

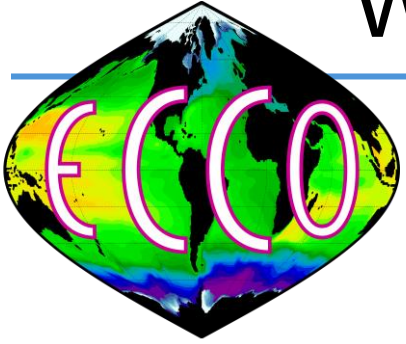
Jet Propulsion Laboratory
California Institute of Technology

ECCO Modeling Utilities (EMU)

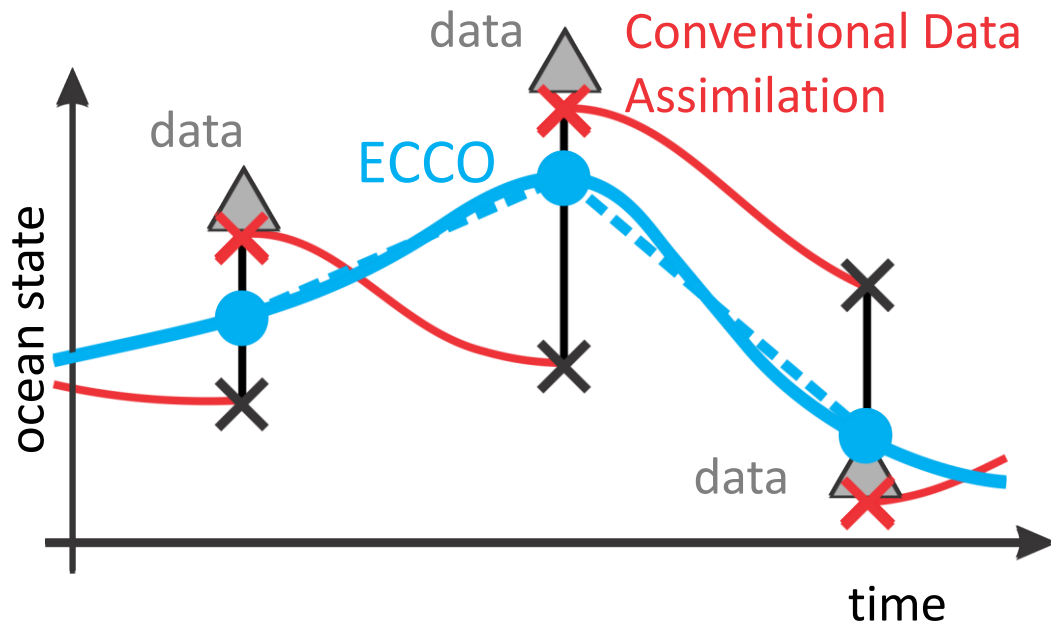
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ECCO Summer School 2025

What is EMU and Why Should You Care?



ECCO Modeling Utilities (EMU) is a set of menu-driven tools for analyzing the ECCO model.



- 1) ECCO is a state-of-the-art synthesis of ocean observations,
- 2) ECCO is characterized by its physical consistency (e.g., closed budgets),
- 3) The physics of this consistency is embodied in the model,
- 4) EMU permits analyses of the model's physics (e.g., causation) without requiring modeling expertise.

What does EMU do? (1/12)

EMU is run with command emu;

```
ifukumori@ip-10-20-22-69:/efs_ecco/ifukumor/emu$ emu
```

ECCO Modeling Utilities (EMU) ...

Choose among the following tools ...

- 1) Sampling (samp); Evaluates time-series from model output.
- 2) Forward Gradient (fgrd); Computes model's forward gradient.
- 3) Adjoint (adj); Computes model's adjoint gradient.
- 4) Convolution (conv); Computes adjoint gradient decomposition.
- 5) Tracer (trc); Computes passive tracer evolution.
- 6) Budget (budg); Evaluates budget time-series from model output.
- 7) Modified Simulation (msim); Re-runs model with modified input.
- 8) Attribution (atrb); Evaluates state time-series by control type.
- 9) Auxiliary (aux); Generates user input files for other EMU tools.

