
Appendix

Liquid Wall Science in other
Scientific Pursuits and Applications

Liquid Wall Science is important in many scientific pursuits and applications

- **Liquid Jet and Film Stability and Dynamics:** fuel injection, combustion processes, water jet cutting, ink jet printers, continuous rod/sheet/ribbon/sphere casting, flood/jet soldering, ocean waves, hull design, ocean/river hydraulic engineering, surfing, liquid walls for fusion reactors
- **Liquid MHD / free surface interactions:** melt/mold stirring and heating, liquid jet/flow control and shaping, crystal growth, astrophysical phenomena, liquid metal walls for particle accelerators and fusion reactors
- **Liquid MHD / turbulence interactions:** microstructure control in casting, boundary layer control, astrophysical dynamos and plasmas, liquid walls for particle accelerators and fusion reactors
- **Free surface heat and mass transfer:** oceanography, meteorology, global climate change, wetted-wall absorbers/chemical reactor, condensers, vertical tube evaporator, film cooling of turbine blades, impurity control in casting, liquid walls for particle accelerators and fusion reactors

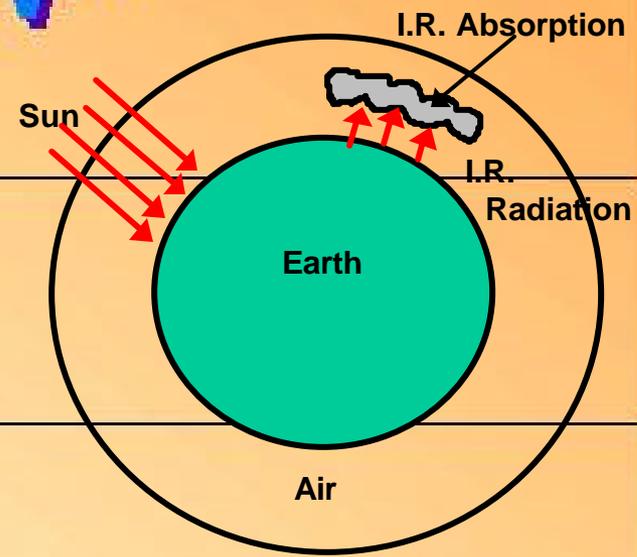
What is Global Warming?

Increasing Green House Gases:
Humidity, CO_2 , Methane, NO_x ,
Sox etc.

