

1
2
3 **Meeting Report** Weather on other planets: Measurement and Interpretation
4
5
6

7 The idea for this meeting was generated by the Royal Meteorological Society's
8 *Special Interest Group on Meteorological Observing Systems* and organised by Ian
9 Strangeways jointly with Colin Wilson of the Atmospheric, Oceanic and Planetary
10 Physics Group of Oxford University, with additional support from Giovanna Tinetti
11 of UCL. It was held as a combined meeting between the Royal Meteorological
12 Society and the Royal Astronomical Society who scheduled it as their first *Specialist*
13 *Discussion Meeting* of the 2015 season on 9 October at The Geological Society
14 Lecture Theatre, Burlington House, Piccadilly. The joint-organisation of the meeting
15 between the two Societies and the Oxford Physics Group reflected its wide
16 interdisciplinary nature, combining meteorology, astronomy and planetary
17 instrumentation, generating a lot of general interest.
18
19
20
21

22 The meeting was an opportunity for planetary scientists to survey the state of a field
23 that is rapidly developing and driven by advances in complex technology, and was
24 set up by the RMetS who are interested in how other planets' weather differs from
25 Earth's and in particular how they are measured. Most of the talks took a review
26 angle, while also looking to the near future in terms of planned spacecraft missions
27 and telescopes. All of the planets and moons with substantial atmospheres were
28 represented in the line-up of talks, along with extra-solar planets and solar weather.
29
30
31

32 The day started and ended with talks on the broad range of atmospheres being
33 revealed through extra-solar planets. *Ray Pierrehumbert* (University of Oxford) began
34 with an introductory talk covering several general principles that govern what we can
35 observe in planetary atmospheres, how they behave, and in particular what physical
36 parameters can be varied to get different types of planet. He identified critical
37 properties as the thermal inertia of the atmosphere and ocean, the degree of orbital
38 eccentricity, whether the planet orbits close to its parent star, and the amount of latent
39 heat and condensable substances in the atmosphere.
40
41
42

43 The first talk covering specific planets was by *John Rogers* (University of Cambridge,
44 British Astronomical Association Jupiter section Director), who discussed impressive
45 observations of the planets being made by amateur astronomers. More and more
46 amateurs worldwide have been regularly taking high quality images of Jupiter in
47 particular, as quality telescopes have become more affordable to the general public.
48 He highlighted some observations that can only come from amateur observers, such
49 as the JUPOS database, which catalogues spot positions on Jupiter, and now has some
50 50,000 measurements added each year. Amateurs also observe the start of dramatic
51 meteorological events and monitor long climatic cycles, neither of which are done by
52 professional astronomers.
53
54
55
56
57
58
59
60

1
2
3 *Leigh Fletcher* (University of Leicester) turned to the professional side of giant planet
4 observations, outlining how spacecraft are currently studying the climate and weather
5 of Jupiter and Saturn. He focused on the various length scales of interest, going from
6 large scale (e.g. Saturn's seasonal cycle and the evolution of vortices at its poles over
7 a year), via medium scale (e.g. belt and zone structure on both giant planets, and
8 multiple levels of clouds driving multiple convective cell systems), to small scales
9 (e.g. convective plumes, injection of energy into storms, and coupling between
10 troposphere and stratosphere). Both the Juno (arriving at Jupiter in 2016) and JUICE
11 (not arriving at Jupiter until 2030) missions will advance our knowledge of Jupiter
12 considerably.
13
14
15

16
17 Moving further out, *Chris Arridge* (Lancaster University) tackled the problem of
18 observing the ice giants Uranus and Neptune. Since *Voyager 2*, observations of the
19 ice giants have been taken solely by ground- and space-based telescopes. Uranus has
20 developed from a very bland appearance into a more active planet as it has
21 approached equinox. Neptune has always been active, however, with cloud features
22 changing rapidly. Linking back to John's earlier talk, he reported that amateur
23 observations are beginning to resolve cloud features on Uranus such as the 2015
24 bright storm. The challenges for observing the ice giants are the spatial resolution due
25 to distance, the low albedo of the planets themselves, the difficulty of distinguishing
26 weather from seasonal behaviour over a long period (these planets have only
27 completed 1-2 orbits around the Sun since their discovery), and the problem of getting
28 enough data back at such low radio power at that distance. The need to understand
29 these bodies is high, however, as exoplanet observations suggest this class of planets
30 is very common.
31
32
33
34

