2024

Contamination Assessment and Reduction Project – Phase 2 (CARP II)

Appendix A-7. CARP II Post-Audit Report

Post-Audit Evaluation of the CARP 1 Model 2040 Projections

Robin E. Landeck Miller[1*], Kevin J. Farley[2], James R. Wands[1], Badri Yadav[1] and Nataliya Kogan[1]
[1]HDR, Inc., 1 International Boulevard, Mahwah, New Jersey 07495; [2]Manhattan College, Riverdale, New York 10471

***ABSTRACT*:** A first-year modeling-related task for the CARP 2 project has been completed. This task involved comparing CARP 1 future projection model results to PCB and dioxin/furan measurements from 2003-2016. The comparisons were used to assess the predictive reliability of the CARP 1 models and to identify potential refinements for CARP 2 modeling. Overall model and measurement comparisons for total PCBs and selected PCB homologs and dioxin and furan congeners in the Newark Bay Complex and western Harbor, where time series measurements are most abundant, are generally satisfactory and do not indicate systematic CARP 1 model deficiencies. The post audit however highlights several areas of focus for CARP 2 modeling, especially in light of the variations in both in-channel and off-channel PCB and dioxin/furan measurements at a given location for a given time. Areas of focus identified for CARP 2 modeling include analysis of sediment chemistry measurements from dredging projects and CARP 2 sampling, model grid resolution, temporal frequency of model outputs, and modeled depth of active bed layers.

KEY WORDS: CARP, model, HARS suitable, navigation channel, PCB, dioxin, NY/NJ Harbor and Estuary, dredged material testing

1.0 INTRODUCTION

The Contamination Assessment and Reduction Project (CARP) 1 model was developed as a series of sub-models to provide a detailed representation of the hydrodynamics, sediment transport, organic carbon cycling, and fate and transport of contaminants in the NY/NJ Harbor and Estuary (HydroQual 2007a, 2007b, 2008). The CARP 1 sub-models were calibrated using field measurements that were primarily collected during the 1999-2002 CARP 1 sampling program. The calibrated sub-models were applied in 2002 to project concentrations of PCBs and PCDD/Fs for a 37-year period commencing in October 2002 and ending in September 2039. Model-projected concentrations were assessed relative to dredged material testing endpoints to estimate the time when Harbor sediments would meet Historic Area Remediation Site (HARS) disposal criteria.

Since the 2002 CARP 1 model projections of time to HARS suitable Harbor sediments were made, the bathymetry of the Harbor has changed significantly. Deepening of navigation channels was accomplished as a result of several projects. In addition, the Harbor has experienced a number of extreme flow events (including Tropical Storms Irene, Lee and Sandy) that were not simulated in the CARP 1 model projections. Further, measurement collection related to several Superfund projects in the Harbor has been ongoing since 2002. Therefore, in order to provide NJDOT with a tool for determining the current and future levels of contamination in the sediments within navigation channels of NJ/NY Harbor, it may be necessary to refine the CARP 1 sub-models to account for the deepening of navigation channels, to assess the impacts of extreme flow events on contaminant responses in Harbor sediments, and to consider additional measurements of Harbor contaminant concentrations. The effort to ultimately provide NJDOT with a tool for determining the current and future levels of contamination in the sediments within navigation channels is now being performed in a series of subtasks starting with a post-audit evaluation of the CARP 1 model

[*] Corresponding author, Email: robin.miller@hdrinc.com

and ending with revised projections of PCB and PCDD/Fs contamination in Harbor sediments and dredged-material-test organisms based on new measurements and potential refinements to the CARP 1 sub-models.

The completed post-audit evaluation of the CARP 1 model is described herein. The purpose of the post-audit evaluation is to assess the reliability of the CARP 1 model time responses for Harbor water and sediment concentrations (i.e., biota exposure concentrations) for 2002 to 2016 based on readily available measurements. Specifically, the reliability of the CARP 1 model results for 2002 to 2016 were tested by comparing field measurements from 2002 to 2016 to the original CARP 1 model projections developed in 2002. No new model simulations were performed as part of the post-audit evaluation. For the post-audit evaluation, time series plots of measured and model calculated contaminant concentrations were developed for various locations in the Harbor. Different from CARP 1, measurements were specifically categorized as either collected within navigation channels or collected outside of navigation channels.

2.0 METHODS

The post-audit evaluation involved selecting measurements and model results for specific contaminants and developing graphical and statistical comparisons of the selected measurements and model results to assess model performance.

2.1 Selection of Contaminants

The measured and calculated contaminant concentrations considered for the post-audit evaluation are those chemicals modeled previously in CARP 1 projections of the future HARS suitability of Harbor sediments (HydroQual, 2008). Specifically, these chemicals include selected dioxin and furan congeners and PCB homologs relevant to Harbor dredged material testing results. Namely, the dioxin and furan congeners 2,3,7,8-TCDD and 2,3,4,7,8-PCDF, based on relative toxicity as compared to other dioxin and furan congeners, and the PCB homologs di-CB, tetra-CB, hexa-CB, and octa-CB, based on representativeness, were considered in CARP1 projections and post-audit evaluations. It was observed during CARP 1 that under 1998-2002 conditions for the Harbor, the summation of measured di-CB, tetra-CB, hexa-CB, and octa-CB concentrations was approximately half of total PCB concentration measurements. For post-audit purposes, similar to CARP 1 projections, the summation of modeled di-CB, tetra-CB, hexa-CB, and octa-CB concentrations were doubled for comparisons to measurements of total PCBs in the sediment bed and the water column.

2.2 Selection of Measurements

Measurements of contaminants in Harbor sediments and water were obtained for the years 1995-2016 from numerous databases, mostly compiled by NOAA's Natural Resource Damage Assessment and retrieved using NOAA's online Diver Explorer tool for the northeast region, https://www.diver.orr.noaa.gov/web/guest/diver-explorer?siteid=5&subtitle=Northeast. Additional databases were obtained by the Hudson River Foundation directly from USEPA Region 2. For overall CARP 2 purposes, these and other databases are being incorporated into a documented CARP 2 project database and GIS portal that will be available to NJDOT and other users. While sediment measurements collected specifically from Harbor dredging projects and obtained by the Hudson River Foundation will be incorporated into the CARP 2 project database and GIS portal and used for subsequent CARP 2 modeling tasks in conjunction with sediment bed measurements to be collected in 2019, the dredging project measurements were not specifically included in the CARP 1 post-audit graphical displays. The CARP 1 post-audit graphical displays focused on locations which were sampled multiple times to assess temporal trends as well as locations for which both the sediment bed and the water column were sampled.

The databases containing the measurements of contaminants in Harbor sediments and water used specifically for the subject 1995 - 2016 model post-audit graphical displays are listed in Table 1 on page 14. Measurements from all the data sources listed in Table 1 were displayed as time series at various locations throughout the Harbor as shown on figures in Attachments 1 and 2. Measurements were selected for the post-audit evaluation diagrams from the top 15 cm of the sediment bed representing the biologically active zone defined for recent sampling and at all water column depths. Care was taken to include measurements from within the entire shoreline of a waterway reach even if the CARP 1 model grid segmentation did not include near shoreline portions of the waterway reach.

2.3 Selection of Model Results

Model results were obtained from HDR's archive of model outputs for the CARP 1 "2040 future without management actions" projection simulation. Model results for sediment bed and water column were selected for model grid cells representative of locations with multiple years of measurements available. Model results were extracted as depth-averaged time series for the top 10 cm of the sediment bed and the full depth of the water column. Model results were available on an annual average basis for 2003 to 2016 and at higher temporal frequency for 1998-2002. The difference in the frequency of availability of model outputs becomes apparent in diagrams displaying model results. The model results were incorporated into the post-audit evaluation time series diagrams included in Attachments 1 and 2 at the highest available temporal frequency.

2.4 Construction of Post-Audit Diagrams

Post-audit evaluation time series diagrams were prepared for multiple Harbor reach locations represented by CARP 1 model computational grid cells. Time series diagrams are shown for six different model computational grid cells on a single page with a map of the model grid cell locations also provided on each page. Measurement locations are shown within the model grid cells displayed on the map. The multiple pages of post-audit diagrams prepared are included in Attachments 1 and 2. The multiple pages of the attachments represent post-audit results for several Harbor areas: Lower Passaic River downstream of Dundee Dam, Lower Passaic River midsection, Lower Passaic River just upstream of Newark Bay, Newark Bay north, Newark Bay south, Kill van Kull, Arthur Kill north, Arthur Kill south, and the broader NJ/NY Harbor and Estuary. The broader NJ/NY Harbor and Estuary area page includes time series diagrams for specific locations in the lower Hackensack River, the lower Hudson River, Upper New York Bay, Gowanus Bay, Raritan Bay, and Lower New York Bay where time series measurements were available. In Attachments 1 and 2 for both the water column and sediment bed contaminant concentration measurement displays, open symbols rather than filled symbols are used to denote non-detected concentrations which are plotted at the sample-specific detection limits. Attachment 1 includes post-audit evaluation time series diagrams for the sediment bed and Attachment 2 includes post-audit evaluation time series diagrams for the water column.

Post-audit evaluation time series diagrams for measured and modeled contaminant concentrations in the sediment bed in Attachment 1 are presented on an organic carbon normalized basis as is customary (Di Toro et al., 1991). Organic carbon normalization eliminates variations in hydrophobic organic contaminant concentrations associated with location-specific differences in the inorganic content of particles in the sediment bed. Measured sediment bed contaminant concentrations are shown as discrete measurements identified as either in-channel or off-channel for the top 15 cm of the bed. Different symbol colors are used to differentiate in-channel and off-channel measurements. Modeled sediment bed contaminant concentrations are shown with green lines and green shading. The lines capture the depth averages while the shading represents the ranges of the averages for each of the ten 1-cm depth layers modeled.

Measured and modeled water column contaminant concentrations shown in Attachment 2 are presented in volumetric concentration units. Measured water column contaminant concentrations are presented on the post-audit evaluation time series diagrams in Attachment 2 both discretely and as annual mean and range bars. Modeled water column contaminant concentrations are shown with blue lines and blue shading. The lines capture the depth averages while the shading represents the ranges of the averages for each of the ten water column layers modeled.

Figures 1 through 5 specifically discussed in Section 3 are representative examples extracted from the Attachment 1 and 2 diagrams for specific model grid cell locations. All tables and figures are found starting on page 13, after Section 8 and before the document attachments.

2.5 Development of Post-Audit Summaries and Statistics

The fifty-four location-specific diagrams on nine pages in each of Attachment 1A for total PCBs and Attachment 1B for 2,3,7,8-TCDD were reduced to a single page for each contaminant with nine area diagrams to facilitate summarization of post-audit results. For each year in each area diagram, annual average model results are averaged for six model grid cells and are shown as a line. For some years, the available discrete measurements varying in sample size from multiple points within the six model grid cells are pooled in space and time and are presented as range bars. Non-detect measurements were omitted from the summary and statistical comparisons as were measurements from cores which did not include the sediment surface. Along with Figures 1 through 5 which were also extracted from Attachments 1 and 2 and discussed in Section 3, the area diagrams are presented as Figures 6 and 7 in Section 3. The underlying information on each area diagram was also used for statistical comparisons presented in a tabular format.

Statistical comparison tables were prepared by considering each measurement from a single point within an area and year as a trial of the model annual mean for the six model grid cells in the area. A log difference between each discrete measurement and the spatially and temporally averaged area model result was calculated. The log differences were then averaged. The average log difference was used as an indicator of model bias. An average log difference of ‘0’ corresponds to no bias in the model mean predictions as compared to averaged discrete measurements. An average log difference of ‘-0.3’ corresponds to an average ‘factor of two’ under-prediction by the model mean as compared to averaged discrete measurements. An average log difference of ‘0.3’ corresponds to an average ‘factor of two’ over-prediction by the model mean as compared to averaged discrete measurements.

The log differences in measured and modeled concentrations were also used to calculate the sum of the squares of the residuals (SSR). SSR values were divided by the measurement count (n) and used as an indicator of model precision. An ‘SSR/n’ value of ‘0’ corresponds to a perfect agreement between model projections of spatial/temporal averages and all of the random discrete measurements. An ‘SSR/n’ value of ‘0.3’ corresponds to a ‘factor of two’ variation between the model projections of spatial/temporal averages and the random discrete measurements. An ‘SSR/n’ value of ‘0.5’ corresponds to a ‘factor of three’ variation between the model projections of spatial/temporal averages and the random discrete measurements.

An obvious limitation of this method of statistical comparison, necessitated by the resolution of the CARP 1 model grid and the availability of archived model outputs, is the mismatch between temporal averaging periods and spatial representativeness, six model grid cells and entire years for model results as compared to discrete locations and intermittent sampling windows for measurements. Comparisons are tabulated for all measurements as well as separately for in-channel and off-channel measurements. The statistical tabulations are included in Section 3 as Tables 2 and 3.

3.0 RESULTS

Post-audit evaluation results are based on the comparison of compiled measurements to the 1998-2002

CARP 1 model calibration results and the 2003-2016 CARP 1 model future projection results as developed in 2002-2007. Further, on a standalone basis, the compiled measurements, of concentrations of selected PCB homologs and PCDD/F congeners collected in the Harbor sediment bed and water column since 1995 and available after CARP 1 ended, are also important post-audit evaluation results. The post-audit evaluation results are useful for ultimately providing NJDOT with a refined tool for determining the current and future levels of contamination in the sediments within the navigation channels of the NJ/NY Harbor and Estuary.

3.1 Measurement Results

Overall post-audit evaluation time series diagrams presented in Attachments 1 and 2 indicate that a greater number of contaminant concentration measurements are available for the sediment bed than the water column. Diagrams presented in Attachments 1 and 2 further indicate that locations within the Lower Passaic River and Newark Bay had the highest temporal frequency and spatial density of contaminant concentration measurements considered for the post-audit evaluation comparisons to model outputs. Measurement frequency and density declined moving away from the Lower Passaic River and Newark Bay. The diagrams presented in Attachments 1 and 2 indicate that measured contaminant concentration variation for a given year at a location defined by the spatial resolution of a CARP 1 model grid cell often exceeded the measured decline in central tendency of the contaminant concentrations at the location over the past two decades. Variation in contaminant concentrations at a location for a given year is evident in both in-navigation-channel and off-navigation-channel sediment bed measurements as presented on the diagrams in Attachment 1.

3.1.1 Measurement Results – Total PCB Temporal Trends

Figures 1 and 2 on pages 18 and 19 are selected representative examples of the model grid cell specific time series diagrams included in Attachments 1 and 2. Figures 1 and 2 each show collocated total PCB measurements from the water column and sediment bed. Figure 1 shows measurements collected from the Lower Passaic River near mile 1.9. Figure 2 shows measurements collected from Upper Newark Bay, upstream of the confluence of the Port Newark Channel with Newark Bay, approximately 2 miles south of Kearny Point. Figures 1 and 2 show the wide range in water column and sediment bed contaminant measurements.

The water column measurements shown in the top panel of Figure 1 for the Lower Passaic River near mile 1.9 represent 2012 and do not provide an opportunity to assess temporal trends in central tendency of measurements. At the same location, sediment bed total PCB measurements shown in the bottom panel of Figure 1 represent 1998 (off-channel measurements only), 2005-2008 (mixture of in-channel and off-channel measurements) and 2011/2012 (mixture of in-channel and off-channel measurements). Considering in-channel (shown with blue circles) and off-channel (shown with red circles) measurements collectively, there is approximately a factor of two to three decline in the mid-range measured total PCB concentrations between 1998 and 2011/2012. The decline in sediment bed measurements near mile 1.9 indicate a similar decreasing total PCB concentration trend as observed further upstream in the Lower Passaic River as shown in Attachment 1A. The additional post audit evaluation time series diagrams presented in Attachments 1A (starting on page 26) and 2A (starting on page 94) for total PCB concentrations indicate smaller decreasing temporal trends based on fewer available measurement events in Newark Bay, the Kills, and the Harbor than as shown in the Figure 1 Lower Passaic River near mile 1.9 example.

Figure 2 shows an example of the total PCB measurement results included in Attachments 1A and 2A for Upper Newark Bay. As was the case for the Lower Passaic River results shown in the top panel of Figure 1, the water column measurements shown in the top panel of Figure 2 for Upper Newark Bay do not provide an opportunity to assess temporal trends in central tendency of measurements. The sediment bed total PCB measurements shown in the bottom panel of Figure 2 for the same location in Newark Bay represent 1998/99 (off-channel measurements only), 2005/2006 (mixture of in-channel and off-channel measurements), and 2007/2008 (mixture of in-channel and off-channel measurements) and do not support a decreasing time trend for PCBs.

3.1.2 Measurement Results – Dioxin Temporal Trends

Similar to Figures 1 and 2, other diagrams in Attachment 1 are useful for assessing temporal declines in PCB homolog and dioxin/furan congener concentrations in the sediment bed. There is a somewhat higher level of scatter in the organic carbon normalized measurements of 2,3,7,8-TCDD concentrations in the sediment bed as compared to total PCBs which complicates the assessment of the temporal trend in 2,3,7,8-TCDD measurements. In general the decline in the central tendency of the measured in-channel and off-channel 2,3,7,8-TCDD concentrations in the sediment bed between 1995 and 2015 ranges between a factor of two and a factor of ten depending upon location, with the greatest decline occurring in the Lower Passaic River.

3.1.3 Measurement Results – Spatial Gradients

In addition to showing temporal behavior in the sediment bed, diagrams in Attachment 1 analogous to Figures 1 and 2 display spatial gradients in collective in-channel and off-channel PCB homolog and dioxin/furan congener sediment bed concentrations. The measurements presented in Attachment 1A suggest that total PCB levels in the sediment bed of the Harbor, Kills, and lower Newark Bay are often greater than 10,000 ng/g-organic carbon and remain relatively constant in time whereas total PCB concentrations in the sediment bed of Upper Newark Bay and the Lower Passaic River are at or below 10,000 ng/g-organic carbon. For 2,3,7,8-TCDD in the sediment bed, spatial gradients indicated by the diagrams in Attachment 1B suggest 2,3,7,8-TCDD concentrations in the sediment bed of 1000 to 100,000 pg/g-organic carbon in the Lower Passaic River to below 1000 pg/g-organic carbon in the Kills and broader Harbor.

3.2 Measurement and Model Projection Comparison Results

While the post-audit diagrams presented in Attachments 1 and 2 and on Figures 1 and 2 display many measurement results, the primary result of the post-audit diagrams is an assessment of the reliability of the CARP1 model time responses for Harbor water, sediment and biota exposure concentrations for 2002 to 2016 based on readily available measurements. Simultaneous evaluation of sediment bed and water column model reliability is critically important in that a reliable result for one without a reliable result for the other could be indicative of a serious measurement or model problem. The time series of model results and measurements presented in Section 3.2.1 on Figures 1 and 2 for total PCB concentrations in the water column and sediment bed at locations in the Lower Passaic River and Upper Newark Bay are examples of CARP 1 model and measurement comparisons. Other examples of CARP 1 model and measurement comparisons are presented in Section 3.2.2 on Figures 3 and 4 for 2,3,7,8-TCDD concentrations in the water column and sediment bed at locations in the Lower Passaic River and in Newark Bay.

3.2.1 Measurement and Model Projection Comparison Results for Total PCB Concentrations

For the sediment bed, within the limitations of the variability in the available measurements, the model and measurement comparisons presented in the bottom panels of Figures 1 and 2 indicate that the CARP 1 model 1998-2002 calibration and 2003-2016 projections for total PCB concentrations in the sediment bed were reasonably reliable. The model results (green lines and shading) shown on the bottom panels of Figures 1 and 2 indicate that the model results represent the central tendency of collective in-channel and off-channel measurements of sediment bed total PCB concentrations included in the two model grid cells presented throughout the 1995 to 2016 period. Based on what is now known from measurements, the model results would have provided a dredged material manager in 2002 with an appropriate estimate of then future average sediment bed total PCB concentrations for the reach of the Lower Passaic River near mile 1.9 and for Upper Newark Bay for 2003 through 2016 as shown in the bottom panels of Figures 1 and 2.

The collocated total PCB concentrations in the water column from the CARP 1 model 1998-2002 calibration and 2003-2016 projection were also reasonably reliable. For the water column, within the limitations of the large variability in the available measurements, the model (blue line and shading) better estimated the central tendency of water column total PCB measurements at the Lower Passaic River location (Figure 1, top panel) as compared to the Newark Bay location (Figure 2, top panel) where the model slightly overestimated the central tendency of the water column total PCB measurements.

A review of diagrams presented in Attachments 1A and 2A for total PCBs at additional locations shows a similar level of model skill as represented in the Figure 1 and 2 examples. An exception shown in Attachment 1A is a model under-prediction of the measured total PCB concentrations in the sediment bed around the south shore of Shooter's Island at the confluence of Newark Bay and the Kills. This specific result will be discussed subsequently in the context of Figure 5. Individual PCB homolog results for di-CB, tetra-CB, hexa-CB, and octa-CB are also presented in Attachments 1C and 2C as further evidence of model performance. No particular systematic biases were identified in model and measurement agreement results for one homolog as compared to the other homologs.

3.2.2 Measurement and Model Projection Comparison Results for Dioxin Concentrations

Figures 3 and 4 on pages 20 and 21 are examples of comparisons of the CARP 1 model 1998-2002 calibration and 2003-2016 projections for dioxin concentrations in the sediments and the water column of the Harbor for two locations. Comparison results for dioxin for additional locations are presented in Attachments 1B and 2B. Figures 3 and 4 each show collocated 2,3,7,8-TCDD concentration measurements and model results from the water column and sediment bed. Figure 3 shows modeled and measured 2,3,7,8-TCDD concentrations for the Lower Passaic River near mile 1.9. Figure 4 shows modeled and measured 2,3,7,8-TCDD concentrations for the center of Newark Bay, east of the Port Newark and Elizabeth Channels, approximately 3 miles south of the confluence of the mouths of the Lower Passaic and Hackensack Rivers at Kearny Point.

For the sediment bed, within the limitations of the variability in the available measurements, the model and measurement comparisons presented in the bottom panels of Figures 3 and 4 indicate that the CARP 1 model 1998-2002 calibration and 2003-2016 projections for 2,3,7,8-TCDD concentrations in the sediment bed were reasonably reliable. The model results (green lines and shading) shown on the bottom panels of Figures 3 and 4 indicate that the model results represent the general central time trend of collective in-channel (blue dots) and off-channel (red dots) measurements of sediment bed 2,3,7,8-TCDD concentrations included in the two model grid cells presented throughout the 1995 to 2016 period. For the Lower Passaic River mile 1.9 example location (bottom panel, Figure 3), the model does a better job of representing the central tendency of in-channel as compared to off-channel 2,3,7,8-TCDD measurements. While the 2,3,7,8-TCDD model results for the sediment bed of the Lower Passaic River (bottom panel, Figure 3) suggest a possible under-prediction of the 2012 measurements, the model results for the sediment bed of Newark Bay are within the range of the 2014/2015 measurements.

For the water column, within the limitations of the variability in the available measurements, the model and measurement comparisons presented in the top panels of Figures 3 and 4 indicate that the CARP 1 model 1998-2002 calibration and 2003-2016 projections for 2,3,7,8-TCDD concentrations in the water column were reasonably reliable, but are likely underestimates for the most recent years, depending upon what the actual concentrations were for measurements reported as non-detected. At both the Lower Passaic River and Newark Bay example locations (top panels, Figures 3 and 4) the model results (blue lines and shading) slightly underestimate the 2011-2013 measured central tendency which is potentially biased high due to the consideration of a large number of non-detected measurements at the detection limits. The detection limits may be higher than actual concentrations and therefore somewhat inflate estimated means of measured concentrations.

The model and measurements comparison results presented for selected sediment bed locations in the bottom panels of Figures 3 and 4 are comparable to results shown for most other locations in Attachment 1B. A noted exception is the extreme upstream Lower Passaic River where the model results over-predict the measured sediment bed concentrations of 2,3,7,8-TCDD by an order of magnitude.

The water column model and measurement results presented in the top panels of Figures 3 and 4 for 2,3,7,8-TCDD are similar to 2,3,7,8-TCDD results shown for most other locations in Attachment 2B. The water column model results somewhat under-predict the central tendency of the measurements for 2011-2013; however the central tendency of the measurements may be biased high by a large number of measurements reported as non-detected, especially considering that 2008 measurements are lower at some locations.

Diagrams in Attachments 1D and 2D display sediment bed and water column model and measurement results for 2,3,4,7,8-PCDF which are similar to results for 2,3,7,8-TCDD.

3.3 Measurement and Model Projection Comparisons Summary Statistical Results

Tables 2 and 3 and Figures 6 and 7 provide statistical and visual summaries of the measurement and model projection results for total PCBs and 2,3,7,8-TCDD. As indicated in Table 2 for total PCBs, when considering in-channel and off-channel results together, the CARP 1 projection model bias is less than a factor of two (i.e., less than ±0.3 log units) in all Harbor areas and model precision is within a factor three (i.e., less than 0.5 log units) as compared to measurements for eight out of nine areas. Similarly, as indicated in Table 3 for 2,3,7,8-TCDD, with the exception of the upper reach of the Lower Passaic River and the Kill van Kull, the CARP 1 projection model bias is less than a factor of two (i.e., less than ±0.3 log units) in all Harbor areas and model precision approaches a factor three (i.e., 0.5 log units) as compared to measurements for most of the Harbor areas when considering in-channel and off-channel results together. Neither the in-channel nor the off-channel results are predominantly more favorable across all locations for either PCBs or for 2,3,7,8-TCDD.

4.0 DISCUSSION

The post-audit evaluation yielded both measurement results and model reliability results. Both types of results are discussed further below. Also discussed below are the implications of the results for HARS suitability determinations.

4.1 Interpretation of Measurement Results

The measurement results indicate a high degree of variability in organic carbon normalized PCB and dioxin/furan concentrations in the sediment bed within the spatial resolution of a CARP 1 model grid cell. This is evident on Figure 1 through Figure 7 and in the diagrams included in Attachment 1. Some, but not all, of the observed measurement variability is likely caused by variations across sampling programs such as differences in sample collection, handling, and processing and uncertainties in analytical chemistry results associated with differences in analytical methods and laboratory-specific performance. During

CARP 2, observed measurement variability may be mitigated in part by evaluating sediment bed measurements for smaller reaches than CARP 1 model grid cells, at depth resolution less than the top 15 cm, and at higher frequency than annually.

The observed measurement variability somewhat hindered the interpretation of measured spatial and temporal trends in organic carbon normalized PCB and dioxin/furan concentrations. Despite the variation in the measurements, the observed regional spatial gradients in central tendency of organic carbon normalized PCB and dioxin/furan concentrations in the sediment bed are consistent with known loading sources. Higher PCB concentrations observed in the sediment bed of southern Newark Bay and broader Harbor areas as compared to lower PCB concentrations observed in northern Newark Bay and the Lower Passaic River are consistent with the known Upper Hudson River PCB source. Similarly, the decline in measured dioxin and furan concentrations moving away from the Lower Passaic River is consistent with the known dioxin source on the Lower Passaic River.

More relevant for future dredged material management is that the high degree of measurement variability did not obscure declines in the central tendency of contaminant levels in the sediment bed from the mid-1990's to early/mid 2010's. Measured declines in contaminant levels were highly location specific and more prominent for dioxin/furans (up to an order of magnitude) as compared to PCBs (up to a factor of 3), perhaps indicative of relatively more ongoing PCB sources as compared to dioxin/furans and/or greater particle association and more rapid burial of dioxin/furans as compared to PCBs. Measured declining trends were not continuous in all cases and included signs of intra-annual oscillations.

The post-audit diagrams were constructed to distinguish between in-channel and off-channel measurements. For most locations, there is a high degree of overlap between the two types of measurements suggesting that there is not a clear line of evidence necessitating that the CARP 2 model grid should include segmentation separately resolving in-channel and off-channel locations. Conceptually, similarities and differences observed for measured contaminant concentrations for proximal in-channel and off-channel sediment bed measurements would depend upon whether or not or when an area was recently dredged. It would be expected that measured in-channel and off-channel sediment bed contaminant concentrations are more similar to each other for areas of the Harbor not recently subject to maintenance dredging, such as the Lower Passaic River, as compared to areas with active maintenance dredging, such as Newark Bay. This expectation, however, does not appear to hold true based upon the available measurements obtained for post-audit purposes.

4.2 Interpretation of Measurement and Model Projection Comparison Results

The model and measurement comparisons in Figures 1 through 7 and throughout Attachments 1 and 2 indicate that while the CARP 1 model results for PCBs and dioxin/furan are reasonable within the uncertainty of the measurements, there is the potential for improvement during CARP2 modeling. Specifically, use of actual rather than CARP 1 approximated meteorological conditions and hydrographs for loading sources during CARP 2 may better represent some of the temporal oscillations in water column measurements such as increases between the later 2000's and early 2010's. Further CARP 2 use of actual hydrographs for loadings may remedy CARP 1 model general water column under-predictions as well as isolated model over-predictions. Similarly, especially for purposes of the sediment bed, a more spatially resolved CARP 2 model segmentation would better focus measurement-based targets for specific CARP 2 model grid cells and reduce the spatial extent of averaging for model mass balance calculations. Computational grid spatial improvements for consideration during CARP 2 modeling include longitudinal, lateral, and vertical.

One clear example for CARP 2 model grid improvement where there is a clear mismatch between model grid resolution and the available measurements occurs in the vicinity of Shooter's Island at the southern end of Newark Bay and the confluence with the Kill van Kull. The mismatch between the available measurements and the CARP 1 model grid is shown in the map diagram presented in Figure 5 on page 22. All of the measurements were collected in the channel south of the Island; however, model results are calculated as average concentrations in both channels surrounding the Island. Figure 5 also shows the alignment of the CARP model grid with the in-channel and off-channel measurements in additional segments in the Kill van Kull. Similar map diagrams, for all of the model grid cells for which model and measurement comparisons in the sediment bed were made, are included on each page of Attachment 1.

The majority of decision-making for CARP 2 measurement collection and model adjustments will necessarily be made by considering location specific results, such as those discussed for Shooter's Island, as presented on the various individual diagrams in the attachments and on Figures 1 through 5. Area averaged statistical results as shown on Tables 2 and 3 and Figures 6 and 7 are however useful for establishing a baseline of model performance for model projections which can be used to readily demonstrate effectiveness of future model adjustments completed during CARP 2. Having all locations shown in a single table or on a single page of diagrams with quantitative metrics for bias and precision will facilitate demonstrating that new CARP 2 model modifications improve model bias and model precision.

The post-audit model and measurement statistical results for model bias and model precision, factors of two and three, obtained for the CARP 1 model projections made in 2002 and now shown in Tables 2 and 3 and Figures 6 and 7 along with measurements collected since CARP 1 are not dissimilar from the original calibration display metrics accepted by the Model Evaluation Group for the CARP 1 model calibration. The CARP 1 model calibration display metrics were factors of two, three, five, and ten based on 10-day averaged model results at the resolution of a model grid cell and spatially and temporally discrete measurements. As evidenced by the statistical results, one goal of CARP 2 modeling will be to close-in on bias and precision in areas such as the upper reach of the Lower Passaic River and off-channel areas around the broader NY/NJ Harbor area where CARP 1 projection model results show the least precision when compared to measurements that became available after CARP 1 was completed.

<u>4.3 Post-Audit Results and HARS Suitability Conclusions</u>

The reliability of the CARP 1 model results for 2002 to 2016 has been tested by comparing field measurements from 2002 to 2016 to the original CARP 1 model projections developed in 2002 through preparation and visual inspection of time series plots of measured and model calculated contaminant concentrations for various locations in the Harbor. Further testing included regional statistical comparisons. Results and discussion of this testing has been provided herein. A further practical consideration is whether or not the measurements recently obtained for the post-audit evaluation contradict conclusions concerning HARS suitability previously reached based on CARP 1 measurements and model results.

During CARP 1, HARS suitability endpoints for the sediment bed were established and are presented in the CARP matrix spreadsheet tool as 0.0192 ppb for dioxin and 75 to 100 ppb for PCBs (depending on location specific homolog distributions) on a solids normalized, not an organic carbon normalized, basis. The tissue-based criteria and BSAF assumptions underlying these previously established CARP 1 sediment bed endpoints are described in Section 13 of HydroQual, 2008. Post-audit measurements of dioxin and PCB concentrations were screened against the CARP 1 HARS suitability endpoints. In the case of PCB's, the post-audit measurements support the previous conclusions reached with CARP 1 model results that sediments in the Hackensack, portions of the Lower Passaic, Newark Bay, Kills and much of the broader Harbor would not be HARS suitable today. This comparison provides an additional line of evidence regarding the reliability of CARP 1 model projections. In the case of dioxin, some of the post-audit measurements in mostly off-channel areas of the Arthur Kill and Kill van Kull are above 0.0192 ppb and are therefore non-HARS suitable, contrary to CARP 1 model predictions which suggested attainment in these waterways. This finding further underscores the need for CARP 2 modeling to address model grid representation of the Kills and actual rather than estimated meteorological conditions and hydrographs for all loading sources. Sediment model and measurement diagrams in solids normalized units useful for HARS suitability discussion are provided in Attachment 3 starting on page 161.

5.0 CONCLUSION

While the post-audit evaluation has demonstrated that CARP 1 model projections of contaminant concentrations in Harbor water and bed sediments are still largely valid based on the central tendency of measurements that have since been collected and compiled for post-audit evaluation purposes, there is a wide range of variability in the measurements. The variability in the measurements necessitates modifications to the modeling approach in CARP 2, specifically, the need for smaller lateral and longitudinal model grid segmentation, higher temporal frequency of model outputs, actual rather than estimated hydrographs and meteorological conditions, and better matching of the depth of the modeled bed active layers (ten 1 cm layers in CARP 1) with the depth represented by the available measurements in the active bed (top 15 cm). The CARP 1 model reproduces the relatively slow measured time responses of Harbor contaminant levels over twenty years, but cannot capture all of the variations in the measurements for a given year. A goal of the CARP 2 model will be to represent or explain more of the observed variation.

6.0 NEXT STEPS

As the post-audit evaluation represents an initial screening exercise to inform model refinements while additional CARP 2–specific measurement collection is underway, there are numerous next steps, many of which are formally documented as tasks in the CARP 2 project agreement with the NJDOT Research Bureau.

Consistent with project scope, additional modeling work has been initiated in year 1 for completion and reporting during year 2. The additional modeling work in-progress includes: updates to loading hydrographs and meteorological conditions in the CARP 1 hydrodynamic model inputs files for 2002-2016; running of the CARP 1 hydrodynamic model with the updated inputs; updates to the sediment transport and organic carbon model loading inputs based on the new hydrographs for 2002-2016; and running of the CARP 1 sediment transport and organic carbon production model with the updated hydrographs. A follow-on will be to carry the input updates through to the CARP 1 contaminant fate model and make an assessment of resulting changes to post-audit evaluation results. From that point, no further work will be conducted with the CARP 1 models per se, rather the focus will shift to refinements and calibration/validation of the CARP 2 models.

The measurements compiled during the post-audit evaluation along with measurements being collected for CARP 2 and measurements from the dredged material testing program obtained and compiled by the Hudson River Foundation will be used to make decisions for CARP 2 model refinements and will provide targets for calibrating/validating the CARP 2 models. In particular future consideration of the dredged material testing program data and measurements being collected for CARP 2 may provide a greater understanding of contaminant concentration differences observed at proximal in-channel and off-channel sediment bed locations that would guide CARP 2 modeling.

CARP 2 model refinements will also include updates to loading source concentrations based on newer available measurements. An example of a necessary refinement to CARP 2 loadings pertains to atmospheric deposition. Deposition fluxes published by NJADN in 2004 for NJDEP (Reinfelder et al., 2004) differ from and supersede deposition fluxes developed by NJADN for the Hudson River Foundation in 2001 and used in CARP 1 modeling. CARP 2 model atmospheric deposition loadings will be updated based on the 2004 report.

7.0 ACKNOWLEDGMENTS AND DISCLAIMERS

The post audit evaluation of the CARP1 model 2040 projections was funded by basic agreement number 2016-MU-1 between the New Jersey Department of Transportation (NJDOT) and Monmouth University. The content of this report is solely the positions of the authors and not the positions of NJDOT and therefore does not constitute a standard, specification or regulation.

8.0 LITERATURE CITED

DiToro, D.M., C.S. Zarba, D.J. Hansen, W.J. Berry, R.C. Swartz, C.E. Cowan, S.P. Pavlou, H.E. Allen, N.A. Thomas, and P.R. Paquin. 1991. Technical basis for establishing sediment quality criteria for nonionic organic chemicals using equilibrium partitioning. *Environ. Toxicol. Chem*. 10(12): 1541-1583.

HydroQual, Inc. (2007a). A Model for the Evaluation and Management of Contaminants of Concern in Water, Sediment, and Biota in the NY/NJ Harbor Estuary: Hydrodynamic Sub-model, Final Report, Submitted to the Hudson River Foundation, New York, NY. (http://www.carpweb.org/main.html).

HydroQual, Inc. (2007b). A Model for the Evaluation and Management of Contaminants of Concern in Water, Sediment, and Biota in the NY/NJ Harbor Estuary: Sediment Transport/Organic Carbon Production, Final Report, Submitted to the Hudson River Foundation, New York, NY. (http://www.carpweb.org/main.html).

HydroQual, Inc. (2008). A Model for the Evaluation and Management of Contaminants of Concern in Water, Sediment, and Biota in the NY/NJ Harbor Estuary: Contaminant Fate and Transport and Bioaccumulation Sub-models, Final Report, Submitted to the Hudson River Foundation, New York, NY. (http://www.carpweb.org/main.html).

Reinfelder, J.R., L.A. Totten, and S.J. Eisenreich, 2004. The New Jersey Atmospheric Deposition Network (NJADN). Final Report to the New Jersey Department of Environmental Protection.

Tables

Table 1. Databases Included in Post-Audit Evaluation Diagrams	
SOURCE[1]	DATABASE NAME IN SOURCE
Water Column	
HDR	CARP
NOAA	Passaic CPG CWCM Sampling High Flow 1/2 2013
NOAA	Passaic CPG CWCM Sampling Low Flow Rounds 2-5-2013
NOAA	Passaic CPG CWCM Sampling Round 1 2011
HRF	2011-2013 LBG Newark Bay CWCM Split Sample
NOAA	2008 USEPA-MPI CSO/SWO Large Volume
Sediment	
HRF	2013 EPA-DESA Post Hurricane Sandy Grab
NOAA	Berry's Creek NJMC Fishery Resource Invertebrate Sediment 2003
NOAA	CARP Sediment Ambient Study 1998-1999
NOAA	CARP Sediment Track-down Study 2000-2001
NOAA	EPA REMAP NY/NJ Harbor 1998
NOAA	Gowanus Canal EPA Ph3 Remedial Invest 2005-06, 2010
NOAA	Hackensack River RI 2006
NOAA	Hackensack River Sampling January 2008
NOAA	Minish Park Monitoring EPA 1999-2000
NOAA	New York DEC 2000 Sediment Data – Atlantic Region
NOAA	New York DEC 2001 Sediment Data – Atlantic Region
NOAA	Newark Bay Elizabeth Channel EPA 1998
NOAA	Newark Bay Reach A EPA 1996
NOAA	Newark Bay Reach B,C,D EPA 1997
NOAA	Newark Bay Sediment Chemistry 2014
NOAA	Newark Bay Toxicity and Bioaccumulation Sept 2015
NOAA	Outfall Sampling Program EPA 1997
NOAA	Passaic CPG Background Sediment & Toxicity 2012
NOAA	Passaic CPG Benthic Sediment 2009
NOAA	Passaic CPG Benthic Sediment 2009 MPI Oversight
NOAA	Passaic CPG Benthic Sediment 2010
NOAA	Passaic CPG Benthic Sediment 2010 EPA Oversight
NOAA	Passaic CPG Low Res Core 2008
NOAA	Passaic CPG Low Res Core Supplemental 2 2013
NOAA	Passaic CPG Low Res Core Supplemental 2012
NOAA	Passaic CPG Mile 10.9 Sediment 2011
NOAA	Passaic CPG Mile 10.9 Sediment 2012
NOAA	Passaic EPA Eco Risk 1999
NOAA	Passaic EPA Eco Risk 2000
NOAA	Passaic EPA-MPI Dundee Dam High Res Core 2007
NOAA	Passaic EPA-MPI EMBM 2007-08
NOAA	Passaic EPA-MPI Dundee Dam High Res Core 2005
NOAA	Passaic Newark Bay RI Phase 1 2005
NOAA	Passaic Newark Bay RI Phase 1 2005 MPI Oversight
NOAA	Passaic Newark Bay RI Phase 2 2007
NOAA	Passaic RI EPA 1995
NOAA	Passaic RI EPA 1995 Maxus Supplemental
NOAA	Passaic RI EPA 1995 Near-shore Supplemental
NOAA	Preliminary Toxicity Identification 1999
NOAA	Sediment Grab Sampling EPA 1995
NOAA	Toxicity Identification Evaluation 2000

[1]Source Notes:
HDR – from CARP 1 archives at HDR
NOAA – from NOAA's online Diver Explorer tool for the northeast region, https://www.diver.orr.noaa.gov/web/guest/diver-explorer?siteid=5&subtitle=Northeast
HRF – from USEPA Region 2 transmittal to the Hudson River Foundation

Table 2. Statistical Summary of Model Performance[1] for Total PCBs[2,3]									
	MODEL GRID CELLS			IN-CHANNEL ONLY			OFF-CHANNEL ONLY		
LOCATIONS	COUNT	BIAS	PRECISION	COUNT	BIAS	PRECISION	COUNT	BIAS	PRECISION
a - Lower Passaic upper reach	64	0.25	0.38	28	0.34	0.49	36	0.18	0.30
b - Lower Passaic middle reach	307	0.00	0.36	131	0.26	0.34	176	-0.18	0.38
c - Lower Passaic lower reach	107	0.11	0.30	69	0.02	0.21	38	0.26	0.45
d - Newark Bay north reach	80	0.29	0.30	26	0.22	0.09	54	0.33	0.39
e - Newark Bay south reach	63	0.17	0.26	23	0.10	0.16	40	0.21	0.33
f - Kill van Kull	13	-0.16	0.21	6	-0.30	0.40	7	-0.04	0.05
g - Arthur Kill north reach	16	0.13	0.25	5	0.09	0.13	11	0.15	0.30
h - Arthur Kill south reach	7	0.14	0.17				7	0.14	0.17
i - Others	72	0.14	0.69				72	0.14	0.69
All (a thru i)	729	0.10	0.36	288	0.18	0.28	441	0.05	0.42
All (c thru i)	358	0.16	0.36	129	0.06	0.18	229	0.21	0.46

Notes:

[1]Model performance results for bias and precision are presented as log values. Model bias is calculated as the average difference between modeled and measured. A bias value of 0 represents no model bias. A bias value of -0.3 represents an average factor of two under-prediction by the model. A bias value of 0.3 represents an average factor of two over-prediction by the model. Model precision is calculated as the sum of the squares of the residuals divided by the count. A precision value of 0 represents perfect agreement between the model and the measurements. A precision value of 0.3 represents a factor of two agreement between the model and the measurements. A precision value of 0.5 represents a factor of three agreement between the model and the measurements.

[2]Model performance results for total PCBs are presented on an organic carbon normalized basis.

[3]Model output for the summation of the four homologs, di-CB, tetra-CB, hexa-CB, and octa-CB is doubled to approximate Total PCBs

Table 3. Statistical Summary of Model Performance[1] for 2,3,7,8-TCDD[2]

LOCATIONS	MODEL GRID CELLS			IN-CHANNEL ONLY			OFF-CHANNEL ONLY		
	COUNT	BIAS	PRECISION	COUNT	BIAS	PRECISION	COUNT	BIAS	PRECISION
a - Lower Passaic upper reach	106	0.86	1.04	45	1.07	1.28	61	0.70	0.86
b - Lower Passaic middle reach	362	-0.06	0.53	134	0.24	0.49	228	-0.24	0.56
c - Lower Passaic lower reach	168	-0.19	0.37	66	-0.18	0.46	102	-0.19	0.31
d - Newark Bay north reach	131	-0.11	0.33	35	-0.09	0.24	96	-0.12	0.36
e - Newark Bay south reach	86	-0.18	0.46	23	-0.20	0.32	63	-0.17	0.51
f - Kill van Kull	20	-0.35	0.54	6	-0.49	0.56	14	-0.29	0.54
g - Arthur Kill north reach	21	-0.23	0.56	5	-0.22	0.44	16	-0.23	0.60
h - Arthur Kill south reach	6	0.14	0.29				6	0.14	0.29
i - Others	34	-0.25	0.64				34	-0.25	0.64
All (a thru i)	934	-0.01	0.53	314	0.18	0.56	620	-0.11	0.52
All (c thru i)	466	-0.17	0.41	135	-0.18	0.38	331	-0.17	0.42

Notes:
[1]Model performance results for bias and precision are presented as log values. Model bias is calculated as the average difference between modeled and measured. A bias value of 0 represents no model bias. A bias value of -0.3 represents an average factor of two under-prediction by the model. A bias value of 0.3 represents an average factor of two over-prediction by the model. Model precision is calculated as the sum of the squares of the residuals divided by the count. A precision value of 0 represents perfect agreement between the model and the measurements. A precision value of 0.3 represents a factor of two agreement between the model and the measurements. A precision value of 0.5 represents a factor of three agreement between the model and the measurements.
[2]Model performance results for 2,3,7,8-TCDD are presented on an organic carbon normalized basis.

FIGURES

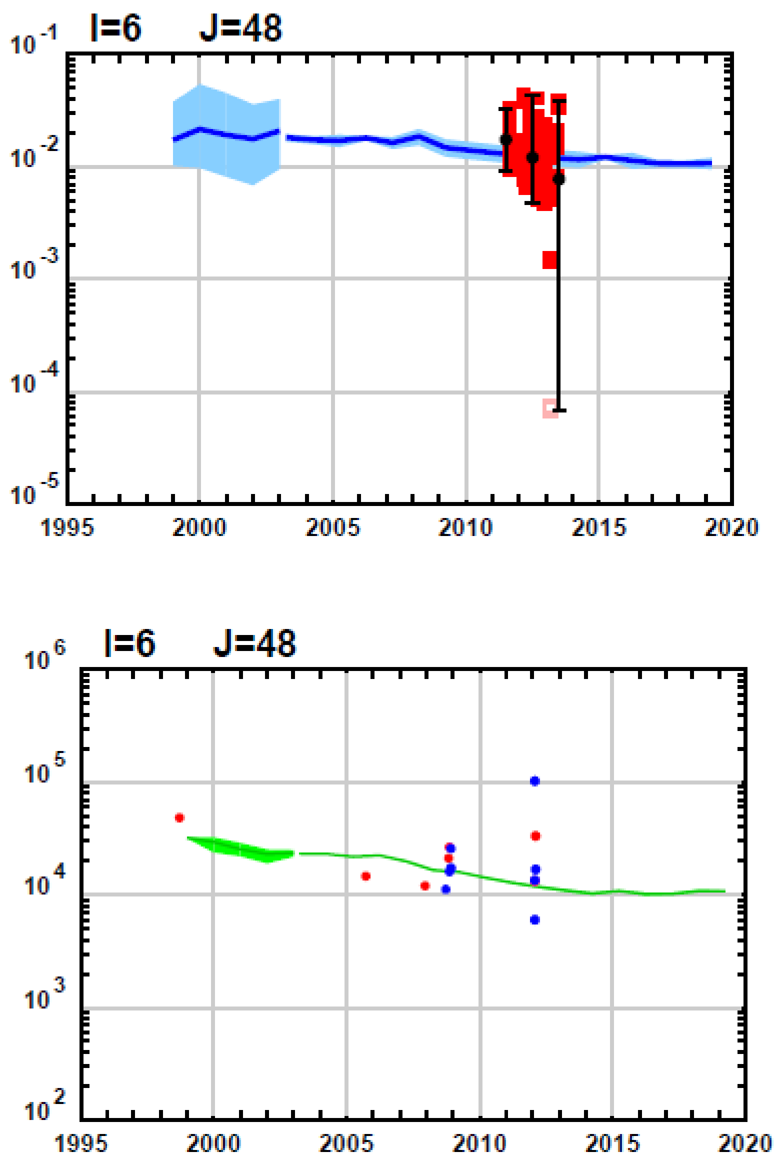


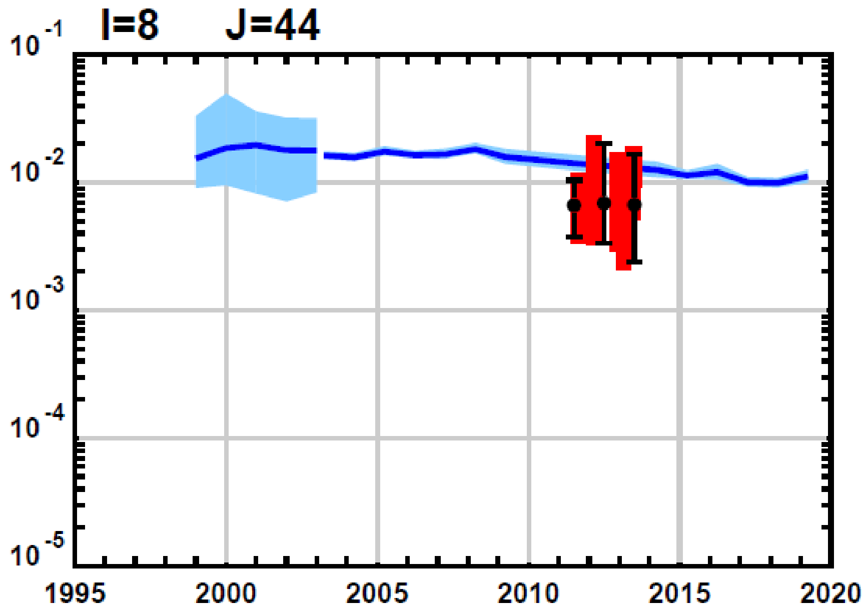
Figure 1. Time series diagrams of measured and modeled total PCB concentrations in the water column (top panel, ug/L) and sediment bed (bottom panel, ng/g-organic carbon) for Lower Passaic River mile 1.9.

For the water column, filled squares are discrete measurements also represented with black mean and range bars. The blue line is the depth averaged model result. The blue shading is the modeled range in depth layer averages.

For the sediment bed, blue circles represent in-channel and red circles represent off-channel measurements in the top 15 cm. The green line is the modeled average for the top 10 cm. The green shading is the modeled range in depth layer averages.

All non-detected measurements plotted with an open symbol at the detection limit.

10-day model averaging prior to 2003, annual averaging thereafter.



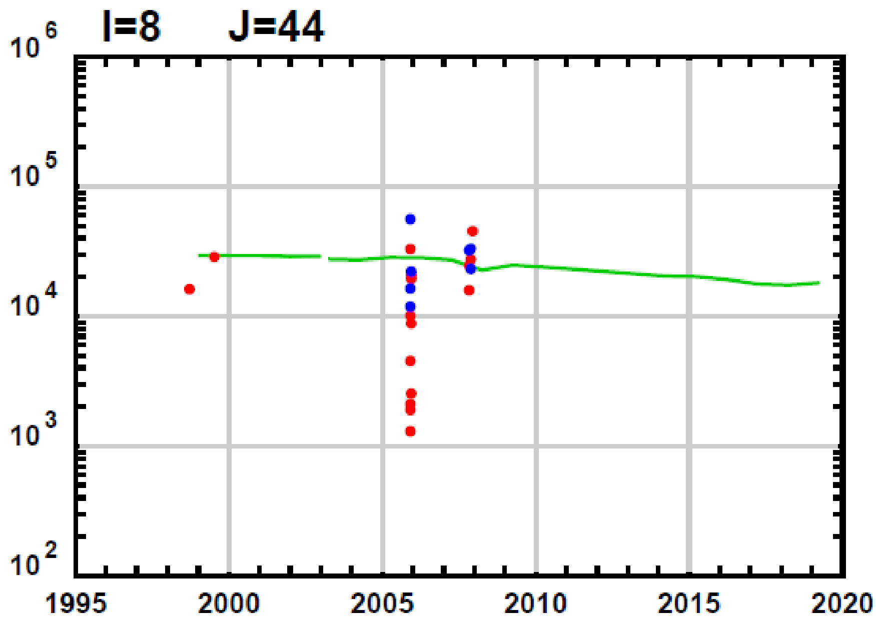
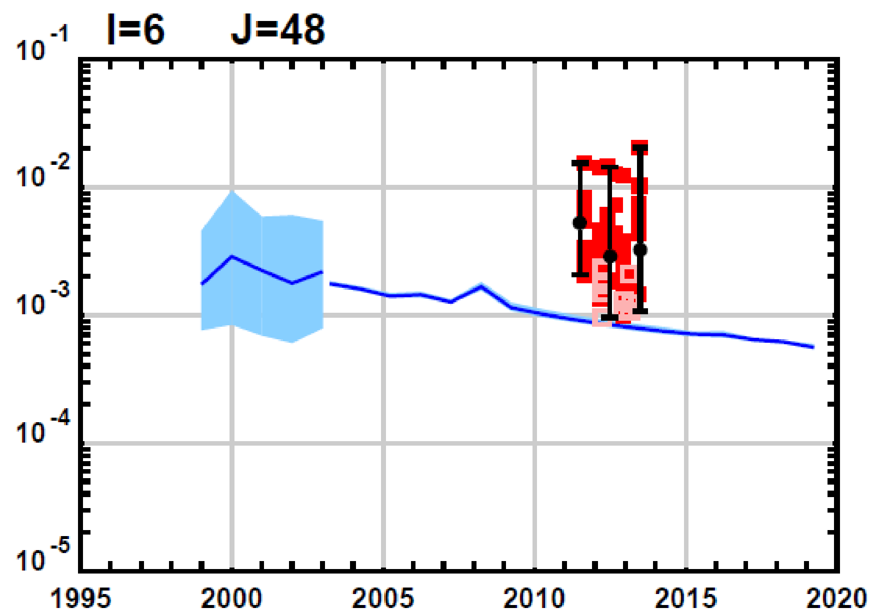


Figure 2. Time series diagrams of measured and modeled total PCB concentrations in the water column (top panel, ug/L) and sediment bed (bottom panel, ng/g-organic carbon) for Upper Newark Bay, just upstream of the confluence with the Port Newark Channel.
For the water column, filled squares are discrete measurements also represented with black mean and range bars. The blue line is the depth averaged model result. The blue shading is the modeled range in depth layer averages.
For the sediment bed, blue circles represent in-channel and red circles represent off-channel measurements in the top 15 cm. The green line is the modeled average for the top 10 cm. The green shading is the modeled range in depth layer averages.
All non-detected measurements plotted with an open symbol at the detection limit.
10-day model averaging prior to 2003, annual averaging thereafter.



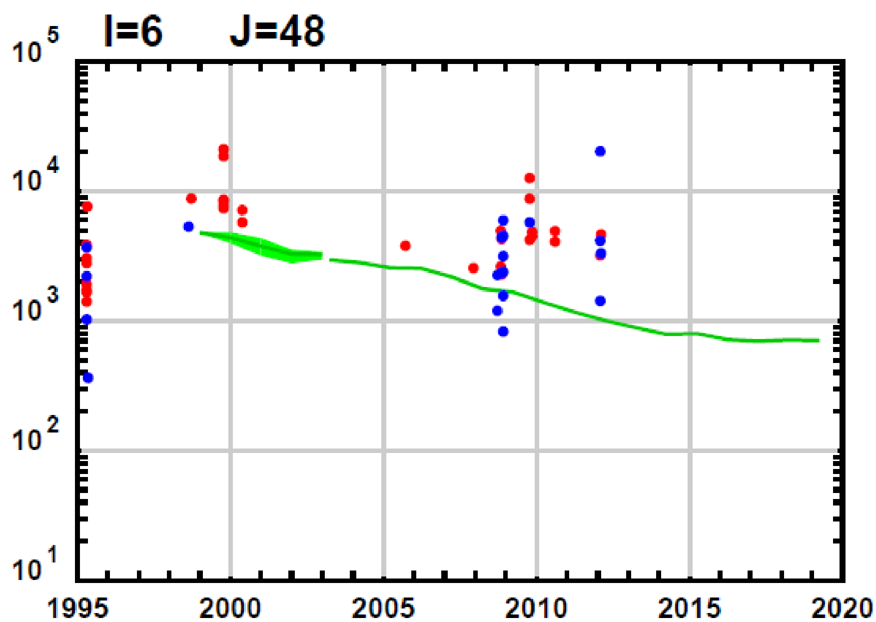


Figure 3. Time series diagrams of measured and modeled 2,3,7,8-TCDD concentrations in the water column (top panel, ng/L) and sediment bed (bottom panel, pg/g-organic carbon) for Lower Passaic River mile 1.9.
For the water column, filled squares are discrete measurements also represented with black mean and range bars. The blue line is the depth averaged model result. The blue shading is the modeled range in depth layer averages.
For the sediment bed, blue circles represent in-channel and red circles represent off-channel measurements in the top 15 cm. The green line is the modeled average for the top 10 cm. The green shading is the modeled range in depth layer averages.
All non-detected measurements plotted with an open symbol at the detection limit.
10-day model averaging prior to 2003, annual averaging thereafter.

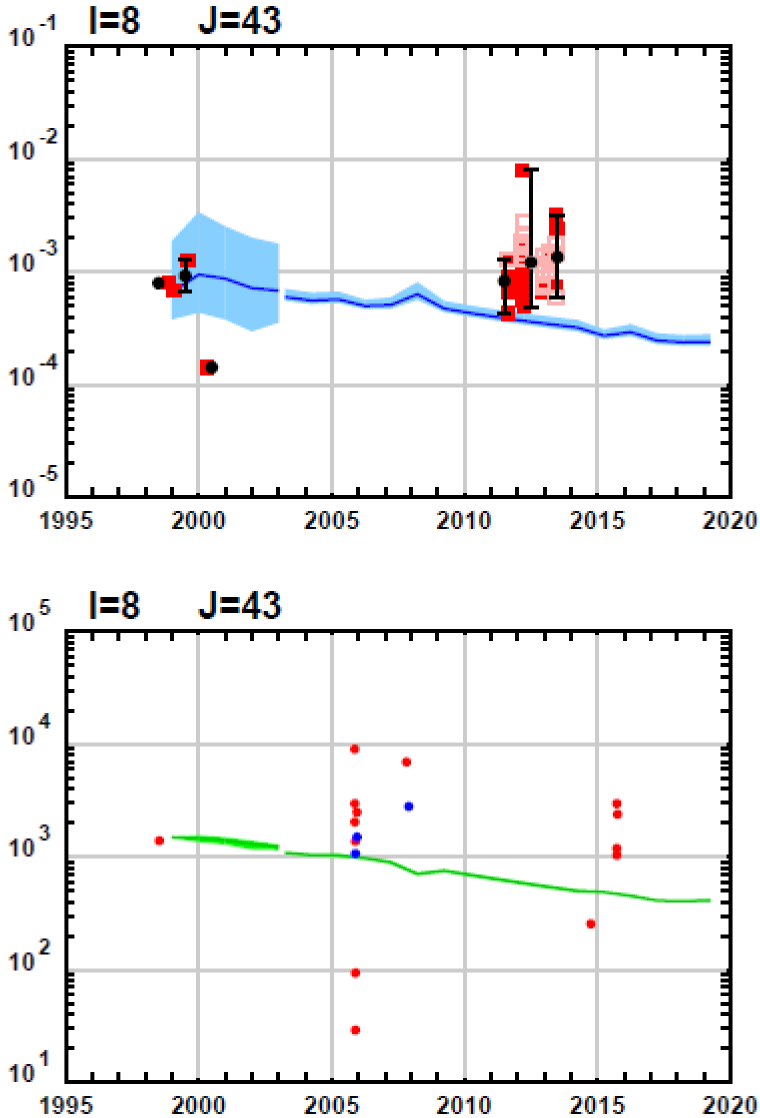


Figure 4. Time series diagrams of measured and modeled 2,3,7,8-TCDD concentrations in the water column (top panel, ng/L) and sediment bed (bottom panel, pg/g-organic carbon) for central Newark Bay, east of the Port Newark and Elizabeth Channels and three miles south of Kearny Point.
For the water column, filled squares are discrete measurements also represented with black mean and range bars. The blue line is the depth averaged model result. The blue shading is the modeled range in depth layer averages.
For the sediment bed, blue circles represent in-channel and red circles represent off-channel measurements in the top 15 cm. The green line is the modeled average for the top 10 cm. The green shading is the modeled range in depth layer averages.
All non-detected measurements plotted with an open symbol at the detection limit.
10-day model averaging prior to 2003, annual averaging thereafter.

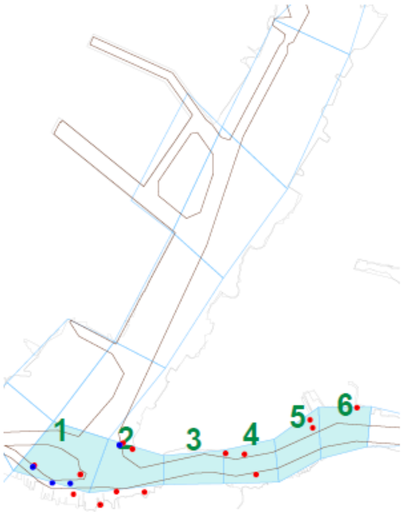


Figure 5. CARP 1 model grid in the vicinity of the confluence of Newark Bay and the Arthur Kill. Highlighted model grid cell 1 covers Shooter's Island as well as the channels north and south of the Island. Model results for model grid cell 1 are calculated as average concentrations over the entire surface area and volume. Inconsistent with the model segmentation, in-channel (blue symbols) and off-channel (red symbols) measurements are all located south of Shooter's Island. Highlighted model grid cells 2 through 5 illustrate the spatial relationship between the channel in the Arthur Kill and off-channel (red symbols) measurements.

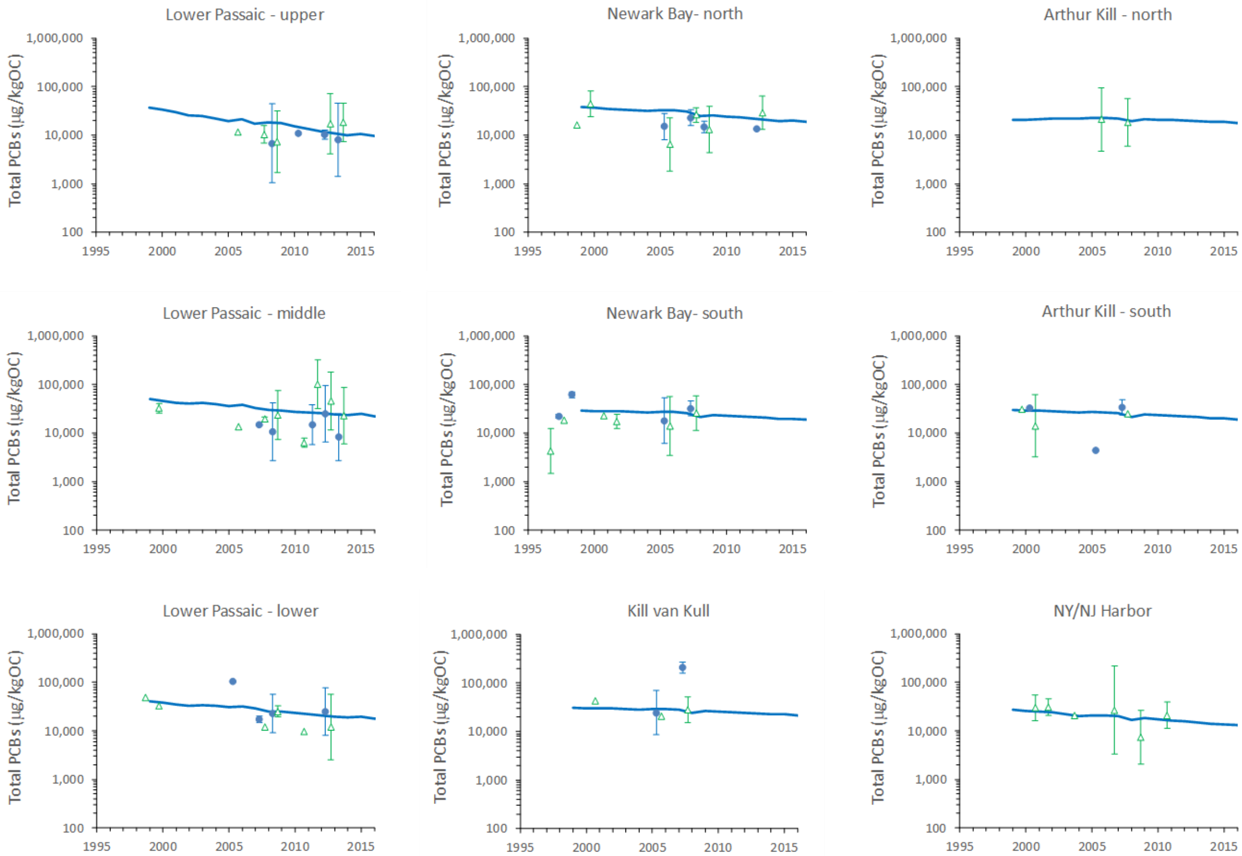


Figure 6. Time series diagrams of measured and modeled Total PCB concentrations in the sediment bed for nine regions of the Harbor where each region represents six model grid cells. Blue circles represent in-channel and green triangles represent off-channel measurements in the top 15 cm. Blue and green bars represent measurement standard deviations. All non-detected measurements were omitted. All measurements from cores not including the surface of the sediment bed were omitted. The blue line shows the modeled annual averages for the top 10 cm averaged across six model grid cells in each region.

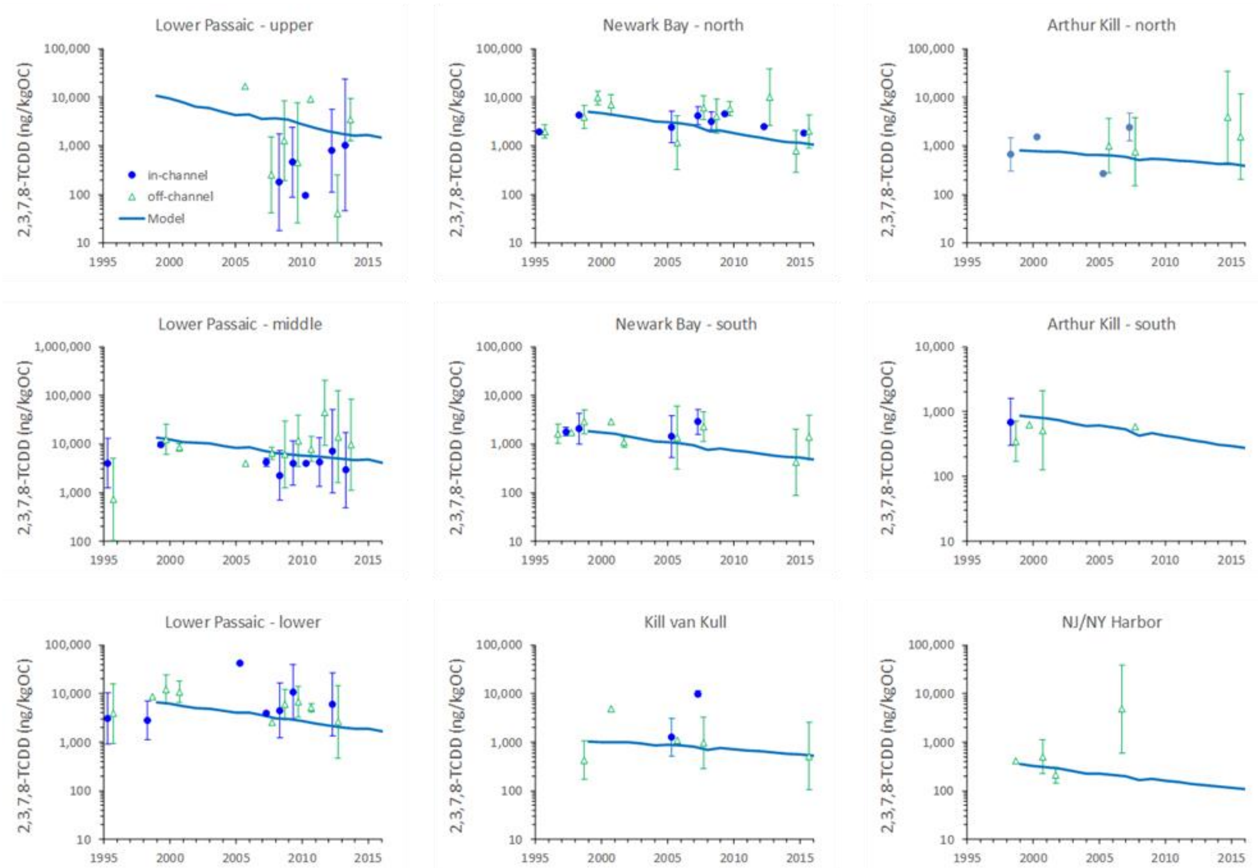


Figure 7. Time series diagrams of measured and modeled 2,3,7,8-TCDD concentrations in the sediment bed for nine regions of the Harbor where each region represents six model grid cells. Blue circles represent in-channel and green triangles represent off-channel measurements in the top 15 cm. Blue and green bars represent measurement standard deviations. All non-detected measurements were omitted. All measurements from cores not including the surface of the sediment bed were omitted. The blue line shows the modeled annual averages for the top 10 cm averaged across six model grid cells in each region.

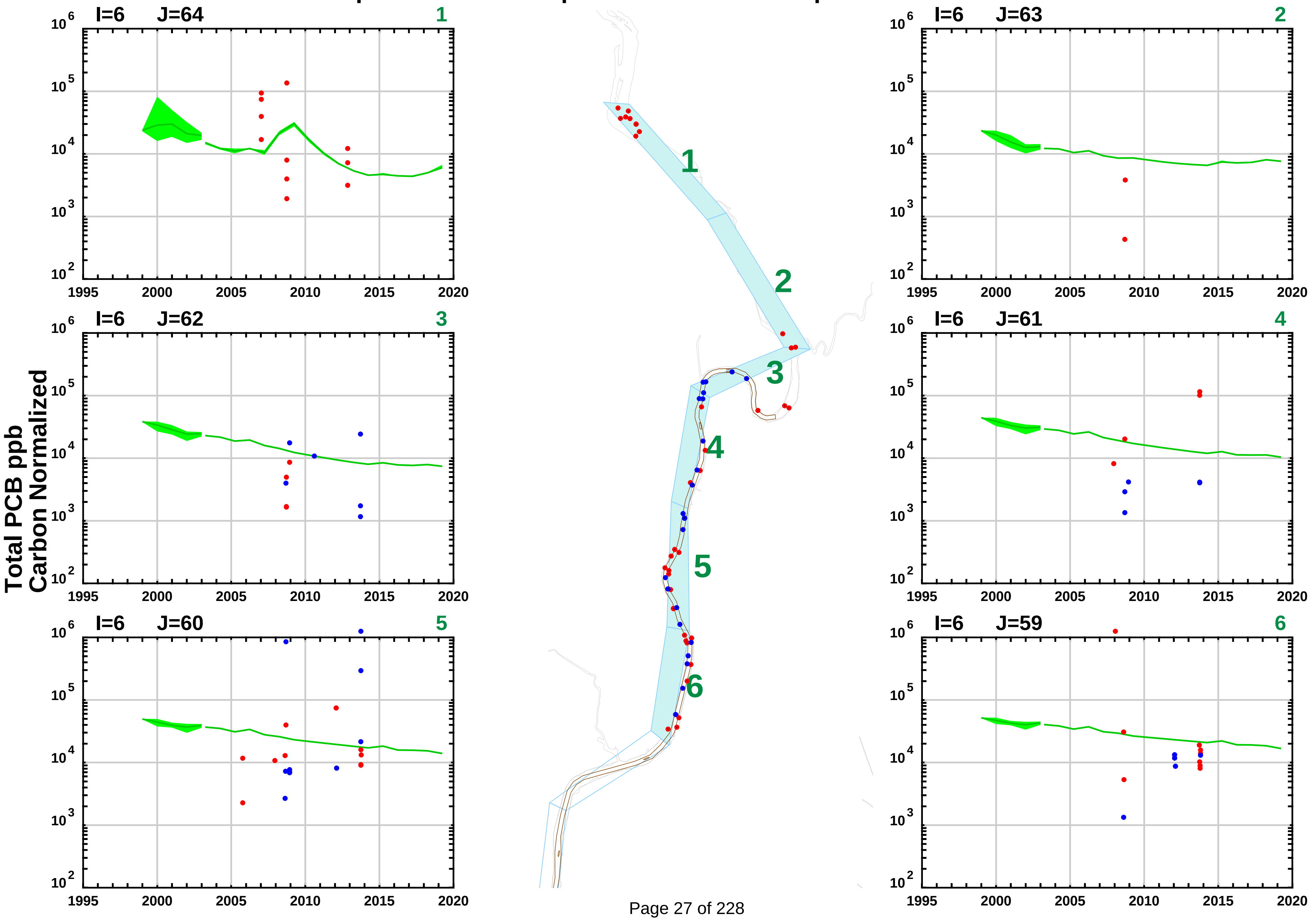
ATTACHMENT 1

SEDIMENT DIAGRAMS, ORGANIC CARBON NORMALIZED

Attachment 1A, Total PCBs
Attachment 1B, 2,3,7,8-TCDD
Attachment 1C, PCB homologs
Attachment 1D, 2,3,4,7,8-PCDF

Attachment 1A, Total PCBs

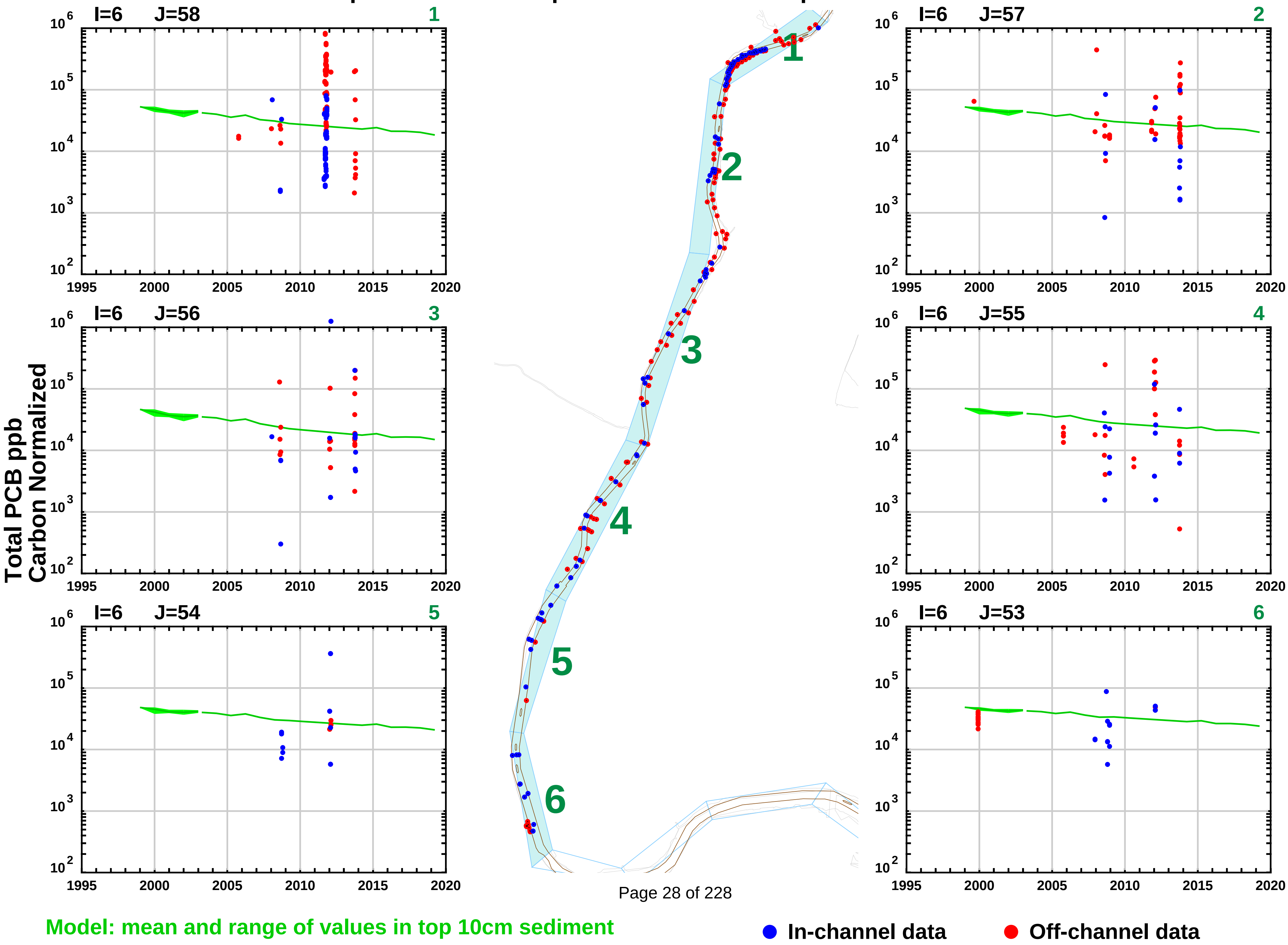
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

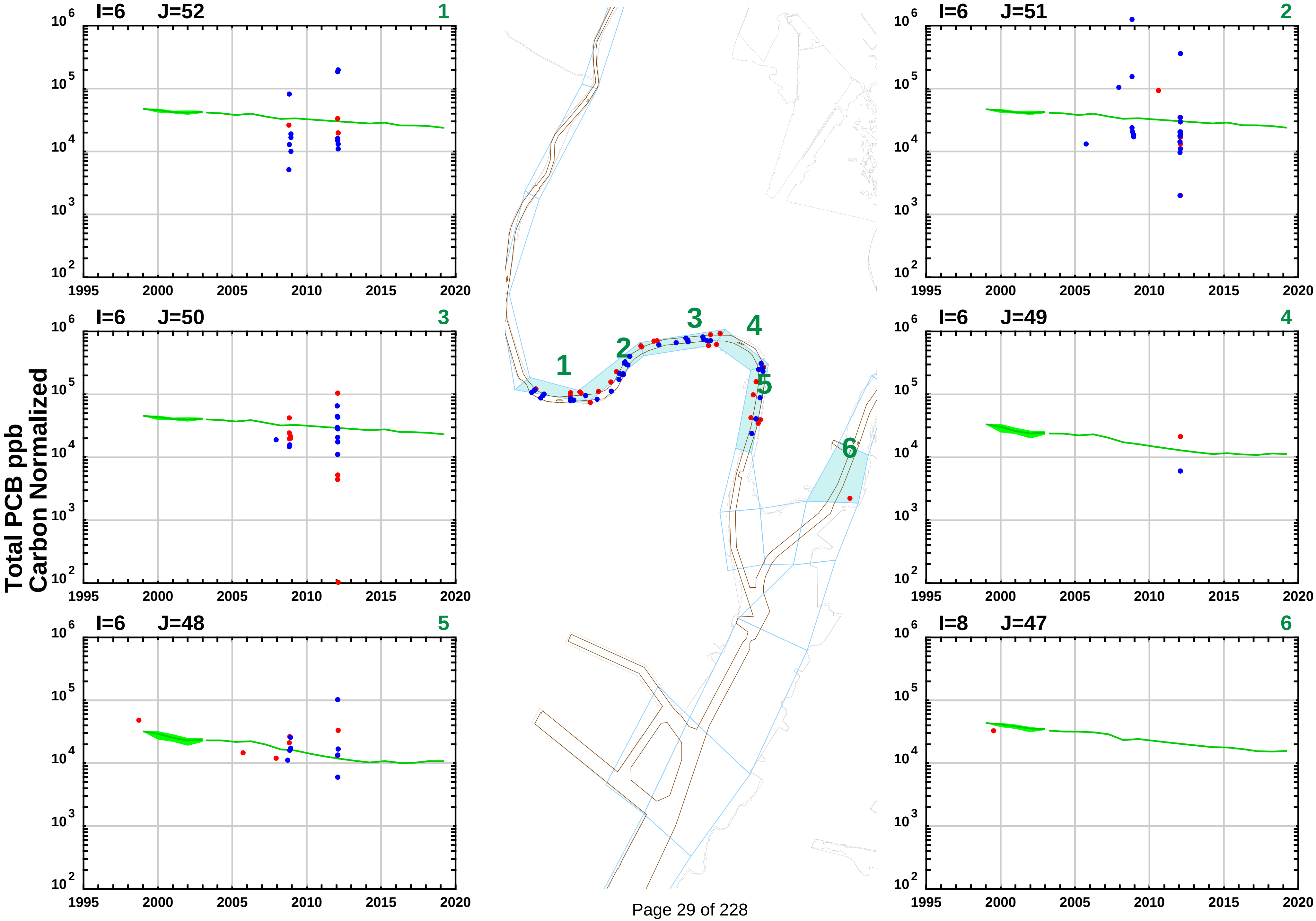
In-channel data Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

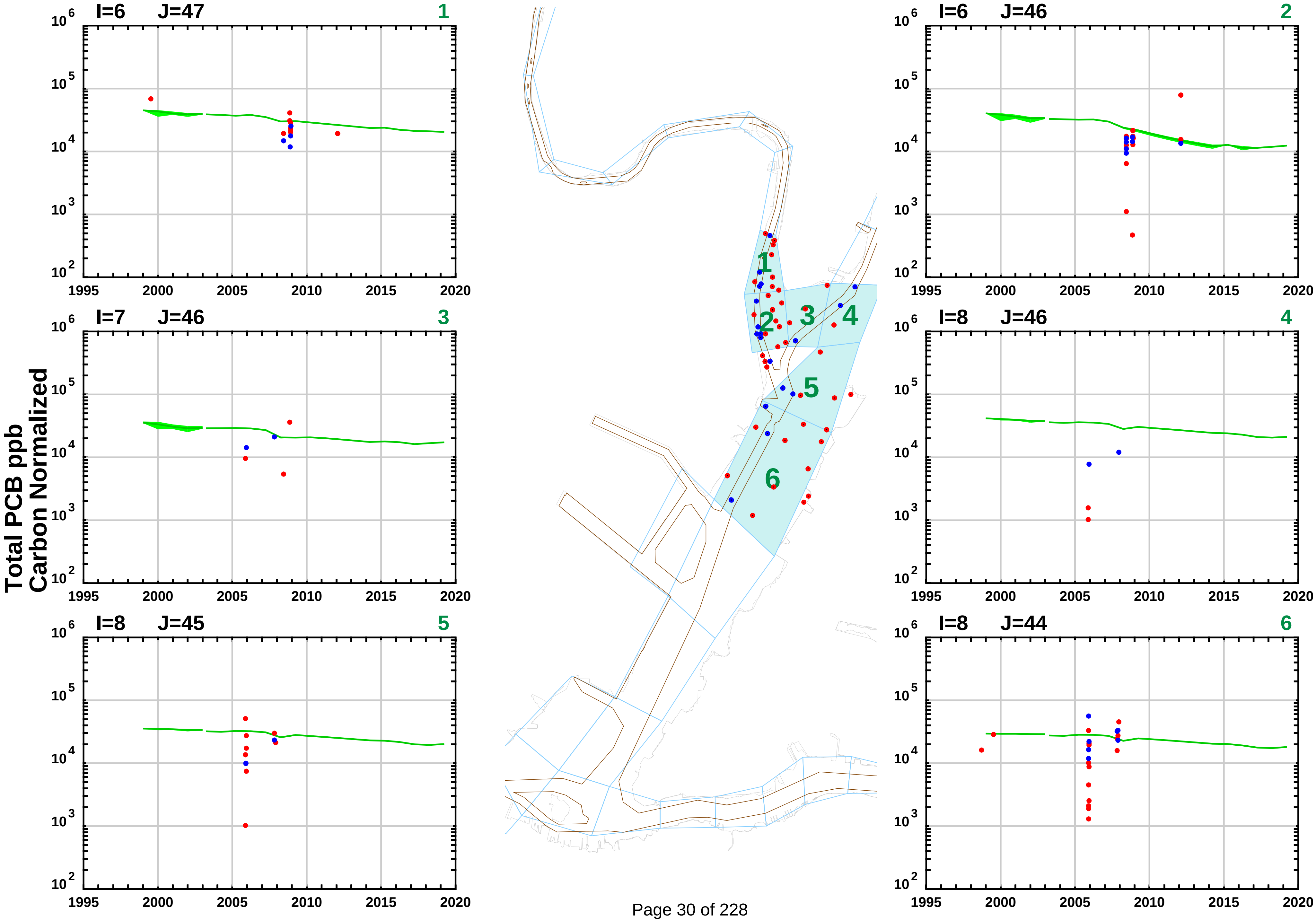
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

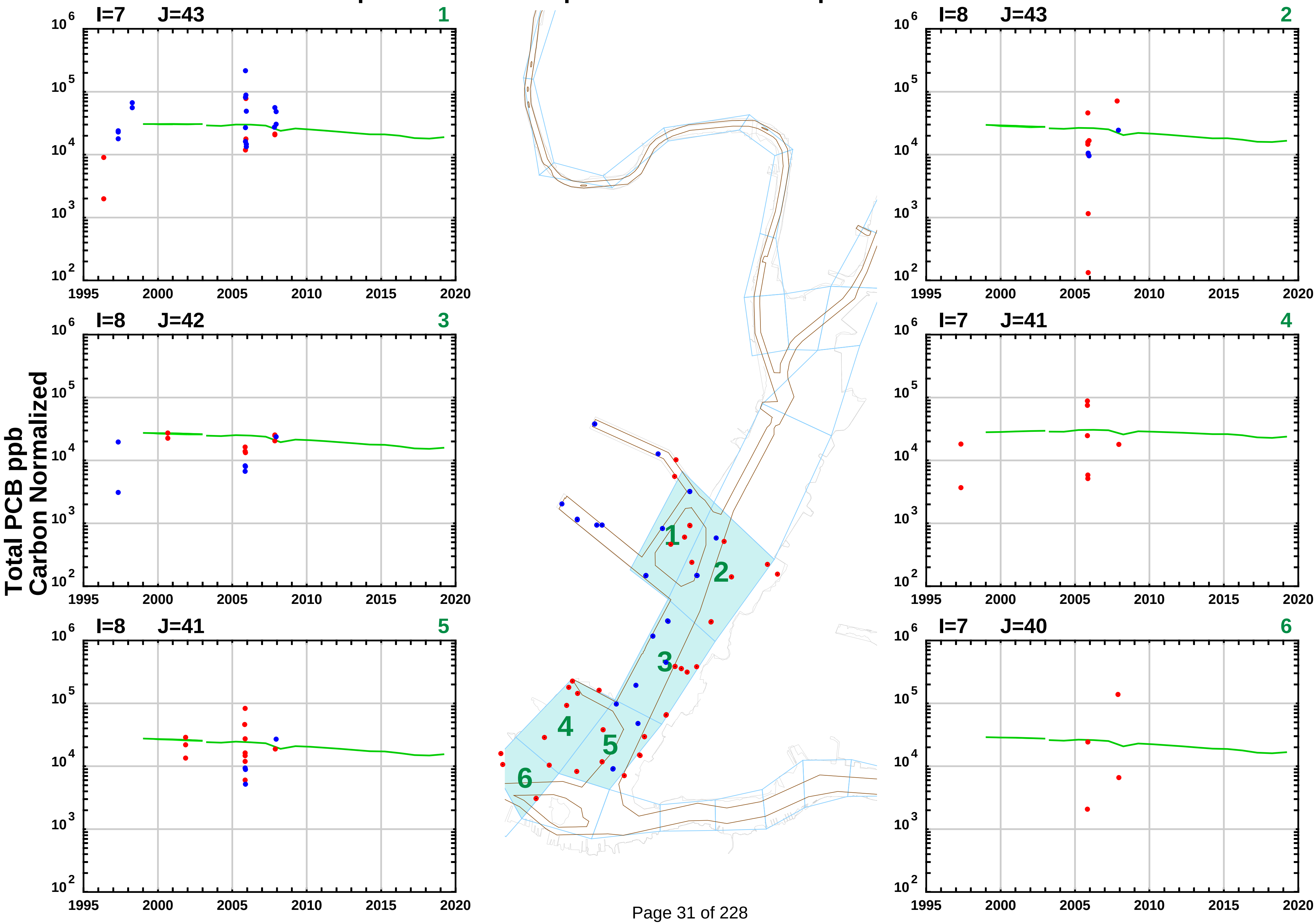
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

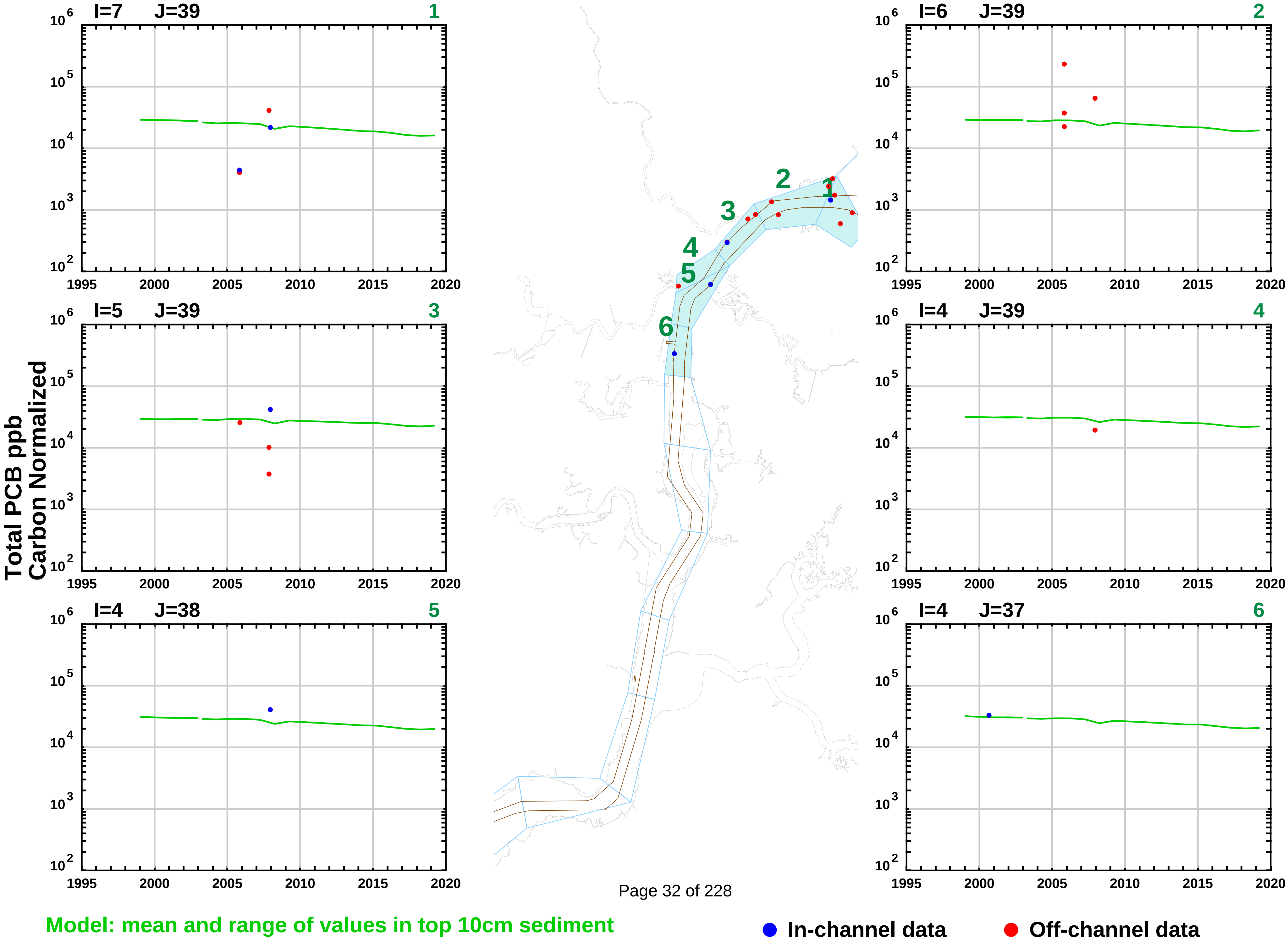
Top 15 cm data comparison with model top 10 cm sediment



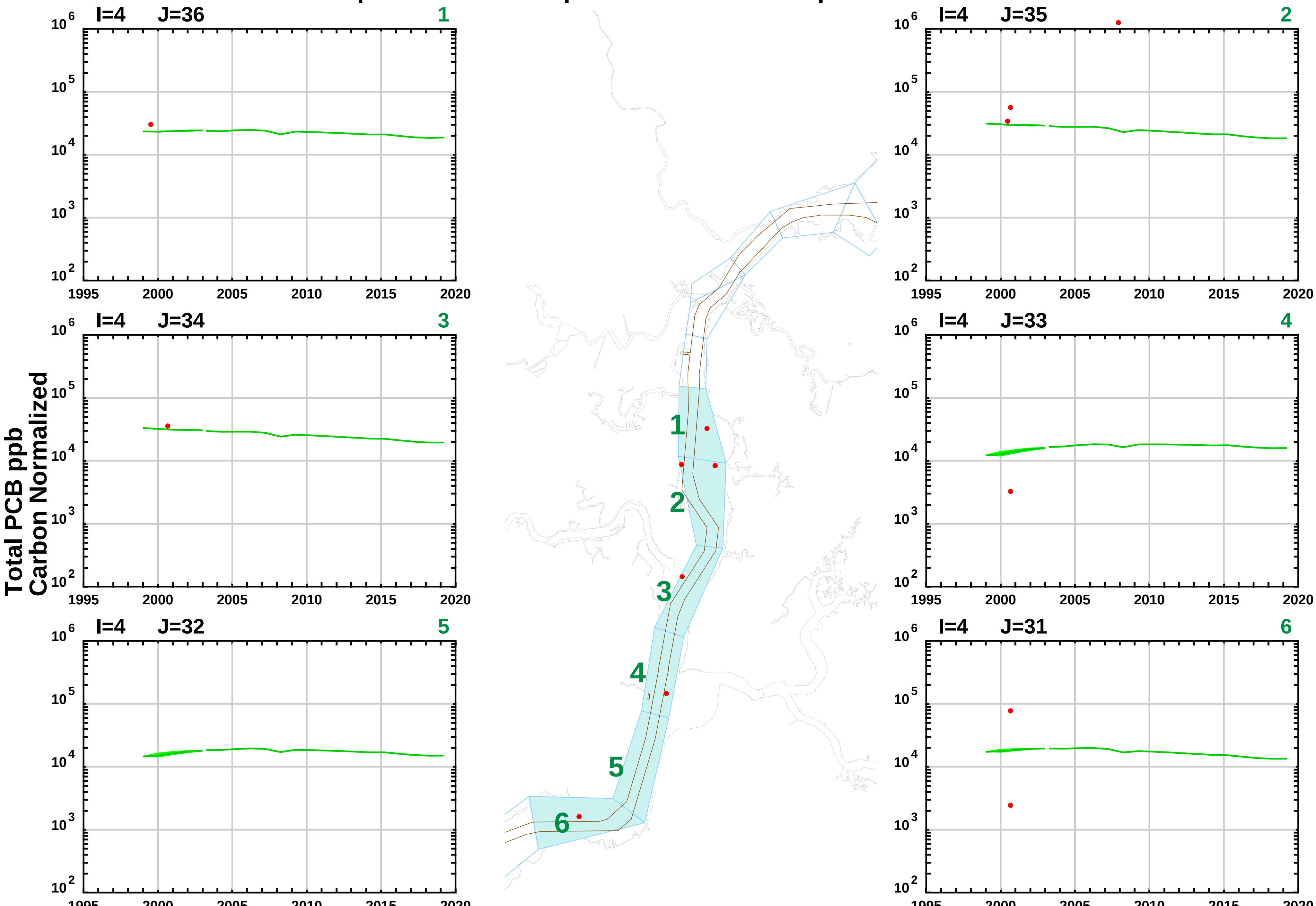
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



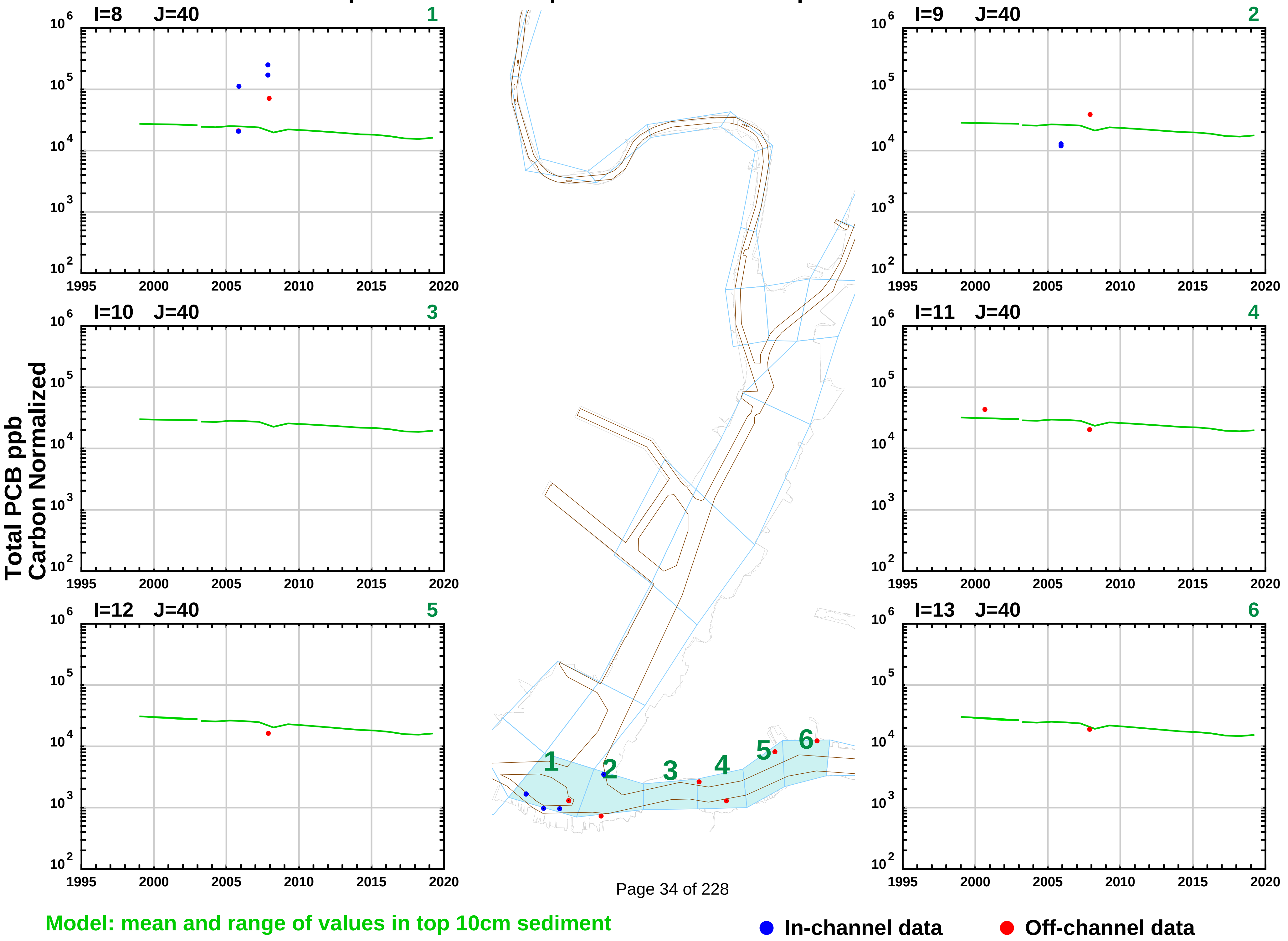
Top 15 cm data comparison with model top 10 cm sediment



