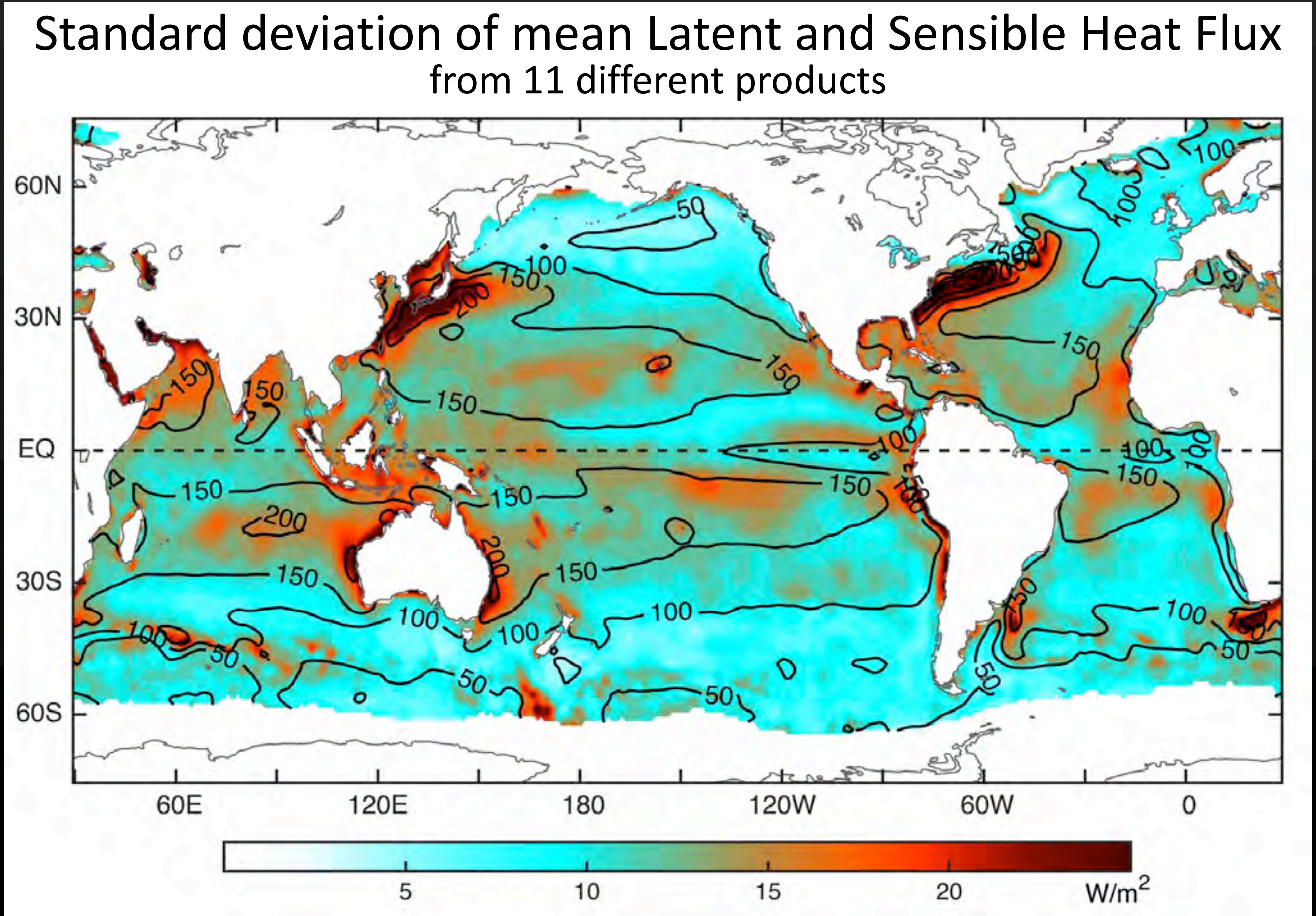
In situ observations of air-sea interactions and feedbacks

Meghan Cronin (NOAA PMEL)

with contributions from Lisan Yu (WHOI), Tony Lee (JPL), …

Goals: Provide overview of basic air-sea interaction principles,
Review how air-sea fluxes are measured, and
Layout strategy for improving global flux products (for OceanObs’19)

Which heat flux product is right ?

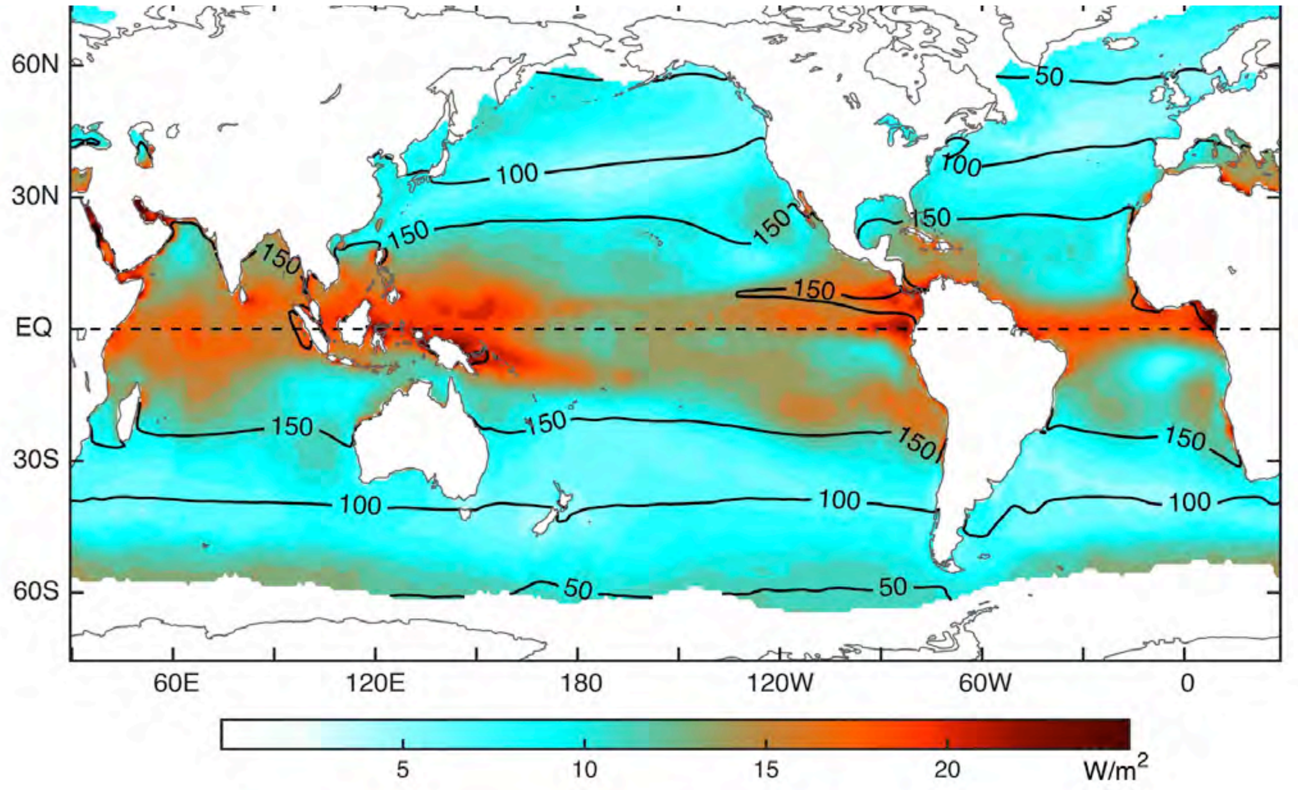


Products: OAFlux, NOC2, ERAinterim, MERRA, CFSR, ERA40, NCEP1, NCEP2, CORE2

Courtesy of Lisan Yu

Which heat flux product is right ?

