Deutscher Wetterdienst
Wetter und Klima aus einer Hand

DWD

Air-Sea Interaction for ICON

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conservation.org

air-sea interaction – processes, time-scales, model

Typhoon, MJO, satellite DA, fluxes (rad, sens, lat) depend on ocean skin temperature

- diurnal to multi-day processes dominated by ocean mixed-layer (mostly local)
- seasonal to climate involve deep ocean dynamics

Observations, Verification

- typhoons in ICON compared with best track observations (Nadine Schittko, Christian Grams, Dominik Büeler)
- SST in ICON (OSTIA, parameterization) compared drift bouys (Felix Fundel, Mengjuan Julia Liu)
- SST from forward operator compared to Meteosat 10µm channel (Robin Faulwetter)

Model hierarchy

- cool skin and warm layer (SST diurnal warming)
- extension of FLAKE to ocean mixed-layer (Dmirtii Mironov)
- ocean mixed-layer model off- or on-line in ICON (Marie-Léa Pouliquen, Bjorn Stevens, James Ruppert)
- full dynamical ocean model (ICON or NEMO)

Zeng and Beljaars (2005)

- Cool skin
- Warm layer

t_g SST

$$T_{sk} = T_{-d} + \underbrace{(T_{-\delta} - T_{-d})}_{\Delta T_{warm}} + \underbrace{(T_{sk} - T_{-\delta})}_{\Delta T_{cold}}$$

OSTIA foundation SST from UK Met Office

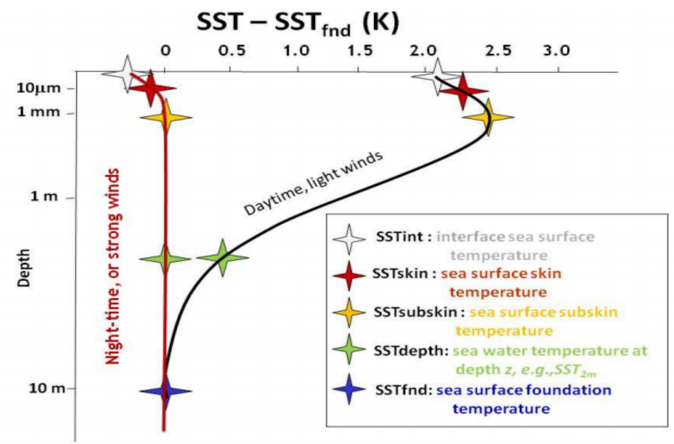


Figure 1. Cartoon of near-surface temperature gradients. The numbers on the axes are for guidance only and to not represent rigorously derived scales. Variability exists in both the temperature and depth scales.

Cool skin, Zeng & Beljaars (IFS documentation)

The cool ocean skin is the result of heat loss to the atmosphere which is balanced by thermal conduction in the quasi-laminar sublayer near the water surface. Scaling arguments for the skin layer lead to the following expression for the temperature difference over the skin layer (cf. Fairall *et al.*, 1996)

$$T_{\mathrm{sk}} - T_{-\delta} = \frac{\delta}{\rho_{\mathrm{w}} c_{\mathrm{w}} k_{\mathrm{w}}} (Q + R_{\mathrm{s}} f_{\mathrm{s}}) \tag{8.151}$$

$$\text{with } Q = H + \lambda E + LW \tag{8.152}$$

where T_{sk} is the skin temperature, $T_{-\delta}$ is the temperature below the cool skin, R_{s} is the net solar radiation at the surface, f_{s} is the fraction of solar radiation absorbed in the skin, H is the sensible heat flux, λE is the latent heat flux, LW is the net long wave radiation at the surface, ρ_{w} (=1025 kgm^{-3}) is the density of sea water (at the surface), c_{w} (=4190 Jkg^{-1}K^{-1}) is the volumetric heat capacity of water, and k_{w} (=0.6 Wm^{-1}K^{-1}) is the molecular thermal conductivity of water. The fraction of solar absorbed radiation is given by

$$f_{\mathrm{s}} = 0.065 + 11\delta - \frac{6.6\,10^{-5}}{\delta}\left(1 - e^{-\delta/0.0008}\right) \tag{8.153}$$

$$\tag{8.154}$$

The thickness of the skin layer δ is (Fairall *et al.*, 1996)

$$\delta = 6\left[1 + \left(\frac{-16 g \alpha_{\mathrm{w}} \nu_{\mathrm{w}}^3}{u_{*\mathrm{w}}^4 k_{\mathrm{w}}^2 \rho_{\mathrm{w}} c_{\mathrm{w}}} (Q + R_{\mathrm{s}} f_{\mathrm{s}})\right)^{3/4}\right]^{-1/3} \tag{8.155}$$

where g is the acceleration of gravity, $\alpha_{\mathrm{w}} = \max(10^{-5}, 10^{-5}(T_{-d} - 273))$ is the thermal expansion coefficient of water and ν_{w} (=1.0 10^{-6} m^{2}s^{-1}) is the kinematic viscosity.

Warm layer, Zeng & Beljaars (IFS documentation)

In the IFS a simple bulk formulation is used based on similarity temperature profiles. It results in the following differential equation for the difference between the temperature just below the cool skin (less than a millimetres deep) $T_{-\delta}$ and the ocean bulk temperature a few metres deep T_{-d}

$$\frac{\partial(T_{-\delta}-T_{-d})}{\partial t}=\frac{Q+R_{\mathrm{s}}-R(-d)}{d\rho_{\mathrm{w}}c_{\mathrm{w}}\nu/(\nu+1)}-\frac{(\nu+1)ku_{*\mathrm{w}}}{d\phi_t(d/L)}(T_{-\delta}-T_{-d}) \qquad (8.156)$$

where d (=3 m) is the depth scale of the warm layer, ν (=0.3) is the profile shape parameter and $\phi_t(d/L)$ is the stability function with L for the Obukhov length. The solar radiation at depth $-d$ is

$$R(-d)=R_{\mathrm{s}}\Sigma_{i=1}^{3}a_i e^{-db_i} \qquad (8.157)$$

with $(a_1, a_2, a_3)=(0.28, 0.27, 0.45)$ and $(b_1, b_2, b_3)=(71.5, 2.8, 0.06\,\mathrm{m}^{-1})$. The stability function is

$$\begin{aligned}\phi_t(-z/L) &= 1+5\frac{-z}{L} \qquad for\,\frac{-z}{L}\geq 0\\ &= (1-16\frac{-z}{L})^{-1/2}\ for\ \frac{-z}{L}<0\end{aligned} \qquad (8.158)$$

The Obukhov length is

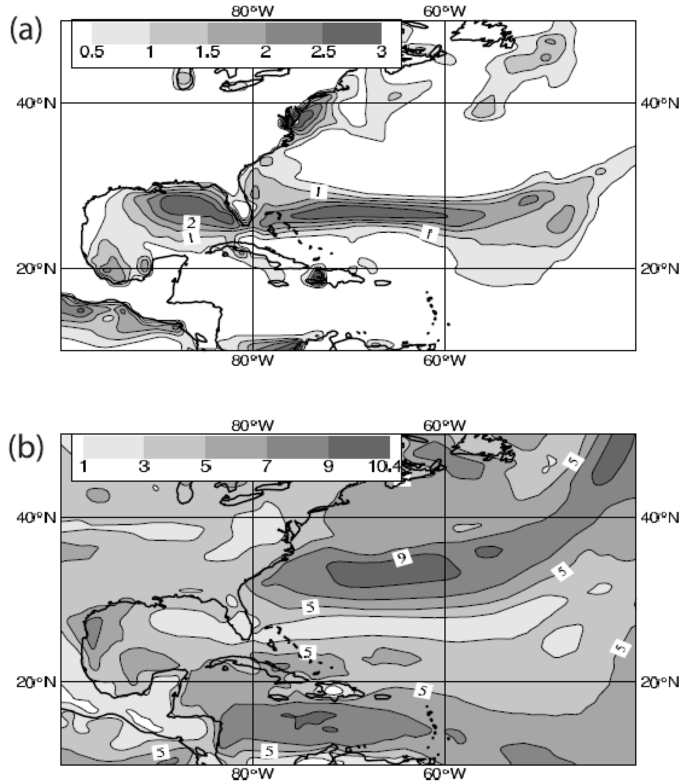
$$L=\rho_{\mathrm{w}}c_{\mathrm{w}}u_{*\mathrm{w}}^{3}/(kF_d) \qquad (8.159)$$

The buoyancy flux F_d is

$$\begin{aligned}F_d &= g\alpha_{\mathrm{w}}[Q+R_{\mathrm{s}}-R(-d)] \qquad for\,(T_{-\delta}-T_{-d})\leq 0\\ &= \left(\frac{\nu g\alpha_{\mathrm{w}}}{5d}\right)^{1/2}\rho_{\mathrm{w}}c_{\mathrm{w}}u_{*\mathrm{w}}^{2}(T_{-\delta}-T_{-d})^{1/2}\ \ for\,(T_{-\delta}-T_{-d})>0\end{aligned} \qquad (8.160)$$

Zeng, Beljaars, 2005
prognostic SST: cold skin & warm layer

20-22 May 1998
20-12 UTC



SST

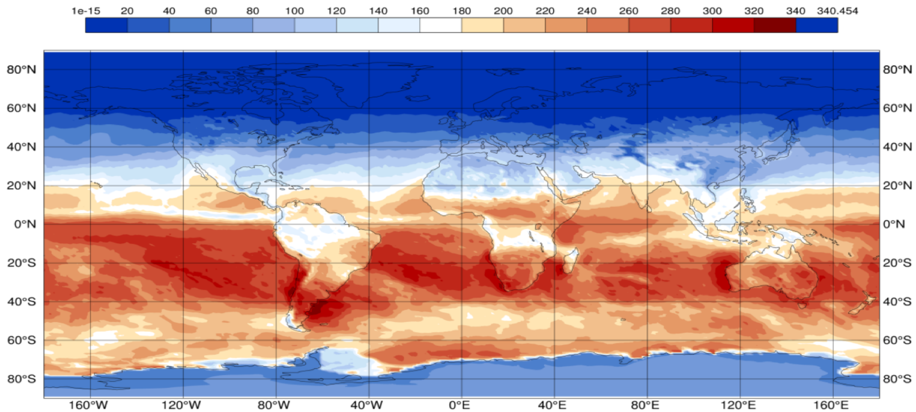
surface wind (average)

Figure 3. (a) The averaged T_s difference (K) between 2000 UTC and 1200 UTC, 20–22 May 1998 based on the ECMWF model along with the new T_s scheme; and (b) the averaged surface wind (m/s).

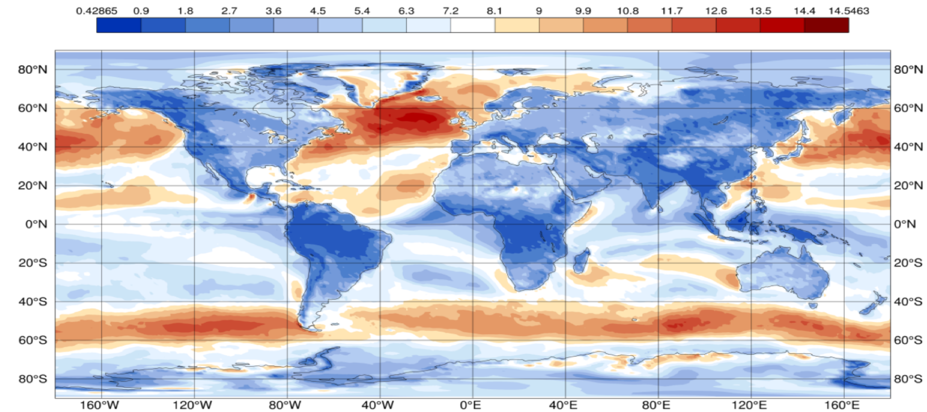
clear sky and low wind conditions

Jan 2018

Net Surface Solar FCh ERA5
Min: 1e-15 Max: 342.4 Mean: 170 RMS: 192.2

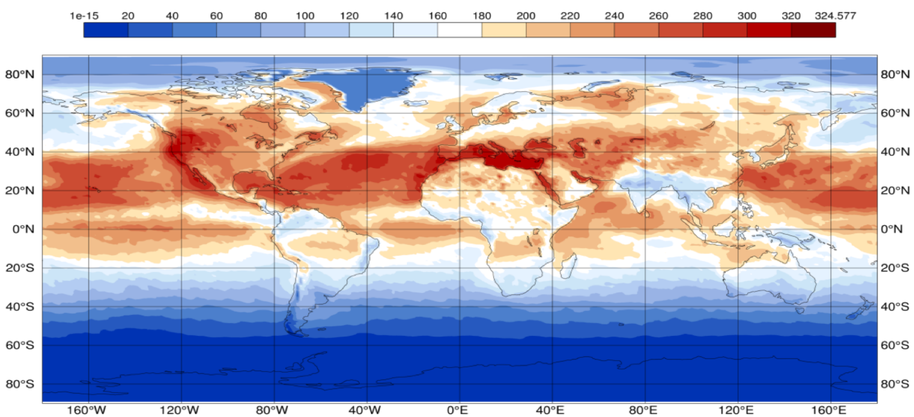


Wind Speed ANA ERA5
Min: 0.3557 Max: 14.55 Mean: 6.253 RMS: 6.795

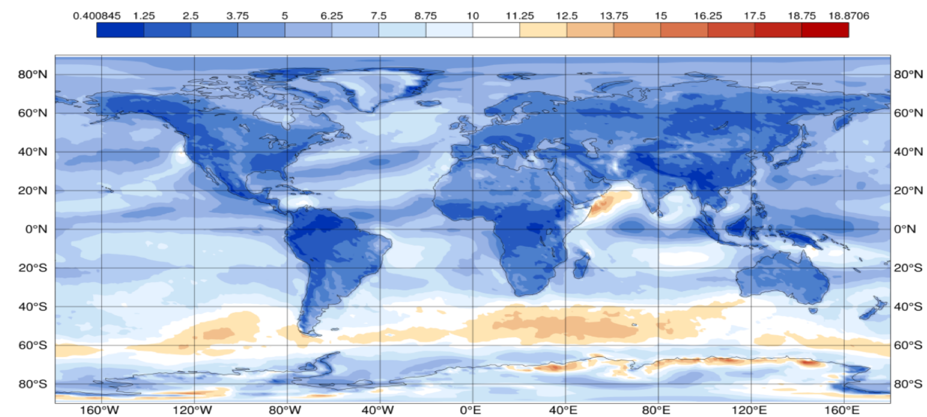


Jul 2017

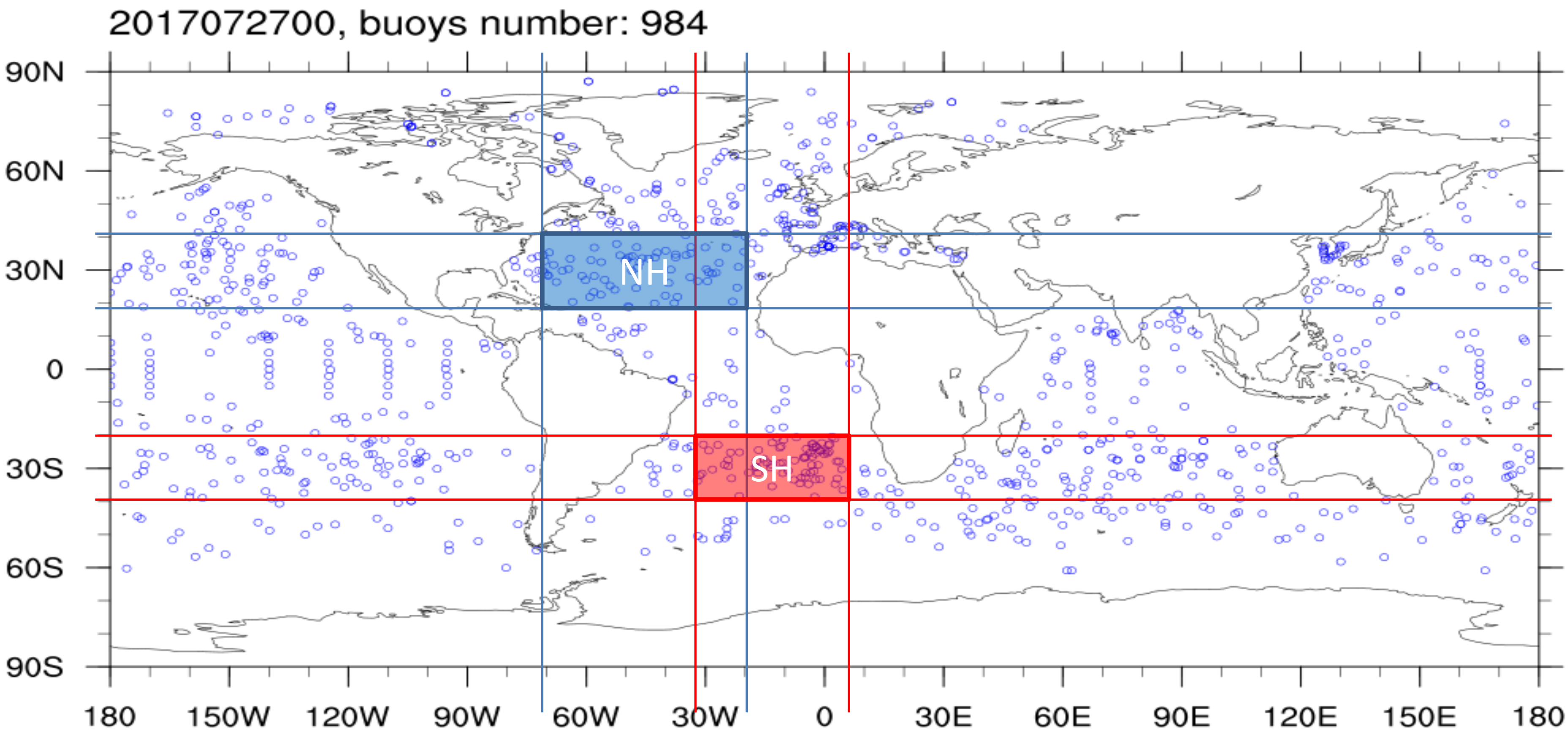
Net Surface Solar FCh ERA5
Min: 1e-15 Max: 330.7 Mean: 156.4 RMS: 175.6



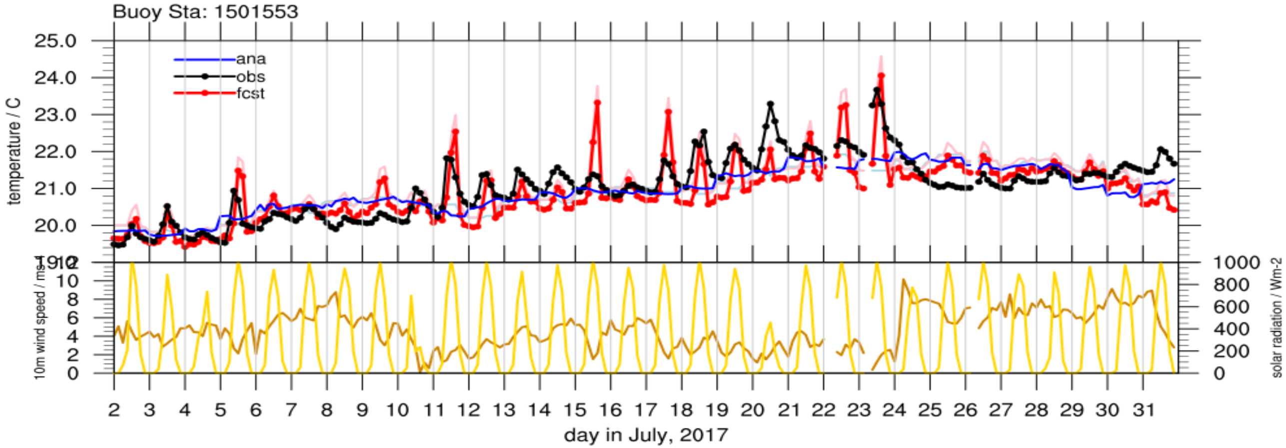
Wind Speed ANA ERA5
Min: 0.3282 Max: 18.87 Mean: 6.348 RMS: 6.952

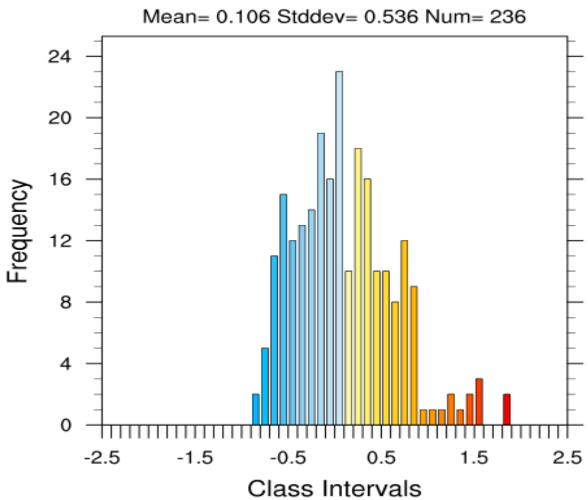


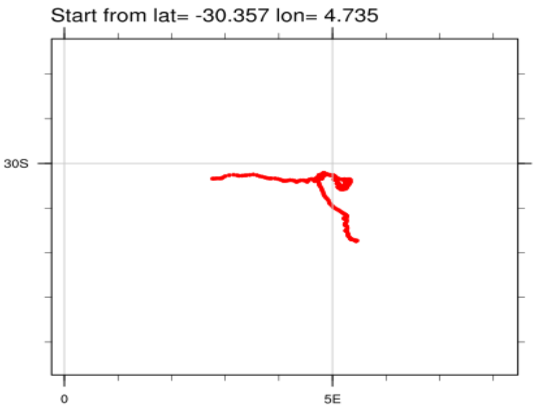
20170701-30,201801-30
start: 00UTC run:72hrs



Jan 2018: 24h-48h forecasts (Zeng Beljaars 2005)





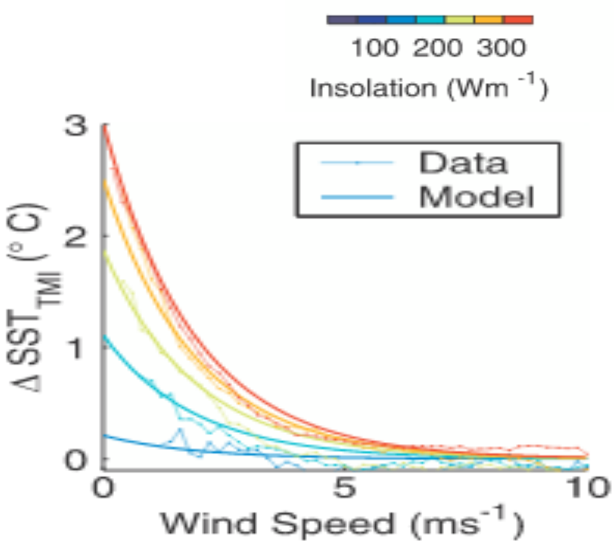


sst

sst+zdwarm

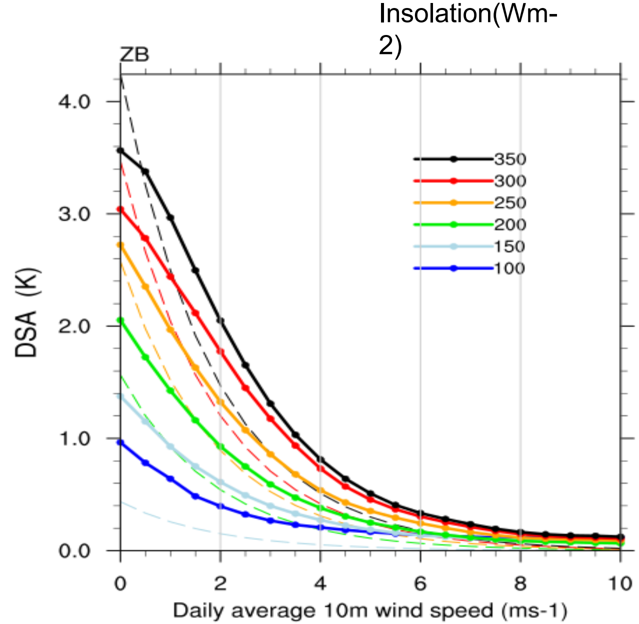
Diurnal SST ampitude (DSA)

While et al (2017):
diurnal cycle in Met Office Model

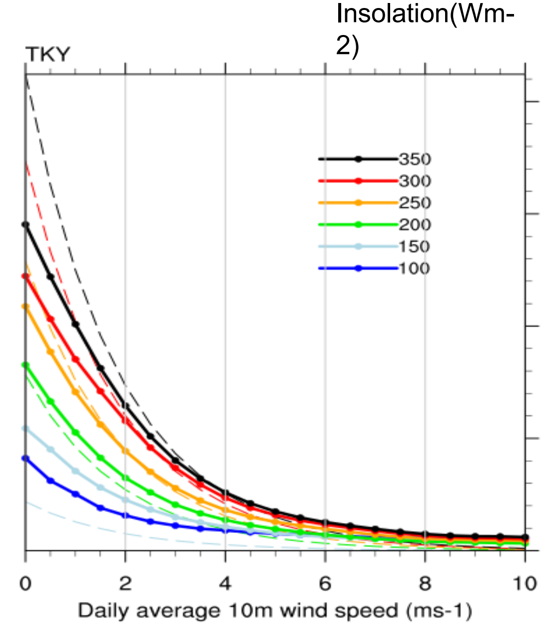


Observations: solid

Zeng, Beljaars (2005)



