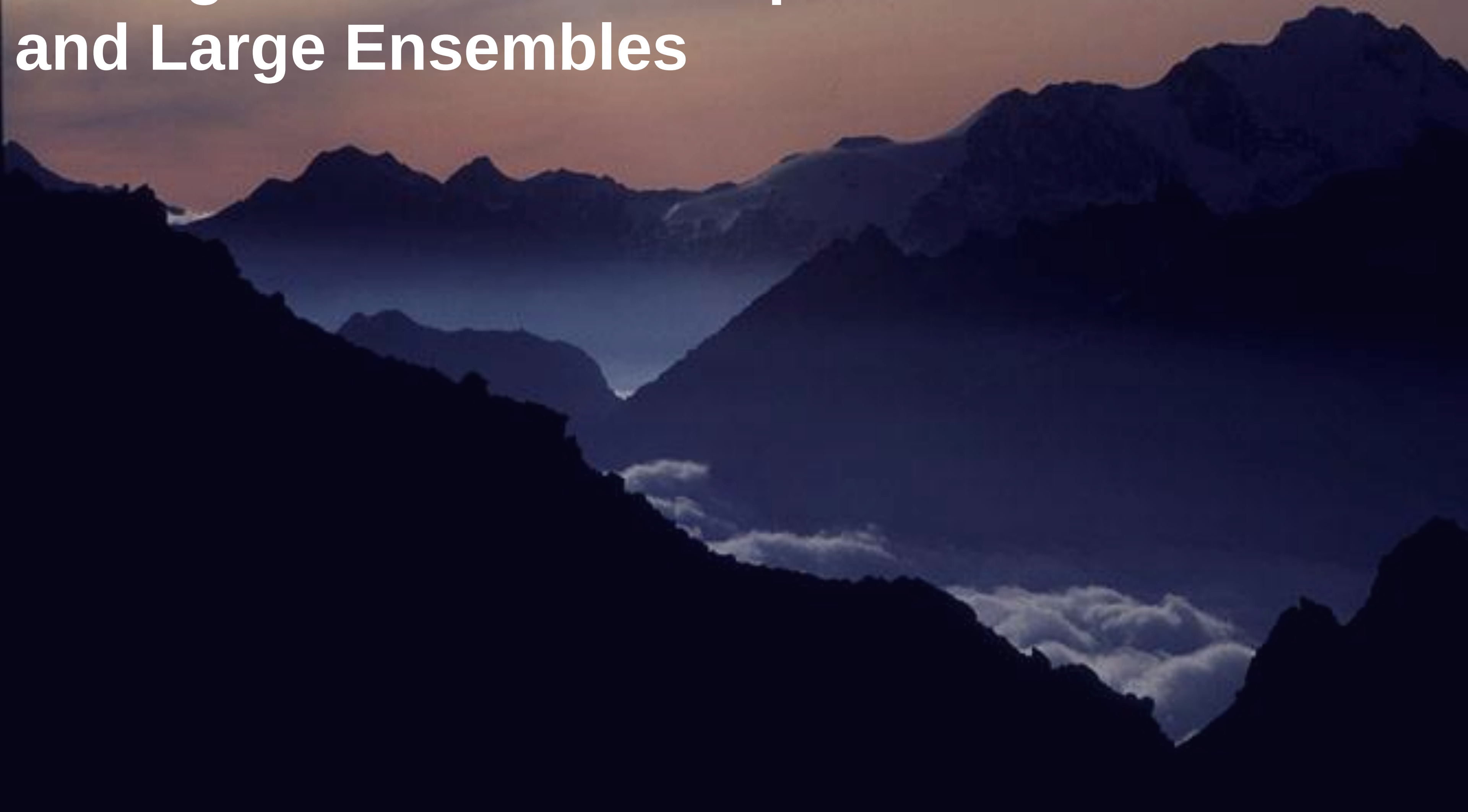
ISI Climate Prediction: Requirements for High-Resolution Coupled Models and Large Ensembles



38th Climate Diagnostics and Prediction Workshop

College Park, MD   23 October 2013

Jim Kinter

COLA & GMU

COLA Moves to GMU Fairfax Campus

GMU Research Hall – Home of AOES and COLA.

The Center for Ocean-Land-Atmosphere Studies (COLA) will become an integral part of George Mason University (GMU) in 2013-14. The COLA scientific and technical staff and the COLA computing facility have collocated with the Climate Dynamics PhD Program and the department of Atmospheric, Oceanic and Earth Sciences on the GMU main campus in Fairfax, Virginia.

GMU Ph.D. Program Climate Dynamics

Affiliated with the Department of Atmospheric, Oceanic, and Earth Sciences

CURRENT SEARCH: 2 ASST. PROFs

& INTERDISC. PROF. GLOBAL ENV. & SOC.

& DEAN OF COLLEGE OF SCIENCE

Faculty

- **T. DelSole;** PhD, Harvard
- **P. Dirmeyer;** PhD, Univ. of Maryland
- **B. Huang**; PhD, Univ. of Maryland
- **V. Krishnamurthy**; PhD, MIT
- **J. Kinter**; PhD, Princeton
- **B. Klinger**; PhD, MIT/WHOI
- **E. Schneider;** PhD, Harvard
- **P. Schopf** (chair, AOES); PhD, Princeton
- **J. Shukla** (director); PhD, BHU; Sc.D., MIT
- **C. Stan**; PhD, Colorado State Univ.
- **D. Straus**; PhD, Cornell

Predictability* of the Climate System

Overarching Scientific Questions

What limits ISI predictability? Is there a fundamental limit? What is the role of model error? Initial conditions error?

How do the initial state, the coupling of system components, and the changes in external forcing contributes to predictability at these time scales?

What aspects of the total climate system (troposphere, stratosphere, world oceans, land surface, vegetation, sea ice, land ice, snow) are predictable in which geographic regions, for which seasons, and how does that change in the future?

*** Note: Predictability is a necessary (but not sufficient) condition for attribution**

Predictability – a Model Construct

Forecast System Structure

What are we trying to predict? NB: ISI prediction problem is probabilistic.
(Significant) shifts in the probability distribution, e.g., ΔPOE; → use ensembles

What is the optimal way to generate an ISI prediction ensemble?

(For NWP: sample uncertainty, e.g. by maximizing projection of ICs on most uncertain modes.)

What is the optimal size of an ISI prediction ensemble?

(Likely depends on the predictand, desired accuracy and resolution of the PDF etc.)

No current model is perfect, e.g., for predicting the regional hydrological cycle, so …
What is the optimal combination of models (NMME) to predict means? extremes?

Does model resolution matter for ISI prediction? What is the optimal atmospheric, oceanic, land surface and sea ice resolution for ISI prediction?

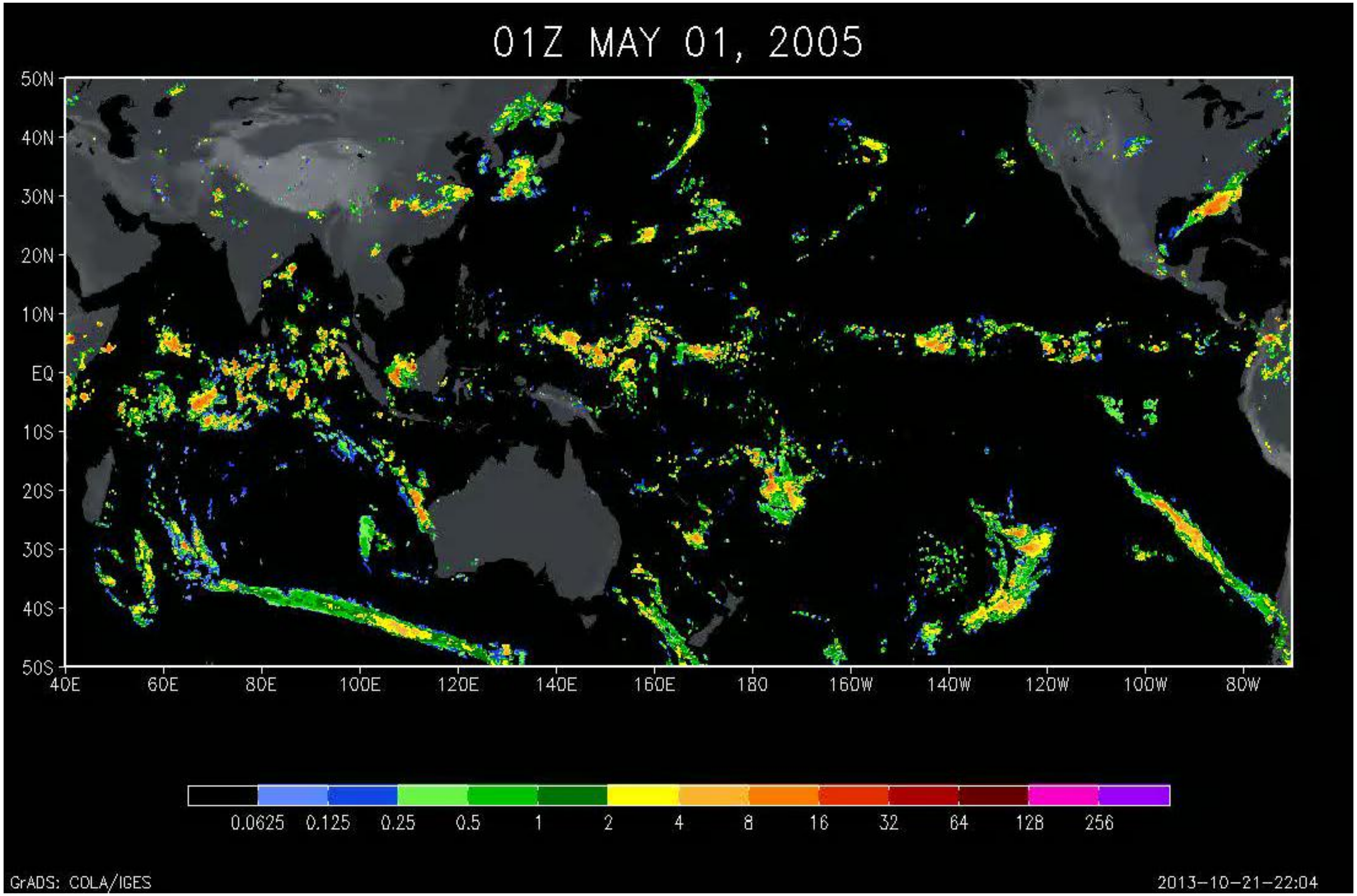
(Depends on predictand, desired accuracy and acuity etc.; e.g. it matters for regional hydrological cycle)

Assertions

- As in any numerical solution to discrete equations, we expect **an asymptotic approach to the true dynamical solution** as we reduce the grid spacing to zero (neglecting SGS physics issues)
- Assuming that ensemble members are generated in such a way as to optimally sample uncertainty, we expect **better resolution of the PDF** as the ensemble size increases, perhaps with diminishing returns
- **Seamless weather and climate prediction** involves initialization (and presumably therefore data assimilation) of climate predictions, identifying “weather in climate” and “climate in weather” and running numerical models through the deterministic NWP lead times to S2S/ISI and longer lead times
- Resources are finite, so trade-offs must be made – **are these trade-offs and limitations masking real progress** or are there systemic limits to predictability that we have begun to reach?

