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A Time-Series Semantic-Computing Method for 5D World Map System Applied to Environmental Changes

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Abstract. "Semantic space creation" and "distance-computing" are basic functions to realize semantic computing for environmental phenomena memorization, retrieval, analysis, integration and visualization. We have introduced "SPA-based (Sensing, Processing and Actuation) Multi-dimensional Semantic Computing Method" for realizing a global environmental system, "5-Dimensional World Map System". This method is important to design new environmental systems with Cyber-Physical Space-integration to detect environmental phenomena occurring in a physical-space (real space). This method maps those phenomena to a multi-dimensional semantic-space, performs semantic computing, and actuates the semantic-computing results to the physical space with visualizations for expressing environmental phenomena, causalities and influences. As an actual system of this method, currently, the 5D World Map System is globally utilized as a Global Environmental Semantic Computing System, in SDG14, United-Nations-ESCAP: (https://sdghelpdesk.unescap.org/toolboxes). This paper presents a semantic computing method, focusing on "Time-series-Analytical Semantic-Space Creation and Semantic Distance Computing on 5D World Map System" for realizing global environmental analysis in time-series. This paper also presents the time-series analysis of actual environmental changes on 5D World Map System. The first analysis is on the depth of earthquakes Earthquake with time-series semantic computing on 5D World Map System, which occurred around the world during the period from Aug. 23rd to Aug. 28th, 2014, and Jan 7th to Jan. 13th, 2023. The second is the experimental analysis of the time-series difference extraction on glacier melting phenomena in Mont Blanc, Alps, during the period from 2013 to 2022, and Puncak Jaya (Jayawijaya Mountains), Papua, during the period from 1991 to 2020 as important environmental changes.

Keywords. (1) Cyber & Physical Space Integration, (2) SPA-function, (3) Spatio-Temporal computing, (4) Semantic computing, (5) Environmental change analysis

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1. Introduction

We have introduced the architecture of a global environmental system, “5-Dimensional World Map System” [3,4,6,10], to realize environmental knowledge memorization, sharing, retrieval, integration and visualization with semantic computing. The basic space of this system consists of a temporal (1st dimension), spatial (2nd, 3rd and 4th dimensions) and semantic dimensions (5^{th-}dimension), representing a large-scale and multiple-dimensional semantic space. This space memorizes and recalls various environmental knowledge expressed in multimedia information resources with temporal, spatial and semantic correlation computing functions, and realizes a 5D World Map for dynamically creating temporal-spatial and semantic multiple views.

We have also proposed the concept of “SPA (Sensing, Processing and Analytical Actuation Functions)” for realizing a global environmental system, to apply it to our 5-Dimensional World Map System[10,11]. This concept is effective and advantageous to design environmental systems with Cyber-Physical integration to detect environmental phenomena as real data resources in a physical space (real space), map them to cyber-space to make analytical and semantic computing, and actuate the analytically computed results to the real space with visualization for expressing environmental phenomena, causalities and influences.

Semantic computing [1,2,5] is an important and promising approach to semantic analysis for various environmental phenomena and changes in a real world. This paper presents a new concept of *"Time-series-Analytical Semantic-Space and Computing for environmental phenomena*” to realize global environmental analysis [7,8,9,10,11,12,13,14]. This space and computing method are based on semantic space creation with time-analysis for analyzing and interpreting environmental phenomena and changes occurring in the world. We focus on semantic interpretations of time-series data, as an experimental study for creating *"Time-Series Analysis Semantic-Space for environment.*”

2. Global Environmental Analysis with Semantic Computing

We have introduced “5D World Map System” with Spatio-Temporal and Semantic Computing in SPA, as the architecture of a multi-visualized and dynamic knowledge representation system [3,4,6,10]” applied to environmental analysis and semantic computing. The basic space of this system consists of a temporal (1st dimension), spatial (2nd, 3rd and 4th dimensions) and semantic dimensions (5th dimension, representing a large-scale and multiple-dimensional semantic space). This space memorizes and recalls various multimedia information resources with temporal, spatial and semantic correlation computing functions, and realizes a 5D World Map for dynamically creating temporal-spatial and semantic multiple views applied for various “environmental multimedia information resources.”

2.1. Semantic Computing in 5D World Map System

We have presented the dynamic evaluation and mapping functions for multiple views of temporal-spatial metrics and integrate the results of semantic evaluation to analyze environmental multimedia information resources [3,4,6,10]. Our semantic computing system realizes the interpretations on "semantics" and “impressions” of environmental phenomena with multimedia information resources, according to "contexts"[1,2,5]. The main feature of this system is to create world-wide global maps and views of environmental situations expressed in multimedia information resources (image, sound, text and video) dynamically, according to user’s viewpoints. Spatially, temporally, semantically and impressionably evaluated and analyzed environmental multimedia information resources are mapped onto a 5D time-series multi-geographical space. The basic concept of the 5D World Map System is shown in **Figures 1** and **2**. The 5D World Map system applied to environmental multimedia computing visualizes world-wide and global relations among different areas and times in environmental aspects, by using dynamic mapping functions with temporal, spatial, semantic and impression-based computations [3,4,6,10,11,13].

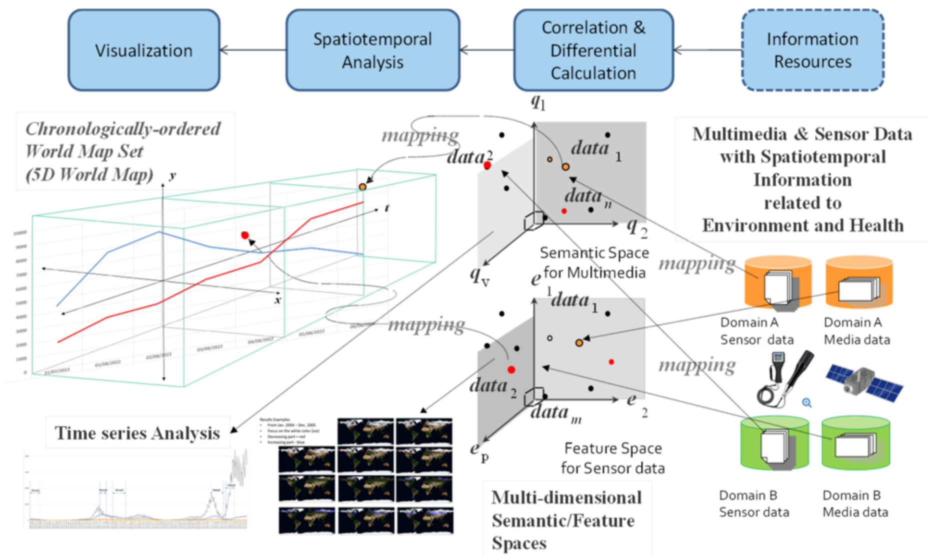


Figure 1. 5D World Map System for world-wide semantic computing for Global Environmental Analysis

