Additional Answers to Seminar Questions: The new normal? Heat waves and ocean blobs, what's next? Nick Bond and Faron Anslow (January 10, 2022)

Gary Morishima:

Regarding my question on attribution science. I was wondering whether some of the techniques and methods that Climate Science uses to estimate probabilistic likelihoods attributable to atmospheric accumulation of greenhouse gases might be usefully applied to salmon to sort out cause-effect relationships.

Faron's Answer: From my point of view, this would mean looking at various metrics of salmon fitness or outright populations and trying to determine to what extent changing climate has influenced those metrics. I think this might be possible with historical data because we have observations of climate and salmon well-being that could be used to build the statistical relationships. For future climate, attribution studies rely on model output to inform likelihood of occurrence of events. For salmon, or any impact study, this requires either direct climate model simulation of the salmon fitness metrics or an impact model that can simulate based on climate model output. I think the former is unlikely to be available, but it seems like there is potential for a climate model to inform an impacts model and then to use that impacts model to perform an attribution study. The difficulty is that conjoined models lead to large uncertainty and that quickly makes attribution difficult.

Nick's Answer: Good question about whether the techniques used for physical predictions might be applicable to examine salmon recruitment and those kinds of relationships. I am by no means an expert on the subject, but determining reliable statistical relationships requires large amounts of data, i.e., many degrees of freedom. It is my understanding that most of the AI methods that have been developed have focused on short-term weather forecasts over periods of days, because of the existence of so many different situations for the fitting. I imagine, but do not know for sure, that for many salmon-related applications that luxury is unavailable. There are some really bright folks such as Eric Ward at NWFSC that know more about the limitations and possible work arounds

Marilyn Scanlan 02:25 PM

Some Salmon stocks are doing ok and made it through the "blob problems", compared to others that are doing terrible. Is it possible that there are some new good food opportunities emerging other than the historical food chain relationship to copepods that these successful stocks are benefiting from? Can salmon benefit and adapt to this "reorganization" of the food web. (i.e., Opal Squid as one example).

Nick's Answer: We covered this to an extent, but I am sure my answer was incomplete. Marilyn posed the issue very well - Just why do some stocks appear to be so much more resilient than others and what are the implications? And what kind of research would be most effective in revealing this kind of information?

Dan Auerbach 02:30 PM

Do the regional/seasonal-scale forecasting efforts include both mechanistic and probabilistic approaches? Curious about scope to examine conditions outside the range of historic obs.

Nick's answer: In principle our dynamical models are fully capable of simulating situations that have not occurred in the historical record. There is a misconception by some groups that our models are "tuned" to get the answers we want. On the other hand, to be sure there is some fitting of parameterizations and relationships, but that fitting does not invalidate their results. Even statistical models based on past empirical relationships can be formulated to be meaningful in future situations if those empirical relationships are grounded by basic physical and biogeochemical principles. In my opinion, what gets tricky with long-term predictions are biological variables. Here we do not have the same constraints (e.g., conservation of energy, etc.) that are available for the physical realm.

Dan Auerbach 02:53 PM

Follow up on my last Q - especially interested in exploring the likelihood of "extreme sequences", i.e., perhaps less about terrifying magnitudes as about terrifying durations and frequencies of events. What's your sense of our understanding of that, given limits in GCMs on capturing interannual variability (for a given forcing)

Faron's Answer: I think this is a fascinating aspect to look at this from. I have in mind the heatwave as well as the Nov 13-15 atmospheric River in BC/Northern Washington and the wildfires that burned suburbs in Boulder County, CO.

The Atmospheric River was particularly interesting from this perspective (the heatwave and CO fires both came on the backs of record conditions). I am part of a group working on a paper on the AR event and it has been hard for us to find a singular smoking gun. The water vapour transport was high, but not record setting, the snowpacks were fairly normal, the precipitation rates were high, but not record setting. Yet, the event has a massive and destructive impact that only comes from adding up the more moderate features of the event. The only record was high temperature on the 14th.

Unfortunately, attributing events is difficult to impossible when multiple phenomena are included because the signal to noise drops quickly, so it's very hard to say a sequence of events was made more likely by climate change. That leaves us with comparing the event to projections and pointing out similarities.

This leaves us with imagination and situational awareness. I was in discussion with Daniel Swain, a climate scientist at UCLA, about the dry Colorado conditions in early December and he indicated the prospect of wildfire in such conditions. I had a similar thought when the December 1 heatwave hit southern BC and much of the NWern US. Unfortunately, a month later, he was proven correct in CO. The problem is that it's hard to make policy based on imagined linkages, so this is a tough nut to crack.

Tim Dalton 03:00 PM

Valentina Zharkova (looking right now at an article in "Temperature") just recently claimed that a new solar activity minimum (Maunder Min.) has begun and will last through 2053, giving us about a 30 year window reprieve to sort out all this Global Warming stuff. Should we take this seriously? (and cancel beach plans too)?

Faron's Answer: A very substantial portion of solar variability is predictable and is included in climate models that project future climate. I haven't looked at this specific issue, but my understanding is that any such low in solar activity would be seen in climate models as a plateauing of temperature. To my knowledge, they don't show this effect. One of the largest drivers of decadal variability in the climate system is how the tropical ocean take up or releases heat through frequency and strength of El Niño events. A part of the so-called warming hiatus in the 2010s was due to an unusual amount of La Niña events.

