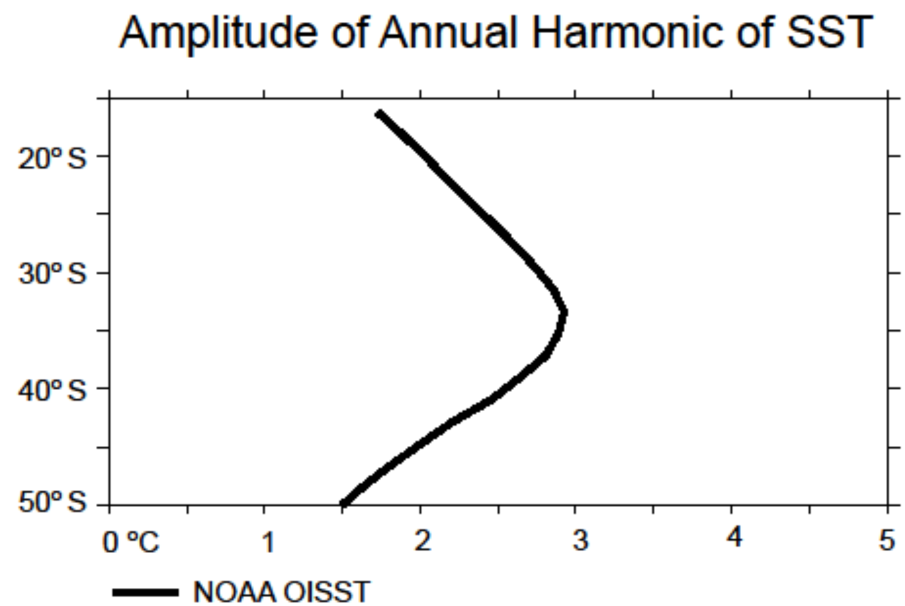
Reproducing the seasonal cycle of SST in ocean mixed layer models forced with contemporary surface flux estimates

What works and opportunities for using improved constraints from one to benefit the other

Andy Chiodi and D.E. Harrison

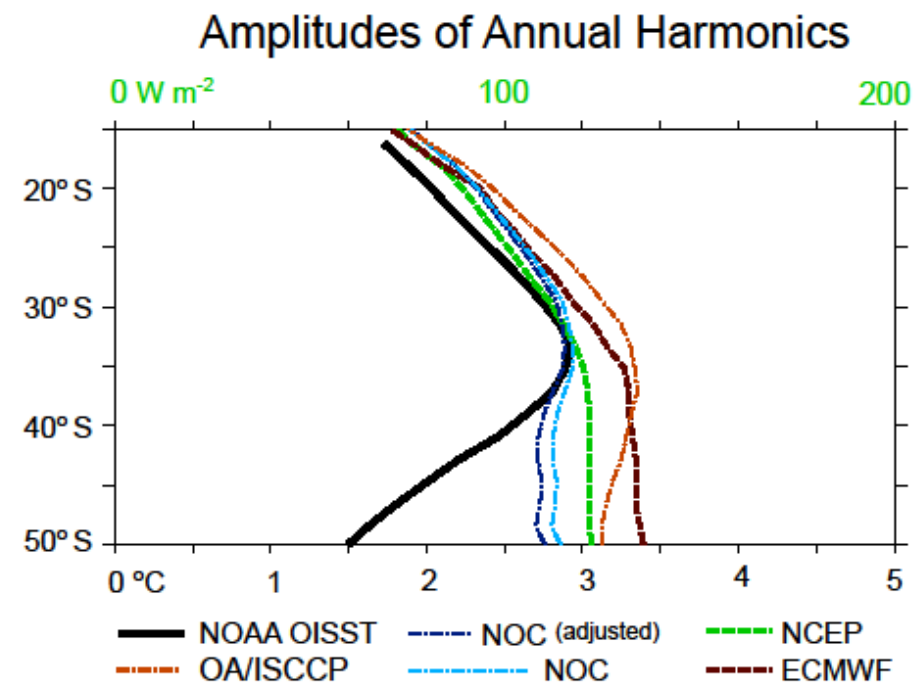
The annual amplitude of SST in the Southern Hemisphere

- The **annual harmonic of SST** is the dominant component of global SST variability, but the reasons for its structure are not fully understood.



The annual amplitude of surface heating in the Southern Hemisphere

- The **annual harmonic of net surface heat flux** dominates heat flux variability, but has different structure than SST ("high latitude fall off")



Background on "high latitude fall-off"

- Sverdrup (1942) did not notice a difference between SST and heat flux structure (limited heat flux measurements).
- Defant (1961) gave an incomplete explanation.
- Pickard and Emery (1990) note only that sea-ice, at higher latitudes than considered here, will act as a buffer to temperature change.

