Variable Mesh CESM for South America

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NCAR/AMP

CESM Workshop June 15, 2021

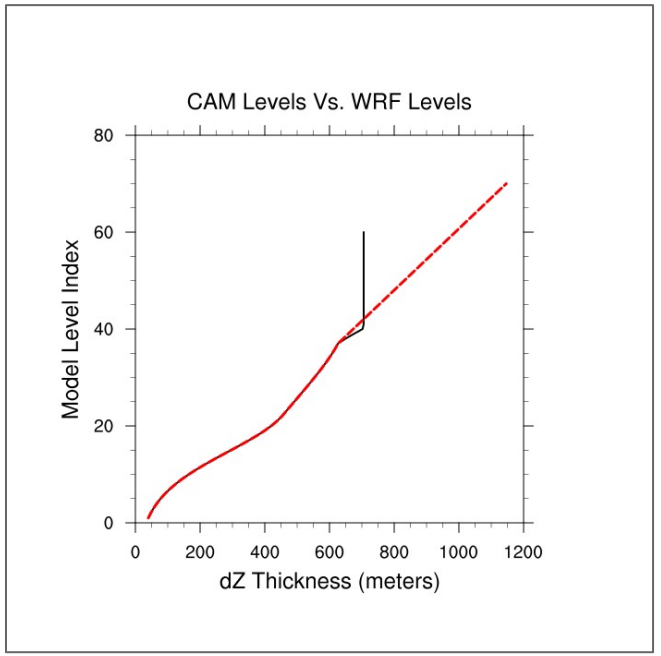
This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Variable Mesh CESM for South America

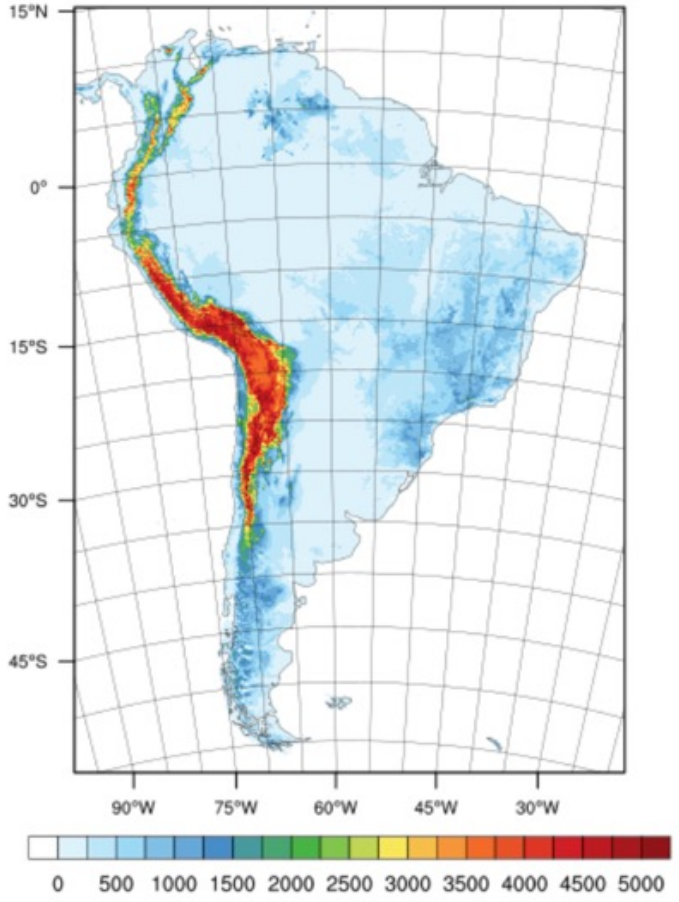
Overview of The South American Grids:

- A family of refinement grids that encompass the South American continent with resolutions ranging from 100km down to 6km.
- For each horizontal grid, the high resolution region is aligned with an existing WRF grid (4km horizontal resolution and 60 levels).
- For each VR horizontal grid, there are two configurations for the vertical grid:

1. The Default L32 levels
2. An L70 option which maintains the same model top, but aligns additional levels with those from WRF.



4km WRF Domain



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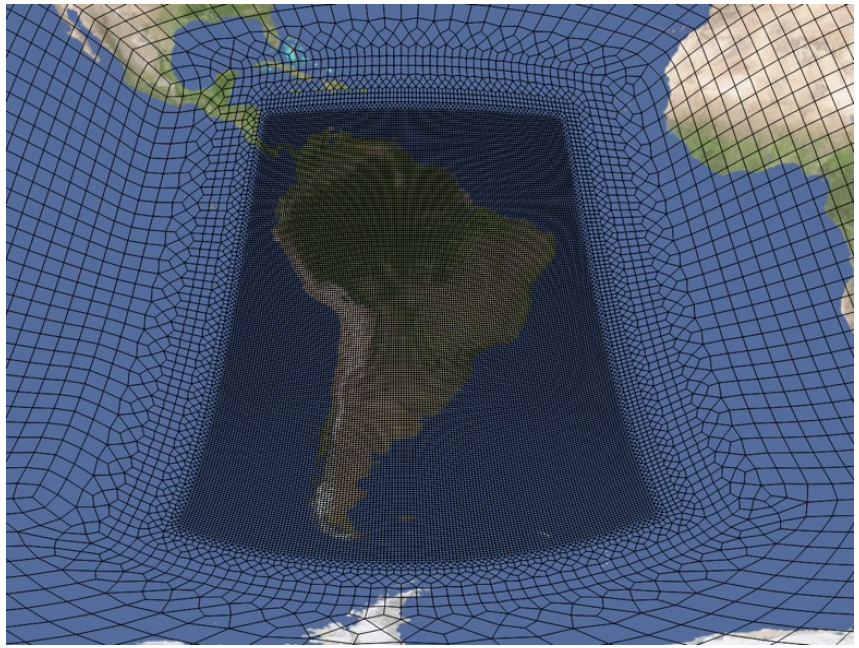
Overview of The South American Grids:

- In order to be consistent with WRF simulations, strong nudging to ERA5 outside the refinement region will be applied to impose boundary conditions.
- Since these grids will be run with nudged boundary conditions, the transitions to lower resolutions are not stretched out over as large a distance scale as they would otherwise be.
- To facilitate intercomparison of results, the VR grids in the high-res domain at each resolution are aligned such that each element corresponds to exactly 4 elements (2x2) at the next highest resolution.
- More details about why these grids were tailored to match this WRF grid in a bit.

12 km (ne240) Refinement



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The development of these grids is part of the CAM7 supplemental funding.

which overlaps with other efforts:

- Target climate configurations for SIMA
- MUSICA development
- NCAR Water Systems Group's recent focus on the South American region

A goal of this project is to simplify and streamline the workflow for VR grids.

So researchers can focus on science questions rather than on the “Modeling Mechanics” of how to setup and run with VR grids.

The Long version of the title is: Variable Mesh CESM for South America as a test-case for....

- Streamlining and simplifying the workflow for the creation, use, and validation of variable resolution grids.

- Assessing the fidelity of higher resolution simulations with intercomparisons with convective-resolving WRF (and future MPAS) results.

Outline:

- A brief summary of the current workflow
- Pending improvements and their impact on the workflow
- The problems that emerge at higher resolutions and the work that is being done to address them.

