Hydrography

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Preface

This book is based on the lecture notes for the graduate and undergraduate courses in hydrography as offered at the Department of Geomatics Engineering of the Universitiy of Calgary and the Department of Mathematical Geodesy and Positioning of Delft University of Technology. The purpose of the book is to present an introduction to and an overview of the broad field of hydrography. Since there is only a weak interdependence between the eleven chapters, each of them can be studied separately. When used for a course, it is therefore also possible to consider only a selected number of chapters.

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Table of contents

1 ELEMENTS OF OCEANOGRAPHY 1

1.1 Water 1

1.2 Ocean currents and general circulation 3

1.3 Waves 12

1.4 Major references 19

2 TIDES AND TIDAL CURRENTS 21

2.1 Introduction 21

2.2 Tide-generating forces 22

2.3 Tidal analysis and prediction 35

2.4 Major references 39

3 ESTIMATION AND QUALITY CONTROL 41

3.1 Least squares estimation 41

3.2 Quality control 48

3.3 Recursive estimation 55

3.4 Recursive quality control 65

3.5 Major references 70

4 COORDINATE SYSTEMS 71

4.1 Geodetic datums 71

4.2 Ellipsoidal computations 76

4.3 Map projections 80

4.4 Vertical datums 84

4.5 Major references 88

5 FUNDAMENTALS OF RADIO FREQUENCY PROPAGATION AND MEASUREMENTS 89

5.1 Radio Frequency definitions 89

5.2 Radiowave propagation 96

5.3 Time keeping 140

5.4 RF-wave measurements 150

5.5 Major references 160

6 UNDERWATER ACOUSTICS 163

6.1 Introduction 163

6.2 Wave equation 164

6.3 Sonar parameters 183

6.4 Sonar equations 191

6.5 Sound in water 193

6.6 Major references 198

7 LAW OF THE SEA 199

7.1 History 199

7.2 Baselines 201

7.3 Maritime zones 204

7.4 Boundaries between states 209

7.5 Third party settlement 215

7.6 Major references 217

8 CONCEPTS OF MARINE POSITIONING 219

8.1 Geometry of positioning 219

8.2 Classification of marine positioning systems 237

8.3 Marine positioning requirements and standards for hydrographic surveys 245

8.4 Major references 253

9 DESCRIPTION OF SELECTED POSITIONING SYSTEMS 255

9.1 Optical and laser systems 255

9.2 Omega 255

9.3 Loran-C 260

9.4 Satellite positioning systems 270

9.5 Speed determination 280

9.6 Major references 301

10 UNDERWATER ACOUSTIC POSITIONING 303

10.1 Introduction 303

10.2 Short baseline systems 305

10.3 Supershort baseline systems 309

10.4 Long baseline systems 311

10.5 Calibration and error sources 313

10.6 Major references 317

11 SOUNDING METHODS 319

11.1	Echo sounder operation	319
11.2	Transducer beam pattern	324
11.3	Single beam echosounders	327
11.4	Multibeam echosounders	327
11.5	Sidescan and oblique sonars	335
11.6	Echosounding measurement corrections	338
11.7	Airborne laser methods	340
11.8	Major references	344

INDEX 347

1 Elements of oceanography

1.1 Water

About 96.5% of the contents of the oceans is water, H_2O. The remaining 3.5% consists of dissolved salts. The two H^+ atoms of a water molecule are connected to the O^{2-} atom in such a way that the two valences of oxygen join the valences of the two hydrogen atoms at an angle of 105°, see Figure 1.1. A consequence of this asymmetric distribution of electric charges is a strong dipole moment. This strong dipole moment, in turn, results in a number of special properties of water:

- Pure water has the highest dielectric constant ε of all liquids. This is of importance for the behaviour of dissolved substances: the larger ε, the smaller the attractive forces between positively charged cations and negatively charged anions.
- There is a great associative power of water molecules, which leads to the formation of molecular groups. This process is called polymerisation. For example, at 0°C, the average group size is six H_2O molecules. These polymers determine to a great extent the physical properties of water, such as the strong surface tension and viscosity and high melting and boiling temperatures.

Water also has a very large heat capacity. This large capacity enables the oceans to

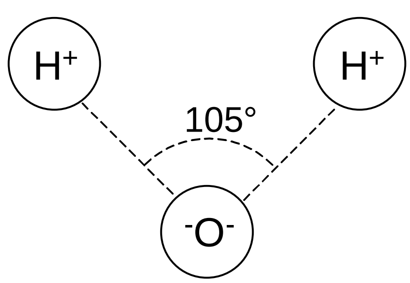

Figure 1.1: H_2O molecule.

Table 1.1: Composition of sea water with a salinity of 35 ppt.