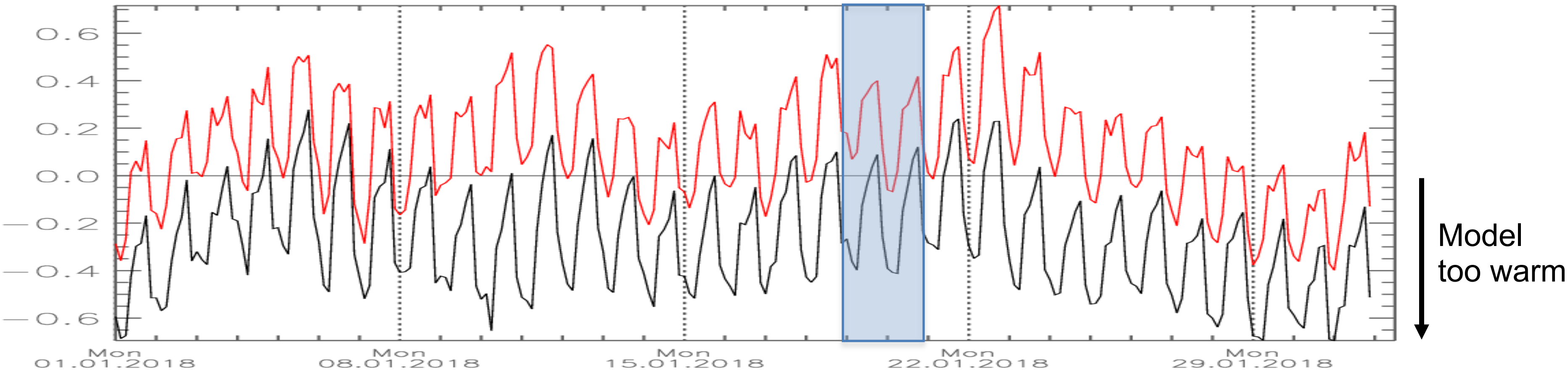
Takaya et al (2010)



Observations: dashed

Reference: An empirical model of diurnal warming using non-linear least-squares regression based on TMI (mircrowave imager) observations (Chelle L. et al, 2003)
Region: 40S-40N oceans

Meteosat 10µm brightness temperature (OMB)



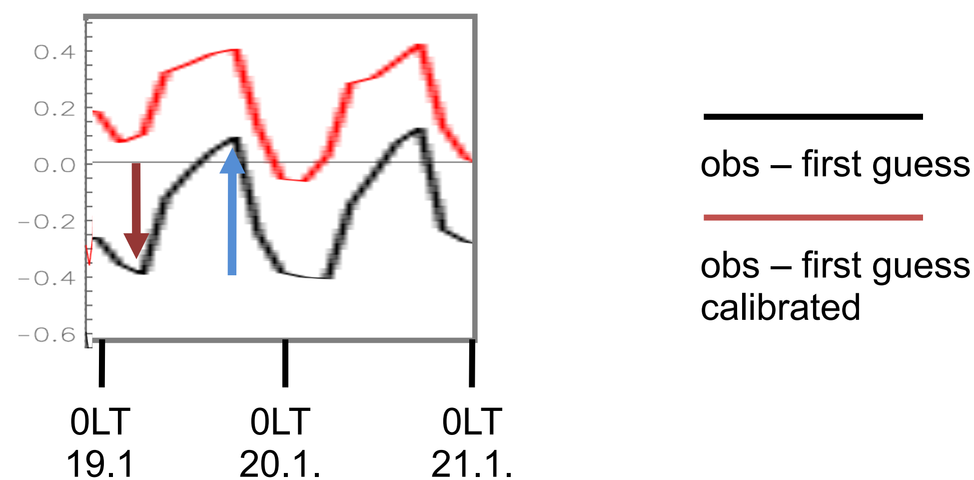
Thanks to Robin Faulwetter

SEVIRI v.s. first guess（operational run）

Lat:-40 ~-10,

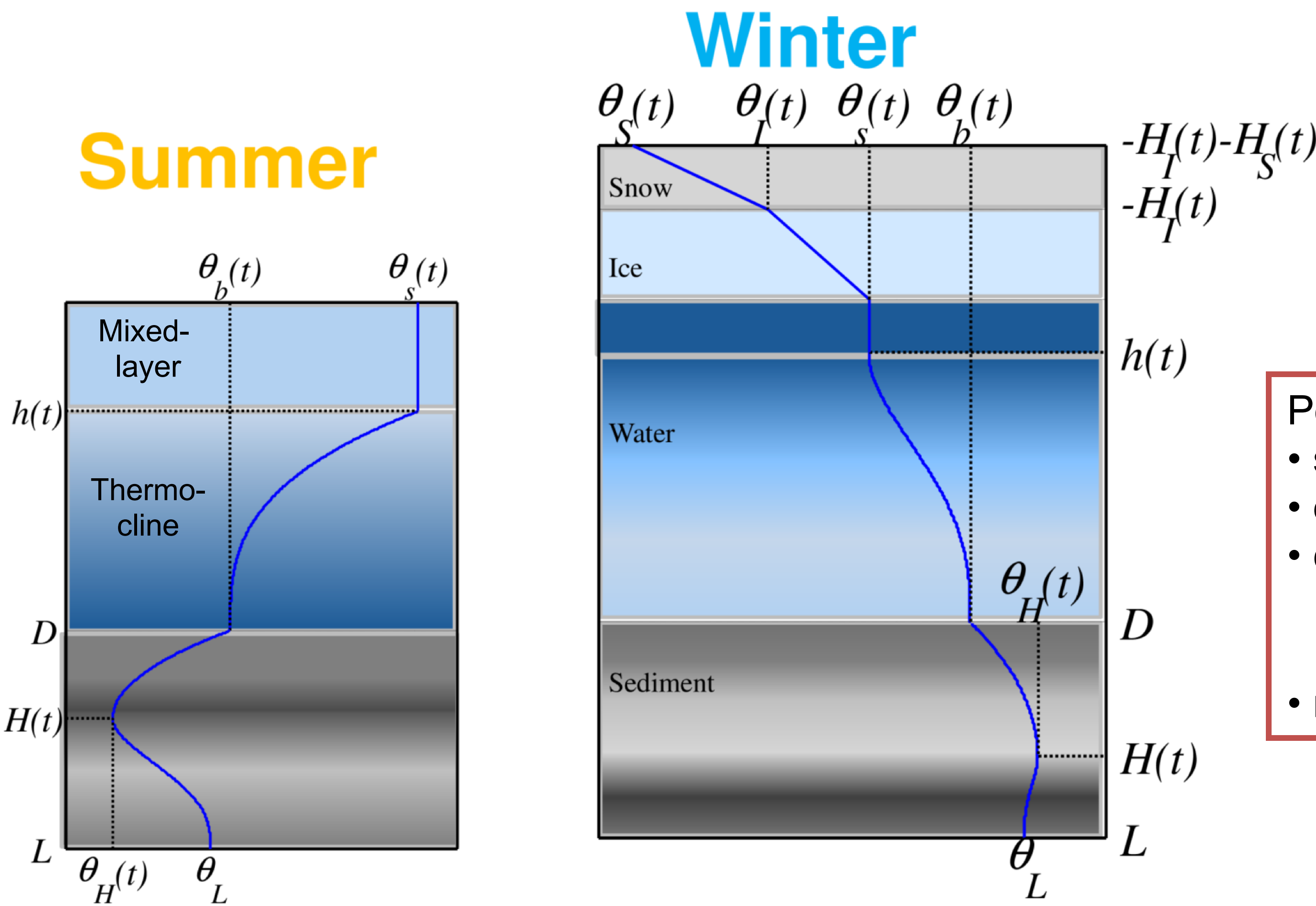
Lon:-30~5

cloud-free pixes



Flake lake model, Dmitrii Mironov

Schematic lake temperature stratification

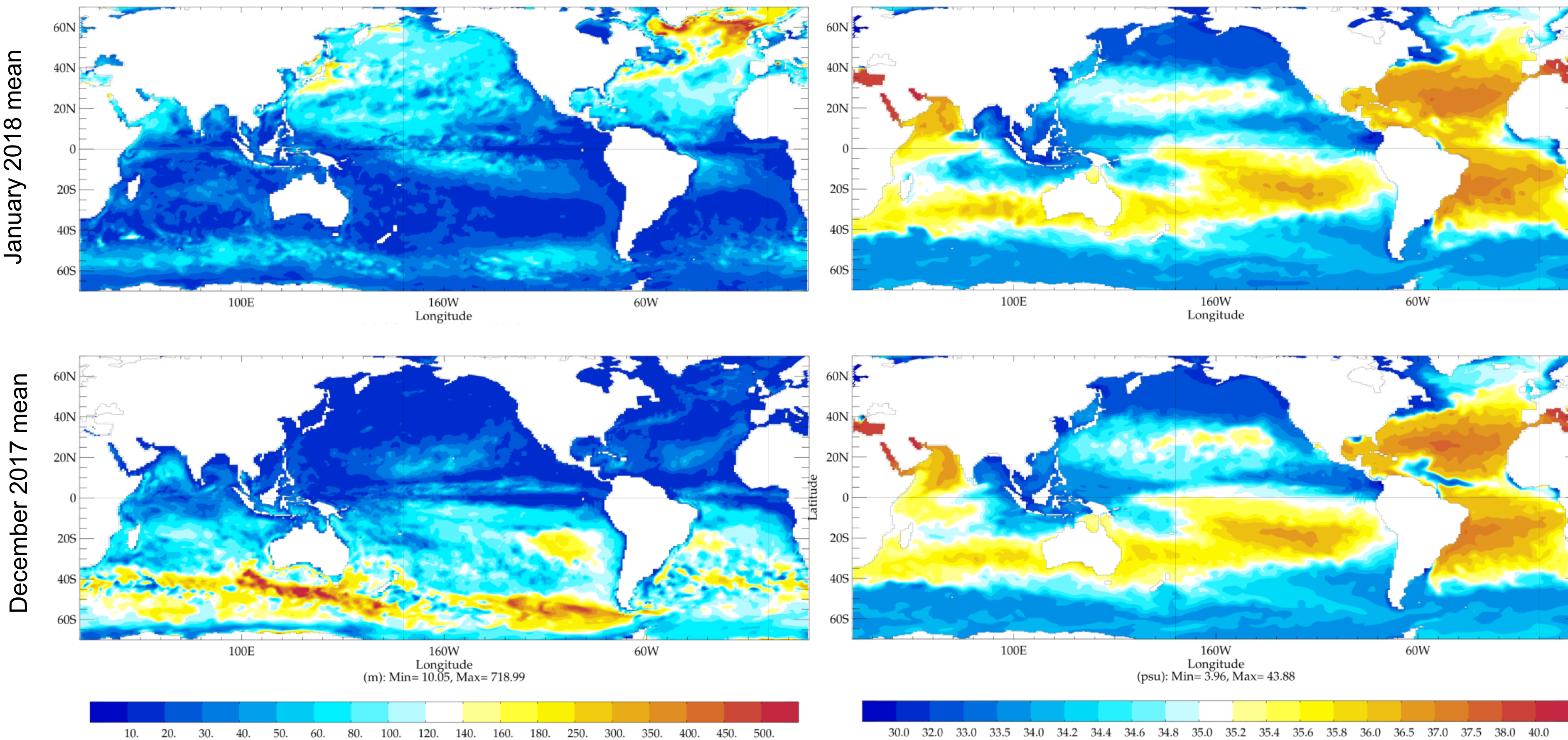


Possible extensions:

- salinity
- extend D (50m to 100m)
- combination with
  - cold skin
  - warm layer
- nudging to NEMOVAR

Ocean Reanalysis ORA-S4

Mixing layer depth (0.01 density criteria) | Surface Salinity



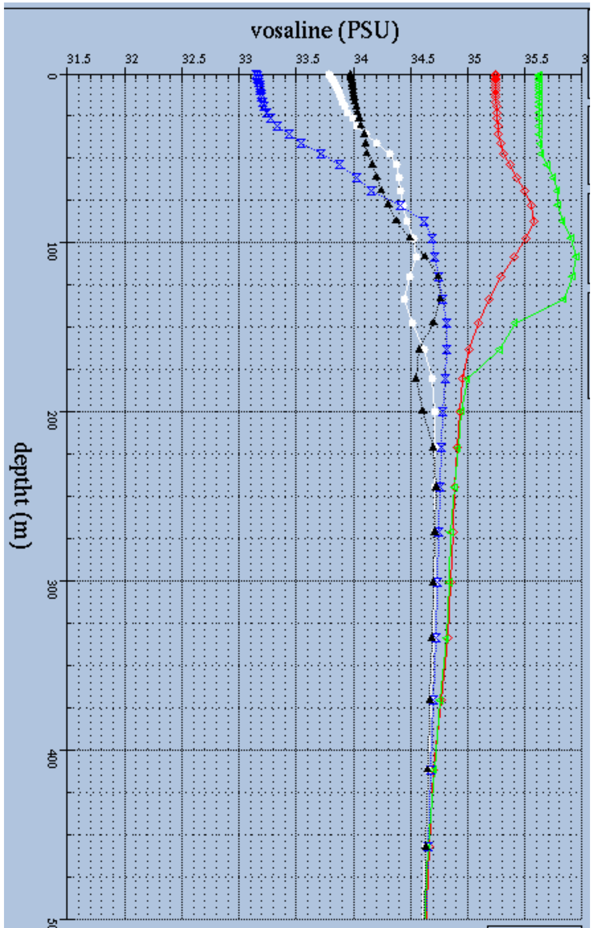
large annual cycle

small annual cycle

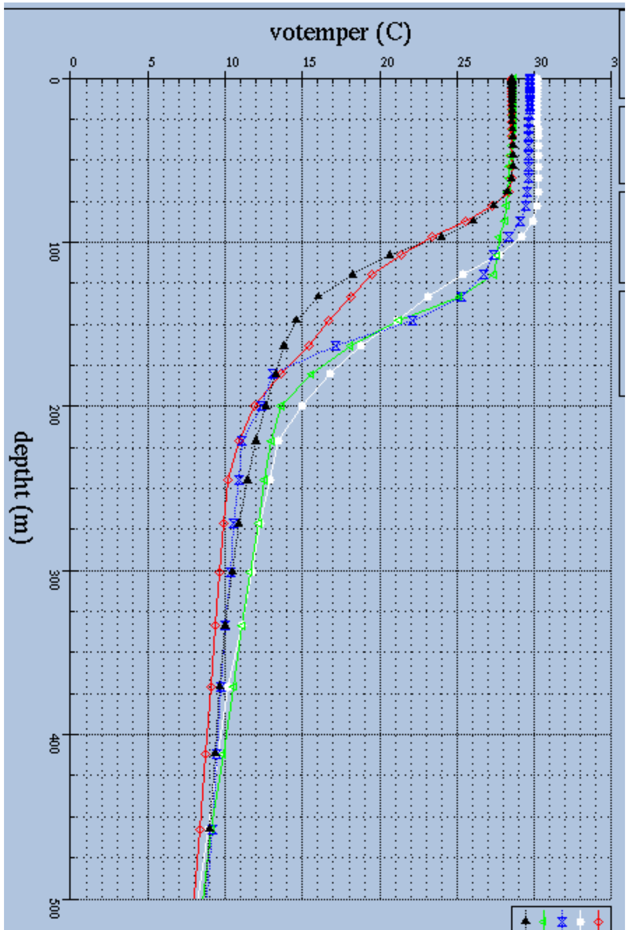
OCEAN5: Jan 2016 mean salinity and temperature

Tropical Pacific

Salinity



Temperature



Outlook: air-sea interaction in ICON

Diurnal cycle of ocean SST

- diagnostic **cool skin**, prognostic **warm layer**
  (Zeng, Beljaars 2005, Takaya, Bidlot, Beljaars, Janssen 2010, Donlon 2002, While et al 2017)
- benefits:
  - **DA** of radiances through forward operators,
  - improved **MJO** (T2010) and **mean climate** (Brunke et al 2008, CAM3.1)
- future: Langmuir circulation enhances ocean mixing in wavy conditions (T2010)
  - need wave model (IAFE position)

Tropical cyclones: ocean mixed layer cooling

- benefit: negative feedback to deep TCs (shallow ocean mixed-layer)
- initialization: ECMWF OCEAN 5 analysis of T, salinity and mixed-layer depth
- ocean modeling:
  - Flake extended with salinity (Mironov et al 2010)
  - mixed-layer ocean model based on prog. TKE (Gaspar et al. 1990, HErZ)
  - coupled ocean model (IAFE position)

Outlook: air-sea interaction in ICON

thanks to:

- Felix Fundel for providing buoy SST observations for comparison
- Robin Faulwetter for help with the bacy cycle
- Martin Lange and Alexander Cress for help with OSTIA data
- Daniel Reinert for assistance with the ICON physics coupling
- Dmitrii Mironov for his effort to think about the difficult extension of FLAKE ot oFLAKE

Extra Slides

Summary

- ZB and extended model can represent the diurnal cycle under clear sky and low wind condition, which helps reduce systematic bias of skin surface.

- Air-sea interaction parameterization enhance the intensity of Tropical cyclones.
  - TC is sensitive to surface fluxes.

- Bacy tests of different cool skin and warm layer model

- Substitute SST with OSTIA foundation products

Grassl, 1976: Dependence of measured cool skin on wind stress and total heat flux

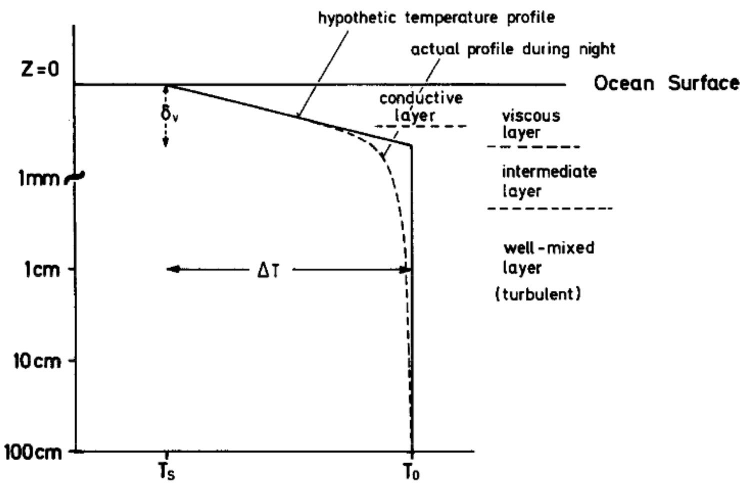


Fig. 1. Schematic representation of the near surface region of the ocean together with basic equations.

$$\delta_v \sim \nu \Big/ \sqrt{\frac{\tau}{\rho_w}}$$

where ν is kinematic viscosity, τ is wind stress, and ρ_w is density of sea water.

$$\Delta T = \lambda \frac{Q \cdot \nu}{k\sqrt{\tau/\rho_w}}$$

with a factor λ containing deviations of the thickness δ_c
k is thermal conductivity

$$\delta_v = \frac{\Delta T \cdot k}{\lambda \cdot Q}$$

based on GATE, phase II, Sept 1974

TABLE I

Depth of the viscous boundary layer δ_v, total heat flux Q, temperature drop ΔT and λ as a function of mean wind speed $\bar{u}_{10}$

$\bar{u}_{10}$ (m s^{-1})	Q (in W m^{-2})	λ	ΔT (in K)	δ_v (in mm)
1	76.3	2.23	0.174	0.62
2	93.0	2.97	0.187	0.41
3	110.0	3.96	0.213	0.28
4	125.6	4.75	0.213	0.21
5	134.1	4.92	0.196	0.18
6	151.7	5.06	0.180	0.14
7	174.7	5.53	0.189	0.12
8	187.8	5.84	0.192	0.10
9	207.5	5.42	0.167	0.09
10	234.7	5.48	0.170	0.08

Alternative parameterization (C.J.Donlon,2002)

- Night time cooling and wind speed relationship

$$\mathrm{V}T_{depth} = -0.14 - 0.3\exp(-\frac{u}{3.7})$$

$$depth = 5m$$

$$u \geq 2m/s$$

- Above a wind speed of 6m/s he relationship between SST_{skin} and SST_{depth} is well charcterized for both day- and nighttime conditions by a cold bias of -0.17+/- 0.07 K rms.

Alternative parameterization

- Warm layer → partial TAKAYA 2010
- New M-O similarity function for SBL
- Mixing enhanced by Largmuir circulation

$$\phi_t(\zeta) = \begin{cases} 1+5\zeta, & \zeta \geq 0 \\ (1-16\zeta)^{-1/2}, & \zeta < 0 \end{cases} \Rightarrow \phi_t(\zeta) = \begin{cases} 1+\dfrac{5\zeta+4\zeta^2}{1+3\zeta+0.25\zeta^2}, & \zeta \geq 0 \\ (1-16\zeta)^{-1/2}, & \zeta < 0 \end{cases} \qquad \zeta = -z/L$$

Extend

- Warm layer → partial TAKAYA 2010
- New M-O similarity function for SBL
- Mixing enhanced by Largmuir circulation(the Stokes drift)

$$\frac{\partial \Delta T_{warm}}{\partial t} = \frac{Q + R_s - R_s \sum_{i=1}^{3} a_i e^{-db_i}}{d \rho_w c_w \upsilon / (\upsilon + 1)} - \frac{(\upsilon + 1) \kappa \, \mathrm{u}_{*w}}{d \phi_t (d / L)} \Delta T_{warm} \Rightarrow \frac{(\upsilon + 1) \kappa \, \mathrm{u}_{*w} \, f(\mathrm{La})}{d \phi_t (d / L)} \Delta T_{warm}$$

$$f(\mathrm{La}) = \mathrm{La}^{-2/3}, \quad La = \sqrt{u_w^* / u_s}$$

$$f(\mathrm{La}) \geq 1$$

u_s Surface Stokes velocity
From ECMWF wave model

Not implemented yet

Warm layer

$$\frac{\partial \Delta T_{warm}}{\partial t} = \frac{Q + R_s - R_s \sum_{i=1}^{3} a_i e^{-db_i}}{d \rho_w c_w \upsilon / (\upsilon + 1)} - \frac{(\upsilon + 1) \kappa u_{*w}}{d \phi_t (d / L)} \Delta T_{warm}$$

Radiation Turbulent transport

Stability function:

$$\phi_t(-z/L) = \begin{cases} 1 + 5\frac{-z}{L}, & for\ \frac{-z}{L} \geq 0 \\ (1 - 16\frac{-z}{L})^{-1/2}, & for\ \frac{-z}{L} < 0 \end{cases}$$

- This warm layer can develop when the wind mixing is not strong enough to prevent a stable layer to build up. (Zeng and Beljaars, 2005)

Fully implicit scheme

$$\frac{\Delta T_{warm}{}^{k+1} - \Delta T_{warm}{}^{k}}{\Delta t} = A - K \Delta T_{warm}{}^{k+1}$$

$$\Delta T_{warm}{}^{k+1} = \frac{\Delta T_{warm}{}^{k} + A \Delta t}{1 + K \Delta t}$$

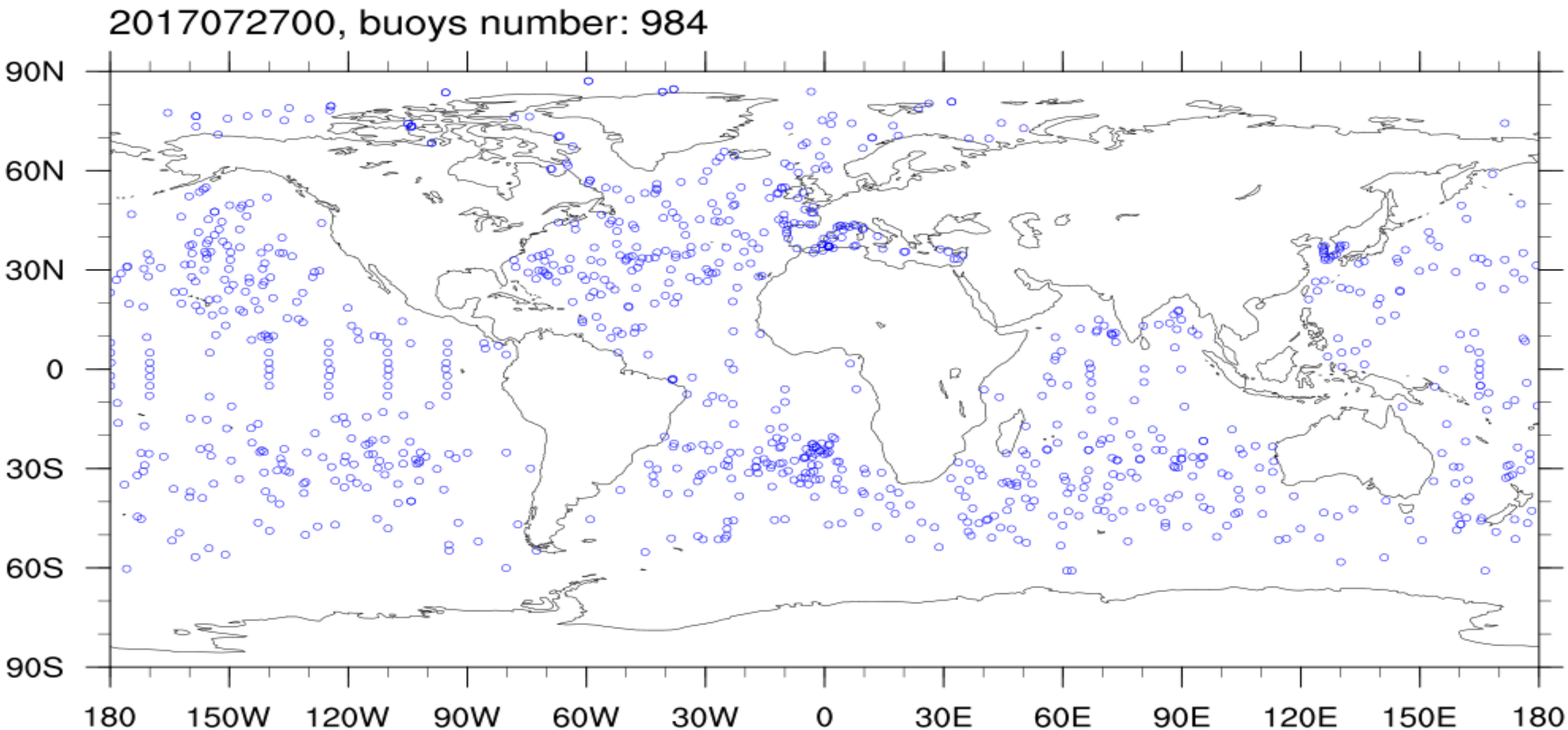
$$A = \frac{Q + R_s - R_s \sum_{i=1}^{3} a_i e^{-db_i}}{d \rho_w c_w \upsilon / (\upsilon + 1)}$$

$$K = \frac{(\upsilon + 1) \kappa u_{*w}}{d \phi_t (d / L)} > 0$$

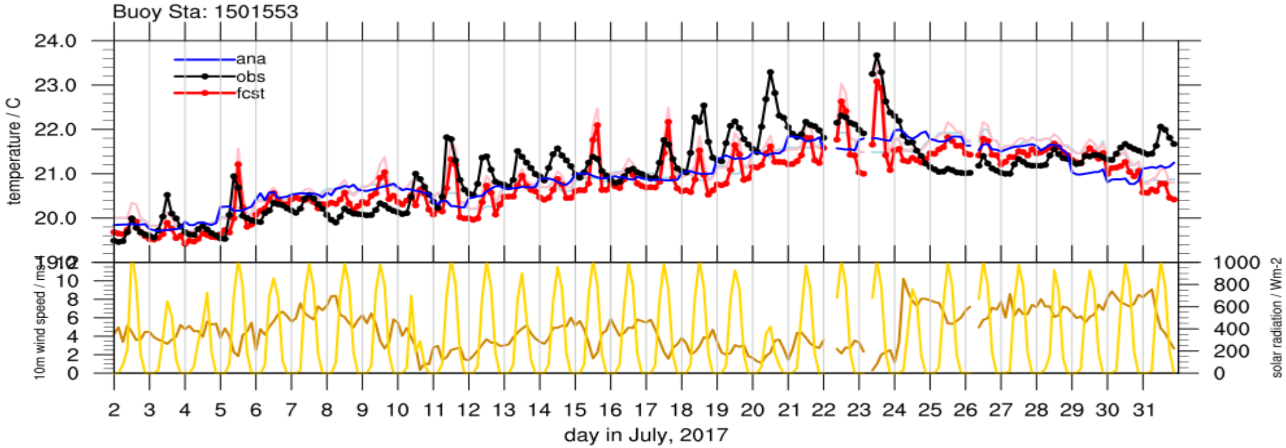
In default scheme, $\Delta T_{warm}{}^{k} \geq 0$ is required.

