WRF as the Atmospheric Model in the Regional Arctic System Model (RASM)

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RASM – Overarching Science Hypothesis

The Regional Arctic System Model (RASM) is a coupled atmosphere-land-ocean-sea ice model with a focus on climate simulations of the Arctic

Mesoscale processes and resulting feedbacks are critical to improved representation of the state of the Arctic Climate System and prediction of polar amplification of global climate change.

Some Arctic processes/feedbacks are poorly resolved/represented in ESMs

- sea ice thickness distribution, deformation and export, fast ice
- oceanic eddies, surface/bottom mixed layer, upper ocean heat content
- atmospheric modes of circulation, clouds, fronts
- shelf-basin, wave-ice and air–sea-ice interactions and coupling

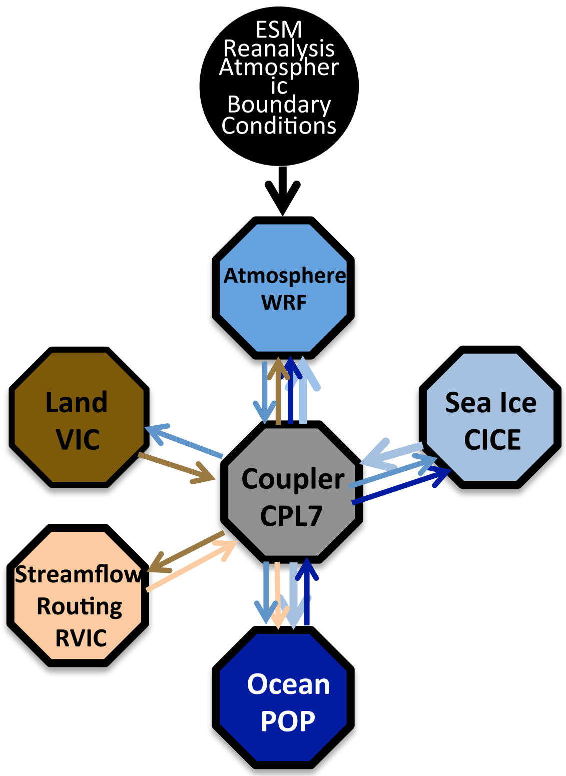
RASM – Overview

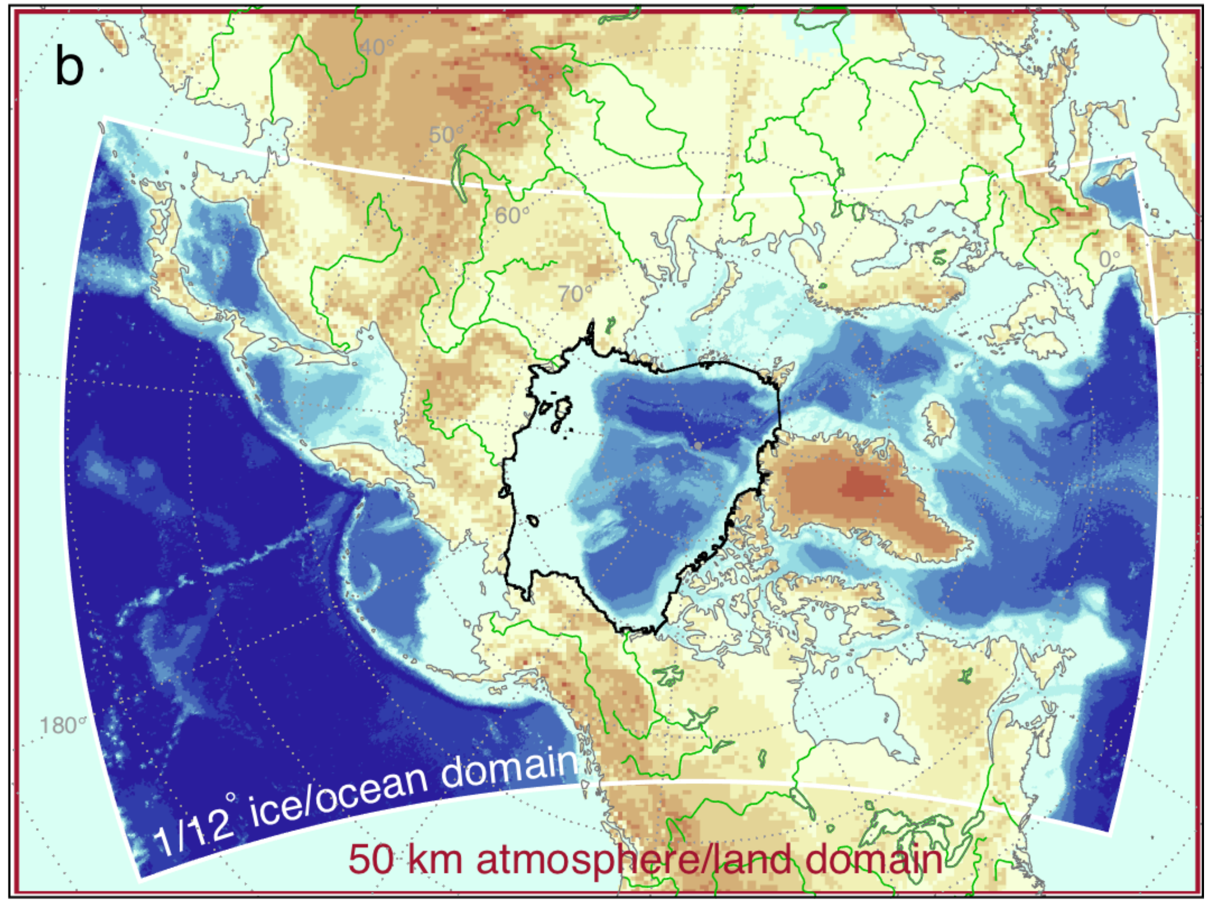
RASM 1.0	Code	Configuration
Atmosphere	WRF	50 km horizontal, 40 vertical levels
Land	VIC	50 km (matching atmosphere), 3 Soil Layers
Ocean	POP2	1/12˚ (~9 km) & 1/48˚ (~2.4 km), 45 levels (7 in the top 42 m),
Sea Ice	CICE5	1/12˚ or 1/48˚, 5 thickness categories Anistropic (EAP) / Isotropic (EVP) rheology
Coupler	CPL7x	Flux exchange every 20 minutes, inertial resolving with minimized lags.

RASM – Participants

RASM 1.0	Code	Contributors
Atmosphere	WRF v3.2	University of Colorado – Boulder: John Cassano, Mark Seefeldt, Alice DuVivier, Mimi Hughes, Matthew Higgins
Land	VIC	University of Washington: Bart Nijssen, Diana Gergel, Joseph Hamman
