Application of Cluster Analysis to GNSS Data in the Angular Velocity Space: Identification of Crustal Blocks and Evaluation of Plate Interaction

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The motion of a rigid plate on a sphere is expressed as rotation around an axis that passes through the center of the earth. Recently, statistical approaches were proposed to identify boundaries of crustal blocks from observed GNSS data. Simpson et al. (2012) showed that through a cluster analysis of GNSS data, block boundaries can be distinguished objectively. Savage and Simpson (2013) extended the study by adding an iterative algorithm to take account of the effect of spherical geometry. These studies successfully showed a way to identify block structures in the West Coast of the U.S.
However, it is still difficult to apply the method to global GNSS data in order to identify plate blocks considering the effect of spherical geometry. So, we developed a more intuitive method to tackle this problem.
The relationship among the geographical location of the GNSS station, observed velocity at the GNSS station, and candidates of the Euler pole can be expressed as a vector equation: the cross product of an angular velocity vector and a position vector of a GNSS station is an observed velocity vector.
From this relationship, candidates of the Euler pole can be expressed as a straight line in the angular velocity space. We can expect that each line that correspond to each GNSS data in the same rigid crustal block crosses at a point in the angular velocity space.
To spot a crossing point, we made a matrix whose components correspond to the distance between lines. In order to find a structure in the matrix, we analyzed this matrix using a clustering algorithm called a Bayesian Community Detection model. The method provides a block matrix structure within it for a given threshold. By this analysis, we can spot the candidates of Euler poles as a crossing point based on the distances of lines in the angular velocity space. Each identified crossing point would represent a cluster, namely a crustal block.
However, an actual crustal block has internal deformation in it. So, we considered how such deformation affect the deviation of the lines from their original crossing point. We first analyzed the same data set of Simpson et al. (2012) in the San Francisco Bay Area, West Coast of U.S. for comparison.
The obtained result had four major crossing points, which was almost the same as Simpson et al. (2012). However, if we gave a smaller threshold, we obtained 16 minor clusters which reflect internal deformation of crustal blocks. The minor crossing points almost aligns on a straight line that connects the major crossing points.
These minor crossing points can be attributed to the effect of coupling on the faults that bound major blocks in this area. If there is some coupling on such faults, crustal movement must systematically deviate from the rigid block rotation due to internal elastic deformation caused by fault coupling. In other words, we can extract information about fault coupling from this clustering analysis.

A self-organizing map exploratory analysis of the flow duration curve in the United States

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The flow duration curve (FDC) describes the full range of streamflow magnitude observed at a site, and is strongly influenced by upstream conditions of the basin. Upstream conditions are quantified using basin characteristics, such as mean elevation and annual precipitation. A large variety of data now exists to characterize basins in the United States (US). However, a greater understanding of how this data relates to the FDC is critical, considering basin characteristics are typically the basis for predicting the FDC of ungauged basins. The present study performs an exploratory analysis of the FDC and characteristics of 918 basins in the US using a neural network technique called the self-organizing map (SOM). The SOM is applied for its ability to cluster and visualize fine-scale variation in large datasets. Both of these exploratory frameworks (i.e. clustering and visualization) are used to compare individual flows of the FDC to basin characteristics. Clusters based on common basin characteristics poorly agree with those of the FDC (36% agreement), which is less than prior work in smaller study areas, such as Italy. This is an important point because clusters based on basin characteristics are used to deploy models for predicting the FDC. Basin characteristics primarily cluster basins into geographic regions, whereas the FDC generates clusters of basins distributed throughout the US. Geographic proximity therefore may not be an indicator of similarity in the FDC between basins. Variation of the FDC is also unrelated to some common basin characteristics, such as topographic variables, as indicated through SOM data visualizations. This may partially explain the disagreement between the two sets of clusters. The disagreement may also be because basin characteristics are only associated with certain parts of the FDC, but not the overall FDC. For instance, aridity, an index of precipitation lost to evapotranspiration, suppresses high flows possibly due to lower antecedent moisture conditions that moderate storm flows. High flows are also related to spring snowmelt represented using the percent of precipitation delivered as snow. Another association to a part of the FDC is that average to low flows vary with groundwater contributions (i.e. baseflow). Basin characteristics describing surface runoff are more related to high flows, whereas subsurface drainage has more influence on average to low flows. The processes that generate different flows should be accounted for in the clusters used to predict the FDC, and future research should evaluate if the tradition of using a single set of basin characteristics to cluster basins for predicting the FDC should be revised to select different basin characteristics depending on the flow targeted for prediction.

