BENCAL, MERIS-MODIS-SeaWiFS SATELLITE CALIBRATION AND VALIDATION IN THE BENGUELA ECOSYSTEM

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ABSTRACT

The BENCAL, MERIS-MODIS-SeaWiFS inter-calibration cruise on the FRS Africana, took place in the Benguela ecosystem, close to the west coast of South Africa, from 4-18 Oct. 2002. The cruise was led by Dr Ray Barlow (MCM, Cape Town) with collaboration from bio-optical teams representing ESA (EU) from PML (UK), LOV (Fr) and NASA (USA). Objectives were to: Conduct diverse bio-optical measurements with in water and above water optical instruments, to vicariously calibrate the several Ocean Colour sensors currently operational: MERIS, SeaWiFS, MODIS-Terra, MODIS-Aqua. Inter-relate diverse measurements of apparent optical properties (AOPs, Ed, Es, Lu, Rrs, Q, at satellite sensor wavelengths) with inherent optical properties (IOPs, absorption, scattering, back-scattering and volume scattering function) and bio-optically active constituents of seawater (particles, pigments, dissolved compounds). Determine inter-relationships between optical properties, phytoplankton pigment composition, photosynthetic rates and primary production (gross and net). Conduct a second pigment inter-calibration round-robin experiment (SeaHARRE-2) with participants from: NASA (HPL); NASA (CHORS); MCM; LOV; DHI; PML.
Accomplishments were: 41 stations AOPs, IOPs, CTD, Pigs, discretes, FRRF; Pigments at 33 CTD, plus 7 surface samples and 12 inter-calibration (SeaHARRE-2) stations; Chlorophyll 33 samples 0.2 to 25.7 $mg.m^{-3}$; Licor spectroradiometer 28 stations plus surface reflectance measurements; PML microPro (MERIS wavelengths) 34 stations, 381 casts; NASA microNESS, 37 stations, 555 casts; NASA Thor 16 stations, 127 casts; AC-9 & bb-6 48 profiles (39 stations); FRRF 47 profiles (37 stations); Hyper-spectral buoy 18 stations + Trios surface reflectance; PABS, SPM, CDOM, Coulter, Phytoplankton, Bacteria; 8 MERIS images, 4 MERIS match-ups.

1. INTRODUCTION

Uniquely in October 2002, four high-precision satellite ocean colour sensors were operational, providing an opportunity for vicarious calibration and inter-comparison of all simultaneously. The BENCAL research team used state-of-the-art sensors and on-board calibration facilities to achieve this goal, together with inter-calibration of ground sensors and analysis techniques. Special attention was focused on the inter-calibration of the measurement of the bio-optically active constituents. Validation of the remote sensing algorithms were undertaken and the validation of the geophysical products produced by the space agencies ground segment processing facilities. The dynamic, highly productive Benguela ecosystem, and off-shore oligotrophic waters, provided bio-optical conditions ranging from 0.1 $mg.m^{-3}$ Chla in 'blue' water up to 30 $mg.m^{-3}$ in the coastal zones influenced by upwelling processes. Concentrations of particles (phytoplankton) and coloured dissolved organic compounds (CDOM) were equally diverse. The region was subject to diverse atmospheric, optical aerosol properties.

1.1 General Cruise Plan Station localities were opportunistic, guided by ocean colour satellite imagery (SeaWiFS) and local weather and sea conditions. Satellite data was transmitted to the *Africana* on a daily basis. Station localities were selected to provide a range of conditions, including high chlorophyll eutrophic waters, intermediate mesotrophic waters, and low chlorophyll oligotrophic waters.
All of the stations were occupied during daylight hours, typically four stations per day at 09h00, 11h00, 13h00 and 15h00 local time, each of approximately 1-2 hours duration. At each station, a CTD cast was made to near bottom (shallow stations), or to 200m (deeper stations), with six depths selected for water sampling. This was followed by an optics cast profiled through the euphotic zone. For the optical rig deployment, the vessel was positioned on station with the sun is on the starboard quarter. For sampling concurrency, a pump was used for surface water sampling, contemporaneous with the optics casts. Free-falling multi-spectral radiometer casts were made off the stern or the port quarter throughout the station duration.
In addition to the CTD and Optical deployments, intensive sampling was undertaken at 12 selected stations for a pigment HPLC inter-comparison experiment (SeaHARRE-2), eight participants: SA (MCM), USA (NASA and CHORS), UK (PML), France (LOV), Denmark, Australia and Canada.

