Estimation of surface ocean pH exploiting SMOS salinity observations

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Outline

- Background: the OA context
- Motivation and Objectives: satellite observations
- The ESA STSE Pathfinders-OA project
- Methodology and datasets
- Total Alkalinity derivation
- Surface ocean pH derivation
- Preliminary sensitivity/variability/error propagation studies
- Qualitative consistency check with climatology
- Remarks and perspectives
Background – The OA problem

• The surface ocean currently absorbs approximately one third of the excess atmospheric carbon dioxide (CO2), mitigating the impact of global warming.

• This anthropogenic CO2 absorption by seawater determines, however, a reduction of both ocean pH and the concentration of carbonate ion.

• The overall process is referred to as Ocean Acidification (OA), with profound impacts at scientific and socio-economic level.

• This can also lead to a decrease in calcium carbonate saturation state $\Omega$, with potential implications for marine animals, especially calcifying organisms.

• Average global surface ocean pH has already fallen from a pre-industrial value of 8.2 to 8.1, corresponding to an increase in acidity of about 30%. Values of 7.8–7.9 are expected by 2100, representing a doubling of acidity.

• Areas that could be particularly vulnerable to OA include upwelling regions, the oceans near the poles and coastal regions that receive freshwater discharge.
Growing international efforts are devoted to develop a coordinated strategy for monitoring OA, with an eager need for global and frequent observations of OA-relevant parameters;

In 2012, OA researchers formed the Global OA Observing Network to bring together datasets, research and resources

Yet, datasets acquired are mostly relevant to in-situ measurements, laboratory-controlled experiments and models simulations.
Motivation and Objectives

- Remote sensing technology can be integrated by providing synoptic and frequent OA-related observations, extending in-situ carbonate chemistry measurements on different spatial/temporal scales.
- Preliminary products developed so far are only regional or derived with a limited variety of satellite datasets.
- The purpose of this study is to quantitatively and routinely estimate surface ocean pH by means of satellite remote sensing observations.
- The thematic objectives are
  
  1) to develop new algorithms and data processing strategies to overcome the relative immaturity of OA satellite products currently available, and
  
  2) to produce a global, temporally evolving, suite of relevant satellite-derived data.
Ocean Acidification using Earth observation

- Pathfinders-OA is an 18 month ESA project to exploit Earth observation to research and monitor Ocean Acidification
- Collect relevant datasets (in situ, EO and model)
- Create a large database of EO-in situ matchups
- Develop and validate algorithms to retrieve OA parameters from EO
- Generate open source software tools and journal publications

www.pathfinders-oceanacidification.org
Case study regions

Pathfinders-OA test areas

Global, SMOS salinity for October 2010 (blue-red)
Sea ice (green)
Carbonate system parameters estimation: Total Alkalinity (AT), pCO2, Dissolved Inorganic Carbon (DIC) and pH

Existing parameterizations

- pCO2: SST, Chl-a, SSS, MLD
- AT: SSS, SST
- DIC: SST, Chl-a, SSS
- pH: SST, Chl-a, O2, nitrate

Parameters function of salinity

- Stoichiometric dissociation constants: $K_{sp}$
- Gas solubility ($\alpha$)
- AT

Existing algorithms are most frequent in the north Pacific, north Atlantic, Bay of Bengal and Barents Sea.
Highlights that salinity from space enables us to monitor and study alkalinity-salinity relationship

AT derived from SMOS and OSTIA (credits N. Reul)
http://www.esa.int/Our_Activities/Observing_the_Earth/SMOS/SMOS_on_acid


http://www.climatenewsnetwork.net/satellite-link-puts-sharper-focus-ocean-acidity-rise/?utm_source=Climate+News+Network&utm_campaign=5bee6595a9-Satellites_focus_on_ocean_acidity2_25_2015&utm_medium=email&utm_term=0_1198ea8936-5bee6595a9-38794069
Methodology

