Soil Samples – Project

Visualização de Dados 2024/2025

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1. Introduction

The objective of this project is to visualize data using ParaView 5.13.1, a powerful visualization tool based on the VTK graphical library. The dataset was initially designed to consist of a 25x25 regular grid, intended to collect 625 samples. However, due to the presence of a rock that covered part of the area, only 575 samples were actually collected. To maintain the grid's regular topology and simplify data processing, fictitious points were added to replace the missing samples. These points were assigned coordinates that aligned with the boundaries of the original grid, ensuring that the spatial reference and data collected remained unaltered. As a result, the grid now contains 625 points, although only 575 correspond to real data from actual samples.

The collected samples include information on plant functional types, plant species, ammonification, and nitrification. Plant functional types are divided into two categories: persistent leaf plants (PFT=1) and semi-deciduous leaf plants (PFT=2). Plant species are identified by integers ranging from 1 to 13, while ammonification and nitrification represent key biochemical processes measured at each sample point. Data were collected during four different periods of the same year, corresponding to the seasons of spring, summer, autumn, and winter, referred to as the first, second, third, and fourth datasets, respectively.

The data are structured into a regular grid with regular topology but irregular geometry. The grid dimensions are 25x25x4, resulting in a total of 2500 data points, representing both spatial and temporal information. This structured format facilitates the visualization and analysis of temporal trends and spatial patterns, providing insights into the relationships between ammonification, nitrification, plant functional types, and species throughout the four seasons.

```
# vtk DataFile Version 3.0
vtk output
ASCII
DATASET STRUCTURED_GRID
DIMENSIONS 25 25 4
POINTS 2500 float
```

Figure 1 - Description of the data set.

Three columns of data were associated with the dataset: the XX and YY coordinates of the grid points, which identify the spatial position of each sample, and the ZZ coordinate, representing the temporal evolution of the data. Each sampling period corresponds to a plane in the grid, with the ZZ axis being orthogonal to the grid and used to model the progression over time. To achieve this, the data for the XX and YY coordinates were replicated four times, each copy being associated with a specific value for the ZZ coordinate: 10, 20, 30, and 40. Specifically, a ZZ value of 10 corresponds to the spring sampling, 20 to the summer sampling, 30 to the autumn sampling, and 40 to the winter sampling. This approach allows for the representation of temporal changes within the structured grid framework.

```
# vtk DataFile Version 3.0
vtk output
ASCII
DATASET STRUCTURED_GRID
DIMENSIONS 25 25 4
POINTS 2500 float

0       0       10
2       0       10
4       0       10
6       0       10
8       0       10
10      0       10
12      0       10
14      0       10
16      0       10
```

```
38      48      10
40      48      10
40      48      10
40      48      10
40      48      10
40      48      10
0       0       20
2       0       20
4       0       20
6       0       20
8       0       20
10      0       20
```

```
38      48      20
40      48      20
40      48      20
40      48      20
40      48      20
40      48      20
0       0       30
2       0       30
4       0       30
6       0       30
8       0       30
10      0       30
```

```
38      48      30
40      48      30
40      48      30
40      48      30
40      48      30
40      48      30
0       0       40
2       0       40
4       0       40
6       0       40
8       0       40
10      0       40
```

Figure 2 - Description of the dataset.

Then, the values of the PFT scalar were written. Below are the first 10 values.

```
POINT_DATA 2500
SCALARS PFT float
LOOKUP_TABLE default

1
1
1
1
1
1
1
1
1
2
```

Figure 3 - Description of the scalar PFT.

In a similar way, it was done with the scalar representing the species, ammonification and nitrification of plants.

```
SCALARS species float   SCALARS ammonification float   SCALARS nitrification float
LOOKUP_TABLE default    LOOKUP_TABLE default           LOOKUP_TABLE default
10                      21.964                         10.2
13                      23.169                         9.8
8                       27.002                         10.23
11                      28.3                           9.12
11                      21.119                         9.13
13                      37.302                         12.67
13                      37.5                           14.66
8                       28.952                         9.87
10                      32.928                         11.78
1                       19.409                         28.89
```

Figure 4 - Description of the scalar species, ammonification, nitrification.

Along with the scalar variables, a vector variable (Trend) was created, enabling a comparison of the Ammonification and Nitrification variables at each grid point. This vector was defined such that in each plane, the X component represented Ammonification, the Y component represented Nitrification, and the Z component was assigned a value of zero.

```
VECTORS Trend float
21.964  10.2    0
23.169  9.8     0
27.002  10.23   0
28.3    9.12    0
21.119  9.13    0
37.302  12.67   0
37.5    14.66   0
28.952  9.87    0
32.928  11.78   0
19.409  28.89   0
```

Figure 5 - Description of the vector variable (Trend).

2. Description of Visualizations

Specific pipelines were created for each request (a-h) as follows:

- **Request (a): Represent the scalar quantity nitrification in the different seasons of the year, using colored planes. Choose a color table suitable for the representation of this variable. Display the color legend in the image. Generate an animation over time. Can you draw conclusions about the evolution of this variable throughout the year?**

To depict the level of nitrification in the soil samples in the various seasons of the year, 4 cutting planes were created (Filter/Alphabetical/Slice), all four orthogonal to the z axis, each corresponding to each season. In fact, for z=10 we will have the cutting plane relating to spring, for z=20 relating to summer, for z=30 relating to autumn and for z=40 relating to winter. The respective graphic representations are shown below.

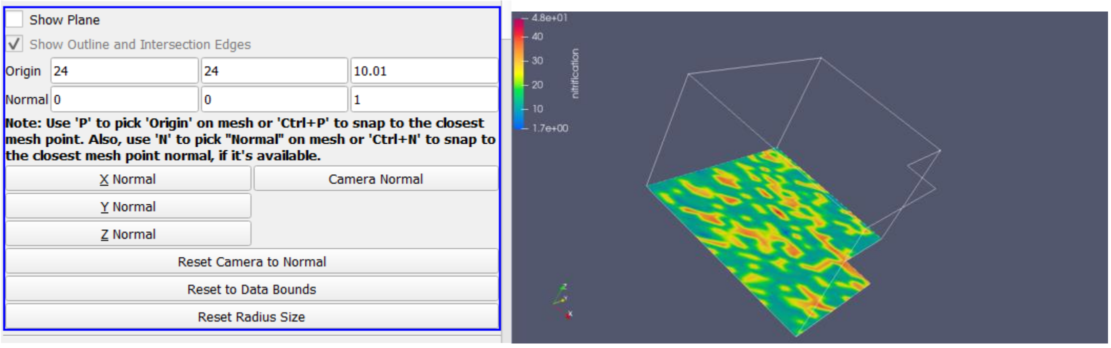


Figure 1 - First cutting plane, spring season, nitrification value.

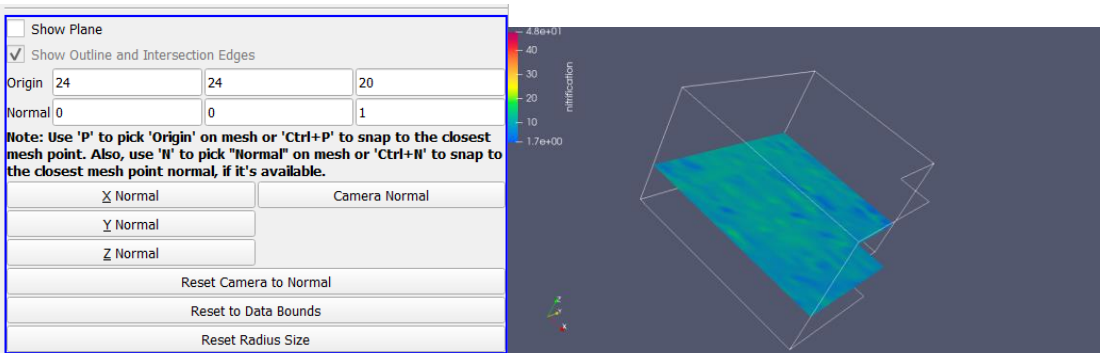


Figure 2 - Second cutting plane, summer season, nitrification value.

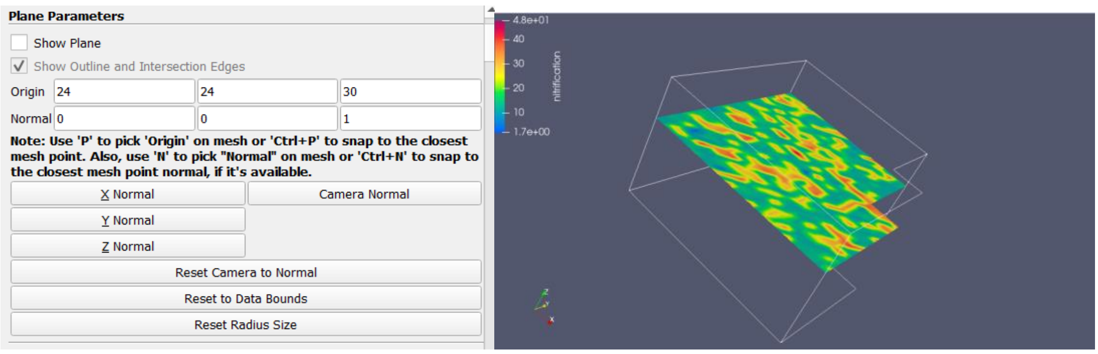


Figure 3 - Third cutting plane, summer season, nitrification value.

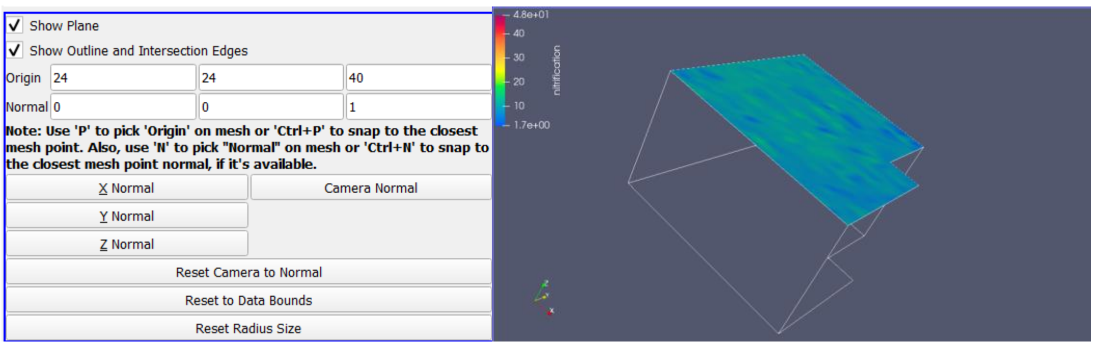


Figure 4 - Fourth cutting plane, winter season, nitrification value.

