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Geoscientific Model Development Discussions

Interactive comment on "ICONGETM v1.0 – Flexible two-way coupling via exchange grids between the unstructured-grid atmospheric model ICON and the structured-grid coastal ocean model GETM" *by* Tobias Peter Bauer et al.

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Discussion review of anonymous referee #1:
This manuscript documents the coupling of an unstructured-grid atmospheric model (ICON, configured as a limited-area model) with a structured-grid coastal ocean model (GETM). It clearly describes the technical route and the model simulations. The utilization of a community-based coupler (NUOPC/ESMF) is a good example for other people who have similar interests. I believe that this work fits within the scope of GMD and deserves publication. My major concern is about its scientific quality. While I think

GMD appreciates technical work and interdisciplinarity, the current manuscript (as a model description paper) does not offer enough information that could be useful to the general readers. The major conclusion merely summarized what the authors have done: "The demonstration example shows that there is now a coupled model available which allows the investigation of processes at the air-sea interface with high-resolved model simulations." I do believe that the manuscript offers more than that, and it can be further improved. I have some questions and comments which might be helpful to the authors.

Many thanks to the reviewer for his motivating criticism.

1. *I find one useful aspect of this manuscript is to offer an example of coupling an unstructured-grid atmospheric model with a structured-grid ocean model, based on a community coupler (NUOPC/ESMF). It would be valuable to put the current work into a broader background. Is there any earlier study that has already explored along this line (including global and regional configuration)? If so, the authors should give a general overview; if not, the present work would be more unique and the authors should explicitly speak out.*

   Motivated by this comment, we rewrote the introduction and more clearly present the novelty of our work:

   "There is an ongoing effort to implement the new NUOPC layer into model systems and equip many popular models with a NUOPC interface under the umbrella of the Earth System Prediction Suite (Theurich et al., 2016). However, until now, there exists only a limited number of publications about its integration. The functioning of the NUOPC layer within the Regional Earth System Model was described by Turuncoglu (2019). Sun et al. (2019) developed the regional integrated prediction system SKRIPS based on NUOPC, coupling the atmosphere model WRF and the nonhydrostatic ocean model MITgcm (Marshall et al., 1997). Only very recently, a coupled unstructured-grid model application consisting of the ocean model ADCIRC (Luettich et al., 1992) and the wave model WAVE-WATCH III (WW3DG, 2019) within the NUOPC-based NOAA Environmental Modeling System (NEMS; https://www.emc.ncep.noaa.gov/emc/pages/infrastructure/nems.php) was reported by Moghimi et al. (2020).

Despite the potential of the ESMF echange grid, its implementation and usage in a mediator component has not been published, yet."

2. *What is the major challenge of coupling an unstructured-grid atmospheric model with a structured-grid coastal ocean model? Or more general, any unstructured-grid model (atmosphere/ocean) with a structured-grid model.*

   In Section "3.4 Regridding", we now write:

   "One major challenge for the coupling between the unstructured grid of ICON and the structured grid of GETM is the interpolation of data on scattered nodes. The irregularity of the unstructured grid complicates the selection of the stencil. The correct interpolation weights for a conservative interpolation require the determination of the intersections of the source and target grids, and the calculation of the resulting areas. The processing of distributed neighbor information in unstructured grids also requires performant data structures and algorithms. The ESMF exchange grid (`ESMF_XGrid`) and the associated interpolation weights stored in the `ESMF_RouteHandle` hide all these aspects from the user and provide an efficient and automatic conservative interpolation infrastructure."

