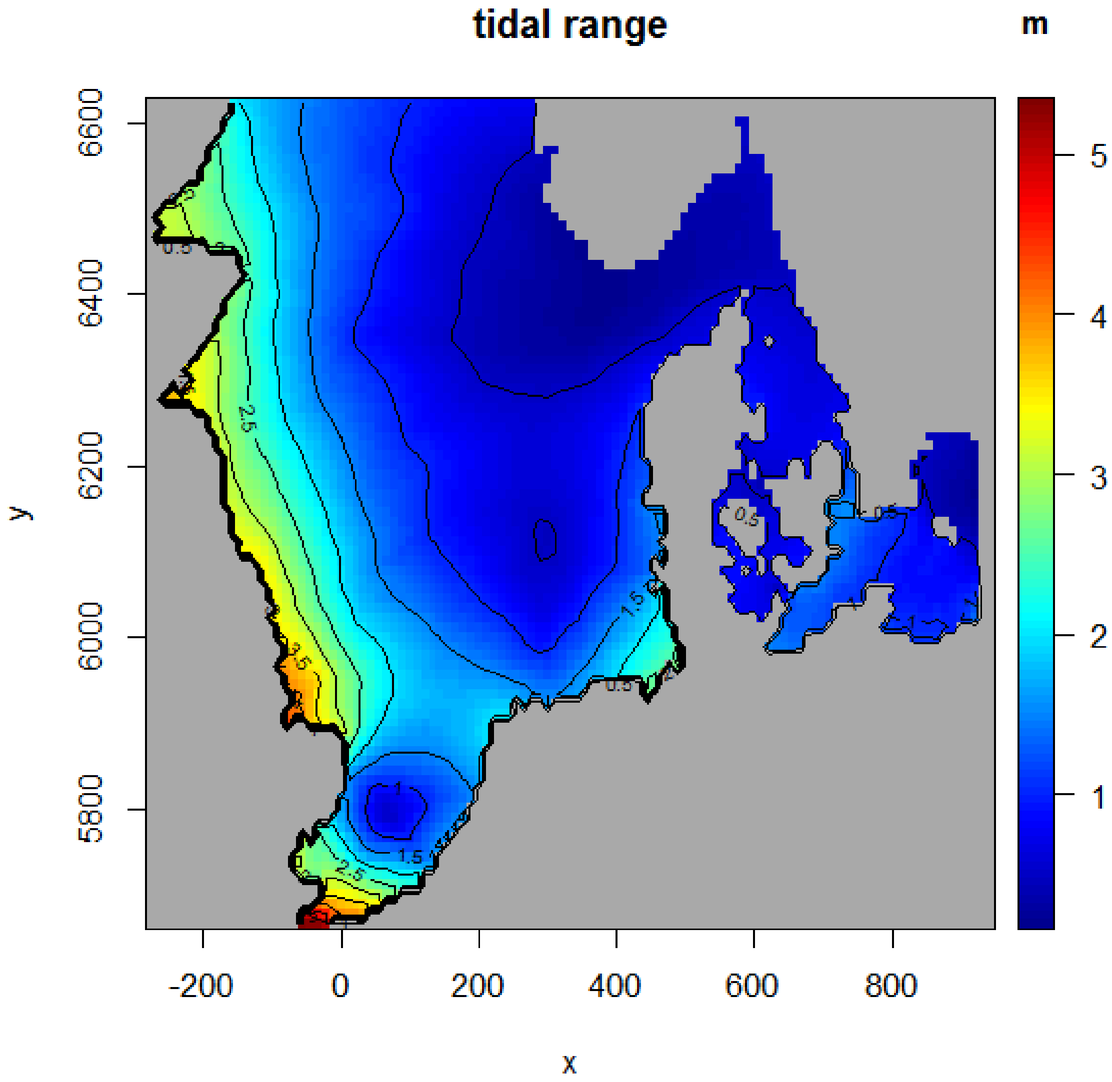
```
par(oma = c(0, 0, 2, 0))
pm <- par(mar = c(2, 2, 2, 0))
image2D(elev, subset = (time %in% tselect), mfrow = c(2, 2),
      NAcol = "black", axes = FALSE, xlab = "", ylab = "",
      contour = TRUE, main = paste("day ", tselect/3600/24),
      zlim = zlim, colkey = FALSE)
colkey(clim = zlim, clab = "m")
mtext (outer = TRUE, side = 3, "SURFACE ELEVATION", line = 0)
par(mar = pm)
```



The range of surface elevation, averaged over time is plotted, and contours are added:

```
tidal.range <- apply(elev, MARGIN = 1:2,
                     FUN = function(x) diff(range(x)))
```

```
tselect <- time[seq(from = 1, to = 30, length.out = 9)]
par(mfrow = c(1, 1))
image2D(x = xc, y = yc, z = tidal.range, contour = TRUE,
  NAcol = "darkgrey", clab = "m", main = "tidal range")
```

