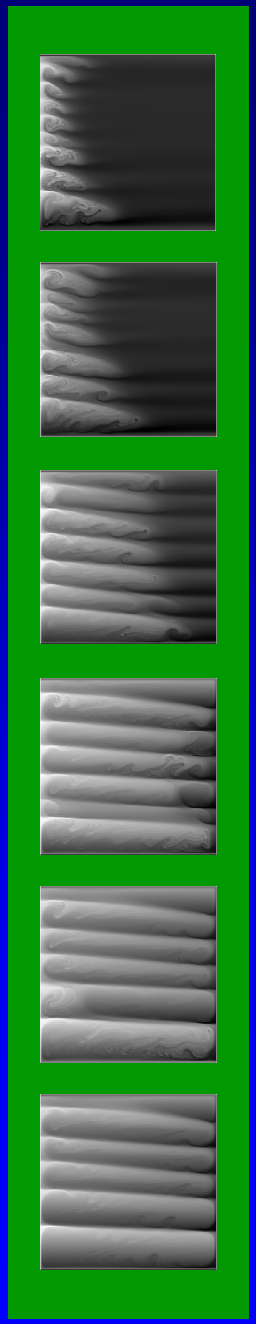


Experiences with Double-Diffusive Convection

E. Jurjen Kranenborg,
ABB Corporate Research,
Västerås, Sweden

Something Personal: Career Path

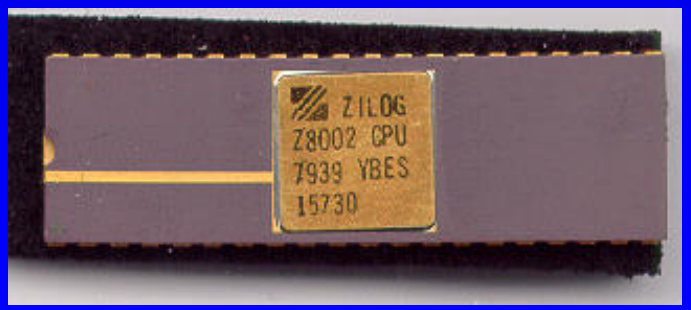
- Childhood Hobbies
- Education at Twente University:
  - Start of Computer Science, Start of Applied Mathematics
  - M.Sc. In Applied Maths., Fluid Dynamics, Grid generation
- Ph.D at Utrecht University, Physics & Astronomy
  - Density driven Convection ("Double-Diffusive Convection")
- PostDoc, Free University of Amsterdam (Earth Sciences)
- Research/Consultancy at Delft Hydraulics
- Research at Philips Research (Software Architectures)
- Currently: ABB Corp. Research (Thermal modeling of Power Transformers using CFD), Västerås, Sweden

Childhood Hobbies

Astronomy …

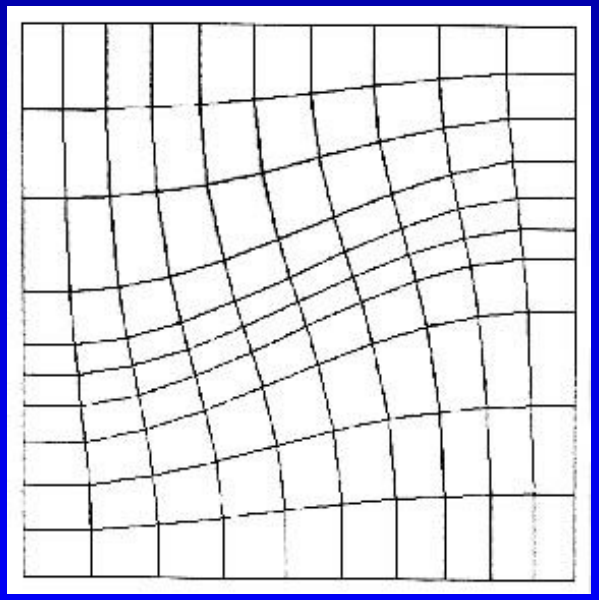
… Analog Electronics

16/32-bit Processor Architecture …

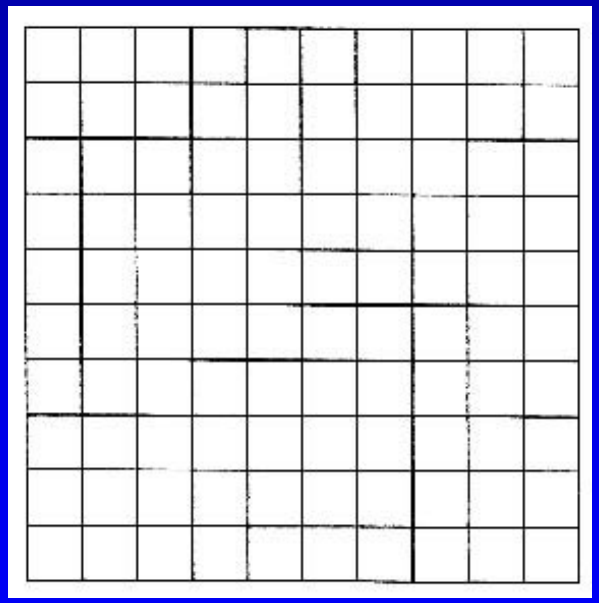


M.Sc. In Applied Mathematics

- Topic: "Control Functions for Numerical Orthogonal Grid generation in Curved Geometries"