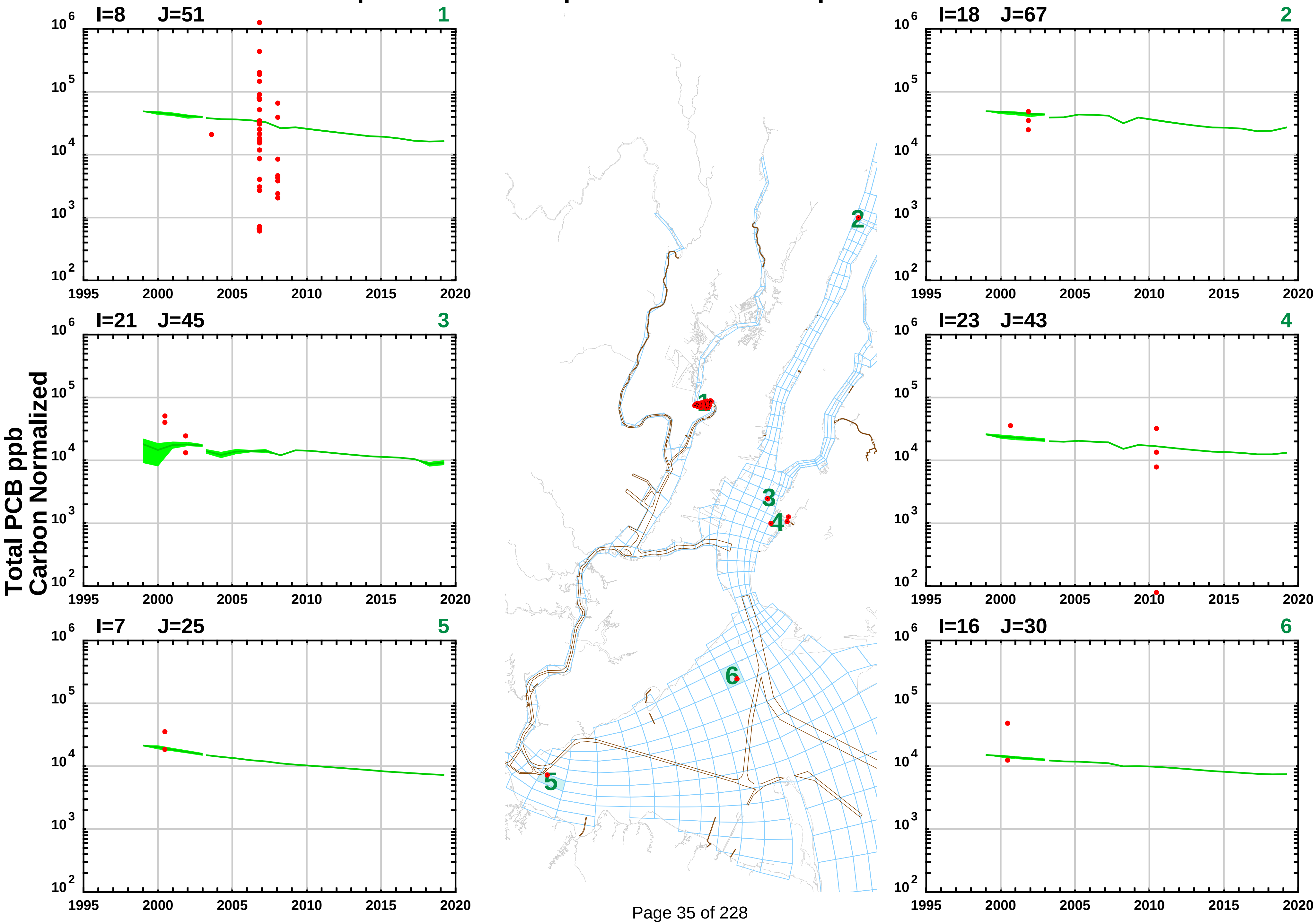
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



Top 15 cm data comparison with model top 10 cm sediment

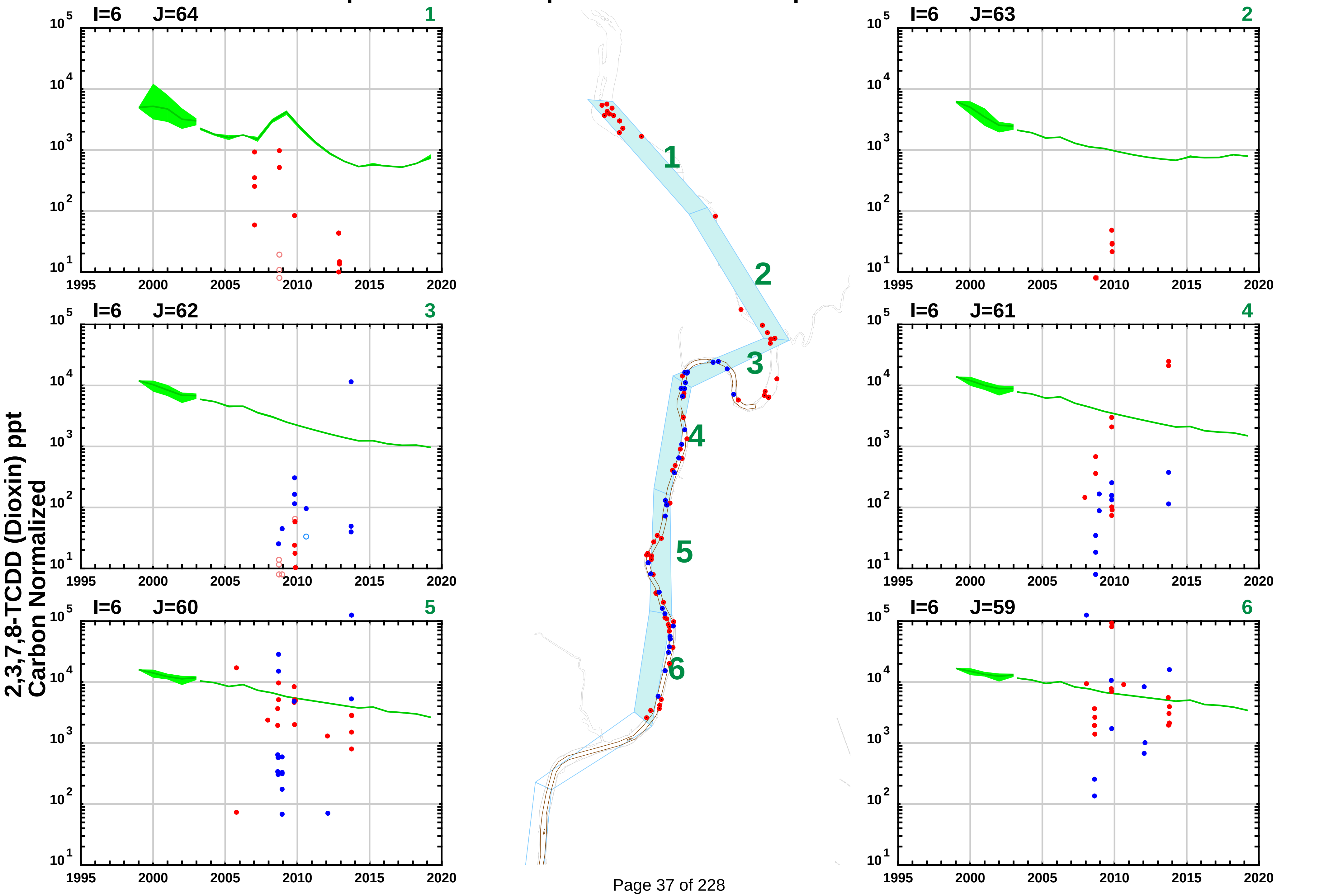


Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Attachment 1B, 2,3,7,8-TCDD

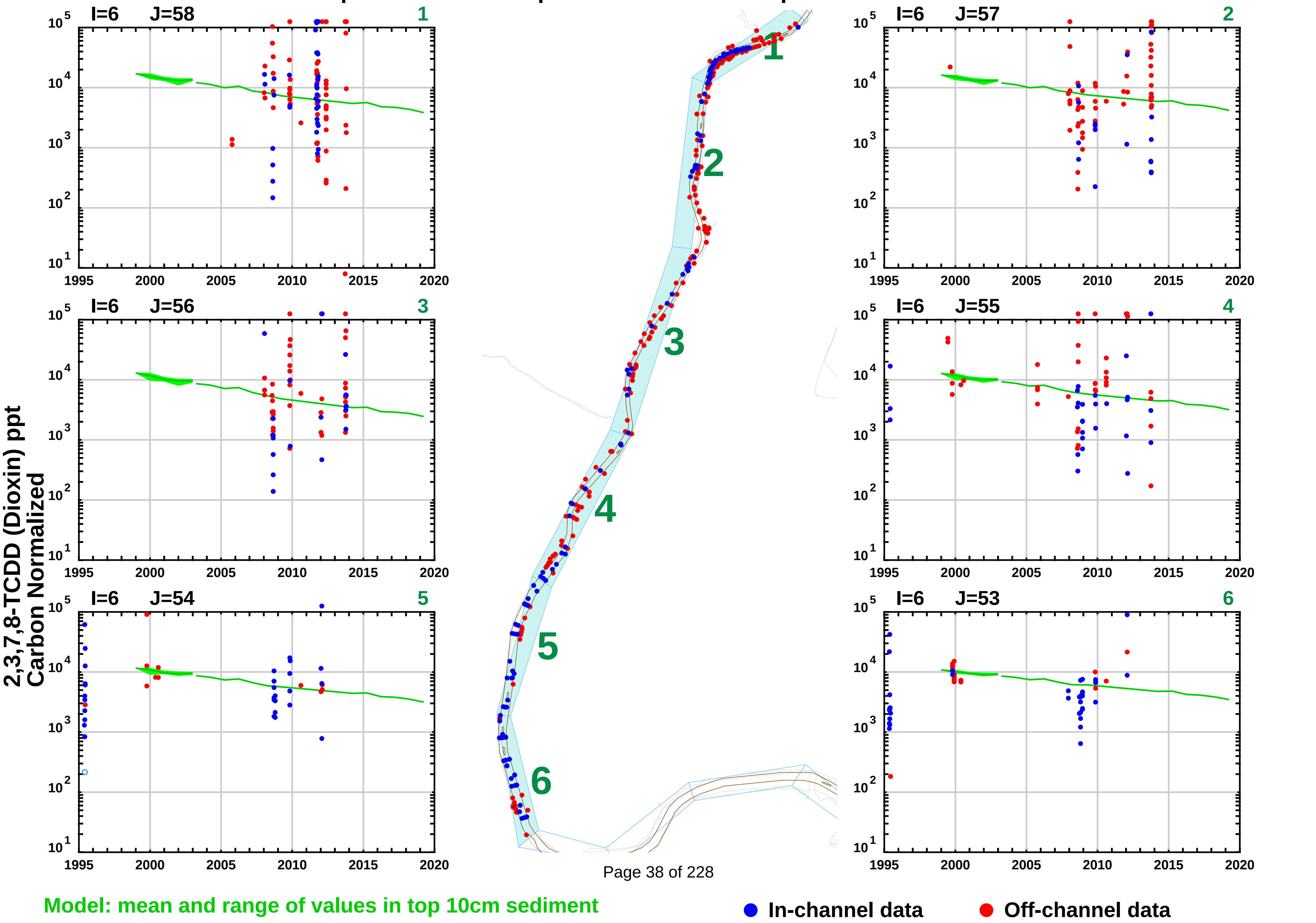
Top 15 cm data comparison with model top 10 cm sediment



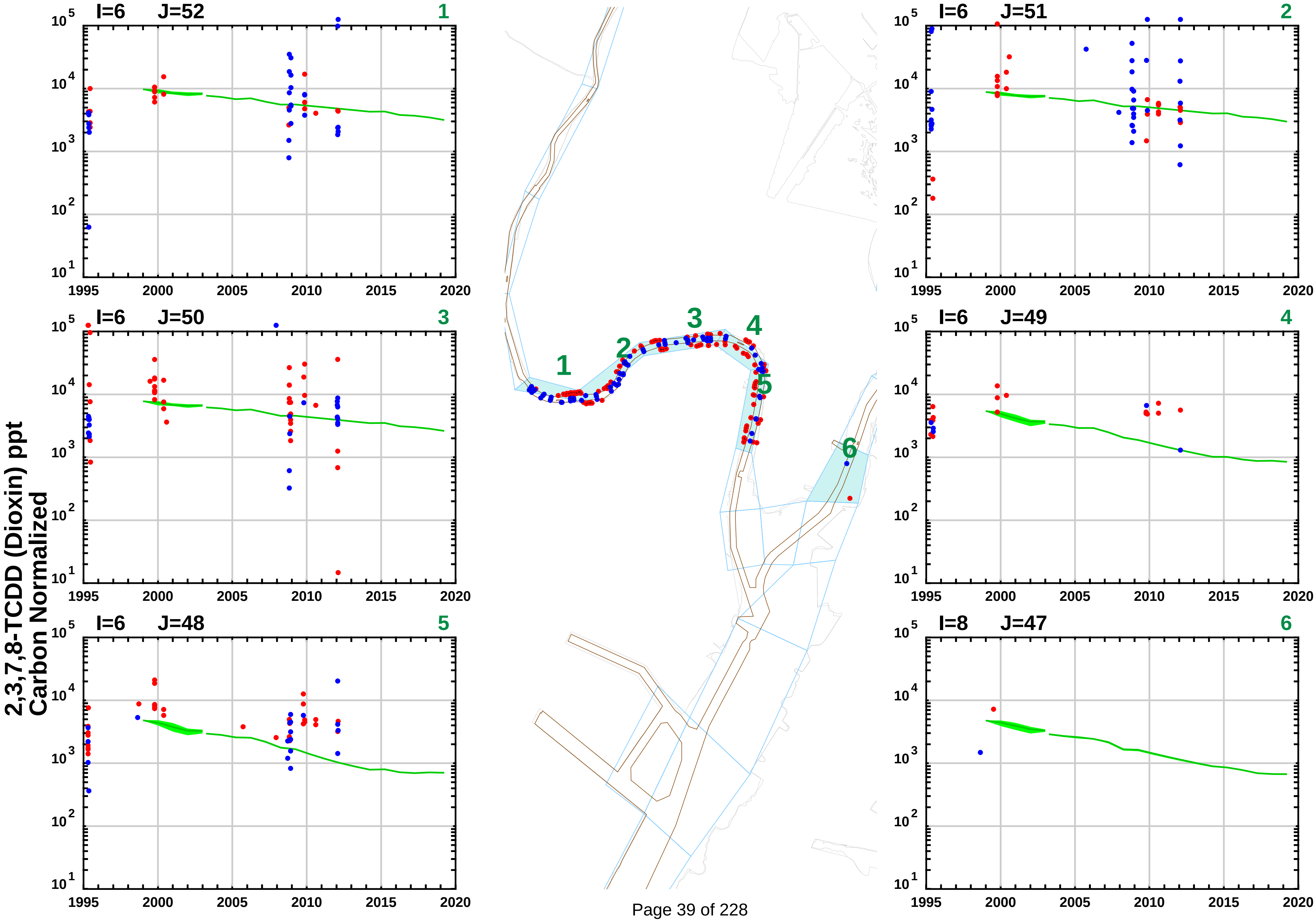
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



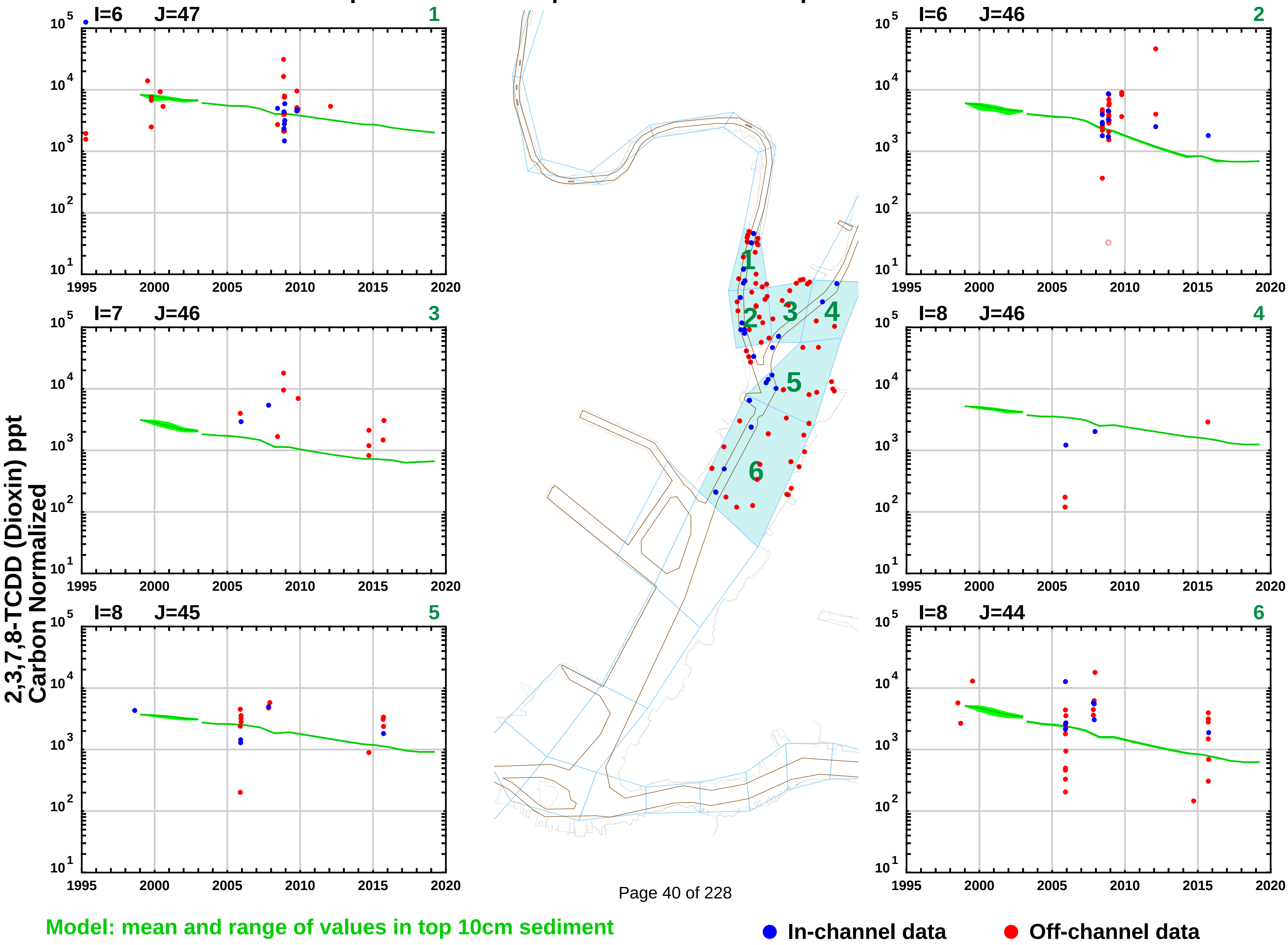
Top 15 cm data comparison with model top 10 cm sediment



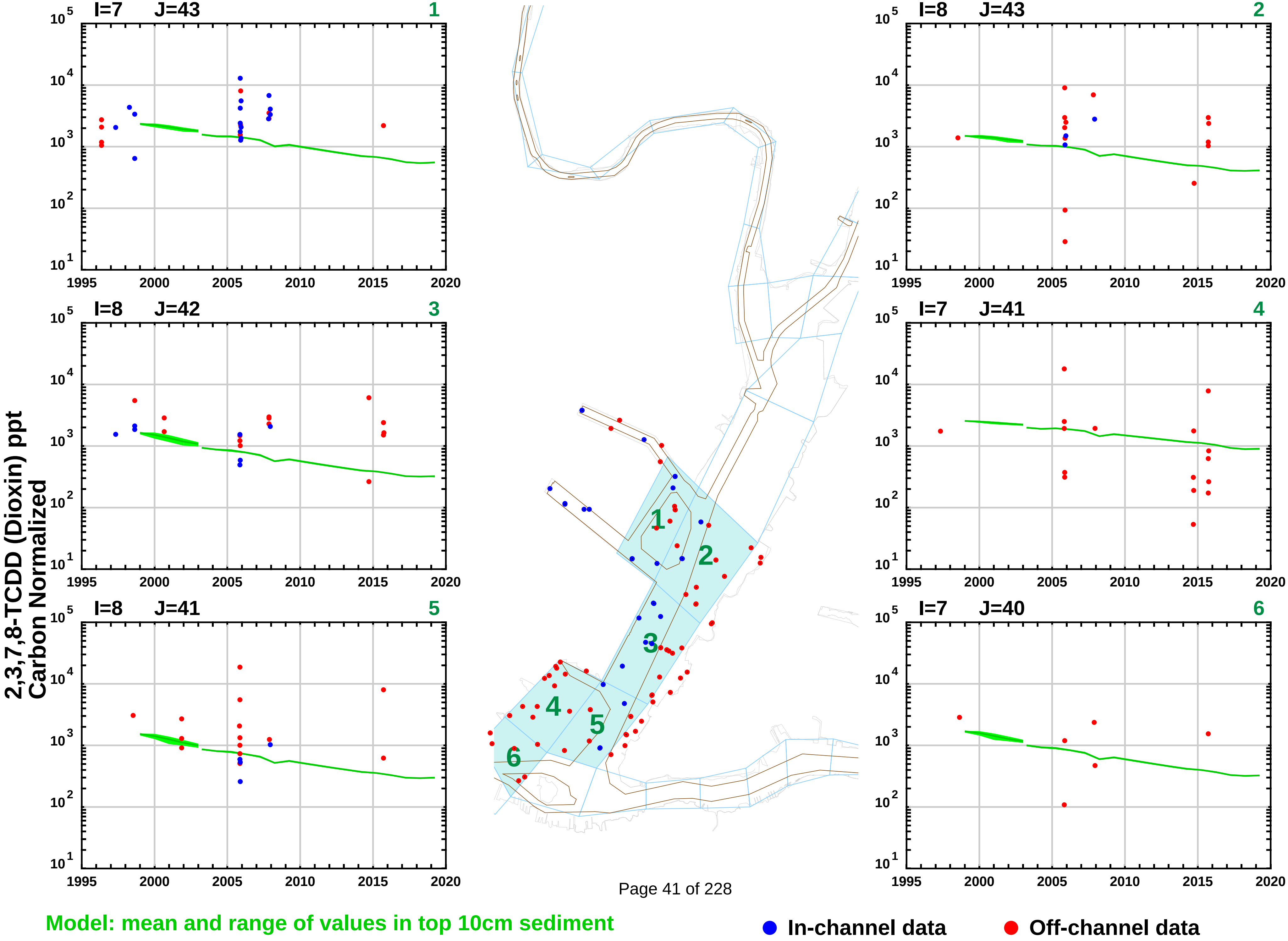
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

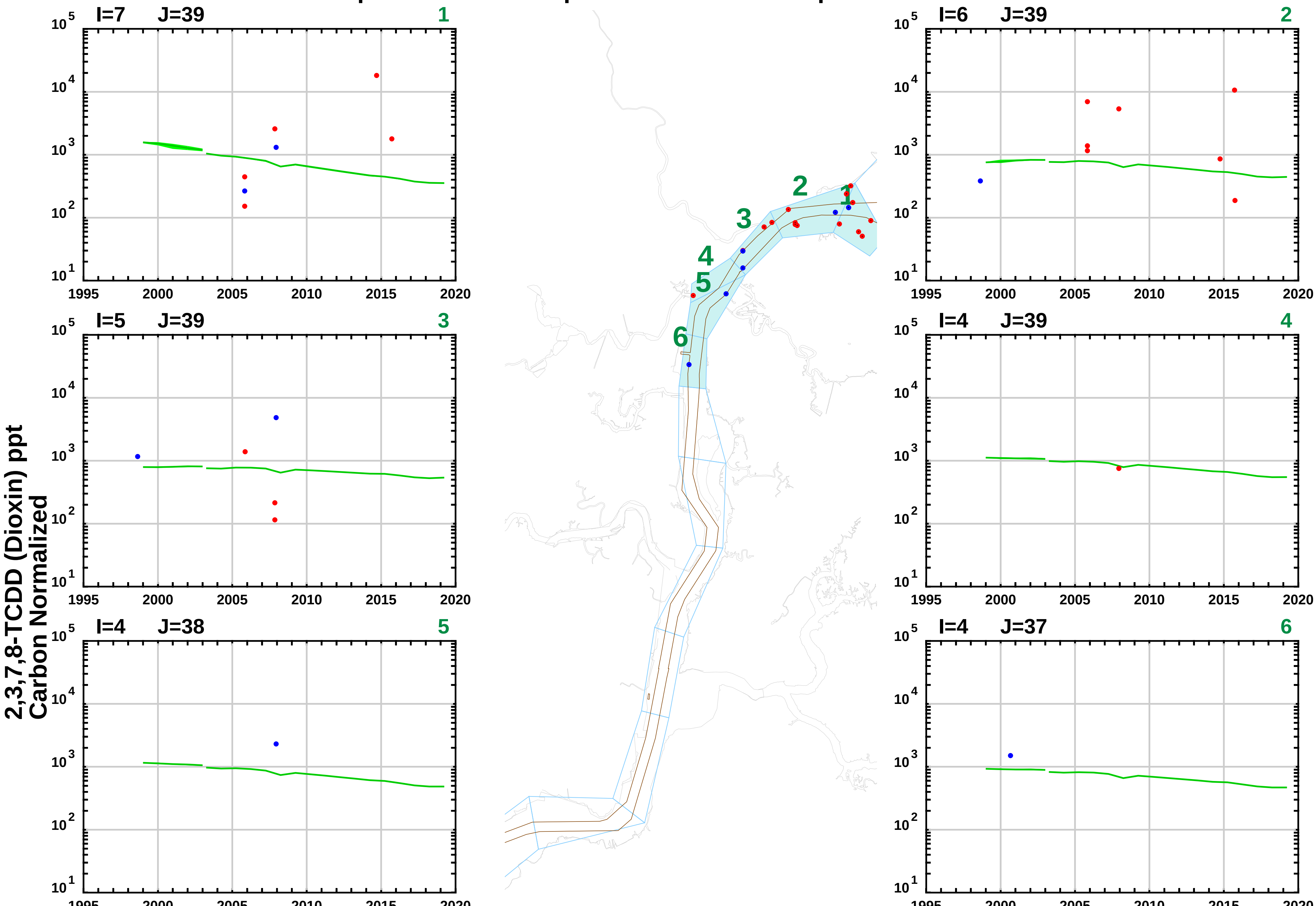
Top 15 cm data comparison with model top 10 cm sediment



Top 15 cm data comparison with model top 10 cm sediment



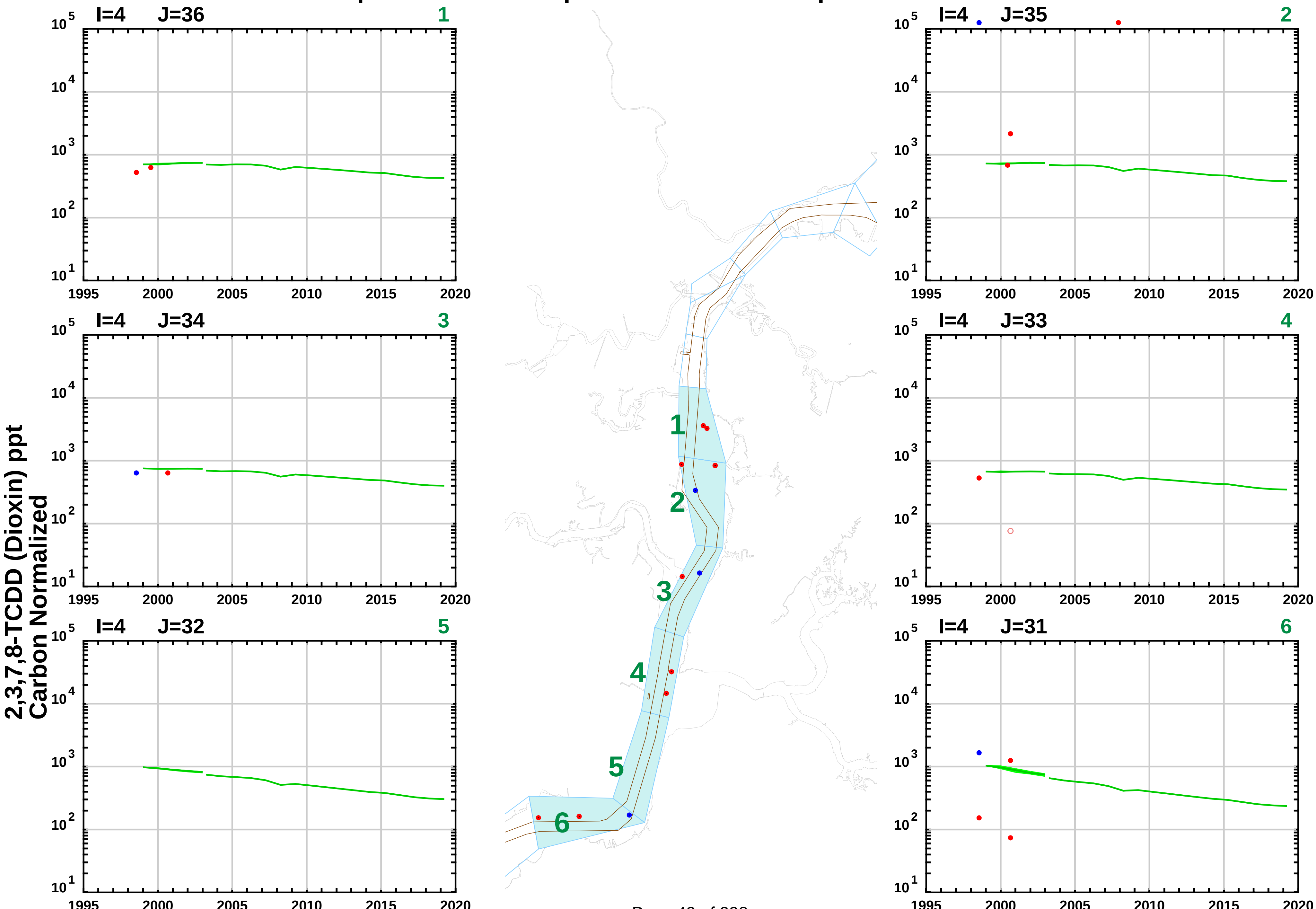
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

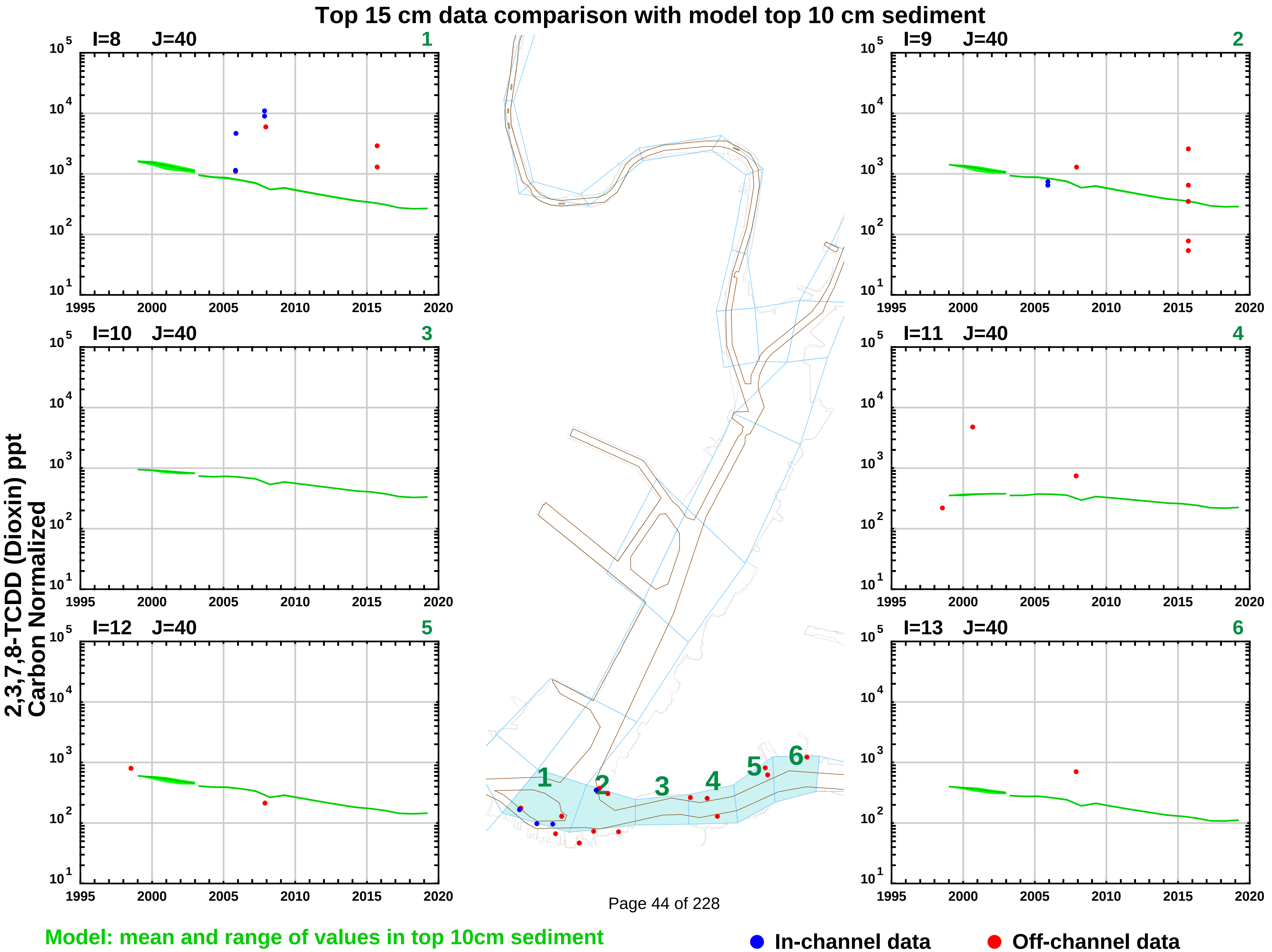
● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



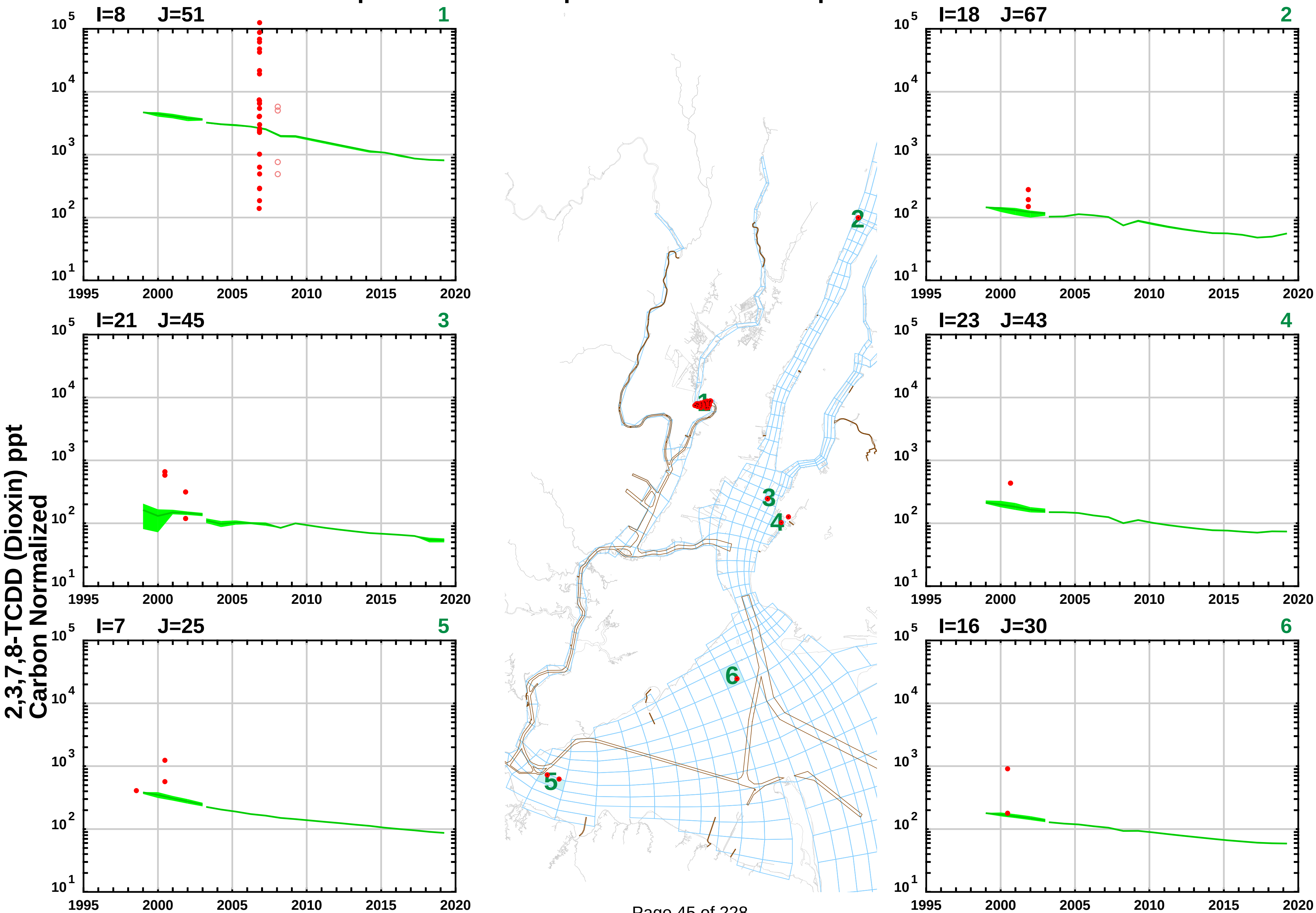
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data



Top 15 cm data comparison with model top 10 cm sediment
I=8 J=40 1
I=9 J=40 2
I=10 J=40 3
I=11 J=40 4
I=12 J=40 5
I=13 J=40 6
2,3,7,8-TCDD (Dioxin) ppt
Carbon Normalized
1995 2000 2005 2010 2015 2020
Model: mean and range of values in top 10cm sediment
In-channel data
Off-channel data

Top 15 cm data comparison with model top 10 cm sediment

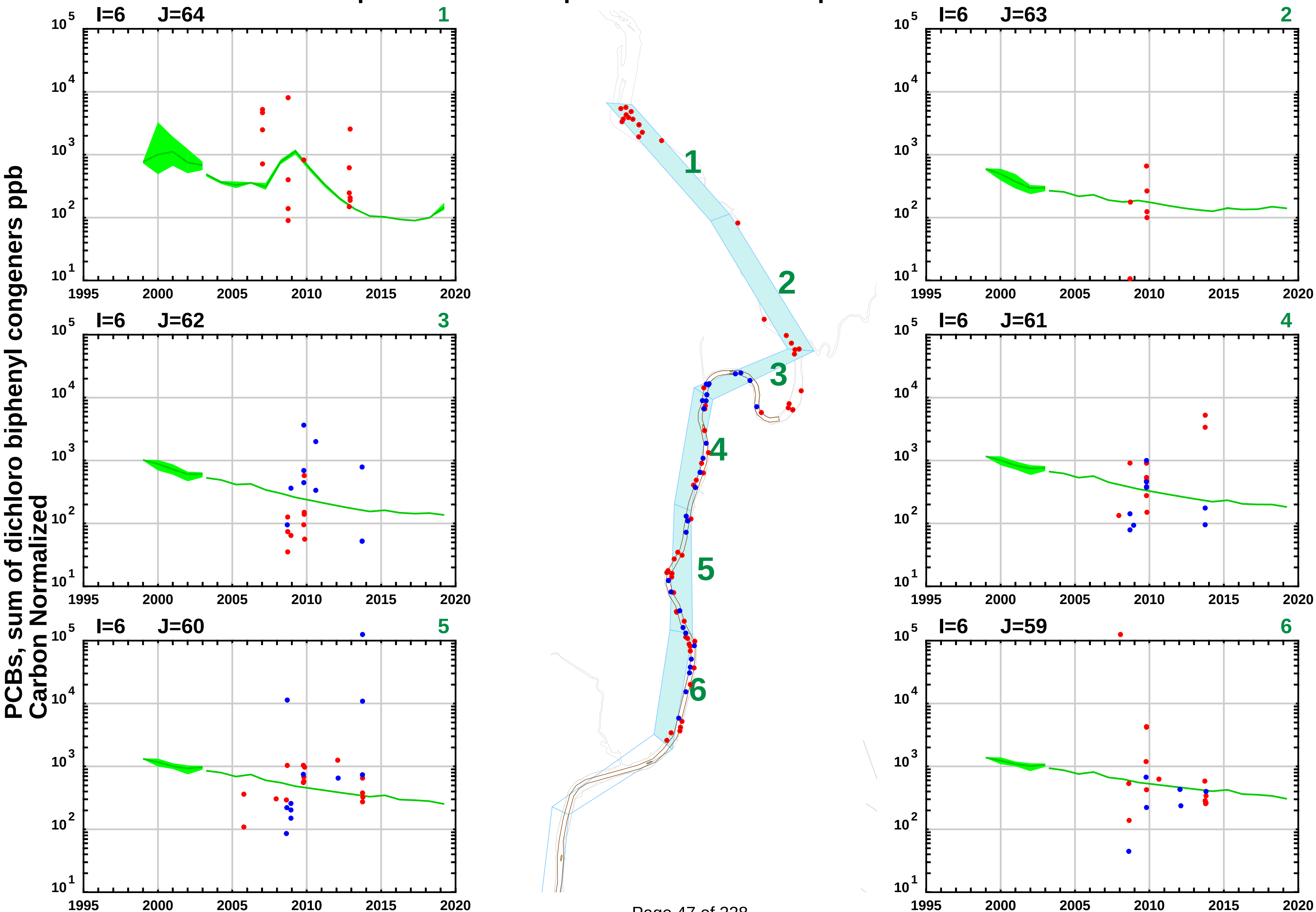


Model: mean and range of values in top 10cm sediment

In-channel data   Off-channel data

Attachment 1C, PCB homologs

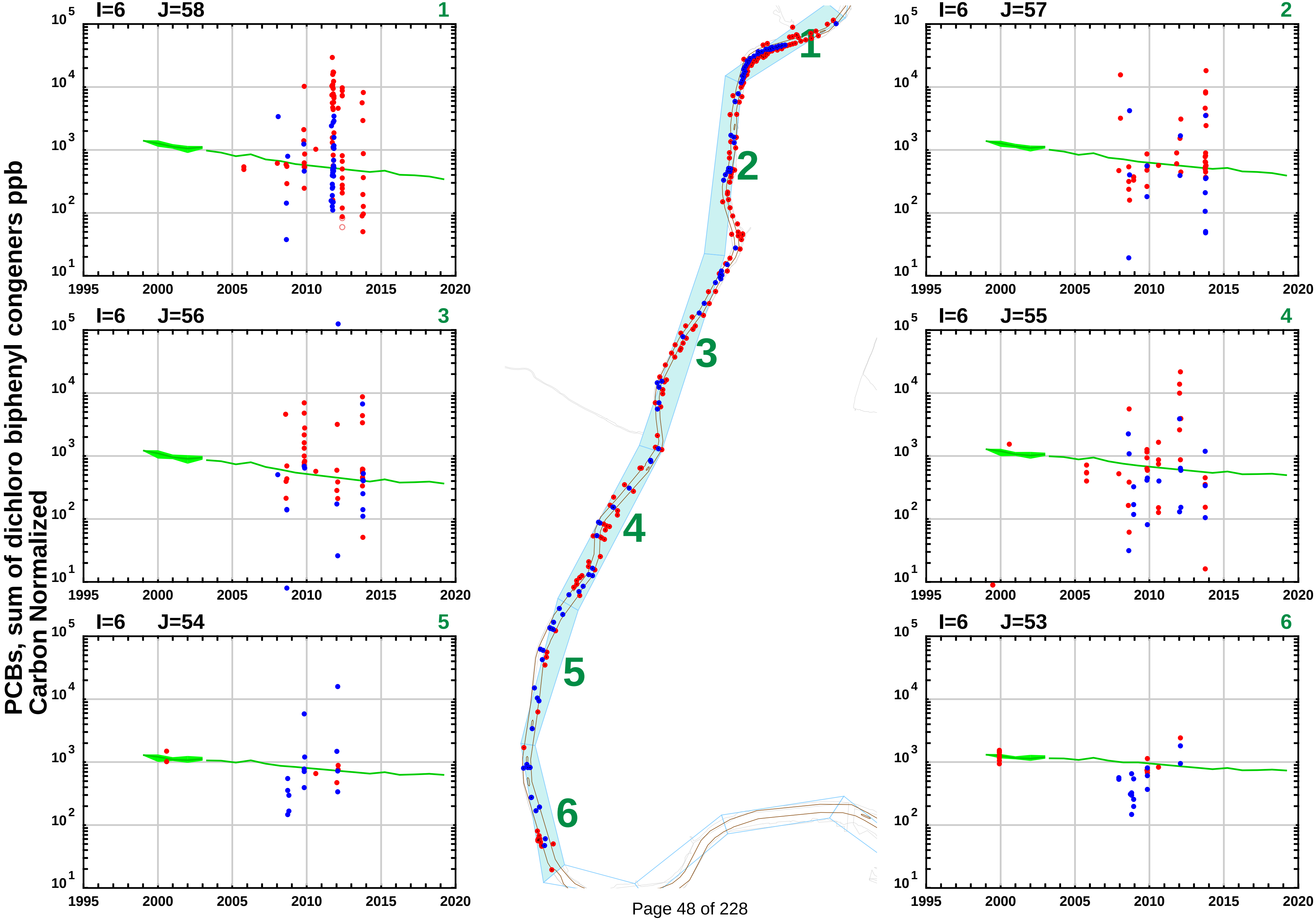
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

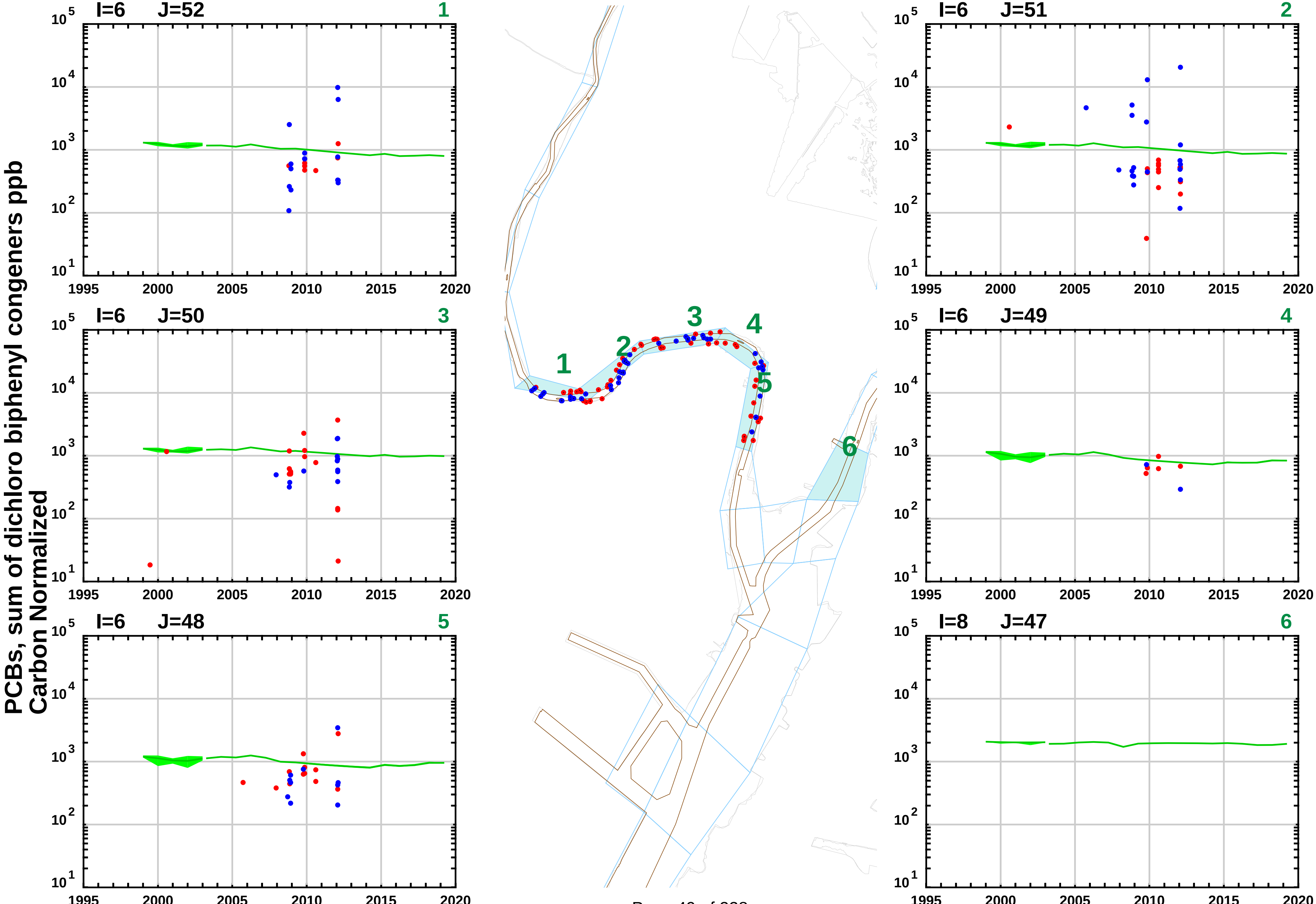
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

In-channel data Off-channel data

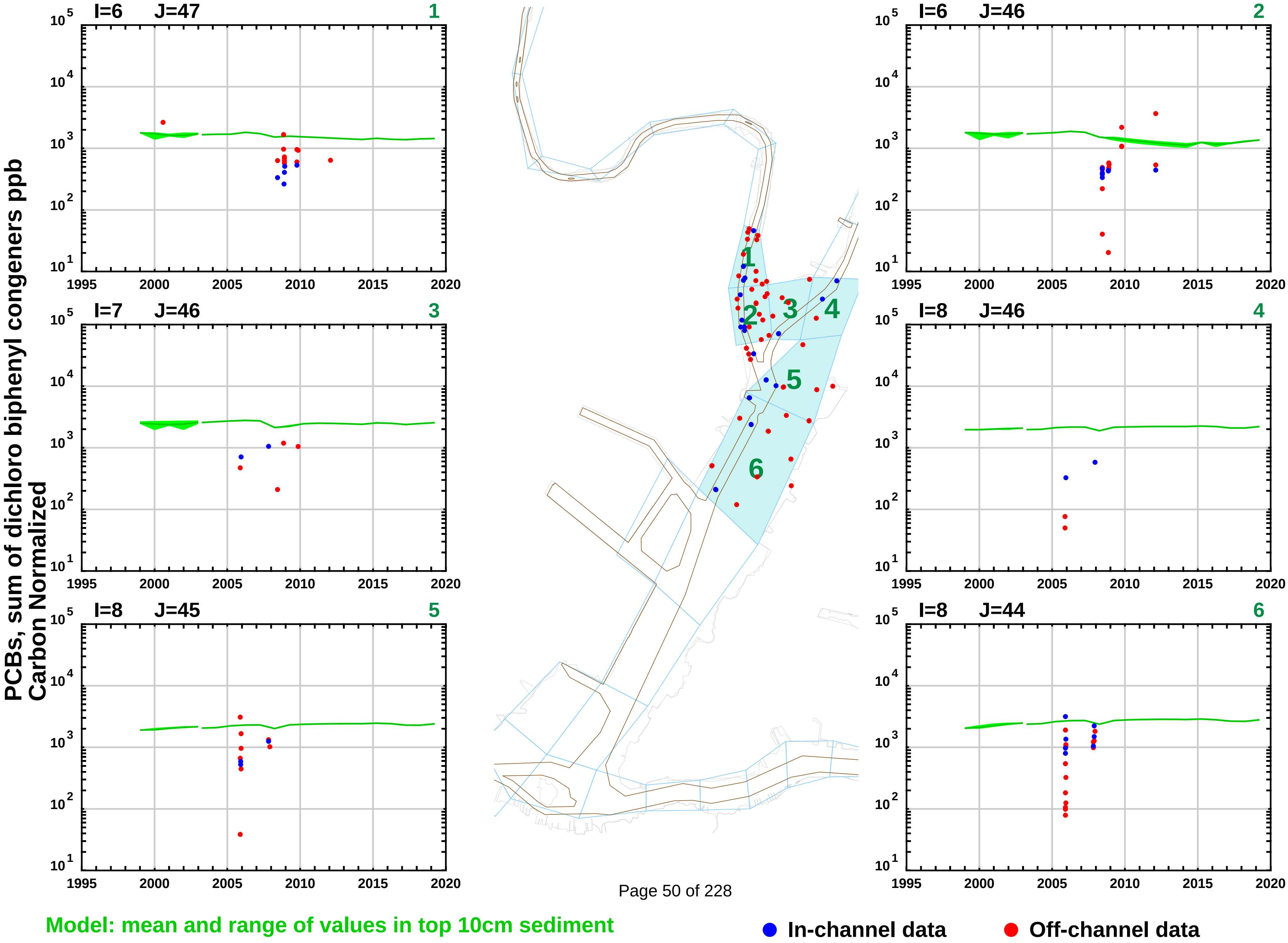
Top 15 cm data comparison with model top 10 cm sediment



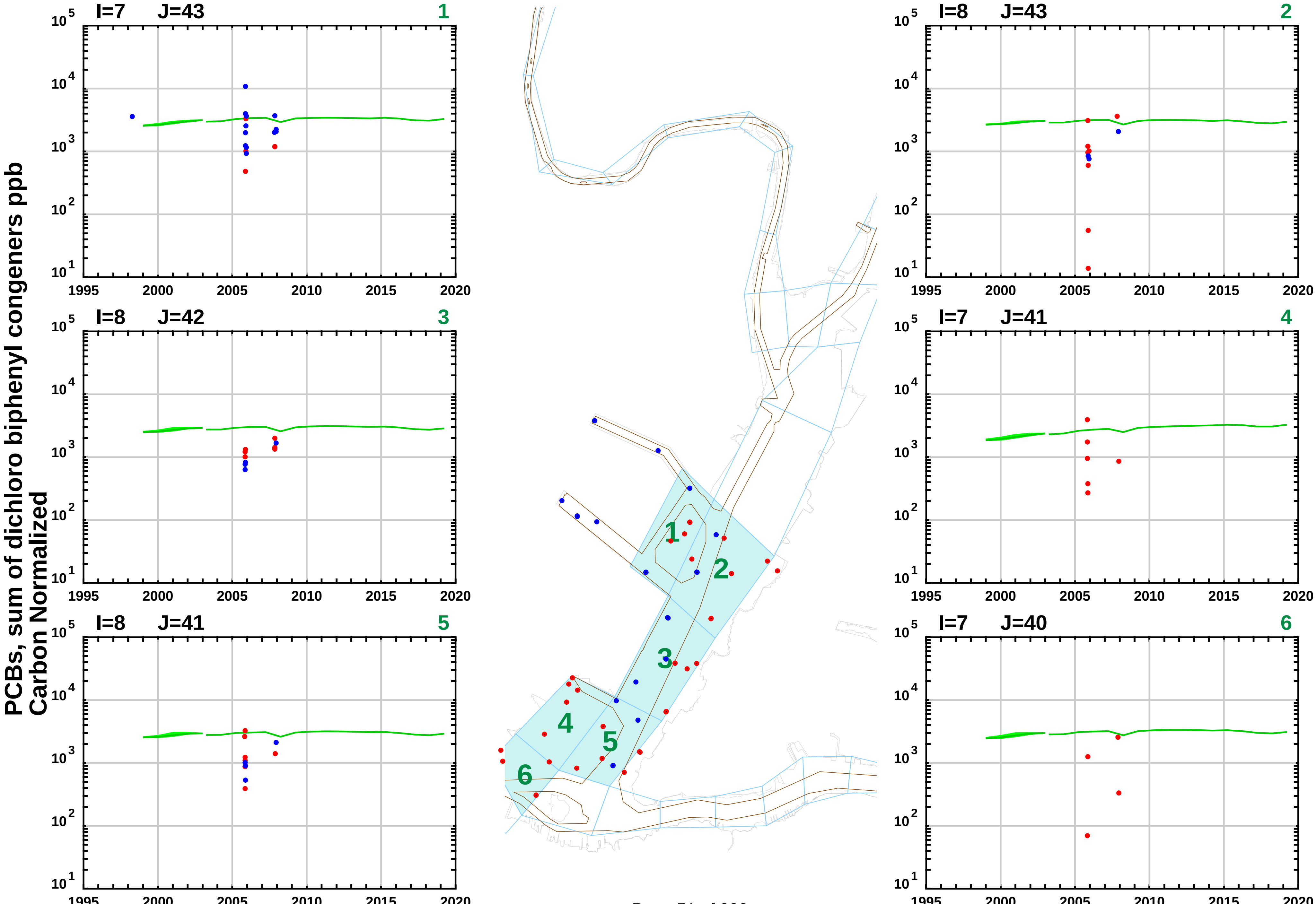
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



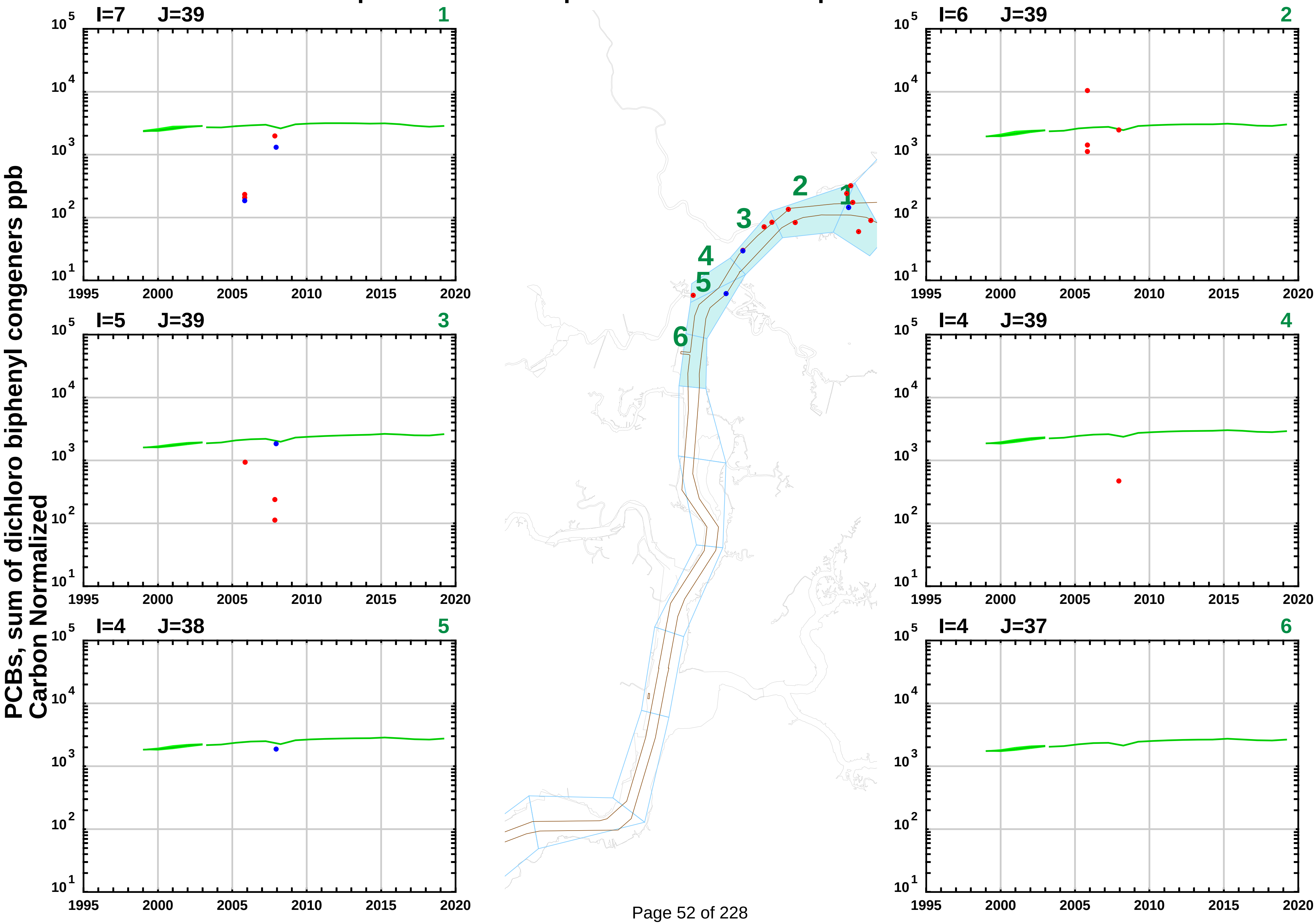
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

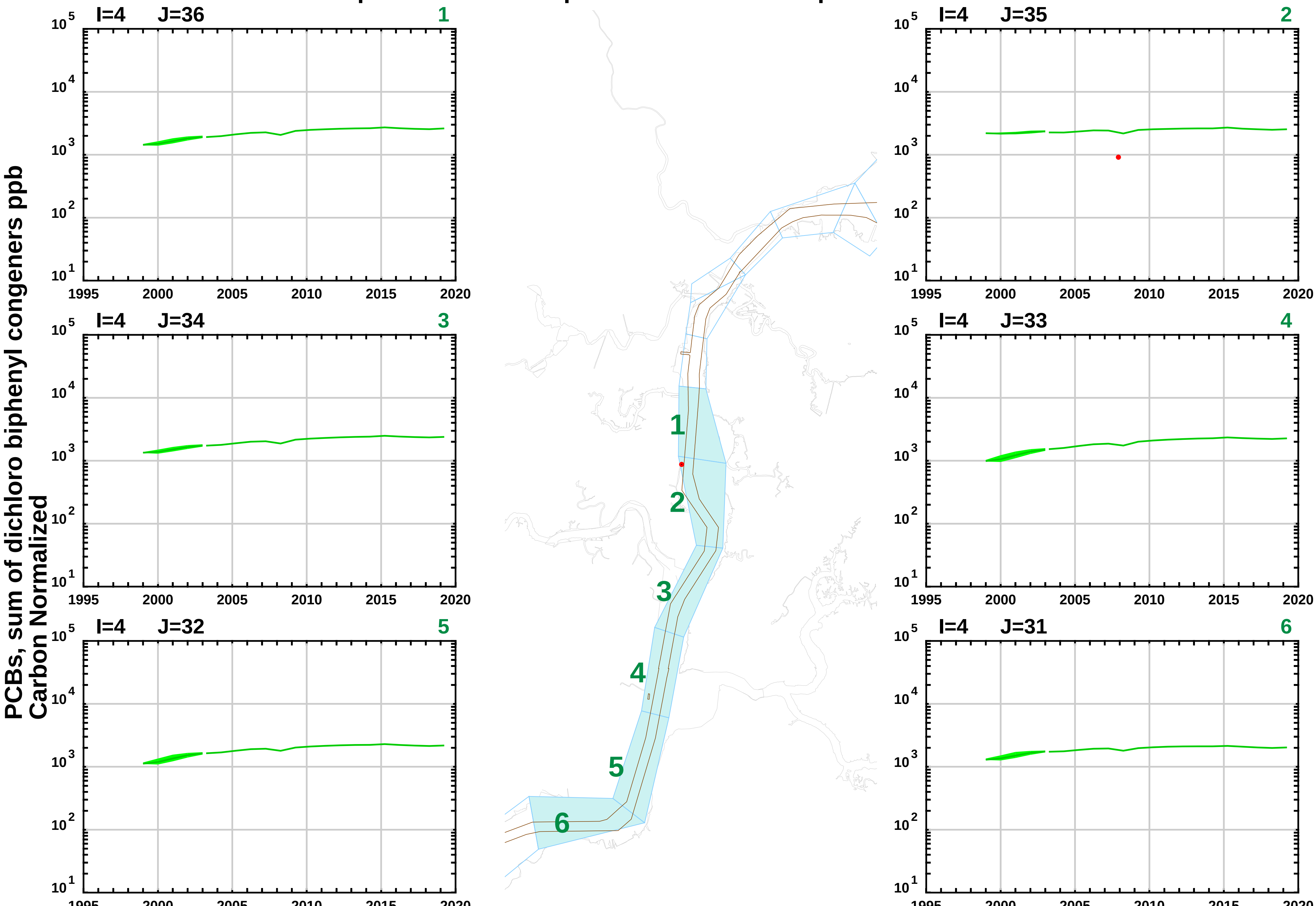
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment

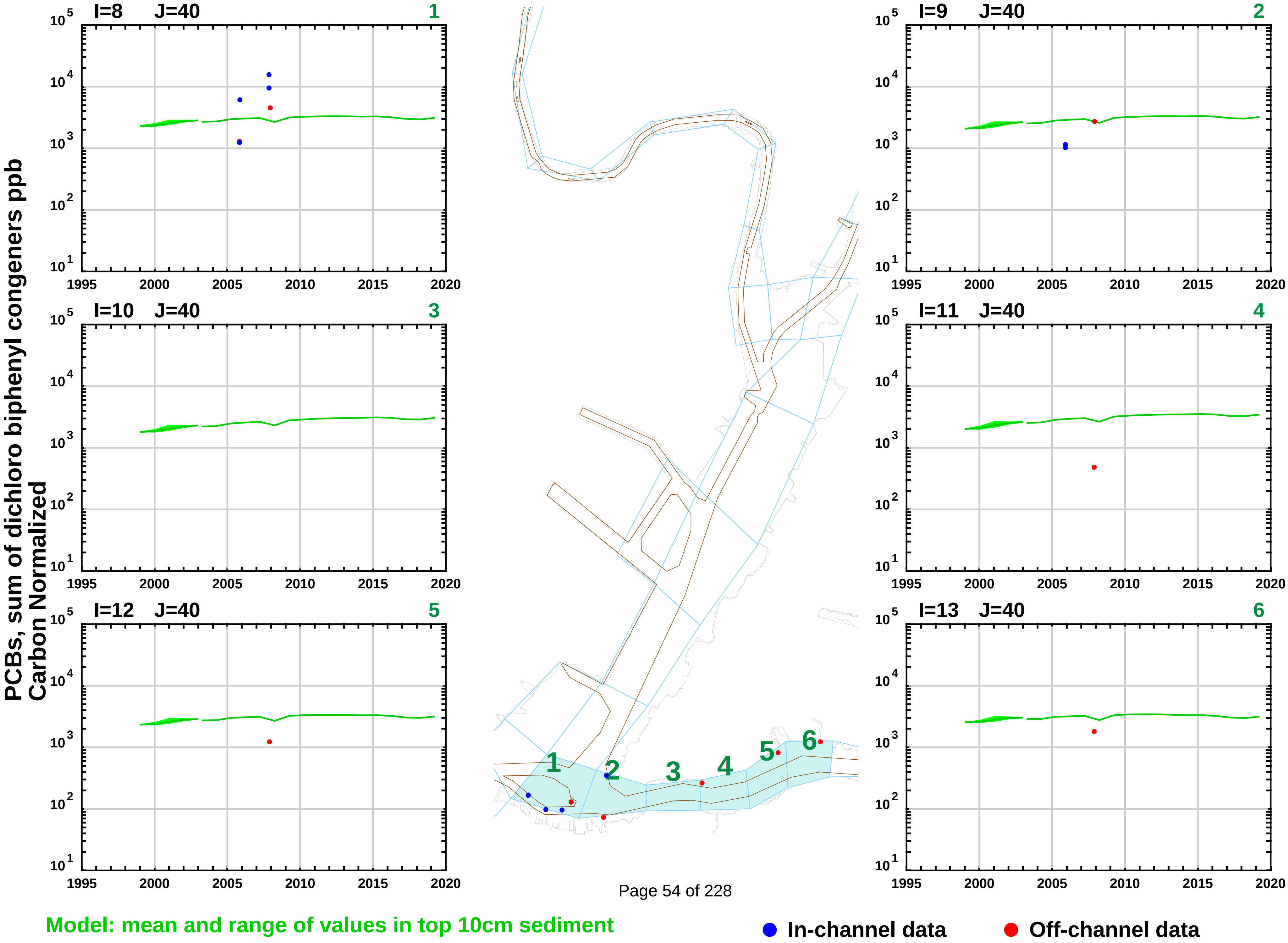


Model: mean and range of values in top 10cm sediment

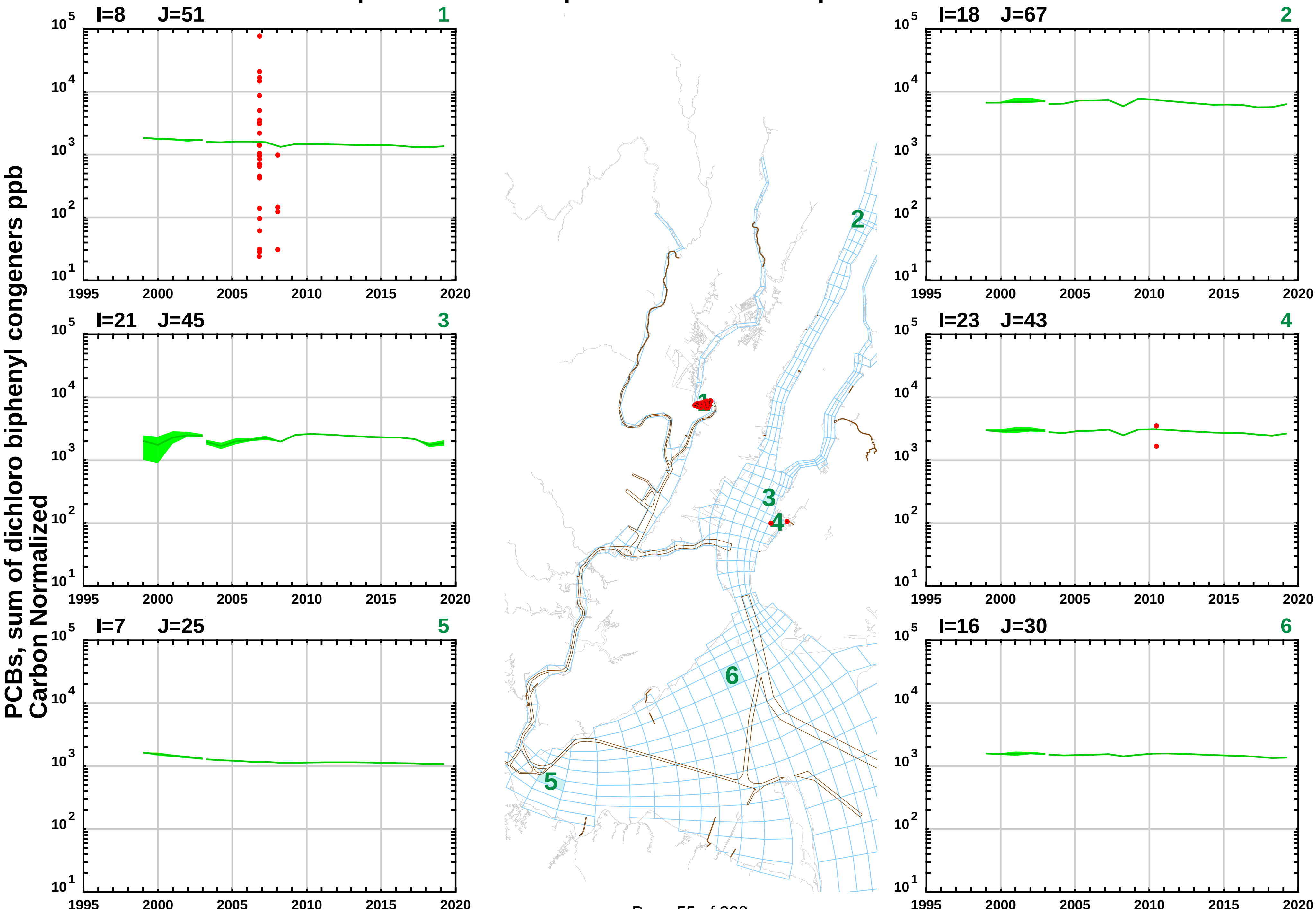
In-channel data

Off-channel data

Top 15 cm data comparison with model top 10 cm sediment

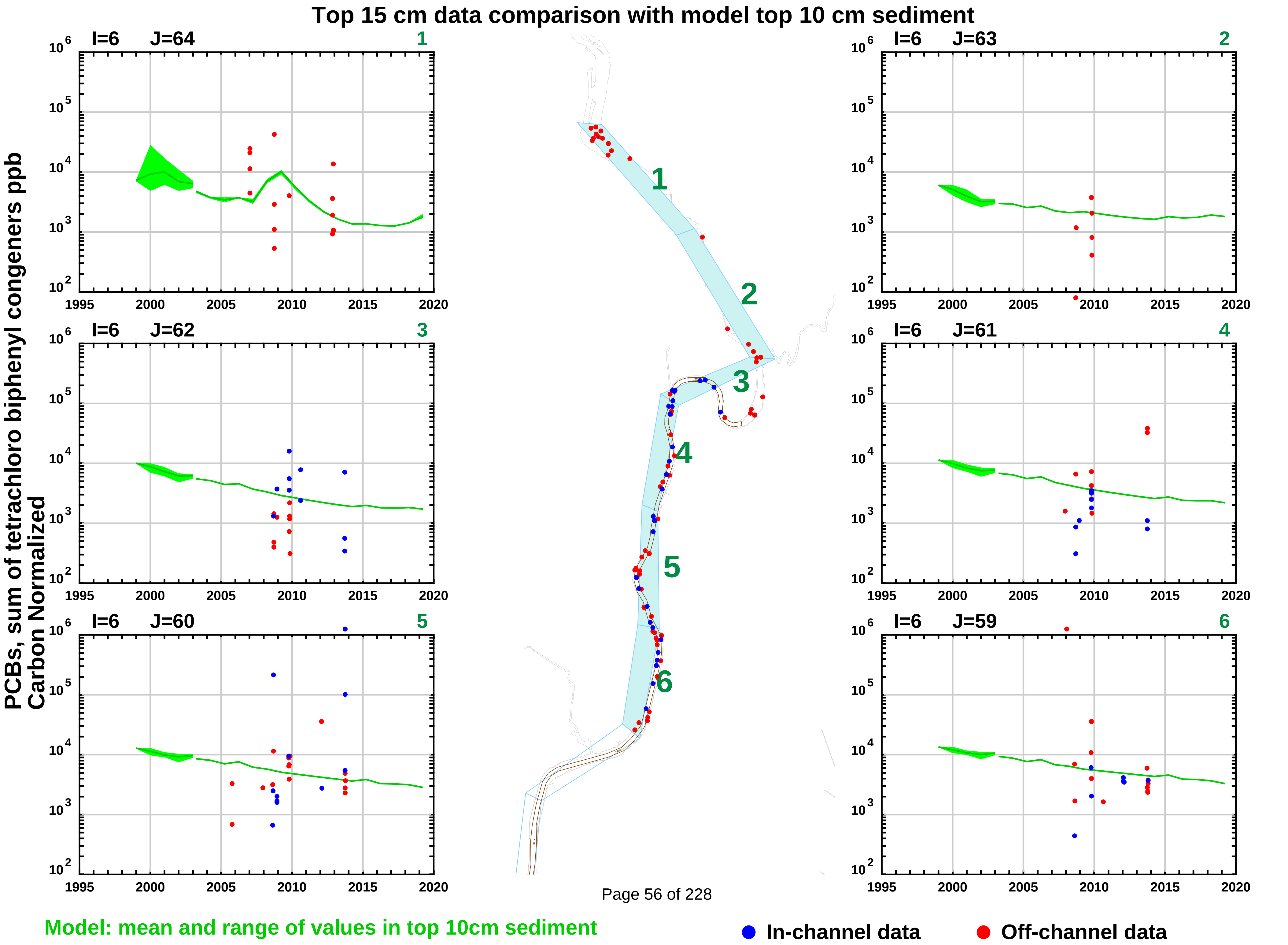


Top 15 cm data comparison with model top 10 cm sediment



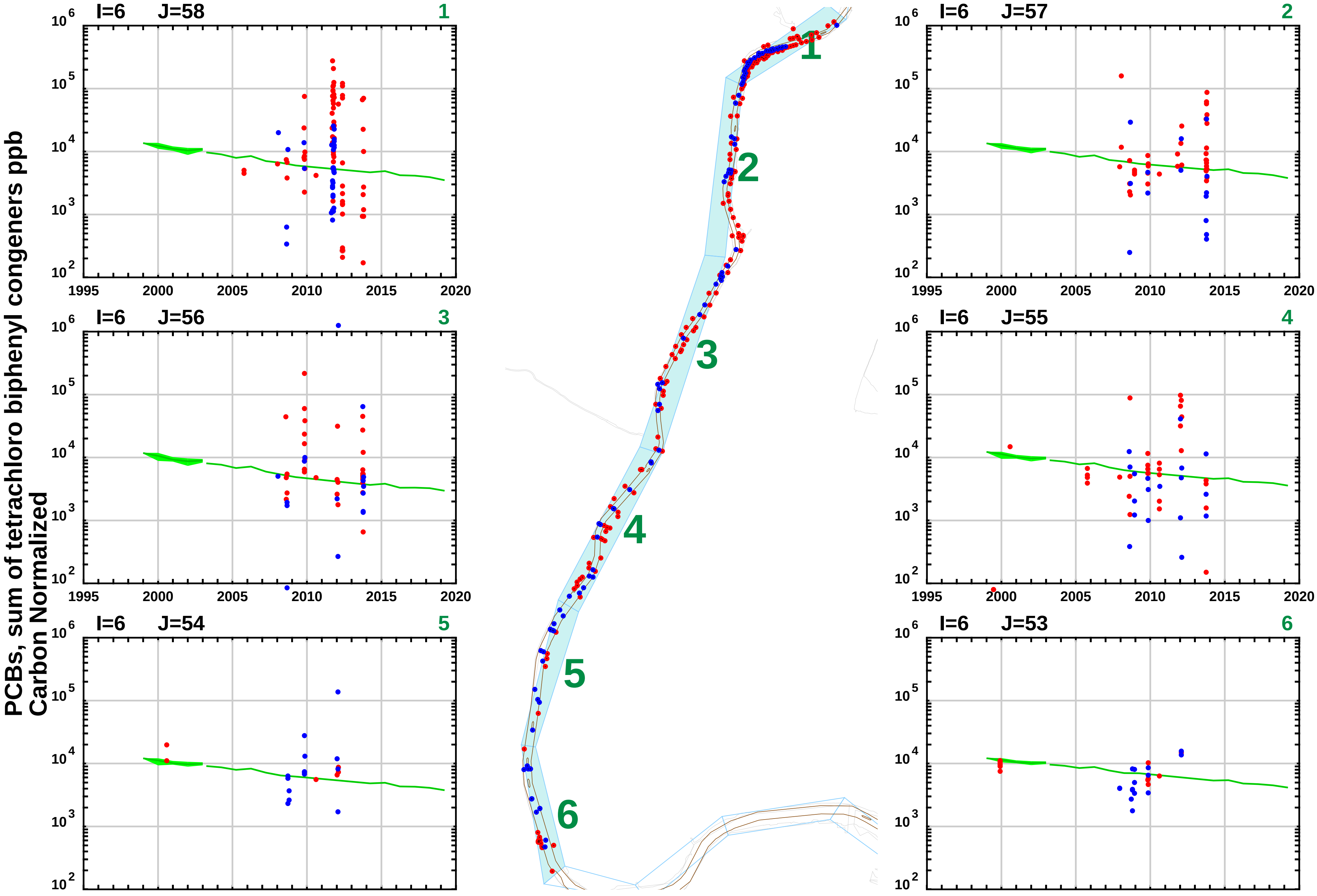
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data



Top 15 cm data comparison with model top 10 cm sediment
PCBs, sum of tetrachloro biphenyl congeners ppb
Carbon Normalized
I=6 J=64 1
I=6 J=63 2
I=6 J=62 3
I=6 J=61 4
I=6 J=60 5
I=6 J=59 6
1995
2000
2005
2010
2015
2020
Model: mean and range of values in top 10cm sediment
In-channel data
Off-channel data

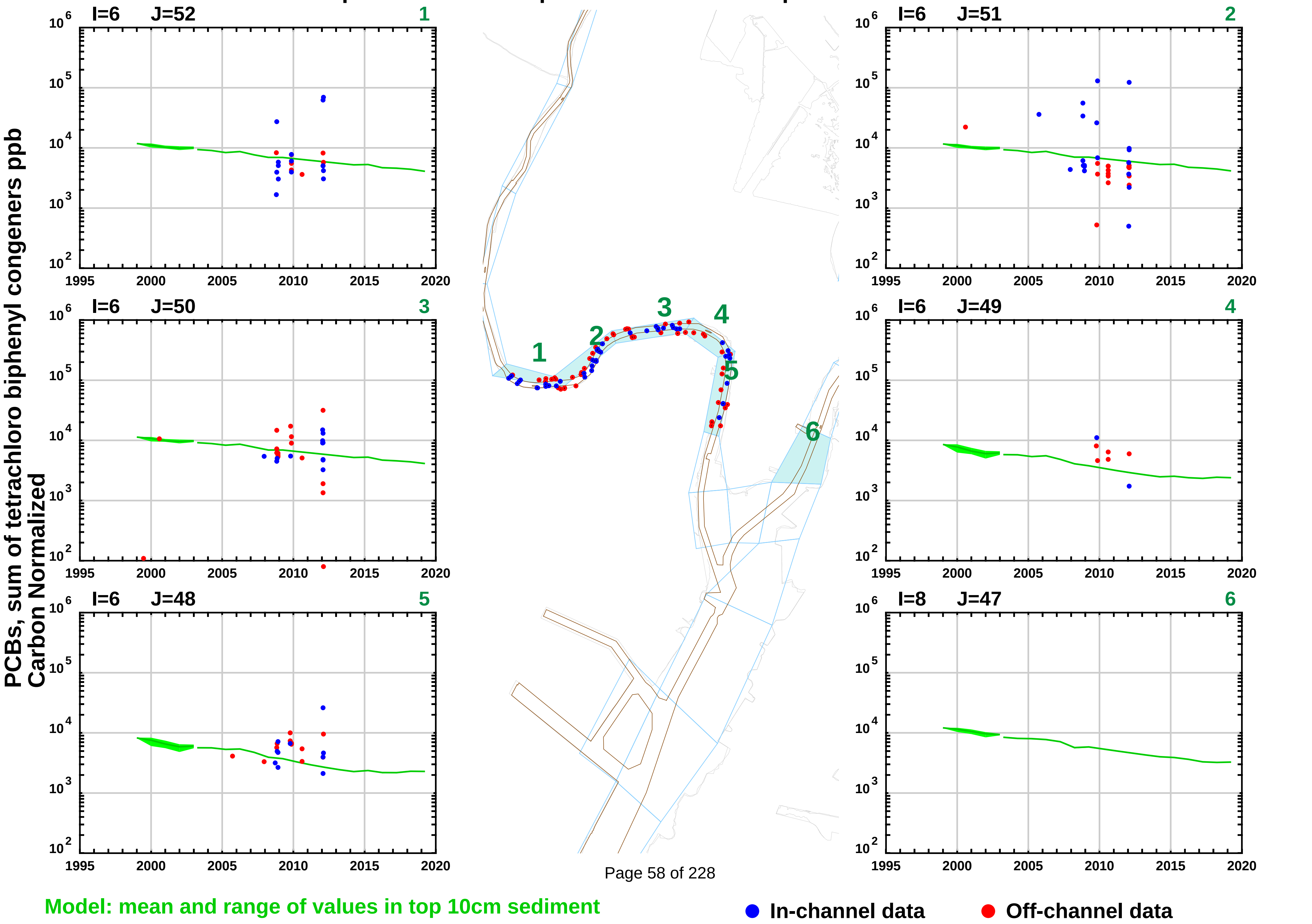
Top 15 cm data comparison with model top 10 cm sediment



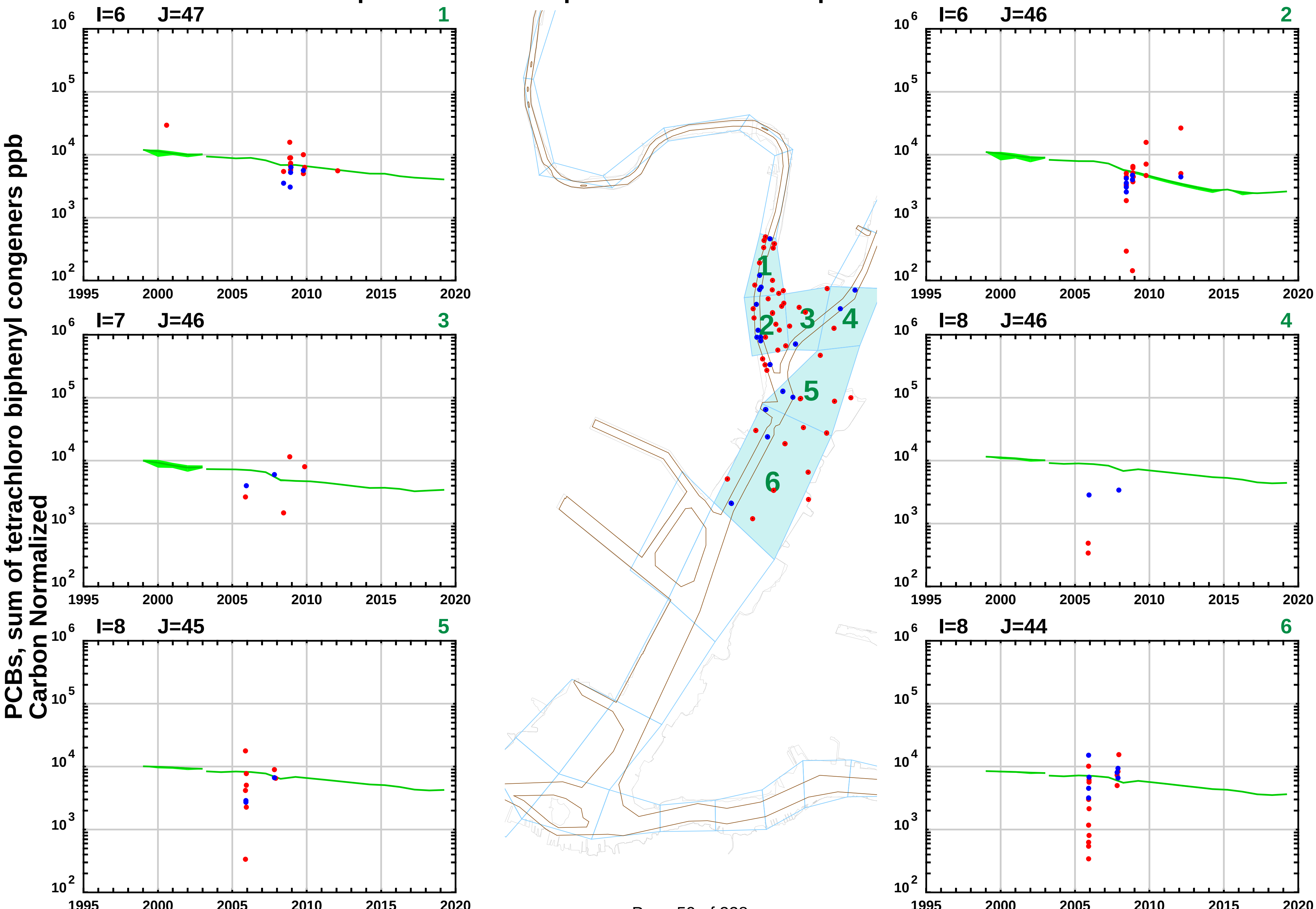
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



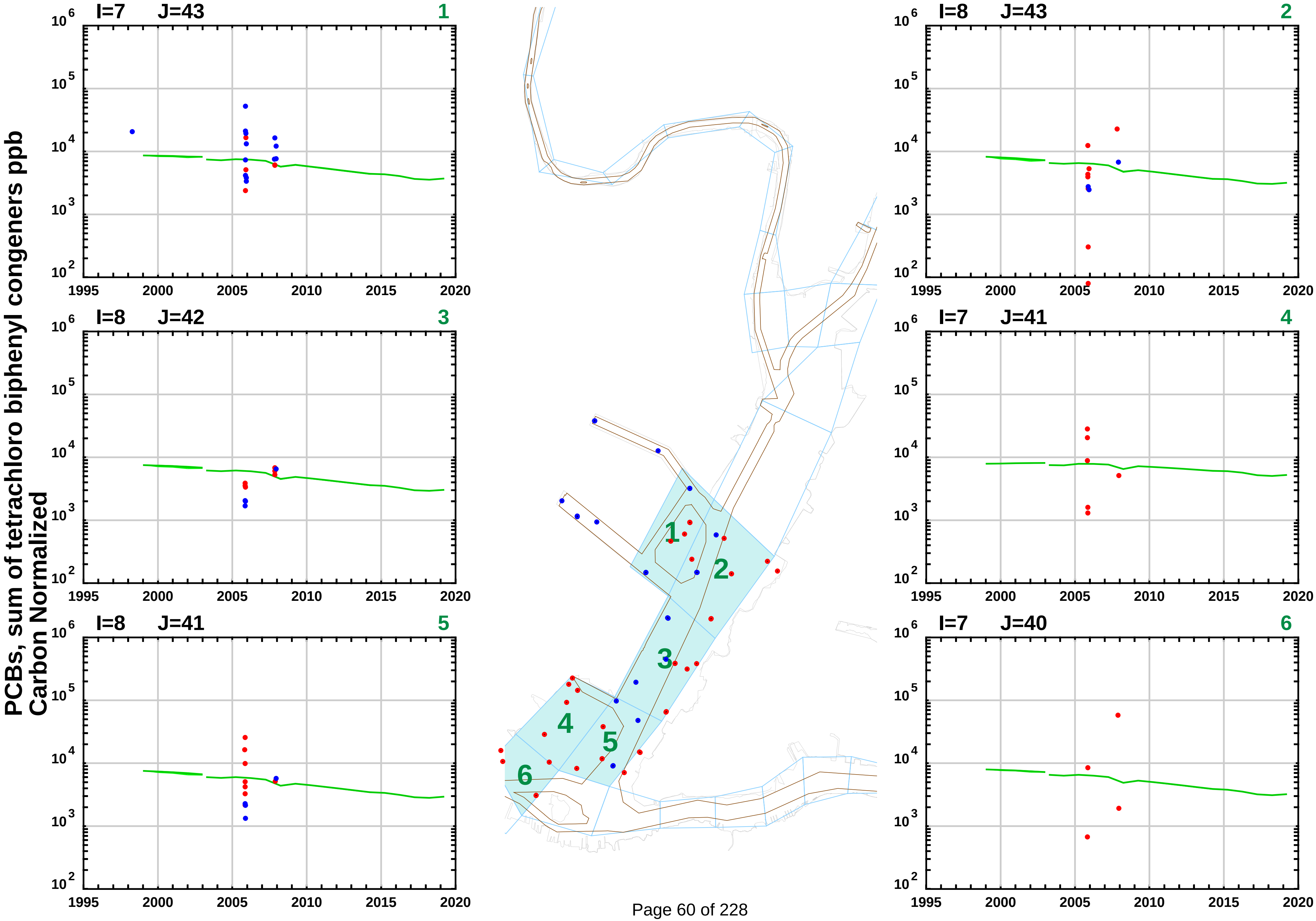
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

In-channel data Off-channel data

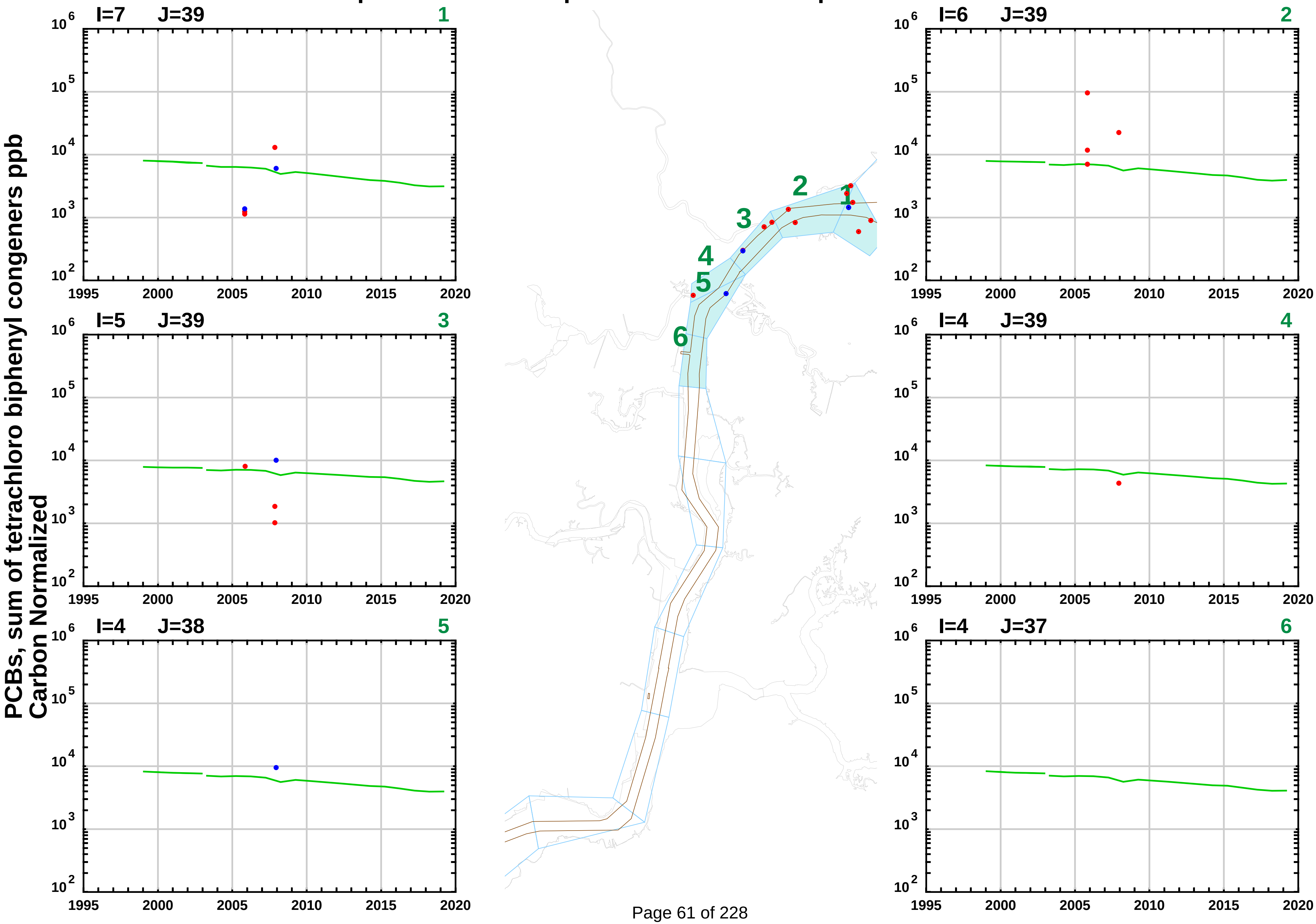
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

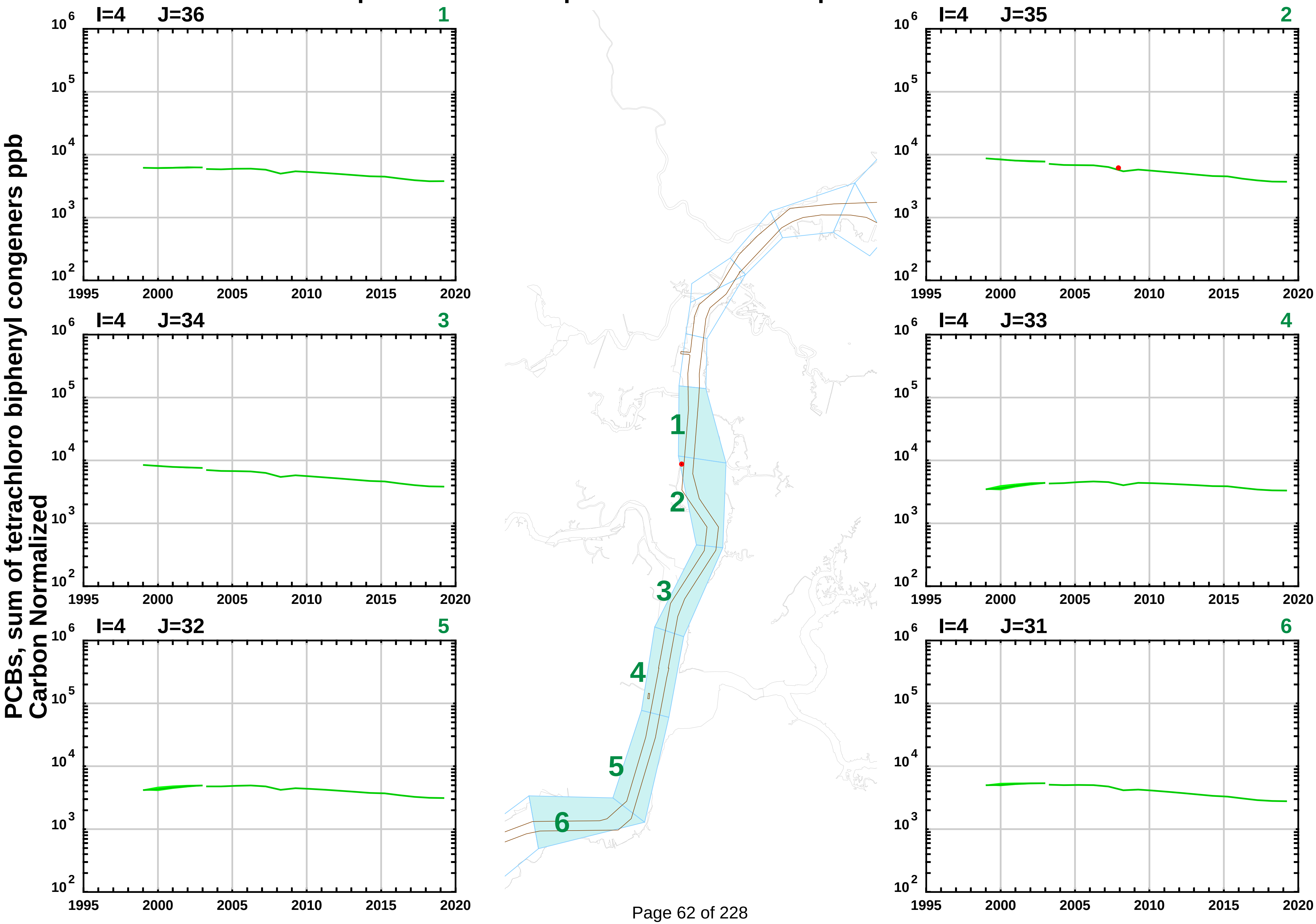
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment

