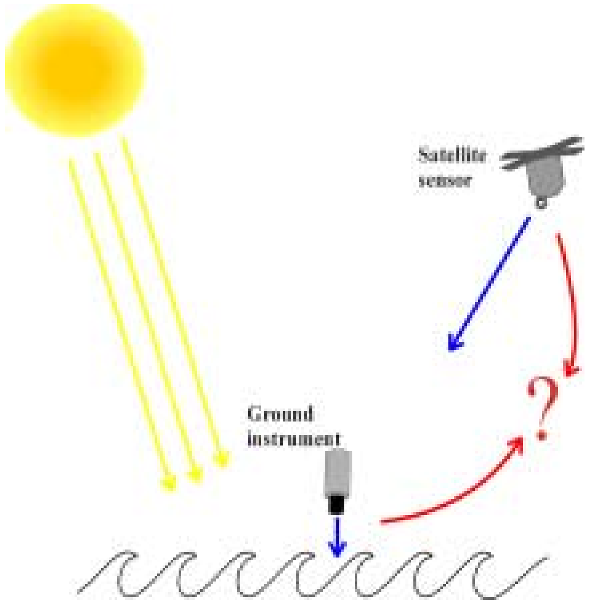
Validation of Ocean Colour Sensors

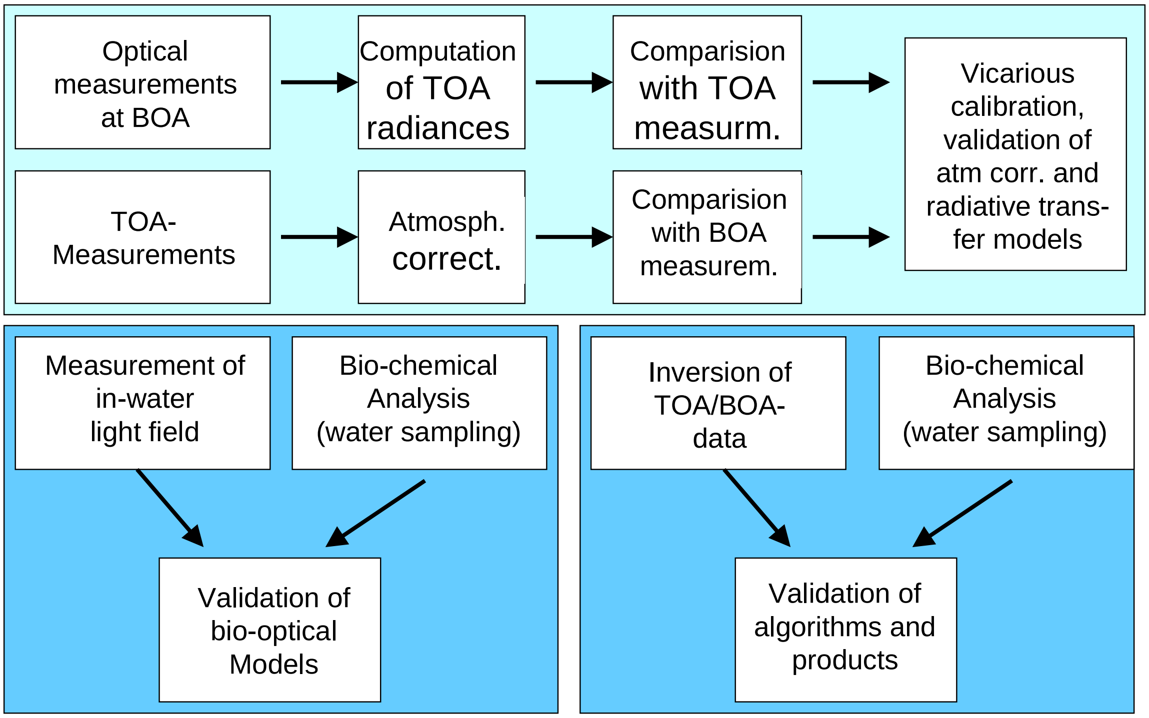
Dr. A. Neumann
German Aerospace Centre DLR
Remote Sensing Technology Institute
Marine Remote Sensing

- What is Validation?
- Validation Scheme, Interacting Components
- Vicarious Calibration
- Ground Truth Measurements
- Validation of Models, Algorithms and Products

Introduction - What is Validation?