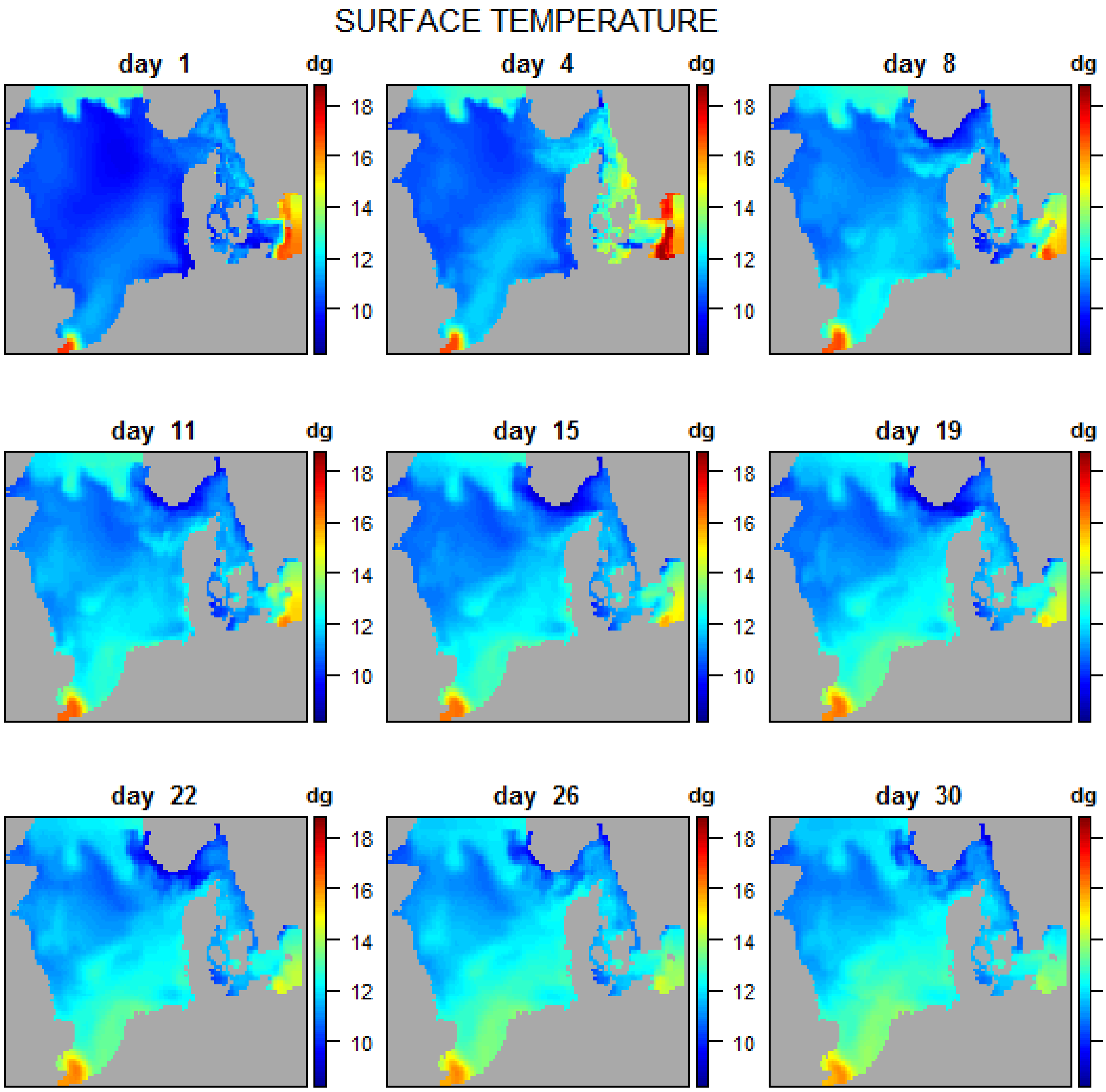

tidal range
m
5
4
3
2
1
6600
6400
6200
6000
5800
y
-200
0
200
400
600
800
x

7. surface temperature, for selected time steps

`temp` contains 3D temperature data at all time steps. The surface data are selected frist, and then plotted for a selection of time steps.

```
surfTemp <- temp[ , , 26, ]
zlim <- range(surfTemp, na.rm = TRUE)
```

