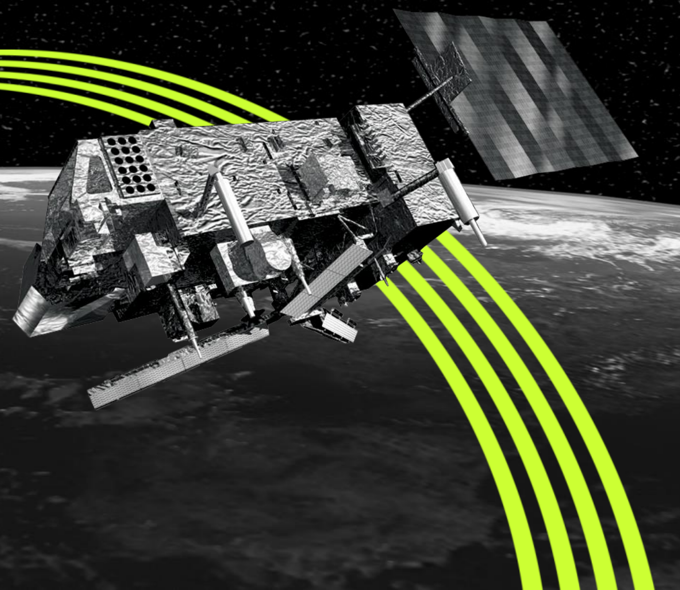
How can we use Satellite CDRs to support climate modelling?

Roger Saunders

Met Office

Acknowledgements

Nick Rayner, Lizzie Good, SMHI, ECMWF



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Topics covered

- How is satellite data used for climate research?
- Satellite climate datasets available
- Examples of use of datasets for climate modelling:
  - Climate monitoring and attribution
  - Validating climate model processes
  - Supporting climate services
  - Input to reanalyses

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GCOS ECVs

Atmosphere	Surface	Air temperature; Precipitation, Pressure, Surface radn budget, Wind
	Upper Air	Clouds, Wind, Earth Radn Budget Upper air temp, water vapour, lightning
	Composition	Carbon dioxide, methane & GHGs Ozone, Aerosol properties
Ocean	Surface	SST, Sea-level, Sea-ice, Ocean colour Sea state, Salinity, CO_2 partial pressure
	Sub-surface	Temperature, Salinity, Current, Nutrients, Carbon, Ocean Tracers, Phytoplankton
Terrestrial	Glaciers & Ice caps, Land cover, Fire disturbance, FaPAR, LAI, Albedo, Biomass, Lake levels, Snow cover, Soil moisture, Water use, Ground water, River discharge, Permafrost, Seasonally frozen ground, Ice Sheets	

What ECVs are measured from space?

Atmosphere	Surface	Air temperature, Precipitation, Pressure, Surface radn budget, Wind
	Upper Air	Clouds, Wind, Earth Radn Budget Upper air temp, water vapour, lightning
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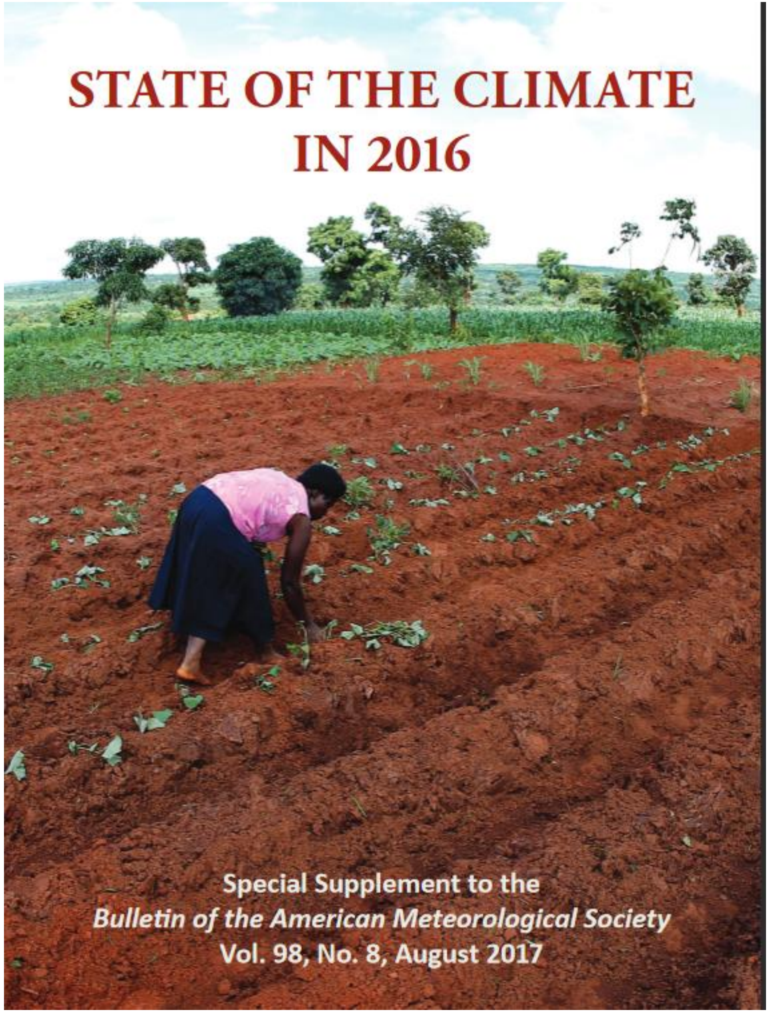

State of the Climate 2016

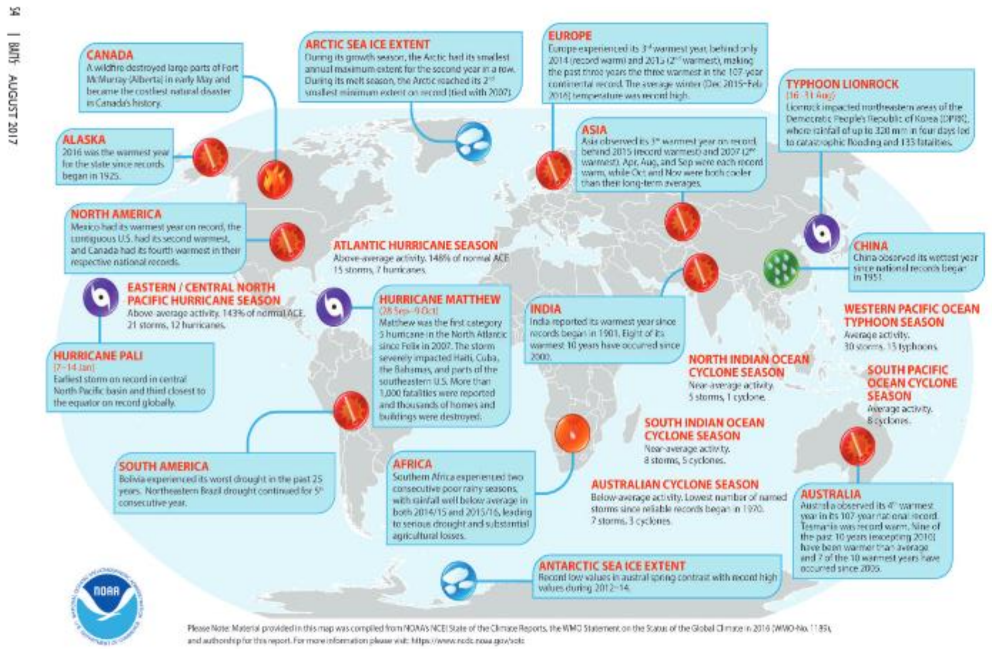

Fig. 1.1. Geographical distribution of selected notable climate anomalies and events in 2016.

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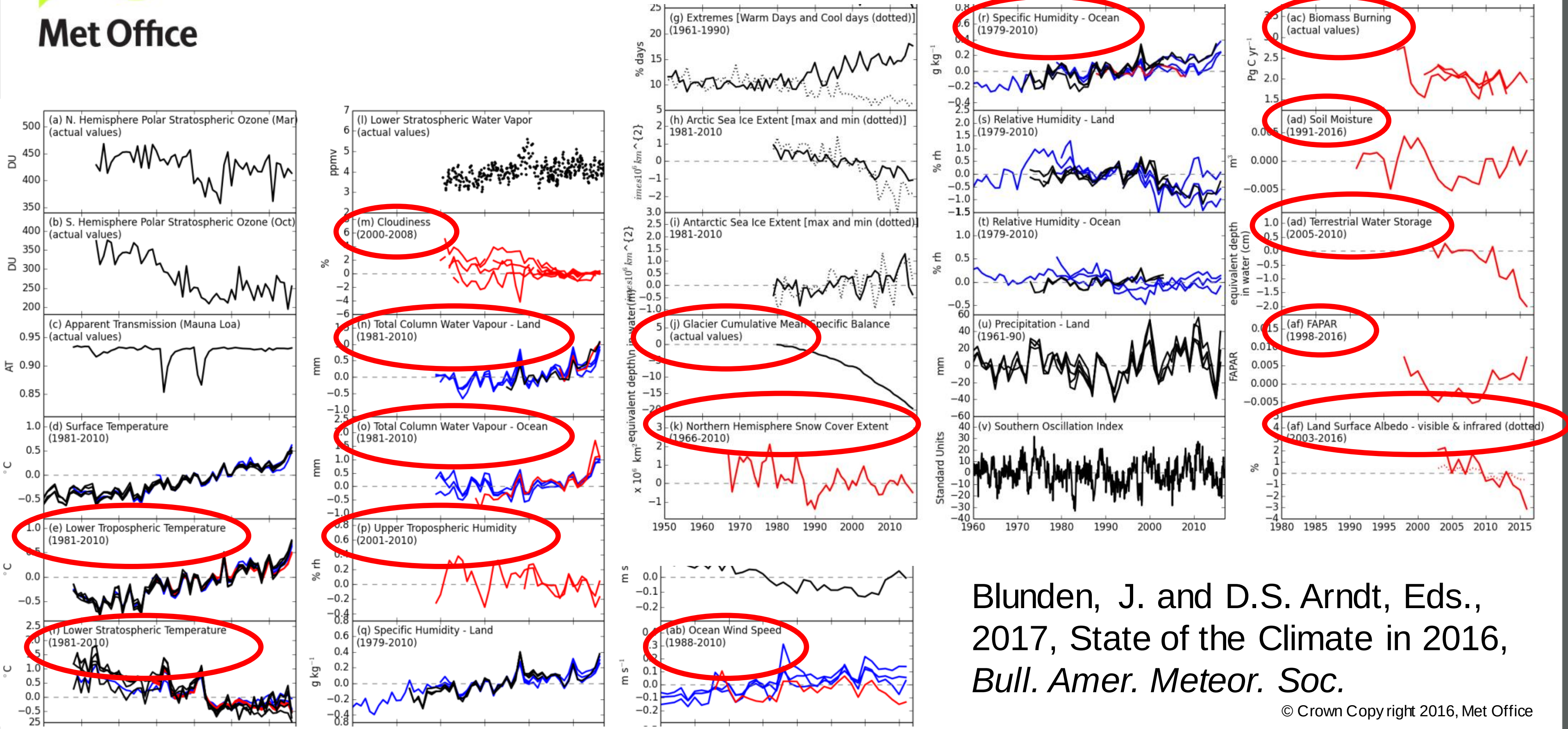
Assessing the State of the Climate



Blunden, J. and D.S. Arndt, Eds., 2017, State of the Climate in 2016, *Bull. Amer. Meteor. Soc.*

How do modellers use satellite climate datasets ?

