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In this issue

Earthquakes, Volcanoes and God: Theological Perspectives on Natural Disaster

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Especially in Christianity and Judaism arguments used to reconcile the concept of a loving and omniscient God, who treats his creatures with justice, and the simultaneous existence of evil and suffering is termed theodicy. The word theodicy was first introduced into philosophical discussion by Leibniz in 1710, although attempts to understand the reasons why innocent people suffer have exercised the minds of philosophers and theologians for thousands of years and are notable features of the Hebrew Bible, the New Testament, works of early Christian writers – in particular Augustine and Irenaeus – and some of the greatest writers of later Christian history. Although in recent years most discussions of theodicy within the Judaeo/Christian tradition have been concerned with the suffering caused by humans to humans (e.g. violence against the individual, warfare, genocide and the holocaust), there is an established tradition of studying what are termed natural evils, which include: sickness; bereavement; as well as disasters following in the wake of extreme natural events.

Philosophical theology is based on the exercise of human reason, in the context of an engagement with scripture which is perceived to be the revealed word of God, and within the Leibnizian tradition there are a number of models of theodicy which are either based on, or may be supported by, scripture, of which the *free will* (*Augustinian*), the *best of all possible worlds* (*Irenaean*) and the *retributive* have been the most significant (see box on page 2).

Scripture and the theodicy of retribution

Biblical narratives focus on the *Holy Land* – present day Israel/Palestine – but allude to a more extensive area covering lands that border the eastern Mediterranean and which encompasses much of the Middle East (Figs. 1 and 2). This large region is notable for its history of disasters, which include droughts, storms and floods, as well as earthquakes and volcanic activity. In this short paper and for reasons of brevity, attention is focused on earthquakes and volcanic eruptions. Frequent and damaging earthquakes have occurred in the Holy Land and, although active volcanism did not occur in Palestine either during the biblical era or subsequently, it is a feature of several other areas mentioned in scripture.

The effects of volcanic activity, earthquakes and other natural disasters are used by the authors of the Hebrew Bible (Old Testament) to support its dominant theodicy: that disasters represent punishment of human sinfulness by an often wrathful God. In the New Testament earthquake imagery is also frequently employed, with the ground

Free Will or Augustinian	Best of all Possible Worlds or Irenaean	Retributive
Suffering is related to the freedom granted to humankind by God. Suffering results from human activity and reflects human sinfulness. It does not reflect God's action and is contrary to God's will.	The universe is controlled by the laws of physics and not by special laws (i.e. providences). Despite the suffering caused by disasters, the earth is the *Best Possible World* (Leibniz) that could be created. Suffering occurs to achieve a *greater good* (e.g. without earthquakes tectonic activity would not be possible and without volcanic activity no atmosphere would have formed). The occurrence and magnitude of earthquakes and volcanic eruptions obey the laws of probability. Our 'law controlled' world facilitates spiritual growth, through dealing with suffering.	This is an important scriptural model of suffering and one that is prominent in accounts of reactions to earthquakes and volcanic eruptions throughout Christian history.

Three prominent 'Leibnizian' models of theodicy (based on Chester, 1998)

shaking that accompanied the crucifixion, the seismic activity which moved the stone from Christ's tomb and the earthquake that opened the doors of the prison in which the Apostles Paul and Silas were incarcerated, all being examples. The events described in the New Testament occurred predominantly in the first century of the Common Era and explanations of suffering caused by natural and human agencies display both a continuity with, and a development of, Old Testament *retributive* theodicy. The most focused treatment of the issue of human suffering and so-called natural evils occurs in two incidents that are recorded in the Gospels. In the first the disciples ask Jesus whether the cause of a man's blindness from birth is his sin or that of his parents (John 9: 2), whilst in the second and referring to eighteen people who have been killed due to the collapse of the Tower of Silo'am – whether caused by an earthquake, or poor building work or both is unknown – Jesus asks the rhetorical question: "do you think they were worse offenders than all others living in Jerusalem?" (Luke 13: 4). In the first incident Jesus upbraids the disciples and in so doing appears to go against Old Testament teaching, "neither this man nor his parents sinned; he was born blind so that God's works might be revealed in him" (John 9: 3), whilst in the second Lucan example Jesus answers his own rhetorical question, "no I tell you; but unless you repent you will all perish just as they did" (Luke 13: 5). Both these passages are difficult to interpret. In the case of the blind man it seems undeserved – that he should have had to endure suffering just so that he could be healed by Jesus, whilst in the Silo'am incident Jesus crucially introduces the notion of collective as opposed to individual guilt, a distinction which has important implications for present day *post-Leibnizian* theodicy.

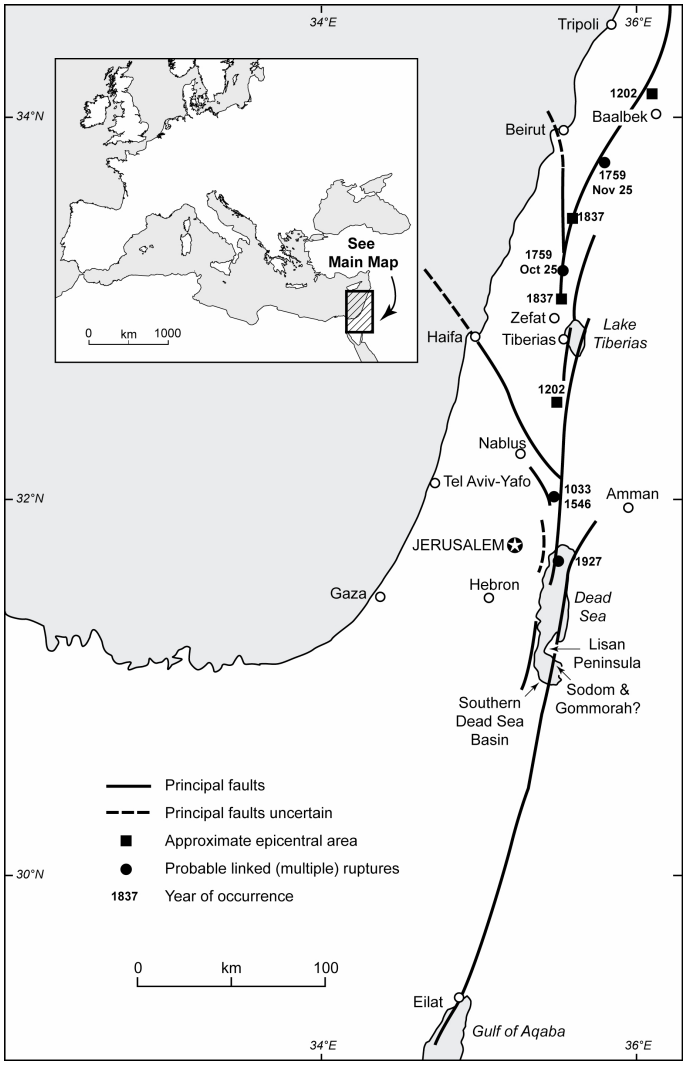

Figure. 1. Active faults in the Holy Land. The dates of large earthquakes (M. 6 and greater) that have occurred in the last 1,000 years are added (source Degg *et al*., 2000).

