# Physical Meteorology

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# Climate Change ?????????????????

**Tourists run through a swarm of pink locusts near Corralejo, on the Canary Island of Fuerteventura, yesterday. Environmental experts estimate that some 100 million of the insects arrived in the Canaries from North Africa at the weekend.**

**(*Irish Times*, Tue Nov 30, 2004)**

# Part 5:

# The Theory of the

# Atmospheric Boundary Layer

# §5.1. Introduction to Turbulent Flow

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**This *no-slip boundary condition* continually leads to the development of turbulent eddies.**

**The eddies have temporal and spatial scales much smaller than can be resolved by observing network or by atmospheric computer models.**

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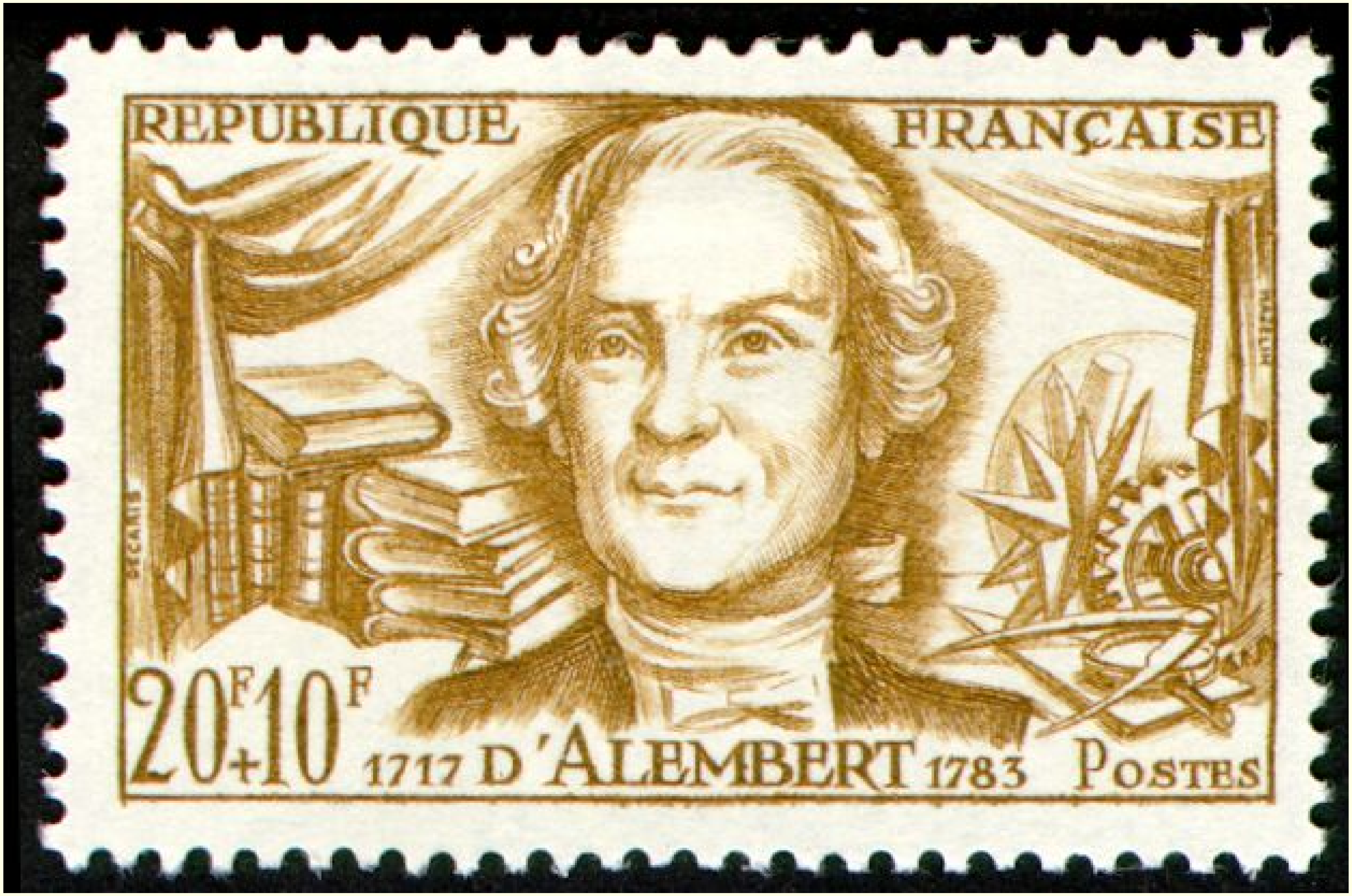
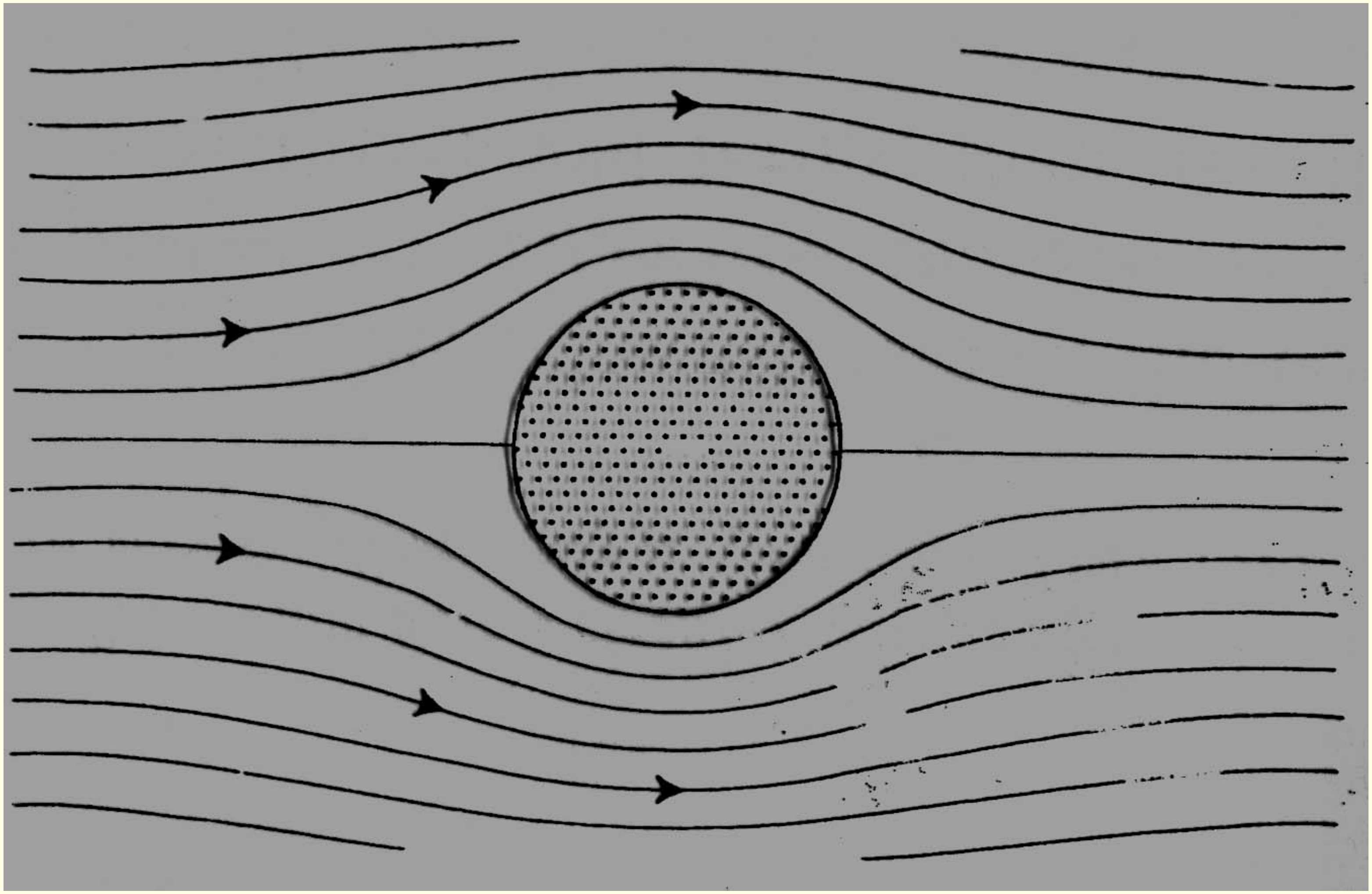
**However, in the boundary layer, it is a dominant process and *must be included* in the model equations.**

