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Saurabh Nath

Education

2014–present **MS in Engineering Mechanics**, *Department of Biomedical Engineering and Mechanics, Virginia Tech*, Blacksburg, Virginia, *GPA - 3.85/4.0.*
Advisor: Jonathan B. Boreyko

2010–2014 **BE in Mechanical Engineering**, *Department of Mechanical Engineering, Jadavpur University*, Kolkata, India, *GPA - 7.76/10.*

Journal Publications

1. **S.Nath**, S.F. Ahmadi and J. B. Boreyko. "A Review of Condensation Frosting." *Nanoscale and Microscale Thermophysical Engineering, Special Issue, 2016 DOI: 10.1080/15567265.2016.1256007,* (In print by December 2016)

2. **S. Nath** andJ. B. Boreyko. "On Localized Vapor Pressure Gradients Governing Condensation and Frost Phenomena." *Langmuir*, (2016), DOI: 10.1021/acs.langmuir.6b01488.

3. J. B. Boreyko, R. R. Hansen, K. R. Murphy, **S. Nath**, S. T. Retterer and C. P. Collier. "Controlling condensation and frost growth with chemical micropatterns." *Scientific Reports*(2016), 6, 19131, DOI:10.1038/srep19131.
   - Featured in *Science News for Students*: "Beetles offer people lessons in moisture control"
   - Featured in *Popular Science*: "Desert Beetle teaches scientists about how frost forms"
   - Featured in *The Christian Science Monitor*: "How the Namib Desert beetle could help stop frost on airplanes"
   - Featured in *USA Today*: "Could this desert beetle be the solution to preventing frost on airplane wings?"
   - Featured in *Discovery Channel Canada*: Daily Planet, Jan. 22.

4. **S. Nath**, A. Mukherjee and S. Chatterjee. "Can Oil Float Completely Submerged in Water?" *arXiv:1309.7727* (2013).

Patent

- **S.Nath**, S. T. Retterer, C. P. Collier, C. E. Bisbano, G. J. Iliff and J. B. Boreyko "Passive Anti-frosting Surfaces Comprised of Microscopic Wettability Patterns Containing Sacrificial Ice", U.S. Patent Application No: 62/403,924 (provisional patent filed).

Honors and Awards

2013 **TIFR Summer Research Fellowship**, Tata Institute of Fundamental Research–Centre for Interdisciplinary Sciences, India.

2012 **Indian Academy of Sciences Fellowship**, Indian Academy of Sciences– Indian National Science Academy–National Academy of Sciences, India.

2011 **First Prize, Jagadis Bose National Scholar Project Presentation**, Jagadis Bose Centre for Excellence, India.
Project: *Analysis of Water Droplet Flotation on Oil* – Saurabh Nath & Anish Mukherjee

2010 **Jagadis Bose National Scholar**, Jagadis Bose Center for Excellence, India.

Research Experience

2015– present **Graduate Research Assistant**, Nature-Inspired Fluids and Interfaces Lab, Department of Biomedical Engineering and Mechanics, Virginia Tech.
Advisor: Dr. Jonathan Boreyko.

June 2015 **Clean Room Experience**, Center for Nanophase Materials Sciences, Oak Ridge National Laboratory, Oak Ridge, Tennessee.
Advisors: Dr. Jonathan Boreyko & Dr. Patrick Collier

Summer & Winter 2013 **Undergraduate Research Assistant**, Tata Institute of Fundamental Research–Center for Interdisciplinary Sciences, Hyderabad, India.
Advisor: Prof. Rama Govindarajan

Summer 2012 **Undergraduate Research Assistant**, Engineering Mechanics Unit, Jawahar Lal Nehru Centre for Advanced Scientific Research, Bangalore, India.
Advisor: Prof. K. R. Sreenivas

Spring 2012– Spring 2014 **Undergraduate Research Assistant**, Department of Mechanical Engineering, Jadavpur University, Kolkata, India.
Advisors: Prof. Swarnendu Sen & Prof. Ranjan Ganguly

Conference Presentations (*denotes speaking author)

1. **S.Nath***, R. R. Hansen, K. R. Murphy and J. B. Boreyko. "Can Ice Prevent Frost Growth?" *68th APS DFD Meeting*, Boston, MA (2015).

2. K. R. Murphy*, R. R. Hansen, **S.Nath**, S. T. Retterer, C. P. Collier and J. B. Boreyko. "Spatial Control of Condensation using Chemical Micropatterns" *68th APS DFD Meeting*, Boston, MA (2015).

3. C. Bisbano*, **S.Nath** and J. B. Boreyko. "Dry Zones around Frozen Droplets" *68th APS DFD Meeting*, Boston, MA (2015).

4. **S.Nath***, A. Mukherjee, S. Chatterjee, R. Ganguly, S. Sen, A. Mukhopadhyay, and J. B. Boreyko. "Inverse Flotation" *67th APS DFD Meeting*, San Francisco, CA (2014).

5. **S.Nath***, A. Mukherjee and S. Chatterjee. "Flotation and Subsequent Spreading of a Submerged Buoyant Drop" *39th National Conference on Fluid Mechanics and Fluid Power*, Surat, India (2012).

Conference Posters (*denotes speaking author)

1. **S.Nath***, G. J. Iliff, B. R. Srijanto, S. T. Retterer, C. P. Collier and J. B. Boreyko. "Ice as an Anti-Frosting Agent" *Macromolecules Innovation Institute Technical Conference and Review*, Blacksburg, VA (2016).

2. G. J. Iliff*, **S.Nath** and J. B. Boreyko. "Phase-Change Driven Pathogen Transport on Wheat Crops" *Macromolecules Innovation Institute Technical Conference and Review*, Blacksburg, VA (2016).

