# Incorporation of surface wave spectral information into an ocean turbulence model

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# Three-dimensional or one-dimensional models for ocean turbulence: why use a 1D model?

- Cheaper to run than 3D models
- Results may be easier to understand
- May be used to explain effects found in 3D simulations
- (e.g. Tang et al. JGR 2007, 3D + WAM, showed that wave-induced Stokes drift was one of the dominant contributions to surface drift)
- Can try out new parameterizations more quickly
- 1D code may be subsequently included in 3D model code.

## From Tang et al. JGR 2007, C0025

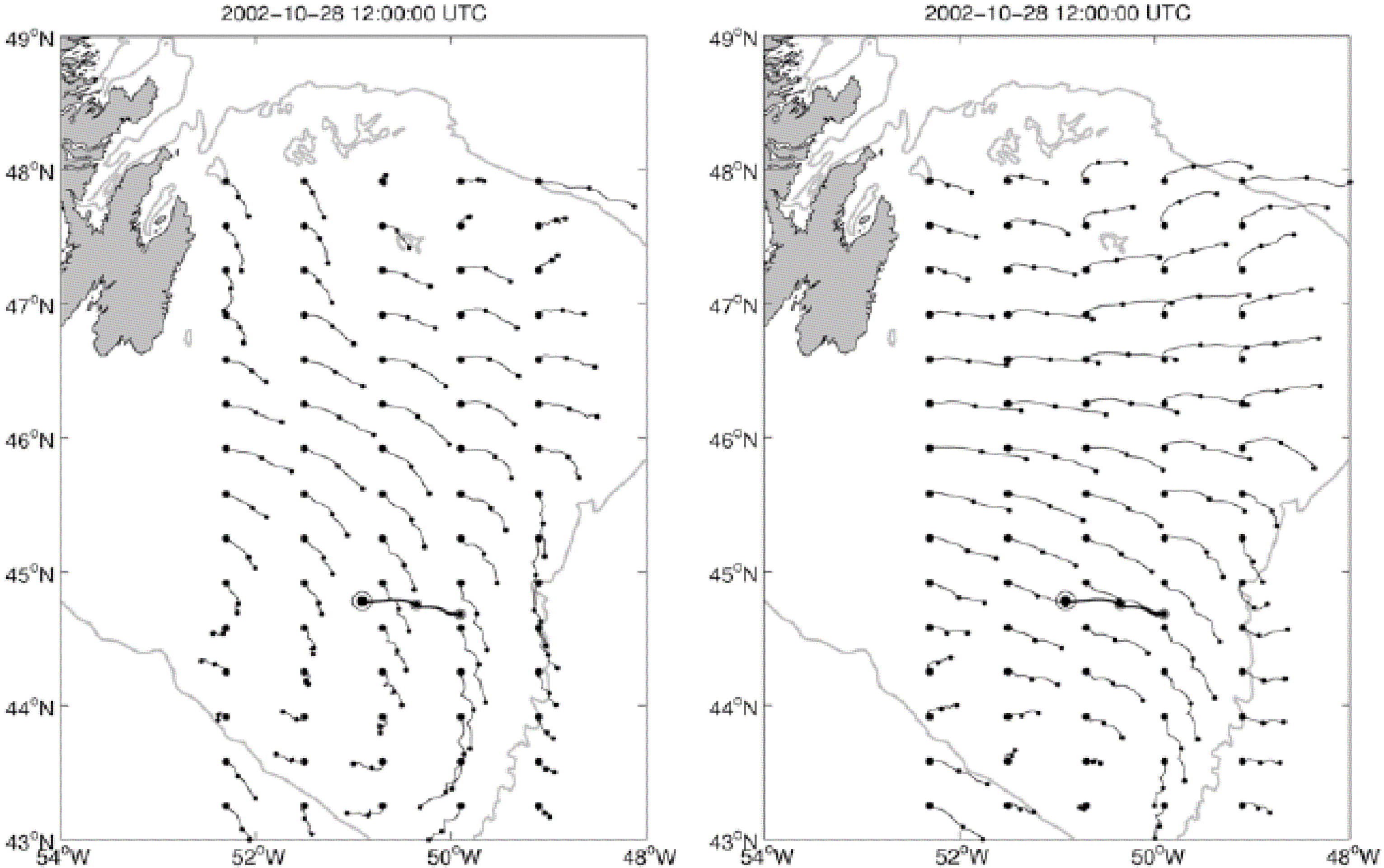


Fig. 8. Two-day model trajectories (October 28, 1200 to October 30, 1200) without (left panel) and with (right panel) the wave effects from the model (thin lines). The thick lines are the observed trajectory in the same period. The solid circles (model) and the open circles (observation) denote the start point.

