

Moored Observations of Nonlinear Internal Waves Near DongSha

Matthew H. Alford
Applied Physics Laboratory
1013 NE 40th Street
Seattle, WA 98105

phone: (206) 221-3257 fax: (206) 543-6785 email: malford@apl.washington.edu

Grant Number: N00014-05-1-0283
<http://faculty.washington.edu/malford/>

LONG-TERM GOALS

I am interested in the general problems of internal waves and ocean mixing. Knowledge of these is important for advancing the performance of operational and climate models, as well as for understanding local problems such as pollutant dispersal and biological productivity. In the specific case of this Directed Research Initiative (DRI)'s focus, nonlinear internal waves (NLIW), the waves' currents and displacements are strong enough to impact Navy operations such as diving, ROV operation and mine detection/removal.

OBJECTIVES

- To understand the generation mechanisms, and to predict the arrival times, of large NLIW in the northeastern South China Sea (SCS).
- To observe NLIW packets and estimate their energy and energy flux in the 2007 South China Sea experiment.
- To relate these to the energy and energy-flux in the low-mode tide, and to measurements of overturn-inferred turbulence.

APPROACH

The field portion of this project involved setting an array of ten moorings spanning the South China Sea basin (Figure 1). My specific observational role was to prepare, deploy and recover the profiling moorings at MP1 and MP2 (Figure 2). Since, I have assembled data from all ten moorings, and taken the lead on a paper (with co-authors Lien, Simmons, Klymak, Ramp, Yang, Tang, and Chang) that presents results from tracking the waves across the array during the 10-day period when all moorings were operational.

Report Documentation Page			Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.				
1. REPORT DATE 30 SEP 2009		2. REPORT TYPE Annual		3. DATES COVERED 00-00-2009 to 00-00-2009
4. TITLE AND SUBTITLE Moored Observations Of Nonlinear Internal Waves Near DongSha			5a. CONTRACT NUMBER	
			5b. GRANT NUMBER	
			5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)			5d. PROJECT NUMBER	
			5e. TASK NUMBER	
			5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Applied Physics Laboratory,1013 NE 40th,Seattle,WA,98105			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)	
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited				
13. SUPPLEMENTARY NOTES Code 1 only				
14. ABSTRACT I am interested in the general problems of internal waves and ocean mixing. Knowledge of these is important for advancing the performance of operational and climate models, as well as for understanding local problems such as pollutant dispersal and biological productivity. In the specific case of this Directed Research Initiative (DRI)?s focus, nonlinear internal waves (NLIW), the waves' currents and displacements are strong enough to impact Navy operations such as diving, ROV operation and mine detection/removal.				
15. SUBJECT TERMS				
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 7
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified		

WORK COMPLETED

Wave arrivals and resultant speeds were computed for fourteen waves transiting the entire moored array. Speeds were compared to linear values computed from in-situ and climatological stratification. The data have been analyzed extensively, and compared to time series of barotropic tidal forcing at Luzon Strait. A paper has just been submitted to the *Journal of Physical Oceanography* (JPO) describing the work.

In a separate effort with Jody Klymak, we are interested in understanding the energy and dissipation associated with the diurnal internal tide (as opposed to the nonlinear waves). Strong dissipation is observed there, as shown in past reports. Numerical modeling shows that a significant fraction of the energy is back-reflected at the shelf break, but that the forward-scattered portion can lead to internal hydraulic jumps and strong mixing in agreement with observations.

RESULTS

The following results are reported in the paper just submitted to JPO. The results from the scattering project with Klymak are still too preliminary to be reported.