Standard deviation of mean net Solar & Longwave Radiation Heat Flux from 11 different products



Just because the products agree, doesn't mean they are right. They could all be wrong.

Products: NOC2, ERAinterim, MERRA, CFSR, ERA40, NCEP1, NCEP2, JRA55, 20CR, ERA20, CORE2, ISCCP, NASA/SRB, CERES

Courtesy of Lisan Yu

Goals of this talk

- Overview of air-sea fluxes, interactions, and some feedbacks

- OceanObs’19 strategy paper: “Quantifying Global Surface Heat Fluxes”

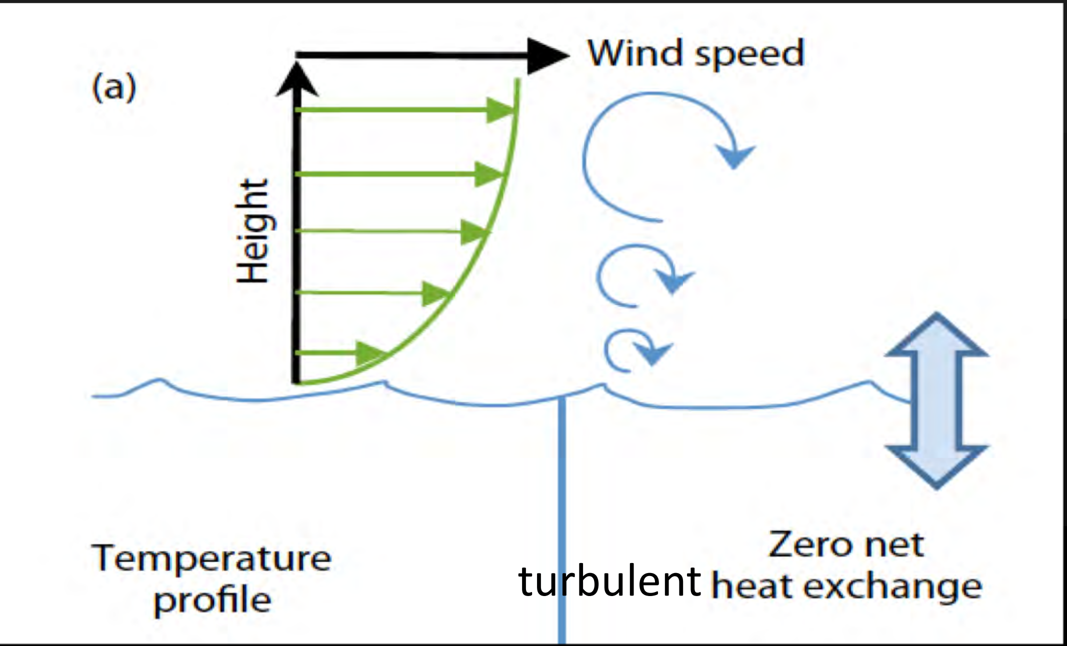
Hierarchy of Observations

- Direct covariance fluxes & state variables for developing bulk algorithm
- Global observations of state variable observations (and fluxes if feasible), from which fluxes are then computed. *For some products, satellite and in situ obs are integrated together through a NWP.*
- Observations for validating fluxes.

Neutral Stratification ($T_s \approx T_{air}$)

No Turbulent Air-Sea Heat Flux. Forced Convection in Atmosphere.

$Ri_f = z/L \approx 0$, where $L = -u^{*3} / (k\beta u^* T^*)$ = Monin-Obukhov Length Scale



$\tau_0 = \rho_a u^* u^* = \rho_a \nu dU/dz$

Assume: $dU/dz = u^*/kz$

i.e., $\nu = kzu^*$ "efficiency of mixing scales as the cell height"

Integrate wrt z:

$U - U_s = (u^*/k)\ln(z/z_0)$ solve for u^*

Rewrite in drag law form:

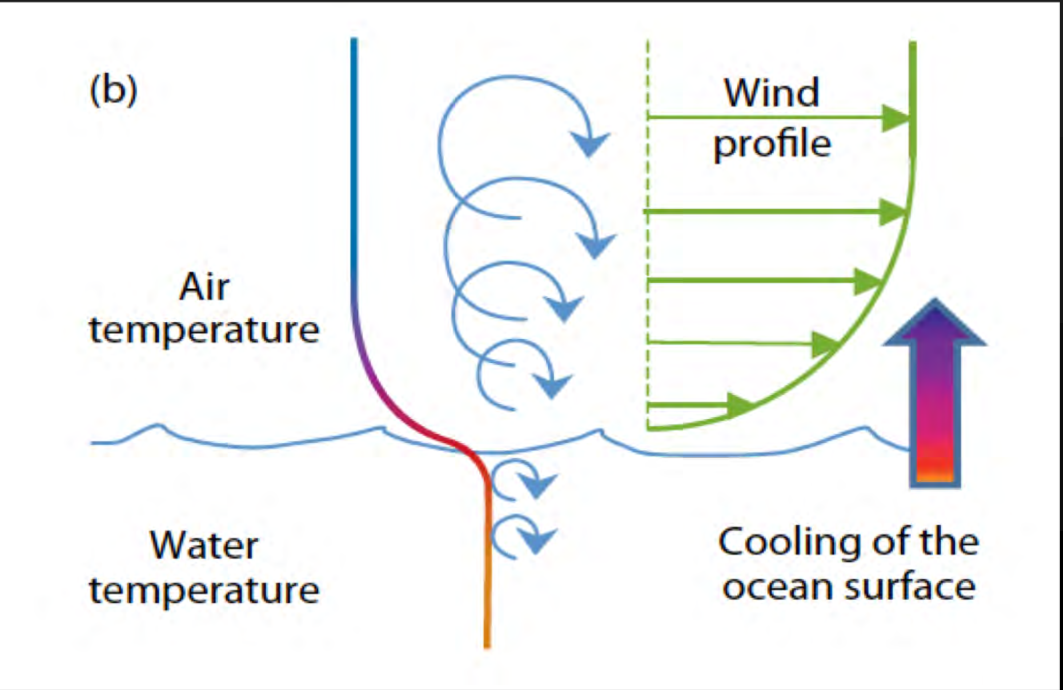
$\tau_0 = \rho_a u^* u^* = \rho_a C_d (U-U_s)^2$

From Bourassa et al. Oceangraphy 2010

Unstable Stratification ($T_s > T_{air}$)

Surface heat loss causes convective turbulence in both atmosphere and ocean.

