The Mountain Terrain Atmospheric Modeling and Observations (MATERHORN) Program: A Progress Report

By

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and
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Univ. of Notre Dame

ONR FY 2011 Multidisciplinary University Research Initiative (MURI)

TOPIC #7:

Improved Meteorological Modeling in Mountain Terrain

Topic Chiefs:
Dr. Ronald J. Ferek and Dr. Daniel Eleuterio (ONR)

Additional support:

Army Research Office
(Dr. Gordon Videen and Dr. Walter Bach)

Air Force Weather Agency
through ARL

www.nd.edu/~dynamics/Materhorn

Principal Investigators:

H.J.S. Fernando

(University of Notre Dame)

Eric Pardyjak

(University of Utah)

Stephan De Wekker

(University of Virginia)

Josh Hacker

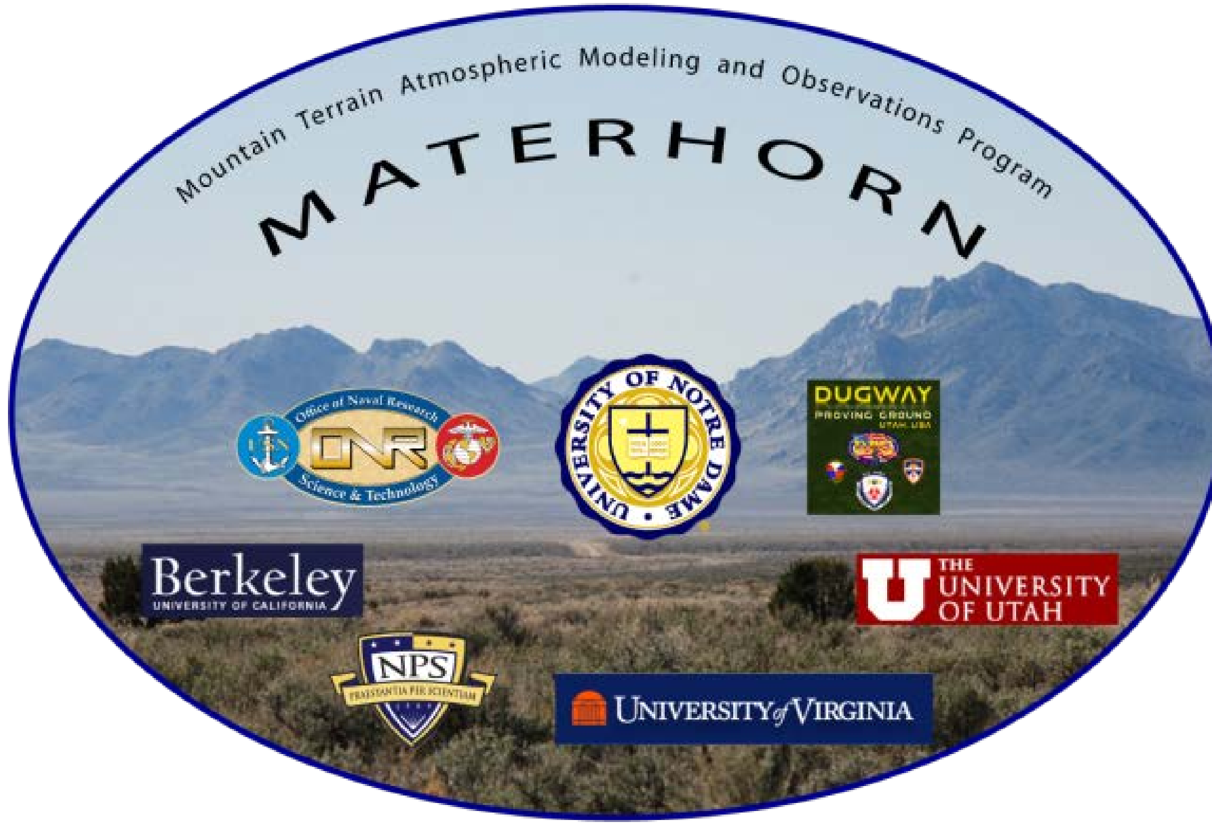
(NPS/NCAR)

Tina Katopodes Chow

(Univ. California, Berkeley)

Multidisciplinary University Research Initiative MURI

www.nd.edu/~dynamics/materhorn 60592 since 1 Feb 2013



Acknowledgments

- University of Utah Team – Pardyjak, Hoch, Pu, Steenburgh and Whiteman – many contributions including logistics for field work
- US Army Dugway Proving Ground – John Pace and Dragan Zajic – continued support for MATERHORN-Fog
- Advisory Committee – Dave Emmitt, John Pace and Vanda Grubišić for continued support for the group
- John and Sarah Pace – for their kind hospitality

accom

Major accomplishments

(since AMS 2014)

- Two year MURI option was granted with:
    - No weaknesses
- Attracted support from three DOD agencies for MATERHORN – ONR, ARO and AWA
- So far,
    - 20 papers published or accepted;
    - 15 submitted;
    - 10 Invited conference presentations;
    - 7 conference papers;
    - 101 conference presentations

Summary (End of 3rd year)

- Senior PIs: 11
- Research faculty: ~~4~~ 5
- Technical staff: 8
- Post docs: ~~8~~ 13
- Graduate Students : ~~18~~ 15 PhD and 7 MS (Total 22)
- Undergraduate Students: ~~13~~ 22
- Collaborators (proposal): 5 (supported – 2)
- Collaborators joined: 11

(total supported fully or partially: ~~67~~ 82)

MATERHORN has four components working symbiotically across institutions and disciplines

Modeling	(MATERHORN-M)
Experiments	(MATERHORN-X)
Technology Development	(MATERHORN-T)
Parameterizations	(MATERHORN-P)

MATERHORN-X
(Fall 2012,Spring 2013, Fog 2014)

Test Beds

MATERHORN Fall and Spring

Granite Mountain Atmospheric Science Test bed (GMAST)

US Army Dugway Proving Ground (1252 sq. miles)

Calm Winds (FALL) – October 1 - 31, 2012

Synoptic Winds (SPRING) – May 1-30, 2013

20 Intensive Operational Periods IOPs (24-36 hrs)

5 Intensive Operational Locations IOLs

~ 55 TB Data from MATERHORN 1 and 2 (stored in ND server)

