OUTLINE

> Preprocessing
  – conversion to physical units
  – dark subtraction
  – data reduction

> Processing
  – conversion to physical units
  – depth correction
  – cosine correction
  – shading correction
  – extrapolation
  – $Rrs$

> Quality Control
  – biofouling
  – intercalibration
CONVERSION TO PHYSICAL UNITS

APPLICATION OF FACTORY CALIBRATION

> Satlantic, NIST traceable, every 6-12 months
  
  \[ E_s(t', \lambda)_{DD} = \left[ E_s(t', \lambda)_{Volt} - Dark_{Cal_{Es}}(\lambda) \right] \cdot Lin_{Cal_{Es}}(\lambda) \]
  
  \[ L_u(z', t', \lambda)_{DD} = \left[ L_u(z', t', \lambda)_{Volt} - Dark_{Cal_{Lu}}(\lambda) \right] \cdot Lin_{Cal_{Lu}}(\lambda) \cdot Imm_{Cal_{Lu}}(\lambda) \]
  
  \[ E_d(z', t', \lambda)_{DD} = \left[ E_d(z', t', \lambda)_{Volt} - Dark_{Cal_{Ed}}(\lambda) \right] \cdot Lin_{Cal_{Ed}}(\lambda) \cdot Imm_{Cal_{Ed}}(\lambda) \]
  
  \[ E_u(z', t', \lambda)_{DD} = \left[ E_u(z', t', \lambda)_{Volt} - Dark_{Cal_{Eu}}(\lambda) \right] \cdot Lin_{Cal_{Eu}}(\lambda) \cdot Imm_{Cal_{Eu}}(\lambda) \]
  
# MVDS s/n 053 with OCI-200 s/n 095
# Final calibration file valid 13 November, 2014
# Villefranche / Project 2007-503

INSTRUMENT SATMVD ' 6 AS 0 NONE
SN 0053 ' 4 AI 0 NONE
RATE 6 'Hz' 0 BU 0 NONE

# Optical data updated by Jennifer

#ES sensor OCI-200 S/N 095 calibrated for LO GAIN in IN AIR
# by Jenn on 11/13/14 at 10:38:11
# LO GAIN calibration, LAMP: f1304 at DIST: 50.0 cm
ES 412.3 'uw/cm^2/nm' 2 BU 1 OPTIC2
  32774.3 9.72971e-003 1.00
ES 442.3 'uw/cm^2/nm' 2 BU 1 OPTIC2
  32775.2 9.45316e-003 1.00
ES 489.5 'uw/cm^2/nm' 2 BU 1 OPTIC2
  32776.6 9.68600e-003 1.00
ES 510.6 'uw/cm^2/nm' 2 BU 1 OPTIC2
  32775.9 9.79014e-003 1.00
ES 560.2 'uw/cm^2/nm' 2 BU 1 OPTIC2
  32775.1 9.89505e-003 1.00
ES 669.5 'uw/cm^2/nm' 2 BU 1 OPTIC2
  32776.7 8.61297e-003 1.00
ES 682.3 'uw/cm^2/nm' 2 BU 1 OPTIC2
  32773.0 9.35531e-003 1.00
**Data Reduction and Dark Subtraction**

**Multispectral Instruments (No Internal Shutter)**

- The median value of 1' records is retained as representative of each quarter (same for ancillary)
  \[
  \overline{E_s(t, \lambda)_{Dd}} = \text{median}[E_s(t', \lambda)_{Dd}]^{60s}_{t'=0s},
  \]
  \[
  \overline{L_u(z, t, \lambda)_{Dd}} = \text{median}[L_u(z', t', \lambda)_{Dd}]^{60s}_{t'=0s},
  \]

- An average daily dark is calculated from night binned measurements and subtracted
  \[
  E_s(t, \lambda)' = \overline{E_s(t, \lambda)_{Dd}} - \text{mean}[E_s(t, \lambda)_{Dd}]^{3h}_{t=22h},
  \]
  \[
  L_u(z, t, \lambda)' = \overline{L_u(z, t, \lambda)_{Dd}} - \text{mean}[L_u(z, t, \lambda)_{Dd}]^{3h}_{t=22h}.
  \]

Mean and median not significantly different when the measurement is not affected by environmental variability (e.g. clouds)
HYPERSPECTRAL INSTRUMENTS (INTERNAL SHUTTER)

> The mean of two consecutive dark measurements is subtracted to light measurements in between

\[
E_s(t', \lambda) = E_s(t', \lambda)_{Dd} - \frac{E_s(t' - 1, \lambda)_{Shutter} + E_s(t' + 1, \lambda)_{Shutter}}{2}
\]

\[
L_u(z', t', \lambda) = L_u(z', t', \lambda)_{Dd} - \frac{L_u(z' - 1, \lambda)_{Shutter} + L_u(z' + 1, \lambda)_{Shutter}}{2}
\]

