

COCO: The Single- and Multi-objective Mixed-Integer Test Suites (**bbob-mixint** and **bbob-biobj-mixint**)

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Introduction

This document presents additional information on the **bbob-mixint** and **bbob-biobj-mixint** benchmark problems introduced in [4] and implemented in the COCO (COMparing Continuous Optimizers) platform [3] available at <https://github.com/numbbo/coco>.

The document first gives a short overview of the mixed-integer problems followed by level sets plots for all problem instances of the **bbob-mixint** suite.

The **bbob-mixint** and **bbob-biobj-mixint** Test Suites

The **bbob-mixint** test suite provides 24 mixed-integer single-objective functions in six dimensions (5, 10, 20, 40, 80 and 160) that were constructed by discretizing the 24 functions from the **bbob** [2] (dimensions up to 40) and **bbob-largescale** [5] suites (dimensions 80 and 160).

The **bbob-biobj-mixint** test suite combines the **bbob-mixint** problems into bi-objective ones in the same way the **bbob-biobj-ext** problems were constructed from the **bbob** problems [1]. This yields 92 mixed-integer bi-objective functions in six dimensions (5, 10, 20, 40, 80 and 160).

For both suites, all decision space dimensions n are multiples of 5. Each n -dimensional problem has $4/5n$ integer and $1/5n$ continuous variables. The arities of $n/5$ consecutive variables are 2, 4, 8, 16 and ∞ . This means that the following holds for the function domain X :

$$X = \{0, 1\}^{n/5} \times \{0, 1, 2, 3\}^{n/5} \times \{0, 1, \dots, 7\}^{n/5} \times \{0, 1, \dots, 15\}^{n/5} \times \mathbb{R}^{n/5} \quad (1)$$

In COCO, the number of integer variables and their lower and upper limits for any mixed-integer problem **PROBLEM** can be accessed through the following language-dependent interfaces:

C/C++ `coco_problem_get_number_of_integer_variables(PROBLEM),`
 `coco_problem_get_smallest_values_of_interest(PROBLEM),`
 `coco_problem_get_largest_values_of_interest(PROBLEM)`

Python `PROBLEM.number_of_integer_variables,`
 `PROBLEM.lower_bounds,`
 `PROBLEM.upper_bounds,`

Java `PROBLEM.getNumberOfIntegerVariables(),`
 `PROBLEM.getSmallestValuesOfInterest(),`
 `PROBLEM.getLargestValuesOfInterest()`

Matlab/Octave `cocoProblemGetNumberOfIntegerVariables(PROBLEM),`
 `cocoProblemGetSmallestValuesOfInterest(PROBLEM),`
 `cocoProblemGetLargestValuesOfInterest(PROBLEM)`

Note that although the functions are defined on \mathbb{R} for any continuous variable, the smallest/largest values of interest correspond to values that contain the optimal solution and equal $-5/5$ for **bbob-mixint** problems and $-100/100$ for **bbob-biobj-mixint** problems.

Level Sets for the **bbob-mixint** Test Suite

In the continuation of this document, we provide level set plots for all problem instances of the **bbob-mixint** test suite. The plots show the objective function values for the cut x_i, x_{i+1} through the region of interest in the decision space that contains the optimal solution (depicted as the black dot), where x_i is the last integer variable and x_{i+1} is the first continuous one. Darker colors denote smaller values. All plots were created on COCO version 2.3. Each page contains level sets for all instances of a **bbob-mixint** problem with the same function and dimension.

References

- [1] D. Brockhoff, T. Tušar, A. Auger, and N. Hansen. Using well-understood single-objective functions in multiobjective black-box optimization test suites. *ArXiv e-prints*, arXiv:1604.00359v3, 2019.
- [2] S. Finck, N. Hansen, R. Ros, and A. Auger. Real-parameter black-box optimization benchmarking 2009: Presentation of the noiseless functions. Technical Report 2009/20, Research Center PPE, Austria, 2009. Updated February 2010.
- [3] N. Hansen, A. Auger, O. Mersmann, T. Tušar, and D. Brockhoff. COCO: A platform for comparing continuous optimizers in a black-box setting. *ArXiv e-prints*, arXiv:1603.08785, 2016.
- [4] T. Tušar, D. Brockhoff, and N. Hansen. Mixed-integer benchmark problems for single- and bi-objective optimization, 2019.
- [5] K. Varelas, A. Auger, D. Brockhoff, N. Hansen, O. A. ElHara, Y. Semet, R. Kassab, and F. Barbaresco. A comparative study of large-scale variants of CMA-ES. In *Proceedings of the International Conference on Parallel Problem Solving from Nature (PPSN XV)*, volume 11101 of *Lecture Notes in Computer Science*, pages 3–15. Springer, 2018.

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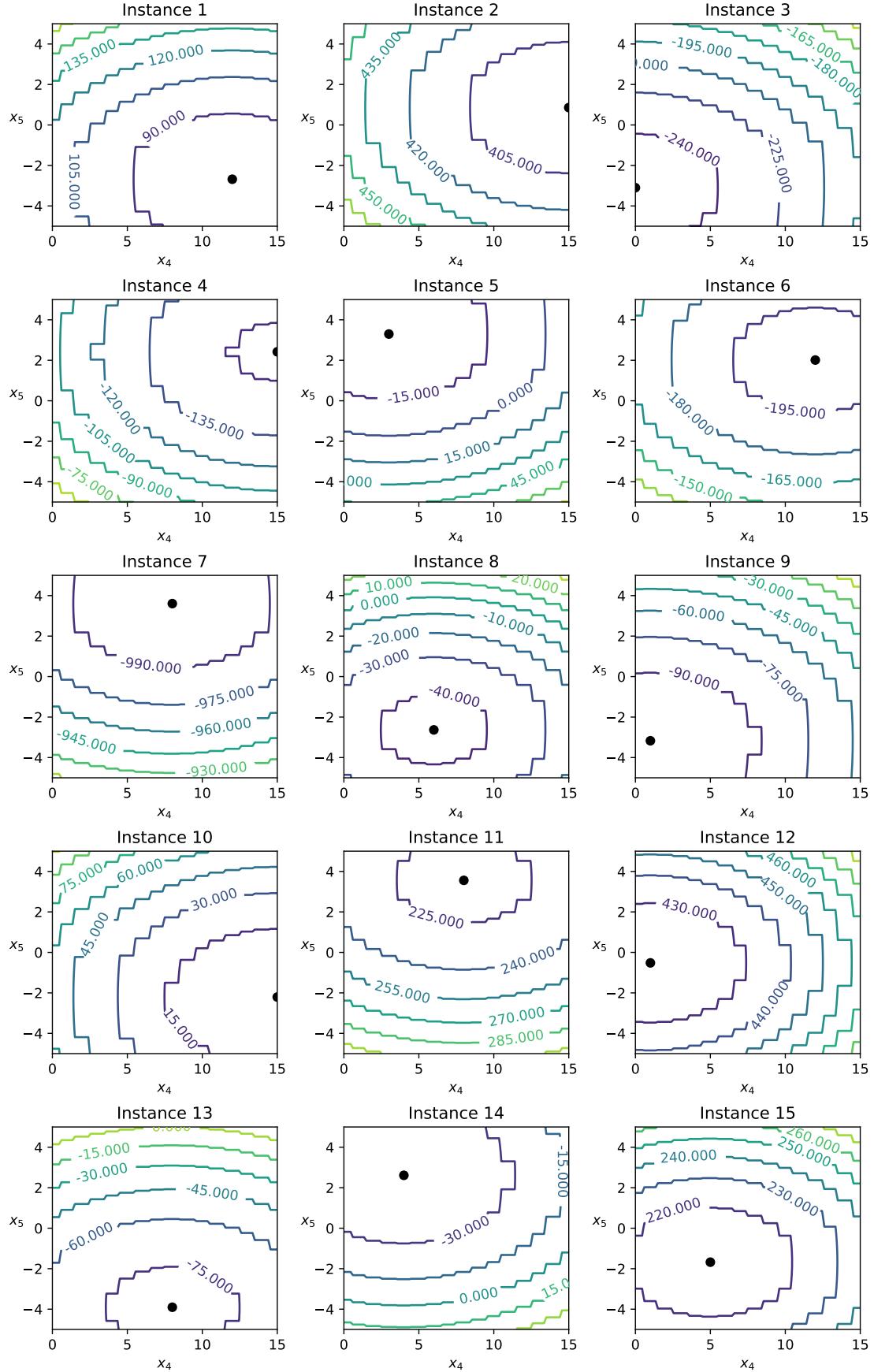
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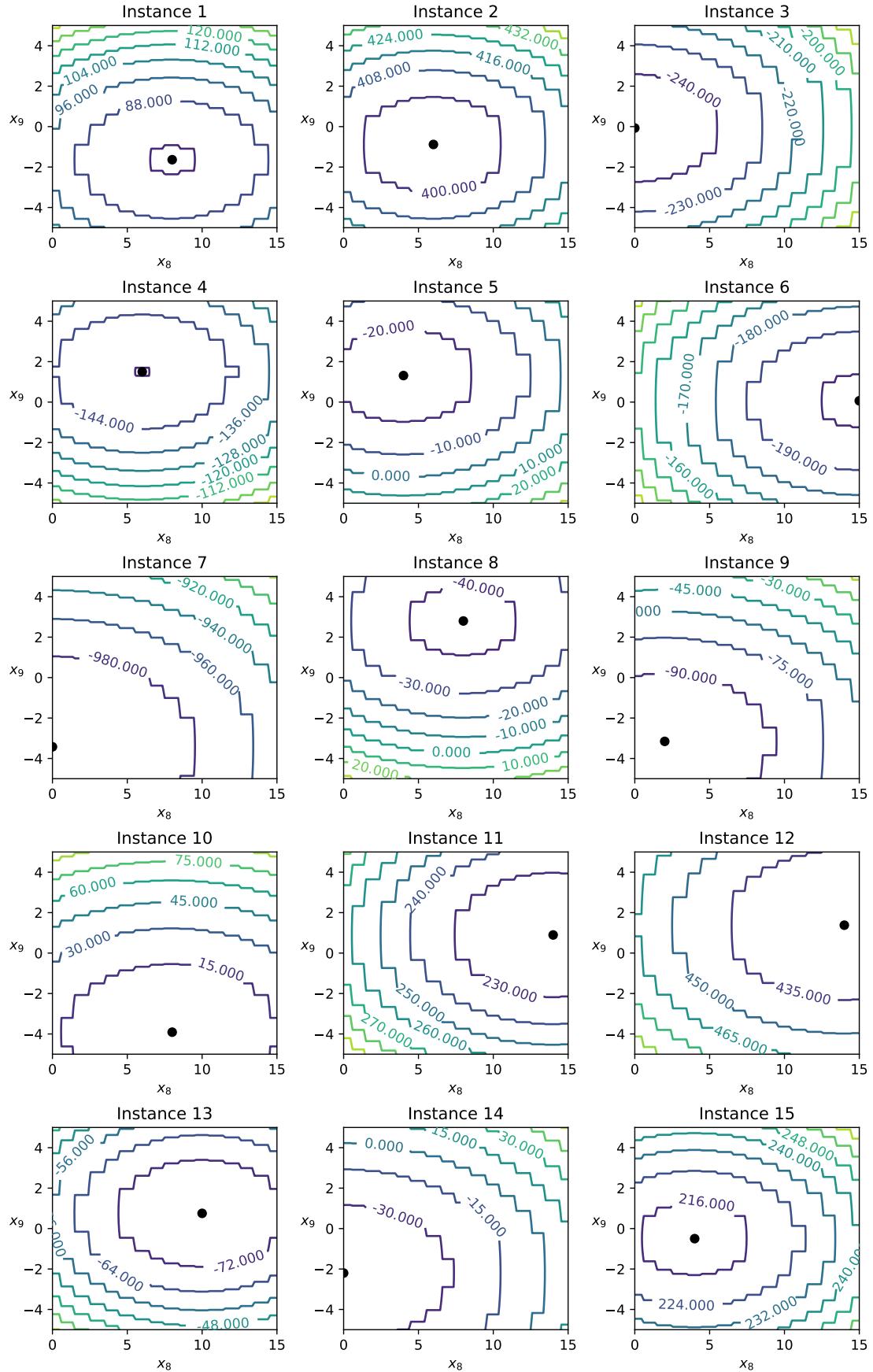
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1 Function f_1 – Sphere

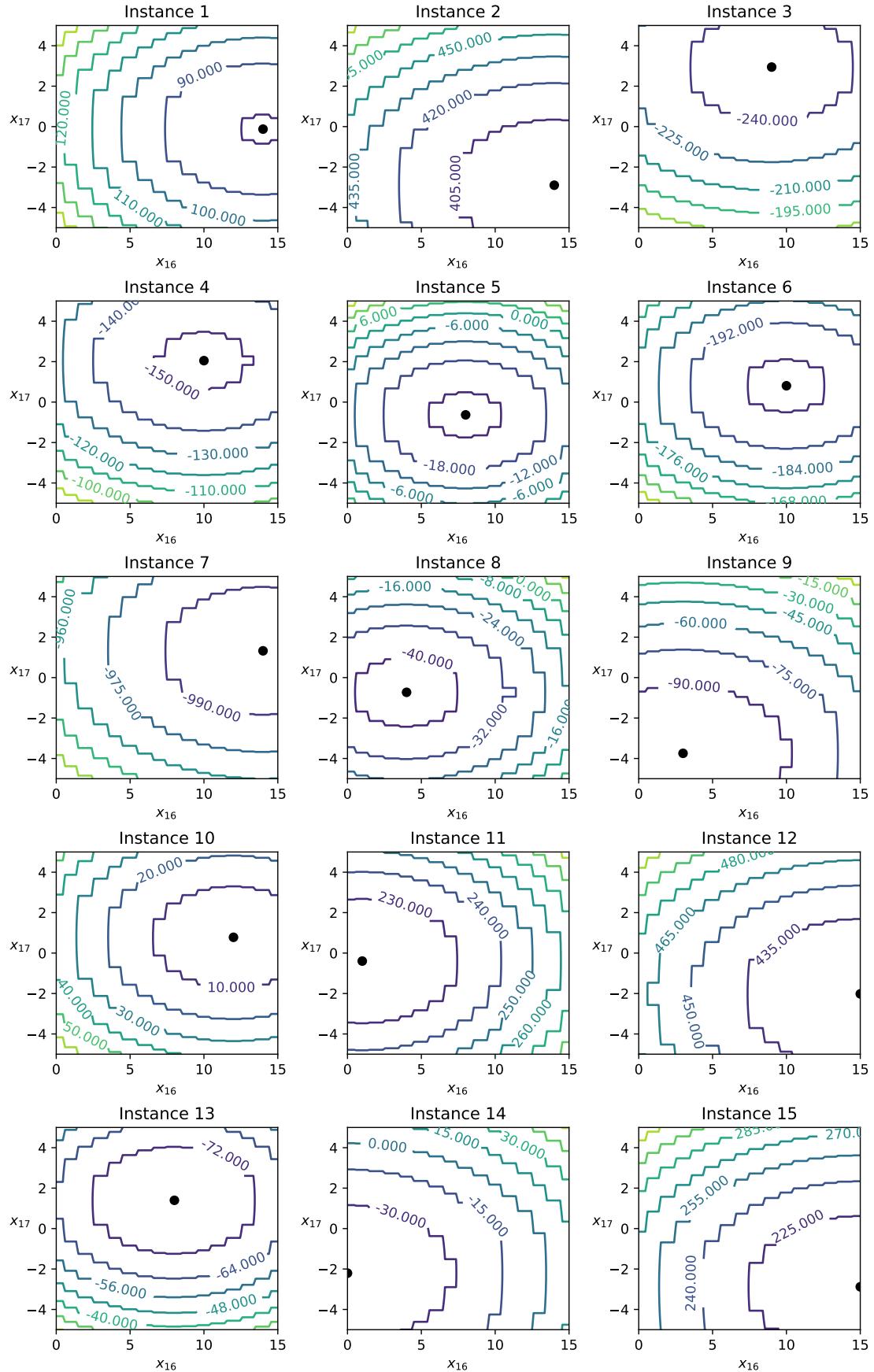
1.1 Function f_1 , Dimension 5



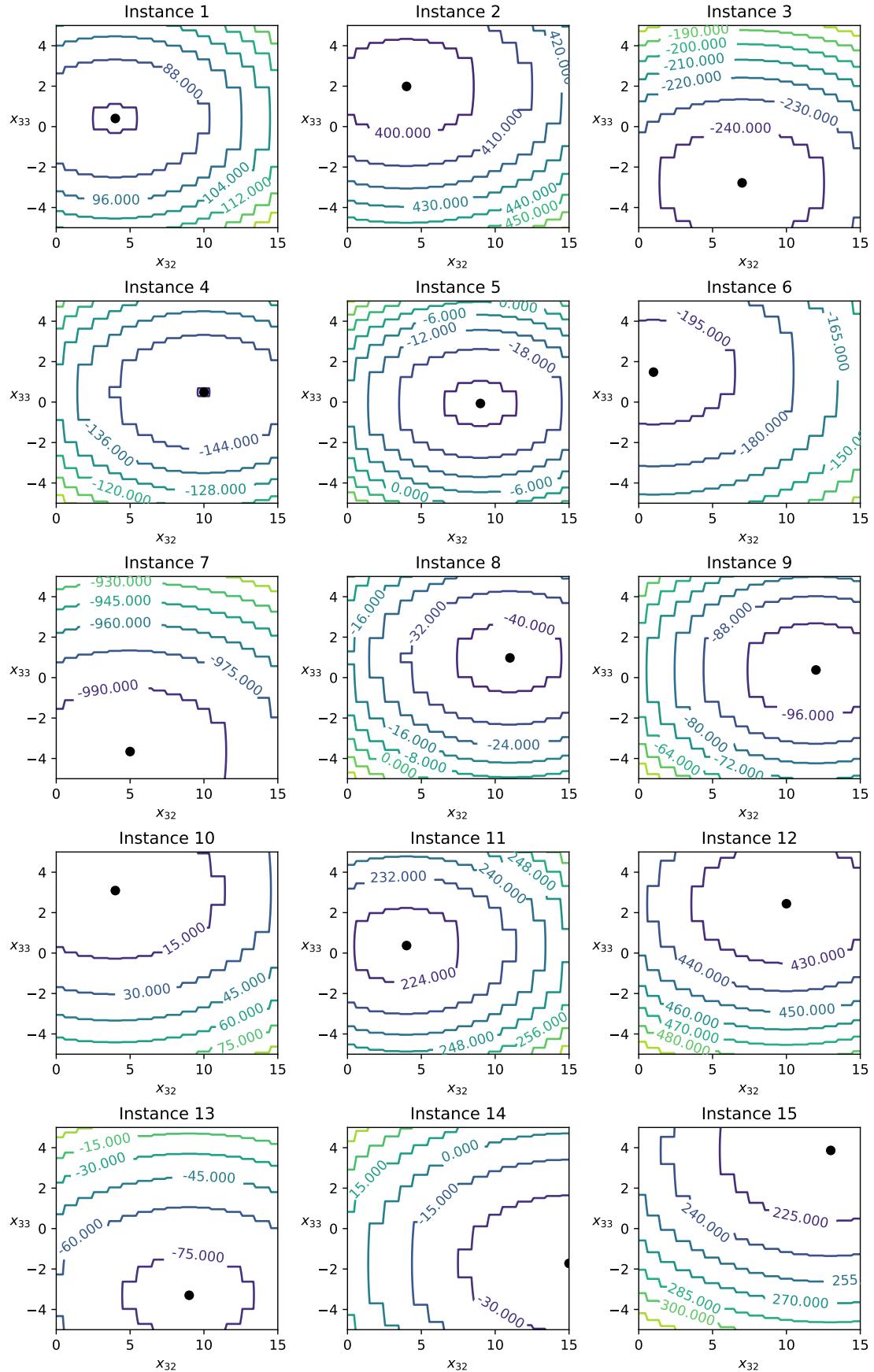
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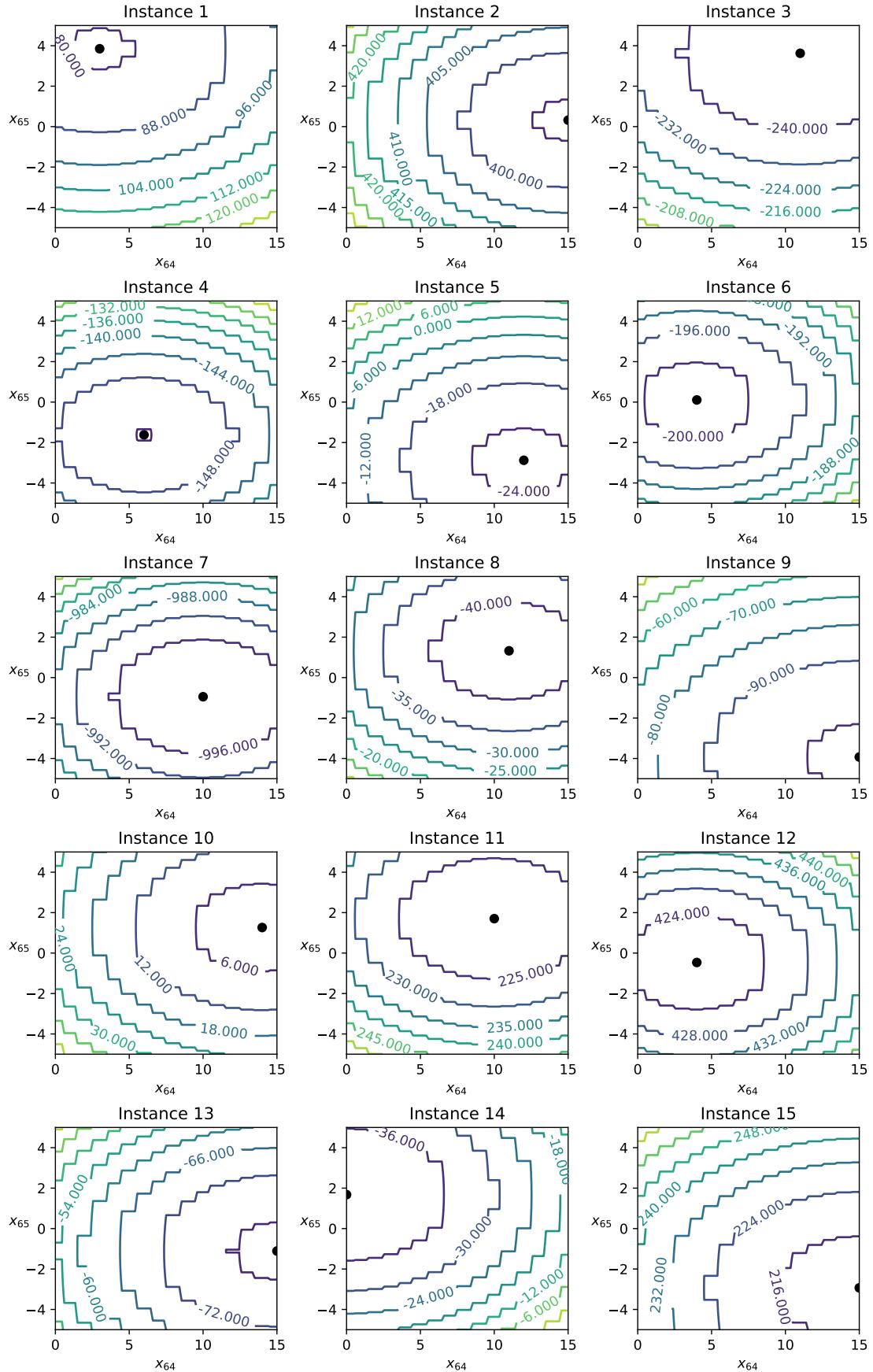
1.3 Function f_1 , Dimension 20



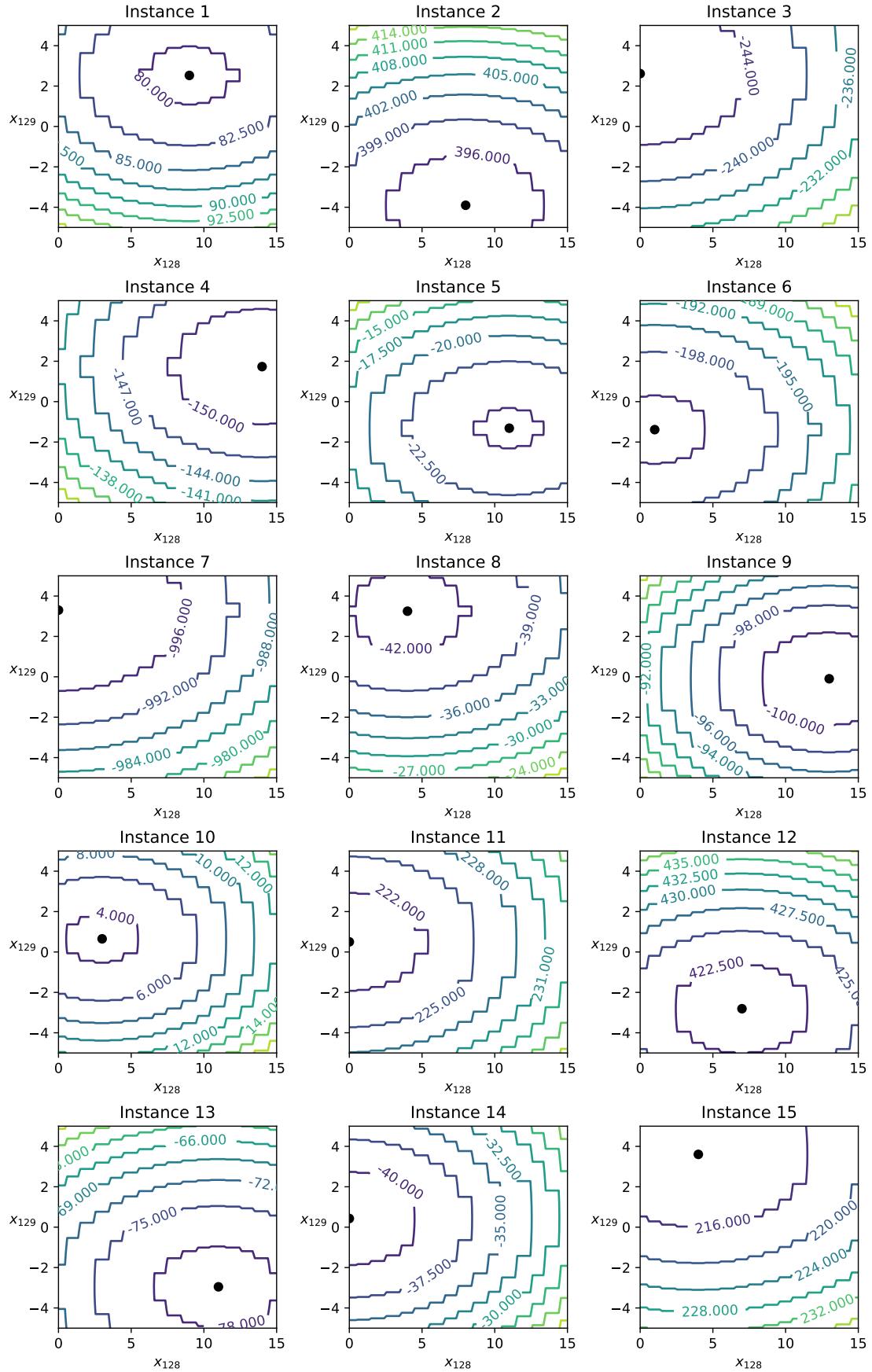
1.4 Function f_1 , Dimension 40



1.5 Function f_1 , Dimension 80

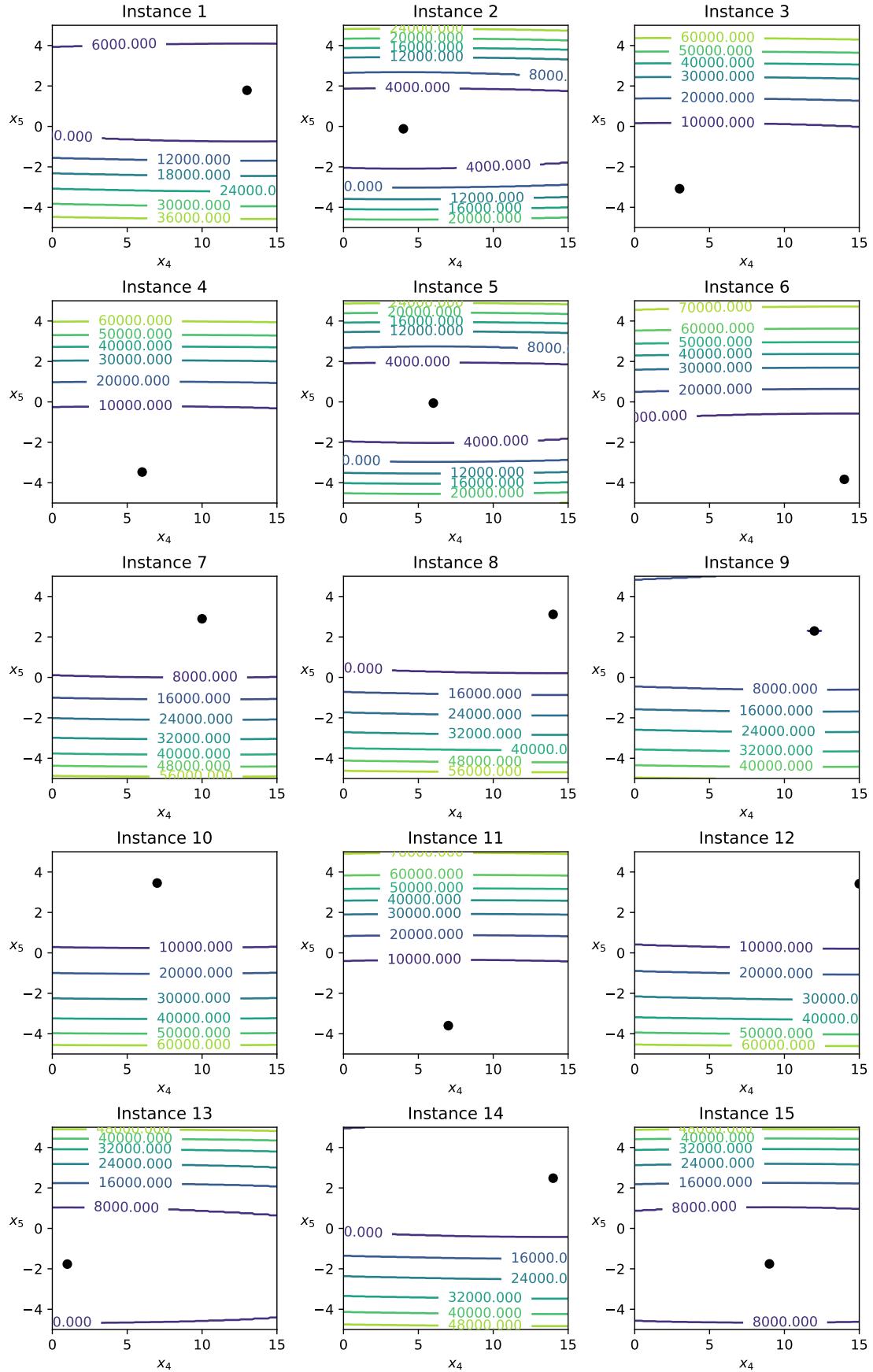


1.6 Function f_1 , Dimension 160

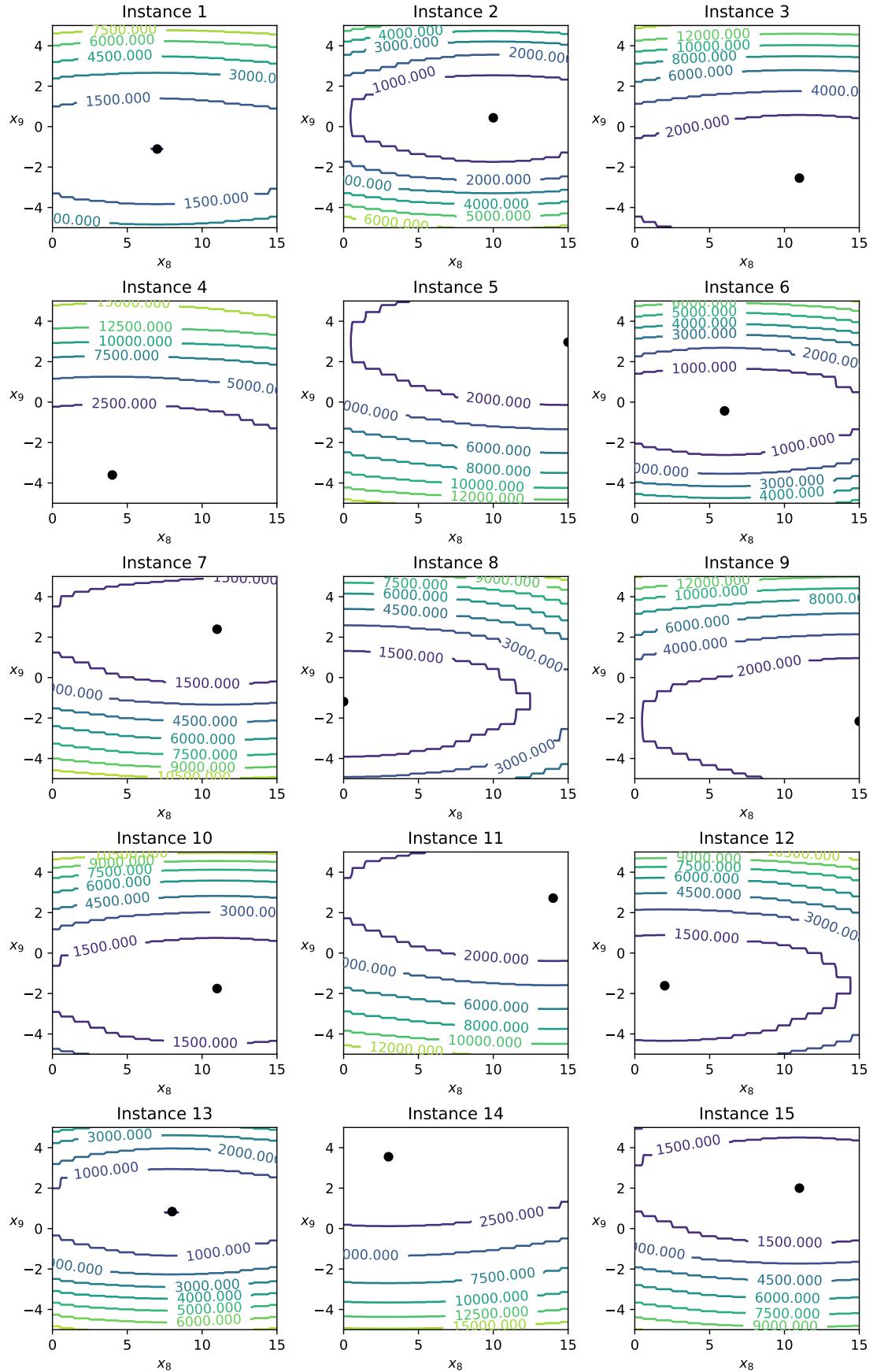


2 Function f_2 – Ellipsoidal

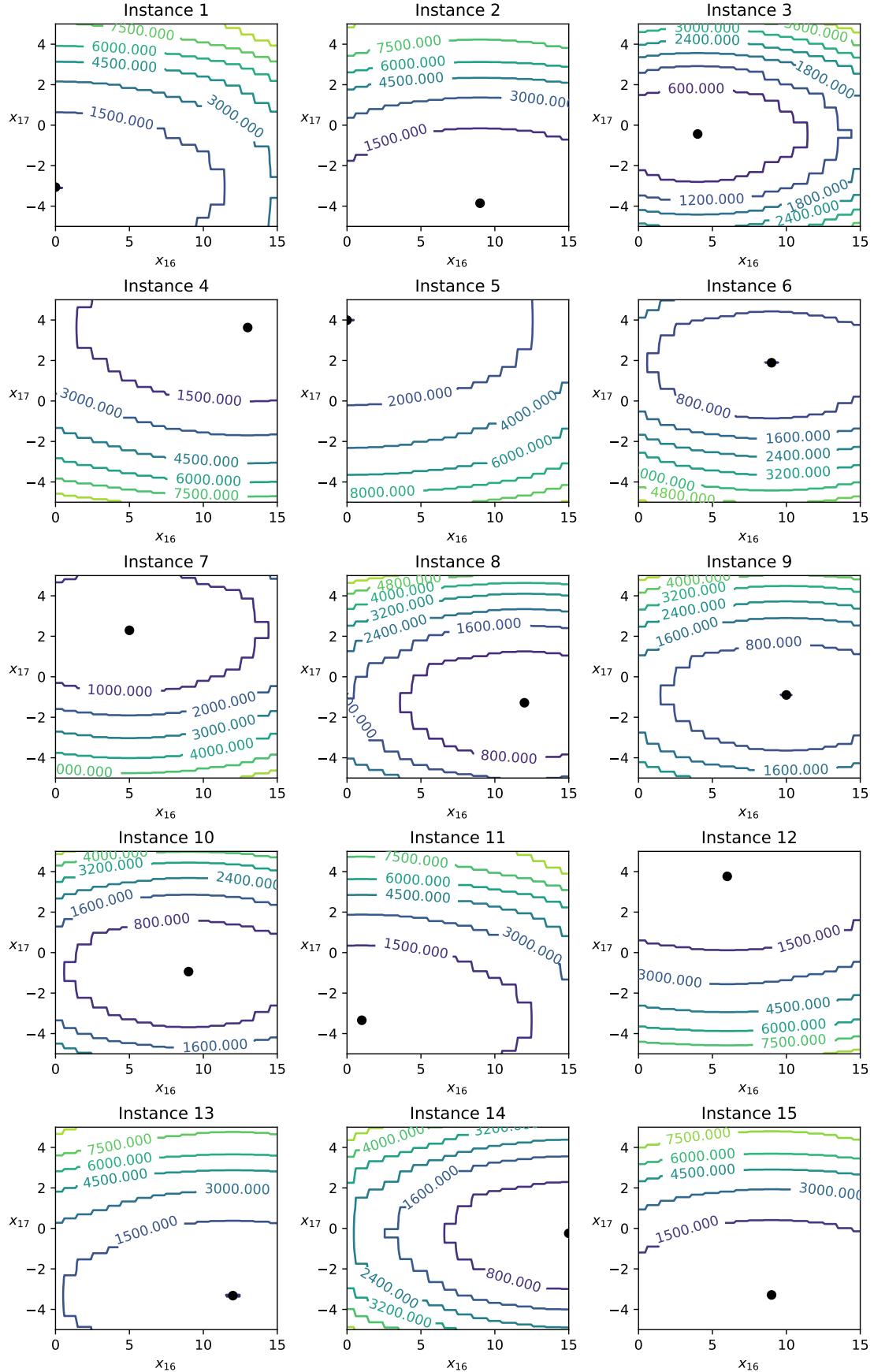
2.1 Function f_2 , Dimension 5



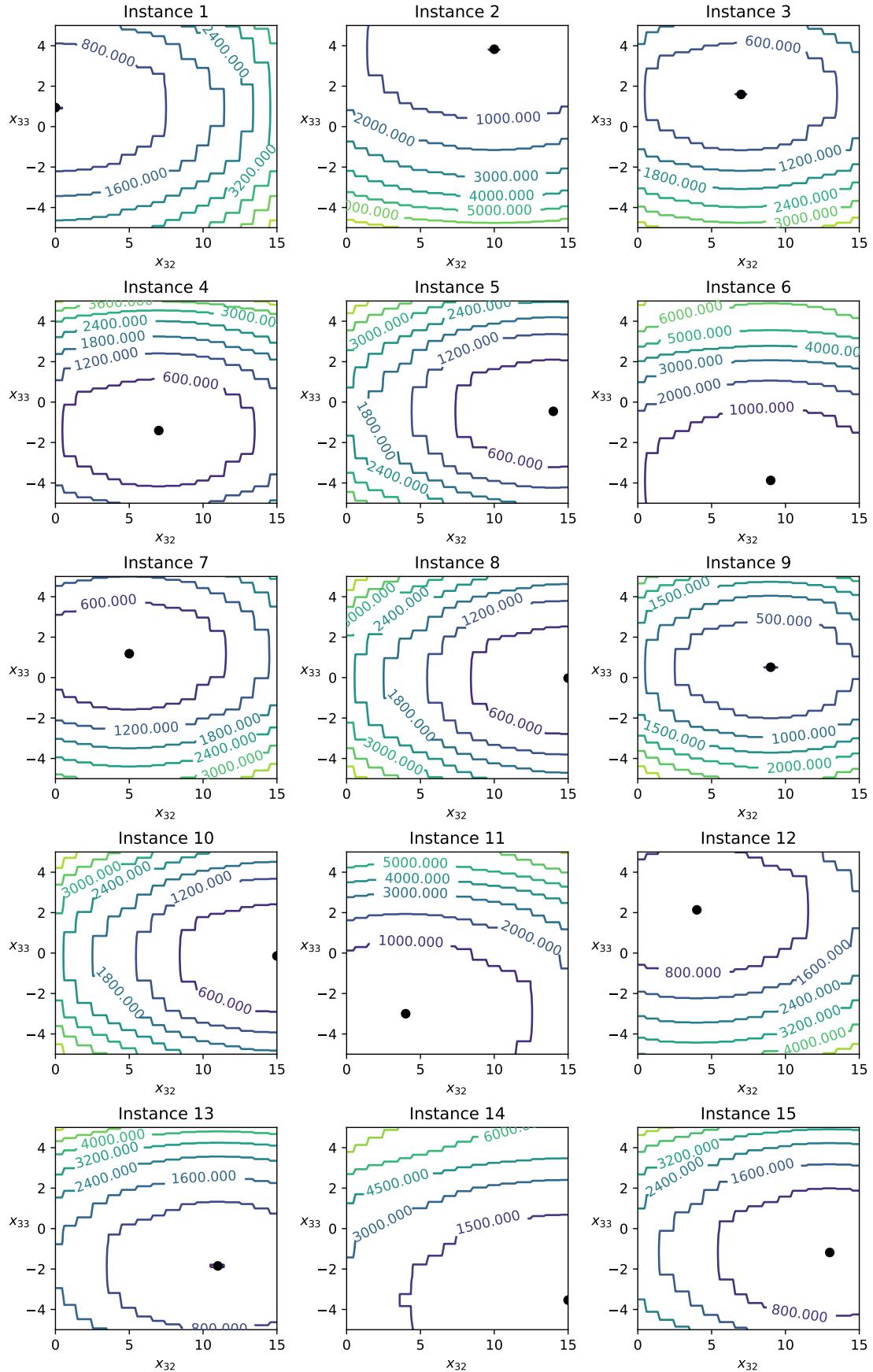
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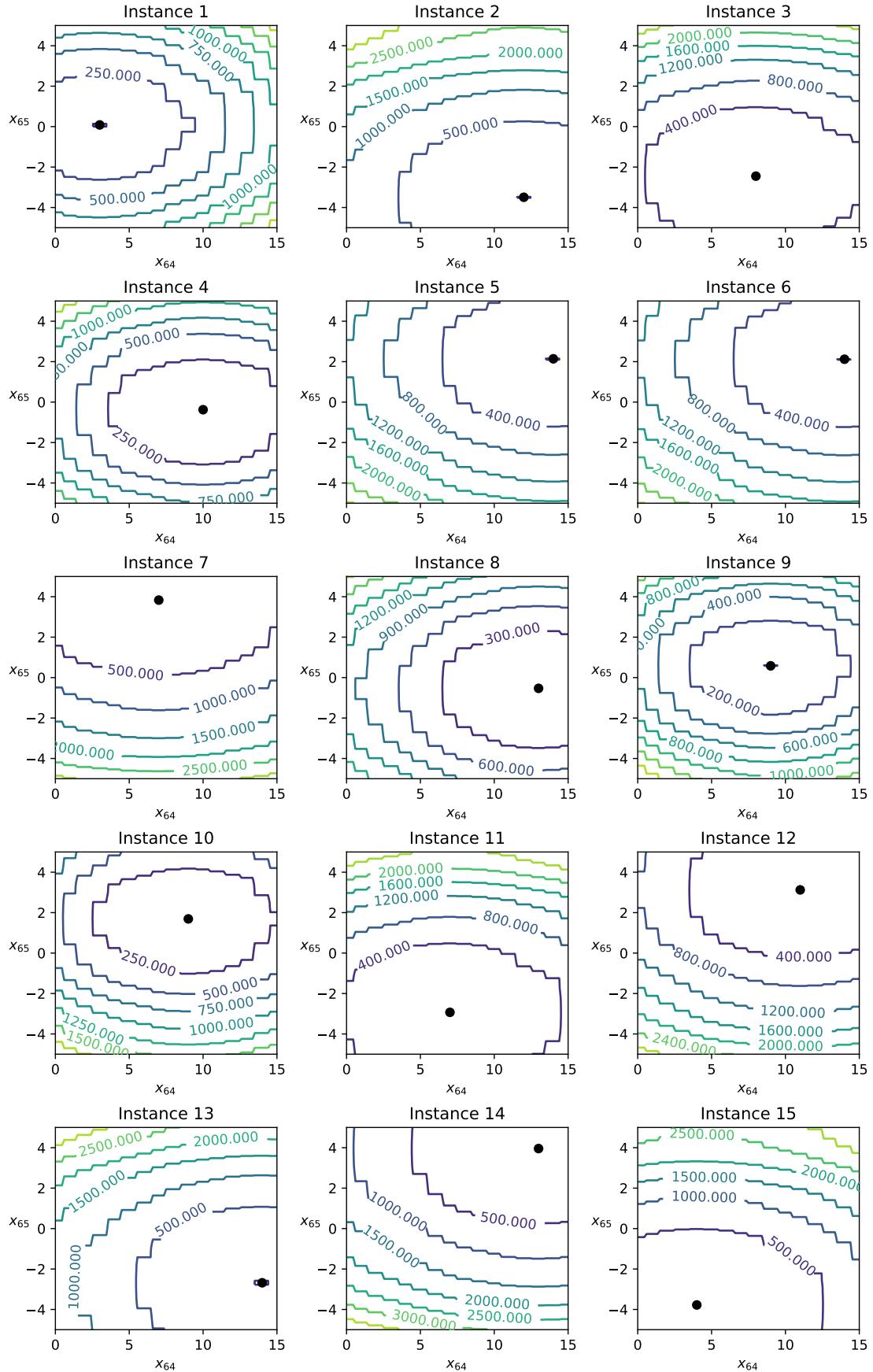
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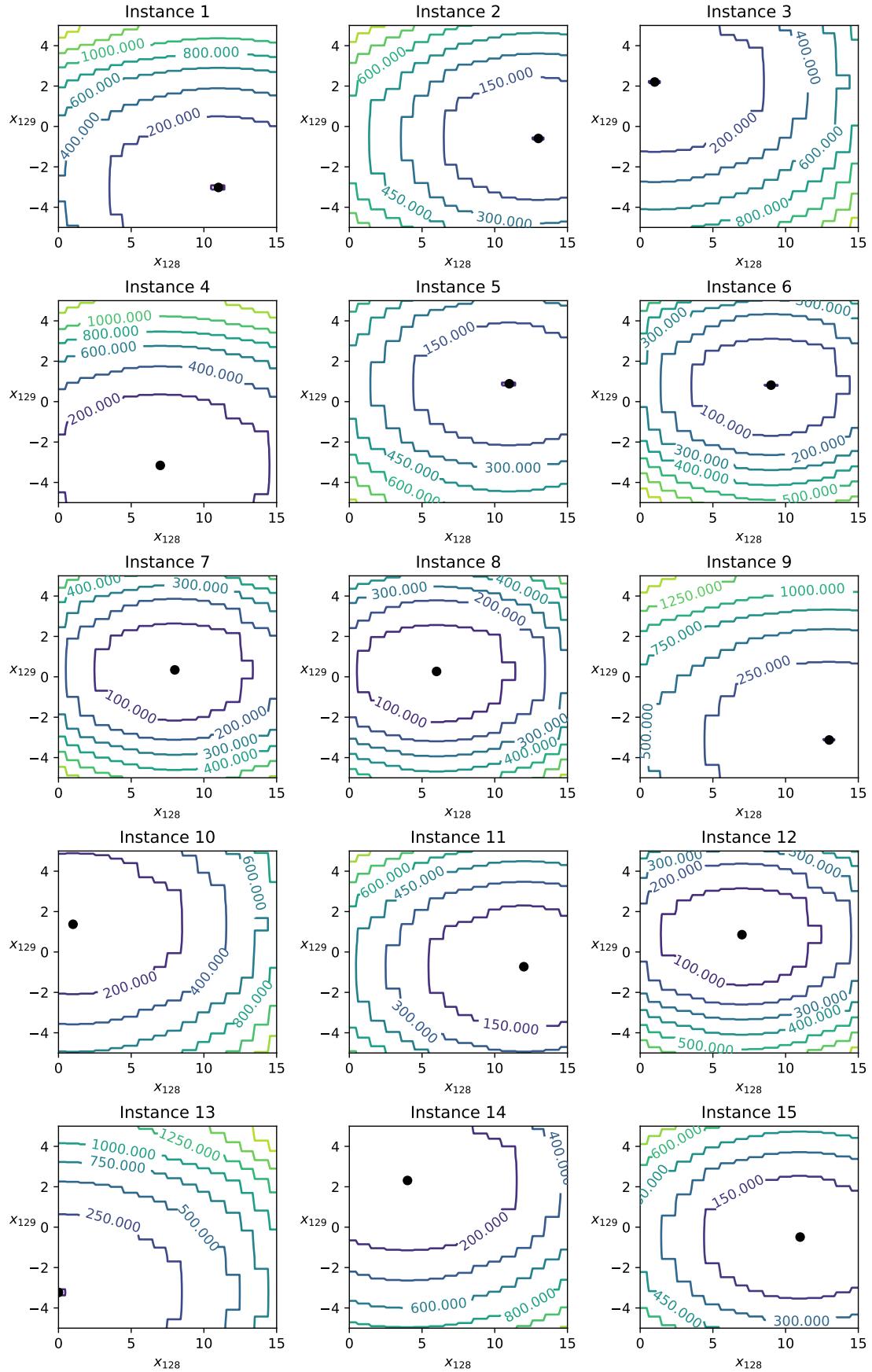
2.4 Function f_2 , Dimension 40



2.5 Function f_2 , Dimension 80

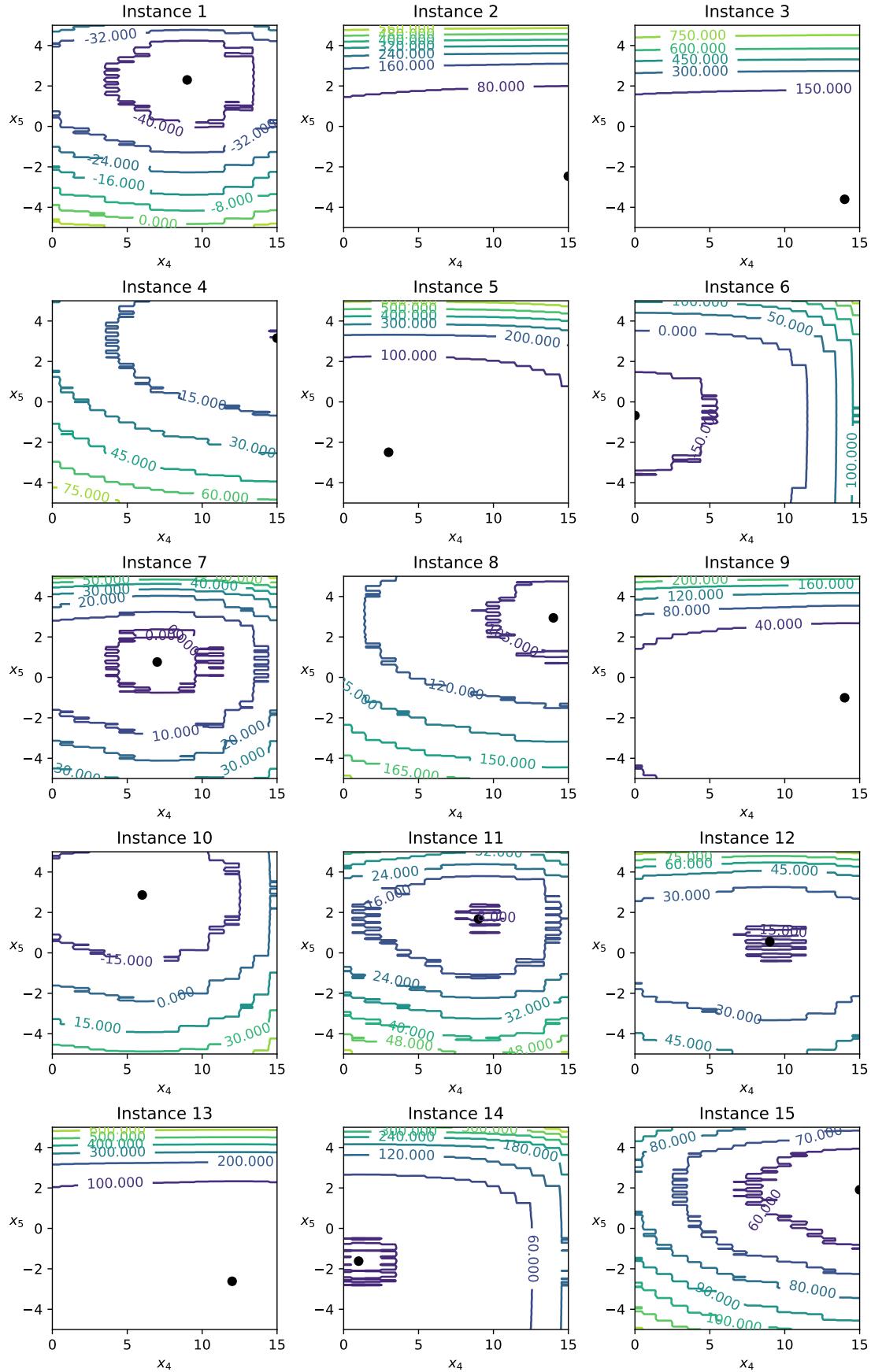


2.6 Function f_2 , Dimension 160

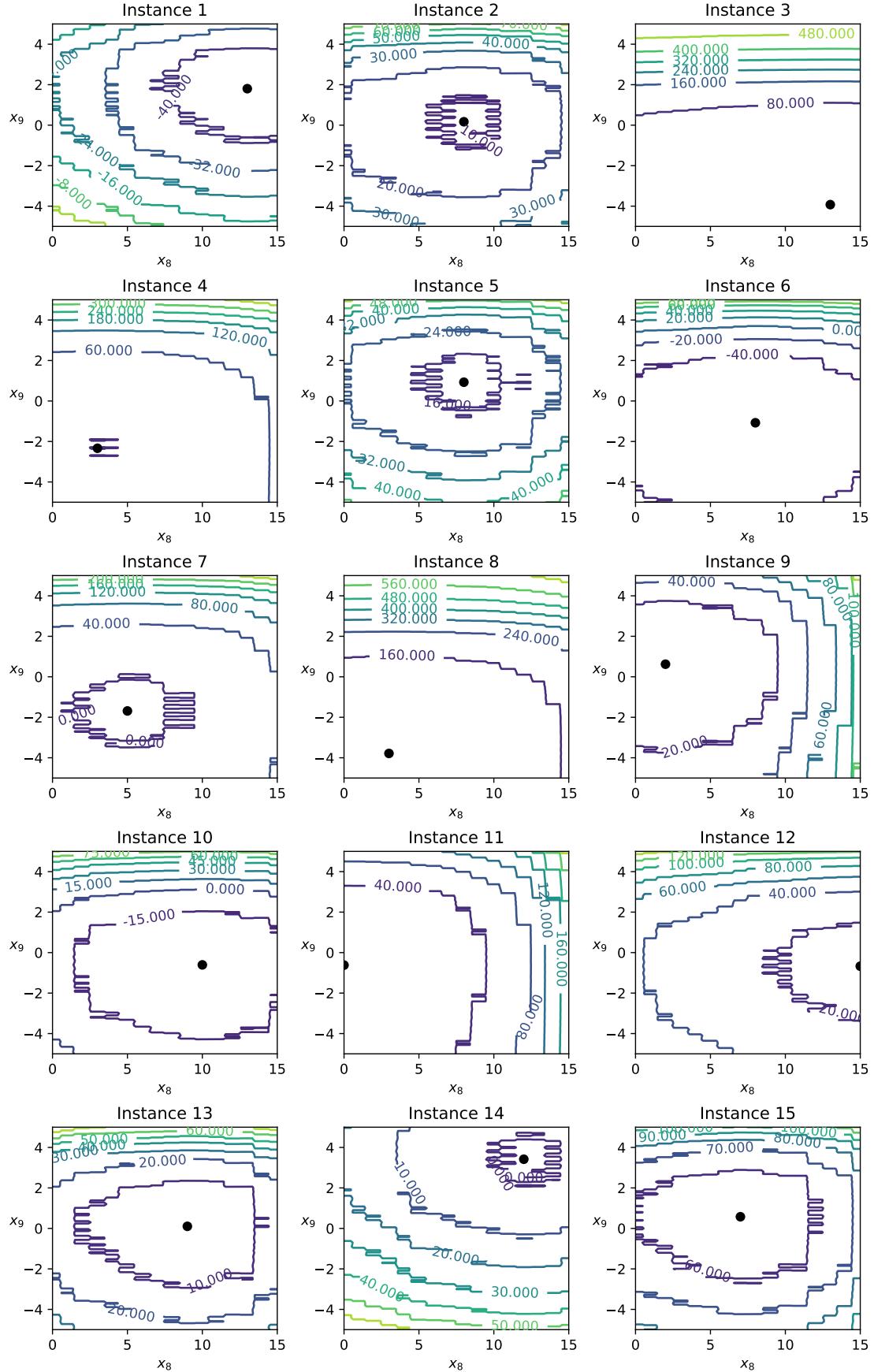


3 Function f_3 – Rastrigin

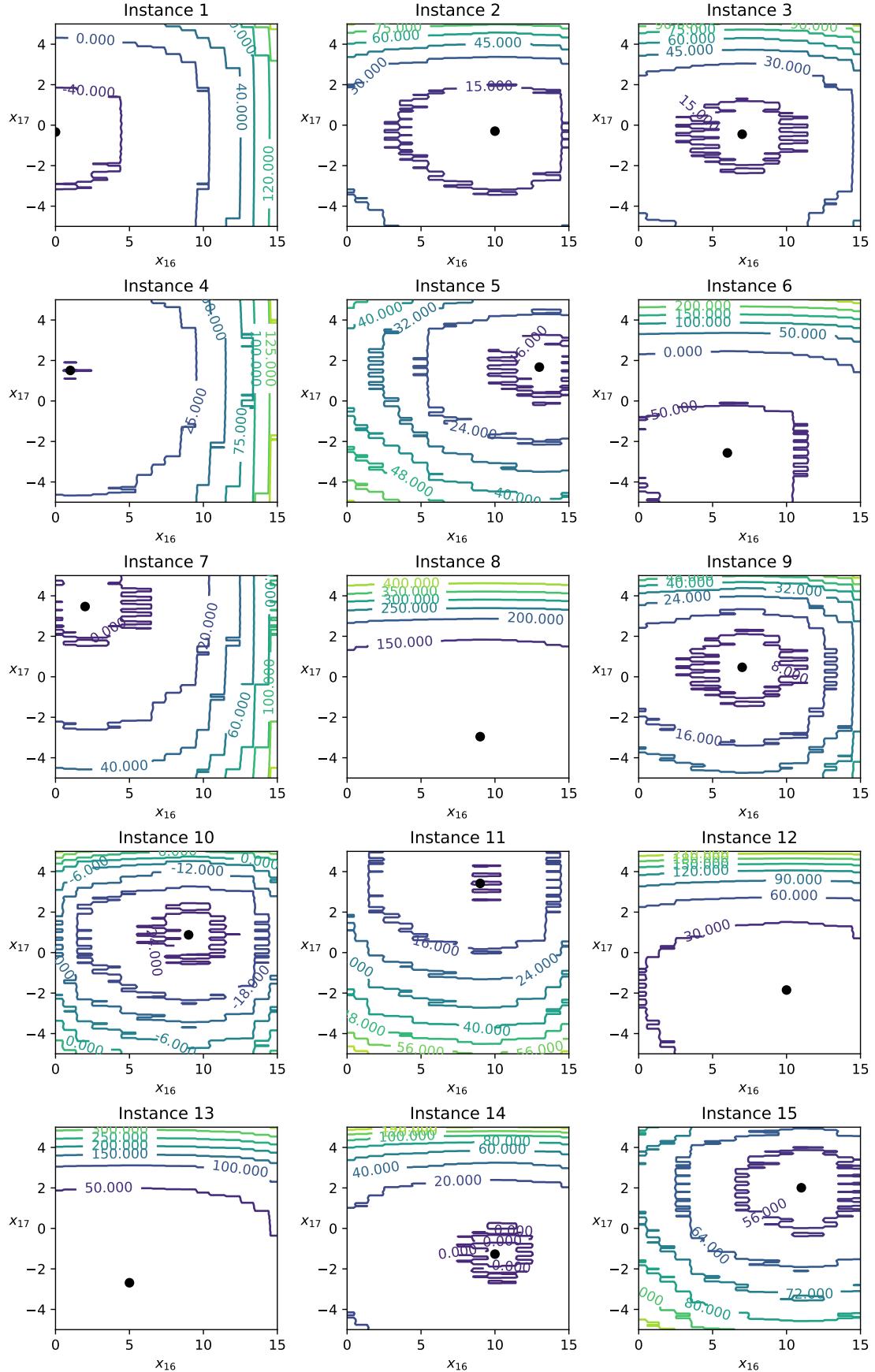
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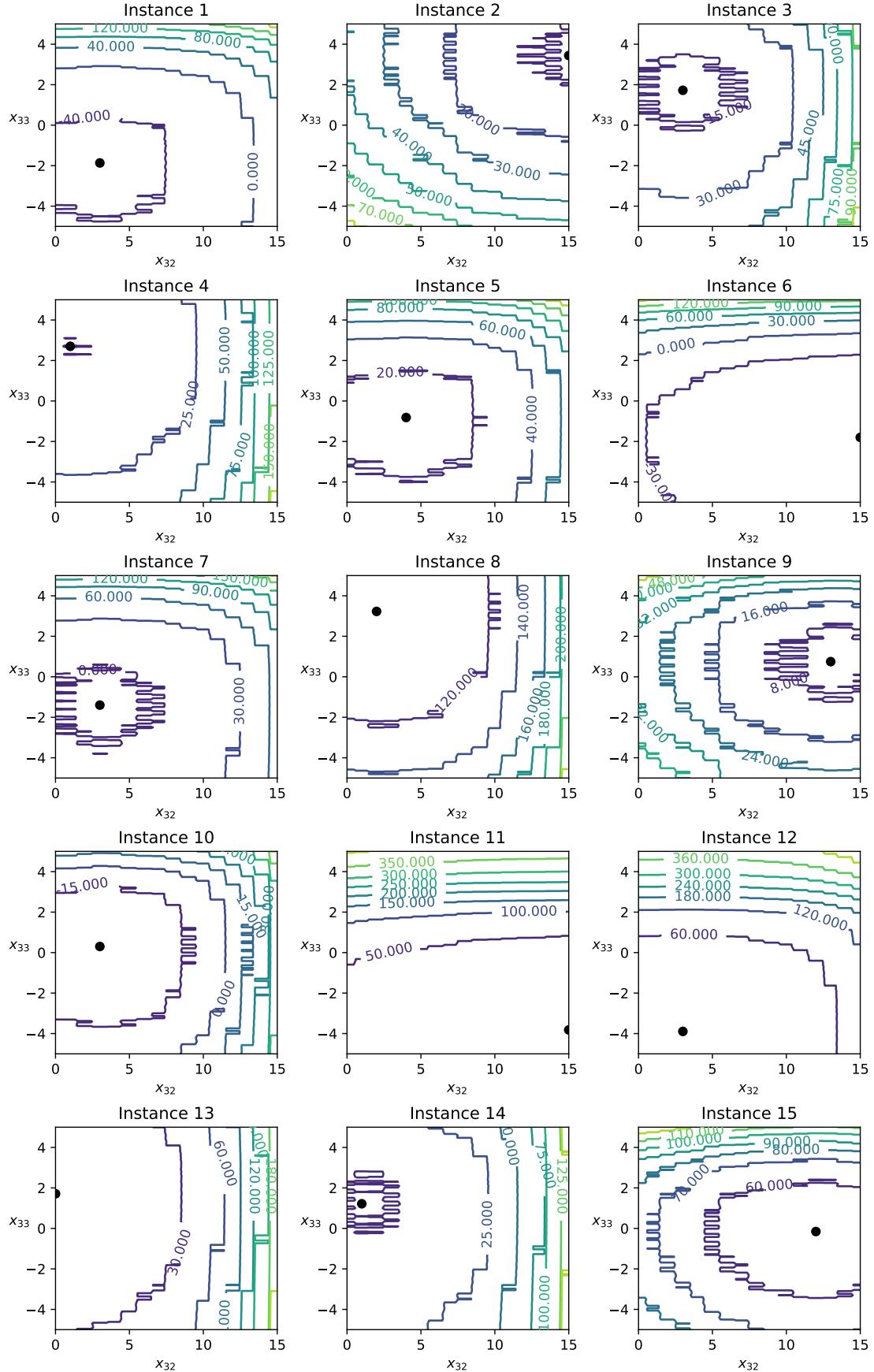
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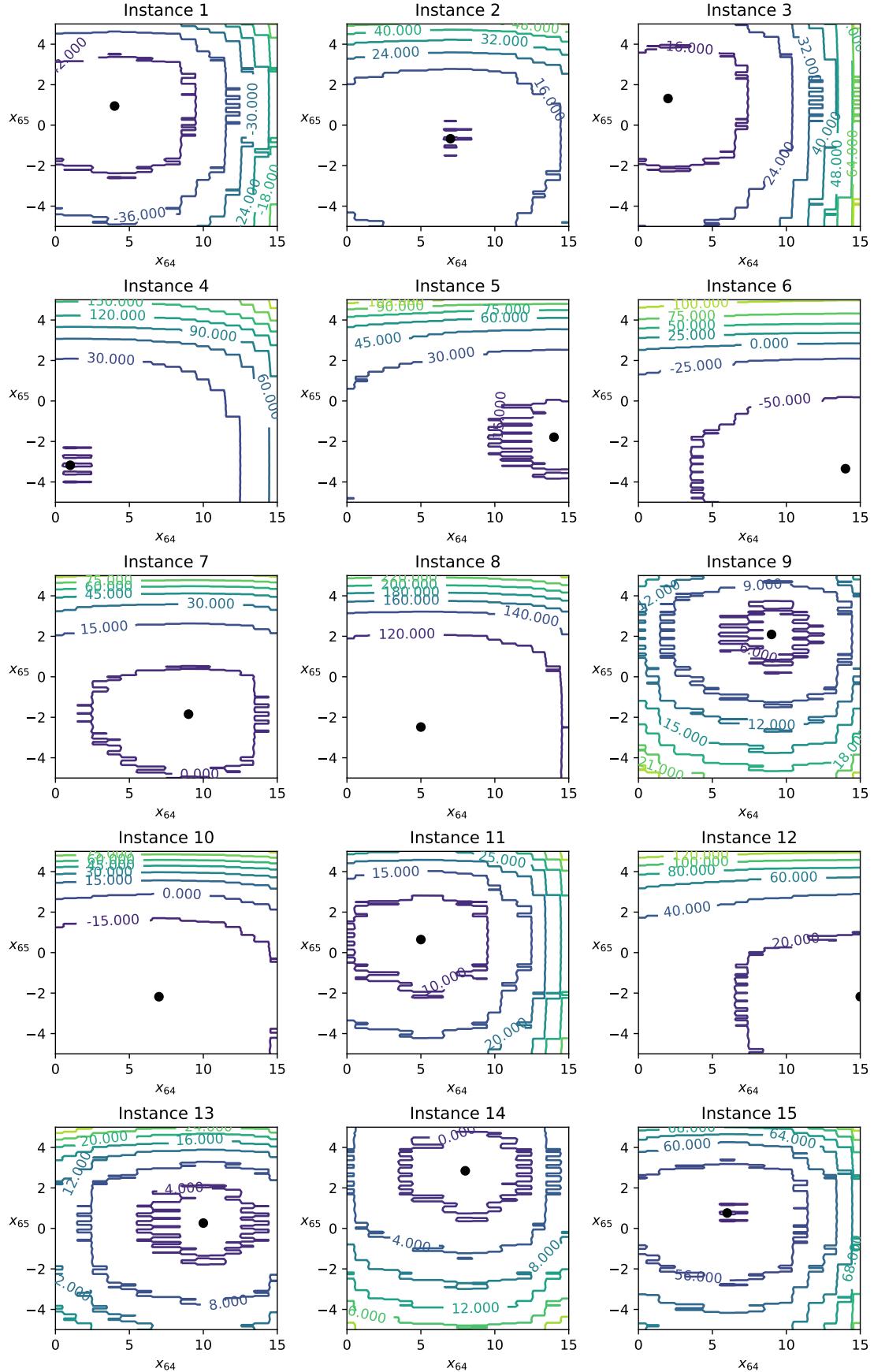
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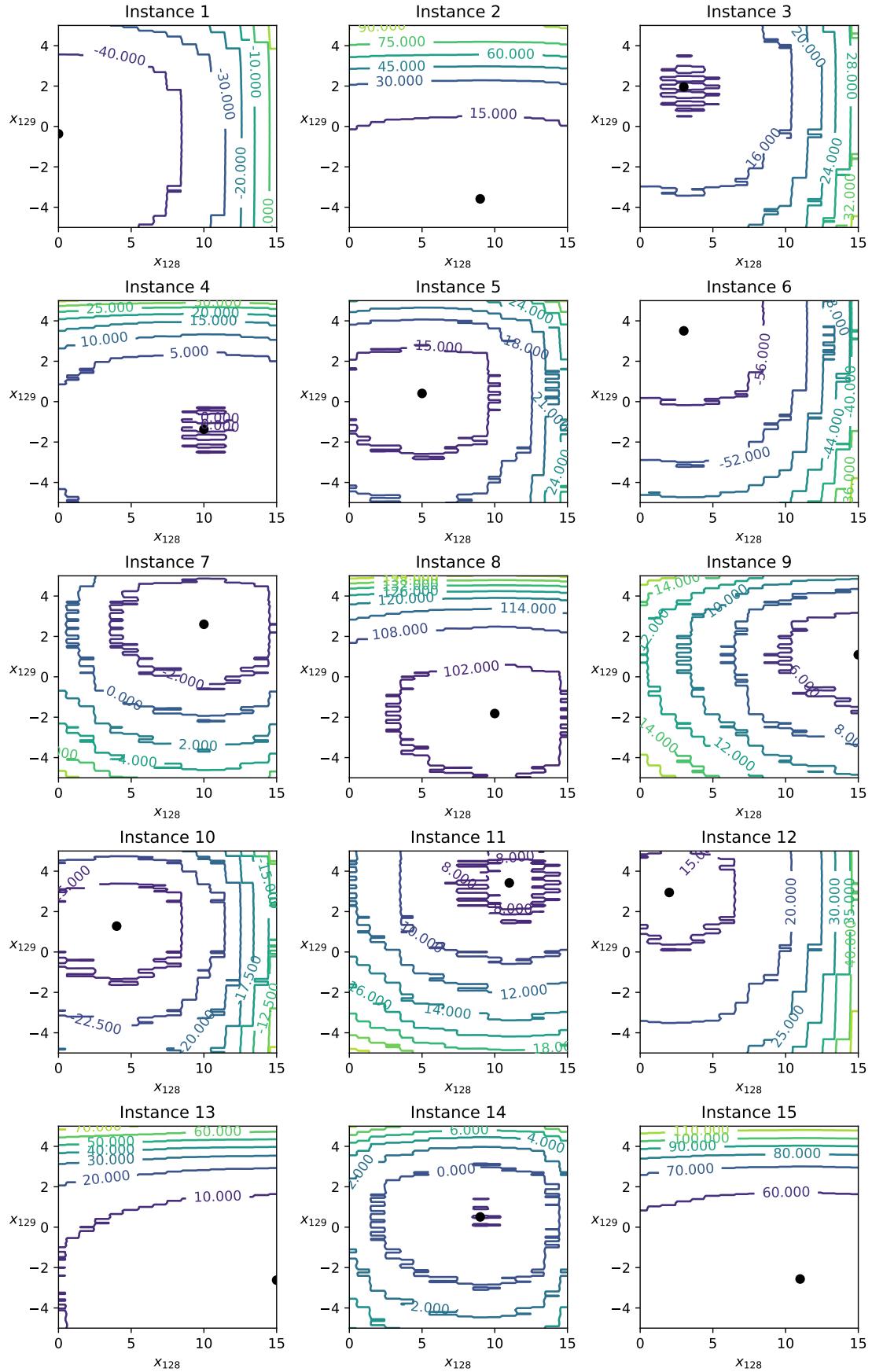
3.4 Function f_3 , Dimension 40