2.2. SPA: Sensing, Processing and Analytical Actuation Functions in 5D World Map

“SPA” is a fundamental concept for realizing environmental systems with three basic functions of “Sensing, Processing and Analytical Actuation” for Physical-Cyber integration. "SPA" is effective and advantageous to detect environmental phenomena as real data resources in a physical space (real space), map them to the cyber-space to make analytical and semantic computing, and actuate the analytically computed results to the real space by visualization for expressing environmental phenomena with causalities and influence. This concept is applied to our semantic computing in 5D World Map System, as shown in **Figures 1, 2** and **3**.

The important application of the semantic computing system are "Global Environment-Analysis" for making appropriate and urgent solutions to global environment changes in terms of short and long-term changes. The "six functional-pillars" are essentially important with "environmental knowledge-base creation" for sharing, analyzing and visualizing various environmental phenomena and changes in a real world.

The 5D World Map System realizes Cyber-Physical Space-integration, as shown in **Figure 1**, to detect environmental phenomena with real data resources in a physical-space (real space), map them to the cyber-space to make knowledge bases and analytical computing, and actuate the computed results to the real space with visualization for expressing environmental phenomena, causalities and influences. The 5D World Map System and its applications create new analytical circumstance with the SPA concept (Sensing, Processing and Analytical Actuation) for sharing, analyzing and visualizing natural and social environmental aspects. This system realizes "environmental analysis and situation-recognition" which will be essential for finding out solutions for global environmental issues. The 5D World Map System collects and facilitates a lot of environmental information resources, which are characteristics of ocean species, disasters, water-quality and deforestation.

3. A Time-series Semantic Computing Method for Global Environmental Analysis

We introduce a concept of "time-series-context", as a context on time-series in semantic computing on a multi-dimensional space. The "time-series-context" is a data structure to specify dimensional projection (dimensional selection), that is, the projection (selection of dimensions) to be applied in "time-series semantic computing."

(1) One of the most important processes of multi-dimensional & time-series semantic computing is to define semantic "time-series-context".
(2) It is essential to compare between two different time-series on semantic features, expressing a time-series-context, for realizing semantic interpretations and predictions on natural environmental phenomena.

We define a multi-dimensional & time-series semantic computing method for time-series data in a time axis with the definition of time-series context.

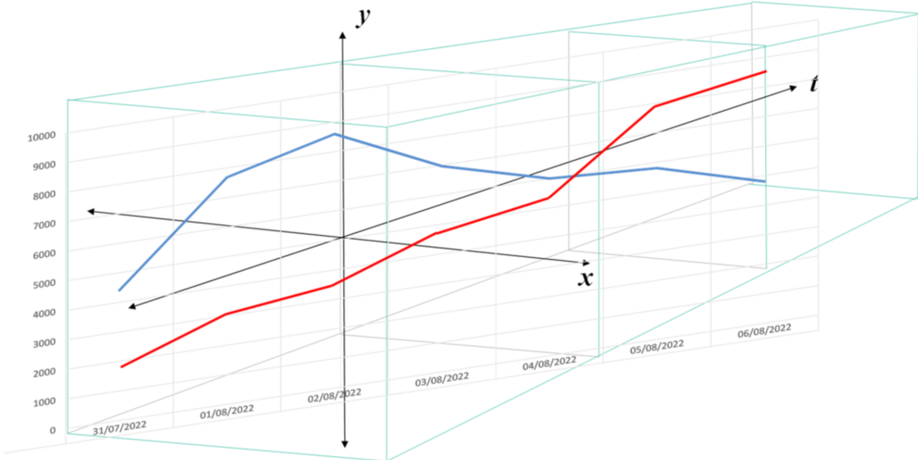


Figure 2. A Time-series Semantic-Computing Space for 5D World Map System

3.1. Basic data structures and operations

The basic data structures for time-series semantic computing are defined as follows:

(1) Space: Multi-Dimensional semantic space with time-axis
(2) Basic elements: point-series --> time-series (point-series along a time-series for expressing a phenomenon)
(3) Time-series-context: “time-series grain” & “time-interval”

3.2. Semantic computing process

To define a time-series-context, we express semantic meaning of temporal difference and its interpretations according to the time-series-context.

- If switching the N time-series-contexts for same data, we can obtain N different semantic meanings of temporal difference in each context.
- The definition of the time-series-context by the 3 steps is corresponding to set the closed world on time axis.

Step 1: Define semantic viewpoint to fix target axes, that are corresponding to multiple parameters as the semantic feature combination, reflecting expert-knowledge and viewpoint.
Step 2: Define semantic viewpoint to fix target time-series data to calculate semantic distances,

3.3. Semantic computing functions

In this section, we express the data structures and functions for “time-series stream-creation”. The following 6 basic functions are defined to express the query-time-series, that creates time-series query expression as a new time-series stream:

(1) Time-series data structures

To realize “time-series stream-creation” (creating time-series stream), the following basic settings on time-series data structures are defined:

(1-1) “time-granularity (granularity in time)” setting,
(1-2) “time-interval” setting,
(1-3) “time-grains-combination” setting,
(1-4) “time-series-context” setting.

(2) Time-series stream

A time-series stream is defined with a basic-atomic-time-element, that is expressed:

(2-1) basic-atomic-time-element form: (time-i, (value-i-1, value-i-2, ---, value-i-m)).

