Seasonal variation of bromine monoxide (BrO) over the Rann of Kutch salt marsh seen from space

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Abstract

We present first satellite observations of enhanced monthly mean BrO VCDs over a salt marsh, the Rann of Kutch (India/Pakistan), during 2004-2014 as seen by the Ozone Monitoring Instrument (OMI). The OMI data reveals recurring maximum BrO VCDs during April/May, but no enhanced column densities during the monsoon season while the area is flooded. While this behaviour may be at least partly caused by strong cloud-shielding during monsoon time, the BrO VCDs are generally much lower during the following winter months, while the salty surface dries up. We discuss the possible effects of temperature, precipitation and relative humidity on the release of enhanced reactive bromine concentrations. In order to investigate a possible diurnal cycle of the BrO concentration, the OMI results (at a local overflight time around 13:30) are compared to corresponding results from the Global Ozone Monitoring Instrument (GOME-2, local overflight time at around 9:30).

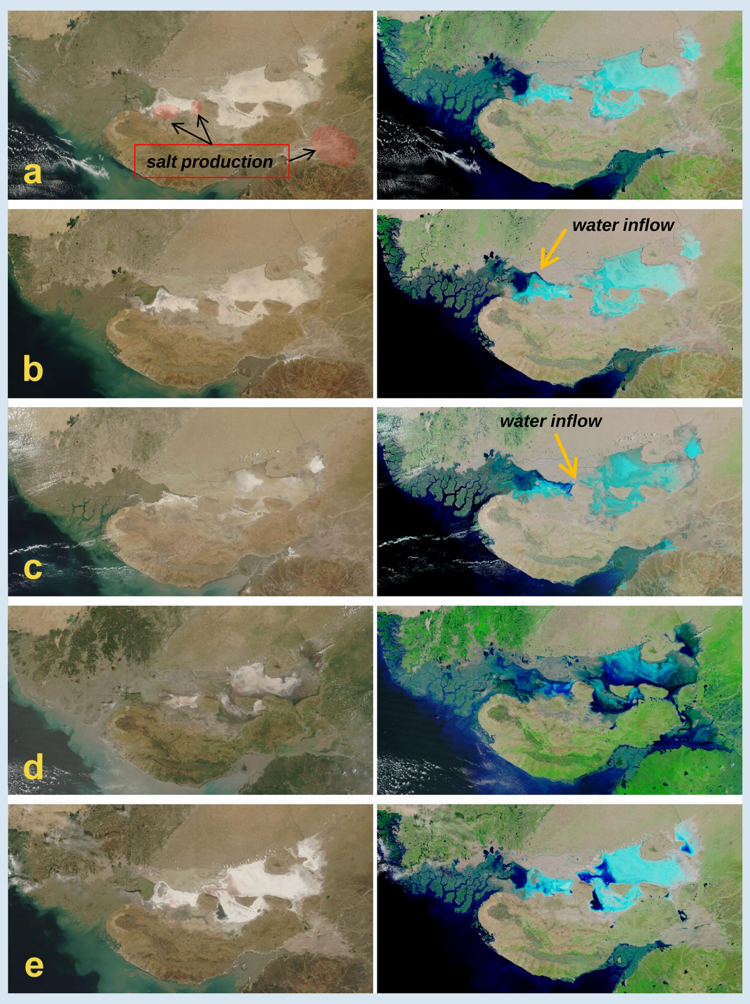

Fig. 1: MODIS TC and Band 7-2-1 images over the Rann of Kutch for single days in February, March, June, September and November 2005, illustrating the flood during the monsoon.