What Aspects of This Can/Should We Predict? At What Lead Times?

NOAA High-Res Precipitation Analysis (courtesy P.-P. Xie)



Courtesy Brian Doty, COLA

Recent Projects Aimed at Questions of Resolution and Ensembles

Project Athena: An International, Dedicated High-End Cor … nize Climate Modelin …

PetaApp … of atmospheric noise in … ity

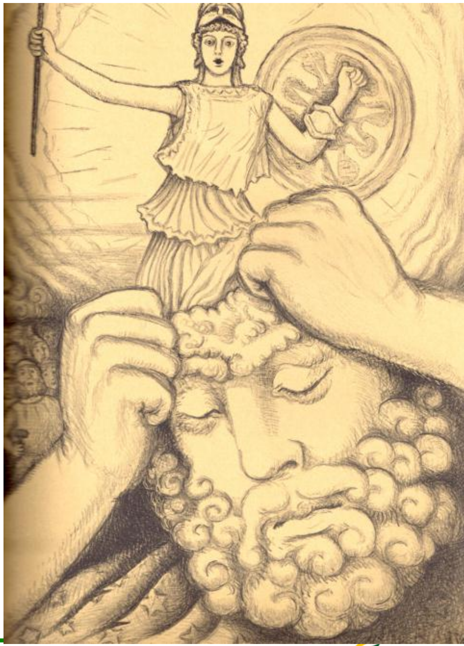
Just Do It! TM

Project Minerva: Toward Seamless, High-Resolution Prediction at Intra-seasonal and Longer Time Scales

COLA Center for Ocean-Land-Atmosphere Studies
GEORGE MASON UNIVERSITY

Origins of *Project Athena*

- 2008 World Modeling Summit: **dedicate petascale supercomputers to climate modeling**
- U.S. **National Science Foundation dedicated 165-TFLOPS Athena supercomputer for 6 months** (10/2009-3/2010) as a pilot study
- An **international collaboration** (***Project Athena***) was formed by groups in the U.S., Japan and the U.K. to use Athena to take up the challenge
- **Unprecedented** (at the time) testing of **global atmospheric model resolution** across range spanning nominal climate and NWP model grid spacings within NICAM and IFS



Project Athena Team

ECMWF
- Mats Hamrud
- Thomas Jung
- Martin Miller
- Tim Palmer (co-PI)
- Peter Towers
- Nils Wedi

NICS
- Phil Andrews (co-PI)*
- Troy Baer
- Matt Ezell
- Christian Halloy
- Dwayne John
- Bruce Loftis
- Kwai Wong

Cray
- Pete Johnsen
- Per Nyberg

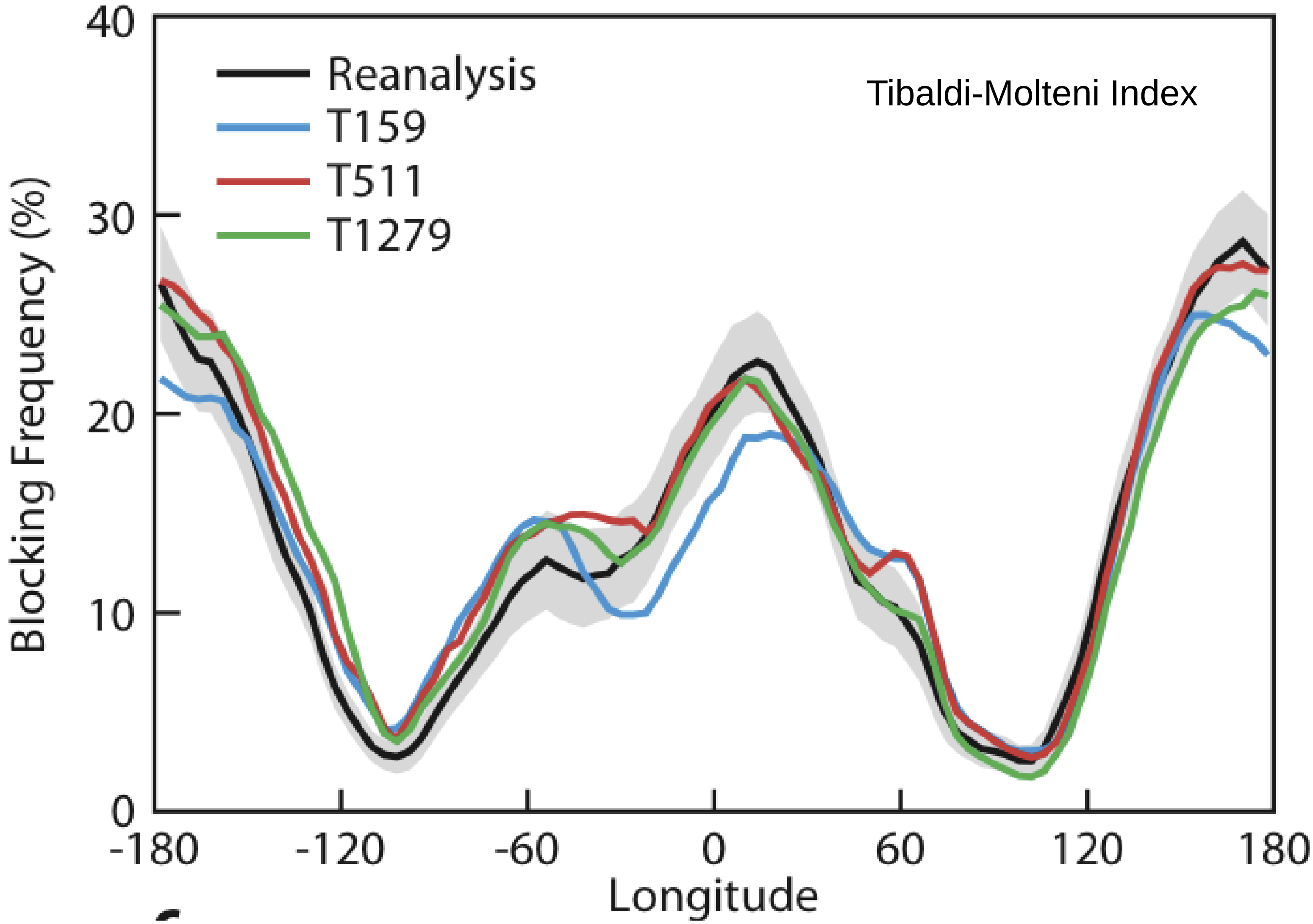
* deceased 2/23/11

JAMSTEC/U. Tokyo
- Chihiro Kodama
- Masaki Satoh (co-PI, U. Tokyo)
- Hirofumi Tomita (co-PI, JAMSTEC)
- Yohei Yamada

NSF
- AGS: Jay Fein
- OCI: Steve Meacham, Rob Pennington

COLA
- Deepthi Achutavarier
- Jennifer Adams
- Eric Altshuler
- Ben Cash
- Paul Dirmeyer
- Bohua Huang
- Emilia Jin
- Jim Kinter (PI)
- Larry Marx
- Julia Manganello
- Cristiana Stan
- Tom Wakefield

