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An analysis system for diurnal Sea Surface Temperature

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What is diurnal SST?

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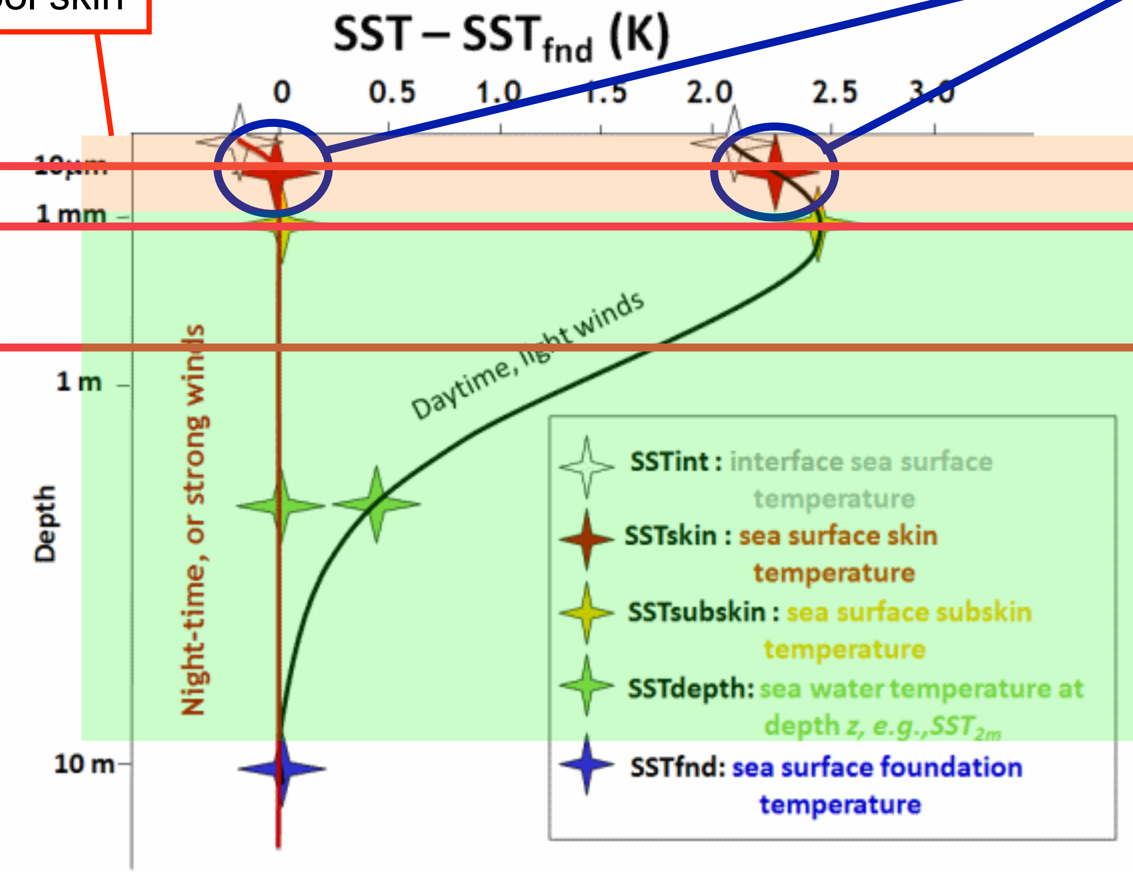
Cool skin

We are most interested in the diurnal cycle at the ocean skin



IR Satellite

Microwave Satellite

In-situ measurements and ocean GCMs

Diurnal SST is the daily cycle in SST due to the action of sunlight moderated by winds.

Warm layer

Picture courtesy of the GHRSST consortium

What do we need to model it?

To produce a diurnal SST model you need:

- An estimate of foundation SST (OSTIA)
- A cool skin model
- A warm layer model

To go further and produce a diurnal analysis you need:

- Observations of diurnal SST
- A data assimilation system

Cool Skin

Theory

We have implemented the Artale et al. (2002) cool skin model.

