

## **Nanomaterials and their impacts on the Earth system**

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A critical missing link in the complete understanding of Earth and global processes involves naturally occurring, incidental, and synthetic or engineered nanomaterials. All three of these types of nanomaterials may be inorganic, organic, or organometallic. Naturally occurring nanomaterials played a major role in the formation of Earth, and they have been abundant on the planet since. In addition, incidental nanomaterials are unintentionally produced as a result of any form of human influence on the natural environment. These types of nanomaterials have been present since the dawn of human existence, but for the last two and a half centuries since the Industrial Revolution began, their abundance has grown dramatically. In certain geographic areas, they may rival the amount of naturally occurring nanomaterials. Engineered nanomaterials are currently produced in very small quantities by comparison, but they can still have consequential influences on the environment. Measuring and understanding the local, regional, and global impacts of these nanomaterials, individually or collectively, requires a complex, convergent approach which almost invariably involves advanced physical-, chemical-, and biological-based assessment. Such research has resulted in the discovery of the Earth's nanomaterial cycle (analogous to the water, rock, or carbon cycles, for example), and a much better understanding of the behaviour and influence of nanomaterials in and above the Critical Zone, as well as in and above the oceans. These have led to the discovery of previously unknown or under-appreciated nanomaterial influences in both natural, engineered, and mixed settings. Examples include their role in the impacts of changing climate on soils, the atmosphere, and the oceans; the generation and/or movement of nutrients and contaminants in all environmental components and systems; and the decisions behind future energy strategies based in part on nanomaterial production type and distribution due to each energy source and use.