The Rann of Kutch salt marsh

The Rann of Kutch is a so-called 'seasonal' salt marsh, stretching from the Indo-Pakistani border into the Kutch District of India's largest state, Gujarat. With more than 30000 km^2 it is the largest salt desert in the world and additionally one of the hottest areas of India with summer temperatures around 50°C and winter temperatures decreasing below 0° C during night. The Rann (Hindi word for desert) can be subdivided into a large northern part (Great Rann of Kutch) and the considerably smaller Little Rann of Kutch (Figure 2), located at the south-eastern border of Gujarat. During India's summer monsoon (June/July - September/October), the flat desert of salty clay and mudflats, which average 15 meters a.s.l, gets flooded by tidal water as well as freshwater from nearby rivers and standing rain (Figure 1). Due to these rather extreme climatical conditions, the area is widely uninhabited. After the monsoon season, the standing water evaporates, leaving large parts of the Rann covered by a snow white salt crust. Large industrial evaporation ponds are used for the production of salt and the subsequent recovery of elemental bromine from sea bittern, i.e. mother liquor left after recovery of common salt from brine. Especially within the Little Rann of Kutch, the salt is also harvested from hand-build salt evaporation ponds constructed by thousands of local families year after year.

Fig. 2: Location of Great and Little Rann of Kutch. While about 10% of the Great Rann belong to Pakistan, the main part as well as the Little Rann are located in Gujarat, India.

OMI BrO retrieval

OMI data of both satellite instruments were analyzed for enhanced BrO column densities for a fit window from 336-360 nm (MPIC own product). Measurements affected by the 'Row Anomaly' as well as from hot and transient pixel were consequently excluded. To minimize the influence of clouds, only OMI measurements with an effective cloud fraction of less than 30% were considered using the NASA OMI L2 OMCLDRR cloud product. The data were corrected for the stratospheric fraction by subtracting the results of a two-dimension spatial polynomial fit of 4th degree to the daily measurements. For final BrO VCDs, box-AMF were calculated using the Monte Carlo radiative transfer model *McArtim*. The simulations were conducted near the strongest BrO absorption band (338.5 nm) under cloud-free conditions for varying homogeneous BrO layer profiles (0-400 m, 0-1 km and 0-2 km), aerosol conditions (AOD=0-1, SSA=0.9, AP=0.72) and surface albedo (0.1/0.15/0.2) based on results from the NASA L2 OMAEROG aerosol product and the reflectivity at 331nm (available via the NASA OMI L2 OMSO2 SO_2 product.

Seasonal BrO VCD variation 2004-2014

The individual daily measurements of each month were gridded on a regular lat-lon grid with a spatial resolution of 0.1°. It is clearly visible from the maps (Figure 3) that the BrO VCDs slowly rise during the first months and reach a maximum during April/May. During the monsoon (June–September), the signal almost completely disappears. This behaviour is, however, at least partly caused by reduced statistics due to large cloud cover over the observed area. After the monsoon (October–December) the BrO VCDs remain at a low level, reaching magnitudes similar to the ones at the beginning of the year.