According to Tu and Tsuang (2005), this model provides the best parameter values at both low and high wind-speed:

$$\Delta T_{cs} = \frac{Q_T \lambda \nu}{k_t u_*}$$

Layer thickness (~1mm)

$$\lambda = \frac{u_* k_t C}{\rho_w c_w h \nu \gamma}$$

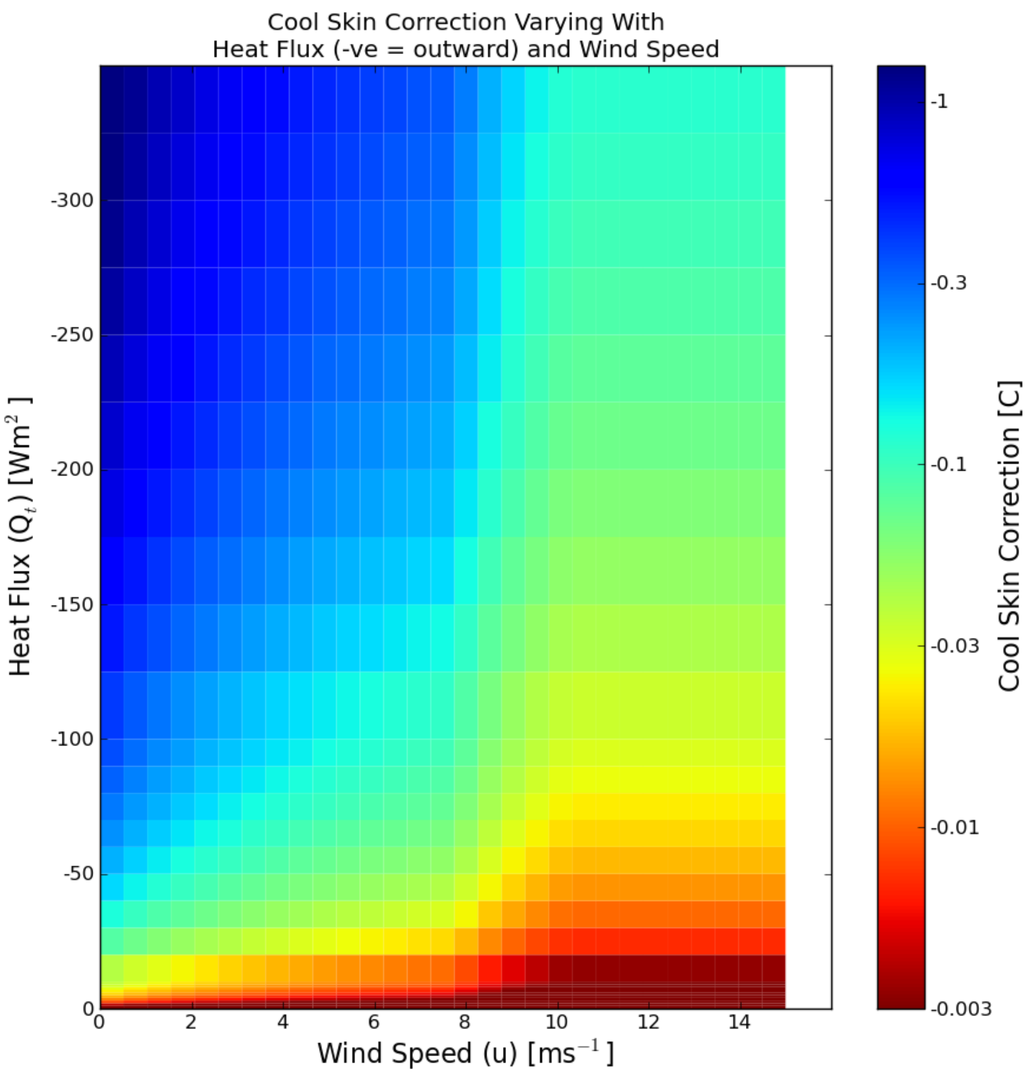
$$\gamma = \begin{cases} 0.2u + 0.5, & u \le 7.5ms^{-1} \\ 1.6u - 10, & 7.5 < u < 10ms^{-1} \\ 6, & u \ge 10ms^{-1} \end{cases}$$

ΔT_{cs} = the skin and bulk difference
Q_t = Total heat flux (-ve in cool skin)
ν = kinematic viscosity of seawater
k_t = thermal conductivity of seawater
u_* = friction velocity of surface water
$= \sqrt{\tau_u / \rho_w}$
τ_u = wind stress
ρ_w = seawater density
λ = a constant of proportionality
$C = 86400s$ (number of secs in 1 day)
c_w = specific heat capacity of seawater at constant pressure
h = a reference depth
γ = dimensionless function of wind speed
u = wind speed

