ECCO Modeling Utilities (EMU)

A set of menu-driven tools
for analyzing the ECCO model.

Ichiro Fukumori, Ou Wang, Ian Fenty
Jet Propulsion Laboratory, California Institute of Technology

20 March 2024, ECCO Meeting, Austin TX

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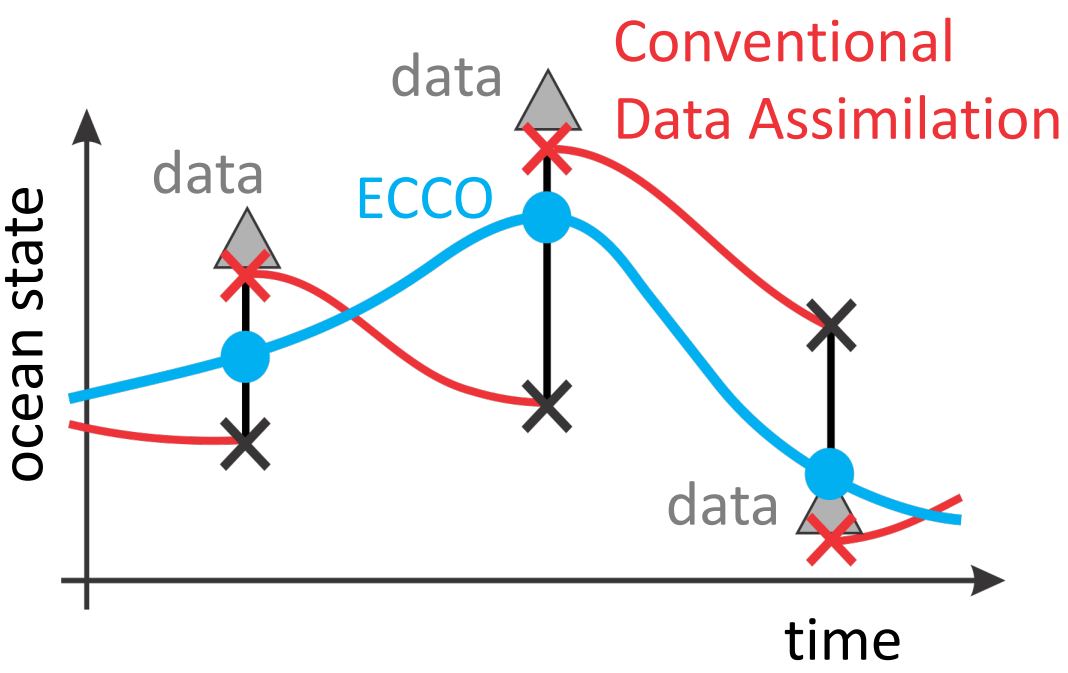
Why? A set of menu-driven tools for analyzing the ECCO model.



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 needing modeling expertise.

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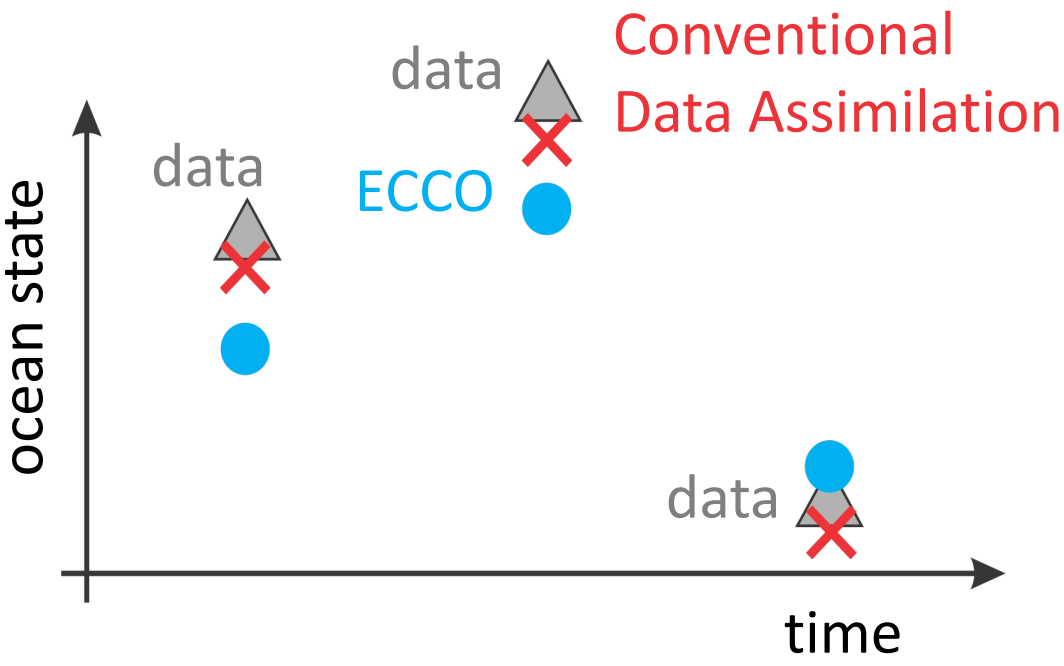

