Sea-salt Aerosol Fluxes from Breaking Waves and Bursting Bubbles: Microphysical, Optical and Spatial Evolution in a Natural Wind-Tunnel

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ONR

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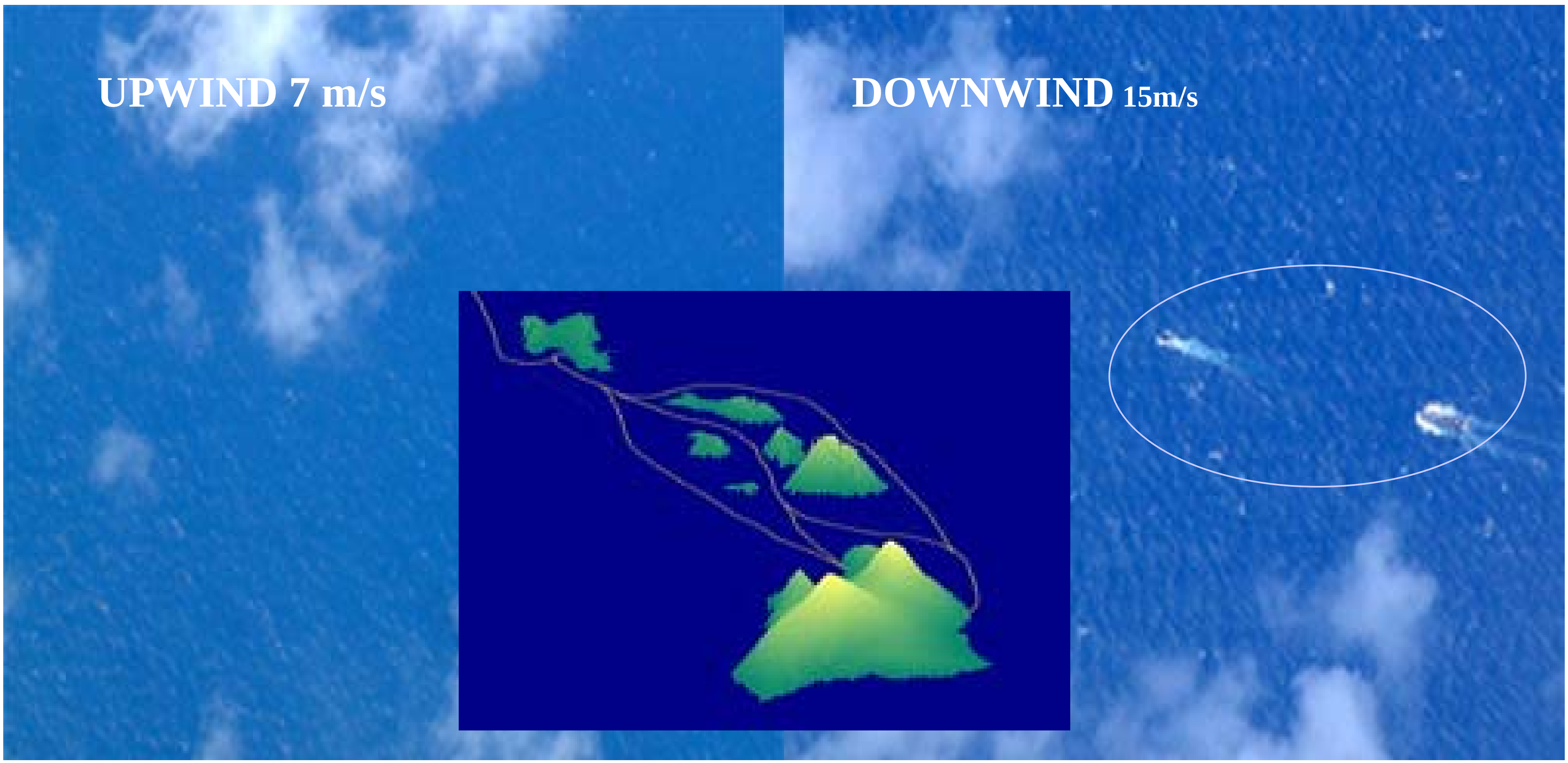

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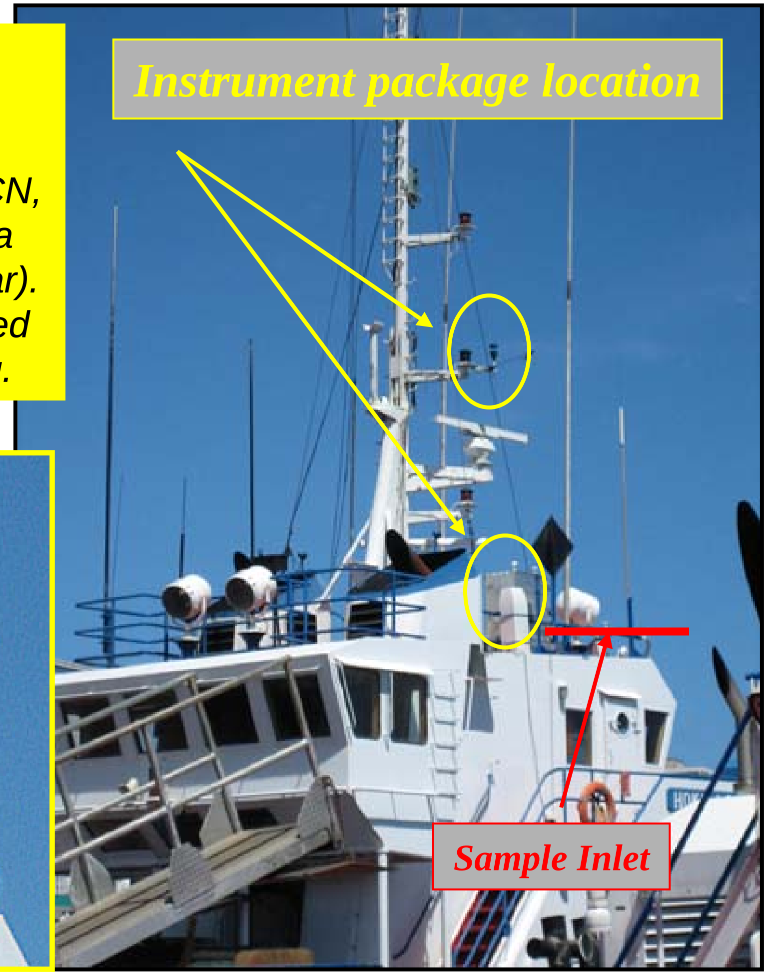
We mount equipment on Young Brothers barge for their weekly channel route.

This provides a climatology of "wind tunnel" aerosol under different wind regimes for comparison with MM5 model and our periodic aircraft overflights.

Instrumentation package with total and sub-μm nephelometers, APS (particle size), Hot/cold CN, GPS, meteorological data and ceilometer (mini- lidar). Instruments were mounted atop the bridge of the tug.