1. A set of fourteen waves was tracked nearly across the entire basin (Figure 3a). As found by Ramp et al (2004), larger waves alternate with smaller ones, termed ‘A’ and ‘B’ waves, respectively. Tracking back to the Luzon Strait eastern ridge assuming travel at the semidiurnal mode-1 speed, their generation time is compared to measured and TPXO model-predicted tidal currents there (b,c). Waves appear to be generated at or somewhat after maximum eastward tidal currents, as suggested by several numerical models (e.g. Buijsman, 2009). This contrasts with the findings of Zhao and Alford (2006), who did not have data in the deep basin.
2. Their speeds were computed by differencing arrival time pairs (Figure 3b), and compared to linear values (3b,c). Speeds are ~10-20% in excess of semidiurnal linear values for all but the smallest waves in the deep basin.
3. Larger ‘A’ waves travel faster than small ones in the deep basin, but the reverse holds true in the shallower water to the west. This is shown to be due to the effect of the diurnal internal tide on the wave speed there. Since the waves arrive twice daily, every other wave opposes the baroclinic flow of the once-daily diurnal internal tide (Figure 4, bottom), which slows the wave speed. Solutions of the Taylor-Goldstein equation give predictions of the correct magnitude and sign as observed. These findings highlight the need to know the background currents in order to accurately predict speed and arrival time, particularly in shallow water where the wave speeds are comparable to the background flows.

IMPACT/APPLICATIONS

Detailed field measurements in the generation region, the subject of the Internal Waves in Straits Experiment (IWSE), will be necessary to unequivocally determine the generation phase and mechanism, but these results provided testable hypotheses and will aid in the design of that experiment.

TRANSITIONS

RELATED PROJECTS

NLIWI purposefully focused its resources on the shallow water near Dong Sha, leaving the generation region for future efforts. IWISE will undertake a major field and modeling effort near Luzon Strait to aid in a better understanding of the waves' generation.

REFERENCES

Alford, M. H., R. Lien, H. Simmons, J. M. Klymak, Y. Yang, D. Tang, and M. Huei Chang. Speed and evolution of nonlinear internal waves transiting the South China Sea. *J. Phys. Ocean.*, submitted, 2010.

Buijsman, M.C, Y. Kanarska, and J. C. McWilliams. On the generation and evolution of nonlinear internal waves in the South China Sea. *J. Geophys. Res.*, in press, 2009.

Ramp, S. R., D. Tang, T. F. Duda, J. F. Lynch, A. K. Liu, C. S. Chiu, F. Bahr, Y. R. Kim, and Y. J. Yang, Internal solitons in the northeastern South China Sea, part I: sources and deep water propagation. *IEEE J. of Oceanic Engr.*, 2004.

Zhao, Z., and M. H. Alford, Source and propagation of nonlinear internal waves in the northeastern South China Sea. *J. Geophys. Res.*, 111, doi:10.1029/2006JC003,644, 2006.

PUBLICATIONS

No articles have been published this year on this project. A manuscript describing this work has just been submitted to JPO.