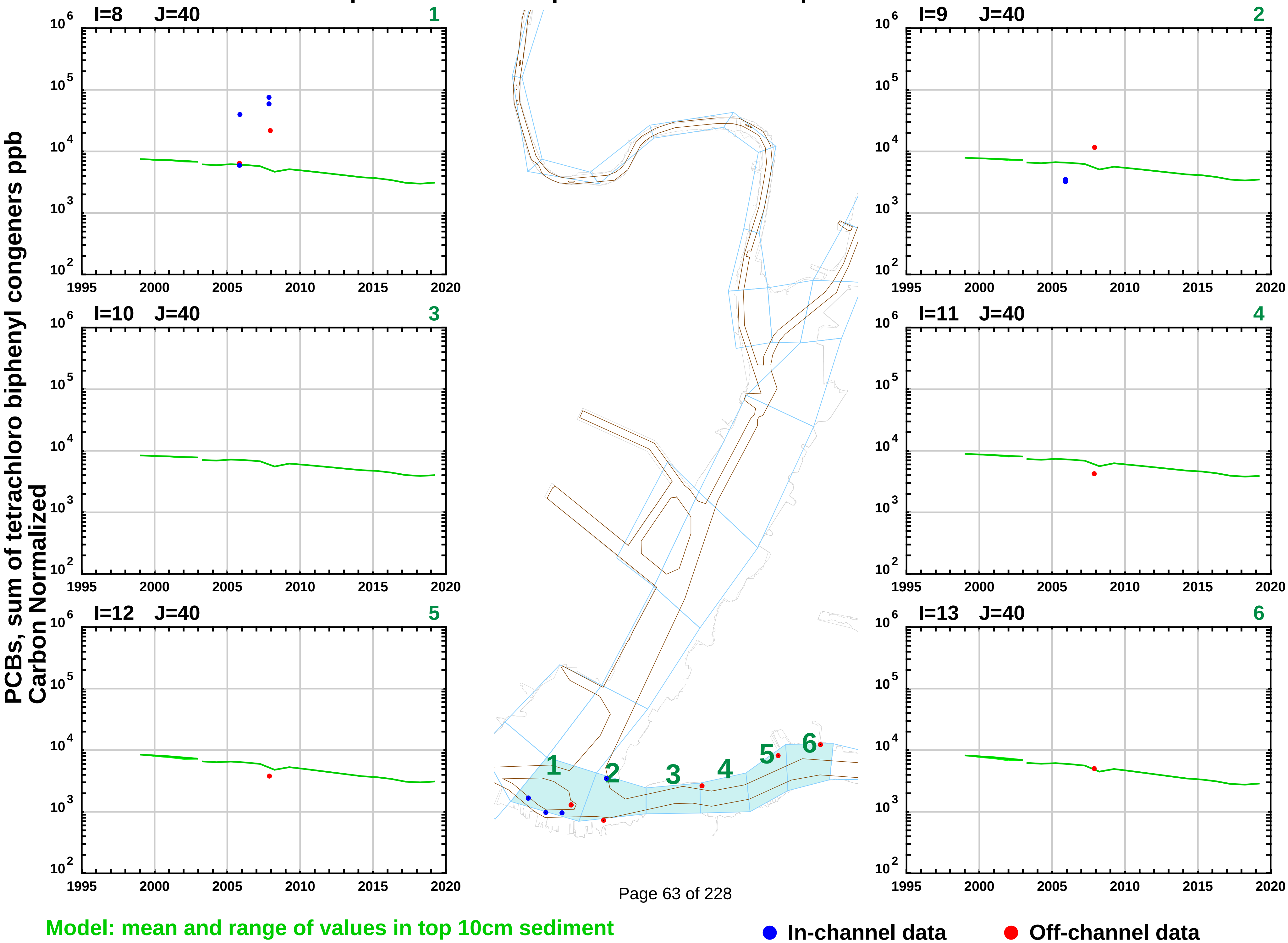


Model: mean and range of values in top 10cm sediment

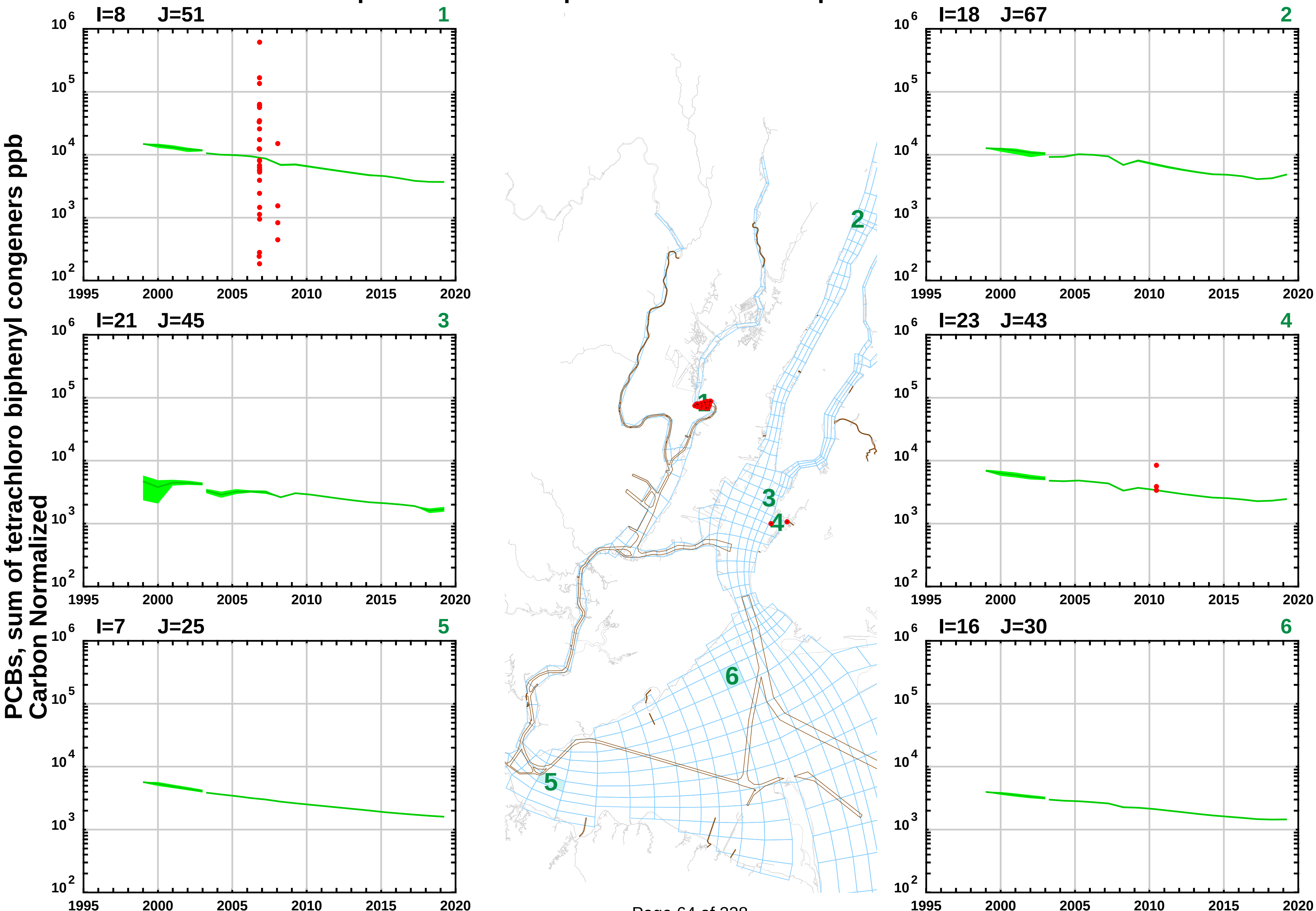
In-channel data

Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



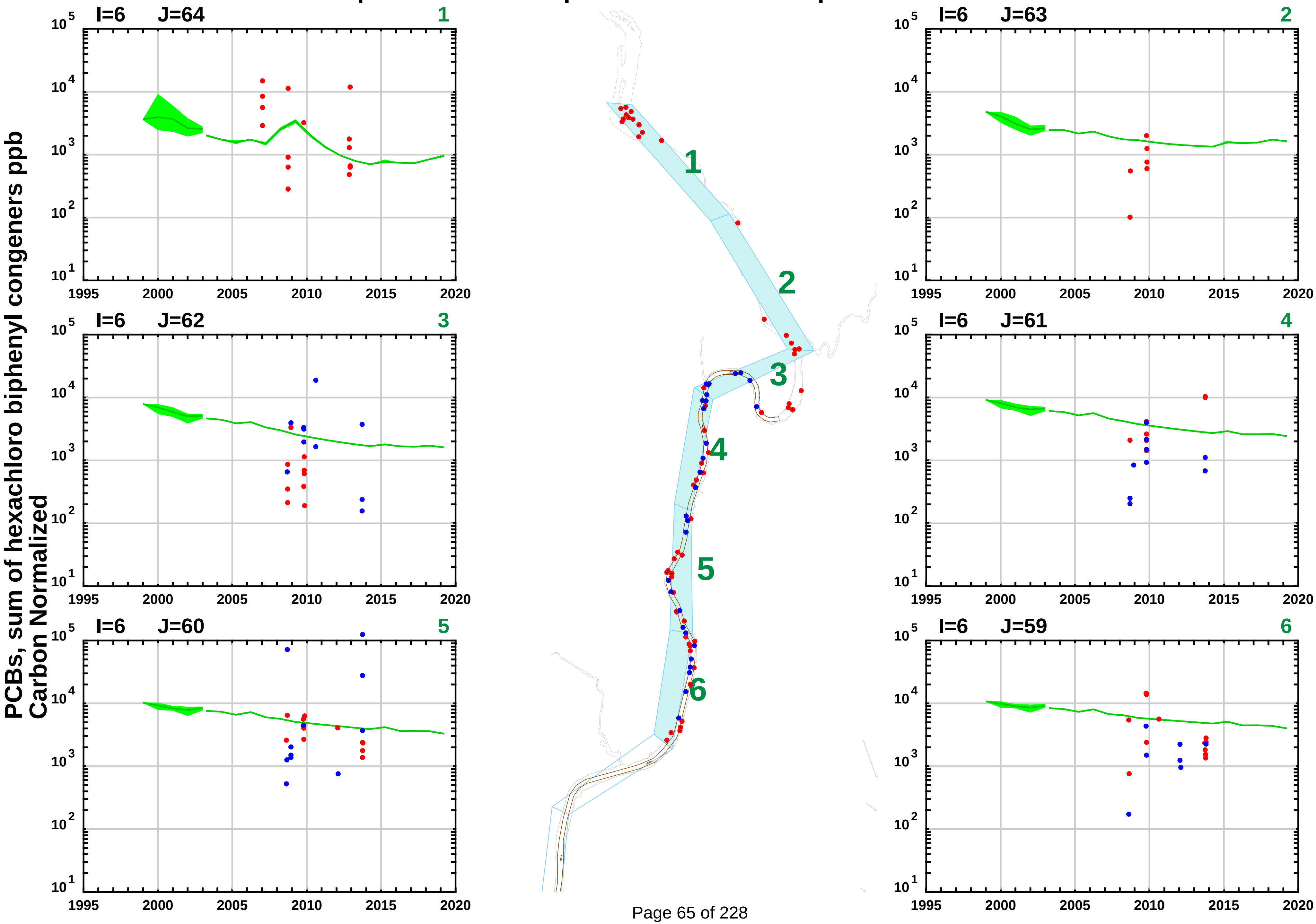
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

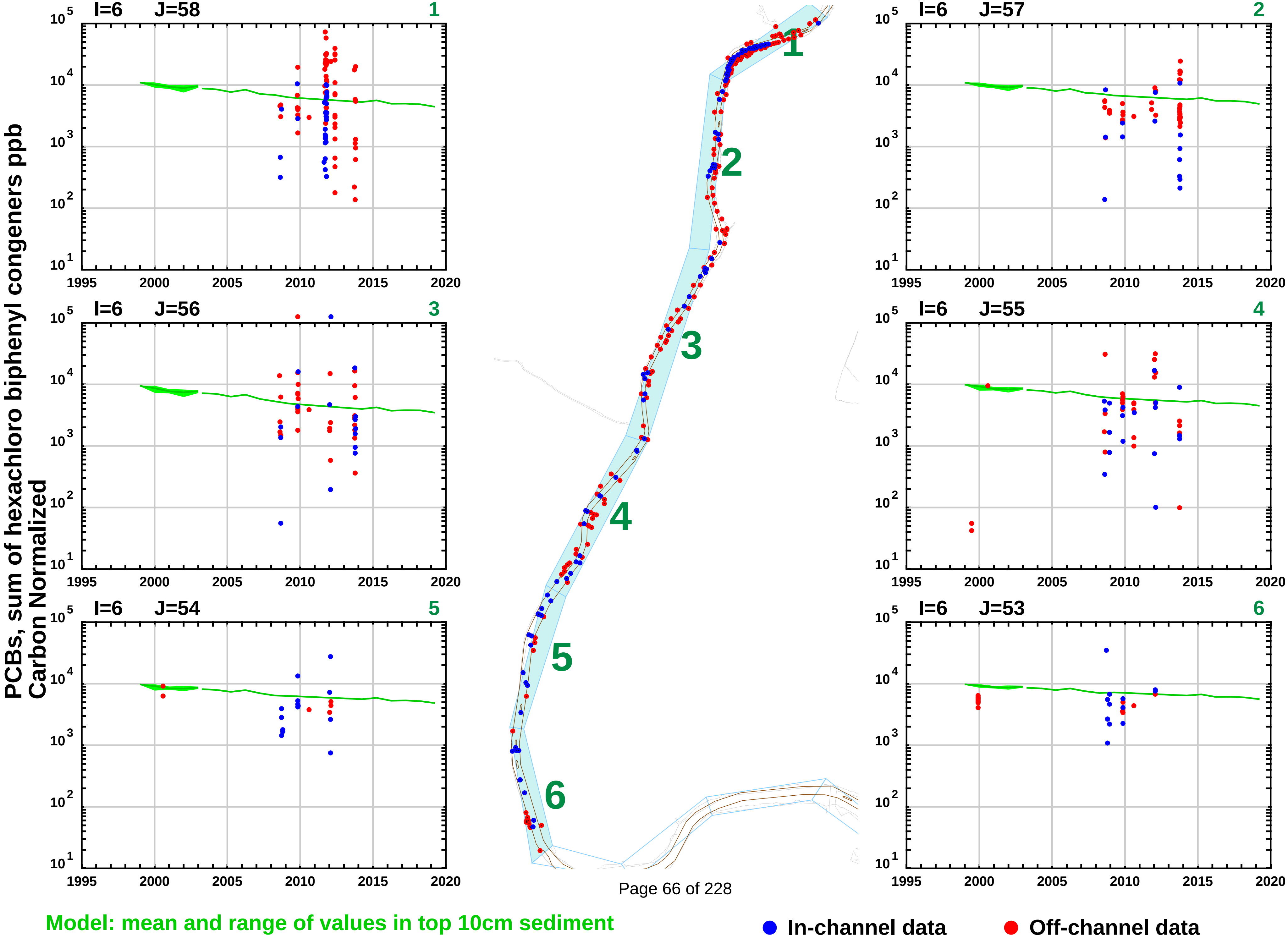
Top 15 cm data comparison with model top 10 cm sediment



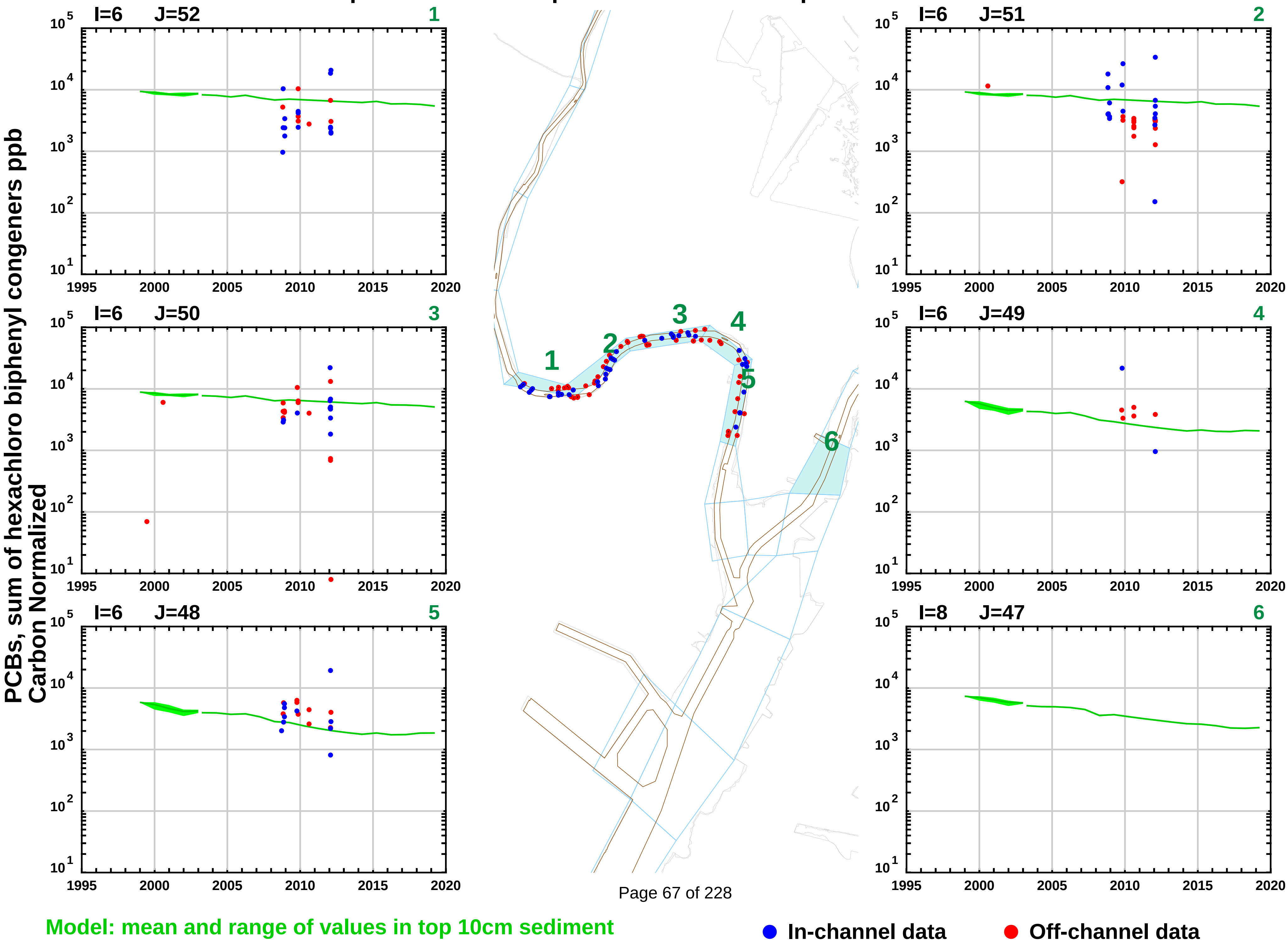
Model: mean and range of values in top 10cm sediment

In-channel data Off-channel data

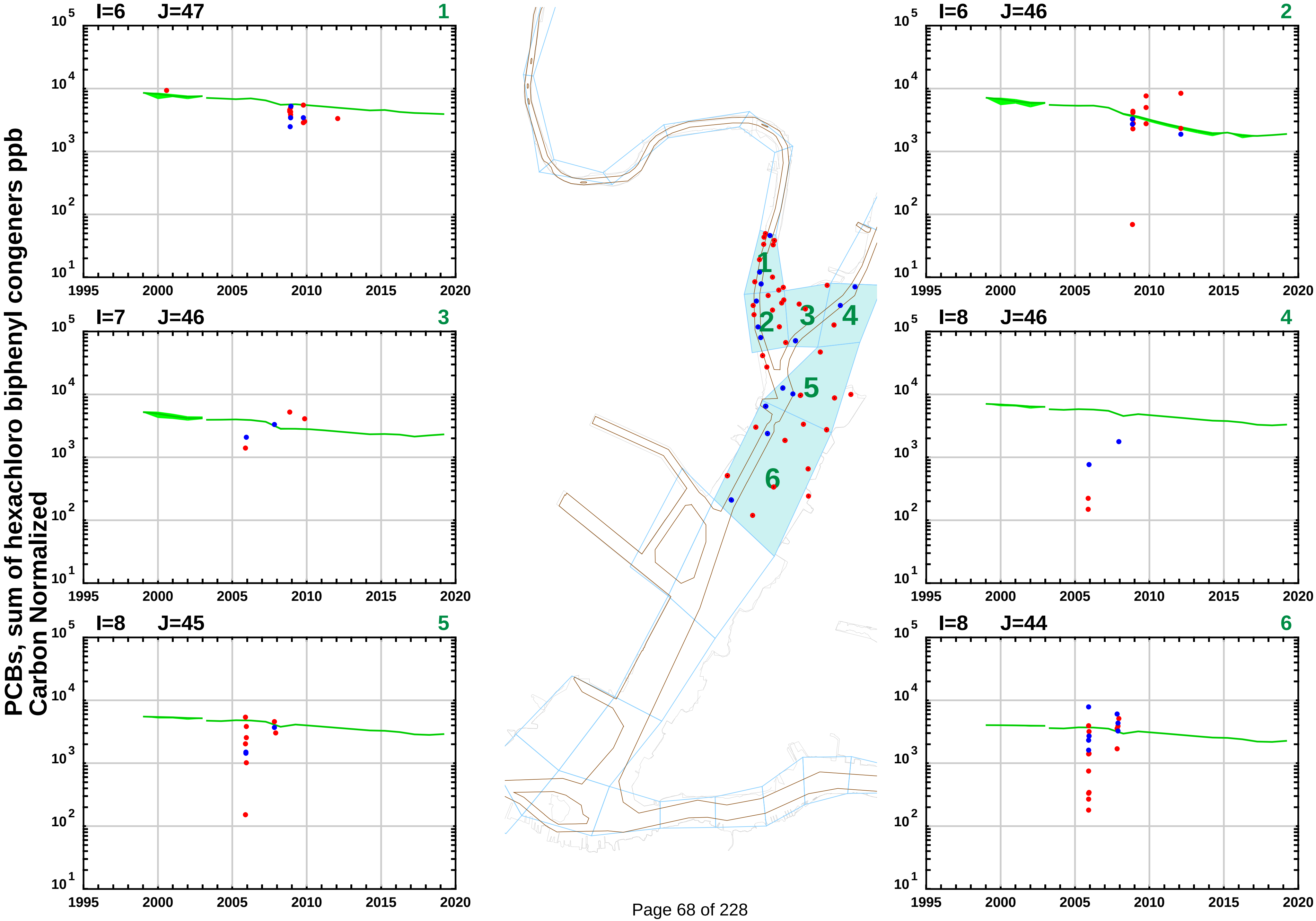
Top 15 cm data comparison with model top 10 cm sediment



Top 15 cm data comparison with model top 10 cm sediment



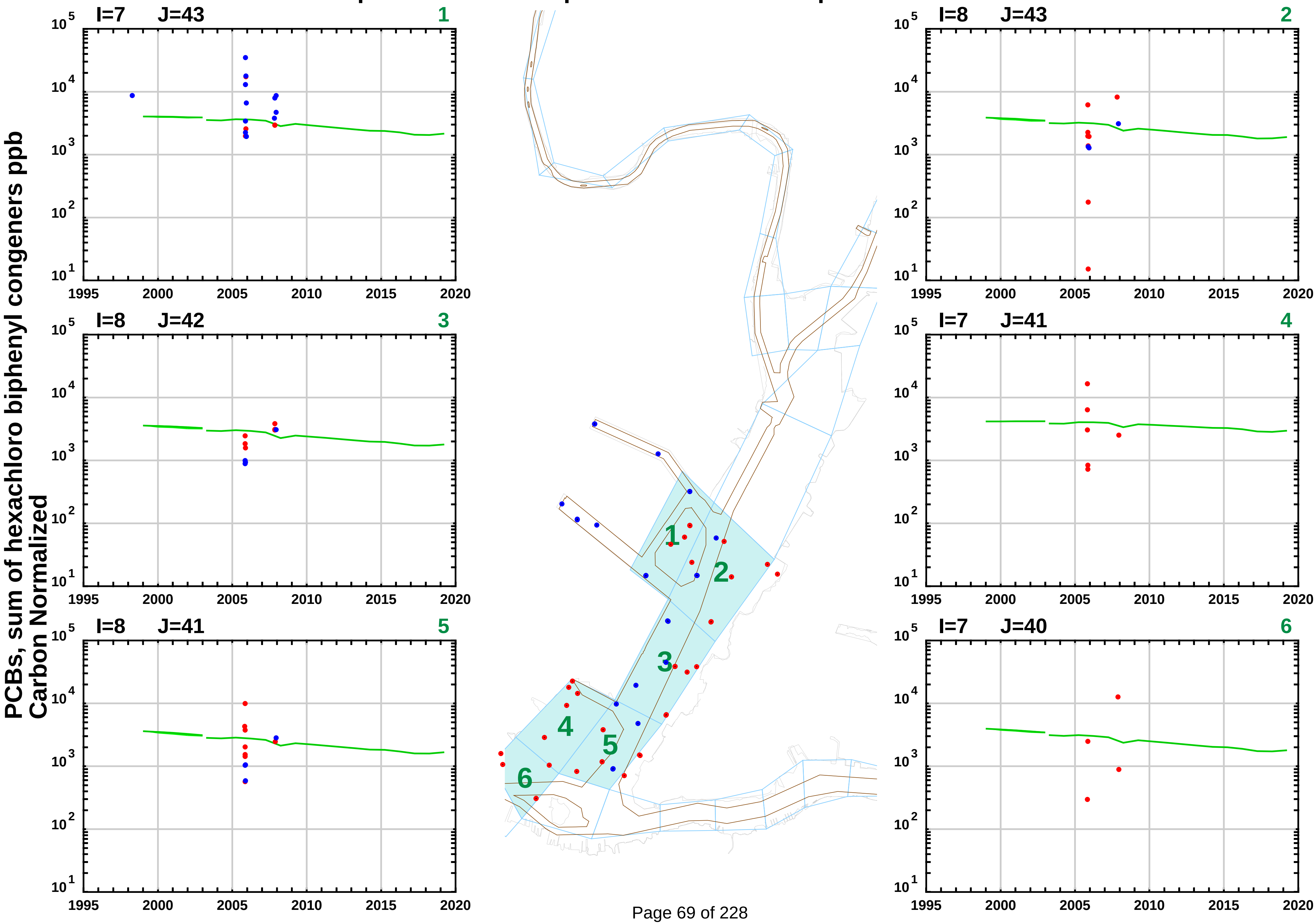
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

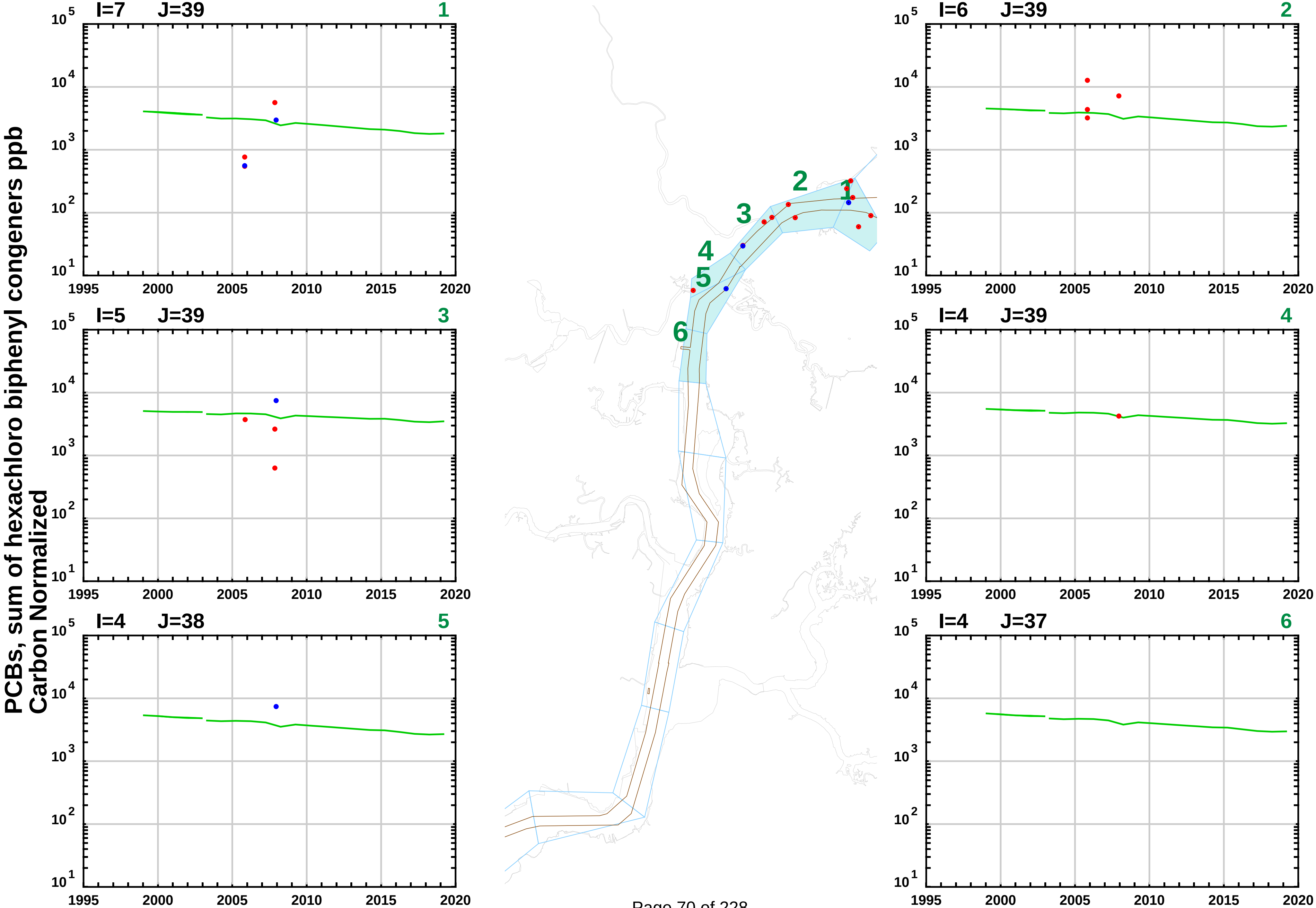
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

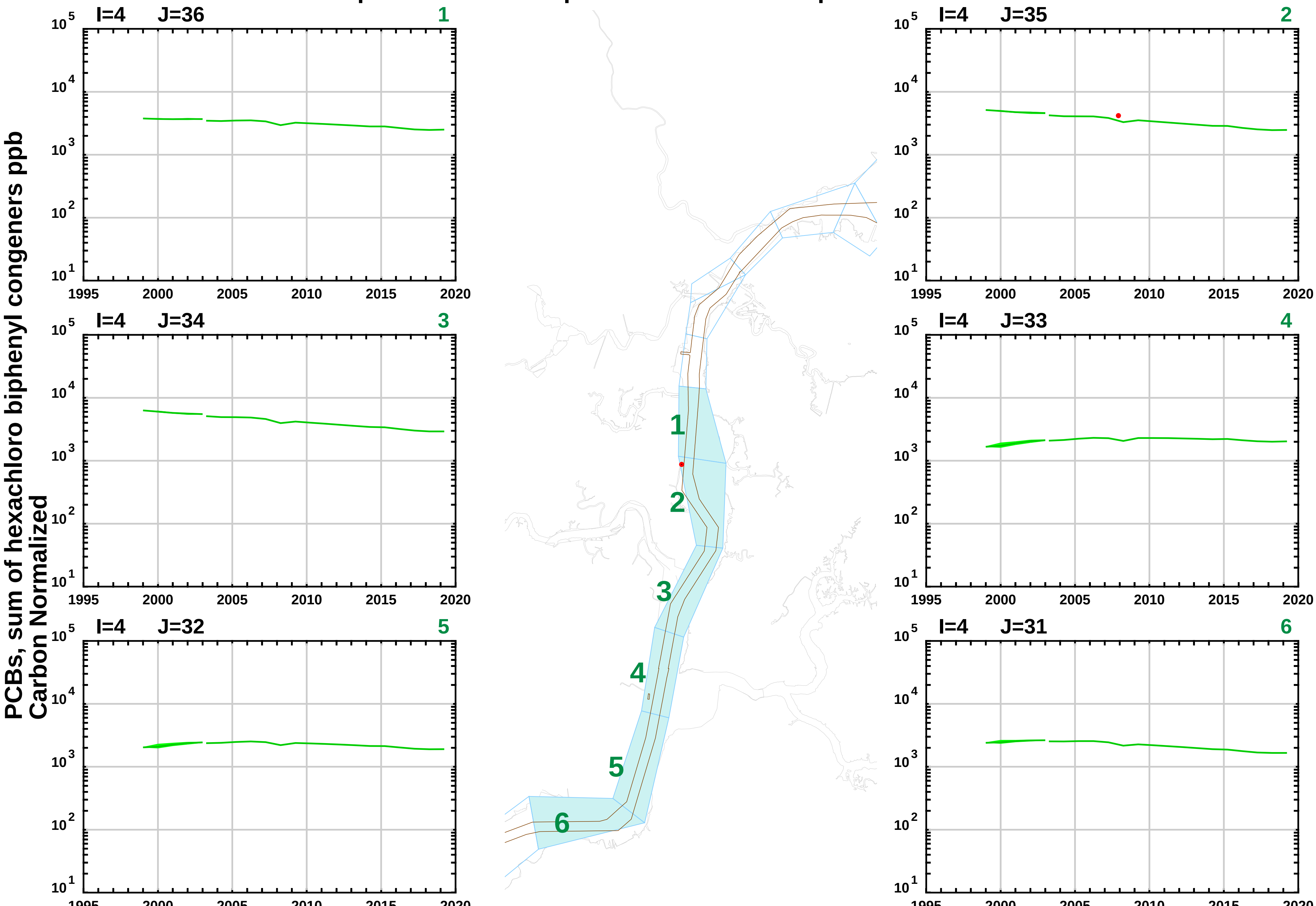
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

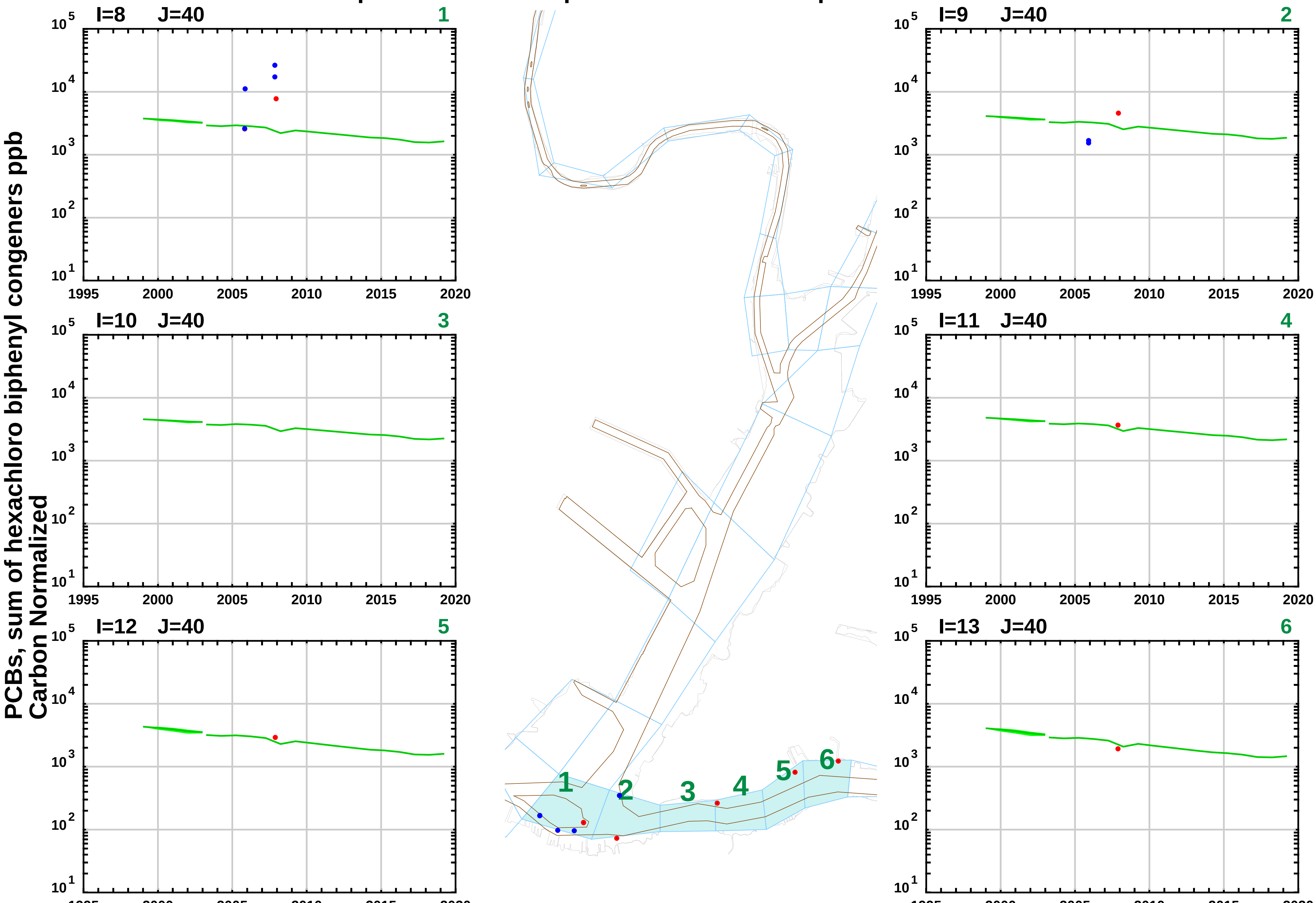
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

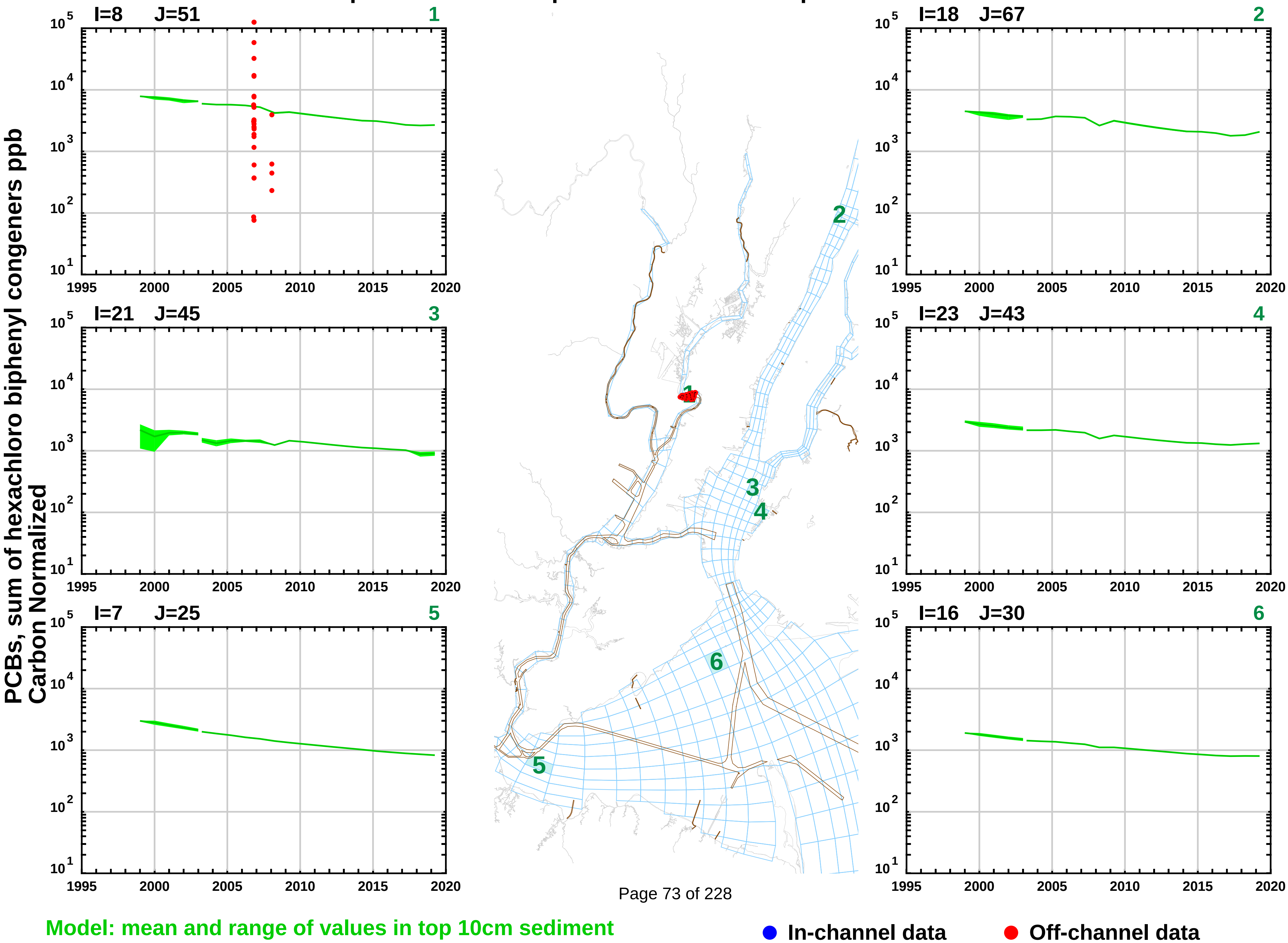
Top 15 cm data comparison with model top 10 cm sediment



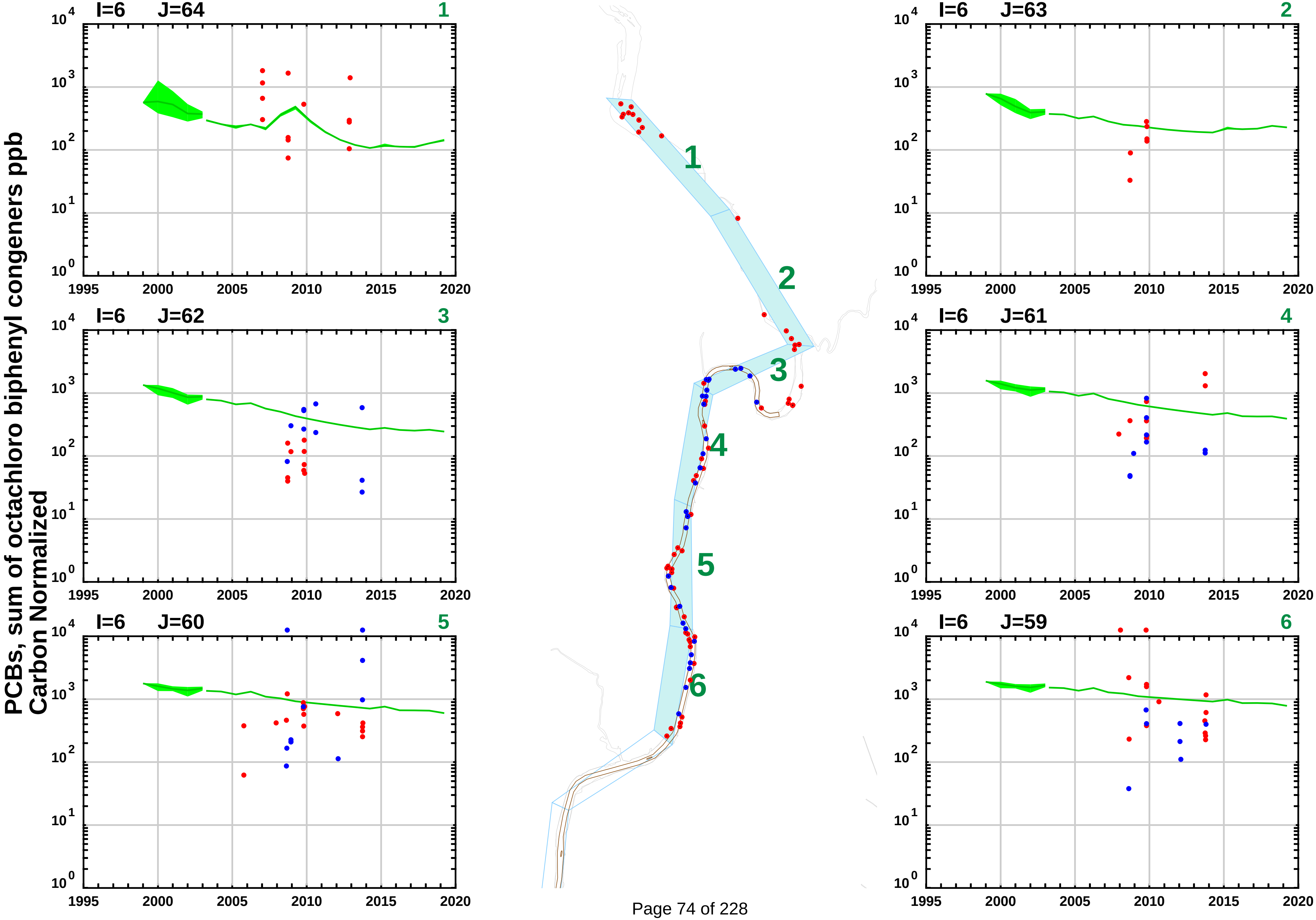
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



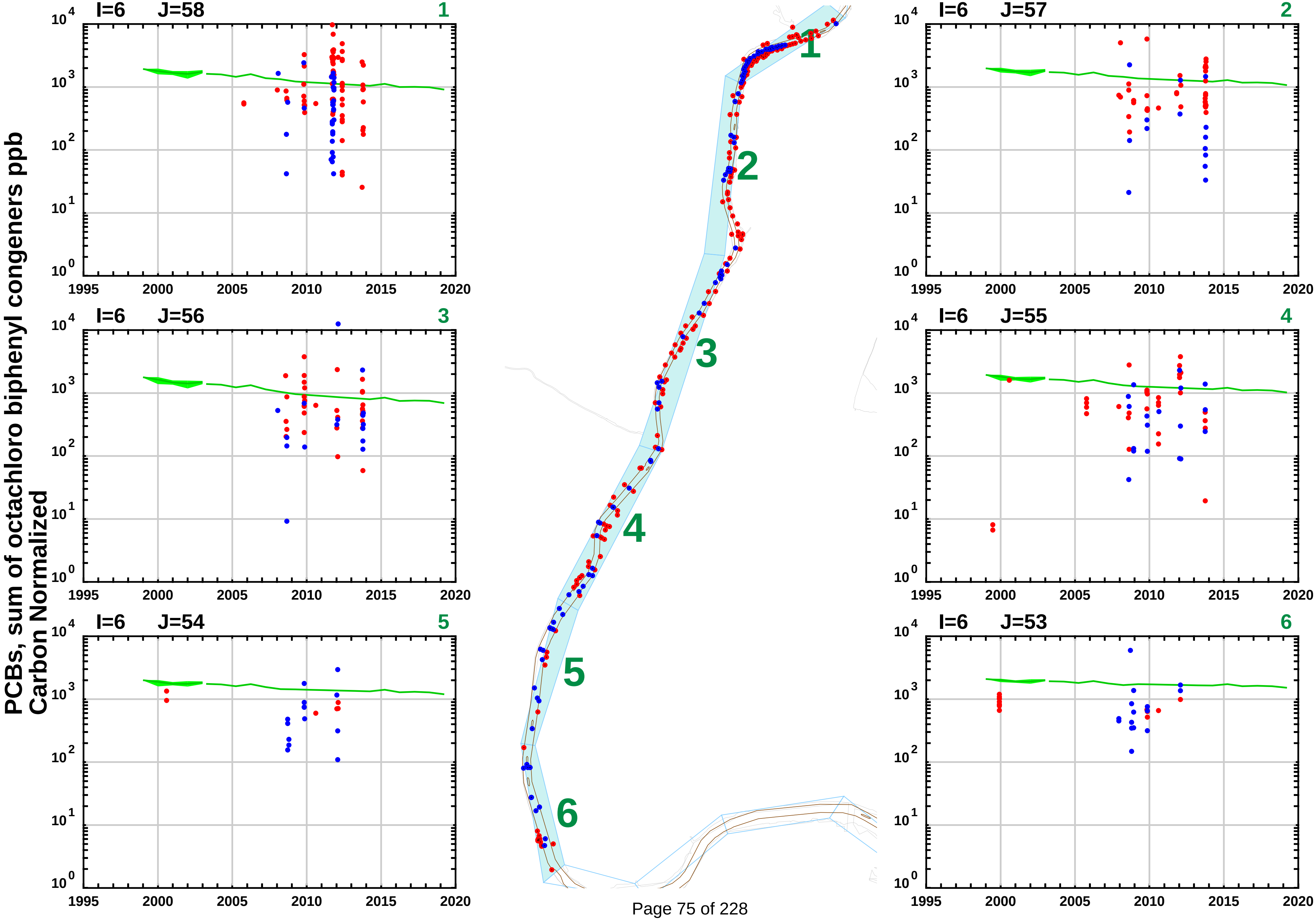
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

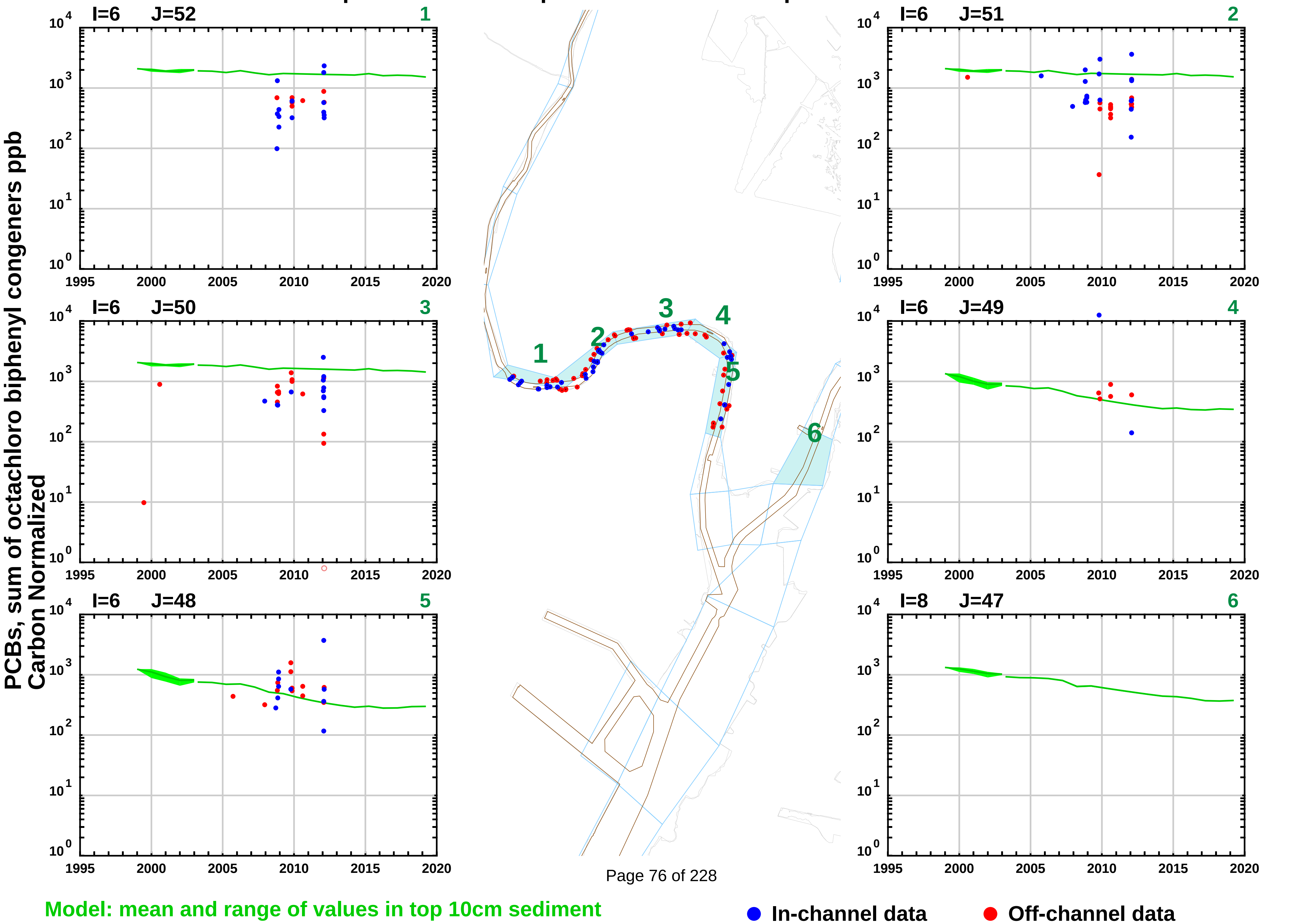
Top 15 cm data comparison with model top 10 cm sediment



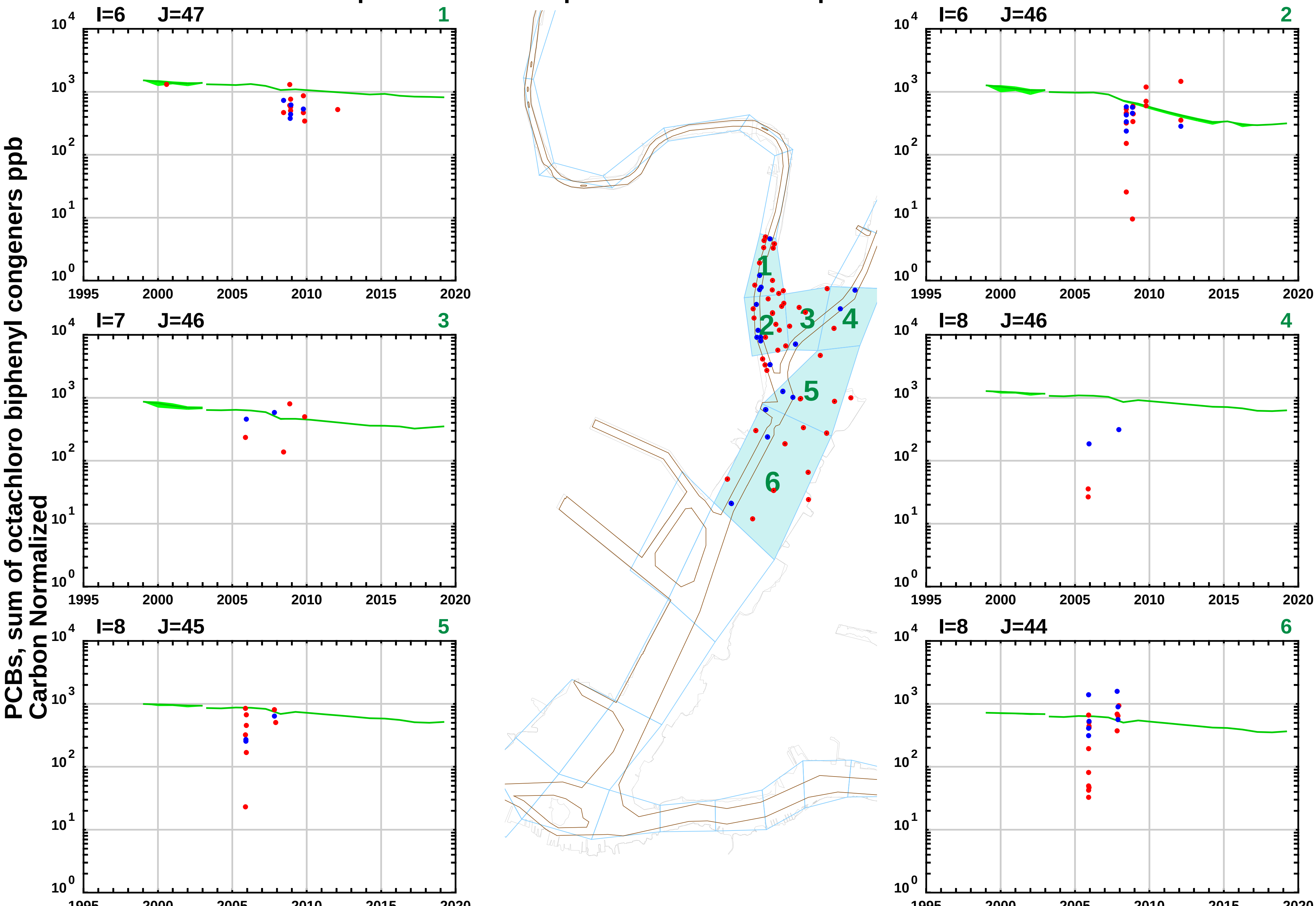
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



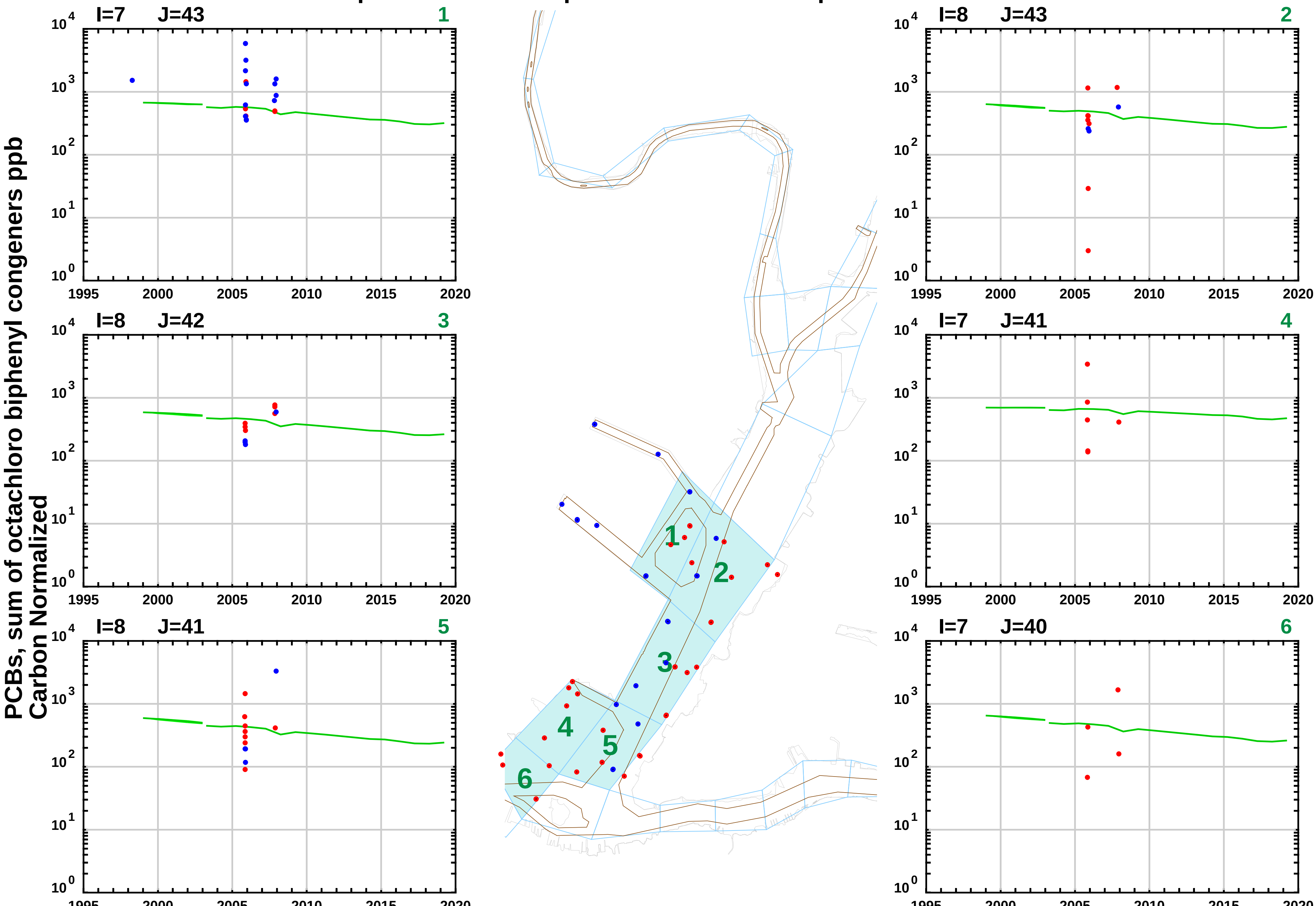
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

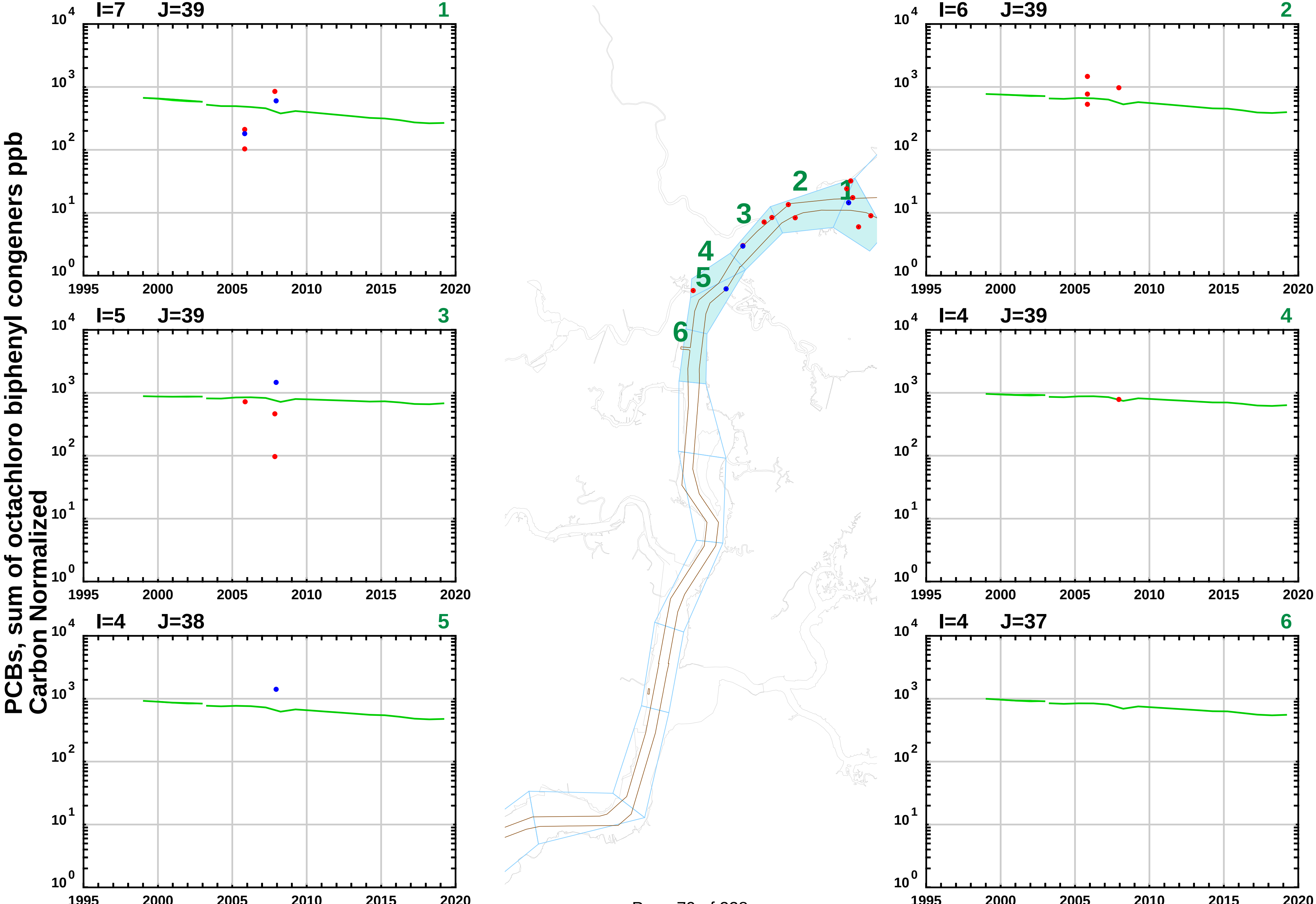
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

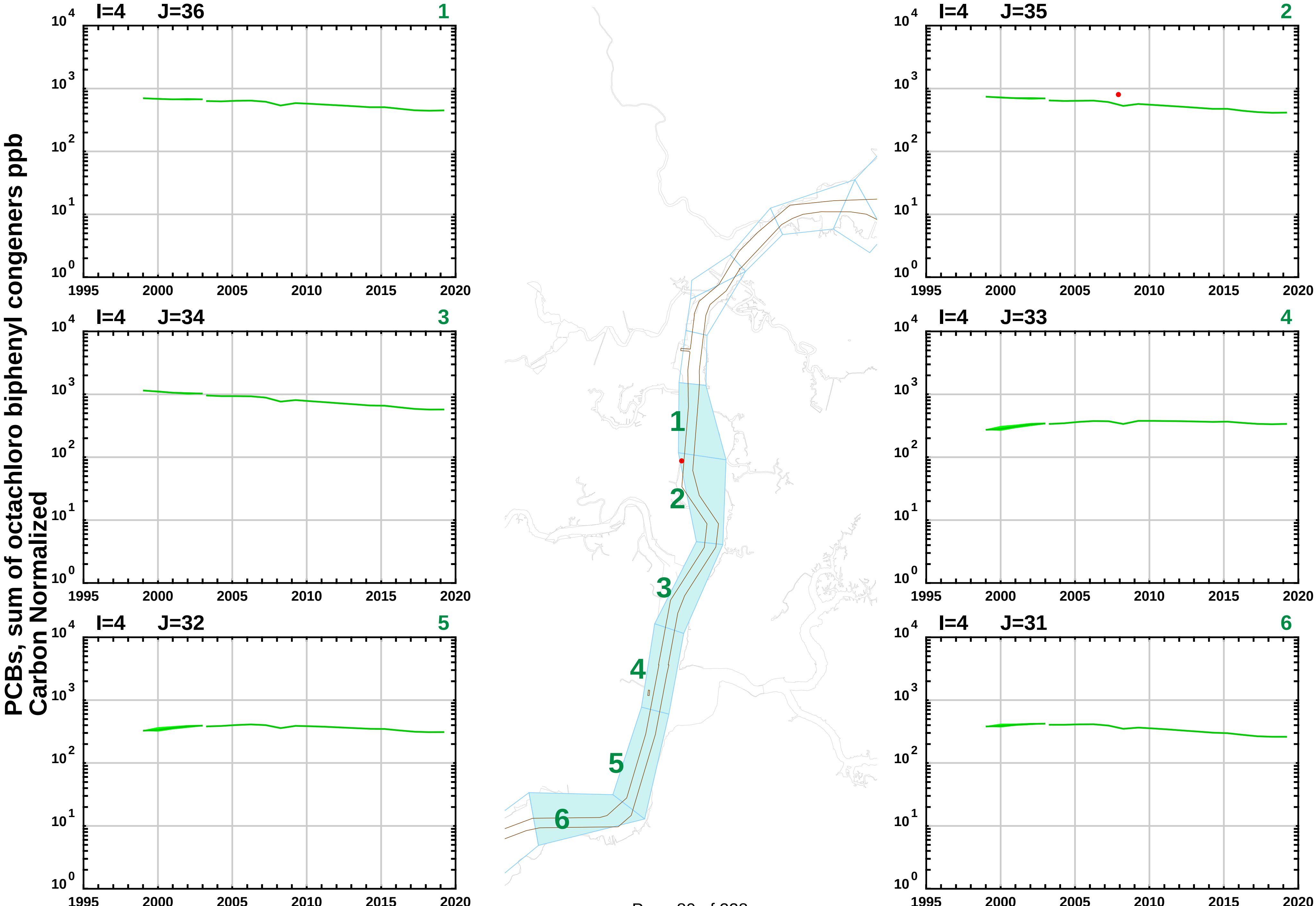
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

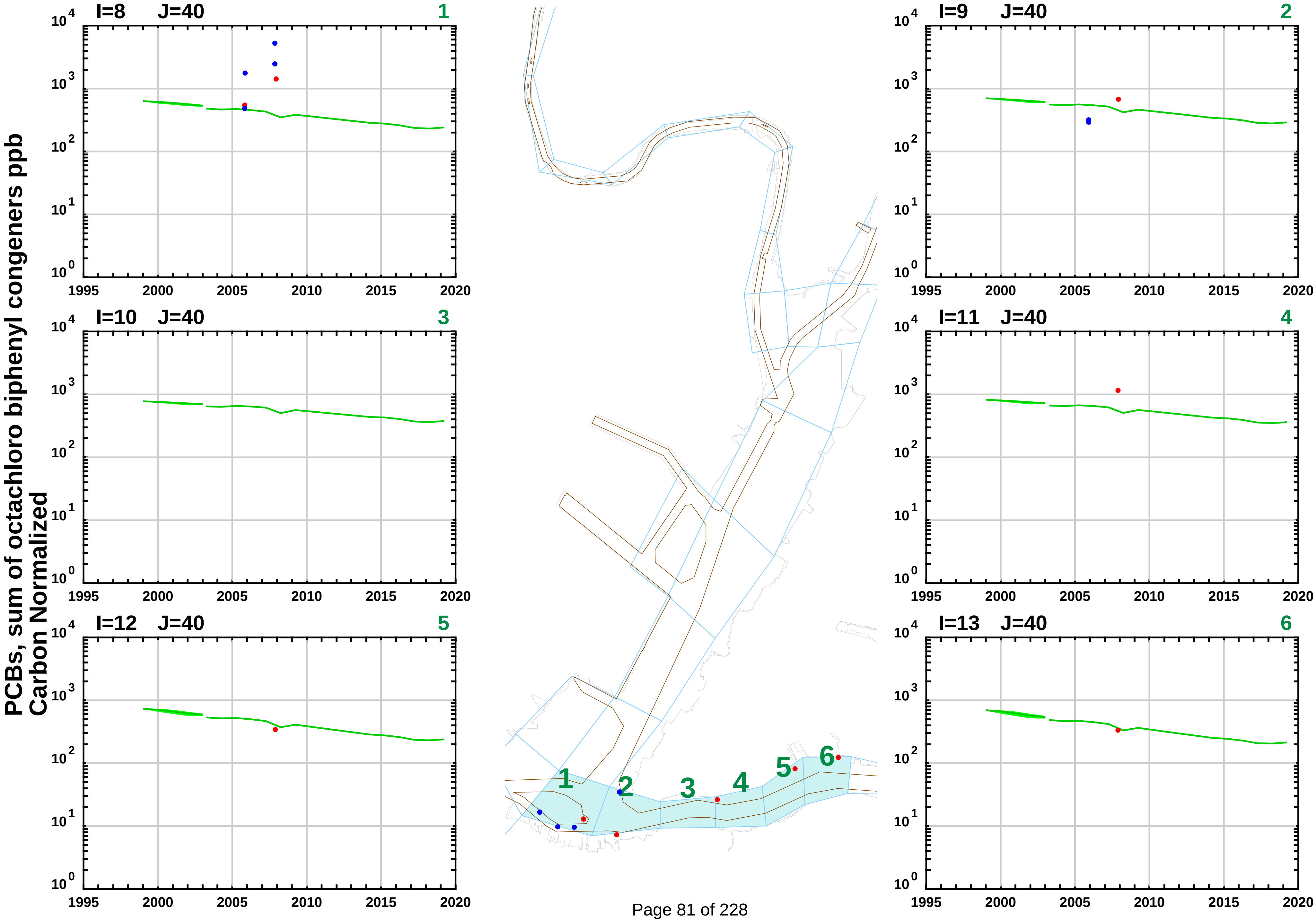
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

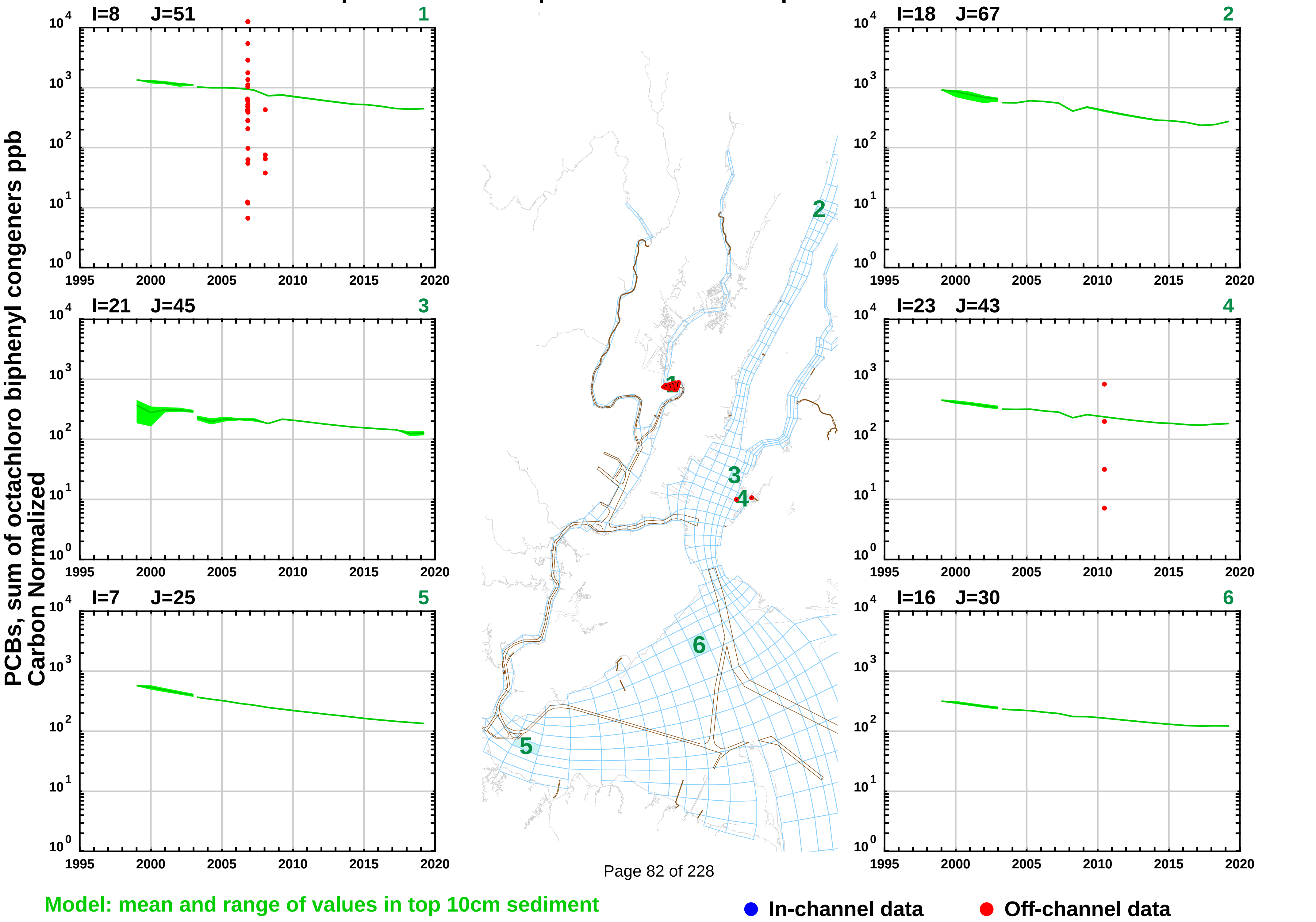
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

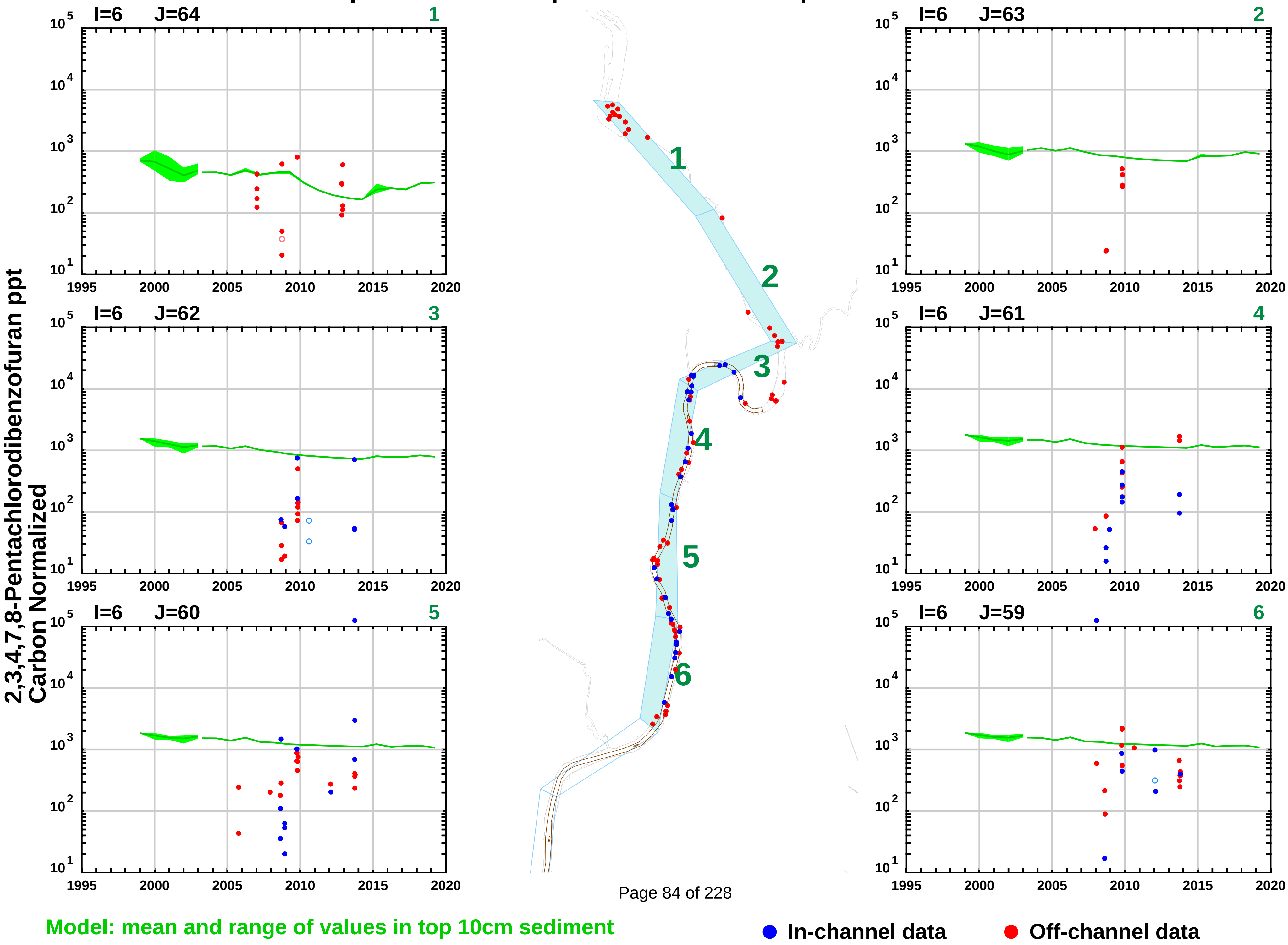
In-channel data   Off-channel data

Top 15 cm data comparison with model top 10 cm sediment

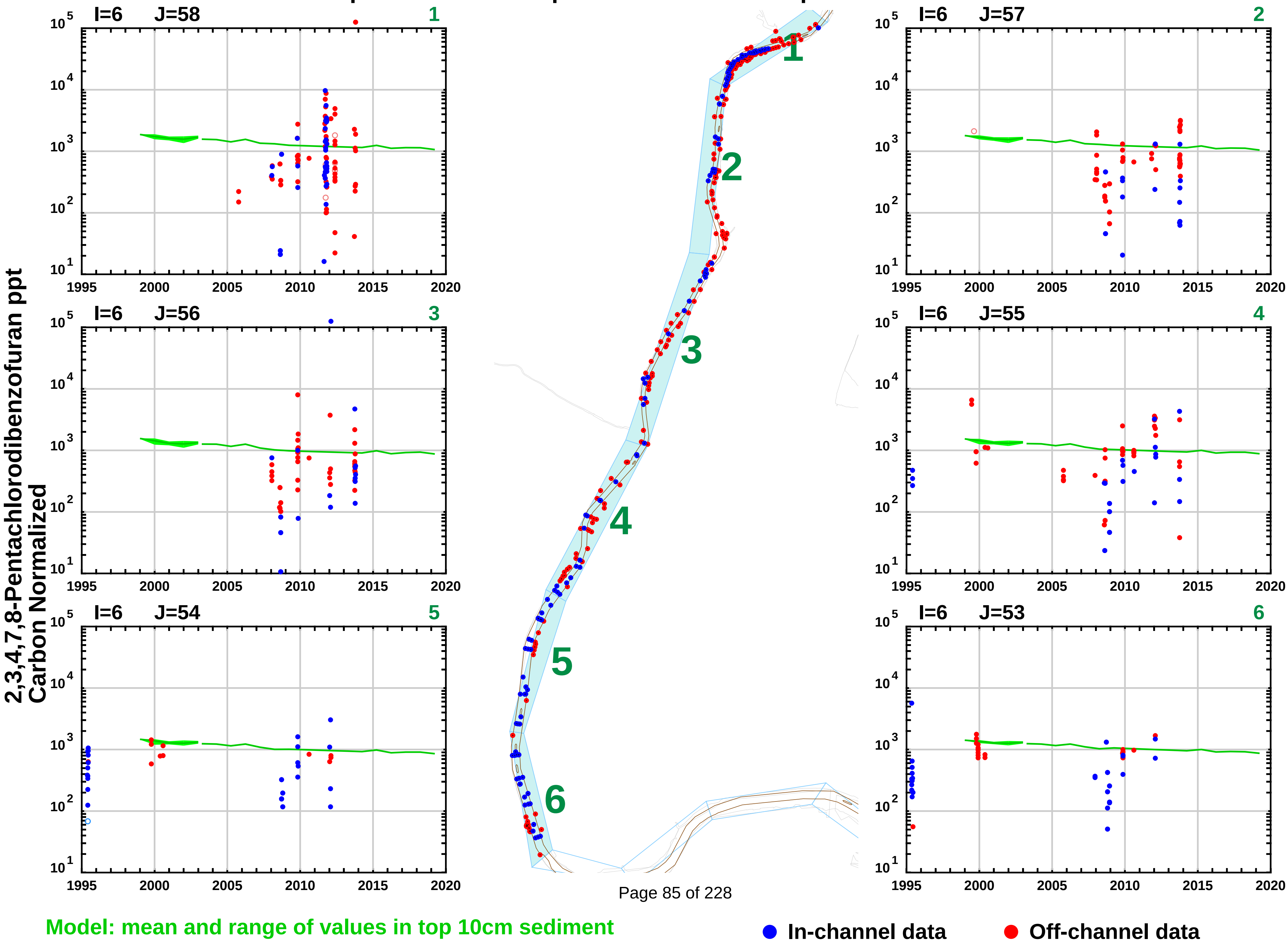


Attachment 1D, 2,3,4,7,8-PCDF

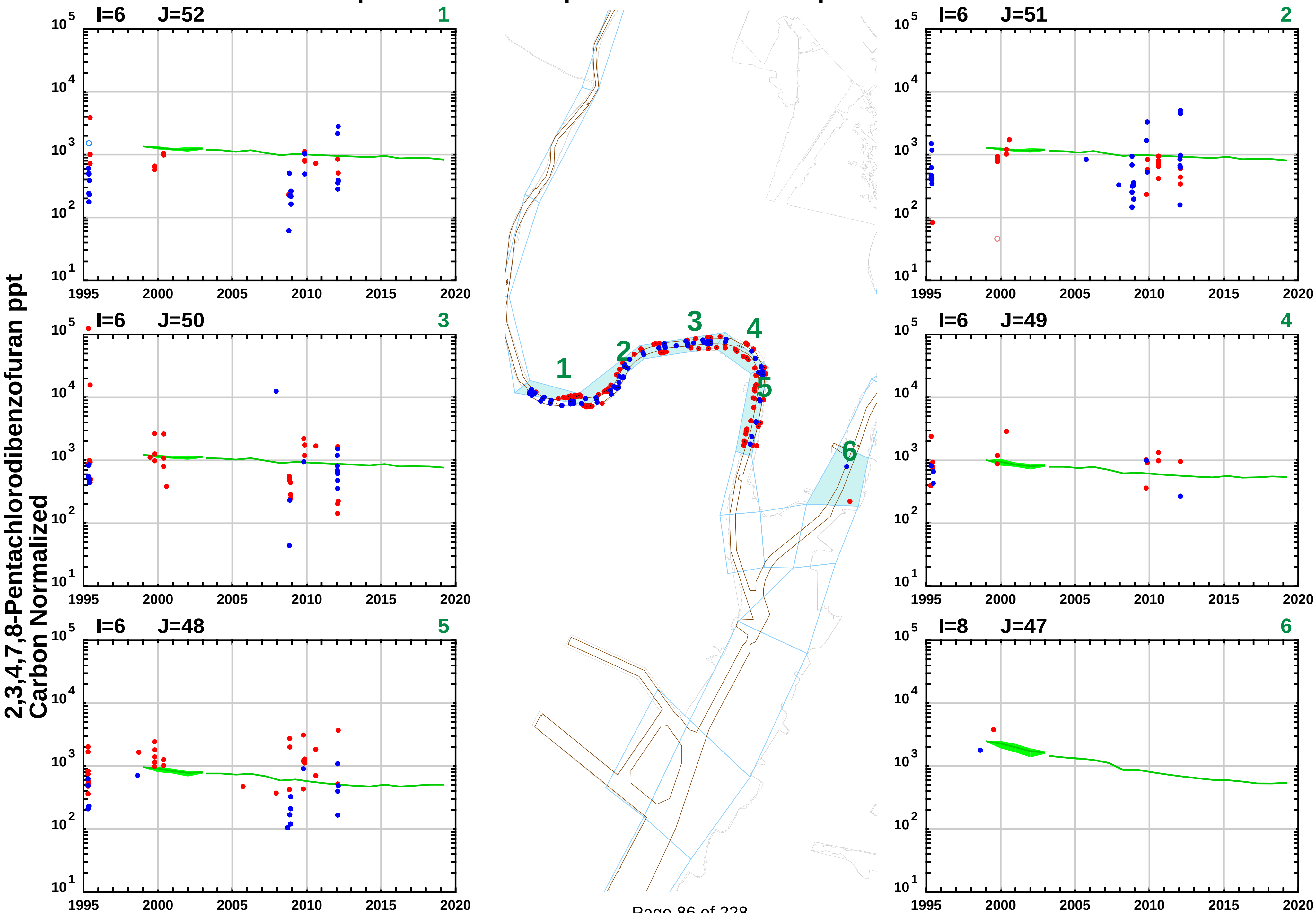
Top 15 cm data comparison with model top 10 cm sediment



Top 15 cm data comparison with model top 10 cm sediment

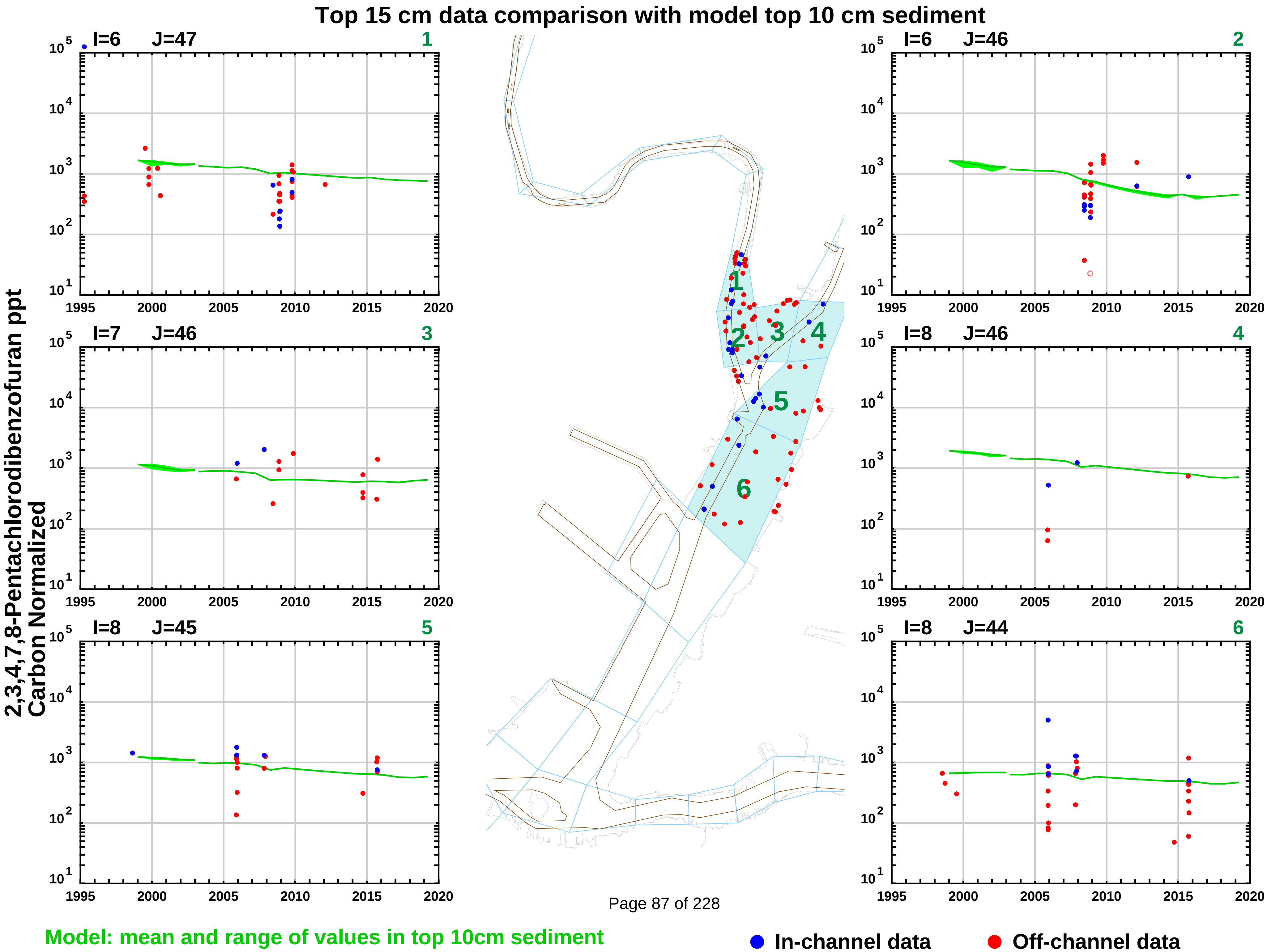


Top 15 cm data comparison with model top 10 cm sediment



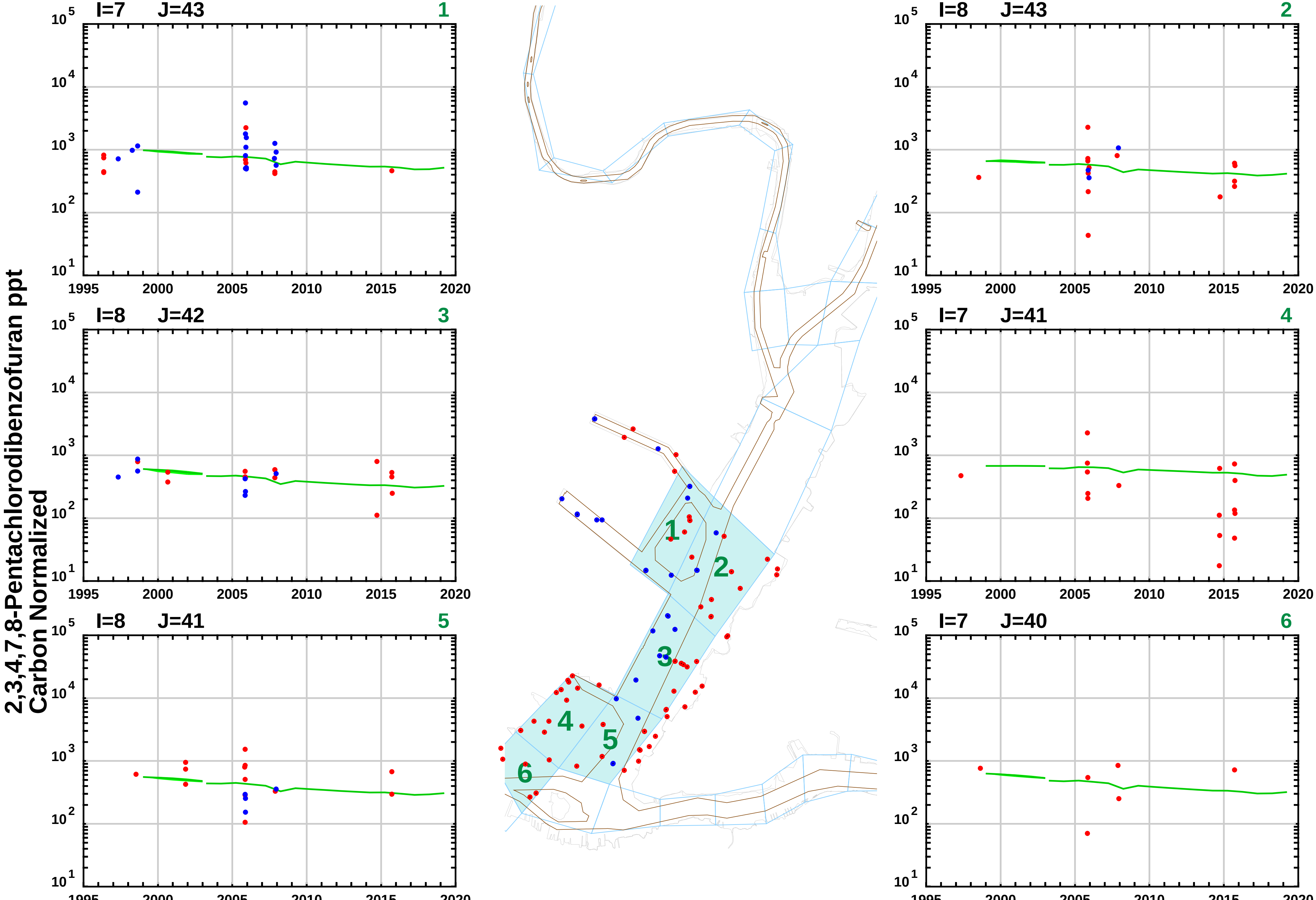
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data



Top 15 cm data comparison with model top 10 cm sediment
2,3,4,7,8-Pentachlorodibenzofuran ppt
Carbon Normalized
I=6 J=47 1
I=6 J=46 2
I=7 J=46 3
I=8 J=46 4
I=8 J=45 5
I=8 J=44 6
1995
2000
2005
2010
2015
2020
Model: mean and range of values in top 10cm sediment
In-channel data
Off-channel data

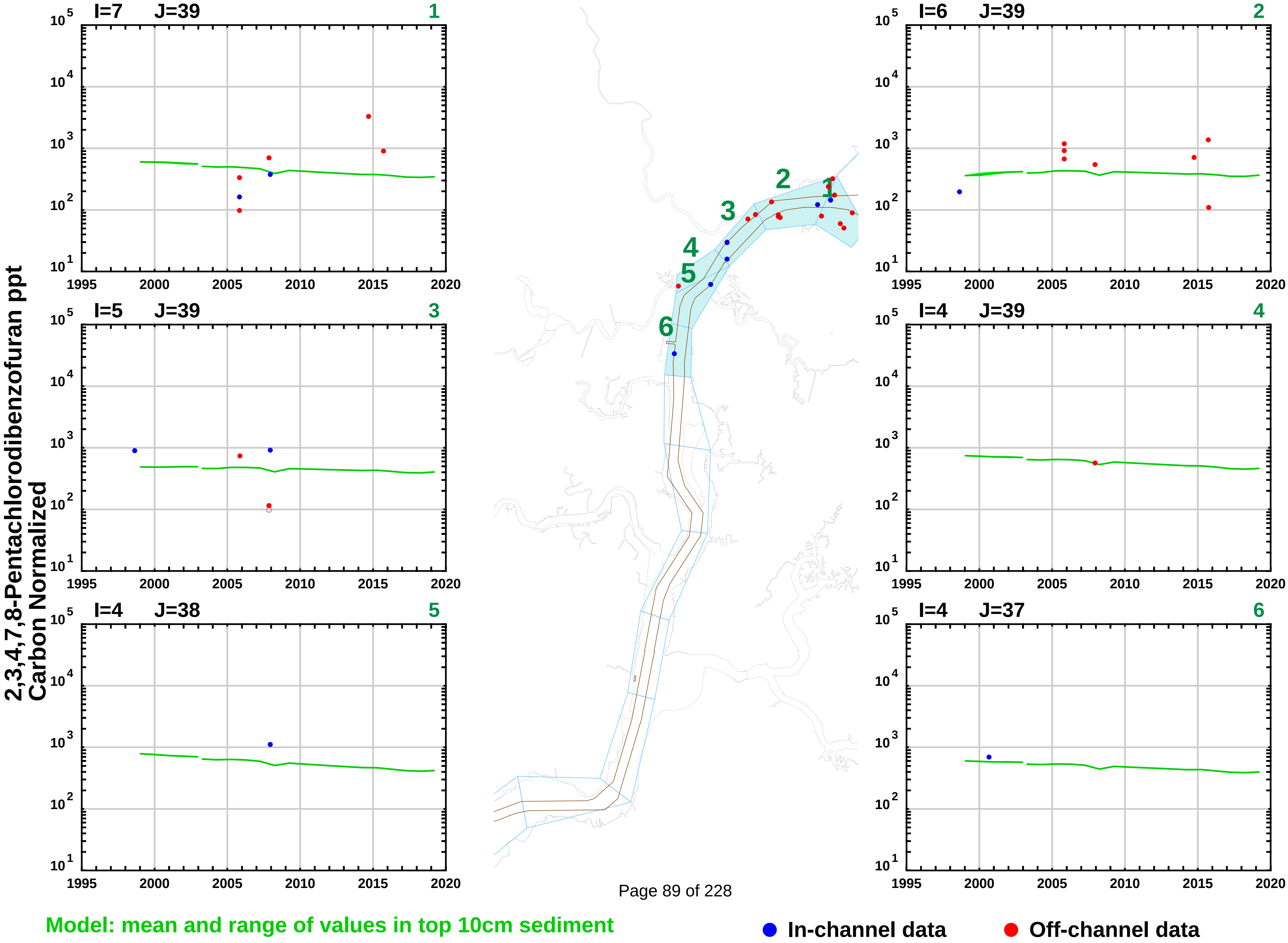
Top 15 cm data comparison with model top 10 cm sediment



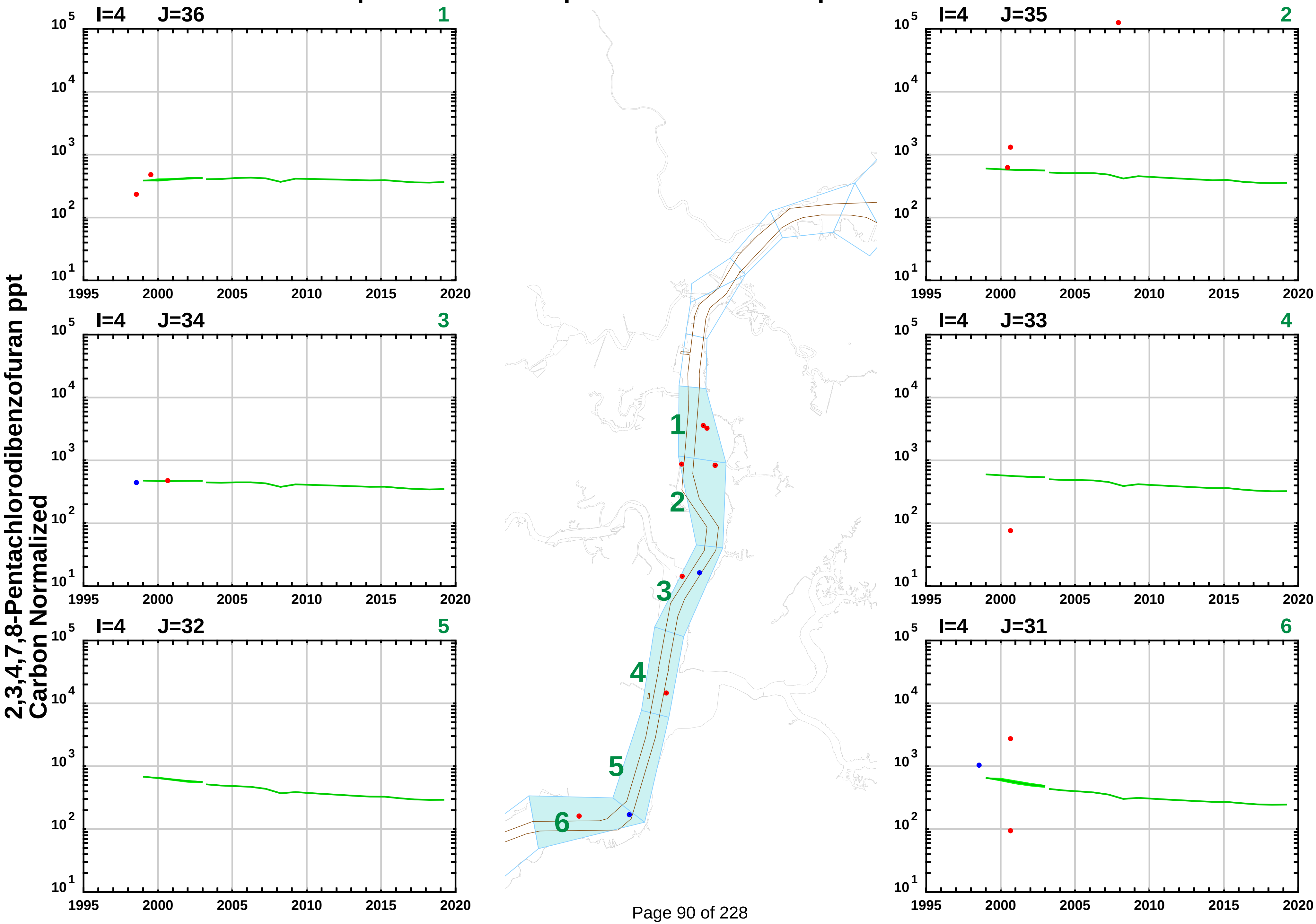
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