# From Tang et al. JGR 2007, C0025

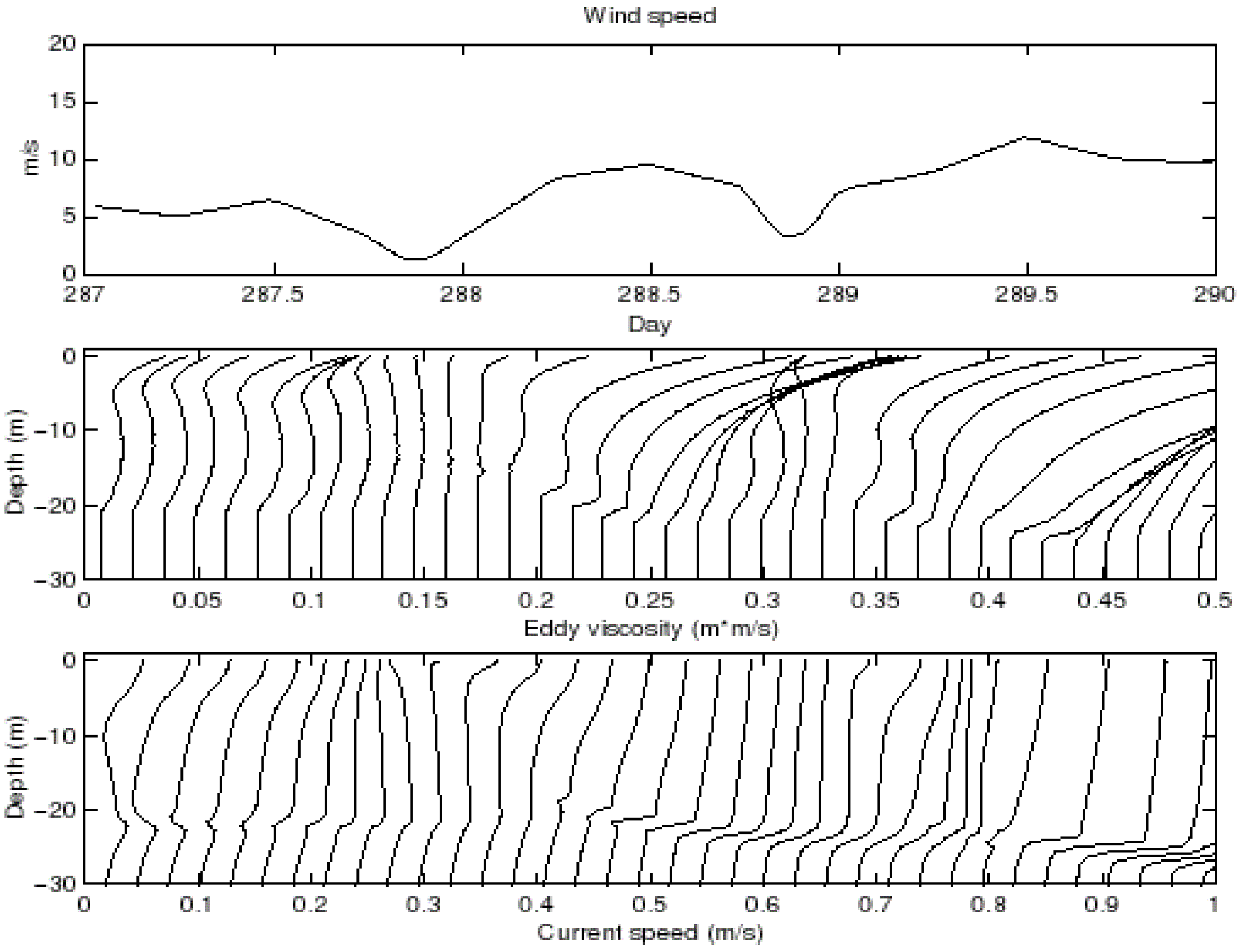


Fig. 2. Wind speed time series (upper panel), vertical profiles of eddy viscosity (middle panel) and current speed (lower panel) computed for Day 287-290, 2002 (October 14-17) at 45.4° N, 51.1°W (central Grand Banks) from an 1-d version of POM. The scales of the x-axis of the lower two panels are for the first profiles only. Successive profiles are offset by 0.0138 $m^2s^{-1}$ in the eddy viscosity and 0.0278 $ms^{-1}$ in the speed plots. The positions of the profiles correspond to the times of the upper panel.

From Tang et al. JGR 2007, C0025

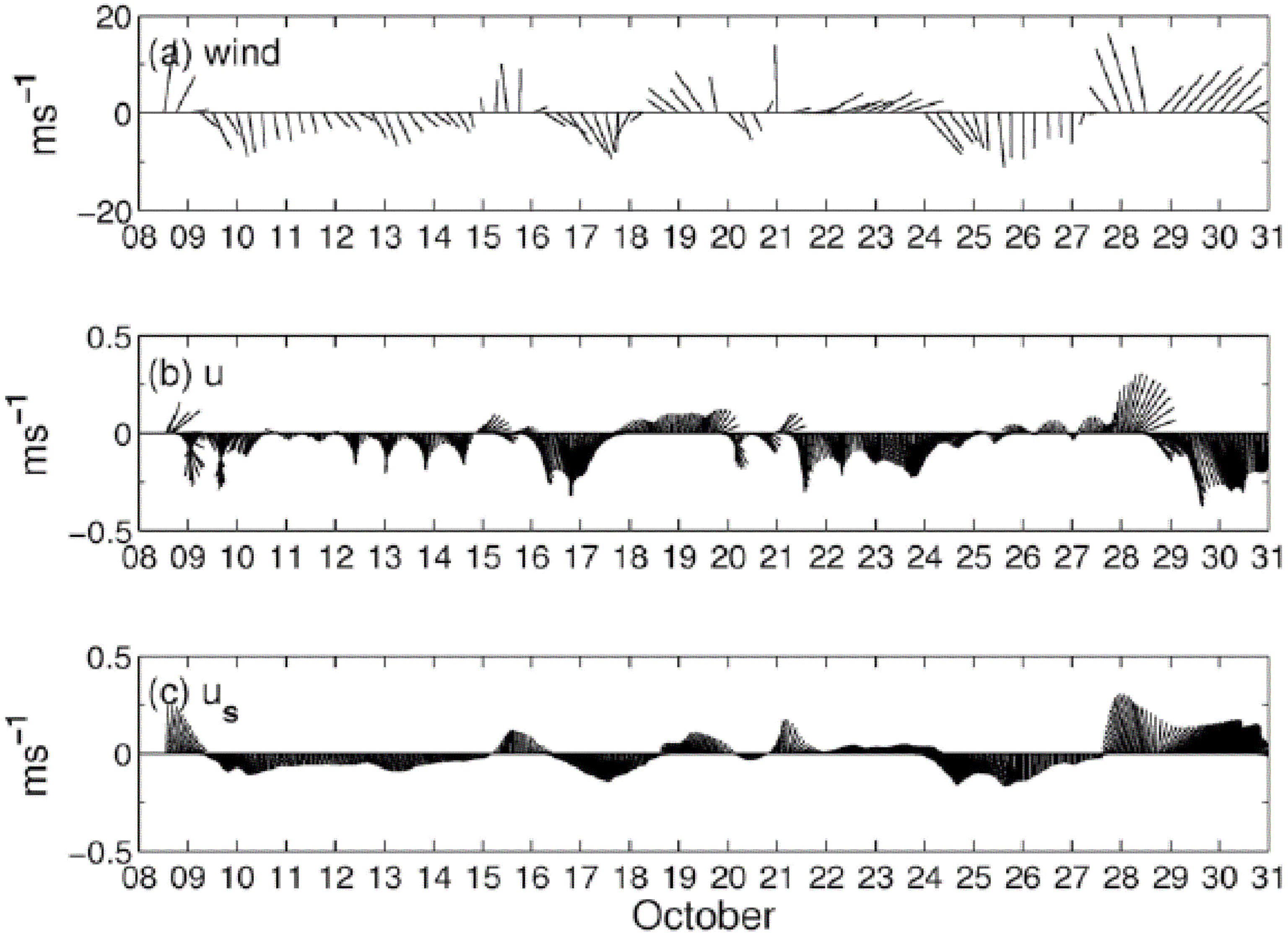


Fig. 10. Time series of (a) winds; (b) **u** from POM (c) the Stokes drift, $\mathbf{u}_s$, from WaveWatch3 at 46°N, 50°W.