1. Evaluate the physical processes most relevant to reducing uncertainty in climate predictions (e.g. cloud, radiation budget, hydrological cycle carbon cycle, surface processes)
2. Inform & prioritise key areas for developing and improving climate models
3. Assimilation in reanalyses (atmosphere, ocean or land)
4. Initialising seasonal to centennial model predictions
5. Provide observational constraint for model intercomparisons (e.g. CMIP)
6. Constraining climate model projections and attribution studies (natural and anthropogenic)

User survey on use of climate datasets

GCOS ECV	Model Initialisation	Prescribe Boundary Conditions	Re-analyses	Data Assimilation	Model Development and Validation	Climate Monitoring/ Attribution	Q/C in situ data	Climate process study
Atmospheric								
Cloud properties	X	X					X	X
Ozone	X	X	X	X	X	X	X	
Greenhouse gases	X	X	X	X	X	X	X	
Aerosols	X	X	X	X	X	X		
Oceanic								
SST	X	X	X		X	X		
Sea level	X	X	X	X	X	X		
Sea-ice	X	X	X		X	X		
Ocean colour				X	X	X		
Terrestrial								
Glaciers and ice caps	X	X			X	X		X
Ice sheets	X	X			X	X		X
Land cover	X	X	X		X	X	X	
Fire	X	X		X	X	X	X	
Soil Moisture	X	X	X	X	X	X	X	X
Users responses								
Declared uses	36	34	23	22	71	39	11	7

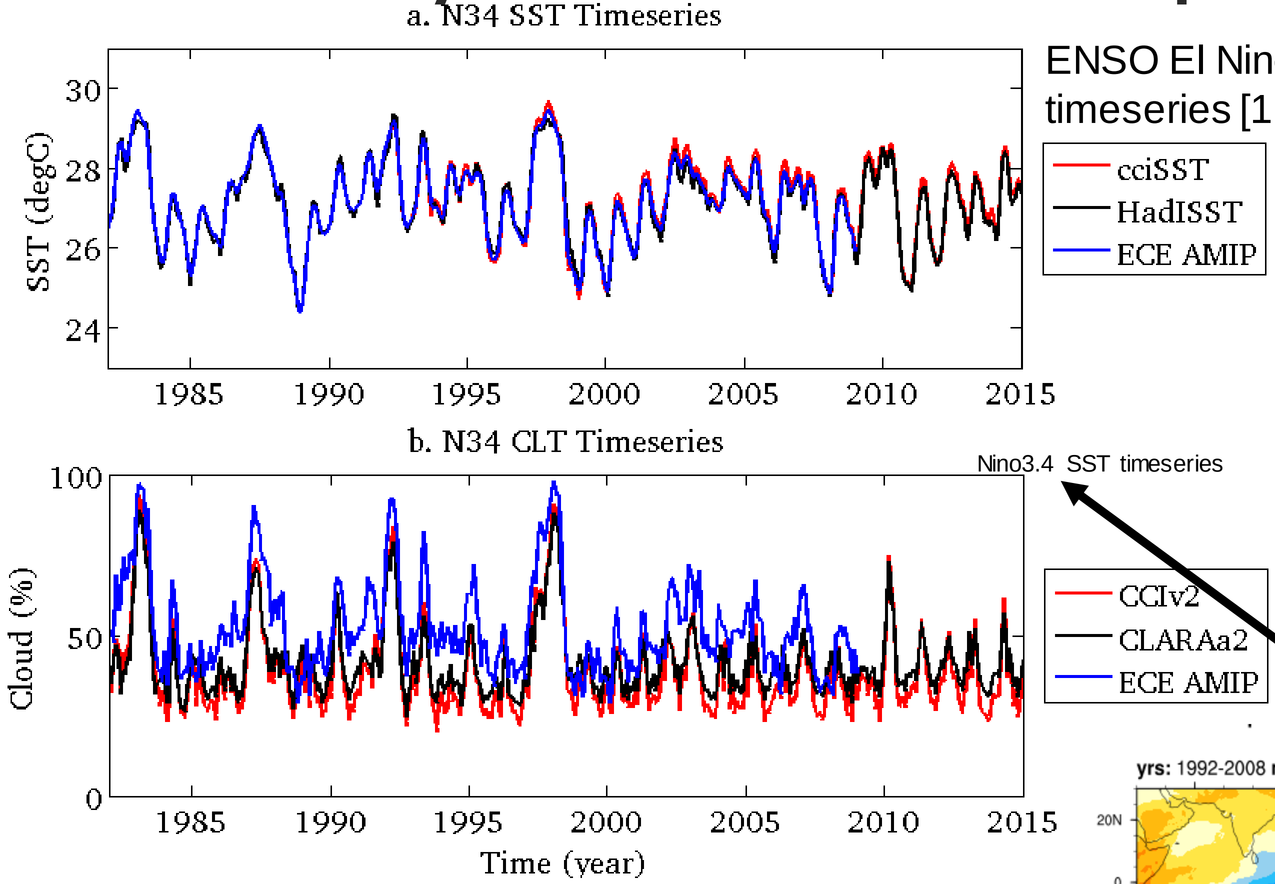
Met Office

Key characteristics of good CDRs

- Simple documentation on datasets for modellers
- Uncertainty provided with data (e.g. from ensembles)
- Long term preservation of data archives
- Seamless access for users (e.g. Earth System Grid Federation for modelers)
- CDRs openly and independently verified, validated and assessed for their utility
- Consistency ensured with related ECVs

Consistency between datasets is important

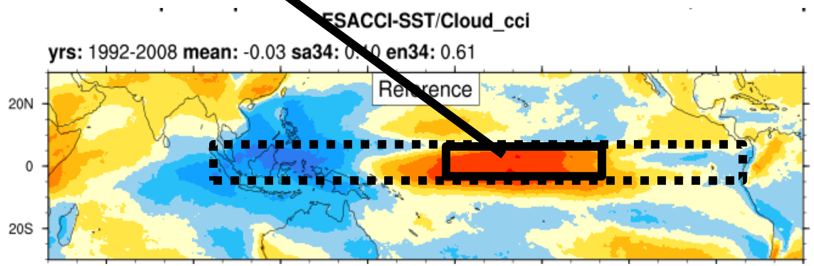
SMHI



ENSO El Nino Southern Oscillation: Nino3.4 timeseries [190E/240E, 5S/5N]

CCI SST slightly warmer max SST than HadISST. CCI Clouds lower minima than CLARA. EC-Earth AMIP5 (prescribed SST), captures cloud variabilty, but higher than observed.

Nino3.4 SST timeseries



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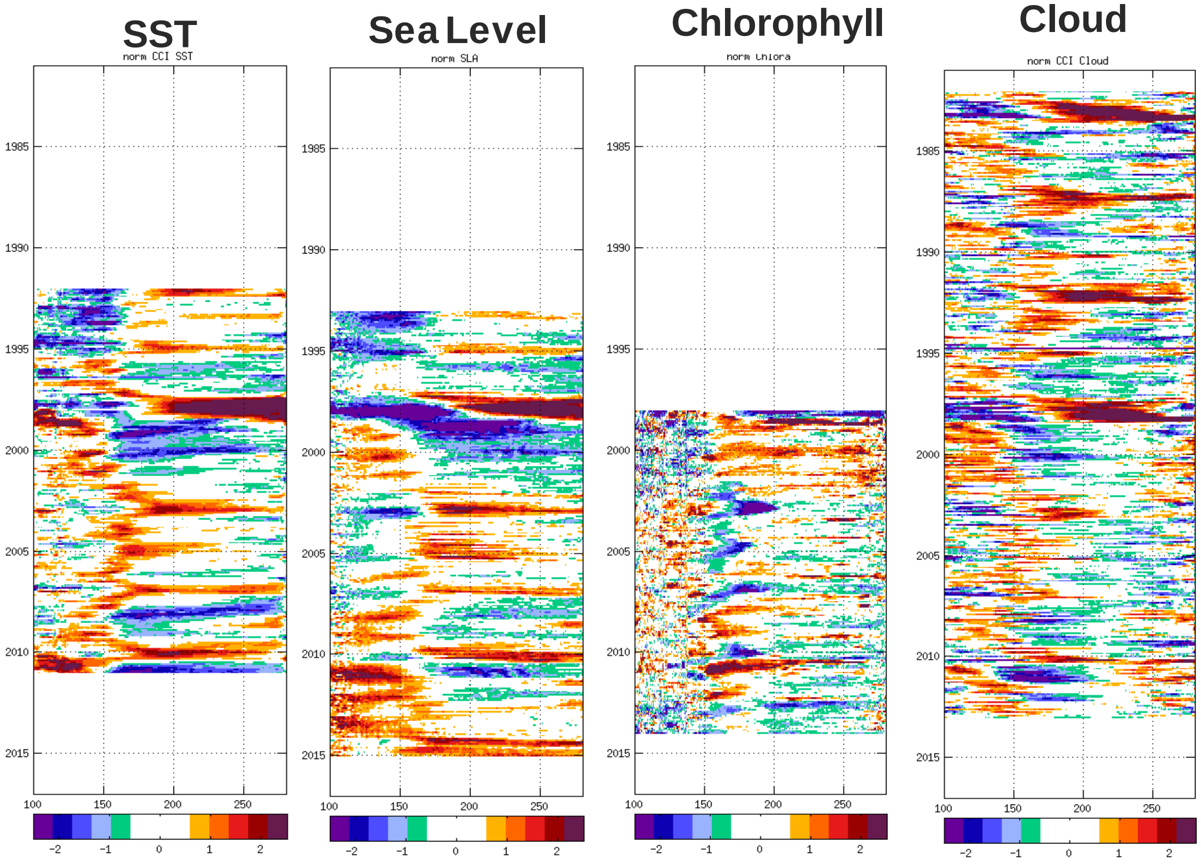
SMHI

Hovmöller diagrams for Pacific Ocean 5S-5N normalized anomalies for CCI SST, Sea Level, Chlorophyll and Cloud cover and longitudes between 100E to 270E



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Reprocessing Activities

Fundamental Climate Data Records

NASA (especially very old satellites)

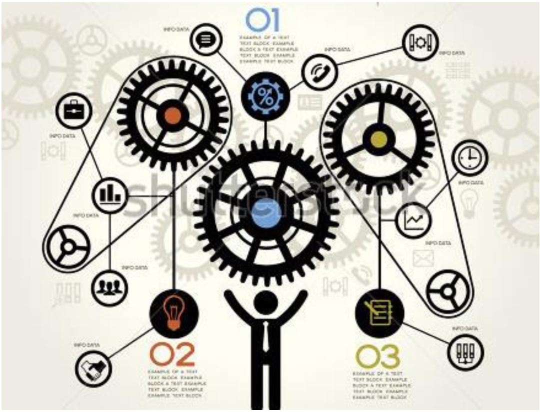
NOAA STAR

ESA

EUMETSAT (CAF, CM-SAF)

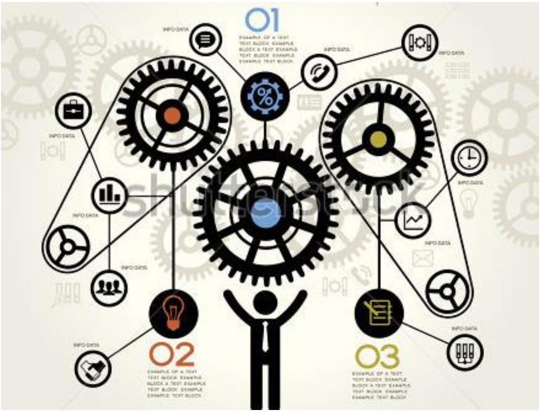
EU (FIDUCEO, ..)

