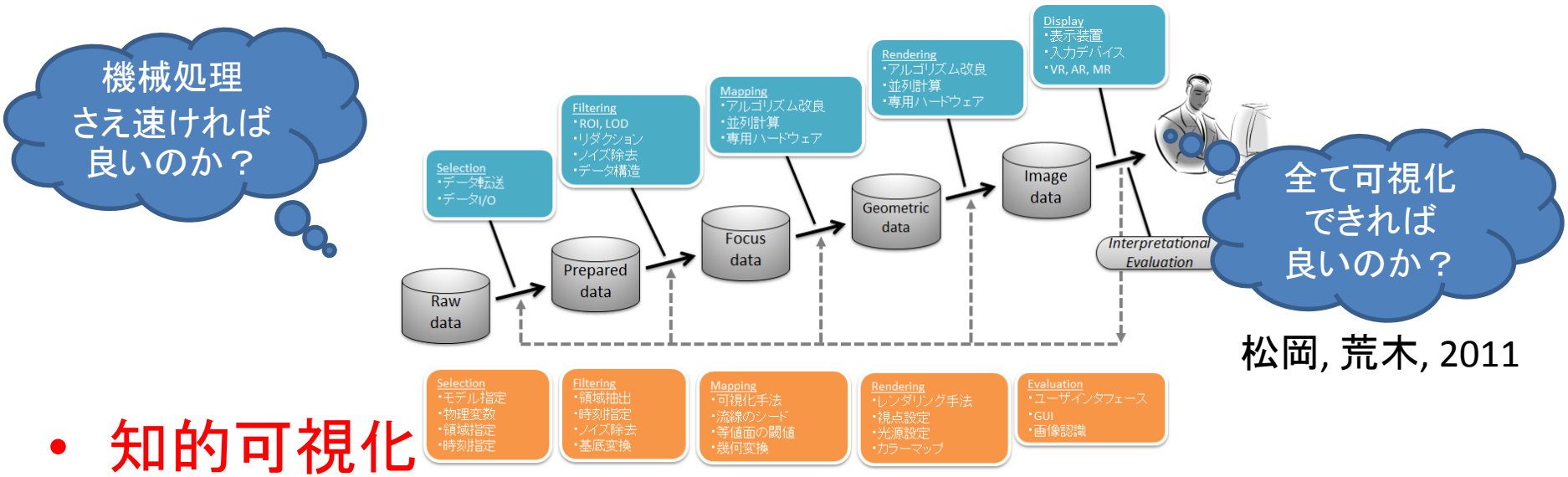
DI Lecture Series 6@東北大学流体科学研究所
2014年10月31日

大規模地球流体シミュレーションと可視化

海洋研究開発機構（JAMSTEC）
地球情報基盤センター
松岡 大祐

研究の背景

- 大規模可視化
  - 計算機が行う処理を効率化
  - 「より大量のデータ」を、「より高速に」可視化



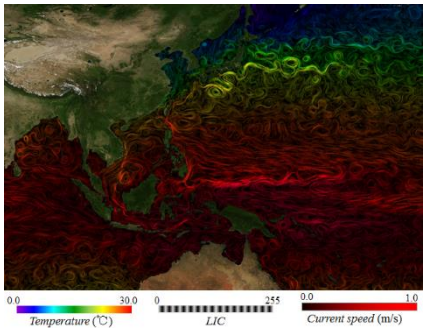
松岡, 荒木, 2011

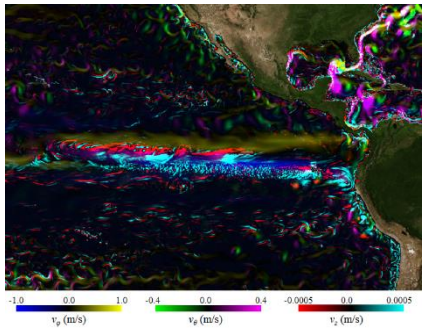
- 知的可視化
  - 解析者の経験的な判断の効率化、高度化
  - データ中に存在する「有益な情報の抽出」から「理解」まで

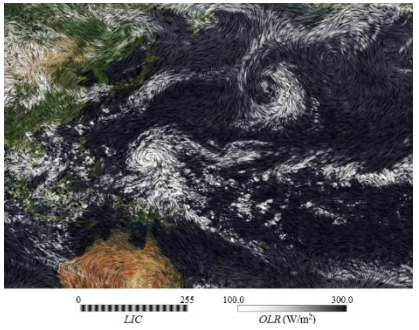
研究の目的

- 「多変量データ」という視点から海洋データを効果的に理解するための可視化手法の研究

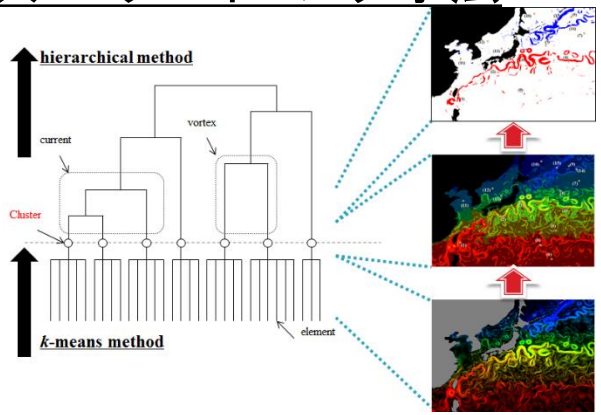
①可視化表現手法



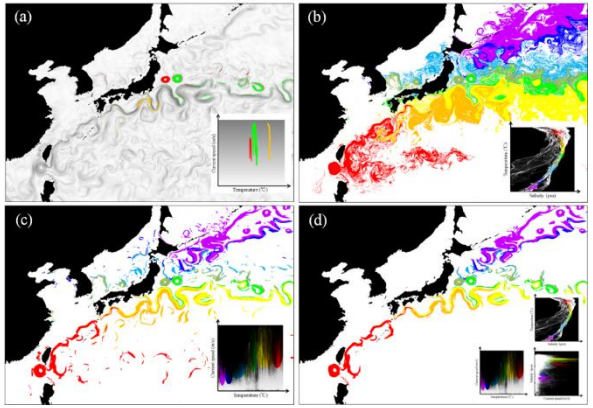




②データマイニング手法



③視覚的分析（Visual analytics）

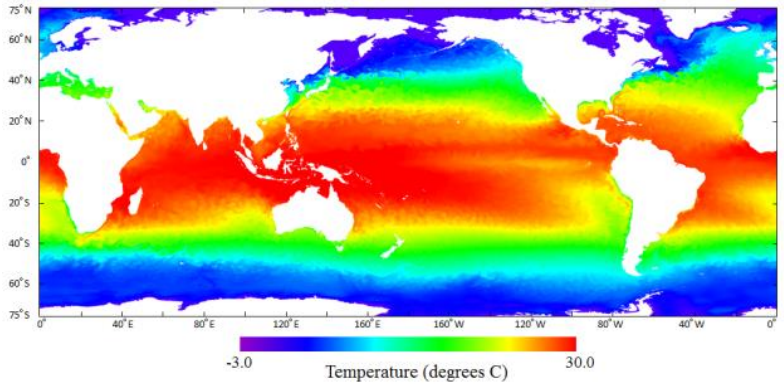


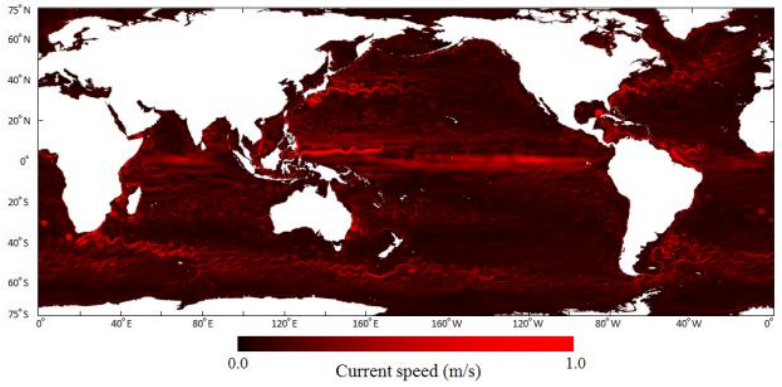
多変量データの可視化表現
-海流の水温の可視化-

D. Matsuoka *et al*., “Visualization for High-Resolution Ocean General Circulation Model via Multi-Dimensional Transfer Function and Multivariate Analysis”, *Proceedings of the International Conference for High Performance Computing, Networking, Storage and Analysis (SC12)*, DOI: 10.1109/SC.Companion.2012.263, 2012

Ocean General Circulation Model

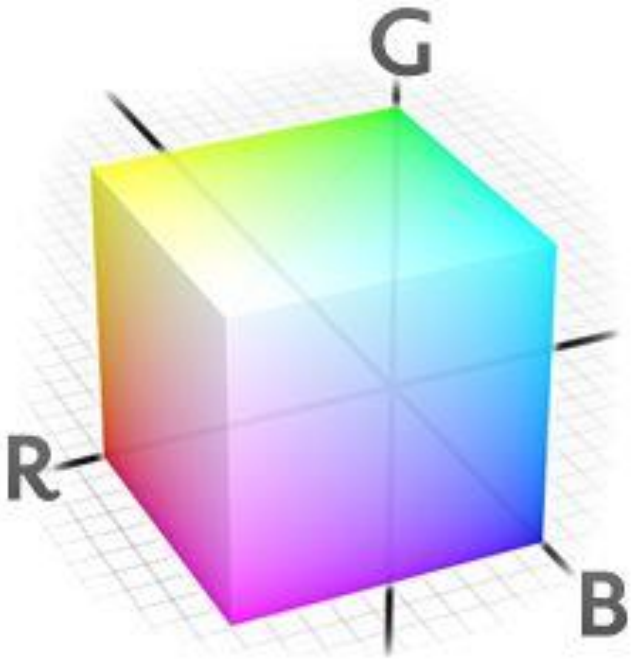
- OFES (OGCM for the Earth Simulator)
  - Navier-stokes equation, Equation of continuity, diffusion equation, state equation (Finite difference method)
  - Quasi-global scale (75S-75N)
  - Resolution: 0.1 deg. (horizontal), 54 layers (vertical)
  - Boundary condition: NCEP/NCAR reanalysis data





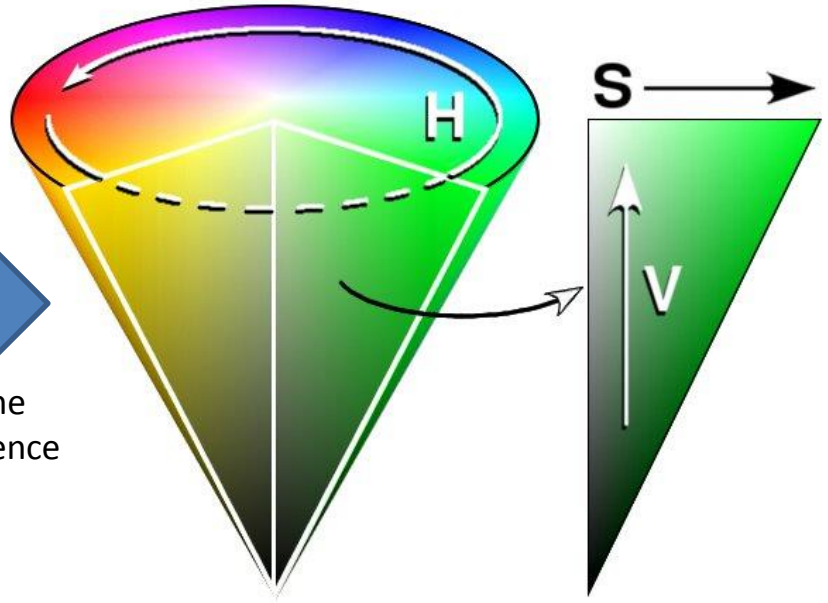
Basics of color model

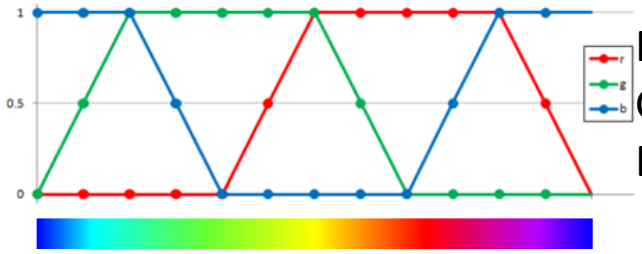
RGB Color Model



One-to-one correspondence

HSV Color Model

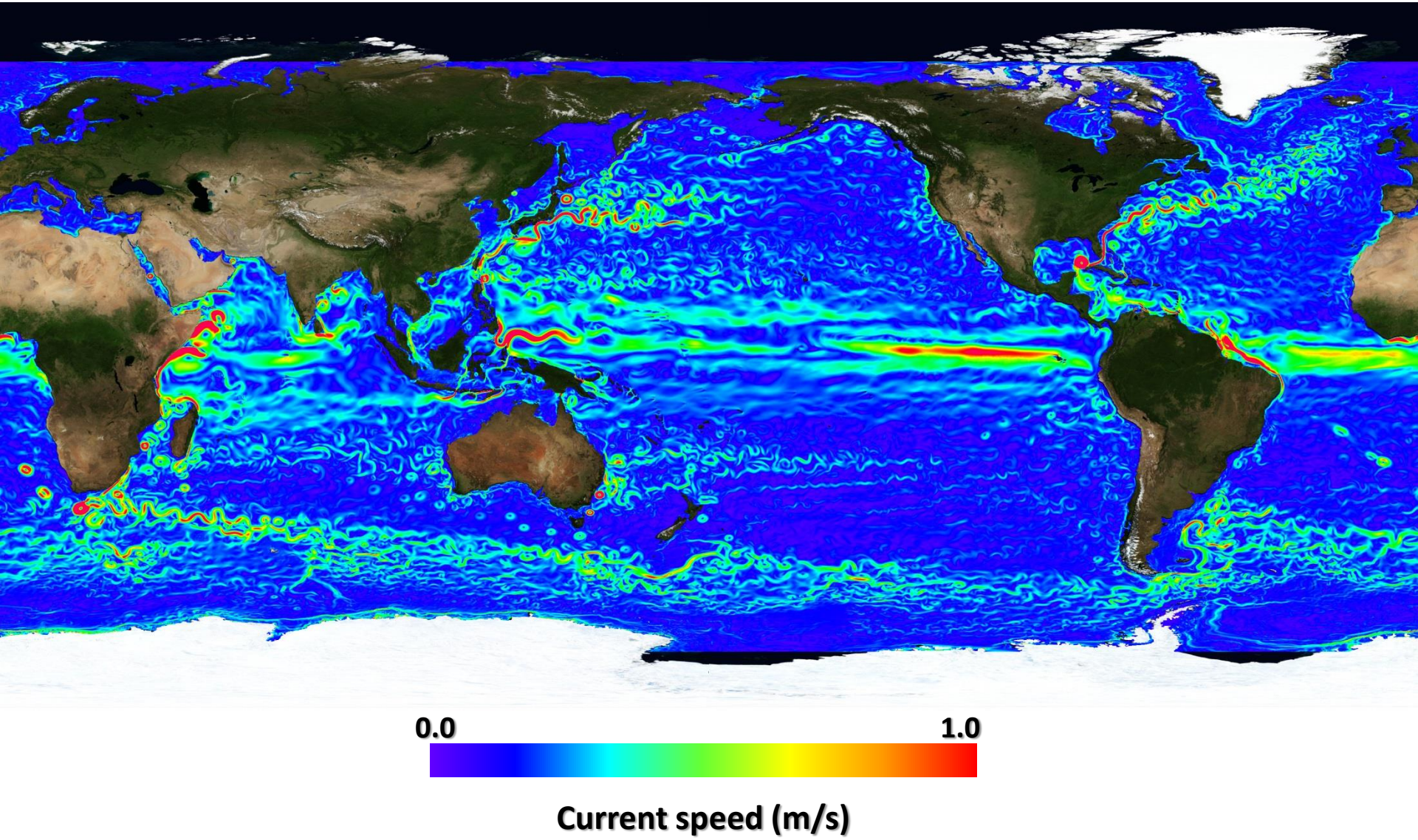




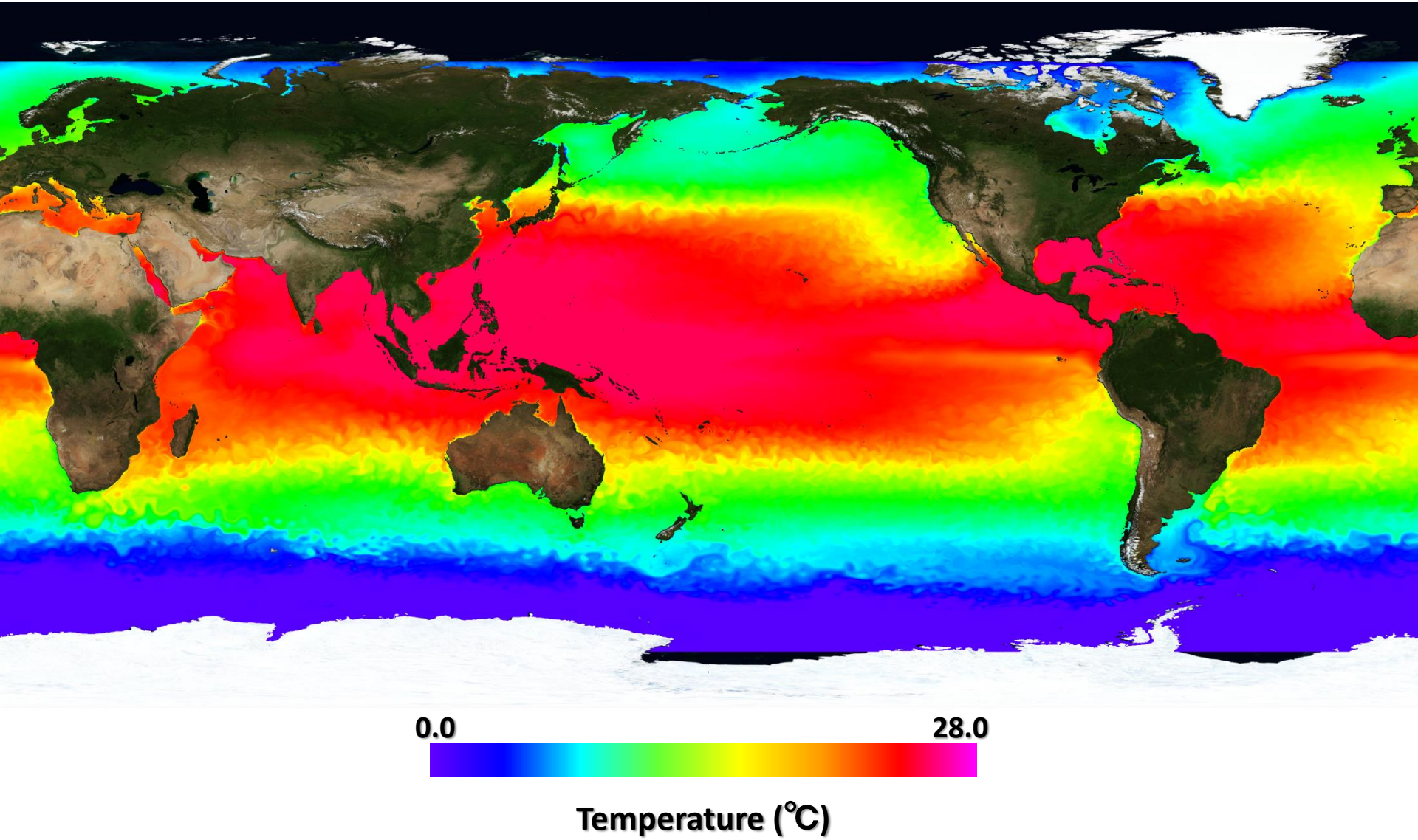
R: Red
G: Green
B: Blue

H: Hue (angle around the axis)
S: Saturation (distance from the axis)
V: Brightness (distance along the axis)

