Plans and results from the NOAA Climate Modeling Program

WGNE-24
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Outline

1. NOAA Climate Modeling from a WGNE perspective
2. Earth System model development
   - Atmospheric physics and chemistry
   - Marine and terrestrial biogeochemistry
3. Climate modeling at high resolution
   - Regional scales are better represented
   - Decadal predictability
   - Hurricanes and climate change
4. Achieving model and data interoperability
   - GFDL models for these studies
   - Model and data interoperability
5. Near-term plans
   - CMIP5 and other model intercomparison projects

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At the boundary of climate and weather models

The NOAA Climate Program has many goals:

- support NOAA's mission to understand and predict changes in the Earth's environment by
  - improving climate predictive capability from weeks to decades with an increased range of applicability for management and policy decisions
  - developing and contributing to routine state-of-the-science assessments for informed decision making
- support NOAA's mission to provide short-range (seasonal to interannual) climate forecasting and services by
  - developing model components with the desired accuracy and conservation properties needed for these integrations;
  - transferring expertise from research to operational short-term climate forecasting by making such model components available using standard interfaces.

Toward "high resolution" in climate and "extended range" in weather

- Climate research and policy increasingly demands accurate understanding and predictive capabilities on the regional scale, driving the models toward higher resolution.
- The range of operational forecasts is increasing, and extended range forecasts of measurable skill are in demand.
- The predictability of the climate system on decadal timescales is a hot area of research.
- The prediction of hurricane frequencies and intensities in a warming world is emerging as a key research-to-operations transitional area of research.

NOAA is actively planning to build a seamless capability spanning these time and space scales, as well as research and operations, with hurricane research and prediction as a central grand challenge.

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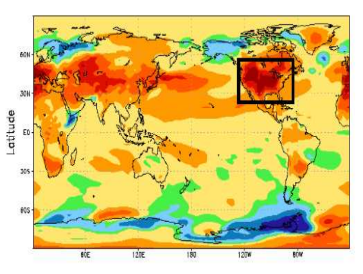
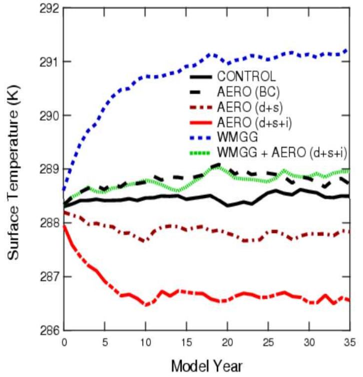
New atmospheric physics and chemistry

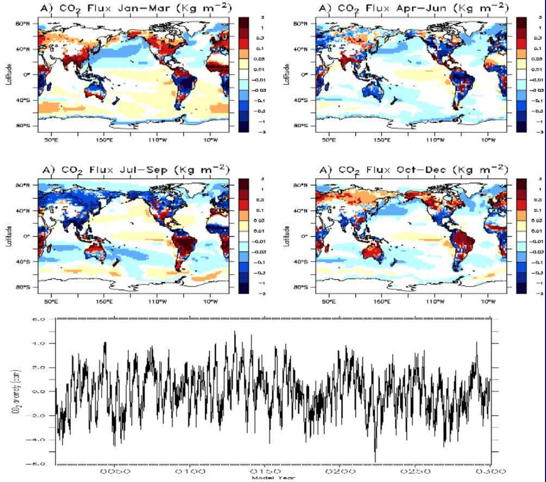


- Aerosol (direct and indirect) effects are comparable in magnitude to greenhouse warming. (Figure courtesy Yi Ming and V. Ramaswamy, NOAA/GFDL).

- Even in the absence of greenhouse forcing, changes to short-lived species are a significant source of warming. (Levy *et al* 2008).



Pre-industrial CO_2 variability in ESM2.1



Free-running carbon cycle in ESM2.1 (interactive biosphere; CO_2 radiatively inactive). Figure courtesy John Dunne, NOAA/GFDL.