MATERHORN - Fog

November 1 2014 (?) – January 20, 2015

10 IOPs

2 Locations

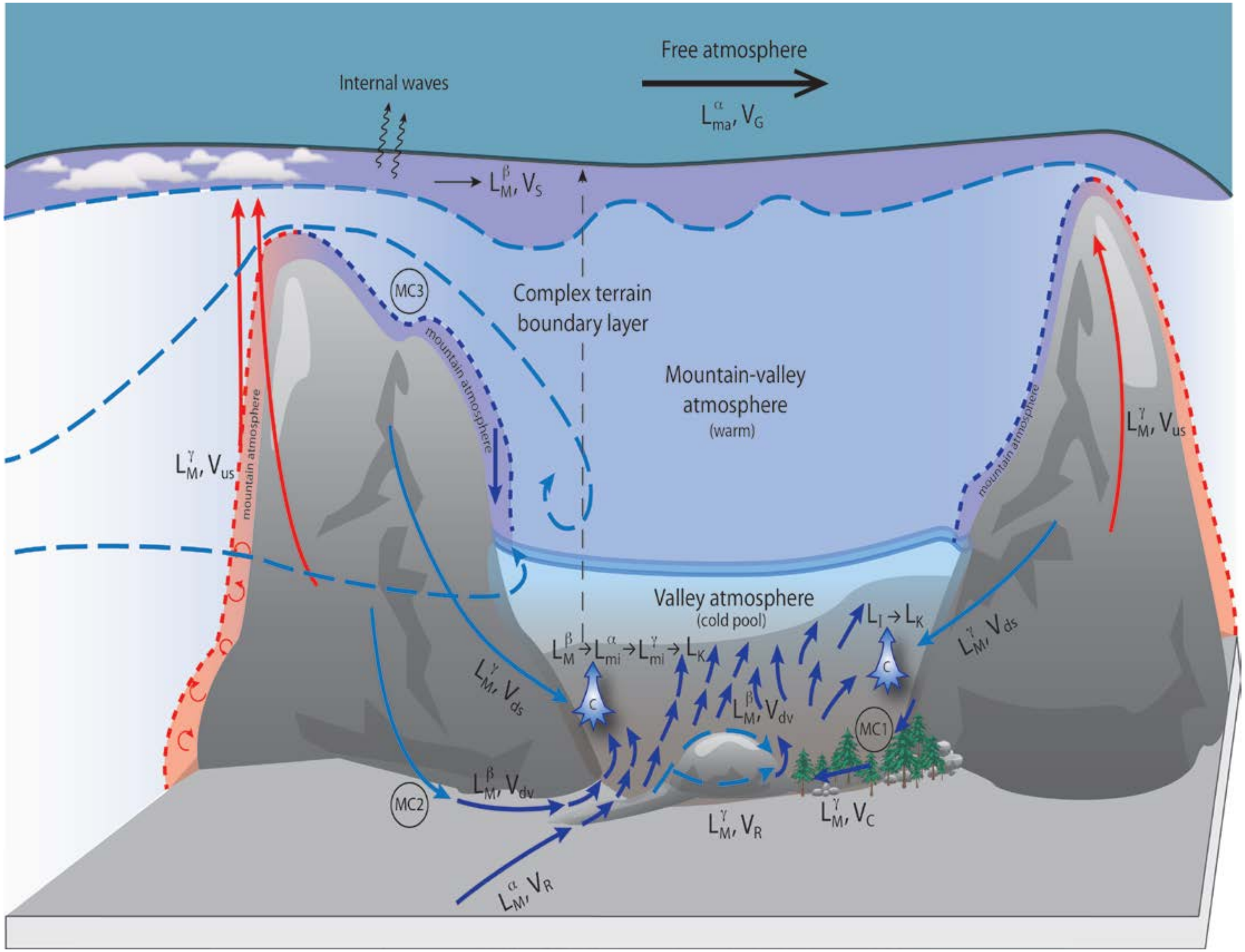
Heber Valley, Salt Lake City Airport

***Canada Environment* is slated to join**

pics

MATERHORN-X

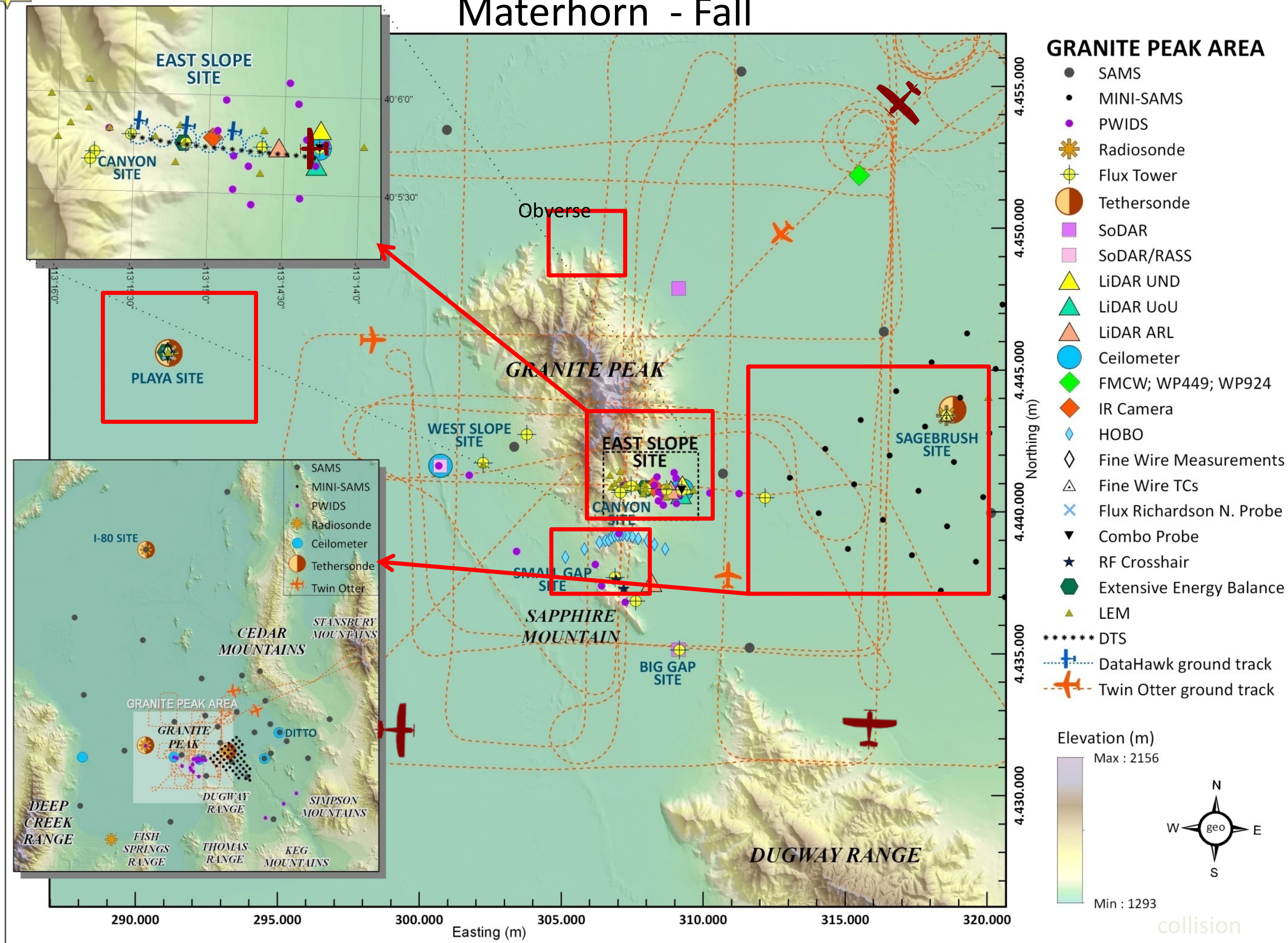
Summary of some results



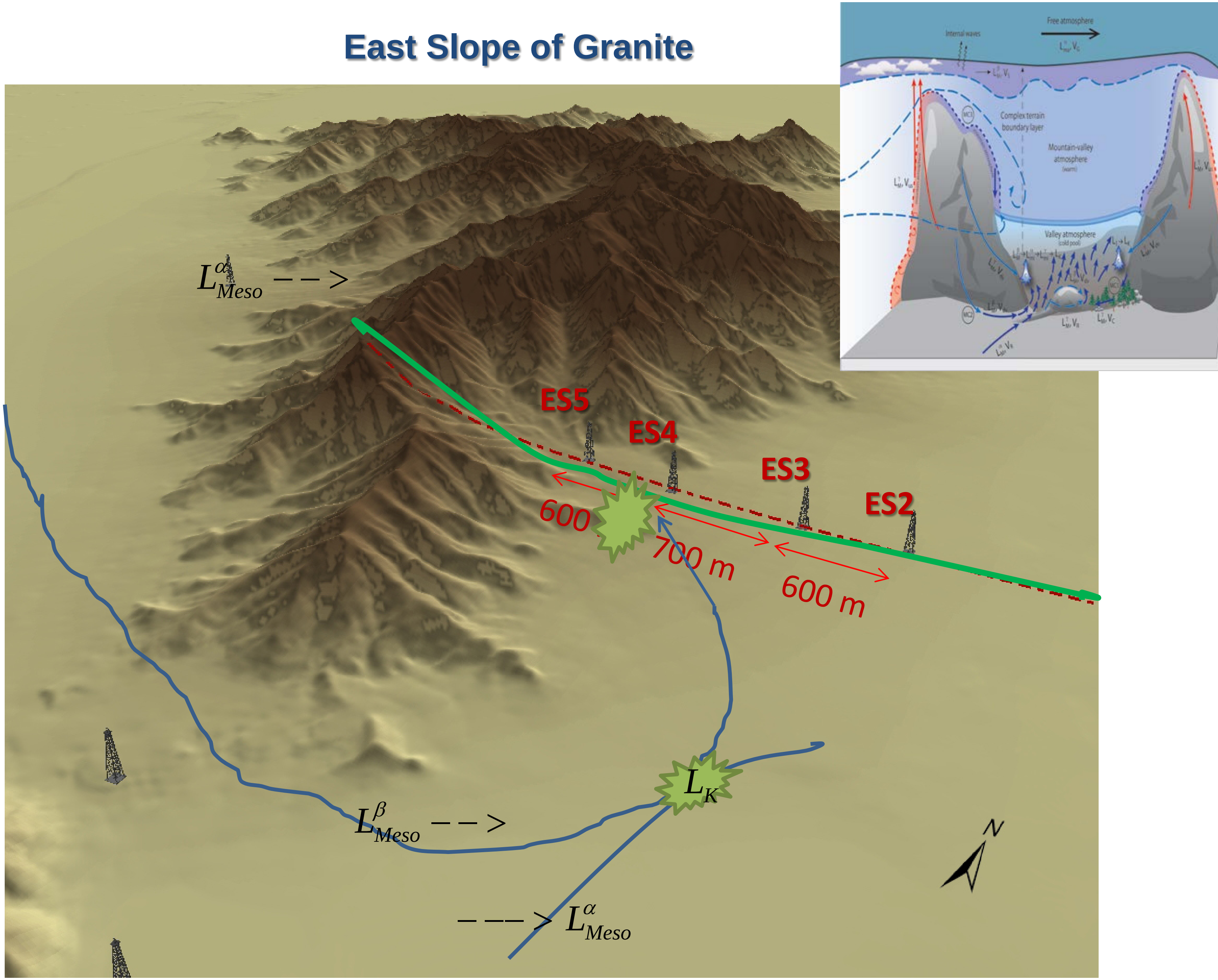
$$L^{\alpha}_{Macro} \; --> \; L^{\beta}_{Macro} \; ---> L^{\gamma}_{Macro} ---> L^{\alpha}_{Meso} \; .... ----> L_{Kolmogorov}$$

testbed

Materhorn - Fall

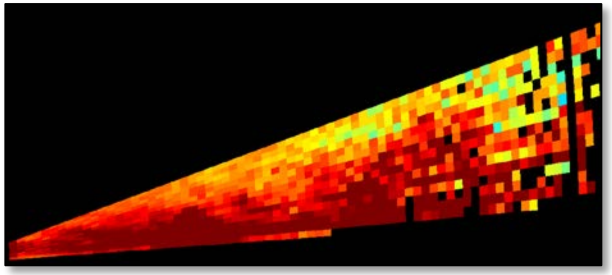


East Slope of Granite

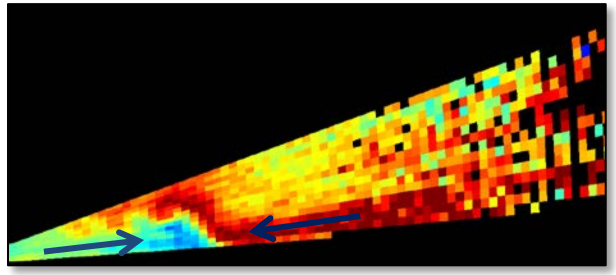


Lidar

Gravity Currents Collide



4:41 UTC (22:41 MDT)