3.5 Function f_3 , Dimension 80

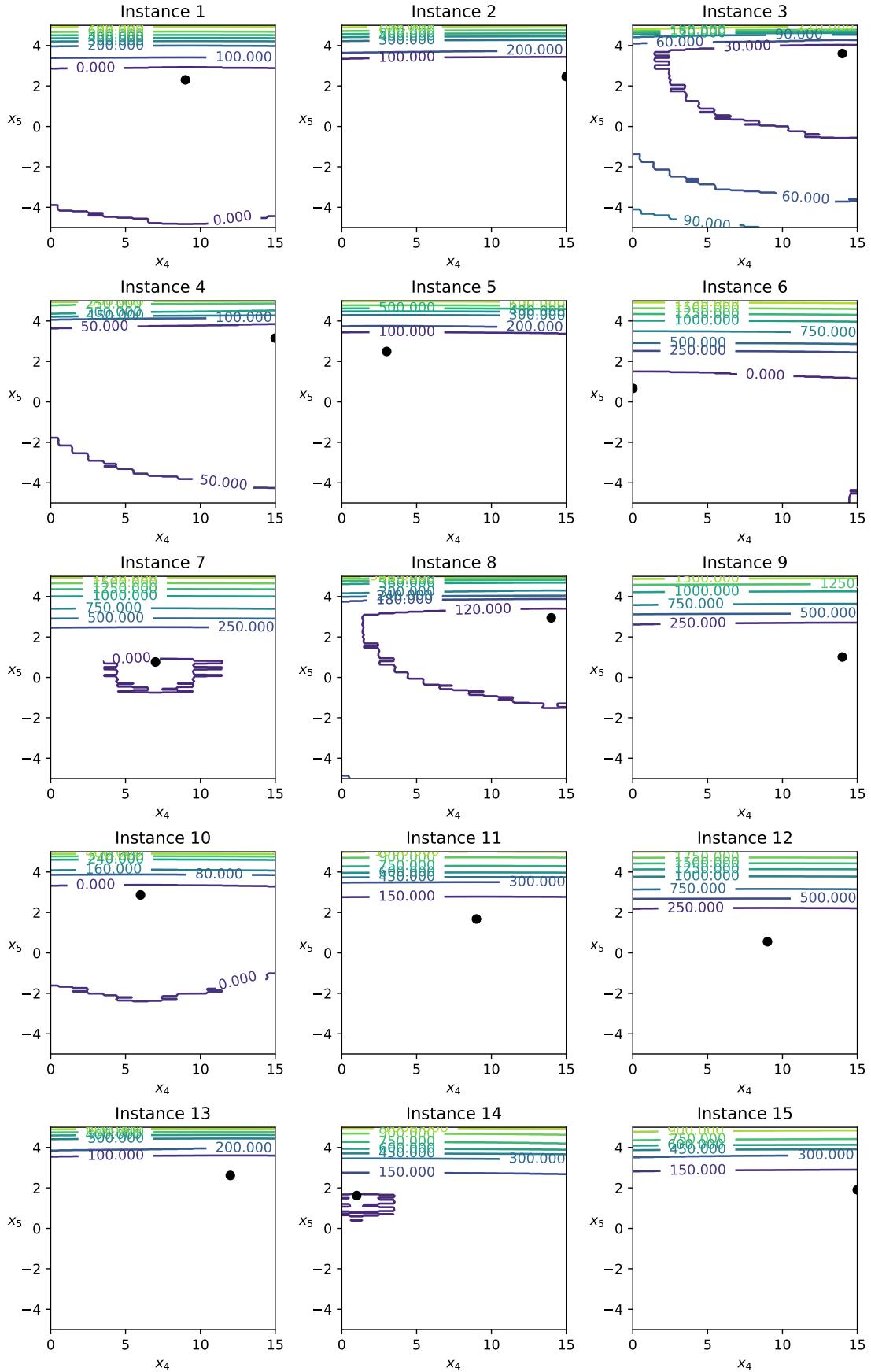


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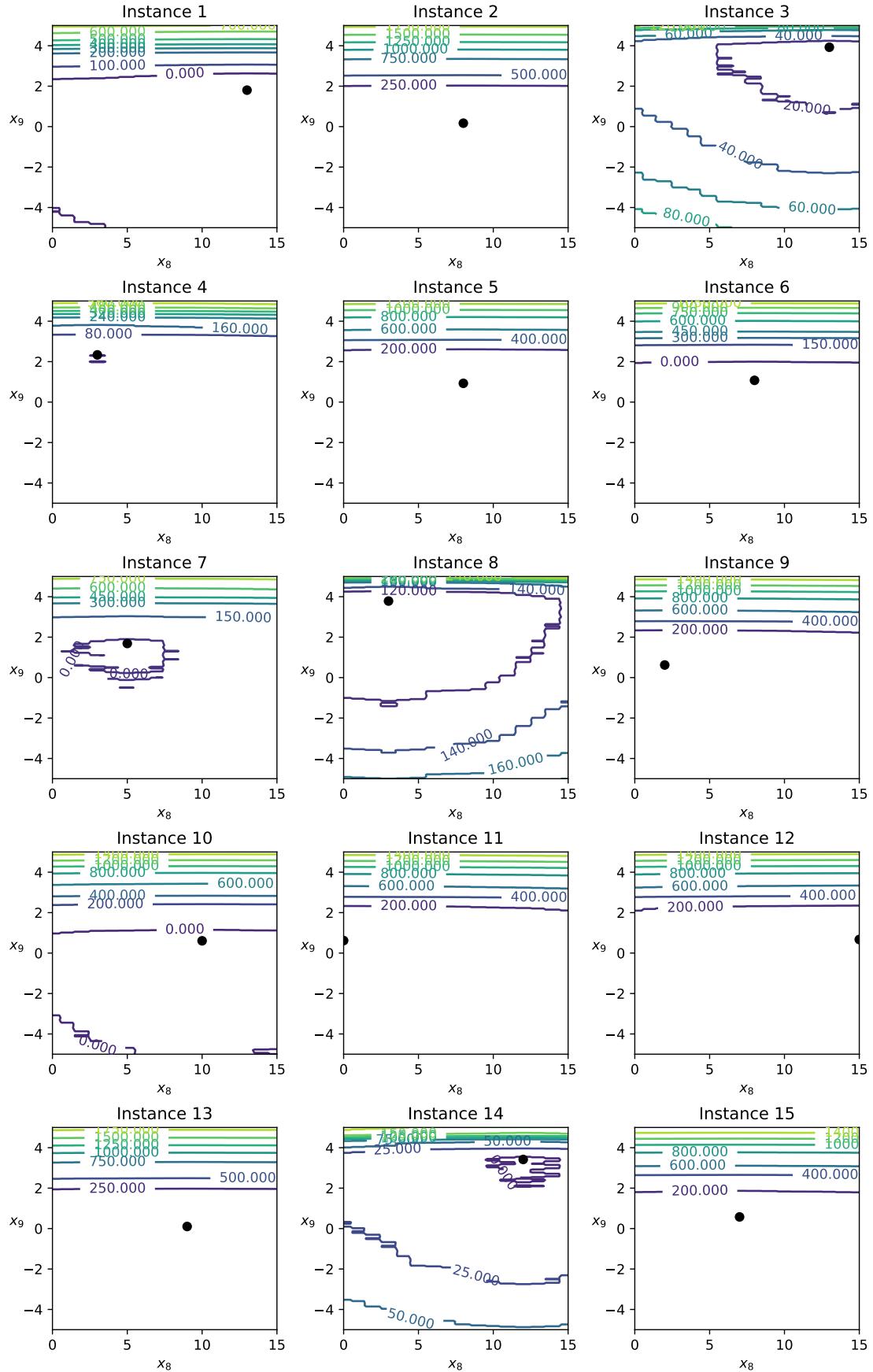


4 Function f_4 – Büche-Rastrigin

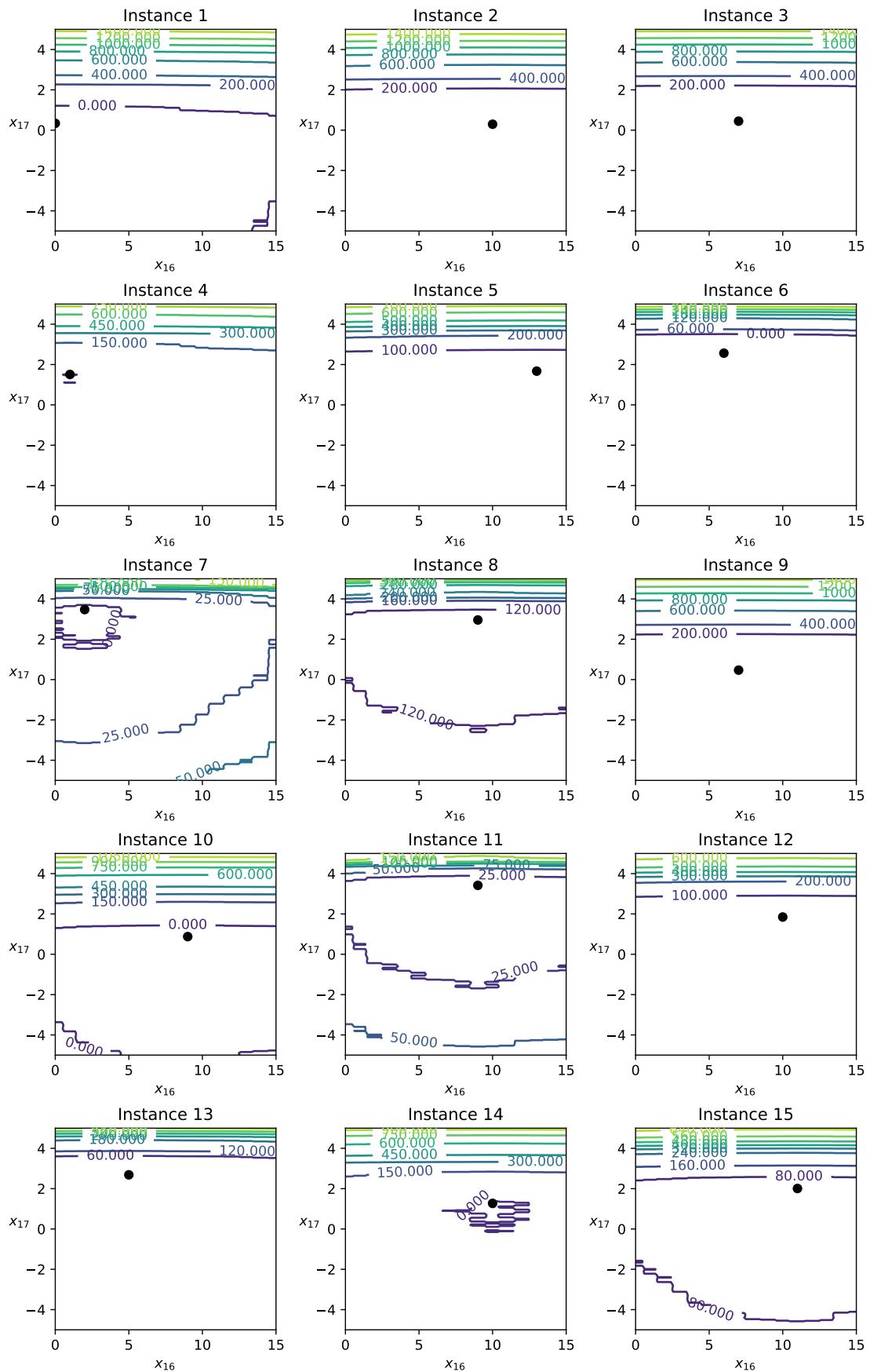
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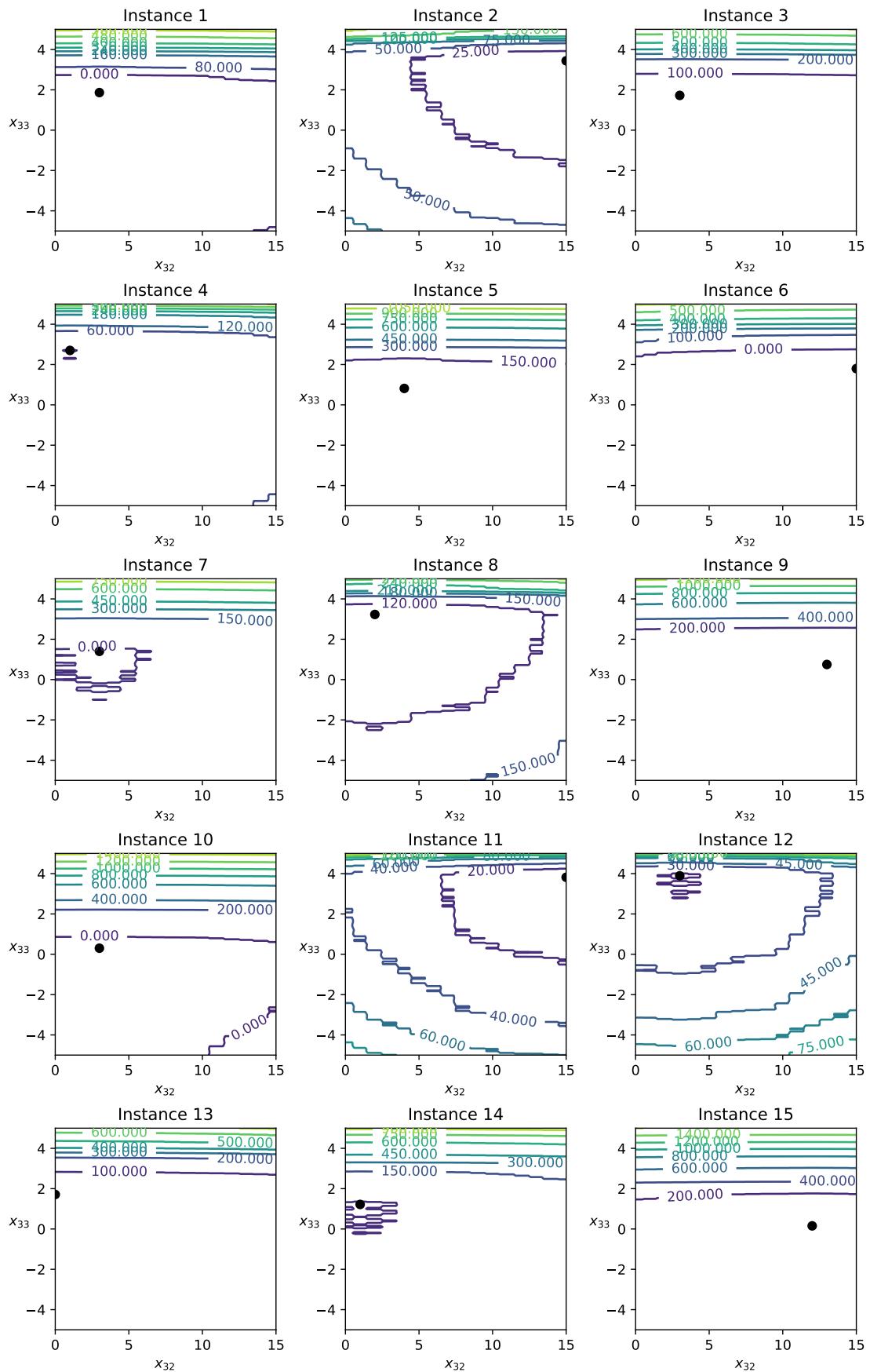
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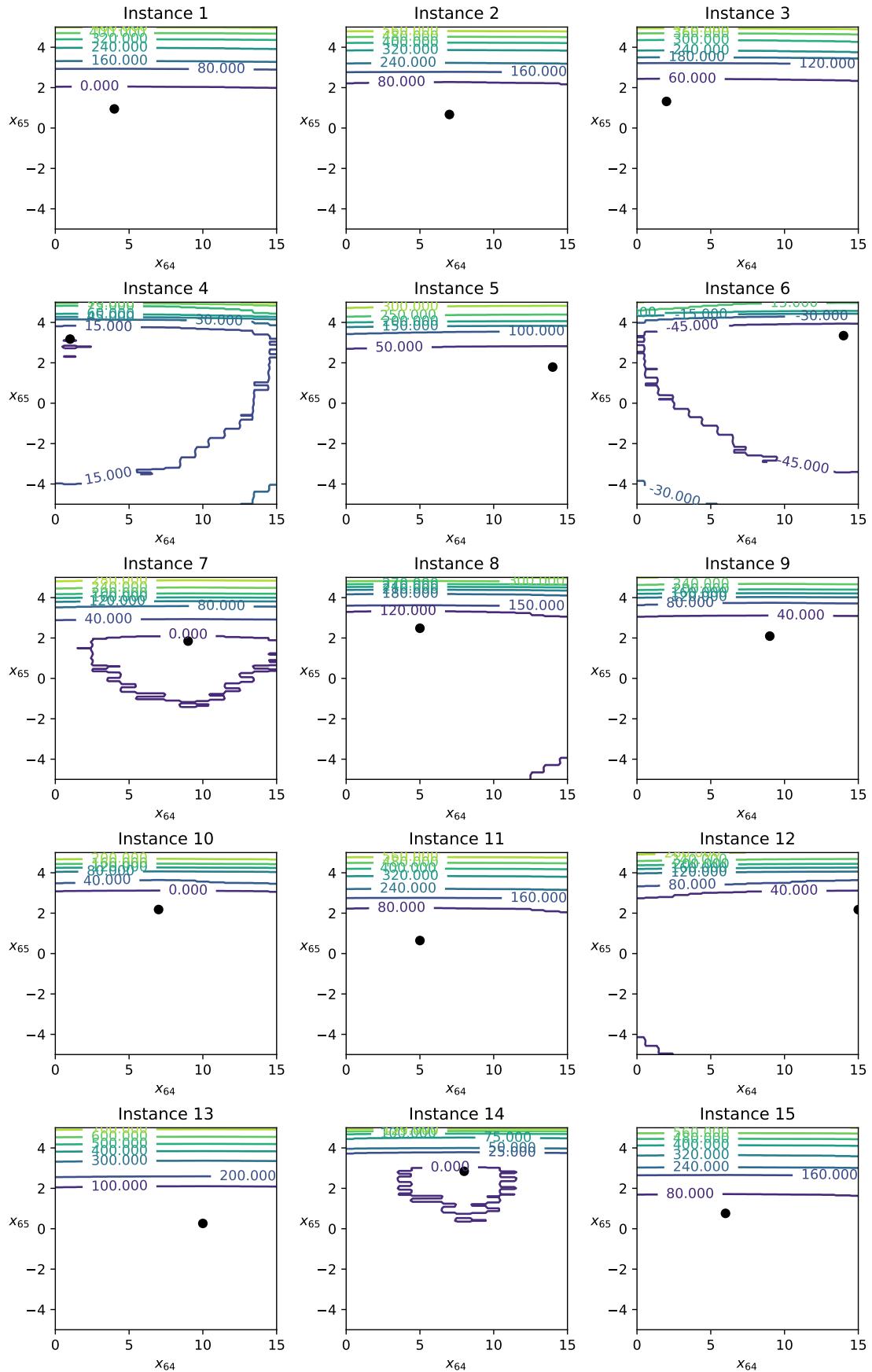
4.3 Function f_4 , Dimension 20



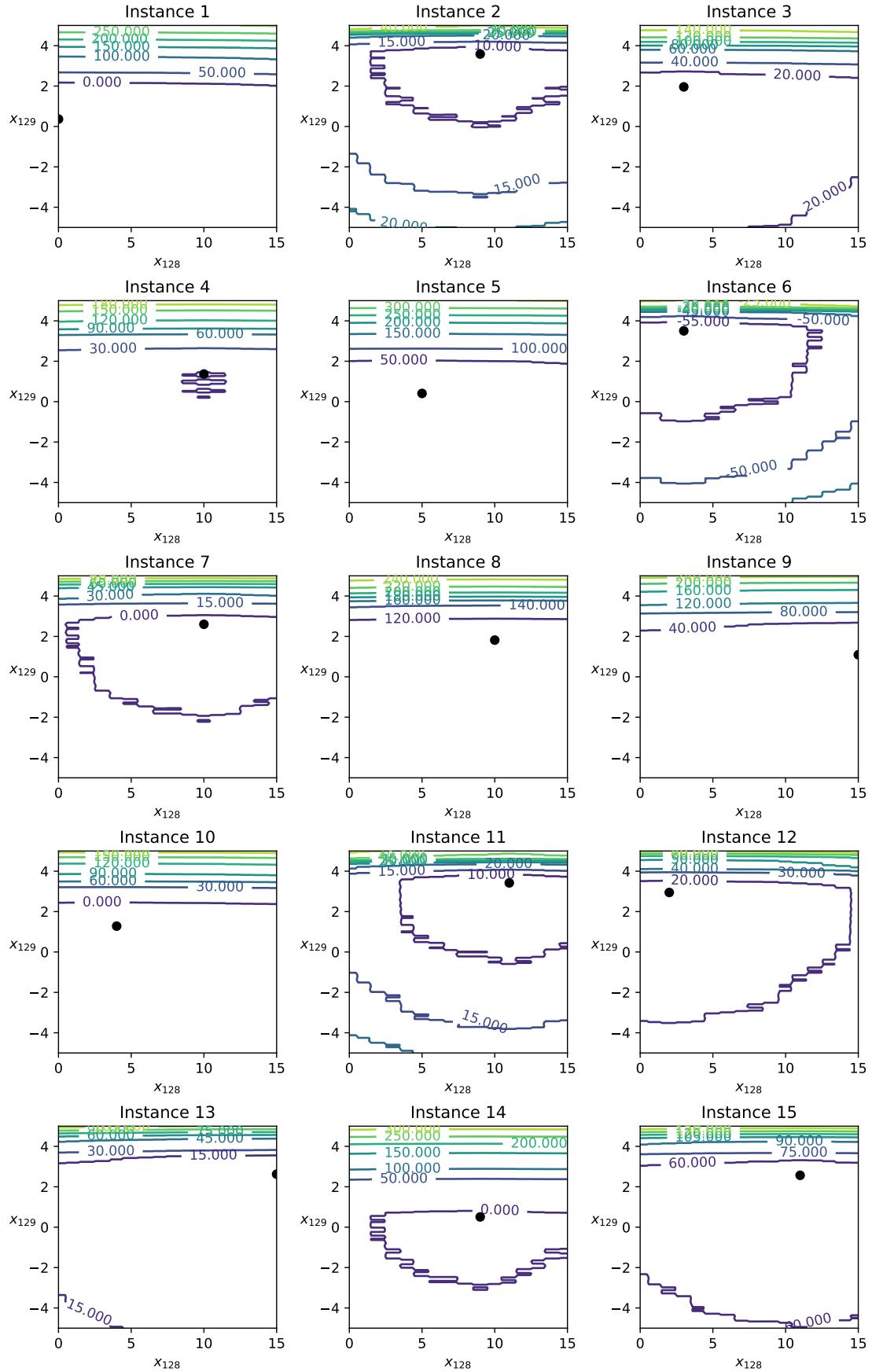
4.4 Function f_4 , Dimension 40



4.5 Function f_4 , Dimension 80

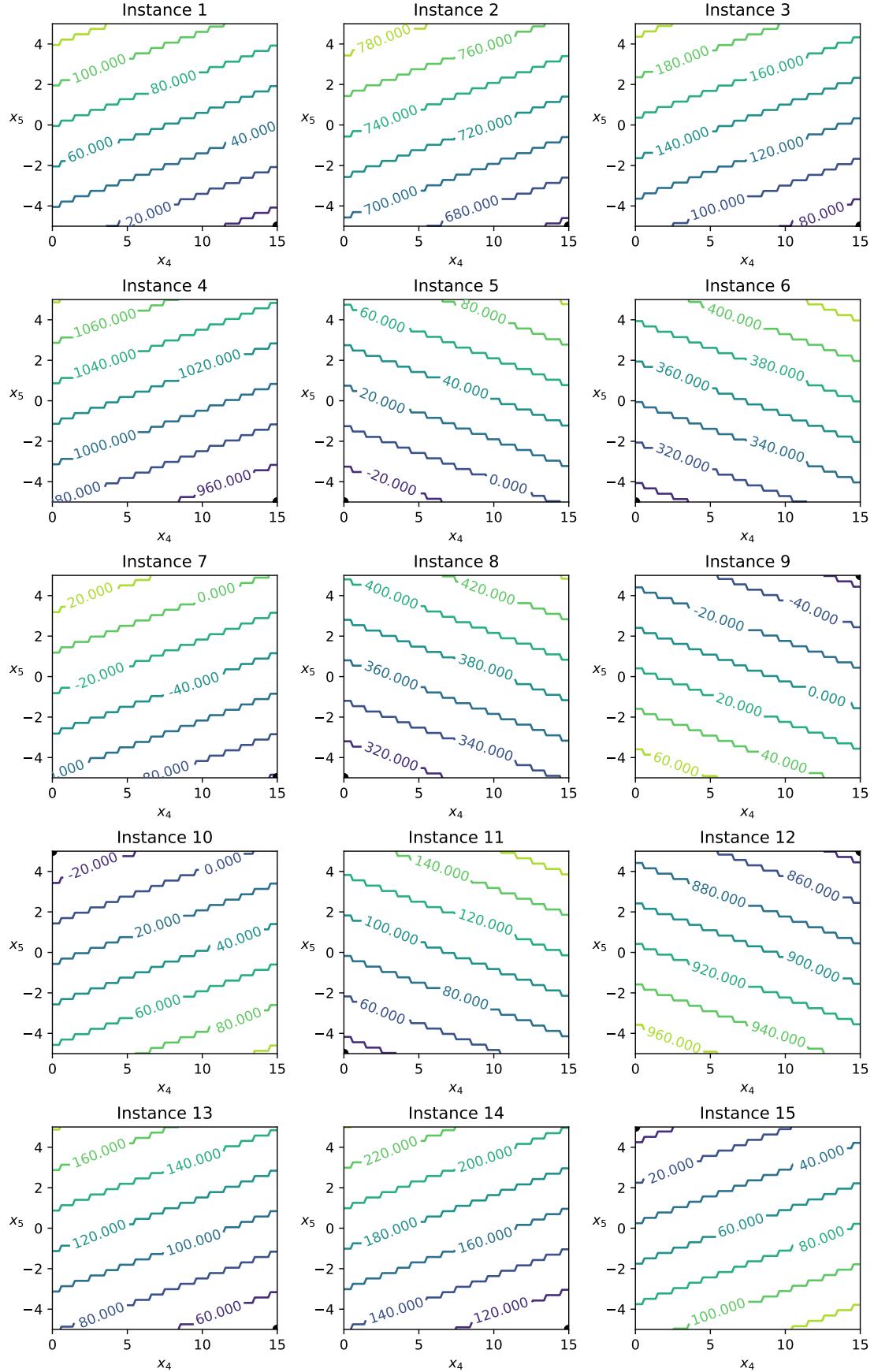


4.6 Function f_4 , Dimension 160

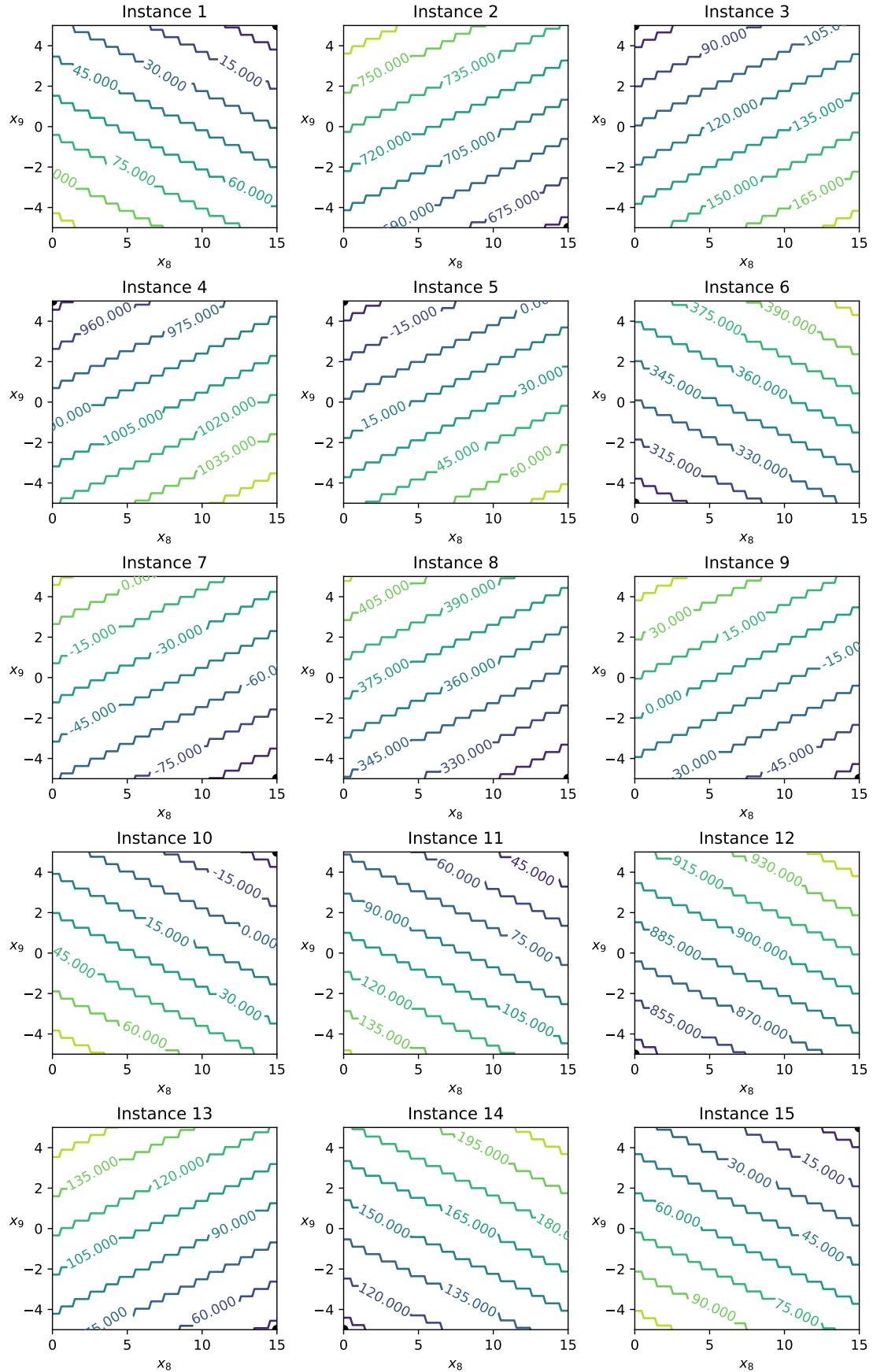


5 Function f_5 – Linear Slope

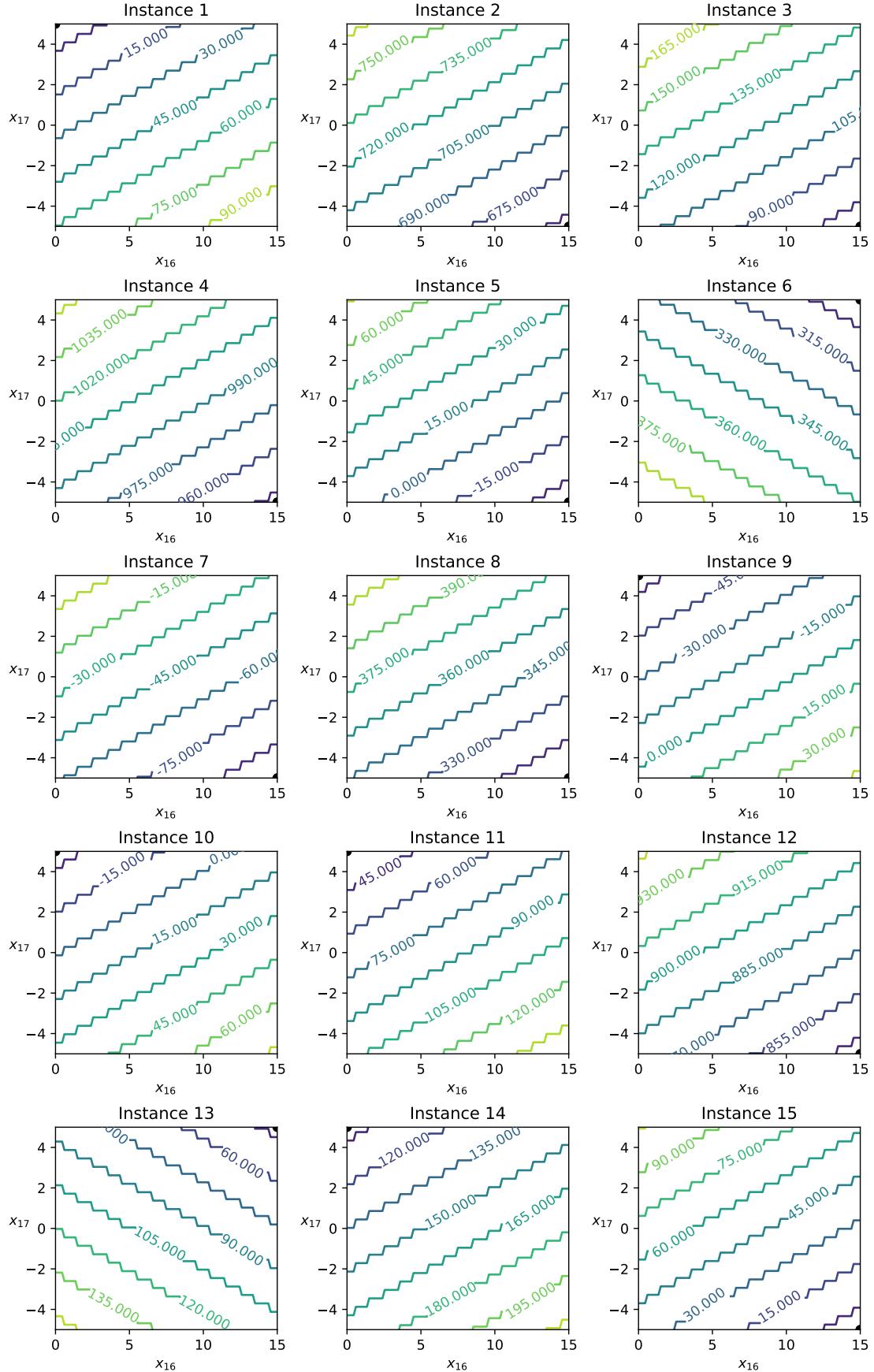
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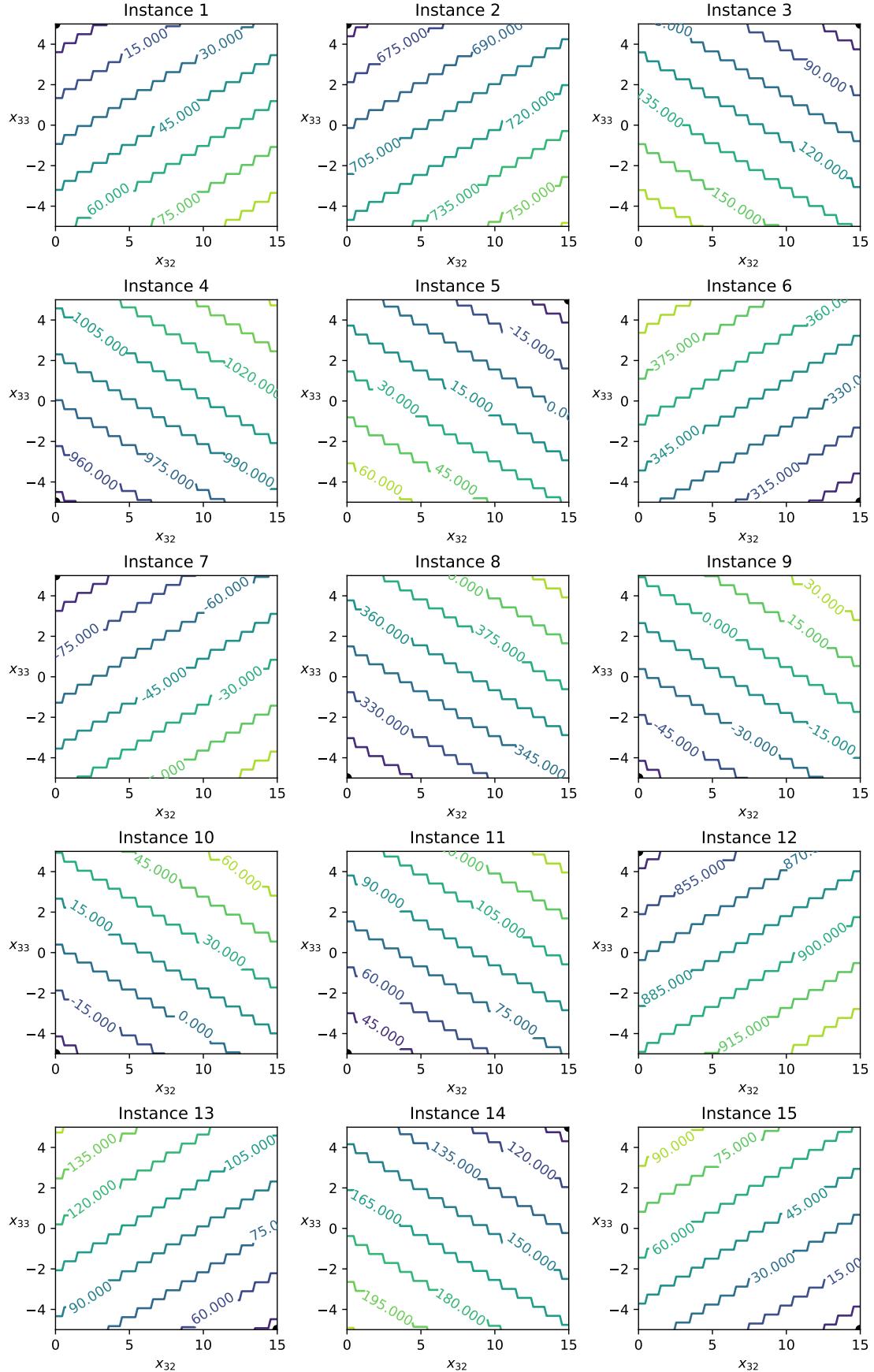
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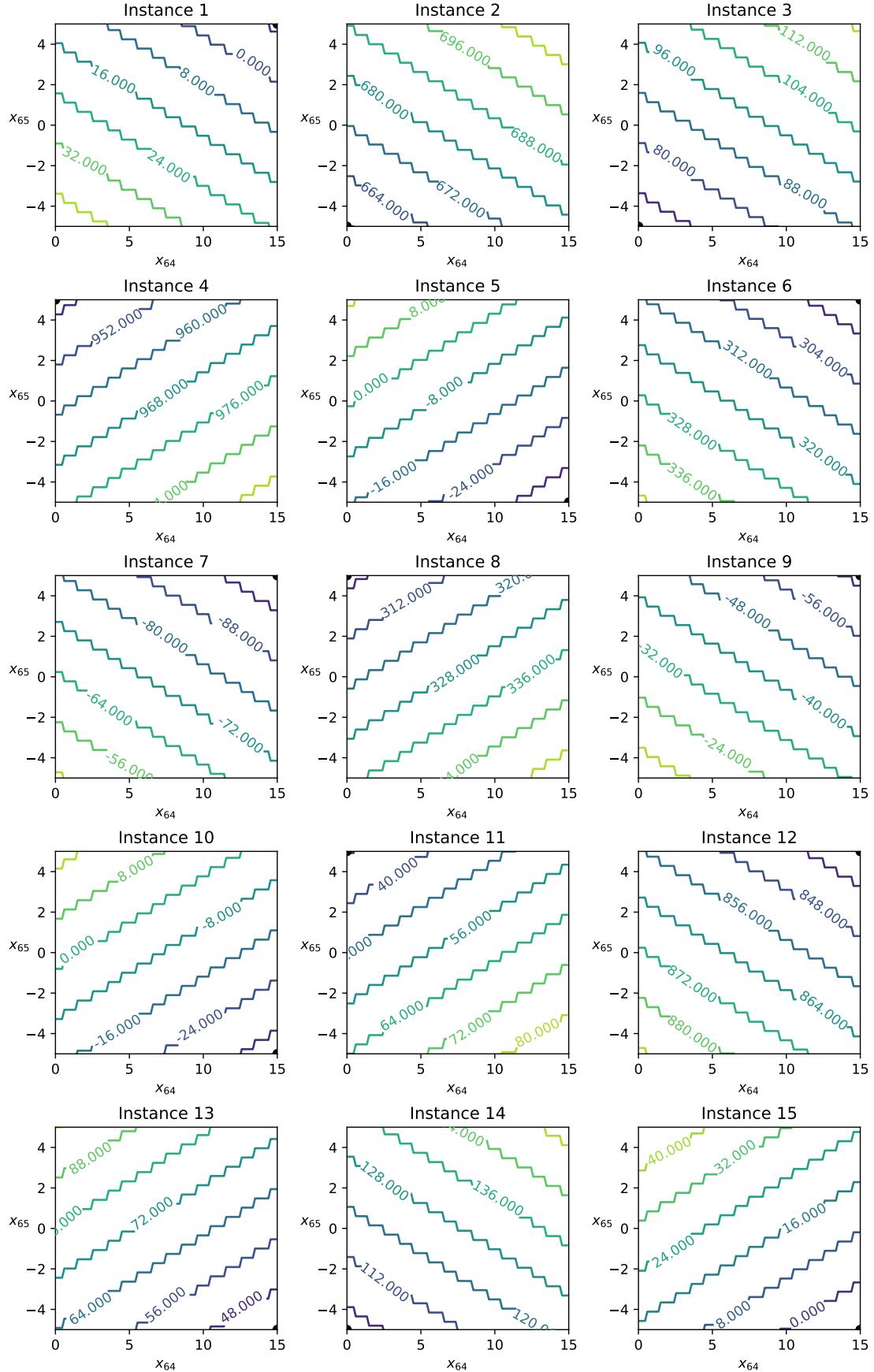
5.3 Function f_5 , Dimension 20