Ocean	POP2	Naval Postgraduate School: Wieslaw Maslowski, Robert Osinski
Sea Ice	CICE5	Naval Postgraduate School: Andrew Roberts
Coupler	CPL7	Naval Postgraduate School: Anthony Craig
Additional Contributors		Iowa State University: William Gutowski, Brandon Fisel University of Arizona: Xubin Zeng, Michael Brunke

RASM – Domains





Model domain, components, and interactions of RASM

RASM / WRF History

- Most of the initial work in implementing WRF with RASM was done with v3.2
  - RASM 1.0 simulations were completed with v3.2
    Cassano et al., 2017, Journal of Climate
- Amy Solomon of NOAA-ESRL upgraded WRF in a RASM branch to v3.6.1 for sea ice
- In the past year, WRF was upgraded to v3.7.1 and verified with a series of simulations
  - Some of the changes and additions from v3.2 to v3.7.1 are beneficial to RASM (e.g. cumulus radiative feedback, pressure-level diagnostics)

RASM / WRF History

- The RASM modifications to WRF fall into three categories:
  - RASM/CESM coupling modifications
  - RASM physics modifications
  - RASM climate diagnostic output

- It is likely that a number of the current RASM modifications in WRF are no longer necessary or were never needed

RASM / CESM Coupling

- WRF is coupled to the other RASM model components using the CPL coupler from CESM1
- WRF transfers variables (radiation fluxes, lowest model level state variables) to CPL and CPL transfers variables to WRF
- The coupling is done in 20 minute intervals – matching the radiation timestep
- The surface layer and radiation parameterizations are the primary locations where the variables from the coupler are integrated into WRF

