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Optical and Radar Satellite Detections of Submerged Turbulence

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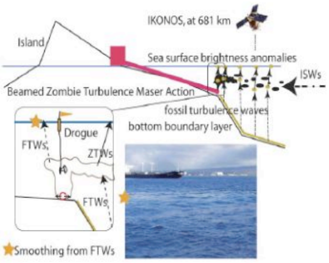
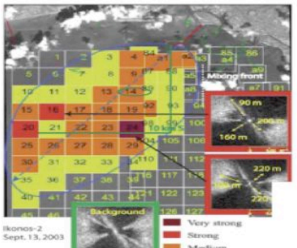
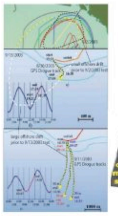
Results from the Remote Anthropogenic Sensor Program (RASP 2002-2004) are presented. Surface manifestations of stratified turbulence from the Honolulu Sand Island Municipal Outfall observed by Ikonos and Quickbird optical satellites are compared to horizontal and vertical microstructure sampling. Narrow spatial frequency band 30-250 m wavelength sea surface brightness anomalies were detected in the optical images at distances up to 20 km from the 70 m deep diffuser in SE and SW directions offshore matching GPS tracks of parachute drifters set at the diffuser near the 50 m trapping depths indicated by microstructure profiles of turbidity, salinity, temperature and density. Outfall fossil turbulence patches beam internal waves in an efficient maser action that transmits most of the stratified turbulent kinetic energy near-vertically. Fossil turbulence waves break to smooth the sea surface over the diffuser with increased near surface viscous and temperature dissipation rates. Advected outfall fossil turbulence patches extract energy from 30-250 m wavelength internal solitary waves in patterns transmitted to the sea surface in chimneys by zombie turbulence internal wave maser action. The detected solitary waves apparently originate as fossil turbulence waves from bottom boundary layer turbulence events at length scales reflecting Ozmidov scales at fossilization. Strong mixing by the beamed zombie turbulence maser action (BZTMA) mixing chimney mechanism was observed following a rain event that advected outfall fossil turbulence patches far offshore. Mixing detected by SAR images extended to distances of 45 km and by optical images to 20 km. Outfall fossil turbulence patch lifetimes were thousands of stratification periods. Thorpe overturn scales and hydrodynamic phase diagram classifications were computed for nearly 20K microstructure patches. Because the BZTMA mixing mechanism is oriented vertically it affects many problems of oceanic mixing and remote sensing of submerged turbulence. The deep dark mixing paradox is resolved since vertical sampling methods will probably under sample such an intermittent nonlinear process driven by rare bottom turbulence events. Visibility of the bottom and large tidal solitons in deep water by SAR and astronauts can be understood as surface manifestations of turbulence produced by these features directly coupled to the surface by BZTMA. Internal tides become the effect of strong turbulent mixing over topography rather than its cause. The cascade of tidal energy is directly from barotropic tides to bottom turbulence, which causes a complex cascade of internal waves and more turbulence on a wide range of scales.







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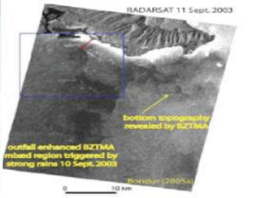
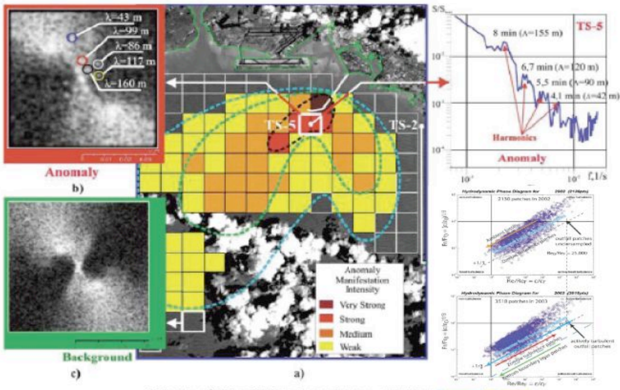
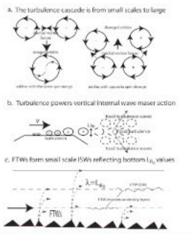
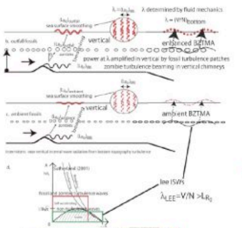
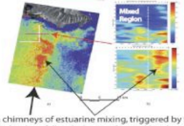






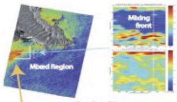
igure 1f. Turbulence cascades from small scales to large driven by inertial-vortex forces $\vec{v} \times \vec{\omega}$ shown by dashed arrows in a. At all scales adjacent eddies with the same spin (left) induce $\vec{v} \times \vec{\omega}$ forces that cause such eddies to merge. Adjacent eddies with opposite spin (right) induce $\vec{v} \times \vec{\omega}$ forces that cause such eddies to diverge and expand the turbulent region. In b. stratified flow over an obstruction produces growing turbulence that fossilizes at the Ozmidov scale L_{R_0} and radiates FTWs. This is an efficient maser action because most of the turbulent kinetic energy is beamed vertically as FTWs. In c. the unstable BBL-FTWs trigger mixing and momentum transport that creates linear $\lambda \approx L_{R_0}$ internal waves (FTW-ISWs) on density layers (dashed lines) that propagate horizontally.





BZTMA chimneys of estuarine mixing, triggered by fossils of Sand Island outfall turbulence advected by alongshore tidal motions and strong offshore flows from Sept. 10 rains

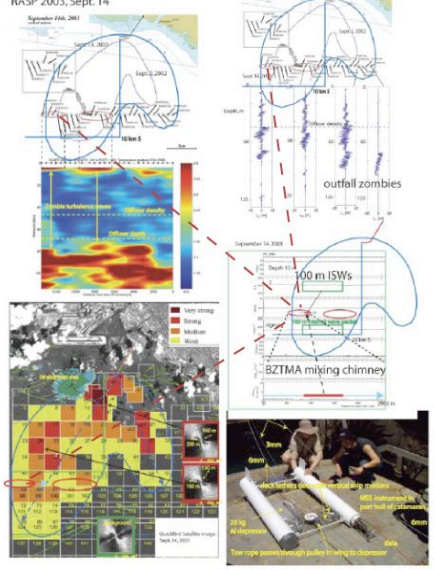
Sept. 11, 2003 RADARSAT radar image



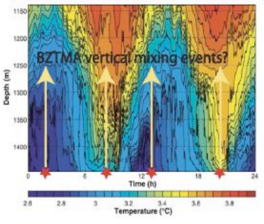
BZTMA waves from fossils of Sand Island outfall turbulence rise in mixing chimneys and break at the surface in patterns that reveal the narrow band wavelengths of the internal waves that power the zombie turbulence patches. The mechanism fails in the mixed regions.

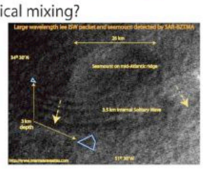
Sept. 13, 2003 ENVISAT radar image

Detection of ISWs in BZTMA mixing chimney
RASP 2003, Sept. 14



Diurnal internal waves or diurnal vertical mixing?





Rudnick et al. 2003

See http://www-acs.ucsd.edu/~ir118