3. *What is the unique aspect of using NUOPC for this particular work? In comparison with other community-based couplers such as OASIS. It's also useful to briefly review the existing coupled models based on NUOPC.*

   We now more clearly state the unique aspects of NUOPC in the introduction:

   "Key technical aspects of coupled model systems are the coordinated execution of and the data exchange between the individual models. Required infrastructure

for time management, communication between different nodes and interpolation between different grids is provided by various coupling libraries, e.g. MCT, OASIS, ESMF. Coupling frameworks, like the Earth System Modeling Framework (ESMF; Hill et al., 2004), provide an additional superstructure layer which offers a standardized execution of models as model components and data exchange in coupler components. On top of ESMF, the National Unified Operational Prediction Capability (NUOPC) layer (Theurich et al., 2016) defines generic components which offer a unified and automated driving of coupled model systems. The generic components require only minimum specialization for the individual models, e.g. registration of routines for initialization and time step advance, definition of required import and possible export data. NUOPC automatically negotiates the data exchange between individual model components based on standard names and synonyms from a dictionary. All required information about the different model grids and their distribution across processors from the models are received during runtime. Therefore, models once equipped with a NUOPC-compliant interface can be plugged into any other coupled model system driven by NUOPC, without the need to adapt coupling specifications.

NUOPC supports a seamless data exchange and interpolation between models operating on different grids via so called connectors. In addition, NUOPC offers mediator components to perform e.g. merging, time-averaging and interface flux calculations on a hub between several models. With ESMF/NUOPC, it is also possible to perform these calculations on automatically generated exchange grids. They have been introduced in Balaji et al. (2006) as the union of two rectangular grids. ESMF extended this functionality to unstructured grids, with the final exchange grid obtained by a triangulation of the union. This triangulation is the basis for conservative interpolation. Moreover, the ESMF exchange grid considers the masking of the original grids, e.g. land/sea mask, such that fluxes can be calculated in a physically consistent way."

For the review of existing coupled models based on NUOPC please see our reply to major point #1 above.

4. *It would be useful to give more details on the construction of a coupled model within NUOPC, for instance, showing some prototype codes to allow people who have similar interests to learn from the authors' work (e.g., https://www.earthsystemcog.org/projects/nuopc/protocodes/). This would be mostly relevant to the value of this work. While I understand that ICON has a license restriction, it would be useful to present the interface of atmosphere/ocean and their positions in the NUOPC/ESMF layer, without freely releasing the actual code of each model component.*

   All details on the construction of the coupled model system in the ICONGETM source code are now freely available from https://gitlab.com/modellers-tropos/icongetm.git. The *Code availability* section has been updated with new Zenodo dois for the used ICONGETM version (10.5281/zenodo.4516568 - open access) and for the modified ICON code (10.5281/zenodo.4432739 - restrictive access). In addition, Fig. 1 has been modified, where now all elements of the NUOPC coupling are interactively linked to the corresponding locations in the source code. Furthermore, we now added to Sec. 2.3:

   "The implementation of the NUOPC layer in ICONGETM was inspired by the prototype codes `AtmOcnMedPetListProto`, `AtmOcnTransferGridProto`, `CustomFieldDictionaryProto` and `AtmOcnFDSynoProto` as well as `AtmOcnConProto` from https://earthsystemmodeling.org/nuopc/#prototype-applications."

5. *The added value of two-way coupling for a high-resolution atmosphere/coastal ocean model is not clearly demonstrated. Such benefits should be explicitly stated in the conclusion to allow the readers better understand the importance of this work. Some of the figures are redundant, and some of them do not give*

enough information (see minor points). The authors need to better describe the gains of the coupled simulations for atmosphere and ocean, respectively.

   The well-known added value of two-way coupling for high-resolution atmosphere-ocean models is now stated in the introduction and used to clearly motivate our work with focus on the technical implementation of the latest ESMF/NUOPC coupling technologies:

   "In numerous studies, the added value of two-way coupled atmosphere-ocean models has been demonstrated. Interactive model coupling is important for representing the mutual interactions and feedbacks between atmosphere and ocean dynamics (e.g., Chelton and Xie, 2010). The sea surface temperature (SST) of the ocean determines moisture fluxes into the atmosphere and the stability of the atmospheric boundary layer (Fallmann et al., 2019). The modulated surface wind in turn affects surface currents and mixing in the ocean, both altering SST patterns. This air-sea interaction is very dynamic and strongly sensitive to fronts and eddies (Small et al., 2008; Shao et al., 2019). In the coastal ocean, fronts are further pronounced due to upwelling and river run-off. Therefore, especially high-resolution coastal applications, where sharp gradients and small-scale eddies are resolved, can benefit from two-way coupled atmosphere-ocean models. The atmosphere model COAMPS (Hodur, 1997) and the regional ocean model ROMS (Shchepetkin and McWilliams, 2005) were coupled with the Model Coupling Toolkit (MCT; Larson et al., 2005) for investigating an upwelling event with a $1\,km$ high resolution (Perlin et al., 2007). In the following decade, numerous high resolution studies were performed with the two-way coupled model system COAMPS-NCOM, in which COAMPS was originally coupled via MCT with the coastal ocean model NCOM (Barron et al., 2006). Pullen et al. (2006, 2007) demonstrated the improved skill of the two-way coupled model system during Bora events in the Adriatic Sea, simulated down to a resolution of $4\,km$ in the atmosphere and $2\,km$ in the ocean. With the same resolution and a coupling time step of $12\,min$, the model system has been applied to the Ligurian Sea and confirmed the importance of the interactive model coupling in the coastal zone (Small et al., 2011). The impact of coastal orography was investigated in a $2\,km$ simulation of Madeira Island (Pullen et al., 2017). Another two-way coupled model system widely applied in high-resolution studies is COAWST (Warner et al., 2010). The atmosphere model WRF (Skamarock et al., 2005), ROMS and the wave model SWAN (Booij et al., 1999) are coupled with MCT. COAWST has been applied for a realistic hindcast of a storm event over the Gulf of Lion and the Balearic Seas with a resolution of $3\,km$ in the atmosphere and $1.8\,km$ in the ocean (Renault et al., 2012). In another application, a Bora event and the dense water formation in the Adriatic sea with $7\,km$ resolution in the atmosphere and $1\,km$ in the ocean was simulated (Carniel et al., 2016). Both studies investigated the effects of different coupling strategies and demonstrated the benefit of the fully coupled model system. Recently, the high-resolution regional coupled environmental prediction system UKC for the northwest European Shelf has been developed (Lewis et al., 2018, 2019a). On a $1.5\,km$ high resolution, the atmosphere model MetUM (Cullen, 1993; Brown et al., 2012) was coupled with the ocean model NEMO (Madec et al., 2017) via OASIS3-MCT (Craig et al., 2017). First results demonstrate reduced bias in SST fields (Lewis et al., 2019b) and impacts on cloud and fog formation over the North Sea (Fallmann et al., 2017, 2019)."

We refer to the effects of the two-way coupling in Sec. 4.2, when we evaluate the results of our demonstration example for the successfully developed coupled model system.

However, an in-depth analysis of the high-resolution air-sea interactions during a specific event and focused on a local scale is out of the scope for our initial technical model description paper and planned as a follow-up study. Instead, the focus of our paper is the added value and potential of using the ESMF exchange

grid in ICONGETM, which is now discussed in more detail in the Discussion section:

"ICONGETM supports the exchange of fluxes and state variables across the air-sea interface. The applied ESMF exchange grid guarantees a conservative flux exchange. The NUOPC-Mediator performs additional unit conversion and merging of precipitation fluxes, see Tab. 1. In ICONGETM v1.0, the air-sea fluxes are taken from the atmosphere model ICON. Their calculation in ICON is very complex and deeply nested in the model code. However, in later releases the air-sea fluxes should be calculated in the mediator, in terms of state variables received from atmosphere and ocean. Their calculation directly on the ESMF exchange grid also solves the problem of different land/sea masks (Balaji et al., 2006) and ensures physical consistency in the sense that no fluxes calculated over land, i.e. not influenced by the sea surface temperature, are provided to the ocean. Without an ESMF exchange grid creep, nearest neighbor and other extrapolation methods might be required (see e.g. Kara et al., 2007; Chen et al., 2010; Turuncoglu, 2019), especially if an atmosphere model with low spatial resolution is coupled. Fluxes provided by the mediator can be applied in the atmosphere and ocean over the same period until new fluxes are calculated in the next coupling time step. Besides this physical and energetic consistency, the flux calculation on the ESMF exchange grid in a central mediator component also offers the most straight-forward extension of the coupled system by models for e.g. waves and sea ice."

