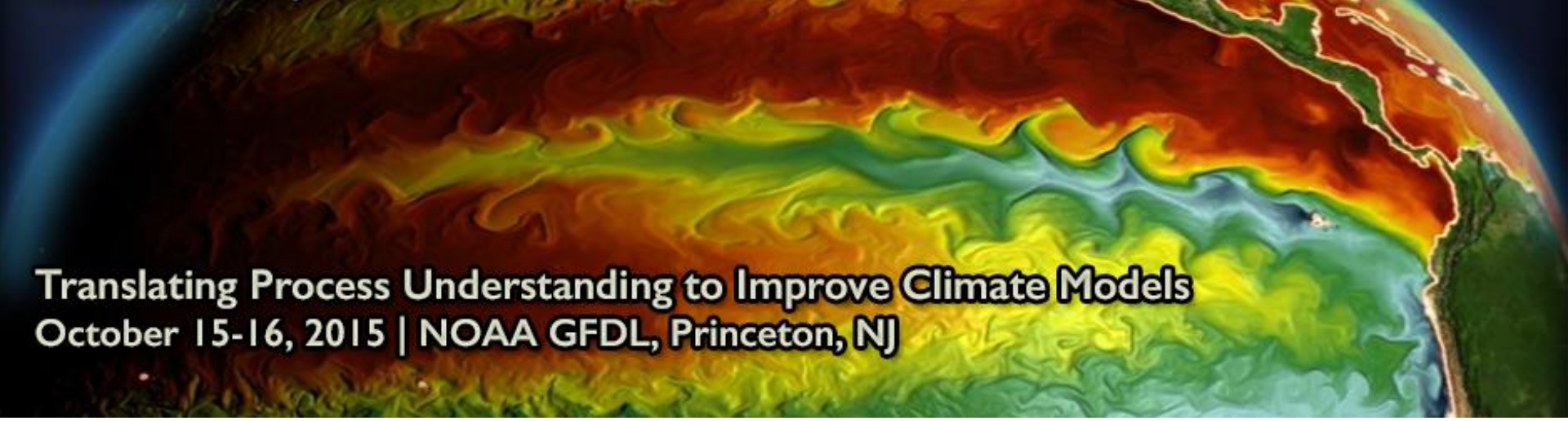
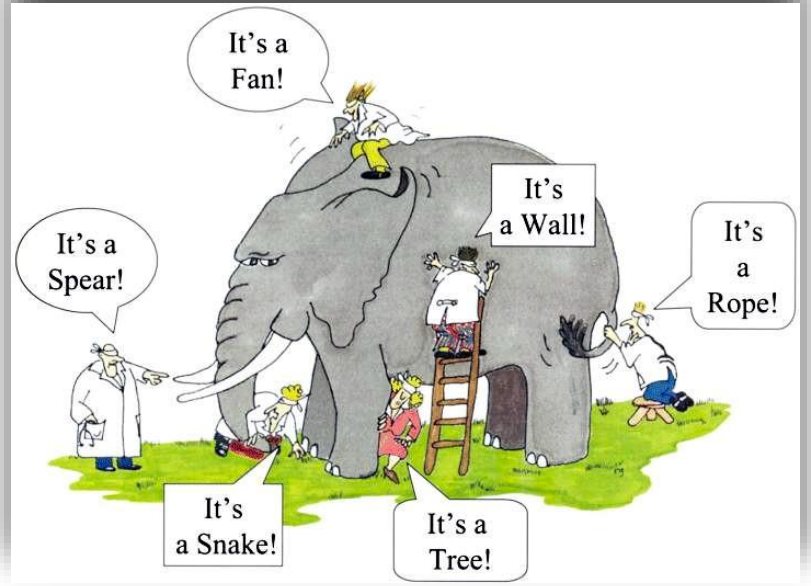


Aneesh Subramanian
Caroline Ummenhofer
Alessandra Giannini
Marika Holland
Sonya Legg
Amala Mahadevan
Joao Teixeira