# 1D ocean turbulence model - GOTM

- **Developed by Hans Burchard and colleagues (Burchard et al. 1999 etc.)**
- **Freely available from www.gotm.net**
- **Modular and flexible**
- **Choice of turbulence closure schemes (*k-ε*, *k-l*, *k-ω*, non-local schemes)**
- **Variables: velocity, temperature, salinity, ... ($O_2$), ...**
- **Air-sea interaction module for wind stress, heat flux etc.**
- **Generation of turbulent kinetic energy (TKE) from surface wave breaking via Craig & Banner (1994) formulation**
- **Model has been applied to marine ecology, sediment transport, gas diffusion etc.**

## Current modified GOTM implementation

- Added an explicit representation of surface wave effects in spectral form
- Wave momentum, Stokes drift
- Momentum and TKE flux associated with wave energy input ($S_{in}$) and dissipation by wave breaking ($S_{ds}$)

# Example of modification to GOTM model code

```
   integer                              :: i
   REALTYPE                             :: ua,omega,cosomeg
------------------------------------------------------------
------------------------------------------------------------
------------------------------------------------------------
!
!-----------------------------------------------------------
!BOC

   omega=cori*dt
   cosomega=cos(omega)
   sinomega=sin(omega)

   do i=1,nlev
------------------------------------------------------------
------------------------------------------------------------
------------------------------------------------------------
------------------------------------------------------------
------------------------------------------------------------
------------------------------------------------------------
      ua=u(i)
      u(i)= u(i)  *cosomega+v(i)*sinomega
      v(i)=-ua    *sinomega+v(i)*cosomega
------------------------------------------------------------
   end do

   return
   end subroutine coriolis
!EOC

+ +--  3 lines: !-------------------------------------------
~
<ling/GOTM/gotm-cvs_adj/src/meanflow/coriolis.F90
```

```
   integer                              :: i
   REALTYPE                             :: ua,omega,cosom
#if WAVE_DRIFT
   REALTYPE                             :: va
#endif
!
!-----------------------------------------------------------
!BOC

   omega=cori*dt
   cosomega=cos(omega)
   sinomega=sin(omega)

   do i=1,nlev
#ifdef WAVE_DRIFT
      ua=u(i)+pwave_x(i)
      va=v(i)+pwave_y(i)
      u(i)= ua*cosomega+va*sinomega
      v(i)=-ua*sinomega+va*cosomega
#else
      ua=u(i)
      u(i)= u(i)  *cosomega+v(i)*sinomega
      v(i)=-ua    *sinomega+v(i)*cosomega
#endif
   end do

   return
   end subroutine coriolis
!EOC

+ +--  3 lines: !-------------------------------------------
~
</GOTM/gotm-3.3.x_adj/src/meanflow/coriolis.F90
```

```
    Files [A]/modules/IFORT/time.mod and [B]/modules/IFORT/time.mod differ
    Files [A]/modules/IFORT/util.mod and [B]/modules/IFORT/util.mod differ
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    Files [A]/src/Rules.make and [B]/src/Rules.make differ
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    Files [A]/src/meanflow/friction.F90 and [B]/src/meanflow/friction.F90 differ
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    Files [A]/src/observations/observations.F90 and [B]/src/observations/observations.F90 differ
    Files [A]/src/output/output.F90 and [B]/src/output/output.F90 differ
/tmp/v513623/0
```

## Model run:

- 300m water depth, 16 x 8 wave components
- Time-dependent, spatially uniform wind-wave spectrum - modified JONSWAP spectrum, according to Donelan, Hamilton & Hui, with duration-constrained significant wave height according to Özger & Şen (Ocean Engng 2007):

$$H_{m0}/(1\ \text{m}) = 0.0146[t/(1\ \text{h})]^{5/7}\,[U/(1\ \text{m/s})]^{9/7}$$

| ***t*/(1 h)** | **$H_{m0}$/(1 m) for U = 20 m/s** |
|---|---|
| 0 | 0 |
| 1 | 0.69 |
| 2 | 1.13 |
| 3 | 1.51 |
| 6 | 2.47 |
| 12 | 4.05 |
| 18 | 5.42 |
| 24 | 6.65 |
| 36 | 8.89 |
| 48 | 10.91 |

- Non-uniform grid, finer near surface and bottom
- *k*-$\omega$ turbulence scheme
- Momentum equation in terms of “quasi-Eulerian” current. Stokes drift and Coriolis-Stokes term added separately (Andrews & McIntyre 1978; Jenkins 1986 JPO)
- Upper boundary condition: Wind-to-wave momentum flux associated with wave energy input $S_{in}$, subtracted from applied wind stress (Jenkins 1986 JPO; 1989 DHZ).
- Extra momentum source term associated with wave energy dissipation $S_{ds}$ (Jenkins 1987; 1989), distributed as exp(2*kz*)
- Slip bottom boundary condition
- Northerly wind 20 m/s, -15°C
- Initial surface-layer temperature gradient (quickly becomes approximately uniform)

## Balance of wave momentum

- The rate of change of the wave energy spectrum (in wavenumber **(k)** space, advected with the wave group velocity), is given by the sum of source terms, $S_{in}(\mathbf{k}) + S_{nl}(\mathbf{k}) + S_{ds}(\mathbf{k})$.
- For surface gravity waves in deep water, the nonlinear wave-wave interaction term $S_{nl}(\mathbf{k})$ has the property that it conserves energy, momentum, and wave action, so that the integrals of $S_{nl}(\mathbf{k})$, $(\mathbf{k}/\sigma)S_{nl}(\mathbf{k})$, and $S_{nl}(\mathbf{k})/\sigma$ over the whole spectrum are all zero. ($\sigma$ is the intrinsic angular frequency.)
- It is important to consider this when employing a spectral wave model which uses parameterizations to extrapolate $S_{nl}(\mathbf{k})$ in the high-wavenumber tail (see Jenkins 1989).

## Balance of wave momentum

- In this study I do not use a wave model (yet).