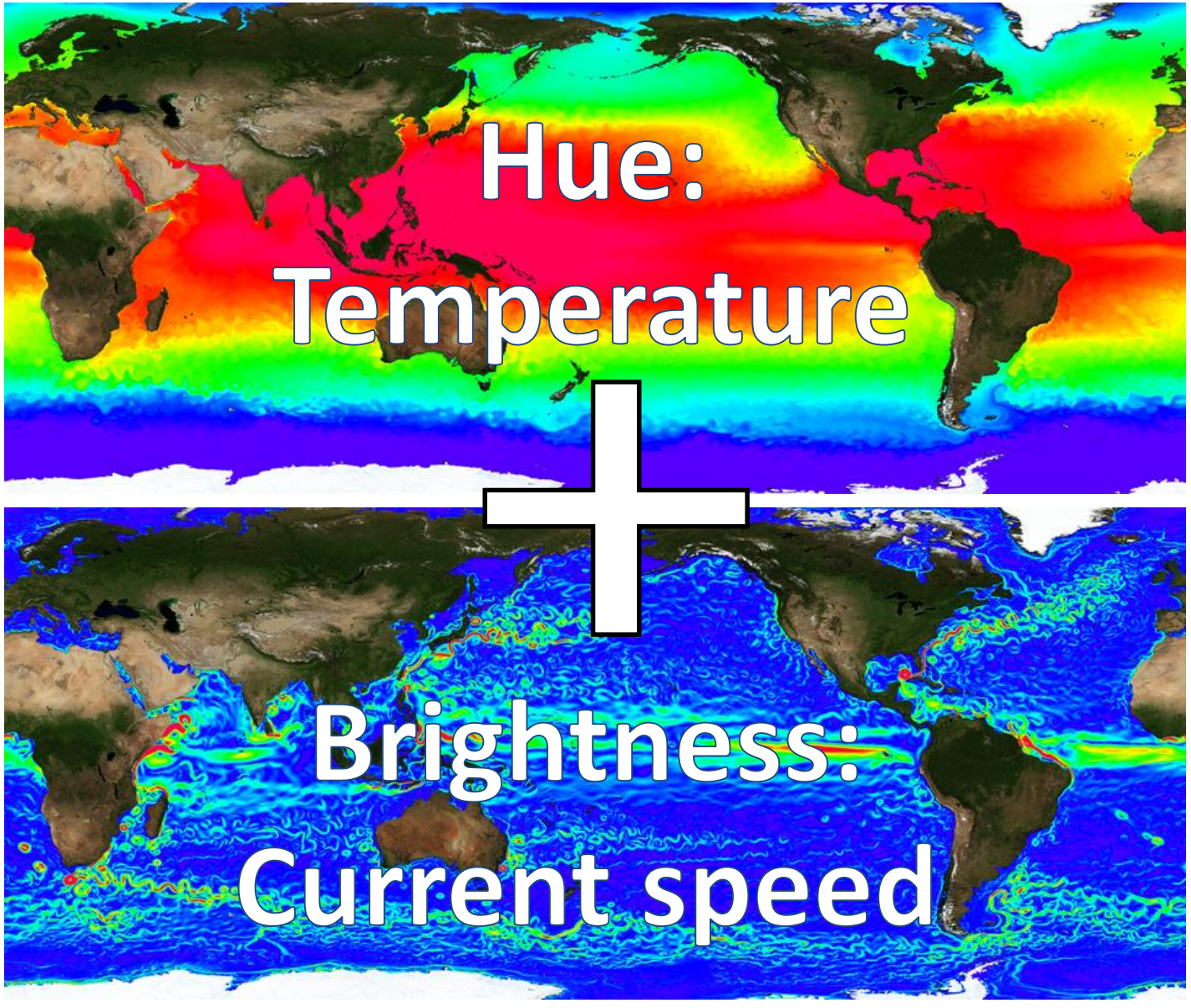
Current speed



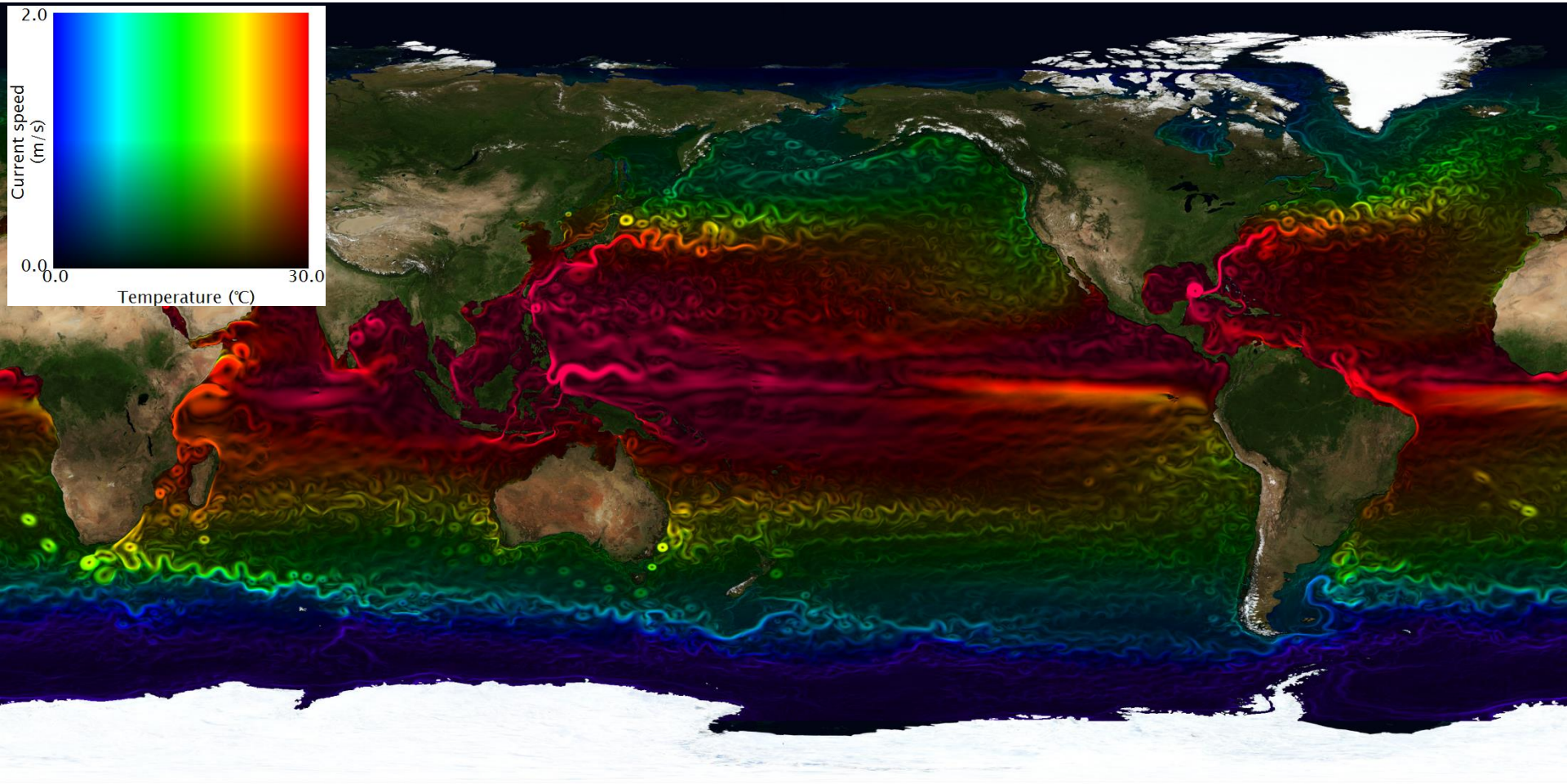
Sea surface temperature



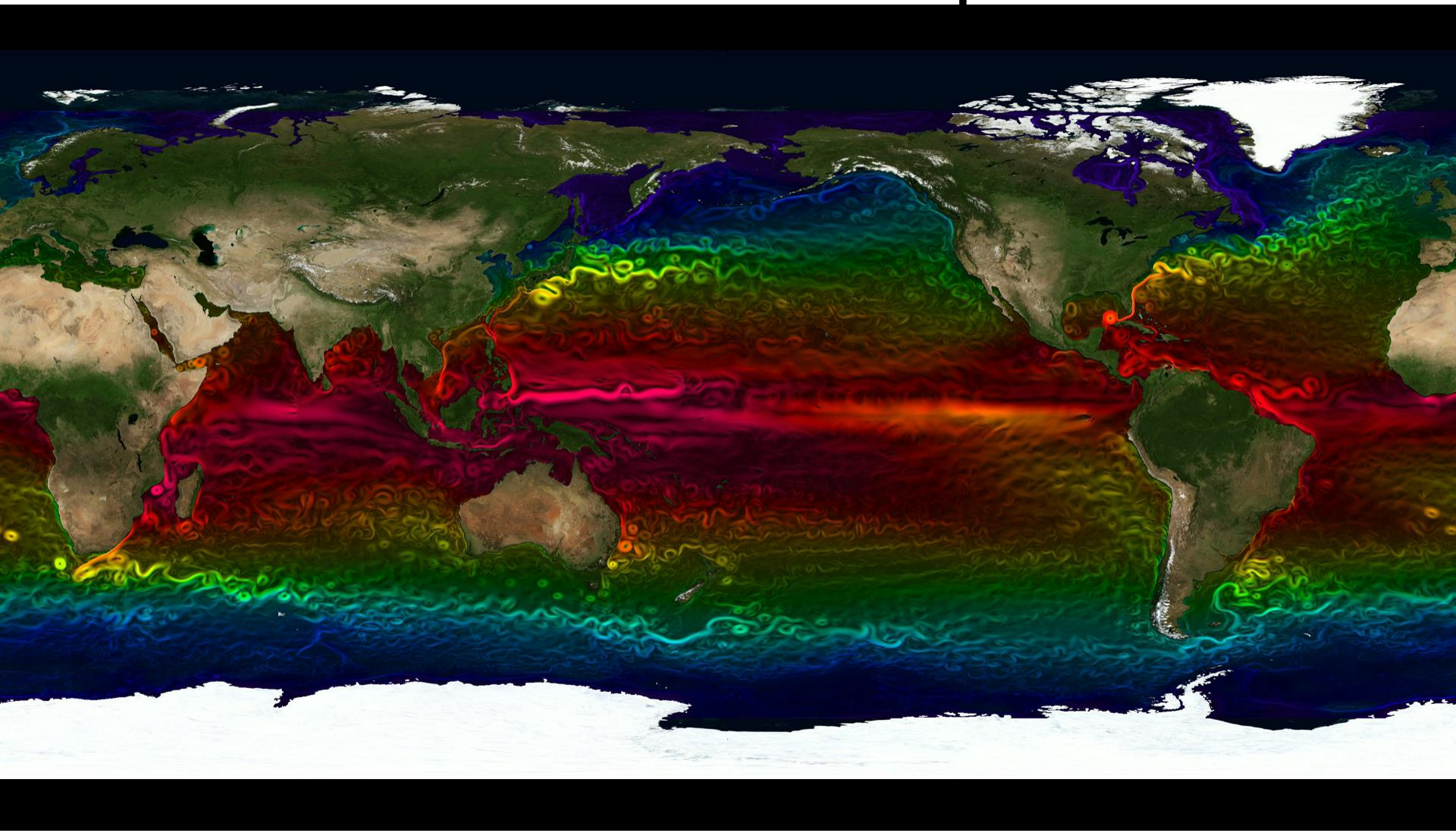
Multivariate visualization in HSV color space



SST and Current speed



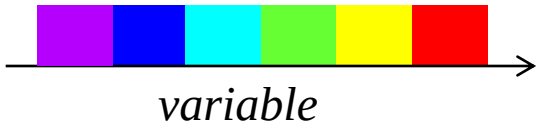
SST and Current speed



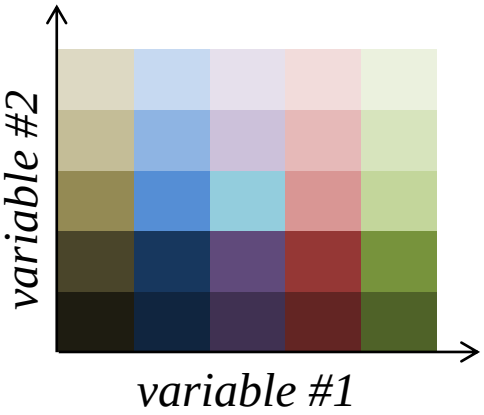
Multi-Dimensional Transfer Function

- Basic concept

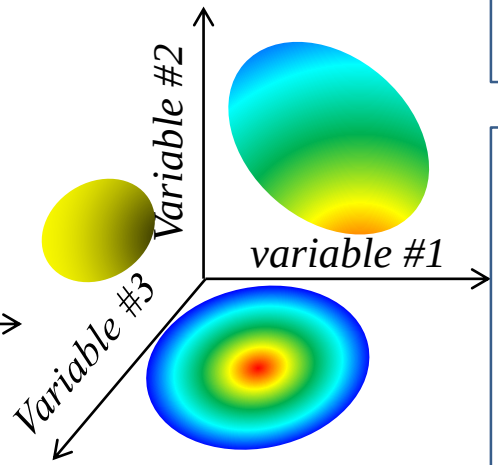
1D colormap



2D colormap



3D colormap



- Source code (ex. 3D)

RGB

```
do i=0, MAXLON
do j=0, MAXLAT
        Read_data()
        Color[i][j].red = temperature
        Color[i][j].green = speed
        Color[i][j].blue = salinity
enddo
enddo
```

* Normalize to 0-255

or

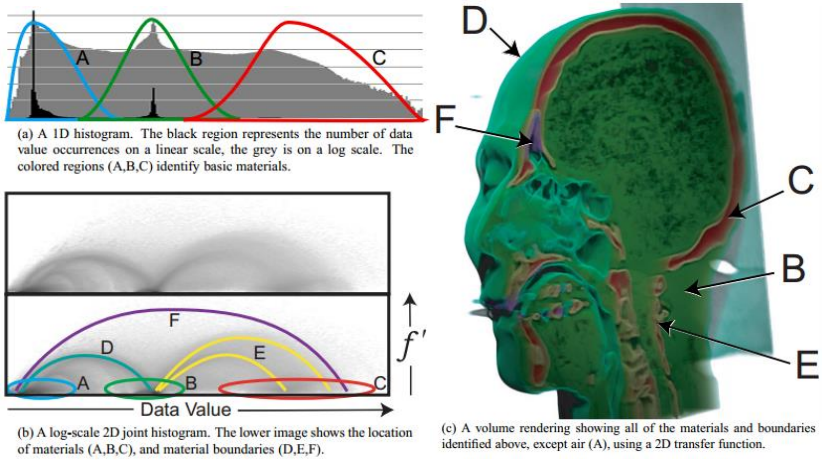
HSV

```
do i=0, MAXLON
do j=0, MAXLAT
        Read_data()
        Color[i][j].hue = temperature
        Color[i][j].saturation = speed
        Color[i][j].brightness = salinity
enddo
enddo
```

* Normalize to 0-255

Related work

Multi-Dimensional Transfer Function

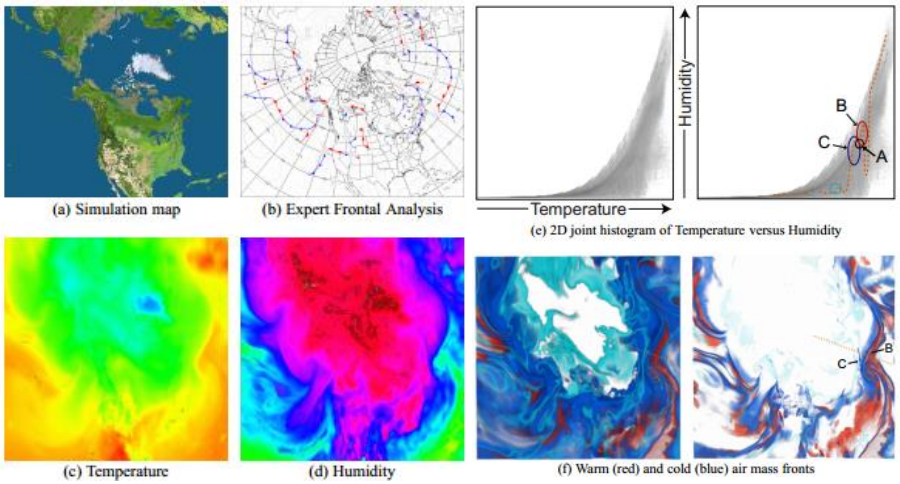


(a) A 1D histogram. The black region represents the number of data value occurrences on a linear scale, the grey is on a log scale. The colored regions (A,B,C) identify basic materials.

(b) A log-scale 2D joint histogram. The lower image shows the location of materials (A,B,C), and material boundaries (D,E,F).

(c) A volume rendering showing all of the materials and boundaries identified above, except air (A), using a 2D transfer function.

Kniss et al., 2001



(a) Simulation map

(b) Expert Frontal Analysis

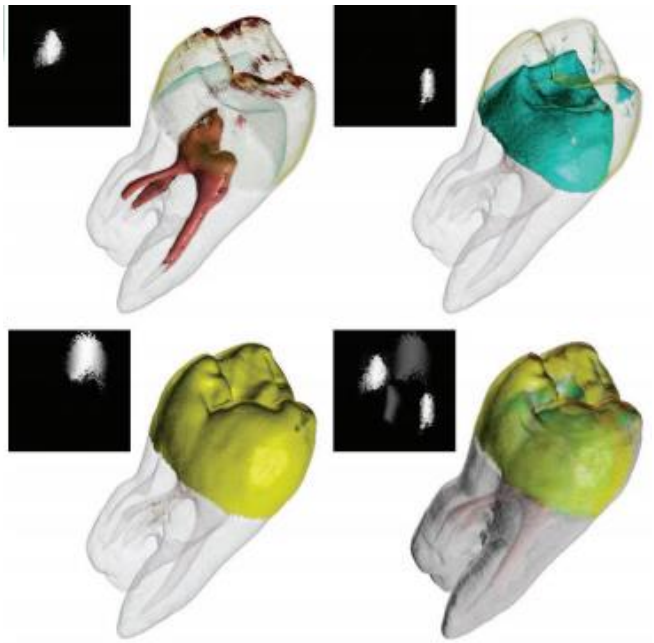
(e) 2D joint histogram of Temperature versus Humidity

(c) Temperature

(d) Humidity

(f) Warm (red) and cold (blue) air mass fronts

Kniss et al., 2002

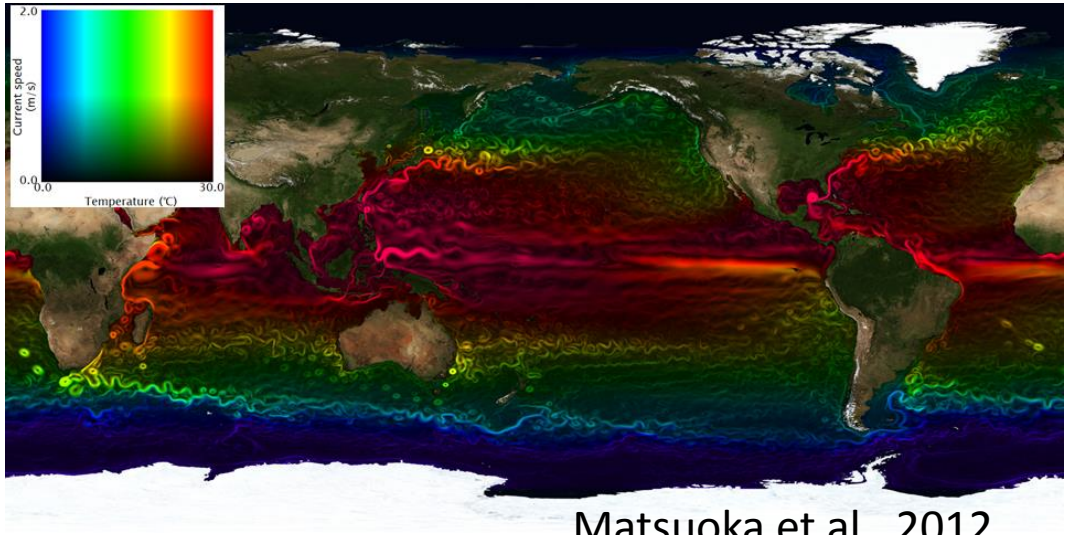


15 Renderings of the tooth data set. Opacity functions are inset in each image; surface colors are determined by the color map in Figure 14.

