

# Index

Page numbers in *italic* denote figures. Page numbers in **bold** denote tables.

- A-train satellite constellation 231, 260, 275
- A'ā lava 117
- AATSR
  - ash detection 276, 301–303, 315
    - Eyjafjallajökull 2010 eruption 312–313
    - Puyehue-Cordón Caulle Volcano 305–307
- AeroPod 335, **336**, 338
- Aerosol Index 276
- aerosols
  - remote-sensing 276
  - sulphate 230, 263, 274
  - UAV sampling 329–332
  - see also* ash plumes
- aerostats 330, 335, **336**, 343–344
- Afar Rift, Ethiopia
  - Dabbahu dyke intrusion 88
  - remote sensing 2
- Aguilucho Cone, Chile, fumaroles 167, 169
- AIRS **261**
- Akita-Komaga-take Volcano, Japan, 1970 eruption, infrared survey 107
- Alaska Volcano Observatory 114, *115*, 188
- algorithms
  - band residual difference 231, 232
  - eruption forecasting, Bezymianny 193–200
  - fire-detection 116–117
  - linear fit 231–234
  - nearest neighbour inversion 45
  - OMSO2 231–234
  - SAPHRA 303
  - thermal anomaly detection 114–117
    - Kalman Filter 137
  - see also* MODLEN; MODVOLC; Okmok; ORAC;
  - temperature-emissivity separation
- Alfár Volcano, Chile, hotspots **164**, *170*, **176**
- ALOS 8, 16
  - Arenal Volcano 32–34
  - Central American Volcanic Arc 17, *18*, 27
- Ambrym Volcano, Vanuatu
  - OMSO2 image 237, 270
  - SO<sub>2</sub> emission 273
- Anatahan Volcano, Northern Mariana Islands
  - OMSO2 image 237, 245
  - satellite sensing 107
- Andes, thermal hotspots 161–182, *163*, **164**, **165**
- andesite
  - Asama Volcano 67, 71
  - Bezymianny Volcano 187
- Aoba Volcano, Vanuatu, OMSO2 image 237
- Arenal Volcano, Costa Rica 21
  - ascending/descending amplitude images 26
  - coherence 27
  - OMSO2 monitoring 282, 283
  - SAR wavelength comparison 32–34
- Arequipa, Peru, 2001 earthquake 182
- ARTS 116
- Asama Volcano, Japan 1, 67–82
  - 2004 eruption 70–73
  - 2008–2009 eruption 73–76
  - Bouguer gravity anomaly 77
  - dyke intrusion 72, 76, 77, 81
  - explosivity 67, **68**
  - ground deformation 72, 75–76
  - hazard to Tokyo 67
  - high-velocity zone 77, 78, 79
  - lava dome 71
  - magma chamber 81–82
  - magma migration 69–70, 72–73
  - magma pathway 76–77, 81–82
  - P-wave velocity 77, 78
  - relocated hypocentres *71*, 72, 73
  - resistivity 79
  - S-wave velocity 80, 81
  - seismicity 67–70, 72, 73–74
    - active source tomography 76–79
    - ambient noise tomography 78, 79–82
  - tectonic setting 68
  - tephra 71
- ascending/descending amplitude images 26
- ash clouds *see* volcanic ash; volcanic clouds
- ash plumes 293–316
  - Asama Volcano 73, 74
  - aviation hazard 263, 293–294, 321–323
    - mitigation 262–263
  - Bezymianny Volcano 189
  - climate change 294
  - dispersal modelling 4–5
  - height 294
  - human health 294
  - identification 297–299
    - Nabro Volcano 309–311
    - Puyehue-Cordón Caulle Volcano 305–308
  - interference with OMI 275–276
  - particle size and shape 294–295, 296
  - refractive indices 295–297
  - remote sensing 2, 7–8, 262–263, 300–304, 325, 327
    - AATSR, ash identification 301–303
    - calibration and validation 327–328
    - MIPAS 300–301
    - ORAC algorithm 303–304
    - SAPHRA 303
    - SEVIRI 303
  - see also* volcanic ash
- ASTER 108, 121–129, **261**
- Andes hotspots 162, 164–166, 167–172
  - characteristics 109, **110**, 111
  - fire-detection algorithms 116–117
- GDEM 4, 24, 25
- Mount Erebus, Antarctica 112
- Mount Etna 2002 eruption *112*

- ASTER (*Continued*)  
 Surface Kinetic Temperature Product (AST08) 162  
 SWIR observation 112, 116, 117, 121–122  
   pixel integrated temperature 113–114  
 TIR observation 113, 121, 122  
 Turrialba Volcano 340–343
- Atitlán Volcano, Guatemala, distortion 25–26  
 atmosphere  
   effect on remote sensing 3  
   phase artifacts 17–19, **20**  
   mitigation potential 22–24
- ATSR 111, 116
- Augustine Volcano, Alaska 107, 113, 115
- Aura satellite 230, 231, 260, **261**
- Autonomous Sciencecraft Experiment 116
- Avachinsky Volcano, Kamchatka, OMSO2 280, 281
- AVHRR  
 Bezymianny Volcano 189–190, 192  
 characteristics 109, **110**, 111  
 MIR observation 113, 128  
   algorithms 114  
 Okmok Algorithm 114  
 pixel resolution 113, 129, 138  
 thermal emissions and volcanic activity 111
- aviation hazard  
 ash plumes 293–294, 321–323  
   jet stream 263, 267  
 Bezymianny Volcano 187  
 Eyjafjallajökull 2010 eruption 101–102, 187, 262,  
   294, 322  
 mitigation, ash and SO<sub>2</sub> detection 262–263  
 unmanned aerial vehicles 323–325  
 volcanic clouds 230, 262–263, 267
- AVOID 323
- Azufre Volcano *see* Falso Azufre Volcano
