Major breakthroughs and future challenges of numerical weather prediction

Eirik Gallefoss

07.10.2019

Geologisk institutt - Universitetet i Oslo

Overview

1. Introduction
2. Historical overview
3. Past breakthroughs
4. Future challenges
5. Conclusion

Introduction

Applications of NWP

- Extreme weather events
- Climate prediction
- Air quality

Dynamical core

$$\frac{d\mathbf{V}}{dt} = -2\Omega \times \mathbf{V} - \frac{1}{\rho}\nabla p - \nabla\Phi + \mathbf{F}$$

$$\frac{dT}{dt} = \frac{R}{C_p}\frac{T}{p}\frac{dp}{dt} + \frac{Q}{C_p}$$

$$\frac{d\rho}{dt} = -\rho\nabla \cdot \mathbf{V}$$

$$\frac{dq}{dt} = M$$

$$p = \rho RT$$

Model physics

- **F** - Momentum
- Q - Heat
- M - Water vapor

Future vision

- Global model 1x1 km grid
- Fully coupled atmosphere, land, ocean and sea ice

Historical overview

- Bjerknes 1904

- Bjerknes 1904
- Richardson 1922

- Bjerknes 1904
- Richardson 1922
- Charney, Fjørtoft, von Neumann 1950

- Bjerknes 1904
- Richardson 1922
- Charney, Fjørtoft, von Neumann 1950
- Rossby 1954

- Bjerknes 1904
- Richardson 1922
- Charney, Fjørtoft, von Neumann 1950
- Rossby 1954
- Charney/U.S. Weather Bureau 1955

- Bjerknes 1904
- Richardson 1922
- Charney, Fjørtoft, von Neumann 1950
- Rossby 1954
- Charney/U.S. Weather Bureau 1955
- Shuman 1966

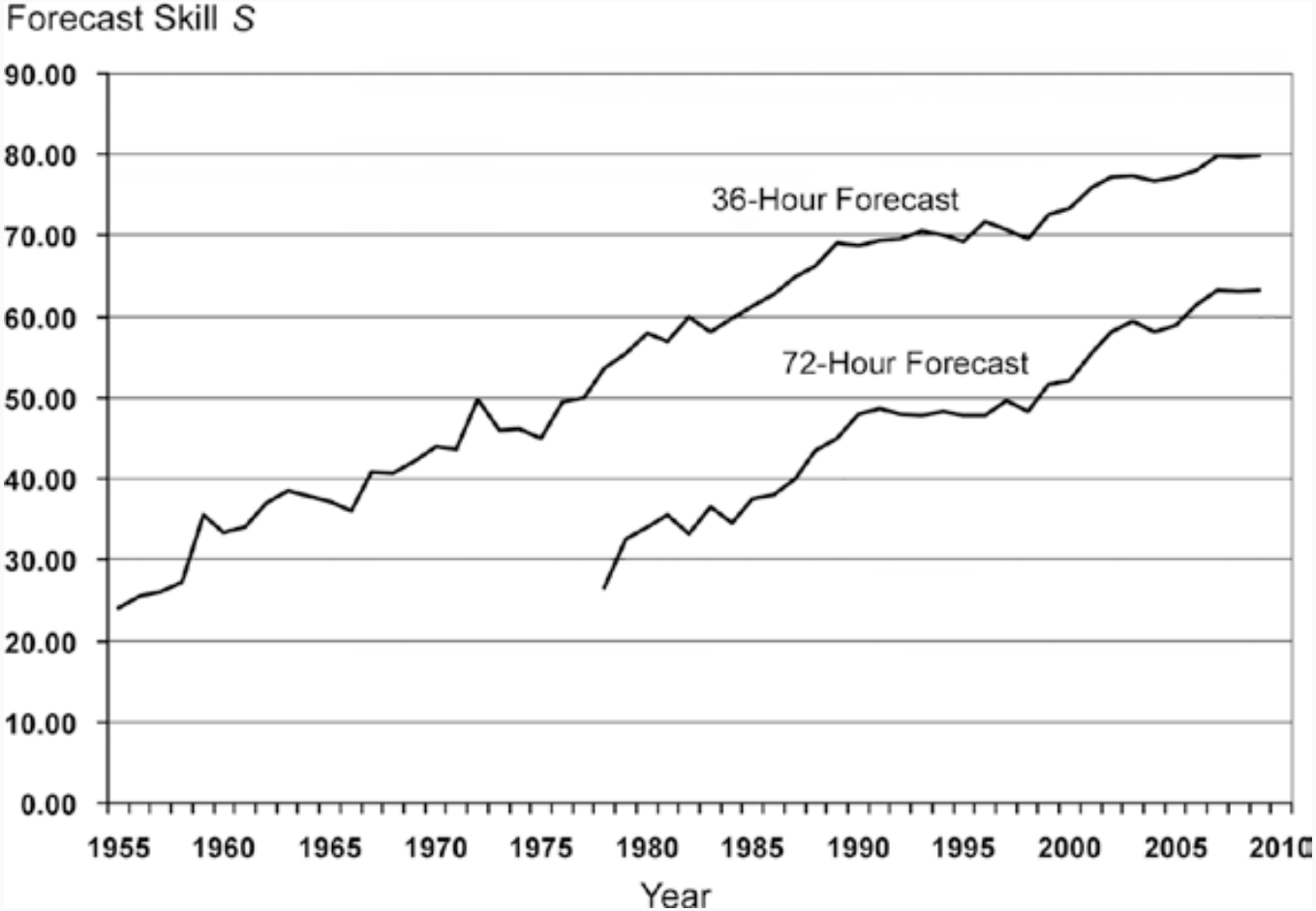
- Bjerknes 1904
- Richardson 1922
- Charney, Fjørtoft, von Neumann 1950
- Rossby 1954
- Charney/U.S. Weather Bureau 1955
- Shuman 1966
- 1990

