From Climate to Weather Coupled Models, Challenges for ACCESS

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Thirteenth Workshop on the Use of High Performance Computing in Meteorology

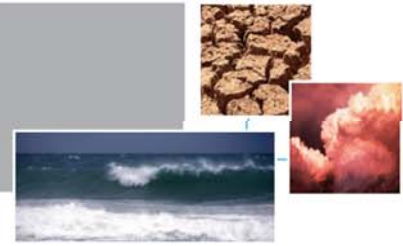
3 - 7 November 2008

Australian Government
Bureau of Meteorology

The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

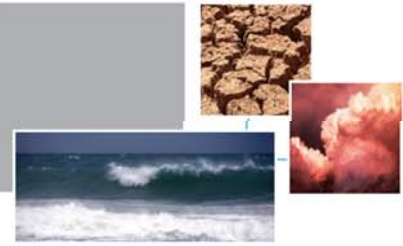
CSIRO

Outline of Talk



- Introduction to the Australian Community Climate Earth-System Simulator (ACCESS) program initiated in 2006
- … and the Centre for Australian Weather and Climate Research (CAWCR) initiated in 2007
- ACCESS status today
  - Earth System Modelling for Climate
  - Numerical Weather Prediction
  - Numerical Ocean Prediction
- ACCESS directions and challenges
  - Earth System Modelling for Climate
  - Earth System Modelling for NWP
- 2008 supercomputer procurement status

Introduction to …



ACCESS

The Australian Community Climate Earth-System Simulator

ACCESS Objectives are to…

- Develop a *national* approach to climate change and weather prediction system development and research, particularly as it manifests in the Australian region
- Focus on the needs of a wide range of stakeholders:
  - Providing the best possible services
  - Analysing climate impacts and adaptation
  - Linkages with relevant University research
  - Meeting policy needs in natural resource management

ACCESS is a joint initiative of the Bureau of Meteorology and CSIRO in cooperation with the university community in Australia

http://www.accessimulator.org.au/

Introduction to CAWCR

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TIFF (Uncompressed) decompressor
are needed to see this picture.

The Centre for Australian Weather and Climate Research
A partnership between CSIRO and the Bureau of Meteorology

(http://www.cawcr.gov.au)

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are needed to see this picture.

- CAWCR replaces the Bureau of Meteorology Research Centre (BMRC) as the main research organisational unit
  - **corker**. something excellent. a good stroke in cricket might be described as a 'corker of a shot'. (http://www.australianhistory.org/australian-slang-atod.php)
- CAWCR involves more than 250 staff located in Canberra, Melbourne, Hobart, Brisbane and Perth
- CAWCR aims to advance the sciences of meteorology, oceanography and related areas, and develop an integrated, comprehensive description and understanding of the nation's weather and climate
  - Research related to water data, analysis and prediction is supported through the Water Information Services program Group.

CAWCR Capability and Groups

Centre Capability – Research Groups

Weather, Ocean and Environment Program

Ocean Prediction
- ✓ Ocean hindcasting
- ✓ Ocean forecasting
- ✓ Marine forecasting
- ✓ Remote sensing

Weather and Environment
- ✓ Radar applications
- ✓ Forecast systems
- ✓ NWP applications
- ✓ High impact weather
- ✓ Meso-scale applications

Complex systems

Earth System Modelling and Climate Science Program

Seasonal & Inter-annual Prediction
- ✓ Seasonal prediction systems
- ✓ Climate variability and applications
- ✓ Climate processes

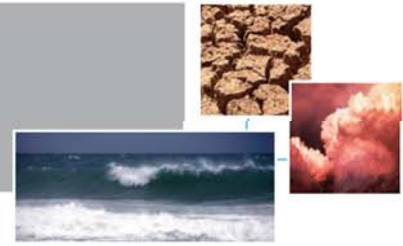
Climate Change
- ✓ Projections science
- ✓ Climate diagnostics
- ✓ Risk adaptation & policy
- ✓ Sea-level rise & coasts

Atmosphere – Land Observation & Assessment
- ✓ Continental scale biogeochemistry
- ✓ Remote sensing
- ✓ Atmospheric reactive gases & aerosol
- ✓ Greenhouse & ozone depleting gases
- ✓ Micrometeorology
- ✓ Radar facilities

ACCESS Modeling, Assimilation
- ✓ Atmospheric modelling
- ✓ Data assimilation
- ✓ Ocean & coupled modelling
- ✓ Model evaluation
- ✓ Land-surface and carbon cycle
- ✓ Model systems (infrastructure)

Ocean Observation and Assessment
- ✓ Ocean mixing and seawater thermodynamics
- ✓ Southern Ocean processes
- ✓ Broad-scale ocean dynamics
- ✓ Micronutrients and primary production
- ✓ Ocean carbon

ACCESS Key Timelines Today



NWP

- 2006/2007 — UM and VAR implemented
- 2007/2008 — Preliminary runs in NWP mode
- 2008 — Consideration of model resolutions and limited area domains
- 1Q 2009 — Operational implementation

