SEA ICE ANALYSIS AND FORECASTING

This book provides an advanced introduction to the science behind automated prediction systems, focusing on sea ice analysis and forecasting. Starting from basic principles, fundamental concepts in sea ice physics, remote sensing, numerical methods and statistics are explained at an accessible level. Existing operational automated prediction systems are described and their impacts on information providers and end clients are discussed. The book also provides insight into the likely future development of sea ice services and how they will evolve from mainly manual processes to increasing automation, with a consequent increase in the diversity and information content of new ice products. With contributions from world-leading experts in the fields of sea ice remote sensing, data assimilation, numerical modelling, verification and operational prediction, this comprehensive reference is ideal for students, sea ice analysts and researchers, as well as decision-makers and professionals working in the ice service industry.

TOM CARRIERES has over 30 years of experience in leading operational ice modelling activities for the Canadian Ice Service. These activities include development, implementation and testing of automated prediction systems, iceberg drift and deterioration models, general circulation models and extended-range statistical models. Tom co-chairs International Ice Charting Working Group Data Assimilation Workshops and Canadian Sea Ice Model Working Group meetings to facilitate collaboration among Canadian and international experts.

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SEA ICE ANALYSIS AND FORECASTING

Towards an Increased Reliance on Automated Prediction Systems

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This is for Annette, Erin, Meaghan, Alessandra and Lola.

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Preface

We are in the midst of a major transformation in the way ice services are provided to the marine community from a labour-intensive manual process to a more automated approach that relies on the output of a numerical prediction system. This book is designed to elaborate on these ideas by briefly reviewing current operational practices, examining in detail the components of automated ice prediction systems and then proposing ideas about how these will lead to the evolution of sea ice services. The four main components of automated prediction systems reviewed here include numerical sea ice models, observations, data assimilation systems and objective evaluation procedures. Starting with basic concepts of the relevant science, each topic will be developed to a moderately advanced level. It is our intention neither to provide a thorough literature review nor to provide detail at the level of scientific journal papers.

The target audience includes sea ice researchers, graduate and undergraduate students and national ice service personnel as well as the marine and weather prediction communities. The book is intended to bridge the gap between researchers and operational personnel as well as to provide an overview of the field to the marine and modelling communities. It is expected that it will appeal to non-experts as well as those who have expertise in more focused aspects of automated prediction systems.

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We would like to thank the many contributors who have provided invaluable information and suggestions. We would also like to thank our external reviewers John Falkingham, Dirk Notz and David Hebert, who all helped ensure that this book consistently addressed the needs of our audience.

Abbreviations

3DVar	Three-Dimensional VARiational data assimilation
4DVar	Four-Dimensional VARiational data assimilation
AARI	Arctic and Antarctic Research Institute
AATSR	Advanced Along-Track Scanning Radiometer
ACC	Anomaly Correlation Coefficient
ACNFS	Arctic Cap Nowcast/Forecast System
AD	Algorithmic Differentiation
AIDJEX	Arctic Ice Dynamics Joint EXperiment
AMSR	Advanced Microwave Scanning Radiometer
APS	Automated Prediction System
ASCAT	Advanced SCATterometer
ASI	Artist Sea Ice (algorithm)
ASPeCt	Antarctic Sea ice ProcEsses and ClimaTe
AVHRR	Advanced Very High Resolution Radiometer
CanSIPS	CANadian Seasonal to Inter-annual Prediction System
CCCma	Canadian Centre for Climate Modelling and Analysis
CCMEP	Canadian Centre for Meteorological and Environmental Prediction
CDI	Close Drift Ice
CERSAT	Centre ERS d'Archivage et Traitement (IFREMER)
CI	Confidence Interval
CICE	Community Ice CodE (Los Alamos)
CIS	Canadian Ice Service
CLS	Collecte Localisation Spatiale
CMCC	Continuous Maximum Cross Correlation
CMEMS	Copernicus Marine Environment Monitoring Service
CRREL	Cold Regions Research and Engineering Laboratory
DMI	Danish Meteorological Institute
EB	Elasto-Brittle (ice rheology)
EM	ElectroMagnetic
EnKF	ENsemble Kalman Filter
ESA	European Space Agency