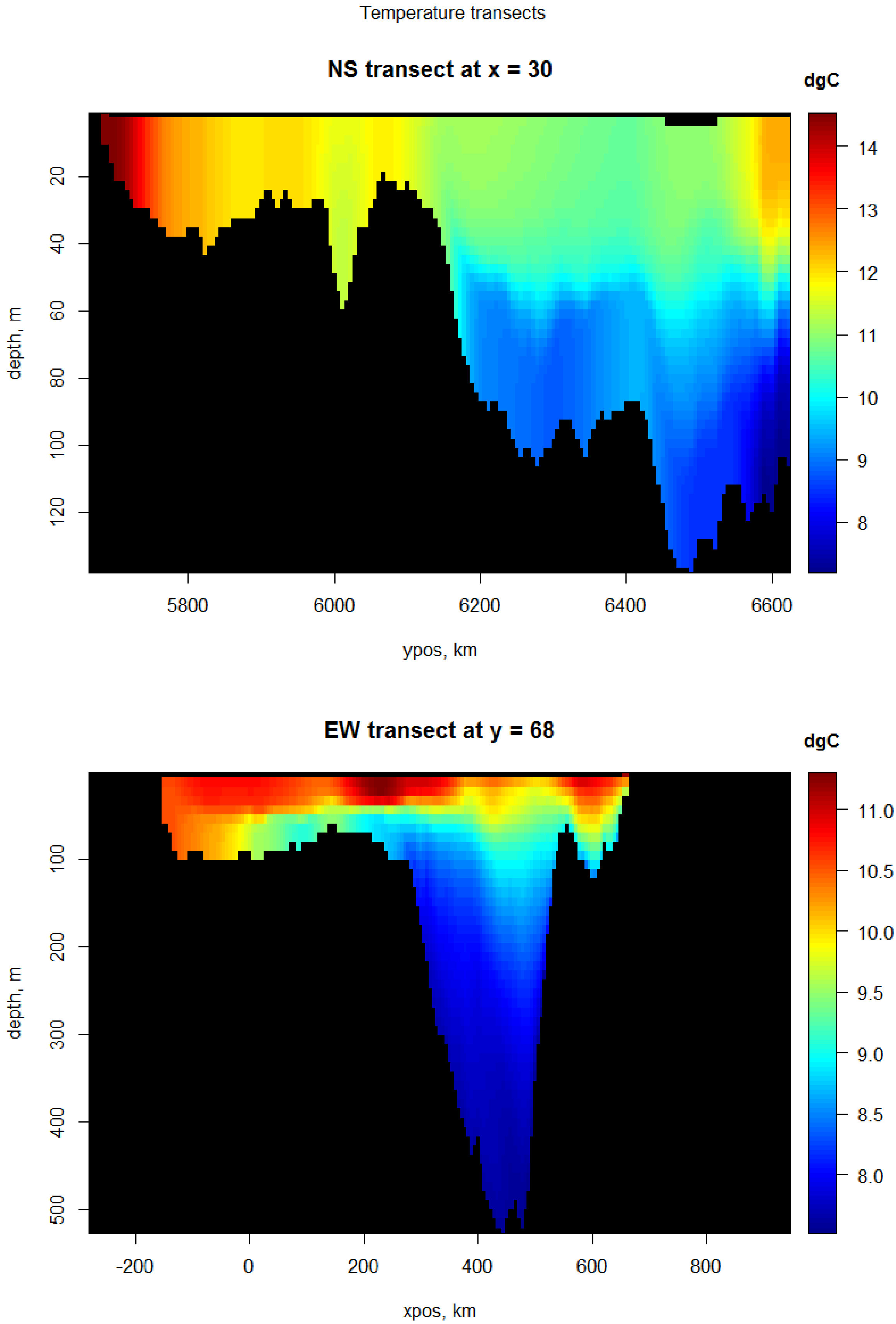
```
par(oma = c(0, 0, 2, 0))
pm <- par(mar = c(2, 2, 2, 0))
image2D(surfTemp, subset = (time %in% tselect), mfrow = c(3, 3),
      NAcol = "darkgrey", axes = FALSE, xlab = "", ylab = "",
      main = paste("day ", tselect/3600/24), zlim = zlim, clab = "dg")
mtext (outer = TRUE, side = 3, "SURFACE TEMPERATURE")
par(mar = pm)
```


SURFACE TEMPERATURE
day 1
day 4
day 8
day 11
day 15
day 19
day 22
day 26
day 30
dg
18
16
14
12
10

8. mean temperature along a NS-depth and a SW-depth transect

For two transects, first the time-mean temperature is estimated (`apply`). The temperature matrix is then converted from sigma coordinates to depth values (`mapsigma`), increasing the resolution (`resfac`). Then the `image` is generated.

```
par(oma = c(0, 0, 2, 0))
par(mfrow = c(2, 1))
TranTemp <- apply(temp[30 , , , ], MARGIN = 1:2, FUN = mean)
MS <- mapsigma(TranTemp, sigma = depth[30, , ], x = yc, resfac = 2)
image2D(MS$var, y = MS$depth, x = MS$x, ylim = rev(range(MS$depth)),
      NAcol = "black", ylab = "depth, m", xlab = "ypos, km",
      main = "NS transect at x = 30", clab = c("","dgC"))
TranTemp <- apply(temp[  , 68, , ], MARGIN = 1:2, FUN = mean)
MS       <- mapsigma(TranTemp, sigma = depth[ ,68, ], x = xc, resfac = 2)
image2D(MS$var, y = MS$depth, x = MS$x, ylim = rev(range(MS$depth)),
      NAcol = "black", ylab = "depth, m", xlab = "xpos, km",
      main = "EW transect at y = 68", clab = c("","dgC"))
mtext (outer = TRUE, side = 3, "Temperature transects")
```