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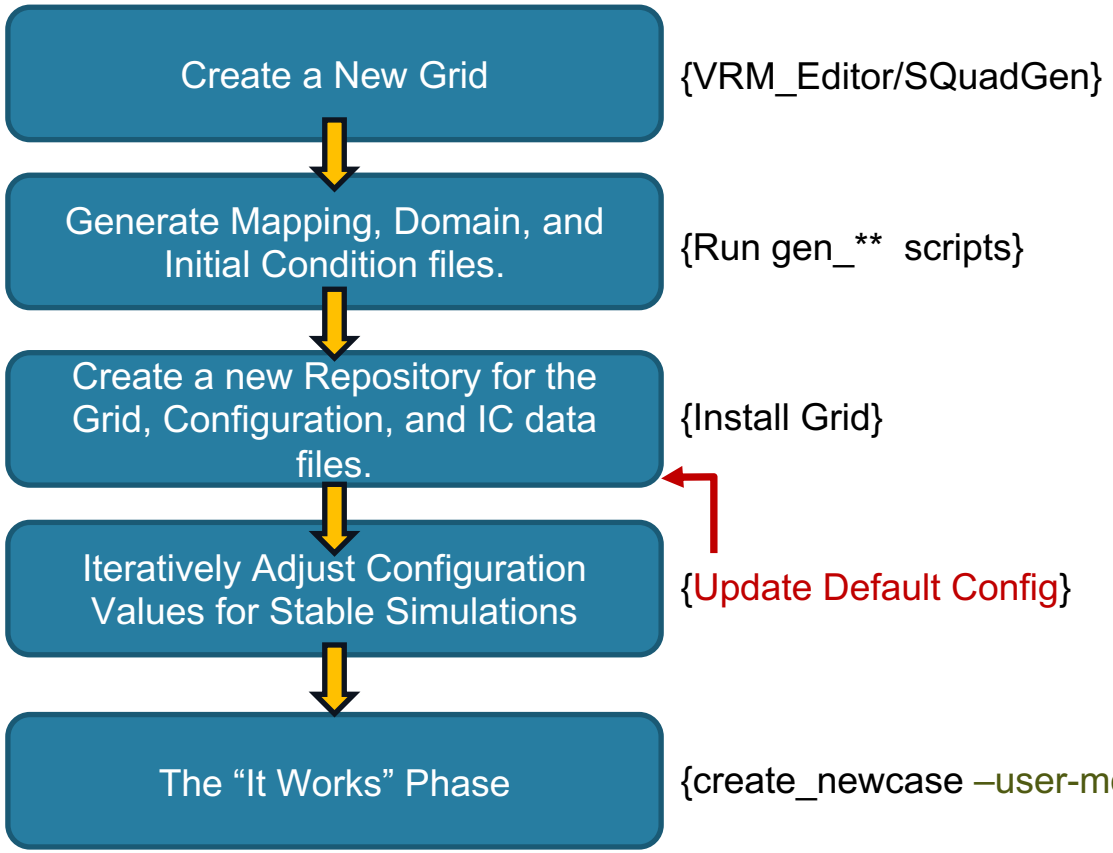
A brief summary of the current workflow:



The current process is fairly smooth and no major problems have been reported.

Some Problems:

- A 3km S. American grid with 4.4M grid points has not passed weak-scaling yet.
- The Topography software was not designed for scales as high as 3km.
- The documentation for running the topography software is confusing because it is a bit out of sync with recent code revisions.
- Processing the IC data can be difficult for Non-NCAR environment – locating and downloading the needed CESM data is NOT simple.

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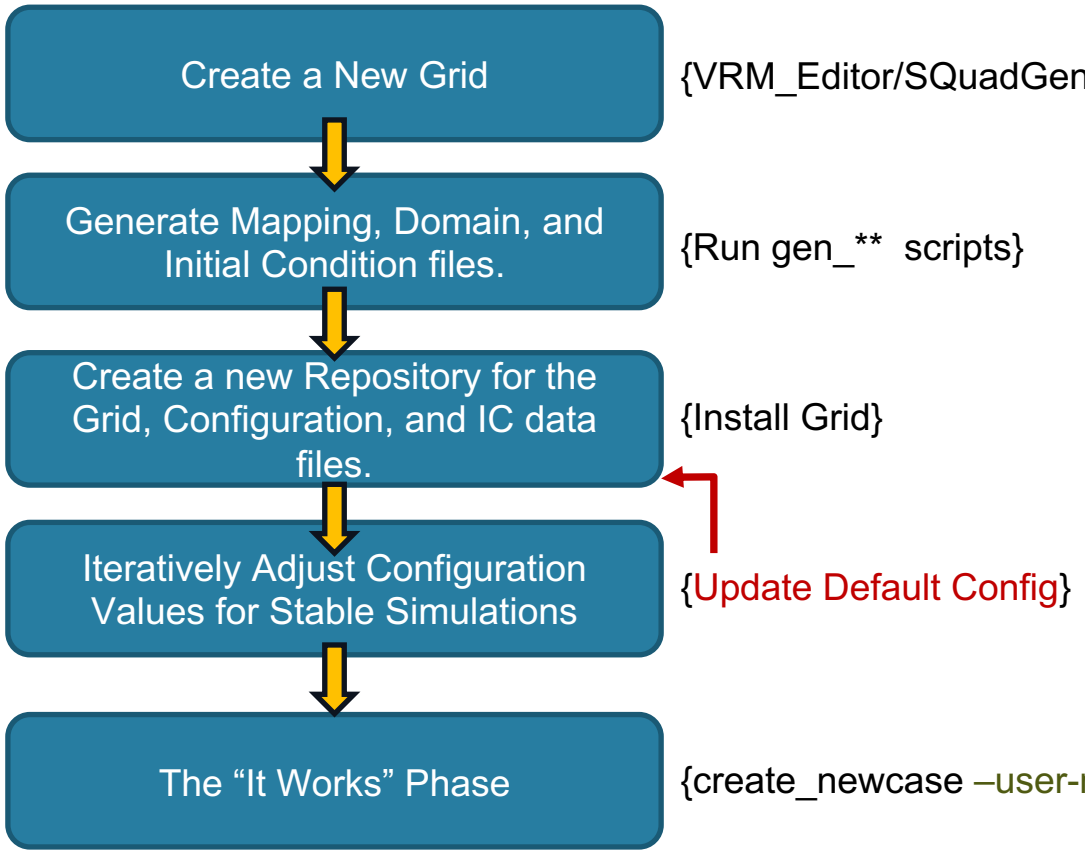
A brief summary of the current workflow:



Resources: (Adam Herrington, John Truesdale)

Tutorial on creating and getting a VR grid running for the South American domain. Available online.

VR tools and Documentation:
https://github.com/ESMCI/Community_Mesh_Generation_Toolkit

High resolution/ Variable resolution bulletin board:
https://bb.cgd.ucar.edu/cesm/forums/high-resolution-variable-resolution.163

High resolution / Variable resolution website:
A website will be available soon to provide:

- Full Documentation
- Tables of working configurations and mesh/datasets.
- FAQ's and links to additional help/resources.

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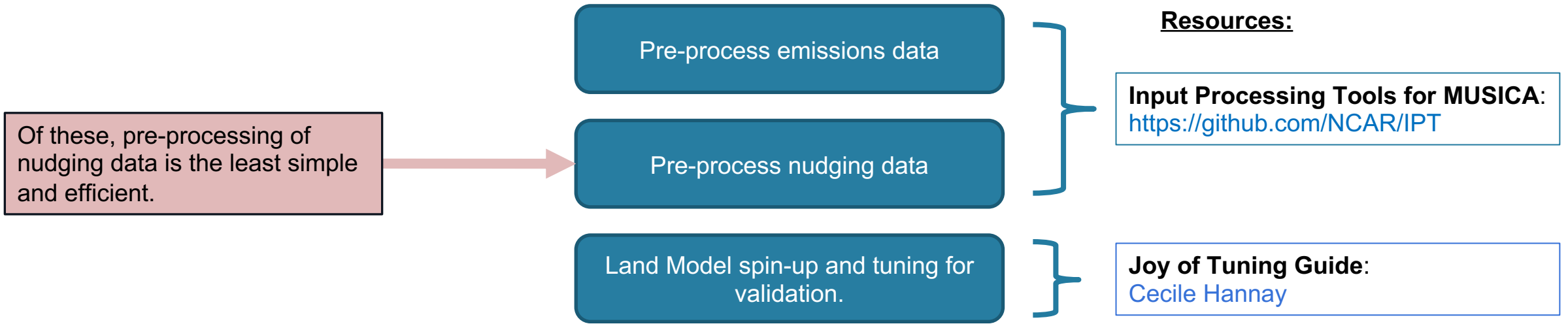
Further steps after the 'it works' phase:

Once the model is running, additional steps are needed to tune the model and preprocess any additional datasets that may be needed (depending on usage).