(2-2) Time-series stream expression:

By combining basic-atomic-time-elements, any time-series stream is expressed and created. (time-grain setting, time-interval setting, time-grains-combination)

Time-series stream expressions:

Time-series-semantic-integration-method:
Temporal-Atomic-element:(time-series), as the time-grain setting:
((time-1, (value-1-1, value-1-2, ---, value1-m)) ,
(time-2, (value-2-1, value-2-2, ---, value-2-m)), ---,
(time-n, (value-n-1, value-n-2, ---, value-n-m))):

Atom-1:
((t-1,t-2,t-3)(v-1-i,v-2-i,v-3-i)) (The “i” is fixed with a “time-series context”.)
Atom-2:
((t-1,t-2,t-3)(v-1-j,v-2-j,v-3-j))
Atom-3:
((t-1,t-2,t-3)(v-1-k,v-2-k,v-3-k))

(2-3) Time-series-semantic-integration (Time-series stream is expressed and created in the following basic structures): (time-grains-combination for time-interval setting,)

(2-3-1) Vertical integration for time-series stream:
(((t-1,t-2,t-3)(v-1-i,v-2-i,v-3-i)), ((t-1,t-2,t-3)(v-1-j,v-2-j,v-3-j)),
((t-1,t-2,t-3)(v-1-k,v-2-k,v-3-k))) - - -

(2-3-2) Horizontal integration for time-series stream:
((t-1,t-2,t-3) ((v-1-i,v-1-j,v-1-k), (v-2-i,v-2-j,v-2-k), (v-3-i,v-3-j,v-3-k)))

(2-3-3) Time-series stream integration:

(((t-1,t-2,t-3), ((t-4,t-5,t-6)) (((v-1-i,v-1-j,v-1-k), (v-2-i,v-2-j,v-2-k),
(v-3-i,v-3-j,v-3-k))), ((v-4-i,v-4-j,v-4-k), (v-5-i,v-5-j,v-5-k),
(v-6-i,v-6-j,v-6-k)))

(3) Geographical-time-series form:

Geographical time-series stream, as a time-series stream, is defined with a basic-geo-atomic-time-element, that is expressed:

(3-1) basic-geo-atomic-time-element form:

S1(place1) (time-1, (value-1-1, value-1-2, ---, value-1-m))
(time-2, (value-2-1, value-2-2, ---, value-2-m))
(time-3, (value-3-1, value-3-2, ---, value-3-m))

S2(place2) (time-4, (value-4-1, value-4-2, ---, value-4-m))
(time-5, (value-5-1, value-5-2, ---, value-5-m))
(time-6, (value-6-1, value-6-2, ---, value-6-m))

S3(place3) (time-7, (value-7-1, value-7-2, ---, value-7-m))
(time-8, (value-8-1, value-8-2, ---, value-8-m))
(time-9, (value-9-1, value-9-2, ---, value-9-m))

(4) Time-series-stream-comparison (semantic-distance computing between two time-series streams)

(4-a) distance of features (time-series-context features) between different timings in same time-series

(4-b) distance of features (time-series-context features) between different phenomena in different time-series

(4-c) distance of features (time-series-context features) between different places (geographical places) in the same phenomena in different time-series

The basic distance function between two time-series streams is defined in the following form:

Timeseries-streams-distance((t1, t2, ---, tn) (y1, y2, ---, yn) , (t1', t2', ---, tn')
(y1', y2' ---, yn')).

(4-1) Timeseries-streams-distance as the sum of each parameters' distances:

Timeseries-streams-distance-1((t1, t2, ---, tn) (y1, y2, ---, yn) , (t1', t2', ---, tn')
(y1', y2' ---, yn')) => Σ(i=0, n) |yi - yi'|

(4-2) Timeseries-streams-distance as distance-in-time-interval-normalization:

Timeseries-streams-distance-2((t1, t2, ---, tn) (y1, y2, ---, yn) , (t1', t2', ---, tn')

(y1', y2' ---, yn')) =>
distance-in-time-interval-normalization ((t1, t2, ---, tn) (y1, y2, ---, yn) ,
(t1', t2', ---, tn') (y1', y2' ---, yn'))

(4-3)Timeseries-streams-distance as distance-in-start-time-normalization

Timeseries-streams-distance-3((t1, t2, ---, tn) (y1, y2, ---, yn) , (t1', t2', ---, tn')
(y1', y2' ---, yn')) =>
distance-in-start-time-normalization ((t1, t2, ---, tn) (y1, y2, ---, yn) ,
(t1', t2', ---, tn') (y1', y2' ---, yn'))

(5) Geographical phenomenon-distance function form is defined for time-series comparison between different places.

Geographical-timeseries-streams-distance((S1(place1),((time-1, (value-1-1, value-1-2, ---, value-1-m)), (time-2, (value-2-1, value-2-2, ---, value-2-m)), (time-3, (value-3-1, value-3-2, ---, value-3-m))), (S2(place2),(time-4, (value-4-1, value-4-2, ---, value-4-m)), (time-5, (value-5-1, value-5-2, ---, value-5-m)), (time-6, (value-6-1, value-6-2, ---, value-6-m))))

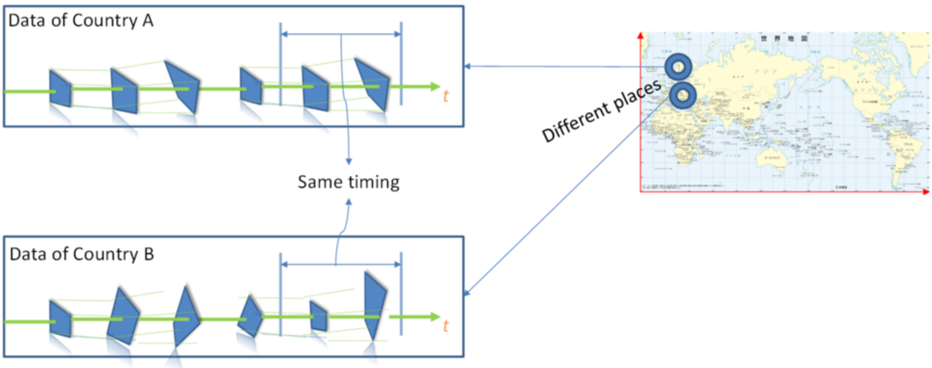


Figure 3. The Concept of a difference comparison with Time-series Semantic-Computing with 5D World Map System

3.4. Time-series semantic computing for phenomenon-prediction with time-interval ratio

We present a ratio computing method for phenomenon-prediction with time-interval ratio between peak values. This method predicts the timing of future peak with differential computing, according to “time-series-context”.

