14-15 August 2012
Scripps Institution of Oceanography, La Jolla, California, United States

2nd meeting of the IOCCG working group on remote sensing of ocean colour in polar seas

Attendees :
Marcel Babin, co-chair, Takuvik ULaval and CNRS (ocean colour and primary production)
Simon Bélanger, co-chair, UQAR (remote sensing of ocean colour in Arctic)
Kevin Arrigo, co-chair, Stanford University (primary production)
Rick Reynolds, host, Scripps Institution of Oceanography – UCSD (ocean optics)
Victoria Hill, Old Dominion University (primary production)
Josefino Comiso, NASA – Goddard (sea ice)
Knut Stamnes, Stevens Institute of Technology (radiative transfer in coupled atmosphere/snow/ice systems)
Don Perovich, EDRC-CRREL (optical properties of ice and snow)
Greg Mitchell, Scripps Institution of Oceanography –UCSD (marine optics, phytoplankton)
Atsushi Matsuoka, Takuvik (PDF – marine optics)
Toru Hirawake, Hokkaido University (primary production)
Robert Frouin, Scripps Institution of Oceanography – UCSD (ocean colour)
Marie-Hélène Forget, coordinator, Takuvik (primary production)
Mati Kahru, Researcher, Scripps (ocean colour remote sensing)
Manfredi Manizza, Project scientist, Scripps (modelling)

Absentees:
Kai Sorensen, Norwegian Institute for Water Research - NIVA (ocean colour and validation in the Arctic)
Mengua Wang, NOAA/NESDIS/STAR (ocean colour)
Dmitry Pozdnyakov, Nansen International Environmental and Remote Sensing Centre St. Petersburg (NIERSC) (Primary production)

Summary

The IOCCG working group on Remote Sensing of Ocean Colour in Polar Seas, co-chaired by Marcel Babin (Takuvik joint laboratory, CNRS-France, Université Laval-Canada), Kevin Arrigo (Stanford University, USA) and Simon Bélanger (Université du Québec à Rimouski, Canada), was created in 2011 to review and address specific issues related to the use of remote sensing of ocean colour in polar regions. The working group is especially concerned by the prevailing low sun elevation, the ice-related adjacency and sub-pixel contamination effects, the relative proportion of the optical components in sea water affecting the ocean colour algorithms, the pronounced deep chlorophyll maxima and the persistent cloud cover.

The second meeting of the working group was hosted by Scripps Institution of Oceanography (La Jolla, USA) on 14-15 August 2012. The twelve members attending the meeting assessed the progress in draft documents, discussed the detailed content of the report and agreed on data processing and sensitivity analyses to be conducted for the

completion of each chapter. The report will cover the following sections: Introduction, The polar environment: sun, cloud and ice, From TOA to the ocean sub-surface at high latitude, IOPs, AOPs and OC algorithms for various products, Primary production and Conclusion and recommendations. The report is expected to be ready for publication by March 2013.

Introduction to the meeting, Marcel Babin

Introducing words from 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. A new item to the terms of reference was added, i.e. to address under-ice spring blooms. The revised timeline propose a submission of the first version of the chapters for internal review on 1st November 2012 and a second version of the report in December 2012 for external review. The final version of the report would be ready for publication in March 2013. A second output of the working group would be a synthesis paper submitted to *Oceanography*. This meeting is mainly focusing on group work and discussion. The meeting will finish with a presentation of the final steps required to provide the final chapters in a timely manner.

Goals of the meeting are to review the draft documents and discuss the detailed content of the chapters, to agree on the deadlines and to agree on the strategy for other publications.

A discussion related to the number of peer-reviewed papers resulting from the working group will take place at the end of the meeting.