- Bagana Volcano, PNG  
 OMSO2 image 237, 270  
 SO<sub>2</sub> emission 273
- balloon sampling 330, **331**, 335, 337, 343–344
- band residual difference algorithm 231, 232
- Bezymianny Volcano, Kamchatka 188  
 AVHRR data 189–190, 192  
 dome growth and explosion 187–188, 189, 192, 194–195  
 explosion forecasting 192–200  
   algorithm 193–194  
   KVERT validation 196, 198–199  
   performance 194–196  
 OMSO2 monitoring 271, 280, 281  
 precursory thermal activity 190–193, 194, 199  
 TIR observation 113, 122
- BIRD 140  
 Mount Etna 2002 eruption 147–148, 149
- Bouguer gravity anomaly, Asama Volcano 77
- bromine monoxide, OMI data 7, 237
- Bukavu 2008 earthquake 60, 61, 62
- Calabozos Volcano, Chile, hotspot 163, **164**, 171
- Calientes Volcano, Peru, fumaroles 167
- CALIOP, Eyjafjallajökull 2010 eruption 314–316
- Callaqui Volcano, Chile, hotspots 163, **164**, 166
- carbon dioxide, measurement from satellites 7
- Central American Volcanic Arc (CAVA)  
 ALOS data 17, 18, 25  
 ascending/descending amplitude images 26  
 coherence 27–29  
 InSAR 16, 17–35  
 OMSO2 282–284
- Cerro Azul Volcano, Chile 163, **164**, 171, **176**
- Cerro Blanco Volcano, Chile, deformation 181
- Cerro Hudson Volcano, Chile  
 1991 eruption, SO<sub>2</sub> detection 260  
 deformation 182
- Cerro Overo Volcano, Chile, deformation 181
- Chaitén Volcano, Chile  
 hotspots 162, 163, **164**, 167, 179–180, 181  
 earthquakes 182  
 OMSO2 observation **266**, 267
- Chikurachki Volcano, Kamchatka, ASTER data 122
- Chile  
 2000 earthquake 182  
 Maule earthquake, 2010, 162  
 SO<sub>2</sub> emissions 250–253
- Chiliques Volcano, Chile, hotspots 162, 163, **164**, 170,  
 177, 179
- Chuquicamata smelter, Chile, SO<sub>2</sub> 252
- clouds  
 meteorological 275  
 volcanic *see* volcanic clouds
- coherence  
 Central American Volcanic Arc 27–29  
   Arenal Volcano 32–34  
 and land use 29, 31–32  
 modelling 27–29, 30  
 pixels 16, 30
- Colima Volcano, Mexico (*see also* Volcán de Colima)  
 OMSO2 monitoring 277, 278, 284  
 water vapour signals **20**
- Colombia, OMI survey 269, **270**
- column averaging kernel 233–234
- Cook Inlet volcanoes, Alaska, SO<sub>2</sub> emission 263
- Copahue Volcano, Chile/Argentina border, hotspots 162, 163,  
**164**, 167, 172, **176**, 177, 181
- copper smelting, Chile, SO<sub>2</sub> emission 250–251, 252
- Cordón Caulle Volcano *see* Puyehue-Cordón Caulle  
 Volcano, Chile
- COSPEC 229, 263, 271
- cropland/vegetation, coherence 31–32
- Dabbahu dyke intrusion, Ethiopia 88
- decorrelation, interferometric 16–17
- deflation 86
- deformation *see* ground deformation
- degassing *see* gas emission; sulphur dioxide emission
- Descabezado Grande Volcano, Chile 163, **164**, 171
- Digital Airborne Imaging Spectrometer 108
- digital elevation models (DEMs) 4  
 limitations and mitigation 24–25
- distortion, InSAR 25–26
- DOAS 263  
 comparison with OMI 271–272
- Dozier method *see* dual-band method

- Dragon Eye UAV 324–325, 326, **331**, 335, **336**, 337–338, 343, 344, 346
- dual-band method 117–118, 119, 121, 139, 140
- ASTER SWIR, Lascar Volcano 122–126
- dyke intrusion 5
- Asama Volcano 72, 76, 77, 81
- Dabbahu 88
- East Rift Zone (Napau), Kilauea Volcano 88–89
- Miyakejima dyke swarm 99
- Nyamuragira 40, 47–50, 51, 53, 54, 55, 57–58, 59
- seismicity and deformation 99–101
- dykes, modelling, three dimensional mixed boundary elements method 43–45
- Earth Observation (EO) 8–9
- earthquakes
- Andes hotspots 182
- Nyamuragira 46, 49, 50, 53, 55, 61, 62
- volcano-tectonic 85
- Asama Volcano 68–70, 72, 73
- Miyakejima dyke swarm 99
- seismicity and deformation joint analysis 99–101
- East African Rift 40
- East Rift Zone (Napau), Kilauea Volcano, dyke intrusion 88–89
- Ecuador, OMI survey 269, **270**
- comparison with DOAS 271
- edifice instability 5
- El Chichón Volcano, Mexico, 1982 eruption
- SO<sub>2</sub> and ash separation 300
- SO<sub>2</sub> detection 3, 260
- El Tatio Volcano, Chile 163, **164**, 169, 175, **176**
- El Teniente smelter SO<sub>2</sub> 252
- emissivity 108, 138
- ENVISAT data, Nyamuragira 52, 53, 55, 57, **58**, 59, 60
- ERS-1/2 data, Arenal volcano 32–34
- eruption forecasting 4, 86, 94–99
- Bezymianny Volcano 192–200
- Hekla Volcano 2000 eruption 96, 97
- inflation predictability 97–99
- Mount Pinatubo 1991 eruption 94–95, 96
- Mount St Helens 1980 eruption 94, 95, 96
- physics-based models 89–94, 101–103
- epistemic uncertainties 103
- Monte Carlo inversion 92–94, 102–103, 104
- Soufrière Hills Volcano 1997 eruption 95–96