Today

Organization	Grid size (km)	Vertical levels
NOAA	13x13	64
UM	10x10	70
ECMWF	9x9	137

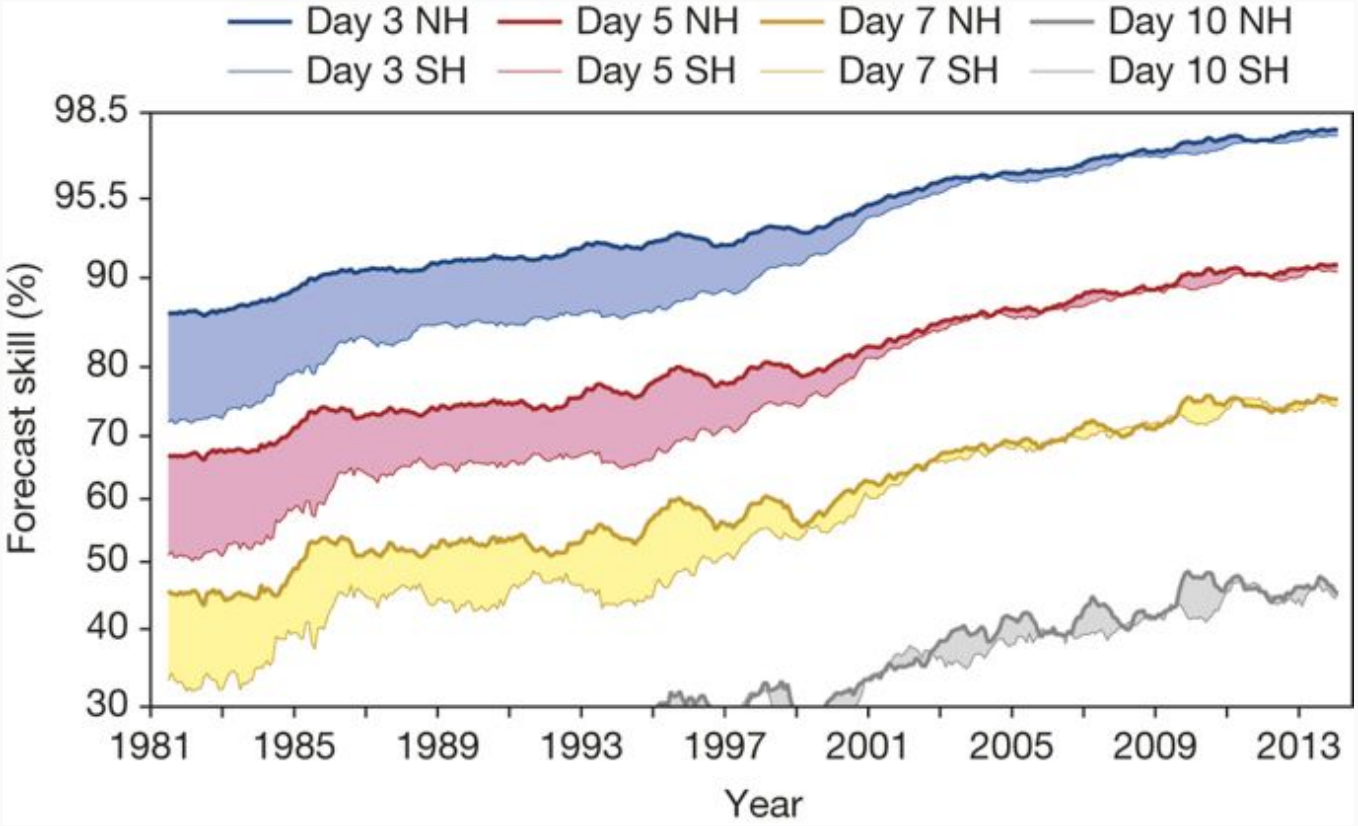
(Coiffier 2012)