3. C. Bisbano*, **S.Nath** and J. B. Boreyko. "Dry Zones around Frozen Droplets" *Macromolecules Innovation Institute Technical Conference and Review*, Blacksburg, VA (2016).

4. **S.Nath***, B. R. Srijanto, S. T. Retterer, C. P. Collier and J. B. Boreyko. "Anti-Frosting Surfaces using Ice as Humidity Sinks" *Oak Ridge National Laboratory CNMS User Meeting*, Portland, OR (2016).

5. **S.Nath** and J. B. Boreyko*. "Passive Anti-Frosting Surfaces" *3M Company, Faculty Day*, St. Paul, MN (2016).

6. **S.Nath***, D. Deka, K. R. Sreenivas and D. K. Singh. "Model Near Surface Temperature Inversion in Boundary Layer and the Role of Suspended Particles" *Indian Aerosol and Technology Association Conference IASTA– 2012*, IASTA-2012/Session-IV/P-125, BARC, Mumbai, India (2012).

Selected Graduate Courses

- Viscous Flow
- Chaos and Nonlinear Dynamics
- Intermediate Dynamics
- Continuum Mechanics
- Theory of Elasticity
- Introduction to Perturbation

Teaching and Mentoring Experience

As a Research Mentor to Undergraduate Students

- C. E. Bisbano (Project: Dry Zone around Frozen Droplets)
- G. J. Iliff (Project: Phase-Change Driven Pathogen Transport on Wheat Leaves)

As a Teaching Assistant

○ **Statics**

Professor: Prof. Scott Hendricks, *Engineering Science and Mechanics Program Chair, Virginia Tech.*

Duration: *Spring 2015*

Responsibilities: *Holding problem sessions, providing solutions for problem sets.*

As a Lab Instructor

○ **Undergraduate Lab– Introduction to Fluid Mechanics**

Professor: Prof. Anne Staples, *Department of Biomedical Engineering and Mechanics, Virginia Tech.*

Duration: *Fall 2014*

Responsibilities: *Supervising as Lab Instructor, preparing lecture notes, grading students' assignments.*

Professional and Synergistic Activities

2016 **Co-creator and Supervisor**.
A 'Jumping Drops and Ice Bridges!' teaching module used for two summer camp programs: C-Tech2 and IMAGINATION. These programs are run through the Center for the Enhancement of Engineering Diversity (CEED); C-Tech2 targets rising high-school junior and senior women while IMAGINATION targets middle school students.

2015– present **Member**, *Macromolecules Innovation Institute, Virginia Tech*.

2014– present **Member**, *Bio-Inspired Science & Technology Center, Virginia Tech*.

Member, *American Physical Society (APS)*.

Member, *Association for India's Development, Blacksburg*.

Member, *Bengali Students' Association, Virginia Tech*.

2012– present **Member**, *Indian Society for Refrigeration, Heating and Air-Condition Engineering*.

Software Knowledge

- Microsoft Word & Excel
- LaTeX
- ImageJ
- Wolfram Mathematica
- Layout Editor
- Matlab

Interests and Hobbies

Watching Movies, Writing, Acting and Directing Plays.
Performed six plays in Jadavpur University and one in Virginia Tech called *'How to Screw Your Grad Life'* on October 4th, 2014 at the Commonwealth Ballroom, Virginia Tech.

References

Dr. Jonathan B. Boreyko
Assistant Professor
Dept. of Biomedical Engineering and Mechanics
Virginia Tech.
e-mail: boreyko@vt.edu

Dr. Pengtao Yue
Associate Professor
Dept. of Mathematics
Virginia Tech.
e-mail: ptyue@math.vt.edu

Dr. Sunny Jung
Associate Professor
Dept. of Biomedical Engineering and Mechanics
Virginia Tech.
e-mail: sunnyjsh@vt.edu

Dr. Mark R. Paul
Professor
Dept. of Mechanical Engineering
Virginia Tech.
e-mail: mrp@vt.edu

Graduate Research Experience

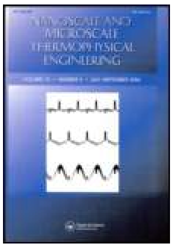
Finished Projects

Website
Google Scholar

A Review of Condensation Frosting

Co-authors: S.F. Ahmadi and J. B. Boreyko

Journal: Nanoscale and Microscale Thermophysical Engineering, Special Issue on Micro & Nanoscale Phase Change Heat Transfer, DOI: 10.1080/15567265.2016.1256007, (In print by December 2016)