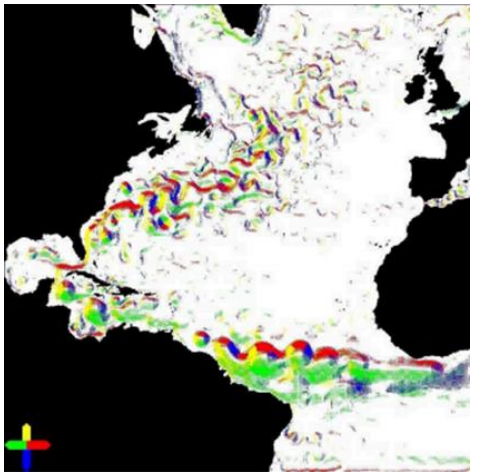
Pfister et al., 2000

Related work

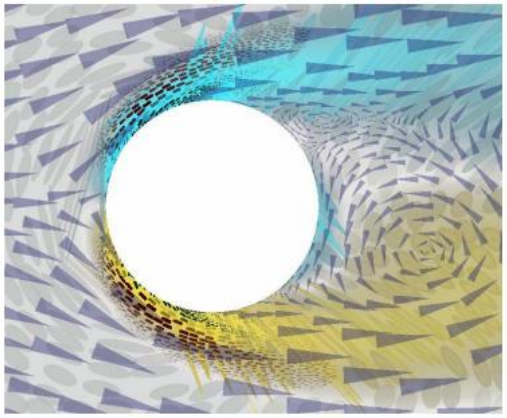
Multi-Dimensional Transfer Function

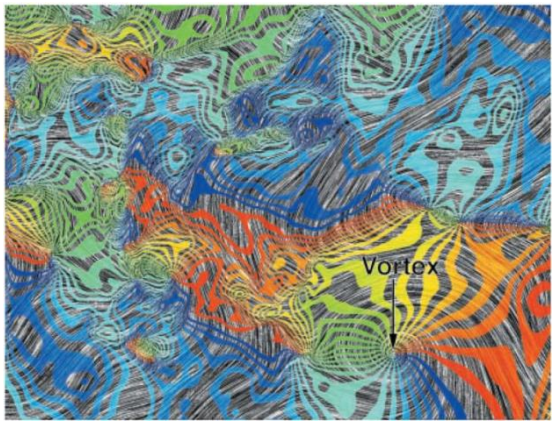


Matsuoka et al., 2012

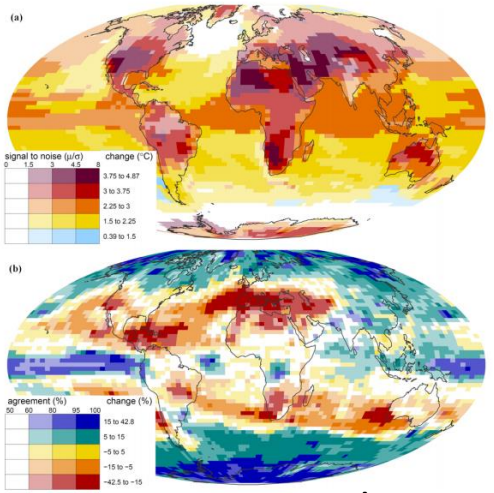


Crossno et al., 2001

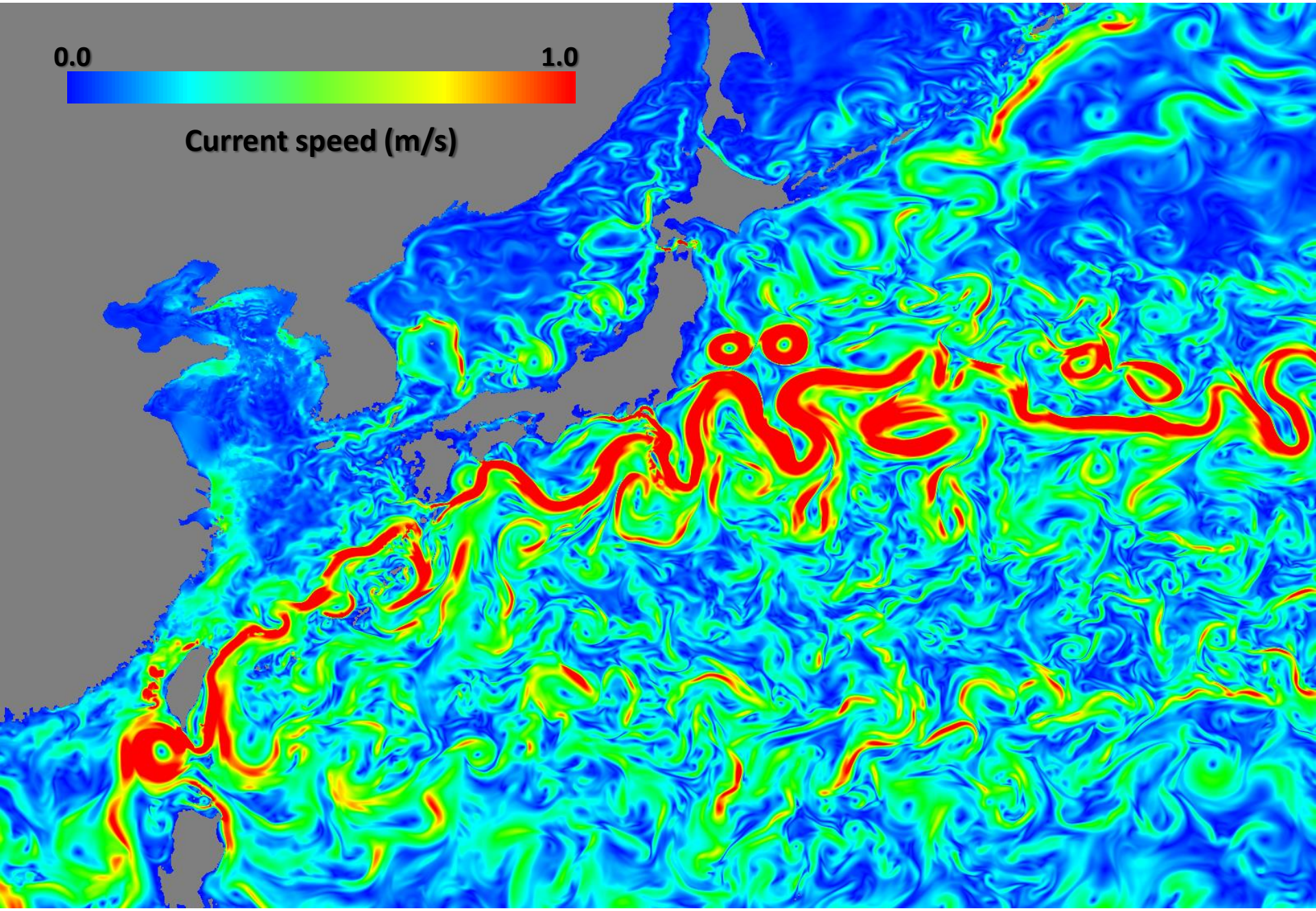


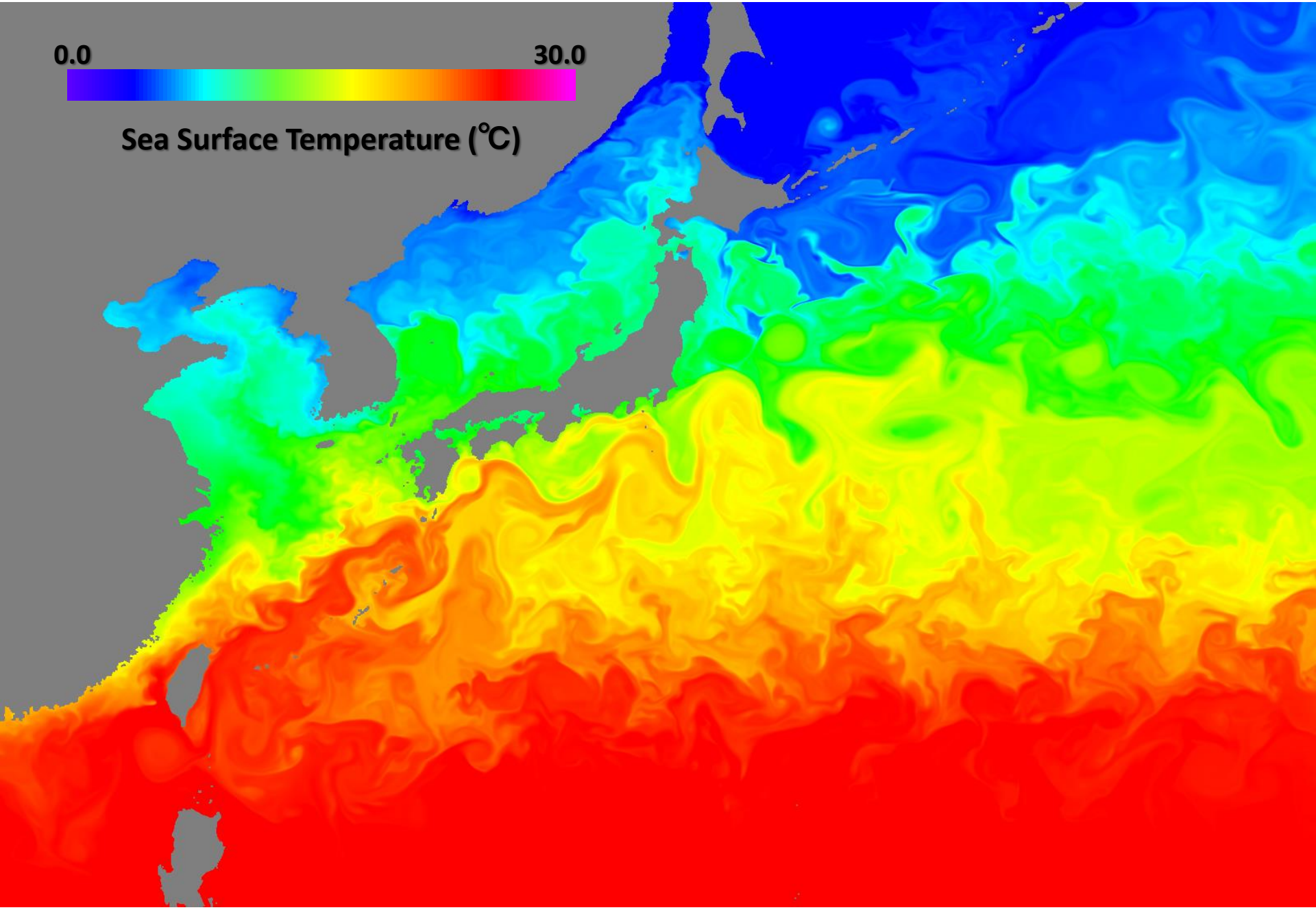


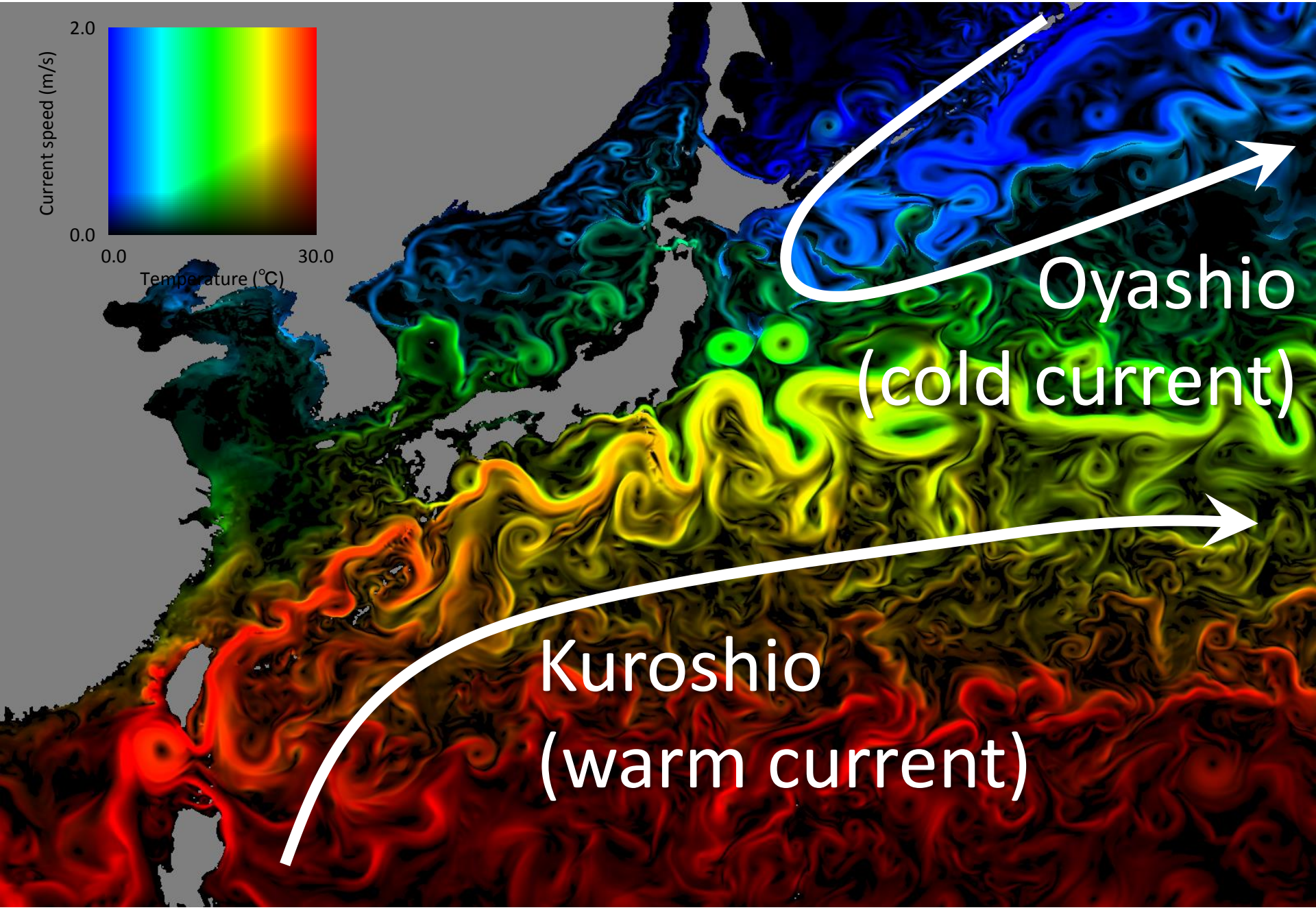
Wong et al., 2002



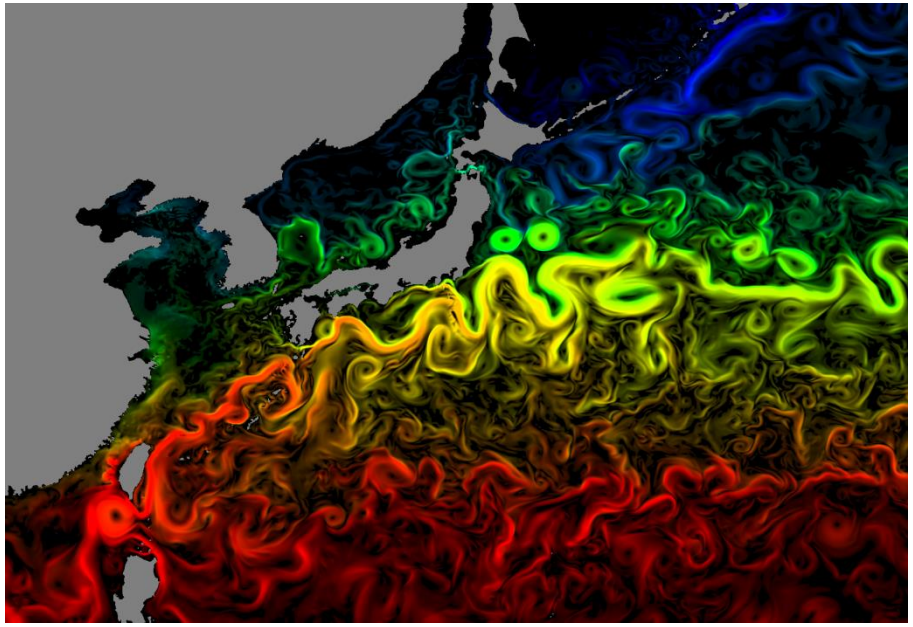
Kaye et al., 2012


0.0
1.0
Current speed (m/s)

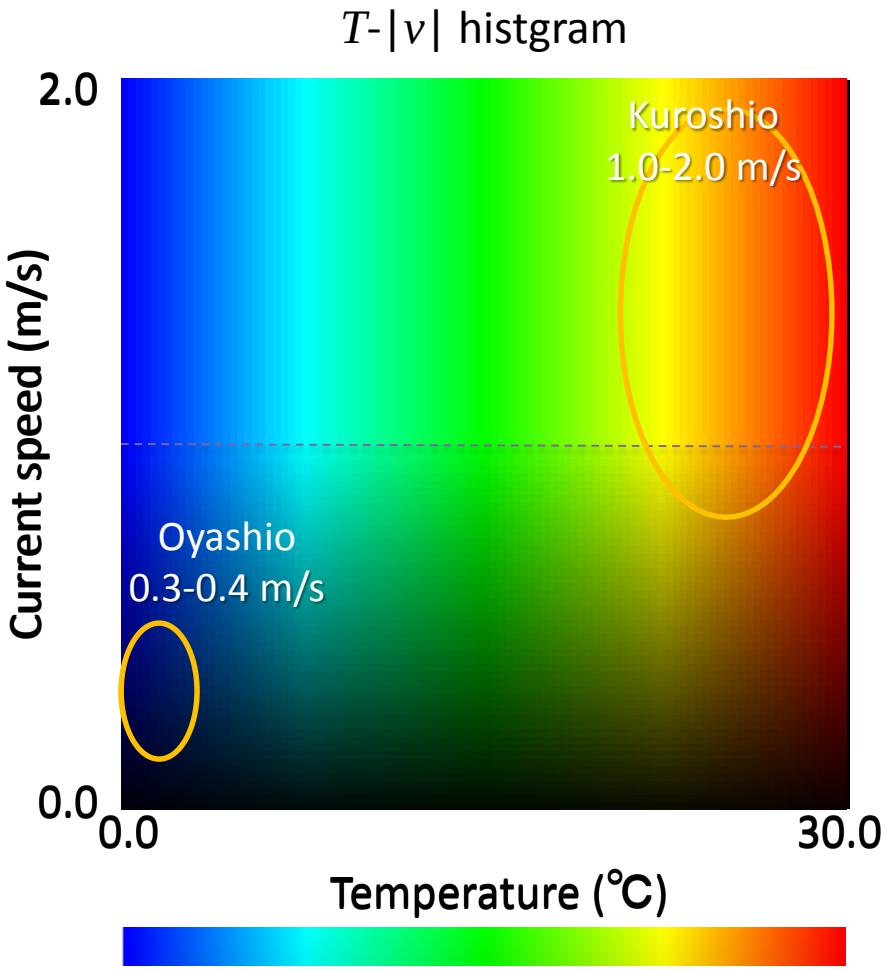

0.0
30.0
Sea Surface Temperature (℃)


2.0
Current speed (m/s)
0.0
0.0
30.0
Temperature (℃)
Oyashio
(cold current)
Kuroshio
(warm current)

2D color map manipulation

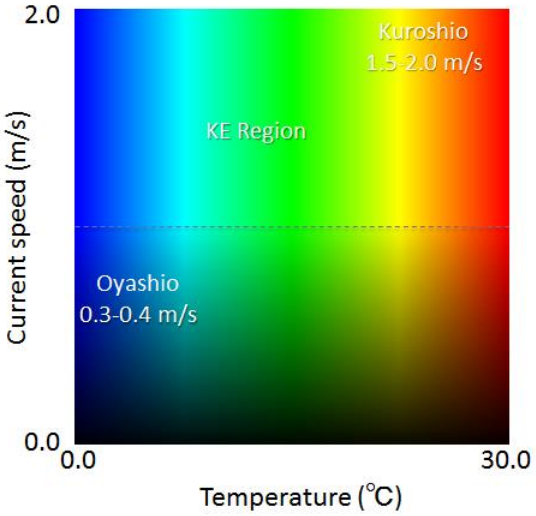


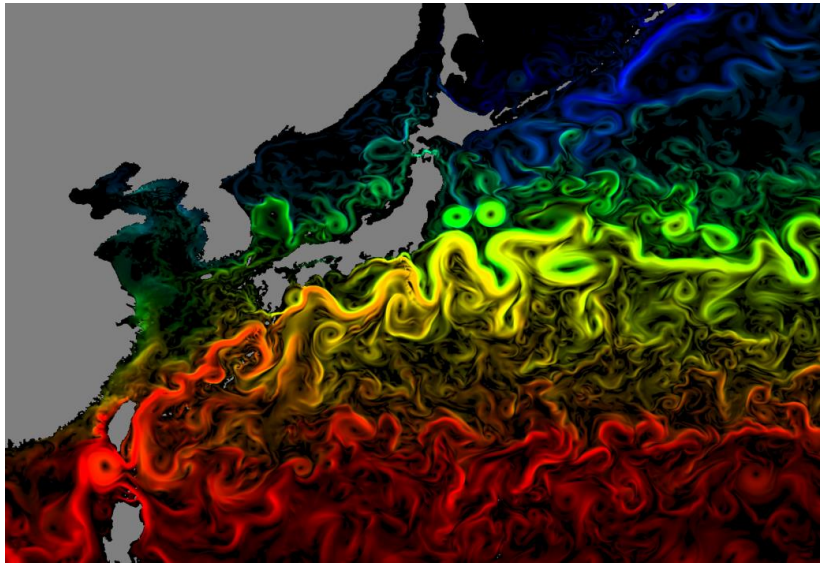
Hue: Temperature
Brightness: Current speed



