Salinity: from Pot to Port

Ebenezer Nyadjro
US Naval Research Lab/
University of New Orleans

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Importance of salt: Food & Health

- NaCl: Sodium Chloride (table salt)
  - food seasoning
  - food preservation
  - regulates body fluids
  - controls blood pH, pressure, and volume
Importance of salt: Industry

- manufacturing: glass, paper, rubber, and textiles
- de-icing
- animal feed
- waste & water treatment
Importance of salinity

- density/water mass
- ocean circulation
- hydrological cycle
- air-sea interaction

Schmitz, 2005
The ocean contains the vast majority of Earth’s water reservoirs, and ~80% of surface water fluxes occur over the ocean. Reservoirs represented by solid boxes: $10^3$ km$^3$, fluxes represented by arrows. Source: Durack (2015-Oceanography)
Ocean salinity

• Salinity—the amount of dissolved salt in the water

• Salt in the ocean comes from rocks on land.

• On average, oceans salinity: 3.5%, or 35 parts per thousand.

• Thus for every 1 liter (1000 mL) of seawater there are 35 grams of salts (mostly ~ 90%, but not entirely, NaCl) dissolved in it.

<table>
<thead>
<tr>
<th>Dissolved salts in sea water (atoms):</th>
</tr>
</thead>
<tbody>
<tr>
<td>55.3 % Chlorine</td>
</tr>
<tr>
<td>30.8 % Sodium</td>
</tr>
<tr>
<td>3.7 % Magnesium</td>
</tr>
<tr>
<td>2.6 % Sulfur</td>
</tr>
<tr>
<td>1.2 % Calcium</td>
</tr>
<tr>
<td>1.1 % Potassium</td>
</tr>
</tbody>
</table>
Ocean salinity

- Units: practical salinity unit (psu); parts per thousand (ppt)

- Based on properties of sea water conductivity

- Equivalent to per thousand ($\%_{00}$) or to $\text{g/kg}$

- Varying from less than 15 psu at the mouth of the rivers to more than 40 psu in the Dead Sea
Ocean salinity

• Ocean salinity based on properties of sea water conductivity

• Conductivity: a substance/material's conductivity is the extent that it allows an electric current to flow through it.

• By measuring conductivity one can get a measurement of that water sample's salinity.

• This is because electric current passes much more easily through water with a higher salt content.

• Thus, if we know the conductivity of the water, we know how much salt is in the water.
Global salinity pattern
Surface salinity variation

Pattern of surface salinity:

- Lowest in temperate and high latitudes
- Highest in the tropics
- Dips at the Equator

• Surface processes help explain pattern
ITCZ

Climate system influenced by wind variability and ITCZ migration

ITCZ: band where the southeasterly and northeasterly wind converge
Net $E = 13$ Sv

$1$ Sv $= 10^6$ m$^3$s$^{-1}$

Net $P = 12.2$ Sv

Net River $= 1.25$ Sv

Diff $= \sim -0.45$ Sv

$FW = E - P + R$
Evaporation Minus Precipitation and Salinity

**Evap minus PPT (June 2010)**

**Argo SSS (June 2010)**
Surface salinity variation

Salt budget estimated from:

\[
\frac{\partial S}{\partial t} = \frac{S(E - P)}{h} - u \frac{\partial S}{\partial x} - v \frac{\partial S}{\partial y} - w \frac{\partial S}{\partial z} + R
\]

Ocean continuity equation

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0
\]

- $S$ = salinity
- $E$ = evaporation
- $P$ = precipitation
- $u$ = zonal advection
- $v$ = meridional advection
- $w$ = vertical advection
- $R$ = residual
Intensification of global water cycle!!!

