Advancing the Understanding of the Earth System: Phenomena, Processes, Variability and Change

Overview (Ocean & Cryosphere Focus)

Presented by

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Geophysical Fluid Dynamics Laboratory Review

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Connection to NOAA/OAR Missions

- Using Earth System Models in conjunction with observations, GFDL has been conducting cutting-edge research to advance the fundamental understanding of major Earth System phenomena and their underlying mechanisms

- This research theme directly addresses NOAA mission:

"To understand and predict changes in climate, weather, oceans and coasts, to share that knowledge and information with others, and to conserve and manage coastal and marine ecosystems and resources."

and OAR mission:

"Conduct research to understand and predict the Earth system; develop technology to improve NOAA science, service, and stewardship; and transition the results so they are useful to society."

- Understanding is critical for informing model development, and provides the scientific foundation for Earth System predictions and projections

- Scope of recent GFDL Theme2 (Ocean & Cryosphere) accomplishments:
    - Small scale ocean processes
    - Large scale variability and change across timescales:
    - Inter-annual variability
    - Decadal-to-multidecadal variability
    - Centennial change

Understanding Sub-Grid Scale Ocean Processes is Crucial for Model Development and Future Projections

Brandon Reichl (4:10pm)
Collaboration with NCEP/EMC on WAVEWATCH III -MOM6 coupling

Reichl and Hallberg, OM, 2018
Reichl and Li, JPO, 2019
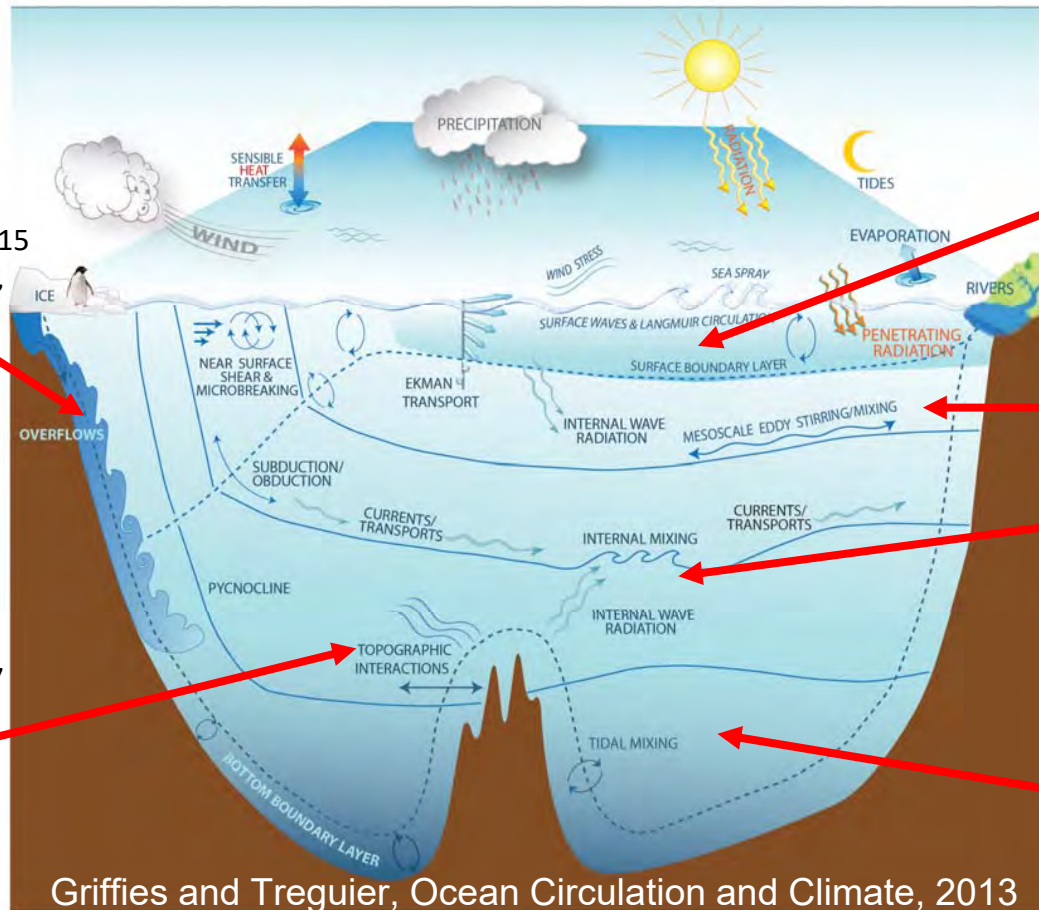
Wang et al., OM, 2015
Yankovsky and Legg, JPO, 2019