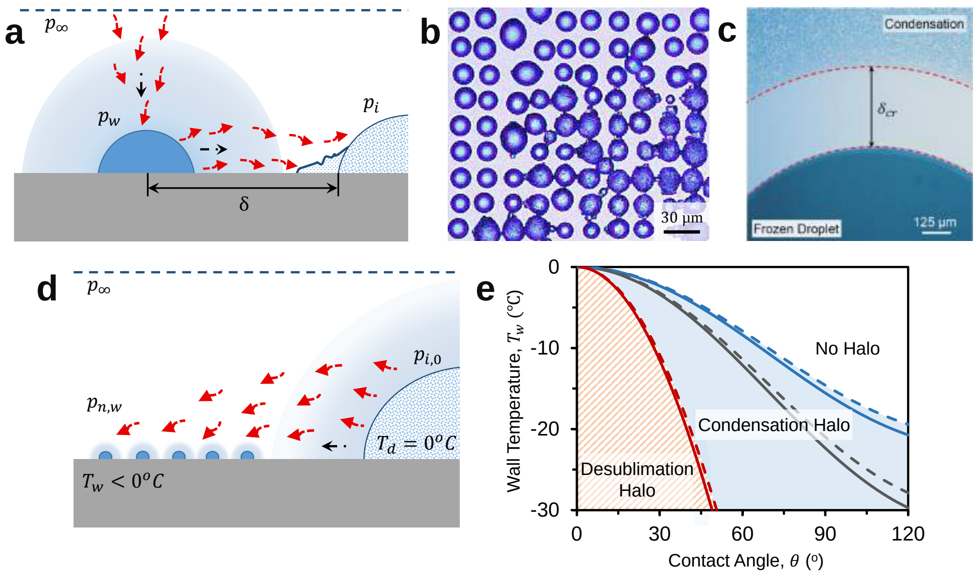


Abstract: The accretion of ice and frost on various infrastructure is ubiquitous in cold and humid environments, causing economic losses amounting to billions of dollars every year worldwide. The past couple of decades have seen unprecedented advances in the elds of surface chemistry and micro/nano-fabrication, enabling the development of hydrophobic and superhydrophobic surfaces that promote facile de-icing and/or passive anti-icing. However, in the light of new discoveries regarding the incipient stages of frost formation, it is becoming increasingly clear that the problems of icing and frosting are not one and the same. Thus passive anti-icing strategies do not exhibit anti-frosting behavior, and the development of passive anti-frosting surfaces remains an unsolved problem. In this review, we provide a critical discussion of condensation frosting and show how the emerging new phenomena of frost halos, interdroplet ice bridges, and dry zones that comprise the incipient stages of frosting set it apart from the conventional problem of icing. Subsequently, we discuss possible strategies to break the sequential chain of events leading to pervasive frost growth.

On Localized Vapor Pressure Gradients Governing Condensation and Frost Phenomena

Advisor: J. B. Boreyko

Journal: *Langmuir 32, 8350-8365 (2016)*



a) Schematic of vapor flowing from a liquid water droplet towards its neighboring frozen droplet under isothermal conditions. The two consequences of this interaction: b) inter-droplet ice bridging, where the vapor depositing on the frozen droplet forms an ice bridge that connects to the neighboring droplet and c) dry zones, where the droplets evaporate significantly faster than growing ice bridges leading to a region with no condensation or frost. d) Schematic of vapor emanating from a frozen droplet at $T_d = 0^\circ$ C and nucleating on the substrate as liquid or frozen condensate. This phenomenon is called frost halo. e) Phase map of the halo effect for different temperatures and wettability of the substrate.

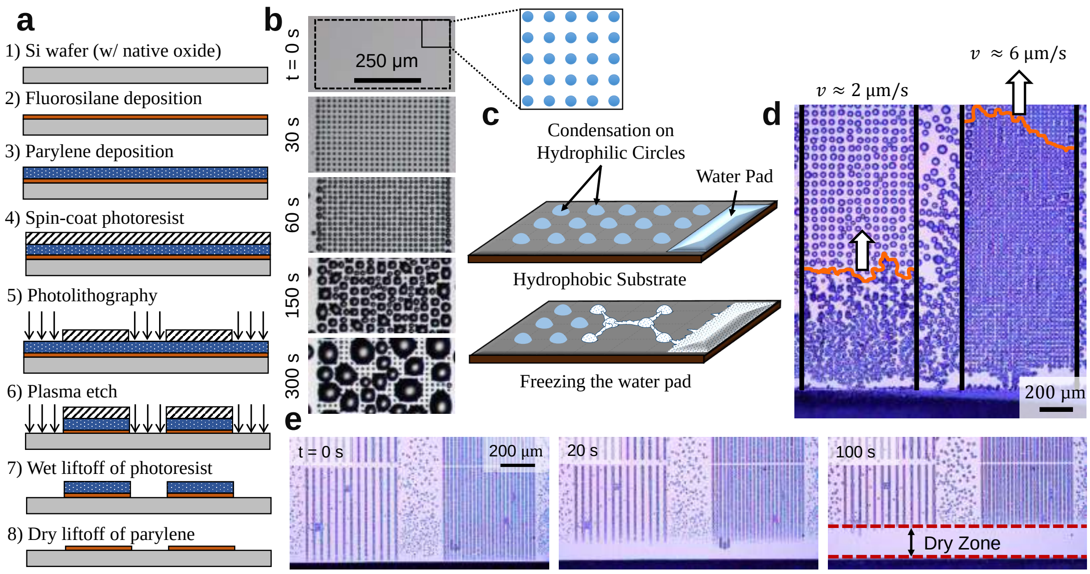
Abstract: Interdroplet vapor pressure gradients are the driving mechanism for several phase-change phenomena such as condensation dry zones, interdroplet ice bridging, dry zones around ice, and frost halos. Despite the fundamental nature of the underlying pressure gradients, the majority of studies on these emerging phenomena have been primarily empirical. Using classical nucleation theory and Becker–Döring embryo formation kinetics, here we calculate the pressure field for all possible modes of condensation and desublimation in order to gain fundamental insight into how pressure gradients govern the behavior of dry zones, condensation frosting, and frost halos. Our findings reveal that in a variety of phase-change systems the thermodynamically favorable mode of nucleation can switch between condensation and desublimation depending upon the temperature and wettability of the surface. The calculated pressure field is used to model the length of a dry zone around liquid or ice droplets over a broad parameter space. The long-standing question of whether the vapor pressure at the interface of growing frost is saturated or supersaturated is resolved by considering the kinetics of interdroplet ice bridging. Finally, on the basis of theoretical calculations, we propose that there exists a new mode of frost halo that is yet to be experimentally observed; a bimodal phase map is developed, demonstrating its dependence on the temperature and wettability of the underlying substrate. We hope that the model and predictions contained herein will assist future efforts to exploit localized vapor pressure gradients for the design of spatially controlled or antifrosting phase-change systems.

