Assessment System and Observation Network

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Contributor: Liz Coleman

We propose to build on and link with the existing research activities and observational networks and infrastructures to specifically address the key North Atlantic challenges that encompass a range of policy areas. This will strengthen the institutional response to weather, climate, environmental and ecological threats and reduce societal risk.

Keywords: observation ; North Atlantic ; integration ; atmospheric composition ; climate change

1. Introduction

A range of scientific assessment and observation support systems have developed to inform and support the implementation of the three MEAs. These include the evolution of a number of environmental measurement communities: The World Meteorological Organisation's Global Atmospheric Watch Programme (WMO GAW), which is mandated to reduce environmental risks to society and meet the requirements of environmental conventions, strengthen capabilities to predict climate, weather and air quality and contribute to scientific assessments in support of environmental policy; GCOS, which monitors Essential Climate Variables (ECVs) under the UNFCCC; EMEP, which provides sound scientific support to the CLRTAP by collecting air pollution emission data via quality-controlled measurement network and modelling of atmospheric transport and deposition; AGAGE, which has been augmenting the WMO GAW by measuring non-CO 2 greenhouse gases and ozone-depleting chemicals (ODCs) to ensure compliance with the Montreal Protocol of the Vienna Convention.

The Earth exists as a complex, synergistic organism in which components and processes are interdependent and self-regulating in response to changes [1]. The atmosphere cannot be considered as a distinct entity, but as a realm that is fundamentally and intrinsically connected to all components of the Earth system. Understanding the impacts of changes and the implications of atmospheric protection strategies requires integration of advanced, sustained measurements that allow the analyses needed to gain a better understanding of interactions and feedbacks and better early warnings for environmental events necessary to address interconnected societal and environmental challenges [2].

Here, we propose the development of an international regional forum to assess integrated environmental threats related to atmospheric compositional changes in the North Atlantic region as has been achieved for the Arctic. This North Atlantic forum will focus on addressing the fundamental scientific issues and key uncertainties that are central to environmental policy areas, thus providing a tangible focus for the planetary boundaries concept in the context of the region.

The need to strengthen the in situ, sustained observational capacity of Essential Climate Variables (ECVs) has been previously highlighted [3][4]. Although there currently exists interaction and collaboration between the various measurement communities serving the North Atlantic region, geographical measurement gaps remain (See **Figure 5**.1 in ACE20 report [5]) which propagate to gaps in scientific understanding of environmental processes and hence the potential impacts of environmental change. Possible mitigation options are not well elucidated [6]. Furthermore, many existing sites struggle to secure sustained funding that is fundamental to the functioning of surface-based observing networks [5].

2. Societal and Scientific Context

Over 40% of the population live in coastal regions in both EU-27 regions and the US [7][8]. Coastal regions are major economic, societal and cultural centres which have developed and evolved over millennia, major coastal cities and population centres thrive as major economic centres, enhanced by the development of recreational and tourism facilities. These developments are contingent on access to a safe, healthy and thriving environment and the continued stability of weather and climate systems. Populations in proximity to the coast are disproportionally vulnerable to the effects of the changing Atlantic region, with significant implications for human health and well-being as well as societal and economic implications.

The North Atlantic Ocean spans an area in excess of 41 million km 2, stretching from Newfoundland to North Africa and Latin America, connecting four major continents, including two of the most developed regions in the world: the USA/Canada and Europe. It contains unique areas with major regional and global influences; dust from the Sahara Desert is advected across the Atlantic to the Amazon, replenishing the stores of phosphorous necessary to sustain the vitality of the great Rain Forests of Latin America [9][10]. The Atlantic is bound in the north by the Arctic Eurasian Basin and surrounds the massive Greenland ice sheet, the existence of which is under threat from climate change and holds enough water to cause 7.4 m of sea-level rise (SLR) [11]. The oceans are a sink for 40% of anthropogenic CO_2 emitted to the atmosphere [12][3] and they absorb over 90% of the additional energy being trapped by addition of anthropogenic GHGs. Increasing ocean temperature leads to sea-level rise and ocean acidification.

