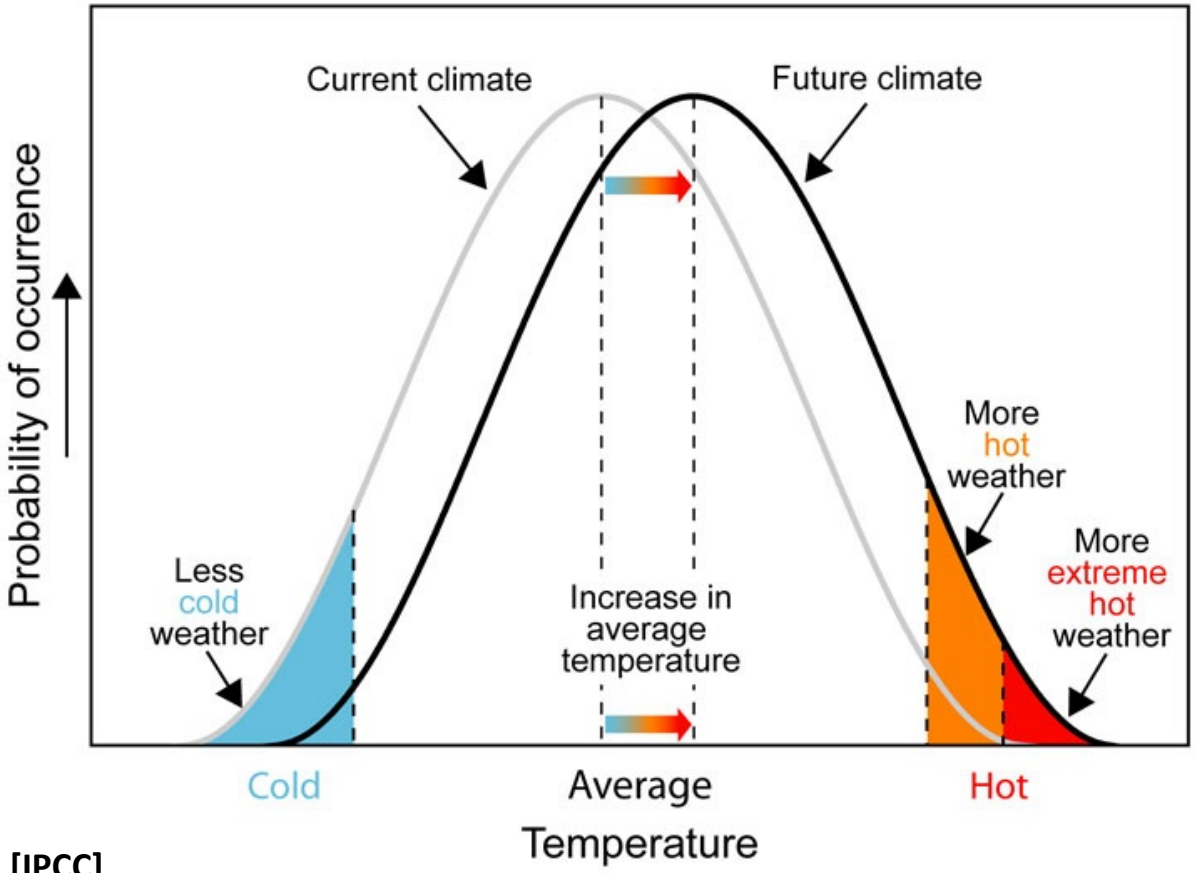
Changing the climate changes weather



[IPCC]