Summary (part 1)

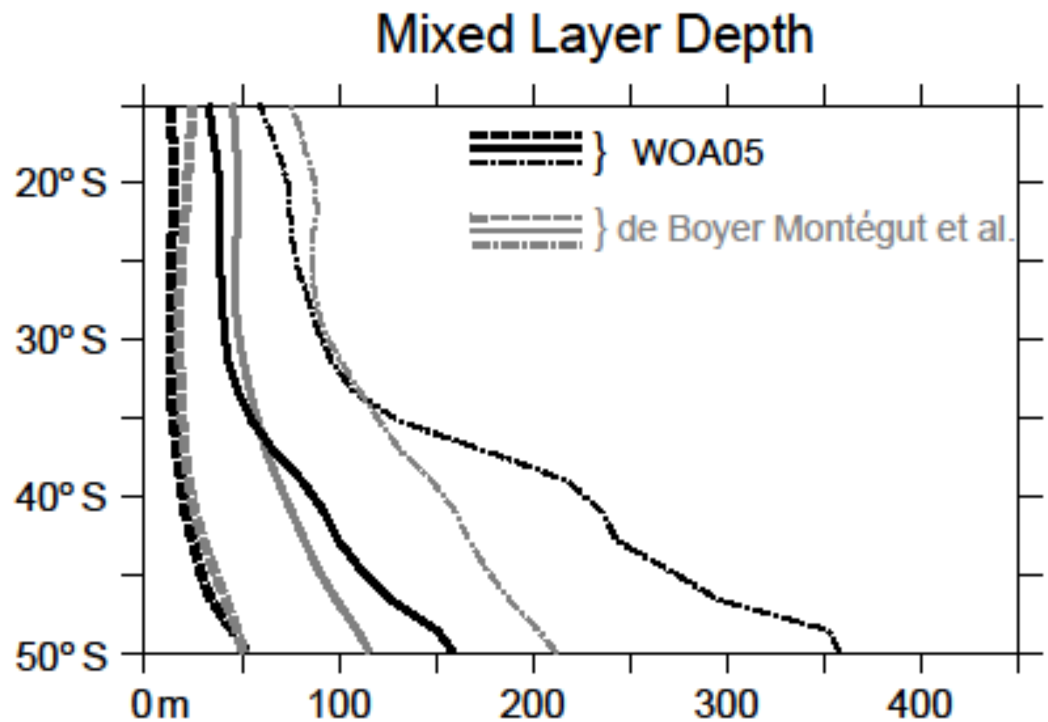
- There is an observed fall-off with increasing southern latitude of the annual range of SST. Although noted in classic texts, this has not been explained.
- Using observed mixed layer depth and various modern net heat fluxes reasonably reproduces the fall-off; thus the fluxes are broadly consistent (some cases more than others) with observed SST, given observed OML depths.
- Using either the KPP or PWP model and existing flux estimates, however, generally gives a less satisfactory answer. There are many possible reasons for this, but we find some evidence that current OML models may not be adequate in the higher southern latitudes.
- Some of the IPCC models adequately reproduce the fall-off, but many do not. There is reason for concern about the ability of the models that are not adequate in this aspect to project future high-latitude SST.

Mixed layer heating by surface fluxes: specified MLD case

- First consider results from a simple model;

