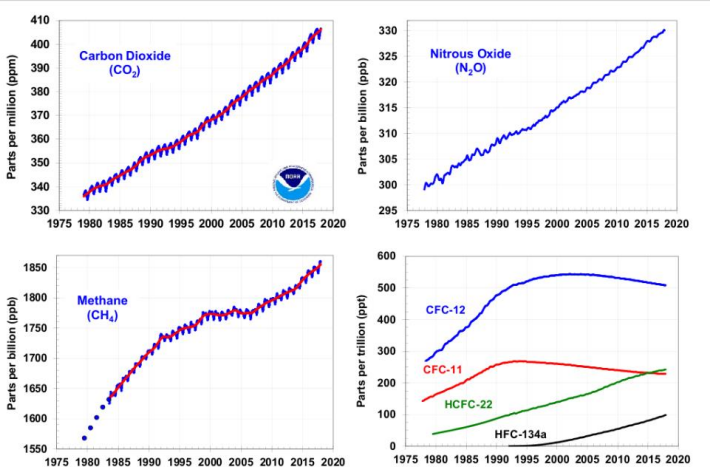
Now Hear This!

The implications of climate data are difficult to understand through a single X Y graph. If time is included as a displayed variable, graphs can show either that temperature is increasing or that the amount of greenhouse gas is increasing, not both. Consequently, those reading the graph must use multiple graphs or be able to infer how the variables in one graph impact and influence other variables. To overcome the limitations of two-variable communication, I created a data sonification that communicates about both the increase in atmospheric greenhouse gas and the consequent radiative forcing of that increase in a single data experience with the goal of designing a usable science sonification for visually impaired audiences and for the general public that motivates listeners to consider appropriate actions to combat climate change.



"Global average abundances of the major, well-mixed, long-lived greenhouse gases - carbon dioxide, methane, nitrous oxide, CFC-12 and CFC-11 - from the NOAA global air sampling network are plotted since the beginning of 1979. These five gases account for about 96% of the direct radiative forcing by long-lived greenhouse gases since 1750."
Source of graph and caption: https://www.esrl.noaa.gov/gmd/aggi/aggi.html

Global Radiative Forcing (W m^{-2})								CO_2-eq (ppm)	AGGI	
Year	CO_2	CH_4	N_2O	CFC12	CFC11	15-minor	Total	Total	1990 = 1	% change
1979	1.027	0.406	0.104	0.092	0.04	0.031	1.699	382	0.785	
1980	1.058	0.413	0.104	0.097	0.042	0.034	1.748	385	0.808	2.2
1981	1.077	0.42	0.107	0.102	0.044	0.036	1.786	388	0.825	1.8
1982	1.089	0.426	0.111	0.107	0.046	0.038	1.818	391	0.84	1.5
1983	1.115	0.429	0.113	0.113	0.048	0.041	1.859	394	0.859	1.9
1984	1.14	0.432	0.116	0.118	0.05	0.044	1.9	397	0.878	1.9
1985	1.162	0.437	0.118	0.123	0.053	0.047	1.94	399	0.896	1.9
1986	1.184	0.442	0.122	0.129	0.056	0.049	1.982	403	0.916	1.9
1987	1.211	0.447	0.12	0.136	0.058	0.053	2.025	406	0.936	2
1988	1.25	0.451	0.122	0.143	0.061	0.057	2.085	410	0.963	2.8
1989	1.275	0.455	0.126	0.149	0.063	0.061	2.13	414	0.984	2.1
1990	1.292	0.459	0.129	0.154	0.065	0.065	2.164	417	1	1.6
1991	1.312	0.463	0.131	0.158	0.066	0.069	2.199	419	1.016	1.6
1992	1.323	0.467	0.133	0.162	0.067	0.072	2.224	421	1.028	1.2