Large-scale ocean currents redistribute heat added to the surface ocean. In the North Atlantic, the AMOC is a primary driver of ocean circulation, regulating regional climate on both sides of the Atlantic, modulating carbon sequestration and interacting with atmospheric circulation patterns marked notably by the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO). The AO determines the strength of the polar vortex which affects stratospheric ozone depletion [13]. The multidecadal climate variability in the North Atlantic is driven by the AMOC and the sea-surface temperature-based Atlantic Multidecadal Oscillation (AMO), the two climatic cycles interacting with each other [14][15]. The AMO has a major societal impact, influencing regional weather events, e.g., Sahel rainfall [16], European precipitation [17], North Atlantic hurricanes [18] and temperature variations [19][20]. It is influenced by the NAO [21]. These periodic circulation patterns all represent different aspects of the physical dynamical aspects of the Atlantic that influence and are influenced by climate and hence, a robust understanding of these regional climate patterns and air–sea interactions is vital in order to assess the state of our changing climate [3][22].

Many global environmental changes and trends are first evident, and in some cases, amplified in the North Atlantic region, which render the region vulnerable to further environmental change. These changes manifest over a range of timescales. Changes occurring due to elevated CO_2 emissions are essentially irreversible over century to millennial time scales [23]. Atmospheric observations and scientific assessment in recent decades have provided significant enhancement in our understanding of Earth-system processes affecting the environment. There now exists an opportunity to take advantage of existing structures to integrate atmospheric observations over the North Atlantic to advance our understanding of drivers and consequences of atmospheric change in terms of the three science-policy thematic challenges identified above.

3. Science-Policy Thematic Challenges

Western Europe is subject to elevated ozone levels due to the transatlantic transport of anthropogenic ozone, contributing on average 5 ppb to background surface ozone, up to 10–20 ppb during transatlantic transport events [24]. Ozone is an atmospheric pollutant with adverse effects on vegetation and human health. In 2018, over one-third of EU citizens were exposed to ozone levels exceeding EU limits [25]. Despite ozone being a major focus of the Task Force on the Hemispheric Transport of Air Pollution (HTAP), there is major uncertainty regarding simulated surface ozone levels in global models [26]. Despite tighter controls on ozone precursors in recent decades, there has been an overall increase in ozone levels in the mid to upper troposphere of the northern hemisphere in recent decades [27], influenced by teleconnections with dynamic transport and atmospheric circulation patterns and modes of climate variability including the AO [28], the NAO [29][30] and stratospheric circulation patterns [31].

Atmospheric carbon is the key player instrumental in anthropogenic radiative forcing, as shown in **Figure 3** . Recent ocean flux measurements suggest that the oceanic carbon sink has been underestimated and there is a need for revision of the global carbon budget [32].

Marine aerosols play a significant role in aerosol load and hence albedo and climate, with phytoplankton blooms playing a key role in the aerosol–cloud–climate feedback system [33][34]. The presence of organic matter in aerosols significantly alters CCN properties [35][36], applying a seasonality to the marine CCN budget. CCN in the pristine environment can be affected by long-range transport of pollutants, which may have significant enhancing effect on dimming [37]. Hence, decreasing levels in background aerosol levels would lead to brightening [38], but the interactions between aerosols, clouds and the energy budget are complex and non-linear. For example, the presence of sea spray in CCN can disproportionately affect cloud albedo compared to the presence of sulphate, yet the magnitude of the effect depends on the ratio of sulphate to sea spray aerosol and meteorological conditions [39].

Forcing effects on North Atlantic Sea Surface Temperature (NASST) concludes that at least two-thirds of the NASST response in an Earth system model is associated with aerosol–cloud interactions, highlighting the need to better understand them [40]. Additionally, a dynamical response of the fully coupled atmosphere–ocean system to changes in the aerosol pattern was evident. This result is consistent with CMIP6 Climate Models [41]. Results from this study suggest that the continued decrease in anthropogenic aerosol emissions in the interest of air quality will reinforce GHG-induced AMOC weakening in recent decades. The aerosol indirect effect in the North Atlantic especially needs further investigation for more complete understanding of our climate system and the knowledge gap will be closed only by continued study of interactions and feedbacks between the ocean and the atmosphere that are facilitated by sustained measurements with advanced atmospheric probing instrumentation for aerosols, clouds, and short-lived gas-phase species, including in situ and remote sensing measurements at key strategic sites. The Arctic region is susceptible to rapid changes in response to changes to the radiative properties in the atmosphere, which will lead to physical and biogeochemical changes in the North Atlantic, with major consequences.

