MASTER OF SCIENCE
IN
METEOROLOGY AND PHYSICAL OCEANOGRAPHY

ICELAND-FÆROE FRONT STRUCTURE AND VARIABILITY

Christopher J. Arends-Lieutenant, United States Navy
B.S., Cornell University, 1990
Master of Science in Meteorology and Physical Oceanography-June 1997
Advisor: Pierre-Marie Poulain, Department of Oceanography
Second Reader: Robert H. Bourke, Department of Oceanography

During the period June 1991 to August 1993, 107 Argos-tracked drifters, drogued to 15m depth, were released in the Greenland, Iceland, and Norwegian (GIN) Seas. The drifter movements revealed the strong and spatially confined current systems along the Iceland-FÆeroe Front (IFF) and provided tracking of the Norwegian Atlantic Current and the general cyclonic gyre circulation in the GIN Sea.

Of the 107 drifters released, 59 were selected for this study due to their proximity to the IFF. Tracked by the Argos system aboard the NOAA polar orbiters, the drifters provided accurate location and sea surface temperature (SST) data. Interpolated and low-pass-filtered position data were used to construct maps of drifter displacement and surface velocity field estimates and to study the correlation between drifter trajectories and satellite-derived SST frontal features.

Drifter SST data were compared to spatially and temporally coincident satellite retrieved SST data. The individual data sets were in good agreement with each other, resulting in a temperature difference of less than 1^0C. Satellite imagery used to estimate surface currents through SST feature tracking provided a snapshot of the flow field over a short time scale.

The drifters revealed a distinct frontal zone (DFF) where the topographically steered flow field approached velocities of 1 m/s. This relatively strong flow became unstable as it propagated eastward and an intense eddy field developed. What began as a stable demarcation between water masses became a flow field dominated by warm and cold instabilities and intrusions. This dynamic transformation occurred over relatively short time (less than 5 days) and distance (several hundred kilometers) scales, testament to the vigorous activity in the IFF. These Lagrangian drifter measurements compose the first comprehensive, accurate near-surface velocity data set in the IFF region.

EVALUATION OF LOW ALTITUDE ROCKET DROPSONDES FOR SHIPBOARD ATMOSPHERIC PROFILING AND ELECTROMAGNETIC PROPAGATION ASSESSMENT

Brian Keith Baldauf-Lieutenant Commander, United States Navy
B. S., University of Delaware, 1985
Master of Science in Meteorology and Physical Oceanography-December 1996
Advisors: Kenneth L. Davidson, Department of Meteorology
Carlyle H. Wash, Department of Meteorology

A study was performed on two measurement systems used to obtain profiles of refraction from a ship–the radiosonde and the rocketsonde. Refractive conditions measured by the Marwin Rawinsonde Set (MRS) utilizing radiosondes launched from U.S. Navy ships can yield misleading modified refractivity (M) versus height profiles. MRS obtained M unit profiles, when incorporated in propagation loss models such as Radio Physical Optics (RPO), also may produce unrepresentative propagation loss assessments. Rocketsonde obtained environmental parameters (temperature, relative humidity, pressure) are measured away from the ships influence. The ship can modify the environmental parameters and affect temperatures by as much as 3°C. Rocketsonde obtained data yield improved fine-scale vertical resolution. Resolution approaching 5m obtained via rocketsondes is found to most closely resemble the actual environment. Rocketsonde data is available down to the near-surface whereas there is a distinct lack of data from the surface to the launch point when utilizing balloon launched

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radiosondes. Inaccuracies in initial surface data drastically impact refractive profiles. Rocketsondes can be used regardless of sea state or wind conditions onboard ship and require no specific ship maneuvering to safely launch. It is found that the rocketsonde can obtain the requisite environmental parameters for refractive assessment on demand in less than half the time required to prepare and launch a balloon guided radiosonde.