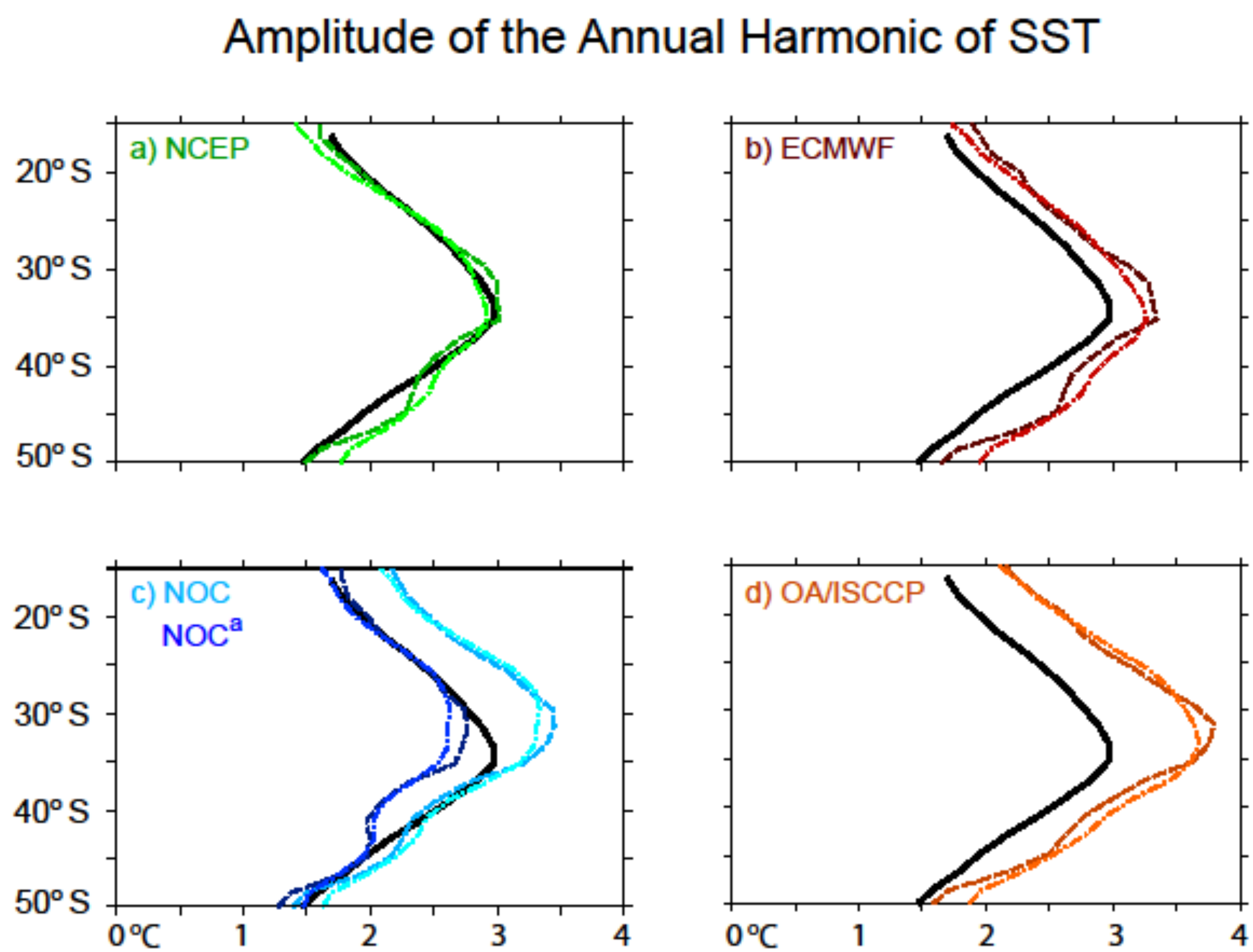
$\partial T/\partial t \approx (Q_{net}-Q_{pen})/c_p\, \rho\, h$,

using observed ocean mixed layer information to determine mixed layer behavior



Mixed layer heating by surface fluxes: specified MLD case

- Results suggest that **mixed layer depth variability** (spatial and temporal) **is mainly responsible** for the “high latitude fall-off”
- The NCEP/NCAR case produces accurate results, but there is still a need to be sure of the component-wise distribution of surface heat flux (e.g. measure surface solar)

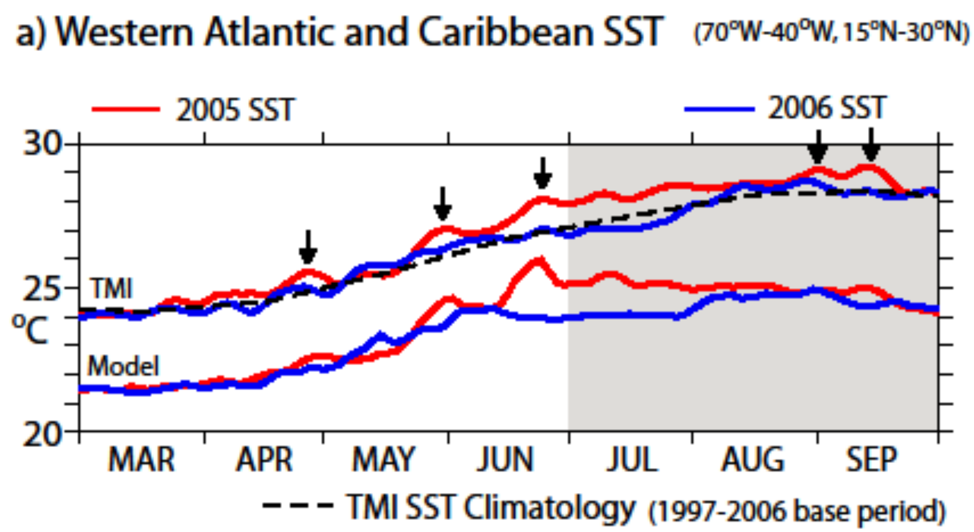


Summary (part 2)