Controlling condensation & frost growth with chemical micropatterns

Co-authors: J. B. Boreyko, R. R. Hansen, K. R. Murphy, S. T. Retterer and C. P. Collier

Journal: *Sci. Rep. 6, 19131 (2016)*

Watch the youtube video summarizing the project: here.



a) Schematic of the procedure for microfabrication of the chemical patterns. b) Spatial control of condensation on smooth chemical micropatterns composed of arrays of hydrophilic circles against a hydrophobic background. c) Schemcatic of experimental set-up for condensation frosting experiments. Chemical patterns give us spatial control over the nucleation sites. Freezing the water pad at a desired time gives us temporal control over the first freezing event. d) Inter-droplet frost growth across patterns of supercooled condensation. Sparsely distributed droplets show a significantly slower frost propagation rate. e) Demonstration of halted inter-droplet frost growth. An early freezing event can cause a global failure of ice bridge connections leading to a dry zone.

Abstract: In-plane frost growth on chilled hydrophobic surfaces is an inter-droplet phenomenon, where frozen droplets harvest water from neighboring supercooled liquid droplets to grow ice bridges that propagate across the surface in a chain reaction. To date, no surface has been able to passively prevent the in-plane growth of ice bridges across the population of supercooled condensate. Here, we demonstrate that when the separation between adjacent nucleation sites for supercooled condensate is properly controlled with chemical micropatterns prior to freezing, inter-droplet ice bridging can be slowed and even halted entirely. Since the edge-to-edge separation between adjacent supercooled droplets decreases with growth time, deliberately triggering an early freezing event to minimize the size of nascent condensation was also necessary. These findings reveal that inter-droplet frost growth can be passively suppressed by designing surfaces to spatially control nucleation sites and by temporally controlling the onset of freezing events.

Graduate Research Experience

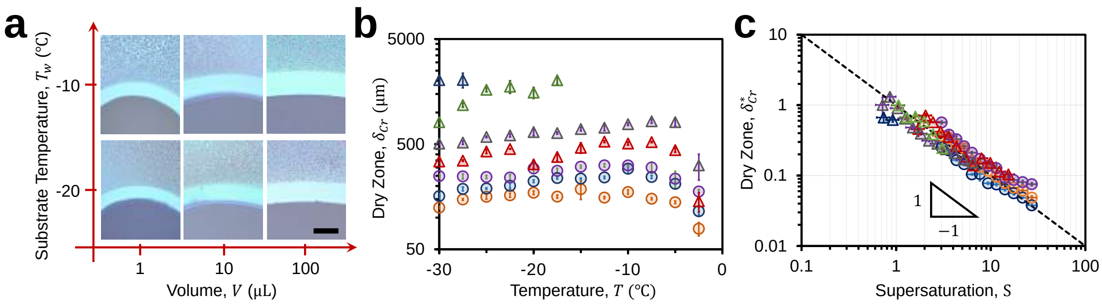
Ongoing Projects

Website
Google Scholar

Dry Zone around Frozen Droplets

Co-authors: C. E. Bisbano, P. Yue and J. B. Boreyko

Journal: In preparation for Nature Physics.



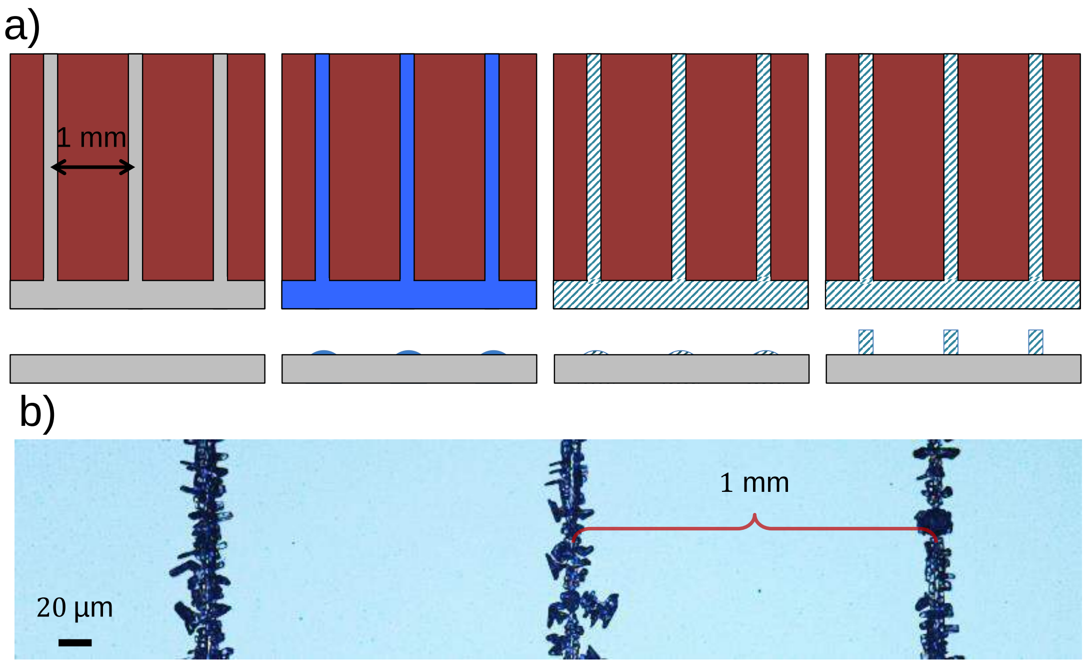
a) Experimental micrographs showing how dry zone lengths around a frozen droplet vary with surface temperature and volume. Scale bar represents 300μm. b) Dry zone lengths as a function of substrate temperature. Each data set corresponds to a fixed ice droplet volume and a fixed relative humidity. c) Collapsed plot of dry zone lengths nondimensionalized with respect to the diffusion length scale plotted against the ambient supersaturation.