Keywords: basin hydrology, flow duration curve, self-organizing map, cluster analysis, data visualization, United States

Uncertainty quantification for groundwater management in the Danish buried valley systems by means of regression tree-based surrogate models

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Uncertainty quantification is a key component for decision making in groundwater management. Such applications involve the building of large complex spatial models, the application of computationally intensive forward modeling codes and the integration of heterogeneous sources of uncertainty.
An integral step for uncertainty quantification is to condition models to a variety of data. In the Danish groundwater management this consists of head, streamflow, recharge, well and geophysical (SkyTEM) data. Uncertainty quantification requires model calibration. This is a challenging problem when dealing with complex systems (such as the Danish buried valley system) and a wealth of data. Another difficulty is computational cost, since a proper model calibration should account for all data, all model variables and geological heterogeneity requires running many forward flow models.
In this research, a workflow is proposed to find posterior multivariate distribution of model parameters and predictions. First, dimensionality reduction with mixed principle component analysis (PCA) is performed to incorporate different types of available data. A regression model is built for uncertain model parameters and misfit between simulated and observed data. As a regression model, we use a boosted regression tree because it offers high quality predictive model in nonlinear problems. Another advantage of tree-based approach is that we can obtain predictor importance, which can be directly used in sensitivity analysis.
Models that match the data are found by Approximate Bayesian Computations (ABC), where the likelihood is simply an indicator function of data mismatch. ABC requires exhaustive Monte Carlo sampling and running forward models. By using the regression model as surrogate forward model, we can obtain models conditioned to the data without intensive full forward runs. Regression models can also be constructed for predictions, such as the effect of establishing new wells for extraction.
We illustrate our method using a real field problem of decision making in the Danish groundwater system. Decisions include where to relocate drinking wells while minimizing the change of water produced and effects on farms and industrial areas. Well head and stream data are observed from monitoring wells. The proposed workflow is used to understand the effect of each parameter and to obtain the posterior distribution of 20 forecasts with newly acquired data.

Keywords: uncertainty quantification, regression analysis, model calibration, groundwater management

Multivariate analysis of visible to near-infrared reflectance spectra of meteorites and asteroids

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Asteroids and meteorites have been considered as remnants of the early evolution of the solar system and understanding their formation history provide constraints on the physical and chemical conditions of the solar nebula and its subsequent evolution [1]. In order to better understand the compositions of asteroids, mineralogical relationship between asteroids and meteorites have been studied based on reflectance spectra obtained by ground- and space-based telescope [2]. Their relationship, however, remains poorly constrained except for a S-type asteroid Itokawa and LL chondrites [3]. Although spectral similarities have been suggested between V-type asteroids and HED meteorites and between carbonaceous chondrites and C- and/or D-type asteroids, detailed relationship is not well constrained. The major obstacle to compare asteroids and meteorites is that the classification scheme between asteroids and meteorites are fundamentally different. Asteroids are classified mainly based on the shape of their reflectance spectra and orbital parameters [4], while meteorites are classified by detailed petrology and mineralogy [5]. Based on principal component analysis, Britt et al. (1992) [6] compare reflectance spectra of asteroids with those of meteorites. They find that most of principal components of meteorite spectra are offset from those of the bulk of the asteroid population. However they used only eight color spectra and the spectra are limited within visible wavelength from 0.35 to 1.0 μm. Since characteristic absorptions are observed in the near-infrared range, including pyroxene (2 μm) and hydrated silicates (3 μm), using reflectance spectra with a wider wavelength range could result in a better spectral matching between asteroids and meteorites. In this study we developed a database of reflectance spectra for asteroids and meteorites with wavelengths ranging from 0.4 to 4 μm and perform multivariate analysis.
We obtained reflectance spectra for meteorites and asteroids from RELAB [7] and the database of Planetary Spectroscopy at MIT [8], respectively. Asteroid spectra for 3 μm band are obtained from previous studies [e.g., 9]. All the spectra were sampled with cubic spline fits at a wavelength interval of 0.05 μm. Meteorite spectra are chosen based on the following criteria: (1) particulate sample, (2) phase angle is 30°, (3) sample is from valid/known meteorite, (4) not heated/laser-irradiated, inclusion or impact melt sample, (5) not moon sample or lunar meteorite. The developed database includes 534 meteorite spectra and 369 asteroid spectra. We performed principal component analysis on the database and measure how well each meteorite group and asteroid group is separated on the principal component space. Our preliminary analyses show that (1) using spectra from 0.4 to 2.5 μm, accuracy of separation among ordinary chondrites, carbonaceous chondrites, HED meteorites is significantly improved compared with the case using spectra from 0.4 to 1.0 μm, and (2) the accuracy of separation is not significantly improved when using meteorite spectra from 0.4 to 4 μm compared with the case using spectra from 0.4 to 2.5 μm.

