What determines the evolution of global mean sea surface temperature?

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Atmospheric and Environmental Research (AER)
Lexington, Massachusetts, USA

ECCO Meeting, California Institute of Technology, Pasadena
November 6-8, 2017

Motivation

- Global mean sea surface temperature (GMSST) is a variable of primary interest in studies of climate variability and change
  GMSST essential in characterizing surface climate
- Temporal evolution of GMSST can be influenced by heat flux forcing at the air-sea interface (*F*) and by diffusion (*D*) and advection (*A*) processes internal to the ocean
  To what extent can *A* affect balance between *F* and *D*?
- Determining these different factors can provide insight on the nature of air-sea interactions and climate processes
  Surface climate controlled by internal heat redistribution?
- Calculations of *F, D, A* from data alone are prone to large uncertainties and plagued by difficulties in getting a closed heat budget

➡ Can we gain insight into the nature of GMSST variability using a state estimate that fits most features of the observed GMSST behavior, while providing a closed heat budget in terms of *F, D, A* consistent with evolution of GMSST?

Approach

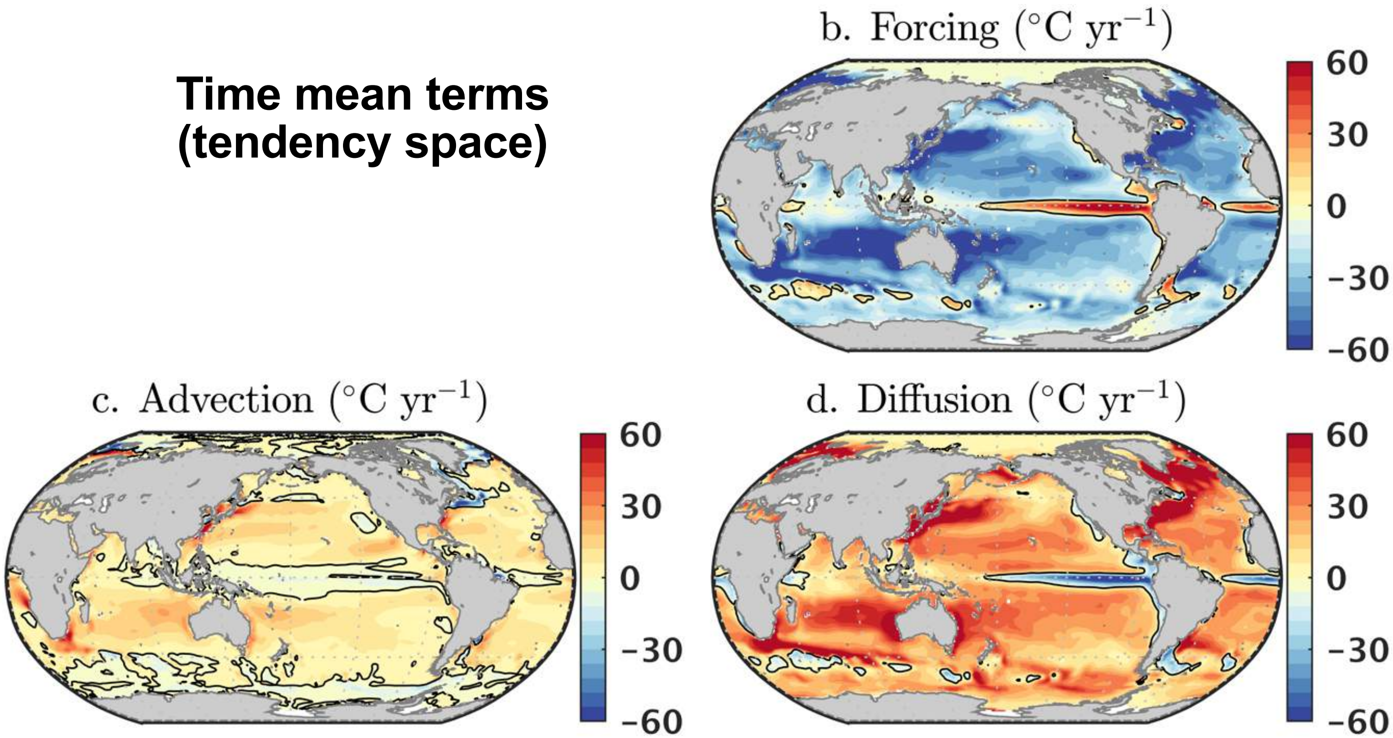
- Examine the latest global state estimate produced by the consortium for Estimating the Circulation and Climate of the Ocean (ECCO version 4; *Forget et al., 2015, Geo. Model Dev.*)
  - Release 3 fields available for period 1993-2015
  - Constrained to most available data (in situ T+S, satellite SST, altimetry, GRACE, Aquarius)
  - Fit to data by adjusting initial conditions, boundary forcing, and internal mixing coefficients within prescribed uncertainties
  - Solution of free running MITgcm with no hidden sources or sinks of heat and a closed heat budget on the model grid
- Explore GMSST budget (in time integrated form)

$$\text{GMSST} = A + D + F$$

where SST taken to be temperature in 10-m thick top layer in solution

Budget fields (mean and trends)

Time mean terms (tendency space)