# Jean Le Rond d'Alembert



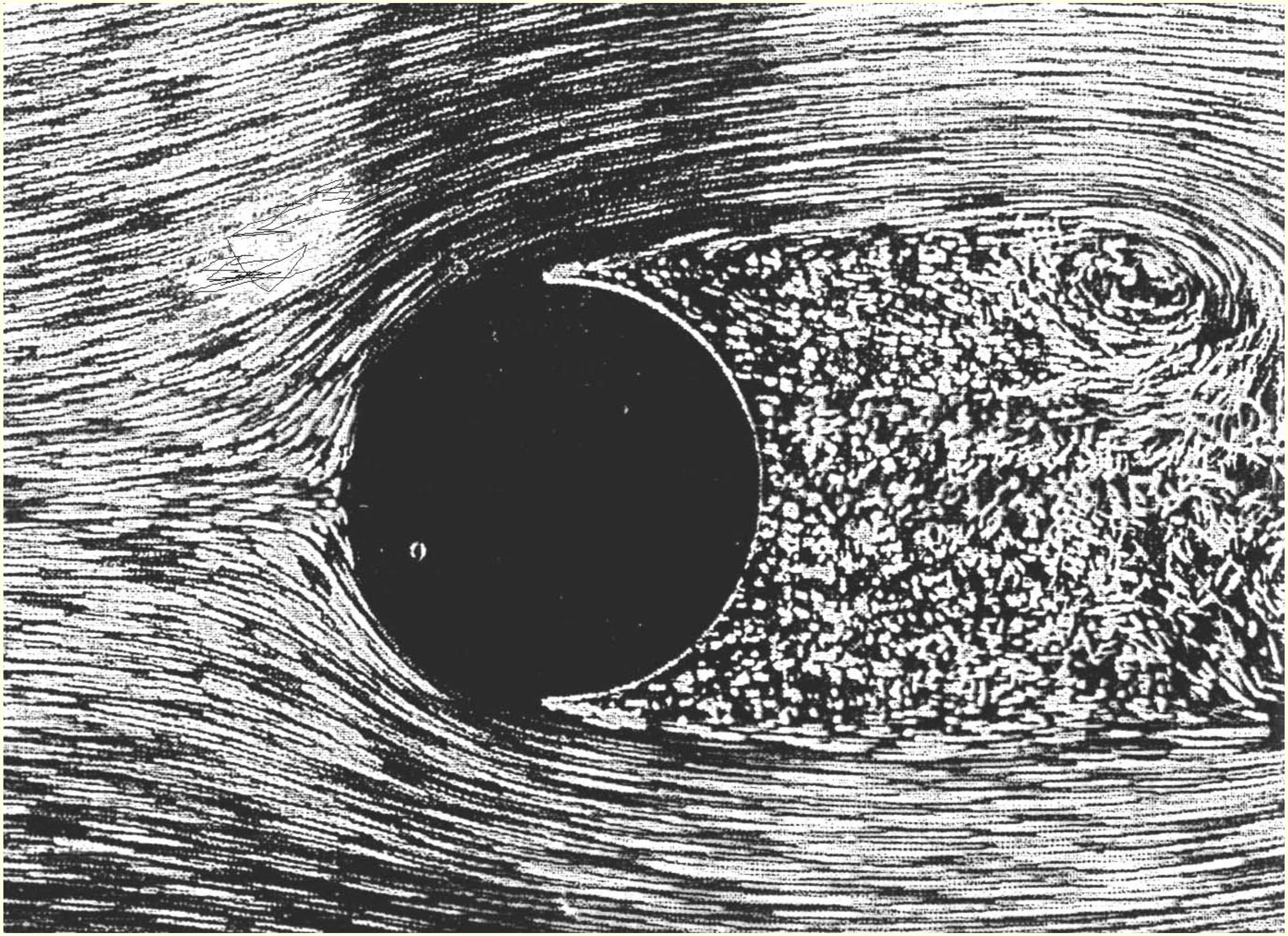

**A body moving at constant speed through a gas or a fluid does not experience any resistance (D'Alembert 1752).**

# Hypothetical Fluid Flow



**Purely Inviscid Flow. Upstream-downstream symmetry.