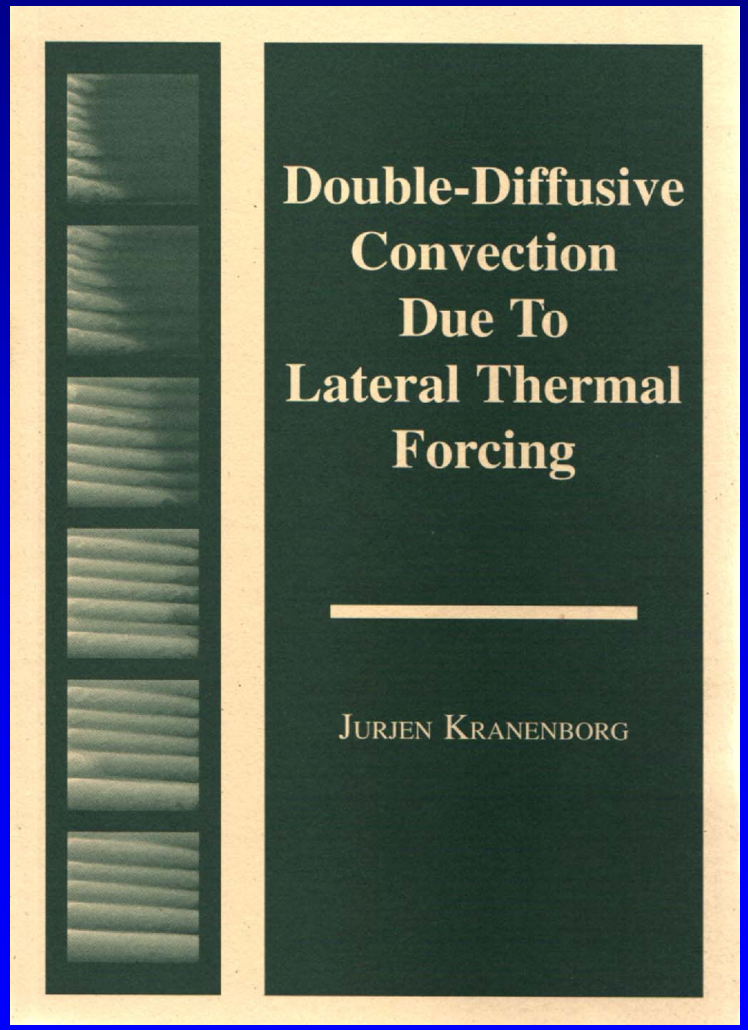


Final grid in physical domain



Computational grid

Main Part: Double-diffusive Convection



Ph.D. Research
(1991-1996)

