2nd international workshop

# Global Ocean Acidification Observing Network

St Andrews, UK: 24-26 July 2013

UK Ocean Acidification Research Programme

DEPARTMENT OF ENERGY & CLIMATE CHANGE

Living With Environmental Change

NATURAL ENVIRONMENT RESEARCH COUNCIL

defra Department for Environment Food and Rural Affairs

UK Science & Innovation Network

IAEA Ocean Acidification International Coordination Centre OA-ICC

NOAA National Oceanic and Atmospheric Administration U.S. Department of Commerce

Intergovernmental Oceanographic Commission

International Ocean Carbon Coordination Project IOCCP

The Global Ocean Observing System GOOS

WENDY SCHMIDT OCEAN HEALTH XPRIZE

W

WELCOME to the 2nd international workshop of the Global Ocean Acidification Observing Network (GOA-ON). The fundamental premise of GOA-ON is that management requires measurement: assessment of the biogeochemical, ecological and societal importance of ocean acidification needs field data on relevant chemical and biological variables at local, regional and global levels, with associated capacity-building. To ensure data quality and comparability, a structured system based on common standards is required. An equally important need is for subsequent information synthesis, to assist policy-making through research products and model-based projections of future potential impacts.

The foundations for a worldwide initiative to collect, collate and interpret information on ocean acidification and its effects were established at the first GOA-ON workshop held in June 2012 at the University of Washington, Seattle. The report from that meeting is a key document for this week's successor event, with linkage also provided by many Seattle participants. However, the widening of involvement is also crucial, made possible by the generous support of many sponsors, as detailed below.

Other antecedents also warrant recognition. These include the OceanObs 09 Conference (September 2009, Venice), with 27 sponsors and endorsing organizations; the Ocean Observing Framework of the Global Ocean Observing System (GOOS); and preparatory planning by the OA Working Group of the Surface Ocean-Lower Atmosphere Study (SOLAS) and the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) project.

The task now is to more explicitly focus OA observing effort on shelf seas and coastal regions, thereby developing a comprehensive Global OA Observing Plan to meet both national and international needs. That is ambitious, yet achievable – through new and strengthened collaborations and partnerships, based on sharing information, knowledge, and technological expertise. And pragmatic goodwill.

***Organizing Committee for 2nd GOA-ON Workshop**: Chen-Tung Arthur Chen (National Sun Yet-Sen University, Taiwan), Richard Feely (NOAA PMEL), Albert Fischer (Global Ocean Observing System), Lina Hansson (OA International Coordination Centre/IAEA), Libby Jewett (NOAA), Jeremy Mathis (NOAA PMEL), Pedro Monteiro (CSIR, South Africa), Jan Newton (Univ of Washington, USA), Yukihiro Nojiri (NIES, Japan), Maciej Telszewski (International Ocean Carbon Coordination Project), Bronte Tilbrook (CSIRO, Australia), and Phil Williamson (NERC/UEA).*

***Main workshop sponsors:***

- *The UK Natural Environment Research Council (NERC), the Department for Environment, Food and Rural Affairs (Defra), and the Department of Energy and Climate Change (DECC) through their co-funded UK Ocean Acidification research programme*
- *The UK Department for Business, Innovation and Skills (BIS) and the Foreign & Commonwealth Office (FCO), through their co-funded Science & Innovation Network*
- *The US National Ocean and Atmospheric Administration, through the NOAA OA Program*
- *The International Atomic Energy Agency (IAEA) through its Ocean Acidification International Coordination Centre (OA-ICC)*
- *The International Ocean Carbon Coordination Project (IOCCP)*
- *The Global Ocean Observing System (GOOS) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO*

*The support provided by the University of Washington, the X PRIZE Foundation and Plymouth Marine Laboratory is also greatly appreciated, with additional assistance by James Orr (CEA/CNRS/UVSQ), Kirsten Isensee (IOC) and Erica Ombres (NOAA).*

# Contents

# 1. Aims of workshop

The 2nd international workshop of the Global Ocean Acidification Observing Network (GOA-ON) has been jointly convened by the research community, national funding bodies and relevant international organizations to deliver the following outcomes:

- A more comprehensive vision of the components of a global observing network for ocean acidification and ecosystem response, integrating observations in coastal waters, regional seas and the open ocean

- Conceptualization of the ideal suite of chemical, physical and biological observations for fixed observing nodes in major sub-regions of the global ocean

- Completion of the draft Global OA Observing Plan arising from the first workshop (Seattle, June 2012), including:
  - arrangements for international data sharing
  - actions to ensure that observing data are relevant to modelling needs
  - identification of geographic priority areas where OA impacts may be particularly high and/or currently under-observed
  - actions to improve coverage in such areas

- Development of a governance structure to achieve implementation of the Global OA Observing Plan

# 2. GOA-ON Workshop schedule

University of St Andrews, North Haugh (main campus), St Andrews KY16 9TF

Meeting sessions to be held in Medical & Biological Sciences building; accommodation in Agnes Blackadder Hall and David Russell Apartments

*See map for venue locations. Separate schedule for UKOA ASM, 22- 24 July*

## Joint session of UKOA ASM and GOA-ON workshop: Wednesday 24 July

| | | |
|---|---|---|
| 12.30 | Lunch | |
| 13.30 | **Ocean acidification research in a wider context**<br>Chair: Carol Turley | |
| | 1. From national to international, from science to policy (*Phil Williamson*) | 15 min |
| | 2. Awareness and action on ocean acidification (*Jane Lubchenco*) | 15 min |
| | 3. Environmental protection in the North Atlantic (*Darius Campbell, Executive Secretary, OSPAR Commission*) | 15 min |
| | 4. Framework for ocean observing and ship-based time series – aiding the design of a global OA observing network (*Maciej Telszewski*) | 15 min |
| | 5. Update on the OA International Coordination Center (*Lina Hansson*) | 10 min |
| | 6. Promoting technological advances: the X-Prize (*Paul Bunje*) | 5 min |
| | **Discussion** | 15 min |
| 15.00 | Tea/coffee | 20 min |
| 15.20 | **The development of a global ocean acidification observing network**<br>Chair: Bronte Tilbrook | |
| | 1. Why we need a global OA network (*Wendy Watson-Wright, Executive Secretary IOC/UNESCO*) | 15 min |
| | 2. Where we are now: outcomes from Seattle 2012 *(Jan Newton)* | 25 min |
| | 3. An introduction to the global OA observing asset map (*Cathy Cosca)* | 5 min |
| | **Discussion:** where we want to be | 15 min |
| 16.20 | Break | 10 min |
| 16.30 | **Global observing of ocean acidification and ecological response**<br>Chair: Arthur Chen | |
| | 1. Observing OA in regional seas: a modeller's perspective (*Jerry Blackford*) | 15 min |
| | 2. OA processes and impacts in US coastal waters (*Richard Feely*) | 15 min |
| | 3. Observing OA in upwelling regions off South America (*Rodrigo Torres & Nelson Lagos*) | 15 min |
| | 4. Observing OA and its impacts in the Pacific-Arctic (*Jeremy Mathis*) | 15 min |
| | 5. Observing OA and its impacts in the Southern Ocean (*Pedro Monteiro*) | 15 min |
| | **Discussion** | 15 min |
| 18.00 | Session ends | |

*Sign-up sheets for Thursday breakout groups*

| | |
|---|---|
| 18.00-19.00 | *Informal briefing meeting for GOA-ON Session Chairs and Breakout Group leaders/co-leaders* |

| | |
|---|---|
| 19.30 | **Dinner** Agnes Blackadder Hall |

# GOA-ON workshop: Thursday 25 July

08.45 **Aims and objectives of the workshop – and the network**

Chair: Libby Jewett

1. Goals for the meeting (*Jeremy Mathis and Phil Williamson*) — 15 min

Discussion: Defining how the network will operate – and what it will deliver — 30 min

09.30 **Best practice for analytical chemistry** (Goal 1, Level 1)

1. Review best practices for OA chemistry ('weather' v 'climate') as decided at Seattle (*Andrew Dickson*) — 10 min
2. Comparison of carbonate chemistry software packages – and implications for GOA-ON (*Jim Orr*) — 10 min

Discussion — 10 min

10.00 **Short presentations on physico-chemical variability (and how it may be affected by biology) in specific environments**

Chair: Maciej Telszewski

What are the key science issues relevant to establishing long-term observing programmes?

- Shelf seas: from sea surface to sediment (*Kim Currie)* — 10 min
- Riverine influences on coastal systems (*Joe Salisbury*) — 10 min
- Polar-specific issues (*Liqi Chen*) — 10 min
- Tropical-specific issues (*Nathalie Lefèvre)* — 10 min

Discussion — 20 min

11.00 Tea/coffee — 15 min

11.15 **Short presentations on ecosystem response to OA in specific habitats and environments**

Chair: Mark Ohman

What are the key science issues relevant to establishing long-term observing programmes?

- Pelagic ecosystems in shelf seas (*Ulf Riebesell*) — 10 min
- Warm water corals (*Rusty Brainard*) — 10 min
- Cold water corals (*Murray Roberts*) — 10 min
- Other coastal benthic and intertidal habitats (*Steve Widdicombe*) — 10 min

Discussion — 20 min

12:15 **Charge to the breakout groups** *(Libby Jewett)* — 5 min

12.20 **Breakout session #1** — 60 min

Discussion on how to observe relevant variability for different ecosystems and habitats, distinguishing signal from noise and including under- observed oceanic and coastal regions. Overall goal: to fine-tune the recommendations for the Ecosystem Response part of the network, taking account of regionally-specific considerations. Issues to include:

- How can we best match chemical, biogeochemical and biological observing to track/predict quantifiable OA impacts of ecological and socio-economic importance?
- What are the (regionally-specific) "essential ocean variables" for biogeochemistry and biology?
- Are there 'indicator species' that may be especially vulnerable to OA impacts?

