A Gridded Product That Uses Dynamical and Thermodynamical Constraints

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With thanks to
NASA OVWST, NASA NEWS, and NOAA/COD

Motivation

- Complete (over water) in space and time
  - This is expected for ease of use
- No boundary condition forced at the sea edge
  - Improved near shore winds
  - Improved high latitude storms near ice
- Reproduction of observed dependence on SST gradients (assumed to be air temperature gradients)
  - This has a substantial impact on upwelling and air/sea fluxes
  - Removes seasonal and regional biases
- Push spatial/temporal resolution as far as reasonable
- The observing system should not be apparent in the product

Our General Approach

- A gridded product based on
  - A misfit to observations
    - Vector winds, scalar winds
    - SST, air temperature, surface pressure, surface humidity,
  - Misfit to a background field (from NWP)
  - A misfit to a physical model linking variables
    - A hard constraint would force an exact match to this model
    - A soft constrain is more realistic since we don’t believe the model is perfect, and misses smaller scales
- The hard part is developing a realistic model!
- First guess is based on NWP and the physical model

Our Approach for the Model

- We have combined two models from oceanography, and applied them to the atmosphere
  - Stommel (1953) Geostrophic flow
    - 1. Vertically uniform eddy diffusivity (*K*).
    - 2. Zero shear, stress (*K* = const) at $z = -H$ and match stress at surface ($du/dz = tau(0)/(\rho K)$)
    - 3. Zonal wind stress uniform in y (curl(*tau*) = 0) implying that the vertically integrated transport is zero (Integral -*H* to 0 of $u(z) = 0$)
    - 4. No "fronts" Grad(*T*) = 0.
  - Lagerloef and Bonjean (2002) links Geostr., Ekman, surface
    - Removes assumptions 3 and 4
  - Coupling with a log profile fixes the problems with (1) and (2)

These are not realistic assumptions for our application – all must be removed

The Solution

- Skipping many steps

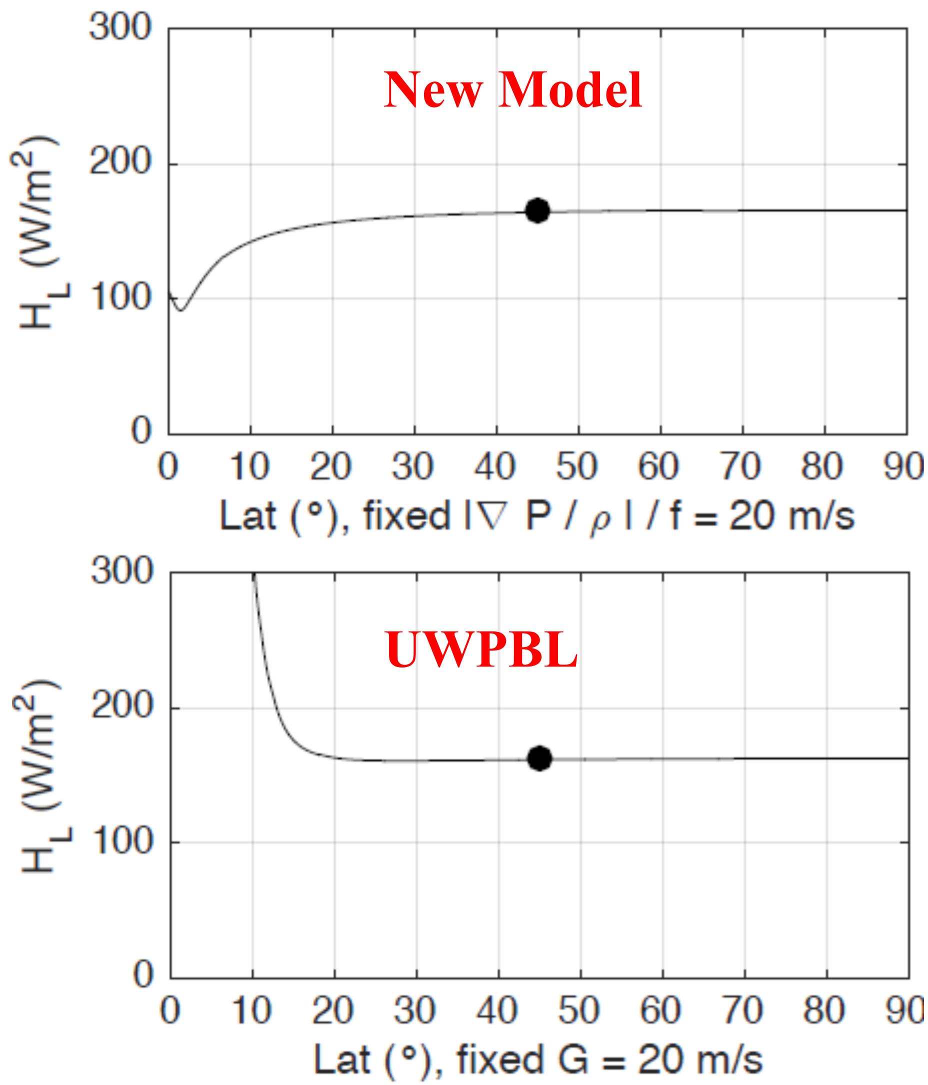
$$\mathbf{U}(z)=\mathbf{U}(h_p)+(z-h_p)\left(\frac{g\nabla T}{T_0}\frac{\left((z-h_p)^2-3(H-h_p)^2\right)}{6K}+\frac{\nabla p(h_p)}{\rho}\frac{(z+hp-2H)}{2K}\right) \quad (14)$$

