Thermal structure in the surface mixed layer : How mixed is mixed ?

Ian Robinson

National Oceanography Centre Southampton

Aiken's first law of Oceanography

Slightly historical reflections by a physical oceanographer of collaborating with Jim over 20 years, focussed (loosely) around a discussion of the hypothesis:

"*A mixed layer is a mixed layer is a mixed layer . . .*"

- What does it mean ?
- Why does it matter ?
- When might it be misleading ?

Working with Jim

- First encounter – before I became an oceanographer
  - Early development of the UOR
- Ocean Remote Sensing – Joint NERC projects
  - **BOFS (**Biogeochemical Ocean Flux Study**) S.T., 1989-92,** PDRA: Alison Weeks, based at SUDO.
  - **WOCE (**World Ocean Circulation Experiment) **S.T. 1992-95,** PDRA: Alison Weeks, based at SUDO.
  - **BAS (**British Antarctic Survey) **S.T. 1992-95,** RA: Gerald Moore, based at PML.
    - Weeks, A., Robinson, I.S., Moore, G.F. & Aiken, J. Maintaining a phytoplankton bloom in low mixed layer illumination in the Bellinghausen Sea in the austral spring, 1992. *Proc of S.P.I.E.*, **2258**, 90-104, 1994
    - Sagan, S., Weeks, A.R., Robinson, I.S., Moore, G.F. and Aiken, J. The relationship between beam attenuation and chlorophyll concentration and reflectance in Antarctic waters, *Deep-sea Res.*, **42**, 983-996, 1995

Jim's 1st Law – what does it mean ?

- Who can be sure ?

  It's not just the phrase "*A mixed layer is a mixed layer is a mixed layer*. . ."

  . . . . to be Jim's 1st law it's all about how you say it !

- Nonetheless, I take it to mean:
  - The water content and properties (including IOPs) are uniform in the ocean's upper mixed layer.
  - If the wind is moderate or greater we can characterise the water content by a single sample at any depth down to the top of the thermocline.
  - It's the basis of many experiments with surface towed instruments . .
  - . . and with ship intake sampling
  - But it's not meant to apply to apparent optical properties (AOPs)

Managing with Jim - 1

SeaWiFS Exploitation Initiative

- 1992 - NASA selects UK project SEASCOPE, co-ordinated by Jim, as part of SeaWiFS science programme.
- 1993 - NERC provides £750,000 for a Special Topic, the SeaWiFS Exploitation Initiative (SEI) - runs from 1994 to 1997.
- Jim is project scientist, Ian chairs the steering committee – Objectives were:
  - Develop atmospheric correction strategies and algorithms suitable for coastal waters;
  - Construct algorithms for recovering biological parameters from R-S ocean colour data, using both archived and new data
  - Innovative use of models which use SeaWiFS data in the study of oceanographic processes
  - Measurement of *in situ* data as part of the SeaWiFS calibration / validation programme.
- **This project helped launch several careers of today's ocean colour generation**

NASA Technical Memorandum 104566, Vol. 33

SeaWiFS Technical Report Series

Stanford B. Hooker and Elaine R. Firestone, Editors

Volume 33, Proceedings of the First SeaWiFS Exploitation Initiative (SEI) Team Meeting

Gerald F. Moore and Stanford B. Hooker

GLOBAL OCEAN COLOR
NASA SeaWiFS GSFC

February 1996

NASA

Jim's 1st Law – Why does it matter ?

- It provides a working hypothesis for using optical methods to characterise water properties of ecosystems
  - E.g. Towed / moored optical sensors; Colour remote sensing
- An essential simplifying assumption for modelling the near surface light field
  - Without it we could not readily retrieve IOPs from AOPs
  - Without it we would need to massively increase the sampling of water properties in depth and along-track
- If it is wrong - the use of optical properties, and remote sensing methods, may be compromised
  - It may be wrong for the light field when there are bubbles
  - What about other phenomena associated with winds ? –
    - Langmuir circulation, Stokes' drift of surface waves, Internal waves