Historical development of Christian ideas on suffering caused by disasters

In the period between the emergence of Christianity as a major world religion and the early nineteenth century, the explanation of major disasters that eclipsed all others was that these phenomena were either manifestations of divine power sent to punish human sinfulness and/or presaged

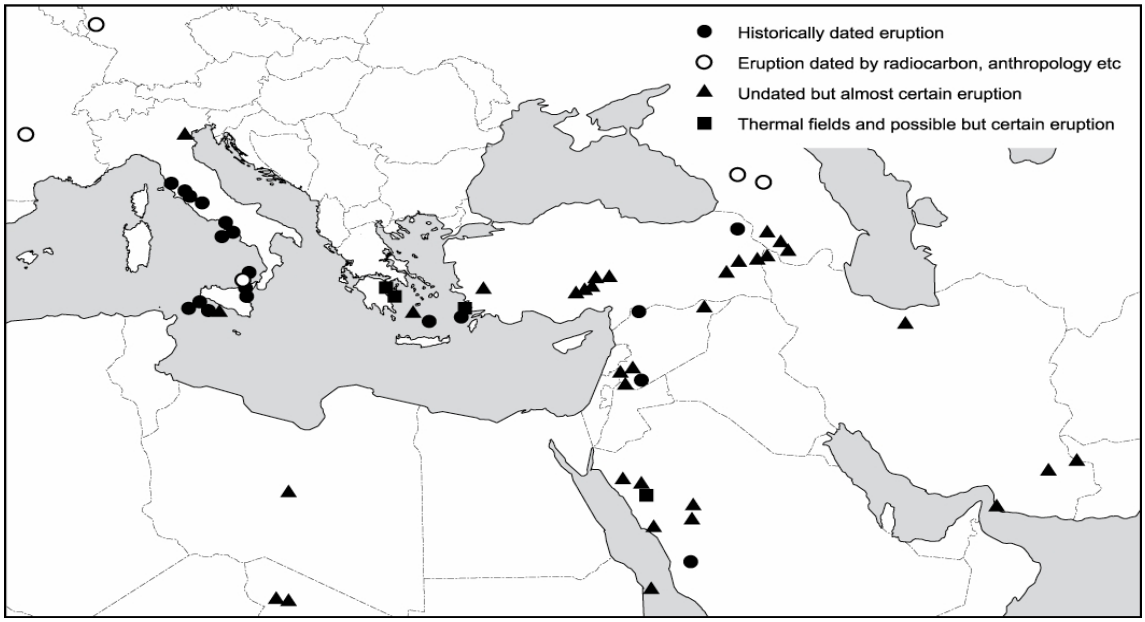

Figure 2. Volcanoes of the Eastern Mediterranean and Middle East which have been active during the Holocene (based on information in Simkin *et al.*, 1981).

the imminent end of the world, views which were also present in many religious interpretations ranging from Islam to Polynesian myths. It is not difficult to support this statement, because the study of historic disasters within societies with a dominant Christian ethos has generated a vast literature.

Making use of the literature on historic eruptions and earthquakes, the consensus of academic scholarship has been highly critical of the impact of Christianity and its *retributive* theodicy on human understanding of natural perils. The period between the rise of Christianity as the officially sanctioned faith of the Roman Empire under the Emperor Constantine and the later eighteenth century, is often considered a long 'Dark Age' in which superstition largely replaced the search for scientific explanations of natural phenomena. According to this reading of intellectual history, the spread of Christianity largely eclipsed the albeit nascent naturalistic explanations of volcanoes and earthquakes that had been proposed by writers in the classical age, and it was only from the time of the European Renaissance, especially during and following the Eighteenth Century Enlightenment, that *retributive* religious explanations of disasters became less prominent; to be superseded progressively by more scientific and social scientific explanations of extreme natural events and their impacts on vulnerable populations. Scholars embracing the *conventional wisdom* conclude by arguing that today the last redoubts of religious explanations of disaster are either to be found in extreme biblical-literalist Christian circles within *economically more developed countries*, and/or in those societies within *economically less developed countries* which are relatively untouched by the forces of modernism.

In order to test the veracity of this conventional interpretation of intellectual history, we studied religious reactions to major earthquakes and volcanic eruptions that have occurred between 1900 and 2008 in countries with a predominantly Christian ethos. This catalogue (Chester and Duncan, 2009) represents an attempt to recover what we have termed a 'hidden history' of responses, because accounts that are cast in the 'language' of faith communities are frequently eliminated from official reports and peer-reviewed international academic science and social science journals. Recovery of these records requires the interrogation of newspapers of record, use of more anthropologically based studies and the study of local archives. Notwithstanding these issues it is significant that, of the 61 discrete events recorded nearly three-quarters show clear evidence of responses being couched in religious terms, a figure that would be even higher if local records could be interrogated for information on earlier events.

One element of the 'conventional wisdom' that can be supported is that a biblical-literalist *retributive* theodicy declined rapidly following the 1755 Lisbon earthquake especially in what may be described today as *economically more developed countries*, though elements of it remain both in these societies and also in many which are *economically less developed*. In Great Britain and other countries which saw rapid industrial growth and major scientific advance from the late eighteenth century, progressively fewer Christians accepted explanations that involved divine *retribution*, but even today notions of divine wrath are still embraced by a small minority of biblical literalists and conservative Evangelicals. Following the 2004 Indian Ocean earthquake and tsunami disaster, for example, a fierce debate raged in

the religious press over the fact that a *retributive* theodicy was still being proposed by some Christians to explain this event and its impact.