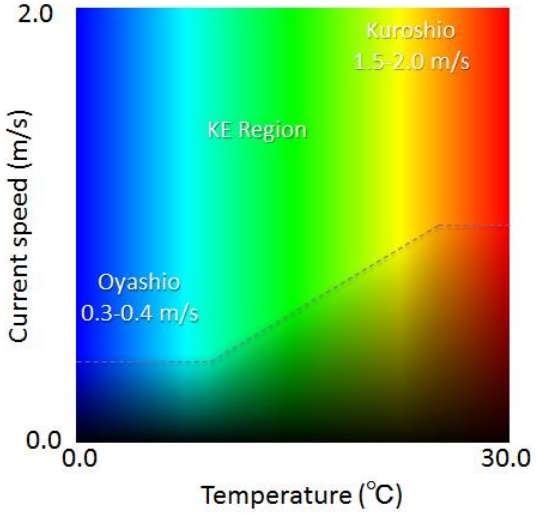
2D color map manipulation

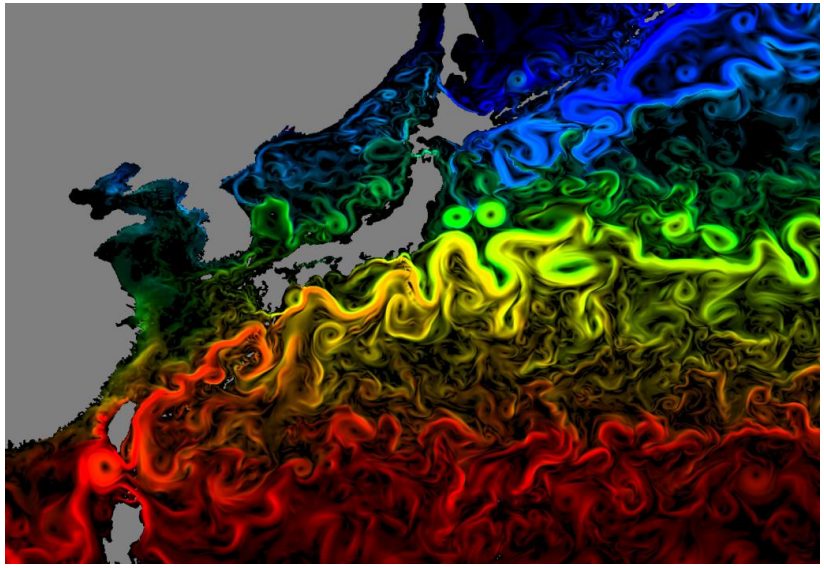
Before color map manipulation





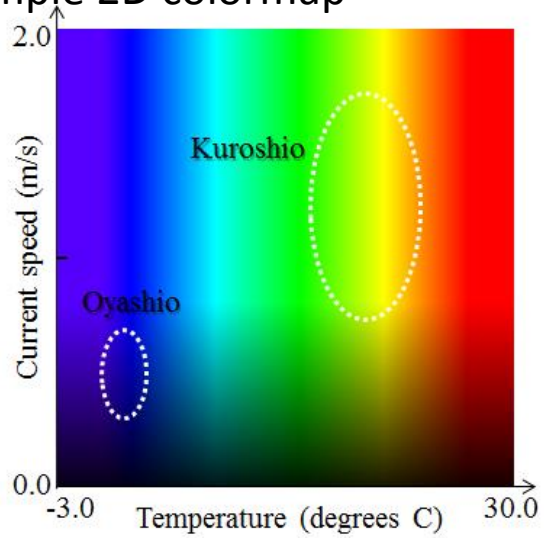
After color map manipulation

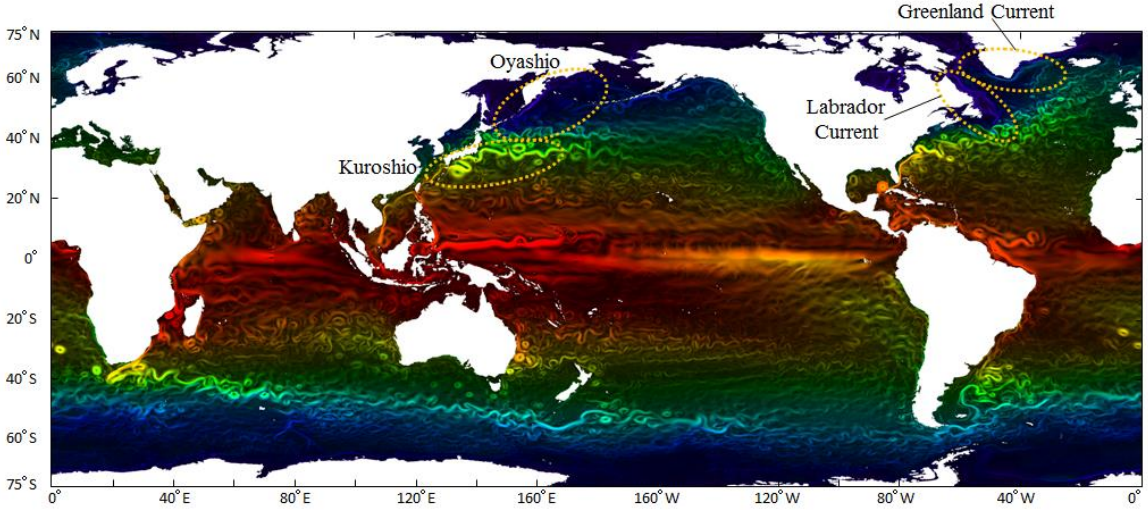




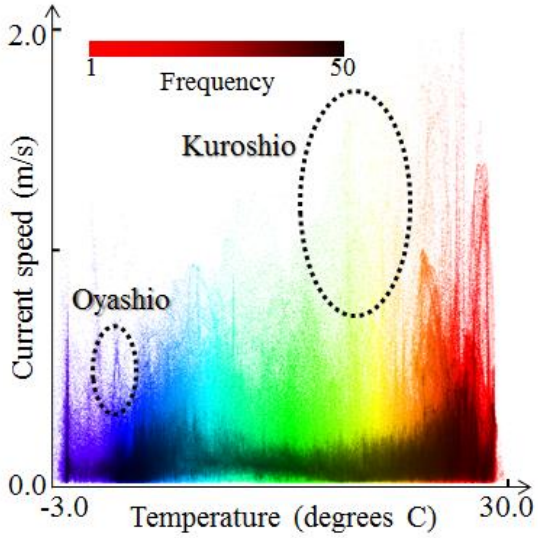
Application of Frequency-based 2D color map

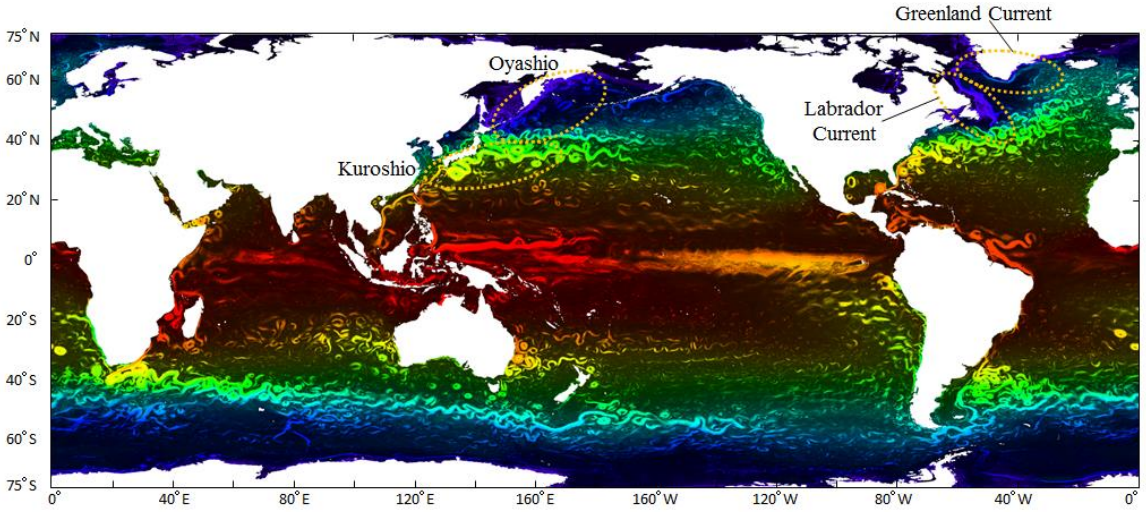
Simple 2D colormap





Frequency-based 2D colormap

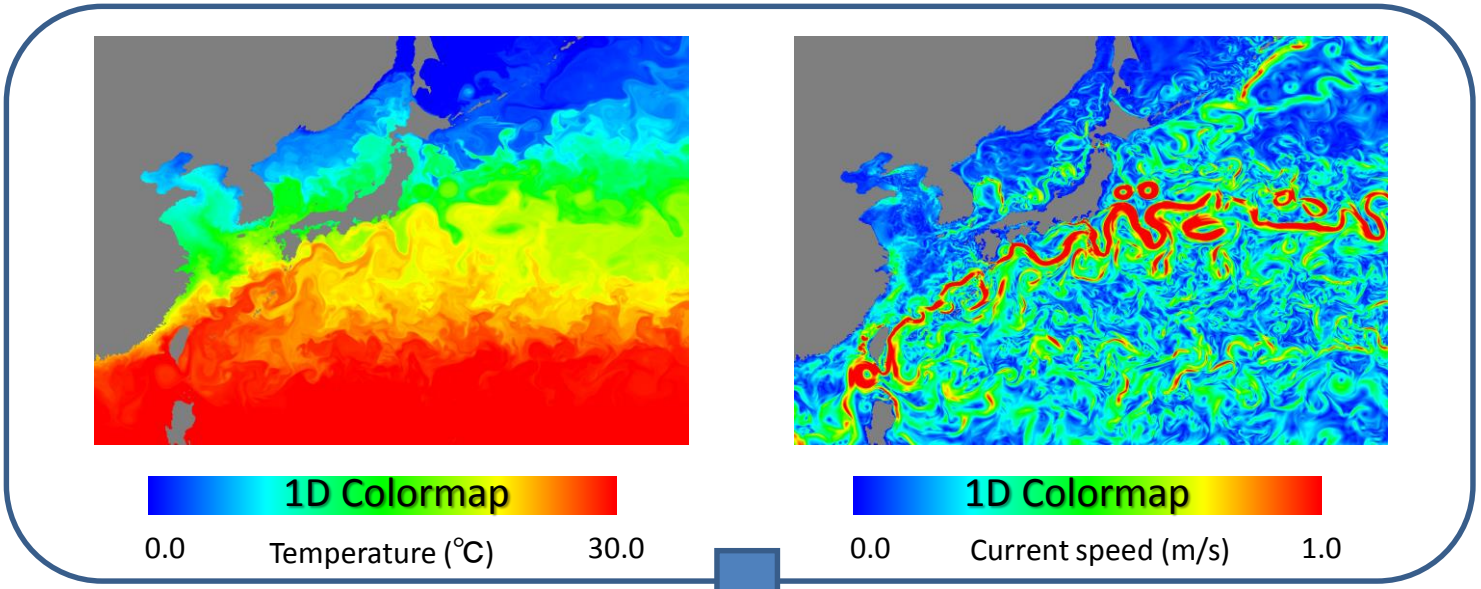


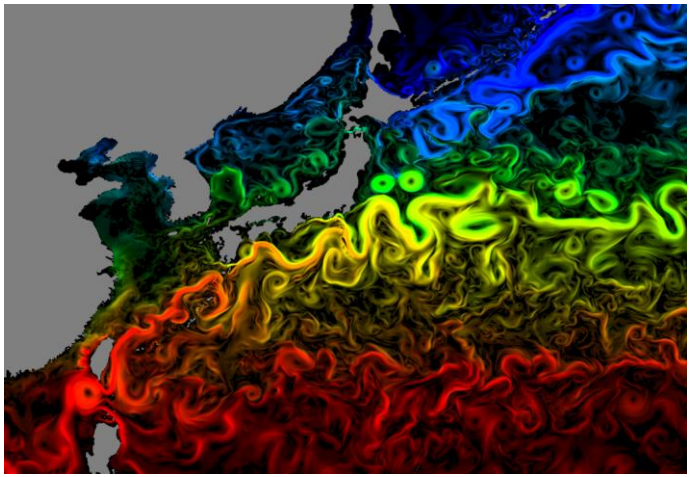


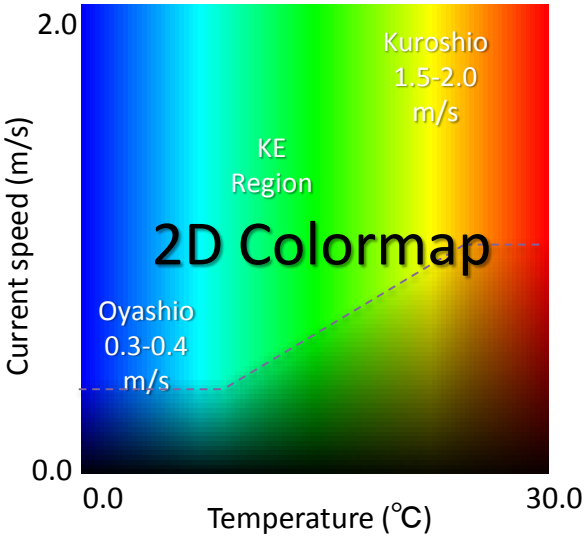
多変量データからの特徴抽出
-海流の抽出と可視化-

D. Matsuoka *et al*., “Visualization for High-Resolution Ocean General Circulation Model via Multi-Dimensional Transfer Function and Multivariate Analysis”, *Proceedings of the International Conference for High Performance Computing, Networking, Storage and Analysis (SC12)*, DOI: 10.1109/SC.Companion.2012.263, 2012

Visualization of multivariate data



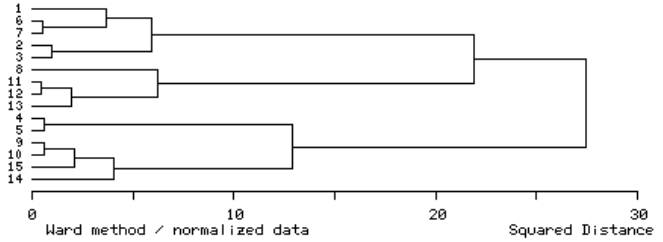




Matsuoka et al., 2012

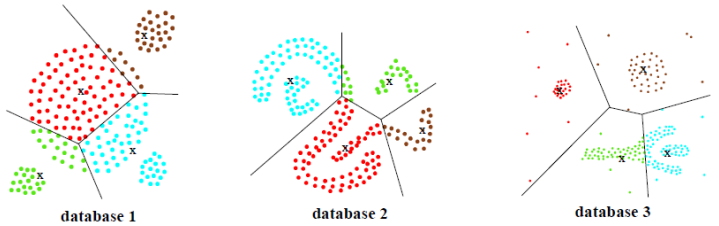
Application of cluster analysis

- Hierarchical method
  - Similarity between elements or clusters
  - Dendorogram as the results



Hierarchical method

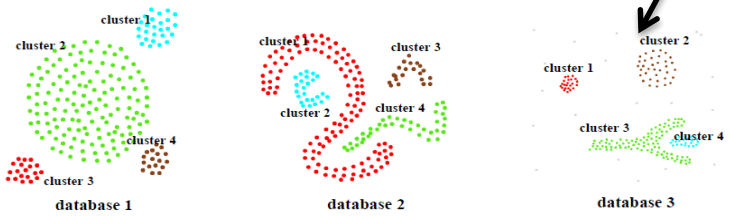
- Non-hierarchical method
  - Similarity between centroid and element
  - *k*-means



Non-hierarchical method

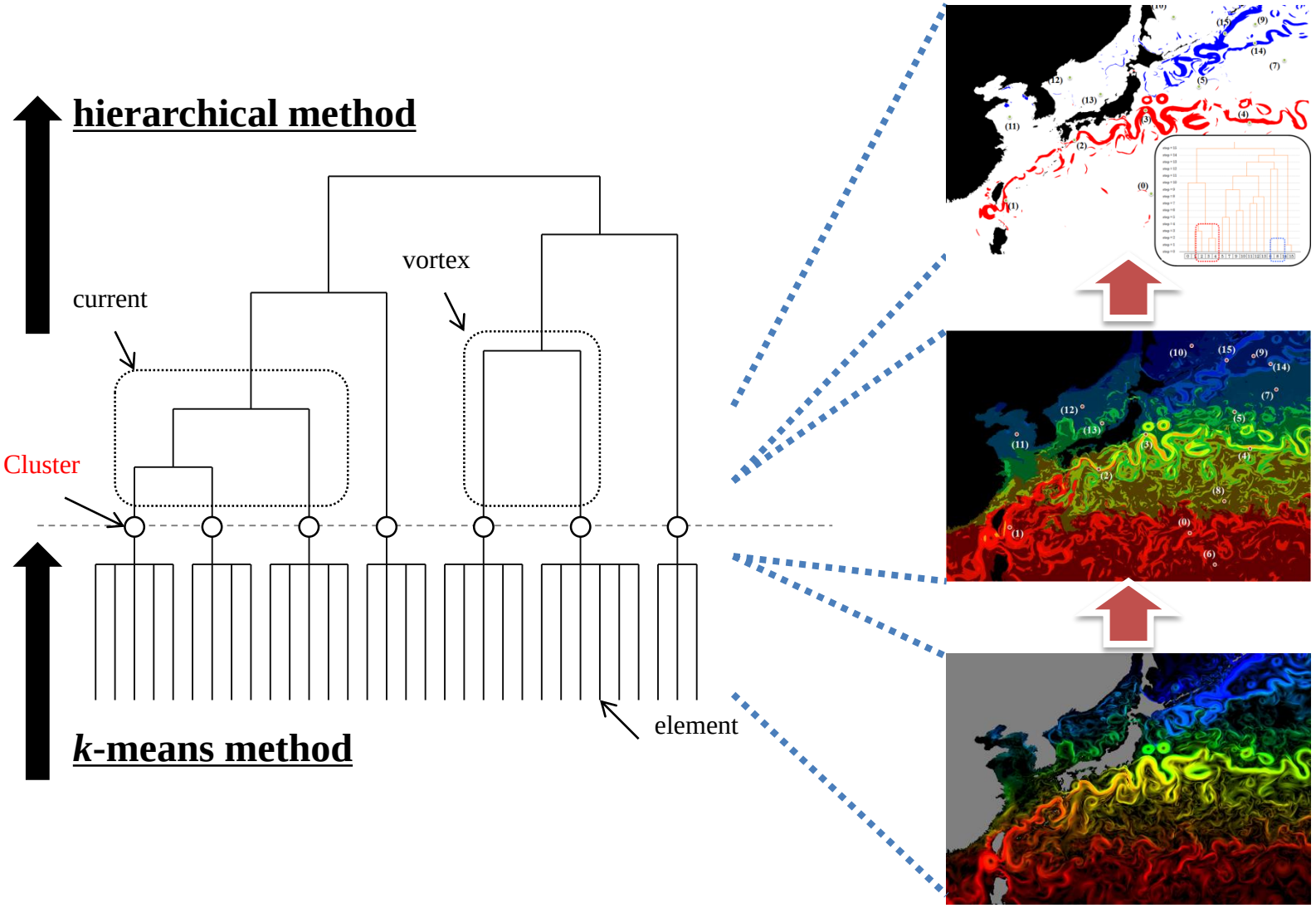
Variable space

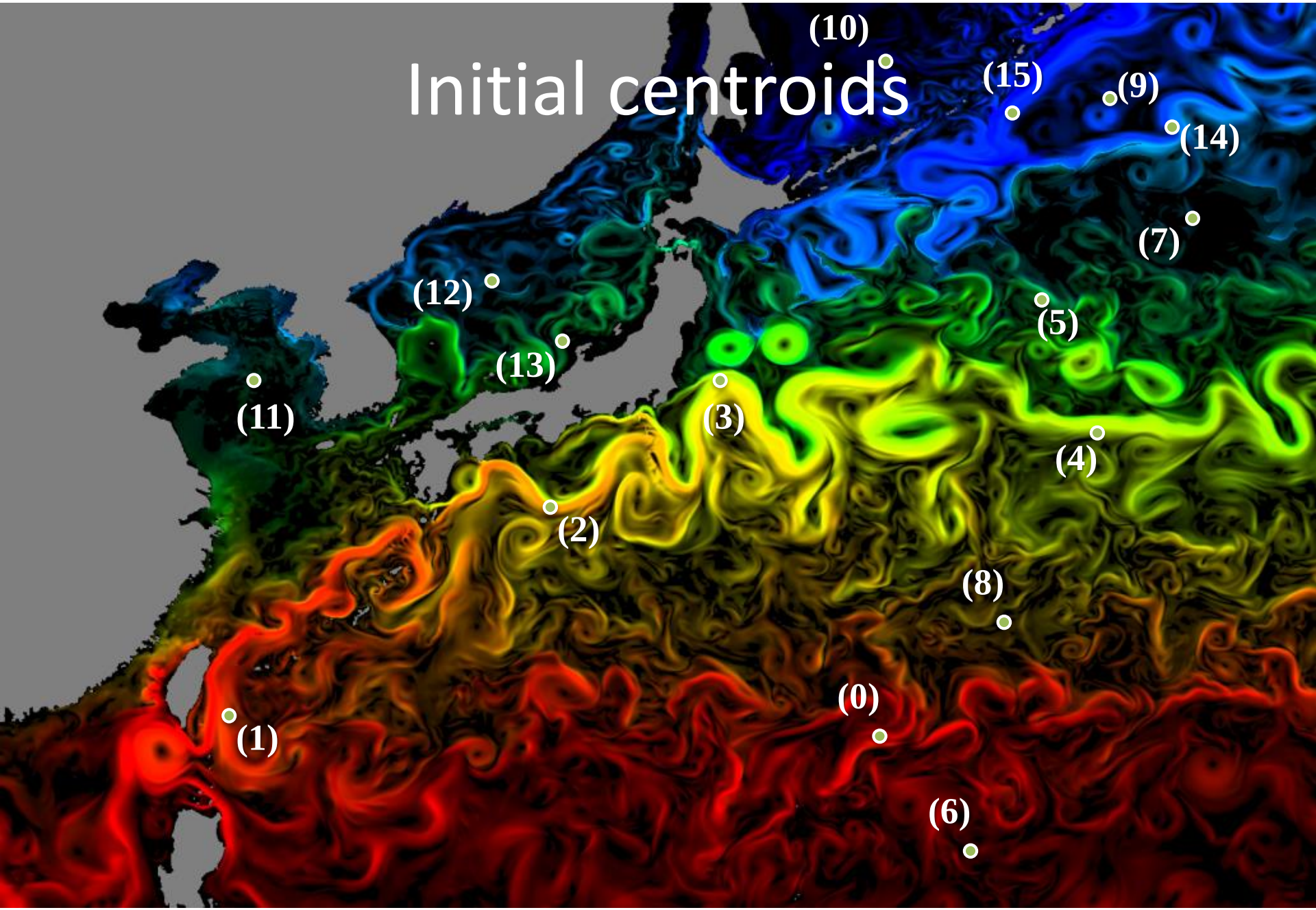
- Density-based method
  - Connectivity and density in the variable space



