Results from the SOSSTA project on developing a statistical-dynamical observation operator for SST data assimilation

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Plenary Session VIII: Diurnal Variability

20th GHRSST Science Team Meeting, Frascati, Italy, 6 June 2019

The Science Problem

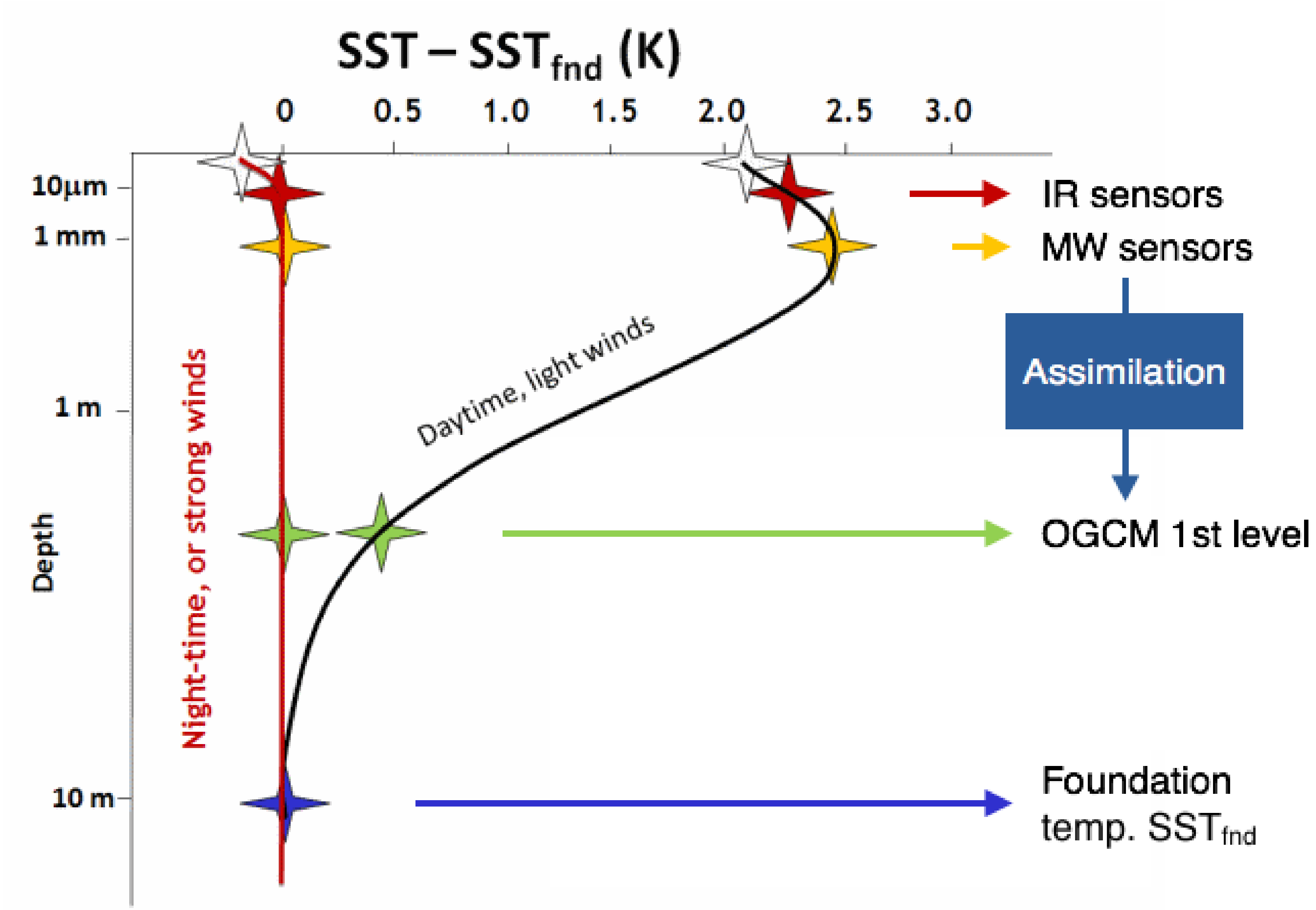

Image modified from ghrsst.org

Aim

- Develop and test a new technique for producing a dynamically-based highly efficient statistical observation operator for the assimilation of satellite SST observations

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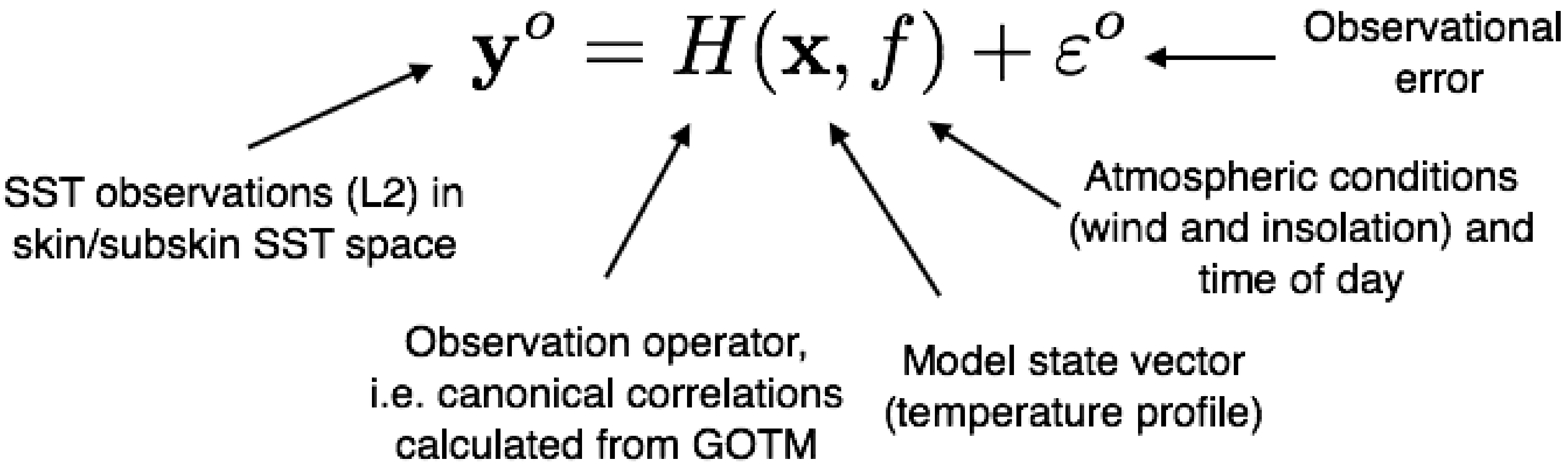
Solution Approach

- Use a **high-resolution process model** of the near surface ocean thermodynamics (GOTM) to generate a training data set
- Perform **Canonical Correlation Analysis** (CCA) to correlate the profile data with skin & sub-skin SST variations
- The resulting statistical observation operator would include diurnal variability conditioned on categories of atmospheric forcing

Solution Approach



- This work provides a statistical observation operator H, that projects the model state x onto the space of the satellite SST observations y

Modelling Diurnal Variability in SST

- GOTM, a 1-D process model of near-surface ocean thermodynamics tailored for modelling the SST diurnal cycle

- 122 levels to depth of 75m, higher resolution near surface (e.g. top level is 0.015m, 21 levels in top 1m, 52 levels in top 5m, and 68 levels in top 10m)

- Various solar absorption parameterisations tested including using MODIS chlorophyll data (Ohlmann & Siegel, 2000) and MODIS IOP data (Lee et al., 2005)

- Skin SST is computed dynamically within GOTM using the parameterisation (Fairall et al., 1996a) and takes into account the fraction of SWR absorbed in the cool-skin layer