Jansen et al., OM, 2015a,b

MacKinnon et al., BAMS, 2017
NSF/NOAA funded CPT effort across multiple institutions

Yi et al., Fluids, 2017
Nazarian and Legg, OM, 2017a,b

Melet et al., JOC, 2016

Griffies and Treguier, Ocean Circulation and Climate, 2013

- Sub-grid scale ocean processes are important for large scale ocean circulation, ocean heat and carbon uptake
- Understanding sub-grid scale processes is crucial for model development and future projections

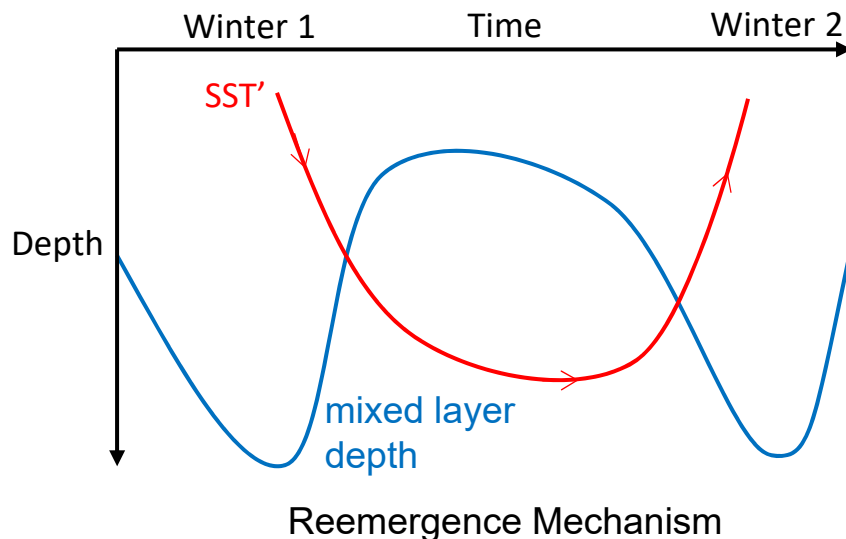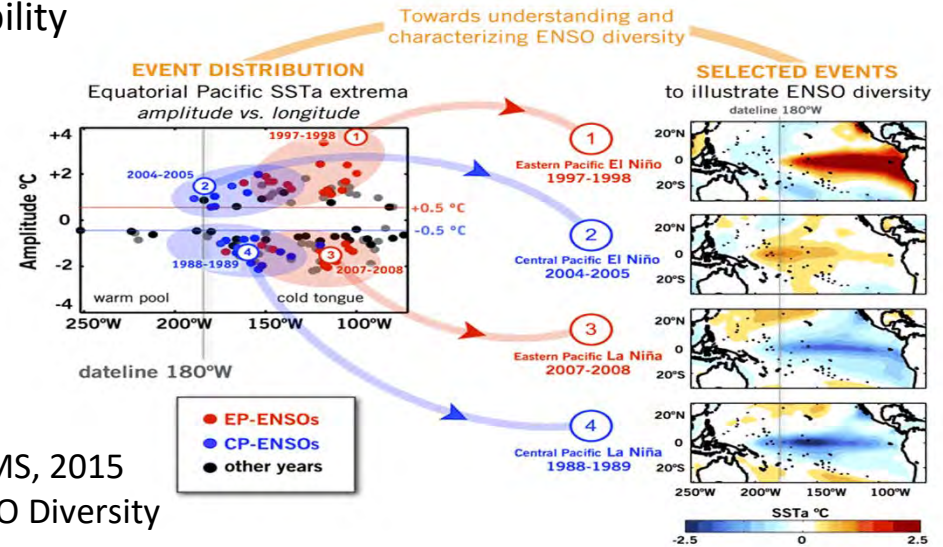- Understanding ENSO and associated predictability

Andrew Wittenberg
(4:25pm)

