J13. Aerosol-Cloud Indirect Effects, Joint Posters 1.

POLAR CLOUD OPACITY AND SURFACE PRESSURE RESPONSES TO ATMOSPHERIC ELECTRICITY FROM GLOBAL CIRCUIT AND SOLAR WIND SOURCES: ELECTRICAL MODULATION OF AEROSOL SCAVENGING RATES?

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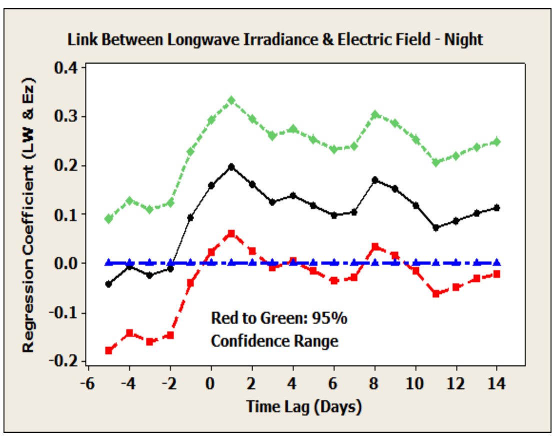
The effect of current flow in the global electric circuit on in-cloud scavenging, aerosol concentrations, and cloud radiative forcing is a phenomenon that is now being explored through both observational and modeling work.

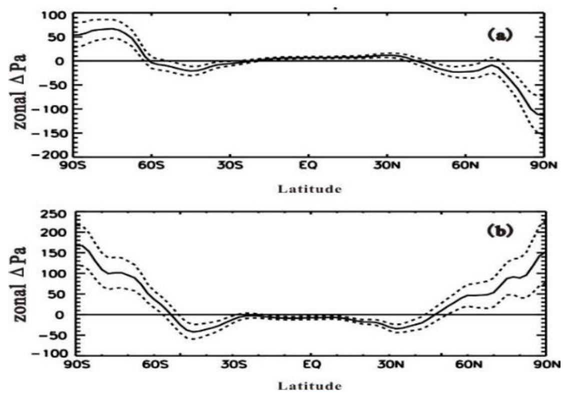
1. OBSERVATIONAL DATA

1.1 Measured visible and downwelling infrared irradiances at the South Pole and Summit, Greenland show small but statistically significant correlations with both internal and external drivers of downward ionosphere-Earth current density (Jz), using Vostok, Antarctica vertical electric field (Ez) measurements as a proxy for Jz (Frederick, 2016, 2017; Kniveton et al., 2008; Frederick and Tinsley, 2018). 017; Kniveton et al., 2008; Frederick and Tinsley, 2018).



Lagged regression coefficient of local cloud opacity (longwave IR irradiance) at South Pole versus daily average Ez. The correlation exceeds 95% statistical significance on days 1-3 and 8-9. A 3% change in opacity at the South Pole corresponds to a 25 V/m Ez change.

1.2. Small surface pressure changes are consistent with the cloud irradiance (opacity) and current density changes in persistent stratus-type clouds in the polar regions (Burns et al. 2008; Lam et al. 2013, 2014; Zhou et al. 2018).



Annual average zonal mean surface pressure (Pascals) responses to changes in Interplanetary Magnetic Field By Component > 6 nT (associated with measured Ez changes > 10 V/m.)

1.3. The Vostok Ez measurements have been shown to be reliable proxies for diurnal varying and average day-to-day changes in both the low latitude thunderstorm and electrified shower cloud generators of upward current in the global electric circuit, and the external source in the solar wind magnetic/electric field inputs (Burns et al., 2005, 2017).

1.4. Other atmospheric responses, including vorticity changes in mid-latitude winter storms, correlate with relativistic electron precipitation inputs from the solar wind and Jz changes (Mironova et al. 2012; Tinsley, 2012; and review by Lam and Tinsley, 2016).

2. THEORY AND MODELING

2.1. Cosmic rays produce ion pairs (air ions) in the global atmosphere. This allows current flow (Jz) in the global electric circuit. Upward current flow generated by thunderstorms and electrified shower clouds charges the global ionosphere on average to about 250 kV (Zhou and Tinsley, 2010). Also, solar wind electric fields modulate the potential by tens of kV at high latitudes (Lam et al. 2013). The Vostok Ez measurements show that the day-to-day variations due to the internal generators are also by tens of keV (Kniveton et al.,2008: Frederick and Tinsley, 2018).