- Satellite datasets (SSS, SST, Chl-a etc) forcing
- Uncertainties coming from the remote sensing data accuracies, from the quality of the algorithms and the adequacy of the carbonate system choice
- Stress on SMOS SSS, checking its impact in the pH estimation and monitoring
- CO2SYS software package v1.1 2011 [Lewis and Wallace, 1998]
- Surface ocean pH maps, dynamical evolution

Indirect satellite-driven surface ocean pH estimation flowchart
Datasets

- Year 2010, 6 months, monthly products, 1° x 1° deg spatial (re)-gridding
- SMOS L3 SSS OI, ascending passes (courtesy SMOS-BEC, Barcelona)
- OSTIA GLO-SST-L4-NRT-OBS-SST-MON-V2 at ¼ deg- distributed by MyOcean
- WOA 2009 SST and SSS climatology (comparison)
- pCO2 2010 updated climatology, ESA OceanFlux-GHG project (courtesy J. Shutler and ESA Pathfinders-OA project)
Satellite-based Total Alkalinity by using SMOS SSS data and OSTIA SST data

- **AT**: buffering capacity of a water body. Measure of the ability of a solution to neutralize acids and thus to resist to changes in pH
- **AT variability attributed for 80% to SSS**
- [Lee et al., GRL 2006] AT formulation, ingesting satellite data
- Parameterizations for the Atlantic ocean (2 basins)
- **CO2SYS:**
  - Ingesting AT and pCO2, supplying SSS and SST as well
  - Total pH scale, surface pressure
  - baseline configuration for other parameters: Si, PO4
  - baseline configuration for the dissociations constants
Satellite-based AT monthly evolution
Satellite-based pH monthly evolution
Clima-based AT monthly evolution
Clima-based pH monthly evolution
AT anomaly monthly evolution

Total Alkalinity differences by using satellite or climatology SSS/SST fields
Surface ocean pH differences by using satellite or climatology SSS/SST fields
AT and pH anomaly vs monthly variability

**Anomaly**

- Mean: $-12.8$
- Std: 26.5

**Variability**

- Mean: 0.4
- Std: 27.2

**Surface pH Difference - November 2010**

- Mean: $-0.0014$
- Std: 0.0032

**Surface ocean pH variability - November 2010**

- Mean: $-0.0009$
- Std: 0.0037
SSS and SST uncertainty propagation

- Misfit computation (satellite-clima)
- L3 ensemble statistics
- Propagation into AT and pH computation
- AT and pH dynamic range (peak-to-peak) excursion estimation

Ensemble std = 0.47 psu

Ensemble std = 0.72 degC
SSS and SST uncertainty propagation

Lower bound

Upper bound

Dynamic range

Total Alkalinity - November 2010

Total Alkalinity peak-to-peak - November 2010

surface ocean pH - November 2010

surface ocean pH - December 2010

Latitudinal and longitudinal maps of SSS and SST uncertainty propagation.
Qualitative consistency check

Takahashi, 2013, climatological surface pH
Monthly maps 4x5 deg grid
Summary and Ongoing work

- Identification of a methodological framework to exploit satellite EO assets in the OA context
- Preliminary satellite-based AT and surface ocean pH
- Preliminary analysis of dynamical features and sensitivities, with a distinct focus on SMOS SSS
- Preliminary consistency check with pH climatology

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- Extension temporal domain and geographical analysis
- Inclusion additional satellite datasets (especially OC-related)
- Inclusion remaining carbonate system parameters, performing different permutations (round-robin approach)
- Systematic sensitivity analysis
- Characterization variability at various t scales
Perspectives

– Foster the advancement of the embryonic phase of OA-related remote sensing, inferring a novel value-added satellite product

– Unify fragmented remote sensing efforts in terms of resolution and variety of datasets used, capitalizing on the recent addition of satellite SSS

– Fine-tune algorithms to derive surface ocean pH atlas, baseline to assess OA severity

– Mid-term objective: quasi-operational surface ocean pH derivation at different time scales

– Outreach: bridging the gap between the satellite and the IMBER / SOLAS communities, benefiting from their cross-fertilization and feedback

– Widen the portfolio of SMOS applications by stretching into the biogeochemical oceanographic context
Thank you
Grazie