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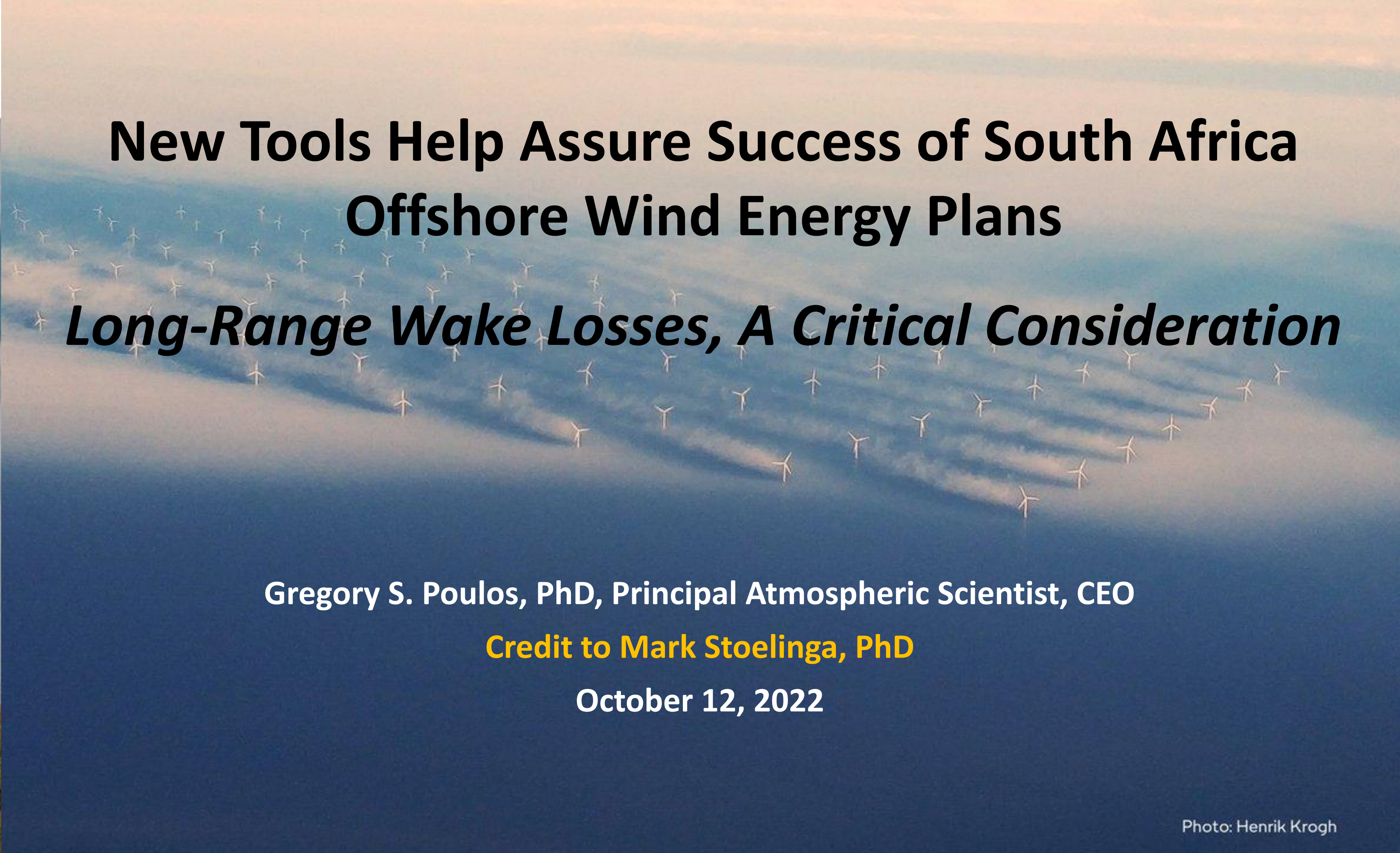
Golden – São Paulo – Cape Town – Bangalore