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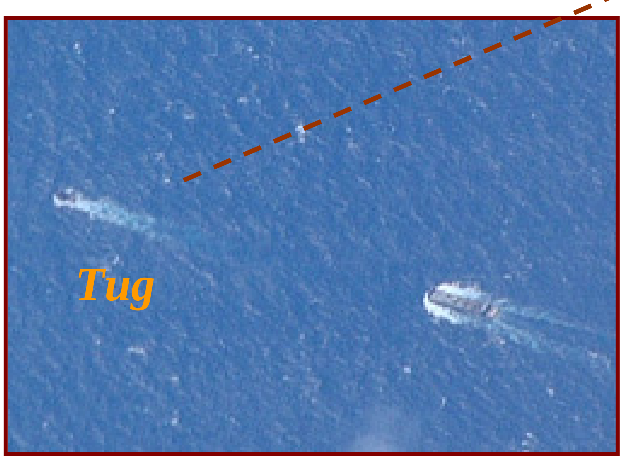
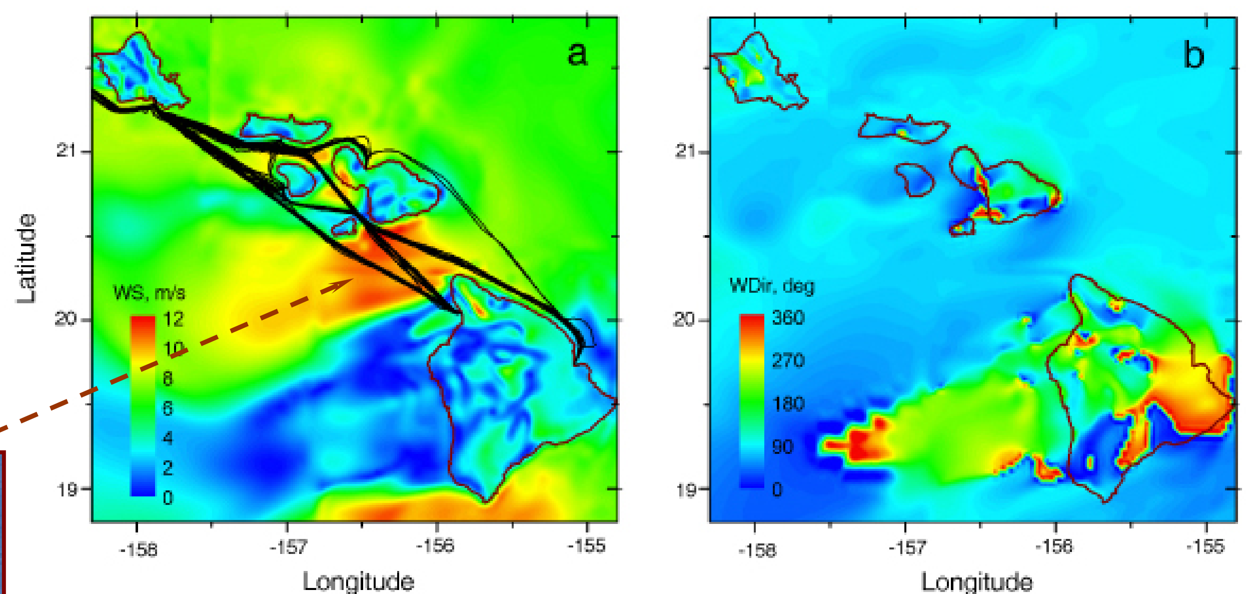
The package was deployed in March of 2005. We have collected five month of the aerosol data including 54 Alenuihaha channel crossings.
We have confirmed that, due to island mountain topography, the induced accelerated trade-wind flow in the Alenuihaha channel provides an ideal natural "wind-tunnel" for the study of sea-salt aerosol production, mixing processes, particle fluxes and related optical effects.

The channel is aligned with the trade winds and provides about 100km of fetch. The winds are focused by mountains on Maui and Hawaii that can nearly double wind speeds over those of the open-ocean, as seen in the MM5 model. This enhances the waves and sea-salt production.





MM5 wind speed (a) and wind direction (b) around the Hawaiian Islands (color-coded) with tugboat route (black line) between Oahu and the Big Island. Note very enhanced winds in main Alenuihaha channel

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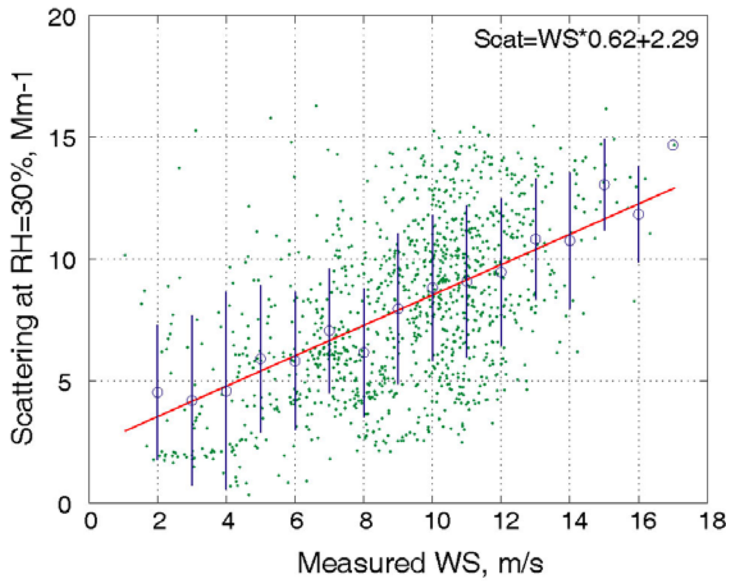
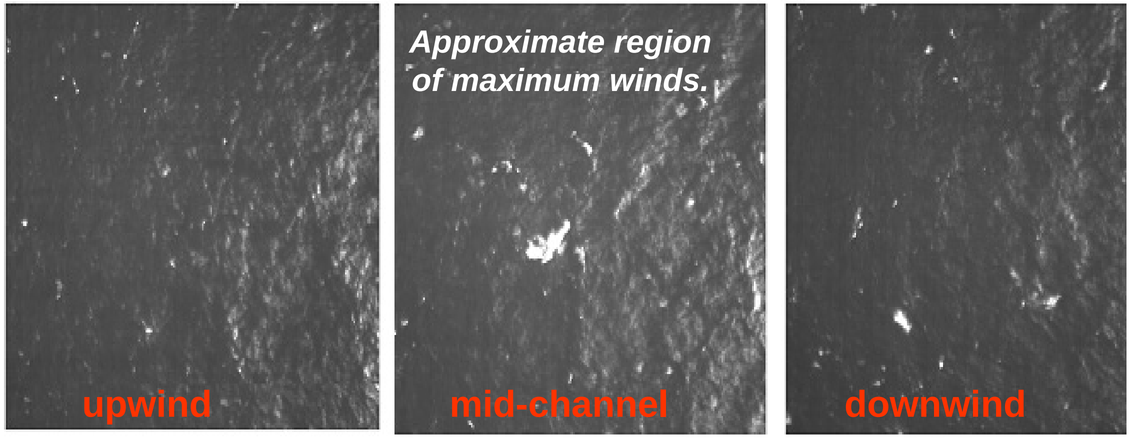
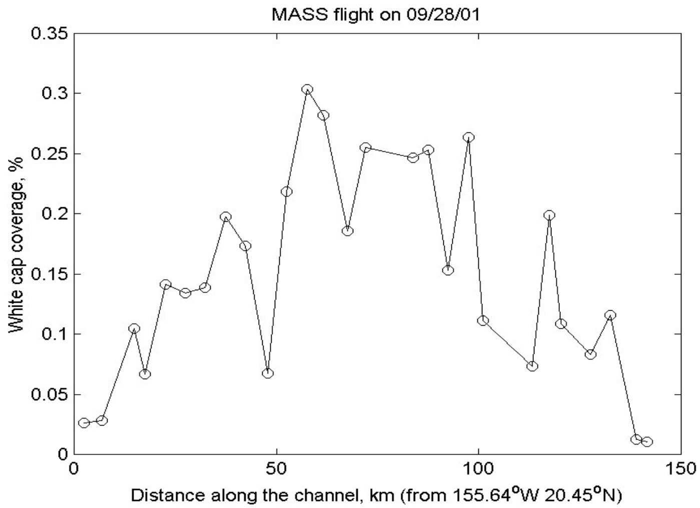
As expected, the light scattering and other aerosol parameters measured within the channel are coupled to variations in wind speed.

