# Lecture 4: Local Particles in Air We Breathe
**Americans now live indoors 90% of the time**

**Review:**
- -Atmosphere is both habitat + conveyance
- -Atmospheric layering changes with seasons, weather, time of day
- -Major particle emitters: cities, forests, deserts & oceans
- -Transport: wind + cloud formation + thunderstorms + rain
- -Tower story: relevance for high-rise dwellings?

**Metrics: Microbial diversity, Counts, Particulate matter (PM), AQI**
**Particle emissions, transport & deposition**
**2-Global  example: dust particle from Chad to Miami**
**3-Regional example: wildfires, hurricanes, microplastics**
**4-Local example: air travel, EPA Clean Air Act**
**5-Indoor example: dust mites + how we co-exist with multitudes**

# Lecture 4: Local Particles

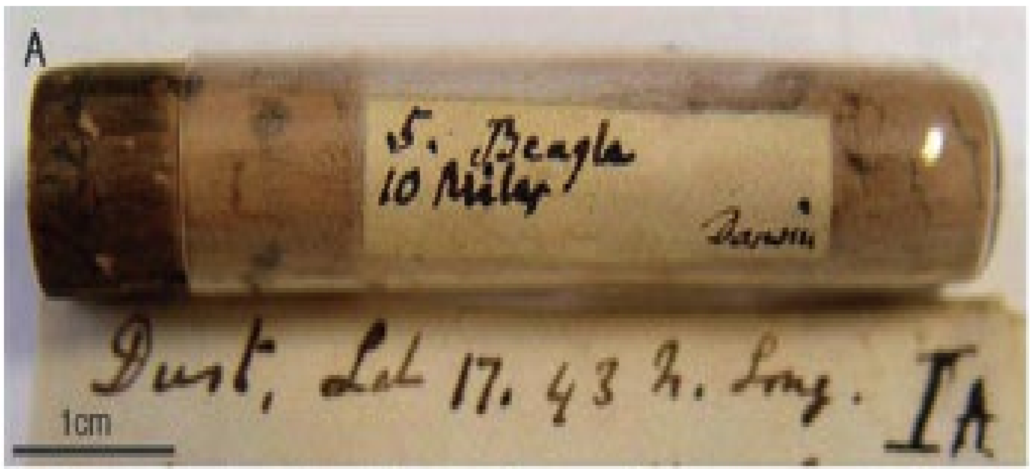
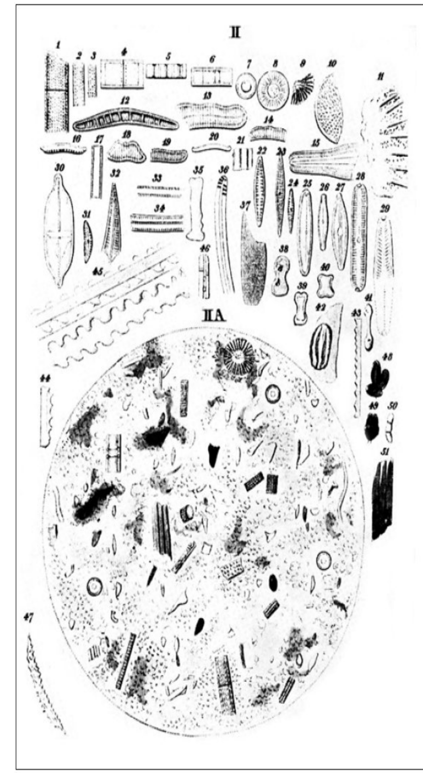
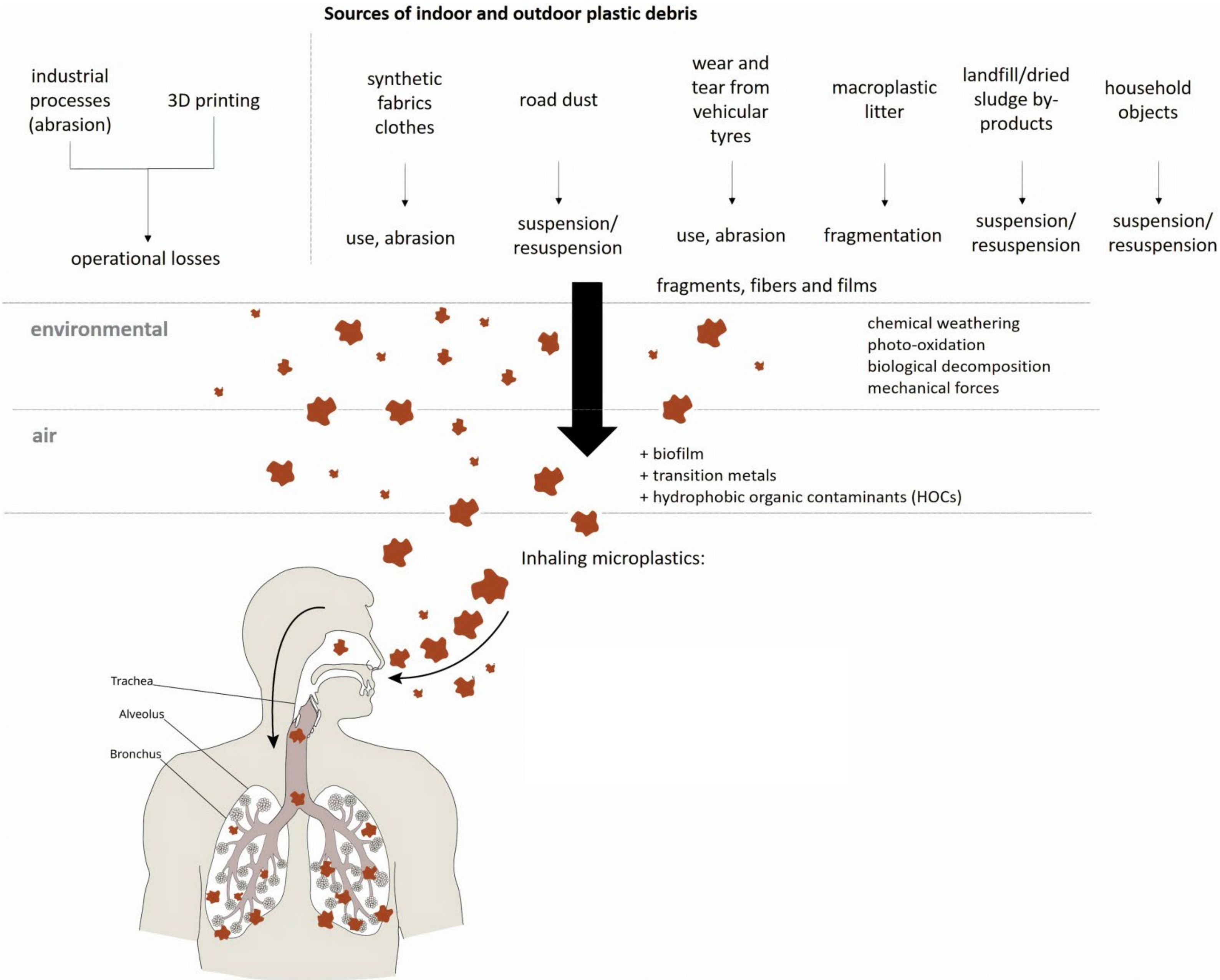



*Figure 1.2*
Ehrenberg's illustration of dust collected by Charles Darwin on the Beagle near the Cape Verde Islands, January 1833 (Gregory, 1973).




**Darwin's Dust Sample for Professor Christian Ehrenberg Museum für Naturkunde (Prussia) Berlin DE**

## Lecture 4: Local Particle *The Lorax* by Dr. Seuss (1971)




Amato-Lourenco L.F. et al. 2020. Science of the Total Environment 749: 141676

# Lecture 3. Aviation cabin micro-organism loading

# LECTURE 3: REGIONAL PARTICLES & AVIATION CABIN STUDY

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1-N | Los Angeles, USA | New York-JFK, USA | 14/11/2005 | 757 | 5 h; 23 min | 3960 | 7 |
| 1R-N | New York-JFK, USA | Los Angeles, USA | 17/11/2005 | 757 | 5 h; 55 min | 3960 | 7 |
| 2-N | Los Angeles, USA | New York-JFK, USA | 5/12/2005 | 757 | 5 h; 23 min | 3960 | 5 |
| 2R-N | New York-JFK, USA | Los Angeles, USA | 8/12/2005 | 757 | 5 h; 55 min | 3960 | 7 |
| 3-L | Los Angeles, USA | London-Heathrow, UK | 15/1/2006 | 777 | 13 h; 10 min | 8730 | 10 |
| 3R-L | London-Heathrow, UK | Los Angeles, USA | 20/1/2006 | 777 | 11 h; 16 min | 8730 | 8 |
| 4-S | Los Angeles, USA | Sydney, Australia | 12/2/2006 | 747 | 14 h; 31 min | 11 973 | 18 |
| 4R-S | Sydney, Australia | Los Angeles, USA | 17/2/2006 | 747 | 13 h; 29 min | 11 973 | 10 |
| 5-N | Los Angeles, USA | New York-JFK, USA | 7/3/2006 | 757 | 5 h; 23 min | 3960 | 4 |
| 5R-N | New York-JFK, USA | Los Angeles, USA | 10/3/2006 | 757 | 5 h; 55 min | 3960 | 5 |
| 6-J | Los Angeles, USA | Narita-Tokyo, Japan | 3/4/2006 | 747 | 11 h; 18 min | 8722 | 8 |
| 6R-J | Narita-Tokyo, Japan | Los Angeles, USA | 7/4/2006 | 747 | 9 h; 57 min | 8722 | 7 |
| 7-N | Los Angeles, USA | New York-JFK, USA | 24/4/2006 | 757 | 5 h; 23 min | 3960 | 6 |
| 7R-N | New York-JFK, USA | Los Angeles, USA | 27/4/2006 | 757 | 5 h; 55 min | 3960 | 6 |
| 8-S | Los Angeles, USA | Sydney, Australia | 7/5/2006 | 747 | 14 h; 31 min | 11 973 | 10 |
| 8R-S | Sydney, Australia | Los Angeles, USA | 7/5/2006 | 747 | 13 h; 29 min | 11 973 | 10 |

**Null Hypothesis: Flight duration has no effect on bacterial diversity**

**Domestic Flights = International Flights**

Osman et al. 2008
(optional reading)
NASA JPL study

**New method**

**DNA sequencing ID rRNA genes**
**Bacterial diversity *higher***

**Domestic Flights (n=8)**

**International Flights (n=8)**

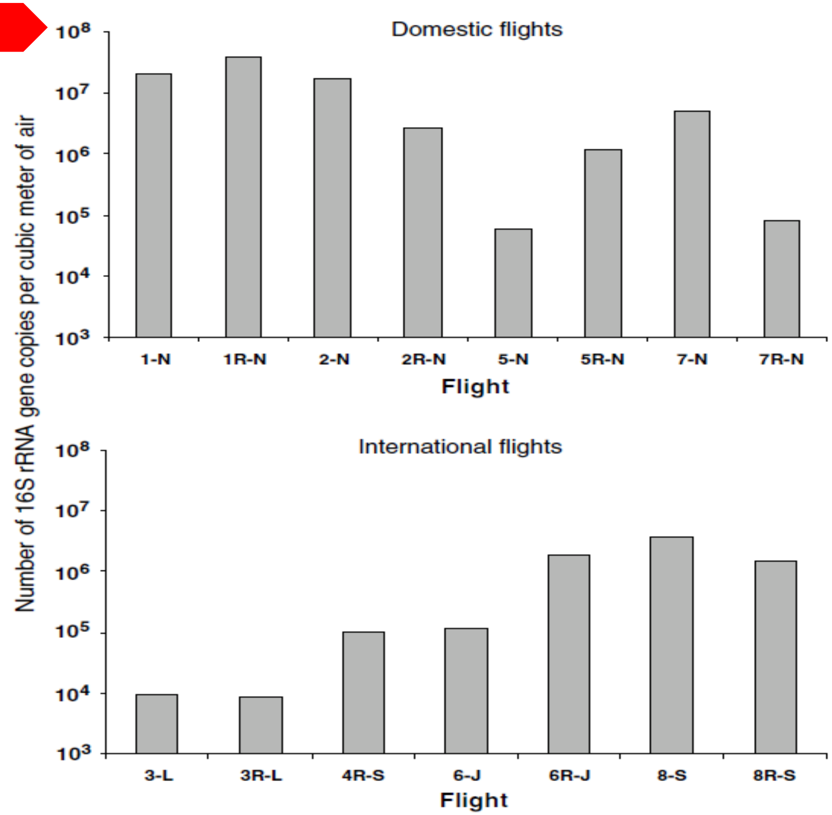



**Figure 2** Total bacterial population as measured by 16S rRNA gene copy numbers of several domestic and international flight cabin air.

