1st Meeting of the IOCCG Working Group on Remote Sensing of Ocean Colour in Polar Seas

Auberge Saint Pierre, Québec City, Canada (10-11 November 2011)

Introduction - Welcoming words from Marcel Babin and David Antoine

D. Antoine : Working groups are one of the main activities of IOCCG and the reports are one of the most successful outputs of IOCCG. IOCCG membership consists of 35 scientists and agency representatives. IOCCG's expectations relative to the polar seas working group are to conduct a literature review of the complexities associated with OC in the Arctic and Antarctic regions and to provide recommendations to the scientific community and related agencies.

M. Babin : The working group was initiated by K. Arrigo, S. Bélanger and M. Babin. The context of the working group is related to the broad use of OC in polar seas. However, many issues are known to affect measurements. OC is needed to provide regular and sustained measurements of PP, CDOM photooxidation, transport of organic matter, coastal erosion, etc. The identified problems for the use of OC in polar seas:

1. Prevailing low sun elevation, directly affecting the OC products at different times of the day or days of the year
2. Ice-related adjacency and sub-pixel pollution effects, resulting in a significant overestimation of *chl a* and other OC products
3. Pronounced deep *chl a* maxima, due to water column stratification by salinity
4. OC algorithms: Optical peculiarity, resulting from the different proportions of the optically active water components and characteristics specific to the phytoplankton community
5. Cloud cover

The current terms of reference were presented. They will be evaluated and adjusted according to working group recommendations. The timeline includes a second meeting in spring 2012, a submitted version of the group's report in October 2012, and a final version in March 2013. A second output of the working group would be a synthesis paper submitted to *Oceanography*. This first meeting will be divided into three main blocks of presentations under the following themes: Atmospheric correction and ice, IOPs, AOPs and OC algorithms, and Primary production. Discussions sessions will follow each block of presentations and will be continued on the second day of the meeting.

G. Mitchell questioned whether the WG should address directly the new production estimates as a major component of the carbon cycle.
J. Comsio pointed out that some algorithms provide estimates of *chl a* within sea ice

Josefino Comiso – Trends in the Arctic and Antarctic Sea Ice Cover

The presentation was mainly based on passive microwave data, SMMR, SSM/I and AMSR-E. Data show strong seasonal variations in sea ice extent in the Arctic, and a decreasing trend over the last 30 years in daily ice extent was presented, with a more prominent decrease in summer months and in the central Arctic. In the Antarctic, no significant decreasing trend has been observed, although the western coast is more susceptible to a retreat in sea ice extent whereas the southern coast shows an increase in sea ice extent. Ice extent and area anomalies show an overall trend of -4% per decade, although since 1996, the trend has been about -8%. Regional trends were presented. The perennial and multi-year ice represents the thick component of sea ice pack. There has been a rapid decline in perennial ice over the last 30 years, although the multi-year ice (defined as ice that survived 2 summers and more) has shown an even more drastic decline. Significant differences between sensors in detecting multi-year ice were shown. This represents a challenge when combining data for multiyear time-series. A strong decline in Arctic ice thickness was presented. In the Arctic, anomalies of sea ice area were inversely related to anomalies of sea surface temperature. In the Antarctic, trends show an increase in sea ice cover and results suggest a link to the ozone hole and its impact on the environmental components. Ice export, production and salination were discussed for different regions. Sea ice data are available on the NASA website: http://neptune.gsfc.nasa.org

R. Frouin: regarding the low-sun elevation problem, a knowledge of the latitudinal ice extent would be useful. It may result in a reduction of the impact of the low sun elevation on OC products.