- eruption style, remotely sensed observation 111–112
- EUFAR 329
- EVOSS project 9
- extrusion rate, Vulcanian eruption, radiance 187
- Exupéry Volcano Fast Response System 137
- Eyjafjallajökull 2010 eruption, Iceland
- ash dispersal 4
- ash plumes 276, 311–315
- height 294, 312
- aviation hazard 187, 262, 294
- disruption 101–102, 187, 322
- gas emissions 7
- InSAR measurement 3
- OMSO2 observation **266**, 267
- SO<sub>2</sub> and ash separation 300
- Falso Azufre Volcano, Argentina/Chile border, hotspot 163, **164**, 171, **176**
- Finite Element Analysis 4
- Fourier transform 154
- Fourpeaked Volcano, Alaska, SO<sub>2</sub> 247, 248, 249, 267
- Fuego Volcano, Guatemala, OMSO2 282, 283
- fumaroles
- Andes hotspots 167, 169, 173–175, **176**
- Nyamuragira 53
- temperature 112
- thermal analysis 3
- Volcán de Colima 204, 205, 206, 212, 215
- see also* gas emission
- Galeras Volcano, Colombia, 1993 casualties 327
- Garbuna Volcano, PNG, SO<sub>2</sub> 247, 248, 249, 267
- gas emission
- hazards 230
- long-term monitoring 263–264, 269–272
- OMI 229–254, 259–285
- comparison with ground-based surveys 271–272
- remote sensing 2, 7–8
- SO<sub>2</sub> chemical processing 274
- UAV sampling 329–332
- see also* volcanic clouds
- GEO-CAPE 253–254
- Global Hawk 323, 324, 344
- GOES, spatial resolution 8, **110**, 113, 129
- GOES-R 129, 130
- GOME 230, 260, **261**
- GOME-2 231, **261**, 271
- GOSAT 7
- GPS (Global Positioning System)
- ground deformation 85
- Kilauea Volcano 88–89
- Sierra Negra Volcano 87–88
- gravitational loading 5
- greenhouse gas, satellite sensing 7
- see also* sulphur dioxide
- Grímsvötn Volcano, Iceland
- IASI ash observation 276
- OMSO2 observation **266**, 267
- ground deformation
- Asama Volcano 72, 75–76
- GPS 85
- and magma chamber properties 86–87
- measurement 85–86
- Nyamuragira 42, 47, 48, 52, 53
- mixed boundary element method 43–45
- remote sensing 2, 5–6, 9
- InSAR 2–3, 4, 15–17
- and seismicity, joint analysis 99–101
- Sierra Negra Volcano, Galapagos 87–88
- ground truthing 7–8, 271–272, 327–346
- GSNL 8
- Guallatiri Volcano, Chile
- earthquake 182
- hotspots 163, **164**, 173
- Halema 'uma'u crater, Kilauea, SO<sub>2</sub> emission 247
- see also* Kilauea Volcano

- Hawaii  
 early monitoring 1  
 infrared imaging 3  
   early surveys 107  
   *see also* Kilauea Volcano  
 hazard management 4–5, 8–9  
 hazard mitigation, ash and SO<sub>2</sub> detection 262–263  
 heat *see* thermal signals, remote sensing  
 Hekla Volcano, Iceland  
   2000 eruption, forecasting 96, 97  
   SO<sub>2</sub> and ash separation 300  
 helicopter UAV **331**  
 Helikite 344  
 hot springs, Andes hotspots 167  
 Hotspot Recognition System, Mount Etna 147  
 hotspots  
   Andes 161–182, *163*, **164**, **165**  
   temporal variability 172, 174–175, 177–178  
   detection  
     dual-band equations 117  
     near-real-time algorithms 114–115, 116  
   Volcán de Colima *212*, 215, 217, 221, 223  
   *see also* thermal anomaly  
 Hualca Hualca Volcano, Peru  
   deformation 181  
   fumaroles 167  
   water vapour signals **20**  
 Huaynaputina Volcano, Peru, hotspot **164**, *168*  
 hydrogen sulphide emission 269  
 hydrothermal circulation 5  
 Hyperion sensor 108, 111  
   characteristics **110**  
   SWIR detection 112, 129  
   thermal anomaly algorithm 116  
 HYSPLIT model 327
- IASI  
 ash detection 276  
 degassing **261**, 269, 271  
 Ikhana 323, *324*, 344  
*in situ* sampling, UAV 328, 329  
   Turrialba Volcano 332–344  
 inflation 86  
   predictability 97–99  
 inflation-deflation cycles 86  
 infrared remote sensing 3, 107–130  
   early surveys 107  
   future prospects 129–130  
   satellite observational functionality 109, **110–111**  
   SO<sub>2</sub> emissions 260, **261**, 262  
   volcanic processes 111–114
- InSAR  
 Arenal Volcano, wavelength comparison 32–34  
 Central American Volcanic Arc 17–35  
 distortion 25–26  
 effect of vegetation 15–16, 27  
 ground deformation measurement 2–3, 4, 8, 85  
 modelling 3–4  
 multi-temporal (MT-InSAR) 39–40  
   Nyamuragira 42–43  
   persistent scatterer (PS) 42–43  
     small baseline 42–43  
     StaMPS technique 43  
 Nyamuragira 41–43  
   non-linear inversion 45–46  
   process 16–17  
   tropical volcanoes 15–35  
   tropospheric water vapour 17–24  
 interferograms 16  
   coherence 27–29  
   Nyamuragira eruptions 46–57, *59*  
   tropospheric water vapour effects 17–24  
     stacking 22–23  
 intertropical convergence zone (ITCZ), water vapour  
   variation 17  
 Irruputuncu Volcano, Chile/Bolivia border, hotspots *163*,  