2. NARRATIVE

The FRS Africana departed Cape Town at 10.00 local (08.00 GMT) on Friday 4 October, in heavy weather (3-5 m swell) following a few days of strong southerly winds 20-30 knots. Due to the unfamiliarity of the officers and crew with the operations of many new instruments, no stations were conducted on the first day, but mobilization and planning continued. The vessel made passage north to St Helena Bay for a planned start of operations in sheltered and shallow waters on Saturday 5 October 2002. Operations at station 1 (5 Oct.) proceeded cautiously as training continued.

Generally the deployment of instruments on station proceeded in a standard order. The first station each morning started with a CTD cast (0630-0700GMT) to near bottom depth, with water samples for productivity, pigments and other water constituents at 6 depths through the euphotic zone. The CTD was deployed mid-ships, starboard and nearly always, depending on wind and sea conditions, with the sun on the starboard beam to eliminate ship-shadow of the PAR sensor. The CTD-data of T, S, Chlorophyll fluorescence, O_2 and PAR provided information of the physical structure (MLD) biomass structure and 1% light depth for production and other research aspects.

Depending on illumination conditions (cloudiness) the station continued with the deployments of the internally self-logging instruments from the crane near the starboard quarter (outboard reach 4-6 m) using Kevlar non-conductor rope: firstly the FRRF (PML), secondly the ac-9 (MCM) and bb-6 (PML) combination and thirdly the Licor spectroradiometer (LOV). At later stations, with the sun high, the Licor was usually the first instrument deployed. Again for the crane operations, the vessel was positioned with the sun on the starboard beam or starboard quarter. These station-keeping requirements were attained for nearly all stations, even in difficult wind and sea conditions, thanks to excellent seamanship.

The PML and NASA MicroPro and MicroNESS free-fall profilers (known as the 'rockets') were deployed from the stern on each quarter, usually prior to the start of the crane operations, with the vessel going ahead at 0.5-1.0 knots, so that the instruments 'drifted' astern relative to the vessel. Depending on the effect of wind and sea on the wire angle of the craned instruments, the 'rocket casts' were limited to 'sorties' of 3-5 successive profiles, as often they ended-up too close to the stern of the vessel, as forward speed was lost. For the Licor-spectroradiometer, a vertical wire was a critical requirement and the rocket sorties were often only 2-3 profiles. For the FRRF and IOP instruments (independent of solar illumination) a wire angle of 10-15 deg could be tolerated, subject to safety considerations, so often the rocket-sorties extended up to 11 profiles.

For subsequent stations each day, the vessel was re-positioned to higher or lower pigmented waters (guided by the most recent satellite imagery) and the deployment order revised. Usually the Licor was deployed first, followed by the FRRF, IOP instruments and finally the CTD cast. The 'rockets' were deployed opportunistically, in 10-20 minute sorties (3-11 profiles/sortie) throughout the station. At least once per day the UCT hyper-spectral data buoy was deployed astern during the crane operations and simultaneous rocket deployments were carried out for inter-comparison.

Most days in good illumination conditions three stations were occupied (from 0800-1600, local, 0600-1400 GMT) and when sky conditions suited, with no clouds on the western horizon, a fourth 'Q-factor' station was occupied, involving double rocket casts (NASA rocket & Thor) every 10 minutes to just before sunset (ca 16.30 GMT).

