(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
16 June 2016 (16.06.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/090478 A1

(51) International Patent Classification:
G01V 9/00 (2006.01)

(21) International Application Number:
PCT/CA2015/051289

(22) International Filing Date:
8 December 2015 (08.12.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
3350-2014 9 December 2014 (09.12.2014) CL

(71) Applicant: **OCEANEOS ENVIRONMENTAL SOLUTIONS, INC.** [CA/CA]; 207-1425 Marine Drive, West Vancouver, British Columbia V7T 1B9 (CA).

(72) Inventor: **GROSS, Peter**; 207-1425 Marine Drive, West Vancouver, British Columbia V7T 1B9 (CA).

(74) Agents: **OSLER, HOSKIN & HARCOURT LLP** et al.; Suite 1900, 340 Albert Street, Ottawa, Ontario K1R 7Y6 (CA).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

WO 2016/090478 A1

(54) Title: PROCESS AND METHOD FOR REMOTELY MEASURING AND QUANTIFYING CARBON DIOXIDE SEQUESTRATION FROM OCEAN IRON ENRICHMENT

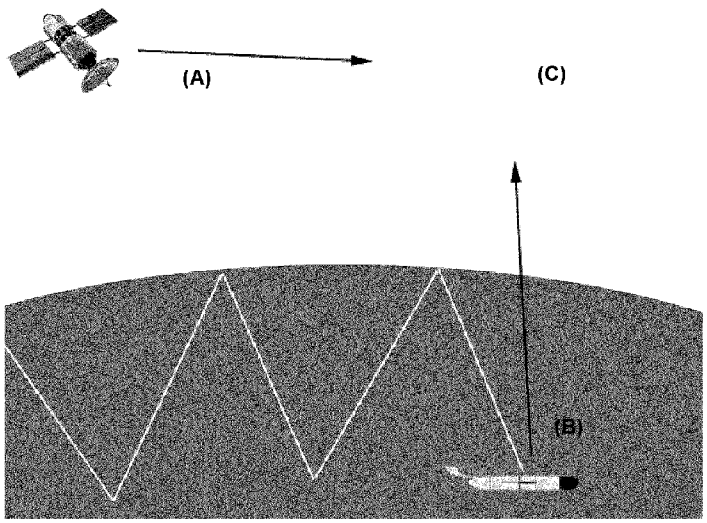

Figure 1

(57) Abstract: Disclosed is a method and process for measuring oceanographic parameters that may be used to create estimates of the quantity of carbon dioxide gas that is removed from the atmosphere from an Ocean Iron Enrichment event. This process uses data observations from Autonomous Underwater Vehicles, Satellite observations and/or Unmanned Aerial Vehicles to determine metrics such as chlorophyll, temperature, turbidity, oxygen, particulate inorganic carbon etc. that may be used to calculate the total anthropogenic carbon dioxide that is removed from the atmosphere. Therefore, the carbon dioxide removal may be determined without requiring a manned presence in the area of study, providing a significant reduction in cost. Direct in-situ measurements of carbon flux through analysis of physical samples through the water column may be used as a verification/calibration metric using sediment traps spaced vertically in the water column from surface to the deep thermocline layer. Alternatively, water samples may be collected and used as an alternative.

PROCESS AND METHOD FOR REMOTELY MEASURING AND QUANTIFYING CARBON DIOXIDE SEQUESTRATION FROM OCEAN IRON ENRICHMENT

FIELD OF THE INVENTION

[0001] This invention relates to oceanography, climatology, and greenhouse gas reduction. Specifically, the present invention relates to methods and a process for measuring key data metrics and how these metrics can be used to measure the quantity of carbon dioxide removed from the atmosphere for a requisite period of time. The carbon dioxide removed from the atmosphere may subsequently be converted into a carbon emission reduction credit.

BACKGROUND OF THE INVENTION

[0002] Ocean Iron Enrichment, also known as Ocean Iron Fertilization or Iron Fertilization is the addition of iron into the surface of the ocean to stimulate a phytoplankton bloom. This is intended to improve biological productivity of the ocean. As phytoplankton grows, it creates a food source for other organisms such as zooplankton, which are subsequently consumed by various larger organisms such as marine cetaceans, fish and others.

[0003] Phytoplankton also consumes large quantities of carbon dioxide through photosynthesis. As the phytoplankton consumes carbon dioxide and light, it releases oxygen and glucose. Because phytoplankton is highly abundant in the world's oceans, the process of Ocean Iron Enrichment may be a highly effective technique to improve the biodiversity of the Ocean and to remove very large quantities of carbon dioxide from the atmosphere.