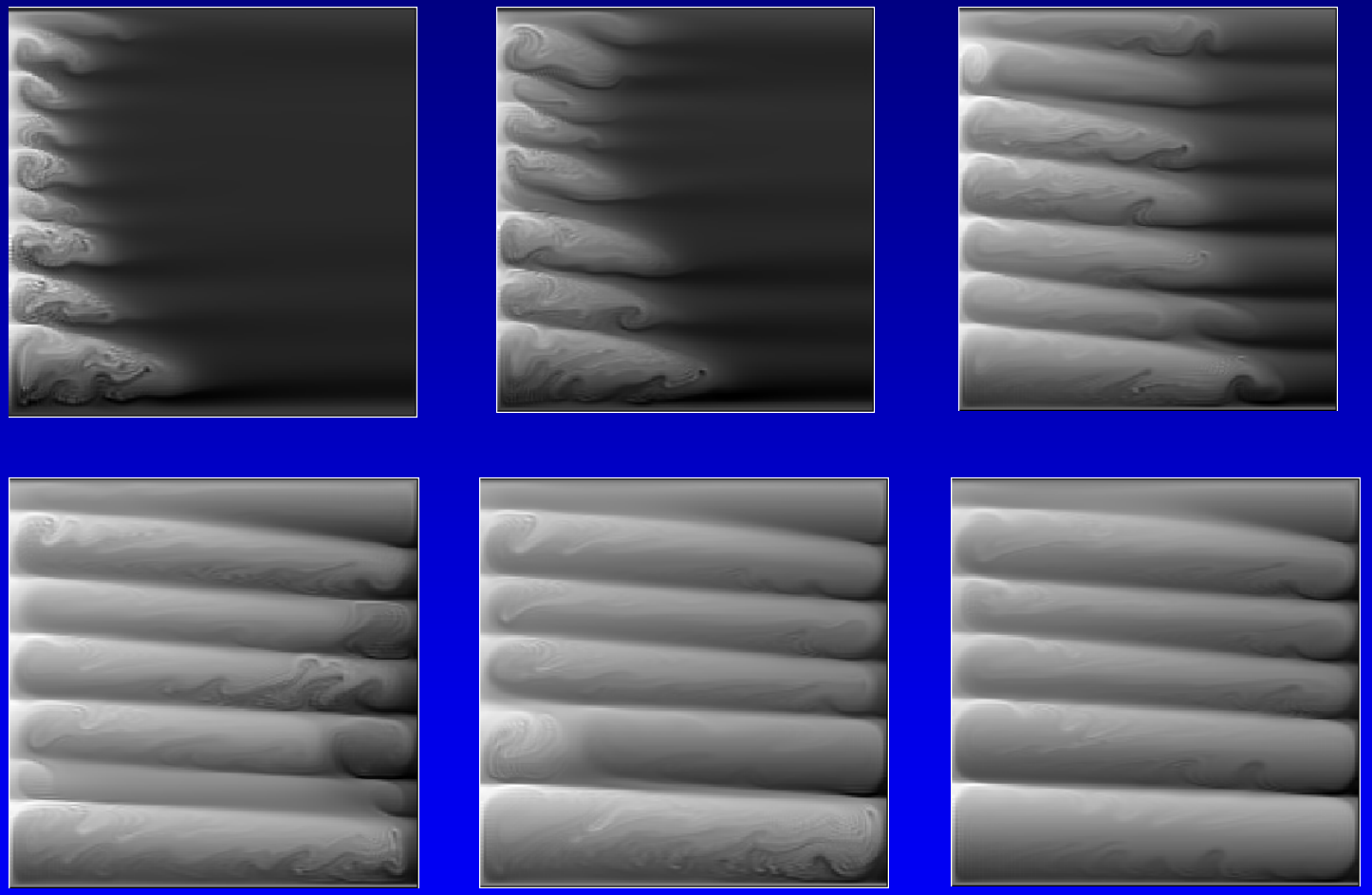
Utrecht University,
Physics & Astronomy

Promotores:
Prof. W.P.M. de Ruijter,
Prof. H.A. Dijkstra

Oceanic layered structures near polar ice

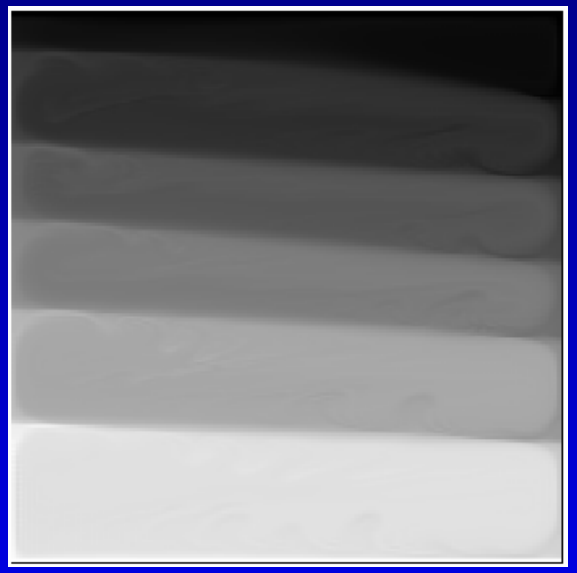
- Convection pattern differs from pure thermal convection:
  - Layered structures (oceanic "staircases")
  - Mainly lateral transport (v.s. vertical for thermal problem)
  - Small-scale patterns present (diffusive interfaces)
  - Complex flow dynamics for different parameter ranges
- Strong influence on iceberg melting
- Focus of Ph.D. work on layer formation, merging dynamics and proper upscaling of model results to ocanographic conditions

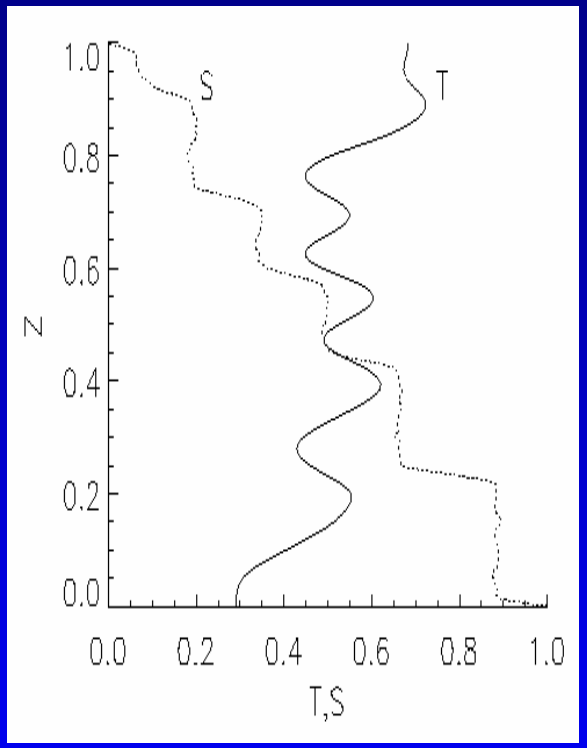
Layer Development

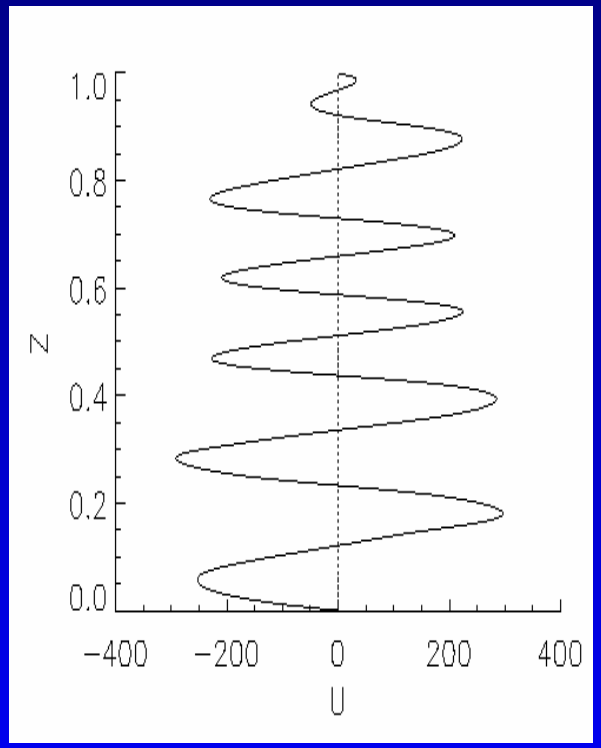


Heating up of left sidewall at t > 0.
Shown: Perturbation of initial stable salt gradient.
Layer thickness η scales with $\alpha.\Delta T / \beta.\phi_s$

Layer properties, problem parameters







Ra (Rayleigh) = $g\alpha.\Delta S.H^3 / \nu k_T$
= measure of buoyant (thermal & saline) forcing intensity