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Keywords: asteroids, meteorites, reflectance spectra

Relationship between reflectance spectra of meteorites and asteroids visualized by the correlation distance and t-SNE

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Classification of asteroids based on orbits, sizes, and reflectance spectra have been performed for decades to understand the nature of small bodies. As for asteroids, asteroid taxonomic systems based on color, albedo, and spectral shape have been developed and modified/expanded to grasp their variations. While each spectral class is believed to represent a specific composition of asteroids, their correlation is still not fully understood because of the nature of reflectance spectrum of rock-forming minerals; The relationship between reflectance spectra of an asteroid and a meteorite is essentially difficult to unravel without detailed analyses of the shapes of spectra. Even so, several previous attempts exist to statistically solve this issue. For example, Britt et al (1992) successfully produced a map of statistically defined spectral similarities and found that principal component analysis is successful at characterizing the primary spectral variance in the asteroid and meteorite populations. In other words, statistical classifications of spectral types without detailed interpretation of spectral shapes can be useful to overview the variation and relationships within a spectral data set, even though there are known difficulties of comminution, melting, mixing, and space weathering. In this work, we expand the above idea by applying to a wider and denser datasets of reflectance spectra for both meteorites and asteroids. We use published databases of RELAB’ s laboratory measurements of meteorites and Planetary Spectroscopy at MIT’ s asteroid spectra, which are resampled by cubic spline fits in the wavelengths ranging from 0.45 to 2.45 μm with the wavelength resolution of 0.05. We statistically analyze the distance of spectra by means of such as Partial Autocorrelation, Dynamic Time Warping, Pearson Correlation, and Euclidean distance. Results are visualized by using 6 kinds of schemes including t-SNE (t-Stochastic Neighbor Embedding). We find that correlations of both meteorites and asteroids are generally shown by this simple scheme. Preliminary results indicate that (1) V-type asteroids generally match HED meteorites, (2) S-type asteroids locate near ordinary chondrites but they do not entirely match each other, which may reflect the effect of space weathering (3) C-type asteroids match carbonaceous chondrites and they are separated into a few sub clusters.

Keywords: asteroid, meteorite, reflectance spectra

Systematic attribution of observed circulation trends to external forcing and internal variability

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The atmospheric circulation can be efficiently described by just a few regime states or teleconnection patterns. For the systematic identification of these regime states a novel space-time clustering method has been developed (FEM-BV-VARX). This method identifies persistent regime states which are important for predictions. In my presentation I will discuss the use of this method for the attribution of circulation trends and extreme events.