Relationship between average light scattering at 30% RH for binned wind speed (blue circles – mean values, blue bars –standard deviations) with green dots showing the raw data. Red line – linear regression of the light scattering data.



Fractional whitecap coverage as a function of location measured within the channel is based on thousands of images. Note the gradient in whitecap coverage that results from the wind acceleration [Terrill and Melville].





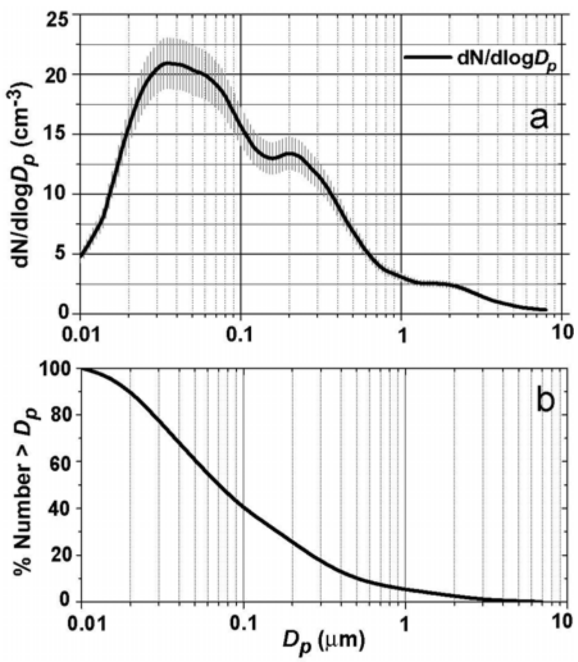
Our prior ONR results below are now in press in JGR where we used our coastal Breaking Wave measurements to establish a new sea-salt flux down to sizes as small as 10 nm

An ultrafine sea-salt flux from breaking waves: Implications for CCN in the remote marine atmosphere; A. Clarke, S. Owens and J. Zhou

Question:

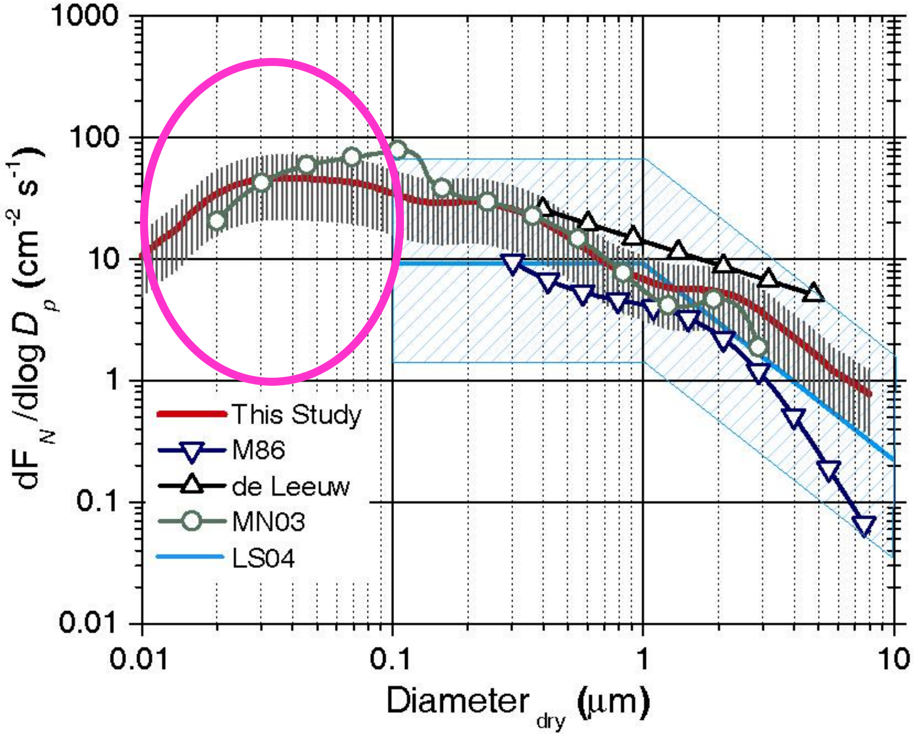
Can we demonstrate evidence of these small sea-salt over the open-ocean?

Mean SSA Size-distribution below was scaled to get flux for bubble coverage as function of wind speed (Monohan, 1986) to get new open-ocean Sea-Salt Aerosol flux @ 9 m/s.



Cumulative Number

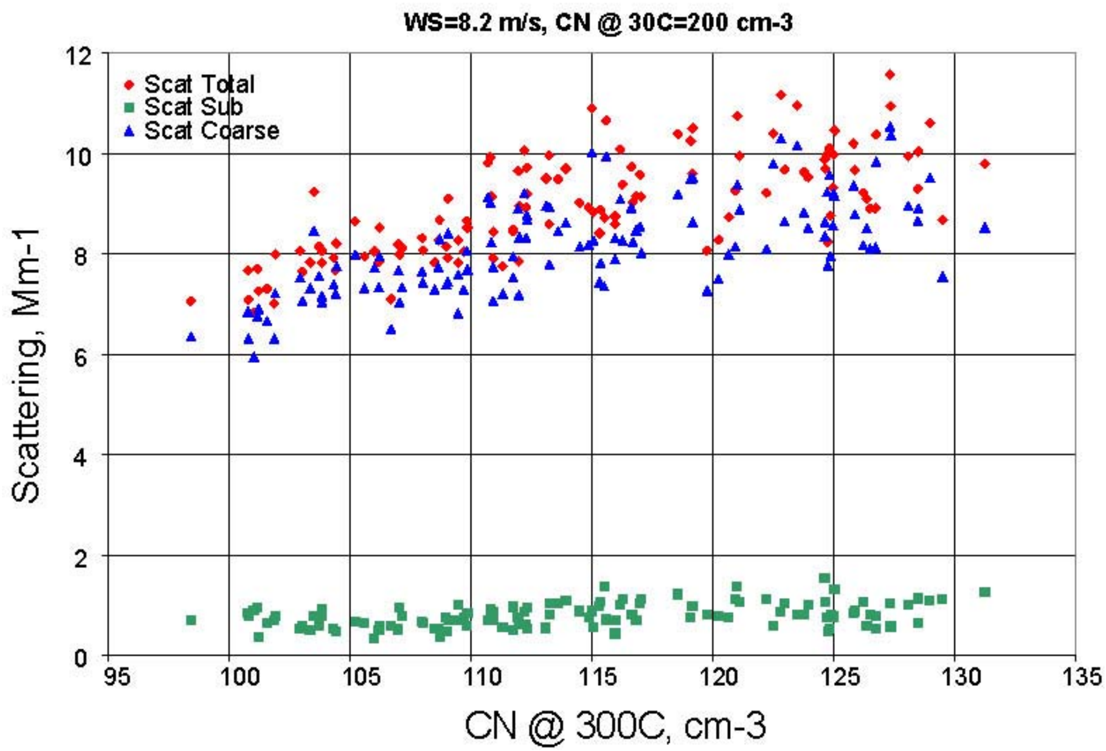
Flux dF/dlogDp = f (U_{10} , Dp) for 9 m/s



Our "wind tunnel" data demonstrate production of small sea-salt is effective over the open ocean.