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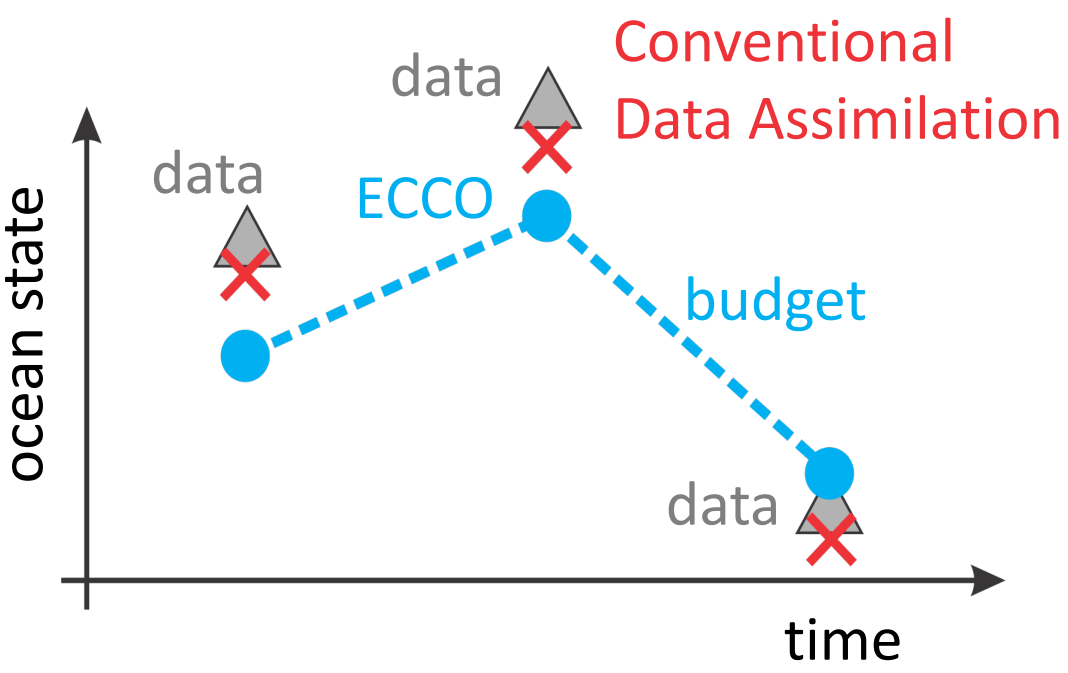

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This is Why!

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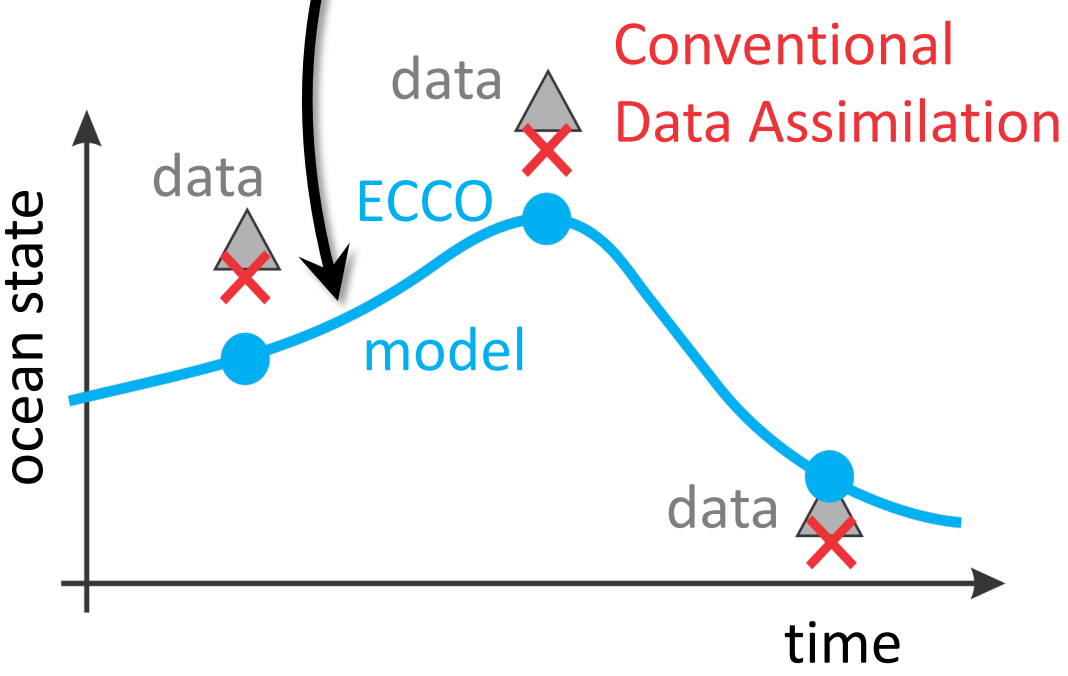