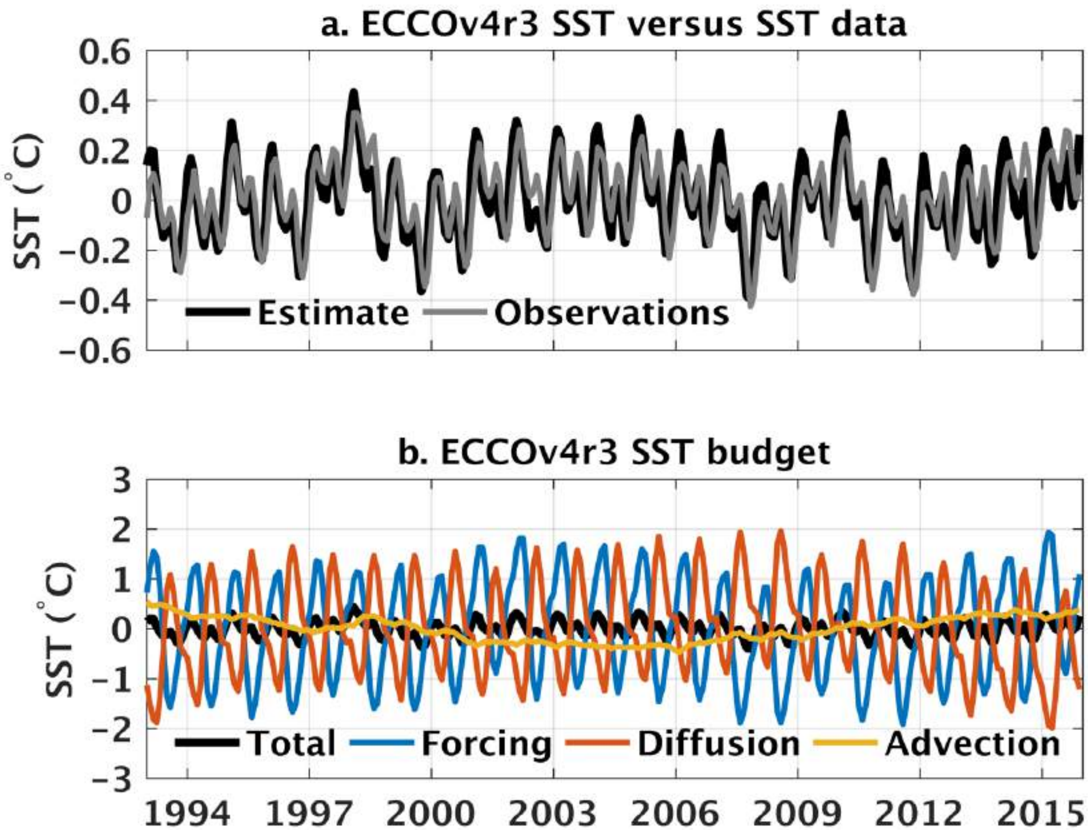


GMSST trends (ºC/yr)

Data:	8.8×10^{-3}
ECCO:	4.2×10^{-3}
Forcing:	–28.79
Diffusion:	23.52
Advection:	5.27

- ❑ For time mean, forcing mostly cools surface (except near equator and some higher latitudes), balanced by warming effects from diffusion and advection
- ❑ Small imbalances in the time mean terms give rise to weak positive trend in GMSST with advection weaker but important for the budget

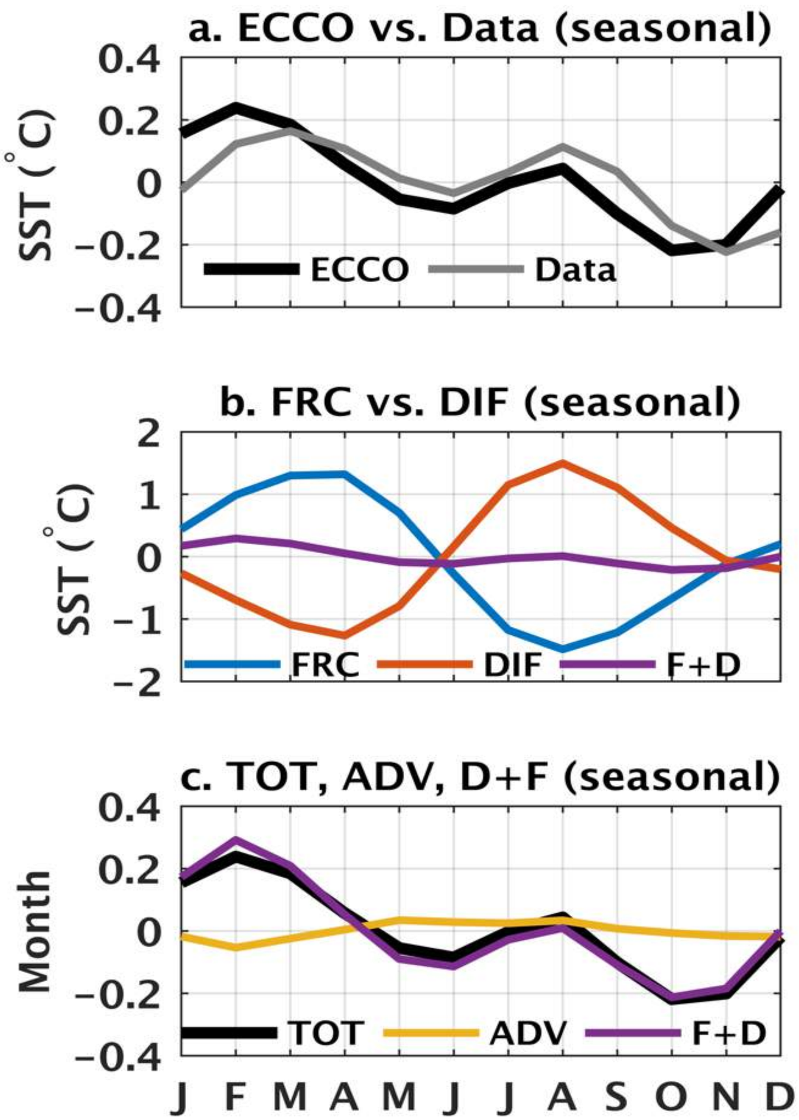
GMSST (detrended fields)