> Then the median value is kept for each quarter

\[
E_s(t, \lambda)' = median[E_s(t', \lambda)]_{t=0}^{60s}
\]

\[
L_u(z, t, \lambda)' = median[E_s(z', t', \lambda)]_{t=0}^{60s}
\]
CORRECTION OF INSTRUMENT DEPTH

- Depth, $Tilt_x$ and $Tilt_y$ are measured in the core of the buoy.
- The distance of each radiometer from the CTD along the buoy principal axis is known, so its depth when $Tilt=0$.
- A correction factor for depth each instrument and measurement is derived from the buoy Tilt and applied:
  
  $$ z_{rad}(t) = [z_{CTD}(t) - \Delta z_{rad}] \cdot f_{depth}(t, Tilt_x, Tilt_y) $$

  $$ f_{depth}(t) = \left(1 - \cos Tilt_y(t)\right) \cdot \left(1 - \cos Tilt_x(t)\right) - L_z \sin Tilt_x(t) $$
**Tilt Correction**

**Cosine Correction of Surface Irradiance**

> First the direct fraction of $E_s$ is estimated following Gregg & Carder, 1990

$$ E_S(t, \lambda)' = E_S(t, \lambda)' \cdot f_{dir} + E_S(t, \lambda)' \cdot (1 - f_{dir}) $$

> The correction is then applied to the direct fraction of $E_s$

$$ E_S(t, \lambda) = E_S(t, \lambda)' \cdot f_{dir} \cdot f_{tilt} + E_S(t, \lambda)' \cdot (1 - f_{dir}) $$

> Where $f_{tilt} = \frac{\cos(\alpha)}{\cos(\alpha')}$$

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**Graphs:**

- **Left Graph:**
  - $E_s(490) \, (\mu W/cm^2/nm)$
  - Time (h)
  - uncorr, corr, theor, RPD

- **Right Graph:**
  - Buoy Tilt (°)
  - Buoy $\delta \psi$
**SHADING CORRECTION**

**BUOY STRUCTURE SHADING AND INSTRUMENT SELF-SHADING**

- Backward 3D *Montecarlo* simulation (*SimulO*) replaces the *Gordon & ding (1992)* correction scheme
- Simulation for each underwater instrument
  - Chl = 0.1, 0.5, 1.0, 5.0 µg l⁻¹
  - Azimuth angle from 0° to 360°, with 5° step
  - Zenith angle from 0° to 90°, with 5° step
  - 7 wavelengths (412, 443, 490, 510, 555, 670 nm)
- A correction factor from LUTs is applied
  - $L_u(z_4, t, \lambda) = L_u(z_4, t, \lambda') \cdot f_{s4}$
  - $L_u(z_9, t, \lambda) = L_u(z_9, t, \lambda') \cdot f_{s9}$

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**Preprocessing – Processing – QC**
SHADING CORRECTION

preprocessing – processing – QC

21-23 February 2017 – FRM4SOC
**Extrapolation of Lu to Surface**

> Diffuse attenuation coefficient for radiance is estimated from the \( L_u \) measurements at 4 m and 9 m

\[
K_L = -\frac{\ln(L_u(z_9,t,\lambda)/L_u(z_4,t,\lambda))}{z_9-z_4}
\]

> \( L_u \) at 4 m is then lognormally extrapolated to surface (below water) and a correction factor is applied*

\[
L_u(0^-, t, \lambda) = L_u(z_4, t, \lambda) e^{-z_4 \cdot K_L} \cdot f_H
\]

> Finally water leaving radiance is calculated as

\[
L_w(t, \lambda) = L_u(0^-, t, \lambda) \cdot \frac{1-\rho}{n^2} ; \text{ where } \frac{1-\rho}{n^2} = 0.543
\]

**Hydrolight Correction**

> Radiative transfer simulation of \( L_u(z, Chl, \theta_s, \lambda) \)

- \( Chl = 0.1, 0.5, 1.0, 5.0 \) µg l\(^{-1}\)
- Zenith angle from 0° to 90°, with 5° step
- 7 wavelengths (412, 443, 490, 510, 555, 670 nm)