Motivation

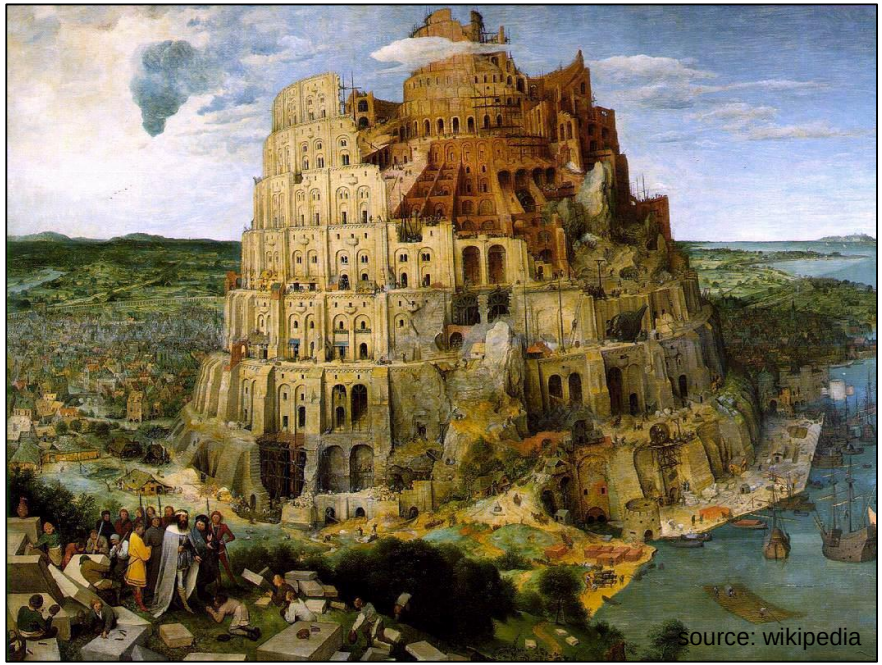
Bringing together **expertise from modelers, theoreticians and process study PIs** to address the **outstanding issues** in representation of **climate processes in models** (especially those that can be targeted on a 5-10 yr time period)



source: wordpress.com

Main goals of the workshop

- **Motivated by the science** of model biases
- Elucidate **priority model improvement needs (Modeling research)**
- **Identify opportunities** for transferring advances in new process understanding (**Observational/Theoretical research**)
- Discussion on the **structure of the next community-driven model development** teams
- **Engagement from a broad cross-section** of the community and a longer discussion



Tower of Babel for Climate Models

Translating Process Understanding to Improve Climate Models
October 15-16, 2015 | NOAA GFDL, Princeton, NJ

Organizing committee:

Members:
Alessandra Giannini (IRI, Columbia)
Marika Holland (NCAR)
Sonya Legg (NOAA GFDL)
Amala Mahadevan, (WHOI)
Aneesh Subramanian, (UCSD, Chair)
Joao Teixeira (JPL)
Caroline Ummenhofer (WHOI)

Support:
Mike Patterson (US CLIVAR)
Kristan Uhlenbrock (US CLIVAR)
Jill Reisdorf (UCAR)

Support: US CLIVAR, UCAR, GFDL

US CLIVAR

Sponsors

NOAA
NSF
GFDL
Geophysical Fluid Dynamics Laboratory
ONR
Science & Technology

US Modeling Center Survey Respondents

Modeling Center	Point of Contact
DOE ACME	Bill Collins
NASA GMAO	Steve Pawson
NASA GISS	Gavin Schmidt
NOAA GFDL	Bob Hallberg
NOAA NCEP EMC	Mark Iredell
NSF NCAR	Bill Large
ONR NAVGEM/HYCOM	Maria Flatau