were $\mathbf{U}(h_p)$ is provided by the surface layer expression,

$$\mathbf{U}(h_p) = \frac{u^*}{k}\left(\ln(h_p/z_0)-\Psi(h_p/L)\right), \quad (15)$$

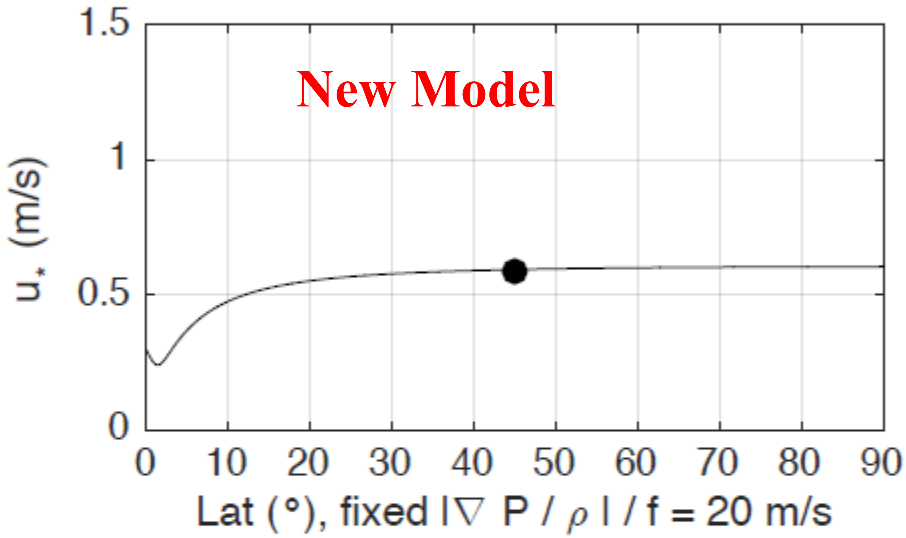
- Where (15) is the standard Boundary-layer log-layer solution
- (14) is a cubic Ekman layer solution at the equator
  - similar to Stommel's result,
  - a lot more flexible and widely applicable

