ENVIRONMENTAL SCIENCE

Ammonia maps make history

Ammonia emissions harm humans and the environment. An analysis shows that satellites can locate sources precisely, and could thus help to monitor compliance with international agreements to limit such emissions. SEE LETTER P.99

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According to the tenth-century Arabic geographer Al-Masudi, travellers through the mountains between Samarkand and China had to pass through a valley where the smoke was so dense that the Sun's rays could not penetrate. Al-Masudi recorded[1] how paid porters would "use sticks to drive the passengers on their journey; for any stoppage or rest would be fatal to the traveller, in consequence of the irritation which the ammoniacal vapours of this valley produce on the brain, and on account of the heat". His graphic account describes the earliest known industrial source of ammonia emissions, and has fresh significance in light of a study reported on page 99 by Van Damme and colleagues[2]. The authors have mapped atmospheric ammonia levels with unprecedented precision around the globe, and have quantified emissions from this ancient source for the first time — along with those from a host of previously uncharacterized industrial and agricultural hotspots.

In the valley mentioned by Al-Masudi, locals were exploiting the spontaneous natural combustion of surface coal seams. They used stone huts to collect ammonium chloride and other ammonium salts[3,4] carried by the fumes, with the remaining emissions contributing to air pollution. Although this oldest of ammonium industries is no longer in business, Van Damme *et al.* identify two sites, at Abakan in Russia and Jharia in India (Fig. 1), that are emitting ammonia from burning coal mines. Their demonstration that global satellite observations can now detect such ammonia sources represents a historic moment for science.

Al-Masudi's example makes it clear why we should care about ammonia. Emitted ammonia reacts rapidly with other air pollutants, and thereby helps to form fine particulate matter that shortens the human lifespan through respiratory and coronary diseases[5]. Moreover, gaseous ammonia and ammonium compounds formed from it in the atmosphere are deposited into ecosystems, damaging sensitive habitats — especially those naturally adapted to need clean air. Ammonia emissions from agricultural sources also reduce the efficiency with which nitrogen is used though the food-production chain, which has knock-on consequences that increase greenhouse-gas emissions and contribute to water pollution[6].

Van Damme *et al.* carried out a high-spatial-resolution analysis based on nine years of data derived from the Infrared Atmospheric Sounding Interferometer (IASI) — an instrument that takes twice-daily measurements of atmospheric ammonia levels — on the Metop-A meteorological satellite. This allowed the researchers to estimate ammonia emissions from 248 hotspots (defined by the authors as areas with diameters of less than 50 kilometres) and a further 178 regional sources (which have no clearly defined hotspot).

This is not the first report of ammonia distribution mapped from satellite observations. Earlier publications used IASI data[7] or measurements from other infrared-observing platforms[8,9] to produce global maps and characterize source regions. What sets Van Damme and colleagues' analysis apart is the comprehensiveness and diversity of quantified ammonia sources. The study shows how satellite technology is coming of age as it starts to fulfil multiple scientific and policy-assessment objectives.

For example, the authors used a method called oversampling to produce a much more precise global map than was previously available. The IASI instrument scans the entire globe daily, and records observations at each observation point at 09:30 and 21:30 hours (local time), but always at slightly different positions. By averaging the nine-year record, the researchers were able to derive fine-scale maps with a resolution of $0.01° \times 0.01°$, from which they identified hundreds of ammonia sources. They also used a simple 'inversion' method to estimate the emissions produced from all of the sources. The authors complemented these approaches by using aerial photographs and other independently obtained data to help them characterize the nature of the hotspots.

Most of the hotspots were found to be associated with intensive livestock farming and industrial activities. Van Damme *et al.* also discovered a previously unknown natural source — Lake Natron in Tanzania, where drying mudflats are found to release substantial amounts of ammonia to the atmosphere.

One of the authors' key findings is that many of the industrial sources are missing from 'bottom-up' inventories of ammonia emissions (which combine data on the intensity of ammonia-emitting activities with estimated quantities called emission factors). This shows that satellite technology can now be used as an auditing tool for the national reporting of ammonia emissions. Some countries might not report emissions from specific sources because, for example, national regulations do not require polluting activities to be registered. The use of standard emission factors in bottom-up inventories might also lead to errors in national reporting, emphasizing the need for independent verification methods.

As with any emerging technology, some limitations of satellite monitoring remain to be overcome. The largest of these are the requirement for the atmosphere to be cloud-free when measurements are made, and the need for a sizeable temperature difference between land or sea surface and the atmosphere — which limits the zones at which measurements can usefully

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Figure 1 | Burning coalfields at Jharia, India.