GOTM Mediterranean Sea Simulations

- GOTM is run on a 3/4 degree grid (391 locations) for 2013-2014

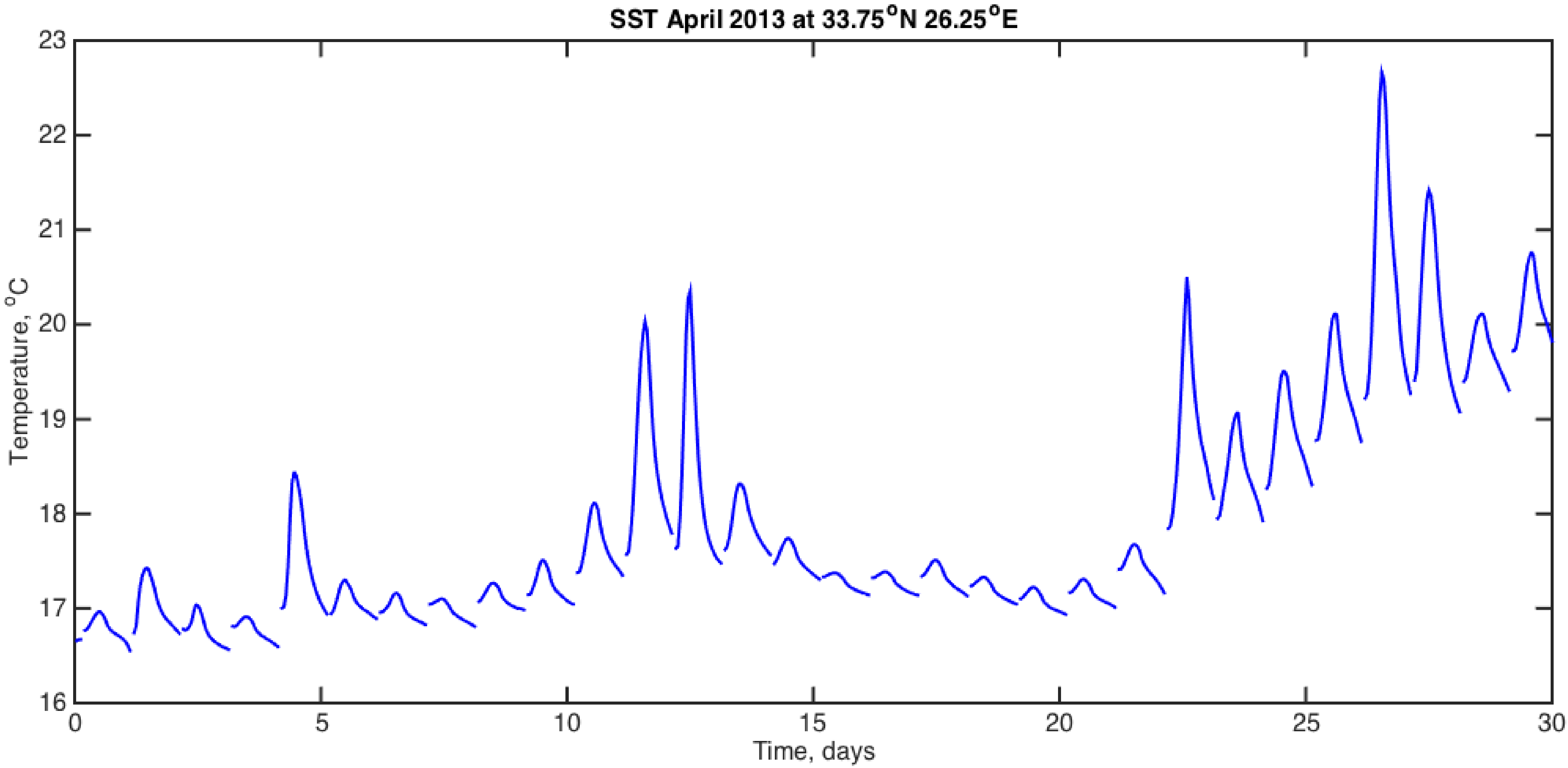
Forcing:

- 3-hourly atmospheric data from ECMWF ERA-Interim: u10m, v10m, t2m, q2m, airp, swrd, lwrd
- Compute air-sea fluxes using linearly interpolated ERA data and modelled skin SST (Fairall et al., 1996a, 1996b, 2003)
- SWR computed every time step, but match 3-hourly integrated ERA-Interim values

Initialization:

- Daily Temperature and Salinity profiles from MED MFC reanalysis are used to initialize GOTM at sunrise each day