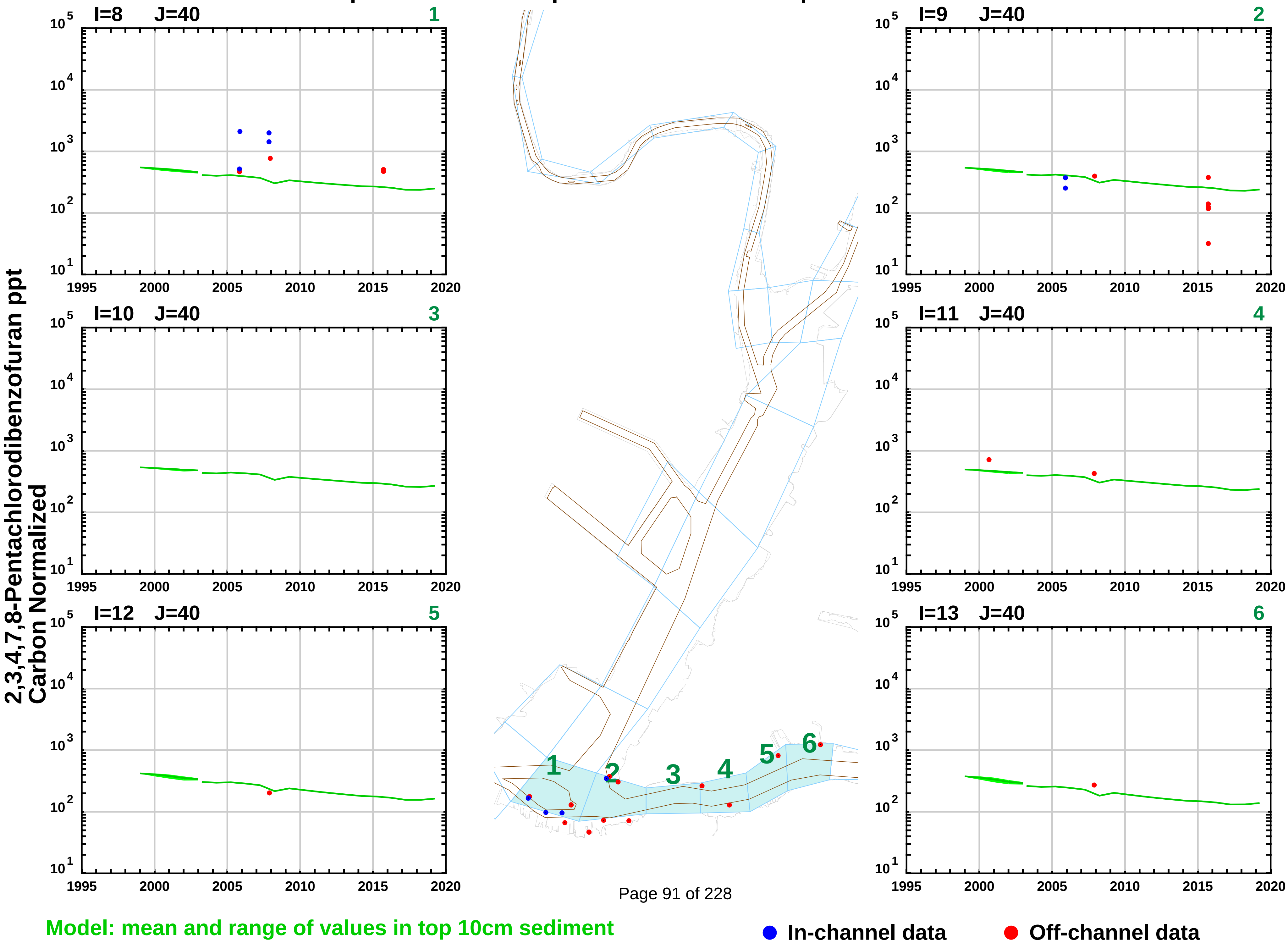
Top 15 cm data comparison with model top 10 cm sediment



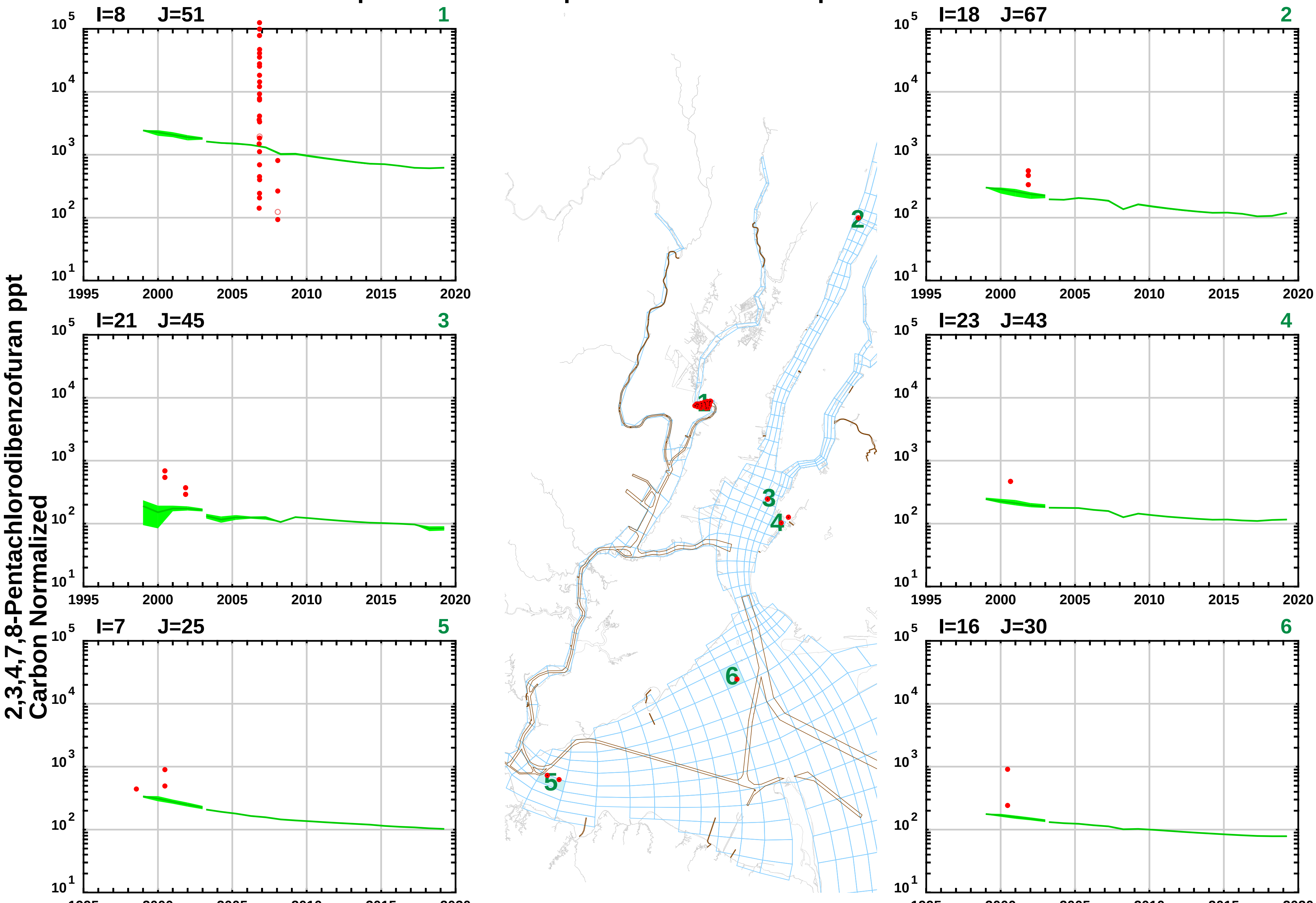
Model: mean and range of values in top 10cm sediment

In-channel data Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

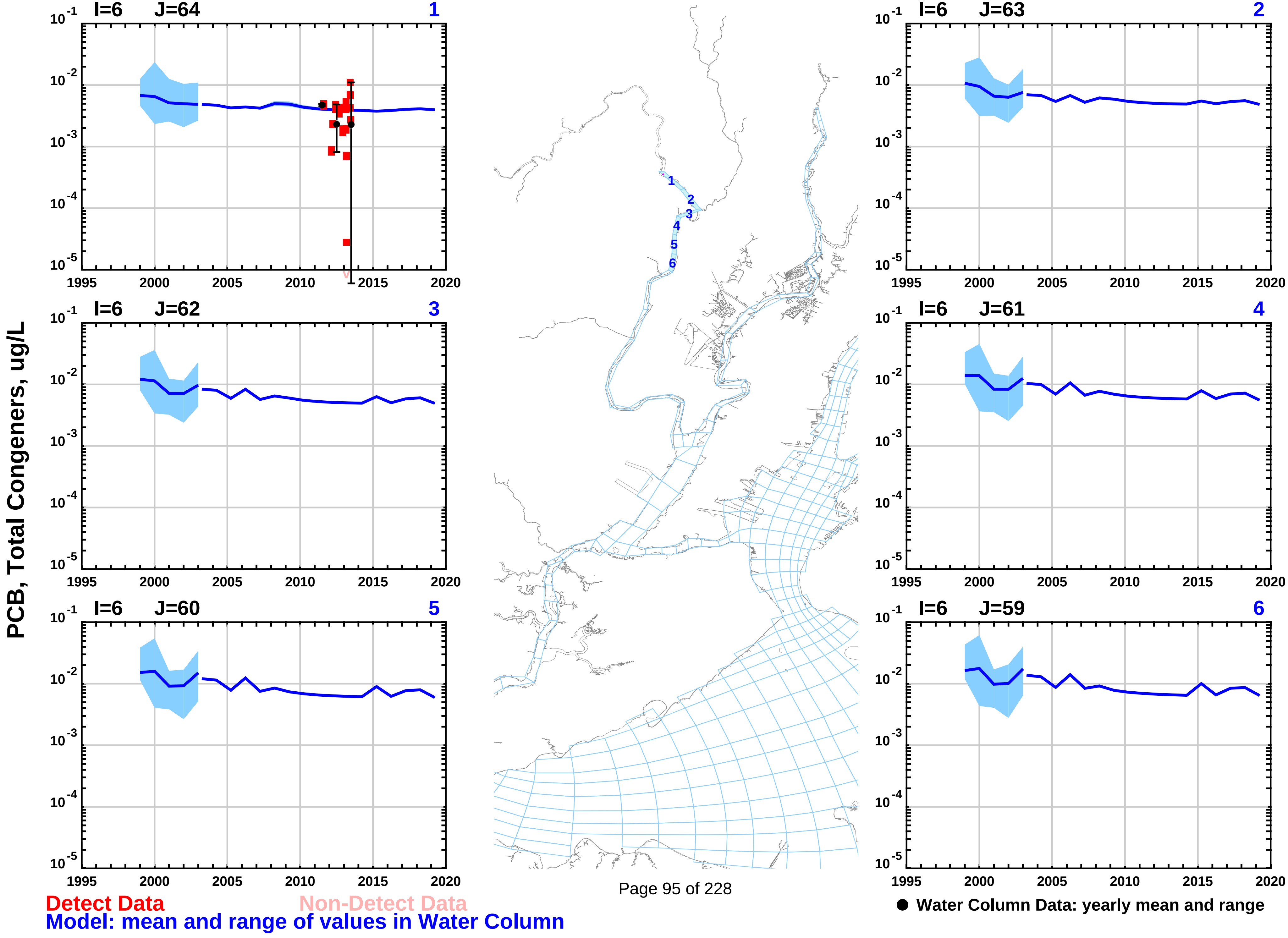
ATTACHMENT 2

WATER COLUMN DIAGRAMS, VOLUMETRIC UNITS

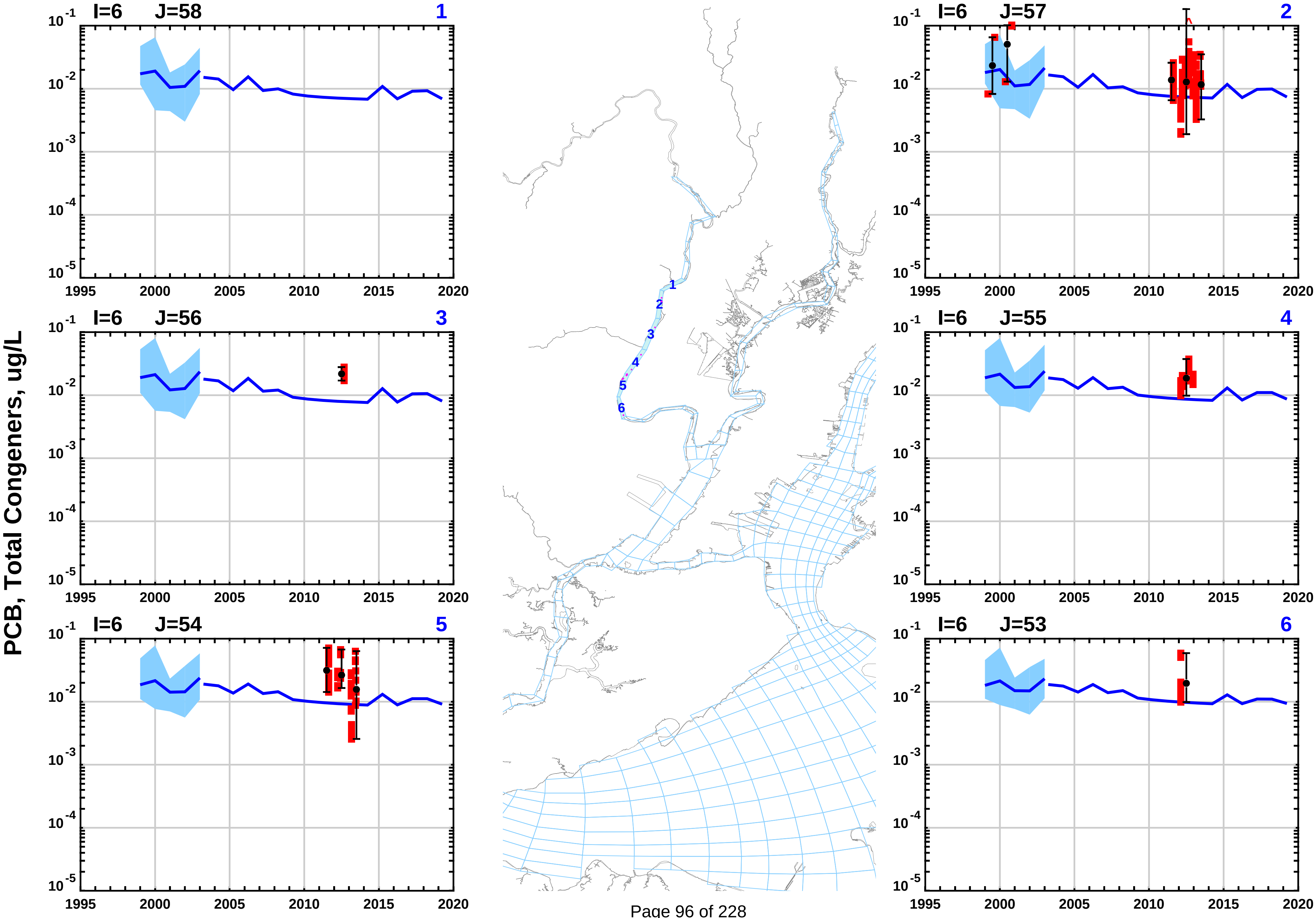
Attachment 2A, Total PCBs
Attachment 2B, 2,3,7,8-TCDD
Attachment 2C, PCB homologs
Attachment 2D, 2,3,4,7,8-PCDF

Attachment 2A, Total PCBs

Water Column Data Comparison With Model All Water Column Layers

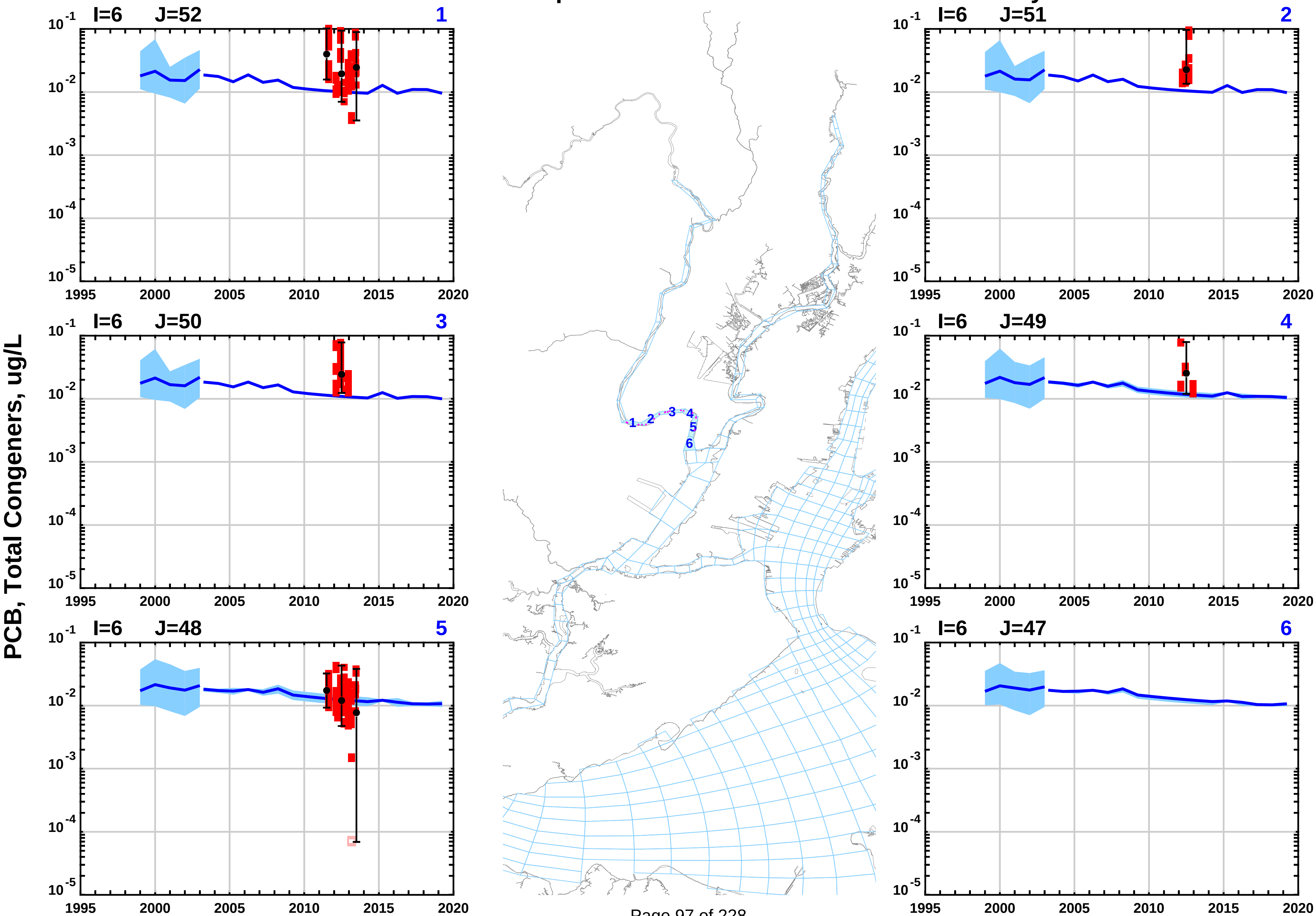


Water Column Data Comparison With Model All Water Column Layers



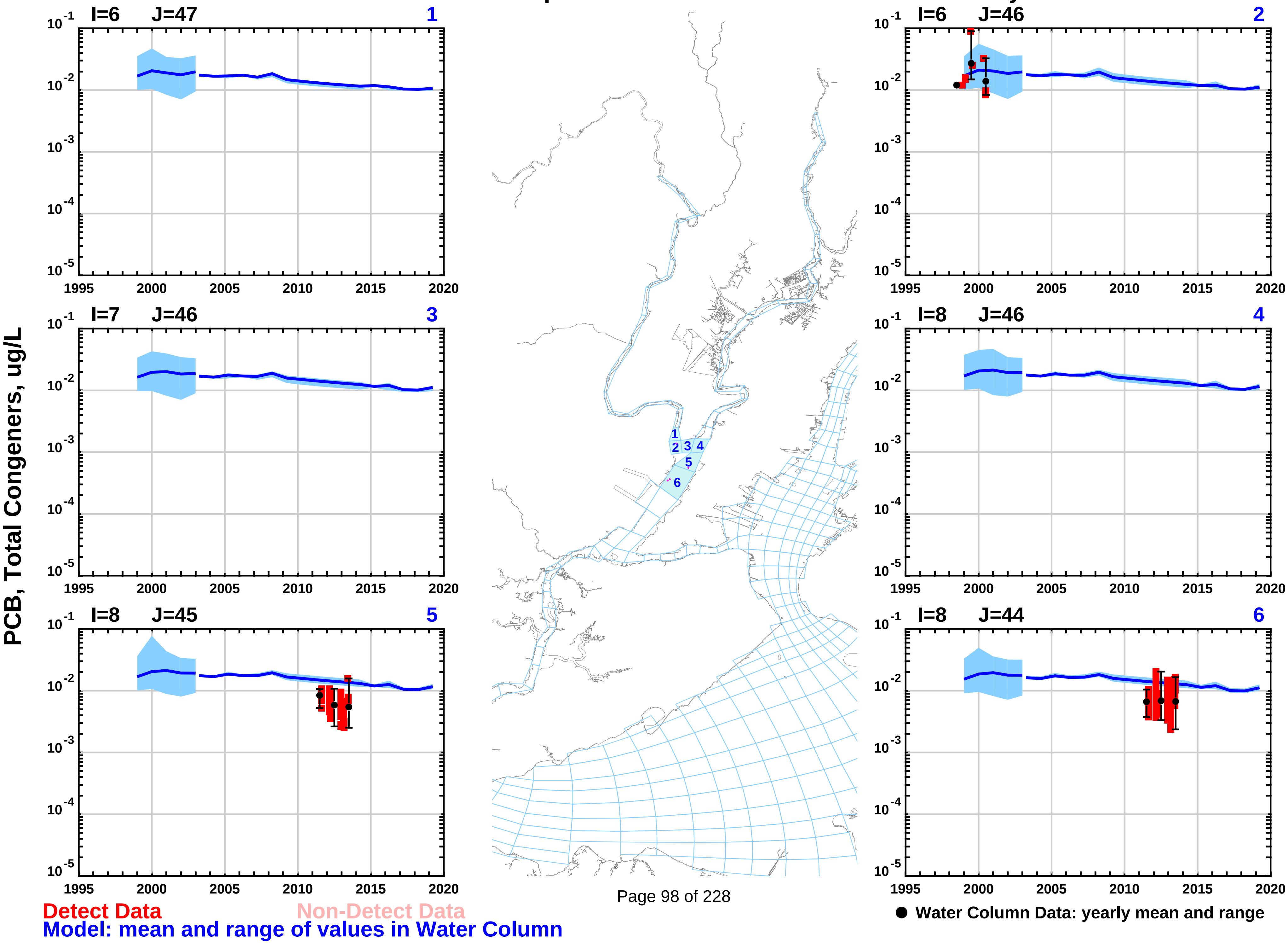
Detect Data Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers

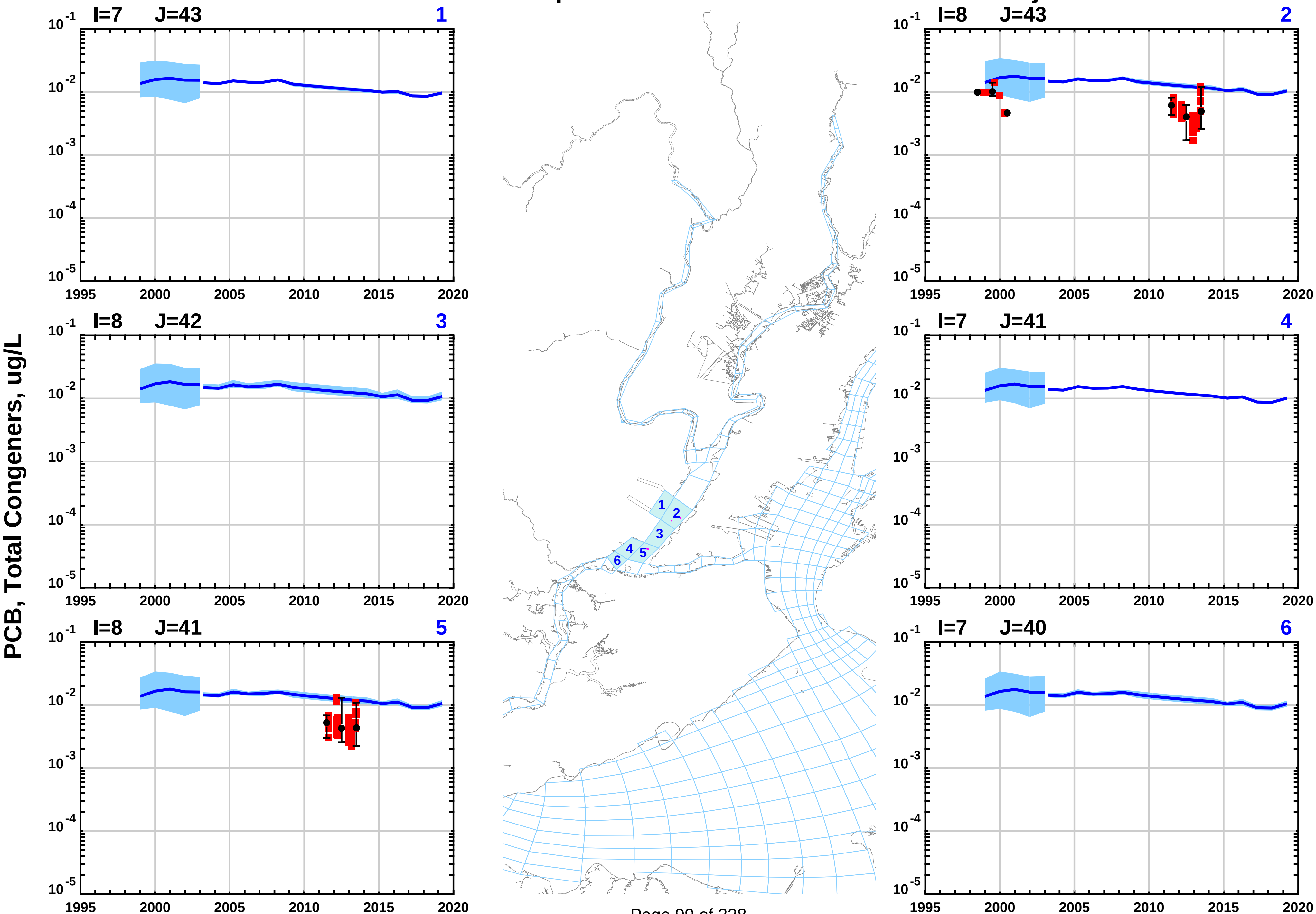


Detect Data
Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers



Water Column Data Comparison With Model All Water Column Layers

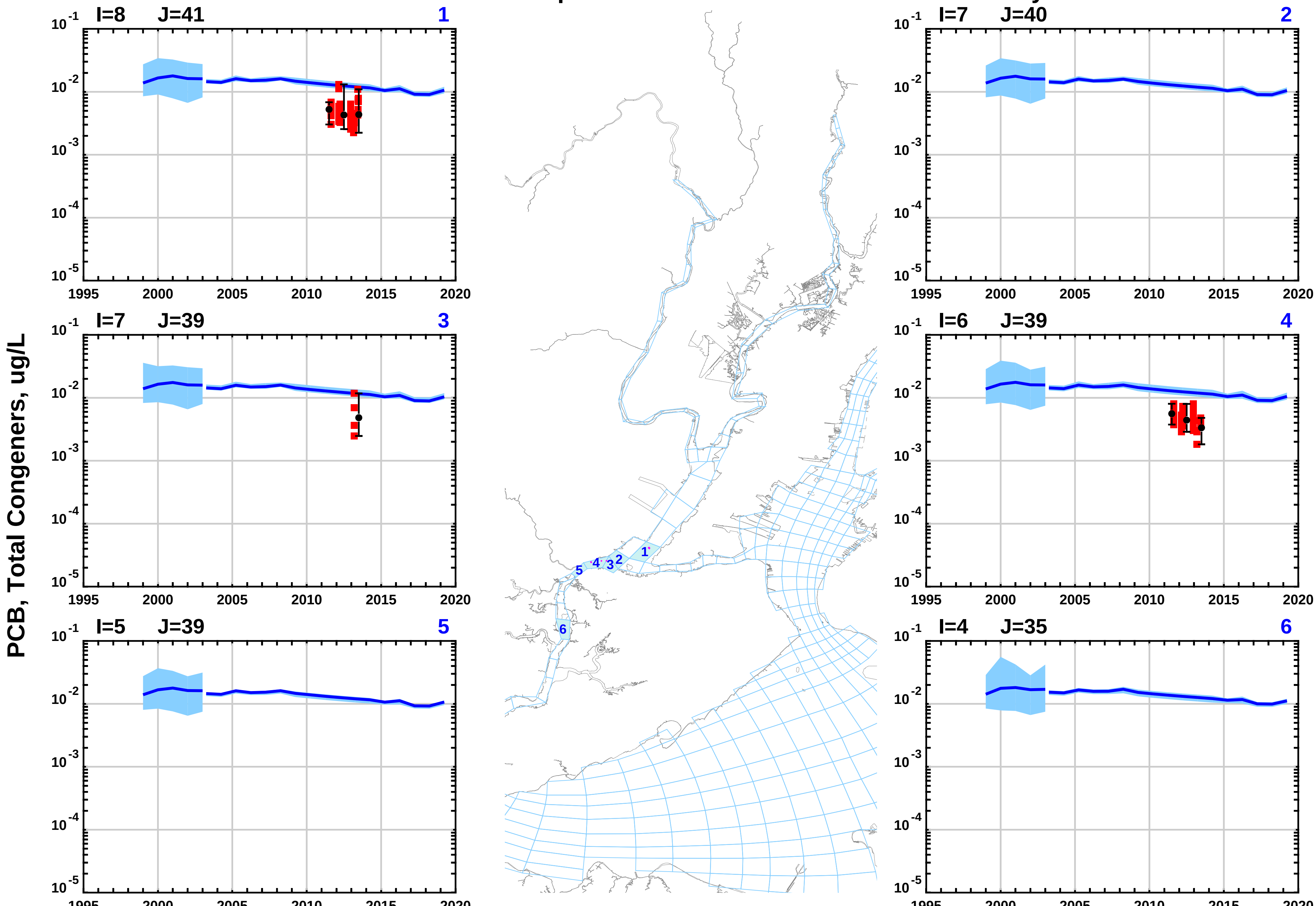


Detect Data Non-Detect Data

Model: mean and range of values in Water Column

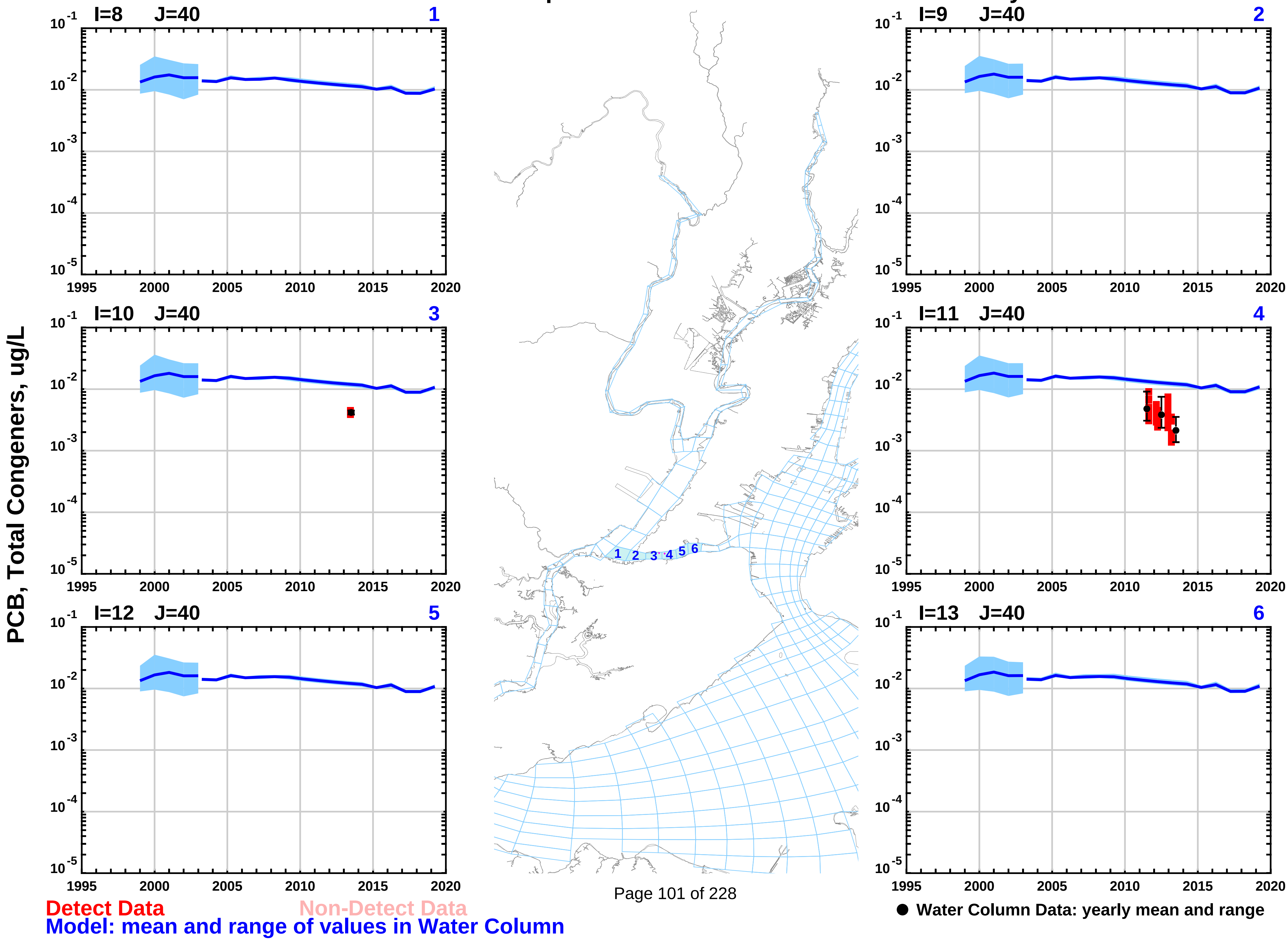
● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers

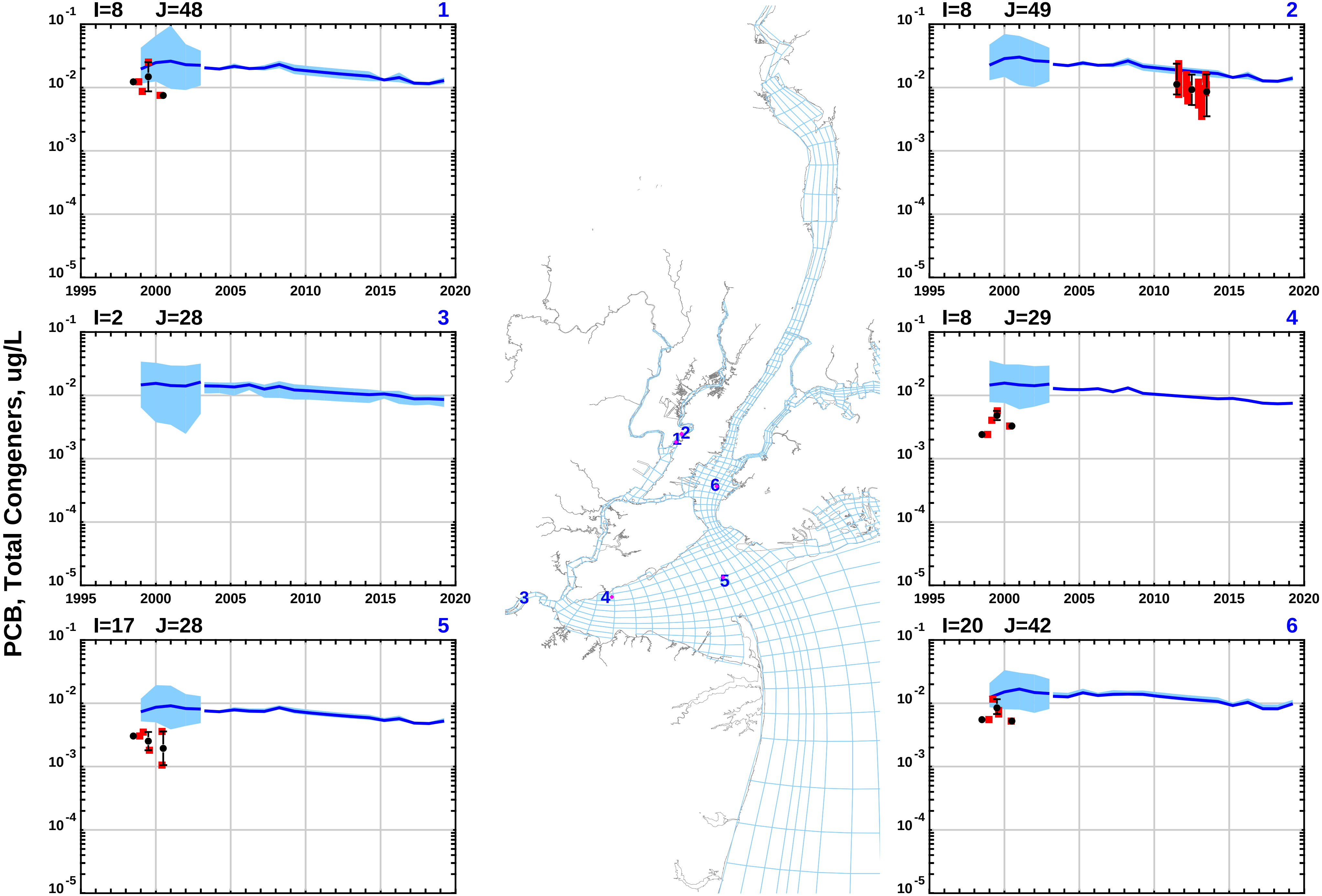


Detect Data
Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers

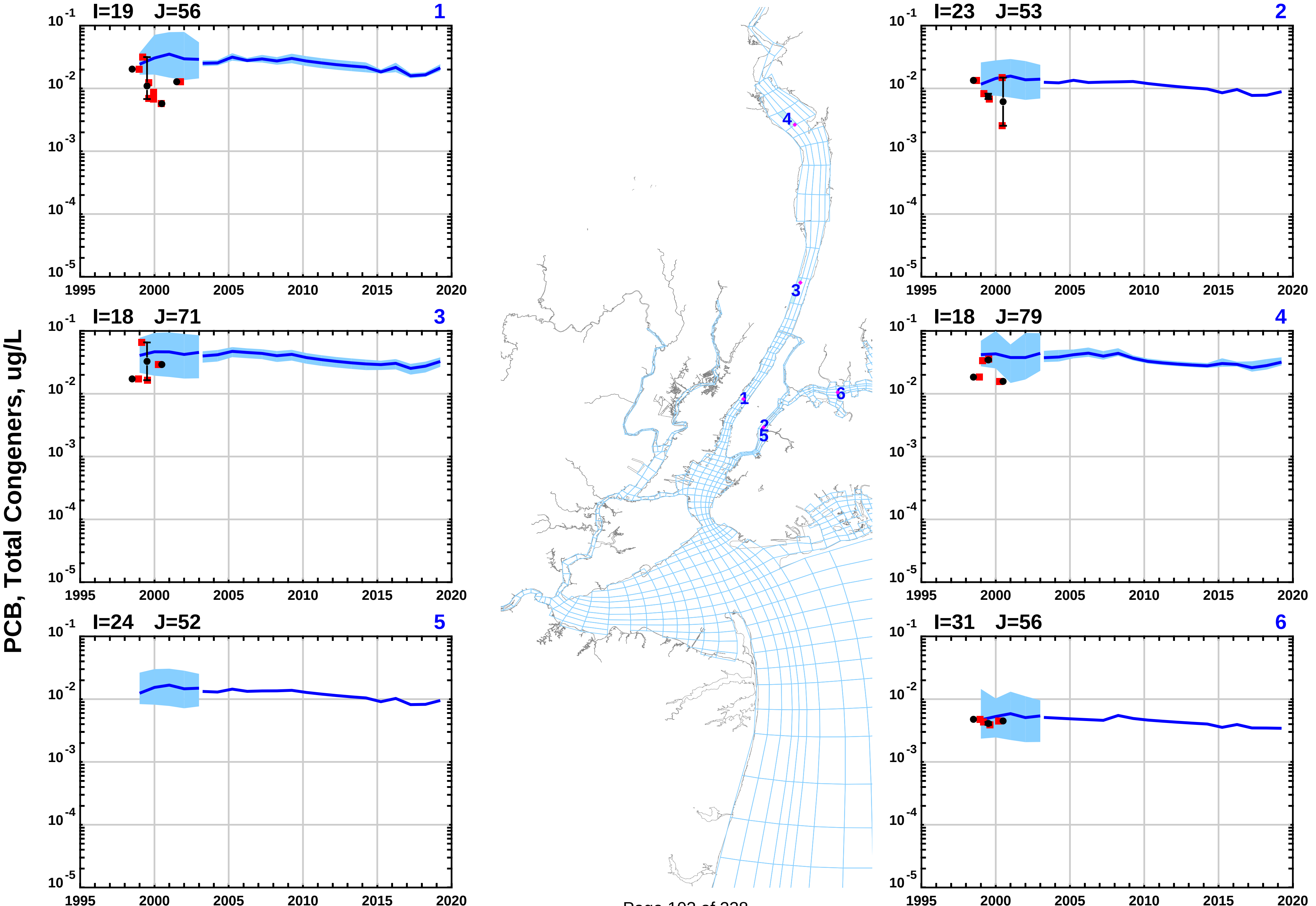


Water Column Data Comparison With Model All Water Column Layers



Detect Data
Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers



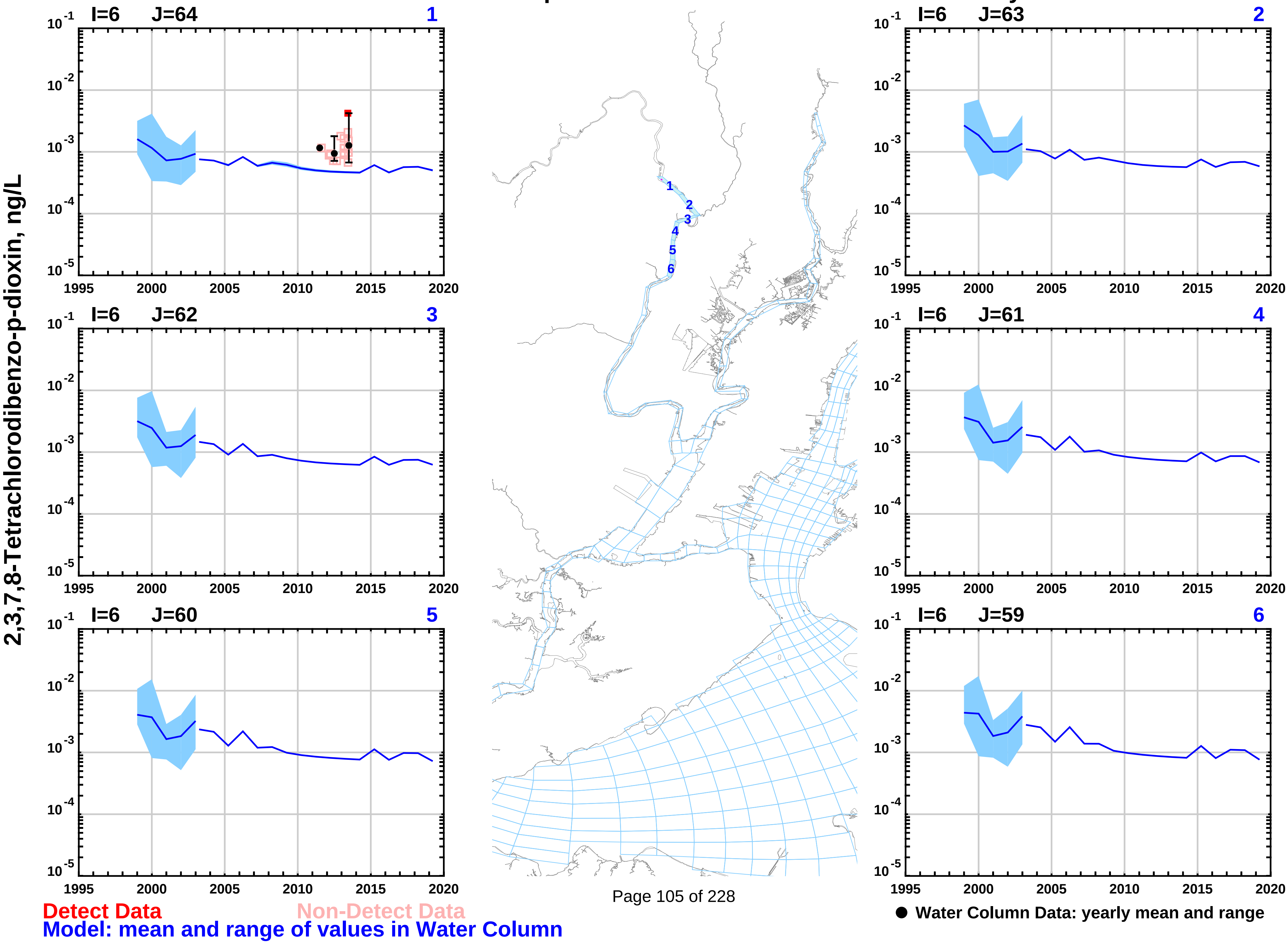
Detect Data Non-Detect Data

Model: mean and range of values in Water Column

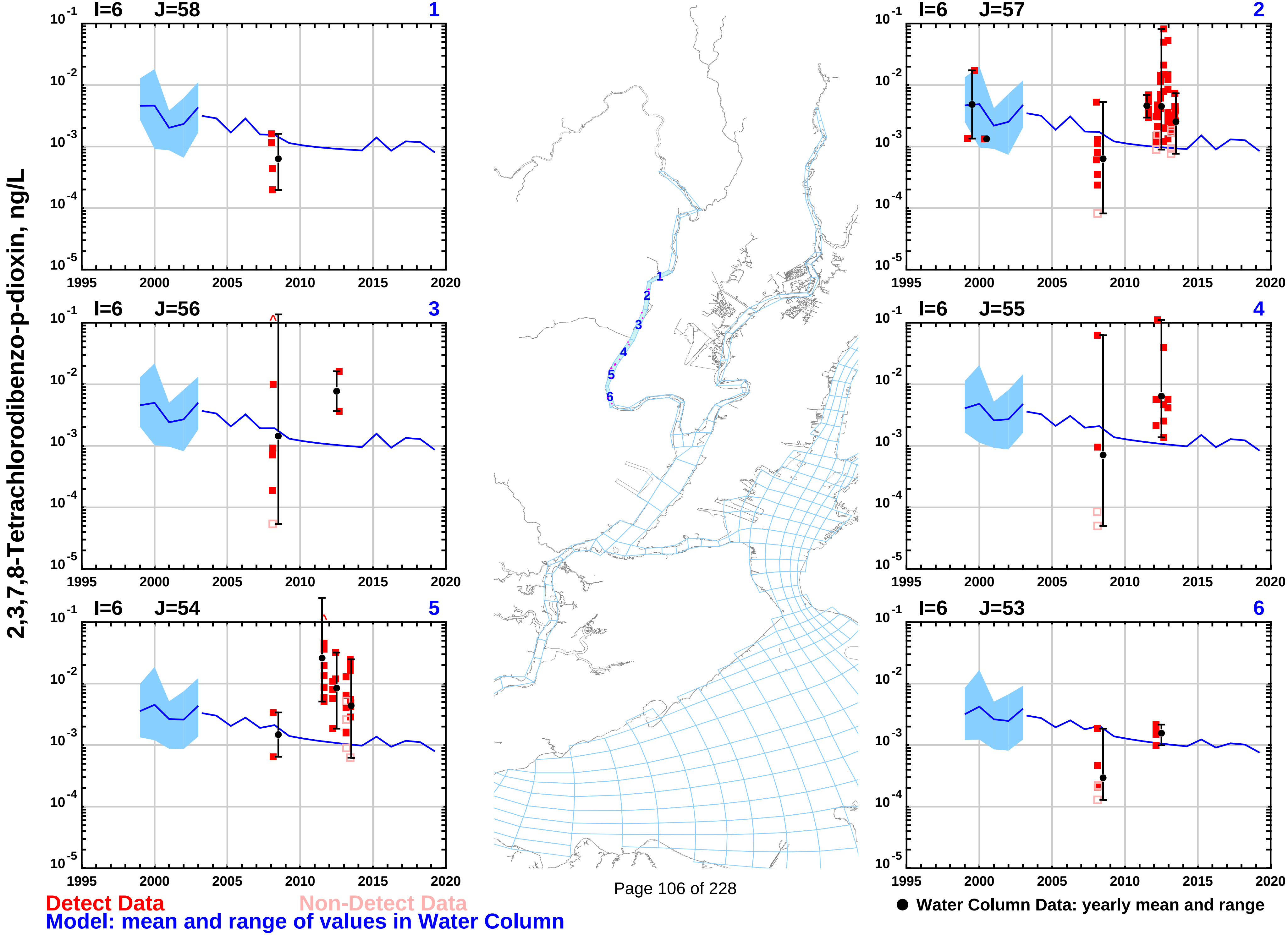
● Water Column Data: yearly mean and range

Attachment 2B, 2,3,7,8-TCDD

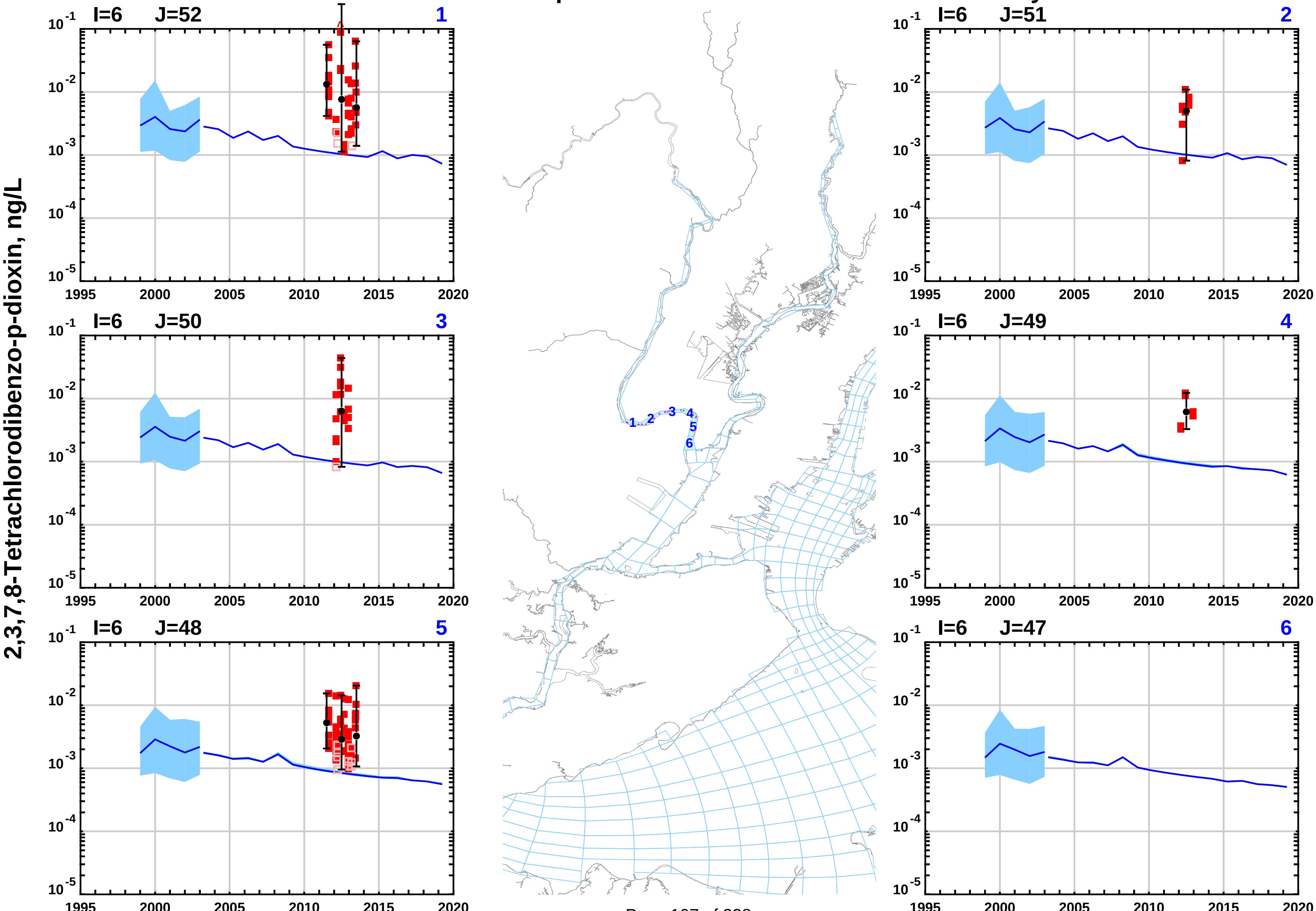
Water Column Data Comparison With Model All Water Column Layers



Water Column Data Comparison With Model All Water Column Layers

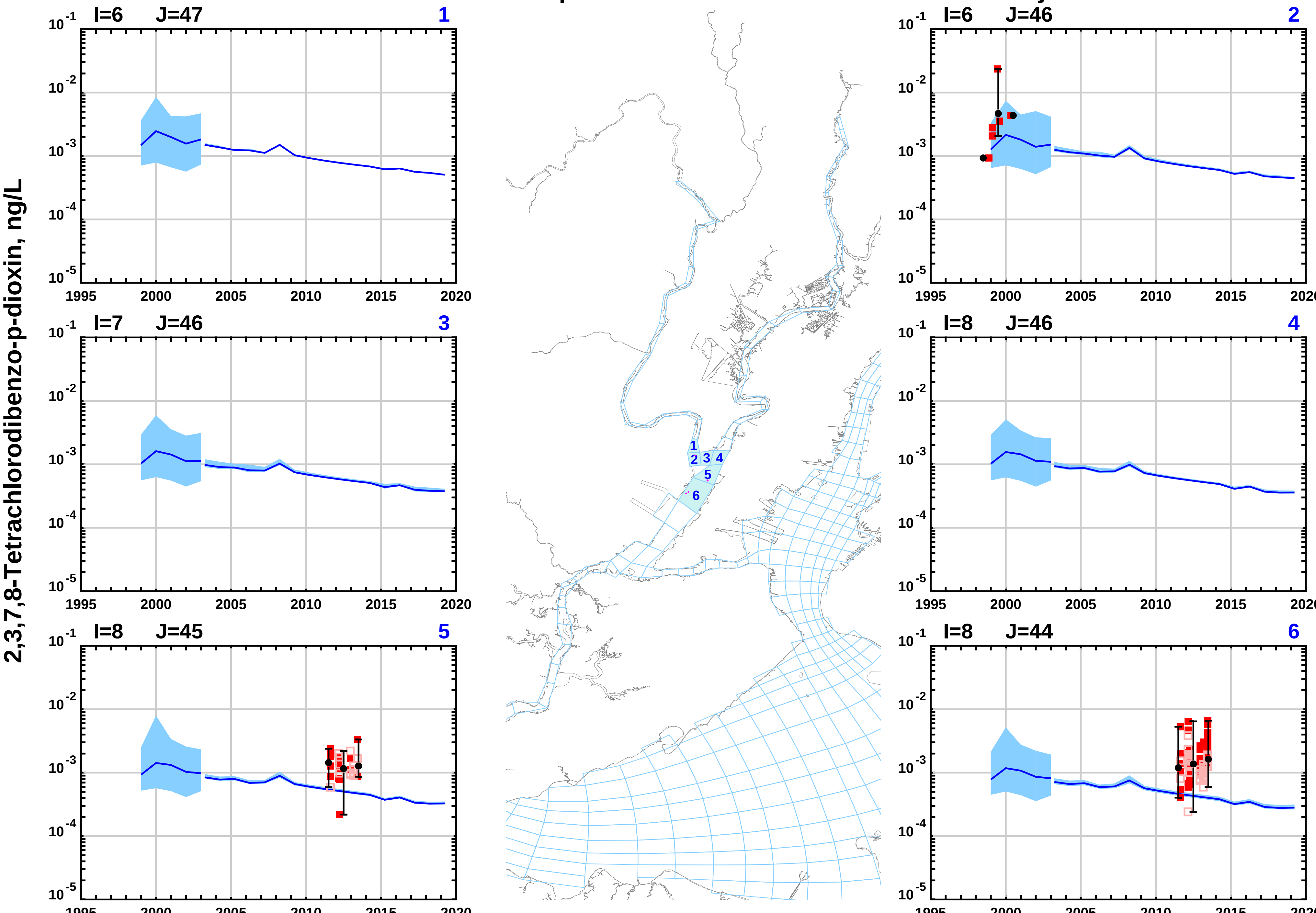


Water Column Data Comparison With Model All Water Column Layers



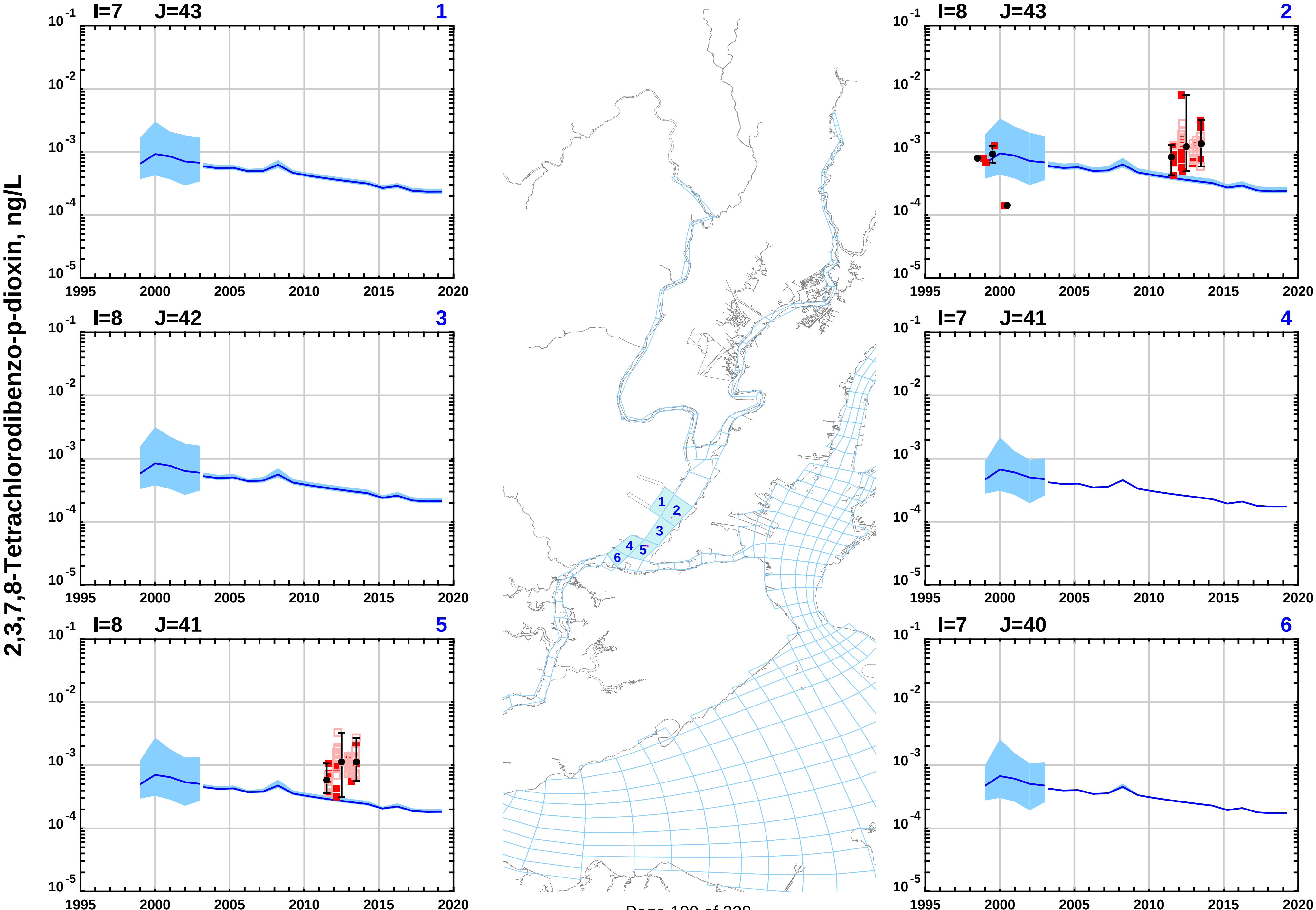
Detect Data Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers



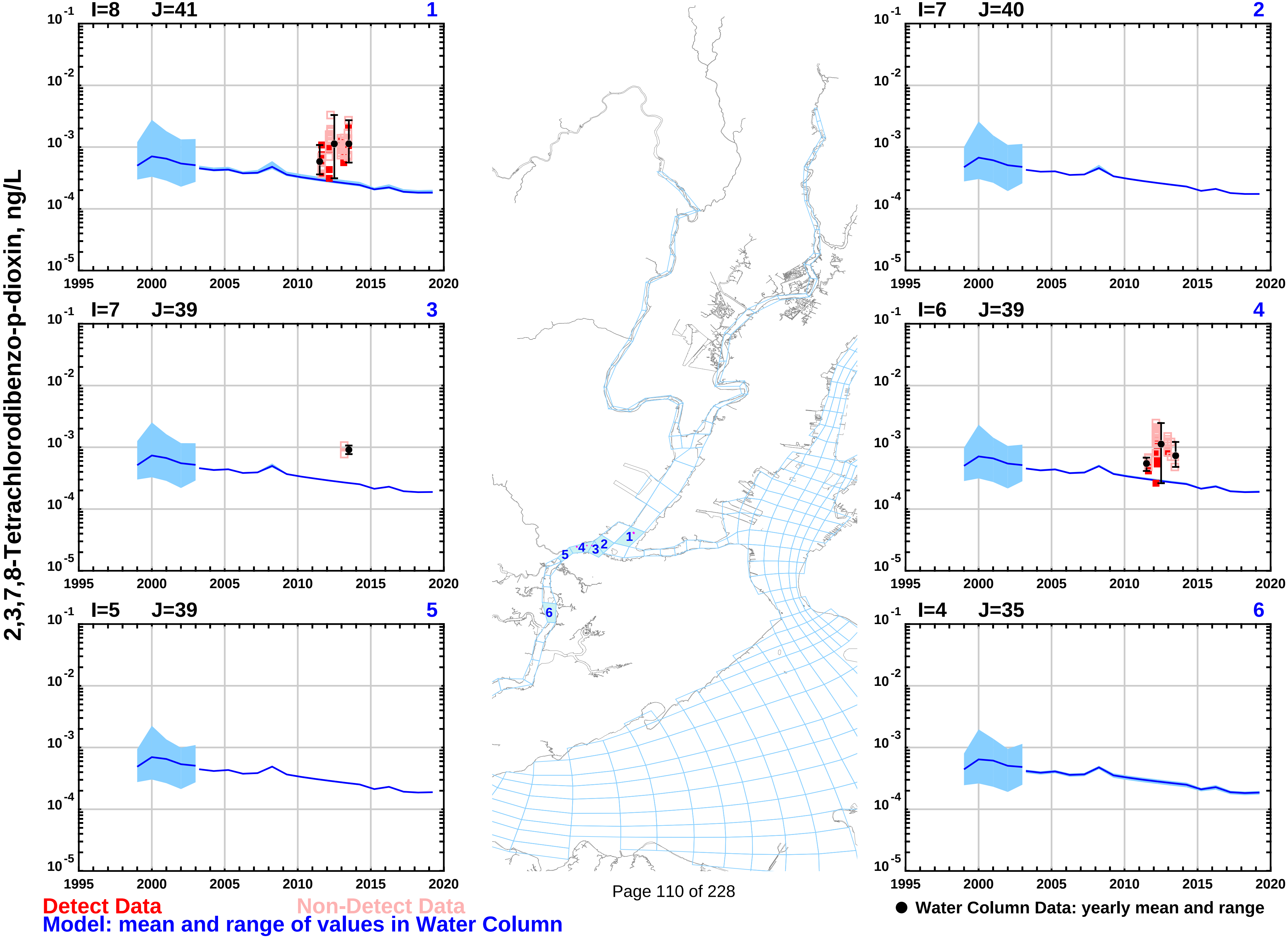
Detect Data
Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers

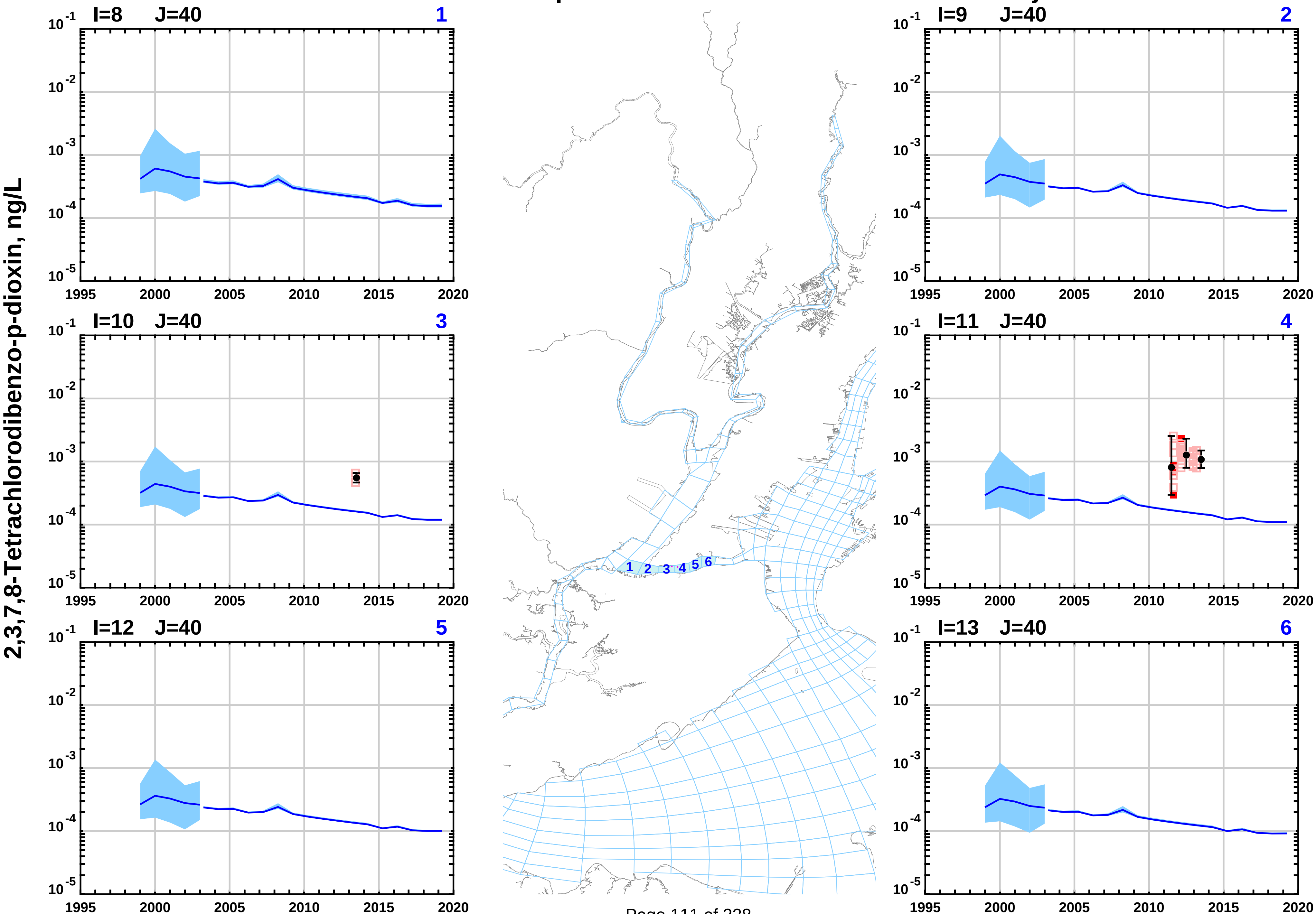


Detect Data Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers

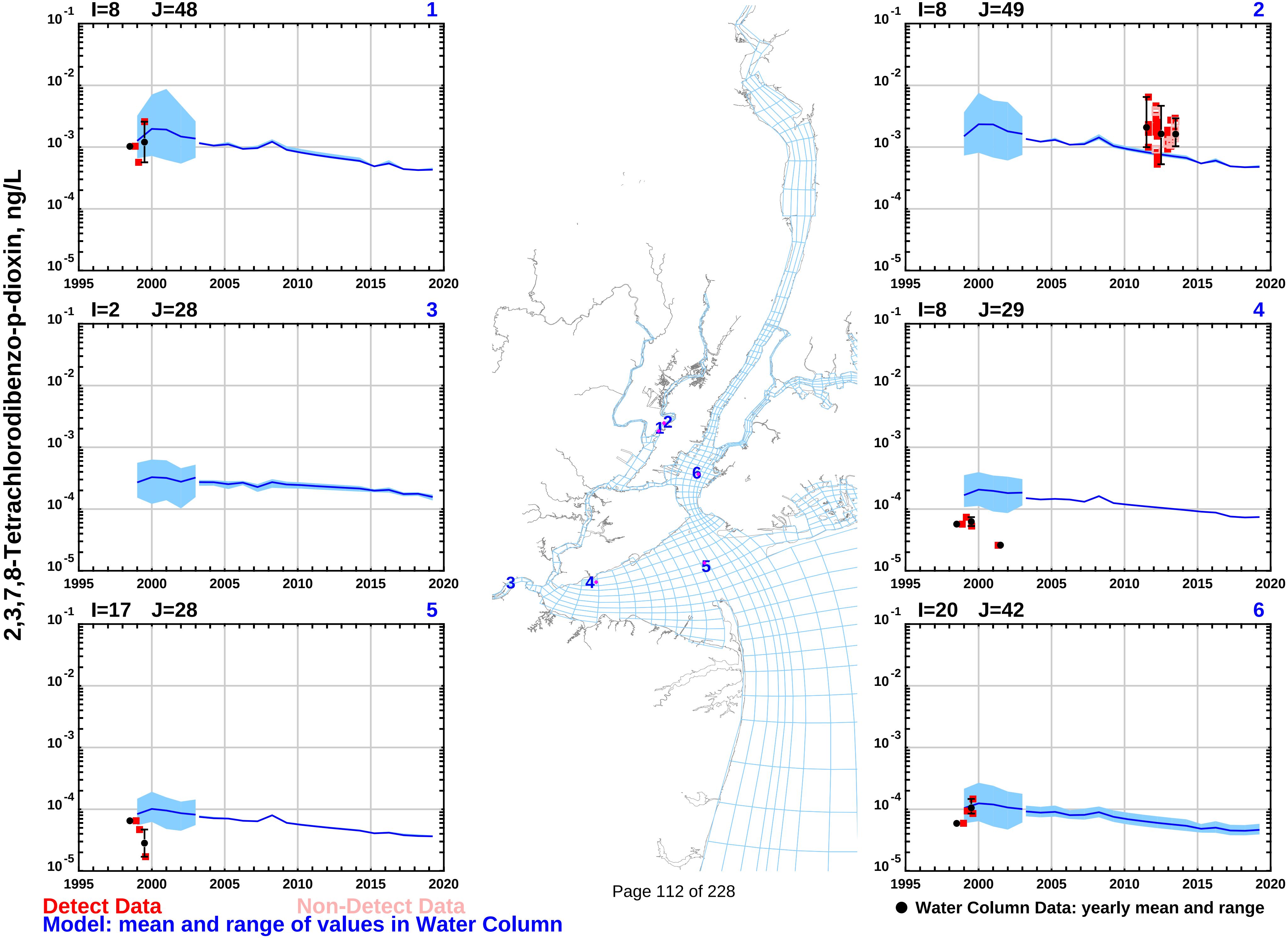


Water Column Data Comparison With Model All Water Column Layers

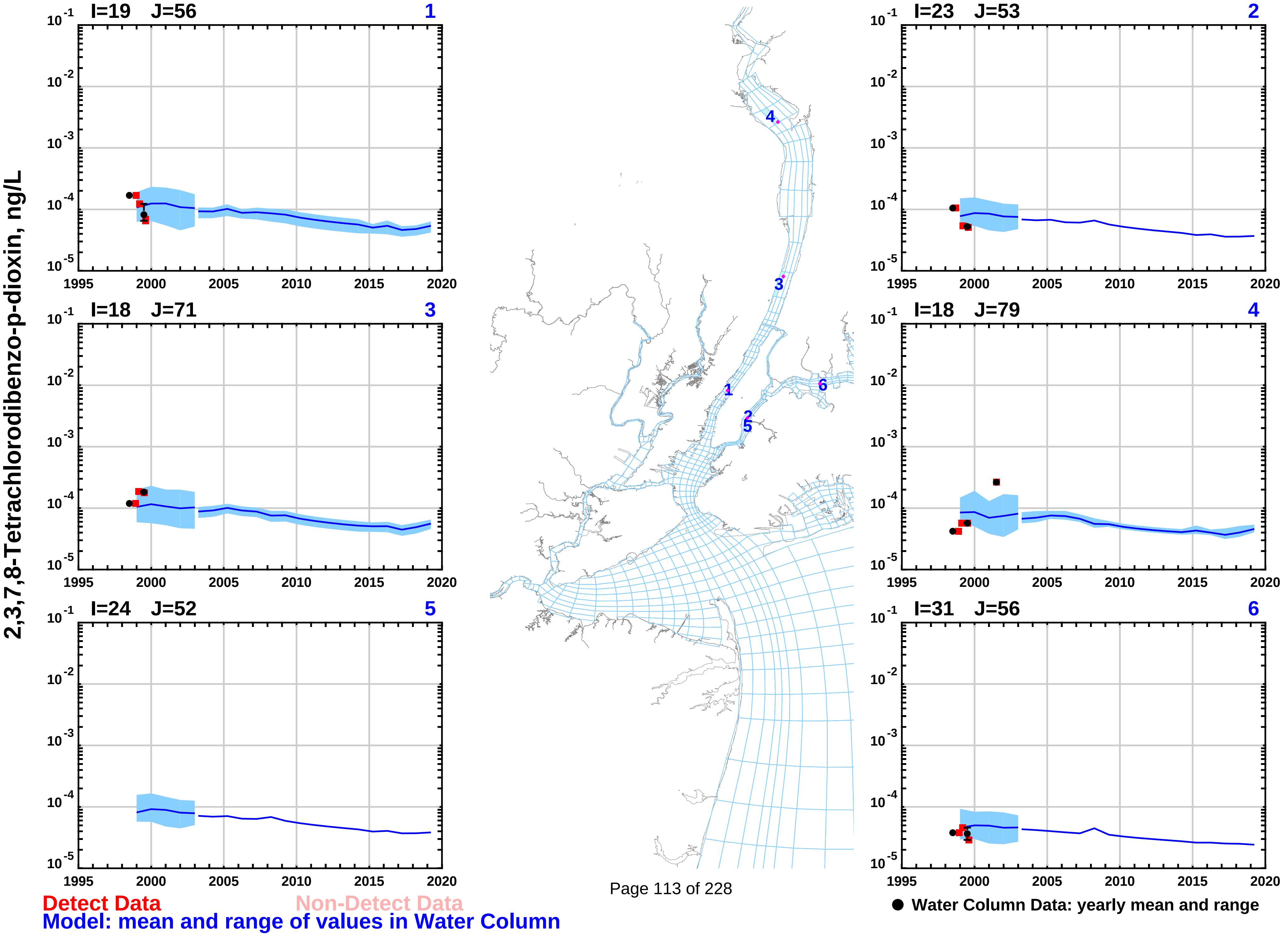


Detect Data Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers

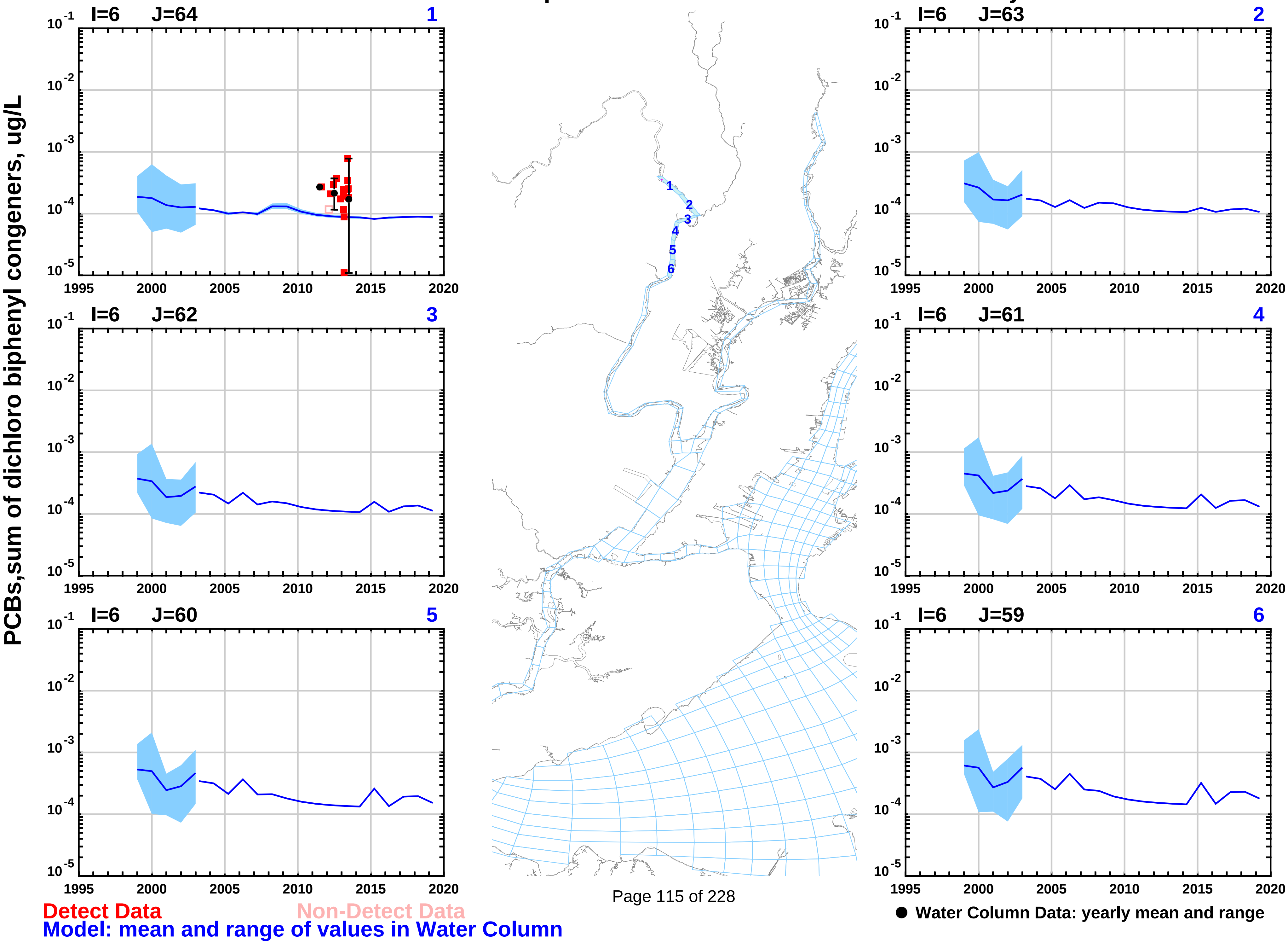


Water Column Data Comparison With Model All Water Column Layers

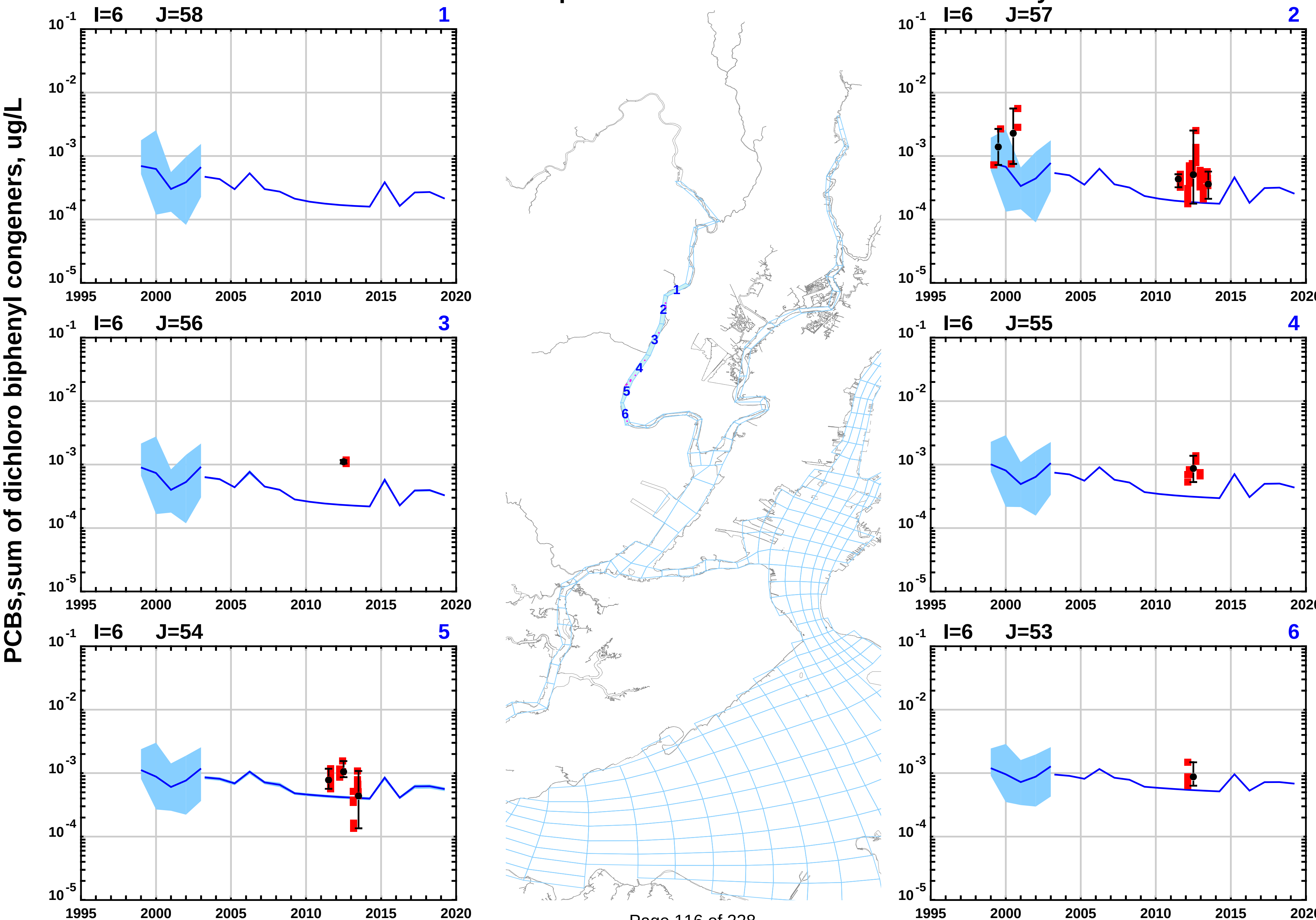


Attachment 2C, PCB homologs

Water Column Data Comparison With Model All Water Column Layers



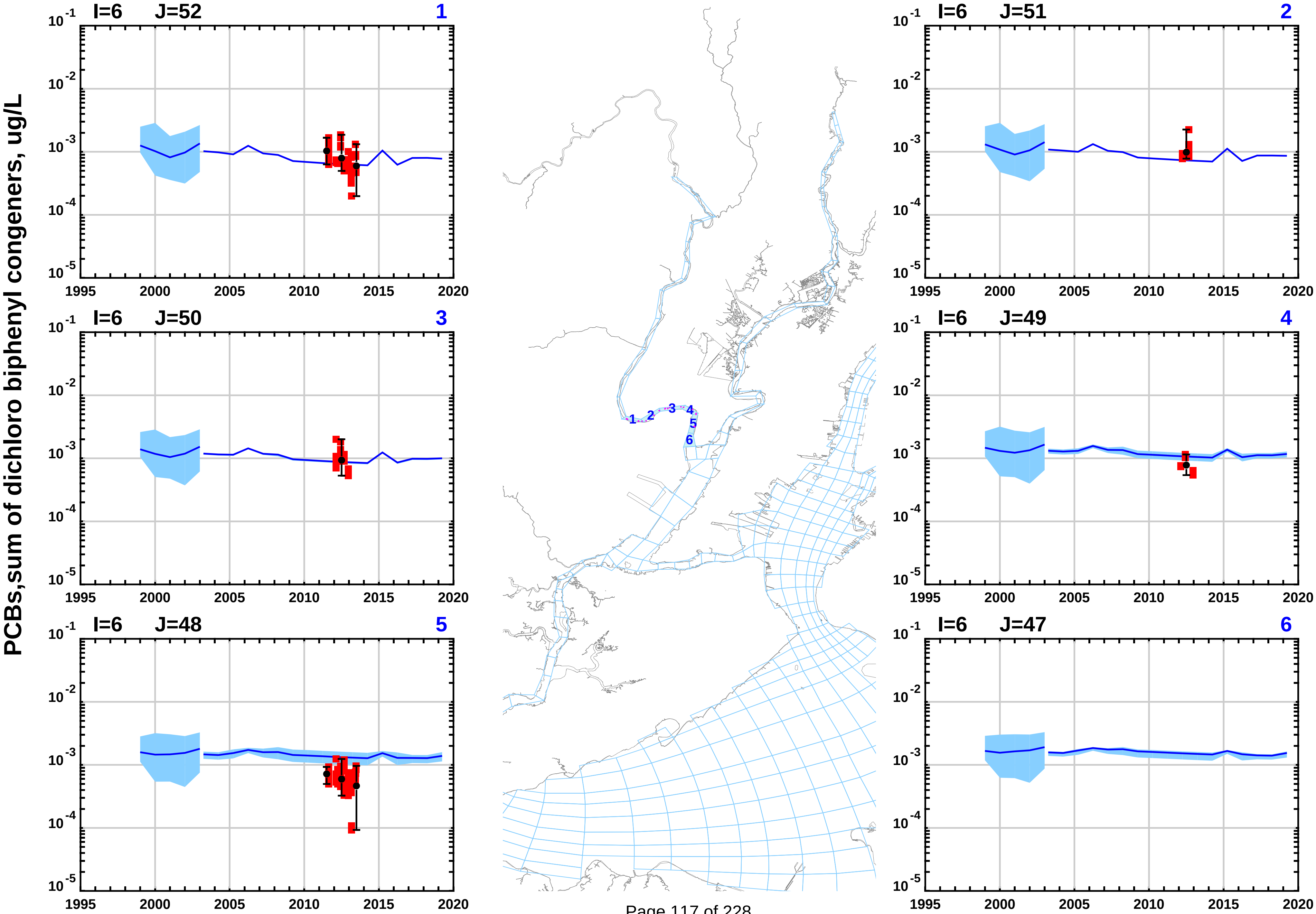
Water Column Data Comparison With Model All Water Column Layers



Detect Data Non-Detect Data
Model: mean and range of values in Water Column

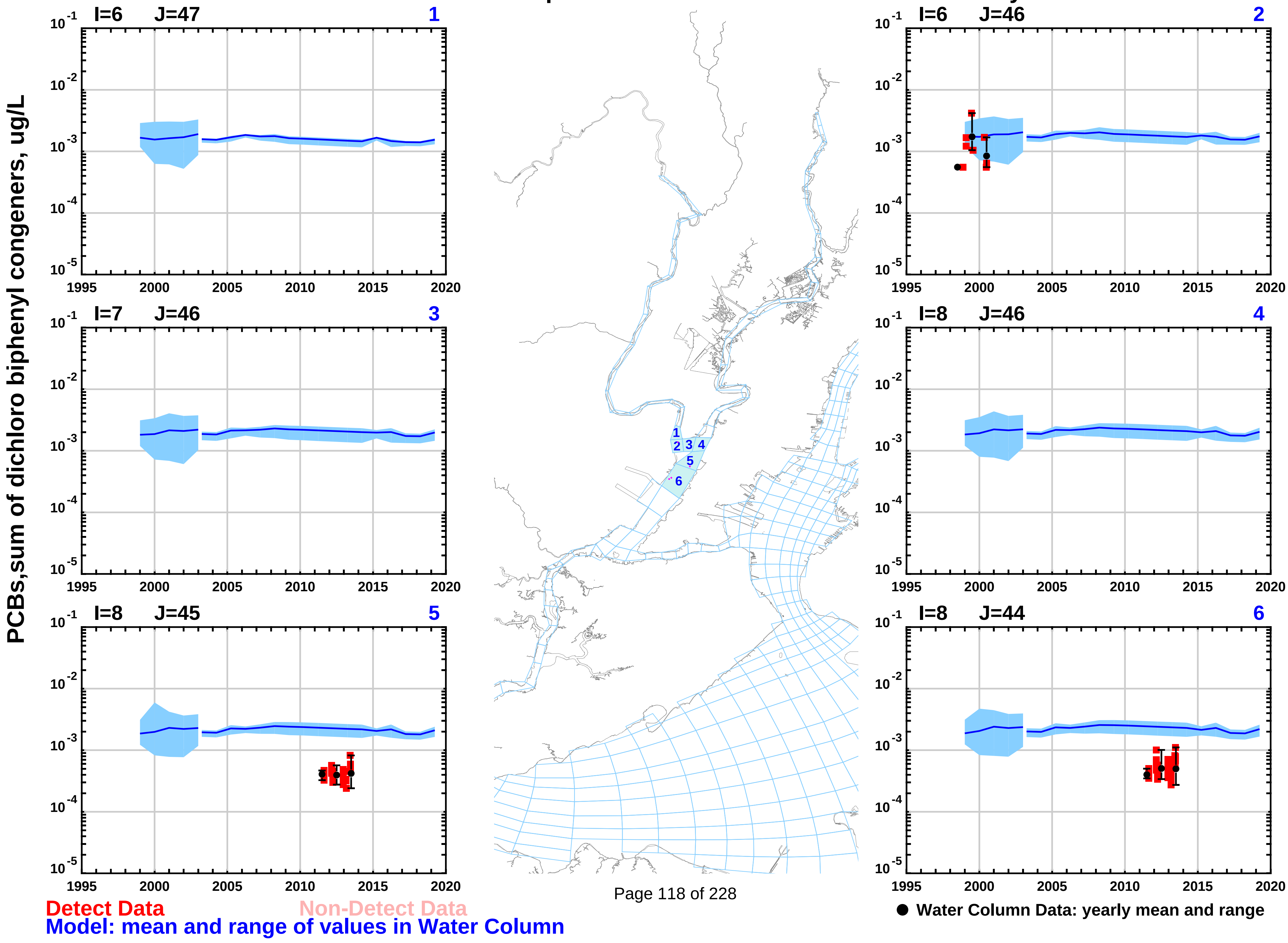
● Water Column Data: yearly mean and range

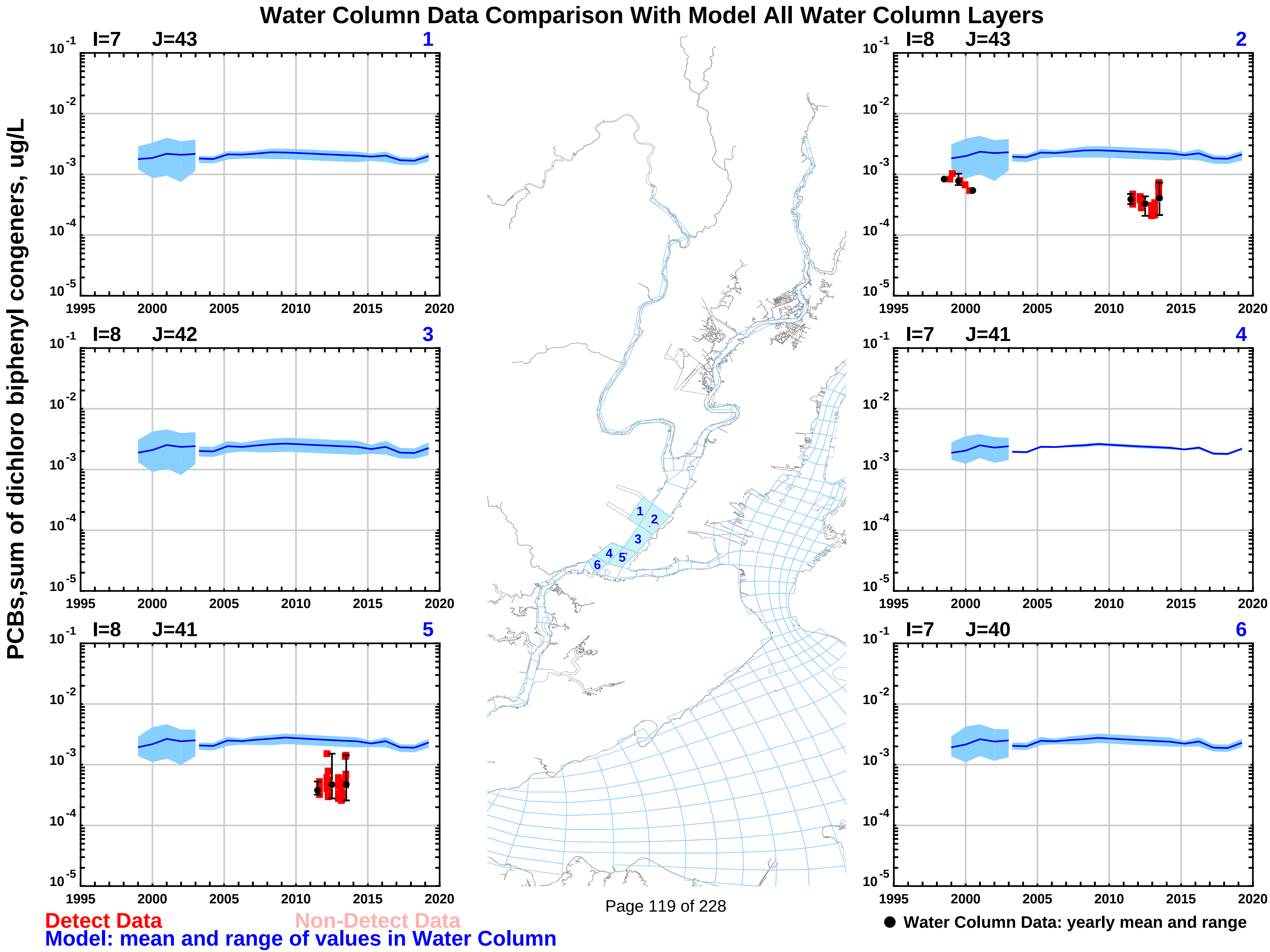
Water Column Data Comparison With Model All Water Column Layers



Detect Data   Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

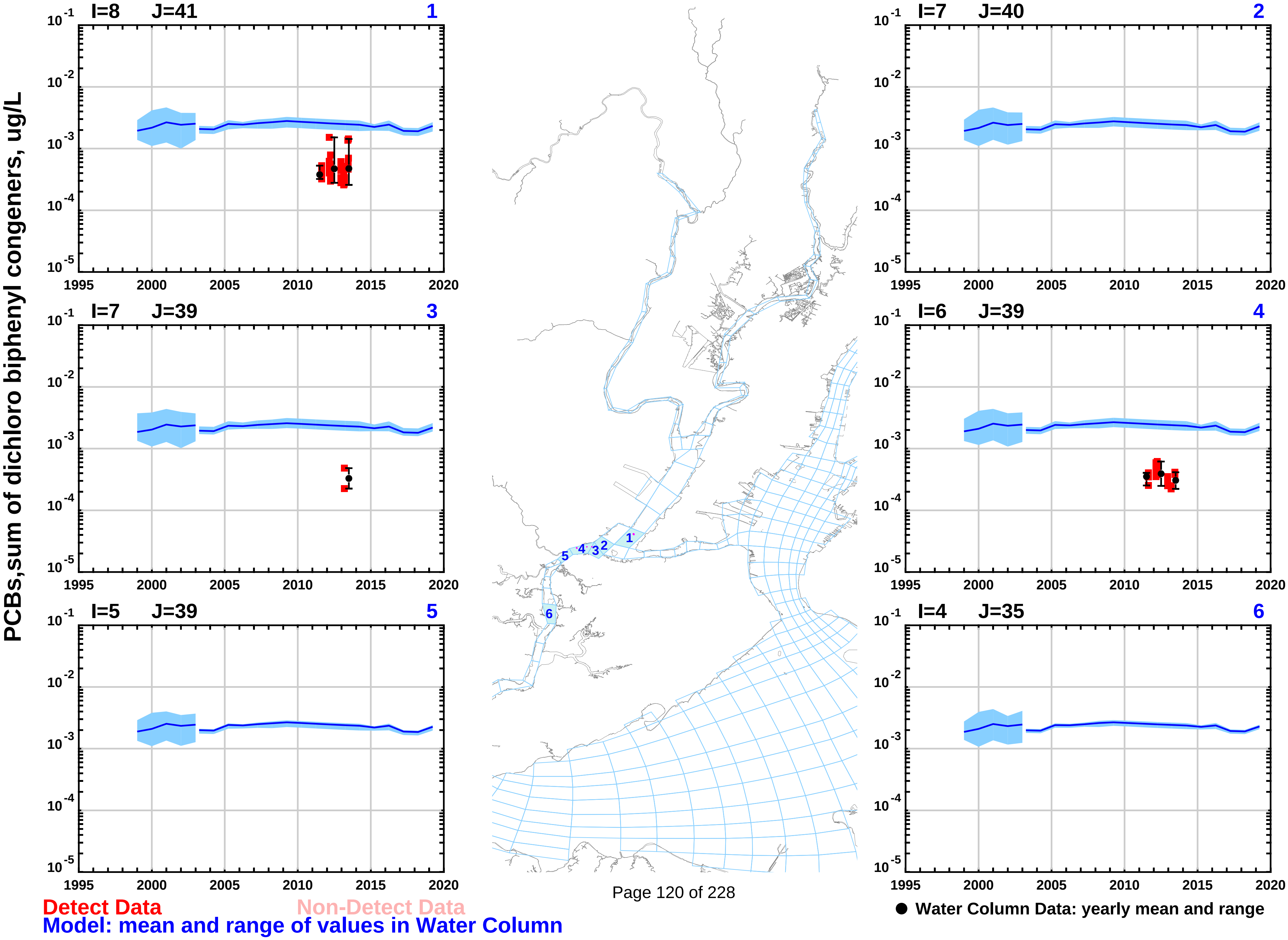
Water Column Data Comparison With Model All Water Column Layers