- There is an observed fall-off with increasing southern latitude of the annual range of SST. Although noted in classic texts, this has not been explained.
- Using observed mixed layer depth and various modern net heat fluxes reasonably reproduces the fall-off; thus the fluxes are broadly consistent (some cases more than others) with observed SST, given observed OML depths.
- Using either the KPP or PWP model and existing flux estimates, however, generally gives a less satisfactory answer. There are many possible reasons for this, but we find some evidence that current OML models may not be adequate in the higher southern latitudes.
- Some of the IPCC models adequately reproduce the fall-off, but many do not. There is reason for concern about the ability of the models that are not adequate in this aspect to project future high-latitude SST.

Mixed layer behavior in prognostic models: Results from the Price-Weller-Pinkel Model

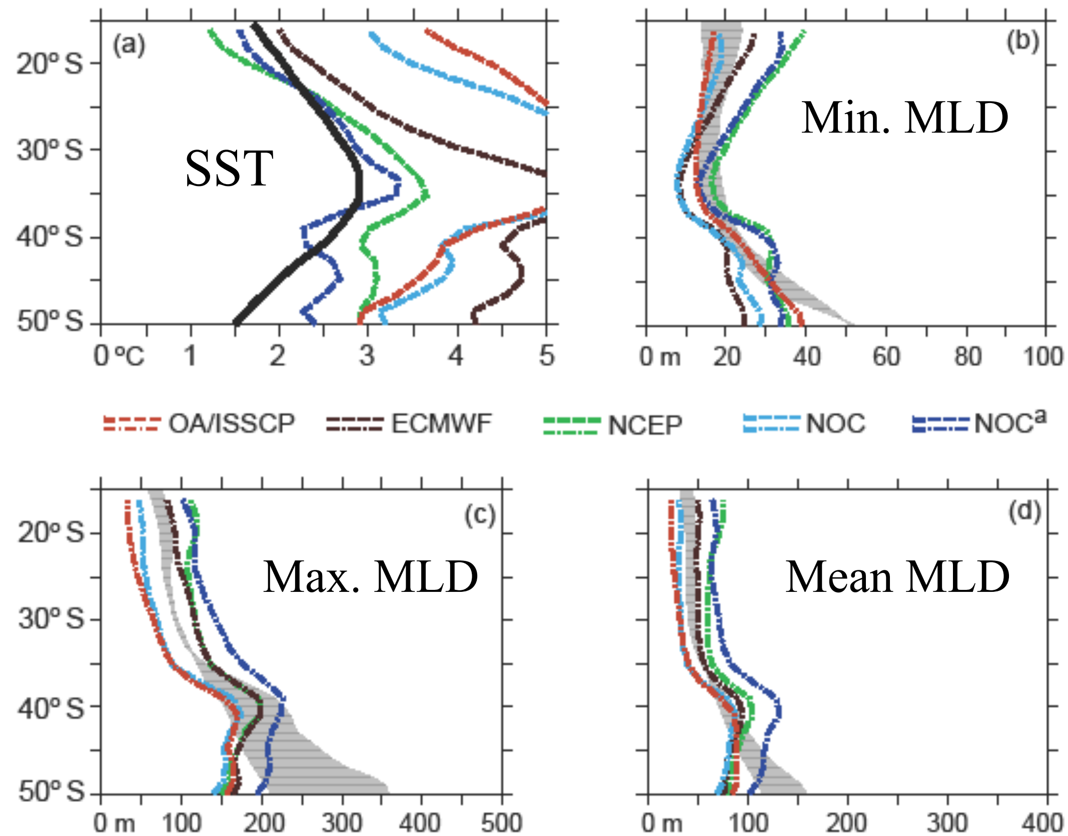
- Model (Price et al. 1986) integrates net surface heat, momentum (IFREMER/ QuikSCAT-derived) and freshwater flux.
- Here, an *a priori* estimate of wind-driven (Ekman) ocean heat flux is added (consistent with Southern Ocean heat budgets described by Sallee et al. 2006 and Dong et al. 2007)
- Mixed layer deepens based on bulk-Richardson number criteria (a function of vertical shear and stratification)