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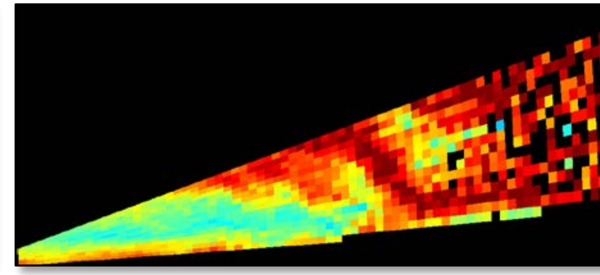
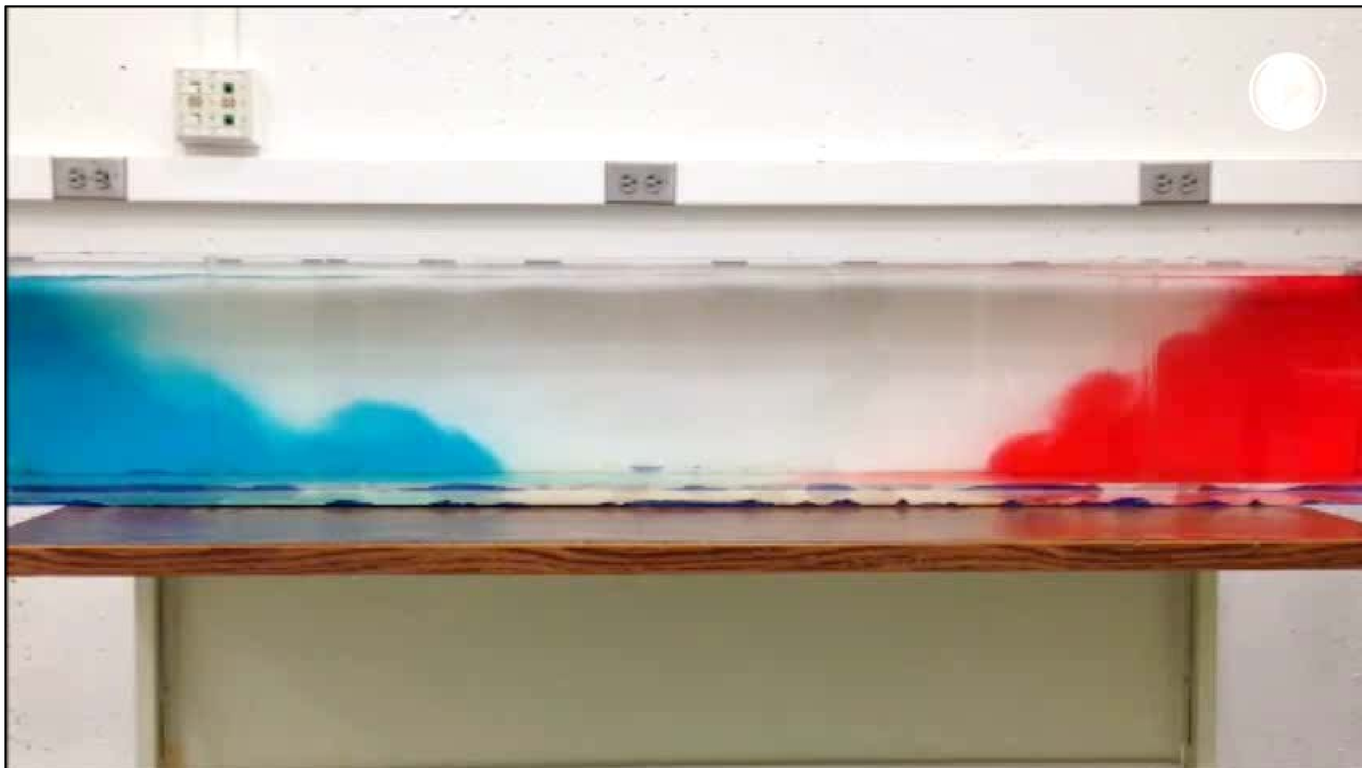
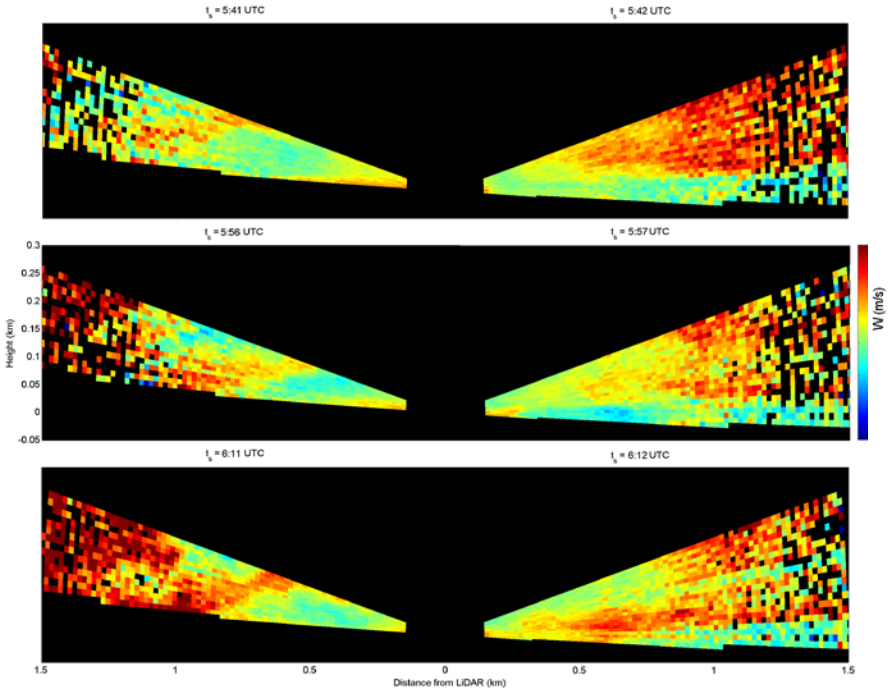


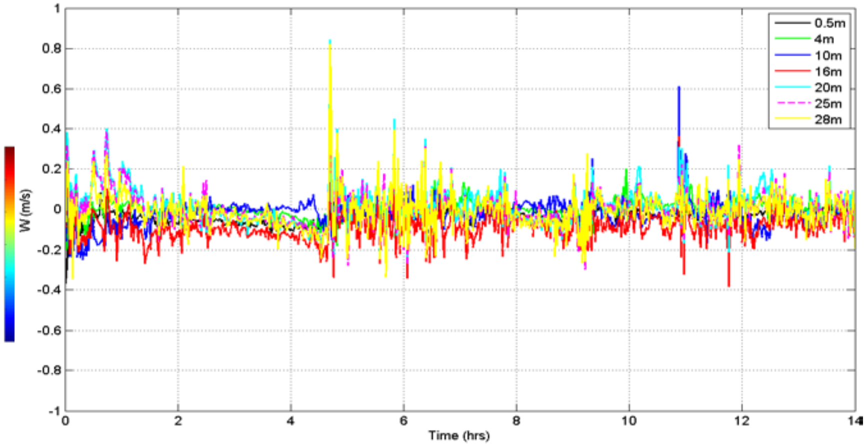
5:11 UTC (23:11 MDT)



