



Modeling the carbon and nitrogen cycles

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The issues of air pollution are inextricably linked to the mechanisms underlying the physicochemical functioning of the biosphere which together with the atmosphere, the cryosphere, the lithosphere, and the hydrosphere constitute the climate system. We herewith present a review of the achievements and unresolved problems concerning the modeling of the biochemical cycles of basic chemicals of the climate system, such as carbon and nitrogen. Although the achievements in this area can roughly describe the carbon and nitrogen cycles, serious problems still remain associated with the accuracy and precision of the processes and assessments employed in the relevant modeling.

Keywords: biochemical processes, carbon cycle, nitrogen cycle, modeling, greenhouse effect

MODELING SCHEMES OF THE GLOBAL CARBON CYCLE

It is generally recognized today that the complete understanding of the CO₂ contribution in the formation of the atmospheric greenhouse effect presupposes a thorough examination of the biogeochemical dynamics of the carbon cycle (Kondratyev and Varotsos, 1995; Kondratyev et al., 2004; Krapivin and Varotsos, 2008; Amann et al., 2011). In the current literature a lot of schematic pathways of carbon cycle are considered in the form of global CO₂ changes. Herewith we refer to the most important ones, demonstrating their main characteristics in order to understand the limits of the simulation of the carbon cycle compounds. It should be worthwhile to note that all the assumed pathways of the CO₂ cycle on a global scale are often separated into two groups, notably: point wise (averaged on a global scale) and spatial (averaged on a local scale). All these schematic pathways consider that the biosphere is consisting of three ecosystems, viz., atmosphere, oceans, and land. In addition, a number of the available schematic diagrams of the carbon cycle distinguish the organic from inorganic types (Kondratyev et al., 2004). Moreover, the temporal averaging of all carbon processes and reservoirs is often performed on an annual basis, and thus the atmosphere is regarded as an homogeneous medium (point-wise). In this investigation the World Ocean and the surface ecosystems are based on global data bases for the carbon reservoirs. In general, these diagrams describe the atmospheric CO₂ concentrations assuming a typical scenario for the anthropogenic activity (Krapivin and Varotsos, 2008).

Most of the modeling estimates of the basic components of the carbon cycle show that its maximum supply is concentrated in the World Ocean and its minimum in the atmosphere. It should be stressed, however, that the natural processes that

determine the global carbon cycle dynamics obey various time scales. For example, the amounts of the dead organic matter that is buried in the the oceans bottom, exhibit temporal scales of the order of 10²–10³ years, while the biological components of the carbon cycle on land, appear a temporal variability of several decades. Consequently, the consideration of the above-mentioned temporal variability of the biospheric carbon cycle is of great importance. Keeping this in mind in the relevant modeling, it is equally important to consider the temporal variability of the complete atmospheric mixing that can last up to a couple of years (Kondratyev et al., 2004).

Additionally the spatial variability in the atmospheric CO₂ concentrations is of crucial importance. Routine observations obtained at different stations revealed that the CO₂ field appears substantial discrepancies in the annual variability. More specifically, the amplitude of the CO₂ variation ranges from 10 ppm over Antarctica to 10–15 ppm at the near Arctic region. This heterogeneity is attributed to the presence of large vegetation communities in the northern hemisphere (NH) which exhibits substantial seasonal photosynthesis (Kondratyev et al., 2004).

In this context, the latitudinal distribution of CO₂ in the atmosphere displays non-linear character (Varotsos, 2005; Varotsos and Kirk-Davidoff, 2006; Varotsos et al., 2012, 2013). The increased CO₂ content in the atmosphere of the NH is closely linked to both the direct CO₂ anthropogenic emissions and the vegetation cover. For instance, it is considered that the organic fuel burning results in almost 90% of the total emissions of carbon which is located in the latitudinal belt 30°N–60°N (Kondratyev et al., 2004).

As previously stated, an important component of the well-known schematic pathways of the carbon cycle on a global basis

is the distribution of carbon fluxes into the World Ocean. In this connection, there is now the required information to select several oceanic layers in various depths to distinguish the spatial heterogeneities. In this regard, most of the relevant studies assume two or three layers in the vertical structure of the oceans considering both the photic and deep layers. More recent schemes of the

global carbon cycle take into account all the above-mentioned heterogeneities, increasing thus considerably the fidelity of the relevant modeling algorithms. Two of the widely used schematic pathways are shown in **Figures 1, 2** (Kondratyev et al., 2004).