*Also see questions for session #2.*

*Two leaders per group, as below; those individuals should also appoint a group rapporteur*

| **Tropical regional seas** (excl coral reef habitats) | **Temperate regional seas** (excl cold-water coral habitats) | **Polar regional seas** | **Warm and cold -water corals** | **Nearshore, intertidal & estuarine habitats** |
|---|---|---|---|---|
| ***Leaders:*** | ***Leaders:*** | ***Leaders:*** | ***Leaders:*** | ***Leaders:*** |
| ***Eric de Carlo*** | ***Bruce Menge*** | ***Richard Bellerby*** | ***Dwight Gledhill*** | ***Sam Dupont*** |
| ***Rodrigo Kerr*** | ***Kirsten Isensee*** | ***Jeremy Mathis*** | ***Andreas Andersson*** | ***Terrie Klinger*** |

| | | |
|---|---|---|
| 13.20 | **Lunch** | 40 min |
| 14.00 | **Breakout session #2** | 60 min |

Discussion on how to observe relevant variability – continued, with same breakout groups (but opportunity for some individuals to change groups). Overall goal: to fine-tune the recommendations for the Ecosystem Response part of the network, developing the optimal observing system for the various ecosystem types, with variables appropriate for model testing and development. Issues requiring attention include:

- What suite of chemical and biological measurements comprise the essential (Level 1) and desirable (Level 2) at the regional level (maximising congruence with Seattle report)?
- What spatial and temporal coverage is essential/desirable for these measurements?
- Are there regionally-specific 'hot spots' (high rate of change or potential for high impacts) for prioritising national and international effort?

*Break-out leaders as identified above*

| **Tropical regional seas** (excl coral reef habitats) | **Temperate regional seas** (excl cold-water coral habitats) | **Polar regional seas** | **Warm and cold -water corals** | **Nearshore, intertidal & estuarine habitats** |
|---|---|---|---|---|
| | | | | |

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|---|---|---|
| 15.00 | Tea/coffee | 15 min |
| 15.15 | Time for breakout leaders to put together their reports. Copy of summary slides/notes to be provided to Jeremy Mathis jeremy.mathis@noaa.gov<br>Opportunity for poster-viewing and other informal discussions. | 30 min |
| 15.45 | **Data sharing and management**<br>Chair: Jim Orr | 90 min |

**Introductory presentation: "The vision for GOA-ON data management"** (*Hernan Garcia & Alex Kozyr*). Discussions on:

1. Specific issues for shelf seas/coastal regions, and integrating chemistry and biology – building on decisions at Seattle
2. Use of the GOA-ON map as a starting point – scope for including links to databases and datasets
3. Importance of metadata
4. Lessons learnt from SOCAT, ICES and EPOCA *(to include inputs from Dorothee Bakker, Evin McGovern and Lina Hansson*)
5. Linkages to other relevant data management activities, via IOCCP and GOOS

| | | |
|---|---|---|
| 17.15 | **break** | 15 min |
| 17:30 – 18.30 | POSTER SESSION | |
| 19.00-20.00 | **X-Prize reception/light buffet** Parliament Hall – Senate Room: location 67 (K3) on St Andrews town map | |

## GOA-ON workshop: Friday 26 July

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|---|---|---|
| 09:00 | **Summary of workshop progress and outcomes. Consensus on how to observe chemistry and biology in shelf seas and coastal regions, across full climatic range**<br>Chair: Jan Newton<br>Two slides from each of yesterday's break out groups (summarizing main outcomes), presented by breakout leaders.<br>Discussion | 90 min |
| 10.30 | Coffee/tea | 15 min |
| 10.45 | **Consensus on how to observe chemistry and biology in shelf seas and coastal regions – continued**<br>Chair: Jeremy Mathis<br>1. What measurements<br>2. How frequently<br>3. Spatial distribution<br>4. How precise do we need the data to be, given the high level of variability<br>5. What technology advancements need to be made? For example, how can gliders contribute and how can we promote that? | 90 min |
| 12.15 | lunch | 45 min |
| 13.00 | **Discussion: what do we mean by a "network"?** Are there examples of observing networks that we can use as a model? What are the optimal governance arrangements?<br>Chair: Libby Jewett<br>Contributions by Maciej Telszewski and Phil Williamson – plus wide input from participants | 45 min |
| 13.45 | **Regional coverage and capacity building.** Can we identify specific regions (currently under-observed but potentially subject to rapid change) which this global OA community will target for improved coverage in the next 2-3 years? How will additional partnerships be created, expertise developed and national funding secured to help fill gaps in the map?<br>Chair: Phil Williamson<br>Contributions by Jim Orr (re role of OA-ICC and iOA-RUG), plus wide input from participants | 45 min |
| 14.30 | **Next steps/ synthesis products:** Jeremy Mathis and Phil Williamson | 30 min |
| 15.00 | **Tea/coffee. END OF WORKSHOP** | |
| 15.15-~16.40 | ***Workshop Organizing Committee meeting:*** *implementing the agreed actions* | 90 min |

images: NOAA-PMEL

# 3. GOA-ON Poster abstracts

**Note:**

- Poster abstracts listed alphabetically according to presenting author (underlined)
- Poster boards are numbered
- Authors are asked to be in attendance for the GOA-ON poster session 17.30-18.30 on 25 July

1

Andreas Andersson[1], Kiley Yeakel[1], Nicholas Bates[2], Tim Noyes[2] & Andrew Collins[2]

*[1]Scripps Institution of Oceanography, University of California, USA*
*[2]Bermuda Institute of Ocean Sciences, Bermuda*

## Temporal and spatial variability in seawater carbonate chemistry on the Bermuda coral reef platform

Monthly time-series seawater $CO_2$ system measurements from the Bermuda coral reef platform since 2007 and the Bermuda Atlantic Time-series Station (BATS) since 1983 reveal complex trends and controls on surface seawater pH, $pCO_2$ and aragonite saturation state (□). The observed trends in seawater $CO_2$ chemistry can be accounted for by a combination of factors including the uptake of anthropogenic $CO_2$ as well as changes in temperature, salinity, and biological activity. These latter forcings are especially important on the shallow coral reef platform where the balance of net ecosystem calcification (NEC) and net organic carbon ecosystem production (NEP) exerts strong control on seawater $CO_2$ chemistry.

2

Moacyr Araujo[1], N Lefèvre[2], C Noreiga & R Araujo

*[1]LOFEC-UFPE, Cidade Universitária Recife, Brazil*
*[2] L'Ocean-IPSL, France*

## The INCT-AmbTropic: a new $CO_2$ observing network in the Southwestern Tropical Atlantic

The Brazilian Ministry of Science, Technology and Innovation created in 2011 four new research networks in Marine Sciences (National Institutes on Science & Technology). One of these networks, the INCT-Tropical Marine Environments ( INCT-AmbTropic) is aimed at investigating the processes, dynamics and functioning of the coastal zone, the continental shelf and the oceanic waters off Brazil. The WG3.2 of the INCT-AmbTropic focuses on the ocean. Its main objective is to determine the variability of the biogeochemical properties of the tropical Atlantic, in particular those associated with uptake and outgassing of atmospheric $CO_2$ and potential acidification of its water. In this poster we present the $CO_2$ observing network that is being implemented in the southwestern tropical Atlantic as part of the WG3.2 activities. It involves: a) continuous $pCO_2/O_2$ measurements in the oceanic islands of St. Peter and St. Paul, Fernando de Noronha and of the Rocas Atol; b) underway $fCO_2$ measurements and water sampling (pH/DIC/TA+biogeochemistry) during ship cruises (oceanic islands and Amazon river plume); and c) monthly/bimonthly water sampling (pH/DIC/TA) in different estuaries and cross-shelf transects along the North-Northeastern Brazilian coast, from the Amazon (equator) to the São Francisco river ($10^oS$).

3

Dorothee CE Bakker[1], S Hankin[2], A Olsen[3,4], B. Pfeil[3,4], K Smith[5], S Alin[2], C Cosca[2], B Hales[6], S Harasawa[7], A Kozyr[8], Y Nojiri[7], K O'Brien[5], U Schuster[1], M Telszewski[9], B Tilbrook[10], C Wada[7] and all other SOCAT contributors

## An update to the Surface Ocean $CO_2$ Atlas (SOCAT version 2)

The Surface Ocean $CO_2$ Atlas (SOCAT) is a major synthesis effort by the international marine carbon research community. It aims to improve access to surface water fugacity of carbon dioxide ($fCO_2$, similar to partial pressure) by regular releases of quality controlled and fully documented synthesis and gridded $fCO_2$ products. SOCAT version 2 has been made public in June 2013. Version 2 extends the SOCAT version 1 data set by 4 years until 2011, while

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[5] *University of Washington, USA*
[6] *Oregon State University, USA*
[7] *National Institute for Environmental Studies, Tsukuba, Japan*
[8] *CDIAC, Oak Ridge, USA*
[9] *IOCCP/Institute of Oceanology of Polish Academy of Sciences*
[10] *CSIRO, Hobart, Australia*

providing many additional data for the years 2006 and 2007. It has 10.1 million surface water $fCO_2$ data from 2660 cruises between 1968 and 2011 for the global oceans and coastal seas. The procedures for creating version 2 are similar to those for version 1. The SOCAT website (www.socat.info) provides access to the individual cruise data files, as well as synthesis and gridded data products. Interactive online tools allow users to visually explore and interpret the data. Scientific users can also access the data as downloadable files or via Ocean Data View. Version 2 enables global carbon scientists to carry out process, budget and modelling studies.

4

Carolina Cantoni[1], Stefania Sparnocchia[1], Anna Luchetta[1], Massimo Celio[2], Stefano Cozzi[1], Stefania Finotto[3], Mauro Bastianini[3], Fabio Raicich[1].

