A New Type of Air-Soil-Land Plant Carbon Cycle System

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Abstract: The paper is focused on a kind of new dynamic evolution of ASP carbon cycle system, which is established on the complex interrelation of carbon cycle among air, soil, land plants. In this paper, model establishment is explicitly introduced and the dynamic behavior of the system is substantially analyzed.

Keywords: Carbon cycle; air; soil; land plant

1 Introduction

The research of carbon cycle system can show clearly the carbon exchange between different spheres on the earth, its impact so as to probe the interaction of the different systems on the earth and the influence of human being’s activities. Researches on carbon cycle have been one of the hot topics.

Goudie and other researchers[1] have studied the impact of weather on the global carbon cycle, especially the dynamic relation and erosion, which will contribute to the carbon cycle research. Strohbach and his team[2] studied how the urban green space works in the global carbon cycle. His research shows urban green space as carbon sink, if designed and maintained well, may have a strong impact on the carbon footprint. Nakata and other researchers[3] studied a physical–biological coupled ocean carbon cycle model and made a primary analysis of their research findings' trend. Dasgupta and others[4] worked on the deep carbon cycle in Earth’s interior. Liu Chunying and his team[5] researched the change in organic carbon storage in soil and its spatial distribution in China wetlands in different climatic regions. His conclusion is significant in indicating the characteristics of organic carbon storage in wet land soil and its interrelations with the carbon cycle in the ecological system on the land. And his research also helps evaluate and protect the ecological system in the wet lands. Leng Fangwei and others[6] made a review on the recent progress in carbon cycle research in East Asia. Fan Yuejun and others[7] probed the effect of global warming on the carbon cycle on the grassland ecosystems after reviewing the relevant researches and also pointed out the exiting problems in the researches on carbon cycle on the grasslands and suggested the direction of future researches.

Chaotic analysis and its application in the dynamic evolutionary system begin to work practically in engineering, biology and economy[8-9]. Carbon cycle system is a complex system characteristic of complex coupling, time lag and non-linearity. The system includes air, soil (wet land, grassland and etc.), land animal, land plant, river, ocean[10-11] and deep carbon cycle in the Earth’s interior[12]. What’s eye-catching now is how to study carbon cycle using non linear dynamics, however, the exiting researches focused on scenario analysis which is not so satisfactory because of no specific carbon cycle model available, too many uncertainty factors in research data and vague regular patterns of carbon cycle. The paper is trying to establish ASP carbon cycle model, a nonlinear evolutionary model of carbon cycle based on the complex interrelations between air, soil and land plant (ASP). The evolutionary regular patterns between variables will be systematically analyzed with non linear dynamics.

The paper is organized as follows. The model is set up in Section 2. Section 3 analyse the basic properties of the ASP carbon cycle system. Conclusions are finally presented in Section 4.

2 Establishment of model

Beginning with terrestrial carbon cycle, many researchers studied the carbon cycle in the ecosystems such as wet land, marsh, grassland and etc. They also took the ocean into carbon cycle system, thus a broader carbon cycle system including
oceans developed. Some of the researchers further studied the deep carbon cycle in the earth interior. Generally speaking, the research trend is to combine biological issues with bigger terrestrial physical issues such as air, ocean, lithosphere, sun-earth space and etc, in a hope for a comprehensive study of carbon cycle and combination with other dynamic process. The paper, based on the complex recycling evolution between air, soil and land plant in certain period and scale, deduces the ASP carbon cycle system as follows:

\[
\begin{align*}
\dot{x} &= p_1 - q_1 x \frac{x}{A} - 1 + a_{21} y - a_{12} x + a_{31} z - b_{13} x z \\
\dot{y} &= p_2 - q_2 y + a_{12} x - a_{21} y + a_{32} z \\
\dot{z} &= b_{13} x z - a_{31} z - a_{32} z
\end{align*}
\]

where \( x(t) \) is the carbon storage changeable with time in air in certain range; \( y(t) \) is the one in soil; \( z(t) \) is the one in land animal. \( p_i, q_i, a_{ijk}, b_{jk}, A \) are positive constants, \( t \in I, I \) is the economy period (\( i = 1, 2, j = 1, 2, 3, k = 1, 2, 3, \)).