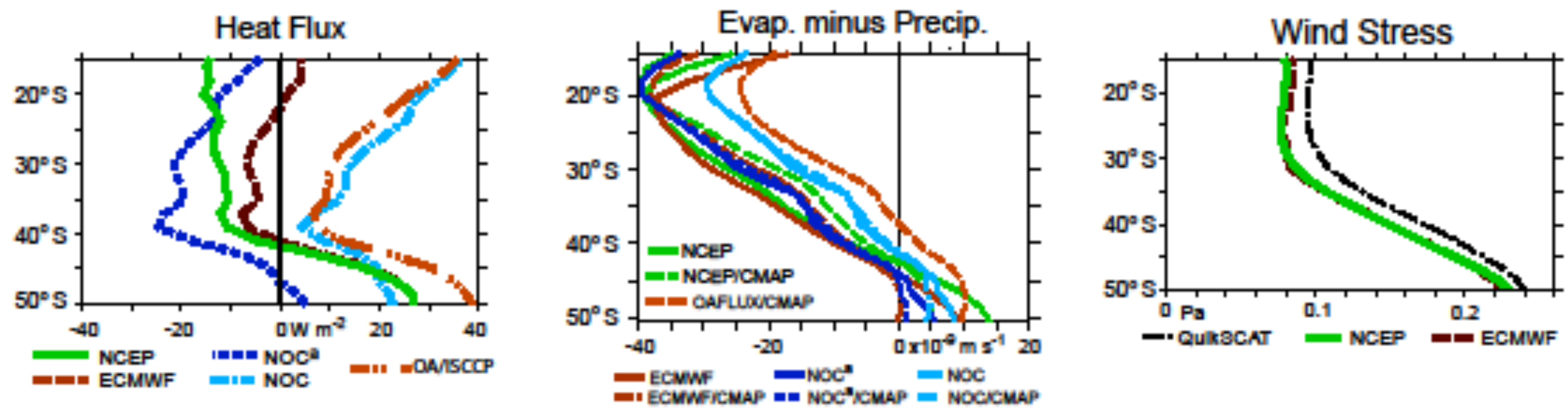
-A previous example of a successful reproduction of the seasonal cycle using this model configuration (Chiodi and Harrison, 2009)

Mixed layer behavior in prognostic models: Results from the Price-Weller-Pinkel Model

- A wider range of results is produced in this case, but none are adequate.
- Model fails to reproduce MLD behavior at higher latitudes.
- Above, just effect of $(Q_{net}\text{-}Q_{pen})/c_p\ \rho\ h)$ term is shown to be consistent with prescribed-MLD results, but full model SST behavior is qualitatively similar.