[1] *CNR - National Research Council of Italy, ISMAR - Marine Sciences Institute, Trieste, Italy*
[2] *Regional Environmental Protection Agency (ARPA) of Friuli Venezia Giulia, Palmanova, Italy*
[3] *CNR - National Research Council of Italy, ISMAR - Marine Sciences Institute, Venice, Italy*

## Five years of observational efforts on ocean acidification in the north Adriatic Sea: The experience of the PALOMA station, Gulf of Trieste

The Gulf of Trieste is a shallow bay (< 25 m) lying in the northernmost part of the Adriatic Sea (Mediterranean Basin), where cold north-easterly winds often blows during winter determining the formation of cold dense water masses that are expected to be enriched in $CO_2$. Meteorological conditions exhibit a pronounced seasonal cycle, causing wide variations of the physical properties in the water column through the year. Since January 2008 a monitoring activity has started by the PALOMA beacon, located in the centre of the Gulf, aimed at studying the inorganic carbon biogeochemistry and ocean acidification process in this highly variable coastal area. It is based on monthly measurements of the main biogeochemical parameters as nutrients, $pH_T$, At and dissolved oxygen as well as on the monitoring of phytoplankton species composition. Since August 2012, the time series has been implemented with continuous measurements of near surface seawater $pCO_2$, temperature and salinity. In 2010, the PALOMA station was included in the North Adriatic LTER site, within the ICOS-Italy network, and is often visited during basin scale surveys. Here we present the main results of these five years activity highlighting the most relevant scientific results and underpinning the potential vulnerability of this area to the acidification process.

5

S Pensieri[1], R Bozzano[1], ME Schiano[1], Carolina Cantoni[1], P Picco[2] & L Pensieri[1]

[1] *National Research Council of Italy (CNR), Italy*
[2] *Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Italy*

## Analysis of meteo-oceanographic time series in the Ligurian Sea: the monitoring of $CO_2$

The world's oceans are affected by dramatic changes due to $CO_2$ uptake from the atmosphere that gradually acidifies the oceans. Hence, monitoring of $CO_2$ concentration over a wide range of timescales is necessary to solve biogeochemical and natural $CO_2$ variability and to characterize physical and biological factors driving the $CO_2$ cycle. Fixed open ocean observatories equipped with autonomous sensors measuring physical, biological and chemical properties of seawater as well as atmospheric parameters close to the ocean interface are the most powerful, efficient and cost-effective tools. In the Ligurian Sea, the W1-M3A observatory hosts several scientific packages to investigate air-sea interaction processes, heat fluxes, upper layer ocean variability and ocean biogeochemistry. A prototype for studying the variability in air-sea $CO_2$ fluxes by conducting high resolution time-series measurements of atmospheric boundary layer and surface ocean $pCO_2$ has been recently included in the buoy payload. These measurements might be integrated by nutrients, dissolved oxygen, chlorophyll-a, turbidity observations as well as net samples during annual cruises. This instrumental set-up might contribute to OA studies both providing in-situ measurements as well as being a reference site for the close-by VOS line maintained by the Barcelona-Express ship.

6 Hon-Kit Lui & Chen-Tung Arthur Chen

*National Sun Yat-Sen University, Kaohsiung, Taiwan*

## Inconsistencies in ocean acidification rates based on $pH_{25°C}$ and $pH_{insitu}$

In this study, acidification rates from two open access time-series studies are shown, to compare with that of six published time series studies. The results show that, although the atmospheric $CO_2$ rises at similar rates globally, reported rates of change in pH either measured at *in situ* temperature ($pH_{insitu}$) or at 25°C ($pH_{25}$) vary. Observations at the SEATS station are consistent with the thermodynamics that $pH_{insitu}$ and $pH_{25}$ time-series are incomparable, as they change in anti-phase when seawater temperature (T) changes. At the SEATS station, the seasonal change in $pH_{insitu}$ when temperature changes is six times that expected under the air-sea $CO_2$ equilibrium. Such a result implies that marine ecosystems could suffer from ocean acidification earlier than expected when warming is considered along with increasing atmospheric $CO_2$.

7 Liqi Chen, Z Gao, L Zhan, Y Zhang et al.

*Key Laboratory of Global Change and Marine-Atmospheric Chemistry, TIO, SOA, Xiamen, China*

## Surface carbon changes in the western Arctic Ocean under sea-ice rapid shrinking and its implications for Arctic Ocean acidification

The Arctic Ocean is rapidly changing with thinning and retreating of the sea ice due to its sensitivity to global warming. The Chinese National Arctic Research Expedition (CHINARE) has experienced this sea-ice retreating in the western Arctic Ocean . MV *Xuelong,* an icebreaker for Chinese polar expeditions, reached 75°N in the marginal sea-ice during the first CHINARE in 1999; 80°N during the second CHIANRE in 2003 and third CHINARE in 2008, to cover the Canada Basin; and 88°N a northernmost in 2010 in the fourth CHINARE to close multi-year seaice area. Based on the survey in the western Arctic Ocean from CHINARE cruises, we estimate an extra $CO_2$ invasion flux of only $4.6\times10^{12}$ gC $yr^{-1}$ with ice-free basins in the Arctic Ocean, much lower than the early evaluation. However, in the continental shelf such Chukchi shelf with a high productivity area, biological pump will act as the main driving force, continually pumping atmospheric carbon dioxide through surface into deep and even the burial of the sea and thus presenting a strong uptake $CO_2$ in surface water. A potential trend in the Arctic Ocean acidification can be found in the center surface Arctic Ocean and subsurface marginal regions from variability of $\Omega$. The center Arctic Ocean surface acidification could be attributed to atmospheric $CO_2$ invasion and ice rapid melting but in the Arctic marginal area the subsurface acidification could be caused by biological recycling.

8 Hernan Garcia, Liqing Jiang, Sheri Phiilps & Krisa Arzayus

*US NODC, NOAA Silver Spring, USA*

## NOAA ocean acidification scientific data stewardship project

The US National Oceanographic Data Center (NODC), through its Ocean Acidification Data Stewardship (OADS) project, serves as the data management focal point for NOAA's Ocean Acidification Program (OAP). NODC provides scientific data management, archival, long-term preservation, online discovery, and access of ocean acidification (OA) and carbon related data. OA observational and biological response rich metadata content are being developed using international standards (ISO 19115-2 and CF-compliant netCDF) to help ensure that the OA data can be utilized for optimal data discovery and interoperable online data service. While NODC's data are accessible via our Geoportal (THREDDS/OPeNDAP), we are developing a data access interface to of allow data searchers based on tailored user constrains (e.g., variables, data quality, temporal and spatial coverage, methods, instruments, data scales, standards, etc). We are implementing computer

automated data extraction scripts for archiving ocean carbon and other oceanographic data from Data Acquisition Centers such as Carbon Dioxide Information Analysis Center (CDIAC), CLIVAR and Carbon Hydrographic Data Office (CCHDO), and Biological and Chemical Oceanography Data management Office (BCO-DMO). NODC is exploring the challenges of coordinated data flow for diverse coastal and ocean monitoring, laboratory and field experiments, model output, data synthesis products, and other ocean acidification data. Additional information is available at www.nodc.noaa.gov/oceanacidification.

9 Michele Giani, G Ingrosso, P Del Negro, C De Vittor, C Fabbro, A Karuza & M Kralj

*OGS - Istituto Nazionale di Oceanografia e Geofisica Sperimentale, Trieste, Italy*

## The implementation of carbonate system measurements at an LTER site in the Gulf of Trieste

At the Long-Term Ecological Research (LTER) C1 site in the Gulf of Trieste (northern Adriatic Sea) many chemical (nutrients, dissolved organic carbon, particulate organic carbon, particulate nitrogen, particulate phosphorus, chlorophyll a) and biological (prokaryotic carbon production, picoplancton, phytoplankton, micro and mesozooplankton) parameters have been measured since 1986 (1998 for most biogeochemical parameters) on samples collected monthly through the water column. The site is representative of the northernmost part of the Mediterranean sea under the influence of rivers and is a site of dense water formation during winter. In the framework of the FP7 MedSeA project, the LTER site in the gulf of Trieste was implemented since March 2011 with monthly measurements of the carbonate system (pH and total alkalinity). Measurements of pH have been carried out spectrophotometrically with m-cresol purple as indicator, and measurements of total alkalinity by open cell potentiometric titration. The two years of data on the carbonate system show elevated seasonal variability of pH and of total alkalinity. Total alkalinity was influenced by the contribution of carbonates carried by the rivers with karstic watershed. The lowest pH were reached during the stratified period, particularly from August to September, in bottom waters where degradation processes prevailed, leading to marked oxygen undersaturation.

10 F Brunetti, V Cardin, R Nair, N Medeot, G Ingrosso & Michele Giani

*OGS - Istituto Nazionale di Oceanografia e Geofisica Sperimentale, Trieste, Italy*

## Short term variability of $pCO_2$ in the Gulf of Trieste

In the Gulf of Trieste (northern Adriatic Sea), an oceanographic buoy was equipped in 1999 for continuous monitoring of physical parameters in the Marine Protected Area of Miramare. Recently the buoy was implemented with a CTD SBE37 and two new sensors for the carbonate system continuous monitoring: a SAMI-pH, and a Proceanus $pCO_2$ sensor, deployed at 15m depth, in the proximity of the seabed, from February 2012 till beginning of April 2013. Technical problems did not allow the correct functioning of the SAMI-pH whereas an hourly data set was registered by the $pCO_2$ sensor. Laboratory comparisons of the $pCO_2$ sensor with standard methods for the determination of the carbonate system were carried out. The first year of data showed a high short term variation of $pCO_2$ during the summer period that could be due to benthic respiration processes.