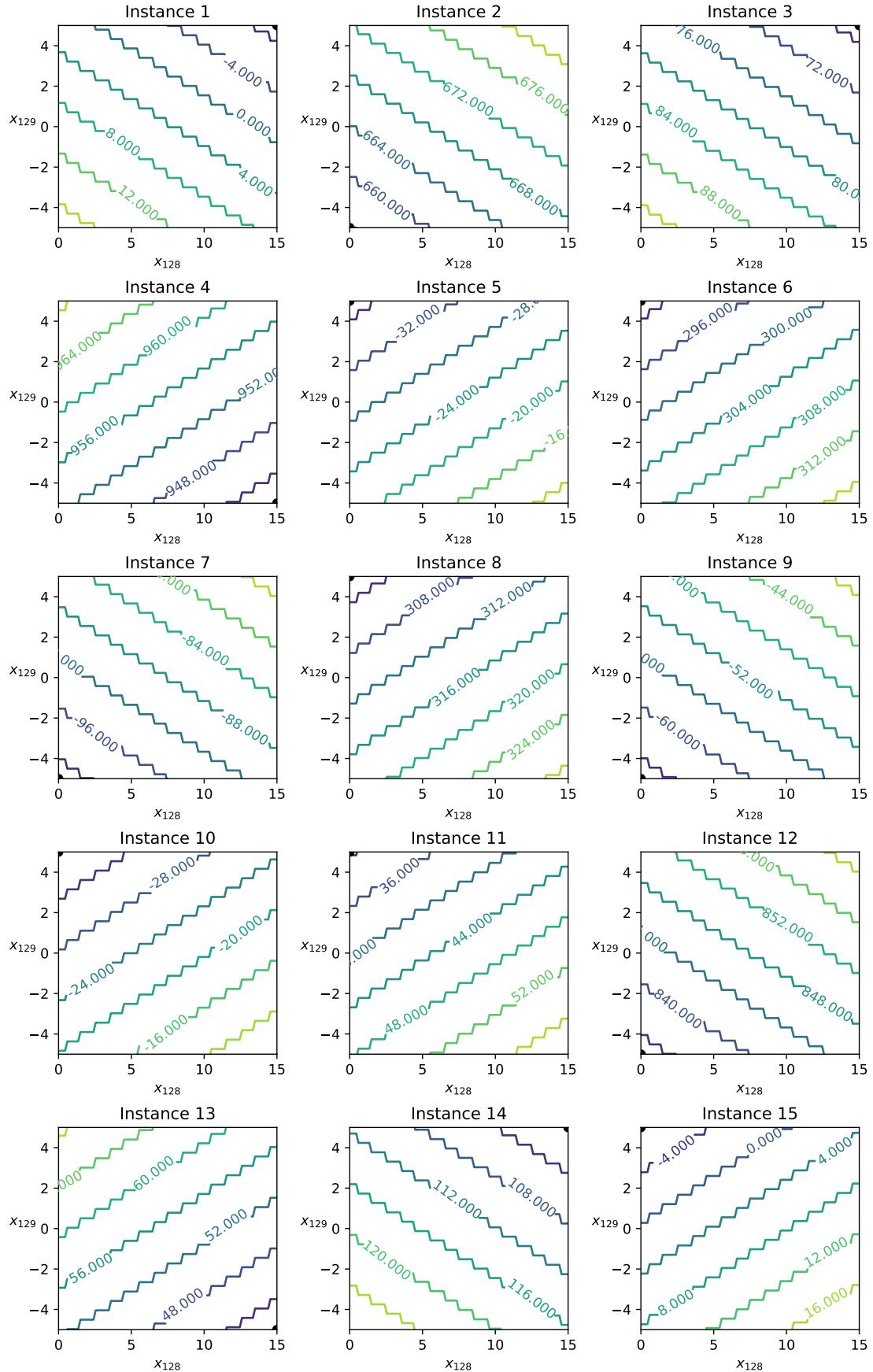
5.4 Function f_5 , Dimension 40



5.5 Function f_5 , Dimension 80

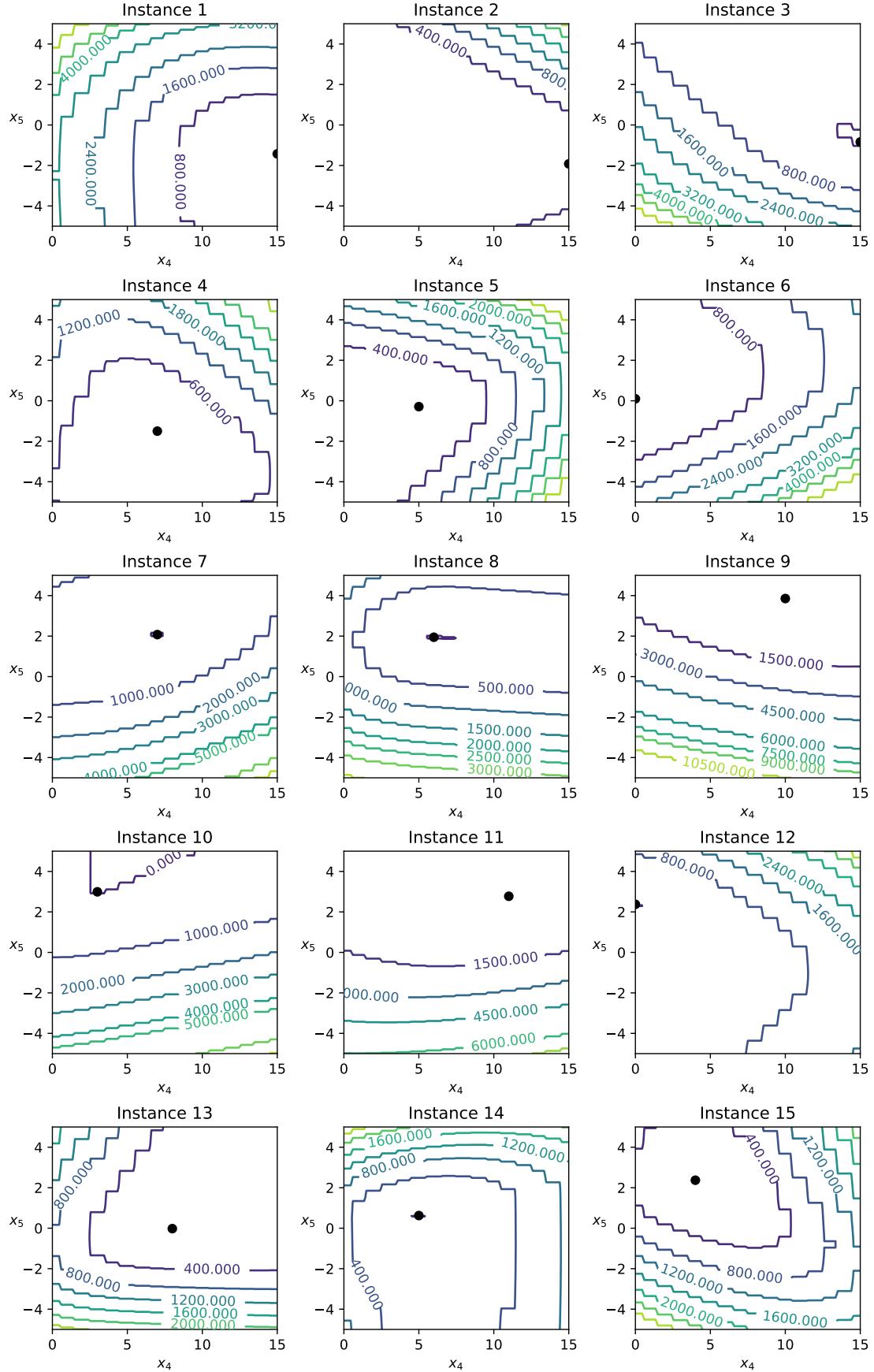


5.6 Function f_5 , Dimension 160

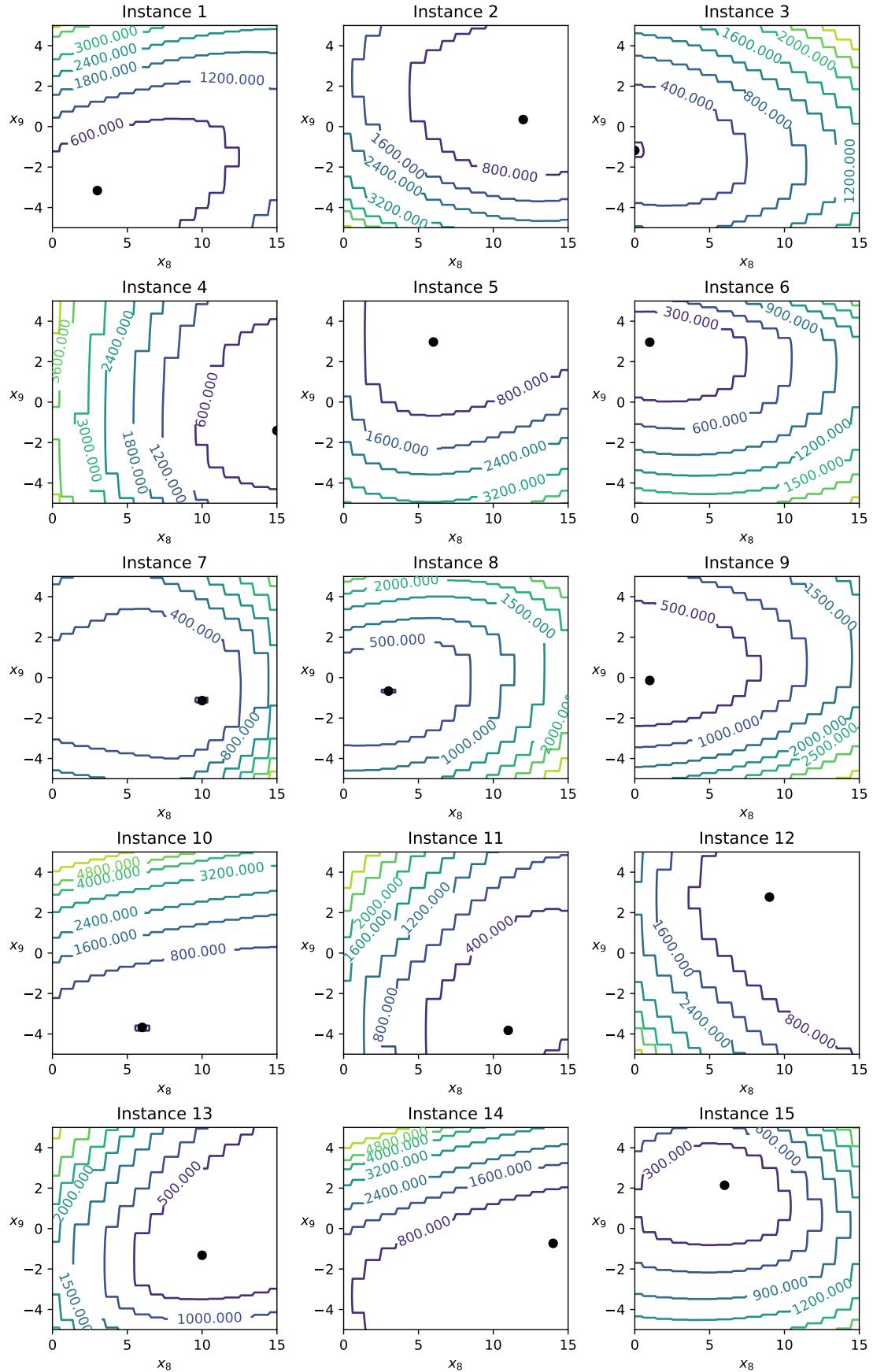


6 Function f_6 – Attractive Sector

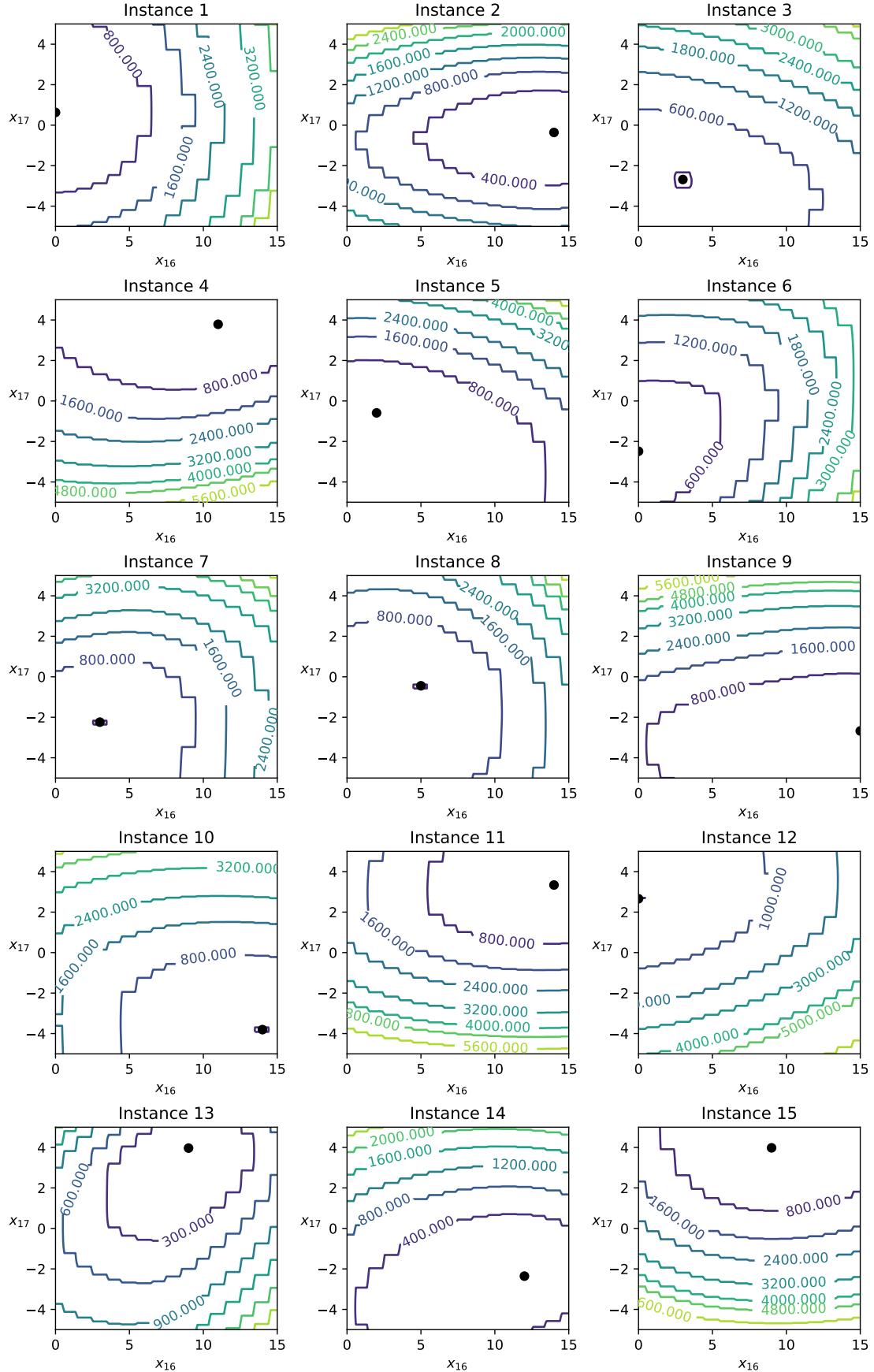
6.1 Function f_6 , Dimension 5



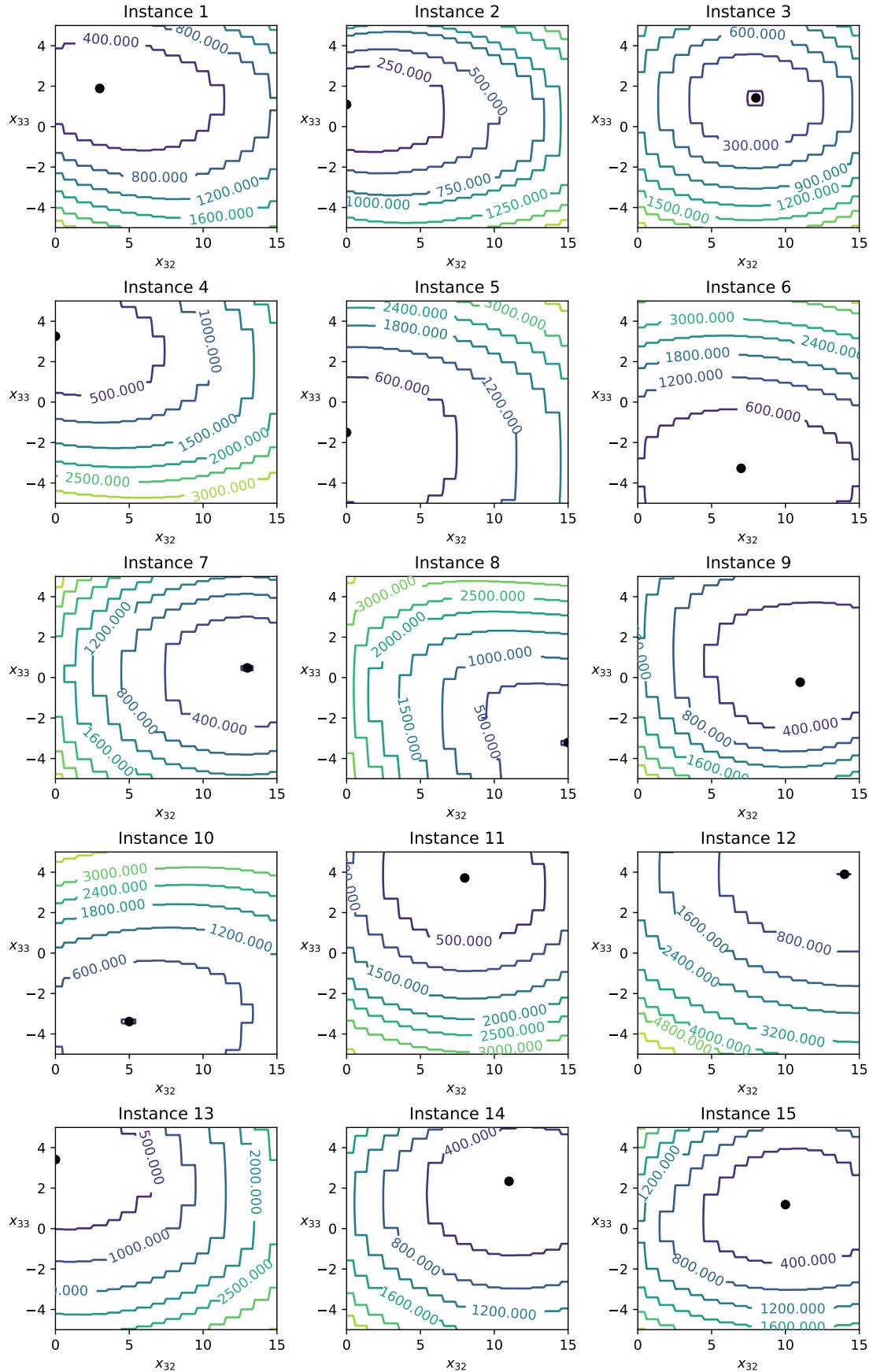
6.2 Function f_6 , Dimension 10



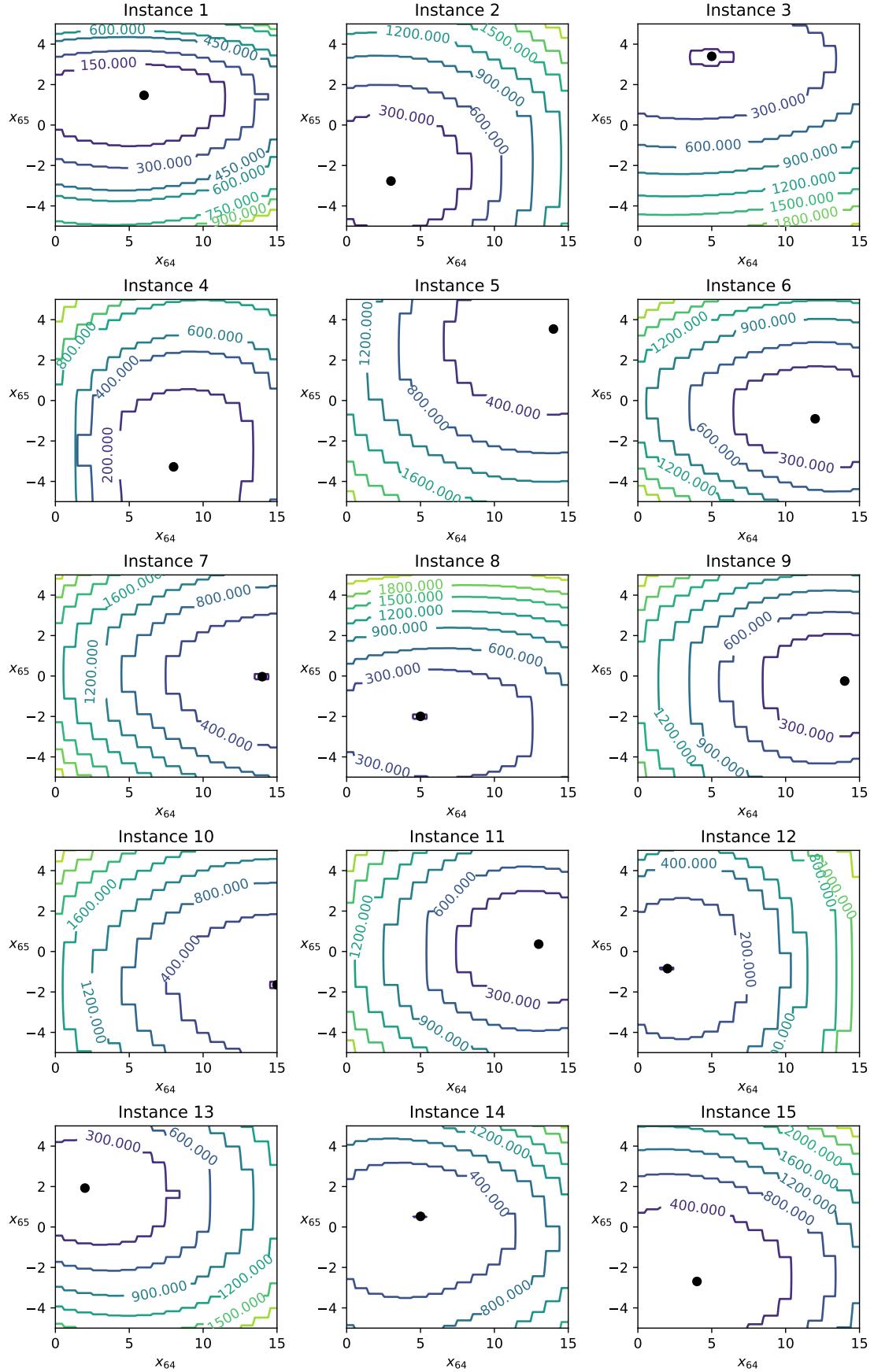
6.3 Function f_6 , Dimension 20



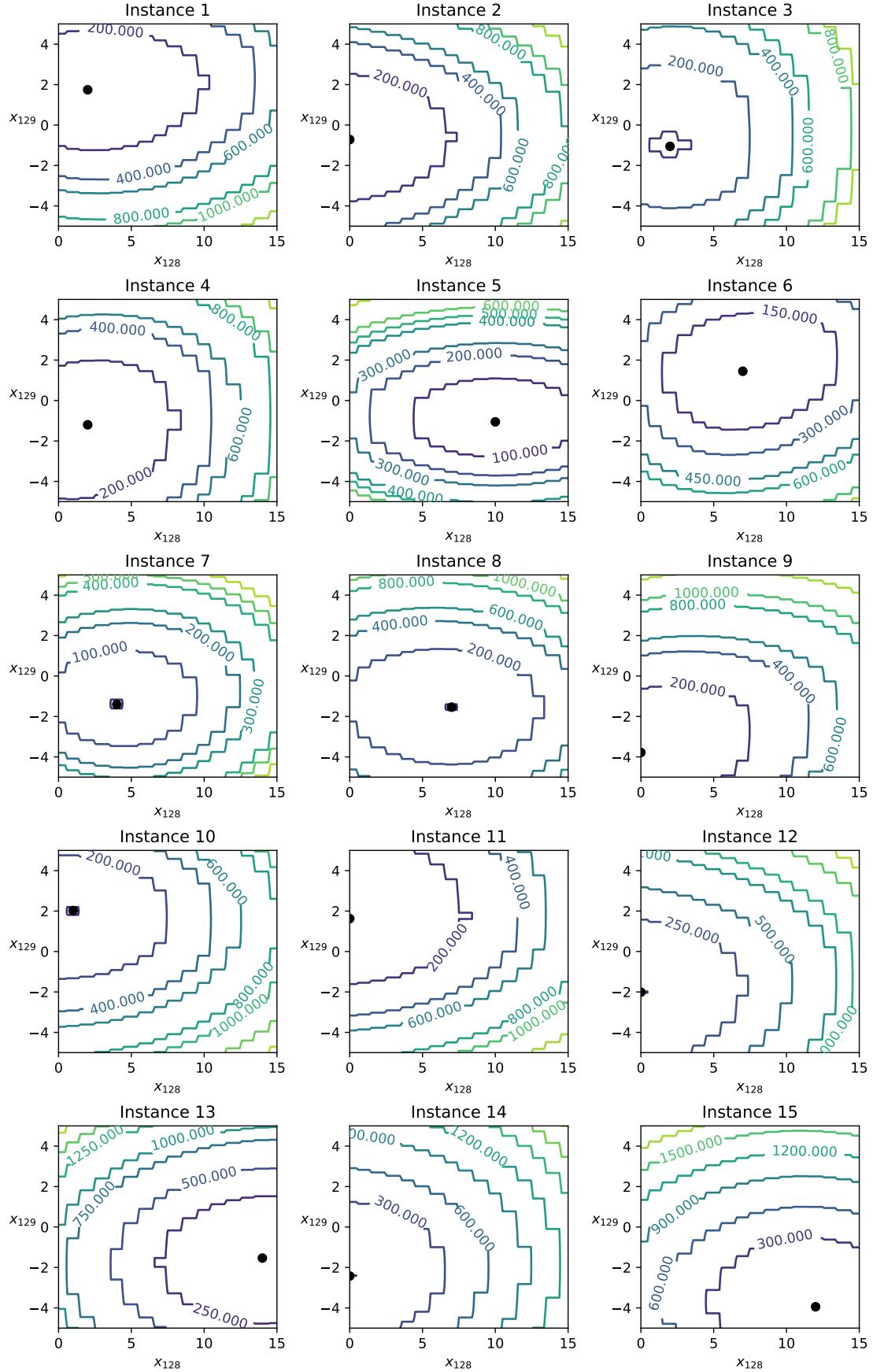
6.4 Function f_6 , Dimension 40



6.5 Function f_6 , Dimension 80

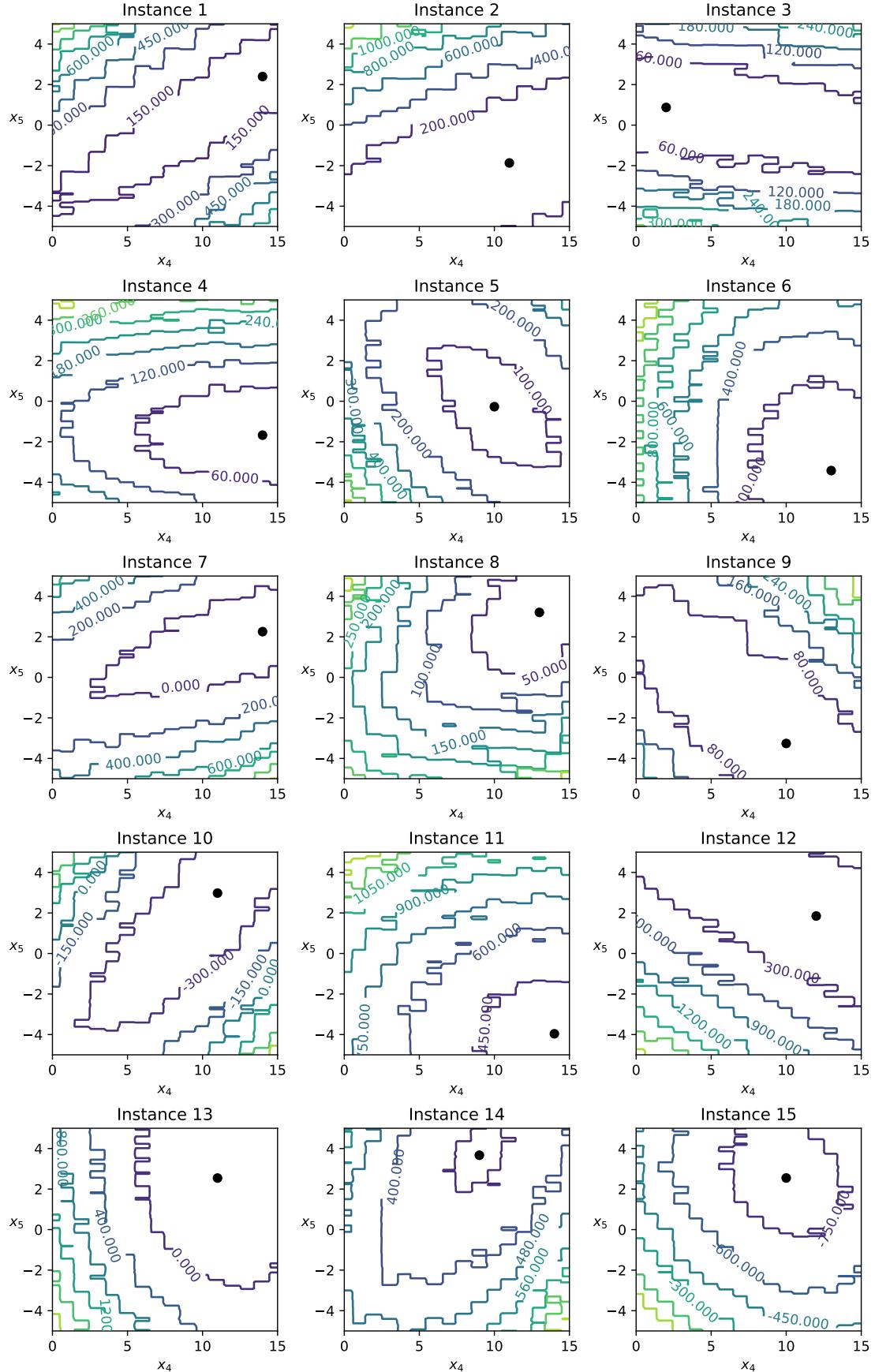


6.6 Function f_6 , Dimension 160

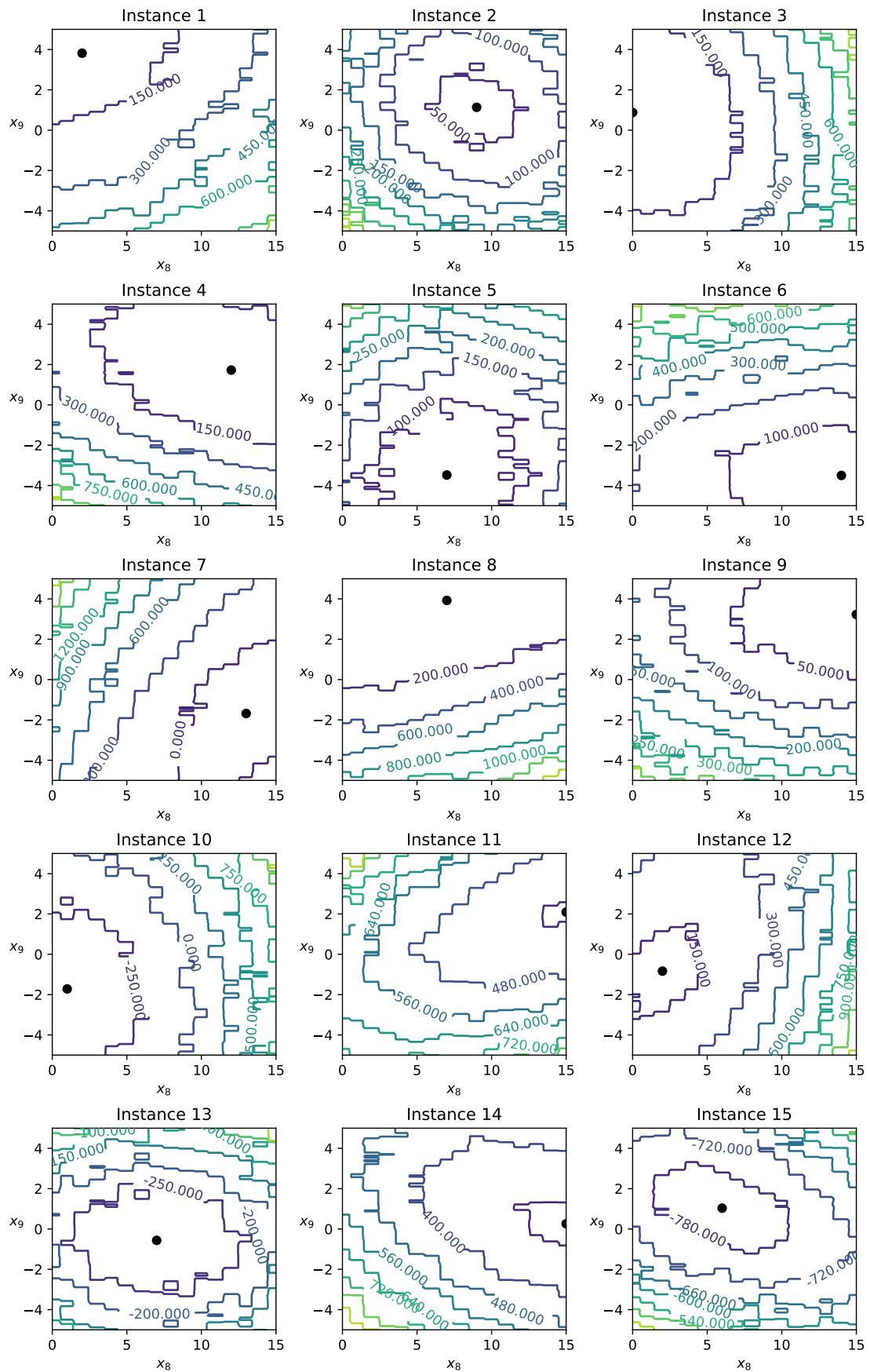


7 Function f_7 – Step Ellipsoidal

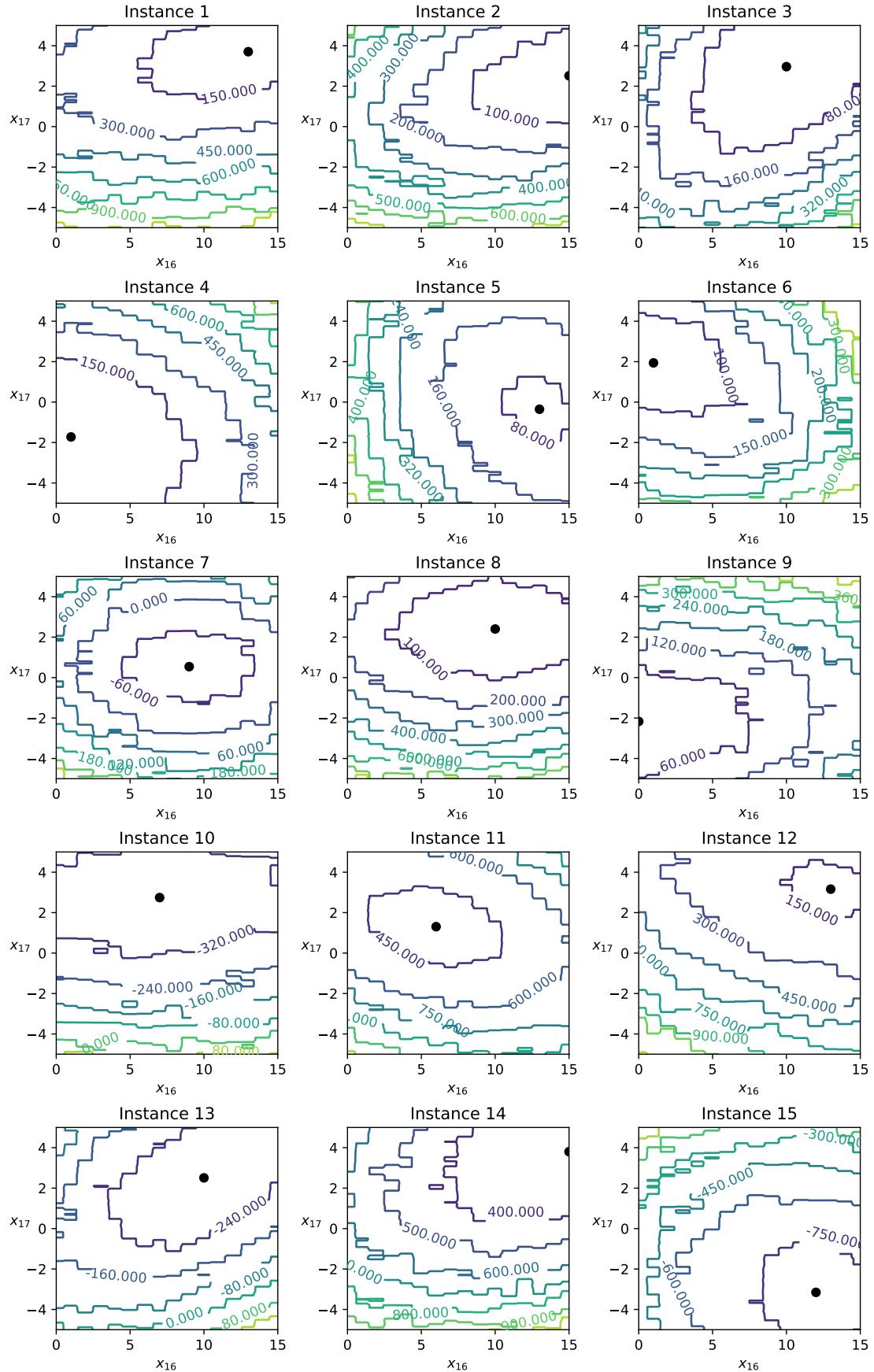
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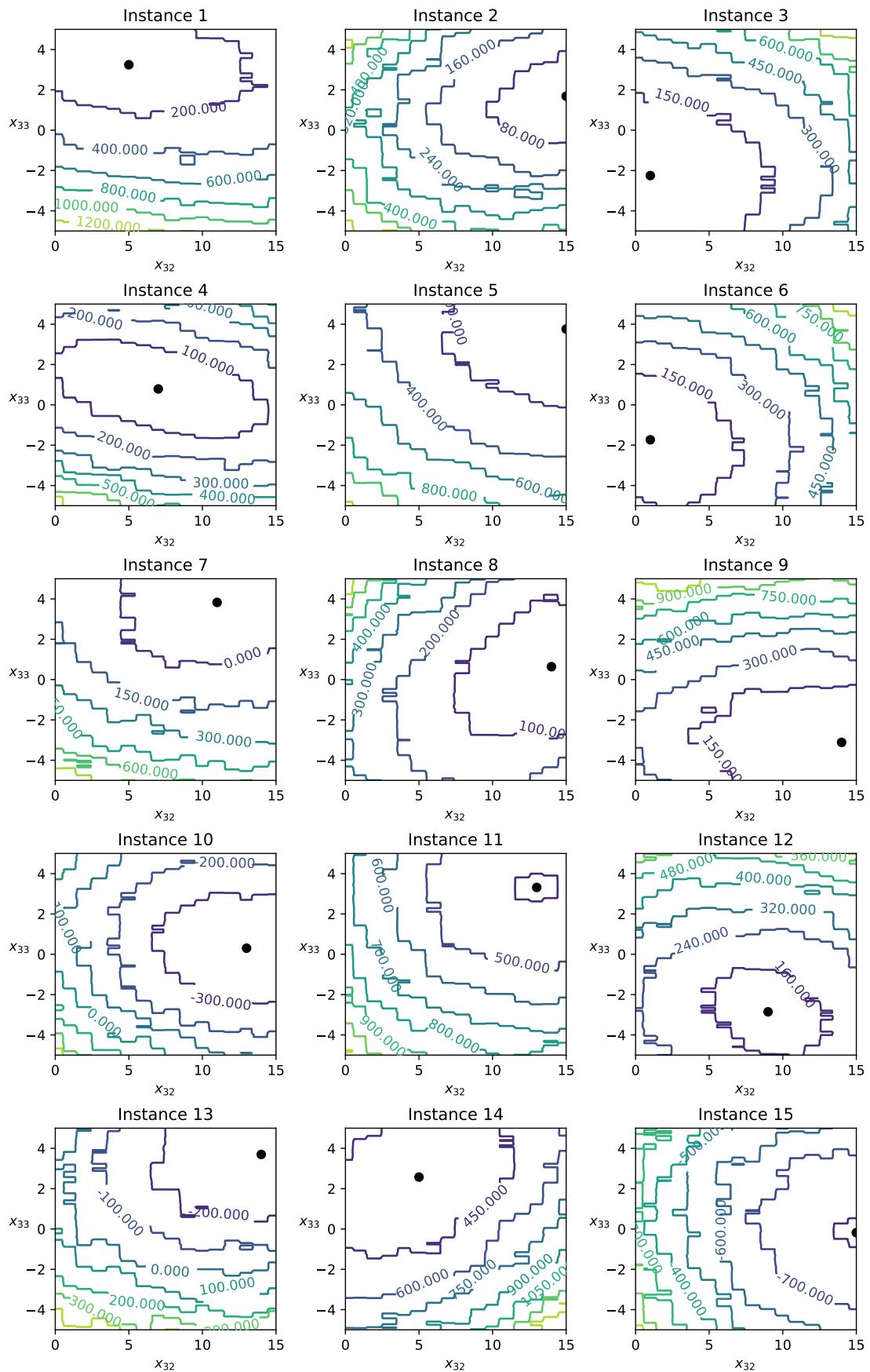
7.2 Function f_7 , Dimension 10