As mentioned above, the process of exchange of CO₂ in the atmosphere-ocean borders reveals the contribution of the World Ocean to the global cycle of CO₂. The extent of this exchange is expressed by the dynamic characteristics of the turbulent layers of water and air near the interface of the ocean and the atmosphere. In this context, numerous physical schemes take into account the sea wave formation, as well as formation of foam and various films. Specifically, these schemes consider that CO₂ either dissolves into the ocean releasing the CO₂ that is required for photosynthesis, or enters the atmosphere. The cause of this twofold process in the atmosphere-ocean boundary is the relative difference between the partial pressures of CO₂ dissolved in the water and that of contained within the atmosphere. Indeed, this oriented CO₂ transport at the frontier “air-water” is much more complex and therefore its investigation postulates expensive in-field campaigns and a detailed classification of both synoptic and geographical conditions of the oceans surface (Ayers, 2005; Krapivin and Varotsos, 2008).

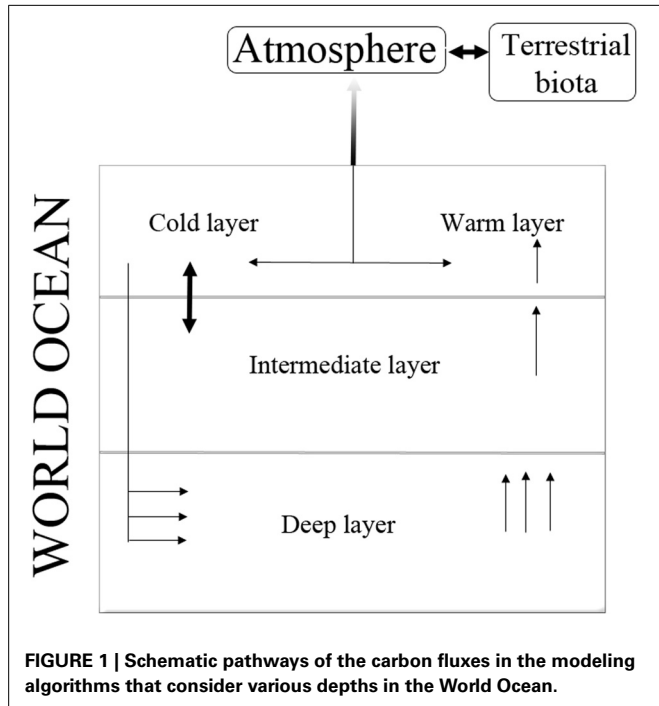


FIGURE 1 | Schematic pathways of the carbon fluxes in the modeling algorithms that consider various depths in the World Ocean.

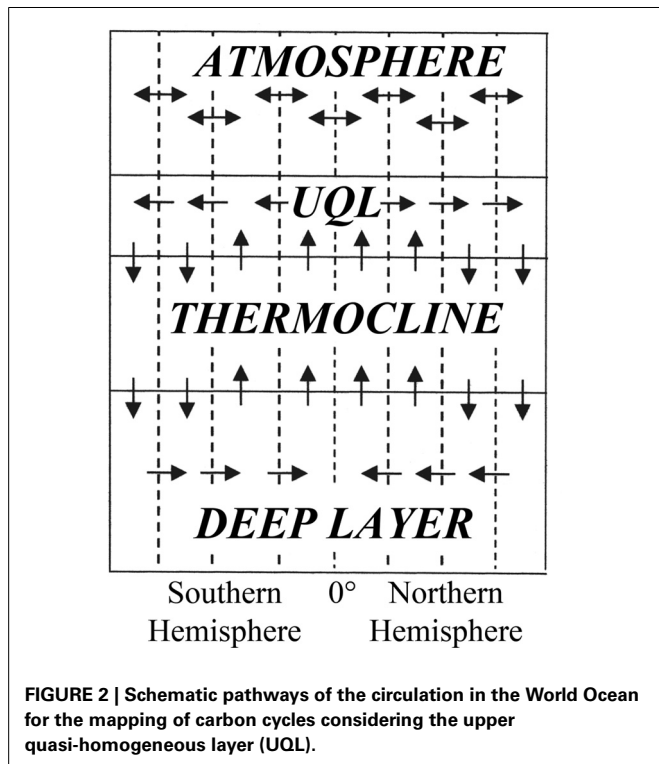


FIGURE 2 | Schematic pathways of the circulation in the World Ocean for the mapping of carbon cycles considering the upper quasi-homogeneous layer (UQL).