11 Naomi Greenwood [1], DJ Pearce [1] T Hull [1], B Silburn [1], DB Sivyer[1] DCE Bakker [2], M Ribas-Ribas [3]

[1] *Cefas, Lowestoft, UK*
[2] *University of East Anglia, UK*
[3] *National Oceanography Centre, Southampton, UK*

## Determining variability in the carbonate system in UK shelf seas

Routine measurements of the carbonate system have been carried out in UK shelf seas within the UKOA research programme since December 2010. Discrete sampling has been conducted on surveys in the North Sea, Channel and Celtic and Irish Seas by augmenting sampling on existing research cruises and three time series stations have been established at SmartBuoy sites in the southern North Sea. In addition, the Cefas research ship *RV Endeavour* has

been instrumented with underway sampling capability for $pCO_2$. Results collected over two years confirm previous findings of large horizontal and vertical gradients in dissolved inorganic carbon in the seasonally stratified North Sea and the strong riverine signal in total alkalinity in the southern North Sea. Results from summer cruises compare well with measurements made on the UKOA D366 cruise in summer 2011. Large seasonal variations in the carbonate system are observed in the southern North Sea. This is a region exhibiting strong biological activity as determined through high resolution measure-ments of inorganic nutrients and chlorophyll made by SmartBuoy over the past 12 years. Good agreement has been found between $pCO_2$ measured directly by the underway system and $pCO_2$ calculated from total alkalinity and dissolved inorganic carbon in discrete samples

12

Claudine Hauri and Jeremy T. Mathis

[1] *University of Alaska Fairbanks, USA*
[2] *Pacific Marine Environmental Laboratory/NOAA, USA*

## Late season subsurface aragonite undersaturation in the Beaufort Sea

Climate change and OA have triggered rapid biogeochemical changes in the Arctic Ocean. A better understanding of the distribution and transport of carbon is crucial to elucidate how the Arctic Ocean will respond to these ongoing changes. Here, we describe the water mass composition in the Beaufort Sea using dissolved inorganic carbon, total alkalinity, inorganic nutrients and hydrographic data from two month-long cruises in October 2011 and 2012. The data indicates high spatial variability in the vertical structure of the water column. We observed a prominent feature in all transects of our study area. Between 100 – 200 m, waters were undersaturated with respect to aragonite. Temperature and silicate measurements show a similar pattern, with minimum temperatures and maximum silicate concentrations located at around 175 m depth. The low temperatures and high silicate content of the water are an indication of its Pacific Ocean origin and additional nutrient regeneration on the Chukchi Shelf. Our data suggests that carbon that is fixed via photosynthesis on the northern Chukchi Shelf is exported to the bottom layer, where it remineralizes and enriches the winter-transformed Bering water with $CO_2$. This water mass then feeds the eastward flowing undercurrent along the Alaskan Beaufort Sea, causing subsurface aragonite undersaturations along the Beaufort shelf break.

13

Masao Ishii[1,2], Naohiro Kosugi[1], Daisuke Sasano[1,2], Kazutaka Enyo[2], Toshiya Nakano[2] and Takashi Midorikawa[3]

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[3] *Nagasaki Marine Observatory, JMA, Japan*

## Ocean acidification over the western North Pacific subtropical and tropical zone for the last decades

The Japan Meteorological Agency has been making atmospheric/oceanic $CO_2$ measurements in the western North Pacific for the last 30 years. Based on the observational records of $pCO_2$sw, DIC and related surface properties, we demonstrate the occurrence of OA in surface waters over the subtropical zone at 137°E repeat line; e.g., the rate of change in $pCO_2$sw, salinity-normalized DIC, pH at SST and $\Omega_{arag}$ are +1.65 µatm $yr^{-1}$, +1.1 µmol $kg^{-1}$ $yr^{-1}$, -0.0017 $yr^{-1}$ and -0.011 $yr^{-1}$ at 27°N and +1.29 µatm $yr^{-1}$, +0.82 µmol $kg^{-1}$ $yr^{-1}$, -0.0013 $yr^{-1}$ and -0.008 $yr^{-1}$ at 7°N. The trend of OA is also shown in the western equatorial Pacific warm pool on the basis of the SOCAT V1.5 and PACIFICA databases that include many data sets provided by JMA; the rates of change here are similar to those at 7°N, 137°E and are a bit smaller than those expected from the rate of atmospheric $CO_2$ increase. The $CO_2$ increase in the interior of the ocean has also been observed in the subtropical gyre at 137°E since mid-1990s. The increase of $CO_2$ is significant in the density classes above $\sigma_\vartheta$ >26.8, i.e., the densities that outcrop in winter in the North Pacific.

14 Libby Jewett, Dwight Gledhill & Erica Ombres

*NOAA Silver Spring, USA*

## The NOAA Ocean Acidification Program

The U.S. National Oceanic and Atmospheric Administration (NOAA) Ocean Acidification Program (OAP) was established under the Federal Ocean Acidification and Monitoring Act (FOARAM) to oversee and coordinate research, monitoring, and other activities consistent with the strategic research and implementation plan developed by the interagency working group on ocean acidification. The program is to foster and direct:

- interdisciplinary research among the ocean and atmospheric sciences, and coordinated research and activities to improve understanding of OA
- the establishment of a long-term monitoring program of OA utilizing existing global and national ocean observing assets, and adding instrumentation and sampling stations as appropriate to the aims of the research program
- research to identify and develop adaptation strategies and techniques for effectively conserving marine ecosystems as they cope with increased OA
- educational opportunities that encourage an interdisciplinary and international approach to exploring the impacts of OA
- national public outreach activities to improve the understanding of current scientific knowledge of OA and its impacts on marine resources
- coordination of OA monitoring and impacts research with other appropriate international ocean science bodies, such as the International Oceanographic Commission, the International Council for the Exploration of the Sea, the North Pacific Marine Science Organization, and others.

The OAP provides grants for critical research projects that explore the effects of OA on ecosystems and the socioeconomic impacts of increased ocean acidification that are relevant to the goals and priorities of the strategic research plan. The OAP incorporates a competitive merit-based process for awarding grants that may be conducted jointly with others.

15 Se-Jong Ju[1] and Geun-Ha Park[2]

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## Ocean acidification research activities in Korea

Although a national ocean acidification (OA) research program has not yet been initiated in Korea, some OA related research projects have been carried out. Therefore, we would like to introduce Korea's OA research activities at this workshop as follows: 1) study on biological and ecological responses under high $CO_2$ world using the mesocosm facility; 2) real-time $pCO_2$ monitoring program; and 3) estimation of air-sea $CO_2$ fluxes in the Korean waters through ship-of-opportunity cruises. However, we strongly feel that it is time to launch a multidisciplinary national OA research program in Korea. We hope that the outcome of this workshop will help us to convince the Korean government and funding agency to initiate a national OA research program, to better understand and monitor OA and furthermore to predict and minimize the damages from OA. We would then also be able to play an important role in the global OA research community and programs.

16 Rodrigo Kerr[1,a], Leticia C da Cunha[2,b], Marcelo FL de Souza[3,c], Ilana Wainer[4], Rosane G. Ito[1], Paulo HR Calil[1,d], Carlos AE Garcia[1,e]

## Activities of the Brazilian Ocean Acidification Research (BROA) group

The Brazilian Ocean Acidification Research (BROA) group was established in December 2012 during the Workshop "Studying Ocean Acidification and its effects on marine ecosystems", organized by the International Geosphere-Biosphere Programme (IGBP), São Paulo University (USP), Council for Research

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[b]*Coastal marine ecosystems*
[c]*FLUXCARB/RECORBA Project PI*
[d]*CSP Project PI*
[e]*SIMCOSTA Project PI*

and Scientific Development of Brazil (CNPq), and National Institute for Space Research (INPE). The group aims to integrate the Brazilian researchers in a wide interdisciplinary national network on OA studies and to contribute with international programs. The group acts on distinct environments along the Brazilian coast from estuaries to open ocean regime. Here, we highlight some projects being executed or in the process to be implemented regarding OA issues. The SIMCOSTA project (www.simcosta.furg.br) will deploy 4 surface buoys coupled with biogeochemical sensors (pH, $pCO_2$, nitrate, DO) along the Brazilian continental shelf, starting probably in November 2013. The EstARte project will seasonally sample surface $pCO_2$, pH, DIC, and TA along the Brazilian south and southwest continental shelf-break (2014-2015). The FLUXCARB project recently contributed to the understanding of biogeochemical processes involving carbon flux on the continental shelf of Bahia State (NE Brazil). Regionally, the marine carbonate system and air-sea $CO_2$ fluxes are under investigation in coastal marine ecosystems in Rio de Janeiro State. The net community metabolism, calcification-dissolution of carbonate, and fluxes of $CO_2$ have been estimated in coastal reefs of Bahia State, as part of the RECORBA project. Additionally, a biogeochemical modeling project is studying the main physical and biological factors influencing the continental shelf pump (CSP Project) of carbon in the Southwest Atlantic Ocean. Previously, observational studies (2008-2011) were performed mainly focusing on $CO_2$ fluxes along the Brazilian and Patagonian continental shelf, crossing the South Atlantic Ocean from Brazil to Africa, and in the Atlantic Sector of the Southern Ocean (Bransfield Strait and NW Weddell Sea).

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[3] *Advanced Industrial Science & Technology, Tsukuba, Japan*
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## Seasonality of shell dissociation of marine calcifiers in the North Pacific and Arctic Ocean

The dissolution of atmospheric $CO_2$ with seawater reduces pH and carbonate ions. It is urgently required to know how these changes affect marine calcifying organisms and marine ecosystems. Using Micro-focus X-ray Computing Tomography (MXCT) techniques, we show evidence of shell dissociation of calcifying zooplankton from time-series sediment trap observations in the western North Pacific (Station K2, 47°N, 160°E) and Arctic Ocean (Station NAP, 75°N, 162°W), where OA is known to be occurring. MXCT can evaluate the shell density and its inner structure of the objects precisely. Inside structures of the shell of planktic foraminifera obtained at Station K2 were severely damaged in late winter 2009. This shell dissociation of planktic foraminifera may have occurred in the water column when they were alive, since it was closely related with a water mass with low pH and high $TCO_2$ in winter, and where the carbonate saturation horizon (Ωcal = 1.0) is relatively shallow ( ~150m water depth). At Station NAP in the Arctic Ocean, pteropods have their aragonitic shells remarkably damaged in the early winter. Our results indicate that living marine calcifers may already be affected by acidification in the western North Pacific and Arctic Ocean, and that biological responses to OA vary between species, areas and seasons.