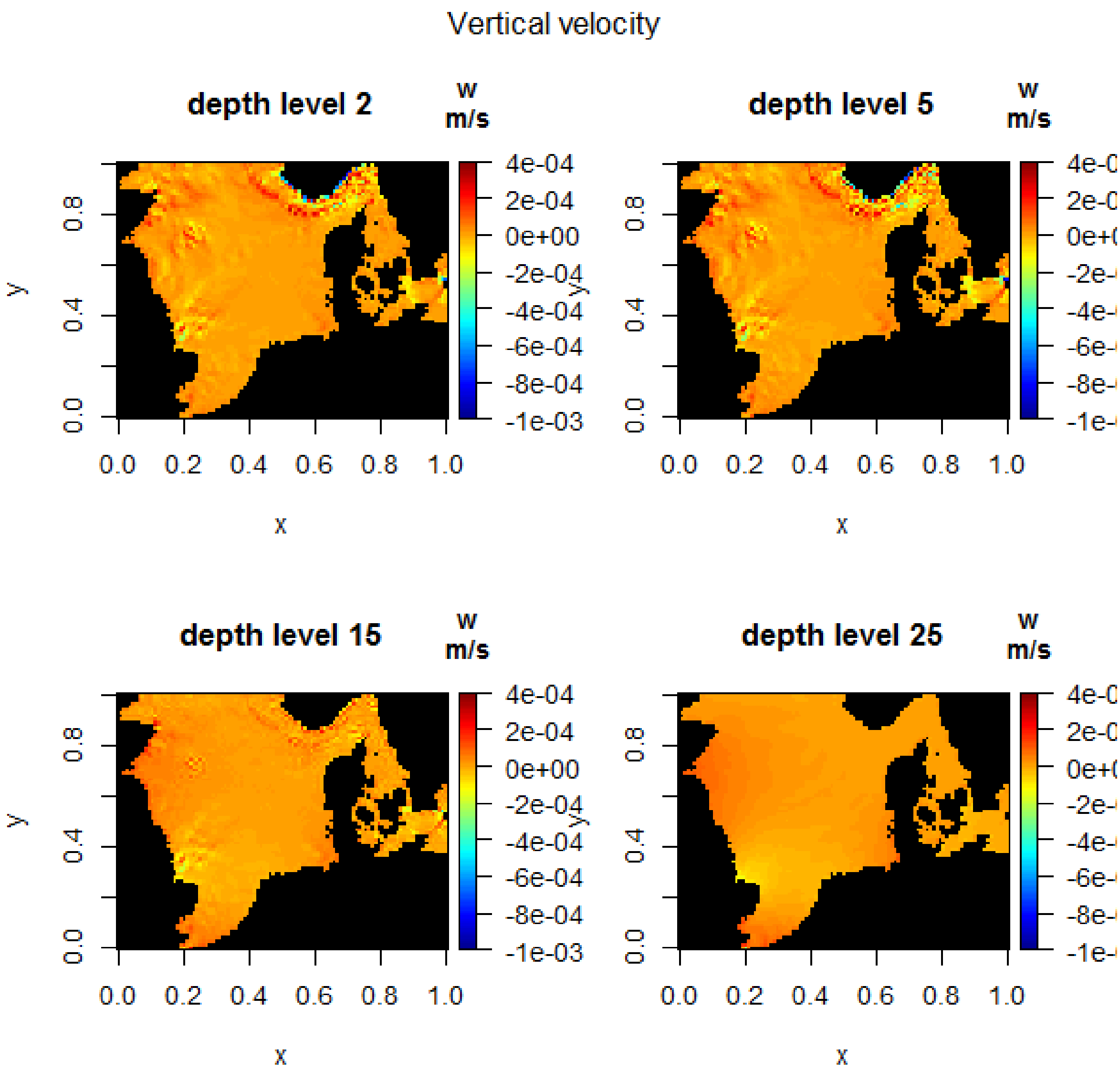

Temperature transects
NS transect at x = 30
dgC
14
13
12
11
10
9
8
depth, m
20
40
60
80
100
120
5800
6000
6200
6400
6600
ypos, km
EW transect at y = 68
dgC
11.0
10.5
10.0
9.5
9.0
8.5
8.0
depth, m
100
200
300
400
500
-200
0
200
400
600
800
xpos, km

9. time-averaged vertical velocities at several depths

Here we create the temporally averaged vertical velocities, at selected depth levels and remove the N and E points, as they are unstable:

```
wmean <- apply(ww, MARGIN = 1:3, FUN = mean)
subset.level <- c(2, 5, 15, 25)
x.remove <- 105:111 ; y.remove <- 82:87

par(oma = c(0, 0, 2, 0))
image2D(wmean[-x.remove, -y.remove, ], NAcol = "black",
      main = paste("depth level", subset.level), zlim = c(-1e-3, 4e-4),
      subset = (level %in% subset.level), clab = c("w","m/s"))
mtext (outer = TRUE, side = 3, "Vertical velocity")
```