Process Studies and Observation Program Survey Respondents

Recent and Planned Process Studies		Field Years	Respondent
ACAPEX	ARM Cloud Precipitation Experiment	2015	Ruby Leung
ASIRI	Air-Sea Interaction in the Northern Indian Ocean - Regional Initiative	2013-2014	Emily Shroyer
AWARE	ARM West Antarctic Radiation Experiment	2015-2016	Dan Lubin
CLIMODE	CLIvar Mode Water Dynamic Experiment	2005-2007	Terry Joyce
DIMES	Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean	2009-2014	Sarah Gille
DYNAMO	Dynamics of the MJO	2011-2012	Eric Maloney
IASCLIP	InterAmericas Study of Climate Processes	N/A	Chunzai Wang
IWISE	Internal Waves in Straits Experiment	2011	Matthew Alford
KESS	Kuroshio Extension System Study	2004-2006	Steven Jayne
LASIC	Layered Atlantic Smoke Interactions with Clouds	2016-2017	Paquita Zuidema
MAGIC	Marine ARM GPCI Investigation of Clouds	2012-2013	Ernie Lewis
ORACLES	Observations of Aerosols above Clouds and their Interactions	2016-2018	Jens Redemann
SOCRATES	Southern Ocean Clouds, Radiation, & Aerosol Transport Experimental Study	2016-2019	Greg McFarquhar
SPICE	Southwest Pacific Ocean Circulation and Climate Experiment	2008-2015	Janet Sprintall
SPURS	Salinity Processes in the Upper Ocean Regional Study (First & Second)	2012-2013 2016-2017	Ray Schmitt
TTide	Tasman Tidal Dissipation Experiment	2015	Rob Pinkel
VOCALS	VAMOS Ocean-Cloud-Atmosphere-Land Study	2008	Roberto Mechoso

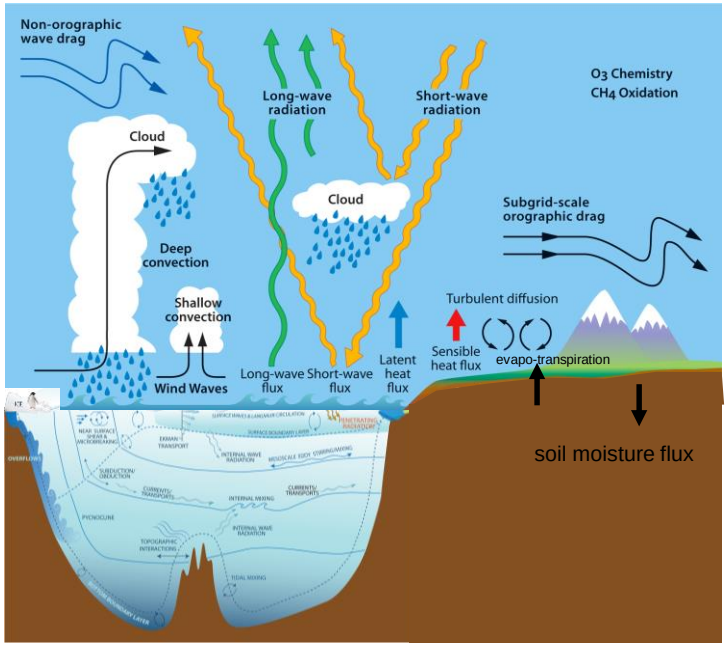
Enhanced Observations Projects		Period	Respondent
AMOC	Atlantic Meridional Overturning Circulation Observing System		
	RAPID/MOCHA: Meridional Overturning Circulation and Heatflux Array	2004-2020	Bill Johns
	OSNAP: Overturning in the Subpolar North Atlantic Program	2014-2018	Susan Lozier
	SAMOC: South Atlantic Meridional Overturning Circulation	2009-	Chris Meinen
ARM	Atmospheric Radiation Measurements Climate Research Facility		
	Eastern North Atlantic	2013-	Rob Wood
	North Slope of Alaska	1997-	Gijs de Boer
OOI	Ocean Observatories Initiative		
	Pioneer Array: Northeast Coast	2013-	Al Plueddemann
	Global Nodes: Irminger Sea, Station Papa, Argentine Basin, Southern Ocean	2014-	Bob Weller

Recently Deployed Satellite Missions		Period	Respondent
Aquarius	Aquarius Sea Surface Salinity Mission	2011-2015	Gary Lagerloef
COSMIC-2	2nd Constellation Observing System for Met, Ionosphere, & Climate	2016-	Ben Ho
GPM	Global Precip. Measurement (& Tropical Rainfall Measuring Mission)	2014-2017	George Huffman
JASON-3	3rd JASON Altimetry Mission	2015-	John Lillibridge

