Introduction to the QJ@150 anniversary collection

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EDITORIAL

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2023 is a momentous year for the Quarterly Journal of the Royal Meteorological Society (QJ), celebrating its 150th anniversary. The QJ was initiated in 1873 at a time when meteorological science was growing rapidly in scope and importance and is one of the first atmospheric science journals to be established. The Meteorological Society had not yet been recognised with the use of "Royal" in its title (that was bestowed by Queen Victoria in 1883). The International Meteorological Organization was also founded in 1873 to build a worldwide network of meteorological observations and agreement on standardized observation methods - this later became the World Meteorological Organization .

This QJ@150 Anniversary collection has been collated to highlight some of the milestone papers from the journal over its history. All papers have been nominated by former and current editors-in-chief of the journal and so inevitably reflects our personal interests, however we hope it will give a flavour of the important contribution the journal has made over its 150 years to advancing the field of meteorology, atmospheric science and related disciplines. We aimed to select papers spanning key advances in atmospheric science, reflecting the wide range of topics covered and covering theoretical developments, observational breakthroughs and numerical modelling studies. Some papers will be exceedingly well known by atmospheric scientists, others perhaps less so, but they have all made an important contribution in their field.

The earliest paper in this collection is Harrison and Dobson (1925). Harrison and Dobson conducted important early work on the upper atmosphere, including this paper which reports some of the first spectral measurements of ozone concentrations in the atmosphere and their links to surface pressure. This work laid the foundations for our understanding of the ozone layer and its impact on the Earth's climate. Dobson went on to have the unit of measurement of the total ozone in a vertical column in the atmosphere (the Dobson unit) named after him.

The first sentences of Callendar (1938) read: "Few of those familiar with the natural heat exchanges of the atmosphere, which go into the making of our climates and weather, would be prepared to admit that the activities of man could have any influence upon phenomena of so vast a scale. In the following paper I hope to show that such influence is not only possible, but is actually occurring at the present time". In this paper Callendar achieved just that, by collation and careful analysis of CO_2 and temperature measurements from round the globe and an understanding and application of the infrared properties of CO_2. His estimates of the warming due to anthropogenic emissions of CO_2 agree remarkably well with the more recent estimates of the observed warming. Other authors had suggested that CO_2 from fossil fuel combustion might lead to rising temperatures but it fell to Callendar to demonstrate the reality. The importance of this paper for climate science has only relatively recently been acknowledged (Hawkins and Jones, 2013) and it is even more remarkable in that Callendar was a steam engineer studying the climate as a hobby.

In contrast, Carl-Gustav Rossby is one of the most influential meteorologists of the 20th century, making important contributions in synoptic and dynamical meteorology. Rossby developed the theory of the planetary scale wave that now bears his name and in Rossby (1940) he introduced the first recorded reference to the term "potential vorticity" in the sense now used in geophysical fluid dynamics. He showed how large scale motions are fundamentally influenced by both the rotation of the Earth and the stable stratification of atmosphere and oceans. In an earlier paper in 1938, Rossby combined the dynamics of vorticity (a measure of fluid rotation) and the conservation of potential temperature following air masses to obtain a single variable, potential vorticity, that is conserved by stratified flows in the absence of diabatic or frictional processes. This enables us to combine the effects of advection of vorticity over large distances with the effects of vortex stretching associated with changes in stratification as air moves. In this 1940 QJ paper he used the theory to explain why "semi-permanent centres of action" exist in the mid-latitude westerlies, associated with meridional meanders of the jet stream and persistent weather regimes dependent on the troughs and ridges in the wave pattern. The concepts developed in this paper have gone on to be crucial tools in understanding the dynamics of the atmosphere and influenced several other

papers in this collection.