This below is the depiction with all 4 cutting planes. Furthermore, an animation was created to show the evolution of nitrification over the seasons.

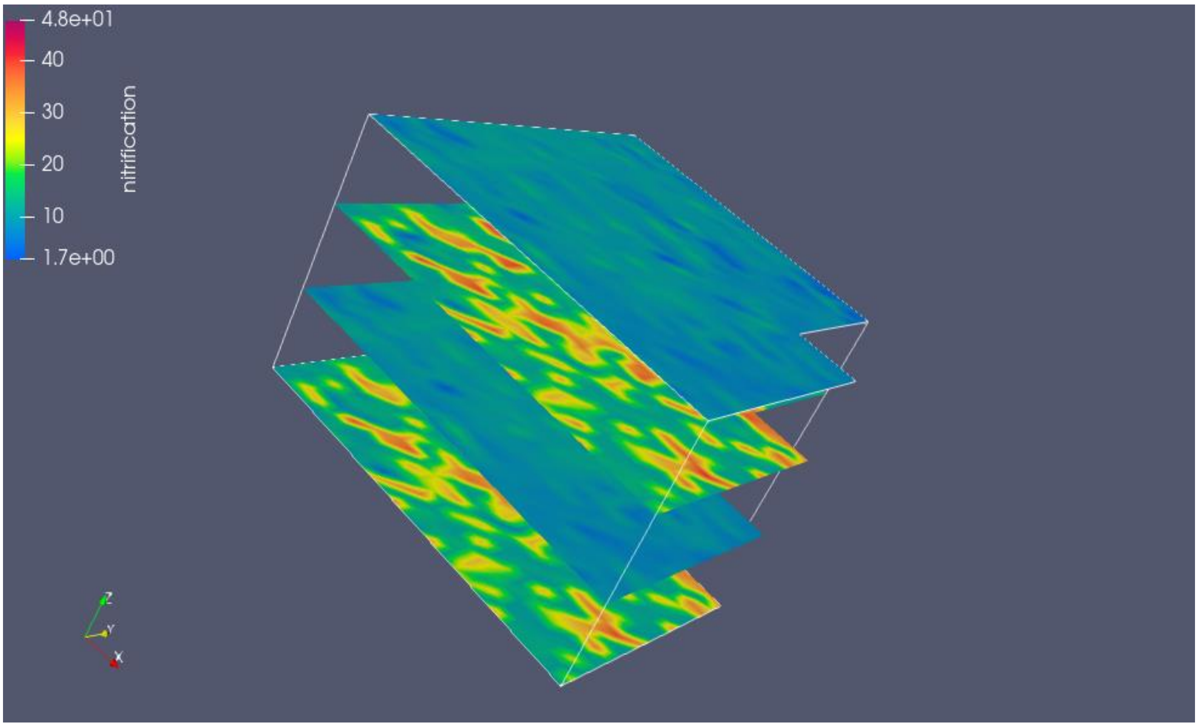


Figure 5 - Raffiguration of the four cutting plains regarding nitrification values.

As a color scale, the Rainbow Uniform scale was chosen. this choice was made because the contrast between the colors is quite evident and highlights the different levels of nitrification in each single cutting plane. So only for aesthetic reasons, otherwise this color scale, despite being quite common, has some defects, in fact it is not uniform and can introduce visual artefacts.

Figure 6 - Colour Scale.

As can be seen from the cutting planes, during spring and autumn nitrification levels can be very high or very low, while in summer and winter the level is practically at its minimum. In fact, nitrification levels vary throughout the year due to several factors related to climate, soil type and biological activity. Nitrification level also depends on the type of species and the PFT.

Animation over time of nitrification values in the soil samples

An animation was created to show the evolution of nitrification values in soil samples over time. Once we had chosen the first cutting plane relating to the spring season, which is the basis of our representation, the animation was created using View/Time Manager, with the following parameters.

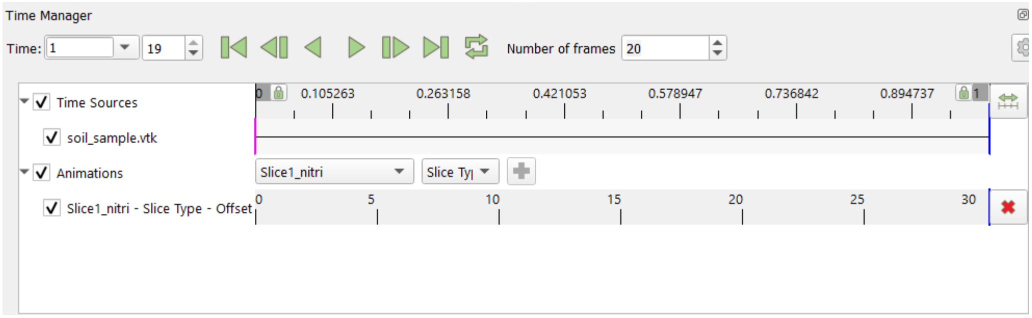


Figure 7 - Time manager parameters.

“Slice Type - Offset” was chosen, and the following Animation Keyframes.

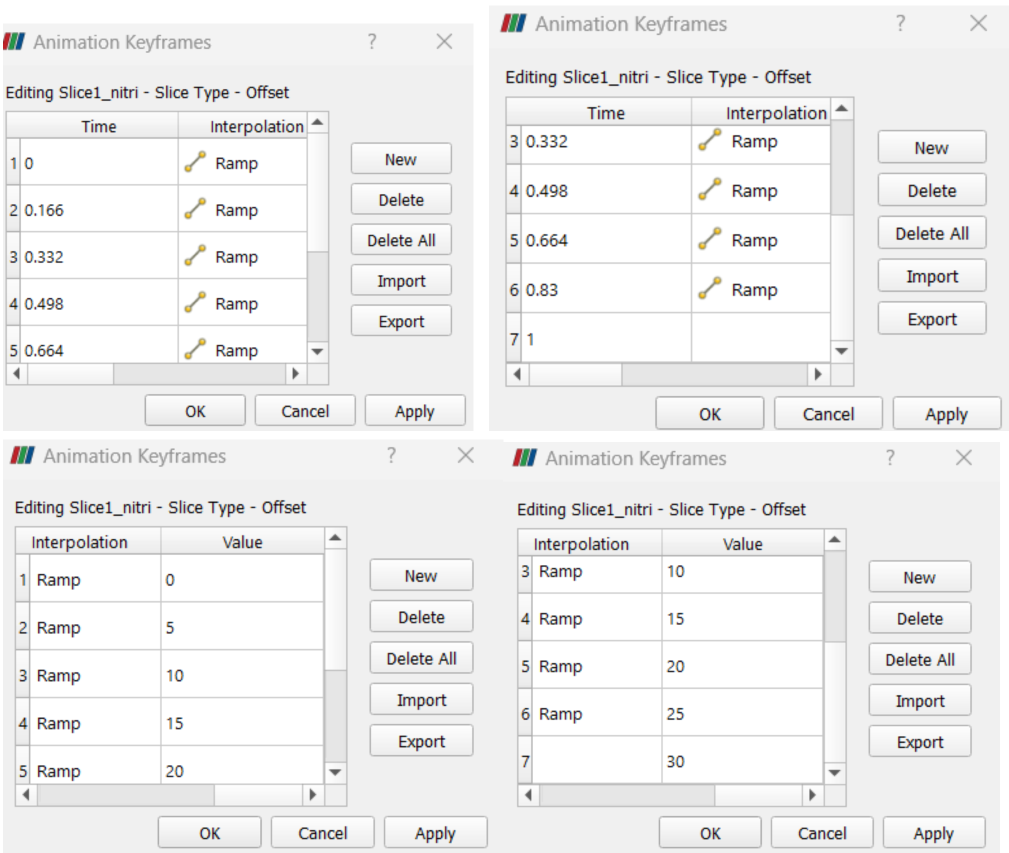


Figure 8 - Animation Keyframes.

Finally, it was saved with the following options. The file is in .AVI format and is attached together with the following report. The animation clearly shows the changes in nitrification between seasons, as mentioned before. In fact, as spring passes and summer arrives, we notice how the levels drop, then increase in autumn and drop again with the arrival of winter.

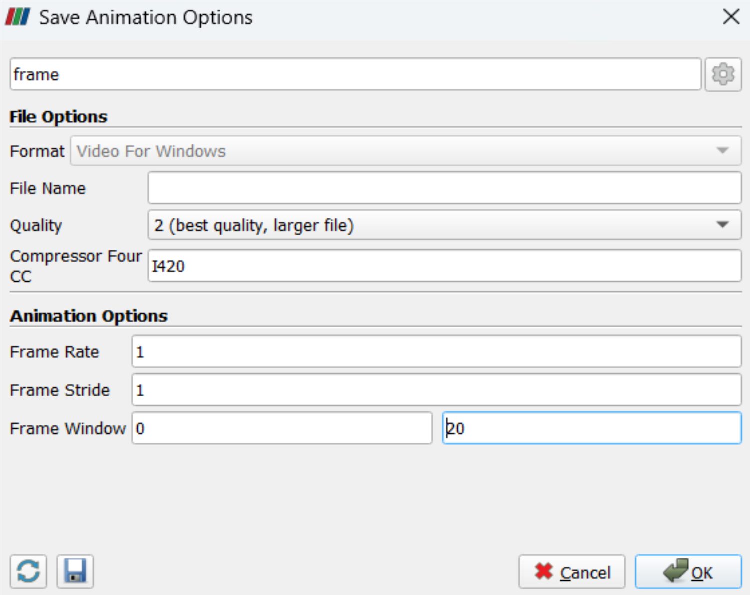


Figure 9 - Save Animation Options.

- **Request (b): On the colored plane representing spring data, draw isolines corresponding to 4 values of the nitrification variable.**

Regarding the cutting plane relating to spring, isolines corresponding to four values of the nitrification variable (10,20,30,40) were depicted (from first cutting place, Filter/Alphabetical/Contour).