This is now also stated in the conclusion.

Regarding the redundancy of the figures please see our reply to minor point #5 below.

Minor points:

1. *Section 2.1, Line 60: when mentioning "the usage of nonhydrostatic Euler equa-*

tions on global domains", I think Gassmann and Herzog (2008) is an important work for ICON and should be cited among others.

Added reference.

2. *Lines 65-70: the description here is a little bit disorganized. It would be useful to say something like "The atmospheric component of ICON can be configured to various models (e.g., LES, NWP, climate) by coupling a common dynamical core with different physics packages. The model used in this study is a configuration led by DWD, mainly used for high-resolution NWP applications. Some physics schemes largely inherit the COSMO model."*

   Added and adopted the suggested details to the description.

3. *Section 2.1: The YAC library, which is the coupler for ICON-ESM, is also mentioned here. Is it possible for YAC to do the work of this paper?*

   Sure, but the implementational effort would be high. According to the latest documentation from https://dkrz-sw.gitlab-pages.dkrz.de/yac/, YAC does not offer the same built-in functionality as NUOPC e.g. generic automated driving of coupled model systems and the features of the ESMF exchange grid.

4. *Line 205: pressure levels? It seems to me ICON is using a height-based vertical coordinate.*

   It is now clearly stated:

   "The vertical terrain-following hybrid grids consist of 90, 65 and 54 height-based vertical levels. The heights are pre-defined depending on the associated pressure in the US 1976 standard atmosphere, with the top boundary of the model domain depending on the numbers of levels (**?**, Fig. 3.5)."

5. *Figures 7 and 8, they are basically telling the same thing as 2-m air temperature is intimately connected with surface temperature.*

   Agreed, (sea) surface and $2\,m$ air temperature are closely related. On the other hand, while the sea surface temperature in either case only represents a lower boundary condition for the atmospheric model, the $2\,m$ air temperature actually shows a response of the ICON model, which was important for us to show. This is also reflected for example by signatures of ocean eddies in SST as well as effect of land and uncoupled ocean surface on $2\,m$ air temperature.

6. *From Fig. 9, it is unclear that the two-way coupled model performs better than the uncoupled one. I understand that after 10 days, temperature is overall enhanced by the coupled model, but such a qualitative comparison is not enough for a scientific journal, especially when demonstrating an issue that is mostly relevant to the value of this work. I think the authors need some additional quantitative metrics to confirm the improvement (e.g., correlation coefficient, averaged temperature over a certain period).*

   A short statistical evaluation is now added to Sec. 4.2.1:

   "The average deviation from the modelled and measured temperature is about $1.6\,K$ / $1.5\,K$ and $1.9\,K$ / $2.0\,K$ for the two-way coupled and uncoupled simulations from 01 / 10 July 2012 onward, respectively. This is a significant improvement of about $15\%/\ 25\%$, respectively. However, the Pearson correlation coefficient is only slightly improved, i.e. 0.7158 / 0.7487 and 0.6996 / 0.7336 for the two-way coupled and uncoupled simulations from 01 / 10 July 2012, respectively. The more reduced average deviation and higher correlation of the two-way coupled simulations after 10 July 2012 is related to the spin up of the model, since GETM is initialized as hot start while ICON uses the IFS reanalysis data."