Osman et al. 2008

**Accept the Null Hypothesis or not?**

**Flight duration has no effect on bacterial diversity so Domestic Flights = International Flights**

# Accept the Null Hypothesis or not?



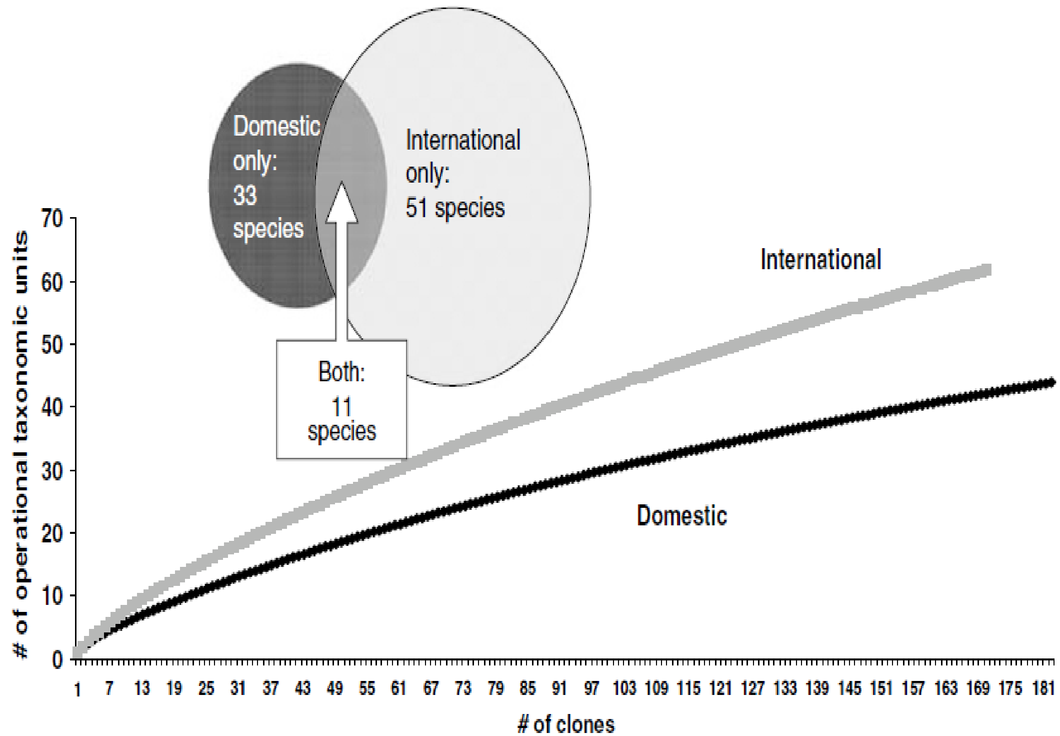



**Figure 5** Rarefaction curves constructed for bacterial clone libraries from several international and domestic flight cabin air. Clones were grouped into OTUs at a level of sequence similarity of >97.5%. The overlapping OTUs between domestic and international flights are given in the inset.

**Lecture 4: Local**

**Question: How can we protect ourselves aside from masks?**

**Question: Story of DC EPA data after 2016?**

**Question: Plastics and Cairo Egypt’s Garbage City slides**

**Question: AQI correlated w life expectancy?**
**Parabolic relationship?**

**Question: Compare cities for Air Now readings?**

# Lecture 4: Local Particles in Air We Breathe
# Cairo Egypt's Garbage City slides

**Lecture 4: L**
**Cairo Egypt**

# Lecture 4: Local Particles in Air We Breathe
# Cairo Egypt’s Garbage City slides

# Lecture 4: Local Particles in Air We Breathe
# Cairo Egypt’s Garbage City slides

# Lecture 4: Local Particles in Air We Breathe
# Cairo Egypt’s Garbage City slides

## Lecture 4: Local Particles in Air We Breathe

**Question: AQI correlated w life expectancy?**
**Higher the AQI, the lower life expectancy drops**

# TABLE XVIII

MEANS OF MONTHLY MEAN NUMBERS OF BACTERIA AND MOULDS PER CUBIC METRE OF OUTDOOR AIR IN PARIS (Miquel, 1899), IN CULTURE IN NEUTRAL BEEF BROTH

| Month | Parc Montsouris (16- and 9-year means, respectively) | | Near Hôtel de Ville, place Saint-Gervais (1888–1897) | | Passage Saint-Pierre 1897–1898 (Mean) | | Main sewer Blvd. Sebastopol (1891–1897) | |
|---|---|---|---|---|---|---|---|---|
| | Bacteria | Moulds | Bacteria | Moulds | Bacteria | Moulds | Bacteria | Moulds |
| January | 198 | 160 | 3,840 | 1,555 | 6,610 | 1,665 | 2,670 | 4,535 |
| February | 148 | 110 | 3,475 | 1,375 | 3,265 | 1,790 | 3,095 | 1,965 |
| March | 209 | 155 | 4,995 | 1,290 | 2,790 | 1,630 | 2,555 | 2,485 |
| April | 362 | 140 | 8,260 | 2,445 | 11,710 | 1,885 | 3,875 | 6,290 |
| May | 295 | 230 | 8,725 | 1,560 | 4,910 | 1,650 | 3,845 | 1,865 |
| June | 355 | 222 | 10,830 | 1,835 | 5,015 | 2,630 | 2,705 | 2,360 |

Source: Gregory 1961

## Lecture 4: Local Particles
## Breathing in an unseen wilderness

**"EPA AQI has five major air pollutants regulated by the Clean Air Act. Each of these pollutants has a national air quality standard to protect public health: ground-level ozone, particle pollution (also known as particulate matter, including PM2.5 and PM10, carbon monoxide, sulfur dioxide (SOX), nitrogen dioxide (NOX)"**

**Q: Where are atmospheric biota?Neo-allergens? Wildfire smoke? Volcanic ash? Radioactive particles? Sea salt?**

**A: They are classified as PM 2.5 "a sized-defined box"**

**https://www.airnow.gov/aqi/aqi-basics/**

# EPA Air Now AQI Score > 100 shows air particle problem https://www.airnow.gov/aqi/aqi-basics/

AirNow | AirNow | AQI & Health | Fires | Maps & Data | Education | International | Resources | Recursos en español

Washington, DC | ZIP Code, City, or State | AQI | 39 °F

AQI Basics for Ozone and Particle Pollution

| Daily AQI Color | Levels of Concern | Values of Index | Description of Air Quality |
|---|---|---|---|
| Green | Good | 0 to 50 | Air quality is satisfactory, and air pollution poses little or no risk. |
| Yellow | Moderate | 51 to 100 | Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution. |
| Orange | Unhealthy for Sensitive Groups | 101 to 150 | Members of sensitive groups may experience health effects. The general public is less likely to be affected. |
| Red | Unhealthy | 151 to 200 | Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects. |
| Purple | Very Unhealthy | 201 to 300 | Health alert: The risk of health effects is increased for everyone. |
| Maroon | Hazardous | 301 and higher | Health warning of emergency conditions: everyone is more likely to be affected. |

See the Activity Guides to learn ways to protect your health when the AQI reaches unhealthy levels.

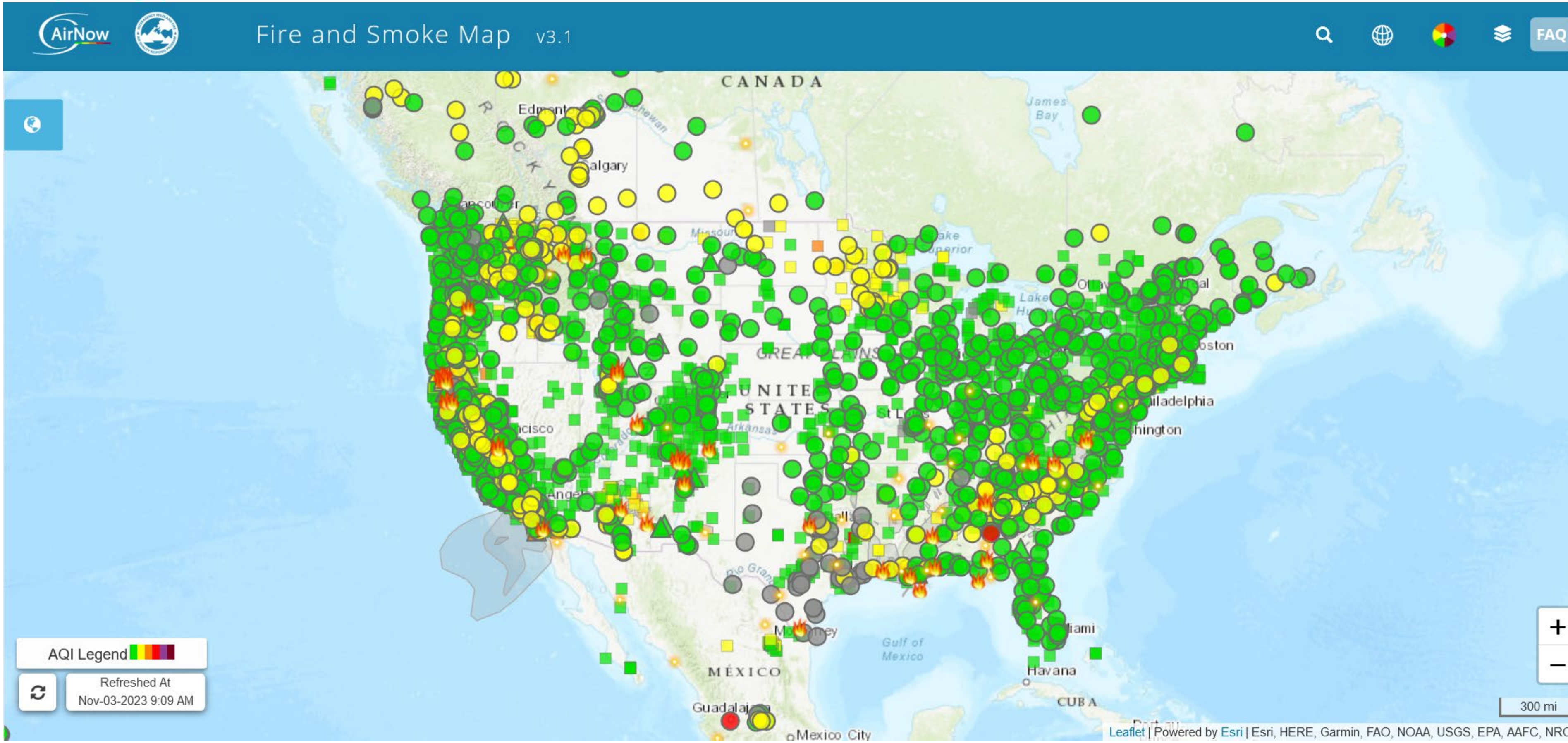
**Lecture 4. Local Particles. Airborne particulate matter (≥ 2.5 micron particles or $PM_{2.5}$) emitted by some Asian cities on December 4 2020. Air Quality Index (AQI) during global coronavirus pandemic. From Air Now program monitored by U.S. Environmental Protection Agency. URL [https://www.airnow.gov/](https://www.airnow.gov/), accessed 12/4/20 + 11/03/23. From Williams & Samara (2023)**

| City & Nation | AQI $PM_{2.5}$ 12/04/2020 | AQI $PM_{2.5}$ 12/04/2023 | Population Size (millions) |
|---|---|---|---|
| Jeddah KSA | 57 | 50 | 3.5 at 1500h |
| Abu Dhabi UAE | 71 | 98 | 1.4 at 1600h |
| Dubai UAE | 101 | 117 | 3.3 at 1600h |
| Khartoum Sudan | 53 | No data | 5.3 |
| New Delhi India | 230 | 209 | 21.7 at 1800h |
| Lahore Pakistan | 278 | 205 | 11.1 at 1700h |

Table 1B. Airborne particulate matter (≥ 2.5 micron particles or $PM_{2.5}$) emitted in Washington DC on November 3 2023

| City & Nation | AQI $PM_{2.5}$ | Time |
|---|---|---|
| Washington DC | 29 | 0900h |

# EPA's Air Now has a Fire and Smoke Map. Accessed November 3 2023 at 0911h.




https://fire.airnow.gov/

**EPA Nonattainment Areas for Critical Pollutants   October 31 2023  Wash DC in compliance**

https://www.epa.gov/green-book   Federal Register  CA, PA,

Counties Designated Nonattainment
for PM-2.5 (1997, 2006, and/or 2012 Standards)

AMERICAN SOCIETY FOR MICROBIOLOGY | Applied and Environmental Microbiology

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# Environmental Stability of Swine and Human Pandemic Influenza Viruses in Water under Variable Conditions of Temperature, Salinity, and pH

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**ABSTRACT**

**The movement of influenza A viruses (IAVs) from wild bird reservoirs to domestic animals and humans is well established, but the transmission mechanisms that facilitate efficient movement across and within these host populations are not fully defined. Although predominant routes of transmission vary between host populations, the extent of environmental stability needed for efficient IAV transmission also may vary. Because of this, we hypothesized that virus stability would differ in response to varied host-related transmission mechanisms; if correct, such phenotypic variation might represent a potential marker for the emergence of novel animal or human influenza viruses. Here, the objective was to evaluate the ability of eight swine and six human IAV isolates to remain infective under various pH, temperature, and salinity conditions using a preestablished distilled water system. Swine and human viruses persisted longest at near-neutral pH, at cold temperatures, or under "freshwater" conditions. Additionally, no significant differences in persistence were observed between pandemic and nonpandemic IAVs. Our results indicate that there have been no apparent changes in the environmental stability of the viruses related to host adaptation.**

**IMPORTANCE**

**This study assessed the environmental stability of eight swine and six human influenza A viruses (IAVs), including viruses associated with the 2009 H1N1 pandemic, in a distilled water system. The important findings of this work are that IAV persistence can be affected by environmental variables and that no marked changes were noted between human and swine IAVs or between pandemic and nonpandemic IAVs.**

Influenza A viruses (IAVs) have been isolated from numerous avian and mammalian hosts, and cross-species transmission commonly occurs between wild bird reservoirs, domestic animals, and humans (1). Swine are susceptible to infection by IAVs of both avian and mammalian origin (2) and are recognized as an intermediate host for the evolution and adaptation of IAVs with pandemic potential (1, 2). From 1930 to 1990, classic H1N1 swine influenza virus (SIV) underwent little genetic change, but by the late 1990s, the "triple-reassortant" SIV viruses H1N1, H3N2, and H1N2 had become predominant in swine in North America (3, 4).

The pandemic H1N1 influenza A virus (pH1N1) was first detected in April 2009 in two human cases in California (2009), and it quickly spread across the world. The emergence of this virus was subsequently traced to the reassortment of recent North American avian/human/swine triple-reassortant viruses with Eurasian swine viruses (5). This virus has since infected swine and continues to reassort with other SIVs (6, 7); pH1N1 is now a part of the endemic human influenza pool (8).