R (Buoyancy Ratio) = $\beta.\Delta S / \alpha.\Delta T$
= relative strength of saline buoyant forcing

Ph.D. Research Issues

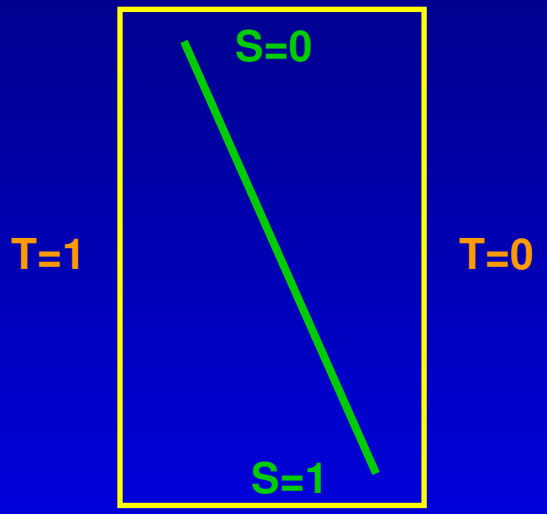
- Flow dynamics & pattern selection
  - Video suggests: transitions between steady states!
  - Continuation and stability analysis to map out solution behaviour in parameter space
- Physical mechanisms?
  - Layer merging
  - Layer self-propagation
- Scaling up towards oceanographic conditions:
  - determination of effective diffusivities to allow incorporation of small-scale processes in large-scale models

Patterns & Pattern selection: "Attractor Analysis"

- Flow Model as a Dynamical System
  - Main steady states?
  - Stability of steady states?
  - Transitions between steady states?

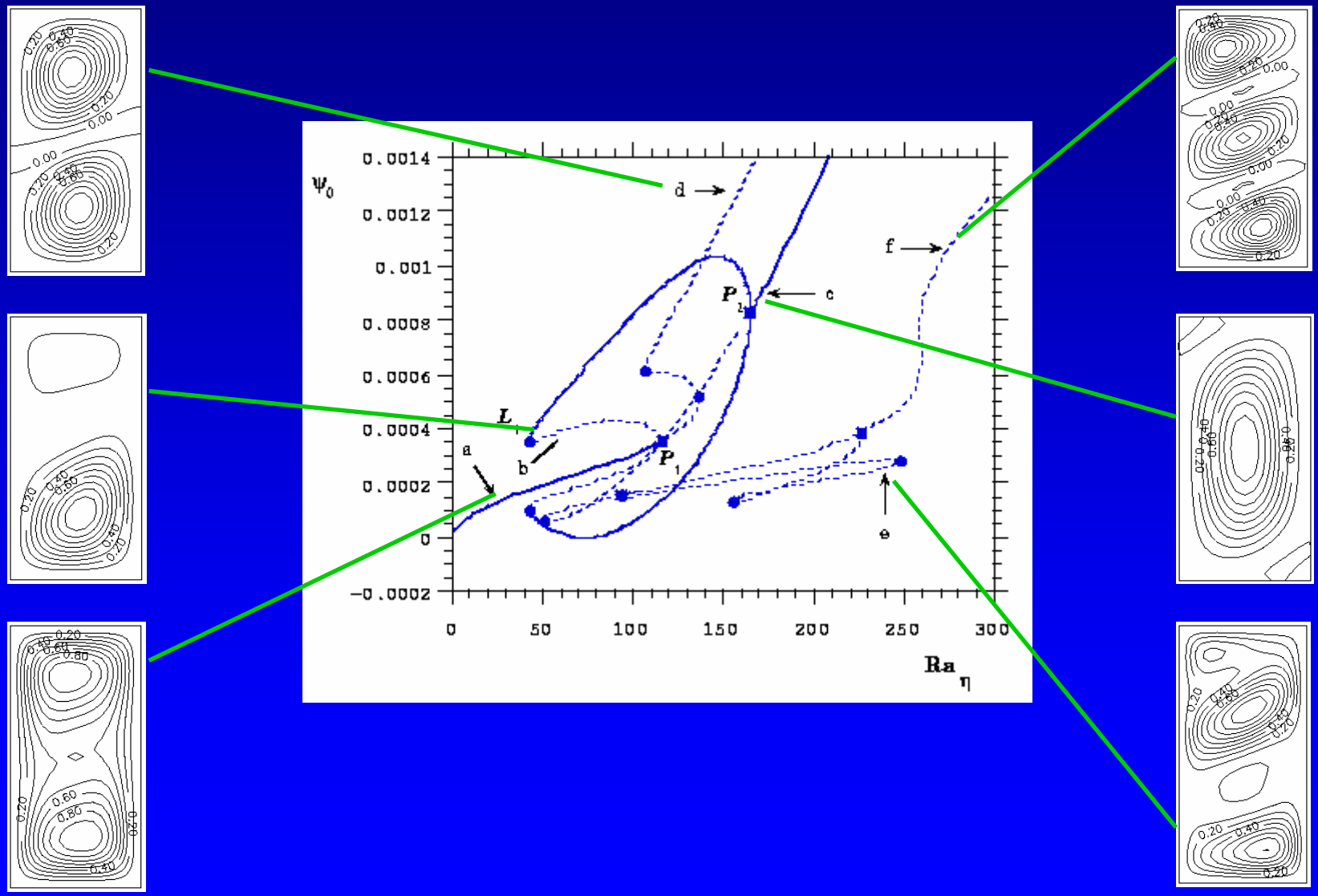
- Result: Qualitative picture of dynamics as a function of combined thermal/saline forcing (**Ra**) and buoyancy ratio (**R**)