35 The last talks before lunch came back to the centre of the Solar System, with *Andrew*
36 *Coates* (UCL) and *Manuel Grande* (Aberystwyth University) discussing planetary
37 space weather – how the space environment varies due to changing conditions on the
38 Sun and in atmospheres. The interaction between the solar wind and magnetised
39 atmospheres (all but Venus, Mars, and Pluto) is extremely complicated, with a need
40 for space weather forecasts to predict the effects on radio propagation, radiation belt
41 conditions, solar monitoring of coronal mass ejections, and to support planetary space
42 missions and Earth monitoring satellites. The COSPAR/ILWS roadmap prioritizes
43 advances that can be made on short, intermediate, and decadal time scales with
44 relevance to people's daily lives, such as electrical systems, navigation,
45 communications, and aerospace. Currently the highest priority research areas are to
46 quantify magnetic structure, and to understand the global solar coronal field and
47 radiation belts. Also highlighted was the Planetary Space Weather Service, which
48 aims to make prototype planetary event and space weather prediction operational in
49 Europe.
50
51
52
53
54

55 During lunchtime several posters were displayed, covering energy cycles on Mars and
56 other planets (*Peter Read*, *Fachreddin Tabataba-Vakili*), the DREAMS experiment
57 on ExoMars (*Colin Wilson*), microlander concepts for Mars (*Michael Johnson*), space
58
59
60

1
2
3 weather at the Met Office (*Suzy Bingham*), analysis and visualisation tools (*Charles*
4 *Roberts*), and Jupiter atmosphere modelling (*Roland Young*).
5

6 After lunch the focus turned to terrestrial planets. First were two talks on Mars, the
7 first given by *Manish Patel* (Open University). He summarised Mars's atmospheric
8 structure, particularly highlighting how the meridional circulation is similar to that
9 found on Earth, but is exaggerated due to lower thermal inertia in a lower temperature
10 and pressure environment. During most of the year a single Hadley cell exists,
11 covering most of the planet. Water ice clouds and atmosphere dust are both critical to
12 the thermal state of the atmosphere, with dust devils considerably larger than those
13 observed on Earth. The near future promises new meteorological data, both from
14 ESA's Schiaparelli ExoMars 2016 lander, which carries a small meteorological
15 package, and NASA's InSight seismic station, which will include an extremely
16 accurate atmospheric pressure sensor.
17
18
19
20

21 *Stephen Lewis* (Open University) focused on the meteorological observations that can
22 be made during a spacecraft's entry, descent, and landing. The Schiaparelli lander will
23 include instruments to measure atmospheric pressure, density, winds, and temperature
24 during its descent. He presented numerical simulations predicting the atmospheric
25 conditions during the Curiosity rover landing at Gale Crater in 2012. A mesoscale
26 weather model was nested inside a global scale climate model and observations from
27 orbiting spacecraft were assimilated into the model to generate high-resolution
28 simulations of the Curiosity landing site and a predictive weather forecast for Gale
29 Crater during the landing itself, to inform the team operating the lander. The surface
30 pressure was successfully forecast two years ahead of time using this method.
31 Schiaparelli will land during a time of year with much higher dust variability,
32 however, which may be harder to predict.
33
34
35
36

37 The topic then turned to Venus. *Colin Wilson* (University of Oxford) reviewed the
38 Venusian weather and climate, along with spacecraft observations. Venus has an
39 extreme environment below the main cloud decks but the atmospheric profile from 1
40 bar pressure to space is similar to that of Earth (with different composition).
41 Information about the lower atmosphere has come from orbiters (most recently Venus
42 Express), balloons (Vega), and 11 descent profiles (Pioneer Venus, Vega, and
43 Venera). These found a convective cloud layer between 50 and 80 km altitude with
44 stable layers above, episodic injections of SO₂ into the mesosphere, and complex
45 cloud chemistry in addition to the predominant H₂SO₄. Surface probes have measured
46 winds around 0-1 m/s, while cloud top winds are around 100 m/s. Future missions of
47 all three kinds are either in progress or proposed. Akatsuki will orbit the planet from 6
48 December 2015, Venera-D will measure descent profiles of temperature and pressure,
49 and proposed balloons would circumnavigate the planet in about a week.
50
51
52
53
54