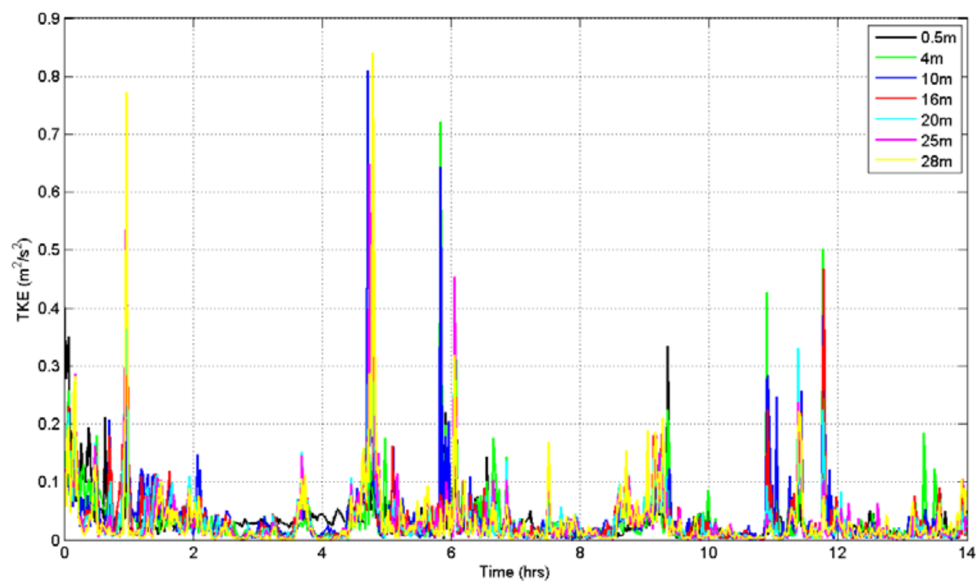
Hocut, Hoch and Wang

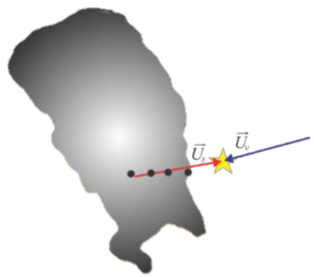
TKE

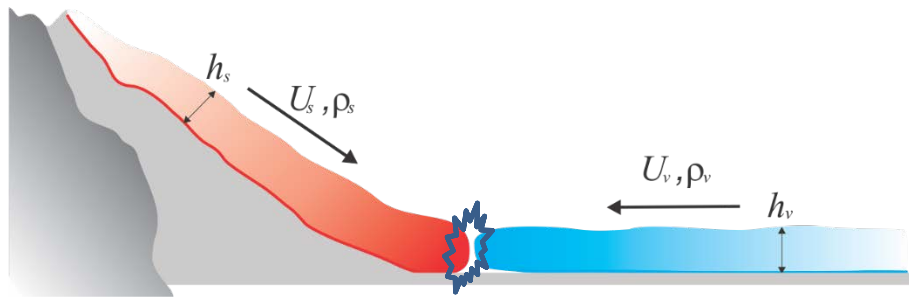




Secondary Collisions



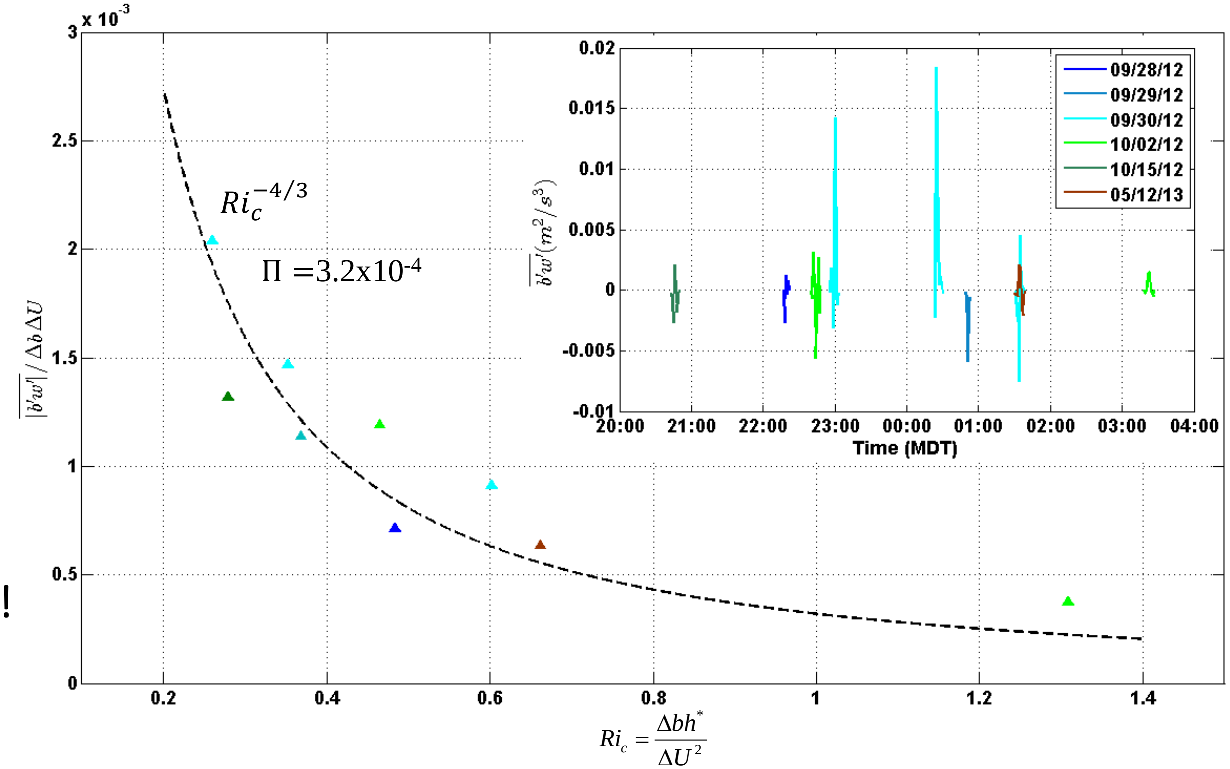




$$-\overline{b'w'} = K \frac{\partial \overline{b}}{\partial z}$$

Eddy Diffusivity

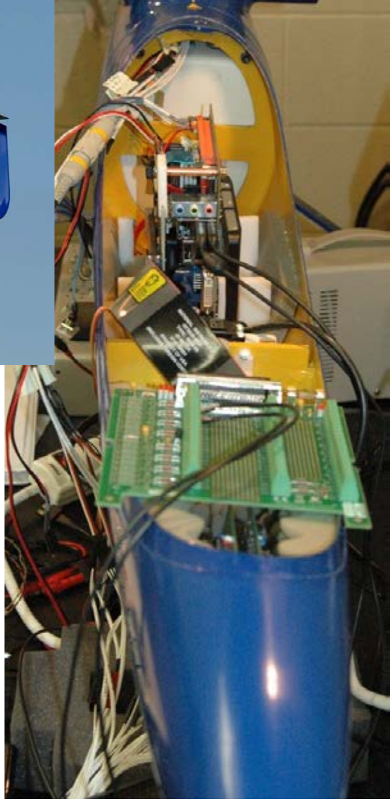
Conditional parameterization!



From: Chris Hocut

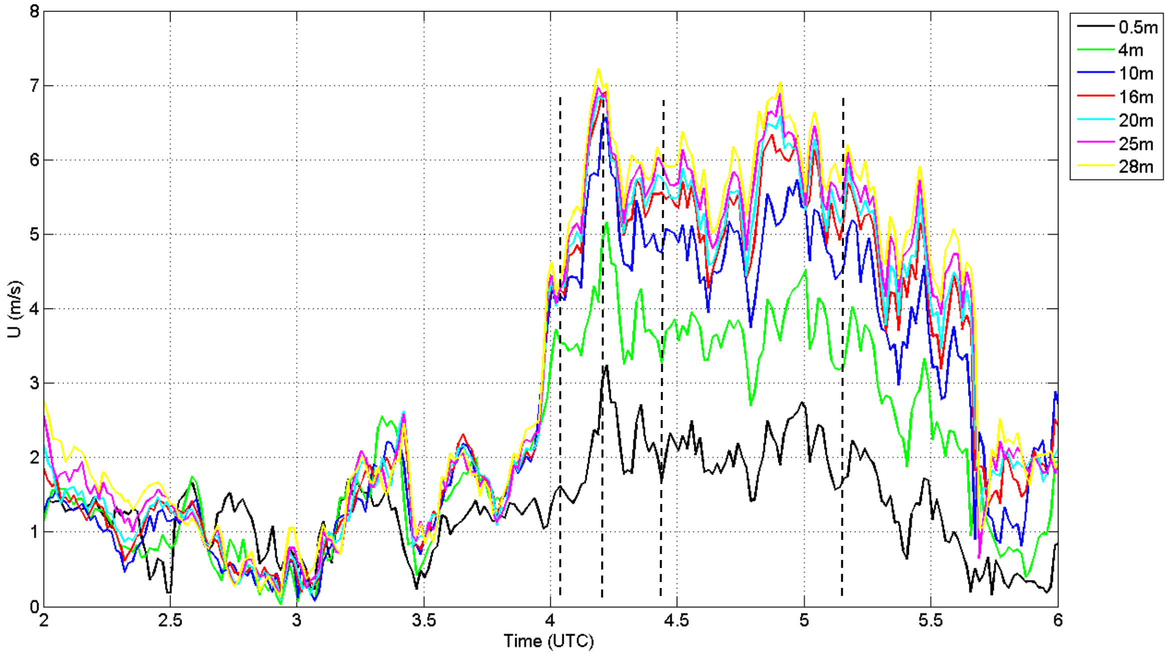
MATERHORN-T

...pushing the technological frontiers

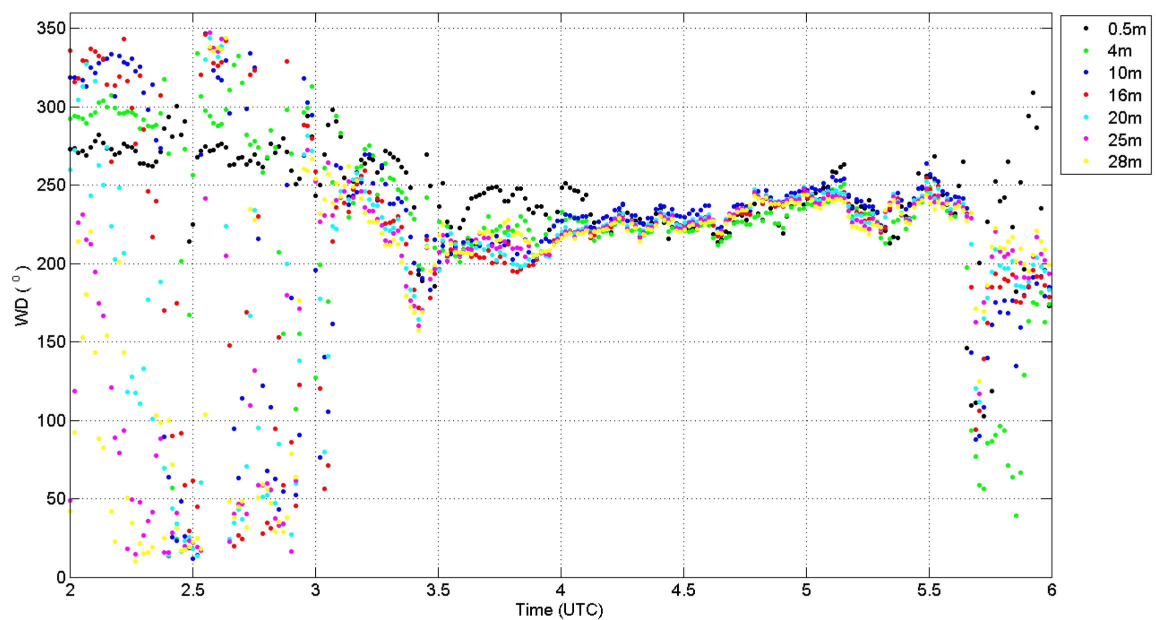


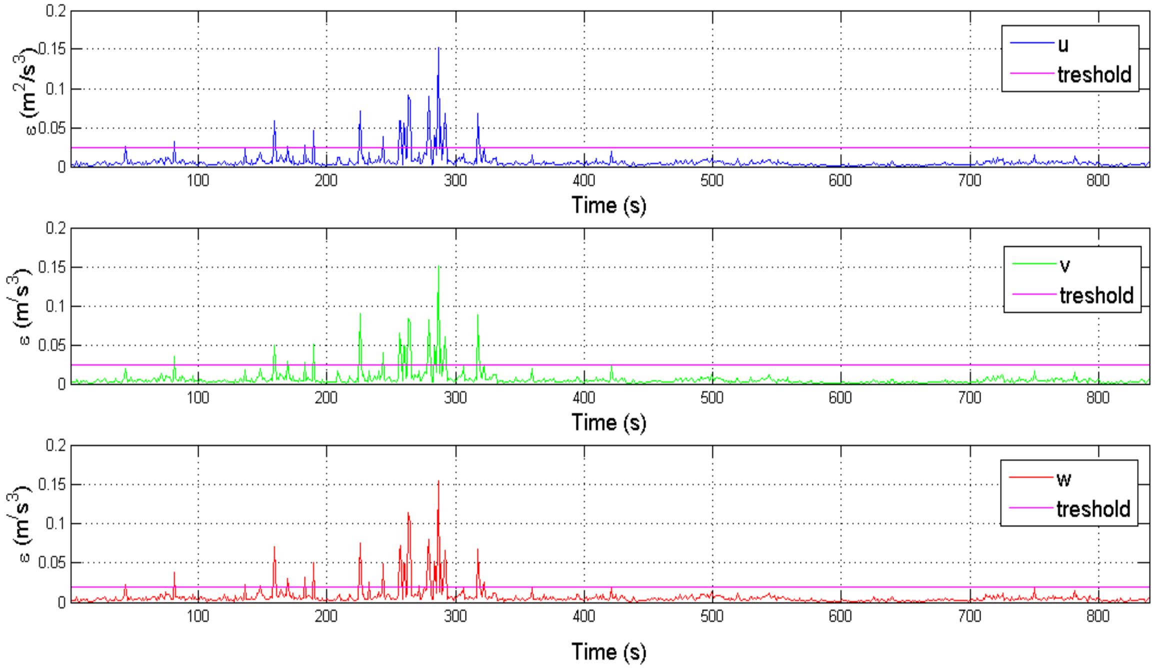
- **<u>Unmanned Aerial Vehicle</u>**
  - Temperature, humidity, wind velocity
  - Turbulent components (combo probe) up to Kolmogorov
  - Onboard data acquisition
  - Automated flight tracks
  - Fog droplet size distribution (FASS)