2.2. The air ions that are present everywhere quickly attach to aerosol particles and droplets, with the

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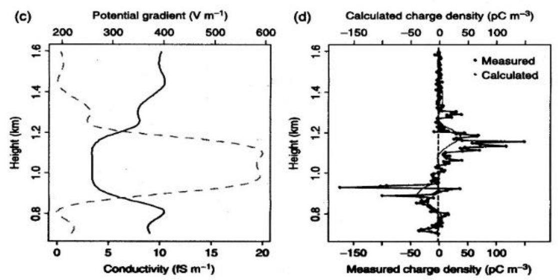
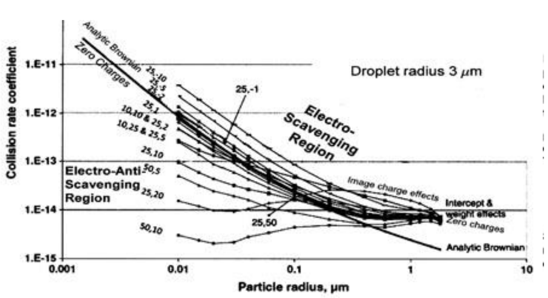
majority of particles charged, either positively or negatively, with 'symmetric' charging (i.e. equal concentrations of positive and negative charges per unit volume). The ionospheric potential drives a downward flow in 'fair weather' of current density (Jz) through gradients of conductivity at gradients of droplet or ice particle concentration at cloud boundaries (Beard et al. 2004; Zhou and Tinsley 2012; Nicoll and Harrison, 2016).



Conductivity and potential gradient models (left) compared with space charge measured by balloon and calculated (right). From Nicoll and Harrison (2016).

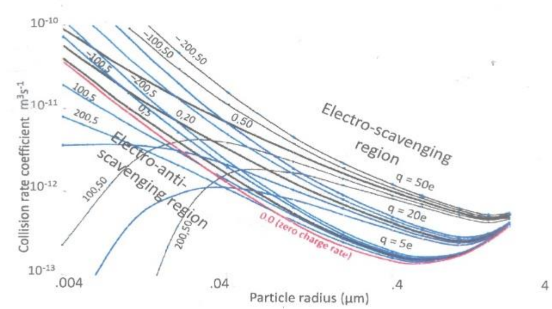
The Jz flow produces 'space charge' at cloud boundaries, especially for stable stratus-type clouds, in accordance with Ohms Law and Gauss's Law. Space charge is excess charge of one sign (unequal numbers of positive and negative charges on ions, particles and droplets) The symmetric charging within stratus-type clouds is bounded at top and bottom by space charge, which mixes into the cloud.

2.3. For small aerosol particles (e.g. < 0.1 μm radius), and especially for collisions of them with small droplets or ice particles (e.g., 3 μm radius as shown below) the net collision rate can be reduced by 'electro-anti-scavenging' due to net Coulomb repulsion in space charge regions, thus decreasing loss rates. The cumulative reduction in loss will increase the concentration of small CCN compared to a situation without space charge. In weak updrafts with continuing activation of CCN this results in increased droplet concentration of smaller average size (Tinsley and Leddon, 2013, Tinsley and Zhou, 2015).



Electro-anti-scavenging occurs in the region below the 'zero-charge' line. Numbers on curves refer to elementary charges on droplet and aerosol particles respectively, e.g., 25,10 means droplet charge 25e, particle charge 10e. From Tinsley and Leddon, (2013).

2.4. For larger aerosol particles (e.g., > 0.1 μm radius) the net collision rates are increased by image charge forces, especially with larger droplets or ice particles (e.g. 15 μm radius, as below). It is the only effect of charge in symmetric charge regions. This narrows the CCN and subsequent droplet or ice particle size distributions, and reduces initial precipitation (Tinsley & Zhou, 2015; Zhang & Tinsley, 2017, 2018a, b).