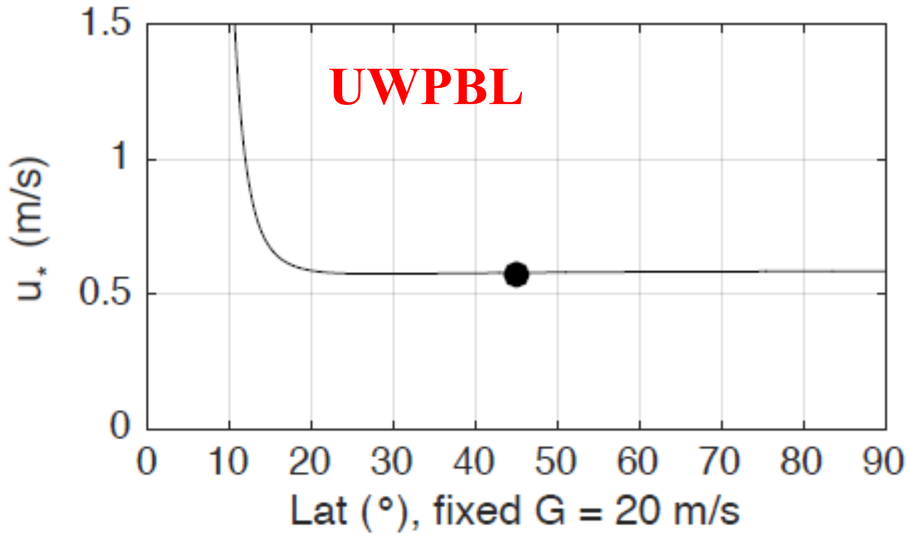
Sensitivity Analysis & Comparison to UWBPL: Latent Heat Flux



- Latent Heat Flux
- Caveat: the results are for the fuller physics version of the UWPBL.
  - The light-physics tropical version of the UWPBL is more stable
  - But does not have needed physics

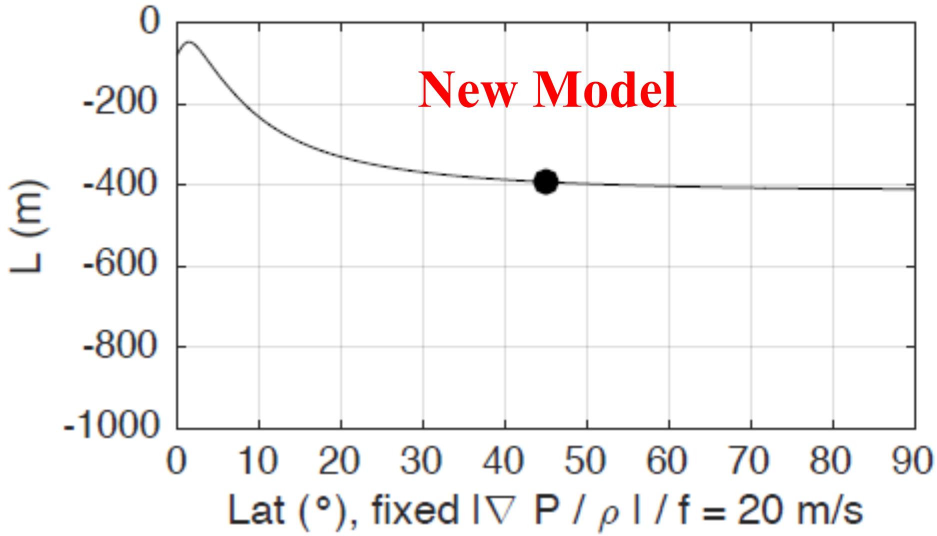
Sensitivity Analysis & Comparison to UWBPL: Friction Velocity