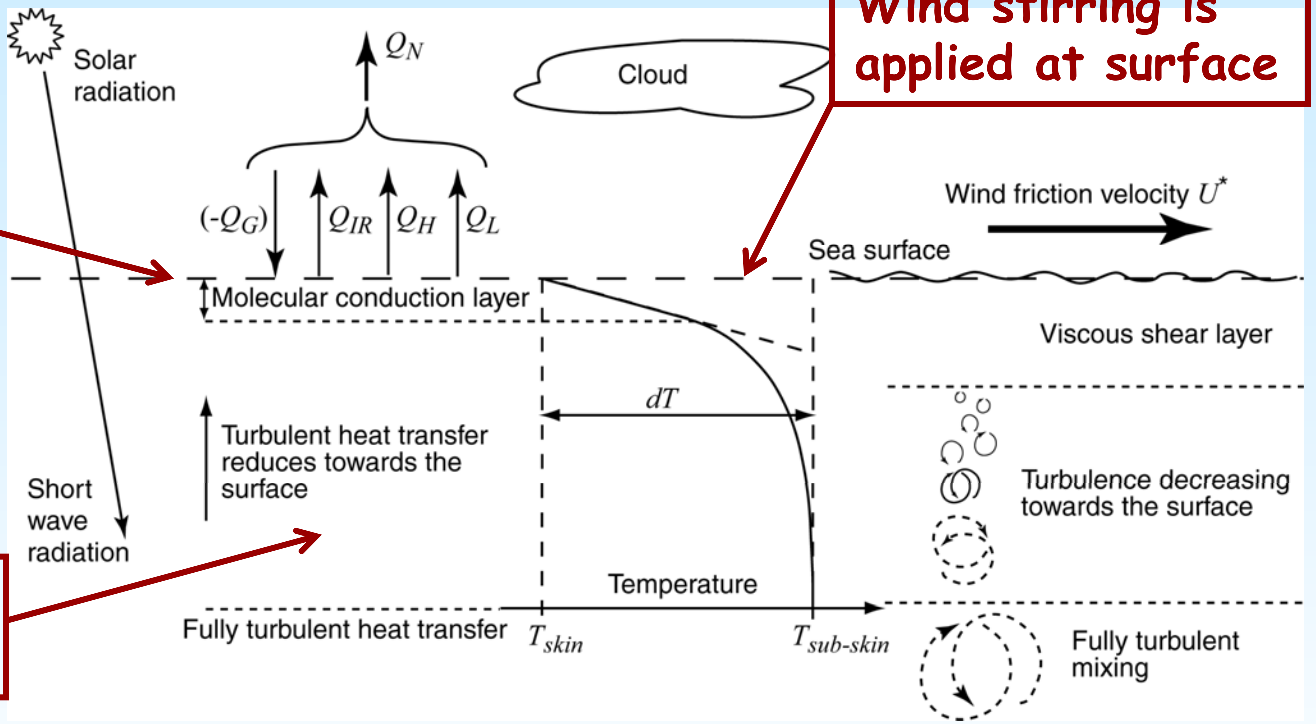
Jim's 1st Law - When does it not apply ?

- Sea surface temperature

Heat loss occurs only at the surface

Wind stirring is applied at surface

Solar radiation heats the sea "from inside"



- Reflections on "almost-collaboration with Jim"
  - AMT and shipborne radiometry on James Clark Ross
  - The "Donlon factor" and the development of GHRSST
  - Skin temperature validation of AATSR

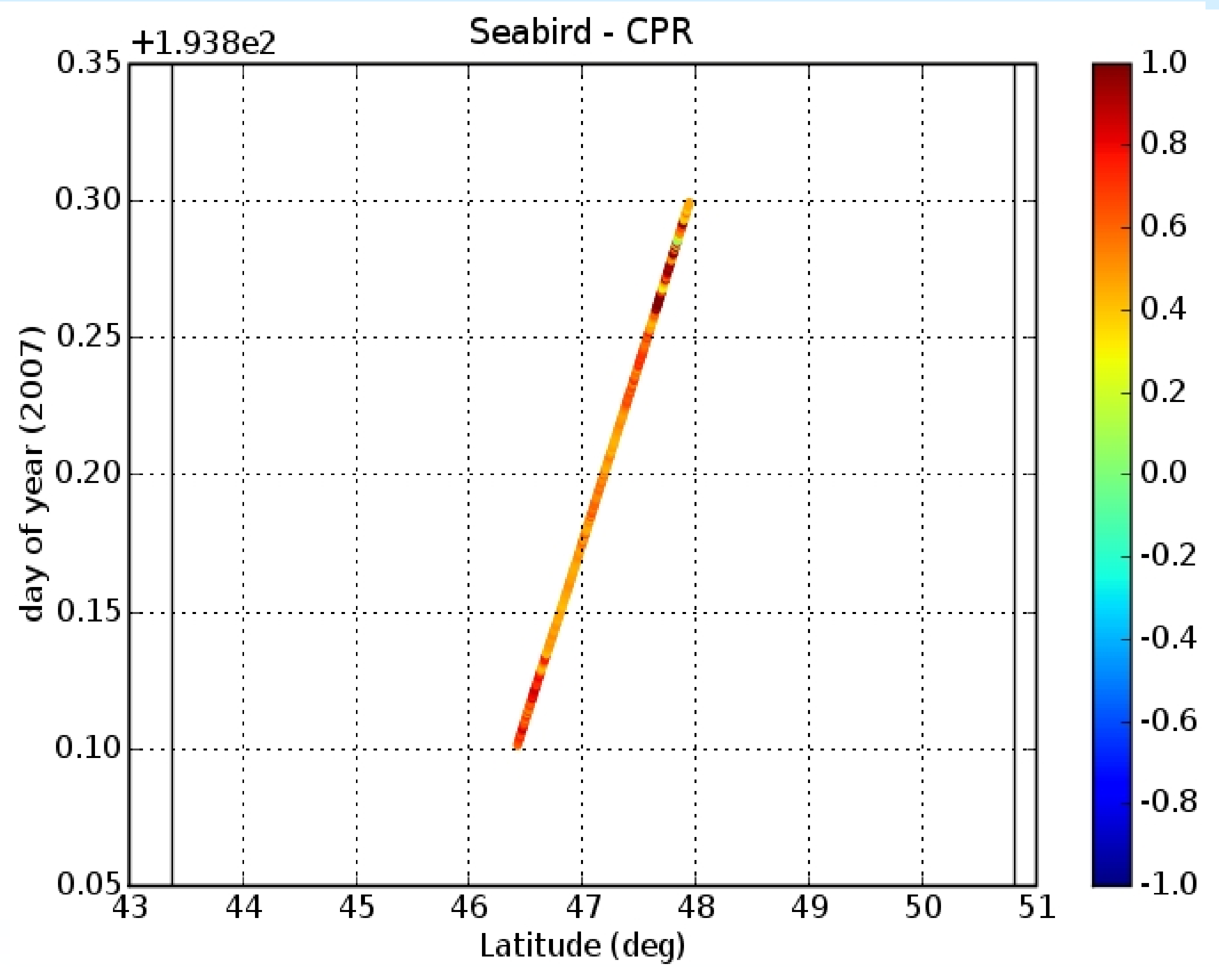
Measurements of skin SST on Pride of Bilbao