7. *Section 4.1.3, is there any guiding principle to obtain a good load balance in this coupled configuration. How do you draw the current conclusion about the number of cores for ICON and GETM.*

   The optimal load-balancing was estimated empirically in terms of minimum idle/waiting times for the single model components. The sentence in the text has been modified:

"For the present setup a good concurrent load-balancing **with minimum idle/waiting times for the single model components was empirically** obtained with 864 processes for ICON and 384 processes for GETM."

References

Balaji, V., Anderson, J., Held, I., Winton, M., Durachta, J., Malyshev, S., and Stouffer, R. J.: The Exchange Grid: A mechanism for data exchange between Earth System components on independent grids, in: Parallel Computational Fluid Dynamics 2005, pp. 179–186, Elsevier, 10.1016/B978-044452206-1/50021-5, https://linkinghub.elsevier.com/retrieve/pii/B9780444522061500215, 2006.

Barron, C. N., Kara, A. B., Martin, P. J., Rhodes, R. C., and Smedstad, L. F.: Formulation, implementation and examination of vertical coordinate choices in the Global Navy Coastal Ocean Model (NCOM), Ocean Modelling, 11, 347–375, 10.1016/j.ocemod.2005.01.004, https://linkinghub.elsevier.com/retrieve/pii/S1463500305000120, 2006.

Booij, N., Ris, R. C., and Holthuijsen, L. H.: A third-generation wave model for coastal regions: 1. Model description and validation, Journal of Geophysical Research: Oceans, 104, 7649–7666, 10.1029/98JC02622, http://doi.wiley.com/10.1029/98JC02622, 1999.

Brown, A., Milton, S., Cullen, M., Golding, B., Mitchell, J., and Shelly, A.: Unified Modeling and Prediction of Weather and Climate: A 25-Year Journey, Bulletin of the American Meteorological Society, 93, 1865–1877, 10.1175/BAMS-D-12-00018.1, https://journals.ametsoc.org/doi/10.1175/BAMS-D-12-00018.1, 2012.

Carniel, S., Benetazzo, A., Bonaldo, D., Falcieri, F. M., Miglietta, M. M., Ricchi, A., and Sclavo, M.: Scratching beneath the surface while coupling atmosphere, ocean and waves: Analysis of a dense water formation event, Ocean Modelling, 101, 101–112, 10.1016/j.ocemod.2016.03.007, https://linkinghub.elsevier.com/retrieve/pii/S1463500316300051http://dx.doi.org/10.1016/j.ocemod.2016.03.007, 2016.

Chelton, D. and Xie, S.-P.: Coupled Ocean-Atmosphere Interaction at Oceanic Mesoscales,

Oceanography, 23, 52–69, 10.5670/oceanog.2010.05, https://tos.org/oceanography/article/coupled-ocean-atmosphere-interaction-at-oceanic-mesoscales, 2010.

Chen, S., Campbell, T. J., Jin, H., Gaberšek, S., Hodur, R. M., and Martin, P.: Effect of Two-Way Air–Sea Coupling in High and Low Wind Speed Regimes, Monthly Weather Review, 138, 3579–3602, 10.1175/2009MWR3119.1, http://journals.ametsoc.org/doi/10.1175/2009MWR3119.1, 2010.

Craig, A., Valcke, S., and Coquart, L.: Development and performance of a new version of the OASIS coupler, OASIS3-MCT_3.0, Geoscientific Model Development, 10, 3297–3308, 10.5194/gmd-10-3297-2017, https://gmd.copernicus.org/articles/10/3297/2017/, 2017.

Cullen, M. J.: The unified forecast/climate model, Meteorological Magazine, 122, 81–94, https://digital.nmla.metoffice.gov.uk/IO{_}faa7dfb4-d31a-4a1b-92ba-16a145be1509/, 1993.