Cool Skin

Phase space

Note: Blue is large -ve



Warm Layer Model
Theory

- Based on the Takaya (2010) diurnal model.
  - Computationally cheap
  - Continuous in time:- beneficial for data assimilation.

$$\frac{\partial T}{\partial t} = \frac{Q(\nu+1)}{D_T \rho c_p \nu} - \frac{(\nu+1) k u_w^* f(L_a)}{D_T \Phi\left(\frac{D_T}{L}\right)} T$$

Bulk thermal heating of a layer

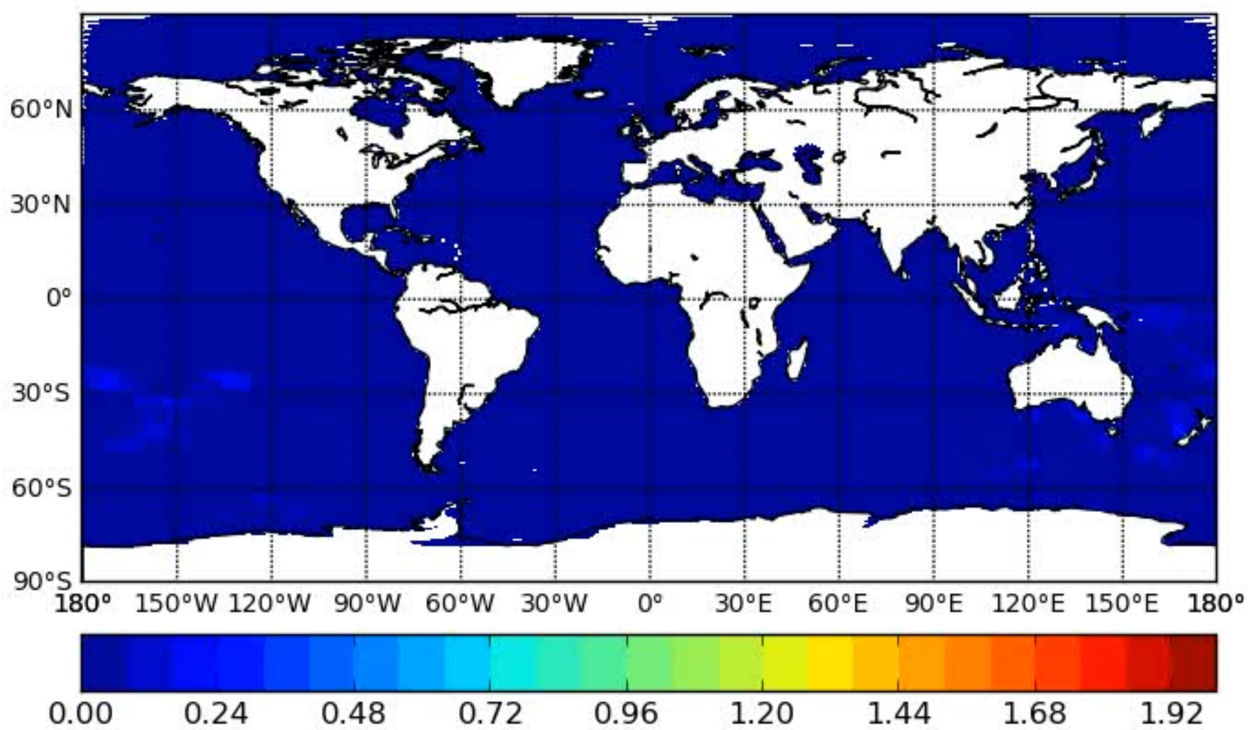
Turbulent damping

T:-	ΔT_{WL}
t :-	Time
Q:-	Thermal energy flux
D_T:-	Layer depth
ρ:-	Water density
c_p:-	Heat capacity
ν:-	Structure parameter
u_w*:-	Friction velocity
L_a:-	Langmuir number
k:-	Von Karman's constant
g:-	Acceleration due to gravity
α_w:-	Thermal expansion coefficient

$$f(L_a) = \max(1, L_a^{\frac{2}{3}}) \qquad L = \frac{\rho c_p {u_w^*}^3}{\kappa g \alpha_w Q} \qquad \Phi(\zeta) = \begin{cases} 1 + \frac{5\zeta + 4\zeta^2}{1 + 3\zeta + 0.25\zeta^2} & (\zeta \geq 0) \\ (1 - 16\zeta)^{-\frac{1}{2}} & (\zeta < 0) \end{cases}$$

