TIDAL DYNAMICS OF O_2, H_2S AND pH IN PERMEABLE SANDS

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Introduction

We studied the dynamics of O_2, H_2S, and pH at the sediment-water interface of intertidal sediments to assess the temporal and spatial scales of change in environmental conditions, their effects on transport phenomena and microbial activities. This particular aquatic ecosystem is affected by highly variable advective transport processes (tides, currents, waves), temporal effects (seasonal or daily changes in temperature and light) and spatial differences (topography, black spot development). The ideal depth zonation of different biogeochemical processes (FROELICH *et al*., 1979) does not exist in permeable intertidal sediments. Thus, highly resolved *in-situ* microsensor measurements were performed seasonally over tidal cycles.

Research Area

The area under investigation was a permeable sand flat in the backbarrier tidal region of Spiekeroog Island, East-Frisian Wadden Sea, Germany (Fig. 1). Sampling sites on Janssand were on top and near the waterline of a slowly ascending slope. They were 45 m apart, the altitude difference was 60 cm. Mean maximal high-water level was 1.30 and 1.90 m, respectively.

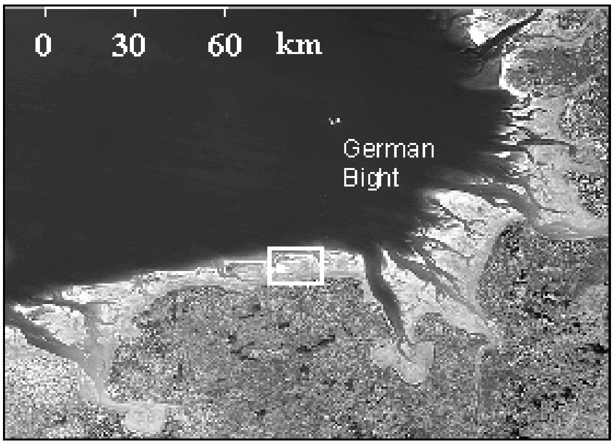

Fig. 1. Aerial view of the German Wadden Sea and the research area.

Methods

In-situ microsensor measurements at the sediment-water interface were performed over a 24 h tidal cycle by use of an autonomous profiling lander (Fig. 2). Simultaneously, depth profiles of O_2, H_2S, pH and temperature were recorded half-hourly. Due to a mean grain size of 120 µm, spatial resolution was set to 1 mm. Disturbance of the sediment caused by microsensors was minimal.

Results

Results are presented for two intermediate seasons, spring (March) and autumn (September/October) 2002.

Seasonal dynamics on Janssand

Seasonal effects on O_2 concentrations and depth penetration on Janssand are shown for the top of the sand flat (Fig. 3).

Fig. 2. Lander used for *in-situ* microsensor measurements.

Different O_2 concentrations in the overlying water can be explained by the temperature-dependent saturation state with about 310 µmol/L at maximum temperatures of 6-7℃ in March and about 250 µmol/L at maximum temperatures of 16-18℃ in October. The penetration in March was ±2 cm, highest observed depth was 4 cm. The thickness of the oxic layer can increase fivefold in winter compared to summer (BINNERUP *et al*., 1992). In October O_2 penetration at the top was reduced to ±0.5 cm due to intense microbial mineralisation of organic matter (algal bloom). Higher activity in autumn is reflected by a maximum total O_2 consumption of ±120 mmol/m^2 over a 6 h tidal cycle. O_2 consumption in winter (28 mmol/m^2) was much lower (see WERNER *et al*., this volume).

H_2S was not detectable in the upper 5 cm of the sediment on top in March, but accumulated at depths below 3 (top) and 4 cm (waterline) in September/October (Figs. 3). Maximum porewater concentrations amounted to 150 and 100 µmol/L, respectively.

Tidal and spatial dynamics

Intense photosynthetic activity caused a fourfold O_2 oversaturation at the sediment surface in September/October 2002 (Fig. 4). This phenomenon appeared only at low tide. At high tide photosynthesis may be light limited due to high amounts of resuspended particles.