Sample GOTM Output



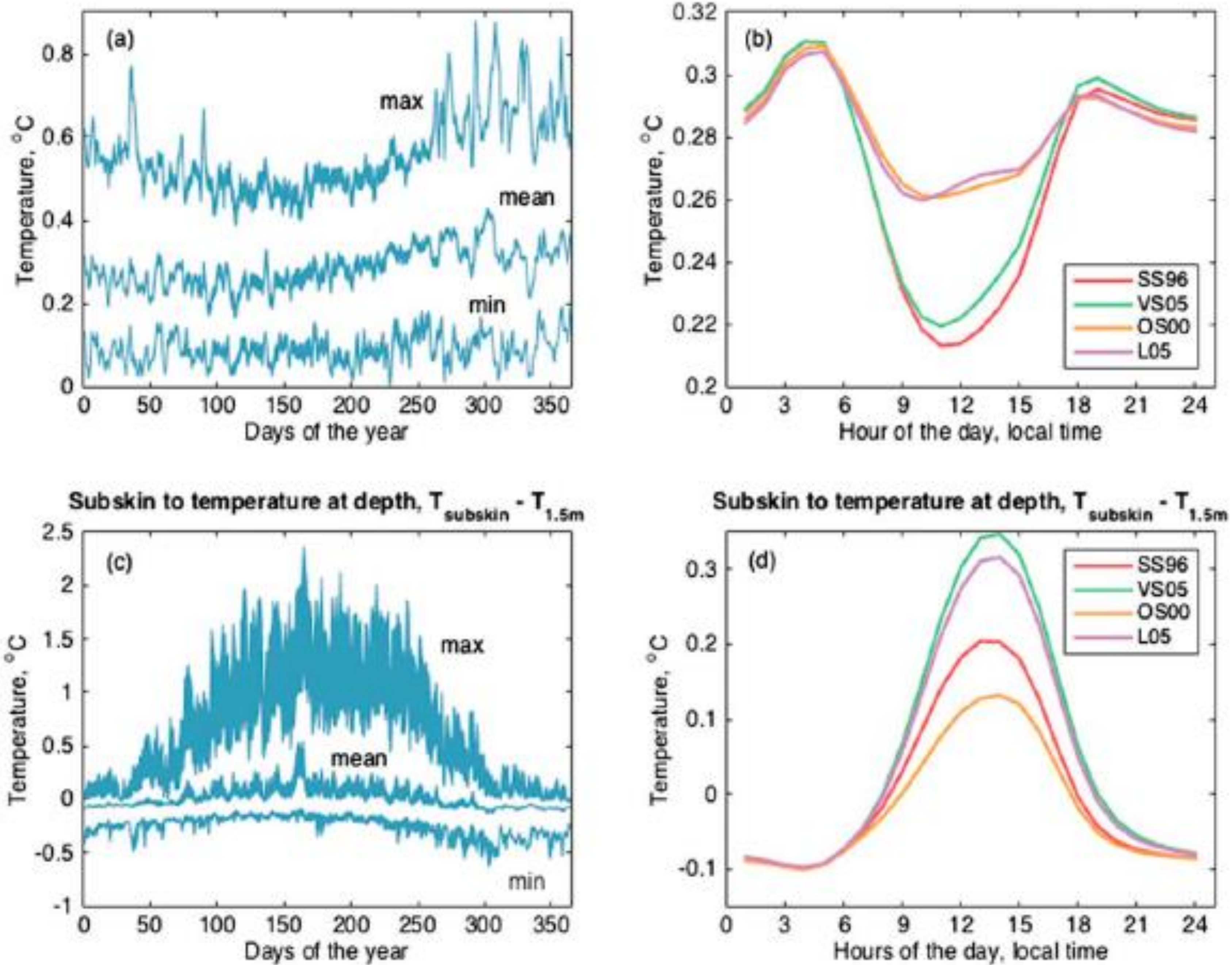
GOTM Results

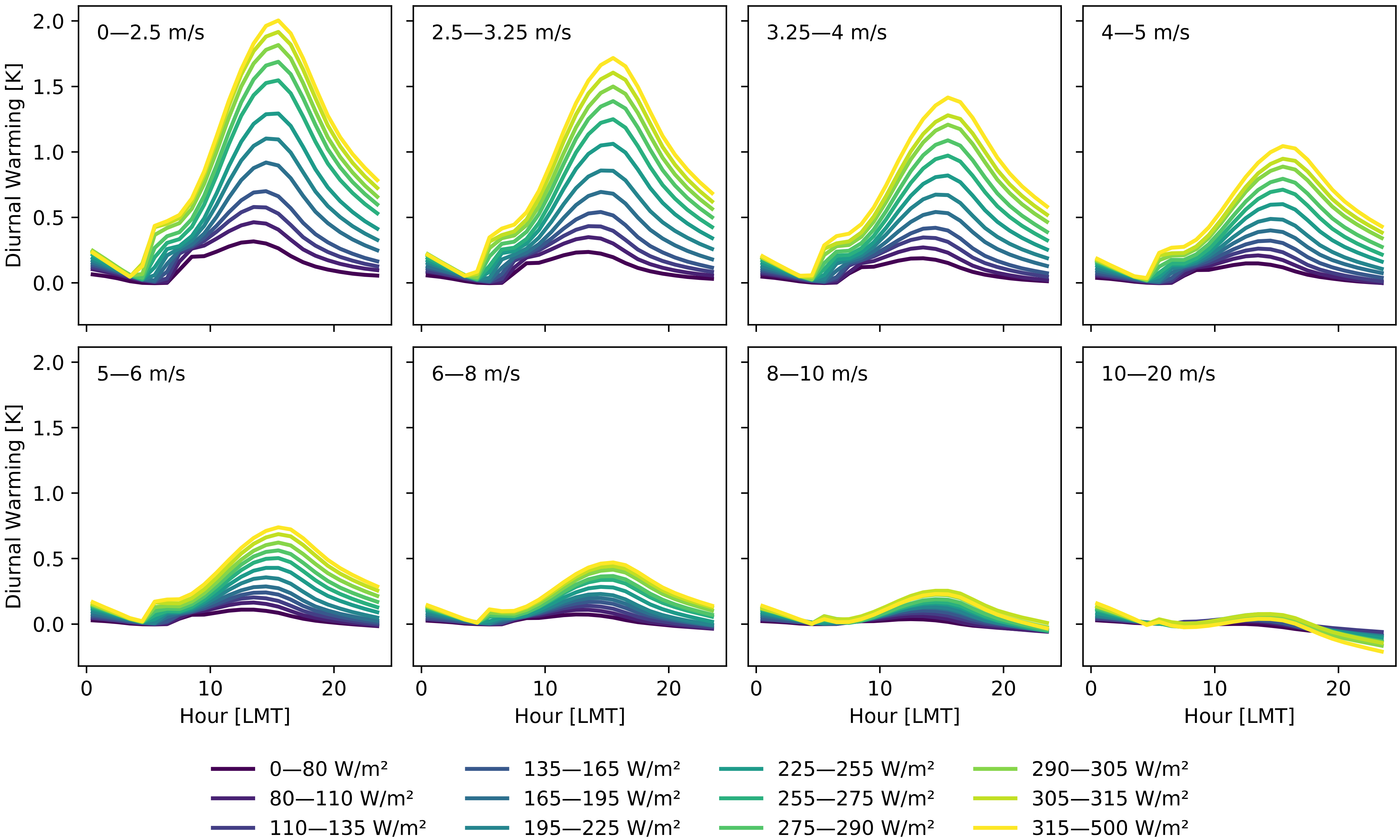
Annual cycle

Diurnal cycle

$T_{subskin} - T_{skin}$

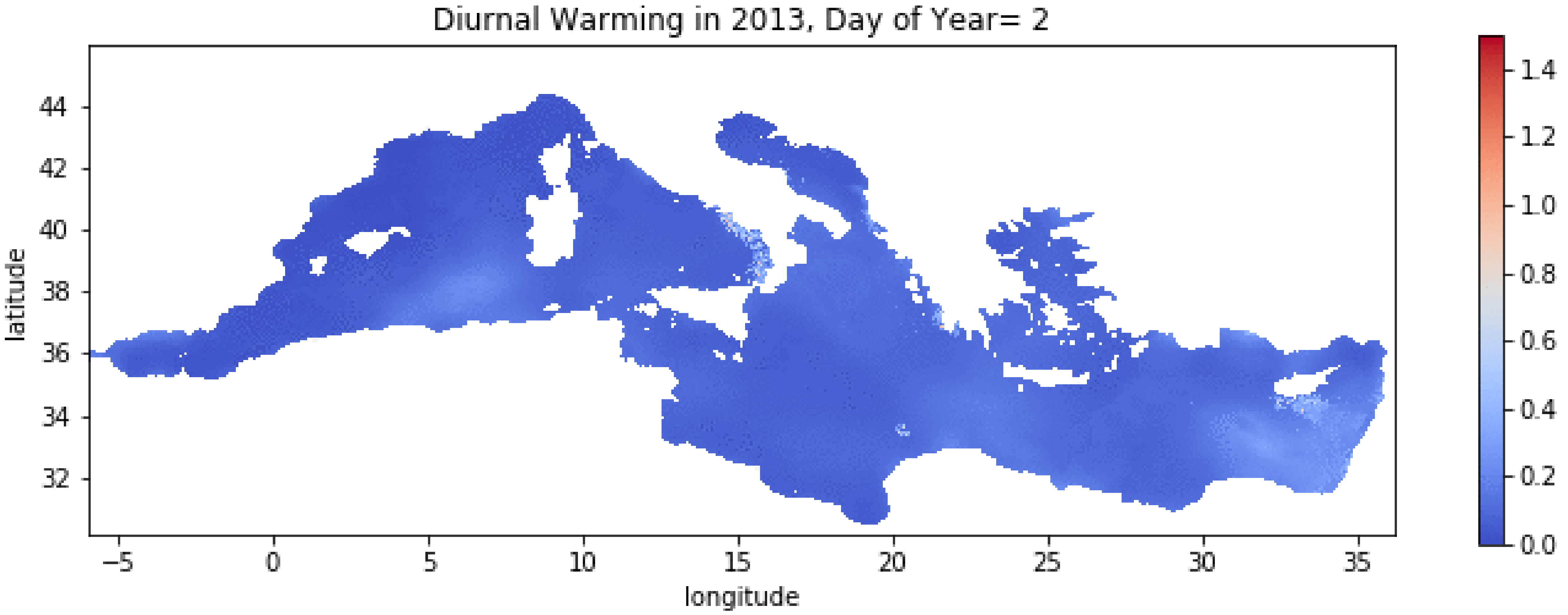
$T_{subskin} - T_{1.5m}$





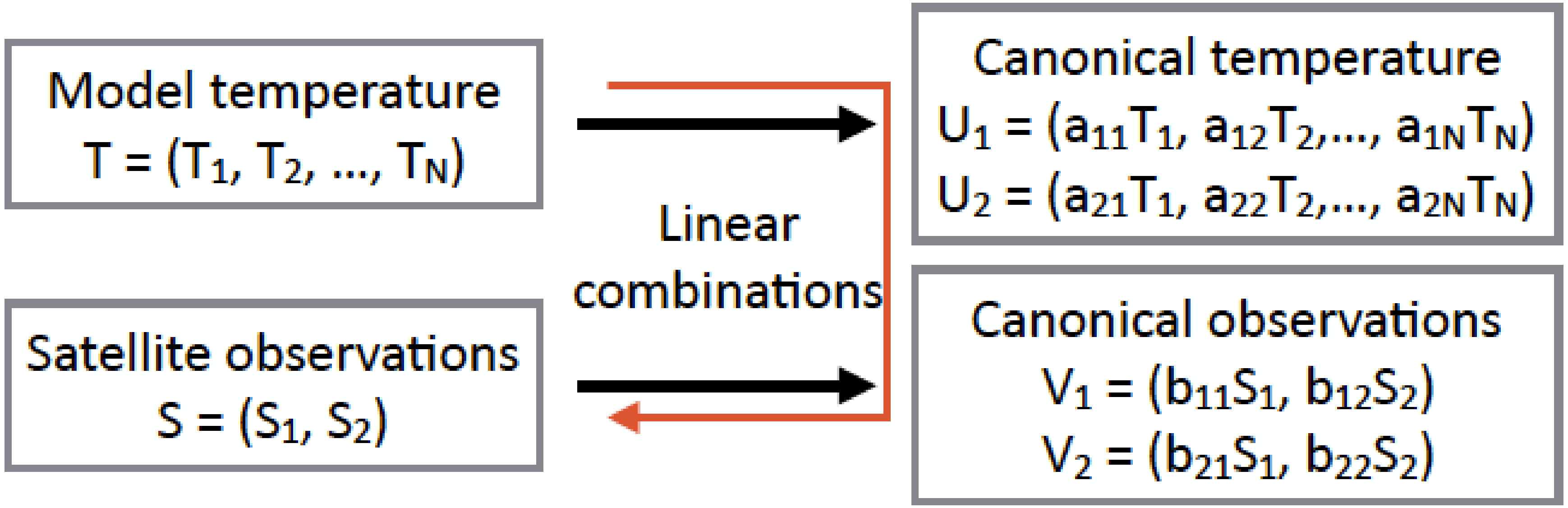
0—2.5 m/s
2.5—3.25 m/s
3.25—4 m/s
4—5 m/s
5—6 m/s
6—8 m/s
8—10 m/s
10—20 m/s
Diurnal Warming [K]
Hour [LMT]
0—80 W/m²
80—110 W/m²
110—135 W/m²
135—165 W/m²
165—195 W/m²
195—225 W/m²
225—255 W/m²
255—275 W/m²
275—290 W/m²
290—305 W/m²
305—315 W/m²
315—500 W/m²

1/16-degree GOTM Output: Mediterranean Sea



Animation showing daily diurnal variability: (max SST – min SST)

Canonical Correlation Analysis (CCA)