Abstract: Frozen droplets, much like hygroscopic chemicals such as glycols and salty water droplets, can also create localized stable dry zones around themselves. This is because the vapor pressure over ice is lower than that above liquid water at the same subzero temperature. One possible mechanism for the formation of such a dry zone is that the in-plane evaporative flux towards the frozen droplet dominates over the out-of plane condensation flux within a critical length from the frozen droplet, causing the condensate to evaporate in this sregion. On the other hand, it is also possible that nucleation itself is suppressed around the frozen droplet as the critical pressure required to nucleate an embryo is larger than the saturation vapor pressure over water. There is no general consensus regarding whether dry zones around hygroscopic chemicals are nucleation dry zones or flux dry zones. In this work, we do a systematic study of dry zones forming around frozen droplets over a wide parameter space– temperatures ranging from $-30 <$ T$_d < 0°$ C, ice droplet volumes $1\mu L <$ V$< 100\mu L$ and supersaturation varying over three orders of magnitude. We observe that barring the initial transience, flux dry zones always dominate over nucleation dry zones for the equilibrium state. This is also validated by our theoretical estimates based on classical nucleation theory and quasi-steady diffusion model. Finally, our extensive experimentation shows that in the regime where the frozen droplet is much larger in size than the condensate, the dry zone length follows a scaling law completely different from what has been proposed in the literature.

Passive Anti-frosting Surfaces using Arrays of Ice Stripes

Co-authors: G. J. Iliff, S. T. Retterer, C. P. Collier and J. B. Boreyko

Journal: In preparation.



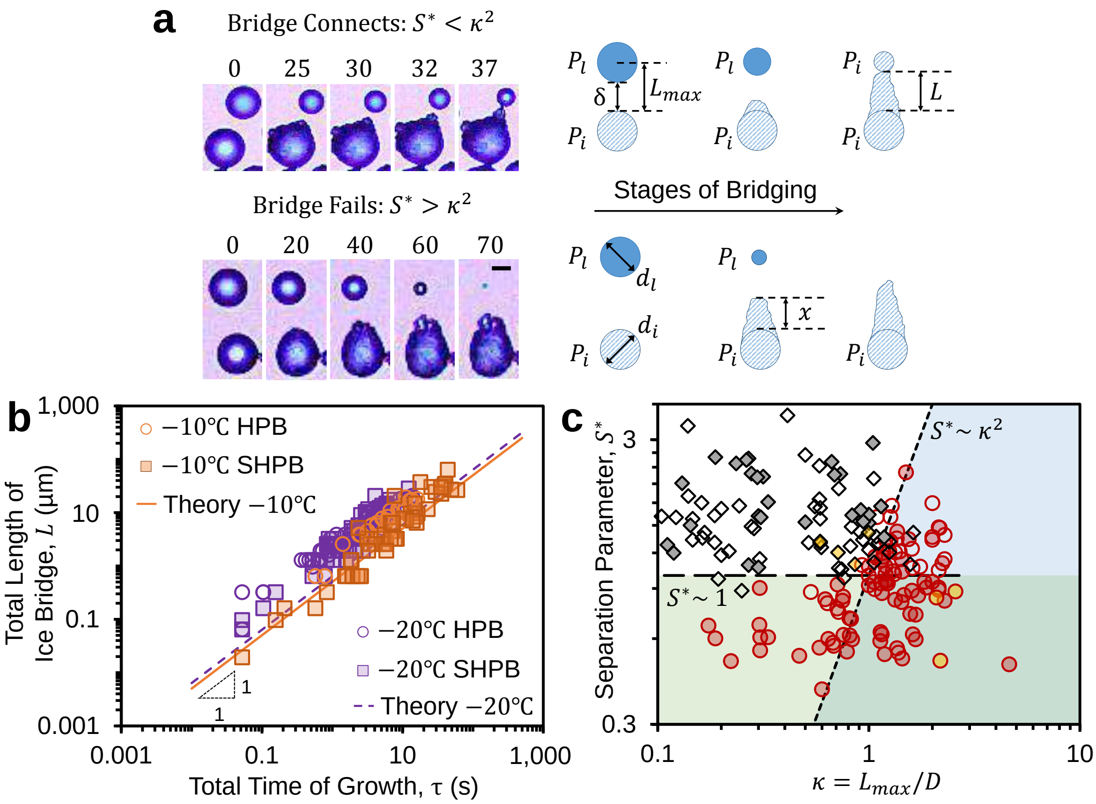
a)Top-down and side-view illustrations of the proposed anti-frosting surface. A microscopic pattern of interconnected hydrophilic stripes (gray features in 1st frame) are wetted with water (2nd frame) and subsequently frozen into ice (3rd frame). The entire surface area between the ice stripes should remain dry from condensation and frost (4th frame) when the spacing between stripes (b) $10\mu m$ water stripes with 1 mm inter-stripe distances are frozen. The ice stripes keep the intermittent distances dry because of overlapping dry zones. Experiment shows near 90% dry surface with no frost or condensation at $T_w = -8°C$ and a supersaturation $S = 1.2$.