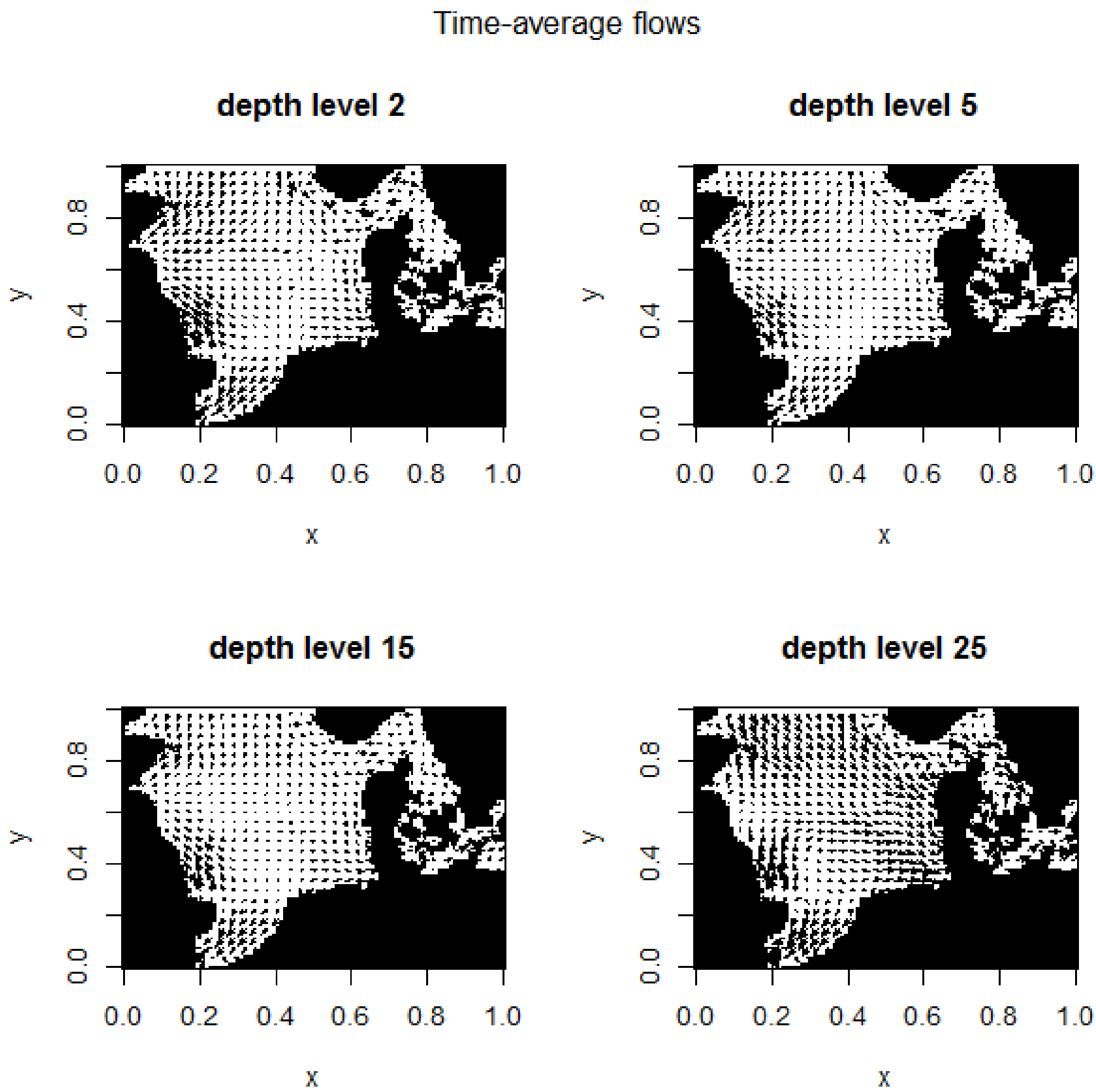
10. time-averaged horizontal velocity vectors at several depths

uu and vv contain 3D output of horizontal velocities at all time points. We first create temporally averaged velocities:

```
umean <- apply(uu, MARGIN = 1:3, FUN = mean)
vmean <- apply(vv, MARGIN = 1:3, FUN = mean)
```

The unstable N and E points are removed and a quiver produced:

```
par(oma = c(0, 0, 2, 0))
quiver2D(umean[-x.remove, -y.remove, ], vmean[-x.remove, -y.remove, ],
       NAcol = "grey", mask = bathy[-x.remove, -y.remove],
       main = paste("depth level", subset.level), by = 3,
       scale = 3, arr.max = 0.2, subset = (level %in% subset.level))
mtext (outer = TRUE, side = 3, "Time-average flows")
```


Time-average flows
depth level 2
depth level 5
depth level 15
depth level 25
y
x
0.0
0.4
0.8
0.0
0.2
0.4
0.6
0.8
1.0