Infra Red Absorption into
Green House Gases and
on the Earth surface

Preserving Heat in the Air

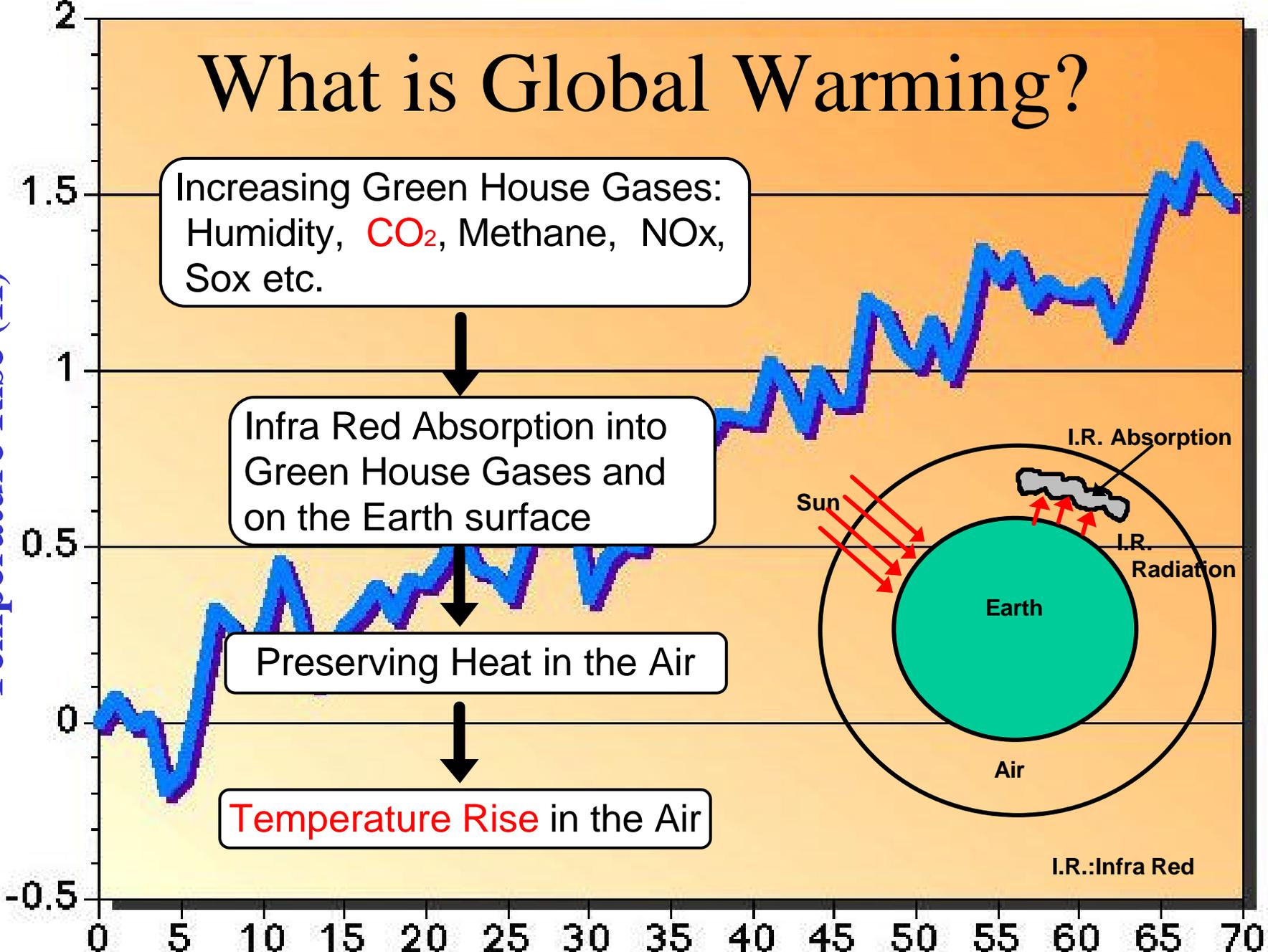
Temperature Rise in the Air



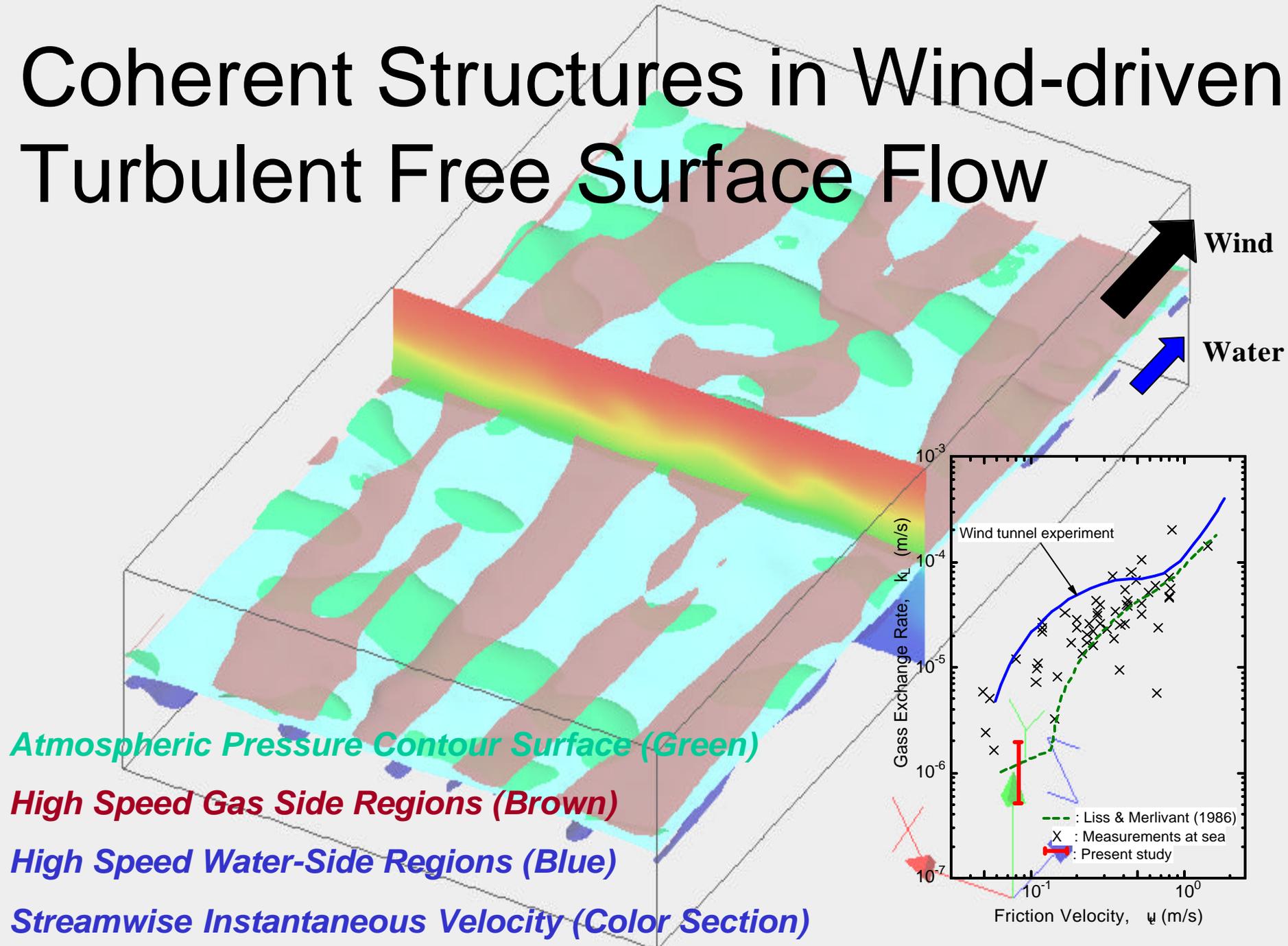
I.R.:Infra Red

Temperature Rise (K)

Year



Coherent Structures in Wind-driven Turbulent Free Surface Flow



Free surface mass transport is affecting CO₂ concentrations

Missing Sink Problem over past 30 years

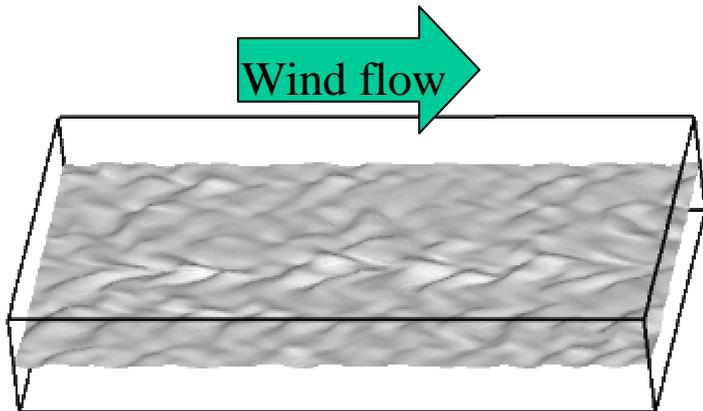
Measured atmospheric CO₂ increase (34 ppm)

- Spent Fossil Fuel emissions (61 ppm)