Keywords: Regime States, Circulation Trends, Extreme Events, Clustering Method

Data-driven science for solving problems in geosciences

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Recent technological development of measurement and observation enables us to obtain a large amount of high-dimensional data. Effective use of high-dimensional data requires a robust framework to make the tight connection of information science to the original purpose of data analysis derived from various scientific disciplines [1]. Since 2013, we have launched a big scientific project entitled as "Initiative for high-dimensional data-driven science through deepening sparse modelling (FY2013-FY2017)" funded by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) in Japan. The aim of this project is to establish a novel framework of data analysis for natural sciences, namely, data-driven science. Its target fields are very wide including geosciences, astronomy, biology, and medical and brain sciences. In this presentation, we introduce the concept of data-driven science and some applications to geosciences [e.g. 2-5].

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Keywords: data-driven science, sparse-modeling, machine learning

Source Term Estimation for atmospheric release In Nuclear Accidents Using ensemble Kalman filter: a validation with wind tunnel experiment

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In a nuclear accident, the source term which contains the release rate of atmospheric radionuclide leakage is a key issue of the nuclear emergency response. One effective way to obtain the source term is the inverse modelling method that is based on radionuclide transportation process and environment radiation monitoring data. However, the inverse modelling method may be sensitive to specific site conditions. Therefore, a case-by-case validation is important.
In this study, a source term estimation method based on the Ensemble Kalman filter (EnKF) data assimilation technique was proposed for source term estimation and a wind tunnel experiment that simulated a highly heterogeneous Chinese nuclear power plant site was performed to validate this method.
The EnKF method takes the concentrations measured at different positions as input parameters and iteratively refined the source term estimate by reducing the discrepancy between the experimental measurements and the concentration prediction that is obtained by certain atmospheric transport model based on the estimated source term. In order to improve the accuracy of the transport model, CALMET was used to generate the wind field that is necessary to drive RIMPUFF.
A 1:2000 wind tunnel was performed to comprehensively evaluate the performance of the proposed method, which simulated both ground and stack release scenarios with a dominant wind direction at a typical Chinese nuclear power plant. The incoming flow in the wind tunnel is adjusted according to the annual mean wind speed and vertical profile that has been measured in recent years near the NPP site. The experiment simulated a ground release scenario by using CO as the tracer gas, which the release position is in the center of the nuclear power plant site. Concentrations are measured at 264 positions in the downwind direction of the release, which equals to 6500m away from the source in a real world scale. The estimated release rate was compared with the true release rate that was used in the wind tunnel experiment, in order to assess the convergence and accuracy of the proposed method. Meanwhile, the concentration measured in the wind tunnel was both qualitatively and quantitatively compared with the simulation values that are calculated by CALMET-RIMPUFF using the estimated release rate.
The validation results demonstrate that the proposed method has a fast convergence rate. The estimated release rate matches the real one used in the experiment well for both release cases, which the bias is less than 50% for the worst case estimate. As for the concentrations predicted with the estimated release rate, they are not only qualitatively consistent with the spatial distribution of the measured concentrations, but also show satisfactory results with respect to statistical evaluation metrics for both release cases. The Pearson correlation coefficient is higher than 74~87%, the FAC2 is 42~54% and the FAC5 is 77~80% for all the experiment cases. The source term estimation of the stack release case slightly outperforms that of the ground release case, due to the better atmospheric transport modelling. The experiment also reveals that CALMET-RIMPUFF tends to underestimate the concentrations, which are the primary source of the bias in the estimates. Therefore, the atmospheric model is critical for the performance of the source term estimation, which shall be our future work focus.

Keywords: Source term estimation, Data assimilation, Atmospheric dispersion, Radioactive release