CHARACTERIZATION OF OSCR HF RADAR DATA IN MONTEREY BAY
Kimberley F. Boyer-Lieutenant, United States Navy
B.S., United States Naval Academy, 1988
Master of Science in Meteorology and Physical Oceanography-March 1997
Advisor: Jeffrey D. Paduan, Department of Oceanography
Second Reader: Leslie K. Rosenfeld, Department of Oceanography

A 53-hour long record of surface current data from the OSCR HF radar system was gathered over Monterey Bay on 6-8 May 1995. In this study,OSCR data is evaluated with regard to semidiurnal (M2) and diurnal (Kl) tidal period fluctuations, the seabreeze, seabreeze influenced flow, and both standard and cannonical-day mean flow patterns. The OSCR data is considered on its own and in comparison to similar data types previously gathered by CODAR, a previously established Monterey Bay HF radar system. Two of three CODAR sites were co-located with the two OSCR sites.

Internal wave influence is observed in the M2 tidal constituent analysis and the seabreeze greatly influences fluctuations of the K1 tidal period. Results from analysis of OSCR data replicated or reinforced data and results from the CODAR system. Initial OSCR data appears not to have been significantly affected by possible distortion of the phased-array beam patterns. However, contamination of OSCR returns by simultaneous activation of the CODAR systems is apparent in the data.

REMOTE MEASUREMENT OF AEROSOL OPTICAL PROPERTIES USING THE NOAA POES AVHRR AND GOES IMAGER DURING TARFOX
Brian B. Brown-Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1986
Master of Science in Meteorology and Physical Oceanography-June 1997
Advisors: Philip A. Durkee, Department of Meteorology
Carlyle H. Wash, Department of Meteorology

A radiative transfer algorithm in the solar wavelengths for the NOAA POES AVHRR and GOES Imager is proposed for the cloud-free, marine atmosphere. The algorithm combines linear single-scattering theory with an estimate of bi-directional surface reflectance. Phase functions are parameterized using an aerosol distribution model and the ratio of radiance values measured in channels 1 and 2 of the AVHRR. Retrieved satellite aerosol optical depth is compared to airborne sunphotometer data and values derived from aerosol particle size distributions collected during the Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX) in July 1996. Error in the satellite derived values from the AVHRR originates in error in modeling aerosol size distributions, corresponding phase function parameterization, and treatment of specular surface reflectance. Extension of the algorithm to the GOES Imager provided results consistent with the AVHRR.

WIND-FORCED MODELING STUDIES OF CURRENTS, MEANDERS, EDDIES, AND FILAMENTS OF THE CANARY CURRENT SYSTEM

Eric J. Buch-Lieutenant, United States Navy
B.S., United States Naval Academy, 1988
Master of Science in Meteorology and Physical Oceanography-June 1997
Advisor: Mary L. Batteen, Department of Oceanography
Second Reader: Jeffrey D. Paduan, Department of Oceanography

A high-resolution, multi-level, primitive equation ocean model is used to examine the response of an eastern boundary oceanic regime to both wind forcing and irregular coastline geometry. The focus of this study is the coastal region from 30°N to 42.5°N, a portion of the Canary Current System (CCS). To study the generation, evolution, and sustainment of the currents, meanders, eddies and filaments of the CCS, the model is forced from rest using seasonal climatological winds. To investigate the role of irregular coastline geometry, the first experiment uses climatological wind forcing along an idealized "straightened" coastline, while the second experiment uses the same wind forcing along an irregular coastline. In both cases a surface current, undercurrent, meanders, eddies, and filaments are generated. The results obtained while using the irregular, rather than the idealized coastline, however, show preferred eddy generation locations as well as enhanced growth of meanders, eddies, and filaments. The features produced by the model are consistent with available observations of the CCS. The model results support the hypothesis that both wind forcing and irregular coastline geometry are important mechanisms in the generation of many of the observed features of the CCS.

A CASE STUDY OF HIGH WINDS INDUCED BY UPPER-LEVEL ERONTOGENESIS AND TROPOPAUSE FOLDING

Sara T. Burke-Lieutenant, United States Navy
B.S., United States Naval Academy, 1990
Master of Science in Meteorology and Physical Oceanography-March 1997
Advisor: Patricia M. Pauley, Department of Meteorology
Second Reader: Qing Wang, Department of Meteorology

High surface winds over California and the bordering Pacific Ocean resulted in the death of one man and the loss of power to approximately 50,000 residences across the state. These damaging winds are hypothesized to result from an upper-level front and associated tropopause folding that rapidly intensify as they move south across the region, causing high-momentum air to be transported to the lower troposphere. Once the high-momentum air reaches the top of the planetary boundary layer, the combined effects of destabilization of the planetary boundary layer by cold air advection aloft and shear-induced turbulence at the top of the layer provide the initial mechanism by which the high-momentum air is entrained into the layer and mixed to the surface. After sunrise, convectively-driven turbulence provides an additional source of mixing in the planetary boundary layer.