**

# Actual Fluid Flow



**Viscous Flow. Strong upstream-downstream assymmetry.**

# Resolution of d'Alembert's Paradox

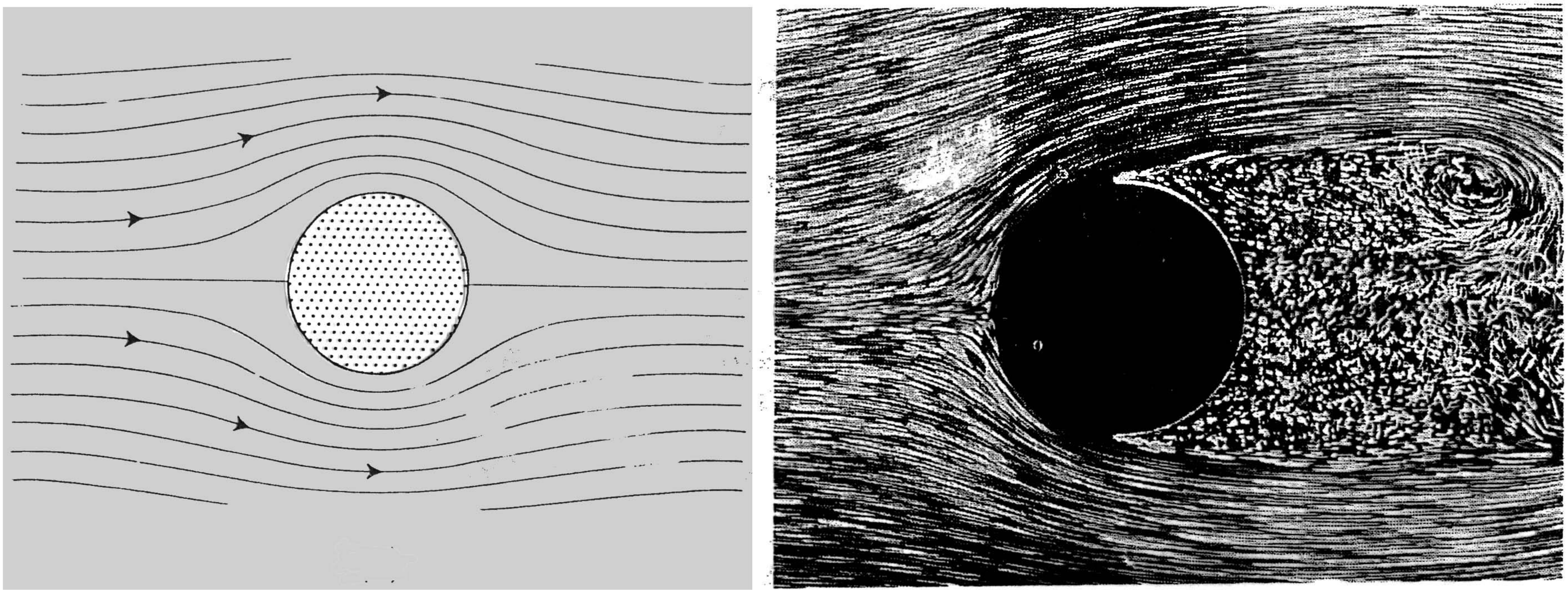
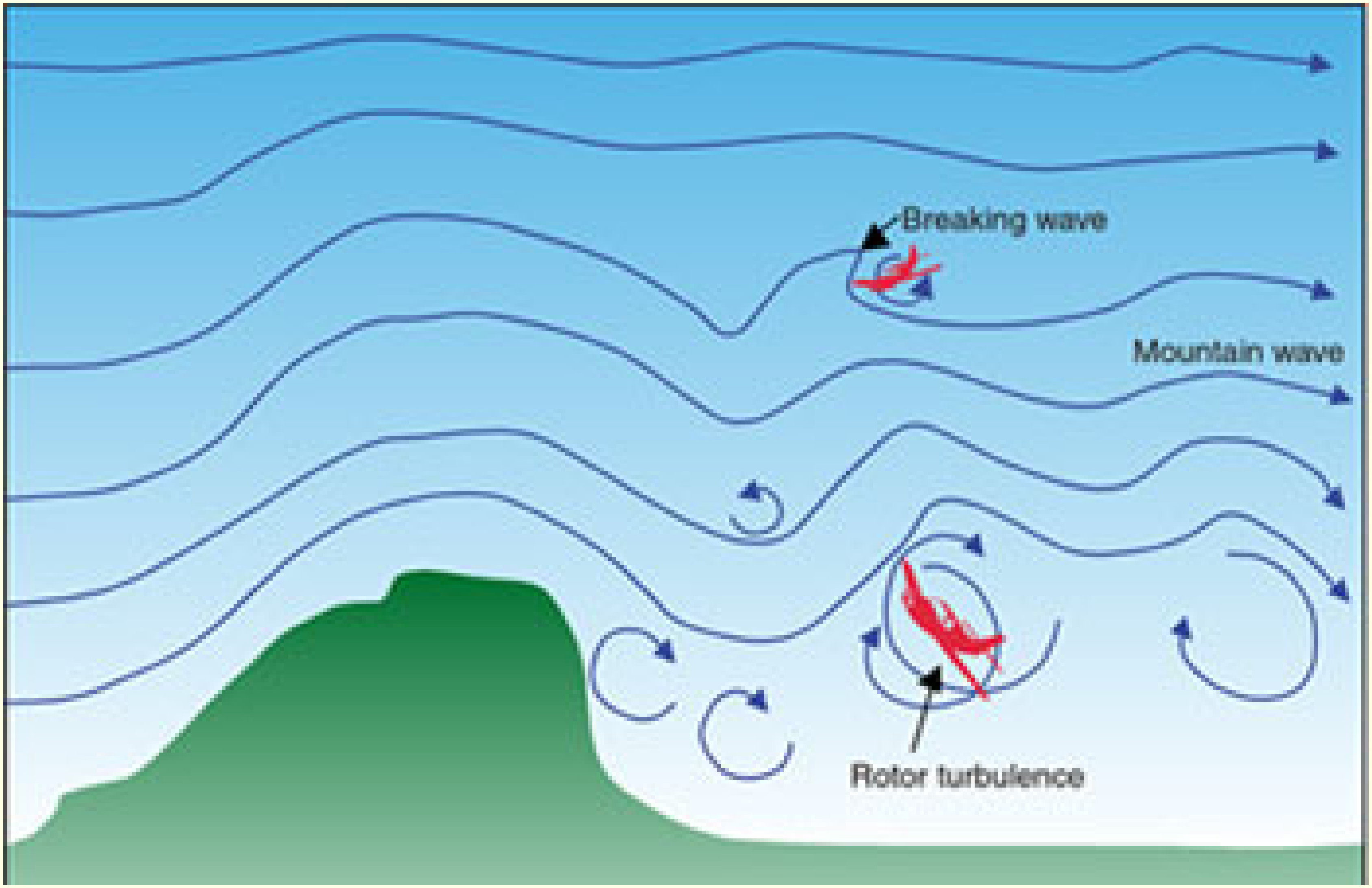