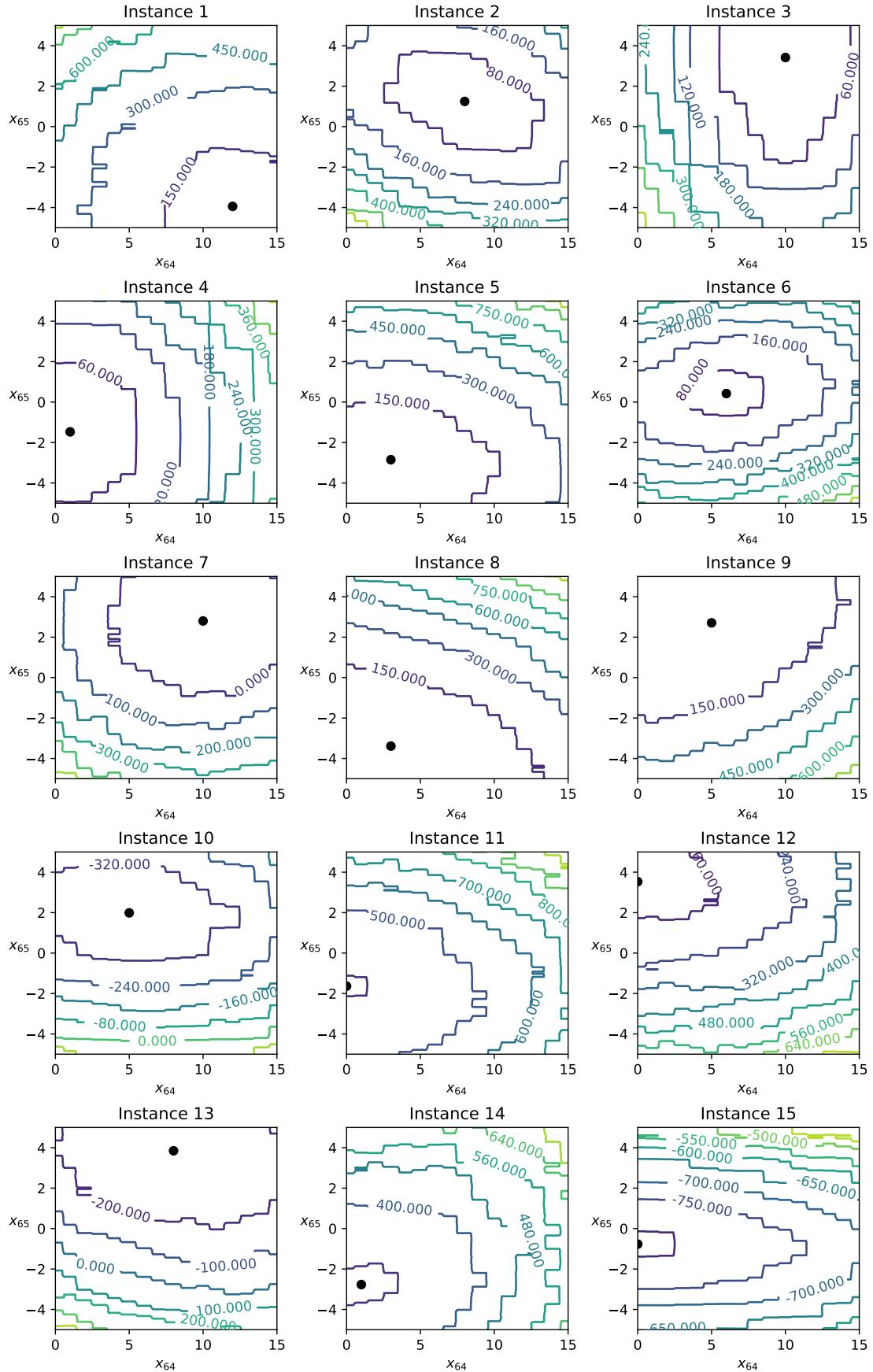
7.3 Function f_7 , Dimension 20



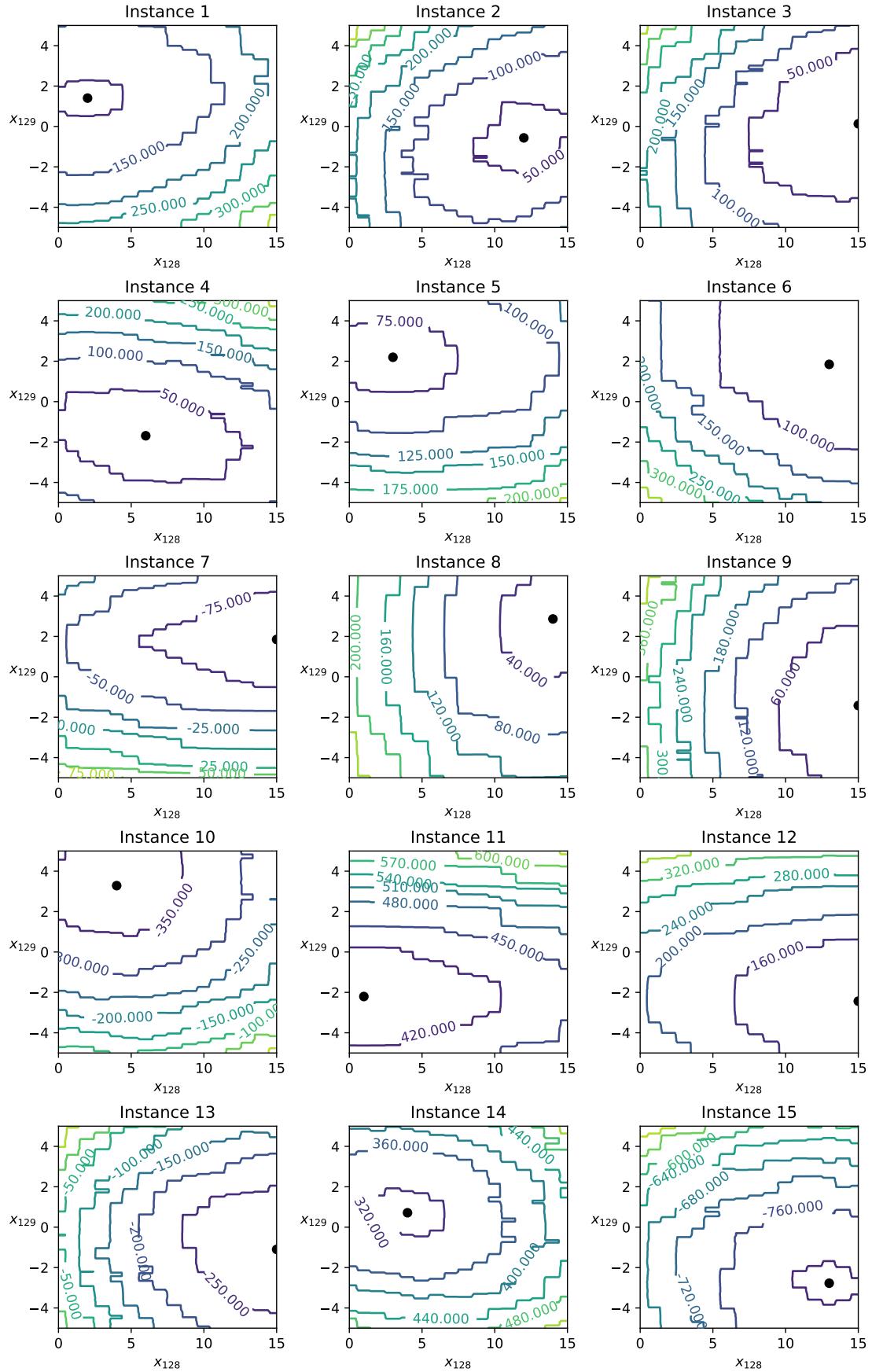
7.4 Function f_7 , Dimension 40



7.5 Function f_7 , Dimension 80

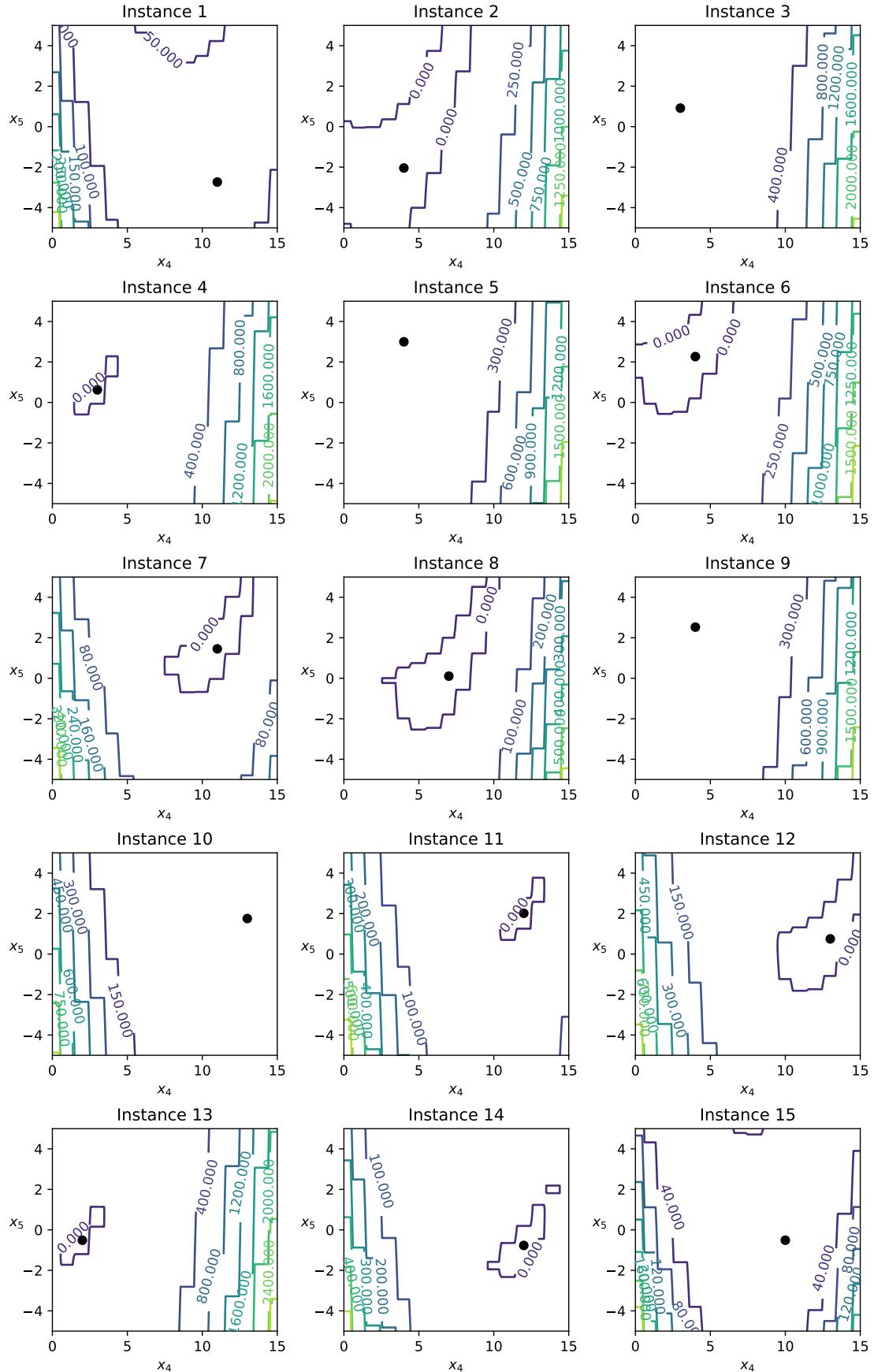


7.6 Function f_7 , Dimension 160

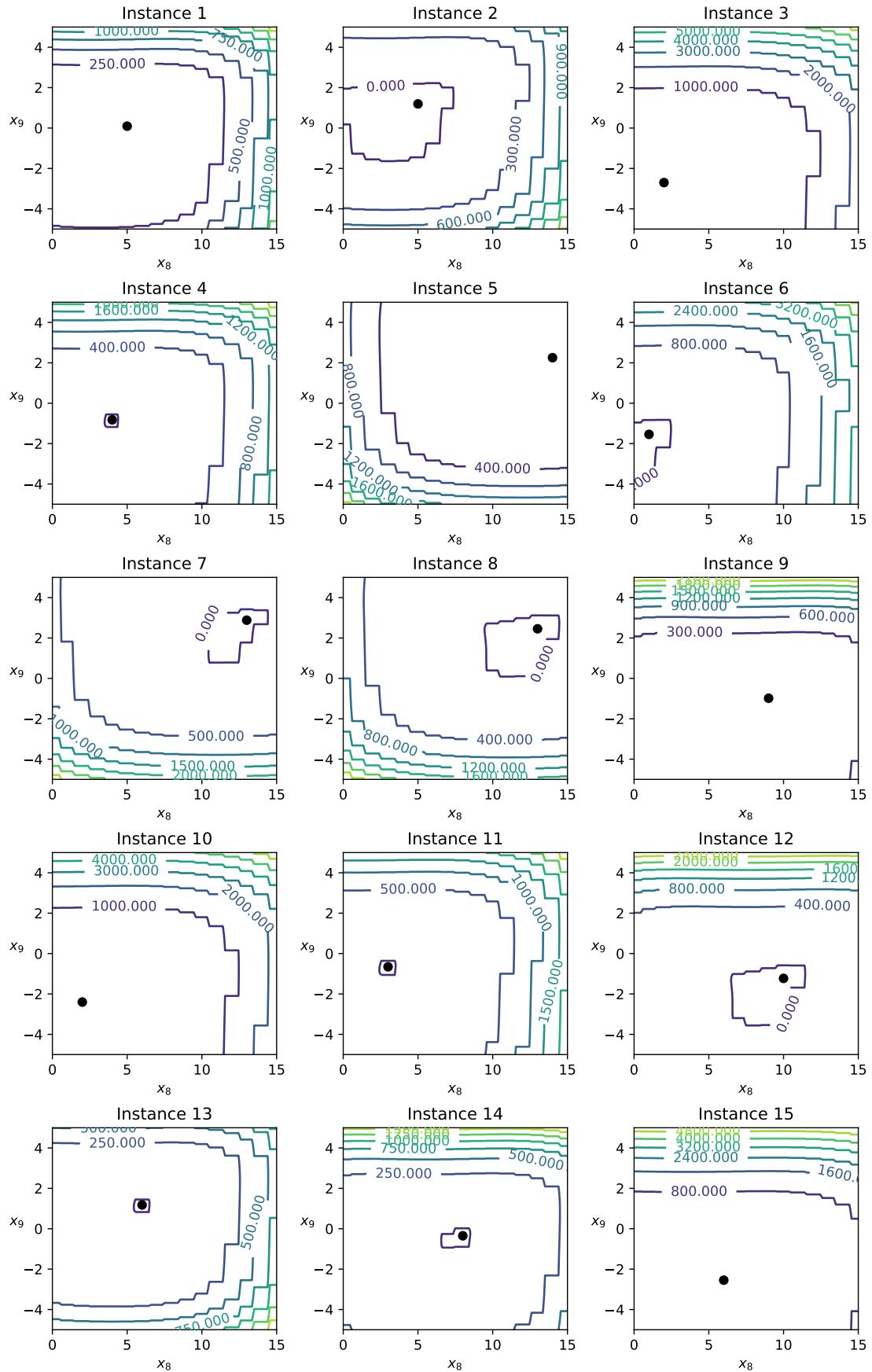


8 Function f_8 – Rosenbrock (Original)

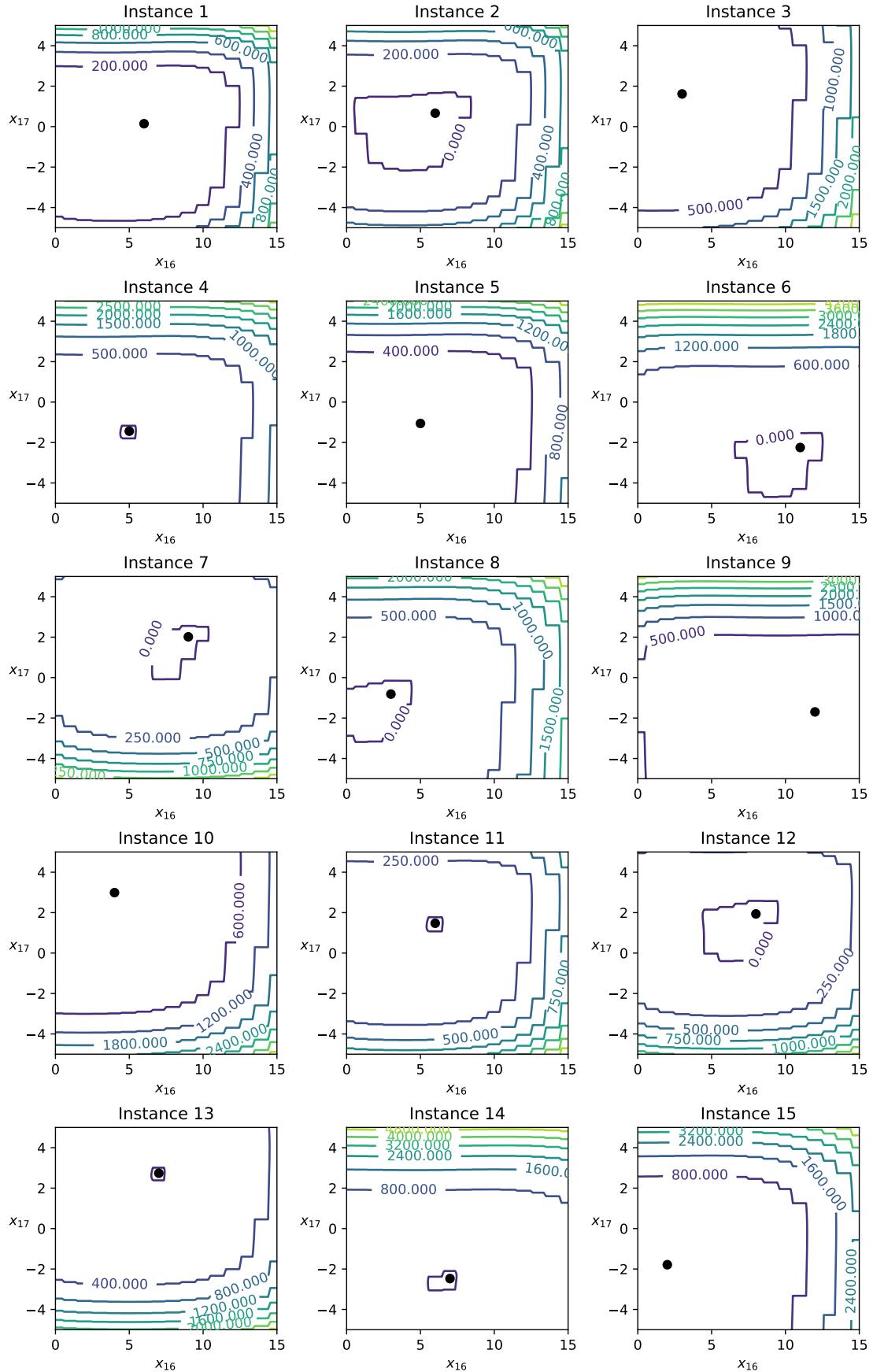
8.1 Function f_8 , Dimension 5



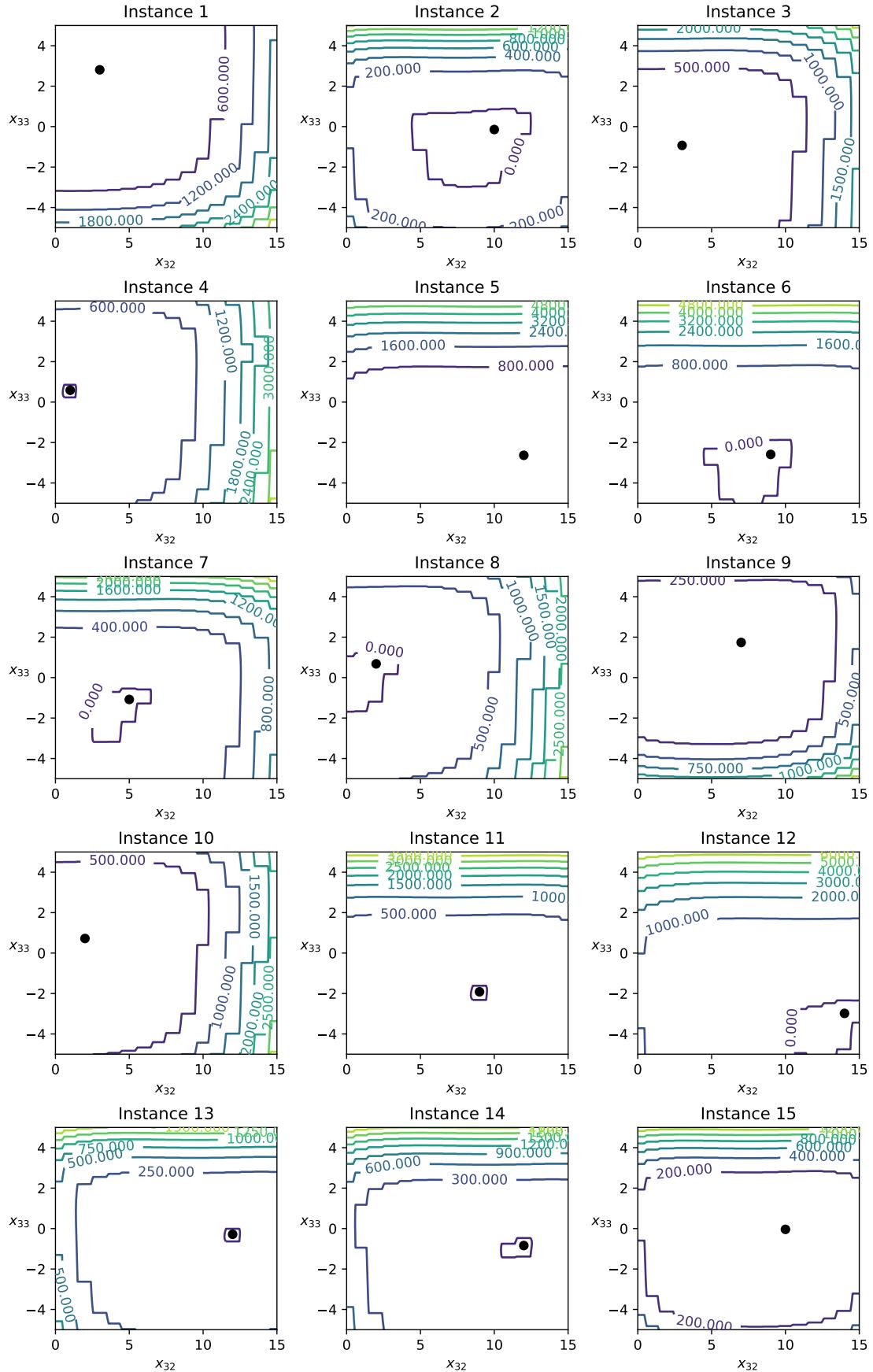
8.2 Function f_8 , Dimension 10



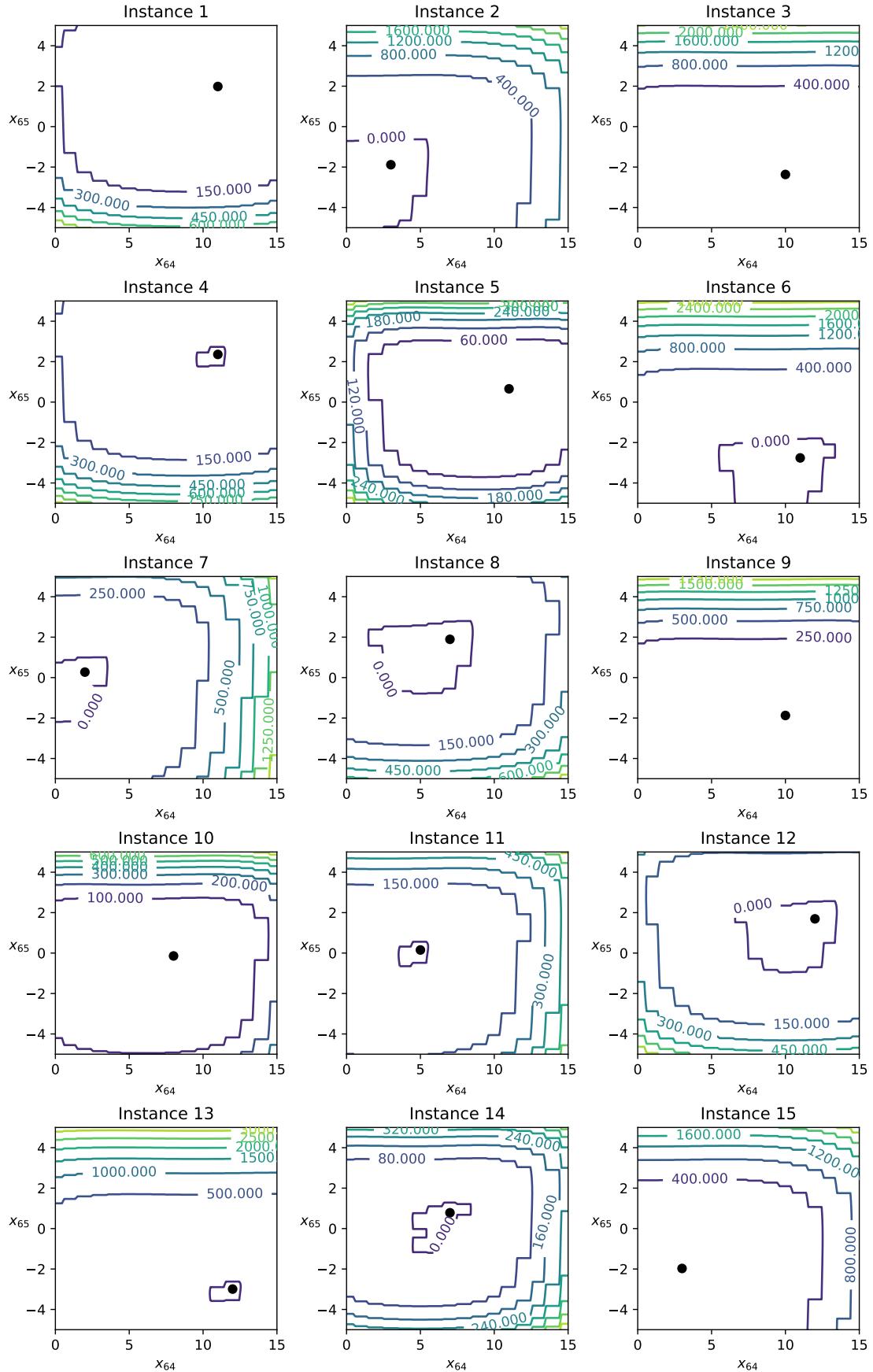
8.3 Function f_8 , Dimension 20



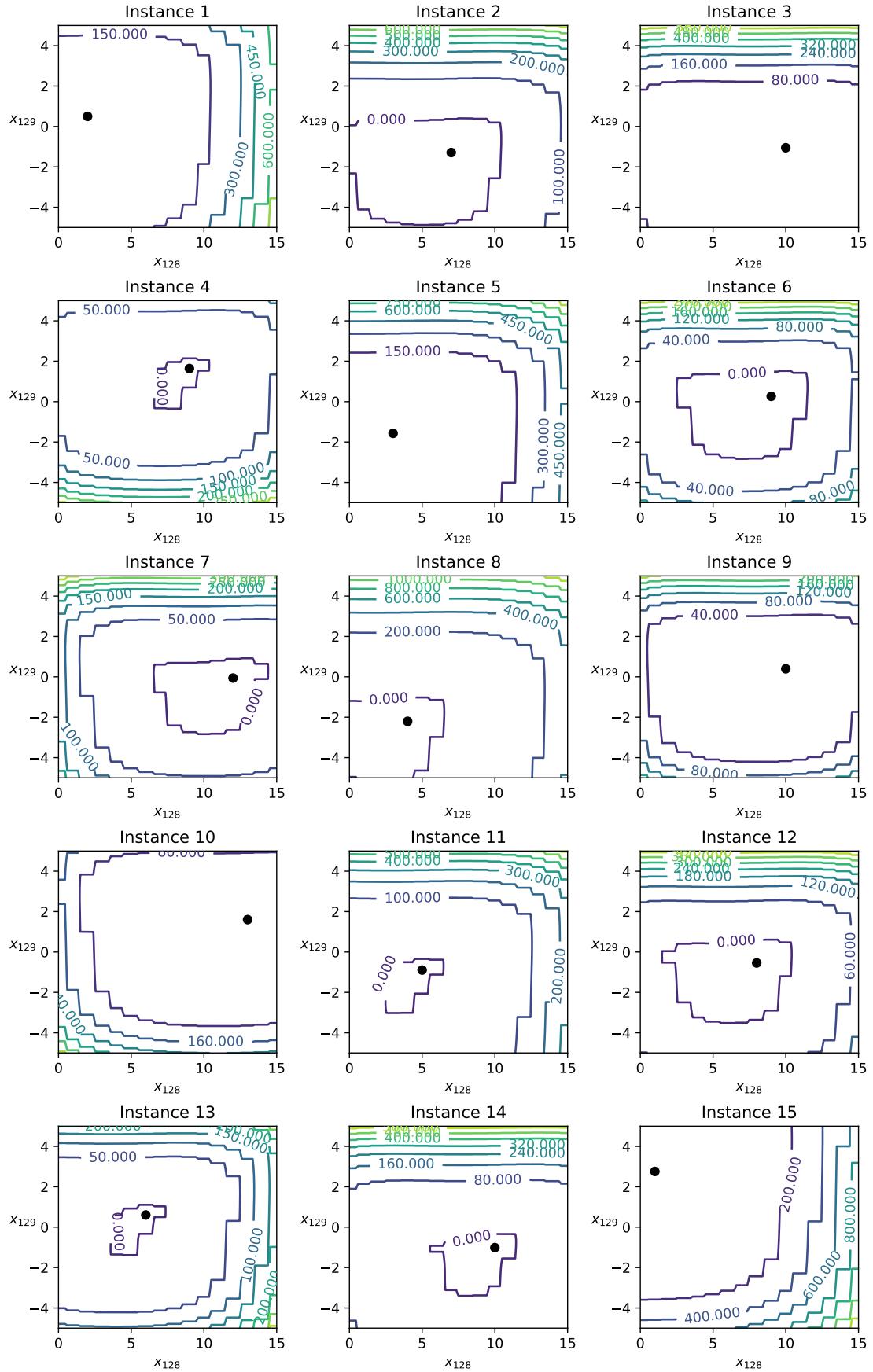
8.4 Function f_8 , Dimension 40



8.5 Function f_8 , Dimension 80

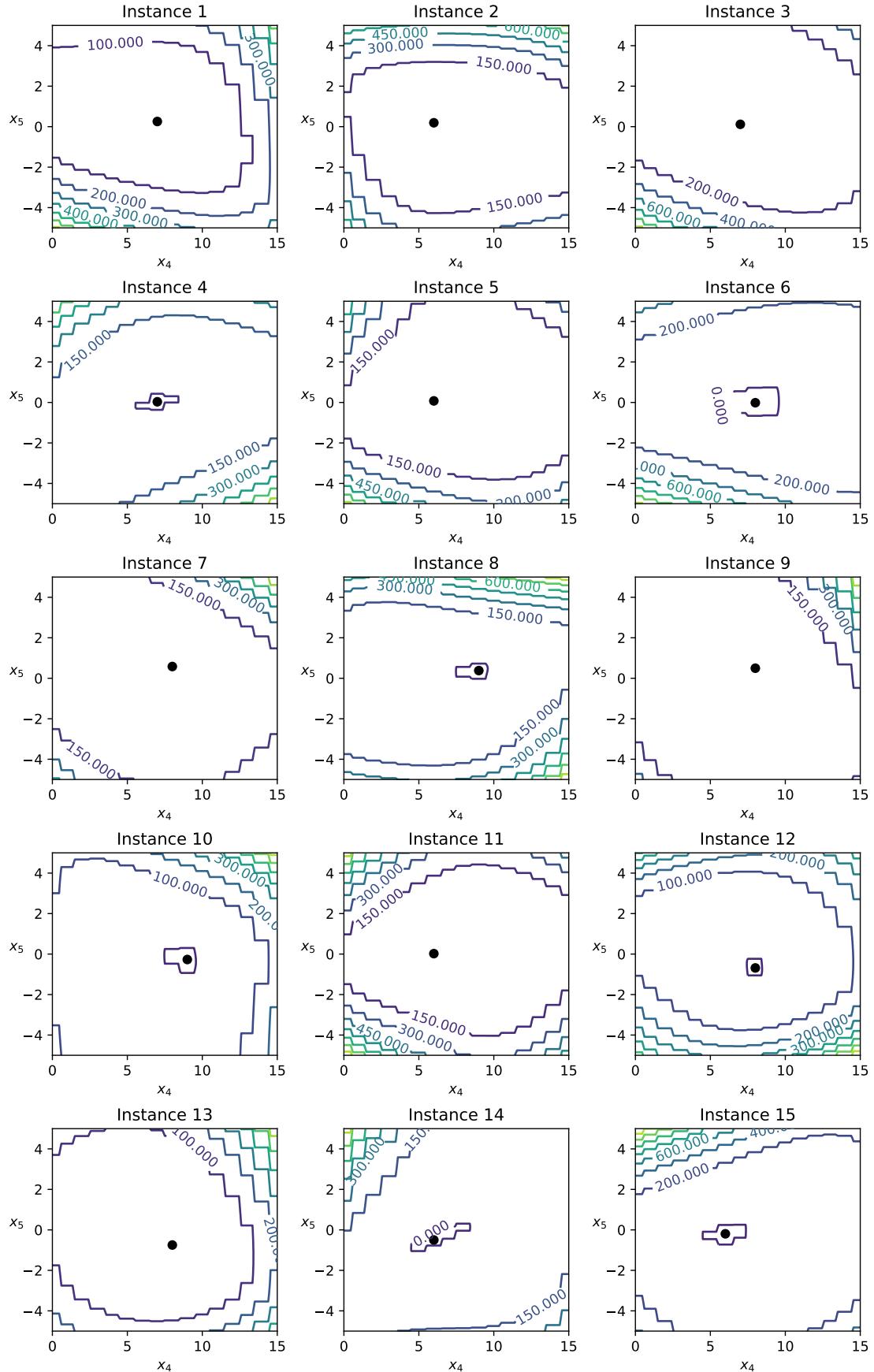


8.6 Function f_8 , Dimension 160

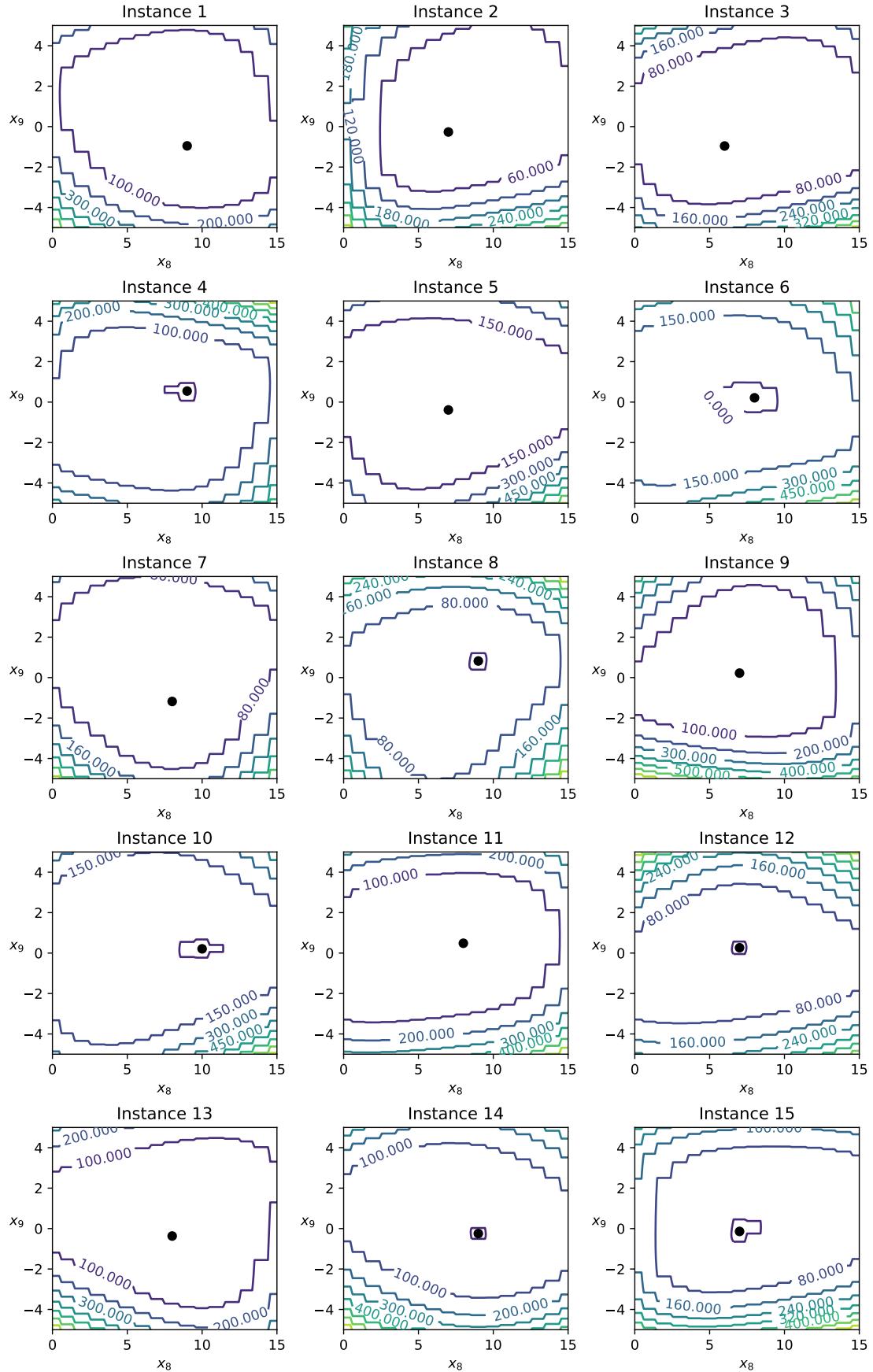


9 Function f_9 – Rosenbrock (Rotated)

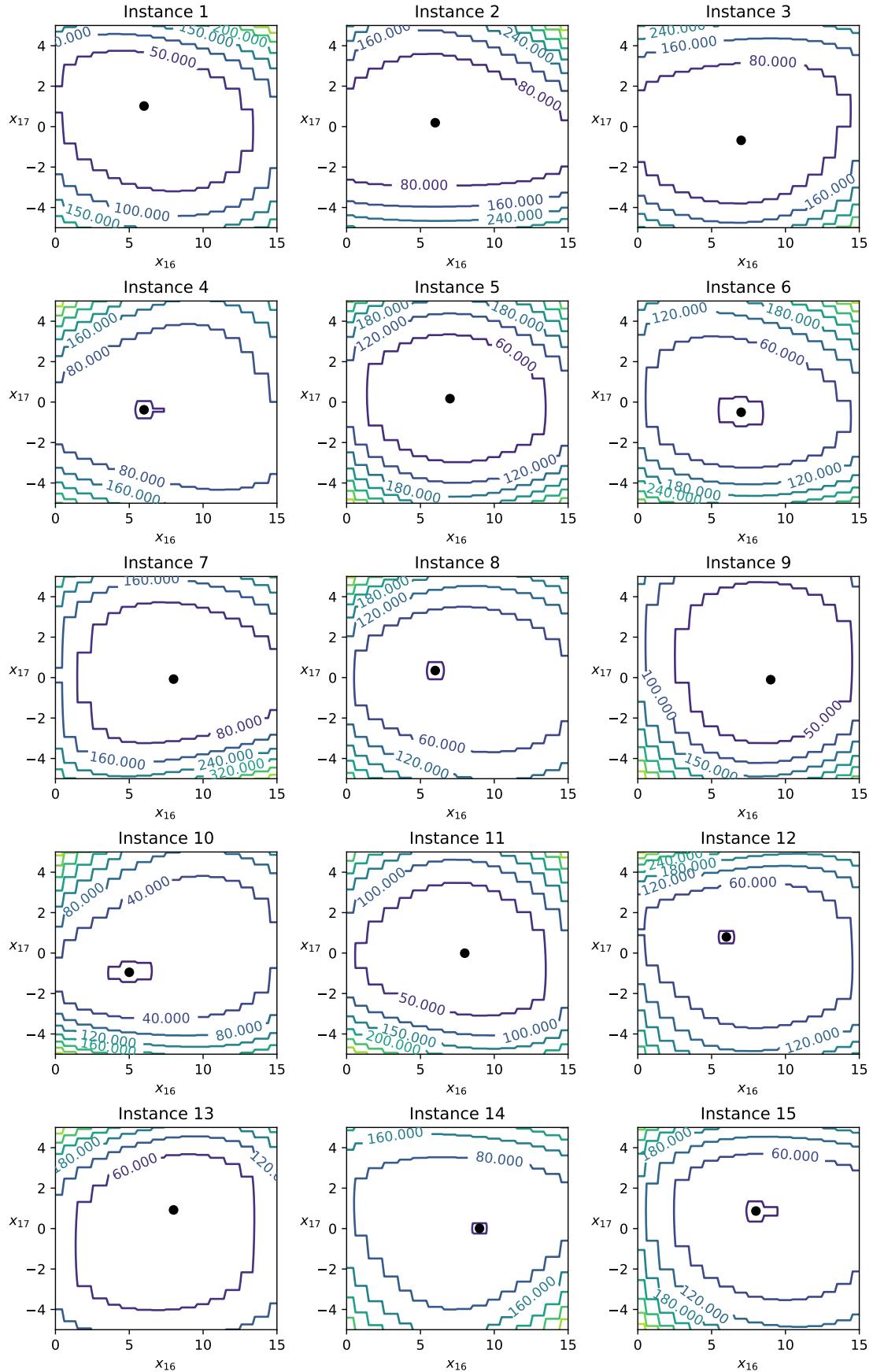
9.1 Function f_9 , Dimension 5



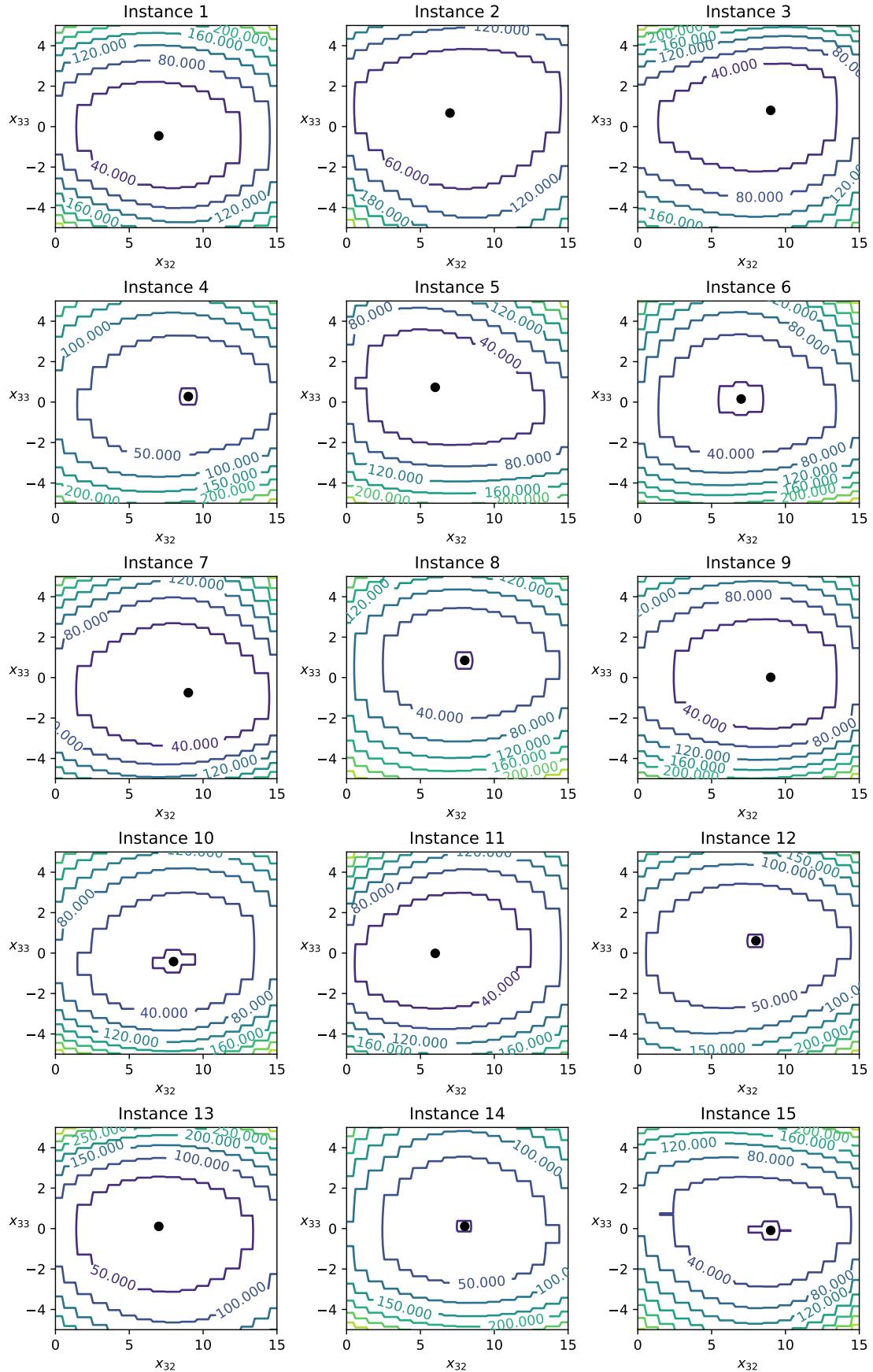
9.2 Function f_9 , Dimension 10



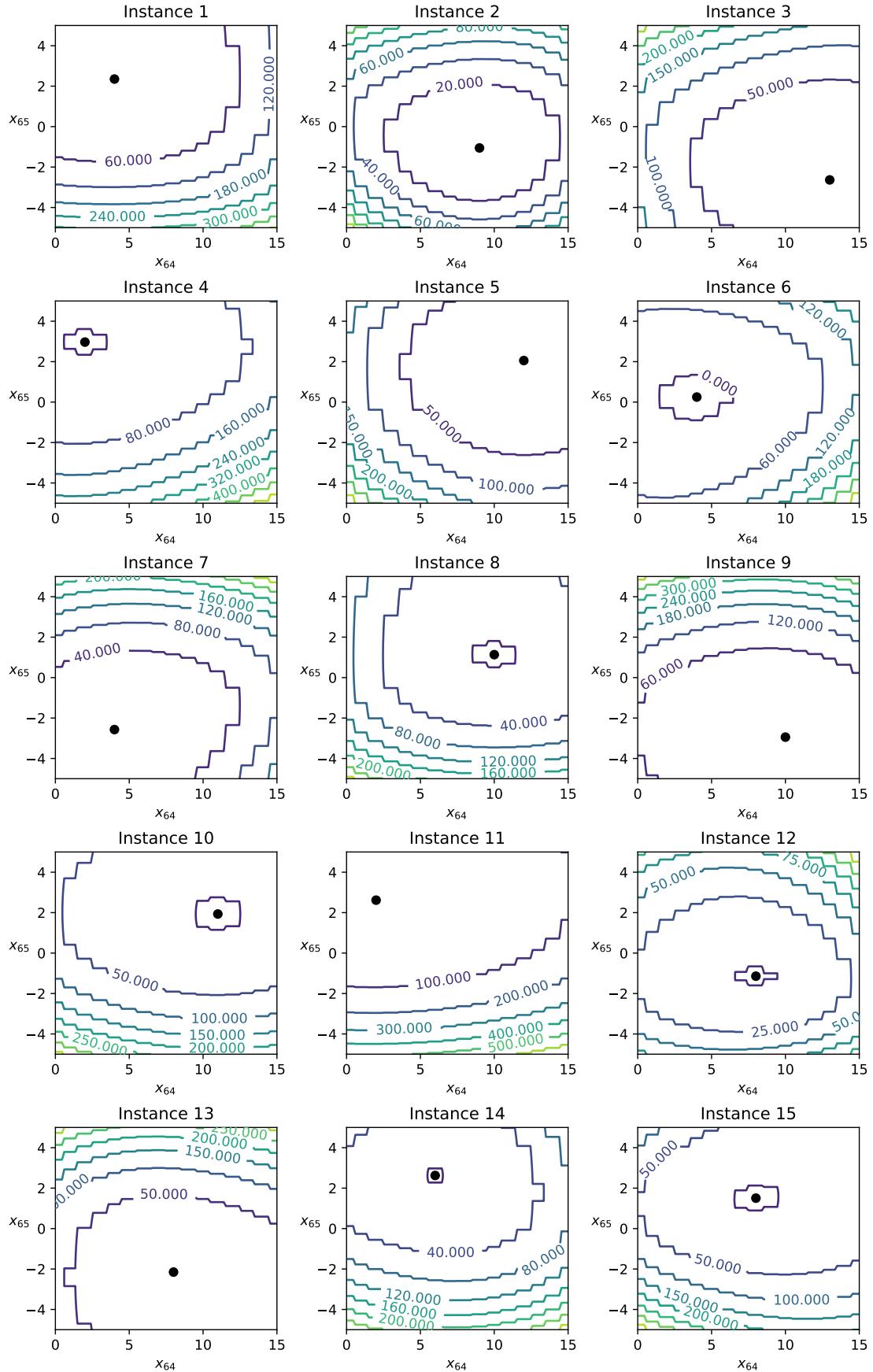
9.3 Function f_9 , Dimension 20



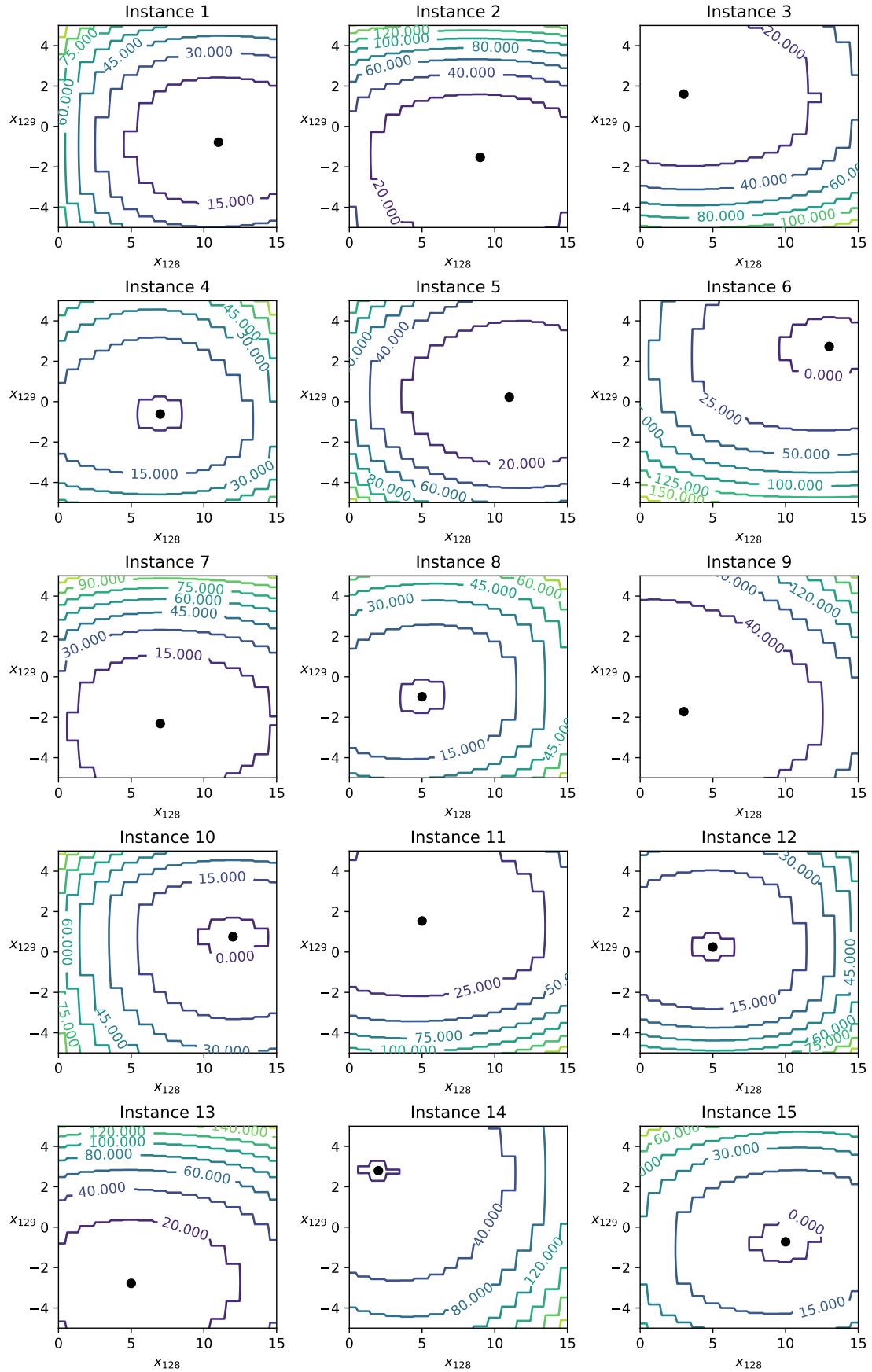
9.4 Function f_9 , Dimension 40



9.5 Function f_9 , Dimension 80

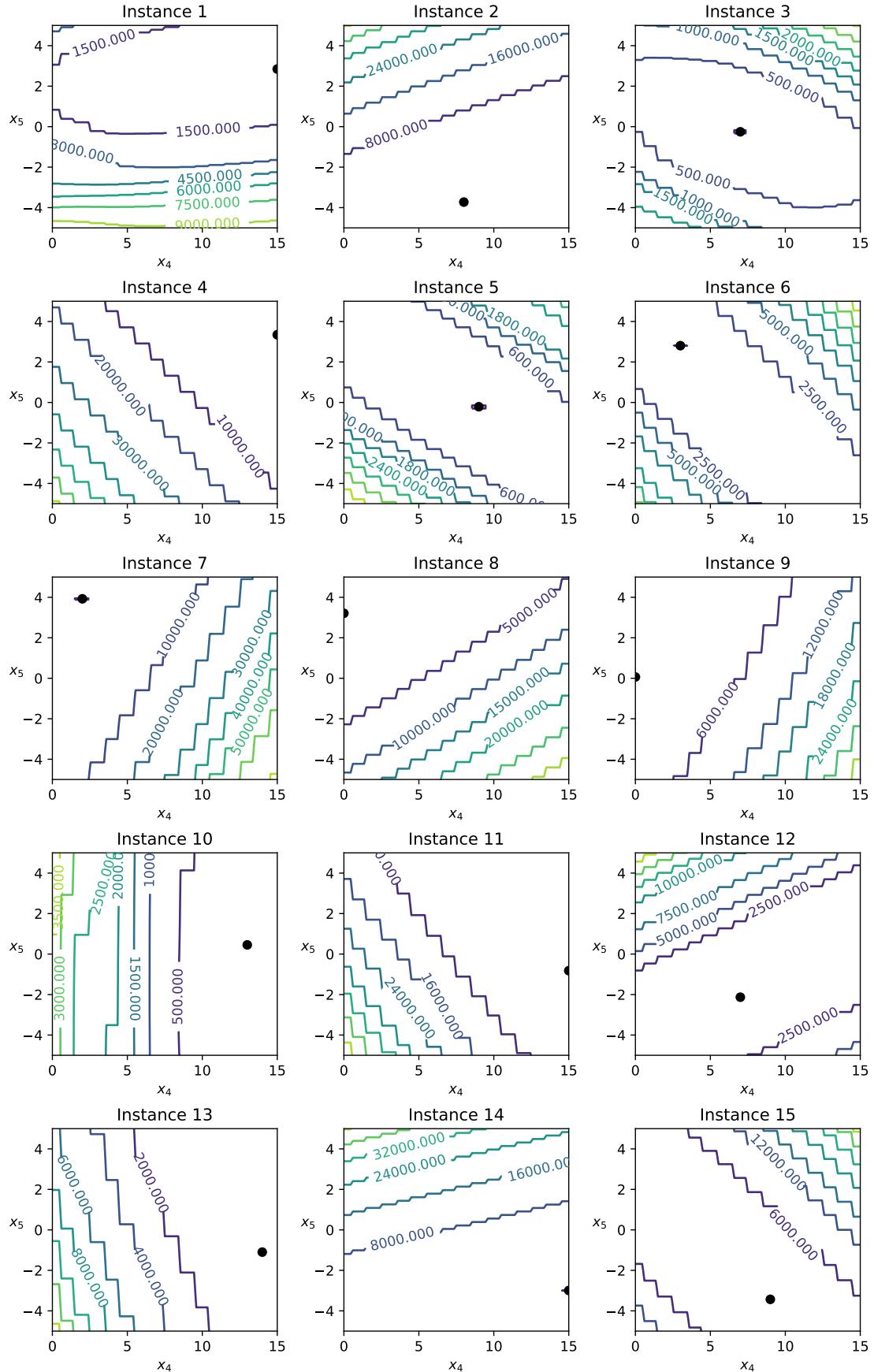


9.6 Function f_9 , Dimension 160

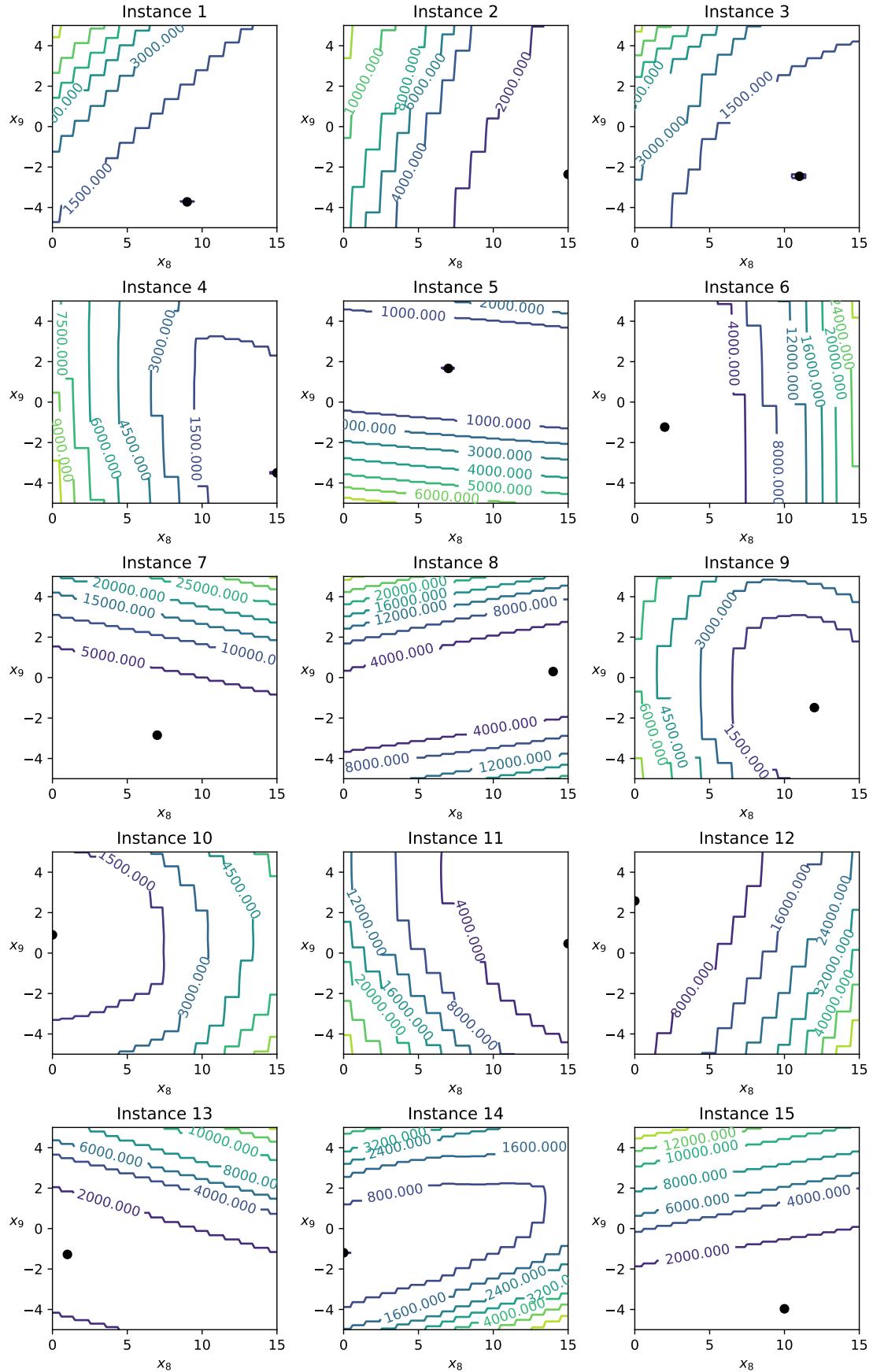


10 Function f_{10} – Ellipsoidal (Rotated)

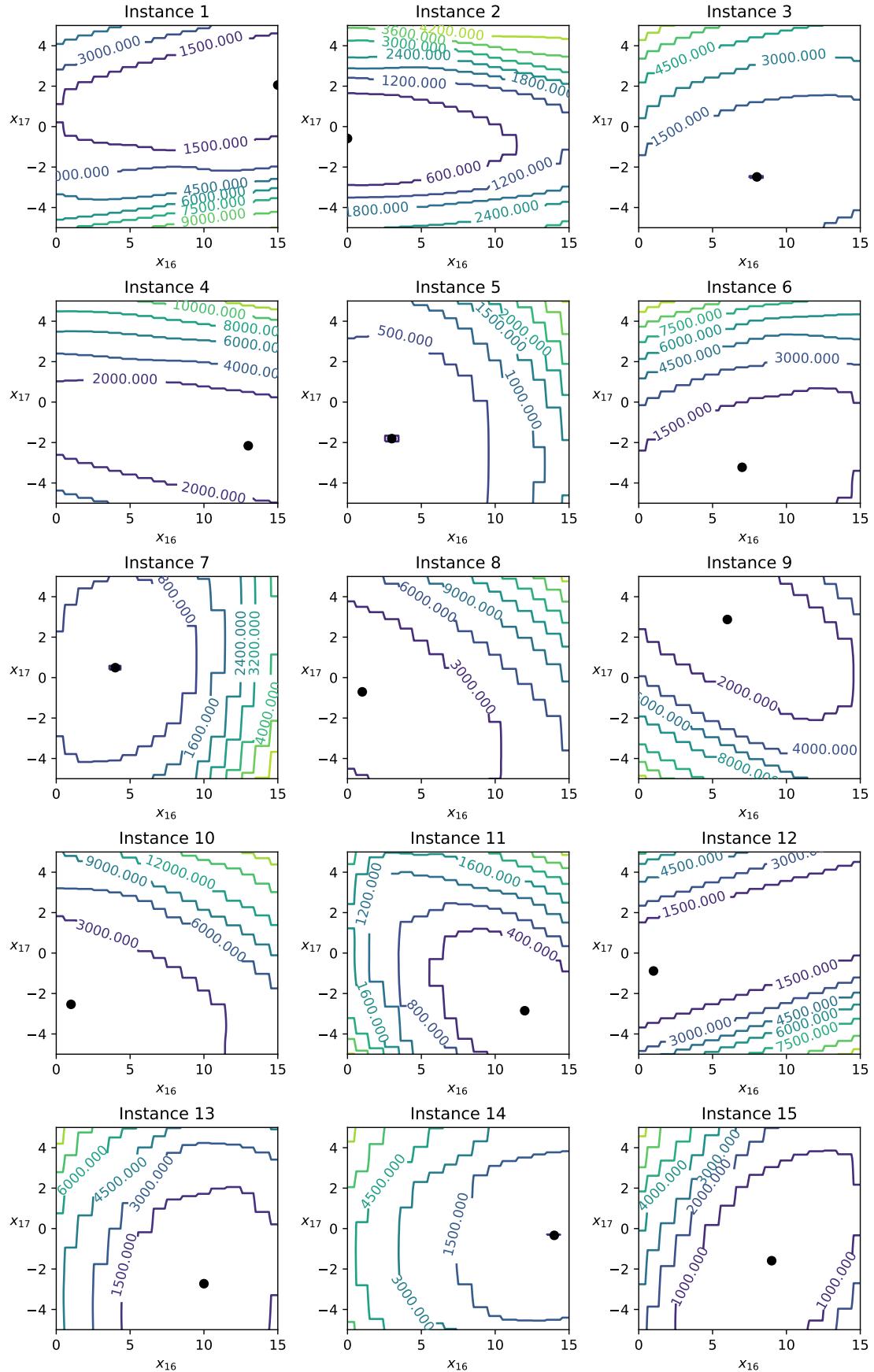
10.1 Function f_{10} , Dimension 5



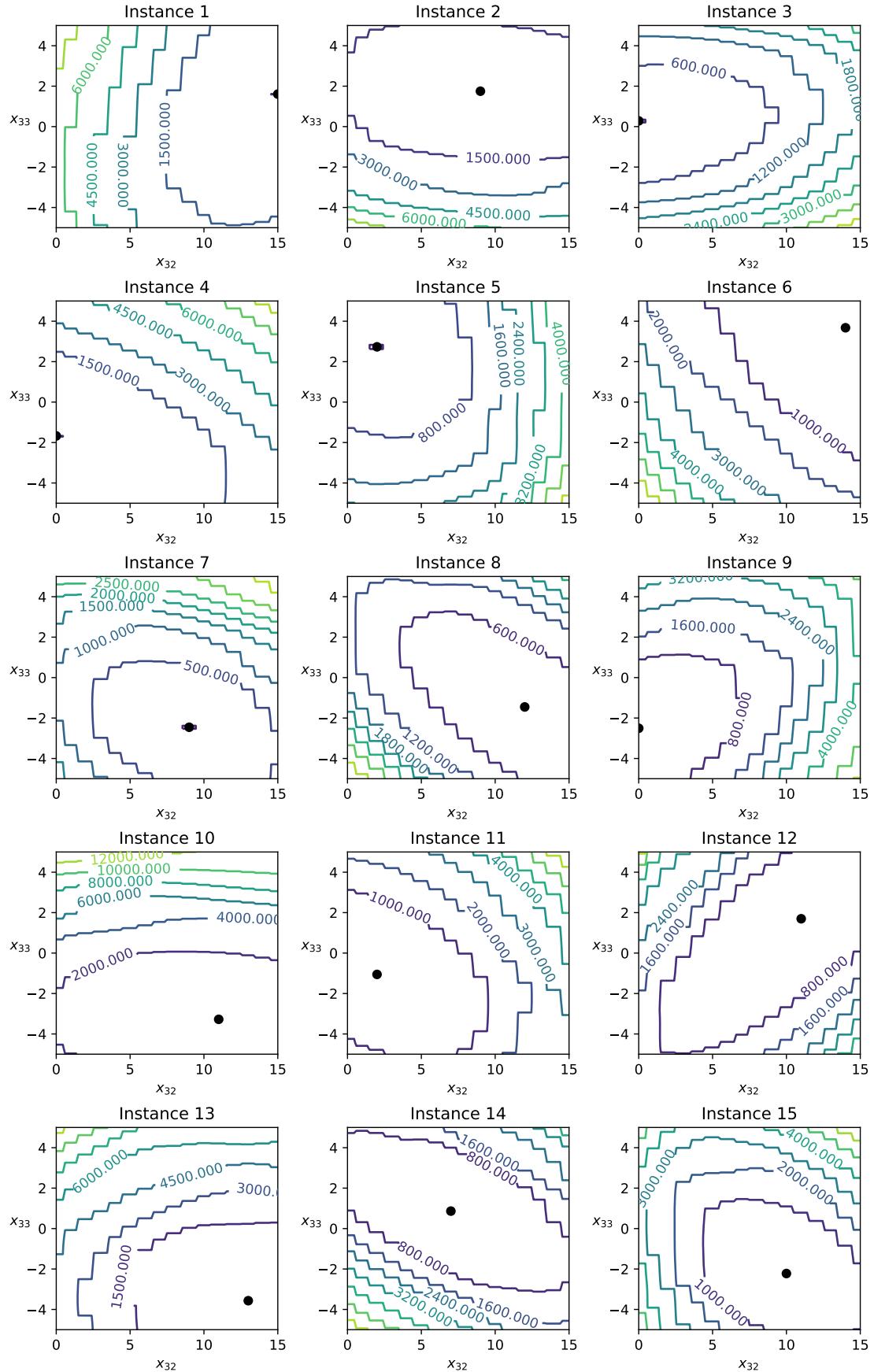
10.2 Function f_{10} , Dimension 10



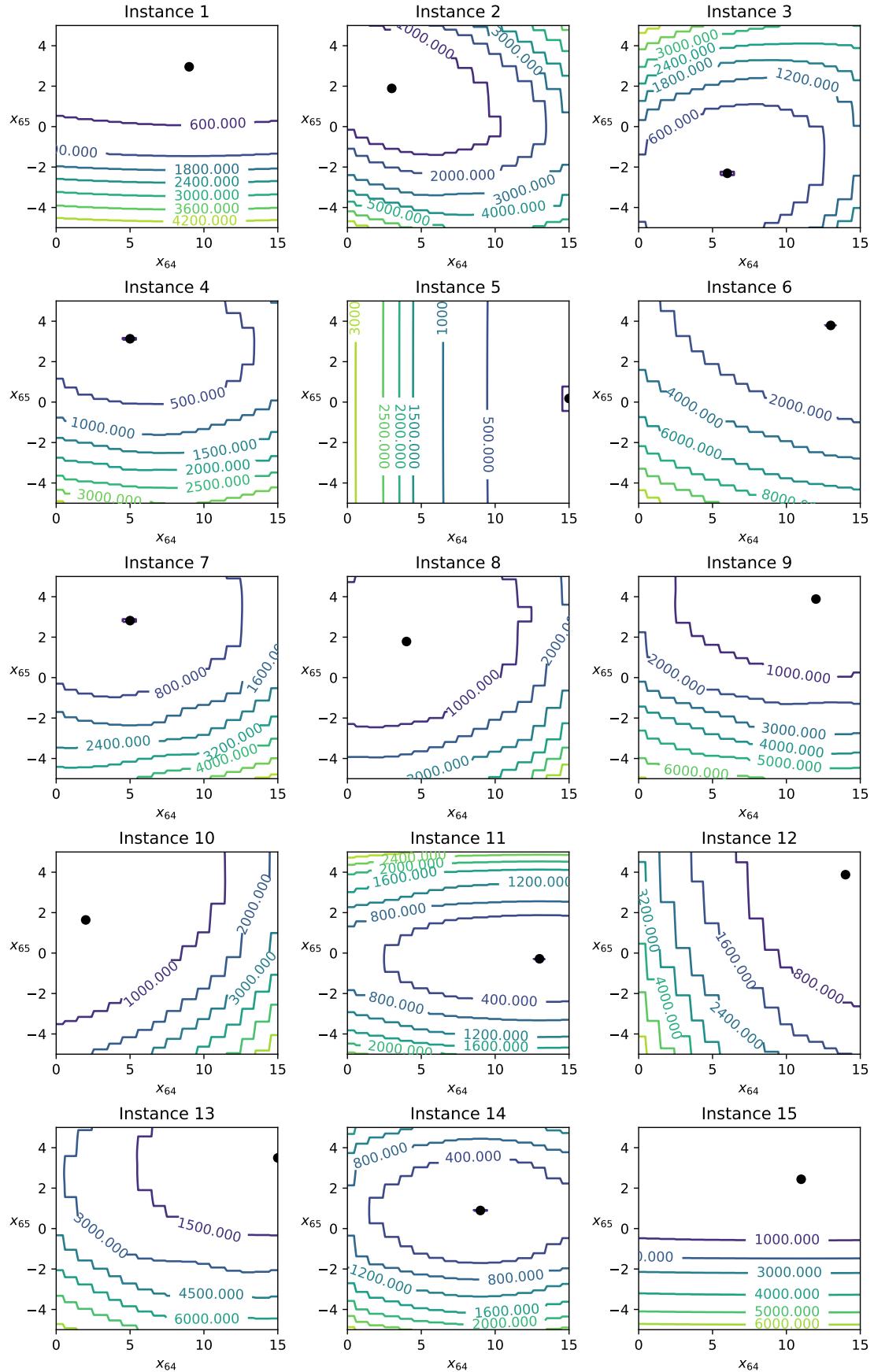
10.3 Function f_{10} , Dimension 20



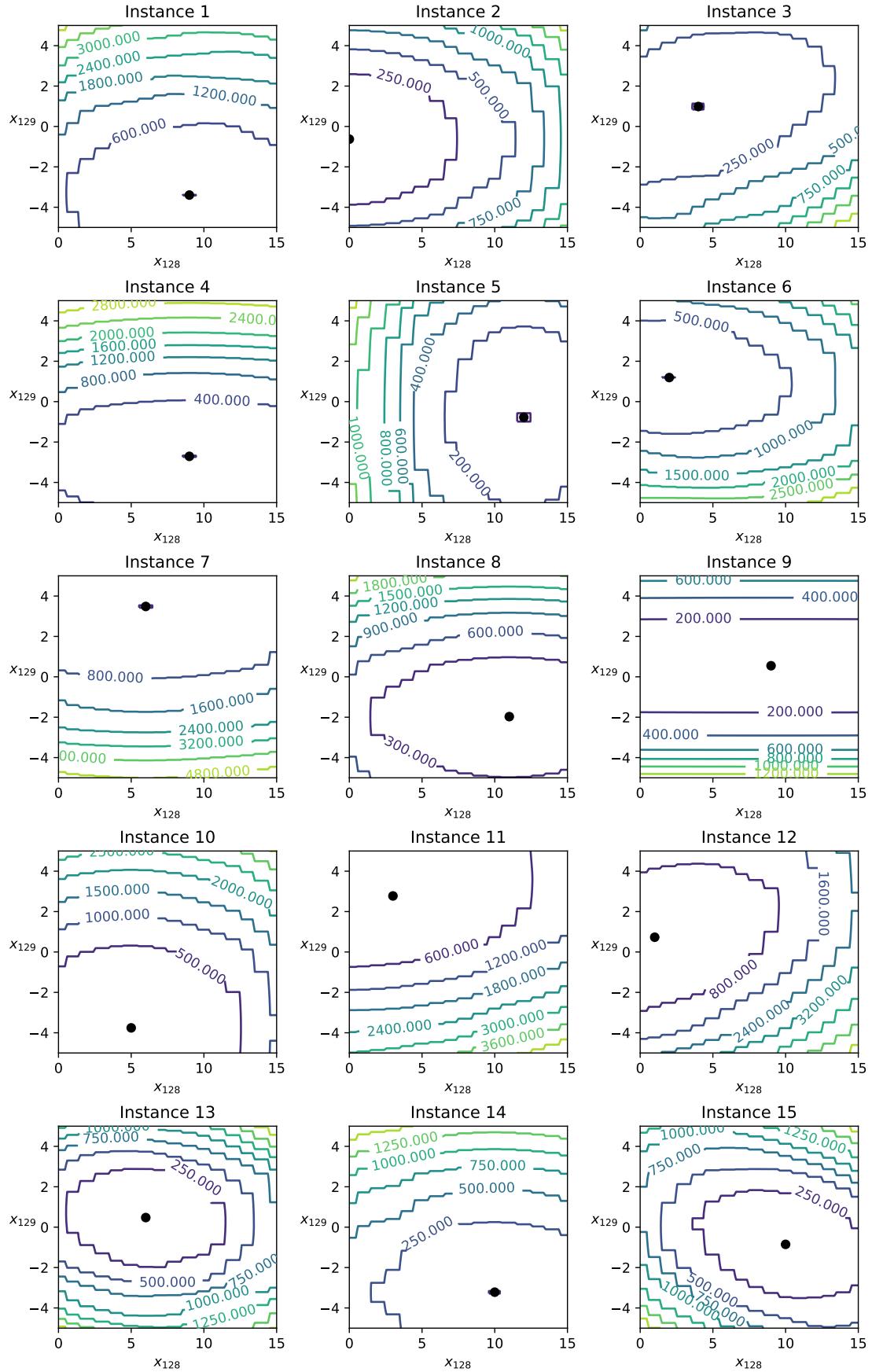
10.4 Function f_{10} , Dimension 40



10.5 Function f_{10} , Dimension 80

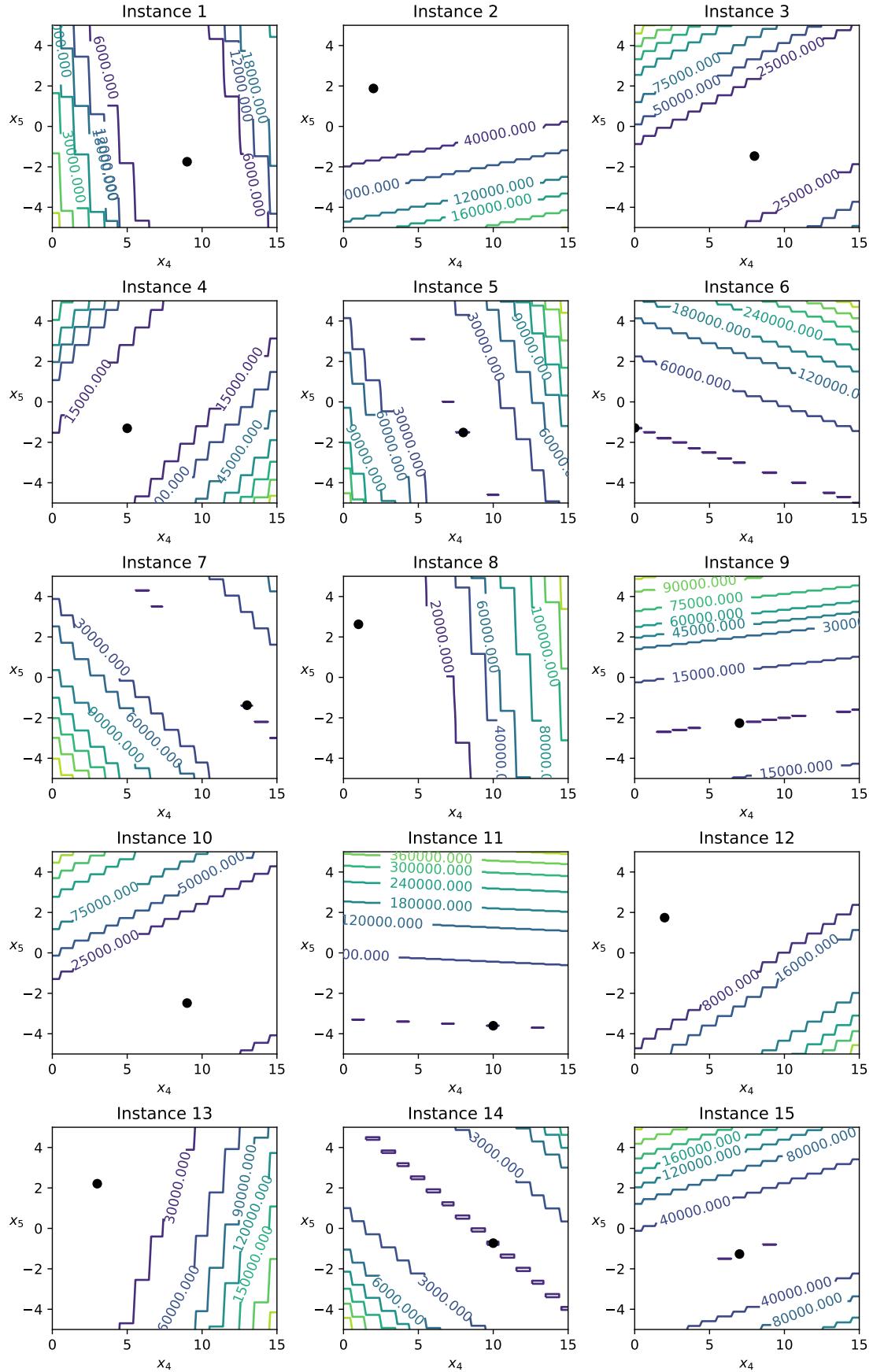


10.6 Function f_{10} , Dimension 160