Towards understanding and characterizing ENSO diversity

EVENT DISTRIBUTION
Equatorial Pacific SSTa extrema
amplitude vs. longitude

SELECTED EVENTS
to illustrate ENSO diversity

Capotondi, Wittenberg et al., BAMS, 2015
US CLIVAR Working Group on ENSO Diversity

Reemergence Mechanism

- Inter-annual SST variability resulted from the reemergence mechanism provides key source of seasonal prediction skill for Barents Sea winter sea ice extent (Bushuk et al., GRL, 2017)
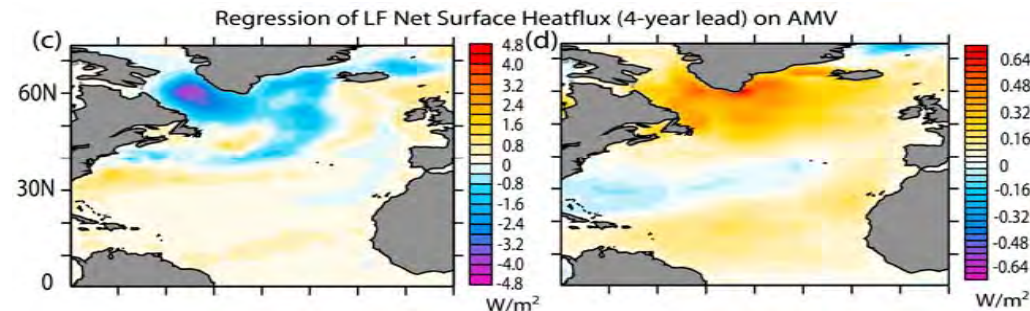
Mitch Bushuk
(Day 2, 10:30 am)

Ocean Dynamics is Important for Atlantic Multidecadal Variability (AMV)

- **AMV has broad impacts with enormous societal/economic implications** (e.g. Sahel/India monsoon, Atlantic hurricane, N. American/European heat waves, Arctic sea ice); **Understanding AMV mechanism is crucial for future predictions**
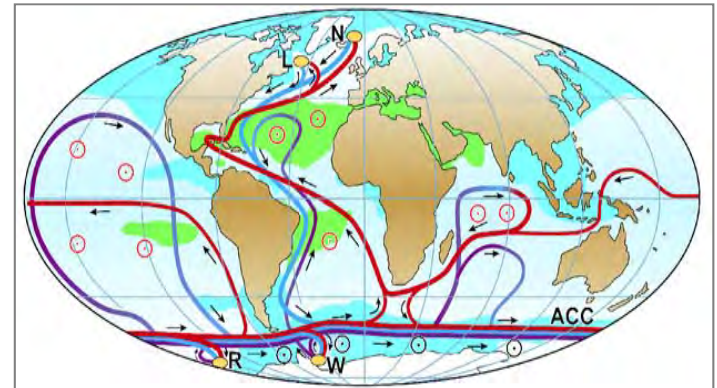

Fully Coupled Models   Slab Ocean Models
Regression of LF SST on AMV
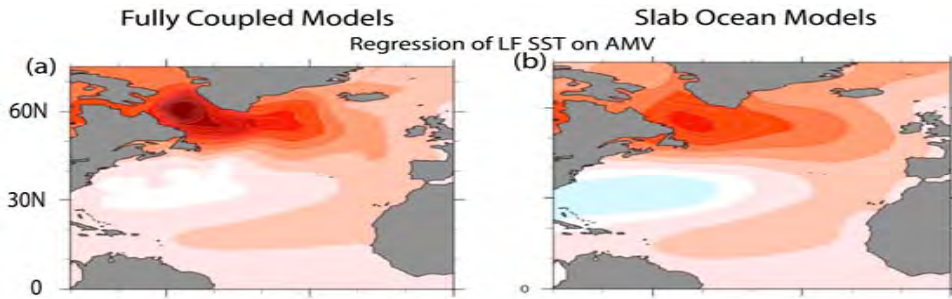
Clement et al., Science, 2015   no role of ocean dynamics

Regression of LF Net Surface Heatflux (4-year lead) on AMV

Zhang et al., Science, 2016 (Collaboration with Univ. Reading, NCAR)
ocean dynamics is crucial