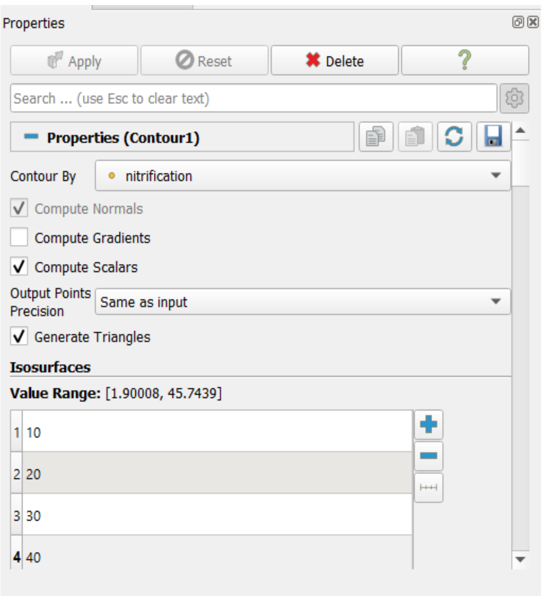


Figure 1 - Creation of isolines in ParaView.

Figure 2 is the result.

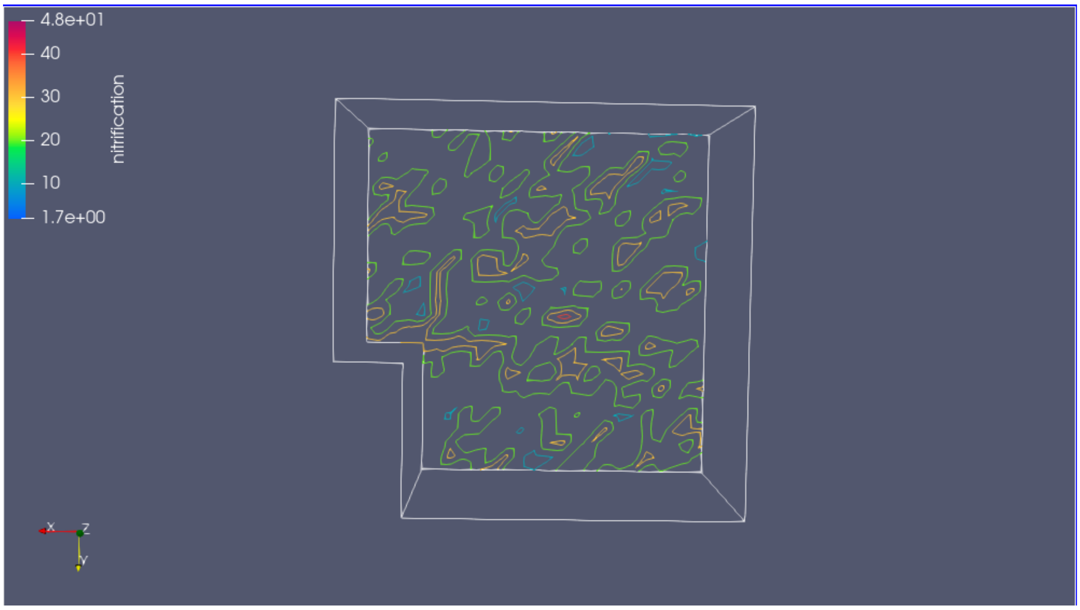
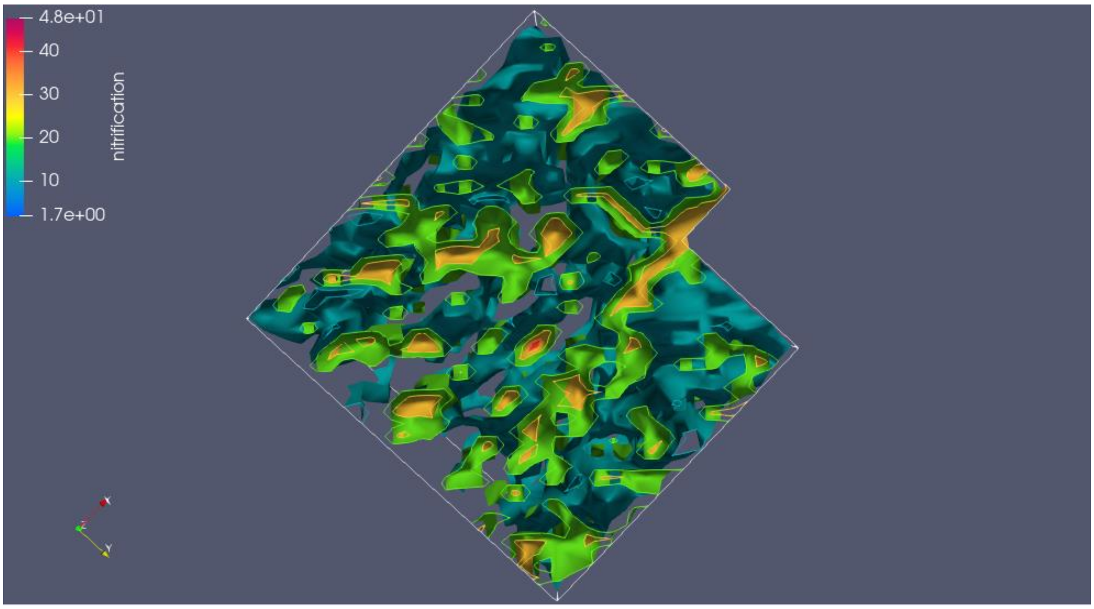


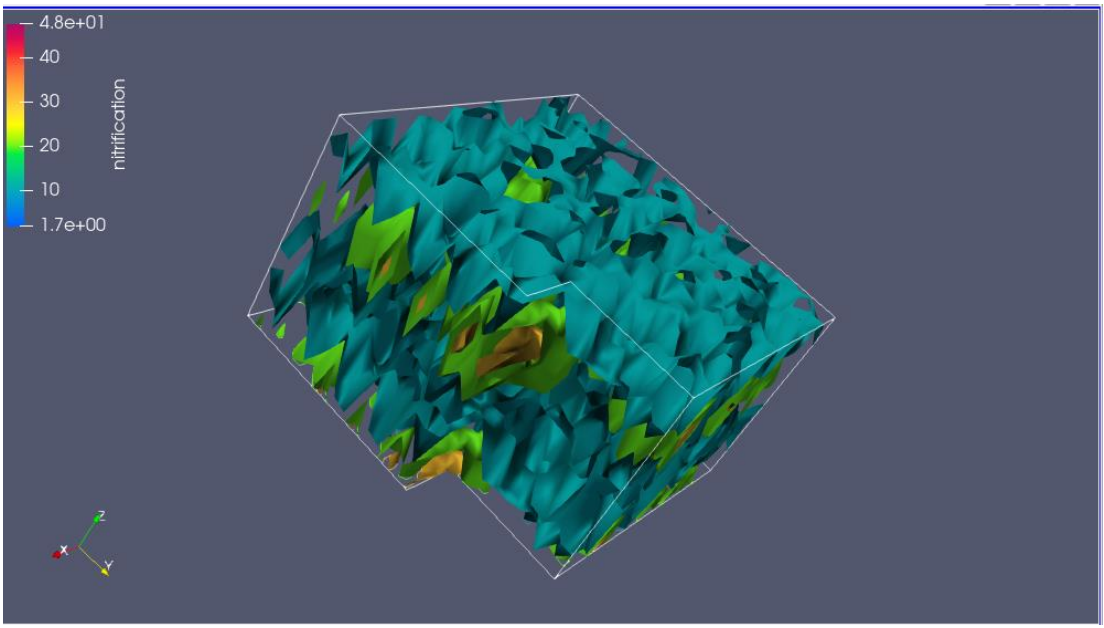
Figure 2 - Isolines, according to nitrification, in the first cutting plane.

The color scale used is in accordance with that of nitrification (Rainbow Uniform). It is easy to notice that most of the isolines are green in color, inherent to the value 20. Only one isoline is drawn for the value 40, which is one of the highest values of the nitrification variable: this means that such a high value is not common to achieve. The other isolines inherent to the values 10 and 30 are however quite present, with the majority for the value 30.

- **Request (c)**: **Build the isosurfaces corresponding to the values chosen in the previous paragraph.**

In addition to the isolines, the isosurfaces were also plotted, relating to the same values as the isolines. The Figure 1, Figure 2, Figure 3 are the results.


4.8e+01
40
30
20
10
1.7e+00
nitrification


4.8e+01
40
30
20
10
1.7e+00
nitrification

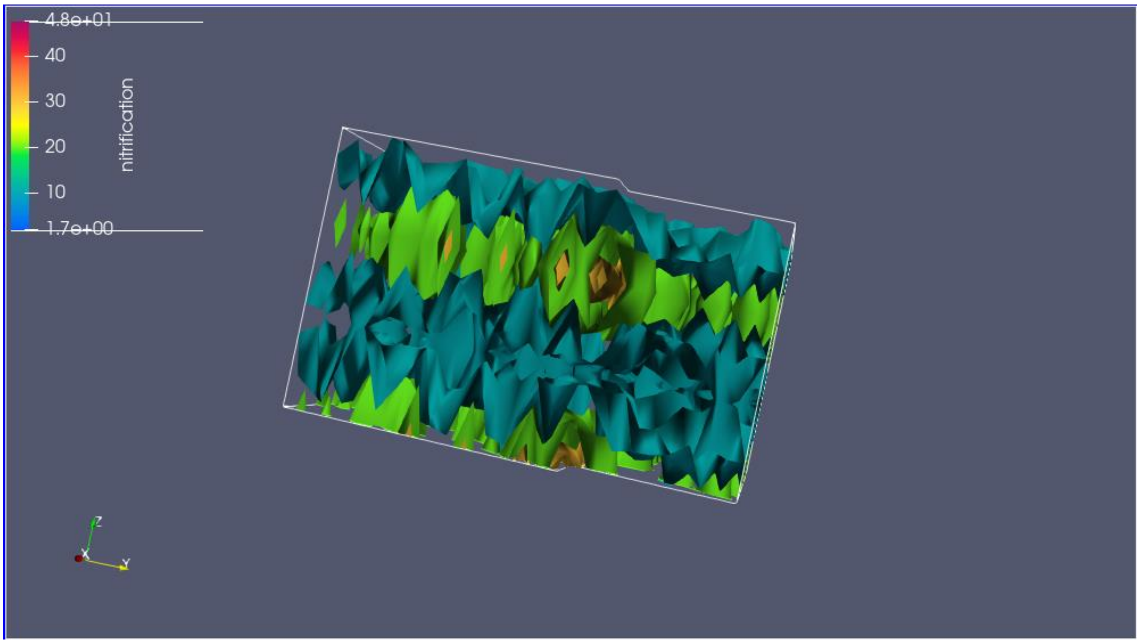


Figure 1,2,3 - Various angles of the isosurfaces.