Other space agencies



Reprocessing Activities Climate Data Records

- ESA (GlobXXX, Climate Change Initiative)
- EUMETSAT (CAF, CM-SAF)
- EU (Copernicus, FIDUCEO)
- NASA MEaSUREs Program
- NOAA STAR (…)
- SCOPE-CM



CCI+

Biomass | HR Land Cover | Lakes | Salinity | Permafrost | Land Surface Temp | Sea State | Snow | Water Vapour

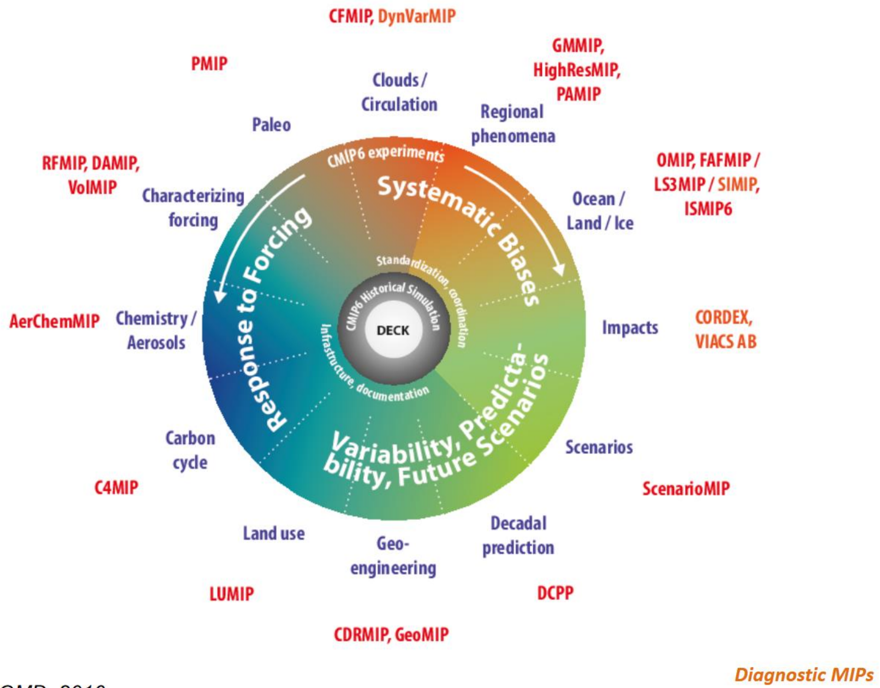
- Long, stable satellite datasets for climate scientists
- Open and free access to the data: cci.esa.int
- Nine new Essential Climate Variables starting in 2018
- Research & development on already existing ECVs
- Knowledge Exchange activities
- Cross ECV activities

Coupled Model Intercomparison Project 6 (CMIP6)

23 CMIP6-Endorsed MIPs

The scientific context for CMIP6 is the WCRP Grand Science Challenges:

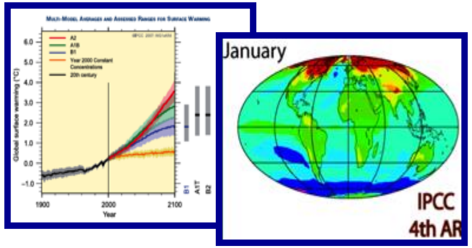
1. Clouds, Circulation and Climate Sensitivity
2. Changes in Cryosphere
3. Climate Extremes
4. Regional Sea-level Rise
5. Water Availability
6. Near-Term Climate Prediction
7. Biogeochemical Cycles and Climate Change

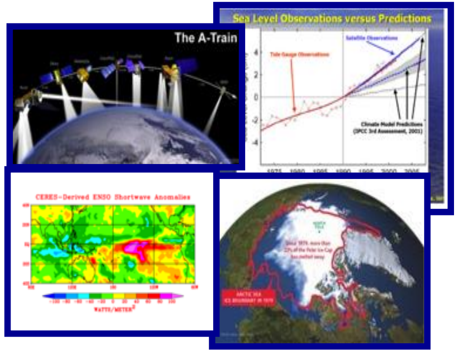


Eyring et al., GMD, 2016

Observationally-based datasets for climate model evaluation. Obs4MIPs is a limited collection of well-established and documented datasets for the CMIP5 model output requirements and made available to all. Each Obs4MIPs dataset corresponds to a field that is output in one or more of the CMIP5 experiments.

CMIP6





https://esgf-node.llnl.gov/projects/obs4mips/

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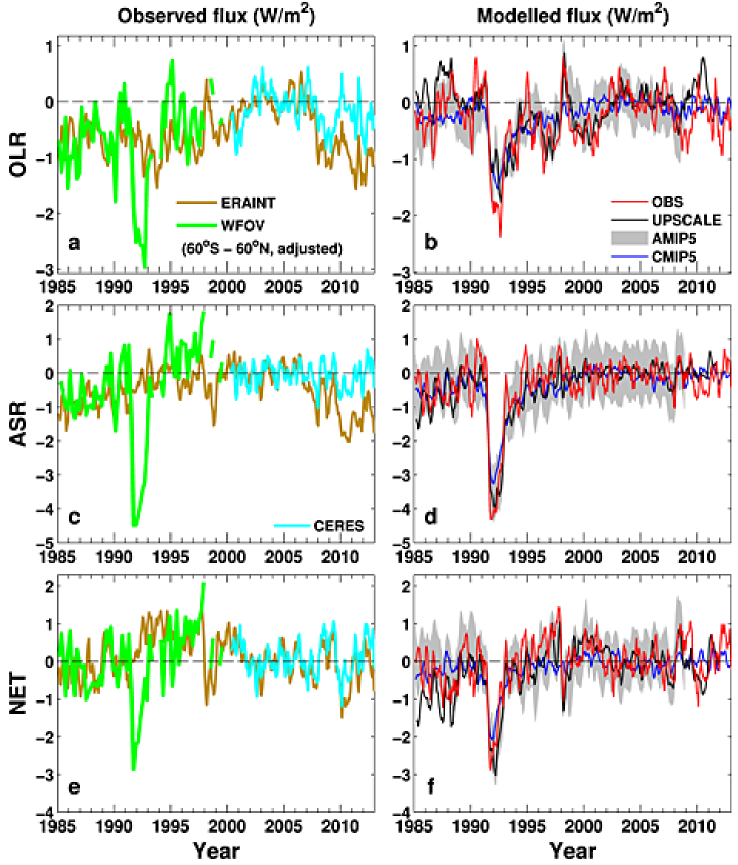
Met Office Hadley Centre

Monitoring and attribution

- Long-term records allow evaluation of variability in models
- Example shows Earth radiation budget since 1985
- Provides another perspective on model performance
- Also need long time series to examine trends and extremes

Source: R.P. Allan et al (2014). Geophys. Res. Lett.



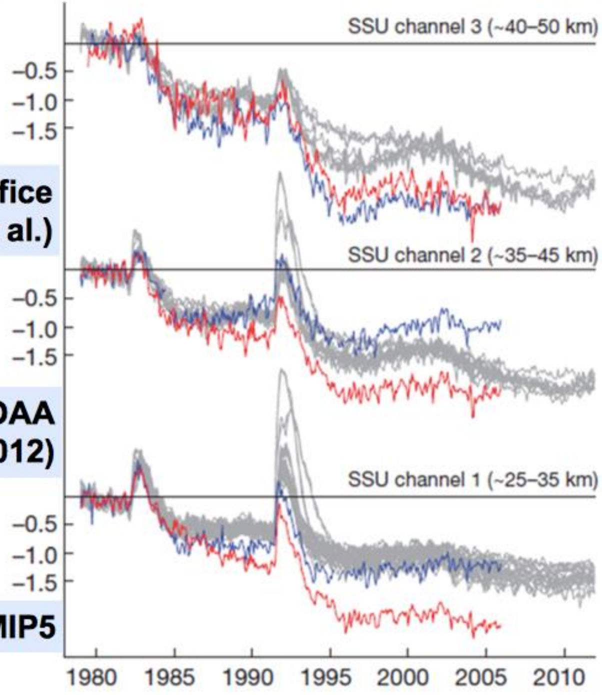
Stratospheric temperatures from SSU

Thompson et al. (2012) Nature Research Perspective: The mystery of recent stratospheric temperature trends

Blue: Met Office (Nash et al.)

Red: NOAA (Wang et al., 2012)

Grey CMIP5



1. Differences between 2 independently processed satellite datasets
2. CMIP5 models differ from observations
3. Impact of Pinatubo well modelled
4. Post eruption change in stratospheric temperature not so well modelled

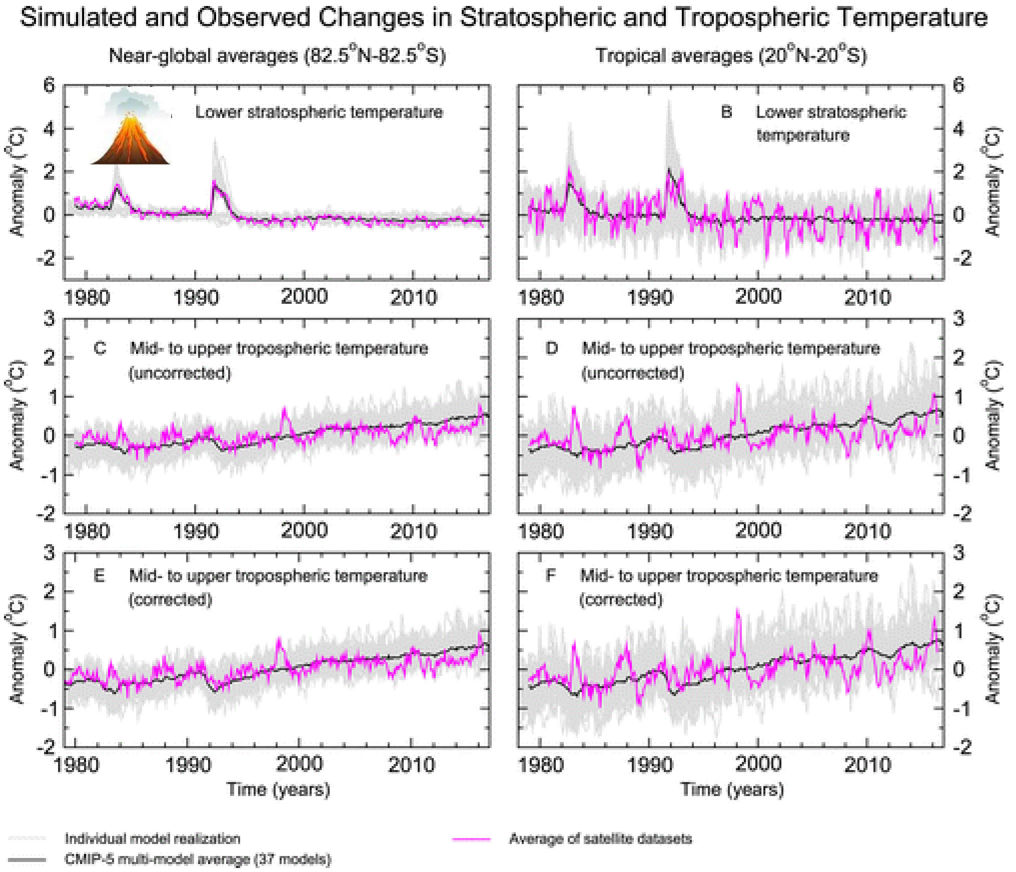
Satellite and Model Temperature Comparisons

Santer et al 2017

Satellite data from MW sounders

37 Models from CMIP-5

Impact of major volcanic eruptions clear but models tend to overestimate or not represent them.

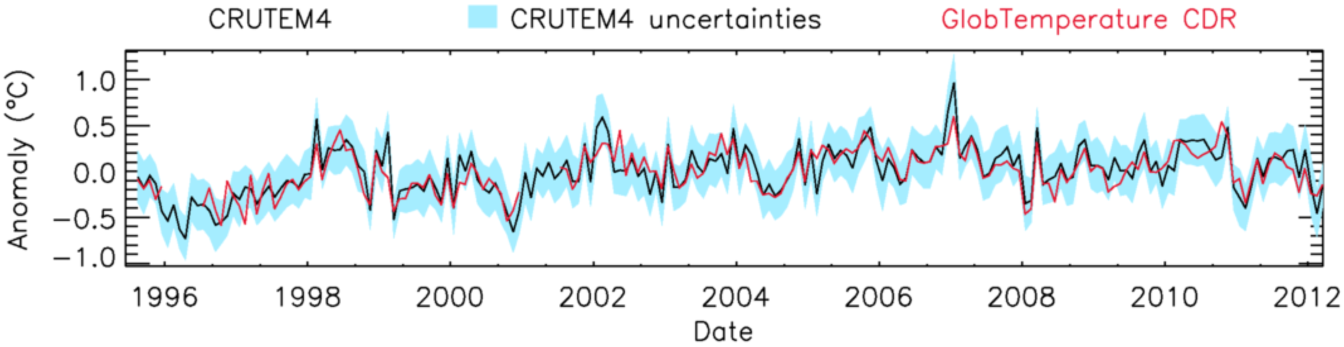


Satellite vs in-situ LST Time series

CRUTEM4: a monthly mean gridded station anomaly data set at 5° lat/long (baseline: 1961-1990).

