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Undergraduate

BEHIND THE CHEMISTRY OF HUMAN ACTIVITY AFFECTING THE EARTH'S ATMOSPHERE

An interview with Professor Ronald C. Cohen

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Professor Ronald Cohen is a professor in the Department of Chemistry and of Earth and Planetary Sciences at University of California, Berkeley. Professor Cohen has been interested in atmospheric chemistry and planetary sciences. In this interview, we focus on one of his specialties, gas emission monitoring.



BSJ: How did you initially get involved and interested in the field of atmospheric chemistry and planetary science?

RC: As a grad student, I was a fundamental physical chemist. I worked on measuring the absorption spectrum of clusters of small molecules, and I had a bunch of skills at the end of that time that had to do with lasers and how to think about interesting problems. I was looking for something where I didn't know anything. I wanted to change as much as I could while finding some place where I could use the skills that I had. So, I went to do my post-doc in atmospheric science. I did my PhD here [at UC Berkeley] and my postdoc at Harvard.

BSJ: In one of your papers you called for higher accuracy when interpreting space-based remote sensing of NO₂ levels, specifically higher spatial and temporal resolution. Generally, how would these improvements affect the broader scheme of monitoring greenhouse gases?

RC: That question tangles up a bunch of different things. So let me try to untangle them. There are some measurements from space right now, especially measurements of NO₂ (nitrogen dioxide), where the measurement of the spectrum itself is

incredibly precise and accurate and our ability to interpret that spectra-what it means physically in the atmosphere- is not as good as its fundamental measurement...In principle, the information available to us is much better than our current ability to interpret it. That's part one- we'd like to figure out a way to get all the information of this expensive and beautiful measurement.

Part two are the natural length scales in the atmosphere...The meteorological time scale for those chemicals to be moved up-wind and diluted and diffused is the same as the chemical time scale...That's part of the reason why we need to have higher resolution. We're trying to measure something that's changing on a 75 km length scale with an instrument in space where the best has only 24km pixel resolution which aren't in perfect registration for a time equals zero experiment. The reason we need higher resolution, the problem we're trying to solve, has variation in the

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length scale that we can’t observe right now.

BSJ: How would you go about choosing which city to study? We saw that you used Atlanta, Georgia as a model city for observing effects of daily NO₂ levels.

RC: In general, we’re thinking about two different lines of research. In one line, we are trying to develop methods to do things better; when we do that, we tend to be quasi-random...The ultimate goal is to apply the methods to the whole earth; there is a separate, parallel effort where we’re not picking any individual city.

BSJ: What are VOC emissions and could this spatial and temporal resolution improvement be applied to VOC emission monitoring?

RC: There are two different kinds of problems my research reports on broadly. One is understanding climate and the chemicals, primarily CO₂, methane, nitrous oxide, ozone, and particles in the atmosphere, that are responsible for climate change; the other is understanding the chemical constituents of the atmosphere from the point of view of public health. In that sense, much of my work on NO₂ and organic molecules-- which is what VOC are-- are related to the public health questions. We also have an interest in how the world works in the same way you might want to understand why there are electrons in atoms. Most of the time, I am approaching things that way and remember that what we do has direct connection to other people’s lives in ways that other fundamental scientists don’t, and we try to engage on that.

What we can see from space is based on things that are both high enough in atmospheric concentration and have strong enough absorption; that limits you to a small subset of molecules that are important. NO₂ is an example: it absorbs in the visible light spectrum, and it’s a brown gas allowing it to have a very strong overlap with the sun thus strong enough absorption to be seen.

BSJ: You’ve worked on designing a new method for monitoring atmospheric composition, Tropospheric emissions: Monitoring of pollution (TEMPO). What kind of data does TEMPO collect?