> Generation of a LUT of the ratio between \( L_u(0^-, t, \lambda) \) as estimated from radiative transfer simulations and lognormal extrapolation of simulated \( L_u(Chl, \theta_s, \lambda) \) at 4 and 9 m
**Remote Sensing Reflectance**

\[ R_{rs}(t, \lambda) = \frac{L_w(t, \lambda)}{E_S(t, \lambda)} \]

\[ R_{rs} = \frac{\overline{L_{u4} f_{cal} f_{s4}} e^{\left[ z_4 \left( -\ln \left( \frac{L_{u9} f_{cal} f_{s9}}{L_{u4} f_{cal} f_{s4}} \right) \right)} \right]}{\overline{E_s f_{cal} f_{cos} f_{tilt} f_{dir} + (1 - f_{dir}) E_s f_{cal}}} \]

**Keep in Mind for the Next Talk**

- \( \overline{E_s} = E_s(t, \lambda)' \)
- \( \overline{L_{u4}} = L_u(4, t, \lambda)' \)
- \( \overline{L_{u9}} = L_u(9, t, \lambda)' \)
- \( f_{cal} = 1 \) next talk for more details

> Product delivered to space agencies, from here data processing for match-up analysis might differ
\[ -R_{rs}(t, \lambda_i)_{sat} = \frac{\int_{\lambda_i}^{\lambda_i+n} L_w(t, \lambda_i) SRF(\lambda_{sat}) d\lambda}{\int_{\lambda_i}^{\lambda_i+n} SRF(\lambda_{sat}) d\lambda} \]

\[ \frac{\int_{\lambda_i}^{\lambda_i+n} E_s(t, \lambda_i) SRF(\lambda_{sat}) d\lambda}{\int_{\lambda_i}^{\lambda_i+n} SRF(\lambda_{sat}) d\lambda} \]

\[ SRF(\lambda_i)_{sat} \] are the spectral response functions of SeaWiFS, MERIS, MODIS, VIIRS, MSI, OLCI.
**CHLOROPHYLL**

**TChl-a Time Series**

1. TChl-a values are needed for LUTs of shading and *Hydrolight* corrections (a single value per day is used)
2. For recent data TChl-a values come from calibrated Fluorescence calibrated (linear regression of an historical data set VS HPLC, mean night value are used to eliminate data affected by non-photochemical quenching)
3. For assessed data a time-series from satellite data calibrated on monthly HPLC is used.

![Graph showing relationship between Log[TChl-a] and Log[Fluorescence]](image)

![Graph showing Chl [mg m^-2] over time](image)
**Quality Control**

**Some Criteria Generally Used for QC**

- Buoy depths < 11 m are discarded (Es too close to sea surface)
- Buoy Tilt > 10°
- 0.8 < Es/Theoretical Es < 1.2

**Finer Criteria not Routinely Used**

- Standard deviation of Es < 2%
- Azimuth angle (i.e. shading correction)
- Further QC is performed case per case on specific data sets
QUALITY CONTROL

BIOFOULING

> Data screening for possible presence of biofouling (sensor cleaning helps)
> Elimination or correction whenever possible
QUALITY CONTROL

BIOFOULING

> Data screening for possible presence of biofouling (sensor cleaning helps)
> Elimination or correction whenever possible
**Quality Control**

**Dynamic Climatology Correction**

> Data from deployments (or partial deployments from known issues) are compared to the rest of data from the same period of the year in terms of median ratio
> Data whose median ratio is within a threshold are retained in the "good" data set
> Thresholds are \(\log(\text{median ratio}) < |0.1|\) for \(E_s\), \(\log(\text{median ratio}) < |0.2|\) for \(L_u, E_d, E_u\)
> A "good" data set is established for each wavelength, instrument, depth
> "Bad data" are compared to its corresponding "good" dynamic climatology and a correction factor estimated
> Keep in mind that in most cases 1/few wavelengths of one of three instruments used to derive \(Rrs\) are concerned
How does it look like in a time series?

The procedure still needs to be settled (i.e.: definition of the thresholds and N of observations needed in the dynamic climatology to assess stable "gains")
PURPOSE OF THESE CORRECTIONS

> Biofouling and Intercalibration corrections are not intended for SVC use
> Still valuable data for science (eg: seasonal variability, modelling assimilation,...)
> Debatable use for validation: the definitive answer can be given after assessment of their uncertainties (to do list)
D. Antoine – PI
V. Vellucci – Project Manager
M. Golbol, E. Soto, E. Diamond – Cruises
V. Taillander – CTD processing
C. Dimier, J. Ras – HPLC
B. Gentili – Code development
A. Bialek – Uncertainties
E. Leymarie – Montecarlo simulations
Bricaud – CDOM
G. De Liege, D. Luquet, D. Robin – Diving
S. Marty – Calibrations
J. Uitz, H. Claustre, F. D’Ortenzio – Expertise
L. Fere, C. Poutier, I. Courtois – Administration

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