Electro-scavenging occurs in the region above the zero-charge line (red). The thick black lines are for droplet charge Q = 0e, with variable particle charge q. The thin lines are for variable particle charge q associated with variable droplet charge Q, labelled as Q,q on curves. The droplet radius was 15 radius 15μm and the relative humidity 100%

2.5. The net effects of electric charge in high latitude stratus-type liquid, ice, or mixed phase clouds are inferred to be an increase in the concentration of small CCN, by electro-anti-scavenging in the space charge regions, and a decrease in the concentration of large CCN by image charge scavenging (electro-scavenging) both at cloud boundaries and cloud interior. The result with continuing activation of CCN in weak updrafts is to increase the concentration and decrease the average size of droplets and/or heterogeneously frozen ice particles, thus increasing the cloud opacity. In high latitude winter and night conditions the consequent radiative forcing would account for observed small atmospheric temperature increases (Lam et al. (2017) and surface pressure increases (Burns et al., 2008; Lam et al., 2013, 2014; Zhou et al., 2018).

2.6. Ice nucleation is enhanced both in space charge and symmetric charge regions by the increased electro-scavenging of the relatively large ice nuclei. Above the freezing level, where supercooled droplets exist, contact ice nucleation is enhanced. Below the freezing level, notably in updrafts where scavenging would otherwise be inhibited by thermophoresis on the condensing droplets, immersion ice nuclei are collected for freezing when droplets are carried above the freezing level. (Tinsley, 2012; Zhang and Tinsley, 2018; Zhang et al., 2018).

2.7. The equilibrium charge on aerosol particles depends on their size, and for diffusive charging it varies as the square root of the particle radius (Beard and Ochs, 1986). However, the residues after evaporation of the much more highly charged droplets, retain the droplet charge for ten minutes or so, and so these residues have relatively large (for an aerosol particle) charge. Also, evaporation residues often have heterogeneous surface coatings from the evaporation process, increasing their ice-nucleation effectiveness. So highly charged evaporation residues may add to the ice-nucleation processes due to electro-scavenging described above, and further enhance ice nucleation. This is also relevant to storm invigoration and storm vorticity in sub-polar regions to J_z. (e.g., Zhou et al., 2014).

3. NEEDED WORK

Continuing observations of global circuit variations are needed. The optimum sites are at high altitude and over ice plateaux, e.g., Vostok, Concordia and Dome C in East Antarctica; Summit on Greenland in the Arctic, and other stations on ice fields or other low aerosol concentration regions with stable air and minimum convection (An optimum sub-auroral location would be on the West Antarctic Ice plateau).

Continuing observations of high latitude stratus-type clouds, with altitude profiles and size distributions of aerosol particles, droplets, ice particles and ion concentrations and mobilities are needed.

Modeling is needed for the cloud charging process (dependent on mixing and above parameters of ions, aerosol particles and droplets).

Modeling is needed for time variations of the electric charge effects on aerosol number and size distributions, and on ice nucleation in clouds, and of these on macroscopic cloud properties and dynamics.

4. CONCLUSIONS

Electric charge effects on in-cloud scavenging occur both in space charge regions and in symmetrically charged regions in cloud interiors. The effects are different for small aerosol particles (electro-anti-scavenging) and large particles (electro-scavenging). These may account for observed changes in cloud opacity and atmospheric dynamics via cloud radiative forcing at high latitudes, and other responses at lower latitudes.

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REFERENCES:

Beard, K. V. K., and H. T. Ochs, 1986: Charging mechanisms in clouds and thunderstorms. In *The Earth's Electrical Environment,* National Academy Press, Washington, DC. 1986.

Beard K. V. K., et al., 2004: Aircraft measurements of high average charges on cloud drops in layer clouds., *Geophys. Res. Lett,* 31, L14111. doi.org/10.1029/2004GL020465.

Burns, G., et al., 2005: Interannual consistency of bi-monthly differences in diurnal variations of the ground-level vertical electric field. *J. Geophys. Res*., 110, D10106. doi:10.1002/jgrd50618.

Burns, G., et al., 2008: Atmospheric circuit influences on ground-level pressure in the Antarctic and Arctic. *J. Geophys. Res.,* 113, D15112. doi.org/10.1029/2007JD009618

Burns, G. et al., 2017: Atmospheric global circuit variations from Vostok and Concordia Electric field measurements. *J. Atmos. Sci.,* 74,783-800. doi:10.1175/JAS-D-16-0159.1

Frederick, J., 2016: Solar irradiance observed at Summit, Greenland: Possible links to magnetic activity on short timescales. *J. Atmos. Solar Terr. Phys.,* 147, 59-70. doi.org/10.1016/j.jastp.2016.07.001

Frederick, J., 2017: An analysis of couplings between solar activity and atmospheric opacity at the South Pole. *J. Atmos. Solar Terr. Phys.,* 164, 97-104. doi.org/10.1016/j.jastp.2017.08.011

Frederick J., and B. A. Tinsley, 2018: The response of longwave radiation to electrical and magnetic variations at the South Pole: correlations with inputs from meteorological generators and the solar wind. *J. Atmos. Solar Terr. Phys.,* 179, 214-224. doi.org/10.1016/j.jastp.2018.08.003.