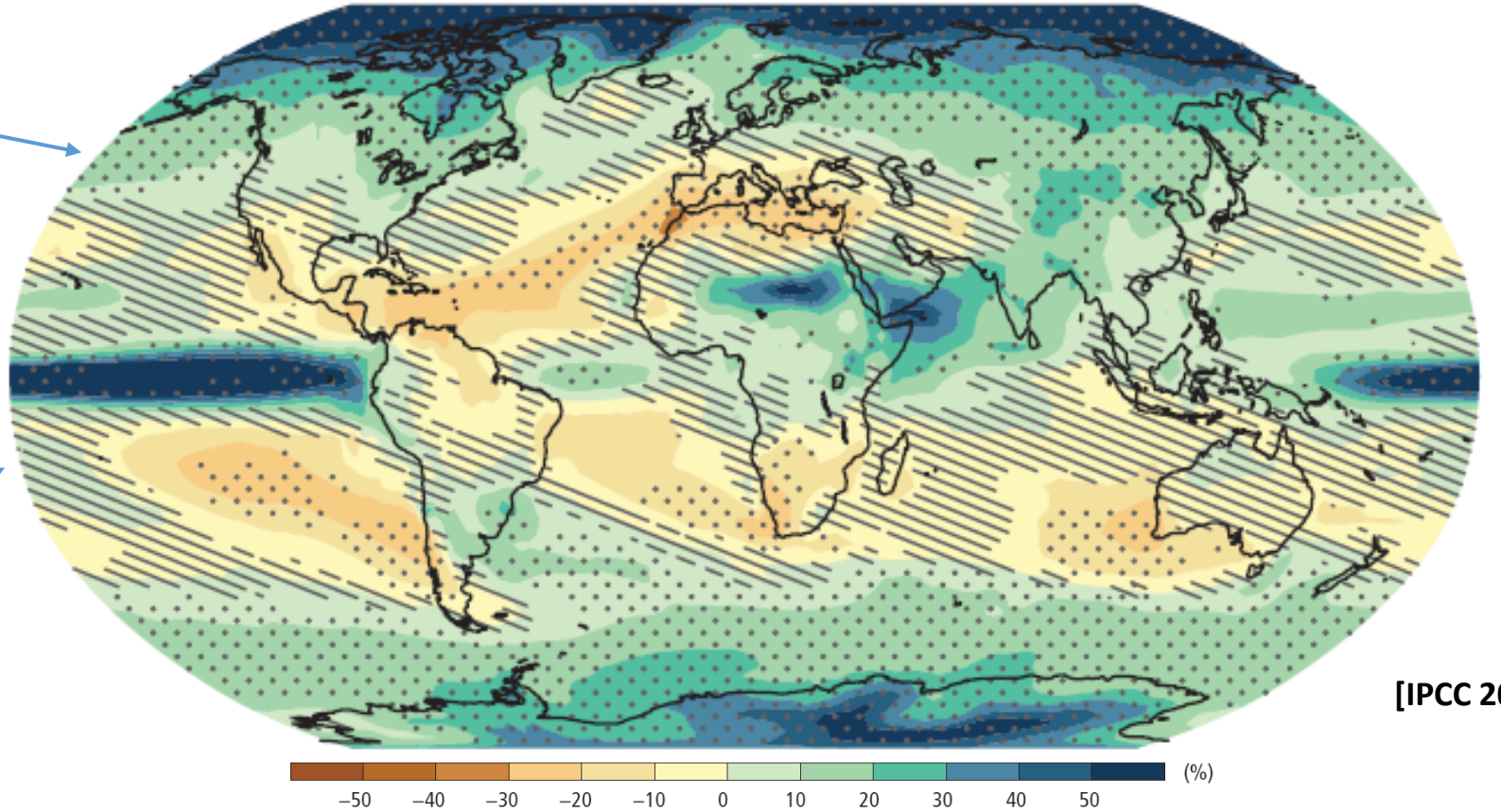
→ A changing climate will produce more weather extremes, with yet unknown geographical distribution and severity

Predictive skill: Climate

Change in average precipitation (1986–2005 to 2081–2100)