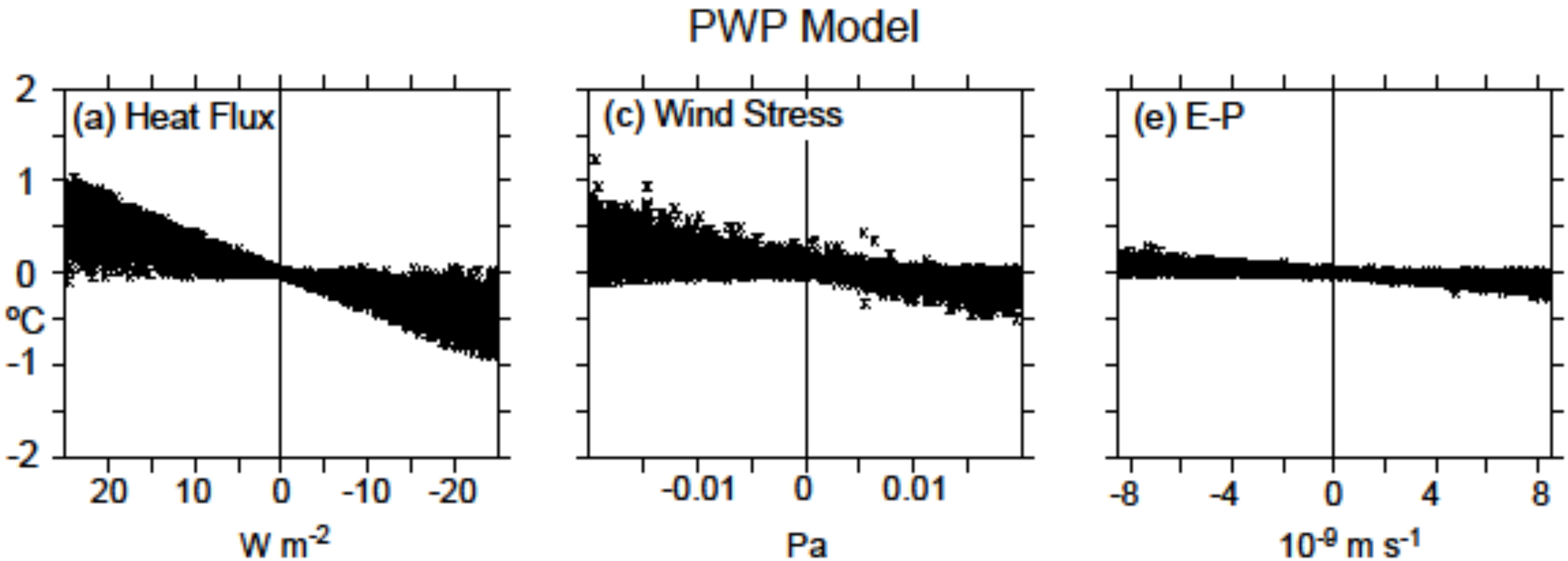


Net Annual Mean Surface Fluxes



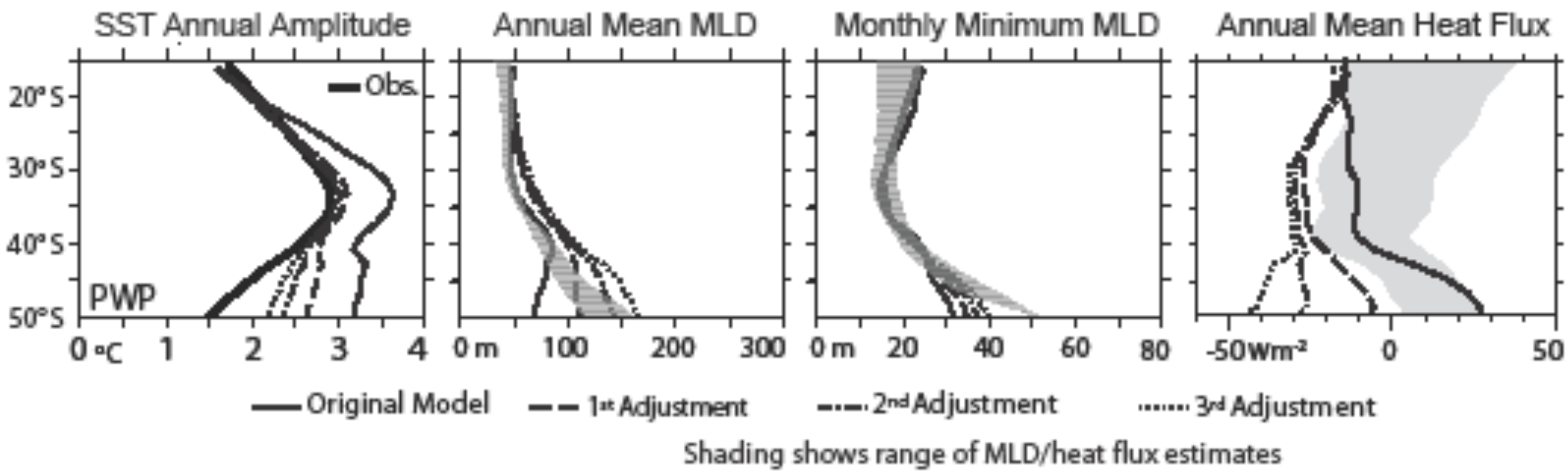
- The data sets considered have substantially different net annual mean fluxes.
- Can the results from mixed layer models be used to say which scenario is more accurate?

Effects on SST amplitudes from perturbations in annual mean fluxes



- Experiments show adjustments (within present uncertainty) to annual mean heat flux are most effective at changing seasonal SST behavior in these models (all other things equal, deepening the MLD decreases the annual SST range). Wind stress, however, is also important.