The winds have a strong cross-isobaric component in the direction of the upper-level winds, and the upper-level frontal movement to the south over central California is synchronous with the increase of surface winds over the same region. The winds decrease as the upper-level front moves into the base of the upper-level trough and the high-momentum source in the lower-troposphere disappears.

AN EXAMINATION OF TWO SYNTHETIC APERTURE RADAR WIND RETRIEVAL MODELS DURING NORCSEX '95

James Brian Hart-Lieutenant Commander, United States Navy
B. S., United States Naval Academy, 1983
Master of Science in Meteorology and Physical Oceanography-December 1996
Advisors: Kenneth L. Davidson, Department of Meteorology
Carlyle H. Wash, Department of Meteorology

Synthetic Aperture Radar wind retrieval models have great potential to accurately depict the mesoscale wind field on the order of hundreds of meters. However, there are still significant hurdles to overcome in applying the theory in a fully automated algorithm. This thesis is a result of collaboration between the Nansen Environmental and Remote Sensing Center, Bergen, Norway and the Naval Postgraduate School. It examines two wind retrieval models on basis of in-situ and remote data from NORCSEX '95 in the interest of improving our understanding and application of these models. The individual models are based on Bragg backscatter from the ocean surface however, the CMOD4 model is directly related to the backscatter while the SWA model is related to the spectral resolution of the backscatter field. Each model has specific advantages and disadvantages related to processing and automation. For this data set they show very good agreement with each other and with in-situ measurements. Plots of optimum wind vectors derived from a combination of CMOD4 and SWA wind vectors are shown to illustrate the high resolution wind fields available with this technology.

TIME AND SPACE RESOLUTION AND MIXED LAYER MODEL ACCURACY

David Michael Hone-Lieutenant, United States Navy
B.S., Florida Institute of Technology, 1988
Master of Science in Meteorology and Physical Oceanography-March 1997
Advisors: Roland W. Garwood, Jr., Department of Oceanography
Arlene A. Guest, Department of Oceanography

The oceanic turbulent boundary layer is a critical region to understand for oceanic and atmospheric prediction. This thesis answers two fundamental questions: (i) what is the response of the ocean mixed layer system to transient forcing at the air sea surface? (ii) what is the necessary time and space resolution in an ocean mixed layer model to resolve important transient responses?

Beginning with replication of de Szoeke and Rhines' (1976) work, additional physical processes were added to include more realistic viscous dissipation and anisotropy in the three-dimensional turbulent kinetic energy (TKE) budget. These refinements resulted in modification of de Szoeke and Rhines' findings. First, TKE unsteadiness is important for a minimum of 10^5 seconds. Second, viscous dissipation should not be approximated as simply proportional to shear production. Third, entrainment shear production remains significant for a minimum of one pendulum-day.

The required temporal model resolution is dependent on the phenomena to be studied. This study focused on the diurnal, synoptic, and annual cycles, which the one-hour time step of the Naval Postgraduate School model adequately resolves. The study of spatial resolution showed unexpectedly that model skill was comparable for 1 m, 10m and even 20m vertical grid spacing.