*Fig. 9.1 Flow past a circular cylinder for (a) a hypothetical fluid with zero viscosity, (b) a real fluid with very small viscosity $\mu$ (from van Dyke 1982).*

**The minutest amount of viscosity has a profound qualitative impact on the character of the solution.**

**The Navier-Stokes equations incorporate the effect of viscosity.**

# Flow around/over a Hill




**Turbulence caused by flow around or over a hill . . .**

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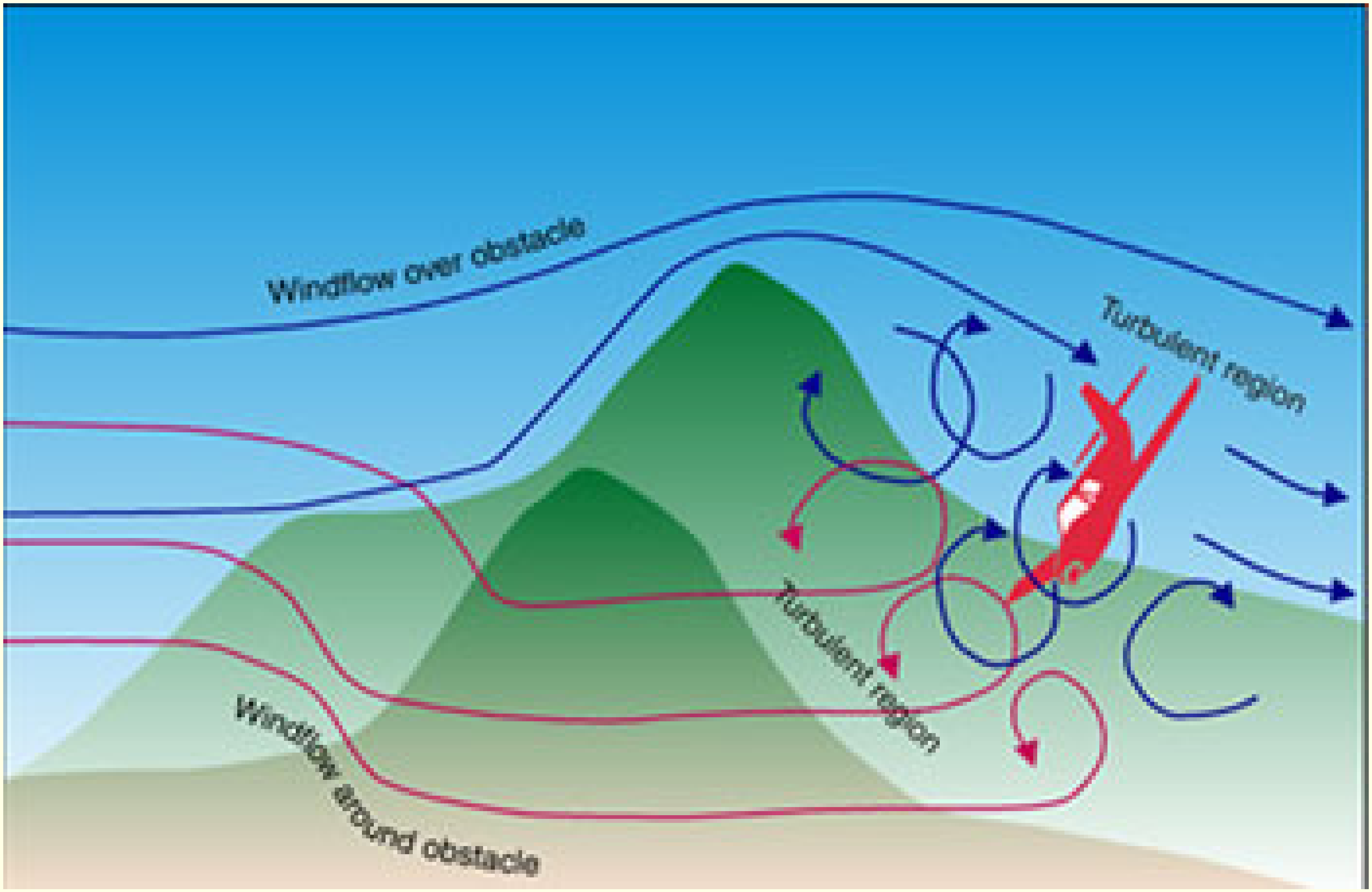