RASM Physics Modifications

- Difficulties in properly simulating clouds and the resultant surface energy balance have resulted in some modifications to the physics parameterizations
- Morrison microphysics
  - Droplet concentration set to 250 cm^{-3} over land, 50 cm^{-3} over water / ice
- RRTMG SW/LW radiation
  - Calculate radiative fluxes based on droplet size from Morrison microphysics
  - Divide the downward radiation into direct and diffuse
- Shallow Cumulus
  - Run the shallow cumulus over ocean points but not land

RASM Diagnostics

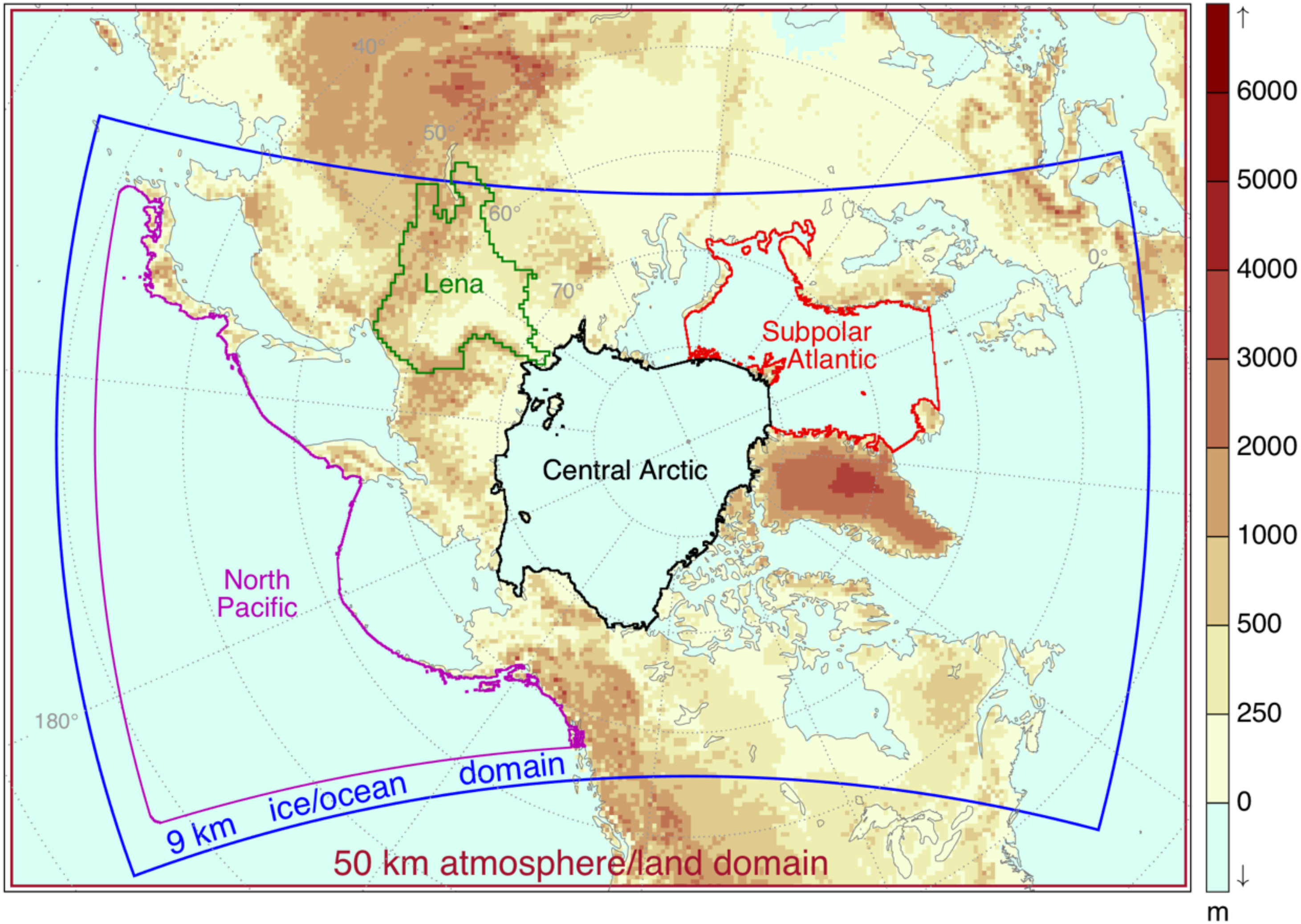
- Timestep averaged output at user selected intervals of seconds, minutes, hours, days, or month
- Provides output of surface meteorology state variables, surface fluxes, and TOA radiation
- Designed to reduce the output load for long duration regional climate simulations
- Contributed to the WRF repository and included in v3.9