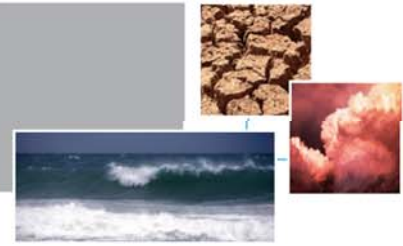
Risk: Data handling and access, particularly satellite data

Climate Change simulation

- 2006/2007 — Port component models to common computing environment
- 2007/2008 — Construct coupled system
- 2009 — Test and balance coupled system
- 2010 — Perform and submit IPCC AR5 runs

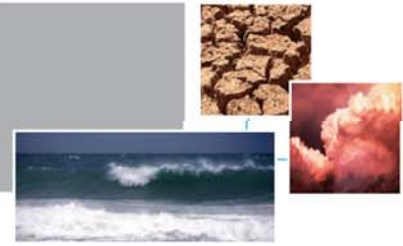
Risks: ***Not meeting AR5 timeline***
Deficiencies in performance of coupled system
Insufficient supercomputer time

Priority ACCESS Work



- **Implementation and continuing development of ACCESS modules - UM/OPS/VAR, Observation Data Base (ODB), AusCOM, CICE-4**
- **Numerical weather prediction implementation, including evaluation and verification**
- **Coupling of AusCOM/CICE and CABLE to the UM**
- **Experimentation with physical parametrisations, including AMIP-type and single column model runs, and model evaluation**
- **Development of ACCESS infrastructure**

Earth System Model for Climate (Today)



OPS

VAR

N
W
P

UM

LPJ

CABLE

OASIS

UKCA

Obs

Assimilation

MOM4

CICE

N
O
P

CSIRO OC

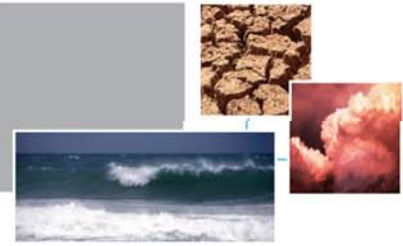
BODAS

OBS

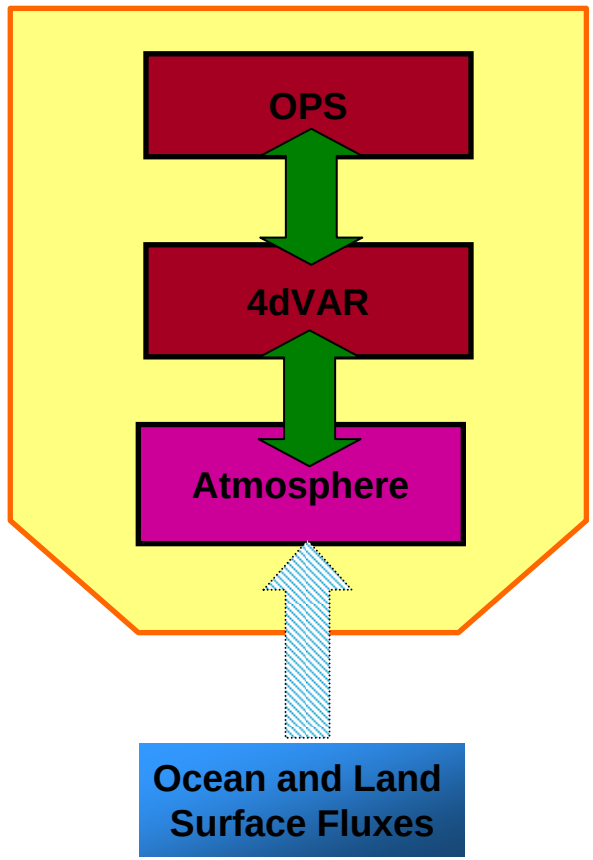
ACCESS modules based on Project Plan recommendations

What we are trying to develop

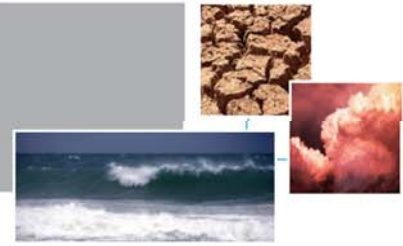
Numerical Weather Prediction (NWP)