~90% of CDR anomalies within CRUTEM4 uncertainties

Anomaly correlations ~0.9.



- Time *series* of LSTngt and T2m anomalies (August 1995 – March 2012)
- CRUTEM4 and LST Climate Data Record (CDR) agree remarkably well
- Data sets are **completely independent**
- Some evidence for temporal instability in CDR, particularly LSTday

Lizzie Good et al, JGR-Atm, 2017

Met Office

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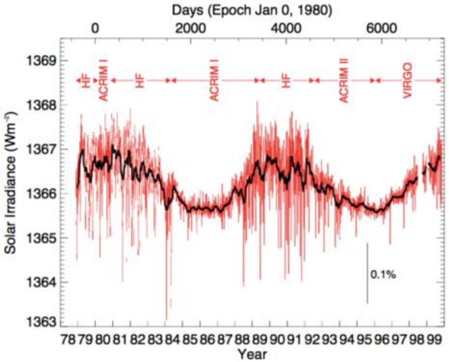
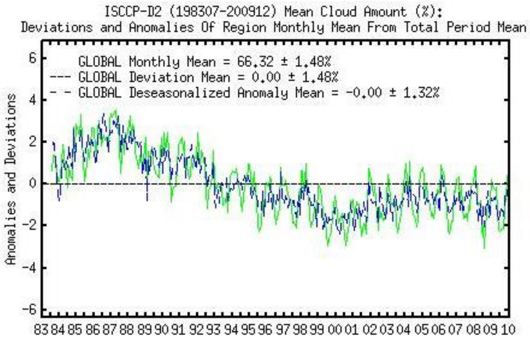
Creation of Early Satellite Climate Datasets

NASA



First Satellite data used to validate climate models
Earth Radiation Budget Measurements
Nimbus-6 ERB 1975 → CERES 2019

ESA/NASA/JMA



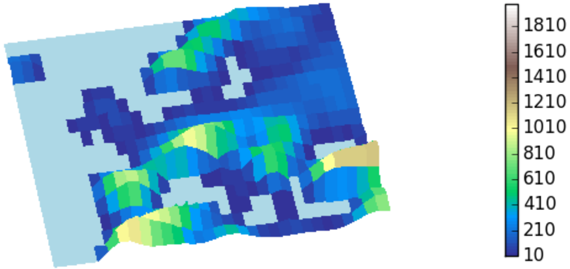
ISCCP Project started in 1982 but it took **15 years** for modellers to use ISCCP data from Geo imagers 1983 – 2009 thanks to COSP ISCCP simulator

How to reduce this time?

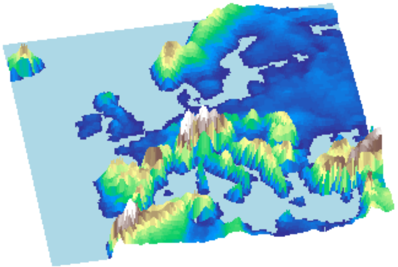
Models are increasing in complexity and resolution

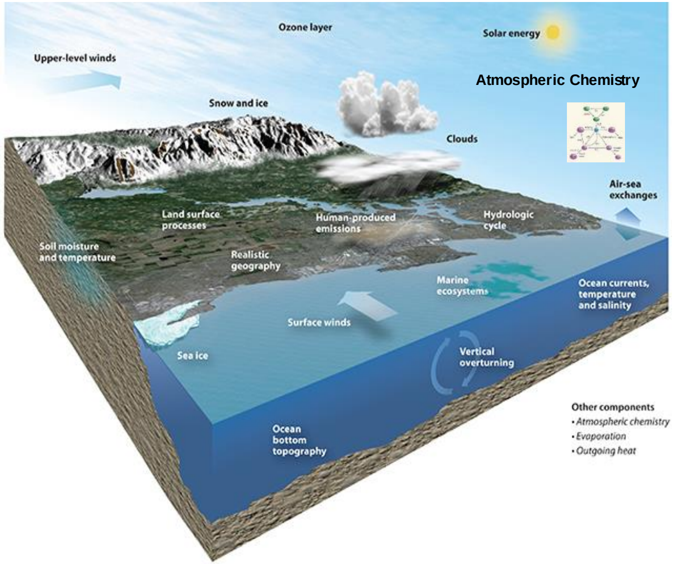
- From AOGCMs to Earth System Models with biogeochemical cycles -

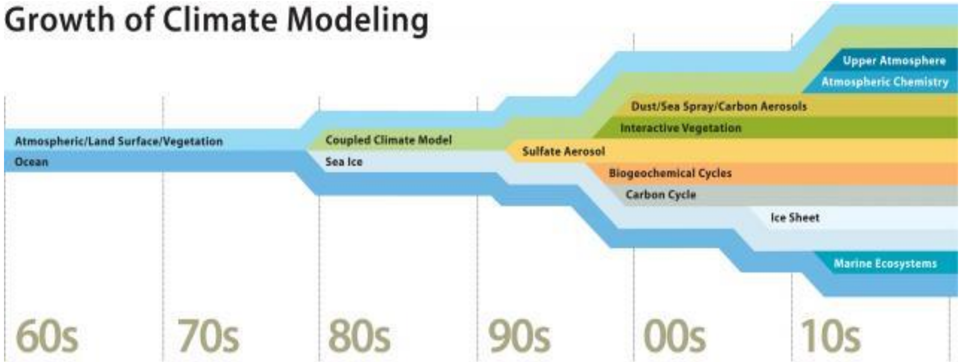
130 km resolution orography



25 km resolution orography







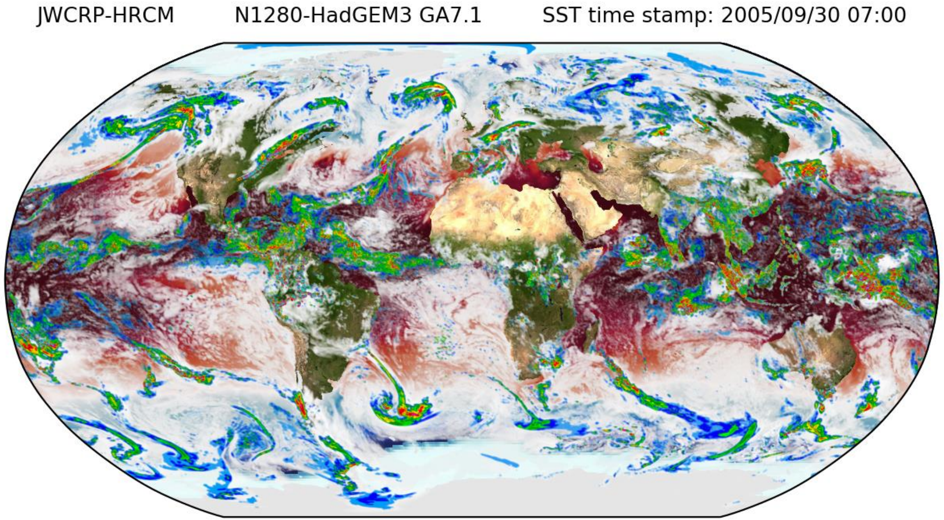
https://www2.ucar.edu/news/understanding-climate-change-multimedia-gallery

Higher resolution and regional detail

Global model run at 10 km resolution

Shows rainfall, cloud water and ice, SST, sea ice, snow.

We wish to evaluate this level of detail at the global scale.

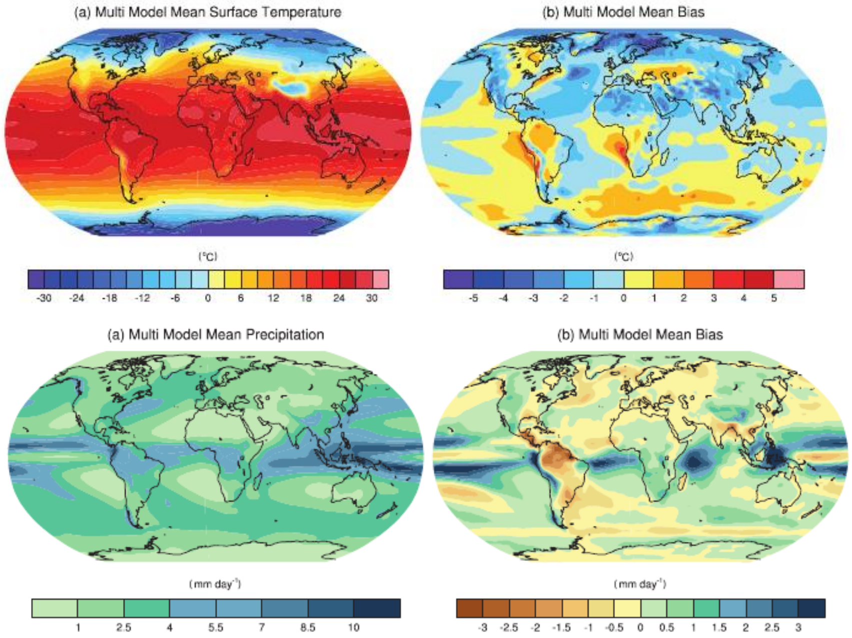


Credit: Malcolm Roberts (Met Office)

& Pier Luigi Vidale (University of Reading)

Model Evaluation: baseline comparisons

- Examine model-simulated climatologies
- Compare with long-term data sets
- Establish mean model biases
- Forms basis for more detailed evaluation



Source: IPCC AR5, Chapter 9

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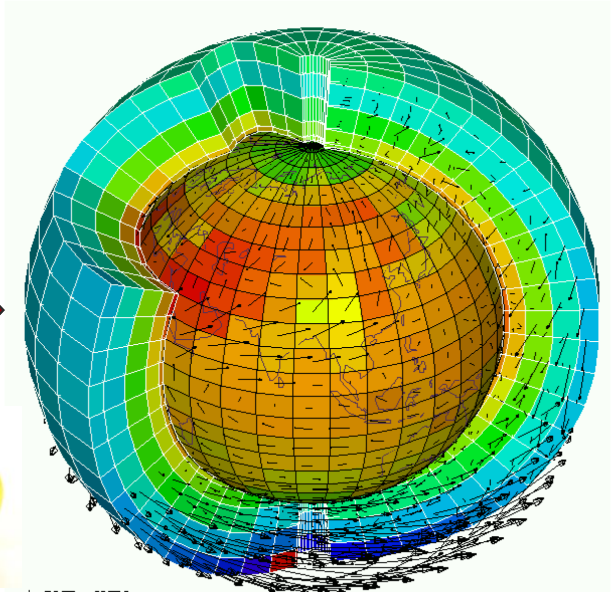
Need for Obs Simulators

Geophysical measurements

(e.g. radiance, bending angle)

?