Change larger than natural variability

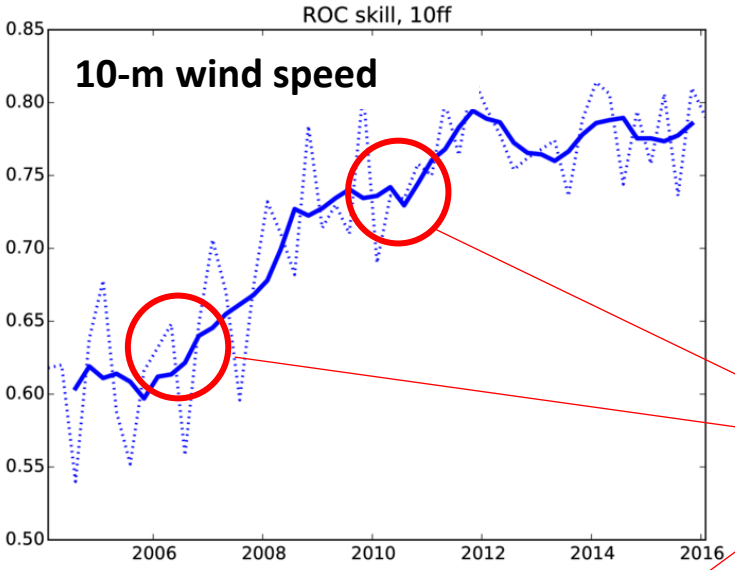
Models agree about sign of change

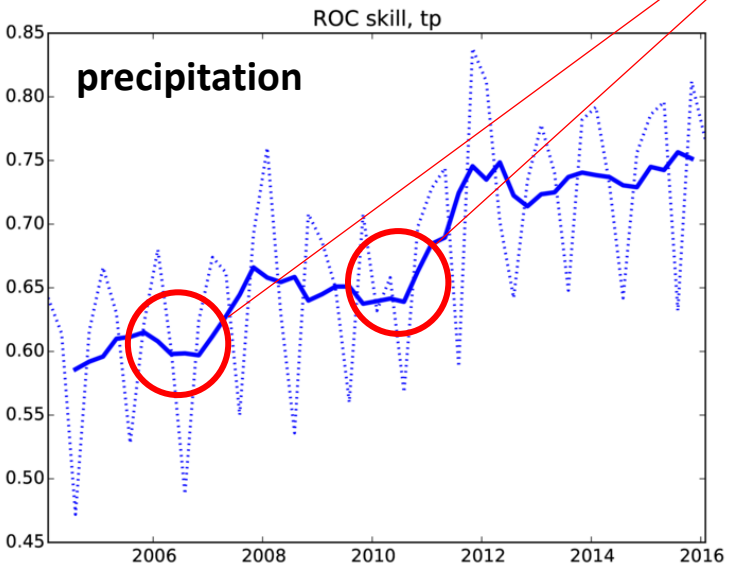


[IPCC 2014]

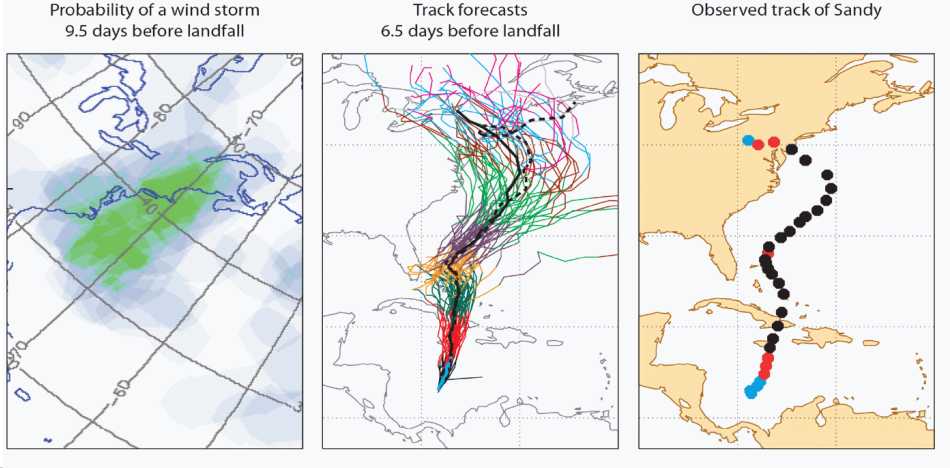
→ Large model dependent systematic errors & much larger uncertainties for moisture, clouds, precipitation