The format of the monograph is dictated by the IOCCG standard. The size of the report targets a total of 120 formatted pages, including the reference section. Chapters 2-5 should aim at a maximum 15 figures with 15-20 pages of text excluding the references. References should follow the format:
Addison, R.F. and Stewart, J.E. (1989). Domoic acid and the eastern Canadian molluscan shellfish industry. Aquaculture 77: 263-269

Session 1. Presentation of chapters:

Don Perovich - Chapter 2. The polar environment: Sun, clouds and ice

The outline of the chapter includes the following sections: Introduction, Sun, Clouds, Ice and Discussions. The introduction will present the key points that are specific to polar regions, and the differences between the Arctic and Antarctic. The spectral incidence of UV and PAR will be presented. The optical properties will be addressed and a comparison between observed vs modelled radiation will be conducted. The cloud effect will be presented showing differences from various satellites and Arctic and Antarctic variability. The effect of clouds on the surface will be discussed. The optical properties of the ice will be presented, as well as the sea ice type and the evolution of ice types and surface conditions (melt ponds, snow, ice, open water, etc) and their effect on the spectral albedo. Time series of ice cover will be discussed showing intra and inter-annual variability and trends. A detailed outline of the chapter is presented in Appendix A.

Questions and comments:

- M. Babin would like to have a section addressing the spatial variability of ice conditions. J. Comiso was suggesting a Landsat image.
- M. Babin was interested in having a section that would present the approaches used to estimate ice cover from remote sensing techniques.
- M. Babin pointed out the need to increase the temporal resolution of cloud images presented, and it was suggested to present monthly distribution and frequency of clouds during the time of interest.
- K. Arrigo was inquiring if it could be possible to discriminate the type of clouds and address the issue of the ozone hole in polar regions in this chapter.
- R. Frouin wondered if we need this level of details in this report, since this IOCCG report is about remote sensing of ocean colour in polar waters, he is suggesting that this chapter only focuses on describing the environment and not the methods to get this type of data. G. Mitchell suggested that this report should only presents what can be measured currently, and that the upcoming approaches for applications of remote sensing of ocean colour in polar regions should be pointed out in the recommendation section.
- R. Frouin suggested that sections 2.3-cloud and 2.4-ice should be presented following a similar format, with the same subsections.
- M. Babin would like to have a description of the diel cycle of light and a comparison of estimates from Plane Parallel and Spherical Atmosphere. K. Stamnes agreed that it would be a pertinent chapter to present these data.

Simon Belanger - Chapter 3. From TOA to the ocean sub-surface at high latitudes

This chapter will explore the difficulties related to the measurements of accurate ocean colour data, after applying proper atmospheric corrections that are influenced by sea ice, clouds and sun elevation. Sea ice contamination has only been addressed in 2 peer-reviewed papers. The atmospheric correction equation was presented. The adjacency effect will increase the radiance from the Rayleigh component of the equation and the spectral dependency of the measured water-leaving radiance will match the Rayleigh spectral properties. The adjacency effect is not accounted for in the current ocean colour algorithms. At low Chla concentration, the effect is minimal, and increases under high Chla concentration up to 10km from the ice pack. Two independent methods were proposed (Belanger et al. 2007, Wang and Shi 2009), one focusing on the blue wavebands and the other on the NIR wavebands. The two methods were tested on Arctic waters and will be applied to Antarctic waters. The sub-pixel effect results from contamination of the signal from small portion of ice in the OC signal. The problem was presented but no current approaches are available to correct for sub-pixel effect. Low solar elevation was addressed by Ding and Gordon in 1994, which presented a strong impact of using Plan Parallel on the estimation of Leaving water radiance above 70o North. MODIS and SeaWiFS measurements from high latitude showed systematic diel variation related to the sun zenith angle. Clouds frequency was presenting according to the number of days used to compute composite images or as a function of day of the year. A detailed outline of the chapter is presented in Appendix A.

Questions and comments:

- M. Babin would like to have results from a sensitivity analysis of the impact of the identified problems on applications of OC to biological questions. S. Belanger is not convinced that this is the chapter to conduct this analysis.
- For the adjacency effect, M. Babin is wondering what the 2.5% in reflectance corresponds to in terms of ice content in a pixel. S. Belanger has done computations and concluded that it corresponds to 6% of ice in a pixel.
- K. Stamnes is wondering if one of the recommendations should specify that data from multiple sensors be combined to have higher numbers of observations in polar regions.