- Craig Donlon designed the Infrared SST Autonomous Radiometer (ISAR) to record skin temperature on ships of opportunity
- It is now deployed on P&O ferry Pride of Bilbao to validate the AATSR SST products
- Werenfrid Wimmer runs the project
- Funded through a Defra contract

- ISAR's self calibration method is accurate to <0.1 K
- 107 matchups between AATSR and ISAR in Oct-Nov 2007 give **$\Delta T = -0.06 \pm 0.32$ K**
- Now the primary source of direct validation for AATSR

"SST" measured by different sensors

Experiments to compare skin SST with hull thermometer (SeaBird), additional hull thermistors and a thermistor on a CPR deployed from *Pride of Bilbao*

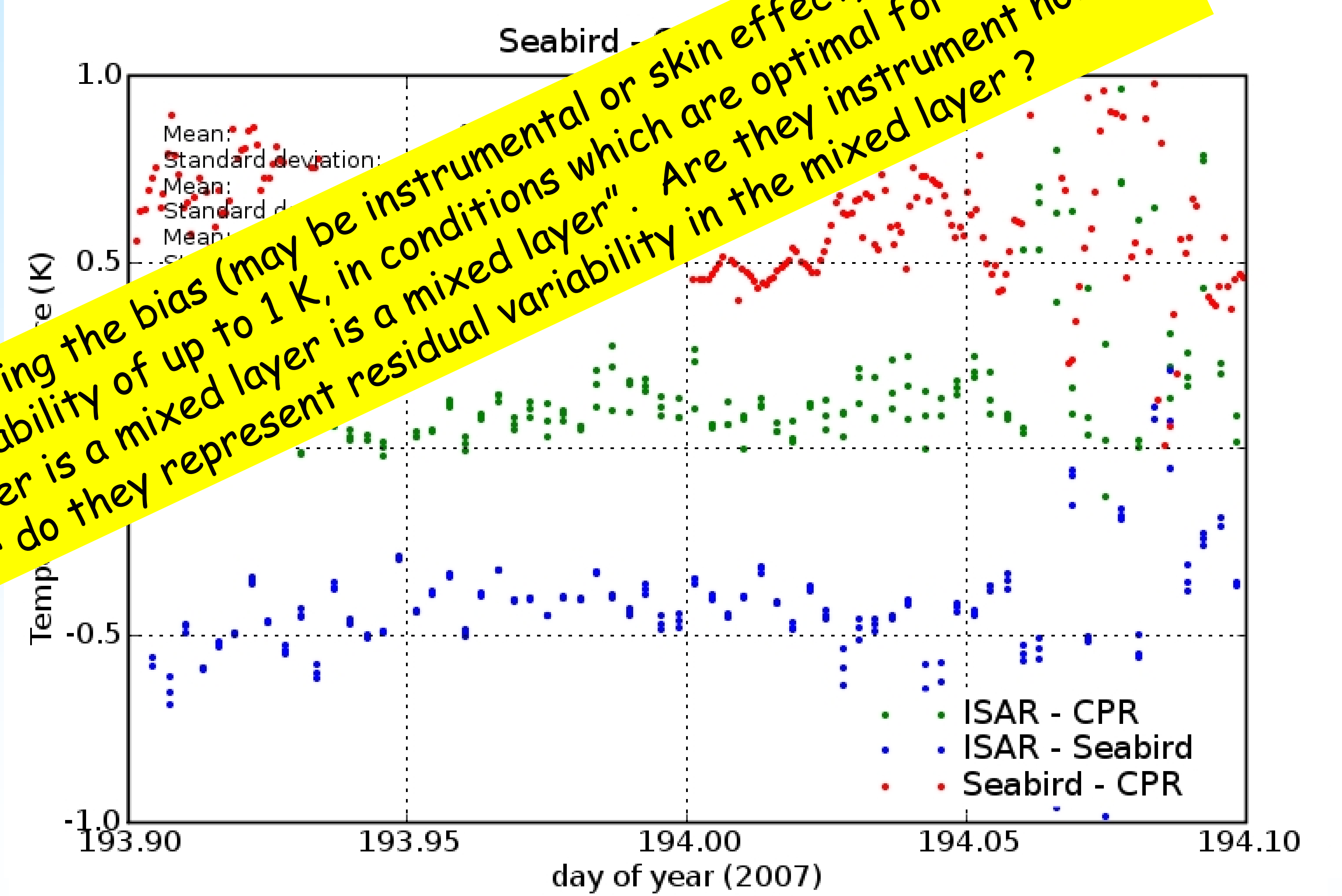


Night time deployment

Wind speed 5–10 m/s

Note the difference between the Hull thermometer and the CPR varies between 0 and 1 K

Comparisons between SeaBird (h… ISAR (skin) and CPR (towe…



Ignoring the bias (may be instrumental or skin effect) note the variability of up to 1 K, in conditions which are optimal for "a mixed layer is a mixed layer". Are they instrument noise or do they represent residual variability in the mixed layer ?