A *retributive theodicy* with liturgies of propitiation, parades of sacred relics/votive images and numerous other ritualistic actions to appease divine wrath, is also still a feature of what has been termed *popular Catholicism* as encountered in places as diverse as: southern Italy and Sicily; on the slopes of Popocatépetl in Mexico, where there is a syncretic relationship between Catholicism and earlier pre-Columbian faiths; and following the earthquakes in El Salvador in 1986, and the 1991 Pinatubo volcanic eruption in the Philippines. Even in the USA and following the eruption of Mt. St. Helens in 1980, a radio commentator blamed the eruption on the consumption of strong liquor.

The 'best of all possible worlds' model of theodicy

Although within the context of disasters *retributive* theodicies are far less common today than they were in the past, there is no evidence to support the contention that naturalistic explanations of death, injuries and destruction have completely replaced those grounded within religious frames of reference in countries where many (or most) inhabitants profess a Christian faith. What is evident is that other models of theodicy, whilst not fully superseding the *retributive*, have become more common. In studies of natural calamities the *best of all possible worlds* (i.e. *Irenaean*) model has been particularly important.

A *best of all possible worlds* theodicy is most commonly associated with Voltaire and his reactions to the Lisbon earthquake of 1755. Summarizing this model of theodicy, the theologian Frederick J. Murphy (2005: 345) concludes that it "would probably be impossible to design any system of nature which did not have the potential to injure unsuspecting humans" and that God's purpose is to accept disasters and use them to complete a greater good. The association of the *best of all possible worlds* theodicy with St. Irenaeus correctly implies that it pre-dates Voltaire and in fact it finds support in scripture, in the history of Christian responses to disasters and in the records of events that have occurred since 1900. Although the Hebrew Bible is generally unwilling to admit that there can be any wholly innocent suffering, some biblical scholars have argued that there are a number of exceptions to this generalization, for instance in Proverbs 3, Hosea 11. In the New Testament there is a discussion of the Greek word παιδεία (*paideia*) in Chapter 11 of the Epistle to the Hebrews. *Paideia* is usually translated discipline, but also has the sense of positive teaching and training that loving parents may give their children. The moral purpose of suffering is also discussed in 1 Peter 4: 12-19.

Within historical records of the human impact of earthquakes and volcanic eruptions many examples of the use of a *best of all possible worlds* theodicy may be found. For example, two small earthquakes struck London on February 8th and March 8th 1750 and, although the majority of clergy preached a theodicy of divine wrath visited on the sinful people of Britain, one group believed that only some earthquakes were sent to punish, while a third – albeit a small minority – group adopted a *best of all possible worlds* position. In the 19th century and preaching on the occasion of a national day of fasting in 1832, Bishop Maltby of Chichester castigated those who saw the hand of providence in all manner of calamities, whilst the reactions of the majority of clergy to earthquakes later in the century were strongly based on explanations grounded in an acceptance of natural processes; the earthquakes in Venice (Italy) in 1873 and Colchester (England) in 1884 being good examples.

Reactions of Christian clergy and laity to more recent earthquakes and volcanic eruptions have often reflected the twin elements contained within many theological writings: of recognizing such events as the outcomes of natural processes; whilst at the same time seeing them as calls to intercessory prayer for victims and for Christian social action. There are many examples of intercessory prayer, and Christian help for victims of disasters goes back to New Testament times when severe famine occurred in Palestine. This took place during the reign of Claudius, and the apostles sent disaster relief to fellow Christians living in Judea (Acts 11). This tradition of charity has continued and has been a feature of reactions to many historic and contemporary earthquakes and volcanic eruptions. Under both a *retributive* and a *best of all possible worlds* theodicy, Christian praxis is justified by the commandment to love one's neighbour and by seeing the suffering of Christ in the distress of the disaster victims.

There is a danger with Christians adopting a *best of all possible worlds* theodicy, however, and this is highlighted in a thoughtful and highly critical review of a conservative evangelical inspired manual on disaster relief entitled *Christian Perspectives on Disaster Management* by Ian Davis and Michael Wall (1992). In a review, Hugo Slim (1994) makes the important point that following a disaster there is a danger when the greater good is narrowly defined as the opportunities that may arise if relief aid is used as a means of assisting the process of conversion, because such a perspective comes perilously close to the concept of a 'good' disaster, far removed from the 'greater good' as understood theologically.

Paradigm shifts of disaster research and Christian theology

In the early 1970s research on disasters was mainly carried out under the banner of what has been termed the *dominant* approach which sought to emphasise the deployment of scientific and technological interventions to mitigate the effects of natural calamities. This approach was first introduced by the American pioneer hazard analyst Gilbert Fowler White in the 1940s to study flooding in the USA

and was later extended to embrace other hazards across a wide range of countries (White, 1974). The theological study of natural perils was focused exclusively within the Leibnizian tradition, where the *best of all possible worlds* model had become progressively more prominent over the preceding two centuries. Paradigm shifts occurred in both academic fields at approximately the same time, starting in the 1980s and gathering momentum in the 1990s, these final ten years of the millennium coinciding with the United Nations' *International Decade for Natural Disaster Reduction* (INDR).

In the case of research on disasters, the *dominant* approach became the subject of trenchant criticism. Briefly, the *dominant* approach accepted that factors such as differences in systems of beliefs, material wealth, previous experience of hazardous events and psychological factors may be of importance in affecting human responses, it nevertheless emphasized the role of environmental extremes as the principal determinants of disasters. In contrast, by the final decades of the twentieth century greater weight was being placed on human vulnerability. It was argued cogently and with increasing force that most of the mortality and morbidity in disasters, especially in *economically less developed countries*, could be explained by factors such as poverty, deprivation, marginalization, lack of disaster preparedness and, in the case of earthquakes, by collapsing buildings constructed to inadequate or non-existent codes. For instance, in the twentieth century ca. 99% of volcano-related deaths occurred in *economically less developed countries*, while examination of the impacts of earthquakes of similar magnitude showed a similar disparate pattern, with major death tolls increasingly becoming the preserve of the world's poor, whereas financial losses were the most striking feature of 'rich' countries. When financial impacts are expressed as percentages of national wealth – Gross Domestic Product, or GDP – however, then the relative economic toll in 'poor' countries is far higher.