Abstract: No engineered surface, to date, has been able to passively suppress the in-plane growth of frost occurring in humid, subfreezing environments. Hygroscopic chemicals, like glycols or salt crystals, can create localized dry zones on condensing surfaces by virtue of their depressed vapor pressure. However, such dry zones are transient, as these hygroscopic humidity sinks become increasingly diluted with condensed water until their vapor pressure is no longer depressed. Here, we show that ice itself can be used to create stable dry zones that are completely free from supercooled condensation and frost even in highly humid environments. The underlying mechanism, like other hygroscopic materials, is that the saturated vapor pressure of ice is lower than that of water at the same temperature. However, unlike other hygroscopic materials which get increasingly diluted with condensed water, ice is composed solely of water molecules and therefore its low vapor pressure remains stable as it harvests water vapor from the ambient. Here, we show that surfaces functionalized with chemical or physical micropatterns that facilitate microscopic arrays of ice stripes can passively suppress in-plane frost growth. The dry zones around each ice stripe can be as large as ∼1 mm and sustained for hours. When these dry zones overlap, they render at least 90% of the surface frost-free, demonstrating the scalability of this application.

Scaling Laws for Inter-droplet Ice Bridging

Co-authors: S. F. Ahmadi and J. B. Boreyko

Journal: In preparation.



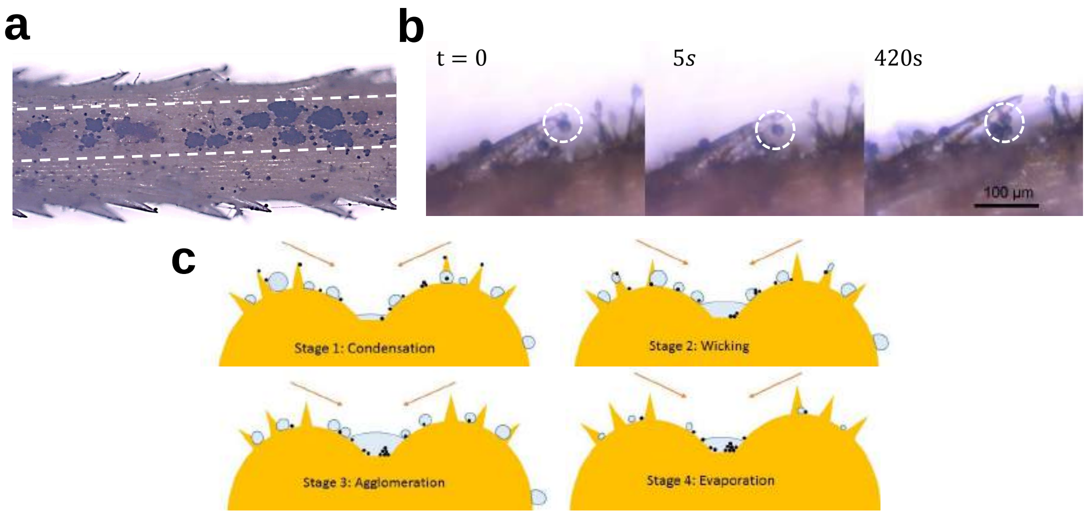
a) Experimental and schematic depiction of the two different regimes of ice bridging that occur between a frozen droplet and a supercooled liquid droplet. Experiments were performed at $T_w = -10^\circ C$ and $p_\infty = 776.3$ Pa; time stamps are in seconds, and the scale bar represents 20 μm. b) Total length of ice bridge varies linearly in time. Experiments performed at $T_w = -10$ and $-20^\circ C$ and hydrophobic and superhydrophobic substrates. c) Phase map of success and failure of ice bridging.

Abstract: In this work, we study the dynamics of an ice bridge growing from a frozen droplet towards its neighboring supercooled liquid droplet. Experiments were done on a Peltier stage inside a humidity chamber with deposited or condensed droplets where the substrate temperature and ambient humidity could be controlled. Following a quasi-steady diffusion-driven model, we develop scaling laws to show how the growth rate depends on the substrate temperature, droplet sizes and inter-droplet distances over and above other environmental parameters such as air temperature and humidity. The growth rate as well as the success or failure of an ice bridge to connect to its neighboring liquid droplet depend on a nondimensional number called the bridging parameter S^*, defined as the ratio of the initial inter-droplet spacing to the diameter of the evaporating liquid droplet. It is shown that the maximum value of S^* for connection scales as 1 as long as frozen drop is larger than the liquid droplet.For the converse case of a larger water drop, there are at least three separate regimes of critical S^*, depending on whether the water drop is a puddle, a spherical cap or if the frozen drop is a puddle.

Phase-Change Driven Pathogen Transport on Wheat Leaves

Co-authors: G. J. Iliff, H. Gruszewski, D. G. Schamle, Sunny Jung and Prof. J. B. Boreyko

Journal: In preparation.



a) Spore agglomeration in stomatal grooves of a wheat awn due to cyclical condensation and evaporation processes. Larger spore agglomerates can be sheared off due to incident rainfall or gravity. b) Spore transportation due to preferential condensation on a fine silica hair on a wheat awn. c) Spore transportation via iterative condensation and evaporation cycles. The morphology of the wheat awn concentrates the spores into agglomerates found in the stomatal grooves.