$Ri_f = z/L < 0$, where $L = - u^{*3} / (k\beta u^* T^*)$ = Monin-Obukhov Length Scale



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$\tau_0 = \rho_a u^* u^* = \rho_a \nu dU/dz$

Assume: $dU/dz = u^*/kz - d(\Psi(z/L))/dz$

"Modified by Stability Profile"

Integrate wrt z:

$U - U_s = (u^*/k)(\ln(z/z_0) - \Psi(z/L))$

Rewrite in drag law form:

$\tau_0 = \rho_a u^* u^* = \rho_a C_d (U - U_s + w_g)^2$

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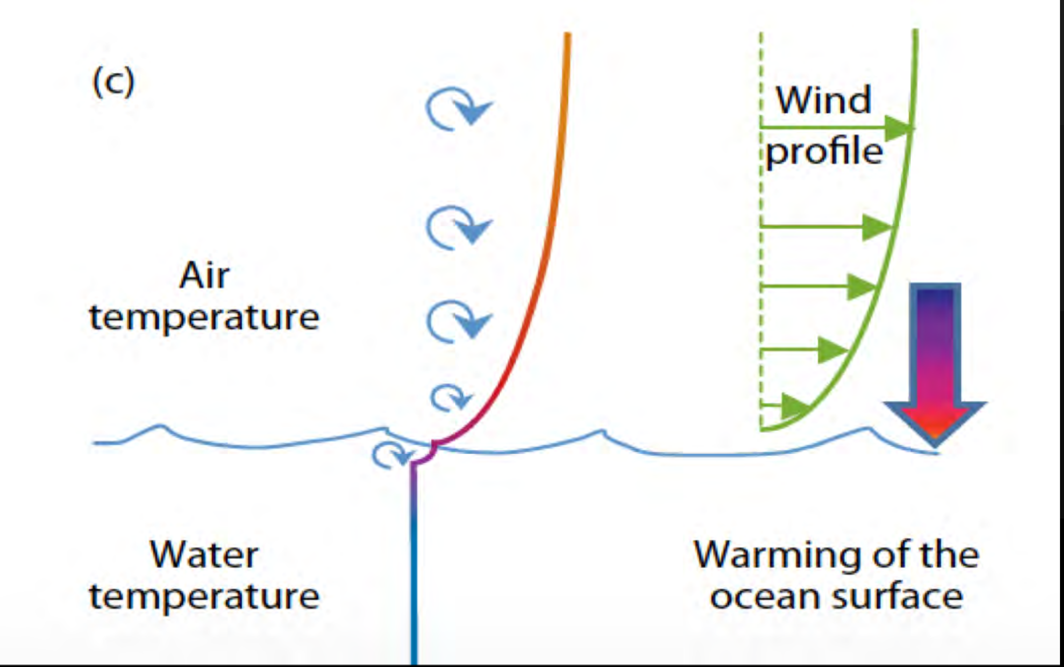

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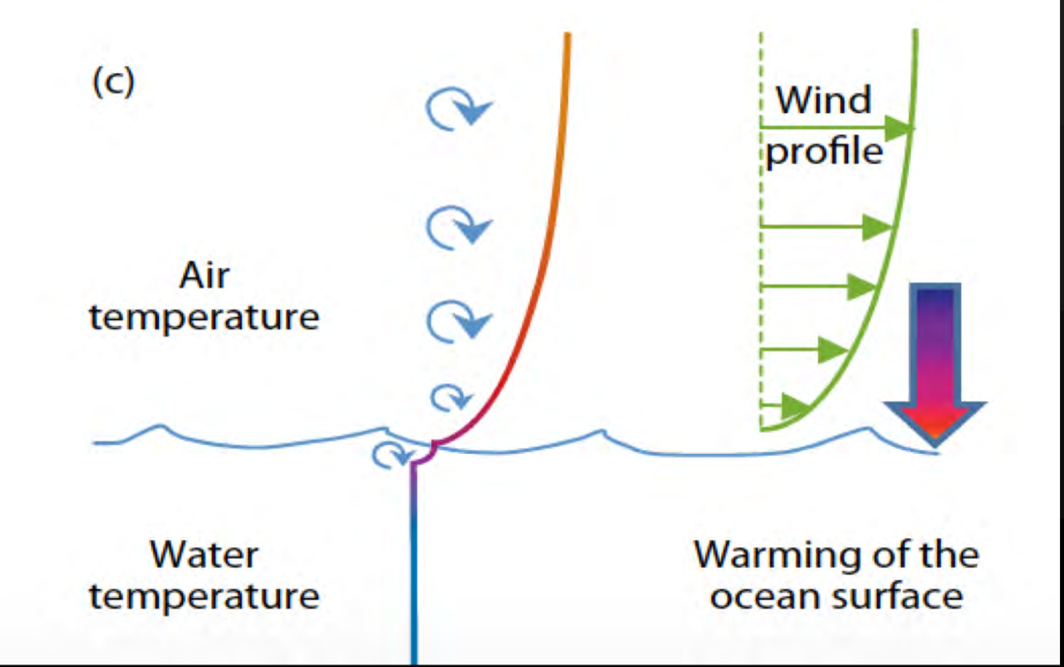
Need: to Improve bulk algorithm
Need: more direct covariance flux obs



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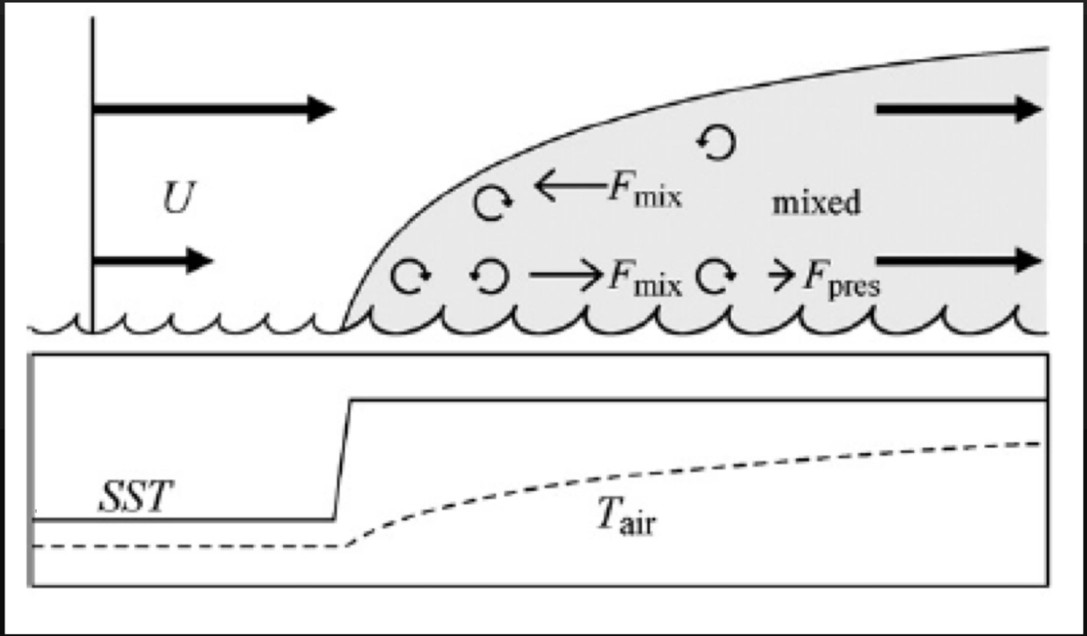
Now consider air-sea interaction in a frontal region: Thermodynamic response