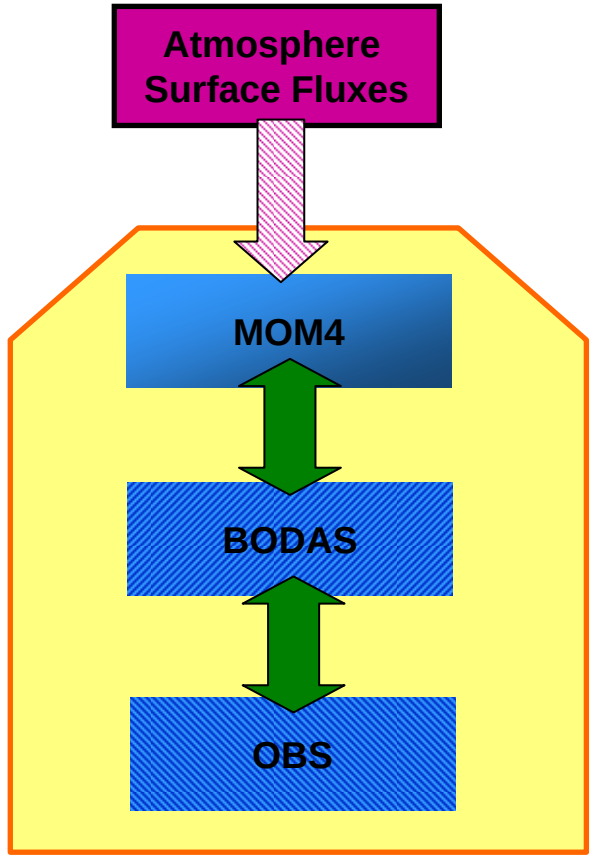
- Global NWP suite (AGFS) running routinely with encouraging results
- Regional 37.5km NWP suite (ARFS) running routinely with encouraging results
- Successful runs have been conducted with the mesoscale Australian domain 12km suite
- VicTas 5km forecast suite running daily
- Detailed testing indicates that ACCESS NWP systems are ready for operational implementation



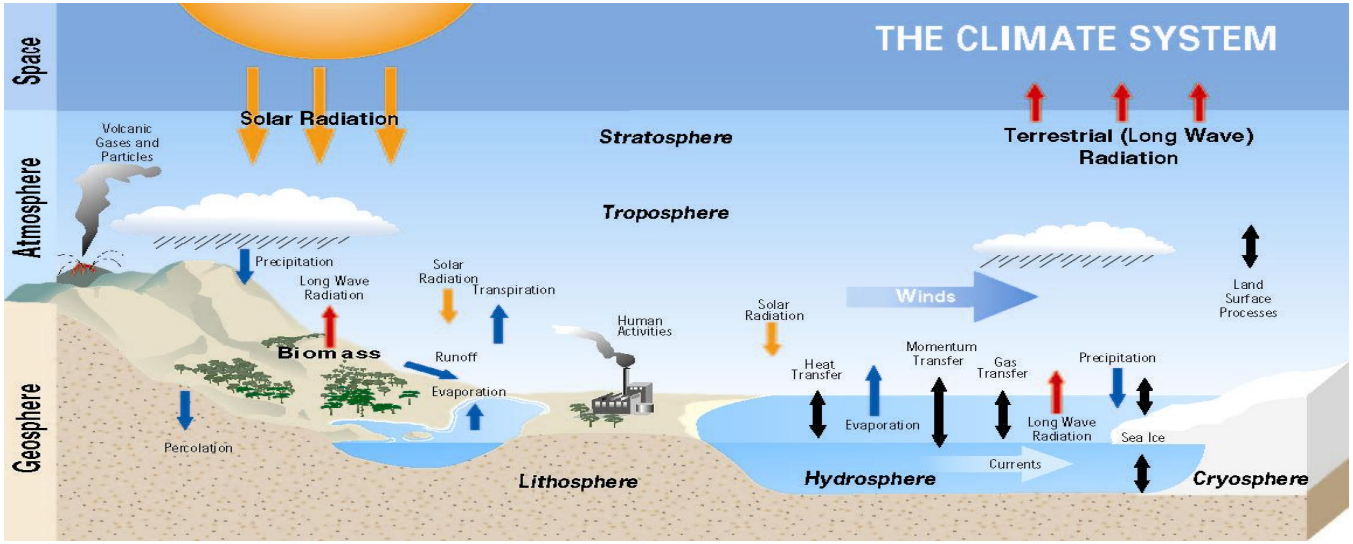
Numerical Ocean Prediction



- Global Numerical Ocean Prediction (NOP) running operationally since 2007.
- High resolution 10km grid embedded in global model for regional forecast
- Currently using GASP atmospheric surface fluxes, changing to UM surface fluxes by 2Q 2009.
- BODAS assimilates remotely sensed sea surface height anomalies and sea surface temperature, as well as in situ data from the WMO GTS and Argo data processing centers.