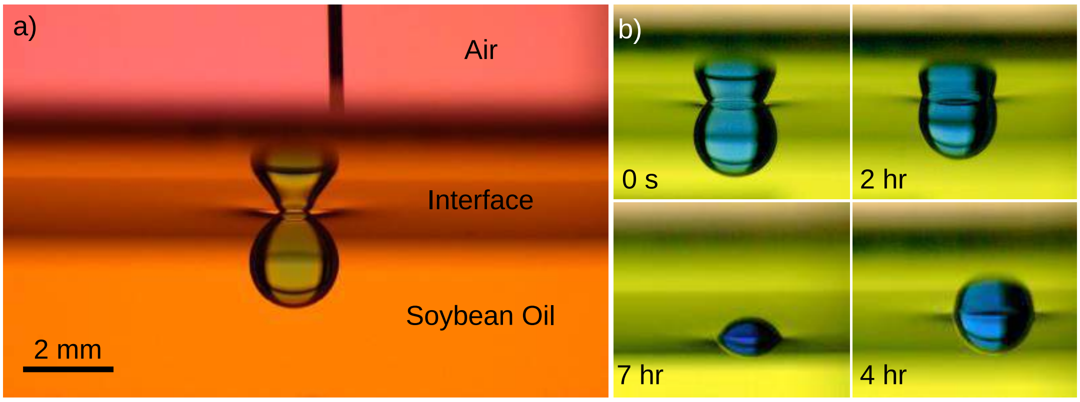
Abstract: Wheat has been a cereal crop for humankind for millennia and currently constitutes 25% of the world's food supply. Despite several pathogens plaguing this staple crop, such as Fusarium Head Blight and Leaf Rust, pathogen transport mechanisms remain poorly understood. Here we show for the first time how phase change phenomena such as condensation and evaporation lead to agglomeration and subsequent transport of fungal spores on and across wheat crops. The kernels and awns of the wheat plant have been observed to demonstrate a hierarchical morphology characterized by micro-grooved structures with fine silica hairs that promotes preferential condensation. Spores tend to adhere to the edge of water droplets on the surface, and as the droplets grow and coalesce, the spores move with them. Through an iterative process of condensation and evaporation, the spores agglomerate into the stomatal grooves that run parallel on the wheat awn. These cohesively bonded agglomerates are more massive than the spores they are composed of and therefore are more susceptible to being sheared off of the plant by rainfall onto neighboring plants.

Inverse Flotation

Collaborators: A .Mukherjee, S. Chatterjee, R. Ganguly, S. Sen and J. B. Boreyko

Presentation: "Inverse Flotation" *67^{th} APS DFD Meeting*, San Francisco, CA (2014)

Journal: In preparation.



a) A 50 μl water droplet (dyed blue) floating on soybean oil in a pendant configuration, captured with color camera at a 10° upward angle. The portion of the droplet above the contact line is its reflection on the interface. b) Long term dynamics of the floating droplet configuration. Time-lapse images show evaporation-induced transformation from a pendant configuration to a sessile shape.

Abstract: Here we show that capillarity forces may cause a heavier liquid droplet (water) to float on a lighter immiscible medium (vegetable oil) in a non-intuitive pendant configuration. We first experimentally determine for a particular combination of liquids, the maximum volume of the heavier droplet that can float on the lighter medium. Water droplets are deposited on the oil interface from different heights to study the regime where inertia can cause droplets to sink at smaller volumes. The stability and uniqueness of configuration of floating droplets of a given volume are also studied. The pendant configuration is also seen to show a slow evaporation-induced transformation to a sessile shape. Using the spherical cap approximation, the maximum floating volumes are estimated and compared with the experiments. The contact line radius of the floating droplet is shown to vary linearly with the Bond number.

Undergraduate Research Experience

2010 – 2014

Website
Google Scholar

Flotation of Heavier Liquid Droplets on a Lighter Liquid Medium

Collaborators: A .Mukherjee, S. Chatterjee, R. Ganguly, S. Sen and J. B. Boreyko

Presentation: "Inverse Flotation" *67^{th} APS DFD Meeting*, San Francisco, CA (2014)

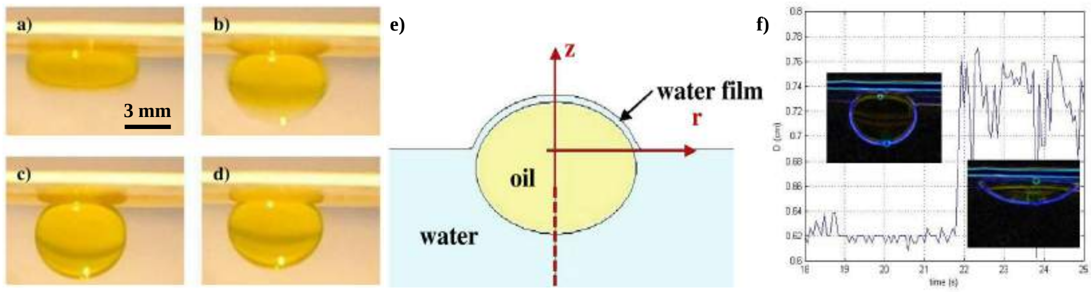
Journal: In preparation.

This work has been described in the previous section '*Inverse Flotation*'. The initial experiments of this work were done in my undergraduate years in Jadavpur University. This work has subsequently been continued at Virginia Tech.

Flotation and Subsequent Spreading of a Submerged Buoyant Drop

Collaborators: A .Mukherjee and S. Chatterjee

Presentation: "Flotation and Subsequent Spreading of a Submerged Buoyant Drop" *39^{th} National Conference on Fluid Mechanics and Fluid Power*, Surat, India (2012).
"Can Oil Float Completely Submerged in Water?" *arXiv:1309.7727* (2013).