Enter choice ... (1-9)?

What does EMU do? (2/12)

EMU offers 9 computational tools.

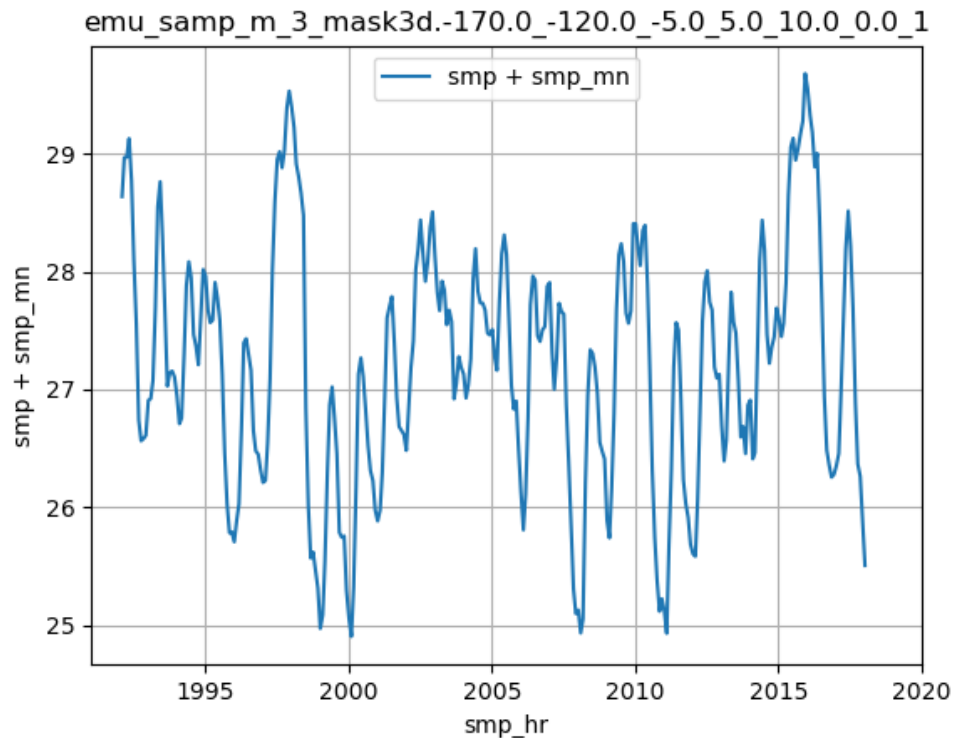
	Tool	Description
1	Sampling	Evaluates time-series of model state and control.
2	Forward Gradient	Computes model's response to change in forcing.
3	Adjoint	Computes model's sensitivity to forcing (adjoint gradient).
4	Convolution	Evaluates convolution of adjoint gradients with forcing (Adjoint Gradient Decomposition).
5	Tracer	Computes evolution of passive tracer and its adjoint.
6	Budget	Evaluates budget time-series.
7	Modified Simulation	Re-runs model with modifications (e.g., forcing, output).
8	Attribution	Evaluates state times-series by control type.
9	Auxiliary	Generates user input files for other EMU tools.

What does EMU do? (3/12)

EMU offers 9 computational tools.

Tool
1 Sampling

Nino3.4 SST



- ✓ Evaluates time-series of the model state and control
- ✓ Options to use latitude, longitude, depth as criteria
- ✓ Useful for assessing fidelity of ECCO

OBJF

$$J(t) = \sum_i \alpha_i \sum_r \mathbf{W}_i(\mathbf{r}) \mathbf{x}_i(\mathbf{r}, t)$$

Scale Weight Variable

Multi-variable Space

et time-series.

with modifications (e.g., forcing, output).

times-series by control type.

Auxiliary Generates user input files for other EMU tools.