Don Perovich: Impact of sea ice trends on radiative forcing, optical properties of sea ice and light penetration into the ocean

In thick multi-year ice conditions, the albedo is about 0.85-0.45. There is currently a substantial reduction in the ice extent and the age of the ice , along with a thinning of the ice cover. In current conditions, the slab usually has a thinner snow cover. However, the snow cover is dense so the change does not have much impact on the albedo. The impact of the change in ice thickness on the light transmission occurs when snow melts and the ice composition permits more light to penetrate and reach the water column. Multi-year ice, with a high bubble content, shows higher scattering properties, which results in higher albedo. The spectral effect of multiyear ice is stronger in melt pond conditions, and at low wavelengths. Spectral transmittance is an order of magnitude higher in ponds than in bare ice conditions, and the light field is highly variable spatially. The behaviour of spectral transmittance exhibits contrasting profiles according to surface conditions, with a maximum transmittance under bare ice conditions. Over the last 30 years, the annual solar heat input has substantially increased, resulting in an increase in open water and a reduction in ice albedo. Overall, the change in ice extent and thickness results in a new distribution of solar radiation.

K. Stamnes questioned if the study included the effect of cloud cover, and D. Perovich answered in the affirmative.

G. Mitchell pointed out that the newly prominence of annual ice will result in high occurrence of melt ponds.
M. Babin wondered if the use of microwave radiations is suitable to evaluate the extend of the melt ponds. J. Comiso explained that the problem is that microwaves only detect water, but cannot discriminate between leads and ponds.

Knut Stamnes: Satellite remote sensing of water, snow, and ice properties at high latitudes.

Retrieval of aerosol and marine parameters in coastal waters is highly susceptible to the effect of high concentrations of optical components. To improve the retrieval accuracy from an inversion approach (OC-SMART) a new algorithm was presented. Results show a good retrieval capacity. A new forward model speeds up computation and provides good retrieval at an operational speed. A comparison of the newly defined algorithm and SeaDAS data shows significant differences in measurements at the TOA. Future efforts will be directed towards the use of polarised characteristics of the light field.
Retrieval of snow and ice properties was explored for different algorithms such as MODIS, GLI and SGLI algorithms. Cloud masks were defined and a comparison of the masks presents strong differences in the OC products. An inverse approach combined to a neural network provided an algorithm for snow properties that compared well with field measurements.

The use of this algorithm could easily be adapted to the new sensor, similar to MODIS.
A pseudo-spherical model is used for atmospheric correction, i.e. spherical model for incoming light, and plane model for scattering properties.

Simon Bélanger: Water-leaving radiance retrieval in presence of sea ice and the effect of low solar elevation

Ice floes, icebergs and landfast ice have different impacts on the retrieval of water-leaving reflectance and the OC products. Ice edges have a stronger signature in the blue wavelengths than in the red portion of the spectra, directly impacting *chla* retrieval. This is explained by scattering in the blue portion of the spectra by snow-covered ice. Thus, the adjacency effect is stronger early in the season and tends to decline in the summer and fall. Absorption retrieval is also affected by ice edges. The aerosol estimates result in an over estimation of *chla* concentration. The adjacency effect results in an increase in the 412/443 ratio, and a flag has been established to reflect this property of the light field. The current atmospheric correction is problematic when sun zenith angle $< 70^{o}$. A study in the NOW polynya (Arctic waters) showed a variation in the water-leaving radiance with the sun zenith angle, directly impacting the *chla* estimates from remote sensing of OC.

Mengua Wang: Sea ice detection and sea ice optical properties measured by MODIS-Aqua in the Bohai Sea

Sea ice represents 7% of the global ocean coverage. Characteristics of ice reflectance results from molecule, aerosol and sea surface reflectance. Sea ice is almost black at

2130nm and 1640nm, but shows various spectra depending on the different optical components, usually peaking at 680nm. From the black band, we can derive sea-ice reflectance. Criteria for detection of sea ice in Bohai Sea, based on reflectance measurements, were presented. Based on a scatter plot of nlw 859 vs p555/p412, three groups can be discriminated: open water, turbid water and sea ice. Identification of sea ice is more difficult when sea ice is covered with snow, since snow shows a high reflectance at wavebands that are black under ice conditions. At high latitudes, the reflectance spectra are dominated by the red portion, as opposed to the blue-green dominated spectra found in mid and low latitudes. Results showed that the water-leaving radiance is highly affected by the solar zenith angle owing to the increase proportion of the atmospheric scattering component in TOA measurements.