U_i maximally correlated with V_i

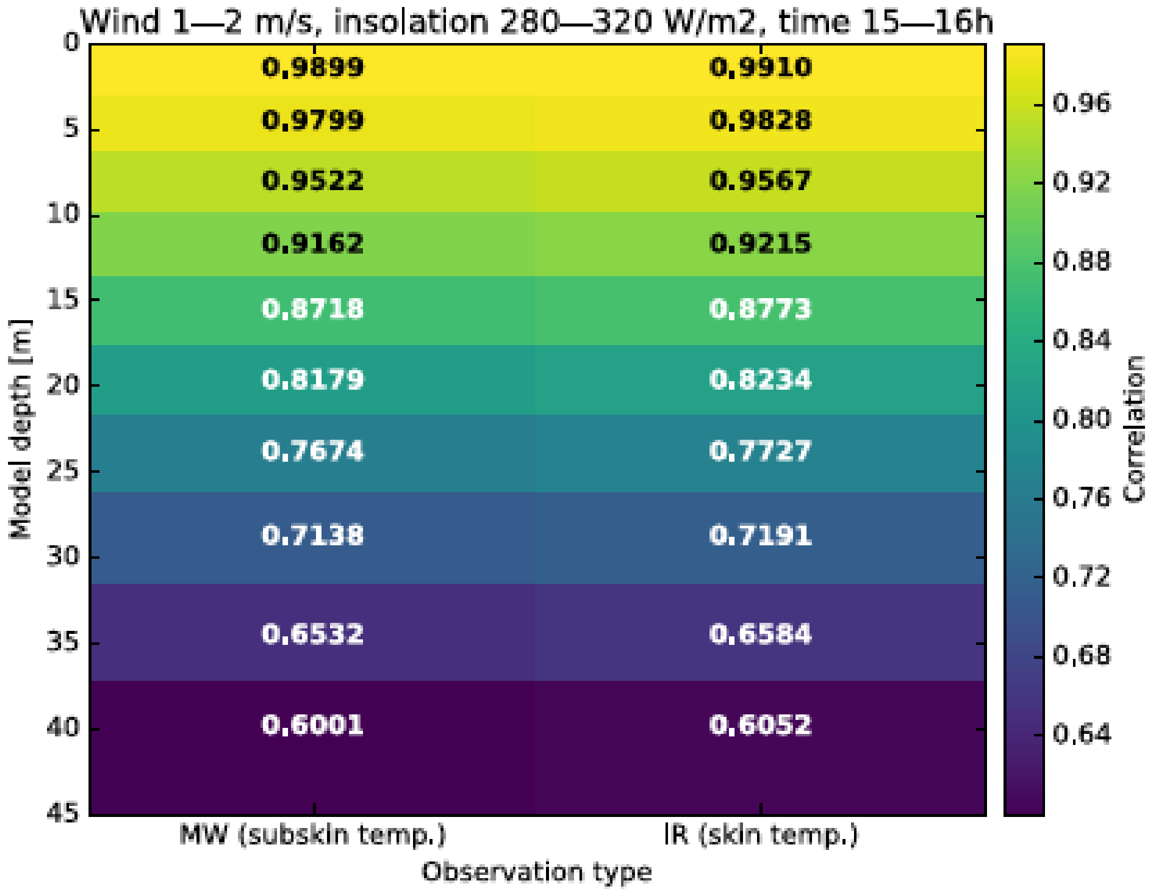
U_i, V_i uncorrelated with U_j, V_j for $j < i$

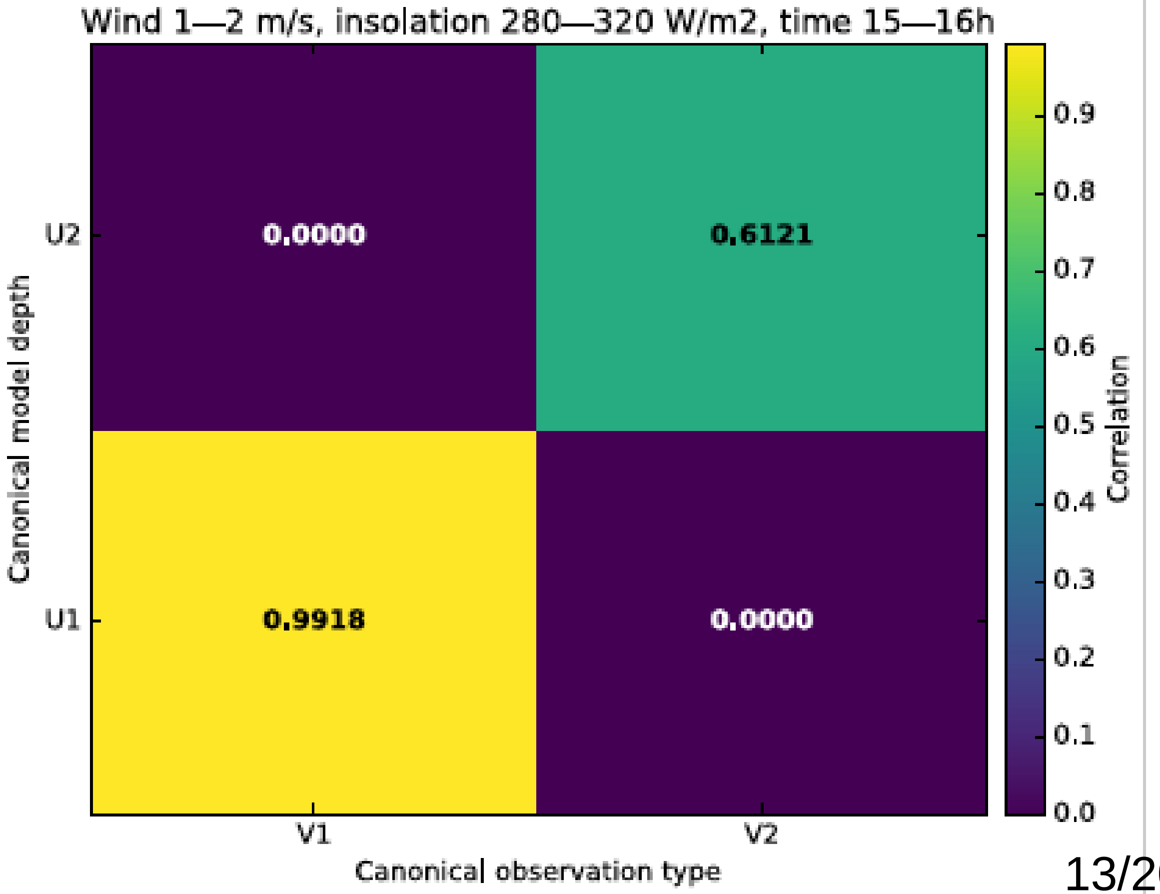
- CCA calculates a transformation into pairs of variables that are maximally correlated, but uncorrelated to all previous pairs
- Matrices a and b can be calculated on a training data set (our GOTM simulations), then the transformation ab^{-1} can be applied to project a temperature profile T onto a satellite observation S

Correlation Plots

Measurement vs. model: measurement is correlated to all levels, BUT all levels are also correlated to each other!

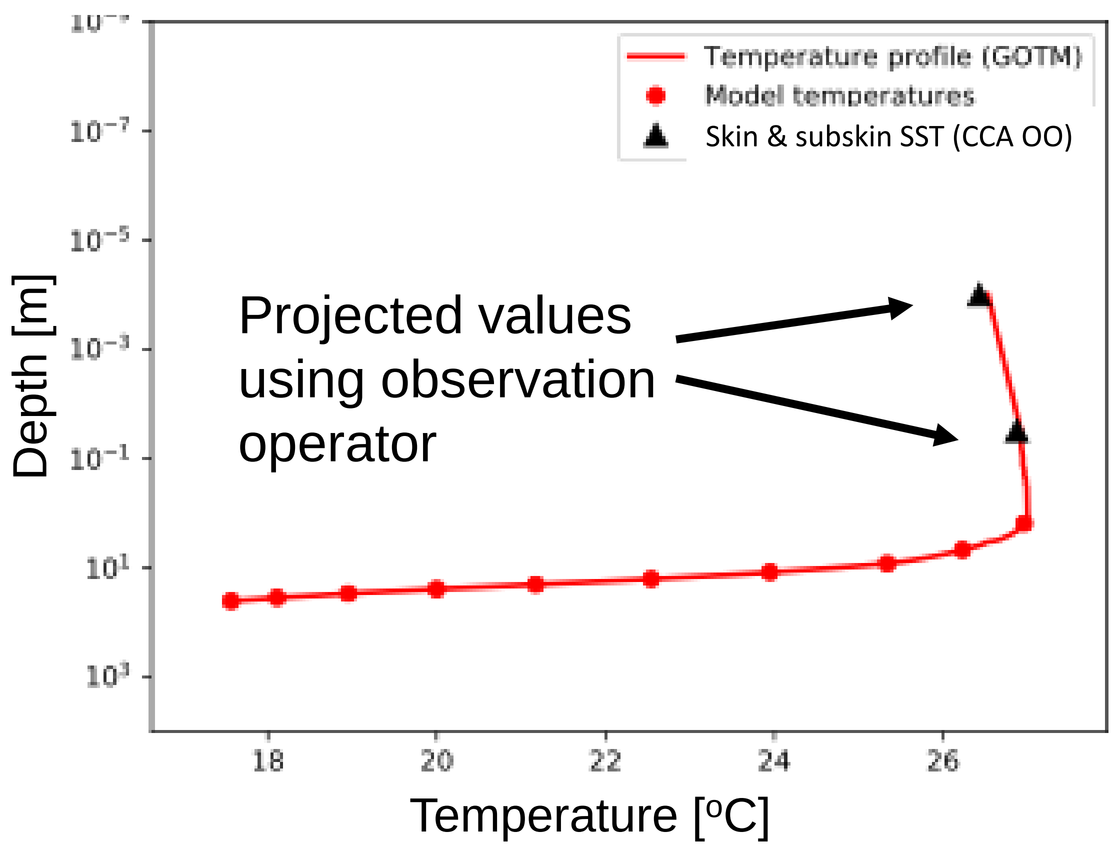
Canonical variables: first correlation is as strong as on the left, BUT we found an additional correlation of 60%!