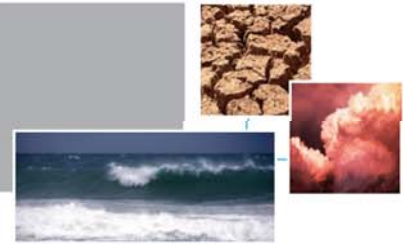


ACCESS Directions



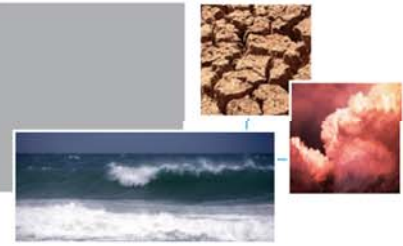
- Beyond 2010, ACCESS will continue to develop an earth system modelling framework for the following applications:
  - Climate change prediction
  - Seasonal forecasting
  - Severe weather forecasting for tropical cyclones and thunderstorms
  - Global and regional weather and ocean forecasting
- The next five years will produce an improved Earth System Model (ESM) for climate and seasonal forecasting, and hopefully the first ESM for NWP.
  - However many challenges have to be resolved first.

ACCESS Challenges of ESM for Climate



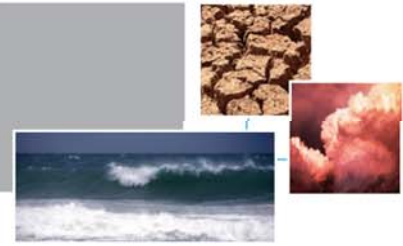
- Challenge: Managing the complexity of interactions and verifying and validating the individual model components and system together.
  - Consistency of numerical differentiation and integration between the UM and Cable models and the UM and CICE models due to implicit computations.
- Challenge: Increasing the spatial resolution of the models to resolve important dynamical scales.
- Challenge: Increasing the coupler flexibility and scalability to manage the field exchanges and conservation, grid complexity, and performance for a given architecture.
  - The improvements in model interactions and spatial resolution put pressure on the coupler to perform on large core counts and with greater I/O bandwidth requirements for the system.
- Challenge: Increasing the model's software ability to scale with increasing spatial resolution and core counts.
  - For example, the MOM4 model is designed for climate modelling, so as the model increases spatial resolution and core counts, the model encounters performance degradation with I/O functions. (fix is in the works)
- Challenge: Managing the hardware/software infrastructure and human resources.

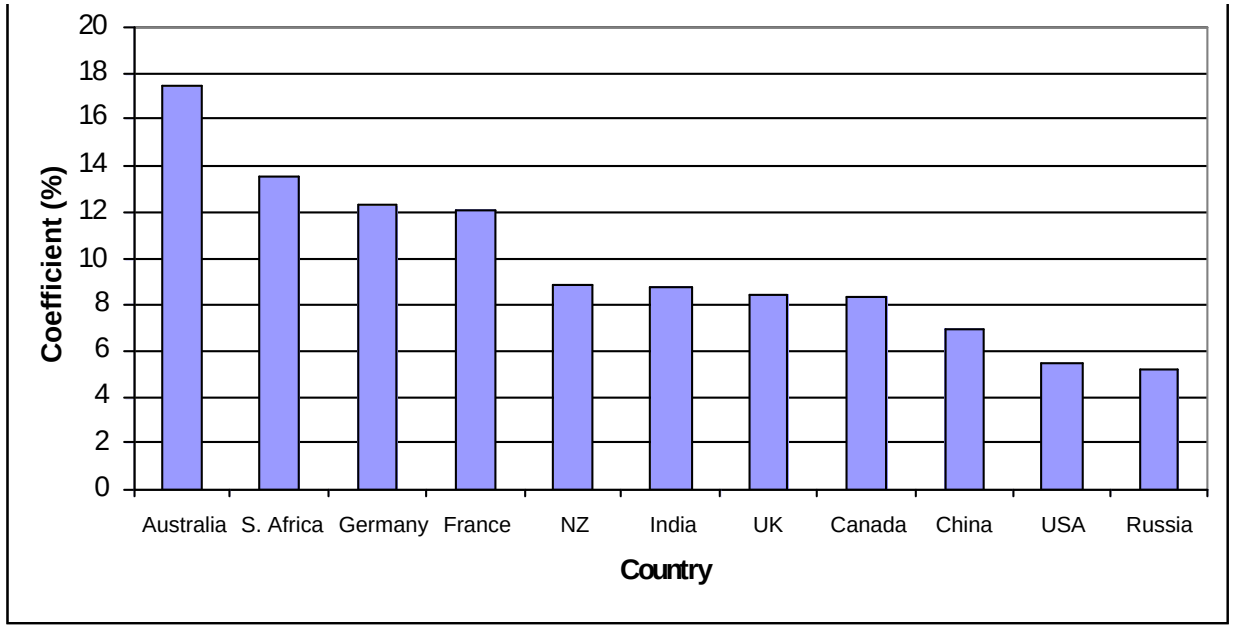
ACCESS Challenges of ESM for NWP



- Challenge: Development of an adjoint model for a coupled ocean-wave-sea ice-land-atmosphere model for studies of the covariability, predictability and 4dVAR assimilation.
- Challenge: Development of a 24-hour global coverage of land, sea ice, ocean and wave observing system to provide the timely feedback of innovations to project onto NWP analysis cycles.
- Challenge: Development of efficient models to resolve the physics and complete its coupled integration within the elapse time window.
- Challenge: Ensemble forecasting benefits to translate to a coupled prediction system.
- Challenge: Matching disparate grids in a coupled environment
  - Unstructured grids of coastal/river/bays used for improved coupled coastal weather
  - Important roles of islands groups in the tropical convection such as the South Pacific Convergence Zone