Especially in Figure 3 it can be seen, even with the representation of the isosurfaces, the difference in the nitrification values as the seasons pass.

- **Request (d): Represent the scalar quantity ammonification in the different seasons of the year, using colored planes. Choose a suitable color table to represent this variable. Justify your choice in the report. Display the color legend on the image. Can you draw conclusions about the evolution of this variable throughout the year?**

Based on the VTK file, where ammonification data is organized into four planes, each representing a season of the year, "Slice" filters in ParaView 5.13.1 were used to create the respective planes. Each slice was configured to correspond to one season, resulting in a total of four planes.

In the filter properties, under the Plane Parameters, the origin of the planes was set with the coordinates x=24 and y=24, while the z-value varied according to the season: for spring, z=10.01; for summer, z=20; for autumn, z=30; and for winter, z=40. Additionally, the normal was set to (0,0,1) to generate a plane perpendicular to the Z-axis.

The coloring (Figure 1) was adjusted for the variable Ammonification, which was selected as the scalar magnitude to visualize. The Viridis colormap (from matplotlib) was used. The same colormap was maintained for all seasons, ensuring uniformity and enabling direct comparisons between different periods of the year.

The Viridis colormap (matplotlib) was chosen due to its characteristics that promote clear and effective visualization. First, perceptual order is guaranteed by the Viridis palette, which uses a progressive and continuous color variation, from purple to yellow, to intuitively reflect the variation of scalar values. This ensures that if numerical values are ordered, the colors representing them also appear ordered.

Uniformity and representative distance are also respected, as the palette was designed to ensure that differences in values are translated into clearly perceptible color differences. This allows easy distinction of distant values and recognition of continuity in closer values, avoiding ambiguities.

Moreover, Viridis is a continuous scale, ideal for representing univariate data, such as ammonification values over the year, without creating perceptions of artificial boundaries or categories.

Finally, the accessibility of Viridis, which is colorblind-friendly, reinforces its choice as an inclusive tool, ensuring that the representations can be interpreted by a wide audience without hindering analysis.

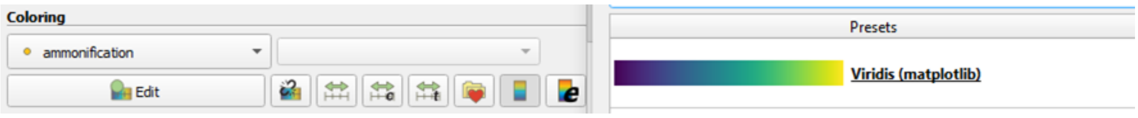


Figure 1 - Coloring: ammonification - Viridis (matplotlib).

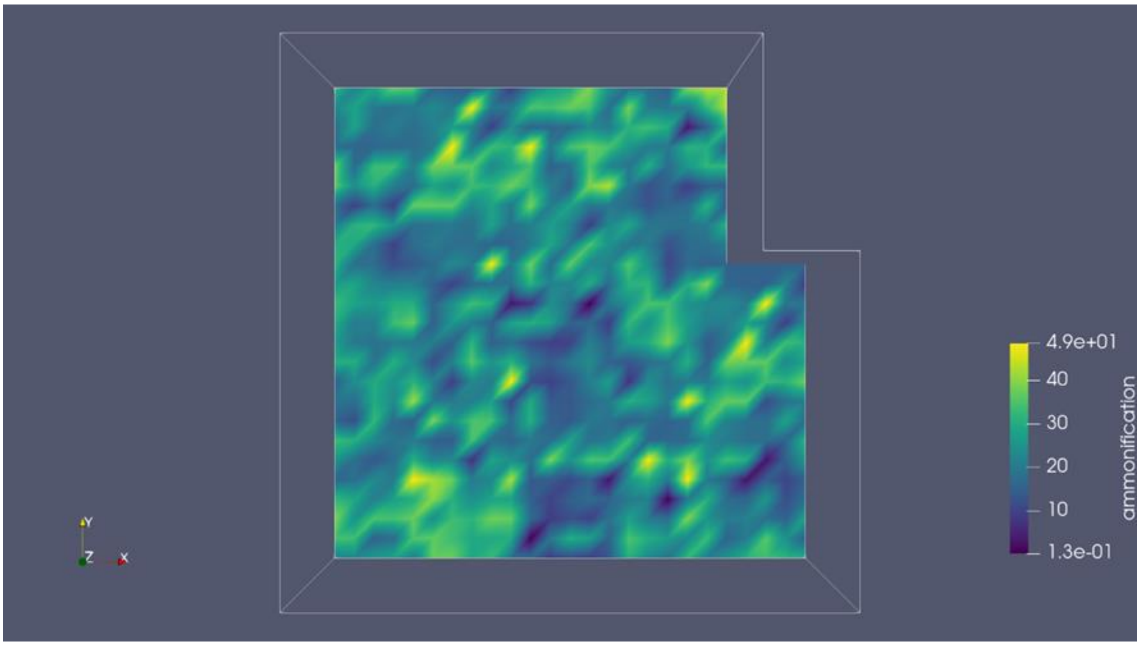


Figure 2 - Ammonification Distribution in Spring.

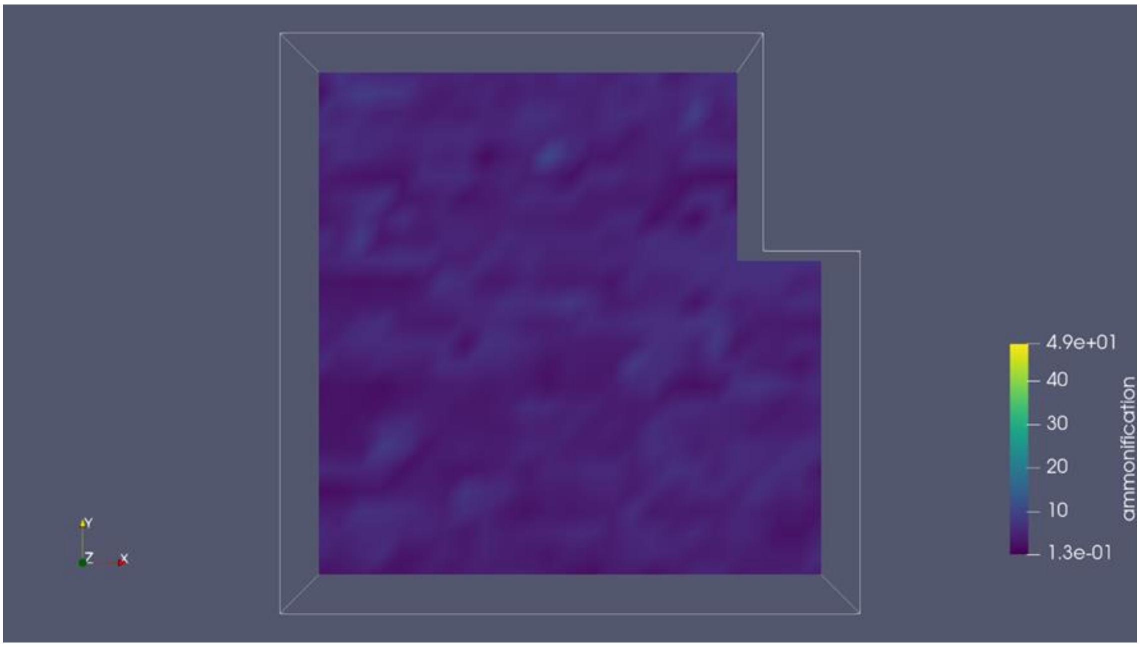


Figure 3 - Ammonification Distribution in Summer.

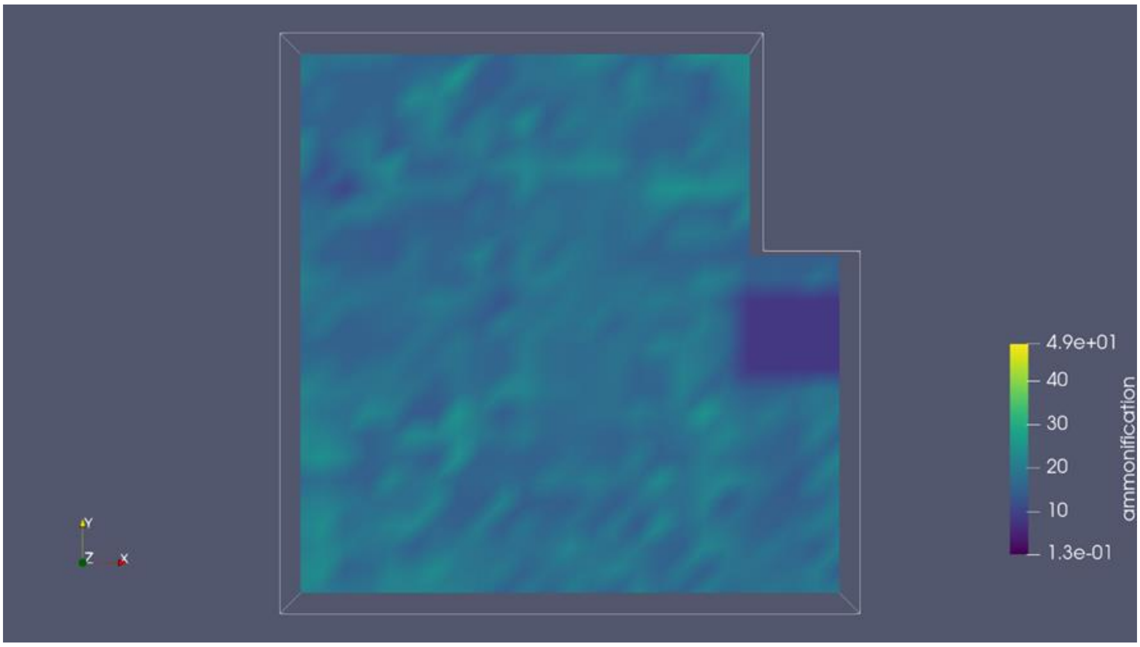


Figure 4 - Ammonification Distribution in Autumn.