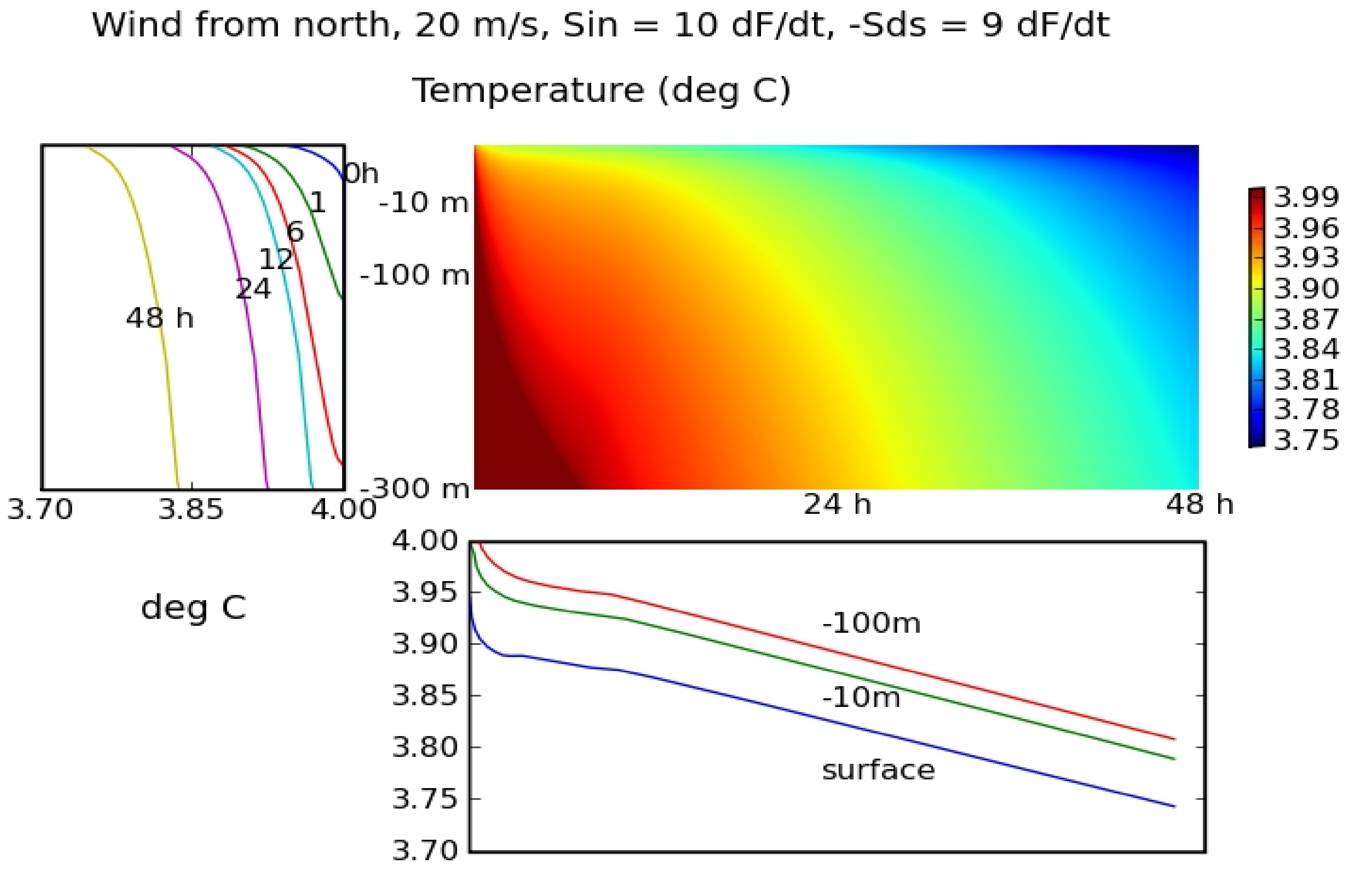
- In the horizontally-uniform wave spectral energy equation

$dF(\mathbf{k})/dt = S_{in}(\mathbf{k}) + S_{nl}(\mathbf{k}) + S_{ds}(\mathbf{k})$,

I assume that $S_{nl}(\mathbf{k}) = 0$ and that

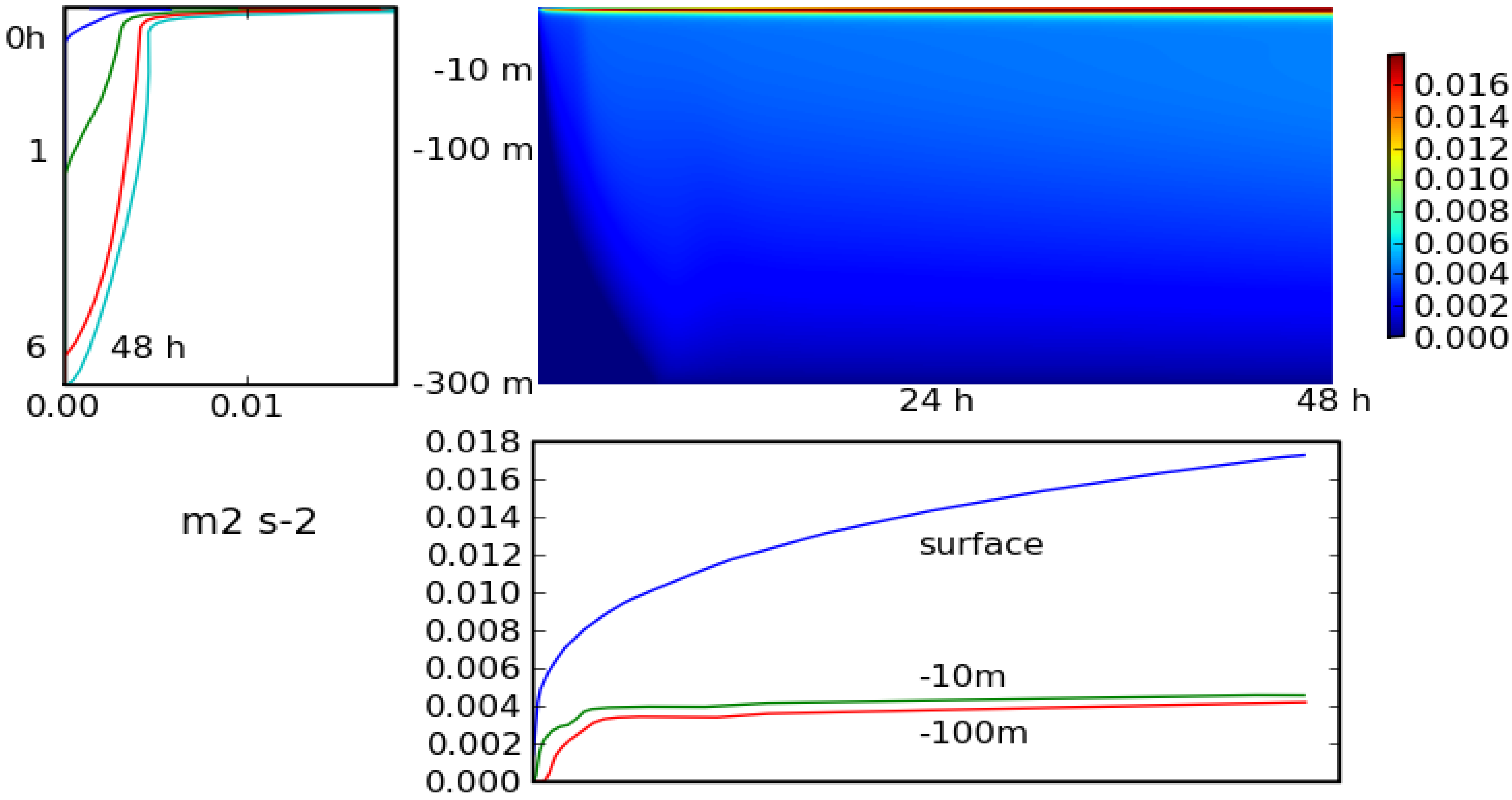
$S_{in}(\mathbf{k}) = 10\, dF(\mathbf{k})/dt;\ -S_{ds}(\mathbf{k}) = 9\, dF(\mathbf{k})/dt$,

which is consistent with the fact that most of the momentum transferred to surface waves from the applied wind stress is quickly dissipated and transferred to the current locally.