Overnight the vessel was re-positioned by 100-200 miles to a new location in the Benguela 'bloom', working northwards for the first few days into the highest pigment concentration waters just south and west of the Orange river, then westwards into low concentration waters offshore (depth > 2000m) and finally southwards for the last few days into Lamberts Bay, off Cape Columbine and St Helena Bay (repeat). FRS Africana docked in Cape Town at 10.00 local (08.00 GMT) on Friday 18 October 2002.

3. ACCOMPLISHMENTS

For the 14 days at sea, in situ optical instruments were deployed for all but the first day (4 Oct. 2002). A total of 41 stations were occupied from 5-17 Oct. 2002.

There were 41 CTD stations, with water samples for pigment profiles for all but 8 casts; 7 casts were for surface water for the pigment inter-calibration experiment (SeaHARRE-2) and 1 cast was for CTD profile only (no water). Pigments were measured on board by spectrophotometry and filtered samples were frozen in liquid nitrogen for analysis ashore by HPLC (MCM and LOV). Additional surface water samples were taken (by pump or bucket) simultaneously with the optical casts during satellite overpasses (filtered and frozen for measurement by HPLC, LOV).

At 12 stations, surface water was filtered (3 x 8 = 24 replicates) for the inter-calibration experiment SeaHARRE-2; triplicate samples for 8 participants.

Chlorophyll concentrations (33 samples) ranged from 0.2 to 25.7 $mg.m^{-3}$, distributed evenly: 8 from 0.2 to 0.9 $mg.m^{-3}$; 11 from 1 to <5 $mg.m^{-3}$; 8 from 5 to <10 $mg.m^{-3}$; 4 >10 and 2 >20 $mg.m^{-3}$.

The Licor spectroradiometer was deployed at 28 stations, mostly when solar illumination conditions were excellent (cloud-free).

The PML MicroPro optical profiler was deployed at 34 stations (all but 7, either Q-cast experiments or aborted stations) for a total of 381 casts.
The NASA microNESS optical profiler was deployed at 37 of the 41 stations (total 555 casts).
Thor was deployed at 16 stations (127 casts) either concurrent with PML or NASA rockets or as an alternative to either.
There were 47 FRRF profiles at all but 4 stations.
There were 48 profiles of the ac-9 and bb-6 at all but 2 stations.
There were 18 deployments of the hyper-spectral buoy with simultaneous rocket casts and surface reflectance recordings from the TRIOS multi-spectral sensors fitted on the bow of the vessel.
Additional water samples were taken during all optical stations, coincident the deployments of the ac-9 and bb-6 and filtered for particle absorption spectra (PABS) and SPM by LOV and PML (inter-comparison). At each station measurements of CDOM were made by spectrophotometry and particle size by coulter counter and water samples preserved for phytoplankton species counts and bacteria counts (UCT).

4. MERIS MATCH-UP DATA

MERIS data were acquired for: 8 Oct, 9 Oct, 11 Oct, 12 Oct, 14 Oct, 15 Oct and 17 Oct.
Of the 1200 radiometric profiles, 90% were in better than 3/8 cloud cover, mostly totally clear skies.
Despite this co-incident match-ups with MERIS were severely restricted due to 3 factors: early morning cloudiness coinciding with the 10.30 UTC crossing time, sun-glint which affects the eastern side of the swath (MERIS cameras 1, 2, and 3 part) and the 3 day repeat cycle of Envisat.
Good match-ups were acquired for MERIS images on the 11 Oct., 14 Oct. and 15 Oct.
Station locations are shown in fig 1 overlaid on the MERIS chlorophyll image for 15 Oct 2003.
Free-fall radiometry has to be quality assured, so comparisons with the satellite reflectance spectra are not completed. Preliminary results show a very good agreement between radiometry and satellite imagery, notably the 'swing-up' value of the 412 nm measurements of both radiometry (in situ) and satellite.