Cations	**gr/kg**	**Anions**	**gr/kg**
Sodium	10.752	Chlorine	19.345
Potassium	0.39	Bromine	0.066
Magnesium	1.295	Fluorine	0.0013
Calcium	0.416	Sulphate	2.701
Strontium	0.013	Bicarbonate	0.145
		Boric acid	0.027

store great quantities of heat, which can be released at differrent places and times. Finally, one of the best known properties of water is the increase in volume while freezing. Pure water has its highest density at 4°C. At 0°C, the volume increases by about 9%. As a results, ice will float on water.

In the open ocean salinity varies between 3.4-3.8%, or, as it is more commonly expressed, 34-38 ppt (parts per thousand). For land-locked adjacent seas, the salinity may differ considerably. In humid zones with strong river run-offs from land it is much lower. For example, salinity in the Baltic Sea can be as low as 0.5-1 ppt. In arid regions, where evaporation exceeds precipitation, salinity is much higher, e.g., 43-45 ppt in the Red Sea. Despite the large variations in salinity, the relative proportions of its constituents are constant to within a few percent. The major constituents of sea water with a salinity of 35 ppt are shown in Table 1.1.

The density ρ of sea water depends on salinity S, temperature T and pressure p (relative to atmospheric pressure). Small differences in density may already result in significant sea level differences and currents. In practice, i.e., on board ships, density cannot be measured directly from the mass of a volume of water. Instead, it is derived from measurements of salinity, temperature and pressure. Since density does not change very much, the quantity σ is introduced, defined as

$$\sigma = (\rho - 1) \cdot 10^3 \tag{1.1}$$

At sea level (p=0) and for a temperature of 0°C, σ_0 is given by the empirical relationship

$$\sigma_0 = -0.0093 + 0.8149 \cdot S - 0.000482 \cdot S^2 + 0.0000068 \cdot S^3 \tag{1.2}$$

where S is expressed in ppt and σ_0 in 10^3 kg/m^3.

Pure water has its maximum density at 4°C. The temperature of maximum density decreases with increasing salinity according to

$$T_{\rho_{max}} = 3.95 - 0.266 \cdot \sigma_0 \tag{1.3}$$

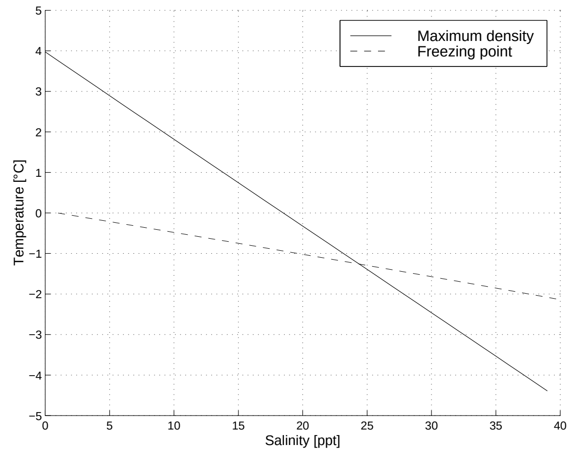

Figure 1.2: Temperature of maximum density and freezing point for sea water of different salinities.

where the temperature is expressed in °C. Thus, for salinities above 18 ppt, the temperature of maximum density is below the freezing temperature of pure water. Due to its salt content, the freezing temperature of sea water is below that of pure water. This temperature T_g, in °C, as a function of salinity is given by the relationship

$$T_g = -0.0086 - 0.064633 \cdot \sigma_0 - 0.0001055 \cdot \sigma_0^2 \tag{1.4}$$

As can be seen from Figure 1.2, the temperature of maximum density and the freezing temperature are the same (-1.33°C) for a salinity of 24.7 ppt. If the salinity is less than 24.7 ppt, the temperature of maximum density, with cooling of the water, is reached before the freezing temperature. At a given temperature above the freezing point, the water from the surface to the bottom has reached its maximum density. A little more cooling of the surface layers results in water at the surface that is lighter than the subsurface waters and therefore does not sink. Eventually, when the freezing point is reached, an ice sheet is formed. If the salinity is above 24.7 ppt, vertical convection continues with coooling until the entire water column has reached its freezing point. Thus, the cooling of water of a high salinity extends to a much greater depth and to much lower temperatures than in the case of low salinities.
In conclusion, it is not just the depression of the freezing point of the sea water that explains why the salty sea does not freeze as rapidly as, e.g., fresh water lakes or seas of low salinity, but rather the relationship between the temperature of density maximum and freezing temperature.

1.2 Ocean currents and general circulation

When the atmosphere and the ocean meet, the energy from the moving air is passed to the water through friction. It results in movement of the surface layer of water due to the drag exerted by winds blowing steadily across the ocean. The major horizontal