Nick's answer: I fully agree with Faron. I would like to add that indeed a signal can be found related to solar variations, but it is relatively small. I would be loathed to rely upon this effect to buy us any extra time.

Gary Morishima:

For Nick or Faron - There is a time lag between the occurrence of an event and how it may affect ecological/biological processes that impact salmon. For example, disruption of food webs impacting the growth and survival of juveniles entering the ocean. Is there any information on developments of attribution science?

Nick's answer: In some cases, the disruption can be more or less immediate. The Fish Ecology group has shown warm waters along the coast of Oregon result in a strong tendency for warm water copepods and skinny juvenile salmon. It is my understanding that after a warm period it does take a while for the cooler water copepods to re-colonize, or at least this seemed to be the case when the intense El Niño of 1997-98 transitioned to La Niña later in 1998.

Gary Morishima:

For Faron - projections for frequency of occurrence appear to be based on historical information, yet events like the June 2021 heat dome were unprecedented and the baseline is shifting. How should the recurrence interval statistics be interpreted?

Faron's Answer: Typically, with record setting events, extreme value analysis will show the new, unprecedented event fitting into the curve with the old events. This usually tells us that the new process is in keeping with the processes that governed the existing data and normally that would be the answer to your question – the extreme analysis framework incorporated the possibility of extreme events.

For the "heat dome" event, the extreme value fitting couldn't do this. Typically, data prior to the event are used to fit a curve and the curve is used to tell us where the new event lies in terms of probability. With the June heatwave, the recorded temperatures didn't at all lie on the curve based on

historical data. Only by including the event was a curve found that included the event and that makes us uncomfortable.

The paper I mentioned that describes how the continuous evolution of climate statistics in a rapidly changing climate is the missing link to be able to describe how such a record shattering event occurred. Because climate is changing fast, our sampling of the climate relevant for the 2021 heatwave will always be too small because only a decade or so of data has a similar climate. Because of the small sampling, an extreme value analysis would be inaccurate. To make extreme value analysis accurate we must look further back which incorporates data from what are now irrelevant climate states.

Dan Auerbach 03:24 PM

What's the remote sensing or other instrumentation advance that you're most excited to see hit our screens in the next 5-10 years?

Faron's Answer: There are improvements to remotely sensed near-surface air temperature that are promising along with better approaches to relate skin-temperature to near surface air temperature. Any improvements to estimating precipitation in complex topography would be a massive help. Precipitation remains an unreasonably large unknown in parts of BC, especially coastal, because of how hard it is to measure snow.

Joe Tadey 03:25 PM

Faron, you posed a question early in your presentation around the 2021 'heat dome' asking "Was it climate change?" And you answered Yes. You arrived at this answer based on the analysis of the event relative to historical data. I persistently hear news reports that link a single 'relatively normal' weather event to 'climate change', but unless some analysis is performed (e.g. like you did looking at the likelihood of this 'heat dome' occurring now versus 60-80 years ago, or looking at long term trends, etc. etc.), I think it is difficult to tease out normal climate variation from the climate change we are concerned about today. Given this salmon biologist is always asked about the link between a single (relatively common) weather event (not the 'heat dome' or the recent 'atmospheric river' events), and climate change and salmon abundance, any tips on how to provide some context around the claim by the people I talk to that every climate event that is 'different' from last year is the result of climate change?

Faron's Answer: I, too, am sometimes frustrated by the reflexive question of any event's climate-change relationship. I think pushing back against the notion that a given event is climate change-related is important. I recently did so with the pac NW cold snap in suggesting that, if anything, observed warming made the event easier on us.

My general transcript for such a statement is to stress that we cannot attribute a given weather event without substantial analysis that comes with some uncertainty. Once that analysis is done, we can begin to make statements. However, if a given event mimics what is expected with climate change, I think that can be stated, but the risk is that the audience may take "looks like" to mean "is". Another way to do this is to deflect. Take what we know (the quantities that define the event in question and climate projections) and use the conditions as a teachable moment. i.e., "Yes, it has been warmer than average lately, but we cannot attribute this to climate change without substantial analysis of the

data. However, did you know that climate projections tell us that by the 2060s we can expect temperatures like these to happen once every X years?"

William Atlas 03:30 PM

Not only food supply, but also metabolic demand is influenced by water temperature.

<u>Nick' Answer</u>: Great point. A telling example here is on the Bering Sea shelf where it appears that colder winters can improve the survival of age-0 pollock and cod for that reason. Along with the possible role of parasites mentioned by Faron below, changes in temperature can also open habitat for predators or competitors that otherwise are not around in significant numbers. It is my understanding that mackerel often move north during El Niño due to the warmer waters along the US west coast at those times and end up being important predators on juvenile salmon.

William Atlas 03:30 PM

warmer water = less food + more energetic demands

<u>Faron's Answer</u>: I don't have anything to add to this other than I wish I had the chance to make this comment to the audience on your behalf. Metabolic stress and parasite loads are important non-food contributors to salmon success/failure.