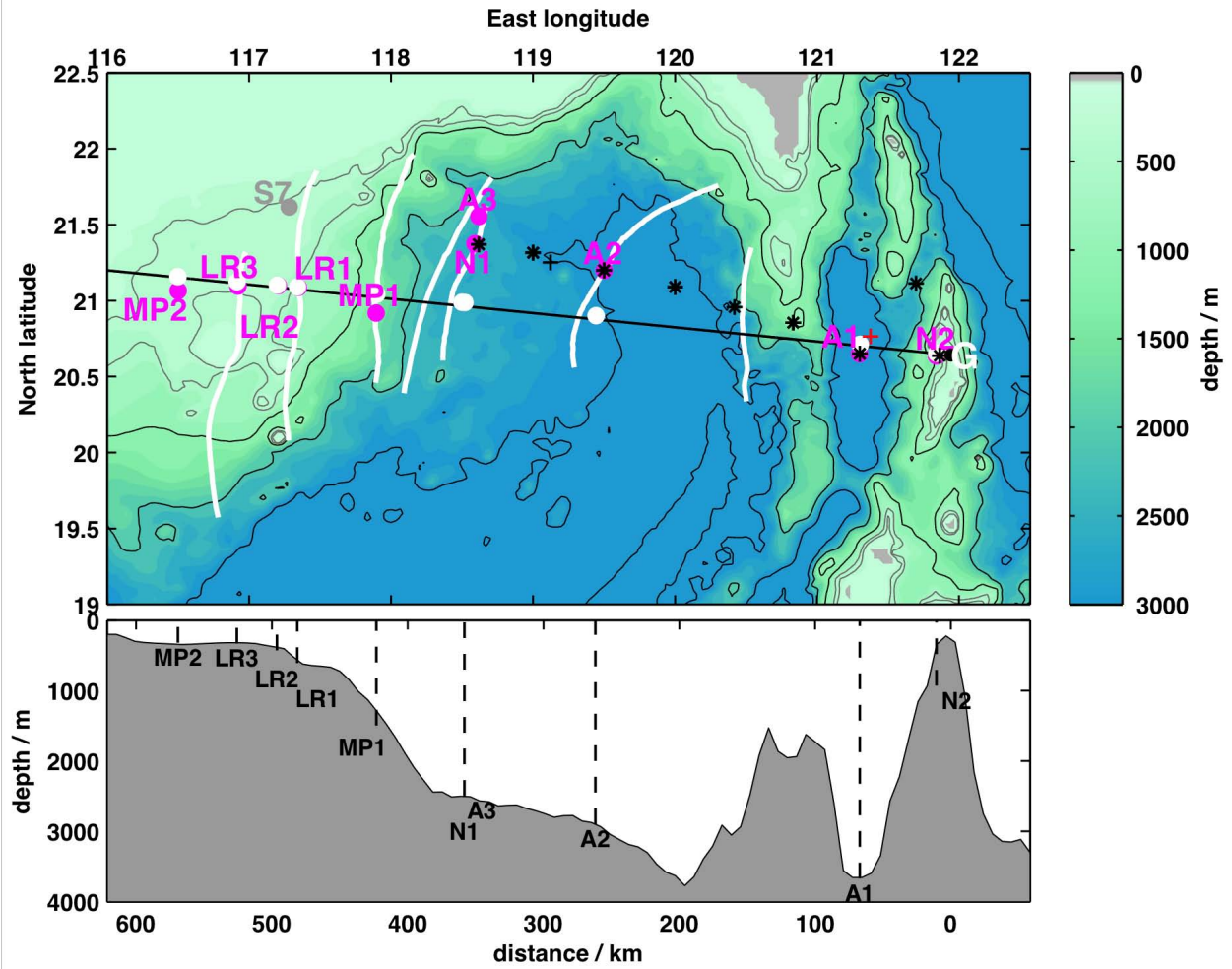


Figure 1: Map of study region showing depth (colors), mooring locations (magenta), the propagation track assumed in calculating wave speed (black line), the assumed generation site ("G"), and the location of each mooring projected onto it assuming cylindrical spreading (white; see text). Selected NLIW crests from 1998-2001 from SAR radar (courtesy of Z. Zhao) are shown in white. Asterisks and pluses indicate the locations of CTD casts used to compute linear phase speeds. Bottom panel shows bathymetry along the track.