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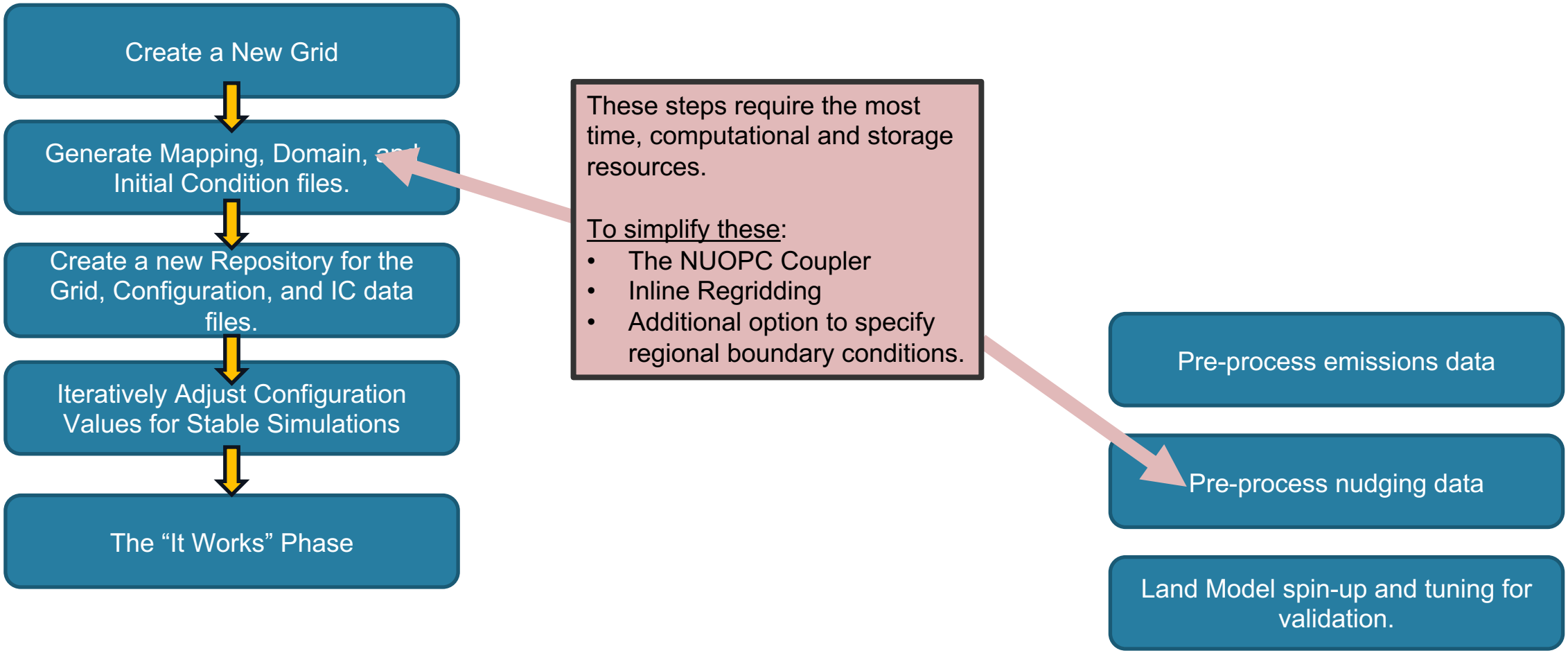
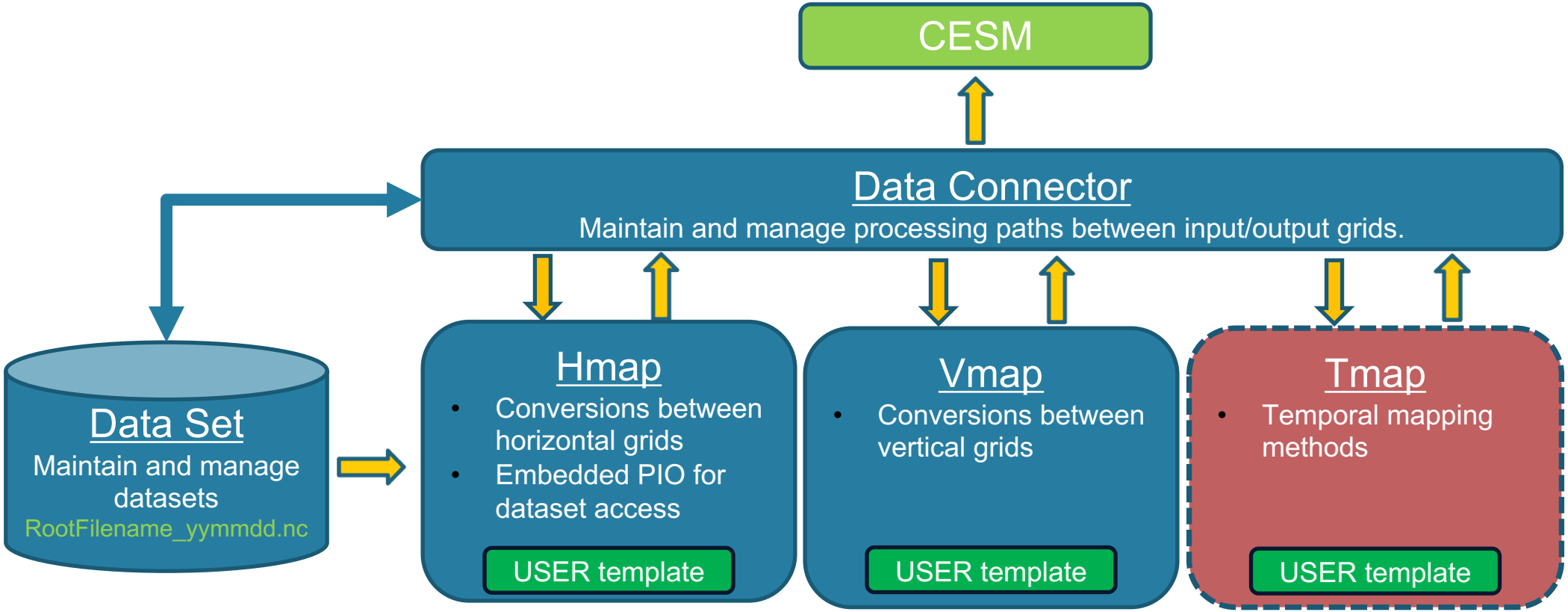


Variable Mesh CESM for South America

Pending Improvements:

The NUOPC Coupler: Will simplify (eliminate) the process of generating Mapping, Domain, and Initial Condition files.

Inline Regridding: Will also simplify this process and also eliminate the need to preprocess nudging data.