Mixing of strong winds from aloft increases surface winds

Near-Neutral winds upwind of front



Induced pressure gradient also forces wind

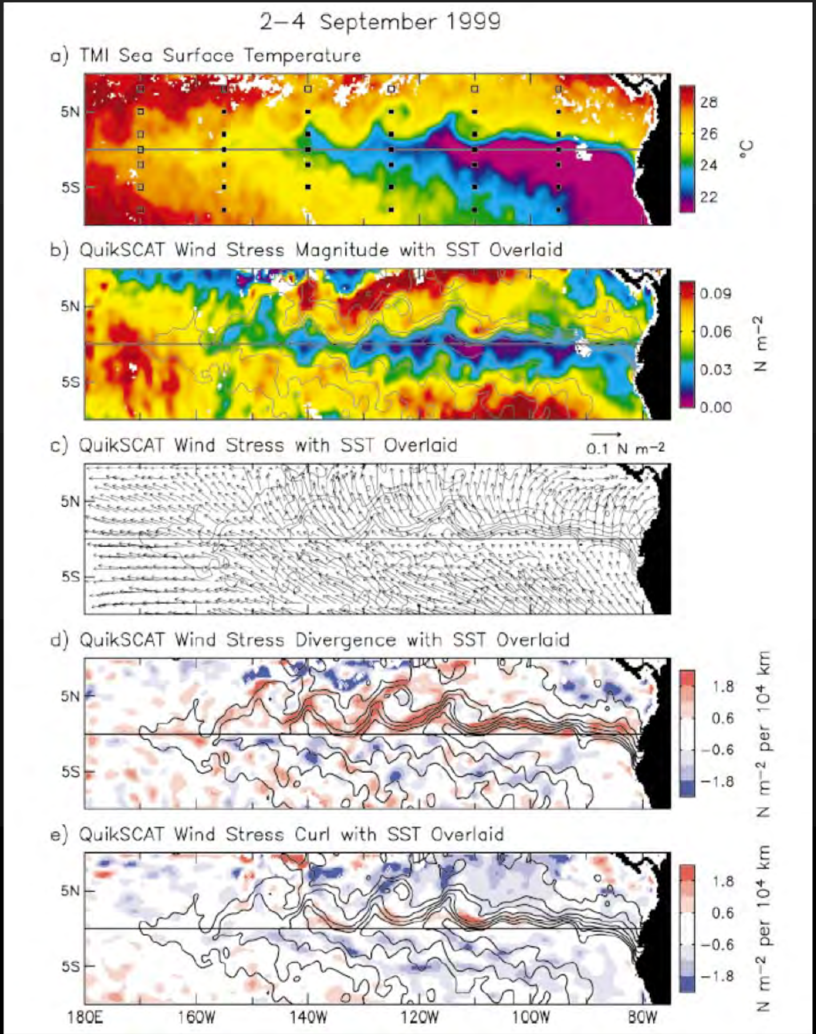
Large surface heat loss downwind of front:
Ocean SST front projects into the atmosphere

Small et al. (Dyn Atm Oc 2008)

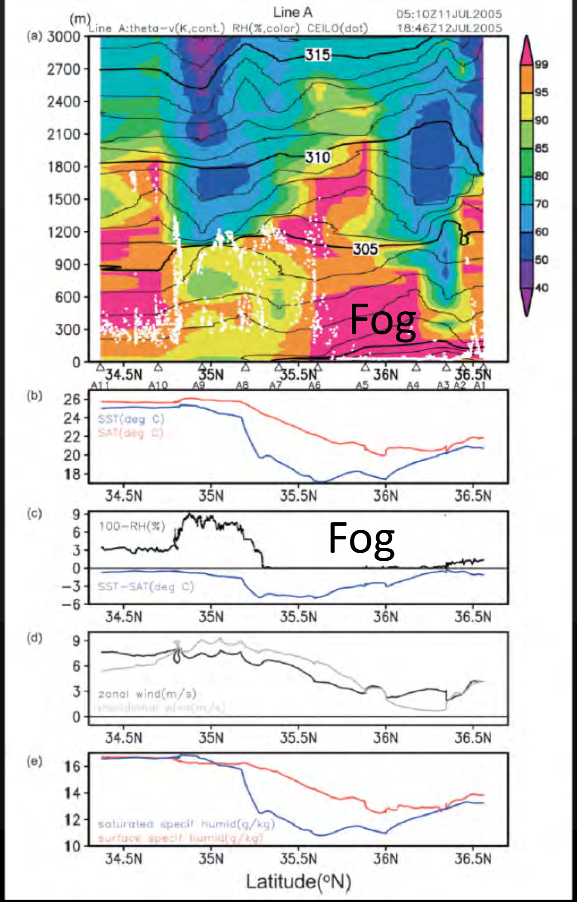
Low wind stress over equatorial cold tongue (stabilizes ABL)

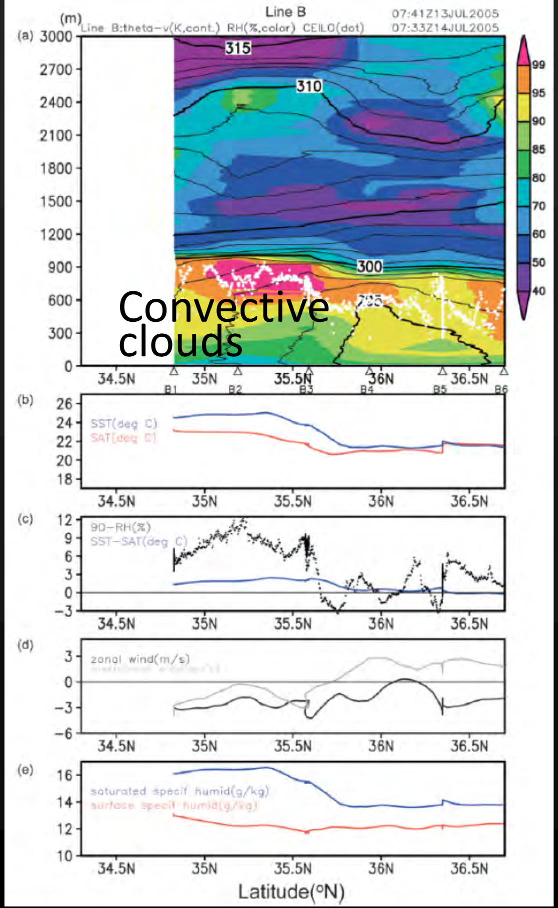
Wind stress divergence as SE Trades blow across cold tongue front

Wind stress curl as SE Trades blow along front



Chelton et al. (JCli 2001)





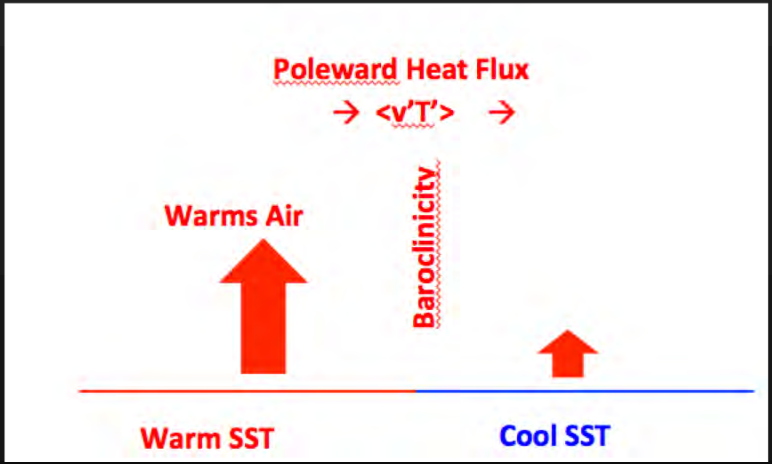
Systematic clouds (and rainfall) associated with fronts make remote sensing of frontal regions challenging