Our coastal observations demonstrated that breaking waves produced large numbers of small sea-salt (Dp< 100nm) identified as refractory condensation nuclei (CN) that were highly correlated with the few large ones that dominate the light scattering (see below).

Figure below shows a similar high correlation of increased light scattering with increasing refractory CN measured under increasing wind in the open waters of the Alenuihaha Channel.

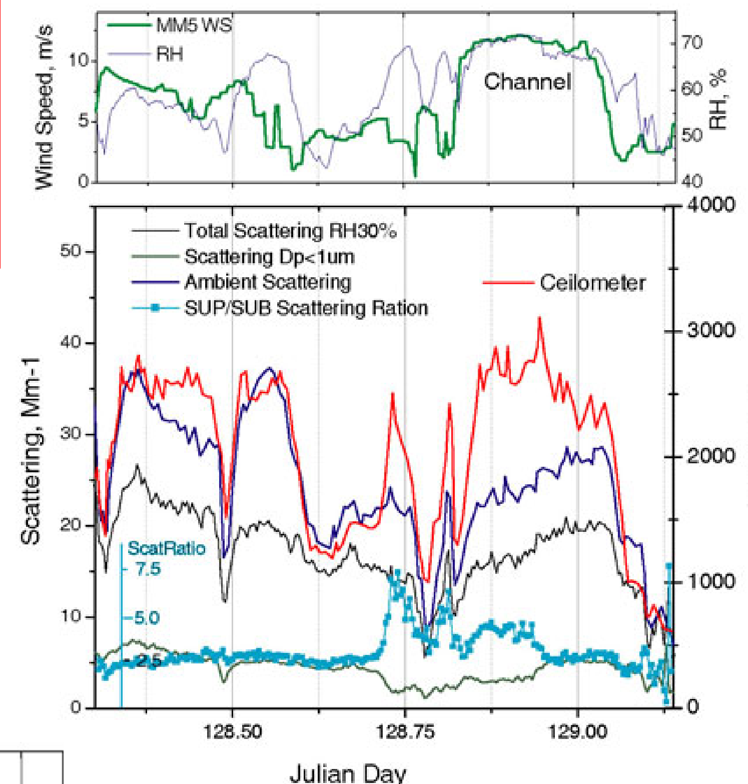


A plot of total (red), coarse (blue) and submicron (green) scattering showing dominance of coarse sea-salt and its relation to refractory CN at 300C.

About 30 refractory CN correspond to a change in scattering of about 4 Mm^{-1} here. The coastal breaking waves showed that 30 refractory CN showed a change in scattering near 15 Mm^{-1}.

This is to be expected as the coastal data fresh particle age was about 5 sec while the open ocean distributions will be much will be much more aged and relatively depleted in coarse sizes dominating scatter but having little influence on number.

The wind speed enhancement and corresponding increase in aerosol concentration and light scattering are evident in our near-surface lidar data and light scattering data taken from aboard ship along the transect lines.

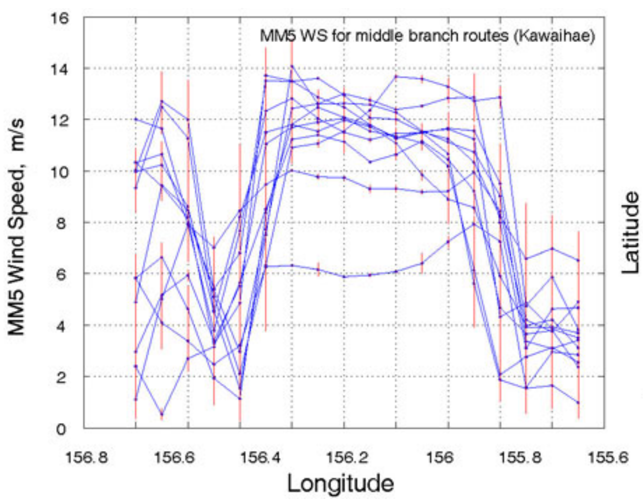


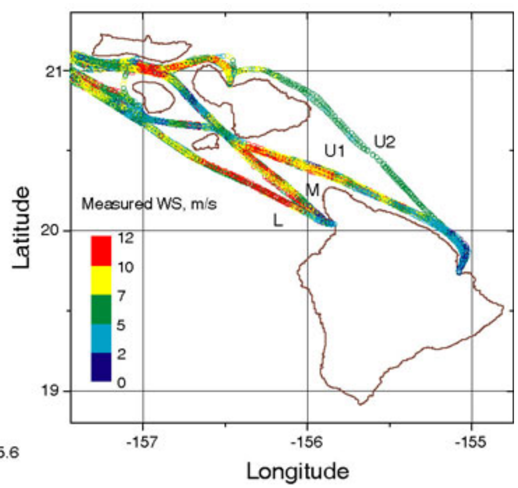
(top) MM5 winds along tugboat route showing the enhancement in channel.

(bottom) Ceilometer lidar backscatter for the near-surface 0-30m range compared with in-situ (blue) and "dry" total (black) and submicrometer (green) scattering data. ***Super*** ***μm sea-salt dominates scattering and backscattering data*** *(ScatRatio, cyan).*