4. Potential Cross-Thematic Benefits of Integrated Assessment System and Monitoring Network

The three science-policy issues pertaining to atmospheric composition can be viewed as distinct environmental challenges facing the North Atlantic region, an integrated assessment of the atmospheric composition and changes would enable an aggregated, co-beneficial policy response addressing each thematic challenge. Integrated assessment requires sustained monitoring of the circulation patterns, radiative parameters, atmospheric composition and air–surface interactions in key strategic sites, as we propose here.

Atmospheric composition contributes to physical changes in the multidecadal climate variability of the North Atlantic [20]; sea surface temperatures, and hence North Atlantic climate variability, is influenced by changes to atmospheric composition from both natural and anthropogenic sources [42][43]. Atmospheric aerosol cooling supresses tropical cyclone activity [44], and significant anti-correlation between Saharan dust and tropical cyclone activity in the North Atlantic [45], where studies have shown Saharan dust plumes to affect environmental stability [46][47], yet causality has not been firmly established.

Tropospheric ozone is both a powerful GHG and a health, ecological and economic concern as it is an agent of crop and vegetation damage. North Atlantic surface ozone levels can be modulated by ocean productivity [48][49][50]. The current generation of chemical transport models still exhibit strong inter-model differences in simulated ozone mixing ratios, especially prevalent in spring time [26]. Owing to the vital role that ozone plays in atmospheric chemistry, radiative forcing, human health, and the exacerbating effect that a changing climate will have on air pollution problems (it is estimated that the annual cost for climate-driven ozone deaths in the US will approach $7 ($10) billion by 2050 and $18 ($26) billion by 2090 under RCP4.5 (RCP8.5) projections [51]), it is vital that global models have the capacity to accurately simulate ozone mixing ratios. The large range in surface atmospheric ozone concentrations between current models indicate the need for better representation of ozone-regulating transport, atmospheric chemistry and removal processes in our models. Improvement of the performance of atmospheric chemical transport models in simulating ozone concentrations and budgets in the North Atlantic requires more comprehensive vertical measurements of ozone and its precursors. Atmospheric circulation patterns significantly affect surface ozone levels in the North Atlantic [29][52], where transport of elevated ozone levels in the marine boundary layer has been previously observed [53][54][55].

As local air pollution sources have declined owing to the success of the unified global effort of the CLRTAP, the contribution of long-range transported precursors to ozone levels in Europe and North America has increased [56][57][58]. Models will not have the capacity to accurately simulate intercontinental ozone transport without a clear understanding of the processes that affect ozone formation and destruction in the marine boundary layer. This understanding necessitates co-ordinated high-precision measurements in and around the region [59].

References

1. Lovelock, J.; Lovelock, J.E. Gaia: A New Look at Life on Earth; Oxford University Press: Oxford, UK, 2000.
2. Hari, P.; Petäjä, T.; Bäck, J.; Kerminen, V.-M.; Lappalainen, H.; Vihma, T.; Laurila, T.; Viisanen, Y.; Vesala, T.; Kulmala, M. Conceptual design of a measurement network of the global change. Atmos. Chem. Phys. Discuss. 2016, 16, 1017–1028.
3. IPCC. Climate Change 2014: Synthesis Report Summary for Policy Makers. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Pachauri, R.K., Meyer, L.A., Eds.; IPCC: Geneva, Switzerland, 2014.
4. Skinner, I.; Farmer, A.; Kuik, O. The Thematic Strategy on Air Pollution; Policy Brief for the EP Environment Committee; IEEP: Brussels, Belgium, 2006.