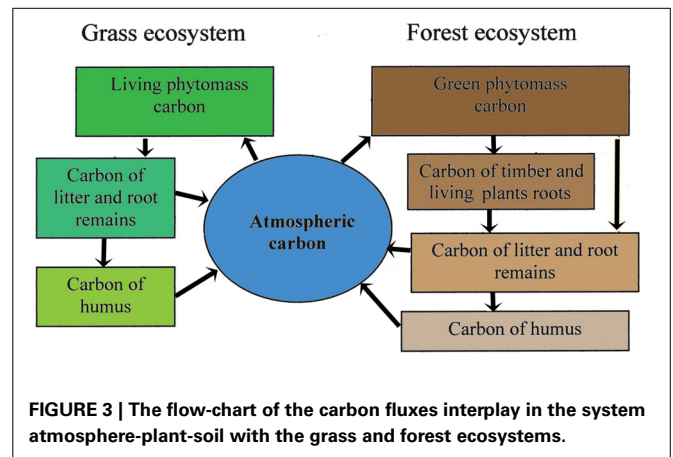


FIGURE 3 | The flow-chart of the carbon fluxes interplay in the system atmosphere-plant-soil with the grass and forest ecosystems.

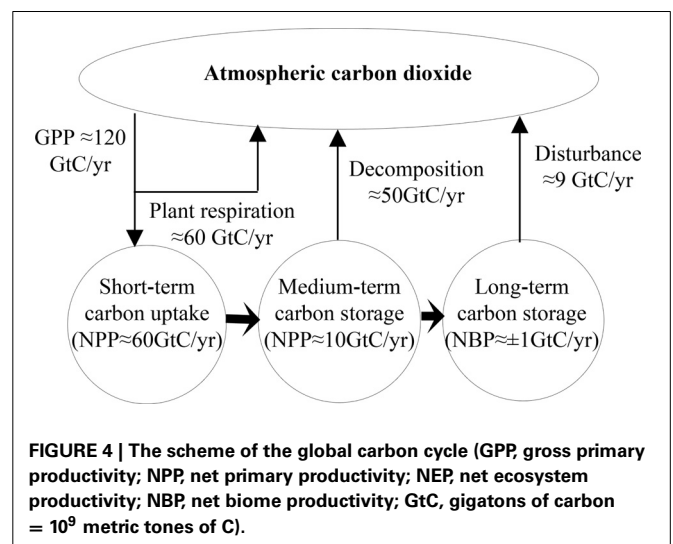


FIGURE 4 | The scheme of the global carbon cycle (GPP, gross primary productivity; NPP, net primary productivity; NEP, net ecosystem productivity; NBP, net biome productivity; GtC, gigatons of carbon = 10⁹ metric tones of C).

In the study of the global carbon cycles the emphasis is placed on the role of the surface ecosystems. In the process of photosynthesis, plants absorb CO₂ and, conversely, the decomposition of dead plants causes the emission of CO₂ into the atmosphere. Thus, between the living and dead organic matter of the land biosphere and the atmosphere a continuous exchange of CO₂ is taking place. Many conceptual schematic diagrams illustrate this exchange and serve as background for modeling algorithms of the global carbon cycle. **Figures 3, 4** show two examples of such diagrams (Kondratyev et al., 2004).