Model grid variables (e.g. temp, water vapour, wind, etc)

Retrieve model variables

→

Compare in model space

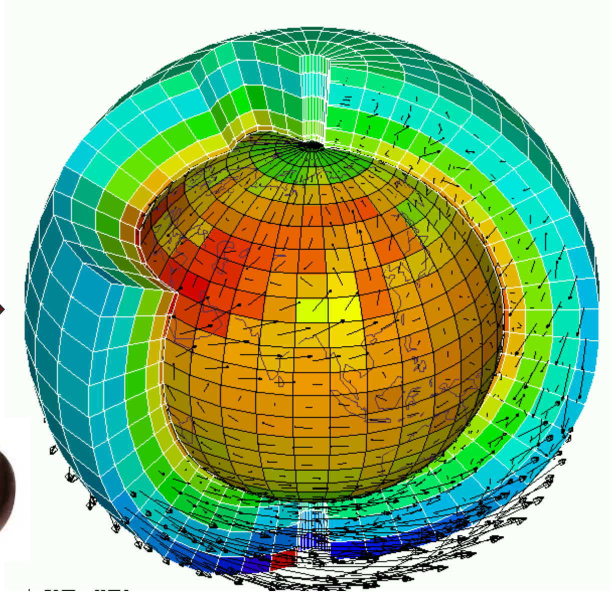
Met Office

Need for Obs Simulators

Geophysical measurements

(e.g. radiance, bending angle)

?



Model grid variables (e.g. temp, water vapour, wind, etc)

Compute satellite measurements using simulator (e.g. COSP)

Compare measured and simulated measurements

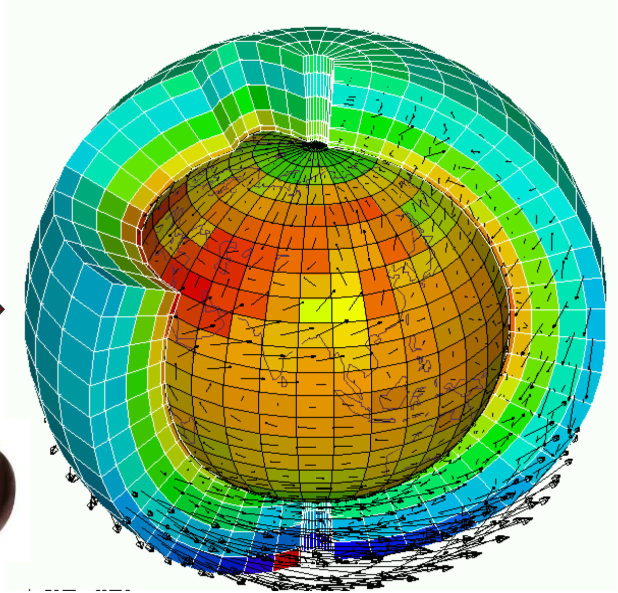
Met Office

Need for Obs Simulators

Geophysical measurements

(e.g. radiance, bending angle)

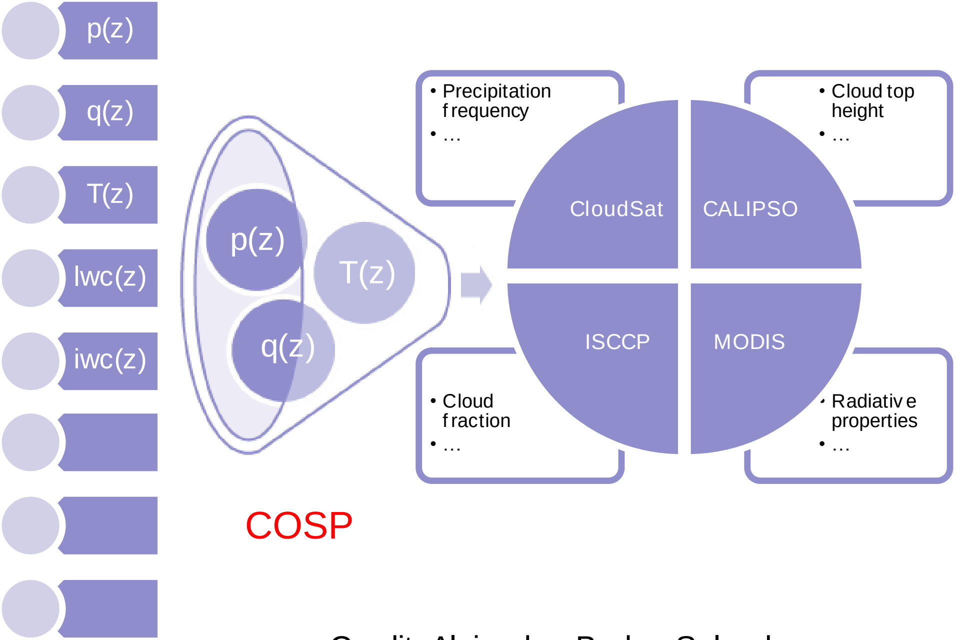
?



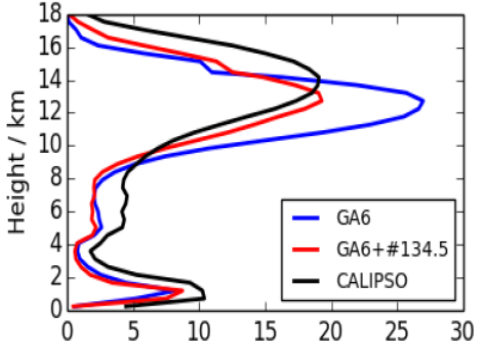
Model grid variables (e.g. temp, water vapour, wind, etc)

Both approaches are useful depending on the ECV

Use of satellite data by modellers becoming more sophisticated as we aim to make optimal use of the information to improve physical processes in models



COSP



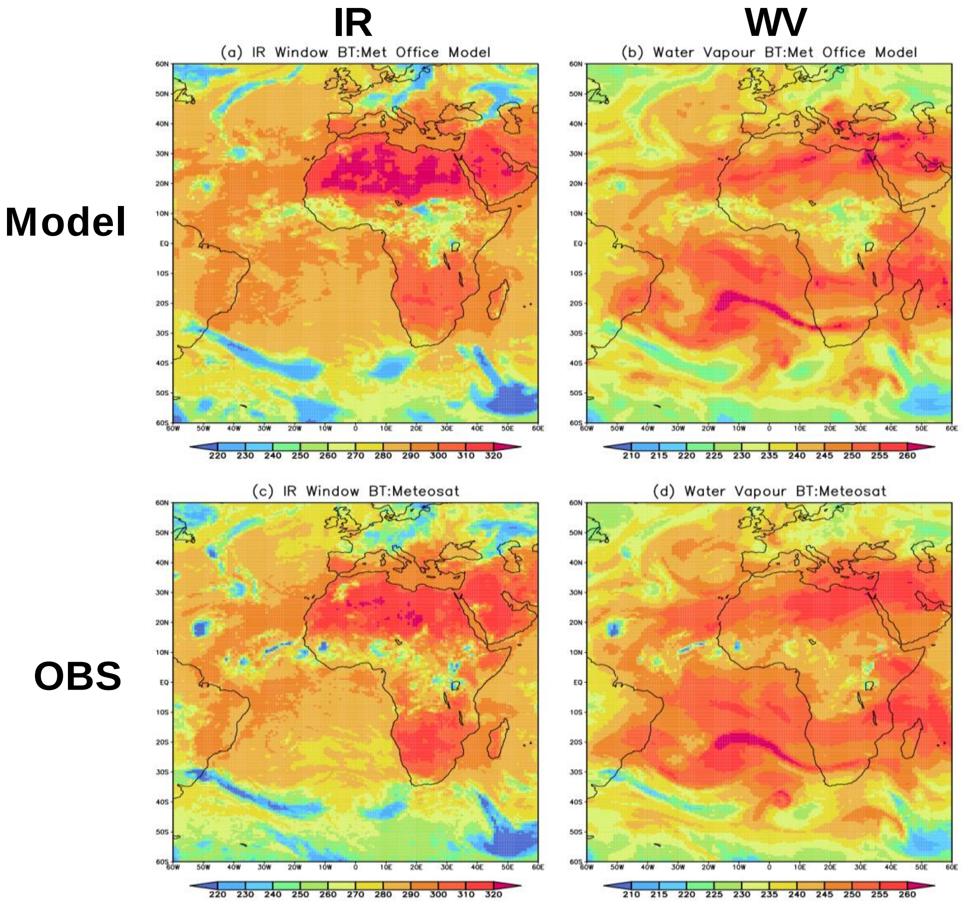
Credit: Alejandro Bodas-Salcedo (Met Office)

Evaluation of model in radiance space

Met Office
Hadley Centre

- Allows direct comparison with measured radiances, etc
- Avoids ambiguities associated with comparing to retrieved quantities
- Example shows HIRS Channel 12 in previous version of Hadley Centre model
- RTTOV is now part of the COSP simulator
- For further details see:

http://cfmip.metoffice.com/COSP.html



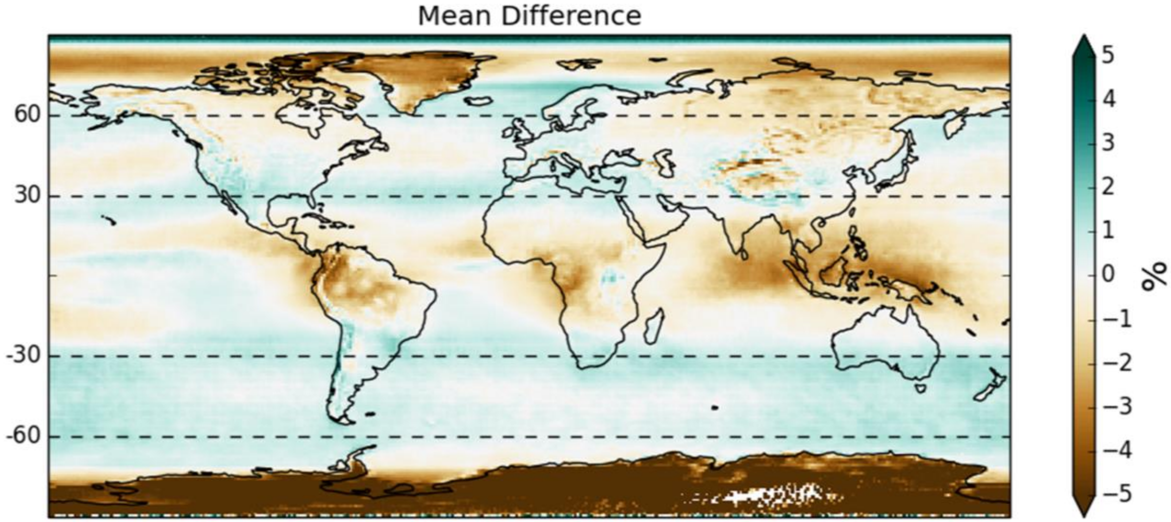
Comparison in Geophysical space UTH

UTH is relevant to anyone interested in the radiative heat balance of the clear troposphere. Upper-tropospheric moisture important for tracking, understanding, modelling and predicting convection and advection at low latitudes

Example uses for UTH:

- Model evaluation
- Variability analysis
- Predictability research
- Physical process studies
- Monitoring

CM SAF product based on microwave observations, which are nearly all-sky.