The potential for viruses such as pH1N1 to emerge as a result of reassortment between human, swine, and avian viruses involves unlikely transmission events. Transmission mechanisms for IAVs not only are poorly understood in all of these host systems but also vary between them. With birds, transmission of IAVs occurs primarily via a fecal-oral route (1, 9), in which water plays a large role. While the primary mode(s) of transmission of influenza between humans is believed to be an aerosol, droplet, or direct contact route (3, 10), indirect transmission through contaminated surfaces may also contribute to transmission. Likewise, swine influenza viruses are transmitted primarily via direct contact or through aerosols or droplets (11), but indirect contact through fomites or shared environments cannot be discounted.

In this study, the infectivities of eight swine and six human (historical, seasonal, and pandemic) influenza viruses were evaluated under variable pH, temperature, and salinity conditions using a distilled water laboratory model system (12). Although modes of transmission for swine and human viruses may not directly involve contact with contaminated water, avian-origin IAVs have been well characterized in this medium (12–18) and, as such, provide a baseline for comparison. Furthermore, the potential implications of fomites in the transmission of IAVs in mammalian systems and swine husbandry practices that utilize common drinking troughs make this laboratory investigation applicable. The mechanisms that facilitate or allow for efficient movement across different host populations are varied, but they all require

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**Editor:** D. W. Schaffner, Rutgers, The State University of New Jersey

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Supplemental material for this article may be found at http://dx.doi.org/10.1128/AEM.00133-16.

**TABLE 1** Description of influenza viruses used in this study

| Origin | Strain | Status[a] | Passage[b] | Subtype | Titer ($TCID_{50}$/ml) |
|---|---|---|---|---|---|
| Avian | A/Green-winged teal/Louisiana/213/1987 | Control | SPFE1/C1 | H1N1 | 6.9 |
| Swine | A/Swine/Minnesota/02719/2009 | Non-PDM | C1/E1/C1 | H3N2 | 7.6 |
| Swine | A/Swine/North Carolina/02744/2009 | Non-PDM | C1/E1/C1 | H1N2 | 7.3 |
| Swine | A/Swine/Minnesota/02746/2009 | pH1N1 | C1/E1/C1 | H1N1 | 8.3 |
| Swine | A/Swine/Minnesota/02749/2009 | pH1N1 | C1/E1/C1 | H1N1 | 8.1 |
| Swine | A/Swine/Minnesota/02751/2009 | pH1N1 | C1/E1/C1 | H1N1 | 7.7 |
| Swine | A/Swine/Illinois/02860/2009 | pH1N1 | C1/E1/C1 | H1N1 | 7.4 |
| Swine | A/Swine/Utah/02861/2009 | Non-PDM | C1/E1/C1 | H1N2 | 7.5 |
| Swine | A/Swine/Iowa/15/1930 | Non-PDM | ?/E1/C1 | H1N1 | 6.5 |
| Human | A/New Jersey/08/1976 | Non-PDM | SPFE7/E1/C1 | H1N1 | 7.7 |
| Human | A/Texas/15/2009 | pH1N1 | C2/E1/C1 | H1N1 | 7.4 |
| Human | A/Mexico/INDRE4487/2009 | pH1N1 | E2/E1/E1/C1 | H1N1 | 7.1 |
| Human | A/Brisbane/10/2007 | Non-PDM | E2/E2/E1/C1 | H3N2 | 7.9 |
| Human | A/Brisbane/59/2007 | Non-PDM | E2/E2/E1/C1 | H1N1 | 6.5 |
| Human | A/California/04/2009 | pH1N1 | C1/C1/C1 | H1N1 | 6.7 |

[a] pH1N1, 2009 pandemic H1N1 viruses; Non-PDM, nonpandemic viruses.

[b] Sequential passage history. C, Madin-Darby canine kidney cells; E, embryonated chicken eggs; SPFE, specific-pathogen-free embryonated chicken eggs; ?, unknown primary isolation source. Numbers indicate the number of passages within each source/passage in a new source.

some degree of environmental stability. Because of this, we hypothesized that virus stability (i.e., environmental fitness) would differ in response to varied host-related transmission mechanisms. If correct, such phenotypic variation could represent a potential marker for the emergence of novel animal or human influenza viruses.

## MATERIALS AND METHODS

**Viruses.** One avian-origin H1N1, eight swine, and six human influenza viruses were assessed using a previously described distilled water system (12, 18); the viruses used in this study are listed in Table 1. Viruses were propagated in Madin-Darby canine kidney (MDCK) cells (ATCC CRL-2936) following the method of Szretter et al. (19) with modifications. Briefly, a 1:1,000 dilution of virus in minimal essential medium (MEM) supplemented with antibiotics and 1 mg/ml trypsin {treated with TPCK [L-(tosylamido-2-phenyl) ethyl chloromethyl ketone], Worthington Biochemical Corporation, Lakewood, NJ} was added to 75-$cm^2$ flasks of confluent and washed MDCK cells. Cells were incubated at 35°C or 37°C, and supernatants were harvested at 75% to 90% monolayer destruction. Stock viruses were stored at −70°C; stock virus titers ranged from $10^{6.5}$ to $10^{8.1}$ 50% tissue culture infectious dose ($TCID_{50}$)/ml, as determined by titration in MDCK cells.

**Virus persistence trials.** Prior to all treatment adjustments, distilled water was buffered with 10 mM HEPES (Sigma, St. Louis, MO). Temperatures evaluated included 4°C, 10°C, 17°C, 23°C, 28°C, 32°C (human) or 35°C (swine) and 37°C. A temperature of −70°C was included as a control. Water used in temperature trials had a pH of 7.2 and a salinity of 0 ppt.

For pH trials, water pH was adjusted from 5.4 to 9.0 at 0.4-unit increments with the addition of 1 N HCl or NaOH. A pH of 7.2 was also included in the analysis. All pH trials were completed at 17°C and a salinity of 0 ppt. Each pH treatment was measured at the start of the study and confirmed at the completion of each trial. In all cases, it did not vary more than 0.1 unit from the starting pH.

Salinity trials were completed in water at 17°C and pH 7.2. Salinity was adjusted with commercially available sea salt (Morton, Chicago, IL) to 0, 5, 10, 15, 20, 25, and 30 ppt.

For each trial, virus stock was diluted 1:25 to 1:100 in the respective water treatments to achieve a starting titer of approximately $10^{5.0}$ to $10^{6.0}$ $TCID_{50}$/ml. Virus-inoculated water was aliquoted as single-use 1-ml volumes into 5-ml polystyrene tubes which were allowed to incubate in environmental chambers or water baths at defined temperatures; tubes were removed from the respective temperatures at the predetermined sampling time points and disposed of following titration. For each trial, virus-inoculated water was titrated at the time of inoculation (0 days postinoculation [dpi]) and at variable time points (from 1 to 14 days); these varied by treatment and were based on data from previous infectivity assays (12, 13, 17, 18). Sampling frequencies ranged from daily (under conditions that have been shown to quickly inactivate viruses) to monthly (under conditions in which viruses have been shown to be long-lived). The numbers of time points recorded are indicated in Tables S1 to S3 in the supplemental material. Virus titrations with MDCK cells were performed as previously described (12). Endpoints were measured via hemagglutination assay using 0.5% chicken red blood cells as described previously (20).

**Statistical analysis.** Titers were calculated by using the method of Reed and Muench (21) and reported as $TCID_{50}$/ml. Linear regression was used to determine a 90% reduction time (Rt) for each virus-treatment combination; Rt values correspond to the time required for a decrease in viral titer by 1 $log_{10}$ $TCID_{50}$/ml. Regression equations are shown in Tables S1 to S3 in the supplemental material. The minimum detectable limit for this procedure is $10^{1.8}$ $TCID_{50}$/ml.

Because Rt values were not normally distributed and their variances differed across environmental conditions, separate nonparametric comparisons of viruses originating from swine and humans and of pandemic and nonpandemic viruses were performed for each condition using the Wilcoxon rank sum test. All tests assumed a two-sided alternative hypothesis, and a $P$ value of $<0.05$ was considered statistically significant. Analyses were performed using commercially available software (JMP, version Pro 12, 1989-2007; SAS Institute, Cary, NC).

## RESULTS

**Temperature.** The MDCK-adapted swine and human viruses persisted longest at cold temperatures and were inactivated at temperatures greater than 17°C (Fig. 1); this pattern of responses is similar to that seen with the single avian control isolate (data shown in Table S1 in the supplemental material). Treatments of 32°C and 35°C were excluded from the statistical comparisons, because none of the swine isolates were evaluated at 32°C, and only one of the human isolates was evaluated at 35°C. No reduction in persistence over the course of the trial (up to 300 days) was observed for viruses held at −70°C (data not shown). The variations in response within swine viruses and within human viruses were greatest at low temperatures. At 4°C, Rt values ranged from

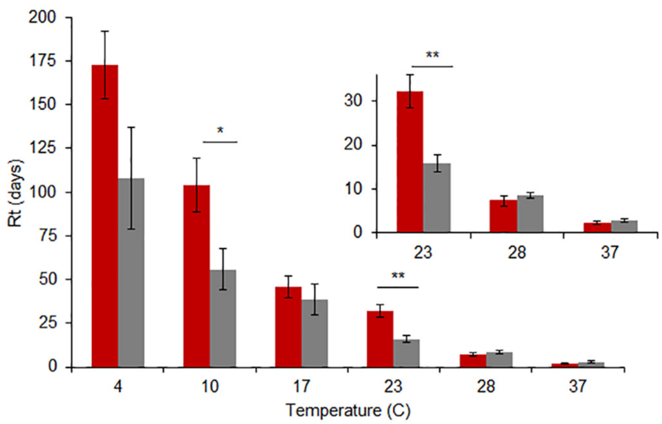


FIG 1 Mean Rt values (± standard error [SE]) for eight swine (red) and six human (gray) viruses in distilled water at temperatures ranging from 4°C to 37°C. The pH was held constant at 7.2, and salinity was 0 ppm. Significant differences in the responses for swine and human viruses exist at temperatures of 10°C (*, $P < 0.05$) and 23°C (**, $P < 0.01$). No other statistically significant differences were observed at an α value of 0.05.

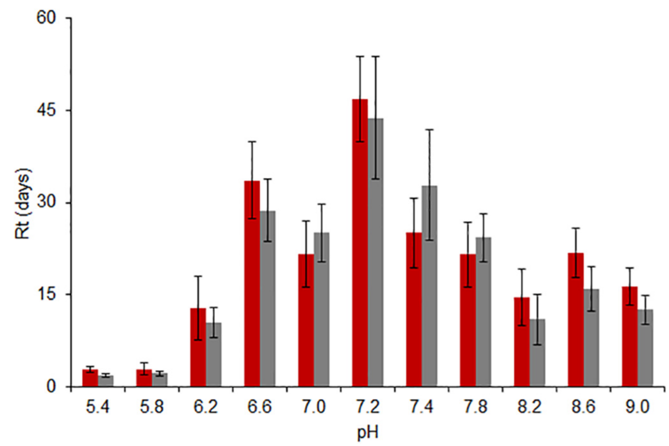


FIG 3 Mean (±SE) Rt values for eight swine (red) and six human (gray) viruses in distilled water at pHs ranging from 5.4 to 9. The temperature was held constant at 17°C, and salinity was 0 ppm. No statistically significant differences were observed in the responses for swine and human viruses at any pH at an α value of 0.05.

55 to 250 days for swine viruses and from 30 to 160 days for human viruses; at 37°C, Rt values ranged from 0.5 to 3.4 days for swine viruses and 0.9 to 4 days for human viruses. Swine viruses persisted longer than human viruses at 10°C and 23°C ($P = 0.045$ and 0.010, respectively). There were no significant differences in environmental persistence between pandemic and nonpandemic viruses (Fig. 2).

**pH.** All swine viruses included in this study were most stable at near-neutral pH and were quickly inactivated at the extremes of the ranges tested; viruses of human origin showed a similar response (Fig. 3). There was rapid inactivation at pHs less than 6.2 and greater than 8.2 for all swine and human viruses, and the majority of viruses in all the groups were most stable at pH 7.2. There were no significant differences in the responses of swine and human viruses at any pH. Seasonal and pandemic human viruses also did not differ significantly in their responses at any pH (Fig. 4). Rt values for all of the individual viruses and pH levels are provided in Table S2 in the supplemental material.

**Salinity.** Increased salinity had a detrimental effect on virus stability. The Rt values of all viruses assessed, regardless of host origin, were greatest in freshwater at a salinity of 0 ppt. Persistence of viruses from either host group (swine or human) showed similar declines with increasing salinity, with a marked decrease in stability as salinity was raised from 0 to 5 ppt (Fig. 5); the response was similar for the single avian control isolate (see Table S3 in the supplemental material). Swine viruses persisted longer than human viruses at 20 ppt ($P = 0.010$), but the two groups did not differ significantly at any other saline concentration. As was the case at colder temperatures, viruses within each host group were most variable in their persistence at a salinity of 0 ppt. Excluding A/Swine/Utah/02861/2009 (H1N2), with an Rt value of 6.3 days at a salinity of 0 ppt, the range of Rt values for all other swine viruses, regardless of subtype, was 33 to 72 days. While A/Mexico/INDRE/2009 (H1N1) was the least stable at 0 ppt, with an Rt value of 14 days, all other human viruses, seasonal and pandemic combined,

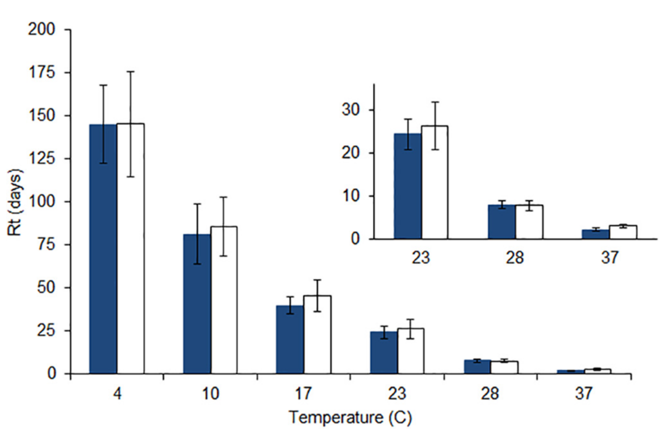


FIG 2 Mean (±SE) Rt values for seven pandemic (blue) and seven nonpandemic (white) viruses in distilled water at temperatures ranging from 4°C to 37°C. The pH was held constant at 7.2, and salinity was 0 ppm. No statistically significant differences were observed in the responses for pandemic and nonpandemic viruses at any temperature at an α value of 0.05.