Wind blows across SST front from warm to cold water

Wind blows across SST front from cold to warm water

Tanimoto et al. (JCli 2009)

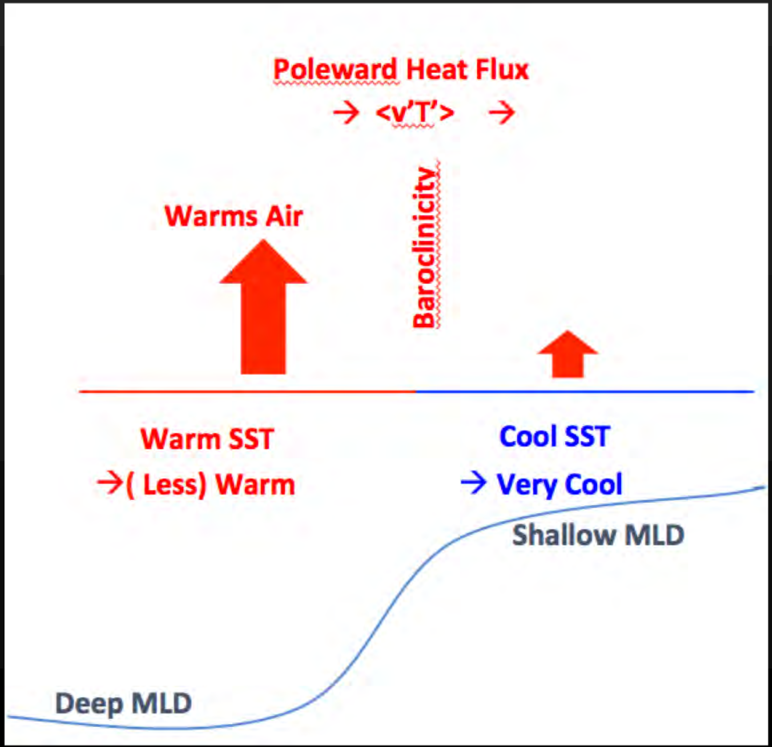
Role of Mixed Layer Depth in Frontogenesis

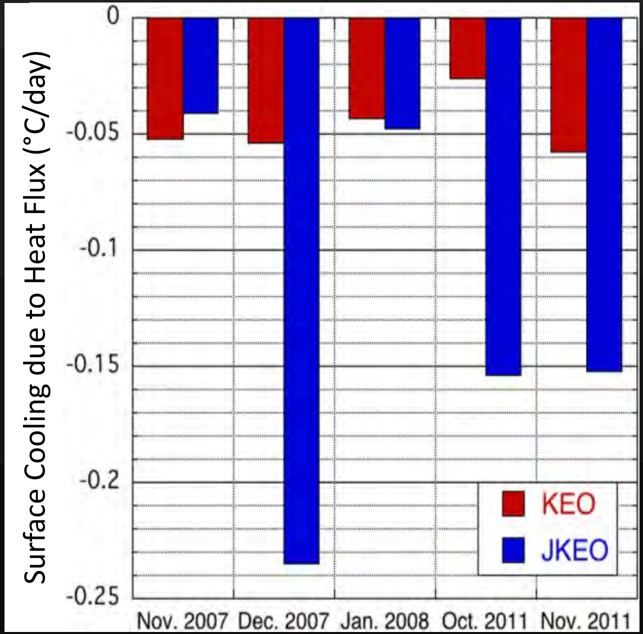


Expect that large ocean heat loss on warm side of jet will cool SST and damp ocean SST front. But...

Tozuka et al. Sci Rep 2017

Role of Mixed Layer Depth in Frontogenesis





Because MLD is deep on warm (KEO) side of jet and shallow on cool (JKEO) side of jet, weaker heat loss on cool side causes large SST cooling on cool side, enhancing the SST front !

A coupled model with poor mixed layer physics could have feedback be wrong sign!

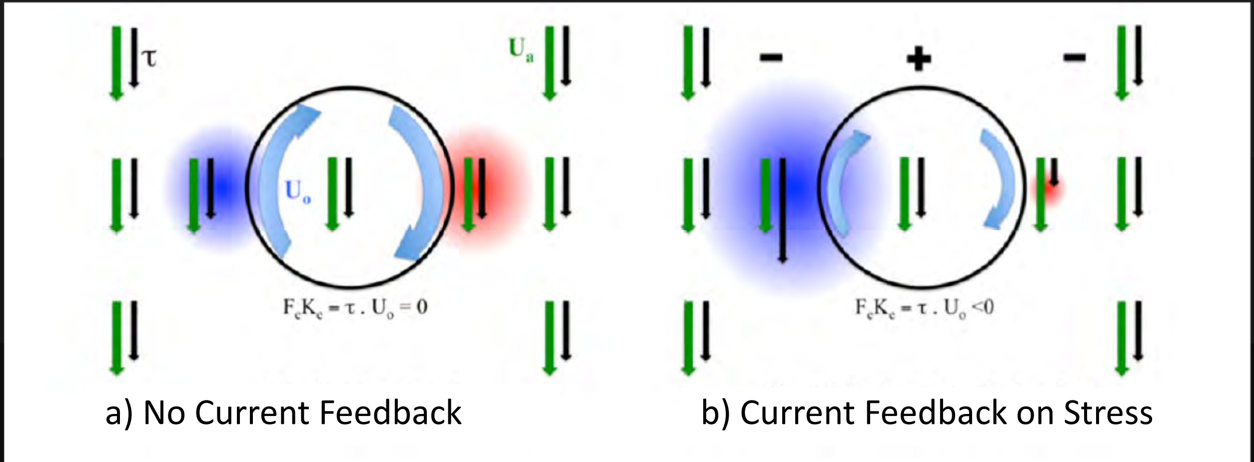
Tozuka et al. Sci Rep 2017

Now consider air-sea interaction in a frontal region: Dynamic response

Winds vs Wind Stress

$$\tau_0 = \rho_a u^* u^* = \rho_a C_d (U - U_s + w_g)^2$$

Winds are not the same as **Wind Stress**: Wind Stress also depends upon **Ocean Currents**



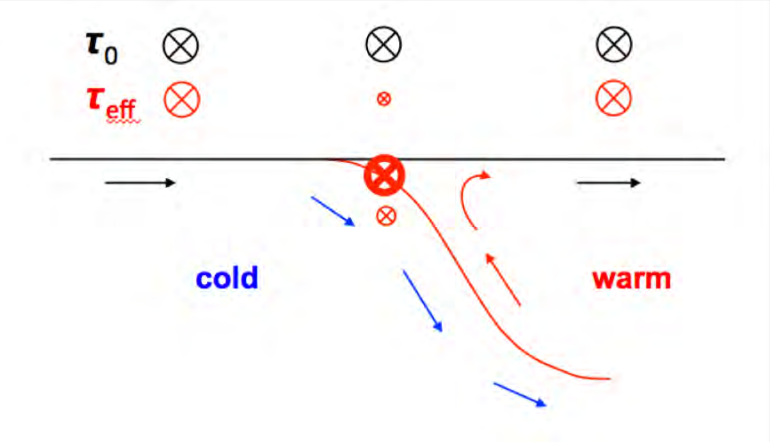
Wind Work = $\tau_0 \bullet U$

For uniform wind acting on eddy, wind stress altered by currents, acts as drag on ocean. Eddies act as Drag on Ocean.