Density-based method

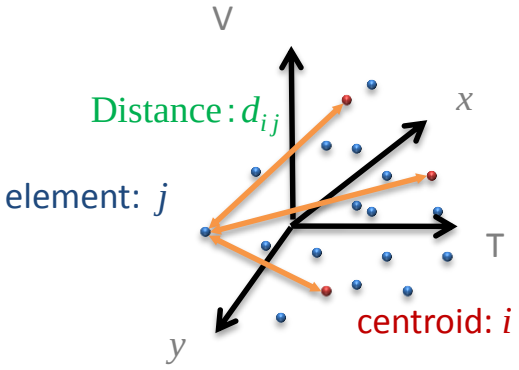
Non-hierarchical and Hierarchical Hybrid Cluster Analysis




Initial centroids
(10)
(15)
(9)
(14)
(7)
(12)
(5)
(13)
(11)
(3)
(4)
(2)
(8)
(0)
(1)
(6)

Extraction the Ocean Currents using Hierarchical method

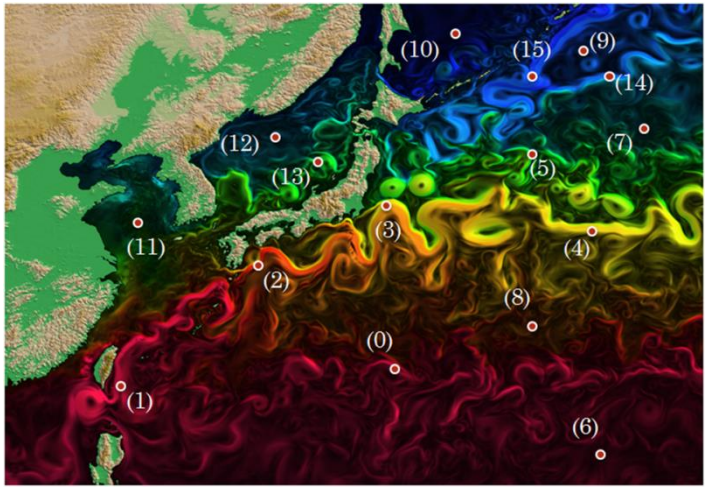
- Algorithm
  - Choose *k* centroids (center of the clusters)
  - Calculate the similarity between all centroids and all elements
  - Assign all elements to clusters with maxime similarity

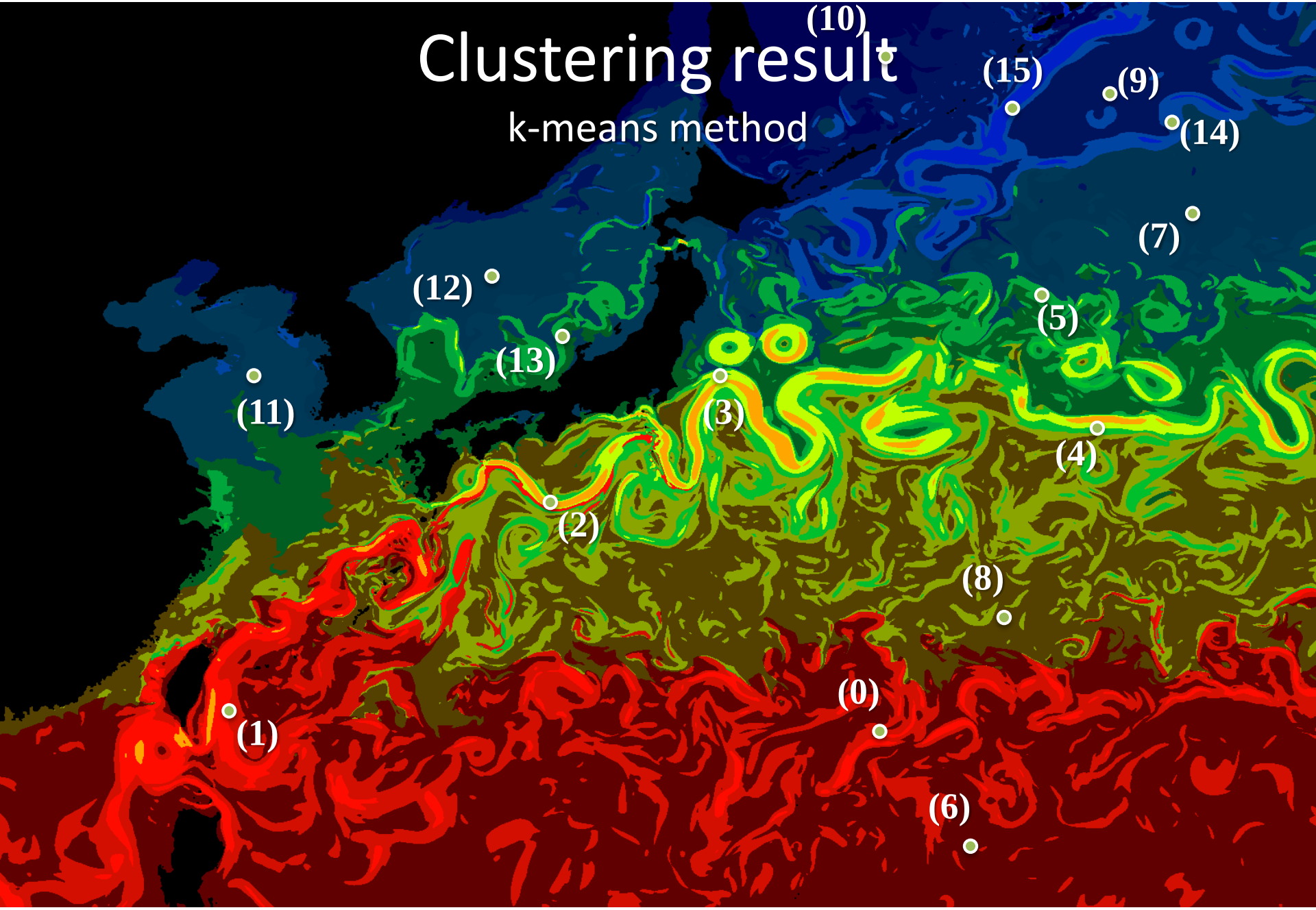


Similarity (reciprocal number of Euclidian distance)

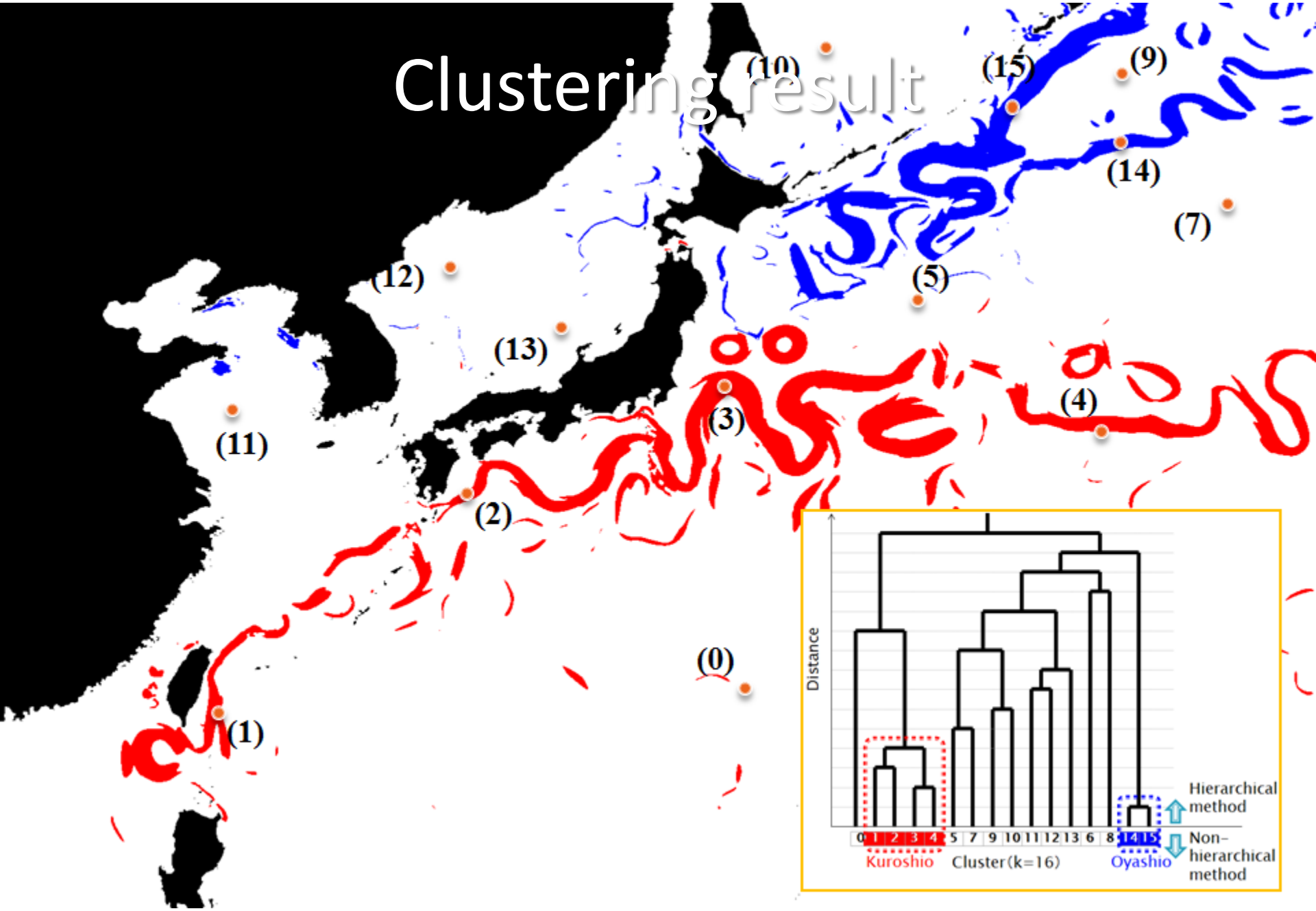
$$d_{ij} = [C_T(T_i - T_j)^2 + C_V(V_i - V_j)^2 + C_X(x_i - x_j)^2 + C_Y(y_i - y_j)^2]^{1/2}$$

- Definition of the similarity
  - Temperature, speed, x and y
  - Similarity is defined as the “euclid distance” in variable space




Clustering result
k-means method
(10)
(15)
(9)
(14)
(7)
(12)
(5)
(13)
(11)
(3)
(4)
(2)
(8)
(0)
(1)
(6)

Clustering result

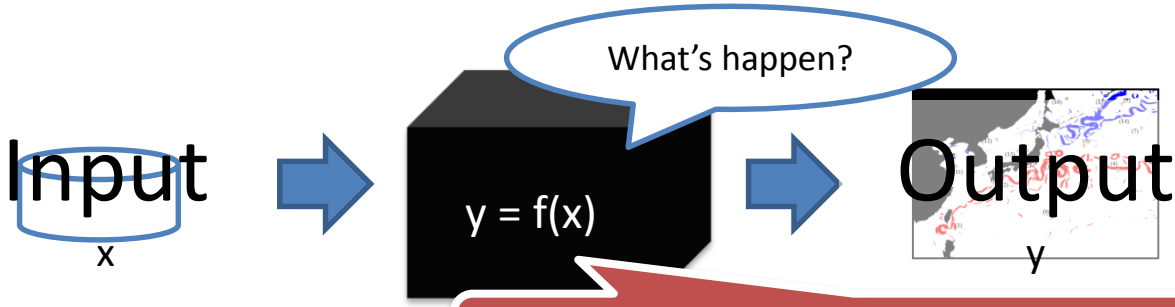


多変量データの視覚的解析
-海流の抽出と可視化-

Matsuoka et al., "Multiple Scatter Plots based Multi-Dimensional Transfer Function for Visualizing Ocean Simulation Data", *Communications in Computer and Information Science*, Vol. 474, pp. 187-200, 2014

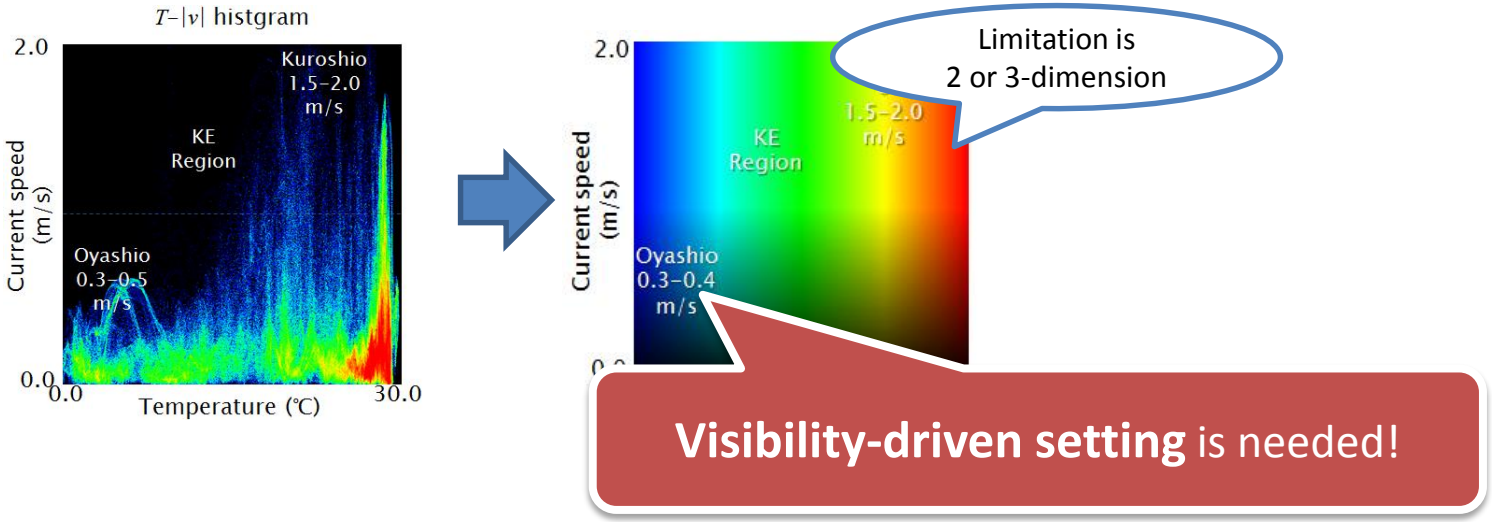
Objective of multivariate visualization

- Feature extraction from multivariate dataset



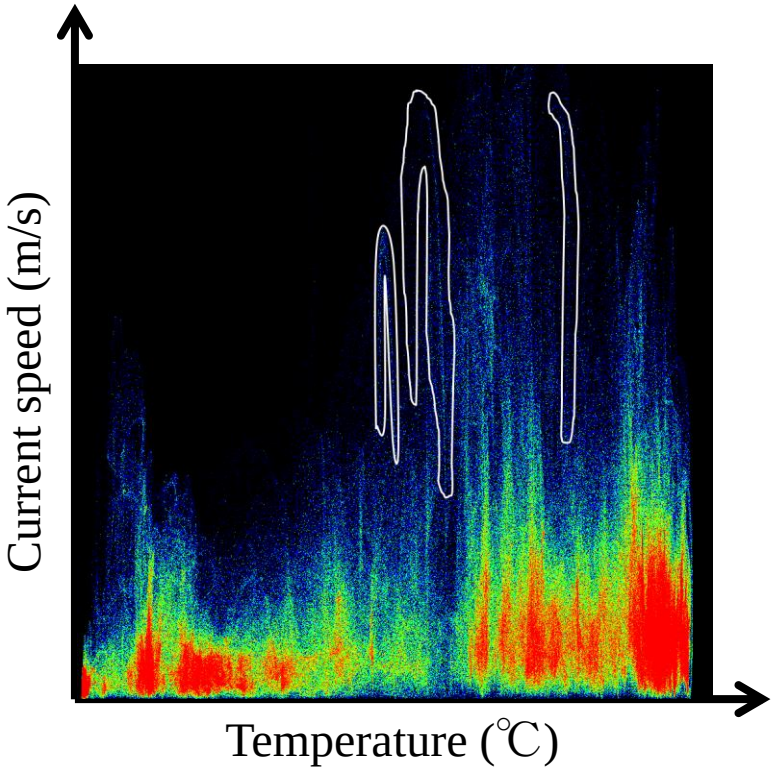
Visibility-driven extraction is needed!

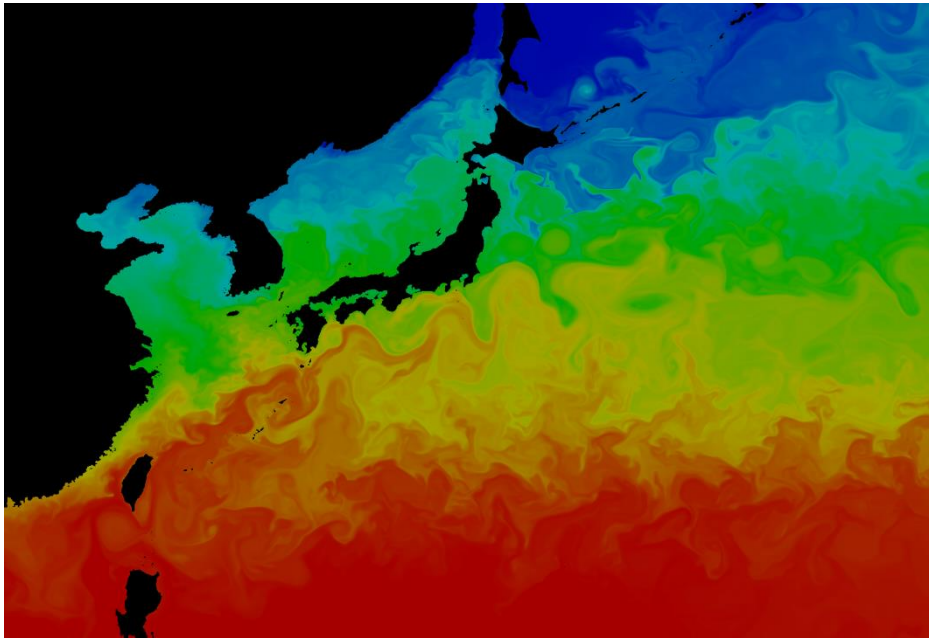
- Representation of multivariate dataset



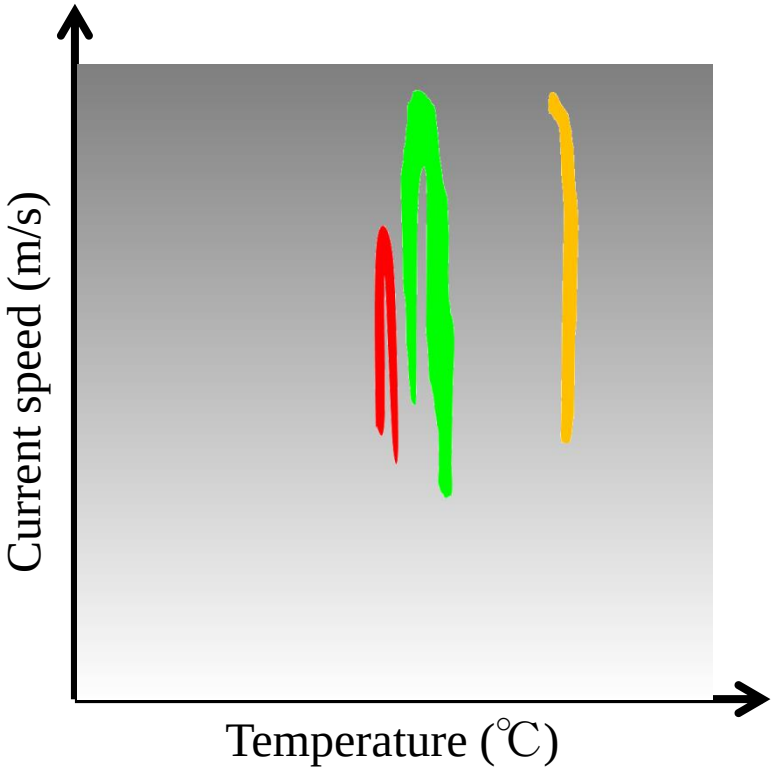
Visibility-driven setting is needed!