55 *Ingo Muller-Wodarg* (Imperial College London) described Titan as *a terrestrial*
56 *planet lost in the outer Solar System*, as he described its weather, in particular the
57 observations made by the Ion Neutral Mass Spectrometer (INMS) on NASA's Cassini
58
59
60

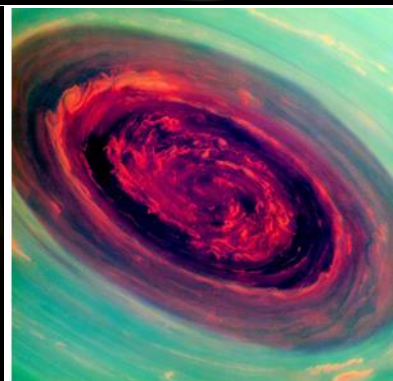
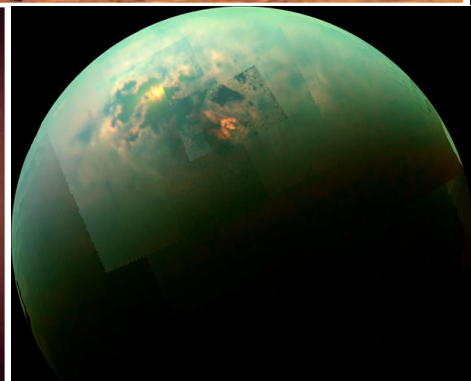
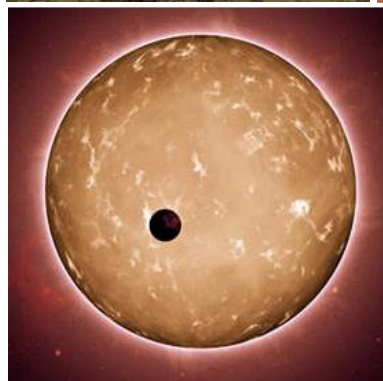
1
2
3 spacecraft. Titan and Earth are similar in terms of vertical structure, and both have
4 active weather systems with liquids on the surface. In the upper atmosphere, CH_x and
5 N_x^+ species react to form large and heavy hydrocarbon haze molecules. The INMS
6 has made density measurements down to 950km altitude during 36 flybys, showing
7 considerable structure and variability that do not correlate with expected energy
8 sources. This has been modelled using a thermospheric general circulation model,
9 with a lower boundary in the stratosphere. Small variations near the bottom of the
10 model cause large variations higher up. Upwards-propagating waves generate
11 variability in the thermosphere consistent with observations, and accelerate Titan's
12 background winds. Atmospheric waves are key to understanding the upper layers of
13 any atmosphere, but are poorly understood.
14
15
16

17
18 Finally, the Solar System was put into a broader context by *Giovanna Tinetti* (UCL),
19 who discussed the rapidly growing field of extra-solar planet atmospheres. Some 2000
20 planets beyond the Solar System have been confirmed in the last 20 years. From this
21 wide range of planets we expect interesting and varied weather that will be
22 challenging to simulate and understand. The atmospheres of these planets are critical
23 to understand as only they can give information about many chemical, physical, and
24 potential biological processes present. Telescopes use a wide range of techniques to
25 probe many different properties of these atmospheres. The most promising technique
26 is to measure the planet's electromagnetic spectrum during transit or by direct
27 imaging, which measures atmospheric composition, temperature structure, and even
28 atmospheric dynamics. Two future mission concepts were highlighted: Twinkle is a
29 UK/SSTL spacecraft using a spectrograph to measure transit spectra for 100
30 exoplanets around bright stars in the near-infrared wavelength range. ARIEL is a 1m
31 class near-infrared space telescope to look at 500 transiting, hot exoplanet
32 atmospheres. The exoplanet field has moved from a focus on discovery to a point
33 where understanding how planets form and evolve is the major aim.
34
35
36
37
38

39 One came away from the meeting with a sense that there are a lot of good ideas for
40 improving our understanding of these planets in the next decade or so. The focus
41 seems to be primarily on Mars, Jupiter, and extra-solar planets during the near future,
42 while new data from other targets such as Venus and the ice giants will take longer to
43 obtain. The breadth of topics presented was a very good overview of the current state
44 of the field.
45
46
47

48 Roland Young
49 roland.young@physics.ox.ac.uk
50
51
52
53
54
55
56
57
58
59
60

Weather



<http://mc.manuscriptcentral.com/weather>

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43