Kniveton, D., et al. 2008: Variations in global cloud cover and the fair-weather vertical electric field. *J. Atmos. Solar Terr. Phys.*, 70, 1633-1642. doi.org/10.1016/j.jastp.2008.07.001

Lam, M. M., and B. A. Tinsley, 2016: Solar wind – atmospheric electricity cloud microphysics connections to weather and climate. *J. Atmos. Solar-Terr. Phys.,* 149, 277-290. doi.org/10.1016/j.jastp.2015.10.019.

Lam, M. M., et al., 2013: The interplanetary magnetic field influences mid-latitude surface atmospheric pressure. *Env. Res. Lett.*, 8, 045001. doi.org/10.1088/1748-9326/8/4/045001

Lam, M. M., et al., 2014: Solar wind driven geopotential height anomalies originate in the Antarctic lower troposphere. *Geophys. Res. Lett.,* 41, 6509-6514. doi.org/10.1002/2014GL061421.

Lam, M. M., et al., 2017: IMF-driven change to the Antarctic tropospheric temperature due to the global atmospheric electric circuit. *J. Atmos. Solar-Terr. Phys.,* doi.org/10.1016/j.jastp.2017.08.027.

Mironova, I., et al., 2012: The links between atmospheric vorticity, radiation belt electrons, and the solar wind. *J. Adv. Space Res.,* 50, 783-790. doi.org/10.1016/j.asr.2011.03.04.

Nicoll, K. A., and R. G. Harrison, 2016: Stratiform cloud electrification: comparison of theory with multiple in-cloud measurements. *Q. J. Roy. Meteol. Soc.* 142, 2679-2691. doi:10.1002/qj.2858.

Tinsley, B. A., 2012: A working hypothesis for connections between electrically-induced changes in cloud microphysics and storm vorticity, with possible effects on circulation. *J. Adv. Space Res.,* 50, 791-805. doi.org/10.1016/j.asr.2012.04.008.

Tinsley, B. A., and D. Leddon, 2013: Charge modulation of scavenging in clouds: Extension of Monte-Carlo simulations and initial parameterization. *J. Geophys. Res.,* 118, 8612-8624. doi:10.1029/2004JD005469.

Tinsley, B. A., and L. Zhou, 2015: Parameterization of aerosol scavenging due to atmospheric ionization. *J. Geophys. Res.,* 120, 8389-8410. doi:10.1002/2014JD023016.

Zhang, L., and B. A. Tinsley, 2017: Parameterization of aerosol scavenging due to atmospheric ionization under varying humidity. *J. Geophys. Res. Atmos.,* 122, 5330-5350. doi:10.1002/2016JD026255.

Zhang, L., and B. A. Tinsley, 2018: Parameterization of aerosol scavenging due to atmospheric ionization 2: Effects of varying particle density. *J. Geophys. Res. Atmos.,* 123, 3099-3115. doi.org/10.1002/2017JD027884.

Zhang, L et al., 2018: Parameterization of aerosol scavenging due to atmospheric ionization: Part 3. Effects of varying droplet radius. *J. Geophys. Res. Atmos.,* in press.

Zhou, L., and B. A. Tinsley, 2010: Global circuit model with clouds. *J. Atmos. Sci.,* 67, 1143-1156. doi:10.1175/2009JAS3208.1

Zhou, L., and B. A. Tinsley, 2012: Time dependent charging of layer clouds in the global electric circuit. *J. Adv. Space Res.*, 50, 828-842. doi:org/10.1016/j.asr.2011.12.018.

Zhou, L., et al., 2014: Effects on winter circulation of short and long-term solar wind changes. *Adv. Space Phys.,* 54, 2478-2490.

Zhou, L., et al., 2018: The zonal-mean and regional tropospheric pressure responses to changes in ionospheric potential. *J. Atmos. Solar Terr. Phys*., 171, 111-118. doi.org/10.1016/j.jastp.2017.07.010.