THE GENERATION AND CHARACTERIZATION OF SURF ZONE AEROSOLS AND THEIR IMPACT ON NAVAL ELECTRO-OPTICAL SYSTEMS

Robert Eugene Kiser-Lieutenant Commander, United States Navy
B. S., United States Naval Academy, 1982
Master of Science in Meteorology and Physical Oceanography-March 1997
Advisors: Kenneth L. Davidson, Department of Meteorology
C. Russell Philbrick, Department of Electrical Engineering, Pennsylvania State University
Roland W. Garwood, Jr., Department of Oceanography

Aerosols are generated within the surf zone by the breaking of waves along the beachfront. The concentration of aerosols, size, and structure of these plumes are impacted by the air/sea temperature differences, breaker type, and local winds. During the EOPACE I surf experiment at LaJolla, CA, it was observed that under light wind conditions, standing aerosol plumes would develop to heights of 31 meters. Concurrently, transmittance at FLIR wavelengths would be degraded up to 35%. Similar aerosol plume structures were observed during EOPACE II at Moss Landing, CA. These results are used to characterize and forecast standing plume conditions that may impact electro-optical transmission.

EXTRATROPICAL TRANSITION OF WESTERN NORTH PACIFIC TROPICAL CYCLONES

Peter M. Klein-Lieutenant Commander, United States Navy
B.S., Cornell University, 1988
Master of Science in Meteorology and Physical Oceanography-September 1997
Advisors: Russell L. Elsberry, Department of Meteorology
Patrick A. Harr, Department of Meteorology

Extratropical transition (ET) of a tropical cyclone (TC) often results in a mid-latitude storm that threatens maritime and coastal interests. Cases of ET between 1 July through 31 October during 1994-1996 are reviewed using Navy Operational Global Atmospheric Prediction System (NOGAPS) analyses and hourly geostationary satellite imagery. Current conceptual models are found to be inadequate to explain the physical processes in ET. ET is redefined to have two stages: transformation, where the TC is transformed from a warm-core vortex into a baroclinic, cold-core extratropical cyclone, and re-intensification, where the transformed TC either deepens or dissipates, depending on the existence of upper-tropospheric support for extratropical cyclogenesis. ET is further defined in terms of two characteristic mid-latitude synoptic patterns: meridional, in which the cyclones have meridional tracks and tend to re-intensify less vigorously than zonal, which have zonal tracks and may deepen explosively. Review of NOGAPS 500-mb anomaly correlation scores in 1996 demonstrated that ET may be associated with significant NOGAPS errors. Sea-level pressure forecasts during ET events involving a merger tend to be too deep. In ET cases of rapidly deepening storms, NOGAPS tends to overforecast their intensity during transformation, and then underforecast during reintensification. Rules of thumb are provided to assist forecasters in improving predictions of the track and intensity of storms undergoing ET.

SET-UP UNDER A NATURAL WAVE

Bruce J. Morris-Lieutenant, United States Navy
B.S., United States Naval Academy, 1988
Master of Science in Meteorology and Physical Oceanography-March 1997
Advisor: Edward B. Thornton, Department of Oceanography
Second Reader: Timothy P. Stanton, Department of Oceanography

Field measurements from a cross-shore array of two pressure sensors to measure waves and eight manometer tubes to measure mean water elevation are used to examine set-down/up across the surf zone. The manometer tubes are connected to differential pressure transducers onshore allowing continuous set-down/up measurements. Flume measurements of set-down/up are also examined. Measured values are compared with numeric set-up values incorporating roller theory describing wave breaking. The model has two free parameters, B representing the vertical fraction of the wave covered by the roller

and ψ a scaling parameter for wave steepness. Optimal values of both are chosen by model fitting. Inclusion of the surface roller improves the set-up model fit to both beach and flume measurements.

UNBALANCED FRONTOGENESIS WITH CONSTANT POTENTIAL VORTICITY

Alberto P. C. Neves-Lieutenant Commander, Brazilian Navy
B.S., Brazilian Naval Academy, 1984
Master of Science in Meteorology and Physical Oceanography-December 1996
Advisors: Roger T. Williams, Department of Meteorology
Melinda S. Peng, Department of Meteorology

The numerical model of Williams et al. (1992) is used to study frontogenesis from unbalanced initial conditions. The dependent variables are assumed to be independent of y. The hydrostatic Boussinesq primitive equations are used with no diffusion of heat or momentum. The model is bounded at the top and bottom by rigid planes. Periodic boundary conditions are used in the horizontal. The lateral boundaries are placed far enough from the imbalance region to avoid wave reflection. The atmosphere is assumed to have constant vertical temperature stratification.