The basic data structure of “time-series context” is defined in 6 Key elements:

- Original time-granularity (granularity in time) (OG)
- Target timing-granularity (TG)

- Feature extraction method (FEM)
- Focusing time-interval (FW) (time-interval)
- Differential computing method (DCM)
- Pivot extraction method on ITD (PEM)

Two time-series data (IRD, ITD) consists of time and its corresponding values expressed in target granularity in two different places, F and J. The ratio computing method is applied to three peaks of the corresponding values existing in IRD (FT1, FT2, FT3) in timing in the place F, and three peaks in ITD (JT1, JT2, "JT3(target for estimation)")) in the place J. Then, JT3 is computed as an estimated timing in the following process, as the timing when the situation corresponding to the third peak will occur in the future in the place J.

The important feature of this method is to define differential computing function as ratio computing between the timing of the peaks in time-series data to estimate the future peak.

Input data for analysis (IRD) = Time-series sequence of (parameter-value, time-point) for expressing the situation with the selected parameter in the place F:

- <u>The number of confirmed-values in the place F.</u>

Input data for prediction (ITD) = Time-series sequence of (parameter-value, time-point) for expressing the situation with the selected parameter in the place J:

- <u>The number of confirmed-values in the place J.</u>

The 6 key elements are defined to express time-series-context. The 6 key element-settings determine "time-series-context" to make common situations comparable between two different time-series.

The 6 key elements are expressed as a "time-series-context" for phenomenon-prediction with time-interval ratio between peak values.

The "time-series-context" definition is set in the following:

- Original time-granularity (granularity in time) = <u>daily</u>
- Target timing-granularity (TG) = <u>peaks</u>
- Feature extraction method (FEM) = <u>time point of peaks</u>
- Focusing time-interval (FW) = <u>from first peak to the last peak 3 or more peaks that matched condition(condition：)</u>
- Differential computing method (DCM) = <u>ratio computing function for the number of days between the selected adjacent peaks, by applying average, difference, and other functions</u>
- Pivot extraction method on ITD (PEM) = <u>most recent 2 or more peaks that matched condition(condition：)</u>

The prediction process with the differential computing method (DCM) is defined as the ratio computing function for computing the number of days between the selected adjacent peaks, by applying average, difference, and other operations.

The basic data structure for the prediction with the differential computing method is expressed:

FT1-3: time points at 3 peaks (FT1, FT2, FT3) timings, corresponding to top-three maximum parameter-values in the time-series sequence in the place F.
JT1-3: time points at 3 peaks (JT1, JT2, "JT3 (target for estimation)") timings, corresponding to top-three maximum parameter-values in the time-series sequence in the place J.

The process for the prediction with the differential computing method is expressed:

(Step-1) 3 peaks selection (FT1, FT2, FT3) in time series in IRD,
(Step-2-1) ratio computing in time-interval: (FT3-FT2)/(FT2-FT1),
(Step-2-2) average computing in time-interval: average((FT3-FT2), (FT2-FT1)),
(Step-2-3) differential computing in time interval: (FT3-FT2) => JT3-JT2 = (FT3-FT2)
(Step-3) (JT3-JT2)/(JT2-JT1) = (FT3-FT2)/(FT2-FT1) => JT3 is computed as an estimated time of peak-3 in this ratio computing if (2-1) is applied.

Then, JT3 is obtained as the prediction result of a next peak timing, occurring in the future.

4. Time-series semantic computing in 5D World Map System

We have integrated the time-series semantic computing method into the 5D World Map System. The following two cases (earthquake and glacier-melting analysis) are example targets of semantic computing in 5D World Map System with geographical time-series stream defined with a basic-geo-atomic-time-element in Section 3: Time-series semantic computing for Global Environmental Analysis.

4.1. Case I: Earthquake analysis with time-series semantic computing on 5D World Map System

This case shows the analysis of the depth of earthquakes, which occurred around the world during the period from Aug. 23rd to Aug. 28th, 2014, and Jan 7th to Jan. 13th, 2023. The target data is acquired from USGS Earthquake Hazard Program, Real-time Notifications Service [15]. The objective is the analysis of significant earthquakes in with time-series semantic computing to predict when and where significant earthquakes will occur especially in earthquake-prone countries and regions.

Figure 4 shows the visualization results of the time-series change of geographical distribution of the depth values of significant earthquakes with over 2.5 magnitude values in one week of August 2014. From the results, we can observe intuitively that there is a point where deep earthquakes had happened through the whole period (eg. Alaska), and there is an emergent timing that deep earthquakes happened in Fiji (2014/08/25) and consequently in Japan (2014/08/26). Also, **Figure 5** shows the visualization results of the depth values of significant earthquakes with over 2.5 magnitude values in one week of January 2023. We observe that there is a point where deep earthquakes had happened through the whole period (eg. New Zealand, Jan 7th, 9th, 10th and 13th).

In this case, the time-series query expression as a new time-series stream is created by the depth value of earthquake by 6 basic functions defined in Section 3 to express the query-time-series-stream for time-series semantic computing. In this case, the time-interval is set as 1 week, and the time-granularity is set as 1 day.

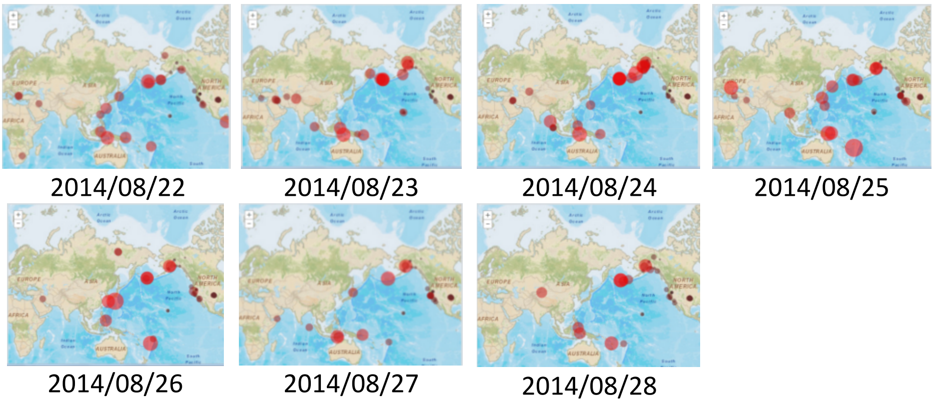


Figure 4. Time-series change of geographical distribution of the depth values in significant earthquakes with over 2.5 magnitude values, which occurred around the world during the period from Aug. 23rd to Aug. 28th, 2014