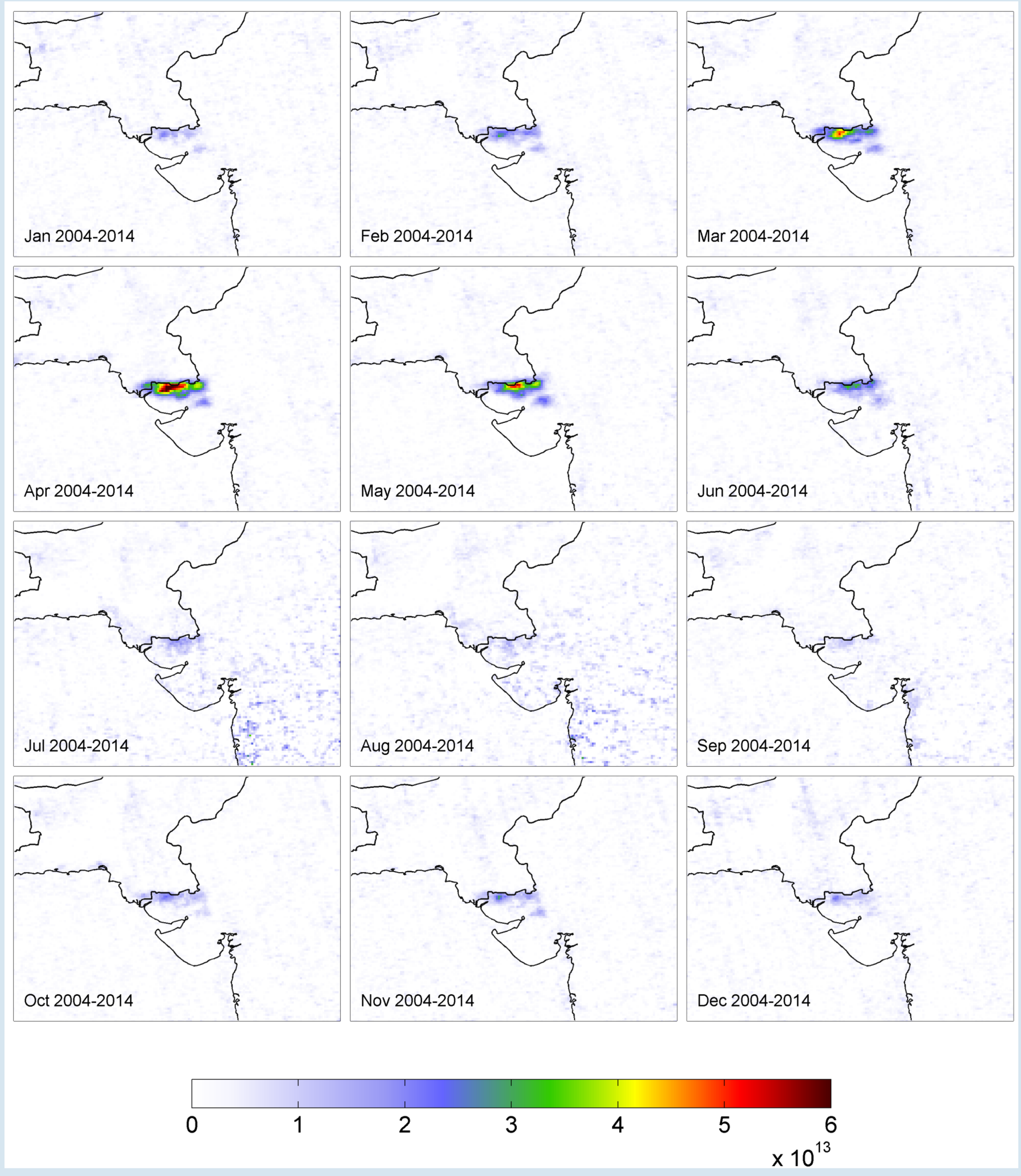

Fig. 3: Seasonal variation of monthly mean BrO VCD over the Rann of Kutch as seen by OMI during 2004-2014. While maximum VCDs are clearly detected in April/May for the Great and Little Rann, only small enhancements can be seen during wintertime. Measurements during monsoon (July–September) are critical due to reduced statistics because less satellite measurements can be found for CF<0.3 (as can also be identified by increased background noise). As indicated by the maps, one source region of the BrO seems to be located right in the western part of the Great Rann where a large industrial salt production complex can be found (compare to red marked areas in Fig. 1).