For theodicy the paradigm shift has been even more significant because the Leibnizian tradition, which represents over 2000 years of theological reflection on the relationships between God, natural processes and human suffering, if not superseded, now has a well supported competitor. From the 1980s an increasing number of theologians found the Leibnizian models increasingly unconvincing and constructed new theodicies which required both a renewed engagement with scripture and intense theological reflection on disasters.

There are several strands to this new theodicy. First, as has already been noted when the collapse of the Tower of Silo'am was discussed, Jesus introduces the notion that guilt may be collective and not individual. Jesus also teaches that punishment was not arbitrarily visited on the individuals who perished, because they were no more to blame than other people living in Jerusalem (Luke 13: 4-5), and there are numerous historical examples where this theme of collective responsibility is mentioned by Christians but not fully developed. In 1382, for example, Archbishop Courtenay called a meeting of the Council in Blackfriers to decide what action to take against the Oxford theologian John Wycliffe and his followers, the 'Lollards', who were seeking to reform the church and were thereby threatening church order. The occurrence of the 1382 earthquake encouraged some bishops to believe that God disapproved of the institutional church and its planned actions against Lollardy, but Archbishop Courtenay stood firm and draw the opposite conclusion, that the earthquake was a sign which supported the *status quo*.

A second strand in post-Leibnizian theodicy emphasises the immanence of God within human affairs. The theologian Terrence Tilley, for instance, argues that the Leibnizian approach is a means of reducing human responsibility for both natural and human-induced suffering because it focuses responsibility on God rather than people: on creator rather than creature. This line of argument may also be seen in the work of two highly influential writers. The Jesuit Raymund Schwager, who in the late 1980s showed how there is both a biblical and historical tendency within Christianity to make God the scapegoat for all manner of human failings; and Ted Steinberg, a secular historian of the environment writing twenty years later, who in reviewing disasters in the USA argues that the perception of such events as being caused by either a malign nature or by God are convenient devices for both commercial interests and institutions of government who can thereby evade responsibility for the poor, the racially disadvantaged and other marginalized groups within American society. In the context of earthquakes a well-known and oft-quoted remark made by Professor Nick Ambraseys in 1972 is of relevance to the discussion. Nearly forty years ago he remarked, what are considered "Acts of God today, are often tomorrow's acts of criminal negligence" on the part of builders, architects or planners (Ambraseys, 1972: 40).

By combining notions of collective guilt, structural (i.e. institutional) sinfulness and human responsibility, it has proved possible to propose in 1998 a *liberationist* theodicy (Chester, 1998). This involves a re-working of the 'classic' Leibnizian *free-will* defence, with human freedom not only being expressed at the level of the individual but also collectively, as greed at the national, international and corporate levels. This 'structural sinfulness', so we have argued, lies behind global differences in wealth and power, as well as dissimilar and unequal disaster outcomes. Structural sinfulness was also identified by the *liberation theologians* of the 1970s and 1980s, where it was viewed as a process which keeps the poor and disadvantaged in a state of subjection. Beginning with the 1970 earthquake in Peru and especially in South America, there has also been intense theological reflection on earthquake losses particularly by Jon Sobrino (2004).

A third strand in post-Leibnizian theodicy stresses the

immanence of God over divine transcendence. According to *liberationist* theodicy, Jesus Christ the 'crucified God' demonstrates how God suffers vicariously with and for all his children. In the view of the German theologian Jürgen Moltmann to think of God as impassible would surely be to fall short of the God revealed in Jesus Christ, a God of love who participates in the sufferings of his creatures and is perhaps the greatest sufferer of all. The doctrine of the Trinity is invoked to demonstrate how God shares, not only in the suffering of his son on the cross of Calvery but also with all suffering humanity, who are linked to God by a shared parenthood.

A *liberationist* theodicy is finally a partial theodicy, because the probability of disaster losses cannot be wholly eliminated. Even in the most well planned society people still suffer. In this, albeit small, minority of cases, recourse has to be made either to the 'classic' Leibnizian models, or to a re-working of one or more of them. One free-will approach is highly germane to people living in hazard prone regions in *economically more developed* parts of the world. In such countries people often make a free choice – either informed or uninformed – to live in an earthquake or eruption prone location and, since God cannot have foreseen their decision, she/he cannot prevent suffering caused when disaster strikes. For example the elderly Harry Truman's well documented action in 1980 not to heed warnings to evacuate his property on the flanks on Mount St. Helens was his uninformed choice, whereas the informed choice would have been to follow the advice of authorities and so reduce his vulnerability.

Conclusions: Moving Forward

In studying evacuations carried out in connection with a range of disasters, it is evident that no plan is likely to be 100 percent successful, but the reasons for the instructions of the civil authorities being resisted are unlikely to be religious. For example, in the predominantly agricultural, strongly Catholic and volcanically active São Miguel Island in the Azores, David Chester in collaboration with Christopher Dibben, carried out a study of probable reactions of the people to a future eruption, and we uncovered a resistance to evacuate which was based on a strong attachment to land, farm and pedigree livestock herds built up over several generations (Dibben and Chester, 1999). Religious beliefs were not an important factor here and many other examples could be quoted.

One feature to emerge from our study of historic eruptions and earthquakes over the course of the past century, is that Christian belief has neither inhibited more practical measures being taken to reduce hazard exposure, nor has it prevented people accepting help from the civil authorities. Believing in two mutually incompatible explanations, or holding one view yet acting contrary to it, is often termed *parallel practice* – sometimes inaccurately *cognitive dissonance* – and this is a particular feature of many closely studied responses in societies with a popular Catholic ethos.

When the occurrence of *parallel practice* is combined with a post-Leibnizian *liberationist* theodicy and new more vulnerability-focused approaches to hazards, it is possible to see synergies developing. Civil defence planners can more easily make use of the often substantial financial and human resources of Christian denominations and their associated charities. Virtually every community in a country with a Christian history has a church, which is not only a religious focus but a social one, with clergy acting as a useful 'resource' in identifying victims and providing counselling, relief and leadership. Under a *liberationist* approach, the presence of the divine is located in disaster victims and is not perceived as being within the geological processes that caused the earthquake or volcanic eruption and this new perspective is already informing Christian attitudes towards disaster relief, being enthusiastically embraced by international Christian charities which seek to provide disaster relief and assist economic development.

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Andreas Rietbrock, Fleur Strasser and Ben Edwards present a summary of recent developments in stochastic ground-motion prediction models for seismic hazard analyses in the UK.