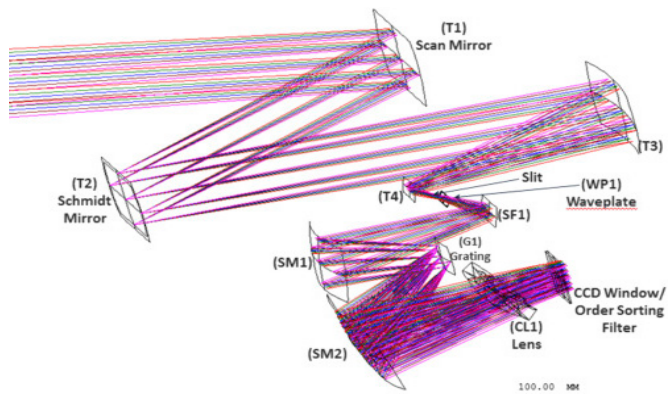
RC: TEMPO, a new satellite instrument, is an improved version of OMI used in the project in Atlanta. Both instruments are standard UV spectrometer with half-nanometer resolutions. What’s different about TEMPO is that it has an imaging camera behind it... We’re getting a map of the spectrum of the reflected sunlight from the Earth. With both of these instruments, we’re doing a standard kind of Beer’s Law absorption experiment...This is, in concept, an incredibly simple experiment; the challenge is that we’re going to put it several hundred miles above the Earth and never be able to touch it again after it’s built. What’s new about TEMPO is it will have a bigger telescope on than the current generation of instruments, so its footprint on the ground will be smaller. The instrument we use now has a 13x24 km dimensions; TEMPO is going to have 3x3 km pixels...It’s going to be launched on a communication satellite, and it will be sitting on the same platform due south of somewhere like Oklahoma near the equator... Between 3 x 3 pixels and 13 x 24 pixels monitoring, we get effectively area that’s almost 100 times better. The science question that we’re trying to address requires understanding the spatial dimension on which the chemicals are changing in the atmosphere. We’ll be able to completely resolve the behavior of chemicals as they change in the atmosphere on the spatial scale of that change.

BSJ: Which methods helped to inform your design of TEMPO?

RC: TEMPO is a big team, and the core designers are not at Berkeley. In concept the spectrometer is simple: the light comes in, it hits the grating, grating spread out light on detector... But there are all kinds of important details for getting a really precise measurement, that’s being handled by a team at the Smithsonian Astrophysical Observatory...

The part of the project that’s delegated to us at Berkeley, or we’re taking the lead on at least, is thinking about once we have a measurement, and are thinking about how to get that measurement into a measurable, sortable amount of NO₂.

“This is, in concept, an incredibly simple experiment; the challenge is that we’re going to put it several hundred miles above the Earth and never be able to touch it again after it’s built.”



OPTICAL RAY TRACE FOR THE TEMPO INSTRUMENT, INCLUDING TELESCOPE AND SPECTROMETER

BSJ: The TEMPO is part of an international satellite constellation. In what ways will TEMPO’s international collaboration benefit current and future studies on air quality

RC: So the atmosphere sits on one planet, and air travels around the whole northern hemisphere in about two weeks. So air that was in

China last week, or Korea, is going to be here in seven days, give or take. So understanding those links, those are really important, so that advantage of cooperating with our international partners in Korea and in Europe and trying to do something at the same time is being able to raise the level of view of every one’s information. We each know about this field that we’re looking at, but we also want to know what’s coming from upwind of us, and what we’re sending down.

There’s also a really valuable science culture side. A year ago, we did an experiment in Korea, near 150 scientists reported by NASA, and 150 Korean scientists...Building that sort of cooperation-the best things that happen in science are often because two people both sit down and say, I want to try something together.

BSJ: How can TEMPO’s scientific studies impact policy on a regional level?

RC: The idea is that we’re going to understand the distribution of NO₂, ozone, and formaldehyde. We’ll understand that distribution on a spatial scale we’ve never been able to map before. So I can give you a model today of the predicted distribution of NO₂ at any spatial resolution you want...We’ll have a complete map every hour and then, that will change our ability to ask good questions.

BSJ: What implications does Berkeley Atmospheric CO₂ Observation Network(BEACO₂N) monitoring -- which is a new, affordable, and more precise method of measuring CO₂ in urban areas -- have on policy legislation and science?