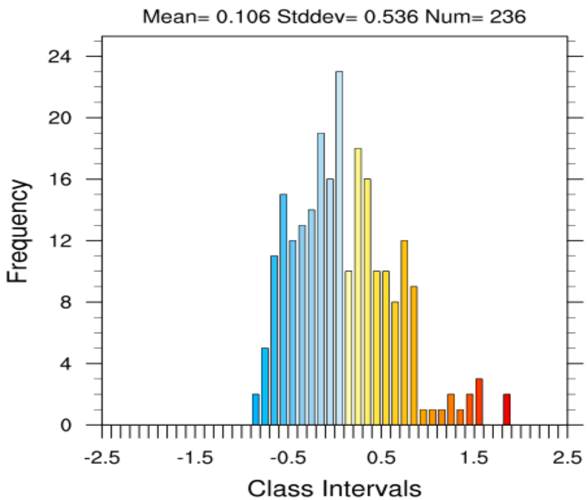
Gradient diffusion

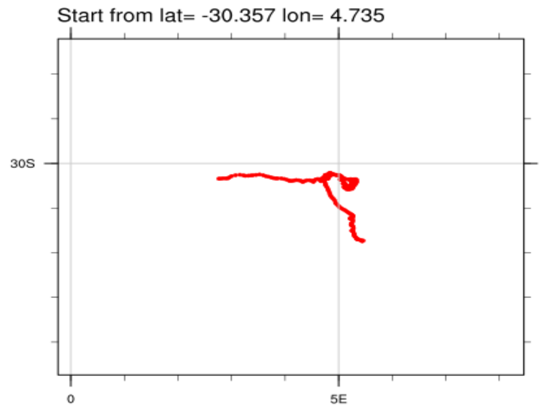
Buoy distribution



Extension to MO-Stability Functions (Takaya et al 2010)







sst

sst+zdwarm

Jan, 2018

Positive means model is cooler

	bias					stddev			
ZB	O-a	O-sst	O-Tsk	O-Twm	num	O-a	O-sst	O-Tsk	O-Twm
all	0.026	0.0638	0.177	-0.119	13808	0.548	0.626	0.544	0.5611
when |o-sst| < 1	-0.03254	0.0002	0.158	-0.1355	12643	0.3767	0.4241	0.4355	0.4543
day time (solar rad > 0.1)	0.056	0.079	0.1375	-0.1462	6953	0.393	0.4361	0.47	0.4924
night time (solar rad < 0.1)	-0.141	-0.096	0.1834	-0.1224	5690	0.324	0.3878	0.3878	0.4025
	bias					stddev			
TKY	O-a	O-sst	O-Tsk	O-Twm	num	O-a	O-sst	O-Tsk	O-Twm
all	0.026	0.0638	0.2477	-0.0451	13808	0.5483	0.6264	0.5377	0.5479
when |o-sst| < 1	-0.0324257	0.00034	0.2120	-0.07933	12645	0.3768	0.4242	0.3989	0.4108
day time (solar rad > 0.1)	0.0564	0.07936	0.2174	-0.0625	6955	0.3933	0.4363	0.4161	0.4297
night time (solar rad < 0.1)	-0.1410	-0.09616	0.205485	-0.0998494	5689	0.324	0.3877	0.3765	0.3856

While et al (2017): diurnal cycle in Met Office Model

$$\Delta SST_{tmi}(t,Q,u) = f(t)\left[(Q - Q_o^t) - 9.632 \times 10^{-4} \cdot (Q - Q_o^t)^2\right] \cdot e^{-0.53u}\} \text{ for } Q \geq Q_o^t \quad (1a)$$

$$\Delta SST_{pf}(t,Q,u) = 0.344 f(t) \cdot \left[(Q - Q_o^p) - 1.444 \times 10^{-3} \cdot (Q - Q_o^p)^2\right] \cdot e^{-0.29u}\} \text{ for } Q \leq Q_o^p \quad (1b)$$

$$f(t) = [6.814 - 6.837\cos(\omega t) - 8.427\sin(\omega t) + 1.447\cos(2\omega t) + 4.274\sin(2\omega t) - 0.407\cos(3\omega t) - 0.851\sin(3\omega t) + 0457\cos(4\omega t) - 0.555\sin(4\omega t) - 0.101\cos(5\omega t) + 0.375\sin(5\omega t)] \times 0.001$$

$$\omega = 0.2668\ \text{hr}^{-1};\ Q_o^t = 132\ \text{Wm}^{-2};\ Q_o^p = 24\ \text{Wm}^{-2};$$

An empirical model of diurnal warming using non-linear least-squares regression (Chelle L. et al, 2003)

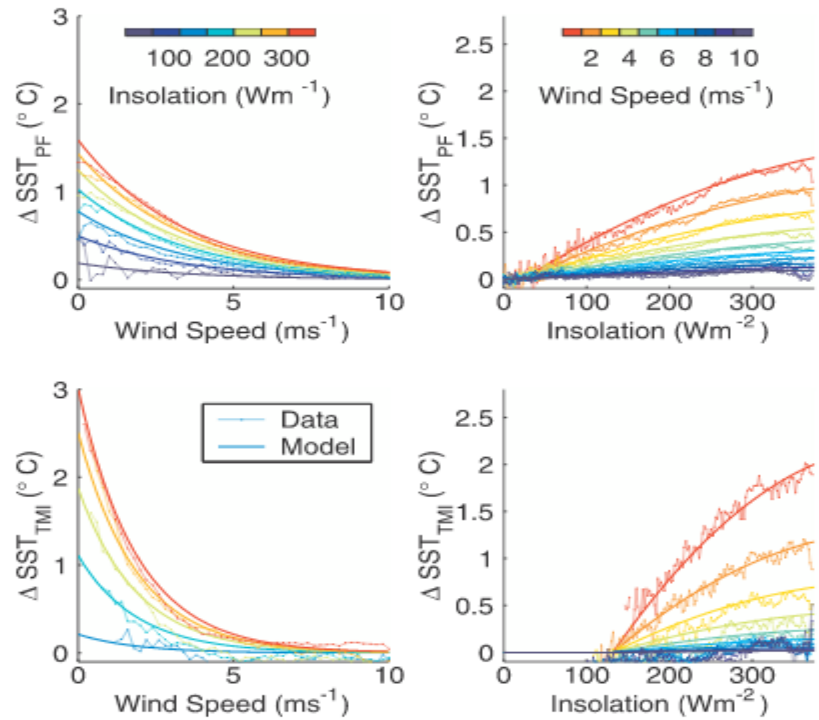
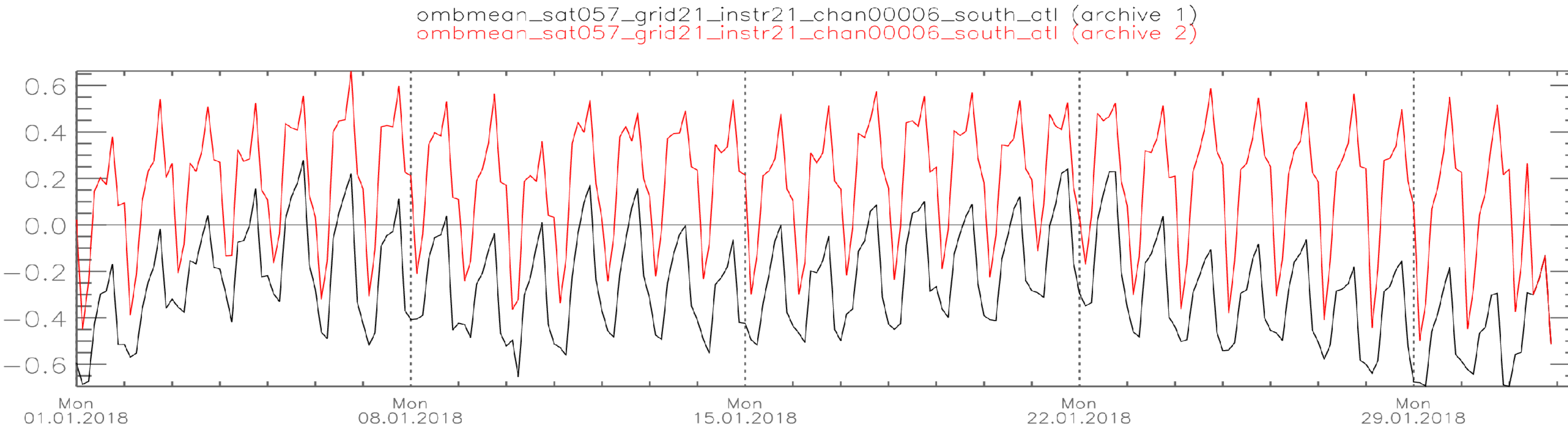
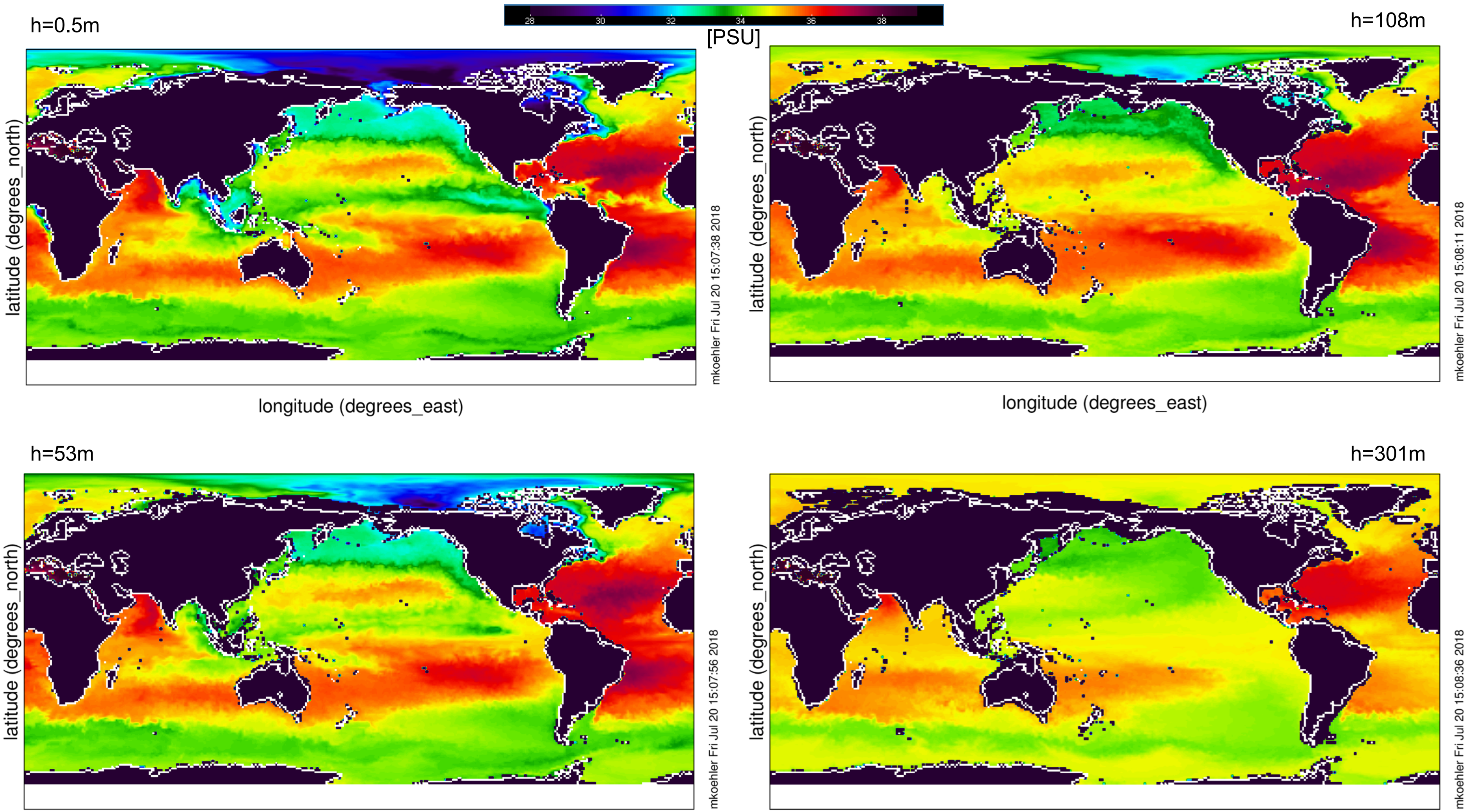


Figure 3. Comparison of data and empirical model at 2PM. The left column shows ΔSST_{PF} (top) and ΔSST_{TMI} (bottom) dependence on wind speed at several insolation values, indicated by line color. The right column shows the dependence on insolation at several different wind speeds.

Bacy TBBT
SEVIRI against 3h forecast



OCEAN5: Jan 2016 mean salinity



Mixed-Layer Ocean Model: TKE SCM

A Simple Eddy Kinetic Energy Model for Simulations of the Oceanic Vertical Mixing: Tests at Station Papa and Long-Term Upper Ocean Study Site

PHILIPPE GASPAR, YVES GRÉGORIS, AND JEAN-MICHEL LEFEVRE

Centre National de Recherches Météorologiques, Toulouse, France

A simple eddy kinetic energy parameterization of the oceanic vertical mixing is presented. The parameterization scheme is based on recent works on atmospheric turbulence modeling. It is designed to simulate vertical mixing at all depths, from the upper boundary layer down to the abyss. This scheme includes a single prognostic equation for the turbulent kinetic energy. The computation of the turbulent length scales is diagnostic, rather than prognostic. In weakly turbulent regions the simulated vertical diffusivity is inversely proportional to the Brunt-Vaïsala frequency. In the first validation experiments presented here, the vertical mixing scheme is embedded into a simple one-dimensional model and used for upper ocean simulations at two very different test sites: the station Papa in the Gulf of Alaska and the Long-Term Upper Ocean Study (LOTUS) mooring in the Sargasso Sea. At station Papa the model successfully simulates the seasonal evolution of the upper ocean temperature field. At LOTUS the focus is on a short 2-week period. A detailed analysis of the oceanic heat budget during that period reveals a large bias in the bulk-derived surface heat fluxes. After correction of the fluxes the model does well in simulating the evolution of the temperature and wind-driven current. In particular, the large observed diurnal cycles of the sea surface temperature are well reproduced. During the second (windy) week of the selected period the model accounts for about two thirds of the kinetic energy of the observed upper ocean currents at periods larger than 6 hours. The local wind forcing thus appears to be the dominant generation mechanism for the near-inertial motions, which are the most energetic. The velocity simulation is especially good at the low frequencies. During the second simulated week the model accounts for as much as 78% of the kinetic energy at subinertial frequencies. The simulated mean velocity profile is reminiscent of an Ekman spiral, in agreement with the observations.

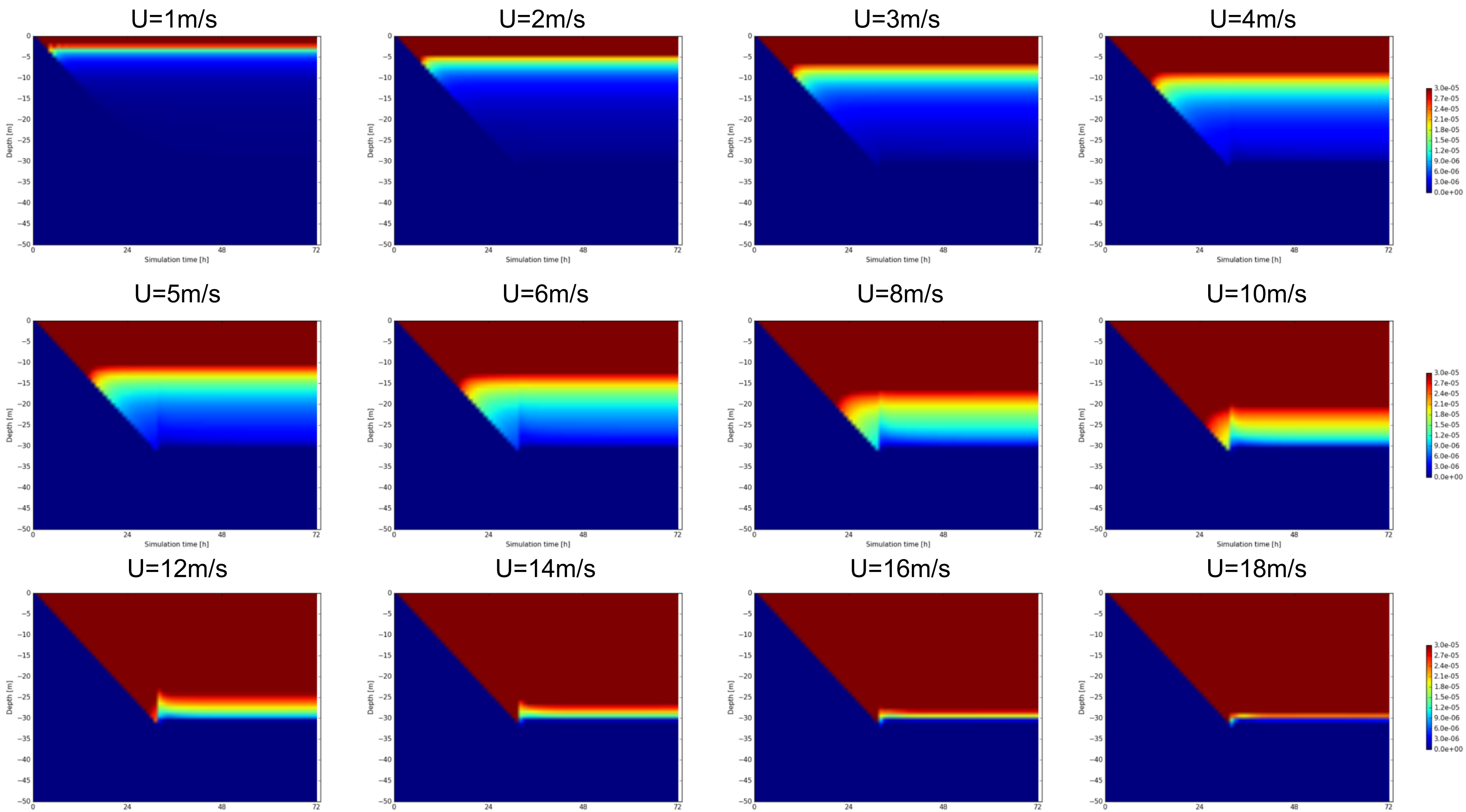
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 95, NO. C9, PAGES 16,179–16,193, SEPTEMBER 15, 1990

Marie-Léa Pouliquen, MPI
James Ruppert, U. Hamburg
Carsten Eden, U. Hamburg
Bjorn Stevens, MPI
offline, then NARVAL coupling

Eden mixed-layer ocean: TKE profiles

Marie-Lea Pouliquen &
James Ruppert, MPI

DWD



Thanks to

- Felix Fundel for providing buoy SST observations for comparison
- Robin Faulwetter for help with the bacy cycle
- Martin Lange and Alexander Cress for help with OSTIA data
- Daniel Reinert for assistance with the ICON physics coupling
- Dmitrii Mironov for his effort to think about the difficult extension of FLAKE ot oFLAKE
- Daniel Klocke for introducing Marie-Léa Pouliquen, James Ruppert from MPI

Setting

Mengjuan Julia Liu visit from Shanghai Met Service and Typhoon Center

- Atmospheric boundary layer
- Air-sea interaction to improve Typhoon prediction (SST cooling)
- Diurnal cycle of SST skin (SST warming, improved fluxes, DA forward operators)

Nadine Schittko, master student at KIT with Christian Grams, Dominik Büeler

- Analysis of 2 ICON hurricane/typhoon seasons
- Forecast quality and systematic errors

Marie-Léa Pouliquen, master student at MPI, Hamburg
with James Ruppert, Bjorn Stevens, Carsten Eden

- Ocean mixed-layer model off-line and for ICON

Purpose

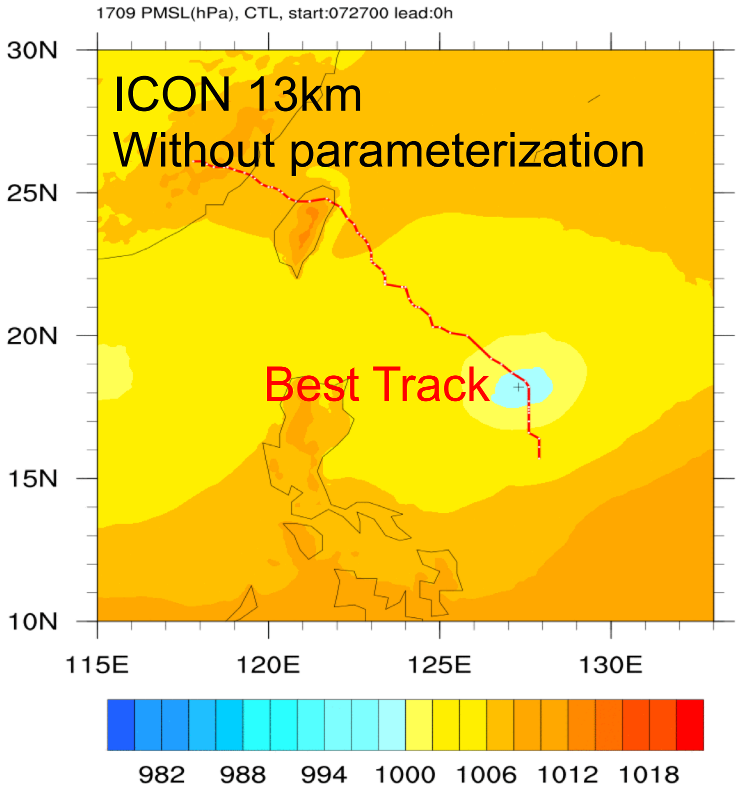
- Sea surface temperature
  - determines the fluxes between ocean and atmosphere.
  - Boundary condition to models
  - Necessary variable for radiance assimilation through forward operators
  - Determines the born, evolution, intensity of tropical cyclones
- ICON
  - Performance on WNPAC TCs?