Wind from north, 20 m/s, Sin = 10 dF/dt, -Sds = 9 dF/dt
Temperature (deg C)
0h
1
6
12
24
48 h
-10 m
-100 m
-300 m
3.70
3.85
4.00
24 h
48 h
3.99
3.96
3.93
3.90
3.87
3.84
3.81
3.78
3.75
deg C
4.00
3.95
3.90
3.85
3.80
3.75
3.70
-100m
-10m
surface

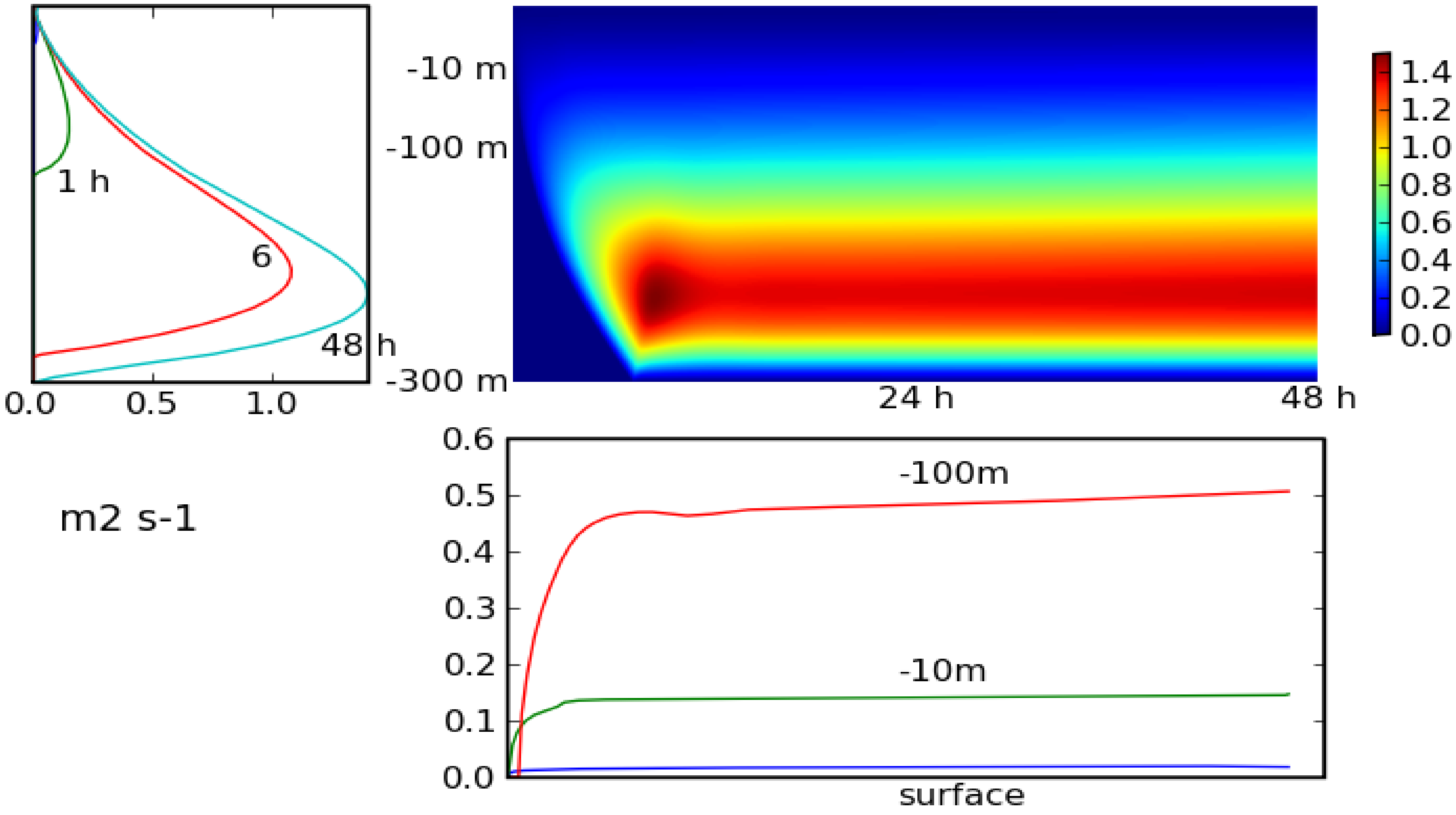
Wind from north, 20 m/s, Sin = 10 dF/dt, -Sds = 9 dF/dt