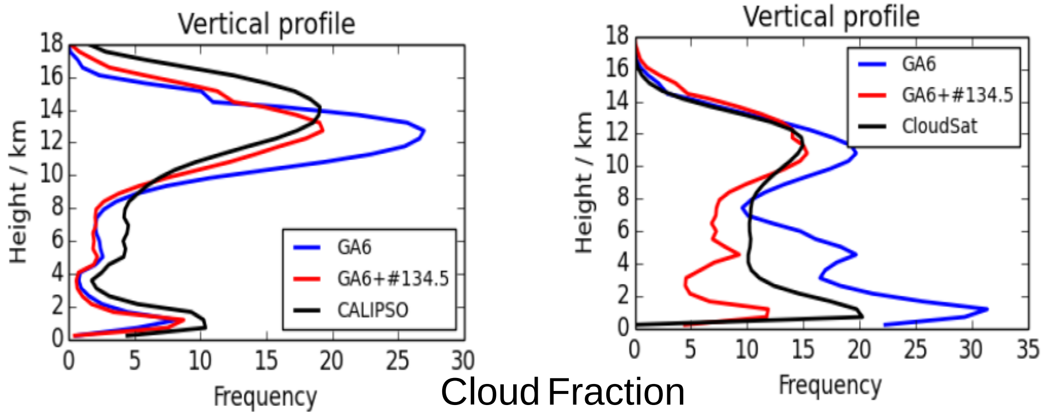


CM SAF UTH v1 product minus ERA-Interim UTH for NOAA-18 (2006-2015, all overpass times)

Use of COSP in model development

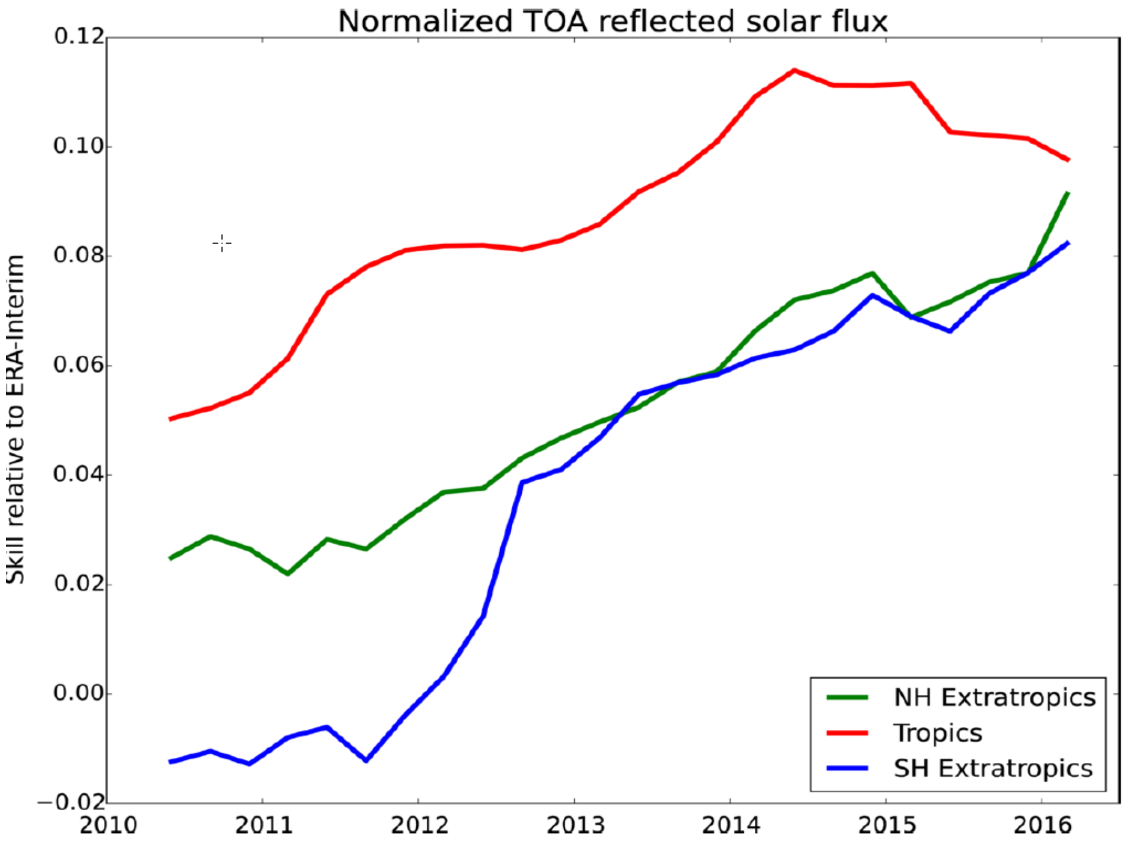
(Williams and Bodas-Salcedo, *GMD*, accepted)

CALIPSO **CloudSat**

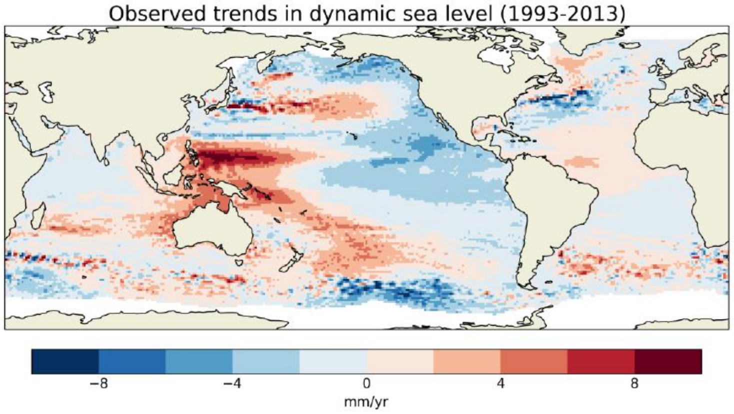


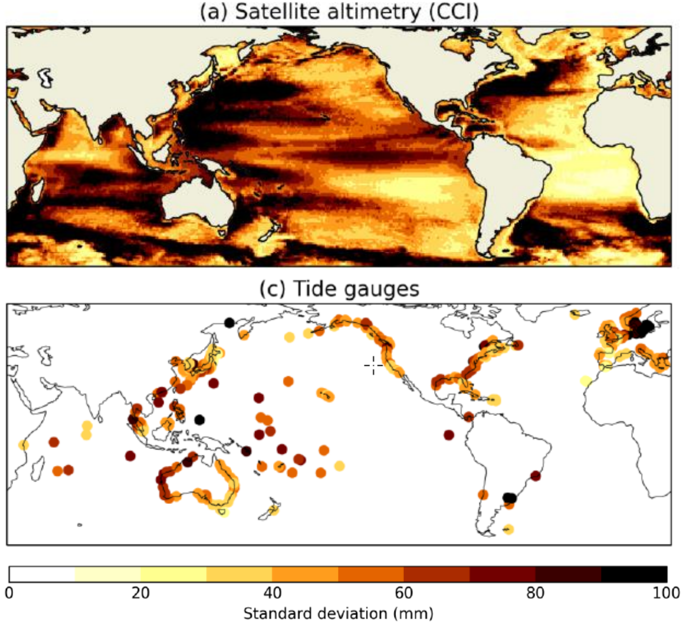
- Software tools such as COSP enhance the value of comparisons between models and observations.
- Promotes wider use of the observations by modellers but also a positive feedback to the data providers - modellers tend to use the data in novel and interesting ways, building links and enabling production of new/improved data sets, e.g. targeted at particular model issues.

CM-SAF Solar Flux verification of ECMWF 3 day forecast

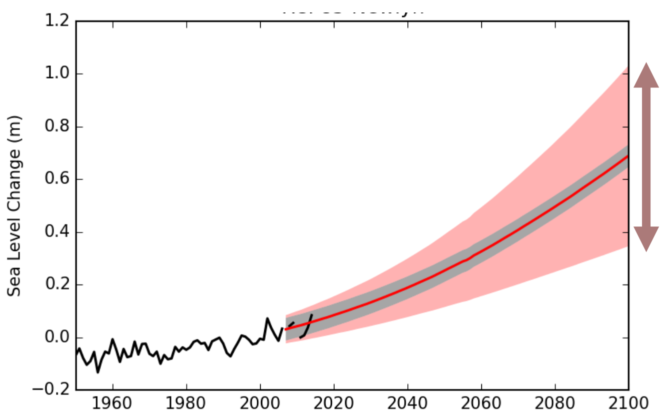


Met Office
Hadley Centre



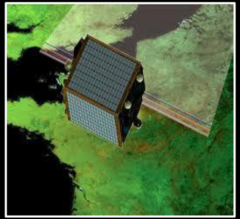


- Understanding the drivers of sea level variability (incl. ocean reanalysis)
- Assessment of seasonal-to-decadal prediction skill
- Climate and ocean model evaluation and development
- To validate model estimates of regional variability for sea level projections



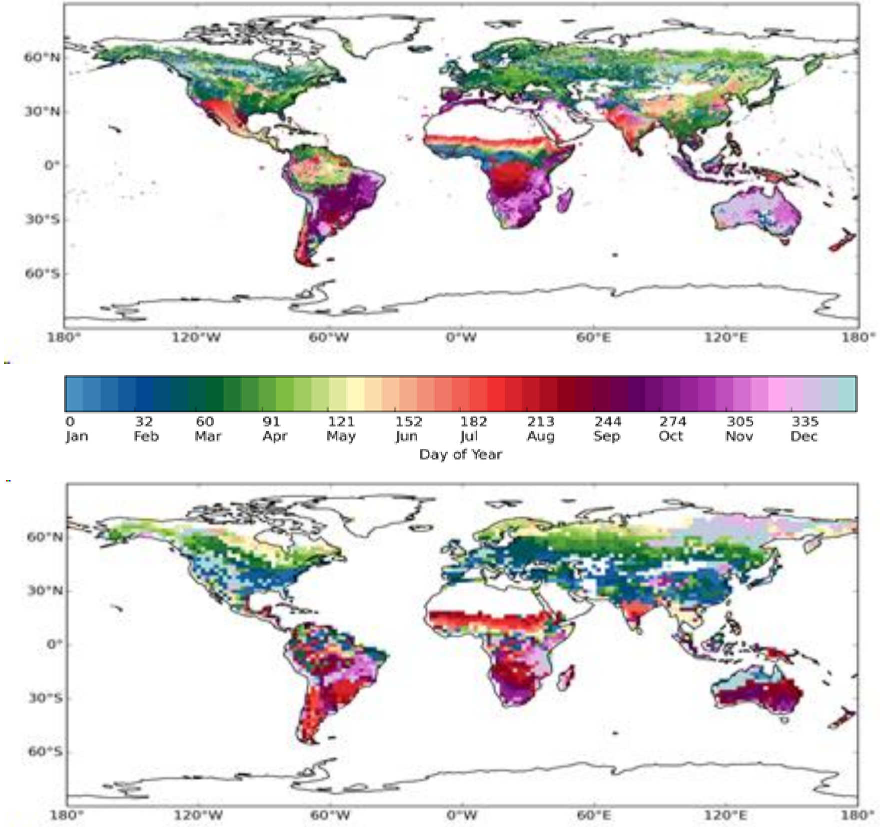
Vegetation phenology observations for model evaluation

Satellite observations vs JULES land surface model



Example: **Start of Season**

Based on observed NDVI →
(Satellite, ESA SPOT-VGT)



Contributing to various projects:

land cover cci

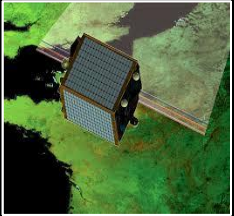
FUTURE CLIMATE FOR AFRICA

CRESCENDO

Based on modelled NDVI →
(Modelled, JULES)

Vegetation phenology observations for model evaluation

Satellite observations vs JULES land surface model

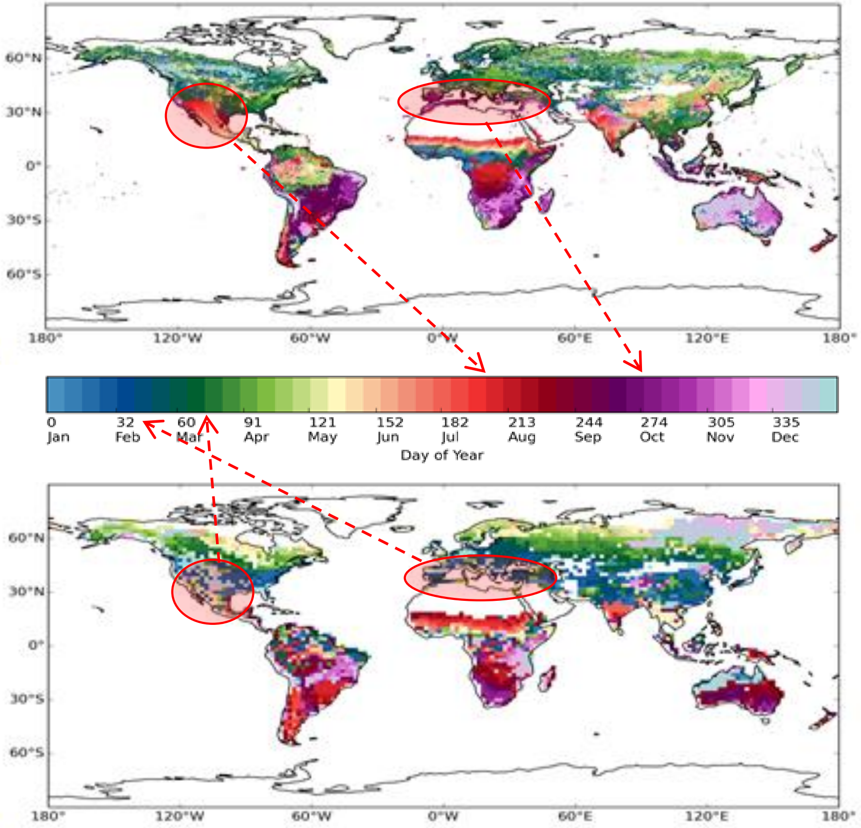


Example: **Start of Season**

Based on observed NDVI →
(Satellite, ESA SPOT-VGT)