Blocking Frequencies: DJFM 1960-2007



Courtesy Thomas Jung, ECMWF

Project Athena **Publications**

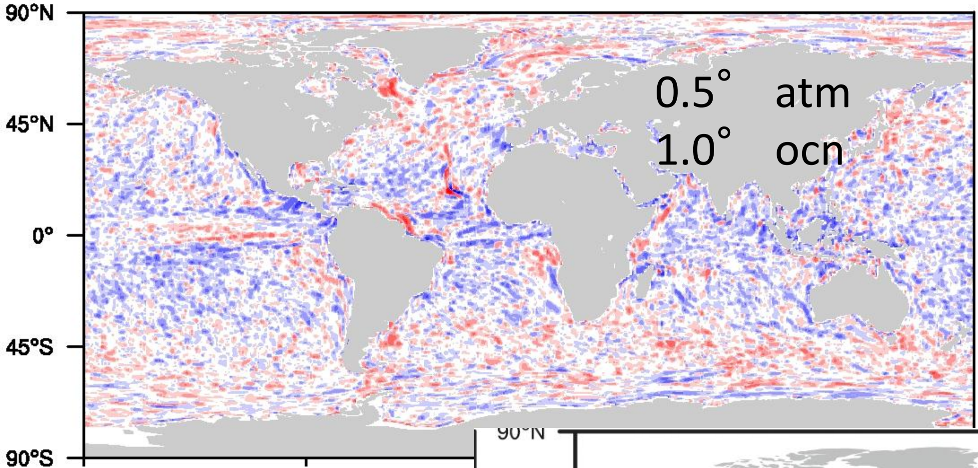
- Dawson, A., T. N. Palmer and S. Corti, 2012: **Simulating regime structures in weather and climate prediction models**. *Geophys. Res. Lett*., 39, doi:10.1029/2012GL053284
- Dirmeyer, P. A. and Co-Authors, 2012: **Evidence for enhanced land-atmosphere feedback in a warming climate**. *J. Hydrometeor.*, 13, 981-995.
- Dirmeyer, P. A. and Co-Authors, 2011: **Simulating the diurnal cycle of rainfall in global climate models: Resolution versus parameterization.** *Climate Dyn*. doi: 10.1007/s00382-011-1127-9.
- Jung, T. and Co-Authors, 2011: **High-Resolution Global Climate Simulations with the ECMWF Model in the Athena Project: Experimental Design, Model Climate and Seasonal Forecast Skill**. *J. Climate*, doi:10.1175/JCLI-D-11-00265.1.
- Kinter III, J. L. and Co-Authors, 2013: **Revolutionizing Climate Modeling – Project Athena: A Multi-Institutional, International Collaboration**. *Bull. Amer. Meteor. Soc.,* 94, 231-245.
- Manganello, J. V. and Co-Authors, 2012: **Tropical Cyclone Climatology in a 10-km Global Atmospheric GCM: Toward Weather-Resolving Climate Modeling**. *J. Climate* 25, 3867-3893.
- Miyamoto, Y., M. Satoh, H. Tomita, K. Oouchi, Y. Yamada; C. Kodama, J. L. Kinter III, 2013: **Gradient wind balance in tropical cyclones in high--resolution--global experiments**. *Mon. Wea. Rev*. (submitted).
- Palipane, E. and Co-Authors, 2013: **Improved Annular Mode Variability in a Global Atmospheric General Circulation Model with 16-km Resolution**. *J. Climate* (submitted).
- Satoh, M. and Co-Authors, 2011**: Intra-Seasonal Oscillation and its control of tropical cyclones simulated by high-resolution global atmospheric models**. *Climate Dyn*., doi10.1007/s00382-011-1235-6.
- Solomon, A. and Co-Authors, 2013: **The distribution of U.S. tornado risk in a changing climate**. *J. Climate* (submitted).

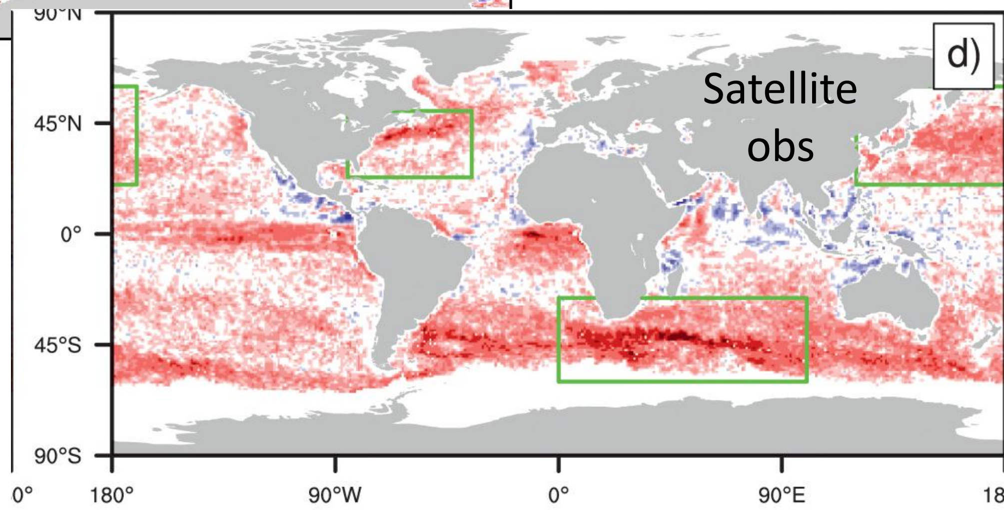
Impact of Ocean Model Resolution on Coupled Climate Simulation

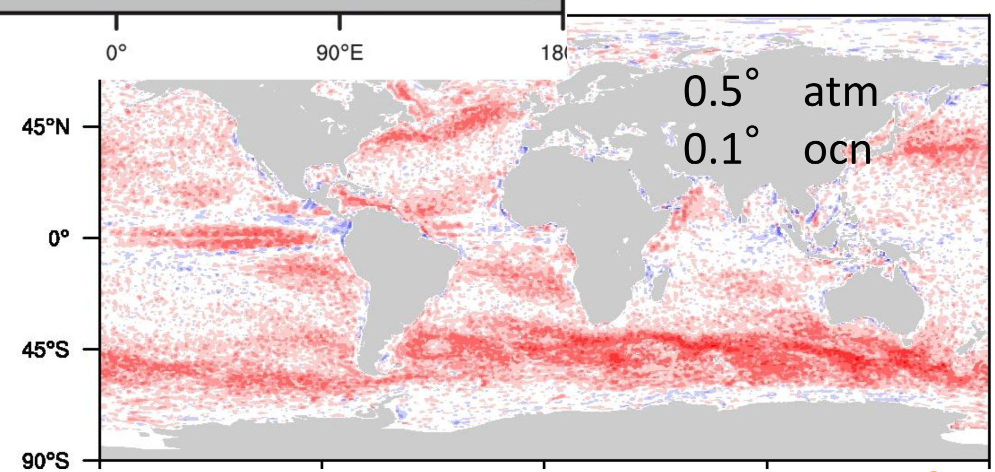
PetaApps Team

Jim Kinter (PI), Cecilia Bitz, Frank Bryan, William Collins, John Dennis, Nathan Hearn, Ben P. Kirtman, Richard Loft, Clem Rousset, Ben Shaw, Leo Siqueira, Cristiana Stan, Robert Tomas and Mariana Vertenstein

Correlation High-Pass SST vs. $|V_{srf}|$

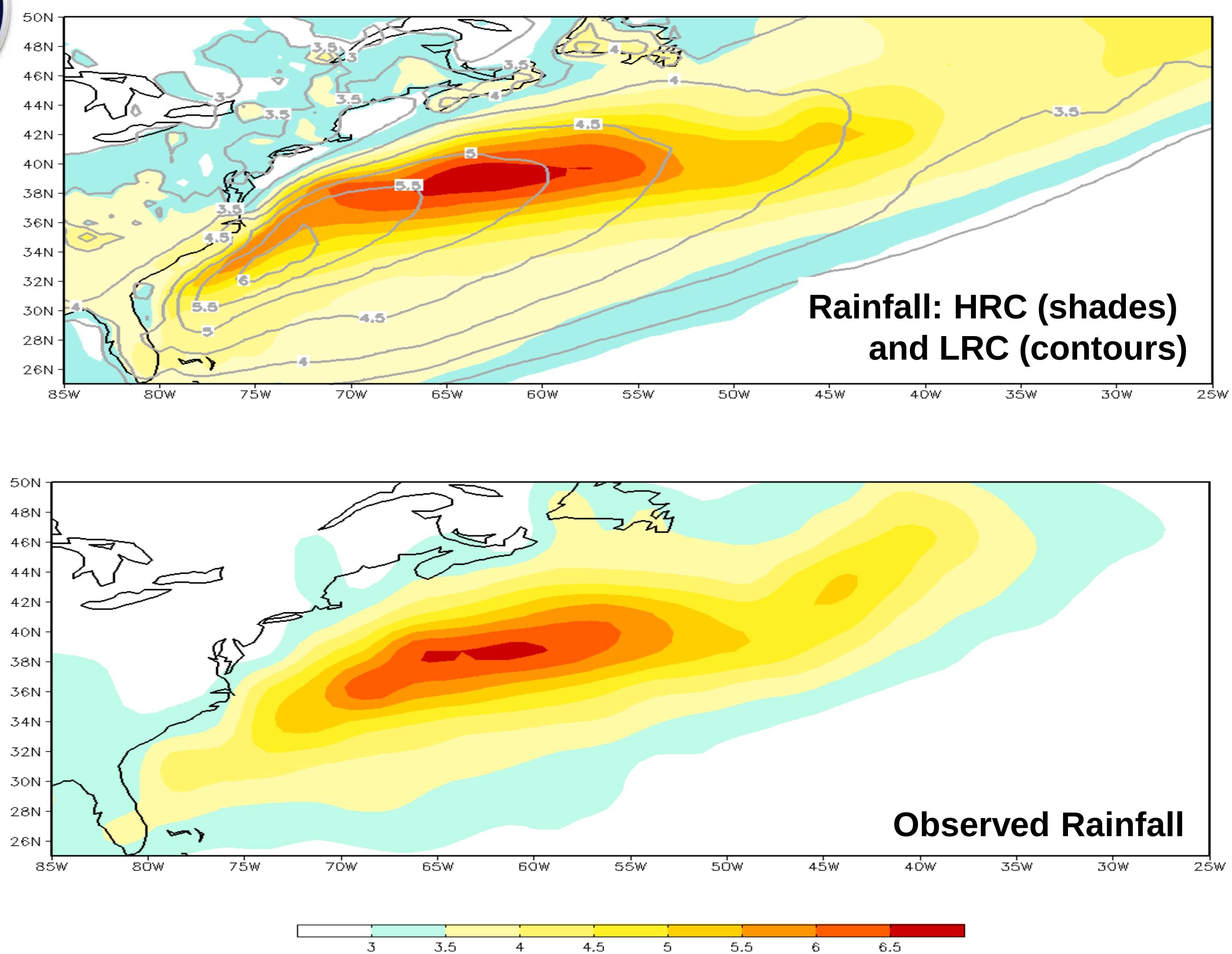






Bryan et al. 2010 *J. Climate*

Courtesy Frank Bryan, NCAR



Courtesy Ben Kirtman, U Miami

Project Minerva

Many thanks to NCAR for resources & sustained support!