- Validation: establish the link between measurements in orbit and measurements made on ground (sensor validation) as well as verification of models, algorithms, derived parameters and data products (algorithm validation)
- essential procedure for the utilisation of „ground truth“ measurements
- essential to understand and quantify the quality and accuracy of data products





Optical measurements at BOA → Computation of TOA radiances → Comparision with TOA measurm. → Vicarious calibration, validation of atm corr. and radiative transfer models

TOA-Measurements → Atmosph. correct. → Comparision with BOA measurem. → Vicarious calibration, validation of atm corr. and radiative transfer models

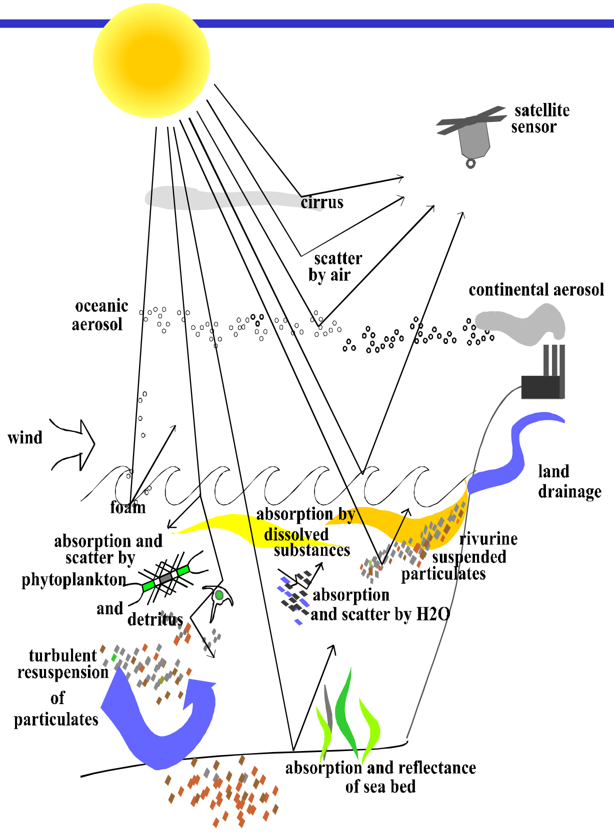
Measurement of in-water light field → Validation of bio-optical Models

Bio-chemical Analysis (water sampling) → Validation of bio-optical Models

Inversion of TOA/BOA-data → Validation of algorithms and products

Bio-chemical Analysis (water sampling) → Validation of algorithms and products

---



Optical Interactions for Ocean Remote Sensing

Sensor Validation - Vicarious Calibration

- The general goal of sensor validation is to realise a radiometric closure between sensor values (top-of-atmosphere radiance, TOA), and measurements made on ground (bottom-of-atmosphere, BOA)
- in general two possible ways:
  - use BOA measurements to compute TOA values and intercompare with satellite data (closure at TOA)
  - correct satellite data with respect to atmospheric signal and intercompare results with BOA measurements (BOA closure)
- both approaches are adequate, differences in detail with respect to influence of assumptions, calibration accuracy and models
- in both cases radiative transfer models (RTM, forward or invers) are the tool to solve the task

---

Vicarious Calibration - General Considerations

- Measurements on ground must be synchronous with overpass of the satellite since several geophysical phenomena show high dynamics with time, especially in the atmosphere
- differences in viewing geometry may cause significant errors (e.g. the aerosol from ground by Sun measurement is determined for a different atmospheric path cp. to viewing from satellite)
- scaling problems: the satellite sensor integrates over a larger area on the surface. This causes the problem to what extent the point measurement on ground represents what the satellite sees (patchiness in the water, foam, small clouds, blurring, ...)
- a sufficient number of synchronous measurements is necessary
- in all cases there is the question which measurement is “true”, i.e. the ground measurement or the satellite. This usually leads to the solution, that all measurements are normalised to a ground based, laboratory reference standard (e.g. MOBY for SeaWiFS)

Sensor Validation - Vicarious Calibration

- Signal components measured at TOA satellite level

$$L_{sat} = L_W + L_A + L_R + L_G + L_M$$

  - with
    - L_{sat} - total radiance measured by satellite
    - L_W - water leaving radiance, the signal „of interest“
    - L_A - aerosol path radiance caused by particle scattering
    - L_R - Rayleigh path radiance, molecular scattering
    - L_G - surface glitter, caused by direct sun glint or sky light
    - L_M - term including additional signals caused by multiple interactions
- in general all terms have to be accounted for in vicarious calibration

---

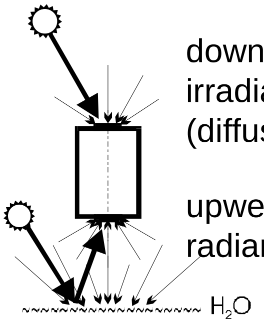
Sensor Validation - Ground Truth Measurements (I)