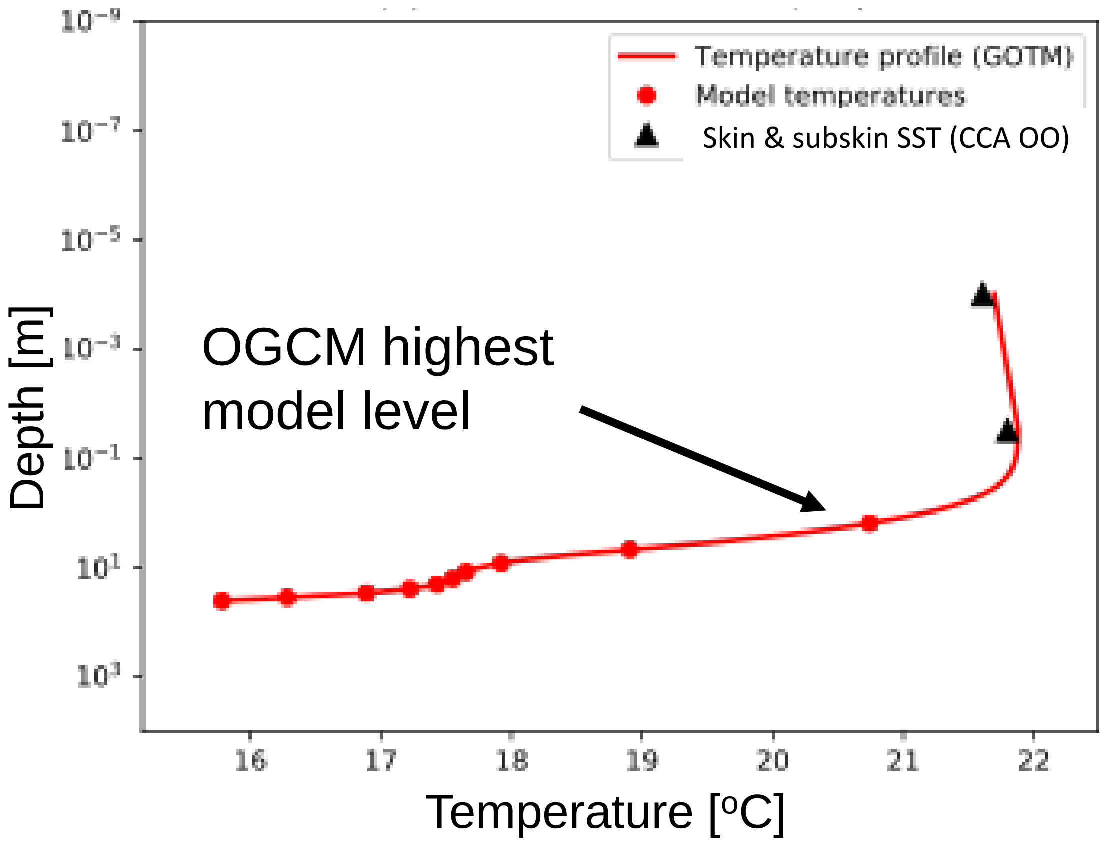


Some Examples

Wind 0-2.5m/s, insolation 305-315W/m^2, time 5-6h

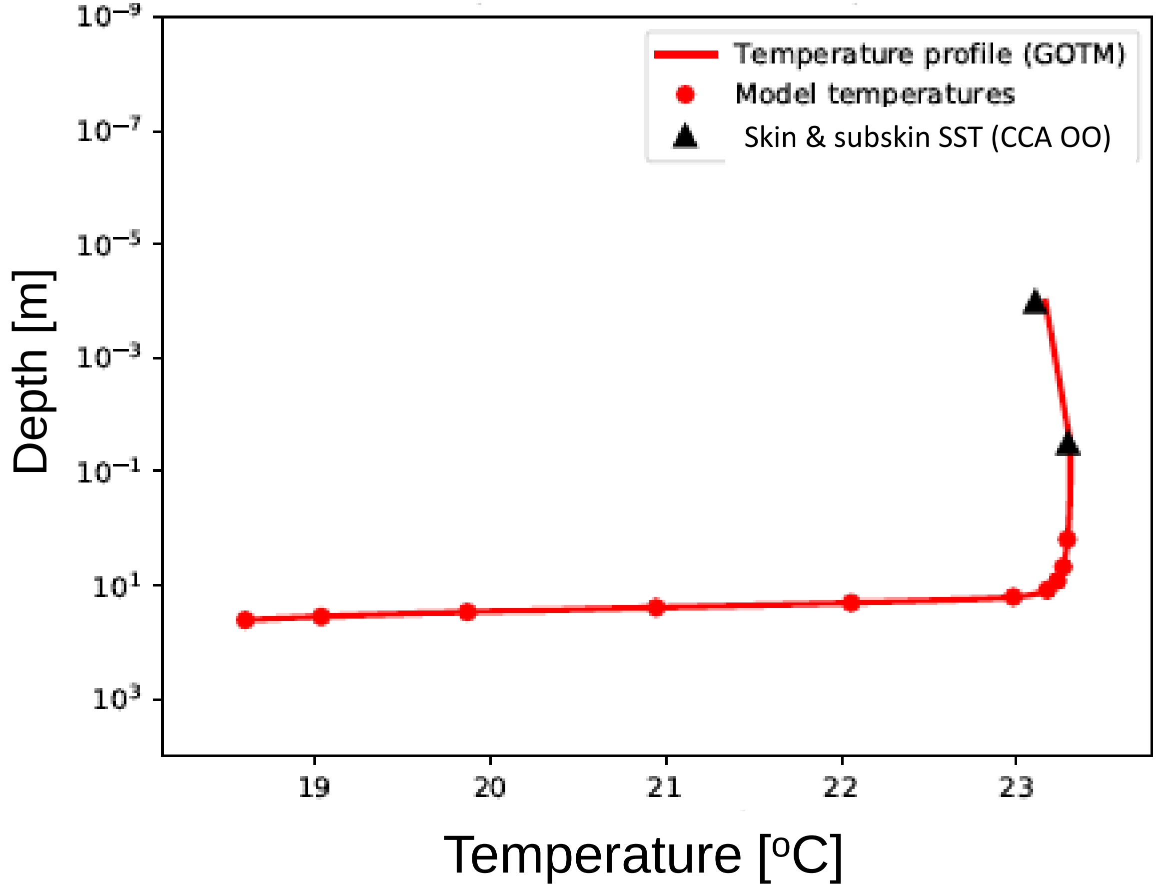


Wind 0-2.5m/s, insolation 305-315W/m^2, time 14-15h

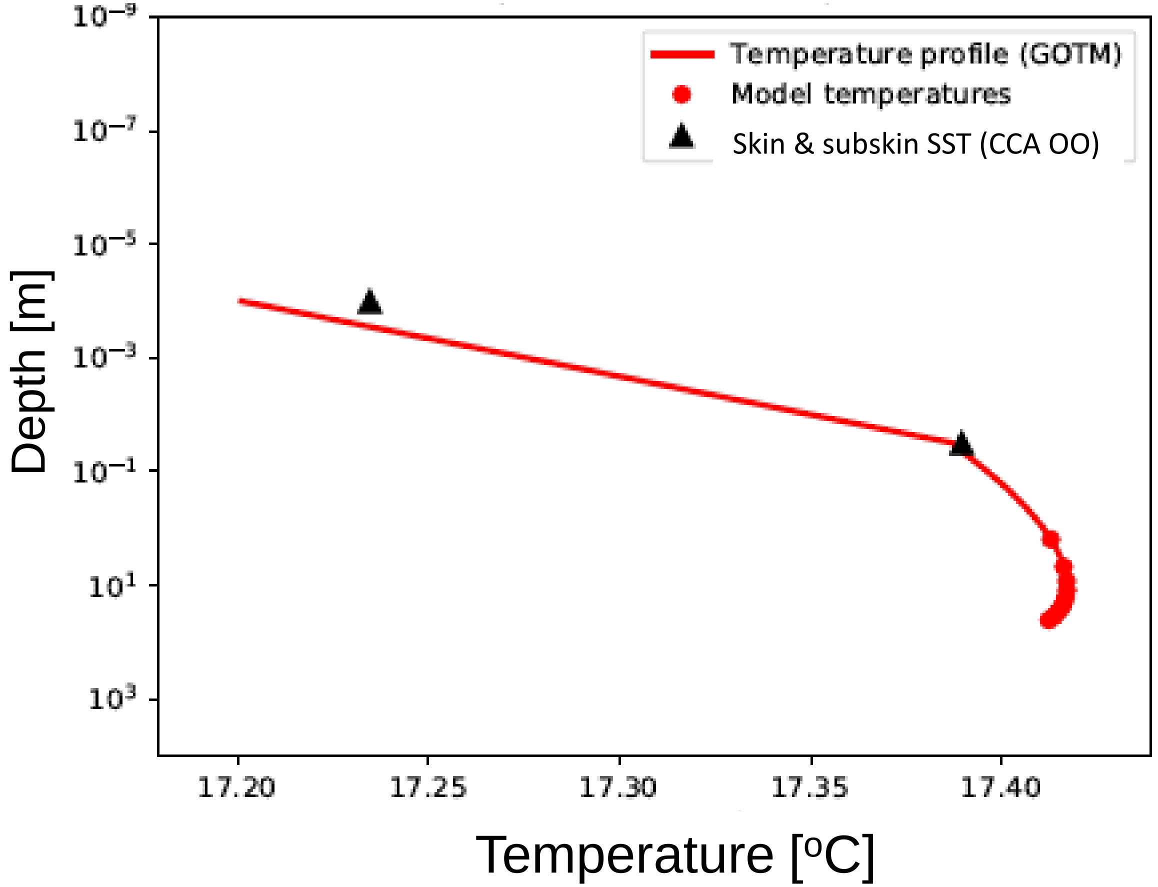


- During low wind and high insolation, the daytime skin and subskin SST can be significantly higher than the highest model level
- The statistical operator can describe these temperatures reasonably well