[0004] Phytoplankton requires small concentrations of iron to enable photosynthesis. Because ocean iron concentrations have lessened notably over the last 50 years, the lack of iron limits the photosynthesis of phytoplankton. Intentional replacement of iron into the ocean to increase phytoplankton abundance is known as Ocean Iron Enrichment.

[0005] An Iron enriched plankton bloom sequesters carbon from the atmosphere. In order to measure the total amount of carbon dioxide that is removed from the atmosphere and sequestered into the deep ocean, several key data metrics must be obtained.

[0006] Smetacek, V et al. Deep carbon export from a Southern Ocean iron-fertilized diatom bloom. Nature 11229 (2012) discloses a Carbon to Chlorophyll ratio (C/Chl, mg/mg) of 32. If new research provides an improved estimate of C/Chl then this improved estimate may be substituted. This metric may also be verified or updated by the use of sediment traps, or water samples in situ, to collect vertical carbon flux in the water column.

[0007] Previously these metrics were collected from manned surface vessels, using manually deployed sensors. The cost of operating a scientific equipped surface vessel, with the additional costs of personnel is prohibitive and excludes analysis of an Ocean Iron Enrichment event to all but the most profoundly funded organizations. Private industrial applications of Ocean Iron Enrichment are also limited by the cost of obtaining the data that may be used to determine the total amount of carbon dioxide sequestration.

PRIOR ART

[0008] In the field of measuring oceanographic parameters are described methods for simulating some features related to plankton growing and the calculation of those parameters in order to take specifics actions.

[0009] Patent document WO 2008131472 A1 (Jones) entitled “Carbon Sequestration using a floating Vessel” with priority day of April 27, 2007 discloses method for removing carbon dioxide from the atmosphere. The method comprises the step of delivering a urea compound from a floating vessel for stimulating plankton growth.

[00010] Patent document WO 2009062093 A1 (Climos) entitled “Quantification and quality grading for carbon sequestered via ocean fertilization” with priority day of November 07, 2007, discloses a computer

software manifestation that is used to calculate various parameters about carbon sequestered via ocean fertilization. This patent is centered around calculations from pre-existing ocean data.

[00011] Patent document WO 2009062097(Climos) entitled "Ocean fertilization project identification and inventorying" with priority day of November 07, 2007, is concerned with making calculations from pre-existing data. The method comprising: identifying an ocean fertilization project location in which carbon has been sequestered; calculating a number of predetermined mass units of the sequestered carbon stored by the ocean fertilization project; associating an identifier with each of the predetermined mass units of the sequestered carbon; indexing the identifiers for the ocean fertilization project in a project tracking database.

[00012] Because most data metrics are obtained from remotely operated sensors, the cost of determining total carbon dioxide sequestration is much less than using manned surface vessels, manned submersibles or manned aircraft.

SUMMARY OF THE INVENTION

[00013] This invention uses a unique combination of remote sensing tools and an *in situ* vertical carbon flux capture device to obtain the data metrics for calculating total carbon dioxide sequestration without requiring a manned presence in the area of study.

[00014] In addition, the invention describes a process and method for acquiring data from ocean. The documents of Climos are materially different. Those documents are related to the calculation of parameters related to ocean fertilization and not with the acquiring data.

BRIEF DESCRIPTION OF THE DRAWINGS

[00015] FIG. 1 is a conceptual diagram illustrating a method for remotely measuring and quantifying carbon, showing the main means used to collect the data according to an embodiment of the invention.

DETAILED DESCRIPTION

[00016] The present invention is related to a method and process for measuring oceanographic parameters that may be used to create estimates of the quantity of carbon dioxide gas that is removed from the atmosphere from an Ocean Iron Enrichment event.

[00017] According to the preferred embodiment of the invention, the data requirements for determining carbon dioxide sequestration into the open (pelagic) ocean through remote means comprise measurement of Chlorophyll concentrations from the ocean surface to the first optical depth and/or Particulate Organic Carbon (POC) concentrations from the ocean surface to the deep thermocline by using autonomous measurement instruments.

[00018] In an embodiment of the invention, the Chlorophyll concentrations are obtained from Satellite observations of Chlorophyll-A (A). Surface carbon fixation may be estimated as Particulate Organic Carbon which is estimated using a Carbon to Chlorophyll conversion ratio (C/Chl). In the absence of satellite observations, Chlorophyll observations from an unmanned areal vehicle (UAV) or drone or any other telecontrolled means, shall be substituted.

[00019] The second step is the obtaining of Ocean Subsurface Measurements, between the Surface to 200 meters or more, specifically the measurements of Chlorophyll concentration (Chlorophyll - A). These readings will be accomplished utilizing an Autonomous Underwater Vehicle (AUV) from surface to a depth of not less than 100 meters (B). This Chlorophyll measurement will used as a term in a Carbon to Chlorophyll conversion ratio (C/Chl) to determine Particulate Organic Carbon in the subsurface.