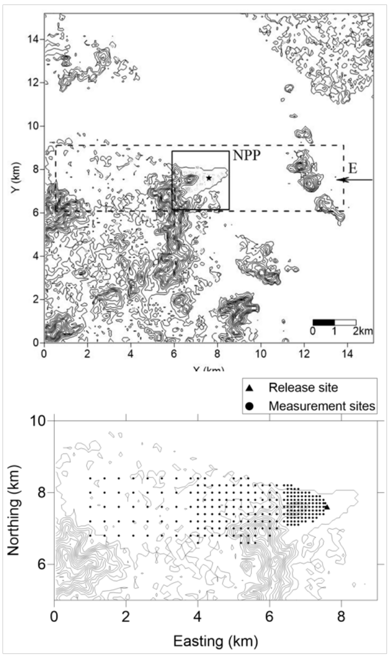

Fig. 1 Topography and measurement network of the wind tunnel experiment

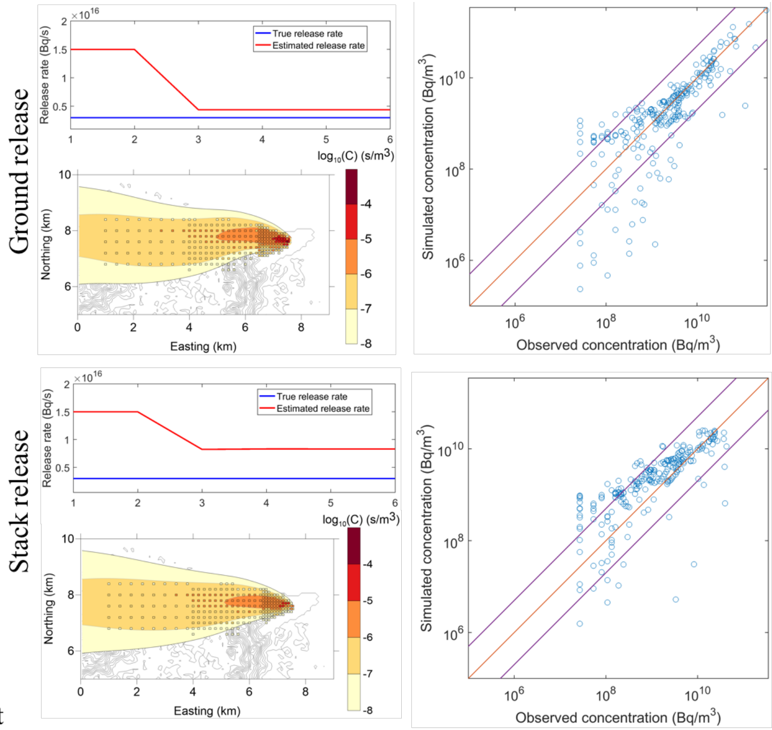

Fig. 2 source term estimation results. Convergence curve, simulated plume using the source term estimate and the corresponding scatter plot

Bayesian inversion analysis of nonlinear spatiotemporal dynamics of heterogeneous reactions in rock-water interactions

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It is essential to extract nonlinear dynamics from time-series data as an inverse problem in natural sciences. We propose a Bayesian statistical framework for extracting nonlinear spatiotemporal dynamics of surface heterogeneous reactions from sparse and noisy observable data. Surface heterogeneous reactions are chemical reactions with conjugation of multiple phases, and they have the intrinsic nonlinearity of their dynamics caused by the effect of surface-area between different phases. We employ sequential Monte Carlo algorithm and other statistical algorithm to partial observation problem, in order to simultaneously estimate the time course of hidden variables and the kinetic parameters underlying dynamics. Using our proposed method, we show that the rate constants of dissolution and precipitation reactions, which are typical examples of surface heterogeneous reactions, and the diffusion constants, as well as the spatiotemporal changes of solid reactants and products, were successfully estimated only from the observable temporal changes in the concentration of the dissolved intermediate product.

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Keywords: Data-driven science, Machine learning

Detection of principal dynamical modes of changing climate

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The success in empirical climate modeling strongly depends on selection of model variables used for reduced representation of system's dynamics. In fact, we can say that the states of the climate system are determined by a combination of external perturbations (forcings) and unknown internal variables. Thus, the detection of principal internal modes of changing climate is crucial point in modeling problem. In the presentation the method for extraction such modes from data is presented. The method is based on the Nonlinear Dynamical Mode (NDM) expansion [1,2], but takes into account forcing time series applied to the system: each NDM is represented by hidden time series governing the observed variability, which, together with external forcing signals, are mapped onto the data space.

In this work the method is used for reconstructing and studying the principal modes of global climate variability on inter-annual and decadal time scales, adjusted for the external forcings such as anthropogenic emissions, variations of the solar activity and volcanic activity. The structure of the obtained modes as well as their response to external factors, e.g. forecast their change in 21 century under different CO2 emission scenarios, are discussed.