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Nelson Lagos, JM Navarro, RT Torres, PH Manriquez, MA Lardies & CA Vargas

## Biological responses to ocean acidification on benthic invertebrates of the Chilean coast

*[Abstract to be provided]*

19 Enrique Montes[1], Yrene Astor[2], Laura Lorenzoni[1] & Frank Muller-Karger[1]

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[2] *EDIMAR, Venezuela*

## The CARIACO Ocean Time-Series: a case study of the value of biogeochemical time-series within the Global Ocean Acidification Network

The CARIACO Ocean Time-Series program has conducted monthly oceanographic cruises to the Cariaco Basin (10.5°N, 64.66°W), Venezuela, since November 1995. This basin is connected openly with the Caribbean Sea in the upper ~140 m. While it is ventilated above this sill depth, waters below ~250 m are anoxic. Continuous measurements at this continental margin site have revealed complex and marked long-term changes in surface and deep DIC. An increase of ~2.2 µatm in $fCO_2$ ($p < 0.05$) has been measured over the 18 years of the time series. This is a response to a combination of factors which include progressive warming of surface waters in the Caribbean Sea due to a decrease in the strength of the trade winds, and a sustained decrease in photosynthetic carbon fixation rates. $TCO_2$ concentrations integrated between 200 and 500 m have also increased significantly since 1995 at a rate of roughly 3 µmol $Kg^{-1}$ $m^{-2}$ $yr^{-1}$. This is mostly a result of accumulation of $CO_2$ from remineralization of sinking organic matter. The changes observed in the inorganic carbon pool, together with changes in other biogeochemical parameters within the Cariaco Basin cascade directly to ecosystem services (i.e. food resources) and highlight the importance of a holistic approach to studying the marine carbon cycle. Such integrated studies are only possible through multidisciplinary biogeo-chemical time series. Integrating these time series into a network is crucial for understanding global ocean changes. By pooling together time-series data which has been collected in a consistent and intercomparable manner, it will be possible to assess changing ocean carbon biogeochemistry at a global scale.

20 Akihiko Murata

*JAMSTEC, Japan*

## Detecting progressive ocean acidification by repeat hydrography: Contribution of JAMSTEC activities

We have conducted repeat hydrography observations mainly in the Pacific Ocean since the early 2000's. Because repeat hydrography is now a program of a global oceanographic network and of $CO_2$-system properties as core measurements, we can evaluate progression of ocean acidification utilizing the data which have at least two observations along same observation lines a decade apart. In JAMSTEC, we have so far conducted repeat hydrography observations along more than 10 WHP lines. For example, along the P14 line, which traverses from the Bering Sea to north of New Zealand at around 179°E, we found that the saturation horizon for aragonite rose by 17 dbar (1.2 dbar $a^{-1}$) between 1993 and 2007 at latitudes 10°N – 50°N. On the other hand, the saturation horizon rose by 60 dbar (4.1 dbar $a^{-1}$) along the P21 line at 17°S between 1994 and 2009. The different rising rates of the saturation horizon mean that ocean acidification occurs in a different manner according to regional oceanic conditions. We believe that it is important to maintain the global network for clarifying regional differences in the progression of OA.

21 Jan Newton

*University of Washington, USA*

## Meeting ocean acidification data needs of shellfish growers via NANOOS and the IOOS system

OA has serious implications for the economy and ecology of the Pacific Northwest United States. A combination of factors renders the Pacific coast and its estuaries particularly vulnerable to acidified water. The Northwest Association of Networked Ocean Observing Systems, (NANOOS), the Regional Association of the United States Integrated Ocean Observing System (IOOS), is set up to deliver coastal data to serve the needs and decisions of its region. NANOOS has worked through IOOS with the NOAA OA Program, NOAA Pacific Marine Environmental Laboratory, academic, local, and commercial and tribal

shellfish-growing partners to provide existing observing assets to accommodate $pCO_2$ and pH sensors, to deliver data streams from these and other providers, including that from sensors in shellfish hatcheries, and to network this capacity regionally and nationally. This increase in data access regarding OA is of value to shellfish growers who are appreciative of the near real-time readouts of the data upon which to make hatchery and remote setting decisions, as well as scientists, managers, and educators. This regional example of NANOOS and IOOS contributions toward societal impacts from ocean acidification is replicated in other IOOS regional associations and being expanded upon through IOOS. Because of an inter-operable design, NANOOS contributions can be scaled up to national and global systems.

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## Surface ocean acidification studies using Ships Of Opportunity

Ships of opportunity (SOOP) are used as a platform for cost-efficient, autonomous and continuous collection of environmental data (CTD, Chl *a* fluorescence, oxygen, cDOM, cyanobacteria, turbidity, optical and meteorological measurements) with a Ferrybox system. A SOOP network covers the majority of the Norwegian coastline from Germany (54˚N) to Svalbard (78˚N) and is used in the national OA monitoring program. New instruments for Ferrybox on these SOOPs are under development and will give high resolution data on OA from the Norwegian coastline and Arctic Seas. OA data can then easily be compared with parameters from the Ferrybox system. The new instruments are a membrane based $pCO_2$ system (Franatech/NIVA) with solid state detector for continuous measurements of $pCO_2$ and a new miniature spectrophotometric detection system (NIVA) measures underway pH. Ongoing developments include the integration of a direct UV carbonate ion detection. Sensor developments are partly performed under the EU Jerico project. Tests and comparisons with GO $pCO_2$ systems have shown comparable results. We suggest that a Standard Operation Procedure (SOP) should be made for membrane-based systems of $pCO_2$ detection, to provide a better understanding of humidity, pressure and temperature effects.

Acknowledgements: The OA programs at The Norwegian Climate and Pollution Agency (Klif), Fram center flagship and NIVA strategic initiative; also collaboration with Michel Masson (Franatech, GmbH) and Tobias Steinhoff (GEOMAR).

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Mark D Ohman[1], Uwe Send[1], Daniel L Rudnick[1], Todd R Martz[1], Richard Feely[2], Christopher L Sabine[2]

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## Integrated mooring and glider observations of aragonite saturation state in the California Current Ecosystem

We have established two interdisciplinary moorings (CCE1, CCE2) in the southern sector of the California Current System that are designed to understand the temporal variability of ocean-atmosphere fluxes of $CO_2$ , upper ocean pH, aragonite saturation, and the biophysical processes that regulate this temporal variability. CCE1 is located in 4,000 m water depth, ~220 km offshore, in the low salinity core of the California Current proper. CCE2 is located in 770 m water depth, ~35 km off Pt. Conception, a major upwelling center off the west coast of North America. These two locations represent two of the major sources of nutrient fluxes into the region, i.e., horizontal advection at CCE1 and vertical advection from upwelling at CCE2. The moorings are collocated with a *Spray* ocean glider transect along CalCOFI line 80, which permits measurements of spatial variations in aragonite saturation to a distance ~350 km offshore, complementary to the temporal variations from the mooring-based measurements. Aragonite saturation state is calculated from the proxy relationship developed for this region by Alin et al. (2012). The mooring and glider autonomous measurements are validated by shipboard calibration measurements made 4 times per year by CalCOFI.

Results from our integrated measurement systems will be presented, illustrating the magnitude, frequency, and duration of upwelling events and their consequences for aragonite saturation state, as well as the spatial extent of selected events in the cross-shore direction.

24 Aida F Ríos[1], MI García-Ibáñez[1], NM Fajar[1], H Mercier[2], FF Pérez[1]

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[2] *IFREMER, Laboratoire de Physique des Océans, France*

## Observed trends of carbon storage, acidification and calcium carbonate saturation along the OVIDE section

The biannual occupations of the Greenland-Portugal OVIDE section (2002-2012) are used to quantify the acidification rates and verify its impacts on $CaCO_3$ saturation and alkalinity. The study area is divided into the Irminger, Iceland and Eastern North Atlantic basins. To evaluate how acidification affects the alkalinity and aragonite saturation trends in the main water masses, the water column was divided into 5 layers for each region. During the first half of 1990s, with high North Atlantic Oscillation (NAO) phase, the anthropogenic $CO_2$ ($C_{ANT}$) storage rates in the subpolar gyre were ~48% higher than during 1997-2006 with low NAO phase. During the OVIDE period (2002-2012), the $C_{ANT}$ storages are increasing, reaching similar rates to the early 90's. High acidification rates were obtained in mode and intermediate waters of the subpolar gyre, and a decrease of the acidification rates through the subtropical zone. There is a positive trend in alkalinity ($0.27\pm0.11$ $\mu mol \cdot kg^{-1} \cdot y^{-1}$) in subsurface waters between 1981 and 2012. Negative trends in aragonite saturation were significant in all except deep water masses. Typical negative trends of -1.5 to $-3 \cdot 10^{-3}$ $y^{-1}$ observed in intermediate waters correspond with an upward migration of 5-12 m $y^{-1}$ in the saturation horizons.

25 Ute Schuster

*University of Exeter (University of East Anglia)*

## Interannual variability of sea surface pH

The oceanic uptake of excess, 'anthropogenic' $CO_2$ chemically reduces the pH of seawater, resulting in potentially significant effects on marine biogeo-chemical cycles. Major challenges are the effects on marine biota, and the identification of longterm trends and inter-annual variability. Here, the spatial and temporal variability of surface pH are presented, estimated from regular observations of sea surface $pCO_2$ and related parameters in the North Atlantic (Watson et al., 2009; Schuster et al., 2009). These estimations are compared with a recent pH climatology (Takahashi & Sutherland, 2013). Results show spatial variability between the tropical, sub-tropical, and temperate North Atlantic waters between the mid-1990s and 2008, with the pH decrease being especially significant in more north-eastern latitudes.