- Explore the impact of **increased atmospheric resolution** on model fidelity and prediction skill in a ***coupled, seamless framework*** by using a state-of-the-art coupled operational long-range prediction system to systematically evaluate the prediction skill and reliability of a robust set of hindcast ensembles at low, medium and high atmospheric resolutions
- **NCAR Advanced Scientific Discovery Program** to inaugurate *Yellowstone* (1.5 PFLOPS peak)
- **Allocated 21 M core-hours** on Yellowstone
- **Used 28 M core-hours**
- **Generated 800 TB** output data

Project Minerva Partners

ECMWF team:

- Frederic Vitart, lead
- Roberto Buizza
- Erland Kallen
- Franco Molteni
- Tim Stockdale
- Peter Towers
- Nils Wedi

COLA team:

- Ben Cash, lead
- Rondro Barimalala
- Paul Dirmeyer
- Mike Fennessy
- Jim Kinter
- V. Krishnamurthy
- Julia Manganello
- David Straus

University of Oxford:

- Tim Palmer
- Andrew Dawson

Project Minerva ECMWF Coupled Ensemble System

Atmosphere model cycle	Atmosphere spectral truncation	Atmosphere vertical levels	Ocean model	Ocean horizontal res, equatorial refinement	Ocean vertical levels
IFS cy 38r1	T319 / T639 / T1279	91 levels, top = 1 Pa	NEMO v 3.0/3.1	1 degree, ~ 0.3 deg. Lat	42 levels

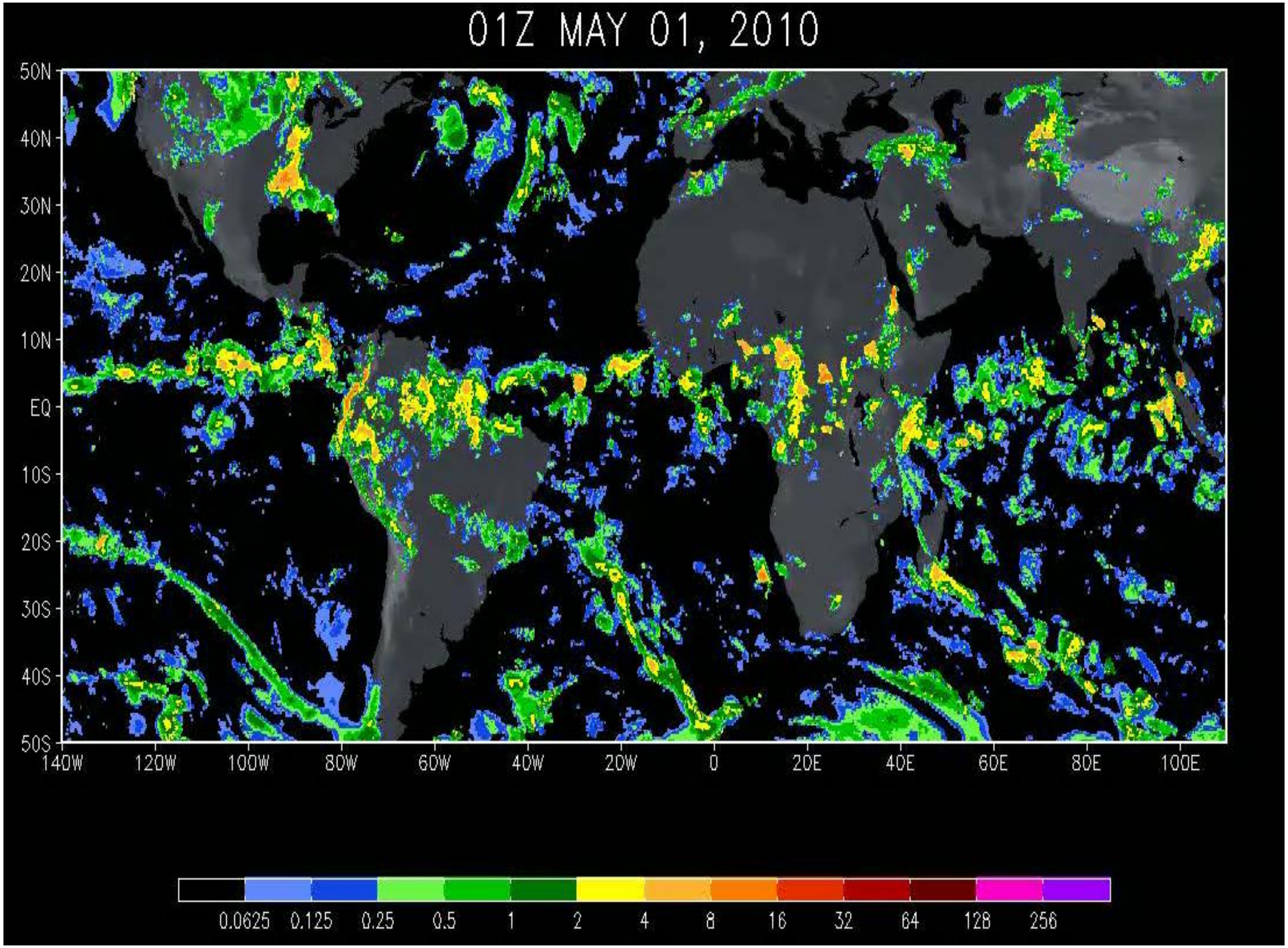
Coupler	Time range of ocean-atmosphere coupling	Coupling frequency	Unperturbed initial cond. for re-forecasts	Atmospheric perturbations	Ocean perturbations	Stochastic model perturbations
OASIS-3	from start	3 hours	ERA-Interim + ORA-S4	SV, EDA from 2011 dates	5 ocean analyses + SST perturbations	3-timescale SPPT + KE backscatter

Courtesy Franco Molteni & Frederic Vitart, ECMWF

Project Minerva: Prediction Experiments

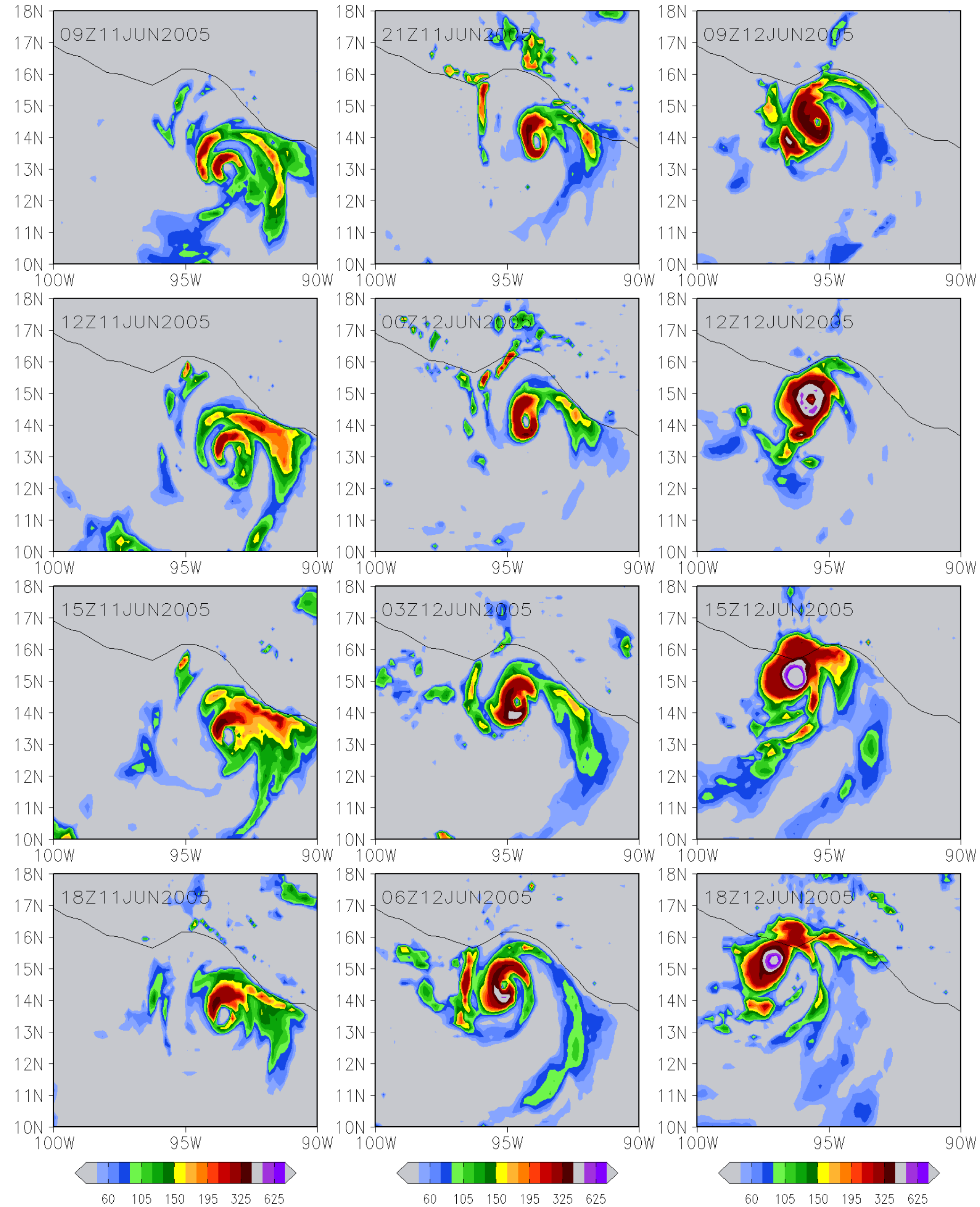
Experiment	Years	Ens. Size	Initial Months	Duration (mon)
T319_base	1980-2011	51	May, Nov	7
T319_2_year_extension	1980-2011	15	May	24
T639_base	1980-2011	15	May, Nov	7
T639_extended_ensemble	1980-2011	36	May, Nov	May: 5 mo Nov: 4 mo
T639_2_year_extension	1980-2011	15	Nov	24
T1279_base	2000-2011	15	May	7

2010 T1279 Precipitation
May – November



Courtesy Brian Doty, COLA

Minerva: Coupled Prediction of Tropical Cyclones



11-12 June 2005 hurricane off west coast of Mexico: precipitation in mm/day every 3 hours (T1279 coupled forecast initialized on 1 May 2005)

The predicted maximum rainfall rate reaches 725 mm/day (30 mm/hr)