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Keywords: nonlinear dynamical modes, data expansion, empirical modeling

Data-adaptive Harmonic Decomposition and Stuart-Landau closure modes

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Novel signal processing technique will be presented that estimates power and phase spectra of mutivariate dataset via data-adaptive modes obtained in time-embedded phase space. The key feature of the Data adaptive Harmonic decomposition (DAH) method relies on the construction of covariance matrices that exploit cross correlations differently than in Principal Component Analysis and Multichannel Singular Spectrum Analysis. Eigenmodes associated with DAH covariance matrices form an orthogonal set of oscillating data-adaptive harmonic modes (DAHMs) that come in pairs and in exact phase quadrature for a given Fourier frequency, aka *sine* and *cosine.*

The recent Multilayer Stochastic Model (MSM) framework introduced in [Kondrashov, Chekroun and Ghil, 2015] emphasizes the ubiquitous role of nonlinear, stochastic as well as memory effects for the derivation of data-driven closure models with good skill in simulating and predicting main dynamical features of the targeted spatiotemporal field as an output of a high-end geophysical model, or as a set of observations. However, if the input data are not numerous enough and exhibit mixture of different spatiotemporal scales, the analysis may reveal multiple predictors and complex model structure. The DAH decomposition provides an attractive data-adaptive alternative via multilayer stochastic Stuart-Landau models (MSLM), which reduce the data driven modeling effort to elemental MSMs stacked per frequency with fixed and much smaller number of coefficients to estimate. In particular, the pairs of data-adaptive harmonic coefficients (DAHCs), obtained by projecting the input dataset onto DAHMs, can be effectively modeled within a universal parametric family of simple nonlinear stochastic models - coupled Stuart-Landau oscillators stacked per frequency, and driven at all frequencies by the same noise realization. DAH-MSLM results for climate modeling and prediction will be presented.

Keywords: stochastic inverse modeling, climate prediction, data-adaptive decomposition

Conditional stochastic model chains in reduced space: Towards efficient simulation of non-stationary typhoon precipitation patterns

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Stochastic simulation of realistic and statistically robust patterns of Tropical Cyclone (TC) induced precipitation is a challenging task. It is even more challenging in a catastrophe modeling context, where tens of thousands of typhoon seasons need to be simulated in order to provide a complete view of flood risk. Ultimately, one could run a coupled global climate model and regional Numerical Weather Prediction (NWP) model, but this approach is not feasible in the catastrophe modeling context and, most importantly, may not provide TC track patterns consistent with observations. Rather, we propose to leverage NWP output for the observed TC precipitation patterns (in terms of downscaled reanalysis 1979-2015) collected on a Lagrangian frame along the historical TC tracks and reduced to the leading spatial principal components of the data. The reduced data from all TCs is then grouped according to timing, storm evolution stage (developing, mature, dissipating, ETC transitioning) and central pressure and used to build a dictionary of stationary (within a group) and non-stationary (for transitions between groups) covariance models. Provided that the stochastic storm tracks with all the parameters describing the TC evolution are already simulated, a sequence of conditional samples from the covariance models chosen according to the TC characteristics at a given moment in time are concatenated, producing a continuous non-stationary precipitation pattern in a Lagrangian framework. The simulated precipitation for each event is finally distributed along the stochastic TC track and blended with a non-TC background precipitation. The proposed framework provides means of efficient simulation (10000 seasons simulated in a couple of days) and robust typhoon precipitation patterns consistent with observed regional climate and visually undistinguishable from high resolution NWP output. The framework is used to simulate a catalog of 10000 typhoon seasons implemented in a flood risk model for Japan.