Incorporating Weak Motion Data in Ground-Motion Predictions for the United Kingdom

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Low-seismicity regions such as the United Kingdom pose a challenge for seismic hazard analysis in view of the limited amount of local data available. In particular, ground-motion prediction is faced with the problem that most of the instrumental observations available have been recorded at large distances from small earthquakes. Direct extrapolation of the results of regression on these data to the range of magnitudes and distances relevant for the seismic hazard analysis of engineered structures is generally considered unsatisfactory since it provides no constraint on near-source attenuation and is unable to capture non-linearity in magnitude scaling (e.g. Bommer *et al.*, 2007). In a forthcoming paper (Rietbrock *et al.*, 2011) new ground-motion prediction equations (GMPE) for the UK in terms of peak ground acceleration (PGA), peak ground velocity (PGV) and 5%-damped pseudo-spectral acceleration (PSA) are presented, which are based on the results of numerical simulations using a stochastic point-source model calibrated with parameters derived from local weak-motion data (Edwards *et al.*, 2008). Here we present a brief summary of the main findings of this research.

Past seismic hazard studies for the UK continental shelf and the North Sea were faced with the challenge of selecting GMPEs appropriate for local conditions. The GMPEs used in these studies included equations for active crustal regions, including equations derived for the wider European region, as well as models for intraplate and stable continental regions. Additionally, a number of equations have been derived specifically for applications in the UK. These include an equation for peak ground acceleration (PGA) derived for the UK by Principia Mechanica Ltd. (PML, 1982) based on 50 recordings from 32 earthquakes that had occurred worldwide, mainly in active crustal regions. This model was later updated with additional data to include a style-of-faulting factor (PML, 1985) and extended for prediction of spectral response ordinates (PML, 1988). These equations have been widely used in seismic hazard analyses for UK nuclear facilities, but they have been found to possess many shortcomings from the point of view of modern seismic hazard analysis (Bommer *et al.*, 2011). For stable continental regions it now has become an accepted standard to use stochastic simulations in order to predict strong ground-motion (e.g. Atkinson & Boore, 2006), in view of the very limited numbers of empirical recordings of larger earthquakes available for such regions.

Edwards *et al.* (2008) recently performed an inversion based on attenuation tomography to obtain the first set of stochastic parameters derived entirely from UK data. They used a database of weak-motion events ($2.0 > M_L > 4.7$) recorded by the BGS network and performed a complete spectral parameterisation of over 3,000 velocimetric records of 273 events occurring in the years 1992 to 2006. Figure 1 gives the recording station locations together with the used ray paths and the distribution of both magnitude and source depth against hypocentral distance. The inversion includes a frequency-independent depth-dependent Q structure together with a multiple-segment apparent geometrical-spreading model. The majority of the values of the stress parameter ($\Delta\sigma$) were found to fall in the range of 0.1 to 10 MPa and a linear relationship proportional to 0.7 M_L between moment magnitude (M_w) and local magnitude (M_L) in the range of 2.0–4.7 M_L was established. In contrast to other studies, where parameters are determined on an individual basis, this approach resulted in jointly determined parameter distributions, including, in particular, the covariance matrix of the parameters determined.

The Rietbrock *et al.* (2011) study uses results of Edwards *et al.* (2008) to obtain input parameters for stochastic simulations using SMSIM (Boore, 2003). A classic Brune-type source model is used, and parameters such as magnitude, stress parameter ($\Delta\sigma$), source depth, Q, kappa, and crustal amplification are varied in light of the Edwards *et al.* (2008) results. In total, 126,000 simulations were carried out, the results of which were used to derive GMPEs – in

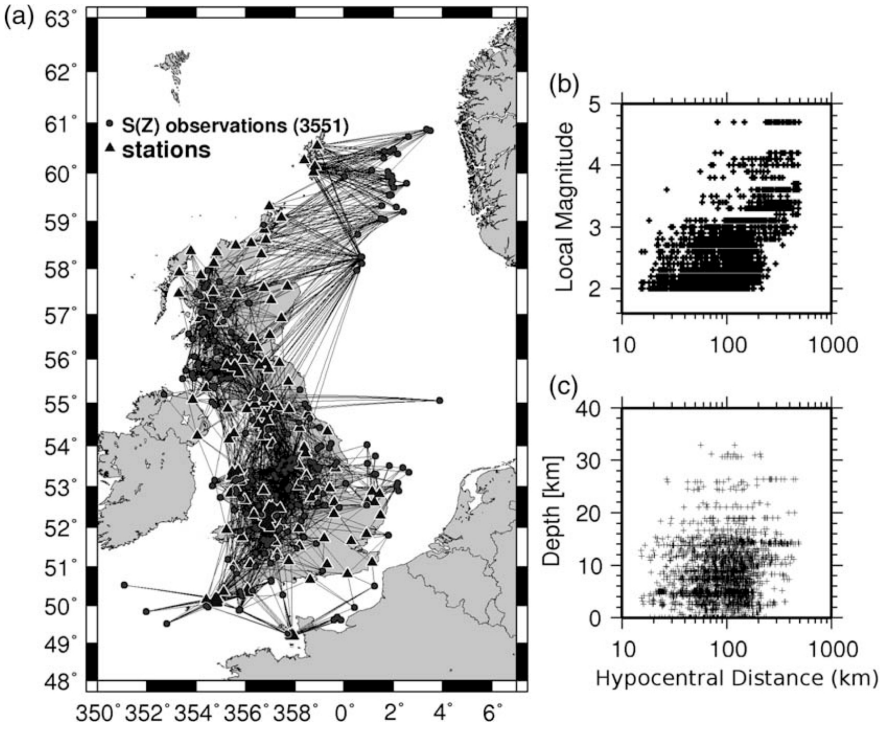

Figure 1. (a) Plot of ray paths used in all inversions. Circles indicate events, triangles indicate stations, and the solid lines joining the two are ray paths. (b) Local magnitude-hypocentral distance distribution. (c) Source depth-hypocentral distance distribution (Edwards *et al*, 2008).

parametric form for ease of implementation – for PGA, PGV and 5%-damped PSA. In order to capture the epistemic uncertainty regarding the magnitude-scaling of the stress parameter ($\Delta\sigma$), two alternative models, one constant with magnitude, the other with larger values of $\Delta\sigma$ at large magnitudes than at small magnitudes, were used to develop two separate GMPEs for each considered ground-motion intensity measure (e.g. PGA). The resulting models for PGA, formulated in terms of moment magnitude (M_W) and the closest horizontal distance to the surface projection of the rupture plane, or Joyner-Boore distance (RJB), are compared to predictions from selected GMPEs in Figures 2 and 3, with the appropriate adjustments for style-of-faulting (strike-slip) and site conditions (hard rock) applied.