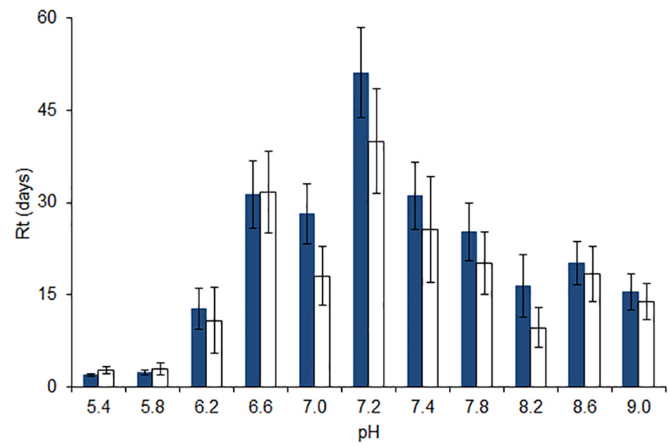


FIG 4 Mean (±SE) Rt values for seven pandemic (blue) and seven nonpandemic (white) viruses in distilled water at pHs ranging from 5.4 to 9. The temperature was held constant at 17°C, and salinity was 0 ppm. No statistically significant differences were observed in the responses for pandemic and nonpandemic viruses at any pH at an α value of 0.05.

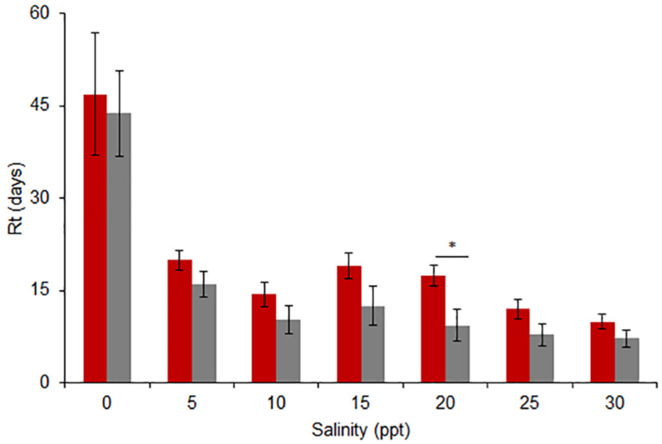


**FIG 5** Mean (±SE) Rt values for eight swine (red) and six human (gray) viruses in distilled water at salinities ranging from 0 to 30 ppt. The temperature was held constant at 17°C, and the pH was 7.2. Significant differences in the responses for swine and human viruses existed at 20 ppt (*, $P < 0.05$). No statistically significant differences were observed in the responses for swine and human viruses at any other saline concentration at an α value of 0.05.

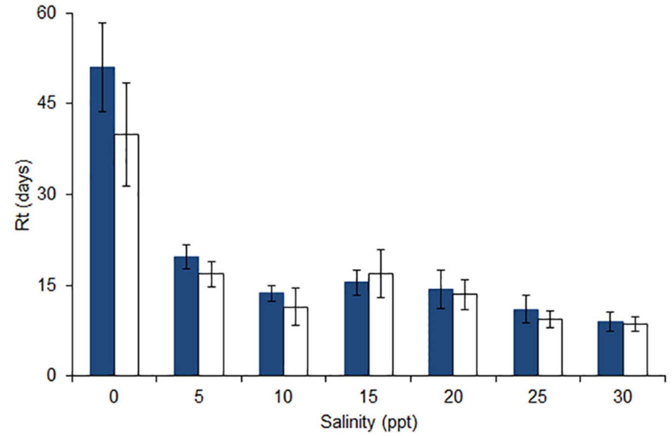


**FIG 6** Mean (±SE) Rt values for seven pandemic (blue) and seven nonpandemic (white) viruses in distilled water at salinities ranging from 0 to 30 ppt. The temperature was held constant at 17°C, and the pH was 7.2. No statistically significant differences were observed in the responses for pandemic and nonpandemic viruses at any salinity at an α value of 0.05.

had Rt values ranging from 21 to 46 days in freshwater. As was the case with temperature and pH, pandemic and nonpandemic viruses responded similarly to salinity, with no significant differences between groups at any saline concentration (Fig. 6). Regression equations for all viruses in the salinity trials are provided in Table S3 in the supplemental material.

## DISCUSSION

Understanding the environmental stability of IAVs has relevance in defining transmission risks both within the avian reservoir and across domestic poultry and mammalian species. Persistence in water may represent a critical factor in virus maintenance and transmission in wild avian populations but also may play a minor role in the transmission of human and swine IAVs, which are transmitted primarily by contact and respiratory droplets. Although transmission mechanisms differ between these host groups, our results indicate no consistent or significant adaptations related to changes in environmental stability as determined by temperature, pH, and salinity. The general trends described for swine and human IAVs are similar to the well-documented responses of avian IAVs.

The interspecies and intraspecies transmission and maintenance of IAVs are dependent on factors at the host, viral, and environmental levels. To be transmitted and maintained, viruses must remain infectious. It has been well established that IAVs persist longest at cold temperatures (12, 13, 17, 22, 23); human and swine viruses analyzed in this study lasted longest at 4°C, and results were consistent with those previously reported for pandemic virus A/Paris/2590/2009 (H1N1), which had a reported Rt value of 178 days at 4°C (22). The swine and human viruses included in this study, however, demonstrated greater persistence at low temperatures than did a suite of viruses of avian origin that were previously analyzed (12). This result may be an artifact of how the human and swine viruses tested in our study were propagated; it has been shown that both human and avian viruses grown on MDCK cells are more stable at higher temperatures than are the same viruses when grown in chicken eggs (24). At higher temperatures, all the viruses assessed, regardless of their subtype and origin, were quickly inactivated, especially at temperatures higher than 28°C; this is similar to the reduction in persistence seen for a 2009 pandemic H1N1 and a 1999 seasonal H1N1 from >150 days at 4°C to just 2 days at 35°C (22). While swine viruses persisted significantly longer than human viruses at 10°C ($P = 0.045$) and 23°C ($P = 0.010$) in this study, such differences were not consistent across the broader range of temperatures evaluated, and given the small sample sizes, the statistical power is low. This study evaluates the thermal stability of swine influenza viruses at a range of temperatures likely encountered in both laboratory and natural settings. Thermal neutrality is important in swine production systems and is dependent largely on age strata and weight (25). Generally, preferred thermal conditions for swine range from 10°C to 32°C (26); under the laboratory conditions of this study, some currently circulating swine influenza viruses can remain infectious for several weeks (35°C) to more than 1 year (10°C) within this temperature range. The temperature stability of these viruses at temperatures consistent with host environments, such as swine production systems, may suggest that environmental adaptation is not necessary for movement of the virus across species barriers, despite the disparate body temperatures seen in avian (42°C), swine (39°C), and human (37°C) hosts.

The role of pH in IAV hemagglutinin (HA) membrane fusion has been well characterized (27–30), and pH might play a role in adaptation of IAV to a new host. From an environmental perspective, the effect of low pH on the integrity of external proteins on the surface of the virus may serve as a preemptive trigger, rendering HAs inactive (31). In the present study, human and swine viruses were most stable within a neutral pH range, as has been found with avian viruses (12). We observed some subtle and nonsignificant differences in persistence across hosts and subtypes, but these differences did not provide clear evidence of pH-related environmental adaptation. Very small differences in the pH of fusion (between 5.0 and 5.7) have been associated with IAV host adaptation and cross-species transmission (32, 33). Changes in environmental stability at pH 7.4 also have been reported with recombinant H5N1 viruses where a 0.5-unit change in the pH of fusion was shown to decrease environmental stability more than 45 days, while a decrease by the same amount increased persistence nearly 20 days compared to that of the wild type (34). While we did not detect any clear evidence of differences in pH tolerance between swine and human IAVs, additional evaluation may be necessary to detect fine-scale differences that may occur early in host adaption, especially those related to virus adaptation from avian to mammalian hosts.

Of the three variables investigated here, salinity is the least understood in its effect or mechanism of action relating to influenza stability in water. As was expected from results of previous studies, virus persistence decreased as the salinity of water increased for all viruses assessed. This loss in infectivity was most marked from 0 to 5 ppt for all viruses except A/Swine/Utah/02861/2009 (H1N2). Increasing osmotic pressure might serve to disrupt the integrity of the virus membrane and/or lead to premature inactivation. The response of individual avian virus stocks to increasing salinity has been shown to take on a number of forms, from negative log-linear to Gaussian (12). While many avian viruses tend to persist longest in moderately saline water, most viruses in our study showed greatest persistence in water with a salinity of 0 ppt. This difference might be due to the host from which the lipid bilayer of the virus was derived, the glycosylation moieties of the surface proteins (also a function of the host cell), or potentially a marker of adaptation. Assessing these markers of adaptation, as well as determining the potential relevance of increased persistence of swine over human viruses at 20 ppt ($P = 0.045$) in this study, would require further investigation with a larger diversity of viruses. Given that IAV transmission in human and swine systems often involves respiratory secretions, salt concentrates in droplets likely play a role in virus viability. Yang et al. (35) proposed three conditions related to relative humidity (RH)—physiological, concentrated, and dry—that play a role in the infectivity of influenza in droplets. Under this schema, virus stability was most jeopardized under conditions of RH between 50% and 99%, at which the evaporation of a given droplet of medium with salts led to an increase in the concentration of solutes; the interaction of mucus and RH yielded a similar effect on virus persistence.

This study provides general response models for the individual effects of temperature, pH, and salinity on the ability of IAVs of different subtypes and from different hosts to remain infective in a distilled water milieu. Altogether, these results shed some light on the dynamics of these avian, swine, human, and pandemic H1N1 viruses under laboratory-simulated "environmental" conditions. Our data indicate that influenza persistence can be modulated by environmental variables and support previous findings for avian influenza viruses (12, 13, 17, 18). Furthermore, and perhaps of greater relevance to the swine and 2009 H1N1 outbreak strains, these data might inform decisions regarding preventive and management practices in both the laboratory and the field.

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We declare no competing interests.

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## SHOWERS OF ORGANIC MATTER.

By WALDO L. MCATEE, Assistant Biologist.

[Address: U. S. Bureau of Biological Survey, Washington, D. C.]

[Paper presented to the Biological Society of Washington, Jan. 27, 1917.]

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### INTRODUCTION.

The idea of organic matter and particularly of living things raining down from the sky, on first thought, is hard to entertain. There have been recorded in all periods of historic time, however, showers of one kind or another of animals and plants or their products—showers of hay, of grain, of manna, of blood, of fishes, of frogs, and even of rats. In ages past, these phenomena, actual or supposed, were all given supernatural significance; the blood rains terrorized the people, the manna rains inspired prayers of thanks—they were miracles. In latter days, the tendency among intellectuals who have given the matter no particular attention, has been to assume that since preternatural explanations had usually been invoked (and they certainly were incredible) therefore the showers themselves probably never occurred.

However, so many wonderful things occur in nature that negation of any observation is dangerous; it is better to preserve a judicial attitude and regard all [authentic] information that comes to hand as so much evidence, some of it supporting one side, some the other, of a given problem.

The evidence that counts the most is that which comes from those we have learned to respect and trust. I may say that two small bits of testimony as to living things falling in rain, given me by my father, and by my friend, Mr. A. N. Caudell, of the United States Bureau of Entomology, did more than all I had ever read to arouse my interest in the phenomena of organic showers. Mr. Caudell relates that at his former home in Oklahoma, on one occasion after a brief shower during an otherwise dry and hot period, numerous earthworms were found on the seat of an open buggy standing in the yard. Mr. Caudell's mother was reminded by this occurrence that years before, in their former home in Indiana, a live minnow was found after a rain in water held by the hollow in the top of a chopping block. The experience of my father that bears on this subject is that when in North Dakota some years ago on coming indoors during a rain he found several earthworms on the brim of his hat. Here are facts vouched for by persons in whom I have every confidence, proving to a certainty that living animals do rain down.

How potent are such small phenomena, once fixed in the mind as well authenticated, to give one faith in the larger ones; but, on the other hand, how important is the conviction that some extensive, some really great happening of the same class really has occurred. When, therefore, I came upon the statement by the famous French scientist, Francis Castlenau, that he had seen fishes rain down in Singapore in such numbers that the natives went about picking them up by the basketful, I was ready to believe almost all the tales, both great and small, relating to showers of organisms.

And why should we not believe them? Surely not from any doubt as to the capacity of the wind to lift up, to transport, and to drop again, at more or less distant places, objects of the character and size usually mentioned as falling in organic showers. All strong winds have some lifting powers; we see papers carried into the air, blown hither and thither, and sometimes carried for long distances. Sheets of paper have been identified as falling at places 20 to 50 miles distant from their starting point. Through experiences, sometimes saddening ones, most of us have learned that the wind can very dexterously lift and transport such objects as hats, and I have known of a silk hat being taken from a dignified gentleman's head as he was walking in front of the Post Office Department in Washington and carried up, up, and away over the Star Newspaper Building (10 stories high). In the same city during the thunder squall of July 31, 1913, tin roofs were torn from many houses and blown into the streets.