Managing with Jim – 2 : CASIX

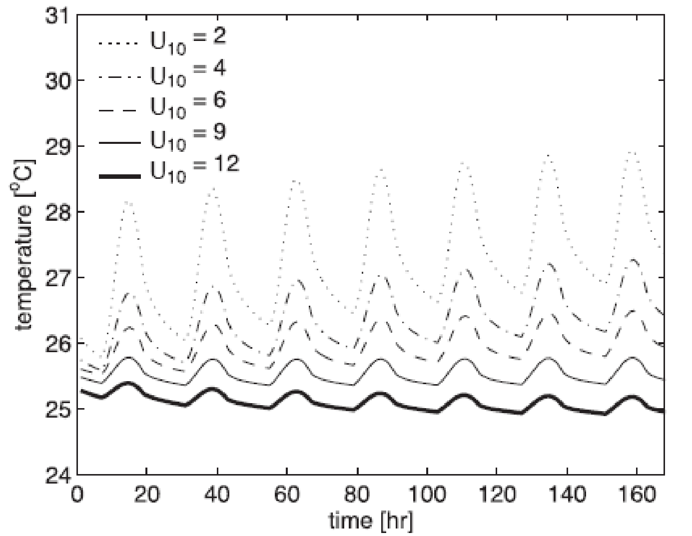
- Jim has led CASIX strongly and successfully
  - A truly multidisciplinary application of satellite remote sensing
  - Draws on all Jim's expertise and more besides
  - We have made significant progress in a challenging filed of science where collaboration and team work are critically essential
- Jim has built a truly collaborative project
  - He has recognised and nurtured the strengths f individuals
  - He has followed a collective, not an individual, vision
  - He established the basis for cross-institutional collaboration for ocean remote sensing in UK
- Once again he has nurtured the growth of new careers
  - New players, new PIs, new postdocs
  - Fostered the "CASIX Graduate School" – fertile ground to grow new talent – the next generation of satellite oceanographers.
  - It is the nature of new research talent to question old wisdom . . .

Impact of thermal structure on CO2 fluxes

- To make progress with SST variability we must apply Aiken's 3rd law
  - *"Every oceanographer is a modeller and every modeller should go to sea"*
  - Chris Jeffery provides a perfect illustration of this
- Recent work by Chris Jeffery
  - CASIX-supported PhD student at NOCS, about to submit thesis
  - Topic: air-sea gas exchange in tropical low-wind conditions
  - Has developed a version of GOTM to represent the mixing processes in the upper ocean and impact on CO2 exchange
  - 2 papers already published / 1 accepted
  - Here we look at one element of his work
    - Effect of diurnal variability on SST and air-sea CO2 exchange . . .

Model of diurnal variations of upper ocean temperatures and fluxes

- 1-D GOTM model uses a 2-equation k-ε turbulence closure
  - A well tested model verified against observational data
- Forced hourly with idealised cloud and wind diurnal profiles
  - Vary the relative phase of the wind, cloud and solar radiation
- Examine temperature and associated CO2 surface flux
  - Diurnal variability of:
  - SST
  - Depth of mixed layer



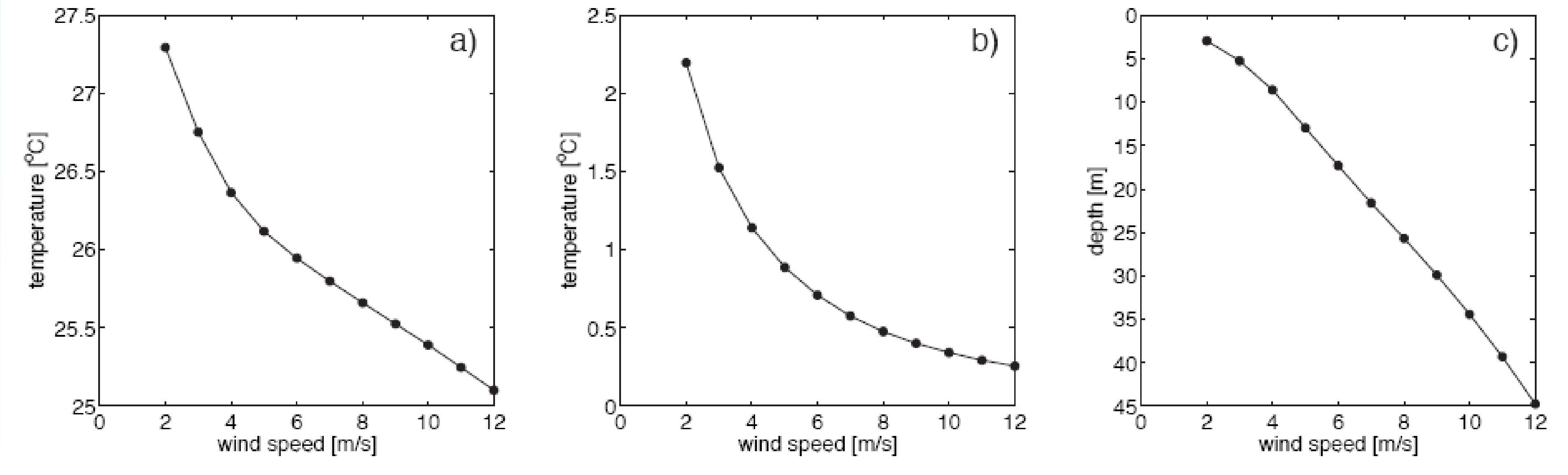
Time series of SST for uniform wind speeds of 2, 4, 6, 9 and 12 ms^{-1}.