5. Barrie, L.; McGovern, F.M. Protecting the North Atlantic atmosphere: A report on the outcome of an international meeting on the twentieth anniversary of the second aerosol characterisation experiment (ACE2). In EPA Research Report; EPA: Tenerife, Spain, 2017.
6. WMO. GCOS/IPCC/UNCCC Workshop on Enhancing Observations to Support Preparedness and Adaptation in a Changing Climate—Learning from the IPCC 5th Assessment Report; WMO: Bonn, Germany, 2015.
7. European Union. Eurostat Regional Yearbook 2011; European Union: Brussels, Belgium, 2011.
8. NOAA. National Coastal Population Report; NOAA: Washington, DC, USA, 2013.
9. Yu, H.; Chin, M.; Yuan, T.; Bian, H.; Remer, L.A.; Prospero, J.M.; Omar, A.; Winker, D.; Yang, Y.; Zhang, Y.; et al. The fertilizing role of African dust in the Amazon rainforest: A first multiyear assessment based on data from Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations. Geophys. Res. Lett. 2015, 42, 1984–1991.
10. Prospero, J.M.; Barkley, A.E.; Gaston, C.J.; Gatineau, A.; Sansano, A.C.Y.; Panechou, K. Characterizing and Quantifying African Dust Transport and Deposition to South America: Implications for the Phosphorus Budget in the Amazon Basin. Glob. Biogeochem. Cycles 2020, 34, 6536.
11. Morlighem, M.; Williams, C.; Rignot, E.; An, L.; Arndt, J.E.; Bamber, J.L.; Catania, G.; Chauché, N.; Dowdeswell, J.; Dorschel, B.; et al. BedMachine v3: Complete Bed Topography and Ocean Bathymetry Mapping of Greenland From Multibeam Echo Sounding Combined With Mass Conservation. Geophys. Res. Lett. 2017, 44, 11.
12. Rogelj, J.; Forster, P.; Kriegler, E.; Smith, C.J.; Séférian, R. Estimating and tracking the remaining carbon budget for stringent climate targets. Nat. Cell Biol. 2019, 571, 335–342.
13. Waugh, D.W.; Polvani, L.M.; Sobel, A.H. Stratospheric polar vortices. Extreme Events 2010, 190, 43–57.
14. Kim, H.; An, S.; Kim, D. Timescale-dependent AMOC–AMO relationship in an earth system model of intermediate complexity. Int. J. Clim. 2021, 41, 3298.
15. Zhang, L.; Wang, C. Multidecadal North Atlantic sea surface temperature and Atlantic meridional overturning circulation variability in CMIP5 historical simulations. J. Geophys. Res. Oceans 2013, 118, 5772–5791.
16. Zhang, R.; Delworth, T. Impact of Atlantic multidecadal oscillations on India/Sahel rainfall and Atlantic hurricanes. Geophys. Res. Lett. 2006, 33.
17. Sutton, R.; Dong, B. Atlantic Ocean influence on a shift in European climate in the 1990s. Nat. Geosci. 2012, 5, 788–792.
18. Goldenberg, S.B.; Landsea, C.W.; Mestas-Nunez, A.; Gray, W.M. The Recent Increase in Atlantic Hurricane Activity: Causes and Implications. Science 2001, 293, 474–479.
19. Chen, X.; Tung, K.-K. Varying planetary heat sink led to global-warming slowdown and acceleration. Science 2014, 345, 897–903.
20. Wang, C.; Dong, S.; Evan, A.T.; Foltz, G.; Lee, S.-K. Multidecadal Covariability of North Atlantic Sea Surface Temperature, African Dust, Sahel Rainfall, and Atlantic Hurricanes. J. Clim. 2012, 25, 5404–5415.
21. McCarthy, G.D.; Haigh, I.D.; Hirschi, J.J.-M.; Grist, J.; Smeed, D. Ocean impact on decadal Atlantic climate variability revealed by sea-level observations. Nat. Cell Biol. 2015, 521, 508–510.
22. Laffoley, D.; Baxter, J.M. Explaining Ocean Warming: Causes, Scale, Effects and Consequences; IUCN: Gland, Switzerland, 2016.
23. Solomon, S.; Plattner, G.-K.; Knutti, R.; Friedlingstein, P. Irreversible climate change due to carbon dioxide emissions. Proc. Natl. Acad. Sci. USA 2009, 106, 1704–1709.
24. Li, Q.; Jacob, D.J.; Bey, I.; Palmer, P.I.; Duncan, B.N.; Field, B.D.; Martin, R.; Fiore, A.; Yantosca, R.M.; Parrish, D.D.; et al. Transatlantic transport of pollution and its effects on surface ozone in Europe and North America. J. Geophys. Res. Space Phys. 2002, 107, ACH 4-1–ACH 4-21.
25. EEA. Indicator Assessment. In Exceedance of Air Quality Standards in Europe; EEA: Geneva, Switzerland, 2020.
26. Butler, T.; Lupascu, A.; Nalam, A. Attribution of ground-level ozone to anthropogenic and natural sources of nitrogen oxides and reactive carbon in a global chemical transport model. Atmos. Chem. Phys. Discuss. 2020, 20, 10707–10731.
27. Gaudel, A.; Cooper, O.R.; Chang, K.-L.; Bourgeois, I.; Ziemke, J.R.; Strode, S.A.; Oman, L.D.; Sellitto, P.; Nédélec, P.; Blot, R.; et al. Aircraft observations since the 1990s reveal increases of tropospheric ozone at multiple locations across the Northern Hemisphere. Sci. Adv. 2020, 6, eaba8272.
28. Zhang, J.; Tian, W.; Xie, F.; Sang, W.; Guo, N.; Chipperfield, M.; Feng, W.; Hu, D. Zonally asymmetric trends of winter total column ozone in the northern middle latitudes. Clim. Dyn. 2018, 52, 4483–4500.