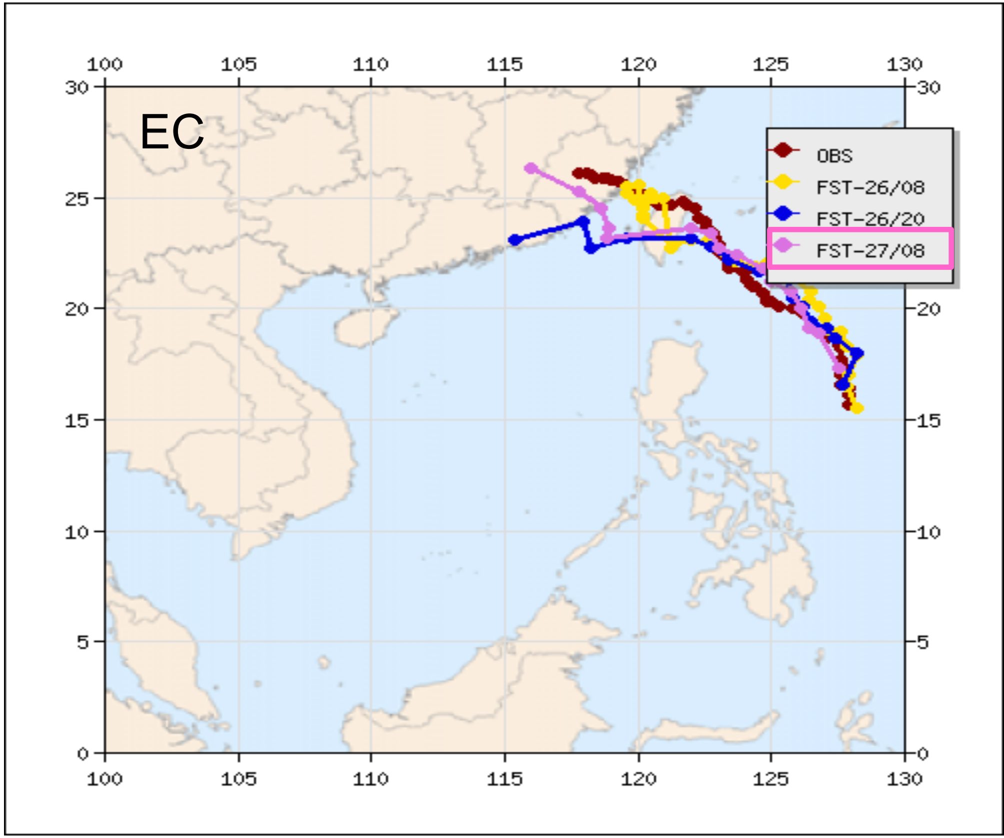
Present

- Picked up 4 TCs (Thanks to L. Qi from SMS) with large uncertainties in 5 days forecast (EC)
- Operational run (13km)
- 3 Domain nested run

Nesat

Start:17072700UTC

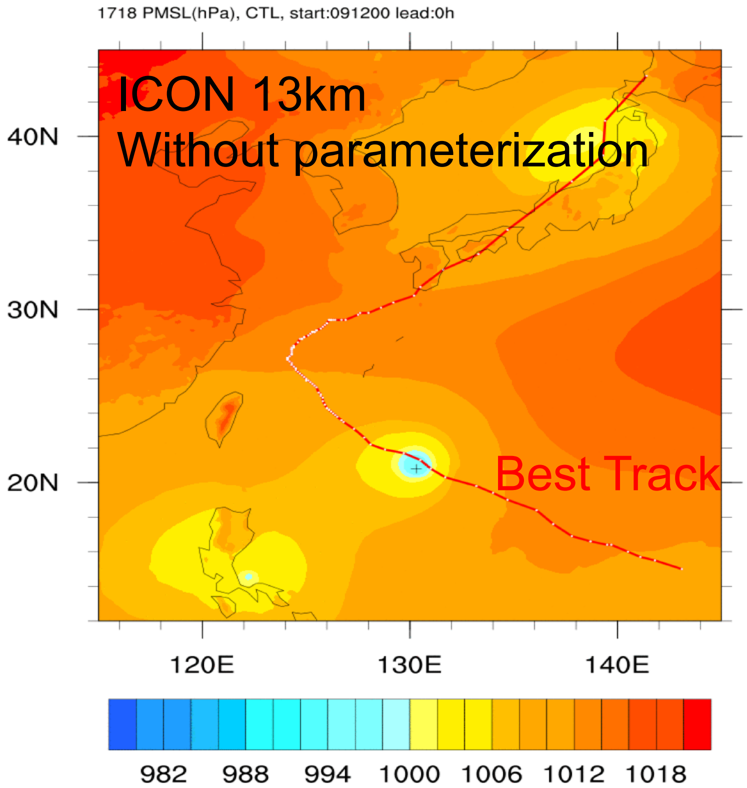


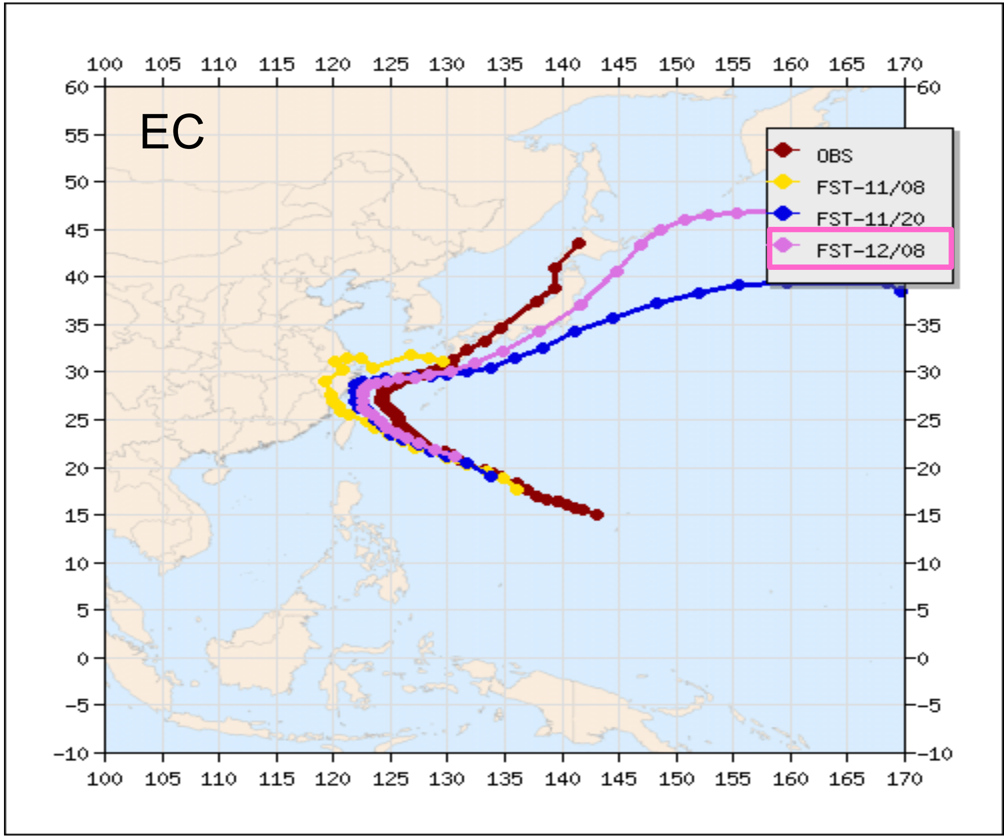


Via Dr. Qi, SMS

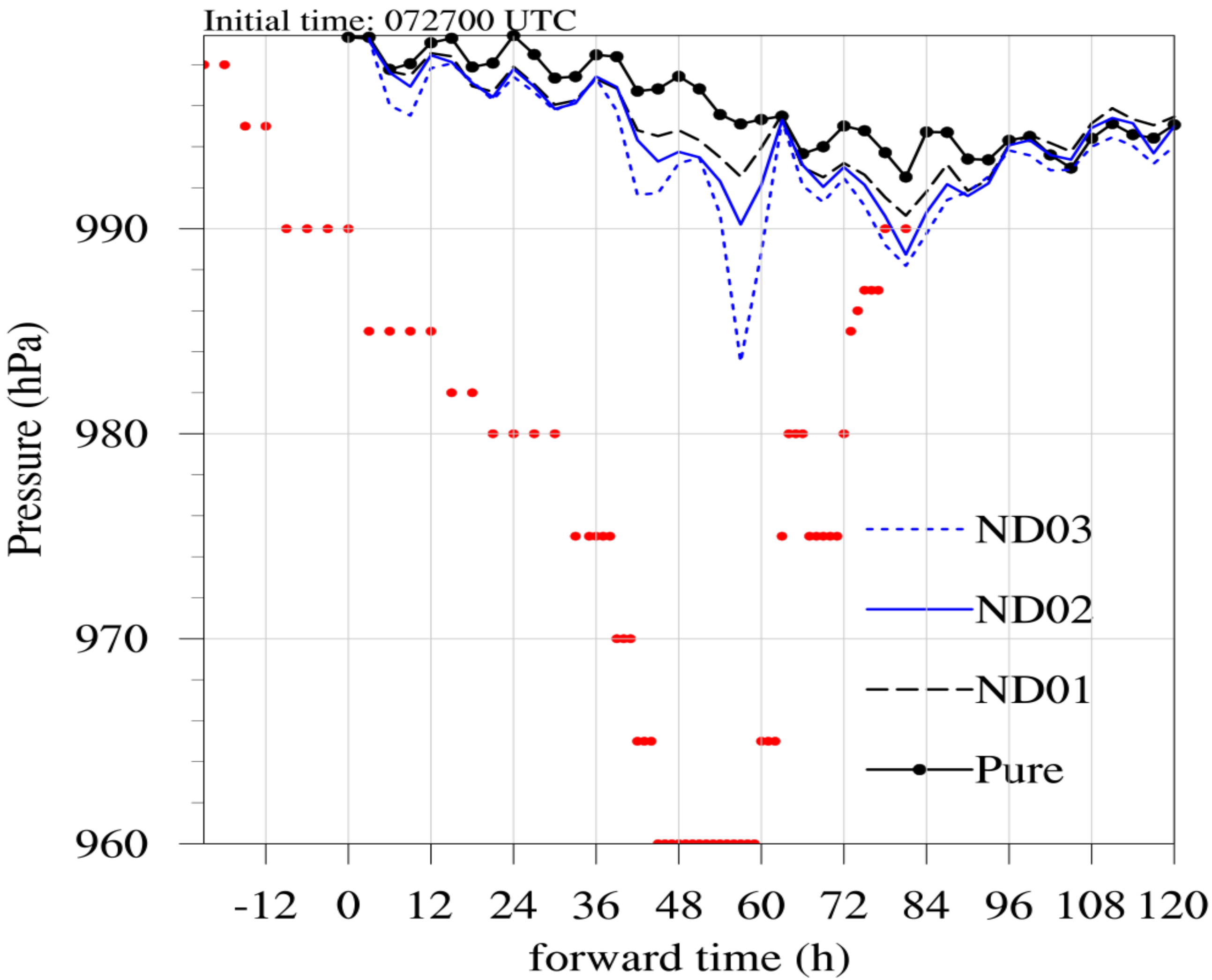
Talim

Start:17091200UTC





Via Dr. Qi, SMS



Initial time: 072700 UTC
Pressure (hPa)
990
980
970
960
-12
0
12
24
36
48
60
72
84
96
108
120
forward time (h)
ND03
ND02
ND01
Pure

Salinity effects

- Salinity reduces the saturation value

$$q_s = 0.98 q_{sat}(T_{sk})$$

- 2% change in saturation value at surface
- → 13% change in air-sea transfer (Zeng et al., 1998)
- → Even large effect during TC cases!

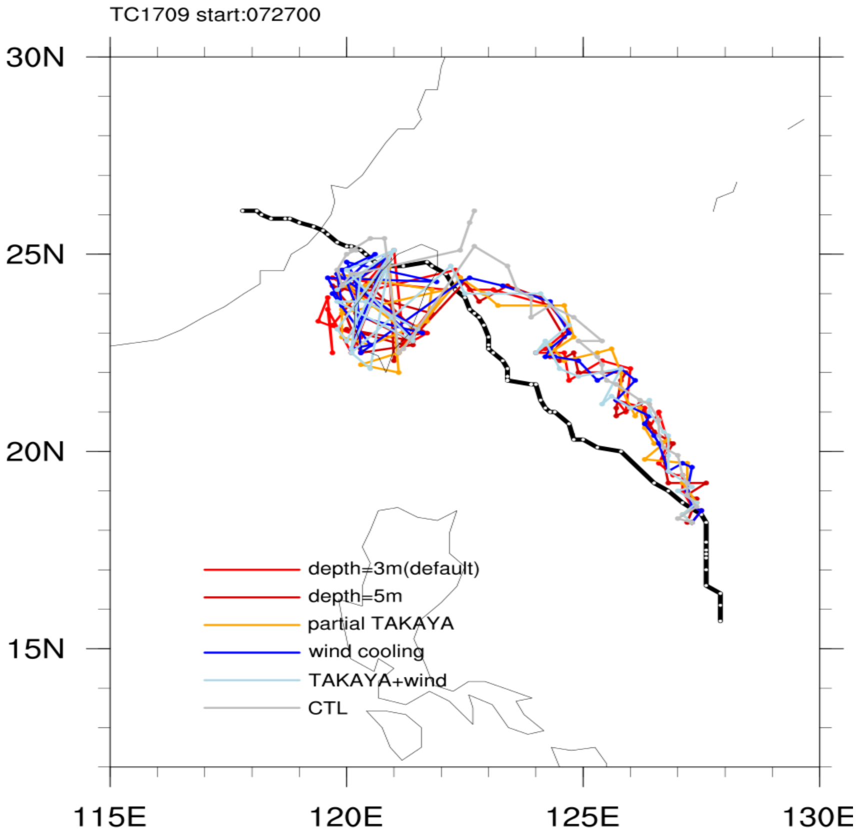
Verification

Tests setup	Observations	Method
• TC case • Monthly run	• Buoys • Satellite	• temperature • fluxes • diurnal cycle

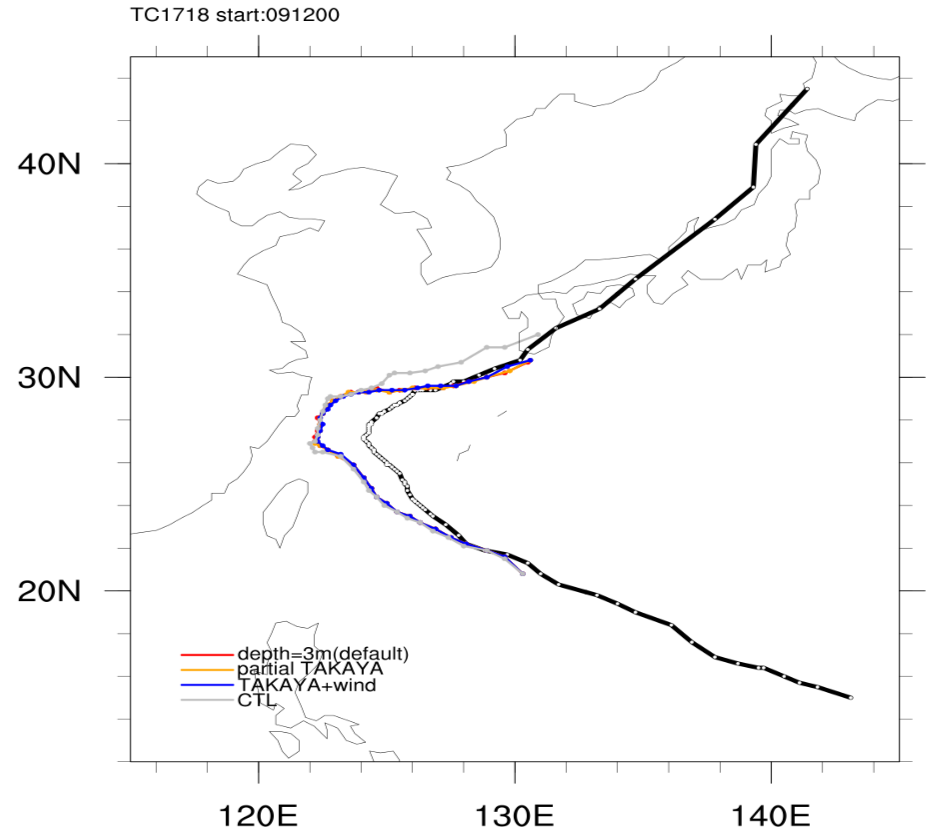
Test setup – TC

Name	Description	Warm layer depth (m)	Warm layer scheme	Cool skin scheme
CTL	Without any parameterization	-	-	-
D3	Default setup of ZB parameterization	3	ZB	ZB
D5	Depth of warm layer =5m	5	ZB	ZB
TKY	Partially Takaya scheme (without Langmiur circulation)	3	part of TAKAYA 2010	ZB
NW	Turn off the restriction on sign of	3	ZB	Donlon 2002

Tracks

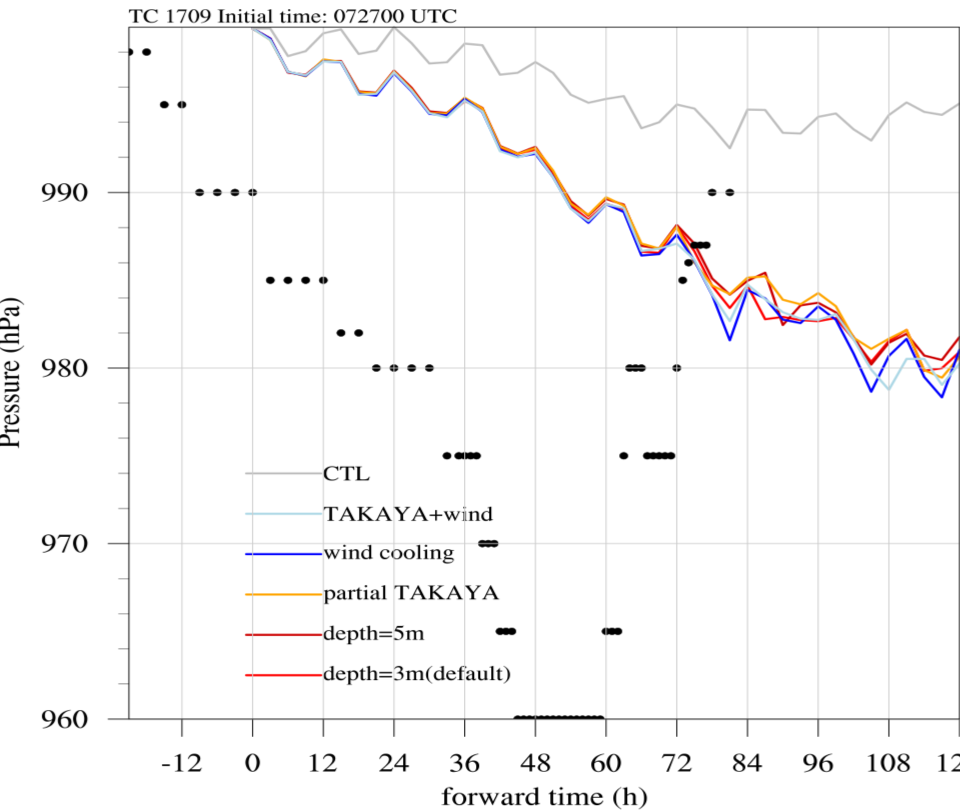


TC1709 start:072700
30N
25N
20N
15N
115E
120E
125E
130E
depth=3m(default)
depth=5m
partial TAKAYA
wind cooling
TAKAYA+wind
CTL

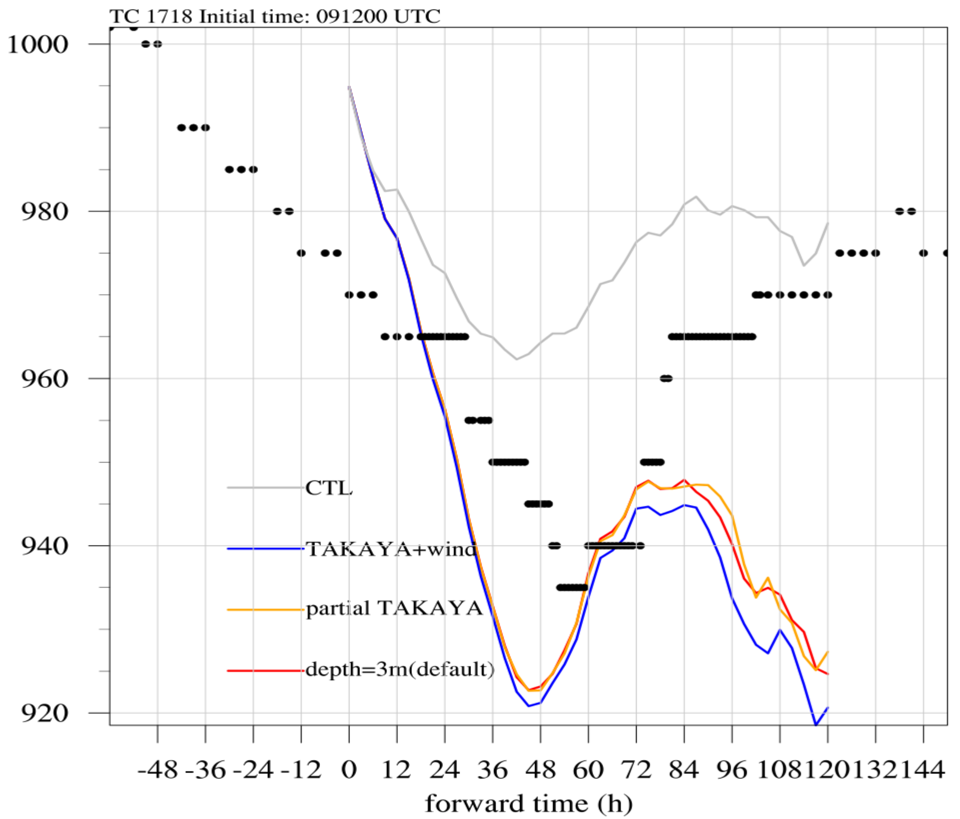


TC1718 start:091200
40N
30N
20N
120E
130E
140E
depth=3m(default)
partial TAKAYA
TAKAYA+wind
CTL

Intensity



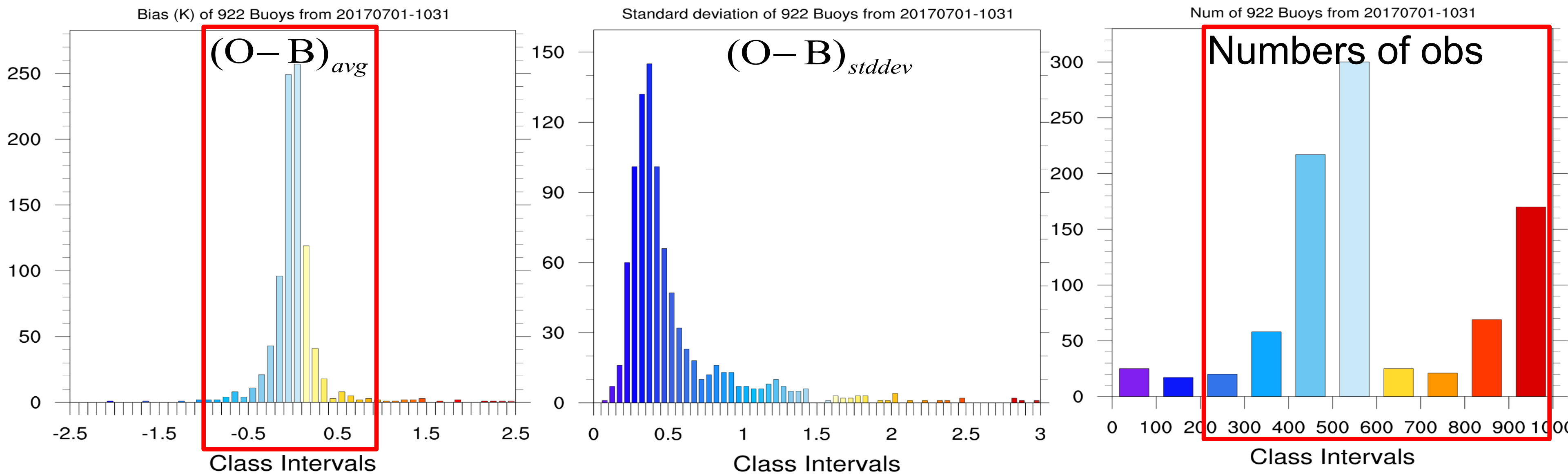
TC 1709 Initial time: 072700 UTC
Pressure (hPa)
990
980
970
960
-12
0
12
24
36
48
60
72
84
96
108
12
forward time (h)
CTL
TAKAYA+wind
wind cooling
partial TAKAYA
depth=5m
depth=3m(default)



TC 1718 Initial time: 091200 UTC
1000
980
960
940
920
-48 -36 -24 -12 0 12 24 36 48 60 72 84 96 108120132144
forward time (h)
CTL
TAKAYA+wind
partial TAKAYA
depth=3m(default)

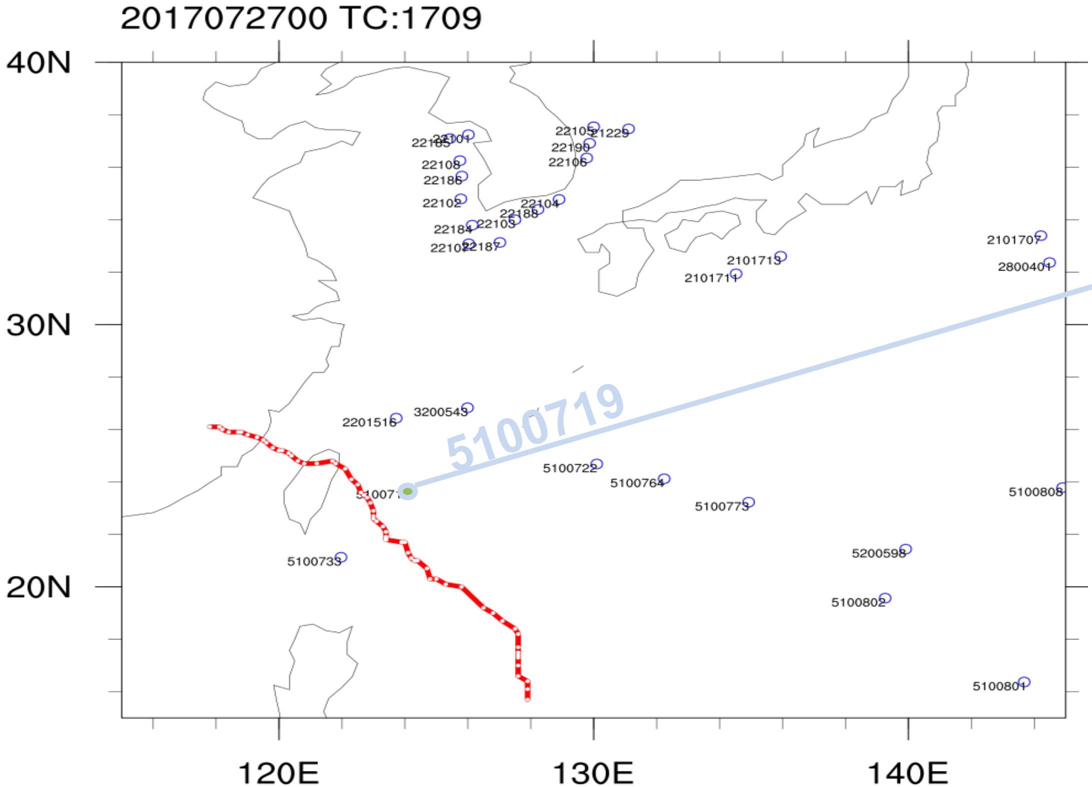
Observation -- buoy

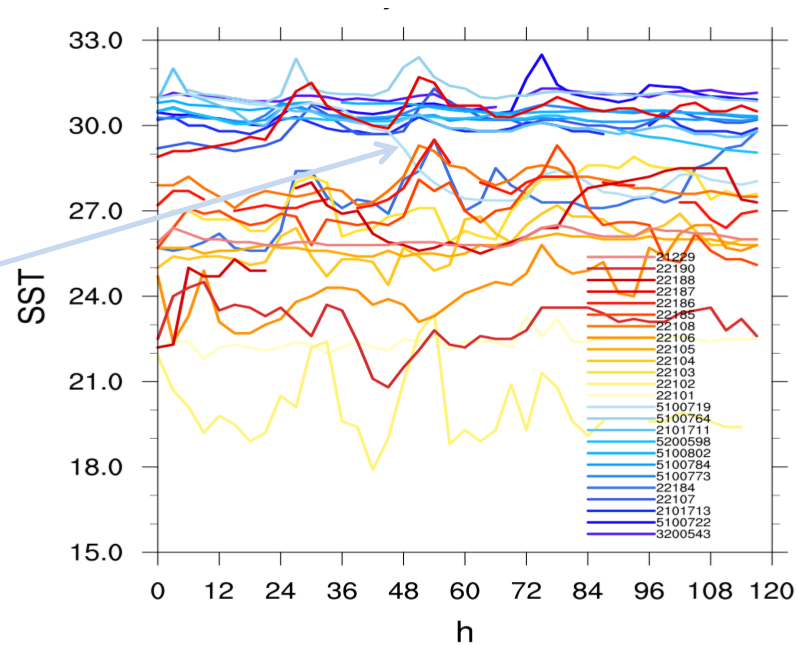
- SST observation from feedback files after assimilation per 3hrs
  - Thanks to Fundel Felix !
- These data are not absorbed by ICON yet