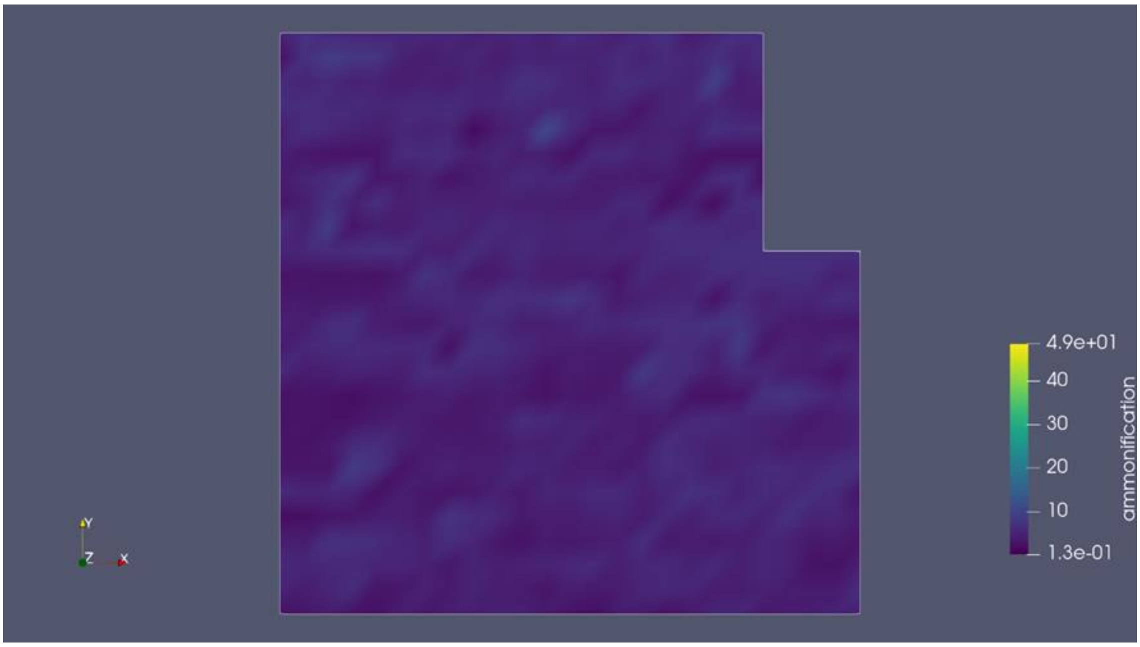


Figure 5 - Ammonification Distribution in Winter.

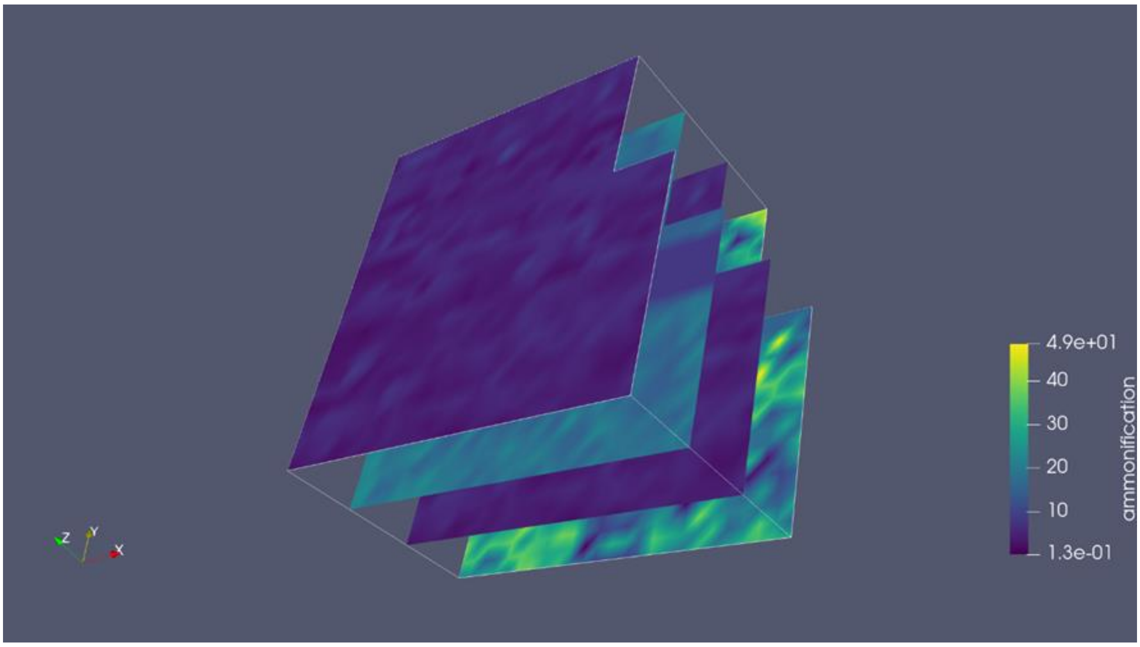


Figure 6 - Ammonification Distribution Across All Seasons.

The analysis of the visualizations allows us to conclude that ammonification exhibits well-defined seasonal patterns:

During spring (Figure 2), the highest ammonification activity is observed, with several areas showing high values between 35 and 49 (represented by yellow and light green). Low-value areas, below 15 (purple and dark blue), are rare, indicating a predominantly high distribution.

In summer (Figure 3), there is a sharp reduction in ammonification, with the plane showing consistently low values across the entire area, ranging between 0.13 and 15 (predominantly purple and dark blue tones).

In autumn (Figure 4), a partial recovery of ammonification activity is observed. The plane is mostly green, representing values between 15 and 25. However, some areas still exhibit low values, between 5 and 15 (purple and dark blue), indicating that the recovery is limited and not uniform throughout the studied area.

In winter (Figure 5), ammonification activity decreases significantly again, presenting a distribution similar to that of summer, with predominantly low values between 0.13 and 15 (purple tones) across the plane.

The progression of ammonification throughout the year reveals a clear seasonal pattern. Activity is highest in spring, drops dramatically in summer, partially recovers in autumn, and decreases again in winter. These results suggest a strong influence of environmental factors, such as temperature and humidity, on the processes regulating ammonification.

Figure 6 provides a three-dimensional representation of ammonification distribution across the four seasons of the year. The visualization includes planes corresponding to each season (spring, summer, autumn, and winter), highlighting the seasonal variation patterns of ammonification.

Animation over time of ammonification values in the soil samples

As in the animation of nitrification, even with animation of ammonification it can be easily seen how the values of this data vary as the seasons pass. The animation was created as before, always choosing the plane relating to the soil samples of the spring season as the starting plane, and with the same parameters, animation keyframes and save animations options. The file is in .avi format and is also attached to the report. The dynamism of the animation does nothing but highlight what was said before regarding the admonition as the seasons of the year pass.

- **Request (e): Obtain a simultaneous representation of ammonification and nitrification quantities in the spring sampling, using a plane colored according to the values of one of the variables and deformed according to the other.**

The images below depict data from spring sampling, with colours indicating nitrification levels and wrapped according to ammonification quantities, enabling the visualization of two scalar values. The colour scale for nitrification ranges from blue (representing low levels) to red (indicating high levels). Higher deformation towards the top of the image corresponds to high ammonification, while lower deformation indicates low ammonification. The observation from the spring data shows an inverse relationship:

when ammonification is high, nitrification tends to be low, and when nitrification is high, ammonification tends to be low.

The *Fast* colour scale was chosen over the rainbow colour scale to enhance clarity and ensure more effective visualization of the data. In this representation of the spring data, where colours indicate nitrification levels and the plane deformation represents ammonification, the *Fast* colour scale improves readability, especially for highlighting the inverse relationship between the two variables.

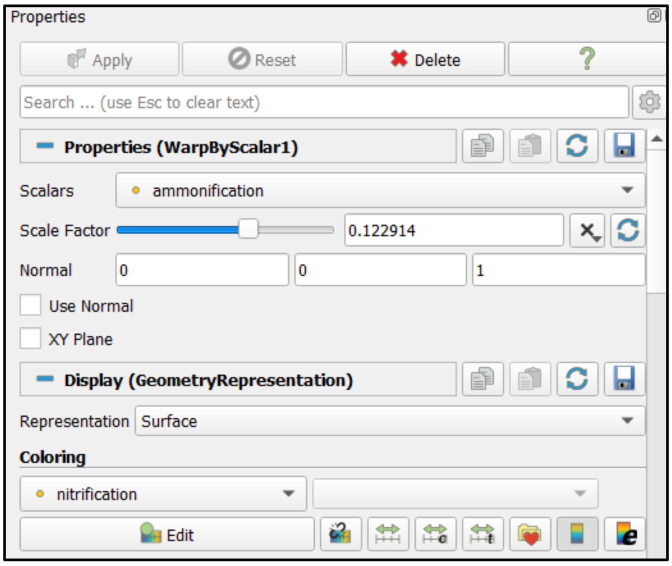


Figure 1 - Configuration of the Warp By Scalar to simultaneously represent ammonification (plane deformation) and nitrification (coloring).

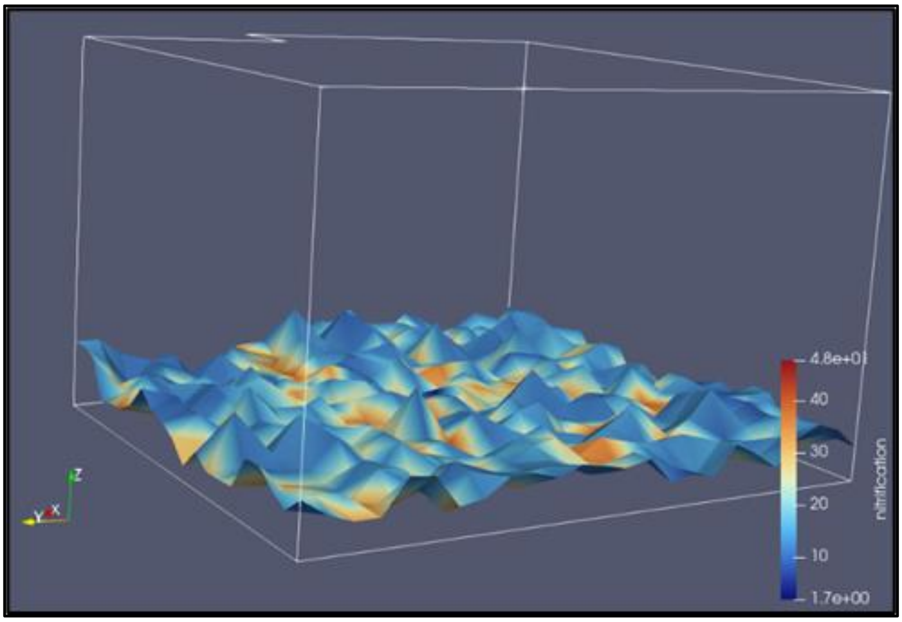


Figure 2 - Visualization of spring data showing plane deformation based on ammonification values and coloring representing nitrification levels.