- ECCO estimate of GMSST consistent with observations
- Large annual cycle in *F, D* but visible semi-annual cycle in GMSST
- Interannual and longer time scale variability relatively weaker

SST data from Reynolds et al. (2002, J. Climate)

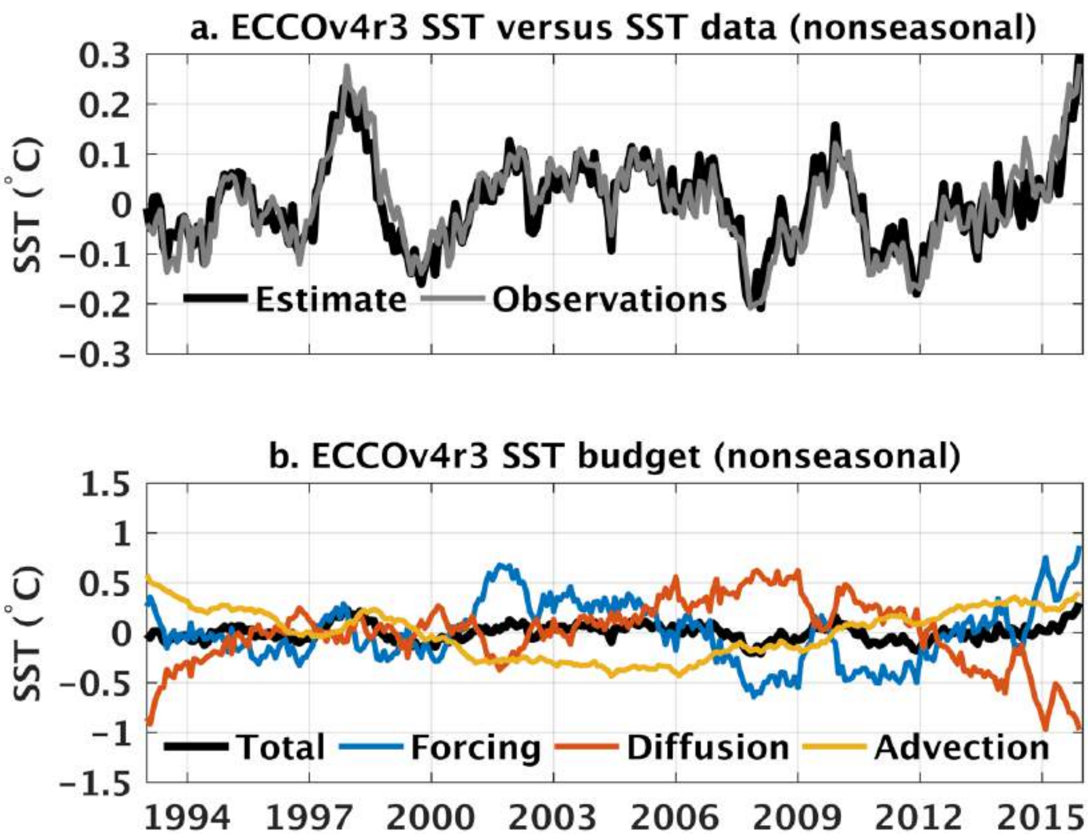
Mean seasonal cycle



- **Good qualitative agreement between amplitude/phase of mean seasonal cycle in ECCO estimate and data**
- **Main balance between forcing and diffusion**
- **Small residual responsible for seasonal cycle, advection negligible**
- **Semi-annual cycle in GMSST**
- **Small differences in phase and amplitude of *F, D***
- **GMSST can follow behavior of *D* (e.g., over July-October) rather than *F***