= **Missing Sink(-27 ppm)**



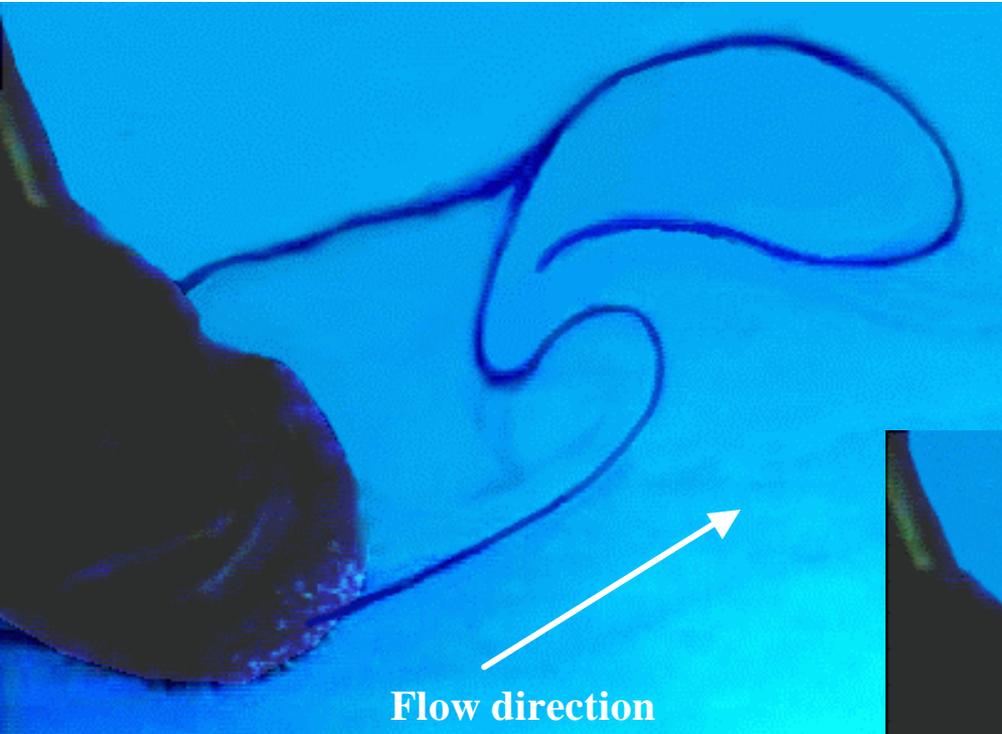
Turbulent Heat and Mass transfer across Free Surface ?



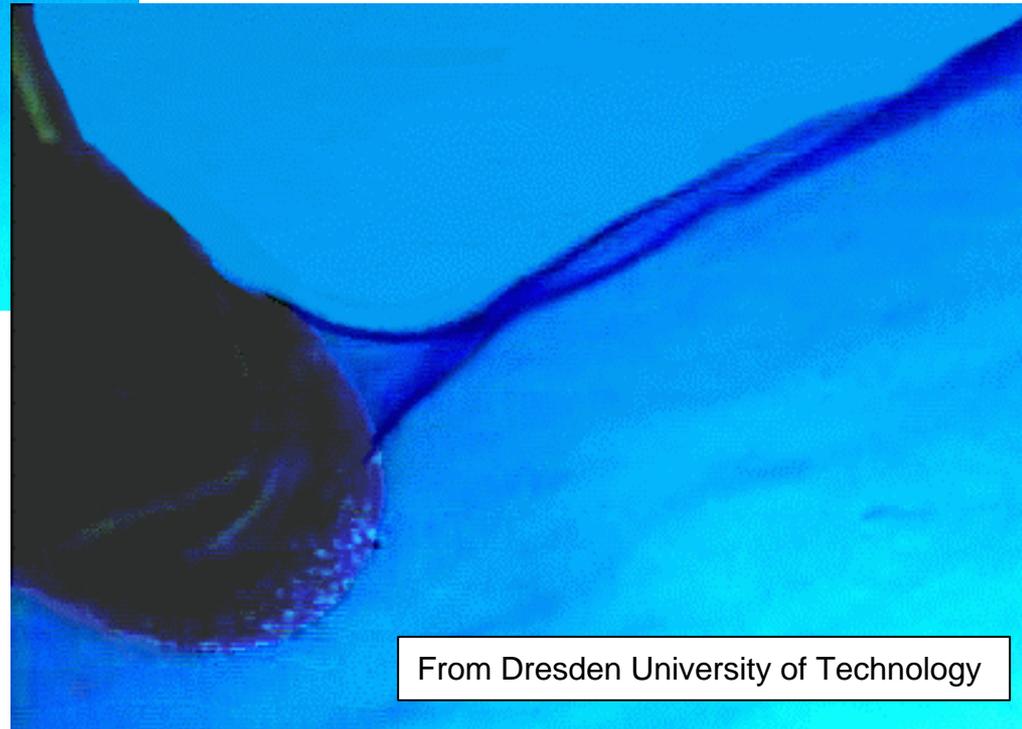
CO₂ absorption at the turbulent free-surface deformed by the shear wind, by means of direct numerical solution procedure for a coupled gas-liquid flow