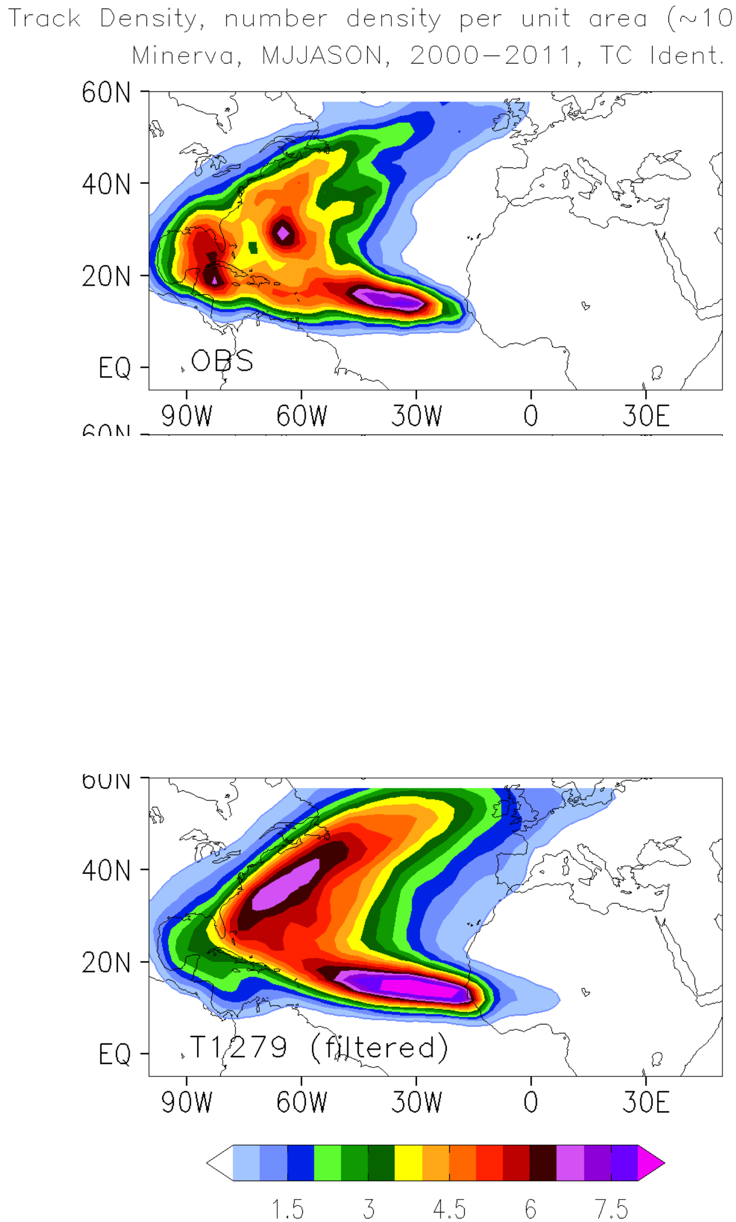
Based TRMM global TC rainfall observations (1998-2000), the frequency of rainfall rates exceeding 30 mm/hr is roughly 1%

Courtesy Julia Manganello, COLA

North Atlantic Track Densities

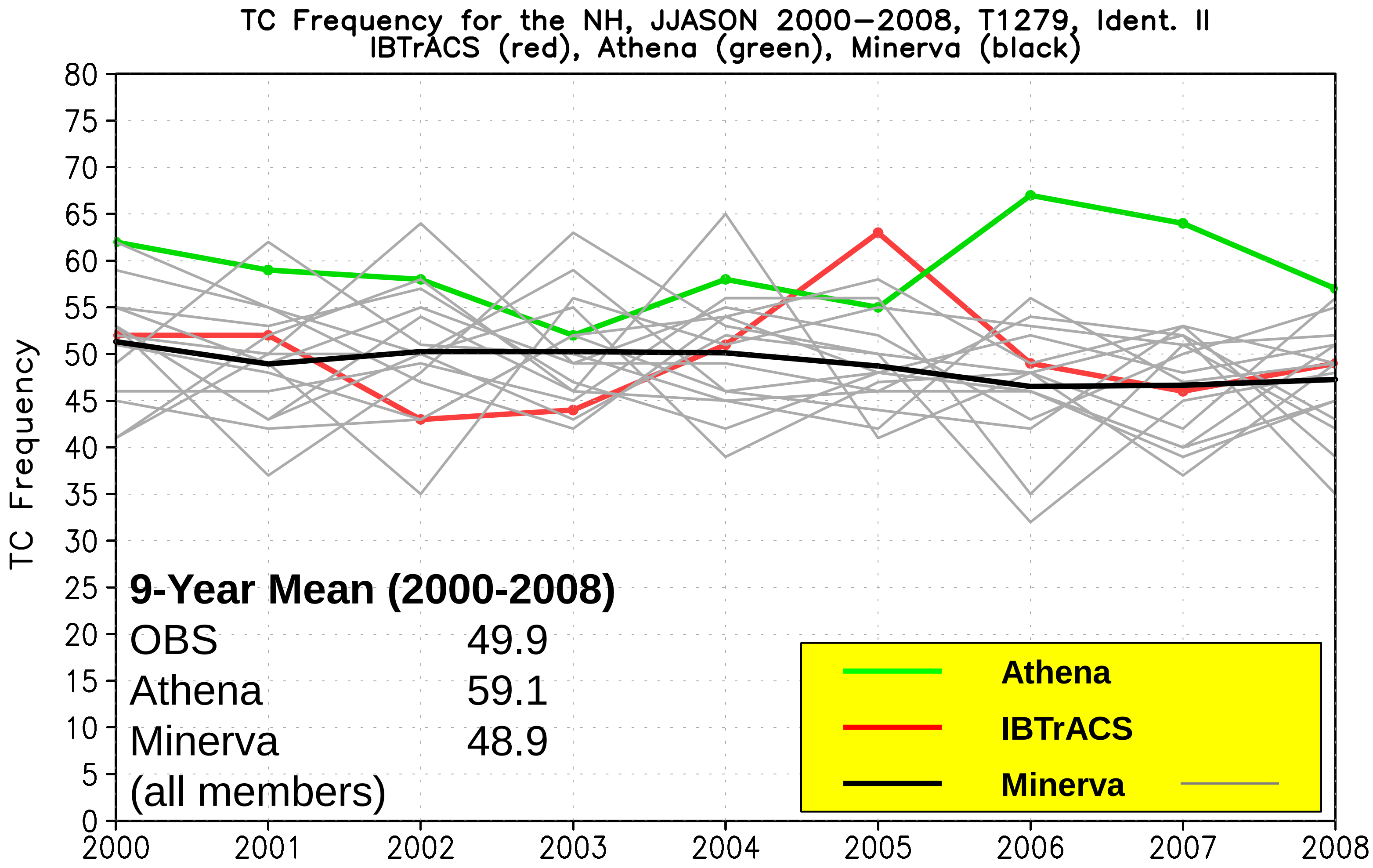
OBS

T1279



Courtesy Julia Manganello, COLA

Minerva vs. *Athena* – TC Frequency (NH; JJASON; T1279)



Courtesy Julia Manganello, COLA

Mean TC frequency, MJJASON, 2000-2011

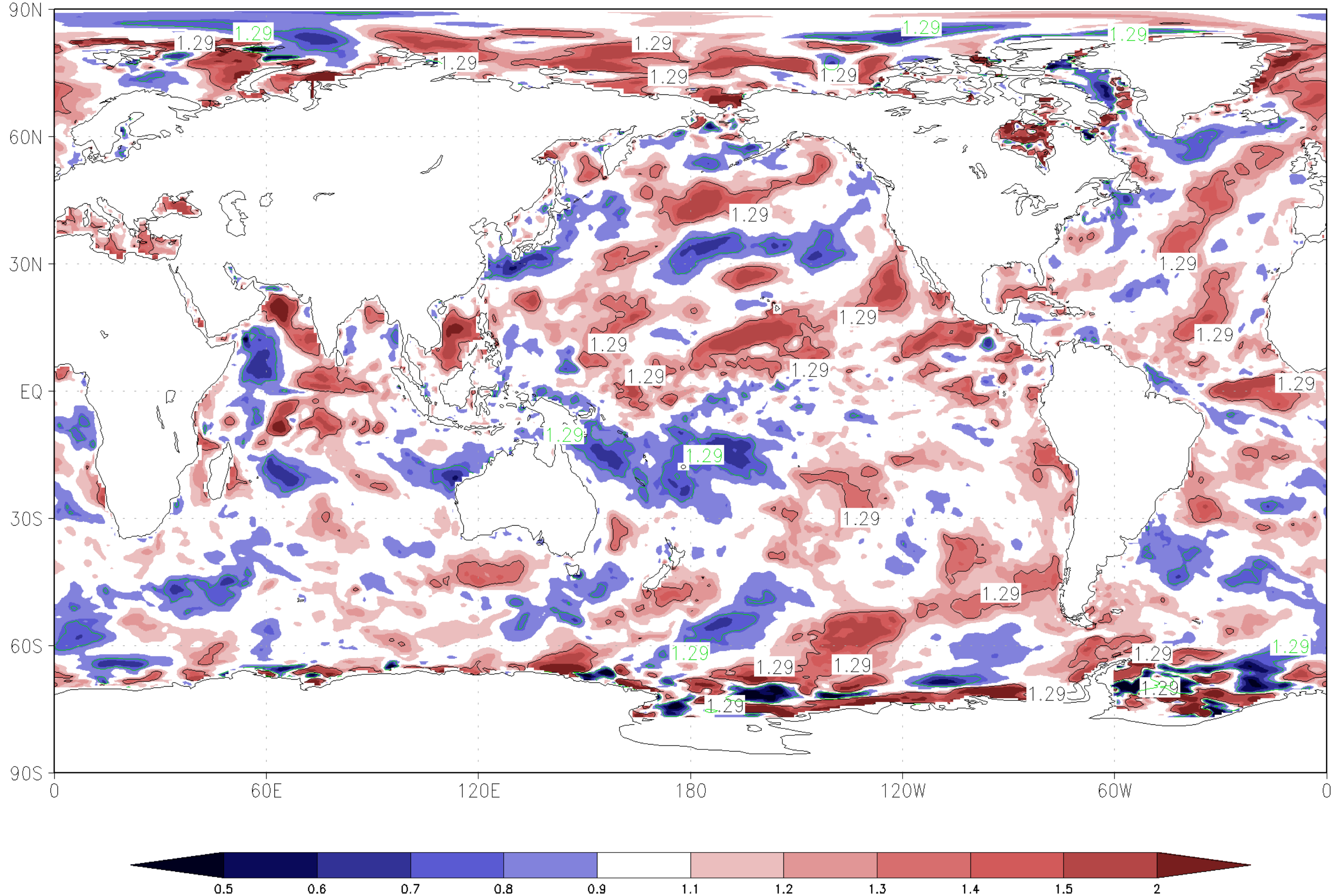
Experiment	NH	NAtl	NPac	NInd
IBTrACS	53.7	13.3	35.9	4.4
Minerva T1279	55.7	11.5	37.3	6.6*
Athena T1279 (13-mo. hndcst, *1990-2008*)	62.3*	9.2*	43.9*	8.7*