Fallmann, J., Lewis, H., Castillo, J. M., Arnold, A., and Ramsdale, S.: Impact of sea surface temperature on stratiform cloud formation over the North Sea, Geophysical Research Letters, 44, 4296–4303, 10.1002/2017GL073105, http://doi.wiley.com/10.1002/2017GL073105, 2017.

Fallmann, J., Lewis, H., Sanchez, J. C., and Lock, A.: Impact of highâĂŘresolution ocean–atmosphere coupling on fog formation over the North Sea, Quarterly Journal of the Royal Meteorological Society, 145, 1180–1201, 10.1002/qj.3488, https://onlinelibrary.wiley.com/doi/abs/10.1002/qj.3488, 2019.

Hill, C., DeLuca, C., Balaji, V., Suarez, M., and Da Silva, A. M.: The architecture of the earth system modeling framework, Computing in Science & Engineering, 6, 18–28, 10.1109/MCISE.2004.1255817, http://ieeexplore.ieee.org/document/1255817/, 2004.

Hodur, R. M.: The Naval Research Laboratory's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS), Monthly Weather Review, 125, 1414–1430, 10.1175/1520-0493(1997)125<1414:TNRLSC>2.0.CO;2, http://journals.ametsoc.org/doi/10.1175/1520-0493(1997)125{%}3C1414:TNRLSC{%}3E2.0.CO;2, 1997.

Kara, A. B., Wallcraft, A. J., and Hurlburt, H. E.: A Correction for Land Contamination of Atmospheric Variables near Land–Sea Boundaries, Journal of Physical Oceanography, 37, 803–818, 10.1175/JPO2984.1, http://journals.ametsoc.org/doi/10.1175/JPO2984.1, 2007.

Larson, J., Jacob, R., and Ong, E.: The Model Coupling Toolkit: A New Fortran90 Toolkit for Building Multiphysics Parallel Coupled Models, The International Journal of High Performance Computing Applications, 19, 277–292, 10.1177/1094342005056115, http://journals.sagepub.com/doi/10.1177/1094342005056115, 2005.

Lewis, H. W., Castillo Sanchez, J. M., Graham, J., Saulter, A., Bornemann, J., Arnold, A., Fallmann, J., Harris, C., Pearson, D., Ramsdale, S., Martínez-de la Torre, A., Bricheno, L., Blyth, E., Bell, V. A., Davies, H., Marthews, T. R., O'Neill, C., Rumbold, H., O'Dea, E., Brereton, A., Guihou, K., Hines, A., Butenschon, M., Dadson, S. J., Palmer, T., Holt, J., Reynard, N., Best, M., Edwards, J., and Siddorn, J.: The UKC2 regional coupled environmental prediction system, Geoscientific Model Development, 11, 1–42, 10.5194/gmd-11-1-2018, https://gmd.copernicus.org/articles/11/1/2018/, 2018.

Lewis, H. W., Castillo Sanchez, J. M., Arnold, A., Fallmann, J., Saulter, A., Graham, J., Bush, M., Siddorn, J., Palmer, T., Lock, A., Edwards, J., Bricheno, L., Martínez-de la Torre, A., and Clark, J.: The UKC3 regional coupled environmental prediction system, Geoscientific Model Development, 12, 2357–2400, 10.5194/gmd-12-2357-2019, https://gmd.copernicus.org/articles/12/2357/2019/, 2019a.

Lewis, H. W., Siddorn, J., Castillo Sanchez, J. M., Petch, J., Edwards, J. M., and Smyth, T.: Evaluating the impact of atmospheric forcing and air–sea coupling on near-coastal regional ocean prediction, Ocean Science, 15, 761–778, 10.5194/os-15-761-2019, https://os.copernicus.org/articles/15/761/2019/, 2019b.

Luettich, Jr., R. A., Westerink, J. J., and Scheffner, N. W.: ADCIRC: An Advanced Three-Dimensional Circulation Model for Shelves, Coasts, and Estuaries. Report 1. Theory and Methodology of ADCIRC-2DDI and ADCIRC-3DL., Tech. rep., Coastal Engineering Research Center, Vicksburg, MS, https://apps.dtic.mil/docs/citations/ADA261608, 1992.