Brewer (1949) is one of the most influential papers ever published in stratospheric science. Based on measurements from a series of aircraft flights over Southern England, Brewer established that, firstly, the helium mixing ratio remained unchanged up 20 km, and secondly that the water vapour mixing ratio decreased drastically with height above the tropopause, to values much lower than the lowest possible saturation mixing ratio at midlatitude tropopause temperatures. From the helium distribution, Brewer argued that the stratosphere could not be free from turbulence, so the only way to reconcile the water vapour observations was to propose a global circulation drawing air upwards into the stratosphere in the tropics (where the tropopause was known to be higher and colder) and transporting it poleward and downward. This circulation is now known as the Brewer-Dobson circulation and is the foundation of our conceptual model of the global stratosphere . To correctly deduce this structure from the limited airborne observations was a remarkable feat. The back-story to this research is that the measurements were made to understand why contrails were sometimes being formed by allied bombers during the second world war; it is an outstanding example of applied research leading to a fundamental discovery.

Malkus (1952) is another fine early example of using aircraft observations together with simple models, in this case to understand the role of shear and entrainment on convection. These are topics which continue to attract attention to this day. Joanne Malkus (later Joanne Simpson) was the first woman to obtain a PhD in Meteorology in the USA and this is the earliest paper in the QJ which we are aware of written by a female lead author. Both this paper and the paper of Rossby also exemplify the fact that although it is the journal of the Royal Meteorological Society, QJ is long established as a respected international journal in the field.

The advent of computers and pioneering work on numerical weather prediction revolutionised atmospheric science long before computation was used in other fields. Phillips (1956) was one of the first studies to use a very simple numerical model to simulate the global circulation. Despite its simplicity and coarse resolution (only two layers in the vertical with 16x17 grid points in the horizontal), the model was able to spin up from rest to generate a qualitatively realistic circulation over several weeks before numerical truncation errors caused the breakdown of the solution. The model is widely regarded as the first atmospheric global circulation model (advancing from the single-layer simulations for the first numerical weather predictions). Pioneering research such as this was instrumental in the development of modern numerical weather prediction and climate modelling.

Rodgers and Walshaw (1966) has proved to be a benchmark paper for calculating radiative heating rates. It is exemplary in the way that the parameterisation is clearly presented, the approximations explored and their impact quantified. The paper was the first to demonstrate the role of all the most important radiatively-active gases, providing much better context than previous studies which had examined only individual gases. It was also the first paper to quantify the contribution of "cooling to space" to the total radiative cooling rate, which substantially influenced both understanding of radiative processes, and the design of more highly-parameterised schemes for general circulation models that were to follow.

Although atmospheric chemistry research is now often published in more specialist journals, QJ has featured some groundbreaking papers in this field. Crutzen (1970) demonstrated that atmospheric NO, introduced into the stratosphere through the breakdown of the N_2O molecule which is produced at the surface by soil bacteria, can initiate a catalytic destruction of ozone. This provided an explanation of why stratospheric ozone measurements were lower than those predicted using the accepted oxygen-only photochemical theory. It also provided a route through which the fertilisers used to enhance soil nitrogen could result in ozone destruction. For this work Paul Crutzen was awarded, jointly with Sherwood Rowland and Mario Molina, the 1995 Nobel Prize for Chemistry.

Green (1970) is an excellent example of clear physical insight combined with mathematical rigour which shapes our understanding of how the atmosphere works. Building on his work on baroclinic instability, Green constructed a theory of global atmospheric circulation based on the idea that large-scale eddies (weather systems) play a cru-

cial role in transferring heat and potential vorticity. For simplified cases the theoretical model was integrated analytically and shows good qualitatively agreement with the observed patterns of winds in the troposphere, the mesospheric wintertime jet and ocean currents in the Gulf Stream. This paper has gone on to be very influential and has been highly cited.

Another revolution in the field of meteorology has been the development of satellite observations. Barnett et al. (1972) presents the first year of infra-red radiometer data from the Nimbus 4 satellite. This was the first satellite to retrieve temperature profiles from observations of infra-red radiation and this paper is therefore an early example of going beyond just satellite images. Since then QJ has published many papers on retrieval of atmospheric measurements from many satellite based instruments and the application of these observations to weather prediction.