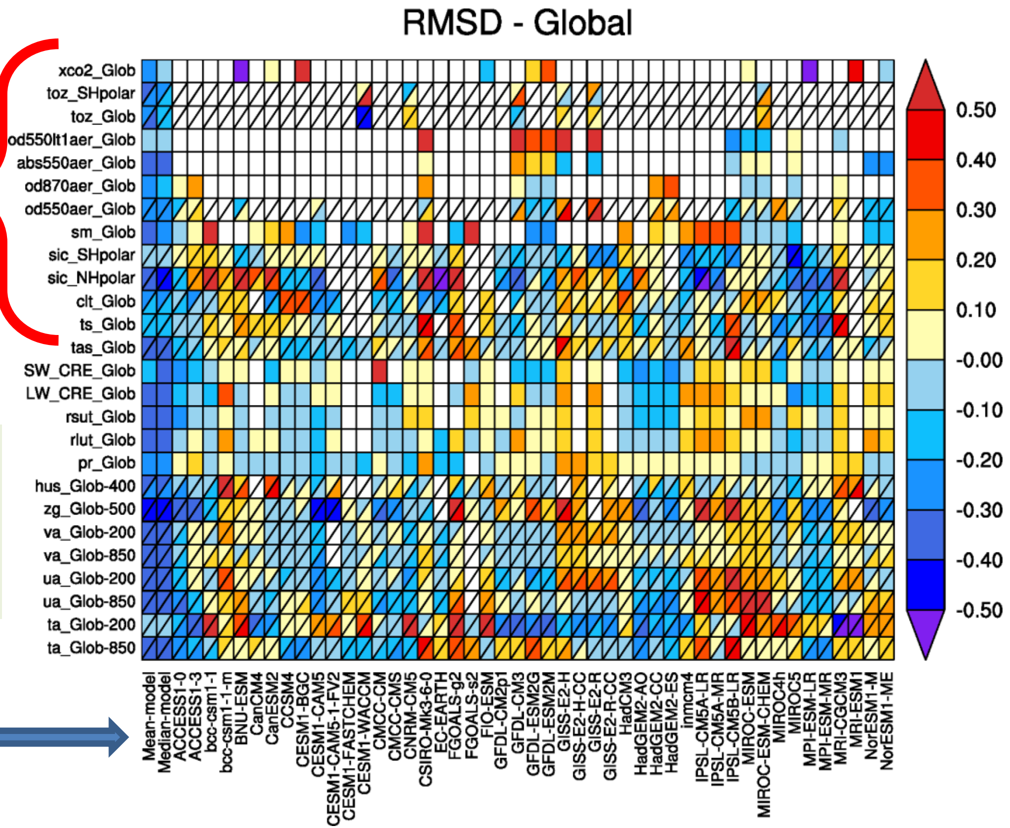
Mediterranean (seasonal dry) climate areas
Observed Start of Season is 5-7 months **LATER** than modelled
Possible reason: JULES defines generic Plant Functional Types that do not represent the drought-adapted characteristics of species in seasonally dry climate zones.
…current focus of research.

Based on modelled NDVI →
(Modelled, JULES)



Metrics for Climate Model assessment

ESA CCI datasets
greenhouse
gases
ozone
aerosol
soil moisture
sea ice
cloud
SST

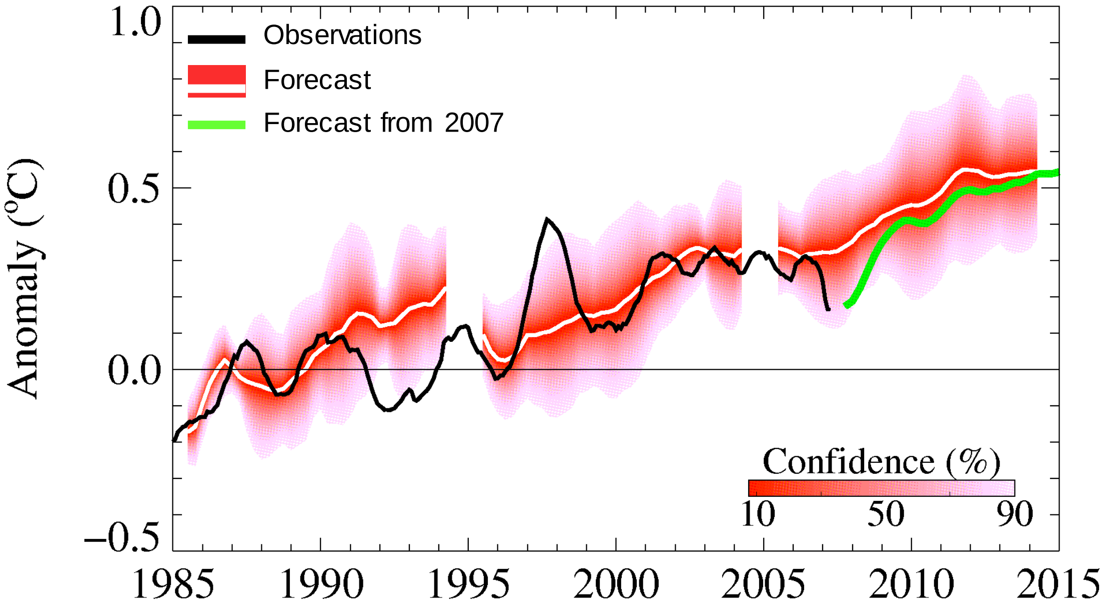


Assessment of climate models using ESMVal tool for several CCI datasets

Climate models

From: Lauer et al. (2016), Remote Sensing of Environment

Decadal prediction:Global mean surface temperature anomaly



D. Smith et al., Science 2007

Requires data for both initialisation and verification of forecasts.

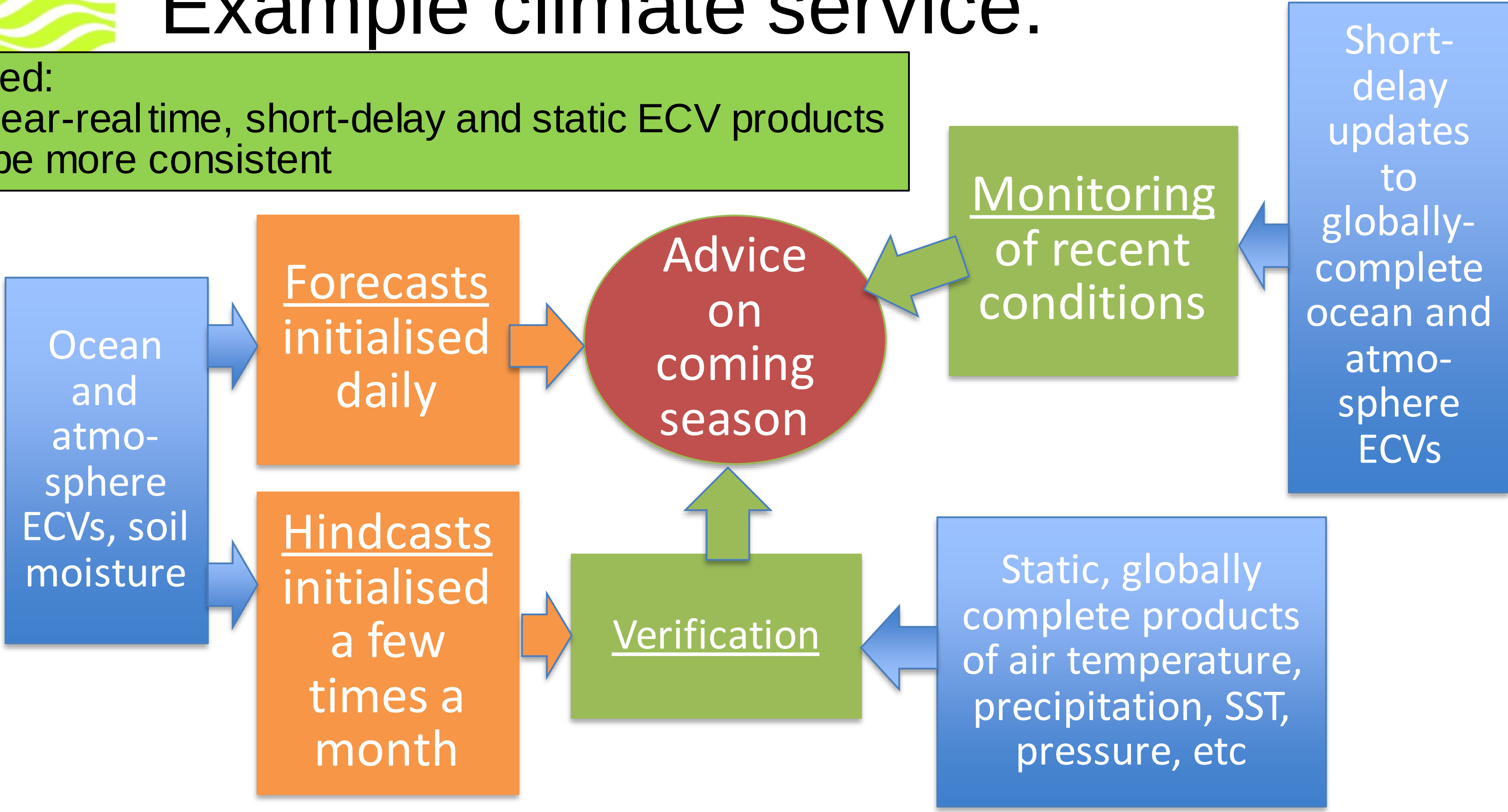
Topics covered

- How is satellite data used for climate research?
- Satellite climate datasets available
- Examples of use of datasets for climate modelling:
  - Climate monitoring and attribution
  - Validating climate model processes
  - Supporting climate services
  - Input to reanalyses

Example climate service:

Need:

• Near-real time, short-delay and static ECV products to be more consistent



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- How is satellite data used for climate research?
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Climate Change

Reanalyses Produced at ECMWF

Atmosphere/land *including ocean waves*

- 1) 1979 - 1981 FGGE
- 2) 1994 - 1996 ERA-15
- 3) 2001 - 2003 ERA-40
- 4) 2006 - … ERA-Interim
- 5) 2016 - … ERA5