   **164**, 169, *173*, **176**  
 Isluga Volcano, Chile *163*, **164**, 169, 172, *173*, 177  
 Italy, OMSO2 279–281  
 Izalco cinder cone, El Salvador 22
- Jebel al-Tair, Yemen, 2007 eruption  
 gas/ash plume 2, 263  
 OMSO2 observation **265**, 267  
 jet stream, volcanic clouds and aviation 263, 267  
 Jólnir, Iceland, infrared imaging 107
- Kalman Filter  
 thermal anomaly uncertainty 137, 144–146, 154, 155–157  
   basics 144–145  
   Mount Etna 2002 eruption 148  
   Nyamuragira 2010 eruption 150–152, *153*  
   set-up 145  
   systematic errors 145–146  
 Kamchatka, OMSO2 280, 281–282  
 Karymsky Volcano, Kamchatka  
   balloon sampling 330  
   OMSO2 monitoring 280, 281  
 Kasatochi Volcano Aleutian Islands  
   IASI H<sub>2</sub>S observation 269  
   OMSO2 observation 7, 264, **266**, 267  
 Kilauea Volcano, Hawaii  
   dyke swarms, Pu'u O'o eruption 99  
   inflation-deflation cycles 86  
   lava flows 121  
   Napau dyke intrusion 88–89  
   Nimbus I HRIR 3  
   SO<sub>2</sub> emission 232, 233, 247, *248*, 271  
   rate estimation *241*  
   uplift 97  
 kites **330**, 335, **336**, *338*, 344  
 Kliuchevskoi Volcano, Kamchatka *188*, 189  
   OMSO2 monitoring 280, 281  
 Krafla dyke swarm 88, 97, 98  
   associated earthquakes 99  
 Kupaianaha lava lake 120  
 KVERT 188  
   validation of Bezymianny forecasting algorithm 196,  
     198–199
- La Negra smelter, Chile, SO<sub>2</sub> *252*  
 Laguna del Maule Volcano, Chile 181–182

- lahars
  - hazard modelling 4
  - Turrialba Volcano 332
- Lake Kivu, InSAR 39–40, 42
- land use, and coherence 29, 31–32
- Landsat Thematic Mapper (TM) 3, 119
- Langila Volcano, PNG
  - OMSO2 image 270
  - SO<sub>2</sub> emission 273
- Las Pilas Volcano, Nicaragua 24
- Láscar Volcano, Chile 108
  - hotspots 162, 163, **164**, 167, 169, 170, **176**, 177
    - ASTER data 122–129, 178–179
    - earthquakes 182
  - lava dome 118, 119
  - SO<sub>2</sub> emissions 251, 252
  - SWIR imagery 111
- Lastarria Volcano, Chile/Argentina border
  - hotspots 163, **164**, 169, 175, **176**, 181
  - SO<sub>2</sub> emissions 251, 252, 253
- lava, temperature 112
- lava domes 203–204
  - Andes hotspots 167
  - Asama Volcano 71
  - Bezymianny Volcano 187–188, 189, 192, 194–195
  - extrusion 5
  - hazard assessment 4
  - Láscar Volcano 118, 119
  - stability 203
  - temperature 112
  - thermal analysis 3
  - thermal camera studies 204
  - Volcán de Colima 204–226
    - growth 204–207
- lava flows
  - Andes hotspots 167
  - compaction 5
  - effusion rate 111
  - hazard assessment 4
  - mapping 108
  - RP measurement, uncertainty 153–154
  - thermal analysis 3, 121
- lava fountains
  - Nyamuragira 61
  - Pu'u O'o 86
  - temperature 111–112
- lava lakes
  - Andes hotspots 167
  - Kupaianaha 120
  - modelling 4
  - Nyamuragira 53
  - temperature 112
  - thermal analysis 3
- lava lobe, Volcán de Colima 205–206, 212, 217, 218, 223–225
- Lazufre region, Chile, magma reservoir inflation 253
- least squares spectral analysis (LSSA) 154–155
  - Nyamuragira 2010 eruption 155, 156
- LIDAR 328
- linear fit algorithm 231–234
- Llaima Volcano, Chile
  - earthquakes 182
  - hotspots 162, 163, **164**, 167, 179, 180, 181
  - OMSO2 observation **265**, 267
- Lonquimay Volcano, Chile, hotspots 162
  - see also* Navidad Crater
- magma chambers *see* magma reservoirs
- magma extrusion, Bezymianny Volcano 192
- magma migration, Asama Volcano 69–70, 72–73
- magma pathway, Asama Volcano 76–77, 81–82
- magma plumbing systems
  - modelling 4
  - Nyamuragira 40
- magma reservoirs
  - Asama Volcano 81–82
  - modelling 44–45
  - Nyamuragira 47, 53, 57, 59, 61–62
  - physics-based modelling 90–92
    - and volcano deformation 86–87
- Manam Volcano, PNG, OMSO2 237, 262, **265**, **270**
- Manda Hararo Volcano, Ethiopia
  - gas/ash plume 2
  - OMSO2 **265**, **266**, 267
- Markov Chain Monte Carlo procedure 92–94, 102–103, 104
- Masaya Volcano, Nicaragua, OMSO2 282, 283
- Maule 2010 earthquake, Chile 162
- Mayon Volcano, Philippines, OMSO2 244
- Merapi Volcano, Indonesia, 2010 eruption, SO<sub>2</sub> monitoring 263, **266**, 267
- methane, GOSAT 7
- Mexico, OMSO2 277–279
- MIPAS, ash plume recognition 300–301, 315
  - Nabro Volcano 308–311
  - Puyehue-Cordón Caulle Volcano 307–308
- MIR imagery 113, 153
  - algorithms 114, 116
- Misti Volcano, Peru
  - hotspots 163, **164**, 168, **176**
  - earthquakes 182
- MIVIS 120, 122
- Miyakejima, Japan
  - degassing 264
  - dyke swarm 99
- Mocho-Choshuenco Volcano, Chile 163, **165**, 167
- modelling 3–4, 9
  - coherence 27–29, 30