At low tide, O_2 was rapidly consumed in the dry sediment. With high tide O_2-rich seawater is pushed deep into the sediment. Within one tidal cycle O_2 penetration, accounting for a change from oxic to suboxic or even anoxic conditions, varied in the range of 2-3 cm in depth. Lower O_2 penetration depths at high tide could be related to topographic effects (Fig. 5, HUETTEL *et al*., 1996), changes in flow velocity and ripple migration. Whereas upstream of a ripple advective flow or wave action led to deep O_2 penetration into the sediment, anoxic porewater was drawn to the surface on top and under the downstream slope (ZIEBIS *et al*., 1996).

Temperature showed a very homogeneous depth distribution in the sediments. Tidal influence was visible by a very sharp transition between seawater temperature of 15-16℃ at high tide and lower temperatures decreasing to 11℃ at low tide especially at night. (Fig. 6, waterline position with oxic surface sediments).

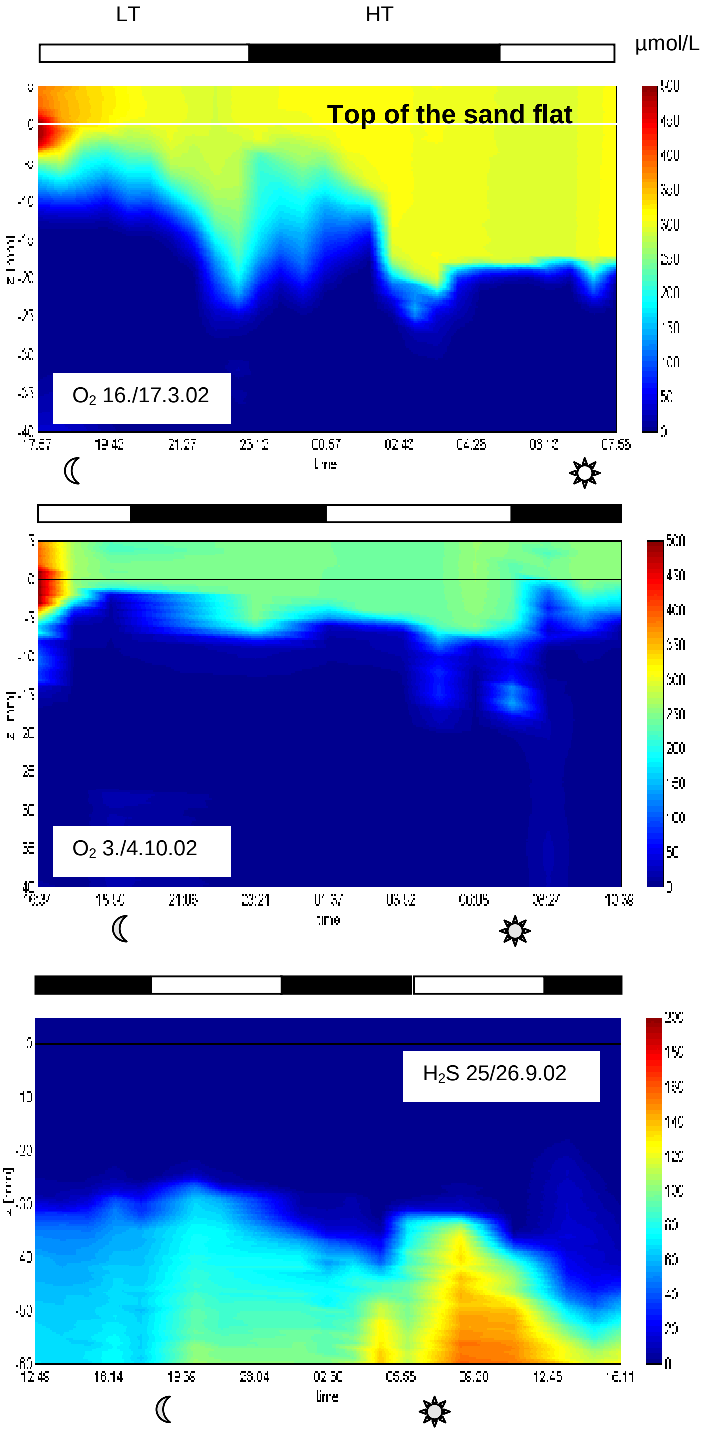

Fig. 3. Seasonal changes of oxygen and H_2S concentration and penetration depth on top of the sand flat (LT: low tide, HT: high tide).