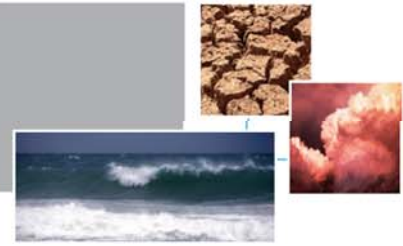
Challenge: Australian Climate Variability



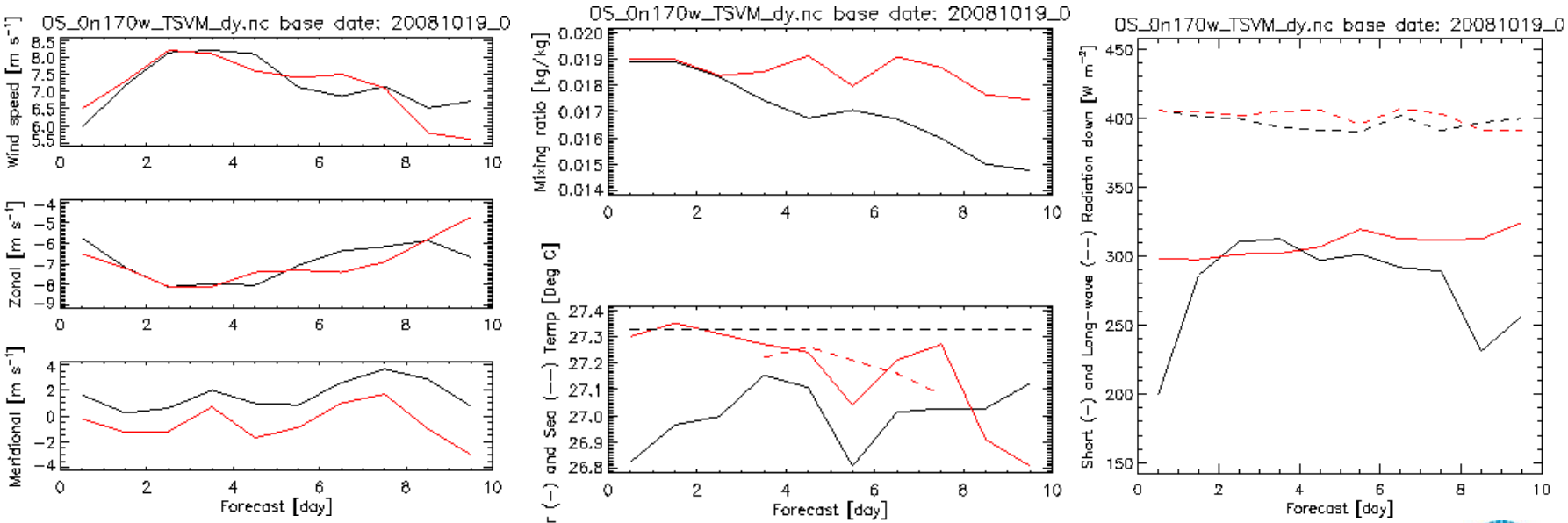


- The coefficient of variation of national annual rainfall for Australia and 10 other countries. (Source: Love (2005))
- Understanding the mechanisms and predicting climate variations on seasonal to interannual time-scales requires globally extensive monitoring of the atmosphere, oceans, and land surface.

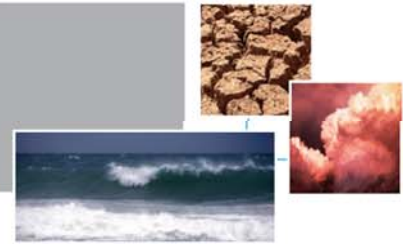
Challenge: Marine Meteorology



- Challenge for coupled boundary layers to include the availability of observational data sets to make progress on coupled boundary layer physics.
- NWP flux verification: http://www.bom.gov.au/bmrc/ocean/staff/ezs/Flux_verification/mooring_fluxes.html
  - Pacific Ocean TAO mooring at 0N, 170W on 19 October 2008
  - Observed in red, ACCESS UM model in black



Advection of cold water across TAO array



TAO mooring SST (5 day avg)
at 0N, 170W

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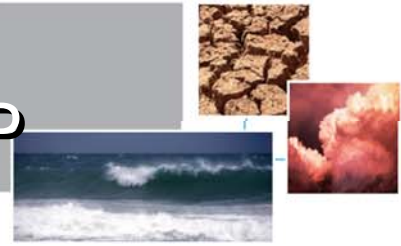
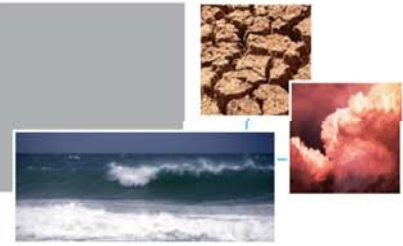
Impacts of an Earth System Model on NWP