Nonseasonal variability

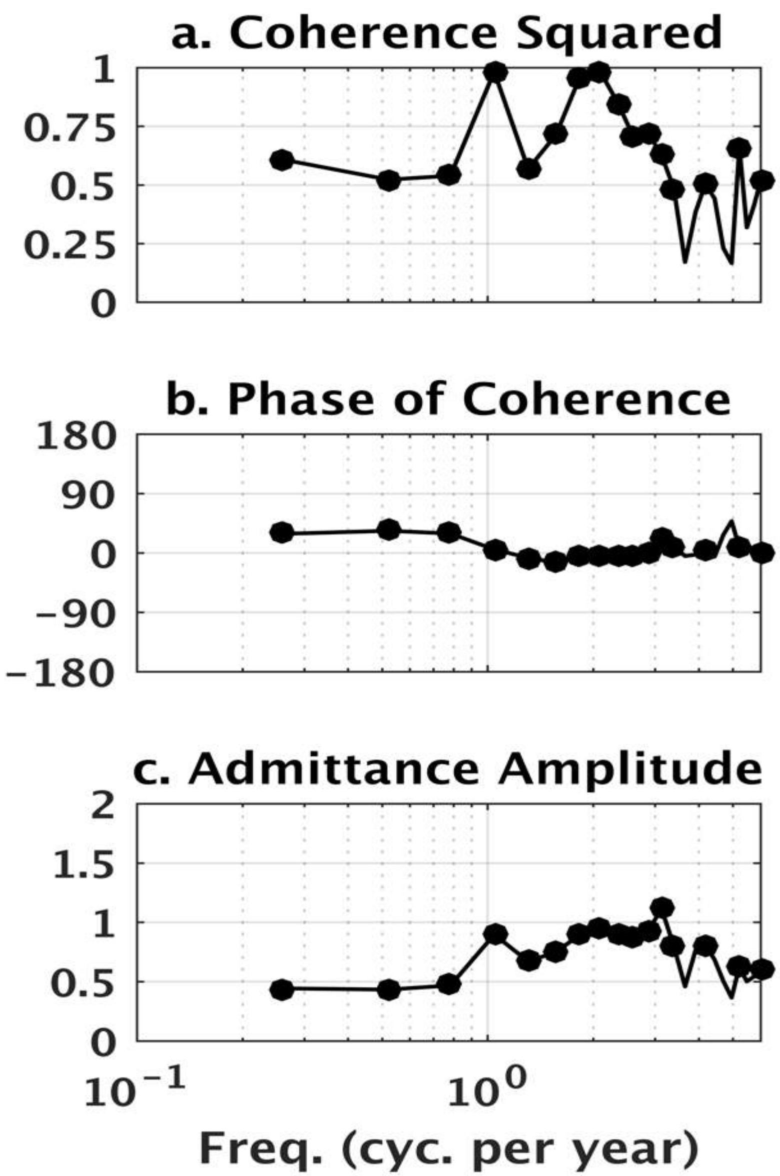
Trends and annual+semiannual cycle removed



- ECCO fit to the data excellent at interannual and longer time scales
- El Niño, La Niña signals well captured
- Balance between *F* and *D* still clear for interannual variability but…
- …advection also important (e.g., 1997-98 El Niño, decadal variations)

Frequency analysis *T vs. F+D*

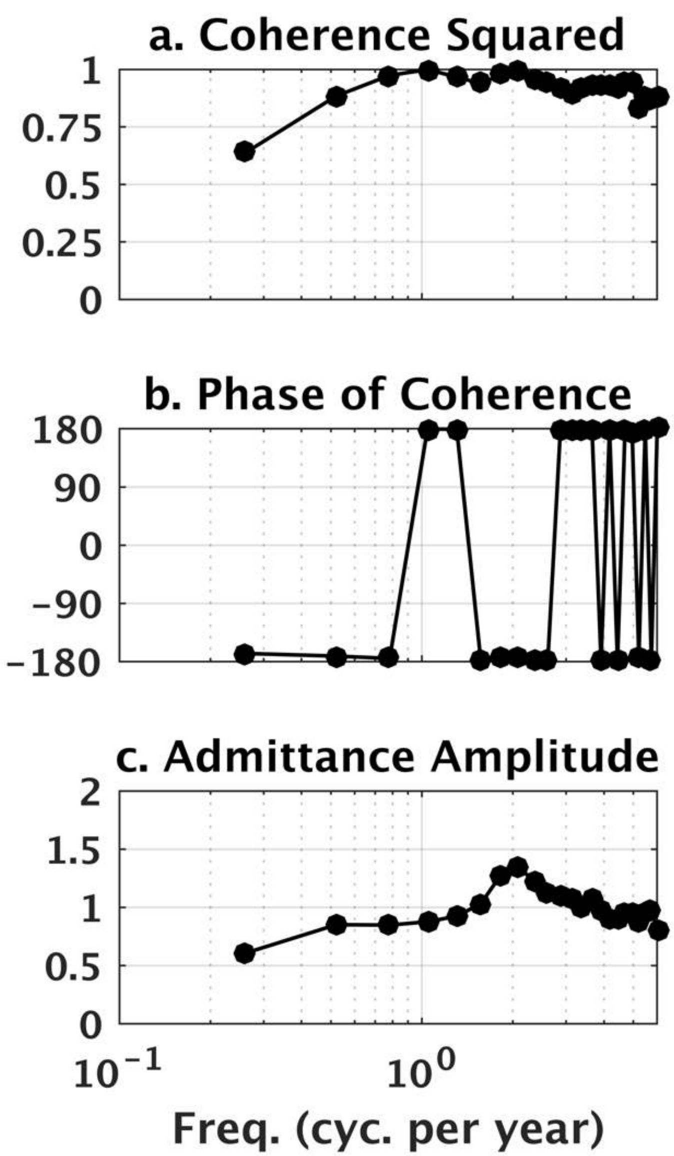
Relation between forcing+diffusion and GMSST