These are things which straight blowing winds can do, but when winds begin to whirl, their lifting and carrying capacity increases enormously. The little dust whirls we see seem inoffensive things, but they have surprising power. I saw one travel down a row of shocks in a cornfield, lift every one of them, and scatter the stalks to the four quarters, doing in a minute work it would take a man a day to do or undo. Of course this whirl was larger than those we frequently see on hot summer days, but whirlwinds, waterspouts, dust storms, and tornadoes are essentially the same thing differing principally in dimensions. Wind whirls which may be said to be practically artificial in origin develop surprising power. Thus Theodore Dwight, of Stockbridge, Mass., states [1] that those created by the burning of wood piled in a clearing had sufficient force to lift trees 6 to 8 inches in diameter to a height of 40 to 50 feet.

All wind whirls are characterized by a more or less strong inflow of air along the surface from all directions to the base of the whirl, where the inflowing currents ascend. The gyratory velocity of a tornado may be as much as 310 miles per hour. This would give at the earth's surface an effective force in moving an object of about 300 pounds [2] for each square foot of surface exposed to the wind. The velocity of the ascending currents also runs high, but if put at 176 miles per hour would yield a lifting power of more than 90 pounds to the square foot. That these forces are actually exerted is shown by some of the remarkable doings of tornadoes. By the tornado at Beauregard, Miss., April 22, 1883, the solid iron screw of a cotton press, weighing 675 pounds,

[1] *Tomlinson, Chas.* The tempest, pp. 117–118.
[2] *Ferrel, Wm.* A popular treatise on the winds. New York, 1889. pp. 377–378.

was carried 900 feet. During the tornado of April 16, 1875, at Walterborough, S. C., a piece of timber 6 inches square and 40 feet long, weighing 600 pounds, was carried a distance of 440 yards, and a chicken coop, 4 by 4 feet and 75 pounds in weight, was transported 4 miles. In the tornado at Mount Carmel, Ill., June 4, 1877, a piece of tin roof was carried 15 miles and a church spire 17 miles.

These examples are quite as marvelous as some of the seemingly miraculous showers recorded of old. The children of Israel believed in their manna because they gathered it with their own hands and ate of it, but surely their credulity would not have stood the test had some prophet told them that in years to come, in a land across the sea, chickencoops and church spires would rain down from the skies.

There is then, we must admit, no reason for general suspicion toward the accounts of organic showers. Like other records, they must be inspected and the good sifted from the mass. We may separate at once certain classes of alleged organic showers as spurious.

### SPURIOUS SHOWERS.

*Insect larvæ.*—The rains of insect larvæ that have been investigated have proved to be merely the appearance in large numbers on the surface of the ground or upon snow of the larvæ of soldier beetles (*Telephorus*), or sometimes caterpillars, which have been driven from their hibernating quarters by the saturation of the soil by heavy rains or melting snow.

*Ants.*—Accounts of showers of ants have usually been founded on incursions of large numbers of winged ants, which of course need no assistance from the elements to follow out their habit of swarming forth periodically in immense numbers.

*Honey; sugar.*—Showers of honey and of sugar are popular names for what scientists know are exudations of certain plants, or of plant lice which feed on a great variety of plants and whose product is often known also as honey-dew.

*Grains.*—Showers of grain, usually considered miraculous, have in most cases been determined to be merely the accumulation by washing during heavy rains of either the seeds or root tubercles of plants of the immediate neighborhood.

*Black rain.*—Black rain is due to the precipitation from the atmosphere by falling water of soot, or in some cases of black dust. These showers are of interest, however, as illustrating the carrying power of the wind; a rain of soot observed in Ireland and over the Atlantic Ocean to the westward is pretty definitely known to have been carried by the wind from Wales.[3] The showers of mud resulting from the precipitation of dark-colored dust or dirt are closely related to the organic showers discussed further on, as the material must have been derived from the earth's surface, transported and deposited in the same way, and in fact it is probable that all such rains bring with them some proportion of small organisms. In the case of a black snow, observed in New York in 1889, it was found that the color was due to "finely divided earth and vegetable mould."[4] In this case it is certain that small organisms were included among the débris, for it would be impossible for the wind to sweep up enough vegetable mould to discolor a snowfall without at the same time taking up a considerable number of spores, seeds, fruits, and small animals.

[3] Symons's met. mag., February, 1908, 43: 2-4.
[4] MONTHLY WEATHER REVIEW, October, 1901, 29: 465-466.

*Blood rains.*—The most frequently reported showers that are spurious, at least in name, are the so-called blood rains. In all times the phenomena going under this name have frightened the people and have been taken as portents of terrific calamities. One of the famous plagues of Egypt was a bloody rain which prevailed throughout the whole land, continuing three days and three nights. Homer and Virgil both allude to blood rains, and, in fact, the general subject of preternatural rains was a favorite with the older writers.

But scientific investigation has done away with the element of mystery in these phenomena and has explained, with the others, the rains of blood. Some blood rains have been found to be the meconial fluid ejected by large numbers of certain lepidoptera simultaneously emerging from their chrysalides; other red rains are due to the rapid multiplication in rain pools of algæ and of rotifers containing red coloring matter; "red snow" results from the presence of similar organisms. But in no case have they rained down, except in the sense that their spores or eggs have at some time been transported, probably by the wind. The precipitation of moisture furnishes favorable conditions for their rapid development and multiplication.

There are several summaries of information relating to the anciently recorded showers of miscellaneous matter. Among them is that of Valentin Alberti, "Dissertatio historica physica de Pluvia prodigiosa", Leipzig, 1674; one by P. J. Hartmann, published as an appendix to the Miscellanea Curiosa * * * Academiae Imperialis Leopoldinae * * * Jena, 1689; another by J. C. Haebler, entitled "Dissertatio de pluviis prodigiosis," published at Erfurt in 1695, and also one by C. G. Ehrenberg in 1847 (Abh. Kgl. Preuss. Akad. Wiss. Berlin.).

For modern bibliographies covering the subject of organic showers, see: Fassig, O. L., Bibliography of Meteorology, United States Signal Service, Showers of Miscellaneous Matter, Part II, 1889, pages 367-391, and Stuntz, S. C., & Free, E. E., Bibliography of Eolian Geology, Bulletin 68, United States Bureau of Soils, 1911, pages 174-263.

*Manna.*—An account of manna "rains" certainly pertains to the discussion of showers of vegetable matter, for the substance manna consists of lichens of the genus *Lecanora*, but in none of the numerous recorded instances of manna "rains" is there any direct evidence that the substance really fell from the sky. These lichens form, small, round bodies that are easily blown over the surface of the ground and accumulate in depressions; they are very buoyant also and hence easily drifted into masses during the run-off of rain water. Manna "rains" have not occurred except in countries where these lichens are common, and as for statements of their falling down upon roofs or upon people, or for any other proofs that they really rained down, I have seen none.

### TRUE SHOWERS.

*Red rains; dust.*—Other red rains are caused by the bringing down in rain water of atmospheric dust of a reddish color. This hue usually is noticed in rain falling in southern Europe at a time when the air is charged with sirocco dust. The composition of this dust has been extensively investigated and it has been found to contain spores, pollen grains, confervoid algæ, diatoms, infusoria, and rotifers. In 50 samples of sirocco dust from various parts of Italy pollen, spores, etc., were found in every one.[5] In sirocco dust collected at Lyons, Ehrenberg claims to have found 111 different species of infusoria, and the total number of organisms enumerated by him from samples of such dust is 320.[6] In the Lyons instance organic forms made up one-eighth of the entire mass of the dust. Since various estimates place the

[5] *Tacchini, P.* Ann., Met. Ital., 1879, pt. 1, pp. 63-115.
[6] *Ehrenberg, C. G.* Passat-staub und Blut-regen. Abh., Preuss. Akad., 1847.

amount of sirocco dust in a fall at from 5½ to 9 tons to the square mile, it will be seen that a fall of a ton of microscopic organisms per square mile is within the bounds of possibility.

It is not only the hot and dry sirocco that is laden with dust containing organisms, for indeed they are in the air everywhere at all times. The researches of MM. Miquel[7] and Boudier[8] in France, particularly have elucidated the nature of atmospheric dust. The atmosphere always is charged with a large number of organic entities. The vegetable constituents are chiefly bacilli and the spores of cryptogams, as of fungi, lichens, mosses, and algæ. There are also hairs of plants, fibers of cotton, flax, and hemp, pollens of every form, and starch grains. The animal remains include epithelial cells, hairs, shreds of feathers, bits of down and wool, scales of lepidoptera, and the eggs of infusoria. The quantity of suspended matter in the air is high in summer and low in winter, and less at high altitudes than in lower areas nearer the source of the bodies found.

Special forms of aeroscopes have been devised to collect samples of atmospheric dust. In one form described by Mr. Hubert Airy,[9] were caught in the city of London, the following things additional to those just named: Living mites, entomostraca, and diatoms.

It appears, therefore, that a great variety of small organisms or their spores are present in the air at all times, that they are freely carried about by the winds, and are constantly being precipitated either in dust or in falling moisture. The possibilities for the distribution of these minute forms are practically unlimited, for dust clouds travel indefinite distances. In the United States a dust storm and mud shower was observed on the same day in Illinois, New York, Pennsylvania, and New Jersey.[10] This shows transport of the material over a third of the breadth of the United States, if indeed all of it did not come from the western plains. A dust cloud a thousand, perhaps two thousand miles in length was observed at sea by J. Milne[11] when 200 to 400 miles distant from the coast of China, from whose loess plains it was probably derived. This dust contained shreds of plants. At times of great volcanic activity, dust clouds have encircled the world. There is, therefore, no limit to the distribution of atmospheric dust, and therefore probably none to that of the minute organisms that are one of its constant components.

### *Showers of plants and invertebrates.*

*Pollen falls, sulphur rains.*—Pollen of various plants, as previously noted, is one of the most common constituents of atmospheric dust; for instance, Miquel found that there are often a thousand pollen grains to each cubic meter of air.[12] But pollen deserves more extended notice because it is really showers of pollen that have been so often reported as showers of sulphur. The yellow color suggested sulphur; pollen, especially of pine, is highly inflammable, the imagination supplied the smell of brimstone, and superstition jumped at the conclusion that the devil had been busy. The occasional phosphorescent appearance of pollen falls at night also has encouraged preternatural speculations.

[7] Ann., L'Observatoire de Montsouris, 1879, pp. 431–512.
[8] Journ. pharm. chim., 4e Ser., 1876, 23: 340–345.
[9] Nature, 1874, 9: 439–40.
[10] MONTHLY WEATHER REVIEW, May, 1902, 30: 269.
[11] Nature, June 9, 1892, 46: 128.
[12] The spores of cryptogams may be 20 times as numerous. It is stated that on Reunion Island the spores of *Lycopodium* sometimes are present in the air in such quantity as to make breathing difficult.



The following is extracted from an account of a pollen shower in England[13] in early June, a fall of fine yellow dust which coated the surface of rain water in barrels and pools, was taken by the uneducated for a fall of sulphur. It was said by the imaginative to smell "awful like brimstone" and to presage the end of the world. Examination of the dust under a microscope at once showed it to be the pollen of pine. Another writer adds:[14]

> As this mystery, if it is not explained, may prove serious to the nervous, superstitious, or credulous part of the community, we may as well add that at this season districts in the neighborhood of fir (*Pinus sylvestris*) plantations run the risk of a thorough dusting of this powder if there is the slightest breeze, as the cones of the young Scots fir are thickly coated with yellow powder or pollen, which will give out a blinding saffron cloud on the slightest disturbance

The appearance of a conspicuous movement of pollen has been well described by Dr. D. P. Thomson.[15]

> On the afternoon of June 11, 1847, the wooded part of Morayshire appeared to smoke, and for a time fears were entertained that the fir plantations were on fire. A smart breeze suddenly got up from the north and above the woods there appeared to rise about 50 columns of something resembling smoke, which was wreathed about like waterspouts. The atmosphere now calmed and the mystery was solved, for what seemed smoke was in reality the pollen of the woods.

The ease with which pollen is taken up into the air together with the prodigal profusion with which it is produced make it easy to understand the frequency of the so-called sulphur rains. In March, 1879, several instances of yellow rain or snow occurred in the United States. Prof. W. H. Chandler of Lehigh University, South Bethlehem, Pa., writes that during Saturday night, March 16, 1879, there was a slight fall of snow in that section, and on Monday morning when the snow had melted, a yellow deposit was found covering the ground more or less. Upon examining the deposit, it was found to be the pollen of pine trees. The United States Signal Corps observer at New Orleans, reports light showers on the 17th of the same month, and states that "a peculiar feature of the rain was its yellow color, which was due to large quantities of the pollen of the cypress tree floating in the atmosphere." The United States Signal Corps observer at Lynchburg, Va., forwarded on March 21, 1879, a sample of the yellow deposit which had fallen with the rain the preceding night and " * * * it was found to consist * * * entirely of the characteristic triple-grained pollen of the pine."[16] A pollen shower at Pictou, Nova Scotia, in June, 1841, was so heavy that bucketfuls were swept up on a ship. This material was entirely the pollen of pine trees.[17] As showing how far pollen may be transported by the wind, it is noted that "A shower of this kind fell at Lund at the south of Sweden, which M. Agardh (Nova Acta, 12) found to contain the pollen of *Pinus sylvestris* or Scotch fir, borne on the wind from a forest about 35 miles distant."[18]

*Hay.*—The vegetable substance, which, after pollen, figures most frequently in the accounts of actual showers of organic matter, is hay. This should not be surprising, since the material is comparatively light and is available at the time of year when wind whirls are most frequent. The first step in the development of a shower of hay was observed by Prof. F. E. Nipher,[19] who describes a whirlwind that picked up hay and carried it in the form of an

[13] *Carpenter, P. H.* Pine-pollen mistaken for flowers of sulphur. Nature, June 26, 1879, 20: 195–196.
[14] *Wilson, Andrew.* Nature, July 17, 1879, 20, 267.
[15] *Thomson, D. P.* Introduction to meteorology. Edinburgh, &c., 1849, p. 151.
[16] MONTHLY WEATHER REVIEW, March, 1879, p. 16.
[17] *Bailey, J. W., in* Amer. jour. sci. and arts, 1842, 42: 195–197.
[18] *Thomson, D. P.* Introduction to Meteorology, 1849, p. 151.
[19] Nature, Sept. 11, 1879, 20: 456.

inverted cone about 200 feet high and 150 feet in diameter at the top. The whirl was followed for about half a mile when it disappeared over a hill. The complete phenomenon, on a small scale, is described as follows by Sir Francis Galton: [20]

We had a curious sight * * * yesterday (July 26, 1891). It was a dead calm, but in a field just below the garden * * * the hay was whirled up high into the sky, a column connecting above and below, and in the course of the evening we found great patches of hay raining down all over the surrounding meadows and our garden. It kept falling quite four hours after the affair.