Variable Mesh CESM for South America

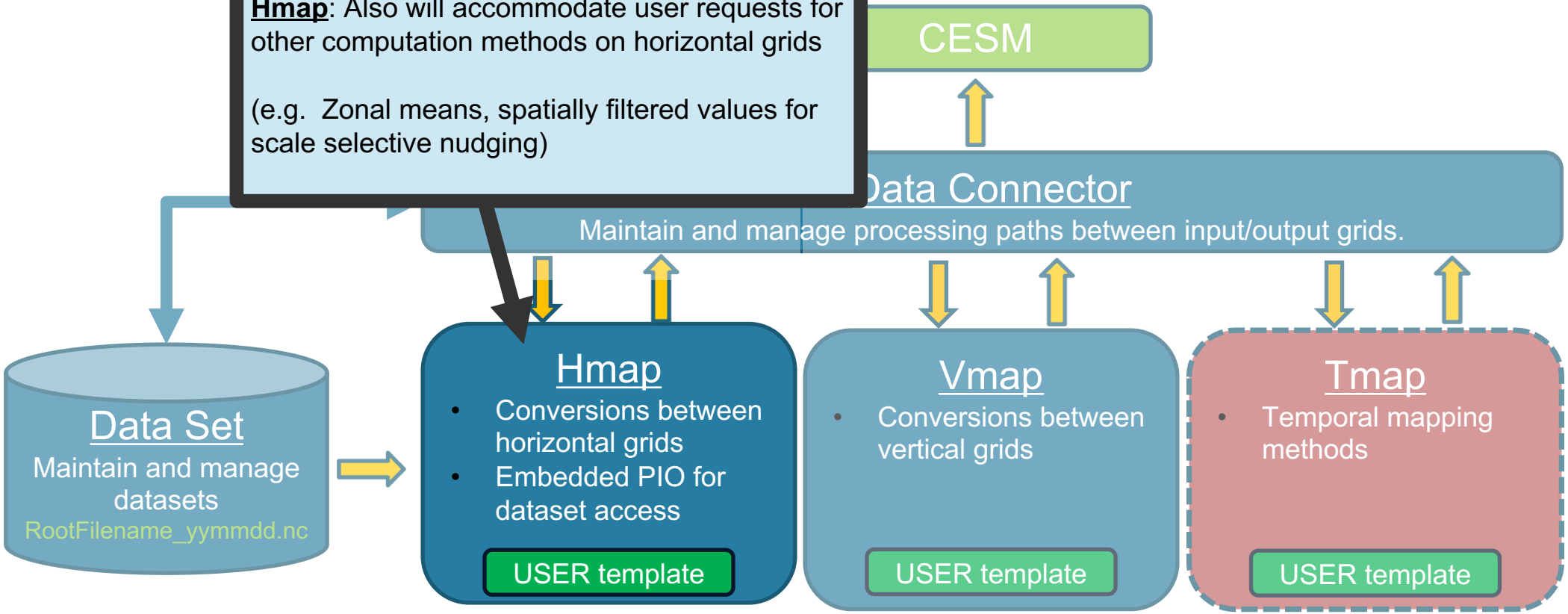
Pending Improvements:

The NUOPC Coupler: Will simplify the process of generating Mapping, Domain, and Initial Condition files.

Inline Regridding: Will also[illegible] preprocess nudging data.

Hmap: Also will accommodate user requests for other computation methods on horizontal grids

(e.g. Zonal means, spatially filtered values for scale selective nudging)



Variable Mesh CESM for South America

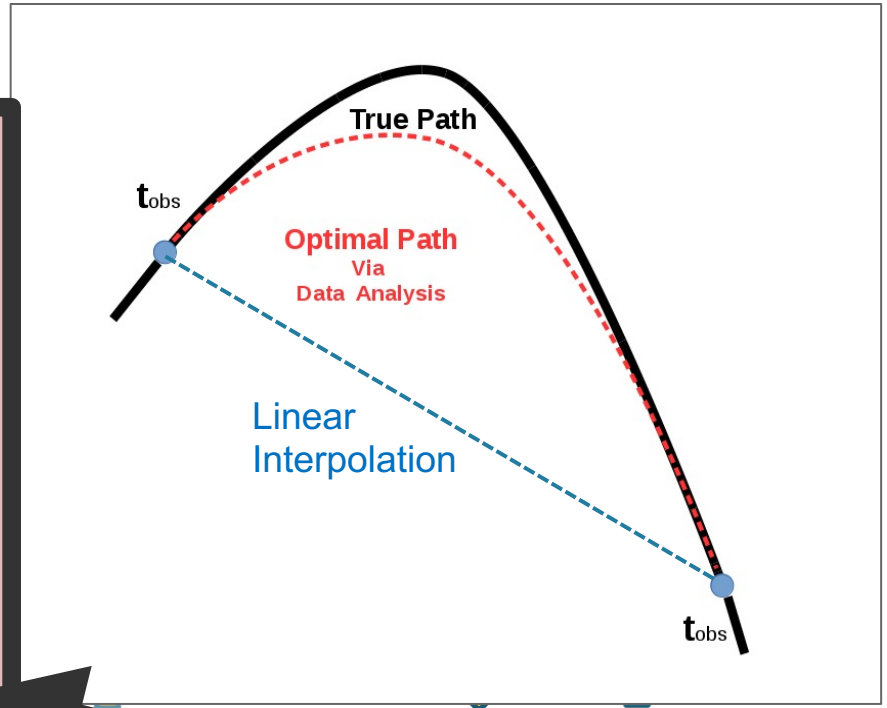
Pending Improvements:

Once the Horizontal/Vertical options have been validated, a temporal map module (Tmap) will be added to manage data time slices for higher order methods (e.g. local fit to a Diurnal cycle).

Currently nudging values applied at a given time are obtained via a linear interpolation between reanalysis time slices.

Davis, N. A., Callaghan, P., Simpson, I. R., and Tilmes, S.: Specified dynamics scheme impacts on wave-mean flow dynamics, convection, and tracer transport in CESM2 (WACCM6), Atmos. Chem. Phys. Discuss. [preprint], https://doi.org/10.5194/acp-2021-169, in review, 2021.

Showed that there are non-negligible errors introduced when the interval between time slices is longer than 1 hour.