These results show that the Rietbrock *et al.* (2011) model behaves similarly to other models derived for stable continental regions, such as the Atkinson & Boore (2006) model, at larger distances from the source. At short distances from the source, the models behave similarly to predictions based on empirical data from shallow crustal earthquakes in active regions, such as the recent Akkar & Bommer (2010) model for the wider Euro-Mediterranean area. This is consistent with the observation that near-source ground motions are predominantly controlled by characteristics of the source, and hence exhibit little variation from one region to another, whereas ground motions at larger distances are influenced by regionally variable parameters such as attenuation along the wave path.

Since the simulations are based on a point-source model, the resulting ground-motion models do not incorporate dynamic rupture effects, which are known to affect ground motions in the immediate vicinity of the source. It should, however, be noted that the depth distribution of UK earthquakes, with larger events tending to be located at greater depths, effectively results in a non-zero minimum value of the source-to-site distance to be considered in PSHA, even when extended-source metrics are considered.

In the context of seismic hazard analysis for the UK, the Rietbrock *et al.* (2011) models provide options for logic-tree branches that are based primarily on locally-recorded data, additionally addressing the issue of parameter trade-offs and uncertainties through the use of joint probability distributions, and conditional sampling in the forward modelling.

SECED

SECED, The Society for Earthquake and Civil Engineering Dynamics, is the UK national section of the International and European Associations for Earthquake Engineering and is an affiliated society of the Institution of Civil Engineers. It is sponsored by the Institution of Mechanical Engineers, the Institution of Structural Engineers, and the Geological Society. The Society is also closely associated with the UK Earthquake Engineering Field Investigation Team. The objective of the Society is to promote co-operation in the advancement of knowledge in the fields of earthquake engineering and civil engineering dynamics including blast, impact and other vibration problems. For further information about SECED contact: The Secretary, SECED, Institution of Civil Engineers, One Great George Street, London, SW1P 3AA, UK. Or visit the SECED website: http://www.seced.org.uk

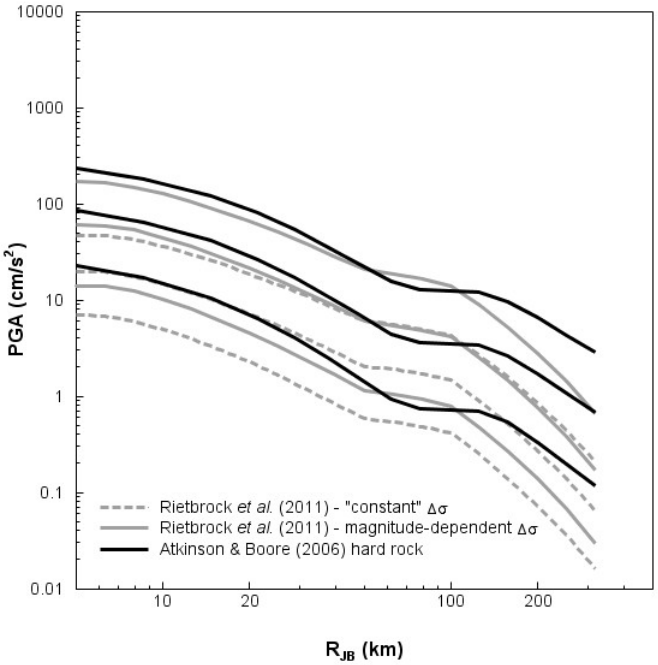

Figure 2. Comparison of the predictions of the Rietbrock et al. (2011) models for PGA with the Atkinson & Boore (2006) equation for Eastern North America, adjusted to strike-slip conditions and RJB. The curves correspond to predictions at moment magnitudes M_W 4.0, 5.0 and 6.0.

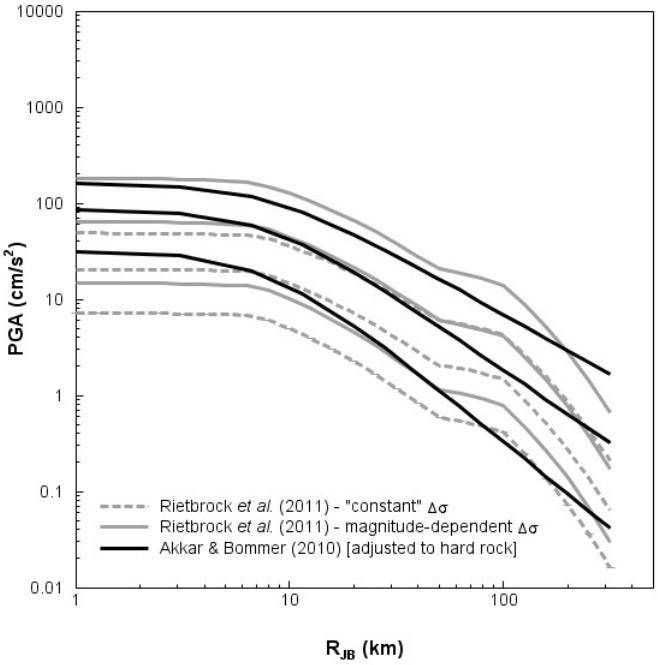

Figure 3. Comparison of the predictions of the Rietbrock *et al*. (2011) models for PGA with the Akkar & Bommer (2010) equations for the wider Euro-Mediterranean region. The curves correspond to predictions at moment magnitudes M_W 4.0, 5.0 and 6.0.

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SECED Newsletter

The SECED Newsletter is published quarterly. All contributions of relevance to the members of the Society are welcome. Manuscripts should be sent by email. Diagrams, pictures and text should be attached in separate electronic files. Hand-drawn diagrams should be scanned in high resolution so as to be suitable for digital reproduction. Photographs should likewise be submitted in high resolution. Colour images are welcome. Hard copy manuscripts are also welcome. Please contact the Editor of the Newsletter, Andreas Nielsen, for further details: email: andreas.nielsen@jacobs.com; telephone: 0141 243 8418.

Notable Earthquakes July – December 2010

Reported by British Geological Survey

Issued by: Davie Galloway, British Geological Survey, February 2011.
Non British Earthquake Data supplied by The United States Geological Survey.