- Closure of the surface flux errors of momentum, heat, and water.
  - Feedbacks from land surface features, waves, SST fronts and surface currents on atmospheric stress, water fluxes, and heat fluxes.
- Constraint of atmospheric variables through coupled data assimilation.
  - Errors in sea level anomaly correlate to errors in heat and momentum fluxes which in turn correlate to atmospheric boundary layer properties, clouds and radiation physics.
  - Errors in wave field correlate to errors in the surface wind stress which also correlate to atmospheric boundary layer properties.
- The ocean also will benefit from the projection of atmospheric innovations onto the ocean state for an improved mixed layer.
- Improvements in atmospheric phenomena that respond to atmospheric heat content. (Tropical Cyclones and Extra-tropical storms)
- Improvements in coastal weather, sea breeze, coastal fog through upwelling water temperature changes.

Why the time is right

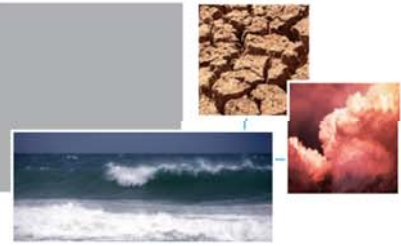


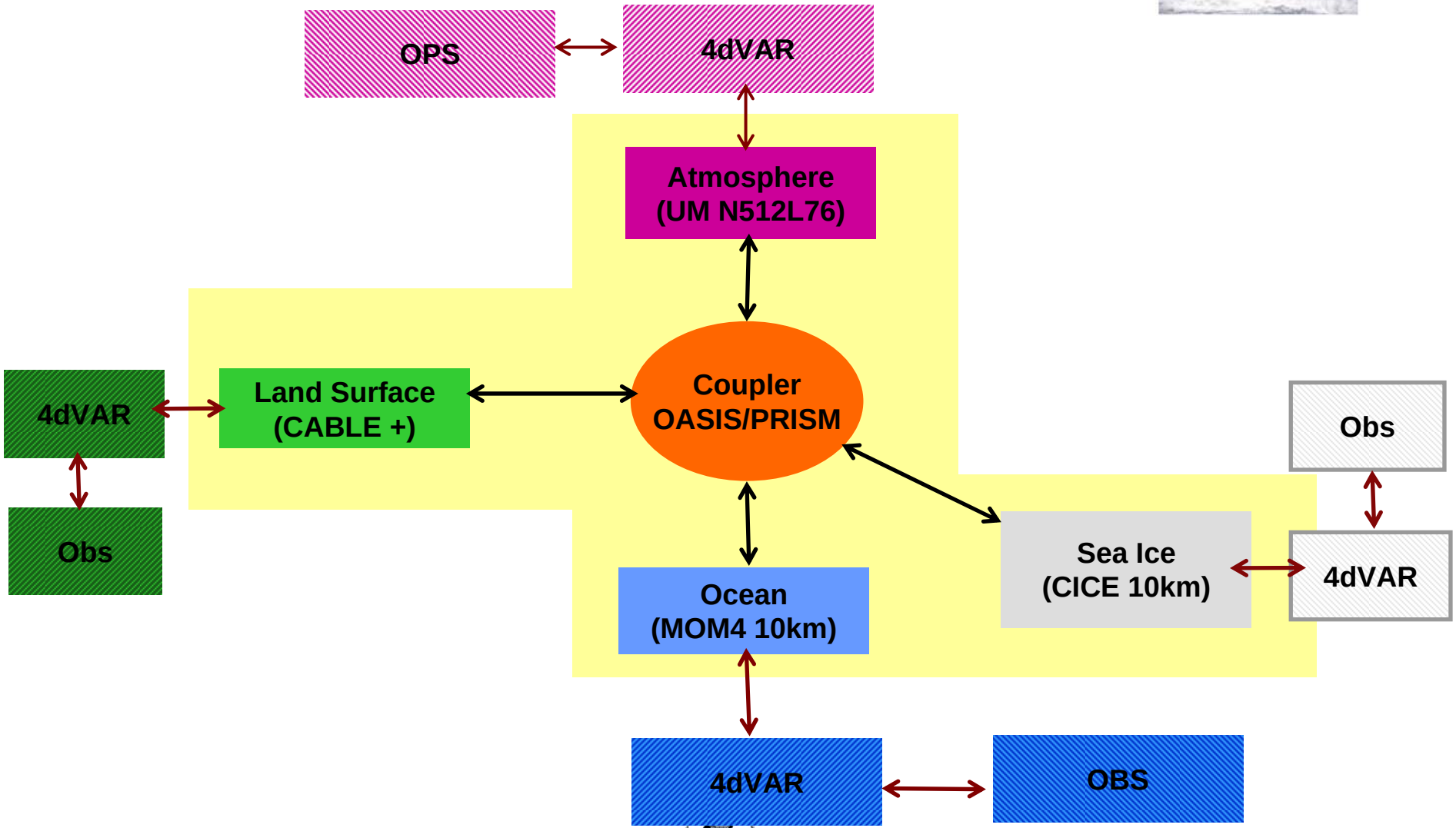
- Observation systems are maturing enough to support coupled NWP.
  - Remote sensing platforms such as MODIS and AVHRR, can provide land surface state information for assimilation.
  - GODAE and GOOS have now established systems that can constrain and forecast the eddy-resolved ocean state.