Rick Reynolds - Chapter 4. IOPs, AOPs & OC algorithms for various products

This chapter will review the performance of empirical and semianalytical OC algorithms when applied to polar regions, with the primary emphasis on chla retrieval. Measurements of inherent optical properties associated with high latitude oceans will be reviewed. The chapter will conclude with an intercomparison and sensitivity analysis of operational chla algorithms. A discussion was related to the definition of the polar seas, and whether latitude or frontal features were most appropriate in the context of remote sensing. It was pointed out that data from the NASA Nomad database are scarce for polar regions, <27% for Antarctic Ocean and <3% for Arctic Ocean. Available data suggests that chla algorithms generally underestimate the chla concentration in the Antarctic Ocean whereas they overestimate the chla in the Arctic Ocean. Is this resulting from different measurement methods? A preliminary comparison of HPLC and fluorometic estimates showed no systematic bias for Antarctic ocean chla measurements. No data are currently available for the Arctic Ocean (S. Belanger and V. Hill have data to contribute to this analysis). Semianalytical algorithms such as QAA for phytoplankton absorption appears to provide good results in the Antarctic, with less success in the Arctic Ocean. The optical properties of seawater constituents measured in polar regions were presented and differences between the Arctic and Antarctic Oceans were highlighted in addition to regional variability. A sensitivity analysis comparing observed trends in OC algorithms to models will be undertaken, and applications will be provided. A recommendation should highlight the need for more in situ data of optical properties in polar regions. A detailed outline of the chapter is presented in Appendix A.

Questions and comments:

- R. Reynolds brought up the issue of how best to proceed for the sensitivity analysis. M. Babin suggests to select one image and apply different algorithms and assess their success over different type of waters (high chla, oligotrophic, high CDOM, etc). This would provide an algorithm intercomparison analysis. M. Babin points out that one of the main differences in Arctic waters is the high packaging effect. A second sensitivity analysis approach would be to start with a dataset of optical measurement and compute remote sensing reflectances as the standard dataset to apply algorithms.
- R. Reynolds would also need to gather data from the Arctic waters for comparison of HPLC and fluorometric data.

Kevin Arrigo - Chapter 5. PP and related products

The outline of the chapter was presented, the sections will describe the photosynthetic properties, a review of productivity algorithm, a comparison of algorithms, the problems with accuracy of algorithm inputs, the CDOM problem and the Subsurface Chlorophyll Maximum (SCM) problem. The 8 algorithms that will be compared were presented. The algorithms are highly sensitive to the accuracy of their inputs, namely chlorophyll estimates, SST and phytoplankton photosynthetic properties. The SCM problem was presented and is consequential to the limited number of observations of the chla vertical distributions in the Arctic. The SCM is a trend mainly observed in the summer in polar regions, and most importantly in the Arctic Ocean and result in a consistent underestimation of PP from remote sensing of OC compared to in situ measurements. This underestimation is on average of about 10%. Moreover, the CDOM concentration in the Arctic being overall very high, generally resulting in an overestimation of chla at the surface and in a significant overestimation of PP on a monthly basis, although the overestimation is in general smaller on a seasonal or on an annual scale. The reasons for obtaining such small errors in computation of PP as related to the problems of SCM and CDOM were discussed. Future directions and recommendations were presented. A detailed outline of the chapter is presented in Appendix A.

Questions and comments:

- M. Babin would like to include the K_d estimation problem in this chapter.
- M. Babin was wondering if this chapter should provide advice regarding photosynthetic parameters values.