New Tools Help Assure Success of South Africa Offshore Wind Energy Plans

Long-Range Wake Losses, A Critical Consideration

Gregory S. Poulos, PhD, Principal Atmospheric Scientist, CEO

Credit to Mark Stoelinga, PhD

October 12, 2022

Photo: Henrik Krogh

EXPERTISE THROUGHOUT THE PROJECT LIFECYCLE

Prospecting → Development → Financing → Construction → Operations → Repowering

Atmospheric Science, Engineering, and Storage/Wind/Solar/Green H_2 Technological Consulting with Roots to the Very Origins of the U.S. Industry

Start 1978, named ArcVera March 2017

- Origins of US renewables
- California, post-oil embargo, 1978 start
- Deep historical project database
- Technology/engineering and expertise/experience used to cut risk

Based in Golden, CO, US & Globally

- Projects on 6 of 7 continents
- 40+ person degreed team - 4 continents
- Senior staff 10+ years experience
- Work on thousands of storage/wind/solar projects globally

Offices in US, Brazil, South Africa and India

Green H_2 projects underway, globally

HYBRID • STORAGE • SOLAR • WIND • GH_2

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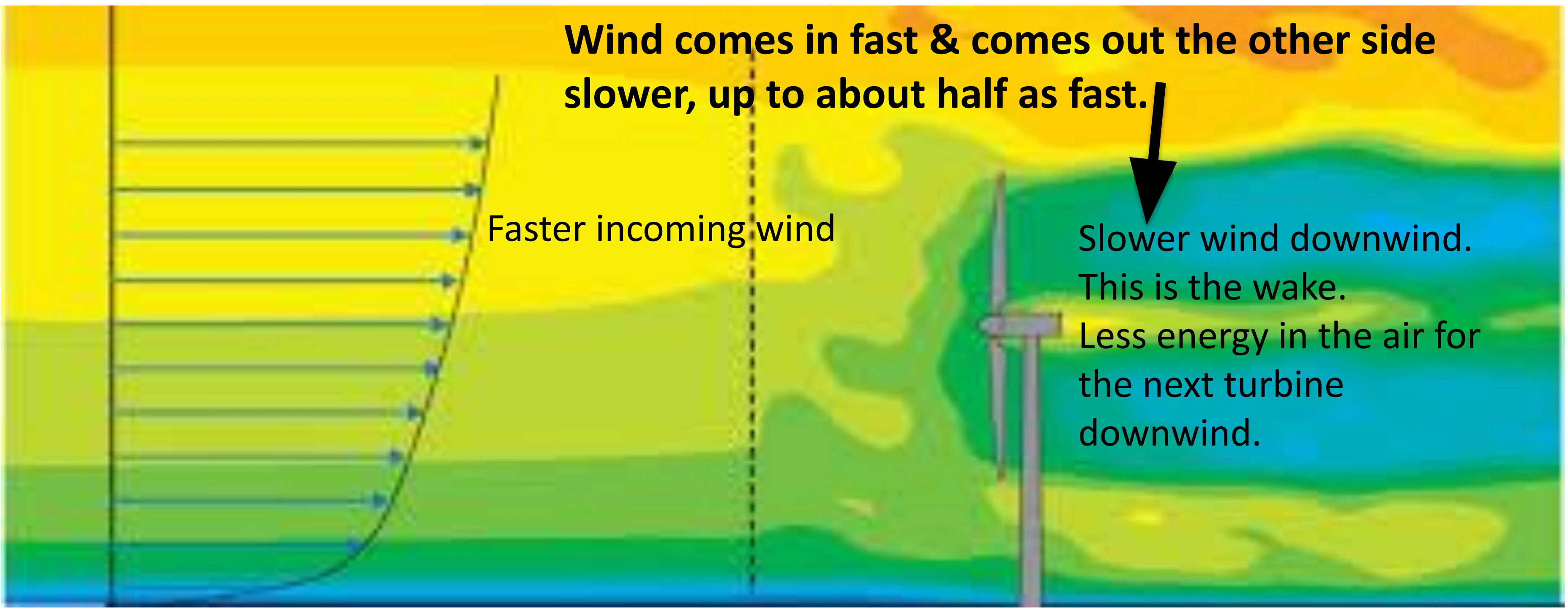
Background: Wind Turbine Wake



Based on the CEWEX field experiment (and others) no substantive impact on farming or environment due to wake wind speed changes.
Wakes and their recovery rate are a critical wind farm design factor.