- Measurements necessary for sensor calibration:

– incident irradiance on surface	$E_d(+0,\lambda)$	⇨ remote sensing reflectance $R_{rs}(+0,\lambda)$
– water leaving radiance	$L_w(+0,\lambda)$	
– global incident irradiance	$G(+0,\lambda)$	⇨ aerosol-optical depth $\tau(\lambda)$
– sky radiance	$H(\lambda)$	⇨ aerosol phase function $P(\Theta,\phi,\lambda)$
– Almukantar	$\mu(\Theta,\phi,\lambda)$	
– Transmission	$T(\lambda)$	

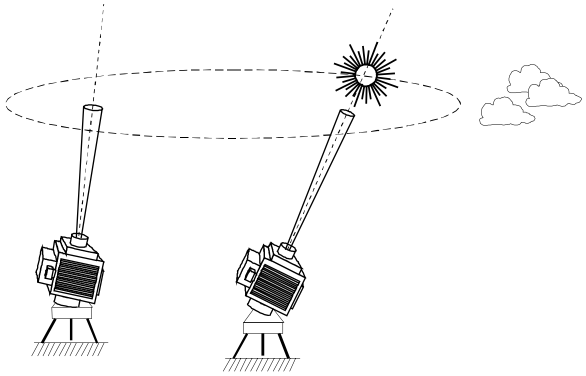
- additional needed parameters: meteorology (surface barometric pressure, wind speed and direction, cloud cover, humidity), wave height, absorber concentration (mainly O_3)

Sensor Validation - Ground Truth Measurements (II)



downwelling
irradiance E_d
(diffuser)

upwelling
radiance L_w



sky radiance   transmission

almukantar

Sensor Validation - Closure at TOA

- The parameters measured on ground are used to compute through radiative transfer modelling the corresponding TOA radiance values which then can be compared to the values measured by the satellite sensor
- since most of the parameters used in forward RTM are known, the calculations can be done very accurate
- measurement errors on ground are directly propagated to TOA level
- crucial parameters of heavy influence are wind speed (resulting in surface signal) and aerosol characteristics, scaling/patchiness

Sensor Validation - Closure at BOA

- An atmospheric correction procedure is applied to the TOA radiance values measured at satellite to compute water leaving radiance values which then are compared to the values measured above sea surface. In addition the aerosol parameters derived both from satellite and ground measurements are compared to get additional clues.
- The inverse algorithms for atmospheric correction can be very accurate, if a sufficient number of usable spectral bands on satellite is available
- calibration errors in the satellite measurement are enhanced by the atmospheric correction procedure
- crucial parameters of heavy influence are wind speed (resulting in surface signal) and aerosol characteristics, scaling/patchiness

---

Validation of Models, Algorithms and Derived Products

- Most up-to-date retrieval algorithms use models to desribe the link between (bio-) physical values, such as concentrations of water constituents, and the spectral signature measured by a satellite sensor or an above water / sub-surface spectrometer
- this link is established by inherent optical properties (IOPs), i.e. absorption and scattering characteristics of the water itself and suspended or dissolved constituents (cp. Part B of this training course)
- the validation of models as well as retrieval algorithms and derived variables requires additional measurements compared to vicarious calibration:
  - under water light field
  - specific optical properties of water constituents
  - in-situ concentrations and composition of suspended or dissolved constituents

Measurement of Under-Water Light Field

- One basic parameter used for model validation is the volume reflectance defined as the ratio of up- and downward fluxes below the surface:

$$R_V = \frac{E_U^-}{E_D^-}$$

- therefore measurement of up- and downwelling spectral irradiance is the minimum, additional measurement of the upwelling spectral radiance allows computation of the remote sensing reflectance and the “Q-factor”

$$R_{RS} = \frac{L_U^-}{E_D^-} \qquad Q = \frac{E_U^-}{L_U^-}$$

- additional measurements allow determination of inherent optical properties under certain assumptions as well as other important parameters
- in-situ measurement of absorption a(λ), beam attenuation c(λ) and backscattering $b_b(\lambda)$ is desirable for determination of IOPs

---

Extended Optical Measurements

Measurements

- **Water**

– incident irradiance on surface		$E_d(+0,\lambda)$
– water leaving radiance		$L_w(+0,\lambda)$
– downwelling irradience (below surface)		$E_d(z,\lambda)$
– downwelling scalar irradiance	(-“-)	$E_{od}(z,\lambda)$
– upwelling irradiance	(-“-)	$E_u(z,\lambda)$
– upwelling scalar irradiance	(-“-)	$E_{ou}(z,\lambda)$
– upwelling radiance	(-“-)	$L_u(z,\lambda)$