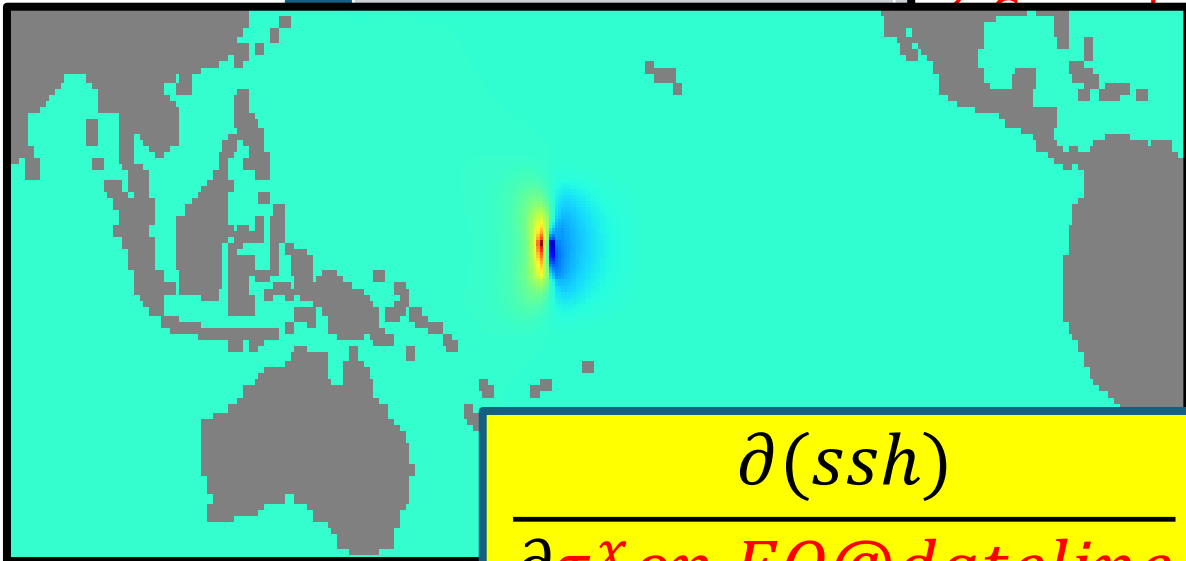
What does EMU do? (4/12)

EMU offers 9 computational tools.

	Tool
1	Sampling
2	Forward Gradient

- ✓ Computes forward gradient
- ✓ Choice of denominator
- ✓ Useful for insight into physics
- ✓ Also useful for validating adjoint

$$\frac{\partial (\text{model state})}{\partial (\text{control})}$$



$$\frac{\partial(ssh)}{\partial \tau^x \text{ on EQ@dateline}}$$

- ✓ Computes adjoint gradient
- ✓ Choice of numerator
- ✓ Useful for insight into physics
- ✓ Useful for model calculus

$$\frac{\partial (\text{model state})}{\partial (\text{control})}$$

OBJF

$$J(t) = \sum_i \alpha_i \sum_r \mathbf{w}_i(\mathbf{r}) \mathbf{x}_i(\mathbf{r}, t)$$

Scale Weight Variable

Multi-variable Space

8	Attribution
9	Auxiliary

Evaluates state times series by control type.

Generates user input files for other EMU tools.

$$\frac{\partial OBP@NP}{\partial \tau^y}$$

What does EMU do? (5/12)

EMU offers 9 computational tools.

Tool

Sampling

Forward Gradient

Adjoint

Convolution

Tracer

Budget

Simulation

Attribution

Auxiliary

- ✓ Computes forward gradient
- ✓ Choice of denominator
- ✓ Useful for insight into physics
- ✓ Also useful for validating adjoint

$$\frac{\partial (\text{model state})}{\partial (\text{control})}$$

- ✓ Computes adjoint gradient
- ✓ Choice of numerator
- ✓ Useful for insight into physics
- ✓ Also useful for model calculus

$$\frac{\partial (\text{model state})}{\partial (\text{control})}$$

Computes evolution

Evaluates budget time

Re-runs model with

Evaluates state times series by control type.

Generates user input files for other EMU tools.

OBJF

$$J(t) = \sum_i \alpha_i \sum_r \mathbf{w}_i(\mathbf{r}) \mathbf{x}_i(\mathbf{r}, t)$$

Scale Weight Variable

Multi-variable Space

What does EMU do? (6/12)

EMU offers 9 computational tools.