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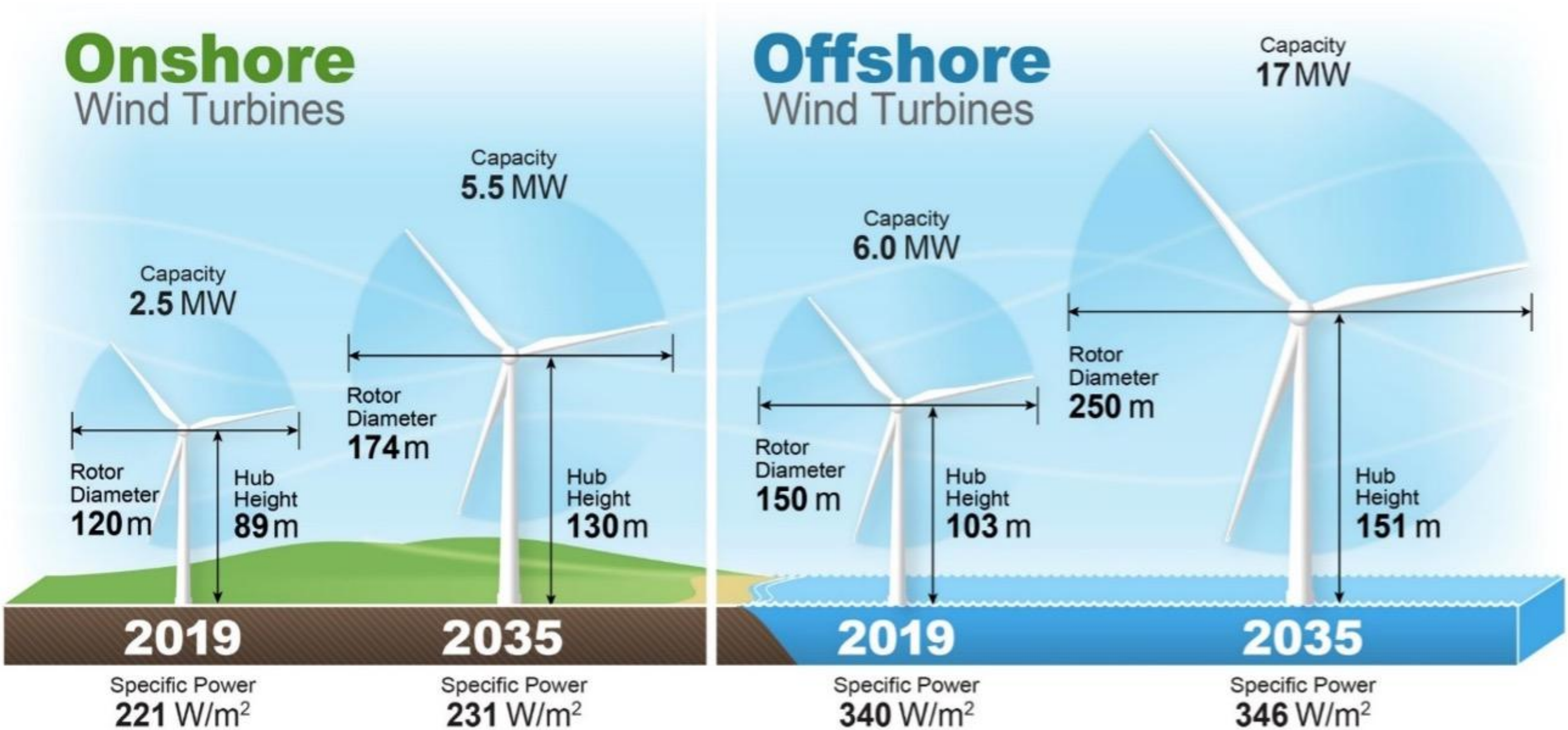
Wind Turbines are Getting Much Bigger



From Renewable Energy World, 2021

Taller turbines reach further into the atmosphere where it is more stable and wakes recover more slowly. Neutral and unstable atmospheres are more common near the surface, but overall are more rare than stable. Stability varies continuously.

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Many in the industry think wakes recover to the upwind speed within 3-5 km or ~30-50 rotor diameters. What if the real answer is 10 times bigger? Then, “Add a zero”.