- These equations are solved using an implicit scheme

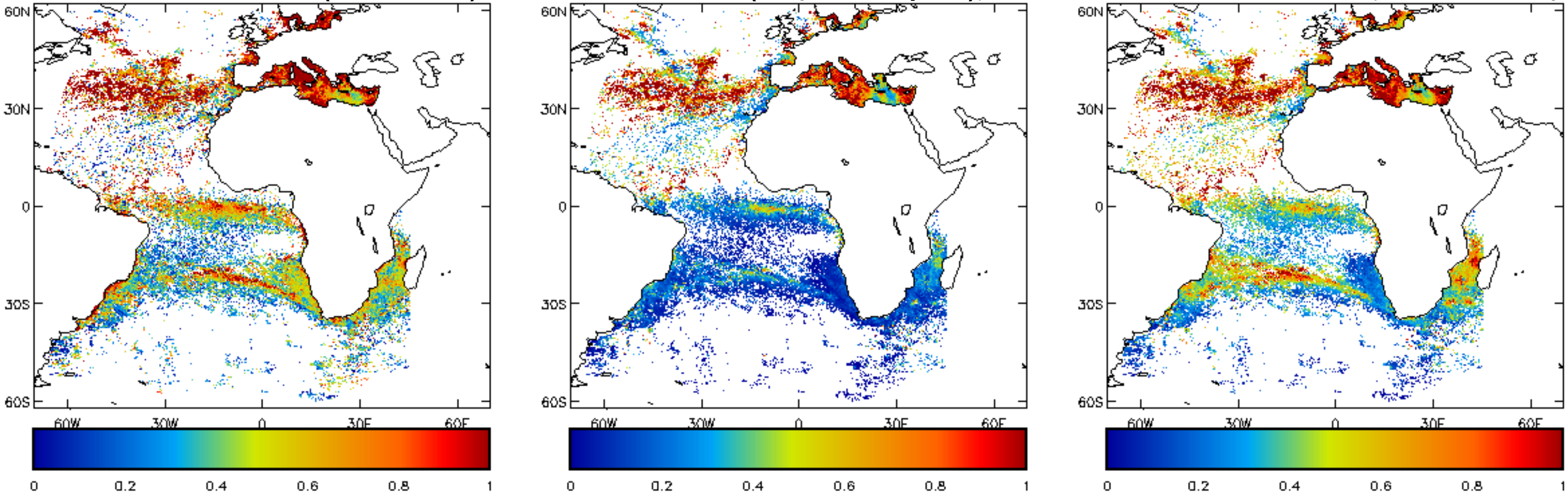
Warm Layer Model
Jan 07



Warm Layer Diurnal Model

Diurnal range validation

Observations (SEVIRI) | FOAM (0.5m depth) | TAKAYA model



Diurnal Observations
Overview

DIURNAL OBSERVATION = SST OBSERVATION – FOUNDATION SST*

•We plan to use Infra-Red satellite data (polar orbiting and geostationary) to constrain our model of ΔSST.

MSG-SEVIRI (geo)	NOAA–AVHRR (polar)
MT-SAT (geo)?	METOP-AVHRR (polar)
GOES-West (geo)?	Sentinel 3 – SLSTR??

•*For foundation SST we plan to use a foundation estimate per satellite.
i.e. For each satellite we will run an OSTIA like system, but with only one observation type as input.

•Due to its lower accuracy and larger footprint, we do not initially plan to use microwave data.

•We also do not plan to use in-situ data – much lower spatial coverage & only provide sub-surface information.

Data assimilation system
Overview

•We have developed a data assimilation system to work with the Takaya (2010) model.