Data Set
Maintain and manage datasets
RootFilename_yymmdd.nc

- Conversions between horizontal grids
- Embedded PIO for dataset access

USER template

ap
- Conversions between vertical grids

USER template

Tmap
- Temporal mapping methods

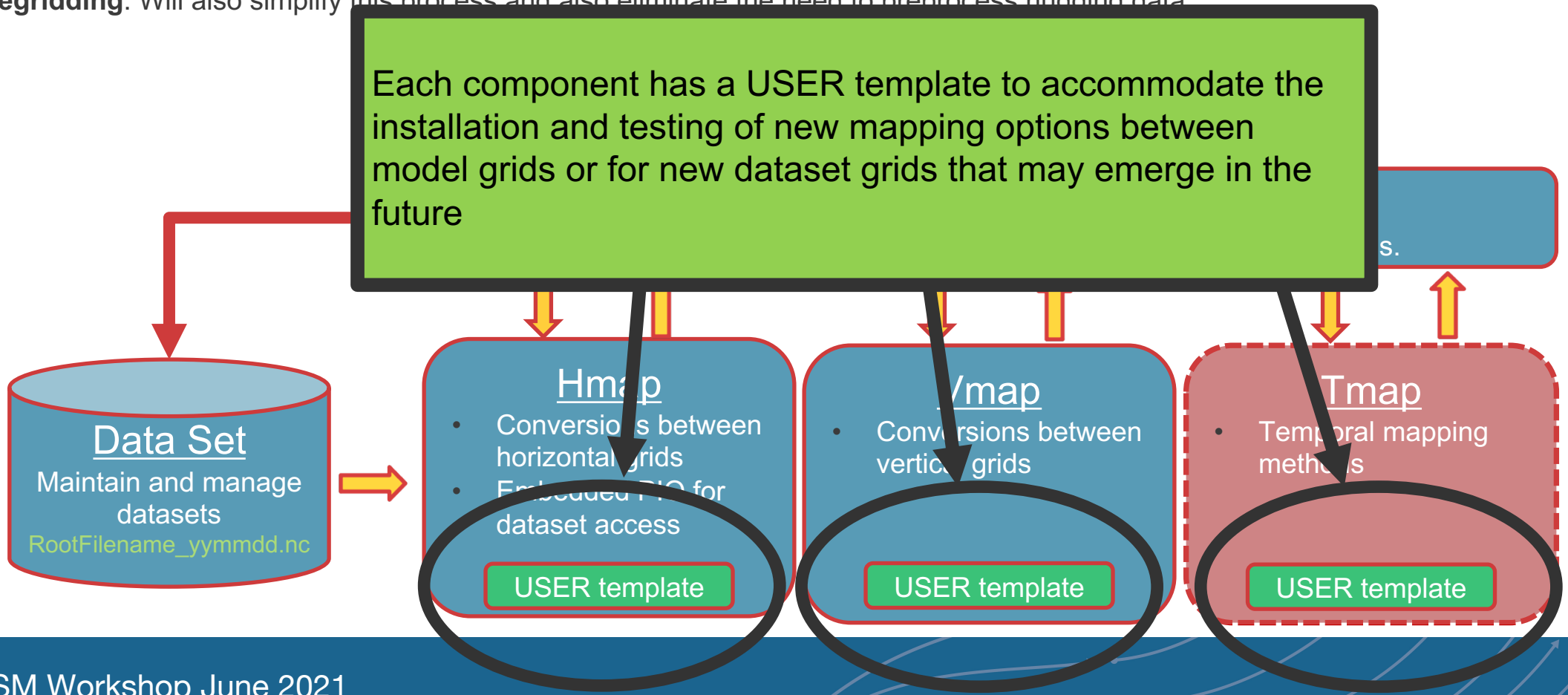
USER template

Variable Mesh CESM for South America

Pending Improvements:

The NUOPC Coupler: Will simplify the process of generating Mapping, Domain, and Initial Condition files.

Inline Regridding: Will also simplify this process and also eliminate the need to preprocess nudging data



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Pending Improvements:

- **Boundary Nudging**: Using the refinement map for the refined grid, or some other defined region, boundary conditions can be imposed independent of interior nudging.

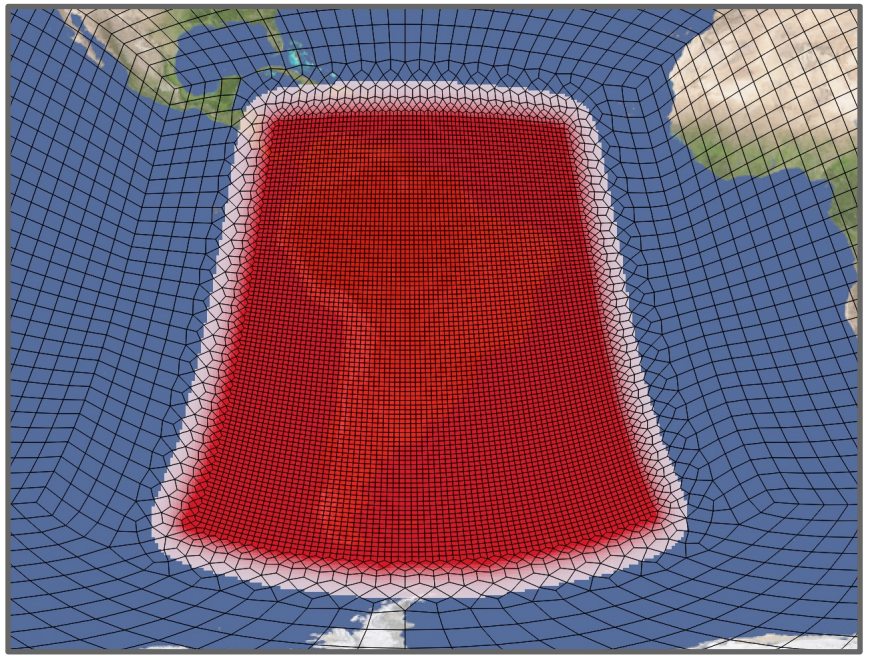
With the addition of runtime regridding, once the user creates a regional grid, the will be able to add boundary nudging to ERA5 (for example) with a few changes to namelist values.

No need to pre-process nudging data unless you really want to.....

New Nudging Features will further simplify the workflow for regional studies:

- Using the refinement map for the refined grid, or some other defined region, boundary conditions can be imposed independent of interior nudging.
- Selective nudging of larger scale variability: spatially filtered values, zonal means, etc.

25 km (ne120) refinement with boundary nudging window



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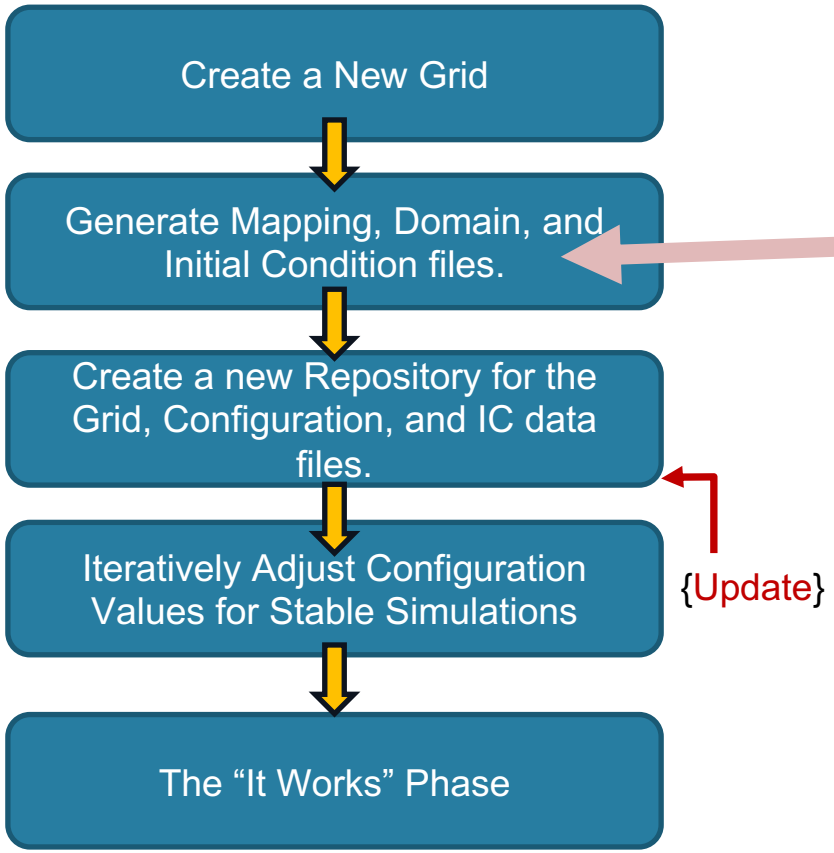
Improved workflow:



The work here will be greatly reduced.

The ultimate goal for optimizing the workflow... **Ease of use**.

Once a grid is created, the user should only have to spend a minimal amount of time getting the model running.

The compute resources, storage resources, and work here will be eliminated

- Pre-process emissions data
- Nudging requires only a modification of namelist values
- Land Model spin-up and tuning for validation.