It turns out that the state of the atmosphere – an inversion, for example – lengthens the distance wakes travel by 10x and this effect is not well captured in all commonly and currently used fast easy-to-use wake models, requiring a more sophisticated approach.

Because long-range (> 30-50 RD) wake losses have not been considered significant they have not been validated in current wake loss models, leaving a gap in knowledge that increases energy production risk as we build more and more wind farms.

How can we possibly understand something so complex?

- Weather Research and Forecasting model, WRF
  - A state-of-the-art model from NCAR/NOAA
  - Continuously models atmospheric physics and thermodynamics and naturally time-varying stability
  - Has ocean interaction with the atmosphere
  - Contains all the weather variables/turbulence
  - Models wind turbine interaction with atmos.
    - Wind Farm Parameterization, WFP

Thus, a solution is found with **WRF-WFP**.

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ArcVera's Study of Long-Range Wakes

Paper available with detailed references and validation

Visit **arcvera.com**, navigate to "Resources", then "News and Publications".

White paper: Estimating Long-Range External Wake Losses in Energy Yield and Operational Performance Assessments Using the WRF Wind Farm Parameterization

Mark Stoelinga, et al. 2022

Key finding: WRF-WFP by far the most accurate long-range wake loss method.

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Existing Wake Loss Tools Inadequate

- Turbines are rapidly changing; tuned models can’t keep up
- They have low sensitivity to changing atmospheric stability
- Tuned to close-in wind farm wakes from smaller turbines and with insufficient turbine size dependence, looking backward

- BOTTOM LINE: Not validated or adequate for long-range external wake losses – a gap in knowledge that can easily translate to <u>billions of ZAR in lifetime lost revenue for a single offshore wind farm.</u>

- <u>USE WRF-WFP method to solve this problem.</u>

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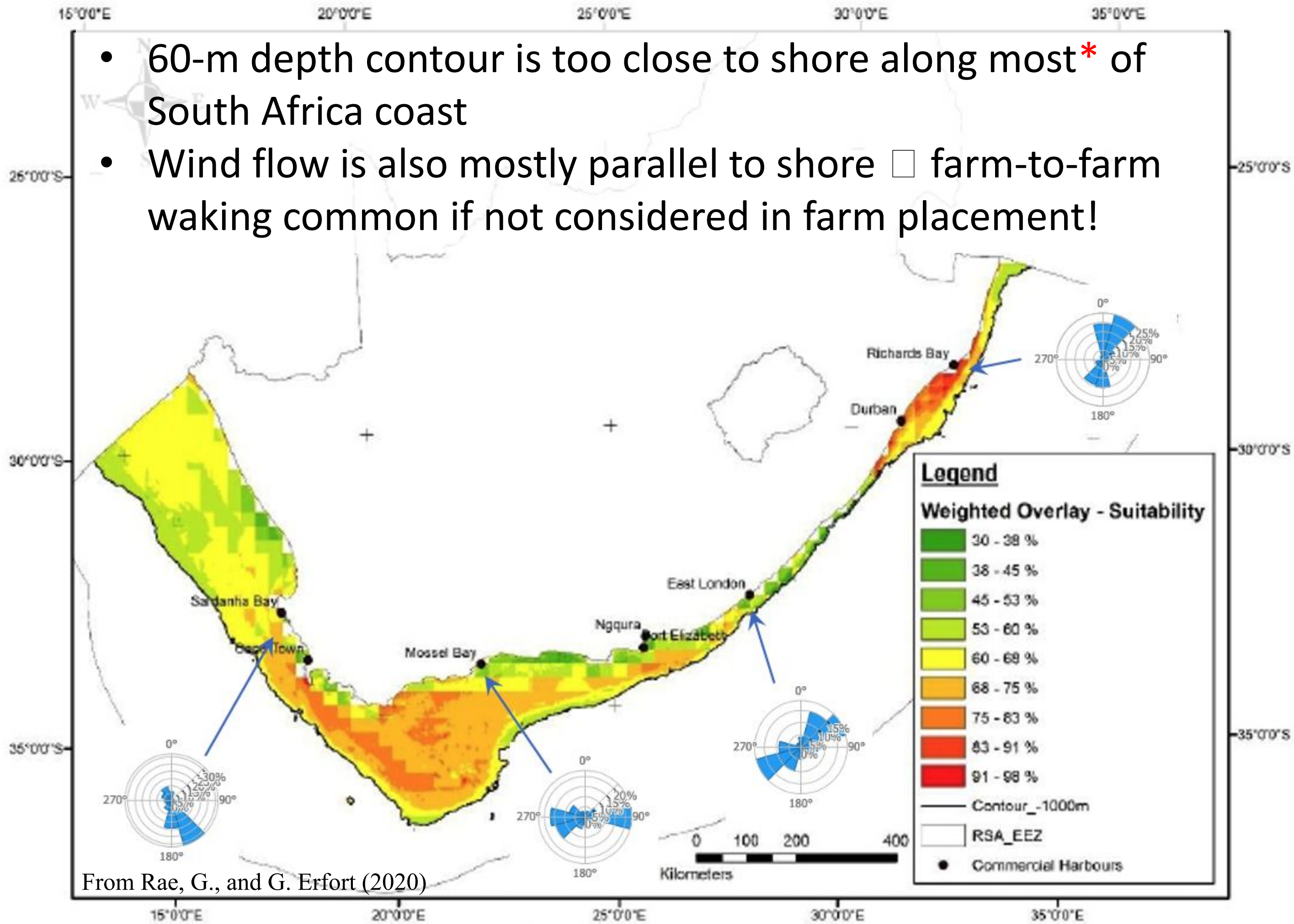
Current Methods Found Unacceptably Inaccurate for Long-Range Wakes