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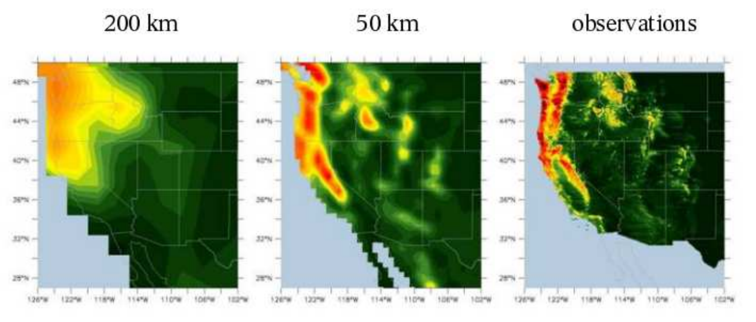
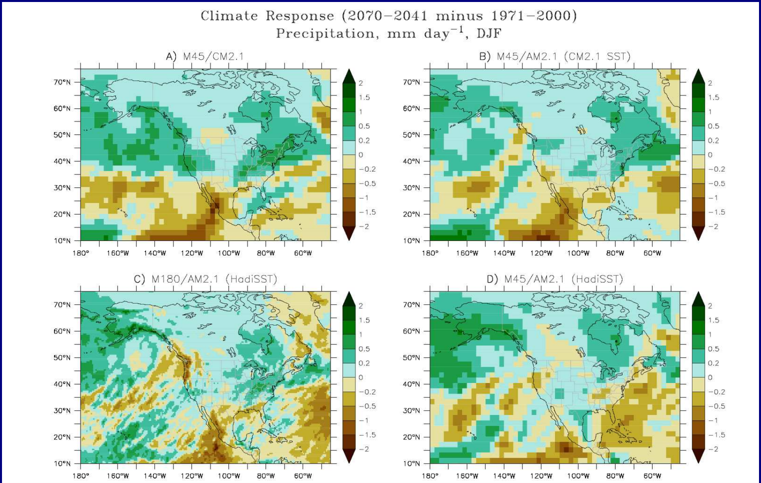
Regional scales are better represented



- There is a dramatic improvement in our ability to model regional scale climate response as we go to “high” (i.e beyond the IPCC AR4 norm) resolution. (Figure courtesy Isaac Held).

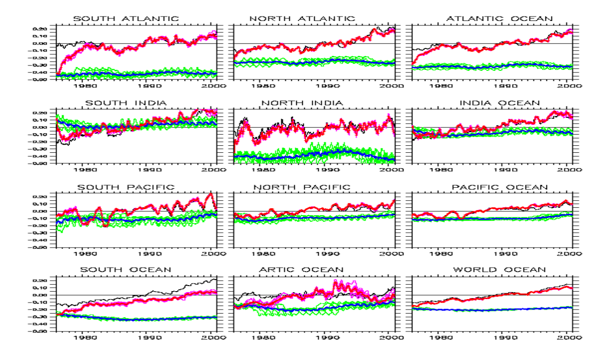
NARCCAP: North American regional climate change



"Global downscaling" time-slice experiment for NARCCAP. (Figure courtesy Bruce Wyman and Isaac Held, NOAA/GFDL).

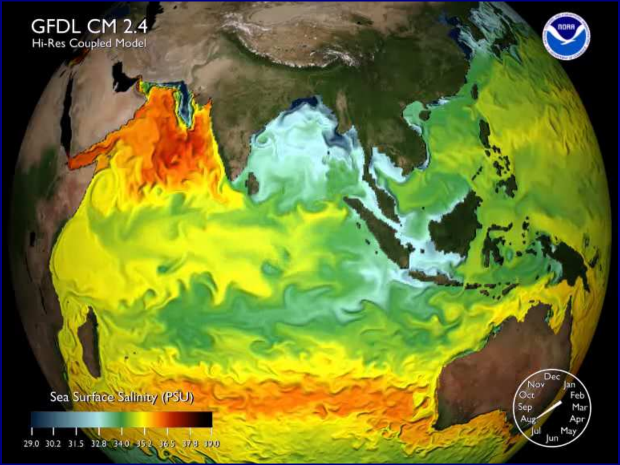
Decadal predictability in the Atlantic

Just as ENSO in the Pacific may modulate climate on a timescale of a few years, the modes in the Atlantic may modulate climate on decadal timescales. This is currently being proposed as the basis for decadal climate prediction (Keenlyside *et al* 2009; Smith *et al* 2007). Can models reproduce decadal predictability?



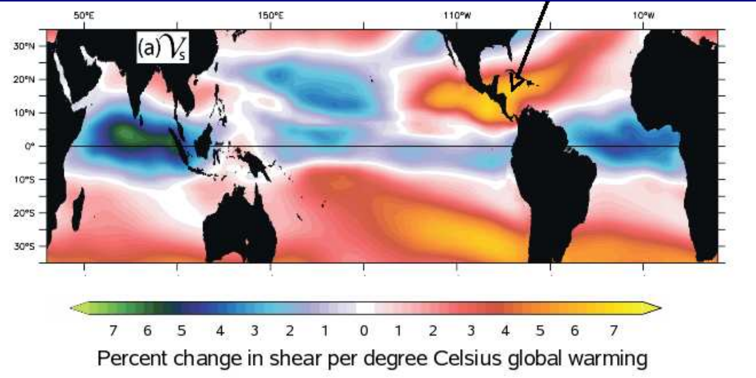
(Figure courtesy Shaoqing Zhang, NOAA/GFDL).