- **<u>Sonic-hotwire Combo System (2-20 kHz)</u>**
  - Developed and deployed
  - unique turbulence information, dissipation scales
    - Allow myriad of turbulence and multiscale studies



Kit, Liberzon, Hocut:




u
treshold
v
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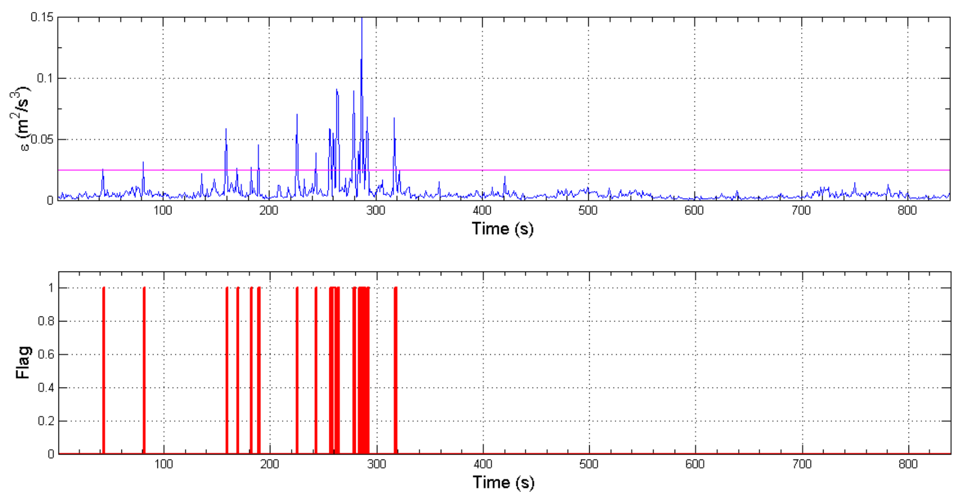
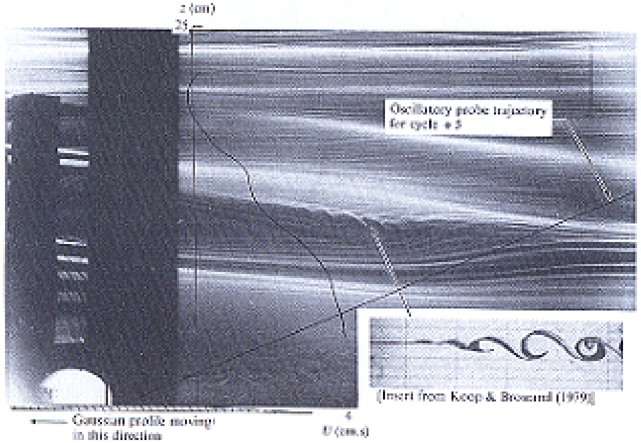
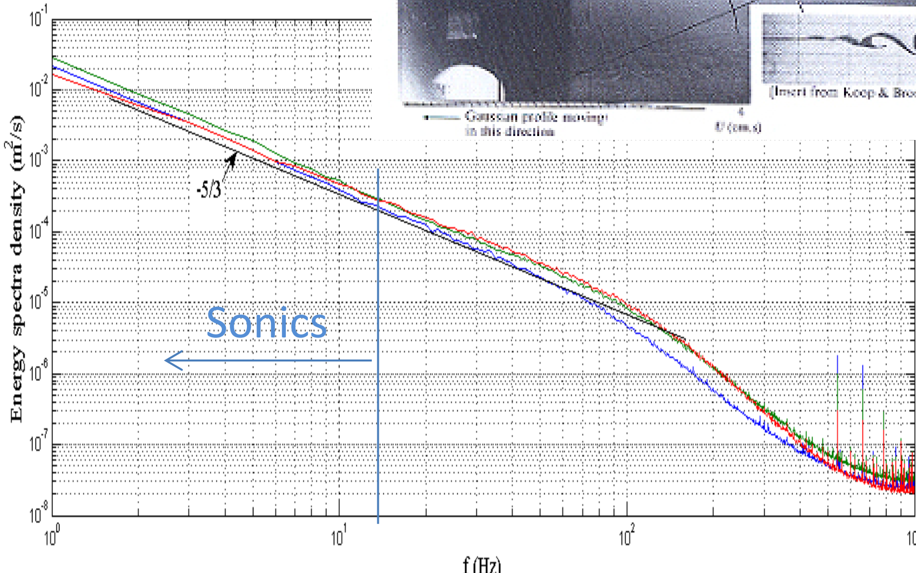
w
treshold
ε (m²/s³)
Time (s)


ε (m²/s³)
Flag
Time (s)

bursts



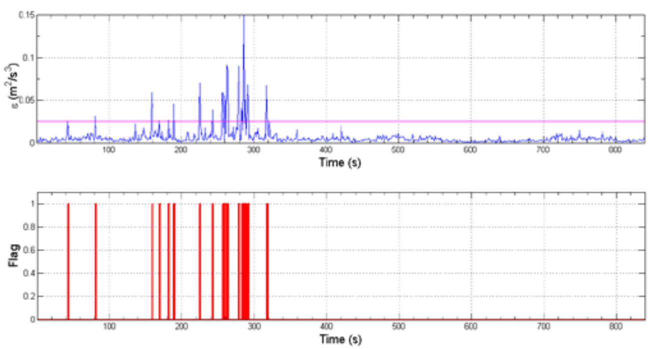


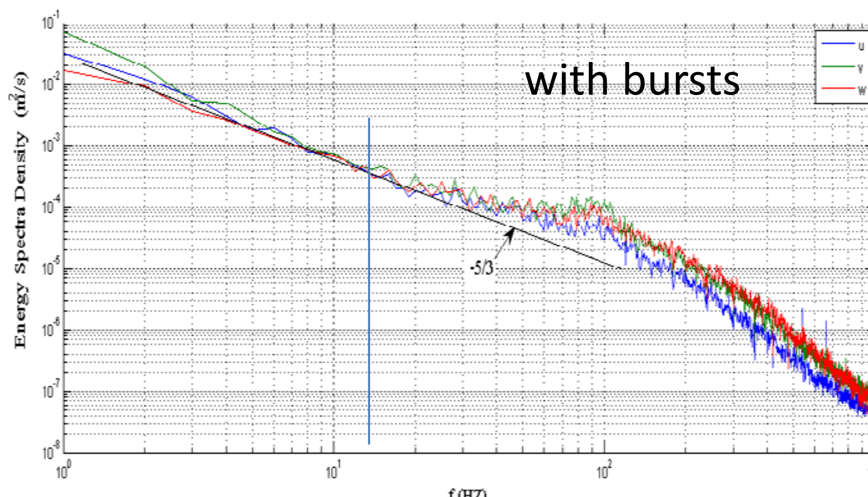
$$k_3(z) = \left[\frac{N_0^2}{(U-c)^2} - k_1^2 \right]^{1/2},$$

$$U = c$$

$$k_3 \Rightarrow \infty$$

Breakdown-bursts





For stratified flows -- Beware of using classical Kolmogorov laws in estimating turbulent kinetic energy dissipation using sonic-derived spectra

$$c \approx \frac{NH}{p\pi} \approx \frac{0.15 \times 20}{1 \times \pi} \approx 1 ms^{-1} \; (long\, Waves\, ?)$$

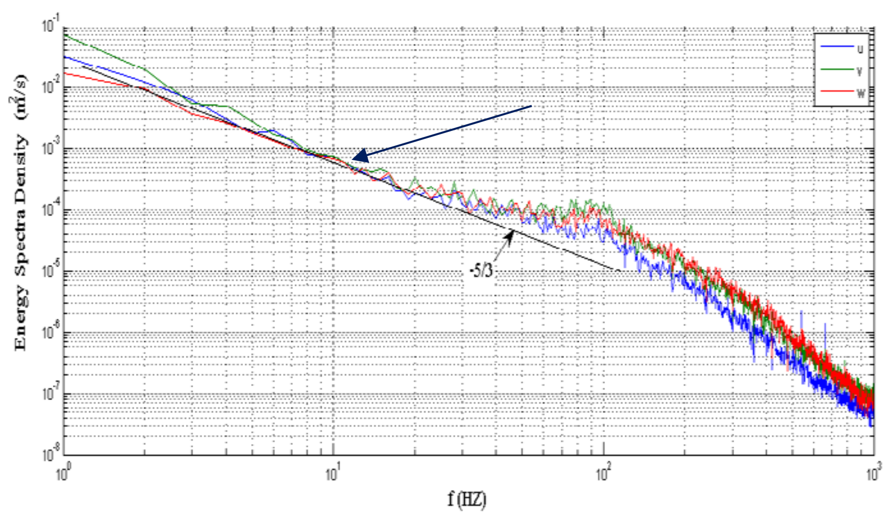
$$U \approx 4\, ms^{-1}$$

Cannot be long waves!

$$kU \approx 10 (\, Hz\,)$$

$$k \approx 15\, m^{-1}$$

$$\lambda \approx 0.4\, m \; \checkmark$$



Triple lidars

New emphasis in MATERHORN-T

Triple Lidar deployment

Wang, Creegan, Fenton, Hocut, Hoch….