Variable Mesh CESM for South America

With the ease-of-use, high resolution regional grids are becoming common.

Unfortunately these high resolutions expose two fundamental problems that may produce biases that limit the realism of CESM at very high resolutions

Breakdown of the Hydrostatic Approximation:

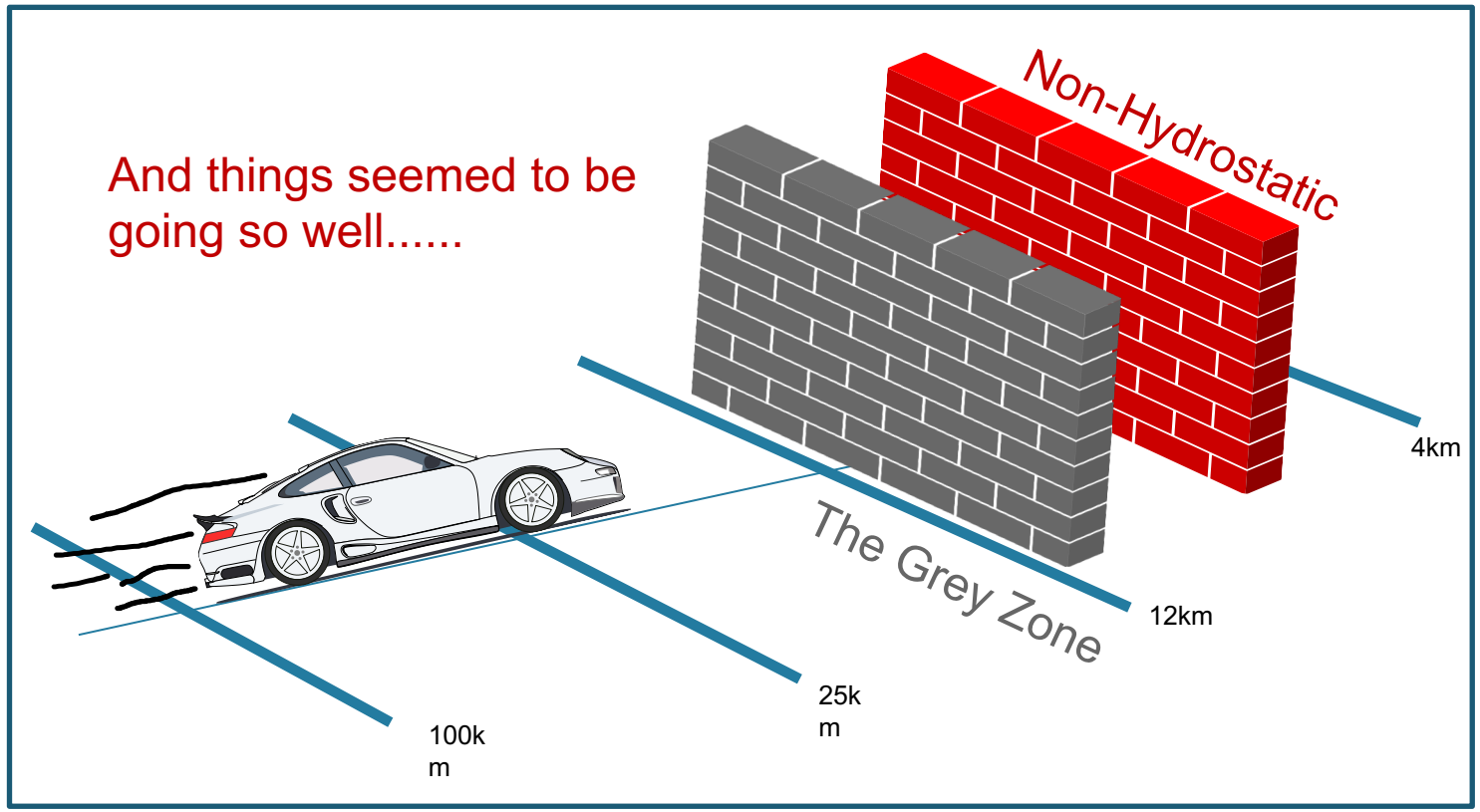
- As the grid resolution increases, the additional terms in the vertical momentum equation are no longer negligible.

The Grey-Zone Problem:

- The gap between scales at which parameterizations are valid and scales at which convection is adequately resolved.

- At resolutions in the sub-10km range, convection becomes partially resolved and the assumptions underlying convective parameterizations break down.

Ultimately, we want a model that is easy to use and also give realistic results.



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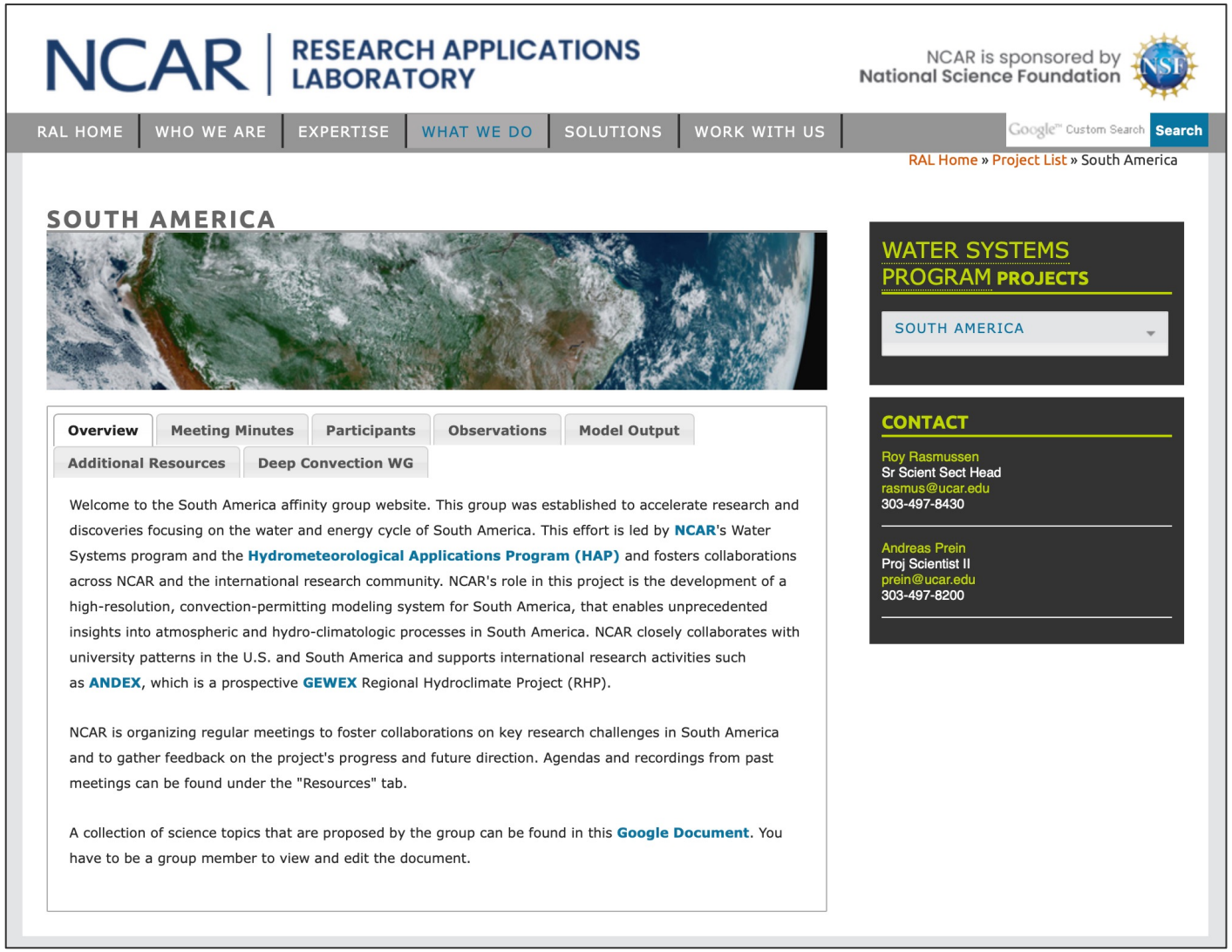
These problems lead us back to why the grid domain was chosen and configured the way it was.