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A set of menu-driven tools
for analyzing the ECCO model.

	Tool	Description
1	**Sampling**	Evaluates time-series of state.
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**	Reruns simulation with changes (e.g., forcing).
8	**Attribution**	Evaluates effects by control type.

ECCO Modeling Utilities (EMU)

A set of menu-driven tools
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- ✓ Evaluates any linear combination of the model state
- ✓ Options to use latitude, longitude, depth as criteria
- ✓ Useful for assessing fidelity of ECCO

	Tool	
1	**Sampling**	
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	Tool	
1	**Sampling**	✓ Computes forward gradient ✓ Choice of denominator ✓ Useful for insight into physics ✓ Also useful for validating adjoint $\frac{\partial\,(\text{model state})}{\partial\,(\text{control})}$
2	**Forward Gradient**	
3	**Adjoint**	✓ Computes adjoint gradient ✓ Choice of numerator ✓ Useful for insight into physics ✓ Also useful for model calculus $\frac{\partial\,(\text{model state})}{\partial\,(\text{control})}$
4	**Convolution**	
5	**Tracer**	Computes evolution of passive tracer and its adjoint.
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	Tool	Description
1	**Sampling**	Evaluates time-series of state.
2	**Forward Gradient**	Computes model's response to change in forcing.
3	**Adjoint**	✓ Expands quantities of interest into their controls
4	**Convolution**	$\delta J(t) \approx \sum_{i}^{\text{type}} \sum_{\mathbf{r}}^{\text{location}} \sum_{\Delta t}^{\text{lag}} \frac{\partial J(t_g)}{\partial \phi_i(\mathbf{r}, t_g - \Delta t)} \delta\phi_i(\mathbf{r}, t - \Delta t)$ adjoint gradient
5	**Tracer**	✓ Options to use modified gradients & forcing ✓ Useful in identifying causal mechanisms
6	**Budget**	Evaluates budget time-series.
7	**Modified Simulation**	Reruns simulation with changes (e.g., forcing).
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5	**Tracer**	✓ Computes evolution of passive tracer and its adjoint ✓ Useful in identifying origin & fate of water masses and their circulation pathways
6	**Budget**	Evaluates budget time-series.
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5	**Tracer**	Computes evolution of passive tracer and its adjoint.
6	**Budget**	✓ Evaluates property budgets ✓ Useful in analyzing controlling processes
7	**Modified Simulation**	Reruns simulation with changes (e.g., forcing).
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7	**Modified Simulation**	
8	**Attribution**	Evaluates effects by control type.

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

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7	**Modified Simulation**	
8	**Attribution**	

- ✓ Evaluates model's variation by control type
  e.g., effect of variable wind = ECCO_V4r4 – Modified_Simulation_w/o_variable_wind
- ✓ Useful in identifying responsible control type
- ✓ Also useful in validating results of Convolution Tool