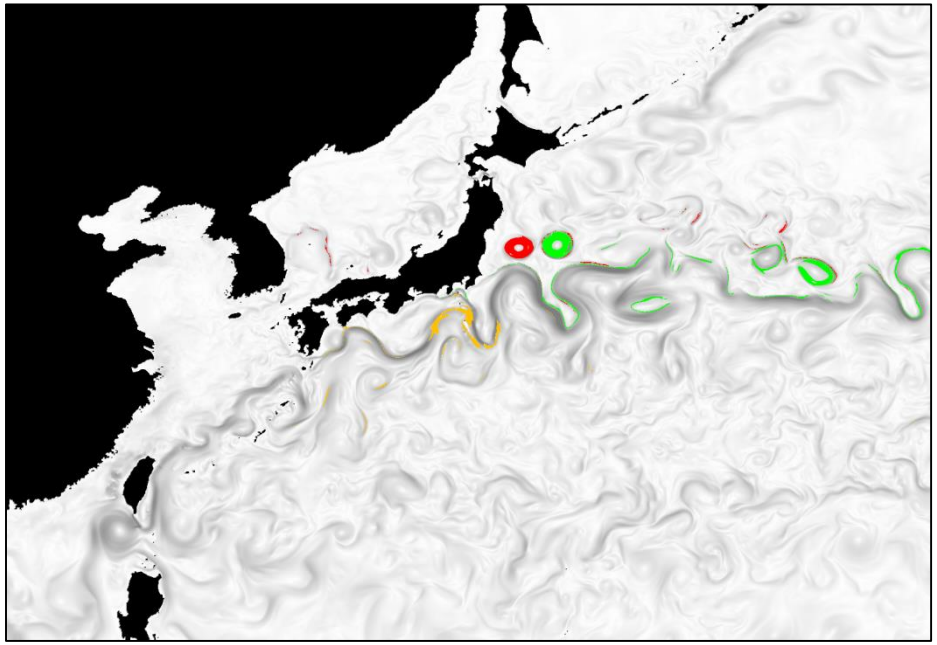
Feature extraction from 2D scatter plot





Feature extraction from 2D scatter plot

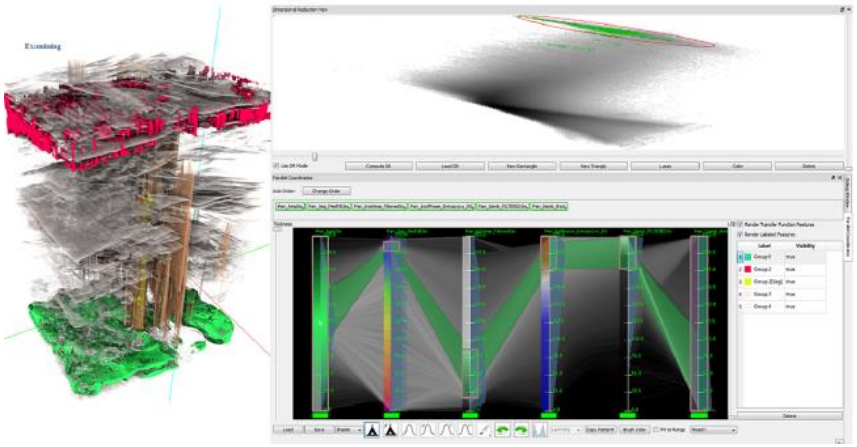




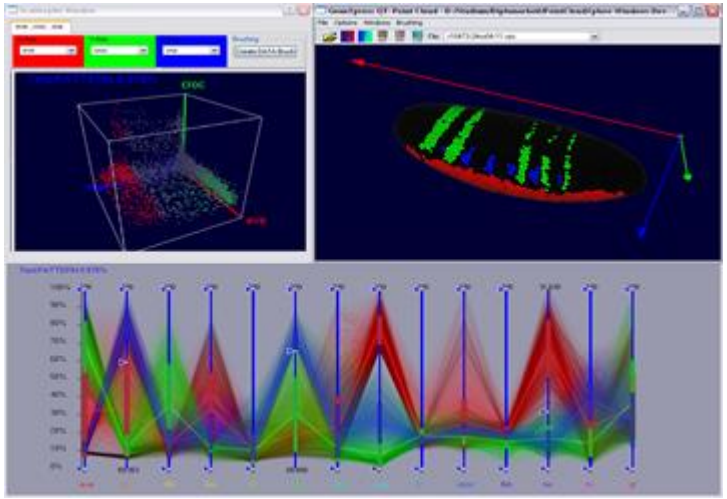
Related work

-Visual feature extraction-

Linked view system



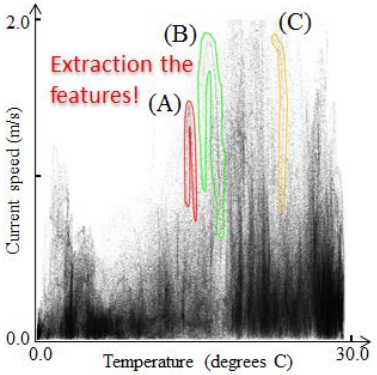
Zhou et al., 2013



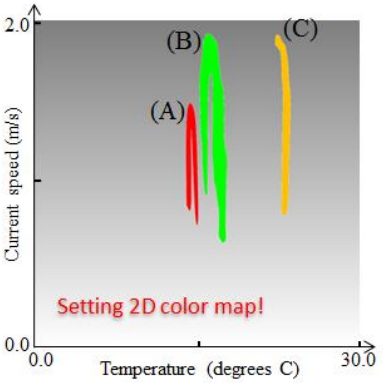
Rübel et al., 2006

Application to ocean data

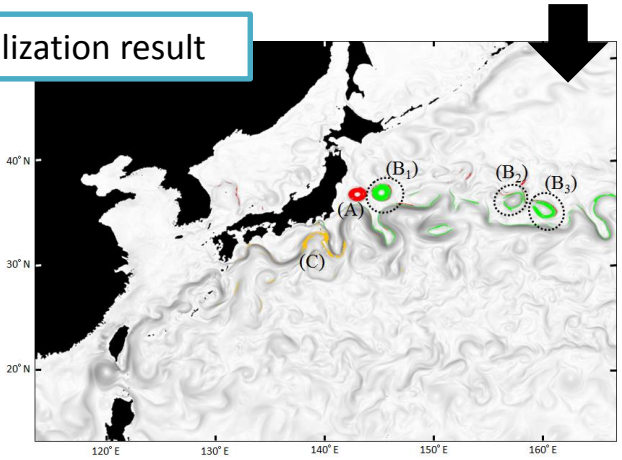
2D scatter plot



2D Transfer function



Visualization result

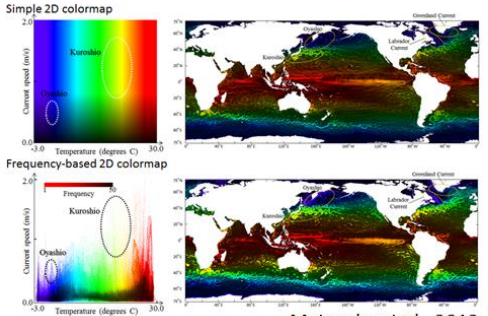


Matsuoka et al., submitted

Related work

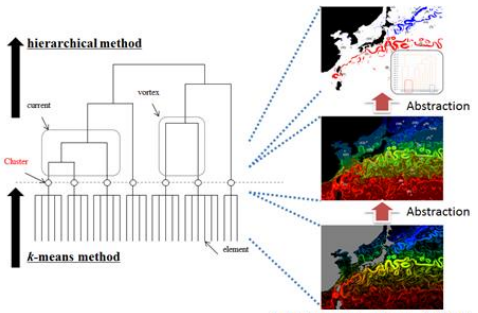
-Advantages and disadvantages-

- Multi-dimensional transfer function
  - can represent multivariable effectively
  - can not analyze the correlation



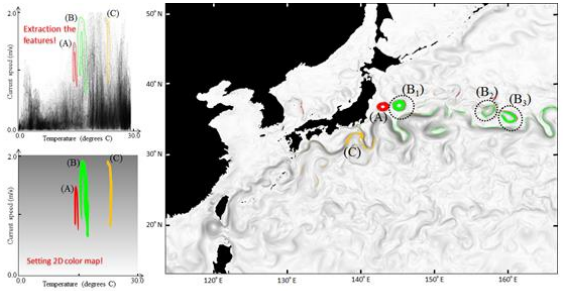
Matsuoka et al., 2012

- Multivariate analysis
  - analyze the correlation
  - validation is difficult



Matsuoka et al., 2012

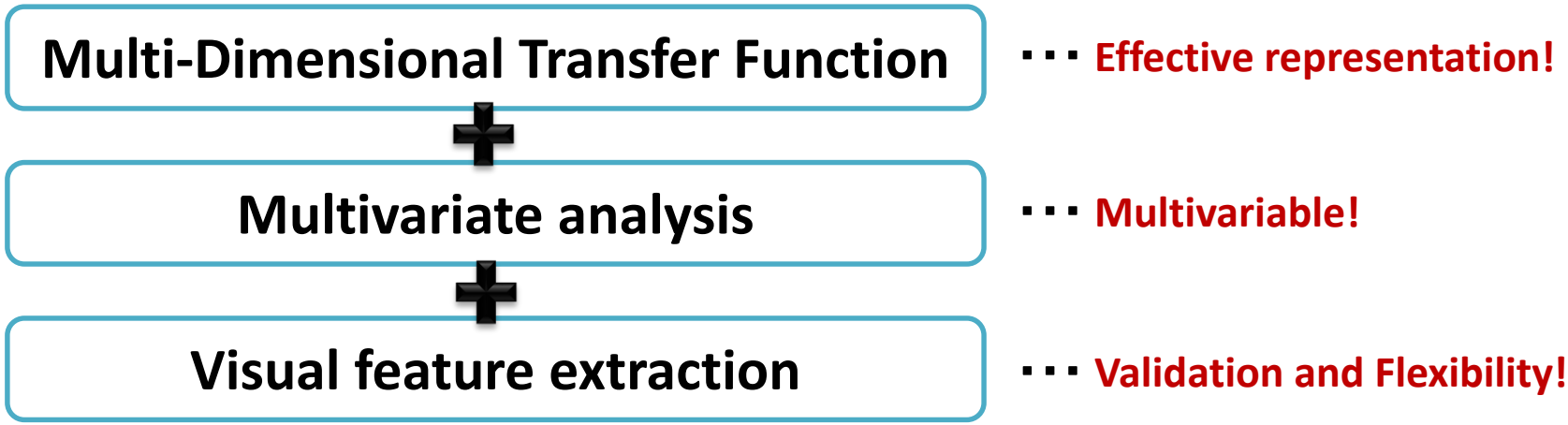
- Visual feature extraction
  - good validation, good flexibility
  - representation of multivariable



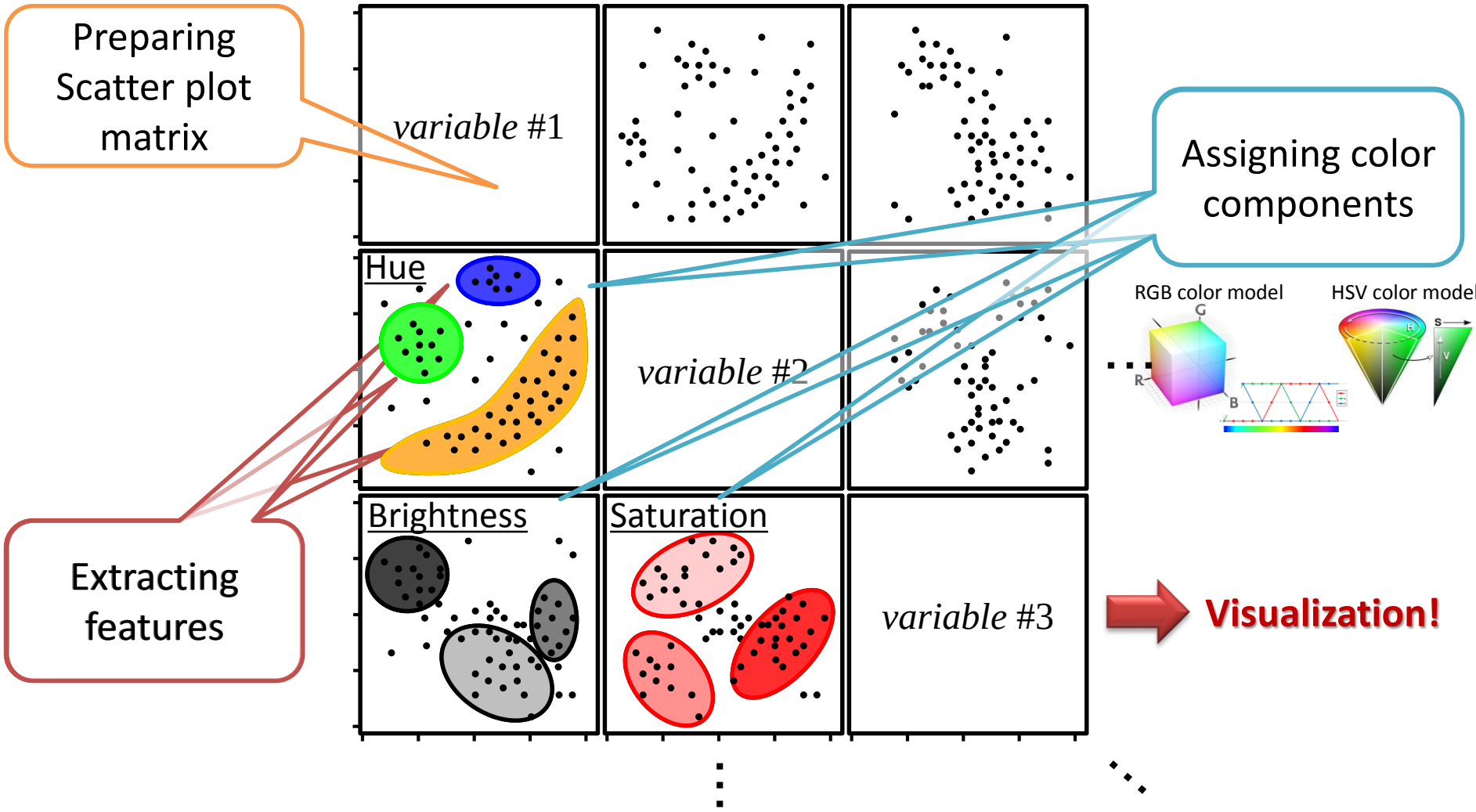
Matsuoka et al., submitted

Method

- **A new feature extraction and visualization method for ocean data**
  - to extract the structures from multivariate data
  - to represent their multiple physical properties

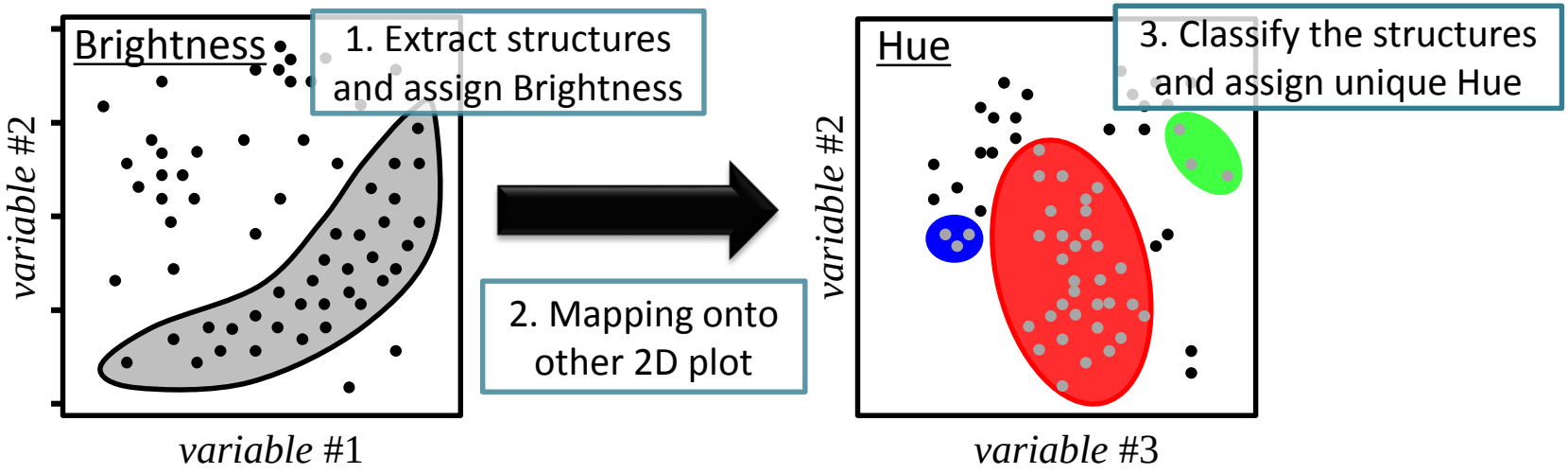


Scatter Plot Matrix based Multi-Dimensional Transfer Function

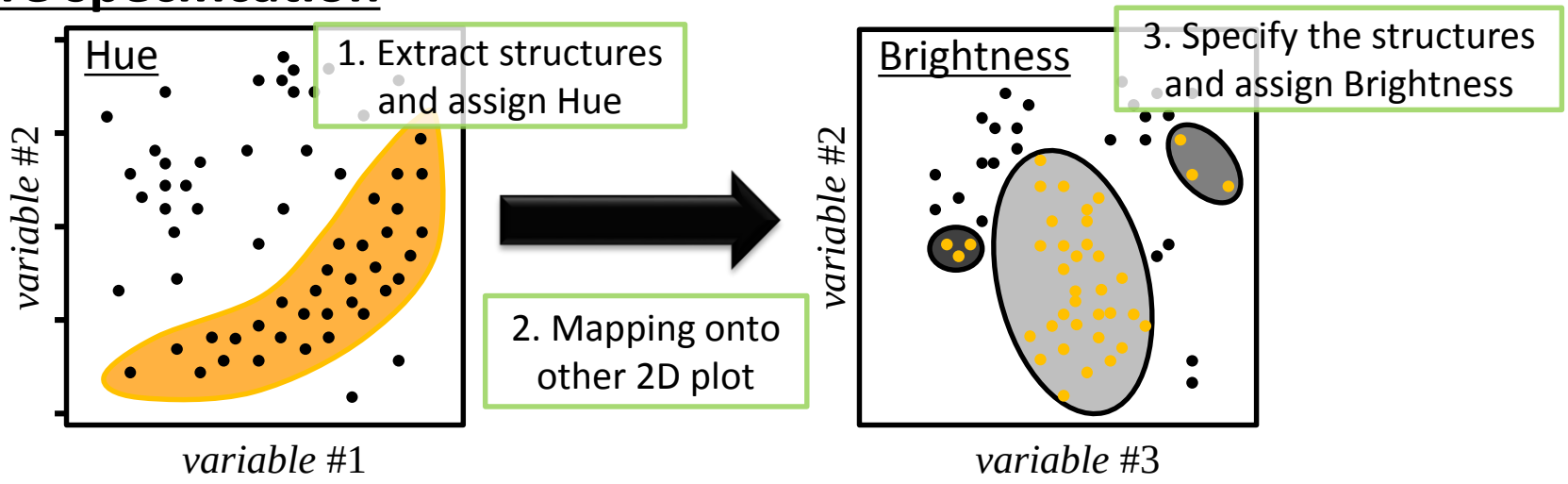


Function of proposed method

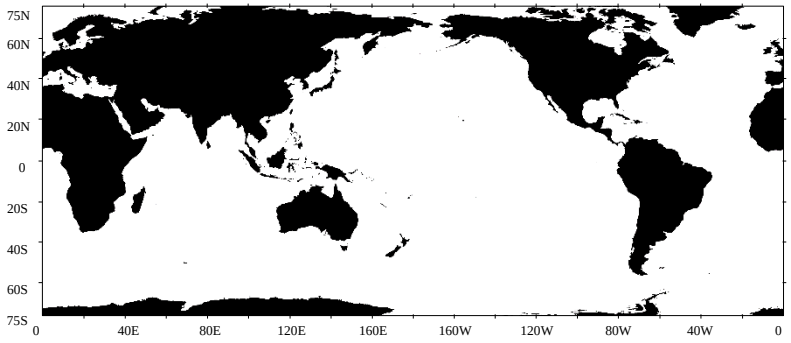
Feature classification



Feature specification



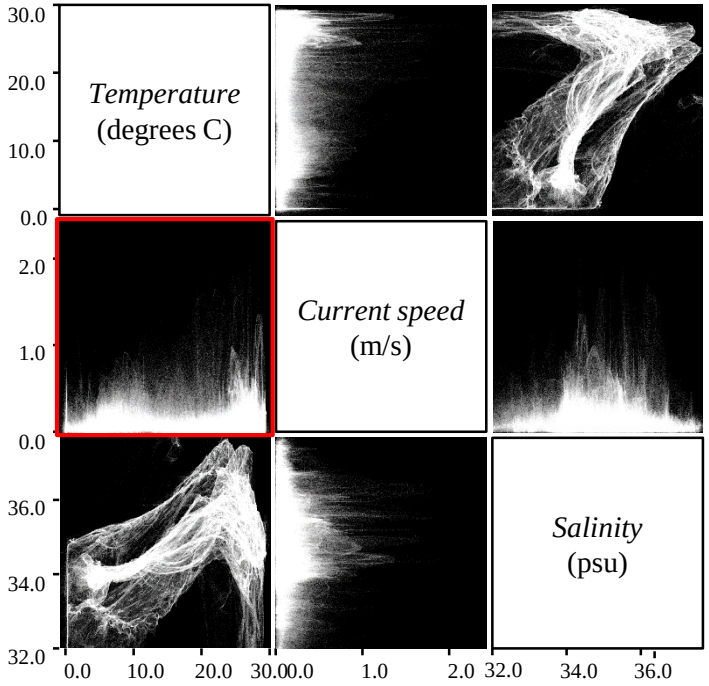
Application of "Feature Classification" to Global Data