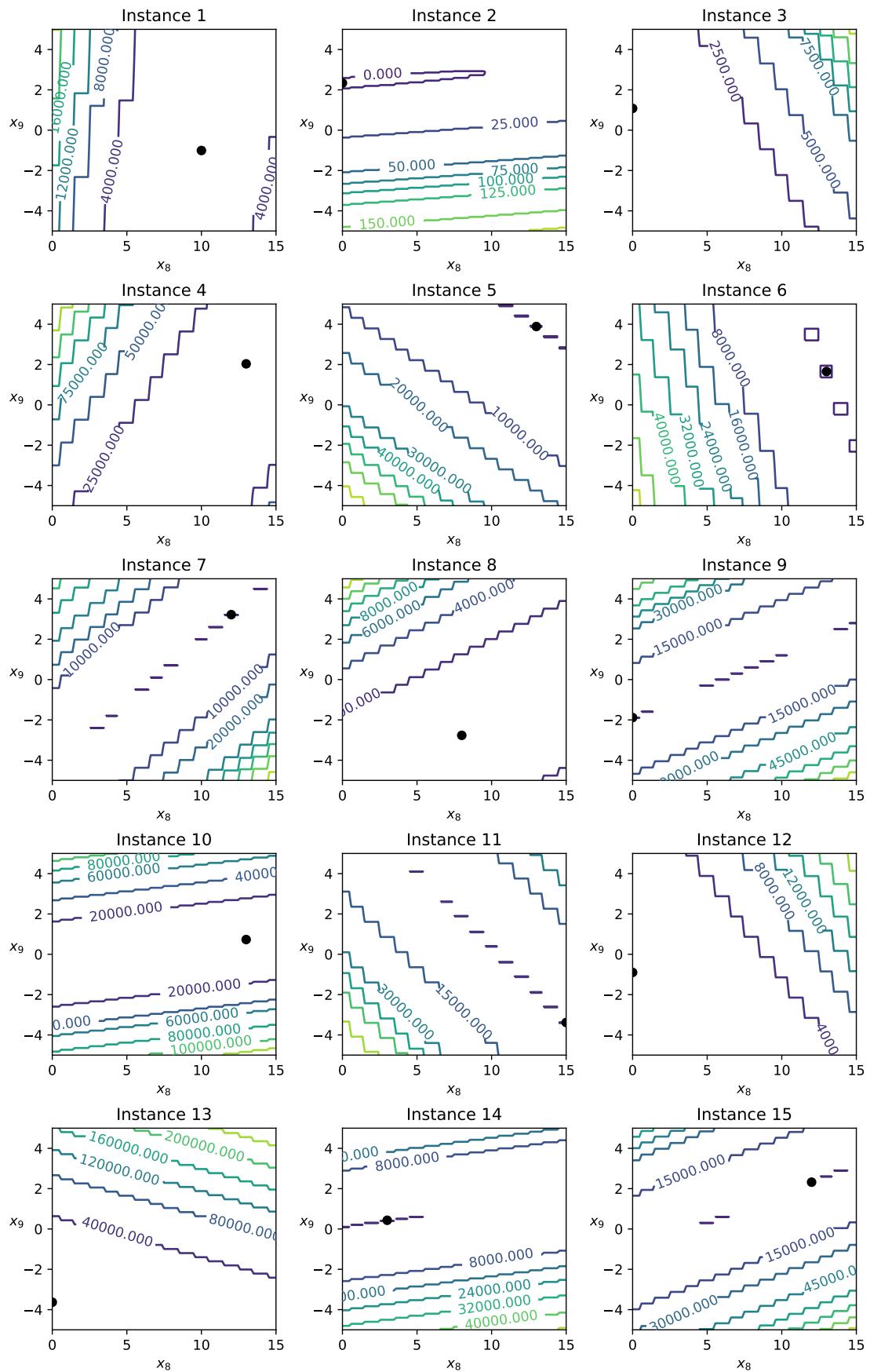


11 Function f_{11} – Discus

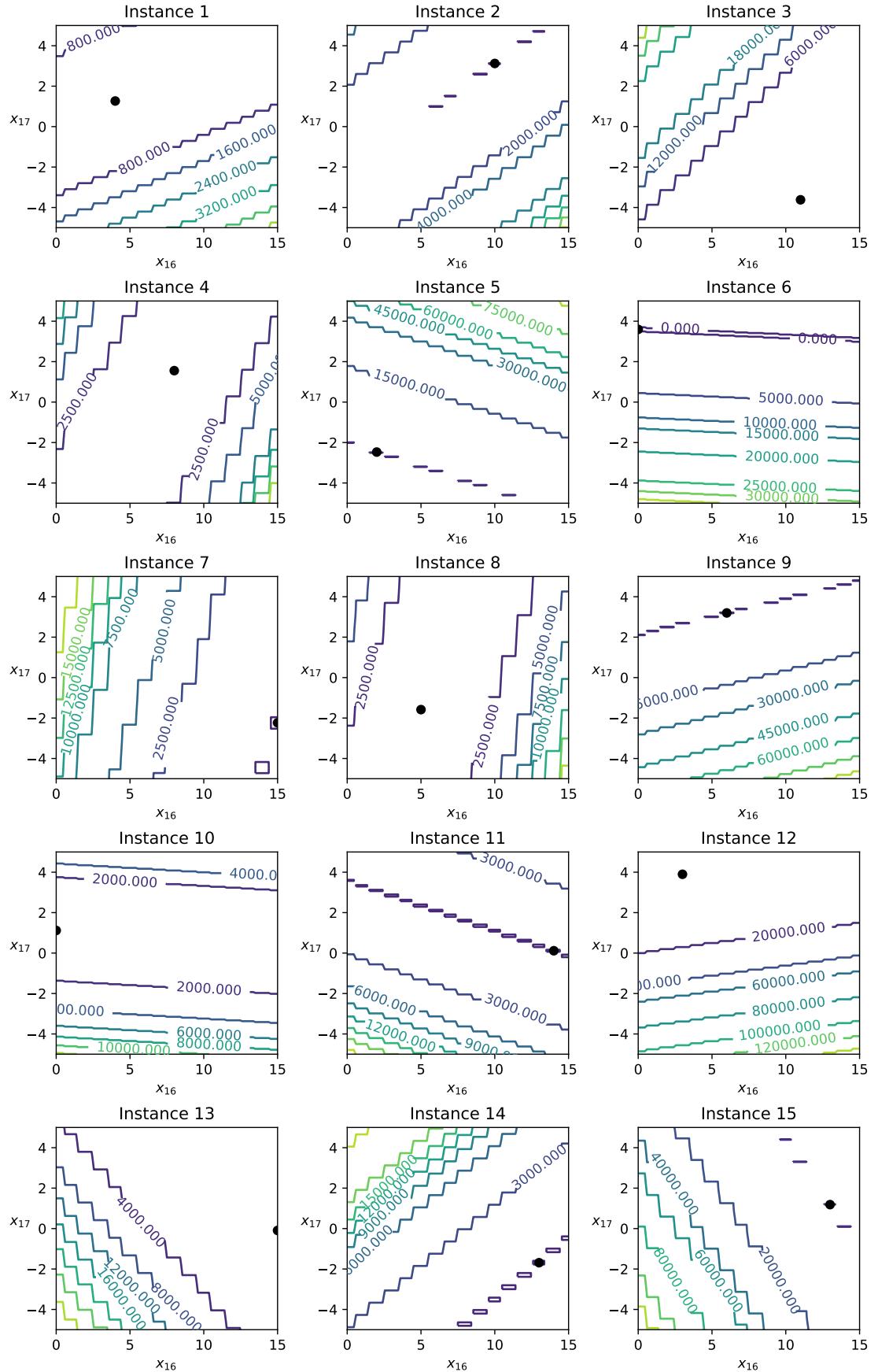
11.1 Function f_{11} , Dimension 5



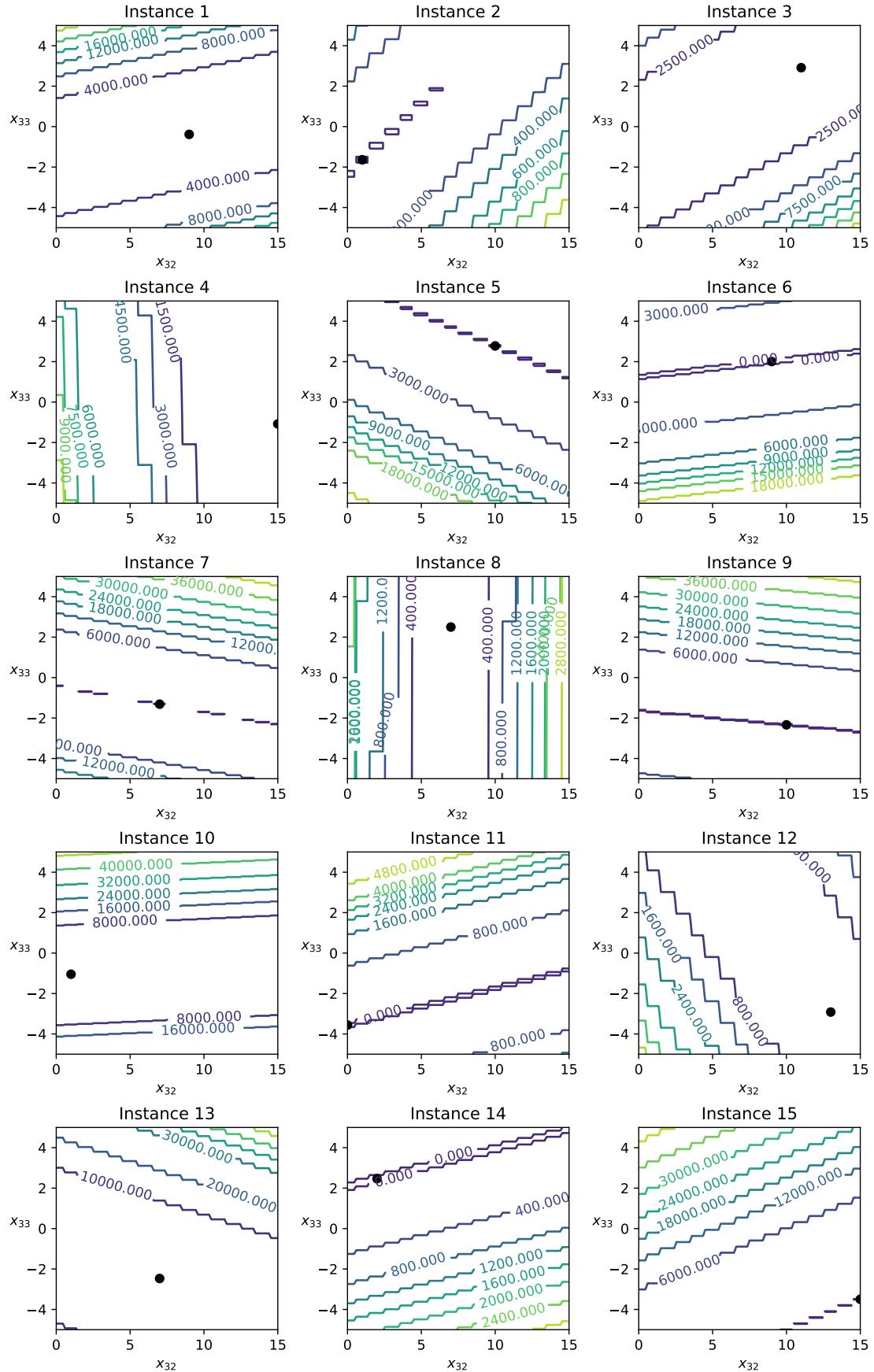
11.2 Function f_{11} , Dimension 10



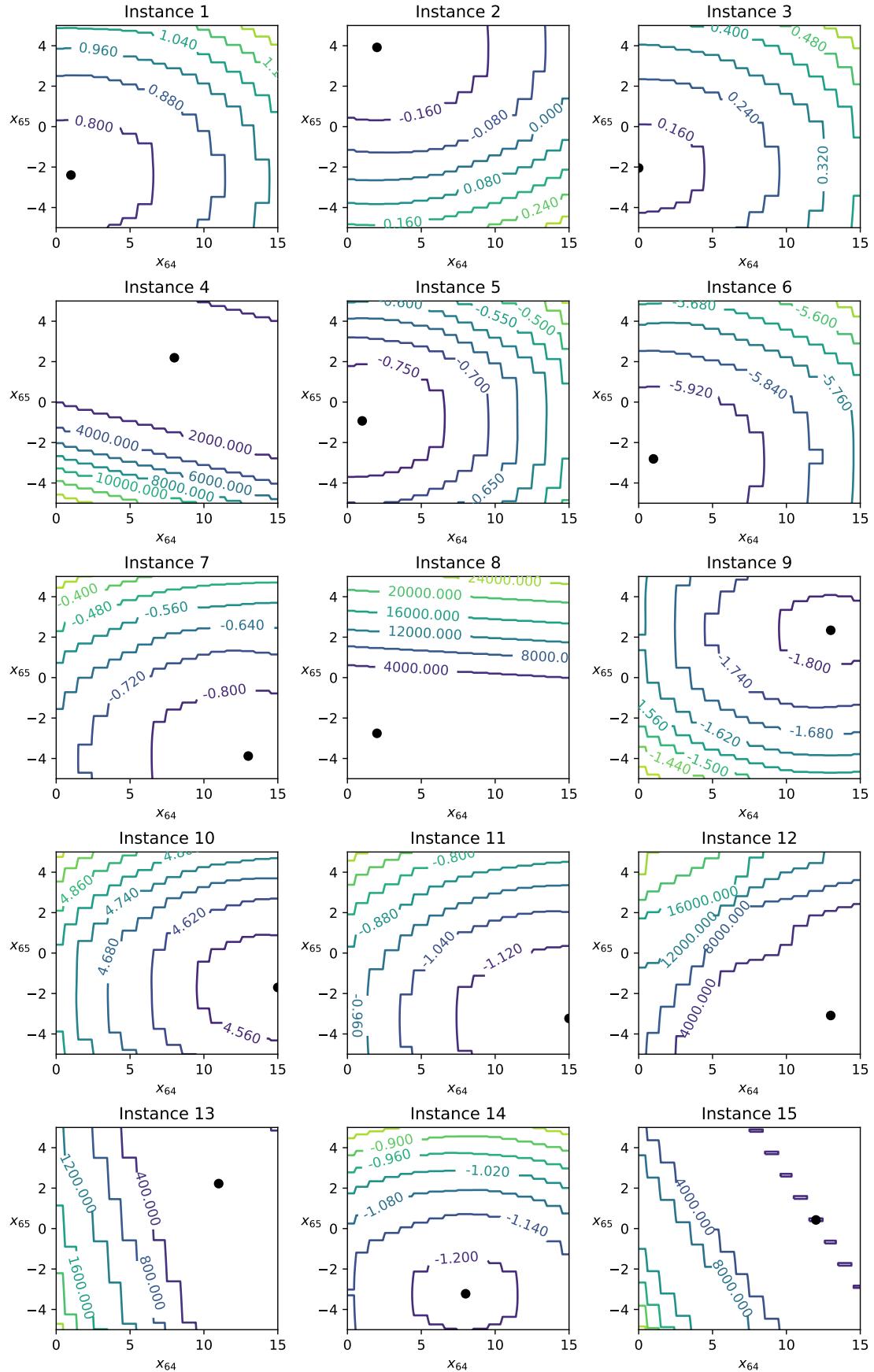
11.3 Function f_{11} , Dimension 20



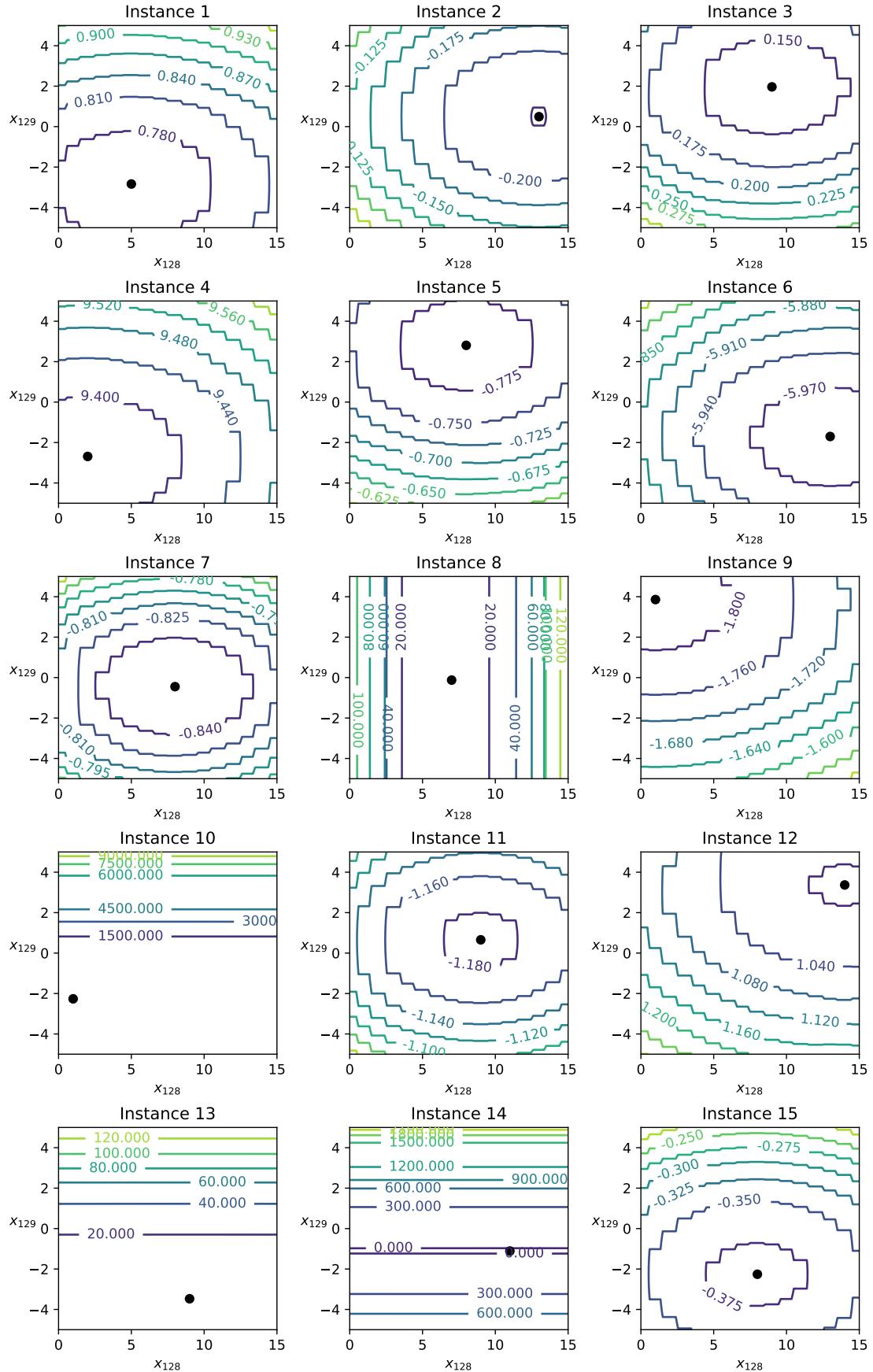
11.4 Function f_{11} , Dimension 40



11.5 Function f_{11} , Dimension 80

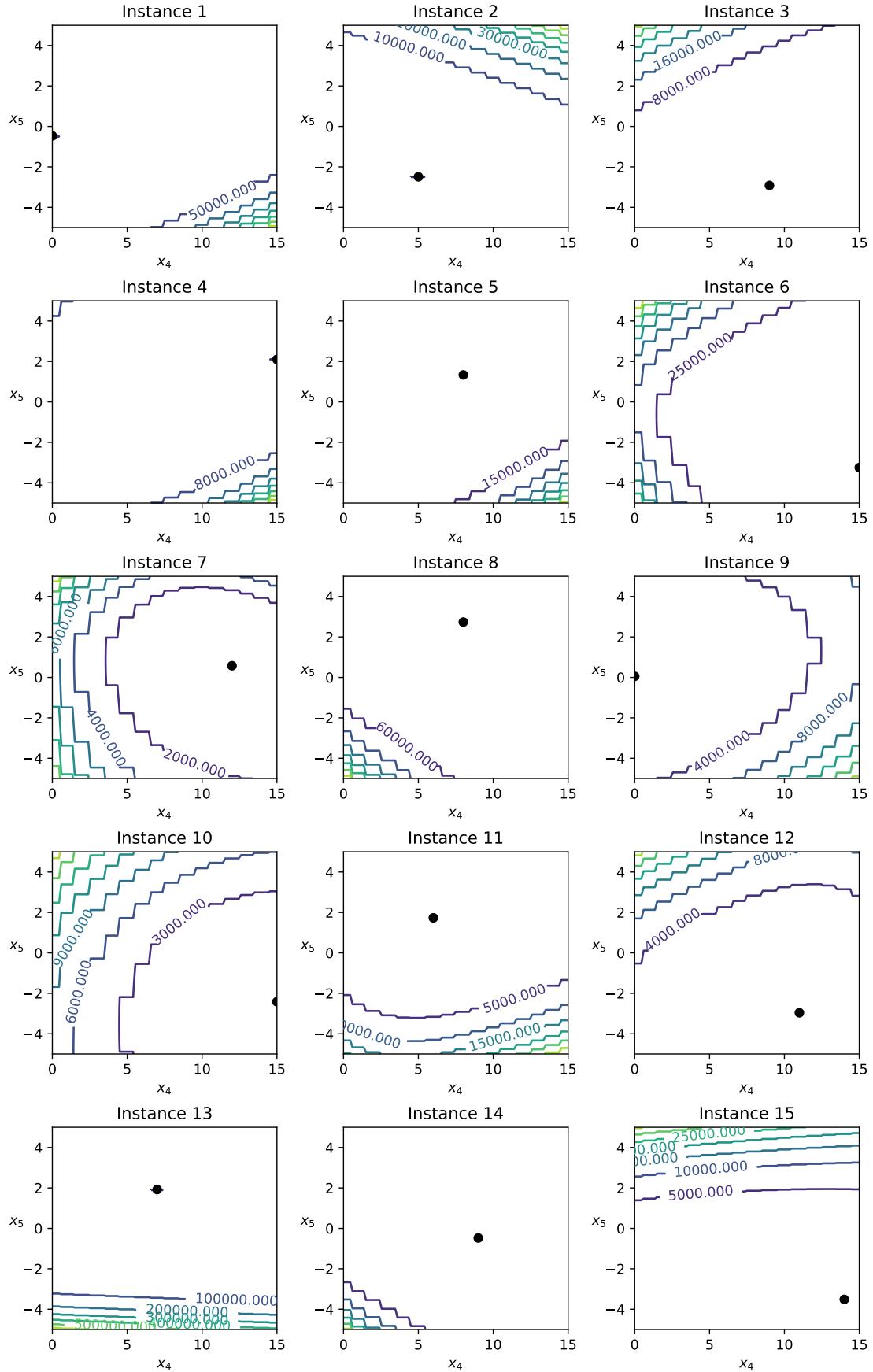


11.6 Function f_{11} , Dimension 160

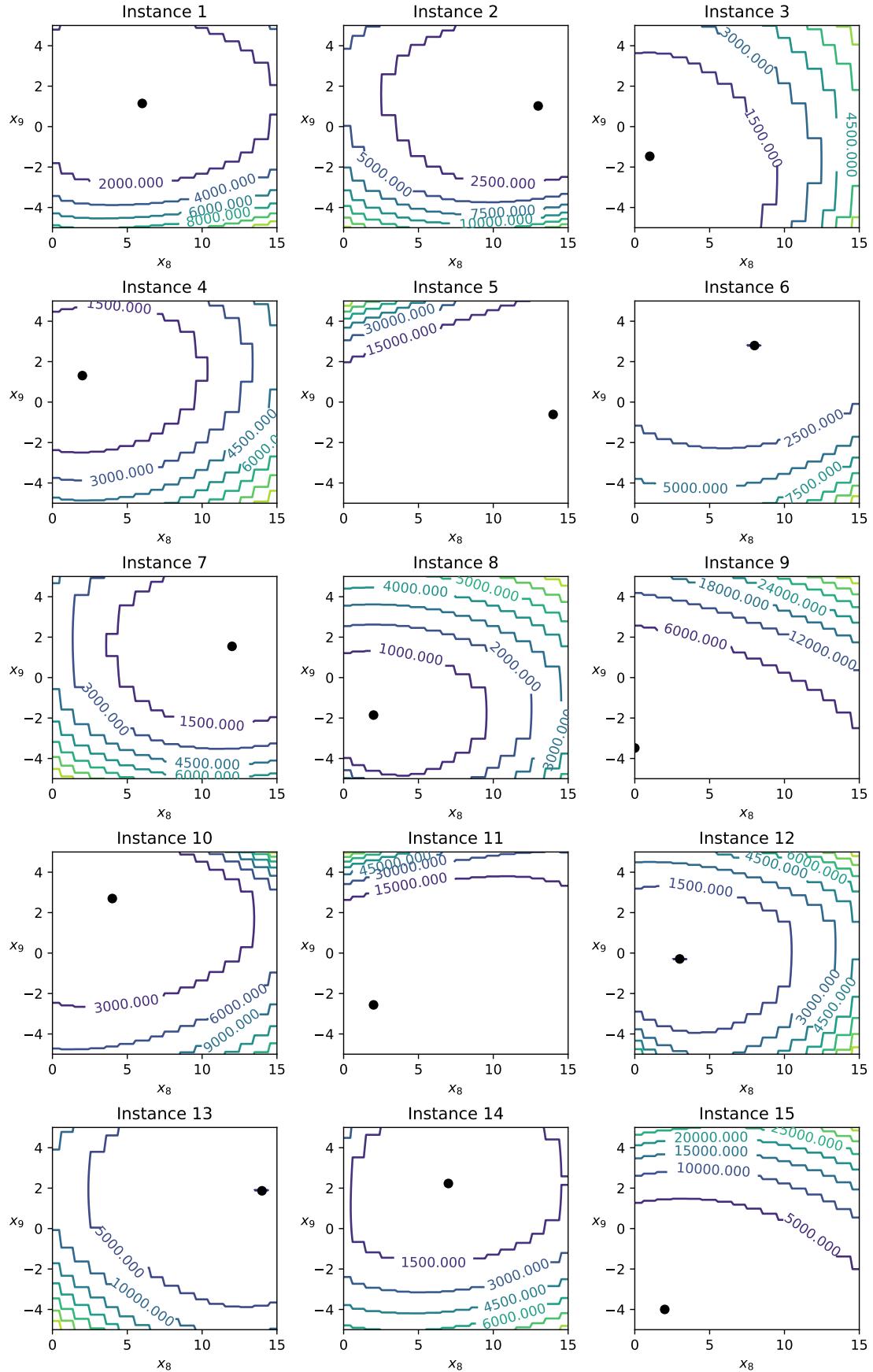


12 Function f_{12} – Bent Cigar

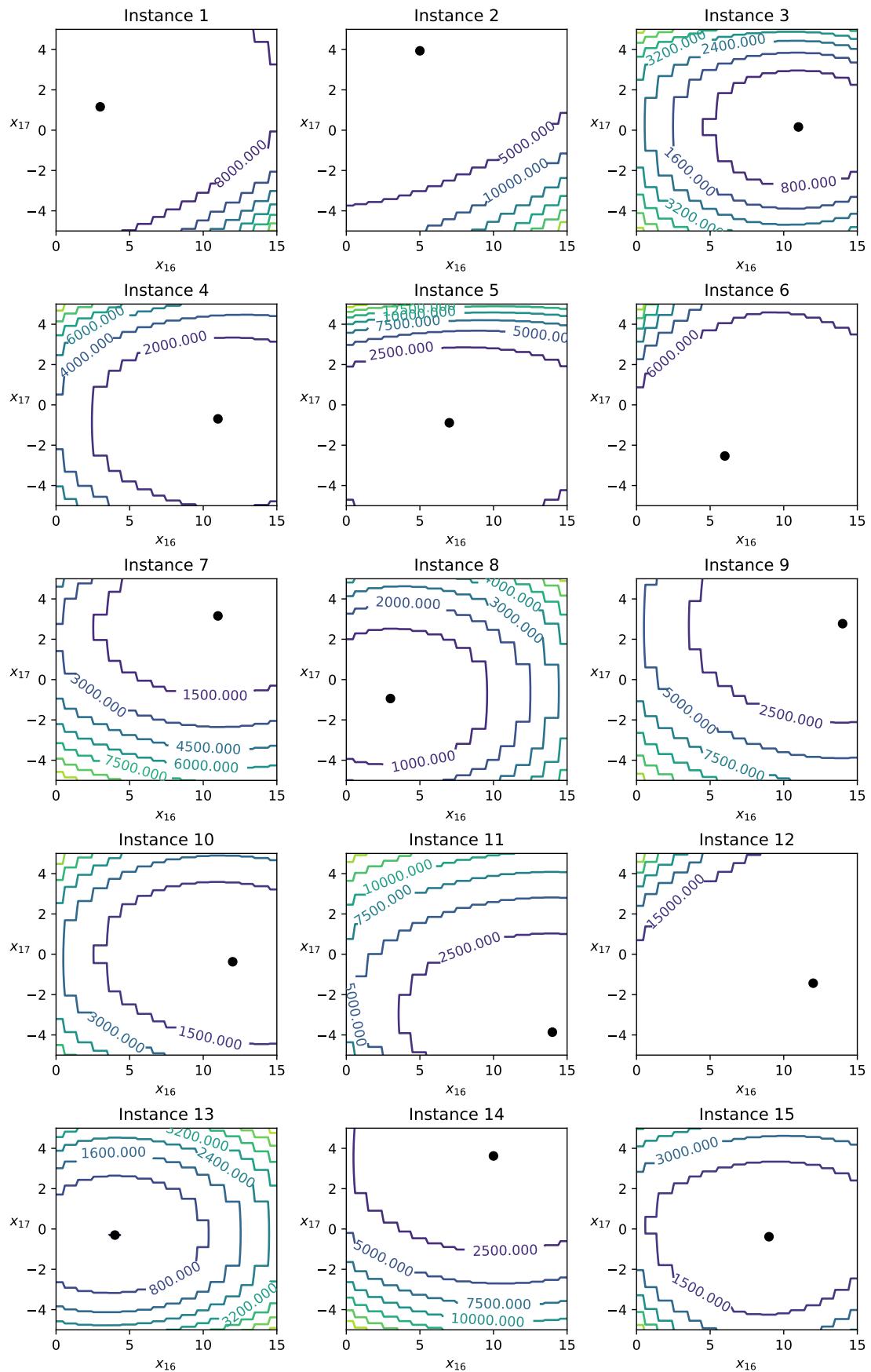
12.1 Function f_{12} , Dimension 5



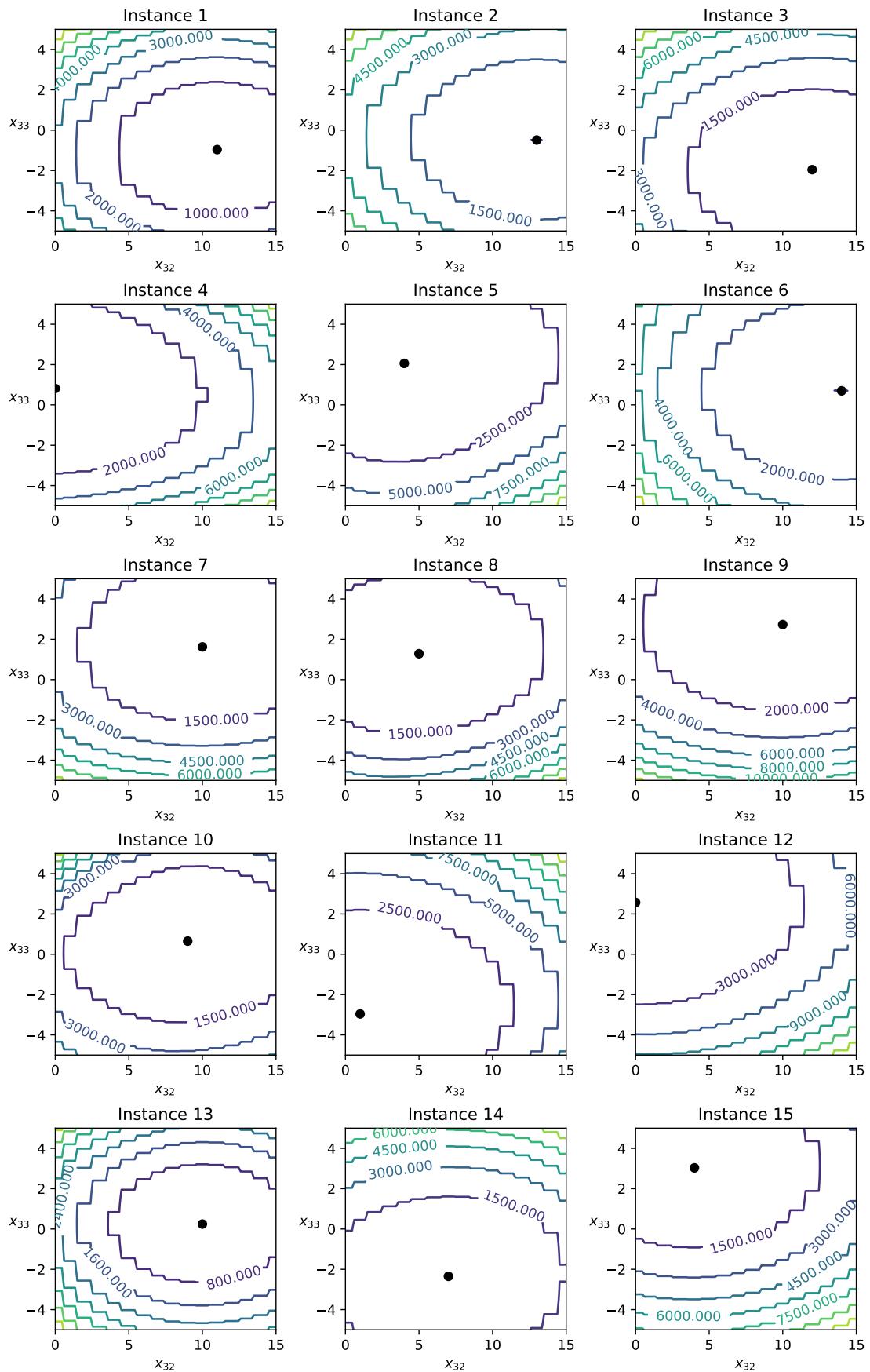
12.2 Function f_{12} , Dimension 10



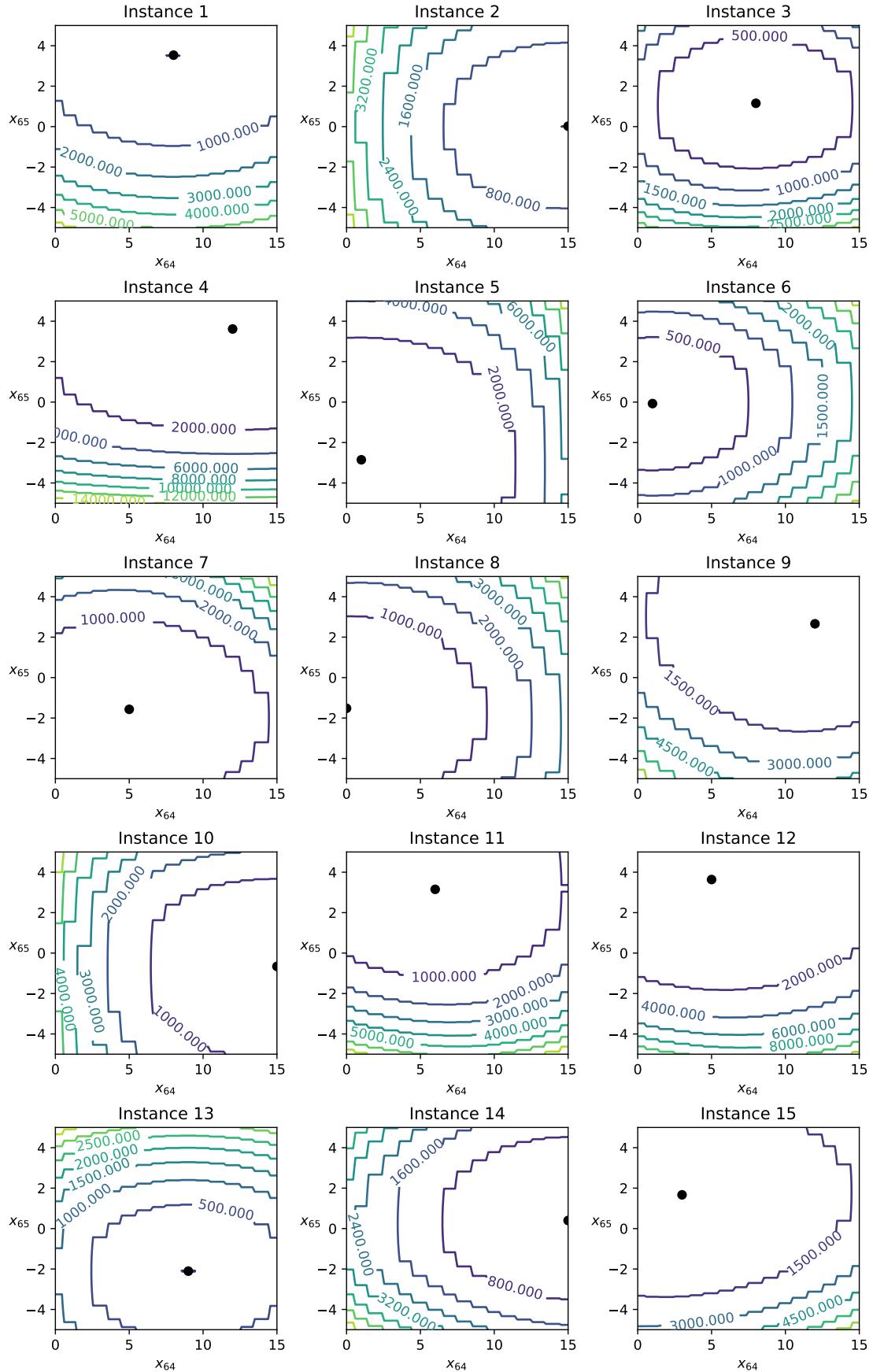
12.3 Function f_{12} , Dimension 20



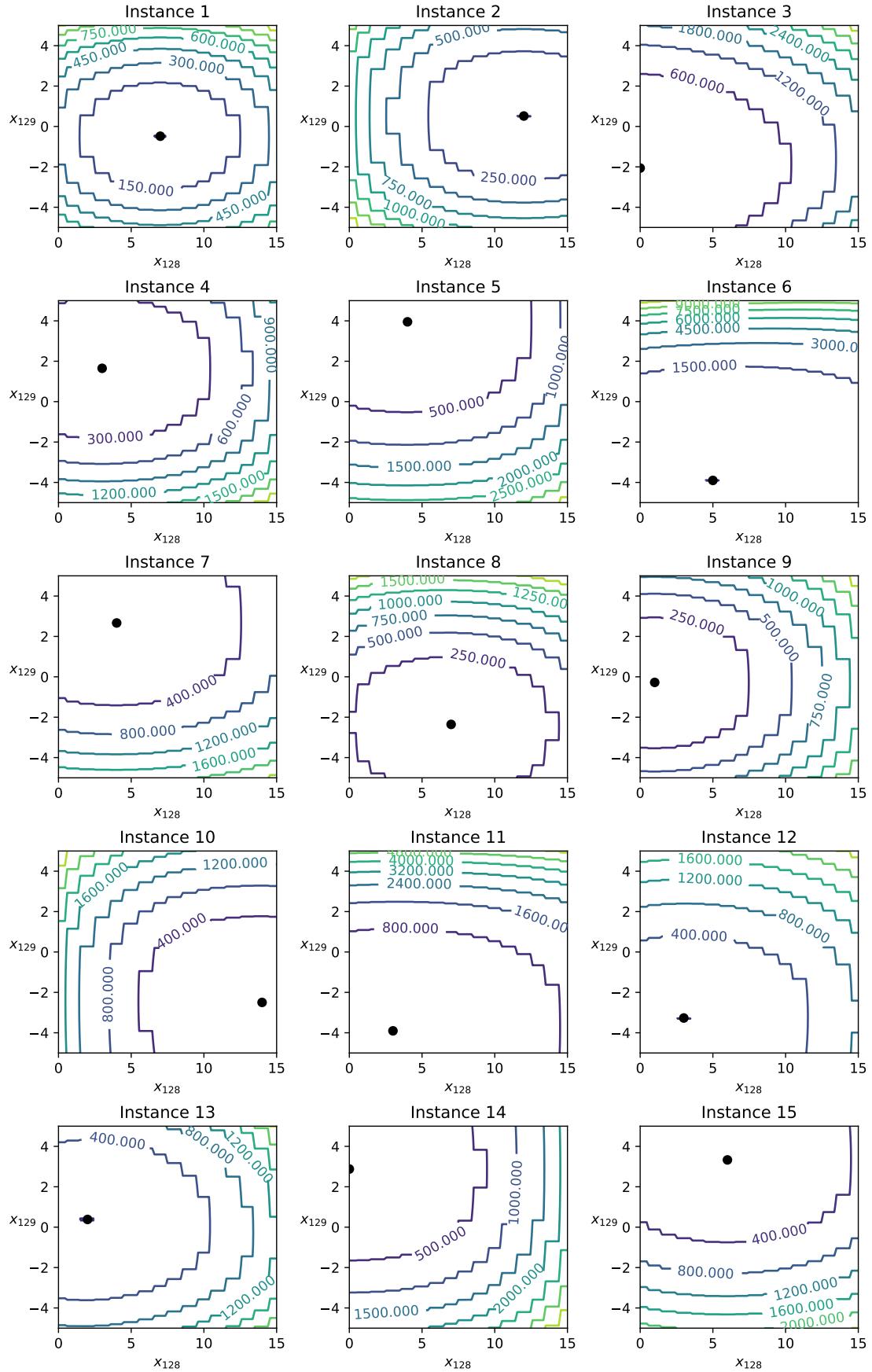
12.4 Function f_{12} , Dimension 40



12.5 Function f_{12} , Dimension 80

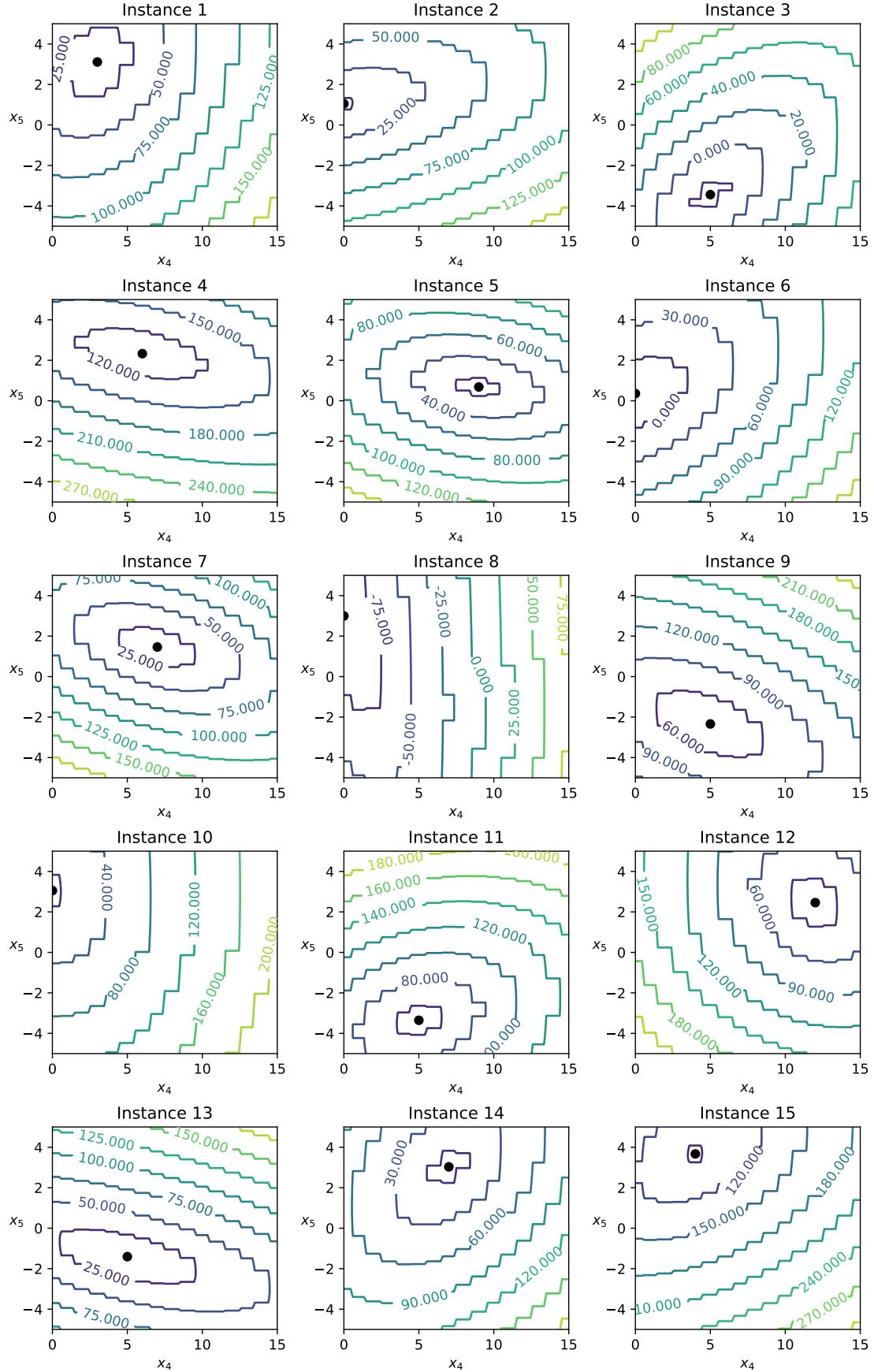


12.6 Function f_{12} , Dimension 160

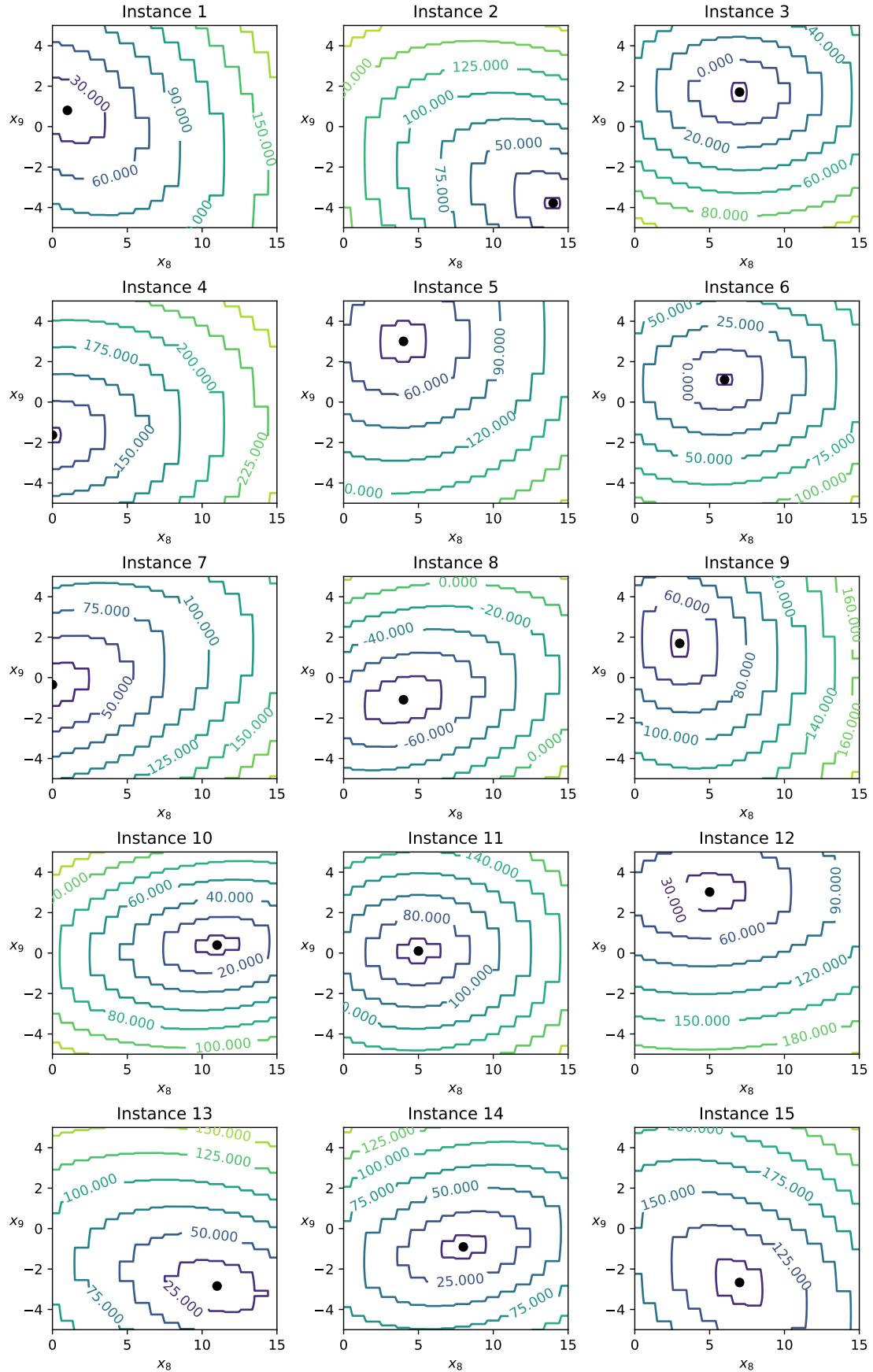


13 Function f_{13} – Sharp Ridge

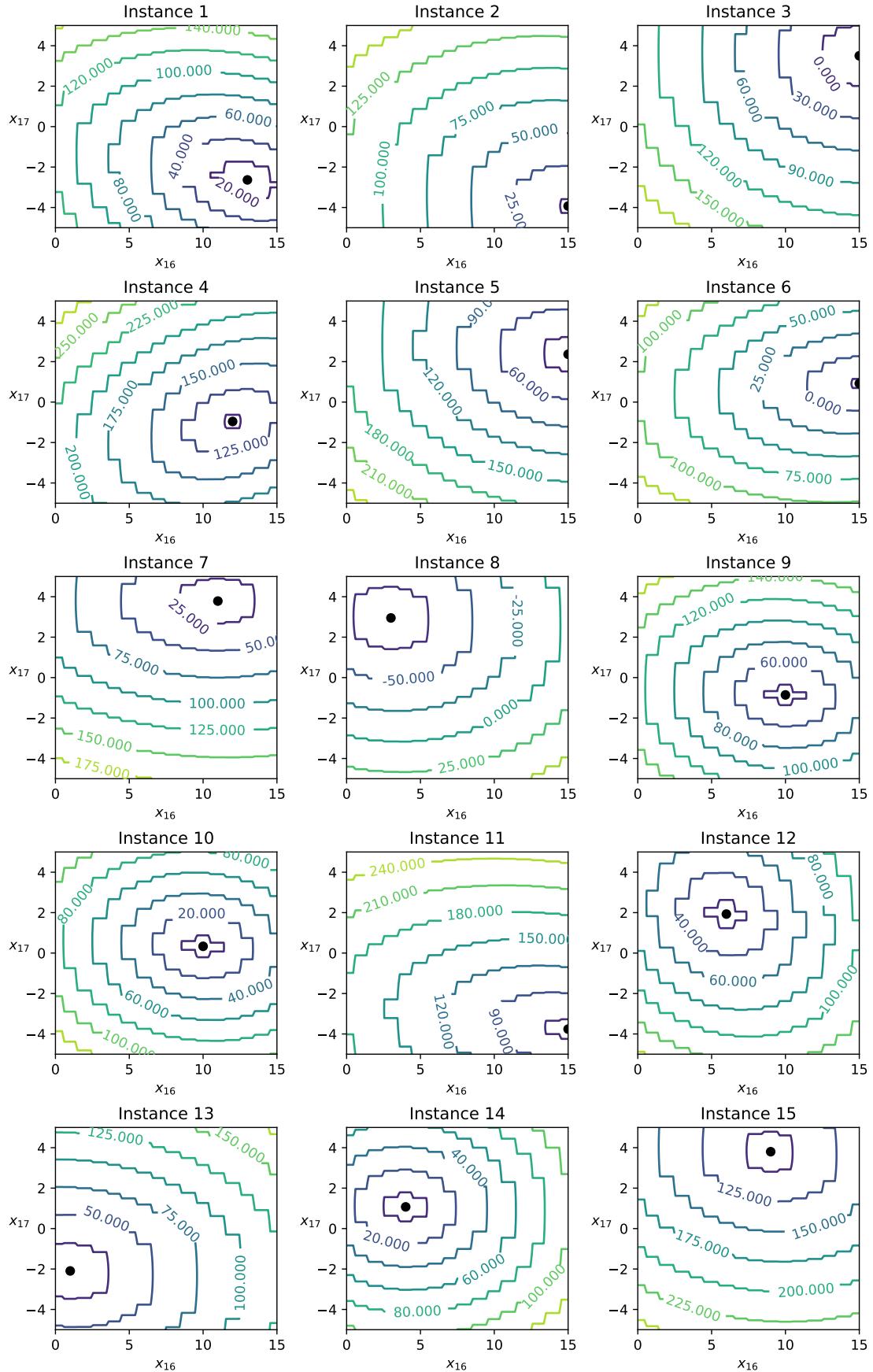
13.1 Function f_{13} , Dimension 5



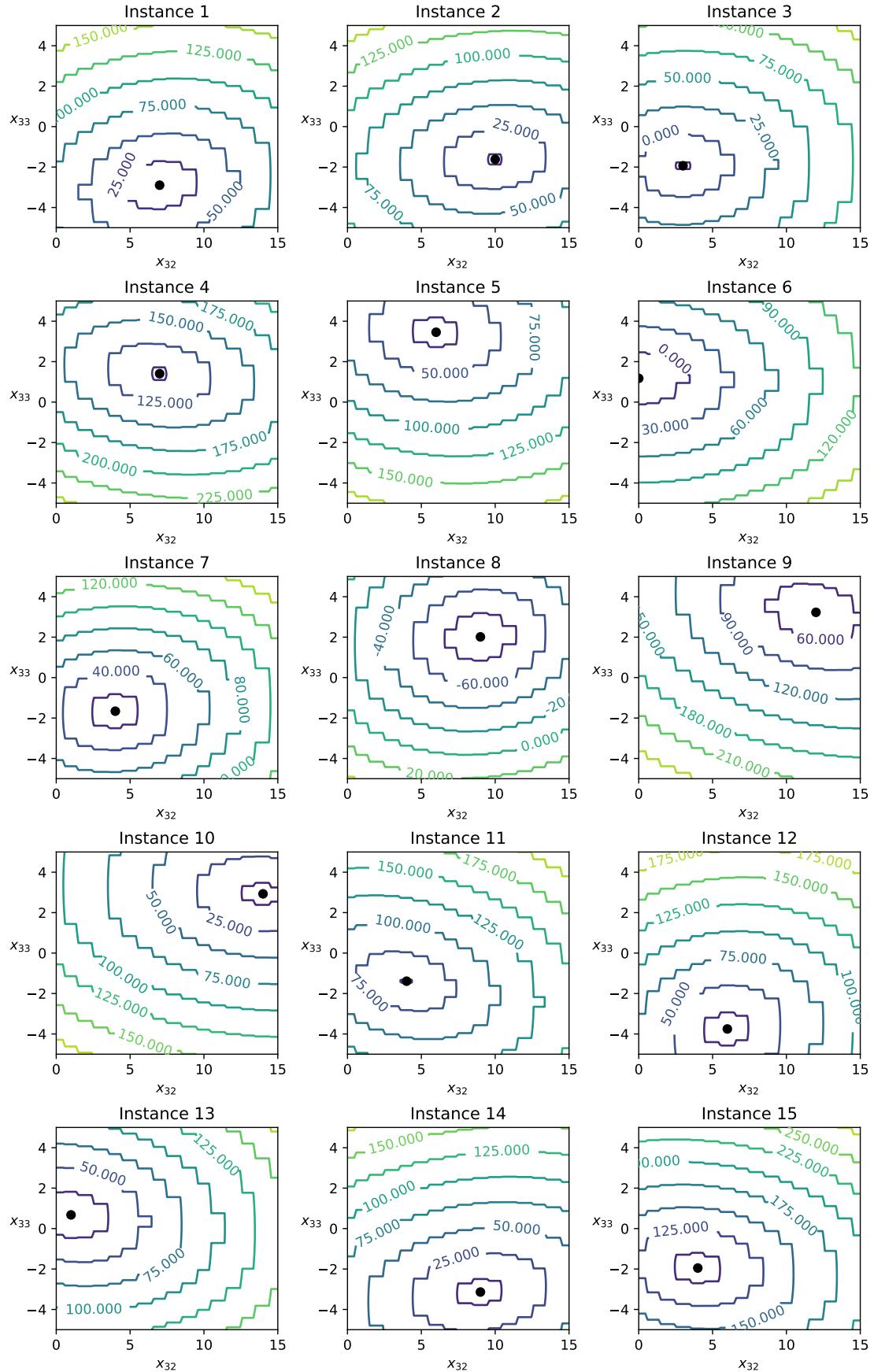
13.2 Function f_{13} , Dimension 10



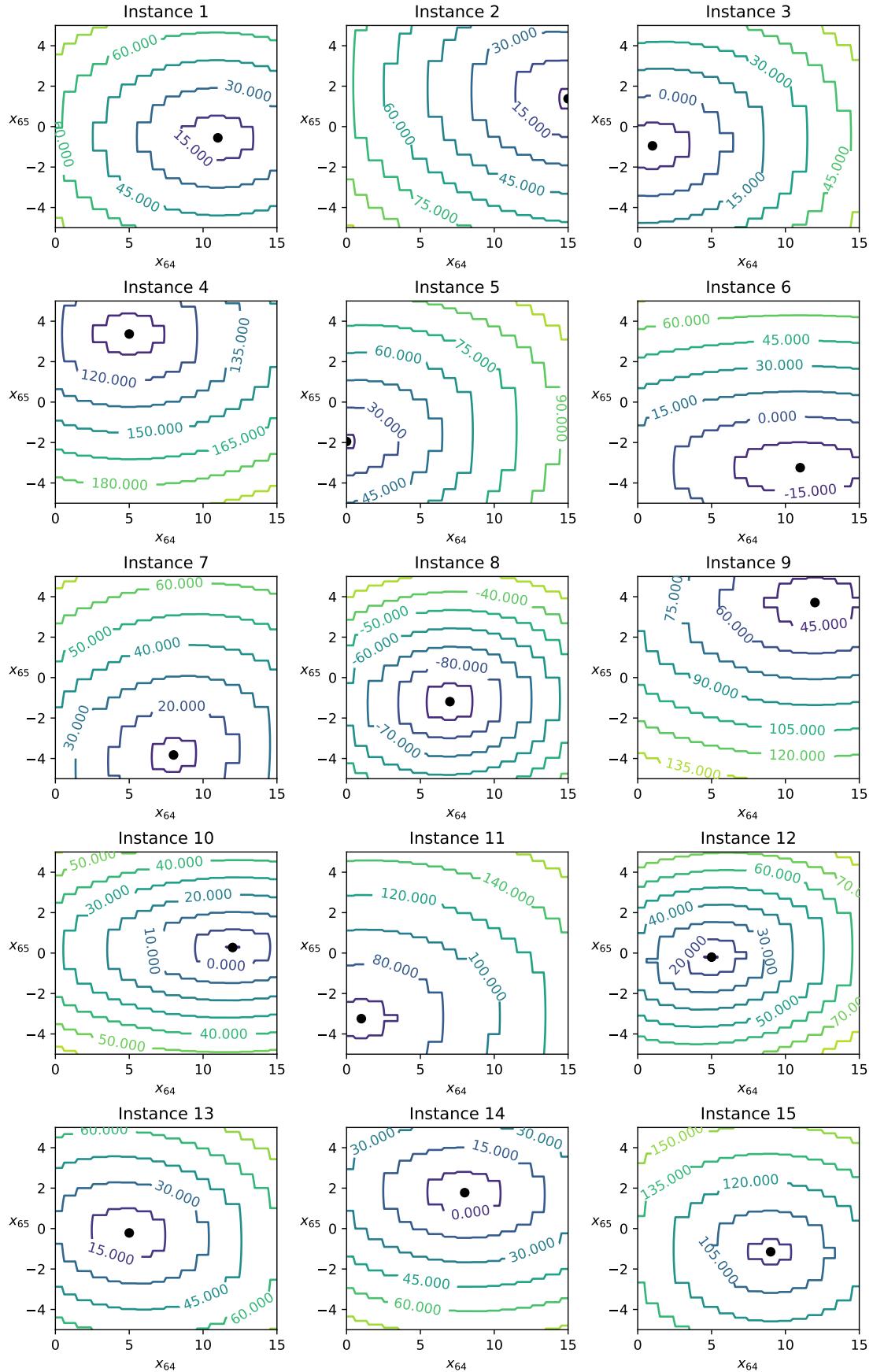
13.3 Function f_{13} , Dimension 20



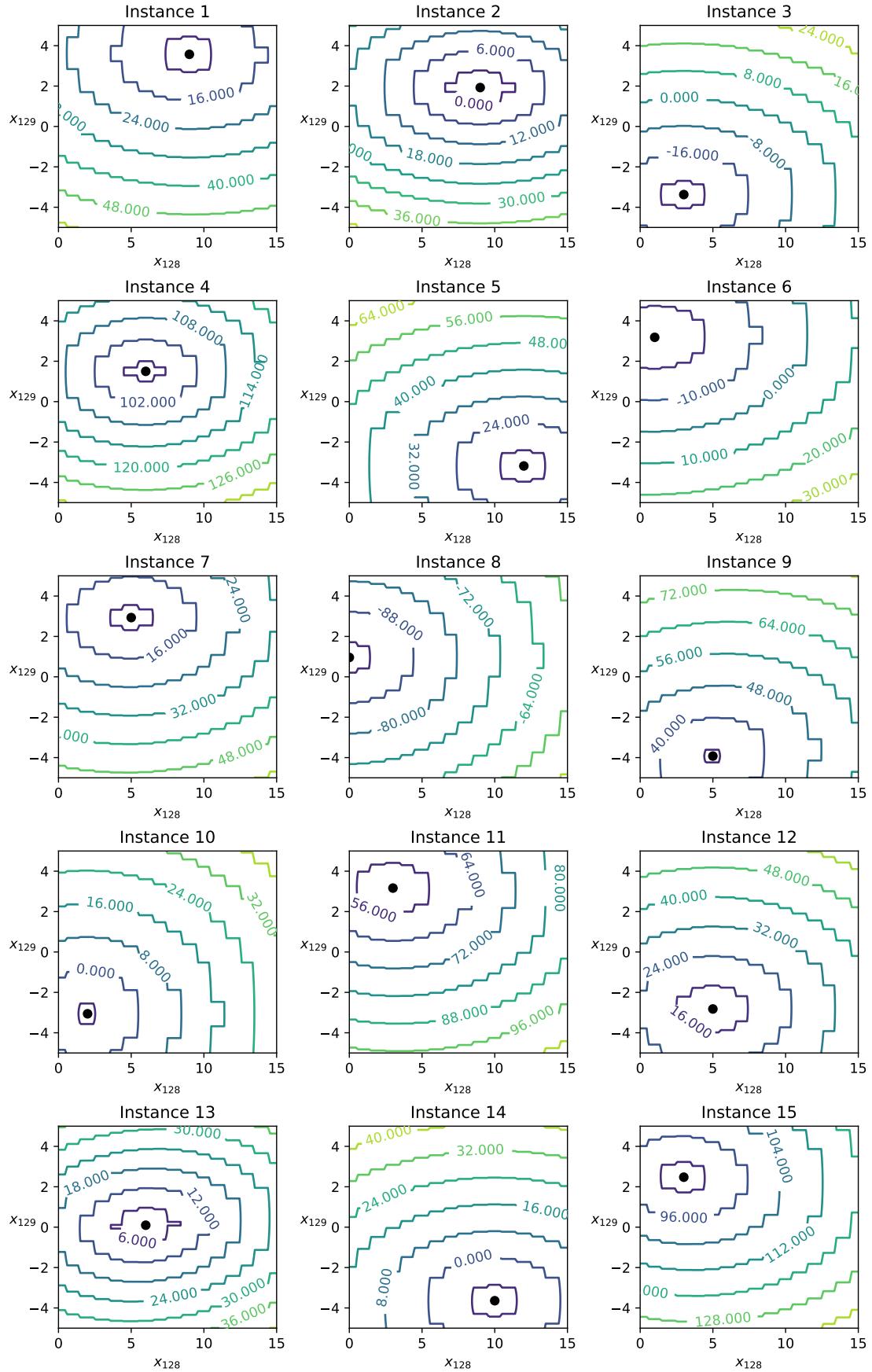
13.4 Function f_{13} , Dimension 40



13.5 Function f_{13} , Dimension 80

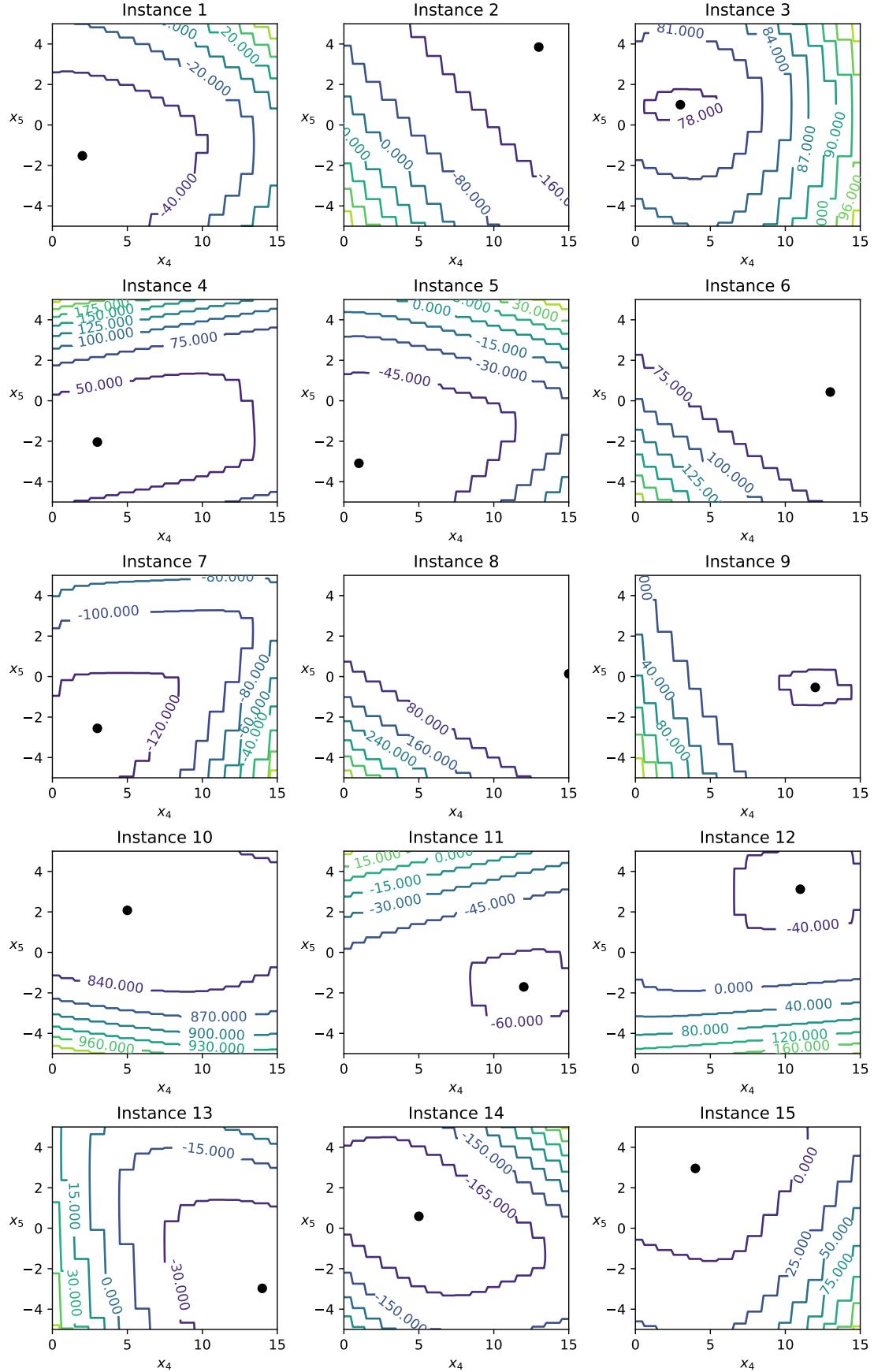


13.6 Function f_{13} , Dimension 160

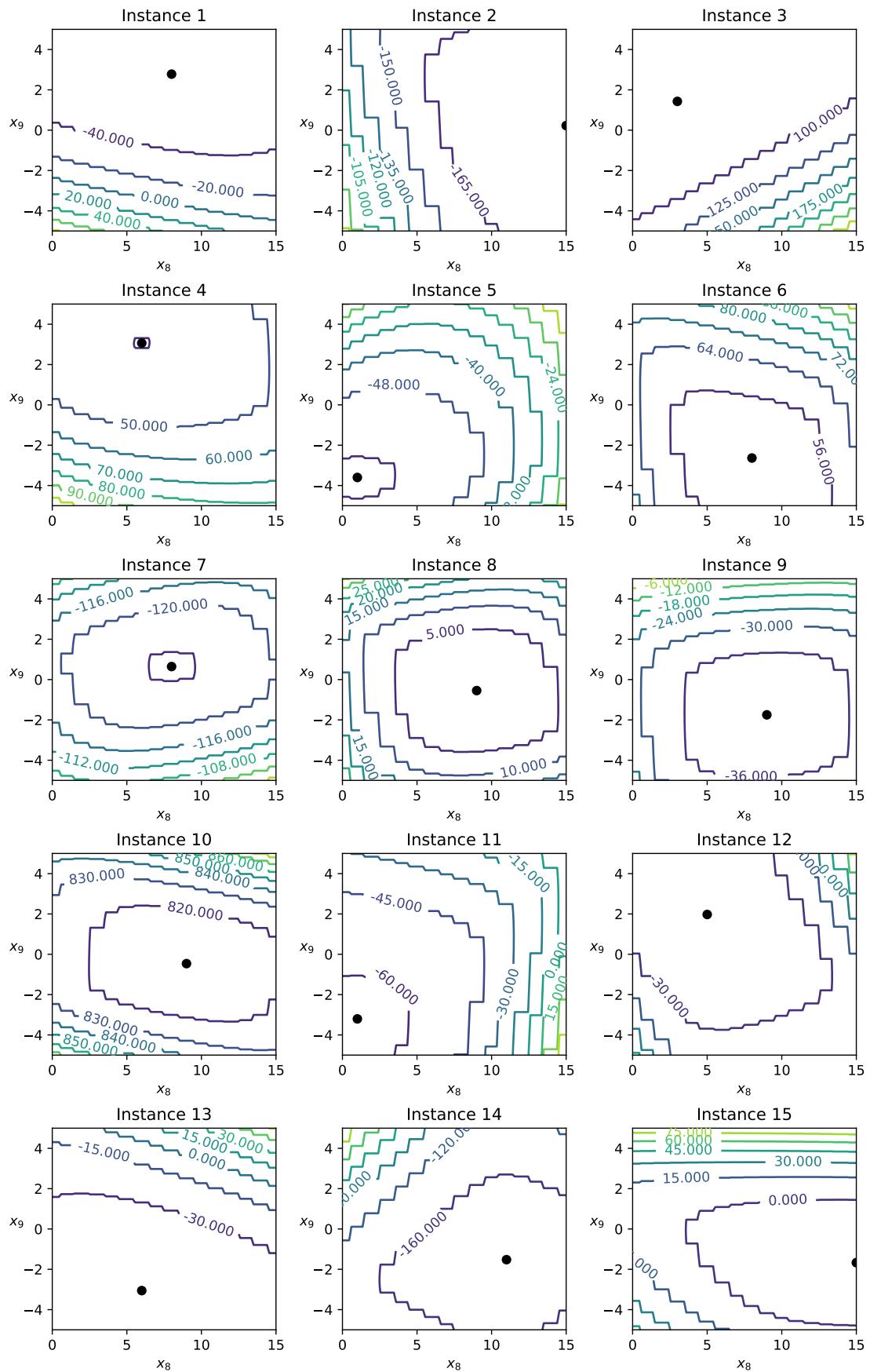


14 Function f_{14} – Different Powers

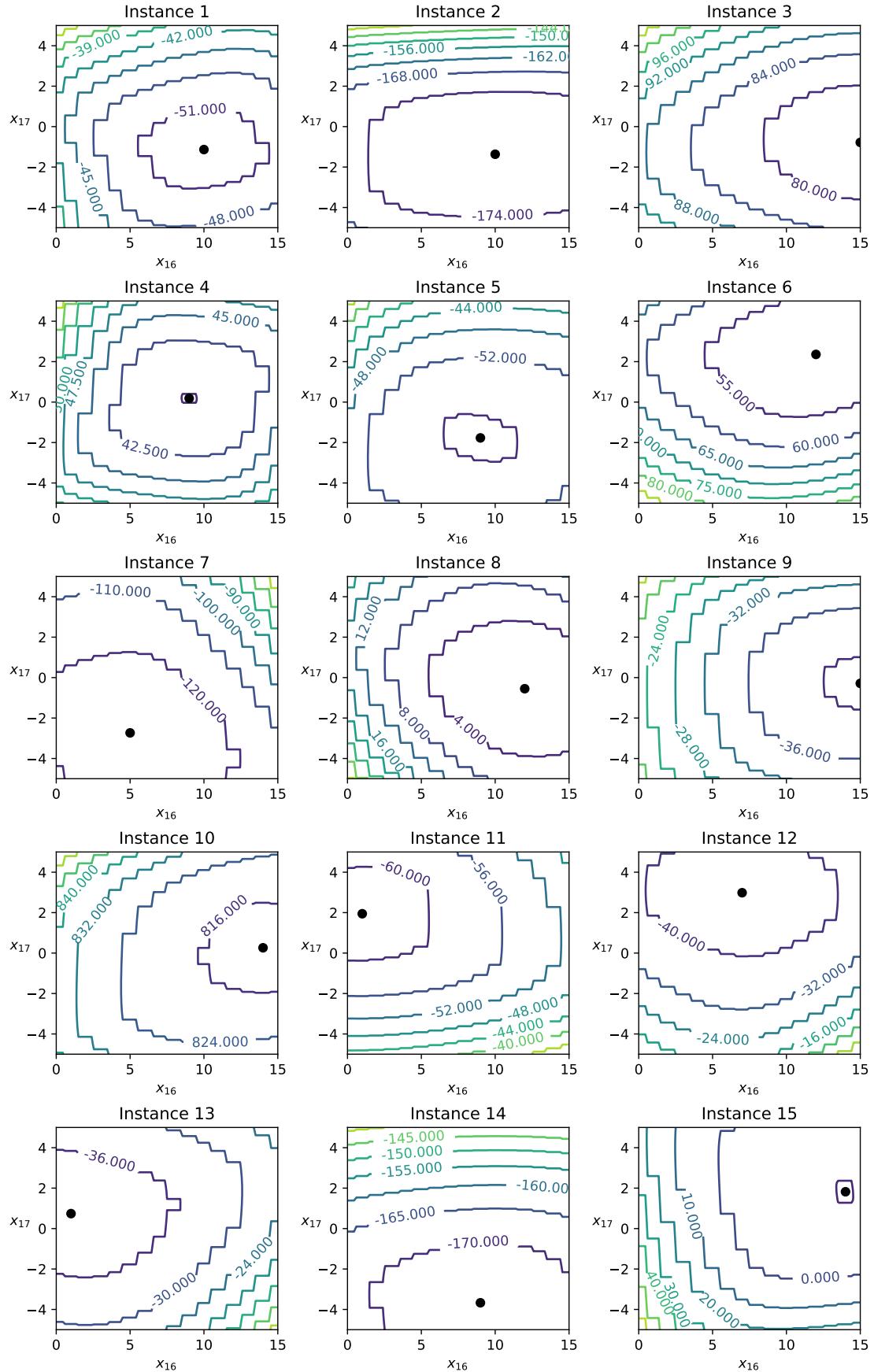
14.1 Function f_{14} , Dimension 5



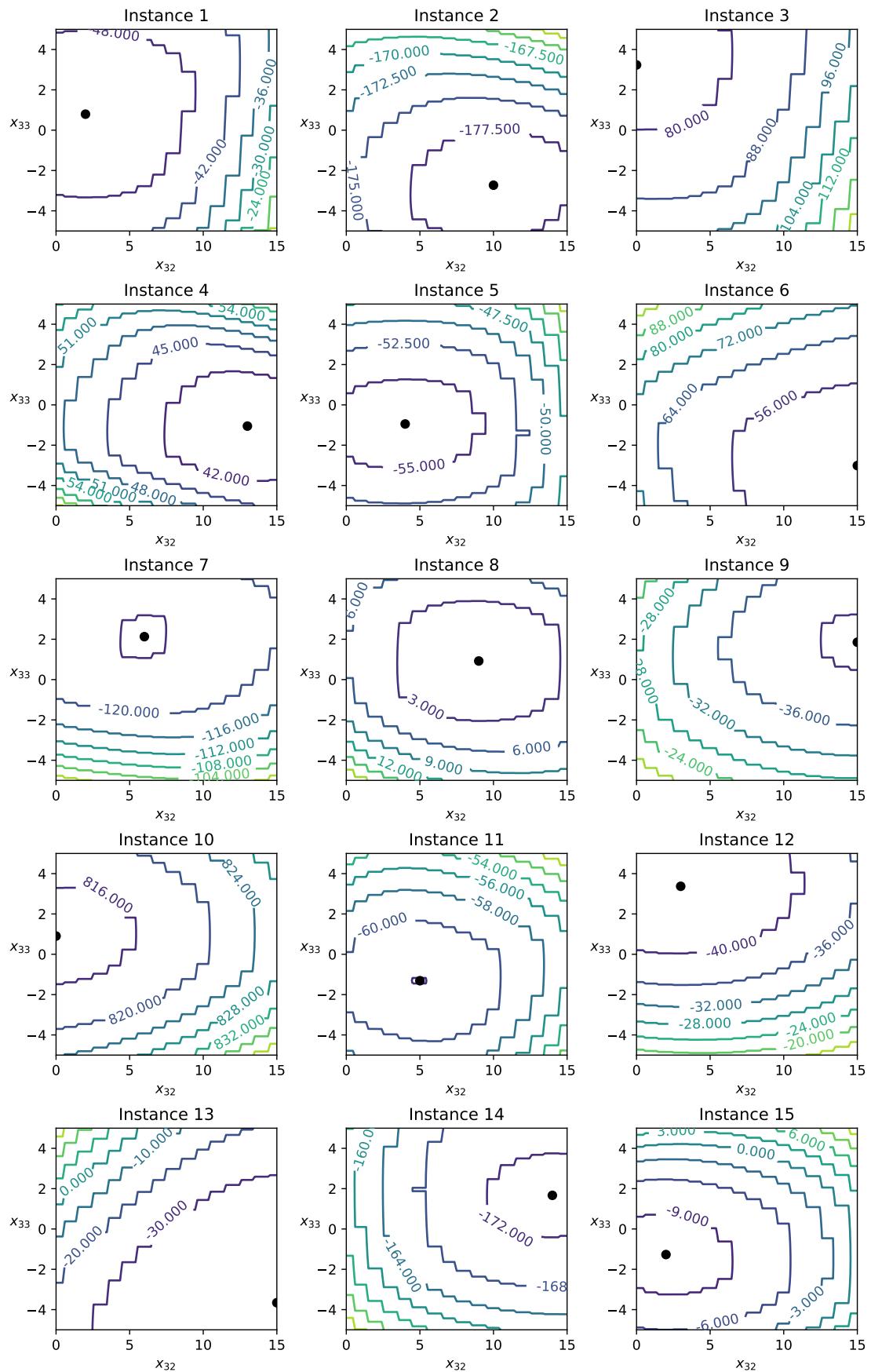
14.2 Function f_{14} , Dimension 10



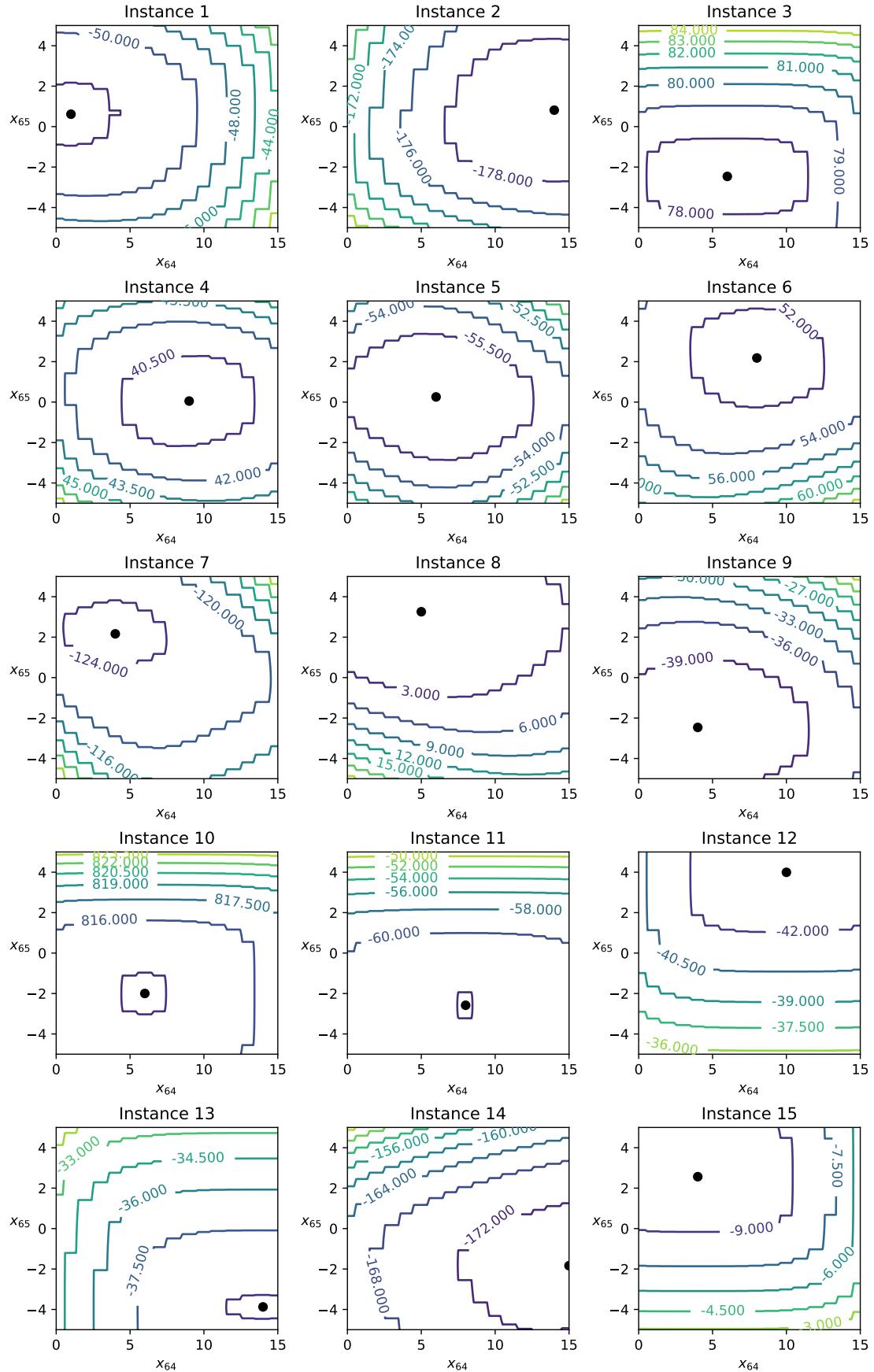