The initial imbalance is obtained by allowing a horizontal temperature gradient to exist while the initial wind is zero. In a stably stratified atmosphere, gravity waves are excited and propagate away from the imbalance region, provided no reflection occurs in the lateral boundaries. Therefore, the atmosphere tends toward a geostrophic balance away from vertical boundaries. Near these boundaries, the temperature gradient oscillates or it collapses into a front, depending on the initial Rossby (Ro) and Froude (F) numbers. A relationship between Ro and F is established which separates situations where a front may or may not form. Numerical solutions show the formation of a front within a finite period of time that tilts toward the cold air.

A STUDY OF SOUTH ASIAN MONSOON CONVECTION AND TROPICAL UPPER EASTERLY JET DURING NORTHERN SUMMER 1991

Michael Scott Nicklin-Lieutenant, United States Navy
B.S., University of Washington, 1990
Master of Science in Meteorology and Physical Oceanography-December 1996
Advisors: Chih-Pei Chang, Department of Meteorology
Peter S. Chu, Department of Oceanography

This work studies the 1991 northern summer monsoon over India and surrounding areas using Japanese (GMS) and Indian (INSAT) geostationary satellite data, the ECMWF objective re-analysis, and the NMC sea surface temperature analysis. Monthly and weekly mean fields are first used to examine the development of the monsoon over the entire domain and to identify the timing of the onset over India. Latent heat fluxes are shown to be important in the monsoon development process. The relationship between the synoptic variations of a convective index derived from satellite data and the upper tropospheric easterly jet show two possible effects of cumulus convection on the easterly jet. The first is a forcing of the jet maximum near southern India when convection flares up to the north in the monsoon trough. This is believed to be the result of the Coriolis acceleration of the southward outflow of the local Hadley cell. The second is a damping of the upper jet by cumulus momentum transport that occurs at the same location as the jet maximum. This second effect is most clearly shown in regions of strong vertical shear.

INVESTIGATION OF STRONG SURFACE WINDS ASSOCIATED WITH AN UPPER FRONT USING COAMPS

Ken Schwingshakl-Lieutenant Commander, United States Navy
B.S., Marquette University, 1986
Master of Science in Meteorology and Physical Oceanography-September 1997
Advisor: Patricia Pauley, Department of Meteorology
Second Reader: Teddy Holt, Naval Research Laboratory-Monterey

On 2 April 1997, strong winds blew through the central coast of California that were accompanied by an intense jet streak and upper front. The event was analyzed with standard synoptic-scale DIFAX charts and mesoscale charts for comparison. The mesoscale model used was the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) developed by Naval Research Laboratory (NRL), Monterey, California.

COAMPS captured features that were not diagnosed on the synoptic charts. Height, isotach and temperature fields showed more detail, although observations were not sufficient to completely verify the model's level of detail. COAMPS was heavily influenced by the topographic field modeling lee troughs and mountain waves along the Sierra Nevada mountains. A strong mountain wave, initiated by the upper front, occurred in central California during this time period. The wave troughs correlated to wind maxima at the surface, including one near San Francisco Bay where winds as high as 66 mph were reported.

COMPARISON OF TRAJECTORIES GENERATED BY THE NOAA OIL SPILL MODEL TO TRAJECTORIES PRODUCED USING HF RADAR-DERIVED SURFACE CURRENTS IN MONTEREY BAY

Margaret A. Smith-Lieutenant Commander, United States Navy
B.S., Jacksonville University, 1988
Master of Science in Meteorology and Physical Oceanography-September 1997
Advisor: Jeffrey D. Paduan, Department of Oceanography
Second Reader: Mary L. Batteen, Department of Oceanography

High Frequency radar-derived surface current data was examined for use in oil spill trajectory prediction in Monterey Bay. Trajectories produced by the NOAA/HAZMAT On-Scene Spill Model (OSSM), using different combinations of surface currents and winds, were compared to trajectories generated using HF radar-derived surface currents. Currents examined included output from the NOAA circulation model and canonical-day averages of the HF radar-derived current maps, either as spatially constant but temporally varying currents (time file) or spatially varying two-hourly current patterns (grids). Results from OSSM using the NOAA circulation model currents did not compare favorably with HF radar-derived trajectories inside Monterey Bay. OSSM produced realistic overall trajectory patterns throughout the Bay using the canonical-day grid current files and, to a lesser degree, canonical-day time file currents. Both OSSM and HF radar-derived trajectories show sensitivity to release time. In the afternoon, trajectories display rapid southeastward flow. At night, currents are weaker. The week's worth of direct surface current data used in this study was found to be representative of the seasonal summertime pattern in Monterey Bay and provided realistic current patterns for use in OSSM for initial trajectory prediction in lieu of real-time HF radar-derived surface currents.