*Free surface contour -
wind-driven calculation*

MHD interactions can change the nature of turbulence - providing a lever of CONTROL



- Applied Lorentz forces act mainly in the fluid regions near the walls where they can prevent flow separation or reduce friction drag by changing the flow structure.
- Because heat and mass transfer rely strongly on the flow structure, they can in turn be controlled in such fashion.



Experimental control of flow separation by a magnetic field:

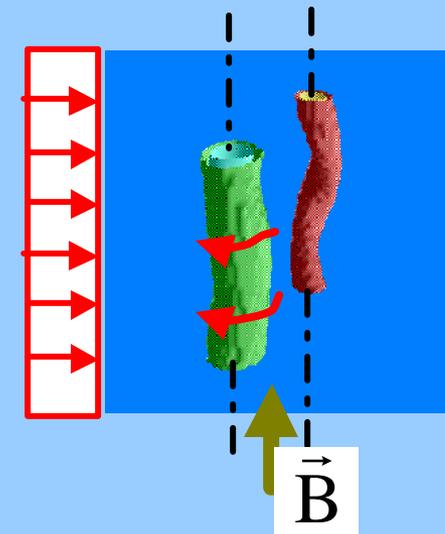
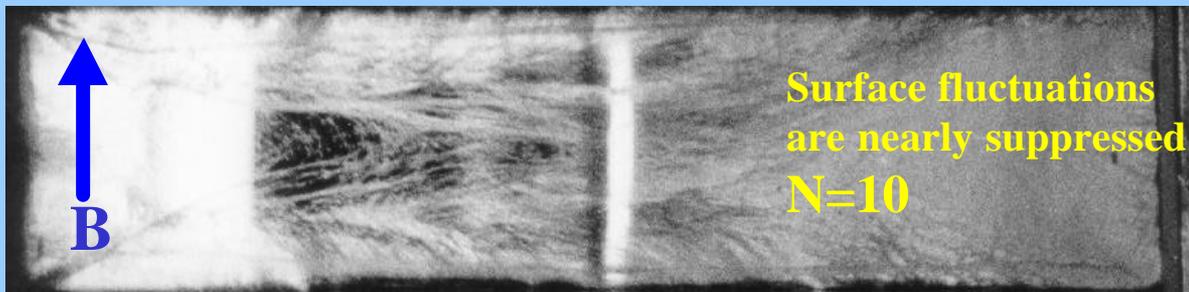
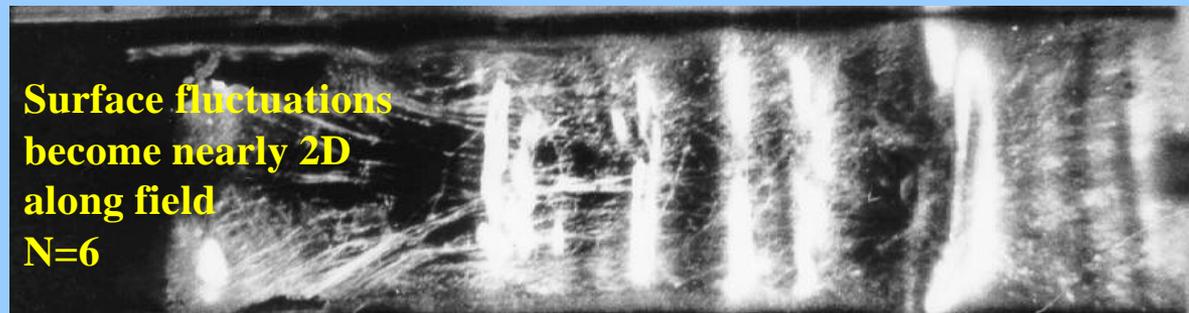
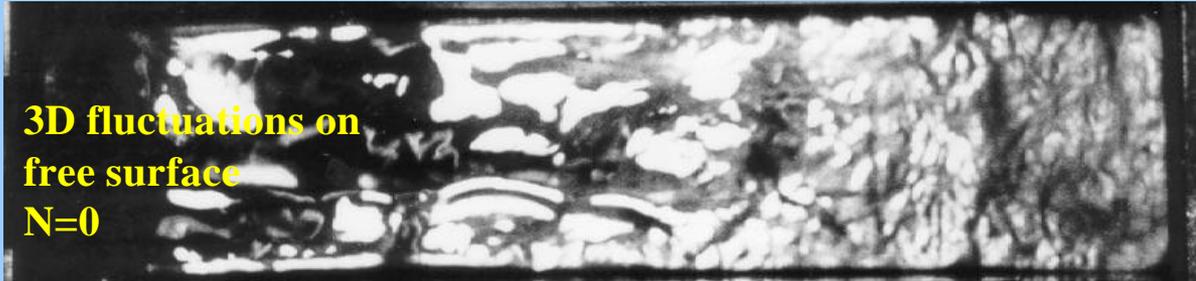
fully developed von Kármán vortex street without a magnetic field (upper)