- Model: Sidewall heating of a stable salinity gradient, using **Ra** as bifurcation parameter, **R** fixed at **R** = 3

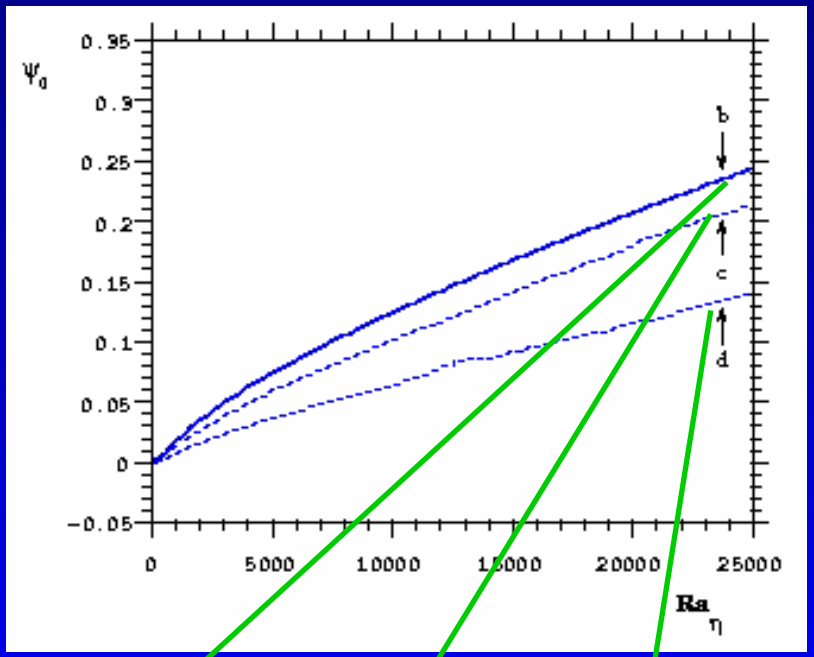


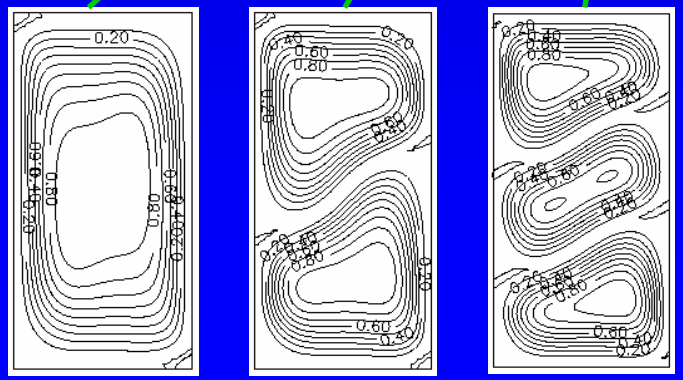
AGU Geophysical Monograph **94**, 89–96, 1995,
Phys. Fluids **7**(3), 680–682, 1995,
Int. J. Heat Mass Transfer **39**, 2699–2710, 1996