Wind 8-10m/s, insolation 305-315W/m^2, time 14-15h



Wind 8-10m/s, insolation 0-80W/m^2, time 14-15h

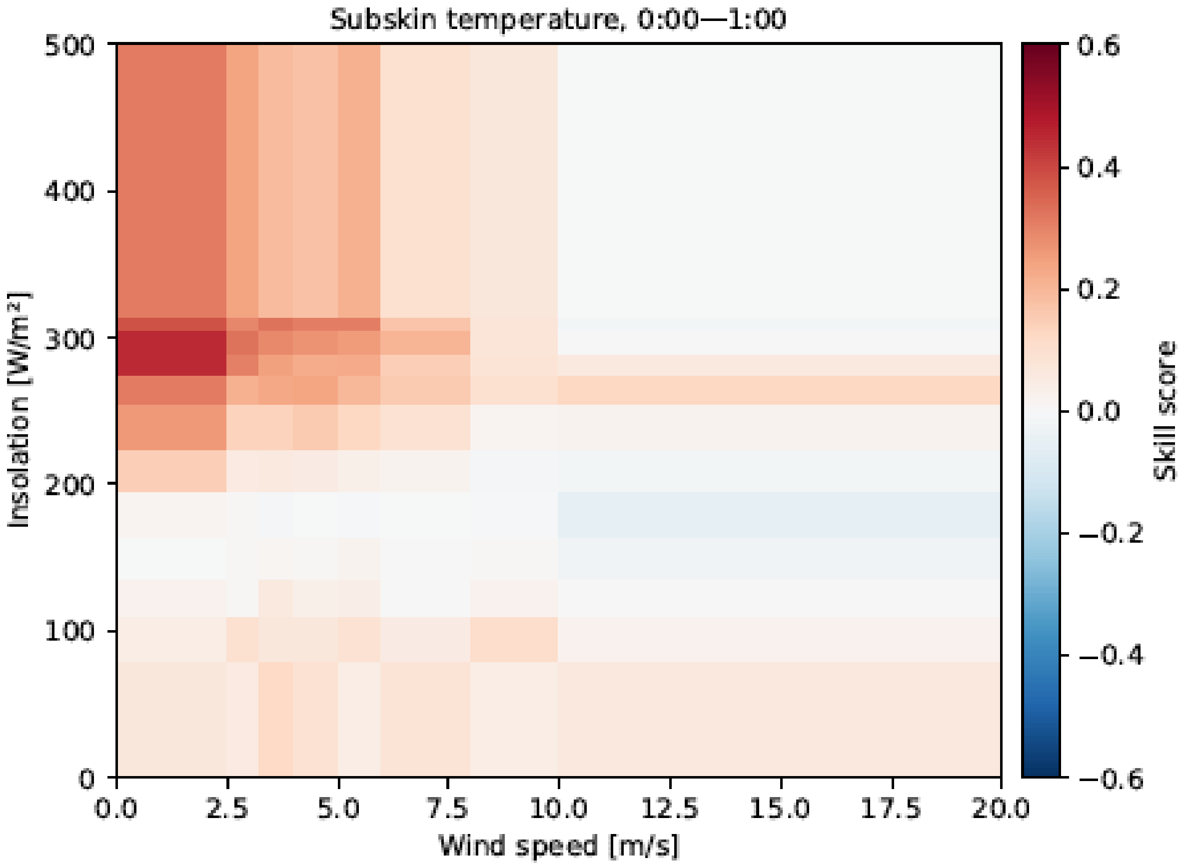


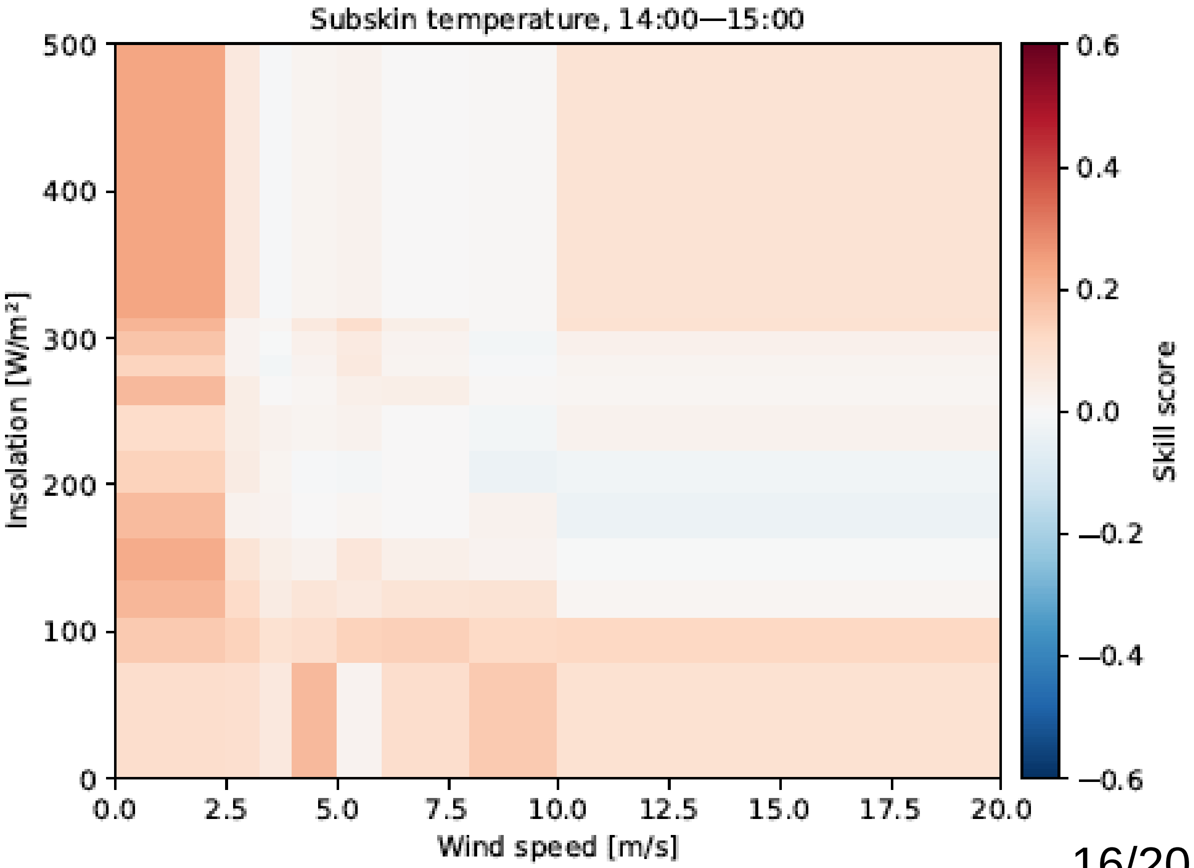
- Higher wind speeds cause more mixing in the water column and the diurnal heating effect essentially disappears
- During days of high wind and low insolation, the skin temperature is evidently below that of the highest model level

Performance: Skill scores

$$SS = 1 - \frac{MSE_{\text{CCA OO}}}{MSE_{\text{reference}}}$$

- *MSE* = mean square error between subskin SEVIRI L3C obs and model SST
- CCA OO = using the subskin SST produced by the CCA observation operator
- Reference = upper MED MFC model level (1.47m)