Other Channels

Alinuihaha Channel

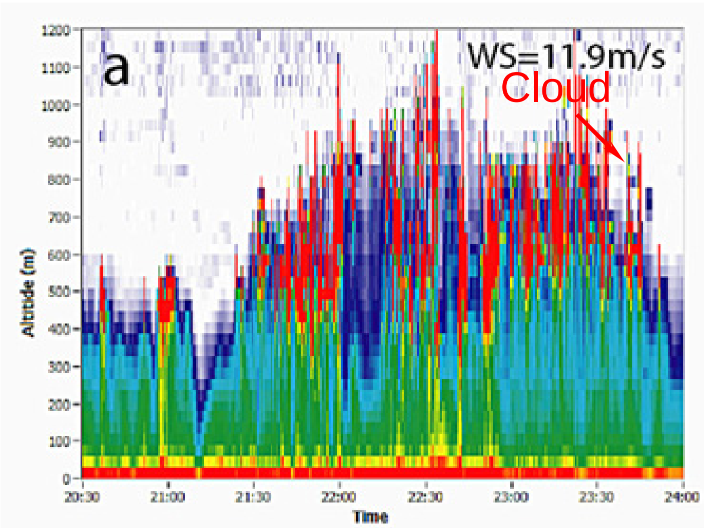


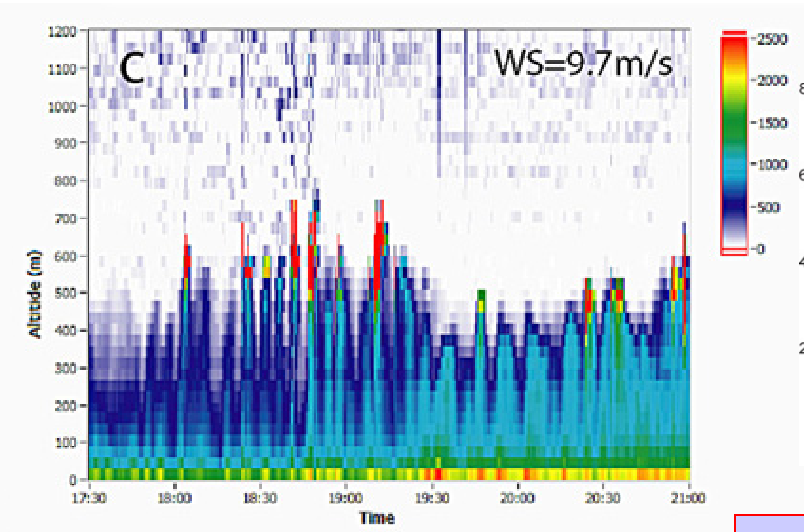


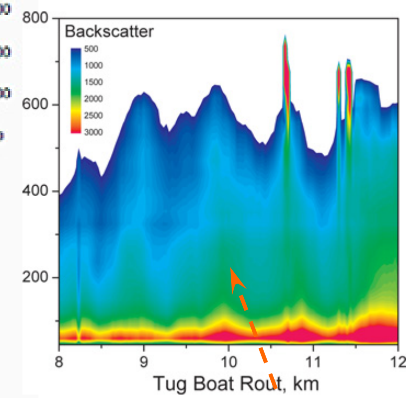
MM5 wind speed for middle branch (M) routes in the channel (left) and tugboat routes color coded with wind speed (right) for lower (L), middle (M) and two upper (U1&U2) branches.

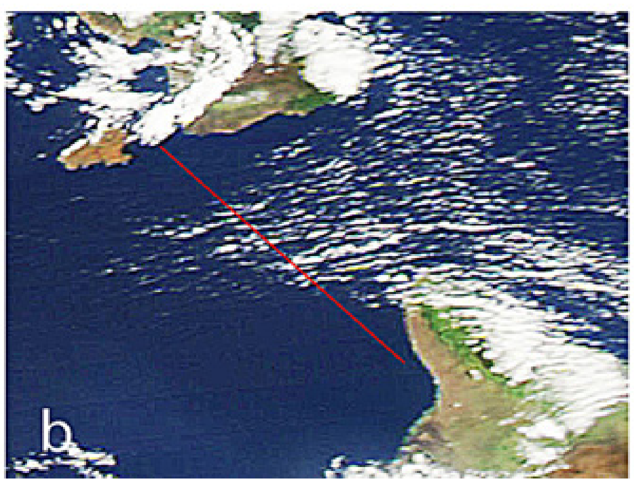
Enhanced backscatter in Boundary Layer: Rolls or Large Organized Structures (LOS)

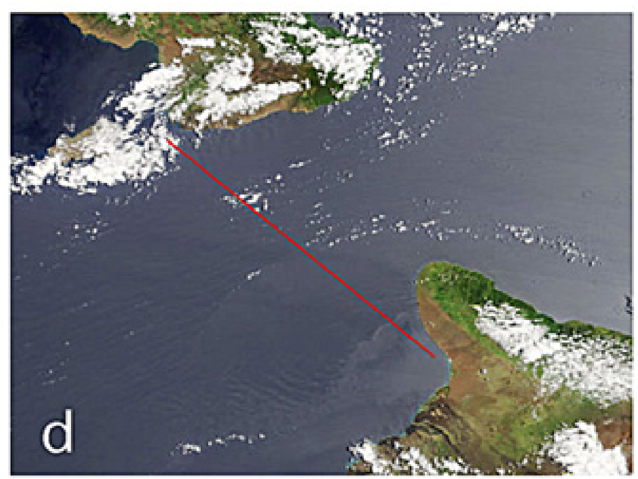
Fingers of enhanced backscatter (a) under "cloud streets" in corresponding MODIS image (b) appear to reflect both increased dry aerosol and increased RH present in updraft under cloud. Lower backscatter "tongues" between clouds may reflect drier air and less aerosol (entrainment?).







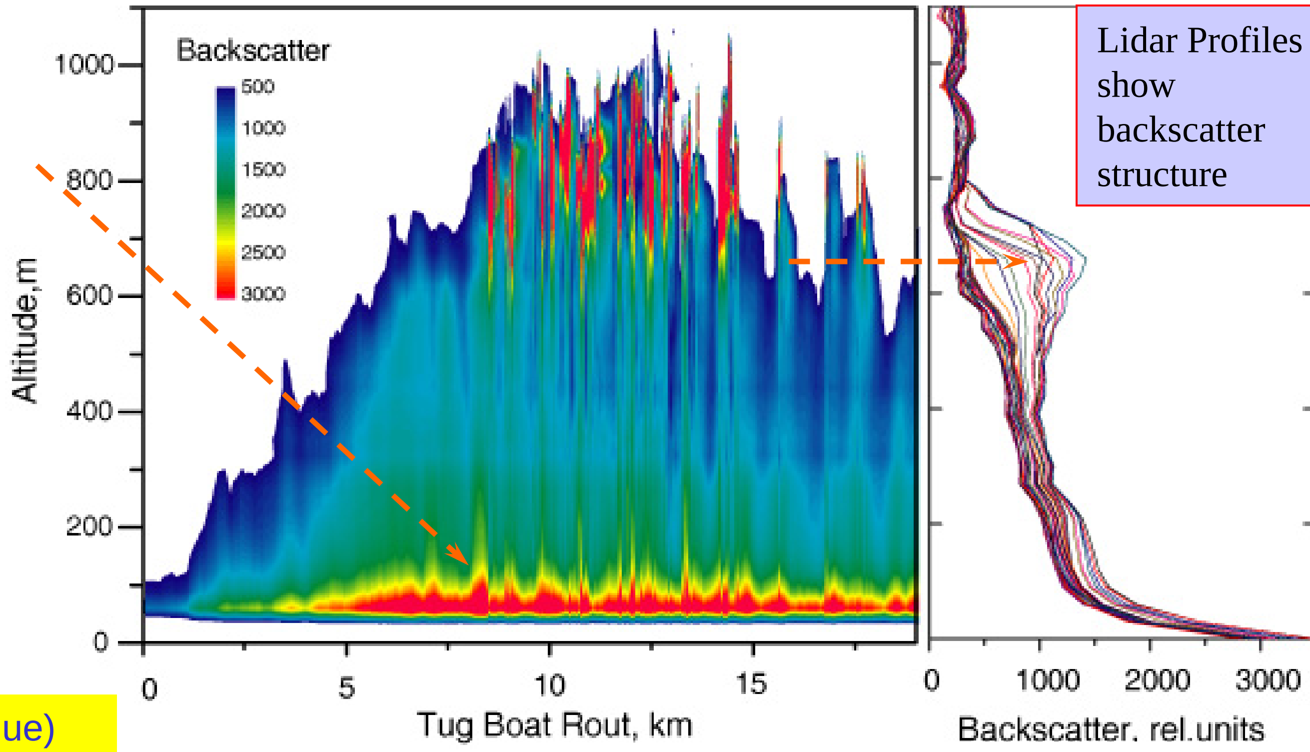




LOS are evident in fingers of enhanced backscatter roughly 1-2 km wide aligned along wind and channel axis whether or not clouds are detected aloft. Implies related structure for both extinction and visibility fields.