* difference wrt OBS is statistically significant at the 95% confidence level

NB: East and West Pacific have compensating errors
(EPac is too high and WPac is too low relative to OBS)

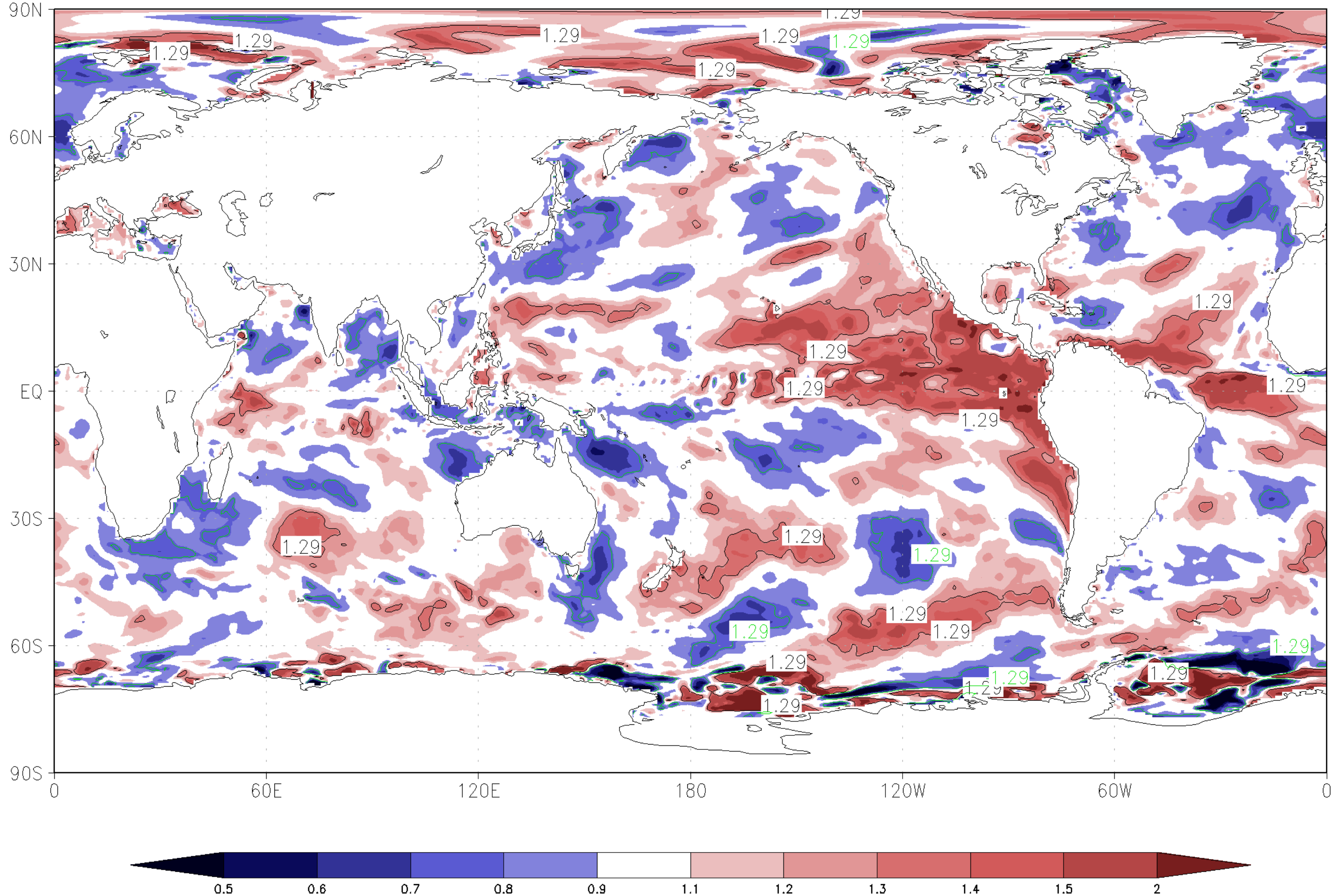
Courtesy Julia Manganello, COLA

Ratio of Ensemble Variance: T639 / T319 SST
2000-2011 May Values (May Initial Conditions)



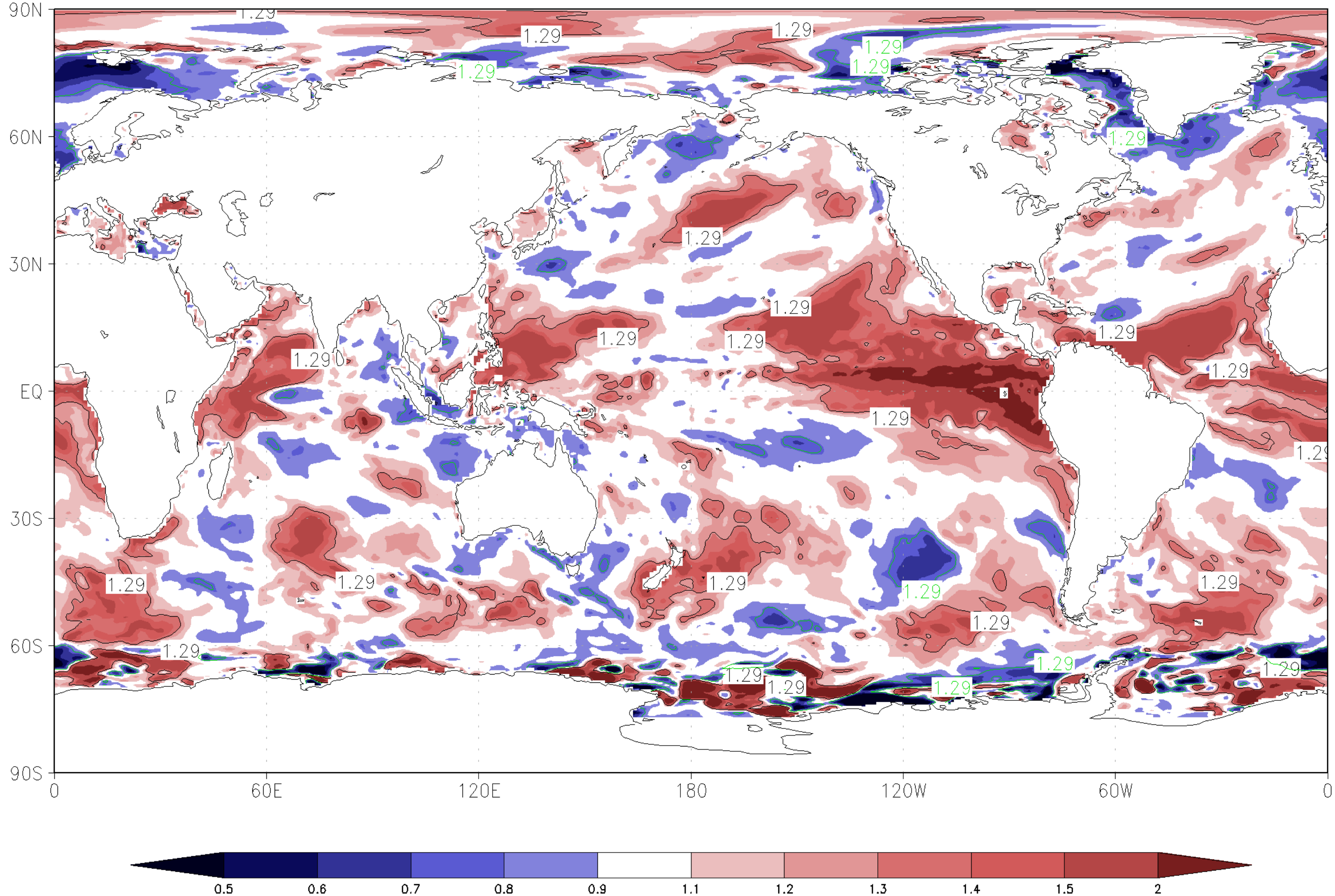
Courtesy Ben Cash, COLA

Ratio of Ensemble Variance: T639 / T319 SST
2000-2011 June Values (May Initial Conditions)