How can WRF-WFP long-range wake loss solution be used for offshore wind development planning in South Africa?

Unique aspects of offshore environment around South Africa

- 60-m depth contour is too close to shore along most* of South Africa coast
- Wind flow is also mostly parallel to shore farm-to-farm waking common if not considered in farm placement!



From Rae, G., and G. Erfort (2020)

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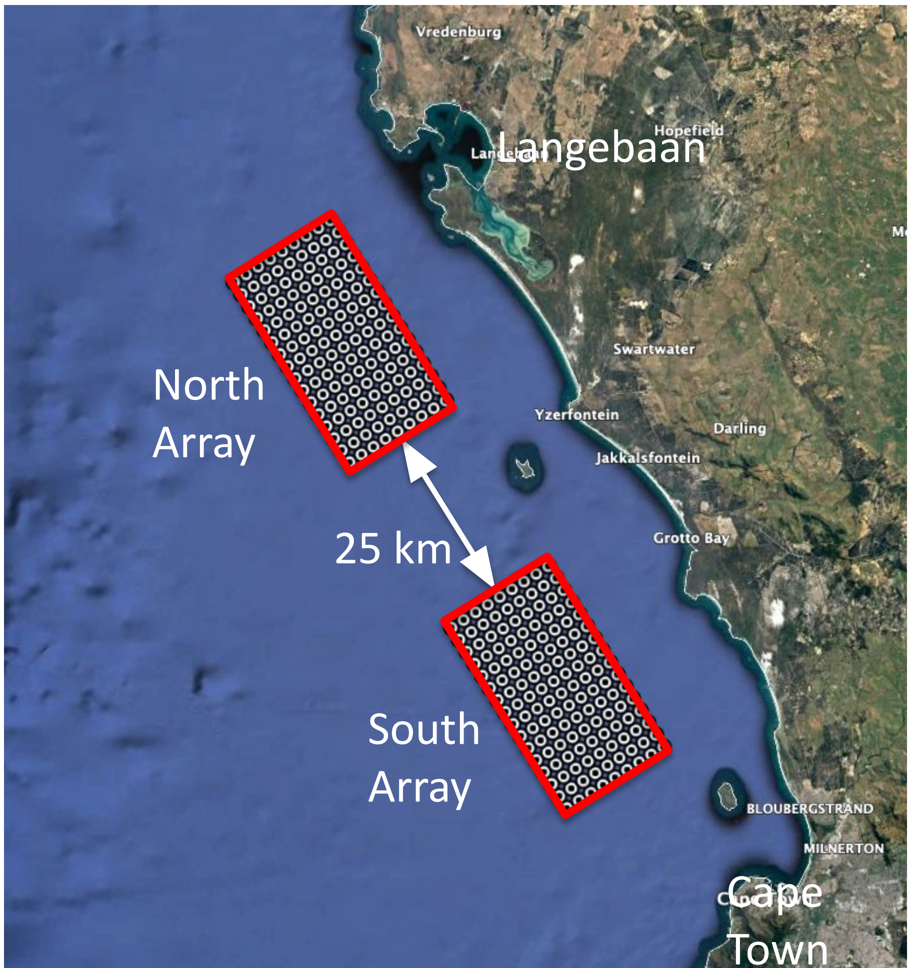
A Hypothetical Cape Town Offshore Wind Farm