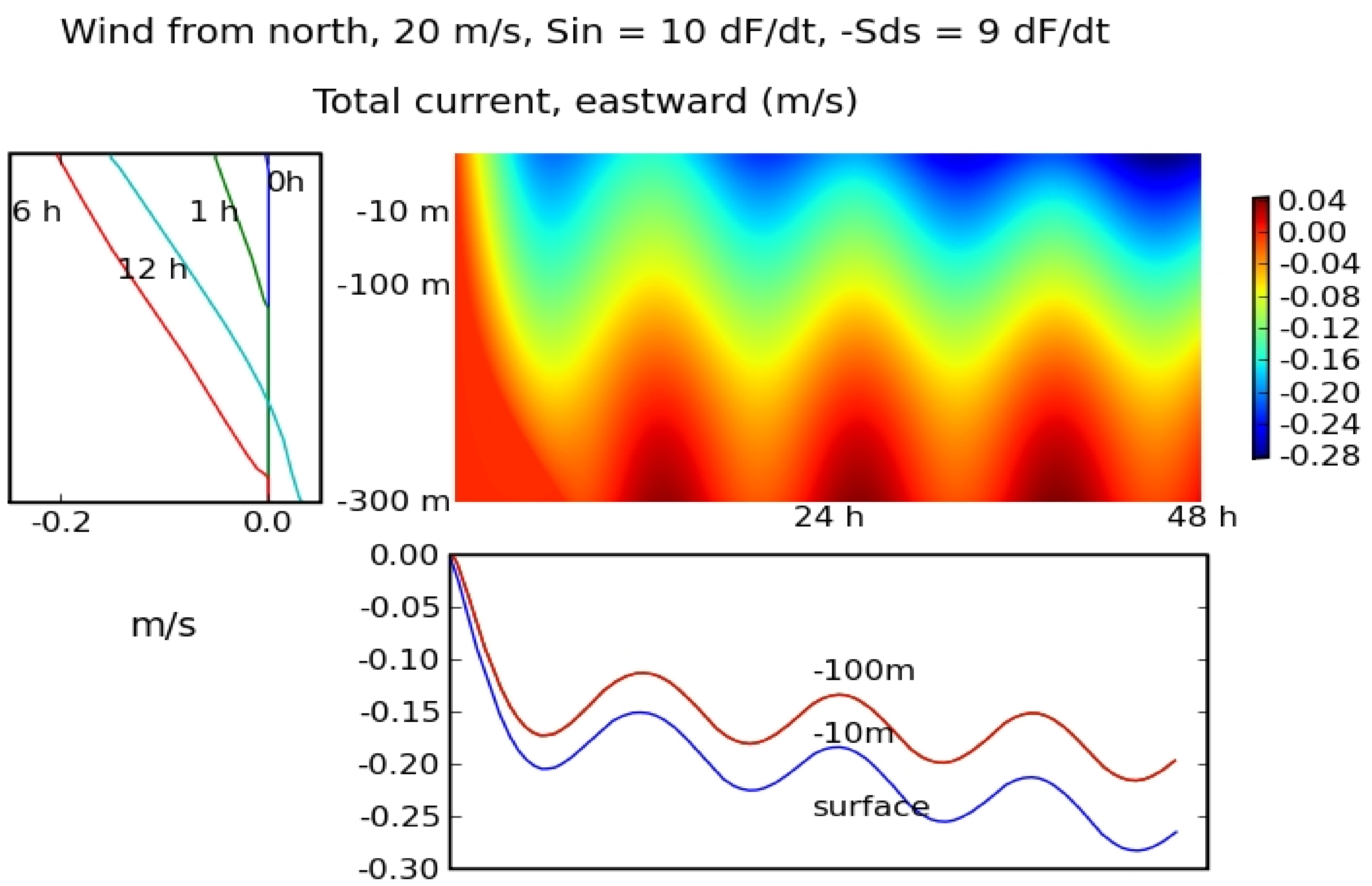
Turbulent kinetic energy (m2/s2)



## Wind from north, 20 m/s, Sin = 10 dF/dt; -Sds = 9 dF/dt

## Eddy viscosity (m2 s-1)

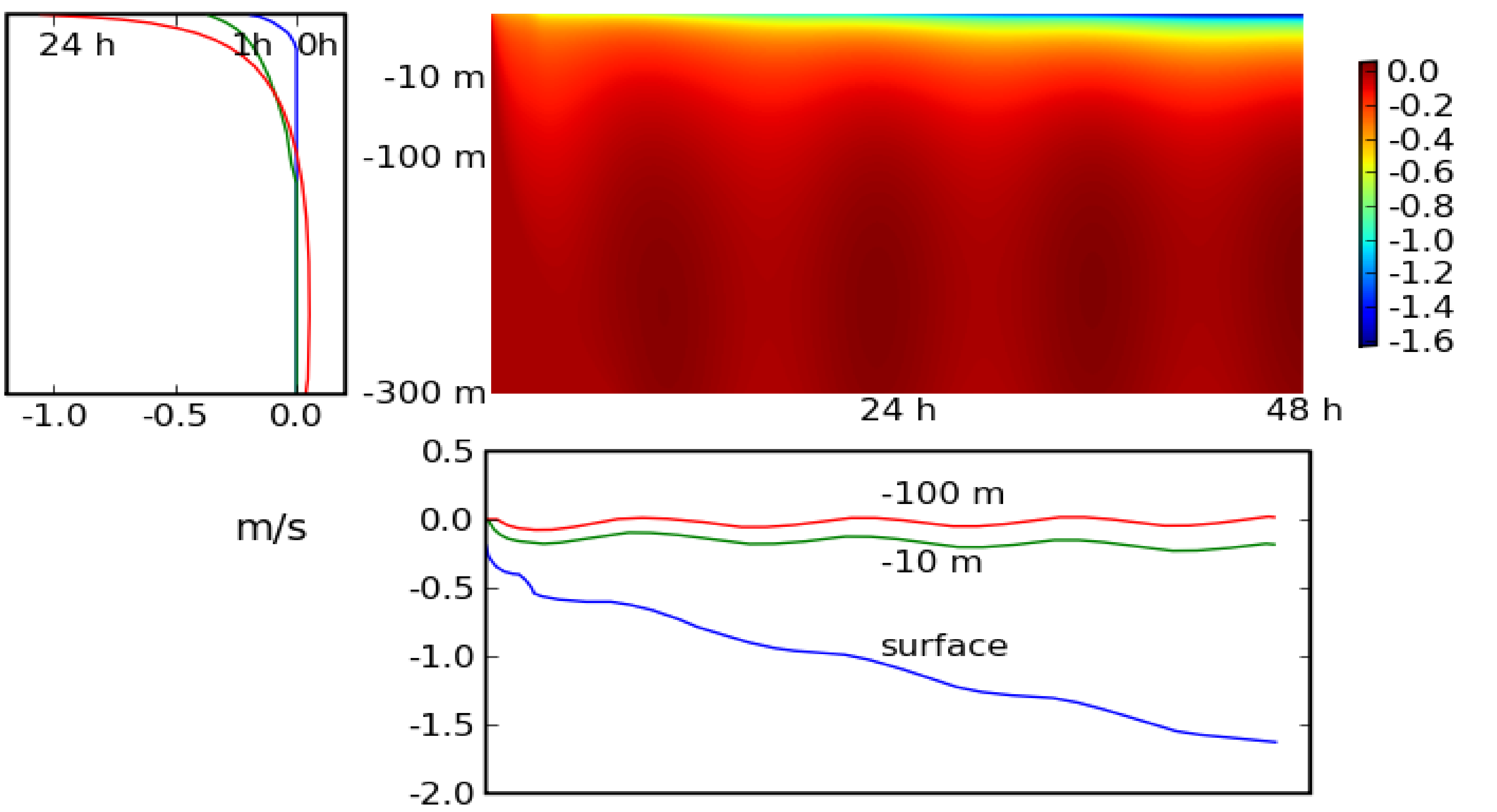




Wind from north, 20 m/s, Sin = 10 dF/dt, -Sds = 9 dF/dt
Total current, eastward (m/s)
0h
6 h
1 h
12 h
-0.2
0.0
m/s
-10 m
-100 m
-300 m
24 h
48 h
0.04
0.00
-0.04
-0.08
-0.12
-0.16
-0.20
-0.24
-0.28
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
-100m
-10m
surface