14.3 Function f_{14} , Dimension 20



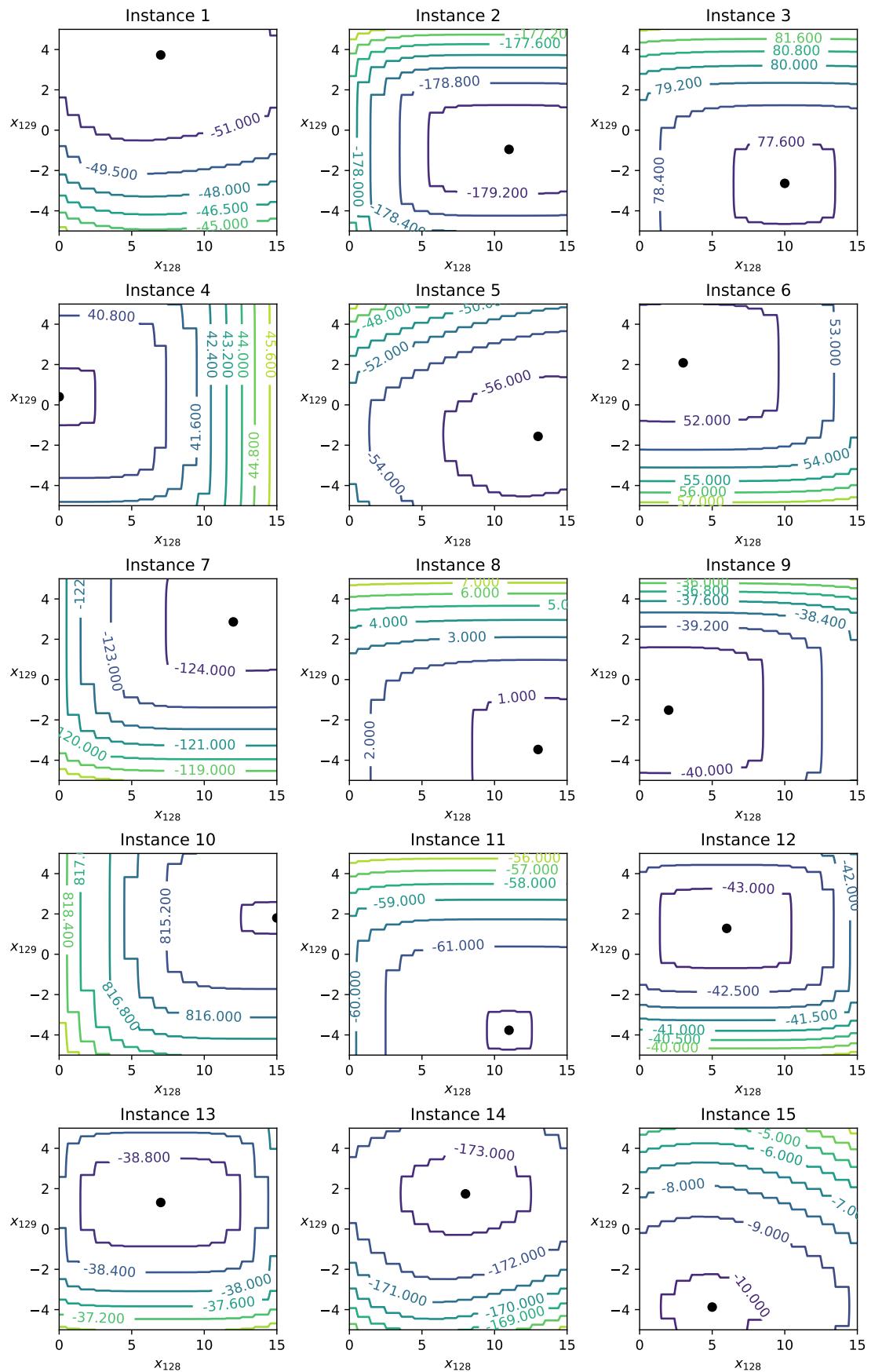
14.4 Function f_{14} , Dimension 40



14.5 Function f_{14} , Dimension 80

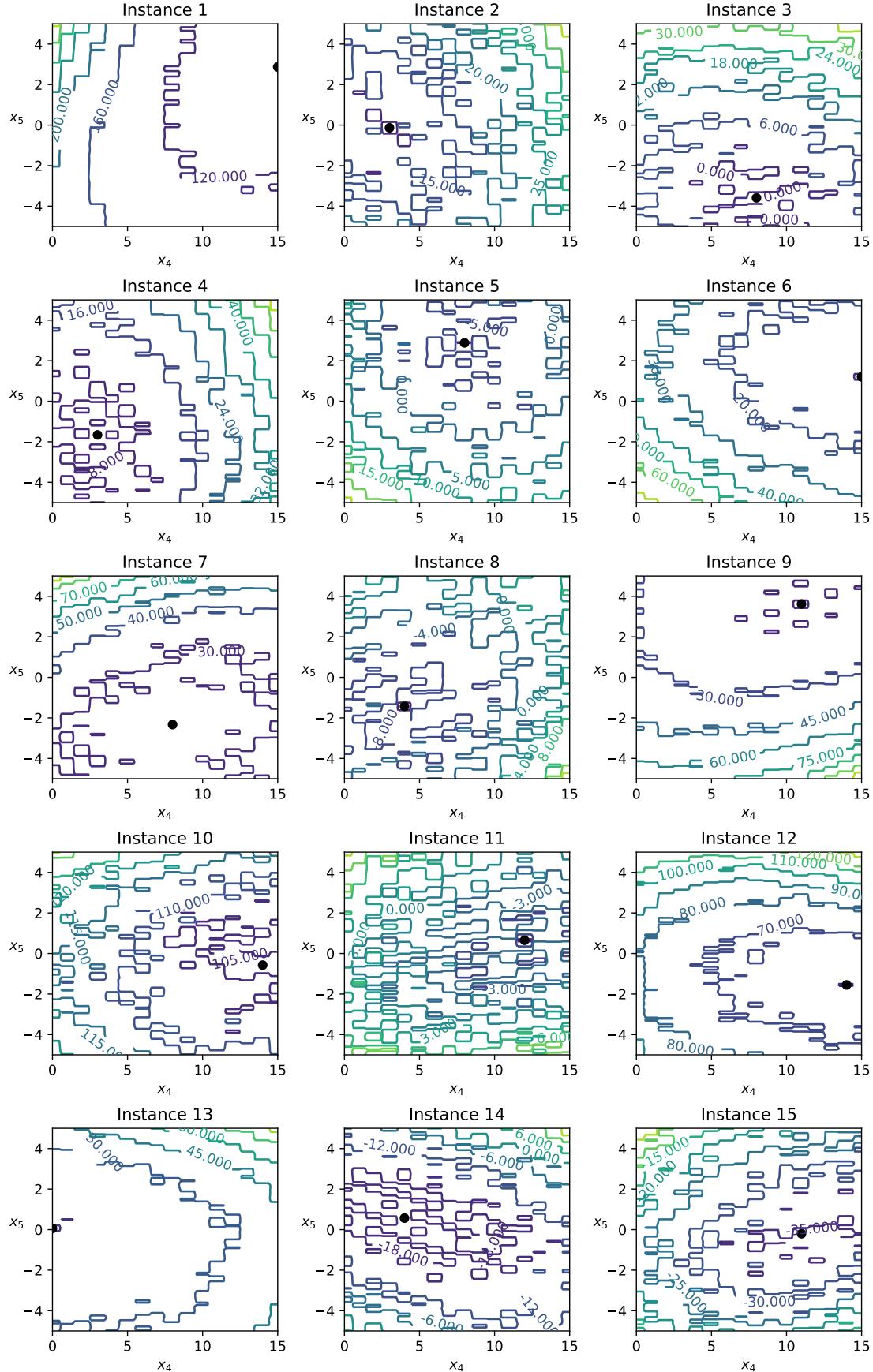


14.6 Function f_{14} , Dimension 160

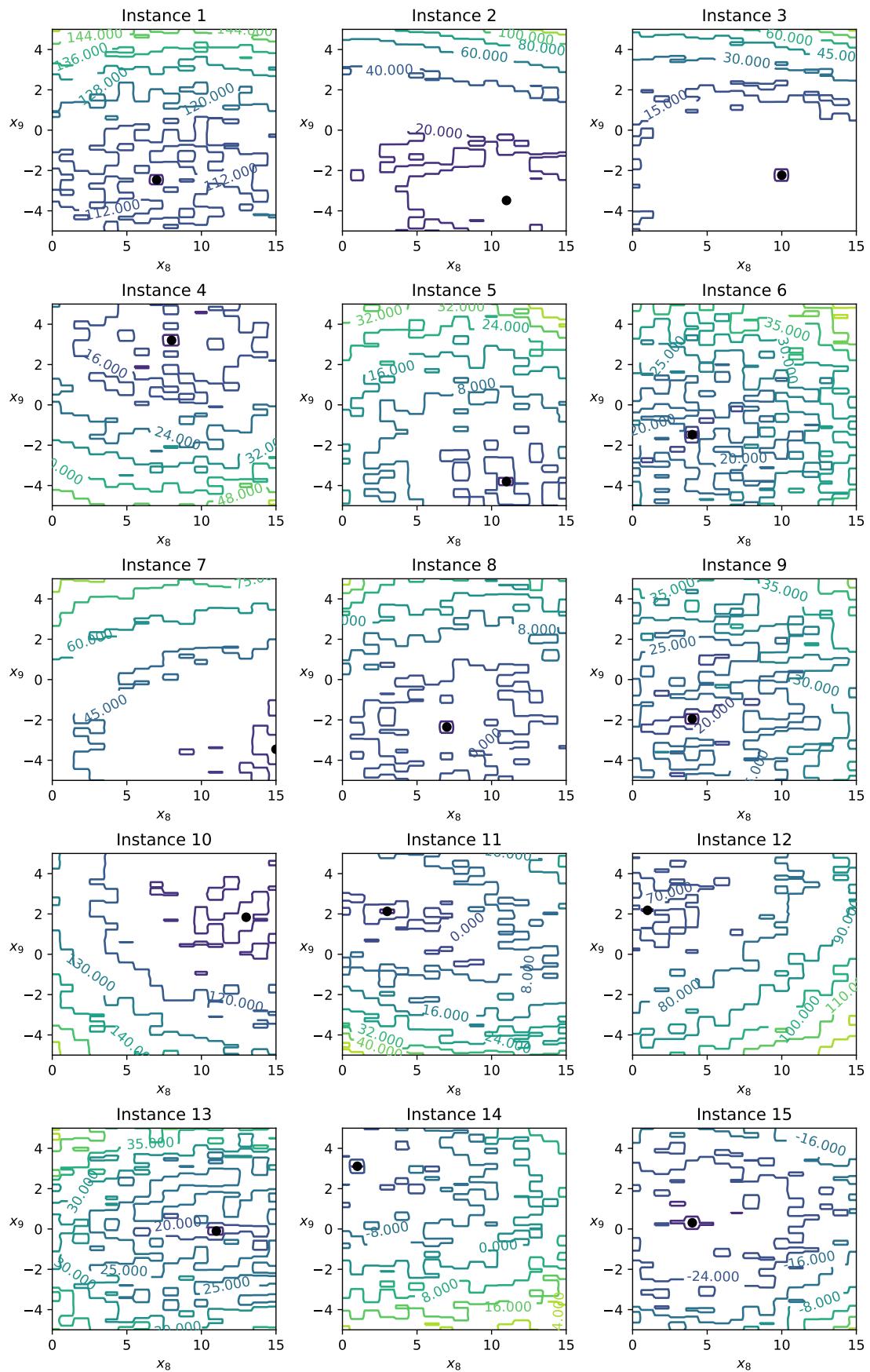


15 Function f_{15} – Rastrigin

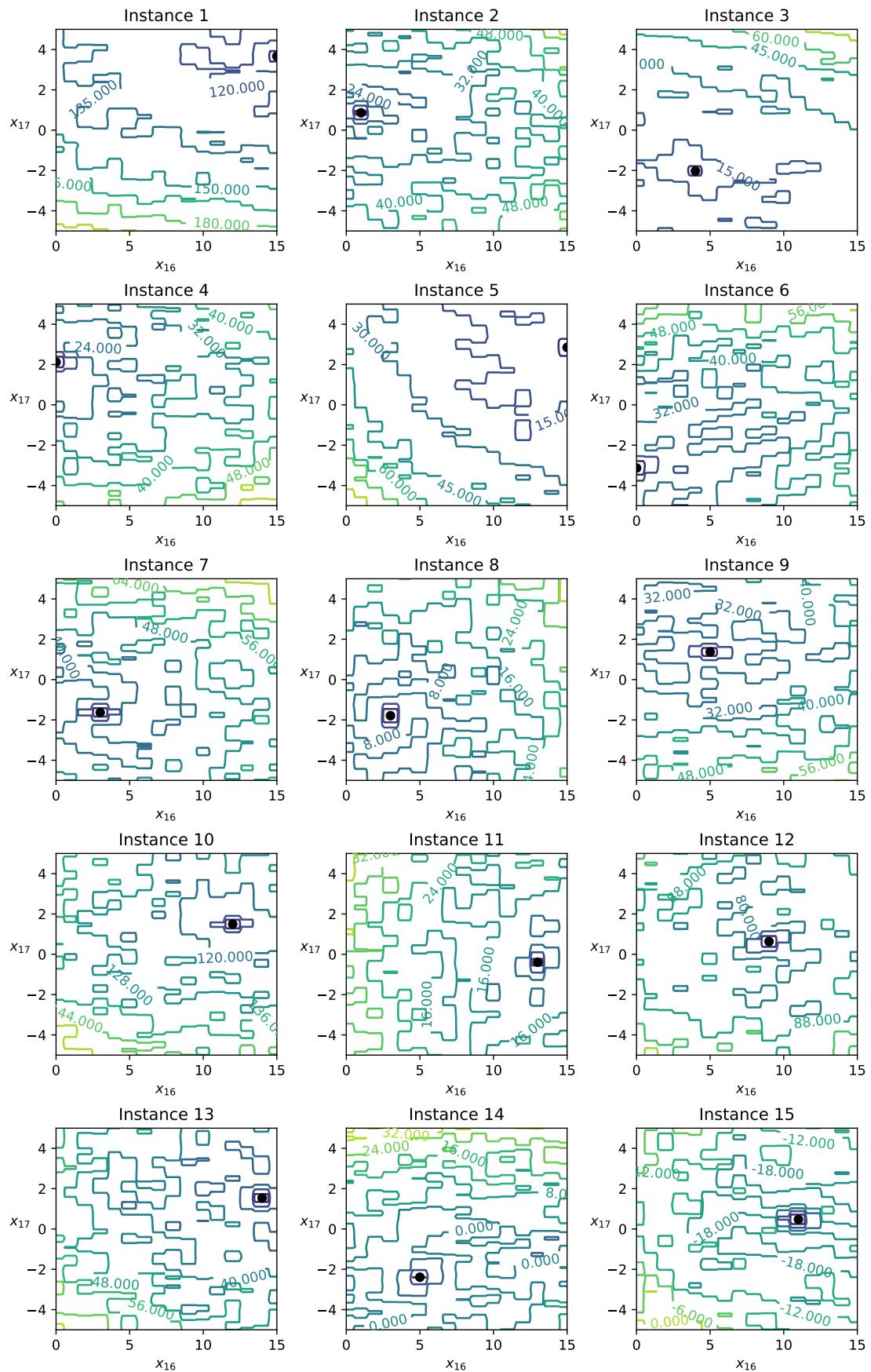
15.1 Function f_{15} , Dimension 5



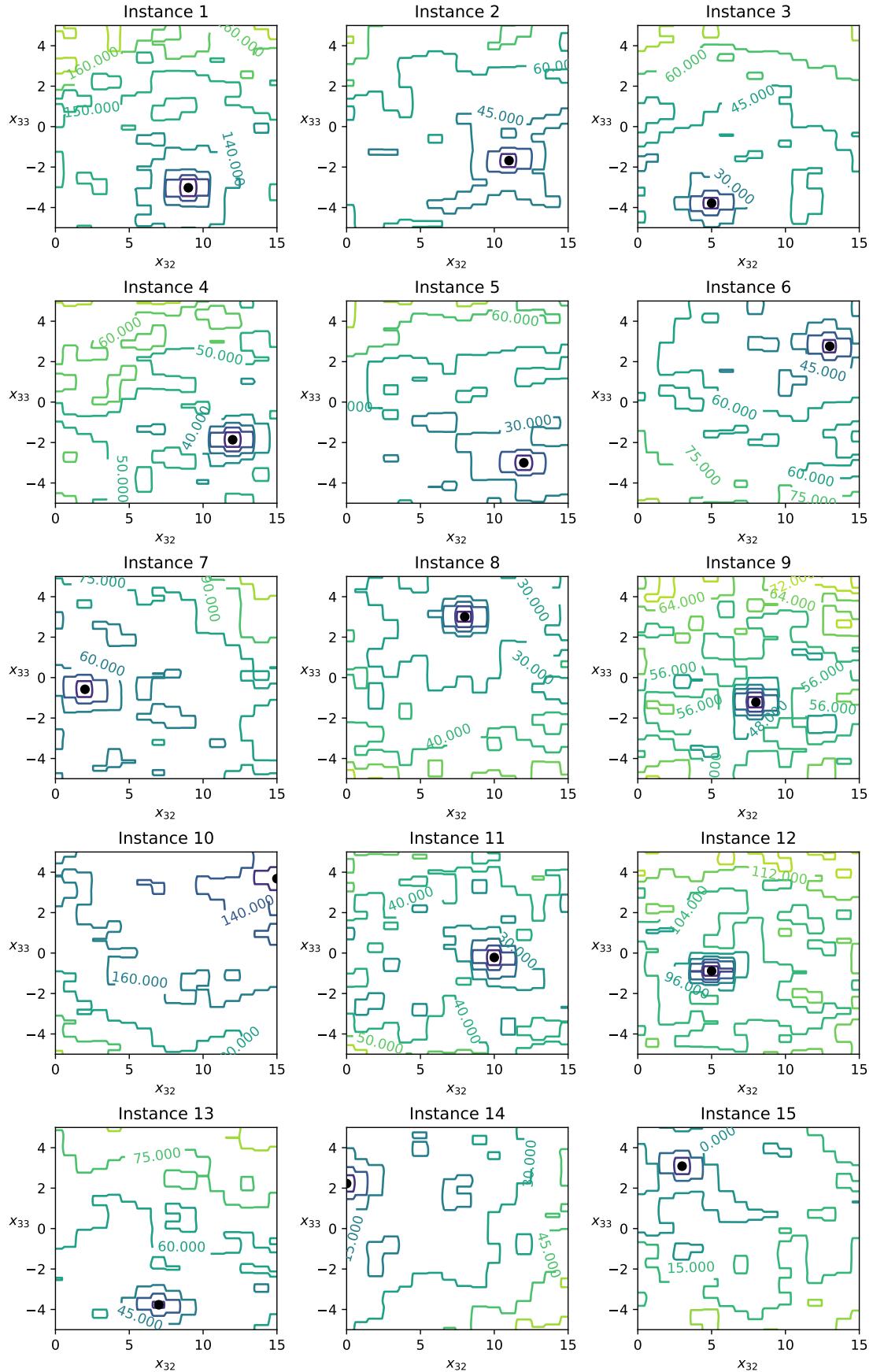
15.2 Function f_{15} , Dimension 10



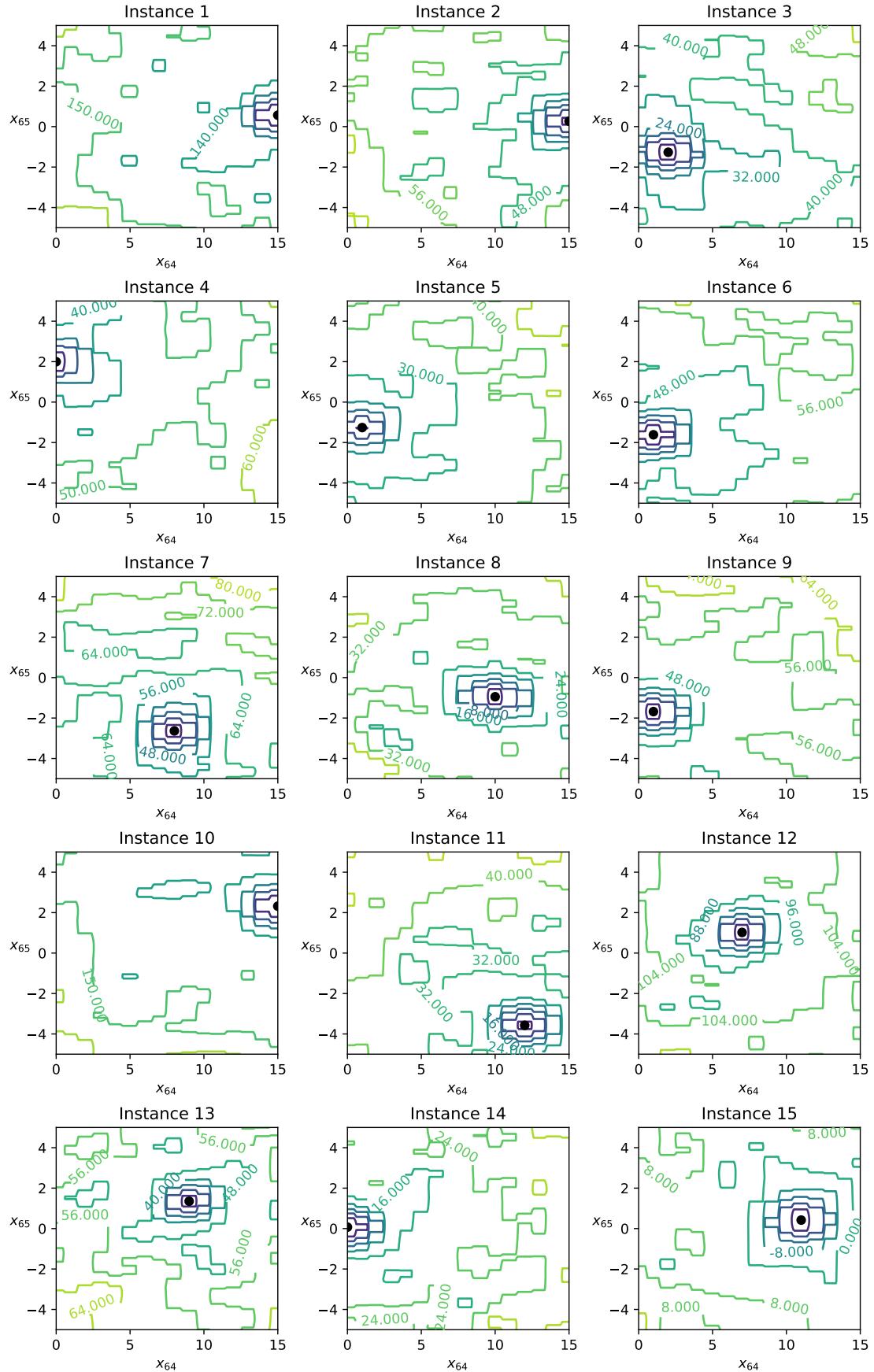
15.3 Function f_{15} , Dimension 20



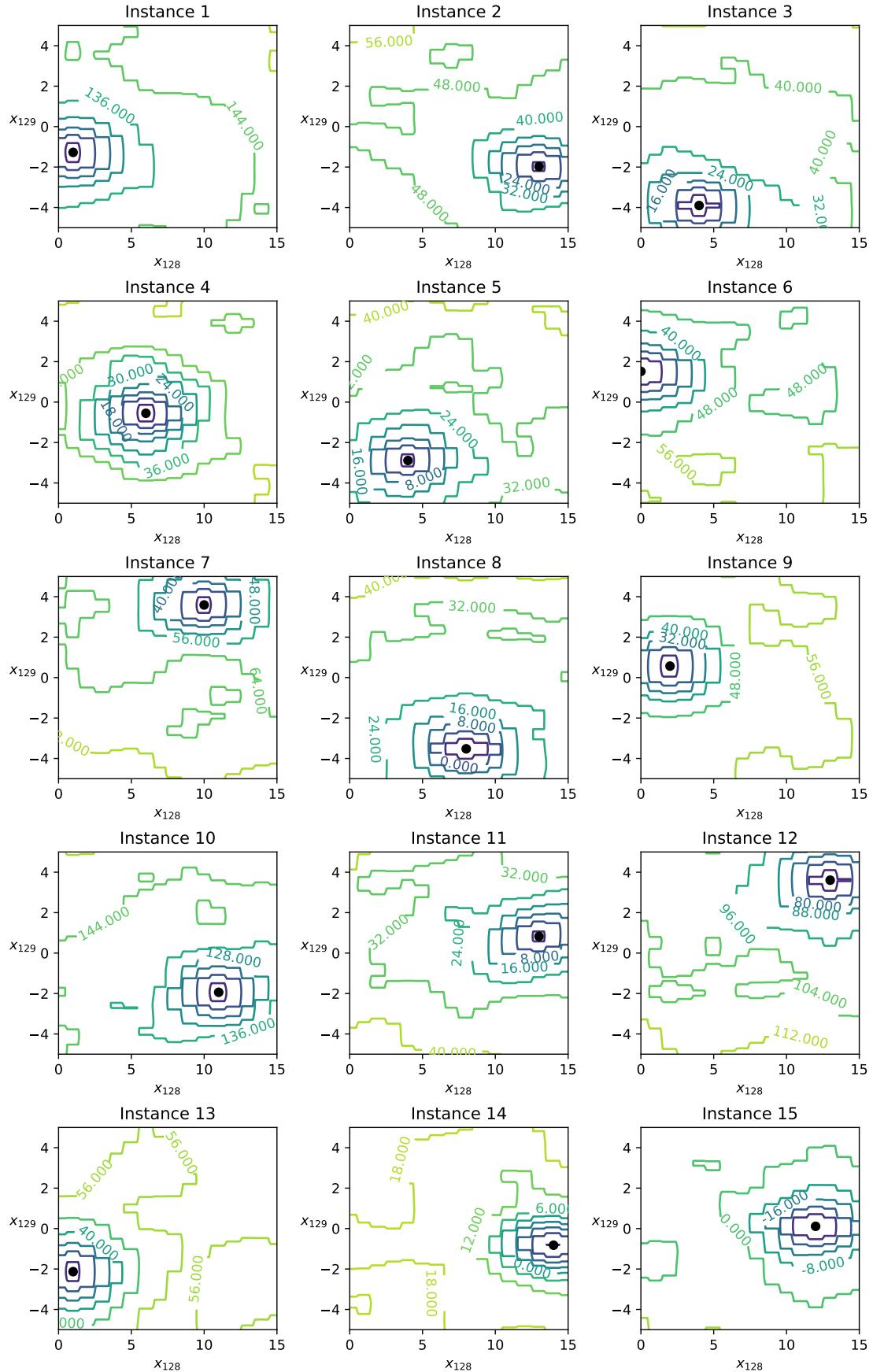
15.4 Function f_{15} , Dimension 40



15.5 Function f_{15} , Dimension 80

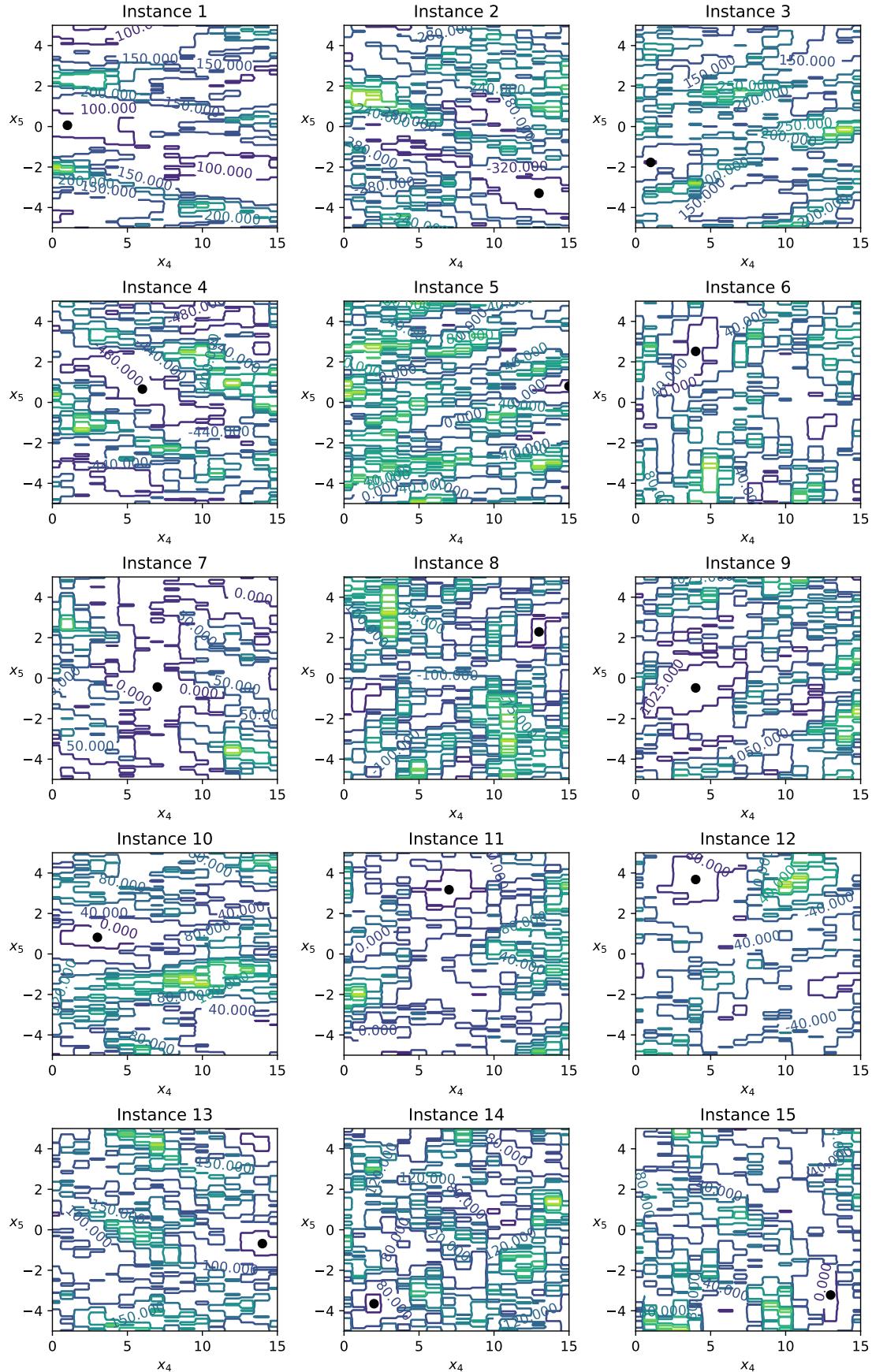


15.6 Function f_{15} , Dimension 160

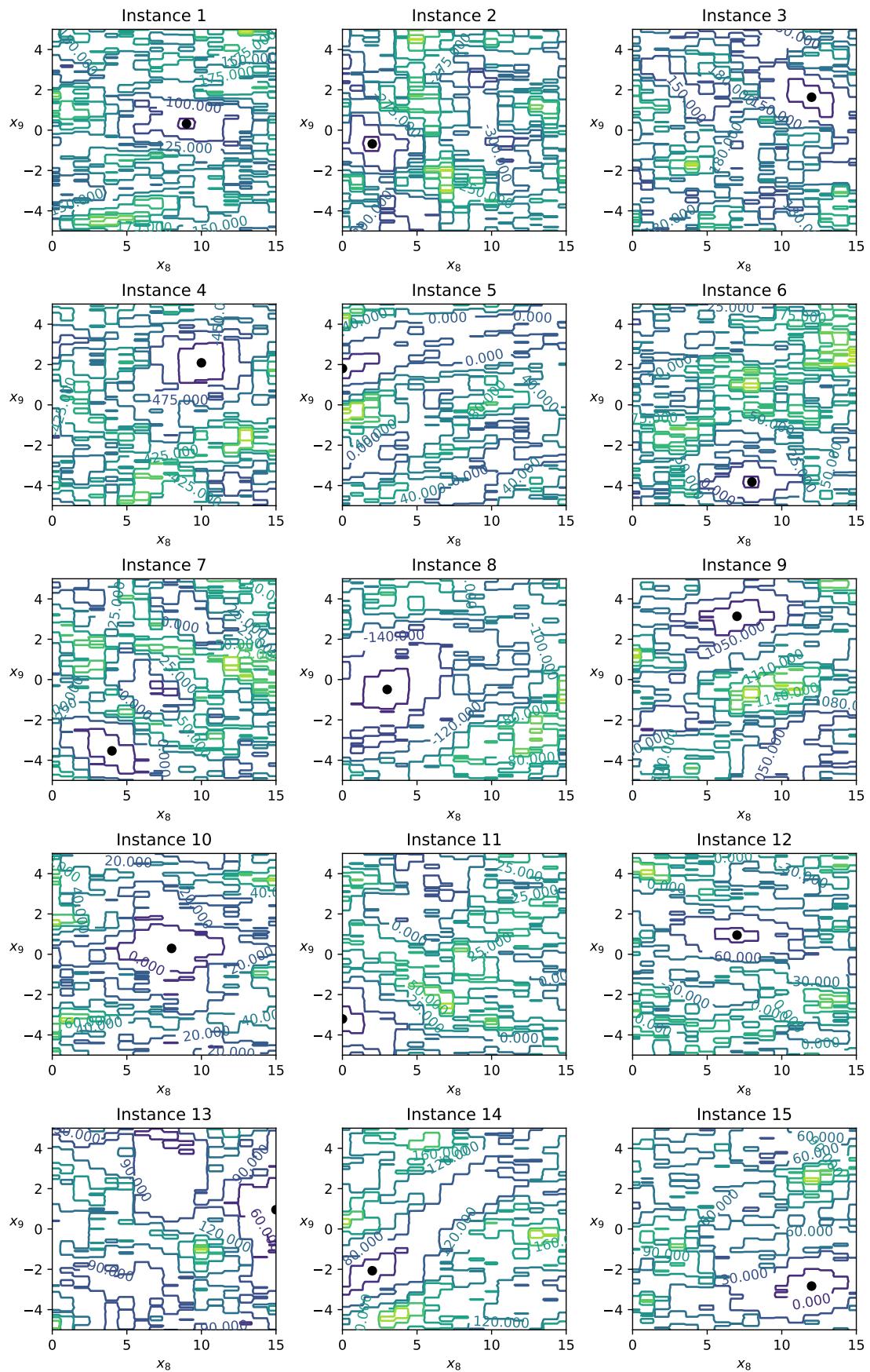


16 Function f_{16} – Weierstrass

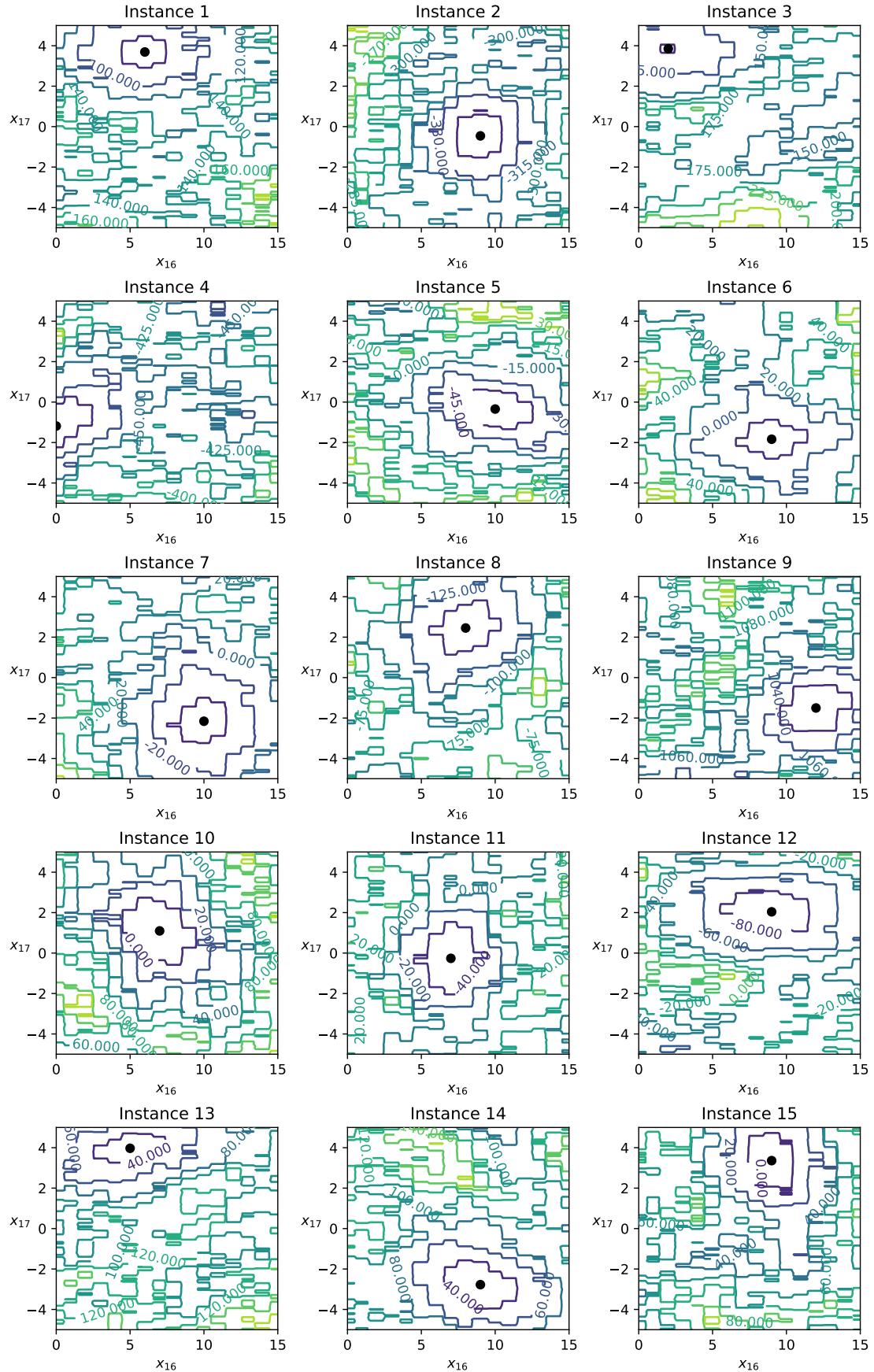
16.1 Function f_{16} , Dimension 5



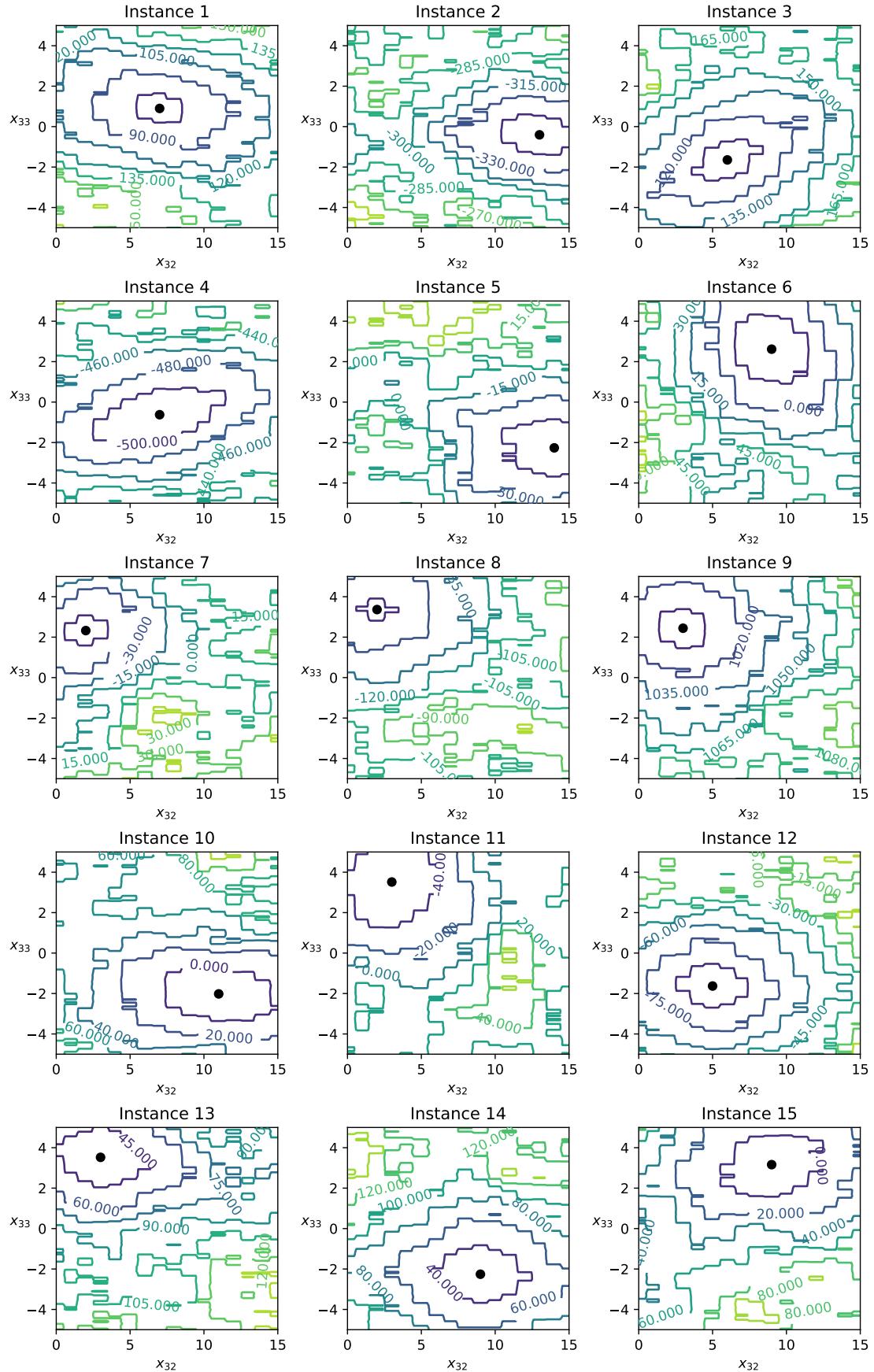
16.2 Function f_{16} , Dimension 10



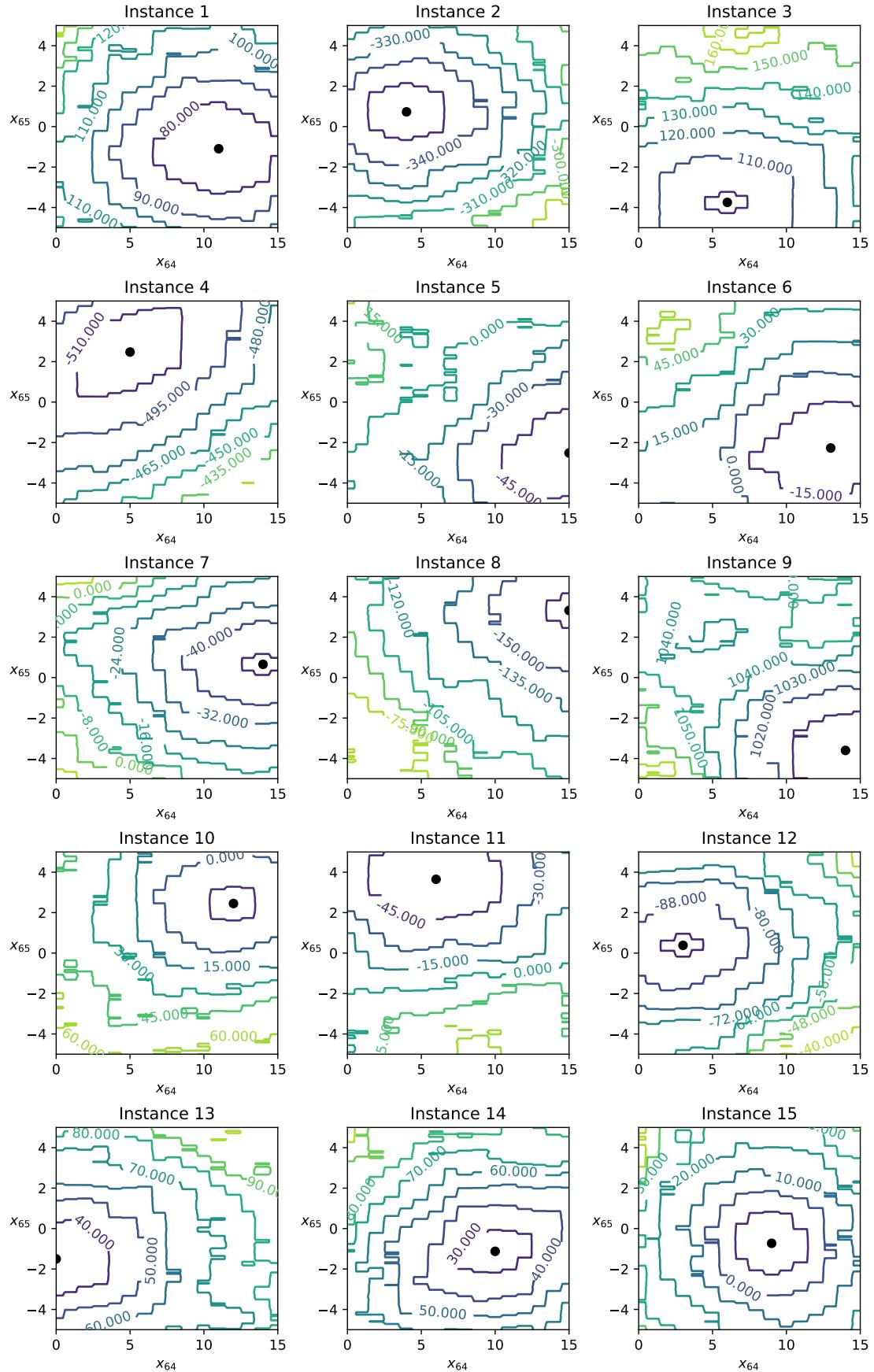
16.3 Function f_{16} , Dimension 20



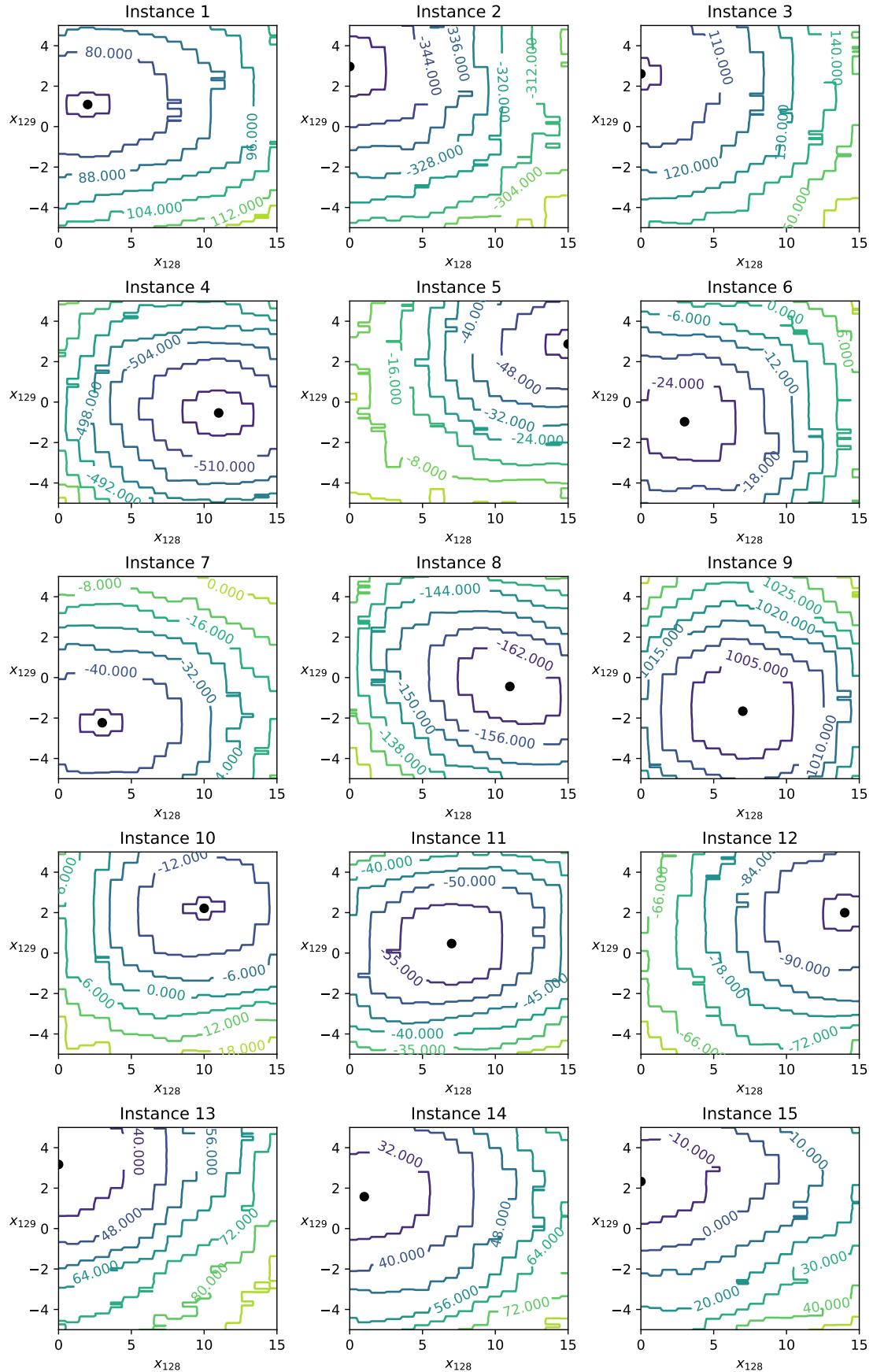
16.4 Function f_{16} , Dimension 40



16.5 Function f_{16} , Dimension 80

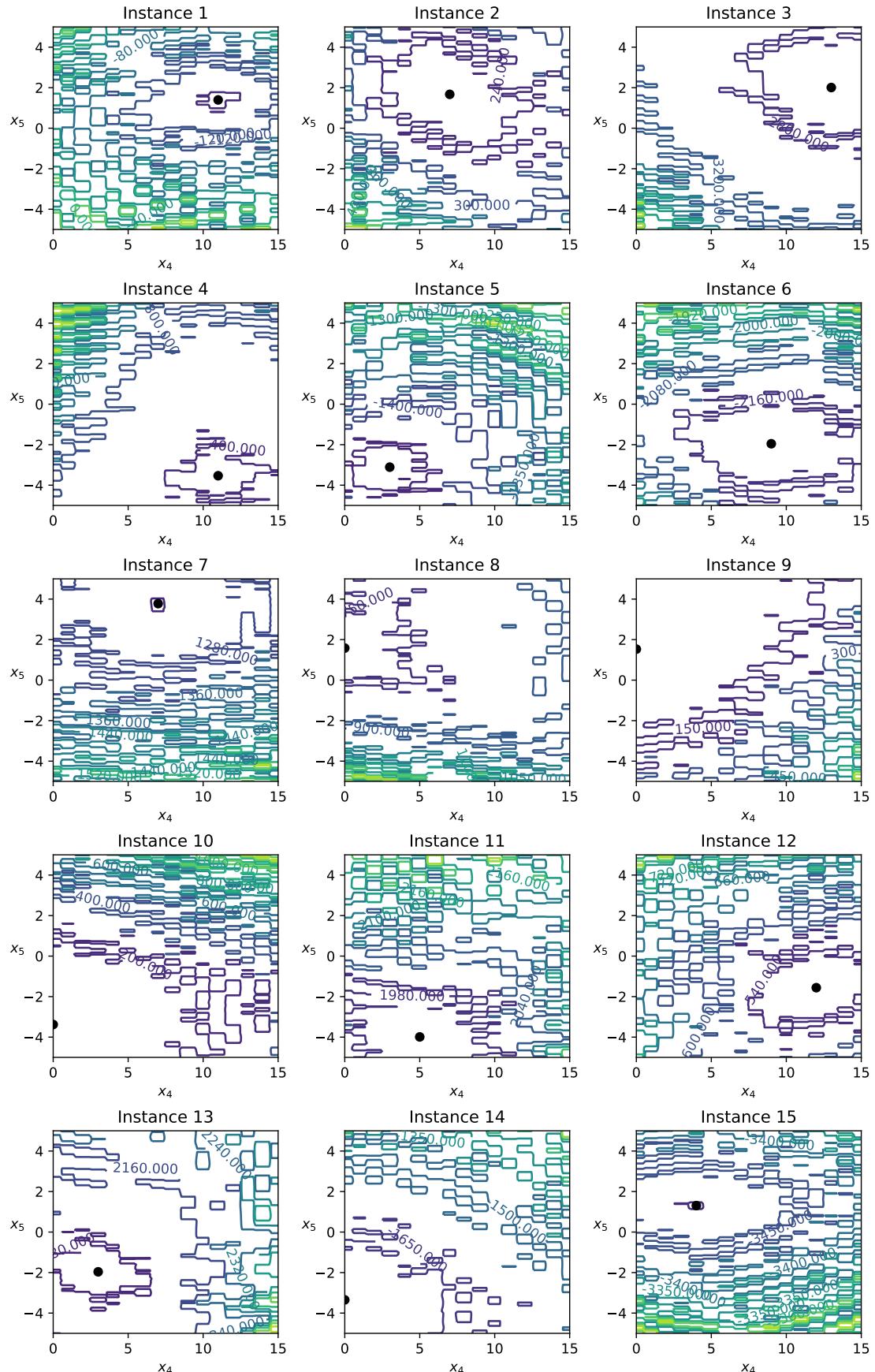


16.6 Function f_{16} , Dimension 160

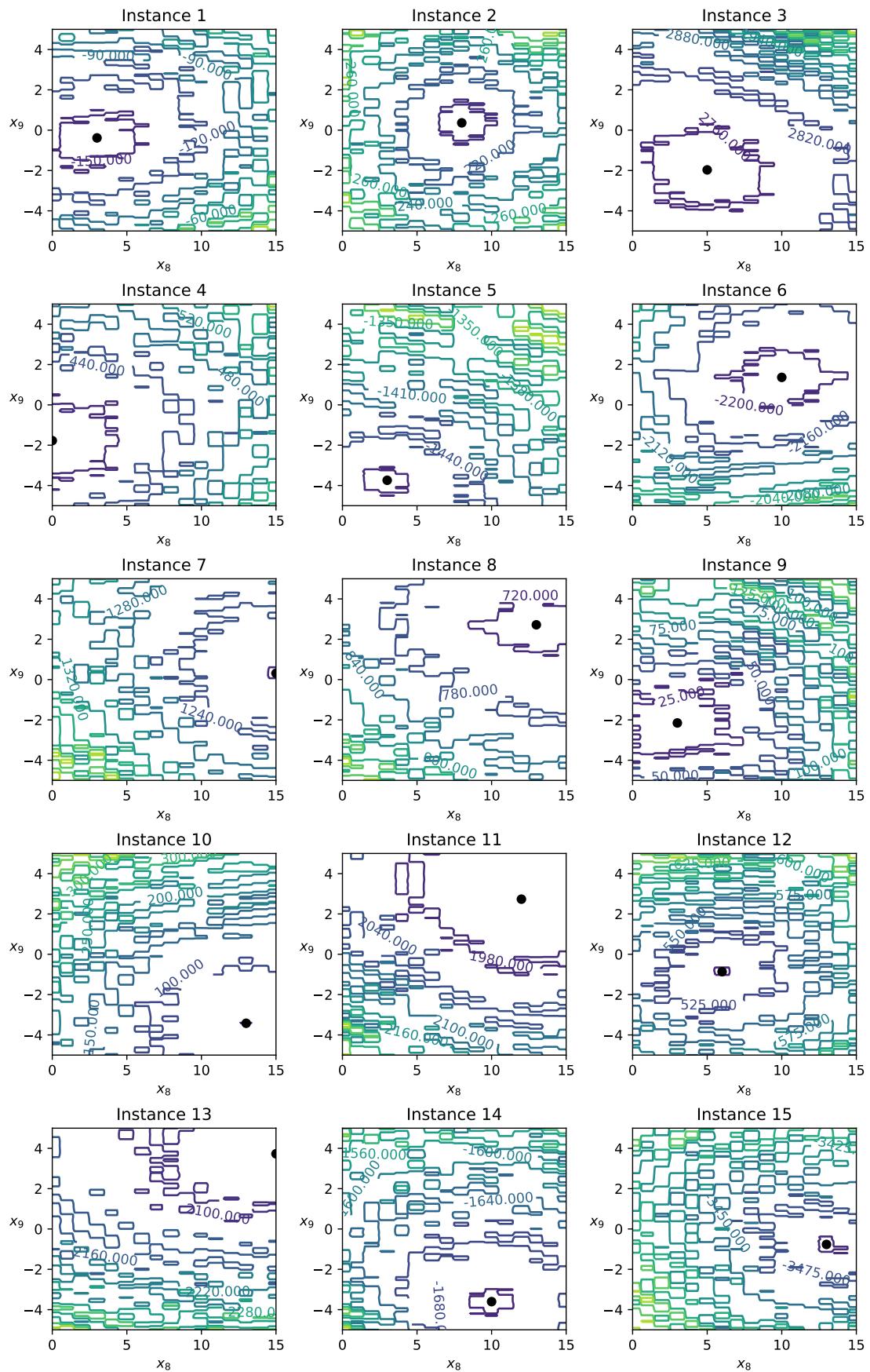


17 Function f_{17} – Schaffers F7

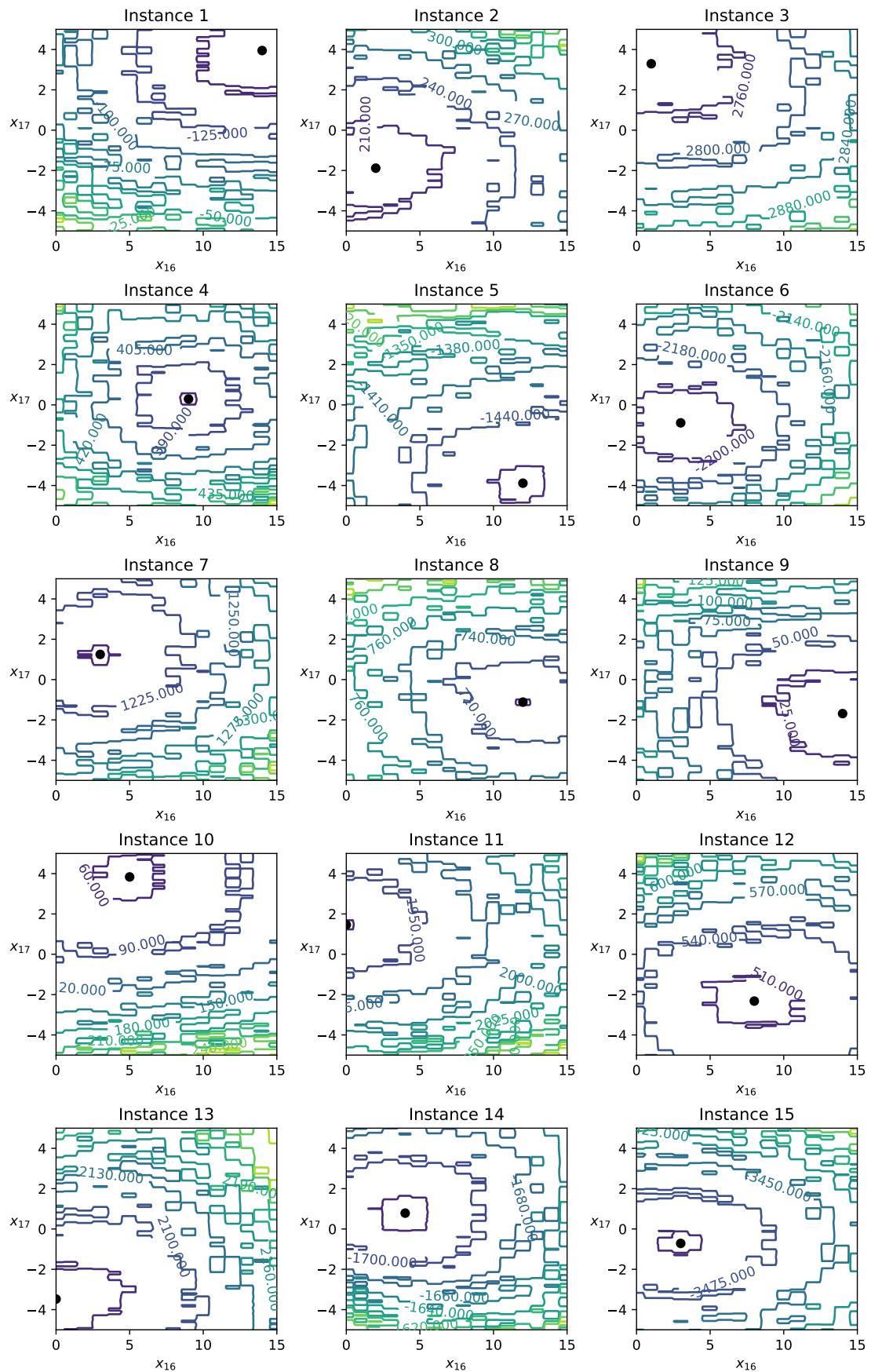
17.1 Function f_{17} , Dimension 5



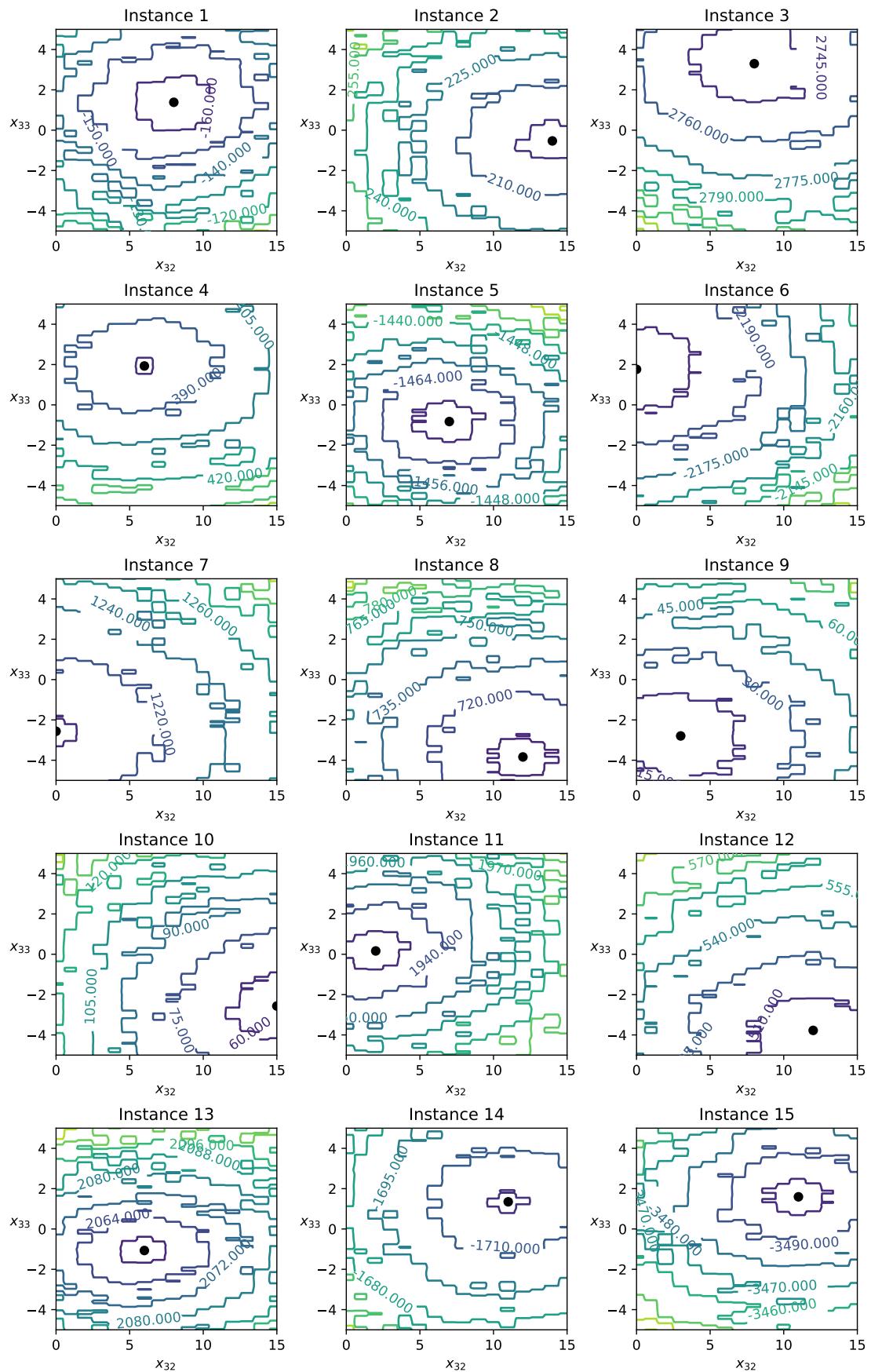
17.2 Function f_{17} , Dimension 10



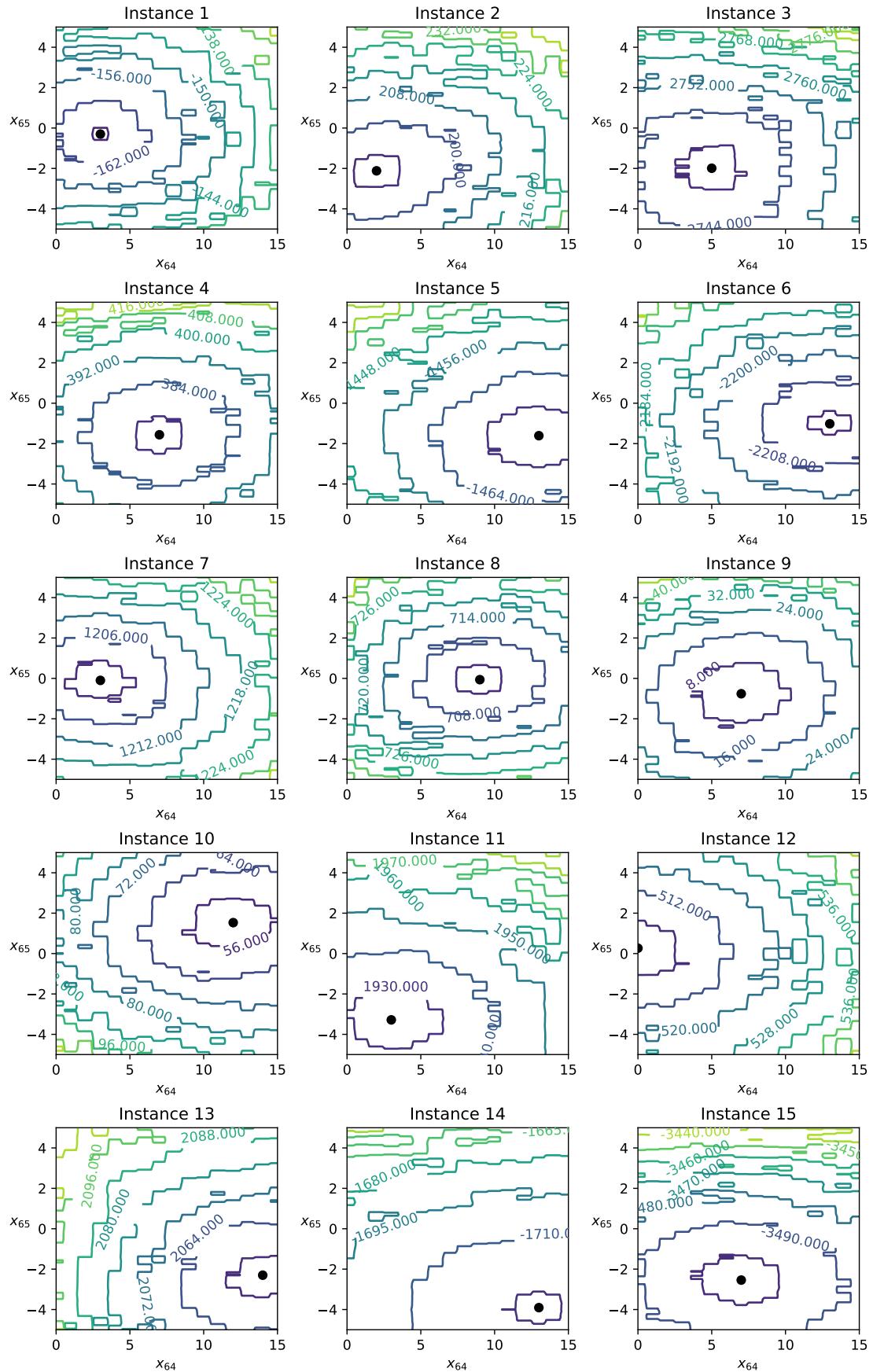
17.3 Function f_{17} , Dimension 20



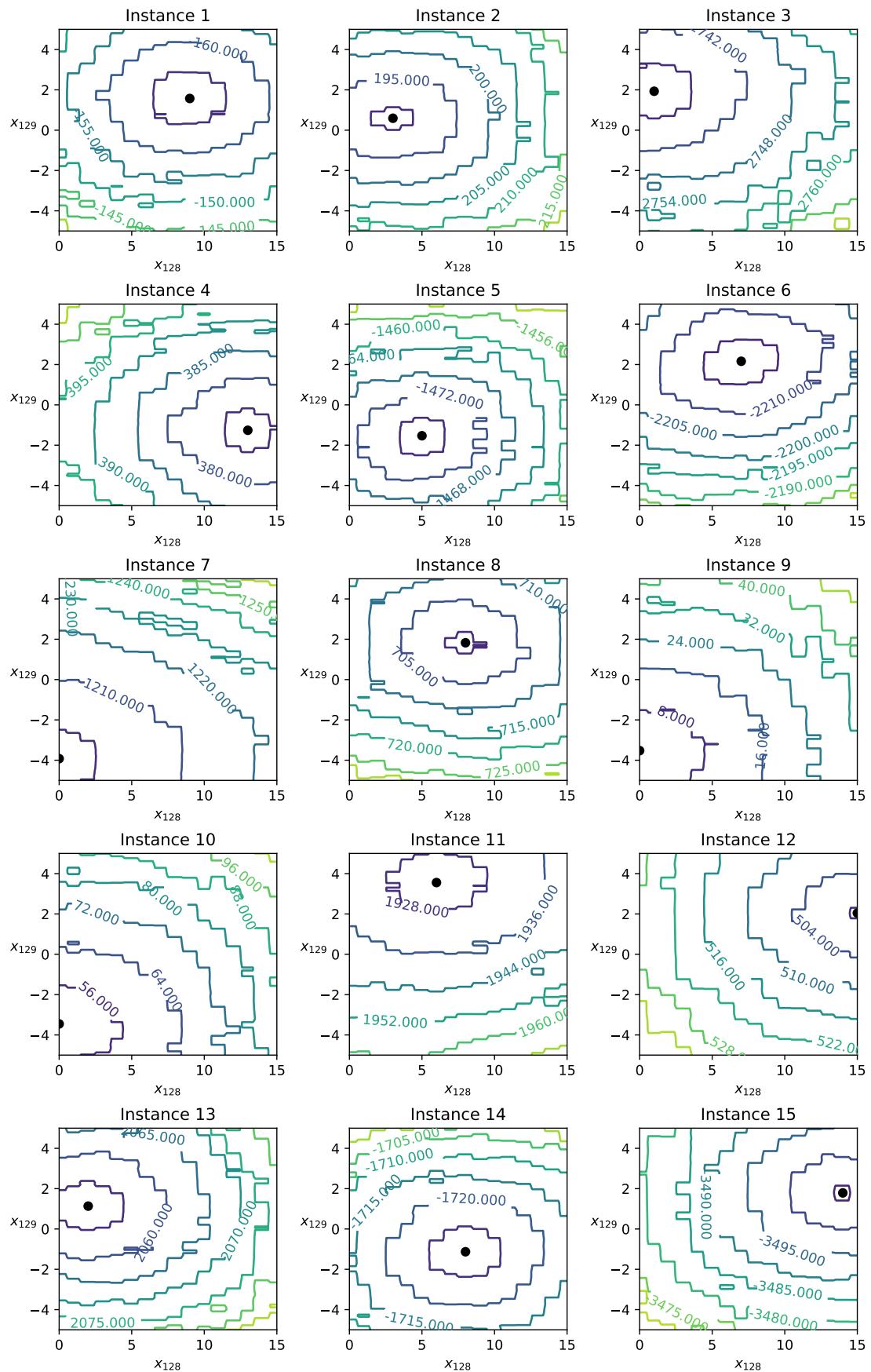
17.4 Function f_{17} , Dimension 40



17.5 Function f_{17} , Dimension 80

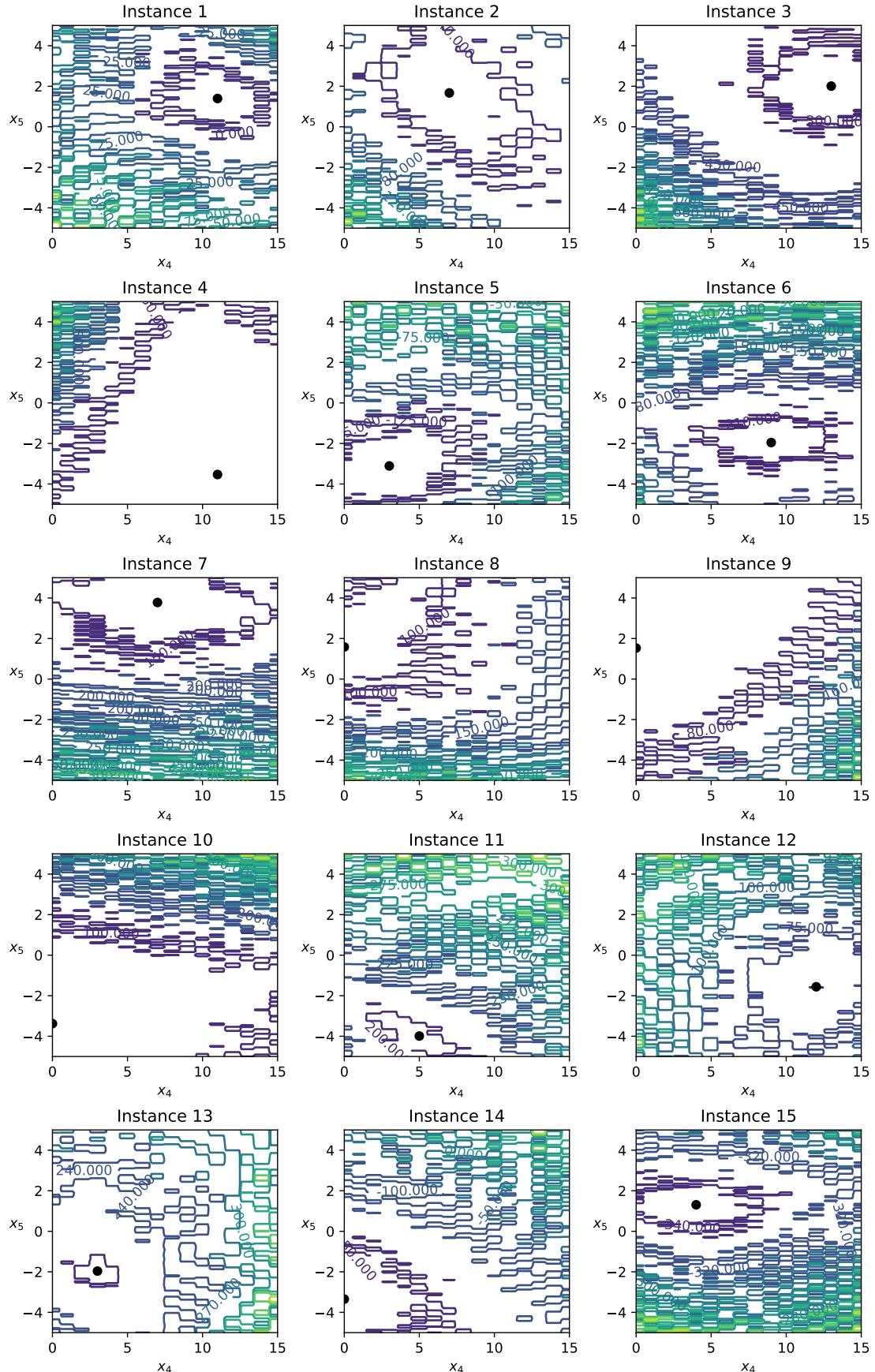


17.6 Function f_{17} , Dimension 160