Predictability

Fully Coupled Models
Slab Ocean Models

Yan et al., GRL, 2018
ocean dynamics provides source of decadal predictability

- **AMV is a multivariate phenomenon with coherent variations in SST, SSS, and air-sea heat fluxes** (Zhang, GRL, 2017; Yan et al., GRL, 2019)

- **Key role of AMOC in AMV and related impacts** (Zhang et al., Reviews of Geophysics, 2019) US AMOC Science Team and UK/US Rapid Program

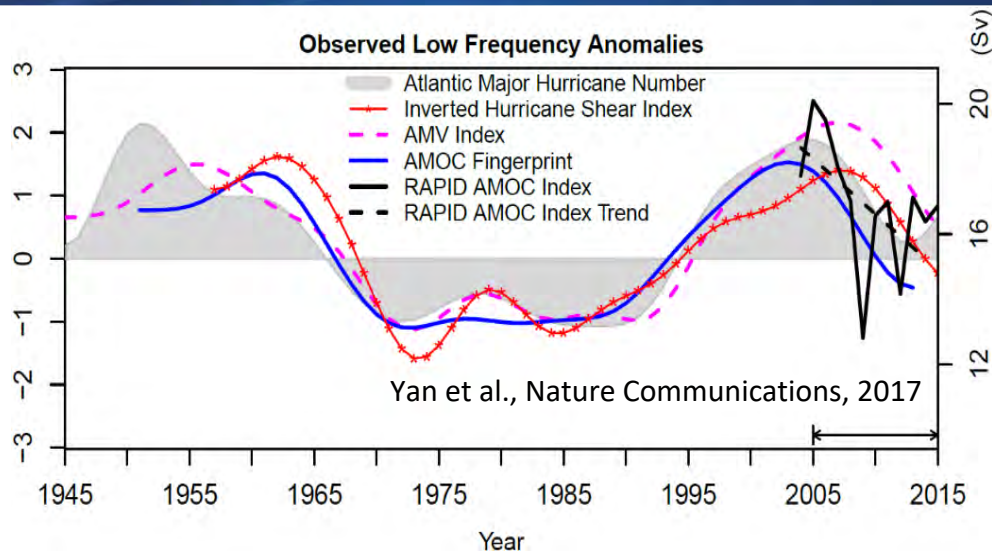**Atlantic Meridional Overturning Circulation (AMOC)**

Kuklbrodt et al., Reviews of Geophysics, 2007

Key Role of AMOC in Atlantic Hurricane Activity and Decadal Predictability

Observed Low Frequency Anomalies

Legend:
- Atlantic Major Hurricane Number
- Inverted Hurricane Shear Index
- AMV Index
- AMOC Fingerprint
- RAPID AMOC Index
- RAPID AMOC Index Trend
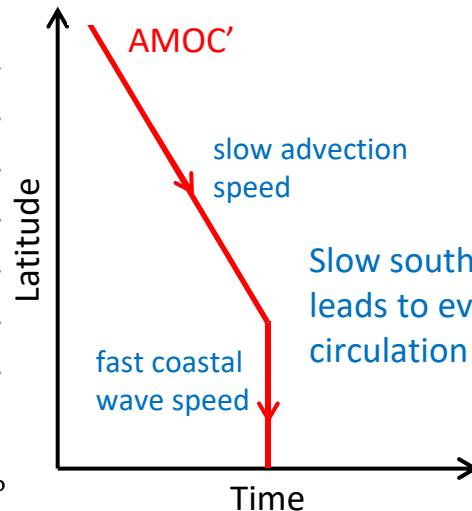
Yan et al., Nature Communications, 2017

Observations and ESM2G control simulation suggest a key role of AMOC in AMV and multidecadal variability of Atlantic major hurricane frequency

AMOC fingerprint is used to reconstruct historical AMOC variations, consistent with recent direct observations

- Role of AMOC in AMV, related impacts, and decadal predictability has been underestimated in many climate models (Yan et al., GRL, 2018)

Dipole Induced by AMOC Strengthening

- weakened subpolar gyre
- warming
- cooling
- southward shift of Gulf Stream

AMOC'
- slow advection speed
- fast coastal wave speed

Slow southward propagation of AMOC anomalies leads to evolution of AMOC fingerprint (gyre circulation changes) and decadal predictability of AMV