Preliminary results from CM2.4



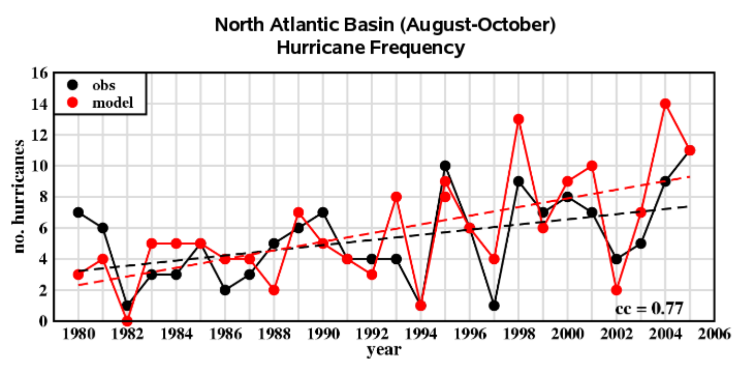
CM2.4 couples a 25 km resolution ocean (“eddy permitting”) model to a 100 km resolution atmosphere (“tropical cyclone permitting”) model. (Figure courtesy Tony Rosati and Tom Delworth, NOAA/GFDL).

Hurricane frequencies might decrease in a warming world. . .



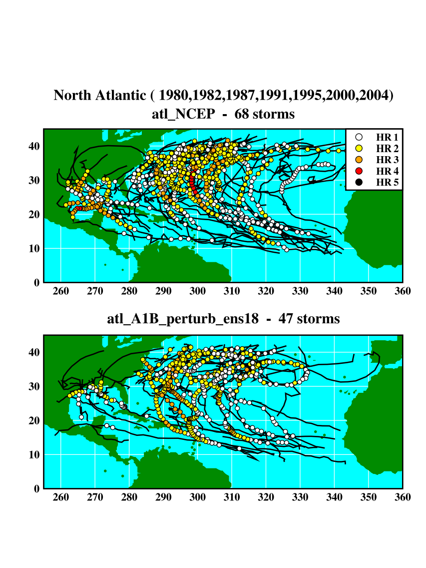
Vecchi and Soden (2007) show wind-shear increasing in a warming world, potentially leading to a decrease in Atlantic hurricane frequency (though not elsewhere. . .)

NOAA high-resolution models capture hurricane statistics



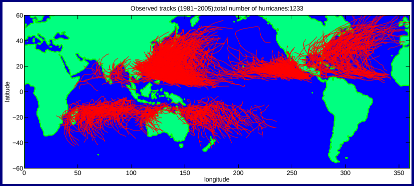
NOAA regional model ZETAC captures inter-annual variability in hurricane frequency when forced with historical data (Knutson et al 2007). This study is being repeated now for a warming world from IPCC AR4 data to confirm or refute Vecchi and Soden.

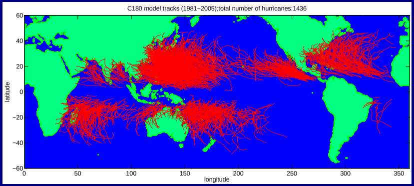
Vecchi and Soden results corroborated



Preliminary regional model results show reduced Atlantic hurricane frequency in the late 21st century. Forced regional model results need to be supported by global coupled models for a complete understanding of this key result. NOAA models are ready to make the leap given enough computing and analysis power. (Figure courtesy Joe Sirutis, NOAA/GFDL).

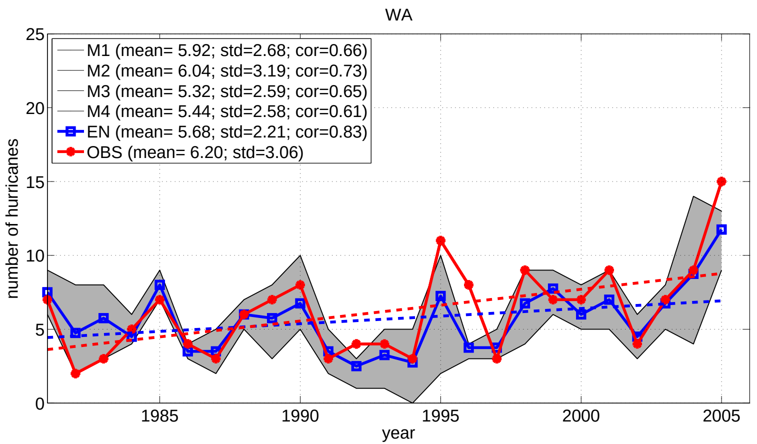
Hurricane statistics from global high-resolution atmosphere models





Observed and modeled hurricane tracks from 1981-2005 in a global 50 km (C180) atmospheric model forced by observed SSTs. (Figure courtesy Ming Zhao and Isaac Held, NOAA/GFDL).