Ocean Salinities Reveal Strong Global Water Cycle Intensification During 1950 to 2000
Paul J. Durack et al.
Science 336, 455 (2012);
DOI: 10.1126/science.1212222

Paul J. Durack,1,2,3,4* Susan E. Wijffels,1,3 Richard J. Matear1,3

Fundamental thermodynamics and climate models suggest that dry regions will become drier and wet regions will become wetter in response to warming. Efforts to detect this long-term response in sparse surface observations of rainfall and evaporation remain ambiguous. We show that ocean salinity patterns express an identifiable fingerprint of an intensifying water cycle. Our 50-year observed global surface salinity changes, combined with changes from global climate models, present robust evidence of an intensified global water cycle at a rate of 8 ± 5% per degree of surface warming. This rate is double the response projected by current-generation climate models and suggests that a substantial (16 to 24%) intensification of the global water cycle will occur in a future 2° to 3° warmer world.

16 to 24% intensification of the global water cycle will occur in a future 2° to 3° warmer world.
Temperatures are rising !!!

Global Land–Ocean Temperature Temperature Index

1.4 °F (0.8°C) around the world since 1880, mostly recent decades
Loss of 0.32 Sv due to evaporation

- Evaporative loss of water from the Atlantic; compensated by a net import of water from the Pacific.
- Increase in Atlantic salinity compensated by less salty Pacific waters
- In warming climate, inter-basin contrasts increase (saltier Atl, fresher Pacific)
- Warming-driven amplification of the Earth’s hydrological cycle
- Due to simple physics - warm air carries more water vapor
Measuring salinity

In-situ: CTD – Conductivity-Temperature-Depth
Argo float

Argo is a global array of more than 3,900 free-drifting profiling floats that measures the temperature and salinity of the upper 2000 m of the ocean.
Salinity from Space
Remote sensing platforms

Ground-based

Airplane-based

Satellite-based
Introduction

**What is remote sensing:** the art, science and technology of

- acquiring,
- processing, and
- interpreting

images and related data that are obtained from **ground-based, air-or space-borne instruments** that record the interaction between matter (target) and electromagnetic radiation

Energy patterns derived from **noncontact sensor systems**

Remote Sensing: using electromagnetic spectrum to image the **land, ocean, and atmosphere**.
Remote Sensing: Primary components

- Energy-radiation
- Sensor
- Object
Remote Sensing: A brief history

Hot-air Balloons
Invented by the Montgolfier Brothers in 1783

1858 Gaspard Felix Tournachon (Nadar) takes first aerial photograph near Paris, using a captive balloon and a collodion plate. Unfortunately, this first aerial photograph did not survive.

Gaspard Felix Tournachon (Nadar)
In 1903, Julius Neubronner patented a breast-mounted camera for carrier pigeons that weighed only 70 grams. A squadron of pigeons is equipped with light-weight 70-mm aerial cameras.
Importance of satellite oceanography

- Observes the distribution of certain ocean surface properties in exquisite spatial detail: allows the true spatial structure to be examine

- Captures a “snapshot” of the spatial distribution. “Freezes” the continually changing ocean

- Offers a repeated view: consistent measurements by a single sensor

- Observes part of the ocean other methods miss
  - Shipping routes are concentrated in certain zones
  - Ships tend to avoid poor weather hazardous regions
  - Drifting buoys tend to avoid regions of divergent currents
Limitations of satellite oceanography

- Can observe only some of the ocean's properties and variables
- Measures the ocean only at or near the surface
  -- Although the surface is the most critical place to measure
- Ocean measurements may be corrupted by the atmosphere
- Some satellites/methods cannot see through clouds at all
- Can make measurements only when the satellite is in the right place at the right time
- All measurements require calibration and validation using in situ data
An obvious limitation of remote sensing

**Challenge:** Understand the processes which produce a surface signature for subsurface phenomena

- Remote sensors observe the sea SURFACE
- We often want to observe processes INSIDE the sea
- Subsurface processes can only be detected if they have a surface signature
Applications of Remote Sensing

- Carbon Management
- Public Health
- Energy Management
- Aviation
- Water Management
- Homeland Security
- Coastal Management
- Disaster Management
- Agricultural Efficiency
- Invasive Species
- Ecological Forecasting
- Air Quality
Basic physics and principles
Sources of energy for remote sensing

- **The Sun**
  - Visible waveband
  - Near Infra red waveband

- **Thermal emission by the ocean surface**
  - Thermal infra red
  - Microwaves

- **Energy source on the satellite**
  - Microwaves (Radar)
  - Visible (Lidar)
The Sun produces a continuous spectrum of energy that continually bathe the Earth in energy.