- Having good observations can aid a reasonably skillful forecast if conditions do not change. But an earth system eventually needs to be modelled by a coupled model to capture the dynamics.
  - The ocean changes heat content through geostrophic turbulence on shorter timescales than the typical atmospheric forecast of 7 days through the propagation of eddies. i.e. 100km hot and cold plates.

- Data assimilation will mask problems in the coupled boundary conditions. However, changing the atmospheric boundary conditions without adjustment to the land or ocean will lead to biases.

Earth System Model (ESM) for Weather





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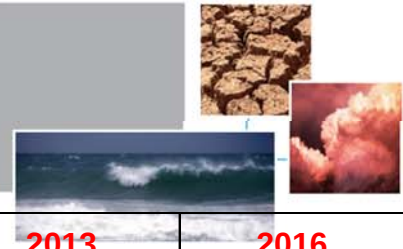
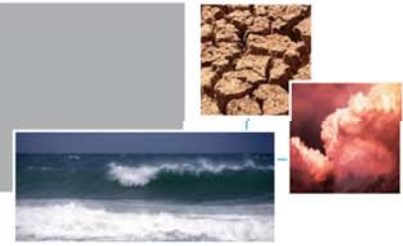
Resources for ESM-NWP

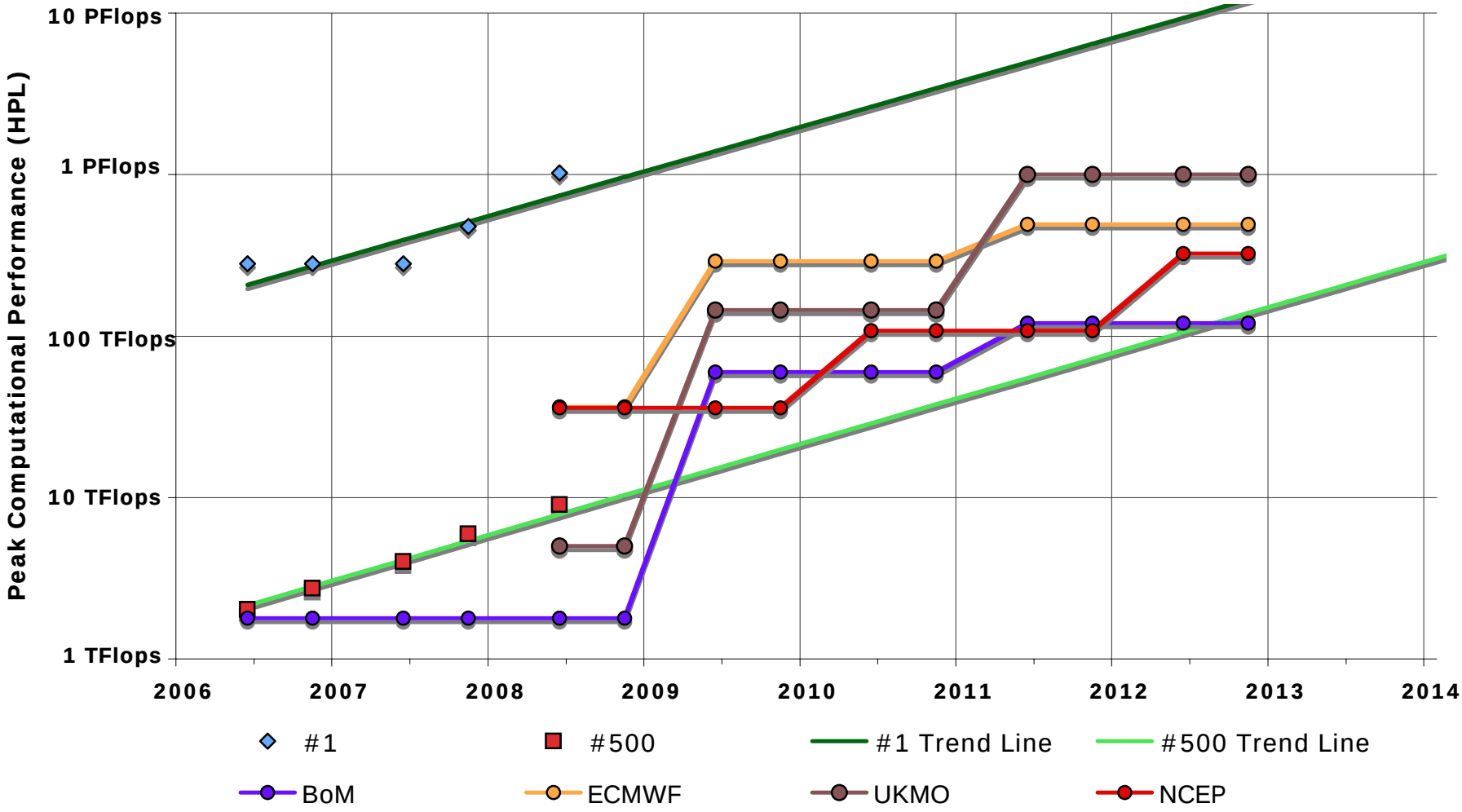


*System		Type	2009	2010	2011	2013	2016
Vertical levels	Domain (time)	Unified Model	L50	L50	L70	L90	L130
AGFS	Global (90 min.)	NWP	N144 (80km) 20 GFlops 11 GB	N320 (40km) 160 GFlops 75 GB	N512 (25km) 917 GFlops 268 GB	15km 5.46 TFlops 960 GB	10km 26.6 TFlops 3.12 TB
ATCFS	TC & severe weather (60min)	NWP	12km	4km	4km	2km	1km
Vertical levels	Domain (time)	Model	L47	L70	L70	L70	L70
OFAM	Global Ocean	NOP MOM4	10km 1191x968 28 GFlops 85 GB	7km 3600x1830 121 GFlops 258 GB	7km 3600x1830 121 GFlops 258 GB	3.5km 7200x4000 972 GFlops 1033 GB	3.5km 7200x4000 972 GFlops 1033 GB
**CLAM-TC	TC & severe weather	ESM-NOP Limited Area MOM4 + UM	15km AGCM 10km OGCM	12km AGCM 10km OGCM	4km AGCM 7km OGCM + Wave	4km AGCM 7km OGCM Land + Wave	2km AGCM 3.km OGCM Land + Wave
	Domain (time)	Coupled Models				AGCM L70 OGCM L70	AGCM L90 OGCM L70
AGFS-ESM	Global (90 min.)	ESM-NWP	na	na	na	na	15km AGCM 7km OGCM Land + Sea Ice + Wave 5.6 TFlops 1.3 TB
ATCFS-ESM	TC & severe weather (60min)	ESM-NWP Limited Area	na	na	na	4km AGCM 7km OGCM + Wave	4km AGCM 7km OGCM Land + Wave

