Final Technical Report

DYNAMICS OF OCEANIC MOTIONS

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by

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This project researched the dynamics of oceanic motions: aspects of the theory and modeling of fundamental dynamical and energetic processes in the sea and their interactions, and the relationship of theory and modeling to the interpretation, analysis and design of observational data and experiments. Research was directed towards the dynamics, simulation and forecasting of the low frequency variability of ocean currents (mid-ocean eddies and intense current systems), and in the physics and dynamics of the mid-latitude general circulation. It included near surface layer/deep current interactions, and the interactions of deep ocean currents with coastal and topographic features. Our modeling research was directed toward studies of the local dynamics of (partially) open regions of the ocean (i.e., arbitrary regions with flow across their boundaries), and the relationship of the regional dynamics to the larger scale dynamics and circulation in which it is embedded. The approach was appropriate for the combined use of intensive in situ data sets in combination with extensive remotely sensed and extensive sparse in situ data sets.

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Developments and applications of an embedded dynamical model hierarchy, with regional to basic scales were carried out. The hierarchy is a set of compatible and intercomparable dynamical models with differing physics allowing for efficiency in computations and physical analyses. Dynamical process studies carried out via detailed vorticity and energy analyses required optimal field estimates with dynamically consistent fields obtained via data assimilation. Because data assimilation was in its infancy in oceanography, methodological studies and dynamical process studies were carried out and interpreted together. Melded data field estimates produced via dynamical interpolation and adjustment we refer to as systematic estimates, where the components of the system are the observational network, the dynamical and statistical models, and the analysis and assimilation schemes. Substantial progress was made in developing components of the Harvard (data assimilative) dynamical model hierarchy which achieved the physical options of: quasigeostrophic (QG) mesoscale dynamics coupled with surface boundary layer (SBL) dynamics, in open or partially closed domains of arbitrary coastal shapes; or primitive equation (PE) dynamics with hybrid coordinates and arbitrarily high topography. A series of process, hindcasting, and predictability studies were: concluded for the POLYMODE Synoptic Dynamics Experiment in the Western North Atlantic; carried out for the California Current system in the OPTOMA program (joint Harvard/Naval Postgraduate School); carried out in the Gulf-Stream Meander & Ring (GSM&R) region associated with GULFCAST and SYNOP; and initiated in the Eastern Mediterranean Sea (POEM).

This report consists of a brief summary of the research results and a listing of the

The project produced 37 refereed publications and 17 additional technical reports which *were produced* are indexed on attached lists. The research summary will be based primarily on the publication list since the reports are for the most part preliminary or extended versions of the publications. An exception is Report # 5 which is the Proceedings of the second Ocean Prediction Workshop (OPW-86) which I co-chaired and co-edited.

Highlight contributions include: the construction and operation in real time for 2 years of a Gulf-Stream meander and ring nowcast and forecast system (Publication # 27), the elucidation of detailed mechanisms of warm and cold core ring formations (15), the assimilation
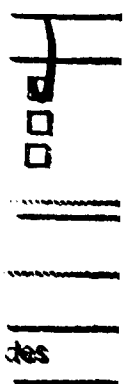
in real time of the relatively weak GEOSAT altimetric signal while forecasting the Iceland-Faeroe front (25), the direct coupling of real-ocean-data-based Harvard dynamical model output to an acoustic propagation model (18), the development of a primitive equation open ocean modeling capability (28), the publication of a comprehensive overview of the field of geophysical fluid dynamics (24), and an extensive summary of the Harvard quasi-geostrophic methodology (13). Two additional review and overview articles dealt with the relationship of data assimilation and dynamics (6) and the ocean prediction problem (12). There were four Ph.D. theses published (1, 14, 16, 21).

Model developments included: the theoretical basis (22) and computational implementation (34) of arbitrary coastal configurations for partially open QG regions (21); the primitive equation open ocean model (16); the 3-d surface boundary layer model coupling to the QG model (14); publication of the Harvard multivariate objective analysis models (7) and the development of an objective "contour" analysis scheme which preserves fronts and gradients (32); and a method for vertical gradient estimation (19). Data analyses in the California Current compared subsurface features with surface IR patterns (2) and determined the vertical modal structure of the mesoscale variability (3). Methodological research related to the quantification of the oceanographic usefulness of satellite altimetric data: demonstrated that assimilation into a dynamical model could achieve accurate deep fields via a simulation in the POLYMODE region (9); analyzed the synoptic signal in the historical GEOS-3 and Seasat data sets (17); and constructed a 'synthetic geoid' for absolute sea surface topographic calculations from GEOSAT by combining the mean of the GULFCAST daily synoptic estimates with the altimetric mean (23). Fundamental dynamical bases were created for the study of energy and vorticity processes ocuring in data dynamically filtered via quasigeostrophic (EVA) (5) or primitive equation (PRE-EVA) (29) dynamics. In the POLYMODE region, the potential vorticity balance was estimated (20) and an EVA analysis of the most energetic events indicated intermittent 'bursts' of baroclinic instability (10) which was modified only slightly via comparison with a PRE-EVA analysis (29). A PE-QG dynamical comparison of warm and cold ring formation

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events showed basically similar processes, but identified quantitative differences due to PE asymmetries (36). This study also importantly established the validity of QG dynamics in the Gulf-Stream region for periods of 2–3 weeks even over high topography because of geostrophic contour constraints. An idealized study induced ring formation by seeding point vortices (30). Forecasting research included: a sensitivity study with OPTOMA data (11); the determination of efficient forecast schemes and their relationships to dynamical events with POLYMODE data (37); a predictability study for the NW Atlantic with POLYMODE data (8); and the establishment of the capability of accurate Gulf Stream front forecasts with adequate data for assimilation (26). Research involving the coupling of acoustic propagation models to dynamical model outputs and the propagation through realistic environmental nowcasts and forecasts resulted in publications on: interfacing (31), on the sensitivities of propagation to the ring-stream environment (33); and first results on three dimensional propagation and combined frontal/topographic effects (35). A study of the effect of the pole tide on the earth's rotation was also completed (4).

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