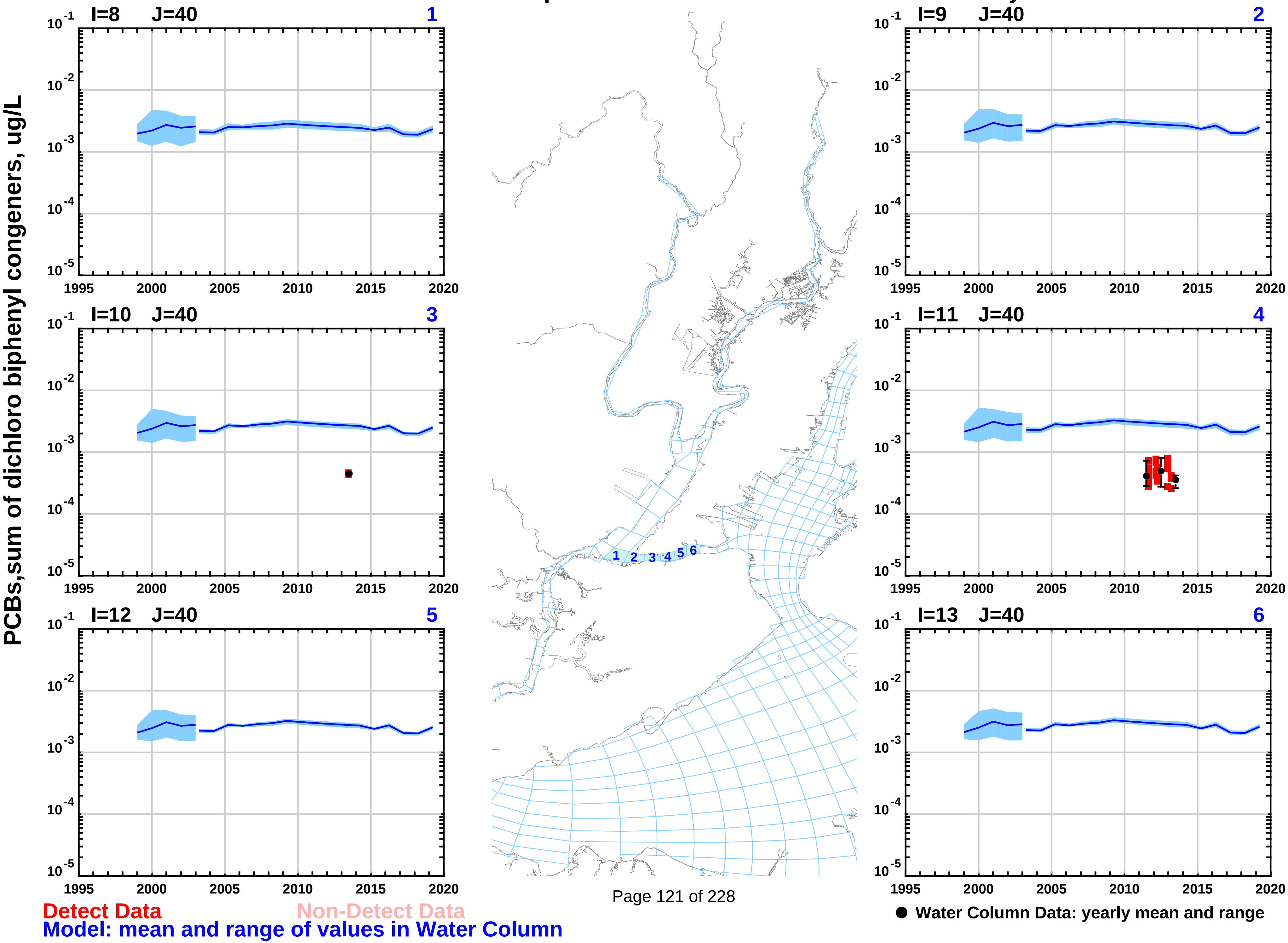


Water Column Data Comparison With Model All Water Column Layers
PCBs,sum of dichloro biphenyl congeners, ug/L
I=7 J=43 1
I=8 J=43 2
I=8 J=42 3
I=7 J=41 4
I=8 J=41 5
I=7 J=40 6
10^-1
10^-2
10^-3
10^-4
10^-5
1995
2000
2005
2010
2015
2020
1
2
3
4
5
6
Detect Data
Non-Detect Data
Model: mean and range of values in Water Column
Water Column Data: yearly mean and range

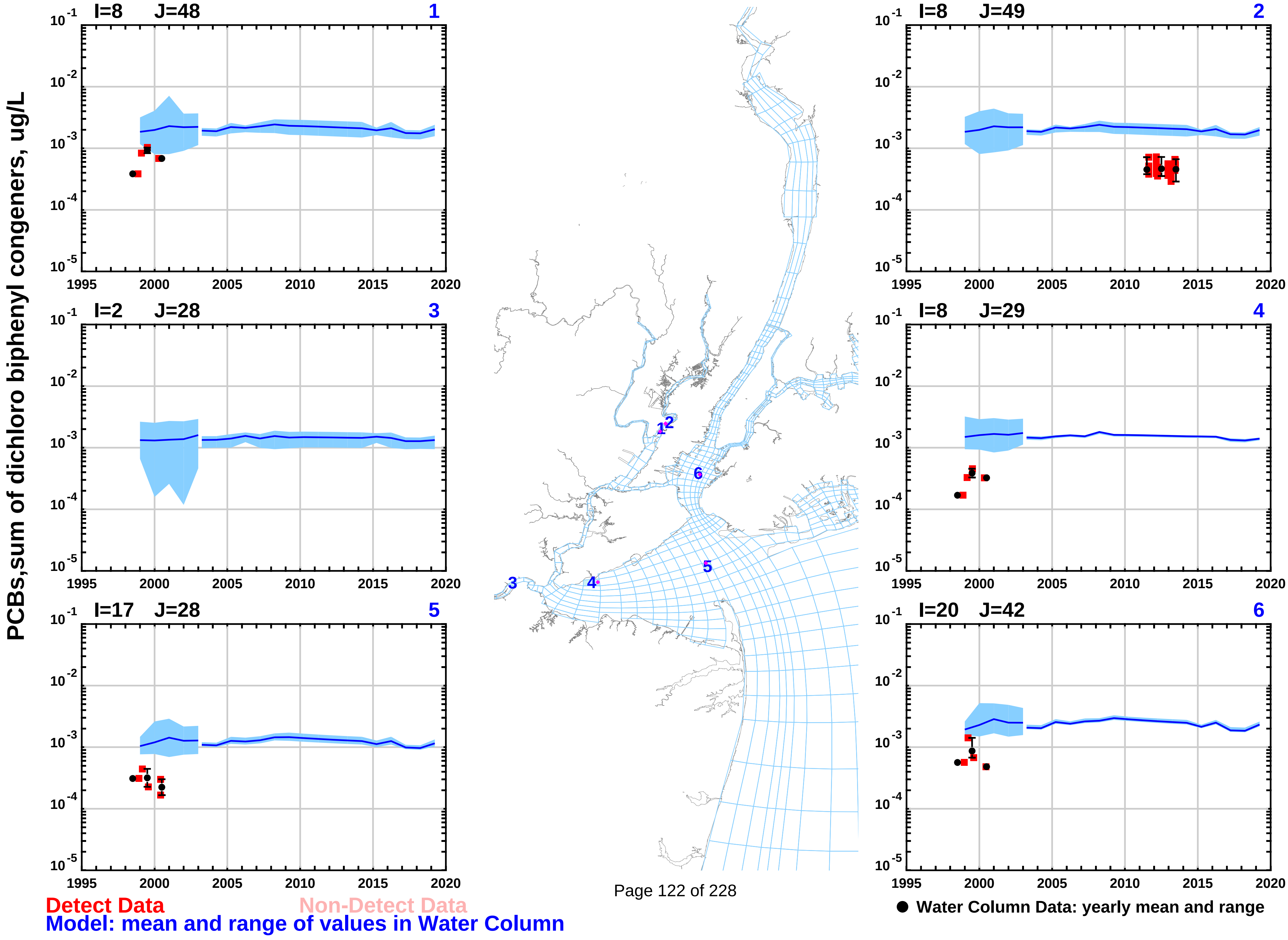
Water Column Data Comparison With Model All Water Column Layers



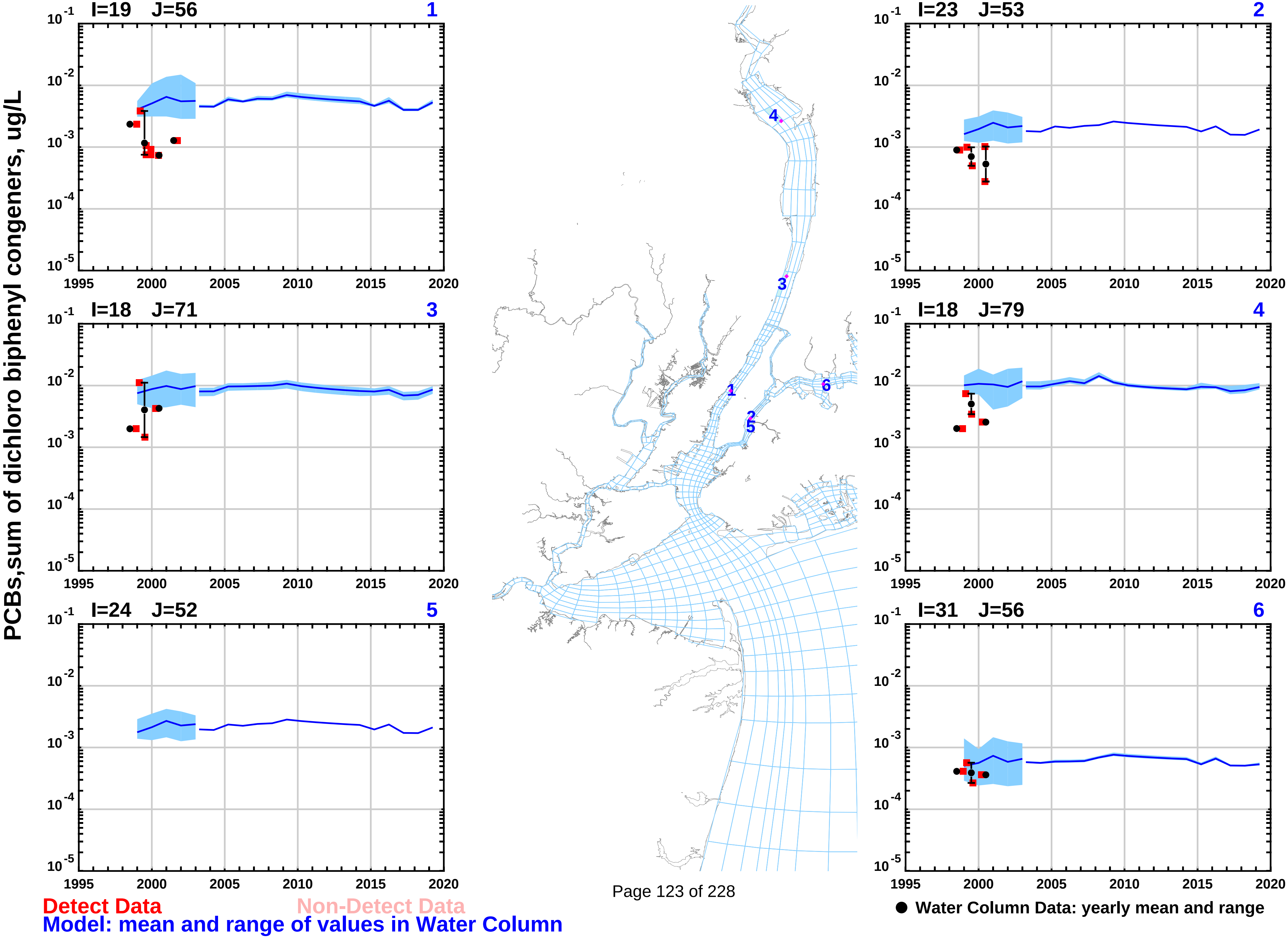
Water Column Data Comparison With Model All Water Column Layers



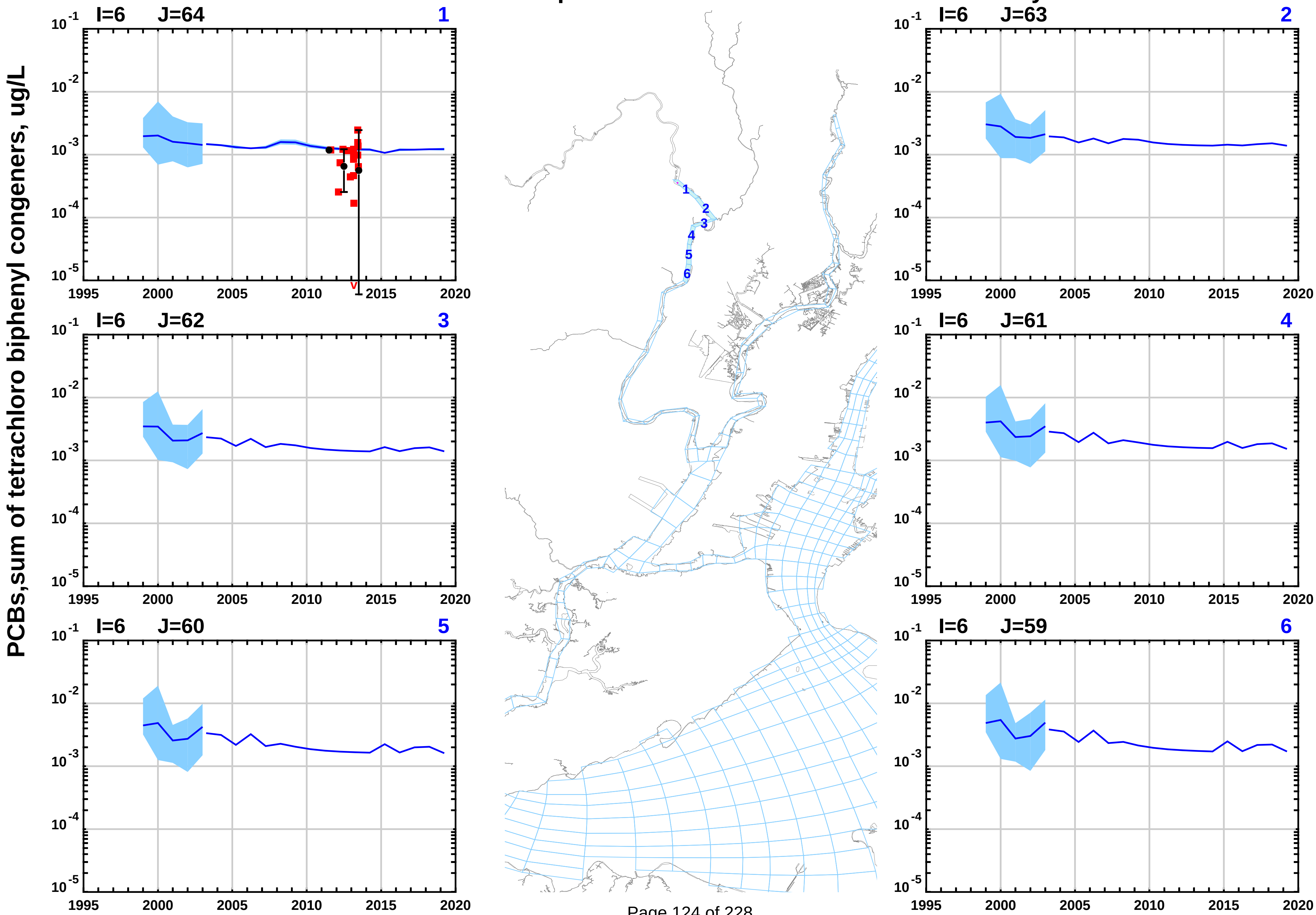
Water Column Data Comparison With Model All Water Column Layers



Water Column Data Comparison With Model All Water Column Layers

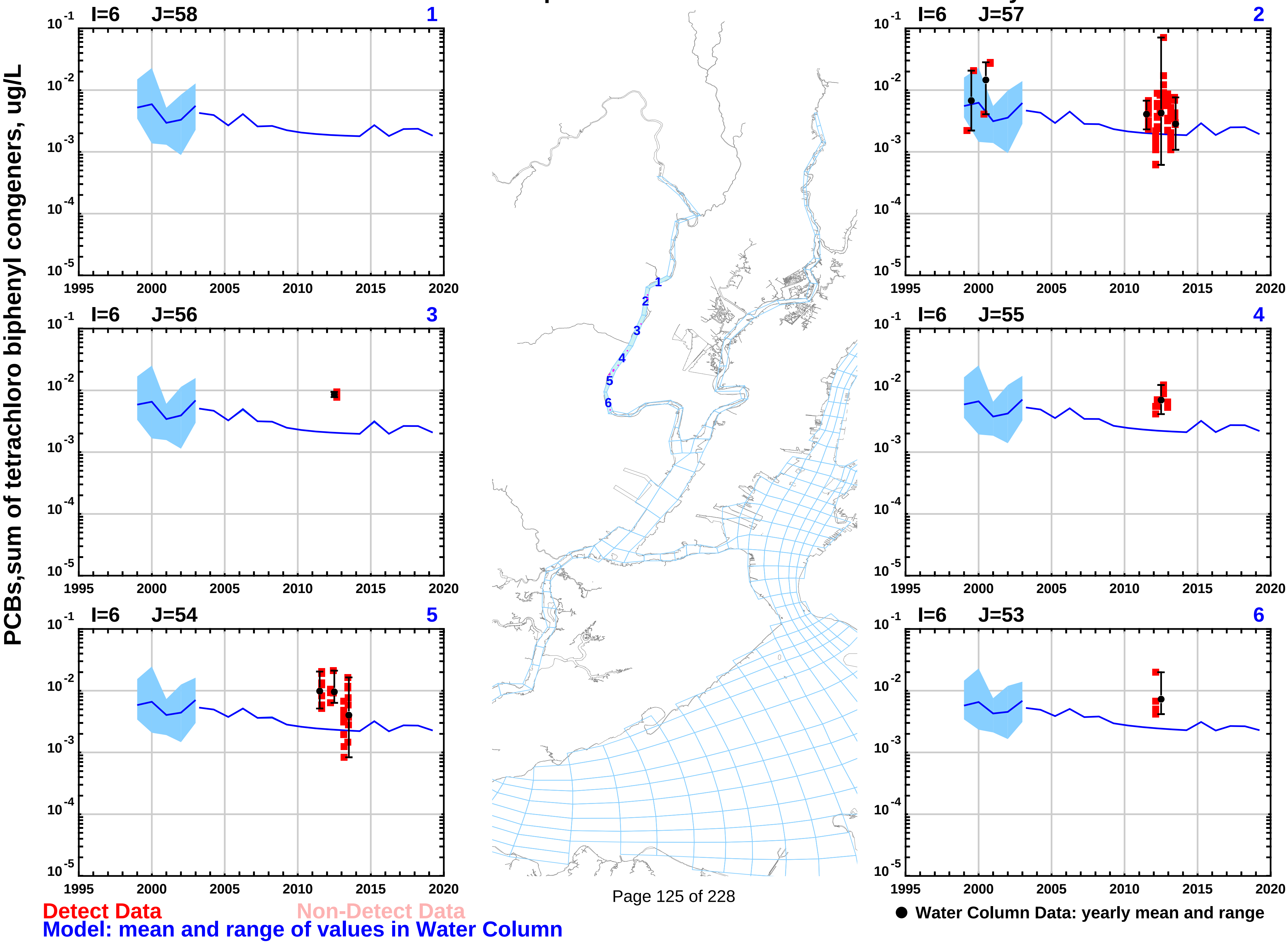


Water Column Data Comparison With Model All Water Column Layers

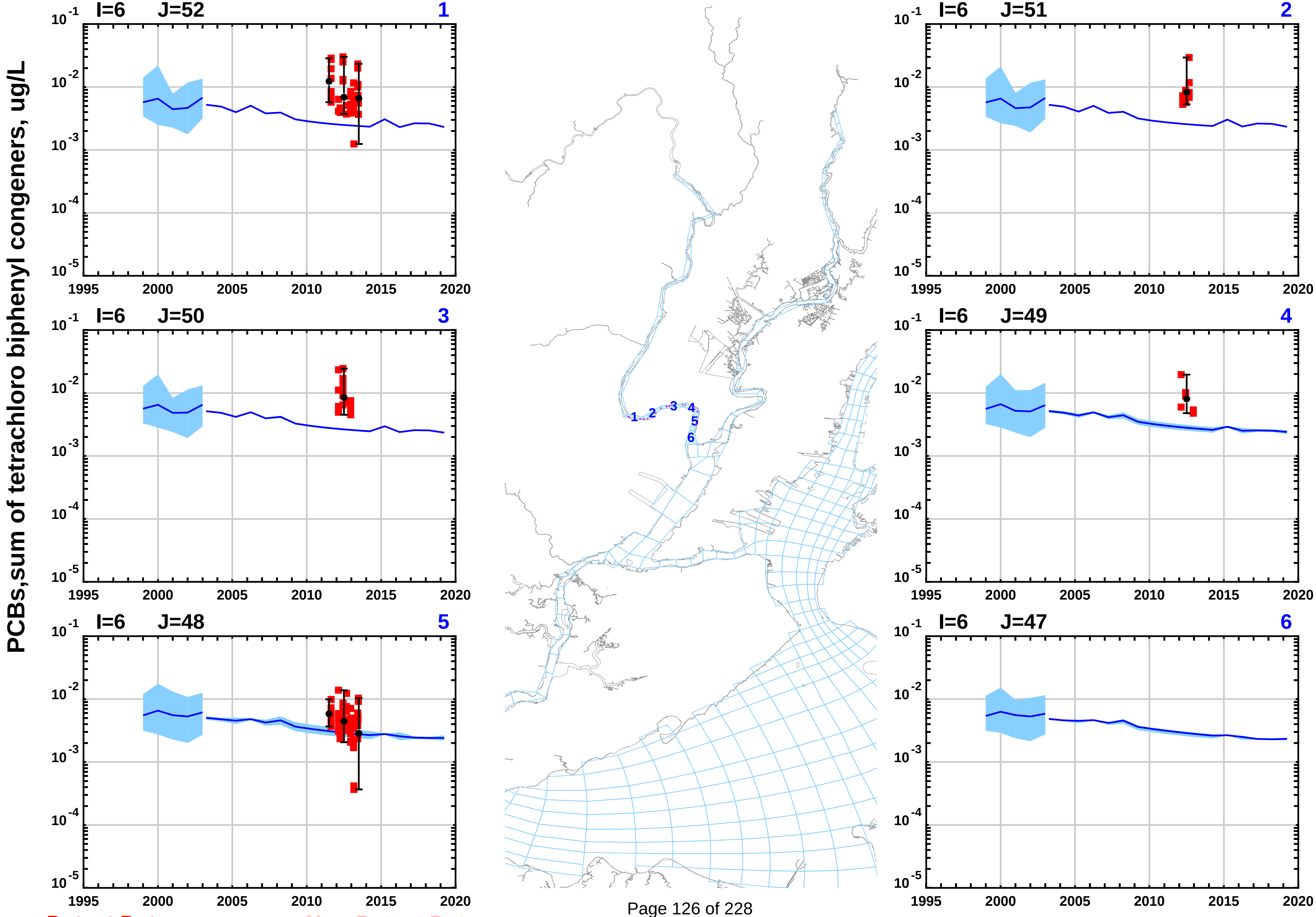


Detect Data
Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers

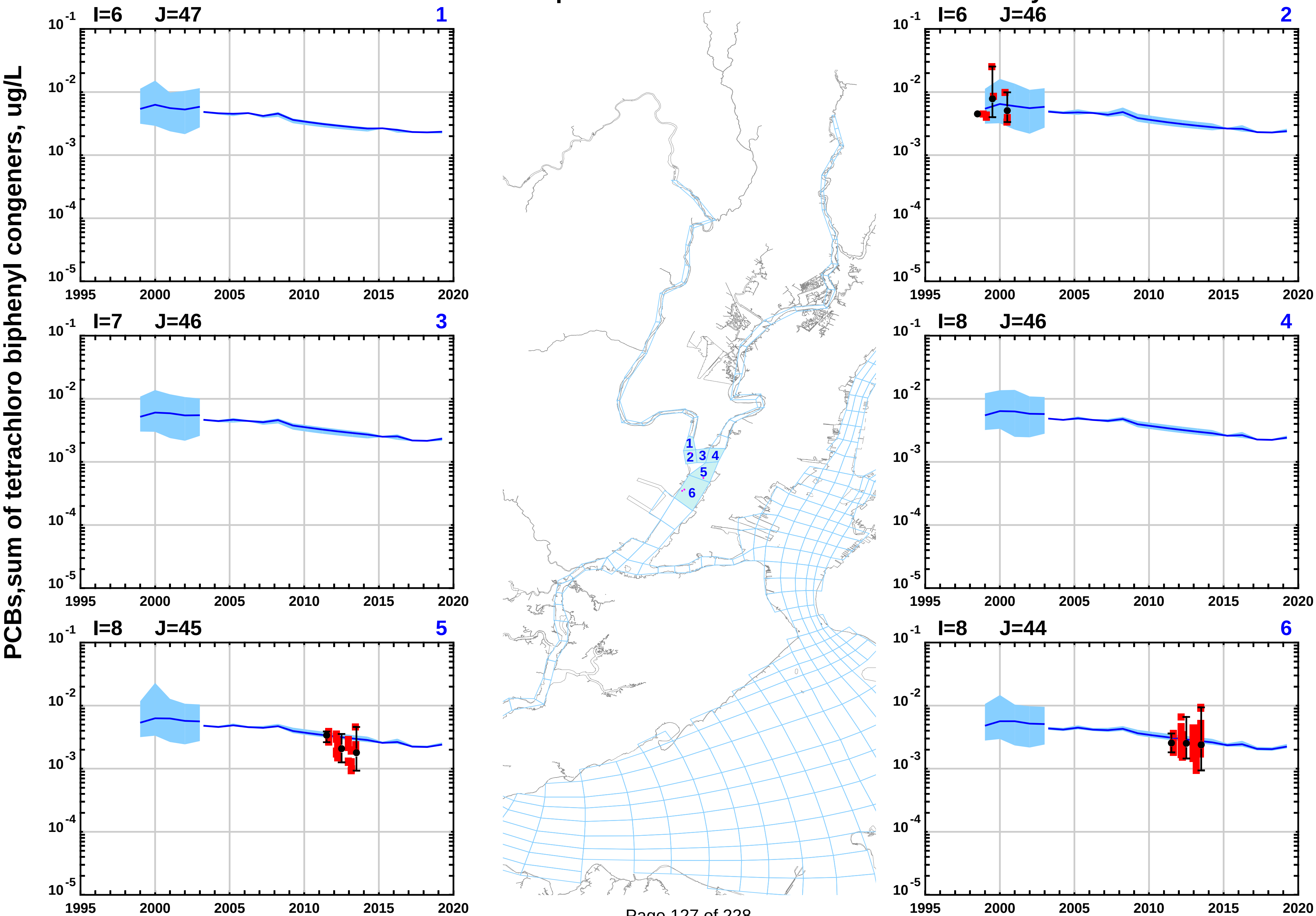


Water Column Data Comparison With Model All Water Column Layers



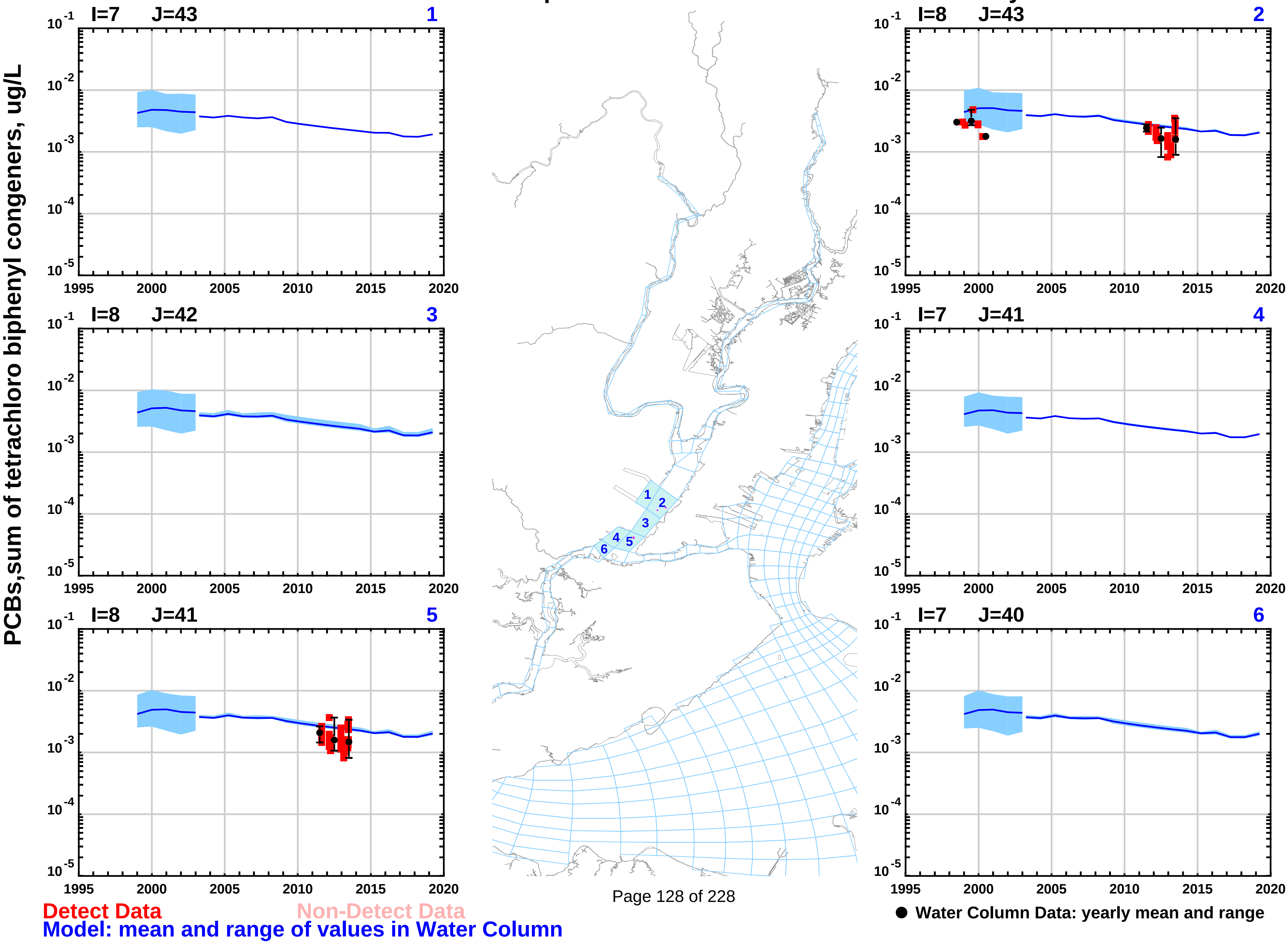
Detect Data Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers

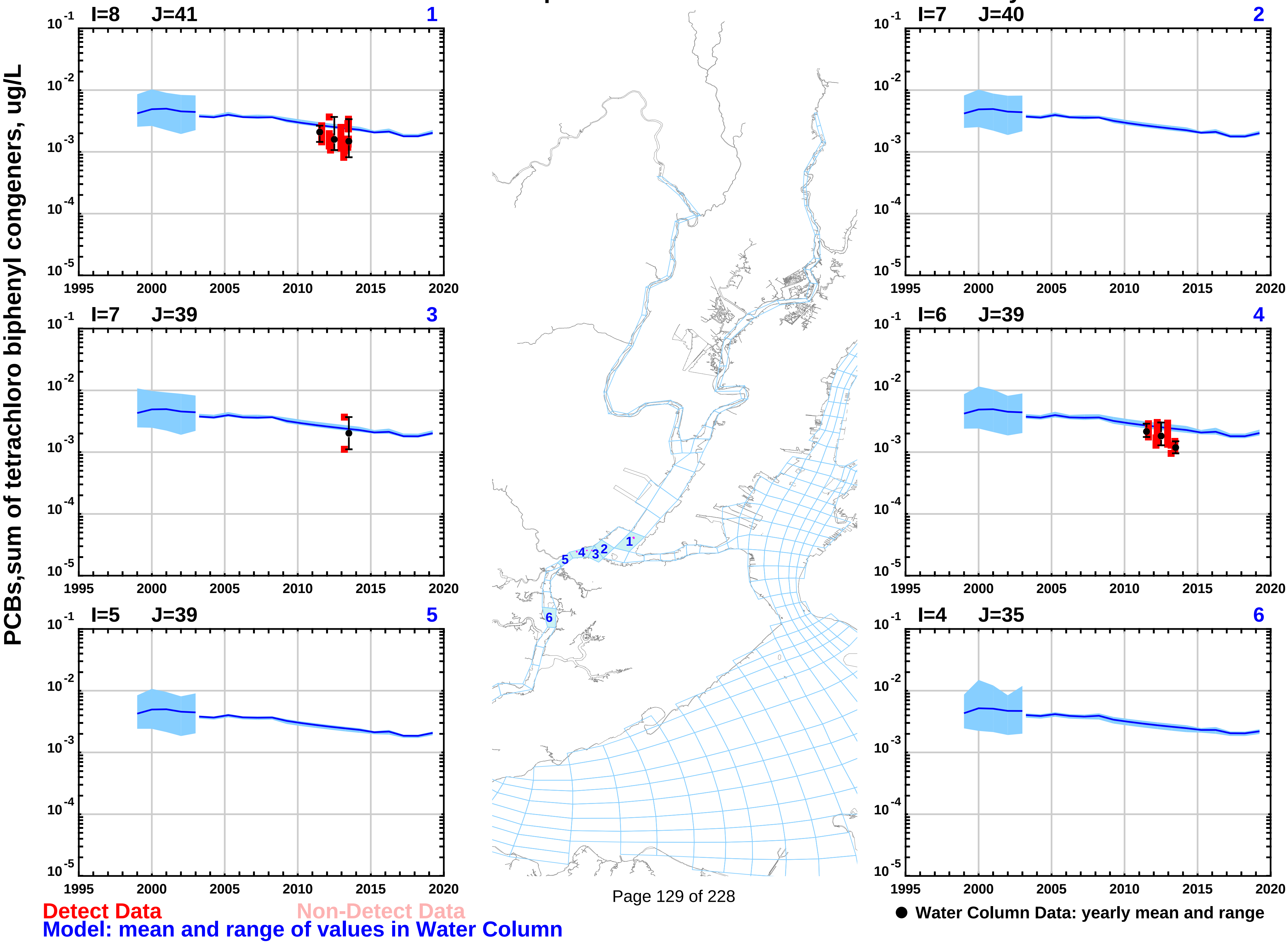


Detect Data Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

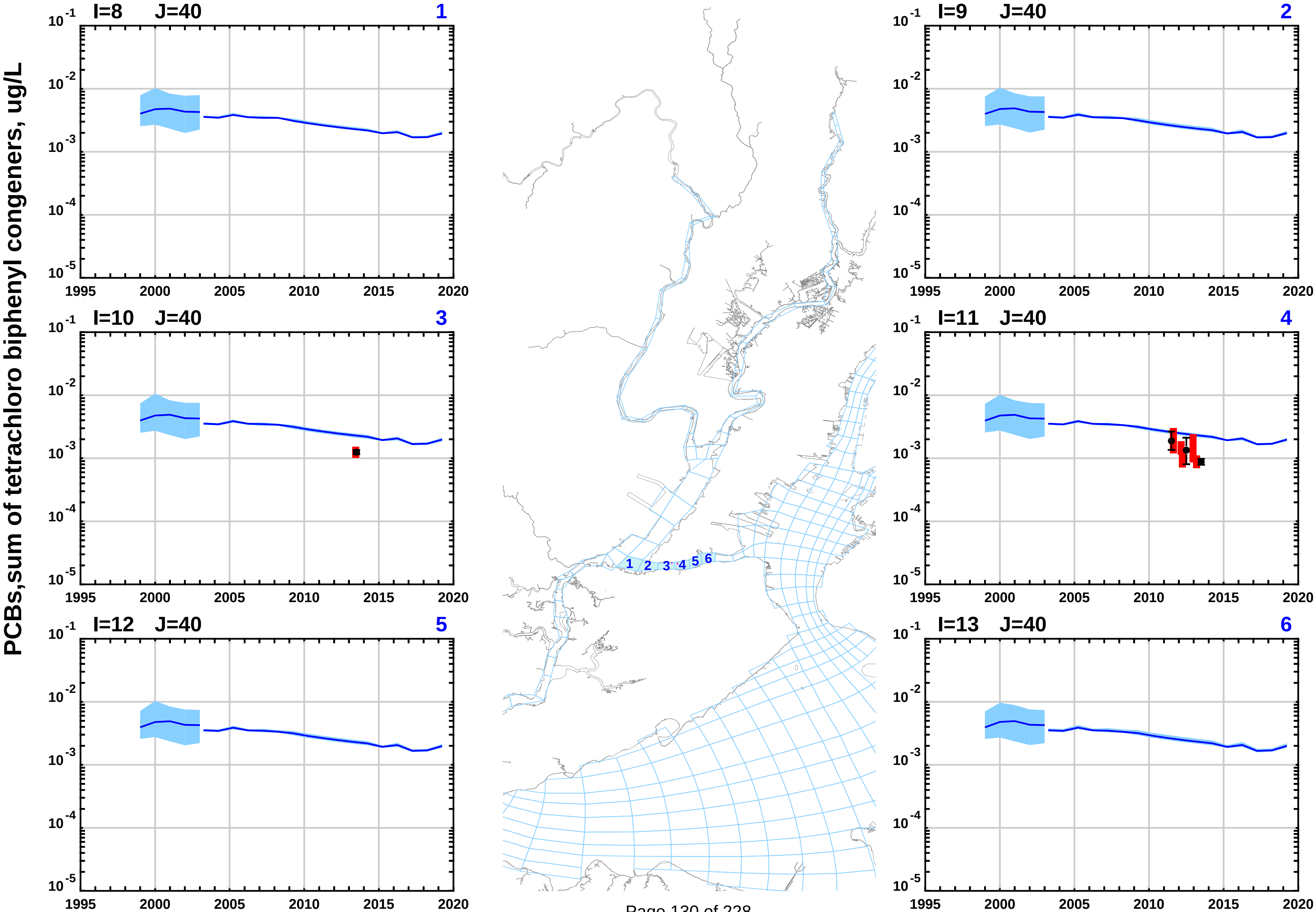
Water Column Data Comparison With Model All Water Column Layers



Water Column Data Comparison With Model All Water Column Layers

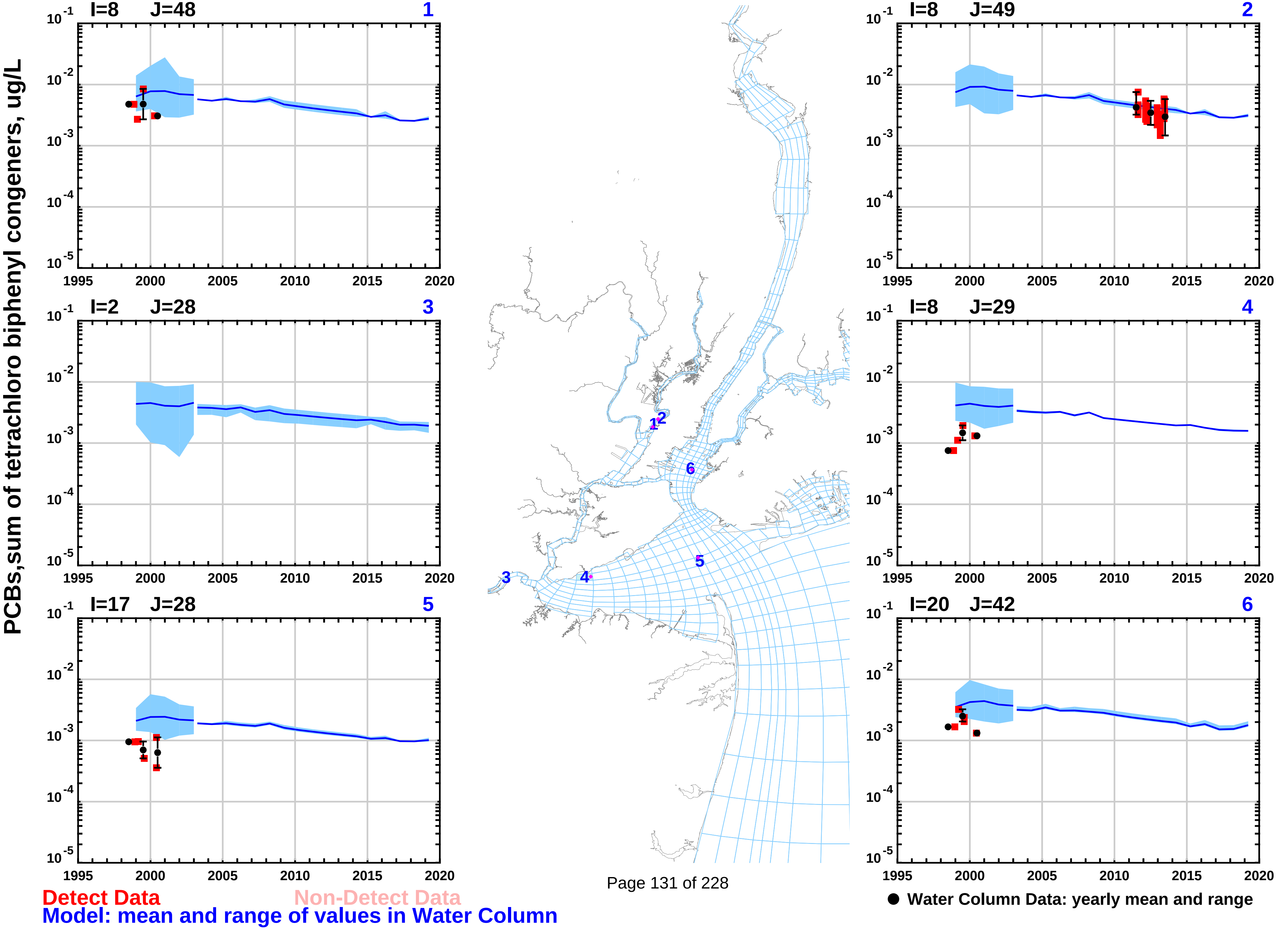


Water Column Data Comparison With Model All Water Column Layers

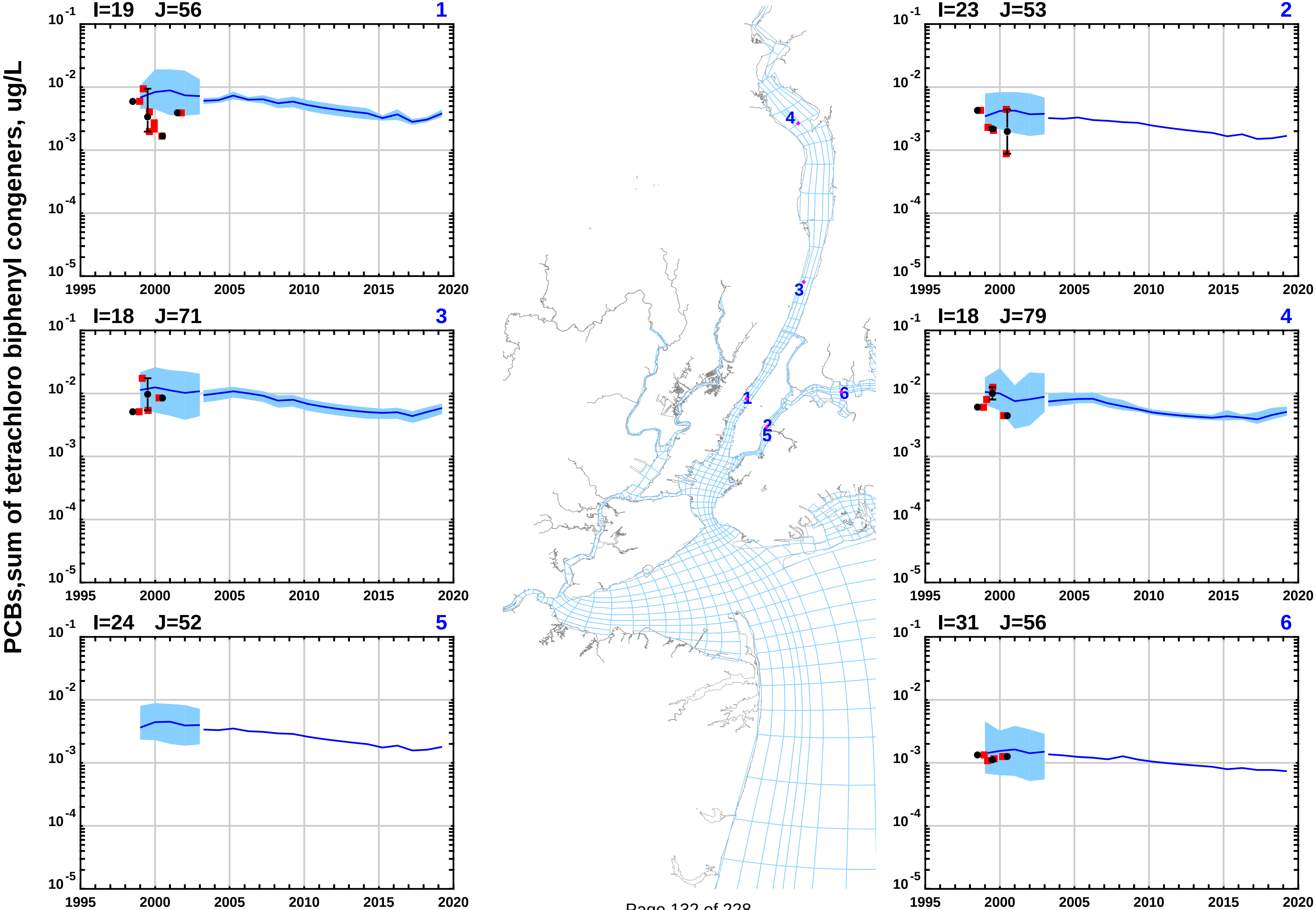


Detect Data Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers



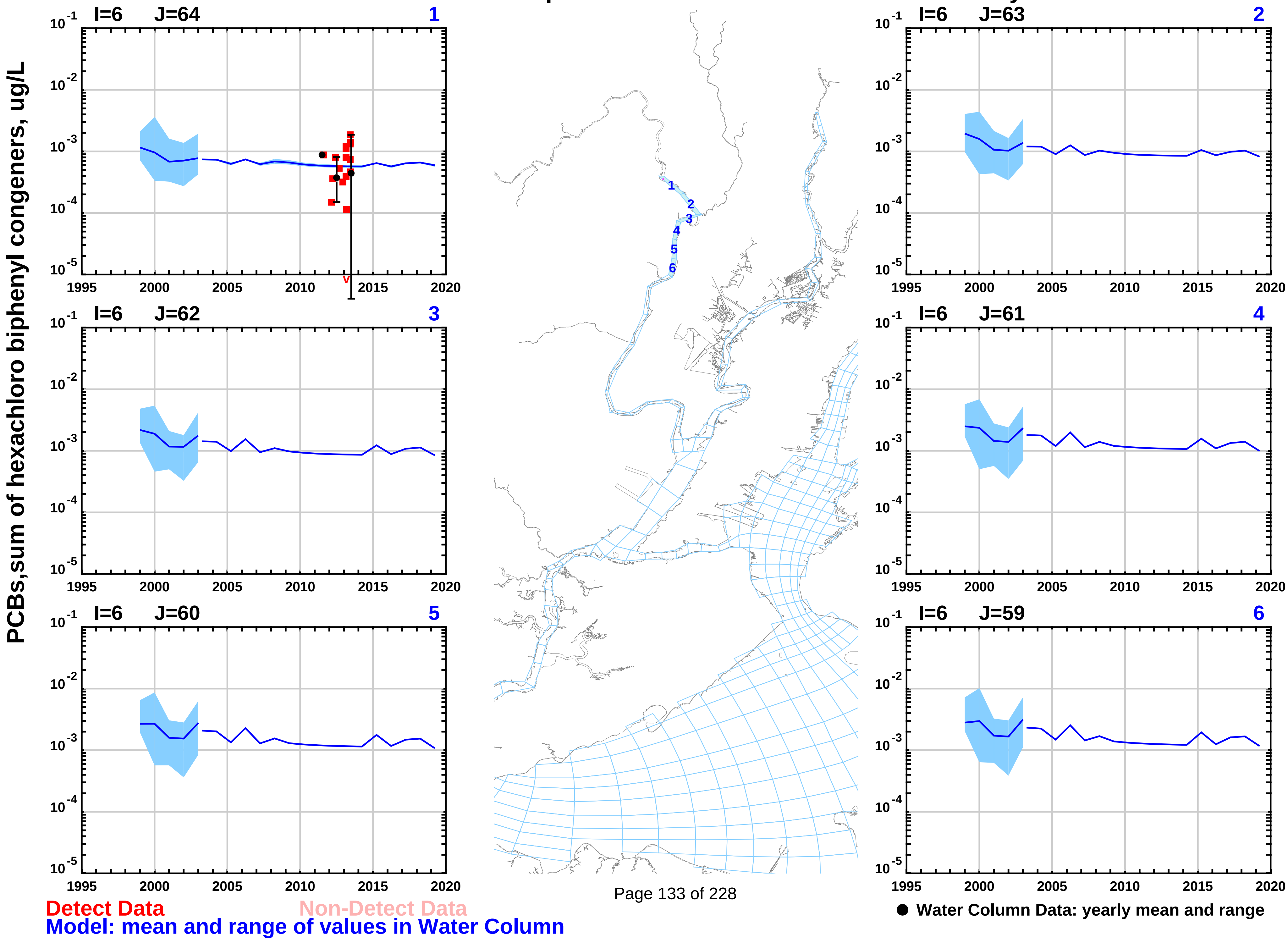
Water Column Data Comparison With Model All Water Column Layers



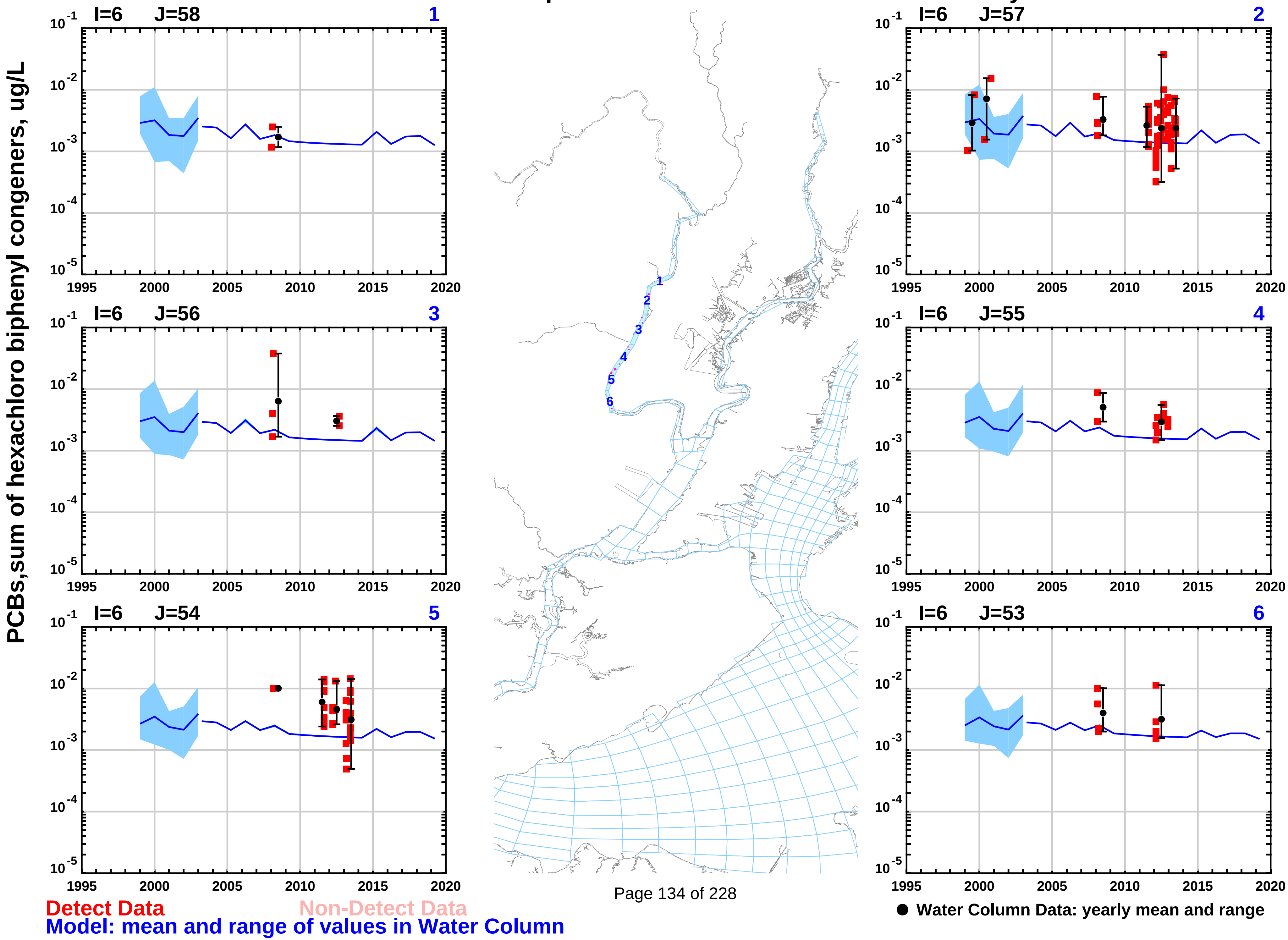
Detect Data Non-Detect Data
Model: mean and range of values in Water Column

● Water Column Data: yearly mean and range

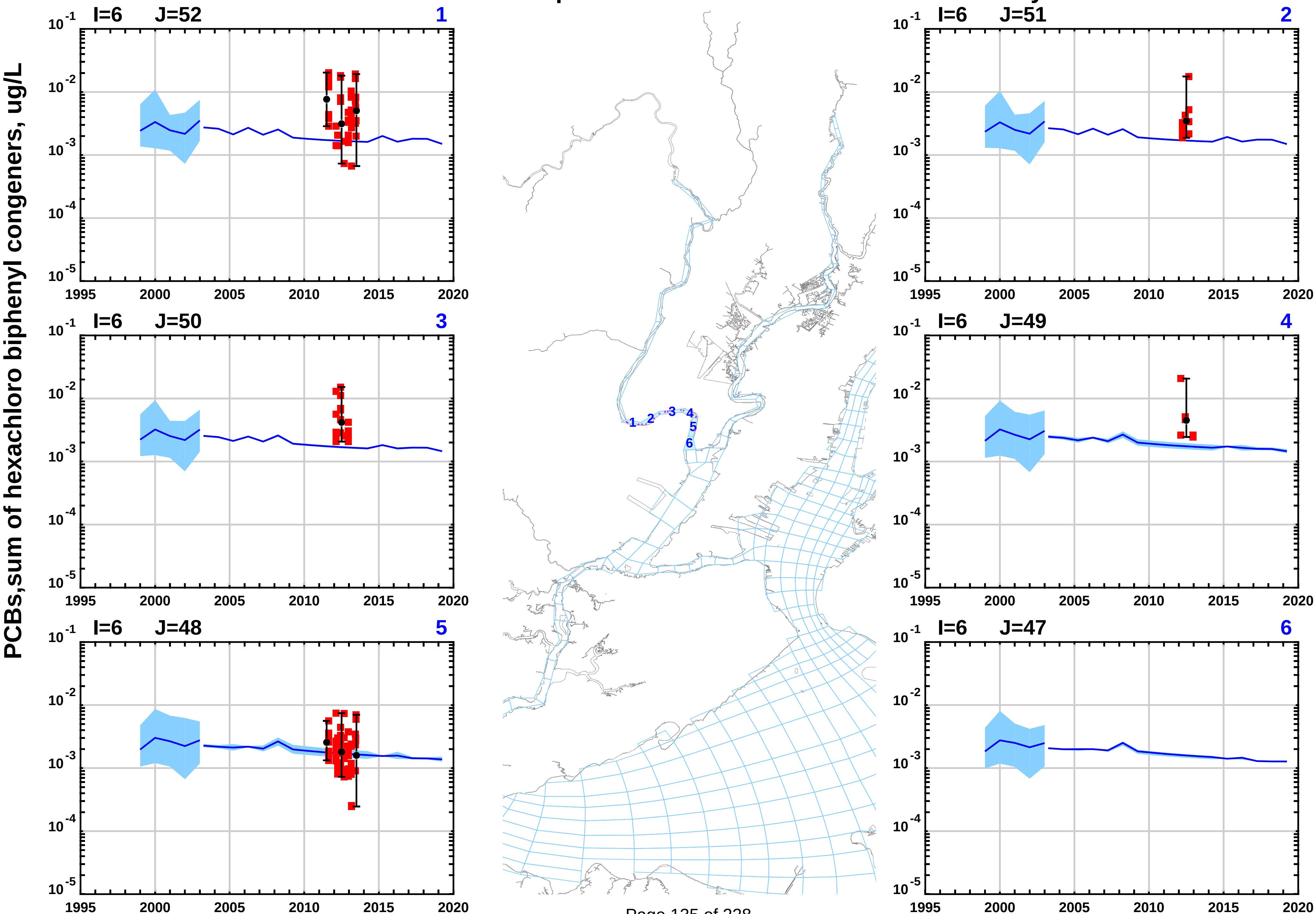
Water Column Data Comparison With Model All Water Column Layers



Water Column Data Comparison With Model All Water Column Layers

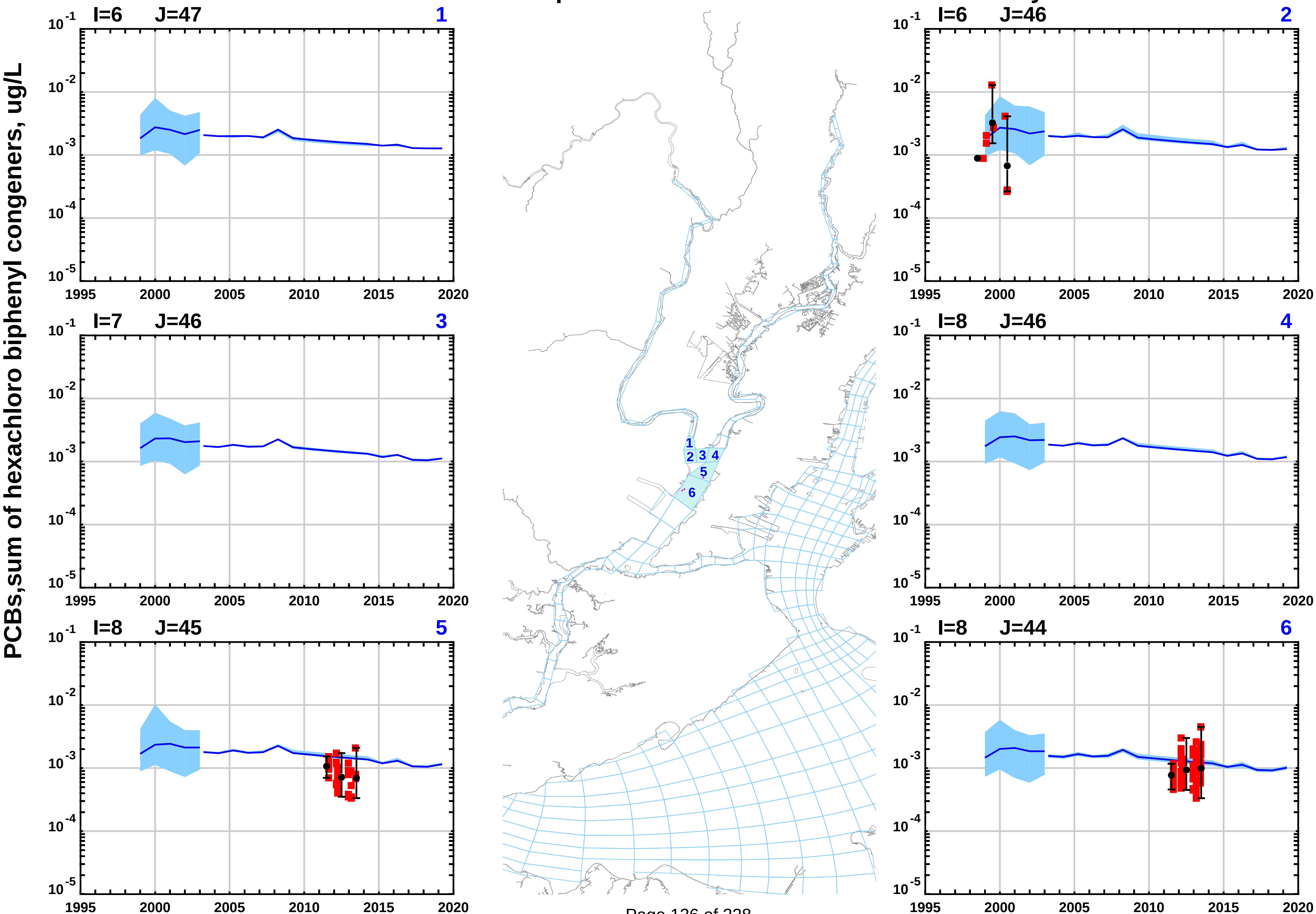


Water Column Data Comparison With Model All Water Column Layers



Detect Data Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

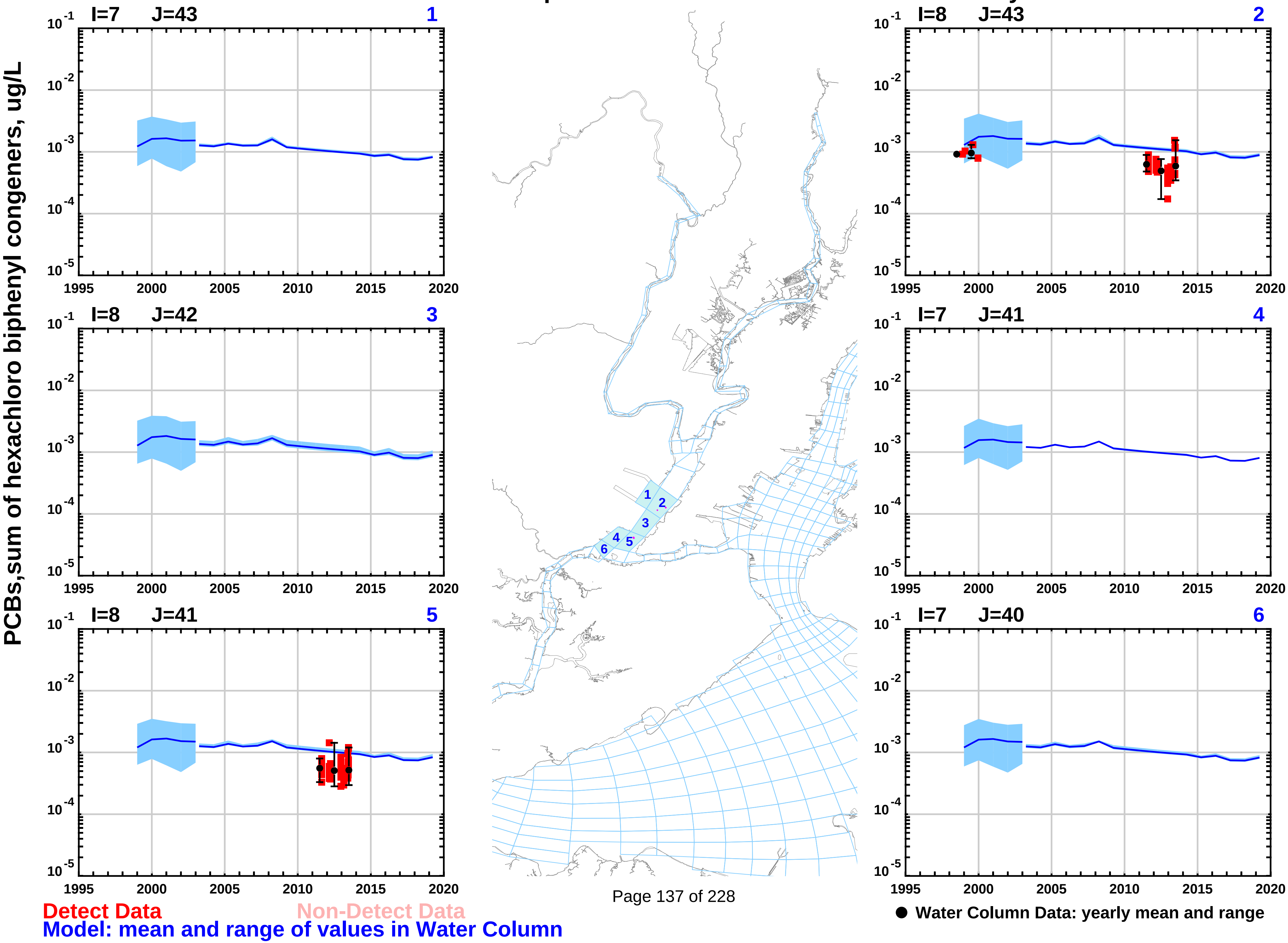
Water Column Data Comparison With Model All Water Column Layers



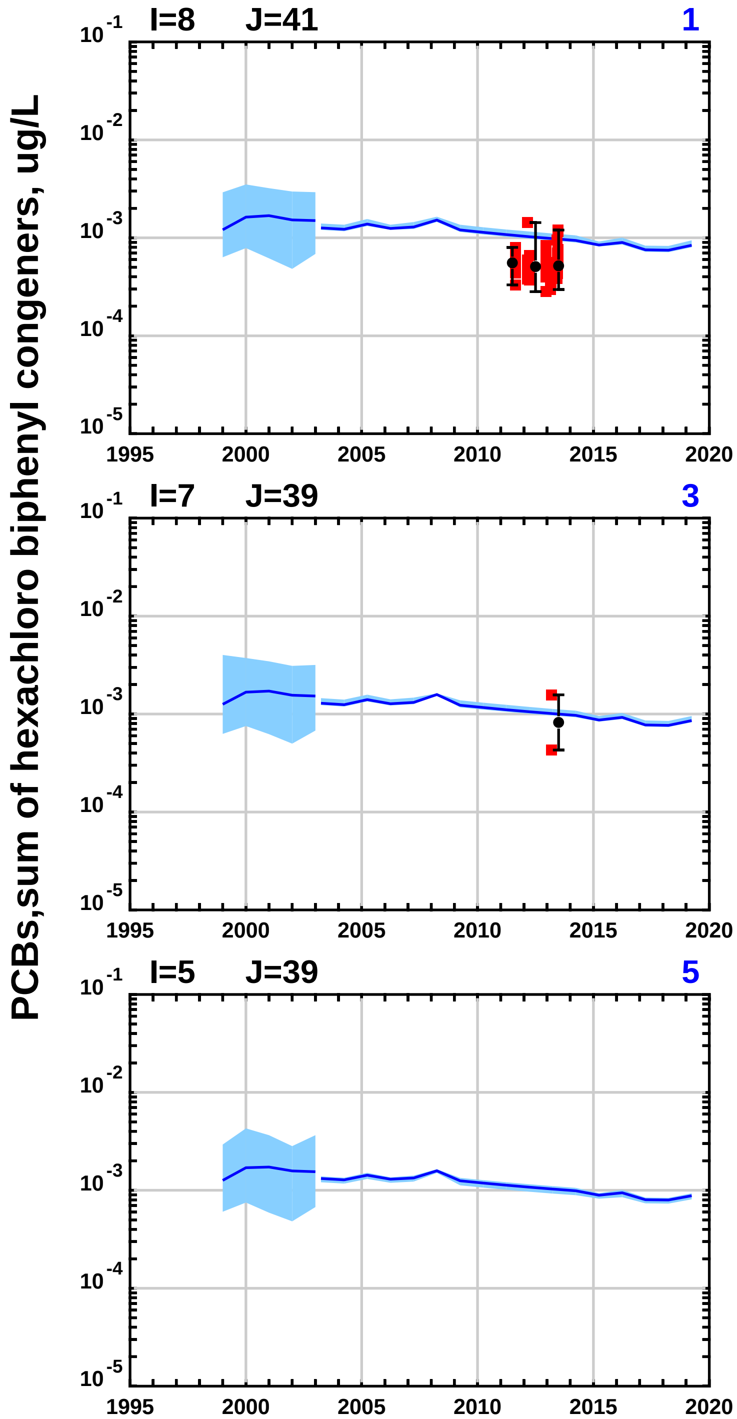
Detect Data Non-Detect Data
Model: mean and range of values in Water Column

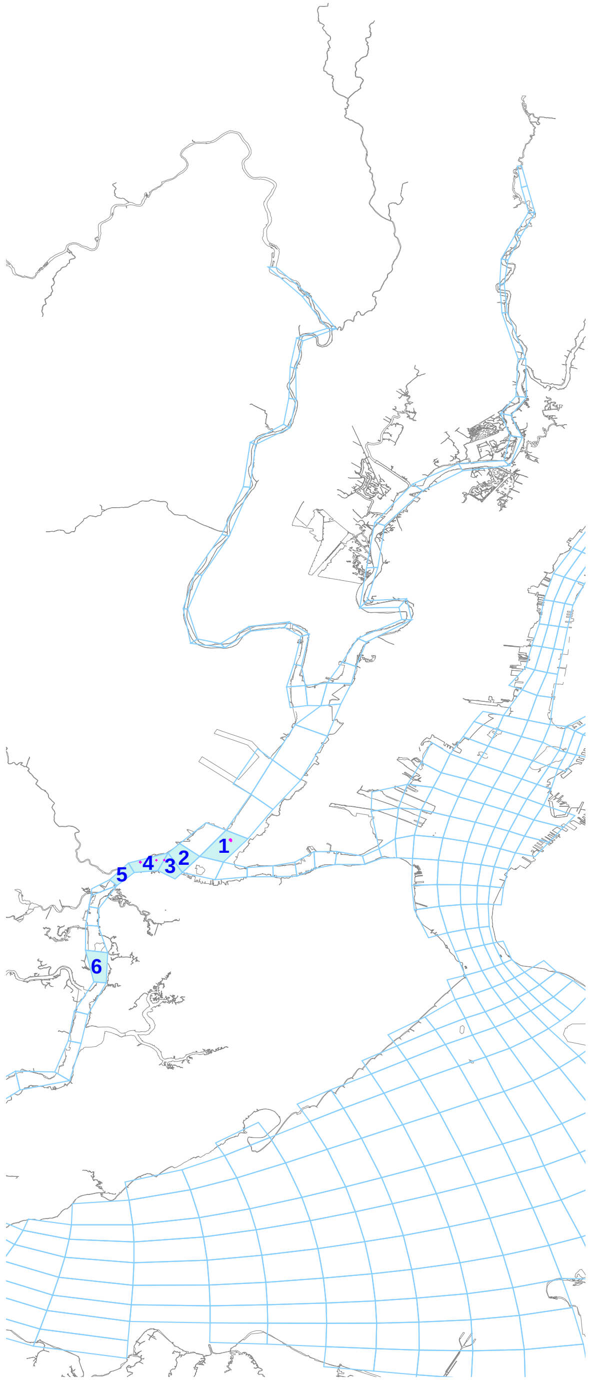
● Water Column Data: yearly mean and range

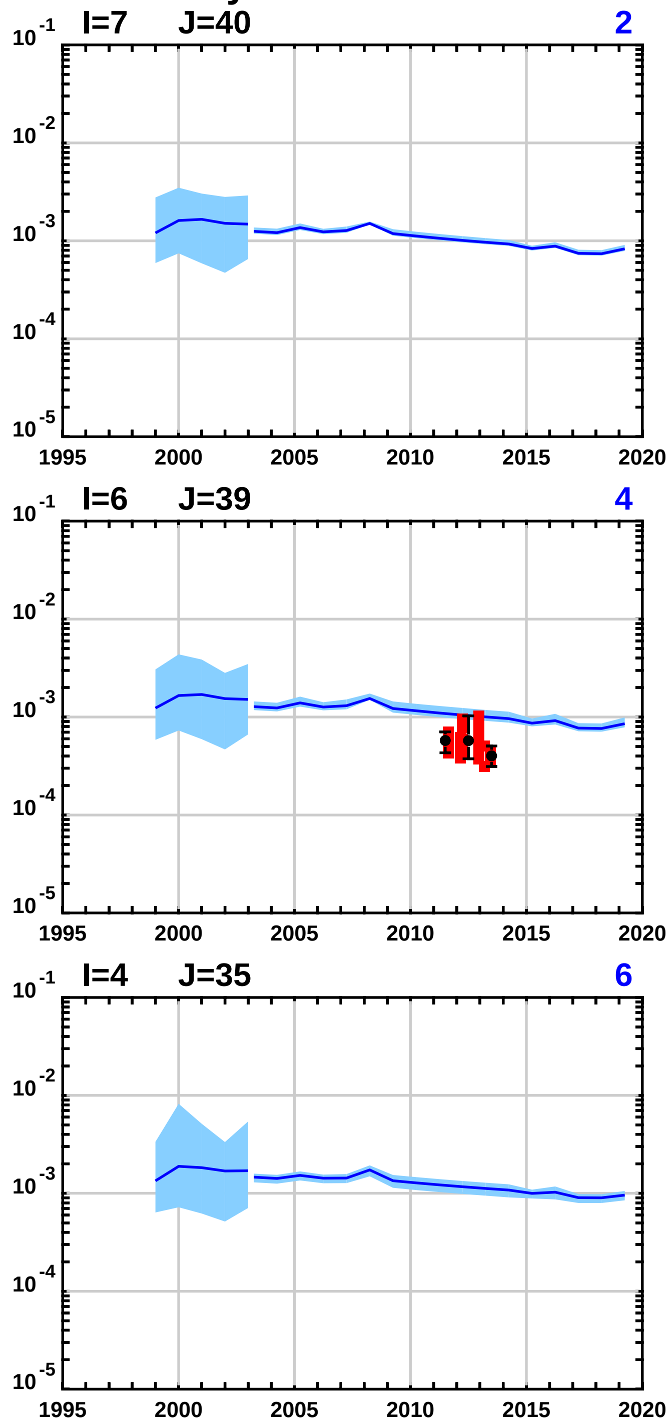
Water Column Data Comparison With Model All Water Column Layers



Water Column Data Comparison With Model All Water Column Layers



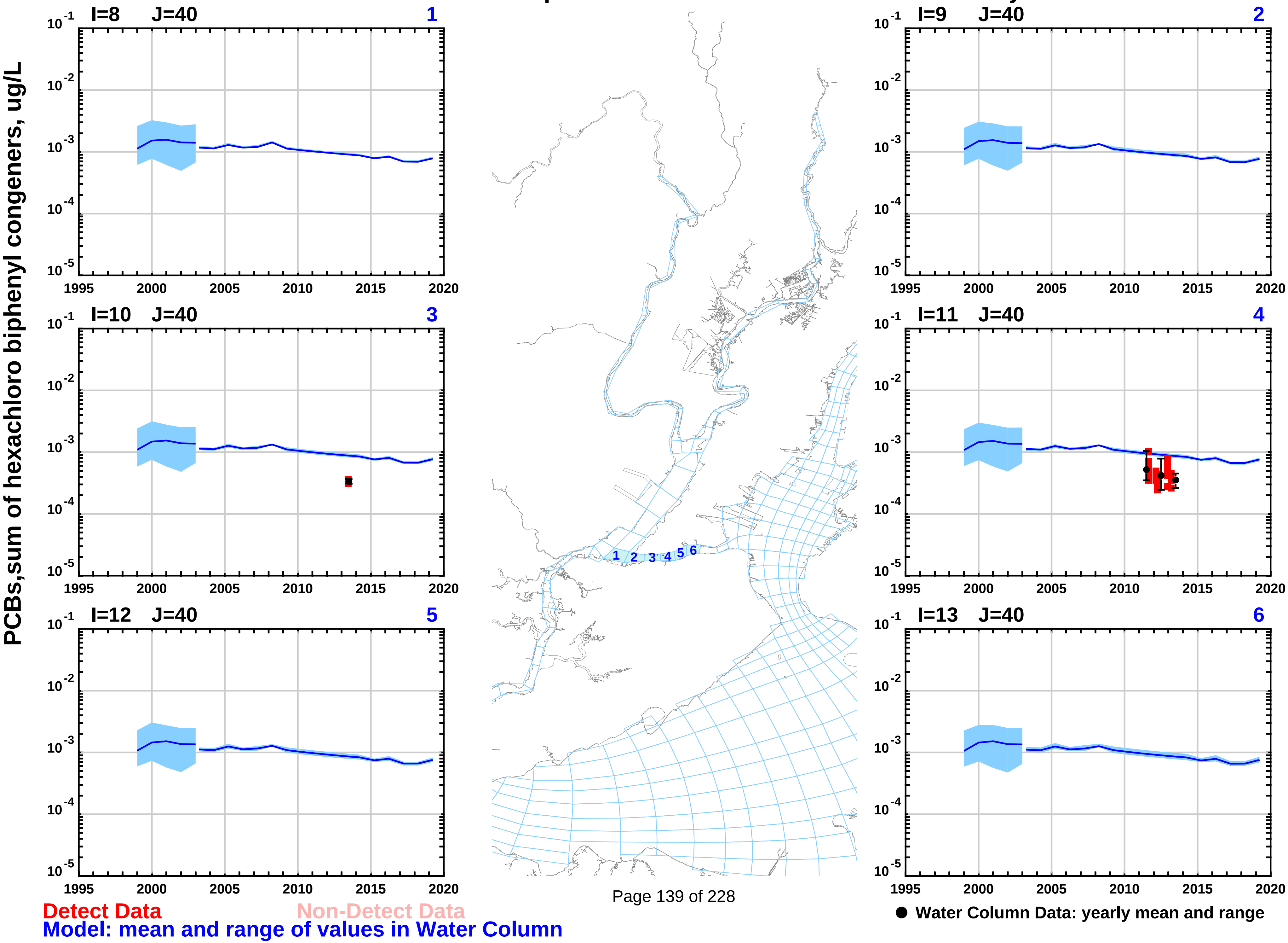




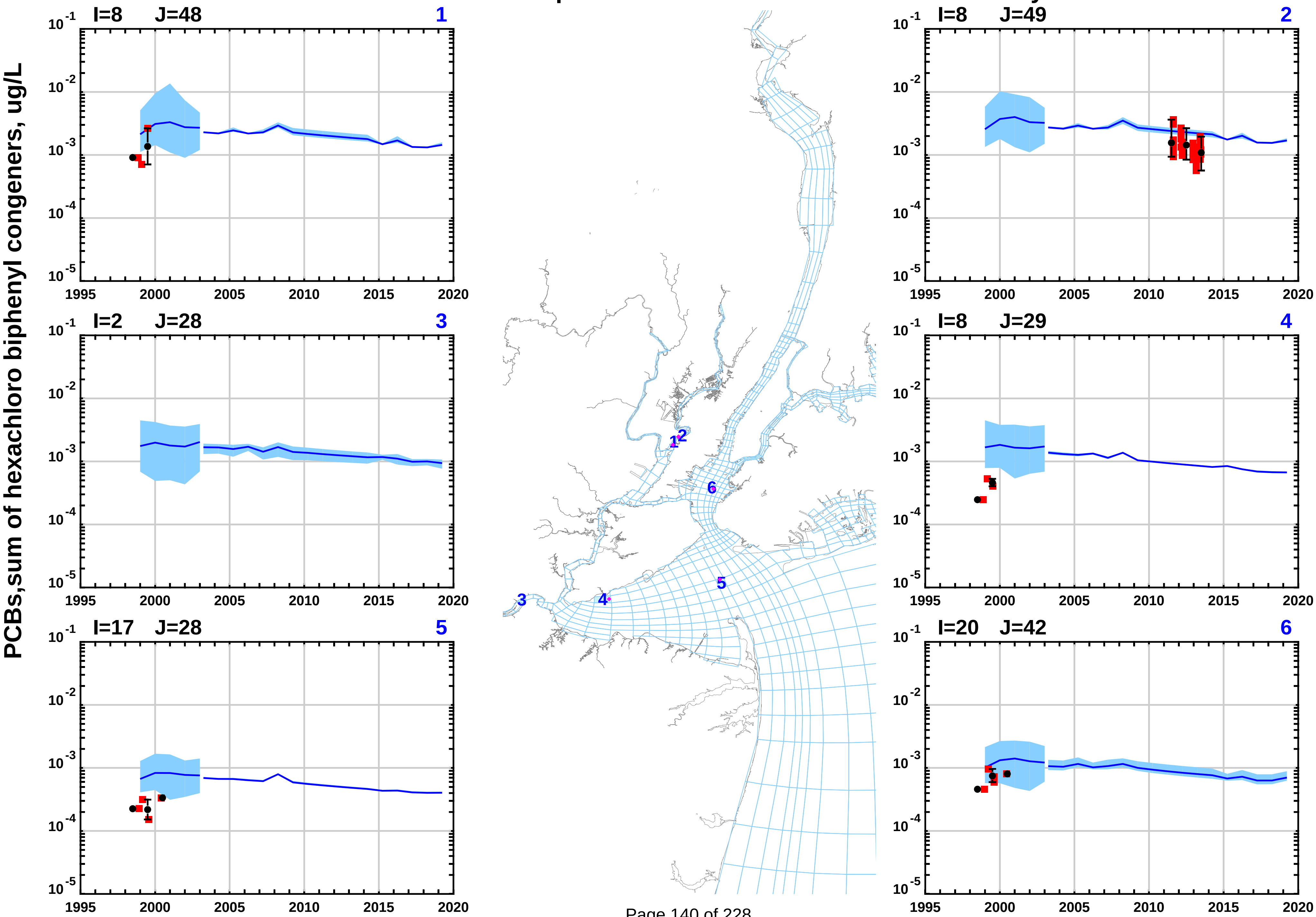
Detect Data Non-Detect Data
Model: mean and range of values in Water Column

● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers



Water Column Data Comparison With Model All Water Column Layers



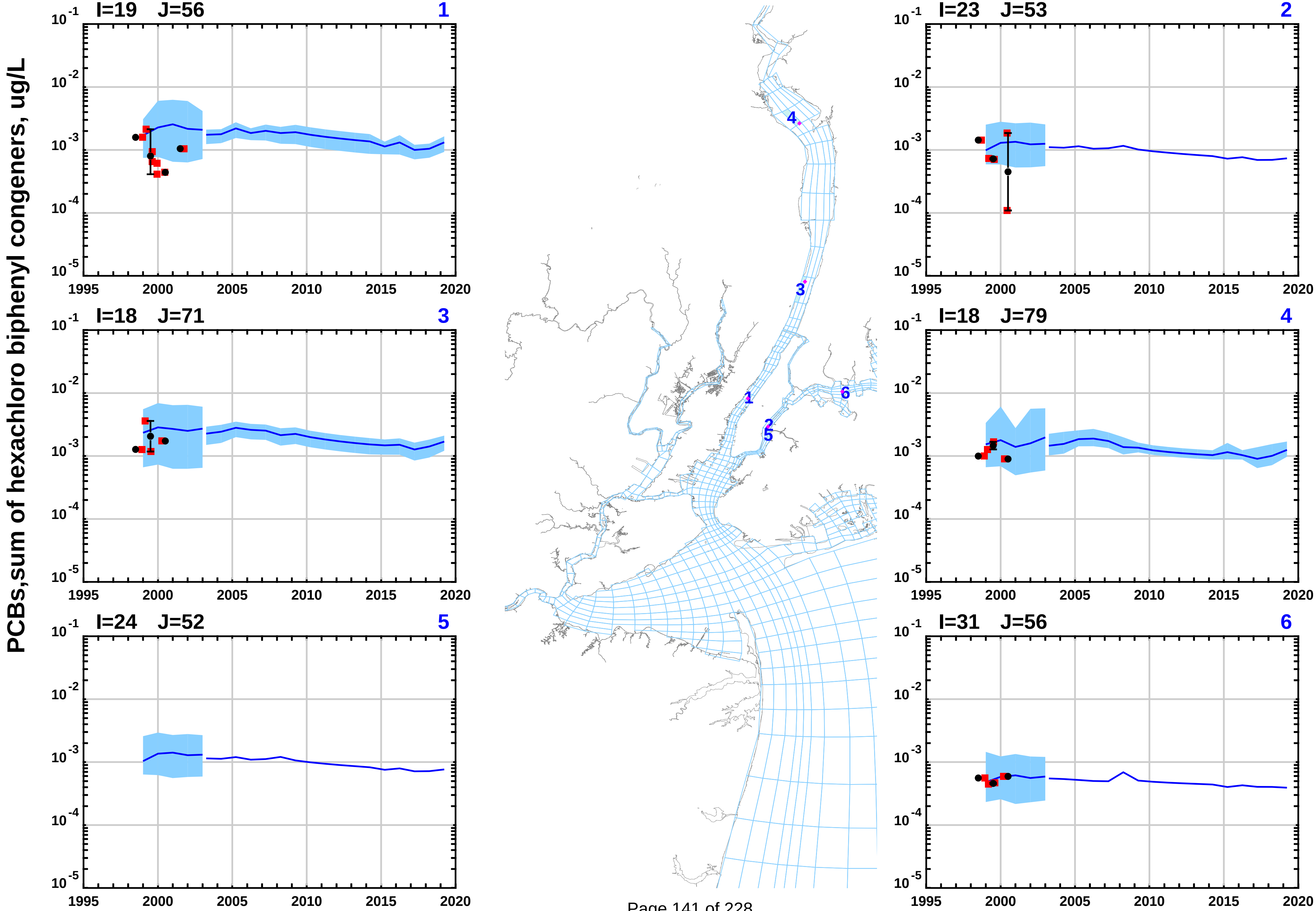
Detect Data

Non-Detect Data

Model: mean and range of values in Water Column

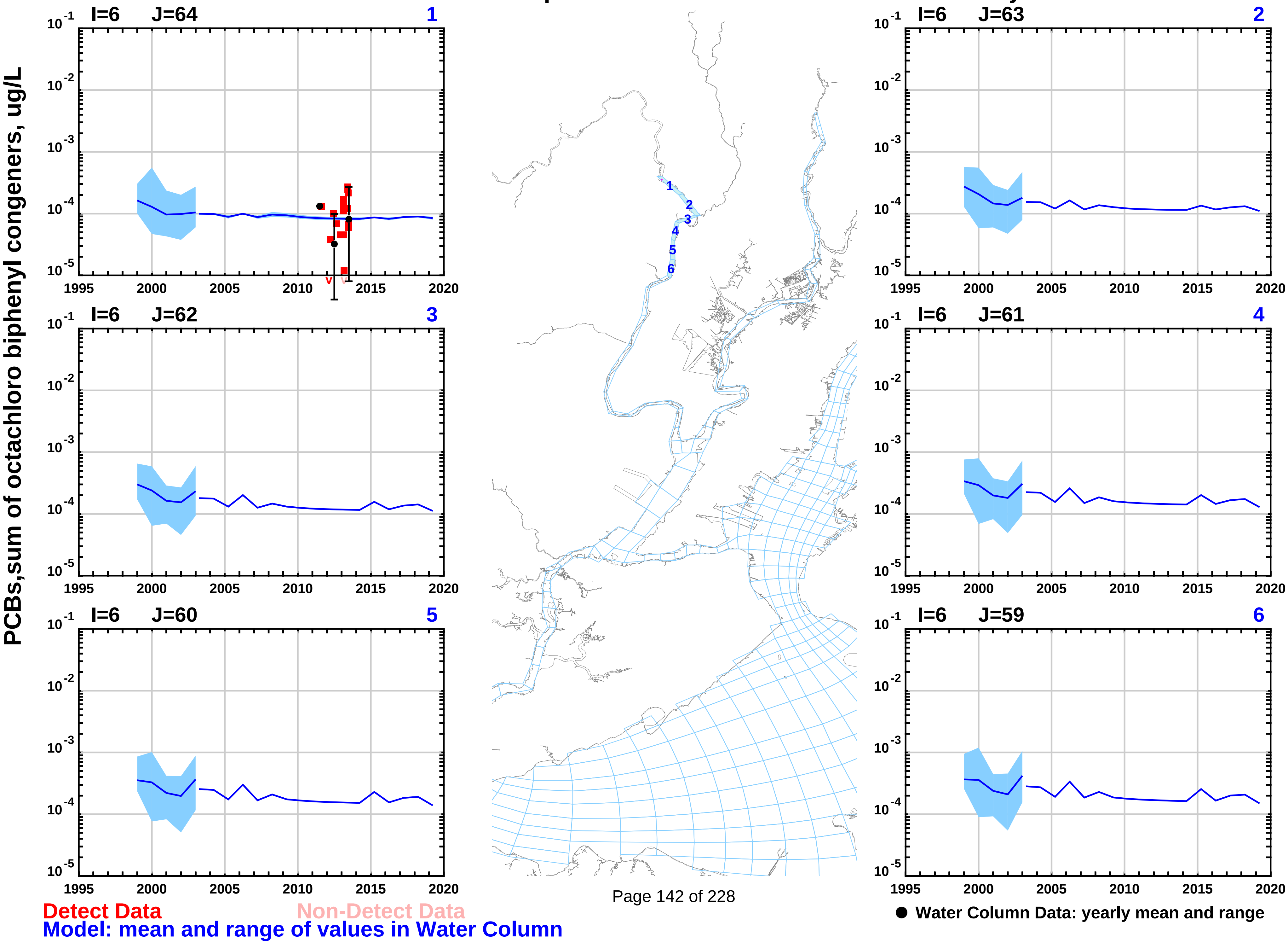
● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers

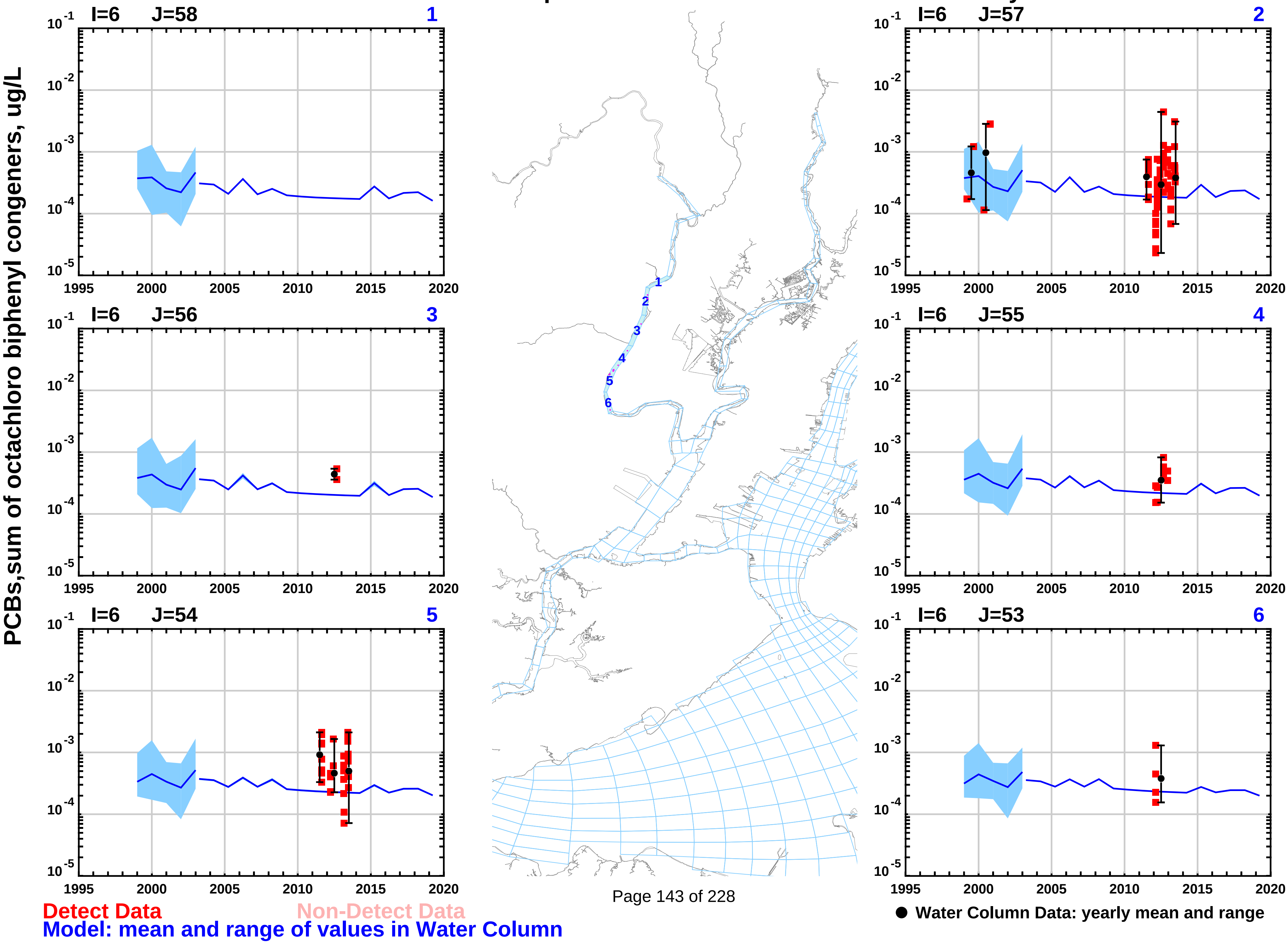


Detect Data Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

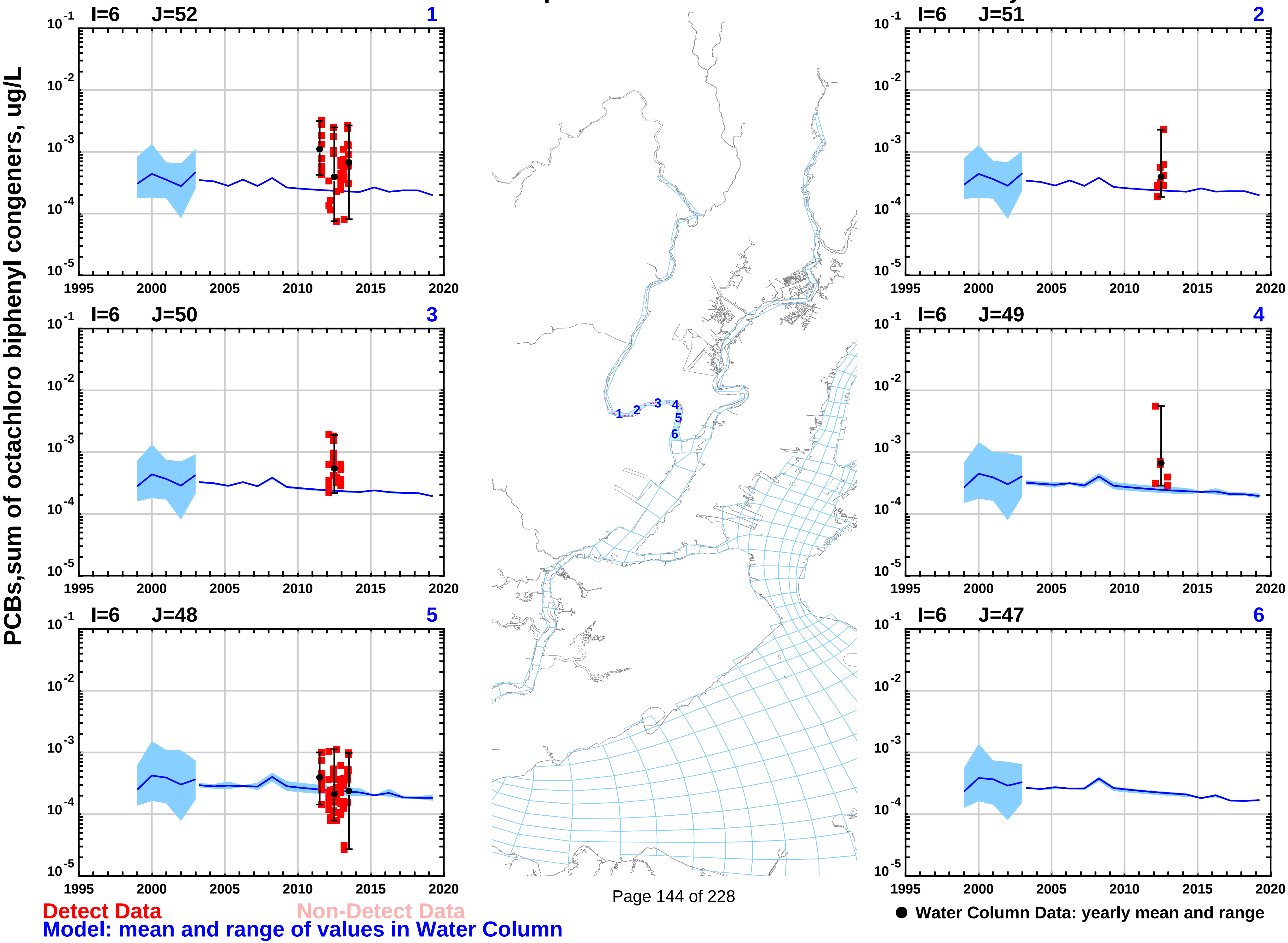
Water Column Data Comparison With Model All Water Column Layers