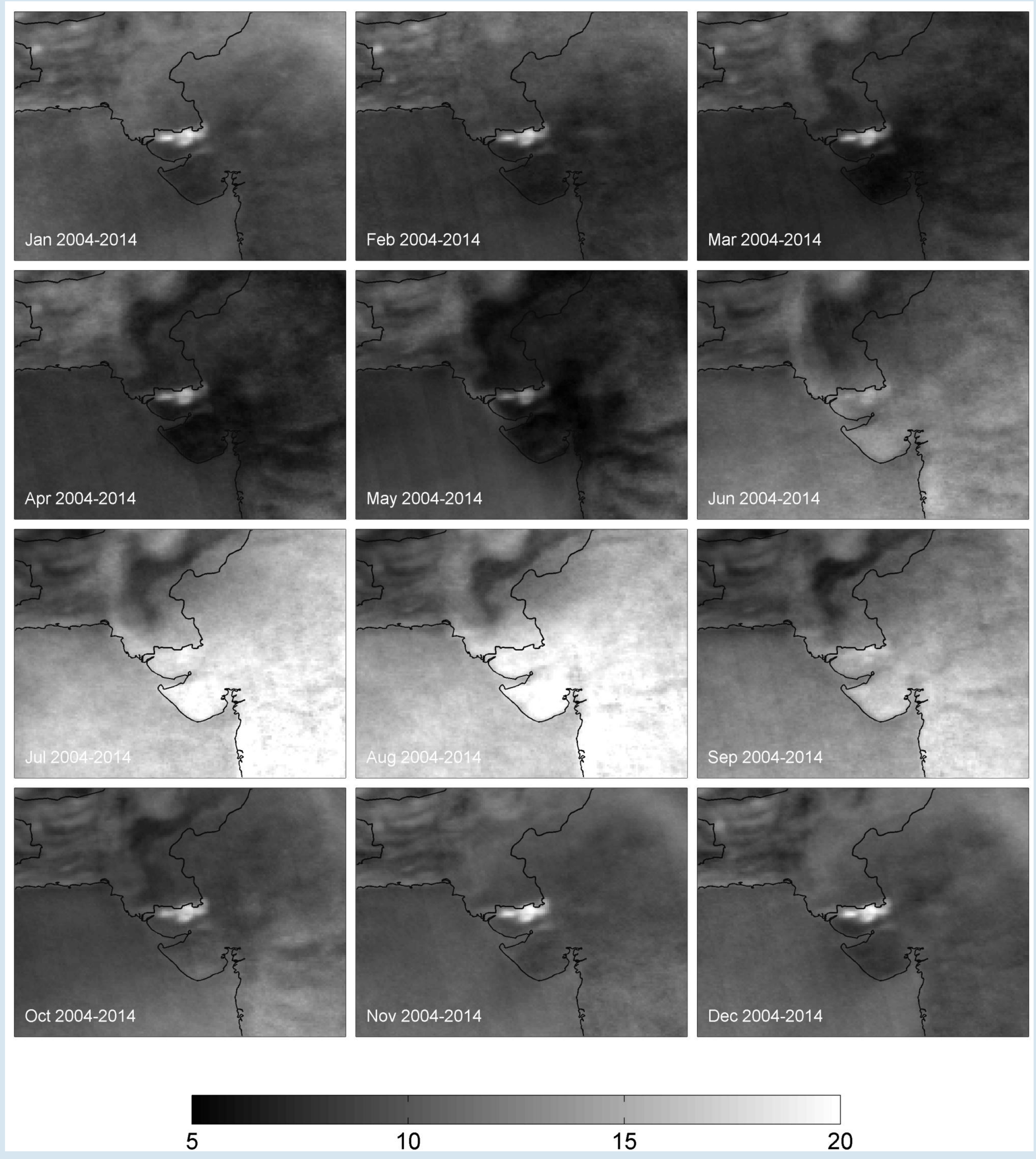

Fig. 4: Seasonal variation of the monthly mean reflectivity at 331 nm over the Rann of Kutch as seen by OMI during 2005-2014 (same data selection as in Fig. 4, i.e. for CF<0.3). Only the Great Rann of Kutch can be clearly identified by enhanced values due to its bright surface compared to the surrounding areas. During the monsoon (July–September), wide areas are still affected by clouds as indicated by the increased background, including the Rann area. It is important to notice that the corresponding enhanced BrO VCDs in Fig. 4 appear only at certain parts of the entire salt marsh and especially for rather low reflectivity in April/May.