\( p_1 \) is the increased carbon amount into \( x(t) \) for airflow and other reasons; \( -q_1 x (x/A - 1) \) is the reduced carbon amount in \( x(t); A \), the peak value; \( a_{21} y \), increased carbon amount in \( x(t) \) for soil breathing, air flowing and etc with \( a_{21} \) as the coefficient; \( -a_{12} x \), the precipitated carbon into \( y(t) \) from \( x(t) \) with \( a_{12} \) as the coefficient; \( a_{31} z \), the discharged carbon into \( x(t) \) from \( z(t) \) for burning or breathing; In formula (1), the first equation indicates: variance rate of carbon storage in \( x(t) \) is relevant both to carbon input and output in \( x(t) \) of carbon cycle system and to carbon exchange between \( y(t), z(t) \); as for \( -q_1 x (x/A - 1) \), when \( x < A \), namely, \( x/A - 1 < 0 \), it shows that the carbon level in air is not saturate and carbon reduces slowly with small or no output; when \( x > A \), namely, \( x/A - 1 > 0 \), it shows that the carbon level in air is saturate and carbon reduces quickly with great output. Recyclable evolutionary process is shown in figure 1.

\( p_2 \) is the input carbon into \( y(t) \) for rivers’ scouring and scrubbing. \( -q_2 y \) is the carbon output from \( y(t) \) with \( q_2 \) as coefficient. \( a_{12} x \) is the carbon precipitated into \( y(t) \) from \( x(t) \). \( -a_{21} y \) is the discharged carbon from \( y(t) \) into \( x(t) \). \( a_{32} z \) is discharged carbon from \( z(t) \) into \( y(t) \) for land plant respiration and dead bodies’ decomposition with \( a_{32} \) as the coefficient. The second equation in the first formula shows variance rate of carbon storage in \( y(t) \) is relevant both to carbon input and output in \( y(t) \) of carbon cycle system and to carbon exchange between \( x(t), z(t) \).

\( b_{13} x z \) is the transmitted carbon from \( x(t) \) to \( z(t) \) with \( b_{13} \) as the transmission coefficient. \( a_{31} z \) is the discharged carbon into \( x(t) \) for burning and breathing while \( a_{32} z \) is the one into \( y(t) \) for land plant respiration and dead bodies’ decomposition. The third equation in the formula indicates the variance rate of carbon storage in \( z(t) \) is relevant to its own development and the carbon exchange between \( x(t), y(t) \).

\[\text{Figure 1: carbon cycle evolution}\]

3 Dynamic analysis

System (1) is a fairly complex one of dynamic evolution. When \( p_i, q_i, a_{ijk}, b_{jk}, A \) take different figures, it will show different dynamic behavior. For example, when system (1) takes the figures as shown in formula (2), it turns out to have a stable solution. Figure 2 shows the three-dimensional phase and time series figure when it takes such coefficient as follows.

\[\text{IUNS email for contribution: editor@nonlinearscience.org.uk}\]
Formula (1) has three equilibrium points

\[ S_1 \left(-2.0942, -1.1566, 0\right), S_2 \left(3.8526, 3.2002, 0\right), S_3 \left(0.4682, 6.2862, 43.3460\right) \]

After calculation, the eigenvalues of the Jacobian matrix-a linear approximation system- at each equilibrium point are as follows: the ones at S1 are \( \lambda_1 = 0.1817, \lambda_2 = -1.0012, \lambda_3 = -0.5637 \); the ones at S2, \( \lambda_1 = -1.2199, \lambda_2 = -0.1491, \lambda_3 = -0.7446 \); the ones at S3, \( \lambda_1 = -9.8741, \lambda_2 = -0.0083, \lambda_3 = -0.7100 \); Therefore, \( S_1, S_2 \) are all saddle points while \( S_3 \) is the stable point.

ASP is a new carbon cycle system, which reflects the real interrelation between variables. Thus, ASP system has ampler theory evidences, which is closer to reality and has more popular application than other carbon cycle theories.

4 Conclusion

The paper brings air, soil, land plant into a nonlinear dynamic evolution model, which explicitly expresses how ASP, the carbon cycle dynamic evolution model, is established. With nonlinear dynamics, the author analyzed the dynamic behavior of ASP carbon cycle system, which is a complex nonlinear system characteristic of coupling, time lag and nonlinearity. For the special structure of ASP system, current research findings indicate that in most cases, the system is stable, and the phase diagram and time series plot are also available in the paper.

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