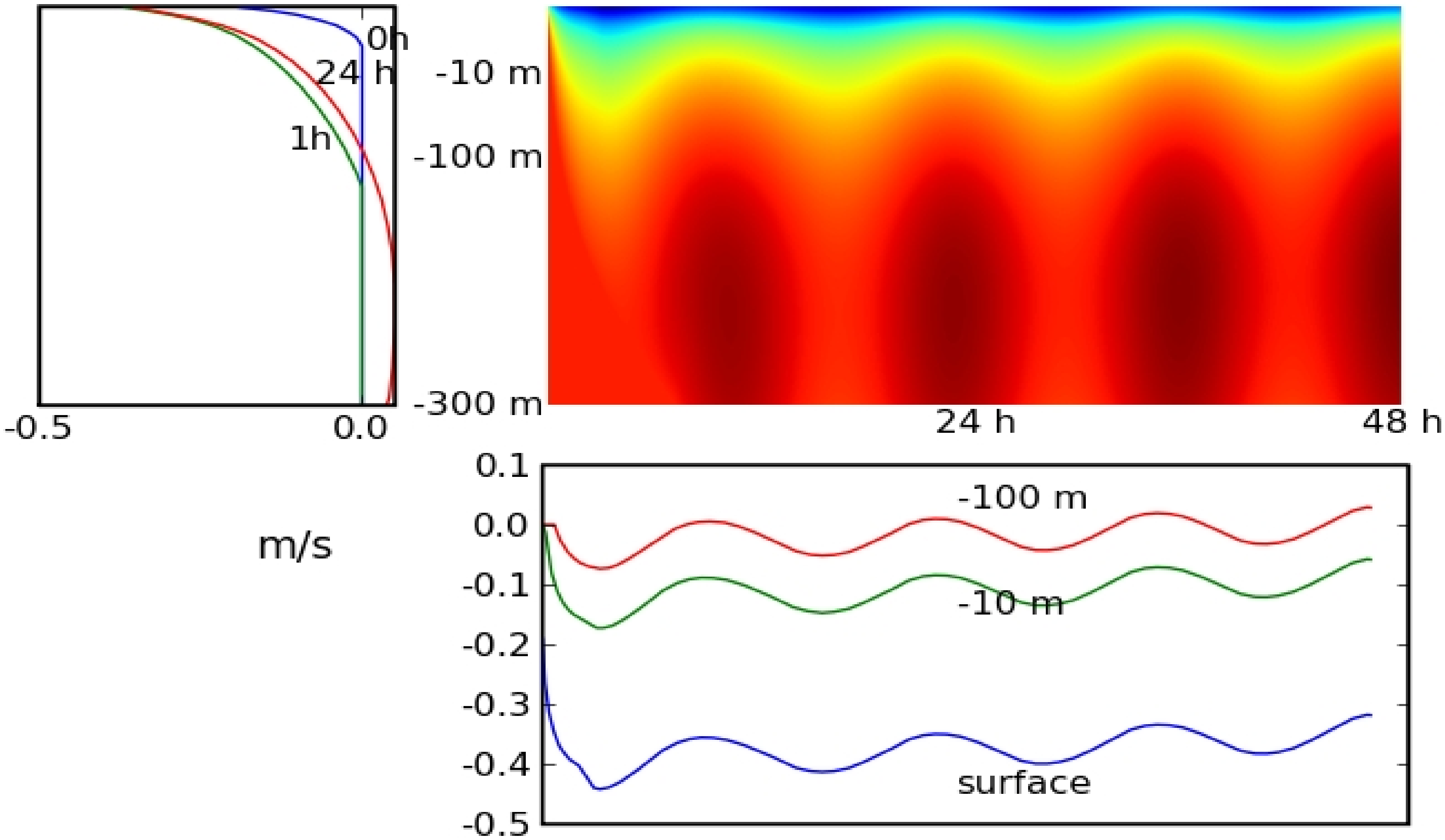
Wind from north, 20 m/s, Sin = 10 dF/dt, -Sds = 9 dF/dt

Total current, northward (m/s)



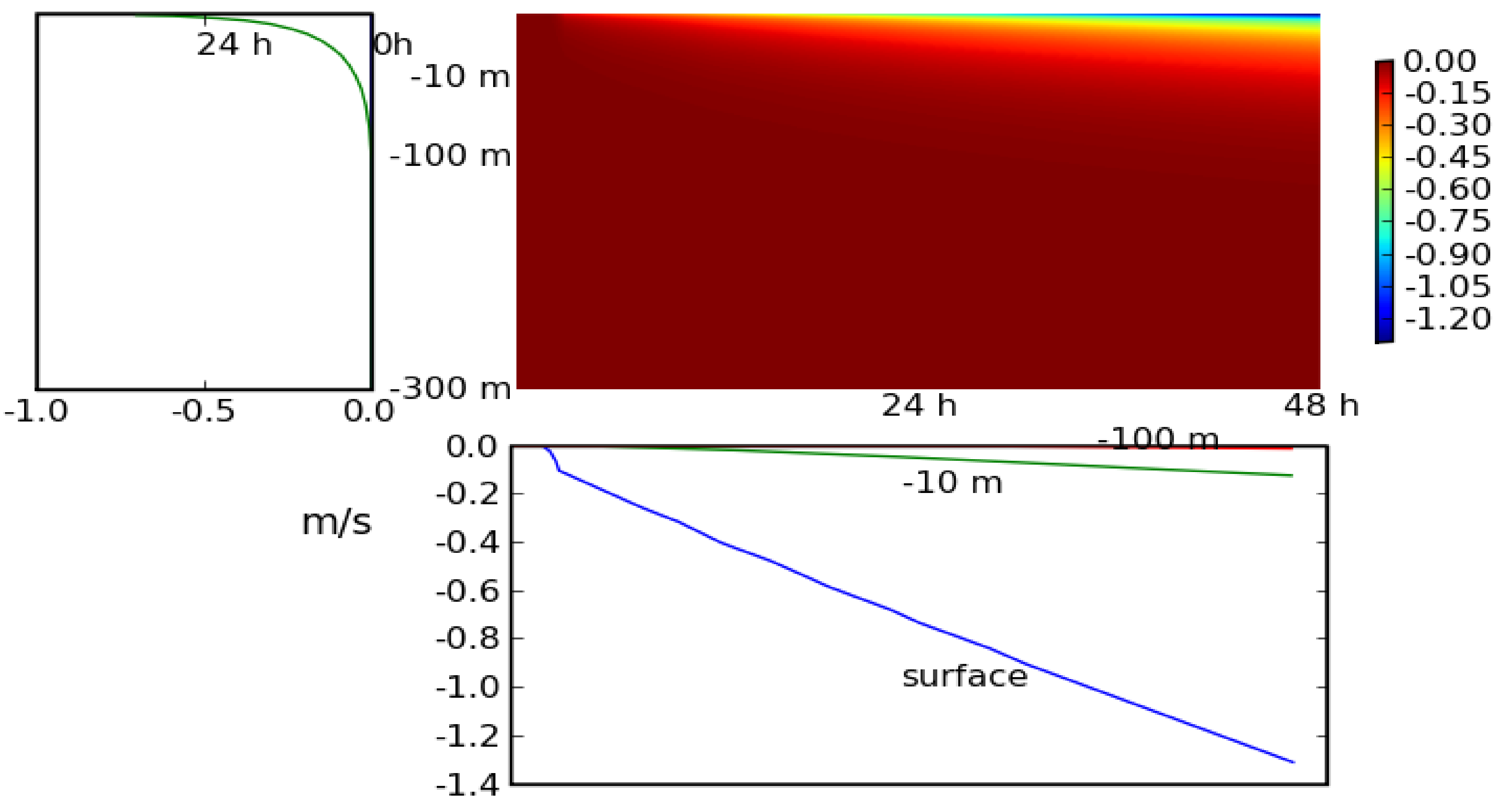
Wind from north, 20 m/s, Sin = 10 dF/dt, -Sds = 9 dF/dt