Skill progress



(Coiffier 2012)

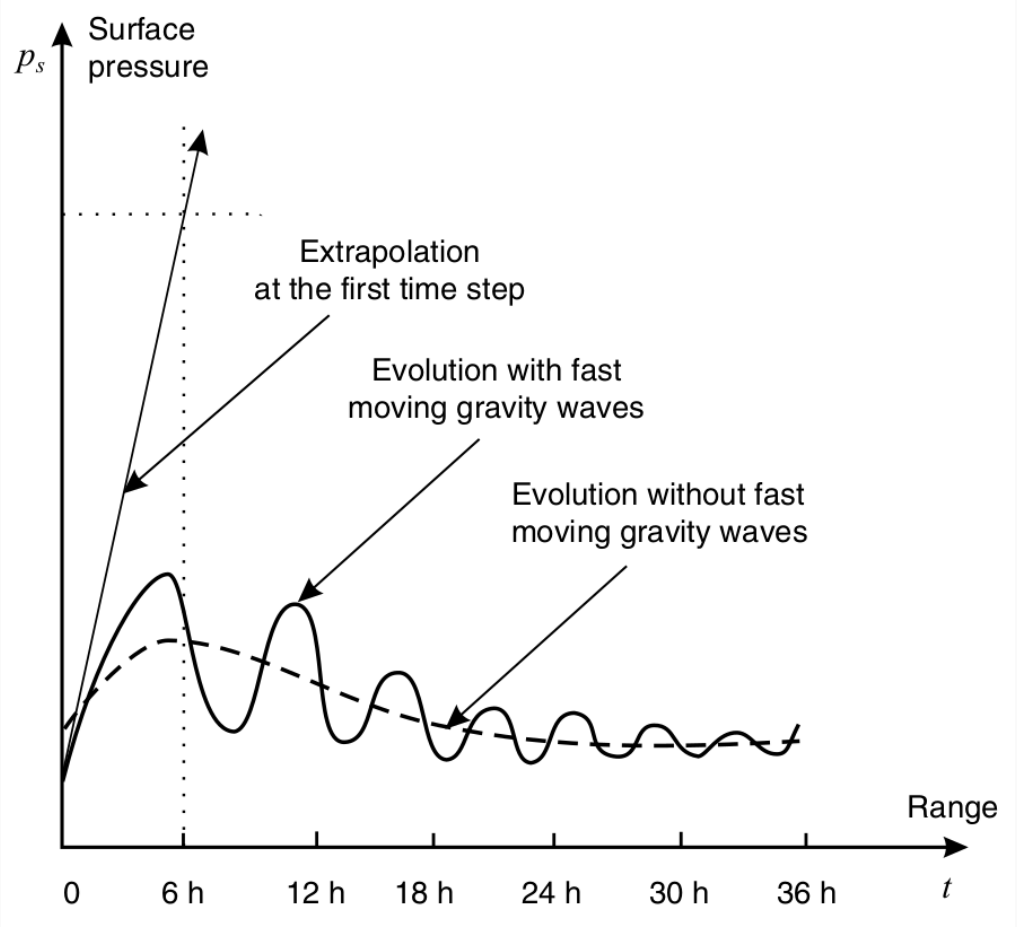
Skill progress



(Bauer, Thorpe, and Brunet 2015)