Considering finer scales, QJ has published a wide range of papers on boundary layer meteorology - covering theory, observations and numerical modelling. Jackson and Hunt (1975) is one of the most influential theoretical papers in this field. It presented an analytical model for the adjustment of a turbulent boundary layer over a hill. The asymptotic approach developed in this paper has inspired a whole range of further studies extending the solution to cover stratified flow and flow over canopy-covered hills and developing solutions for flow over a range of other surface heterogeneities. The analytical solutions have been a benchmark for interpreting field and wind tunnel observations and for validating numerical models and the paper continues to be widely cited, nearly 50 years after its first publication.

Gill (1980) is another hugely influential theoretical paper from the journal. In this paper Gill presented simple analytical solutions for the wave response of the tropical atmosphere to diabatic heating caused by convection. These solutions have been an important component in developing our understanding of the importance of convection on the tropical atmosphere and the role of Kelvin waves in propagating that impact around the tropics. While some of the ideas in this paper had been discussed in previous literature, the clear presentation of the analytical solutions in Gill (1980) remains the key reference in the field and his drawings of the solution have been included in countless other papers and talks over the last 40 years.

Baker et al. (1980) is one of a series of seminal papers in cloud physics published in QJ. The paper marked the beginning of a new understanding of entrainment into cumulus clouds and how that entrainment influenced the cloud droplets and the development of warm rain. This paper introduced several new ideas. It was the first paper to introduce the idea of inhomogeneous mixing where pockets of entrained air affected a population of drops in the vicinity of the pocket, but left drops further afield unscathed. The affected drops were completely evaporated. It compared inhomogeneous mixing with homogeneous mixing where essentially all drops at a particular level (or region) were affected by the entrained air resulting in partial evaporation. The paper introduced the time scales involved. As a result of inhomogeneous mixing, some of the larger drops were able to grow much faster (due to an enhanced supersaturation) than normal, hence speeding up the development of warm rain. That was a major question at the time – how to explain the observed times for the production of warm rain. Finally, inherent in the idea of inhomogeneous mixing is the concept of entrainment occurring via blobs, or turbulent entities. The paper was revolutionary and led to fierce debate at conferences and in the literature. The ideas of inhomogenous versus homogeneous mixing are still debated to this day.

Plumb and Bell (1982) was the first detailed 2-D analysis of the structure of the Quasi-Biennial Oscillation (QBO). The paper gave us an easy to understand model of the QBO, driven by wave forcing from upward propagating Kelvin and mixed Rossby-gravity waves. Its diagrams were so clear and compelling that it continues to be cited — and the diagrams reproduced.

Hoskins et al. (1985) has had a huge impact on dynamic meteorology — and continues to do so, even in 2023. It basically explained the rationale for understanding the evolution of the atmosphere from the perspective of “PV thinking” and its theoretical basis. The work covers the development of cyclones and anticyclones within mid-latitude weather systems through the coupling of wave-like disturbances at the tropopause and near the ground,

vertical motion within the weather systems and mid-latitude flow blocking. The paper gave many people across the breadth of the Society's scientific specialisms far deeper dynamical insight into atmospheric dynamics. For instance, it has helped support profound and useful connections between the atmospheric composition (chemistry) and dynamics communities. Specialists in atmospheric dynamics may argue that the paper is a review, rather than an article describing new research, but its power to explain deep concepts is probably unrivalled in our field.

Emanuel et al. (1994) has been a key paper in advancing the idea that small-scale cumulus convection and large-scale circulations are tightly coupled, clarifying what are the controlling processes, and promoting 'statistical equilibrium thinking'. The paper led to a new way of thinking about the role of convection in large scale circulations such as the Hadley and Walker circulations. The paper has continued to be very influential in subsequent thinking.

