Questions in blue, my responses in plain text.

For the senior leaders who may be on here... Growing that capacity hurt my starting salary... Because HR said it (the graduate classes I took in Machine Learning, Computer Engineering, Statistics, Ocean Modeling, etc.) wasn't closely aligned with meteorology enough to count towards an advanced degree. So just food for thought... make sure that you can hire folks with these skills at the salary they should because they can likely get paid more in the private sector anyways.

There is already significant competition for people with ML skills (beyond atmospheric sciences), so this point is highly relevant to workforce development.

How well would an agent-based model work with constantly changing politics and funding?

It depends on what is being simulated by the model. If the inputs being used are the outcome of politics and funding (such as the Public University model), then the model won't care about how those values came to be. But if the political process is part of the model, then that has to be captured somehow for it to work.

On long-term projects, there is a risk that as the ML algorithms kept by our contractors changes (e.g., improvements by Google), that discontinuities in the consistency of the method may force recomputing. How can we best stay aware of the significance of the changes to see if they warrant re-runs of ML?

I think the best approach is to use adaptive methods, in other words an ML system that retrains continuously. This is possible. See, for example:

Roebber, P.J., 2021: Towards an adaptive artificial neural network based postprocessor. *Mon. Wea. Rev*., **149**, 4045-4055.

How might AI/ML be integrated into model physics? What sort of training resources would be required?

Here's an example. Radiation codes are called frequently in numerical weather prediction (NWP) models. One could run those codes to generate a sufficient training dataset, then use an ML approach to "learn" the output of those codes based on the inputs. This would be straightforward. The ML model is then inserted into the NWP code (just a few lines), and execution is much faster, so the NWP model is much faster. I would bet that a simple multilayer perceptron artificial neural network could do this quite efficiently. The only downside is the answer to the question, how good is your radiation code? The ML model will do a great job reproducing the radiation model outputs, warts and all!

I am curious about the agent based modeling when trying to model customer activity (human action). so many unknowns/unknowable pieces. Can you speak to how those are either estimated or skipped over?

This is where social science comes in. One has to understand how these interactions work in order to simulate them. This can be done crudely, depending on what the overarching goal of the modeling exercise is, but it still has to capture the essence of the interactions. As Ed Lorenz put it, "A model should be as simple as possible, but no simpler!" Often the data obtained from social science methods are qualitative, but this can still be enough to capture the essence of the interactions. Where it is most problematic is when there is simply no information. If that is the case, and you still need to model the interaction, then you will have to estimate it. The best you can do there is to test the model against known cases and see if it responds, in terms of its outputs, in a way that conforms to the data you do have. It is also to test the sensitivity of the model to different estimates regarding those uncertain interactions. It may turn out to not be very important. But if these test suggest that they are important, then you will have to put some large error bars around your conclusions and seek more data.

Any advice for overcoming a problem where NN suffer from a regression to the mean destroying variance? Other methods not so subject to that problem?

One method I have used to get a better estimate of dispersion in solution is a form of agent-based modeling called evolutionary programs. I used a predator-prey model in which the agents were algorithms (predators or prey) and the evolutionary process worked towards agents solving a particular problem (temperature forecasts); their evolutionary fitness depended on their ability to solve this problem. We found that this agent dynamic, which by its nature also generates large member ensembles, corrected a considerable portion of NWP model ensemble underdispersion while also providing better deterministic performance. You can read about it in the following paper:

Roebber, P.J., and J. Crockett, 2019: Using a coevolutionary post-processor to improve skill for both forecasts of surface temperature and nowcasts of convection occurrence. *Mon. Wea. Rev*., **147**, 4241-4259.

Agent-based model is more a model for ecosystem, do you have more detail about how AI would work for hurricane-impact-evacuation?

We used agent based modeling to simulate the hurricane evacuation "ecosystem" in:

Harris, Austin, P. J. Roebber, and R. Morss, 2021: An agent-based modeling framework for examining the dynamics of the hurricane-forecast-evacuation system. *International Journal of Disaster Risk Reduction*, **7**:102669, DOI:10.1016/j.ijdrr.2021.102669.

What are the advantages and disadvantages of using Markov chains relative to stochastic Monte Carlo approaches. You mentioned emergent properties in traffic ABMs. What approach would be used to model Braess's paradox, for example?

Not being a traffic engineer, I had to look that one up. According to Wikipedia:

Braess's paradox is the observation that adding one or more roads to a road network can slow down overall traffic flow through it. The paradox was discovered by German mathematician Dietrich Braess in 1968. The paradox may have analogies in electrical power grids and biological systems. It has been suggested that in theory, the improvement of a malfunctioning network could be accomplished by removing certain parts of it. The paradox has been used to explain instances of improved traffic flow when existing major roads are closed.

An agent based model could certainly be developed within the context of a particular road system to test the impact of reorganizing the network in various ways. It would not give you a general solution but a very specific solution to the problem at hand. Essentially, you would define the road network (including number of lanes) and whatever additional details are needed such as speed limits, and the behavior of drivers (I am from New England and I also spent a good deal of time in Quebec, and I now live in Wisconsin, and I can tell you that driver behavior is distinctly different in each of these places), most particularly with respect to their interaction with the roadway and with other vehicles. Ideally, you would need to know things like the distribution of departure locations and times and their accompanying destinations. It would be an interesting modeling exercise!