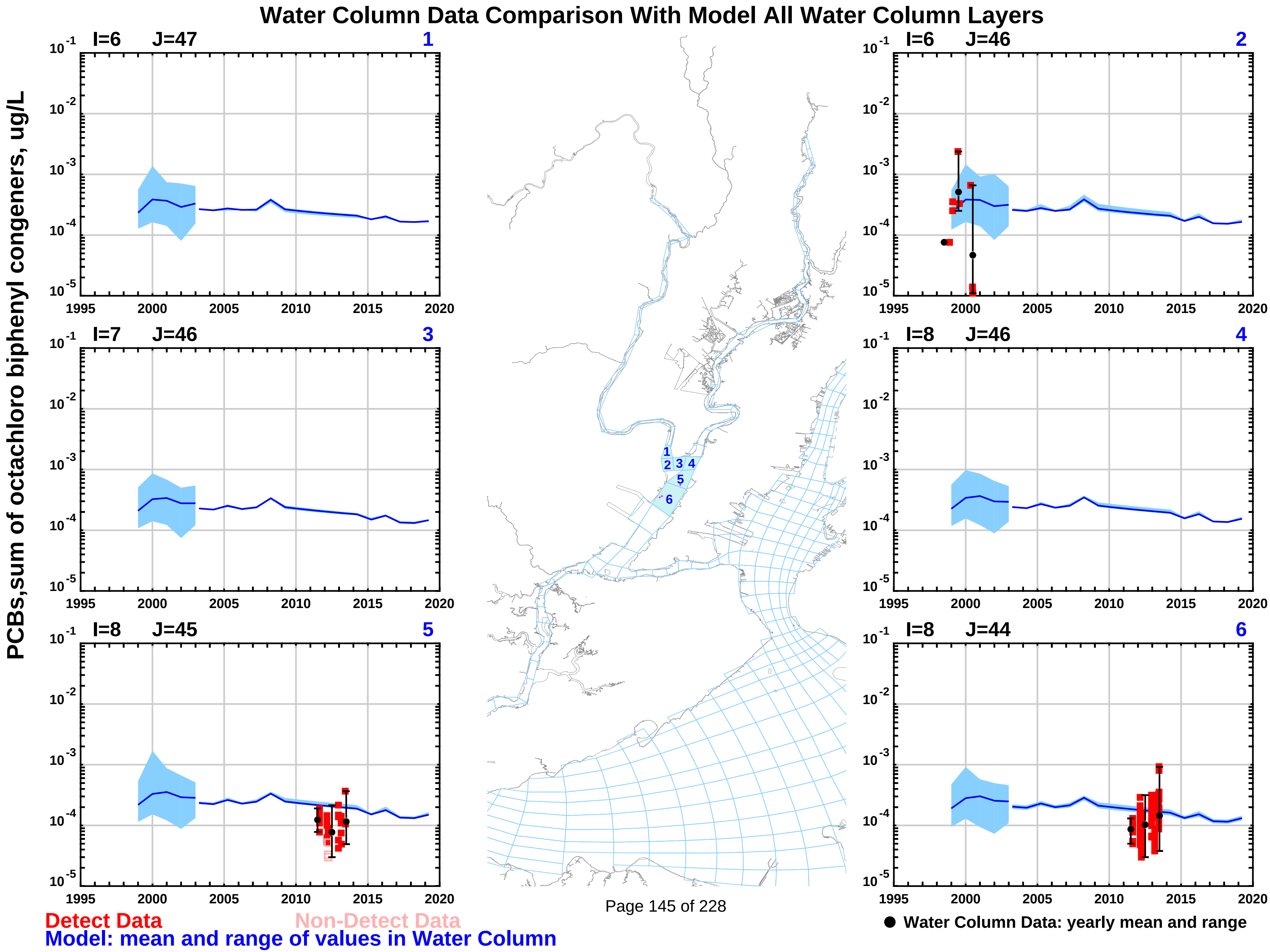


Water Column Data Comparison With Model All Water Column Layers



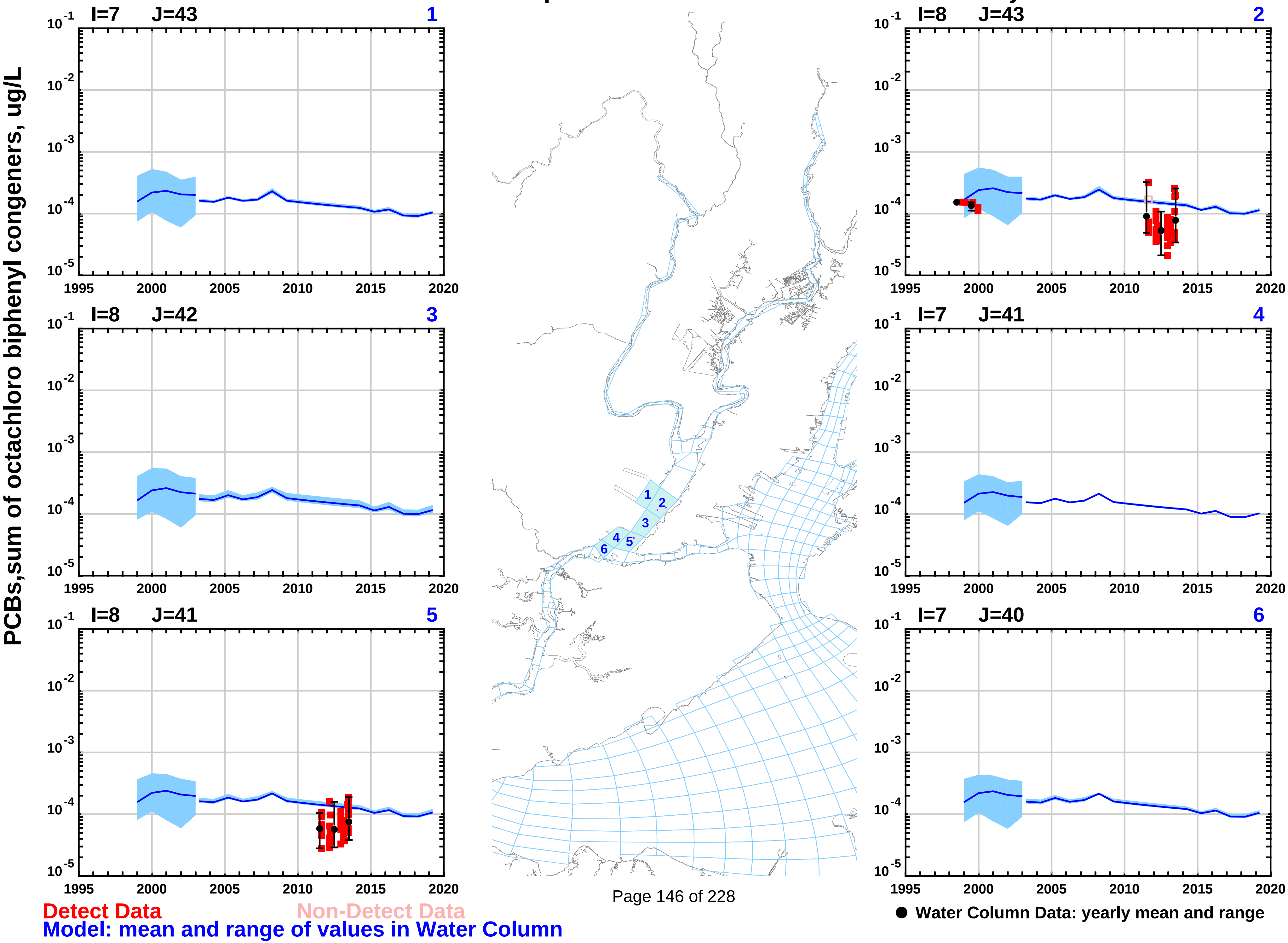
Water Column Data Comparison With Model All Water Column Layers



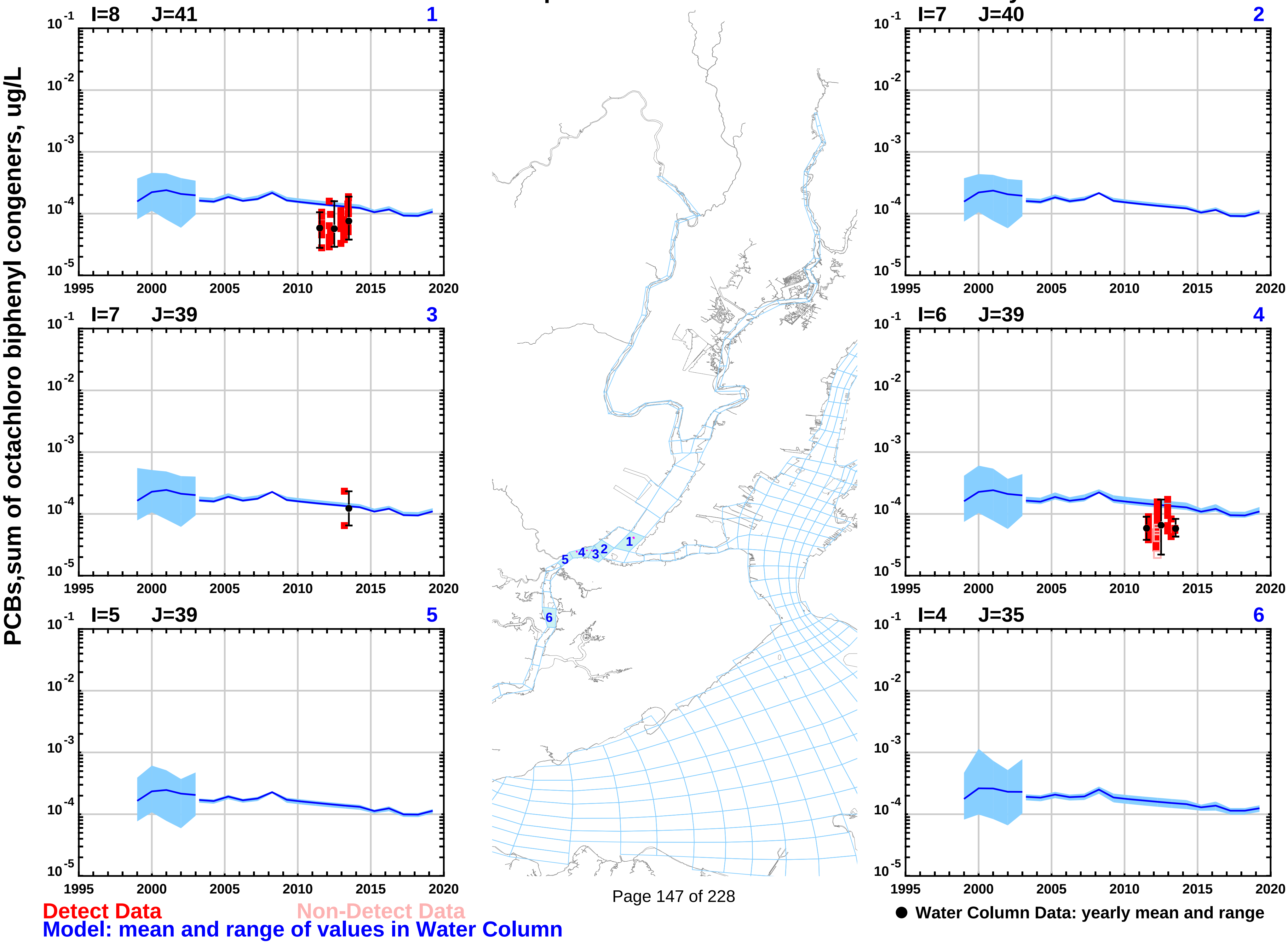


Water Column Data Comparison With Model All Water Column Layers
PCBs,sum of octachloro biphenyl congeners, ug/L
I=6 J=47 1
I=6 J=46 2
I=7 J=46 3
I=8 J=46 4
I=8 J=45 5
I=8 J=44 6
10^-1
10^-2
10^-3
10^-4
10^-5
1995
2000
2005
2010
2015
2020
1
2
3
4
5
6
Detect Data
Non-Detect Data
Model: mean and range of values in Water Column
Water Column Data: yearly mean and range

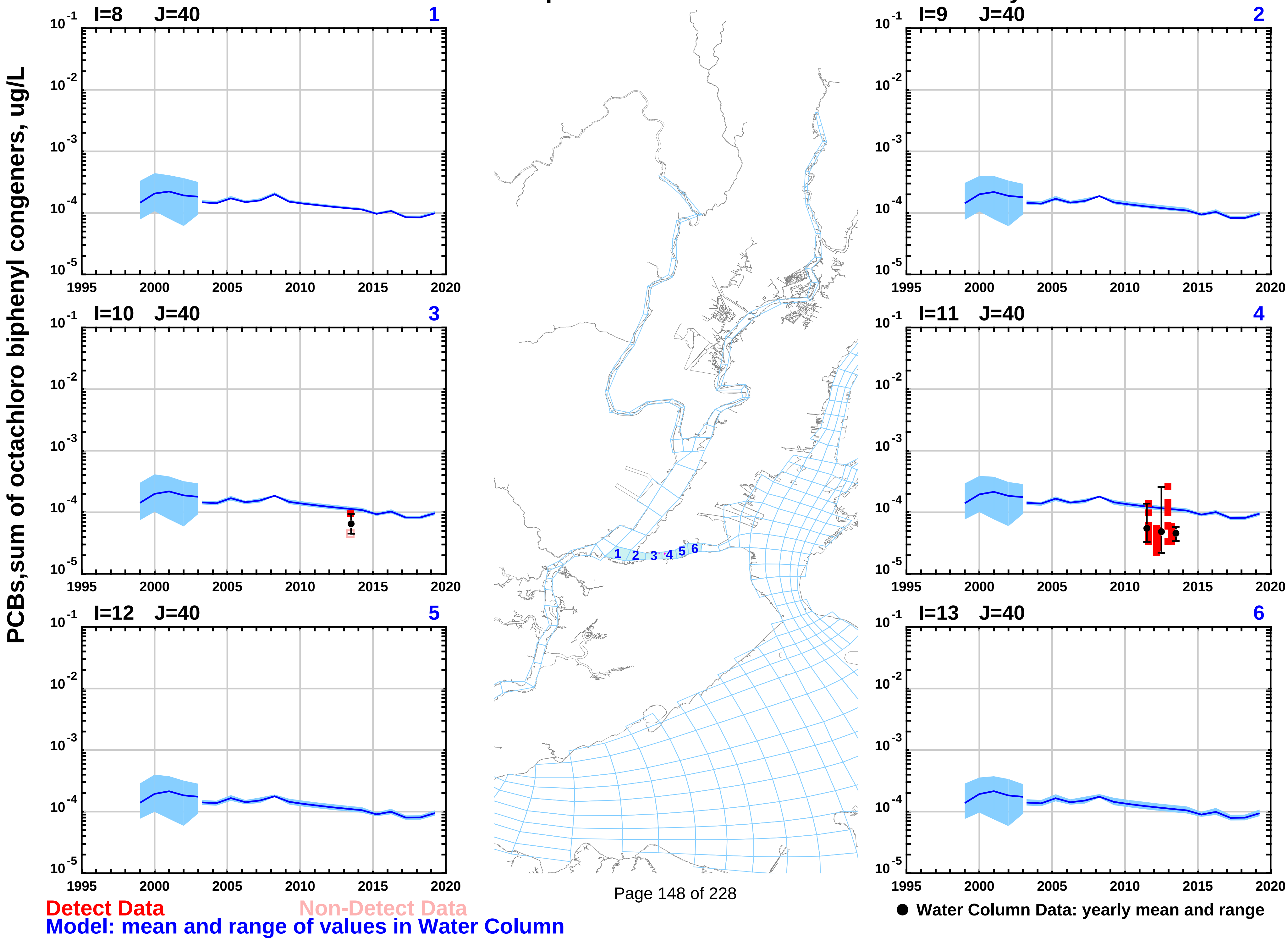
Water Column Data Comparison With Model All Water Column Layers



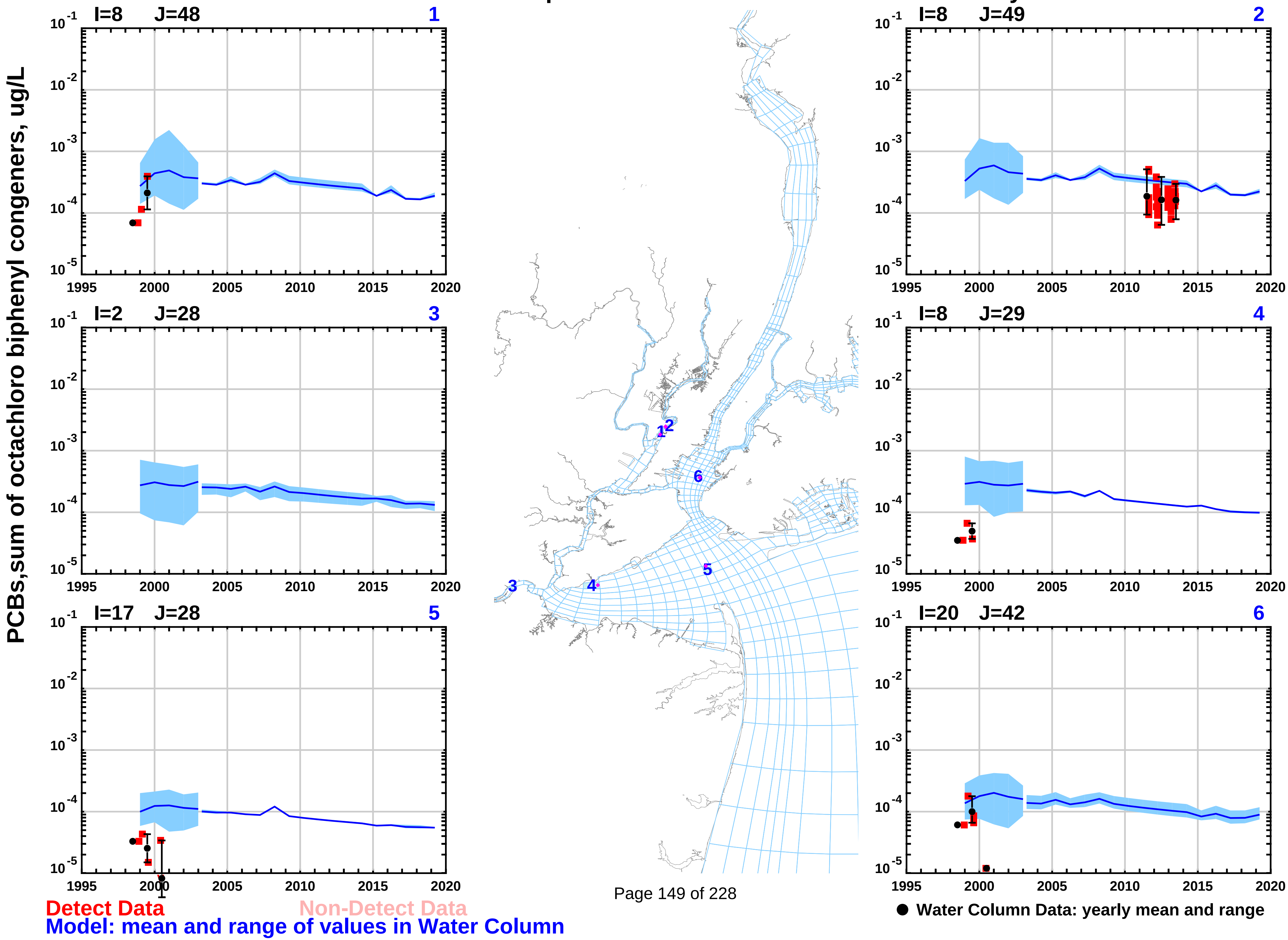
Water Column Data Comparison With Model All Water Column Layers



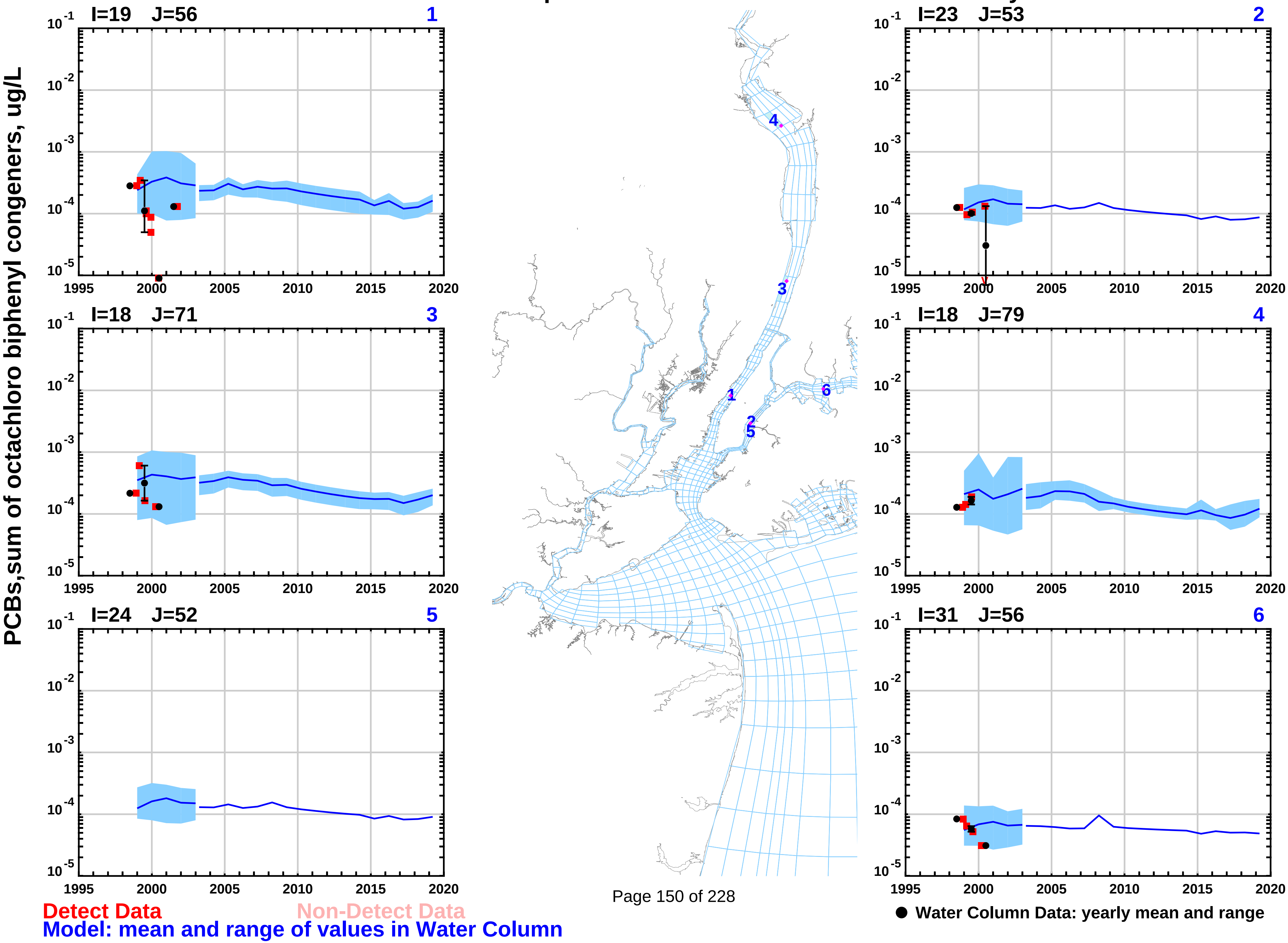
Water Column Data Comparison With Model All Water Column Layers



Water Column Data Comparison With Model All Water Column Layers

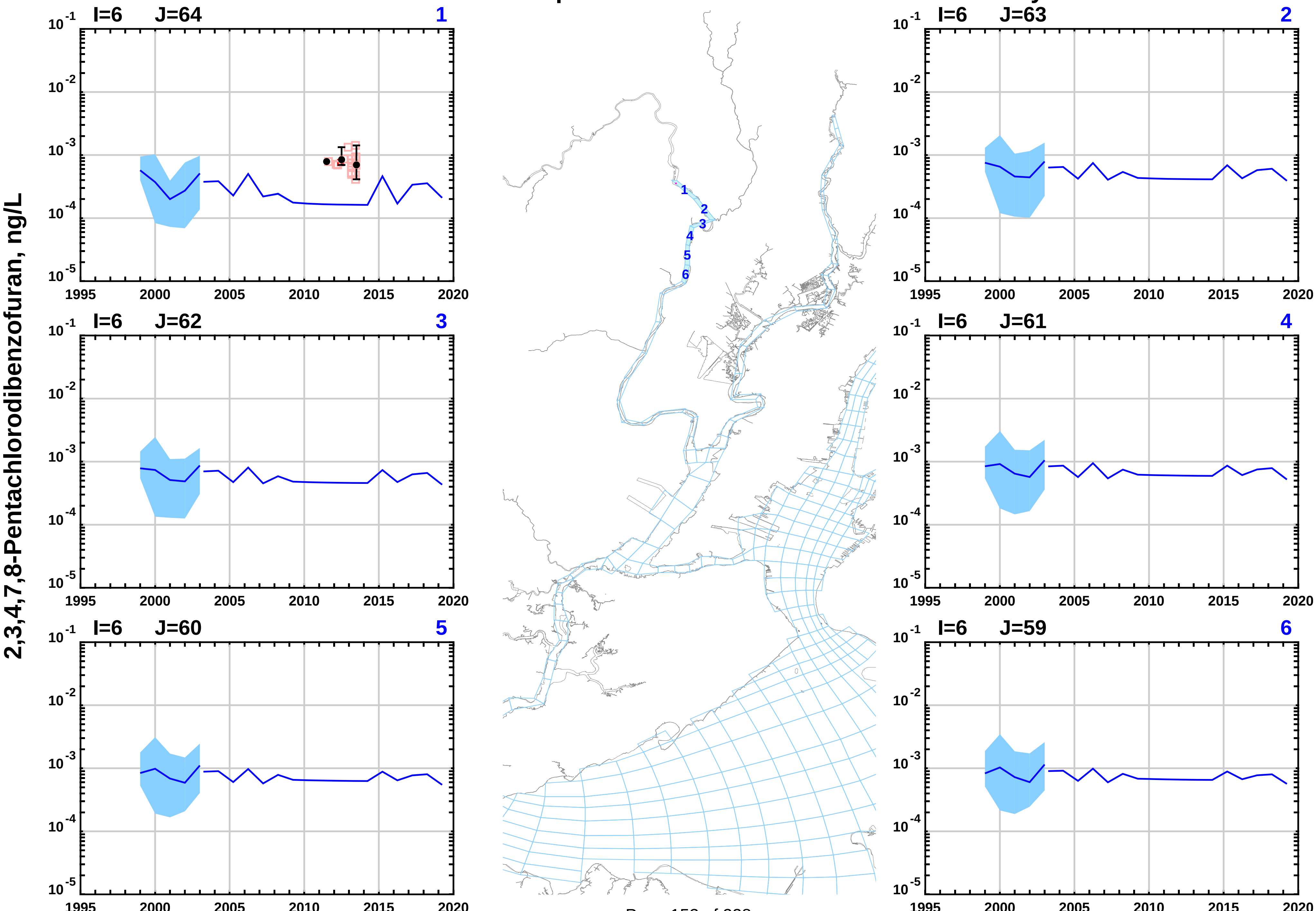


Water Column Data Comparison With Model All Water Column Layers



Attachment 2D, 2,3,4,7,8-PCDF

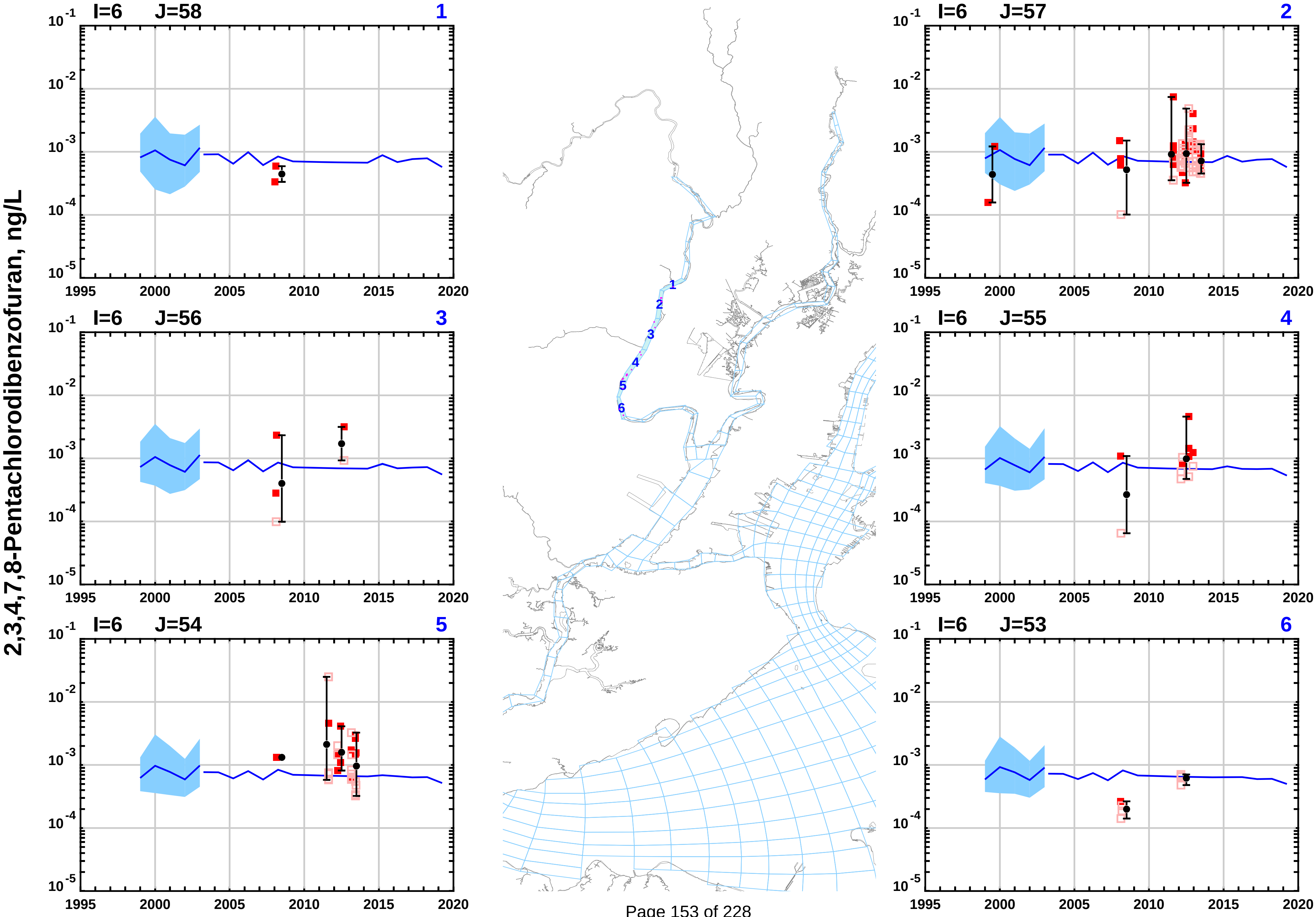
Water Column Data Comparison With Model All Water Column Layers



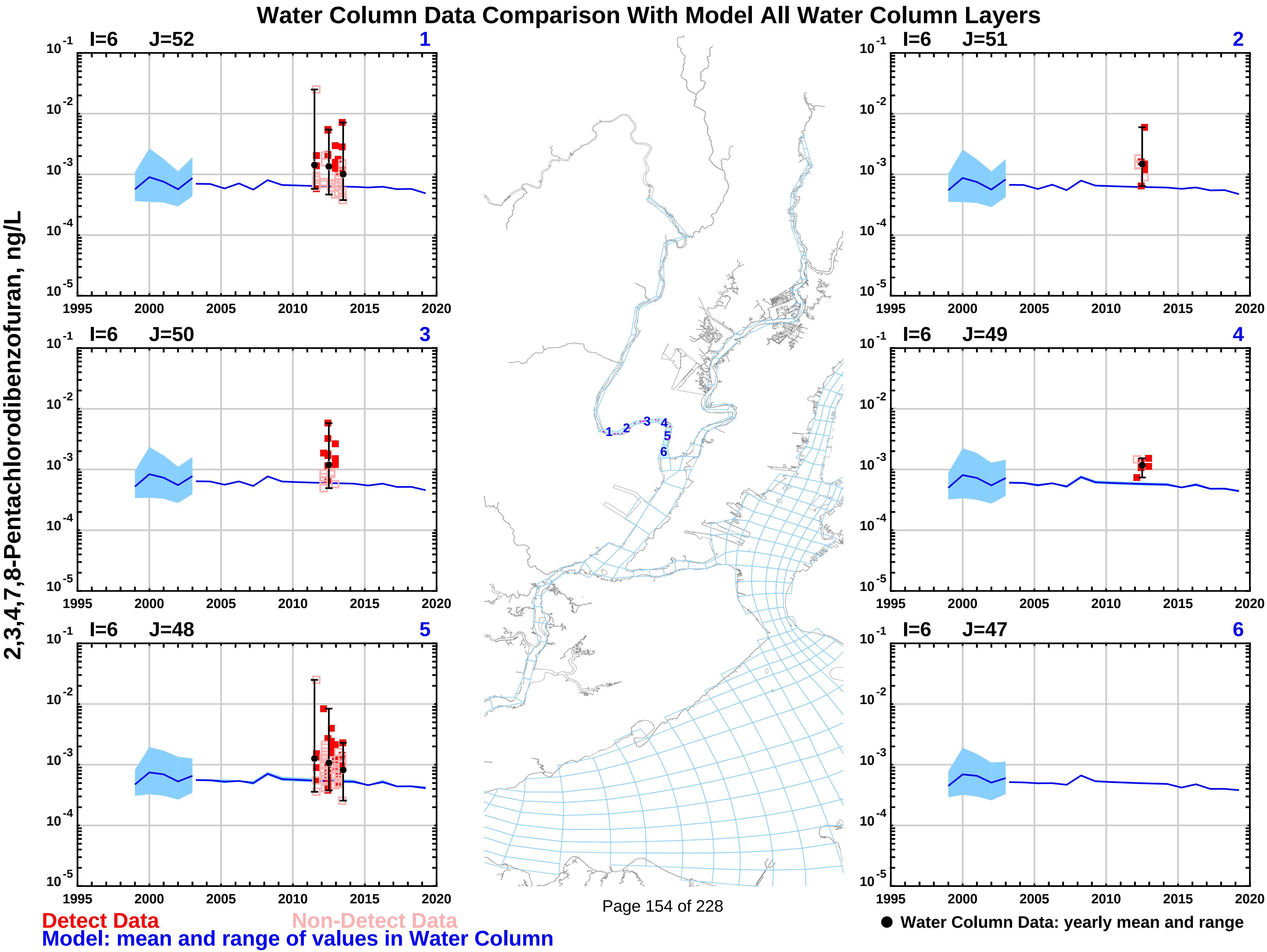
Detect Data Non-Detect Data
Model: mean and range of values in Water Column

● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers

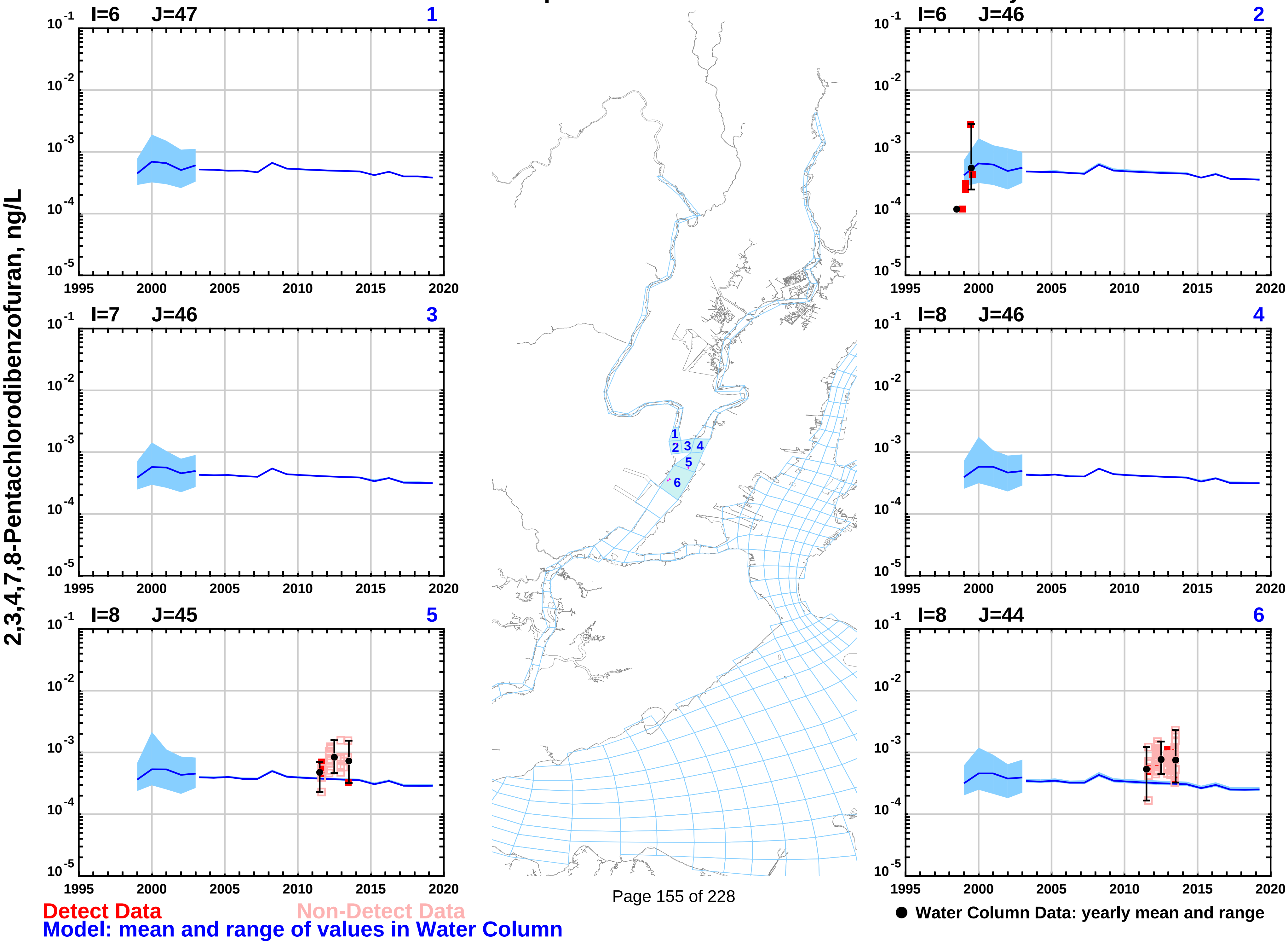


Detect Data Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

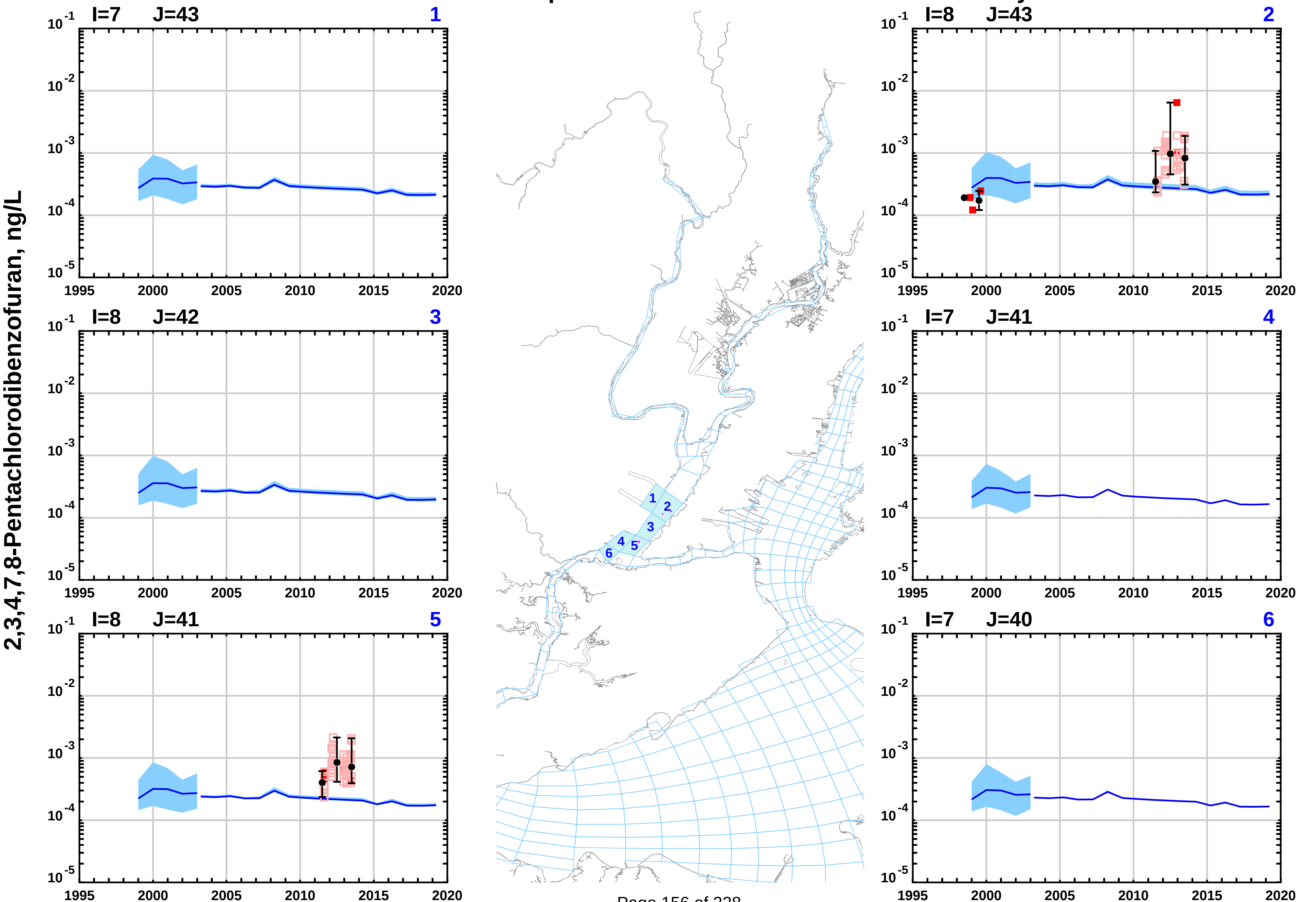


Water Column Data Comparison With Model All Water Column Layers
2,3,4,7,8-Pentachlorodibenzofuran, ng/L
I=6 J=52 1
I=6 J=51 2
I=6 J=50 3
I=6 J=49 4
I=6 J=48 5
I=6 J=47 6
10^-1
10^-2
10^-3
10^-4
10^-5
1995 2000 2005 2010 2015 2020
1 2 3 4 5 6
Detect Data
Non-Detect Data
Model: mean and range of values in Water Column
Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers



Water Column Data Comparison With Model All Water Column Layers

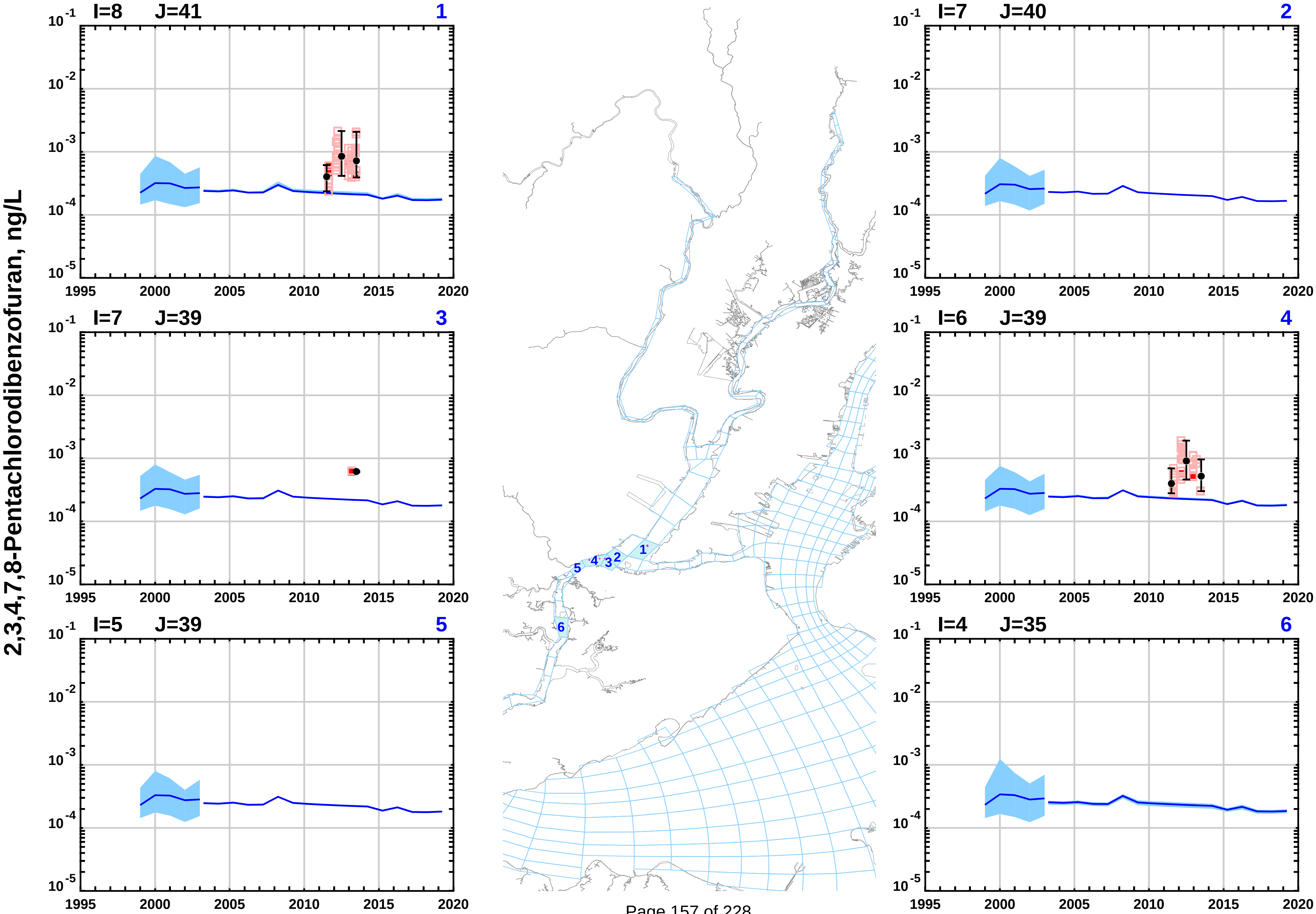


Detect Data Non-Detect Data

Model: mean and range of values in Water Column

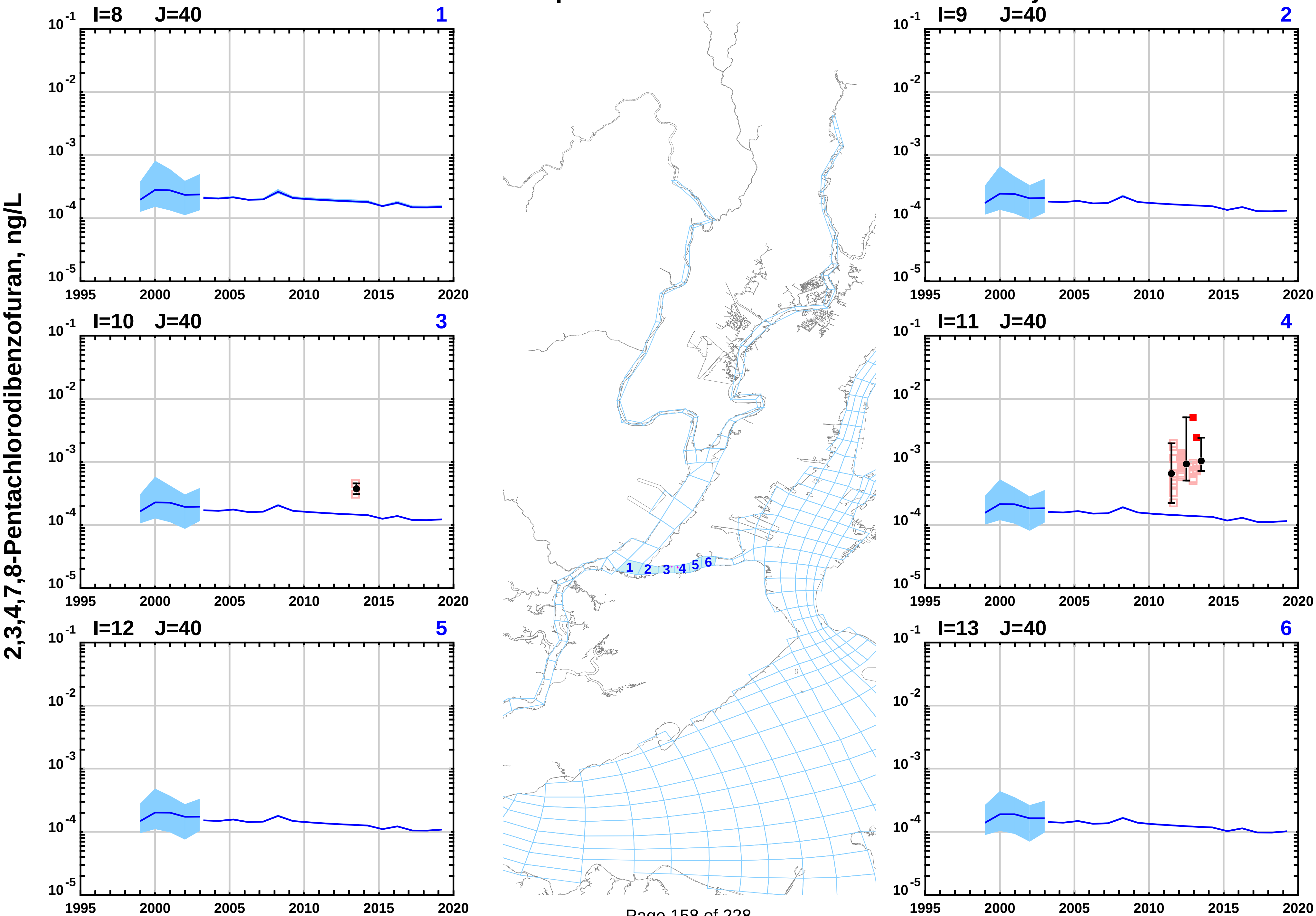
● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers



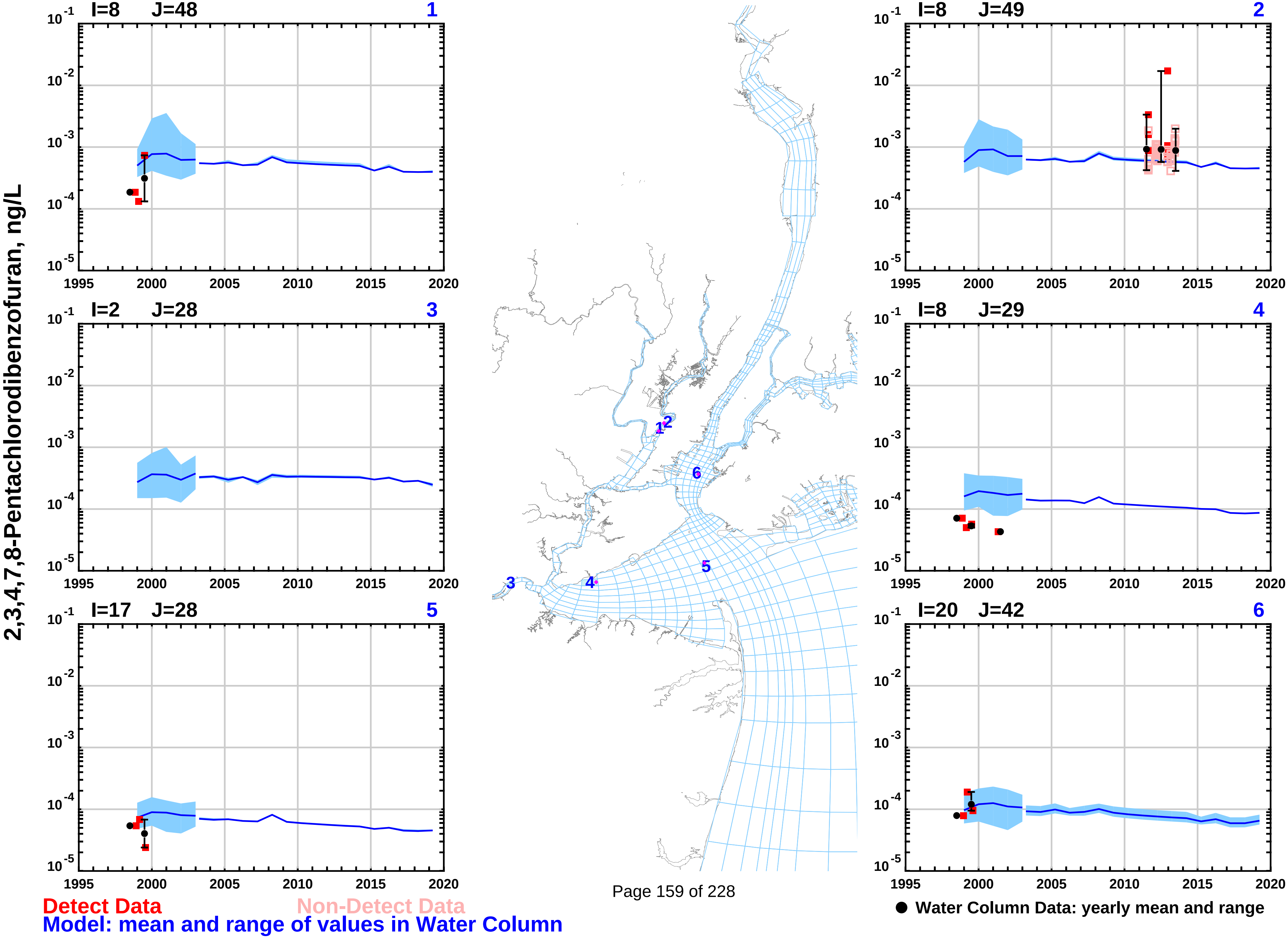
Detect Data Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers

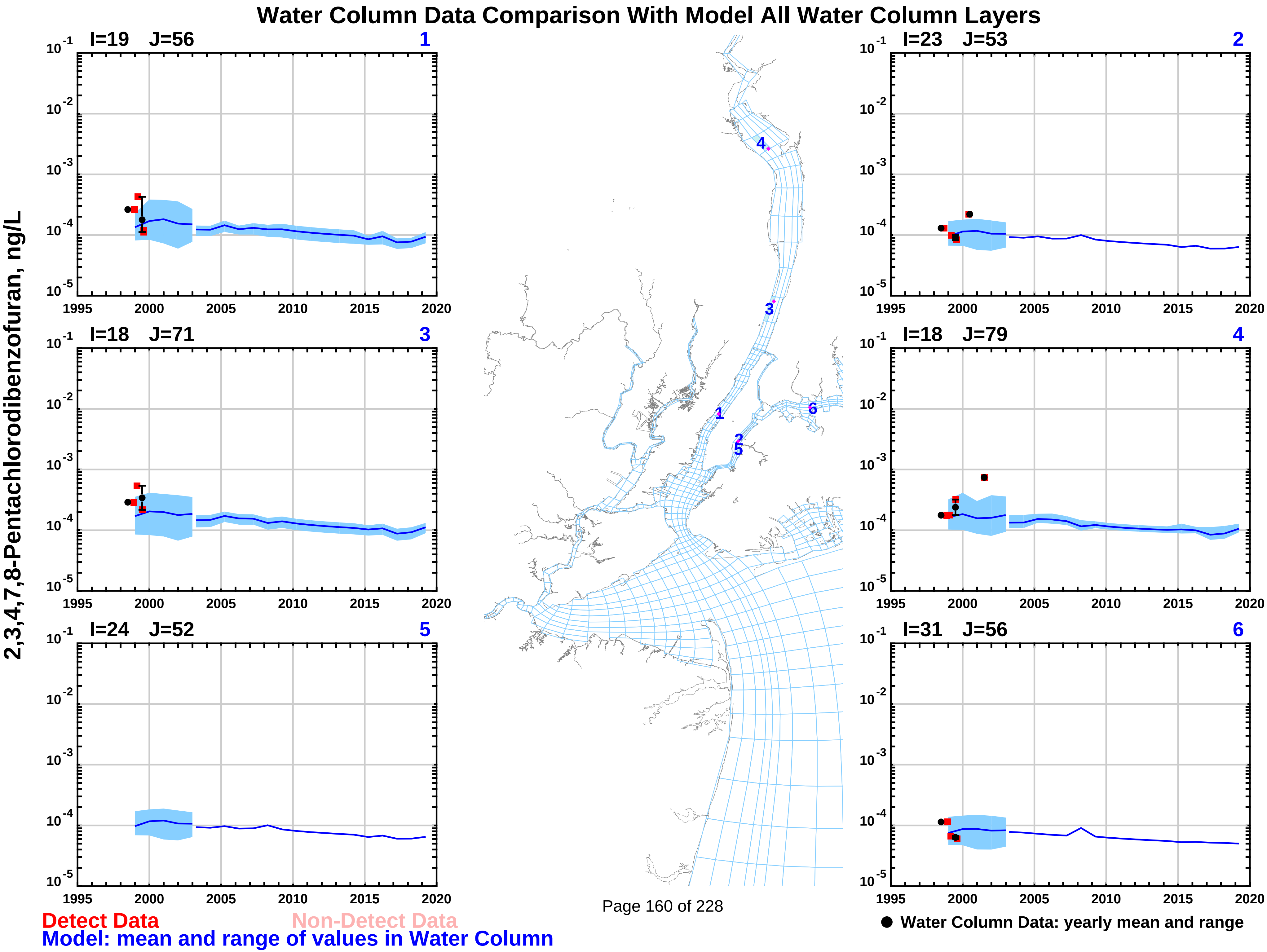


Detect Data
Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range

Water Column Data Comparison With Model All Water Column Layers



Detect Data
Non-Detect Data
Model: mean and range of values in Water Column
● Water Column Data: yearly mean and range


Water Column Data Comparison With Model All Water Column Layers
2,3,4,7,8-Pentachlorodibenzofuran, ng/L
I=19 J=56 1
I=23 J=53 2
I=18 J=71 3
I=18 J=79 4
I=24 J=52 5
I=31 J=56 6
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
1995
2000
2005
2010
2015
2020
Detect Data
Non-Detect Data
Model: mean and range of values in Water Column
Water Column Data: yearly mean and range

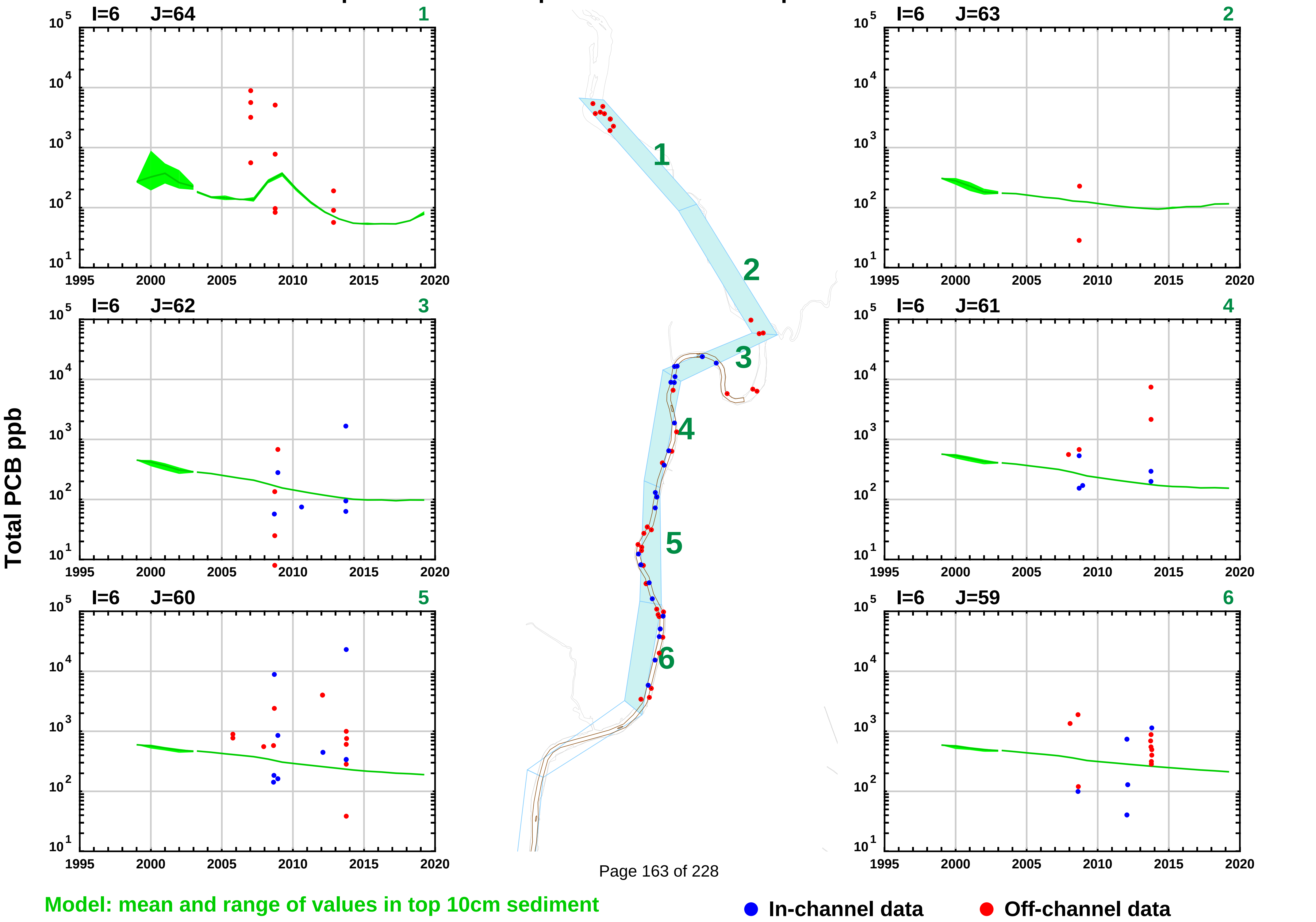
ATTACHMENT 3

SEDIMENT DIAGRAMS, SOLIDS NORMALIZED

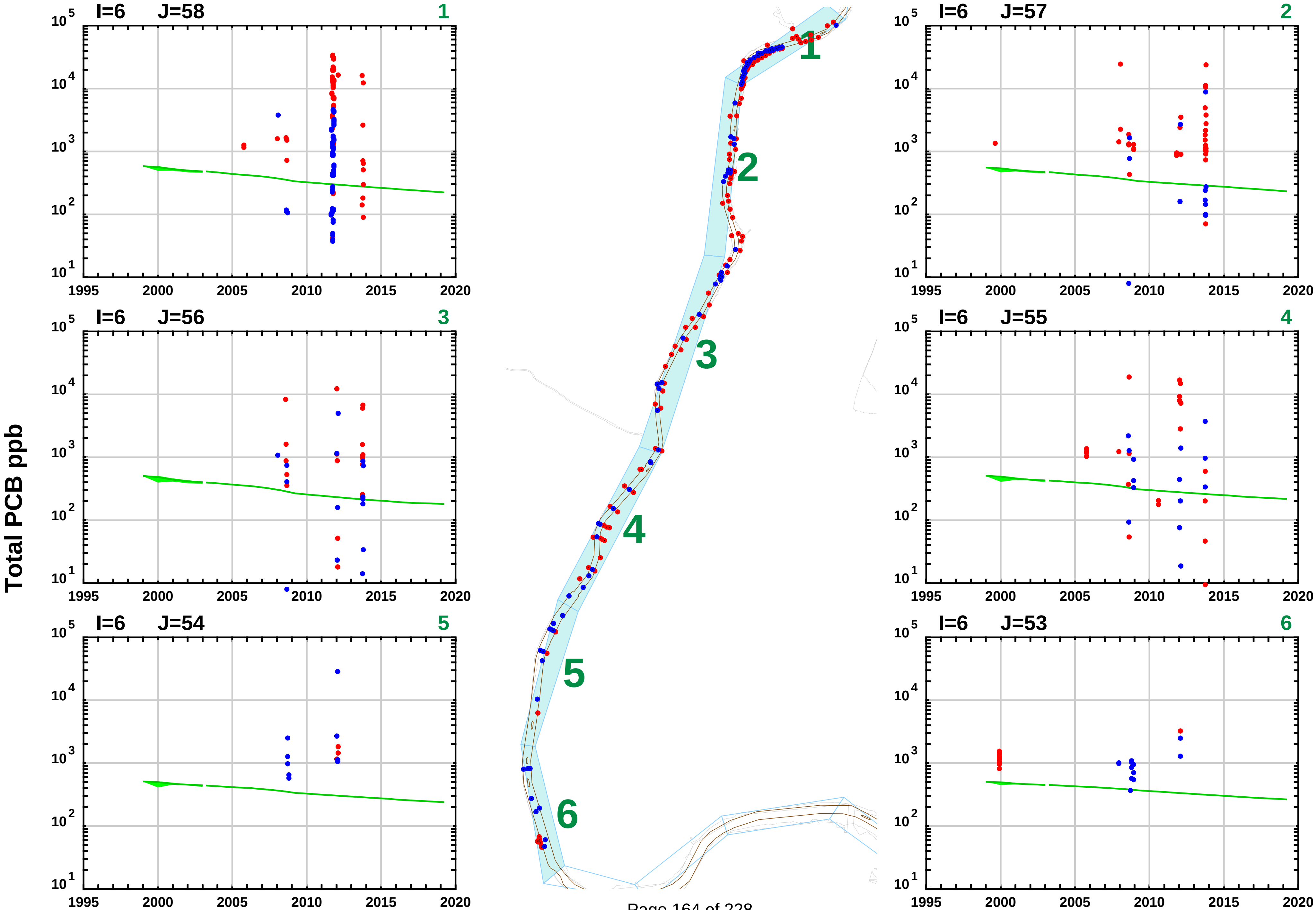
Attachment 3A, Total PCBs
Attachment 3B, 2,3,7,8-TCDD
Attachment 3C, PCB homologs
Attachment 3D, 2,3,4,7,8-PCDF

Attachment 3A, Total PCBs

Top 15 cm data comparison with model top 10 cm sediment



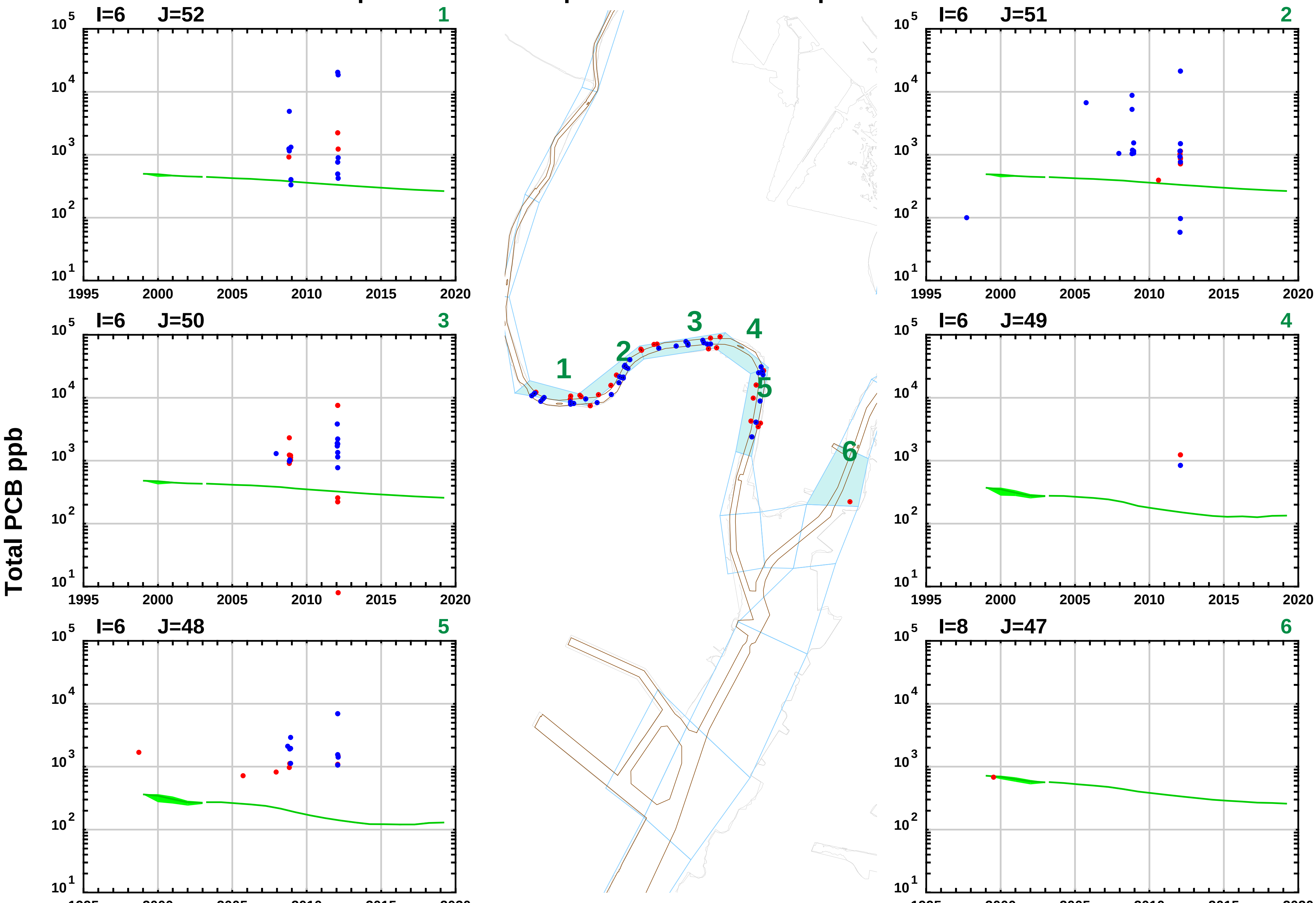
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

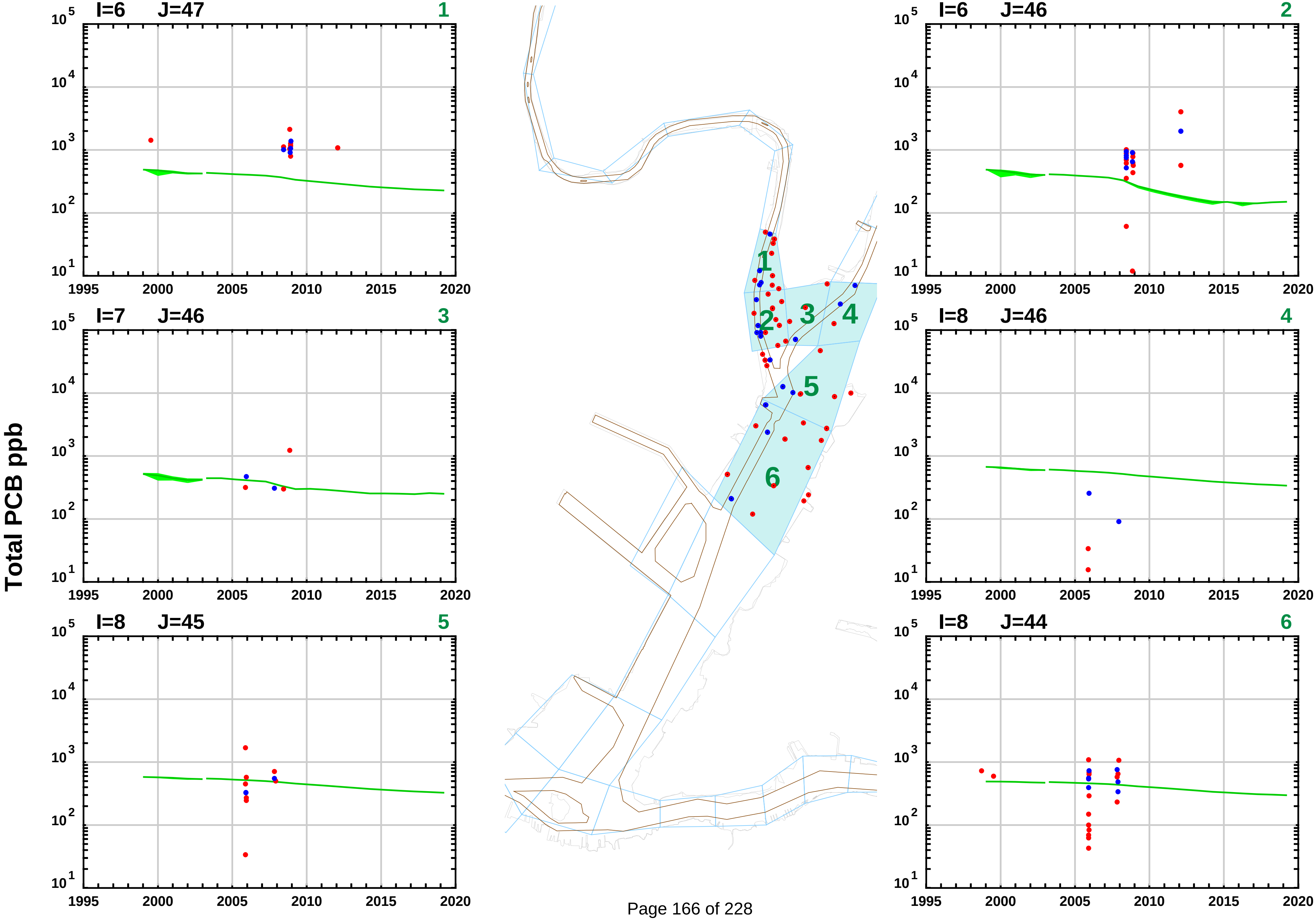
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

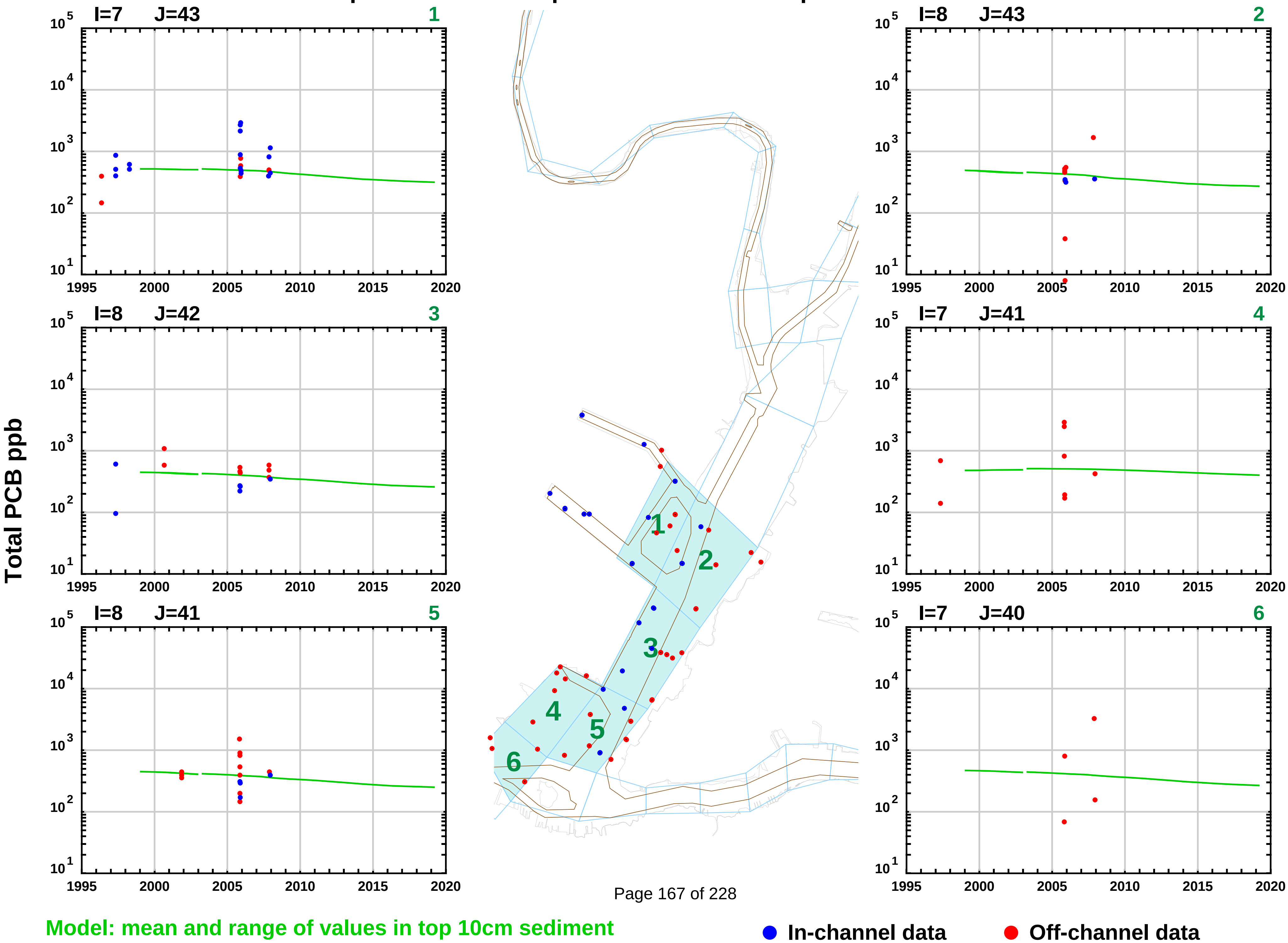
Top 15 cm data comparison with model top 10 cm sediment



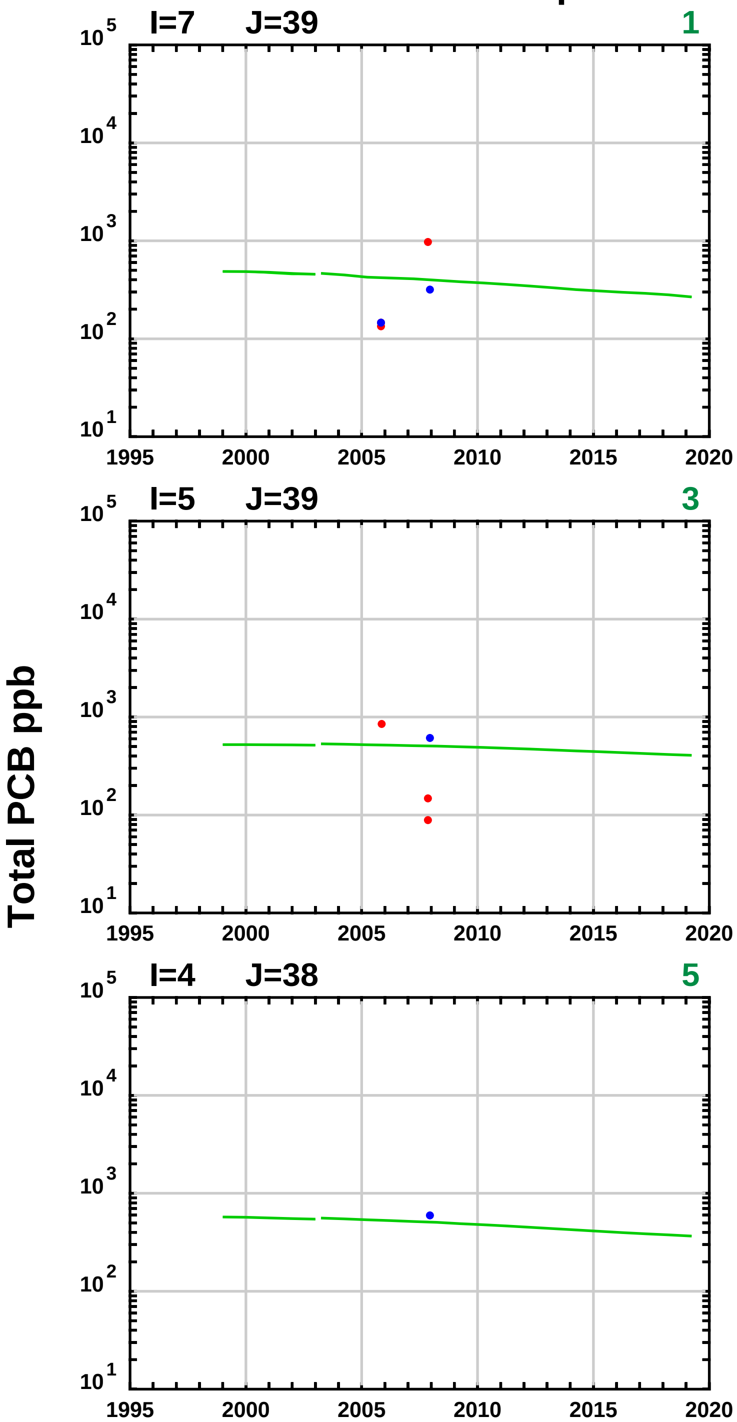
Model: mean and range of values in top 10cm sediment

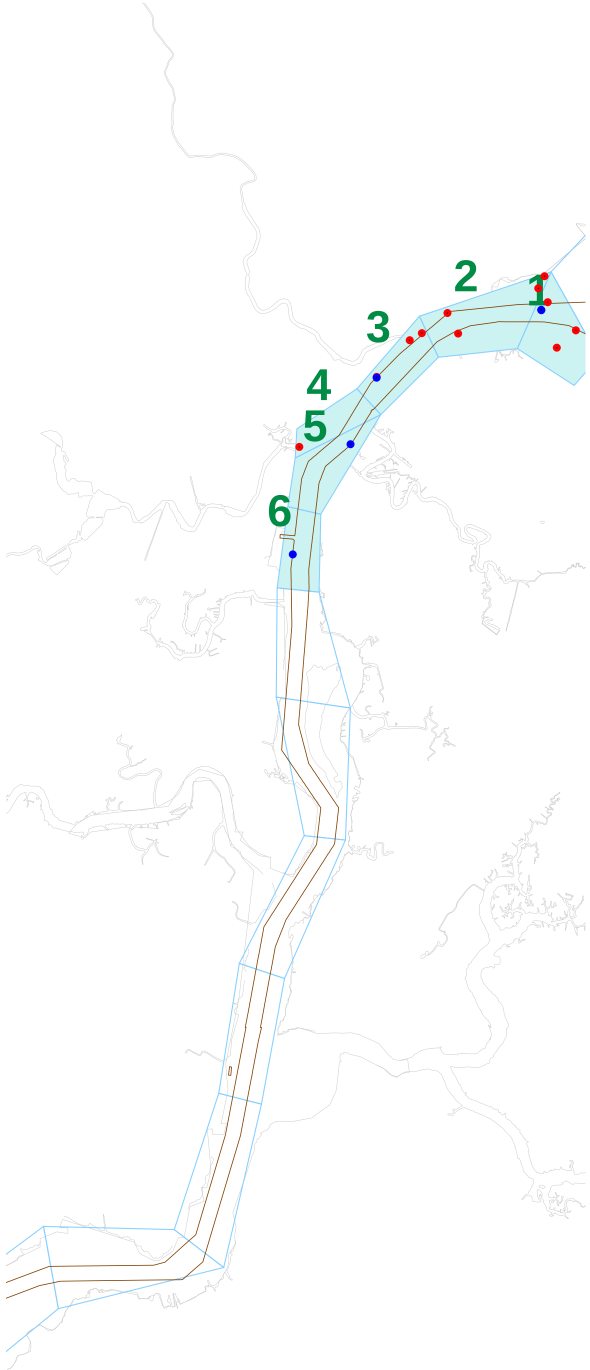
● In-channel data ● Off-channel data

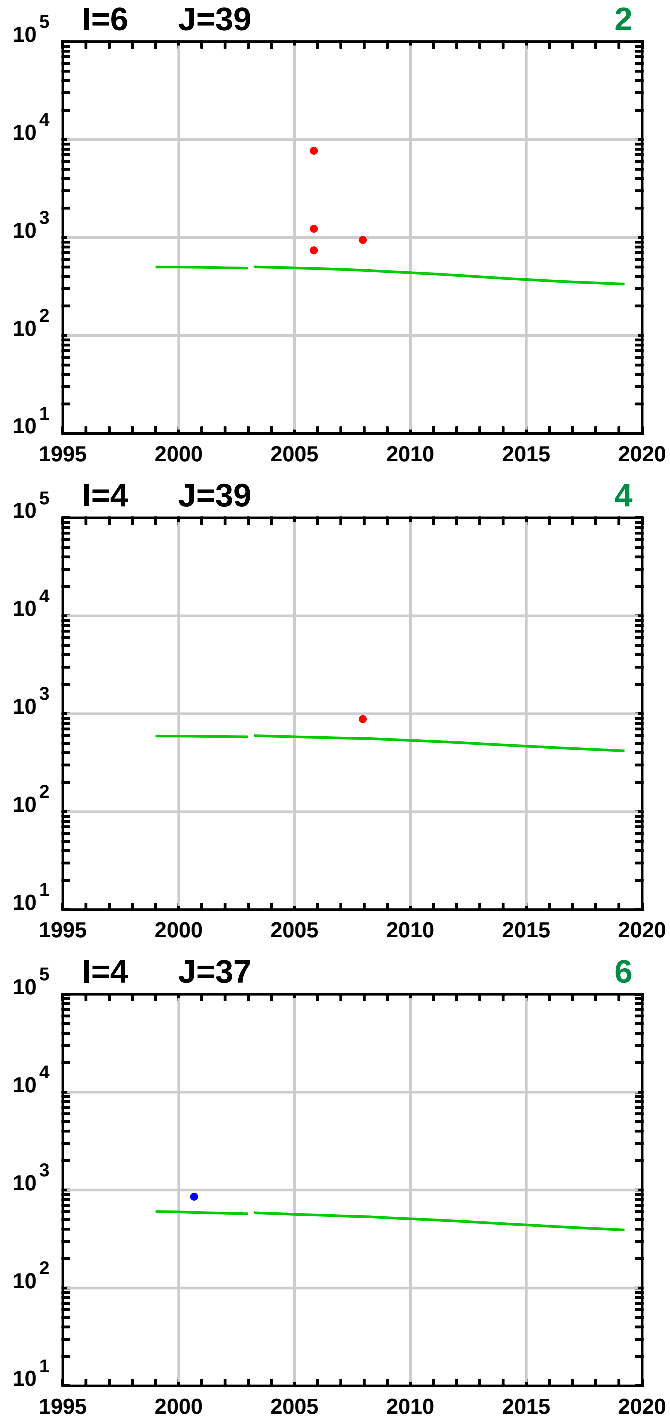
Top 15 cm data comparison with model top 10 cm sediment



Top 15 cm data comparison with model top 10 cm sediment



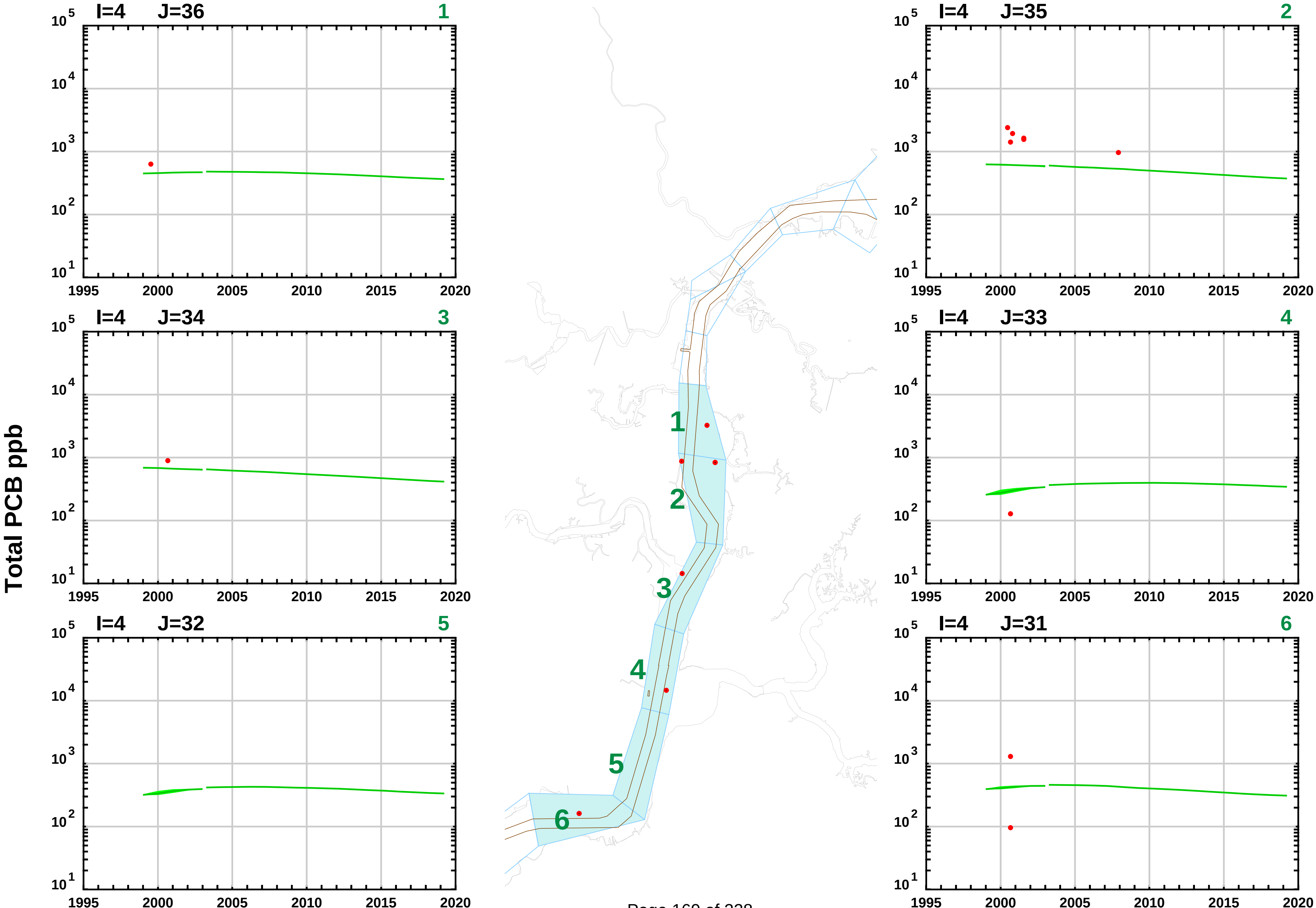




Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

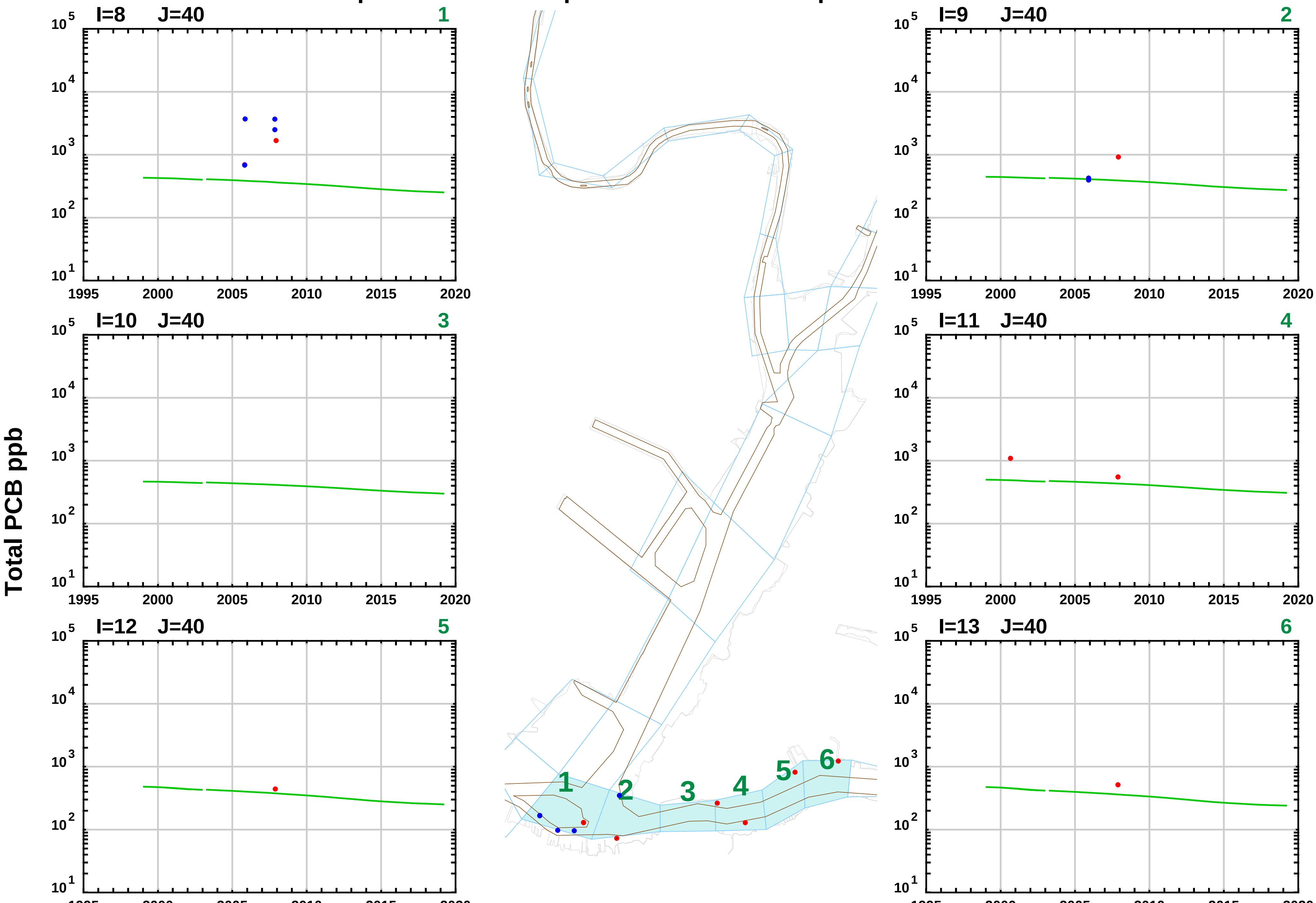
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

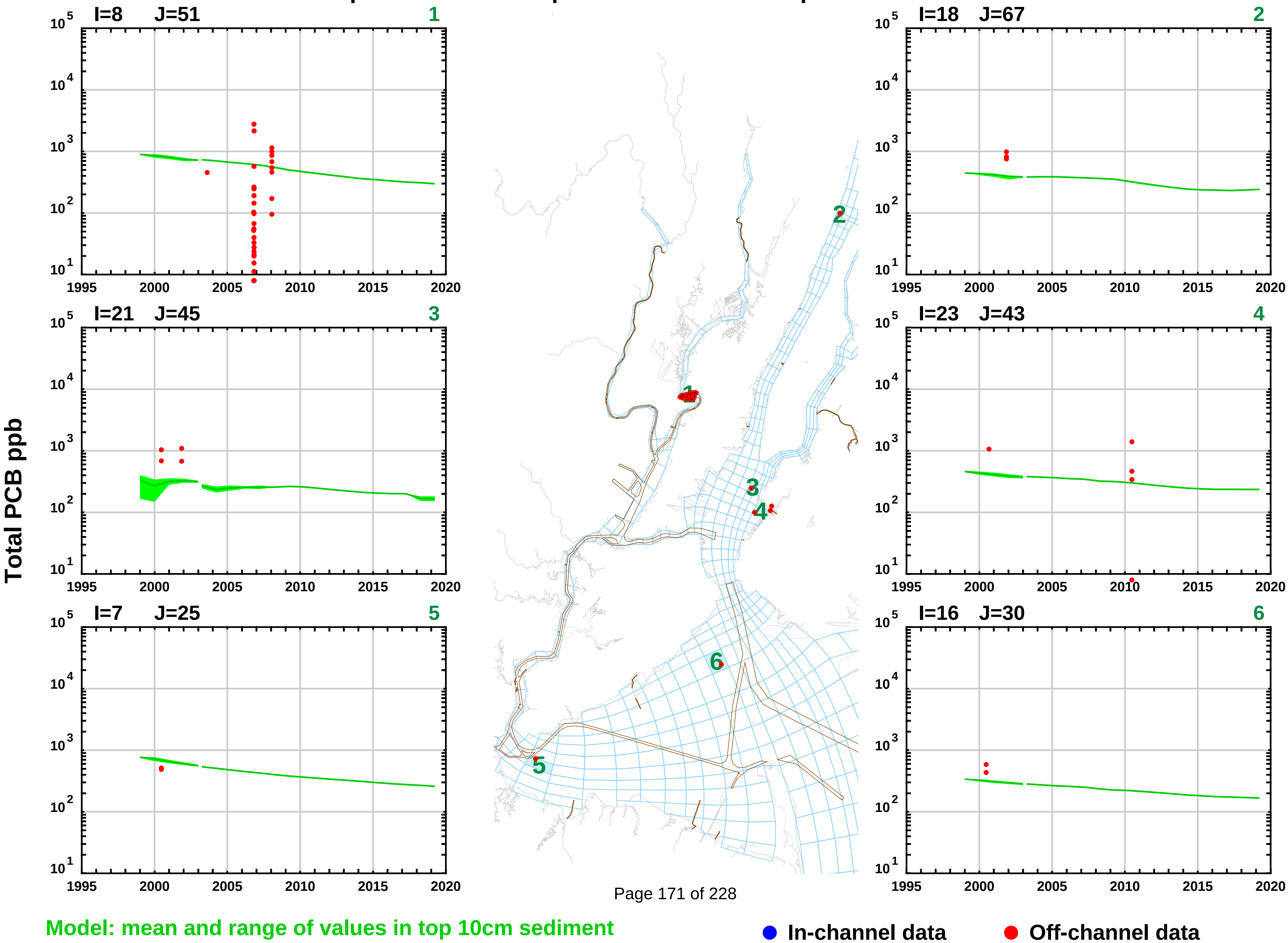
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

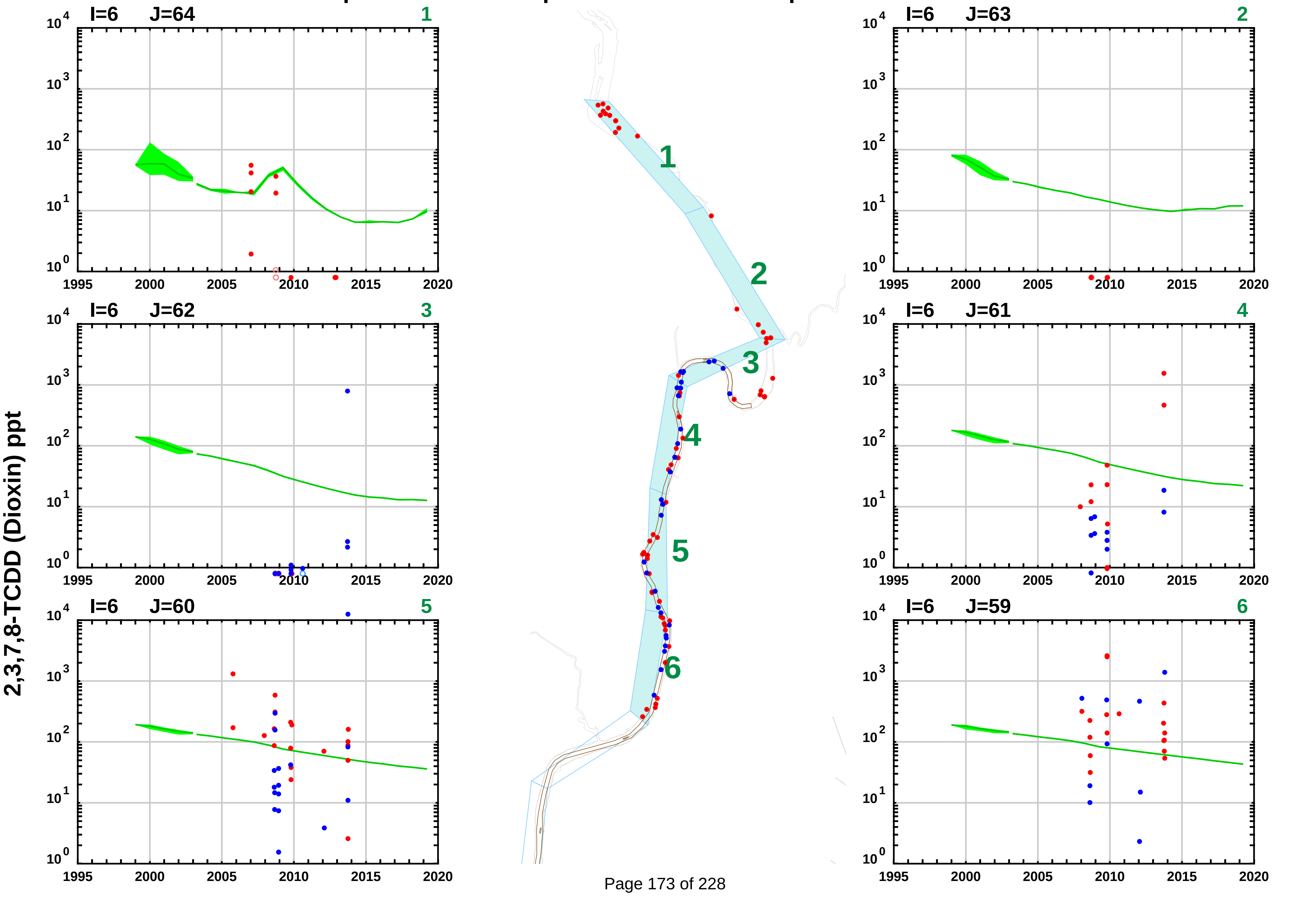
● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



Attachment 3B, 2,3,7,8-TCDD

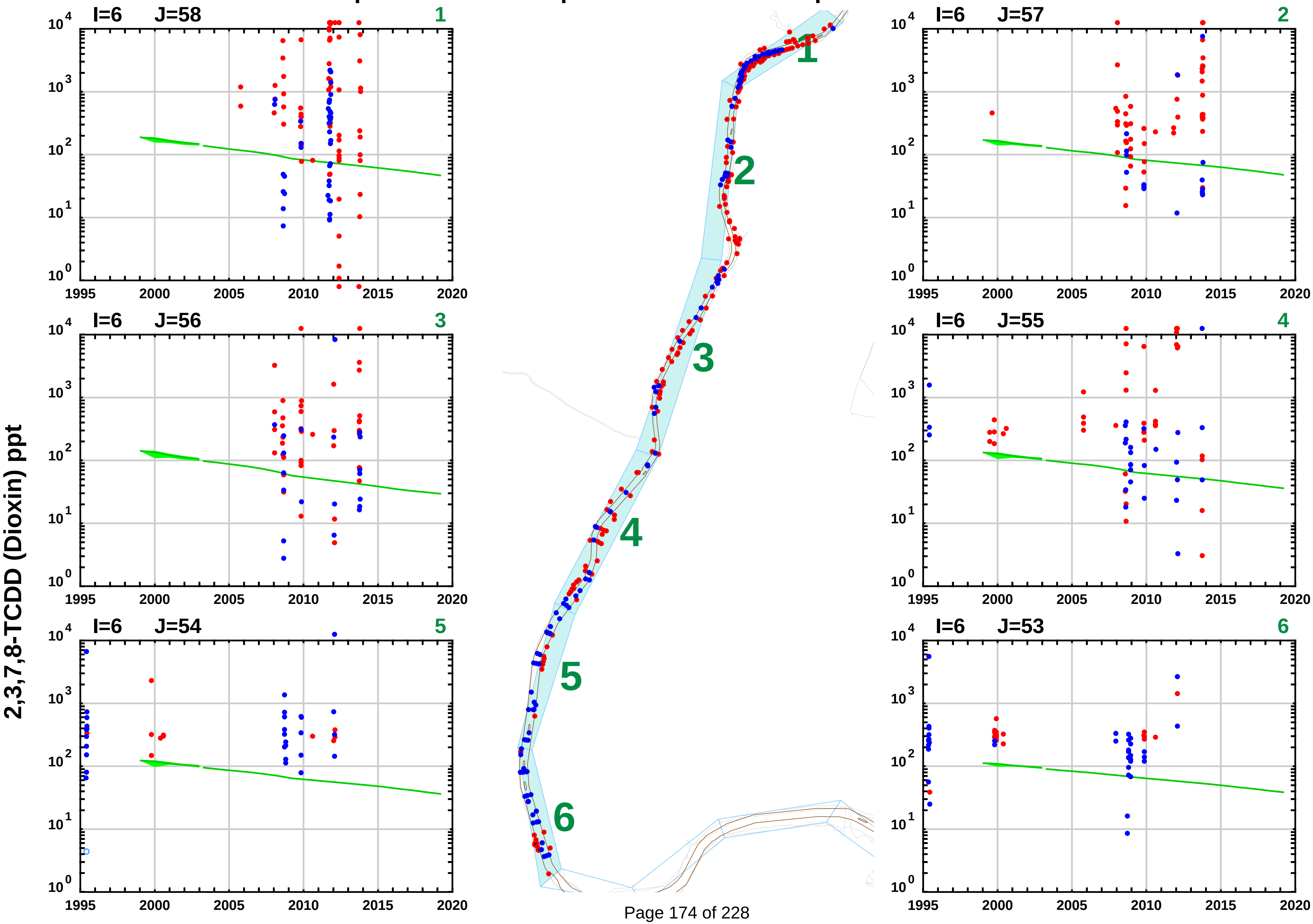
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