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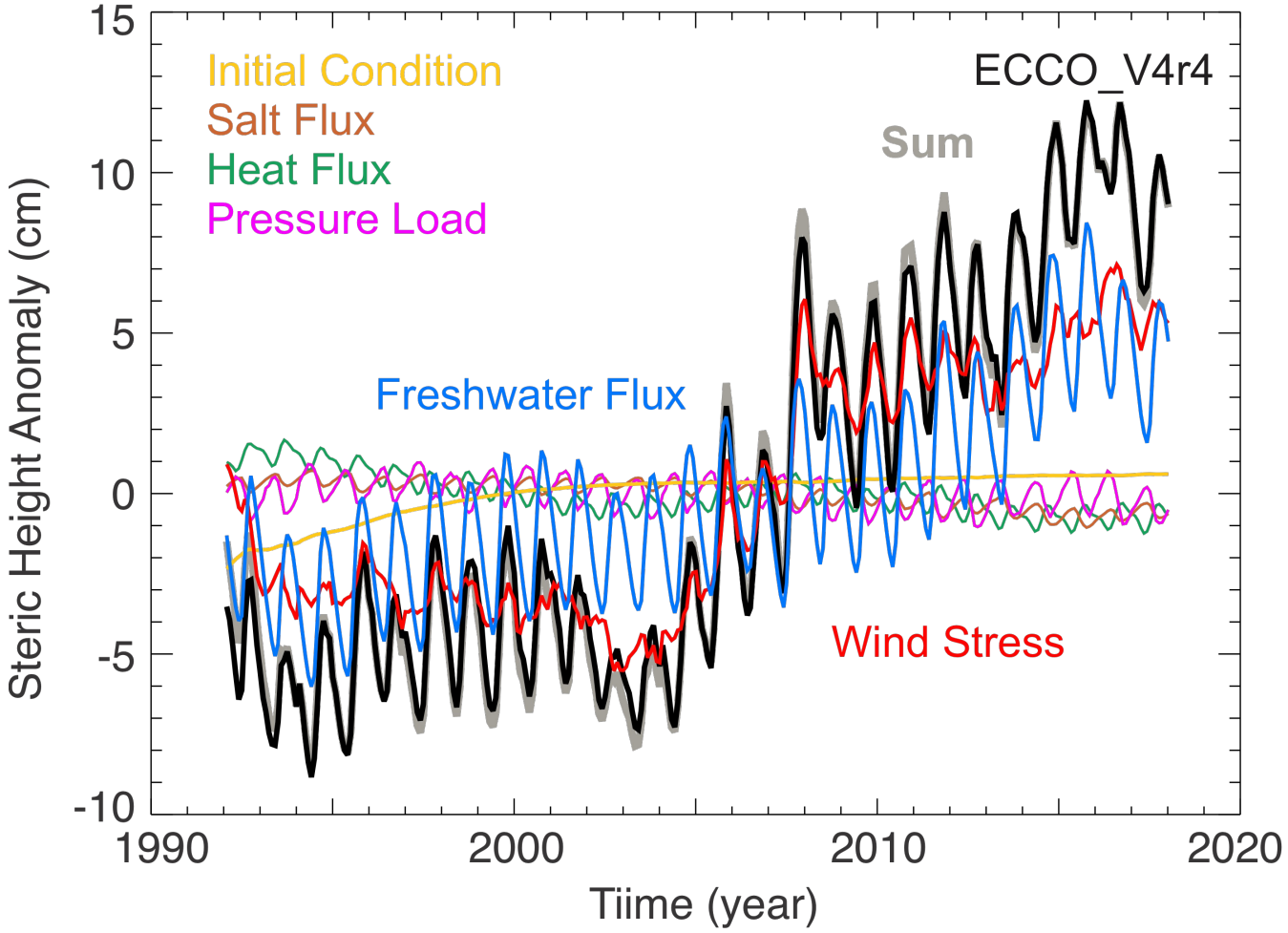
7	**Modified Simulation**	✓ Useful in identifying responsible control type
8	**Attribution**	✓ Also useful in validating results of Convolution Tool

$$\delta J(t) \approx \sum_{i}^{\text{type}} \sum_{\mathbf{r}}^{\text{location}} \sum_{\Delta t}^{\text{lag}} \frac{\partial J(t_g)}{\partial \phi_i(\mathbf{r}, t_g - \Delta t)} \delta \phi_i(\mathbf{r}, t - \Delta t)$$

adjoint gradient

Attribution Tool Example

Beaufort Sea Mean Steric Sea Level Change



Fukumori, I., O. Wang, and I. Fenty, 2021: Causal Mechanisms of Sea Level and Freshwater Content Change in the Beaufort Sea. *J. Phys. Oceanogr.*, **51**, 3217–3234, https://doi.org/10.1175/jpo-d-21-0069.1.

Example Running EMU (1/4)

pfe25>**emu**

EMU is launched by command “emu.”