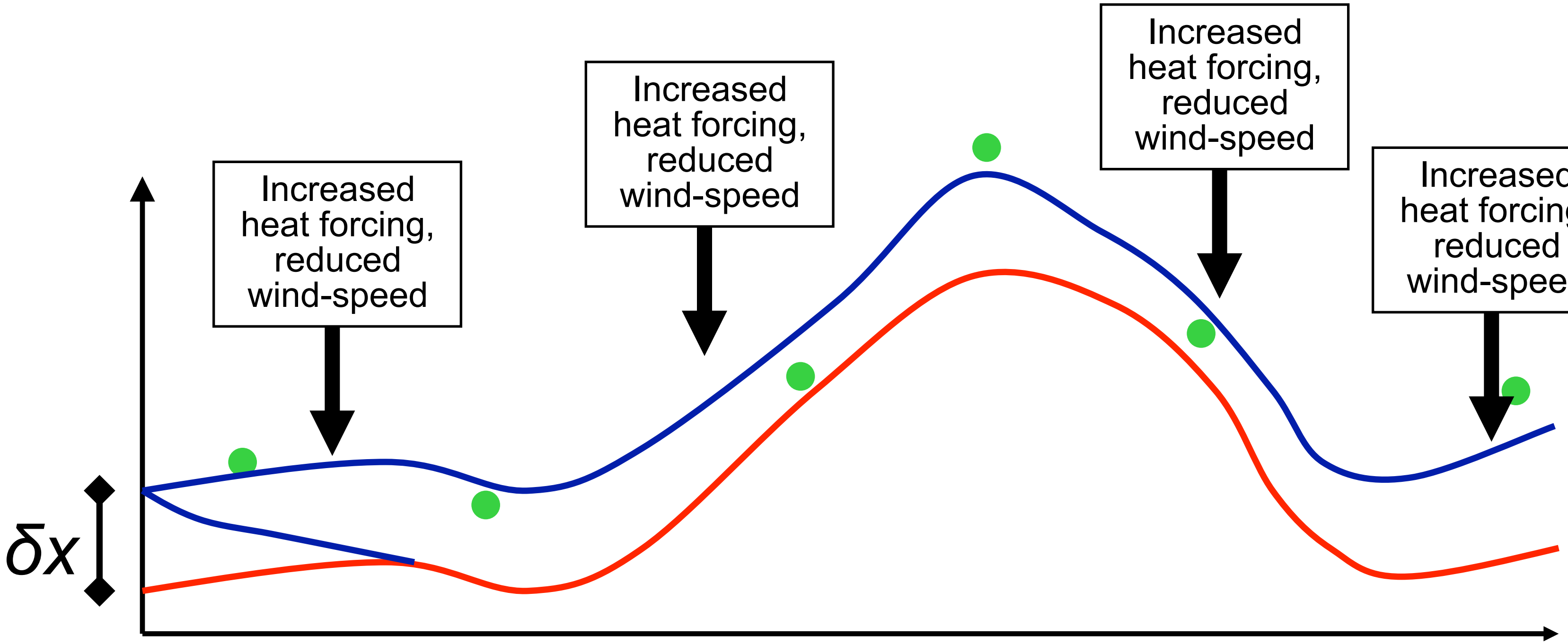
•The cool skin model is not constrained by the data assimilation.

•The system uses a version of 4DVar, without a depth dimension.

•It is not sufficient to minimise with respect to the initial temperature, so the assimilation also constrains the heat and wind forcing.

Data assimilation system
Theory

•In its most common application, 4DVar is used to adjust the model initial state only.