See poster: P4

RASM – WRF v3.7.1 Configuration

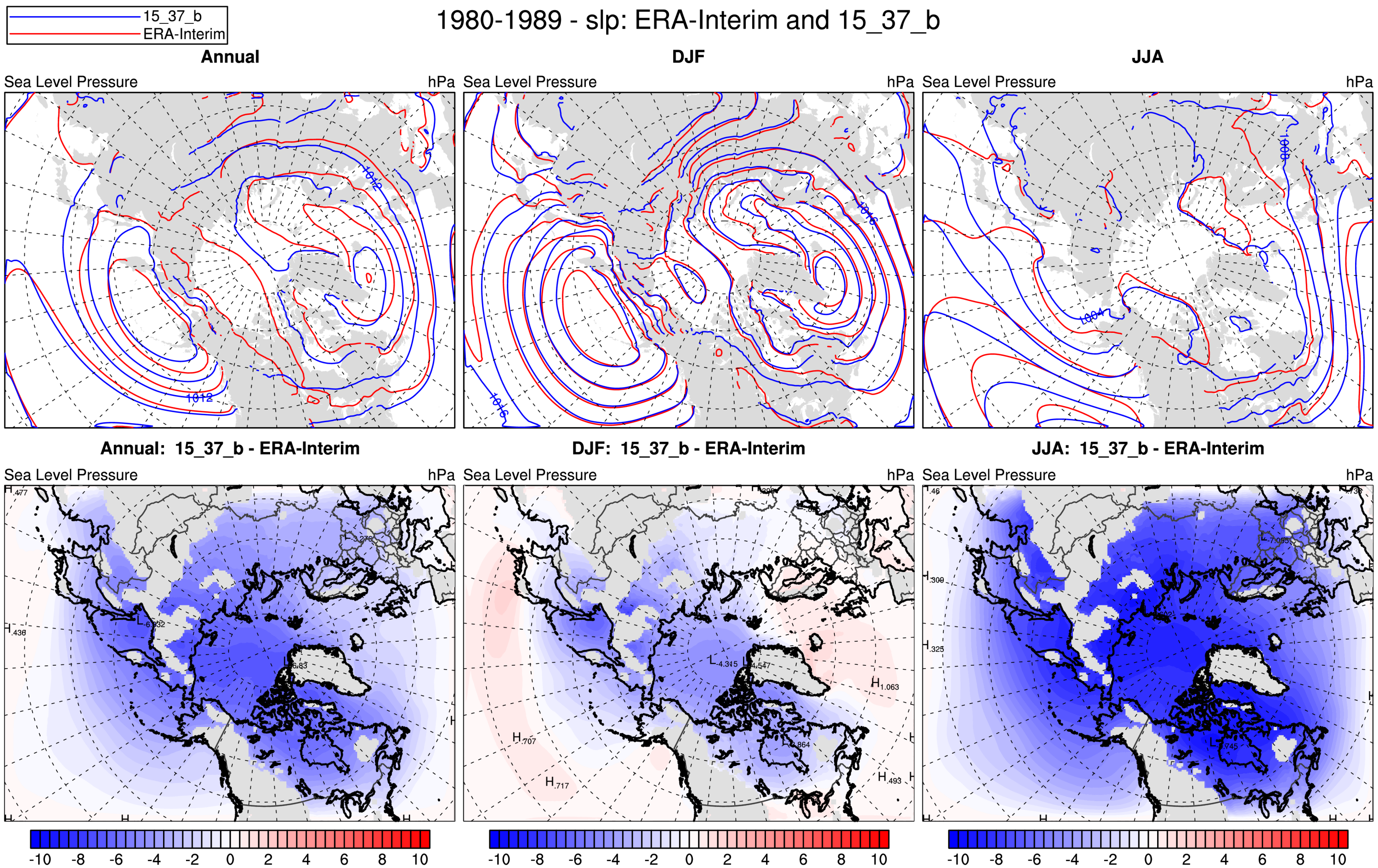
- 50 km horizontal grid, 40 vertical levels
- Physics:
  - Microphysics: Morrison
  - Droplet concentration set to 250 cm^{-3} over land, 50 cm^{-3} over water / ice
  - Radiation: RRTMG LW and SW
  - Calculate radiative fluxes based on droplet size from Morrison microphysics
  - PBL: MYNN PBL
  - Surface layer: Revised MM5
  - Cumulus: Kain-Fritsch / Grell-Freitas / Grell 3D
- Land: VIC
- ~~Spectral~~ Grid nudging of wind and T (top 20 levels)