- M. Babin discussed the proposed methods to improve the CDOM estimates. G. Mitchell is currently working on some of these issues.
- R. Frouin was wondering if there is a need to make a sensitivity analysis to address the 'missing pixel' problem resulting from the cloud cover. S. Belanger pointed out that a suggested approach is to use the climatological data to fill the gaps.
- K. Stamnes was wondering how the light field is estimated keeping in mind that cloud cover is an issue in the Arctic. This will be addressed in the chapter.
- M. Babin would like to address separately the effect of CDOM and packaging effect on the PP estimates.
- R. Frouin was suggesting point out the importance to have match-ups between in situ PP and remotely-sensed estimates in the recommendation section.
- M. Babin would like to include a discussion on the importance of under-ice blooms
- M. Babin presented new results on SCM from a paper to be published shortly by Ardyna et al. in Biogeosciences. These data could be included in this chapter.

Marcel Babin - Chapter 1 and 6, Introduction, conclusion and recommendations

The introduction and conclusion should be self-sufficient and could become the synthesis paper to be published in Oceanography. The introduction will discuss the effect of climate change on the polar environment and introduce the problems related to remote sensing of OC in polar regions.

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. The implication to ice-edge blooms will also be discussed.
3. Pronounced deep *chl a* maxima, du e 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

Questions and comments

- R. Frouin is wondering if all the figures presented will be in the introduction. M. Babin specified that only five figures, one for each issue identified in the use of remote sensing in the Arctic, would be included in that chapter.
- It was agreed that detailed recommendations be included in each chapter and an overview of the recommendations be presented in the 'conclusion and recommendation' chapter.

Session 2. Review of chapters and planning of remaining tasks:

Don Perovich - Chapter 2. The polar environment: Sun, clouds and ice

Over the meeting, the group reviewed the figures to be included in the chapter. Tasks were assigned to each member, with a chapter target deadline for 1st of October.

Simon Bélanger - Chapter 3. From TOA to the ocean sub-surface at high latitudes

A list of data processing and sensitivity analyses was established. K. Stamnes will contribute to this chapter by providing light field information from light transmission models. M. Wang will probably be involved in the estimation of the ice albedo, which could be interesting for the underwater light field. M. Babin is wondering if this analysis should instead be included in Chapter 2. A list of assignments has been established. S. Bélanger will contact M. Wang to update him on the meeting and decide what his tasks will be. J. Comiso suggested to use passive microwave to look at ice concentration. M. Babin has offered the time of E. Devred and M. Benoit-Gagné to help with the workload to process new results. R. Frouin will produce maps with the number of days with ice-free conditions. R. Frouin will also make a data analysis of the cloud effect. There will also be examples of correction of adjacency effects, which will result in a recommendation to agencies to apply a correction when a pixel is flagged for adjacency effects.

Rick Reynolds - Chapter 4. IOPs, AOPs & OC algorithms for various products

A list of tasks was established. It was pointed out that the retrieval of K_d could be included in this chapter, or possibly in the PP chapter. Two types of sensitivity analyses will be undertaken. The first one will be to apply different algorithms to one single image and to assess the differences in chla retrieval between the algorithms. A second sensitivity analysis will look at the range of IOPs within specified ranges of chla, and how the variation of the chla-specific IOPs will alter the shape of the reflectance spectra. The data analyses should be conducted over the next month.

Kevin Arrigo - Chapter 5. PP and related products

A list of tasks was established:

5.1. Compile photosynthetic parameters, lit search – all

a. Victoria will look for unpublished data from Glenn.

5.2 Review of algorithms –all

a. Everyone to write a paragraph outlining their algorithm

5.3 Comparison of different algorithms – all

a. Kevin to find cloud free image to run algorithms on, Chukchi, Beaufort, Barents, early July, plus other input (these scenes also used in IOP chapter 4). Antarctica, early December regions East of Peninsula.
b. Everyone run their algorithms, and return results to Kevin.

5.4 Problems with accuracy of algorithm input - Kevin

a. Chl a, SST, data gap, incident irradiance (different ways of getting it) – Kevin
b. Simon has analysis of cloud gaps.