On June 30, 1892, a large quantity of hay was taken up by a whirlwind at Nether Priors, Essex, England, and fell at Belchamp, about 3 miles to the north.[21] In two other cases noted, one in London,[22] the other in Ireland,[23] the hay was seen floating at a great height in the atmosphere and then to fall.

*Wheat.*—In my introductory remarks I stated that most of the so-called showers of grain were spurious. However "in 1804 * * * a real rainfall of wheat took place in Andalusia, which had been carried by a hurricane across the Straits of Gibraltar, from a threshing floor at Tetuan." [24]

*Meteoric "paper."*—A substance which has fallen from the sky, and has been called "meteoric paper," was proved in one case at least to be vegetable matter of terrestrial origin. Ehrenberg who investigated the case says [25] "On the 31st of January, 1687, a great mass of paper-like, black substance fell with a violent snowstorm * * * near the village of Rauden in Courland." Some of the substance was preserved and it was 152 years later that Ehrenberg examined it and found it to consist "of a compactly matted mass of *Conferva crispata*, traces of *Nostoc* and of about 29 * * * species of infusoria." This material was undoubtedly the crusts of dried algæ which form on the surface of the ground exposed by the evaporation of the water of shallow ponds. This paper-like substance could easily be lifted up by the wind and carried a long distance.

*Jelly or "flesh."*—Manna is the bread of organic showers; but what is the meat? Showers of flesh have often been recorded and they have proved to be precipitations of a glairy substance, which upon partial drying formed enough of a skin on the outside to induce people to call it flesh. When found fresh, this material has been compared to butter. Probably most if not all of it is the material known as zooglea formed on the surface of water where bacteria are actively multiplying. The substance known as zoogen or zoiodin is probably the same. An extensive shower of such jelly-like material occurred in Bath County, Ky., in 1876, and was referred to as the dried spawn of fishes or of some batrachian.

Such spawn really has rained down also, if we may believe the account of M. Moreau de St. Mery, relating to an observation in San Domingo.[26]

From November, 1785, to the 5th of May, 1786, there was experienced a terrible drought. The last day, viz, May 5, 1786, there fell during a strong east wind, in several parts of the city of Port au Prince * * * a great quantity of black eggs, which hatched the following day. M. Mozard preserved about 50 of these small animals in a flask half full of water, where they shed their skins several times. They resembled tadpoles.

Other jelly rains have proved to consist of the egg masses of midges, and of colonies of infusoria. A shower of the latter is described as follows by L. Jenyns [27] in his article on a so-called storm of insects at Bath, England:

There had been a sudden squall of wind before there came a heavy rain, and my idea is that these organisms must have been lifted up by the force of the wind, acting in a gyratory manner, from some shallow pool in the neighborhood. * * * A boy at the station first noticed them (that is, the spherical masses in which the organisms were grouped) falling on his coat * * *; as the rain fell more heavily the platform * * * was covered with them.

*Insects.*—The popular designation of these infusoria as insects of course was due to the very wide misuse of this term. I have noted previously that the alleged showers of insect larvæ also were not genuine, but there have been apparently a few real rains of insects. Two which occurred in Germany are described as follows: [28]

At Szentes, August 14, between 9 and 10 p. m. a deep-black cloud suddenly appeared in the evening sky. Soon thereafter began a downpour, not of rain, but of winged insects, which in a few minutes covered the ground a foot deep. At St. Catherine a. d. Lamming (Obersteiermark), on the 10th and 11th of August, insect rains also occurred, which while not so remarkable, still were very annoying. The insects were in part small neuropteroids and in part winged ants.

Accounts of three other showers which have been gleaned from French publications are circumstantial, and clearly show sustained transport of insects by the wind and their falling from the skies after the manner of rain:

Toward the end of May, M. L. Audé, * * * while returning from Mortagne to Herbiers, was caught in a violent storm from the northeast which, during a heavy rain, covered his conveyance with a multitude of *Gryllus*. The wind was cold and the Orthoptera falling in the midst of the rain appeared lifeless. These * * * are all in the larval state and are *Gryllus domesticus* of authors.[29]

Rey de Morande in describing a shower of insects and spiders in Haute-Savoie, says: [30]

On the night of January 29-30 [1869?], about 4:30 a. m., with a violent gust of wind which soon ceased, snow fell until day, and in the morning there were found on this snow a large quantity of living larvæ. * * * (The temperature for some days before had been very low.) * * * They appeared to be, for the most part, larvæ of *Trogosita mauritanica*, which are common in old trees in the forests in southern France. There were found also larvæ of a little moth * * * probably *Stibia stagnicola*. This shower of insects and spiders at an altitude of 1,000 to 1,200 meters, can not be explained except by transportation by a violent wind from central or southern France. M. Tissot, * * * who observed the phenomenon, adds, that in November, 1854, several thousands of insects, mostly living, were thrown down by a violent wind in the vicinity of Turin. Some were larvæ and some adult and all appeared to be of a species of hemiptera that had never been collected except on the isle of Sardinia.

*Molluscs.*—Before leaving the consideration of invertebrates we may note that: "A shower of mussels, some weighting about 2 ounces, fell during a severe storm, on the 9th of August, 1834, in the United States.[31] The following year another shower of molluscous animals, *Bulimus truncatus*, took place at Montpelier [France]." [32]

*Falls of vertebrate organisms.*

The fall of vertebrate animals from the skies like rain is, of course, the most interesting of all the showers of organic matter, and—it must be admitted—the hardest to believe. Yet there cannot be the slightest doubt that there are genuine phenomena of this character, though perhaps not so numerous as the recorded instances. These occurrences, if observed by man, naturally make profound impressions and in the olden times especially, the tales of showers of fishes and the like were improved

[20] Nature, July 30, 1891, 44: 294.
[21] Symons's met. mag., August, 1892, 32: 106-107.
[22] Comptes rendus, 1861, 52: 108-109.
[23] Nature, 1875, 12: 279.
[24] *Hartwig, G.* The Aerial world, 1874, p. 194.
[25] Ann., Nat. Hist., 1839, 3: 185-186.
[26] *Moreau de St. Mery.* Descrip. de Saint Dominique, t. 2, p. 413, cited in *P. H. Gosse*, A Naturalist's sojourn in Jamaica, 1851, p. 430.
[27] Zoölogist, 1871, 6: 2286-7.
[28] Meteorol. Ztschr., Wien, 1901, 18: 426.
[29] *Lucas, H.* Bul., Soc. ent. France, 1858, p. xcvi.
[30] *Rey de Morande.* Bul. hebd., Assoc. sci. de France, 1869, 5: 242.
[31] Pittsburgh Gazette.
[32] Athen. No. 373, December, 1834, p. 923. The last two citations from *David Purdie Thomson*, "Introduction to Meteorology," Ch. VIII, pp. 163-164.

by each teller, so that soon they reached the stage of the unbelievable.

*Frogs, toads.*—I quote only one of the older writers, Athenæus, who flourished about 200 A. D. He is the author of a polyhistorical work called the "Deipnosophists," in which he quotes about 800 authors, whose works he consulted at the Alexandrian Library, 700 of whom would have been unknown, except for the fortunate preservation of Athenæus' work. In a chapter entitled "De pluvius piscium," he says: [33]

I know also that it has very often rained fishes. At all events Phænias, in the second book of his Eresian Magistrates, says that in the Chersonesus it once rained fish uninterruptedly for three days; and Phylarchus in his fourth book, says that people had often seen it raining fish, and often also raining wheat, and that the same thing had happened with respect to frogs. At all events Heraclides Lembus, in the 21st book of his history, says: "In Pæonia and Dardania, it has, they say, before now rained frogs; and so great has been the number of these frogs that the houses and the roads have been full with them; and at first for some days the inhabitants, endeavoring to kill them, and shutting up their houses endured the pest; but when they did no good, but found that all their vessels were filled with them, and the frogs were found to be boiled up and roasted with everything they ate, and when besides all this they could not make use of any water, nor put their feet on the ground for the heaps of frogs that were everywhere, and were annoyed also by the smell of those that died, they fled the country."

For numbers of frogs and the far reaching effects of their fall [34] this tale can scarcely be surpassed, but it will be well to recount some later instances, especially some of the more circumstantial ones. Holinshed [35] informs us that in Great Britain—

frogs fell in Angusshire during the time of Agricola. Frogs were reported to have descended, during the summer of 1846 over the Humber, upon the decks of vessels in the river and on the coast near Killinghome lights.

A later account [36] recites that—

During the storm that raged with considerable fury in Birmingham (England) on Wednesday morning, June 30 [1892], a shower of frogs fell in the suburb of Moseley. They were found scattered about several gardens. Almost white in color, they had evidently been absorbed in a small waterspout that was driven over Birmingham by the tempest.

Several notices have from time to time been brought before the French Academy of showers of frogs having fallen in different parts of France. M. Duparque [37] states in a letter that—

In August, 1814, after several weeks of drouth and heat, a storm broke one Sunday about 3:30 p. m., upon the village of Fremon, a quarter league from Amiens. This storm was preceded by bursts of wind so violent that they shook the church and frightened the congregation. While traversing the space separating the church from presbytery, we were soaked, but what surprised me was to be struck on my person and my clothing by small frogs. * * *. A large number of these small animals hopped about on the ground. On arriving at the presbytery, we found the floor of one of the rooms in which a window facing the storm had been left open covered with water and frogs. * * *.

Showers of toads seem to be more common in some regions than those of frogs. I have seen accounts of 13 different occurrences of the kind in France. A French scientist M. Mauduy, curator of natural history at Poitiers, had personal experience with two such showers, which he narrates briefly as follows: [38]

On the 23d of June, 1809, during a hot spell, I was caught in a rain storm in which with the very large drops were mixed little bodies the size of hazelnuts, which in a moment, covered the ground, and which I recognized as little toads. * * * The second occasion, occurred in August, 1822, during a stormy and very hot period; I was again surprised by a heavy shower of large drops mixed, as was the other, with little toads, some of which fell on my hat. This time the animals were the size of walnuts. I found that I was more than a league distant from any brook, river, or marsh.

A considerable discussion of the subject of rains of toads was carried on in 1834 in the French scientific magazine from which I have quoted. I cite two more bits of testimony by eye witnesses, one of which has been widely reproduced.

M. Heard, writes: [39]

In June, 1833, I was at Jouy near Versaille. I saw toads falling from the sky; they struck my umbrella; I saw them hopping on the pavement, during about 10 minutes in which time the drops of water were not more numerous than the toads. The space upon which I saw the multitude of these animals was about 200 fathoms.

M. Peltier in his oft-copied statement says: [40]

In support of the communication of Col. Marmier, I cite an incident I observed in my youth; a storm advanced upon the little village of Ham, Department of the Somme, where I lived, and I observed its menacing march, when suddenly rain fell in torrents. I saw the village square covered everywhere with little toads. Astonished by this sight, I held out my hand and was struck by several of the reptiles. The dooryard also was covered; I saw them fall upon the slate roof and rebound to the pavement. * * * Whatever the difficulty of explaining the transport of the reptiles, I affirm, without doubt the fact which made such a profound impression upon my memory.

The most remarkable account of a shower of toads, that I have seen, so far, is the following: [41]

In the summer of 1794 M. Gayet was quartered in the village of Lalain, Department du Nord, * * * near the territory which the Austrians, then masters of Valenciennes, had flooded with water from the Scarpe. It was very hot. Suddenly, at about 3 o'clock in the afternoon, there fell such an abundance of rain that 150 men of the grand guard, in order not to be submerged, were obliged to leave a large depression in which they were hidden. But what was their surprise when there began to fall on the ground all about a considerable number of toads, the size of hazelnuts, which began to jump about in every direction. M. Gayet, who could not believe that these myriads of reptiles fell with the rain, stretched out his handkerchief at the height of a man, his comrades holding the corners; they caught a considerable number of toads, most of which had the posterior part elongated into a tail, that is to say, in the tadpole state. During this rain storm, which lasted about half an hour, the men of the grand guard felt very distinctly on their hats and on their clothing the blows struck by the falling toads. As a final proof of the reality of this phenomenon, M. Gayet reports that after the storm the three-cornered hats of the men of the guard held in their folds some of the reptiles.

*Fish.*—For reports of the falling of frogs and toads from the skies, we have been far afield, for the very good reason that I have not found any cases reported for the United States. But for fishes, there are several reports. Before giving these accounts, allow me to introduce a few statements that tend to show how fishes get started on the aerial journeys that terminate in fish rains.

To show the tremendous power of waterspouts, we may quote M. Oersted's declaration [42] that "At Christiansoë a waterspout emptied the harbor to such an extent that the greater part of the bottom was uncovered." Naturally under such circumstances fishes and any other organisms in the water may change their habitat very abruptly. Waterspouts have been observed to accomplish the comparatively insignificant tasks of emptying fish ponds and scattering their occupants.