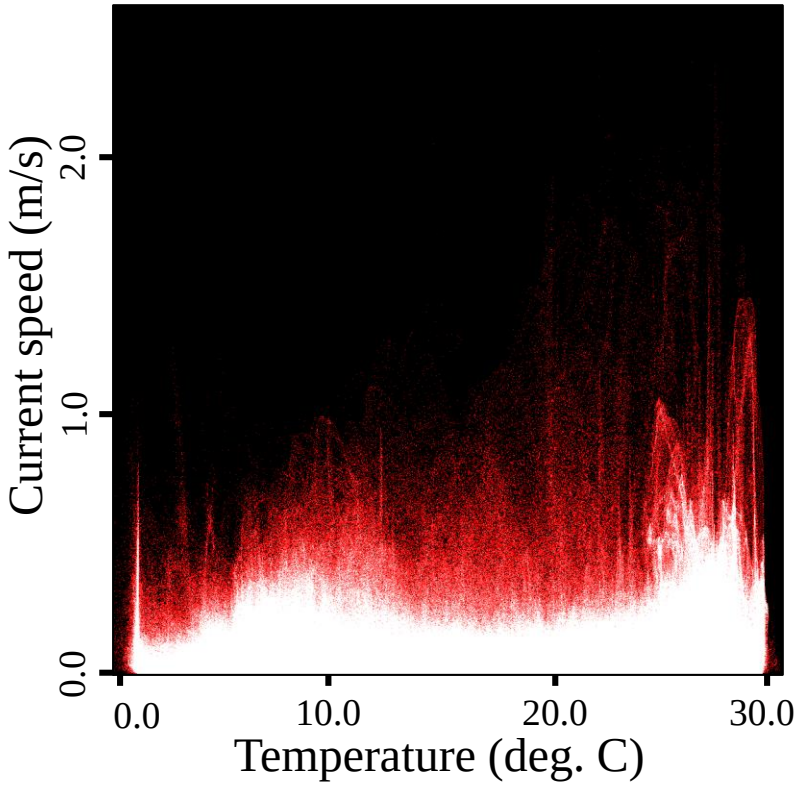
Result

-Application of feature classification-

Step. 0 Preparing scatter plot matrix



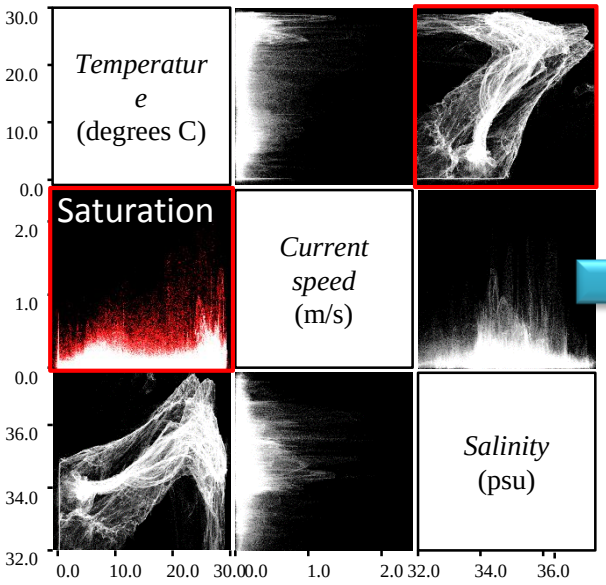
Step. 1 Setting color (Saturation) on *V*-*T* space



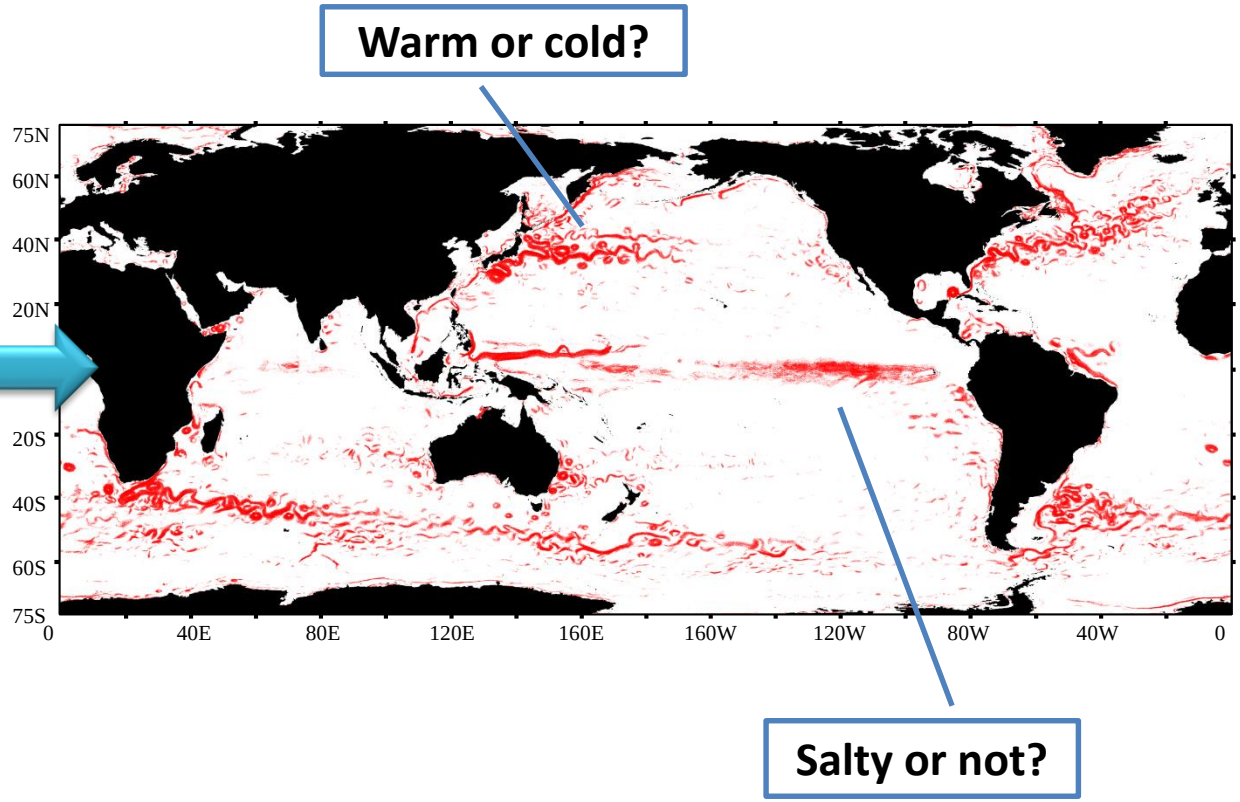
Result

-Application of feature classification-

Step. 2 Visualization using 2D Transfer function (**Saturation**)



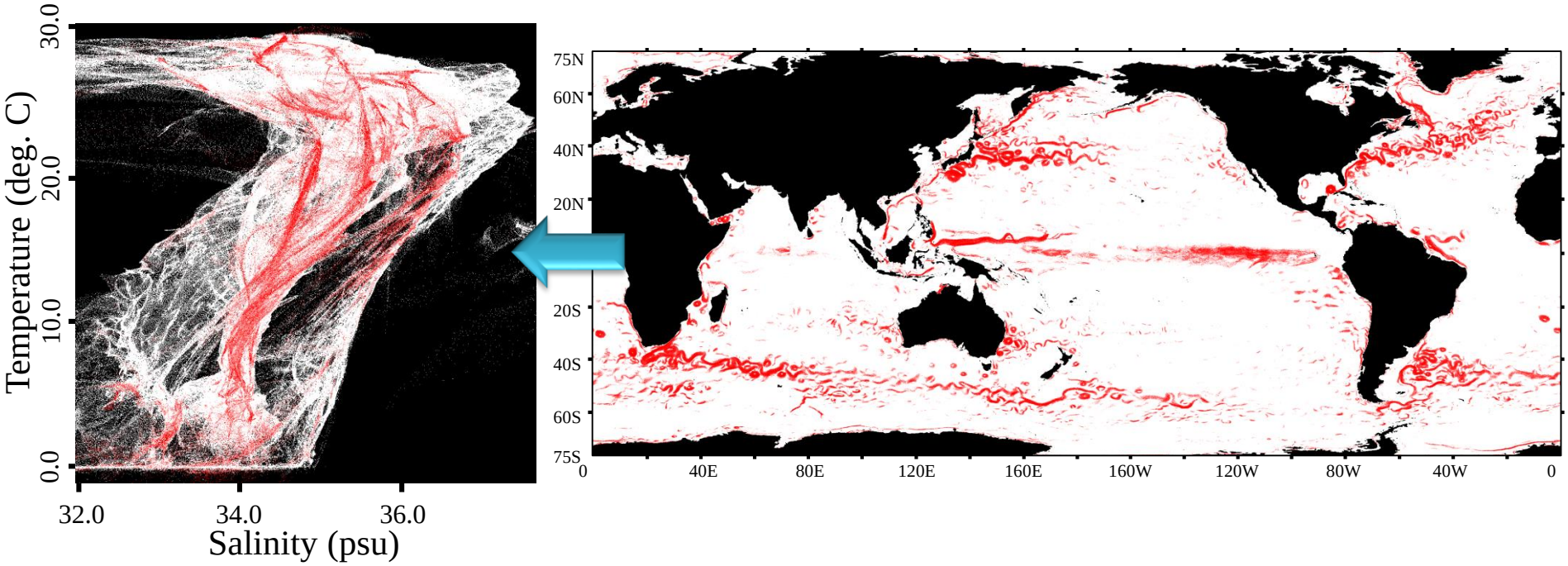
Hue = Red
Brightness = MAX



Result

-Application of feature classification-

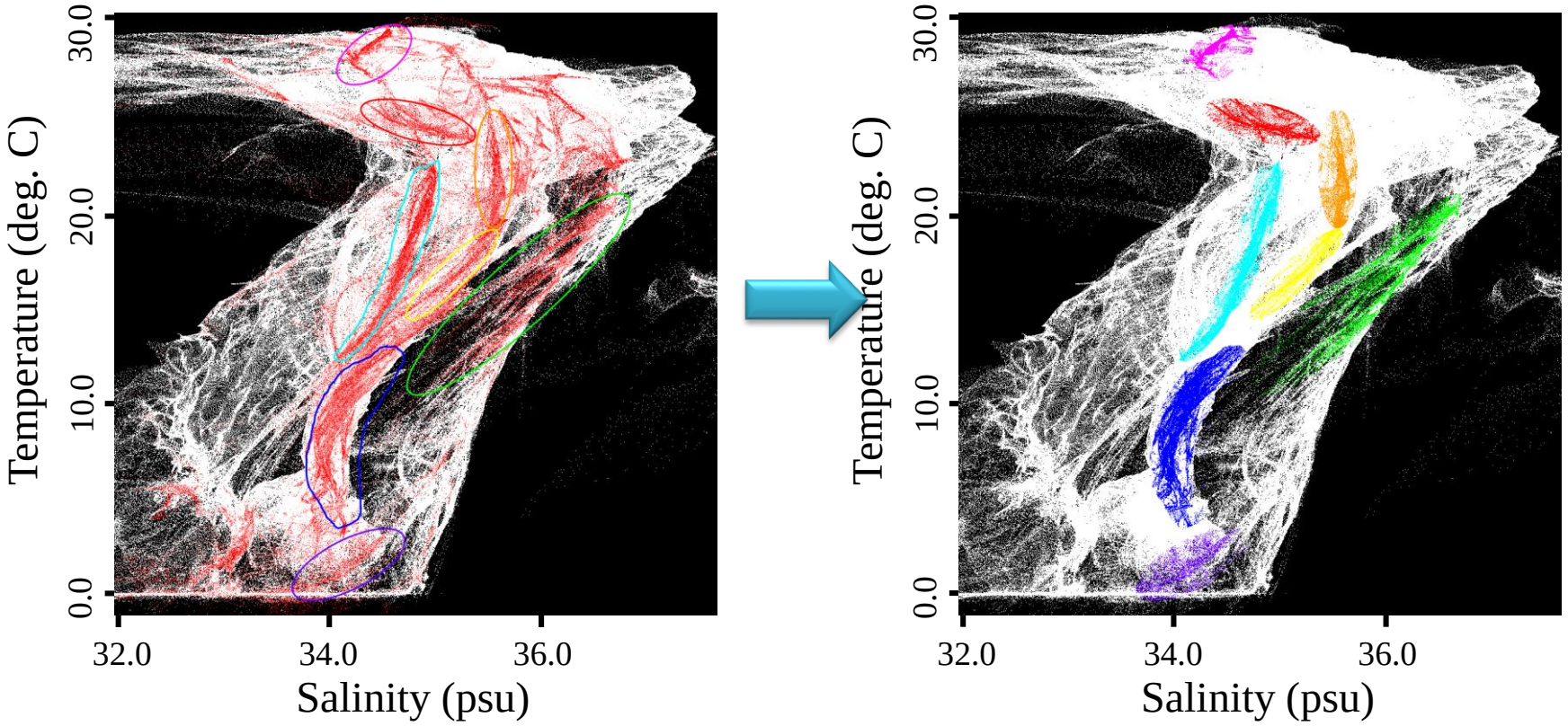
Step. 3 Mapping onto *T*-*S* space



Result

-Application of feature classification-

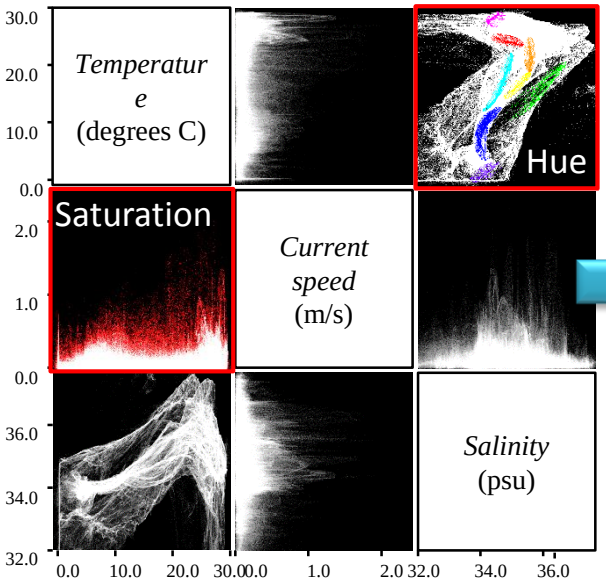
Step. 4 Setting 2D transfer function (**Hue**) on *T-S* space

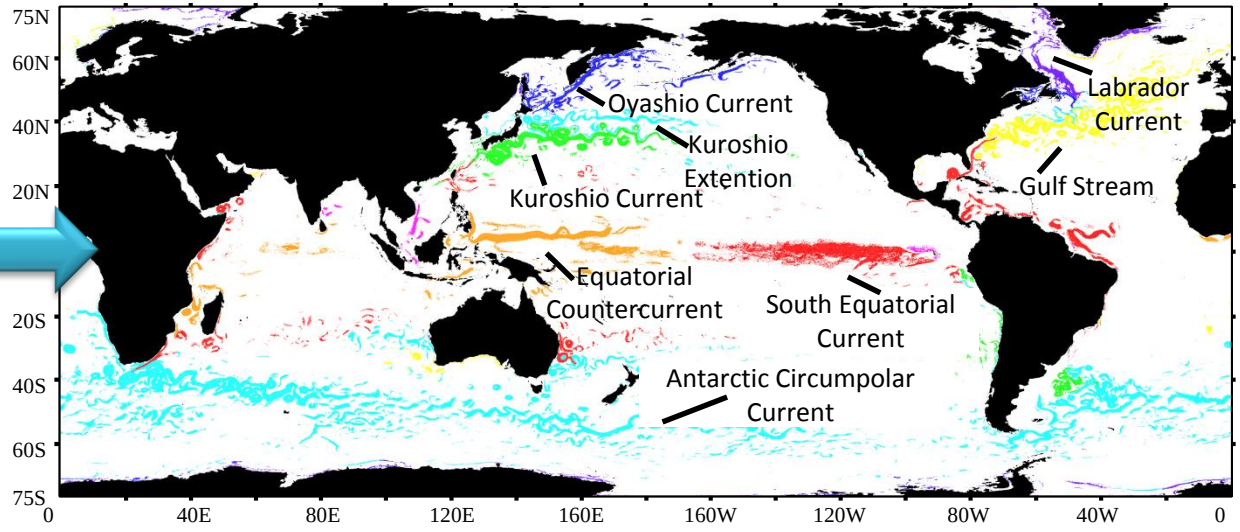


Result

-Application of feature classification-

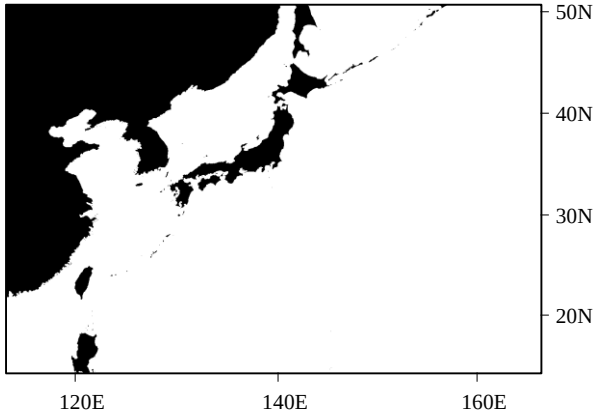
Step. 5 Visualization using 2D Transfer function (**Saturation** and **Hue**)





Brightness = MAX

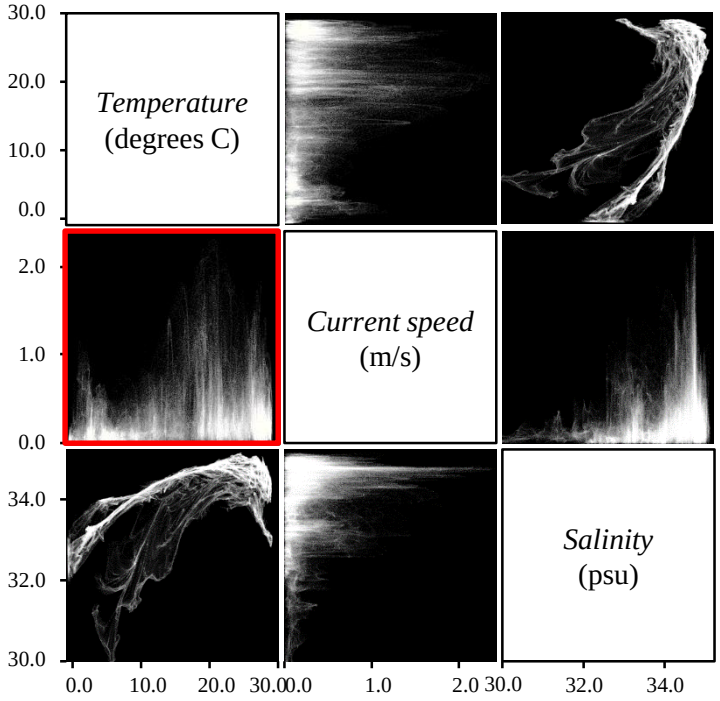
Application of
"Feature Specification"
to Regional Data



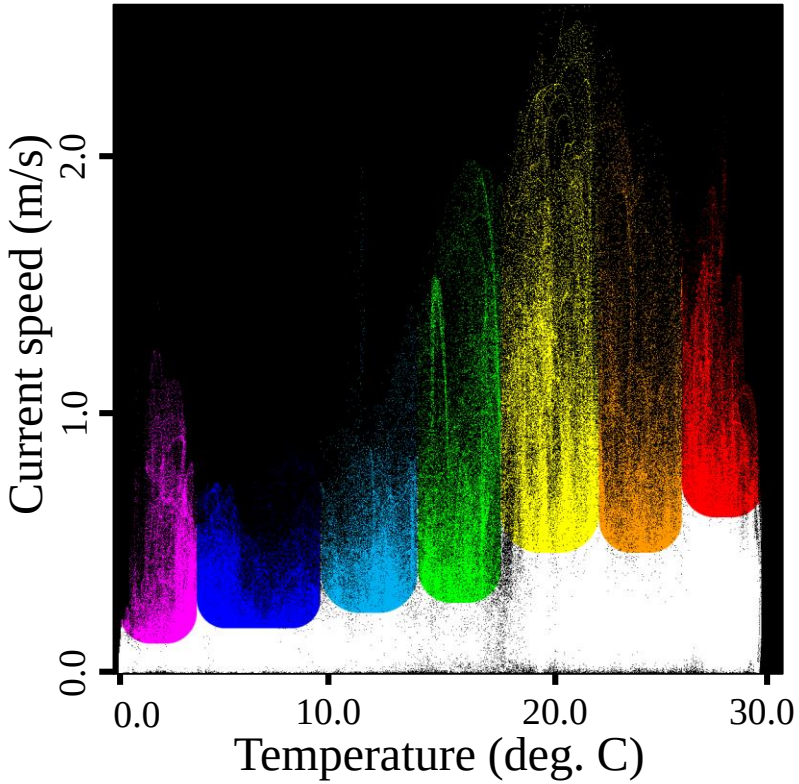
Result

-Application of feature specification-

Step. 0 Preparing scatter plot matrix



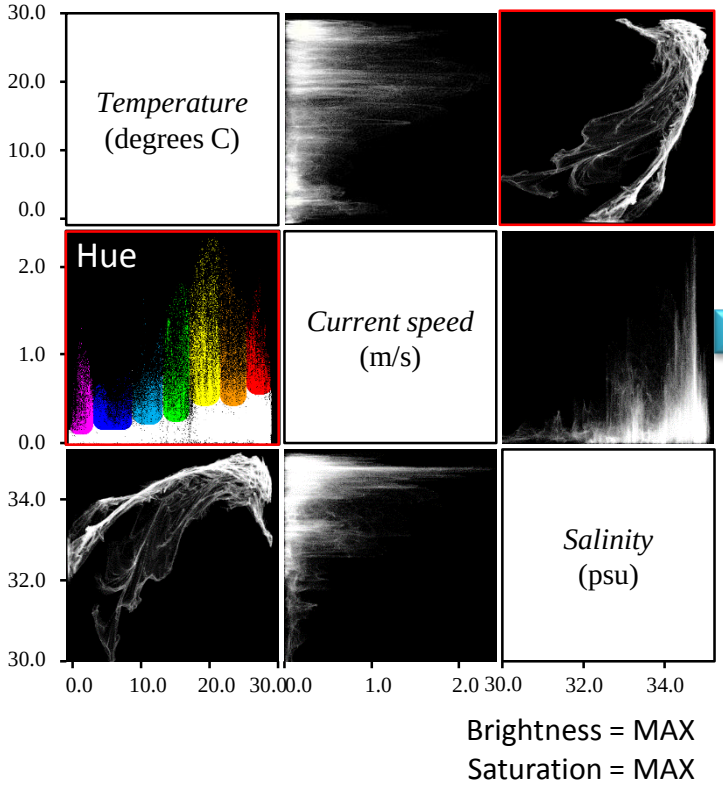
Step. 1 Setting 2D color map (Hue) on *V*-*T* space