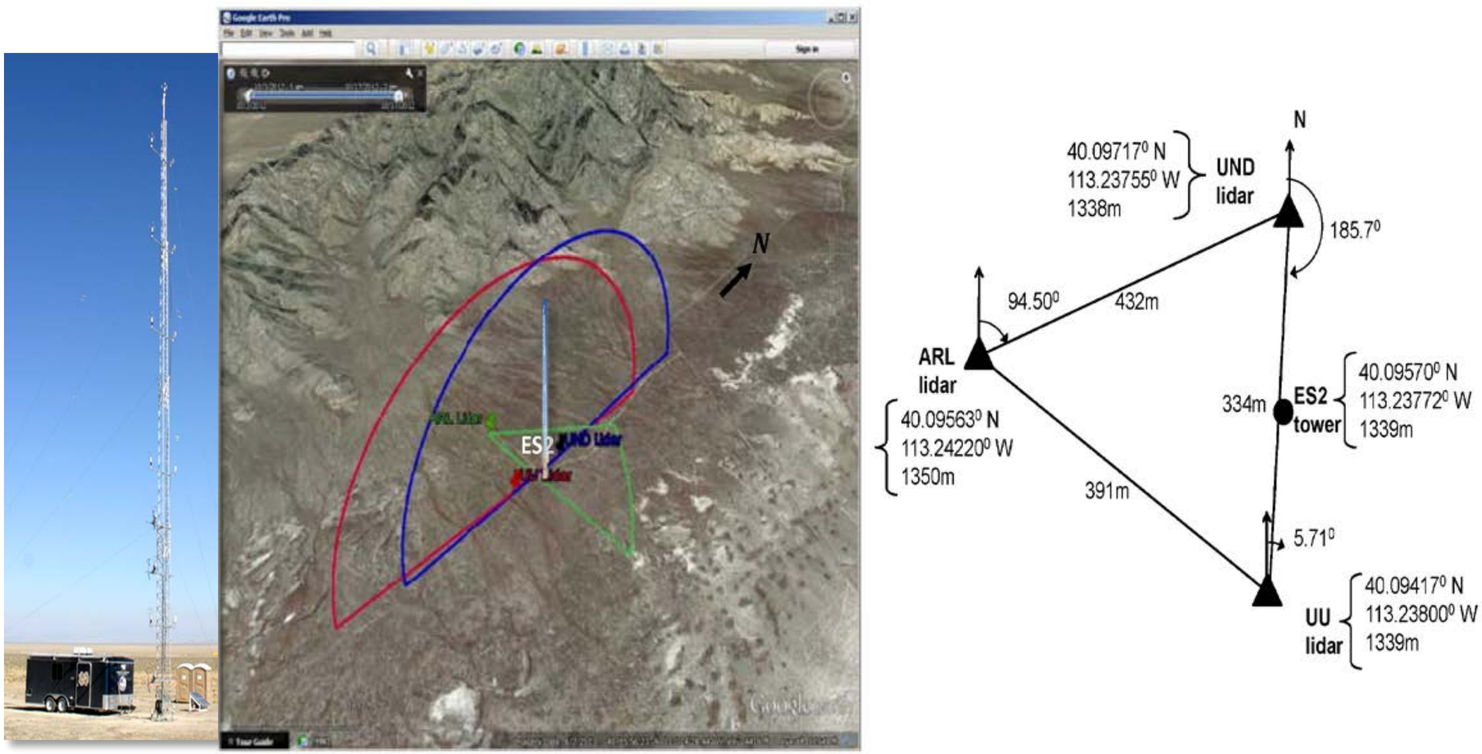
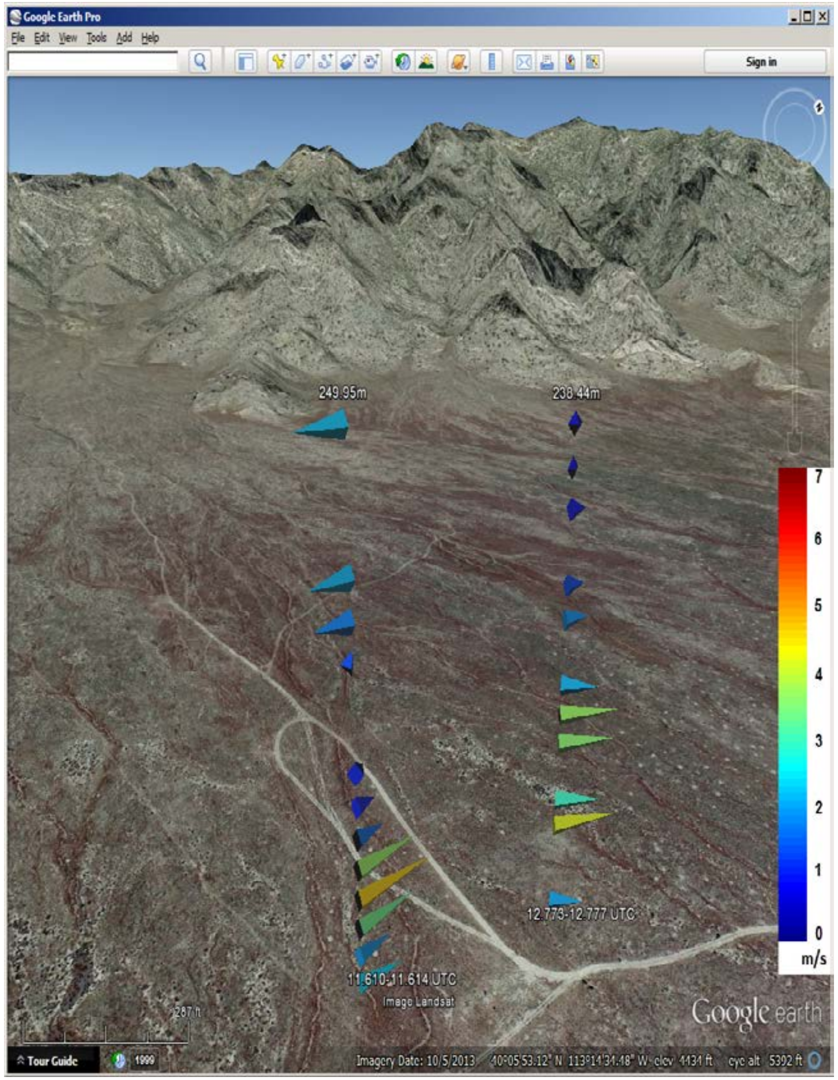


Fig. 3. 7 October 2012 setup of three Doppler wind lidars from ARL (green), UND (blue), and UU (red). The left panel is a 3D depiction of RHI scans from three Doppler wind lidars. The right panel is a latitude, longitude and altitude coordinate for three Doppler wind lidars. Note that a 32 m meteorological tower (ES2) with a 28 m AGL sonic anemometer was located between the UND and UU lidars.

Virtual Tower using Triple Lidar!



Examples of vertical profile (virtual towers) 3D wind vectors retrieved from coordinated triple Doppler wind lidars scanning on 7 October 2012. The down valley low-level jet was evident in these virtual towers at 11.61 to 12.77 UTC (0537 to 0646 MDT). The horizontal distance between two virtual towers is 134 m.

Long-range WindScanner system

Courtesy: Nikola Vasiljević

Master

With master computer

MATERHORN-P

Improve mixing parameterizations via improved physics

(observations, high resolution simulations, laboratory experiments)

Implement them in models

Dividing Streamline Concept (DSLC)

Based on energy arguments:

$$\frac{H_s}{h} = 1 - \gamma\, Fr$$

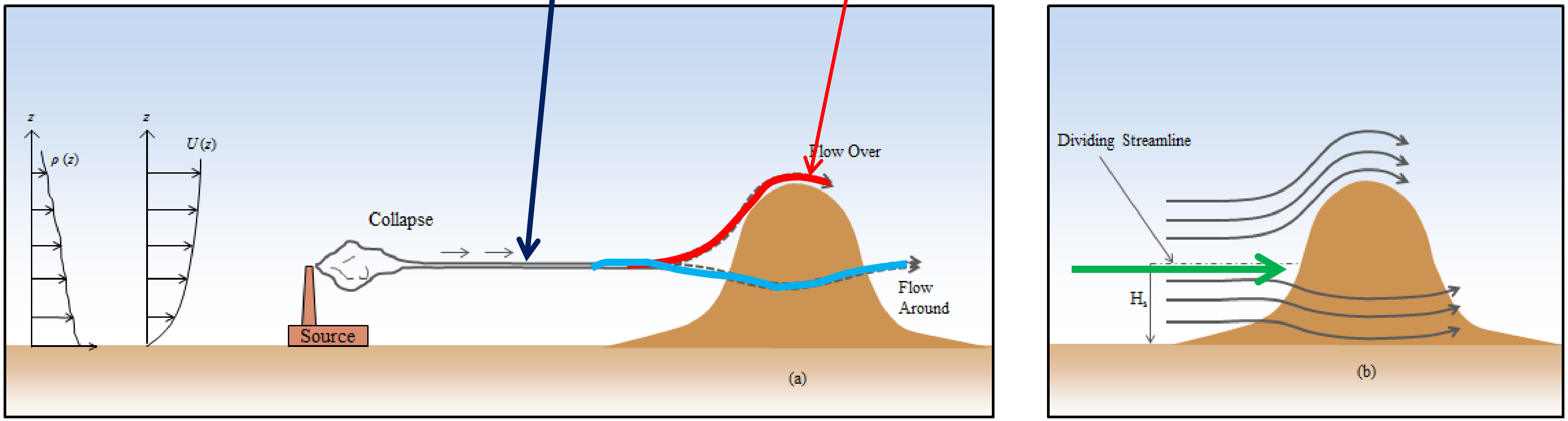
Sheppard's Equation:

$$\frac{1}{2}\rho\left(U_0(H_s)\right)^2 = g\int_{H_s}^{h}(h-z)\left(-\frac{\partial \rho}{\partial z}\right)dz \qquad (1)$$

Sheppard (1956)

The kinetic energy of the parcel far upstream at elevation H_s

The potential energy gained by the parcel in being lifted from the dividing streamline H, to the top of the hill h through the density gradient ∂ρ/∂z



A conceptualization of source pollution within a stably stratified flow collapsing into a thin layer, and becoming entrained in the flow.