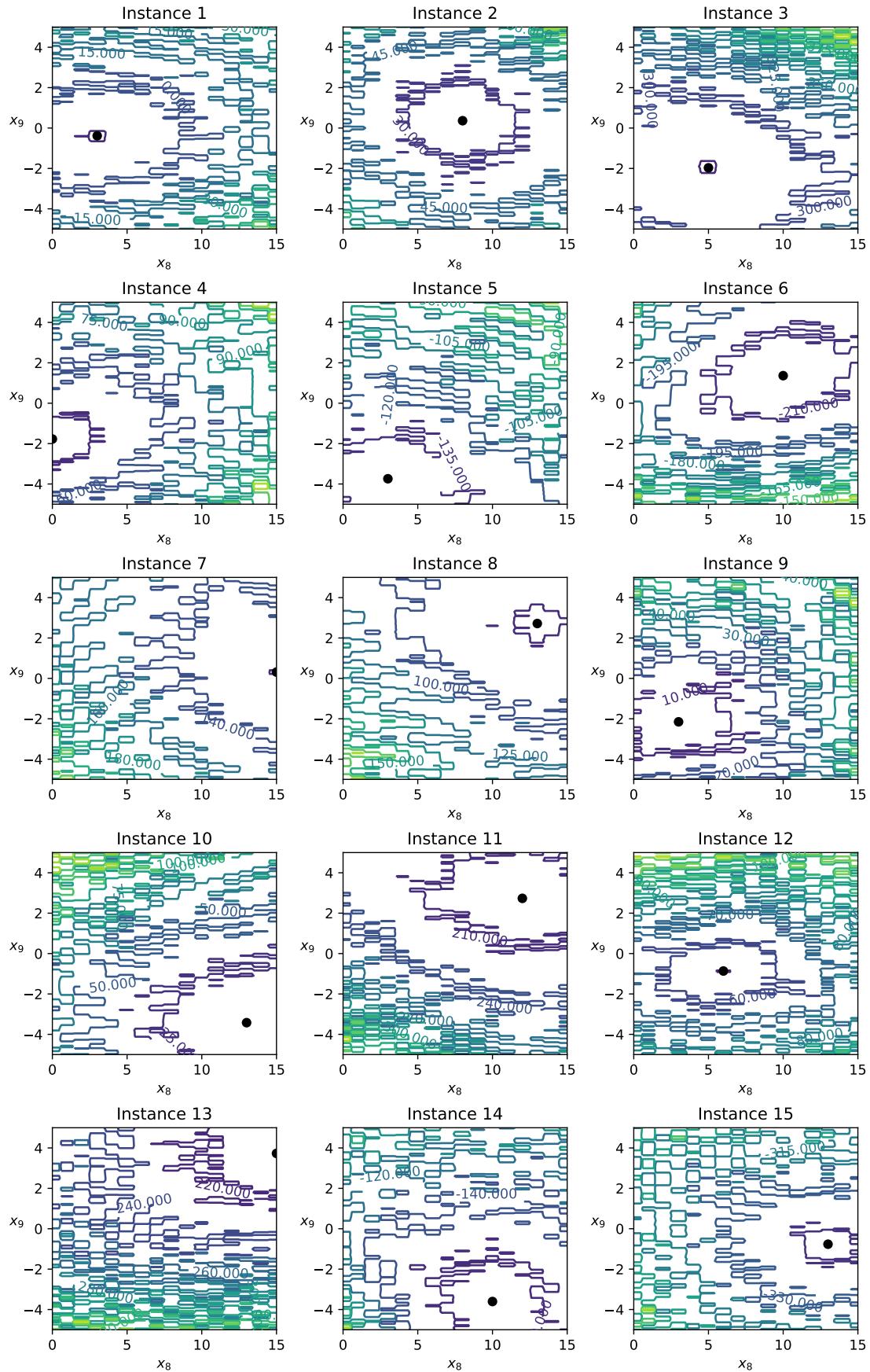


18 Function f_{18} – Schaffers F7 (Moderately Ill-Conditioned)

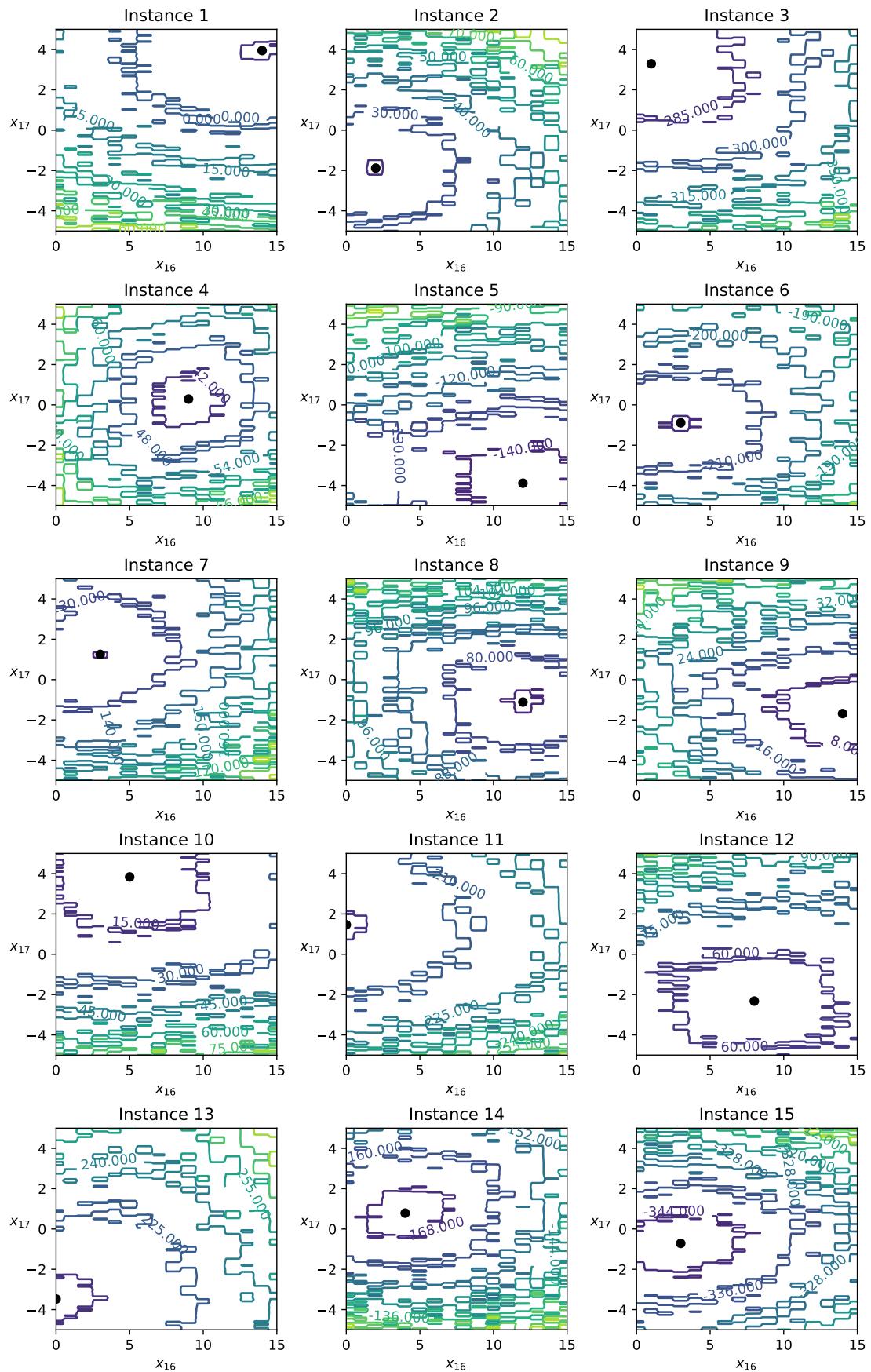
18.1 Function f_{18} , Dimension 5



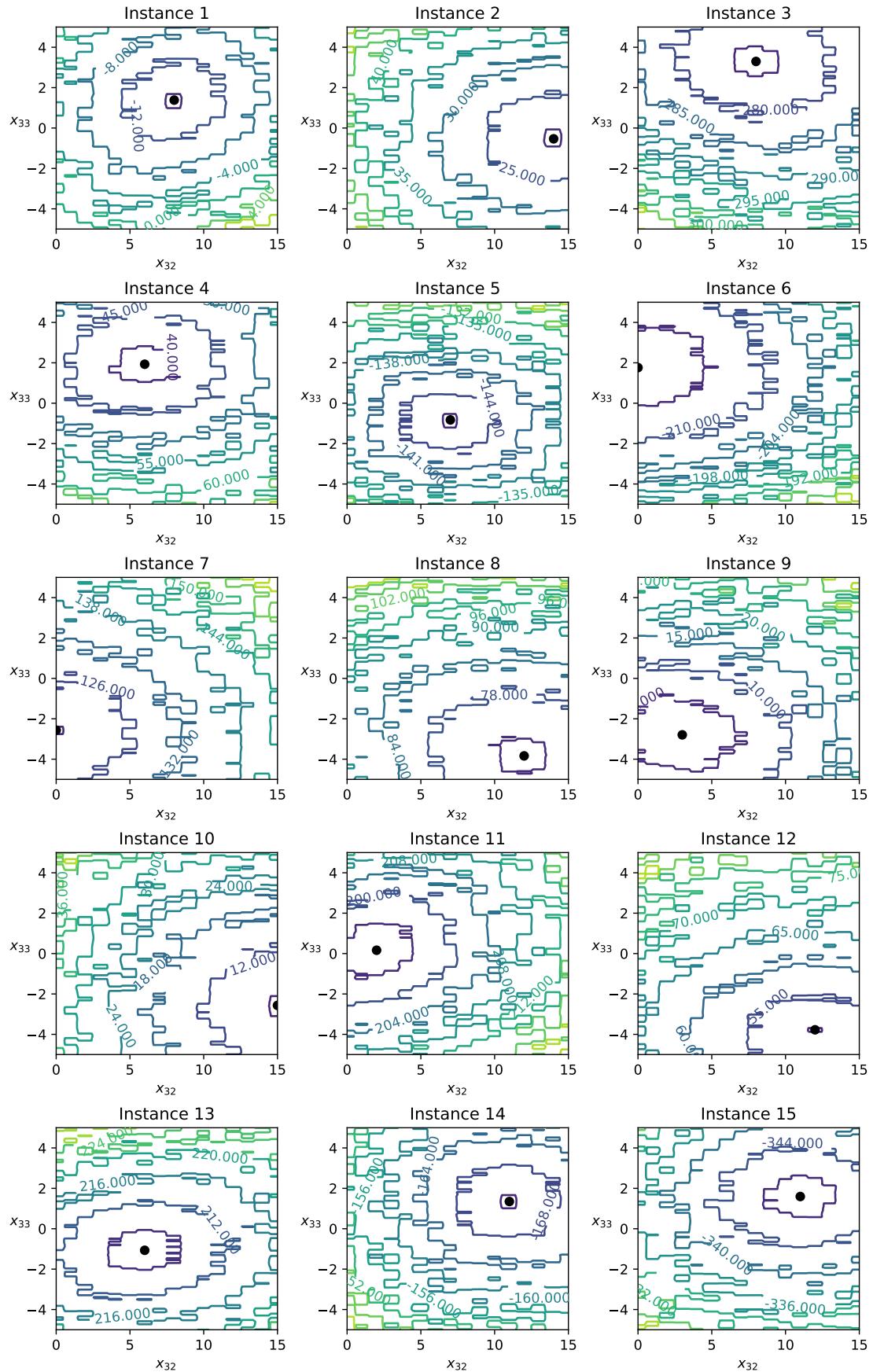
18.2 Function f_{18} , Dimension 10



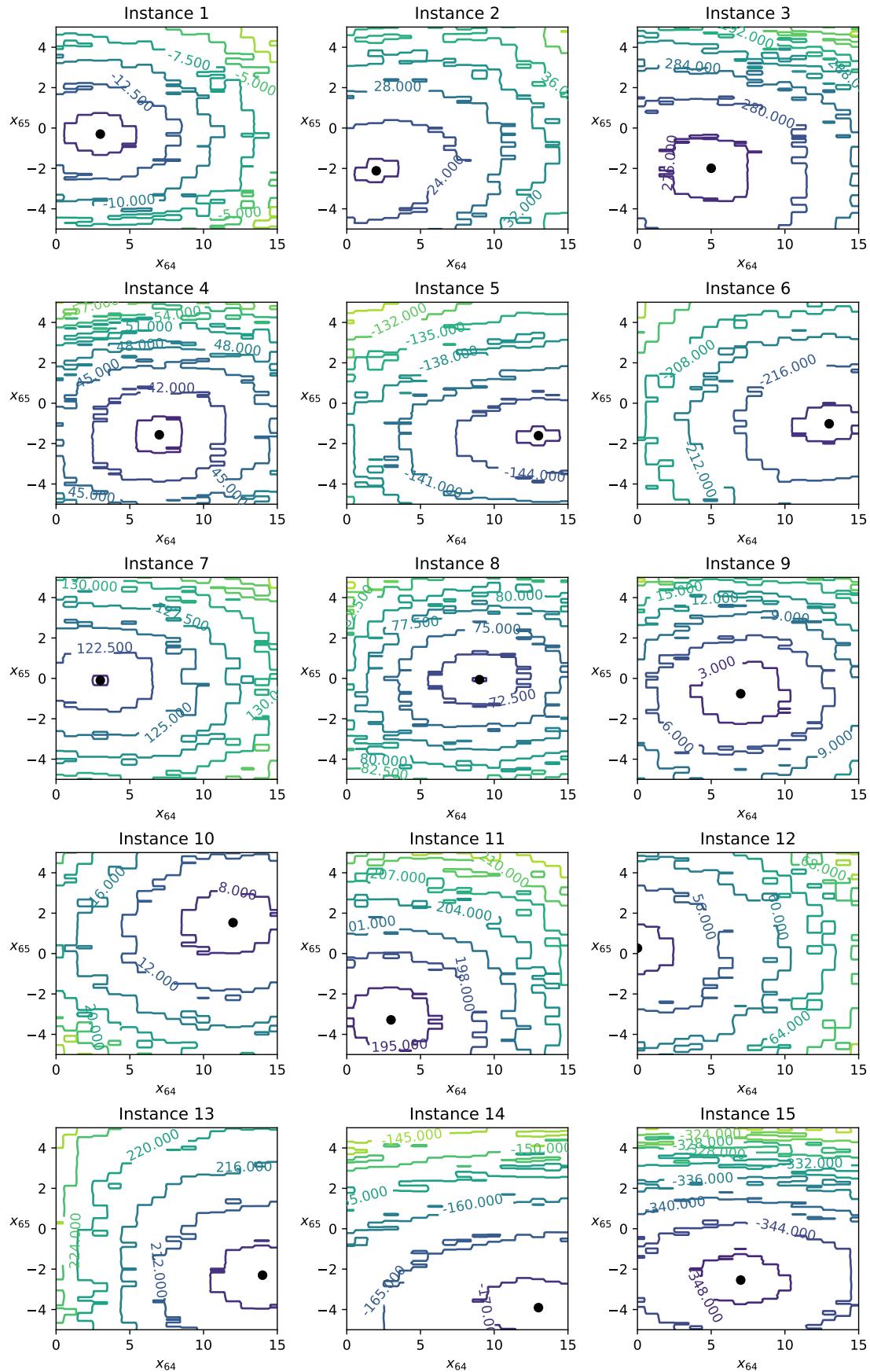
18.3 Function f_{18} , Dimension 20



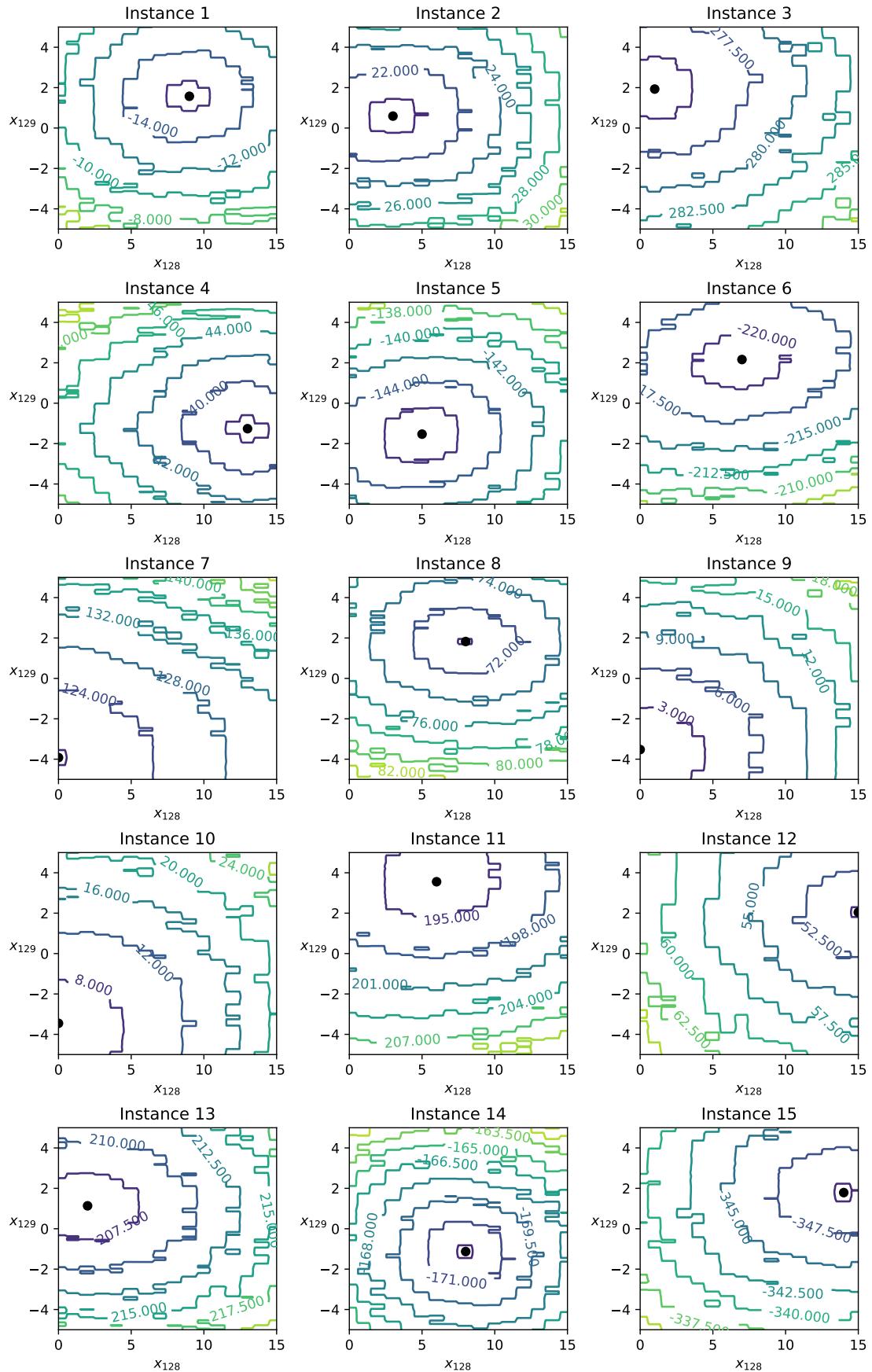
18.4 Function f_{18} , Dimension 40



18.5 Function f_{18} , Dimension 80

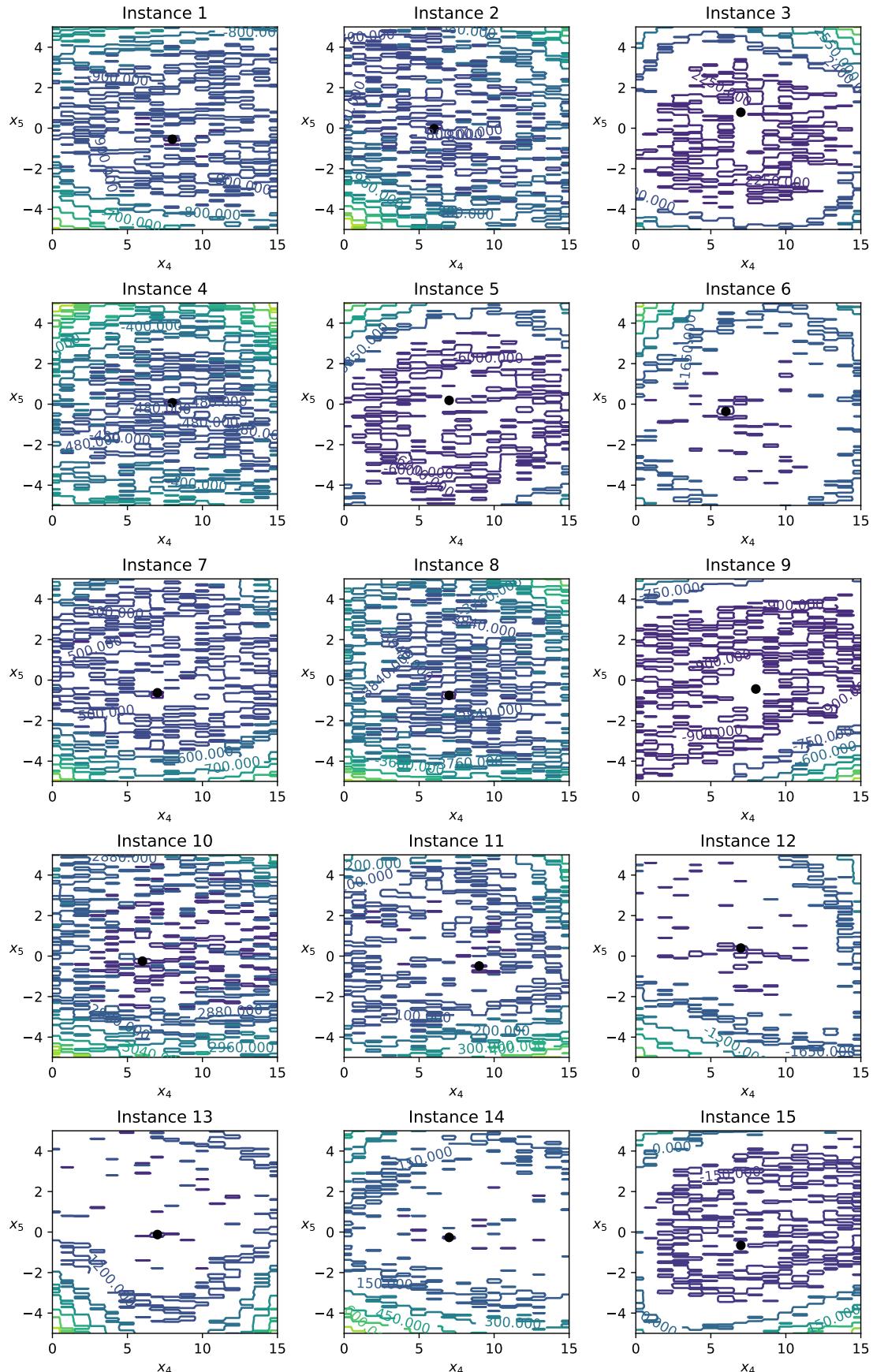


18.6 Function f_{18} , Dimension 160

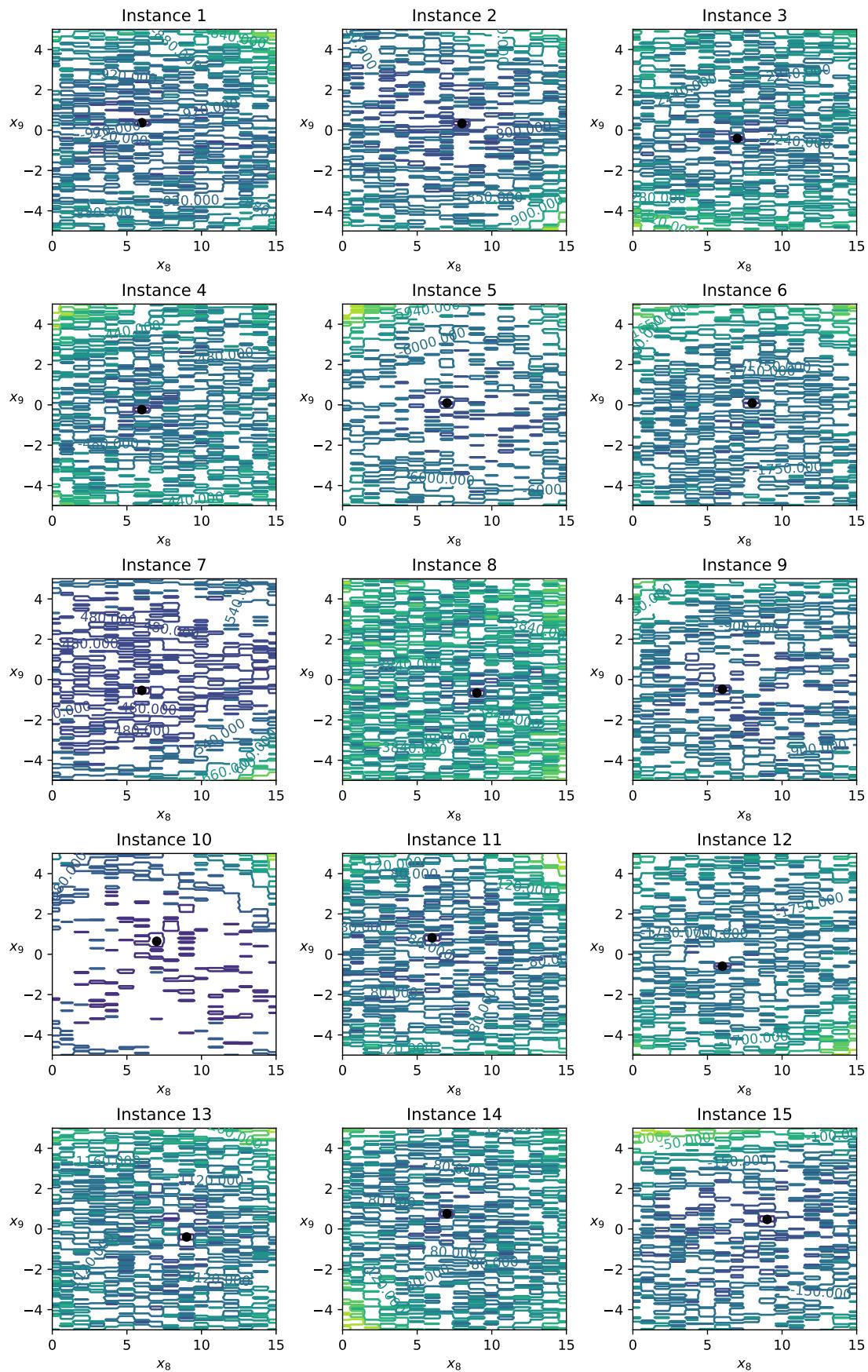


19 Function f_{19} – Composite Griewank-Rosenbrock F8F2

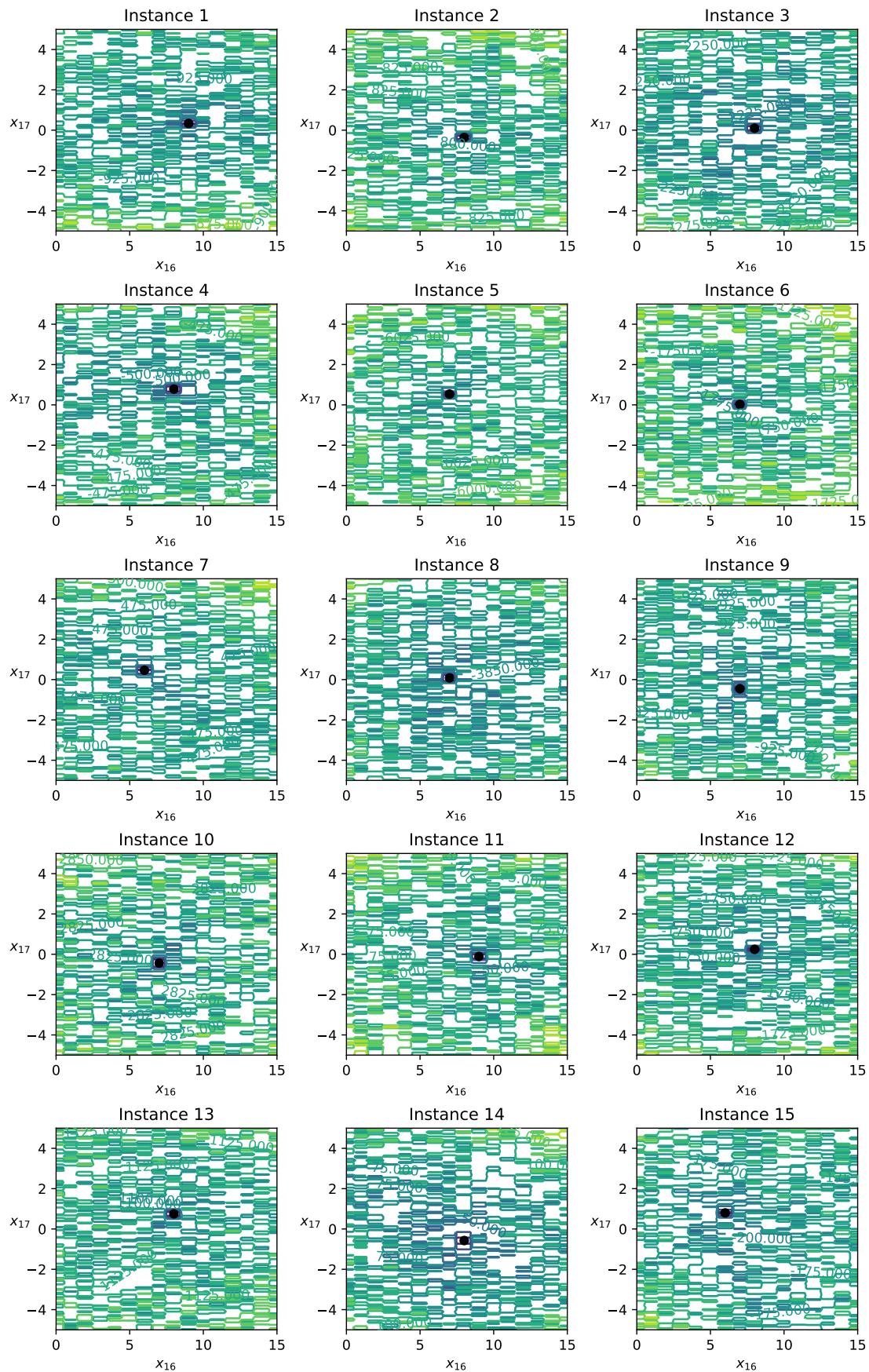
19.1 Function f_{19} , Dimension 5



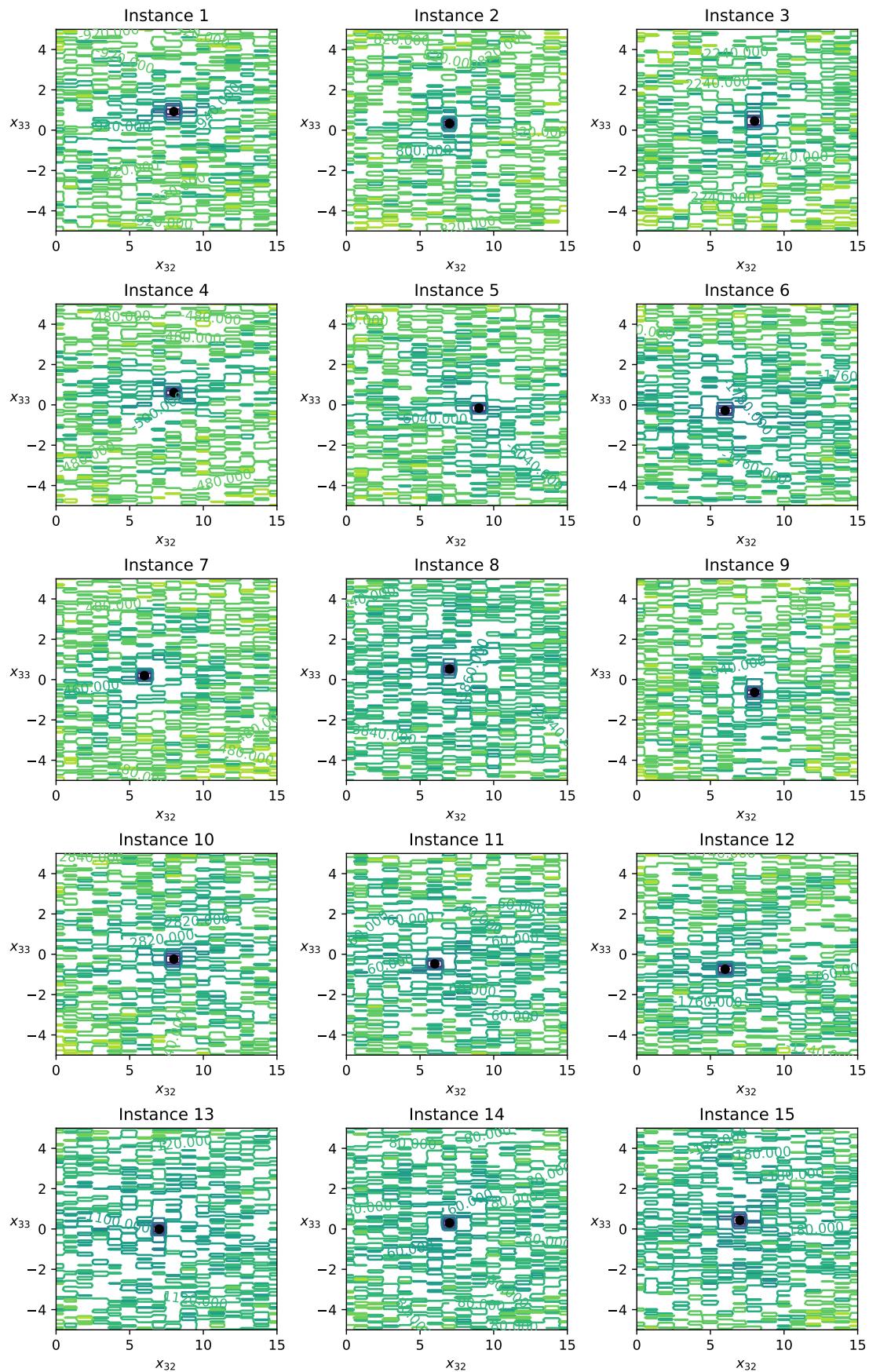
19.2 Function f_{19} , Dimension 10



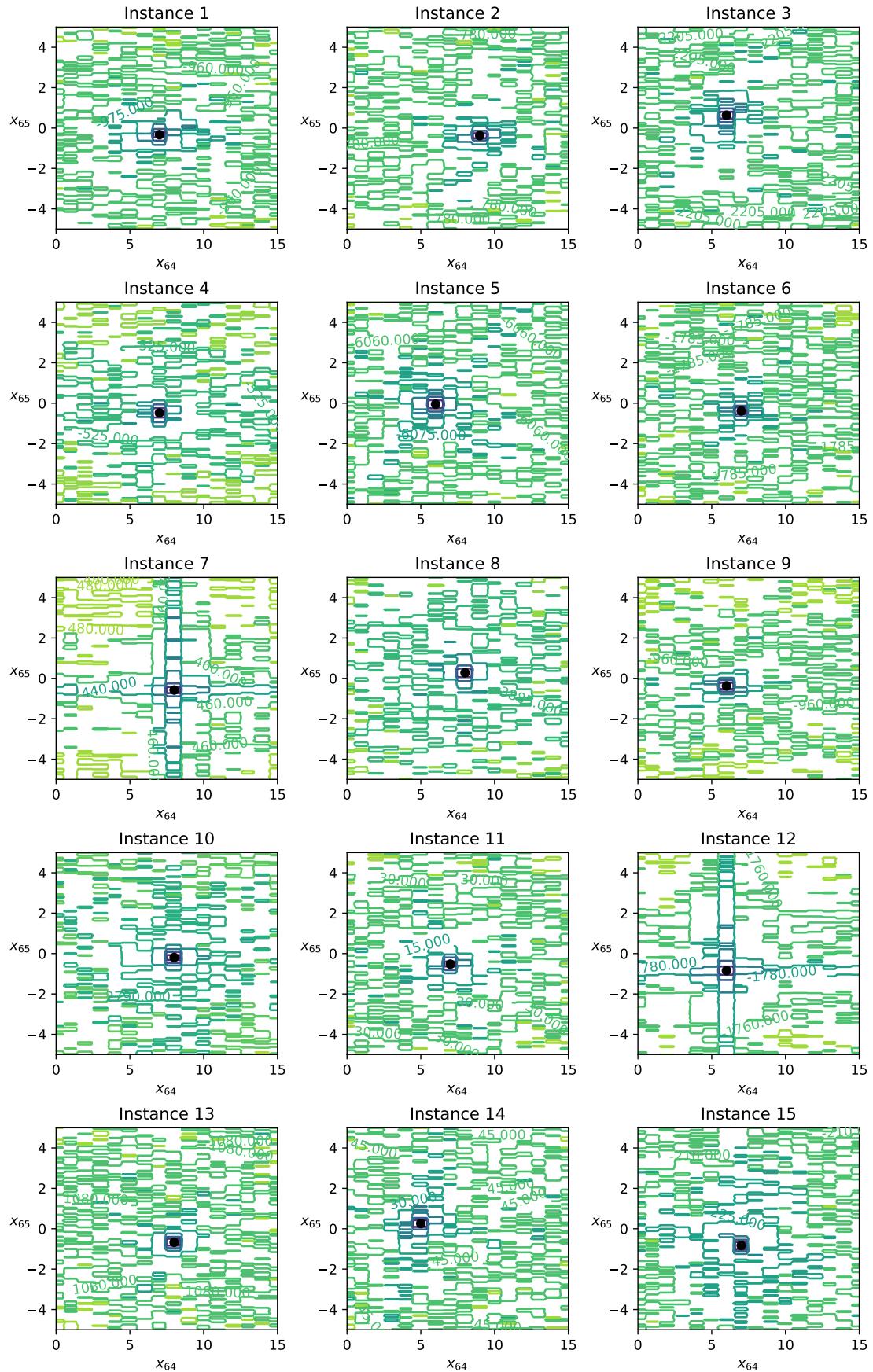
19.3 Function f_{19} , Dimension 20



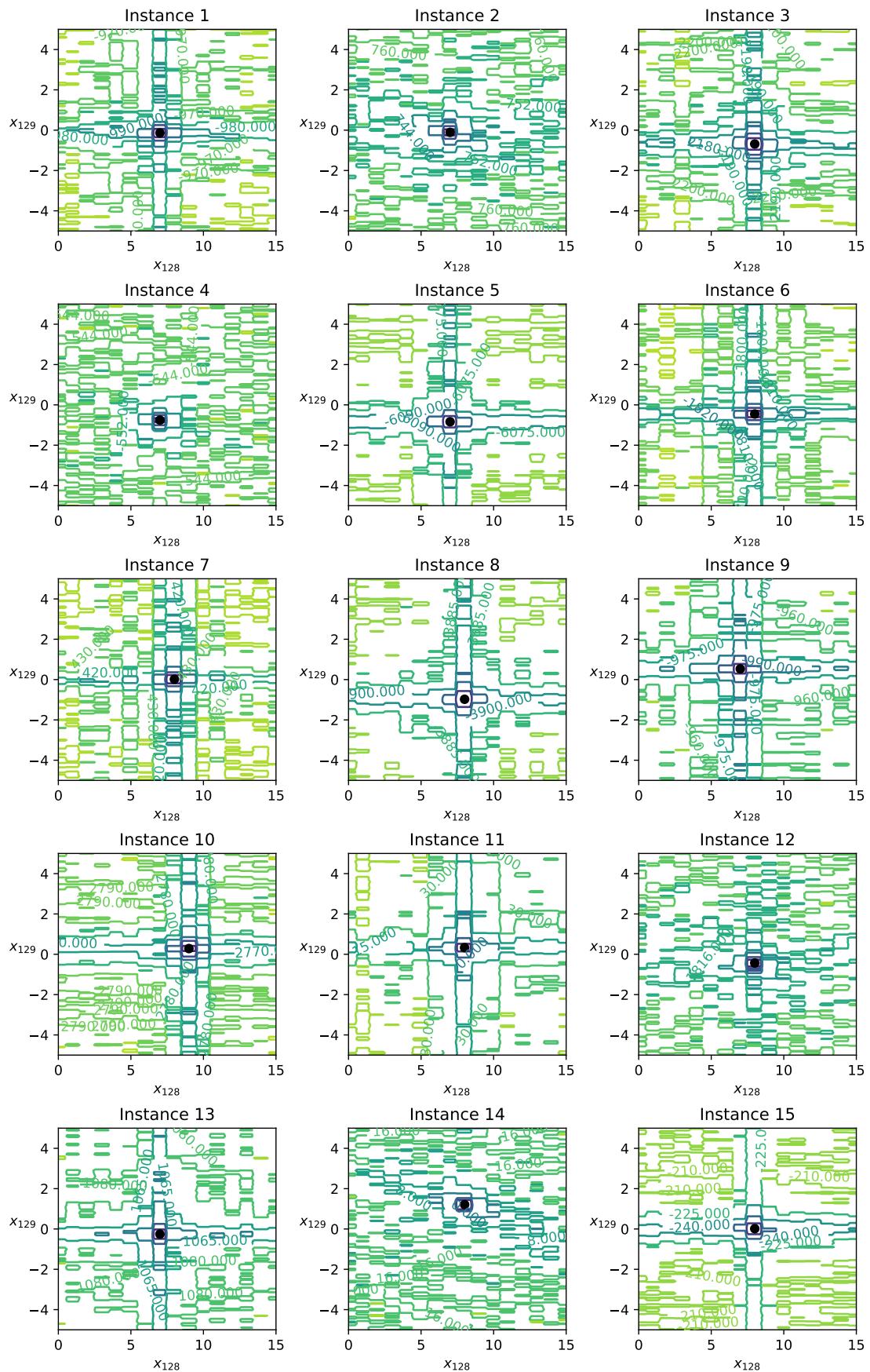
19.4 Function f_{19} , Dimension 40



19.5 Function f_{19} , Dimension 80

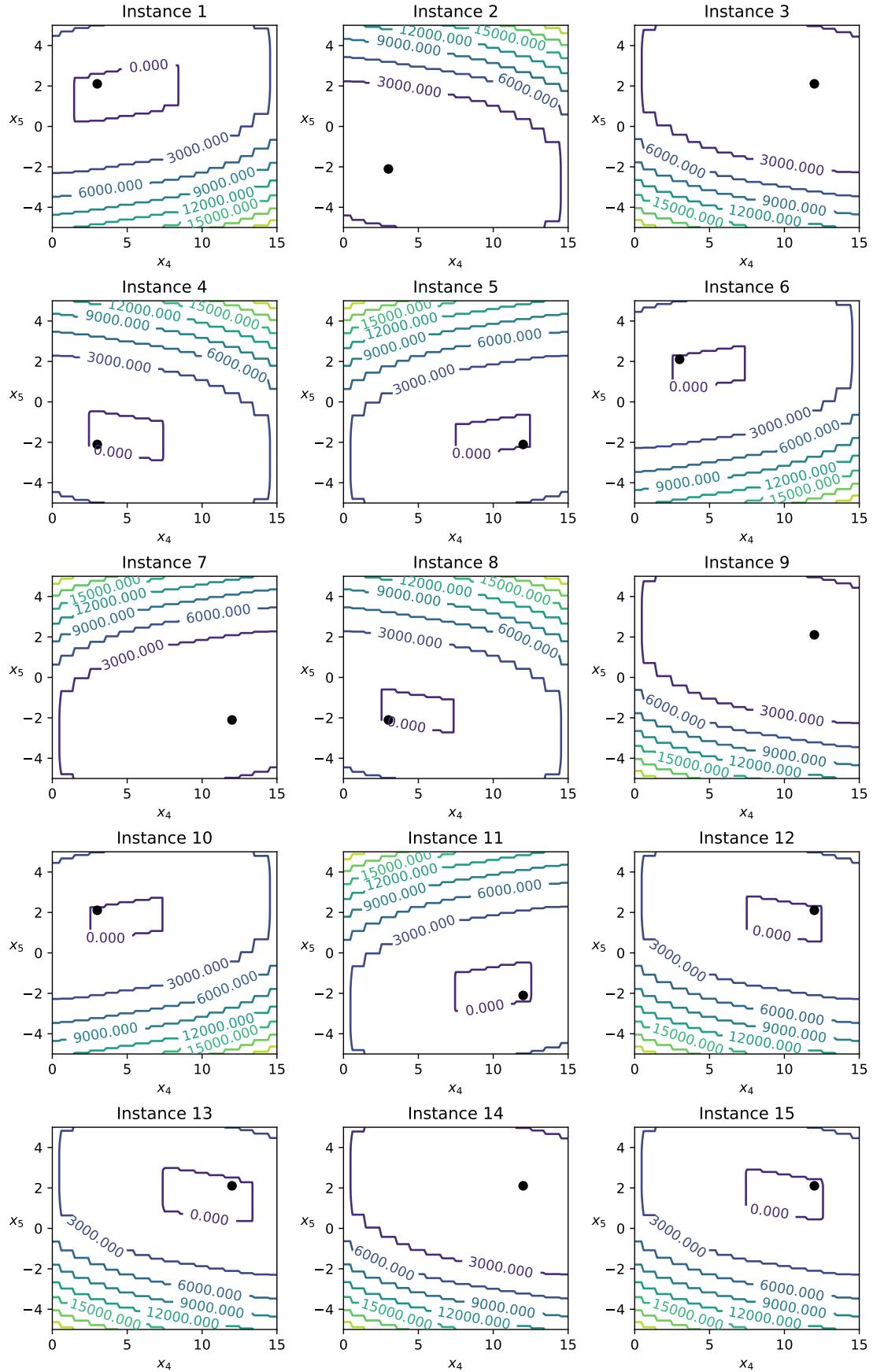


19.6 Function f_{19} , Dimension 160

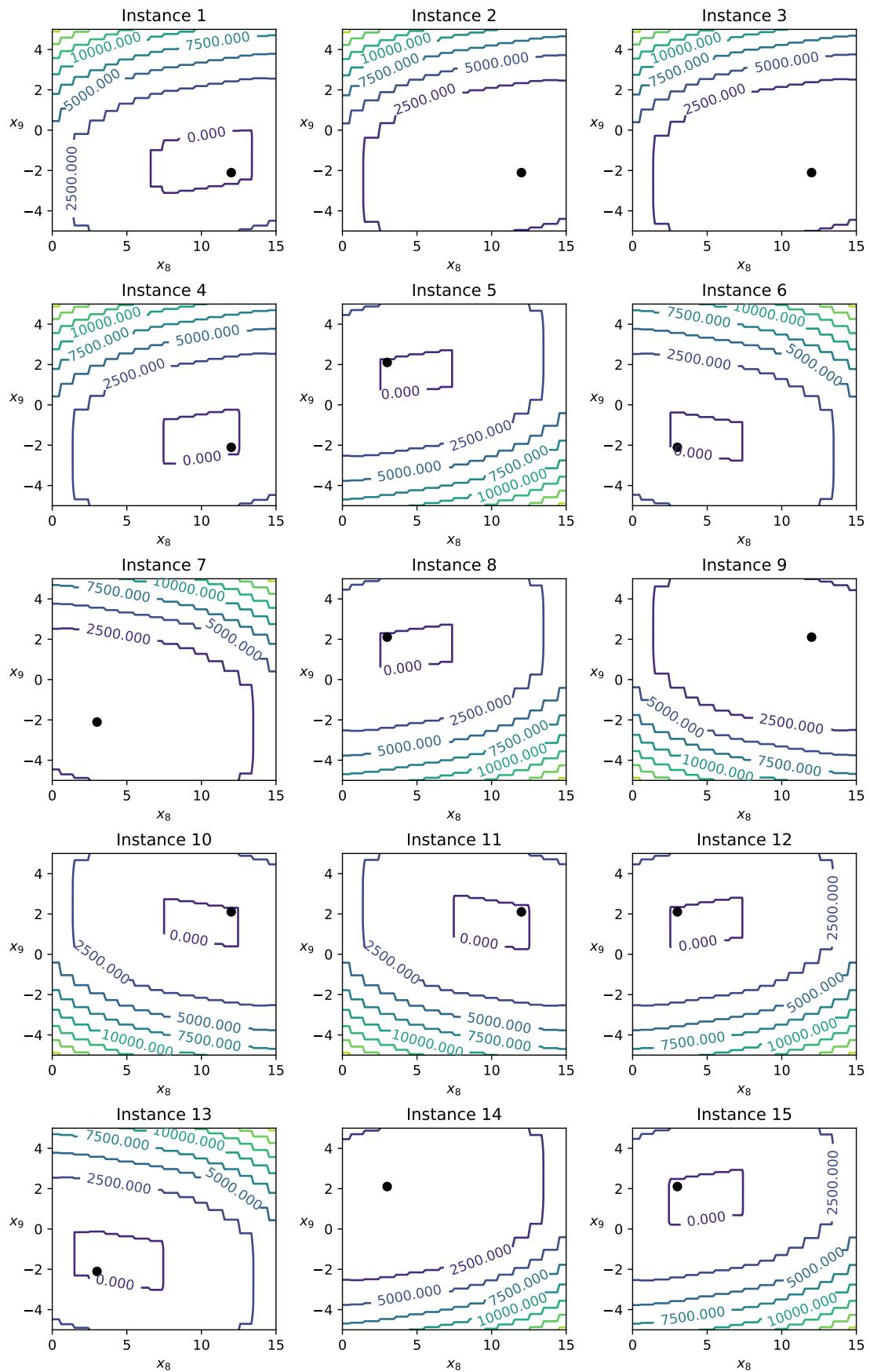


20 Function f_{20} – Schwefel

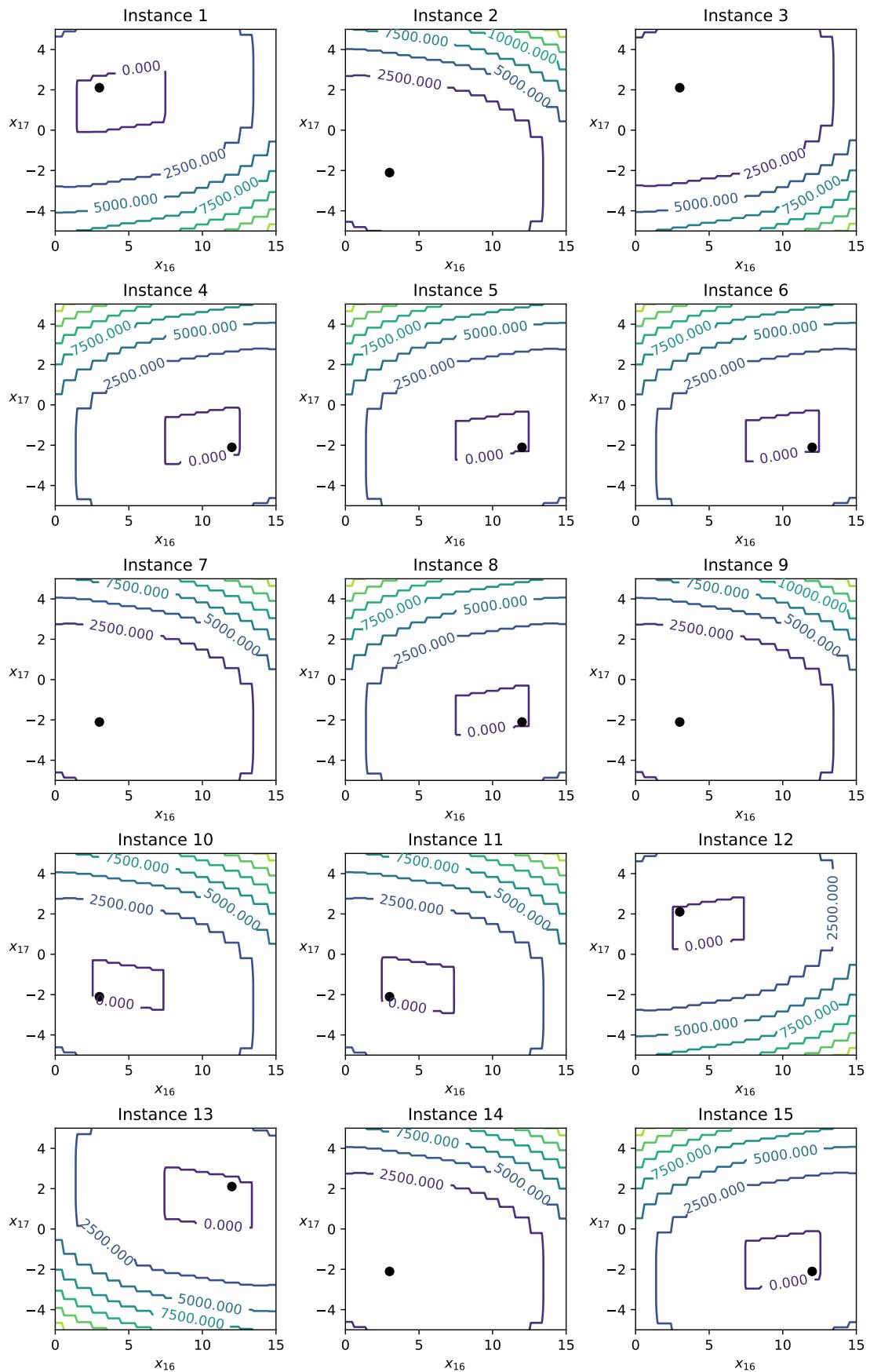
20.1 Function f_{20} , Dimension 5



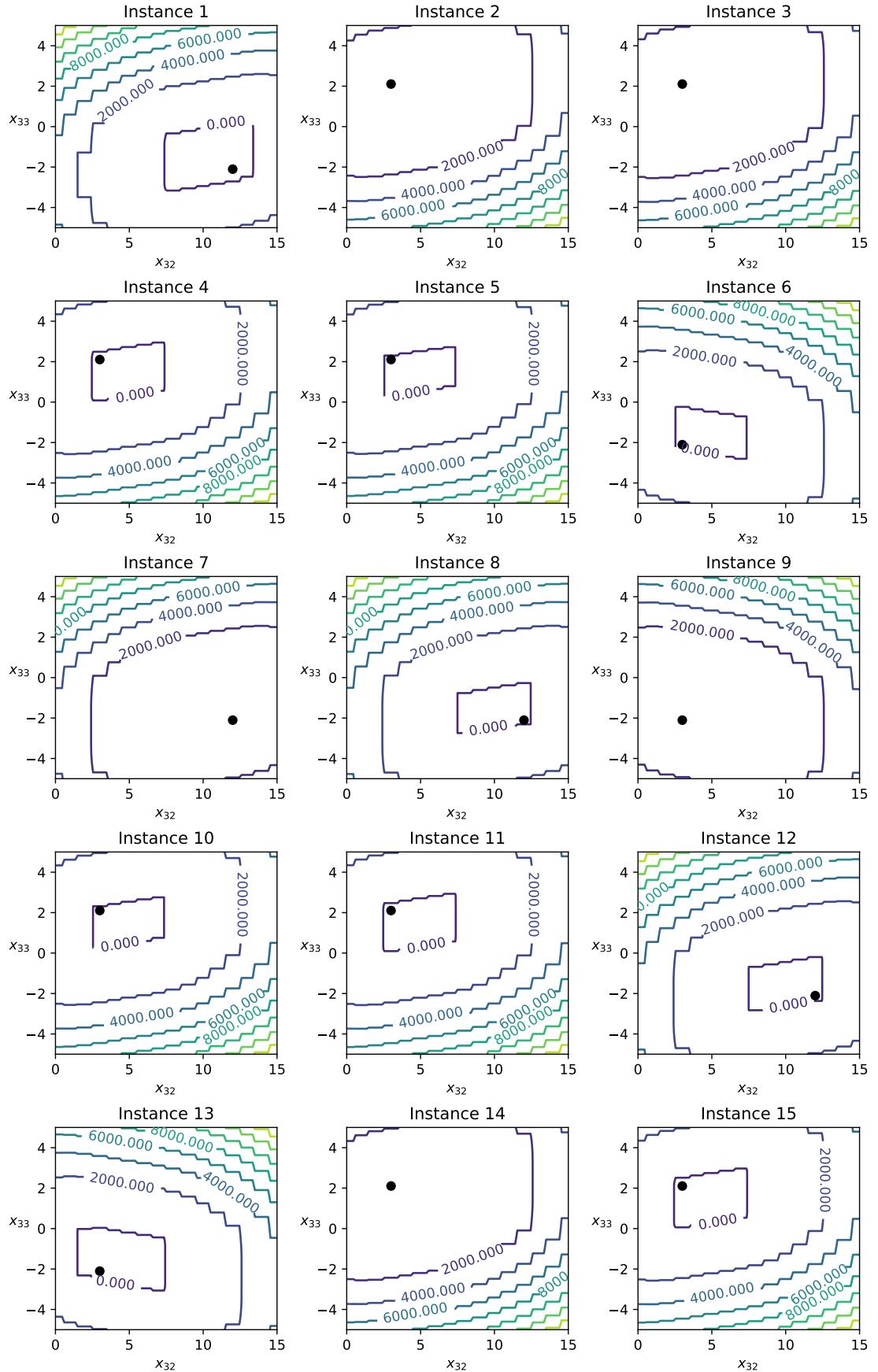
20.2 Function f_{20} , Dimension 10



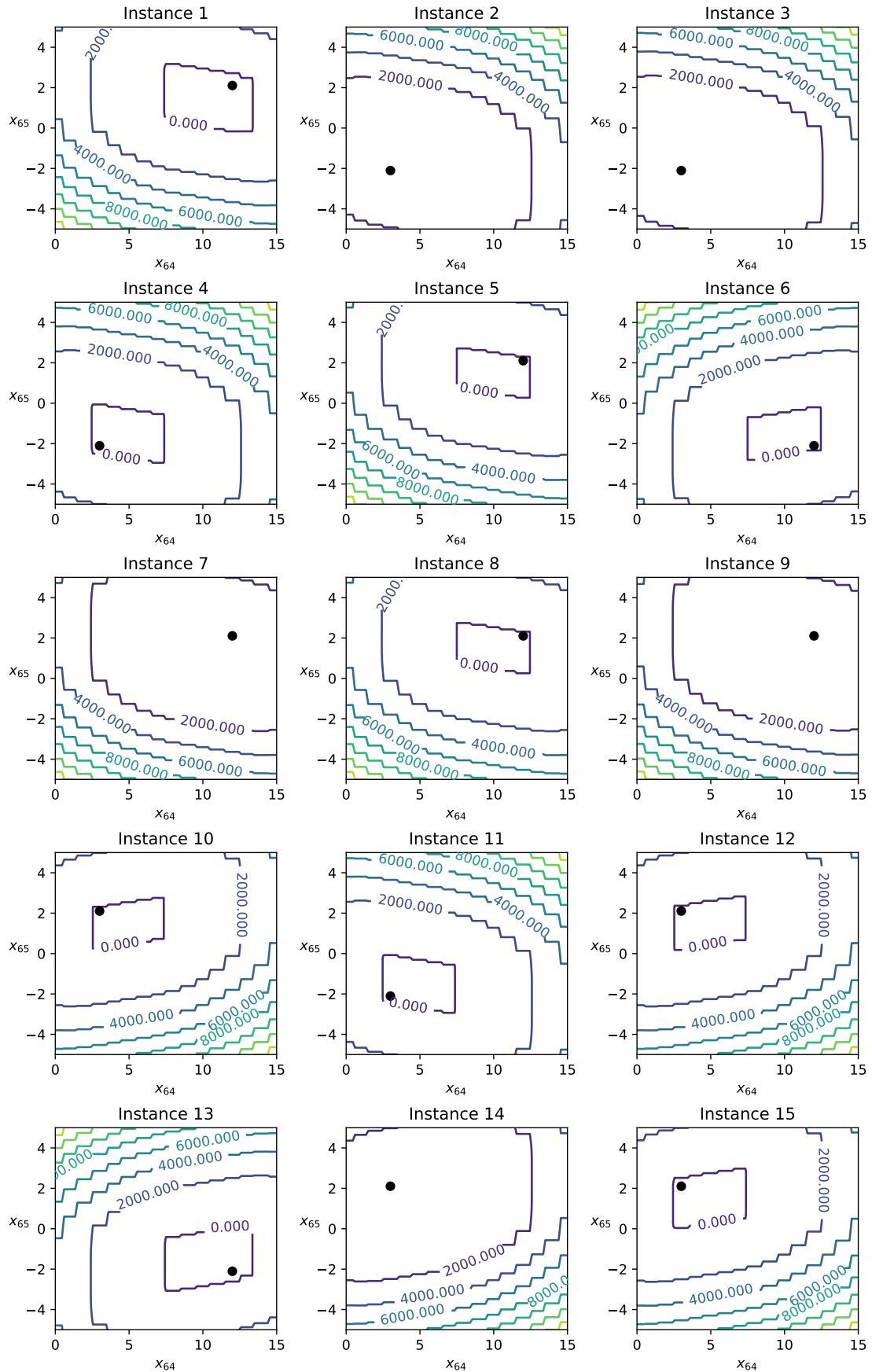
20.3 Function f_{20} , Dimension 20



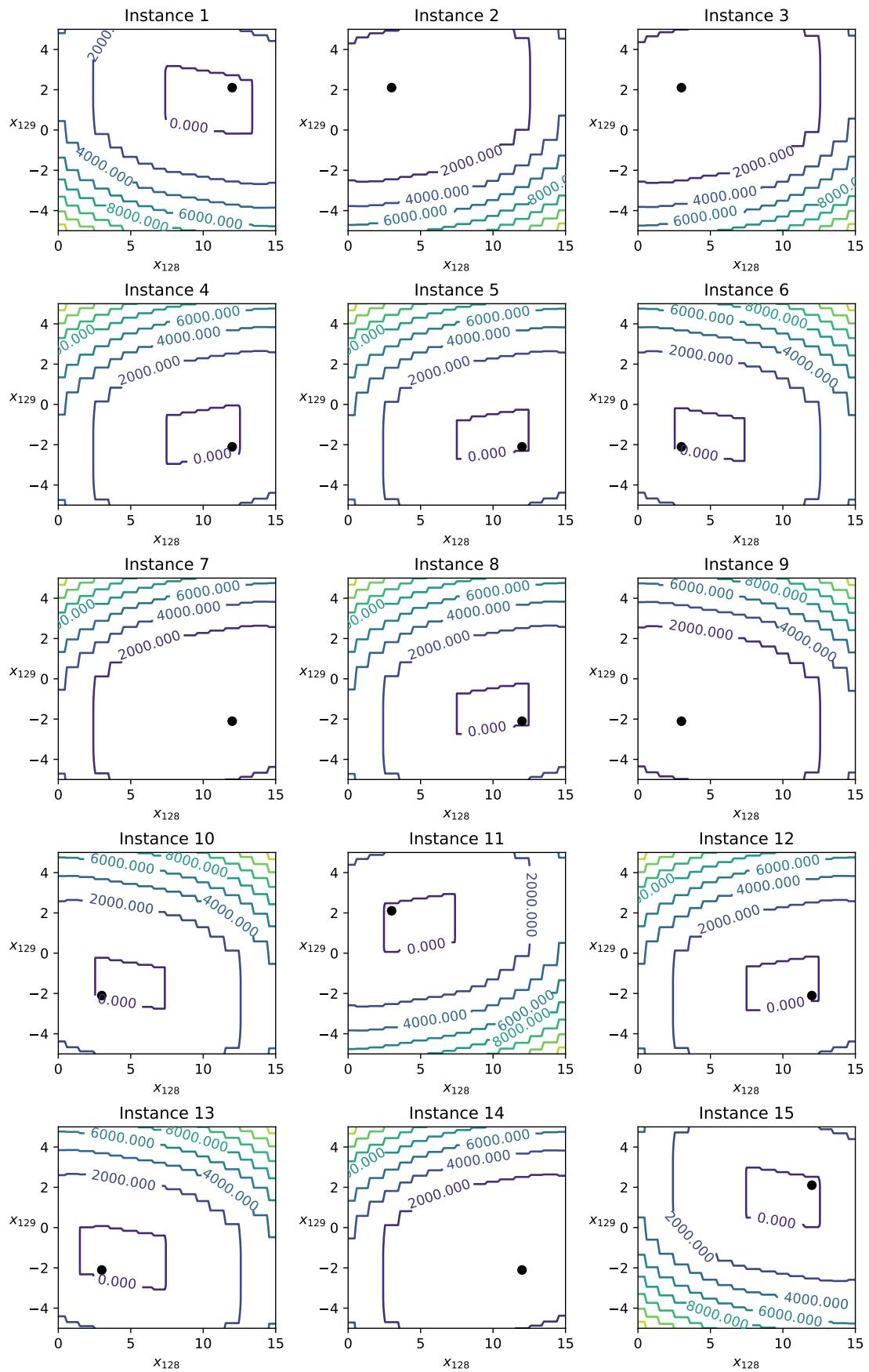
20.4 Function f_{20} , Dimension 40



20.5 Function f_{20} , Dimension 80

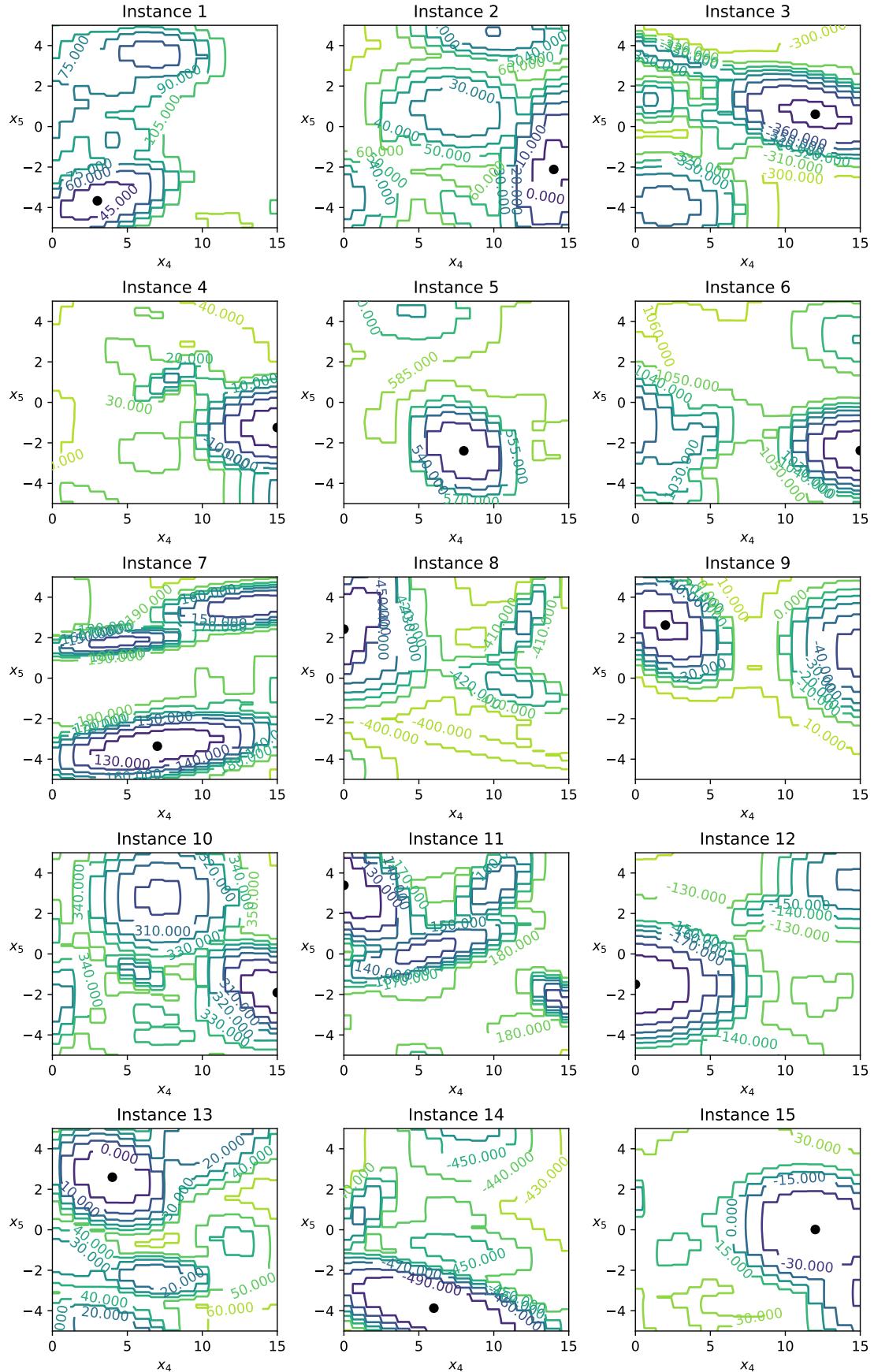


20.6 Function f_{20} , Dimension 160

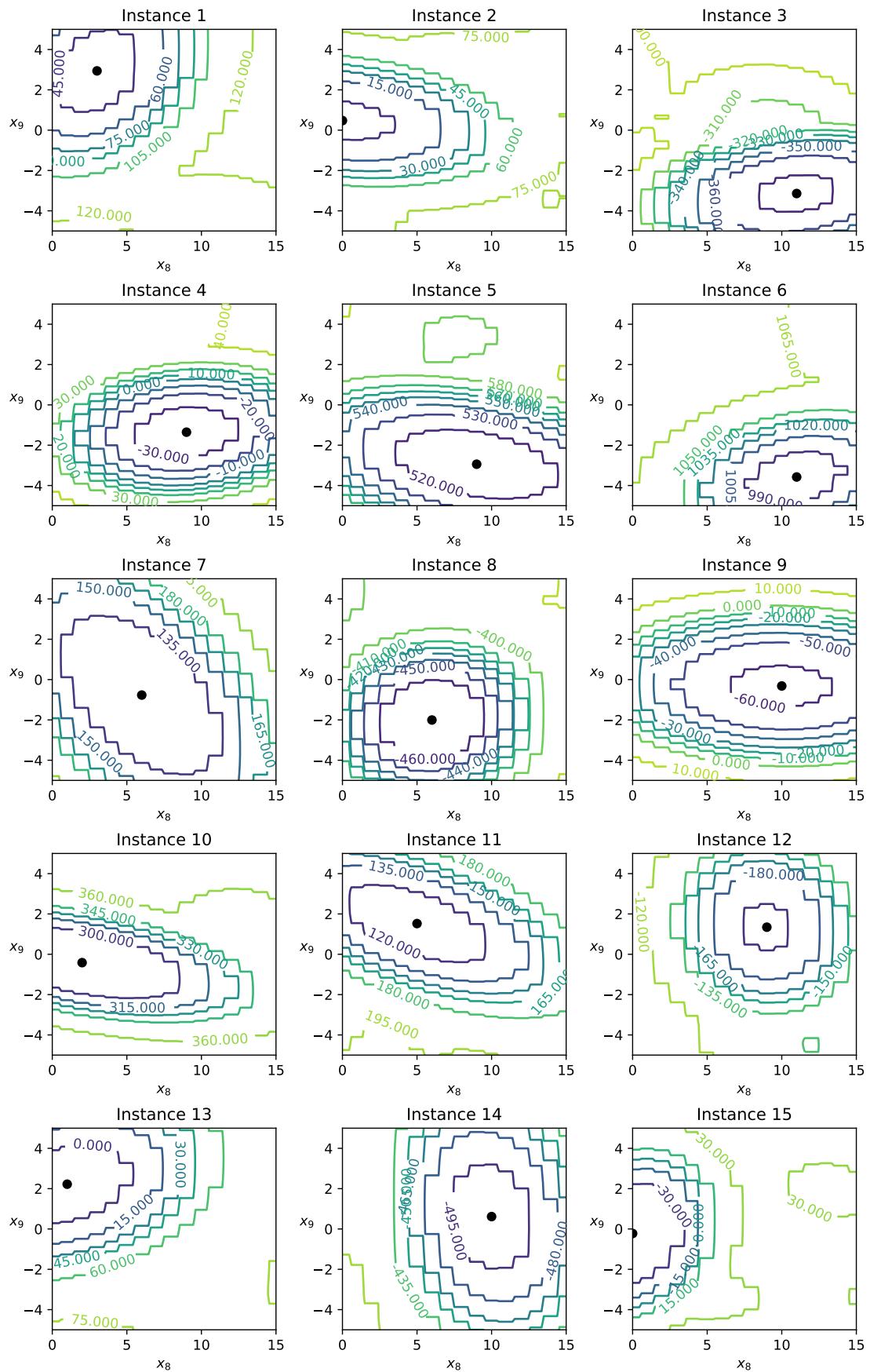


21 Function f_{21} – Gallagher's Gaussian 101-me Peaks

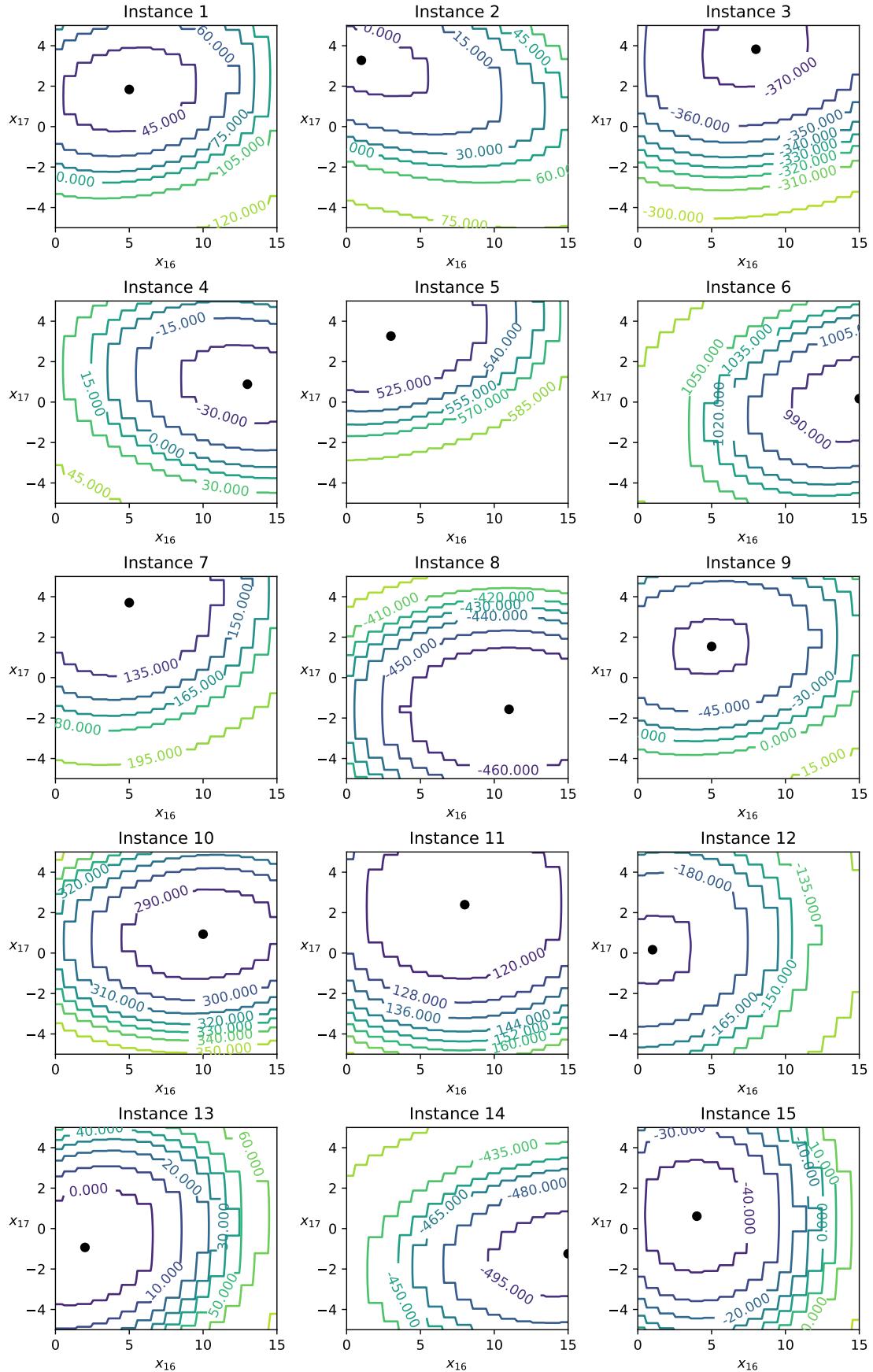
21.1 Function f_{21} , Dimension 5



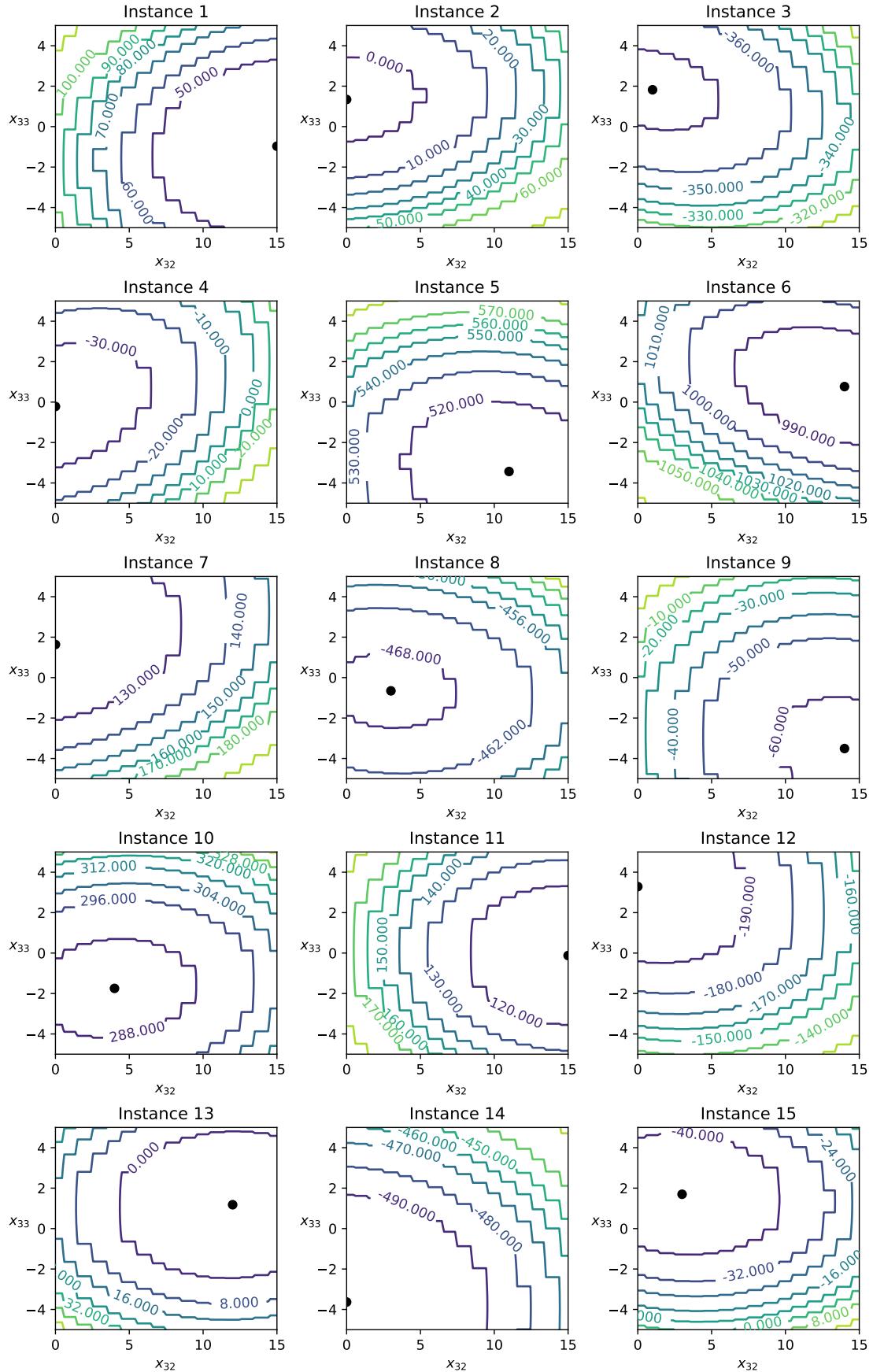