Wind related enhancement in aerosol concentrations and scattering reveal more detailed structure when examined as individual cross-wind transects.

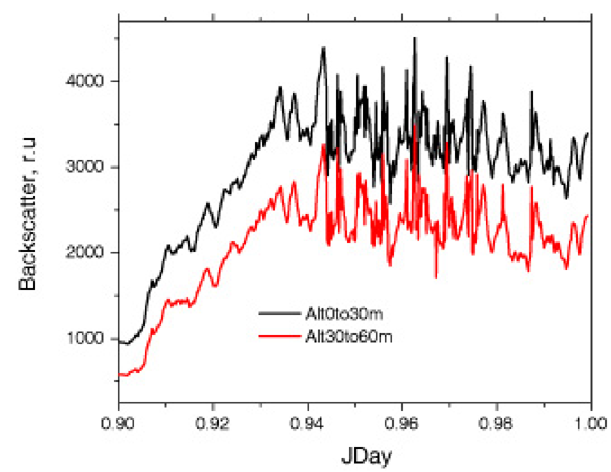
NEW MIXING FINDING
Boundary Layer Rolls with increased aerosol backscatter have scales about 1-2 km and extend to cloud layer.
Hence, MBL mixing may be several times more rapid than conventional turbulent mixing and requires new measurement strategy.
Implies enhanced fluxes of aerosol, water vapor, momentum etc.

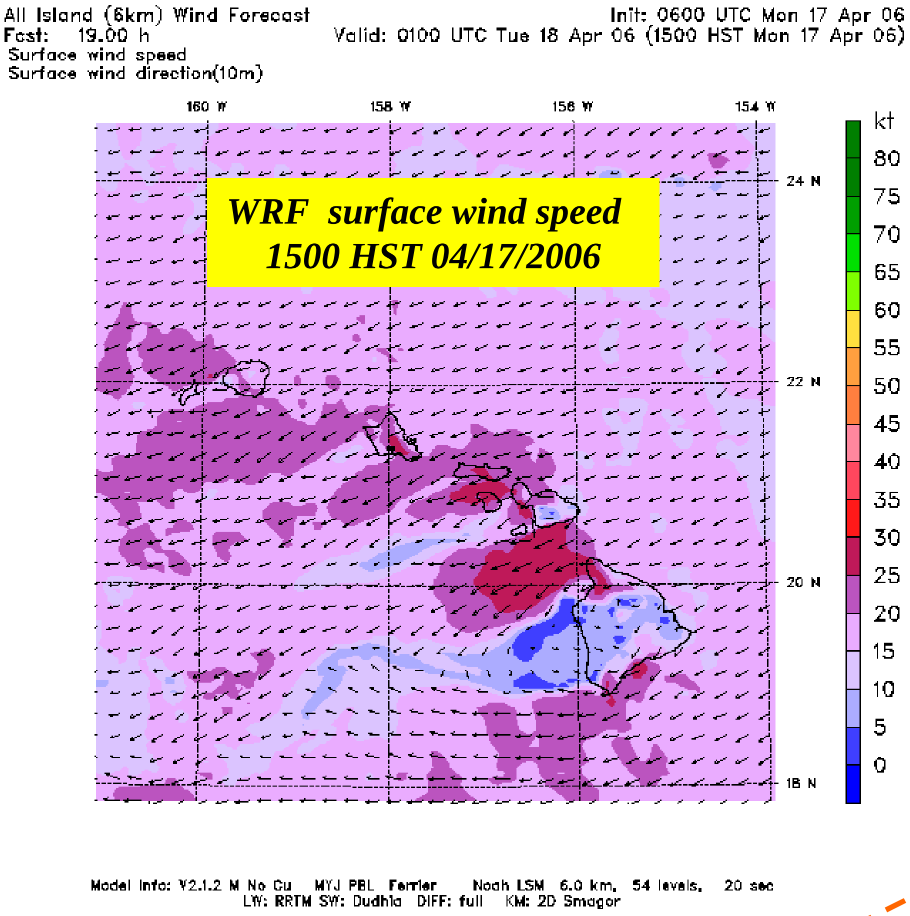


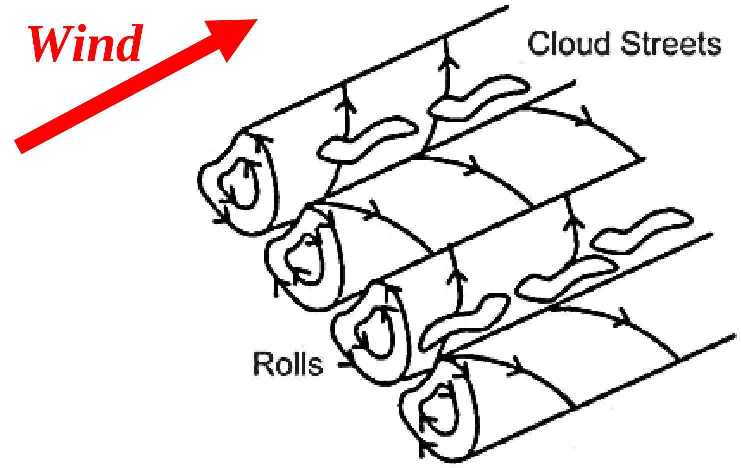
Lidar Profiles show backscatter structure

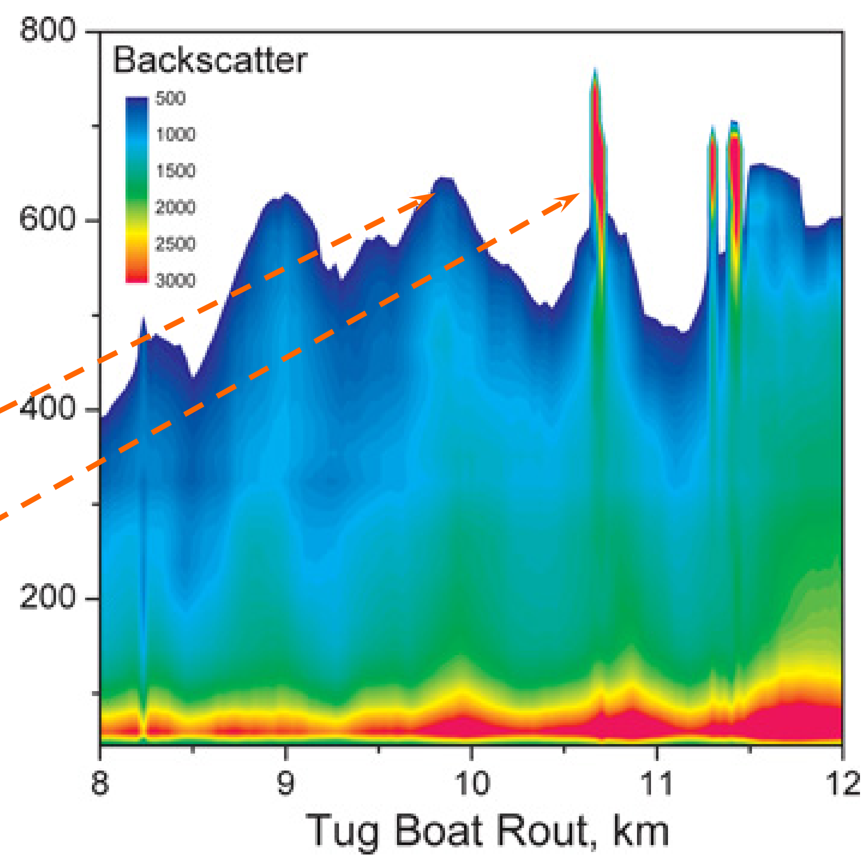
The higher (red) and lower (blue) backscatter tongues are related to rising air with higher relative humidity (RH) and subsiding air with lower RH (possibly in part due to entrained dry air). However, near-surface dry coarse aerosol scattering is also enhanced in the rising fingers indicating both sea-salt aerosol and RH are higher in these rising regions.