South American Affinity Group (SAAG)
Website: **https://ral.ucar.edu/projects/south-america**

NCAR Water Systems Group's focus on the energy and water cycle of the South American region.

A collaborative effort across NCAR and the international research community.

NCAR's role: The development of a high resolution, convective-permitting modeling system for South America.



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SAAG Overarching Research Areas

This graphic provides an overview of proposed topics in overarching research areas.

Deep convection and extreme precipitation (tracking)
- Christopher Castro, UA
- Andreas Prein, NCAR
- Zhe Feng, PNNL
- Adam Varble, PNNL
- Lluís Fita, CIMA
- Erin Doughtery, NCAR
- Kristen Rasmussen, CSU
- Leila Carvalo, UCSB
- Aiguo Dai, SUNY
- Maria Laura Bettolli, CIMA
- Anton Seimon, Appalachian State
- Wojciech Grabowski, NCAR
- Sarah Tessendorf, NCAR

Orographic precipitation and glacier modeling
- Mathias Vuille & Justin Minder, SUNY
- Justin Minder, SUNY
- Mariano Masiokas
- Roy Rasmussen, NCAR
- Charles Jones, UCSB
- Monica Morrison, NCAR
- Trude Eidhammer, NCAR
- Julio Bacmeister, NCAR
- Clémentine Junquas, IGE/IRD

Tropical Waves
- Rich Neale, NCAR

Regional Downscaling over Colombia
- Germán Poveda, UNAL
- Lucia Scaff, UCSB

Low-Level Jets
- Alejandro Martinez and Paola Arias
- Lucia Scaff, UCSB
- Charles Jone, UCSB
- Germán Poveda, UNAL

La Plate basin hydrology
- Moira Doyle, CIMA
- Lluís Fita; CIMA

Land-Atmosphere Interactions
- Francina Dominguez, UI
- Fei Chen, NCAR
- Stephanie Spera, Urichmond
- Kate Halladay, UKMO
- Franciano Puhales,
- Peter Lawrence, NCAR
- Curtis Walker, NCAR
- Alejandro Martinez, UdeA
- Clémentine Junquas, IGE/IRD
- Marcia T Zilli, U. Oxford

Model Inter-comparison
- Julio Bacmeister, NCAR
- Patrick Callaghan, NCAR
- Zhe Feng, PNNL
- Kate Halladay, UKMO
- Monica Morrison, NCAR
- Andreas Prein, NCAR
- Marcia T Zilli, U. Oxford

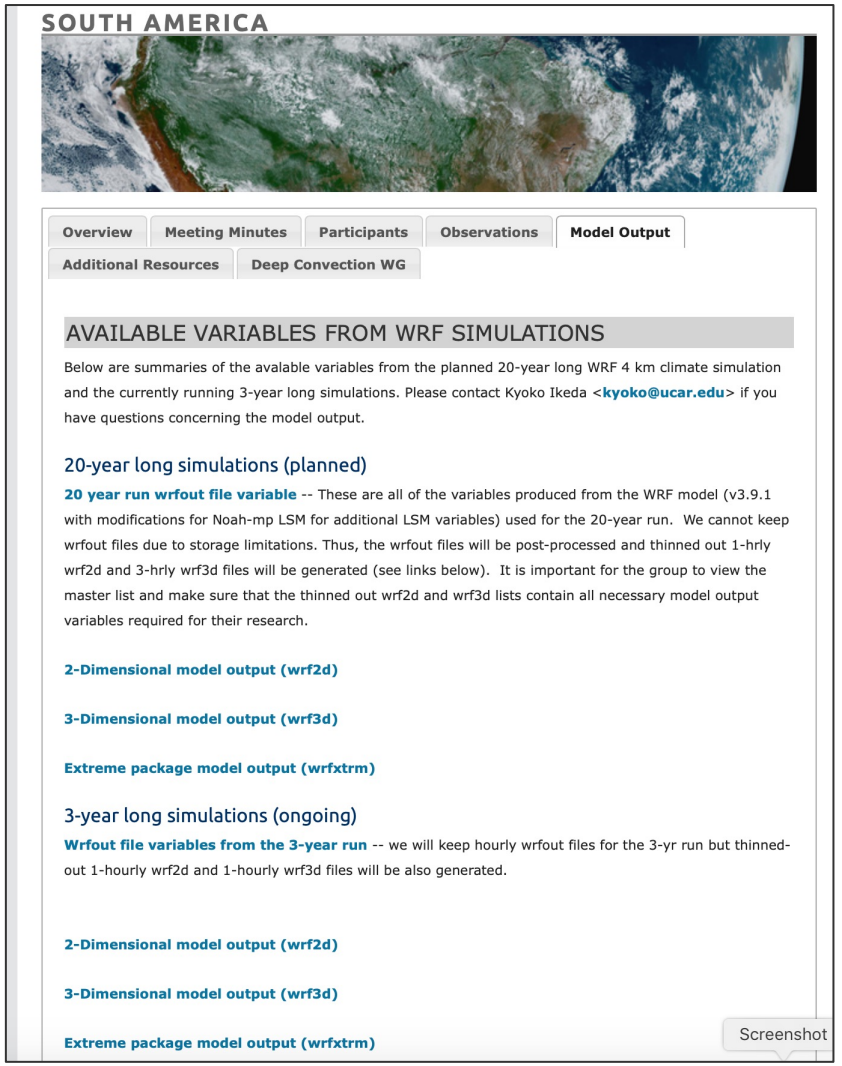
Three 1-year long simulations are underway for each Phase of ENSO:

June 2010 – May 2011	La Nina year
June 2015 – May 2016	El Nino year
June 2018 – May 2019	ENSO Neutral

The results from these simulations provide a great resource for assessing CESM results across horizontal resolutions.

Observational data for the region will be used to evaluate results from WRF and CESM.

Future: 20-year long simulations are planned.



High Resolution Intercomparison of Variable Resolution CESM with Convection Resolving WRF Simulations of the South American Continent

Spring 21 NSC Allocation:
Patrick Callaghan (AMP)
Richard Neale (AMP)
Julio Bacmeister (AMP)
Kristen Rasmussen (CSU)

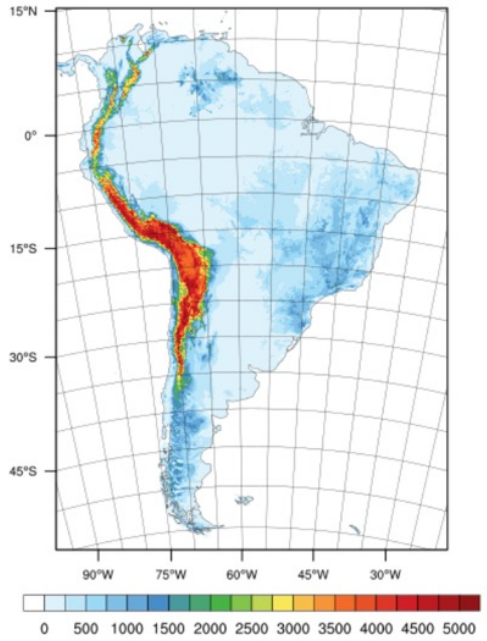
A series of 1 year simulations for refined regions over the South American continent aligned with 4km WRF domain:

Resolution		# of Grid points	
100 km	(ne30)	48,602	[no refinement]
25 km	(ne120)	116,534	
12 km	(ne240)	337,503	
6 km	(ne480)	1,167,113	

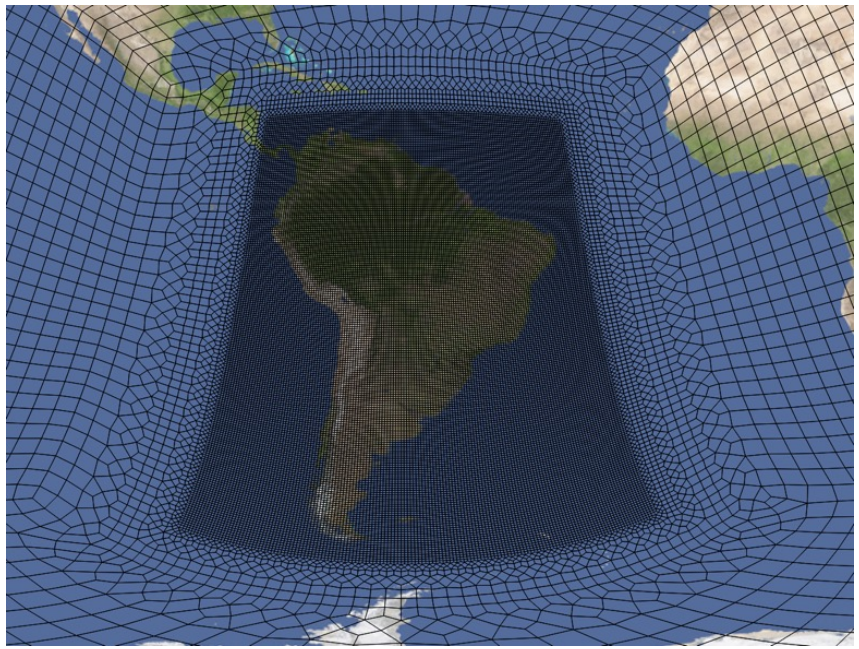
3 Phases of ENSO:

June 2010 – May 2011	La Nina year
June 2015 – May 2016	El Nino year
June 2018 – May 2019	ENSO Neutral

4km WRF Domain



12 km (ne240) Refinement



Vertical Resolutions
CESM default 32 levels
70 level configuration aligned with WRF levels

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All experiments consist of a set of simulations for the four horizontal resolutions (100, 25, 12, 6) km.

Baseline 1-year simulations for each phase of ENSO:

- With deep convection on/off
- With 70 levels.

1-year simulations for select ENSO phases:

- With deep convection on/off
- With the default 32 vertical levels.
- With alternate reference surfaces for damping.
- With alternate spectral damping

The alignment of the spectral elements for these grids allows for a high order partitioning of the 4km WRF results into resolved and sub-grid values at each resolution.

The resolved values nominally represent the results we expect to obtain from lower resolution simulations.

Ideally, parameterizations representing this sub-grid variability will reproduce tendencies that recover the evolution of the resolved scales.

Non-Hydrostatic Corrections:
To address the hydrostatic limitations, additional non-hydrostatic correction terms will be included and evaluated in comparisons with WRF results.

Hydrostatic Approximation replaces the vertical momentum equation with an analytical constraint.

Non-Hydrostatic correction terms other than those associated with $\left(\frac{\partial \dot{\eta}}{\partial t}\right)$ and $\left(\frac{\partial Z_\eta}{\partial t}\right)$ can be included in the vertical momentum equation without having to modify the current prognostic equations.

The resulting differential constraint, cast in terms of a hydrostatic defect H, can be readily solved via a fixed point iteration.

With associated non-hydrostatic contributions, (where H≠1), distributed throughout the governing equations.

Variable Mesh CESM for South America

These South American VR simulations and the contemporaneous high resolution WRF simulations will provide a valuable resource for the development/improvement of parameterizations.

Future work:

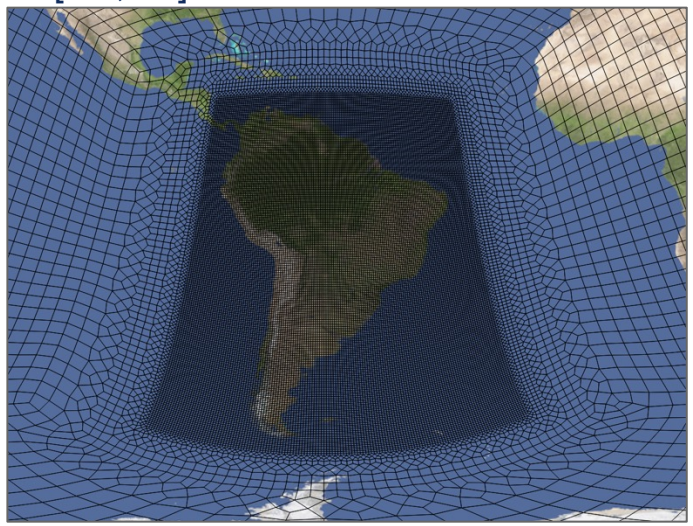
A 3km (ne960) option will be added to the current family of grids when the remaining problems with it are resolved.

A future Non-hydrostatic MPAS simulation for South America will provide an additional resource for model intercomparison and development.

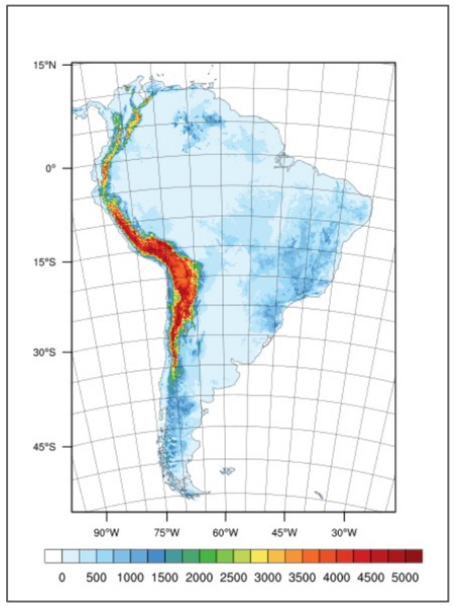
Family of VR Grids For S. America

[100, 25, 12, 6, and 3] km horizontal grids

[32, 70] vertical levels

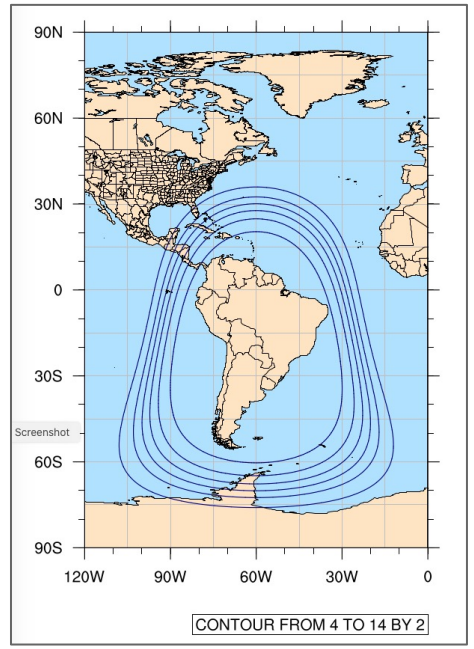


4km WRF Domain



MPAS S. America Grid

B. Skamarock, NCAR



Thank You