- **Close correspondence between *F + D* and GMSST at annual and semi-annual periods**
- **Results for most other periods, particularly > 1 year, imply non-negligible effects of advection**

Frequency analysis *F vs. D*

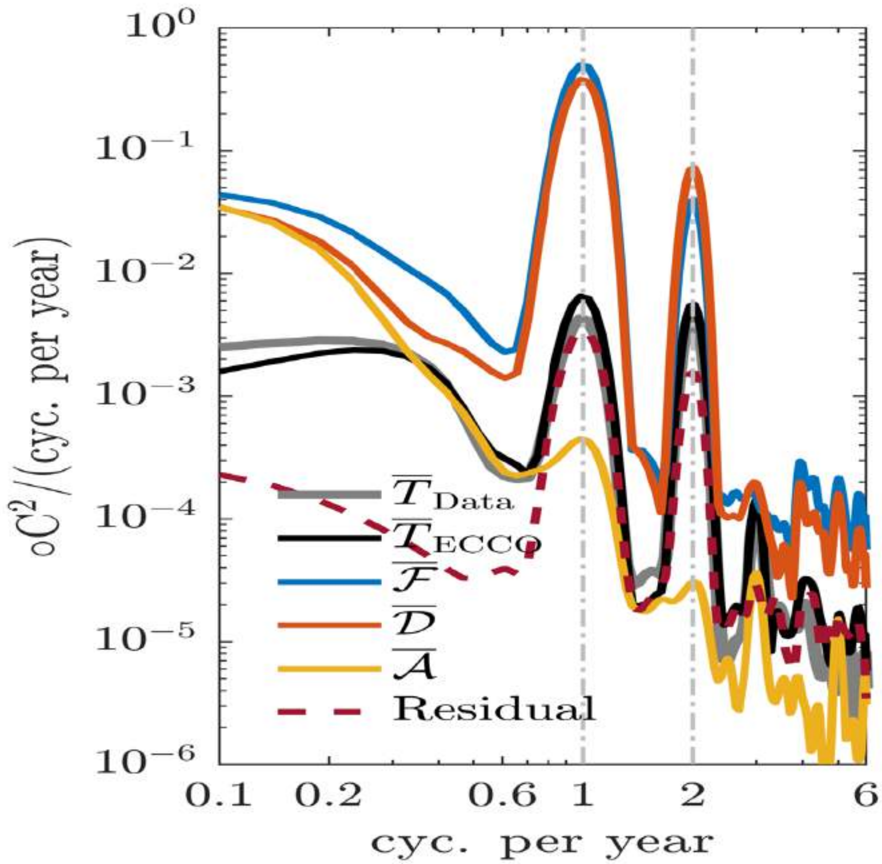
Relation between forcing and diffusion



- ❑ **Mostly out of phase over all periods**
- ❑ ***D* coherent with and larger than *F* at semi-annual band**
- ❑ **Decaying coherence and admittance amplitudes at periods > 1 year**

Frequency analysis

Power spectra of all budget terms and residual temperature (ECCO minus data)



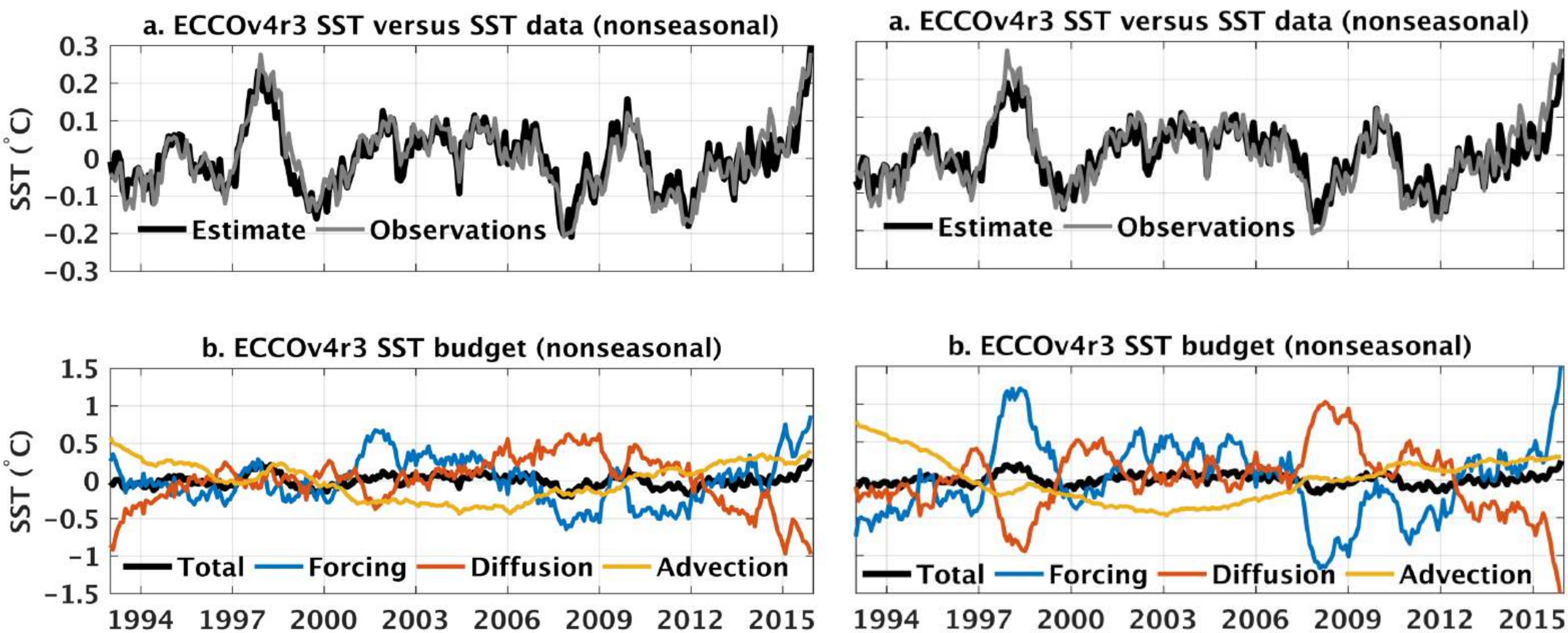
- ❑ **Advection most important at longest periods**
- ❑ **Interannual GMSST well resolved (small residual ECCO minus data)**
- ❑ ***D* slightly larger than *F* at semi-annual band, vice versa for annual band**
- ❑ **GMSST typically smaller than other terms in budget**