Explained variance of
OBP@NP by meridional wind

Forward Gradient Computes model's response to change in forcing.

Adjoint

Convolution

Tracer

Budget

✓ Expands quantities of interest into their controls

$$\delta J(t) \approx \sum_i^{\text{type}} \sum_{\mathbf{r}}^{\text{location}} \sum_{\Delta t}^{\text{lag}} \frac{\partial J(T)}{\partial u_i(\mathbf{r}, T - \Delta t)} \delta u_i(\mathbf{r}, t - \Delta t)$$

adjoint gradient

✓ Options to use modified gradients & forcing

✓ Useful in identifying causal mechanisms

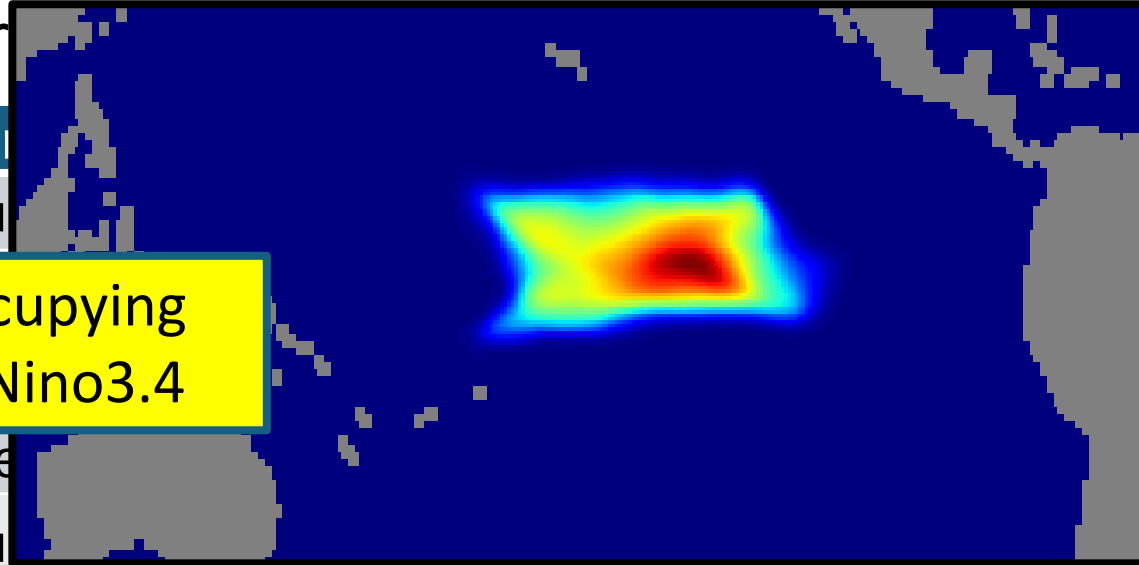
$$\frac{1}{dS(\mathbf{r})} \left[1 - \frac{\text{var} \left(\delta J - \sum_{i=\text{wind}} \sum_{\Delta t} \frac{\partial J}{\partial u_i} \delta u_i(\mathbf{r}, t - \Delta t) \right)}{\text{var}(\delta J)} \right]$$