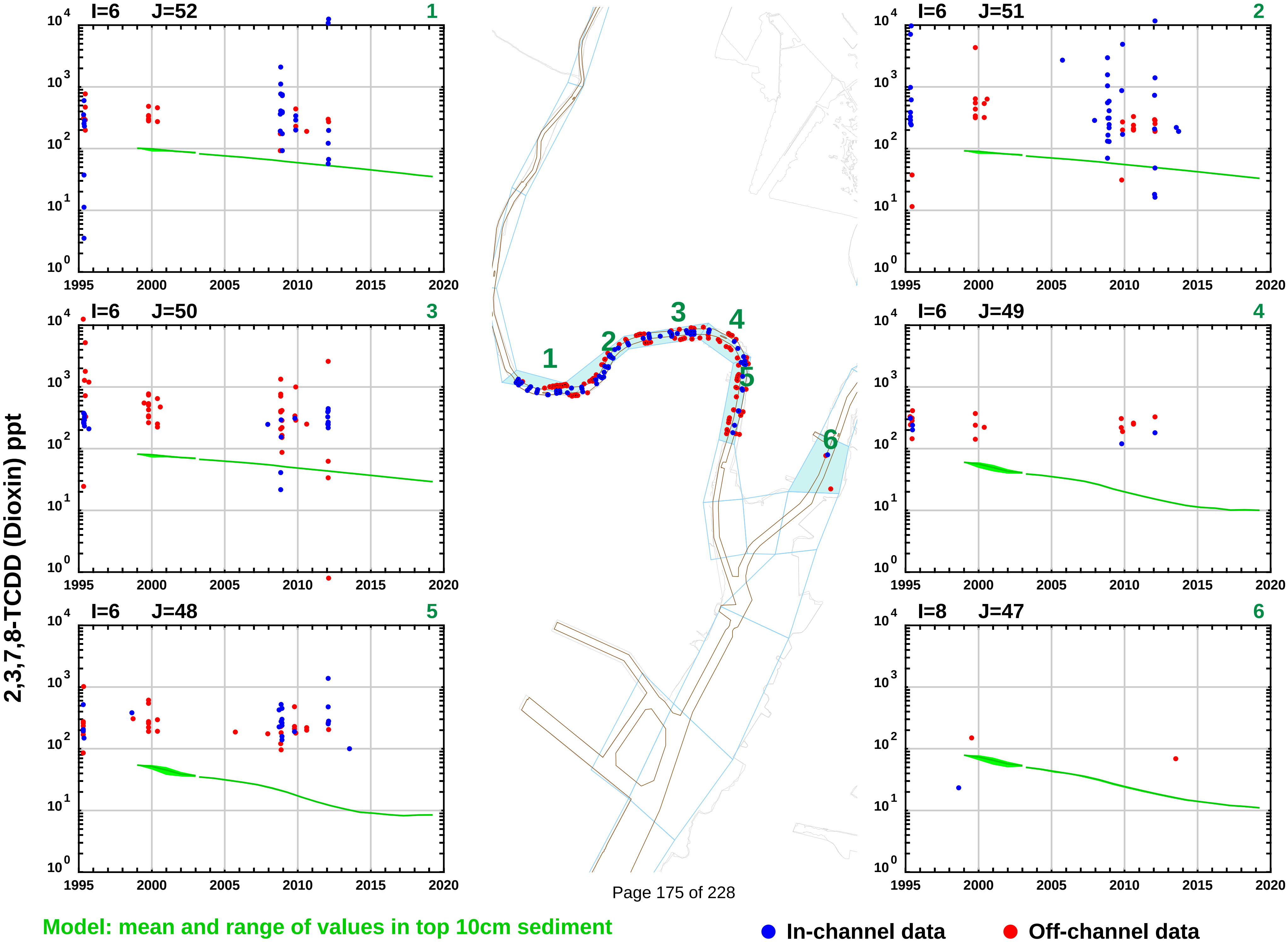
Top 15 cm data comparison with model top 10 cm sediment



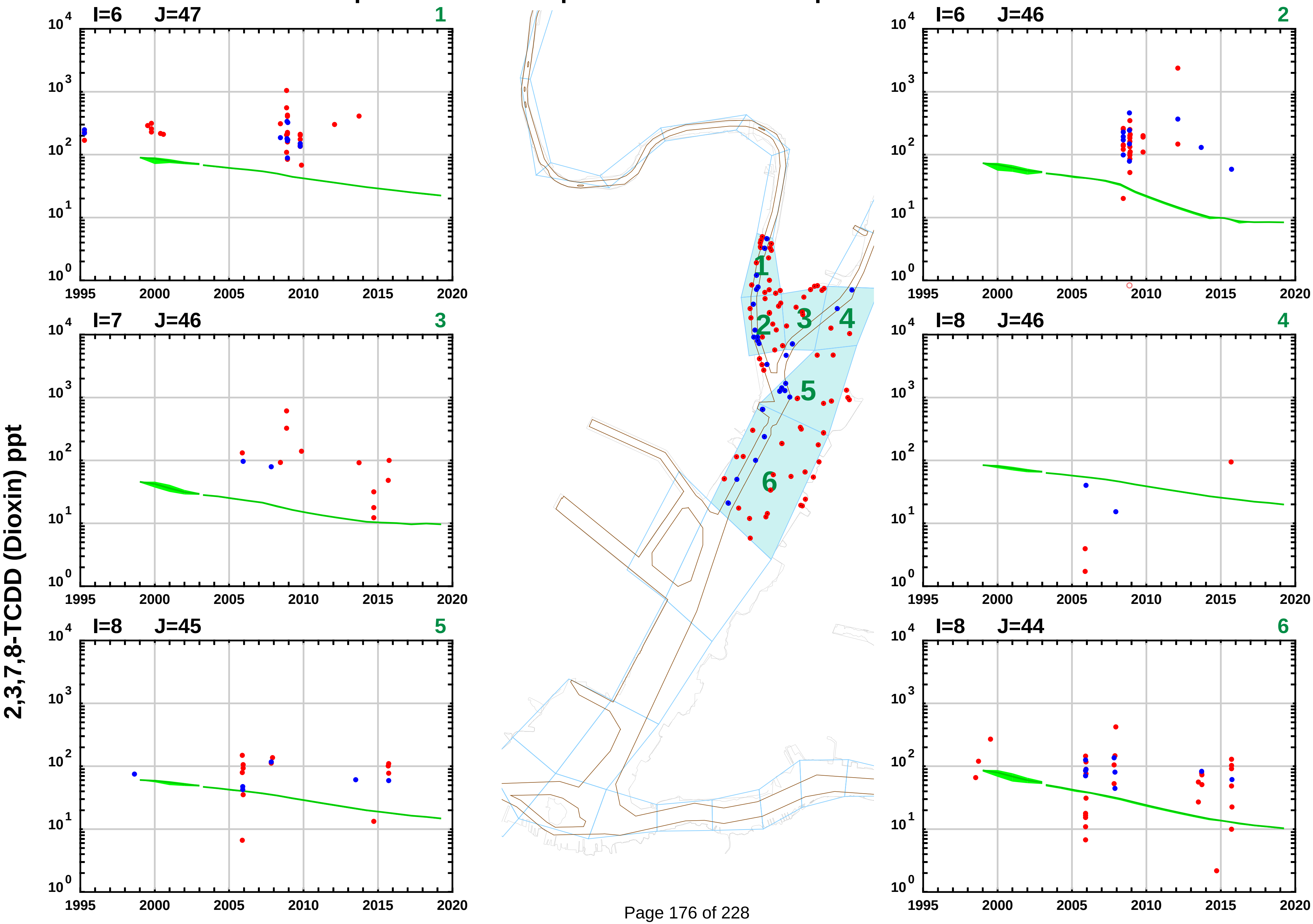
Model: mean and range of values in top 10cm sediment

In-channel data Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



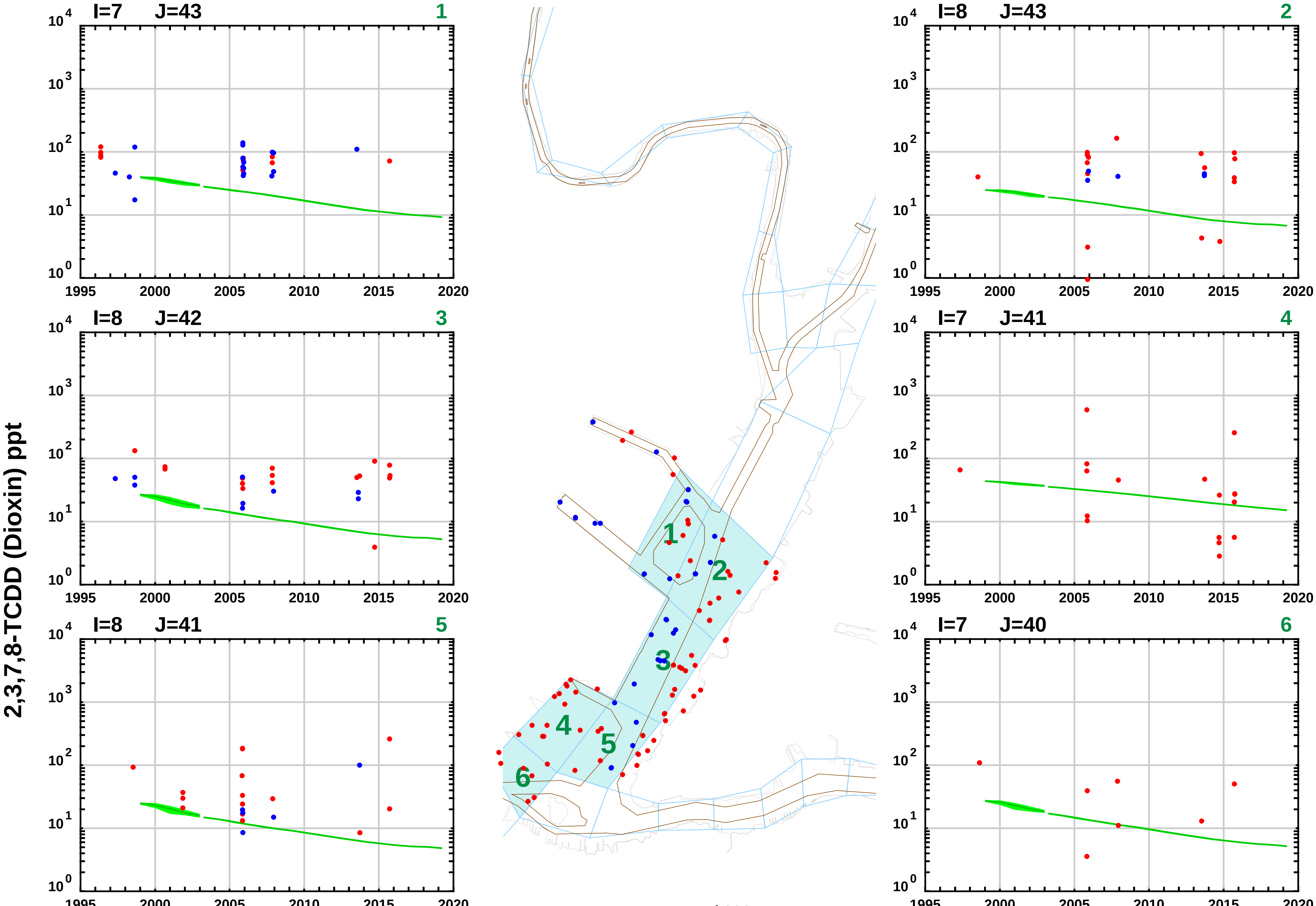
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

In-channel data Off-channel data

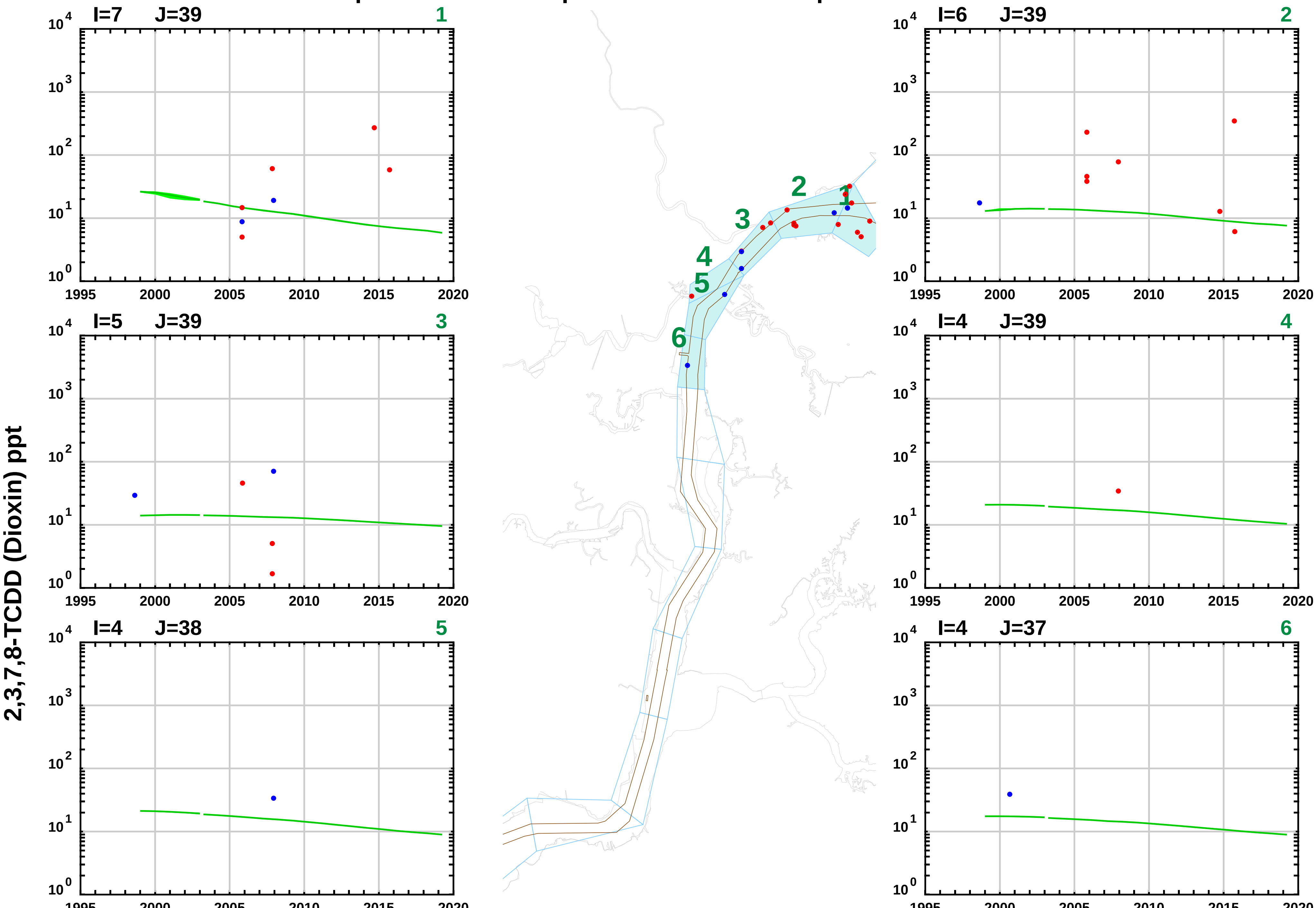
Top 15 cm data comparison with model top 10 cm sediment



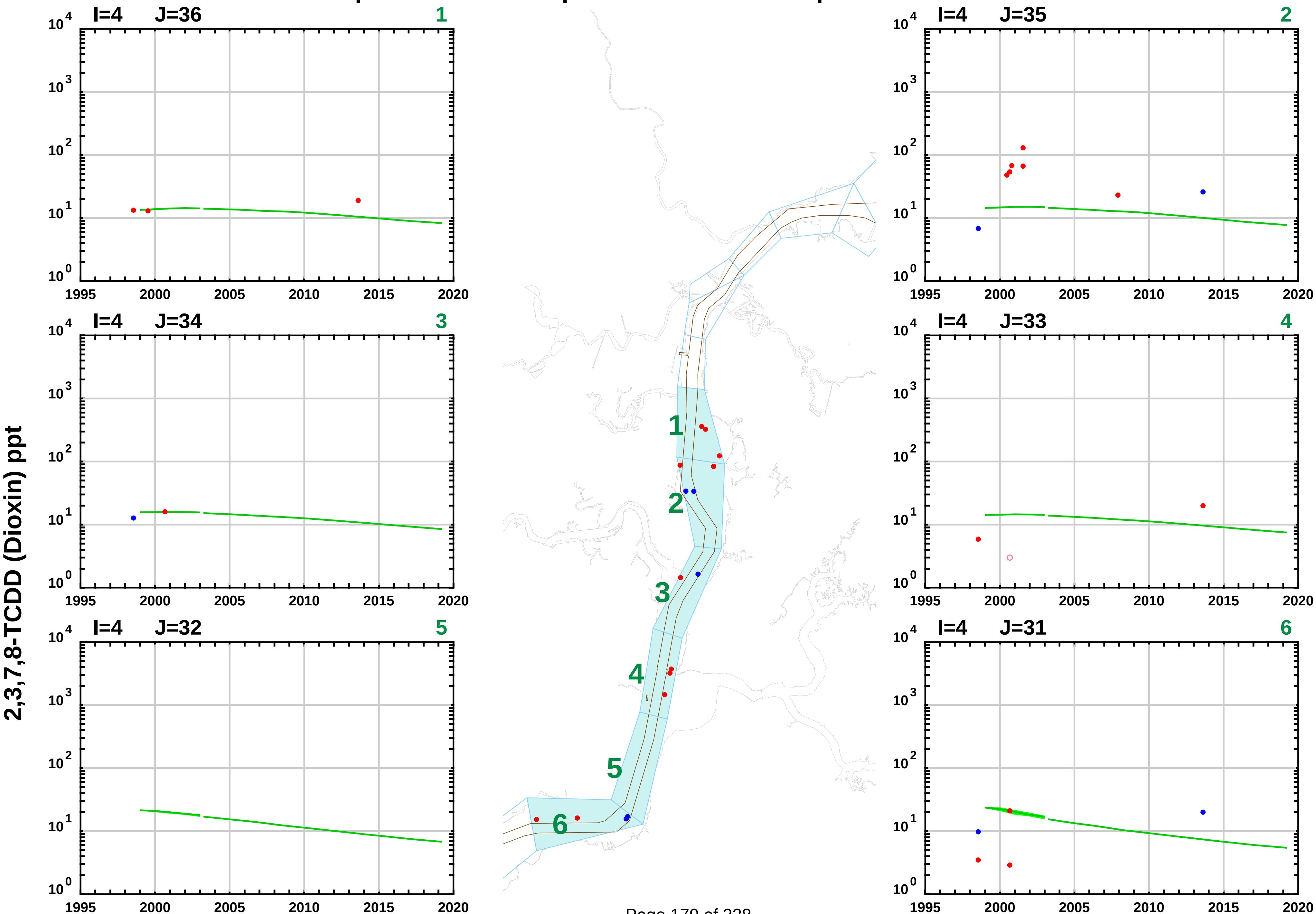
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment

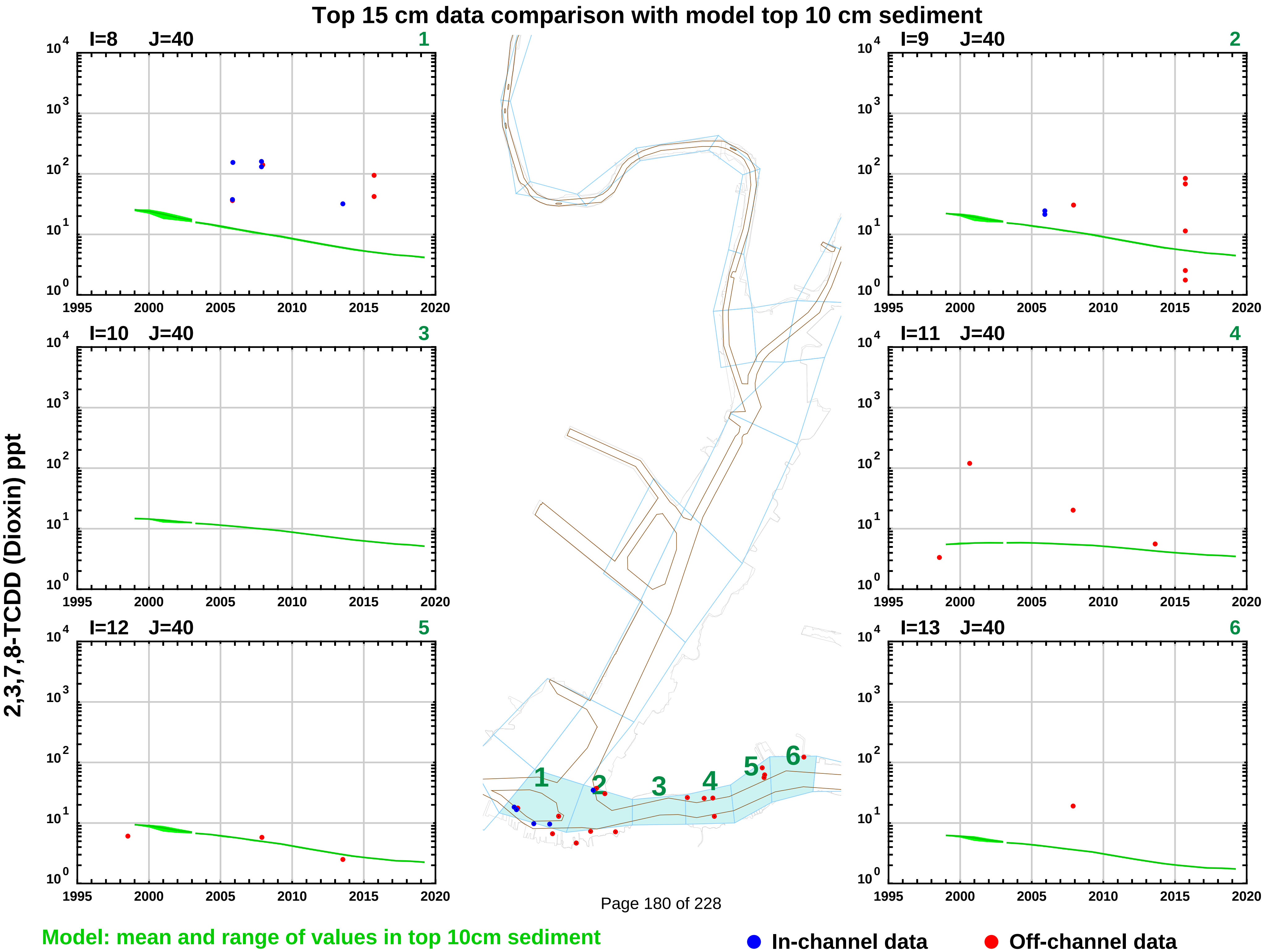


Top 15 cm data comparison with model top 10 cm sediment

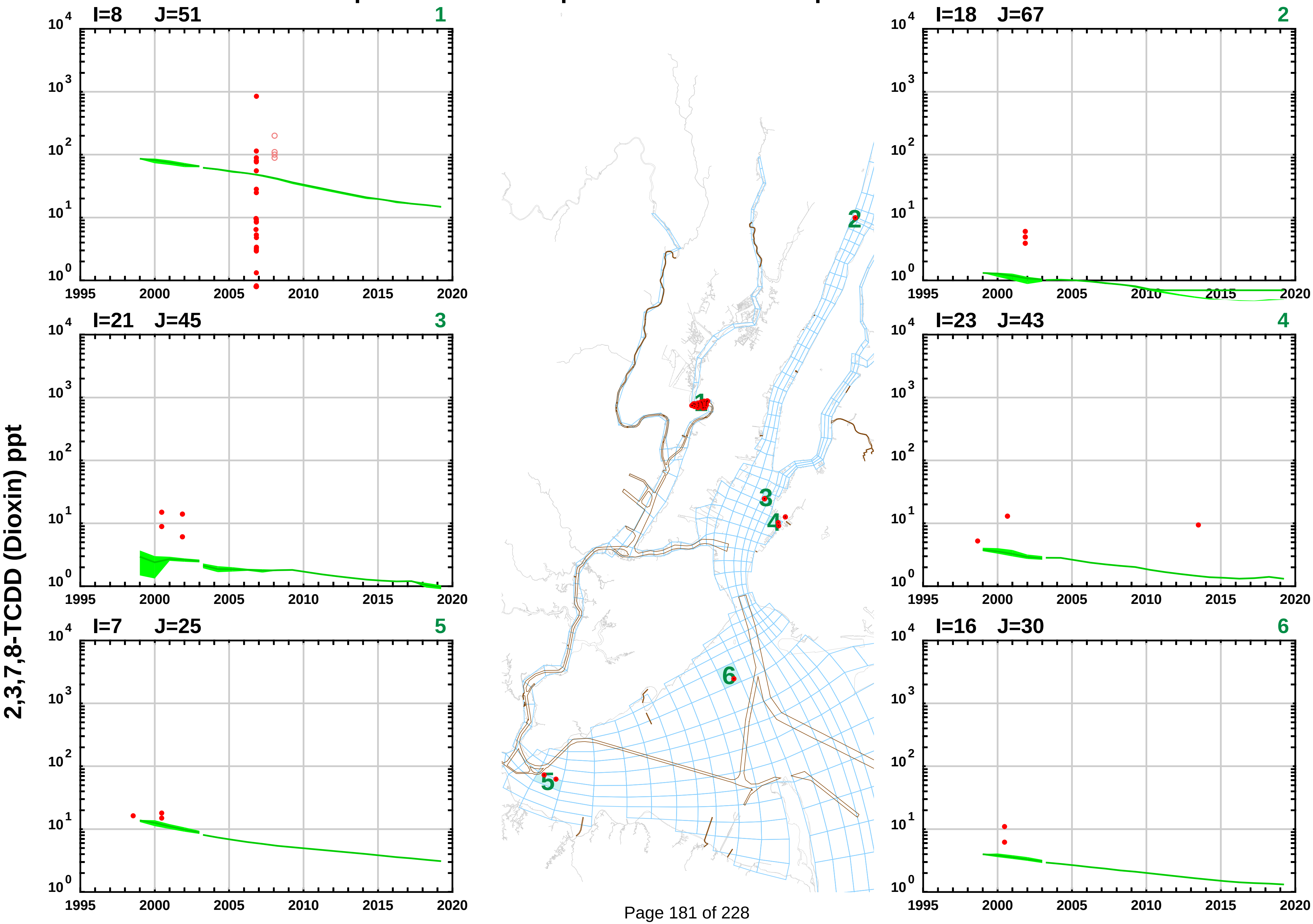


Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data


Top 15 cm data comparison with model top 10 cm sediment
2,3,7,8-TCDD (Dioxin) ppt
I=8 J=40 1
I=9 J=40 2
I=10 J=40 3
I=11 J=40 4
I=12 J=40 5
I=13 J=40 6
1995 2000 2005 2010 2015 2020
Model: mean and range of values in top 10cm sediment
In-channel data
Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



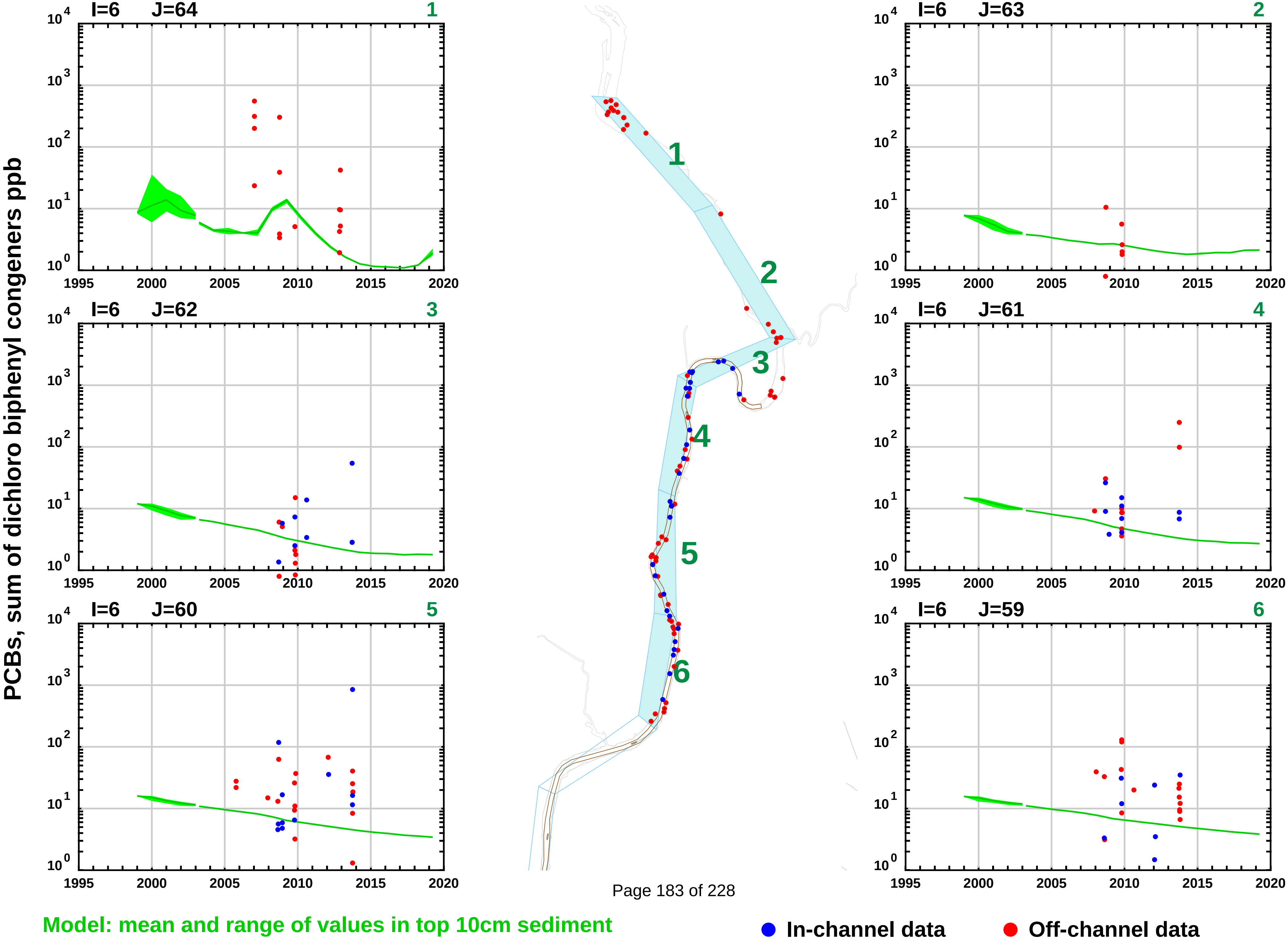
Model: mean and range of values in top 10cm sediment

In-channel data

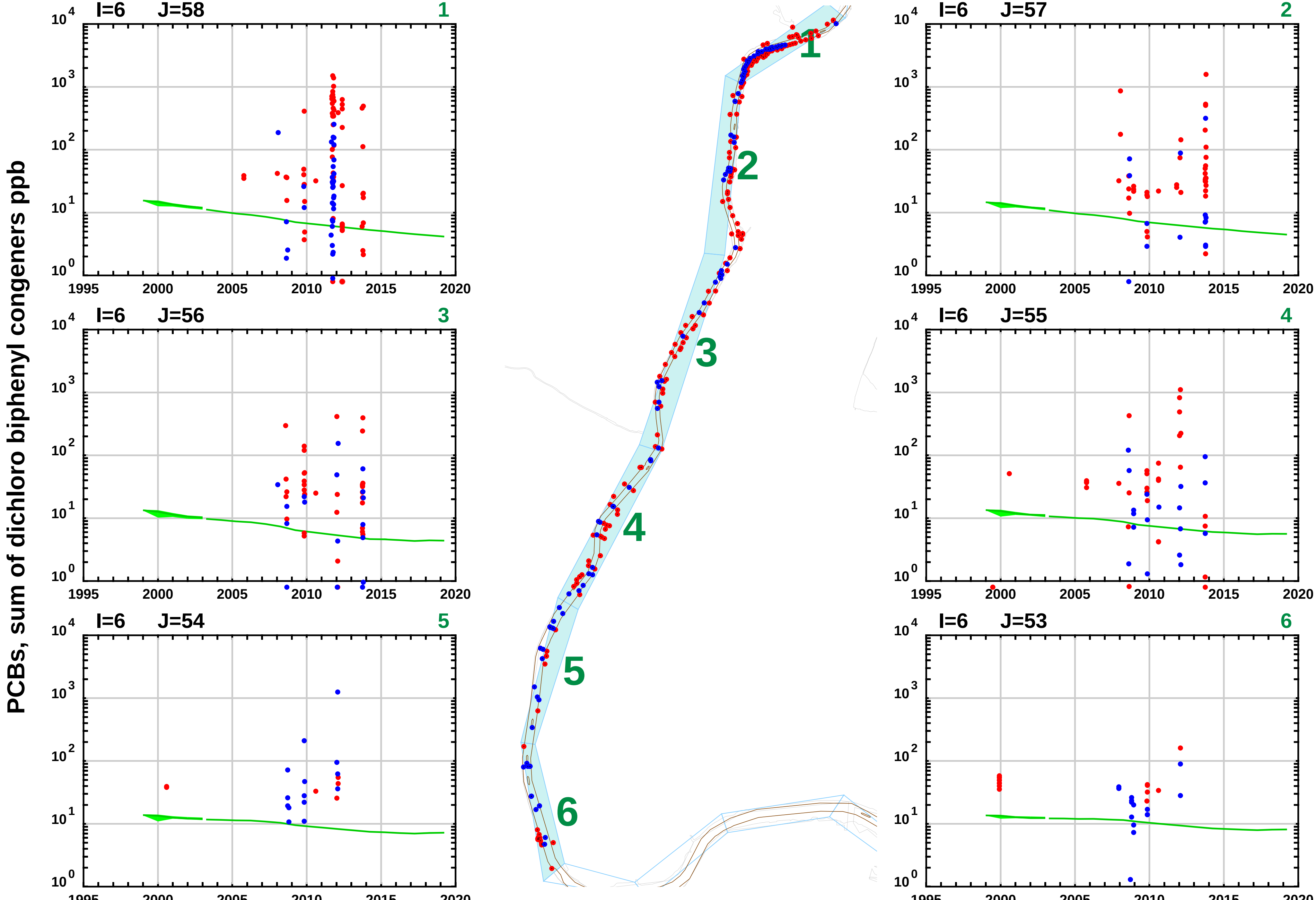
Off-channel data

Attachment 3C, PCB homologs

Top 15 cm data comparison with model top 10 cm sediment



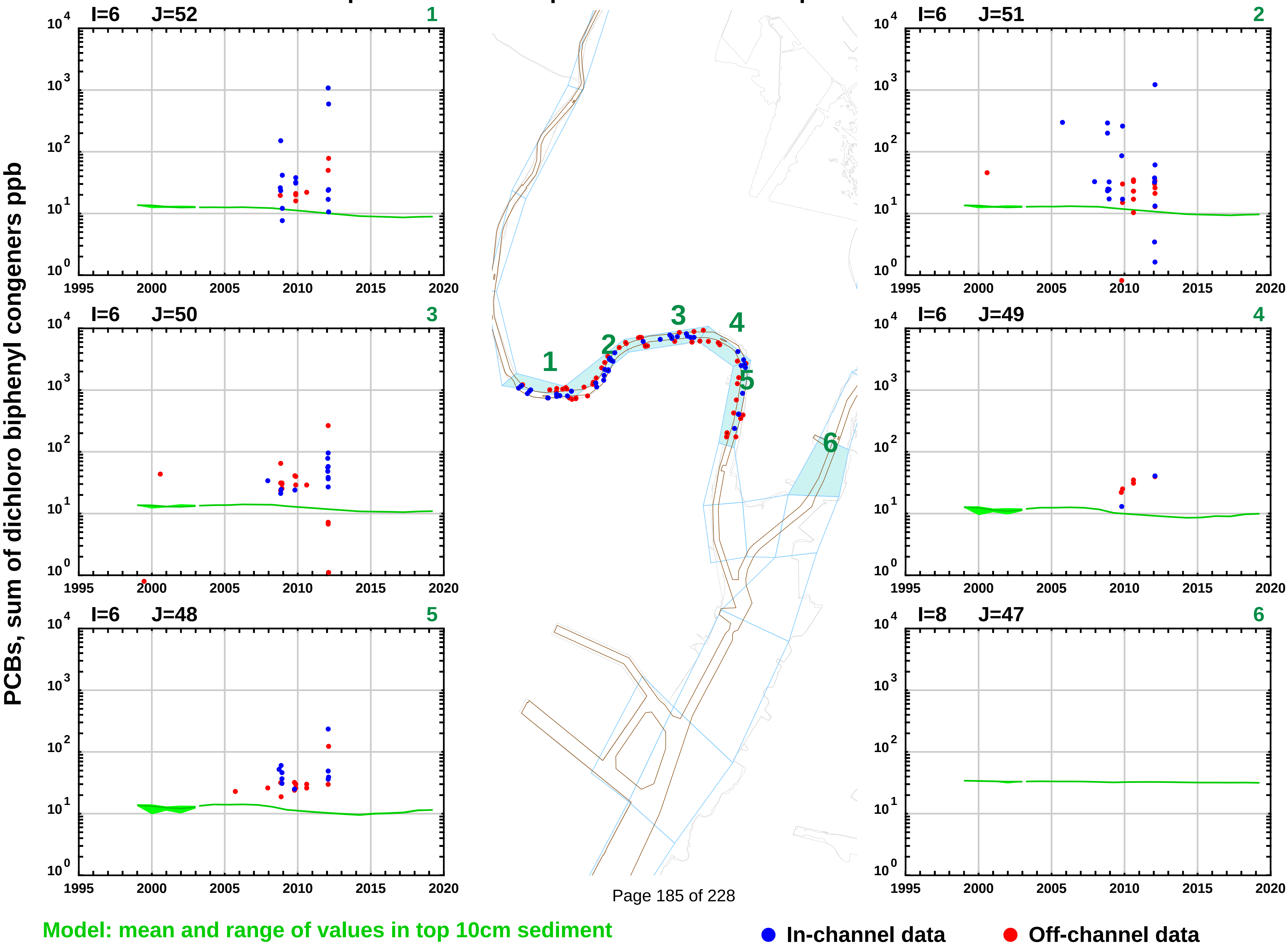
Top 15 cm data comparison with model top 10 cm sediment



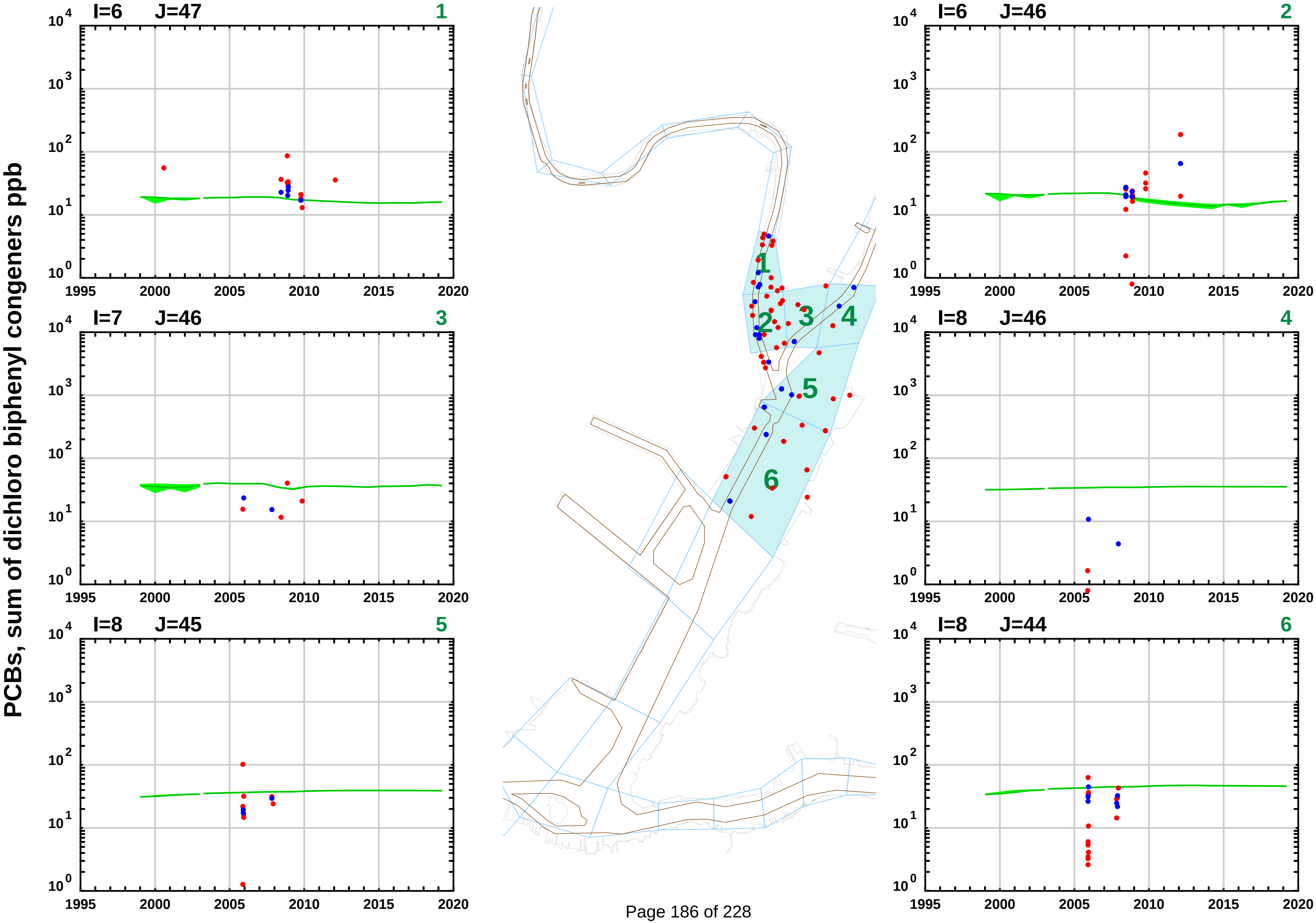
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



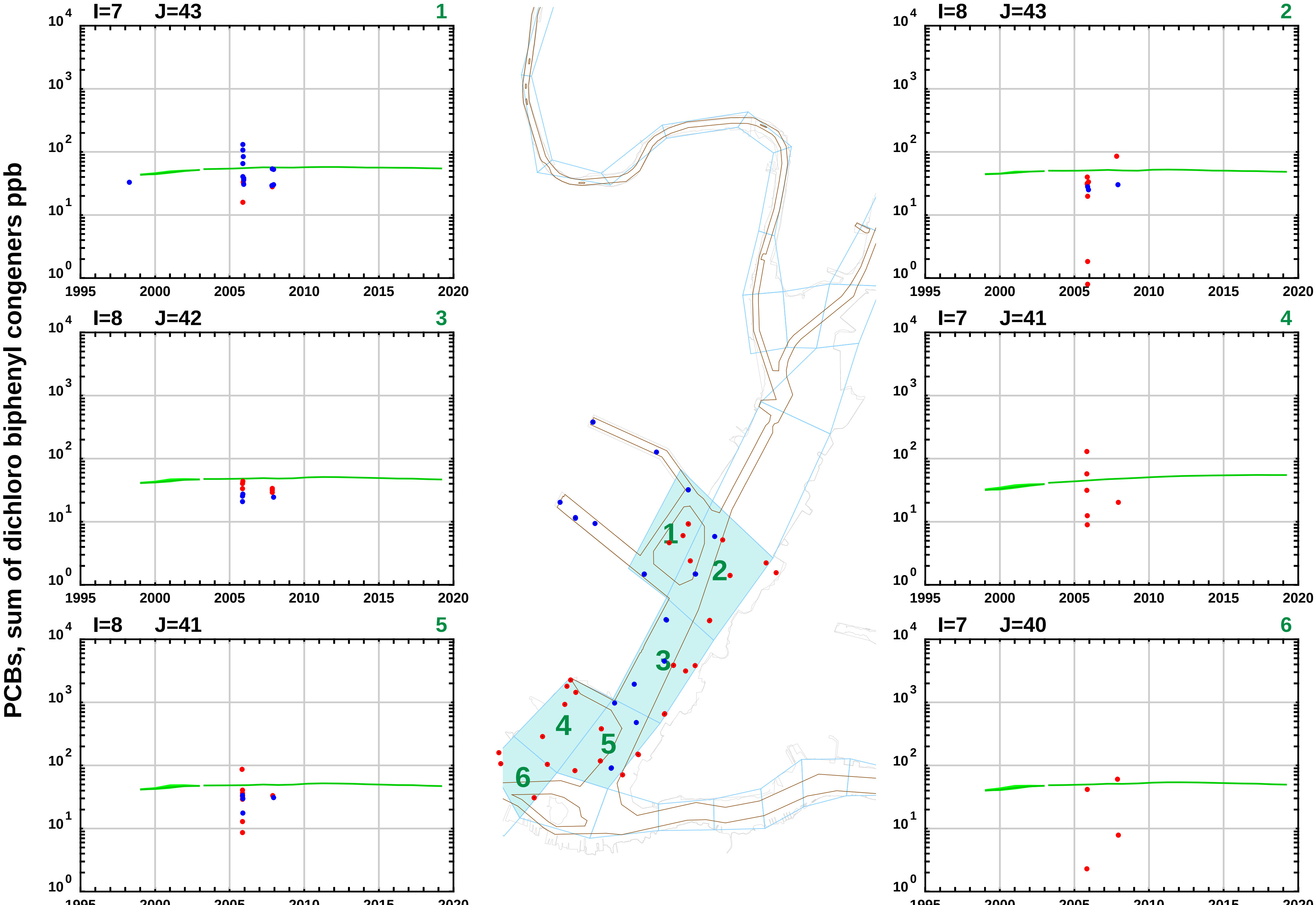
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

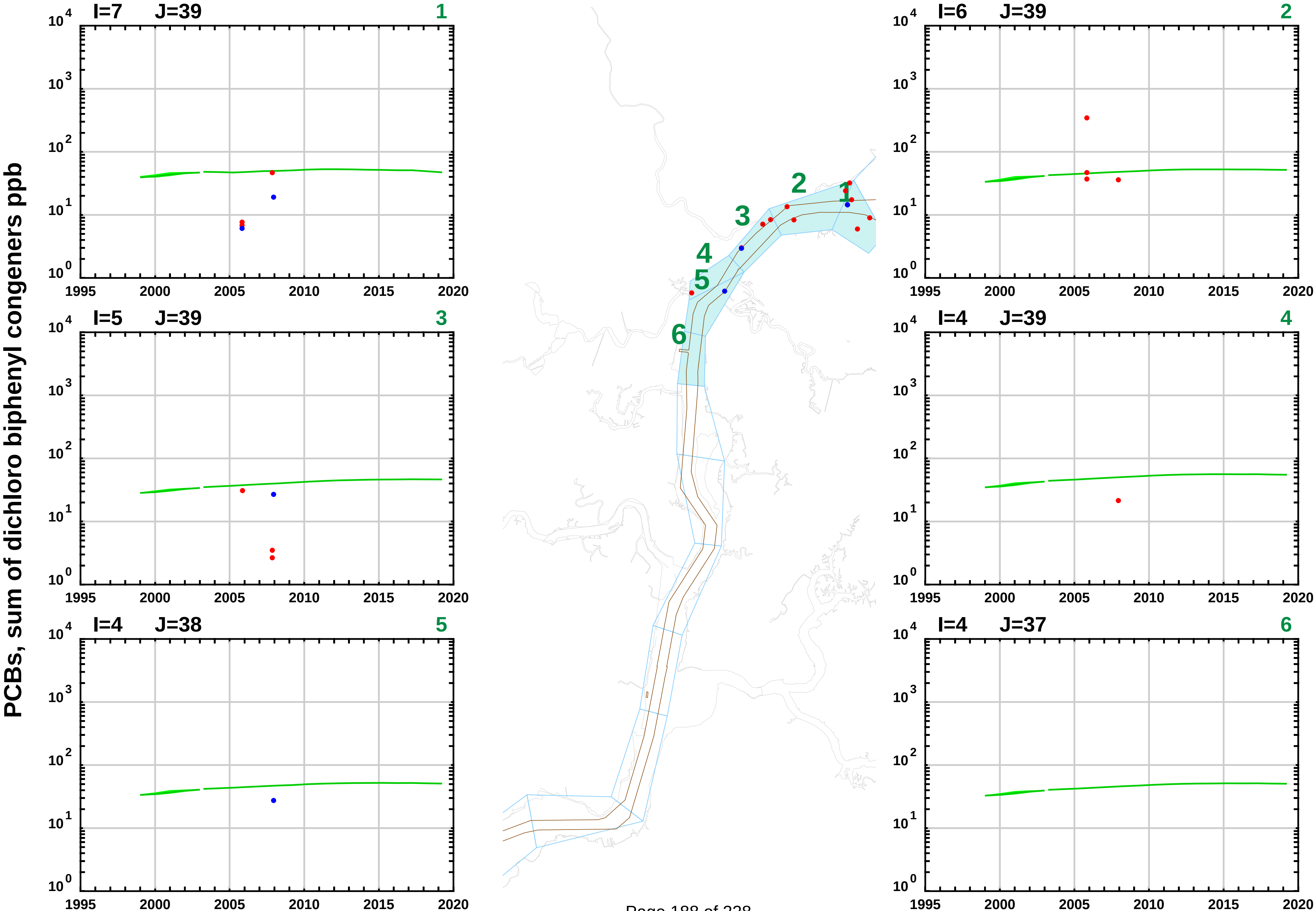
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

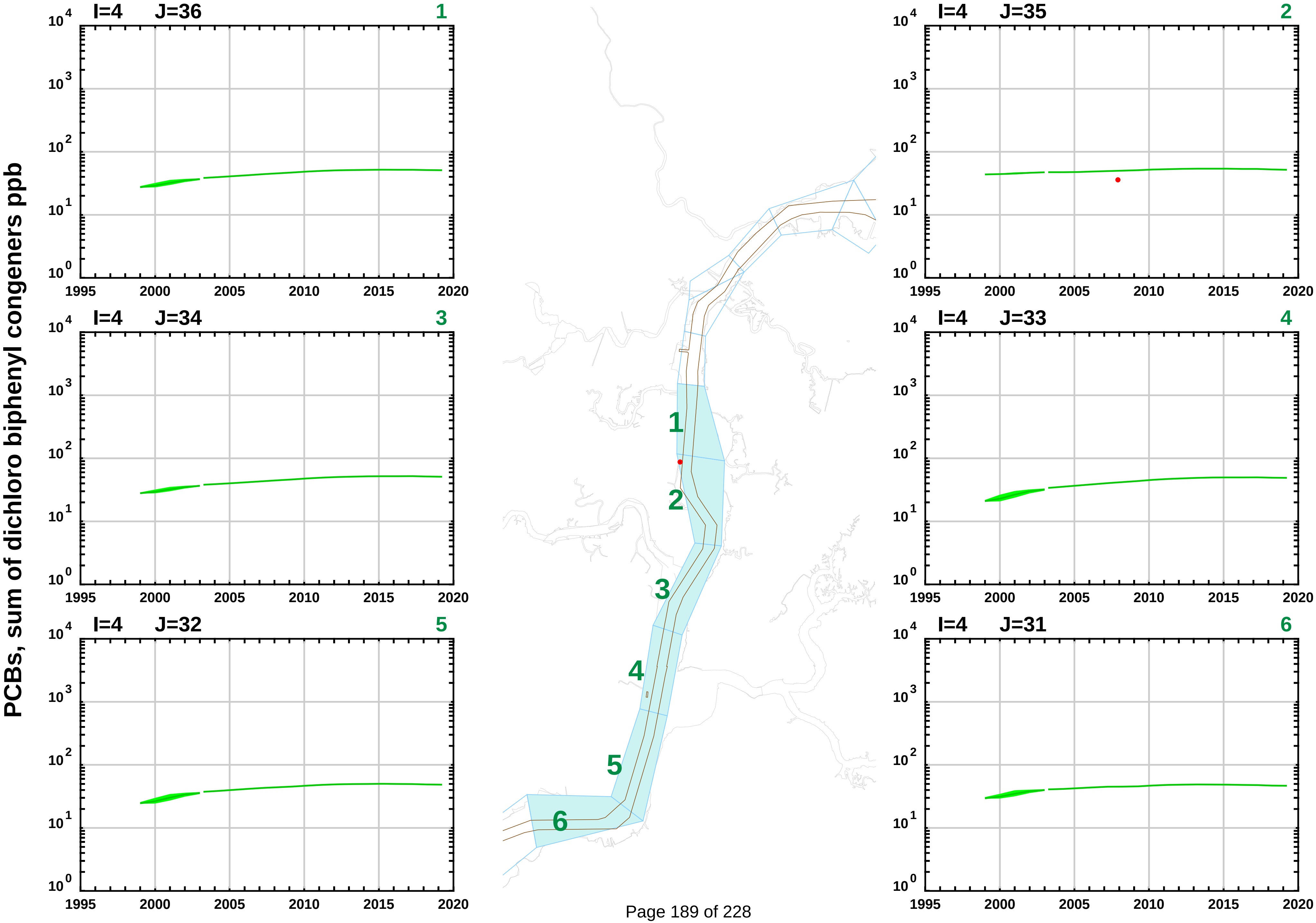
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

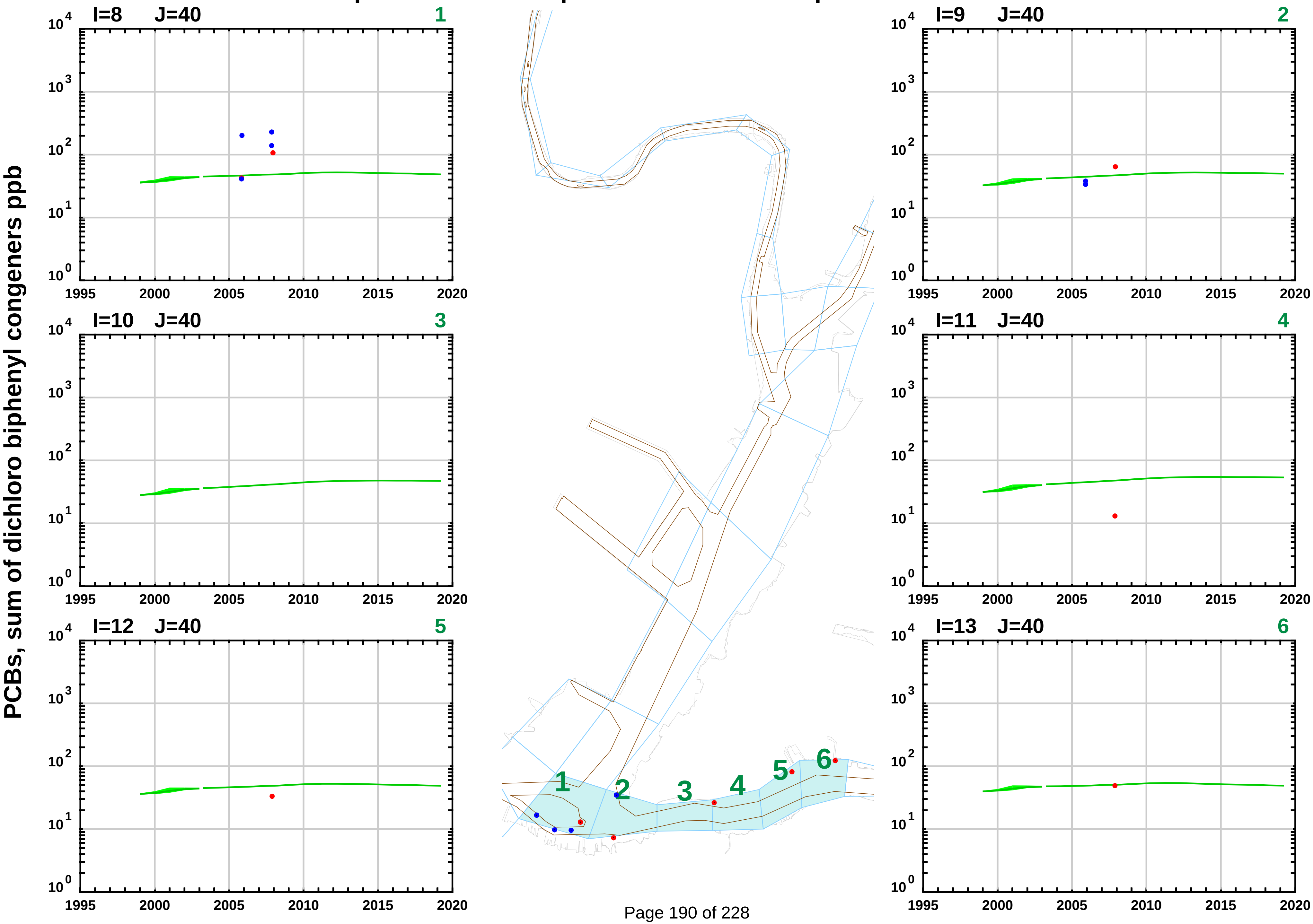
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

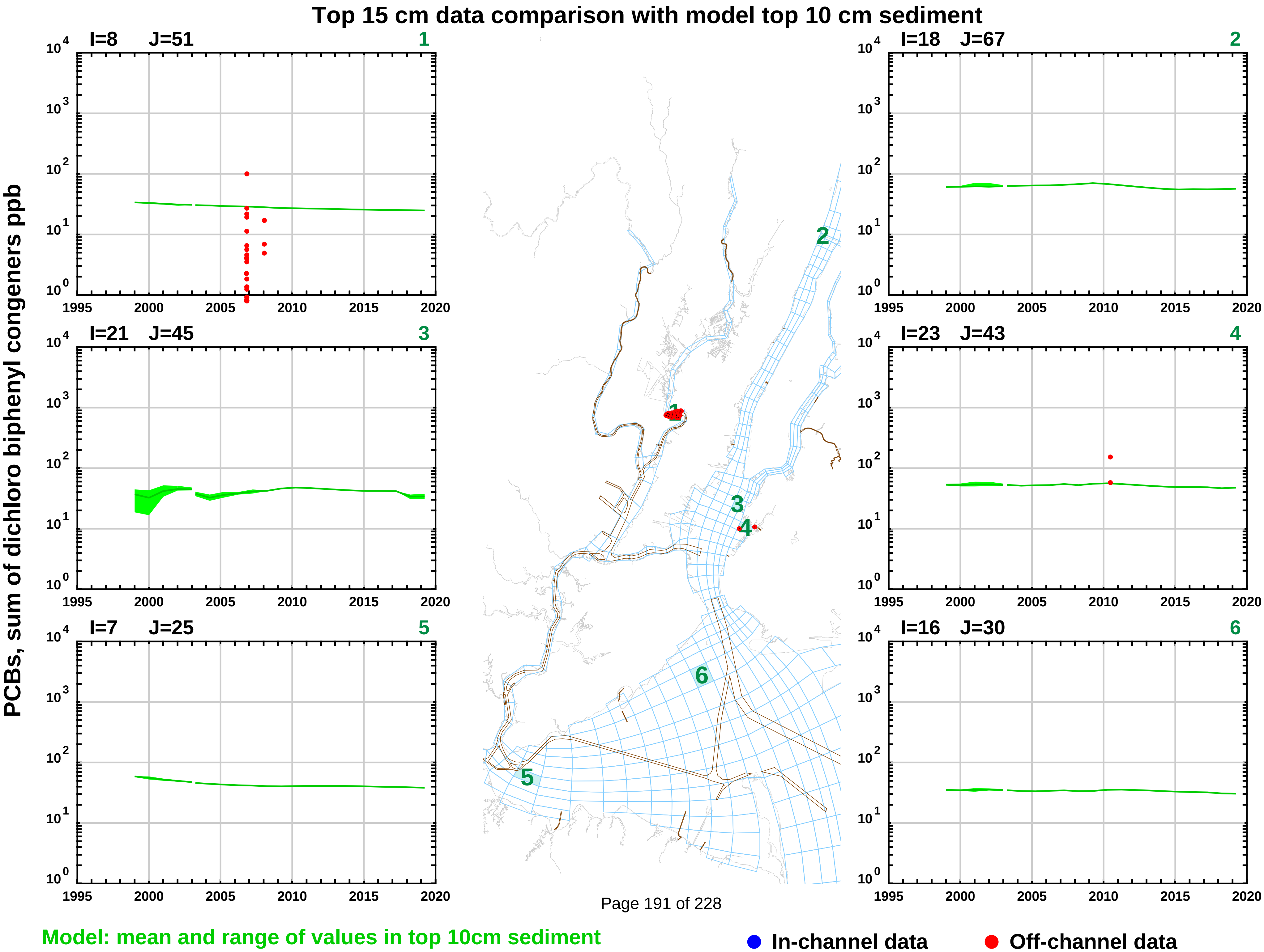
In-channel data Off-channel data

Top 15 cm data comparison with model top 10 cm sediment

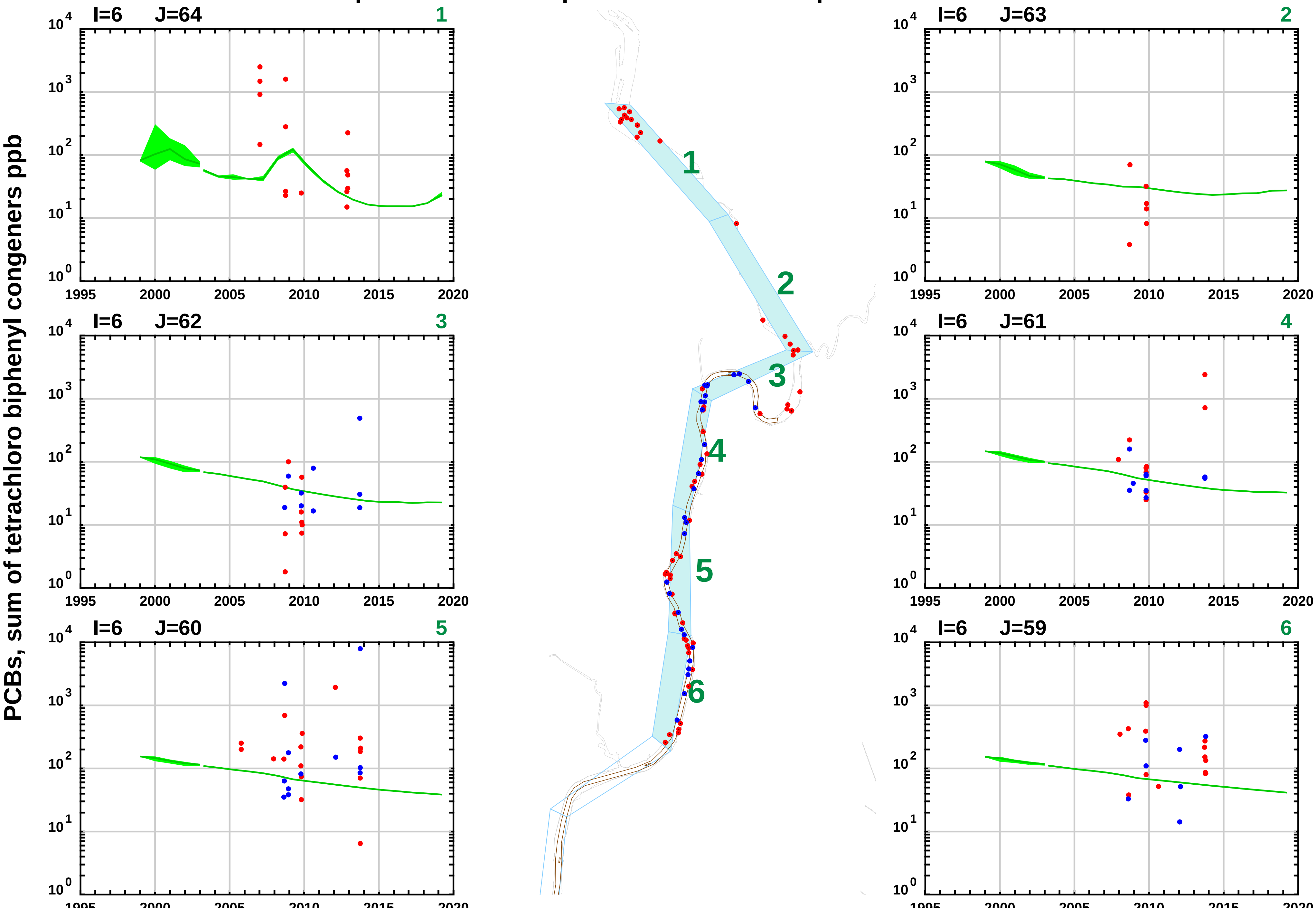


Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data


Top 15 cm data comparison with model top 10 cm sediment
PCBs, sum of dichloro biphenyl congeners ppb
I=8 J=51 1
I=18 J=67 2
I=21 J=45 3
I=23 J=43 4
I=7 J=25 5
I=16 J=30 6
10^0
10^1
10^2
10^3
10^4
1995
2000
2005
2010
2015
2020
1
2
3
4
5
6
Model: mean and range of values in top 10cm sediment
In-channel data
Off-channel data

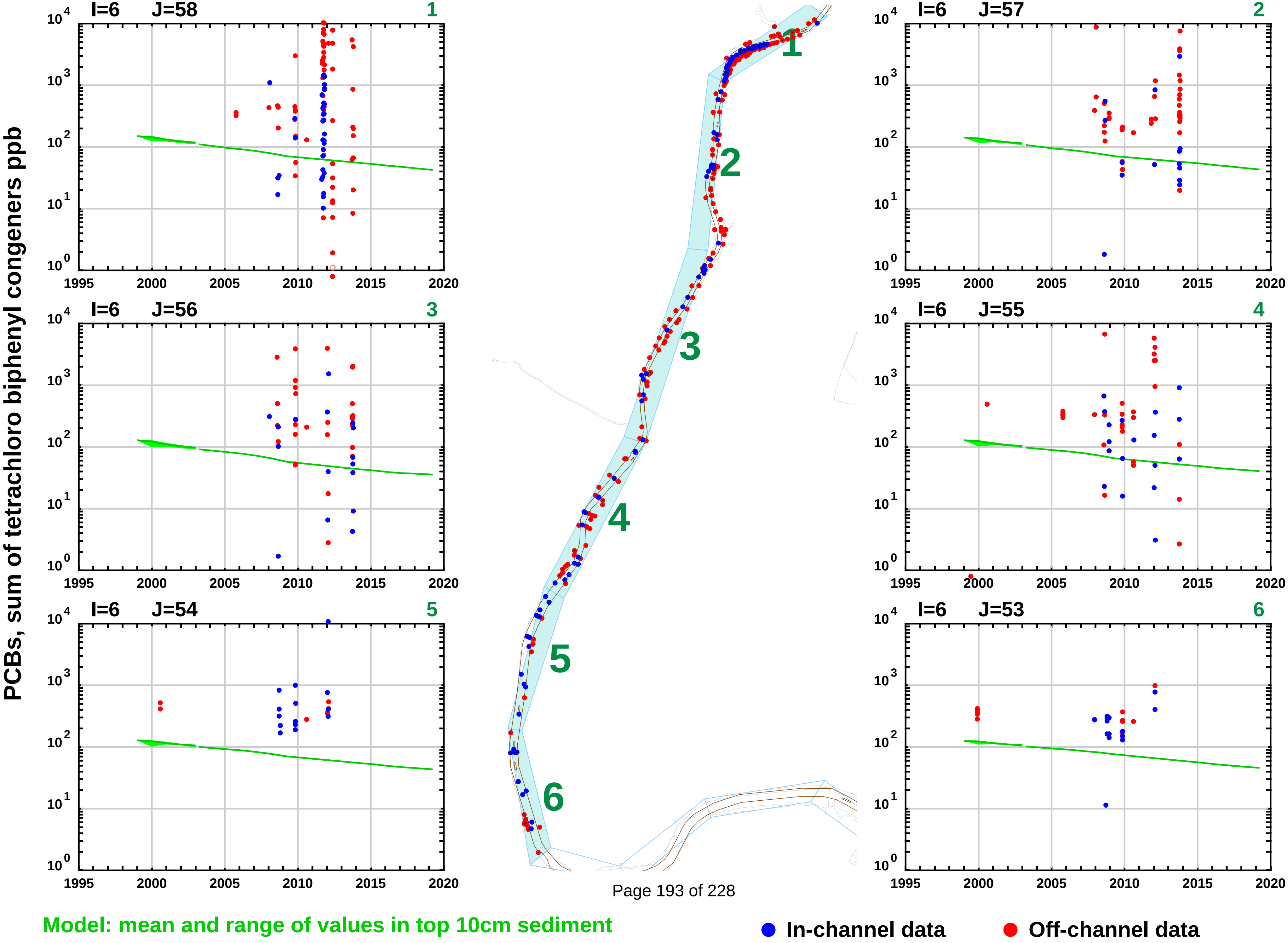
Top 15 cm data comparison with model top 10 cm sediment



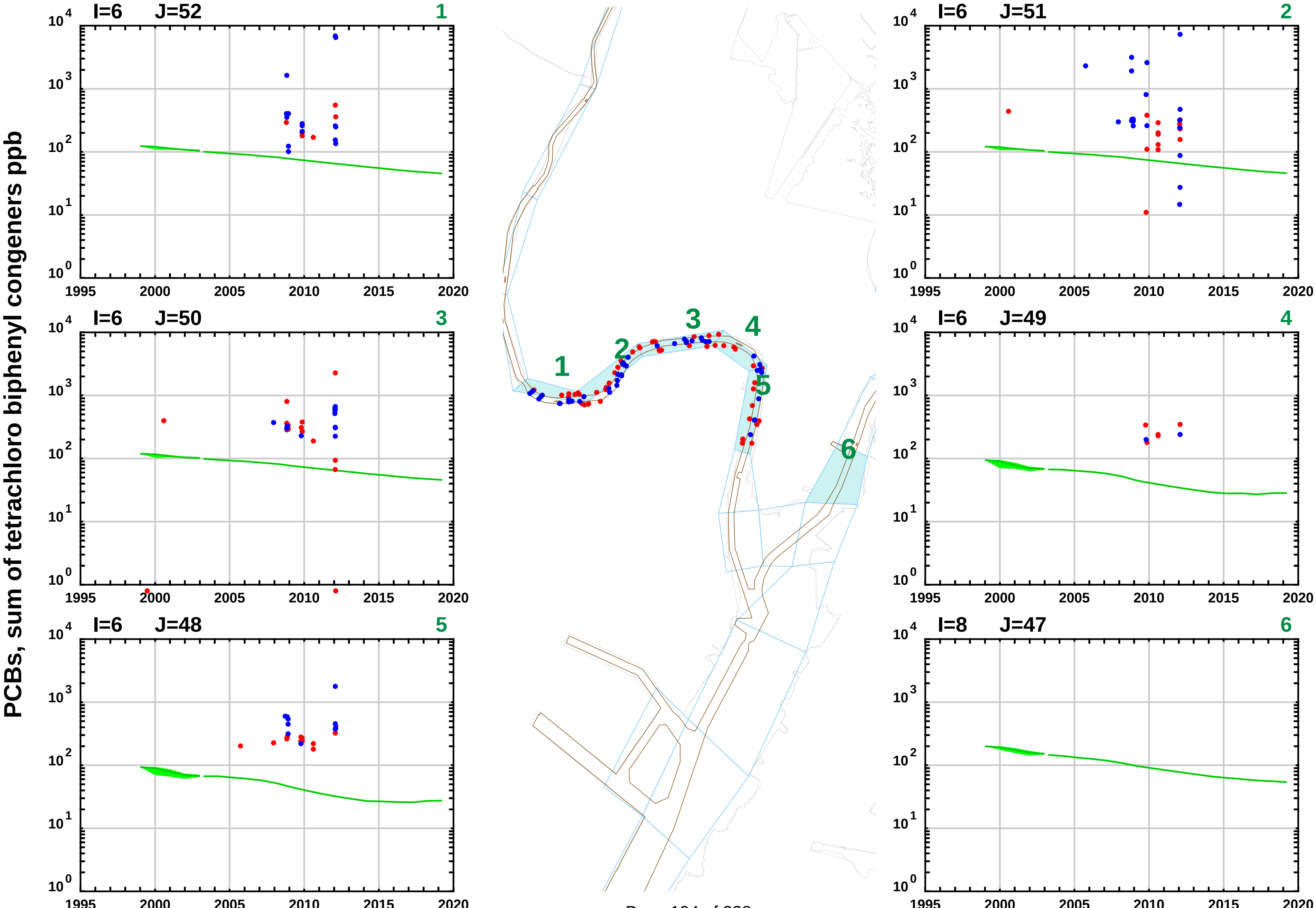
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



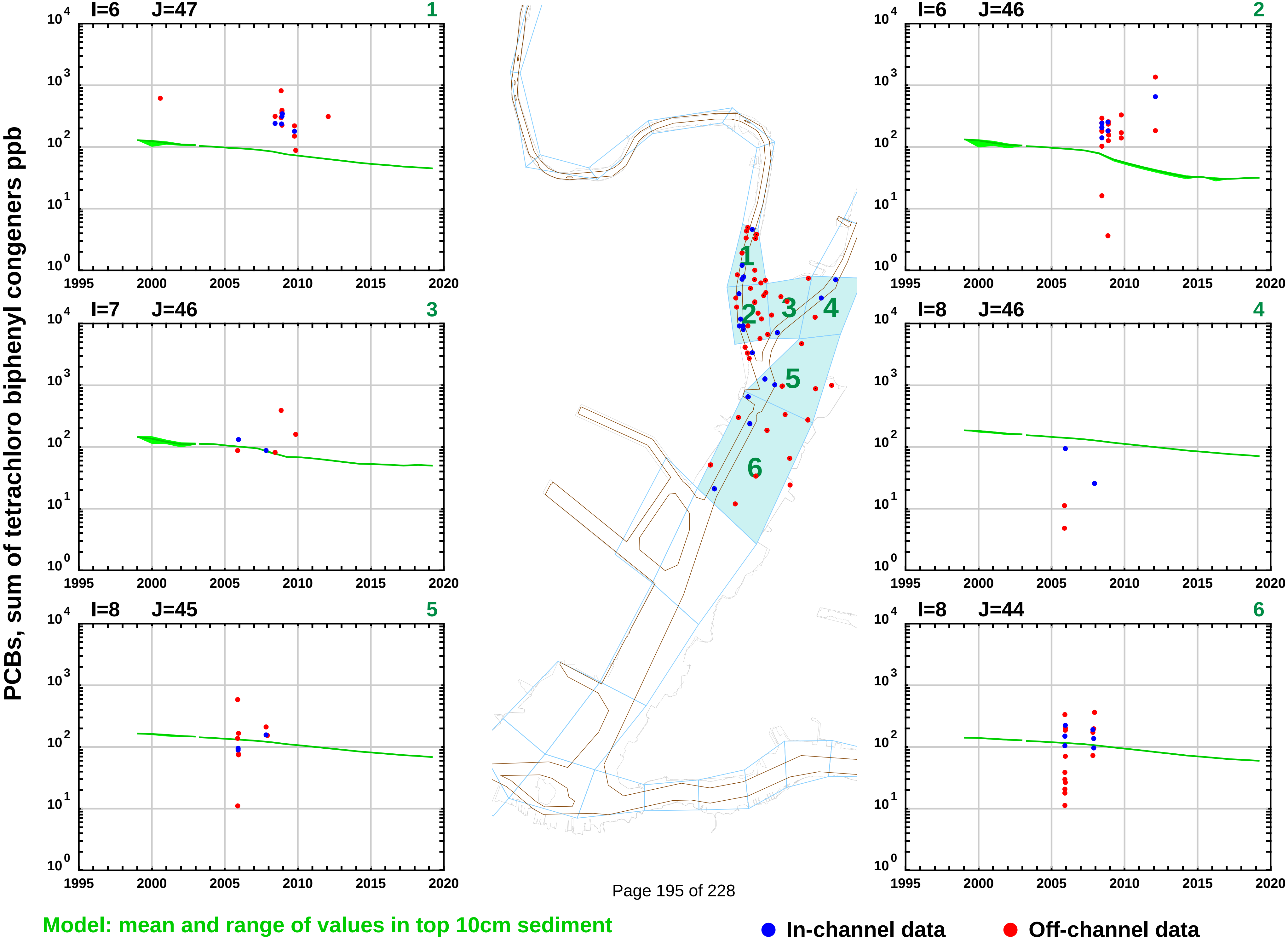
Top 15 cm data comparison with model top 10 cm sediment



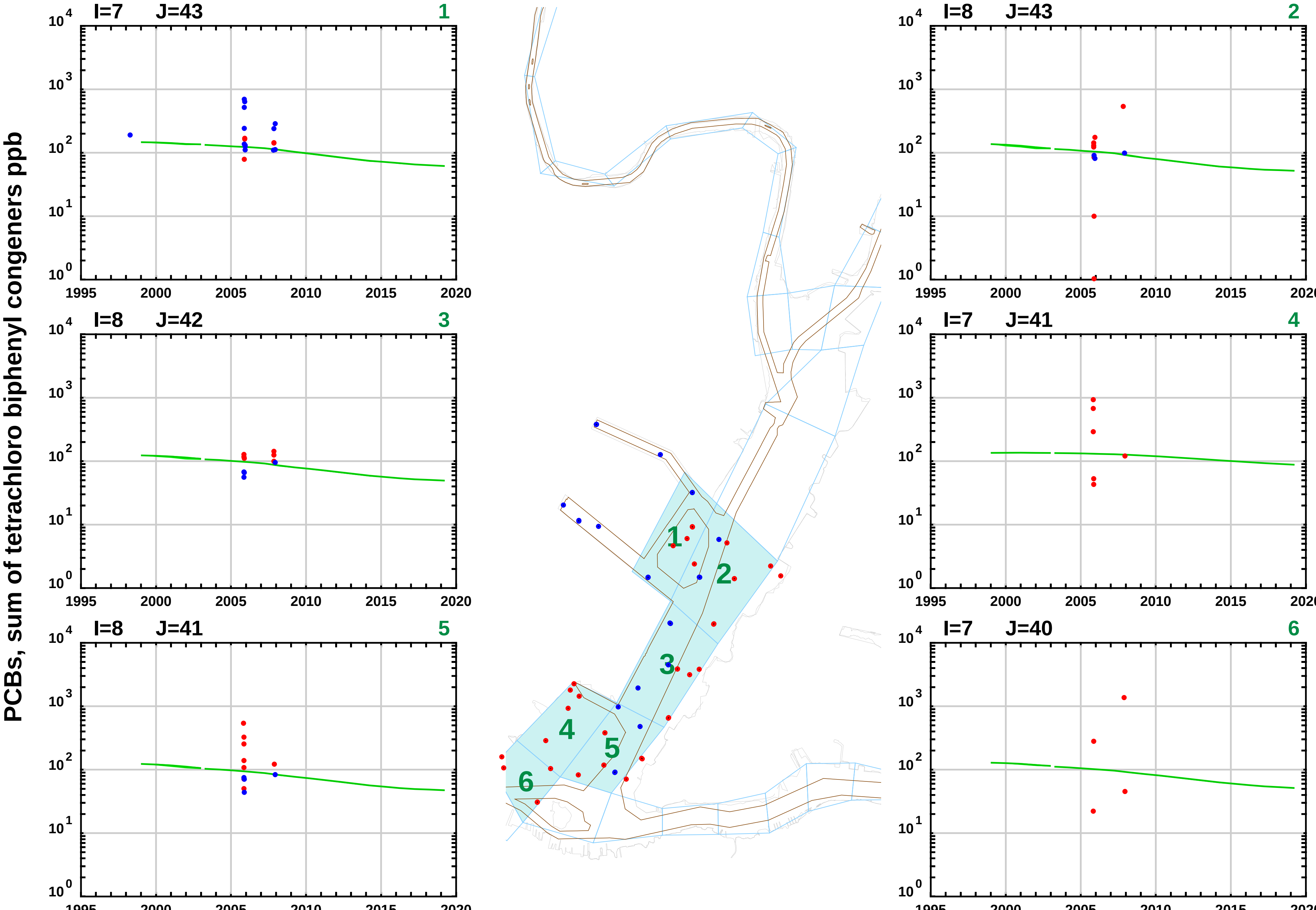
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



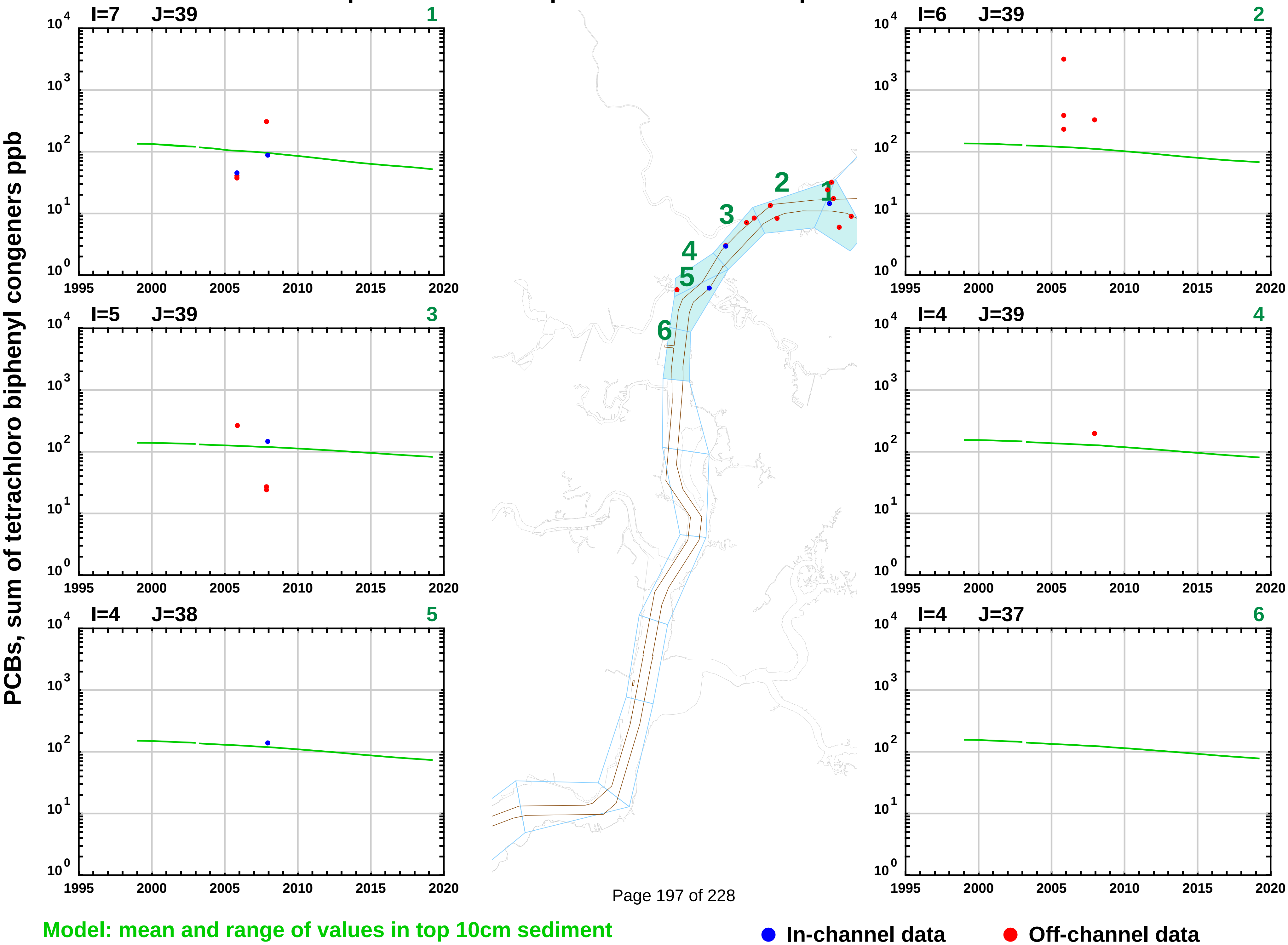
Top 15 cm data comparison with model top 10 cm sediment



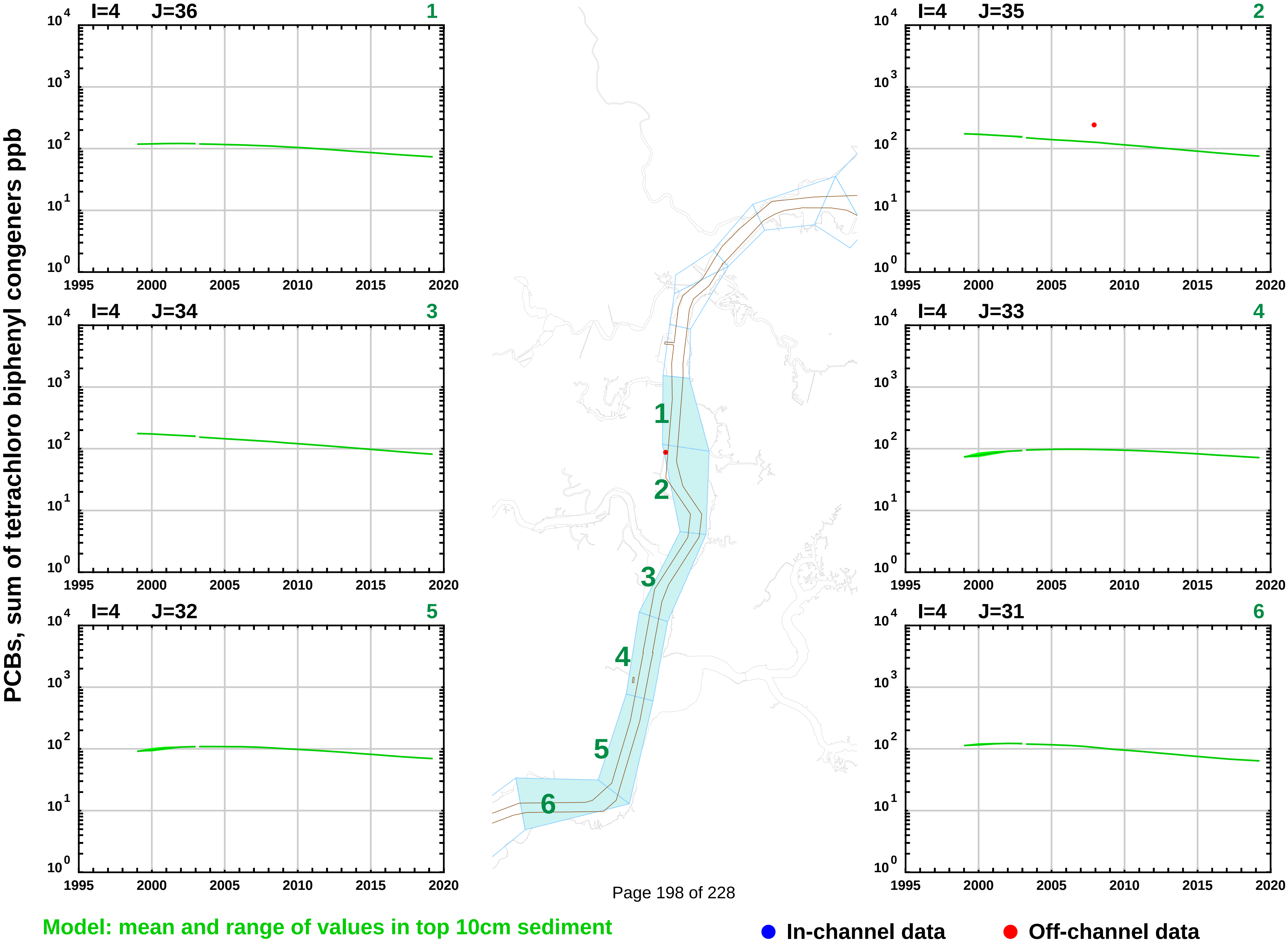
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

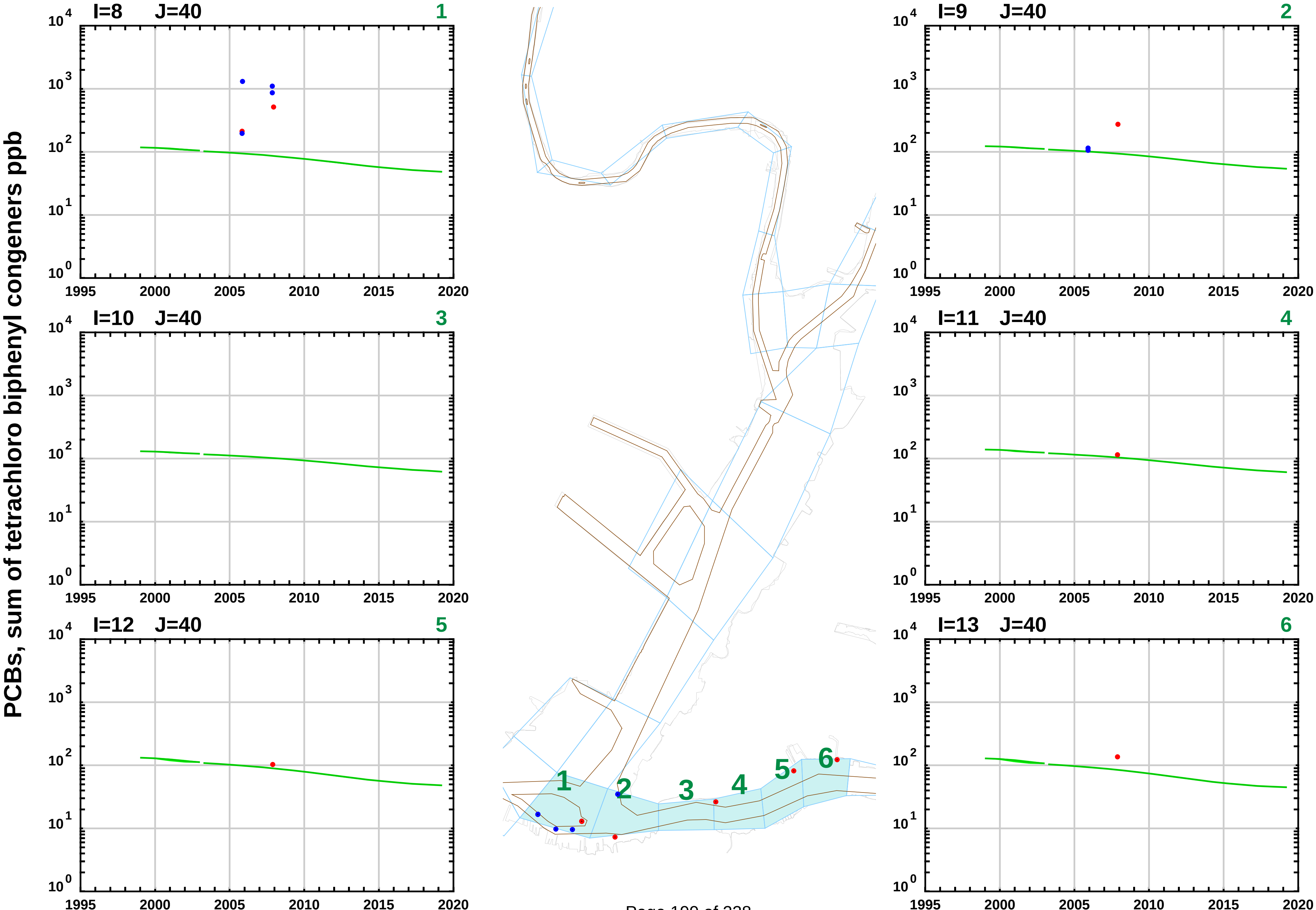
Top 15 cm data comparison with model top 10 cm sediment



Top 15 cm data comparison with model top 10 cm sediment

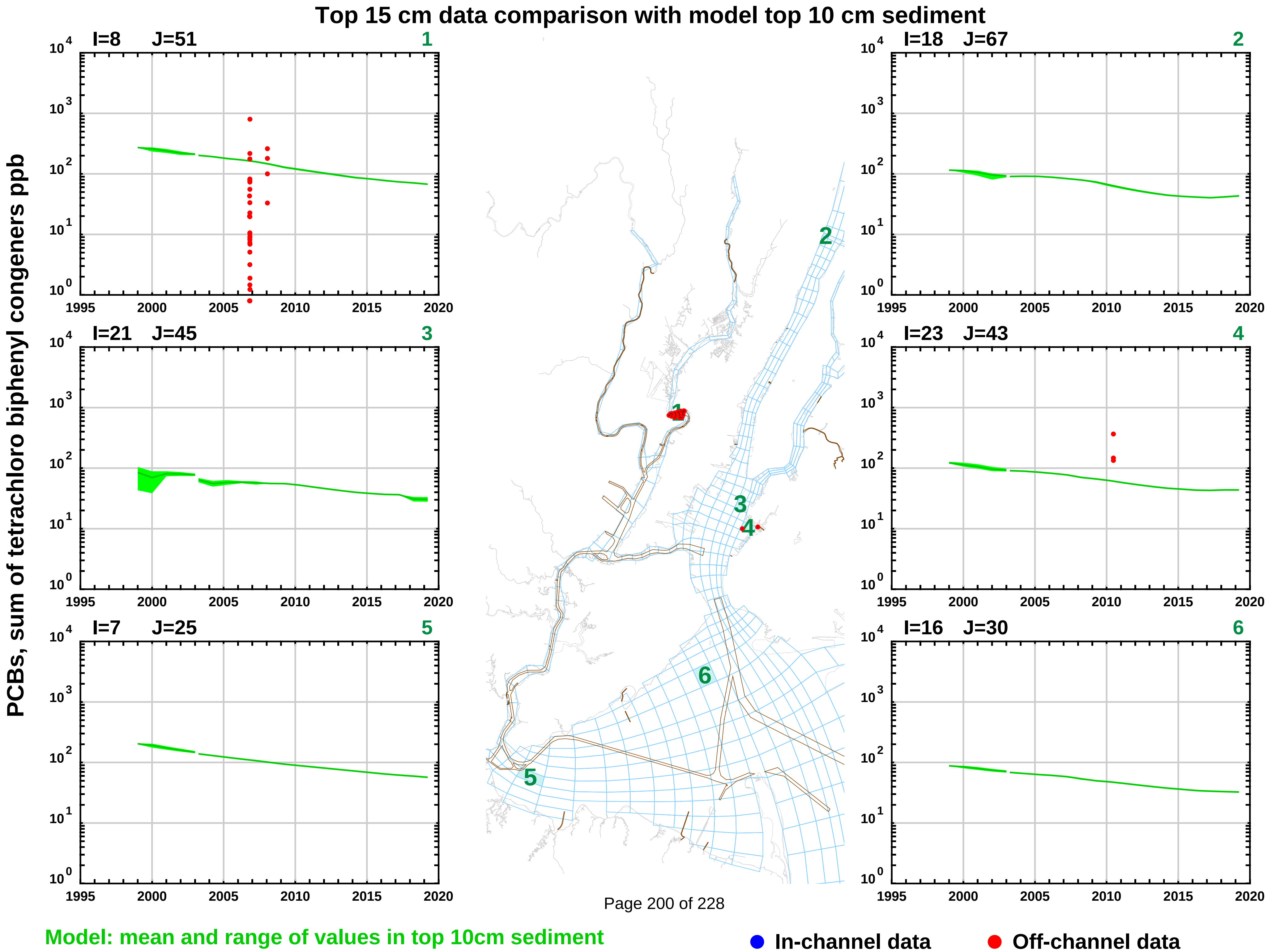


Top 15 cm data comparison with model top 10 cm sediment



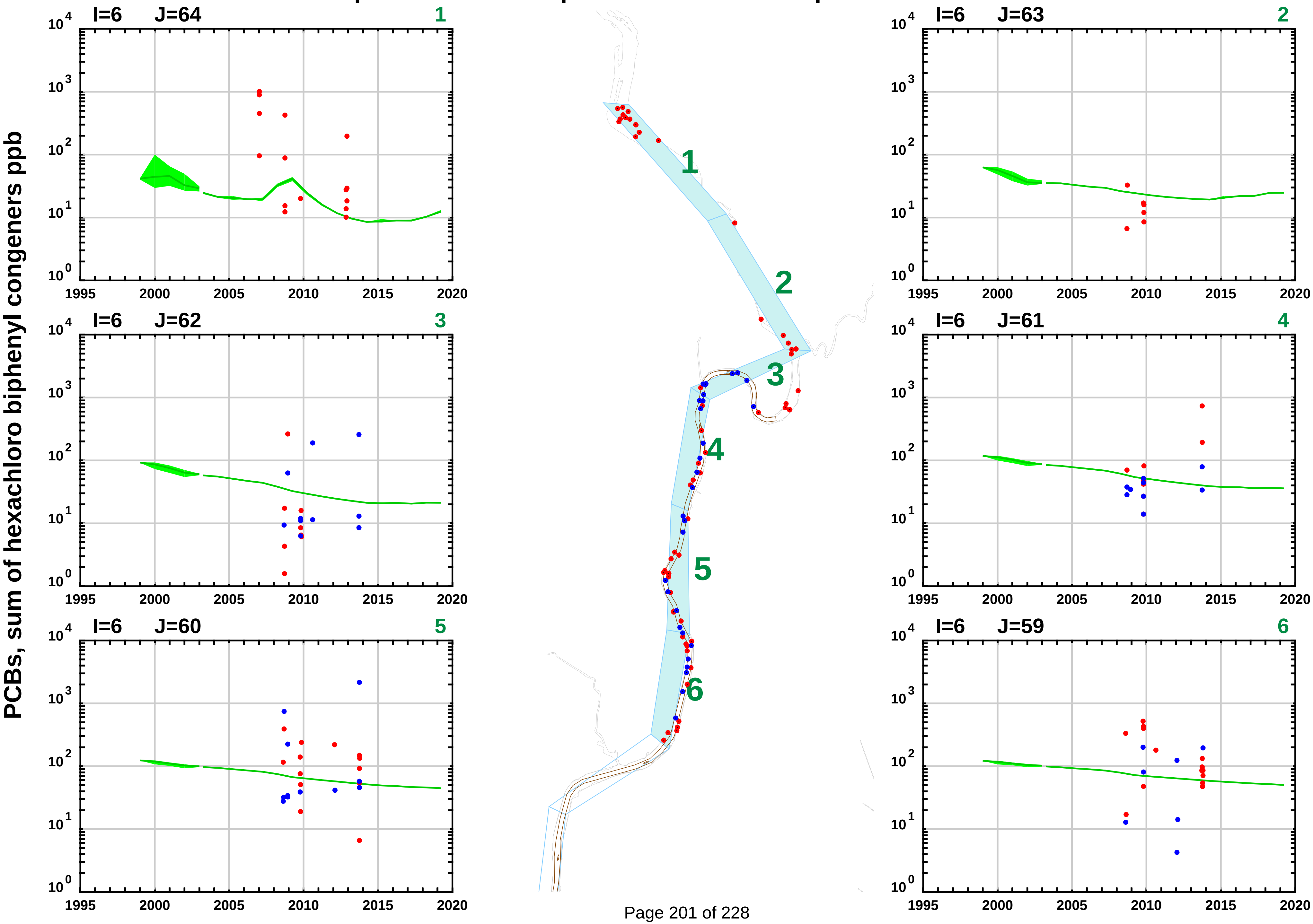
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data