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A COMPARISON OF UPPER FRONT STRENGTH AS ANALYZED BY NORAPS AND AS OBSERVED BY ACARS-EQUIPPED AIRCRAFT

Edward L. Stephens II-Lieutenant, United States Naval Reserve
B.S., United States Naval Academy, 1987
M.B.A., Embry-Riddle Aeronautical University, 1994
Master of Science in Meteorology and Physical Oceanography-September 1997
Advisor: Patricia M. Pauley, Department of Meteorology
Second Reader: Wendell A. Nuss, Department of Meteorology

Upper fronts are associated with strong horizontal gradients of both temperature and wind speed on a scale that is not well resolved by rawinsonde observations. Even so, mesoscale data assimilation systems are capable of ingesting observations from a variety of sources and depicting such features. This study examines upper fronts that occurred over the continental U.S. during March-April 1996 with the objective of verifying the performance of the NORAPS (Navy Operational Regional Atmospheric Prediction System) data assimilation system using ACARS (ARTNC Communications, Addressing, And Reporting System) aircraft observations. ACARS observations are taken every 5-8 minutes during level flight, which yields a horizontal resolution along the flight track of less than 100 km and so can resolve the approximately 200 km width scale for upper fronts. The ACARS temperature observations are not currently used in the data assimilation system and so present an independent set of observations.

Thirty distinct upper fronts (duration greater than 12 h and temperature gradient greater than 2°C/l00km) were identified and tracked from the NORAPS analyses during the period of the study. In general, the analyzed temperature gradient was weaker than that observed in the ACARS data. The latter depicted a temperature gradient of 8°C/ 100 km for two cases, whereas the analyzed gradient did not exceed 6°C/100 km. Most upper fronts (47%) attained maximum intensity when located in the base of the upper-level trough, although 33% (13%) did so just downstream (upstream) of the trough line. Most of the useable aircraft tracks were near 200-300 mb, therefore the portion of the upper front above the tropopause was examined in greater detail than the portion below the tropopause, although the latter would be expected to contain stronger temperature gradients

SENSITIVITY OF THE CALIFORNIA COASTAL JET TO SYNOPTIC SCALE FLOW

R. Scott Stevens-Lieutenant, United States Navy
B.S., University of Washington, 1992
Master of Science in Meteorology and Physical Oceanography-September 1997
Advisor: Wendell A. Nuss, Department of Meteorology
Second Reader: Patricia M. Pauley, Department of Meteorology

The California Coastal Jet can have a significant impact on many operations. This study examines the sensitivity of the California Coastal Jet to the synoptic-scale flow by examining the surface reflection of the jet at a particular buoy (buoy 46028) off the Central California coast. Statistical analysis and subjective examination of surface charts were performed to help determine the relationship between the synoptic flow regime and the observed surface winds. The main results of the study are: (1) The magnitude of the California Coastal Jet is sensitive to the geostrophic wind direction, (2) The surface reflection of the California Coastal Jet at buoy 46028 does not exhibit diurnal variation. The day to day variability in the observed winds is much larger than the diurnal variation at buoy 46028, and (3) Higher wind speed events at buoy 46028 correspond to periods when meso-scale effects such as flow blocking and supercritical flow are important and are missed in the analysis. Lower wind speed events correspond to periods when the synoptic-scale analyses successfully describe the coastal flow.