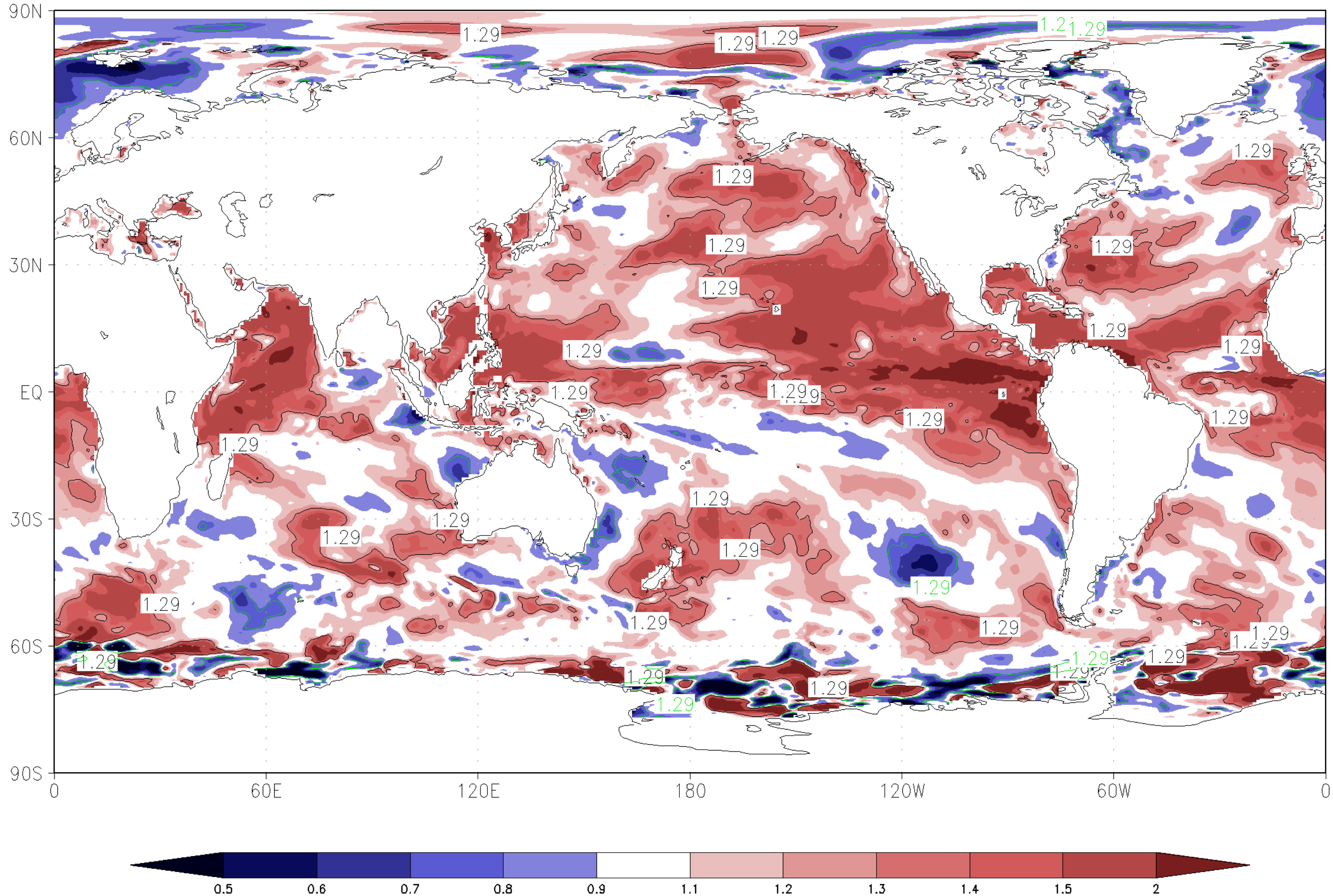
Courtesy Ben Cash, COLA

Ratio of Ensemble Variance: T639 / T319 SST
2000-2011 July Values (May Initial Conditions)



Courtesy Ben Cash, COLA

Ratio of Ensemble Variance: T639 / T319 SST
2000-2011 August Values (May Initial Conditions)

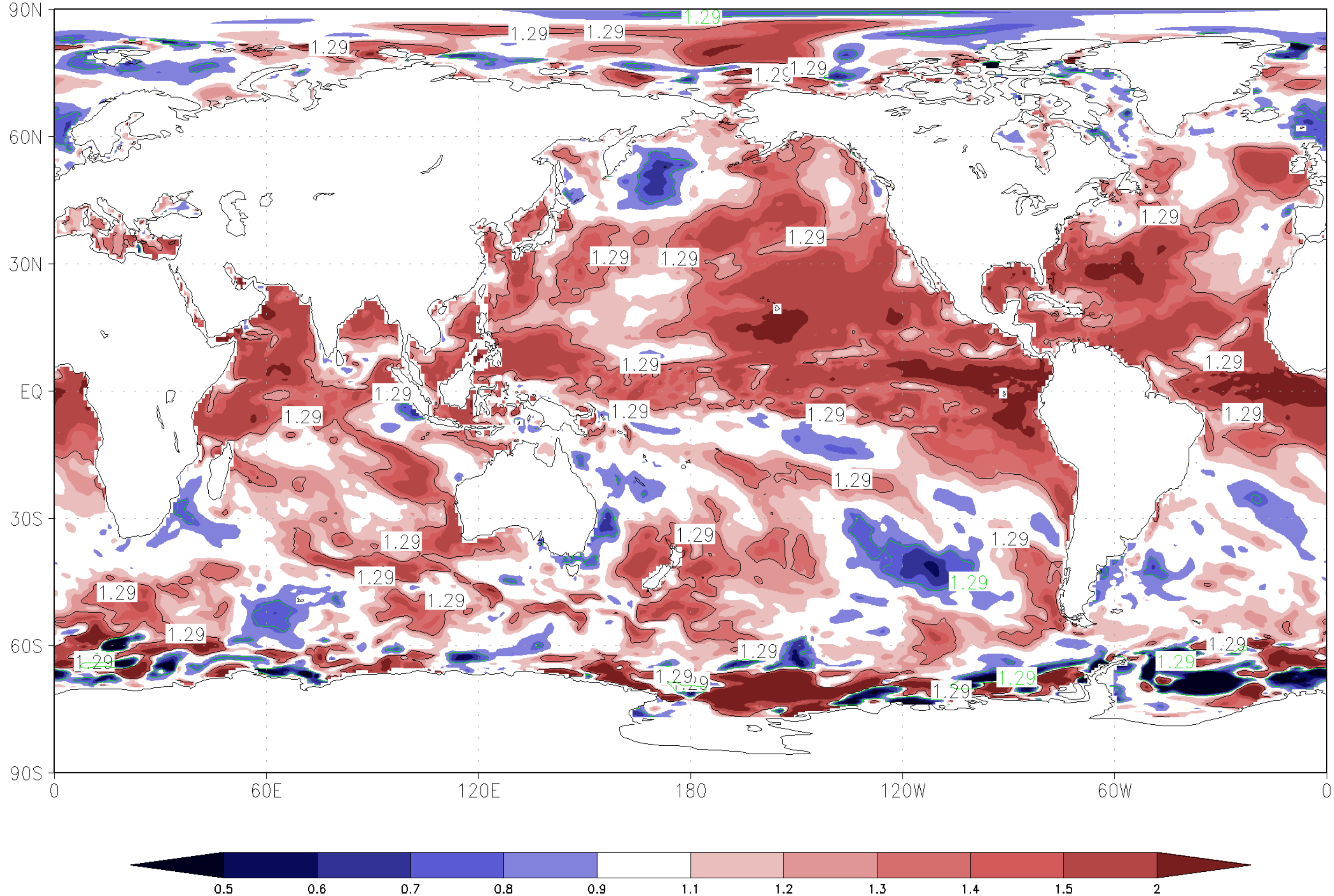


Courtesy Ben Cash, COLA

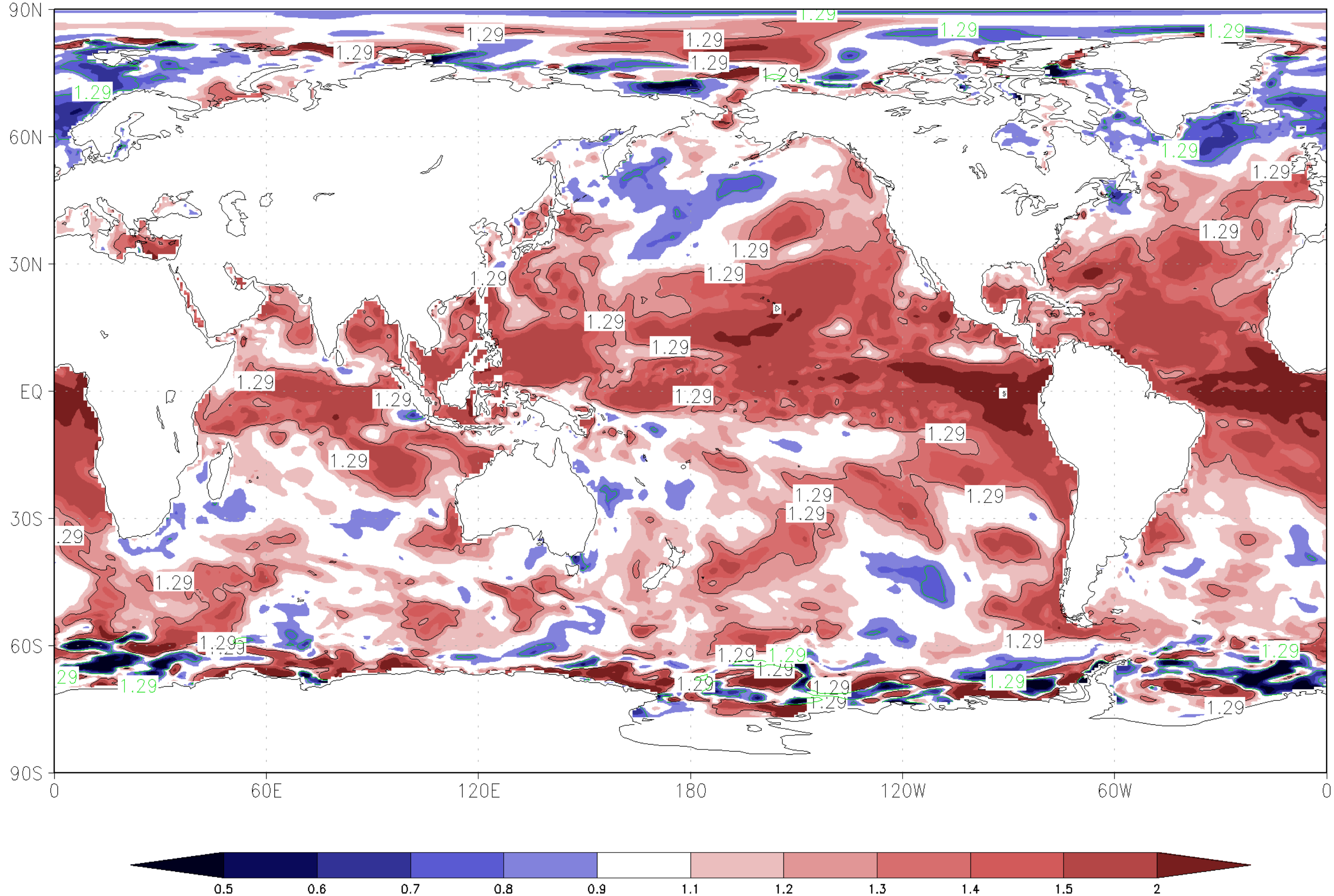
COLA Center for Ocean-Land-Atmosphere Studies