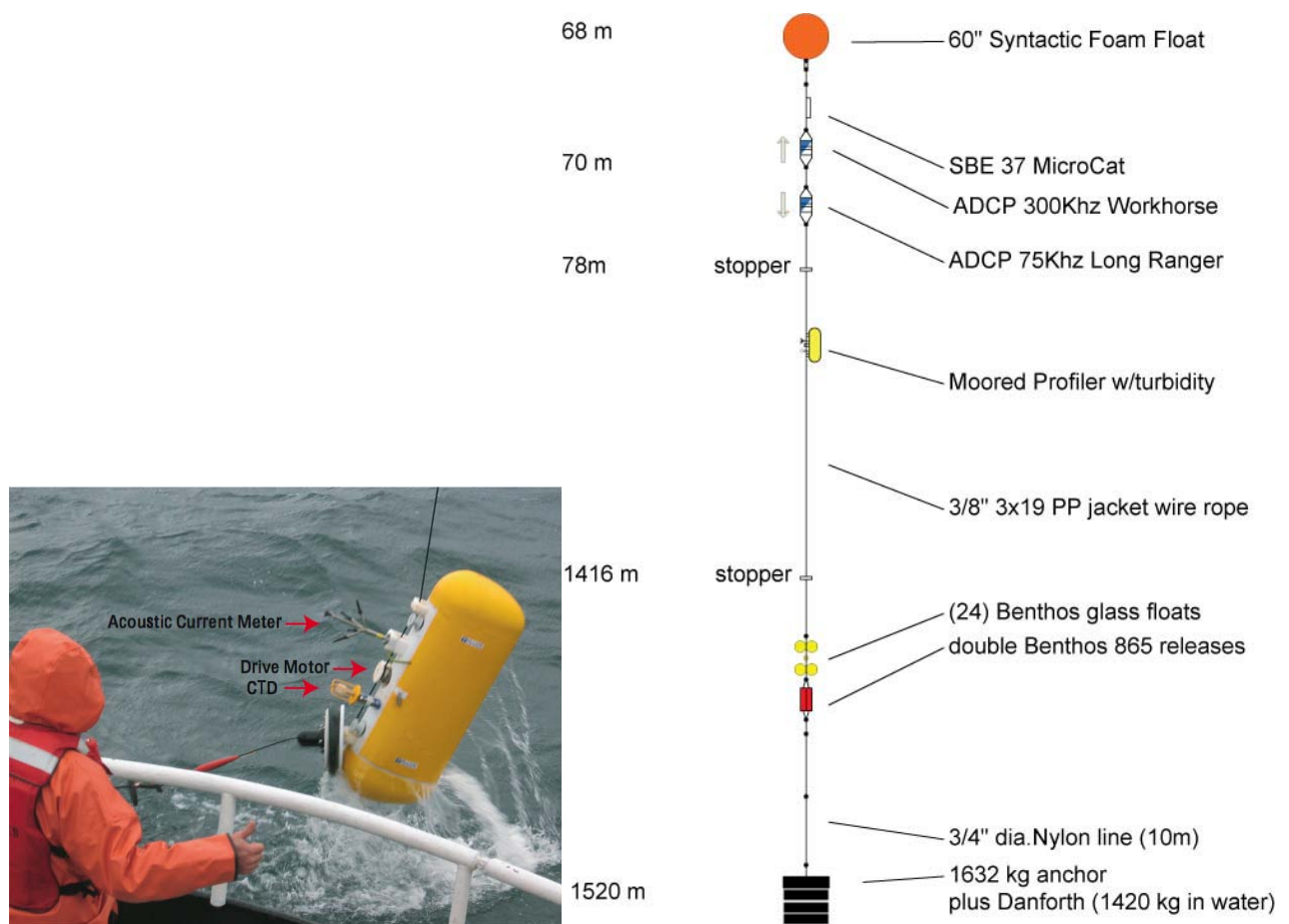


Figure 2: (Left) The McLane Moored Profiler being recovered in Puget Sound, WA. (Right) Mooring diagram at MP1. The uplooking ADCP did not function owing to a failed memory card. The shallow mooring at MP2 (not shown) is similar, with the MP sampling the range 60-300 m in 320 m of water.