with a magnetic field (right)

From Dresden University of Technology

NEW PHENOMENA IN LM-MHD FLOW

2D Turbulence



SOME PROPERTIES OF 2-D MHD TURBULENCE:

- Inverse energy cascade;
- Large energy containing vortices;
- Low Joule and Viscous dissipation;
- Insignificant effect on the hydraulic drag.

2-D turbulence could be very useful as a mean of intensifying heat transfer.

Some Common Aspects between Global Warming and Fusion Science Thermofluid Research

Similar Phenomena

- High Pr flow with radiation heating at free surface from plasma
- High Sc flow with CO₂ absorption at free surface of sea

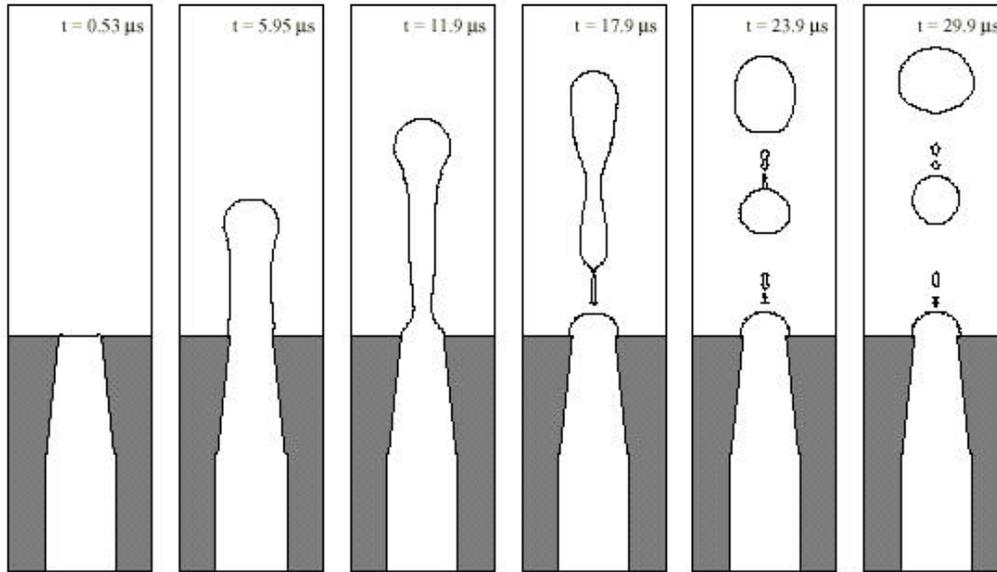
Similar Flow Characteristics