Predictive skill: Weather



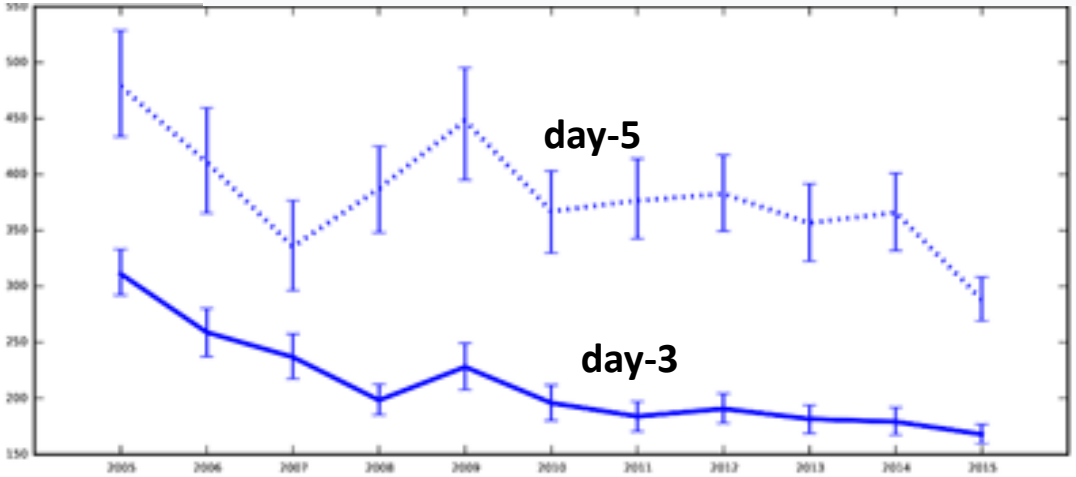


resolution upgrades



Mean tropical cyclone position error

150 km



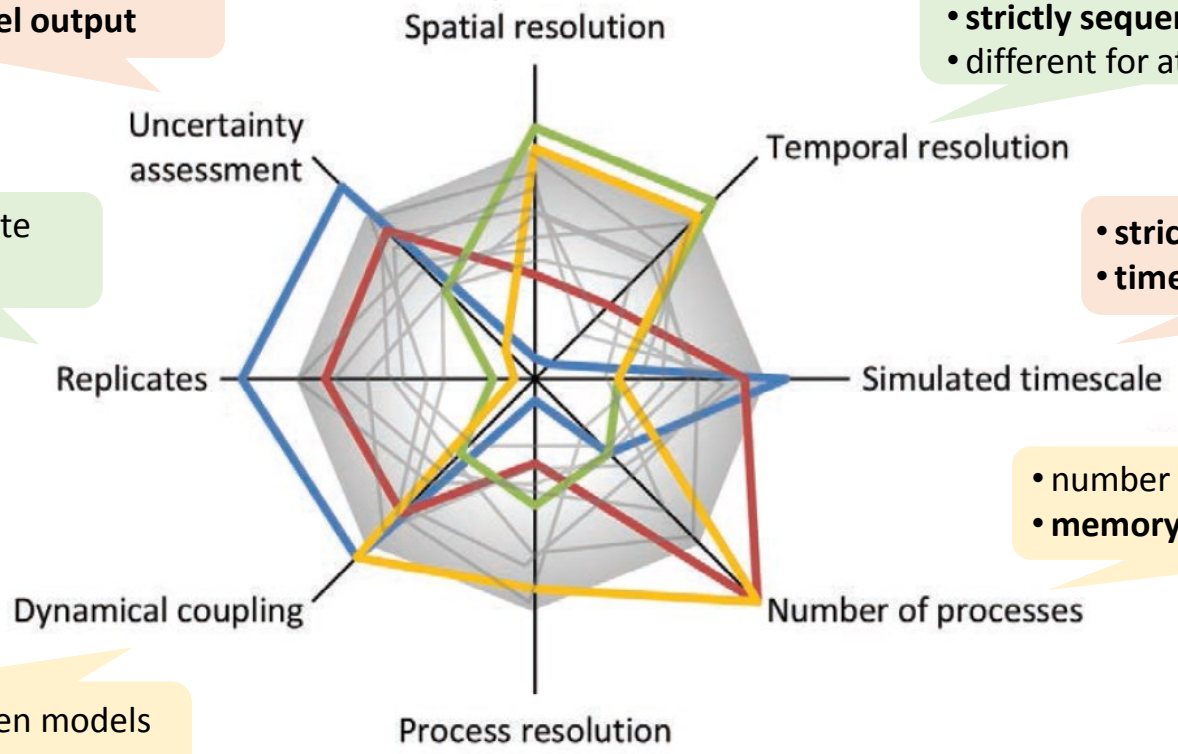
→ Despite good medium-range skill, much poorer performance at sub-seasonal-to-seasonal range in mid latitudes

Can’t have it all?

