Interview: Paul Ginoux

What is Dust?

Few of the fairy tales of science are more marvellous than these recent discoveries as to the varied effects and important uses of dust in the economy of nature.
Alfred Russel Wallace (1898)

Since Alfred Russel Wallace wrote his paean to dust in 1889, the importance of dust in the economy of nature has become increasingly clear. Dust, as it turns out, reflects about a quarter of the Sun's energy back into space, which, among other things, provides a steady stream of climate data to orbiting satellites whose accounts of what the dust is doing say a lot about the weather, and what the weather is doing. In 2013, the American Geophysical Union recognized Paul Ginoux for his pioneering research on the remote sensing of dust, and in January 2014 we sat down with him to better understand what the dust is doing, and what strange materials are contained in the term.

Scapegoat
What is dust?

Paul Ginoux
Dust is any particle in the atmosphere with a radius less than 10 micrometres.

Scapegoat
So in other words, dust is entirely a size? It has nothing to do with materials?

Paul Ginoux
No. It should be from the crust, from the terrestrial crust. It's not organic like skin, or chemically produced like sulphate. Dust is mineral, from the ground.

Scapegoat
What are aerosol particles then?

Paul Ginoux
Aerosols are solid or liquid particles in suspension in the atmosphere. They have radii between 0.1 to 10 micrometres. They are generally distributed into two modes: fine (0.1–1 micrometres) and coarse (1–10 micrometres). The fine mode includes sulphates, nitrates, organic carbons, and black carbons. The coarse mode includes sea salt and mineral dust.

Scapegoat
You made a very high-resolution model of the circulation of these particles during 2012. Your model shows four kinds of aerosol particles moving around the earth: dust, carbon from fires, sulphates from fossil-fuel burning, and sea salt. What did you see in the time period you analyzed?

Paul Ginoux
In the model you will first see a huge dust storm in October 2012. Dust particles less than one-tenth of the diameter of a human hair are uplifted by sand particles bombarding (sandblasting) the ground, and dislocating clay or silt particles, also known as mineral dust. October 2012 was very dry, and because of crop failure the soil was exposed for sandblasting. In this particular case, an intrusion from the stratosphere, induced by atmospheric waves driven by the winds over the Rocky Mountains, created very strong surface winds along a front from Nebraska starting on October 18.

Then one week later you will see Hurricane Sandy moving along the East Coast. What you "see" in the animation we made is sea salt produced in large quantities by the splash of waves. The splashes create air bubbles which then rapidly move to the surface of the water and break. When the film of the bubble breaks, it disperses tiny droplets of water and sea-salt particles (one-tenth the diameter of a hair), which are transported up by eddies and winds. The low pressure inside the hurricane makes these particles move upward in a cyclonic (counter-clockwise) circulation. This is what we observed by satellite.

Scapegoat
How does the satellite observe these tiny particles?

Paul Ginoux
It's looking at the solar radiation reflected by aerosol particles, which is called "backscattering." The amount of energy reflected back to the satellite depends on surface brightness, atmospheric absorption, and scattering by molecules and aerosols. You then measure the amount of energy on the surface of the earth, and the reduction can only be due to two things: absorption and scattering by molecules (like air and ozone), or aerosol particles. For the molecules it's very easy to calculate using a simple formula. If you know the air density in the atmosphere you can easily calculate the scattering and absorption by molecules. For aerosols, it's more complicated because we generally don't know the composition and size of aerosols. By testing many different possibilities of aerosol composition and size, the one giving the best match of theoretical and observed radiances is assumed to correspond to "reality."

Scapegoat
You wrote a paper distinguishing natural from anthropogenic dust recently, called "Global-scale Attribution of Anthropogenic and Natural Dust Sources and Their Emission Rates Based on MODIS Deep Blue Aerosol Products."[1]

Paul Ginoux
Yes.

Scapegoat
So what is "anthropogenic dust"?

Paul Ginoux
You can have different types of anthropogenic dust. Anthropogenic dust is dust in the atmosphere that has been transferred or emitted into the atmosphere by anthropogenic processes or is emitted from disturbed soils due to land use. This can be from trucks, cement factories, agriculture when you are ploughing the field, cattle when they move around the pasture breaking down the crust... things related to human activities.

Scapegoat
Is dust simply the inevitable end-stage that all matter passes through before being redistributed through the air, and reincorporated into new materials?

Paul Ginoux

The cycle you imagine is correct, but on very long timescales. You have the weathering of mountains, ice breaking rocks, then this rock is transported by rivers through erosion, and then it forms small pebbles, then tiny pebbles, and then it accumulates in depressions. All these particles less than 10 micrometres are known as silt and clay, which means that they have been weathering through this process for quite some time. They accumulate in rivers and then lakes, and the new lakes tend to dry up. You have winds that blow the dry particles, and then the material that accumulates after the wind stops is called "loess." When loess accumulates into huge deposits, the pressure builds and forms a new type of rock: sedimentary rock.

You see, so you were right about the cycle. Human activity tends to destroy the cohesion of the soil. Because you know that these tiny particles are very cohesive. You know clay ... if you walk on clay you have a lot of mud on your shoes. This dust is not sand, which is too large. This has been shown in wind tunnels. When you have winds reaching a speed of about six metres per second at the surface, it will push sand particles, like at the beach, and you will have a horizontal flow of sand particles. But because they are large, between 50 and 100 micrometres, they don't go far, and so they end up bombarding the surface. When they bombard a dry lake or anything with clay or silt, the clay and silt, which are much smaller (less than 10 micrometres), are ejected into the atmosphere. These particles are so tiny that gravity has little effect on them. Instead, the turbulence of the air, or the effect of buoyancy of air rising from a hot surface, moves them up-up-up. Horizontal winds higher up in the atmosphere can then move them thousands of kilometres. It's these physical processes which are key to understanding dust emission.