RASM Domains and Evaluation Regions



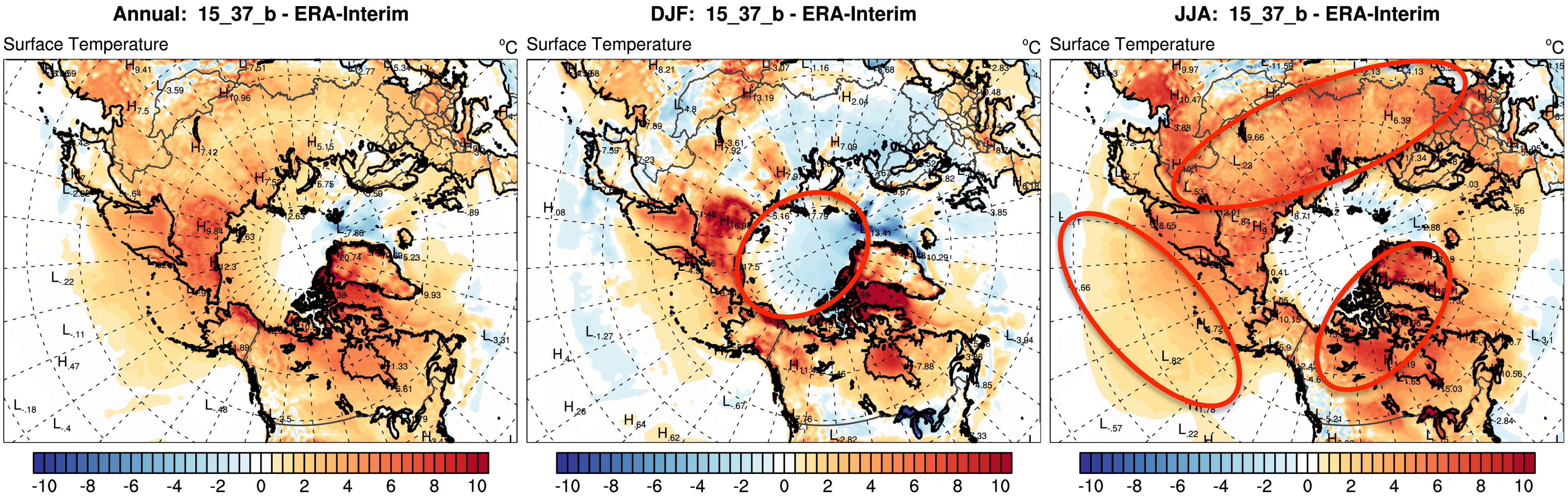
RASM: Sea Level Pressure

- Sea-level pressure (atmospheric circulation) is well simulated



RASM: Surface Temperature

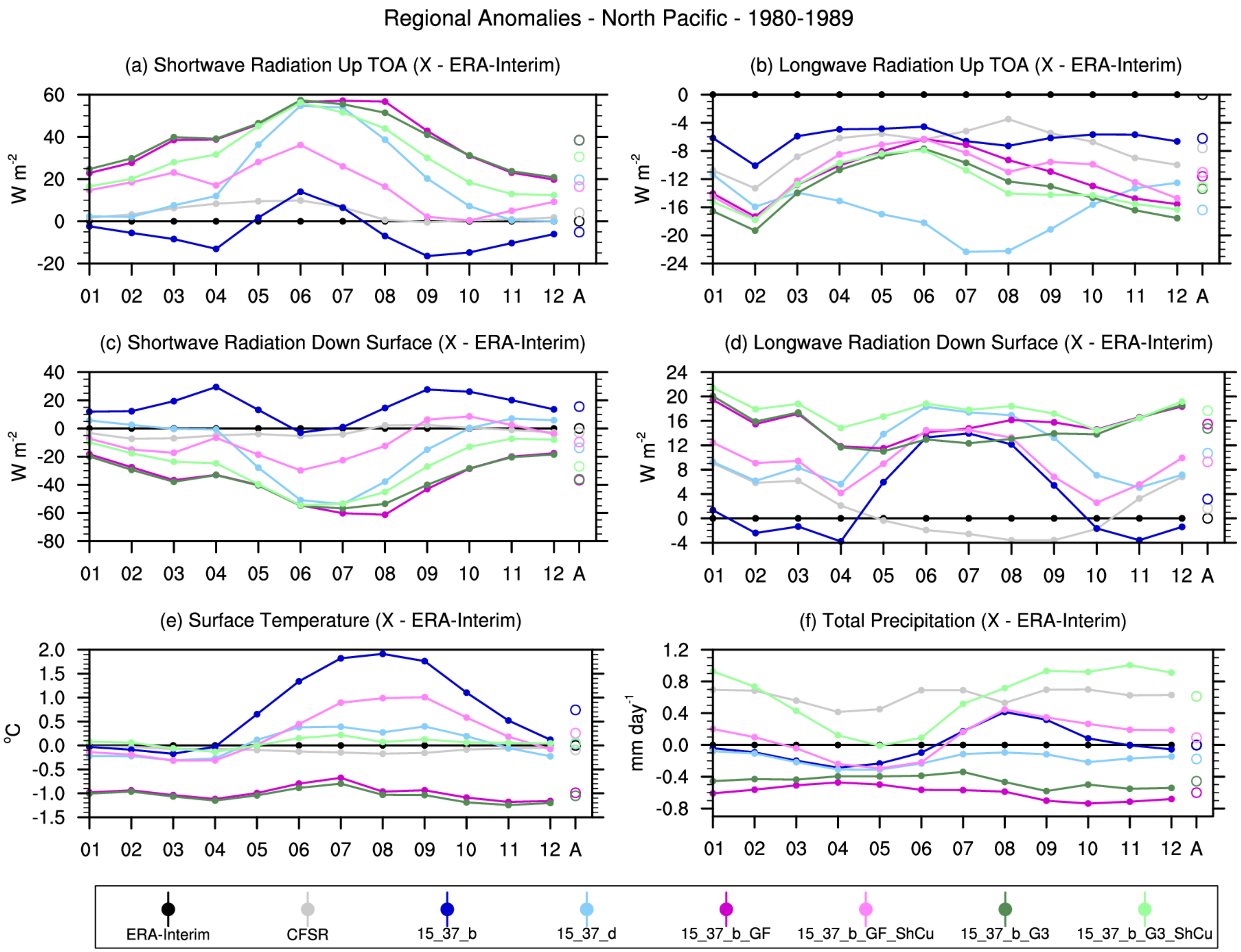
- Large warm-bias over land – especially during the JJA months
- Slight warm bias over the North Pacific and North Atlantic
- Only small biases in the Central Arctic



New WRF Physics Configurations

- Assessed changes to WRF boundary layer, microphysics, convective parameterizations, and inclusion of shallow convection
- Largest improvements seen with cumulus / shallow conv. changes
- Simulations discussed below:
  - 15_37_b_G3
    - use Grell 3D instead of KF
  - 15_37_b_G3_ShCu
    - use Grell 3D and shallow convection option instead of KF
  - 15_37_b_GF
    - use Grell-Freitas instead of KF
  - 15_37_b_GF_ShCu
    - use Grell-Freitas and shallow convection option instead of KF
  - 15_37_d
    - use KF but with icloud = 3 instead of icloud = 1