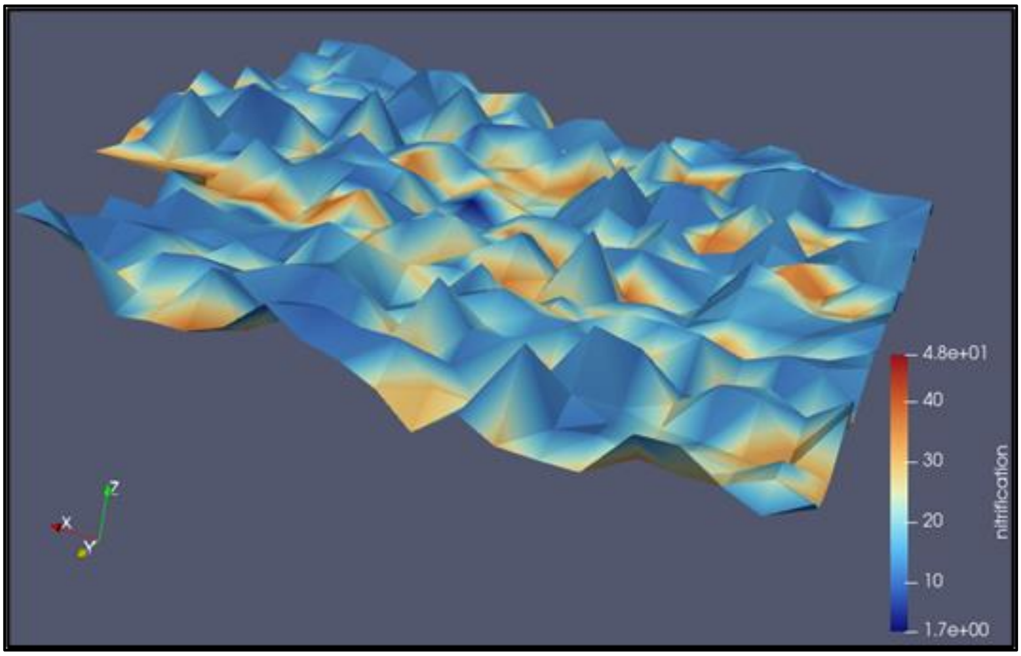


Figure 3 - Perspective view of the representation of spring data, where ammonification values deform the surface and nitrification levels are represented by the colour scale.

- **Request (f): Represent ammonification data from spring sampling simultaneously with plant functional type data.**

In the spring dataset, ammonification levels are visualized alongside plant functional types (PFTs). Ammonification values are shown using a colour scale, while PFTs are represented by glyphs (spheres) *(refer below images)*. The data includes two PFT categories (1 and 2); PFT=2 plant functional type (semi-deciduous leaf plants), and PFT=1 (evergreen leaf plants). Sphere size indicates PFT value: larger spheres represent the higher PFT value of 2, while smaller spheres indicate the lower PFT value of 1. A linear green colour scale is used instead of a rainbow scale to enhance the visualization of both scalar variables. It is observed that for PFT value 2, ammonification is consistently on the lower side, whereas for PFT value 1, ammonification tends to be higher, reaching peak levels in certain regions.

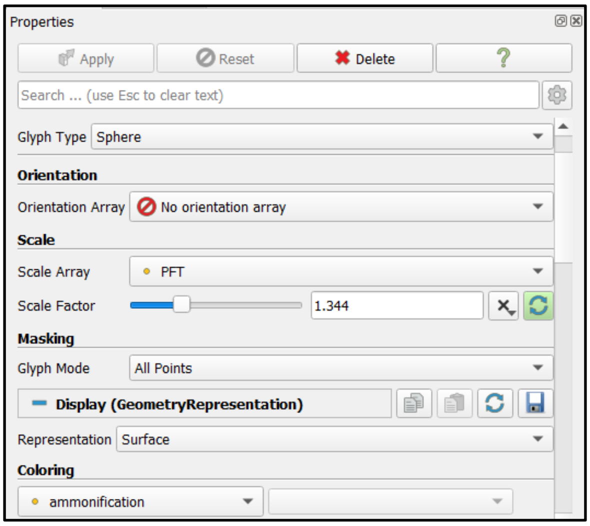


Figure 1 - Configuration of the Glyph to represent plant functional types (PFT) using spheres and colours according to ammonification.

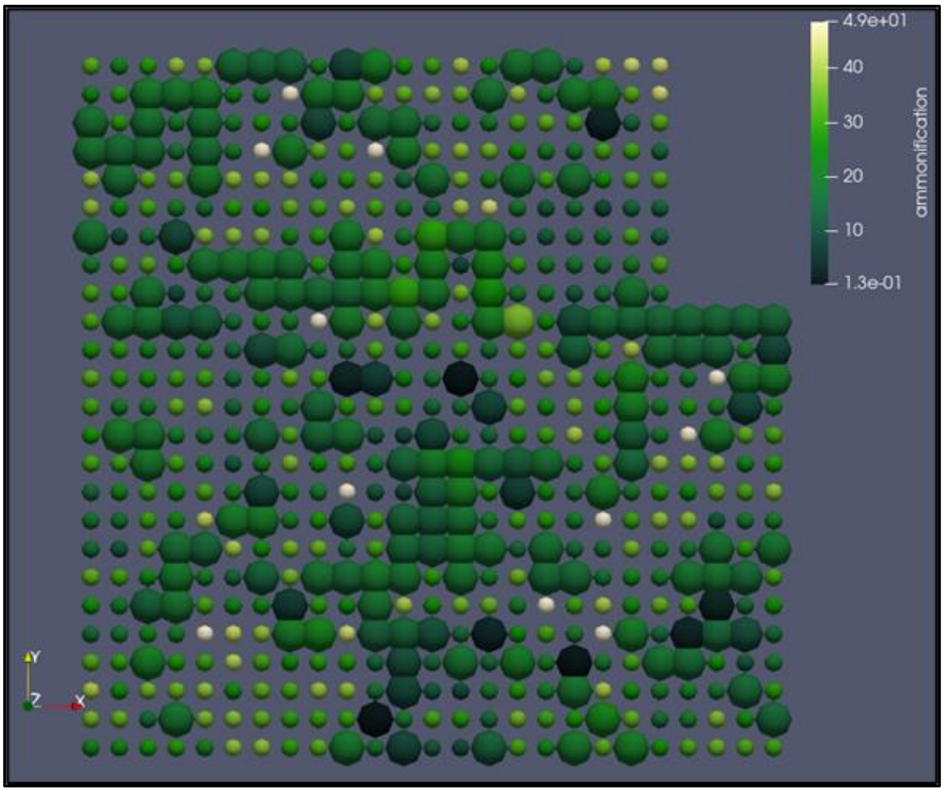


Figure 2 - Visualization of spring data showing ammonification levels (colour scale) and plant functional types (PFT) represented by spheres.

- **Request (g): Represent the Trend variable in the 4 samples. Can you detect any relationship between the nitrification and ammonification variables? Justify**

A vector variable named Trend was established to enable comparison between the Ammonification and Nitrification variables at each grid point. The vector's X component represents Ammonification, the Y component corresponds to Nitrification, and the Z component is set to zero. The following image snapshot illustrates the Ammonification and Nitrification variables for different seasons. The colour indicates the Nitrification variable, while the vector's magnitude reflects higher Ammonification when inclined in the X direction and higher Nitrification when inclined in the Y direction.

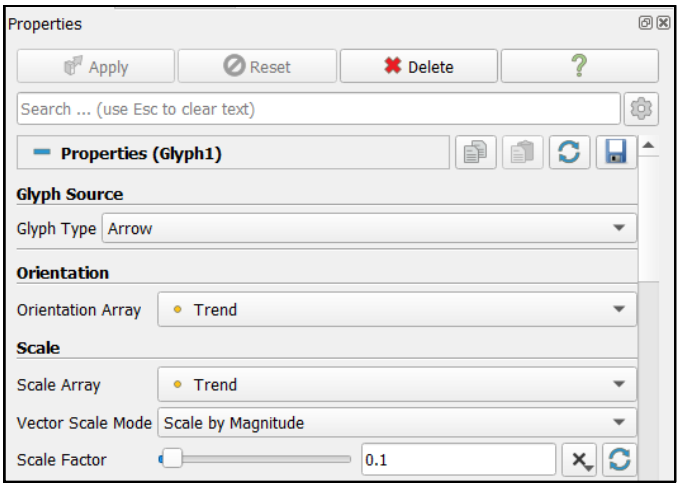


Figure 1 - Configuration of the Glyph for the representation of the "Trend" vector variable across the four seasons.

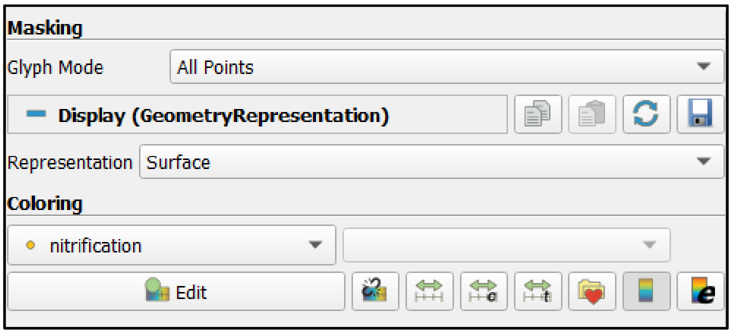


Figure 2 - Configuration of the Display settings for the visualization of the "Trend" vector variable.

1. **Spring season:** The image below represents the spring season. In the image, higher nitrification values are shown by arrows pointing toward the Y direction and marked with orange/red colours, signifying high nitrification levels. It can be noted that when ammonification values are high, represented by arrows oriented closer to the X direction, the nitrification values tend to be low (arrows also depicted in blue), and vice versa—lower ammonification values coincide with higher nitrification levels. This pattern is similarly observed in point (e), where both ammonification and nitrification are represented simultaneously in the spring. The plane is coloured based on nitrification values and deformed according to ammonification values.