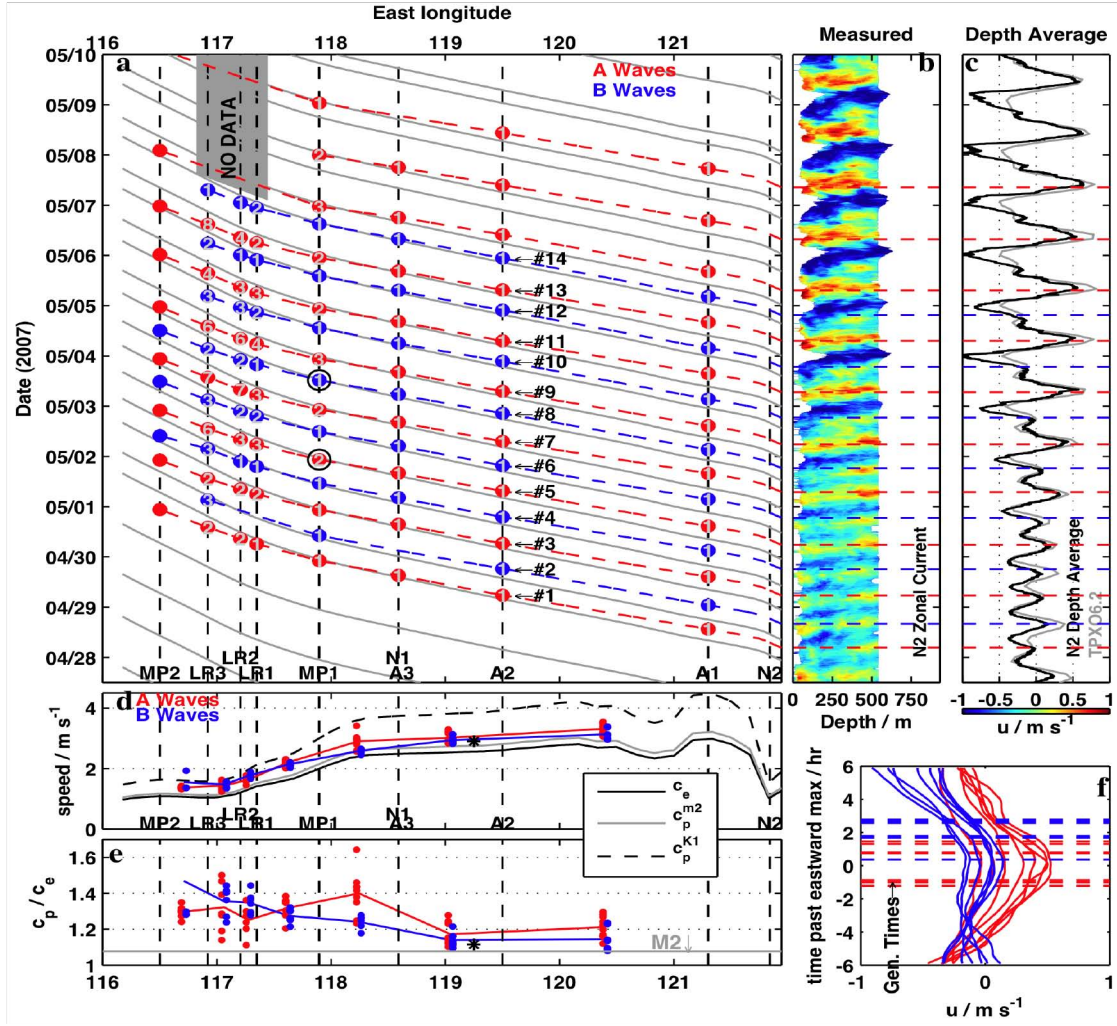


Figure 3: Summary of all detected wave arrivals and corresponding speed. (a) Arrival times of A and B waves (red and blue dots). White numbers indicate the number of waves in the train (1 indicating a single wave). Red/blue dashed lines are the interpolated observed arrivals, with the linear semidiurnal phase speed used to extrapolate east of A1. The right plotting limit is the assumed generation site. Gray lines are trajectories beginning at westward current maxima at Luzon Strait and traveling at the linear irrotational phase speed. (b) Zonal barotropic currents at Luzon Strait predicted from TPXO6.2 (gray) and depth-averaged zonal currents measured at N2 (black). The depth-dependent currents are contoured versus depth and time in (c). The right axis limit is the water depth, and the color bar is shown below (b). Dashed lines in (b, c) indicate generation times determined from the intercept of the extrapolated trajectories in (a). (d) Speed along the track in Figure 1 determined from differential arrival times for A waves (red dots) and B waves (blue dots), plotted slightly to the left/right of the mooring location for visibility, and the mean over all A and B waves (red and blue line, respectively). Linear long-wave speeds for waves with no rotation (black), semidiurnal waves (gray) and K1 (dashed) are overplotted. (e) The ratio of observed speed to irrotational linear speed for A and B waves (red and blue dots), and their mean (lines). The ratio for semidiurnal waves is shown in gray. (f) Generation time (horizontal dashed lines) and depth-average current at N2 (solid) for A and B waves (red and blue, respectively). Time is relative to that of maximum eastward flow.