- Re is high, both have the similar turbulence characteristics.
- MHD (fusion) and Coriolis (global warming) forces can influence the average velocity

Heat and Mass Transfer Similarity

- High Pr, very low thermal diffusivity → very thin thermal boundary layer → large temperature gradient at interface
- High Sc, very low molecular diffusivity → very thin concentration boundary layer → large concentration gradient at interface

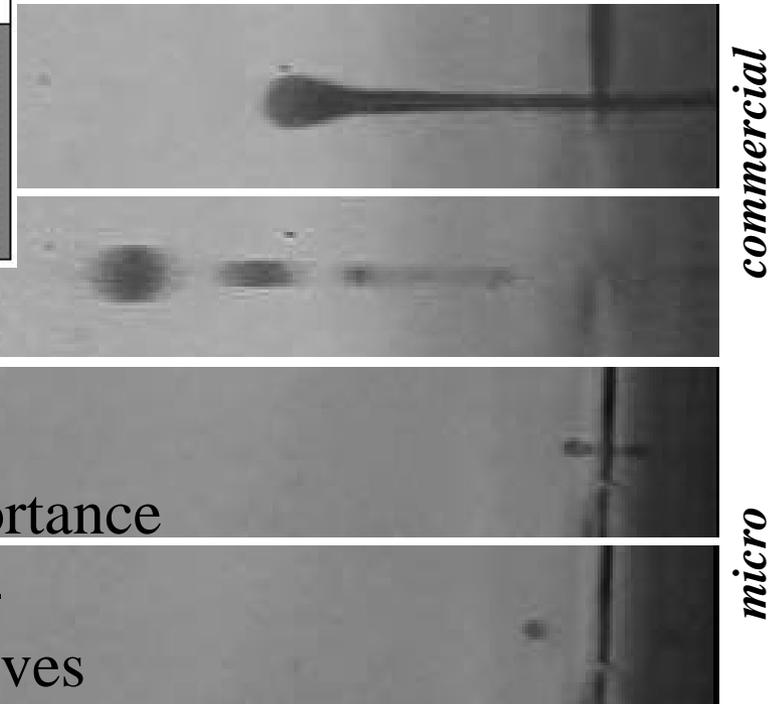
Liquid Jet Stability and Breakup



Inkjet Printer quality is hampered by formation of “satellite” droplets

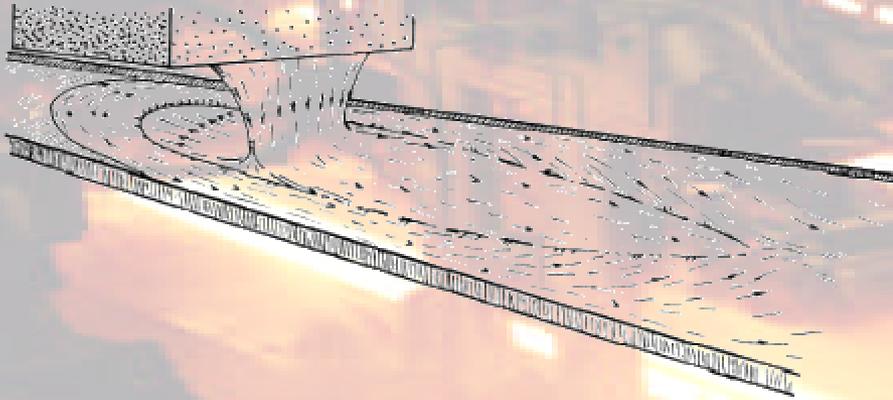
Simulation of commercial inkjet by Rider, Kothe, et al. - LANL

