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Current Characterization at the Amazon estuary

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At the estuary there are several mechanisms that cause turbulence: influence of solid contours (estuary bottom and shores), speed vertical shearing (fluid inside), wind shearing stress (free surface) and surface and internal gravity waves. Turbulence intensity controls vertical distribution of estuary water mass property concentration. As flow into the estuary takes place during the transition or turbulent regimen, produced by small space and time scale movements, entrainment, turbulent scattering and advection are the processes responsible for fresh water mixing up with the sea and for local salinity variation, as well as for concentration of natural properties and man-made ones. According to this focus, we shall describe general circulation, conveyance and mixing characteristics of the Amazon low estuary waters.
Amazon estuary shows unusual characteristics: it is of vast length and enormous outflow. It is extremely wide – 150 Km – and its discharge into the Atlantic amounts to 180,000 m3s-1 (Otman, 1968, Figueiredo et al, 1991), which means 18% of all water discharged by rivers into oceans; this is the largest punctual source of fresh water for oceans (Milliman and Meade, 1983). Maximum outflow is 2.5 x 105 m3s-1, and it happens at the end of May. Minimum outflow is 1.2 x 105 m3 s-1, and it takes place in November.
At Amazon River, the Mixing Zone occurs where the Coastal Zone usually is. The reason for that is the extension of fresh water plume moves Northeast for over 1000 Km (Gibbs, 1970; Muller-Karger et al 1988). This is the most extensive estuarine plume ever found in the ocean. During low fluvial discharge (June-November) plume reaches 300 Km; however, on high discharge (November-May) plume reaches 500 Km. Plume already is 3 to 10 m thick and 80 to 300 Km wide (Lentz and Limeburner, 1995). From June to January plume moves towards Africa, from whence 70% of it goes east carried by North Brazil Current retroflection and 30% goes towards the Caribbean. From February to May, the plume goes northwest towards the Caribbean.
As to classification according to salinity stratification, at the quadrature the Amazon estuary is considered as “Saline Wedge” type (highly stratified estuary), salinity at 120 Km way from river moth standing out, whereas at sysygy it can be classified as well mixed (Limeburner et al. 1991e 1992; Patchineelam, 2004). Fresh water is everywhere in the river area, salty or mixed water is located in the ocean. In this estuary 90 Km away from the mouth surface water salinity is less than 0.05 and bottom salinity at 14 m deep is about 19 at high water on quadrature at the end of the rainy season. This behavior produces marked difference in the vertical salinity profile, showing the current is moving in the opposite direction (river fresh water and salty water brought by the tide). In this scenario, speed shearing at the interface produces interfacial friction stress that, from the entrainment process carries portions of water from the sea to the upper part.

Usually, therefore, in “saline wedge” (highly stratified estuary) type estuaries, when river discharge is more intensive than the tide wave, entrainment is the predominant mechanism; and the greater tide amplitude is, the greater will its influence be to produce turbulent scattering and mixing be. Probably, at Amazon estuary quadrature entrainment processes are predominant and are the ones responsible for increased salinity in surface layer, whereas turbulence scattering mixing is secondary to it.

“Saline wedge” (highly stratified estuary) type estuaries are typical of large fluvial discharge and microtide regions. But although the Amazon estuary is a macrotide region, this stratification is due to the river’s exceptional discharge.

Due to the remarkable river plume discharge on the platform, the tide – a dominant in macrotide region estuarine circulation – now has a secondary role, albeit not a negligible one, with quadrature amplitudes varying from 2 m to 90 Km from the mouth. It is important to point out that tide-induced mixing processes determine saline front position and structure.

The circulation pattern is bidirectional: at the surface layer near river mouth, medium current flows perpendicular to isobates towards the sea, turning north until it starts to flow parallel to the continent. At the lower layer near river mouth, current flows towards the continent. At the upper layer one finds more intensive tidal current (Gibbs, 1982). Flow is weak at the bottom, showing shoreward movement under the plume that moves towards the platform. Great speed shearing is compensated by high salinity stratification at the middle of the water column and by the high concentration of sediments (fluid mud) near ocean bed (Geyer e Kineke, 1995).

As for the behavior of tide-produced currents, the main tide forcing mechanism is semidiurnal (a 12.4-hour period), M2 component predominating, which in its turn is influenced by Amazon Continental Platform morphology, which breaks at the 100 m isobate. This Platform width varies significantly along the coast from 125 km to 325 km, which causes tide semidiurnal components to be enlarged at some points. North Cabo Norte, platform extension is less than at the mouth; thus, M2 travels as a stationary wave due to the near-resonant character present in coastal embayments between Cabo Norte and Cabo Cassiporé. Near the mouth M2 travels as a progressive wave due to its convergent character, whose amplitude decreases and phase grows upstream. (Beardsley et al).

Tide amplitude at the coast is usually about 5 m; however, it is possible to find tide channels of up to 14 m (Vinzon, S. spoken lecture).
Tide wave propagation along the channel makes the wave to be laterally compressed by river shores; however, friction exceeds convergence and causes tide height to decrease along the channel, it then being classified as a hyposynchronous estuary. At maximum outflow dynamic tide travels to the neighborhood of Gurupa Island and, at minimum outflow, dynamic tide travels to Óbidos, 840 Km upstream the river mouth (Ferraz 1975; Vinzon el al, 2007).
Tide current speed component condemned axles show up in the river channel and up to about 70 Km from the mouth, that is, at the Platform, having an alternative and axial character and ebb and flood, and at more than 90 Km from the mouth tide ellipse axles tend to a rotating patter, always keeping, however, a greater axle aligned to channel configuration (Gallo et al, 2007 and Pontes, 2007).
Tide speed components show quite an energetic behavior, being able to reach speeds over 2 m/s. Tide currents – usually perpendicular to the coast – vary from 200 cm/s at high tides to 80 cm/s at ebb tide in mouth neighborhood. Once tides are removed, residual currents show strong shearing, with surface speeds over 100 cm/s (Geyer and Kineke, 1995).

Tide shows asymmetry, taking 4-5 hours to flood and 8-9 hours to ebb. If time intervals between ebb and flood differ, it follows from the volume conservation principle that during the shorter event – such as at Amazon estuary flood tide – speed shall be greater; as a consequence, suspended sediment transportation shall be greater during flood in comparison to ebb, assuming adequate sediment/water supply at both events. This is not to say, however, that at Amazon estuary speed shall be greater during ebb, for the large river outflow is added to ebb currents. The Amazon estuary is a peculiar case: albeit flood time is less than ebb one, the estuary is dominated by ebb tide, becoming a sediment exporter (Vinzón, et al 2007).
The Amazon River discharges 3 million tons a day of sediments into the Amazon Continental Platform (Nittrouer et al 1986). These sediments are deposited NW of the outfall; there then happens a concentration rate of sediments in layers (“fluid mud”) about 4 m thick in contact with sea bed (Geuer and Kineke, 1995). Fluid mud concentration is 10g/l of sediment.