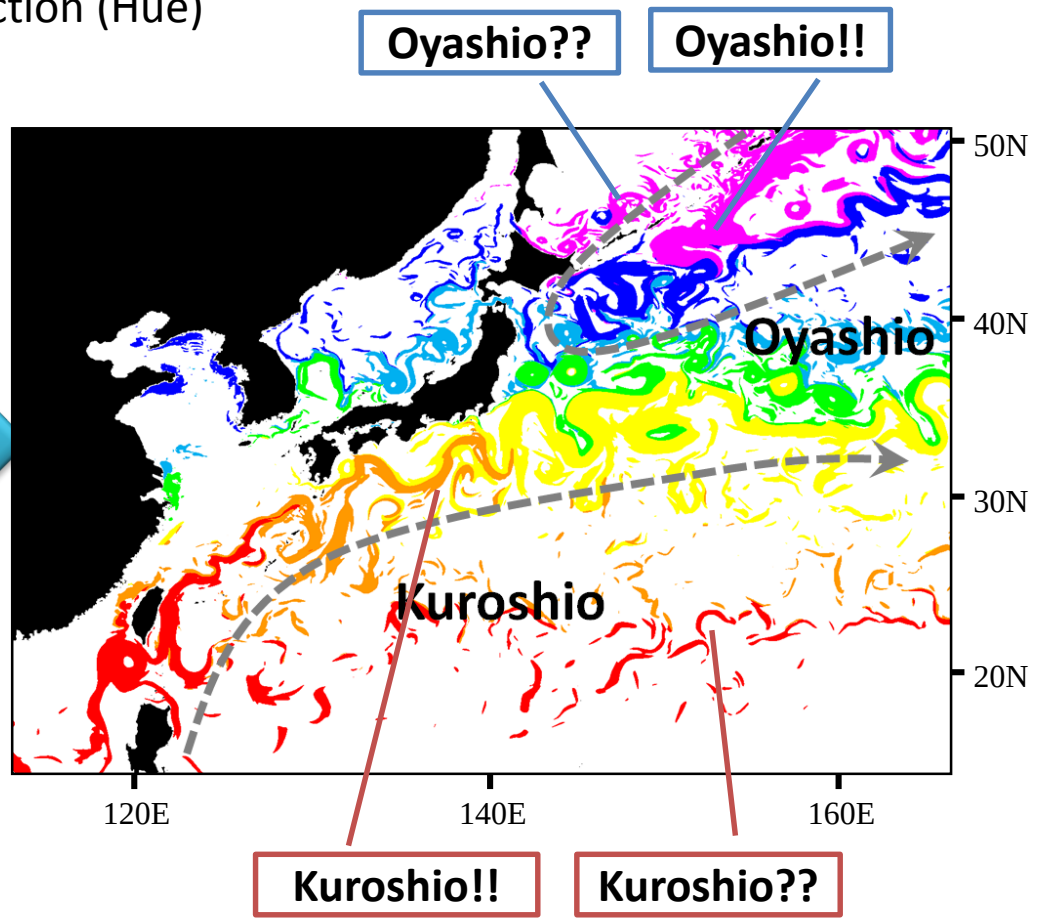


Result

-Application of feature specification-

Step. 2 Visualization using 2D Transfer function (Hue)

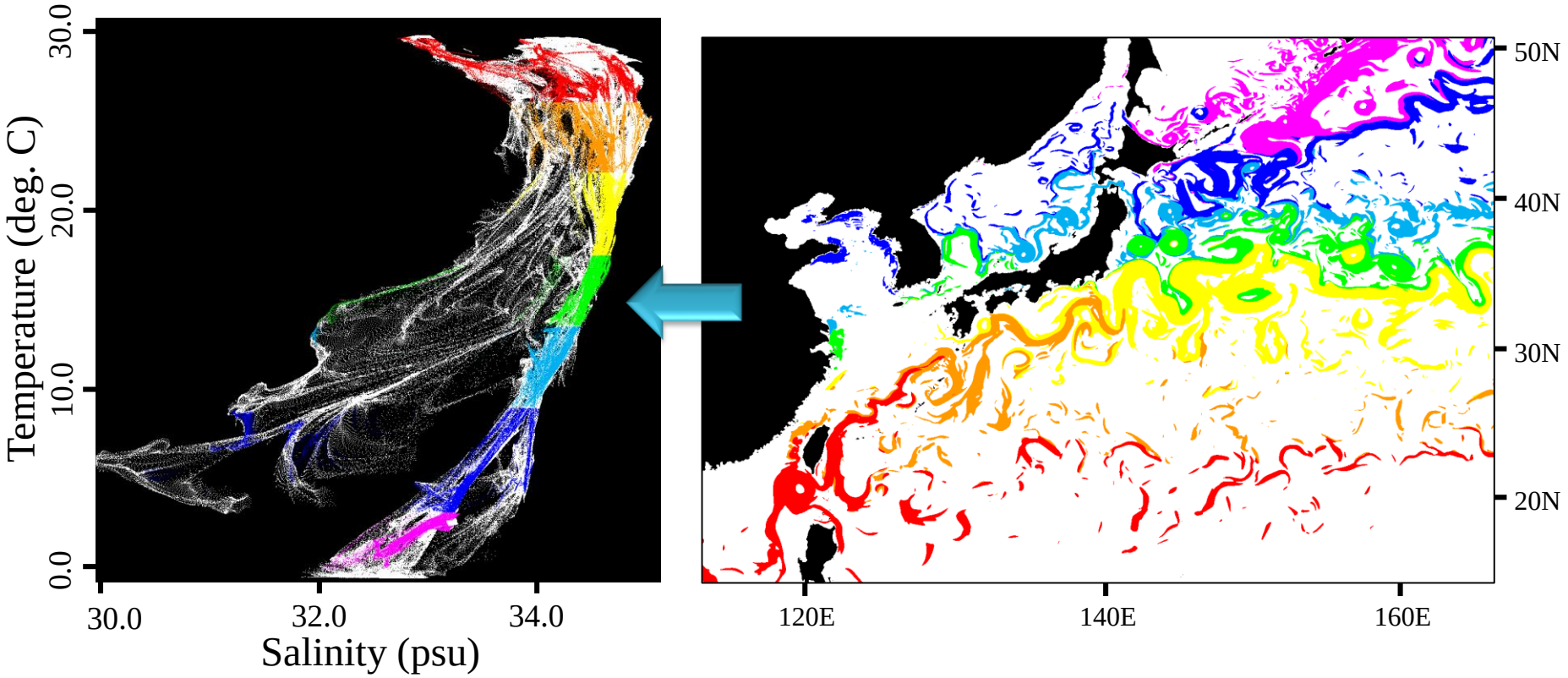




Result

-Application of feature specification-

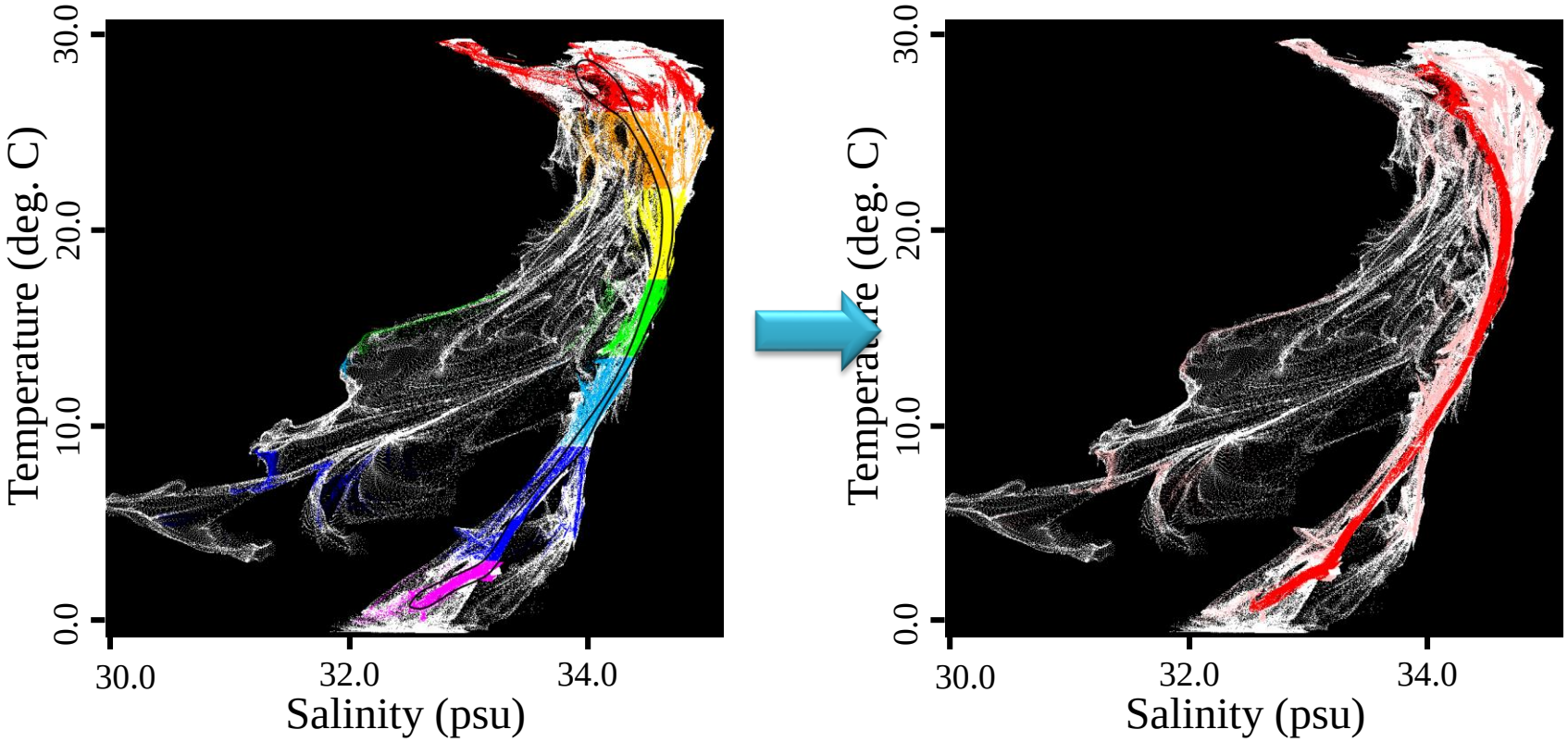
Step. 3 Mapping onto *T*-*S* space



Result

-Application of feature specification-

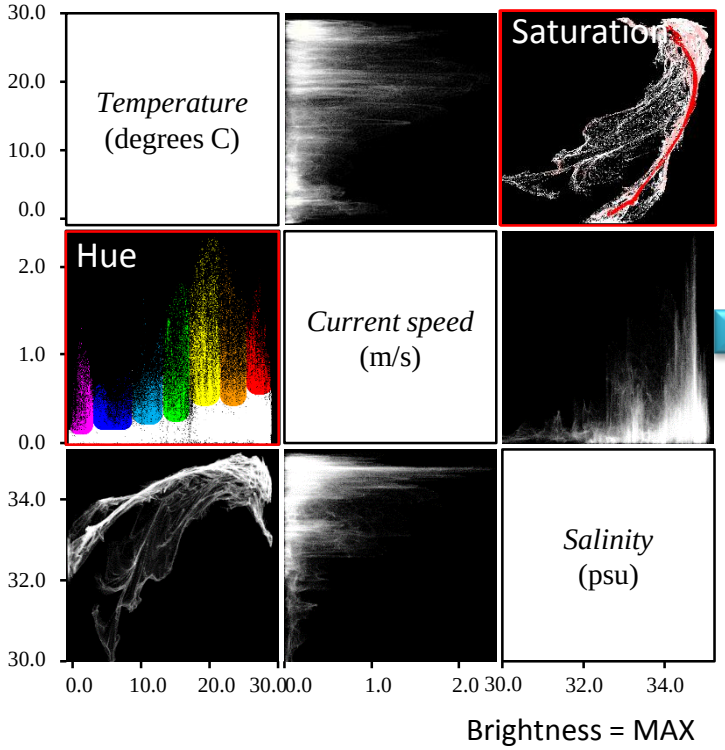
Step. 4 Setting color (Saturation) on *T-S* space

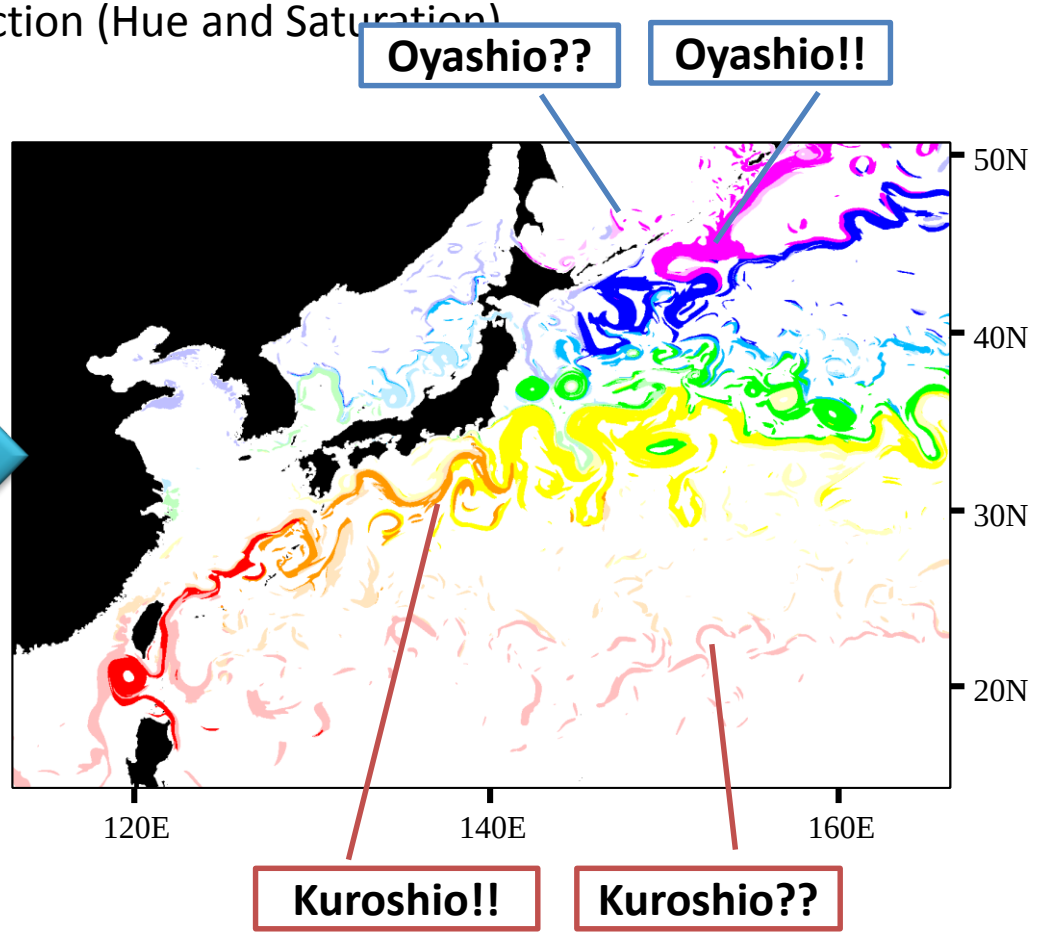


Result

-Application of feature specification-

Step. 5 Visualization using 2D Transfer function (Hue and Saturation)

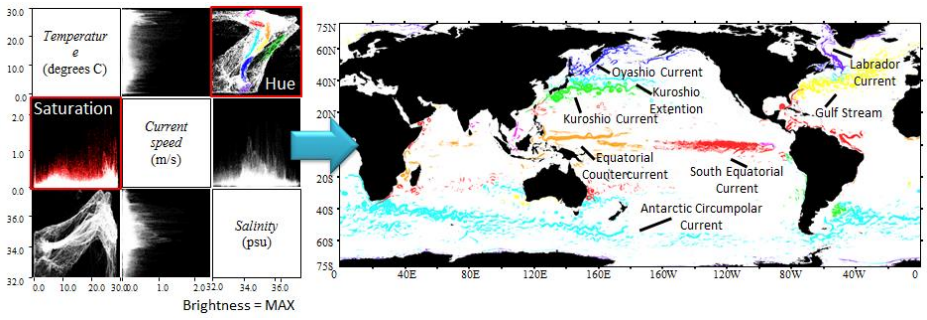




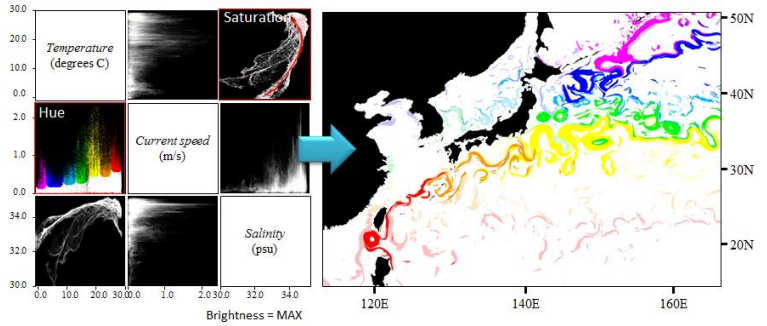
Summary and discussion

- Summary
  - Multiple scatter plot based multi-dimensional transfer function is proposed
  - Application to visualizing ocean currents and their multiple physical properties
  - Good results are obtained in two case studies

Feature classification



Feature specification



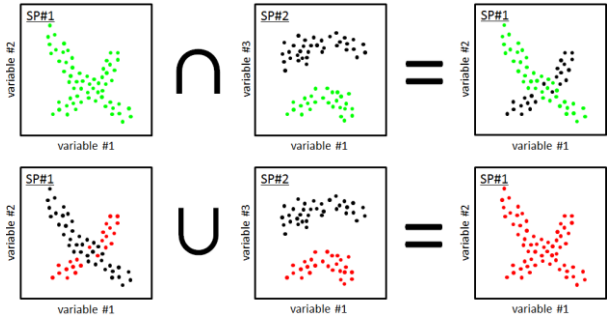
Effective representation **Multivariable** **Easy Validation and Good Flexibility!**

Summary and discussion

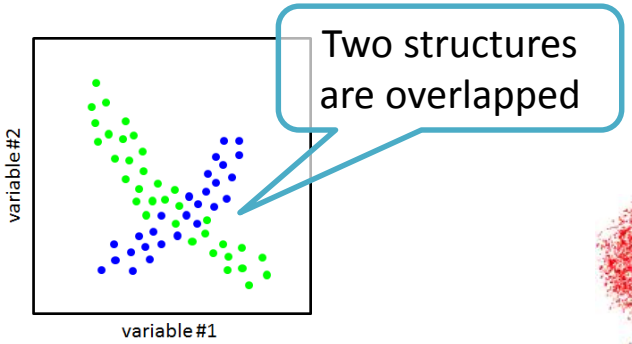
- Discussion
  - About the limitation of number of physical variables (depend on the number of color components = 3)

Application of Logical operation

- Logical conjunction (**AND**)
- Logical disjunction (**OR**)
- Negation (**NOT**)

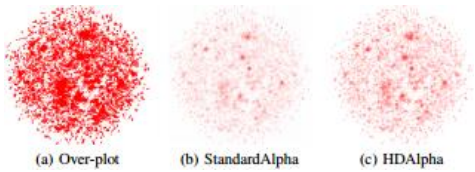


  - About data representation

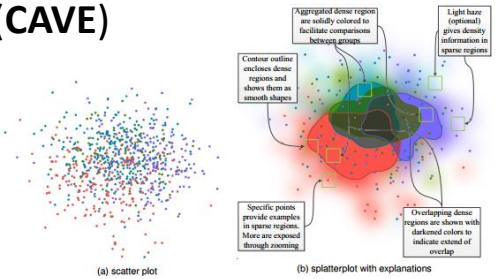


Application of Big data visualization

- Advanced **InfoVis** techniques
- Virtual reality system (**CAVE**)



Cottam et al. 2013



Mayorga et al. 2014