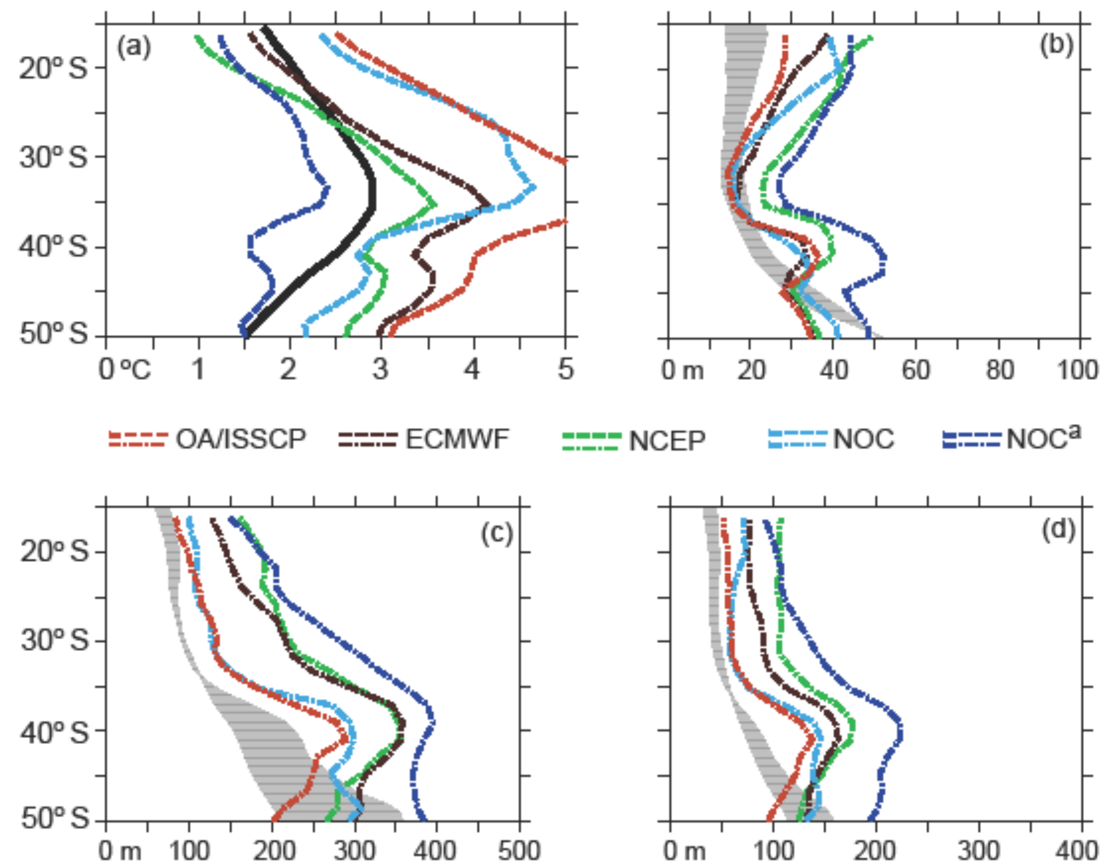
An example of “nudging” the model by adjusting net mean heat flux



- We have tried but failed to find adjustments that, i) correct both predicted model SST and MLD behavior, and ii) are within present uncertainty limits.
- The example above adjusted heat flux to improve SST, but simultaneously including wind stress, heat flux, E-P, and background diffusion effects, while also adjusting to correct MLD behavior has not improved matters much.