A prodigy of this kind is recorded to have occurred in France, at a town some distance from Paris, during a violent storm. When morning dawned, the streets were found strewed with fish of various sizes.

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[33] *Athenæus.* The deipnosophists or banquet of the learned (Transl. by C. D. Yonge 1854). Book XV, pt. 2, pp. 526-527.
[34] Is it not much more reasonable to conclude that the plague of frogs reported by Heraclides Lembus was due to a migration, rather than to a precipitation of the batrachians?—C. A., jr.
[35] Chron., Vol. II, p. 59. *Thomson, David Purdie.* Introduction to Meteorology. Ch. VIII, pp. 164-165, 1849.
[36] Symons's met. mag., August, 1892, 32: 107.
[37] L'Institut, 1834, 2: 354.
[38] L'Institut, 1834, 2: 409-410.
[39] L'Institut, 1834, 2: 353.
[40] L'Institut, 1834, 2: 346-7.
[41] L'Institut, 1834, 2: 354.
[42] *Tomlinson, Charles.* The Tempest, pp. 136-137.

The mystery was soon solved, for a fish pond in the vicinity had been blown dry, and only the large fish left behind.[43]

So, during a storm on December 28, 1845, at Bassenthwaite, England, fish were blown from the lake to dry land.[44]

Proceeding now to the United States records, Mr. Thomas R. Baker[45] states that—

> During a recent thunderstorm at Winter Park, Fla., a number of fish fell with the rain. They were sunfish from 2 to 4 inches long. It is supposed that they were taken up by a waterspout from Lake Virginia, and carried westward by the strong wind that was blowing at the time. The distance from the lake to the place where they fell is about a mile.

In the MONTHLY WEATHER REVIEW for June, 1901 (p. 263), is the note "Mr. J. W. Gardner, voluntary observer at Tillers Ferry, S. C., reports that during a heavy local shower about June 27 [1901] there fell hundreds of little fish (cat, perch, trout, etc.) that were afterwards found swimming in the pools between the cotton rows."

In all, I am acquainted with four records of falls of fishes in the United States, two in South America, eight in Great Britain, two in France, and six in India and neighboring countries. These are all well vouched for, or fairly modern and circumstantially related instances. The older, chiefly traditional, records would make a long list.

One of the most ancient records of fish having fallen from the atmosphere in Great Britain is the following: About Easter, 1666, in the parish of Stanstead, which is a considerable distance from the sea, or any branch of it, and a place where there are no fish ponds, and rather scarcity of water, a pasture field was scattered all over with small fish, in quantity about a bushel, supposed to have been rained down from a cloud, there having been at the time a great tempest of thunder, rain, and wind. The fish were about the size of a man's little finger. Some were like small whitings, others like sprats, and some smaller, like smelts. Several of these fish were sold publicly at Maidstone and Dartford.[46] A shower of herrings is recorded to have taken place near to Loch Leven, in Kinross-shire, about the year 1825; the wind blew from the Frith of Forth at the time, and doubtless the fish had been thereby carried from the sea across Fifeshire to the place where they were found.[47] In 1828, similar fish fell in the county of Ross, 3 miles distant from the Frith of Dingwall.[48] On the 9th of March, 1830, in the Isle of Ula, in Argyleshire, after a heavy rain, numbers of small herrings were found scattered over the fields; they were perfectly fresh, and some not quite dead. On the 30th of June, 1841, a fish measuring 10 inches in length, with others of smaller size, fell at Boston; and during a thunderstorm, on the 8th of July, in the same year, fish and ice fell together at Derby.[49]

A convincing statement of personal experience with a rain of fishes is that of John Lewis, of Abderdare, who says that while working, February 9:

> I was startled by something falling all over me—down my neck, on my head, and on my back. On putting my hand down my neck I was surprised to find they were little fish. By this time I saw the whole ground covered with them. I took off my hat, the brim of which was full of them. * * * They covered the ground in a long strip about 80 yards by 12 yards, as we measured afterwards. * * * We gathered a great many of them * * * and threw them into the rain pool, where some of them now are. * * * It was not blowing very hard, but uncommon wet. * * * The person who took this testimony adds that he secured about 20 of the little fish, some of which were 4 and 5 inches long. A number of these fishes were exhibited for several weeks in the aquaria house of the Zoological Society in the Regent's Park, London.[50]

The accounts of rains of fishes in South America are by Alexander von Humboldt,[51] whose language relating to them is as follows:

> When the earthquakes, which precede every eruption in the chain of the Andes, shake with mighty force the entire mass of the volcano, the subterranean vaults are opened and emit at the same time water, fishes, and tufa-mud. This is the singular phenomenon that furnishes the fish *Pimelodes cyclopum*, which the inhabitants of the highlands of Quito call "Preñadilla," and which was described by me soon after my return. When the summit of the mountain Carguairazo, to the north of Chimborazo and 18,000 feet high, fell, in the night between the 19th and 20th of June, 1698, the surrounding fields, to the extent of about 43 English square miles, were covered with mud and fishes. The fever which raged in the town of Ibarra seven years before had been ascribed to a similar eruption of fishes from the volcano Imbaburu.

There are several well authenticated reports of falls of fish in India, and this has given rise to the belief that the phenomenon is more frequent there than elsewhere. This may be true on account of the favoring circumstances of extensive river flood plains, numerous shallow water tanks, a fish fauna rich in shoal water forms, and a hot, whirlwind-breeding climate. Certainly the descriptions of fish rains in that part of the world are numerous, specific, and astonishing as to the magnitude of the phenomena.

One of the oldest reports, brief but with a humorous touch, I quote first. It is by Lieut. John Harriott,[52] who says:

> In a heavy shower of rain, while our army was on the march a short distance from Pondicherry, a quantity of small fish fell with the rain, to the astonishment of all. Many of them lodged on the men's hats. * * * They were not *flying fish*, they were dead and falling from the well-known effect of gravity; but how they ascended or where they existed I do not pretend to account. I merely relate the simple fact.

A very valuable account of a shower of fishes is that by J. Prinsep, editor of the Journal of the Asiatic Society of Bengal. He writes:[53]

> The phenomenon of fish falling from the sky in the rainy season, however incredible it may appear, has been attested by such circumstantial evidence that no reasonable doubt can be entertained of the fact. I was as incredulous as my neighbors until I once found a small fish in the brass funnel of my pluviometer at Benares. I have now before me a note of a similar phenomenon, on a considerable scale, which happened at the Nokulhatty factory, Zillah Dacca Jedalpur, in 1830.
>
> Mr. Cameron, who communicated the fact, took the precaution of having a regular deposition of the evidence of several natives who had witnessed the fall made in Bengalee and attested before the magistrate; the statement is well worthy of preservation in a journal of science. * * * The shower of fish took place on the 19th of February, 1830, in the neighborhood of the Surbundy factory, Feridpoor (p. 650).

There are depositions of nine eye witnesses, of which I quote two:

> Shekh Chaudari Ahmed, son of Mutiullah, inhabitant of Nagdi, relates in his deposition: "I had been doing my work at a meadow, where I perceived at the hour of 12 o'clock the sky gather clouds, and began to rain slightly, then a large fish touching my back by its head fell on the ground. Being surprised I looked about, and behold a number of fish likewise fell from heaven. They were saul, sale, guzal, mirgal, and bodul. I took 10 or 11 fish in number, and I saw many other persons take many."
>
> Shekh Suduruddin, inhabitant of Nagdi, was called in and declared in his deposition saying: "On Friday, at 12 o'clock p. m., in the month of Phalgun * * * when I was at work in a field, I perceived the sky darkened by clouds, began to rain a little and a large fish fell from the sky. I was confounded at the sight, and soon entered my small cottage, which I had there, but I came out again as soon as the rain had ceased and found every part of my hut scattered with fish; they were boduli, mirgal, and nouchi, and amounted to 25 in number."

The large number of fishes that may rain down is illustrated by another Indian instance which was reported as follows:[54]

> On the 16th or 17th of May last a fall of fish happened in monza Sonare, pergunna Dhata Ekdullah, Zillah Futteppur. The zemindars

[43] Reess' Cyclopedia.
[44] *Thomson, D. P.* Introduction to Meteorology, 1849, pp. 163–164.
[45] Science, June 16, 1893, 21: 335.
[46] *Hasted.* History of Kent, cited by Thomson.
[47] Ed., Phil. journ., 1826; cited by Thomson.
[48] Inverness Courier, April, 1828; cited by Thomson.
[49] *Thomson, D. P.* Introduction to Meteorology, 1849, p. 163.
[50] *Tomlinson, Charles.* The Rain-cloud and the Snow-storm, pp. 193–194.
[51] *Humboldt, Alexander von.* On the constitution and mode of action of volcanoes in different parts of the earth. Ann. Phil., 1823, 22 (N. S., 6): 130.
[52] *Harriott, John.* Struggles through Life, 1809, v. 1, pp. 141–142.
[53] *P[rinsep], J.* Fall of fish from the sky. Jour., Asiatic society of Bengal, 1833, 2: 650–652.
[54] Jour., Asiatic soc. of Bengal, 1834, 3:367.

of the village have furnished the following particulars which are confirmed by other accounts. About noon, the wind being from the west, and a few distant clouds visible, a blast of high wind, accompanied with much dust, which changed the atmosphere to a reddish yellow hue, came on; the blast appeared to extend in breadth about 400 yards. * * * When the storm had passed over, they found the ground south of the village to the extent of two bigahs strewed with fish, in number not less than three or four thousand. The fish were all of the Chalwa species (*Clupea cultrata*), a span or less in length, and from 1½ to ½ seer in weight; when found they were all dead and dry. Chalwa fish are found in the tanks and rivers of the neighborhood; * * * the nearest water is about half a mile south of the village.

For the number of fishes that fell this account is not surpassed, but for all-around interest, and credulity inspired by the name of its distinguished author, the testimony of Francis de Castelnau, mentioned at the beginning of this paper, is supreme. The note is entitled "Shower of Fishes; earthquake at Singapore," and was published in 1861.[55]

We experienced here an earthquake at 7:34 p. m., February 16, that lasted about two minutes; it was followed by hard rains, which on the 20th, 21st, and 22d became veritable torrents. The last day at 9 a. m. the rain redoubled in fury, and in a half hour our inclosed plot became a sea of water * * *.

At 10 o'clock the sun lifted and from my window I saw a large number of Malays and Chinese filling baskets with fishes which they picked up in the pools of water which covered the ground. On being asked where the fishes came from, the natives replied that they had fallen from the sky. Three days afterwards, when the pools had dried up, we found many dead fishes.

Having examined the animals, I recognized them as *Clarias batrachus*, Cuvier and Valenciennes, a species of catfish which is very abundant in fresh water in Singapore, and the nearer Malayan Islands, in Siam, Borneo, etc. They were from 25 to 30 centimeters long, and therefore adult.

These siluroids, the same as Ophicephalus, etc., are able to live a long time out of water, and to progress some distance on land, and I thought at once that they had come from some small streams near by; but the yard of the house I inhabited is inclosed in a wall that would prevent them entering in this manner. An old Malay has since told me that in his youth he had seen a similar phenomenon.

*Other vertebrates.*—Showers of vertebrates other than frogs, toads, and fishes are rare indeed. It was recorded in 1873 that a shower of reptiles fell in Minnesota,[56] and from the description it is evident the creatures were larvæ of a salamander, probably of *Amblystoma tigrinum*. The MONTHLY WEATHER REVIEW for May, 1894 (p. 215) states that during a severe hailstorm "at Boving, 8 miles east of Vicksburg, Miss., a gopher turtle 6 by 8 inches and entirely incased in ice fell with the hail."

This is a most remarkable occurrence, but what shall we say of a shower of birds, in which hundreds dropped dead in the streets of a Louisiana city? In the Baton Rouge, La., correspondence of the Philadelphia Times, some time in 1896, it is stated[57] that—

On Friday morning last early risers in the little capital [Baton Rouge, La.] witnessed a peculiar sight in the shape of a shower of birds that fell from a clear sky, literally cluttering the streets of the city. There were wild ducks, catbirds, woodpeckers, and many birds of strange plumage, some of them resembling canaries, but all dead, falling in heaps along the thoroughfares, the singular phenomenon attracting many spectators and causing much comment.

The most plausible theory as to the strange windfall is that the birds were driven inland by the recent storm on the Florida coast, the force of the current of air and the sudden change of temperature causing death to many of the feathered creatures when they reached Baton Rouge. Some idea of the extent of the shower may be gathered from the estimate that out on National Avenue alone the children of the neighborhood collected 200 birds.

This seems clearly not to have been a case of migrants becoming confused by city lights, nor killing themselves by flying against obstacles, mishaps which rather frequently occur to bird travelers. The phenomenon of migration among mammals gives rise to the only story of a shower of those animals that I have seen. It is given by Charles Tomlinson, who writes:[58]

In some countries rats migrate in vast numbers from the high to the low countries; and it is recorded in the history of Norway that a shower of these, transported by the wind, fell in an adjacent valley.

I have not seen the original of this tale, but it may have been prompted by the appearance, in large numbers, of lemmings which frequently migrate in hordes in Scandinavia. It is possible, of course, that during one of these migratory movements some of the animals were transported by a violent wind and precipitated as "a shower of rats."

### WIND AS A DISTRIBUTING AGENT.

We have reviewed instances of the rain-like fall of various animal and plant bodies, of pollen, of hay, of diatoms, algæ, rotifers, of insects, frogs, toads, fishes, salamanders, turtles, birds, and rats. It remains to inquire what significance, if any, these phenomena have for the distribution of living things upon the earth.