5.5 The CDOM problem, assessing the errors – Kevin & Toru
a. Separate pigment packaging from CDOM effect.

5.6 Subsurface chl a max contribution – Kevin
a. Recalculate PP profiles from Chl a profiles in Arrigo using P vs. E from Hill et al produce upper end of SCM contribution.

G. Mitchell is pointing out that in the comparison of algorithms, the inputs of chla and light should be uniform to all algorithms to ensure that the results shown are related uniquely to the PP model. M. Babin also suggested to conduct a sensitivity analysis where, for one specific model, the input would vary on a consistent fashion to investigate its impact on the estimates. A simple comparison of PAR between monthly SeaWiFS estimates, S. Belanger's approach and K. Arrigo approach will be conducted.

Marcel Babin: Discussion

A list of tasks for each chapter, with members and timeline assigned to each task is requested by M. Babin.

G. Mitchell is pointing out the challenges related to writing a chapter and a peer-reviewed paper. R. Reynolds is questioning the feasibility to have a stand alone review article from chapter 4, but it may be a good idea to combine with Chapter 5. D. Perovich believed that Chapter 2 being a review chapter, it may not be appropriate to publish a stand-alone peer-reviewed paper. K. Arrigo would prefer to have all chapters published in *Oceanography*. M. Babin will provide more information to the group within the next 2 weeks regarding the strategy for peer-reviewed papers as an output from the working group.

Suggested journals: *Oceanography, Progress in Oceanography, International Journal of Oceanography, Ocean Sciences*

Oceanography was selected as the preferred journal by the working group.

Action 1: M. Babin to contact the editor of Oceanography to discuss the possibility to publish chapters or section of chapters in a special issue of the journal.

Action 2: M. Babin to contact D. Antoine, the Chair of the IOCCG to discuss the format of publication suggested by this Working group

Action 3: All chapter leads are to send an updated list of tasks and timeline for each chapter to M.-H. Forget to facilitate the coordination of the report.

Appendix A: Detailed outline of the report

Chapter 1. Introduction (*K. Arrigo, **M. Babin** & S. Belanger*)

Chapter 2. The polar environment: Sun, clouds and ice (*J. Comiso, **D. Perovich**, K. Stamnes*)
2.1 Introduction (*D. Perovich*)
 2.1.1 The polar environment
 2.2.2 Arctic and Antarctic contrasts
2.2 Sun (*K. Stamnes*)
 2.2.1 Solar elevation
 2.2.2 Spectral incidence, UV, and PAR
  2.2.2.a Observations
  2.2.2.b Model results
2.3 Clouds (*K. Stamnes, J. Comiso*)
 2.3.1 Cloud climatology
 2.3.2 Trends in cloud climatology
2.4 Ice
 2.4.1 Optical properties of the ice cover (*D. Perovich*)
 2.4.2 Ice types and evolution (*D. Perovich*)
 2.4.2 Ice morphology (ice edge, floe size, ponds)
 2.4.3 Snow on ice (*D. Perovich*)
 2.4.4 Modeled and observed albedo
 2.4.5 Remote sensing of sea ice
 2.4.5 Variability and trends in sea ice (*J. Comiso*)
  2.4.5.a Concentration
  2.4.5.b Age
  2.4.5.c Thickness
2.5 Discussion (interconnections between elements) (*J. Comiso*)

Chapter 3. From TOA to the ocean sub-surface at high latitude (***S. Bélanger,** R. Frouin, D. Perovich, M. Wang*)
3.1 Introduction (*S. Bélanger*)
3.2 Issues related to sea ice (*S. Bélanger*, *M. Wang*)
 3.2.1 Contamination of ocean color retrievals
 3.2.2 Sea ice detection
 3.2.3 Sea ice properties from OC data
3.3 Issues related to clouds (*R. Frouin, M. Wang*, *E. Devred*)
 3.3.1 Clouds detection
 3.3.2 Satellite coverage (multi-sensors, geostationary-like orbits)
3.4 Issues related to low sun elevation (*S. Bélanger*, *R. Frouin*)
 3.4.1 Illustration of the problem
 3.4.2 Plane parallel versus Spherical
3.5 Issues related to coastal and shallow waters with significant turbidity (*S. Bélanger*, *M. Wang*)