Madec, G., Bourdallé-Badie, R., Bouttier, P.-A., Bricaud, C., Bruciaferri, D., Calvert, D., Chanut, J., Clementi, E., Coward, A., Delrosso, D., Ethé, C., Flavoni, S., Graham, T., Harle, J., Iovino, D., Lea, D., Lévy, C., Lovato, T., Martin, N., Masson, S., Mocavero, S., Paul, J., Rousset, C., Storkey, D., Storto, A., and Vancoppenolle, M.: NEMO ocean engine (Version v3.6-patch), Tech. rep., Pôle De Modélisation De L'institut Pierre-simon Laplace (IPSL), 10.5281/ZENODO.3248739, https://doi.org/10.5281/zenodo.3248739, 2017.

Marshall, J., Adcroft, A., Hill, C., Perelman, L., and Heisey, C.: A finite-volume, incompressible Navier Stokes model for studies of the ocean on parallel computers, Journal of Geophysical Research: Oceans, 102, 5753–5766, 10.1029/96JC02775, http://doi.wiley.com/10.1029/96JC02775, 1997.

Moghimi, S., Van der Westhuysen, A., Abdolali, A., Myers, E., Vinogradov, S., Ma, Z., Liu, F., Mehra, A., and Kurkowski, N.: Development of an ESMF Based Flexible Coupling Application of ADCIRC and WAVEWATCH III for High Fidelity Coastal Inundation Stud-

ies, Journal of Marine Science and Engineering, 8, 308, 10.3390/jmse8050308, https://www.mdpi.com/2077-1312/8/5/308, 2020.

Perlin, N., Skyllingstad, E. D., Samelson, R. M., and Barbour, P. L.: Numerical Simulation of Air–Sea Coupling during Coastal Upwelling, Journal of Physical Oceanography, 37, 2081–2093, 10.1175/JPO3104.1, http://journals.ametsoc.org/doi/10.1175/JPO3104.1, 2007.

Pullen, J., Doyle, J. D., and Signell, R. P.: Two-Way Air–Sea Coupling: A Study of the Adriatic, Monthly Weather Review, 134, 1465–1483, 10.1175/MWR3137.1, http://journals.ametsoc.org/doi/10.1175/MWR3137.1, 2006.

Pullen, J., Doyle, J. D., Haack, T., Dorman, C., Signell, R. P., and Lee, C. M.: Bora event variability and the role of air-sea feedback, Journal of Geophysical Research, 112, C03S18, 10.1029/2006JC003726, http://doi.wiley.com/10.1029/2006JC003726, 2007.

Pullen, J., Caldeira, R., Doyle, J. D., May, P., and Tomé, R.: Modeling the airâĂŘsea feedback system of Madeira Island, Journal of Advances in Modeling Earth Systems, 9, 1641–1664, 10.1002/2016MS000861, https://onlinelibrary.wiley.com/doi/abs/10.1002/2016MS000861, 2017.

Renault, L., Chiggiato, J., Warner, J. C., Gomez, M., Vizoso, G., and Tintoré, J.: Coupled atmosphere-ocean-wave simulations of a storm event over the Gulf of Lion and Balearic Sea, Journal of Geophysical Research: Oceans, 117, n/a–n/a, 10.1029/2012JC007924, http://doi.wiley.com/10.1029/2012JC007924, 2012.

Shao, M., OrtizâĂŘSuslow, D. G., Haus, B. K., Lund, B., Williams, N. J., Özgökmen, T. M., Laxague, N. J. M., Horstmann, J., and Klymak, J. M.: The Variability of Winds and Fluxes Observed Near Submesoscale Fronts, Journal of Geophysical Research: Oceans, 124, 7756–7780, 10.1029/2019JC015236, https://onlinelibrary.wiley.com/doi/10.1029/2019JC015236, 2019.