Near the waterline organic-matter-rich clay layers were embedded in the sandy sediments. Besides oxic surface sediments, spots, ripple troughs or channels were observed where black anoxic iron sulfide-rich sediments cropped out. These black surface sediments develop within a limited areal extent (<3 m^2) due to erosion or locally increased supply of organic matter (e. g. burial of macroalgae and mussels) and enhanced microbial activity at higher temperatures (BÖTTCHER *et al*., 1998).

Measurements of O_2, H_2S and pH were performed directly above a black spot emitting sulfur milk similar to that shown in Fig. 6.

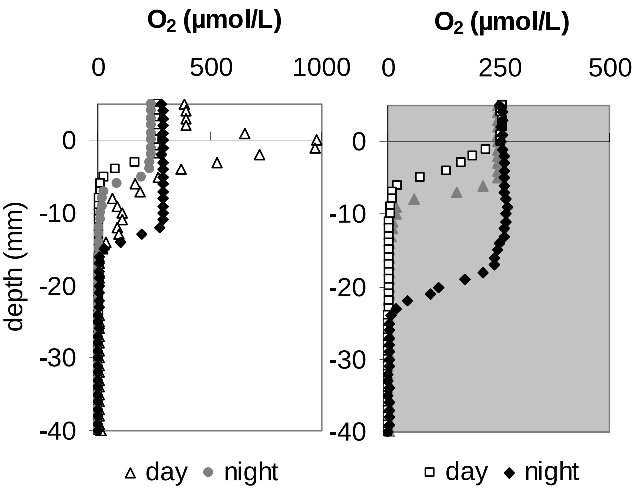

Fig. 4. O_2 production and spatial differences of depth distribution on top of the sand flat ($3^{rd}/4^{th}$ Oct 2002, right: high tide) measured a few cm apart.

In contrast to sediments with oxic surface, black spots showed an extremely tidal-dependent behavior. On the black spot tidal-induced periodic upward movement of anoxic porewater was visible: During low tide total O_2 depletion occurred in the overlying water combined with surface-directed increase in H_2S and decrease in pH. Maximum H_2S concentrations were in the range of 1-2 mmol/L. This activity decreased by night and ceased during the next day due to changing temperature conditions. During high tide O_2 and pH distribution reflected seawater penetration into the sediment.

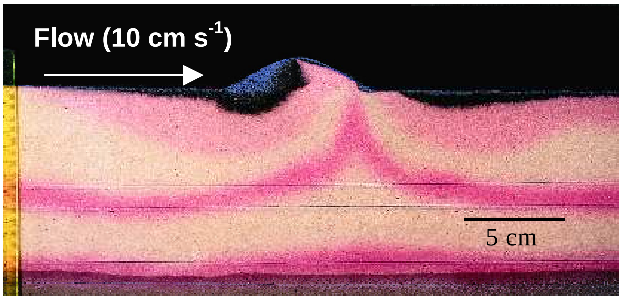

Fig. 5. Results of a dye experiment showing advective flow patterns underneath a mound of sediment. Black lines: porewater layers at the beginning, pink: porewater distribution after 16 hrs. (HUETTEL *et al.*, 1996).

Conclusions

Seasonal effects and in particular advective transport processes (tidal pumping) and surface topography control O_2, H_2S and pH dynamics in permeable sandy sediments. During high tide sediments were supplied to several cm depth with oxic seawater, whereas anoxic porewater drained off the plate during low tide. Black spots or channels could act as windows for transport of anoxic porewater to the surface.

Enhanced transport of O_2 (and organic matter) into permeable sediments can increase microbial activity, in particular oxic mineralisation of organic matter. Microorganisms have to overcome rapid changes from oxic to suboxic or even anoxic redox conditions in a few hours.