Some conclusions

- Physically consistent state estimates (free solutions of a model constrained by data) make it possible to explore mechanisms responsible for GMSST variability
- Expected balance between surface heat flux and mixing is clear at the seasonal time scale, but advection is not negligible particularly at periods longer than one year
- GMSST not simply tracking surface heat flux effects with diffusion mitigating the forcing (e.g., semi-annual periods)
- Advection plays a visible role in the GMSST budget but there are no instances where it seems to dominate the variability in GMSST

Effects of nonseasonal winds

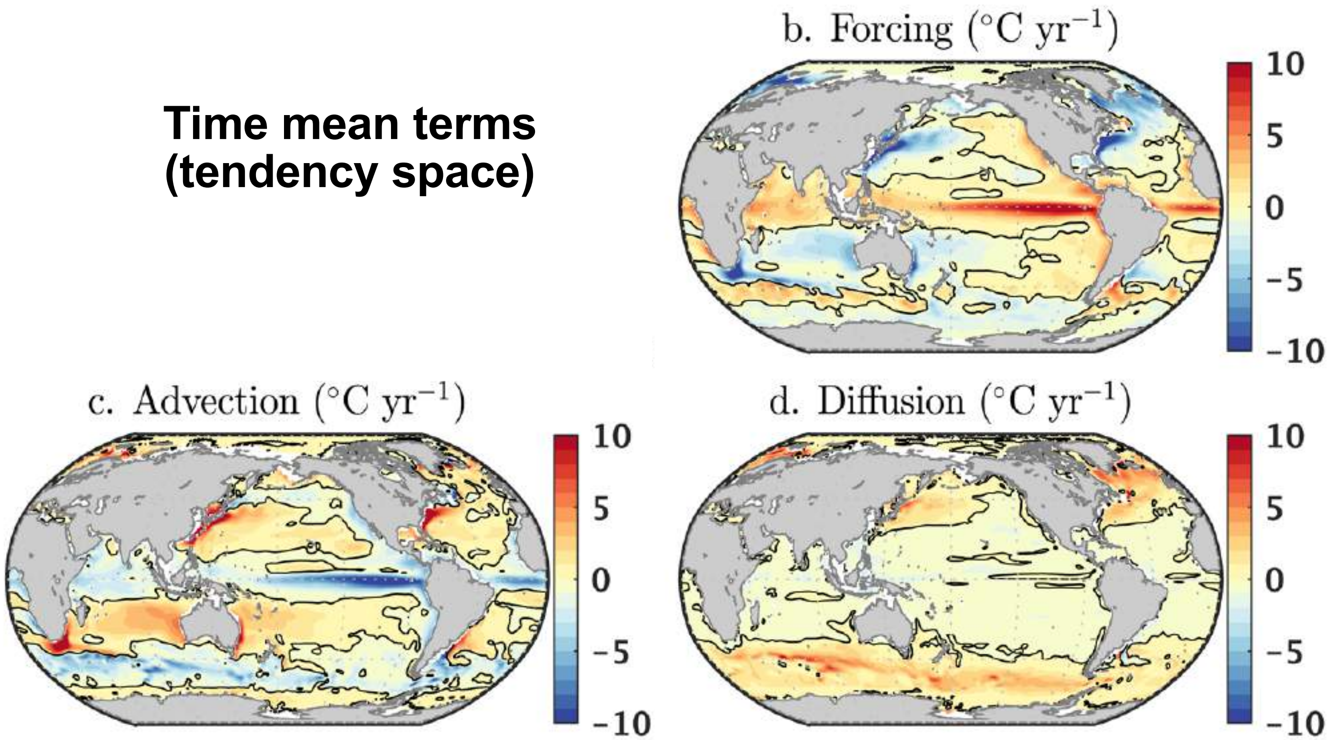
Climatological wind stress forcing



- ❑ **Observed evolution of GMSST reproduced without any nonseasonal wind stress forcing**
- ❑ **Heat flux forcing differences relate to impact of wind forcing on SST**
- ❑ **Differences in *F* mostly compensated by changes in *D***
- ❑ **Decadal variability in *A* not primarily controlled by wind forcing**