S.S. patterns, function of buoy. forcing
A: weak forcing regime

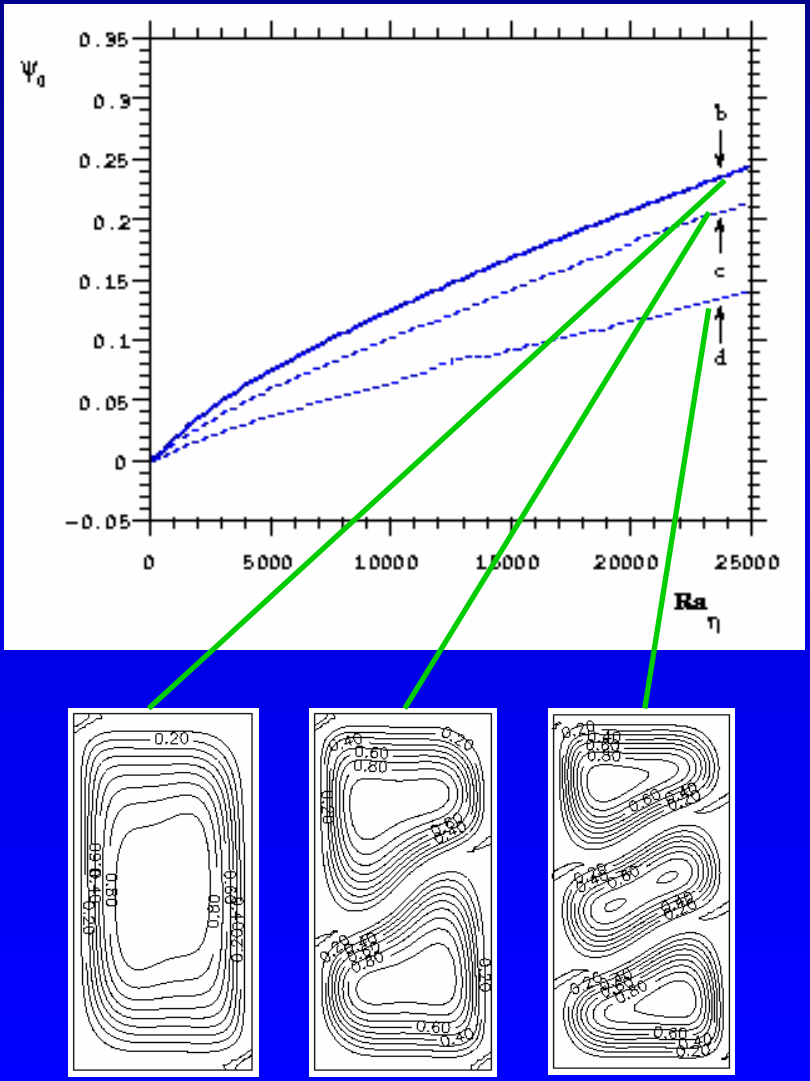


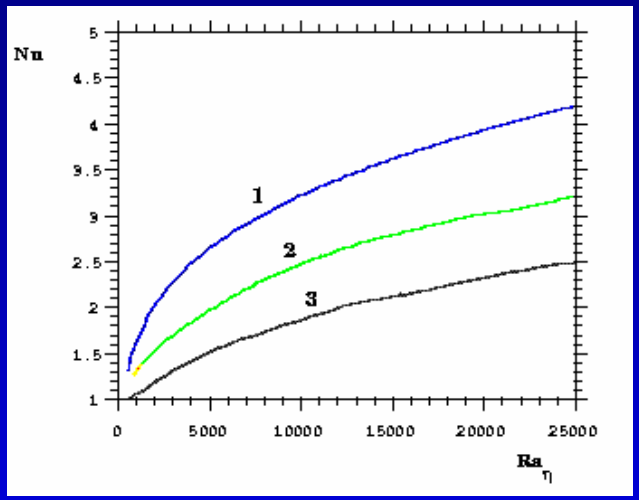
S.S. patterns, function of buoy. forcing
B: strong forcing regime



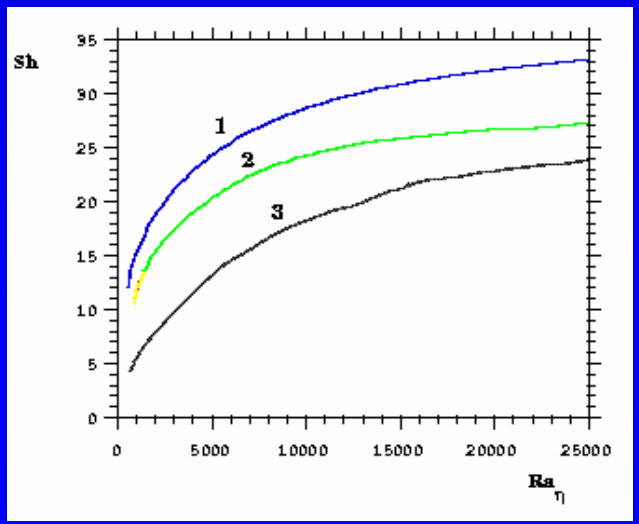


Heat, salt transport





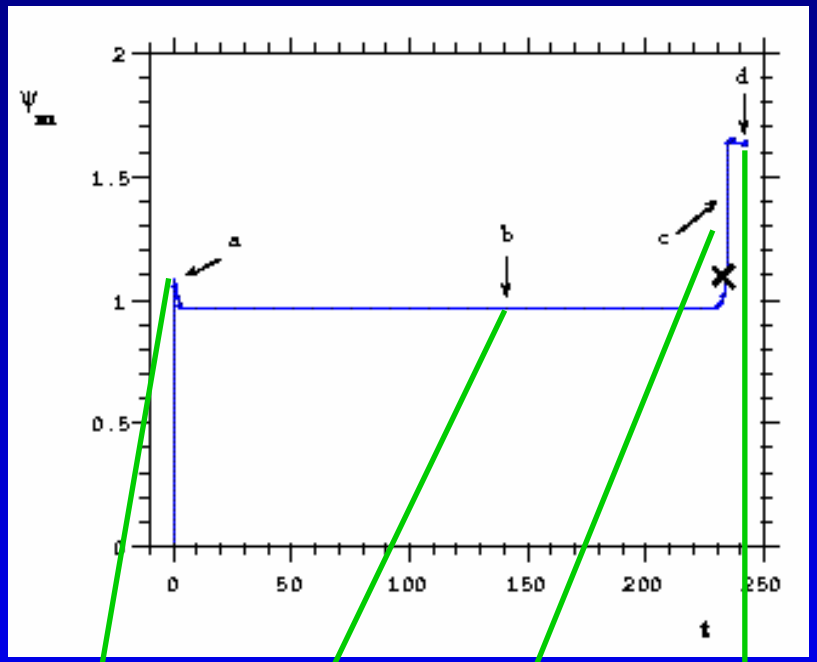
Heat
(Nu)

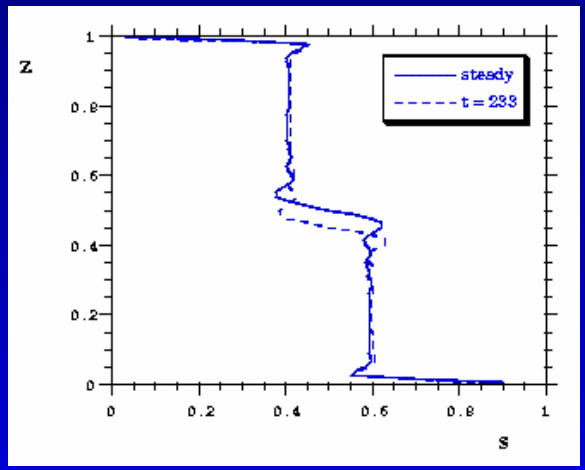


Salt
(Sh)

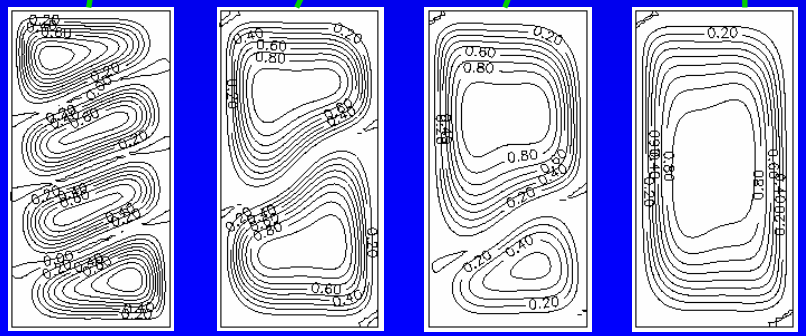
Transitions between flow patterns

Unstable states may be physically relevant!