CPT and CPT-like Projects		Period	Respondent
US CLIVAR	Ocean Eddy Mixed-Layer Interactions	2003-2008	Dan Rudnick
US CLIVAR	Gravity Current Entrainment	2003-2008	Sonya Legg
US CLIVAR	Ocean Mixing Processes Associated w/ High Spatial Heterogeneity in Sea Ice	2010-2015	Meibing Jin
US CLIVAR	Cloud Parameterization and Aerosol Indirect Effects	2010-2015	Vince Larson
NOAA MAPP	Improving Turbulence and Cloud Processes in the NCEP Global Models	2013-2016	Steven Krueger
NOAA MAPP	Representing Calving and Iceberg Dynamics in Global Climate Models	2013-2016	Olga Sergienko

Workshop Topics (survey of modeling centers and Obs./Theory PIs)

- Scale-aware parameterization of subgrid scale processes
- Ice-ocean interactions and sea-ice dynamics
- Air-sea interactions
- Shallow and deep convection in the atmosphere
- Coastal/marginal sea processes
- Vertical transports and surface processes in the ocean
- Land surface physics parameterizations
- Processes influencing polar feedbacks
- Diurnal-to-annual surface processes (land and ocean)
- Ocean eddy processes
- Physical processes that affect carbon cycle
- Others



source: ECMWF, GFDL

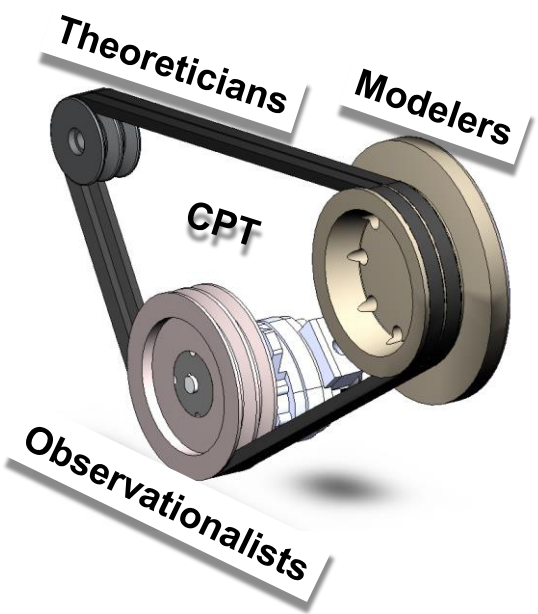
White paper and Summary Document

Past CPT Experience

- Effective mechanisms to facilitate **close collaboration** between **process experts and model developers** to improve parameterizations of a particular process in one or more IPCC-class models.

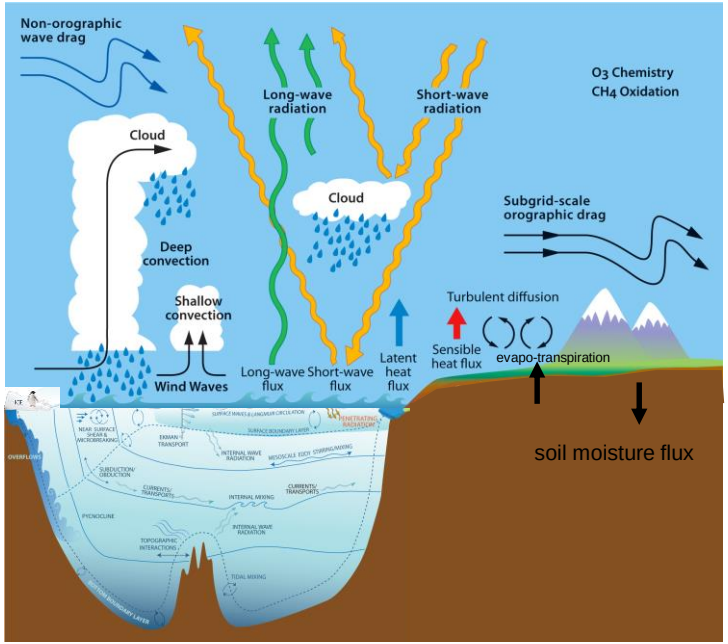
- Strong community recognition that bringing process experts together with climate modelers is a **useful means of improving representation of physical processes** in large-scale models.