Theoretical extensions: Log Vel. Profile

Remember assumptions:

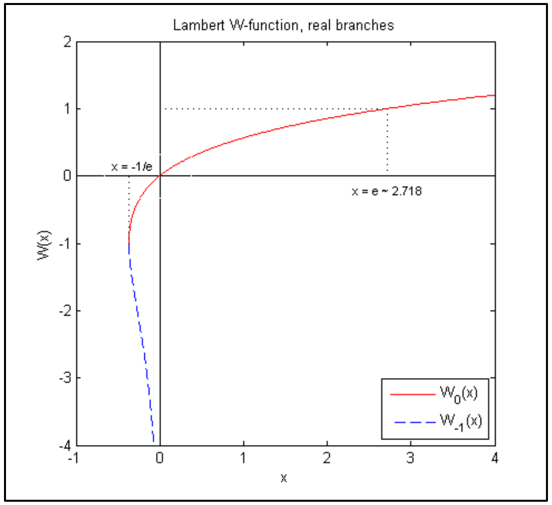
1. Constant density gradient $\beta = \frac{\partial \rho}{\partial z}$
2. Velocity profile: U_0 ⟶ $u(z) = \frac{u_*}{\kappa} \ln\left(\frac{z}{z_0}\right)$

$$\frac{1}{2}\rho\left(\frac{u_*}{\kappa}\ln\left(\frac{H_s}{z_0}\right)\right)^2 = g\int_{H_s}^{h}(h-z)(-\beta)dz$$

$$x = ye^y$$

$$y = W(x)$$

$$H_s = \frac{u_*}{N\kappa} W\left(e^{\left(\frac{N\kappa}{u_*}h\right)}\left(\frac{N\kappa}{u_*}z_0\right)\right)$$

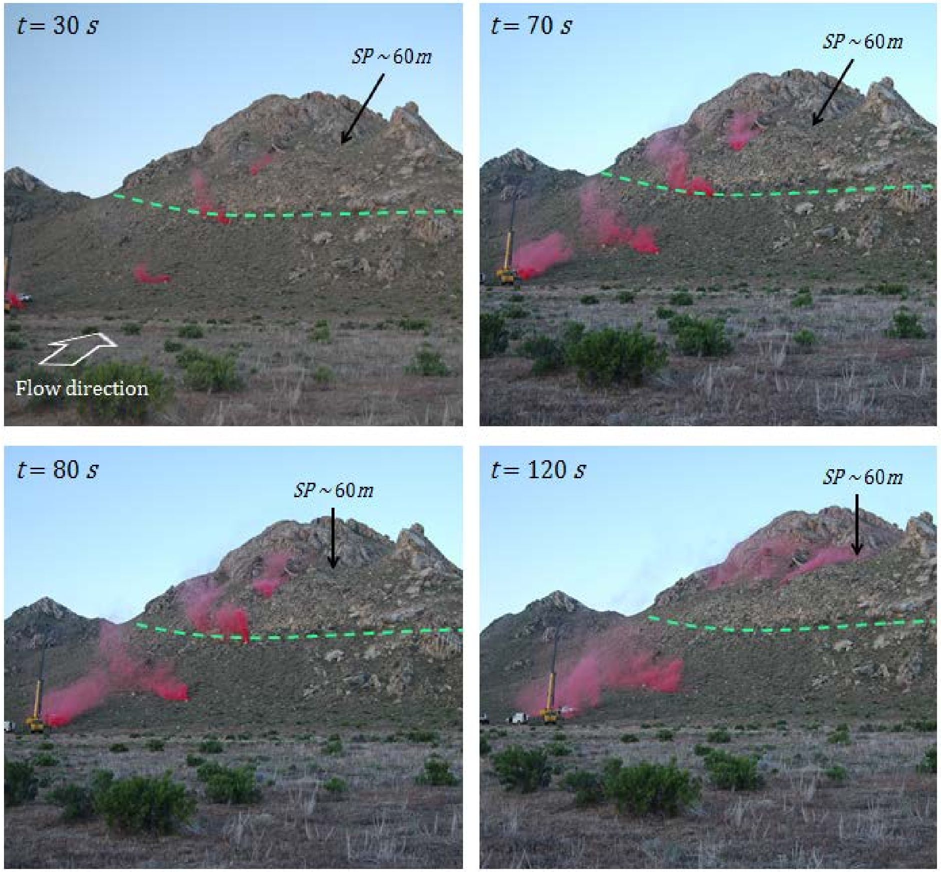


Lambert W Function

$$\frac{H_s}{h} = 1 - \gamma\, Fr$$

$$Buoyancy\ Scale\ L_b = \frac{u_*}{N\kappa}$$

May 30th *(Stratified):* Visualization

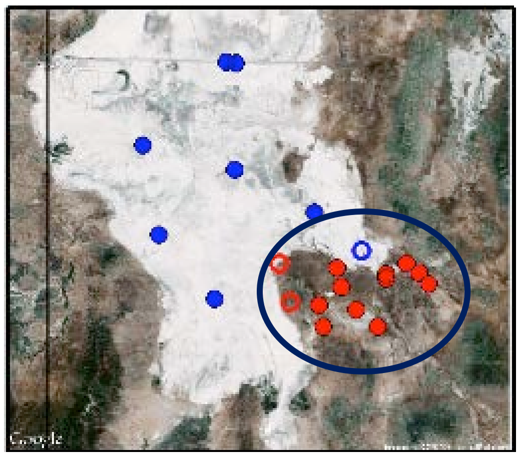


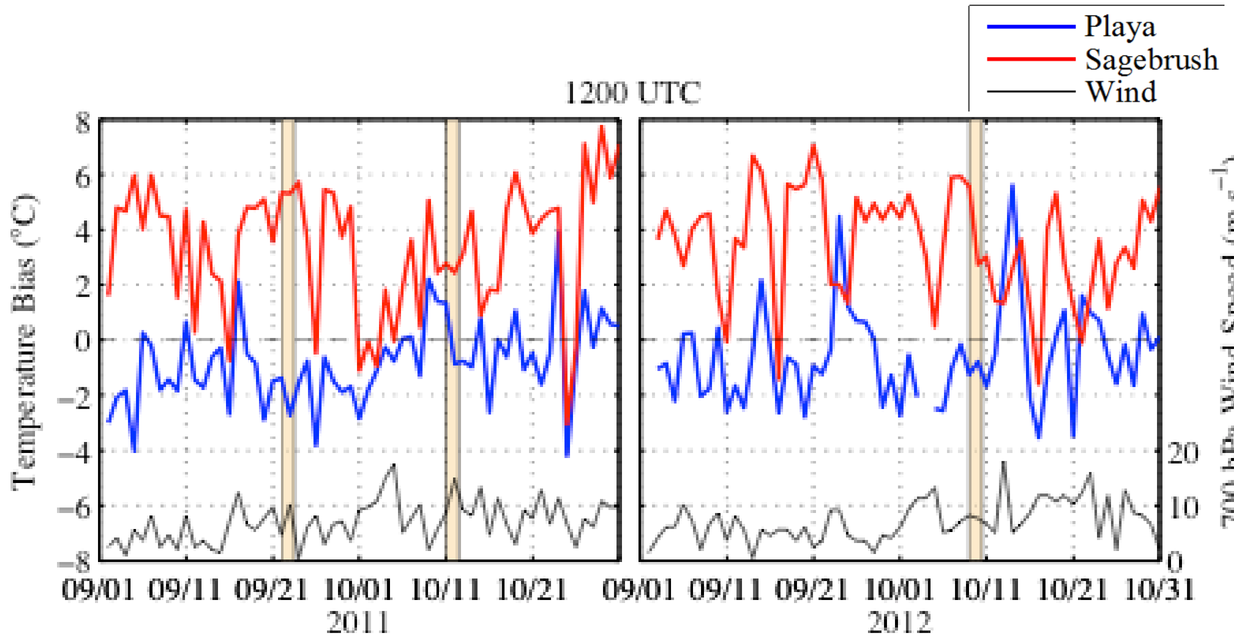
Movie 1: Red smoke release.

Red smoke release during May 30th, 2013. The still photos are taken at approximately 30, 70, 80, and 120 seconds after the release of the smoke canisters. The dashed green line is a visual guide to approximate .

MATERHORN-M

Example - Improving Surface Forecasts



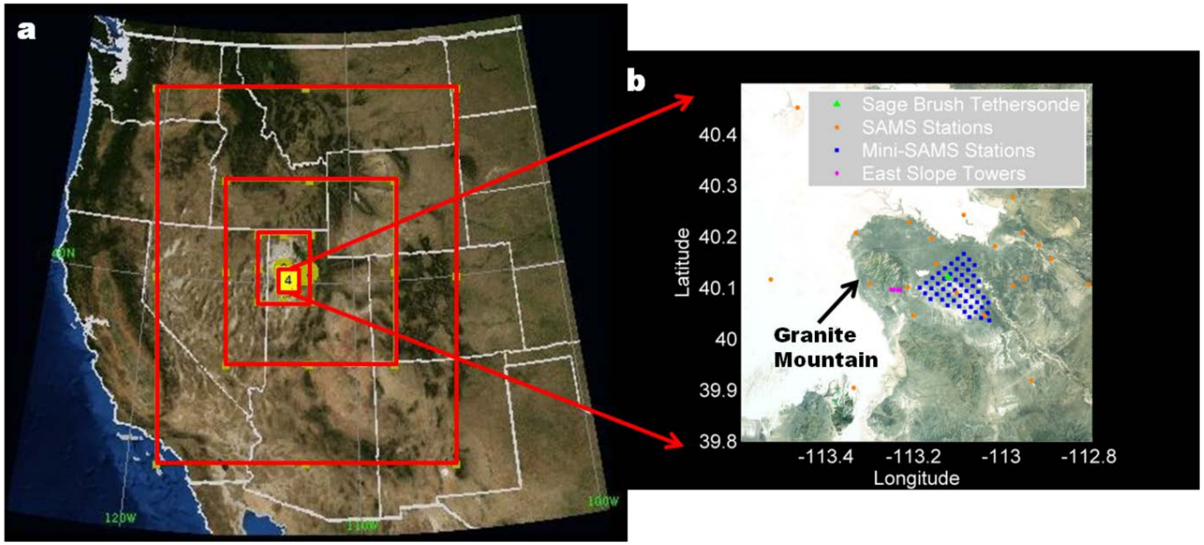


Issue: Atmospheric models (e.g., WRF) are too warm at night over the sagebrush region at DPG (systemic)

Implications: Poorly simulated NBL -> errors in the prediction of near-surface winds and turbulence, dust emissions and transport, etc.