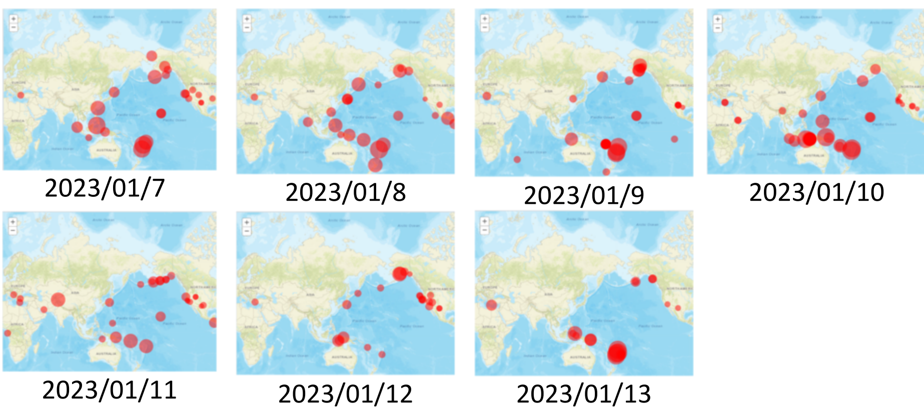


Figure 5. Time-series change of geographical distribution of the depth values in significant earthquakes with over 2.5 magnitude values, which occurred around the world during the period from Jan. 7th to Jan. 13th, 2023

The following is an example of query creation and time-series-context settings for the analysis of significant earthquake and prediction with time-series semantic computing.

Input data for analysis (IRD) = time-series values of earthquake depth in two points

- <u>Depth value of earthquake in Alaska</u>
- <u>Depth value of earthquake in New Zealand</u>

Input data for prediction (ITD) = time-series values of earthquake depth in a target point

- <u>Depth value of earthquake in Japan</u>

As for the 6 key elements to express time-series-context, we can apply the followings.

6 Key elements for express time-series-context are:

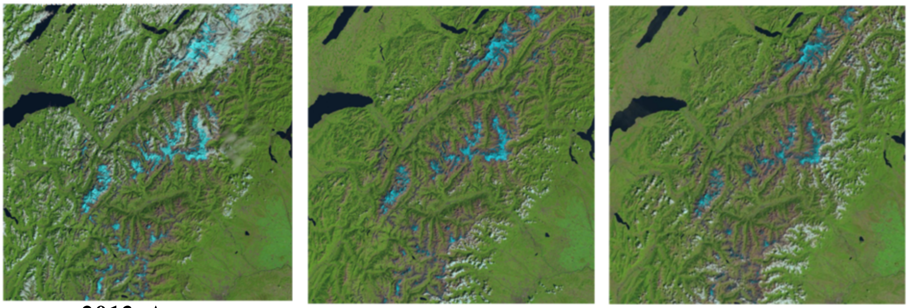
- Original time-granularity (OG) = daily
- Target timing-granularity (TG) = peaks of earthquake depth
- Feature extraction method (FEM) = time point of peaks
- Focusing time-interval (FW) = from first peak to the last peak 3 or more peaks that matched condition
- Differential computing method (DCM) = ratio computing function for, number of days between the selected adjacent peaks, by applying average, difference, and other functions
- Pivot extraction method on ITD (PEM) = most recent 2 or more peaks that matched condition

4.2. Case II: Glacier melting analysis with time-series semantic computing on 5D World Map System

4.2.1. Case II-(1): Glacier melting in Mont Blanc, Alps, Europe

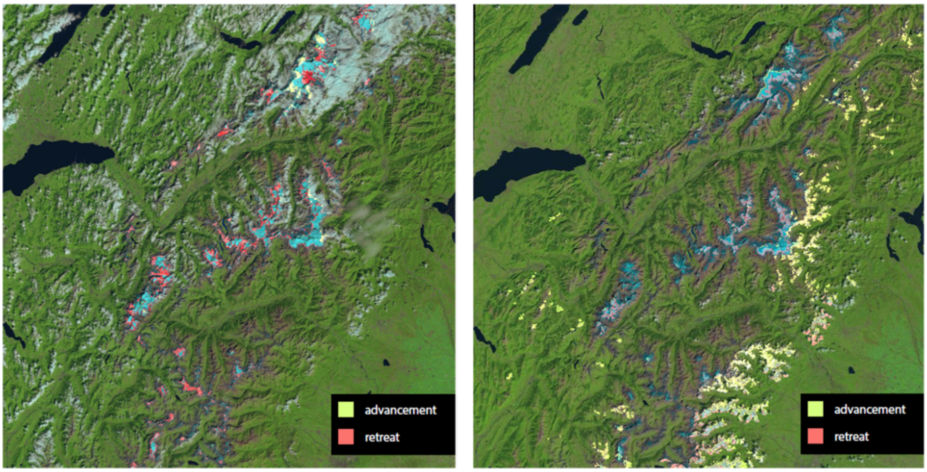
This case shows the analysis of the time-series difference extraction on glacier melting phenomena in Mont Blanc, Alps, Europe during the period from 2013 to 2022 for the analysis and prediction of time-series area-size change of other European countries' mountains' glaciers, when severe glacier melting has been reported in Mont Blanc area [16].

Figure 6 shows the original satellite images of Landsat 8 and 9 of the Mont Blanc area for Aug. 2013, 2015 and 2022, acquired from USGS EarthExplorer [17]. To detect the change in the same season with stable conditions, the RGB images in August (in summer, less cloud and no storms or snow falls) are obtained for each year.