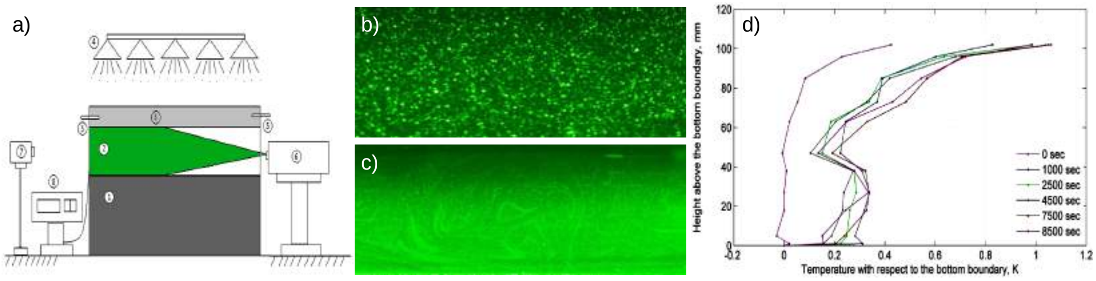
a-d) A fully submerged oil droplet of characteristic diameter 5.9 mm impinging on the air-water interface from the water side and stabilizing beneath the interface within $t = 1$ s. e) The fully submerged floating configuration is due to the water film entrapped between the oil and the air outside. f) Temporal variation of the diameter of the droplet shows how the droplet changes its configuration from a fully submerged one to a partially submerged one. This corresponds to the drainage time of entrapped water film which was calculated to be $t \approx 22$s.

Summary: In this work, we study an innovative phenomenon where oil when injected drop-wise into a pool of water moves towards the air-water interface where it floats in a fully submerged condition. The configuration of such a fully submerged drop, however, is not stable and a slight perturbation to the system causes the droplet to burst and float in partially submerged condition. The droplet contour is analyzed using edge detection. Temporal variation of characteristic length of the droplet is analyzed using MATLAB image processing. The constraint of small Bond Number establishes the assumption of lubrication regime in the thin gap. A brief theoretical formulation also shows the temporal variation of the gap thickness.

Near-Surface Temperature Inversion in Boundary Layer and the Role of Suspended Particles

Collaborators: D. Deka, D. Singh and K. R. Sreenivas

Presentation: "Model Near Surface Temperature Inversion in Boundary Layer and the Role of Suspended Particles" *Indian Aerosol and Technology Association Conference IASTA– 2012*, IASTA-2012/Session-IV/P-125, BARC, Mumbai, India (2012).



a) Experimental set-up comprising a water reservoir. Temperature at the top and bottom walls were held constant with regulated water flow. Reservoir was illuminated with a 532 nm laser sheet through it and radially heated with halogen bulbs places atop. b) Suspended graphite particles c) Convection rolls d) Vertical temperature profiles as captured by thermocouples. Note that conductive effects become dominant close to 50 mm from the ground. The Lifted Temperature Maximum, as determined from the experiments, was at a height of 3 *cm from the bottom surface.*

Summary: The vertical distribution of temperature in the atmospheric boundary layer is primarily governed by radiation, convection and aerosol concentration in the air. In 1930, Ramdas et al. discovered a curious atmospheric phenomenon where he observed that the nocturnal boundary layer in the atmosphere, on calm, clear windless nights, exhibited a near-surface temperature inversion. He observed that the air temperature profile reached its minimum, surprisingly, not at the ground, rather $1/10^{\text{th}}$ of a meter above. This phenomena today is also known as the *Lifted Temperature Minimum*. Seventy years later, a diurnal analogue of such a near-surface temperature inversion was reported to exist in the sub-cloud layer beneath the mixing layer over the Arabian Sea (Bhat et. al., 2006). Here, we performed laboratory experiments to simulate the field experiments over Arabian Sea and investigate the existence of the diurnal *Lifted Temperature Maximum* as reported by Bhat et. al. In order to systematically analyze the effect of suspended particles on the radiative heat transfer in our system, we used 45 μm graphite particles as suspension. Halogen bulbs were used to simulate solar radiation and water was chosen as the medium to minimize conduction. Experiments were performed for two different concentrations of the suspension and the control test was performed with de-ionized water without any suspension. Experiments not only showed a *Lifted Temperature Maximum*, but also provided strong evidence that near-surface radiative heating is precisely the reason behind this temperature inversion.

A Discussion on Apparent Surface Tension Paradoxes

Advisor: Rama Govindarajan

Duration: Summer 2013

Summary: In the 2006 paper '*Contact Angle in Capillarity*', Robert Finn proposed a paradox in the Young's description of surface tension. He illustrated the paradox by analyzing the balance of surface tension forces on a solid ball floating in a liquid bath in zero gravity. He showed that the Young's surface tension diagram, in this case, yields a net unbalanced force on the ball, which is unacceptable as the ball is in equilibrium. He proposes a general class of paradoxes that may emerge in the Young's description of surface tension. In this work, we show how all of these apparent paradoxes can be resolved by proper consideration of the forces at play.

Dynamics of the Drinking Duck Toy

Advisor: Rama Govindarajan

Duration: Summer 2013

Summary: The drinking duck toy constitutes a well-known thermodynamic problem that has been studied since the 1930-s and is often cited in Thermodynamics text books as a simple example of an apparent perpetual motion machine of the second kind. The toy can be described as a straight tube (neck) attached to two bulbs (head and bottom) that it keeps swinging about an axis. The bottom flask is filled with a refrigerant and there is a beaker filled with water where it dips its beak. The oscillations initially appear to dampen out due to friction but just before coming to rest, the amplitude starts increasing again, all by itself. The increasing amplitude results in the toy duck dipping its beak into the water container, which restarts the process. In this work, we studied the strange dynamics of the drinking toy bird, looking in particular for transient growth-like behavior in its oscillatory motion of the bird. In broad terms we were trying to answer if the drinking duck can serve as a physical analogy to the transient growth problems of fluid mechanics.The equations of motion of the toy were non-linear, non-autonomous and non-homogeneous. As a part of the project, I learned transient growth in dynamical systems, linear stability analysis in fluids and bifurcation theory.