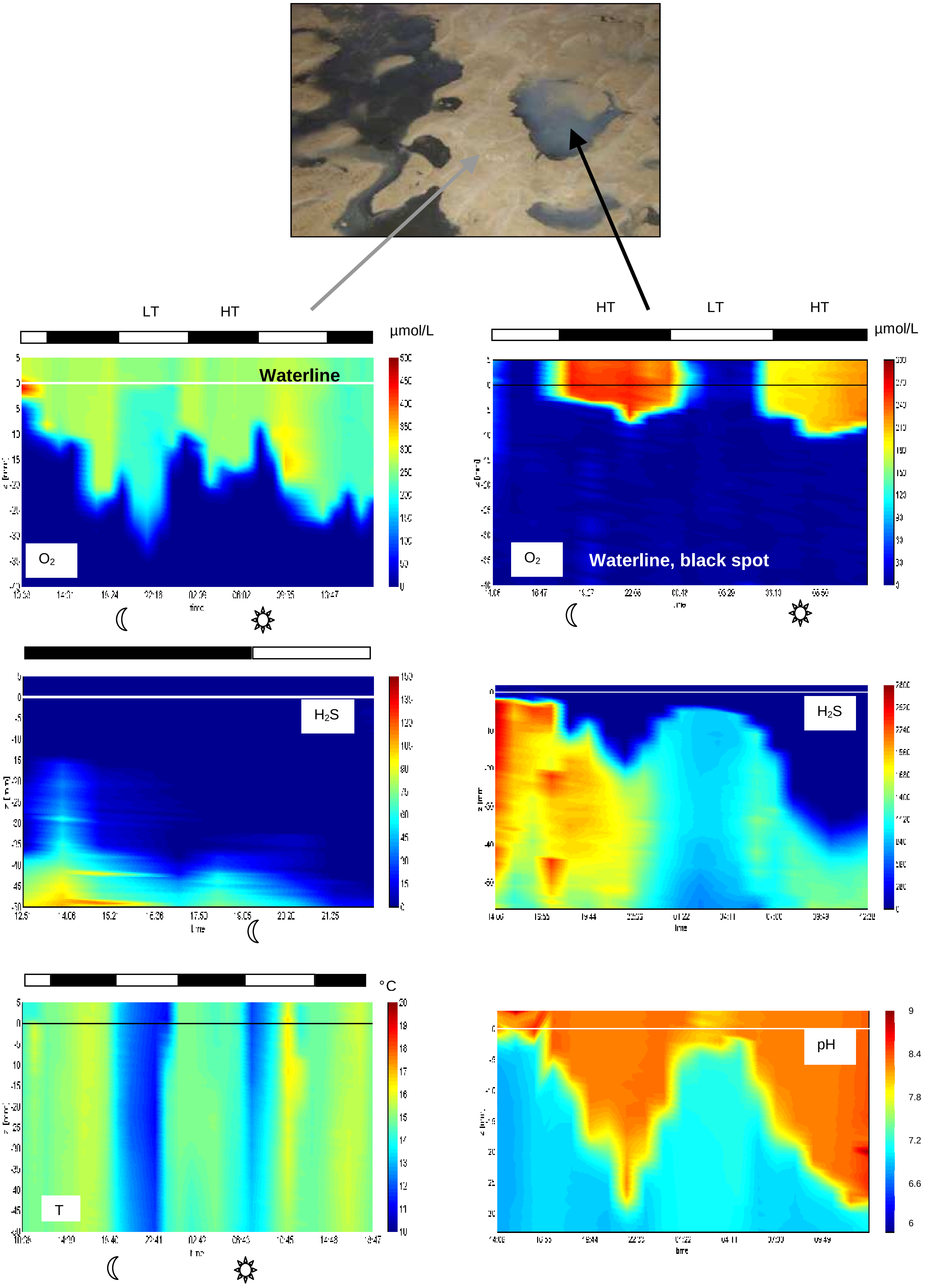

Fig. 6. O_2, H_2S, pH and T dynamics at the waterline measured in oxic surface sediments (left) and directly on a black spot emitting sulfur milk (right).

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