21.2 Function f_{21} , Dimension 10



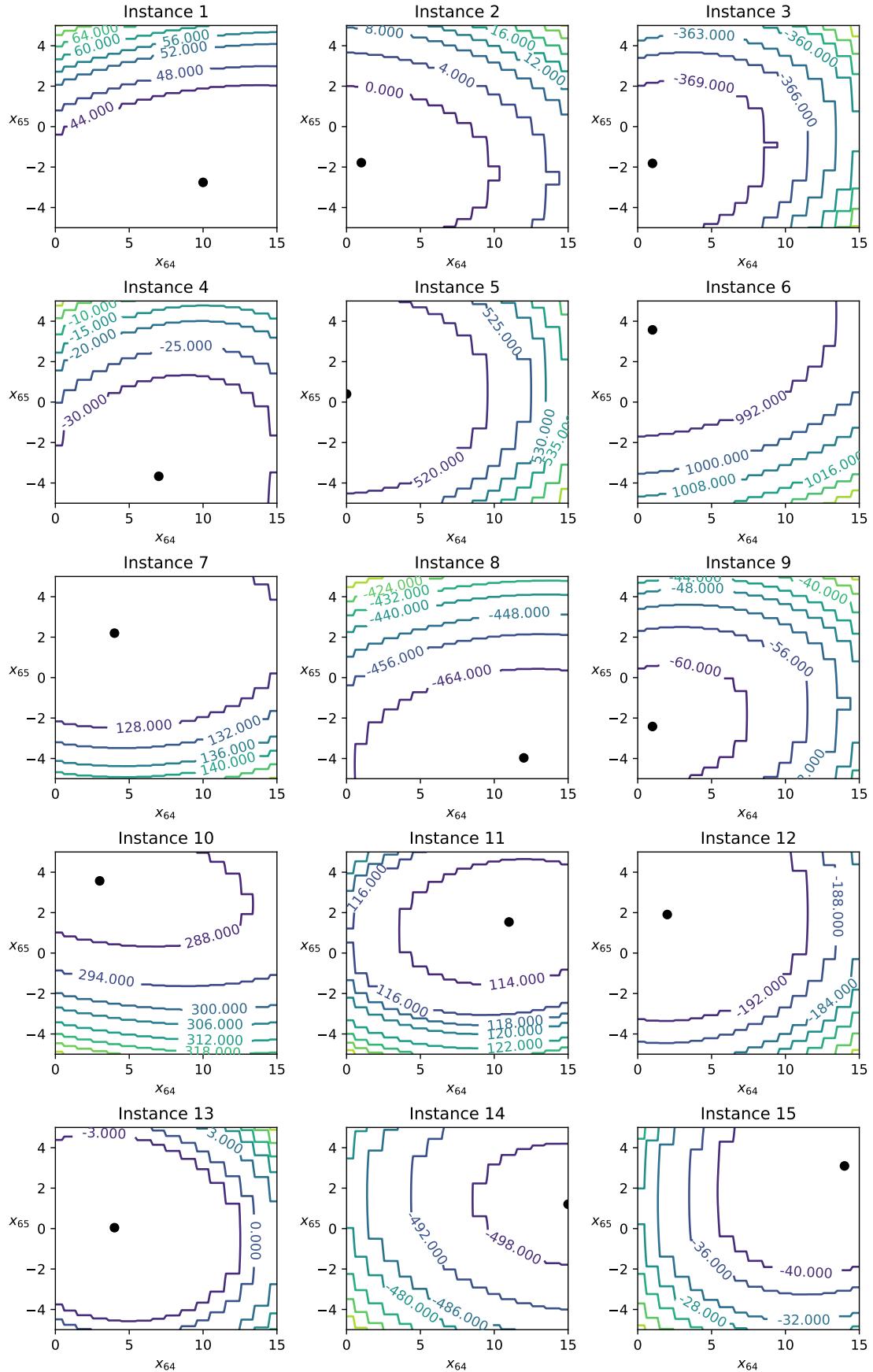
21.3 Function f_{21} , Dimension 20



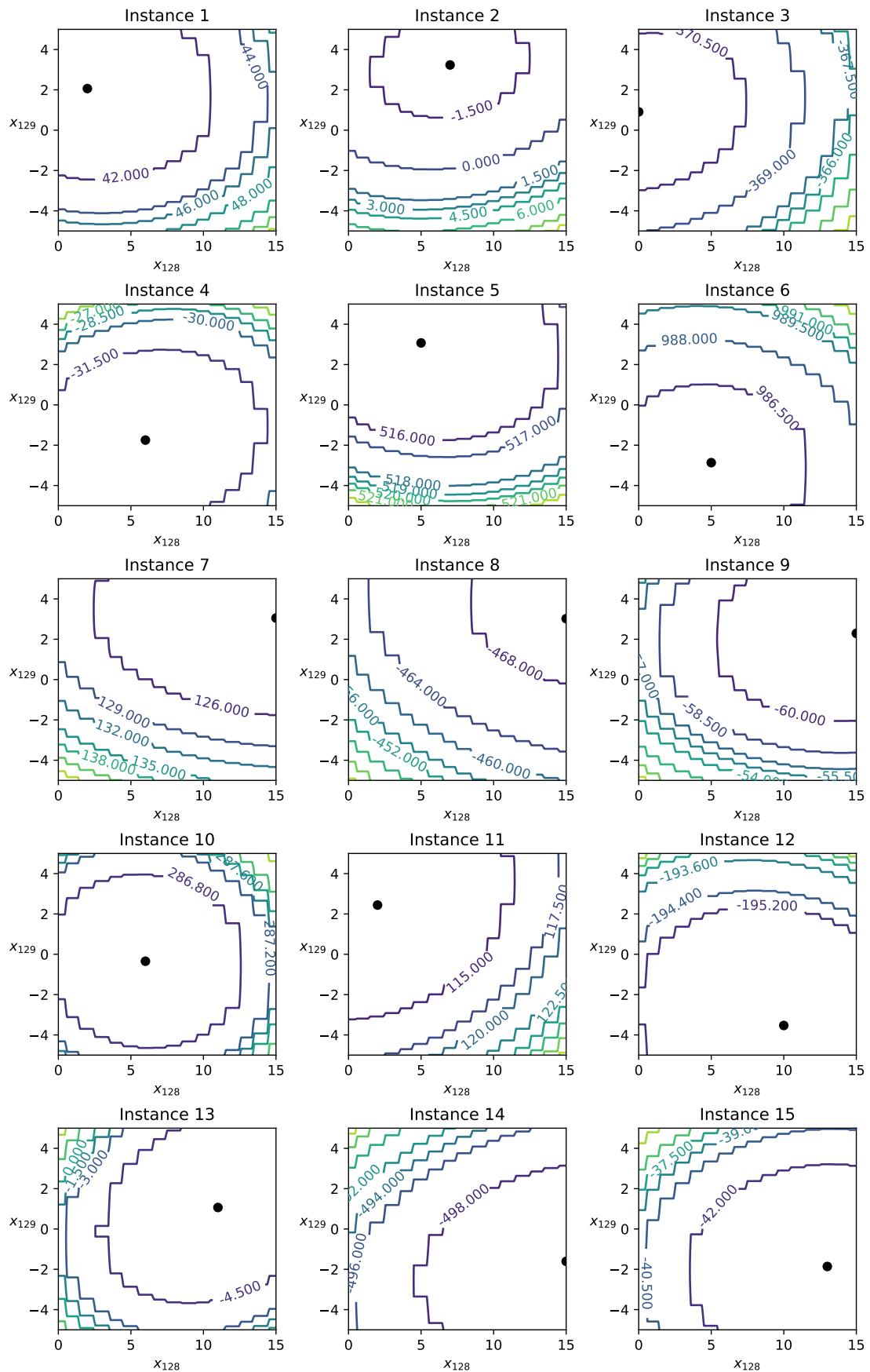
21.4 Function f_{21} , Dimension 40



21.5 Function f_{21} , Dimension 80

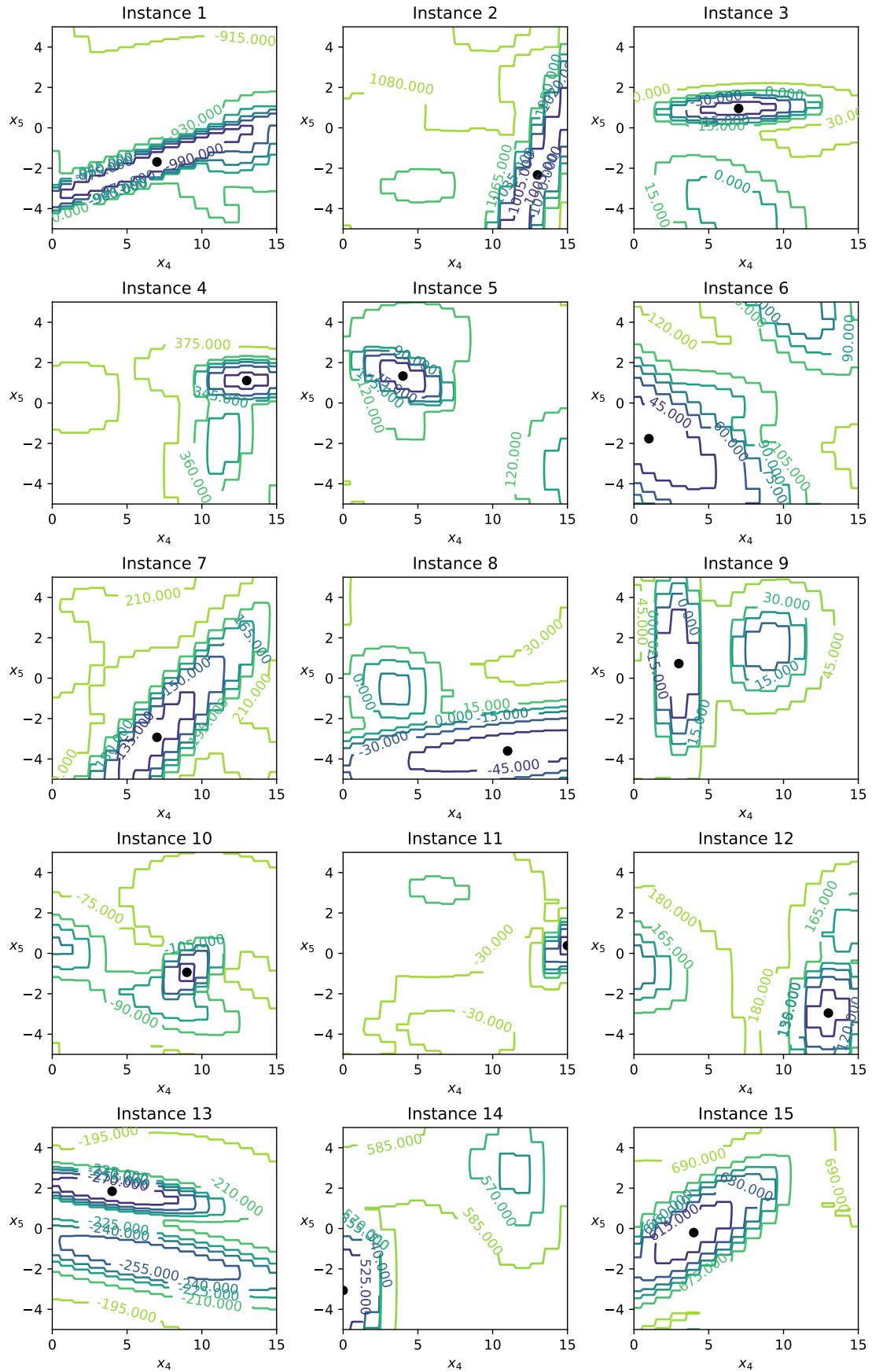


21.6 Function f_{21} , Dimension 160

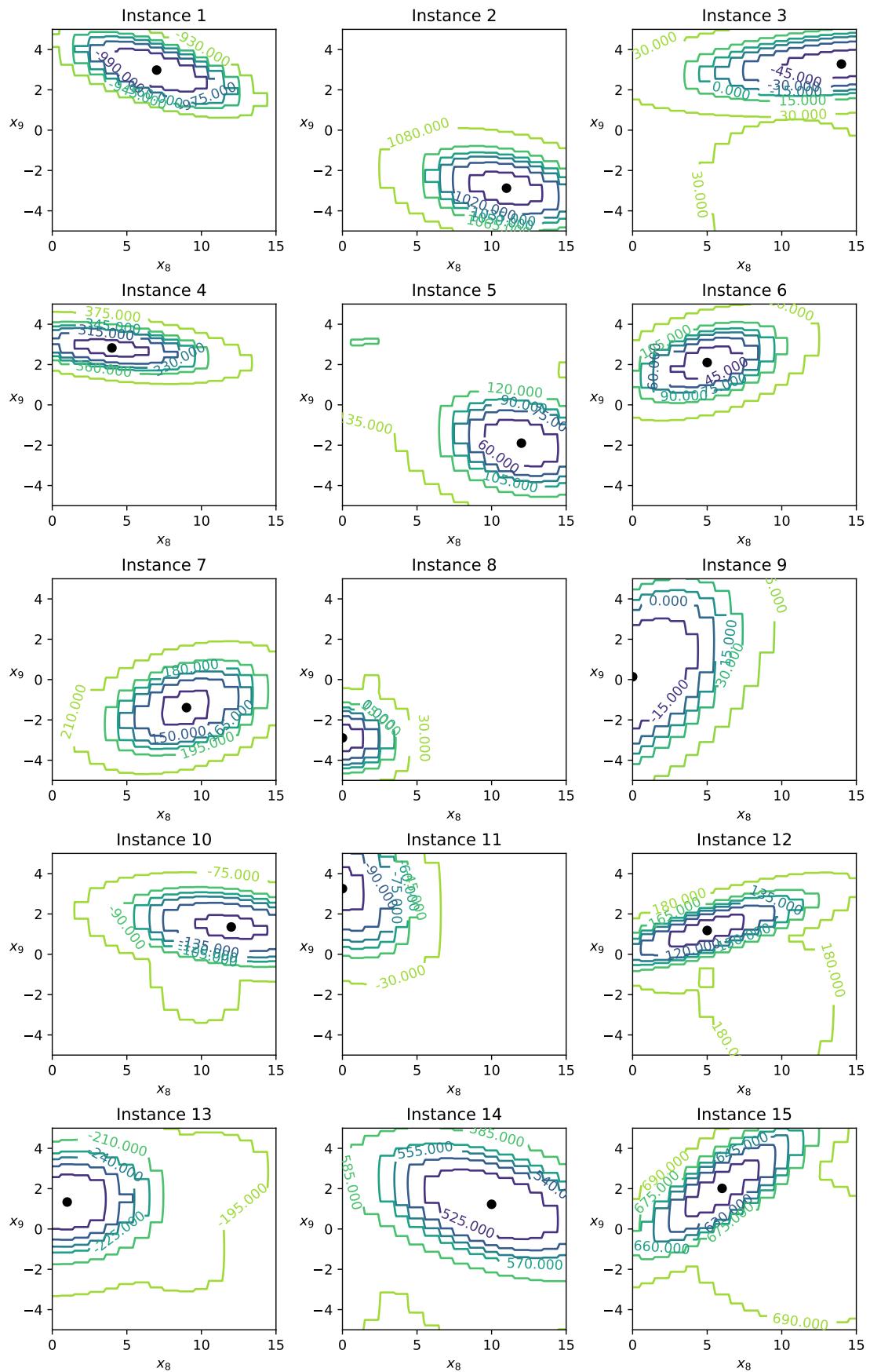


22 Function f_{22} – Gallagher's Gaussian 21-hi Peaks

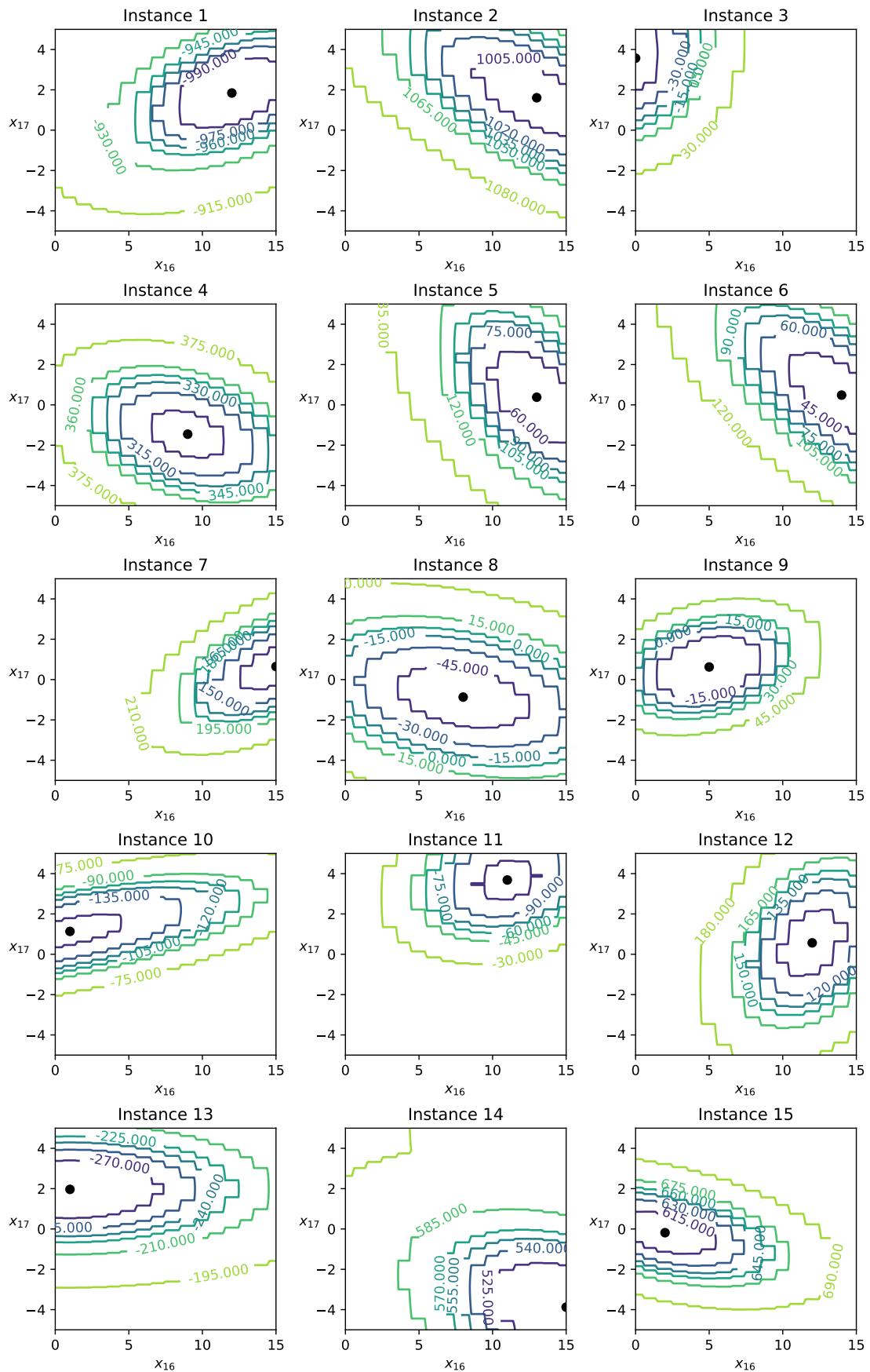
22.1 Function f_{22} , Dimension 5



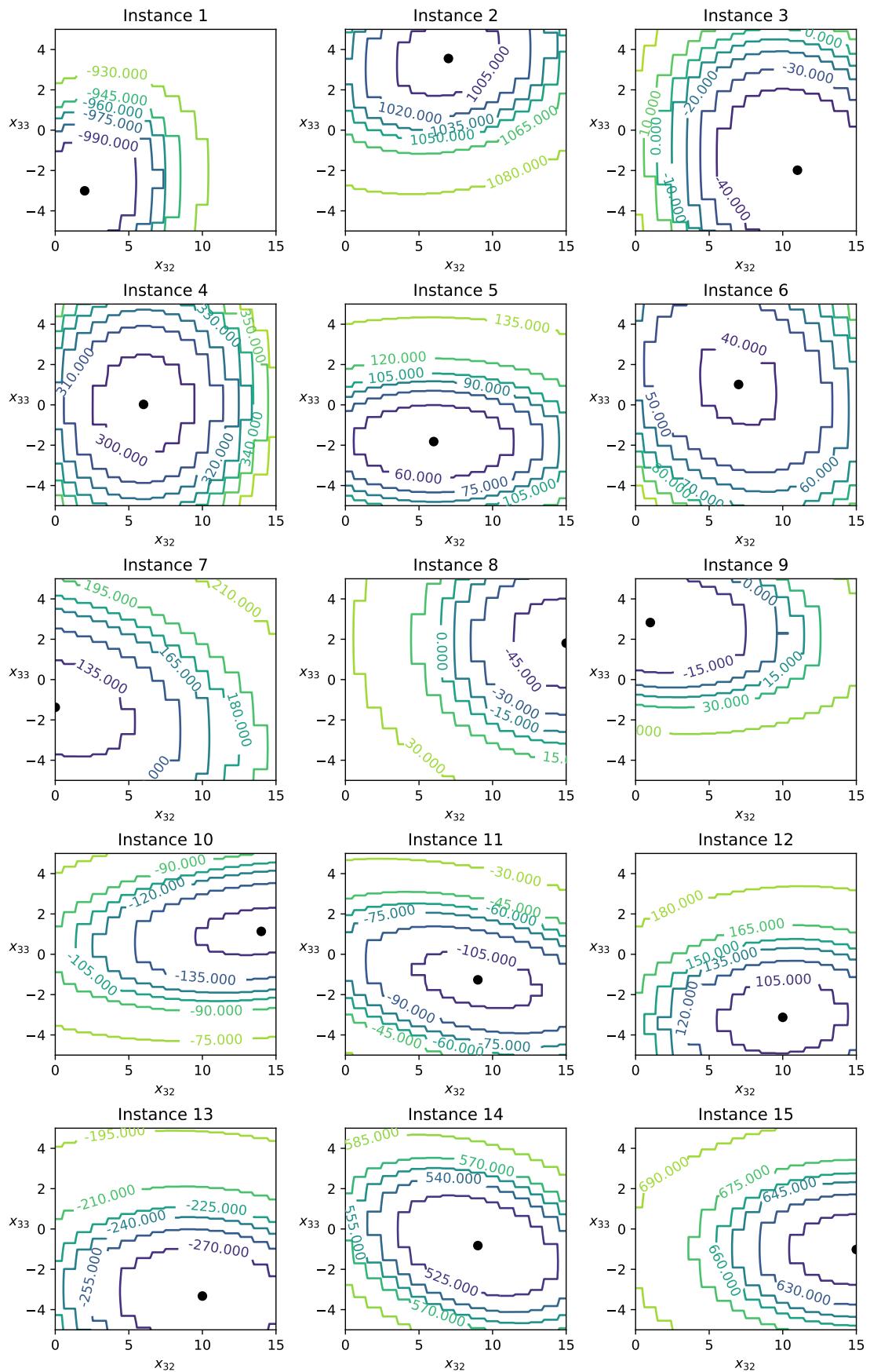
22.2 Function f_{22} , Dimension 10



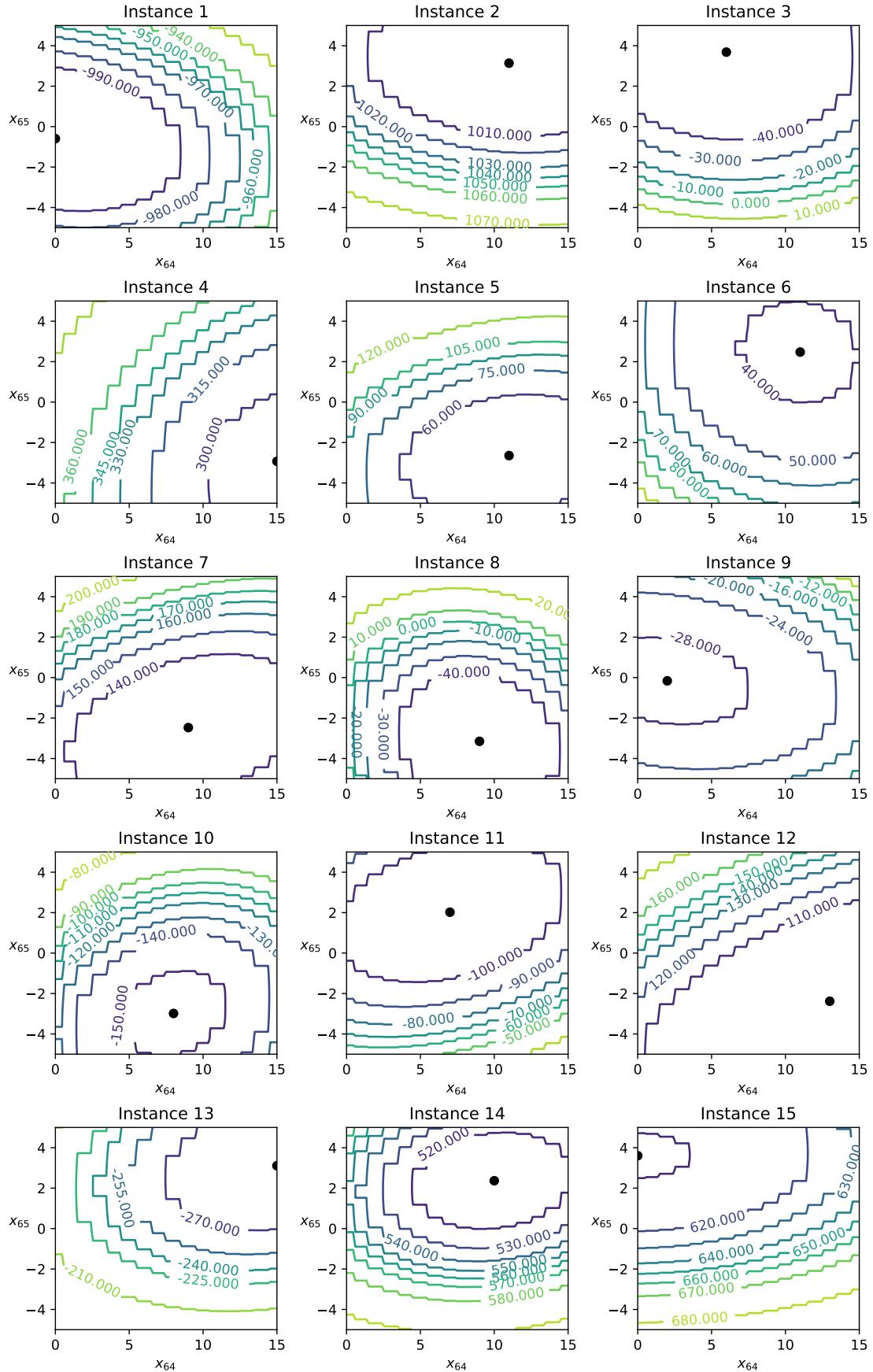
22.3 Function f_{22} , Dimension 20



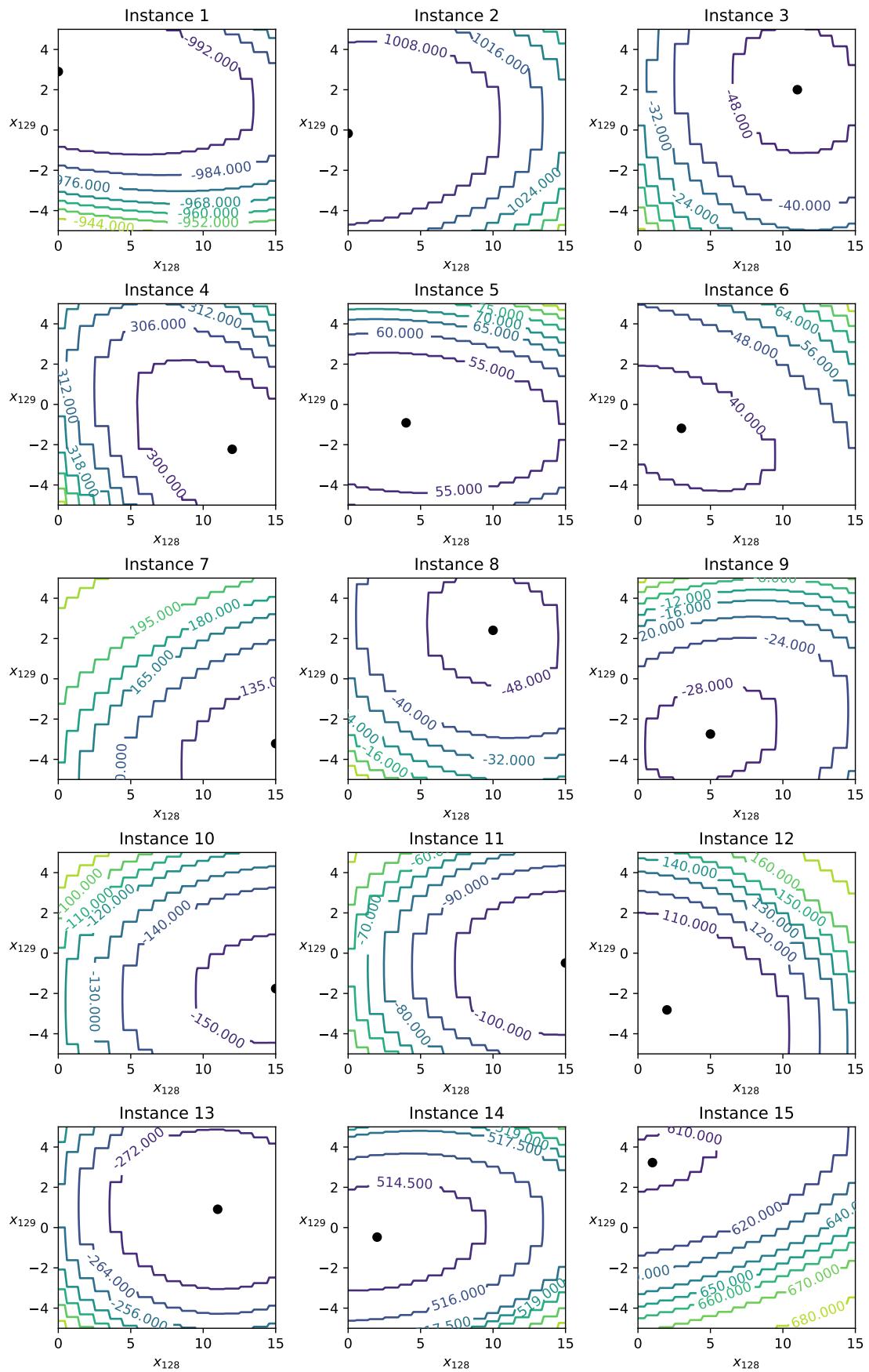
22.4 Function f_{22} , Dimension 40



22.5 Function f_{22} , Dimension 80

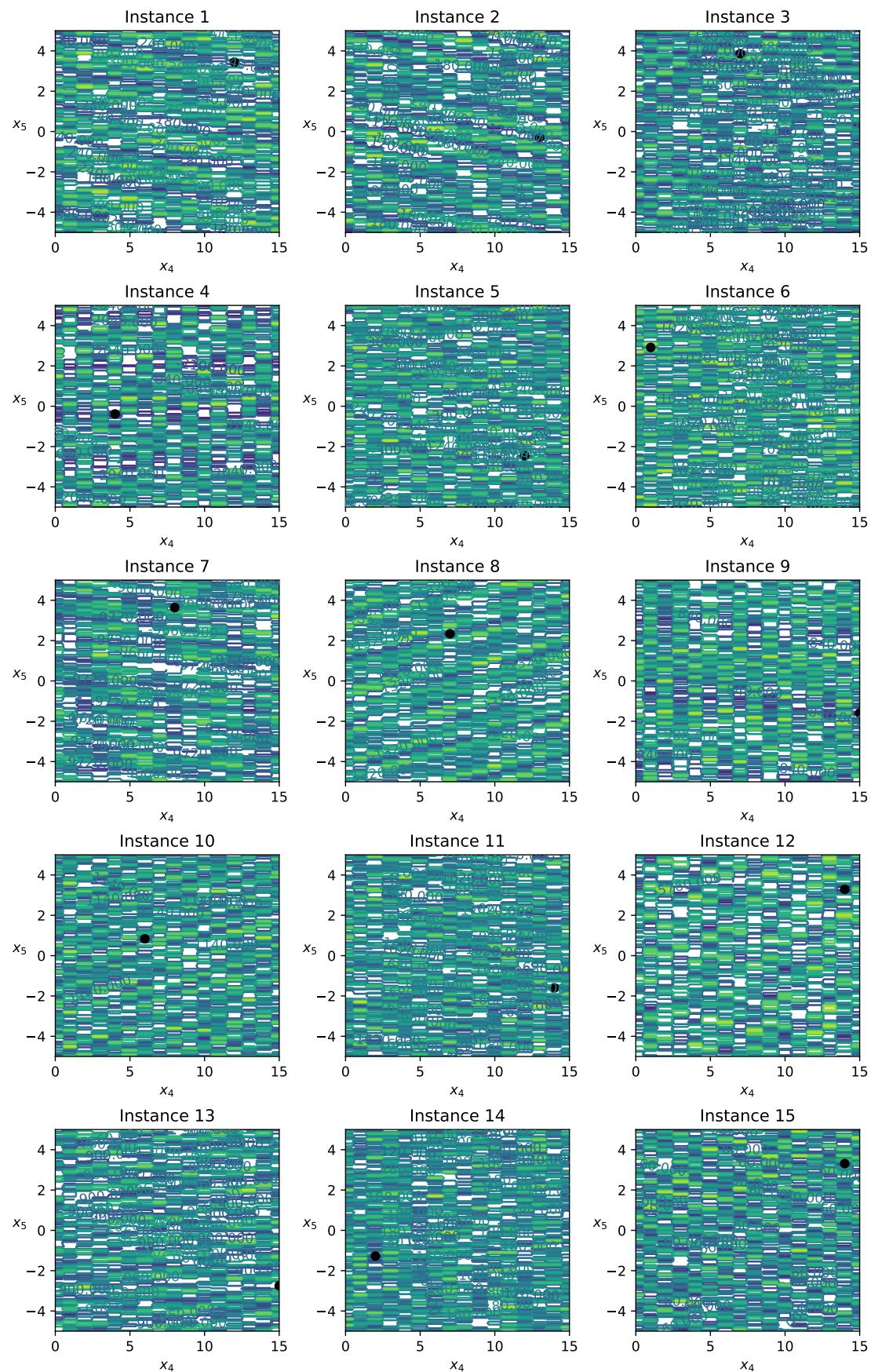


22.6 Function f_{22} , Dimension 160

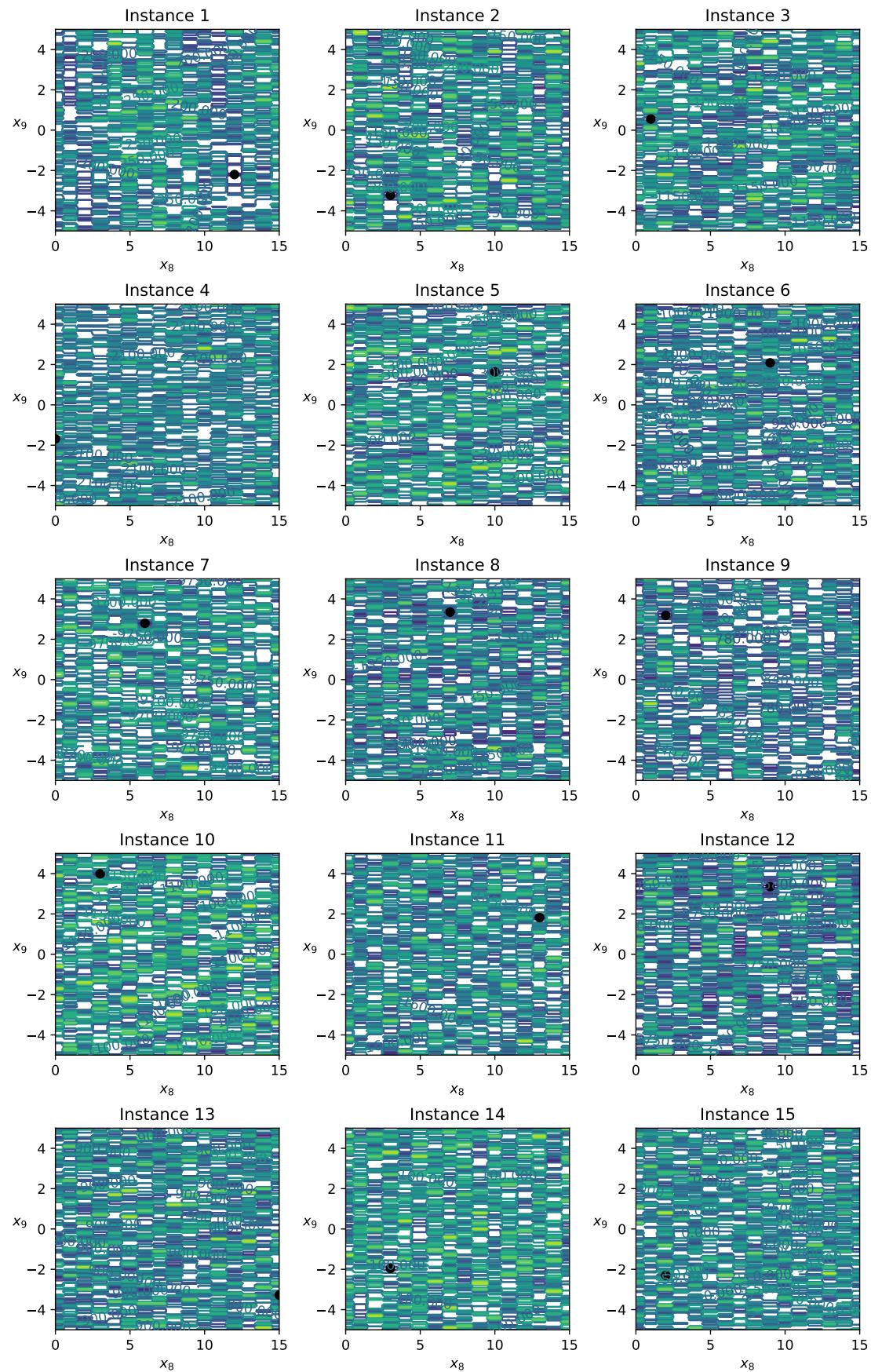


23 Function f_{23} – Katsuura

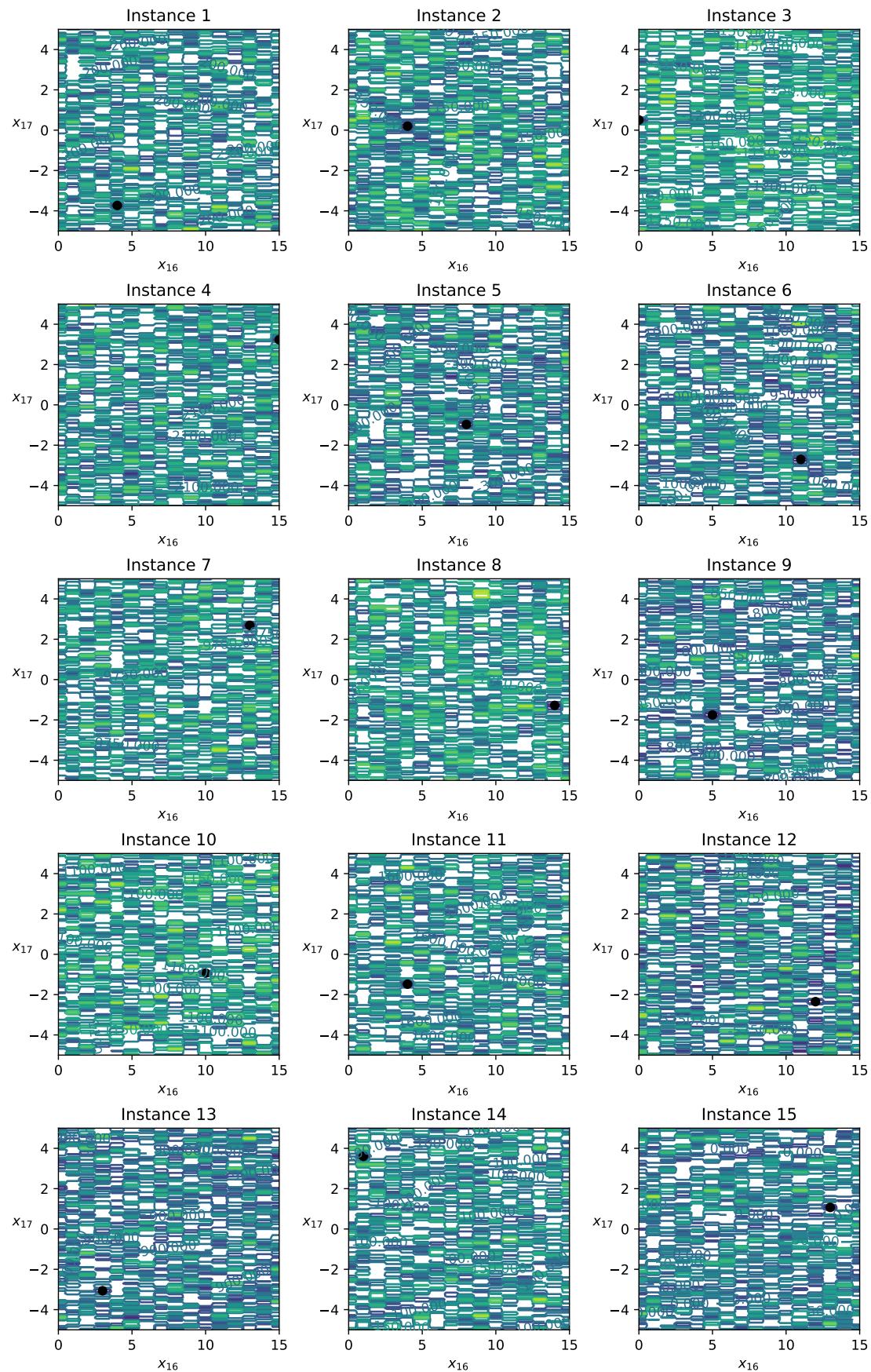
23.1 Function f_{23} , Dimension 5



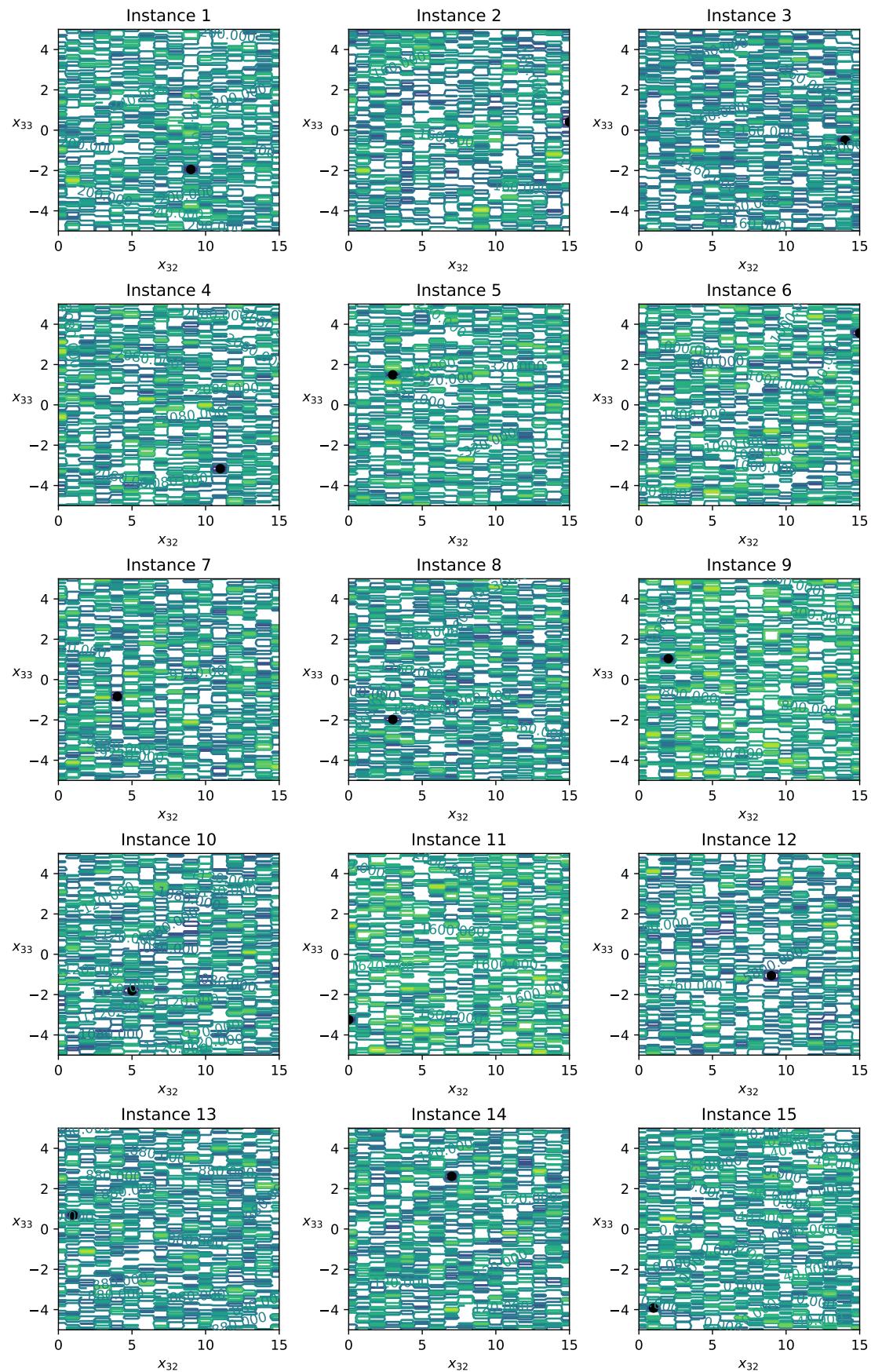
23.2 Function f_{23} , Dimension 10



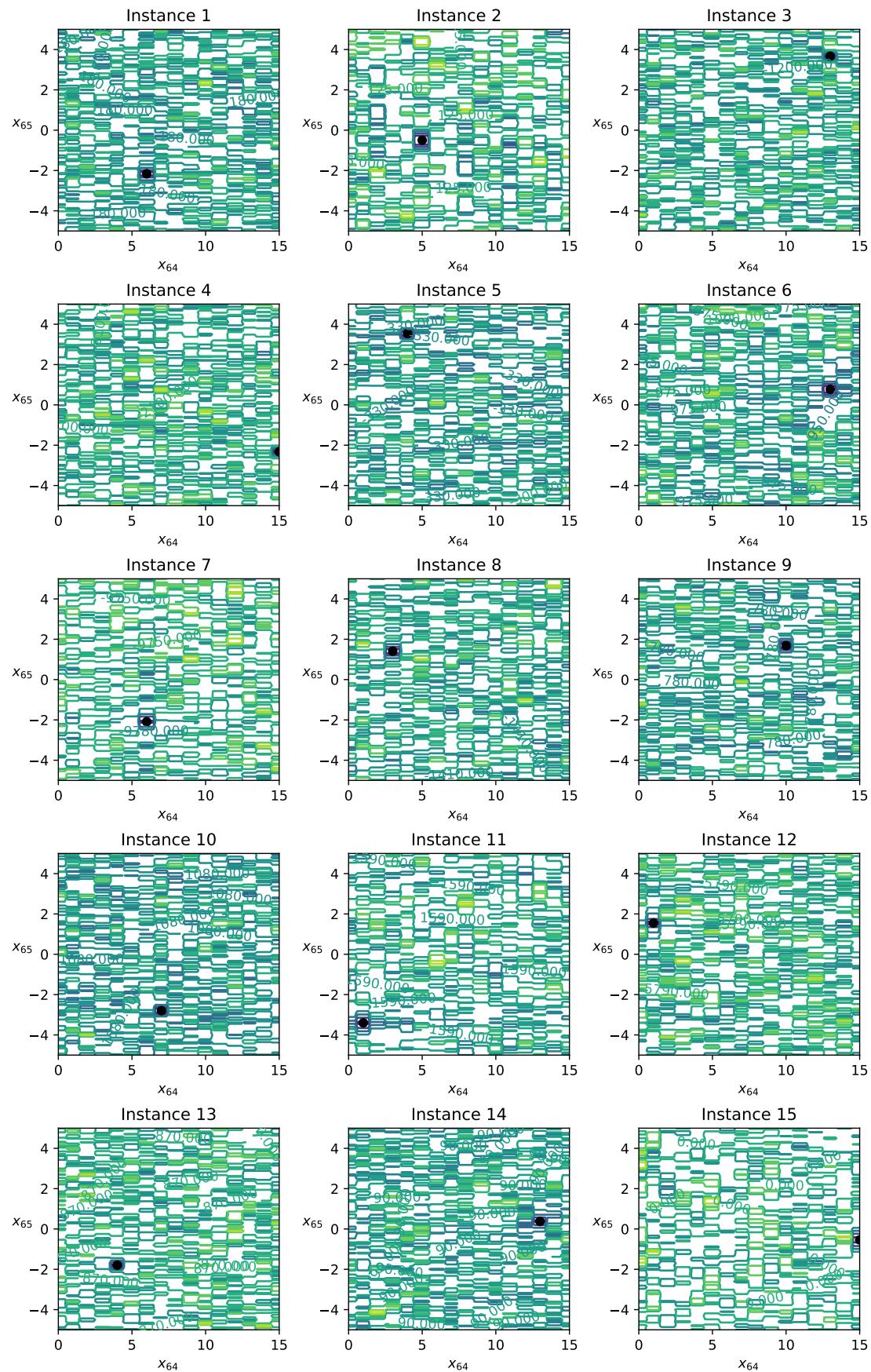
23.3 Function f_{23} , Dimension 20



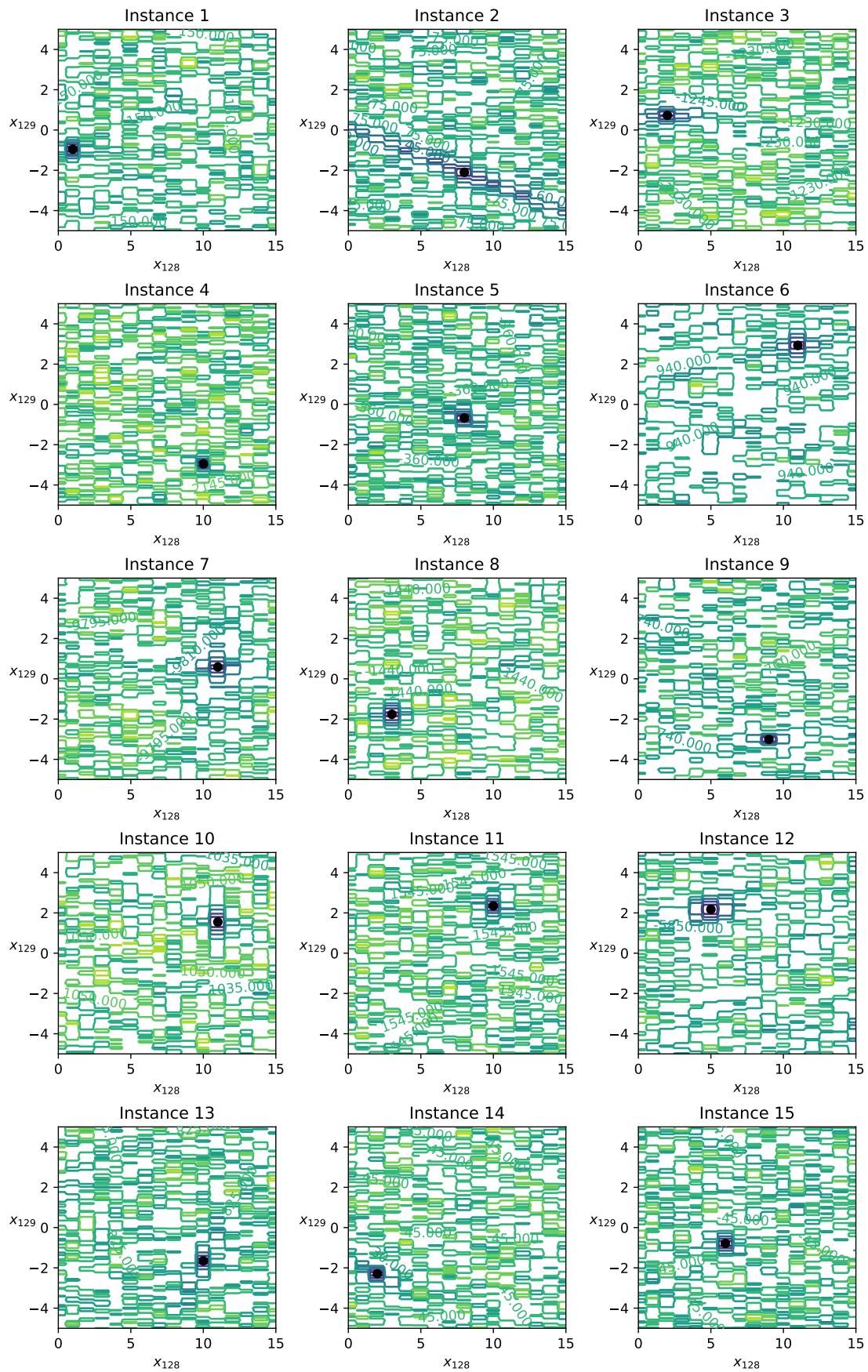
23.4 Function f_{23} , Dimension 40



23.5 Function f_{23} , Dimension 80

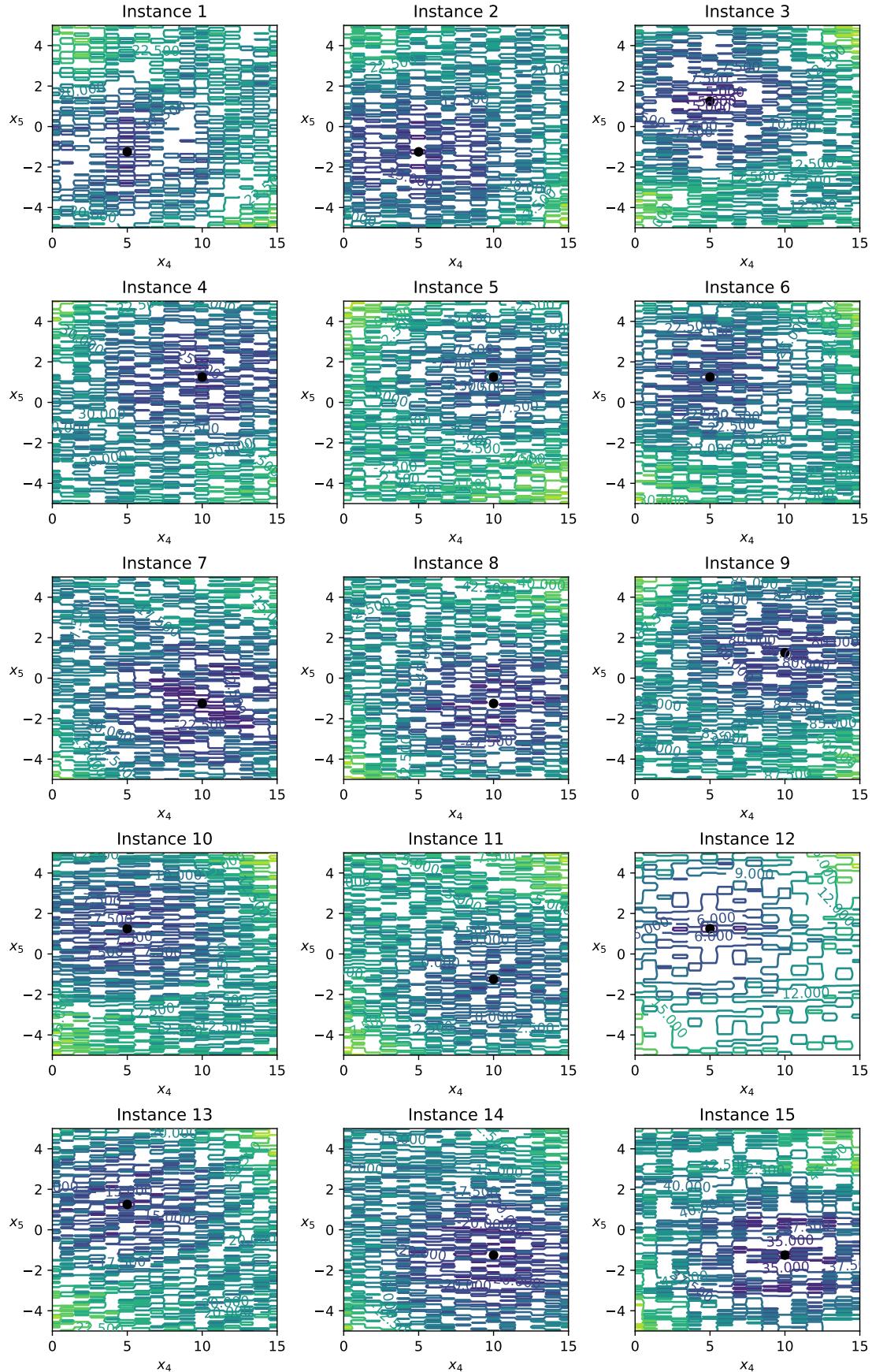


23.6 Function f_{23} , Dimension 160

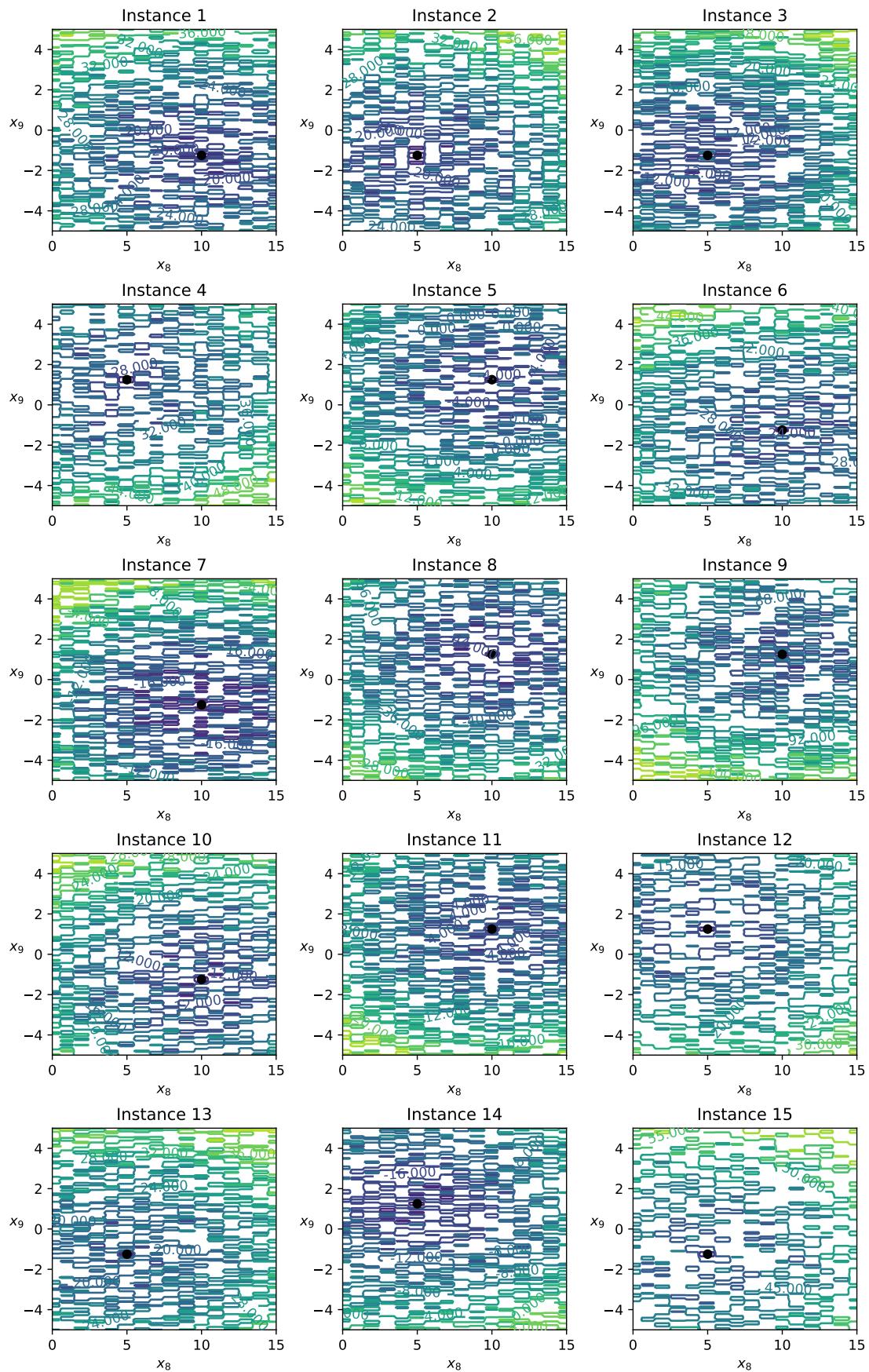


24 Function f_{24} – Lunacek bi-Rastrigin

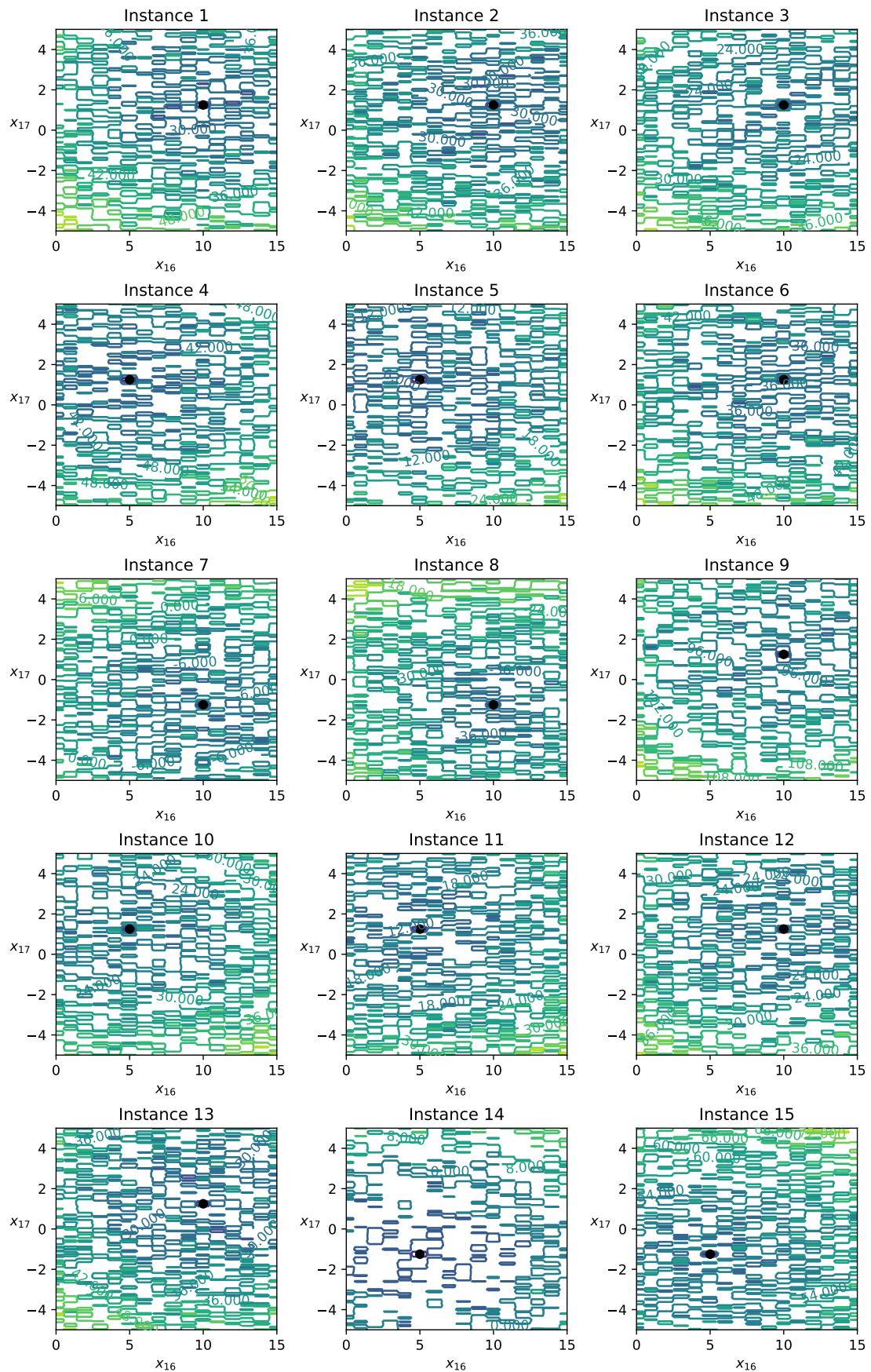
24.1 Function f_{24} , Dimension 5



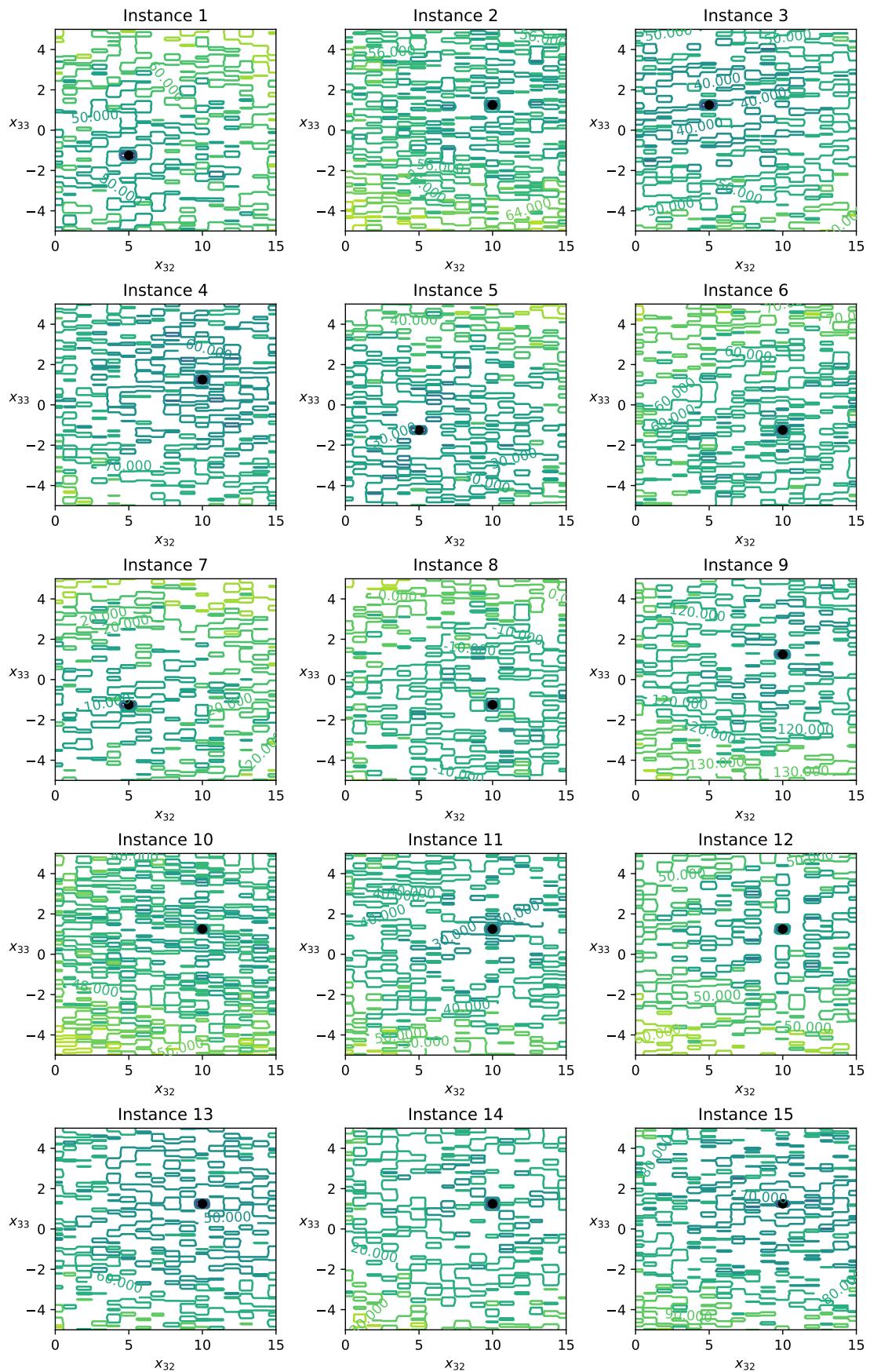
24.2 Function f_{24} , Dimension 10



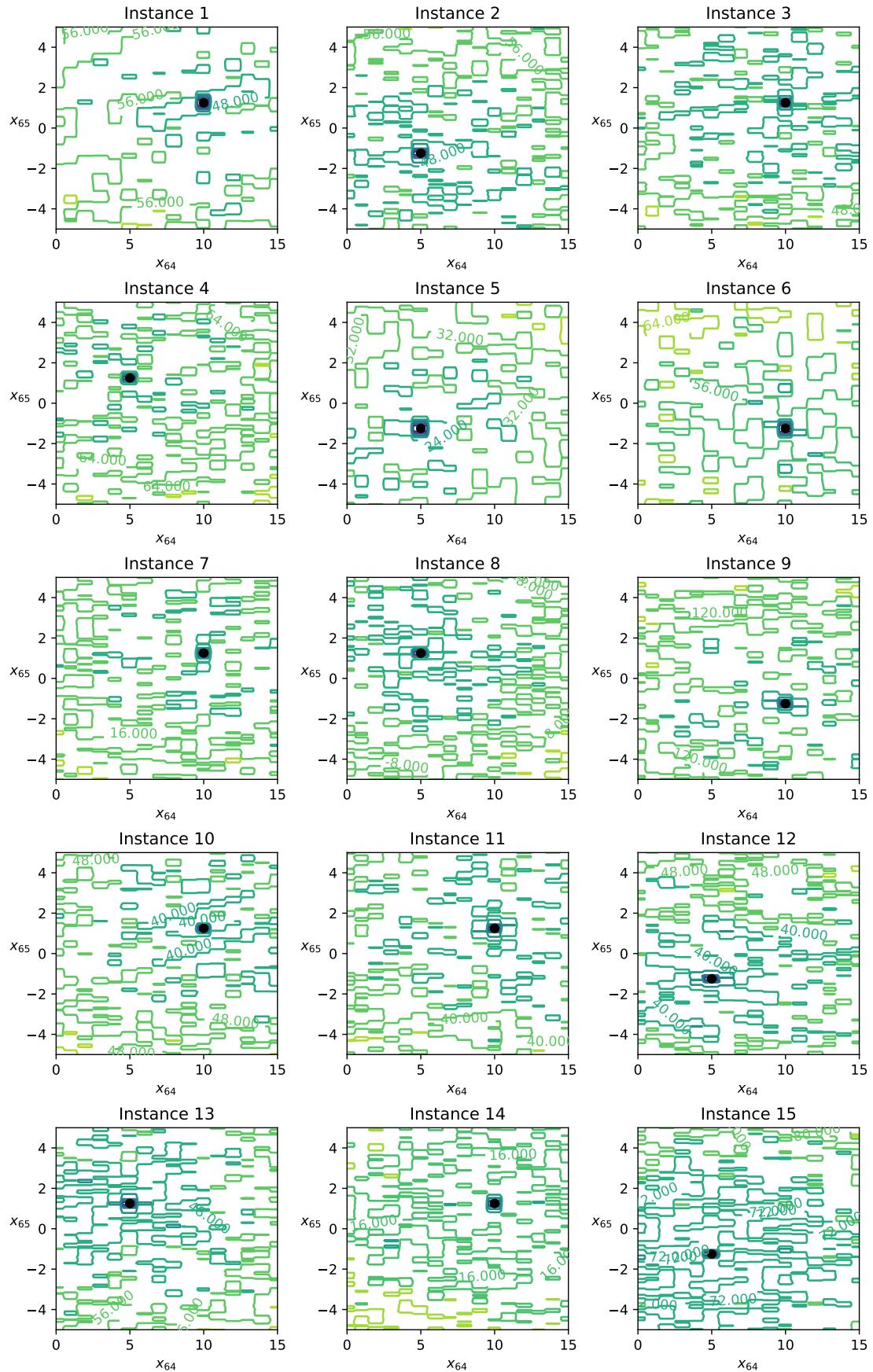
24.3 Function f_{24} , Dimension 20



24.4 Function f_{24} , Dimension 40



24.5 Function f_{24} , Dimension 80



24.6 Function f_{24} , Dimension 160