Renault et al. JPO 2016

Stress is proportional to shear

In frontal region, surface shear has geostrophic component (thermal wind shear). Only a portion of the wind stress ("effective wind stress") balances ageostrophic "Ekman" shear.



Steady state, linear Ekman flow results in vertical velocities at front

$$\boldsymbol{\tau}_0 = \rho_0 \nu \frac{\partial \mathbf{u}}{\partial z} \quad \text{at} \quad z = 0.$$

Rearrange to solve for "Ekman" ageostrophic flow:

$$\frac{\partial \mathbf{u}_a}{\partial z} = \frac{1}{\rho_0 \nu} \boldsymbol{\tau}_0 - \frac{\partial \mathbf{u}_g}{\partial z} \equiv \frac{1}{\rho_0 \nu} \boldsymbol{\tau}_{\mathrm{eff}} \quad \text{at} \quad z = 0,$$

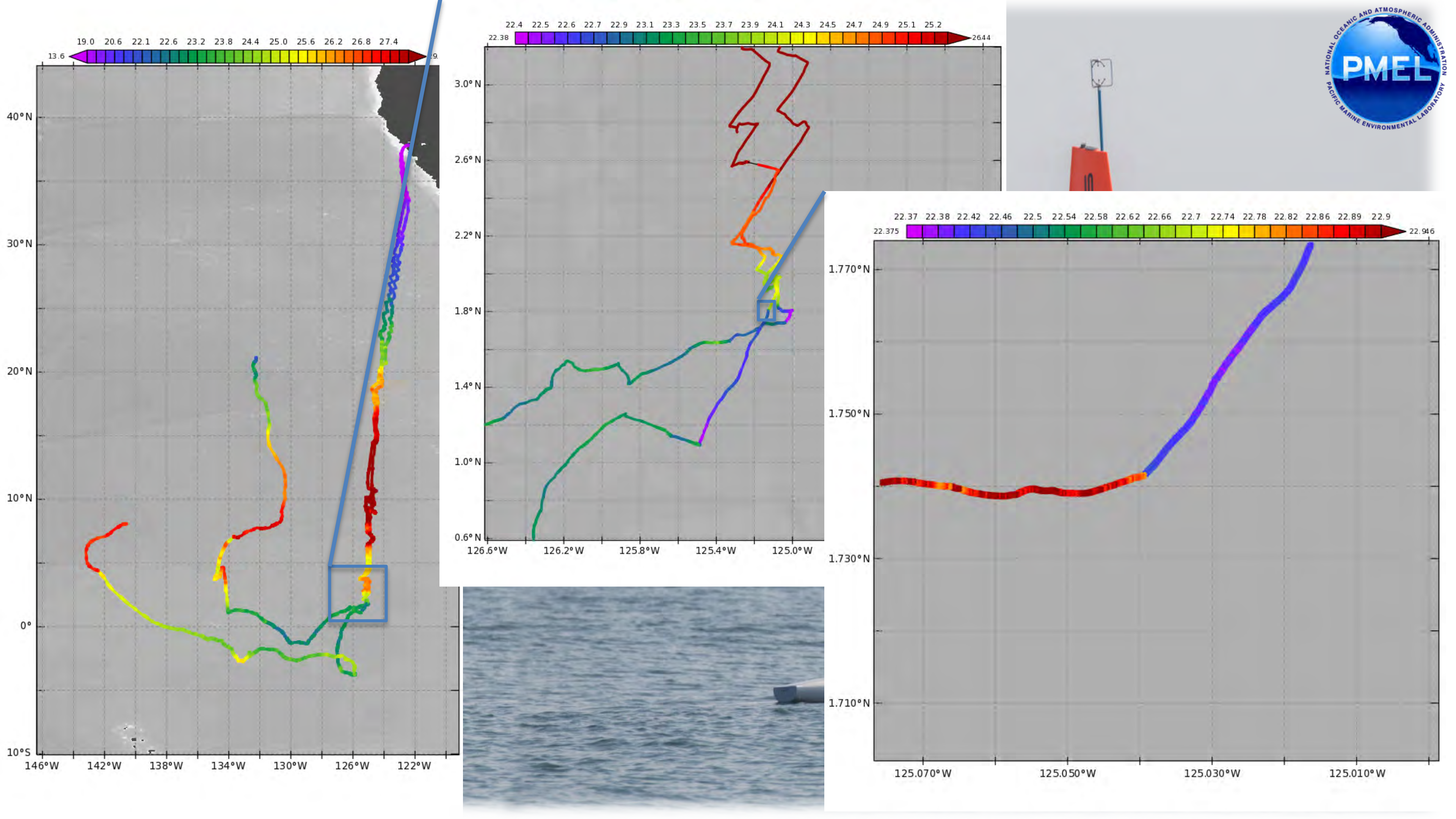
Ekman Buoyancy Flux is balanced by Geostrophic Shear Stress flux. No enhanced mixing.

Cronin and Kessler (2009)

Saildrone: A new autonomous surface vehicle for boundary layer observations

Meghan F. Cronin (NOAA PMEL)

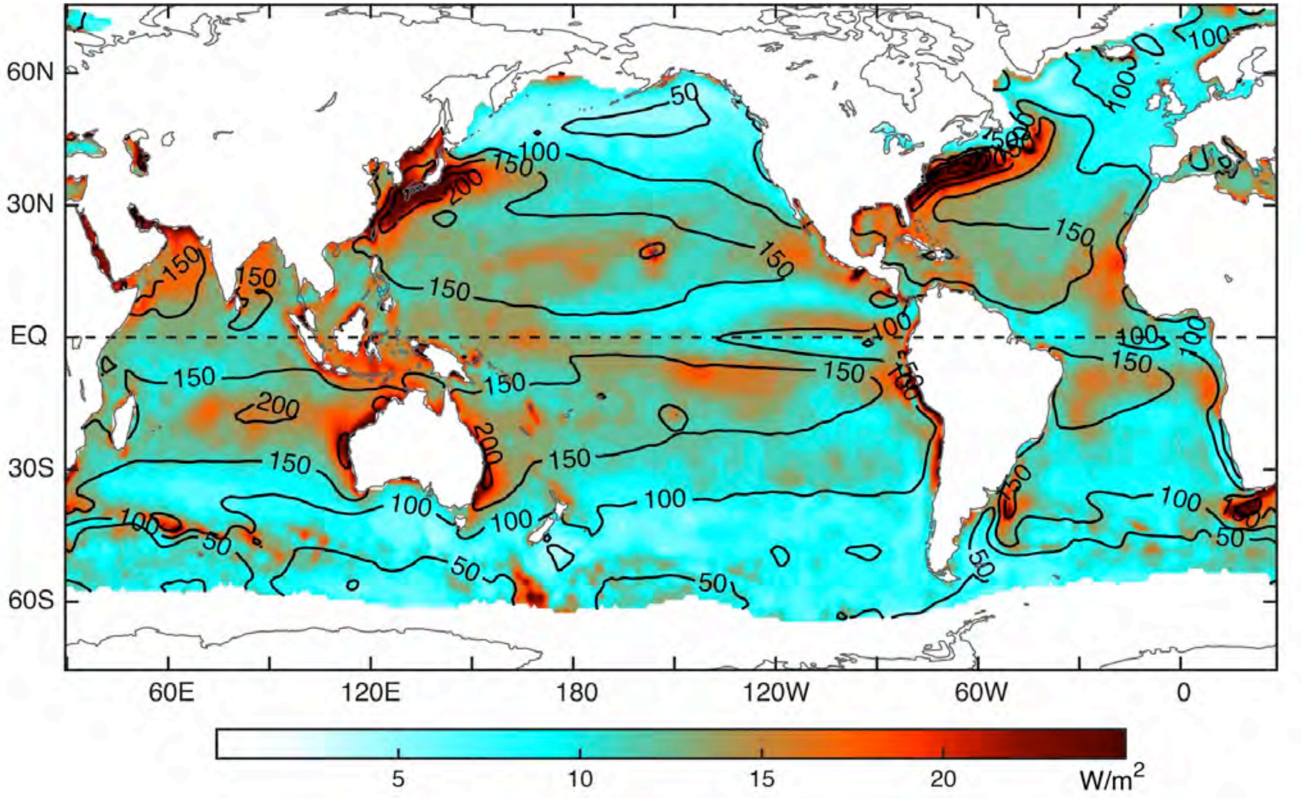
Photo courtesy Saildrone, Inc.