Ocean *including sea ice*

- 2006 ORAS3
- 2010 - … ORAS4
- 2016 - … ORAS5

ERA CLIM

ERA CLIM2

Centennial

- 2013 - 2015 ERA-20CM/20C
- 2016 CERA-20C

Enhanced land

- 2012 ERA-Int/Land
- 2014 ERA-20C/Land
- 2017 - … ERA5L

Atmospheric composition

- 2008 - 2009 GEMS
- 2010 - 2011 MACC
- 2017 - … CAMS

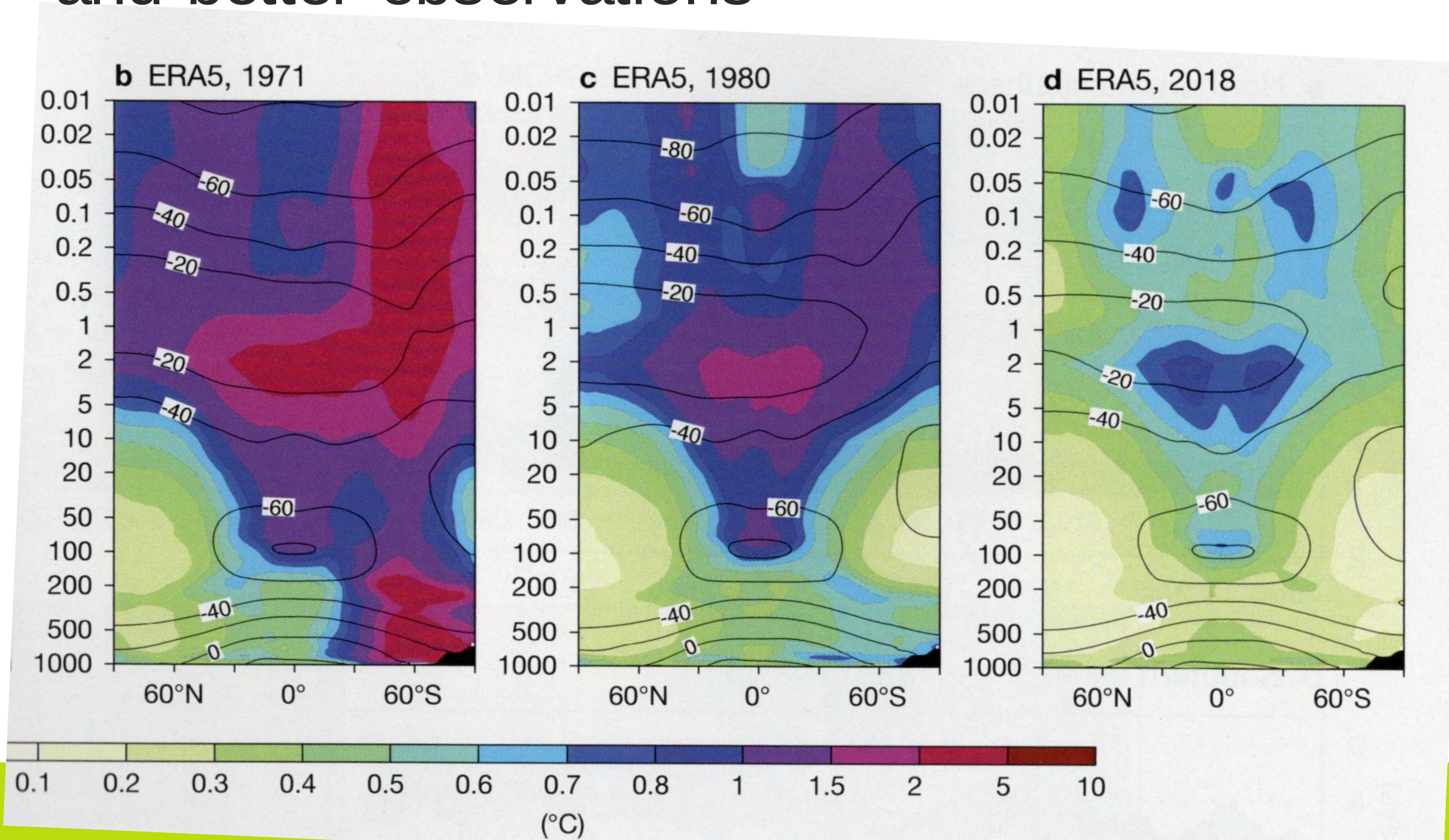
Towards a coupled earth system

LAND	ATMOSPHERE	COMPOSITION
OCEAN	WAVE	ICE

ECMWF

Uncertainties in Reanalysis reduce with more and better observations

Sub-daily ensemble spread of upper-air temperature averaged over March–April–May

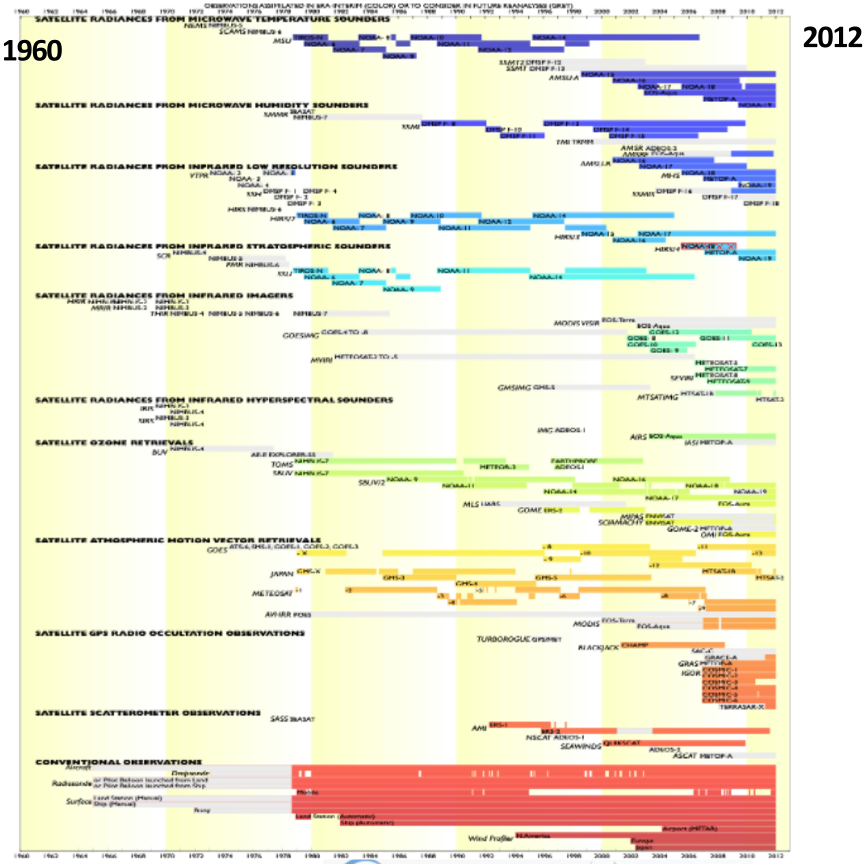


Climate Change

The evolving observing system

Newly reprocessed data sets

Radiances: SSM/I brightness temp from CM-SAF
METEOSAT from EUMETSAT
Atmospheric motion vector winds: METEOSAT, GMS/GOES-9/MTSAT, GOES-8 to 15, AVHRR METOP and NOAA
Scatterometers: ASCAT-A, ERS 1/2 soil moisture
Radio Occultation: METOP GRAS, COSMIC, CHAMP, GRACE, SAC-C, TERRASAR-x
Ozone: NIMBUS-7, EP TOMS, ERS-2 GOME, ENVISAT SCIAMACHY, Aura MLS, OMI
Altimeter: ERS1/2, ENVISAT, Jason-1



Extra data (not used in ERA-Interim)

lack of infrastructure ERA-Interim

IASI, ASCAT, ATMS, Cris, MWHS2, Himawari-8, ...

Typically the latest instruments:

ERA5 is more future proof!

Improved data usage

all-sky vs clear-sky assimilation,
latest radiative transfer model,
...

Met Office

Summary

- Satellites have now been in orbit for >40 years which allows trends to be inferred and compared with climate model predictions

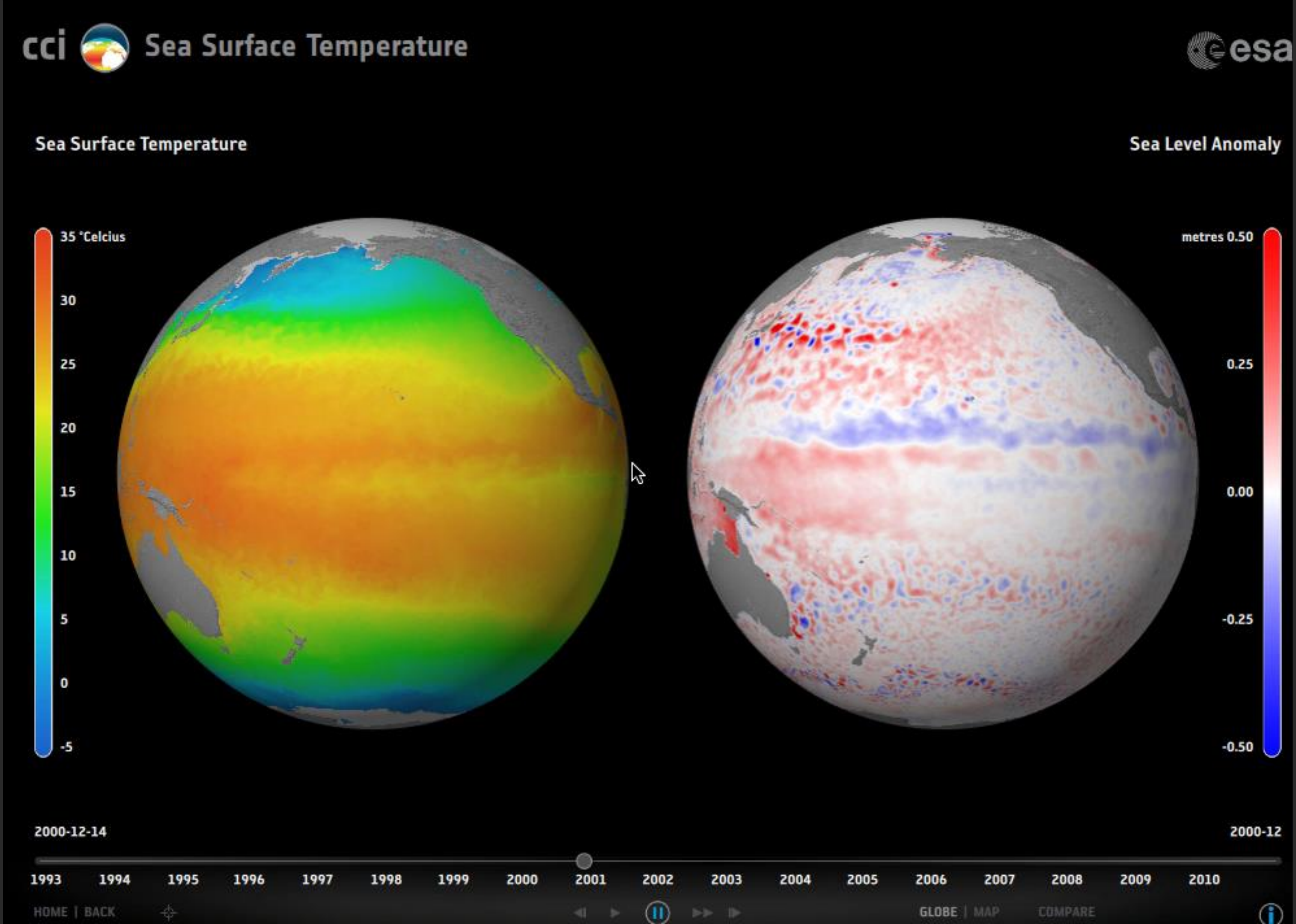
- Satellite FCDRs are now being generated by space agencies and CDRs are being generated by several centres

- Data portals for satellite climate data records (e.g. CCI, EUMETSAT, Obs4MIPS, NCEI) have been established

- Observation simulators for climate model comparisons are a key part of exploiting satellite data for climate model process studies

- The CMIPs are providing a rich source of model predictions to compare with satellite data.

- Latest climate quality reanalyses assimilating both FCDRs and CDRs



cci Sea Surface Temperature
esa
Sea Surface Temperature
Sea Level Anomaly
35 °Celcius
30
25
20
15
10
5
0
-5
metres 0.50
0.25
0.00
-0.25
-0.50
2000-12-14
2000-12
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
HOME | BACK
GLOBE | MAP
COMPARE

Met Office

Any questions?