Coherence in backscatter of 0-30m range (black) with 60-90m range (red). Coherence often persists throughout boundary layer in regions with and without clouds.



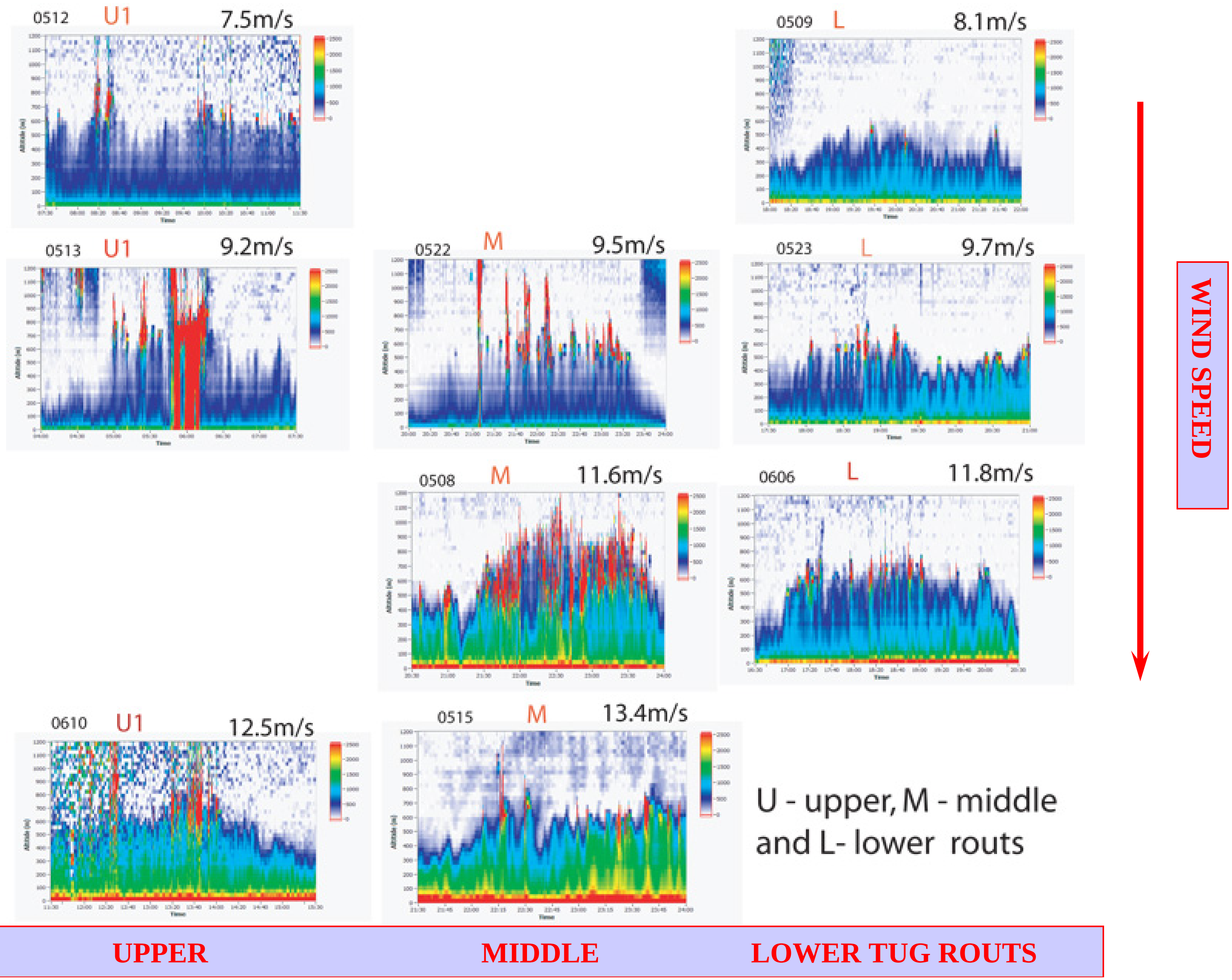






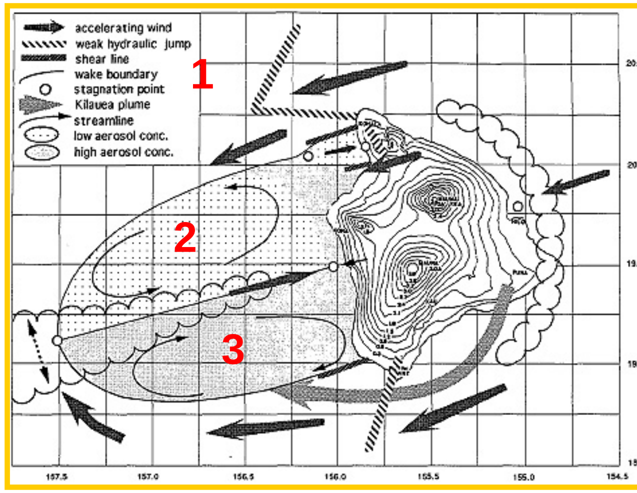
LOS are present whether or not clouds are detected aloft. This suggests related structure for both extinction and visibility fields.

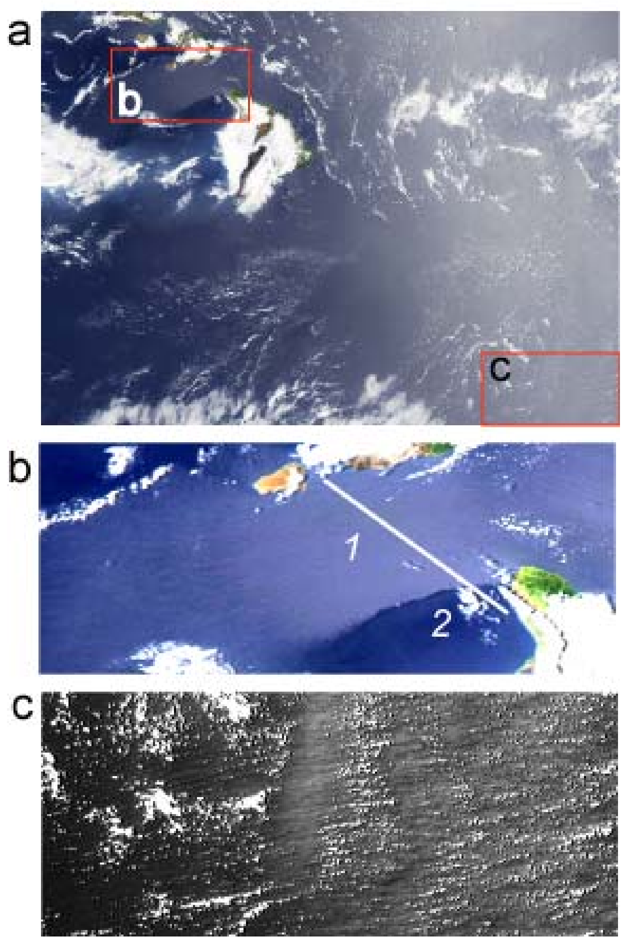
Our results suggest that the large organized structures (LOS) are a common feature in channel and sea salt production and vertical mixing increases with wind speed