Two 2.2 GW arrays, 25 km apart

Each array has:

- 16 rows of 9 turbines, 144 total
- 1 nautical mile (1.85 km) spacing in both directions
- IEA reference 15 MW turbine
    - Rotor diameter = 240 m
    - Hub height = 150 m
- Array capacity: 2.2 gigawatts

Two experiments:

- No turbines
- South Array turbines

☐ Assess affect of external wakes from South Array on North Array production

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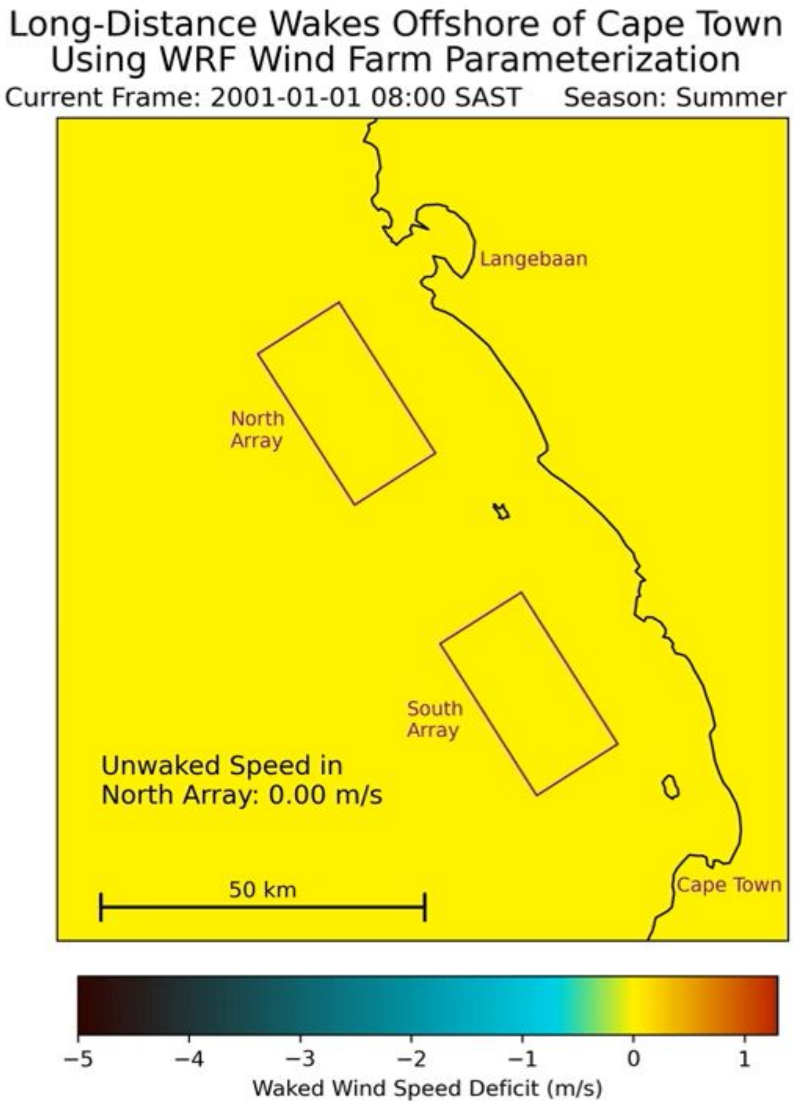
Animated Loop of Long-Range Wakes: 3 Days

Each frame is 10 minutes in simulated time.