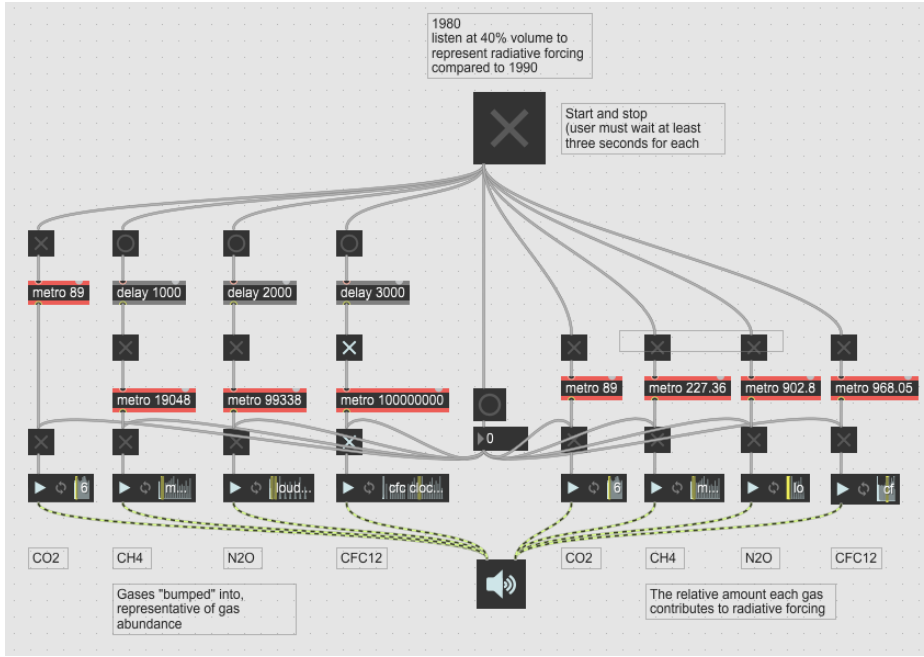
"Global Radiative Forcing, CO2-equivalent mixing ratio, and the AGGI 1979-2016 ."
Source of graph and caption: https://www.esrl.noaa.gov/gmd/aggi/aggi.html

Amount of gas in the atmosphere	1980	1990	2000	2010
CO2	338 ppm	354 ppm	368 ppm	388 ppb
CH4	1575 ppb	1710 ppb	1770 ppb	1795 ppb
N2O	302 ppb	309 ppb	315 ppb	323 ppb
CFC12	300 ppt	475 ppt	540 ppt	530 ppt
CO2- ppm	338	354	368	388
CH4- ppm	1.575	1.71	1.77	1.795
N2O- ppm	0.302	0.309	0.315	0.323
CFC12- ppm	0.0003	0.000475	0.00054	0.00053
At spped of 1M parts/minute, ppm = bpm				
Rate of the meronome in milleseconds				
CO2 = every X ms*	89	85	82	77
CH4 = every X ms	19048	17544	16949	16713
N2O = every X ms	99338	97087	95238	92879
CFC12 - = every X ms	100000000	63157895	55555556	56603774
*if speed is 1 million parts of air/minute				
(Rate= 60k milliseconds/ppm)/2 for on/off				
Proportionate Radiative Forcing*				
CO2	1.058	1.292	1.513	1.791
CH4	0.413	0.459	0.481	0.491
N2O	0.104	0.129	0.151	0.175
CFC12	0.097	0.154	0.173	0.17
Total (includes CFC11 and 15 minor gases	1.748	2.164	2.466	2.792
Compared to 1750 values (W m-2)				
BPM based on proportionate Radiative forcing*				
CO2	0.6052=338	0.597=354	0.6135= 368	0.6415= 388
CH4	131.95	125.77	117	106.37
N2O	33.23	35.35	36.73	37.91
CFC12	30.99	42.2	42.08	36.83
Total (includes CFC11 and 15 minor gases)	558.49	592.96	599.84	604.83
*If carbon equals the same bpm as atmospheric volume Example= 1.052/1.748= .6052 (Carbon Equals 60.52% of the total forcing), .6052 equals 338. Therefore the total parts equal 558.49.				
Rate of the metronome in milliseconds based on proportionate RF				
CO2 = every X ms*	89	85	82	77
CH4 = every X ms	227.36	238.53	256.41	282.04
N2O = every X ms	902.8	848.66	816.77	791.35
CFC12 - = every X ms	968.05	710.9	712.93	814.55
User volumn adjustment based on AGGI	0.808	1	1.139	1.29
Volumn (50=1, rounded to whole numbers)	40	50	57	65