Systematic error check: $(O-B)_{avg} \leq 1, num \geq 200$

Buoys in WNpacific

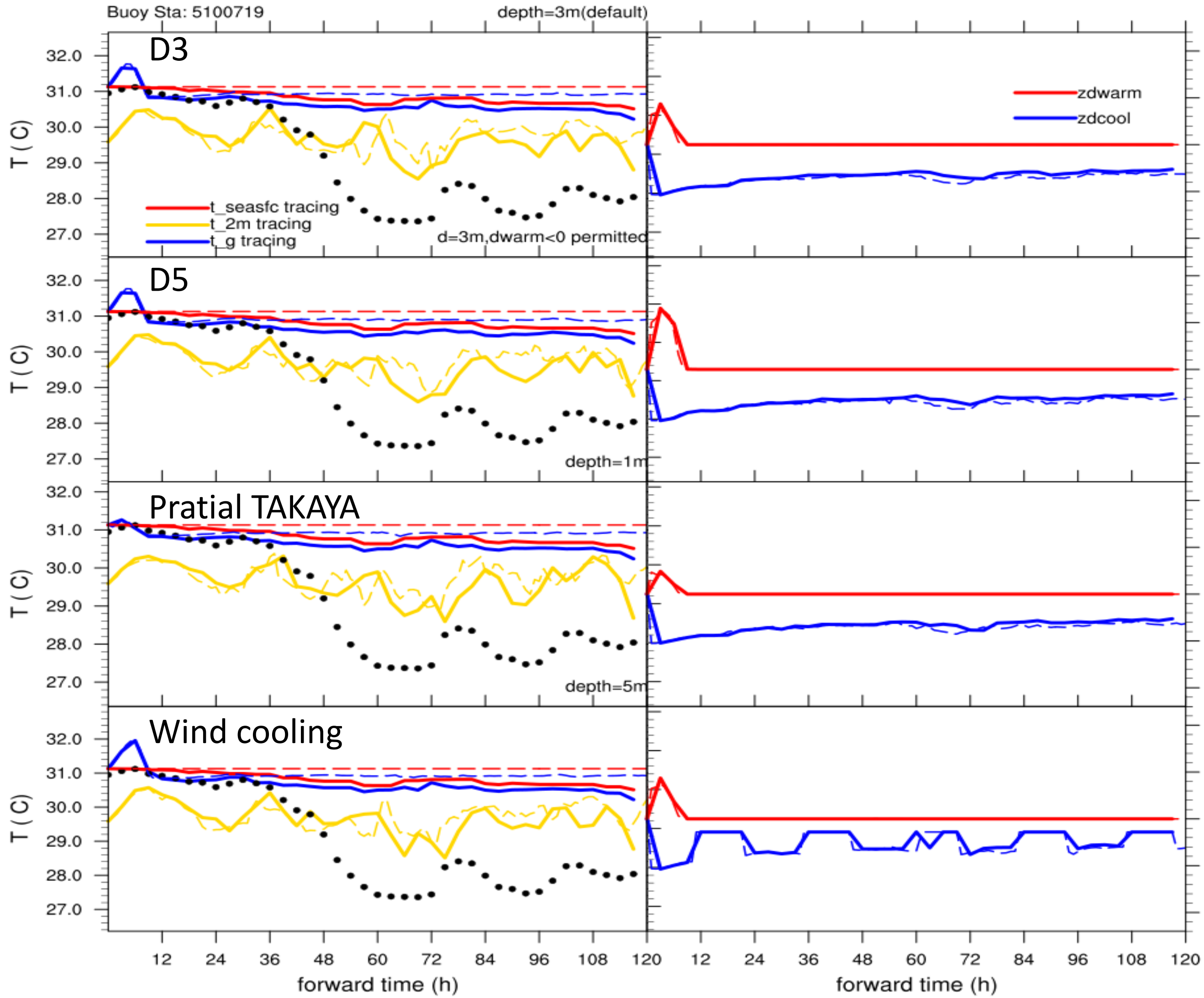




Lat=23.686, Lon=124.153
Avg= -0.026,stddev=0.689

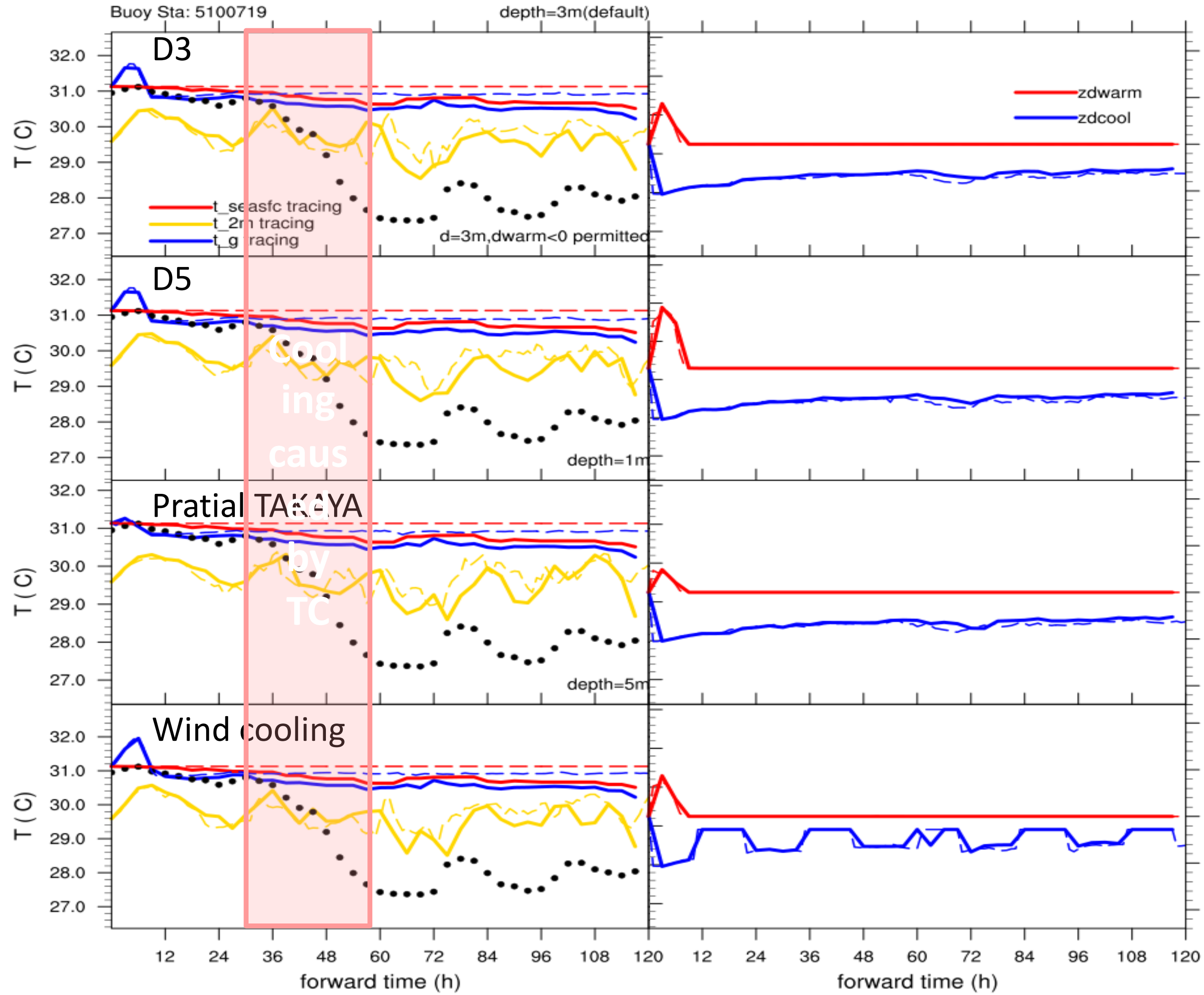
Solid lines: Tracing buoys

Dash lines: Fixed grid points (the location of start time)



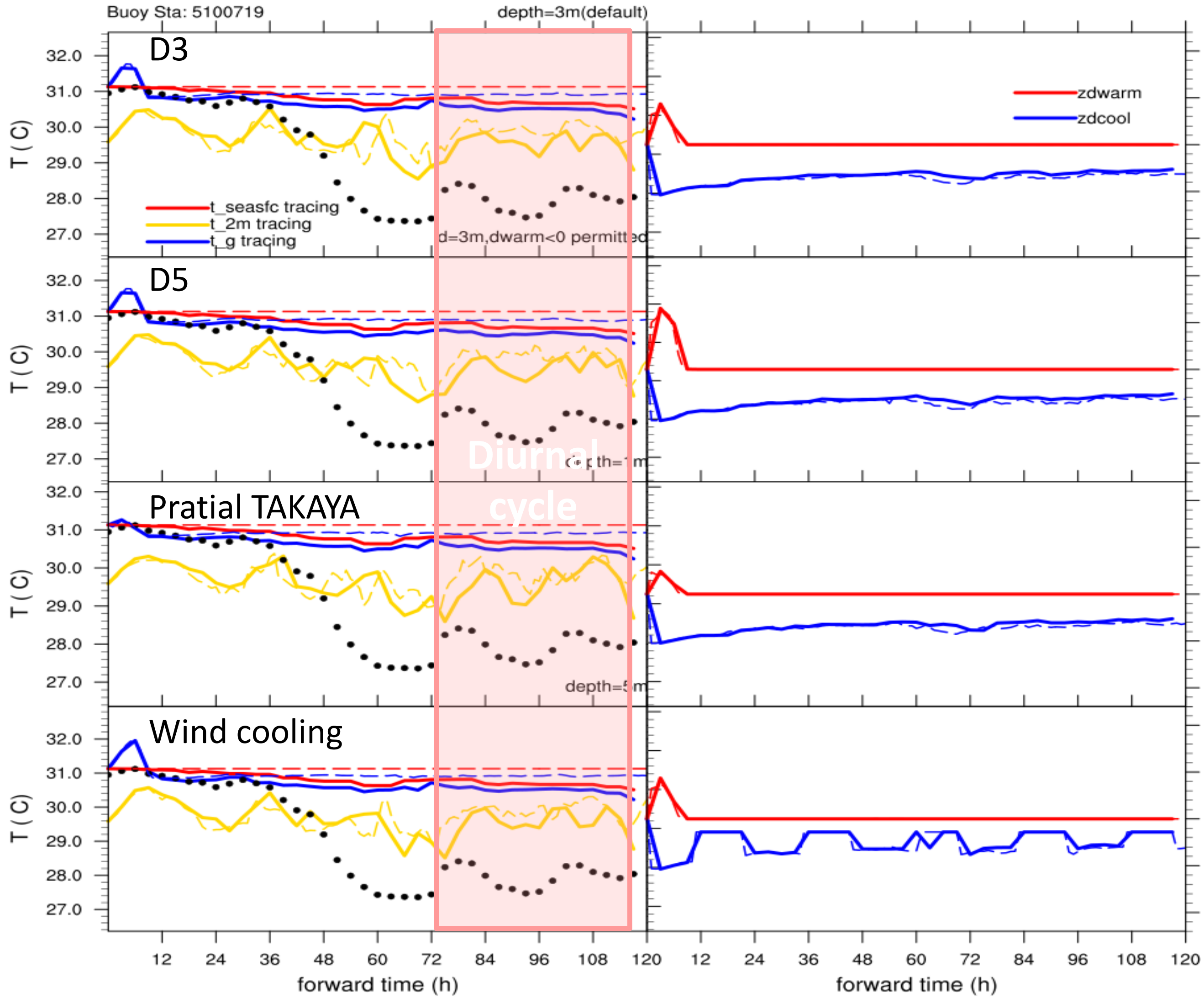
Solid lines: Tracing buoys

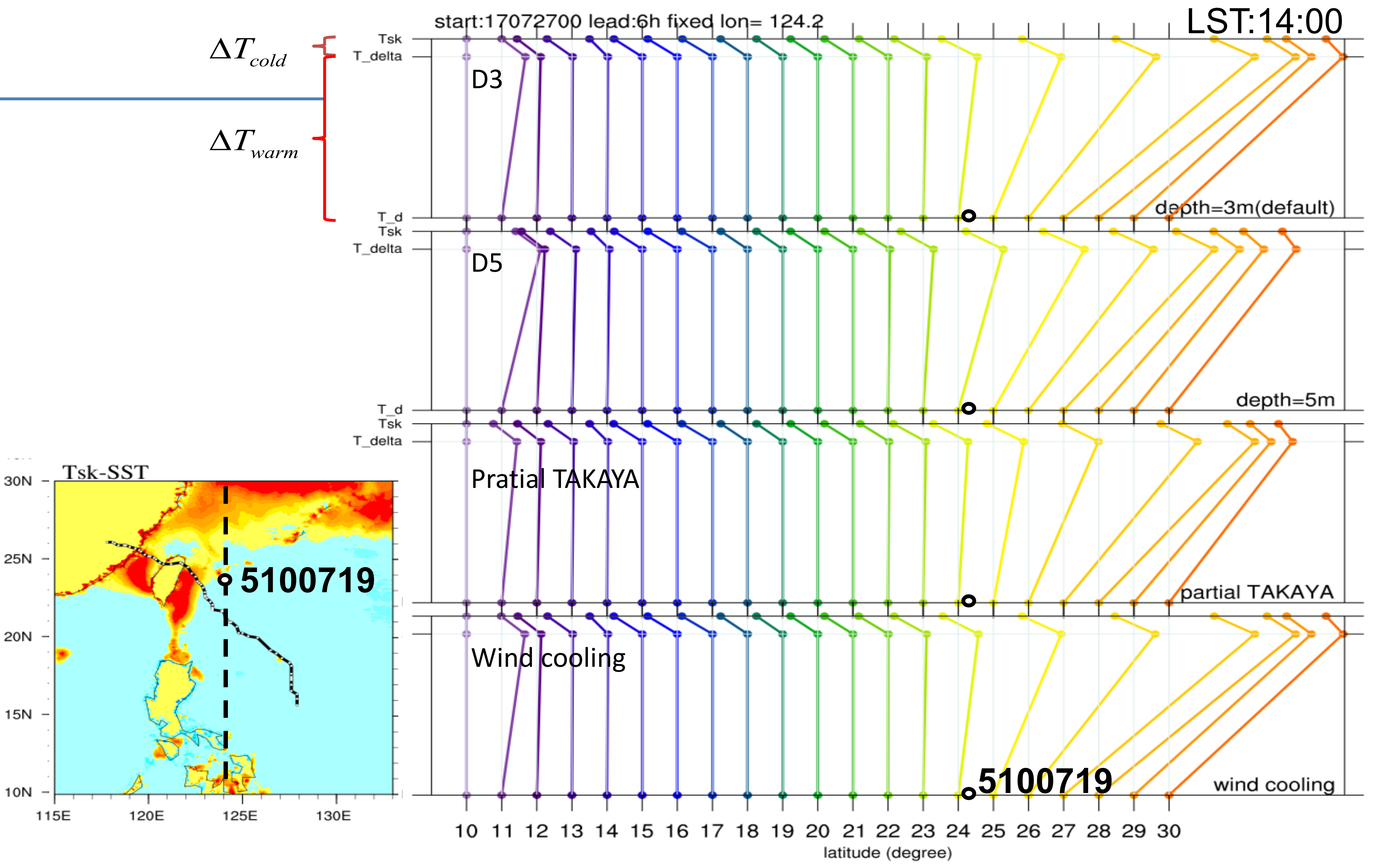
Dash lines: Fixed grid points (the location of start time)



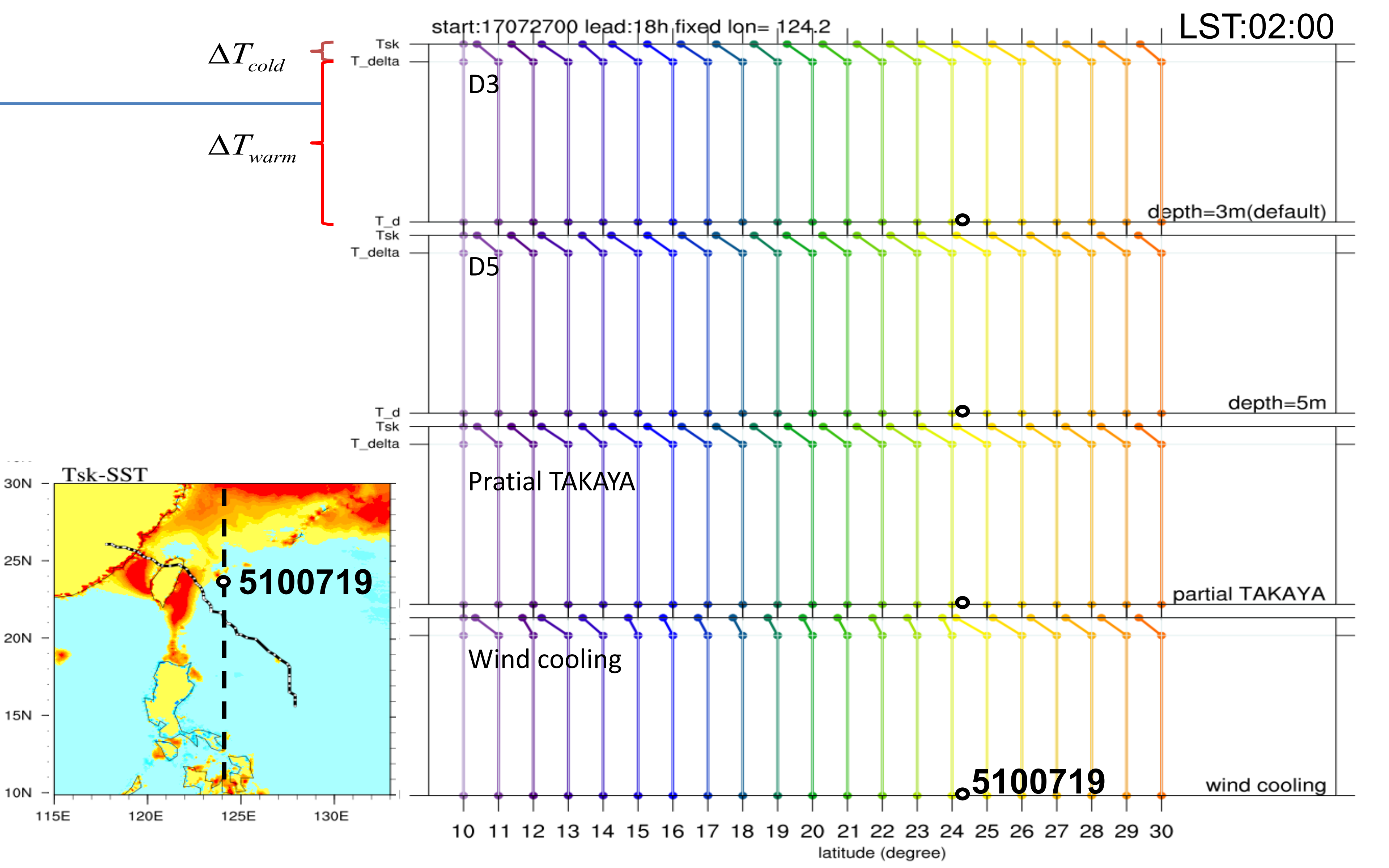
Solid lines: Tracing buoys

Dash lines: Fixed grid points (the location of start time)





start:17072700 lead:6h fixed lon= 124.2
LST:14:00
ΔT_{cold}
ΔT_{warm}
Tsk
T_delta
T_d
D3
depth=3m(default)
D5
depth=5m
Pratial TAKAYA
partial TAKAYA
Wind cooling
wind cooling
5100719
Tsk-SST
30N
25N
20N
15N
10N
115E
120E
125E
130E
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
latitude (degree)

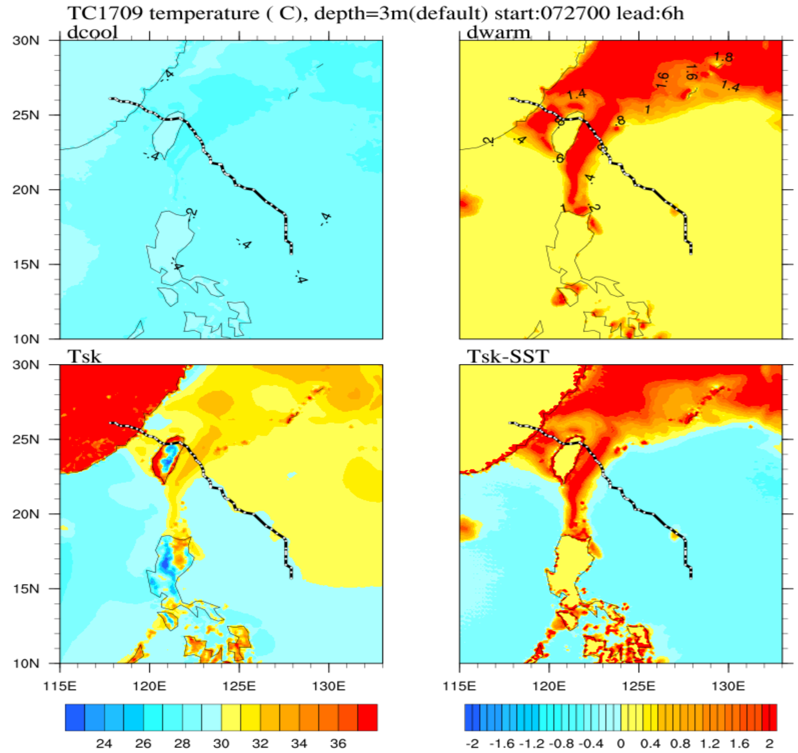


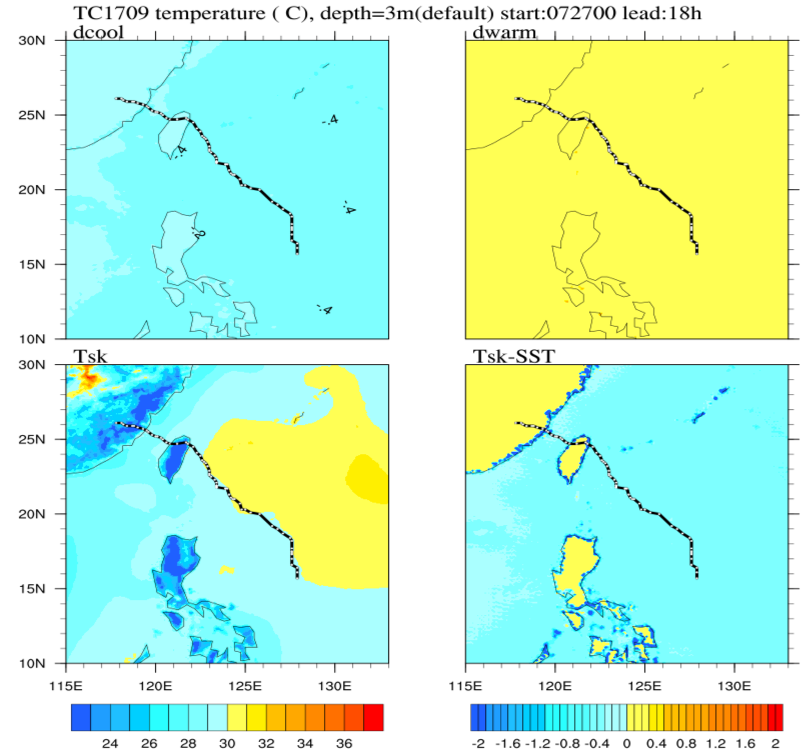
LST:02:00
start:17072700 lead:18h fixed lon= 124.2
ΔT_{cold}
ΔT_{warm}
Tsk
T_delta
T_d
D3
depth=3m(default)
D5
depth=5m
Pratial TAKAYA
partial TAKAYA
Wind cooling
wind cooling
5100719
Tsk-SST
30N
25N
20N
15N
10N
115E
120E
125E
130E
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
latitude (degree)

Distribution of temperature (C)