DEEP MIXED LAYER ENTRAINMENT

Rebecca E. Stone-Lieutenant Commander, United States Navy
B.S., San Diego State University, 1985
Master of Science in Meteorology and Physical Oceanography-March 1997
Advisors: Roland W. Garwood, Department of Oceanography
Peter S. Guest, Department of Meteorology

A bulk turbulence-closure mixed layer model is generalized to allow prediction of very deep polar sea mixing. The model includes unsteady three-component turbulent kinetic energy budgets. In addition to terms for shear production, pressure redistribution, and dissipation, special attention is devoted to realistic treatment of thermobaric enhancement of buoyancy flux and to Coriolis effects on turbulence. The model is initialized and verified with CTD data taken by R/V *Valdivia* in the Greenland Sea during winter 1993-1994. Model simulations show: (i) mixed layer deepening is significantly enhanced when the thermal expansion coefficient's increase with pressure is included; (ii) entrainment rate is sensitive to the direction of wind stress because of Coriolis; and (iii) the predicted mixed layer depth evolution agrees qualitatively with the observations. Results demonstrate the importance of water column initial conditions, accurate representation of strong surface cooling events, and inclusion of the thermobaric effect on buoyancy, to determine the depth of mixing and ultimately the heat and salt flux into the deep ocean. Since coupling of the ocean to the atmosphere through deep mixed layers in polar regions is fundamental to our climate system, it is important that regional and global models be developed that incorporate realistic representation of this coupling.

BUBBLE INJECTION BREAKING WAVES

James Brian Tannahill-Lieutenant, United States Navy
B.S., United States Naval Academy, 1990
Master of Science in Meteorology and Physical Oceanography-December 1996
Advisors: Edward B. Thornton, Department of Oceanography
Timothy P. Stanton, Department of Oceanography

Wave energy dissipation due to bubble penetration and inferred turbulent penetration from breaking waves in the surf zone is related to the total energy of dissipation. Bubble injection is inferred from void fraction measurements obtained using a 2.3 meter vertical array of eight conductivity sensors extending from the bottom through the water surface. Potential energy and dissipation associated with bubble injection are calculated and compared with total wave dissipation. Total wave dissipation is calculated from the energy flux balance measured using an array of seven pressure sensors in the surf zone.

Percent of total wave potential energy of the bubbles due to spilling breakers is on the order of 0.18% to 0.62%, consistent with past measurements in the surf zone. Percent of the bubble potential energy dissipation rates to total wave dissipation in the cross-shore direction is on the order of 8% to 20%. The potential energy dissipation is largest immediately after injection, decaying exponentially after that. Bubble potential energy dissipation results within 1.2 seconds even for void fraction events greater than 36% and usually in less than 1.0 seconds. Energy dissipation was found linearly related (0.95 correlation coefficient) with the ratios of wave height to water depth, a measure of the percent of breaking waves within the surf zone.

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A STUDY OF THE SURFACE HEAT BUDGET OF THE WEDDELL SEA USING A RADIATIVE TRANSFER MODEL DURING THE AUSTRAL WINTER 1994

Eugene P. Tramm-Lieutenant Commander, United States Navy
B.A., University of Virginia, 1983
B.S., University of La Verne, 1991
Master of Science in Meteorology and Physical Oceanography-March 1997
Advisors: Peter S. Guest, Department of Meteorology
Roland W. Garwood, Department of Oceanography

This study uses rawinsonde soundings and irradiance measurements taken in the Weddell Sea during the 1994 ANZFLUX experiment. A radiative transfer model was used to determine the influence of aerosols, cloud droplet size, and water content on the radiative heat budget of the Weddell Sea. The modeled irradiances were compared with observations, and the model calculated the upward longwave irradiance from the Weddell Sea ice pack. Turbulent heat fluxes were calculated and combined with radiative terms to provide a net heat flux at the ice surface. While turbulent heat flux is the major factor affecting the Weddell Sea's heat budget in windy conditions, during calm conditions longwave radiative transfer becomes important. The modeled downward irradiances were compared to results obtained from empirical equations developed for the Weddell Sea during the winter. The atmosphere above the Weddell Sea appears to have an aerosol structure similar to marine environments. Stratus clouds over the Weddell Sea appear to be made up of cloud droplets with an effective radius of 2.5 microns and a water concentration close to 0.05 grams per cubic meter. The dominant terms in the surface heat budget are the longwave irradiances with the upward longwave term being the largest.