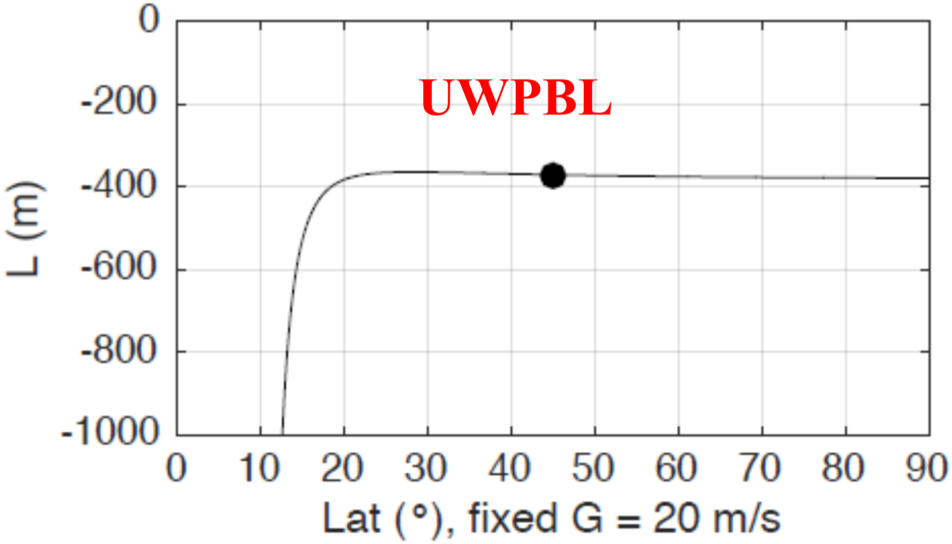




- Reasonable input for unstable boundary-layer stratification
- The new model is quite stable
- UWPBL does not converge within 8° of the equator, and would give unfortunately large stress with about 20° of the equator