This table explains the numbers used for the Max/MSP sonification created. Numbers based on NOAA's "Global Radiative Forcing, CO2-equivalent mixing ratio, and the AGGI 1979-2016" table.

Methodology

I choose Max/MSP because it offers a simple and intuitive tool for the non-programmer to create a sound machine. Using predefined objects with embedded code enables the user to focus on function rather than learning a full programming language. The bangs, buttons, and objects of Max are very user friendly. "The Annual Greenhouse Gas Index (AGGI) is defined as the ratio of the total direct radiative forcing due to long-lived greenhouse gases for any year for which adequate global measurements exist to that which was present in 1990" (NOAA). Four sonifications were designed for this project to create a single user experience of the AGGI representing gas abundance, proportionate radiative forcing, and comparative radiative forcing. Sounds chosen were based on the percussive noises made by a clock to create sense of urgency that comes from the increased tempo which is the audible representation of increased gas amounts and radiative forcing. The number of molecules encountered and their relative radiative forcing were represented with two different sets of sound, one played into the right speaker and the other played into the left, and the AGGI numbers were represented through volume.



Screenshot of the Max/MSP patcher depicting 1980 values for gas abundance and proportionate radiative forcing.

A framework as criteria for design:

Interdisciplinarity: This project required experts from the fields of science, music, education, and computer programming.

Stakeholder Engagement: The experts mentioned above represent one group of stakeholders and representatives from the two intended user groups, visually impaired individuals and members of the general public, will also be asked to help inform sonification design as progress continues. In order to include the visually impaired, the Colorado School for the Blind will be contacted this spring to find appropriate classrooms to demonstrate the sonification for students and record their feedback to test whether the tool is effective at conveying atmospheric gas levels and radiative forcing. A pilot exhibit to solicit feedback from users at informal education institutions will also be designed for the general public.

Usability: Global scale environmental issues can create a sense of hopelessness, especially among the youth. One way to avoid this is to focus on solutions when introducing the problems in order to leave learners empowered rather than worried. Meaningful solutions require an accurate understanding of the issue. This sonification hopes to provide that understanding. If listeners comprehend the disproportionate impact that CH4, NO2, and CFC12 have on global warming in addition to the amount of greenhouse gases present in the atmosphere, then they will have the ability to consider which actions are appropriate for each gas. For CO2, only major global efforts will be meaningful because of the amount of the gas that humans create and its prevalence in the atmosphere. Conversely, smaller targeted efforts that reduce CH4, NO2, CFC12 and other refrigerant associated gases may have significant impact. The overall usability of this project will be rated based on how listening to the sonification impacts listeners' understanding of climate change and leads to further research and action. To test impact, a grounded theory approach will be used and semi-structured interviews with participants will take place six months after they listen to the sonification. Students and educators at the School for the Blind will be contacted through the school. Public participants who experience the sonification through an exhibit will be asked to provide an email so that they can also be contacted six months after they listen and educators from exhibit sites will also be interviewed. If the sonification doesn't prove usable, then it will be modified through coordinated efforts of the expert team and retested.

Acknowledgements: This work was made possible in part through funding provided by the ESIP Community with support from the National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA) and the United States Geologic Survey (USGS)