Results from the K-Profile Parameterization (KPP) Model

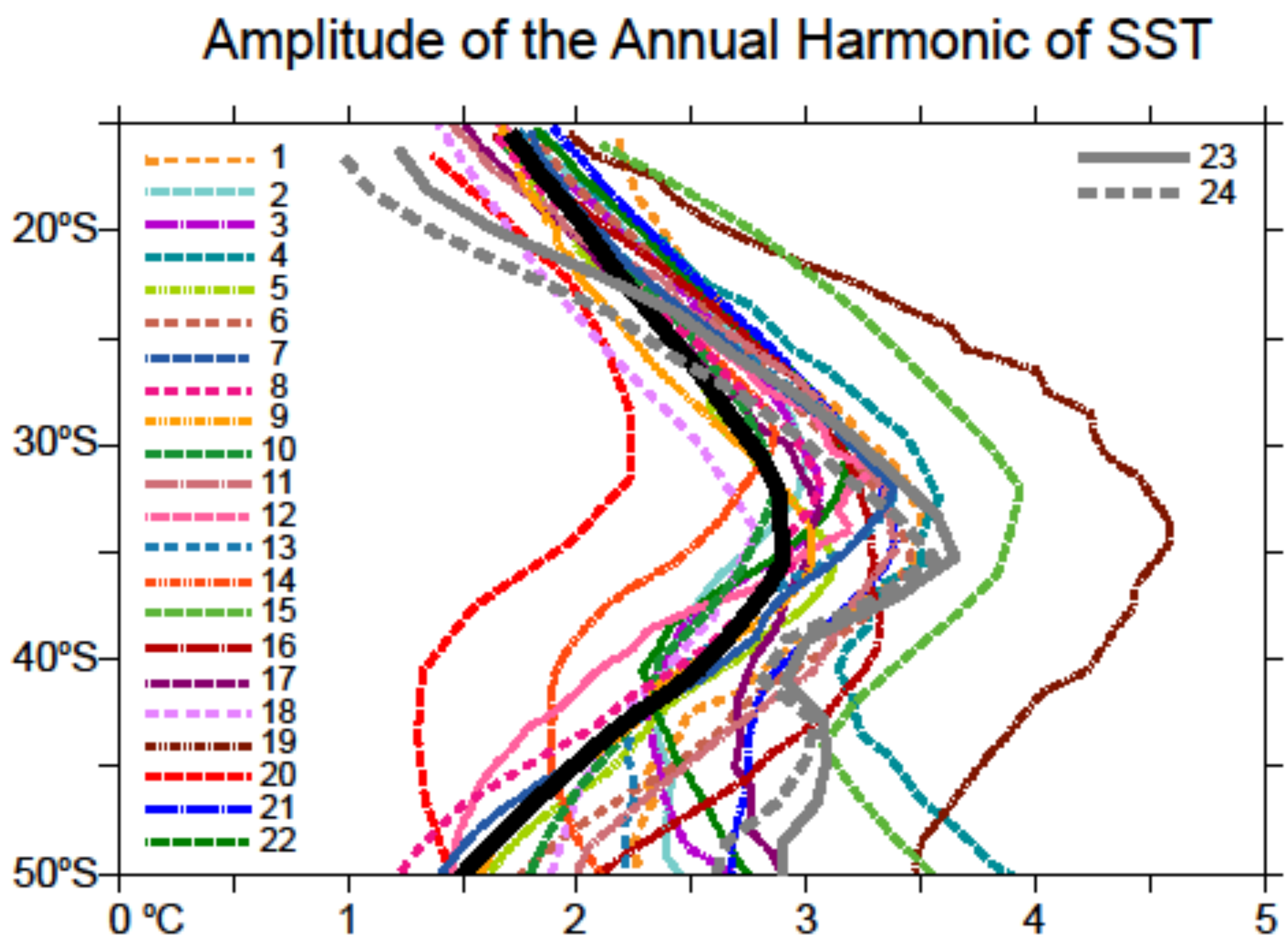
- Model (Large et al. 1994) integrates net surface heat (as labeled), momentum (IFREMER/QuikSCAT-derived) and freshwater flux.
- An *a priori* estimate of wind-driven (Ekman) ocean heat flux is added (consistent with Southern Ocean heat budgets described by Sallee et al. 2006 and Dong et al. 2007)
- Planetary boundary layer depth determined based on bulk-Richardson number criteria ("mixed layer depth" estimated from profiles in this case)



Summary (part 3)

- There is an observed fall-off with increasing southern latitude of the annual range of SST. Although noted in classic texts, this has not been explained.
- Using observed mixed layer depth and various modern net heat fluxes reasonably reproduces the fall-off; thus the fluxes are broadly consistent (some cases more than others) with observed SST, given observed OML depths.
- Using either the KPP or PWP model and existing flux estimates, however, generally gives a less satisfactory answer. There are many possible reasons for this, but we find some evidence that current OML models may not be adequate in the higher southern latitudes.
- Some of the IPCC models adequately reproduce the fall-off, but many do not. There is reason for concern about the ability of the models that are not adequate in this aspect to project future high-latitude SST.

Comparison with results from simple IPCC AR4 coupled models



Summary (part 4)

- There is an observed fall-off with increasing southern latitude of the annual range of SST. Although noted in classic texts, this has not been explained.
- Using observed mixed layer depth and various modern net heat fluxes reasonably reproduces the fall-off; thus the fluxes are broadly consistent (some cases more than others) with observed SST, given observed OML depths.
- Using either the KPP or PWP model and existing flux estimates, however, generally gives a less satisfactory answer. There are many possible reasons for this, but we find some evidence that current OML models may not be adequate in the higher southern latitudes.
- Some of the IPCC models adequately reproduce the fall-off, but many do not. There is reason for concern about the ability of the models that are not adequate in this aspect to project future high-latitude SST.

Conclusions

- The combination of current (Argo-era) observational estimates of OML behavior, SST range and simple physics likely provides a useful test of current surface heat flux estimates. Though, it remains to verify that the better performing heat flux data sets have the correct distribution (penetrative vs. non; measuring solar would be useful) and that the effects of other ocean processes (e.g. horizontal eddy and vertical diffusion) are small.
- The KPP and PWP results were not as adequate as the observed-OML case in the higher southern latitudes. We suggest taking a closer look at the processes controlling the OML in this region.
- Some IPCC results accurately reproduce the fall-off of SST, and may provide useful insight provided the "right answer" is obtained for the "right reason".
- We need more comprehensive observations of higher-latitude Southern Hemisphere OML processes, heat budgets, and components of surface heat fluxes to sort this out.

End of Talk

Components of Surface Heating

- Distribution matters because penetrative (solar) and non-penetrative heating have somewhat different effects.
- From a forced-model perspective, it is possible to have the right net amplitude, but wrong distribution.