Sensitivity Analysis & Comparison to UWBPL: M-O Scale Length

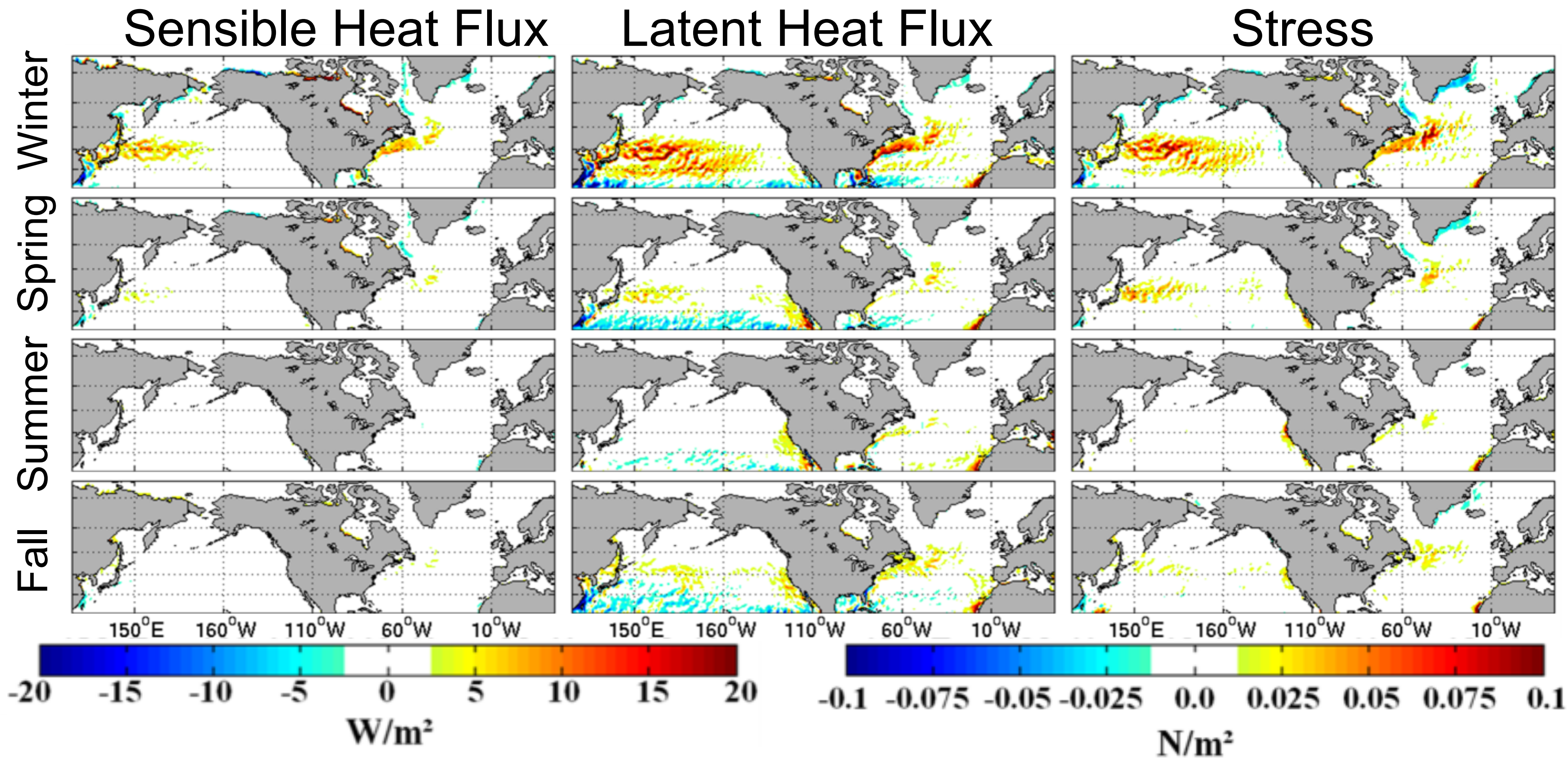




- M-O scale length is stable for new model
- Latitudinal dependence quite different depending on what is held constant
- UWPBL M-O length approaches negative infinity
  - Very deep boundary layer

Preliminary Seasonal Results

Flux Differences Relative to case with No SST Dependence



2002 – 2003 seasonal average differences in SHF (left), LHF (middle), and wind stress (right) for DJF (top row), MAM (2nd row), JJA (3rd row), and SON (bottom row)

Courtesy John Steffen

Conclusions

- A purely statistical approach cannot achieve the desired spatial/temporal resolution without far more data than are available
- We believe that a physical model can be used to provide the far more connectivity between observations, and hence fill gaps and improve resolution
  - Like NWP, but far less sophisticated, and hopefully a better fit to the data (particularly in the tropics and the high latitudes)
  - Like NWP, other types of data are useful: speeds, SSTs, ….
  - While also producing consistent fields of surface fluxes
- Preliminary results (shown several meeting prior) support that the model contains the physics needed to have a reasonable dependence on temperatures and temperature gradients
- Unlike the UWPBL model, this model works globally with the same model for SST dependence

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Backup Slides

Solution

$$i\ f\ \mathbf{U} = -1/\rho_0 \nabla p + K\ \frac{\partial^2 \mathbf{U}}{\partial z^2} \qquad (1)$$

where: $\nabla \equiv \partial/\partial x \ + \ i\ \partial/\partial y$

$$\mathbf{U} \equiv u + i\ v$$

The boundary conditions are that the stress vanishes at the top of the Ekman layer $z = H$ and is matched to the surface layer stress at $z = h_p$. K is assumed constant, implying that the shear at the top of the Ekman layer vanishes. Our boundary conditions are

$$\partial \mathbf{U}/\partial z = 0 \qquad z = H \qquad (2)$$

$$\partial \mathbf{U}/\partial z = \mathbf{t}/(\rho_0\ K) \qquad z = h_p \qquad (3)$$

where $\mathbf{t}$ is the complex surface layer stress, $\mathbf{t} = \tau^x + i\ \tau^y$. The classical Ekman model would have taken the drag to vanish at $z \to \infty$, which with constant K gives

$$\frac{\partial^2 \mathbf{U}}{\partial z^2} \to 0\ ,\ z \to \infty .$$

Solution Continued

The model Ekman layer includes a simplified buoyancy forcing in the vertical hydrostatic balance allowing for thermal wind.