Micro-injector increases relative importance of surface tension by decreasing size - eliminates satellite droplets and improves precision

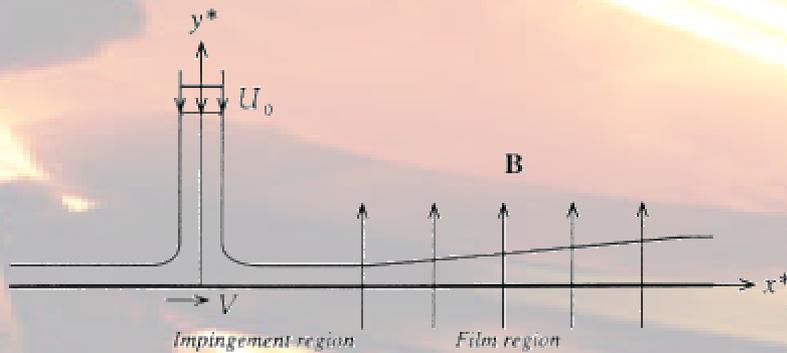


Data from Ho - UCLA

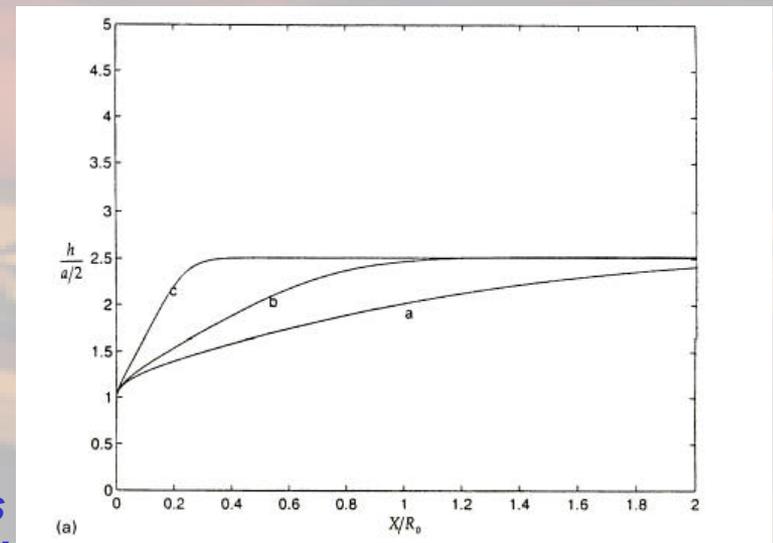
Vertical B field effects on Liquid Metal Film Flows



Continuous sheet casting can produce smooth free surfaces and film thickness control via MHD forces



**Film thickness profiles for various Hartmann Numbers
Simulation by Lofgren, et al.**



21st Century Frontiers

Moving Beyond “Prediction” of Fluid Physics To “Control” of Fluid Dynamics

- With the rapid advances in teraflop computers, fluid dynamicists are increasingly able to move beyond predicting the effects of fluid behavior to actually controlling them; **with enormous benefits to mankind!**

Examples

- **Reduction in the Drag of Aircraft**

The surface of a wing would be moved slightly in response to fluctuations in the turbulence of the fluid flowing over it. The wings surface would have millions of embedded sensors and actuators that respond to fluctuations in the fluids, P, V as to control eddies and turbulence drag. DNS shows scientific feasibility and MEMS can fabricate integrated circuits with the necessary microsensors, control logic and actuators

- **Fusion Liquid Walls**

Control of “free surface-turbulence-MHD” interactions to achieve fast interfacial transport and “guided motion” in complex geometries (“smart-liquids”)

- **Nano Fluidics: Pathway to Bio-Technologies**

Appropriately controlled fluid molecules moving through nano/micro passages can efficiently manipulate the evolution of the embedded macro DNA molecules or affect the physiology of cells through gene expression.