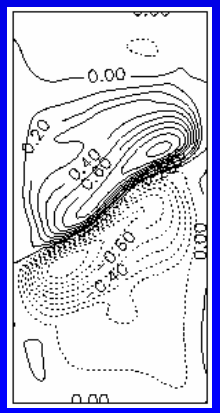




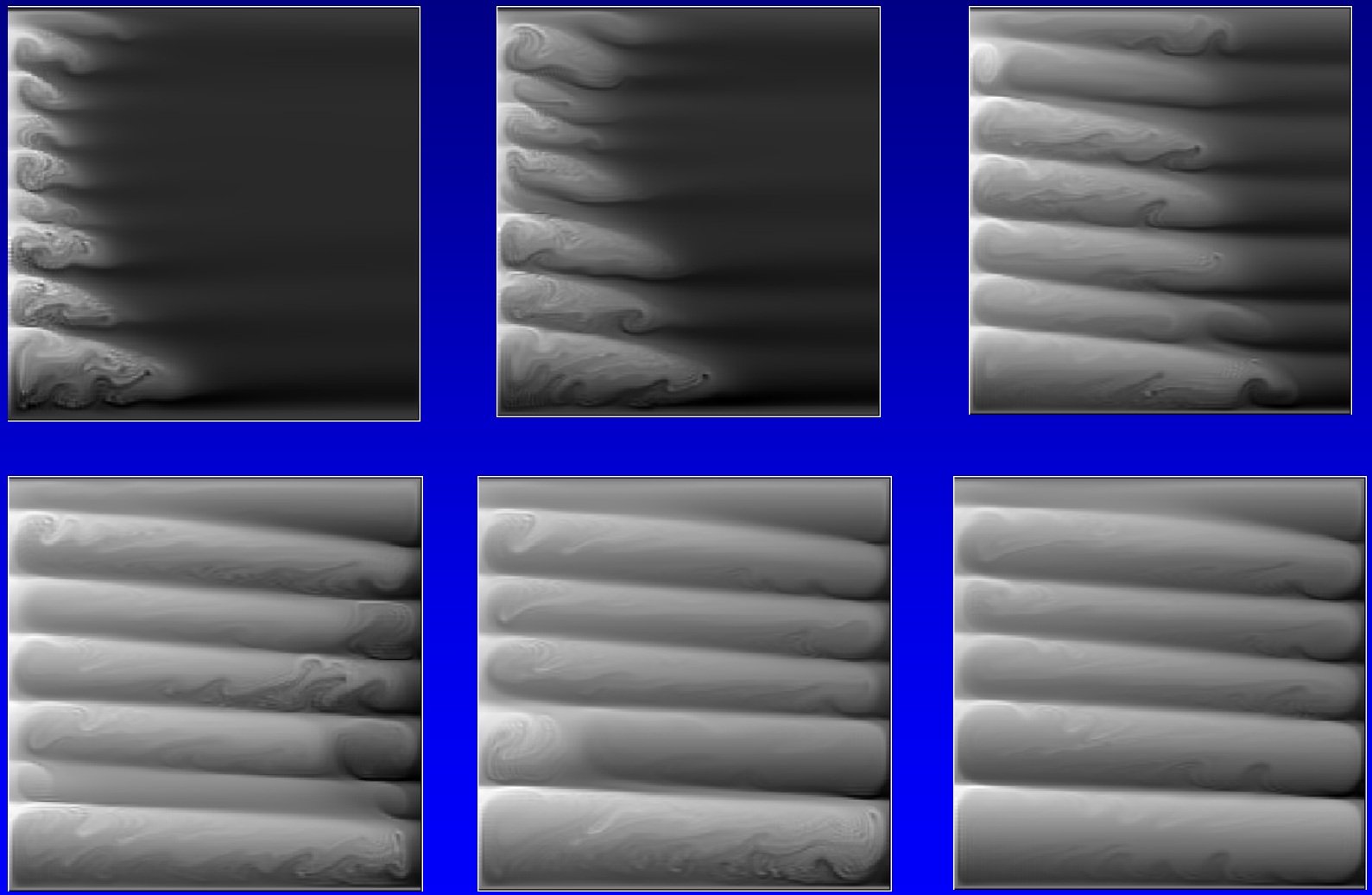
Interface migration



Perturbation causing this ...