2013, Aug **2015, Aug** **2022, Aug**

Figure 6. Original RGB Landsat 8 & 9 satellite images in Mont Blanc, Alps, Europe of 2013, 2015 and 2022



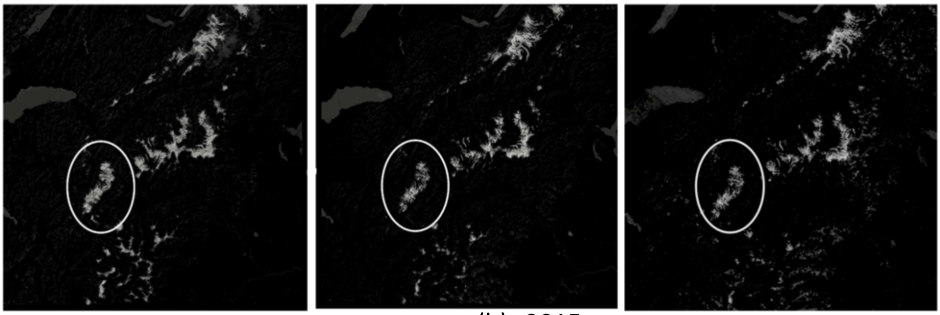
(a) Diff: 2013 - 2015 **(b) Diff: 2015 - 2022**

Figure 7. Difference extraction results from RGB Landsat 8 & 9 satellite images in Mont Blanc, Alps, Europe: (a) difference between 2013 and 2015, and (b) difference between 2015 and 2022

Figure 7 shows the difference extraction results by image processing: (a) difference between 2013 and 2015, and (b) difference between 2015 and 2022. The number of color clustering was set as 4 clusters. The focused colors are pale blue and gray which represent glacier area and cloud. In the results, retreated parts are represented in red color, and advanced parts are represented in yellow color. The results show that the glacier melting and retreating happened at the edges at the period between 2013 and 2015 (**Figure 7 (a)**), and the cloud increasing happened in the valleys at the foot of the mountain at the period between 2015 and 2022 (**Figure 7 (b)**).

Figure 8 shows the Normalized Difference Snow Index (NDSI) calculation results of each year, which indicate snow areas as bright white colors. In this experiment, we collected multispectral satellite images (Band 3 and Band 6 from Landsat 8 & 9 in USGS EarthExplorer [17]) by the following formula using Green (G) band and Short Wave Infra-Red (SWIR1) band.

$$NDSI = (G - SWIR1)/(G+SWIR1)$$



(a) 2013 (NDSI) (b) 2015 (NDSI) (c) 2022 (NDSI)

Figure 8 Normalized Difference Snow Index (NDSI) calculation results for Mont Blanc area: (a) 2013, (b) 2015 and (c) 2022 by using multispectral images (Band 3 and Band6 from Landsat 8 & 9)

As it is difficult to judge the glacier melting, whether it is increasing or not by these results. We examined the details to judge if these results mean that the speed of glacier melting is increased year by year or not, though in August 2021. Scientists reported that the danger of collapse due to rising temperatures threatens the lower valley on the Italian side of the Mont Blanc area [16].

In this case, to analyze and predict the time-series area size of glacier other European countries' mountains, the time-series query expression as a new time-series stream is created by the area size of glacier by the 6 basic functions defined in Section 3 to express the query-time-series-stream. In this case, the time-interval is set as 20 years, and the time-granularity in time-series-stream is set as 1 year.

The following is an example of query creation and time-series-context settings for the analysis of deforestation and prediction with time-series semantic computing.

Input data for analysis (IRD) = time-series values of area-size of glacier in Mont Blanc

- Area-size of glacier in Mont Blanc (4,808 m), Alps, Europe

Input data for prediction (ITD) = time-series values of area-size of glacier in other European countries' mountains with similar altitude

- Area-size of glacier in Matterhorn (4,478 m)
- Area-size of glacier in Aiguille du Midi (3,842 m)
- Area-size of glacier in Tsebrya Novitsa (4,485 m)

As for the 6 key elements to express the time-series-context, we applied the followings.

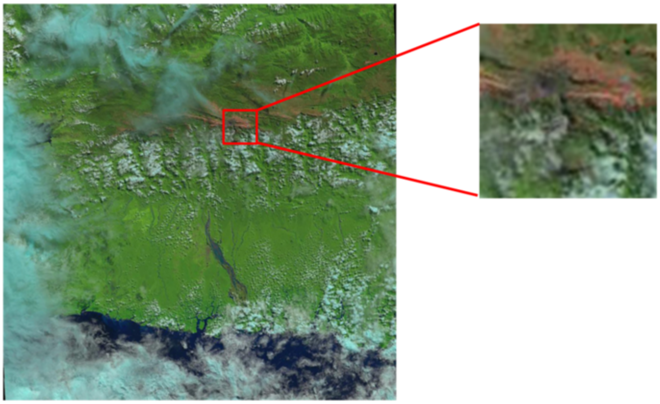
6 Key elements for express time-series-context are:

- Original time-granularity (OG) = yearly
- Target timing-granularity (TG) = peaks of glacier-melting ratio (speed)
- Feature extraction method (FEM) = time point of peaks
- Focusing time-interval (FW) = from first peak to the last peak or more peaks that matched condition
- Differential computing method (DCM) = ratio computing function for, number of years between the selected adjacent peaks, by applying average, difference, and other functions
- Pivot extraction method on ITD (PEM) = most recent 2 or more peaks that matched condition

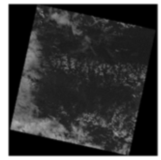
4.2.2. Case II-(2): Glacier melting in Puncak Jaya, Papua, Indonesia

This case shows the analysis of the time-series difference extraction on glacier melting phenomena in Puncak Jaya (Jayawijaya Mountains) during the period from 1936 to 2020. Puncak Jaya is located in Indonesia's West Papua Province as the highest peak in Oceania, which has been noted to have glacier melting over the years due to rising temperatures and climate change. The objective is to acquire an up-to-date picture of the extent of melting of the glaciers in the region, which will completely disappear by 2026 in their models [18][19][20], and to predict the actual speed of their disappearance.

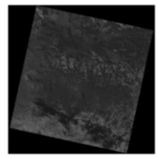
Figure 9 shows the target area images of peak in Puncak Jaya taken from Landsat 9. To detect the glacier area size by calculating NDSI (Normalized Difference Snow Index) in the same season (June to Aug., less clouds and no storm), the multispectral images are acquired from USGS EarthExplorer [16]. Because we need to calculate NDSI by Green and Short Wave Infra-Red (SWIR) bands, Band 2 and Band 5 of Landsat 5 for 1991, Band 2 and Band 5 of Landsat 7 for 2004, Band 3 and Band 6 of Landsat 8 for 2015 and 2020 were obtained and used.