Correlation with meteorological parameters

To investigate possible dependencies of the observed total BrO mass over the Rann of Kutch on humidity and other parameters, data from the European Centre for Medium-Range Weather Forecasts (ECMWF) for the whole investigated time period and within a 1° x 1° area located over the central part of the Great Rann (23.5–24.5°N, 69–70 °E) were used to calculate monthly averaged values for different meteorological parameters around the time of the OMI overpass. Figure 5 shows the annual variation of the BrO mass together with total precipitation (P), cloud coverage (CC), relative humidity (RH), temperature (T), boundary layer height (BLH) and UV radiation at the surface (UV_{rad}). At first glance, the parameters can be divided into two groups by their seasonal behaviour (indicated by different colors for left and right column in Figure 5a–f). While P, CC and RH are closely related to the Indian monsoon, T, BLH and UV_{rad} are closely related to each other via their dependence on solar irradiation.

To further investigate whether a combination of these quantities can be used to model the annual BrO variation over the salt marsh, a systematic multilinear regression analysis was conducted. Starting from a single parameter up to a combination of all six (P, CC, RH, T, BLH and UV_{rad}), a simple linear function was determined to describe the observed BrO cycle. The resulting r^2 value for each linear fit of the total BrO mass and individual multivariable function was finally used to indicate the goodness of fit. Figure 5g depicts the model results for all functions featuring the highest r^2 value for a given number of parameters.