Slingo et al. (1999) made important contributions to our understanding of the Madden-Julian Oscillation (MJO) and how it links to sea surface temperature (SST) variations and in particular El Niño. At the time reanalysis datasets showed an increase in MJO activity from the 1970s onwards, but it wasn't clear if this was a real physical effect or due to changes in the reanalysis quality due to the assimilation of satellite data. By using a multi-decadal global climate model driven by observed SSTs they showed that the change was real and not an artefact of the observations used in the reanalysis, and hence was likely driven by warming SSTs. On the other hand year to year variability in the MJO was not explained by the year to year variability in SSTs and hence the MJO was not strongly coupled to the El Niño phase. This has continued to be an important and well cited paper which advanced our understanding of the drivers of the MJO.

For many years QJ has been an important place for publishing work on developing and applying methods for data assimilation in operational weather prediction systems. An excellent example of this is Rabier et al. (2000). This was the first in a series of 3 papers describing and testing the implementation of 4D-Var data assimilation in the European Centre for Medium Range Forecasting (ECMWF) model. This was the first operational implementation of 4D-Var and an important step forward in data assimilation which led to improvements in short range forecasts. More accurate data assimilation is an essential ingredient in improving both weather forecasts and the reanalysis datasets produced by centres such as ECMWF.

Inspired by a combination of detailed observational evidence and modelling analysis of the Great Storm of October 1987, Browning (2004) introduced the term "sting jet" to the meteorological literature as a description of the damaging surface winds found in the southern quadrant of the cyclone. The hurricane-force winds in the storm led to 22 deaths in England and France - the highest recorded wind gust reaching $60\,\mathrm{m\,s^{-1}}$. A key tenet of this work is that the "sting jet" occurs in a region distinct from the low level jet running polewards along the warm side of the cold front and also distinct from the "cold conveyor belt" wrapping around the northern and western flanks of many intense extratropical cyclones. It is important because sting jets do not occur in all cyclones of similar intensity, but when they do occur they are expected to be associated with mesoscale instability and severe wind gusts. Therefore, it is a pertinent issue for the predictability of severe weather and the term has even been used in recent years in TV broadcasts announcing weather warnings for similar "sting jet cyclones". The paper inspired a host of further studies to better understand and predict these phenomena. It is an excellent example of careful mesoscale analysis of meteorological observations, guided by scientific intuition.

The paper by Bhat (2006) from the Indian Institute of Science, Bangalore, uses field measurements from an oceanic campaign with Indian research vessels, to understand and explain the physics of drought within the monsoon season. It is an exemplar of how to use observations made from a particular time and spatial location to answer important science questions with large societal impact. Recent decades have seen a renewed interest from researchers across the globe in understanding the key processes driving weather and climate in the tropics (particularly over Asia and Africa) as well as improving our ability to forecast them. QJ has become an important voice in disseminating this research to a wide international readership. We continue to develop our international reach

in terms of authors, editorial board members and readership.

Hersbach et al. (2020) documents the development of the ERA5 reanalysis dataset and early results from it. This is the latest in the series of reanalysis products from ECMWF and relies on using state-of-the-art data assimilation and re-forecasts to produce the best estimate of the global atmospheric state, physically consistent among the variables and extending backwards over many decades. Reanalysis datasets such as ERA5 have proved to be a genuinely revolutionary research tools and have been used globally to address a whole range of questions about our atmosphere and changing climate. Their importance is reflected in the huge number of citations the landmark papers published in QJ which document the ECMWF ERA5, ERA-Interim and ERA-40 reanalyses as well as the NOAA 20th century reanalysis (20CR) have received.

We would like to thank the former editors (Alan Blyth, Lesley Gray, Doug Parker, John Thuburn, Mark Baldwin, Peter Read, Geraint Vaughan, Keith Shine and Joanna Haigh) who suggested papers to include in this collection and provided insight into why the papers are so important to them. The Royal Meteorological Society history group has also been immensely helpful in collating a list of important papers in QJ. As the current Editors-in-Chief, we have taken the liberty of including some of our own suggestions for noteworthy papers. Of course there have been many significant and exciting papers published in QJ over its 150 years and it is impossible to cover everything, but we hope this special collection highlights some of the more impactful papers and topics from the journal's archives. QJ remains an important and well respected journal in the field and continues to attract high quality and novel submissions from across the world. We look forward to another 150 successful years for the journal!

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