Past breakthroughs

Model initialization

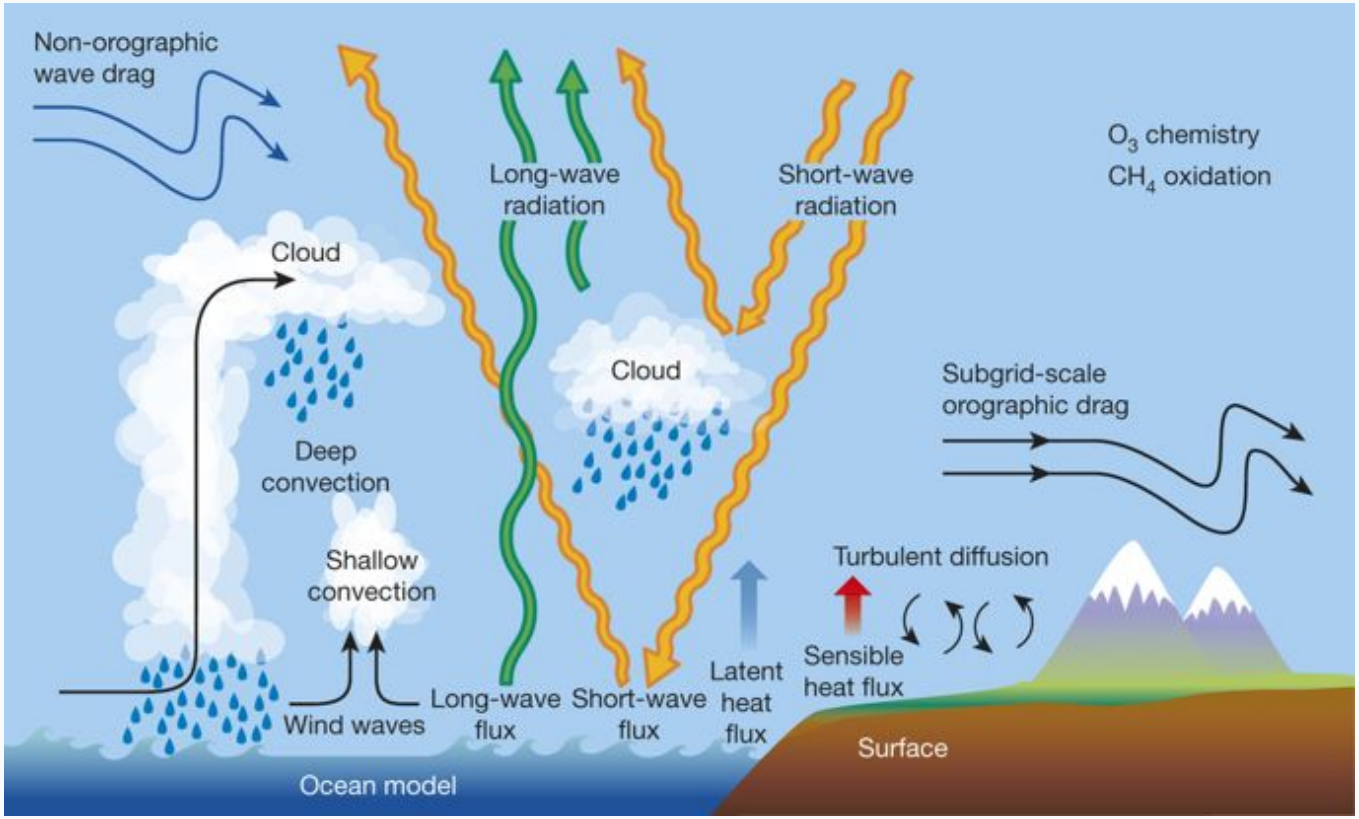


(Coiffier 2012)

Model initialization

- Synoptic analysis
- Objective analysis
- 3D / 4D variational data assimilation

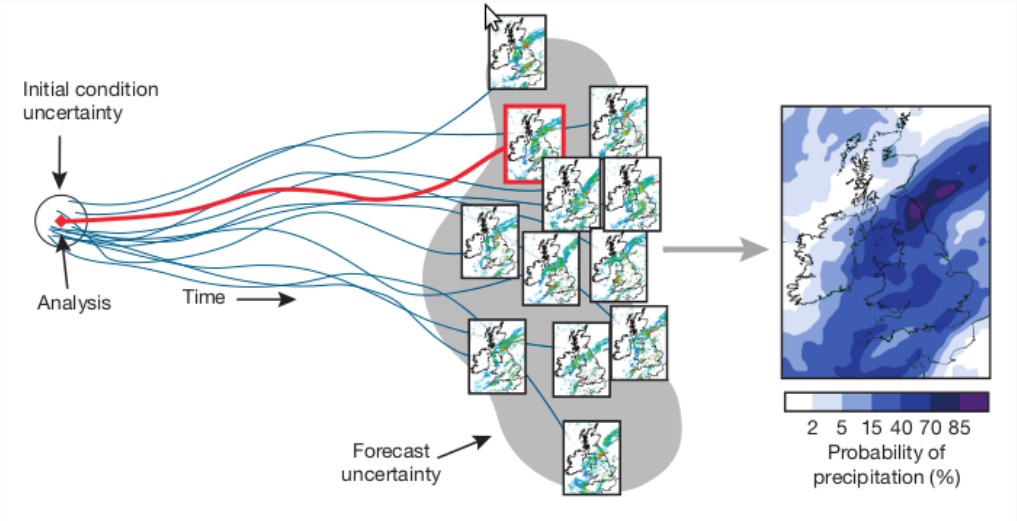
Physical processes



(Bauer, Thorpe, and Brunet 2015)