26 Jacob Silverman[1], N David[2], Y Gertner[1] & N Kress[1]

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## Total alkalinity distribution in the Eastern Levantine Basin, Eastern Mediterranean Sea

During March 2012 and 2013 hydrographic profiles were measured along a cross-shore transect from Carmel Headland (north Israel, bottom depth ~50m) to the WNW ca. 70 nautical miles (bottom depth ca. 1700m). Deep and surface water total alkalinity ($A_T$), potential temperature and salinity varied between 2.633-2.602 mmol/kg, 13.57˚C-17.98˚C and 38.747-39.147, respectively. In the surface layer (<300 m) $A_T$ increased conservatively with salinity. In the deep layer (>300 m) the difference between measured $A_T$ and values calculated as a function of potential temperature and salinity using the relation developed for the entire Mediterranean Sea (Touratier and Goyet, 2011) is up to 0.03 mmol/kg, while in the surface layer measured $A_T$ agrees well with calculated values. Anthropogenic $CO_2$ penetration ($C_{ant}$) calculated using $A_T$ derived from temperature and salinity (Op. Cit.) was double the value calculated using the measured data. This discrepancy is quite large and should not be discounted

considering that the Eastern Levantine Basin is ultra oligotrophic and the deep water mass originating in the Northern Adriatic is ca. 100 yrs old. The source as well as the spatial extent of this additional total alkalinity in the Eastern Levantine Basin is unknown and both are currently under investigation.

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[2] *Universidad Austral de Chile, Valdivia, Chile*
[3] *Universidad Andrés Bello, Santiago Chile*
[4] *Universidad Santo Tomás, Santiago, Chile*
[5] *CUniversidad de Concepción.*
[6] *Universidad Adolfo Ibáñez, Santiago, Chile*

## Carbonate system monitoring along the coast of Chile

Carbonate system parameters monitoring at coastal water of Chile began in the early nineties. This early work resulted in the description of the spatial and short-term variability in the carbonate system parameters in coastal upwelling areas of central and northern Chile. Wind-forced coastal upwelling events drive extreme variability of seawater pH, Omega and $pCO_2$ along the coast of northern and central Chile (40˚S to 20˚S). In Southern Chile (42˚S-56˚S, Patagonia), the rainy Patagonian Archipelago Interior Sea (PAIS) is characterized by low alkalinity surface seawater compared with offshore oceanic region. Here, the low alkalinity fresh water discharges results in estuaries with low $CaCO_3$ saturation state. Information regarding the carbonate system characteristics of Chilean coastal waters, derived from several expeditions, suggests an extremely high temporal variability. Only a few attempts at clustering time series carbonate system monitoring have been made: 1) a 4 month monitoring of surface seawater $pCO_2$ at an upwelling area of northern Chile (21˚S; Friederich *et al.*, 2008); and 2) a seasonal monitoring pH and alkalinity at Northern Patagonia fiordland (42˚S, Torres *et al.*, 2011). In this poster we show the results of a ~2 year monitoring program aimed to describe in coastal and shallow intertidal seawaters the changes in pH, $A_T$, nutrients, chlorophyll, temperature and salinity at Calfuco (40˚S). This data set suggests that in this particular environment, events of low pH and low Omega aragonite are strongly associated with the occurrence of cold upwelled waters.

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VVSS Sarma Vedula

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## Acidification along the coastal Bay of Bengal

*[Poster abstract to follow]*

29

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## The marine inorganic carbon system along the Gulf of Mexico and Atlantic coasts of the United States: Insights from a trans-regional coastal carbon study

Distributions of total alkalinity (TA), dissolved inorganic carbon (DIC), and other parameters relevant to the marine inorganic carbon system were investigated in shelf and adjacent ocean waters during a US Gulf of Mexico and East Coast Carbon (GOMECC) cruise in July–August 2007. TA exhibited near-conservative behavior with respect to salinity. Shelf concentrations were generally high in southern waters (Gulf of Mexico and East Florida) and decreased northward from Georgia to the Gulf of Maine. DIC was less variable geographically and exhibited strongly non-conservative behavior. As a result, the ratio of TA to DIC generally decreased northward. The spatial patterns of other $CO_2$ system parameters closely followed those of the TA:DIC ratio. All sampled shelf waters were supersaturated with respect to aragonite (saturation state $\Omega_A > 1$). The most intensely buffered and supersaturated waters ($\Omega_A > 5.0$) were in northern Gulf of Mexico river plume waters; the least intensely buffered and least supersaturated waters ($\Omega_A < 1.3$) were in the deep Gulf of Maine. Due to their relatively low pH, $\Omega_A$, and buffer intensity, waters of the north-eastern US shelves may be more susceptible to acidification pressures than are their southern counterparts. In the Mid-Atlantic Bight, alongshore mixing tended to increase DIC concentrations southward, but this effect was largely offset by the opposing effects of biogeochemical processing. In the Gulf of Mexico,

downstream increases in Loop Current DIC suggested significant contributions from shelf and Gulf waters, estimated at $9.1\times10^9$ mol carbon per day. Off the south-eastern US, along-flow chemical changes in the Florida Current were dominated by mixing associated with North Atlantic subtropical recirculation.

30

Leticia Barbero[1], Rik Wanninkhof[2], Wei-Jun Cai[3], Lisa Robbins[4], Shari Yvon-Lewis[5] & Xinping Hu[6]

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[6]*Texas A&M University Corpus Christi, USA*

## Climatology of $pCO_2$ and aragonite saturation state in the Gulf of Mexico

Until recently, very few surface carbon measurements had been made in the Gulf of Mexico either spatially or temporally. The unique geographical features of the Gulf make it an important contributor to the total air-sea $CO_2$ flux of the coastal United States. We present the first extensive set of surface ocean carbon measurements in the region, collected on board of Ships of Opportunity and NOAA research vessels. Climatological air-sea $CO_2$ fluxes centered on the year 2009 were determined and seasonal and spatial variability are analyzed for the whole Gulf of Mexico. Our results suggest that the Gulf of Mexico is a weak sink for $CO_2$. We also show initial aragonite saturation maps in the Gulf.

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Phil Williamson[1], Carol Turley[2] & the UKOA research community

[1] *NERC/University of East Anglia*
[2] *Plymouth Marine Laboratory, UK*

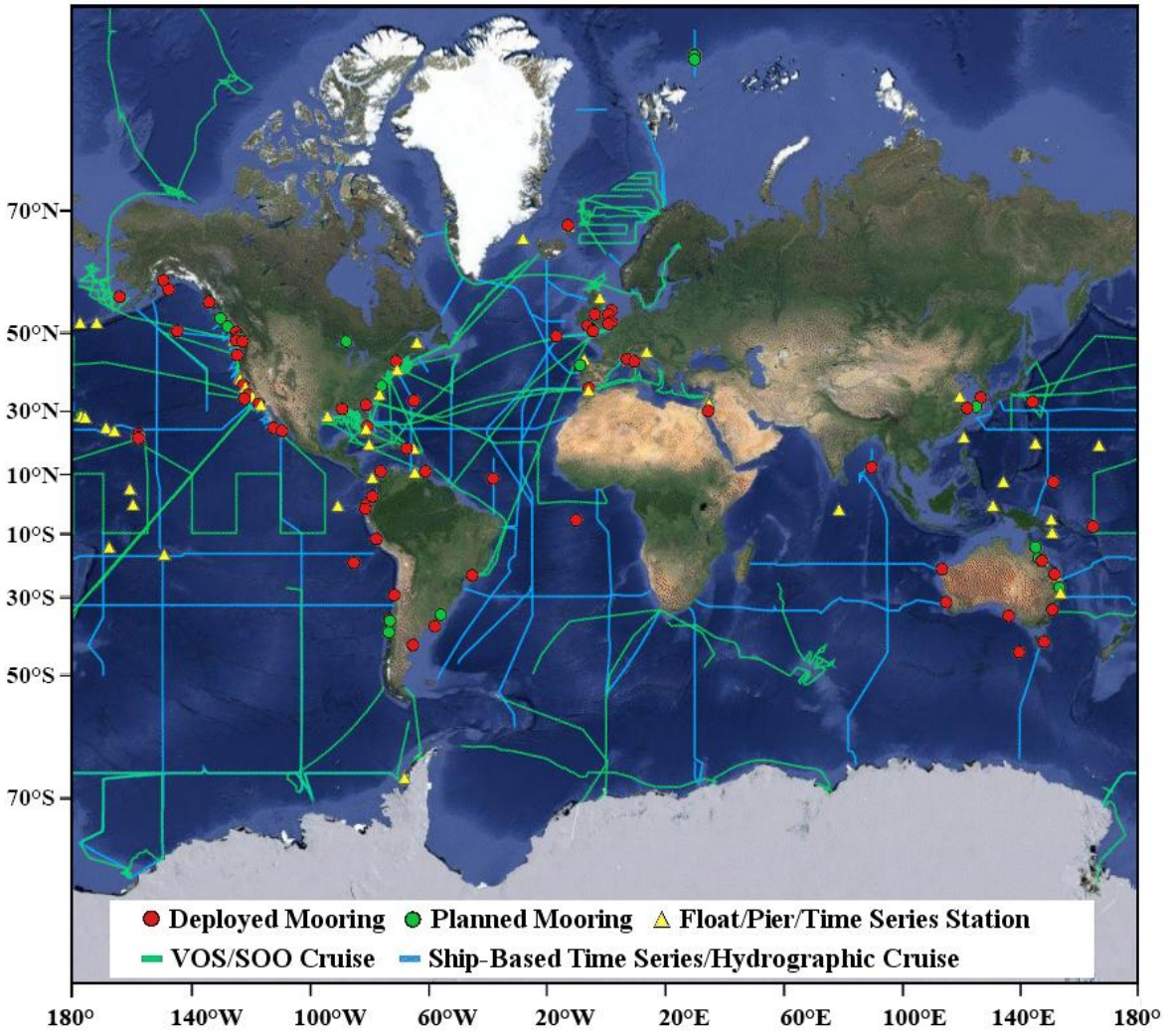
## Overview of the UK Ocean Acidification research programme

The £12m UKOA research programme (2010-2015) involves over 120 scientists in 26 research laboratories across the UK, working closely with European partners and other relevant international activities. Seven multi-institute consortium projects address: observation and synthesis; upper ocean biogeo-chemistry; OA impacts on benthic ecosystems; commercially important species and socio-economic implications; effects of palaeo- OA events; and regional and global modelling of OA processes and future impacts. Ship-based fieldwork, now complete, has included research cruises in European shelf seas (2011), the North East Atlantic and Arctic (2012), and the Southern Ocean (2013), and studies of cold-water corals (2011, 2012). UKOA outreach and knowledge exchange includes work with UNFCCC, CBD and other international bodies.