Dependence of thermal structure on wind speed

Modelled period is 1-8 Feb 2002 at 10°S, 10°W

Wind is uniform over time

Skin SST, degC | **Diurnal range of T at 1m, degC** | **Diurnal layer depth, m**

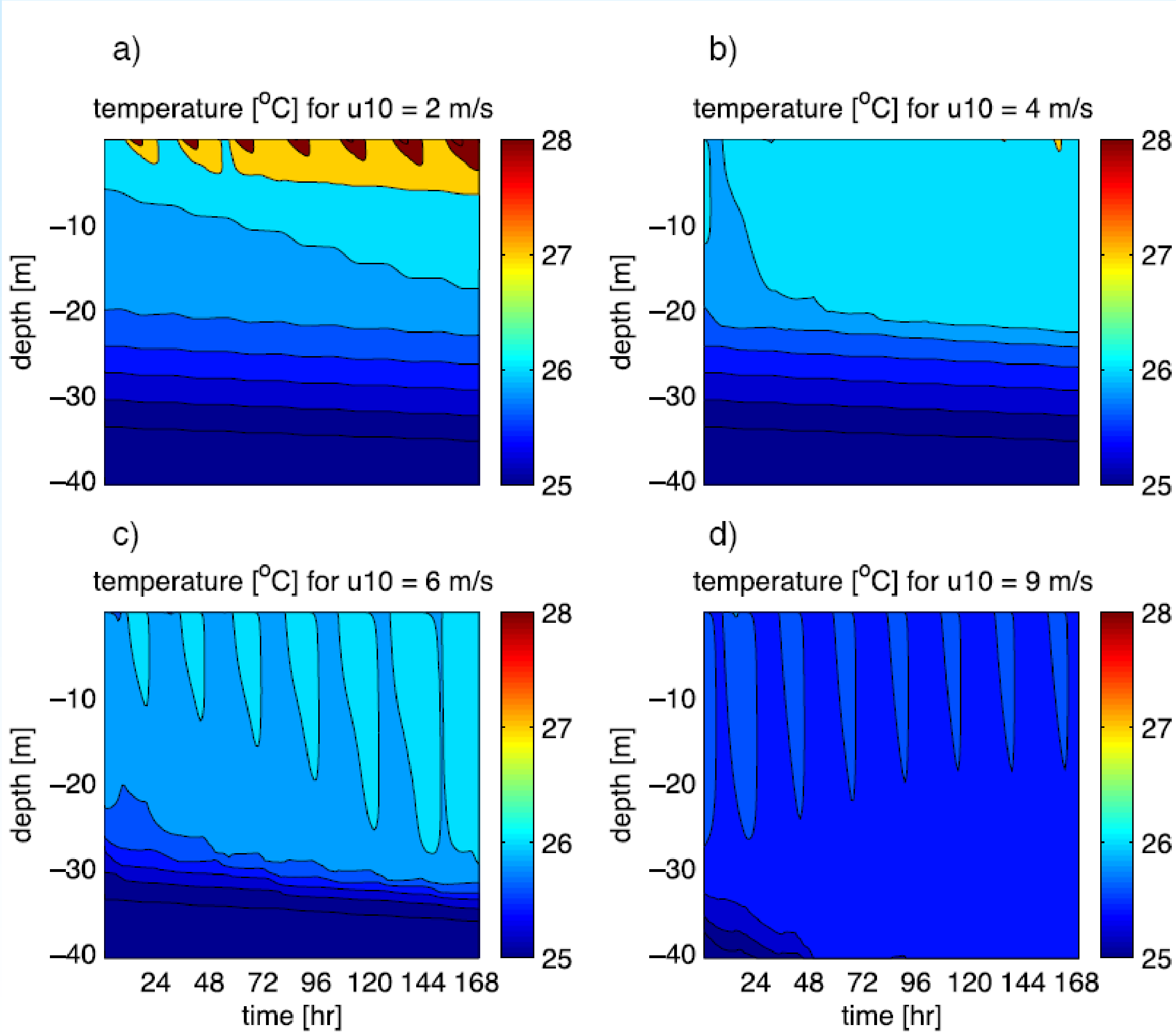