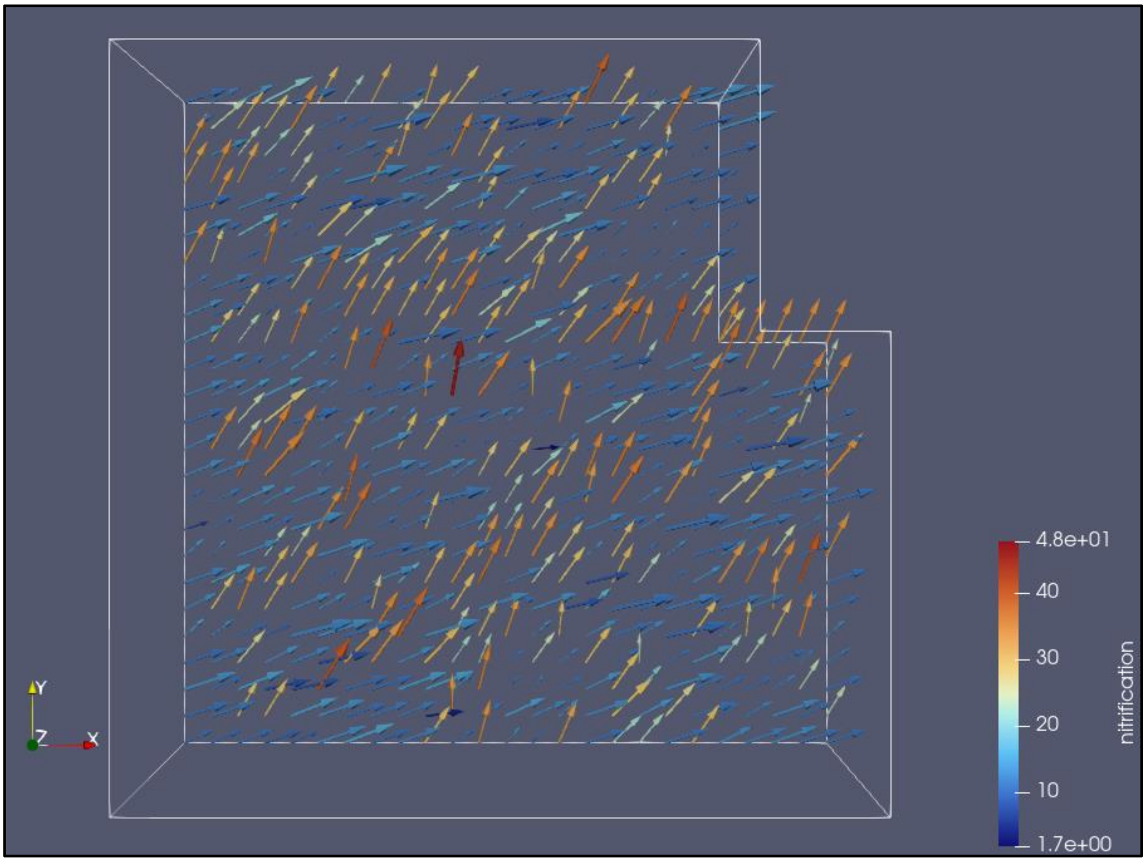


Figure 3 - Visualization of the spring season data representing the "Trend" variable as arrows.

2. **Summer Season:** In the summer season, both ammonification and nitrification are low. Consequently, the image below shows arrows that are not directed strongly toward either the X or Y direction. Instead, the arrows maintain an angle of approximately 45 degrees (except for some of the points), indicating that both ammonification and nitrification values are low. This is further supported by the colour scale (blue), which represents the lower end of nitrification values.

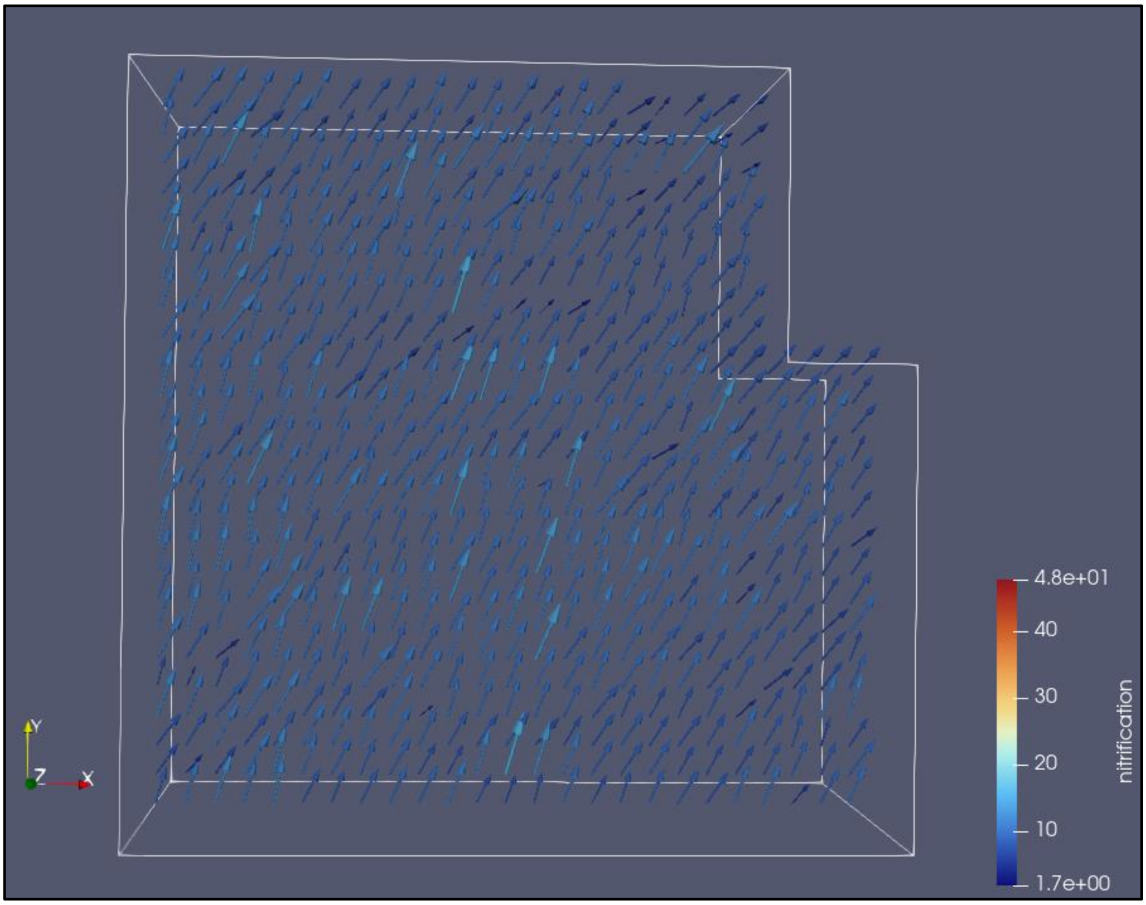


Figure 4 - Visualization of the summer season data showing the "Trend" variable as arrows.

3. **Autumn Season:** During the autumn season, it is observed that at certain points on the grid, high ammonification values are represented by arrows oriented closer to the X direction, while nitrification values tend to be low (indicated by blue arrows). Conversely, when ammonification values are lower (with arrows pointing away from the X direction and closer to the Y direction), nitrification levels are higher. A similar pattern is also seen in the spring season.

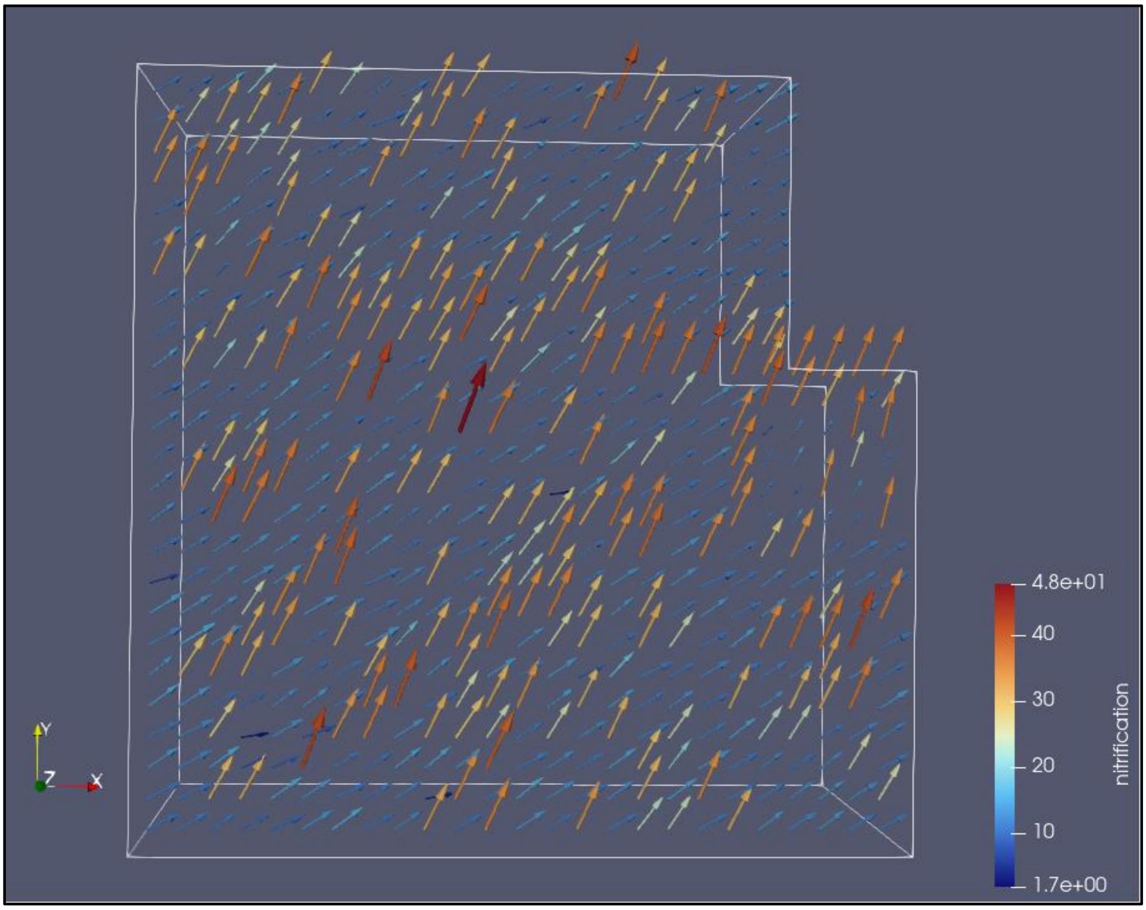


Figure 5 - Visualization of the autumn season data showing the "Trend" variable as arrows.