11. NE and SW transects of time-averaged flows

The vertical velocities are 1000 times smaller than the horizontal ones; so to produce the quiver plots, they are multiplied with 1000:

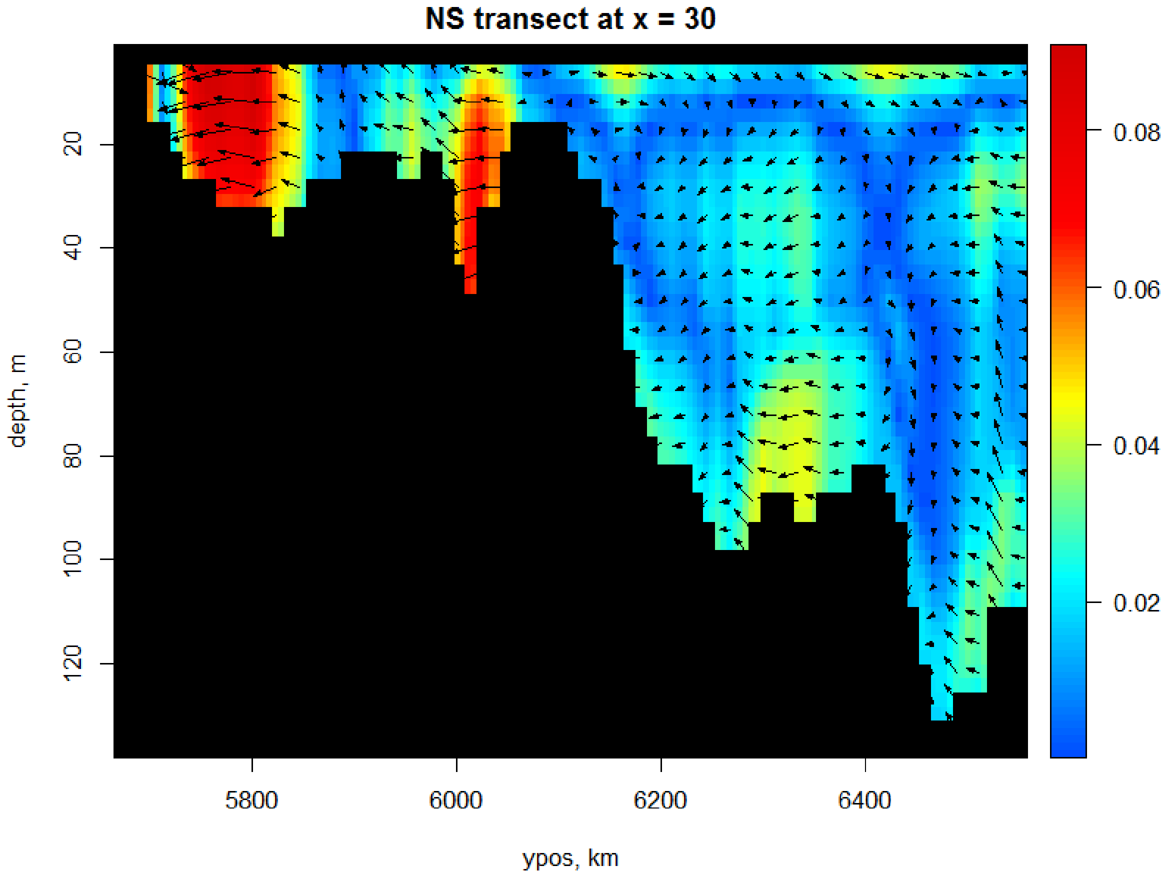
```
par(mfrow = c(2, 1), mar = c(4, 4, 2, 2))
# NS transect
Tran.u <- mapsigma(umean[30 , -y.remove, ], sigma = depth[30, -y.remove,])
Tran.w <- mapsigma(wmean[30 , -y.remove, ], sigma = depth[30, -y.remove,])
TotVelo <- sqrt(Tran.u$var^2 + Tran.w$var^2 )
DD <- Tran.w$depth
# ranges of u and v
range(Tran.u$var, na.rm = TRUE)
```