Keywords: Reduced models, Stochastic simulation, Typhoon precipitation

Data-driven Nonlinear Dynamical Models for Forecast of Climate Variability

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We apply new methodology of empirical modeling and forecast of nonlinear dynamical system variability [1] to study of climate systems' variability. The methodology is based on two approaches: (i) nonlinear decomposition of spatially distributed data [2], that provides low-dimensional embedding for further modeling, and (ii) construction of empirical model in the form of low dimensional random dynamical (“stochastic”) system [3].
The methodology abilities are demonstrated by modeling and forecast of ENSO system variability. Three monthly data sets are used: global sea surface temperature anomalies, troposphere zonal wind speed, and thermocline depth; all data sets are limited by 30 S, 30 N and have horizontal resolution 1^0x1^0.
We compare results of optimal data decomposition as well as prognostic skill of the constructed models for different combinations of involved data sets. We also present comparative analysis of ENSO indices forecasts fulfilled by our models and by IRI/CPC ENSO Predictions Plume.

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Keywords: Nonlinear Dynamical Model, Forecast of Climate Variability, Nonlinear Data Decomposition

Data-driven model for investigation of the mid-Pleistocene transition

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In this work we apply a data-driven model for the analysis of complex spatially distributed geophysical data. We are focused on the investigation of critical transitions on paleo timescales. Namely we investigated mid-Pleistocene transition which led to change of dominate cycles of glacial variability in Pleistocene.
We demonstrate the good performance of applying our data-driven model to analysis of paleoclimate variability. In particular, we discuss the possibility of detecting, identifying and prediction of the mid-Pleistocene transition by means of nonlinear empirical modeling using the paleoclimate record time series.
The study is supported by Government of Russian Federation (agreement #14.Z50.31.0033 with the Institute of Applied Physics of RAS).

Keywords: Data-driven Modeling, Critical Transitions, Time Series Analysis, Mid Pleistocene Transition

Analysis of zonal structure of phenocryst minerals considering element diffusion: Approach based on Bayesian statistics

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From the zonation structure found in the phenocrysts in the volcanic rocks, when the equilibrium with the melt is guaranteed, sequence data on melt composition with high degree of freedom and short time scale of homogenization can be obtained by using partitioning coefficients. Then, it is expected that constraints on physical processes related to the differentiation process inside the crust and on primary magma will be possible. However, due to the diffusion of elements in the crystal, analysis using partitioning coefficients is often insufficient. On the other hand, if the influence of diffusion can be estimated from the compositional zoning structure affected by element diffusion, time information can be obtained. However, when the zonal structure becomes complicated, such as when formed in multiple crystal growth stages, the number of parameters to be considered in analysis increases and the dependence among the parameters becomes complicated.
In this study, we developed a method to elucidate the physical processes experienced by magma system through restored information on temporal change of melt composition by evaluating the influence of element diffusion quantitatively from the zonation structure of the phenocryst mineral that experienced the multistage crystallization process.

In this study, we have constructed a forward model for the formation of zonal structure by crystal growth and subsequent element diffusion, and estimated the parameters characterizing the model by Parallel tempering Markov Chain Monte Carlo (PT-MCMC) method. We conducted validation test for our method by using numerically generated zonal structure which is added noise. In our crystal growth model, the zonal structure is formed by several stages where the element diffusion progresses after crystal growth. Classification of the crystal growth stage was constrained based on a profile with a low diffusion rate such as Cr_2O_3 in the case of orthopyroxene.

In our model on crystal growth, the melt composition as the starting point of calculation is the whole rock composition of the most primitive natural lava. The melt composition change is calculated by fractionation or addition of small amount of olivine, orthopyroxene, and spinel repeatedly. Each solid phase is spherically symmetric and the spherical shell with the composition that is local equilibrium with melt grows for each calculation step. Calculation was made with assuming that the partition coefficients are always constant. It is assumed that olivine and orthopyroxene affect trace elements and major components MgO, FeO and SiO_2, and spinel affects a trace element only.

In our model on element diffusion, based on the method of Ozawa (2004), nondimensionalized was calculated. The diffusion coefficient considered only temperature dependence. In the calculation scheme, the second order center difference is adopted in the spatial direction, and the backward difference was adopted in the time direction.