Zhang, GRL, 2008; Sanchez-Franks and Zhang; Zhang and Zhang, GRL, 2015

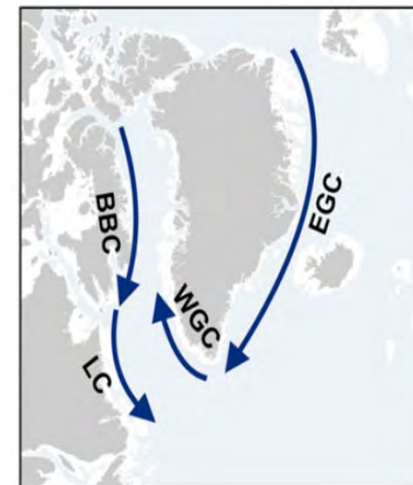# Heat and Freshwater Exchanges are Key for Atlantic-Arctic Interactions

- AMOC and Atlantic heat transport is a key player for multidecadal Arctic sea ice variability
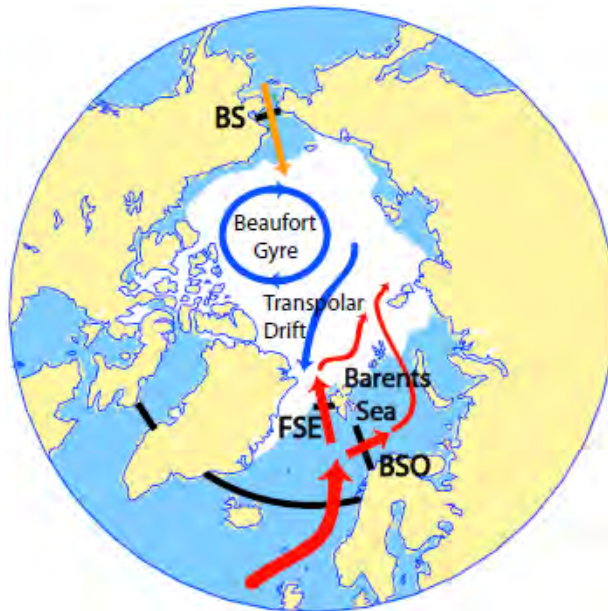
Zhang, PNAS, 2015
Li et al., JOC, 2018

- Impact of different Arctic freshwater pathways on North Atlantic convection and AMOC
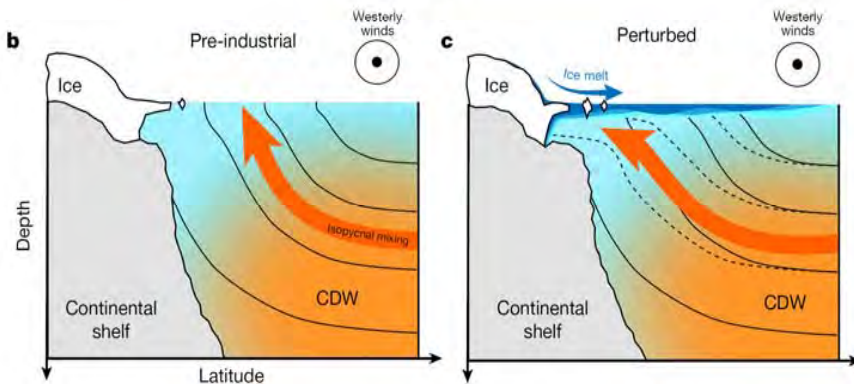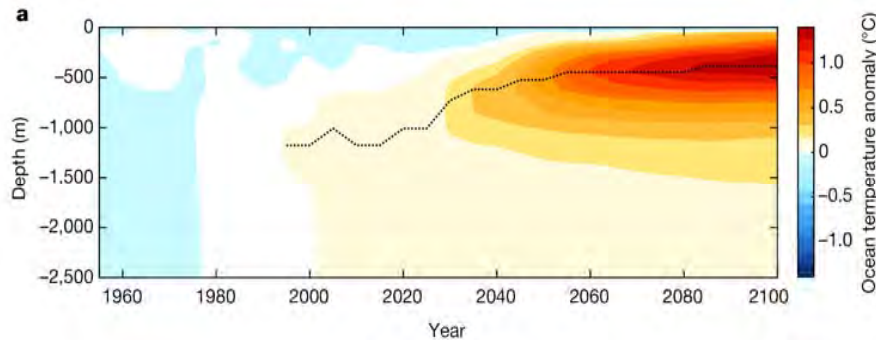
(Wang et al., JOC, 2018)