Shchepetkin, A. F. and McWilliams, J. C.: The regional oceanic modeling system (ROMS): a split-explicit, free-surface, topography-following-coordinate oceanic model, Ocean Modelling, 9, 347–404, 10.1016/j.ocemod.2004.08.002, https://linkinghub.elsevier.com/retrieve/pii/S1463500304000484, 2005.

Skamarock, W. C., Klemp, J. B., Dudhia, J., Gill, D. O., Barker, D. M., Wang, W., and Powers, J. G.: A Description of the Advanced Research WRF Version 2, Tech. rep., UCAR, 10.5065/D6DZ069T, 2005.

Small, R., DeSzoeke, S., Xie, S., O'Neill, L., Seo, H., Song, Q., Cornillon, P., Spall, M., and Minobe, S.: Air–sea interaction over ocean fronts and eddies, Dynamics of Atmospheres

and Oceans, 45, 274–319, 10.1016/j.dynatmoce.2008.01.001, https://linkinghub.elsevier.com/retrieve/pii/S0377026508000341, 2008.
Small, R. J., Campbell, T., Teixeira, J., Carniel, S., Smith, T. A., Dykes, J., Chen, S., and Allard, R.: Air–Sea Interaction in the Ligurian Sea: Assessment of a Coupled Ocean–Atmosphere Model Using In Situ Data from LASIE07, Monthly Weather Review, 139, 1785–1808, 10.1175/2010MWR3431.1, http://journals.ametsoc.org/doi/10.1175/2010MWR3431.1, 2011.
Sun, R., Subramanian, A. C., Miller, A. J., Mazloff, M. R., Hoteit, I., and Cornuelle, B. D.: SKRIPS v1.0: a regional coupled ocean–atmosphere modeling framework (MITgcm–WRF) using ESMF/NUOPC, description and preliminary results for the Red Sea, Geoscientific Model Development, 12, 4221–4244, 10.5194/gmd-12-4221-2019, https://gmd.copernicus.org/articles/12/4221/2019/, 2019.
Theurich, G., DeLuca, C., Campbell, T., Liu, F., Saint, K., Vertenstein, M., Chen, J., Oehmke, R., Doyle, J. D., Whitcomb, T., Wallcraft, A. J., Iredell, M., Black, T., Da Silva, A. M., Clune, T., Ferraro, R., Li, P., Kelley, M., Aleinov, I., Balaji, V., Zadeh, N., Jacob, R., Kirtman, B., Giraldo, F., McCarren, D., Sandgathe, S., Peckham, S., and Dunlap, R.: The earth system prediction suite: Toward a coordinated U.S. modeling capability, Bulletin of the American Meteorological Society, 97, 1229–1247, 10.1175/BAMS-D-14-00164.1, 2016.
Turuncoglu, U. U.: Toward modular in situ visualization in Earth system models: the regional modeling system RegESM 1.1, Geoscientific Model Development, 12, 233–259, 10.5194/gmd-12-233-2019, https://gmd.copernicus.org/articles/12/233/2019/, 2019.
Warner, J. C., Armstrong, B., He, R., and Zambon, J. B.: Development of a Coupled Ocean–Atmosphere–Wave–Sediment Transport (COAWST) Modeling System, Ocean Modelling, 35, 230–244, 10.1016/j.ocemod.2010.07.010, http://linkinghub.elsevier.com/retrieve/pii/S1463500310001113https://linkinghub.elsevier.com/retrieve/pii/S1463500310001113, 2010.
WW3DG, The WAVEWATCH III Development Group.: User Manual and System Documentation of WAVEWATCH III version 6.07, Tech. Rep. Tech. Note 33, NOAA/NWS/NCEP/MMAB, https://github.com/NOAA-EMC/WW3/wiki/files/manual.pdf, 2019.

Interactive comment on Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2020-269, 2020.