Interannual variability of hurricane frequency



Interannual variability of W. Atlantic hurricane number from 1981-2005 in the C180 runs. (Figure courtesy Ming Zhao and Isaac Held, NOAA/GFDL).

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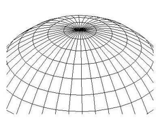
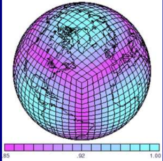
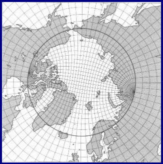
NOAA/GFDL Models and the FMS Mosaic infrastructure



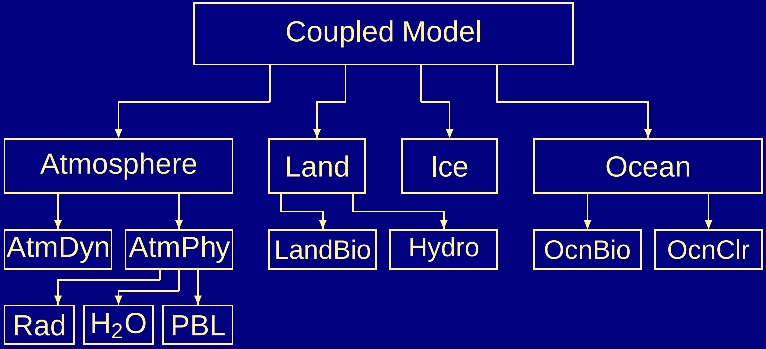




- The Finite-Volume conventional grid dycore (`FVLL`): Fourier filter at the pole limits scalability on distributed memory.
- The Finite-Volume Cubed-Sphere dycore (`FVCS`) eliminates the pole and vastly increases scalability on distributed memory.
- The ocean model in these experiments is `MOM4`, running on a tripolar grid: also has no pole problem. The newer `GOLD` model is also tripolar.
- Parallelism in all the models is provided by the FMS `Mosaic` infrastructure, which handles parallel I/O and communication (`MPI`, `shmem`, threads).

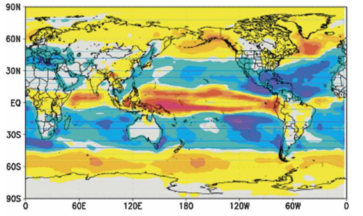
Model interoperability

The construction of complex Earth system models out of *components* is now commonplace in the design of modeling software. ESMF (US) and PRISM (EU) are emerging standards for making interoperable model components.



Data interoperability

- *Multi-model ensembles*, where experiments are replicated across many models, are a key element in the arsenal of extended-range forecasting and climate research. Example: the IPCC data archive, a composite analysis across 24 models from 18 institutions shown on right.



Held and Soden (2006).

- Weather and climate communities typically use different formats (netCDF, GRIB). The *CF Conventions* are developing common format-neutral standards and conventions for climate and forecasting. The GO-ESSP consortium provides a venue for debating and designing these standards.
- The Task Force on Seasonal Prediction (TFSP) is developing conventions specifically aimed at a multi-model ensemble.

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Participation in comparative modeling studies

A considerable fraction of NOAA/GFDL's model development activity has been geared toward participation in CMIP5 and related model comparison projects (CFMIP, CORE, OCMIP, NARCCAP/RCMIP, ozone assessment, . . .). These runs encompass several broad thrusts:

- Decadal predictability studies at the highest practical resolution (CM2.4 or CM2.5);
- CMIP5 "carbon" runs in an Earth System model (resolutions comparable to CM2.1);
- atmospheric and coupled model runs with enhanced physics and chemistry, enhanced vertical extent and resolution.
- The CHiMES project is a collaboration between NOAA and DoE to apply large-scale computing resources to these efforts.
- Close collaboration with PCMDI and others to develop standards, protocols, and a distributed archive for these projects. GFDL expects to host 100-200 TB.

Concluding remarks

- Decadal prediction is a key area of NOAA climate research. Current activities include running high (cyclone- and eddy-permitting) resolution coupled models initialized from observations to explore the limits of decadal predictability. These runs will also be part of NOAA's contribution to CMIP5.
- High resolution regional and global models demonstrate impressive skill in modeling overall numbers and interannual variability of tropical cyclones.
- The CHiMES project (`http://www.gfdl.noaa.gov/~vb/chimes`) is a collaboration between NOAA and DoE to apply large-scale computing resources to these efforts.
- As multi-model ensembles become a central methodology in both extended-range forecasting and climate prediction, data and model interoperability are areas requiring urgent attention.

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