LOS are a common feature of the Hawaii environment and are evident in most of our data and also MODIS images

Schematic of flows and wake around Big Island
Region 1 : Accelerated channel flow
Region 2 : Calmer north wake eddy air - sea-salt dominant
Region 3: Calmer south wake eddy – volcanic sulfate dominant



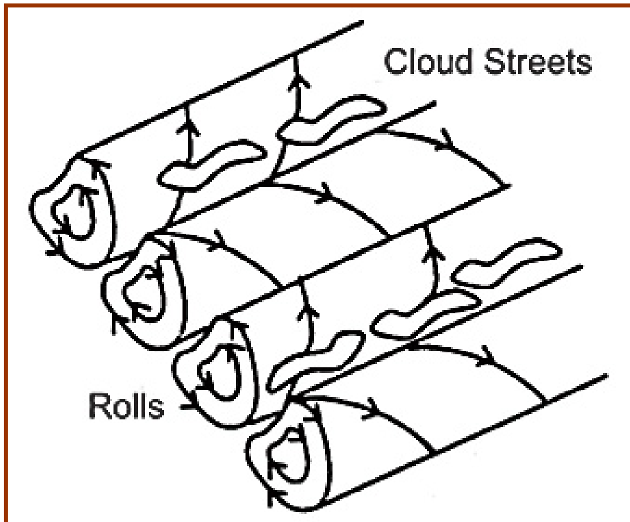


MODIS image of region around the Big Island (a) with enlarged panels (b) and (c) that illustrate combined influences of LOS, variations in AOD and surface roughness. LOS are common both in channel and around the islands.

(b) Though not easy to see in channel, LOS were observed in the clear air without clouds. Sunglint enhances difference between rough (1) and calm (2) regions1

(c) Also from the same image: LOS are evident in MODIS AOD both in cloud streets and adjacent clear areas.

LOS with cloud streets organized along wind



Ongoing Issues

- **What controls the development and the horizontal and vertical scales of LOS in the channel ?**

  (eg. wind profiles, shear, entrainment etc. *Morrison, Businger et al, JAS 2005)*

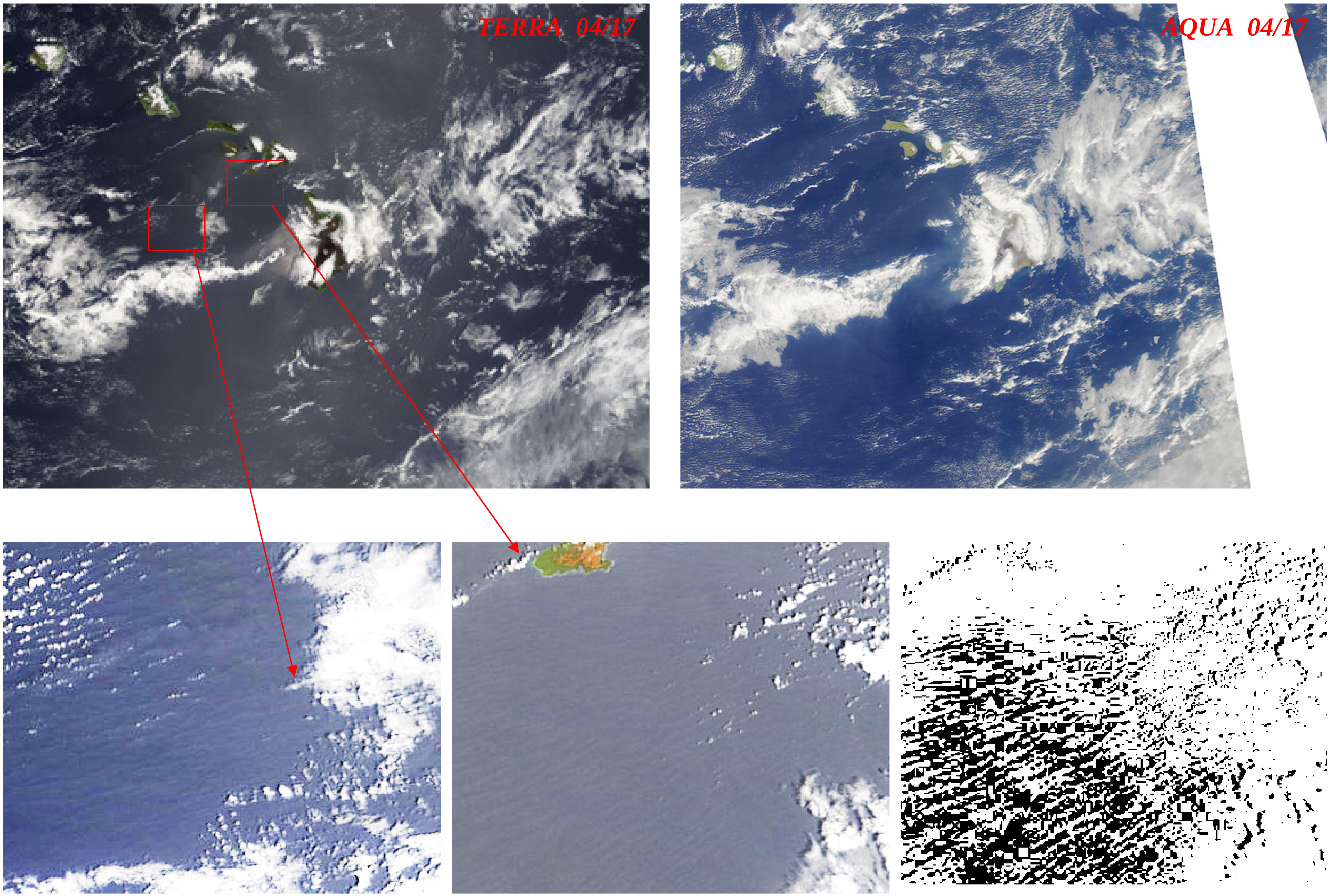
- **To what extent are the backscatter differences in updraft and downdraft caused by RH, aerosol and entrainment?**

- **Can along-wind and across-wind extinction differences be characterized and predicted for LOS.**

- **What are implications of roll structure for extinction measurements or remote sensing.**

- **To what extent do models of turbulent fluxes (sea-salt aerosol, water vapor, momentum etc.) need to be modified to include LOS fluxes.**

  {collaboration with Dr. S. Businger, UH Meteorology}



Rolls are present whether or not clouds are detected aloft

Photoshop threshold enhancement

Example of enhanced Aerosol Optical Depth due to Sulfate from Kiluaea Volcano

Largest point SO2 source in world