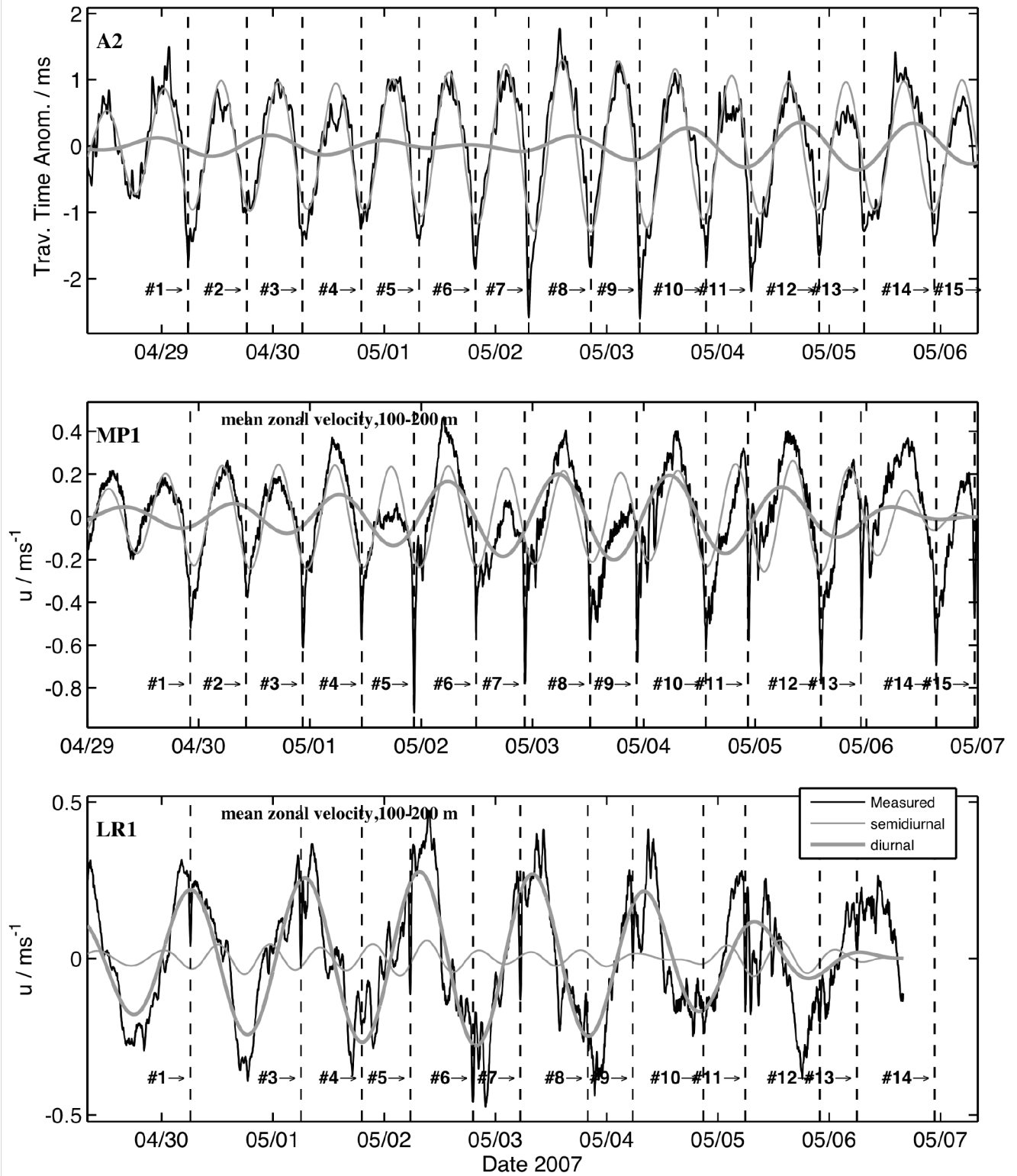


Figure 4: (a) Total (black), semidiurnal (light gray), and diurnal (heavy gray) travel time anomaly at A2. (b, c) As (a) but for zonal current averaged between 100-200 m at MP1 (b) and LR1 (c). Wave arrivals are indicated. Each panel is lagged for mean travel time.