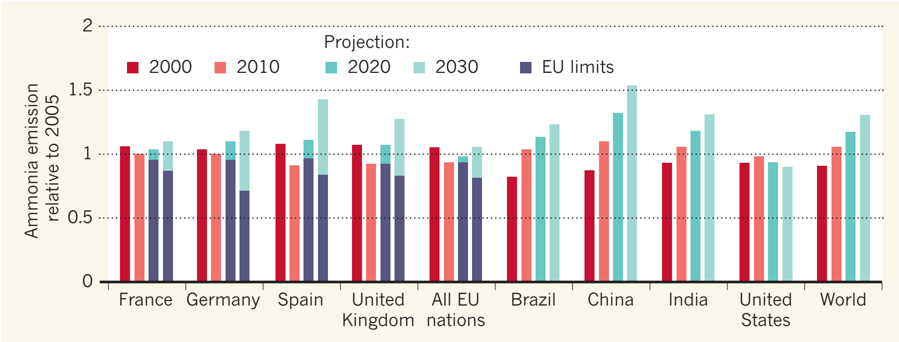

Figure 2 | Past and projected ammonia emissions. Ammonia emissions from many countries are on course to increase in the next couple of decades — including in the European Union, where several countries are set to exceed legally binding limits for 2020 and 2030. Data are shown relative to ammonia emissions in 2005 for each country. Graphs for the European countries are plotted from official EU data (see go.nature.com/2awg8sc), whereas non-EU data are from the EDGAR 4.3 inventory[11]. Projected future values are extrapolated from the most recent five years of available data. Both data sources are 'bottom-up' inventories, which combine data on the intensity of ammonia-emitting activities with estimated quantities called emission factors. Van Damme *et al.*[2] show that satellites now have the capability to help assess compliance with legally binding limits.

be made to warm-temperate and tropical climates. There is also huge potential to improve on Van Damme and colleagues' inversion technique, which assumes that the atmospheric lifetime of ammonia is constant everywhere. This simplification will underestimate ammonia emissions at sources in windy locations, such as on coasts or in mountain areas. Together, these limitations might explain why the authors do not detect high ammonia levels at any seabird colonies, which are known to be substantial ammonia hotspots, especially in sub-polar regions[10]. Curiously enough, the authors identify several fire-based sources (including the second-largest global ammonia hotspot, found in West Africa), but exclude many of these from their detailed analysis.

Perhaps the most important feature of the new analysis, however, is that it has demonstrated ammonia trends at specific locations. For example, the authors detected changes of 15–20% in ammonia levels at hotspots over the period of the study (see Fig. 4 of the paper[2]). The achievment of this accuracy for hotspots implies that even better precision could probably be achieved for observations at national and regional scales.

Achieving this capability now is especially timely. Ammonia emissions in many countries are currently increasing (Fig. 2), even in the European Union, which has committed to achieving an overall reduction of 6% by 2020 and 19% by 2030, compared with 2005 levels (see Annex II at go.nature.com/2e2gphe). Combined with atmospheric models (which are necessary for considering the effects of ammonia's interactions with acidic gases and particulate matter), satellite technology offers a valuable independent tool with which to check whether countries are really achieving their goals. ■

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DEVELOPMENTAL BIOLOGY

Location matters for insulin-producing cells

Intrinsic and extrinsic cues drive dynamic processes that control cell fate during organ development. A study of mouse and human cells reveals how these inputs affect cells that make the essential hormone insulin. **See Letter p.114**

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During development, cells proliferate and differentiate to enable organs to achieve their final functional architecture[1]. As cells develop to reach their mature state, they respond to various extrinsic cues provided by the surrounding microenvironment and acquire a fate that can be determined by their location in a tissue. But little is known about how these cues drive intracellular changes, such as transcription or differentiation, or how tissue architecture and cellular rearrangements can, in turn, affect cell fate. On page 114, Mamidi *et al.*[2] provide insight into how cell location and exposure to certain external cues can affect whether cells in the developing pancreas give rise to β-cells that make the protein insulin. Deficiencies in insulin-producing cells can lead to diabetes, so a better understanding of how these cells form could have clinical implications.

As well as the hormone insulin, which has an essential role in the regulation of blood-glucose levels[3], the pancreas produces digestive enzymes. The organ develops by a complex stepwise process that gives rise to many cell types[3,4]. Embryonic pancreatic cells, also termed progenitor cells, initially express the transcription factor PDX1 and can generate all of the cell types found in the pancreas[3,5]. When the pancreas begins to form, these progenitor cells are segregated into domains that give rise to specific cell lineages[5].

One domain forms the cells that make digestive enzymes, and the other domain, termed the trunk domain, develops from cells called bipotent pancreatic progenitors (bi-PPs) that can give rise to two cell types (Fig. 1), pancreatic duct cells and hormone-producing cells[4,5]. A hallmark of the bi-PP cells that will differentiate into hormone-producing cells[3,4], such as β-cells, is the expression of the transcription factor NGN3.

Mamidi and colleagues investigated what determines the type of cell that develops from a bi-PP cell. They used experimental systems that included *in vivo* mouse models and *in vitro* studies of organ cultures and human embryonic stem cells that had differentiated to form pancreatic cells.

In some of the *in vitro* studies, the authors used micropatterned glass slides to restrict the location and shape of the regions to which stem cells could attach and, hence, grow on. This revealed that cells confined to a limited space were more likely to differentiate into hormone-producing cells, and that cells that could spread out over a large area were less likely to form this type of cell.