**. . . can be fatal for light aircraft.**

# Wake Turbulence

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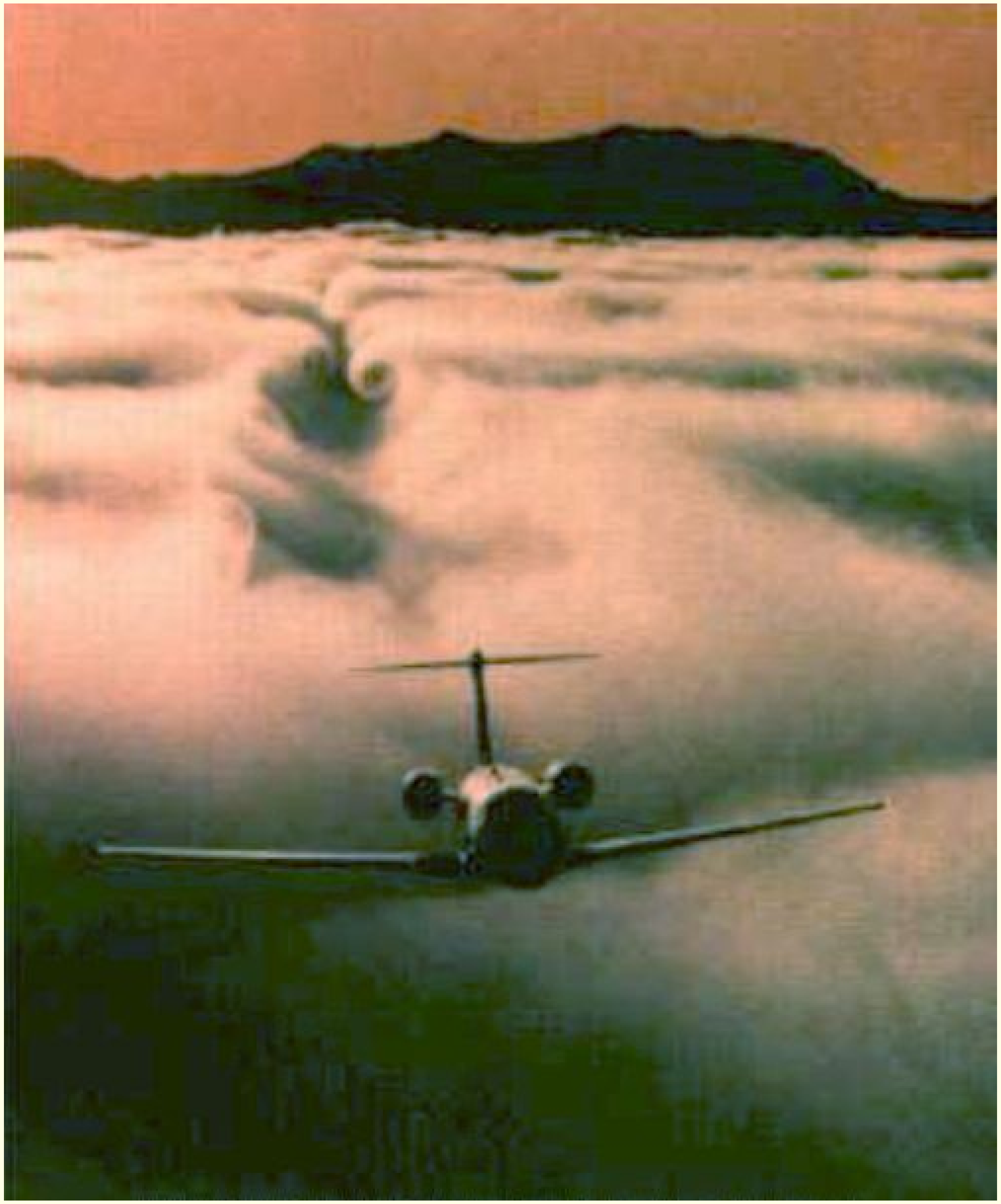