29. Pausata, F.S.R.; Pozzoli, L.; Vignati, E.; Dentener, F.J. North Atlantic Oscillation and tropospheric ozone variability in Europe: Model analysis and measurements intercomparison. Atmos. Chem. Phys. Discuss. 2012, 12, 6357–6376.

30. Lin, M.; Fiore, A.; Horowitz, L.W.; Langford, A.; Oltmans, S.J.; Tarasick, D.; Rieder, H.E. Climate variability modulates western US ozone air quality in spring via deep stratospheric intrusions. Nat. Commun. 2015, 6, 710.

31. Neu, J.L.; Flury, T.; Manney, G.L.; Santee, M.L.; Livesey, N.J.; Worden, J. Tropospheric ozone variations governed by changes in stratospheric circulation. Nat. Geosci. 2014, 7, 340–344.

32. Watson, A.J.; Schuster, U.; Shutler, J.D.; Holding, T.; Ashton, I.G.C.; Landschützer, P.; Woolf, D.K.; Goddijn-Murphy, L. Revised estimates of ocean-atmosphere CO2 flux are consistent with ocean carbon inventory. Nat. Commun. 2020, 11, 1–6.

33. O'Dowd, C.; Facchini, M.C.; Cavalli, F.; Ceburnis, D.; Mircea, M.; Decesari, S.; Fuzzi, S.; Yoon, Y.J.; Putaud, J.-P. Biogenically driven organic contribution to marine aerosol. Nat. Cell Biol. 2004, 431, 676–680.

34. O'Dowd, C.; Ceburnis, D.; Ovadnevaite, J.; Vaishya, A.; Rinaldi, M.; Facchini, M.C. Do anthropogenic, continental or coastal aerosol sources impact on a marine aerosol signature at Mace Head? Atmos. Chem. Phys. Discuss. 2014, 14, 10687–10704.

35. Sanchez, K.J.; Chen, C.-L.; Russell, L.M.; Betha, R.; Liu, J.; Price, D.J.; Massoli, P.; Ziemba, L.D.; Crosbie, E.C.; Moore, R.H.; et al. Substantial Seasonal Contribution of Observed Biogenic Sulfate Particles to Cloud Condensation Nuclei. Sci. Rep. 2018, 8, 1–14.

36. Ovadnevaite, J.; Zuend, A.; Laaksonen, A.; Sanchez, K.J.; Roberts, G.; Ceburnis, D.; Decesari, S.; Rinaldi, M.; Hodas, N.; Facchini, M.C.; et al. Surface tension prevails over solute effect in organic-influenced cloud droplet activation. Nat. Cell Biol. 2017, 546, 637–641.

37. Wild, M. Enlightening Global Dimming and Brightening. Bull. Am. Meteorol. Soc. 2012, 93, 27–37.

38. O'Dowd, C.; Ceburnis, D.; Vaishya, A.; Jennings, S.G.; Moran, E. Cleaner air: Brightening the pollution perspective? AIP Conf. Proc. 2013, 1527, 579–582.

39. Fossum, K.N.; Ovadnevaite, J.; Ceburnis, D.; Preißler, J.; Snider, J.R.; Huang, R.-J.; Zuend, A.; O'Dowd, C. Sea-spray regulates sulfate cloud droplet activation over oceans. NPJ Clim. Atmos. Sci. 2020, 3, 1–6.

40. Fiedler, S.; Putrasahan, D. How Does the North Atlantic SST Pattern Respond to Anthropogenic Aerosols in the 1970s and 2000s? Geophys. Res. Lett. 2021, 48, e2020GL092142.

41. Hassan, T.; Allen, R.J.; Liu, W.; Randles, C.A. Anthropogenic aerosol forcing of the Atlantic meridional overturning circulation and the associated mechanisms in CMIP6 models. Atmos. Chem. Phys. Discuss. 2021, 21, 5821–5846.