Top 100m budget (mean, trends)

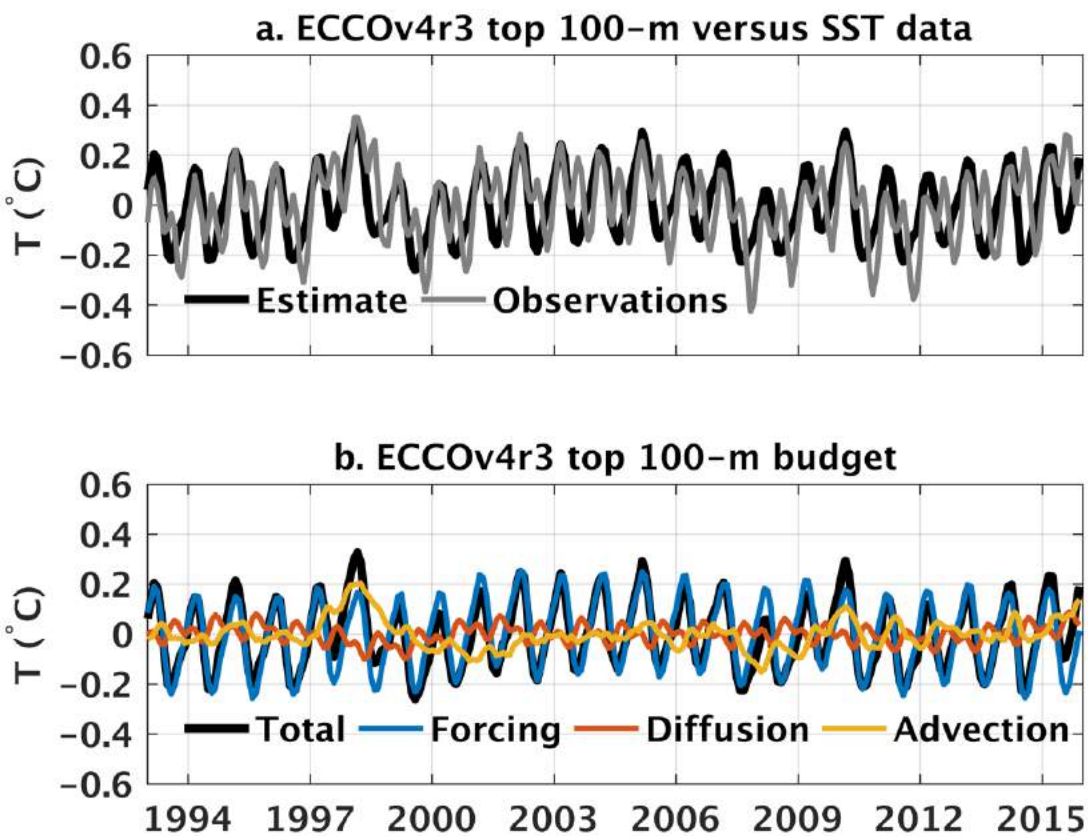
Time mean terms (tendency space)



GMSST trends (ºC/yr)	
ECCO:	0.0026
Forcing:	–0.0267
Diffusion:	0.2637
Advection:	–0.2344

- Top 100m global mean temperature warmed by diffusion, cooled by advection and forcing!
- Forcing trend becomes positive if integrated over top 150m (influence of small shortwave radiation flux)