(a) RGB satellite image of target area: Peak area of Puncak Jaya (Jajavijaya Mount) in 2020



(b) Multispectral image (Band 3: Green, Landsat 9) in 2020



(c) Multispectral image (Band 6: SWIR1, Landsat 9) in 2020

Figure 9. Target area of Puncak Jaya, Papua, Indonesia in 2020: (a) RGB satellite image, (b) high-resolution multispectral images: (b) Green band and (c) SWIR1 band

Figure 10 shows the size of glacier in Puncak Jaya in 1991 by calculating NDSI (Normalized Difference Snow Index). NDSI is calculated by the following formula using Green (G) band and Short Wave Infra-Red (SWIR1) band.

$$NDSI = (G - SWIR1)/(G+SWIR1)$$

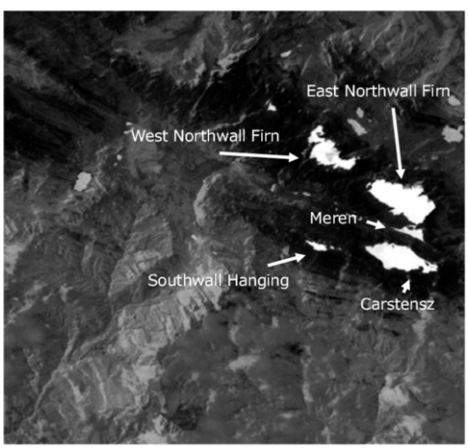


Figure 10. Calculation result of NDSI (Normalized Difference Snow Index) from multispectral images of Band 2 and Band 5 of Landsat 5 in 1991: Five original glaciers (East Northwall Firn, West Norththwall Firn, Meren Glacier, Southwall Hanging Glacier and Carstensz Glacier System) are observed.

Figure 10 is the NDSI calculation result using Band 2 (G) and Band 5 (SWIR1) of Landsat 5 for 1991. From **Figure 10**, five original glaciers (East Northwall Firn, West Norththwall Firn, Meren Glacier, Southwall Hanging Glacier and Carstensz Glacier System) are still observed.

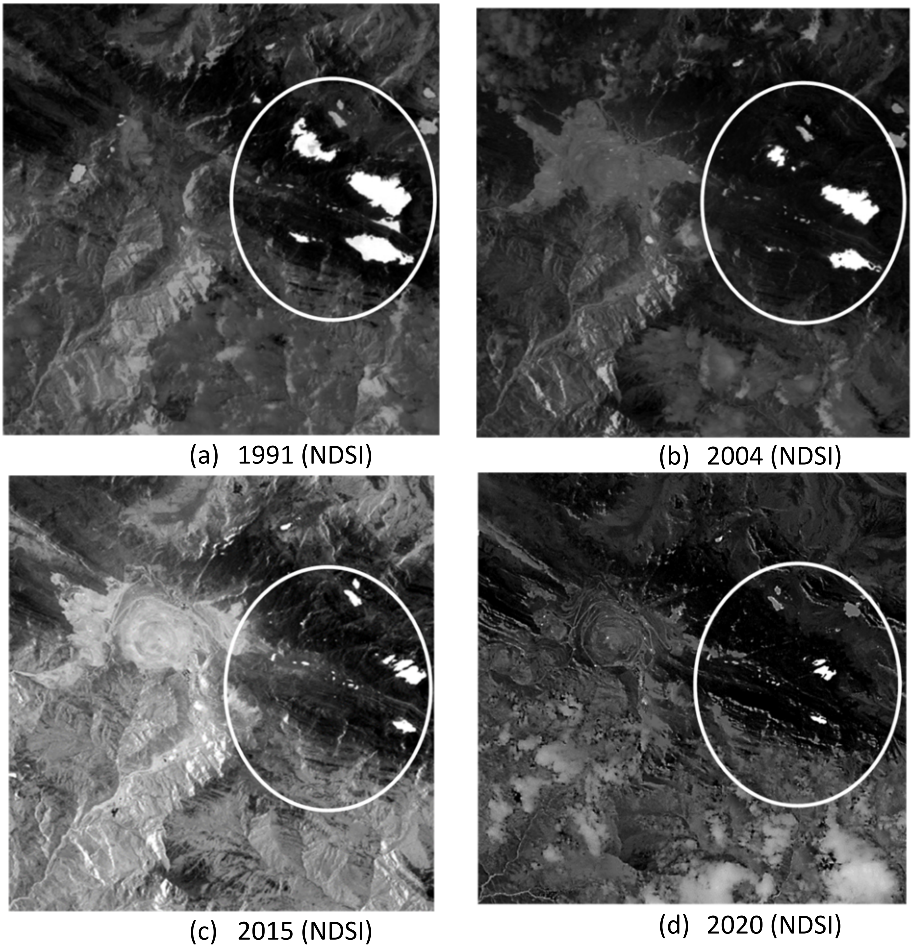


Figure 11. Calculation result of NDVI (Normalized Difference Snow Index) from 1991 to 2020 of Puncak Jaya glaciers: (a) 1991, (b) 2004, (c) 2015 and (d) 2020

Figure 10 and **Figure 11 (a)** show that five original glaciers (East Northwall Firn, West Norththwall Firn, Meren Glacier, Southwall Hanging Glacier and Carstensz Glacier System) are observed in 1991. In 2004, Meren glacier disappeared (**Figure 11 (b)**). In 2015, it is found that West Northwall Firn and South Hangging Glacier almost disappeared and the largest glacier, East Northewall Firn was split to three pieces (**Figure 11 (c)**). Actually, IKONOS satellite imagery studies indicate that the Eastern Northwall Firn lost an additional 4.5% of its surface area in the two years 2000-2002 [18][19], and another study by NASA Earth Observatory also reported that prior to 2017, West Northwall Firn had completely disappeared and the East Northwall Firn was broken up in three smaller patches [20]. In 2020, the East Northwall Firn was split to two smaller patches and Carstensz Glacier is shrined to a small piece (**Figure 11 (d)**).

To calculate the precise area size of glacier, we performed glacier area-size estimation by counting of the number of pixels with high NDSI values over a threshold based on the following formula:

$$A_{glacier} = L_{res}^2 * N_{pix}$$

where, $A_{glacier}$: Estimated size of glacier area [m^2]

L_{res}: Resolution of a target image [m/pix]

N_{pix}: Total number of pixels in the glacier area

In the case of using Landsat 5, 7, 8 & 9, the estimated size of the glacier area can be expressed by $A_{glacier} = 30^2 * N_{pix}$ because the resolution of G and SWIR of Landsat 5, 7, 8 and 9 is 30 [m/pix].