$$1/\rho_0 \partial p/\partial z = -g + g\,(T - T_0)/T_0 \qquad (4)$$

where T_0 is the surface temperature. Applying the ∇ operator to (4) gives

$$1/\rho_0 \partial \nabla p/\partial z = g\,\nabla T/T_0 \qquad (5)$$

- This is very important for modeling the impact of SST gradients

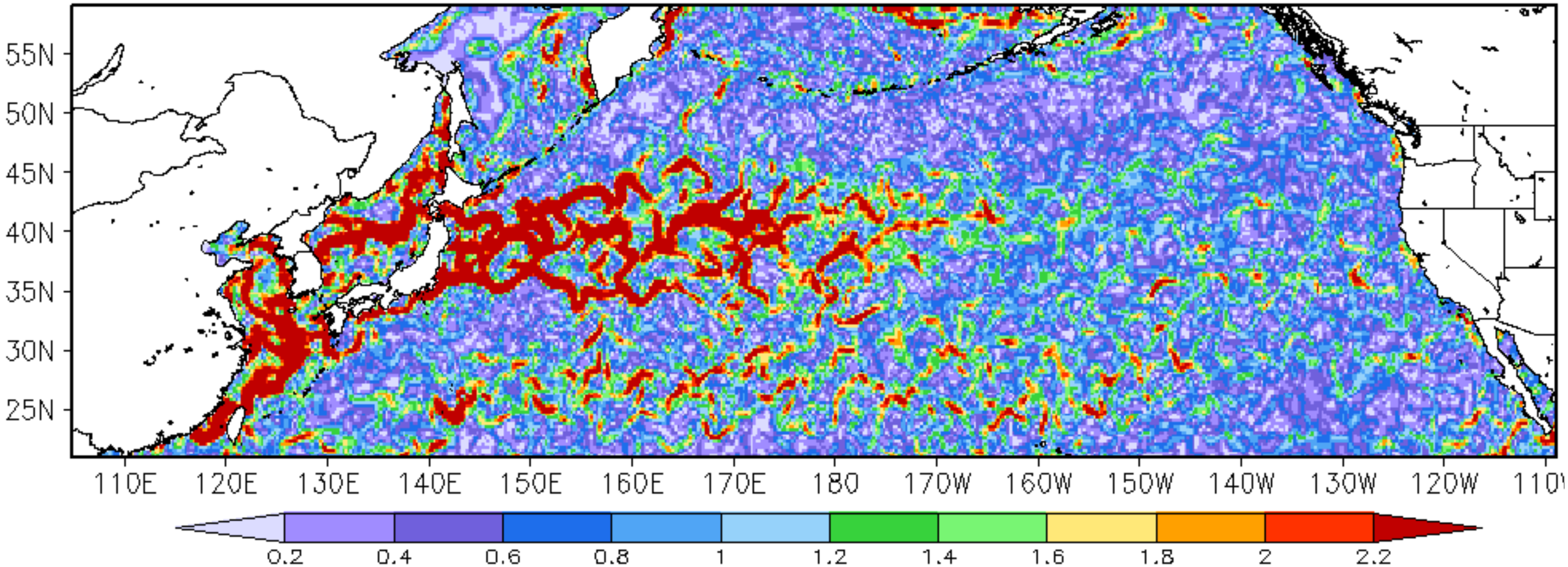
Further Minor Caveats

- The new model is numerically unstable or overly sensitive if
  - The unstable boundary-layer is too shallow
    - Solution: set $H \approx 1500$m
  - The stable boundary-layer is too deep
    - 3 to 5 solutions for deep layers
    - Solution: set $H \approx 200$m
- At the suggested thicknesses, the results are very insensitive to the value of H.
- Alternatively, we could also use boundary-layer heights from NWP.