7-day evolution of temperature structure

Wind is uniform over time

2 ms^{-1}

4 ms^{-1}



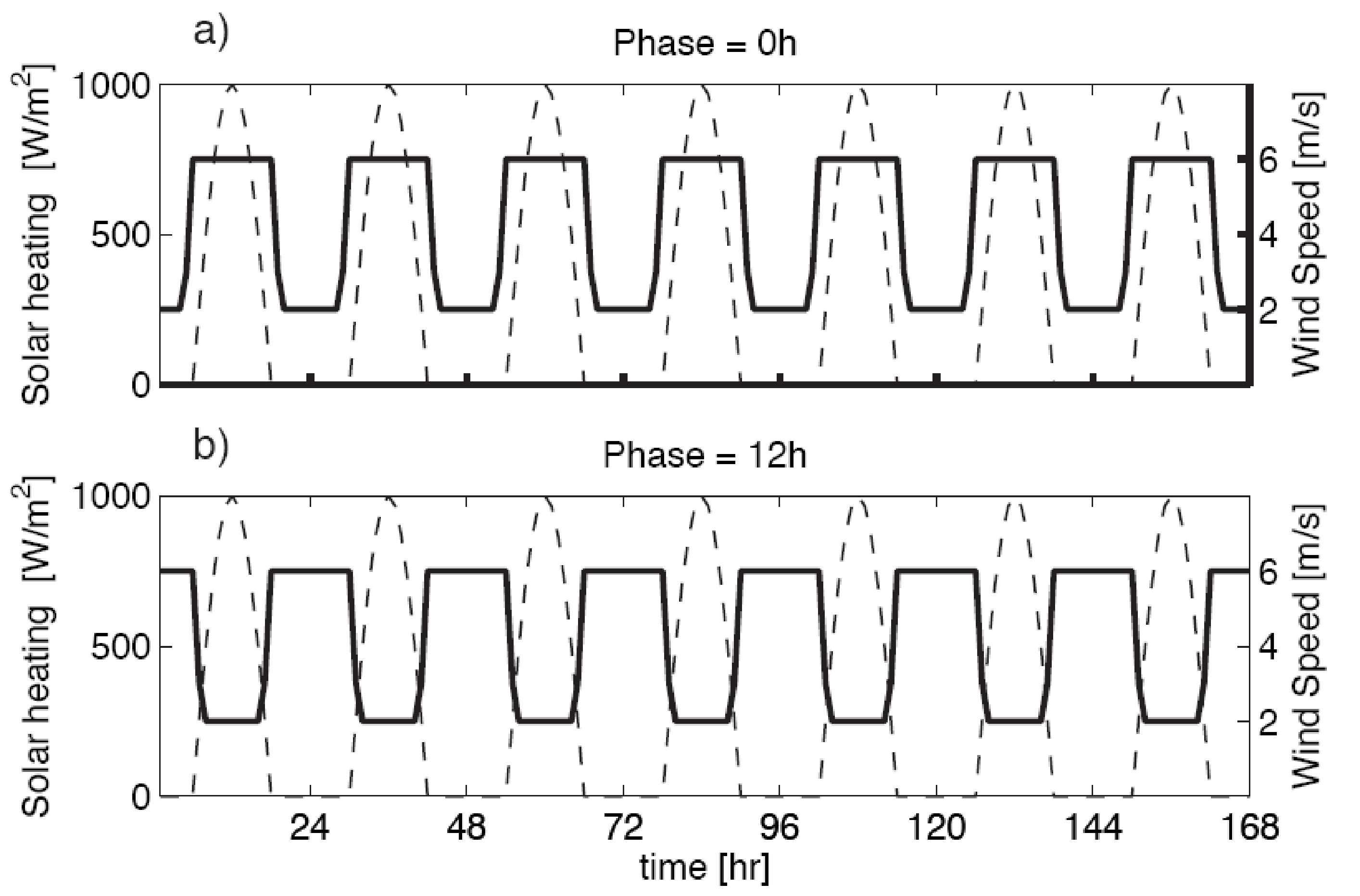
6 ms^{-1}

9 ms^{-1}

Experiments with variable winds at different phases relative to the solar heating