[00020] A transmissometer or Particulate Organic Carbon sensor mounted on an AUV can be used to measure Particulate Organic Carbon directly as an alternative to estimating Particulate Organic Carbon via Chlorophyll, or in combination with measurements of Chlorophyll to determine metrics for Particulate Organic Carbon.

[00021] The final step is obtaining physical samples of carbon transport, between the surface to 200 meters or more. According to the invention, the physical samples comprises sediment traps that collect vertical carbon flux physically and/or Water samples containing vertical carbon flux which may be subjected to laboratory analysis to determine carbon concentration Finally, the satellite data an subsurface data are sent to remote facility for analysis and carbon quantification (C).

[00022] The physical samples of vertical carbon flux may be collected within the area of interest to calibrate the information collected from remote sensors as stated before.

CLAIMS

1. A method for remotely measuring and quantifying carbon dioxide sequestration from Ocean Iron Enrichment comprises by using remote measurements of chlorophyll using a combination of remote sensing devices like: satellite data, unmanned aerial and/or underwater vehicles, wherein the method comprise the steps of:

    a. measure a Chlorophyll concentrations from the ocean surface to the first optical depth and/or Particulate Organic Carbon (POC) concentrations from the ocean surface to the first optical depth by using remote measurements;

    b. obtain of Ocean Subsurface Measurements, between the Surface to 200 meters or more, specifically the measurements of Chlorophyll concentration (Chlorophyll - A) and Transmissivity or Particulate Organic Carbon which may be substituted for Chlorophyll concentration; and

    c. obtain physical samples of carbon transport, between the surface to 200 meters or more

2. The method for remotely measuring and quantifying carbon dioxide sequestration from Ocean Iron Enrichment according to claim 1, wherein the ocean surface Chlorophyll is remotely sensed and used to provide estimates of carbon sequestration from the ocean surface layer.

3. The method for remotely measuring and quantifying carbon dioxide sequestration from Ocean Iron Enrichment according to claim 2, wherein Chlorophyll readings are obtained from the ocean surface using satellite observations of Chlorophyll-A.

4. The method for remotely measuring and quantifying carbon dioxide sequestration from Ocean Iron Enrichment according to claims 2, 3, wherein the surface carbon sequestration as particulate organic carbon

from the ocean surface to the first optical depth can thereby be calculated using a C/Chl (mg/mg) ratio.

5. The method for remotely measuring and quantifying carbon dioxide sequestration from Ocean Iron Enrichment according to claim 4, wherein in the absence of satellite observations, multispectral Chlorophyl observations from an unmanned aerial vehicle (UAV) containing chlorophyll measurement equipment can be substituted for satellite observations of chlorophyll.

6. The method for remotely measuring and quantifying carbon dioxide sequestration from Ocean Iron Enrichment according to claim 5, wherein the subsurface ocean Chlorophyll is used to provide estimates of carbon sequestration beneath the sea surface.

7. The method for remotely measuring and quantifying carbon dioxide sequestration from Ocean Iron Enrichment according to claim 6, wherein the subsurface readings of Chlorophyl are obtained using an Autonomous Underwater Vehicle (AUV).

8. The method for remotely measuring and quantifying carbon dioxide sequestration from Ocean Iron Enrichment according to claim 7, wherein the subsurface readings of Chlorophyl from surface to a depth of not less than 100 meters are used to provide estimates of Particulate Organic Carbon below the first optical depth of satellite observations.

9. The method for remotely measuring and quantifying carbon dioxide sequestration from Ocean Iron Enrichment according to claim 7, wherein subsurface carbon sequestration as Particulate Organic Carbon is calculated using a C/Chl (mg/mg) ratio.

10. The method for remotely measuring and quantifying carbon dioxide sequestration from Ocean Iron Enrichment according to claims 2 and 9, wherein total carbon sequestration is a sum of carbon sequestration from the ocean surface layer and subsurface carbon sequestration.

11. The method for remotely measuring and quantifying carbon dioxide sequestration from Ocean Iron Enrichment according to claim 7, wherein a transmissometer or Particulate Organic Carbon sensing device mounted on an AUV can be used to measure Particulate Organic Carbon directly as an alternative to estimating Particulate Organic Carbon via Chlorophyll, or in combination with measurements of Chlorophyll to determine metrics for Particulate Organic Carbon.

12. The method for remotely measuring and quantifying carbon dioxide sequestration from Ocean Iron Enrichment according to claims 1 to 11, wherein physical samples of vertical carbon flux may be collected within the area of interest to calibrate the information collected from remote sensors as stated in Claims 1-5.