Depth of warm layer =3m

Smaller coverage, more intensive, larger gradient

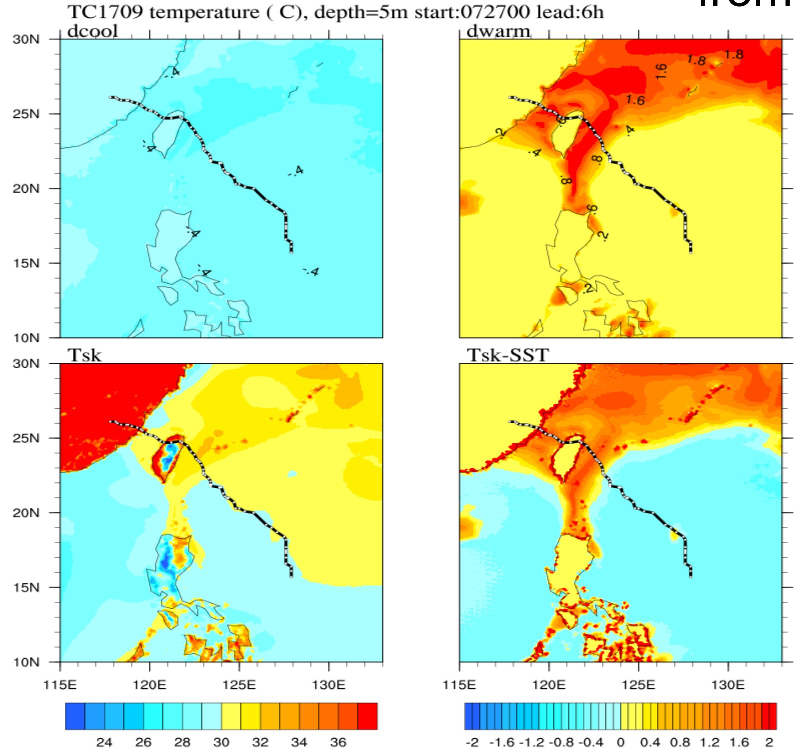


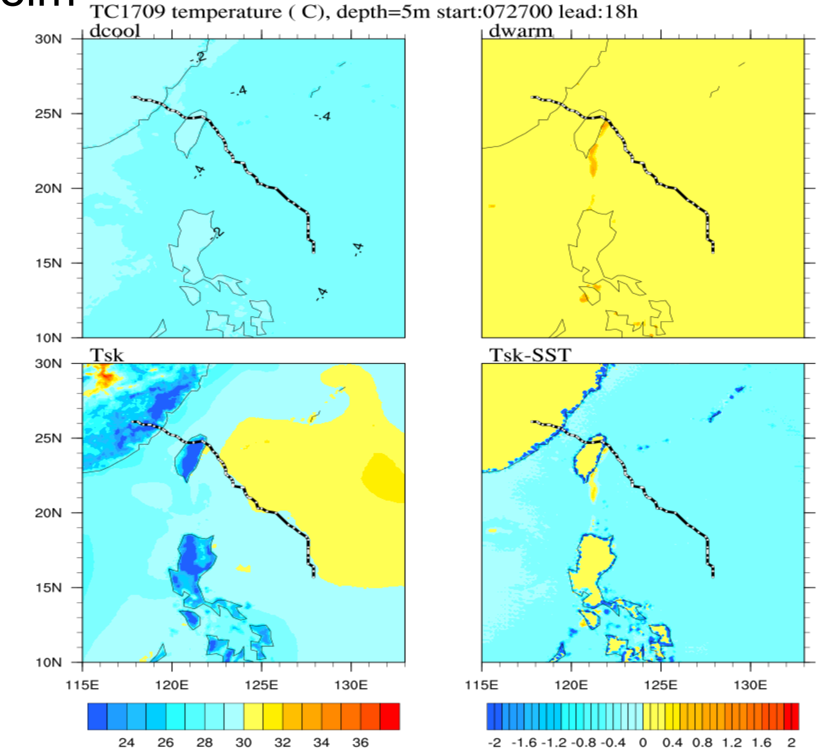


Distribution of temperature (C)

Depth of warm layer =5m

Larger coverage, smoother gradient, residual from dateim

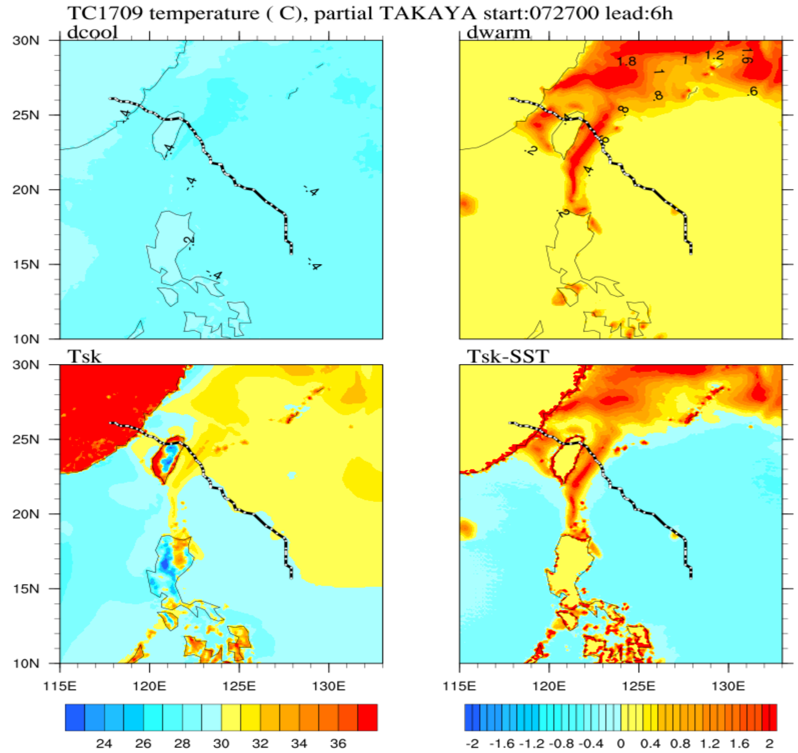


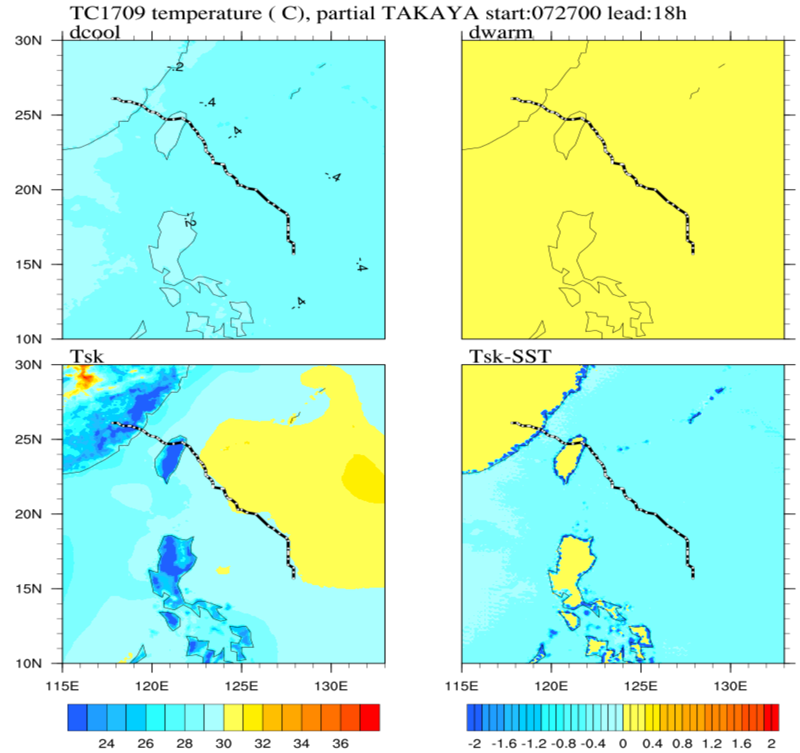


Distribution of temperature (C)

Partial TAKAYA

Weaker in daytime

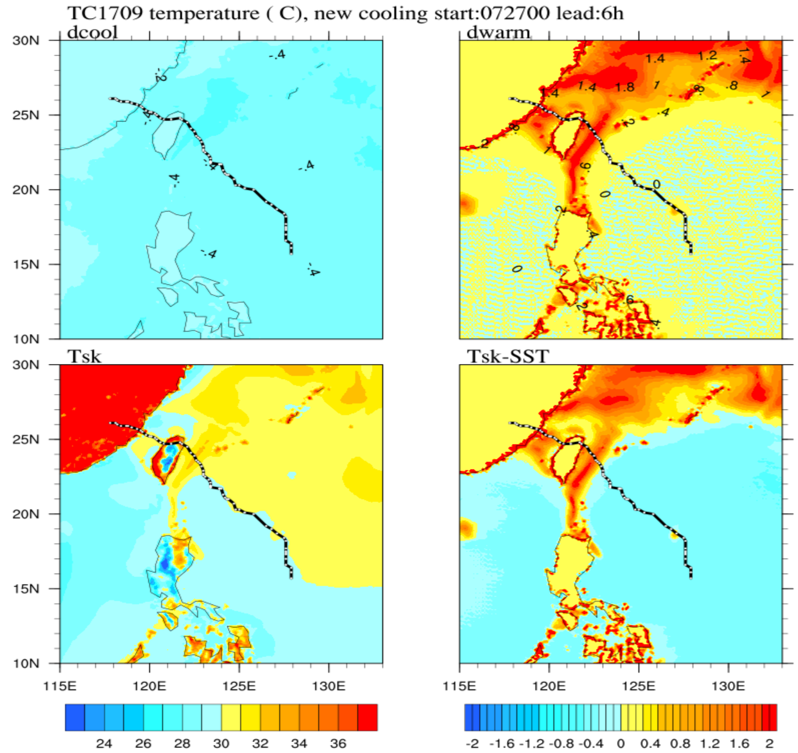


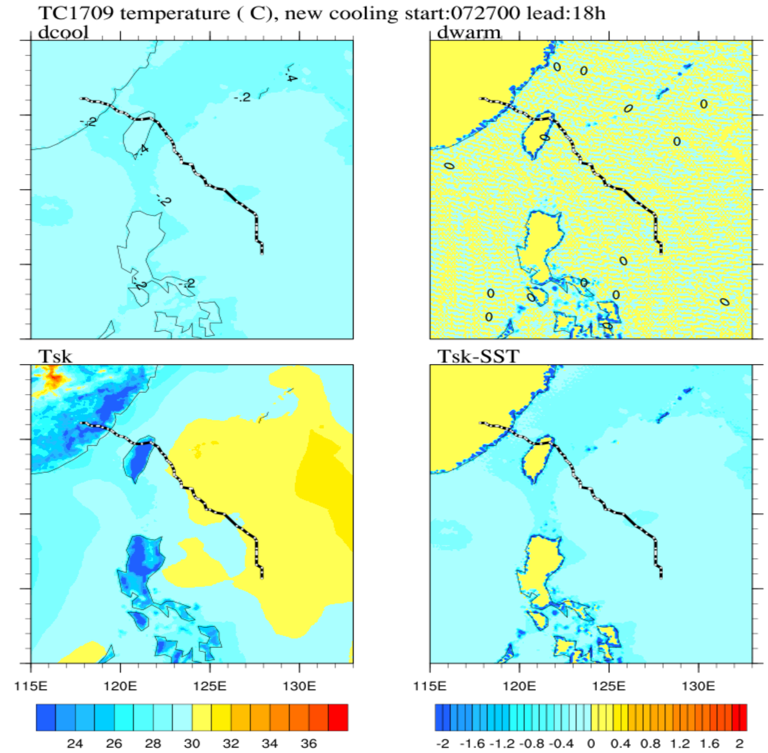


Distribution of temperature (C)

Wind cooling

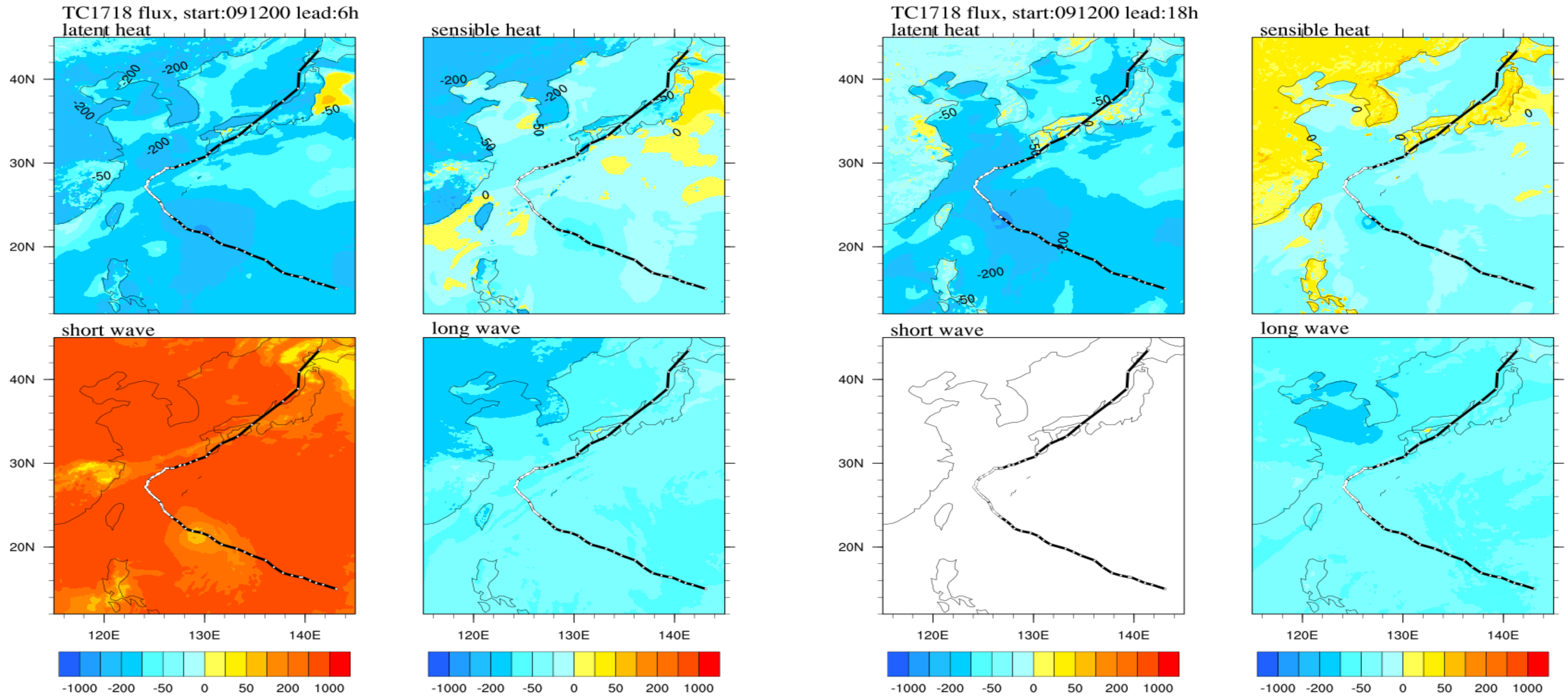
Weaker in night time





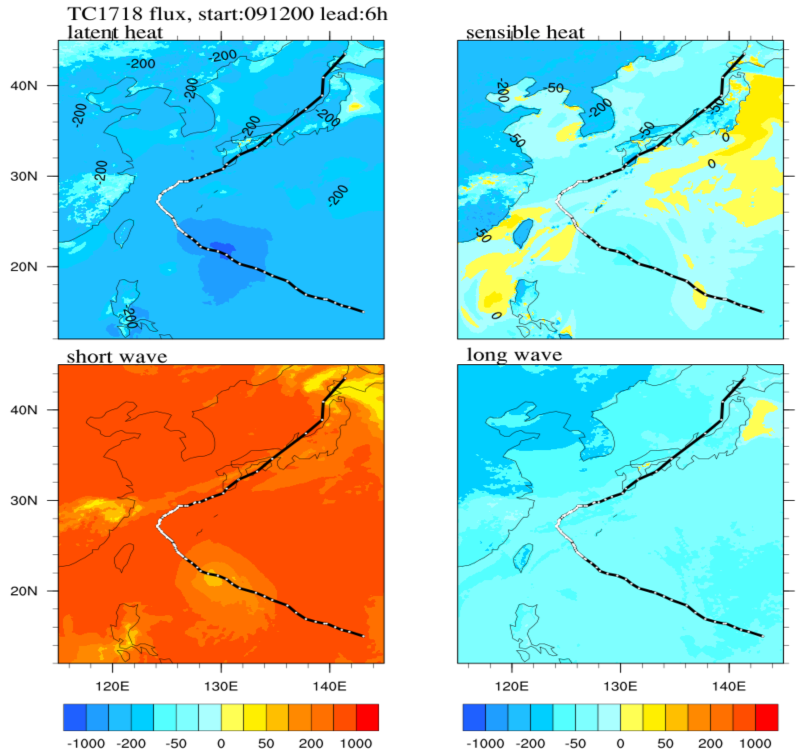
Difference on fluxes

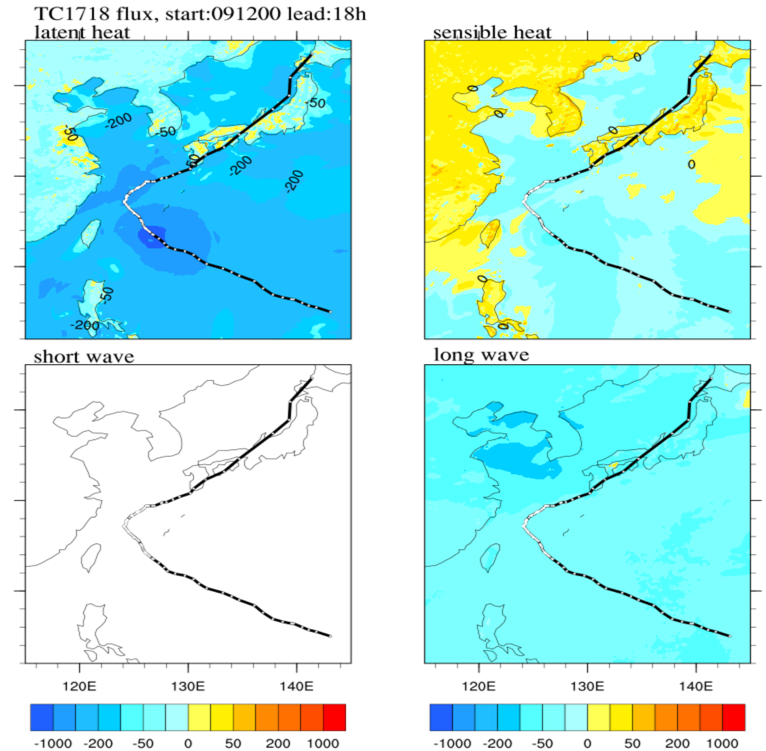
CTRL 091200



Difference on fluxes

default 091200





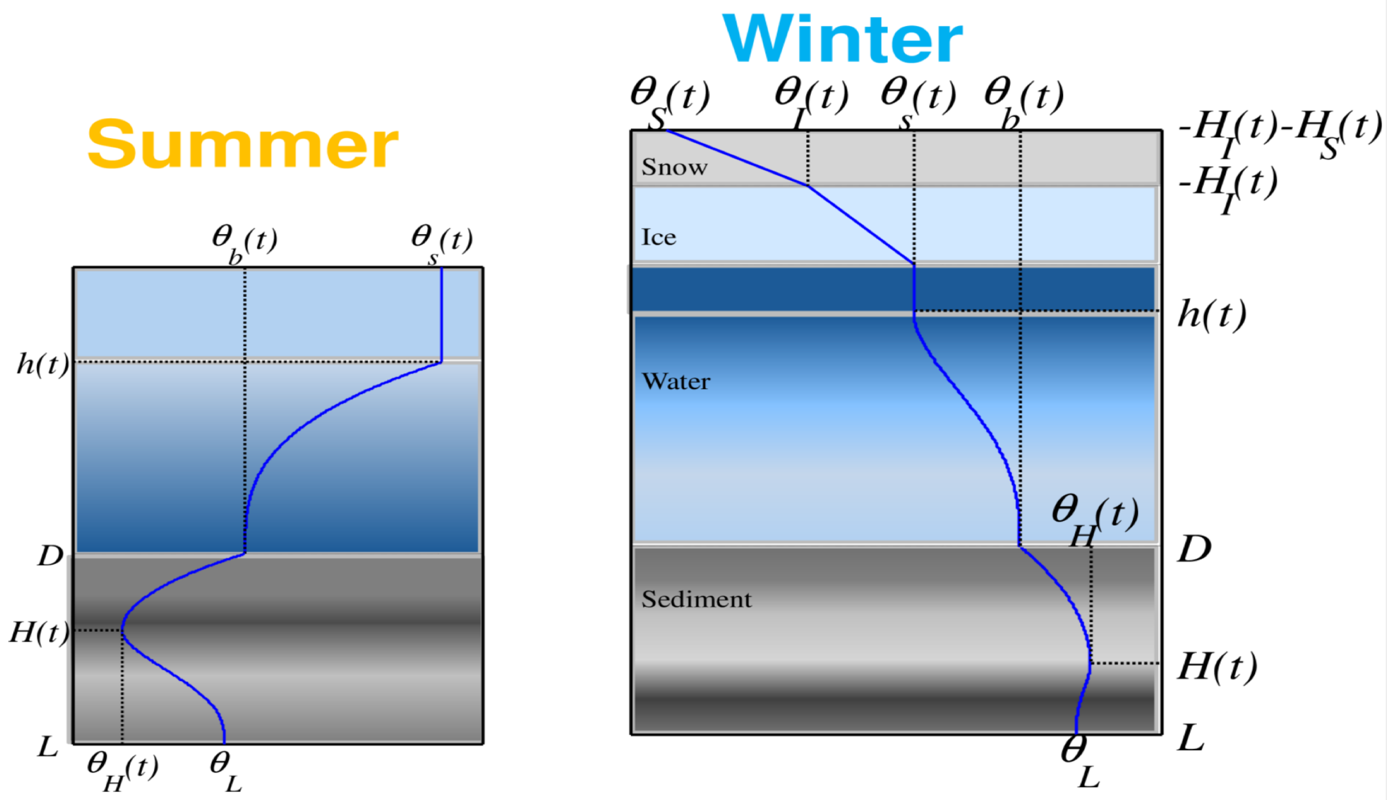
Problems arisen

- Cooling effect by Typhoon
  - Strong wind , strong latent heat
- Diurnal cycle of warm layer

Seeking solution

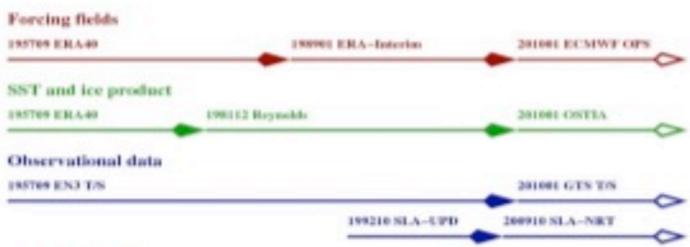
- FLAKE?

Schematic lake temperature stratification



- Initial condition
  - Mixing layer depth
  - Thermocline depth
  - Bottom temperature
  - …
- Modify temperature profile
- Add salinity profile

NEMOVAR – Ocean Reanalysis S4



The NEMO **ocean model** spatial discretisation is that of the tripolar ORCA1 configuration of NEMO, which has a horizontal resolution of about 1 degree, with equatorial refinement. It uses 42 levels in the vertical, 18 of which are in the upper 200m. ORCA1 configuration used in Ocean-S4 has been prepared at NOCS. Ocean-S4 uses version 3.0 of NEMO.

Daily surface fluxes of heat, momentum and fresh water are used to force the ocean model and to produce the first guess or the state of the ocean. The source of fluxes used in Ocean-S4 is shown in the diagram above. Prior to 1989, the surface fluxes are from the ERA-40 atmospheric reanalysis. From the period 1989-2009, the surface fluxes are from ERA-Interim reanalysis. From 2010 onwards, when Ocean-S4 started operational running, daily surface fluxes were derived from the operational ECMWF atmospheric analysis.

The NEMOVAR

to assimilate temperature and salinity profiles as well as along track altimeter derived sea level anomalies. The assimilation window is 10 days for the reanalysis stream ORAS4, while a variable length window is used for the real time stream ORTS4 (for more information about the Ocean-S4 streams see below). **A bias correction scheme** is used to correct the model/forcing errors. The bias correction is needed to ameliorate the spurious variability that can arise from changes in the observing system. The spatial distribution and time variations of the assimilation increments and bias correction terms is displayed in the Ocean-S4 ocean reanalysis product web pages

Ocean Observations are used to improve the ocean estimate given by the first guess. The figure above offers an schematic view of the different data sources used in Ocean-S4. The following types of ocean observation are used:

- **Temperature and salinity profiles** (T/S). The profiles are from the quality-controlled EN3 v2a data-set with XBT depth corrections until 2010, and from the Global Telecommunications System (GTS) thereafter. The T/S profiles consisting of the several data-types: XBTs (T only); CTDs (T/S); moorings (T/S); Argo profilers (T/S); and APBs (or elephant seals, T/S).

Diurnal Cycle Performance

Monthly run

DSA

Vielen Dank!

Ich habe mein Herz in Deutschland verloren!