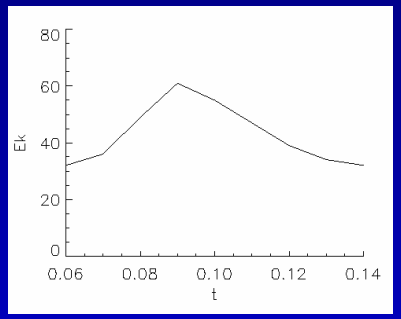
Layer merging



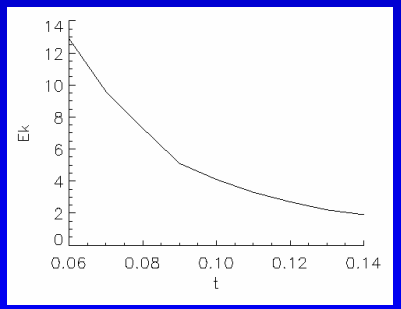
Int. J. Heat Mass Transfer **41**, 2743–2756, 1998

Self-propagation of layers

Propagation after forcing stopped …



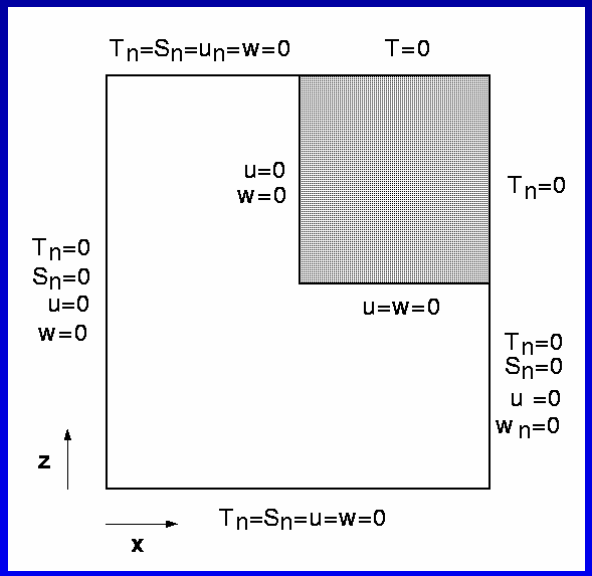
Kinetic energy increase …

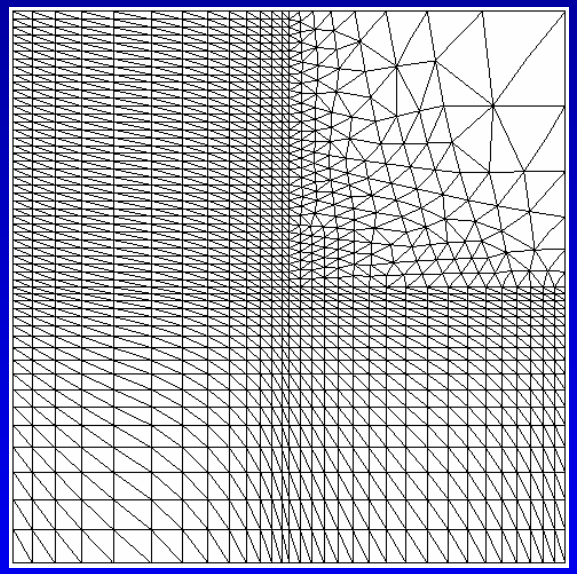


… does not happen if initial vertical temperature gradient is absent

Int. J. Heat Mass Transfer **41**, 2113–2124, 1998

Convection near an ice plate geometry





Int. J. Heat Mass Transfer **41**, 1873–1884, 1998.

Global transport: effective diffusivities

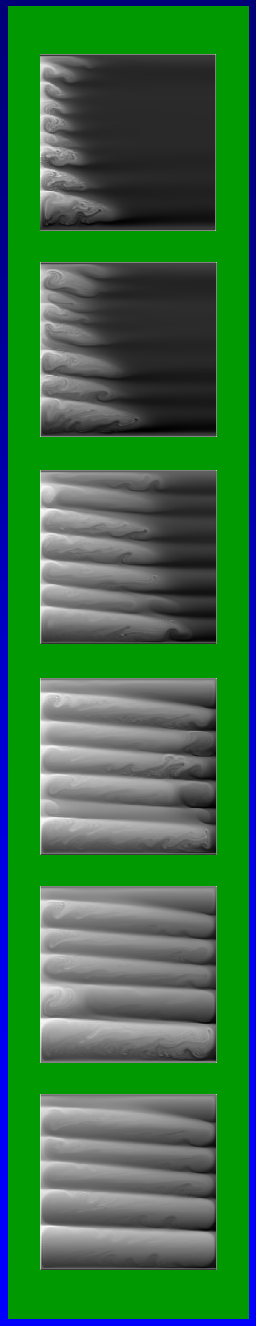
- Vertical salt fluxes determined for several simulations:
  - **Ra** = [$5*10^4$ - $1*10^6$]
  - **R** = [2.5 - 10]
- Results satisfy a published Flux law for vertical salt transport validated by laboratory experiments
- After analysis : net vertical salt diffusivity of staircase takes extremely simple form:
  - $K_S = c_S * \mathbf{Ra}^{1/3}$ (dim. less, $c_S = 1.15*10^{-3}$ from simulations)
  - independent of diffusive interface stability
- K_S in fair agreement with oceanographic measurements
  - **Ra** is much larger ($O(10^9)$, i.e. 10^4 times)
  - Fails only for diffusive interfaces with very low stability

Time-Dependent Nonlinear Convection (Advances in Fluid Mechanics), 1998

… [*Experiment*] make your own private layered structure [*Experiment*] …

- Ocean Model: *Cup of HOT coffee*
- Ice-edge model: *Use a Transparent, Glass Cup*
- Add Salt Stratification: *GENTLY pour some coffee milk)**
- Wait for a few minutes and …
- Your private oceanic staircase is ready for consumption !

** Note: must be "thick", high-density coffee milk (Dutch); ordinary milk + some added salt might work as well!*



The End

WEB publications:

- Personal: www.kranenborg.org/jurjen
- Ph.D. work: www.kranenborg.org/doublediff
- Electronics: www.kranenborg.org/ee