  - physics-based 89–94, 101–103
  - three dimensional mixed boundary elements method 43–45
- MODIS 108, 111, **261**
  - characteristics 109, **110**
  - hotspot detection algorithms 114–115
  - MIR observation 113, 114
  - Mount Etna 2002 eruption 112, 146–148
  - Normalized Thermal Index 138–139
  - Nyamuragira 2010 eruption 150–152
  - RP estimation 140
  - spatial resolution 113, 129
  - thermal emissions and volcanic activity 111
- MODLEN algorithm 116
- MODTRAN 109

- MODVOLC algorithm 115–116, 128, 138–139  
Andes hotspots 165–167, 169, 177, 178, 182
- Mogi source model 4, 44, 49, 86
- Momotombo Volcano, Nicaragua  
SRTM 90 DEM images 25  
temporal development of phase 18, 23
- monitoring systems  
future perspectives 8–9  
gas emissions 259–285  
long-term 263–264, 269–272  
historical perspectives 1–3
- Montserrat *see* Soufrière Hills Volcano, Montserrat
- Monte Carlo inversion 92–94, 102–103, 104
- Mount Aso, Japan, ash particles 294, 295  
refractive indices 295–297, 298
- Mount Cameroon, water vapour 17, **20**
- Mount Erebus, Antarctica  
ASTER observations 112  
lava lake 118
- Mount Etna, Sicily  
2002 eruption  
NTI thresholds 146  
thermal anomalies 112, 146–148, 149  
Kalman Filter 148  
NTI thresholds 146  
RP uncertainty 147–148, 154  
dual-band method 120  
infrared monitoring 108, 112  
InSAR measurement 2  
lava flow radiative power 119  
OMSO2 monitoring 279–281, 284  
SO<sub>2</sub> emission 271, 273  
Thematic Mapper Simulator imagery 119  
water vapour signals **20**
- Mount Pelée, Martinique, 1902 eruption, photographs 107
- Mount Pinatubo, Philippines, 1991 eruption  
forecasting 94–95, 96  
SO<sub>2</sub> detection 260, 263
- Mount St Helens, USA  
1980 eruption forecasting 94, 95, 96  
2004–2008 eruption forecasting 102, 204  
remote sensing techniques 2, 107  
ASTER TIR 122
- Mount Unzen, Japan, dome collapse 203
- MSG-SEVIRI *see* SEVIRI
- MT-InSAR (multi-temporal InSAR) 39–40  
persistent scatterer (PS) 42–43  
small baseline 42–43  
StaMPS technique 43, 58, 60–61
- Multi-functional Transport Satellite, thermal anomaly  
detection algorithms 114
- Mutnovsky Volcano, Kamchatka, OMSO2 280, 281
- Nabro Volcano, Eritrea  
2011 eruption, ash cloud 2, 263, 308–311  
OMSO2 observation **266**, 267
- Napau dyke intrusion, Kilauea Volcano 88–89
- NASA EOS project 115  
*see also* Hyperion sensor
- NASA Joint Polar Satellite System Mission 129
- NASA UAVs 323, 324, 339–340
- Navidad Crater, Lonquimay Volcano, Chile, hotspot 163, **164**, 172, 181
- Nevado del Ruiz Volcano, Colombia, 1985 eruption, SO<sub>2</sub>  
detection 260
- Nevados de Chillán, Chile, hotspot 163, **164**, 167, **176**, 177–178
- Nimbus I High Resolution Infrared Radiometer 3, 107
- noise, radiometric 143  
Kalman Filter 144–146
- Normalized Difference Vegetation Index, Central America 31
- Normalized Thermal Index 138–139, 141–142  
incorrect threshold 141–142
- Nyamulagira *see* Nyamuragira
- Nyamuragira, DRC 39, 41  
1996 eruption 46–47, 48, **52**  
1998 eruption 47–48, 49  
2000 eruption 48, 49  
2001 eruption 48–49  
2002 eruption 49–50, 51, **52**  
2004 eruption 50, 52, 53, 54  
2006 eruption 42, **52**, 53, 55, 56, 263  
2010 eruption **52**, 55, 57–58, 59  
LSSA 155, 156  
MODIS and SEVIRI measurements 150–152  
RP filtering 150, 152, 155  
thermal anomalies 148–152  
caldera 40, 42, 53, 62  
dyke intrusion 40, 47–50, 51, 53, 54, 55, 57–58, 59  
eruptions 40–41, 42, 46–58  
fracture network 40, 41  
fumaroles 53  
geological setting 40–41  
graben 40, 42  
ground deformation 42, 47, 48, 52, 53  
InSAR 41–43  
lava field 41  
lava flow volume 46, 47, 48, 49, 50, 53, 55  
lava lakes 53  
magma plumbing system 40, 61–62  
magma reservoir 47, 53, 57, 59, 61–62  
non-linear inversion 45–46  
OMSO2 observation **265**, 267  
seismicity 46, 49, 50, 53, 55, 61, 62  
sill intrusion 53, 57–58  
StaMPS technique 58, 60–61  
thermal anomaly uncertainty 141  
topographic mesh 45
- Nyiragongo, DRC 39, 40  
earthquakes 46, 49, 50, 53, 55, 61, 62  
MODVOLC observations 116  
SO<sub>2</sub> emission 239, 250, 251, 271  
rate estimation 242, 243
- Ojos del Salado Volcano, Chile/Argentina border, hotspots  
163, **164**, 169, 175
- Okada solution model 4, 44
- Okmok algorithm 114, 190
- Okmok Volcano, Aleutian Islands  
InSAR measurement 3  
OMSO2 observation 264, **266**
- Olca-Paruma Volcano, Chile/Bolivia border, hotspots 163, **164**, 169, 172, 174, **176**

- Oldoinyo Lengai Volcano, Tanzania 108  
 ASTER VNIR data 122  
 lava temperature 112, 122  
 MODLEN algorithm 116