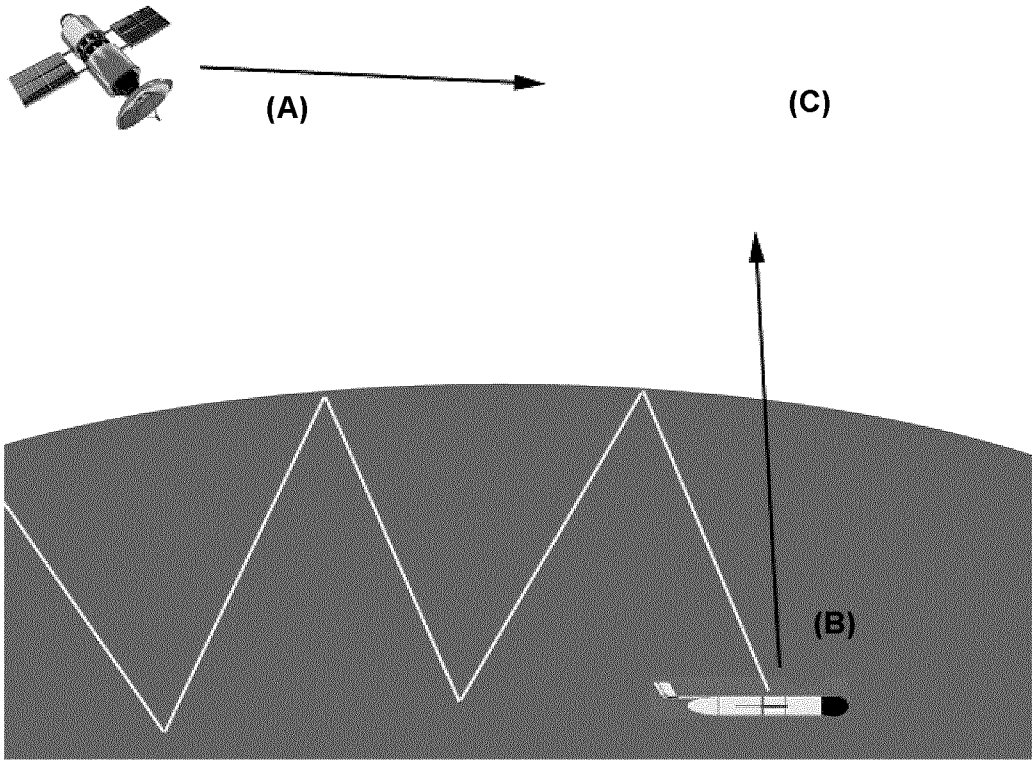

Figure 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2015/051289

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***G01V 9/00*** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: ***G01V 9/00*** (2006.01) (in combination with keywords)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Questel-Orbit (keywords carbon dioxide sequestration, ocean iron enrichment, measur+, sens+, remote, chlorophyll, concentration)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	CA2835792A1, Blue Carbon Solutions Inc. 28 July 2015 (28-07-2015) (See whole document)	1-10
A	WO2008124883A1, Jones 23 October 2008 (23-10-2008) (See whole document)	1-10
A	CA2899051A1, Gross 01 December 2015 (01-12-2015) (See whole document)	1-10
A	US2012202274A1, Yancey, JR. 09 August 2012 (09-08-2012) (See whole document)	1-10

☐ Further documents are listed in the continuation of Box C.

☑ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier application or patent but published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 17 February 2016 (17-02-2016)	Date of mailing of the international search report 22 February 2016 (22-02-2016)
Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 819-953-2476	Authorized officer David E. Green (819) 635-2861

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2015/051289

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
CA2835792A1	28 July 2015 (28-07-2015)	None	
WO2008124883A1	23 October 2008 (23-10-2008)	WO2008124883A1	23 October 2008 (23-10-2008)
		AU2007201687A1	06 November 2008 (06-11-2008)
		AU2008238614A1	23 October 2008 (23-10-2008)
		AU2008238614B2	06 December 2012 (06-12-2012)
CA2899051A1	01 December 2015 (01-12-2015)	None	
US2012202274A1	09 August 2012 (09-08-2012)	US2012202274A1	09 August 2012 (09-08-2012)
		US8628948B2	14 January 2014 (14-01-2014)
		AU2010256745A1	19 January 2012 (19-01-2012)
		CN102803464A	28 November 2012 (28-11-2012)
		EP2438150A2	11 April 2012 (11-04-2012)
		US2014113331A1	24 April 2014 (24-04-2014)
		WO2010141559A2	09 December 2010 (09-12-2010)
		WO2010141559A3	21 April 2011 (21-04-2011)