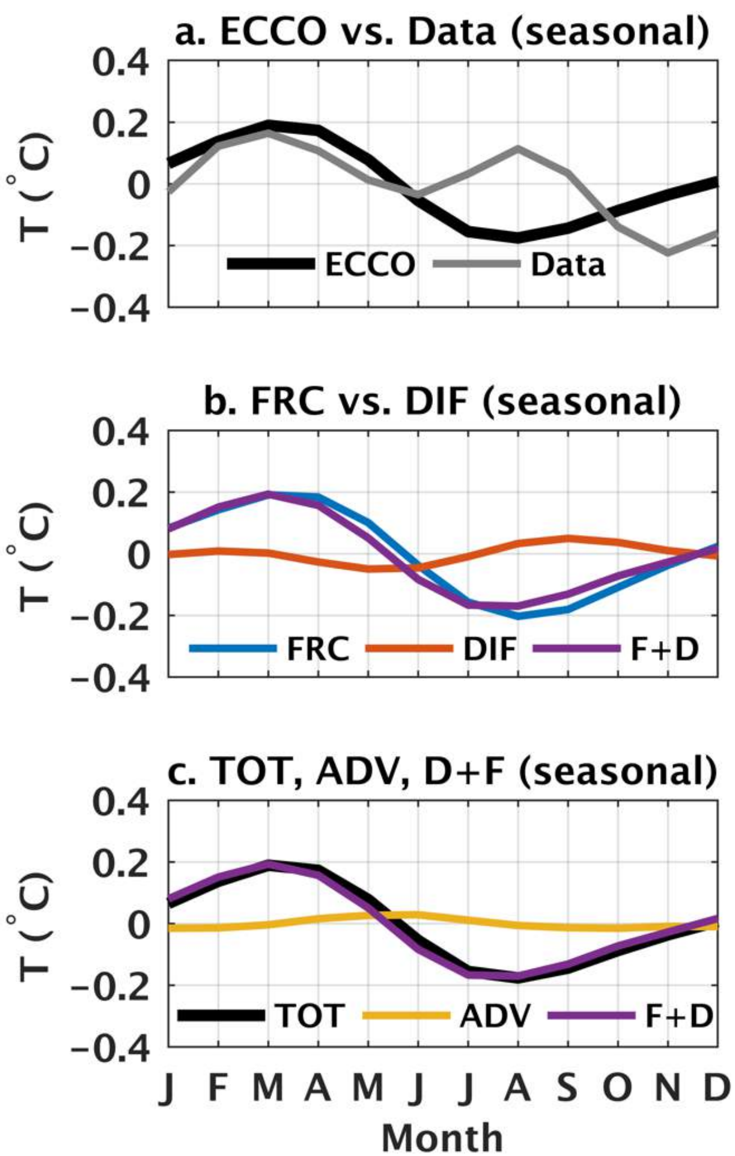
Top 100 m (detrended fields)



- Annual cycle in near-surface global mean temperature driven by *F, D* much less important
- No semi-annual cycle in near-surface global mean temperature

SST data from Reynolds et al. (2002, J. Climate)

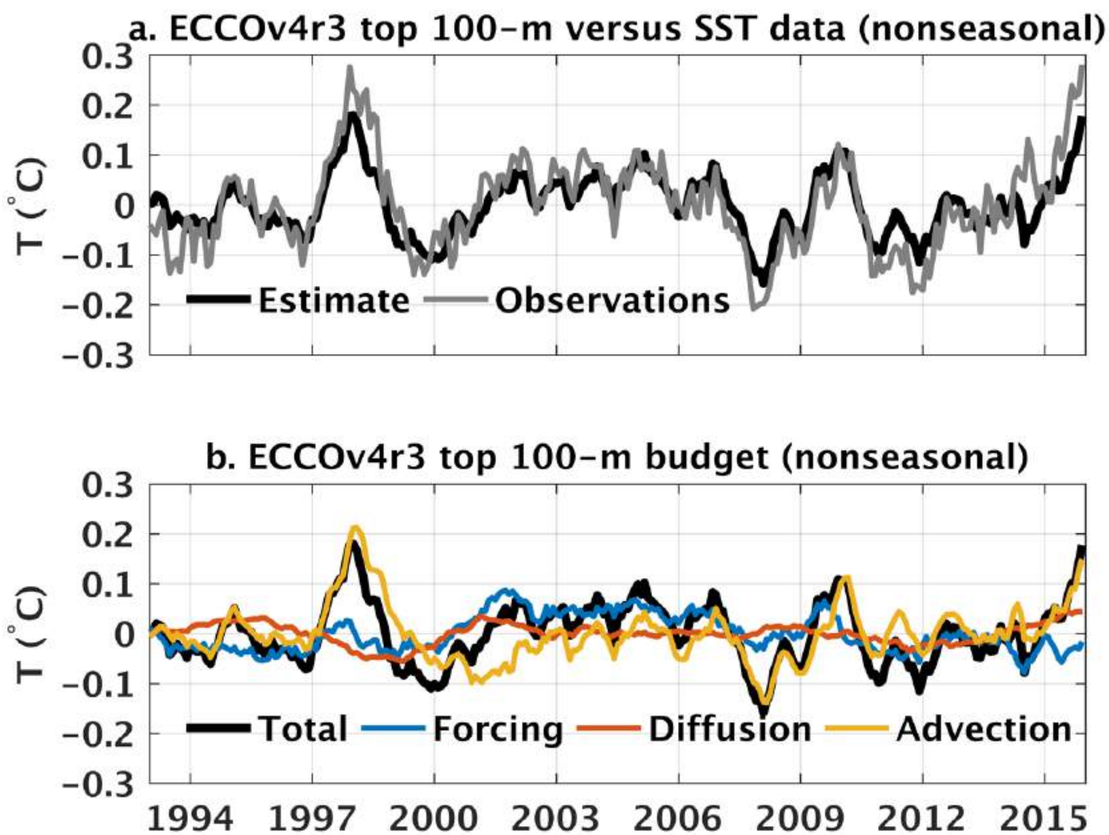
Mean seasonal cycle (top 100 m)



- Global mean temperature over top 100m follows mainly surface forcing
- Advection and diffusion both negligible
- Much weaker semi-annual cycle

Nonseasonal variability (top 100 m)

Trends and annual+semiannual cycle removed



- ❑ **Interannual variability in temperature over top 100 m tracks observed GMSST**
- ❑ **Top 100 m temperature follows advection to a large extent, particularly over some El Niño/La Niña events**