- Ollagüe Volcano, Chile/Bolivia border, hotspots *163, 164, 169, 174*
- OMPS 253, 285
- ORAC algorithm  
 ash detection 303–304, 315–316  
 ash plume properties 303–304  
 Eyjafjallajökull 2010 eruption 312–314
- Osservatorio Vesuviano, Italy 1
- ozone  
 interference from 276, 277  
 OMT03 232
- Ozone Monitoring Instrument (OMI) 231, 260, **261**, 262  
 Aerosol Index 276  
 degassing  
 long-term monitoring 263–264, 269–272  
 comparison with ground-based data 271–272  
 measurement 229–254  
 row anomaly 238, 276
- Ozone Monitoring Instrument SO<sub>2</sub> monitoring (OMSO2)  
 229–254  
 algorithms 231–234  
 applications 259–285  
 automated web-based data analysis 238–240  
 Central American Volcanic Arc 282–284  
 Chile 250–253  
 data access 235–236  
 data structure and analysis 237–238  
 detection thresholds 245–247  
 eruption monitoring 264–269  
 inactive volcanoes 247–250  
 Fourpeaked Volcano 247, 248, 249  
 Garbuna Volcano 247, 248, 249  
 Raoul Island 247, 248  
 Italy 279–281  
 Kamchatka 281–282  
 Kilauea Volcano 233, 247, 248  
 limitations to volcano monitoring 272–276  
 meteorological conditions 275  
 OMI row anomaly (ORA) 238, 276  
 ozone column 276, 277  
 SO<sub>2</sub> detection limit 272–273  
 SO<sub>2</sub> persistence/transience 274–275  
 volcanic ash 275–276  
 wind dispersal of plumes 274–275
- Mexico 277–279
- Nyiragongo, DRC 239, 242, 243, 250, 251  
 signal-to-noise ratio 245–247, 272
- SO<sub>2</sub> emission rate estimation  
 lifetime 240–242  
 plume transects 242–243  
 single pixel 243–245
- SO<sub>2</sub> erupted mass estimation 267–269  
 SO<sub>2</sub> mass calculations 239–240  
 units 234–235
- Pacaya Volcano, Guatemala, ASTER GDEM 25  
 pāhoehoe lava, surface temperature 112, 117
- pair-wise logic 18, **20**, 23, 42
- Papua New Guinea  
 OMI survey 269–270  
 comparison with DOAS 271
- phase correlation, Arenal Volcano, Costa Rica 32  
 phase unwrapping, Nyamuragira 42  
 Pisco, Peru 2007 earthquake 182
- Piton de la Fournaise Volcano, Réunion Island  
 dyke modelling 45, 46  
 OMSO2 observation **265**, 267
- pixel integrated temperature 113–114, 118
- pixels  
 coherence 16, 30  
 thermal anomaly 138  
 quantification 139–140  
 radiometric noise 143
- Planchón-Peteroa Volcano, Argentina/Chile border, hotspot  
*163, 164, 171*
- Planck's Law 109, 118, 138
- Plinian eruption  
 plume height 294  
 Volcán de Colima 204
- Poás Volcano, Costa Rica, OMSO2 282, 283
- Popocatepetl Volcano, Mexico  
 ASTER VNIR data 122  
 OMSO2 monitoring 277, 278, 279, 284  
 SO<sub>2</sub> emission rate estimation 240  
 TOMS monitoring 264  
 water vapour signals **20**
- Potrerrillos smelter, SO<sub>2</sub> 252
- Puchuldiza Volcano, Chile, hotspot *163, 164, 168*
- PUFF, volcanic ash tracking model 327
- Pular/Pajonales Volcano, Argentina *163, 164, 170*
- Putana Volcano, Bolivia/Chile border, hotspots *163, 164, 170, 176, 181*
- Pu'u O'o, Hawaii  
 eruption 99  
 lava fountains 86  
 SO<sub>2</sub> emission 247
- Puyehue-Cordón Caulle Volcano, Chile  
 2011 eruption, ash plumes 304–308, 309  
 hotspot *163, 164, 172, 176, 181*  
 OMSO2 observation 267
- pyroclastic flows, hazard assessment 4
- Rabaul Volcano, PNG, OMSO2 **265**, 267, 270
- RadarSat data  
 Arenal volcano 32–34  
 Nyamuragira 47, 48, 49, 50, 51, 52, 53, 57, **58**
- radiance  
 atmospheric 109  
 spectral 108–109, 138  
 surface, Vulcanian eruptions 187
- radiant power (RP)  
 estimation 139–140  
 retrieval 118–119, 120  
 uncertainty 140–144, 153–154  
 incorrect NTI threshold 141–142  
 Mount Etna, 2002 eruption 147–148, *154*  
 Nyamuragira 2010 eruption 150–152, *155*  
 radiometric noise 143

- radiant power (RP) (*Continued*)  
 Kalman Filter 137, 144–146, 154, 155–157  
 total uncertainty 143–144  
 Wooster's approximation 142–143, 147, 153
- radiation, electromagnetic 108–109
- rainforest, coherence 31–32
- Raoul Island, Kermadec Islands, SO<sub>2</sub> emission 247, 248, 267
- Raven UAV **331**
- Red Sea region, remote sensing 2
- Redoubt Volcano, Alaska  
 ash cloud 322  
 OMSO2 observation 107, 264, **266**, 267, 271  
 ozone column 276
- remote sensing  
 ash plumes 2, 7–8, 262–263, 300–304, 325, 327  
 gas emissions 2, 7–8  
 sulphur dioxide 3, 7, 229  
 techniques 1, 2, 325, 327  
 Mount St Helens 2  
 thermal anomaly monitoring 138–140  
 validation *see* ground truthing; unmanned aerial vehicles
- rockfalls, and heat emission, Volcán de Colima 221
- root mean squared variation 21
- row anomaly 238, 276
- Sabayanca Volcano, Peru, hotspot 163, **164**, 167, 168