# 4. GOA-ON interactive map

An 'in development' version of the GOA-ON interactive map is below, showing most of the current and planned OA observing activities considered to be part of the Network. An online version is at www.pmel.noaa.gov/co2/GOA-ON/2013 with link to GOA-ON Questionnaire (providing the opportunity for additional information to be added).

This map will be presented to the workshop by Cathy Cosca at ~16.00 on 24 July.



# 5. Key background documents and relevant links

The most important single document as background for the 2nd GOA-ON workshop is the report of the 1st workshop *Towards a Global Ocean Acidification Observing Network* (Newton, Feely, Jewett & Gledhill, 2013). This report was distributed to workshop participants; it is also online via www.pmel.noaa.gov/co2/GOA-ON/2013 (click on underlined 'international workshop' in first paragraph), and a limited numbers of printed copies will be available at St Andrews.

Other relevant documents and reports (with a northern hemisphere bias) include:

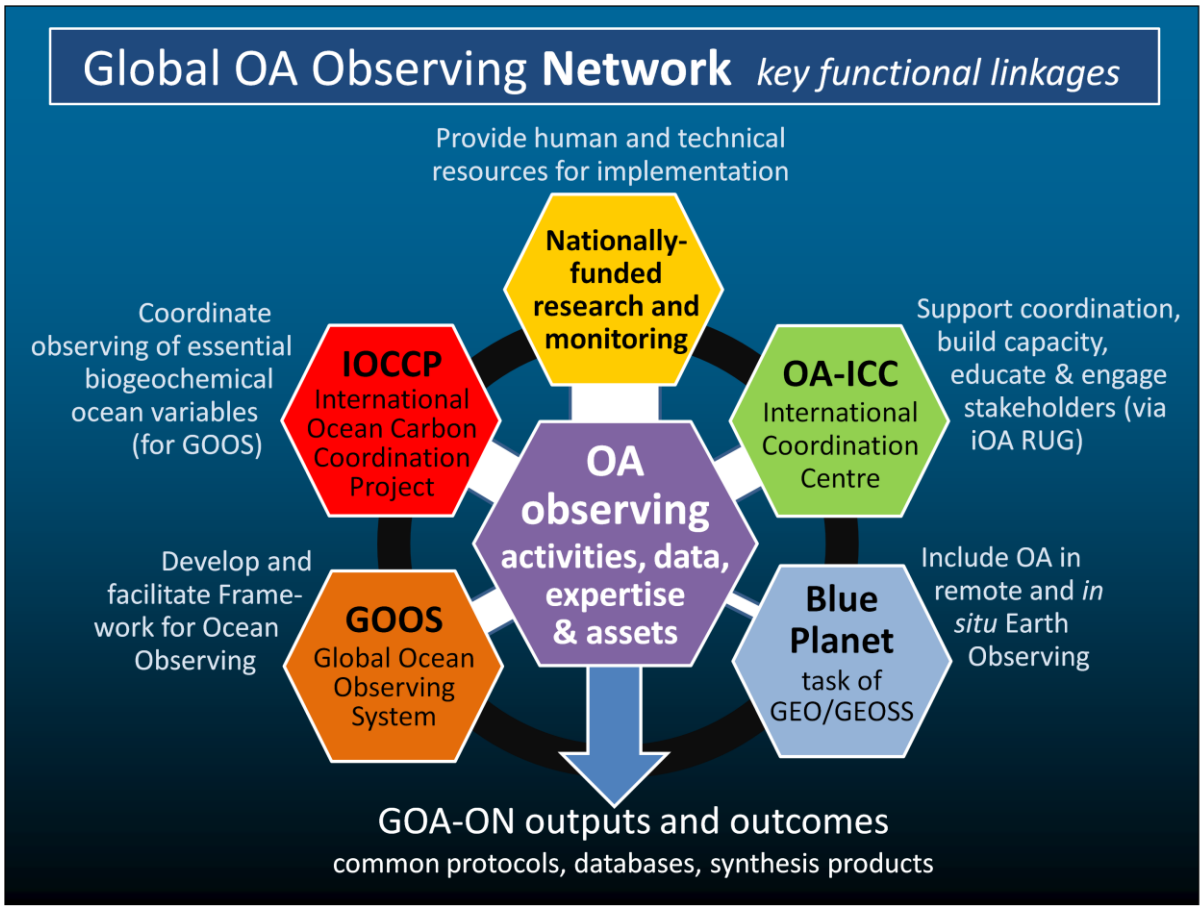
- *Arctic Ocean Acidification Assessment: Summary for Policymakers* (AMAP: Arctic Monitoring and Assessment Programme). This report was circulated to workshop participants and is online at www.amap.no/documents/doc/AMAP-Arctic-Ocean-Acidification-Assessment-Summary-for-Policy-makers/808
- *First report of the joint OSPAR/ICES Ocean Acidification Study Group (SGOA*). Includes "Draft monitoring guidelines for chemical aspects of ocean acidification" (Annex 5, p 54-62). Online at www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2012/SGOA/sgoa_2012.pdf
- *Ocean Acidification: from Knowledge to Action. Washington State's Strategic Response*. Online via https://fortress.wa.gov/ecy/publications/publications/1201015.pdf
- *California Current Acidification Network (C-CAN): Vision for Development of a West Coast Network for Monitoring Marine Acidification and its Linkage to Biological effects in the Nearshore Environment*. Online via http://c-can.msi.ucsb.edu
- *Guide to Best Practices for Ocean Acidification Research and Data Reporting* (Riebesell et al, 2011). Online at www.epoca-project.eu/index.php/guide-to-best-practices-for-ocean-acidification-research-and-data-reporting.html

Links to relevant data portals include the following:

- The Intergovernmental Oceanographic Commission (IOC) of UNESCO has a global compilation of shipboard biogeochemical time series data that can be accessed via www.unesco.org/new/en/natural-sciences/ioc-oceans/sections-and-programmes/ocean-sciences/biogeochemical-time-series
- The Surface Ocean $CO_2$ Atlas (SOCAT) can be accessed from www.socat.info
- Information on the Global Ocean Observing System (GOOS) can be accessed from www.ioc-goos.org
- Information on the Ocean Biogeographic Information System (OBIS) can be accessed at www.iobis.org
- Data from the European Project on Ocean Acidification (EPOCA) can be found on the PANGAEA website www.pangaea.de
- The Carbon Dioxide Information Analysis Center (CDIAC) can be accessed from http://cdiac.ornl.gov. CDIAC hosts the GLobal Ocean Data Analysis Project (GLODAP) http://cdiac.ornl.gov/oceans/glodap
- The US National Oceanographic Data Center (NODC) ocean acidification data portal can be accessed from www.nodc.noaa.gov/oceanacidification/index.html and the US Biological and Chemical Oceanography Data Management Office (BDMO) can be found at http://bcodmo.org
- The British Oceanographic Data Centre (BODC) manages data from the UK Ocean Acidification research programme; such data can be accessed via www.bodc.ac.uk/projects/uk/ukoa

# 6. GOA-ON connections and governance

The Global Ocean Acidification Observing Network is a nascent entity, that has received its DNA from many 'parents'. The conceptual diagram below summarise the main connections between GOA-ON and other bodies and organisations, academic and governmental, and indicates how such bodies may together functionally contribute to the further development of the Network. These issues will be discussed further in the concluding sessions of the workshop on 26 July.



# 7. Participants in GOA-ON Workshop

Blue-shaded names: funder, stakeholder or programme management role
*Names in italics: participant on 24 July only, not attending UKOA ASM.* [Information update: 19 July]

| | Name | Affiliation | email | Accommodation* | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 21 | 22 | 23 | 24 | 25 | 26 |
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| 23 | Vicky Fabry | California State Univ, San Marcos, USA | fabry-at-csusm.edu | | | D | D | D | D |
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| 25 | Helen Findlay | Plymouth Marine Laboratory, UK | hefi-at-pml.ac.uk | | | | | | |
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**Bookings for 27 July and other "own arrangements" not shown. D, double*

| | | | | 21 | 22 | 23 | 24 | 25 | 26 |
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| 51 | Bruce Menge | Oregon State University, USA | mengeb-at-oregonstate.edu | | | D | D | D | |
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| | | | | 21 | 22 | 23 | 24 | 25 | 26 |
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# 8. Information on accommodation, meeting venue and travel

### Accommodation and meeting venue

For those who identified their accommodation needs online, hotel-quality rooms (en suite, with TV and WiFi) will be provided on campus at the University of St Andrews, at Agnes Blackadder Hall (for single occupancy) and David Russell Apartments (for double occupancy). Further information at www.discoverstandrews.com/view_Group_Accommodation.aspx.

All workshop participants should initially register at **Agnes Blackadder Hall**, North Haugh, St Andrews, Fife KY16 9XW (location 4 on the St Andrews town map at the end of this section)

The GOA-ON workshop, lunches and light refreshments will be held in the **Medical and Biological Sciences Building**, North Haugh campus (location 17 on map). For those also participating in the UKOA Annual Science Meeting and/or arriving in time for an evening meal on Tuesday 23 July, that dinner will be at 19.30 in **Lower College Hall** in St Andrews (location 44 on map, within walking distance). The reception and buffet on the evening of Thursday 25 July will be at **Parliament Hall** in St Andrews (location 67 on map). On the evenings of 22 and 24 July, dinner will be at Agnes Blackadder Hall.