Scapegoat

We think about dust storms as so exceptional, such an unexpected problem, but it sounds like what you are describing is a constant process.

Paul Ginoux

Yeah, I mean it's not exceptional. It's almost every day, every year. And lots of dust. There's about one billion tons of dust emitted into the atmosphere every year. There are weekly events in Africa. Every two weeks there are huge dust storms in China. Cold fronts make the dust storms much more intense in China than in Africa, but in China they are less frequent.

Scapegoat

These cold fronts in China you just mentioned, where do they come from? Does this wind originate from the Himalayas in some way?

Paul Ginoux

No, you have a low-pressure front moving over from Inner Mongolia and a convergence zone of winds. You get very strong winds on the cold side of

the convergence zone, if I remember correctly, and the winds accelerate because of this pressure gradient. When the wind is greater than six metres per second or so, the sand starts to move, it starts to sandblast the ephemeral lakes and any bare surface with alluvium or silt or clay, and the eddies produced will move the dust up along this front. It can reach an altitude of eight kilometres, where dust can be entrained by jet streams.

Scapegoat
One of the largest sources of dust in this region is a depression in the northern deserts of China called the Taklimakan Desert, and the dust it emits during these events can reach Beijing, where they call the phenomenon "Yellow Dragon." Where did the dust in the Taklimakan originally come from?

Paul Ginoux
You mean in time or space?

Scapegoat
Um, well I guess both?

Paul Ginoux
Well in time it is a long geological process over millions of years. I guess it was the erosion of the Himalayas. The Taklimakan is a depression, so as I said you have the weathering of the mountains and accumulation in the depressions. What's interesting in the Taklimakan is that on the edge of it—I didn't know this until I did this work with MODIS and looked at Google—you can see farming activity. Did you know that? If you look carefully at my paper, on the edge of the Taklimakan you will see some anthropogenic dust, and it's confirmed when you zoom in on Google you see all this farming with irrigated fields. If they stop irrigating, however, and if it starts to get dry, you have a fantastic dust source there. Once the sand moves, just next door, into this huge depression of the Taklimakan, and it hits the fine alluvium for crops, there you are: you have dust. So indeed, there's a lot of anthropogenic dust there on the edge of the basin. In Inner Mongolia, it's more a question of overgrazing by sheep and less a question of agriculture.

Scapegoat
So does this mean that dust storms in Asia are of an anthropogenic origin?

Paul Ginoux
No. The agriculture on the Taklimakan is only on the south-west, but the big source is the desert itself, which is natural. In my paper I reported the global ratio of natural to anthropogenic dust as 75 to 25 percent.

Scapegoat
What was your methodology for distinguishing natural from anthropogenic sources of dust?

Paul Ginoux
I observed dust using a MODIS satellite instrument, and then referenced that data with a land-use dataset, which is partly based on satellite data and partly based on documents from different

countries. So these documents can be totally wrong. You see? I depend totally on them.

Scapegoat
So there really is no way to distinguish anthropogenic and natural dust from a satellite. It's all the same once it gets into the air?

Paul Ginoux
After I wrote the paper on anthropogenic dust, I saw another paper in the journal Nature about ammonia retrieved from satellites. Ammonia is NH_3, and comes mostly from agriculture, fertilizer, and cows. The paper published in Nature looked at atmospheric NH_3, and when I saw it I was amazed by the similarity between the hot spots of NH_3 and the hot spots of anthropogenic dust that I had found. So I contacted the authors, they sent me the data, and we published a paper called "Ammonia in Dust" in Atmospheric Chemistry and Physics showing that within the anthropogenic dust plume you also have some ammonia. What I did was check the optical properties of this anthropogenic ammonia to see if it would change the optical properties of the dust. The answer was yes; it's brighter than the dust. And ammonia forms salts, like sea salt on the beach. It's very bright white, while dust is more yellowish. So this coating of dust by salt brightens the dust, changing its colour from brown to more white; or rather, the dust becomes more reflective and absorbs less solar radiation.

Scapegoat
So that means that anthropogenic dust would be optically brighter than dust because of the ammonia salts? It's a correlation then?

Paul Ginoux
Yes. It should be possible to detect it, but you would need much more sensitive instruments. But the paper showed that, indeed, you could detect it with more sensitive instruments than the current orbiting satellites are equipped with.

Scapegoat
So, in your paper, after looking at the global distribution of dust, where does China fall in the world picture?

Paul Ginoux
China is the second highest dust source in the world after West Africa. It used to be the third highest after Australia, but dust sources in Australia have been reduced drastically. So China is now number two, and, as mentioned, though it has very intense dust storms, they are less frequent than in Africa.

Scapegoat
And why is that?

Paul Ginoux
Because dust emission is produced by different processes in both regions. In China, it is essentially a passing cold front, while in West Africa there are other types of disturbances, like downdraft within convective clouds creating fast-moving walls of dust ahead of the cloud, called a "haboob."

Scapegoat
In China, there's a massive effort under way to plant trees to reduce dust storms. Is this going to work?

Paul Ginoux
It will indeed remove some dust particles, but you will still have a lot of dust particles above the trees that will never be removed. The only way is to plant over the dust source or increase soil moisture. When the soil moisture is high, then you have no emissions at all. The worst is drought because then the vegetation disappears, the roots die, the soil dries up... and everything can become a dust source.