- quadratic # grid points
- **global communication**
- **memory limited**

- **multiplies entire model compute**
- **multiplies entire model output**

- depends on spatial resolution
- **strictly sequential**
- different for atmosphere, ocean



- multiplies entire model compute
- multiplies entire model output

- **strictly sequential**
- **time to solution** (weather vs climate)

- number of prognostic variables
- **memory limited**

- communication of data between models
- **latency between models**

- number of prognostic variables
- **memory limited**

[Smith et al. 2014, BAMS]

The nature of climate & weather model codes

```
Name of the executable : /fws2/lb/work/rd/mpm/RAPS11/T2047/../bin/ifsMASTER
Number of MPI-tasks : 512
Number of OpenMP-threads : 8
Wall-times over all MPI-tasks (secs) : Min=1020.070, Max=1025.730, Avg=1022.972, StDev=1.261
Routines whose total time (i.e. sum) > 1.000 secs will be included in the listing
  Avg-%   Avg.time   Min.time   Max.time   St.dev  Imbal-%   # of calls : Name of the routine
  7.91%     80.951     71.799     86.287    1.554   16.79%      6545408 : MXMAOP
  4.15%     42.488     39.259     47.132    1.530   16.70%     87748608 : CLOUDSC
  3.65%     37.345     31.398     43.424    1.999   27.69%  44742137979 : CUADJTQ
  3.62%     37.059     36.473     38.821    0.240    6.05%    350994432 : LAITRI
  3.59%     36.672     35.747     38.017    0.342    5.97%    482818560 : VERINT
  3.12%     31.937     27.864     36.514    1.297   23.69%       100352 : >MPL-TRMTOL_COMMS(807)
  3.03%     30.991     15.474     70.559   10.875   78.07%        98816 : >MPL-TRLTOM_COMMS(806)
  2.93%     29.964      3.977     71.212   12.580   94.42%        98816 : >MPL-TRGTOL_COMMS(803)
  2.45%     25.066     12.663     37.822    5.504   66.52%         1611 : >MPL-IOSTREAMREAD_RECORD(650)
  2.43%     24.853      8.287     33.075    3.370   74.94%       100352 : >MPL-TRLTOG_COMMS(805)
  2.21%     22.597     21.537     23.729    0.336    9.24%    175497216 : LASCAW
  2.03%     20.776     20.174     21.547    0.242    6.37%     87748608 : VDFMAIN
  1.85%     18.952     18.393     20.062    0.245    8.32%    789737472 : LAITLI
  1.70%     17.341     16.440     18.936    0.364   13.18%     87748608 : VDFEXCU
  1.55%     15.812     13.110     22.851    1.057   42.63%        98816 : >BAR-BARRIERINSIGCHECK(718)
  1.49%     15.241      6.446     25.483    4.342   74.70%       802816 : >OMP-FTINV_CTL(1639)
  1.40%     14.324      9.447     23.023    1.886   58.97%        99840 : >MPL-SLCOMM1_COMMS(509)
  1.39%     14.183     13.788     14.387    0.076    4.16%    175497216 : LARCHE
  1.37%     14.056      8.137     25.275    2.968   67.81%     43874304 : CUBASEN
  1.18%     12.059      1.922     25.705    5.039   92.52%     43874304 : CLOUDVAR
```

(IFS: 3 million lines of Fortran code, C++ drivers, shell scripts)

A combination of large matrix manipulations, nested loops, complex numerics, lots of calls …