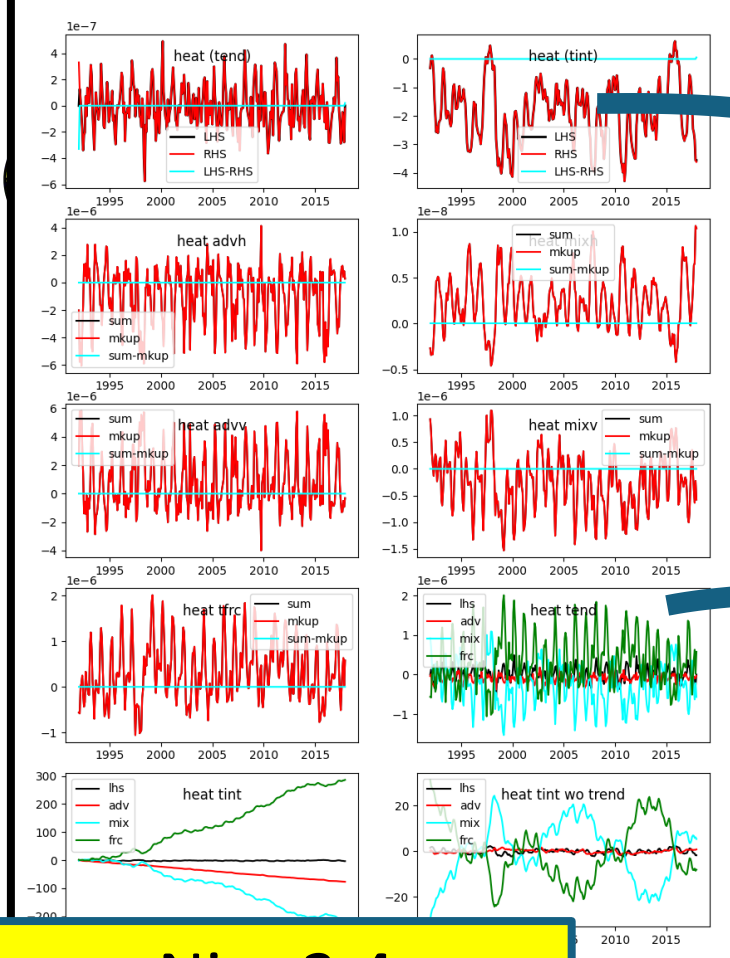
Auxiliary Generates user input files for other EMU tools.

What does EMU do? (7/12)

EMU offers

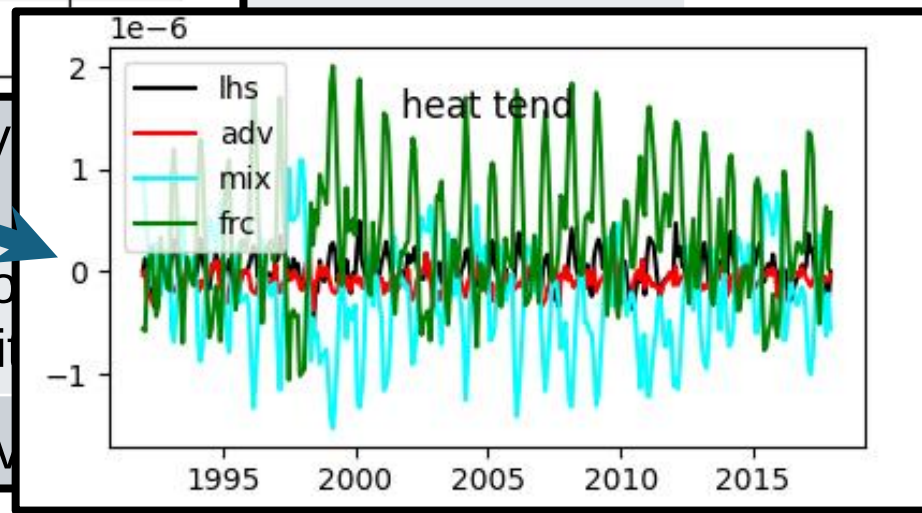
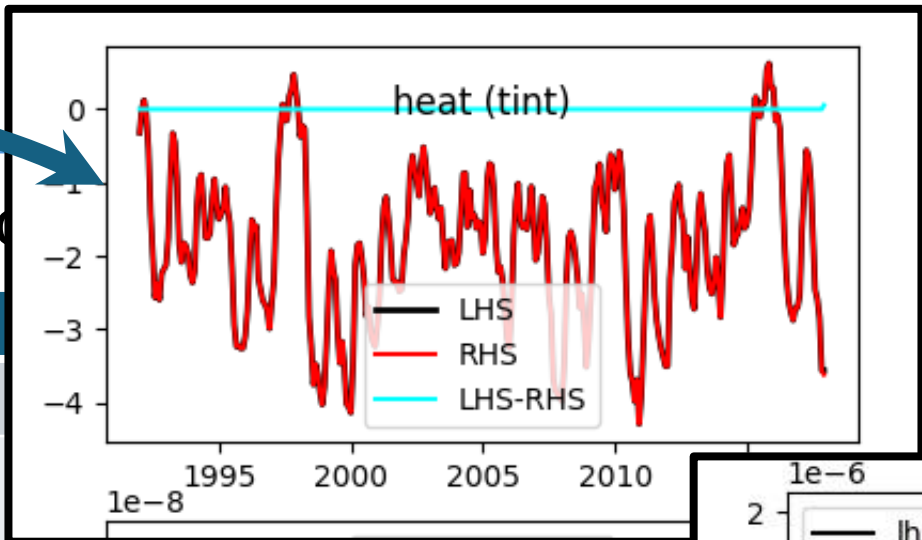
	Tool	Description
1	Sampling	Evaluates
2	Forecast	Fate of water occupying surface layer of Nino3.4
3	Adjoint	gradient
4	Convolution	Evaluates
5	Tracer	✓ Computes evolution of passive tracer and its adjoint ✓ Useful in identifying fate & origin of water masses and their circulation pathways
6	Budget	Evaluates budget time-series.
7	Modified Simulation	Re-runs model with modifications (e.g., forcing, output).
8	Attribution	Evaluates state times-series by control type.
9	Auxiliary	Generates user input files for other EMU tools.