Technical Details I

- Steady, horizontally uniform, two-layer model consisting of an upper Ekman layer that is matched to a surface layer below. The surface layer is a standard stratified Monin-Obukhov type layer extending from the surface to a height $z = h_p$ where the matching to the Ekman layer occurs.
- The difference between this model and some other PBL models is structure of the Ekman layer. Rather than extending to $z = \infty$, the model Ekman layer occupies the region $h_p < z < H$, from the top of the surface layer to a *finite* height H.

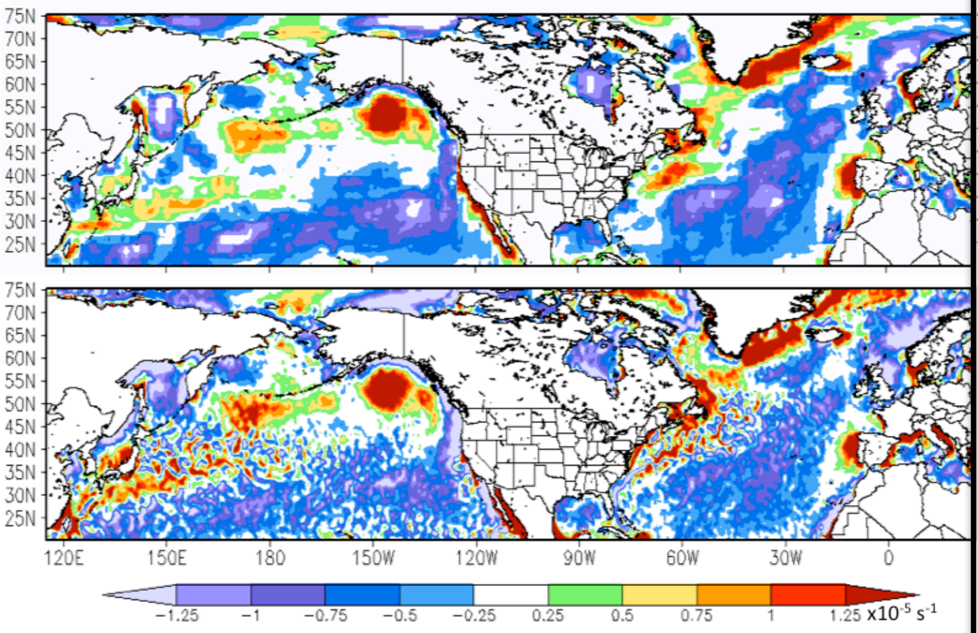
Example Reynolds SST Gradients



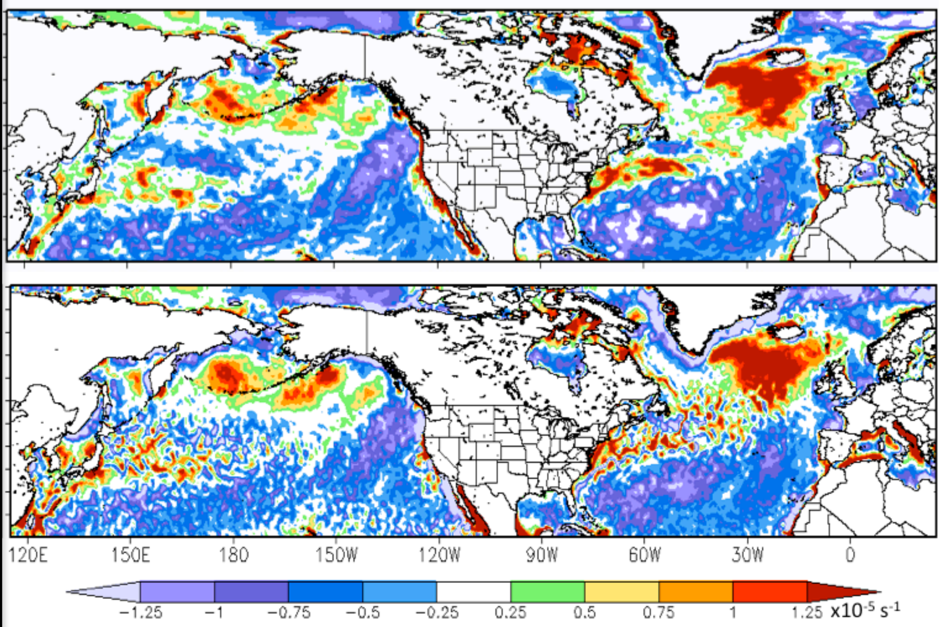
- Example gradients of Reynolds SSTs (K/100km).
  - These fields are noisy and require smoothing
  - Smoothing can be tuned to match the spatial scales in wind observations.