Table 1 shows the estimation results of area size of glacier by this study combined with the values acquired by other existing glaciology studies [18][19].

Table 1 Estimated area size (km^2) of the Pucak Jaya glaciers

Glacier area	1936	1972	1987	**1991**	2002	**2004**	**2015**	**2020**
West Northwall Firn	6.7	3.6	*1.3*	**0.8287**	*0.28*	**0.2142**	**0**	0
East Northwall Firn	1.6	1.1	N/A	**1.5266**	N/A	**1.088**	**0.4829**	**0.20768**
Meren Glacier	2.8	2.2	N/A	**0.1463**	N/A	**0**	**0**	**0**
Carstensz Glacier	1.6	1.2	*1.4*	**1.117**	*0.7*	**0.565**	**0.161**	**0.05219**
Southwall Hanging Glacier	0.3	0.2	*0.09*	**0.1178**	N/A	**0.009**	**0**	**0**
Total (Entire Puncak Jaya)	13	7.3	*5.09*	**3.7364**	*2.15*	**1.8766**	**0.643**	**0.25987**

Note: Bold values represent our estimated size by this study. Italicized values represent computed totals from published areas by glaciology studies (Kincaid and Klen, 2004) [18] and (Klein and Kincaid, 2017) [19]. Normal values were acquired during the field expeditions by experts in glaciology (Allison and Peterson, 1976, 1989, 1994)

In this case, to predict the time-series area size of existing glaciers in Puncak Jaya, the time-series query expression as a new time-series stream is created by the area size of glacier by 6 basic functions defined in Section 3 to express the query-time-series-stream. In this case, the time-interval is set as 10 years, and the time-granularity in time-series-stream is set as 1 year. The other parameters such as temperature, snowfall, depth of ice will be additional conditions for creating context to increase the precision of prediction.

The following is an example of query creation and time-series-context settings for the analysis of glacier melting and prediction with time-series semantic computing.

Input data for analysis (IRD) = time-series values of area-size of disappeared glaciers

- <u>Area-size of West Northwall Firn</u>
- <u>Area-size of Meren Glacier</u>
- <u>Area-size of Southwall Hanging Glacier</u>

Input data for prediction (ITD) = time-series values of area-size of existing glaciers

- <u>Area-size of East Northwall Firn</u>

- Area-size of Carstensz Glacier

As for the 6 key elements to express time-series-context, we apply the followings.

6 Key elements for express time-series-context are:

- Original time-granularity (OG) = yearly
- Target timing-granularity (TG) = peaks of glacier-melting ratio (speed)
- Feature extraction method (FEM) = time point of peaks
- Focusing time-interval (FW) = from first peak to the last peak or more peaks that matched condition
- Differential computing method (DCM) = ratio computing function for, number of years between the selected adjacent peaks, by applying average, difference, and other functions
- Pivot extraction method on ITD (PEM) = most recent 2 or more peaks that matched condition

Finally, **Figure 12** shows that the original satellite images with geo information, the difference-visualized images and calculated NDSI images are mapped onto 5D World Map System and visualized with other data such as sensor, statistic and multimedia data of weather which are related to glacier melting around the world. This visualization enables users to understand the complicated relations among various elements of environmental phenomena intuitively.

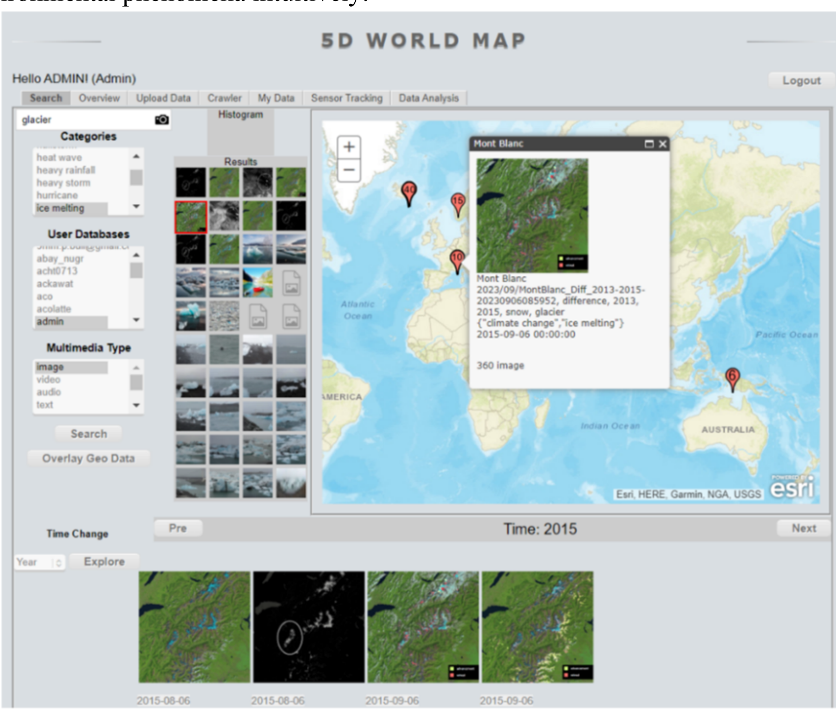


Figure 12. Mapping of an original satellite image with geo information, difference-images, NDVI calculation results of Mont Blanc, Europe and Puncak Jaya, Indonesia on 5D World Map System

5. Conclusion

We have presented a new concept of *"Time-series Semantic Computing*" for realizing global and temporal environmental analysis. The main feature of this system is to realize semantic time-series analysis in a multiple dimensional semantic space. This space is created for dynamically computing semantic relations between time-series data resources in different places and time. We have applied this method to time-series data resources in 5D World Map.

This system realizes a remote, interactive and real-time environmental research exchange among multiple and different remote spots in different areas. We have created a semantic-space for time-series analysis in environmental phenomena with multiple-dimensional axes along the time-axis. As the first step, this space is expandable to multiple spots to analyze and compare their time-series data in the global scope for environmental phenomena. We mapped them onto 5-Dimensional World Map System to make time-series semantic interpretations in those spots, as an international collaborative platform for environment analysis, to realize spatio-temporal and semantic interpretations.

As our future work, we will extend the *Time-series Semantic Computing*" realized onto 5-Dimensional World Map System to an international and collaborative research and education system for realizing mutual understanding and global knowledge-sharing on environmental issues in the world-wide scope.

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