42. Evan, A.T.; Vimont, D.J.; Heidinger, A.K.; Kossin, J.P.; Bennartz, R. The Role of Aerosols in the Evolution of Tropical North Atlantic Ocean Temperature Anomalies. Science 2009, 324, 778–781.

43. Birkel, S.D.; Mayewski, P.A.; Maasch, K.A.; Kurbatov, A.V.; Lyon, B. Evidence for a volcanic underpinning of the Atlantic multidecadal oscillation. NPJ Clim. Atmos. Sci. 2018, 1, 24.

44. Mann, M.E.; Emanuel, K.A. Atlantic hurricane trends linked to climate change. Eos 2006, 87, 233–241.

45. Evan, A.T.; Dunion, J.; Foley, J.A.; Heidinger, A.K.; Velden, C.S. New evidence for a relationship between Atlantic tropical cyclone activity and African dust outbreaks. Geophys. Res. Lett. 2006, 33, 33.

46. Wang, K.Y.; Liu, C.H.; Wan, K.-Y. Transport of the Saharan dust air plumes over the tropical North Atlantic from FORMOSAT–3/COSMIC observation. Atmos. Pollut. Res. 2014, 5, 539–553.

47. Carlson, T.N.; Prospero, J. The Large-Scale Movement of Saharan Air Outbreaks over the Northern Equatorial Atlantic. J. Appl. Meteorol. 1972, 11, 283–297.

48. Coleman, L. Regional Scale Modelling of Boundary Layer Ozone and Influences of Climate Change; National University of Ireland: Galway, Ireland, 2012.

49. Coleman, L.; Martin, D.; Varghese, S.; Jennings, S.; O'Dowd, C. Assessment of changing meteorology and emissions on air quality using a regional climate model: Impact on ozone. Atmos. Environ. 2013, 69, 198–210.

50. Coleman, L.; McVeigh, P.; Berresheim, H.; Martino, M.; O'Dowd, C.D. Photochemical Impact on Ozone Fluxes in Coastal Waters. Adv. Meteorol. 2012, 2012, 1–6.

51. USEPA. Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment; US Environmental Protection Agency: Washington, DC, USA, 2017.

52. Parrish, D.D.; Law, K.; Staehelin, J.; Derwent, R.; Cooper, O.R.; Tanimoto, H.; Volz-Thomas, A.; Gilge, S.; Scheel, H.-E.; Steinbacher, M.; et al. Lower tropospheric ozone at northern midlatitudes: Changing seasonal cycle. Geophys. Res. Lett. 2013, 40, 1631–1636.

53. Simmonds, P.; Derwent, R. Measurements of ozone and other radiatively active gases at Mace Head in the Republic of Ireland. Atmos. Environ. Part A Gen. Top. 1991, 25, 1795–1808.

54. Derwent, R.; Manning, A.J.; Simmonds, P.G.; Spain, G.; O'Doherty, S. Analysis and interpretation of 25 years of ozone observations at the Mace Head Atmospheric Research Station on the Atlantic Ocean coast of Ireland from 1987 to 2012. Atmos. Environ. 2013, 80, 361–368.

55. Rodríguez, S.; Torres, C.; Guerra, J.-C.; Cuevas, E. Transport pathways of ozone to marine and free-troposphere sites in Tenerife, Canary Islands. Atmos. Environ. 2004, 38, 4733–4747.

56. Parrish, D.D.; Trainer, M.; Holloway, J.S.; Yee, J.E.; Warshawsky, M.S.; Fehsenfeld, F.C.; Forbes, G.L.; Moody, J.L. Relationships between ozone and carbon monoxide at surface sites in the North Atlantic region. J. Geophys. Res. Space Phys. 1998, 103, 13357–13376.

57. Oltmans, S.J.; Levy, H. Surface ozone measurements from a global network. Atmos. Environ. 1994, 28, 9–24.

58. Lelieveld, J.; Van Aardenne, J.; Fischer, H.; De Reus, M.; Williams, J.; Winkler, P. Increasing Ozone over the Atlantic Ocean. Science 2004, 304, 1483–1487.

59. Boylan, P.; Helmig, D.; Oltmans, S.J. Ozone in the Atlantic Ocean marine boundary layer. Elem. Sci. Anth. 2015, 3, 000045.