Year	Day	Mon	Time UTC	Lat	Lon	Dep km	Magnitude M_L	Magnitude M_b	Magnitude M_w	Location
2010	03	JUL	11:33	56.58N	5.62W	8	1.5			LOCHALINE, HIGHLAND
2010	14	JUL	08:32	38.07S	73.31W	22			6.6	BIO-BIO, CHILE
2010	15	JUL	10:22	51.90N	0.64W	14	2.0			DUNSTABLE, BEDS
2010	18	JUL	05:56	52.88N	169.85W	14			6.6	ALEUTIAN ISLANDS
2010	18	JUL	13:04	5.97S	150.43E	28			6.9	PAPUA NEW GUINEA
2010	18	JUL	13:34	5.93S	150.59E	35			7.3	PAPUA NEW GUINEA
2010	20	JUL	19:38	27.02N	53.86E	10			5.8	SOUTHERN IRAN
One person killed and 32 other injured in Fars and at least 50% of buildings damaged in Lamerd.										
2010	23	JUL	22:08	6.72N	123.41E	607			7.3	MINDANAO, PHILIPPINES
2010	23	JUL	22:51	6.49N	123.47E	586			7.6	MINDANAO, PHILIPPINES
2010	23	JUL	23:15	6.78N	123.26E	641			7.4	MINDANAO, PHILIPPINES
2010	24	JUL	05:35	6.22N	123.52E	553			6.6	MINDANAO, PHILIPPINES
2010	27	JUL	01:56	53.61N	2.41W	12	1.9			BOLTON, LANCASHIRE
2010	29	JUL	07:31	6.53N	123.25E	627			6.6	MINDANAO, PHILIPPINES
2010	30	JUL	13:50	35.22N	59.31E	24			5.4	NORTHEASTERN IRAN
At least 275 people injured and severe damage in the Torbat-e Heydarieh area.										
2010	30	JUL	21:17	57.12N	5.24W	6	1.5			GLEN SHEIL, HIGHLAND
2010	30	JUL	23:39	51.67N	2.42W	11	2.7			STROUD, GLOS
Felt Stroud (3 EMS).										
2010	04	AUG	00:02	54.36N	2.88W	4	1.7			WINDERMERE, CUMBRIA
Felt Staveley and Kendal (3 EMS).										
2010	04	AUG	07:15	5.50S	146.81E	226			6.5	PAPUA NEW GUINEA
2010	04	AUG	22:01	5.75S	150.77E	44			7.0	PAPUA NEW GUINEA
2010	06	AUG	03:39	54.11N	2.53W	8	1.5			BENTHAM, N YORKSHIRE
2010	09	AUG	11:26	51.67N	2.41W	14	1.5			STROUD, GLOS
2010	10	AUG	05:23	17.54S	168.07E	25			7.3	VANUATU
2010	12	AUG	11:54	1.27S	77.31W	207			7.1	ECUADOR
Slight damage in Manta, Guayaquil and Loja.										
2010	13	AUG	21:19	12.48N	141.48E	10			6.9	MARIANA ISLANDS
2010	14	AUG	23:01	12.27N	141.43E	13			6.6	MARIANA ISLANDS
2010	22	AUG	18:51	52.56N	4.23W	7	1.7			CARDIGAN BAY, WALES
2010	26	AUG	07:01	57.08N	4.34W	7	1.8			KINGUSSIE, HIGHLAND
2010	27	AUG	19:23	35.49N	54.47E	7			5.7	NORTHERN IRAN
At least three people killed, several hundred injured and over 700 homes destroyed in the Damghan/Torud area.										
2010	28	AUG	16:12	53.94N	1.25W	6	1.6			TADCASTER, N YORKSHIRE
2010	29	AUG	00:53	27.20N	103.01E	35		4.9		SICHUAN/YUNNAN, CHINA
Fourteen people killed and over 1,000 homes damaged in Ningnan and Ziaojia.										
2010	31	AUG	09:20	54.31N	1.90W	9	1.6			LEYBURN, N YORKSHIRE
2010	01	SEP	05:45	57.02N	1.97E	15	3.5			CENTRAL NORTH SEA
Felt onboard accommodation vessel (3 EMS).										