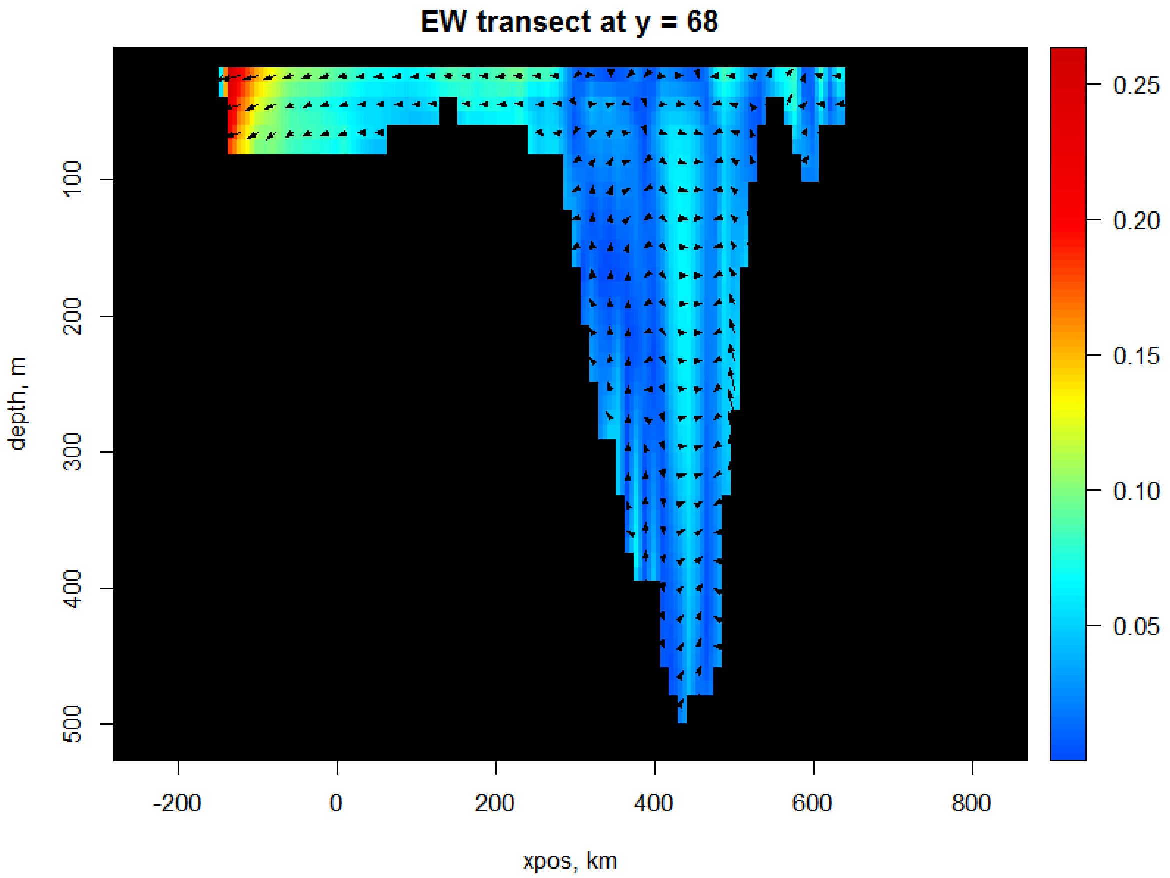
```
[1] -0.09098173  0.12890817
```

```
range(Tran.w$var, na.rm = TRUE)
```

```
[1] -7.923670e-05  7.631142e-05
```

```
#
image2D(TotVelo, y = DD, x = yc[ -y.remove], col = col,
      ylim = rev(range(DD)), NAcol = "black", resfac = 2,
      ylab = "depth, m", xlab = "ypos, km",
      main = "NS transect at x = 30")
quiver2D(Tran.u$var, Tran.w$var*1000, arr.min = 0.1, arr.max = 0.1,
       y = DD, x = yc[ -y.remove],
       by = c(2,1), scale = 3, add = TRUE)
#
# EW transect
Tran.v <- mapsigma(vmean[-x.remove , 68, ], sigma = depth[-x.remove, 68,])
Tran.w <- mapsigma(wmean[-x.remove , 68, ], sigma = depth[-x.remove, 68,])
TotVelo <- sqrt(Tran.v$var^2 + Tran.w$var^2 + 1e-8)
DD <- Tran.w$depth
image2D(TotVelo, y = DD, x = xc[ -x.remove], col = col,
      ylim = rev(range(DD)), NAcol = "black", resfac = 2,
      ylab = "depth, m", xlab = "xpos, km",
      main = "EW transect at y = 68")
quiver2D(Tran.v$var, Tran.w$var*1000, arr.min = 0.1, arr.max = 0.1,
       y = DD, x = xc[ -x.remove],
       by = c(2, 1), scale = 3, add = TRUE)
mtext (outer = TRUE, side = 3, "Flow transects")
```