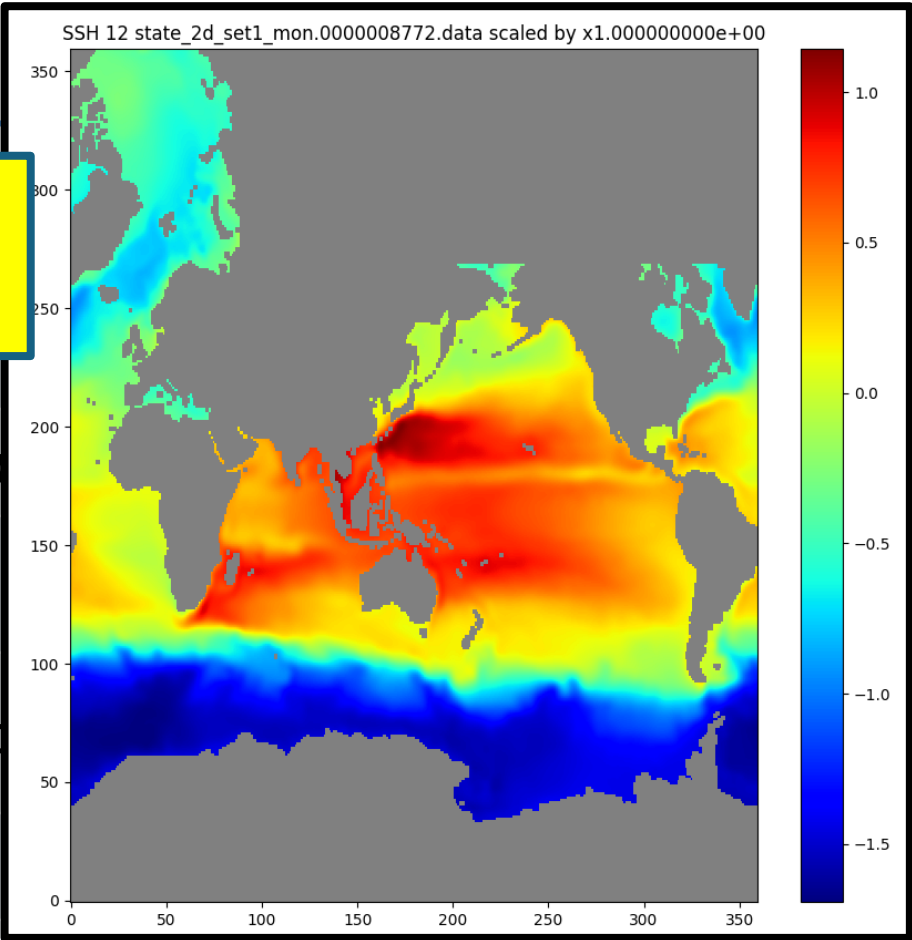
Nino3.4
SST budget

What	
EMU	
Tool	
Coupling	
Gradient	
Adjoint	Computes model's sensitivity (adjoint gradient).
Attribution	Evaluates convolution of adjoint (Adjoint Gradient Decomposition).
Tracer	Computes evolution of passive tracers.
Budget	✓ Evaluates property budgets ✓ Useful in analyzing controlling processes
7	7. Modified Simulation Re-runs model with modifications (e.g., forcing, output).
8	8. Attribution Evaluates state times-series by control type.
9	9. Auxiliary Generates user input files for other EMU tools.



SSH w/
time-mean wind

1	
2	Forward
3	