*Vertebrates.*—In the case of vertebrates distribution by wind transport must be of practically no importance. Mammals and birds thus snatched up by the wind, if carried any distance, arrive dead. Batrachians also often are killed, and if not, usually must be carried for short distances only; the chances are also that they will reach an unfavorable environment and perish for that reason. Fishes, most of all, are fated to fall where they can not survive, and their inability to live long out of water strictly limits the possibilities of their deriving advantage by wind transport. In addition, it must be remembered that in all these groups instances of their being carried by the wind are really rare. All in all, we must conclude that the wind is a very unimportant factor in the distribution of vertebrate animals.

*Plant seeds.*—In the case of most seed-producing plants, although hundreds of species have seeds modified for wind transport, it has not been shown that they are especially successful in making rapid strides in distribution. Kerner says:[59]

The distance to which specially adapted seeds may be carried by the wind is considerable, but in ordinary course is not attained. * * * Among the numerous species of fruits and seeds obtained from snow fields and glaciers high in the Alps not one was derived from a distant district.

Vogler,[60] who made a special study of the means of distribution of alpine plants, found that instances of spread by the wind to distances of from 3 to 40 kilometers were not rare, while "transport of seeds * * * to great distances, even hundreds of kilometers * * * is possible, but in the actual distribution of plants plays a minor rôle."

*Spores, etc.*—When we come to consider, however, the distribution of plants and animals that have spores, eggs, statoblasts, or other minute but resistant resting stages, it is apparent that winds are their most important means of spread.

The United States Bureau of Entomology has shown that winds are important in the distribution of mites (McGregor, E. A., & McDonough, F. L., Dept. Agr. Bul. 416, 1917, pp. 31–32), and the gipsy-moth (Collins, C. W., Dept. Agr. Bul. 273, 1915). Small larvæ of the last-named pest were found to be carried 13½ miles by ordinary winds. For a typical exposition of the agency of wind in distributing fungus spores, see Journ. agric. research, Washington, March, 1915, **3**:493–525.

Reflect what opportunities are offered to the wind in every dry basin left by the evaporation of shallow pools. The drying of the water stimulates all the organisms to

[55] Comptes Rendus, 1861, 52:880–881.
[56] Am. sportsman, Oct. 11, 1873, No. 2, 3: 22.
[57] Gazette, San Jose, Cal., Nov. 4, 1896.
[58] *Tomlinson, Charles.* The rain cloud and the snowstorm, p. 194.
[59] *Kerner.* Natural history of plants, vol. 2, 1895, p. 861. Transl.
[60] *Vogler.* Flora, 1901, 89: 95.

produce their encysted forms. The bottom is crusted with matted algæ bearing their own spores or oögonia, resting stages which long retain their vitality and which are ready at any time to profit by wind transport. Among the algæ there may be flagellates, bacteria, diatoms, the spores of aquatic mosses, of horsetails, of club mosses, and quillworts, and the minute seeds of rushes. There may be also cysts of protozoa, gemmules of fresh-water sponges, the statoblasts of bryozoa, and the eggs of worms, leeches, crustacea, insects, and molluscs, all of which may be minute enough to be carried readily by the wind and resistant enough to survive the process. Untold numbers of these reproductive bodies may be gathered up by the wind and carried long distances. This goes far to explain the extremely wide, often cosmopolitan distribution of fresh water microorganisms.

It is not only aquatic organisms that have spores suitable for carriage by the wind, but also a long series of terrestrial ones including bacteria, algæ, fungi, mosses, liverworts, ferns, and club mosses. Dust-like seeds as those of orchids, broom-rapes, pyrolas, live-for-evers, etc., are almost as well adapted to wind transport as are spores. Perhaps the best illustration that can be given of the potency of the wind in distributing these plants is the part it played in the revegetation of the isolated volcanic island Krakatoa from which all life was extirpated by the 1883 eruption of almost unparalleled violence. From 16 to 30 per cent of the phanerogams established on Krakatoa 25 years after the catastrophe of 1883 were carried there by winds, as were all of the ferns (16 species) and lower cryptogams, almost without exception (more than 30 species). Between 49 and 63 per cent of its flora, therefore, is wind-borne. The first recolonization of the island in 1886 was entirely by wind-distributed species as algæ, bacteria, diatoms, liverworts, mosses, and ferns.[61]

The distribution of spores and other light reproductive cells does not depend on sporadic gusts of wind that suddenly pick up a quantity of these objects to later drop them as showers of organisms; there seem to be a certain number of them always in the atmosphere. In fact, aeroscopes reveal a steady fall of atmospheric dust, including minute organisms, that must be a far more important element in the distribution of such life than the more impressive but sporadic showers.

### CONCLUSION.

It would appear, therefore, that the more spectacular the shower of organic matter the less its importance in the distribution of life. The rains of larger animals have attracted much attention and excited wonder, but in many cases the animals have been dead; in others they were doomed to die because of falling in an unsuitable environment. Not often are all the conditions propitious for the species to secure a new foothold.

The unobtrusive, but steady and widespread movement of minute eggs and spores by the atmosphere, however, is of great importance in distribution because these organic bodies are adapted to survive such transport; their numbers are so great and their dispersal so wide that some of them will necessarily fall in favorable places. The chances are, in fact, that every suitable environment will be populated. So far as mere preservation of species is concerned, we see here, as in other phases of biological investigation, the superiority of the pigmy over the giant, of insignificance over conspicuousness, of passivity and adaptability over strenuous effort. "Blessed are the meek, for they shall inherit the earth."

[61] *Ernst, A.* The new flora of the volcanic island of Krakatau (Engl. transl. by A. C. Seward, 1908), pp. 60–68.

## RECORDS AT THE ABBE METEOROLOGICAL OBSERVATORY COMPARED WITH THOSE AT THE GOVERNMENT BUILDING, CINCINNATI.

By WILLIAM CHARLES DEVEREAUX, Meteorologist.

[Abbe Meteorological Observatory, Lafayette Circle, Cincinnati, Ohio, Apr. 11, 1917.]

During the 24 months from April 1, 1915, to March 31, 1917, both inclusive, complete weather records were made at the Government Building, Cincinnati, and at the Abbe Meteorological Observatory maintained by the United States Weather Bureau at Lafayette Circle, Clifton, Cincinnati, Ohio. The following pages present a discussion of these comparative observations.

### LOCATIONS OF EXPOSURES.

*The Government Building*, Cincinnati, is located 900 yards from the Ohio River, which forms the southern boundary of the city, and is near the center of the principal business section. (See fig. 1). Moderately high hills form a semicircle around the business section, which lies on the comparatively level ground between the hills and the river. The Government Building stands some distance east of the center of the semicircle of inclosing hills; the nearest hill is northeast from the building, the ground beginning to rise rapidly within a distance of half a mile and reaching an altitude of 247 feet above the ground at the Government Building, or of 800 feet above sea level. The hills to the north are distant ¾ mile, to the west 2 miles, to the southwest in Kentucky 1½ miles, and to the south 2½ miles from the Government Building. The highest of these hills lies between 800 and 900 feet above sealevel.

The elevations of the instruments above the ground at the Government building are as follows: Barometer, 74 feet; raingage, 145 feet; thermometers, 152 feet; anemometer, 160 feet; and wind vane, 161 feet. Within a radius of 600 feet and from a point directly southwest to a point a little east of south, there are buildings considerably higher than the wind vane. To the east, north, and west the buildings are about the same height as the wind vane. The general surroundings are illustrated in figures 2 and 3.

*The Abbe Meteorological Observatory* is located on Lafayette Circle, in the suburb of Clifton, and is near the geographic center of the city. This is not the highest point in the city but is one of the highest, and the nearest hill of the same elevation is about 2 miles distant. The visible horizon of the Observatory is nearly level on all sides. The ground slopes away from the Observatory in all directions, and is mostly covered with trees. The only buildings in the vicinity of the Observatory are residences. The elevations of the instruments above ground are as follows: Barometer, 5.8 feet; raingage, 3.1 feet; thermometers, 10.8 feet; anemometer, 50.8 feet; and wind vane, 52.2 feet. (See figs. 1, 4, and 5.)

### WIND RECORD.

In order to tabulate in detail the direction and velocity of the wind, a new form was prepared which shows the number of hours the wind blows from each direction, and the velocity of the wind from each direction. By the use of this form the percentage of time the wind blew from each direction and the mean velocity for each direction were obtained for each month, season, and the two years. Table 1 presents the form secured for March, 1916.

Pours down in many regions simultaneously. Likewise,
Many bolts of lightning fall together from the skies.

And last, why does he blast the sacred shrines of gods asunder
And wreck his *own* renowned abodes with brutal bolts of
thunder?
Why does he smash the well-wrought images of gods and maim
His own statues, disfiguring their splendour with his aim?
Why as a rule is it the higher places that he seeks;
Why do we find his scorch-marks mostly on the mountain
peaks?

It's easy from the earlier explanations to see why
What Greeks call 'blowers' – waterspouts – descend out of the
sky
Onto the water. For, at times, a kind of column falls
Out of the sky and touches the sea. And whipped up by the
squalls
Of heavy, hissing blasts, the sea around it seethes and brawls.
And any bark that's caught out in the hurricane is tossed,
Pitching and yawing on the waves, in danger of being lost.

Sometimes this happens when a stirred-up force of wind at first
Attempts to rend a cloud, but when it cannot make it burst
Presses it down instead, so that it drops upon the seas
Like a column let down from the heavens, as though, by degrees,
Something inside the cloud reached towards the water from
above –
As if a fist on outstretched arm pushed down a cloudy glove.
And when the force rips open the cloud at last and it bursts free
On the waves, it unleashes an amazing boiling of the sea,
For as it's lowering, the whirlwind twists, and it drags down
The pliant substance of the cloud along with it, but soon
As it thrusts the pregnant cloud on the face of the waters, in a
flash
It plunges itself in the waves, and roils them up with a
monstrous crash.



Or at times a whirling wind will wrap itself inside a shroud
Of mist by scraping together from the air the seeds of cloud
And imitates a 'blower' that's been lowered from the sky.
And when it gusts in off the sea and touches down on dry
Land, it disperses itself and vomits forth an enormous force
Of funnel clouds. But this is rare, and as a matter of course
The mountains block our view on land. So it's out on the deep
We tend to see them, against the whole sky's panoramic
sweep.

Now, clouds are formed when in the upper reaches of the sky
Many floating bodies come together suddenly,
Rather rough in texture, so that they can cling, despite
The fact that bonds among the particles of cloud are slight.
The seeds combine together to make cloudlings first, and these
Catch onto one another, accumulating by degrees,
And driven by the wind in racks, they gather in a swarm,
Until the point when they build up into a raging storm.

It also happens that the higher up the mountains crowd
Against the sky, the more their peaks continuously cloud
With a thick scrim of tawny mist, because when clouds begin
To form – before the eye can make them out, they are so
thin –
The wind harries and herds them up against the summits. Here
At length they flock together thickly enough that they appear,
While seeming at the same time to rise from the mountain
peaks
Into the aether. Indeed, experience itself bespeaks
The windiness of upper altitudes; for when we scale
Towering mountain steeps, continuous blasts of air assail
Our senses.

In addition, the fact that laundry hung up near
The seashore becomes damp with clinging moisture makes it
clear
That Nature is ever lifting a host of particles from the sea,
Making it probable that clouds swell from the quantity

Of particles rising from the briny tossing of the tides,
The moisture in either case entirely akin.

Besides,
We notice that from all the rivers and from the very earth
Mists and vapours rise, exhaling from the land like breath.
And in this manner, steams are borne aloft, and steep the sky
In murkiness, and gathering by degrees, they resupply
The lofty clouds. For also the seething of the starry aether
Pushes from above and squeezes the vapours close together
So that they weave a tapestry of cloud beneath the blue.

The bodies that make clouds and scudding racks, it's also true,
Can enter our heavens from beyond. For I have shown the sum
Of atoms is innumerable, and the Deep from whence they come
Is bottomless, and I have shown how nimbly and how fast
They speed, how in a trice they regularly cross such vast
Distances as boggle the mind. It's therefore no surprise
It doesn't take much time for gloom and storm hung from the skies
To bury underneath huge thunderheads both sea and land,
Since on all sides, through every corridor of aether and
Through all the breathing pores and passageways of the whole world round,
Entrances and exits for the elements abound.

Now pay attention, and I'll show how moisture of the rain
Is collected in the clouds above and is sent down again
To the earth in showers. First I'll prove that many seeds of water
Arise with the clouds themselves from all things. And both grow together,
The clouds and whatever moisture the clouds hold. It is the same
With us, the flesh grows with the blood, or anything the frame
Contains by way of moisture: sweat, et cetera. Like wool
Fleeces hung out on the line, clouds also often pull
Large amounts of water from the sea when winds convey
Them over the vasty deep. And water in the selfsame way



Is lifted to the clouds from all the rivers. When enough
Water-seeds accrue in various ways and build and stuff
The clouds to bursting from every side, the saturated clouds
Strive to release their moisture in a twofold way: wind crowds
The clouds together with its force, and heaps them in a tower,
And the pressure of their own mass bearing down wrings out a shower;
Whereas when clouds are loosened by the winds or come undone,
Scattered thin when they are beaten by the heat of the sun,
They give off drops of rain and drip, just as candles grow lax
When held above a burning flame, and run with melting wax.

Two factors are at work when violent downpours come to pass:
The clouds are violently pressed by winds and squeezed by their own mass,
While steady rains that don't let up and last for quite a while
Happen when many water-seeds arise and cloud-racks pile
On sopping clouds, gathered from every quarter, and the terrain,
Steaming everywhere, exhales the moisture up again.
And it is at such times, when the sun shines through the murky rack
With its rays, and raindrops of the clouds it strikes against gleam back,
That the colours of the rainbow glow against the tempest's black.

And all the other things created overhead which grow
Condensing in the clouds, yes every one of them – the snow,
The winds, the hail, the chilling frost, ice with its power to stay
The waters, Mighty Hardener that makes rivers delay,
Reining them back along their headlong course at every turn –
How and why these things arise is easy to discern
For all their variety – the mind discovers and it sees –
Once you have grasped their elements' inherent properties.