- Sakurajima Volcano, Japan  
 water vapour 17, **20**  
 wind dispersal of SO<sub>2</sub> plumes 275
- San Miguel Volcano, El Salvador 22, 24
- San Pedro Volcano, Chile, hotspot 163, **164**, 168
- Santa Ana, El Salvador, r.m.s. variation 21–22
- Santa María Volcano, Guatemala, OMSO2 282, 283
- Santiaguito Volcano, Guatemala, Caliente lava dome 204
- SAPHRA 303, 315
- Sarychev Peak Volcano, Kamchatka  
 OMSO2 observation 264, **266**, 267  
 SO<sub>2</sub> mass estimation 268, 269
- satellites  
 comparison with ground-based data 7–8, 271–272, 327–346  
 emission monitoring 260–264  
 gas measurement 7, 107, 229–230  
 infrared observational functionality 109, **110–111**  
 volcanic surface observation 107
- savannah *see* woody savannah
- SCIAMACHY 230, 260, **261**
- Sebastián Volcano, Chile, lava field 177–178
- seismic tomography  
 active source, Asama Volcano 76–79  
 ambient noise, Asama Volcano 78, 79–82
- seismicity  
 Andes volcanoes 182  
 Asama Volcano 67–70, 72, 73–4  
 and deformation, joint analysis 99–101  
 Nyamuragira 46, 49, 50, 53, 55, 61, 62  
*see also* earthquakes
- seismicity rate theory 99–101
- SENTINEL 8, 9  
 Arenal volcano 32–34  
 Semeru Volcano, Indonesia, ASTER TIR data 122
- SEVIRI 8, 108, 130, **261**  
 ash detection 276, 303, 315  
 Eyjafjallajökull 2010 eruption 313–315  
 characteristics **110**  
 Nyamuragira 2010 eruption 150–152  
 thermal emissions and volcanic activity 111
- Shiveluch Volcano, Kamchatka, OMSO2 280, 281
- Sierra Negra Volcano, Galápagos  
 deformation 87–88, 97  
 OMSO2 observation 262, **265**, 268  
 SO<sub>2</sub> mass estimation 269
- SIERRA 323, 324, 339–340, 344–345
- sill intrusion 5, 53, 57–58  
 Sierra Negra Volcano 87
- singular vector decomposition, MIPAS 300–301
- Sol de Mañana Volcano, Bolivia 163, **164**, 170
- Soufrière Hills Volcano, Monserrat  
 1997 eruption, forecasting 95–96, 263  
 OMSO2 observation **265**, 267, 268, 269, 271, 273  
 water vapour 17, **20**
- South Atlantic radiation anomaly 250
- spectroscopy *see* COSPEC; DOAS
- stacking 22–23
- StaMPS technique 43  
 Nyamuragira 58, 60–61
- Stefan-Boltzmann Law 108, 118, 120, 140
- stressing rate 99–101
- STRM, 90 DEM 4, 24, 25
- Stromboli Volcano, Italy, OMSO2 280–281, 284
- subsidence 5
- sulphate aerosol 230, 263, 274
- sulphur dioxide, oxidation *see* sulphate aerosol
- sulphur dioxide emission  
 anthropogenic, Chile 250–253  
 Asama Volcano 70  
 aviation hazard mitigation 262–263  
 chemical processing 274  
 hazards 230  
 Ozone Monitoring Instrument 229–254, 259–285  
 applications 259–285  
 comparison with ground-based data 271–272  
 detection limits 272–273  
 dispersal of plumes 274–275  
 eruption monitoring 264–269  
 long-term monitoring 269–272  
 persistence/transience of SO<sub>2</sub> clouds 274–275  
 total SO<sub>2</sub> mass 267, 269
- rate estimation  
 lifetime 240–242  
 plume transects 242–243  
 single pixel 243–245
- remote sensing 3, 7, 229
- satellite monitoring 230, 260  
 column averaging kernel 233–234
- Surtsey, Iceland, infrared imaging 3, 107
- SWIR imagery 112, 116
- Tacaná Volcano, Guatemala, OMSO2 282, 283
- Tacora Volcano, Chile, fumaroles 167, 169



- talus apron  
   and lava dome stability 203, 223  
   Volcán de Colima 205, 217, 218–219, 221, 223–225  
 TanDEM-X 4  
 Tarapaca, Chile 2005 earthquake 182  
 Teide volcanic complex, Tenerife, ASTER VNIR data 122  
 temperature-emissivity separation algorithm 162, 165  
 temporal development of phase 18, 20, 23  
 tephra  
   Asama Volcano 71  
   Krafla dyke swarm 99  
 TerraSAR-X data, Arenal volcano 32–34  
 Tethersonde 335, 336, 337, 340–341, 343–344  
 Thematic Mapper Simulator 3, 119  
 thermal anomaly  
   characteristics 138  
   detection 138–139  
     uncertainty 141–142  
   monitoring 137  
     algorithms 114–117, 138  
       Kalman Filter 137  
       MODVOLC 115–116, 128, 138–139  
     characterization 117–121  
       dual-band method 117–118, 119, 121, 139, 140  
       tri-band methods 119–120, 127–128  
     remote sensing 138–140  
   quantification 139–140  
   *see also* hotspots  
 Thermal Hyperspectral Imager 129  
 thermal signals, remote sensing 3  
   surface 6–7  
 Ticsani Volcano, Peru, deformation 181  
 tilt records 95, 97  
 Tinakula Volcano, Solomon Islands, OMSO2 237  
 TIR observation 4, 6, 113  
 Tocopilla, Chile 2007 earthquake 182  
 Tokyo, Asama Volcano hazard 67  
 Toliman Volcano, Guatemala, distortion 26  
 TOMS 3, 229, 260, 261  
 topographic mesh, Nyamulagira 45  
 topography, correlation with atmospheric phase 17, 18, 19, 20, 22  