- TC performance
  - ICON run global /nest
- Implement ZB scheme
  - Sensitive tests
- Verification
- Diurnal Cycle
- Strong wind
- Seeking solution
- Flake? Ocean model?
  - salinity
- More verification …
- 30 days run
- Satellite (Robin Faulwetter)
- Ostia
- Update ZB model to…
- Warm layer TAKAYA 10
- Cool skin
- Outlook

Martin

air-sea interaction

Ocean coupling in TC forecasts (Mogensen et al 2017)

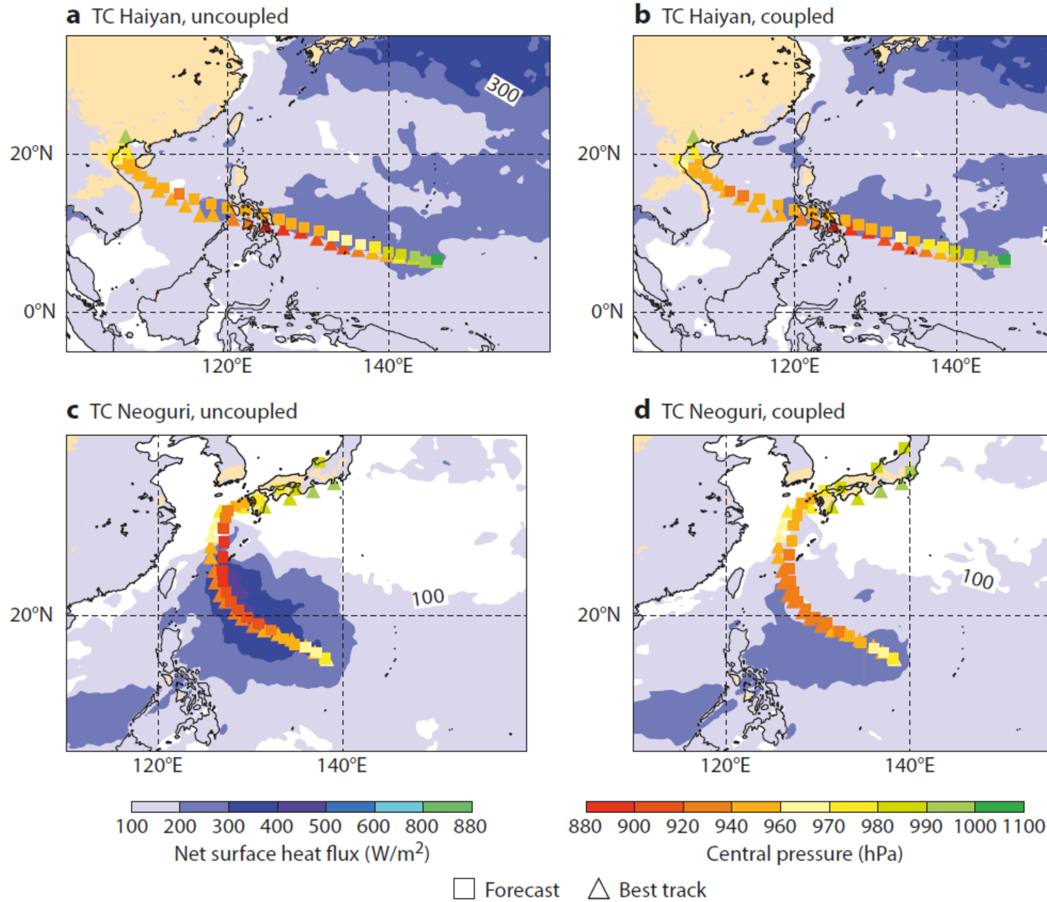


Figure 1 The plots show five-day HRES track and intensity forecasts (squares) together with 'best track' estimates (triangles) and the predicted net surface heat flux (shading) for (a) TC Haiyan (starting date 5 November 2013) using the uncoupled model, (b) TC Haiyan using the coupled model, (c) TC Neoguri (starting date 5 July 2014) using the uncoupled model, and (d) TC Neoguri using the coupled model.

Ocean coupling in TC forecasts (Mogensen et al 2017)

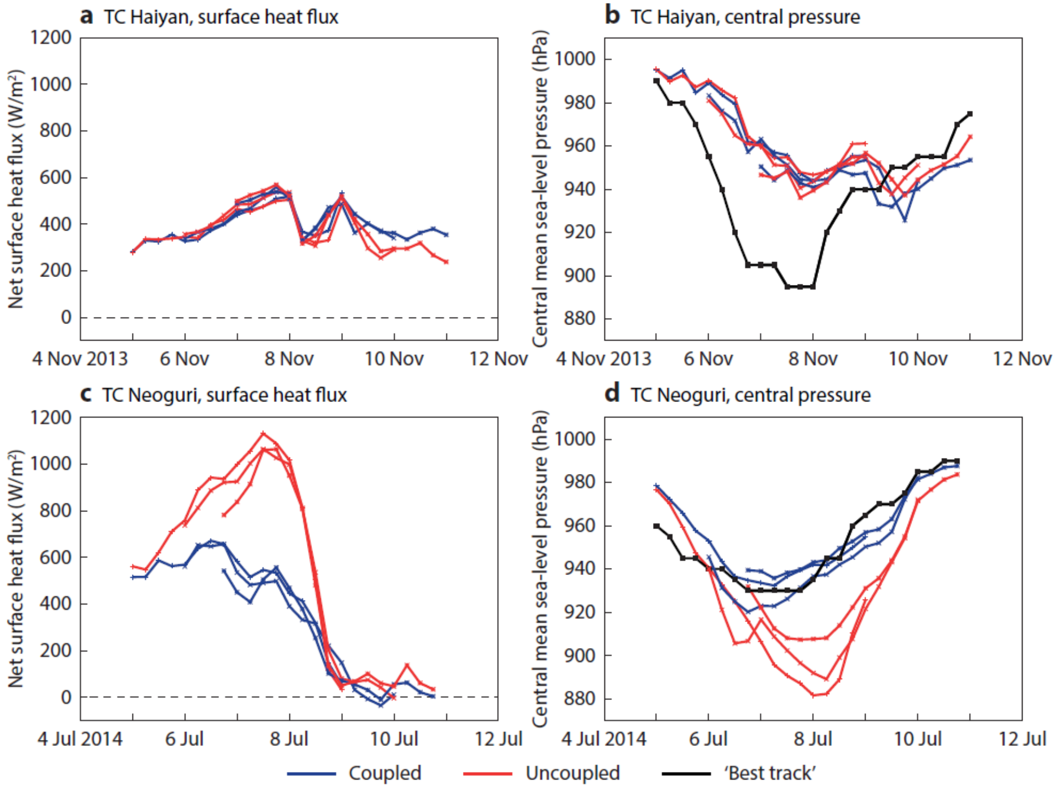
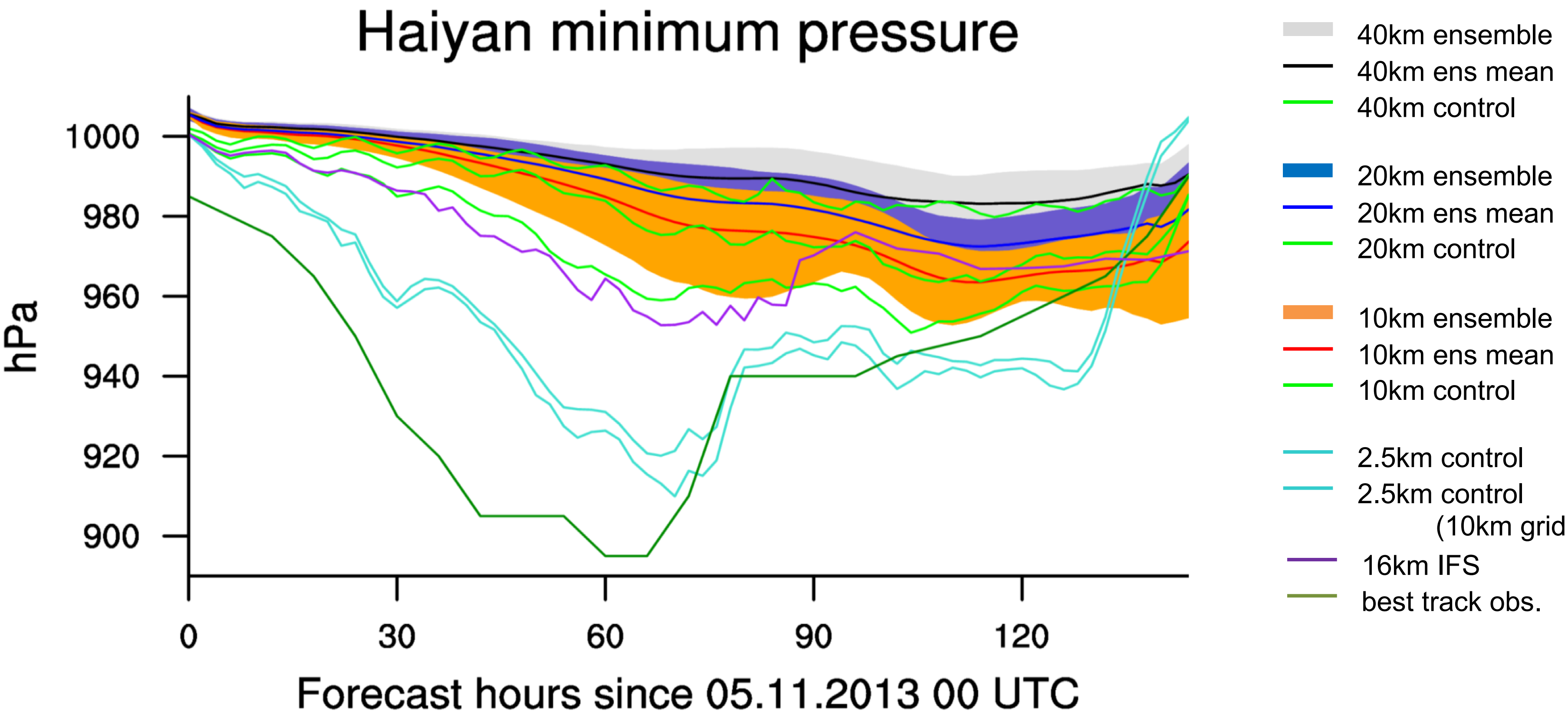


Figure 2 The plots show HRES forecasts of (a) net (sensible + latent) surface heat flux for TC Haiyan, (b) central pressure for TC Haiyan, (c) net surface heat flux for TC Neoguri, and (d) central pressure for TC Neoguri. 'Best track' estimates for central pressure are also shown.

Typhoon Haiyan

Julia Keller, Daniel Klocke



Ocean coupling in TC forecasts (Mogensen et al 2017)

Neoguri

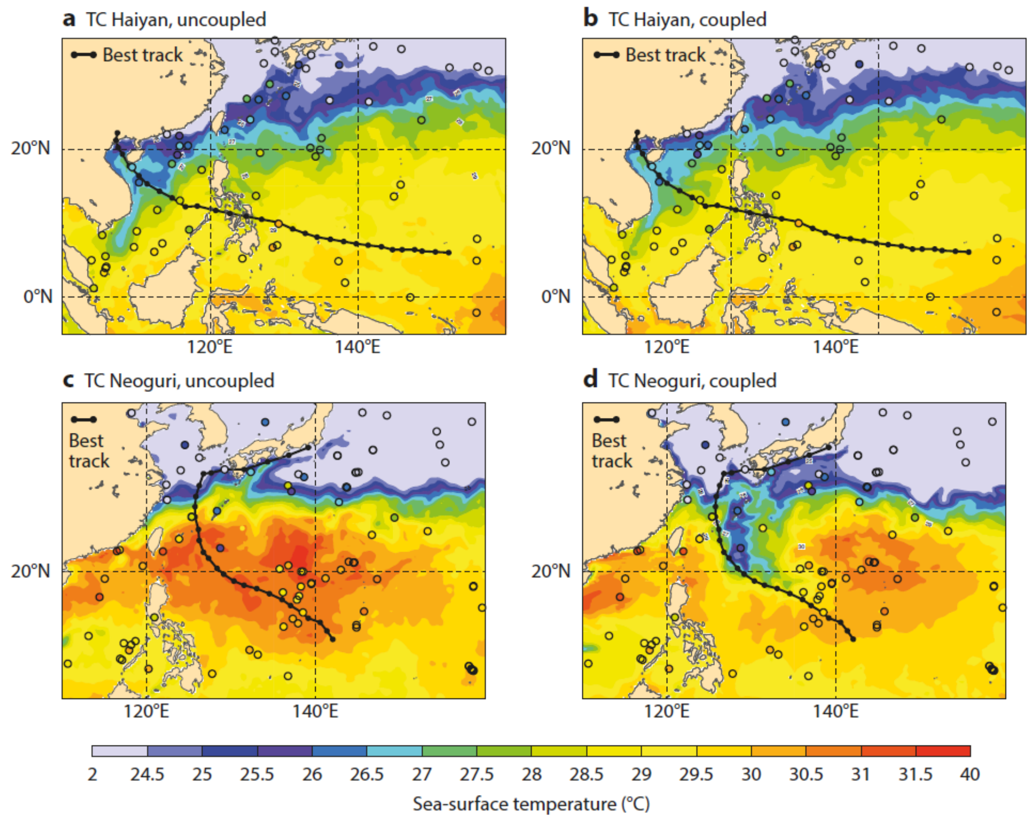


Figure 3 Five-day sea-surface temperature forecasts for (a) TC Haiyan (starting date 5 November 2013) using the uncoupled model, (b) TC Haiyan using the coupled model, (c) TC Neoguri (starting date 5 July 2014) using the uncoupled model, and (d) TC Neoguri using the coupled model, with SST observations (circles) valid at 00 UTC on 10 November 2013 and 00 UTC on 10 July 2014, respectively.

Ocean coupling in TC forecasts (Mogensen et al 2017)

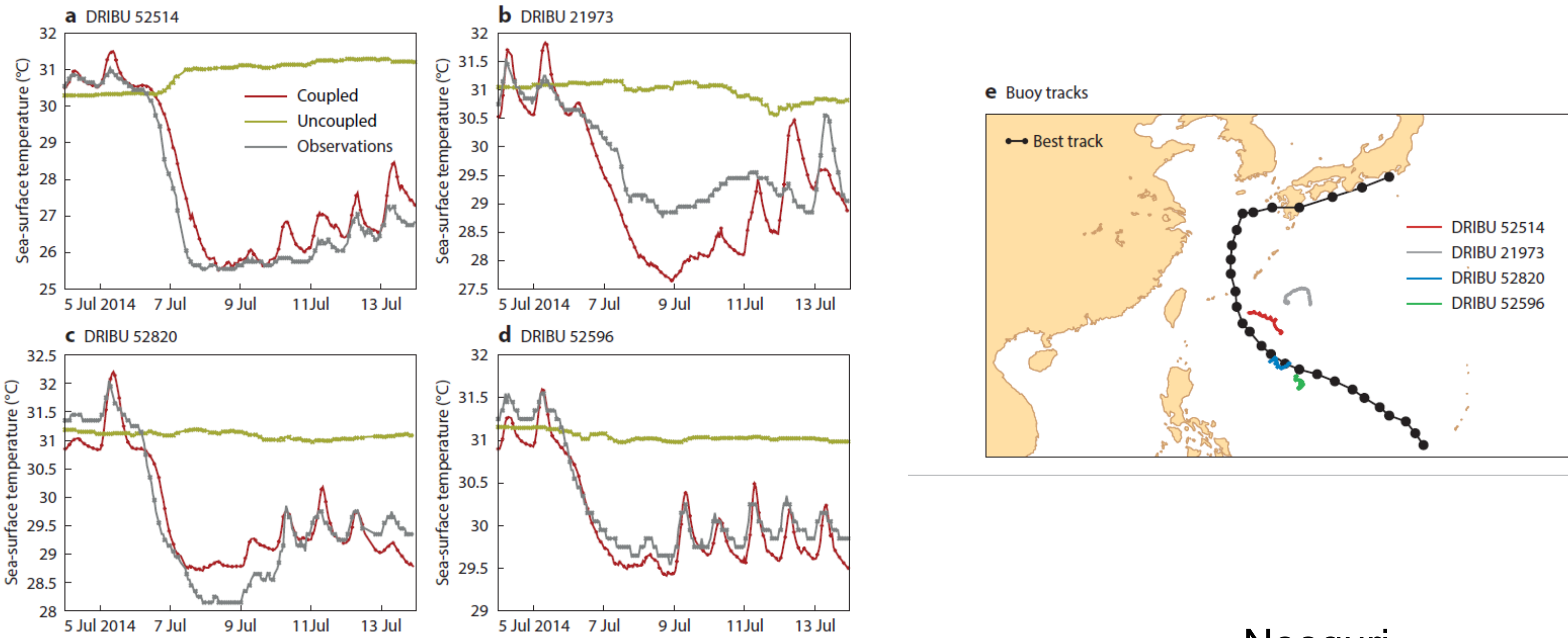


Figure 4
Observations from four DRIBU buoys and SST forecasts starting on 4 July for the same locations in the Neoguri case for (a) DRIBU 52514, (b) DRIBU 21973, (c) DRIBU 52820 and (d) DRIBU 52596, along the tracks shown in (e).

Neoguri

Ocean coupling in TC forecasts (Mogensen et al 2017)

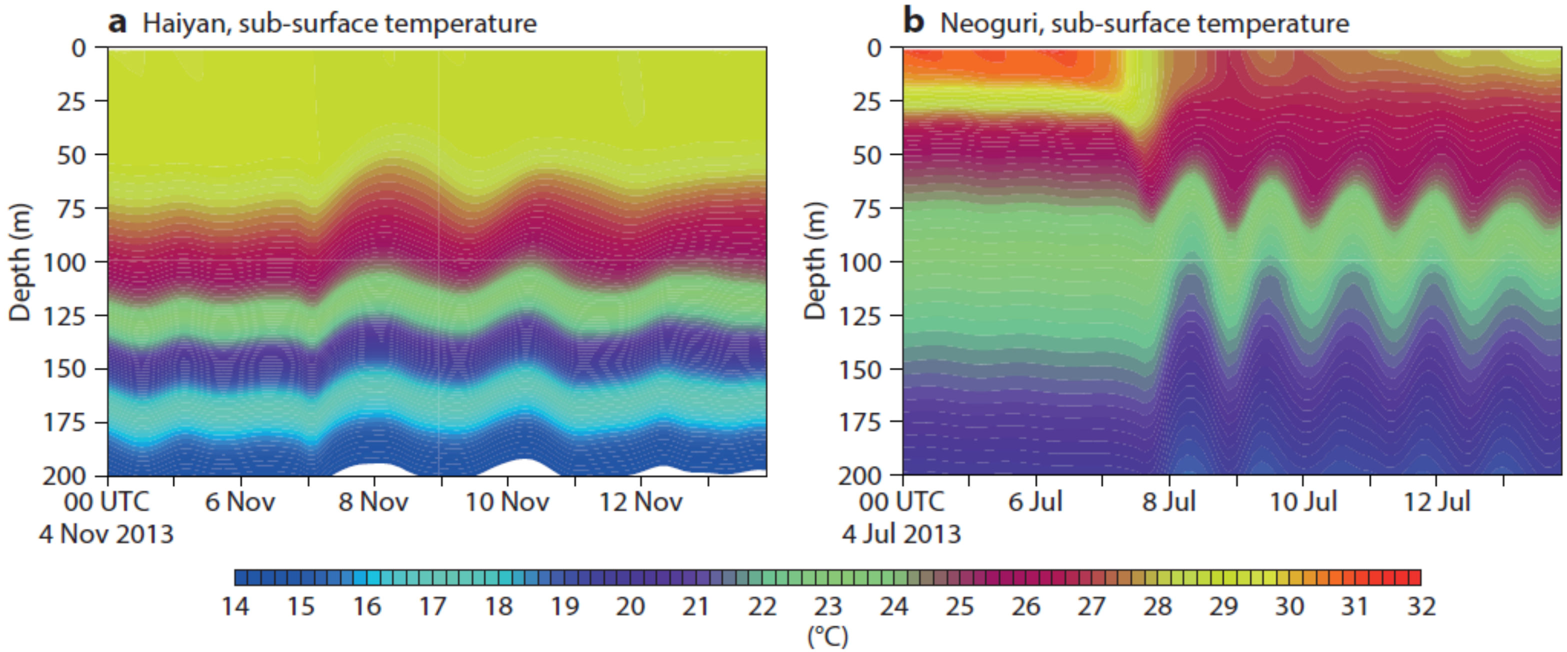


Figure 5 Plots of sub-surface temperature and currents for the two points on the model track closest to the estimated Haiyan 'best track' position at 00 UTC on 7 November 2013 and for Neoguri at 18 UTC on 7 July 2014, showing ocean forecasts of (a) sub-surface temperature for Haiyan, (b) sub-surface temperature for Neoguri, (c) zonal (east–west) currents for Haiyan, (d) zonal currents for Neoguri, (e) meridional (north–south) currents for Haiyan, and (f) meridional currents for Neoguri.

Ocean coupling in TC forecasts (Mogensen et al 2017)

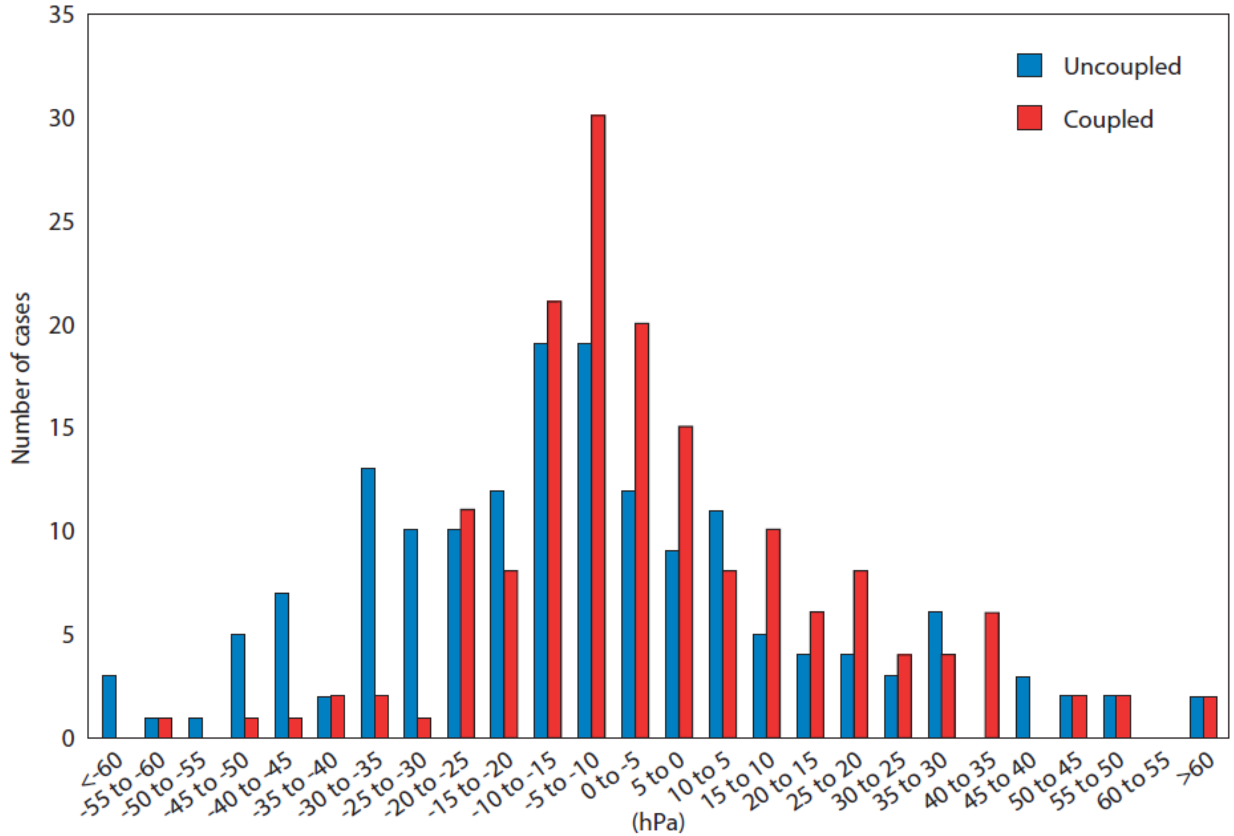


Figure 6 Distribution of 7-day TC intensity forecast errors for coupled and uncoupled high-resolution forecast experiments. The experiments cover the period of March 2015 to June 2017 and were carried out over all basins for a total of 163 TCs.

Zeng, Beljaars, 2005
prognostic SST: cold skin & warm layer

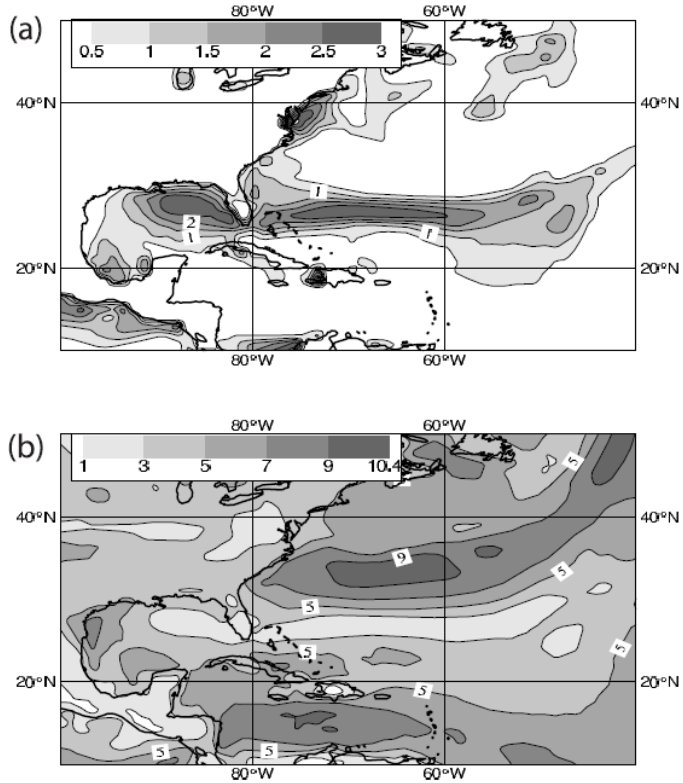
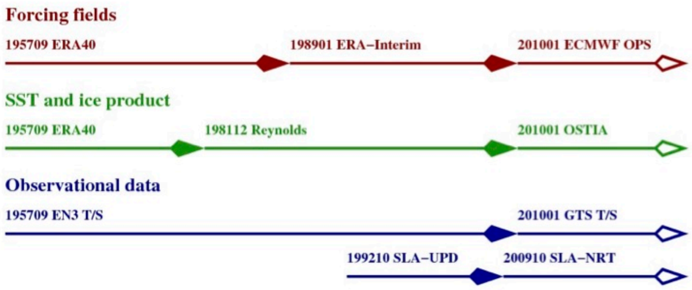


Figure 3. (a) The averaged T_s difference (K) between 2000 UTC and 1200 UTC, 20–22 May 1998 based on the ECMWF model along with the new T_s scheme; and (b) the averaged surface wind (m/s).

SST 2000-1200 UTC

surface wind (average)

NEMOVAR – Ocean Reanalysis S4



The NEMO ocean model spatial discretisation is that of the tripolar ORCA1 configuration of NEMO, which has a horizontal resolution of about 1 degree, with equatorial refinement. It uses 42 levels in the vertical, 18 of which are in the upper 200m. ORCA1 configuration used in Ocean-S4 has been prepared at NOCS. Ocean-S4 uses version 3.0 of NEMO.