ECCO Modeling Utilities (EMU) Version 1.0a ...
See /nobackup/ifukumor/emu_v1_access/README

Choose among the following tools ...

1) Sampling (samp); Evaluates state 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); Evaluates 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.

Choice of Tools

Enter choice ... (1-8)?
8

Choose Tool.

choice is 8) Attribution Tool (atrb)

Example Running EMU (2/4)

See /nobackup/ifukumor/emu_v1_access/README_atrb

README file for Attribution Tool

Define objective function (OBJF) ...
Available VARIABLES are ...

1) SSH (m)
2) OBP (equivalent sea level m)
3) THETA (deg C)
4) SALT (PSU)
5) UV (m/s)

OBJF

Scale Weight Variable

$$J(t) = \sum_{i} \alpha_i \sum_{\mathbf{x}} \mathbf{T}_i(\mathbf{x}) v_i(\mathbf{x}, t)$$

Multi-variable Space

Example:
Steric Sea Level = SSH – OBP
averaged over Beaufort Sea

Choose OBFJ variable (v in Eq 1 of Guide) # 1 ... (1-5)?
(Enter 0 to end variable selection)

1 ← Choosing SSH as first variable.

OBJF variable 1 is SSH
Choose either VARIABLE at a point (1) or VARIABLE weighted in space (2) ... (1/2)?

2 ← Choosing a spatially weighted variable.

Example Running EMU (3/4)

Enter MASK filename (T in Eq 1 of Guide) ... ?

beaufortsea.msk ← Entering filename for weight.

Enter scaling factor (alpha in Eq 1 of Guide)... ?

1. ← Entering scaling factor.

OBJF

$$J(t) = \sum_{i} \alpha_i \sum_{\mathbf{x}} \mathbf{T}_i(\mathbf{x}) v_i(\mathbf{x}, t)$$

Scale: α_i — Weight: $\mathbf{T}_i(\mathbf{x})$ — Variable: $v_i(\mathbf{x}, t)$

Multi-variable: i — Space: $\mathbf{x}$

Choose OBFJ variable (v in Eq 1 of Guide) # 2 ... (1-5)?

(Enter 0 to end variable selection)

2 ← Choosing OBP as 2nd variable.

OBJF variable 2 is OBP

Choose either VARIABLE at a point (1) or VARIABLE weighted in space (2) ... (1/2)?

2 ← Choosing a spatially weighted variable.

Enter MASK filename (T in Eq 1 of Guide) ... ?

beaufortsea.msk ← Entering filename for weight.

Enter scaling factor (alpha in Eq 1 of Guide)... ?

-1. ← Entering scaling factor.

Example Running EMU (4/4)

```
-----------------
 Choose OBFJ variable (v in Eq 1 of Guide) # 3 ... (1-5)?
 (Enter 0 to end variable selection)
0
```

Entering 0 to end OBJF specification.

```
Done interactive specification.
Begin extracting time-series ...

*****************************************

 Done. Results are in  emu_atrb_m_1_beaufortsea.msk_2/output
*****************************************
```

Location of results.

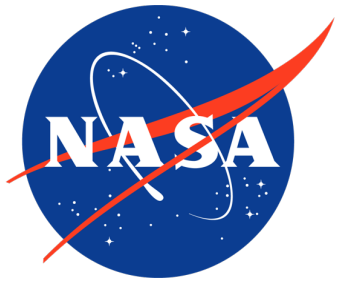
```
pfe25>ls -l emu_atrb_m_1_beaufortsea.msk_2/output/
total 72
-rw-r--r-- 1 ifukumor s2904   8764 Mar 16 19:33 atrb.out_312
-rw-r--r-- 1 ifukumor s2904   1248 Mar 16 19:33 atrb.step_312
-rw-r--r-- 1 ifukumor s2904  48202 Mar 16 19:33 atrb.txt
-rw-r--r-- 1 ifukumor s2904    544 Mar 16 19:32 data.ecco
-rw-r--r-- 1 ifukumor s2904    949 Mar 16 19:32 set_samp.info
```

Listing results.

Summary & Outlook

1. EMU is available at NAS
   /nobackup/ifukumor/emu_v1_access/emu

2. Ongoing work
   a) Containerization with Singularity & Docker
   b) Visualization (e.g., Jupyter, Python, Matlab, IDL)
   c) Updating Github repository
   d) Cloud implementation
   e) Enhancements (e.g., masks, budget)



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