CCMP (top) vs. FSU (bottom): Curl

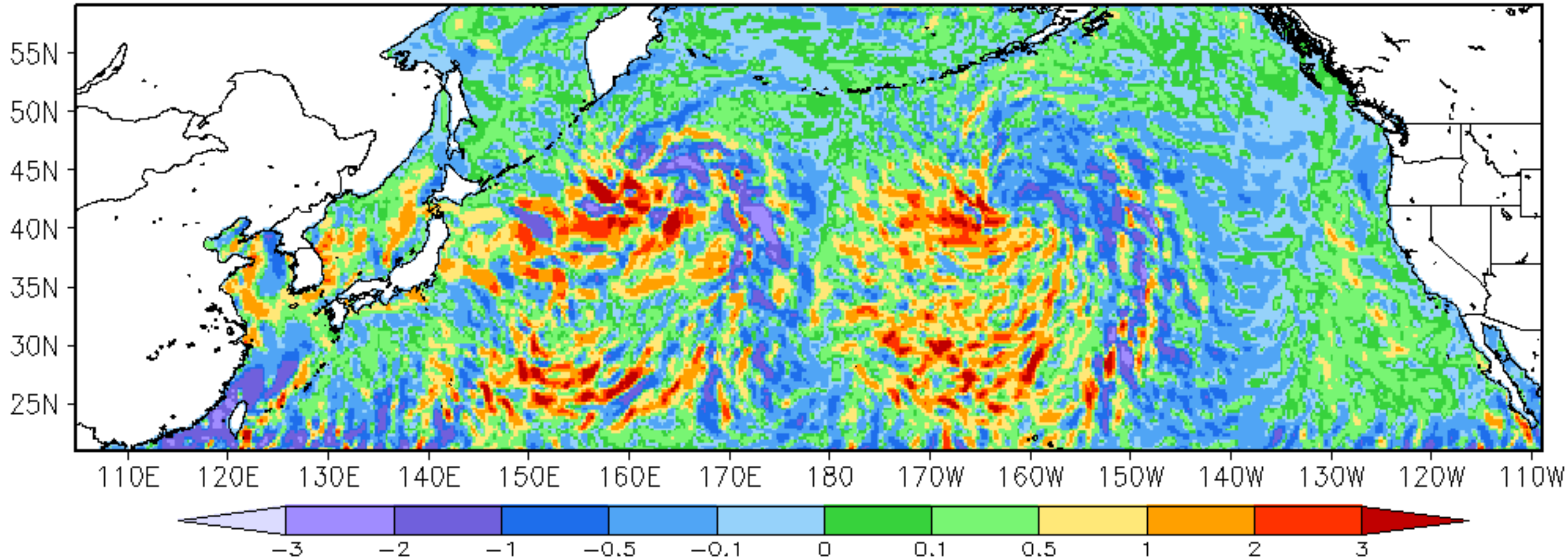
June **1988**: 1 Satellite Source



June **2003**: 7 Satellite Sources



Example Change in Surface Wind Speed



- Change in surface wind speed (ms^{-1}) due to above SST gradients (Reynolds SSTs).
  - These changes are largely observed in OVW swaths
  - SST gradient must be considered to add such features in areas with only speed data and in data voids

Ekman Upwelling