3.5.1 Illustration of the problem
3.6. Recommendations

Chapter 4. Ocean color algorithms and bio-optical relationships for polar seas (*S. Bélanger, R. Frouin, T. Hirawake, G. Mitchell,* ***R. Reynolds,*** *K. Sorensen*)
4.1 Performance of extant ocean colour algorithms in polar regions.
4.1.1 Empirical models for chlorophyll a (*Reynolds, Mitchell*)
4.1.2 Empirical models for POC and other products (*Hirawake, Reynolds*)
4.1.3 Semianalytical models (*Hirawake, Mitchell, Matsuoka*)
4.1.4 Handling transitions and boundaries (*Mitchell*)
4.2 Inherent optical properties and bio-optical relationships in polar seas.
4.2.1 IOPs and role of seawater constituents (*Reynolds, Matsuoka*)
4.2.2 AOPs (*Belanger, Babin*) – may move to CH5 (specifically Kd)
4.3 Comparison and sensitivity analysis of operational algorithms
4.3.1 Algorithm intercomparison analysis for Chl (*Reynolds, Matusoka*)
4.3.2 Sensitivity analysis (*Reynolds, Belanger*)
4.4 Summary and Recommendations (*All*)

Chapter 5. Primary production and related products (K. Arrigo, S. Bélanger, V. Hill, T. Hirawake, G. Mitchell, D. Pozdnyakov)
5.1. Photosynthetic properties of polar phytoplankton (*all*)
5.2. Review of productivity algorithms for polar regions (*all*)
5.3. Comparison of algorithm output using standardized input dataset (new results) (*all*)
5.4. Problems with accuracy of algorithm input (*K. Arrigo*)
5.5. The CDOM problem (add Kd modeling) (*K. Arrigo, T. Hirawake*)
5.6. The SCM problem (*K. Arrigo*)
5.7. Future issues (*K. Arrigo*)

Chapter 6. Conclusion and recommendations (***M. Babin*** *et al.*)

Appendix B. Revised timetable

Nov. 2011, first meeting of working group
Aug. 2012, second meeting of working group
Nov. 2012, 1st version of the report for internal review
Dec. 2012, 2nd version of the report for external review
Feb. 2012, IOCCG annual meeting and review of the report
March 2013, final version submitted for publication

Appendix C: Agenda of the 2nd meeting of the IOCCG working group on remote sensing of ocean colour in polar seas.

Date	Start time	Proposed title / activity	Speaker
Tuesday, 14 August	09:00	small group meetings (break at the coffee shop; library)	
	12:00	lunch at the Scripps Cafe	
	13:30	Introduction to the meeting	Babin
	13:45	Chapter 2. The polar environment: Sun, clouds and ice	Perovich
	14:15	Chapter 3. From TOA to the ocean sub-surface at high latitudes	Belanger
	14:45	break	
	15:15	Chapter 4. IOPs, AOPs & OC algorithms for various products	Reynolds
	15:45	Chapter 5. PP and related products	Arrigo
	16:15	Chapter 1 and 6, Introduction and recommendations	Babin
	16:45	Adjourn, dinner at Mexican restaurant (18:30)	
Wednesday, 15 August	09:00	small group meetings (break at the coffee shop; library)	
	12:00	lunch at the Scripps Cafe	
	13:30	small group meeting	
	15:00	Break	
	15:30	Chapter 2. The polar environment: Sun, clouds and ice	Perovich
	15:45	Chapter 3. From TOA to the ocean sub-surface at high latitudes	Belanger
	16:00	Chapter 4. IOPs, AOPs & OC algorithms for various products	Reynolds
	16:15	Chapter 5. PP and related products	Arrigo
	16:30	Chapter 1 and 6, Introduction and recommendations	Babin
	16:30	Wrap up and end, 5pm-7pm farewell gathering at the MJ house	Babin