Top 15 cm data comparison with model top 10 cm sediment
PCBs, sum of tetrachloro biphenyl congeners ppb
I=8 J=51 1
I=18 J=67 2
I=21 J=45 3
I=23 J=43 4
I=7 J=25 5
I=16 J=30 6
10^0
10^1
10^2
10^3
10^4
1995
2000
2005
2010
2015
2020
Model: mean and range of values in top 10cm sediment
In-channel data
Off-channel data

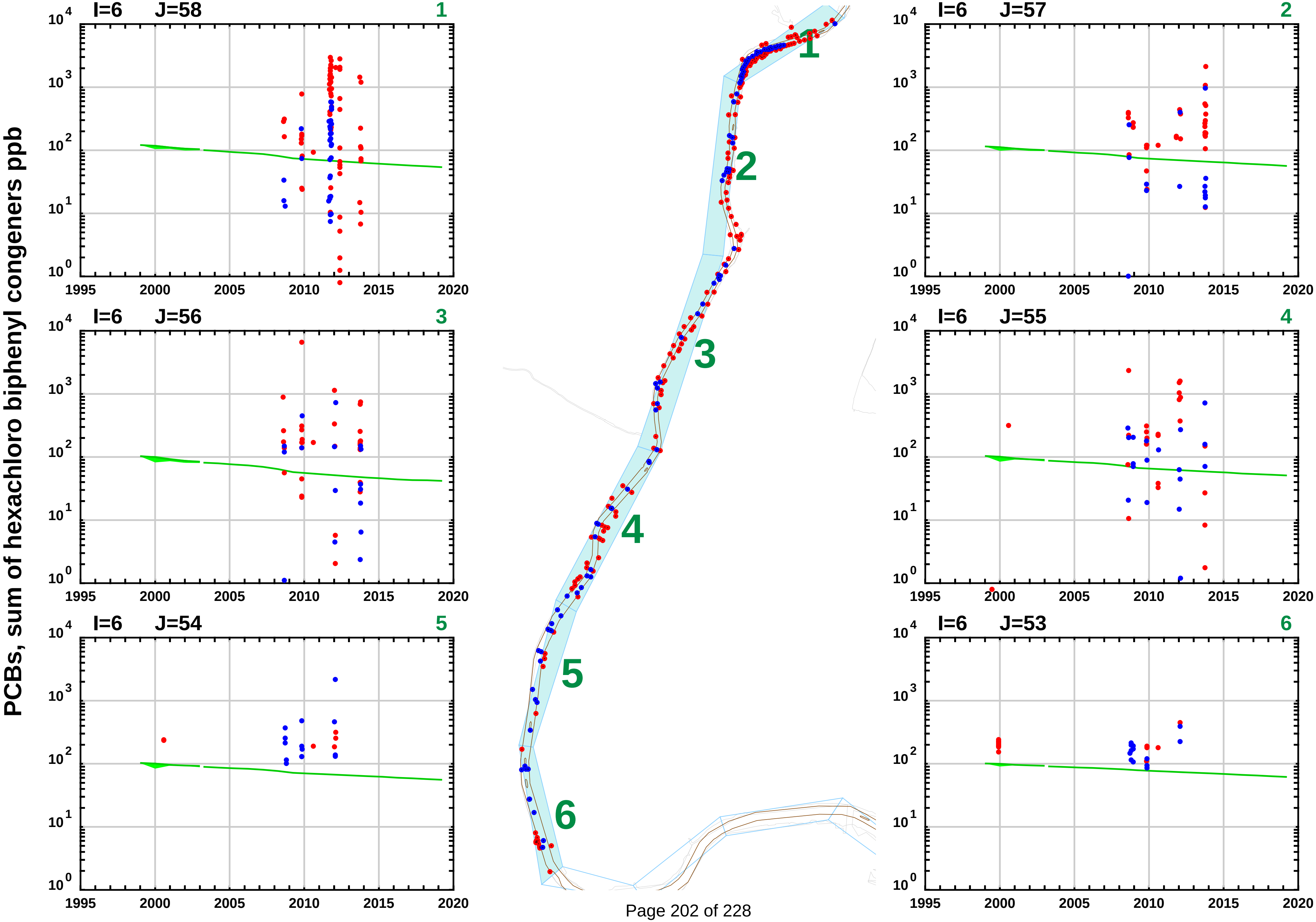
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

In-channel data Off-channel data

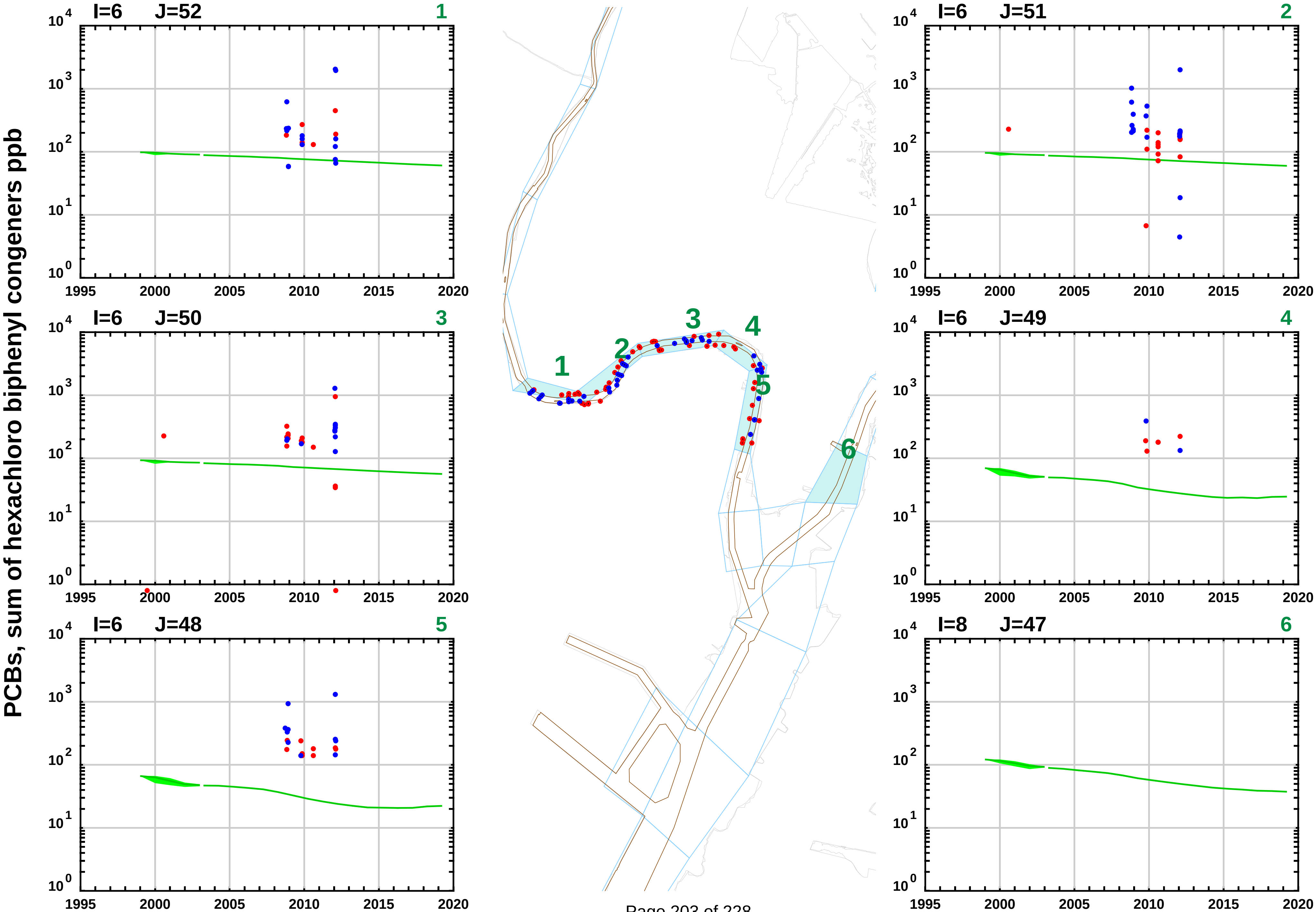
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

In-channel data Off-channel data

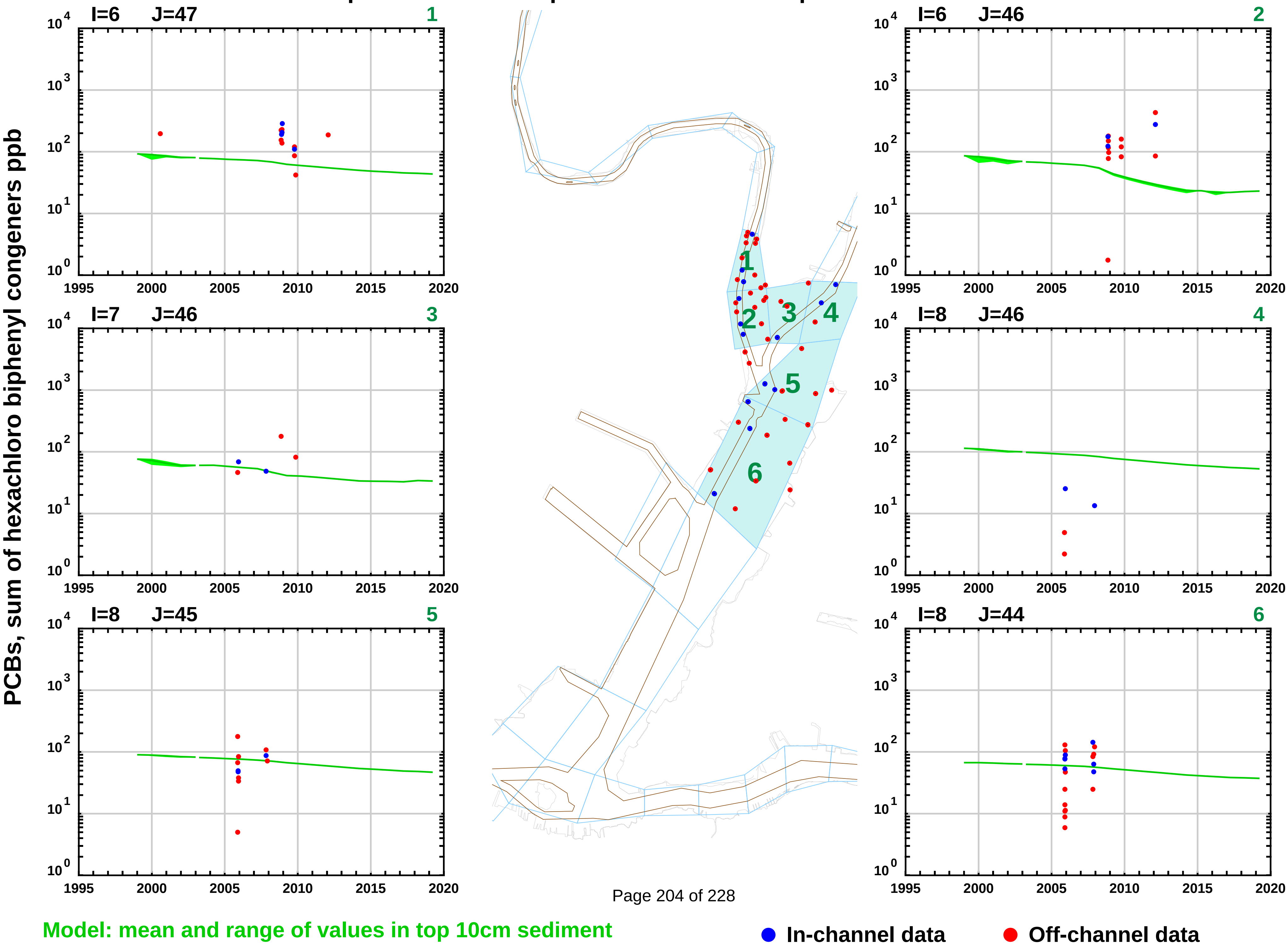
Top 15 cm data comparison with model top 10 cm sediment



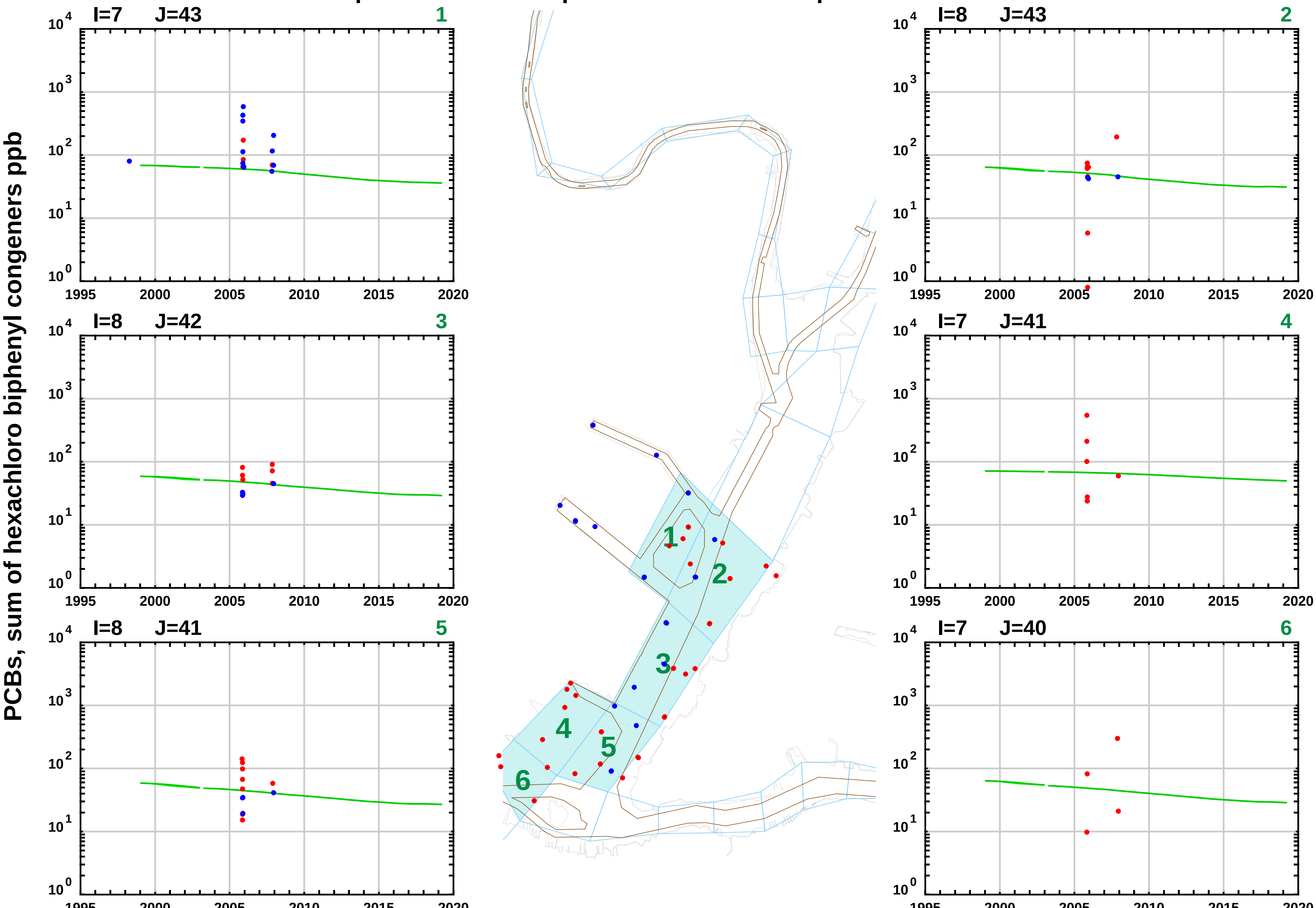
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



Top 15 cm data comparison with model top 10 cm sediment

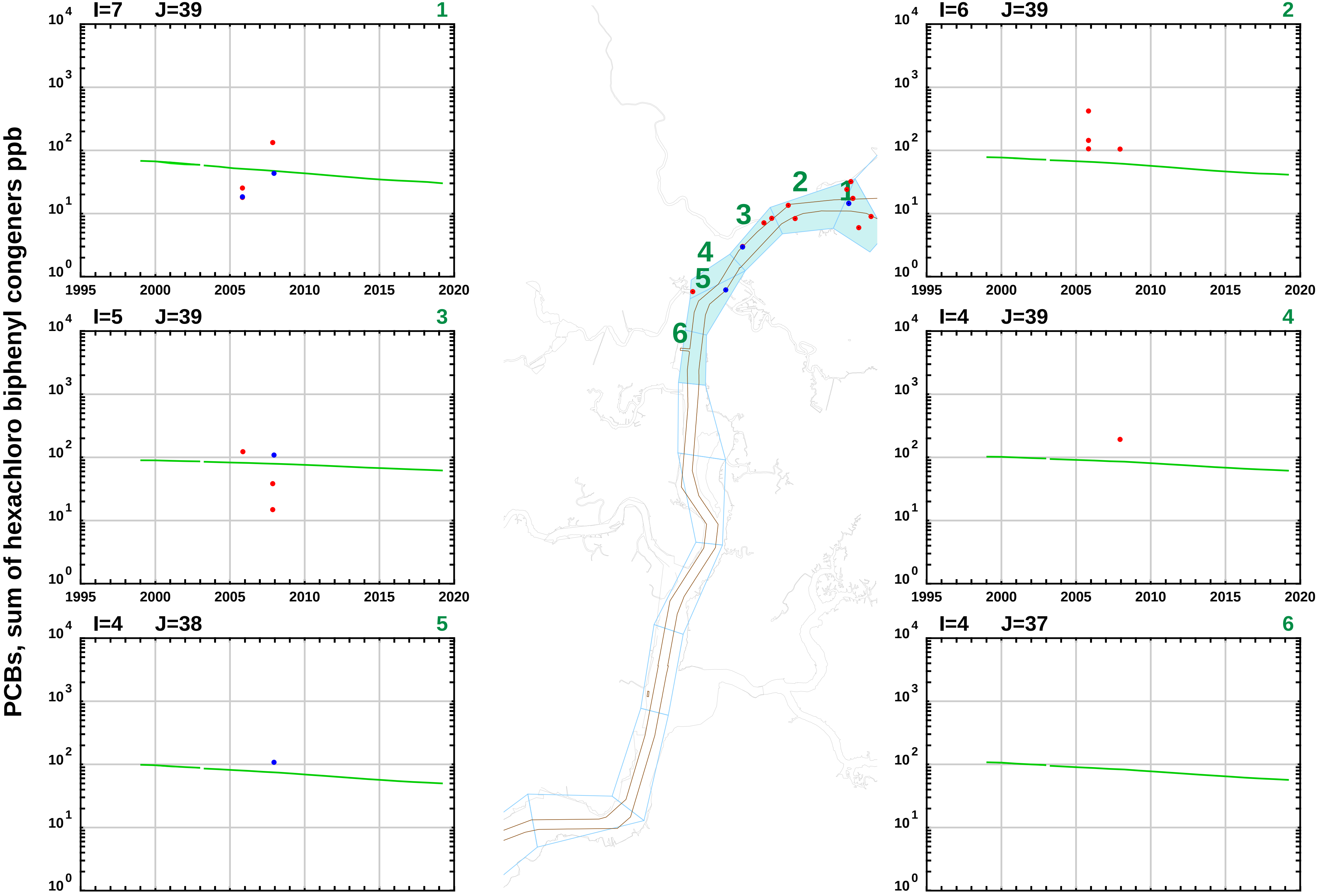


Model: mean and range of values in top 10cm sediment

In-channel data

Off-channel data

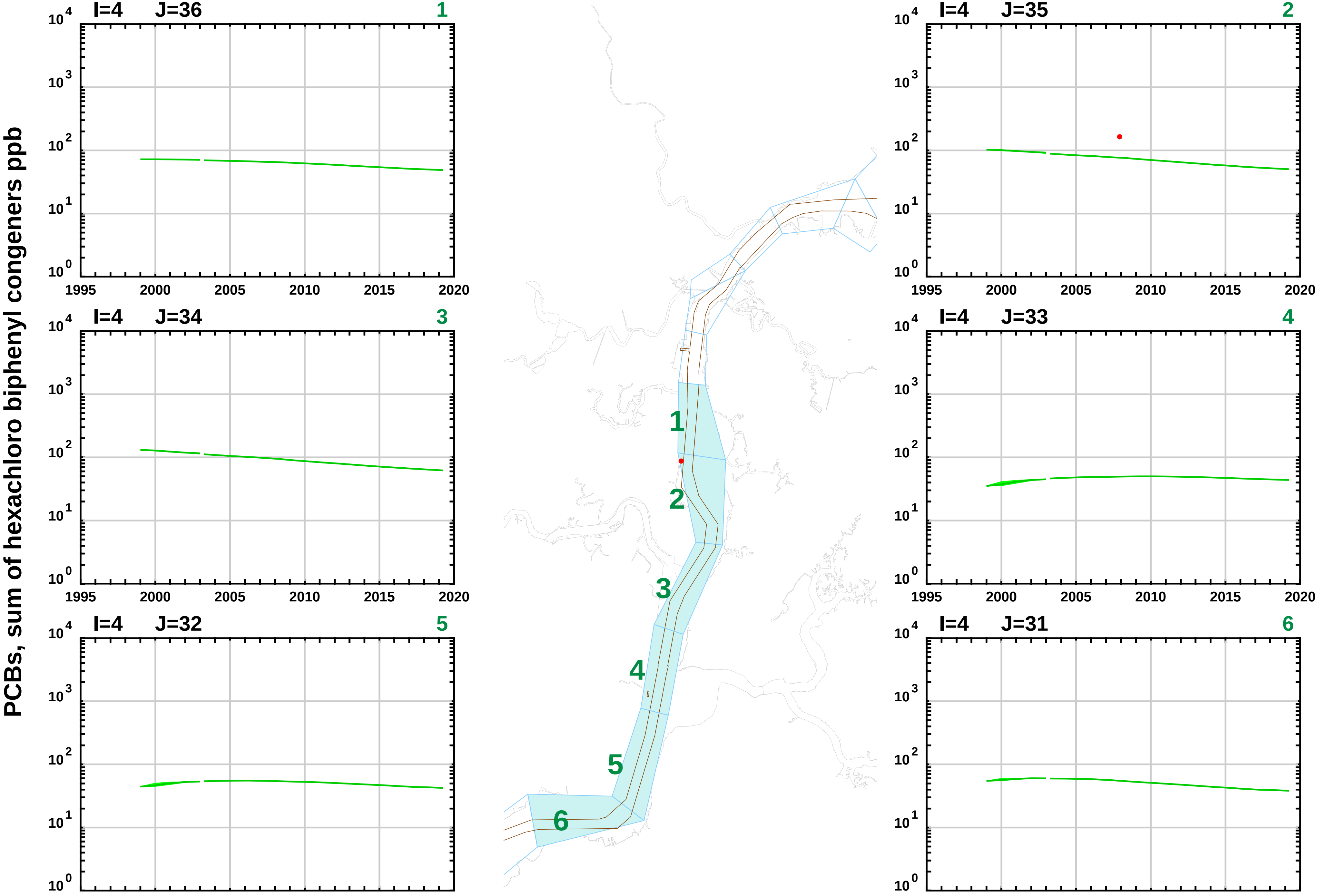
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment

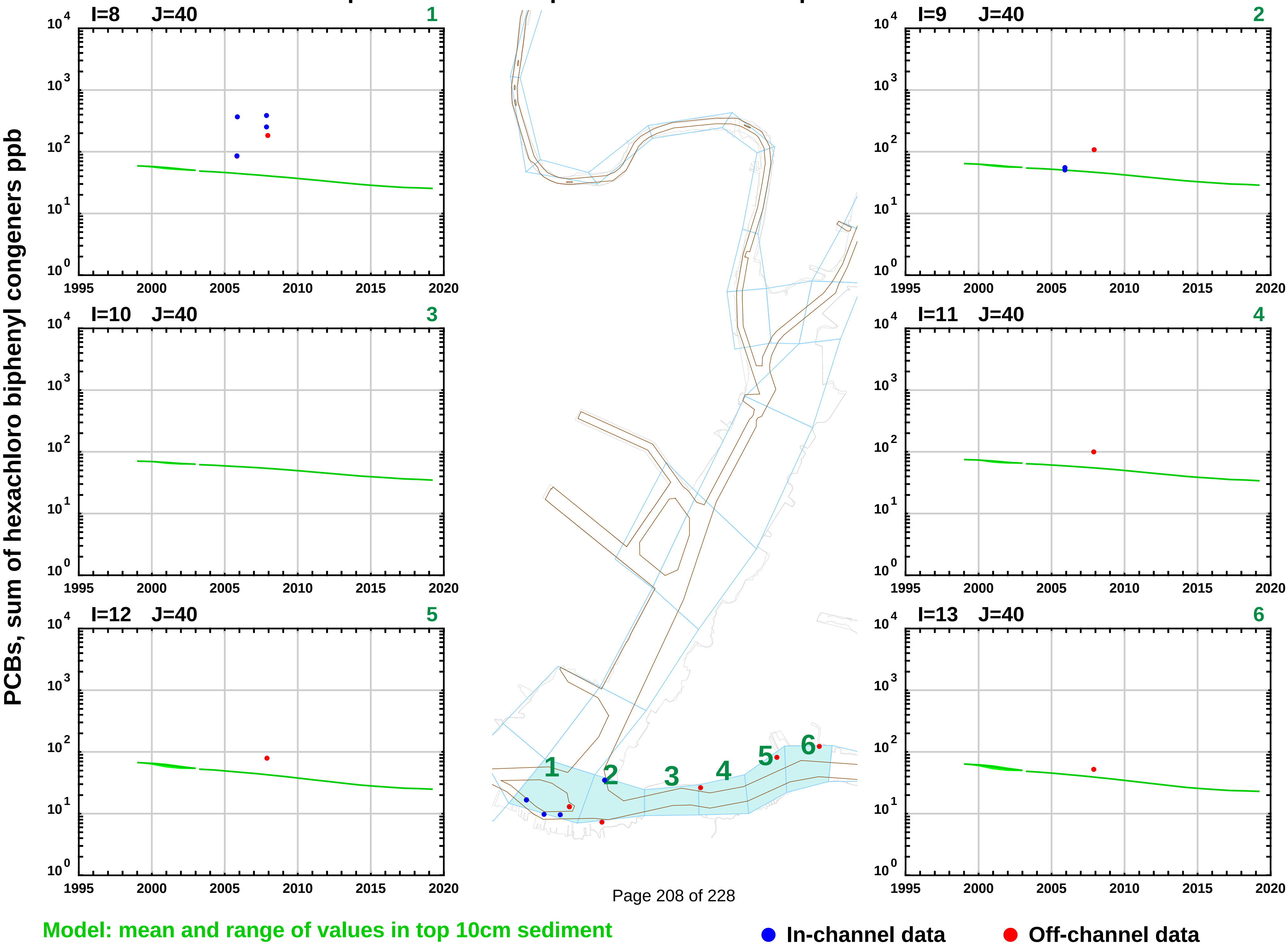


Model: mean and range of values in top 10cm sediment

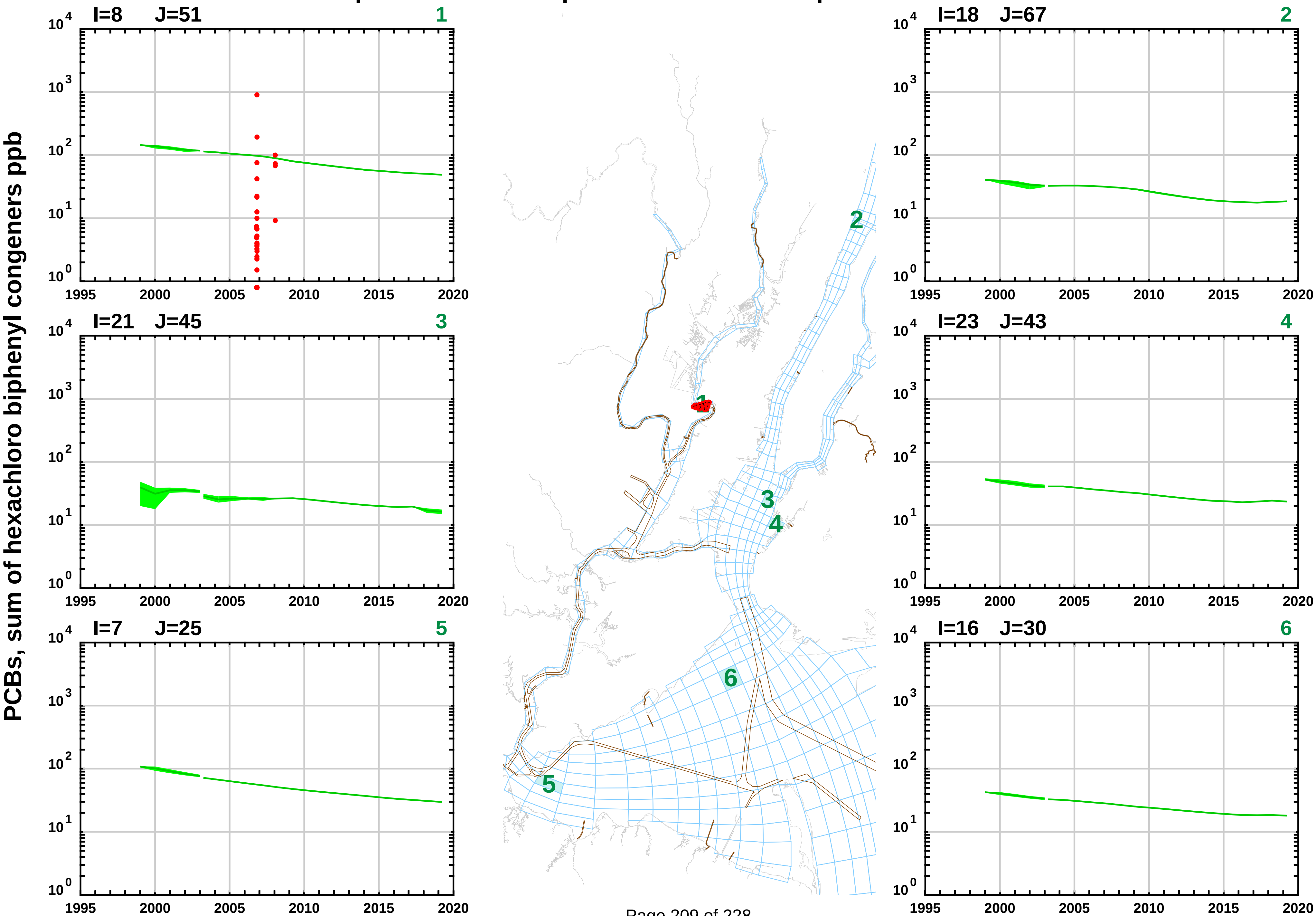
In-channel data

Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



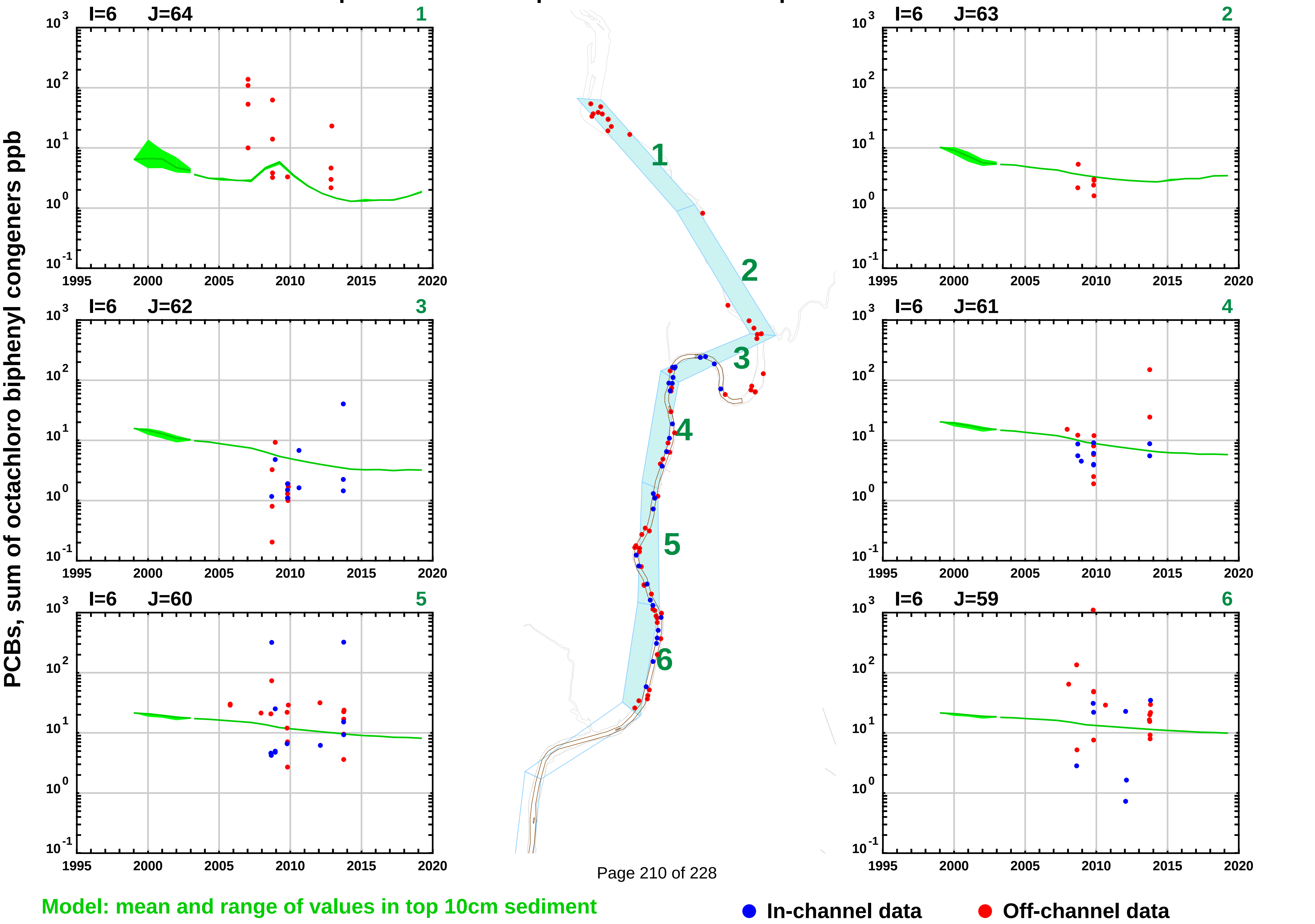
Top 15 cm data comparison with model top 10 cm sediment



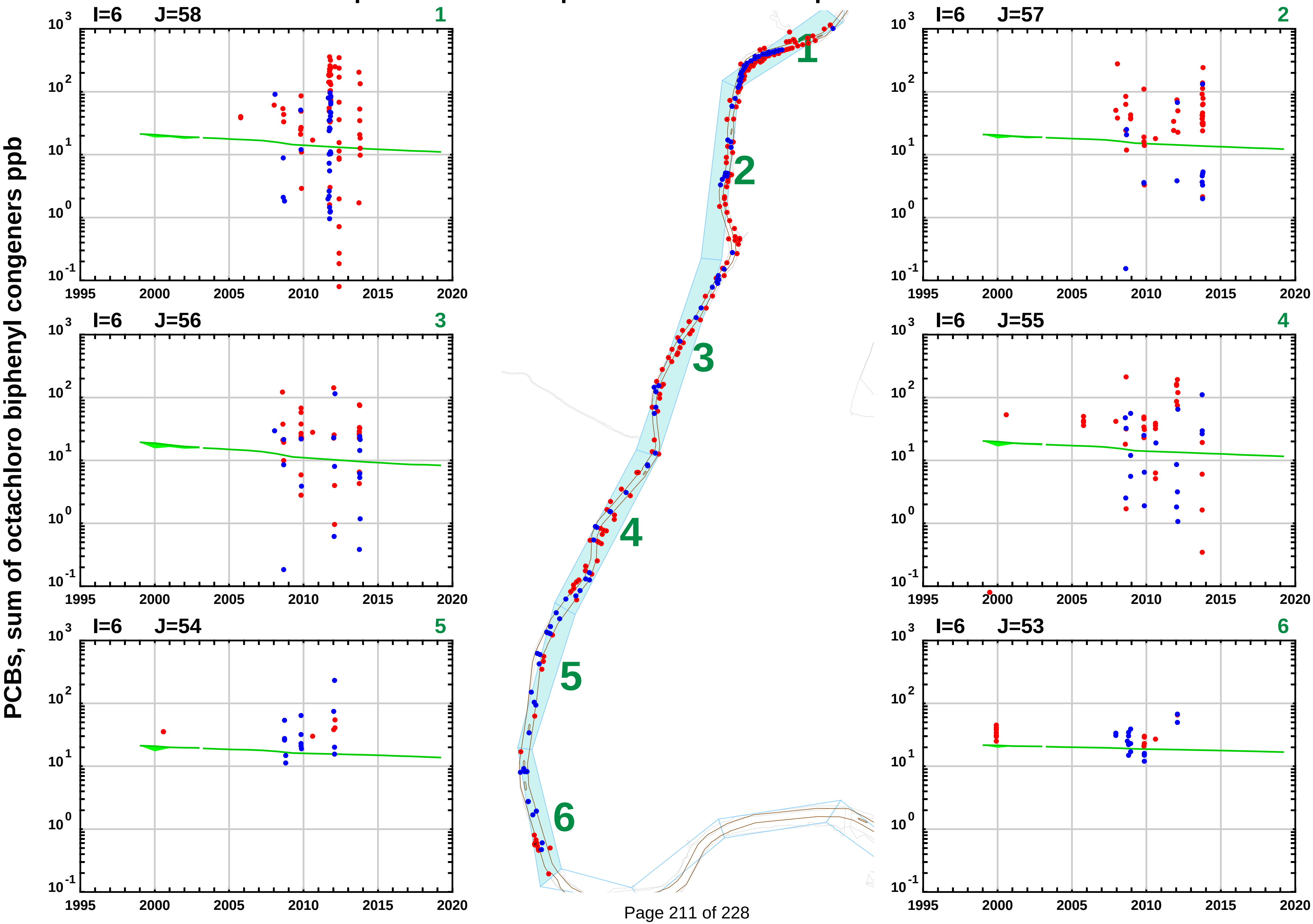
Model: mean and range of values in top 10cm sediment

In-channel data   Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



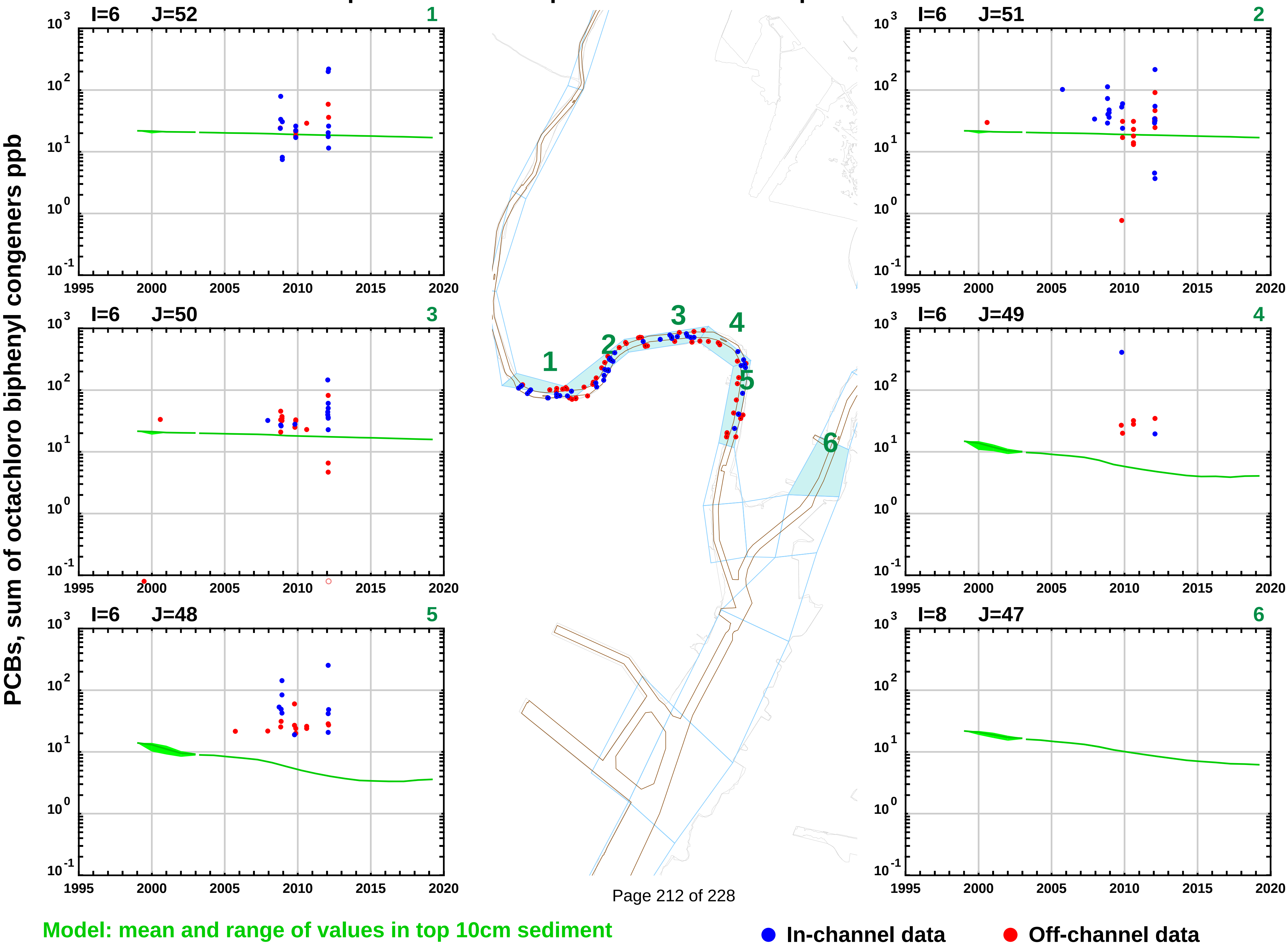
Top 15 cm data comparison with model top 10 cm sediment



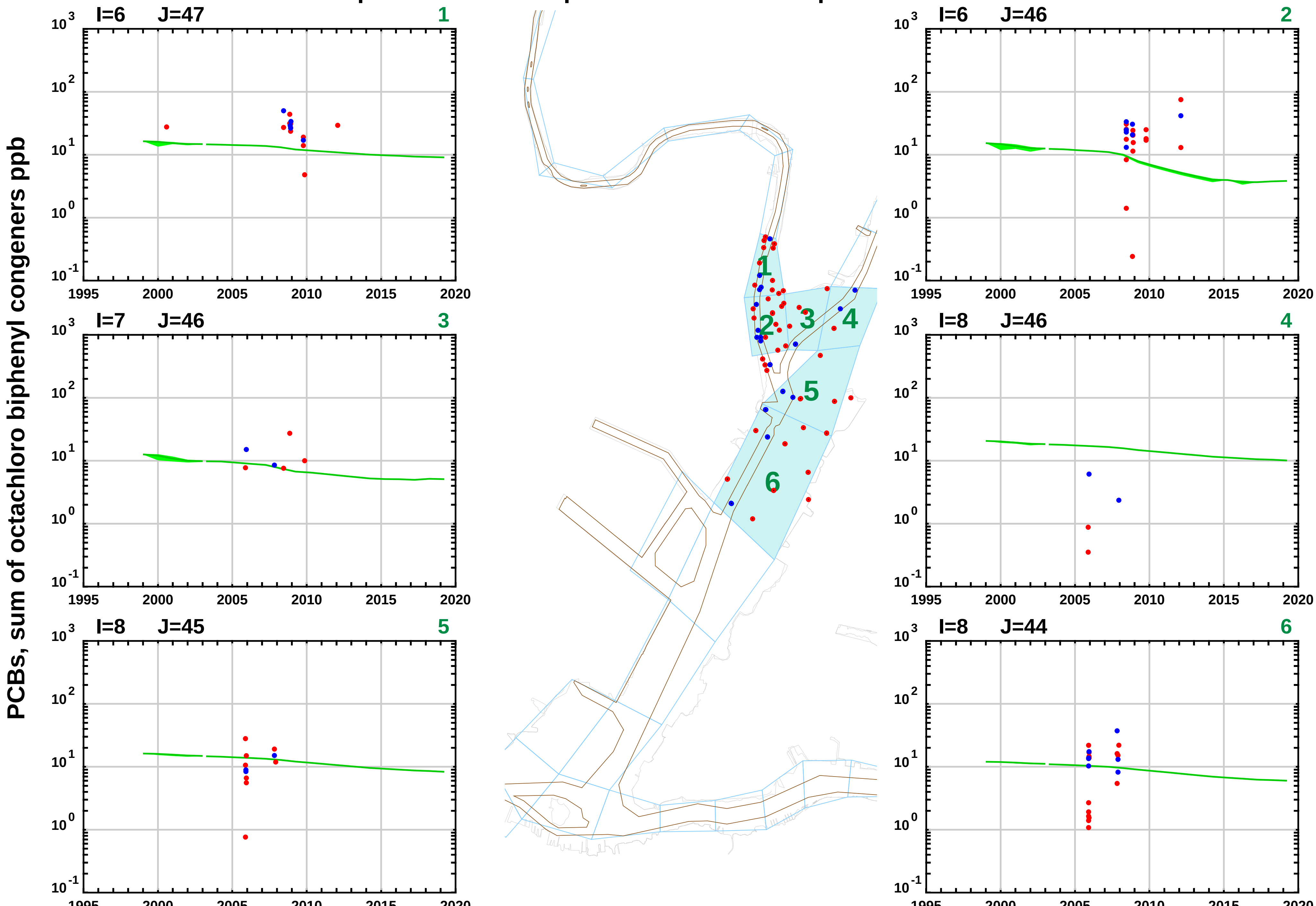
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment

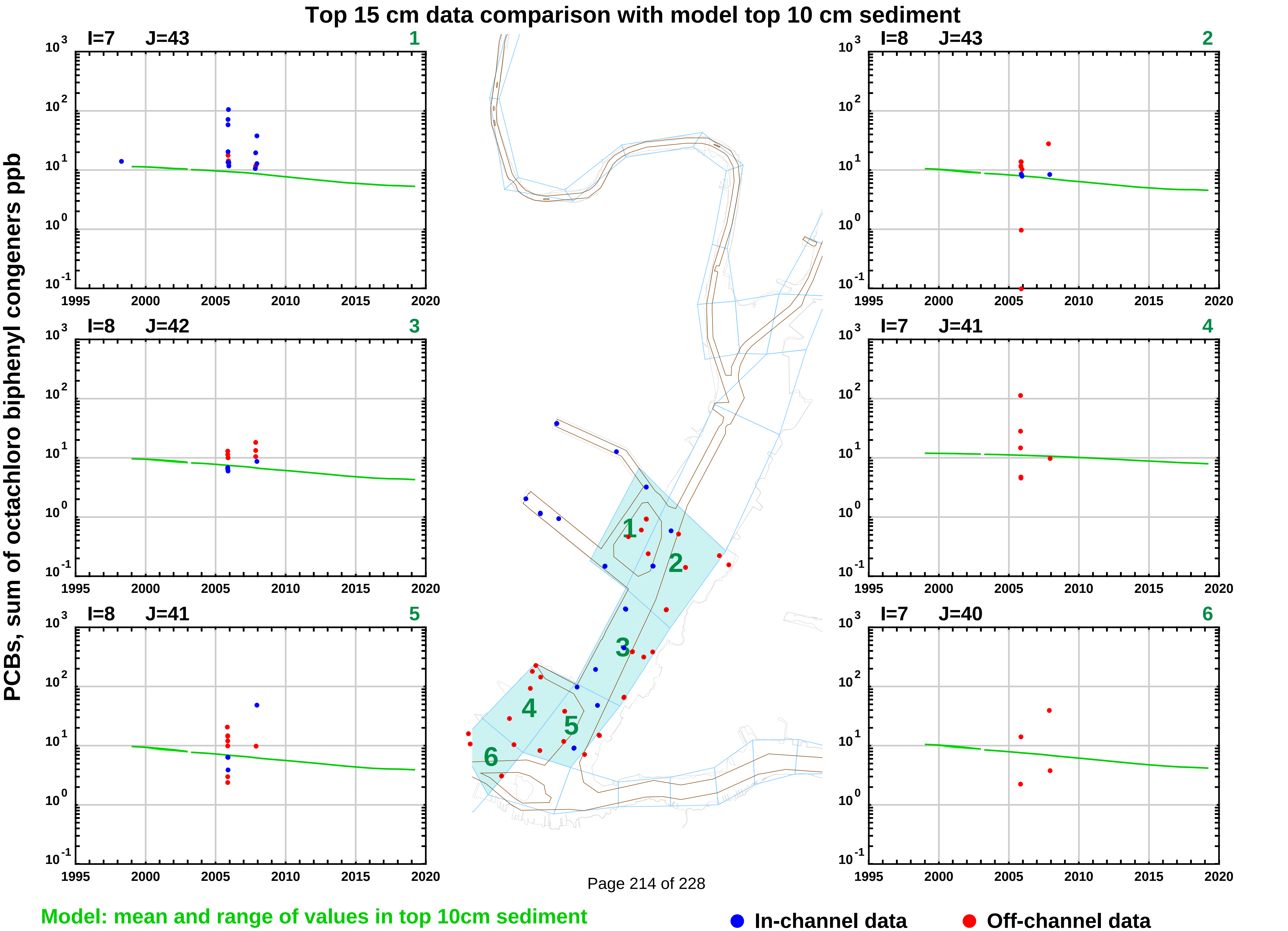


Top 15 cm data comparison with model top 10 cm sediment



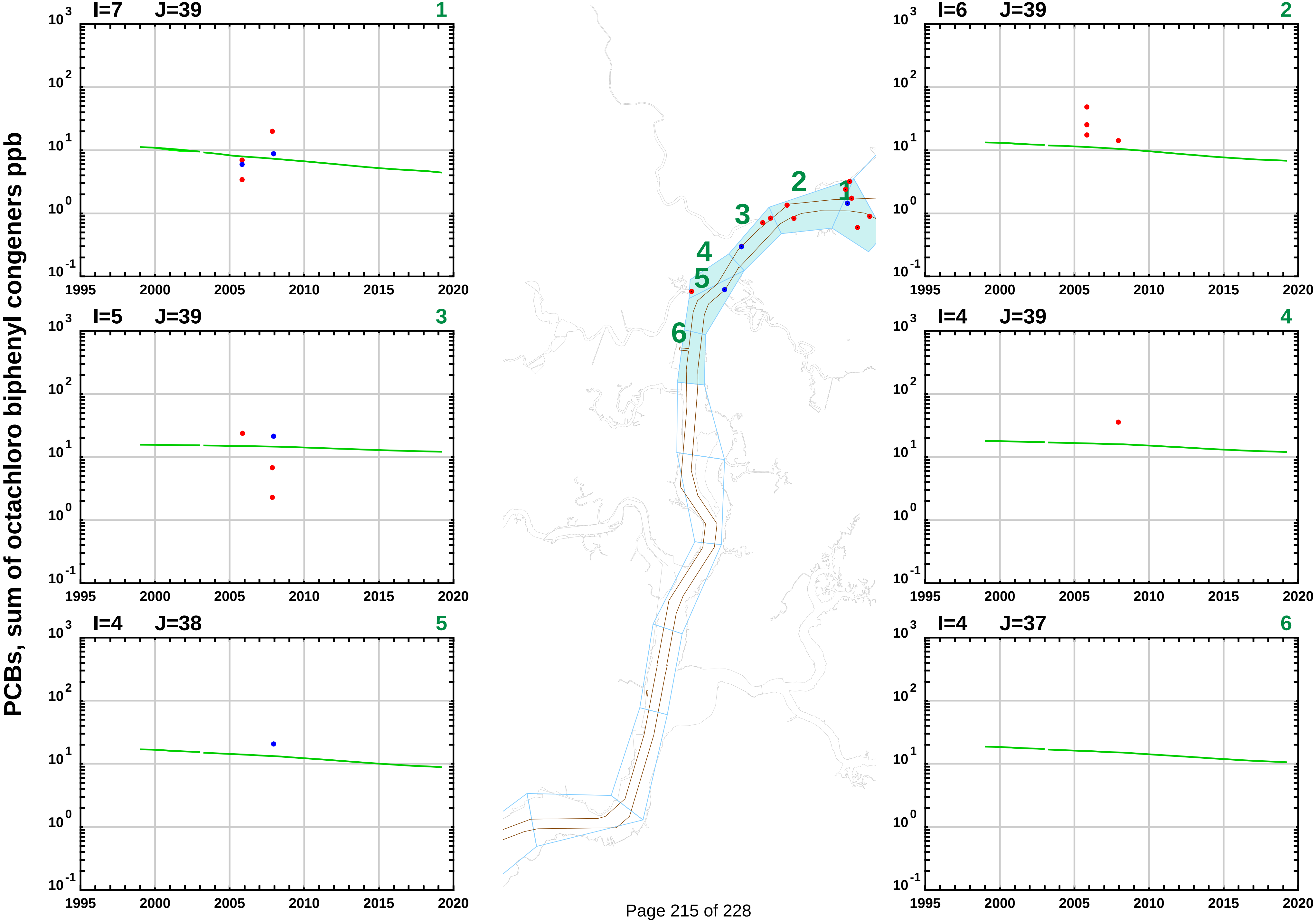
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data



Top 15 cm data comparison with model top 10 cm sediment
PCBs, sum of octachloro biphenyl congeners ppb
I=7 J=43 1
I=8 J=43 2
I=8 J=42 3
I=7 J=41 4
I=8 J=41 5
I=7 J=40 6
10^3
10^2
10^1
10^0
10^{-1}
1995 2000 2005 2010 2015 2020
1
2
3
4
5
6
Model: mean and range of values in top 10cm sediment
In-channel data
Off-channel data

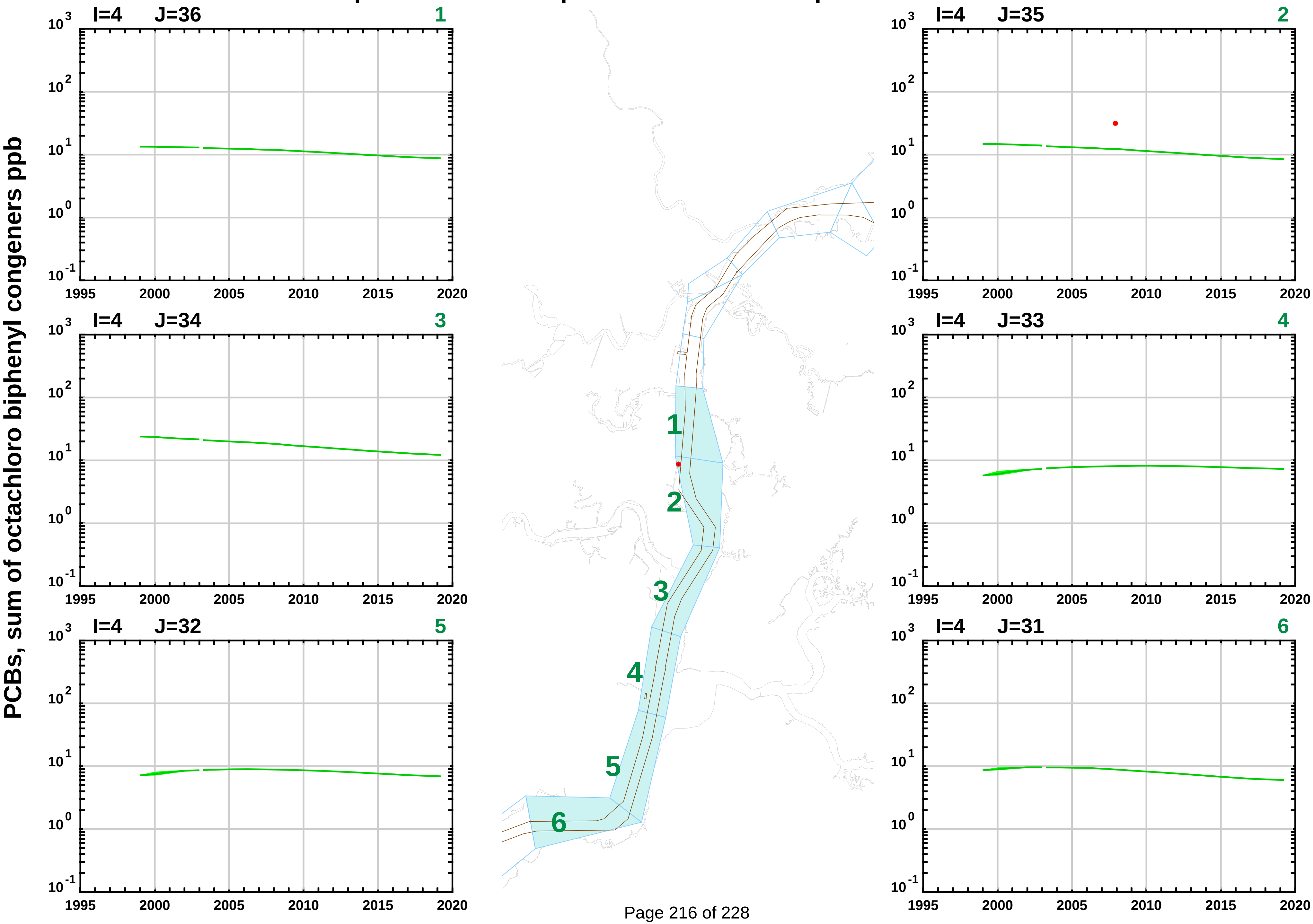
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

In-channel data   Off-channel data

Top 15 cm data comparison with model top 10 cm sediment

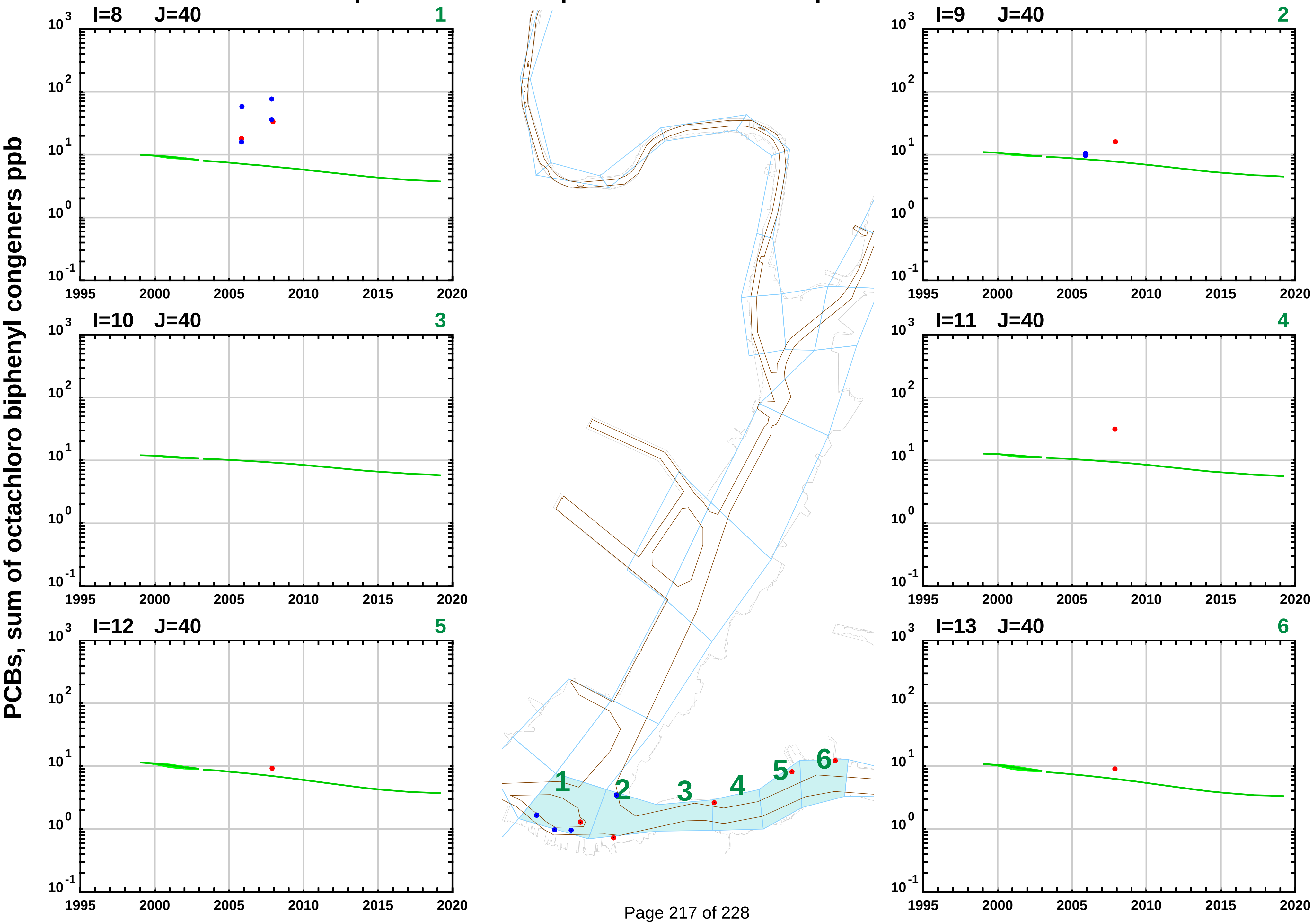


Model: mean and range of values in top 10cm sediment

In-channel data

Off-channel data

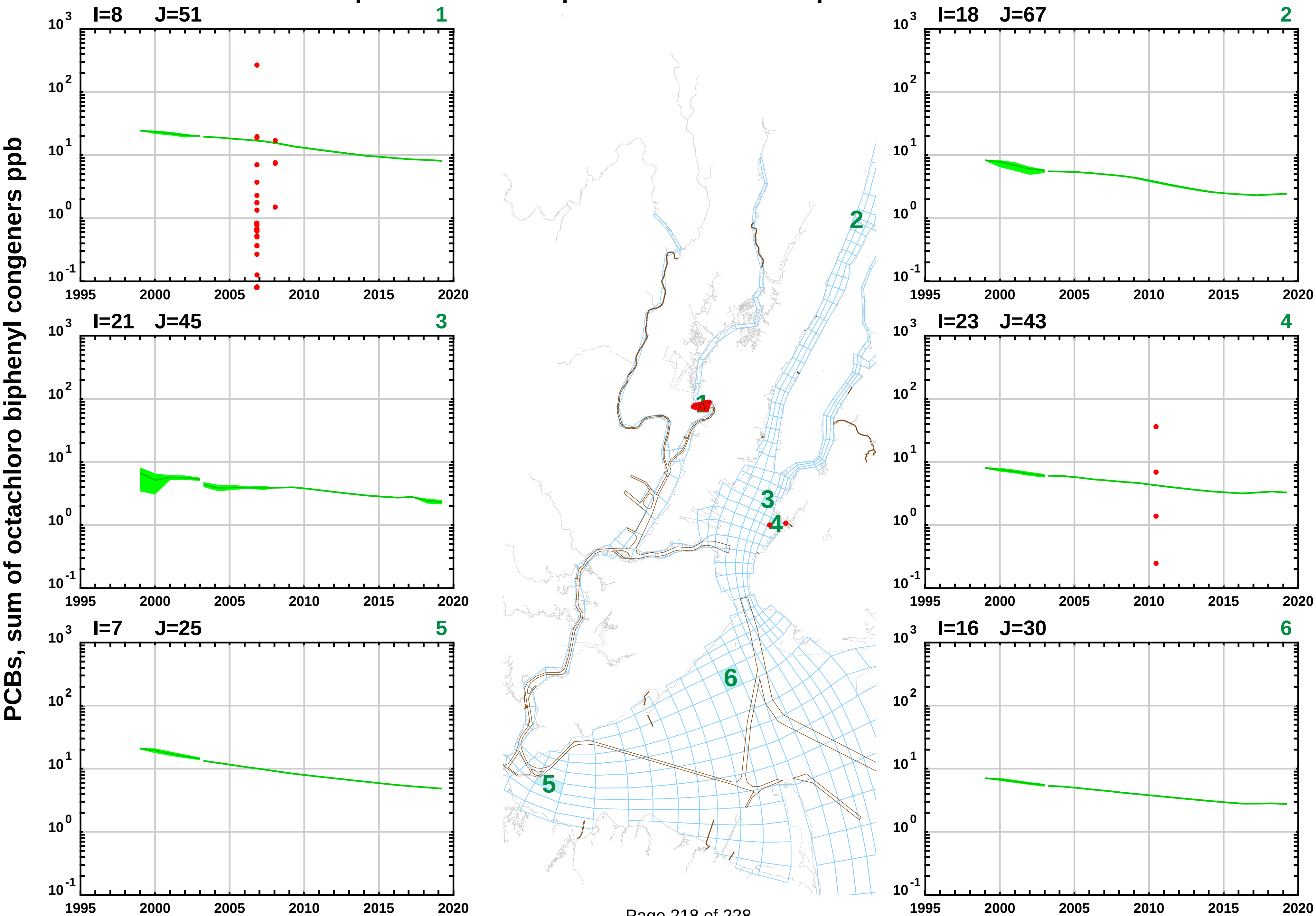
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment

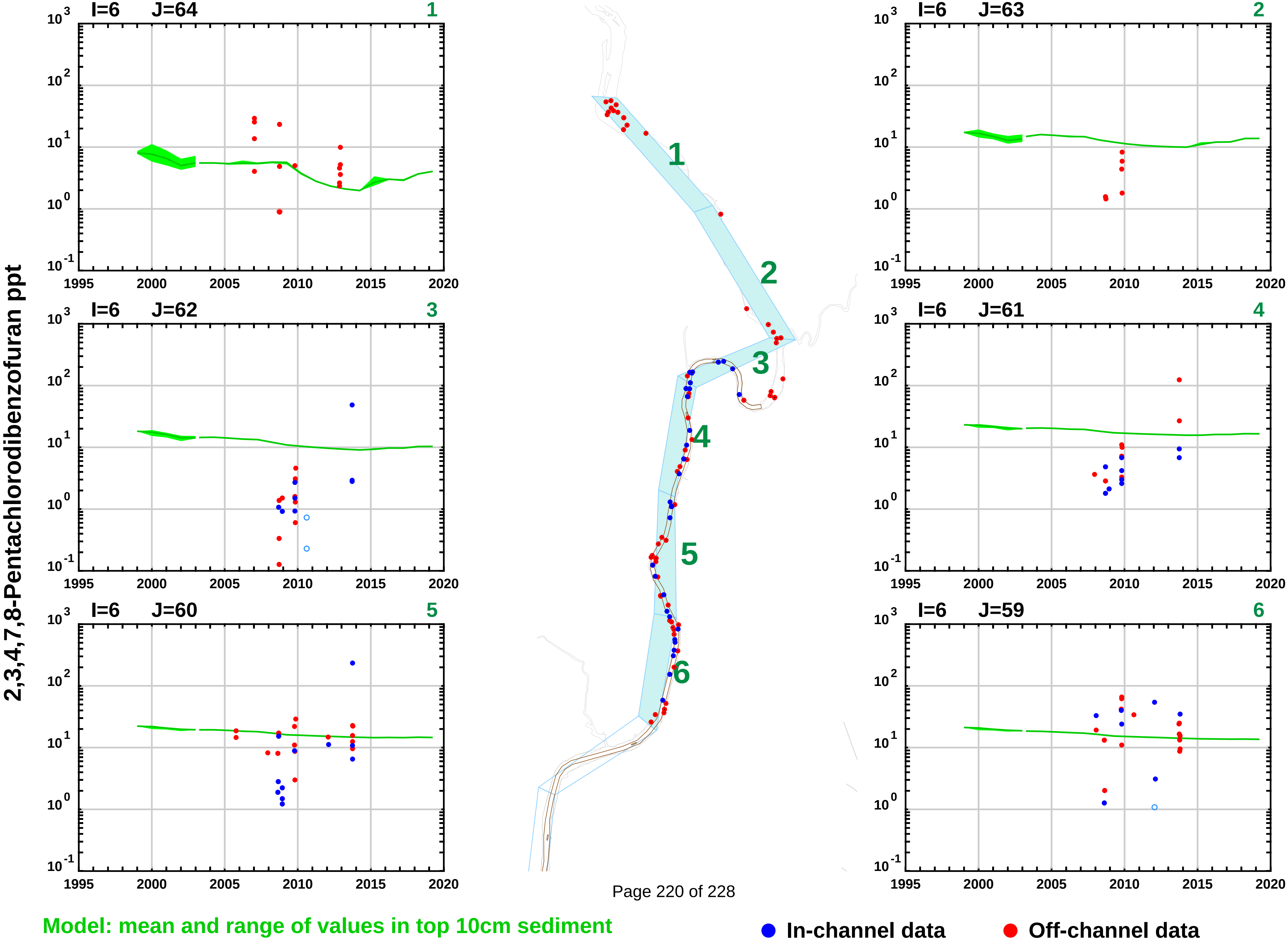


Model: mean and range of values in top 10cm sediment

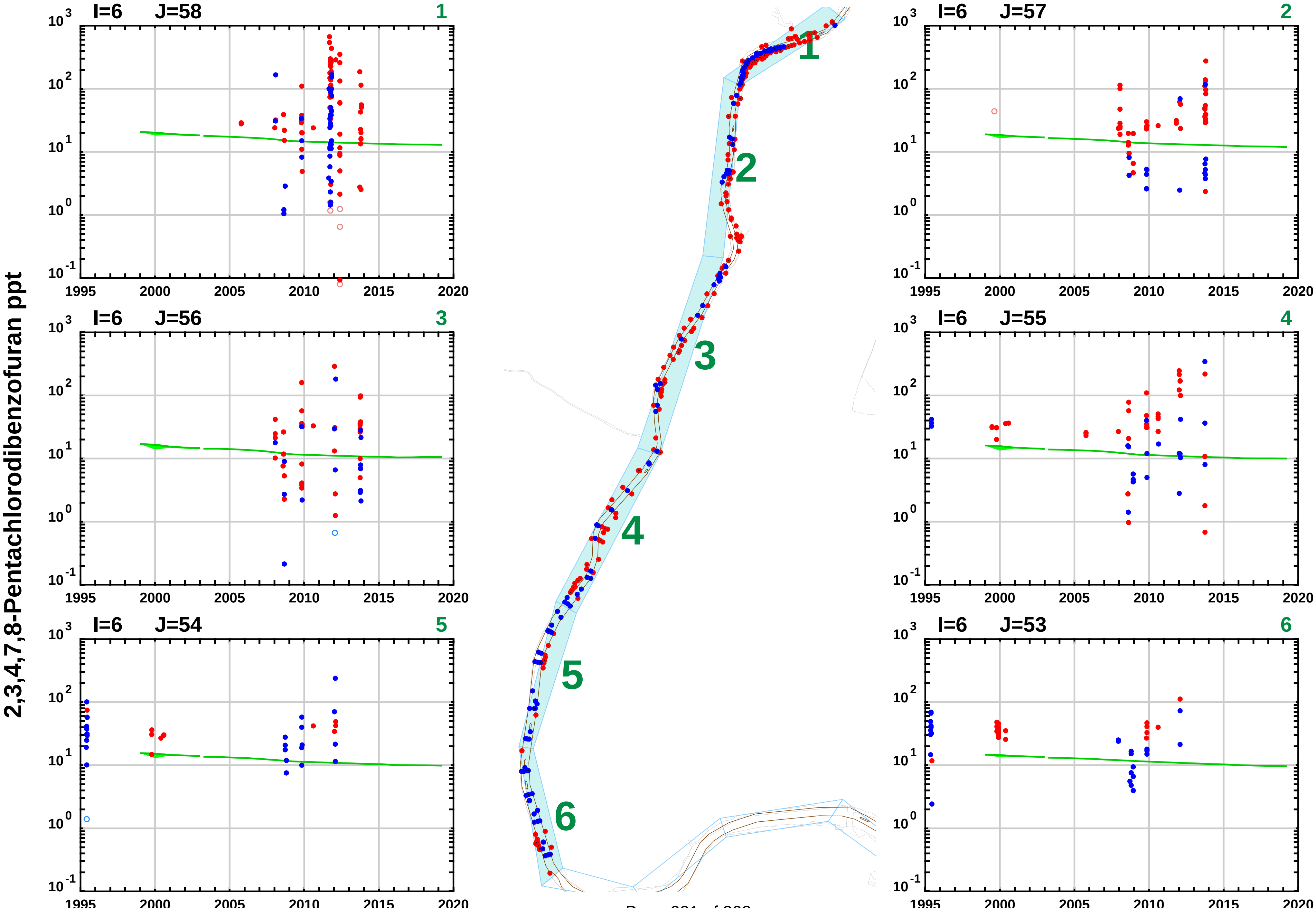
● In-channel data ● Off-channel data

Attachment 3D, 2,3,4,7,8-PCDF

Top 15 cm data comparison with model top 10 cm sediment



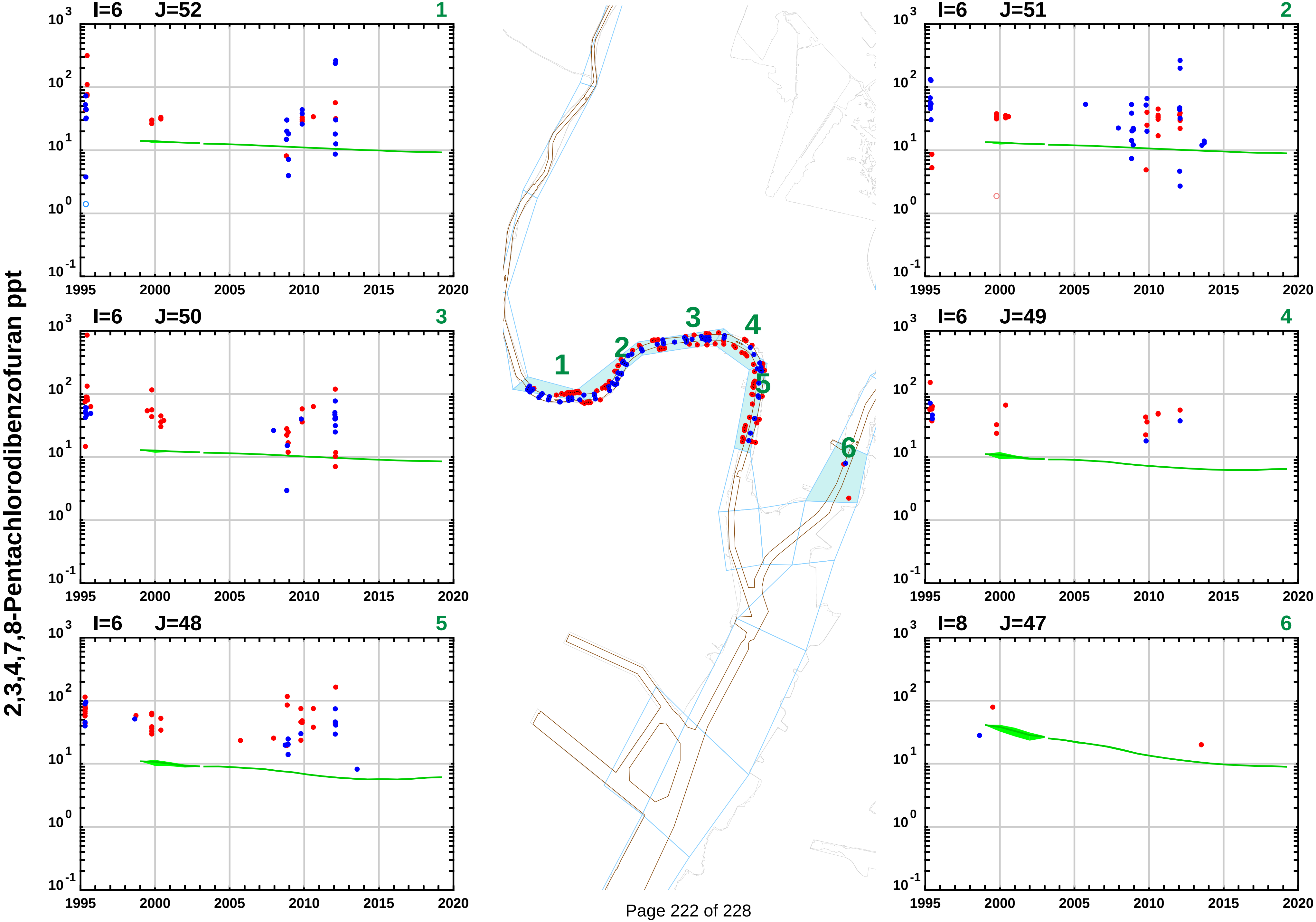
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

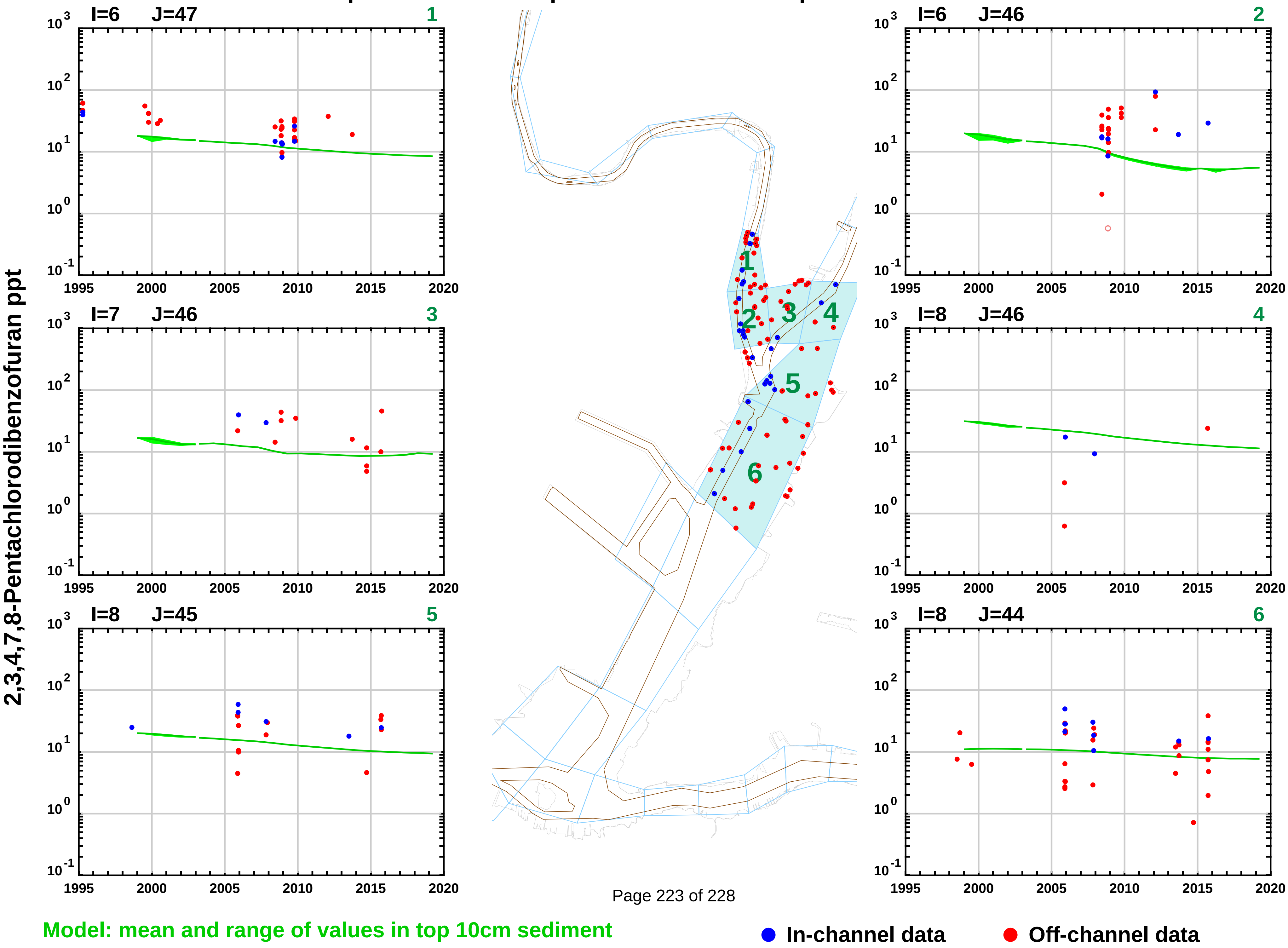
Top 15 cm data comparison with model top 10 cm sediment



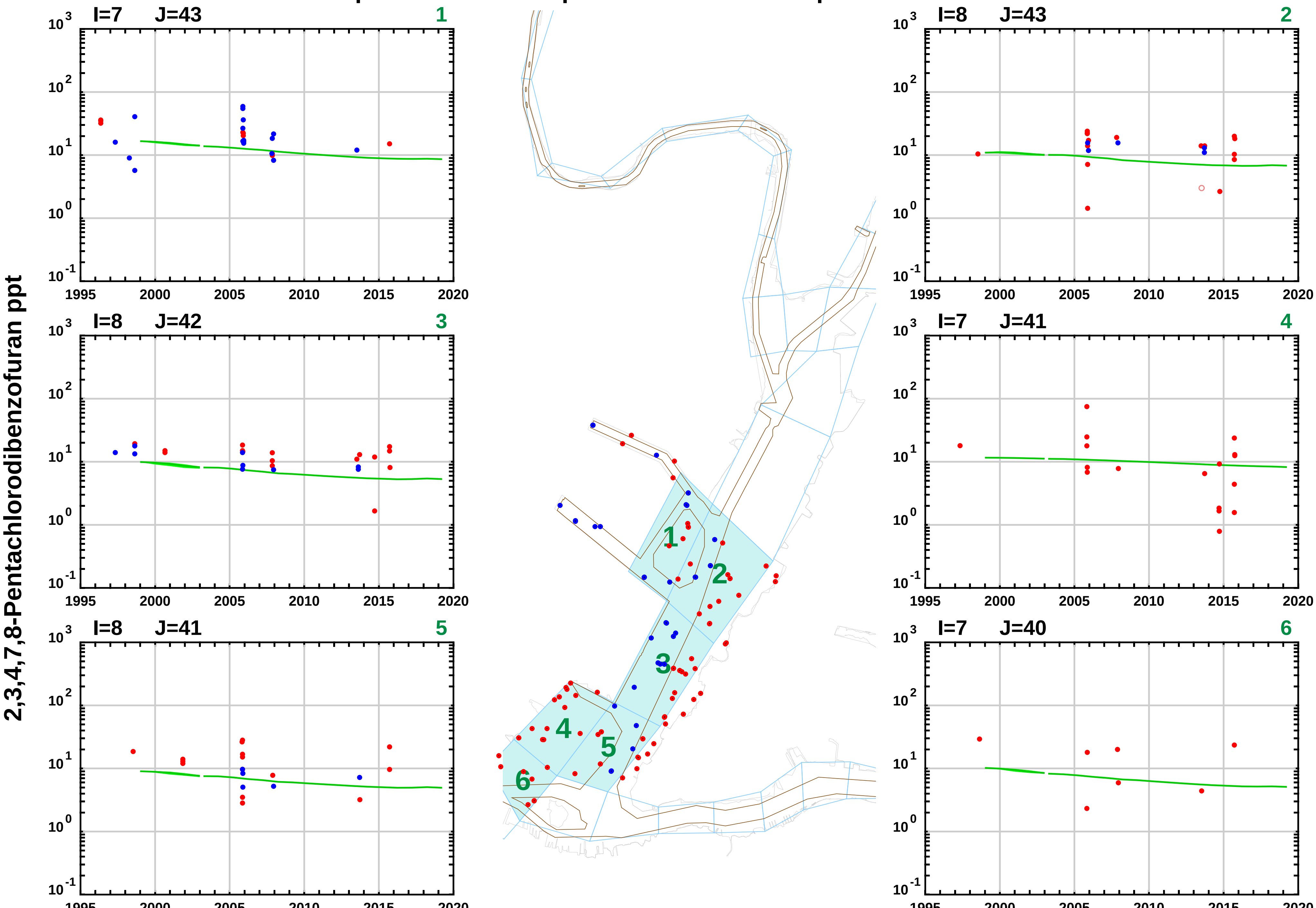
Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



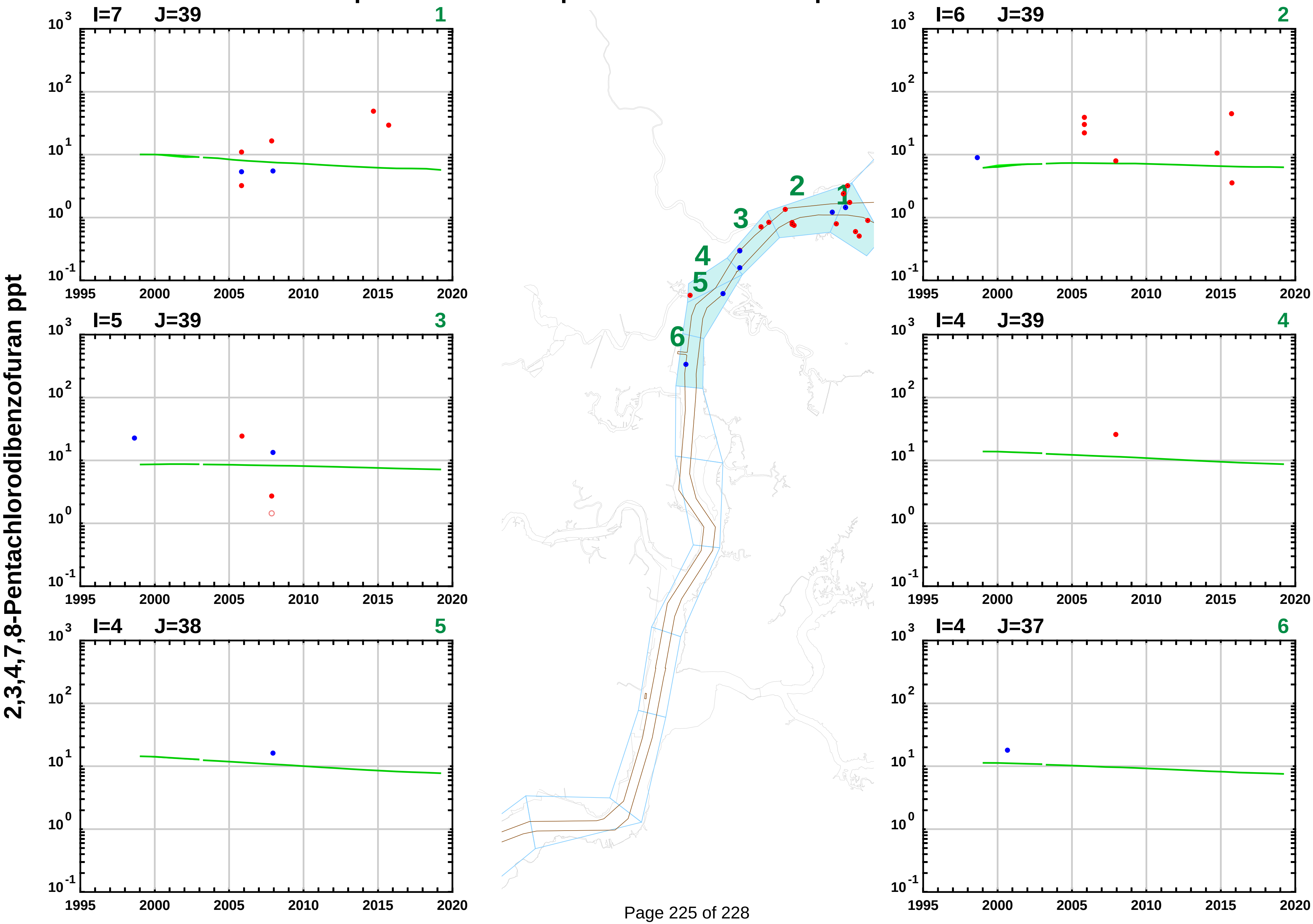
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

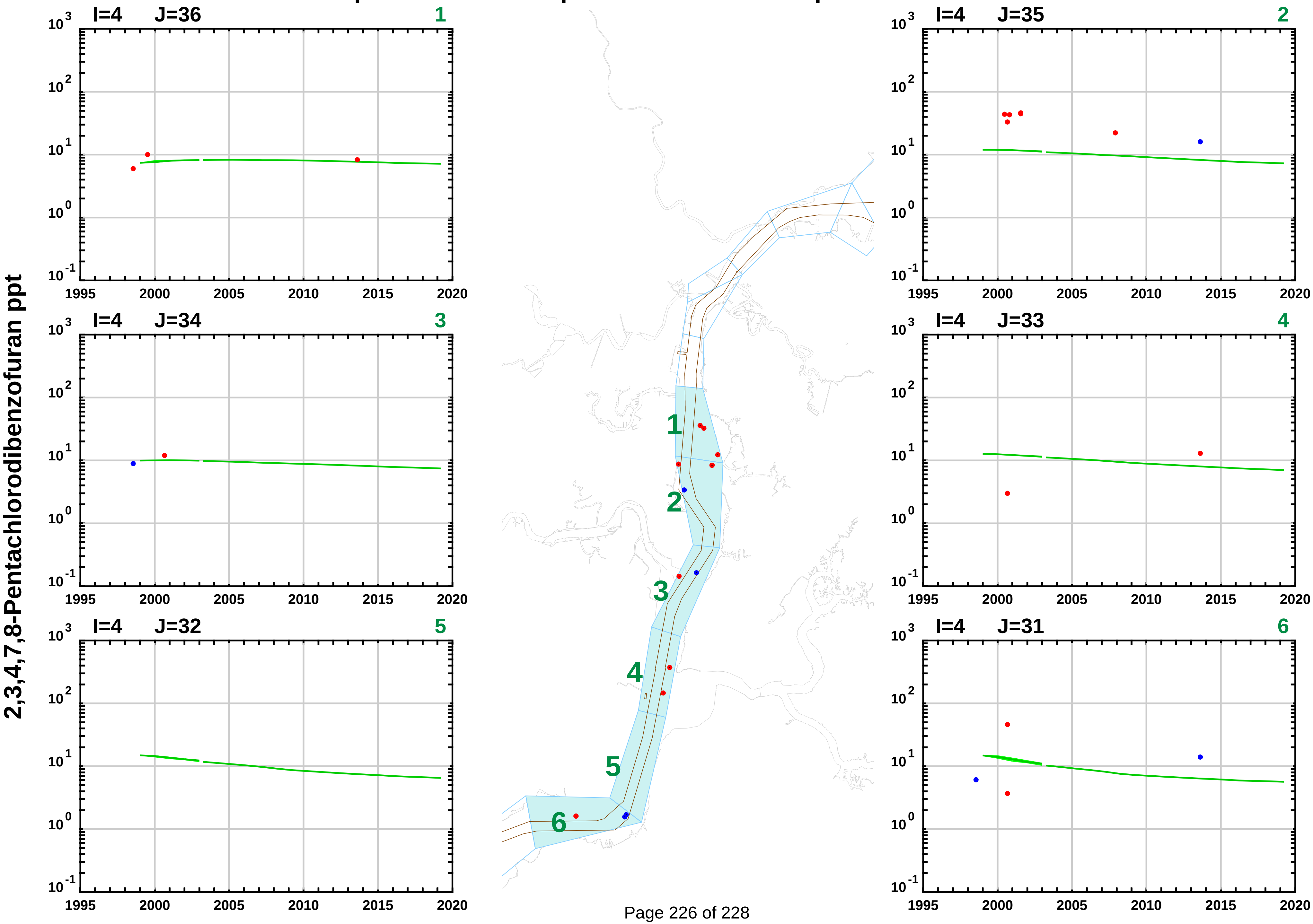
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data

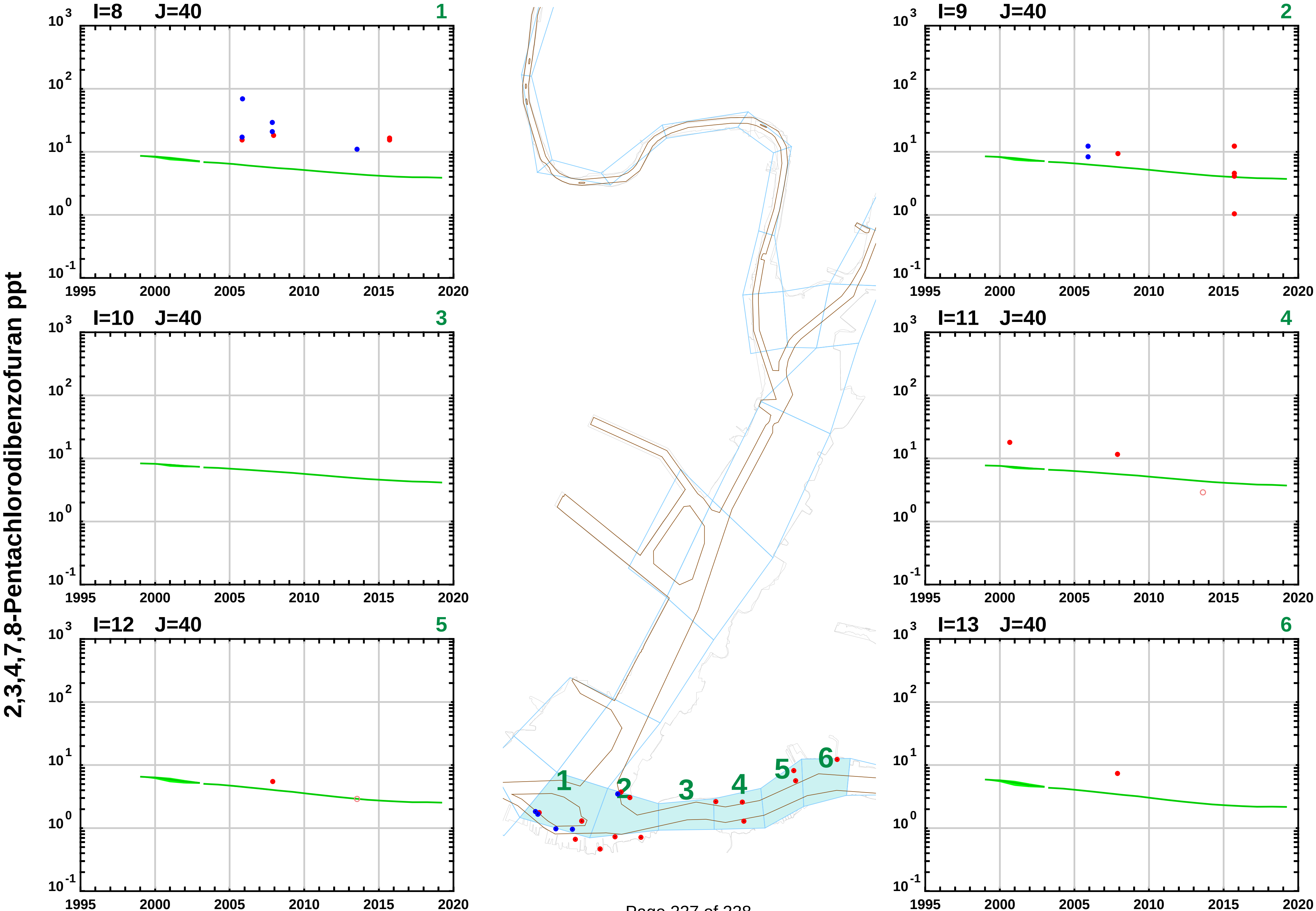
Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

In-channel data Off-channel data

Top 15 cm data comparison with model top 10 cm sediment

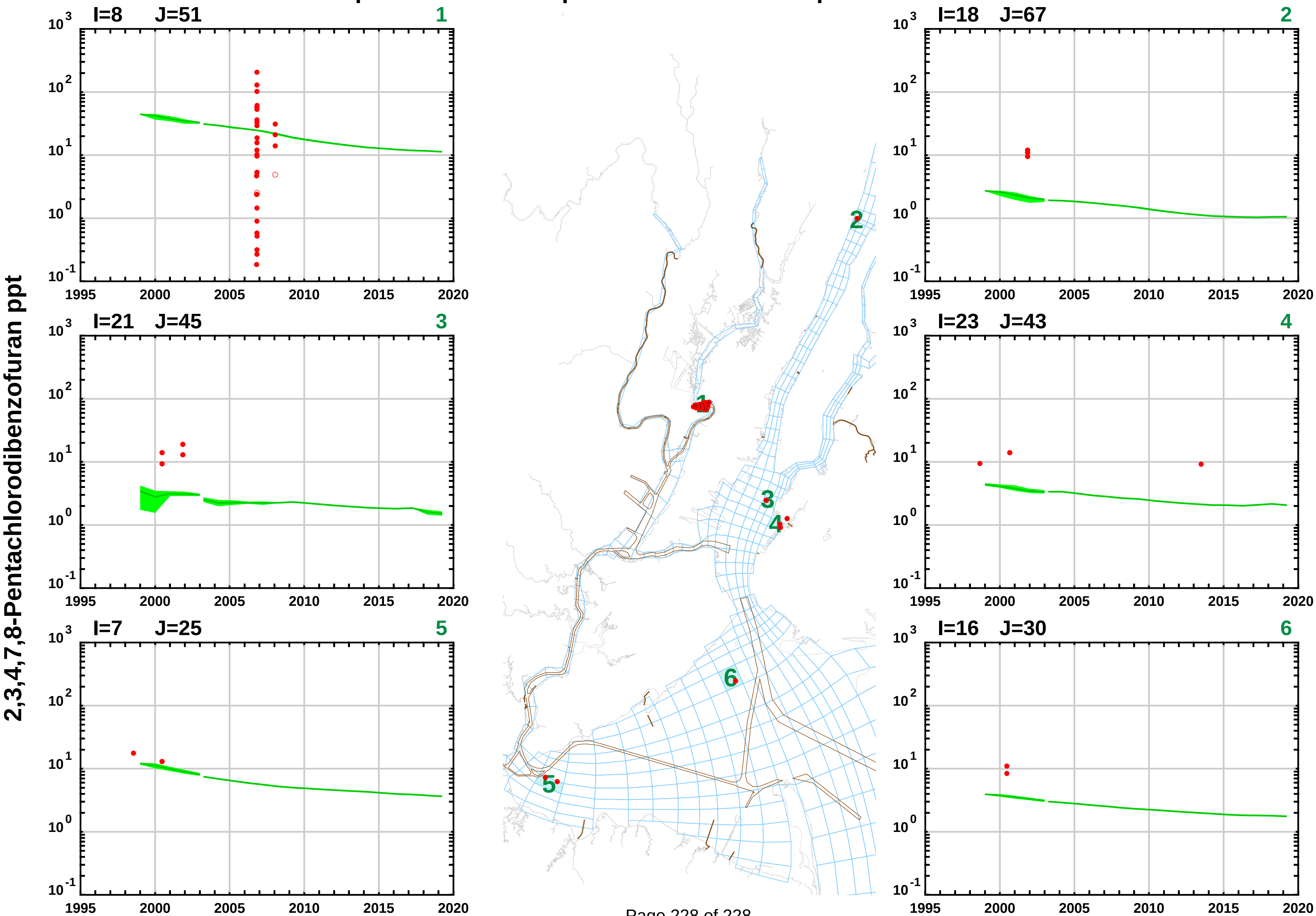


Model: mean and range of values in top 10cm sediment

In-channel data

Off-channel data

Top 15 cm data comparison with model top 10 cm sediment



Model: mean and range of values in top 10cm sediment

● In-channel data ● Off-channel data