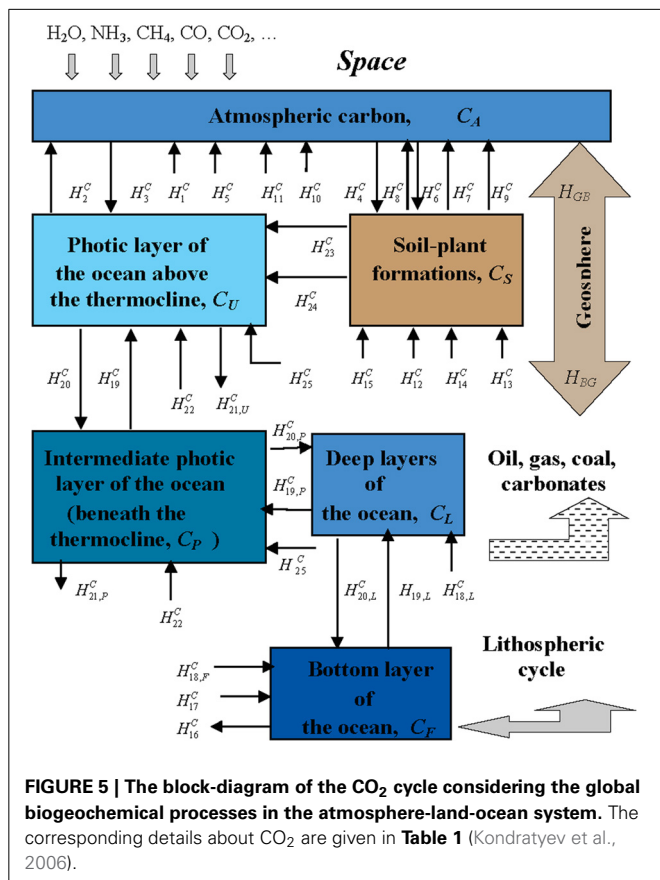
Of course, the correct assessment of the carbon fluxes in the terrestrial biosphere involves both the detailed quantization of the types of soil-plant formations and the correct assessment of the parameterization of the biocenotic processes. For this approach, the knowledge of the following parameters would be available: areas of vegetation and soils, data of the vital functions of soil microorganisms, and technologies of an operational monitoring of landscapes. However, the accurate figures about the details of the soil-plant formations are not available so far, and therefore the current accuracy of the estimates of carbon fluxes is poor (Kondratyev et al., 2004).

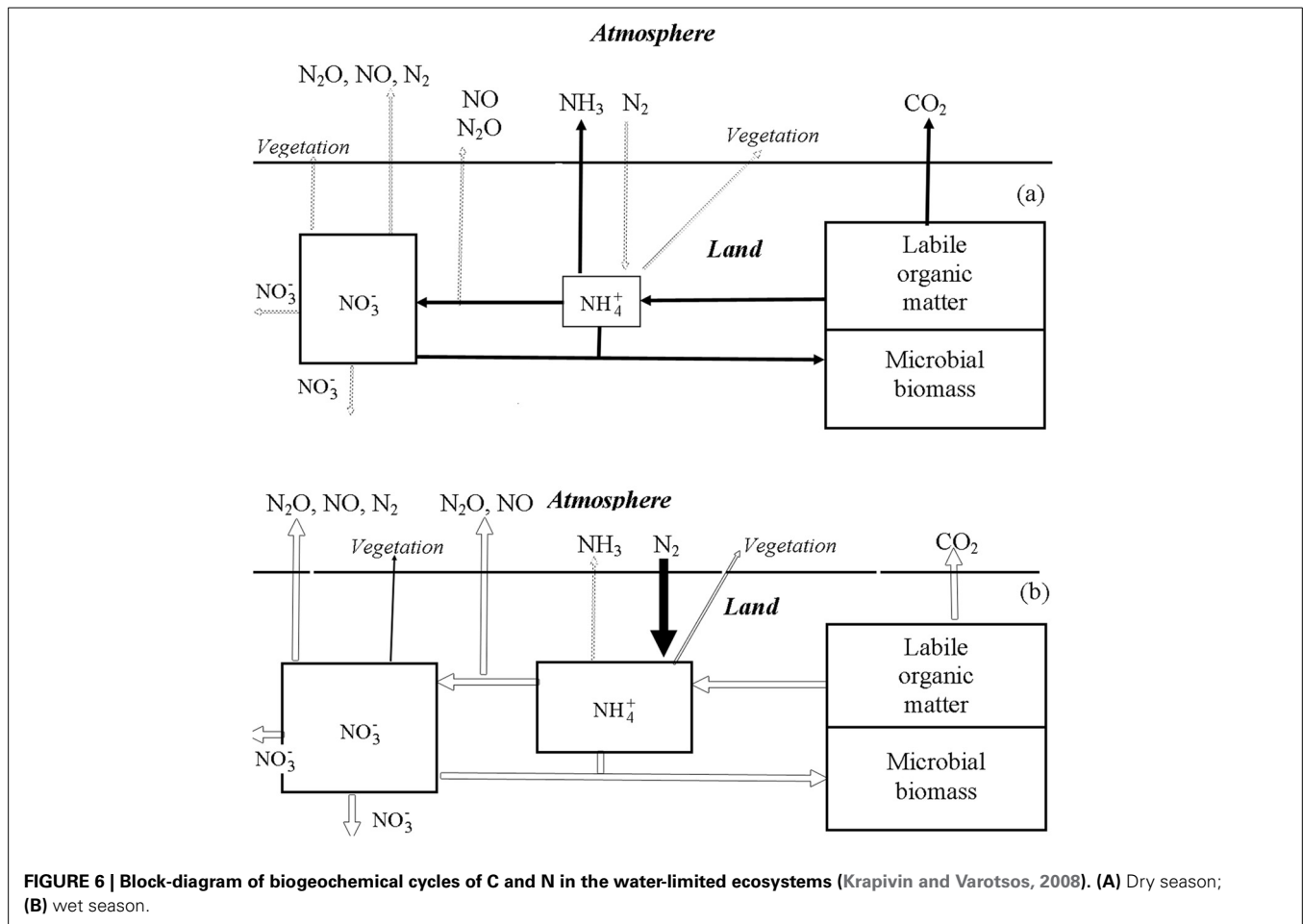
To overcome this difficulty, a modeling scheme of carbon cycle is required, which would describe the ranking of the important biospheric components and the possible pathways of transformation of carbon. As an example, an indicative schematic