 Trans-Mexican Volcanic Belt 204, 205  
 transmittance 109  
 tri-band methods 119–120, 127–128  
 tropics  
   InSAR measurement 15–35  
     effect of vegetation 15–16, 31–32  
     tropospheric water vapour 17–24  
 TROPOMI 253, 285  
 troposphere, water vapour 17–24  
 Tula industrial complex, Mexico, OMSO2 277, 278, 279  
 Tungurahua Volcano, Ecuador, OMSO2 265, 267, 270, 271  
 Tupungatito Volcano, Chile/Argentina border, hotspot 163, 164, 171  
 Turrialba Volcano, Costa Rica 332, 333, 334  
   SO<sub>2</sub> monitoring 271, 282, 283  
   ASTER data 340–343  
   UAV *in situ* observations 325, 332–344  
   aerostats 335  
   balloon/tethersonde 337, 340–341  
   Dragon Eye 335, 336, 337–338  
   NASA SIERRA 336, 339–340  
   Vector Wing 100 336, 338–339, 341, 343  
 Tutupaca Volcano, Peru, hotspots 176  
 UAV *see* unmanned aerial vehicles  
 Ubinas Volcano, Peru, hotspots 162, 163, 164, 167, 168, 175, 177  
 Ulawun Volcano, PNG  
   OMSO2 image 237, 270  
   SO<sub>2</sub> emission 273  
 ultraviolet Aerosol Index 237  
 ultraviolet correlation spectroscopy 229, 263, 271  
 ultraviolet imaging 3, 260  
   OMSO2 229–254, 260, 262  
 Umkehr layers 232  
 uncertainty, epistemic 103  
 unmanned aerial vehicles (UAV) 323–325, 328, 329–347  
   Dragon Eye 324–325, 326, 335, 336, 337–338, 343, 344, 346  
   Global Hawk 323, 324  
   Ikhana 323, 324  
   Raven 331  
   SIERRA 323, 324, 336, 339–340  
   Vector Wing 100 331, 338–339, 341, 343  
 uplift 5  
 Uturuncu Volcano, Bolivia, hotspots 163, 164, 169, 172, 174, 176, 181  
 VAFTAD model 327  
 Vanuatu  
   OMI survey 269–270  
   comparison with DOAS 271  
 VATD models 327, 328  
 Vector Wing 100 UAV 331, 338–339, 341, 343  
 vegetation  
   and coherence 29, 31–32  
   effect on InSAR measurement 15–16, 27  
   Lake Kivu area 42  
 Vesuvius, Osservatorio Vesuviano 1  
 VIIRS 129  
   characteristics 111  
 Villarrica Volcano, Chile  
   hotspots 162, 163, 164, 167, 172, 177, 179  
   earthquakes 182  
   SO<sub>2</sub> emissions 252  
 Virunga Volcanic Province, Rwanda 40, 41  
   lavas 41  
   seismicity 53  
 Volcán de Colima, Mexico  
   lava dome  
     dome sides 212, 214, 217, 218–219  
     dynamic controls on heat emission 221–222  
     emplacement 222–225  
       extrusion rate models 222  
       independent talus models 222–223  
       surface cooling/crust models 222  
       thermal-mechanical framework 223–225  
   fumaroles 204, 205, 206, 212, 215  
   growth 204–207, 215, 217, 223–225  
   heat budget 219–222

- Volcán de Colima, Mexico (*Continued*)  
 hot spots 212, 215, 217, 221, 223  
 lava lobe 205–206, 217, 218–219, 223–225  
 stability 225–226  
 talus apron 205, 217, 218–219, 221, 223–225  
 thermal imaging 204–226  
 error sources  
   emissivity 207, **210**, 213  
   instrumental 207, **209**, 213  
   solar heating 208, **210**, 211, 213  
   temperature uncertainty 207, 213  
   transmissivity 208, **209**, 213  
   variable pixel area 207, **210**  
   volcanic gas and ash 207, **210**, 213  
 surface heat flux density 215, 216, 218–219  
 surface temperature 214, 217–218  
 surface thermal mapping 215, 217  
 time series 212, 214  
 top surface 212, 214, 217, 218–219  
 Plinian eruption 204  
 Vulcanian eruption 204
- volcanic ash  
*in situ* sampling 328, 329  
 interference from 275–276  
 manned airborne observation 329  
 models 327  
 unmanned aerial vehicles 328, 329–332  
*see also* ash plumes
- Volcanic Ash Advisory Centres (VAACs) 1, 322
- volcanic clouds  
 aviation hazard 262–263, 267  
 dispersal 263, 267, 274–275  
 remote sensing 3, 7, 262–263, 267  
 trajectory 325, 327  
*see also* gas emission
- volcanic plumes 293–316  
 remote sensing 325, 327  
*see also* ash plumes; volcanic ash;  
   volcanic clouds
- volcanic processes, IR remote sensing  
 111–114, 138
- Volcano Explosivity Index 67, 112, 187
- Vulcanian eruption  
 2004 Asama Volcano 71  
 extrusion rate and surface radiance 187  
 Volcán de Colima 204
- Vulcano Volcano, Italy, OMSO2 280–281, 284
- WAOSS-B, Mount Etna 2002 eruption 147
- water vapour  
 tropospheric 17–24  
   atmospheric phase artifacts 17–19, **20**  
   mitigation potential 22–24  
   Central America 19, 21–22
- Wien's displacement law 108, 138
- wind dispersal, volcanic clouds 263, 274–275  
*see also* jet stream
- woody savannah, coherence 31–32
- Wooster's approximation 142–143, 147, 153
- World Organization of Volcano Observatories 1
- World Virtual Orbiting Volcano Observatory 9
- Yucamane Volcano, Peru 163, **165**