### Travel

See www.st-andrews.ac.uk/visiting/gettingtostandrews for general information on how to get to St Andrews. From Edinburgh airport (the most likely starting point for non-UK participants) allow up to 3 hr from your flight arrival time to reach St Andrews by public transport, or around 2 hr by hire-car (depending on traffic and the effectiveness of your map-reading/satnav)

Although there is no direct public transport link between Edinburgh airport and St Andrews, the three parts to that journey are relatively straightforward:

- Airlink bus from Edinburgh airport to Edinburgh city centre, cost £6 return. Edinburgh main railway station (Waverley) is the final stop, with journey time of ~30 min (frequent service, 24 hr); information at http://lothianbuses.com/services/airlink
- Train from Edinburgh main station to Leuchars, the nearest station for St Andrews (journey time around 1 hr); information at http://ojp.nationalrail.co.uk. A standard return ticket to Leuchars costs around £20 (advance reservation is not needed). Note that trains to Leuchars continue to Dundee or Aberdeen; the names of those towns will be shown on displayed departure information. A timetable is given below.
- Bus or taxi from Leuchars station to St Andrews (journey time around 20 min; cost ~ £15). You may be able to share the taxi with others arriving for the workshop. Ask the taxi driver to take you to Agnes Blackadder Hall, main campus, University of St Andrews.

For return travel to Edinburgh airport, the first train from Leuchars on Saturday morning is at 06.17, arriving Edinburgh station 07.40; hence the earliest arrival at the airport is 08.15-08.30. If you need to get to the airport before then, a taxi can be organized (probably sharing with other early departures?), at a fixed price cost of around £75.

# Trains between Edinburgh main station (Waverley) and Leuchars, the nearest station to St Andrews

Information from http://ojp.nationalrail.co.uk

*Note: the final destination of trains to Leuchars is likely to be Dundee or Aberdeen*

**EDINBURGH TO LEUCHARS**

Monday- Friday
(22-26 July)

| *E'burgh* | *Leuchars* |
|---|---|
| 05.30 | 06.32 |
| 07.00 | 08.08 |
| 07.30 | 08.26 |
| 08.00 | 09.07 |
| 08.28 | 09.23 |
| 09.00 | 10.03 |
| 10.00 | 11.04 |
| 10.27 | 11.28 |
| 11.00 | 12.03 |
| 11.28 | 12.25 |
| 12.00 | 13.04 |
| 12.28 | 13.23 |
| 13.00 | 14.03 |
| 13.28 | 14.23 |
| 14.00 | 15.04 |
| 14.27 | 15.28 |
| 15.00 | 16.06 |
| 15.28 | 16.24 |
| 16.00 | 17.03 |
| 18.29 | 17.26 |
| 17.00 | 18.12 |
| 17.37 | 18.33 |
| 18.00 | 19.10 |
| 18.11 | 19.22 |
| 18.32 | 19.37 |
| 19.00 | 20.02 |
| 19.28 | 20.28 |
| 20.00 | 20.12 |
| 20.14 | 21.25 |
| 20.31 | 21.32 |
| 21.07 | 22.22 |
| 21.40 | 22.34 |
| 22.09 | 23.28 |
| 23.09 | 00.23 |

**LEUCHARS TO EDINBURGH**

Friday; after 15.00
(26 July)

| *Leuchars* | *E'burgh* |
|---|---|
| 15.29 | 16.29 |
| 15.48 | 16.56 |
| 16.21 | 17.26 |
| 17.02 | 18.23 |
| 17.30 | 18.32 |
| 17.39 | 18.49 |
| 18.31 | 19.34 |
| 18.54 | 20.09 |
| 19.46 | 20.50 |
| 20.33 | 21.31 |
| 20.54 | 22.16 |
| 21.32 | 22.52 |
| 22.27 | 23.49 |

Saturday
(27 July)

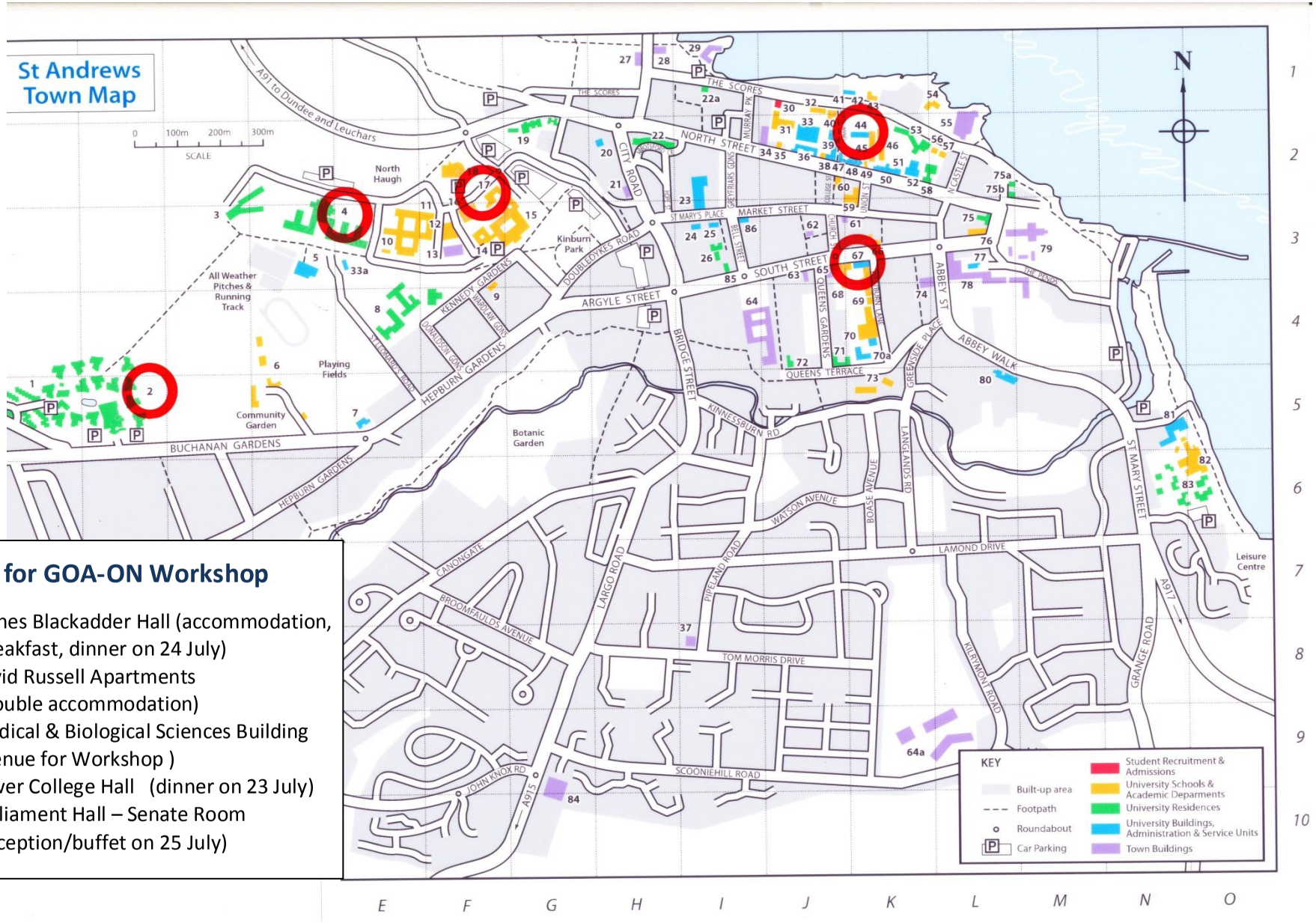
| *Leuchars* | *E'burgh* |
|---|---|
| 06.17 | 07.40 |
| 06.46 | 08.01 |
| 07.11 | 08.21 |
| 07.22 | 08.48 |
| 07.49 | 08.59 |
| 08.42 | 09.59 |
| 09.20 | 10.25 |
| 09.47 | 10.58 |
| 09.53 | 11.11 |
| 10.28 | 11.28 |
| 10.47 | 11.57 |
| 11.22 | 12.26 |
| 11.45 | 12.55 |
| 12.28 | 13.31 |
| 12.46 | 13.57 |
| 13.28 | 14.26 |
| 13.46 | 14.54 |
| 14.29 | 15.34 |
| 14.46 | 15.58 |
| 15.29 | 16.29 |
| 15.48 | 16.56 |
| 16.21 | 17.26 |
| 17.02 | 18.23 |

Saturday
(27 July) - continued

| *Leuchars* | *E'burgh* |
|---|---|
| 17.30 | 18.32 |
| 17.39 | 18.49 |
| 18.31 | 19.34 |
| 18.54 | 20.09 |
| 19.46 | 20.50 |
| 20.33 | 21.31 |
| 20.54 | 22.16 |
| 21.32 | 22.52 |
| 22.27 | 23.49 |
| 22.43 | 23.55 |

Sunday
(28 July)

| *Leuchars* | *E'burgh* |
|---|---|
| O7.37 | 09.01 |
| 09.37 | 11.06 |
| 11.16 | 12.23 |
| 11.37 | 13.06 |
| 12.38 | 13.42 |
| 13.16 | 14.25 |
| 13.35 | 15.06 |
| 14.20 | 15.23 |
| 15.15 | 16.23 |
| 15.37 | 17.02 |
| 16.37 | 17.41 |
| 17.37 | 18.58 |
| 18.31 | 19.35 |
| 19.39 | 21.00 |
| 20.33 | 21.38 |
| 21.33 | 22.43 |
| 22.52 | 23.58 |




## Map for GOA-ON Workshop

4 . Agnes Blackadder Hall (accommodation, breakfast, dinner on 24 July)

2. David Russell Apartments (double accommodation)

17. Medical & Biological Sciences Building (venue for Workshop )

44. Lower College Hall (dinner on 23 July)

67. Parliament Hall – Senate Room (reception/buffet on 25 July)