diagram of carbon flux for the required modeling assessment is given in **Figure 5** and in **Table 1**. The employment of this model allows numerical experiments for the optimal spatial quantization, considering comparative estimates of the constituents involved and thus to successively approach required quantization (Kondratyev et al., 2004).

Table 1 | Model of global CO₂ cycle (MGDC): Carbon reservoirs and fluxes and their average estimates considering the global processes illustrated in Figure 5 (Kondratyev et al., 2006).

CO ₂ reservoirs and fluxes	Identifier in the model	Average estimate of reservoir (10 ⁹ t) and flux (10 ⁹ t/year)
CARBON		
Atmosphere	C _A	650–750
Photic layer of the ocean	C _U	580–1020
Deep layers of the ocean	C _L	34,500–37,890
Soil humus	C _S	1500–3000
EMISSION DUE TO BURNING		
Vegetation	H ₈ ^C	6.9
Fossil fuel	H ₁ ^C	3.6
Desorption	H ₂ ^C	97.08
Sorption	H ₃ ^C	100
Rock weathering	H ₄ ^C	0.04
Volcanic emanations	H ₅ ^C	2.7
Assimilation by land vegetation	H ₆ ^C	224.4
RESPIRATION		
Plants	H ₇ ^C	50–59.3
People	H ₁₀ ^C	0.7
Animals	H ₁₁ ^C	4.1
EMISSION		
Decomposed soil humus	H ₉ ^C	139.5
Plants' roots	H ₁₅ ^C	56.1
VITAL FUNCTIONS		
Population	H ₁₂ ^C	0.3
Animals	H ₁₃ ^C	3.1
Vegetation decay	H ₁₄ ^C	31.5–50
Sedimentation to bottom deposits	H ₁₆ ^C	0.1–0.2
DECOMPOSITION OF DETRITUS		
Photic layer	H ₂₂ ^C	35
Deep layers of the ocean	H ₁₈ ^C	5
Uplifting with deep waters	H ₁₉ ^C	45
Lowering with surface waters and due to gravitational sedimentation	H ₂₀ ^C	40
Photosynthesis	H ₂₁ ^C	69
Underground sink	H ₂₃ ^C	0.5
Surface sink	H ₂₄ ^C	0.5–0.6
Breathing of living organisms in the ocean	H ₂₅ ^C	25
Geospheric sink of carbon	H _{BG}	70
Geospheric source of carbon	H _{GB}	17