The visible portion of the spectrum may be measured using wavelength (micrometers or nanometers) or electron volts (eV).

Electromagnetic radiation behaves in most circumstances as waves and can thus be characterized as waves.
A human detected by different instruments

- IR device
- Bare eyes
- X-ray
- Microscope
All matter above absolute zero (0 Kelvin = -273°C = -459.4°F) emits radiant energy in form of electromagnetic waves.

3 key additional properties of surfaces which control the radiation heat transfer of a surface:

• absorptivity $\alpha$,
• transmissivity $T$ and
• reflectivity $\rho$. 

$\alpha + \tau + \rho = 1$

Incoming Radiation = 1
How is Energy Transferred?

Energy may be transferred 3 ways: *conduction*, *convection*, and *radiation*:

(a) **conduction**: one body (molecule or atom) transfers its kinetic energy to another by colliding with it (direct contact).

(b) **convection**: the KE of a body is transferred from one place to another by physically moving the bodies. E.g. the convectional heating of air in the atmosphere in the early afternoon.

(c) Electromagnetic energy in the form of *electromagnetic* waves (radiation) transmitted through the vacuum of space from the Sun to the Earth.
Active and passive sensors

**Active sensors** (microwave) create their own radiation with which to illuminate the target, and then observe the nature of the reflected signal, in contrast to **passive** (sun, IR and visible wavelength) sensors which rely on naturally occurring radiation.

<table>
<thead>
<tr>
<th>Passive sensors</th>
<th>Wavelength</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible wavelength radiometers</td>
<td>400 nm - 1 µm</td>
<td>Solar radiation reflected by Earth surface</td>
</tr>
<tr>
<td>Infrared (IR) radiometers</td>
<td>about 10 µm</td>
<td>Thermal emission of the Earth</td>
</tr>
<tr>
<td>Microwave radiometers</td>
<td>1.5 - 300 mm</td>
<td>Thermal emission of the Earth in the microwave</td>
</tr>
</tbody>
</table>

**Active devices**

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<th>Wavelength</th>
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<tr>
<td>Altimeters</td>
<td>3 - 30 GHz</td>
<td>Earth surface topography</td>
</tr>
<tr>
<td>Scatterometers</td>
<td>3 - 30 GHz</td>
<td>Sea surface roughness</td>
</tr>
<tr>
<td>Synthetic aperture radars</td>
<td>3 - 30 GHz</td>
<td>Sea surface roughness and movement</td>
</tr>
</tbody>
</table>
A summary of sensor types & what they measure

- **Sensor Class**
  - Passive Sensors
    - Visible Waveband sensors
    - Multi-spectral scanners Imaging spectrometers
    - Infra-red sensors
    - Infra-red imaging radiometers
    - Microwave sensors
    - Scanning microwave radiometers
  - Active
    - Radar instruments
    - Scatterometer Imaging radar Altimeter

- **Primary measure**
  - Ocean colour
  - Sea surface temperature
  - Surface roughness
  - Surface slope

- **Derived parameters**
  - Chlorophyll Suspended particles Bathymetry
  - Mixed-layer temperature Skin temperature
  - Surface winds Wave height Wave spectra Internal waves surface slicks
  - Geostrophic currents Ocean geoid Sea-floor bathymetry
Remote Sensor Resolution Considerations

- **Spatial** - the size of the field-of-view, e.g. $10 \times 10$ m.