- The past CPTs have also led to **strong and enduring links** between specific scientific communities in academia and model developers.



Need for Future CPTs

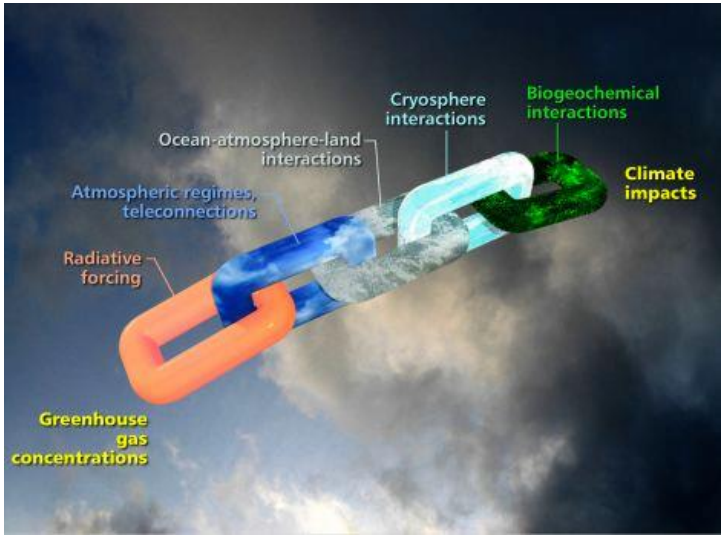
- Only a limited number of processes have been targeted so far.
- Interactions between processes are poorly represented in current climate and weather models.
- Ability for different modeling centers to work together may depend on setting a common goal and coordination among different funding agencies to fund the CPT.
- Synthesis of process study results needed for compatibility with what can be used in climate models.



source: ECMWF, GFDL

Future CPT Activity

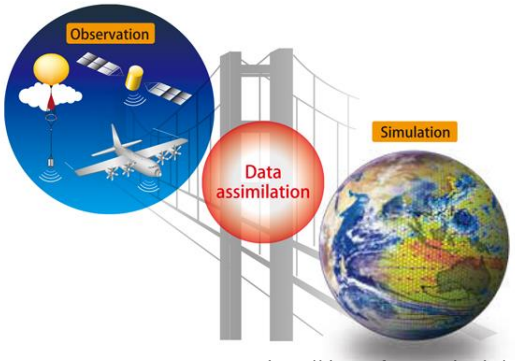
- Many of the current and past CPTs have successfully focused on specific processes.
- New efforts could be focused on questions related to the interactions between different components of the climate system.
- Useful to explore process translation themes that would attract interest from multiple modeling centers and agencies, including both weather and climate prediction centers.



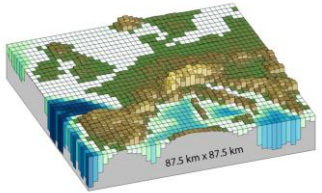
source: BAMS

Future CPT Activity

- Data-assimilation - help bridge the gaps between different communities
- Ensemble prediction - different parameterization challenges (e.g., stochastic physics)
- Sensitivity experiments - identify parameters and processes responsible for coupled biases.
- New computational capabilities - ultra high resolution - role of deep convection and mesoscale dynamics in the atmosphere, ocean.
- New observational capabilities - large data sets (e.g., from new Autonomous Underwater Vehicle capabilities, satellite data) and data mining capabilities can be explored for potential new process understanding.



http://daconf15.umd.edu/



IPCC WG1 Chapter 1

Opportunities for translating process understanding to model improvement

- A need for scale-aware parameterizations
- Biases discussed included pervasive and persistent issues that have existed over numerous model generations
- Examples of CPT-like activities in white paper :
  - Moist Convection
  - Mesoscale ocean eddy lifecycles
  - Snow on sea-ice
  - Eastern boundary upwelling systems