Quasi-Eulerian current, northward (m/s)



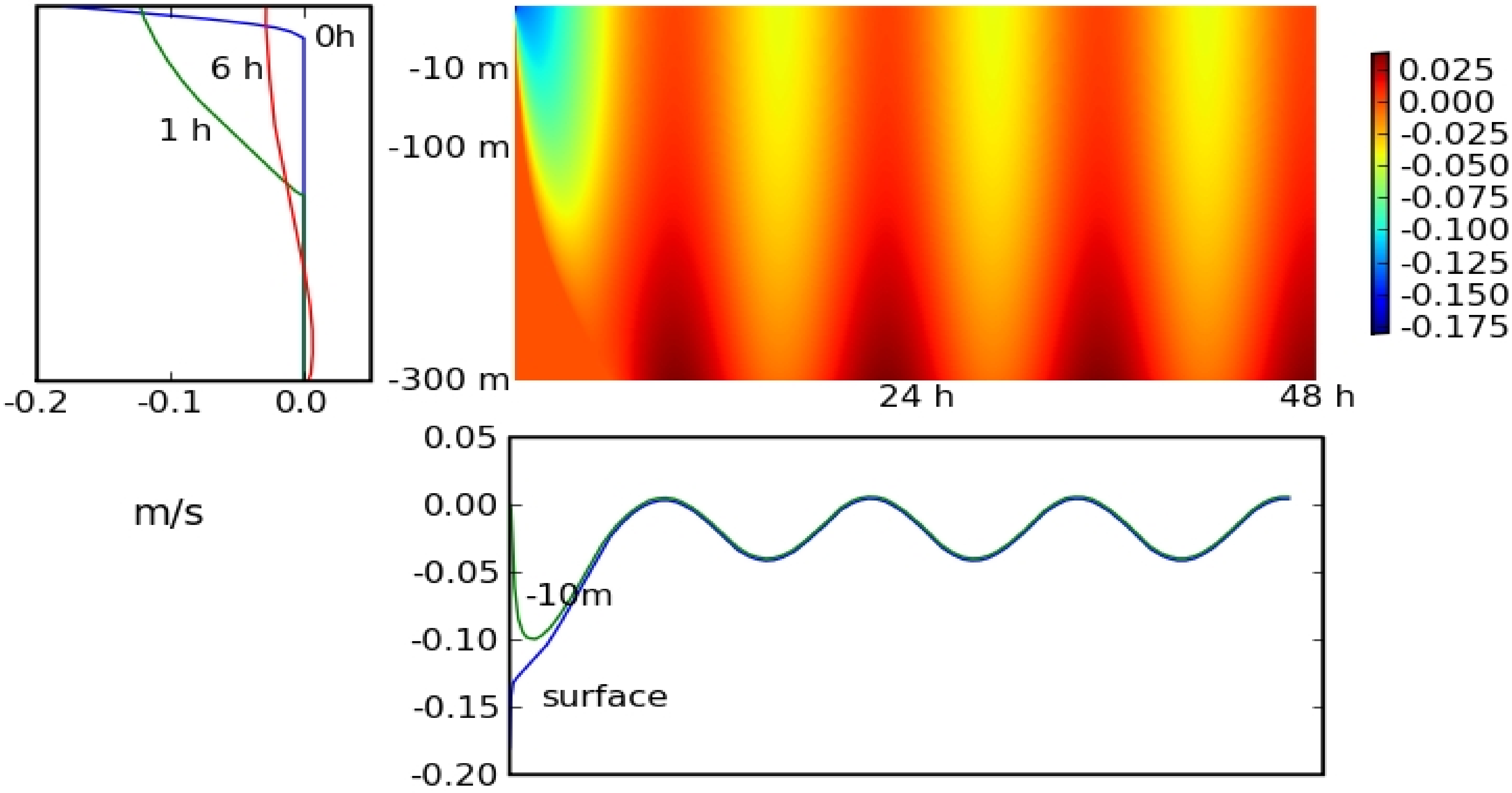
## Wind from north, 20 m/s, Sin = 10 dF/dt, -Sds = 9 dF/dt

Stokes drift, northward (m/s)



Wind from north, 20 m/s, no waves

Total current, northward (m/s)



## Discussion/conclusion

- I have presented preliminary results on the effect of surface waves on GOTM ocean hydrodynamic/turbulence model performance: some “tuning” will be required before a more detailed comparison with measurements is performed
- Qualitatively, the dominance of the Stokes drift for the near-surface current is consistent with field studies and the model of Tang et al. (2007)
- Simple JONSWAP horizontally-uniform non-model wave field requires revision. Specifically, the Stokes drift appears to be unrealistically large for this particular model run wave spectrum.
- Future work should include:
  - Incorporation of a simple but consistently momentum-conserving wave model
  - More detailed look at evolution of temperature/salinity/density
  - Coupling to a self-consistent model of atmospheric boundary layer