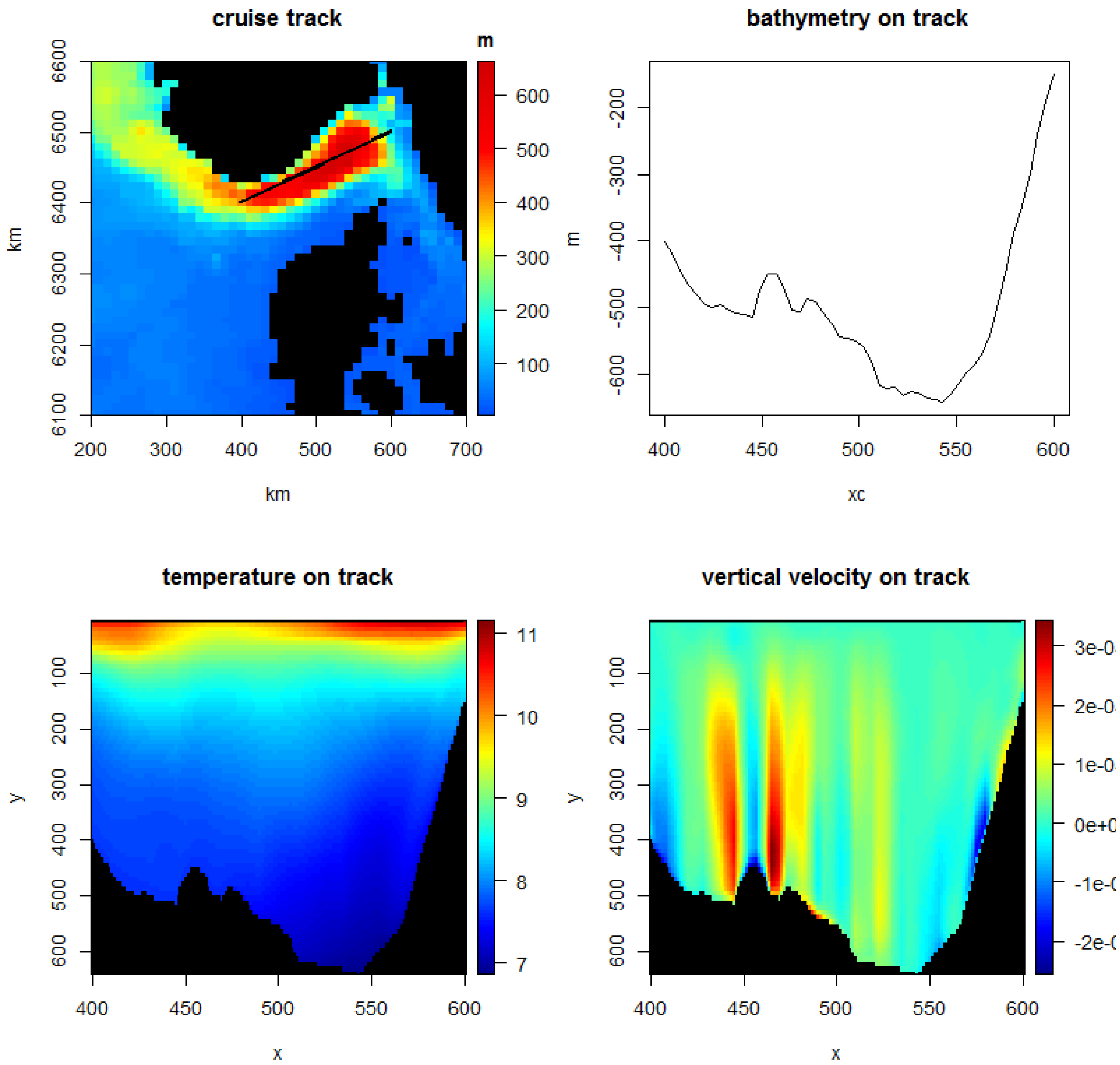

NS transect at x = 30
depth, m
20
40
60
80
100
120
5800
6000
6200
6400
ypos, km
0.08
0.06
0.04
0.02


EW transect at y = 68
depth, m
100
200
300
400
500
-200
0
200
400
600
800
xpos, km
0.25
0.20
0.15
0.10
0.05

12. plotting irregular transects, along a ship track

Fot this figure, we will extract data along a (hypothetical) ship track:

```
track <- cbind(seq(400, 600, length.out = 50),
               seq(6400, 6500, length.out = 50))
# Draw the bathymetry on km grid
par(mfrow = c(2, 2))
image2D(bathy, x = xc, y = yc, NAcol = "black",
      xlim = c(200, 700), ylim = c(6100, 6600),
      col = col, xlab = "km", ylab = "km",
      clab = c("","","m"), main = "cruise track")
# add track
points(track, pch = ".", cex=3)
# Depth on track
trackBat <- extract(var = bathy, x = xc, y = yc, xyto = track)
plot(x = trackBat$xy[,1], y =-trackBat$var, type = "l", xlab = "xc",
  ylab = "m", main = "bathymetry on track")
# temperature
Avgtemp <- apply(temp, MARGIN = 1:3, FUN = mean, na.rm = TRUE)
tempSigma <- transectsigma(var = Avgtemp, sigma = depth,
  x = as.vector(xc), y = as.vector(yc), to = track, resfac = 3)
image2D(tempSigma$var, x = tempSigma$x, y = tempSigma$depth,
  ylim = rev(range(tempSigma$depth)), NAcol = "black",
  main = "temperature on track")
# vertical velocity
wSigma <- transectsigma(var = wmean, sigma = depth,
  x = as.vector(xc), y = as.vector(yc), to = track, resfac = 3)
image2D(wSigma$var, x = wSigma$x, y = wSigma$depth,
  ylim = rev(range(tempSigma$depth)), NAcol = "black",
  main = "vertical velocity on track")
```



13. Finally

This vignette was made with Sweave (Leisch 2002).

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