Using the simulated zonal structure by the forward model and the analyzed zonal structure, eight series of Markov chains expanded with parameters expressing pseudo temperature were generated, and parameter estimation was performed by parallel tempering Markov Chain Monte Carlo method (Hukushima & Nemoto, 1996). After a given sampling times, the optimum value of the parameter was determined from the average value or the mode value while checking the histogram shape of the obtained sample.

Sampled parameters are following five types in each zoning section: initial Mg#, final Mg#, modal fraction of orthopyroxene, and modal fraction of spinel in the crystal growth stage; logarithm of maximum compression time in element diffusion stage.

Keywords: Volcanic rocks, Crystal growth, Element diffusion

Managing soil organic carbon sequestration in China's croplands

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Increasing the soil organic carbon (SOC) pool in croplands can not only promote crop production but also mitigate climate change; however, the amounts of organic C that are input to balance the soil C loss and for targeted soil C sequestration in China's croplands are unclear. By using a biogeophysical model (Agro-C), we performed simulations with a high spatial resolution (10 km×10 km) across China's croplands to quantify the rate of C input under given scenarios. The model simulations showed that an average C input of 2.1 Mg C ha^{-1} yr^{-1} is required to stop soil C loss and that SOC density could approach the global mean of 55 Mg C ha^{-1} by 2050 when 5.1 Mg C ha^{-1} per year is incorporated into the soils of China's croplands. The quantified C inputs showed a large spatial disparity, depending on the existing SOC level, mean annual temperature and precipitation. The existing SOC level in Heilongjiang Province, where the cropland area accounts for 9.2% of the national total, is much higher but the current C input is much lower than it is in other regions in China. Increasing the organic C input should be given priority in this province; otherwise, the risk of SOC loss may increase.

Spatial modeling by joint use of physical law and geostatistics for grade analysis in geofluid-caused ore deposit

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Fluids play an important role in various aspects related to ore deposits and are crucial to the formation and development of ore deposits. This study aims to develop a method combines spatial statistics and physical law for metal contents in an ore deposit. Semivariogram clarified spatial correlation structure of the metal data and then kriging and sequential Gaussian simulation were used to generate spatial distribution of ore grade in three-dimensions. Transports of ore fluid and deposition process of metals were assumed as a physical process governed by the advection and diffusion. Analytical and numerical solution of an advection-diffusion equation was applied to ore grade data by calculating key parameters, advective velocity and diffusion coefficient. In order to simulate accurately, parameters were then revised as variables in different zone according to geological structure and geostatistical model. Matsumine and Fukazawa mines, typical large kuroko deposits in the Hokuroku district, Akita Pref., northern Japan, are selected to verify the combined method. Metal elements such as Cu, Zn, and Pb (chief metals of kuroko) of drilling cores were used for the spatial and physical modeling analyses. This method termed SPG (Spatial modeling by joint use of Physical law & Geostatistics) presents general main paths of ore fluid with respect to source, flow direction, and flow rate. The same technique and SPG are applied to a hydrothermal deposit in Sulawesi Islands, Indonesia. As the result, high metal content zones are well clarified and characterized, and a fluid flow pattern that formed the zones is expressed as colloidal texture which could indicate temperature and pressure changes in shallow subvolcanic activities.
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Keywords: ore deposit, metal content, fluid flow, geostatistics, advection-diffusion

Solar terrestrial modelling: Application of systems methodologies

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The response of the magnetosphere to changes in the solar wind is the result of the a complex series of processes, each acting over disparate scales in both space and time. The basic premise of physics based modelling is to understand each of these processes separately before coupling them into a single model. This diversity in process mechanisms and their temporal/spatial scales is one of the main reasons that such models have not been developed. Systems science provides a complementary route for modeling. This data driven approach involves the study of the evolution of a system as a whole based on a set of driving parameters. In this presentation we show how the application of systems modelling can be used to investigate such complex problems in space physics as magnetospheric response to the solar wind to the evolution of turbulence. In contrast to other data driven methodologies, systems techniques can also advance understanding of the micro-processes within the system. In addition, use of the systems approach, and especially frequency domain analysis, may be employed to validate analytical and numerical models.

Keywords: systems modelling, magnetospheric processes, solar wind response