* Disclaimer, the systems listed are not the operational roadmap for the Bureau of Meteorology, only a what-if exercise for this presentation.

Supercomputer Resource Projections





Source: WNGE Met centre projections/estimates

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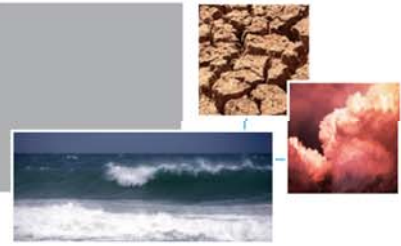
Supercomputer Procurement Status



- The Bureau of Meteorology and the Australian National University
  - Joint supercomputer procurement to obtain …
    - One System to support the Bureau of Meteorology's Operational NWP suite
    - One System to support the CAWCR and University researchers for ACCESS development within the Australian National Computational Infrastructure (NCI)
    - Both Systems are to have a high degree of interoperable to ease the transfer of technology, to leverage technical expertise between sites, and to provide enhanced user support for weather and climate modelling activities.
  - UK Met Office Unified Model benchmarks plus MOM4 climate and ocean forecast benchmark plus the usual industry standard benchmarks
  - Timelines…
    - RFT released in beginning of April 2008
    - RFT responses returned at the end of May 2008
    - Preferred Tender selected in October 2008
    - Contract negotiations ongoing with a Contract expected before the end of 2008
    - New Systems expected by mid-2009
- Sorry, that's all for now.

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Thank you

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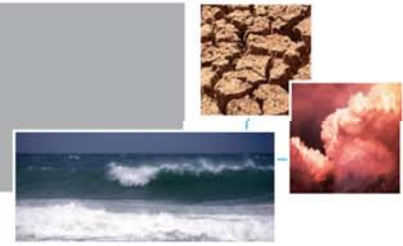
NWP Component Comparison



Met Office		ACCESS
UKMO Obs	Observations	BoM Obs.
MetDB	Observation Data-Base	ODB (ECMWF)
OPS	Observation	OPS
VAR	Variational Assimilation	VAR
UM	Unified Model	UM
MetDB	Met. Archive Retrieval	MARS

Earth System Model (ESM) for Weather