Metals in the Mesosphere:
Meteors, Satellite Retrievals and Modelling

1. Rationale
- The mesosphere/lower thermosphere (MLT) (75-130 km) remains poorly studied.
- Evidence that processes which occur here are relevant to whole atmosphere.
- Metal species, originating from ablated meteoroids, act as unique tracers of dynamics and chemistry.
- To date, most observations have come from sparse network of lidar stations.
- Satellite borne observations remain the only way to get a global view of these metal species.

2. Objectives
- Develop and ground-truth a new near-global satellite dataset with which to investigate atmospheric phenomena relevant to the MLT region and to inform climate models.
- Examine whether the semi-annual behaviour of meteoric potassium is global in extent and to investigate the causal mechanism.
- Present a number of possible applications of the new satellite dataset.

3. Potassium (K) shows Unusual Semi-Annual Seasonality
- Ca, Fe and Na all display an annual seasonality with a wintertime maximum.
- The behaviour of K is quite surprising: lidar observations at Arecibo (18\textdegree) show an annual seasonality with a wintertime maximum.
- Peak densities > 2.5 larger than typical peak density.
- Future work will investigate use of observed and modelled K layer as atmospheric forcings.

4. The Challenge of Retrieving Potassium
- Previous work has focused on retrieving Na at 589 nm (Fan et al., 2007; Gumbel et al., 2007).
- K at 770 nm presents a bigger challenge: K has a much smaller atmospheric abundance than Na, and also the signal-to-background ratio is considerably smaller.

5. Potassium Retrieval Algorithm
- Optimal estimation method, using a forward model. Converts observed radiances to height-resolved metal number densities.
- Uses radiance data from the OSIRIS (Optical Spectrograph and Infrared Imaging System) instrument onboard the Odin satellite.
- Basic concept:
  \[ f(x, y) = \begin{cases} 0 & \text{for } x = 0, y = 0 \\ 1 & \text{otherwise} \end{cases} \]
- Inverted using Gauss-Newton iteration.
- Iterative solution for state vector and its covariance:
  \[ x_i = x_{i-1} - F_i^+ e_i \\ \text{where } i = 1, 2, \ldots, 10 \]
- Capable of retrieving number density profiles with 15% error within the peak layer region (85-95 km).

6. Ground-truthing with Available Lidar Data
- Considerable spatio-temporal differences between lidar and satellite datasets exist.
- Despite this, there is good overall agreement between the OSIRIS-K monthly column density profile and Arecibo (18\textdegree) and Kühlungsborn (54\textdegree) respectively.

7. First Look at OSIRIS Global K Layer and Comparison to OSIRIS Na Layer
- OSIRIS data first to show that semi-annual seasonality is global in extent.
- Global K layer is very different to global Na layer; only K has a summertime maximum.

8. Why does K Behave Differently to Na?
- Although both Group I (alkali) metals, the chemistry of the Na and K metal layers is very different. Complex behaviour, but key points are:
  - NaHCO$_3$ + OH $\leftrightarrow$ K reaction pathway (activation energy too high: >34 kJ mol$^{-1}$)
  - By contrast, the NaHCO$_3$ + OH $\leftrightarrow$ K reaction has an activation energy of 10.1 kJ mol$^{-1}$, strong positive temperature dependence, not evident in K reaction.
  - Additionally, K is a larger ion with a single charge. It forms weakly bound clusters which undergo dissociative recombination back to the neutral K layer. This is efficient even at very low summertime mesopause temperatures.

Conclusions and Future Work
- OSIRIS data provide support for neutralisation of metal ions via interaction with sporadic E as being dominant mechanism for appearance of sporadic K layers.
- K layer is sensitive to both solar cycle effects and long-term changes in the upper atmosphere.
- Future work will investigate use of observed and modelled K layer as an atmospheric tracer, particularly in response to anthropogenic climate change and the associated changes within the upper atmosphere.
- Additionally, examine response of metal layers to other atmospheric phenomena such as sudden stratospheric warming events, and solar proton events.

10. Depletion of K layer by Polar Mesospheric Clouds (PMCs)
- Very high altitude ice clouds (80-110 km) form within the very cold (< -150 K) summertime mesopause region at latitudes >60\textdegree.
- Uptake of metal ions on ice surfaces leads to depletion (a "bite-out") on underside of K layer.

11. Sporadic K Layers (K) are an Atmospheric Phenomenon
- Thin metal layers (full-width half maximum < 3 km).
- Peak densities > 2.5 larger than typical peak density.
- Apparent explosively – duration of few minutes to several hours.
- Causal mechanism(s) unclear, but neutralisation of metal ions via interaction with sporadic E layer (ES) is thought to be major mechanism.

12. Response of Modelled K Layer to Solar cycle and Long-term Changes
- 50-year NCAR WACCM simulations for period 1915-2006.
- Indicates long-term cooling trend within the MLT.
- Corresponding increase in K layer across the same time period. No overall trend seen in other metals (e.g. Na and Fe).
- Solar cycle effects: striking anti-correlation between modelled K layer and both temperature and solar (10.7) flux.
- Anti-correlation is also apparent in OSIRIS observations (not shown) for most recent solar cycle (cycle 24).

References:
- Dawkins et al. (2014), OSIRIS (in review)
- Plane et al., 2014, QJR (accepted)
- Dawkins et al., 2014, JGR (in review)
- Fan et al., 2007, J. Geophys. Res.
- Gumbel et al., 2007, Journal of Geophysical Research

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