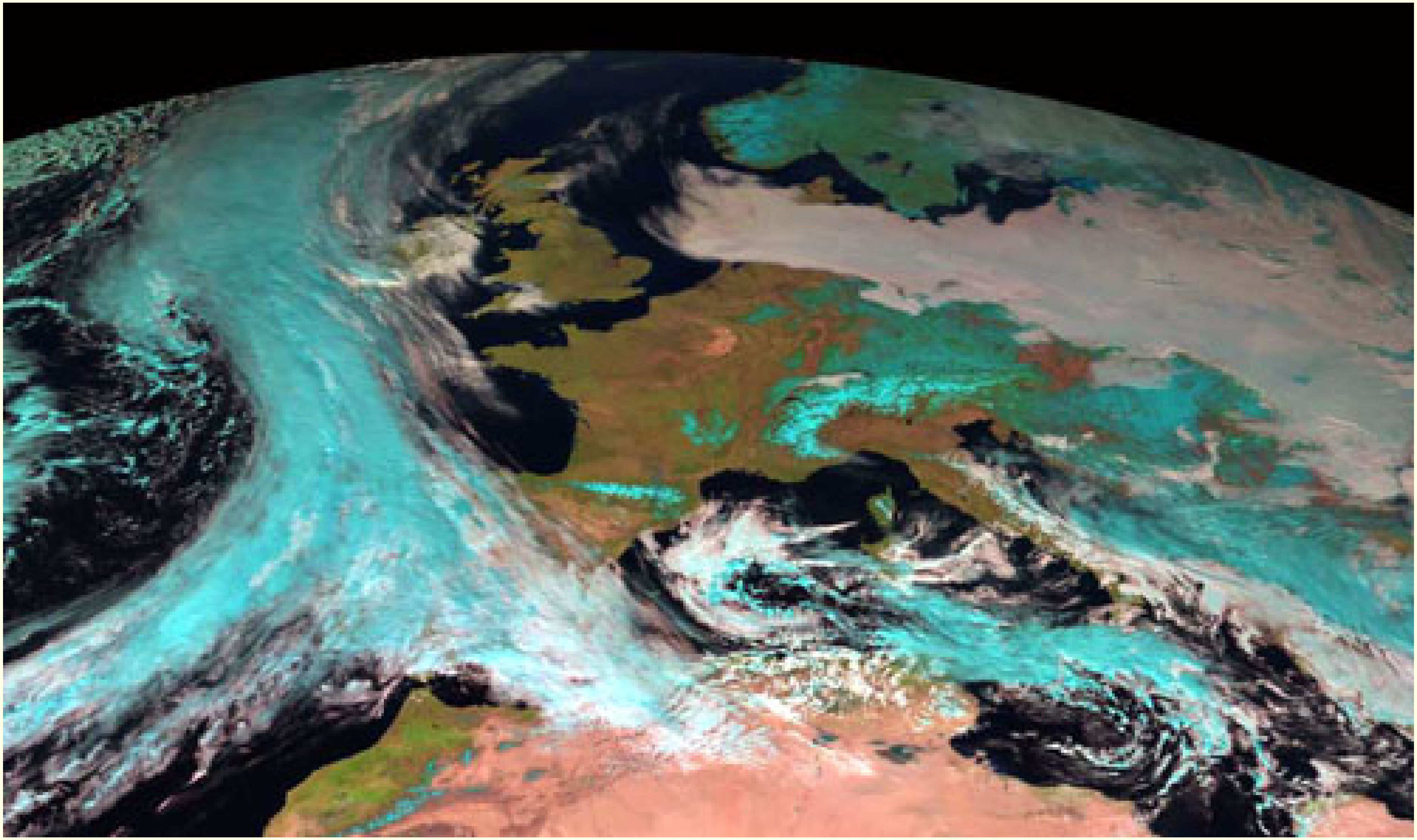
# Small-scale Turbulence

**The smoke rising from a cigarette flows upwards first in laminar motion. But, as its speed grows, this motion becomes unstable and breaks down into turbulent flow.**

# Larger-scale Turbulence

**Although they seem to hang motionless in the sky, clouds are in perpetual turbulent motion. Constantly dissolving and reforming, clouds take their shape from the ever-changing conditions that form them.**