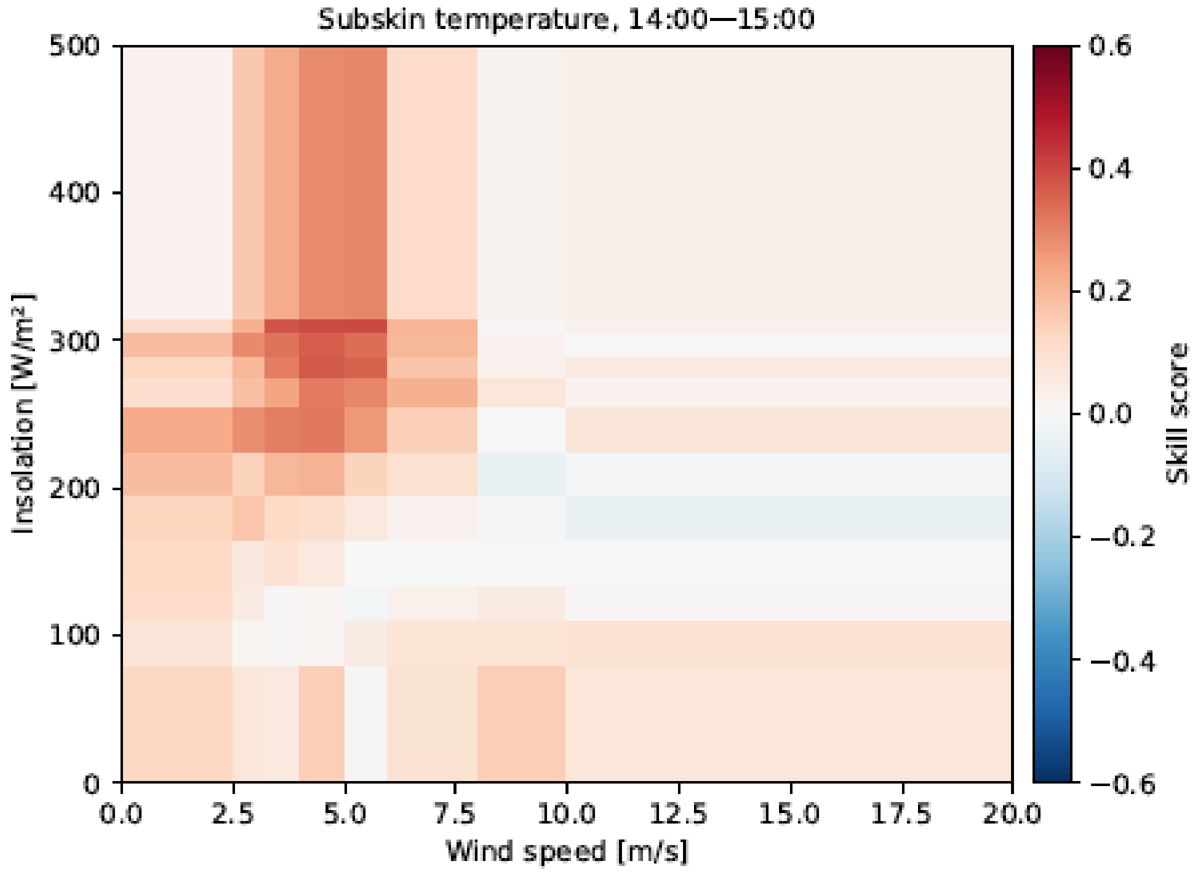


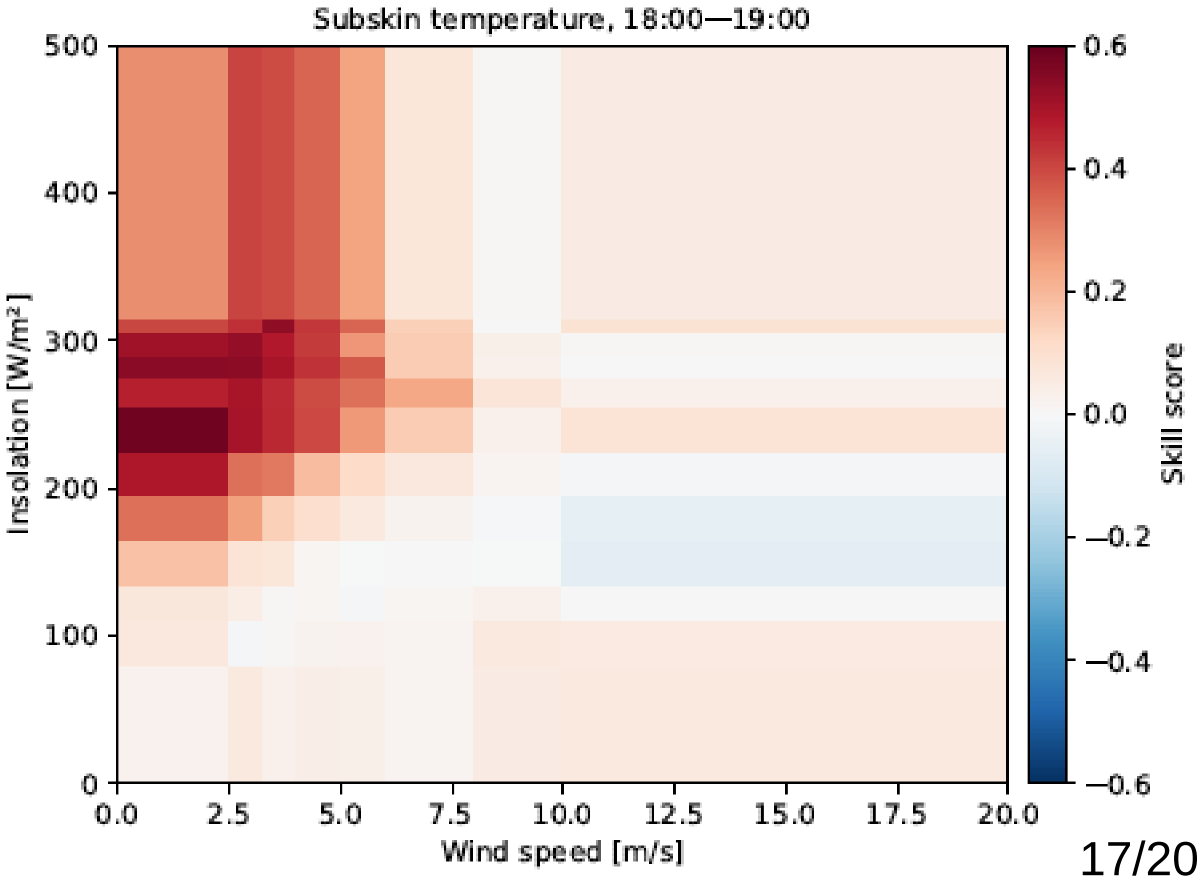


Performance: Skill scores

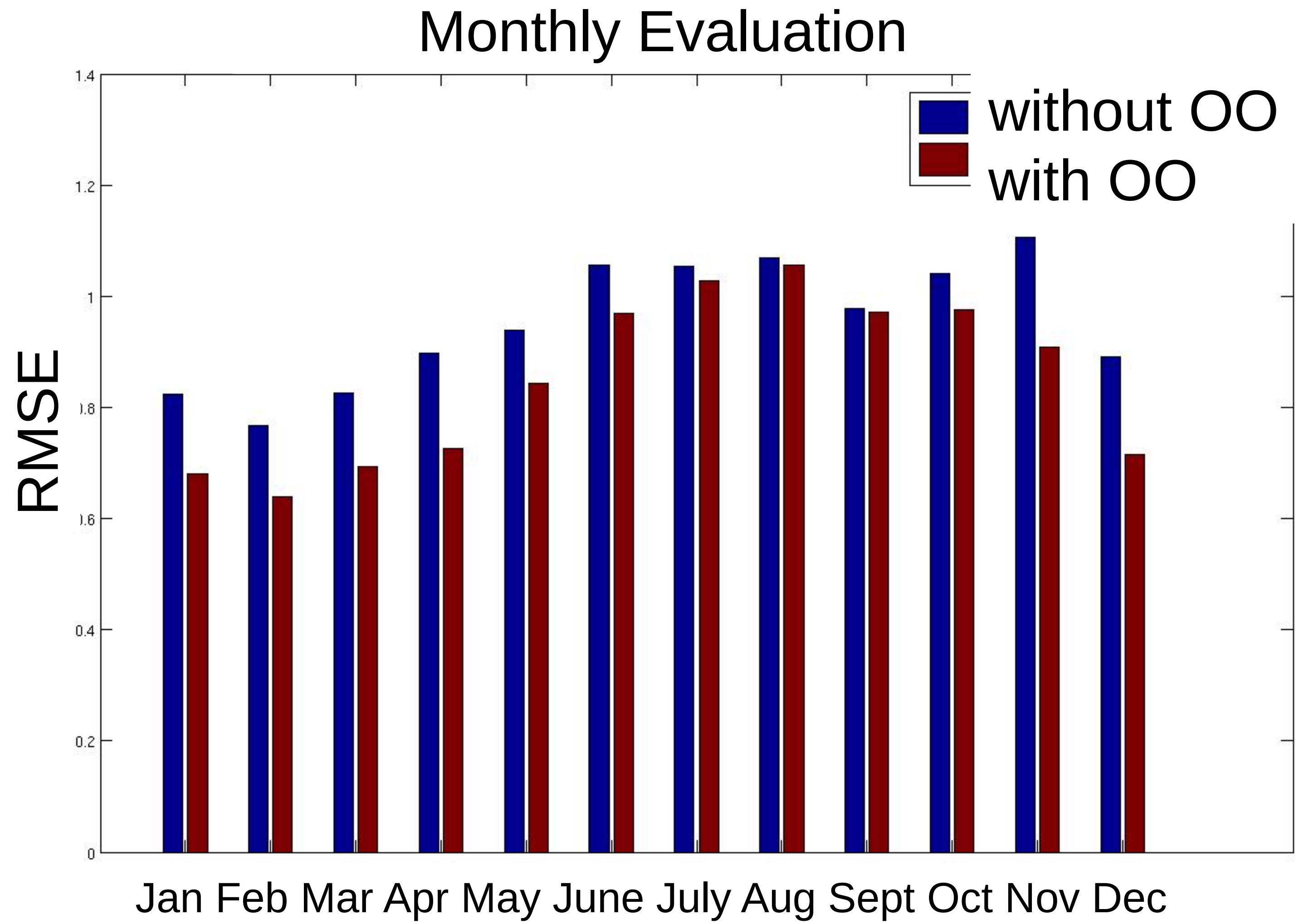
$$SS = 1 - \frac{MSE_{\text{CCA OO}}}{MSE_{\text{Bernie}}}$$