M. Babin questioned the possibility to improve atmospheric correction? M. Wang explained that the improvement is much needed but not a simple task.

Robert Frouin: Atmospheric correction of ocean color imagery in high latitude regions

The atmospheric correction of OC depends on four main issues that standard algorithms usually ignore: i) low solar elevation, ii) high cloud cover, iii) adjacency effects from snow, ice and clouds and iv) the presence of ice in the field of view. These issues are generally related to multiple scattering, which modifies the spectral signal. The threshold of 0.03, as currently used in operational processes, results in very low amount of available pixels. To address the high cloud cover, in RT modelling, additional terms related to the cloud albedo were included. This resulted in computation difficulties. Different algorithms were presented for the retrieval of atmospheric terms based on an optimisation of all the wavebands. The use of these algorithms significantly improves the retrieval of OC products with cloud albedo of up to 0.2. For the adjacency effects, three main approaches were proposed to correct the TOA signal. Results show that these corrections have a significant effect on *chla* retrieval by de-correlating the *chla* in distant pixels. The POLYMER algorithm showed an improved retrieval of *chla* estimates in pixels adjacent to ice. However, the sub pixel ice contamination, which is similar to the problem of whitecaps, is complicated by the variability in the spectral signal of ice. The POLYMER algorithm tends to correct for these signal contaminants. Overall, it is difficult to address the atmospheric correction problem. Approaches exist, but are both time consuming and computationally demanding.

Greg Mitchell: OC algorithms in Polar Regions and concepts for satellite estimate of export flux.

Photobiology group data cover a wide range of bio-optical conditions and regional oceans. Results show a difference in bio-optical values in Arctic and Antarctic environments. From the Southern Ocean data, *chla* estimates show a different relationship to water-leaving radiance. Using the newly defined relationships delineated from in situ relationships, NPP is modeled and shows good agreement with in situ measurements. Similarly, Arctic data showed contrasting optical properties, different from both the NOMAD low latitude dataset and the Southern Ocean dataset. Export fluxes in the Southern Ocean as estimated from OC show high inter annual variability. The explanation of these variations, which represents an important goal for the Polar Seas scientific community, was addressed using various approaches.

Rick Reynolds, as presented by Greg Mitchell: The role of IOPs and seawater constituents in influencing ocean color algorithms in polar seas

The role of IOPs and sea-water components were explored and relationships between different IOPs and *chla* were shown. Overall, contrasting relationships were found in the Arctic and the Southern Oceans. Representative regions for IOP characteristics were identified.

Atsushi Matsuoka: Inherent optical properties and ocean color algorithms for Arctic waters

The Artic Ocean receives about 10% of global freshwater, which strongly affect the optical properties of the sea-water components. Absorption and scattering properties were measured both for CDOM and particulate matter. The pigment packaging effect is higher in Arctic waters. Results show a high contribution of the CDOM absorption to the optical signal. When looking at the three main *chla* algorithms, regional responses vary. in some case showing strong disagreement with in situ measurements. Overall, IOPs show different relationships than the global dataset, and a new parameterisation of these relationships was presented. These regional relationships were used to develop a modified GSM inversion model and have provided good IOPs maps. The modified GSM model is not yet available but will be available soon. The CDOM algorithm remains to be validated with an independent dataset.

Kai Sorensen: CalVal activities in Arctic Ocean

The in situ database consists of the Ferrybox network. High cloud cover is a challenge in CalVal activities. Good agreement was found between MERIS *chla* and Ferrybox measurements for some of the transects. A Coccolithophore bloom event showed reflectance spectra closely related to the MERIS spectra. A bio-optical field mission was undertaken and MERIS products were compared to in situ measurements. The planning, implementing and operating infrastructure of SIOS (**S**valbard **I**ntegrated Arctic Earth **O**bserving **S**ystem), a multi-national research network dedicated to circum-Arctic monitoring, was introduced to the working group.