MODELING SCHEMES OF THE NITROGEN CYCLE IN NATURE

It is a truism that nitrogen is one of the basic nutrient elements in nature. That is why its global cycle is of great interest. According to the current understanding its cycle exhibits a complex structure of several processes of its compounds that are mainly formed due to water migration and plethora of relevant atmospheric processes (Varotsos et al., 1998; Akimoto, 2003; Wilson et al., 2007; Van der A et al., 2008; Tzanis et al., 2009, 2011; Xue et al., 2010). The known nitrogen cycle is subject to intense anthropogenic forcings generated by the interaction of the nitrogen cycle both directly and through the influence on the related processes (Krapivin and Varotsos, 2008). Therefore, the development of a reliable model of the nitrogen cycle in nature should be based on the consideration of the whole complex natural processes and those initiated by human activities. **Figures 6, 7** illustrate a schematic pattern of the main supplies and fluxes of nitrogen.

It is generally recognized that the natural sources of nitrogen oxides are strongly related to bacteria, volcanic eruptions, and several atmospheric phenomena, like the lightning discharges. More specifically, the biogeochemical cycle of nitrogen includes among others, fixation, mineralization, nitrification, assimilation, and dissimilation mechanisms that have been investigated in many studies (e.g., Krapivin and Varotsos, 2008). Their

complexity is determined by the rates of transformation of the nitrogen compounds their supplies, etc.

It is well-known that nitrogen participates in the biospheric processes with a complex structure of fluxes that are characterized by a hierarchical sequence of cycles in the biosphere. For example, starting from the atmosphere, nitrogen enters the microorganisms, migrating successively to soil, higher plants, animals, and humans. Then nitrogen returns back to the soil due to the death of living organisms. From the soil nitrogen, is either consumed by plants and living organisms or is emitted into the atmosphere. Approximately the same pattern is observed in the hydrosphere. The feature of the above-mentioned cycles is their openness to the available nitrogen removal processes from the biospheric balance into rocks, from which returns much slower. Given the nature of the nitrogen cycle in the biosphere and its reservoir structure, it is quite possible to formulate a global scheme of nitrogen fluxes (Krapivin and Kelley, 2009).

To simplify the scheme of the calculation of nitrogen fluxes presented in **Figure 7** (bottom), the advection processes in the balance equations of nitrogen cycle can be illustrated by a superposition of the fluxes H_{14}^N and H_{15}^N . However, for the development of such a model by employing these equations several corrections are necessary. Therefore, the estimates of the fluxes H_i^N given in **Table 2** for their consideration in the GIMS should be corrected