Daily surface fluxes of heat, momentum and fresh water are used to force the ocean model and to produce the first guess or the state of the ocean. The source of fluxes used in Ocean-S4 is shown in the diagram above. Prior to 1989, the surface fluxes are from the ERA-40 atmospheric reanalysis. From the period 1989-2009, the surface fluxes are from ERA-Interim reanalysis. From 2010 onwards, when Ocean-S4 started operational running, daily surface fluxes were derived from the operational ECMWF atmospheric analysis.

The NEMOVAR

ocean data assimilation, in its 3D-var FGAT mode, is used to assimilate temperature and salinity profiles as well as along track altimeter derived sea level anomalies. The assimilation window is 10 days for the reanalysis stream ORAS4, while a variable length window is used for the real time stream ORTS4 (for more information about the Ocean-S4 streams see below). **A bias correction scheme** is used to correct the model/forcing errors. The bias correction is needed to ameliorate the spurious variability that can arise from changes in the observing system. The spatial distribution and time variations of the assimilation increments and bias correction terms is displayed in the Ocean-S4 ocean reanalysis product web pages

Ocean Observations are used to improve the ocean estimate given by the first guess. The figure above offers an schematic view of the different data sources used in Ocean-S4. The following types of ocean observation are used:

- **Temperature and salinity profiles** (T/S). The profiles are from the quality-controlled EN3 v2a data-set with XBT depth corrections until 2010, and from the Global Telecommunications System (GTS) thereafter. The T/S profiles consisting of the several data-types: XBTs (T only); CTDs (T/S); moorings (T/S); Argo profilers (T/S); and APBs (or elephant seals, T/S).
- **Altimeter derived sea level anomalies (SLA),** from

NEMOVAR – Ocean Reanalysis S4

AVISO, available from November 1992 onwards. The along track product is assimilated via NEMOVAR. Global mean values from the AVISO gridded maps of sea level anomaly (MSLA) are used to constrain the global fresh water budget.

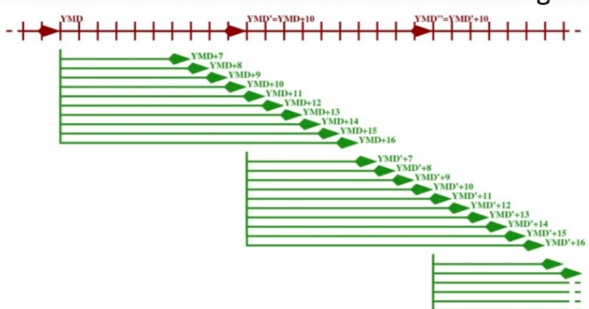
Sea Surface Temperature (SST) and sea-ice. From September 1957 until November 1981) the SST/sea-ice are taken from the ERA-40 archive. From December 1981 until December 2009, SST/sea-ice are taken from the NCEP OI v2 weekly product, (Reynolds in the figure) and from January 2010 onwards the OSTIA SST/sea-ice is used. The SST and sea-ice information is used to constrain the upper level ocean temperature via a newtonian relaxation scheme.

The reanalysis and real time streams

The current ECMWF operational ocean analysis system is Ocean-S4. As for previous systems, Ocean-S4 consists of two analysis streams:

- A historical ocean reanalysis from 19570901 to present, updated every 10 days with a 6 day delay. It is used to initialise the coupled hindcasts needed for calibration of coupled model output. This stream is called **ORAS4**, for Ocean Re-Analysis System 4.
- A real time ocean analysis, produced daily, used to initialise the coupled forecasts. The real time stream is called **ORTA4**, for Ocean Real Time Analysis System 4.

The figure below shows schematically the operational schedule followed in the production of the two streams. Every 10 days, ORAS4 ocean analysis is advanced by 1 assimilation cycle (10 days). It runs with a delay of 6 days, in order to wait for the arrival of ocean observations (in particular, the 6 day delay is set by the retrieval of the sea-level products to constrain the global mean of the model sea level). This means that initial conditions from the reanalysis system could be up to 16 days old and thus not suitable to initialise monthly and seasonal forecasts. In order to create real-time ocean initial conditions on a daily basis, ORTA4 brings the latest ORAS4 state up to real time every day, using the available observations in a variable assimilation window. The length of the window is determined by the time difference between the latest ORAS4 reanalysis and the present day plus 1 day, so the output initial conditions will be valid on 0Z the following morning.



NEMOVAR – Ocean Reanalysis S4

The data archive

You can view the monthly mean output from selected fields.

The output is in netCDF, and the ocean variables follow the naming convention of the NEMO model. For example:

- votemper: Ocean Potential Temperature (deg C)
- vosaline: Ocean Salinity (psu)
- vozocrtx: zonal velocity (m/s)
- vomecrty: meridional velocity (m/s)

Contact address: magdalena.balmaseda at ecmwf.int

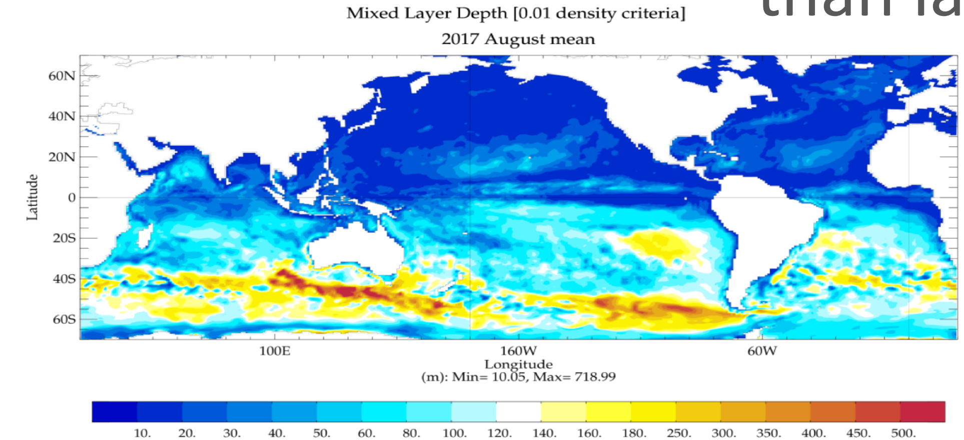
References and further reading

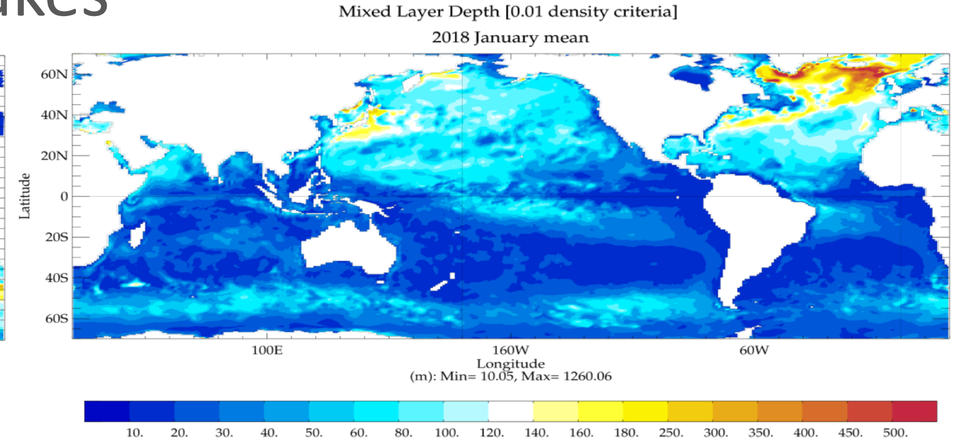
Balmaseda, M. A., Mogensen, K. and Weaver, A. T. (2013), Evaluation of the ECMWF ocean reanalysis system ORAS4. Q.J.R. Meteorol. Soc., 139: 1132–1161. doi: 10.1002/qj.2063

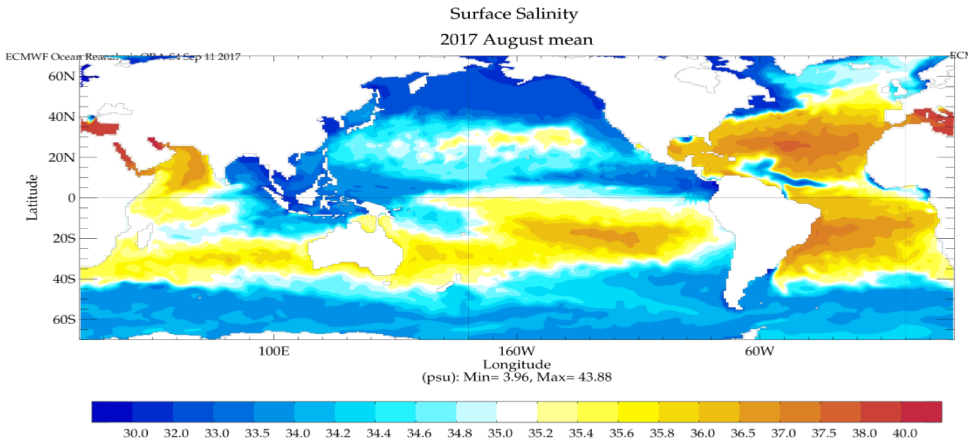
Mogensen, K., M. Alonso Balmaseda, A. Weaver (2012), The NEMOVAR ocean data assimilation system as implemented in the ECMWF ocean analysis for System 4. ECMWF Technical Memorandum 66. 59 pages

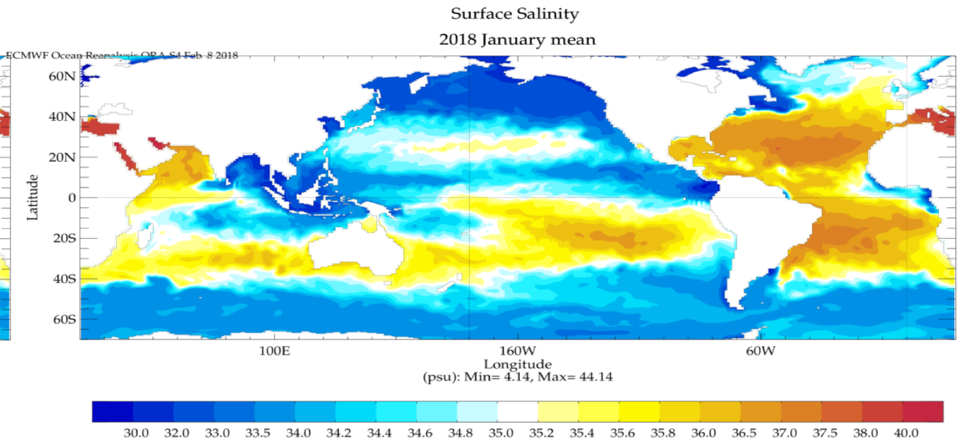
Balmaseda, M. A., K. E. Trenberth, and E. Källén (2013), Distinctive climate signals in reanalysis of global ocean heat

Mixing layer and thermocline layer are much deeper than lakes



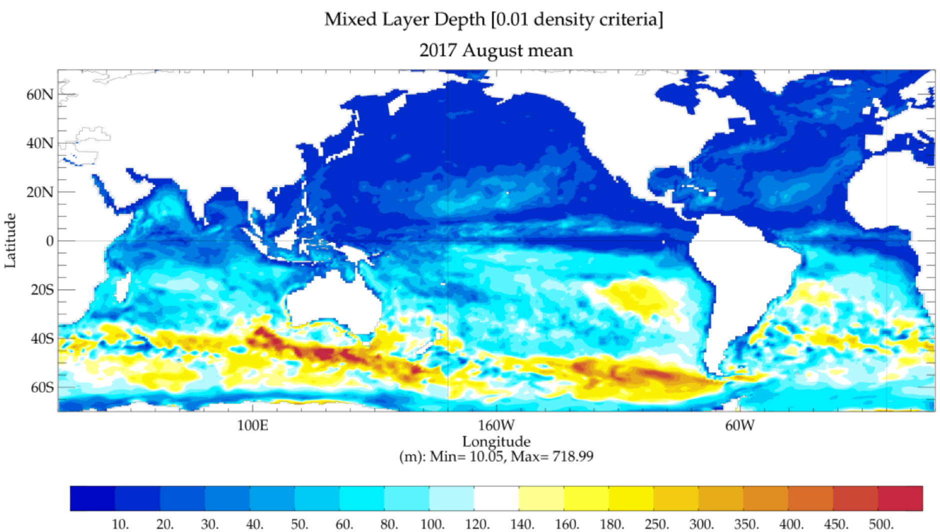




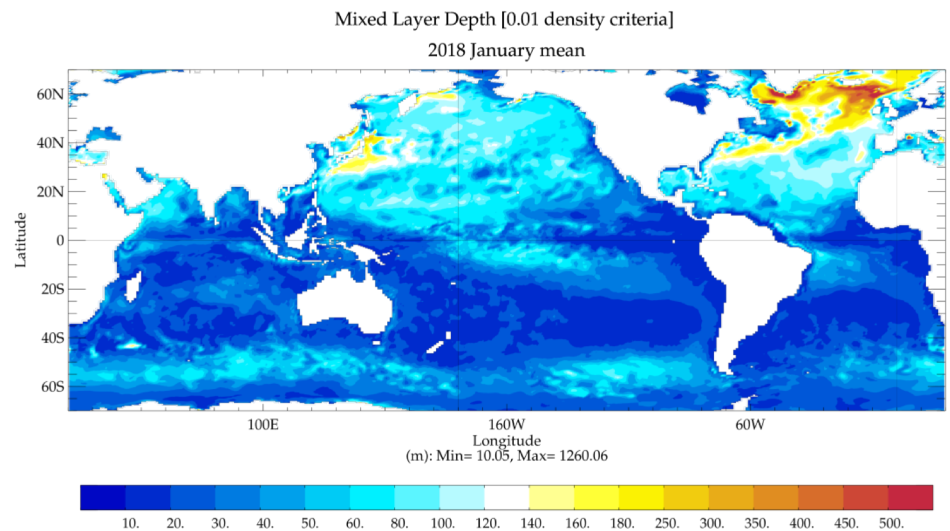


Mixing layer and thermocline

Ocean Reanalysis ORA-S4



ECMWF Ocean Reanalysis ORA-S4 Sep 11 2017

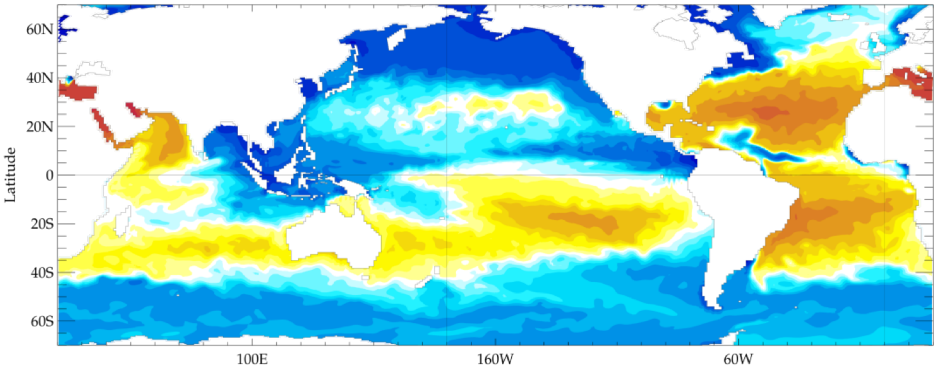


ECMWF Ocean Reanalysis ORA-S4 Feb 8 2018

Ocean Reanalysis ORA-S4

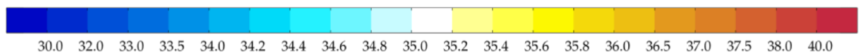
Surface Salinity

2017 August mean



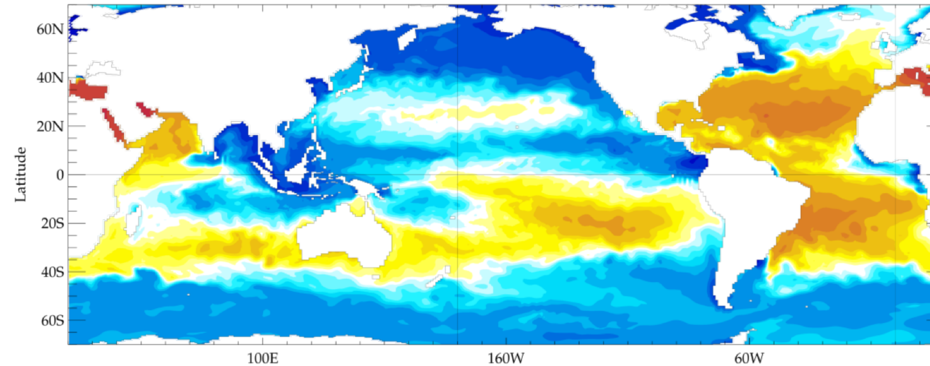
Longitude

(psu): Min= 3.96, Max= 43.88



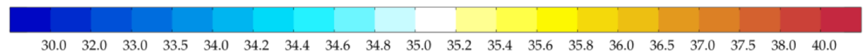
Surface Salinity

2018 January mean



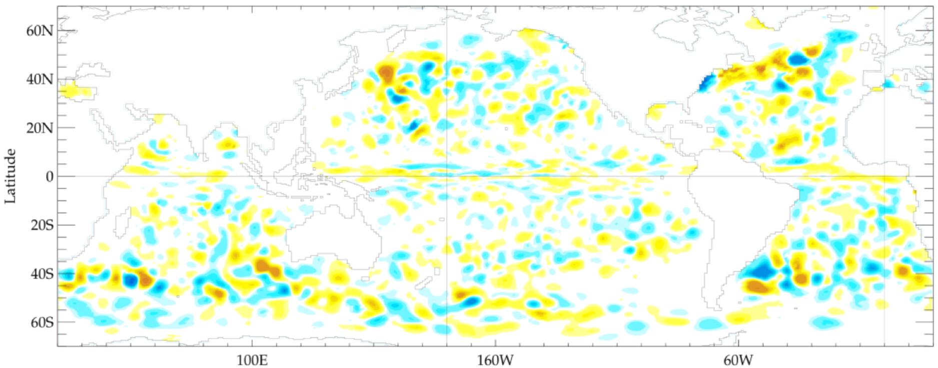
Longitude

(psu): Min= 4.14, Max= 44.14



Salinity Increment Upper 300m

2017 August mean

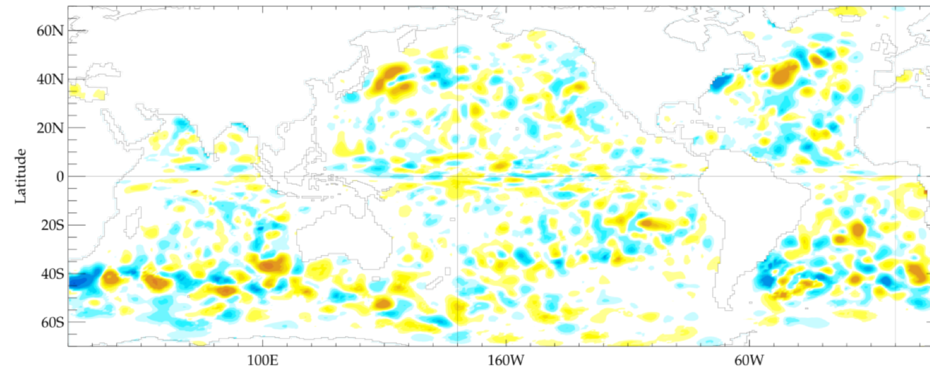


Longitude

(psu/10-days): Min= -0.27, Max= 0.31

Salinity Increment Upper 300m

2018 January mean

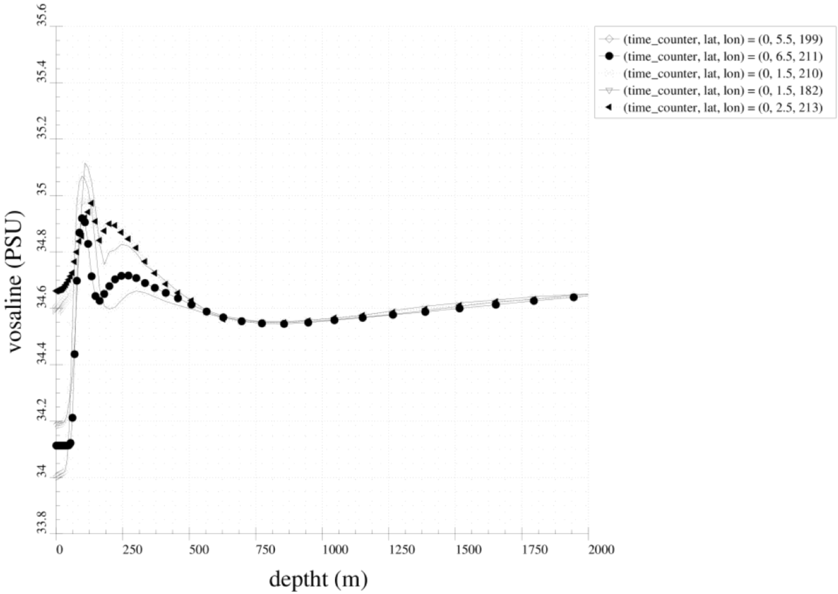


Longitude

(psu/10-days): Min= -0.31, Max= 0.32

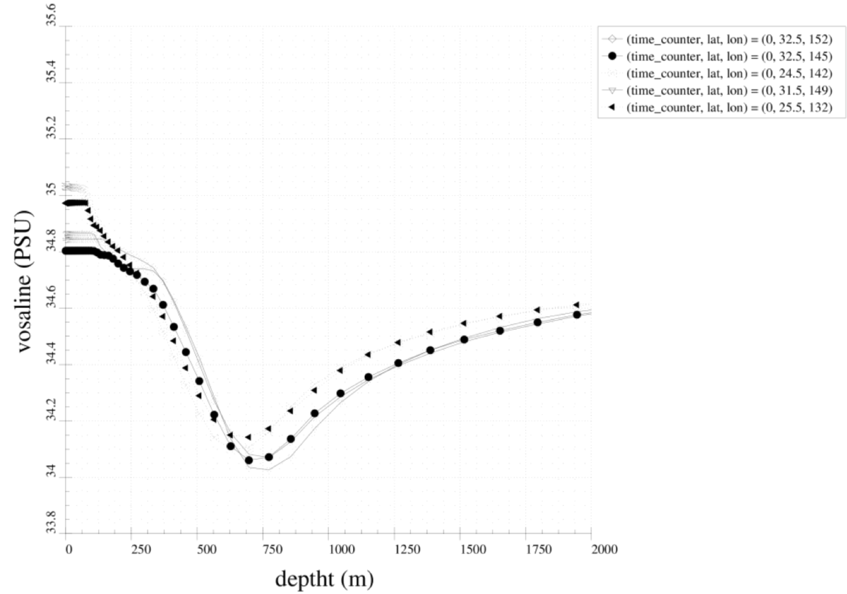
OCEAN5: Jan 2016 mean salinity

Tropical Pacific



Salinity

Off Japan



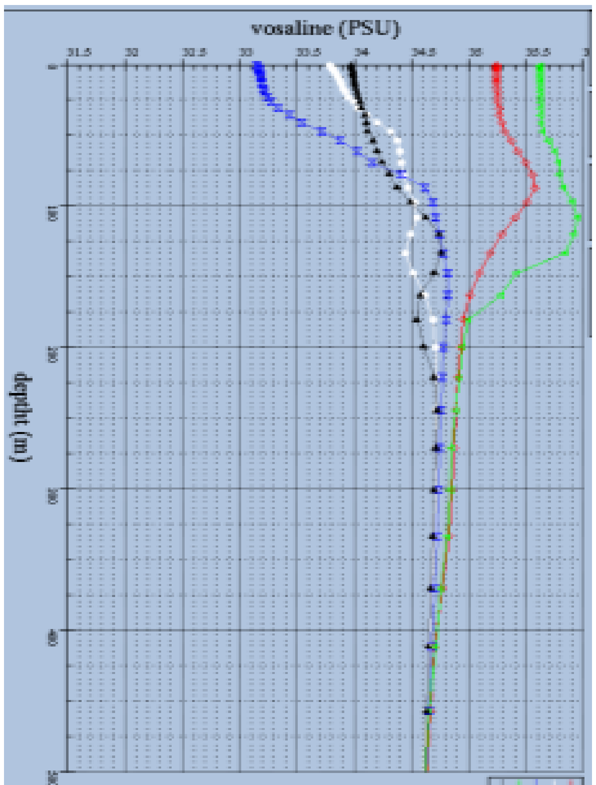
Salinity

Salinity is not a conservative variable
Hard to describe by a simple self-similarity profile

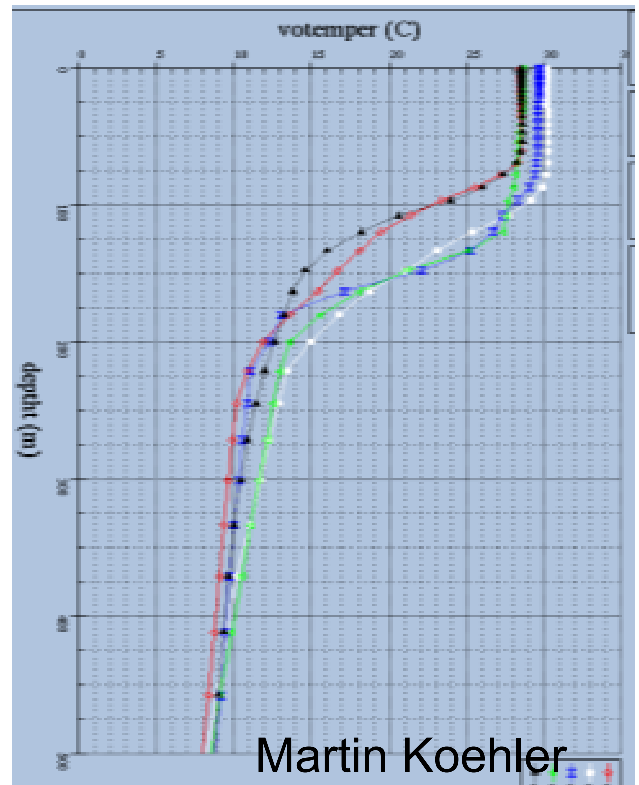
OCEAN5: Jan 2016 mean salinity and temperature

Tropical Pacific

Salinity



Temperature



Martin Koehler

Temperature-Salinity-Density