Ensemble

- Probabilistic forecasting
- Poor mans ensemble
- Singular vector + Vector breeding



(Coiffier 2012)

Computational power

- Model run time
- CFL-criteria

$$T = \frac{N_v N_c N_t}{R}$$

$$\frac{U \Delta t}{\Delta x} < C$$

Future challenges

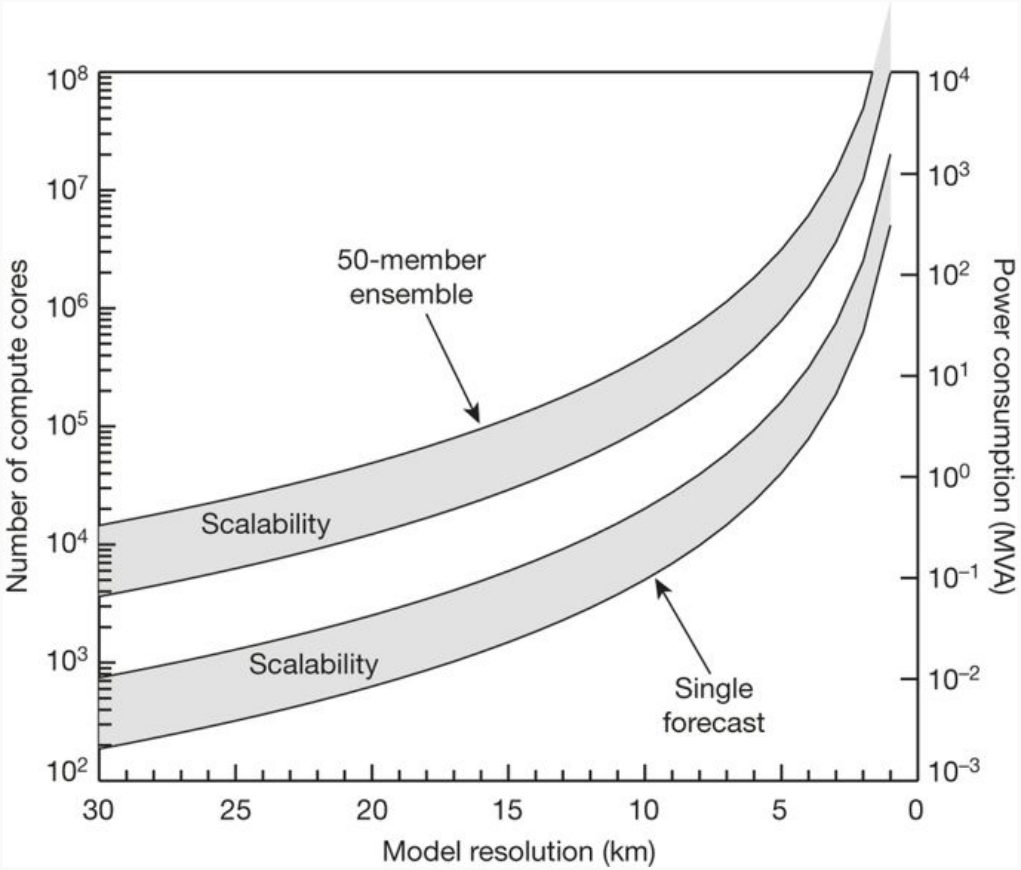
Model physics

- Uncertainties in parameterizations
- Gray zone of convection

Model initialization

- Lack of observations

Computational challenges



(Bauer, Thorpe, and Brunet 2015)

Conclusion

Conclusion

- Significant progress made in 70 years
- Great scientific and technological progress to reach 1x1 km fully coupled models

References

P. Bauer, A. Thorpe, and G. Brunet. "The quiet revolution of numerical weather prediction". In: *Nature* (2015). DOI: 10.1038/nature14956. URL: https://doi.org/10.1038/nature14956.

Jean Coiffier. *Fundamentals of Numerical Weather Prediction*. 2012.