- **Spectral** - the *number* and size of spectral regions (or frequencies) the sensor records data in, e.g. blue, green, red, near-infrared, thermal infrared.

- **Temporal** - how often the sensor acquires data, e.g., every 30 days.

- **Radiometric** - sensitivity of detectors to small difference in electromagnetic energy.

![Diagram showing spatial, spectral, and temporal considerations for remote sensor resolution.](image)
Spatial Resolution

Variations of IFOV (spatial resolution) with view angle

Imagery of Harbor Town in Hilton Head, SC, at Various Nominal Spatial Resolutions

- a. 0.5 x 0.5 m.
- b. 1 x 1 m.
- c. 2.5 x 2.5 m.
- d. 5 x 5 m.
- e. 10 x 10 m.
- g. 40 x 40 m.
- h. 80 x 80 m.

Nadir IFOV

Oblique IFOV
Salinity sensing
Dependence of $T_B$ at nadir with SST and SSS [Camps et al., 2003]

**The Technology**

- L-Band microwave (passive) radiometer
- 1.413 GHz
- Radiometer measures the brightness temperature ($T_b$)

$T_b$ is linked to salinity through the dielectric constant of the sea water via its emissivity, $e$:

$$T_b = eT$$

This is then linked to the Klein-Swift model (1977) & retrieval algorithms to obtain SSS
• $T_b$ depends on salinity through the dielectric constant ($\varepsilon_r$)

$$\varepsilon_r = 88.045 - 0.4147T + 6.295 \times 10^{-4} T^2 + 1.075 \times 10^{-5} T^3$$

(Klein and Swift, 1977)
The Technology

Error sources:
• solar reflection
• atmospheric oxygen
• galactic noises

• SST
• wind speed (sea surface roughness)

Geophysical sources that influence the microwave radiation from sea surface [Yueh et al., 2001]
Radio Frequency Interference (RFI)
Soil Moisture and Ocean Salinity (SMOS)

- European Space Agency (ESA)
- Launched on 2 November 2009
- Soil moisture (SM) and ocean salinity (OS)
- Resolution: 1-3 days & 45 km
- Accuracy of 0.1 psu/30 days/200 km

The SMOS satellite

Amazon freshwater plume
Antenna aperture synthesis, as used in radio-astronomy: an array of receivers constitute a **Very Large baseline Antenna** and generate an image by *interferometry*.
MIRAS: MICrowave Radiometer with Aperture Synthesis

- Passive microwave radiometer (L-band - 1.4GHz)
- 2D interferometry
- Multi-incident angles (0-55°)
- 755.5 km altitude
- ~1000 km swath
- Polarimetric observations
- 30° steer angle
- 32.5° tilt angle

Technical Concept

69 receivers in total
(18 in each arm, 15 on the hub)

21 receiver elements per arm:
6 x 3 + 3 (hub)

6 redundant receivers (in hub)
Aquarius
• NASA & CONAE; launched 10 June 2011; died June 2015
• MWR-ocean wind & direction, rain, sea ice
• NIRST – SST; 3 bands
• Resolution: 7 days & 150 km
• Accuracy: 0.2 psu/30 days/150 km

Aquarius satellite in orbit
Aquarius global mean SSS
Global salinity pattern
SMAP (Soil Moisture Active Passive)

- NASA; launched 31 Jan 2015
- Resolution : 2-3 days; Footprint of \sim 9\ km.
- uses both an L-band \textit{radar} and an L-band \textit{radiometer}
- takes advantage of the relative strengths of active (radar-SAR) and passive (radiometer) microwave remote sensing;
- advantage of the spatial resolution of radar and sensing accuracy of radiometer
SMAP

• measures the amount of water in the top 5 cm (2 in) of soil
• help study Earth's water, energy and carbon cycles
• soil moisture is a primary state variable of hydrology and the water cycle over land.