RASM: North Pacific



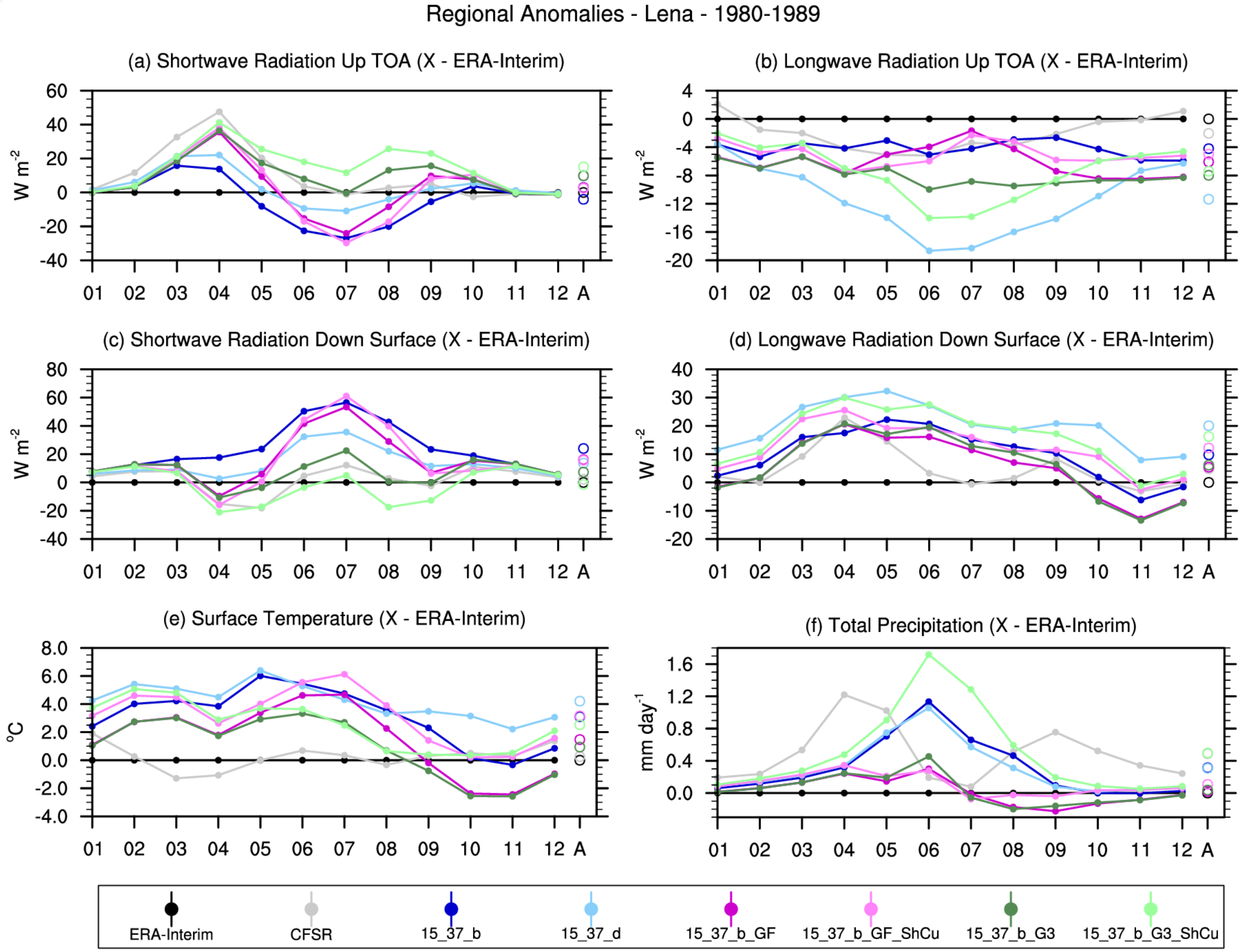
Tsfc:

- Range in T_sfc biases from -1°C to 2°C
- Simulations without ShCu have cold bias
- KF and GF_ShCu have largest warm bias
- G3_ShCu provides the best results

SW_d_sfc:

- Range in biases from -60 W/m^2 to 20 W/m^2
- ShCu have large negative bias – related to large negative T_sfc

RASM: Lena



Tsfc:

- Warm biases for all cases except for late in the year
- G3 and GF (without ShCu) have the smallest warm bias

SW_d_sfc:

- G3 and GF (without ShCu) have the smallest warm bias

Conclusion: ShCu works well over the ocean but not over the land

RASM – Atmosphere: Conclusions

- RASM climate shows significant sensitivity to WRF physical parameterization choices
- Changing PBL and cumulus parameterizations changes the sign of large cloud / radiation biases
  - Improves ocean simulation but degrades land simulation and vice versa
- These biases have a large impact on other aspects of the simulated climate including:
  - Surface temperature (resulting impacts on evaporation)
  - Precipitation
  - Sea ice thickness and extent
- Next steps
  - Identify WRF physics options that produce realistic cloud cover and radiative fluxes across entire model domain

RASM

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