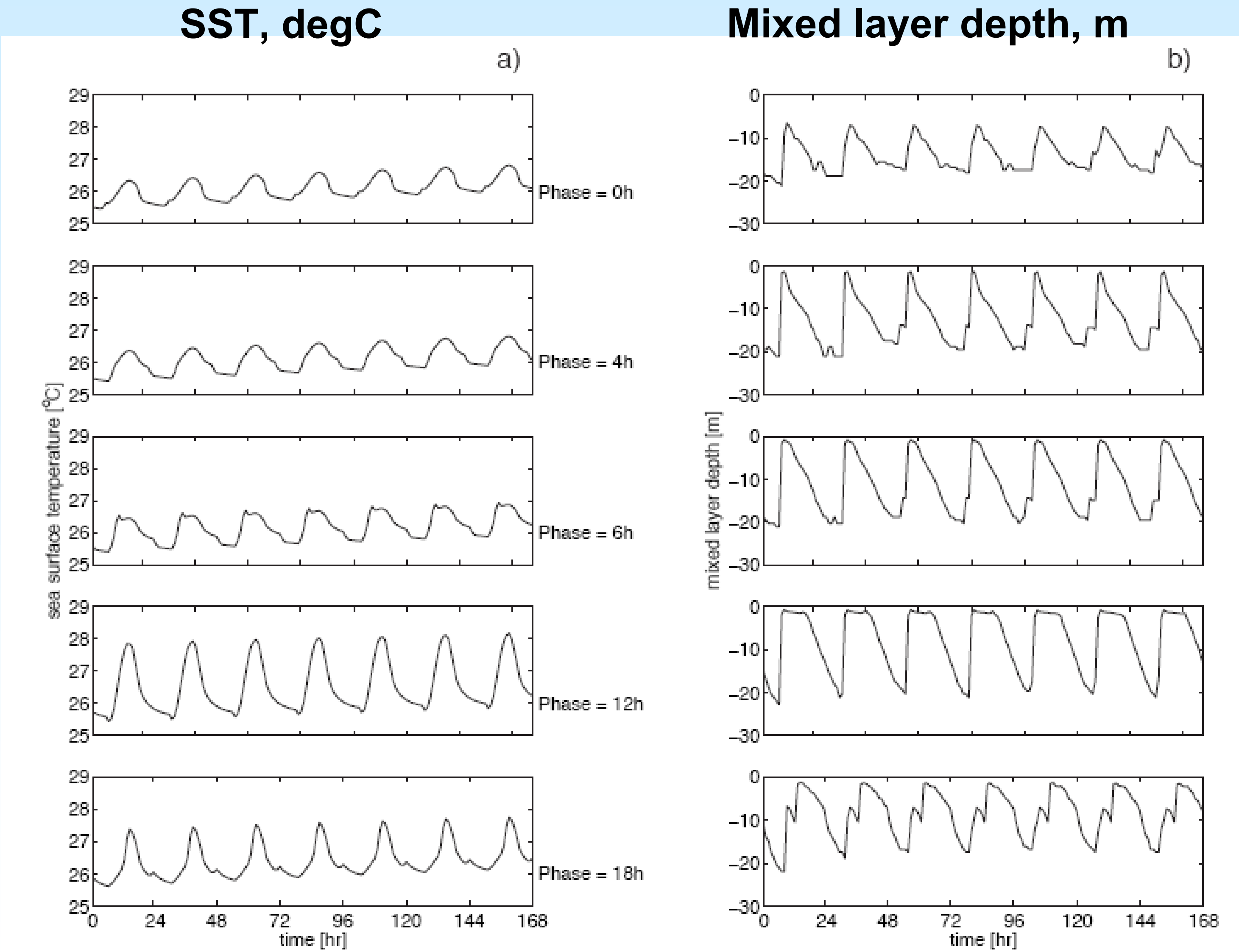
Solar heating = dashed line

Wind profile = solid line

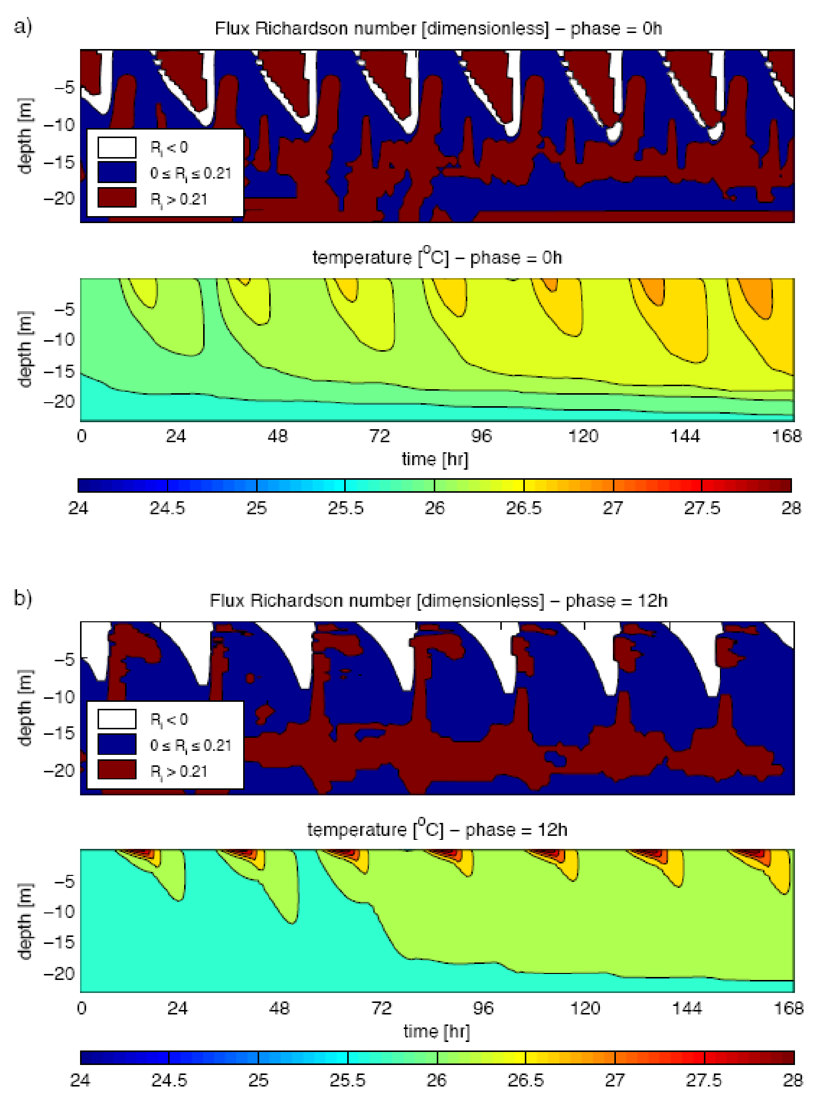


The model was run with full range of phase differences; 0 and 12 h are shown

Outcome of wind phase experiments



Outcome of wind phase experiments

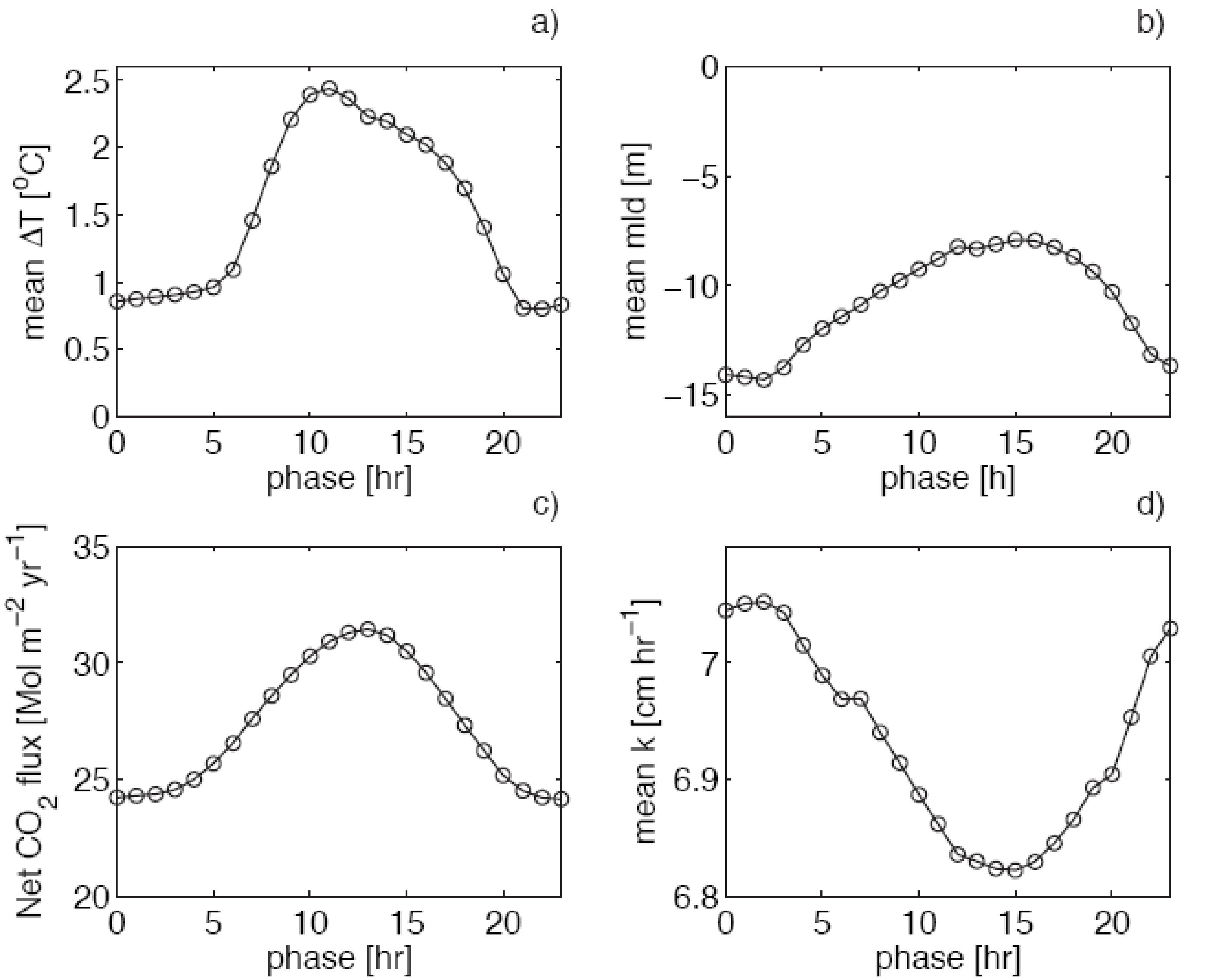


- The model allows us to explore the turbulent mixing processes
- Here the flux Richardson No. is mapped in depth v. time
- Identify mixing regimes
  - White = gravitationally unstable
  - Blue – Gravitationally stable but dynamically unstable
  - Brown = Stable – no / little mixing
- When wind opposes warming in phase note how the layered structure penetrates deeper
- A mixed layer is a mixed layer except when it's not a mixed layer
- What happens horizontally \/
  - We may expect variability associ-ated with spatial wind gradients

Wind-phase dependence of mean properties

ΔT

Mixed layer depth



Net CO2 flux

Gas transfer velocity

Conclusions

- Modelling and observations of thermal structure alert us to the fact that, even under relatively strong winds, mixing does not always imply uniformity of ocean properties.

- I propose a revision of Aiken's 1st law, with two corollaries:-

  A mixed layer is a mixed layer only when it's a mixed layer

  - A mixed layer is not necessarily uniform
  - Don't assume uniformity without evidence

- Jim Aiken has made a truly significant scientific contribution to how we use optics and ocean colour remote sensing to observe and understand marine ecosystems, bridging the gap between physicistsand ecologist.

- Jim has made a lasting contribution to UK marine science through leading, inspiring and facilitating the development of a new generation of ocean colour scientists.