ESD	Error Standard Deviation
ESMR	Electrically Scanning Microwave Radiometer
EUMETSAT	EUropean organization for the exploitation of METeorological SATellites
EVP	Elastic–Viscous–Plastic (ice rheology)
FDD	Freezing Degree Days
FESOM	Finite-Element Sea-ice Ocean circulation Model
FI	Fast Ice
FMI	Finnish Meteorological Institute
FSD	Floe Size Distribution
FSTD	sea ice Floe Size and Thickness Distribution
FY	First Year
GD	Giops weekly Delayed model analysis
GDPS	Global Deterministic Prediction System
GIOPS	Global Ice Ocean Prediction System
GIS	Geographic Information System
GOFS	Global Ocean Forecast System
GR	Giops Real-time weekly analysis
HH	Horizontal transmit–Horizontal receive
HSS	Heidke Skill Score
HyCOM	HYbrid Coordinate Ocean Model
IA	Ice Analyst
IMB	Ice Mass Balance buoy
IMS	Interactive multisensor snow and ice Mapping System
IR	InfraRed
ISRO	Indian Space Research Organization
JAXA	Japanese Aerospace eXploration Agency
ITD	sea Ice Thickness Distribution
ITP	Ice Tethered Profiler
LIM	Louvain-la-neuve sea Ice Model
MAE	Mean Absolute Error
MAGIC	MAp-Guided Ice Classification (algorithm)
MCA	Maximum Covariance Analysis
MCC	Maximum Cross-Correlation
MEMLS	Microwave Emissivity Model for Layered Snowpacks
MITgcm	Massachusetts Institute of Technology General Circulation Model
MIZ	Marginal Ice Zone
MLR	Multiple Linear Regression
MODIS	MODerate-resolution Imaging Spectroradiometer
MOS	Model Output Statistics
MSE	Mean Square Error
MY	Multi-Year

NASA	National Aeronautics and Space Administration
NAVGEM	NAVy Global Environmental Model
NAVOCEANO	NAVal OCEANographic Office
NCODA	Navy Coupled Ocean Data Assimilation
NEMO	Nucleus for European Modelling of the Ocean
neXtSIM	NEXT-generation Sea Ice Model
NIC	National Ice Center
NIIS	National Ice Information Service
NPP	Noaa Polar Platform
NRL	Naval Research Laboratory
NSCAT	Nasa SCATterometer
NSIDC	National Snow and Ice Data Center
NT2	Nasa Team 2 (algorithm)
NWP	Numerical Weather Prediction
ODI	Open Drift Ice
OI	Optimal Interpolation
OIB	Operation Ice Bridge
OPA	Océan PArallélisé
OSCAT	Oceansat-2 SCATterometer (ISRO)
OSISAF	Ocean and Sea Ice Satellite Application Facility
OVP	Ocean Vertical Profiles
OW	Open Water
PCT	Proportion Correct Total
pdf	Probability Density Function
PET	Proportion Error Total
PM	Passive Microwave
PP	Perfect Prognosis
QuikSCAT	QUIcK SCATterometer
RDPS	Regional Deterministic Prediction System
RGPS	RADARSAT Geophysical Processing System
RHS	Right-Hand Side
RIPS	Regional Ice Prediction System
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
SEEK	Singular Evolutive Extended Kalman (filter)
SICCI	Sea Ice Climate Change Initiative
SLA	Sea Level Anomalies
SLAR	Side-Looking Airborne Radar
SMAP	Soil Moisture Active Passive
SMHI	Swedish Meteorological and Hydrographic Institute
SMMR	Scanning Multi-channel Microwave Radiometer
SMOS	Soil Moisture and Ocean Salinity

SS	Skill Score
SSM/I	Special Sensor Microwave Imager
SSMIS	Special Sensor Microwave Imager/Sounder
SST	Sea Surface Temperature
TIROS	Television InfraRed Observation Satellite
TOPAZ	Towards an Operational Prediction system for the north Atlantic european coastal Zones
ULS	Upward-Looking Sonar
UTC	Universal Time (Coordinated)
VCDI	Very Close Drift Ice
VIIRS	Visible Infrared Imaging Radiometer Suite
VODI	Very Open Drift Ice
VP	Viscous–Plastic (rheology)
VV	Vertical transmit–Vertical receive
WHOI	Woods Hole Oceanographic Institute
WMO	World Meteorological Organization