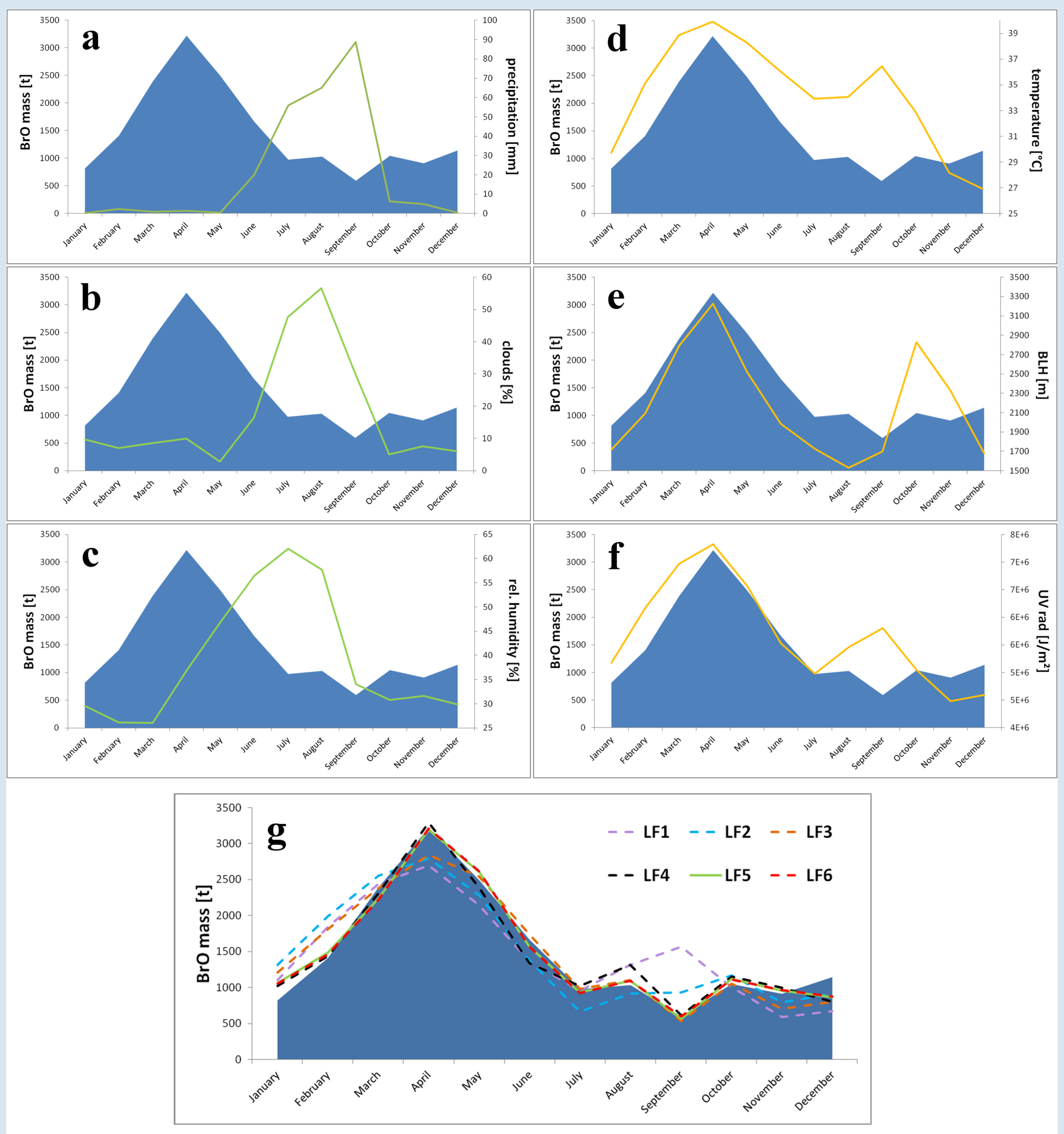

Fig. 5: Monthly averaged ECMWF meteorological parameters (thin lines) in comparison to the total BrO mass (blue area) over the RoK during 2004-2014 (a–f). The results of a multilinear regression analysis suggest that a simple linear model (linear functions LF1-6, g) can be used to adequately describe the annual variations.

Comparison with GOME-2

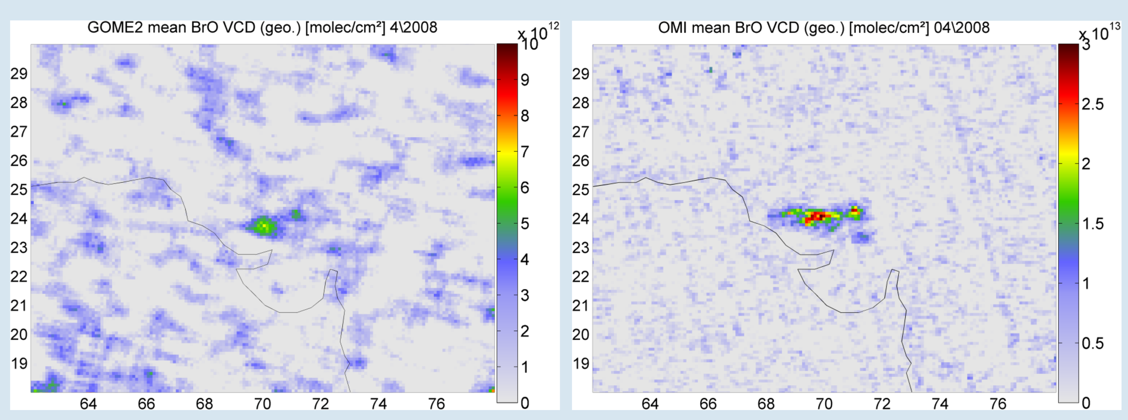

Fig. 6: Monthly mean BrO VCDs over the Rann of Kutch area as seen by GOME-2 (left) and OMI (right) in April 2008. Although a small BrO enhancement can be seen by GOME-2, the VCDs are (generally) about a factor of 3 lower than for OMI.

In order to investigate a possible diurnal cycle of the BrO concentration, the OMI results (local overflight time around 13:30) were compared to corresponding results from GOME-2 (local overflight time around 9:30). Even for April/May, the resulting BrO VCDs are about a factor of 3 lower than for the OMI instrument or below the detection limit for other months.

Despite differences of the instrumental properties like the spectral/spatial resolution, one of the main differences of the two satellite instruments is the overflight time that certainly leads to different ambient conditions that may influence the bromine explosion reaction cycle by a lower UV irradiation and boundary layer height (-50 %), and a 30% higher relative humidity during the morning. In general, ground-based measurements at other salt lakes (like the Dead Sea) have shown that much higher BrO VCD typically appear close to noon time.