Year	Day	Mon	Time UTC	Lat	Lon	Dep km	Magnitude M_L	Magnitude M_b	Magnitude M_w	Location
2010	03	SEP	08:13	54.25N	2.66W	10	2.4			KENDAL, CUMBRIA
										Felt Kendal & Staveley (3 EMS).
2010	03	SEP	11:16	51.45N	175.87W	24			6.5	ALEUTIAN ISLANDS
2010	03	SEP	16:35	43.52S	171.83E	12			7.0	DARFIELD, NEW ZEALAND
										Two people seriously injured, six bridges and many buildings damaged in the Christchurch area. Damage reported in Bexley as a result of liquefaction and several landslides were observed along the Rakaia River area.
2010	07	SEP	23:21	53.45N	1.15W	1	2.2			DONCASTER, S YORKSHIRE
Felt Rossington (3 EMS).										
2010	10	SEP	12:05	51.83N	3.02W	25	1.6			ABERGAVENNY, GWENT
2010	13	SEP	10:31	58.69N	0.82E	10	2.5			NORTHERN NORTH SEA
2010	25	SEP	23:17	57.09N	4.33W	7	1.7			NEWTONMORE, HIGHLAND
2010	27	SEP	05:32	52.05N	0.79W	4	1.9			MILTON KEYNES, BUCKS
2010	27	SEP	11:22	29.65N	51.67E	27			5.8	SOUTHERN IRAN
										One person killed and three injured in Konar Takhteh.
2010	29	SEP	17:11	4.96S	133.76E	26			7.0	PAPUA, INDONESIA
2010	10	OCT	21:44	33.87N	72.89E	33		5.2		PAKISTAN
										One person killed, fifteen injured and at least 100 buildings damaged in the Khanpur/Haripur area.
2010	15	OCT	05:49	53.26N	1.04W	6	1.7			WORKSOP, NOTTS
2010	21	OCT	17:53	24.66N	109.15W	10			6.7	GULF OF CALIFORNIA
2010	21	OCT	22:30	52.91N	1.21W	7	1.9			BEESTON, NOTTS
2010	25	OCT	04:12	53.63N	1.01W	1	1.8			THORNE, S YORKSHIRE
2010	25	OCT	14:42	3.49S	100.09E	20			7.8	MENTAWAI, INDONESIA
										At least 340 people killed and 330 missing from the earthquake and resultant tsunami.
2010	04	NOV	07:47	61.30N	3.75E	15	3.0			NORWEGIAN SEA
2010	06	NOV	03:52	33.37N	48.94E	5		4.9		WESTERN IRAN
										At least 104 people injured and some houses damaged in the Dorud/Razan area.
2010	10	NOV	04:05	45.46S	96.39E	10			6.5	SOUTHEAST INDIAN RIDGE
2010	30	NOV	03:24	28.36N	139.15E	487			6.8	BONIN ISLANDS, JAPAN
2010	02	DEC	03:12	6.00S	149.98E	33			6.6	PAPUA NEW GUINEA
2010	04	DEC	01:53	53.98N	0.87E	15	2.6			SOUTHERN NORTH SEA
2010	15	DEC	10:27	50.01N	0.56W	5	2.2			ENGLISH CHANNEL
2010	15	DEC	14:09	49.87N	0.50W	5	1.5			ENGLISH CHANNEL
2010	18	DEC	06:19	57.46N	5.94W	4	2.3			APPLECROSS, HIGHLAND
2010	19	DEC	12:14	7.52N	37.84E	10		5.1		ETHIOPIA
										Scores of people injured and many buildings damaged in the Jima and Hosa'ina-Shenk'ola-Wenjela areas.
2010	20	DEC	00:43	59.87N	5.07E	10	3.4			NORWEGIAN COAST
2010	20	DEC	12:30	59.91N	5.01E	10	3.8			NORWEGIAN COAST
2010	20	DEC	18:41	28.44N	59.17E	12			6.7	SOUTHEASTERN IRAN
										Seven people killed, 25 others injured and three villages destroyed in eastern Kerman.
2010	21	DEC	17:19	26.90N	143.70E	17			7.4	BONIN ISLANDS, JAPAN
2010	21	DEC	22:59	54.39N	3.15W	13	3.5			CONISTON, CUMBRIA
										Felt throughout Cumbria and surrounding counties (5 EMS).
2010	22	DEC	05:13	57.12N	6.73E	22	3.5			EASTERN NORTH SEA
2010	25	DEC	13:16	19.73S	167.90E	12			7.3	VANUATU

The Thirteenth Mallet-Milne Lecture

The Practice of Earthquake Geology: Career-Changing Events & Life Stories

Lloyd S Cluff

Pacific Gas & Electricity, California

Synopsis

The Thirteenth Mallet-Milne Lecture will give a view of earthquake geology through the long and distinguished career of Lloyd S Cluff, who has studied numerous earthquakes in the field and has led the seismic hazard assessments for many major projects around the world.

An early experience as a mountain guide for the US Geological Survey awakened Lloyd to the possibility of a new career path in physical geology, and upon discharge from the Army he attended the University of Utah, majoring in geology. After graduating in 1960, he joined Woodward-Clyde Consultants (WCC) in Oakland, California, as a field geologist.

Lloyd's first earthquake field investigation was in 1959, after the Hebgen Lake, Montana, event. Many others followed, including the 1964 Alaska, 1972 Managua and 1976 Guatemala earthquakes. Lloyd realized the field of earthquake geology represented an opportunity to follow his personal interests that also could be a business opportunity for WCC. Learning from earthquakes became an obsession. The lecture will include examples from these field reconnaissance studies, and many of the lessons learned.

Lloyd's lecture also explains how there was a growing awareness of the need to apply this type of knowledge to safeguard critical structures. Projects were many, and grew to comprise critical facilities around the world, including the Trans-Alaska Pipeline, the Aswan Dam in Egypt, the Diablo Canyon Nuclear Power Plant in California, and the Panama Canal, among others. The lecture will include highlights from many of these projects and the innovative work carried out in assessing the earthquake threat and characterizing active geological faults. Some of the projects for which these studies provided the basis for their seismic design were subsequently tested in major earthquakes.

The lecture will also give an on overview of how Lloyd created within the group he came to lead at WCC, a unique team of more than 150 geologists, seismologists, and engineers working at a time when major advances were being made in earthquake science. A unique and abiding contribution that Lloyd Cluff has made was to encourage and engender this interaction that in many ways defined Engineering Seismology as a field of practice rather than of academic pursuit. Under Lloyd's leadership, geologists and seismologists advised earthquake engineers, architects, and policy makers and, in turn, they all influenced seismic safety and public policy. Many of the leading practitioners in earthquake hazard assessment working in the US today can be traced back to the WCC stable, and the lecture will name several of these leading lights and their contributions.

Biography

During the past four decades, Lloyd Cluff has been a leader in the reduction of the risks from earthquake hazards in the United States and worldwide. From 1985-1999, he served as Commissioner, vice-chairman, and chairman of the California Seismic Safety Commission, and served numerous other organizations dedicated to earthquake safety, including the Department of Energy, the Nuclear Regulatory Commission, the Office of Science and Technology Policy, the National Science Foundation, and the National Research Council.

As director of the Geosciences Department of Pacific Gas and Electric Company (PG&E), Lloyd Cluff was instrumental in developing a Cooperative Research and Development Agreement (CRADA) with the USGS for earthquake hazards assessment work in California. Joint work under this agreement has made significant advances in the understanding of earthquake hazards and their effects in California and worldwide.

Lloyd Cluff has also counselled the governments of numerous countries on the siting of critical facilities threatened by active faults and earthquakes. He led PG&E's team to investigate recent earthquakes in Turkey and Taiwan. These investigations have provided critical information about ways to reduce risks related to buildings, as well as gas and electric systems that are located on or across active faults.

Attendance details

The 13th Mallet-Milne Lecture will take place at the **Institution Of Civil Engineers, One Great George Street, Westminster, London,** on **Wednesday 25th May 2011,** at **6pm**. The lecture is chaired by Professor Ahmed Elghazouli (Imperial College London). There is no charge to attend. Seats will be allocated on a first come, first served basis. Tea and biscuits will be served from 5.30pm. The lecture is followed by an informal reception. Tickets for the reception are available for a price of £10. For further information please contact Ben McAlinden, Associated Societies Executive, at the ICE on tel. 020 7665 2229 or email ben.mcalinden@ice.org.uk or visit the SECED website at: **www.seced.org.uk**.