13.6
19.0 20.6 22.1 22.6 23.2 23.8 24.4 25.0 25.6 26.2 26.8 27.4
40°N
30°N
20°N
10°N
0°
10°S
146°W 142°W 138°W 134°W 130°W 126°W 122°W
22.38
22.4 22.5 22.6 22.7 22.9 23.1 23.3 23.5 23.7 23.9 24.1 24.3 24.5 24.7 24.9 25.1 25.2
26.44
3.0°N
2.6°N
2.2°N
1.8°N
1.4°N
1.0°N
0.6°N
126.6°W 126.2°W 125.8°W 125.4°W 125.0°W
22.375
22.37 22.38 22.42 22.46 22.5 22.54 22.58 22.62 22.66 22.7 22.74 22.78 22.82 22.86 22.89 22.9
22.946
1.770°N
1.750°N
1.730°N
1.710°N
125.070°W 125.050°W 125.030°W 125.010°W
PMEL
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
PACIFIC MARINE ENVIRONMENTAL LABORATORY

Which heat flux product is right ?

Standard deviation of mean Latent and Sensible Heat Flux
from 11 different products



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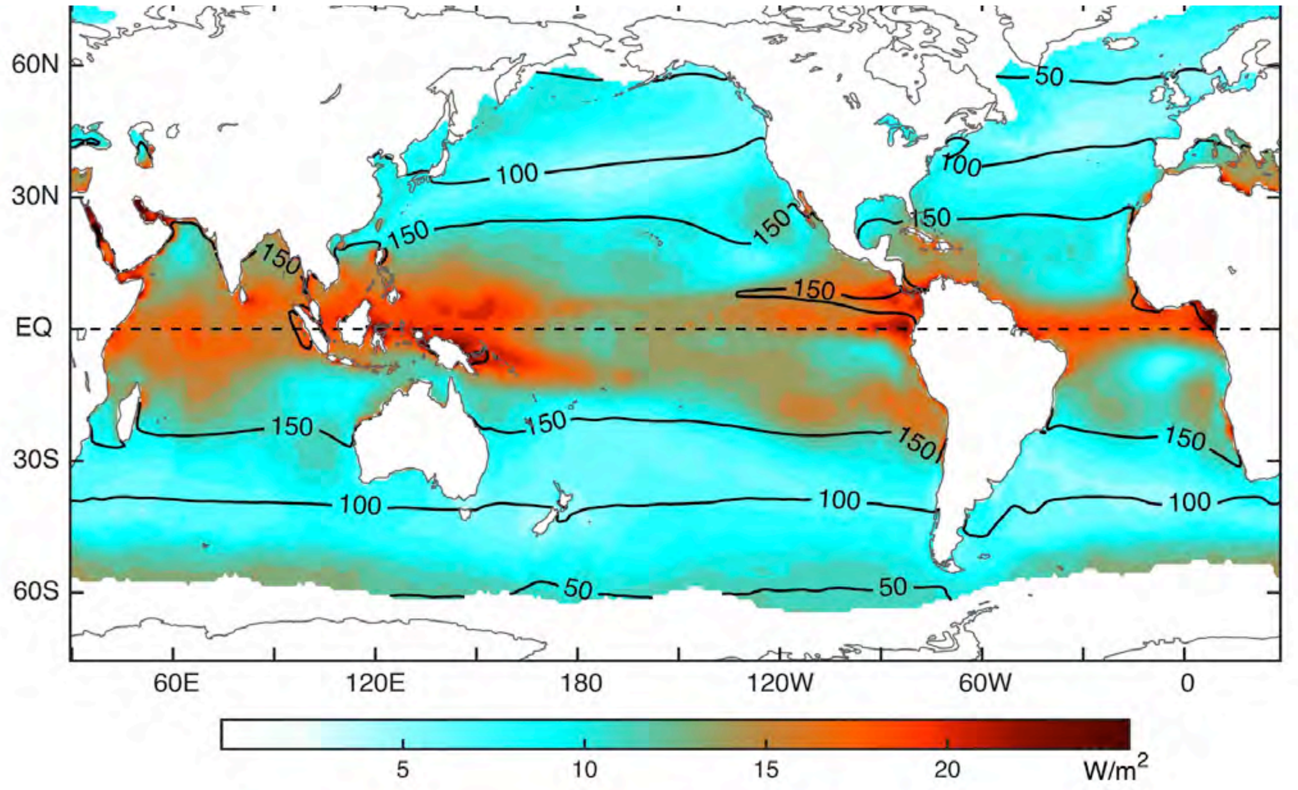

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Hierarchy of Observations

- Direct covariance fluxes & state variables for developing bulk algorithm

- Global observations of state variable observations (and fluxes if feasible), from which fluxes are then computed. *For some products, satellite and in situ obs are integrated together through a NWP.*

- Observations for validating fluxes.

Hierarchy of Observations

- Direct covariance fluxes & state variables for developing bulk algorithm

Need: Improved bulk algorithm *(roughness dependence upon waves, rain, gustiness; Stability profiles dependence;…)* .... for estimation of fluxes from observations and in NWP models

Need: more direct covariance flux observations in different climate regimes *(high wind, high wave, low wind, stable, unstable,...)*

Hierarchy of Observations

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Need: Better resolved and more accurate state variables

Issues with flux calculation

Very non-linear. Fluxes computed from average quantities not equal to average of fluxes computed from highest resolution state variables.