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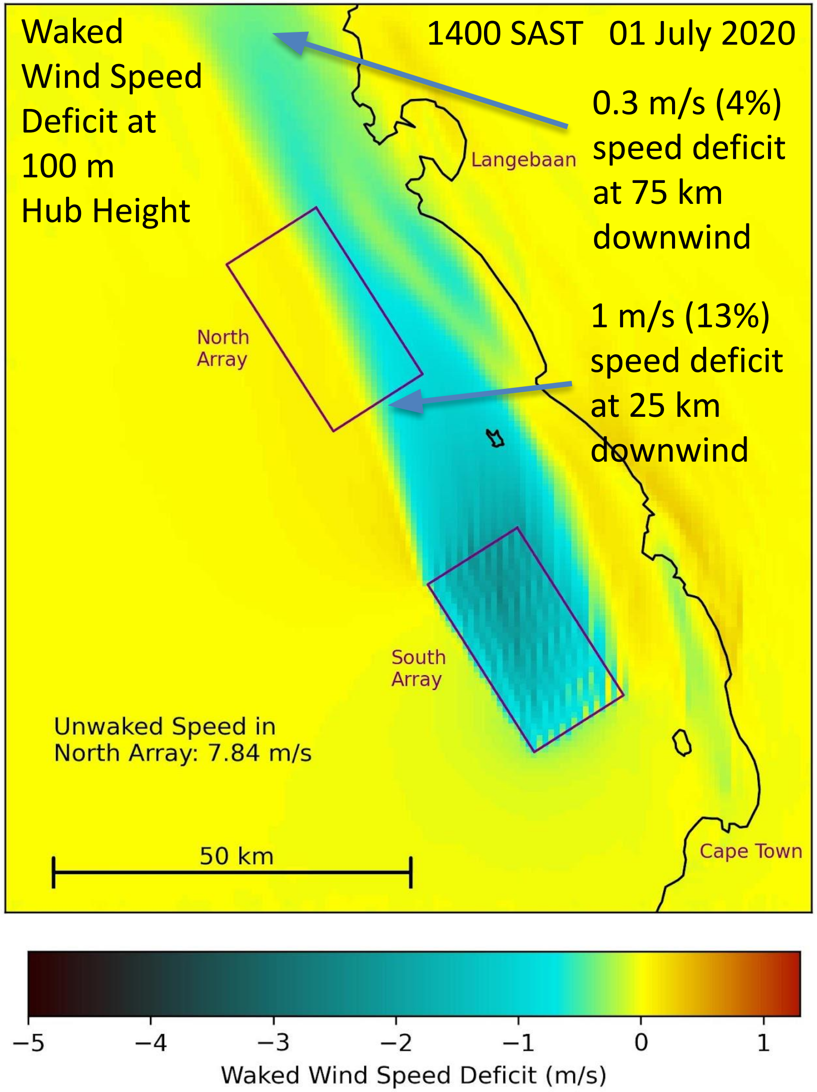
Snapshot of a Long-Range Wake

During a full year of simulated wakes from the South Array, the average speed and energy deficits at the North Array are:

- Speed: 1.7%
- **Energy: 2.1%**

This energy loss would not be considered without WRF-WFP.



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Summary

- Long-range wakes of large magnitude travel much further than expected, 300-500 rotor diameters (50-100 km or more).
- Long-range wakes are vastly underpredicted by traditional/current engineering wake loss models at these distances.
- This new WRF-WFP based method excels.
- This capability is available now and amounts to potentially many billions of ZAR for a single project's lifetime revenue.
- South Africa should carefully consider these impacts for accurate grid modeling.
- Policy makers/developer/owners will now be able to act on best information and optimize offshore wind energy polygons.

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Points to Finish

- Bottom line: As on and offshore wind farm density increases, with ever larger rotor diameters, long-term green energy production risk increases greatly due to long-range wakes. We have demonstrated that the WRF-WFP works well. **Use it to reduce project risk.**
- Deeper Insight: Such analysis is critical for project optimization and hybrid project time series modeling of energy production and for grid stability/worst-case-scenario modeling and for state-of-charge/revenue modeling for green H_2 and battery projects.
- Recommendation: Considering the unique environment of wind and bathymetry offshore of South Africa, long-range wakes will be especially important here. Use WRF-WFP to study long time series of full-build effects on grid management and project performance.

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