4. **Winter Season:** In this season, both ammonification and nitrification have relatively low values. As a result, the arrows do not point distinctly toward either the X or Y direction. The maximum ammonification value is approximately 10.95, while the maximum nitrification value is around 14.62. The arrows generally form an angle of 45 degrees (with some exceptions), similar to what is observed in the summer season.

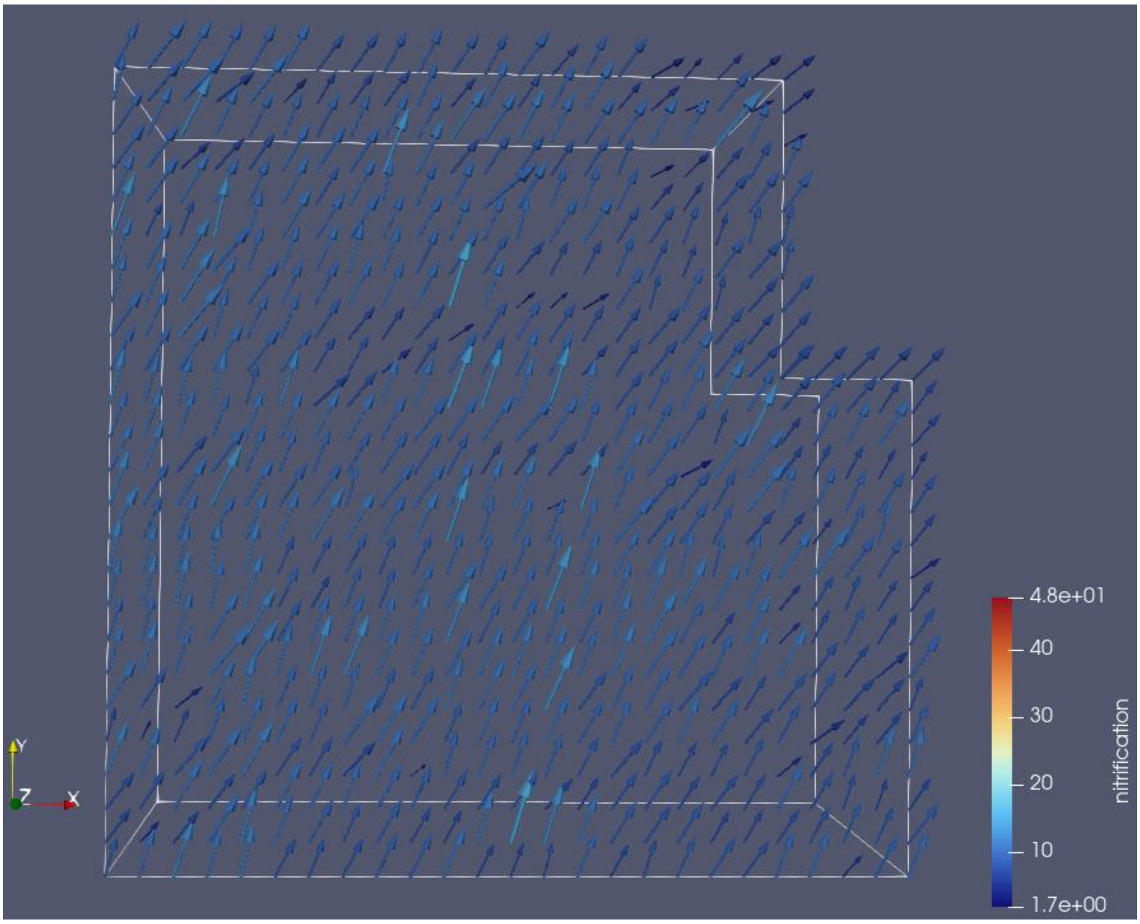


Figure 6 - Visualization of the winter season data representing the "Trend" variable as arrows.

Conclusion: The analysis reveals that ammonification and nitrification exhibit seasonal variations. In spring and autumn, it displays an inverse relationship: high ammonification aligns with low nitrification and vice versa. During summer and winter, both variables remain low. Overall, ammonification and nitrification are more dynamic in spring and autumn, while summer and winter show minimal activity.

- **Request (h): Generate a visualization to represent simultaneously data on Species and one of the other variables under study.**

To generate the requested visualization, the VTK-format data file was first loaded into ParaView. Then, the Slice filter, available under Filters > Common > Slice, was applied. In the filter's properties, the plane parameters were configured with the origin set to x=24, y=24, z=10.01, corresponding to the spring season. The normal was defined as (0,0,1) to generate a plane perpendicular to the Z-axis. After applying the filter, the resulting plane was hidden to focus on the overlaid data.

To represent the species, the Glyph filter, also accessible via Filters > Common > Glyph, was applied. In this filter, the glyph type was set to Sphere, and the scale was configured based on the variable PFT (Plant Functional Type) by selecting Scale Array: PFT and setting the scale factor to 1. To include all available points in the grid, the Glyph Mode: All Points option was used. The spheres' colouring was based on the variable Species, using the Rainbow Uniform color palette. The opacity was set to 1, ensuring full visibility of the elements.

In the Color Map Editor, the Discretize option was enabled, and the number of table values was adjusted to 13 to assign a distinct colour to each of the 13 species represented.

Based on the generated visualization (Figure 1), the spatial distribution of the 13 species across the spring plane can be identified. The representation uses spheres of two sizes, where larger spheres correspond to PFT=2 plant functional type (semi-deciduous leaf plants), and smaller spheres represent PFT=1 (evergreen leaf plants). This distinction allows for a clear observation of the different spatial distributions of the two plant functional types in the study area.

The colour palette used, with distinct colours assigned to each of the 13 species, facilitates visual differentiation, allowing analysis of the coexistence and distribution patterns of different species alongside the plant functional type. PFT=2 plants (larger spheres) are more concentrated in certain areas of the grid, suggesting possible ecological or environmental preferences. On the other hand, PFT=1 plants (smaller spheres) are more evenly and widely distributed across various zones of the plane. Additionally, the variation in colours shows that certain species coexist in close proximity, while others appear more isolated or restricted to specific regions of the grid. This visualization makes it possible to identify not only the predominant species but also the relationship between sphere size (indicative of the functional type) and species distribution in space.

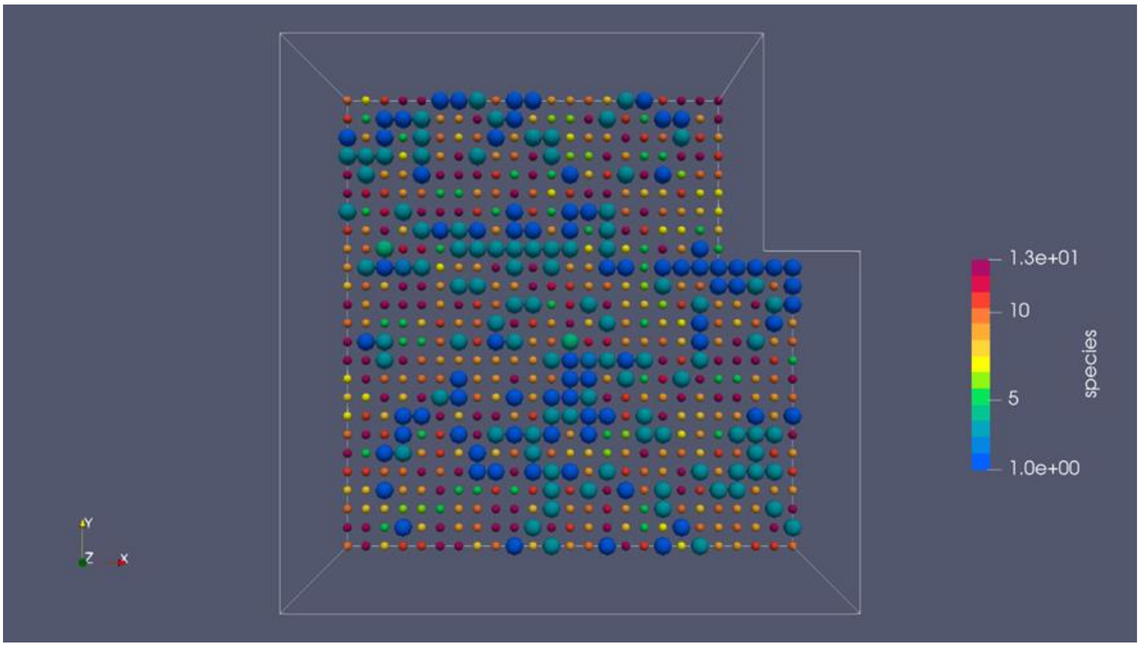


Figure 1 - Spatial distribution of species during spring. The colours represent species (1-13), and sizes indicate functional type: larger spheres (PFT=2) and smaller spheres (PFT=1).

3. Conclusion

This project aimed to visualize and analyze a dataset using ParaView, focusing on understanding the connections between soil biochemical processes—ammonification and nitrification—and ecological factors like plant functional types (PFTs) and species distribution. The data, gathered from soil samples across four seasons, was organized in a regular grid format to allow for both spatial and temporal analysis.

Different visualization methods were applied to address the questions. These included color-coded planes, isolines, isosurfaces and trend vectors to explore changes over time and patterns in space. The nitrification and ammonification processes were analyzed separately and together, showing distinct seasonal patterns. When examining the trend vector, an inverse relationship between ammonification and nitrification was observed during spring and autumn. A similar pattern was noted when analyzing two scalar values (nitrification and ammonification) by wrapping ammonification and coloring according to nitrification in the spring. These observations highlighted the impact of environmental factors on soil biochemical activity.

The visualizations of plant functional types and species distribution offered some insights into ecological patterns, showing spatial trends and preferences. Simple and clear visualizations with glyphs and consistent color scales made it easier to distinguish the variables and their relationships.