RC: ...About five years ago I was watching some news piece about CO₂ treaties and there was a buzz in the

scientific community about how if we did sign a treaty that was going to reduce CO₂ emission, how would we know we were doing it? As you know from reading the news, if we say we’re going to reduce the emissions from cars and we don’t test, we’re not going to get the emissions reductions we expect, the diesel engine example being high in my mind there- but it’s not only one. The heavy duty diesel truck manufacturers did the same thing 20 years ago. They had some strategy for complying with regulations when trucks weren’t moving and on the road they did something totally different. So if you also think about the CO₂ treaty, the most important thing is to give good feedback to all the people who actually have good will...So we wanted to think about how we would help those people. But what information did they need? How could absorbing the atmosphere really tell us that the things we are doing are having an effect? [One piece of our thinking is] that- “I think my CO₂ emissions went down by 20%, what does the world say? Are they saying it only went down by 10? By 40? And how are we going to figure that out?”

The other piece was that something like half the people in the world live in cities right now, and 25 years from now, it’s going to be three-quarters- if we’re going to solve the climate problem, it’s going to be in cities. So, we really wanted a better way to think about cities. Then the third line of thinking was that there was a tremendous sort of thoughts about networks of sensors and networks of all kinds of things. One way you see it is when you get on the road and you pull out Google maps and it tells you where the traffic is. You know that because hundreds of dozens of people let Apple or Google know where there phone is, and it shows when you’re not moving out on the road. That’s a network in action...

The initial vision of BEACON was that we would put all the sensors on the roofs of middle schools and high schools. And, we would have a curriculum for science teachers to use the data directly from the roof and talk about what it means to make a measurement, how you think about the statistics, what’s different about what

you're measuring in a real-world setting, from a controlled laboratory setting. The wonderful thing about the lab is you can have something that depends on dozens of parameters and you can change them one at a time. When you study the atmosphere, you don't have that luxury, you get what you get...

BSJ: What technological advancements and economic markets allowed more affordable and accurate monitoring of greenhouse gas emissions (such as carbon dioxide and nitrous oxides)?

RC: What really makes this possible is mostly better communication. Free public Wi-Fi- kinds of things, that's a key. Much, much less expensive computers. Another part is really small and inexpensive chemical sensors- we're using sensors that were originally targeting the market for industrial alarms. They were originally just trying to be a threshold sensors to alarm you that certain concentrations of chemicals are higher than is safe in your house or business. They got to be good enough, that they are now used for more continuous measurements, not just for digital alarms. A household carbon monoxide alarm is one of the classic things that we are talking about.

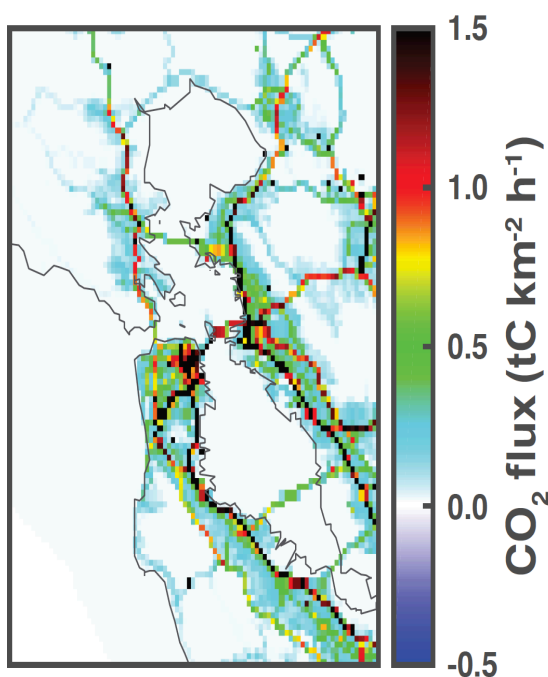


FIGURE 3. A SAMPLE HIGH-RESOLUTION BOTTOM-UP EMISSIONS INVENTORY FOR THE BAY AREA ADAPTED FROM TURNER ET AL. (2016).