Kevin Arrigo, as presented by Mathieu Ardyna: Estimation of primary production from ocean color in polar seas: potential and limitations

Four methods of estimating Arctic NPP were presented. The errors associated with each method were assessed. Generally, a broader and deeper Deep $Chla_{max}$ results in higher errors. A higher % change is found in winter months, when *chla* concentrations are low, and the % change in summer month is less significant. Results from ICESCAPE showed strong stratification of nutrients and a related *chla* concentration. Moreover, a strong *chla* concentration under ice-covered conditions was observed. The seasonal production rate was consistent with earlier findings. During ICESCAPE 2011, the ice was thick but the melt pond fraction was high, allowing transmission of >50% incident irradiance. Estimates of PP from remote sensing of OC were strongly underestimated compared to in situ measurements, which was most likely due to primary production under the ice cover.

Toru Hirawake: Estimation of primary production from OC in polar seas: potential and limitations

Issues related to estimation of PP from OC are associated with the relationship between PP and SST, as well as the estimation of *chla* from OC algorithms. An absorption-based model to estimate PP in the Southern Ocean provided results that agreed well with in situ measurements. This is contrary to the VGPM model (which is based on SST), particularly for station with SST < 1°C. Phytoplankton absorption was related to primary production at the surface. Uncertainty related to *chla* estimation was addressed by using absorption model. The absorption-based model may provide an improved approach for the estimation of PP in cold polar seas.

Simon Bélanger: Primary production from ocean color in the Arctic Ocean

Two photochemical reactions were presented: photosynthesis and photooxidation. These two photochemical reactions were taken into account in the development of the primary production model. The photosynthetic parameters were introduced and methods to estimate them were presented: P^B_{max} is constant, I_k is related to *PUR*, *PUR* and *chla* are estimated by OC. A newly developed algorithm was presented to estimate PUR at the sea surface, correcting for cloud, optical thickness, ice and time-dependency. Validation remains to be completed from in situ data. Calculations have been conducted on two modes, high resolution for a time-series mode, and 9km resolution for the Pan-Arctic mode. Estimates of PP using this model are concurrent with in situ measurements of environmental factors such as salinity, nutrients and *chla*. Maps of PP estimates and trends in PP over the Pan-Arctic Ocean were presented, with a general increase in PP over the 1998-2010 period. A data analysis was conducted on the impact of temporal variation in cloud and sea ice over PP estimates, and a general positive trend was found, with the exception of an increase in cloud cover, which reduces the available light. A sensitivity analysis to OC algorithms of K_d and *chla* showed best results from PP estimated with GSM for *chl*a estimates and Lee et al. for Kd estimates.

In the Beaufort Sea, it was noticed that fluorometric data are usually twice the value of HPLC data.

Victoria Hill: Potential and limitations of OC remote sensing for Arctic PP

The estimates of *chla* for open water were discussed, with a bias pointed out for monthly images compared to 8-day averages. The limitation of passive OC was compared to results obtained from microwave radiations.

Marcel Babin: Discussion and working group planning

To illustrate the type of original work that could be produced in the report, a sensitivity analysis was presented on the impact of pixels with no OC data on PP estimates.

It was suggested that teleconferences should be held on a monthly basis between the members of each subgroup, with participation of either Marcel Babin or Marie-Hélène Forget.

Proposed timetable
Nov. 2011, first meeting of working group
May 2012, second meeting of working group
Oct, 2012, submitted version of the report for internal review
Dec 2012, 2nd version of report for external review
March 2013, final version

General Outline of the report

1. Introduction
    a. Arrigo, **Babin** & Belanger
2. The polar environment: Sun, clouds and ice
    a. Comiso, **Perovich**, Stamnes
3. From TOA to the ocean sub-surface at high latitudes
    a. **Belanger,** Frouin, Perovich, Wang
    b. Literature review mostly, but may include original work in some sections such as low sun angle
4. IOPs, AOPs & OC algorithms for various products
    a. Belanger, Frouin, Hirawake, Mitchell, **Reynolds,** Sorensen
5. PP and related products
    a. **Arrigo**, Belanger, Hill, Hirawake, Mitchell
6. Recommendations
    a. **Babin** et al.