4	Co
5	
6	Budget
7	Modified Simulation
8	Attribution
9	Auxiliary



al tools.

- odel state and control.
- se to change in forcing.
- ity to forcing (adjoint
- adjoint gradients with forcing position).
- sive tracer and its adjoint.

Evaluates budget time-series

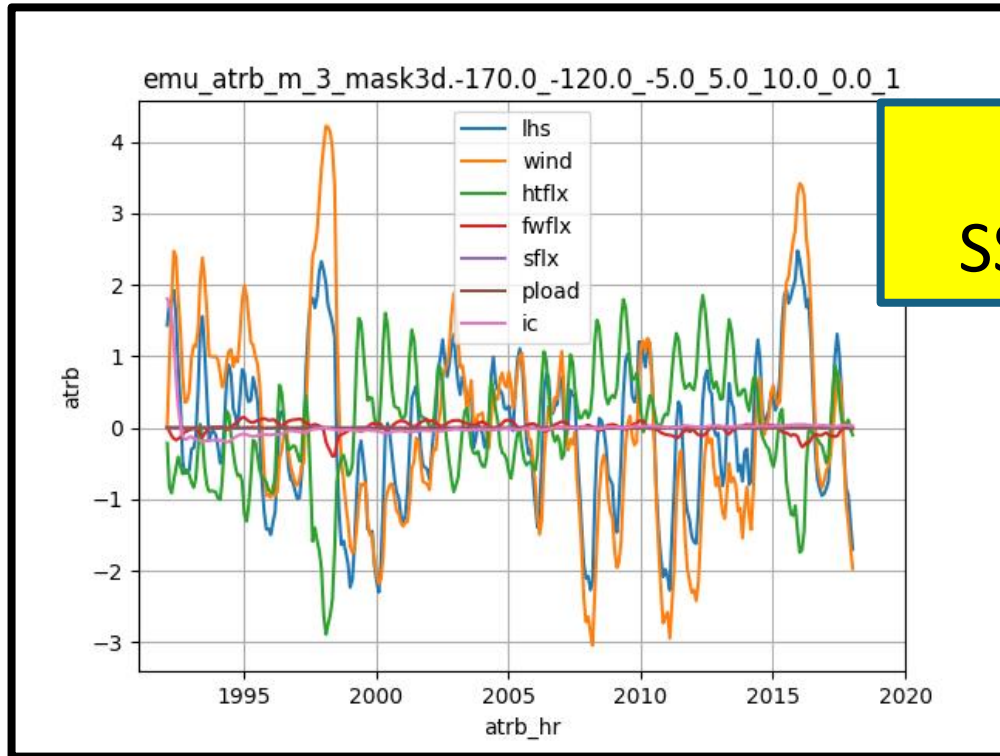
- ✓ Reruns model with changes (e.g., forcing)
- ✓ Useful in conducting experiments with the model
- ✓ Also useful in producing non-standard output

Evaluates state times-series by control type.

Generates user input files for other EMU tools.

What does EMU do? (10/12)

EMU offers 9 computational tools.