Topics discussed dependent on the subset of the climate science community who could attend the workshop

Process / Phenomenon	Potential Bias Improvement	Motivation	References
Estuarine/fjord – ocean interactions	Salinity near estuaries and rivers; coastal ocean stratification	Allows for riverine nutrient & heat transport; impacts coastal biogeochemistry	Geyer and MacCready (2014), Horner-Devine et al. (2015)
Atmospheric boundary layer and land surface interaction	Forecast biases on sub-seasonal timescales	Improvements in soil moisture coupling to atmospheric boundary layer	Kumar et al. (2014)
Equatorial mixing	Cold tongue bias	Can influence simulated variability (ENSO), surface coupling	Sasaki et al. (2013)
Eddy life cycle and energetics	Mixed layer depth; primary production	Controls on vertical ocean exchange, upper ocean stratification, non-Newtonian mixing parameterization	Mana and Zanna (2014), Jansen et al. (2015b)

Eastern boundary upwelling	Warm regional SST bias	Improve coupled interactions and feedbacks; impacts on BGC	Small et al. (2015)
Western boundary currents	SST, surface heat fluxes, and oceanic heat transport	Potential links to AMOC, decadal variability	Carton et al. (2014), Hu et al. (2015)
Swell and Langmuir turbulence	Southern ocean mixed layer bias	Potentially influence ocean transient response	Fan and Griffies (2014)
Shelf–open ocean exchange	Ocean water mass and density structure	Potential influence on shelf biogeochemical processes including upwelling driven primary production, hypoxia, and low pH events	Bryan et al. (2015)

Gravity wave drag	Large-scale atmospheric circulation	Improved wind stress and coupling	Geller et al. (2013)
Topographic wave drag	Internal wave representation and large-scale ocean circulation	Improved energy balance representation in ocean interior	Trossman et al. (2016)
Atmospheric moist convection	Diurnal cycle of precipitation, MJO	Improvements to tropical climate and variability	Pearson et al. (2014)
Mixed-phase clouds	Radiation biases, precipitation biases	Potential influence on cloud feedbacks	Pithan et al. (2014)
Glacier/ice shelf – ocean interaction	Ocean influence on glacial and ice-sheet retreat	Potential impact of increased glacial meltwater discharge on ocean circulation including AMOC and of ocean dynamics on variable submarine melting of glaciers/ice shelves	Straneo and Heimbach 2013
Snow on sea ice	Snow and albedo biases	Influences polar feedbacks	Hezel et al. (2012)

Summary and Conclusion

- The workshop **highlighted key current biases** across the plethora of climate and weather models developed and maintained by **seven different modeling centers** in the US.
- **Past CPTs** led to **significant model improvements** and **enduring scientific collaborations.**
- **Strong recommendation for future activities** in this arena: better representation of specific processes and complex interactions amongst them likely to reduce still pervasive model biases.
- Recommendation applies to **continuing existing approaches**, such as teams built around the theme of improving the representation of a specific process, **in addition to new ideas** of teams focused on **coupled processes** and/or **model component interactions** to address specific biases or climate phenomena.
- Though not without challenges, **multi-agency, multi-modeling center efforts are crucial** and best-suited to deliver sustainable and comprehensive improvements to climate models.

Selected set of examples of the type of processes/phenomena identified at the workshop that participants felt were in a reasonable state of readiness for translation into climate model improvements.

Illustrative list of processes ready for implementation

- Atmospheric and oceanic boundary layers/air-sea interaction
- Atmospheric boundary layer and land surface interaction
- Atmospheric moist convection
- Cloud macro and microphysics (e.g.,mixed-phase)
- Coastal-open ocean interaction (shelf-basin exchange/cross-shelf transport)
- Eastern boundary upwelling systems
- Equatorial ocean mixing
- Estuarine/fjord processes
- Gravity wave drag
- Mesoscale eddies
- Ocean-ice interactions (ice-ocean boundary layer/ice-sheet-ocean interactions/fjords)
- Snow on sea ice
- Western boundary currents