Appendix I

List of Attendees:
Josefino Comiso, NASA – Goddard (sea ice)
Knut Stamnes, Stevens Institute of Technology (radiative transfer in coupled atmosphere/snow/ice systems)
Kai Sorensen, Norwegian Institute for Water Research - NIVA (ocean colour and validation in the Arctic)
Don Perovich, EDRC-CRREL (optical properties of ice and snow)
Gregg Mitchell, Scripps Institution of Oceanography –UCSD (marine optics)
Claudie Marec, Takuvik (instrumentation)
Joannie Ferland, Takuvik (phytoplankton)
Guislain Becu, Takuvik (instrumentation)
Mathieu Ardyna, Takuvik (PhD student – primary productivity)
Emmauel Devred, Takuvik (remote sensing)
Maxime Benoît-Gagné, Takuvik (remote sensing)
Thomas Lacour, Takuvik (primary production)
Atsushi Matsuaka, Takuvik (PDF – marine optics)
Toru Hirawaka, Hokkaido University (primary production)
Robert Frouin, Scripps Institution of Oceanography – UCSD (ocean colour)
Mengua Wang, NOAA/NESDIS/STAR (ocean colour)
Simon Bélanger, UQAR (remote sensing of ocean colour in Arctic)
Marcel Babin, Chairman, ULaval
Marie-Hélène Forget, Takuvik (Coordinator, CERC)
Debbie Christiansen Stowe, Takuvik (Asst. Coordinator, CERC)

Apologies:
Kevin Arrigo, Stanford University (primary production)
Rick Reynolds Scripps Institution of Oceanography – UCSD (ocean optics)
Victoria Hill Old Dominion University (primary production)

AppendixII: Agenda of the 1st meeting of the IOCCG working group on remote sensing of ocean colour in polar seas.

Theme	Start time	Proposed title / activity	Speaker
Introduction	09:00	Scope of the WG job	Babin
Atmospheric corrections and ice	09:45	Trends in sea ice (Arctic and Antarctic)	Comiso
	10:05	Impact of sea ice trends on radiative forcing, optical properties of sea ice and light penetration into the ocean	Perovich
	10:25	Radiative transfer in coupled atmosphere-snow-ice-ocean systems, and retrieval of snow-ice optical properties	Stamnes
	10:45	Break	
	11:15	Contamination of remotely sensed ocean color by sea ice and the problem of low Sun elevation	Bélanger
	11:35	Sea ice detetion, atmospheric corrections and the problem of low Sun elevation	Wang
	11:55	Atmospheric corrections in the presence of sea ice	Frouin
	12:15	Lunch	
	13:45	Discussion about chapter to be prepared under that theme	
IOPs, AOPs and OC algorithms	14:15	IOPs and OC algorithms in polar seas	Mitchell
	14:35	IOPs and OC algorithms in polar seas	Reynolds
	14:55	IOPs and OC algorithms in polar seas	Matsuoka/Babin
	15:15	Break	
	15:45	Calval activities in the Arctic Ocean	Sorensen
	16:05	Discussion about chapter to be prepared under that theme	
Primary production	16:35	Estimation of primary production from ocean color in polar seas: potential and limitations	Arrigo
	16:55	Estimation of primary production from ocean color in polar seas: potential and limitations	Hirawake
	17:15	Estimation of primary production from ocean color in polar seas: potential and limitations	Bélanger/Babin
	17:35	Adjourn	
	09:00	Estimation of primary production from ocean color in polar seas: potential and limitations	Hill
	09:20	Discussion about chapter to be prepared under that theme	
Detailed planning of the job to be done	09:40	Breakup into seperate theme working groups to detail the outline of chapters and share the work	
	10:50	Break	
	11:20	Continue	
	11:50	Wrap up and end, lunch	Babin