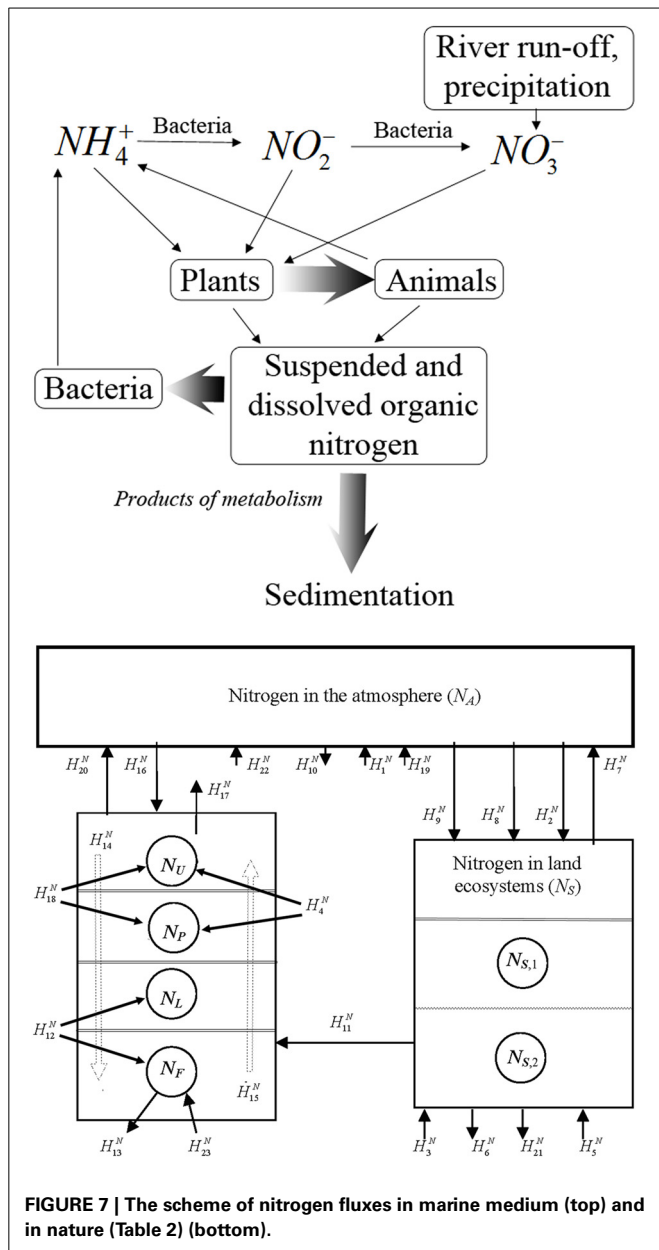


FIGURE 7 | The scheme of nitrogen fluxes in marine medium (top) and in nature (Table 2) (bottom).

following this criterion. Detailed description of the nitrogen cycle as unit of the GIMS was given by Krapivin and Varotsos (2008).

CONCLUSIONS

The problem of reliable modeling of biochemical cycles that control greenhouse effect, bioproductivity and environmental quality, is far from being solved. The correlations between biochemical cycles and the many activities of human society show that a deeper knowledge of the mechanisms involved must be obtained especially through the observational data of the biochemical processes. In this connection, the reliable assessment of the role that the biochemical cycles play in global ecodynamics is crucial considering that these are the main indicators of sustainable development (Kondratyev et al., 1995, 2006; Nitu et al., 2013a,b). As an example, in the formation of the carbon cycle

Table 2 | Characteristics of reservoirs and fluxes of nitrogen in the biosphere (Figure 7 bottom).

Reservoirs (Gt) and fluxes (10^6 t/year)	Identifier	Estimate
NITROGEN SUPPLIES		
Atmosphere	N_A	39.10^5
Soil	N_S	280
Photic and intermediate layer of the ocean	$N_U + N_P$	2800
Deep and bottom layer of the ocean	$N_L + N_F$	36400
Natural sources of the hydrosphere	H_1^N	0.392
TECHNOGENIC ACCUMULATION		
Fuel burning	H_2^N	22.8
Fertilizers production	H_9^N	41.8
INPUT DUE TO DEAD ORGANISMS		
On land	H_3^N	42.2
In upper layers of the World Ocean	H_{18}^N	5
In deep layers of the World Ocean	H_{12}^N	7.8
INPUT DUE TO ORGANISMS FUNCTIONING		
On land	H_5^N	0.1
In the World Ocean	H_4^N	0.3
BIOLOGICAL FIXATION		
On land	H_6^N	20.3
In the World Ocean	H_{17}^N	10
In the atmosphere	H_{10}^N	40
DENITRIFICATION		
On land	H_7^N	52
In the World Ocean	H_{20}^N	49.8
ATMOSPHERIC FIXATION		
Over land	H_8^N	4
Over the World Ocean	H_{16}^N	3.6
Run-off from land into the World Ocean	H_{11}^N	38.6
Precipitation	H_{13}^N	0.5
Vertical exchange processes in the oceans	H_{14}^N	0.2
Descending	H_{15}^N	7.5
Lifting	H_{19}^N	15
ANTHROPOGENIC EMISSIONS TO THE ATMOSPHERE		
Removal of nitrogen from the cycle due to sedimentation	H_{21}^N	0.2
Input of nitrogen to the atmosphere during rocks weathering	H_{22}^N	0.217
Input of nitrogen to the water medium with dissolving sediments	H_{23}^N	0.091

the soil-plants and the World Ocean play a crucial role which may be assessed by the global carbon cycle model. This model considers different scenarios with geographical grids greater than the needed ones for a reliable assessment.

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