- **Atmosphere**

– global incident irradiance	G(+0,λ)	
– sky radiance		H(λ)
– Almukantar		μ(Θ,ϕ,λ)
– Transmission	T(λ)	

Derived parameters

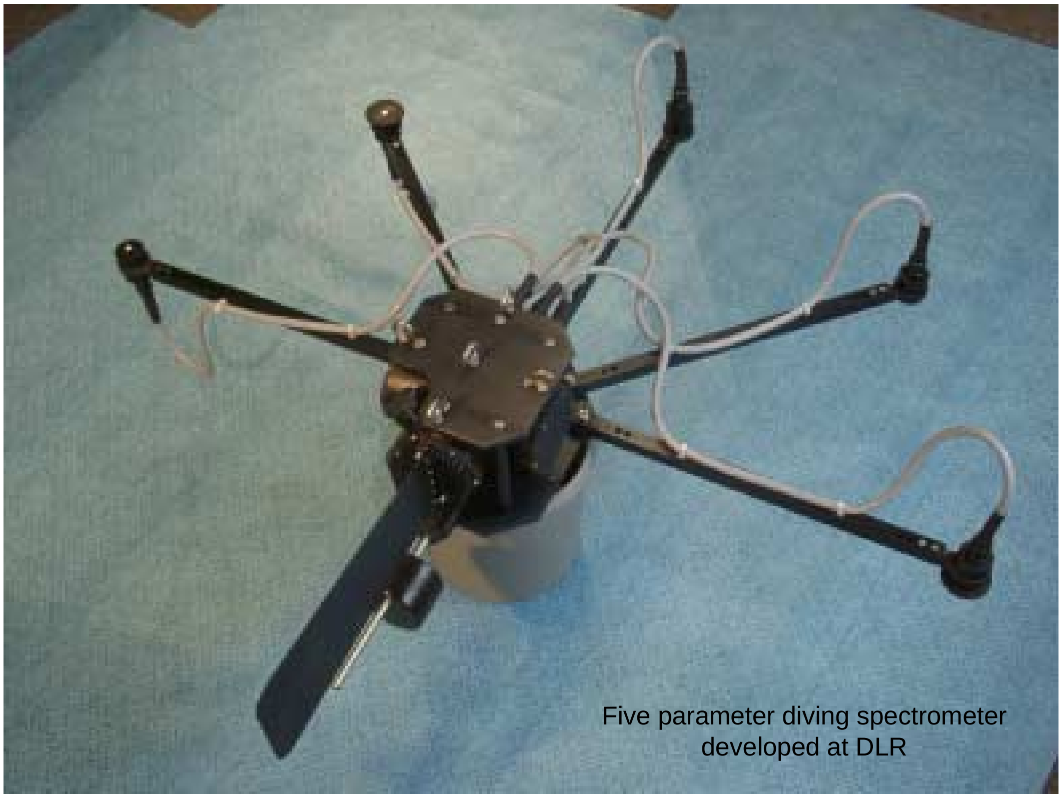
- remote sensing reflectance $R_{rs}(+0,\lambda)$
- volume reflectance $R_v(z,\lambda)$
- diffuse attenuation coefficient $K_d(z,\lambda)$
- inherent optical properties (a, b)

- aerosol-optical depth τ(λ)
- aerosol phase function P(Θ,ϕ,λ)

Ground Truth Instruments

- bio-chemical analyses are usual standard at ocean biology research institutes or services
- several instruments are available off-the-shelf for the basic set of optical measurements, most of them corresponding to SeaWiFS wavelengths
- spectrometers measuring the complete under-water light field were developed for research purposes at different institutes, they are significantly larger and complicated to handle cp. to standard equipment
- measurement of specific absorption and scattering properties needs extensive laboratory equipment

⇨ Still unsolved is the intercalibration of ground truth instruments. NASA's SIMBIOS programme has put significant effort to this problem.



Five parameter diving spectrometer
developed at DLR

Validation of Derived Products

- The goal of product validation is to get an understanding on the accuracy of (bio-) physical parameters derived from satellite measurements. The results are statistical uncertainty values, or, for some semi-analytical algorithms, error maps for each derived parameter.
- The validation needs a large number of in-situ measurements (concentrations) synchronous to satellite overpasses to be intercompared. Since point-to-point comparison due to the discussed problems are questionable it is more likely to compare statistical parameters (distribution functions and momentums)
- The validation needs to be done for each sensor, each algorithm and each parameter separately. Intercomparision of algorithms and products is again an extra process.

⇨ And: also in-situ measurements of concentrations may have not negligible errors!