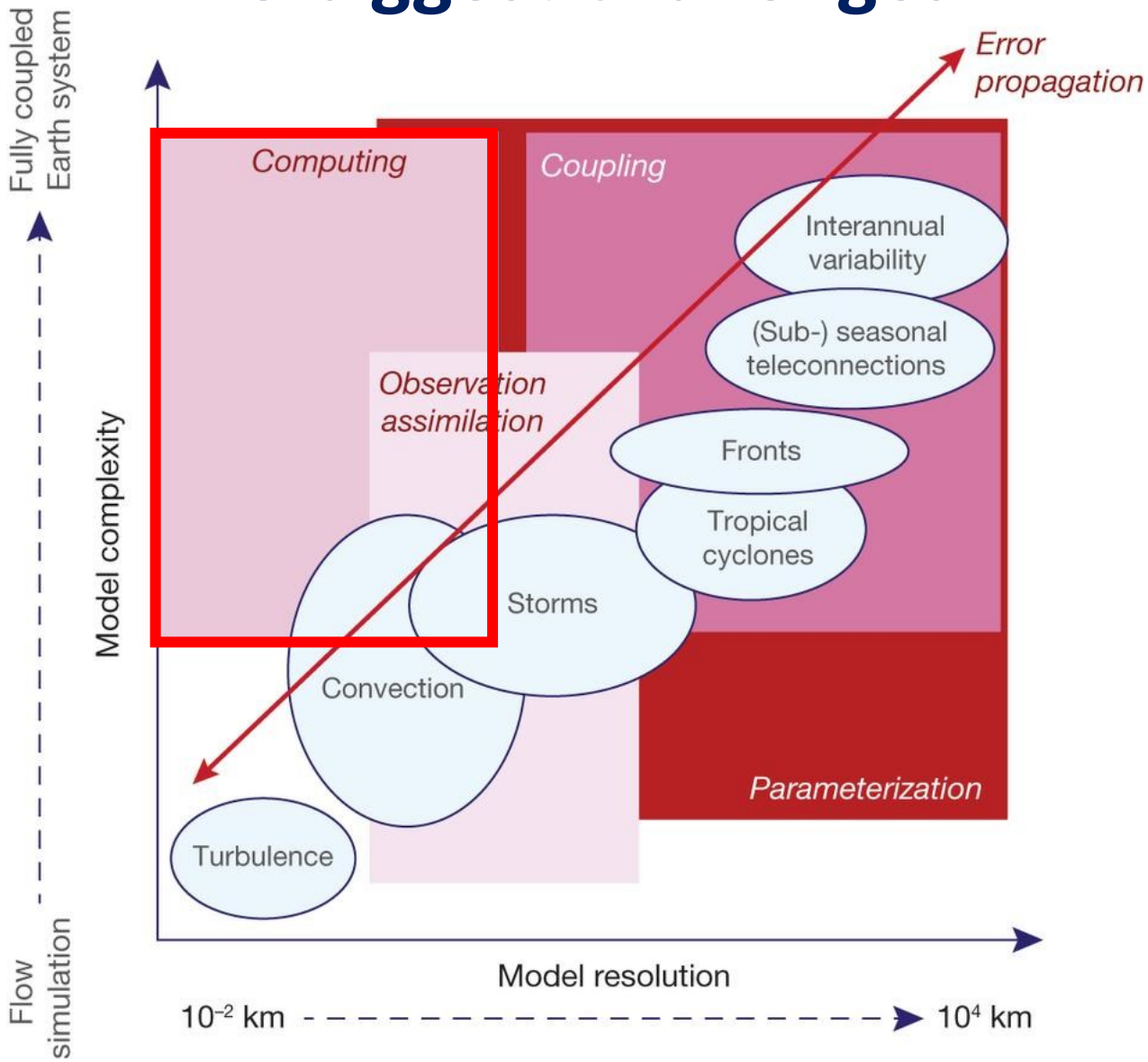
MXMAOP: matrix multiplication for spectral transforms
CLOUDSC: cloud scheme
CUADJTQ: condensation/evaporation
LAITRI: 32-point interpolation for advection
VERINT: vertical integral
…
…

…. being memory intensive, communication intensive, compute intensive …

… challenging both efficiency and scalability at all levels!

The biggest challenges

Computing & data handling will be the no. 1 challenges for weather and climate prediction in the next 10 years



[Bauer et al. 2015]

nature

Weather and climate prediction application for EsD

To achieve a <u>quantum leap</u> in predictive skill, we need:

- Global coupled & uncoupled simulations at **1 km** spatial resolution; as ensembles to characterize forecast uncertainty

→ **EsD applications**:

- Full-sized global 1 km models
- Tailor-made, cost-driving model components (to be highly optimized and made scalable) for both computing and data handling

- **in production mode**
- **in research + production mode**
- **across scale**
- **verifiable science performance**

… to be provided by ESiWACE (CoE), ESCAPE and NextGenIO (both FET)