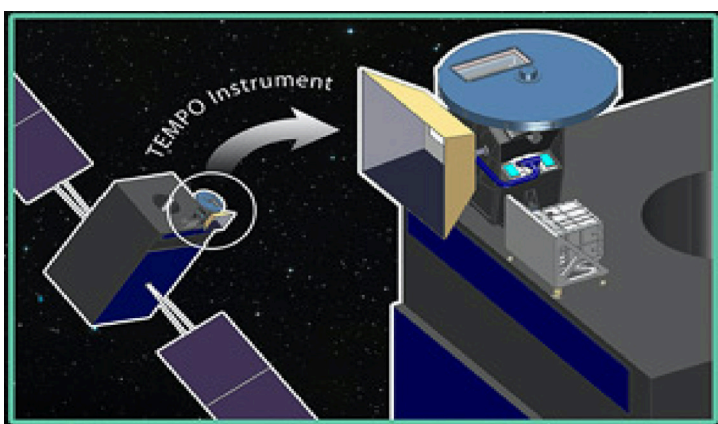
The other thing was that the normal way people go about measuring CO₂ is to buy \$75,000 instrument which is incredibly precise and accurate. Carbon Dioxide is the hardest thing that we measure. In the sense that the concentration of Carbon Dioxide in the atmosphere is 400 ppm mole fraction, and the interesting variations are at about 1. So, if you don't make a measurement that is good to about one part of 400, it's boring. Whereas if we make a measurement of NO₂ to 10% were good. So, CO₂ was much, much more challenging because the interesting variation is so much smaller; you have to make a measurement with super high precision and accuracy or it's not useful. We made a compromise in our network by buying an intermediate quality instrument that's good enough for our purpose, banking on the idea that... if we have 20 instruments for the same price, then we get 20 times the square root of N-advantage... We are not putting 20 instruments in the same location and getting a direct square root advantage by measuring exactly the same thing- we have the square root of N advantage distributed over space, where each one is measuring something different. That sort of understanding is one of the challenges that made us excited to do this.

BSJ: Relating to these 20 intermediate quality devices, what impact does more accurate and localized monitoring have on public health and public health policy?

RC: We believe that we are going to be able to make maps of admissions and exposure that are better than anyone has ever had before, but we're not there yet. We have a new project using the BEACON network, it's called the CRAT institute for personal prevention. It's a collaboration with colleagues in public health where we're going to think about asthma and exposure in Richmond and the surroundings. We go back and forth a little bit in the project- sometimes this is a CO₂ greenhouse gas project and sometimes is an air pollution public health project. The emission that cause both those problems all have the same source. So, in many ways the fundamental science we are trying to address is identical, it's the applications that are different.

BSJ: Where do you see your research going in the future-with your lab and with the field?

RC: I'm pretty excited about the things we talked about today. They have an intersection, thinking about ways to get space and time resolution measurements of the atmosphere at the scale of the true variability. Then using those to address some of the fundamental questions about emission and chemistry in the atmosphere- that's one theme.



“Building that sort of cooperation—the best things that happen in science are often because two people both sit down and say, I want to try something together.”

We have some other long standing questions we are trying to think about. One is climate-related in the sense that we are trying to think about the role of temperature in changing the chemistry of the atmosphere. How to think about response to changing temperature on different space and time scales. We have some other projects, where we’re thinking about the role of interaction between the atmosphere and forest in the biosphere. About one part of 400, it’s boring. Whereas if we make a measurement of NO₂ to 10% were good. So, CO₂ was much, much more challenging because the interesting variation is so much smaller; you have to make a measurement with super high precision and accuracy or it’s not useful. We made a compromise in our network by buying an intermediate quality instrument that’s good enough for our purpose, banking on the idea that...if we have 20 instruments for the same price, then we get 20 times the square root of N-advantage... We are not putting 20 instruments in the same location and getting a direct square root advantage by measuring exactly the same thing- we have the square root of N advantage distributed over space, where each one is measuring something different. That sort of understanding is one of the challenges that made us excited to do this.

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