# Larger Still



**Colour-enhanced image from the Eumetsat MSG-1 satellite (18 February, 2003).**

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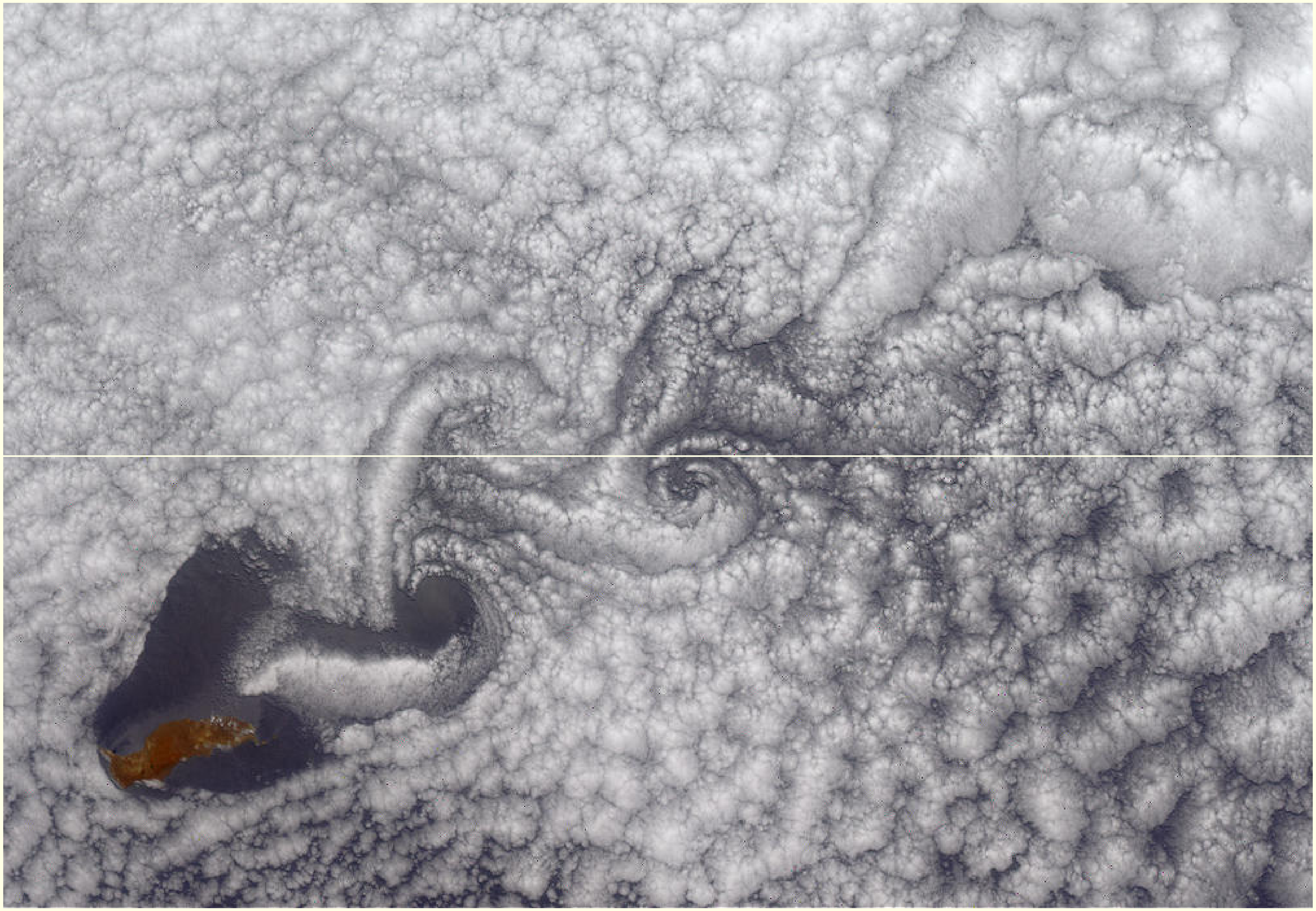
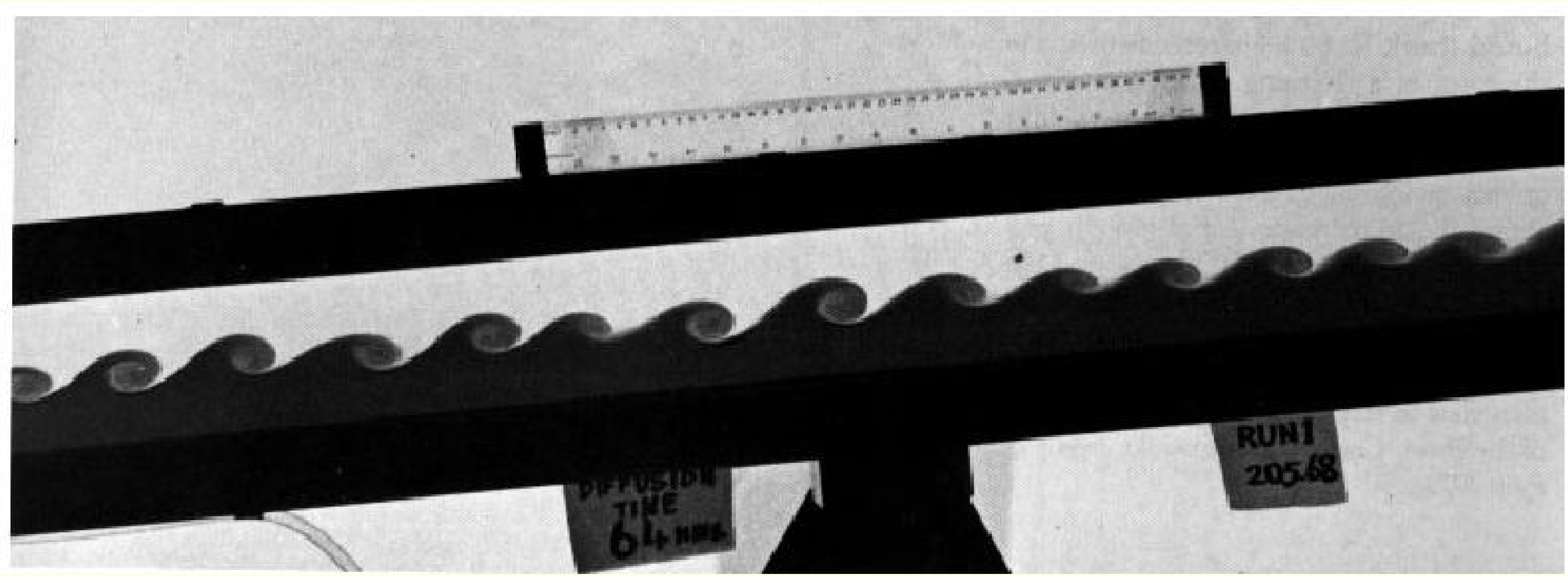
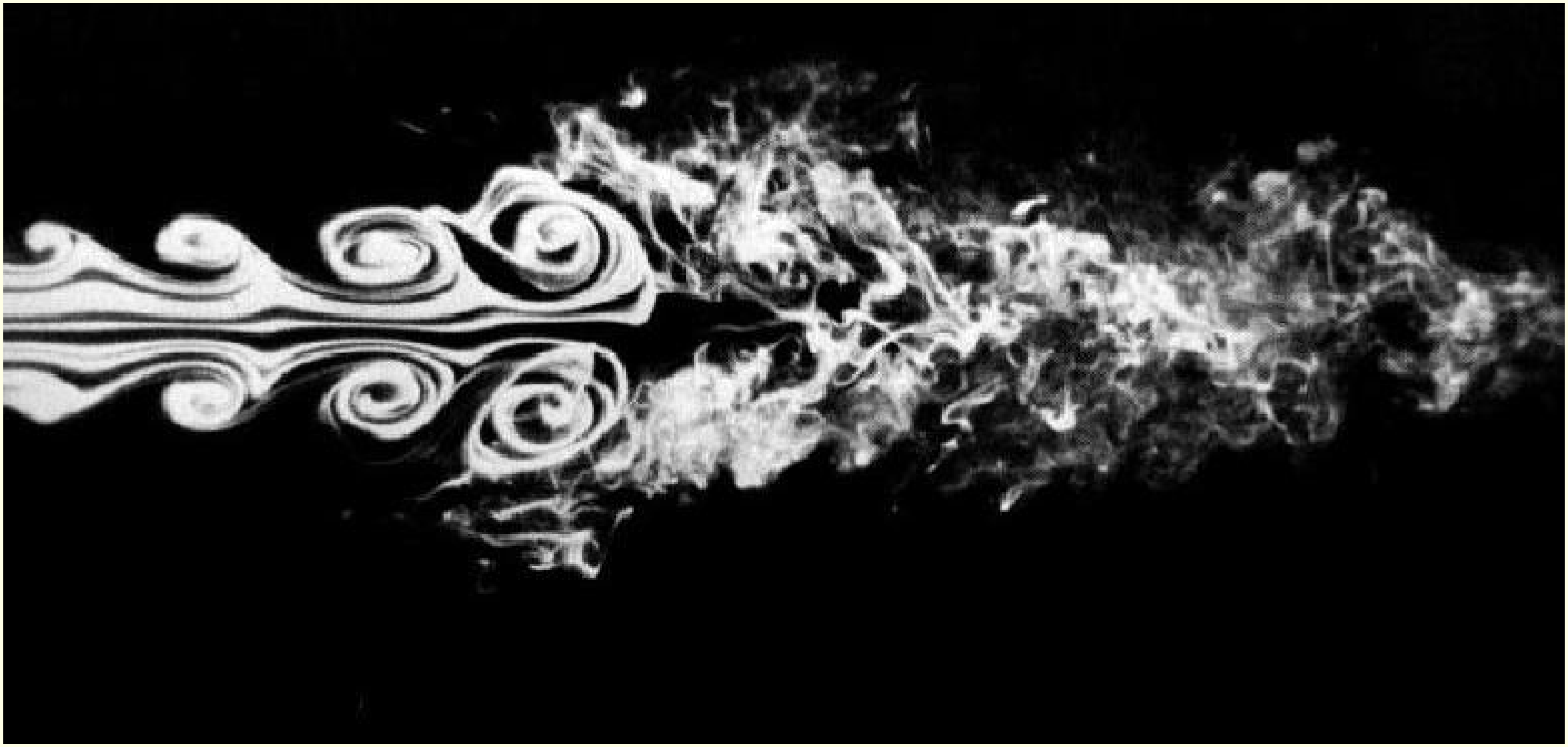