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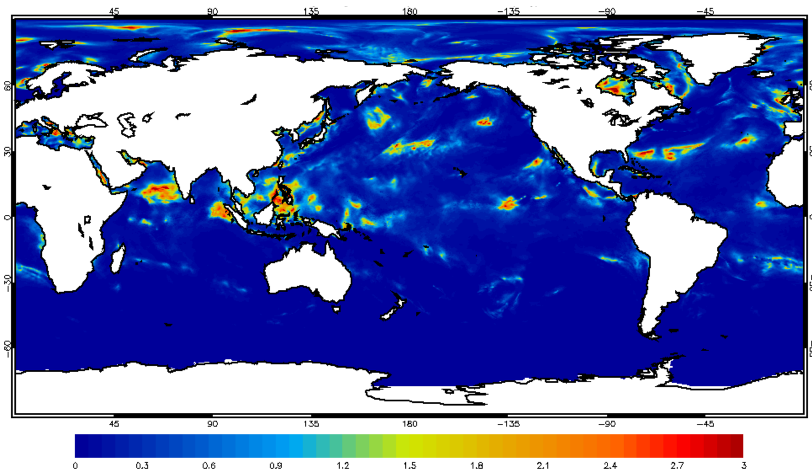
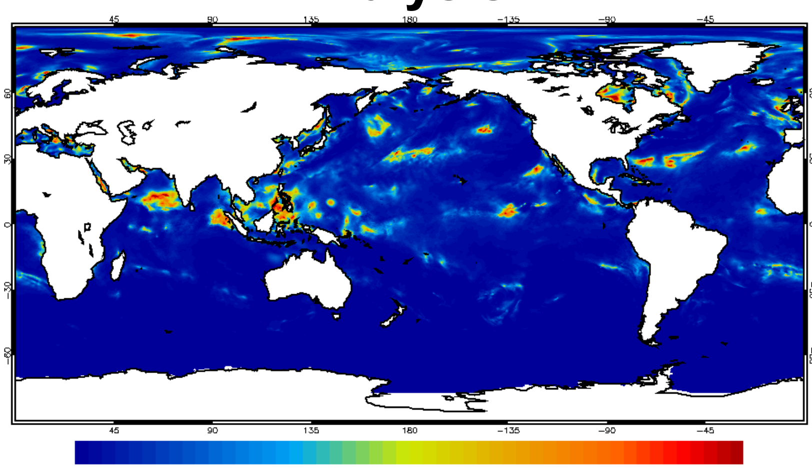
Peak warm layer temperature on 29/05/14

Background



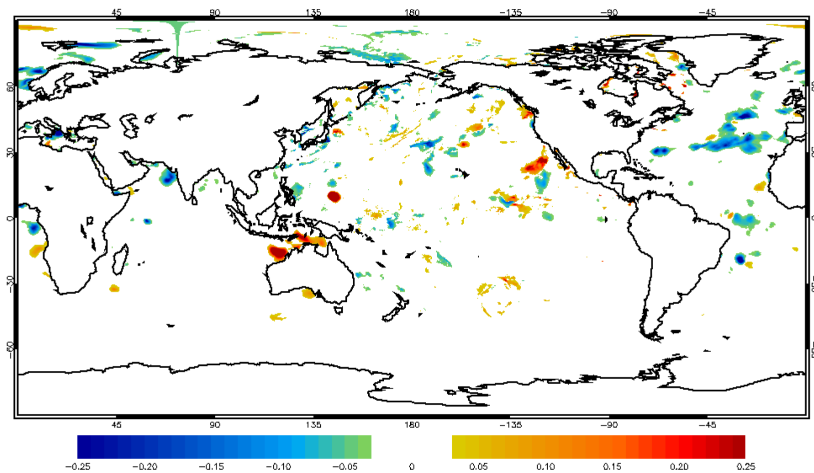
RMS observations minus background: 0.4966

Analysis



RMS observations minus analysis: 0.4886

Analysis minus background



Note: there is still a lot of tuning to do

Questions?

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Data assimilation system
Theory

- Our data assimilation method is based upon a 4DVar methodology.
- Fundamentally, 4DVar attempts to find the model state and parameters that minimise the cost function:

$$J(\mathbf{x}) = 0.5\left(\mathbf{x}^{\mathbf{b}} - \mathbf{x}\right)^{\mathrm{T}} \mathbf{B}^{-1} \left(\mathbf{x}^{\mathbf{b}} - \mathbf{x}\right) + 0.5\left(\mathbf{y} - \mathcal{G}(\mathbf{x})\right)^{\mathrm{T}} \mathbf{R}^{-1} \left(\mathbf{y} - \mathcal{G}(\mathbf{x})\right)$$

Cost = Difference between model and background (weighted by $\mathbf{B}^{-1}$) ^{2} + Difference from observations (weighted by $\mathbf{R}^{-1}$) ^{2}

- Incremental 4DVar iteratively minimises a series of linearised versions of this equation through a set of outer loops.

Data assimilation system
Control vector

$$\mathbf{x} = \begin{pmatrix} T_0 \\ Q_0 \\ Q_1 \\ \vdots \\ Q_N \\ u^*_{w_0} \\ u^*_{w_1} \\ \vdots \\ u^*_{w_N} \end{pmatrix}$$

- T_0: Initial temperature
- $Q_0, Q_1, \ldots, Q_N$: Thermal energy flux at all time-steps
- $u^*_{w_0}, u^*_{w_1}, \ldots, u^*_{w_N}$: Friction velocity at all time-steps

NOTE: We do not allow the assimilation to adjust the forcing at night.