George Mason University

Ratio of Ensemble Variance: T639 / T319 SST
2000-2011 September Values (May Initial Conditions)

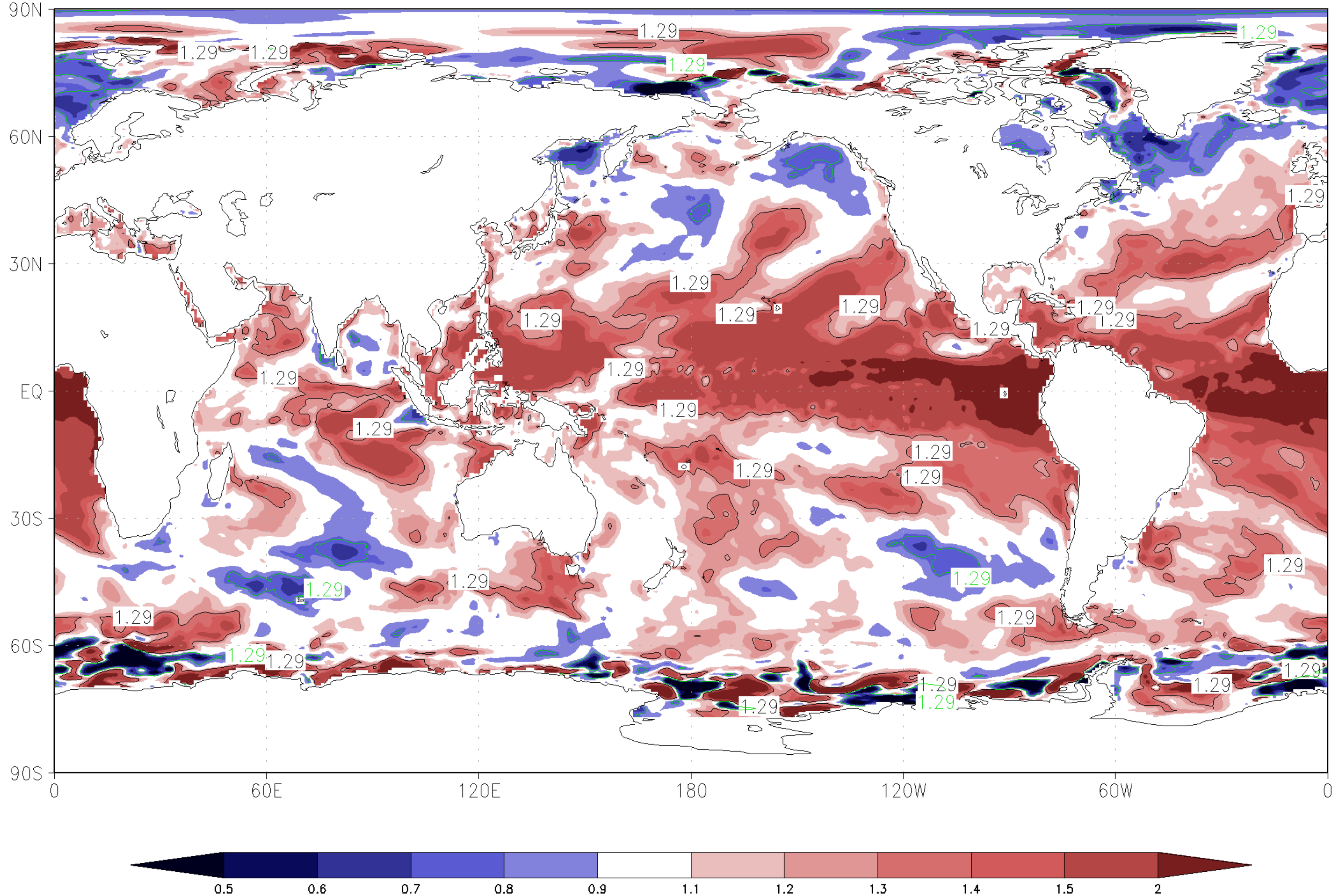


Ratio of Ensemble Variance: T639 / T319 SST
2000-2011 October Values (May Initial Conditions)



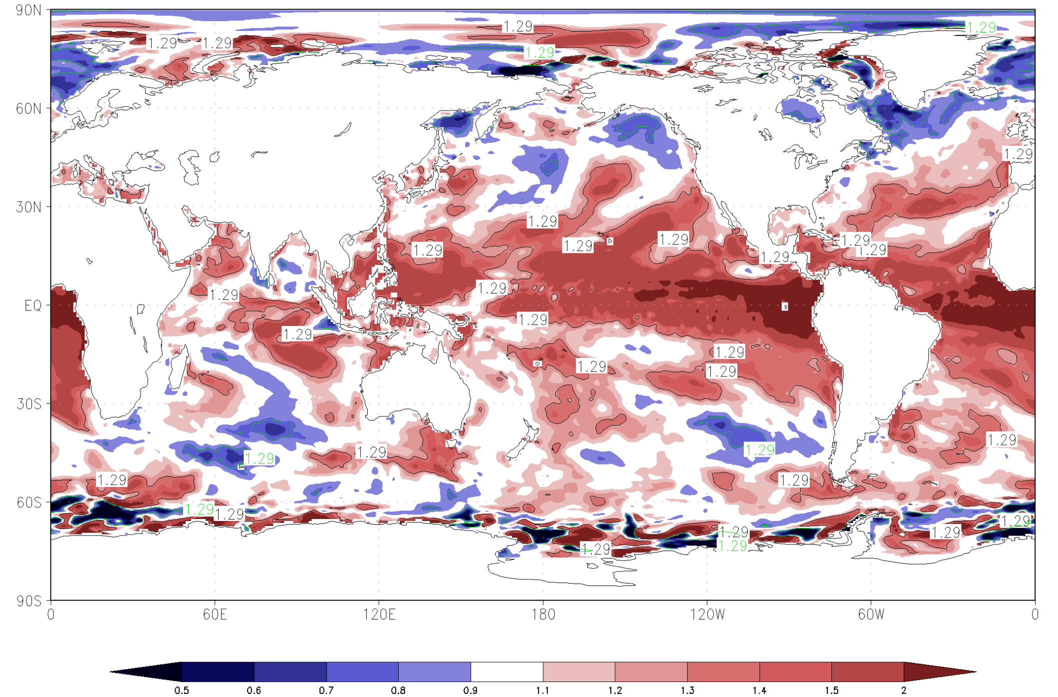
Courtesy Ben Cash, COLA

Ratio of Ensemble Variance: T639 / T319 SST
2000-2011 November Values (May Initial Conditions)

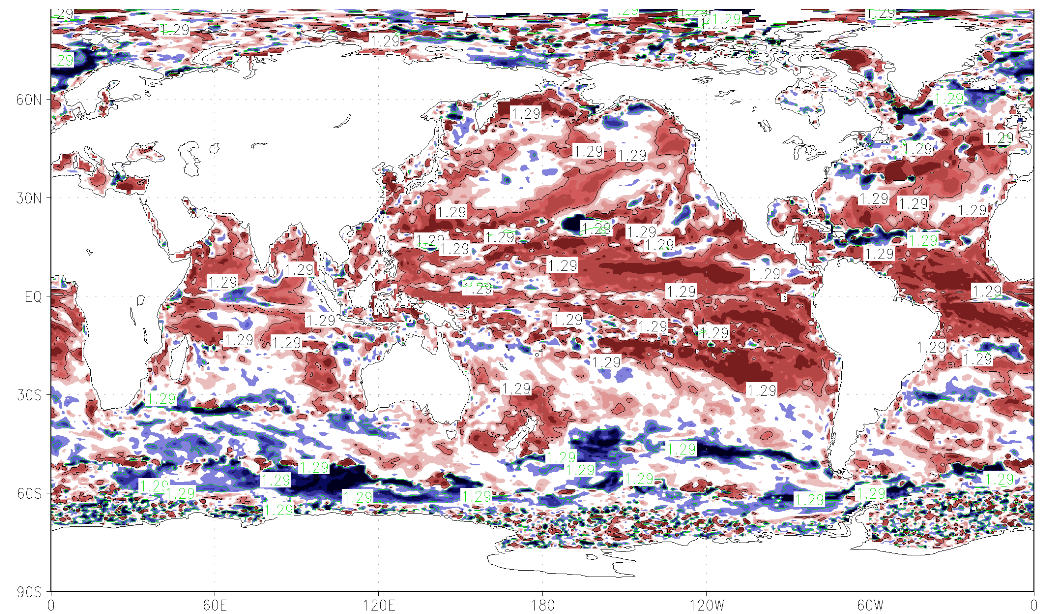


Courtesy Ben Cash, COLA

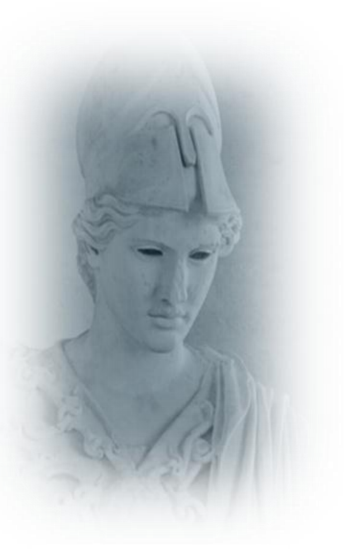
Ratio of Variances: November SST



Ratio of Variances: November Thermocline



Courtesy Ben Cash, COLA



Summary and Conclusions

- Resolving mesoscales in the global atmosphere is essential for several climate-relevant processes at ISI time scales
- Resolving ocean eddies is likewise essential to representing air-sea fluxes and coupled processes at frontal boundaries
- Viewing weather and climate in a seamless framework can lead to interesting insights and improved forecasts at ISI time scales
- Model resolution and ensemble size may be related and both must be considered in design of a prediction system
- Systematic, controlled experiments are needed to properly assess resolution and ensemble size requirements with associated hindcast and re-tuning

ANY QUESTIONS?