Massey, Steenburgh, Pu (Utah), Hacker (NPS/NCAR)

Evaluation of PBL Schemes in WRF using MATERHORN Data (started with Massey et al. surface properties)

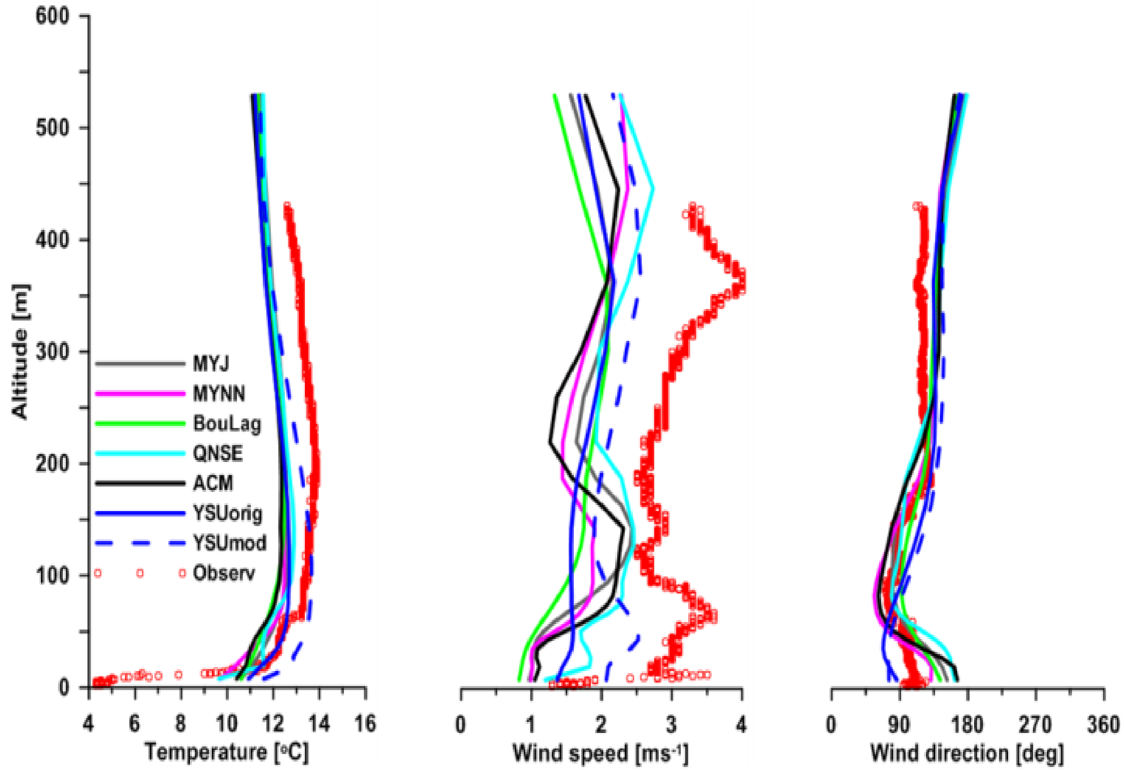


Dimitrova et al. BLM submitted

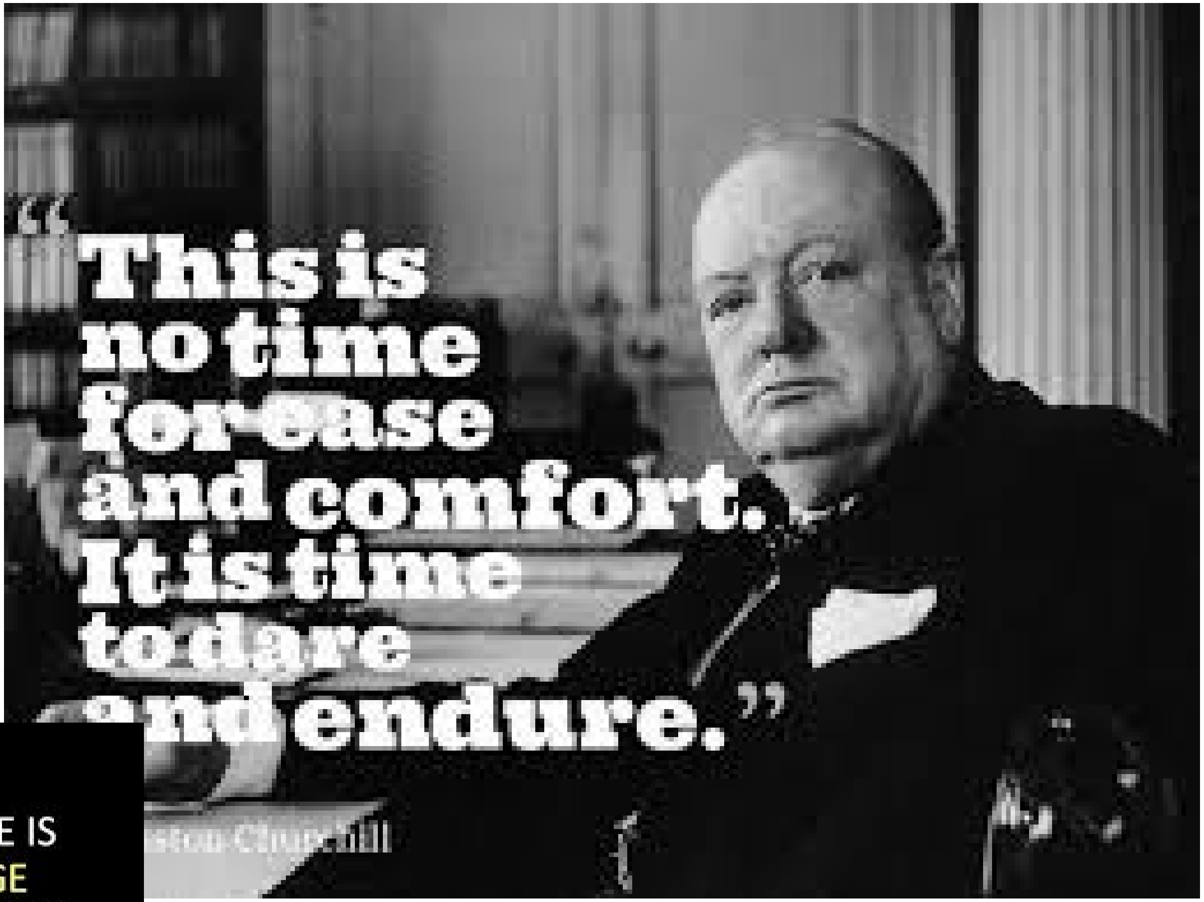
- Yonsei University - YSU (Hong et al. 2006)
- Asymmetric Convective Model - ACM2 (Pleim, 2007a)
- Mellor-Yamada-Janjic - MYJ (Janjic, 1990)
- Mellor-Yamada Nakanishi and Niino Level 2.5 – MYNN (Nakanishi and Niino, 2006)
- Bougeault and Lacarrere - BouLac (Bougeault and Lacarrere, 1989)
- Quasi-Normal Scale Elimination - QNSE (Sukoriansky et al. 2005)

YSU Modified $K_m = 0.34 Ri_g^{-0.02}\, \sigma_w^2 \left| d\vec{V} / dz \right|^{-1}$ $K_h = 0.08 Ri_g^{-0.49}\, \sigma_w^2 \left| d\vec{V} / dz \right|^{-1}$

Vertical profile comparison between different PBL schemes and tethered-balloon soundings at SB site, IOP 8



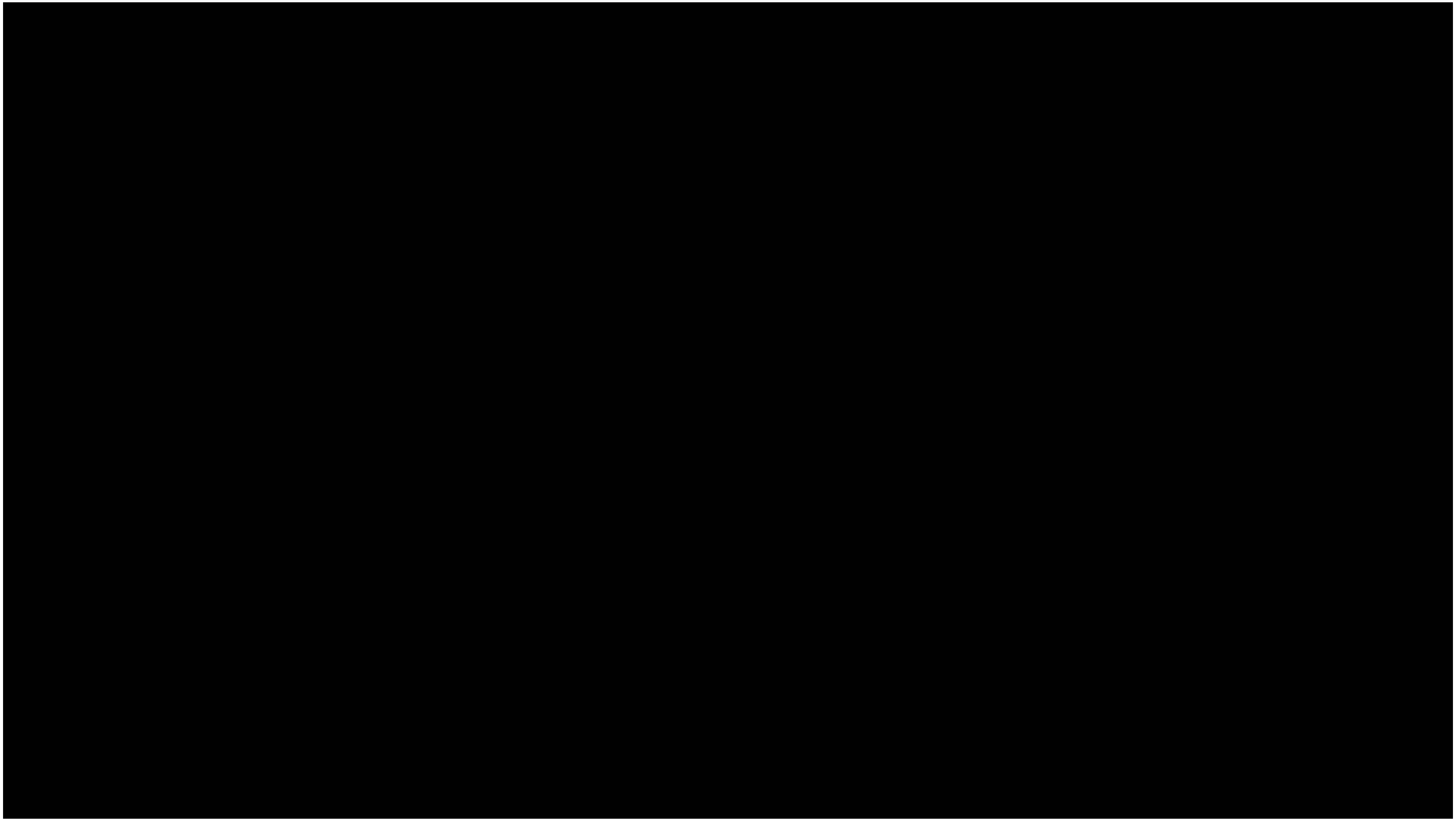

KEEP
CALM
AND
CARRY
ON


"This is no time for ease and comfort. It is time to dare and endure."


TO IMPROVE IS
TO CHANGE
TO BE PERFECT IS
TO CHANGE OFTEN
Winston Churchill
celebquote.com

Thank you

May 30th *(Stratified):* Movie



Movie 3 : Full flow visualization movie.