Nino3.4
SST attribution

OBJF

$$J(t) = \sum_i \alpha_i \sum_r \mathbf{W}_i(\mathbf{r}) \mathbf{x}_i(\mathbf{r}, t)$$

Scale Weight Variable

Multi-variable Space

7 Modified Simulation

8 Attribution

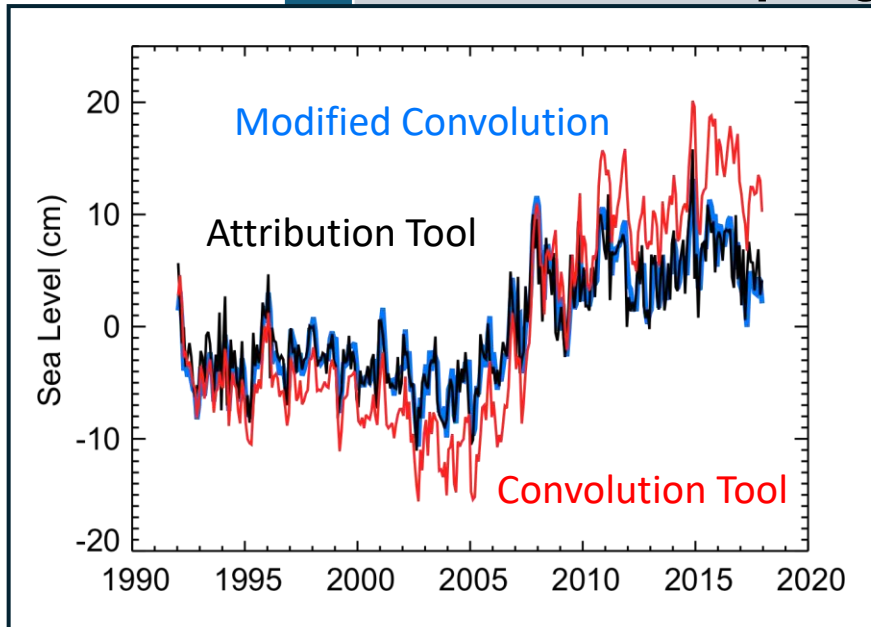
9 Auxiliary

- ✓ Evaluates model's variation by control type
e.g., effect of variable wind = (ECCO Solution) – (Modified Solution w/o Variable Wind)
- ✓ Useful in identifying responsible control type
- ✓ Also useful in validating results of Convolution Tool

What does EMU do? (11/12)

EMU offers 9 computational tools.

	Tool	Description
1	Sampling	Evaluates time-series of model state and control. Computes model's response to change in forcing. ✓ Expands quantities of interest into their controls $\delta J(t) \approx \sum_i^{\text{type}} \sum_{\mathbf{r}}^{\text{location}} \sum_{\Delta t}^{\text{lag}} \frac{\partial J(T)}{\partial u_i(\mathbf{r}, T - \Delta t)} \delta u_i(\mathbf{r}, t - \Delta t)$ adjoint gradient ✓ Options to use modified gradients & forcing ✓ Useful in identifying causal mechanisms
7	Modified Simulation	✓ Evaluates model's variation by control type e.g., effect of variable wind = (ECCO Solution) – (Modified Solution w/o Variable Wind)
8	Attribution	✓ Useful in identifying responsible control type
9	Auxiliary	✓ Also useful in validating results of Convolution Tool



What does EMU do? (12/12)

	Tool	Description
1	Sampling	Evaluates time-series of model state and control.
2		Model's response
3		Model's sensitivity
4		Involved Decompos
5		Evolution of passive tracer and its adjoint
6	Budget	
7	Modified Simulation	
8	Attribution	
9	Auxiliary	

In file "data" ...

Time stepping parameters
&PARM03
nlter0=201612,
nTimeSteps=1560,

↔

In file "data" ...

Time stepping parameters
&PARM03
nlter0=1,
nTimeSteps=227903,

✓ Generates example user input files for other EMU tools, especially Modified Simulation

- Start date and duration of simulation
- Diagnostic output variable and its frequency
- Setting initial condition from end state of another
- Modify forcing and initial condition

How do you EMU?

1) To run EMU, enter command,

`emu`

2) To read & plot EMU results, run python script,

`emu_plot.py`

3) To install EMU elsewhere, run shell script,

`emu_setup.sh`

(EMU is available as source code & container image.)



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