# Kelvin-Helmholtz Instability




(c) Brooks Martner

# Onset of Turbulent Flow

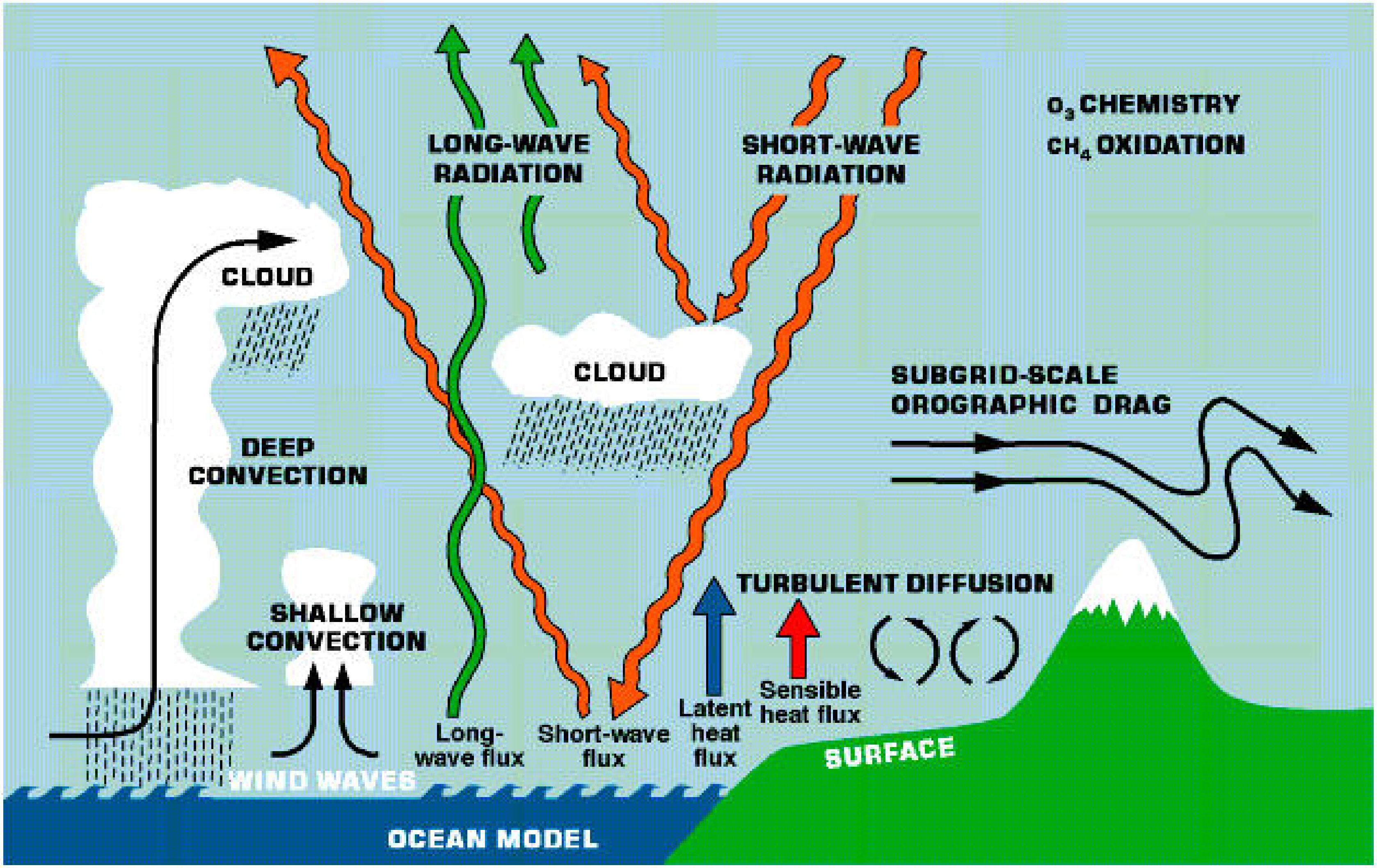


# Parameterization Schemes

**We consider now the various parameterization schemes used in the ECMWF Weather Forecast Model.**

**This model is known as the IFS, for Integrated Forecast System.**

# Integrated Forecast System




**Physical processes represented in the IFS model.**

**The physical processes associated with**

- **radiative transfer,**
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- **subgrid-scale orographic drag,**
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**have a strong impact on the large scale flow of the atmosphere.**

**However, these mechanisms are often active at scales smaller than the horizontal grid size.**

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**Furthermore, forecast weather parameters, such as two-metre temperature, precipitation and cloud cover, are computed by the physical parametrization part of the model.**

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**The input information for the physics consists of the values of the mean prognostic variables (wind components, temperature, specific humidity, liquid/ice water content and cloud fraction), the provisional dynamical tendencies for the same variables and various surface fields, both fixed and variable.**

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**For the estimation of these parameters the model uses the larger scale variables such as wind, temperature and specific humidity.**

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**The *sea-ice fraction* is based on satellite observations. The temperature at the surface of the ice is variable, according to a simple energy balance/heat budget scheme.**

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**The *thermal properties of snow covered ground* depend only on the snow mass per unit area. The snow depth evolves through the combined effect of snowfall, evaporation and melting. As the snow ages, the albedo decreases and the density increases.**

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**The *vegetation ratio* is separated into low and high vegetation fractions and the corresponding dominant types of vegetation are specified in each grid point and used by the model to estimate the evaporation.**

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***Comprehensive information on the IFS code is available at***

**www.ecmwf.int**

# End of §5.1