- MSE = mean square error between subskin SEVIRI L3C obs and model SST
- CCA OO = using the subskin SST produced by the CCA observation operator
- Bernie = using the diurnal SST parameterisation of Bernie et al., 2007

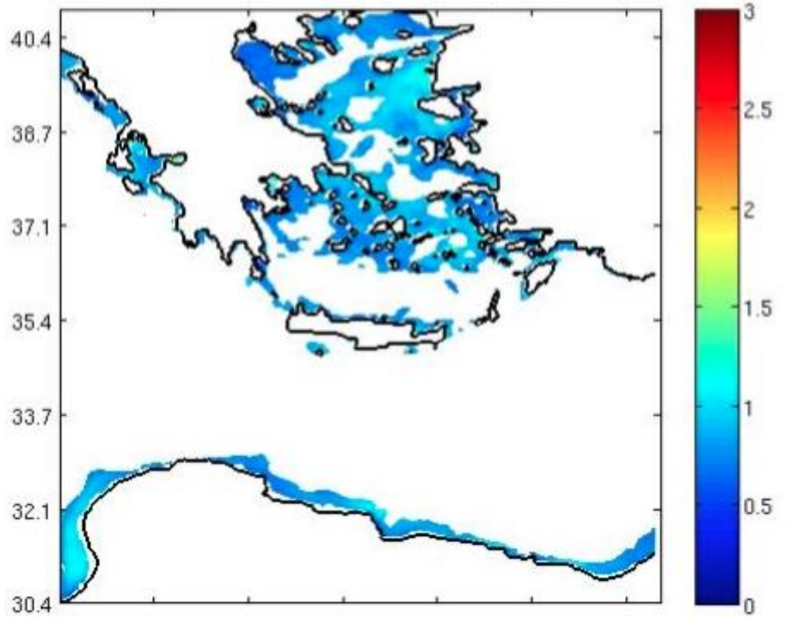




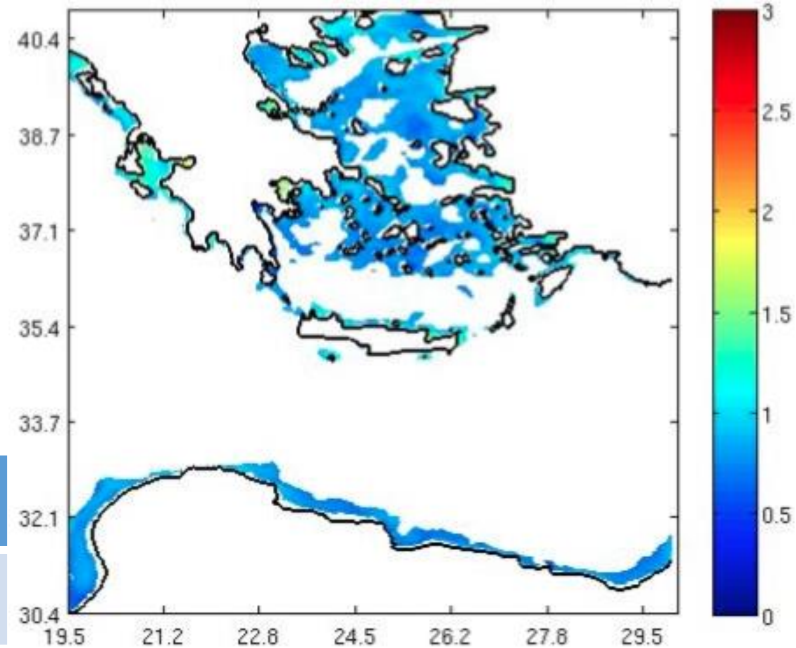
Offline results – Aegean Sea
Greek POSEIDON SEEK Filter



RMSE with OO



RMSE without OO

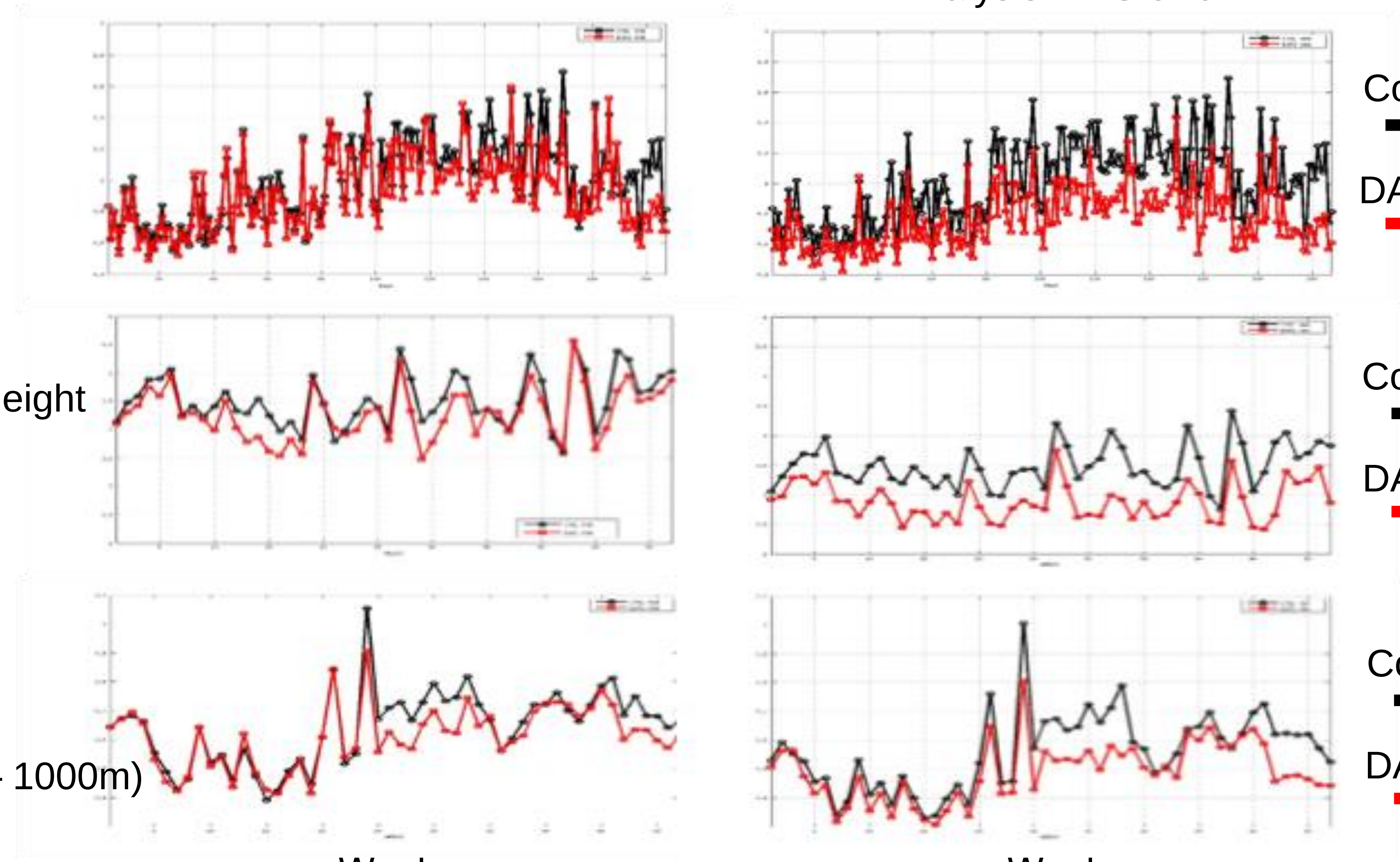


2014	without operator	with operator	Improvement
RMSE	**0.9412**	**0.8380**	**11%**

Online results – Aegean Sea

Forecast RMS error

Analysis RMS error



Skin SST

Control

DA using OO

Sea surface height

Control

DA using OO

Temperature
(below skin — 1000m)

Control

DA using OO

Weeks →

Weeks →

Conclusions

- GOTM is used to produce a high-resolution data set of diurnal SSTs in the Mediterranean Sea to compare skin SST, subskin SST, SST at depth, and foundation SST
  - *Pimentel et al., Modeling the near-surface diurnal cycle of sea surface temperatures in the Mediterranean Sea, JGR-Oceans, https://doi.org/10.1029/2018JC014289, 2019.*
- This training data set was used to produce canonical correlations, which we found to be a simple and efficient means to provide good estimates of the skin and sub-skin SST. The CCA is used to create a low computational cost observation operator for assimilating satellite SST
  - *Jansen, Pimentel, Tse, Denaxa, Korres, Mirouze and Storto, Using Canonical Correlation Analysis to produce dynamically-based highly-efficient statistical observation operators, Ocean Sci. Discuss., https://doi.org/10.5194/os-2018-166, in review, 2019.*
- The CCA OO has been tried in the POSIEDON Aegean Sea model, finalized results are forthcoming
- Other potential uses of this method: diurnal skin SST for air-sea flux calculations, comparing different in-situ observations to satellite, diurnal SST in climate models, …