- The observed winter sea ice decline in Barents Sea is closely linked to enhanced Atlantic heat transport across Barents Sea Opening (BSO)
(Li et al., Nature Communications, 2017)

Understanding Ocean/Ice Sheet Interaction is Crucial for Projecting Future Climate Change
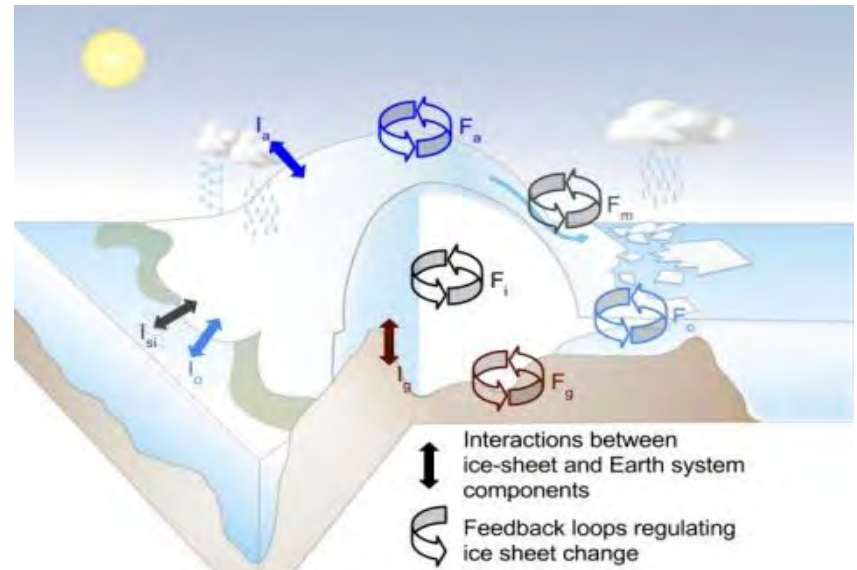

Bronselaer et al., Nature, 2018

- Understanding impact of Antarctic meltwater on projected climate change

GFDL-SOCCOM Collaboration

Steve Griffies
(4:40pm)

- Understanding ocean/ice sheet interactions

Olga Sergienko
(4:55pm)

Interactions between ice-sheet and Earth system components

Feedback loops regulating ice sheet change

Fyke, Sergienko et al., Reviews of Geophysics, 2018
Collaboration with DOE, NCAR, Univ. of Colorado Boulder

Projected AMOC Weakening: Key Mechanism for Projected Enhanced Atlantic Sea Level Rise and Warming along the U.S. East Coast

John Krasting
(Day 2, 11:15am)

Vincent Saba
(Day 2, 11:30am)

- Projected enhanced Atlantic sea level rise

(Krasting et al., Nature Geoscience, 2016)

- Projected enhanced warming along the U.S. East Coast

(Saba et al., JGR: Oceans, 2016, Collaboration with NOAA Fisheries, OAR/ESRL)

deepened Atlantic thermocline depth

northward shift of Gulf Stream path

Projected AMOC weakening

Uncertainties of future projections of Atlantic sea level rise and surface warming along the U.S. East Coast are related to uncertainties of projected AMOC weakening

Future Plans & Challenges

GFDL will continue to advance the understanding of:

- Subgrid-scale processes and their impacts on ocean circulation and climate

- Role of ocean & cryosphere in weather, climate, sea level, and ecosystems

- Internal variability vs. externally forced response

- Drivers of predictions and projections across timescales

- Coupled interactions between Earth System components

Future Challenges:

- How to improve long-standing model biases and their impacts on predictions/projections

- How to balance between breadth and depth of understanding

- How to maintain leadership in key areas while engaging in new frontiers

Summary

- It is crucial to understand impacts of key model biases and unresolved processes on errors/uncertainties of future predictions and projections

- Understanding of the Earth System is critical for both Earth System Modeling (Theme 1) and predictions/projections (Theme 3)

- GFDL has conducted a broad scope of cutting-edge research to advance the fundamental understanding of Earth System and facilitated close interactions across all three Themes