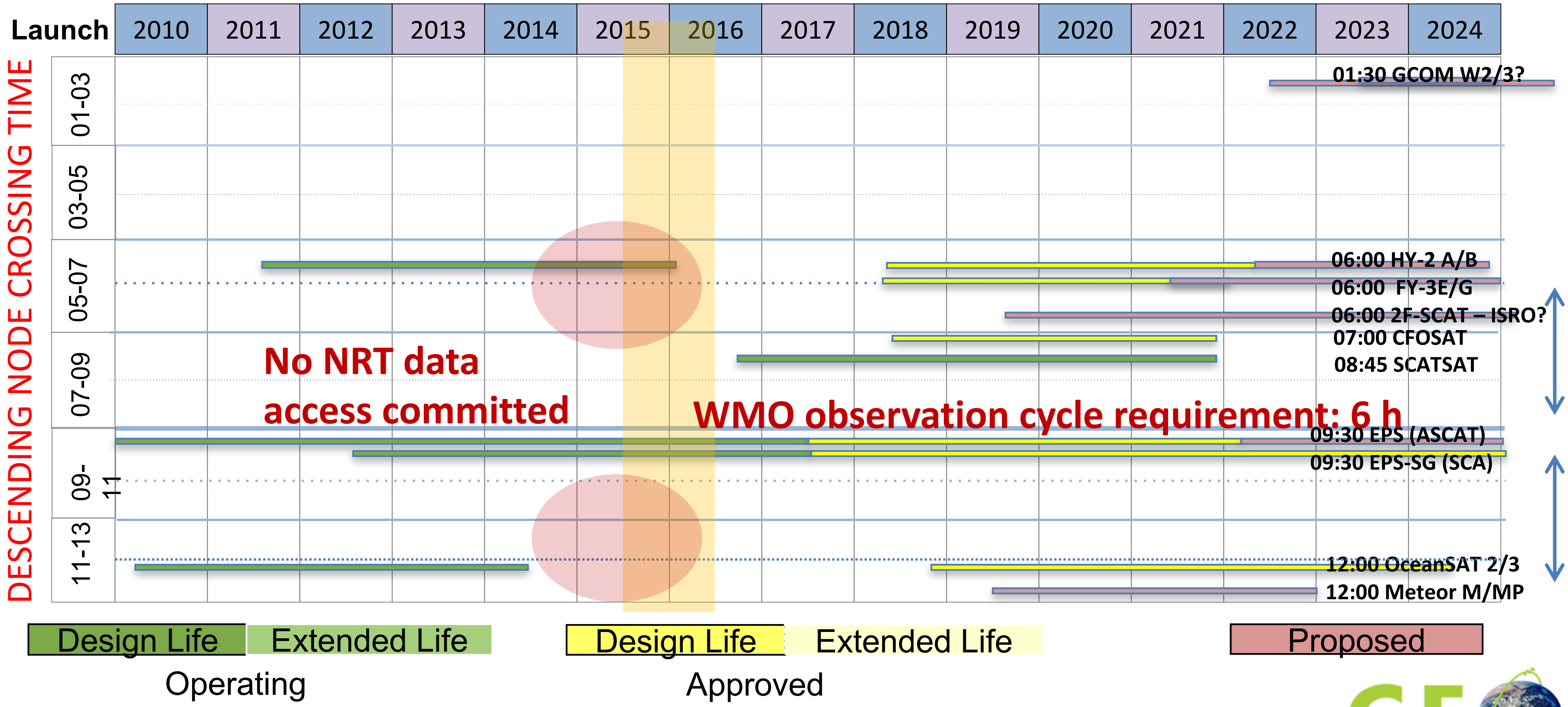
- Gustiness – vector average wind speed ≠ scalar average.
- In low wind regions, SST has large diurnal cycle. Skin T ≠ bulk SST
- Extreme weather can be short duration.
- Large heat fluxes associated with ocean fronts.

Must resolve diurnal cycle and eddies !

	For daily averages from moorings in Tropical Pacific			
	er	**Std**	**Std/er**	**er(Q0)**
Variable				W/m^2
wind speed (m/s)	0.1	1.75	17.5	2.1
SST (C)	0.1	1.45	14.5	4.4
air temp. (C)	0.1	1.30	13.0	3.6
rel. hum. (percent)	2.7	4.83	1.8	11.9
SWR (W/m^2)	6	42.00	7.0	5.6
LWR (W/m^2)	4	13.75	3.4	3
sfc currents (m/s)	0.05	0.25	5.0	0.65
Total of meas. errors				**14.3**
				Q0
Mean (across equator)				125.6

et al. (2014)

Ocean Vector Surface Winds Constellation
Local time coverage assessment (ground track) - NRT data access

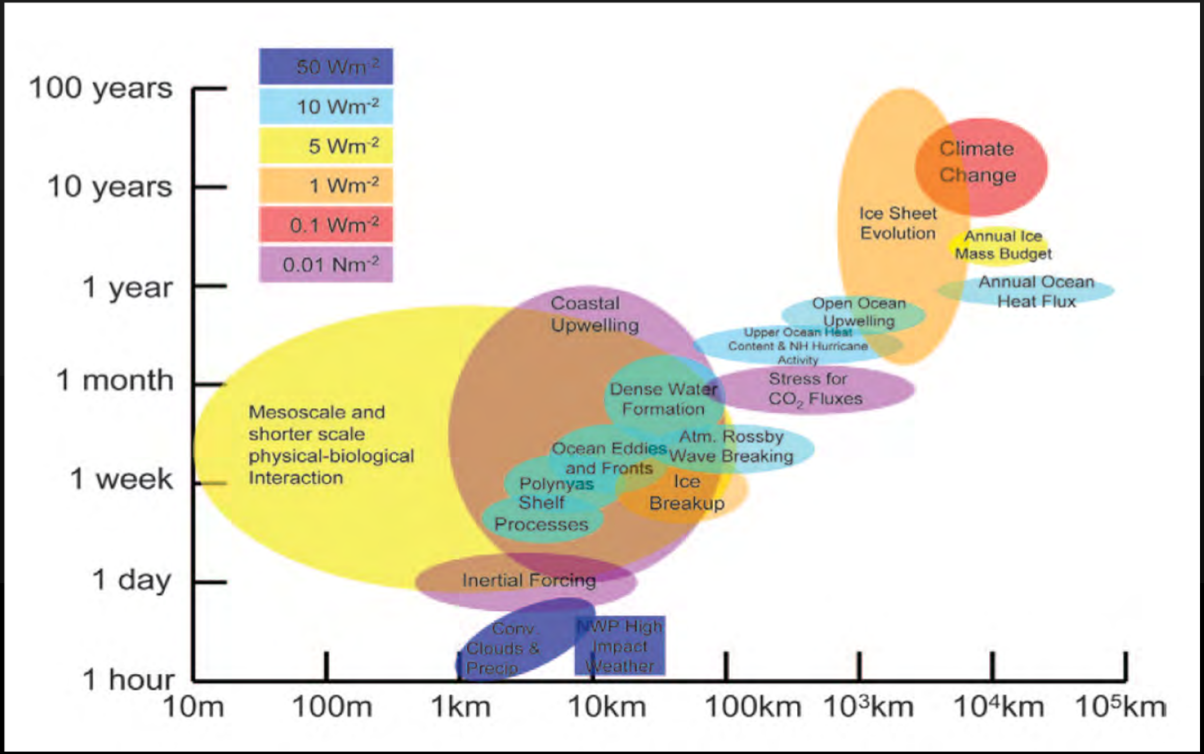


Compiled by Paul Chang. Source: WMO OSCAR database and direct interactions with agencies

Slide courtesy Tony Lee

CEOS Committee on Earth Observation Satellites

Would be nice to have an aspirational goal of resolving Climate Change. But might not be possible.



Bourassa et al. (BAMS 2013)

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- Observations for validating fluxes. Need reference stations more and different regimes (e.g. Southern O.)